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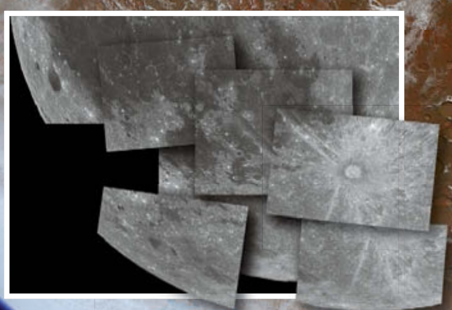

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SKY & TELESCOPE

September 2013 VOL. 126, NO. 3

On the cover: Scientists suspect Mars once boasted surface water — and plenty of it.

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OBSERVING SEPTEMBER

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Image by Jeff Dai

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Emil Ivanov captures the zodiacal light from the Rozhen Observatory in Bulgaria. See more beautiful astrophotos, or submit your own, to our online Photo Gallery.

Robert Naeye
Spectrum

A Star Party Dear to My Heart

I ATTEND SEVERAL STAR PARTIES every year, and really enjoy observing and interacting with amateur astronomers at these events. In early June I gave two talks at the Cherry Springs Star Party, held at Cherry Springs State Park in north-central Pennsylvania. This particular star party is dear to my heart, and not just because it's held in one of the darkest and most remote sites in the eastern United States.

The event is run by the Astronomical Society of Harrisburg (ASH), the first club I joined, a club I have belonged to since the 1980s, and the club through which I started my subscription to *S&T*. I see a lot of familiar faces every year I attend the star party. These include ASH president and long-time friend Bob Young (a former president of the Astronomical League), vice president Doug Grove, and long-time member Dr. Mike Snider (who worked with my father at Penn State University's medical school in Hershey, Pa.).

It was encouraging to learn that this year's star party had more pre-registrants (441) than any previous year. This is despite the fact that many star parties have seen declining attendance in recent years. And even though the weather was cloudy for much of the week, I was impressed with how many folks stuck around through Saturday night (when we enjoyed some clear skies), and how many people registered at the last minute despite the uncertain weather prospects. Attendees came from as far away as Ontario, Virginia, and Ohio.

S&T: ROBERT NAEYE

Astronomical Society of Harrisburg members Doug Grove and Mike Snider at Cherry Springs.

On the down side, I didn't see a lot of kids (or even young adults) in attendance. Moreover, ASH members are concerned that light pollution is starting to creep in at this site, which is also home to the Black Forest Star Party in September. The light pollution comes from nearby drilling rigs for natural gas in the Marcellus Shale. Fortunately, the sky was very dark on Saturday night. Cherry Springs State Park operations manager Chip Harrison gave a talk about how the fracking companies frequently cut back on flaring activity during star parties. He pointed out that these companies receive a lot of negative publicity, so they're usually happy to generate goodwill by cooperating with star party organizers. The key is to understand their concerns, make reasonable requests, and communicate clearly the desired actions and the reasons for them. Thanks to the efforts of people such as Bob, Doug, Mike, and Chip, the Cherry Springs Star Party will continue to prosper. ✦

Robert Naeye
Editor in Chief

SKY & TELESCOPE

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

The Essential Guide to Astronomy

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GOTO

Bishop Museum's Voyage Continues

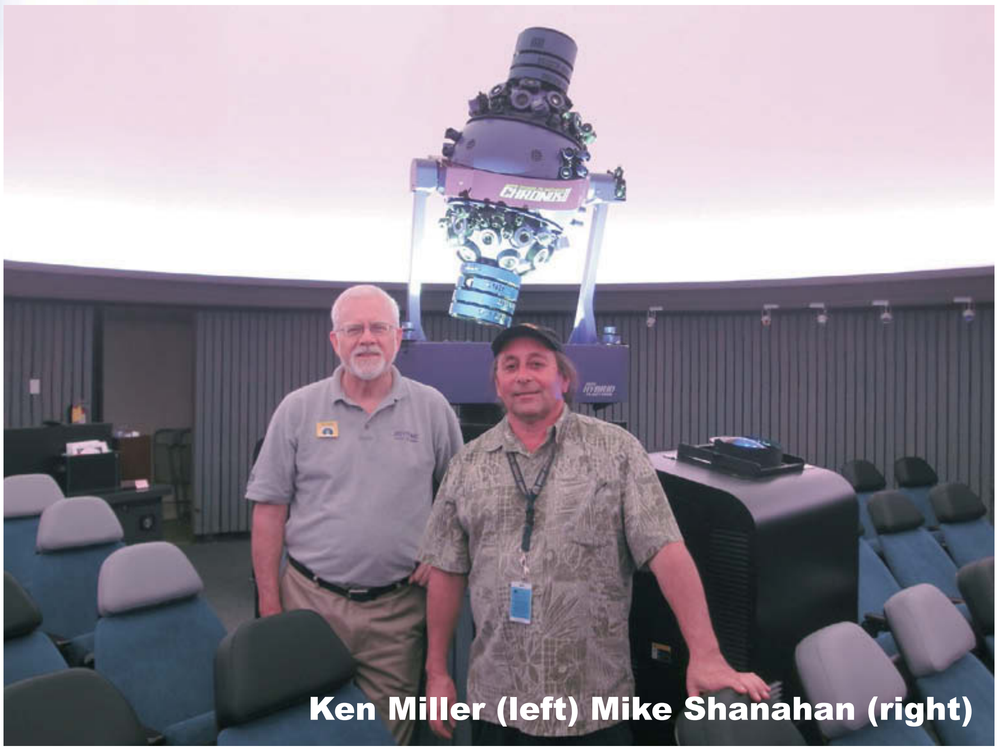
Many planetarians remember Bishop Museum, in Honolulu, Hawaii, as the creator of the NASA-sponsored “Explorers of Polynesia” planetarium show. It told the story of modern Hawaiians recreating migratory voyages around the Pacific in double-hulled sailing canoes. That show revealed some of the non-instrument navigational techniques which were developed using observations inside this planetarium 35 years ago.

Of course Bishop also features programs on modern astronomy and the discoveries atop Mauna Kea, but planetarium director Mike Shanahan continues to tell the story of Hawaiian voyaging to tens of thousands of visitors and residents annually. And the planetarium continues to train new Polynesian navigators to sail with a deep understanding of the sky and signs from Nature, but without compass or sextant; without maps or GPS.

Bishop Museum recently renovated the planetarium with a new dome, seats, audio, lighting, and GOTO CHRONOS II HYBRID projection and control system. The CHRONOS II star projector uses long-life LEDs to illuminate 8,500 perfect stars and a gorgeous Milky Way to put audiences “on the canoe” at sea, on a perfect night. And unlike older analog projectors, the digitally-controlled CHRONOS II is able to “jump” to any location on earth, at any time in the past, present, or future, in a matter of seconds rather than minutes or hours.

A synchronized fulldome video system adds enhancements to the CHRONOS II sky which can include coordinate lines, constellation figures, or even partial clouds (!) to aide in the realistic simulations used to teach navigation. The intuitive and ergonomically-designed GOTO HYBRID control console recently allowed Hawaii’s master navigator to simply walk up and begin using it to teach his current class of Polynesian navigators!

GOTO INC is very proud to have used input from former Bishop Museum planetarium director Ken Miller and hundreds of other planetarium professionals in the design of the CHRONOS II HYBRID system. Ken joined GOTO INC 13 years ago, where he helps custom fit GOTO systems to users around the world.



Ken Miller (left) Mike Shanahan (right)

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This clever observatory design uses an electric drill to control its rotation.

CARL MORESCHI

Homemade Rotating Observatory

I would like to share with my fellow *S&T* readers my design for the rotating, 8-foot-wide cube observatory (above) that is home to my Obsession 18-inch reflector, in hopes that it will be as useful to them as it has been for me.

The floor of the observatory has a 3-foot-wide hole in the exact center, with 16 rods sticking out from the concrete pad around the circumference of the hole. The rods make a logical center post for the building to turn around. The telescope rests on a stand in the center of the hole, meaning it's not connected to the moving building. (If you look very closely at the picture, you can see there is a separation between the stand the telescope is on and the building floor.)

The building has four wheels, one on each corner. One of the wheels has a belt that goes to a gear reduction box. A simple electric drill powers this wheel through the gear box. Thus, the building turns with a simple on/off power switch and a reverse switch.

One advantage of the design is that you can observe right down to the horizon. The main door and roof doors on the building form an observing slit that mimics dome-type observatories, and the opening is large enough such that I only need to move the building once every 20 minutes or so.

Carl Moreschi
Hays, North Carolina

Moons of Moons Revisited

I was dissatisfied by the answer in your June Astro Q&A (page 68) to Scott Hill's question about whether moons can have moons: it seemed to dismiss the issue without giving the real physical reason for the lack of "moons of moons." A quick discussion of the three-body problem would have been more on target. Under most physical circumstances, the smallest of the three bodies (the moon of the moon) does not have a stable orbit and is commonly ejected from the system. A moon of Ganymede, for example, would experience perturbing influences on its orbit both from Ganymede and Jupiter — not to mention additional gravitational tugs from the other three Galilean moons. So can Ganymede have a moon? Yes, but not for long.

Leo Connolly
San Bernardino, California

Editor's Note: *The reader's analysis is correct. Ganymede also has a synchronous orbit around Jupiter, so any Ganymede satellite would likely orbit faster than it would rotate, inducing orbital decay. While a moon's moon might exist when a binary asteroid is briefly caught as a satellite, a primordial moon's moon is unlikely. For example, the space probes going around the Moon have unstable orbits, maintained by thruster corrections.*

Stonewall's Demise

As a longtime subscriber and student of the American Civil War, I enjoyed your two recent articles tied to the sesquicentennial of that conflict. The path that Thomas "Stonewall" Jackson and his scouting party followed on the May 1863 night he was wounded by friendly fire (May issue, page 32) is still dense with trees, and the full Moon silhouetting them wouldn't have helped matters either.

Two other factors could have played a part. Unlike the historical pictures in your article that show Stonewall in an officer's dress uniform, he was actually wearing a black waterproof coat that night. The coat is now in the possession of the Virginia Military Institute in Lexington, Virginia.

The other factor is that, due to their diets of meat (pork and beef), the cracker-like bread called hardtack, and very few fresh vegetables, soldiers on both sides had little or no night vision thanks to a lack of vitamins. In fact, of the 10,000 engagements of all sizes that took place during the Civil War, very few occurred at night for this reason.

Given these factors and with talk of Union cavalry in the area, it's not surprising that the 18th North Carolina fired on that unknown party before them.

Tom Callen
Vaxholm, Sweden

As both an amateur astronomer and military historian, I have greatly enjoyed your articles on the Moon's role in historical events. The article on Stonewall Jackson brought back memories of my time in the intelligence section of a light infantry division's helicopter attack battalion. Although

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weather was a prime concern, moonrise and the lunar phase were also very important, as were the onsets of civil and nautical twilight. Light divisions are trained to fight extensively at night, and the availability of ambient light was a big factor in the use of night vision devices. Those systems now might not be as sensitive to sudden changes in ambient light, but in the '80s and '90s pilots feared the danger of "green out," especially in "nap-of-the-earth" (low-altitude) flying.

Andrew Chmyr
Gettysburg, Pennsylvania

For the Record

✷ *The letter on page 9 of the June issue incorrectly implied that Sir Patrick Moore lived in Chelsea. Moore lived in Selsey.*

✷ *It would take about 10 protons to make the dark matter particle (mass 10 GeV) implied by the CDMS experiment, not 10 protons to make 1 GeV (July issue, page 16).*

✷ *Despite Friedrich Georg Wilhelm von Struve's preeminence, William Herschel discovered that Eta Coronae Borealis is a double star in 1782, long before Struve's work in 1826 (July issue, page 38). For all 2013 errata, see* **skypub.com/errata**.

75, 50 & 25 Years Ago

Roger W. Sinnott

September 1938

Great Fireball "At just 9 o'clock . . . on the warm summer evening of July 26th, persons all over the northeastern United States [witnessed] . . . one of the most amazing of fireballs. . . . During the first part of its flight it appeared as a very brilliant shooting star, almost as if the planet Venus had suddenly started to move at a great rate of speed toward the earth; then it quickly changed to what looked like a sky-rocket, with a glowing tail seemingly filled with sparks. . . . The total duration of its flight was from 6 to 10 seconds. . . .

"[T]he large number of prompt reports . . . [may allow us to] eventually determine the exact path of the fireball. This may, in the near future, lead to finding fragments of meteoric material once the place of its landing in northern New England has been determined."

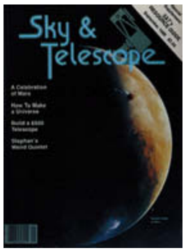
Charles Federer's note was optimistic. It took two decades for Charles P. Olivier (American Meteor Society) to analyze 800 reports and publish his findings in Science. *The object actually didn't land: it burned up in the air. The high velocity Olivier calculated implied the object might have come from outside the solar system.*

September 1963

Historic Refractor "On July 7th, observations halted at the astronomical station maintained jointly by Yale and Columbia universities on Mount Stromlo, Australia, and ownership of its 26-inch refractor was transferred to Mount Stromlo Observatory. . . .

"This is one of the most useful telescopes ever constructed, for measures from its plates have provided 40 percent of all trigonometric determinations of star distances. . . . It continues to be officially known as the Yale-Columbia refractor."

Sadly, this is one of the many major telescopes destroyed in a raging bushfire on January 18, 2003. Fires have also damaged other sites, including Siding Spring Observatory (April issue, page 10).



September 1988

Gamma Rays "Energetic radiation from Cygnus X-1 has given astronomers new hints about the nature of this enigmatic object, which lies in the Milky Way some 8,000 light-years from us. . . . Gamma rays were detected by the High Energy Astronomical Observatory satellite (HEAO) 3, which observed Cygnus X-1 for 170 days in 1979 and 1980. James C. Ling and collaborators from the Jet Propulsion Laboratory discovered their presence during a recent reanalysis of the data. . . .

"One idea is that the radiation came from photons produced by the annihilation of matter and antimatter in the form of electrons and positrons. . . . The new results strongly support the picture of an accreting black hole for Cygnus X-1 and pretty much rule out a neutron star candidate."

The existence of Cygnus X-1's black hole is now basically certain, settling a light-hearted bet between physicists Kip Thorne and Stephen Hawking (in Thorne's favor).

SPACE & SOCIETY
Sequestration Impacts Astronomy, Space Science

The U.S. federal budget cuts imposed by sequestration are having major impacts on both ground- and space-based astronomy, turning the budget screws tighter on the two largest U.S. funding agencies for astronomy: the National Science Foundation (NSF) and NASA.

NSF funding forms the public-funding backbone of U.S. ground-based astronomy. It underwrites national facilities open to all U.S. astronomers and awarded about $80 million in research grants in 2012. In March Congress partially offset NSF's 5% sequestration cut by a last-minute increase in its 2013 budget, but the net result is still a 2.1% cut relative to 2012, and it comes awkwardly in the middle of the fiscal year. "The most immediate impact will be on our small- and mid-scale research grants programs," says James Ulvestad, director of the organization's astronomy division.

NASA responded to its own mandatory 5% cut by suspending many education and public-outreach activities. It also eliminated international travel and limited NASA attendance at any domestic conference to 50 personnel. NASA managers have further announced a string of cancelled conferences, including December's Kepler Science Conference and the annual Sagan Exoplanet Summer Workshop.

"Conferences are where part of the scientific process happens," says Peter Plavchan (Caltech), a researcher of exoplanets who has authored four papers using Kepler data. "Canceling this conference will slow down the process of discovery, and taxpayers won't get the most new discoveries for their dollar as a result."

Perhaps the most politically embroiled impact of sequestration on space science has been on the budget for NASA's solar system division. This area has suffered severe cuts in recent years, caused in part by the cost overruns of the James Webb Space Telescope, which caused tension between supporters of astrophysics and planetary missions.

The Obama administration's FY 2013 budget request slashed planetary funding by $300 million, or 20%, to $1.2 billion. But a bipartisan group of supporters in Congress countered by inserting an additional $222 million into its FY 2013 appropriations bill, which President Obama signed in March.

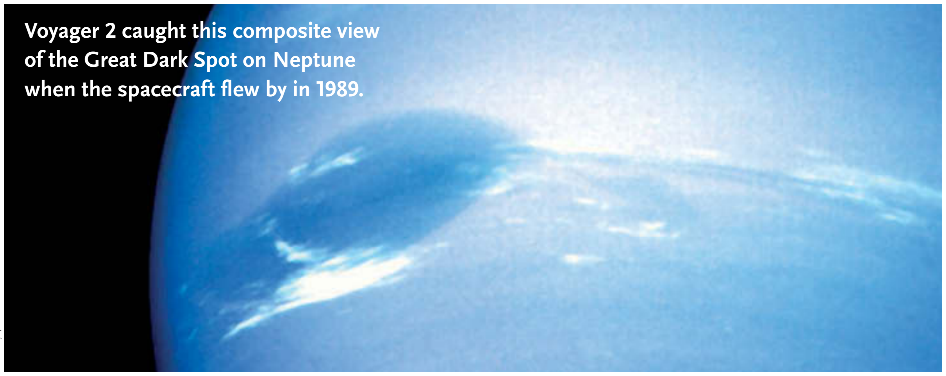
However, most of that help won't reach its target. Sequestration offered NASA an opportunity to reshape its appropriations internally. Instead of spreading the cuts across all divisions equally, NASA's operating plan for the rest of FY 2013 singles out planetary science for a 15% cut, according to a copy of the plan obtained by the Planetary Science Institute's director, Mark Sykes. The result wipes out all but $3.7 million of the additional $222 million allocated by Congress.

In other words, says Sykes, the Obama administration and NASA used the sequestration cuts as a means to evade Congressional intent. "I thought it was disdainful," says Sykes.

One thing sequestration will not affect, Ulvestad says, is NSF's plan to divest by 2017 its interests in several ground-based facilities, including the Green Bank Telescope, the Very Long Baseline Array, and three optical telescopes at Kitt Peak National Observatory in Arizona. That timetable was set to allow these facilities time to seek new partnerships and operating models, which they are already doing.
■ **MARK ZASTROW**

Read more about sequestration's effects at skypub.com/sequester.

SOLAR SYSTEM | Uranus & Neptune Have Thin Weather Layers



Voyager 2 caught this composite view of the Great Dark Spot on Neptune when the spacecraft flew by in 1989.

NASA / JPL

Careful analysis of the gravity fields of our solar system's ice giants suggests that weather patterns on these worlds are confined to a layer less than 1,000 km (600 miles) deep, far less than the depth of their enormous atmospheres.

Both planets display fast winds streaming east and west in their outer atmospheres, much like those on Jupiter and Saturn. Neptune shows more vigorous cloud activity than its near-twin — one jet stream was clocked at 2,500 km per hour, making Neptune home to the fastest wind measured in the solar system.

The question has been, does the energy to drive these planets' jet streams come from their deep interiors, drawing on the heat inside, or is the weather layer skin-deep, powered only by the weak light of the faraway Sun? Five researchers led by Yohai Kaspi (Weizmann Institute of Science, Israel) have taken a fresh look at this question and conclude in the May 16th issue of *Nature* that the weather layers are indeed shallow.

The team combined Voyager 2 and Hubble Space Telescope observations of the planets' wind patterns with theories of global circulation, which were developed by Kaspi and coauthor Adam Showman (University of Arizona) to predict what the gravitational fields of Neptune and Uranus should look like. Then they compared those models to actual Voyager 2 gravity data. During each planet flyby, precise tracking revealed how the gravitational pull of Uranus and Neptune altered the spacecraft's trajectory. This in turn provided a rough estimate of the distribution of "rock," ice compounds such as water and ammonia (virtually all in liquid form deep down), and gas inside each globe.

The researchers included in their analysis a fudge factor for the mass of each planet's upper atmosphere, which can vary because — just as on Earth — regions of high and low pressure, and thus density, are in constant motion. Deeper weather layers mean more mass is sloshing around, which in turn affects how the planet's gravity pulled on the spacecraft. The best match came when they restricted the dynamic weather layer to just the outermost 0.15% of Uranus's total mass and 0.2% of Neptune's.

The result is at odds with a longstanding notion, first proposed by theorist Fritz Busse in 1976, that the fluid interiors of these planets work like a set of nested cylinders rotating at different rates.

■ **J. KELLY BEATTY**

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

IN BRIEF

Curiosity readies for a long drive. Its tests and calibrations complete, NASA's Curiosity Mars rover is switching to long-distance mode as it heads for its main objective, the 5-kilometer-high (3-mile-high) mound of layered sediments called Aeolis Mons ("Mount Sharp"). The mount is about 8 km southwest of the rover's current position, and reaching it might take 10 to 12 months — assuming no extended sightseeing en route.

■ **J. KELLY BEATTY**

Radiation risk survivable for future Marsonauts. Recordings from Curiosity's Radiation Assessment Detector (RAD) during its 8½-month interplanetary cruise suggest that galactic cosmic rays and high-energy solar particles will give future astronauts a significant but survivable dose of radiation on a round-trip journey to Mars. As reported by Cary Zeitlin (Southwest Research Institute) and colleagues in the May 31st *Science*, RAD recorded the equivalent of 0.466 sievert while en route to Mars. NASA draws the line at 1 sievert of accumulated radiation exposure over an astronaut's entire career, a dose that statistically increases the chance of cancer-induced death by 3%. The team estimates that the shortest possible round-trip mission (360 days) would expose the crew to about 0.7 sievert.

■ **J. KELLY BEATTY**

Visiting Earth, 1998 QE_2 brought a friend. On May 31st, one of the largest known near-Earth asteroids (NEAs) passed our planet at a distance of 5.8 million km, about 15 times farther than the Moon but close enough for radar studies. Observations just before closest approach by Marina Brozović (Jet Propulsion Laboratory) and colleagues using the 70-meter antenna at Goldstone, California, revealed that the asteroid has a satellite. The moonlet is about 600 m wide, one-fifth the asteroid's 3-km girth. Binary asteroids are not rare among NEAs: statistically, about one-sixth of objects at least 200 m wide have a sidekick. The radar observations should reveal details down to several meters wide on the parent body.

■ **J. KELLY BEATTY**

Hot Jupiters act like toasters. Gas giants closely orbiting their stars might be strangely inflated because they heat up electrically like toaster coils plugged into their stars via the power lines of the stellar wind, Derek Buzasi (Florida Gulf Coast University) proposed June 4th at the American Astronomical Society meeting. A decade's worth of transit observations have shown that, when planets hug their stars too tightly, they puff up bigger than the incoming energy can explain. Astronomers have proposed a variety of interior heat sources to explain the mystery, from heavy-element makeups that would absorb more starlight to tidal heating. Buzasi's model suggests that these planets are instead heated by an electric current running deep through the planet's interior, created when the planet's magnetic shield links up with the wind of charged particles flowing from the star. A weaker but similar circuit exists high in Earth's atmosphere.

■ **MARK ZASTROW**

Milky Way Galaxy grows a branch. New radio observations indicate that the Sun's galactic neighborhood is bigger and more important than astronomers thought, Alberto Sanna (Max Planck Institute for Radio Astronomy, Germany) reported June 3rd at the American Astronomical Society meeting. Sanna and his colleagues carefully calculated distances to nearby star-forming regions as part of the Bar and Spiral Structure Legacy (BeSSeL) survey, an ongoing project to map the Milky Way. The new data suggest that the Orion Spur, once thought to be merely a hiccup between the Sagittarius and Perseus Arms (see the July issue's foldout), is more likely a full-fledged branch of the Perseus Arm.

■ **CAMILLE M. CARLISLE**

IN BRIEF

Dispute continues over SS Cygni. New radio observations by James Miller-Jones (Curtin University, Australia) and his colleagues feed the debate over the true distance to one of the most-watched variable stars. SS Cygni is an amateur favorite and a well-known dwarf nova, in which material siphoned off a main-sequence *M* star occasionally dumps onto a white dwarf companion, fueling an outburst. But in 1999 Hubble Space Telescope observations pushed the binary's distance back, ruining the theoretical match for how bright and voracious the system is. Reporting in the May 24th *Science* and thanks to AAVSO collaboration, the team determined a distance of about 370 light-years, more palatable to theorists than the 500-plus from Hubble. But it's unclear why Hubble's measurement would be wrong (not everyone's convinced it is) and whether observing in radio unduly limits what the team can detect. Everyone hopes the ESA's Gaia mission, set to launch next month, will solve the conundrum.
■ **MONICA YOUNG**

Herschel kicks the light bucket. On April 29th the largest infrared space telescope yet launched ran out of cryogenic coolant, permanently ending its science operations. ESA's Herschel launched in 2009 with the Planck satellite (June issue, page 10), and its 3.5-meter primary mirror worked with two spectroscopy-capable cameras and a high-resolution spectrometer to observe the far infrared. The instruments were cryogenically cooled by superfluid liquid helium to –271°C (–456°F), which mission planners estimated would be exhausted in late March. Herschel studied star and galaxy formation and the chemical makeup of both solar system objects and the larger universe. After using the defunct scope to test some hardware and software ideas for future missions, the team sent Herschel into its "disposal" solar orbit on June 17th.
■ **CAMILLE M. CARLISLE**

STARS | A Surprise Class of Variables

ESO

Long-term observations of the open cluster NGC 3766 (above) have shown that 36 of its stars belong to a mysterious new class of variables.

Astronomers have discovered new kids on the variable-star block, living in a neighborhood that they thought such stars wouldn't inhabit.

The kids are 36 young, massive *B* and *A* stars, still fusing hydrogen in their cores and having temperatures roughly twice that of the Sun. Their light varies by a few thousandths of a magnitude with periods ranging from 0.1 to 1.1 days. One-third of these stars have multiple periods of variability. The changes are small, but they shouldn't be happening at all.

The stars came to light (no pun intended) as part of a seven-year survey conducted by Nami Mowlavi (Geneva Observatory, Switzerland) and colleagues with the 1.2-meter Swiss Euler telescope in Chile. From 2002 to 2009, the team pointed the telescope at 27 open clusters, regions of fairly recent star formation (like the Pleiades). The new study, appearing in the June 12th *Astronomy & Astrophysics*, focuses on NGC 3766, which lies about 7,000 light-years away in Centaurus.

The easiest explanation for this variability (although certainly not the only one) is that the stars pulsate. Stars generally pulse for two reasons, says Pieter Degroote (KU Leuven, Belgium), who works on variable stars. One, the "boiling" convective motions in the surface act like constant punches that set the star to vibrating at resonant frequencies. This process happens for cooler main-sequence stars and older, fluffier red giants.

Two, some stars contract and expand in a cyclic, engine-like process. Normally, a star's gravity pulling inward and its heat pressing outward minimize this effect. But if the temperature is just right in certain zones inside the star, the balancing act becomes wobbly. The heat instead ionizes atoms, using up the energy the star needs to counter gravity. The star continues shrinking until it heats up enough to push its layers back out.

The ionized atoms fall into three categories: hydrogen, helium, and heavier "iron-like elements." Certain temperatures and pressures are required to ionize each. The new stars fall awkwardly between two realms — they're too hot for helium ionization (found in Delta Scuti variables) and too cool for the iron-like one (found in slowly pulsating *B* stars).

"If there are stars pulsating there, we either do not have a good enough knowledge of the pulsation mechanism, or our knowledge of the interior of the star is not good enough — or most likely both," Degroote says.

Degroote and his colleagues discovered other variable stars in this presumed gap in 2009, but he says that those results were shakier. With more certain stellar temperatures and distances, the new observations are more suited to exploring this question.

The authors suspect fast rotations might sustain these stars' pulsations, but the final answer remains unknown.
■ **CAMILLE M. CARLISLE**

EXOPLANETS | Alien Dust Trap Finally Detected

ESO / LUÍS CALÇADA

This artist's illustration shows the dust trap (glowing section) in the system Oph IRS 48. The dust trap provides a safe haven for tiny rocks in the disk, potentially allowing them to clump together and grow to sizes that allow them to survive long-term.

New ALMA observations reveal a huge dust pileup that could solve a longstanding dilemma, Nienke van der Marel (Leiden University, the Netherlands) and colleagues report in the June 7th *Science*.

We know that dusty disks form around many young stars, and that in some of these disks young planets are carving gaps. But the details behind how little dust clumps in these disks build up into planets remain a mystery.

The astronomers observed the young star Oph IRS 48, which is roughly 15 million years old and twice as massive as the Sun. It's surrounded by a wide disk, with an inner gap reaching from the star out to about 25 Earth-Sun distances. The team created a high-resolution map of the disk's radio emission at three wavelengths to trace the distribution of its material.

Each wavelength is sensitive to different sizes of grains. At a wavelength of 0.44 mm — where sand-grain-size particles emit strongest — the team found a large, banana-shaped asymmetry near the disk's inner edge. The other two wavelengths, sensitive to molecular gas and smaller dust grains, did not show this asymmetry. The feature spans nearly one-third of the inner rim of the disk and is more than 100 times brighter than the opposite side.

The ALMA observations are the first smoking-gun signature of a so-called "dust trap." A dust trap is a mechanism, until now just theoretical, that herds together larger dust grains, keeping them from spiraling in toward the star. These larger particles — the exact size depends on the distance from the star — are victim to drag forces that smaller particles typically escape as they travel around the gas disk.

The team suggests that the gravitational influence of a massive planet or brown dwarf orbiting in the disk's gap could create the trap by making a hurricane-like vortex on the disk's edge that would stop the inward-migrating particles. The particles could then pile up in this trap and have time to coalesce into planetesimals.

■ **JOHN BOCHANSKI**

EXOPLANETS | No Planet for Alpha Centauri B?

The uncertain tale of our closest exoplanet neighbor — is it there or not? — is still a cliffhanger. Last October, astronomers announced the potential discovery of a hot Earth-mass world circling Alpha Centauri B (January issue, page 14). Now, an independent analysis of the data in the June 20th *Astrophysical Journal* has failed to confirm the planet's existence.

There are many ways a star can fake the slight wobble in its light caused by the gravitational pull of an unseen planet. Alpha Cen Bb's original detection, made by Xavier Dumusque (now at the Harvard-Smithsonian Center for Astrophysics) and colleagues, was a heroic effort to strip away all sources of "jitter." The work pushed the limits of modern technology (and statistics) and was "a paper with a lot of firsts in the way that they tried to deal with the stellar signal," says Suzanne Aigrain (University of Oxford, UK), an astronomer not connected to either study.

But even as scientists welcomed the exciting find, many (including the discoverers) acknowledged that it needed confirmation. To aid this, the authors made their data publicly available for analysis.

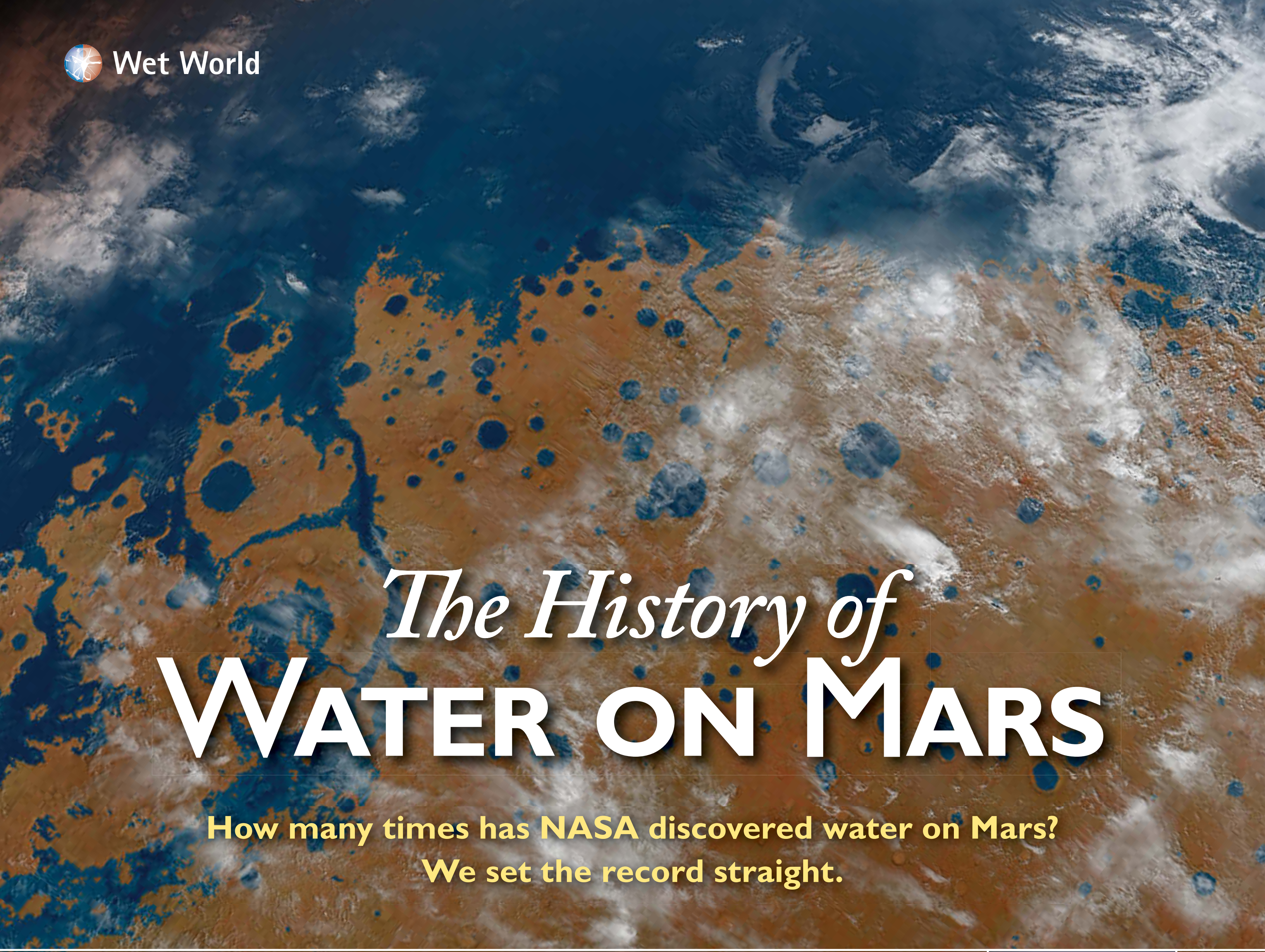
Artie Hatzes (Thuringian State Observatory, Germany), driven by a "gut feeling of skepticism," decided to take his own crack at interpreting the observations. On his first try, using methods similar to the original team's, he found the planetlike signal. But on his second try he used a more targeted method, breaking the data up and removing the jitter from one data chunk at a time. When he reassembled the pieces, he couldn't find the planet at all.

To test his method's strength, Hatzes also created simulated data sets, inserting fake planet signals into the actual data. He found that his method should have detected Alpha Cen Bb.

Dumusque stands by his team's work but says that Hatzes' analysis is "very healthy for science," because this kind of back-and-forth is always fruitful.

So what will resolve the matter? On this, everyone agrees: more data. But as soon as year's end Alpha Cen B will be too close to its binary partner Alpha Cen A to measure the star's wobble without contamination by light from the brighter companion. Astronomers must wait several years before the stars separate. ✦

■ **MARK ZASTROW**



The History of WATER ON MARS

How many times has NASA discovered water on Mars? We set the record straight.

ITTIZ / WIKIPEDIA COMMONS

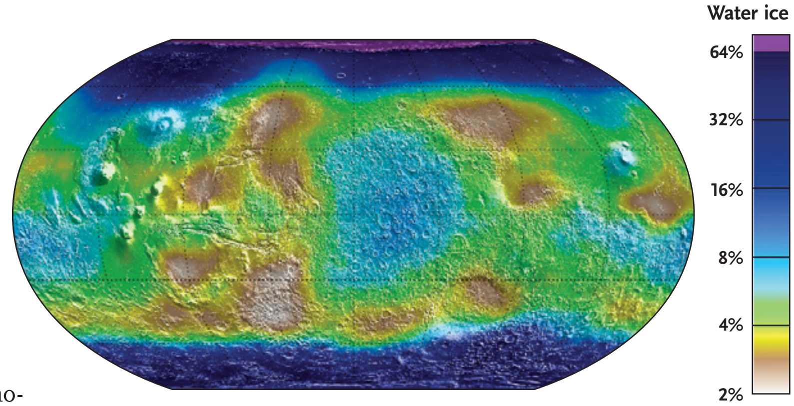
Emily Lakdawalla

Water on Mars? Again? Didn't we discover that already? NASA has "discovered water on Mars" so many times over the last two decades that some editors have forbidden their writers from covering the topic. Water on Mars today is easy for anyone to spot: you can see it plainly on Mars through a small telescope. The white polar caps are made mostly of water ice, as are the thin blue-white clouds.

In fact, water is everywhere in the solar system. The moons of the outer planets are made mostly of water ice, as are comets and trans-Neptunian objects. Water is bound into the minerals on asteroids and rocky planets. There is even water ice at the surface on the Moon and Mercury. If water is common, why are we fascinated with water on Mars?

It's because most people are not very interested in ice water, mineral-bound water, and intensely high-pressure water sealed under thick, icy crusts. We want running, swirling, pooling, eroding, dissolving, chemistry-facilitating liquid water. Beyond Earth, Mars is the only place where water has done nearly all of the myriad things that it does on Earth: it has rained, snowed, run off, eroded hills, filled basins, hosted chemistry, and glued sediments into rocks. These sedimentary rocks preserve the evidence of water's activity billions of years ago.

But Mars is not Earth and there are crucial unanswered questions. Did Mars's liquid water persist for millions of years or more in seas or oceans? And did its presence give life a chance to originate and, for a little while, flourish? If liquid water persisted on Mars, and we don't find evidence for life there, what does that mean? Those questions have motivated modern Mars exploration.



NASA / JPL-CALTECH

WET MARS ***Left*****: Mars's surface is a barren desert today. But 3 billion years ago, large bodies of water may have covered much of it, including most of the northern hemisphere, as depicted in this illustration.** ***Right*****: This map from Mars Odyssey's neutron spectrometer shows the location of water ice near the surface. As expected, there is lots of ice at high latitudes, but scientists were surprised by the relatively high abundance of subsurface ice around the equator.**

Water Everywhere, But Not a Drop to Drink

Cold and hyper-arid, Mars is inhospitable today. Its atmospheric pressure is so low (less than 1% that at sea level on Earth) that an open container of water exposed on its surface would boil or evaporate faster than it would freeze. But water can be found nearly everywhere on Mars, not just in its polar caps.

Most of Mars's remaining water supply is hidden underground, frozen into a global ice table. In many places, the ice is deep below the surface, but in the vast northern lowland plains it lies just centimeters underground. Polygonally patterned ground hints at its presence. More evidence for near-surface ice came from NASA's 2001 Mars Odyssey orbiter, which detected large amounts of hydrogen buried in the top meter or so of soil.

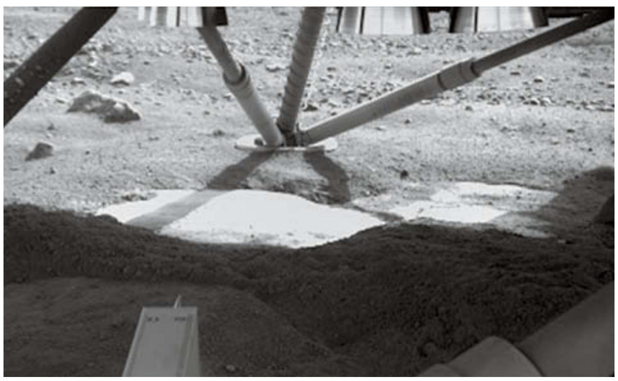
This discovery prompted NASA to launch the Phoenix lander to Mars in 2007. When Phoenix's robotic arm imaged the lander's footpads on the fifth day after landing, scientists discovered that the retrorockets had exposed a flat layer of bright ice. Although the team had been expecting to find some ice, the surprising sight of such bright, pure ice inspired them to name the deposit "Holy Cow!"

In addition, NASA's Mars Reconnaissance Orbiter (MRO) has spotted 18 fresh craters whose centers are blue-white with pure, fresh ice. When researchers repeated the observations months or years later, the ice had either vaporized or been covered by settling dust.

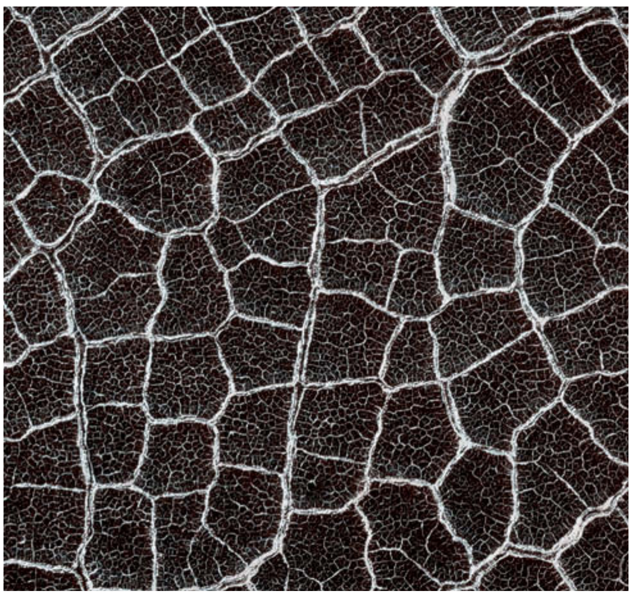
Ice is so ubiquitous beneath the northern plains that NASA's Viking 2 lander — which touched down at latitude 48° north — might have been able to investigate it if scientists had only known it was there. If Viking 2 had been commanded to dig its trench just 10 centimeters (4 inches) deeper, it might have struck ice. After a journey of hundreds of millions of kilometers, we probably stopped 10 cm short, and the discovery of ground ice was delayed by a quarter century.

Other features on Mars hint at near-surface ground ice. Glacial landforms such as moraines and pingos dot both northern and southern landscapes. It's difficult to know whether they are active today, but their relative dearth of impact craters suggests the ice has moved in the geologically recent past.

But evidence for liquid water is harder to find. Year after year, we see small gully features form on steep, equator-facing canyon and crater walls. Are they carved by water flowing downhill? Not all scientists are convinced. Some speculate that they exist where salt-rich soil depresses the freezing point of water, making brines

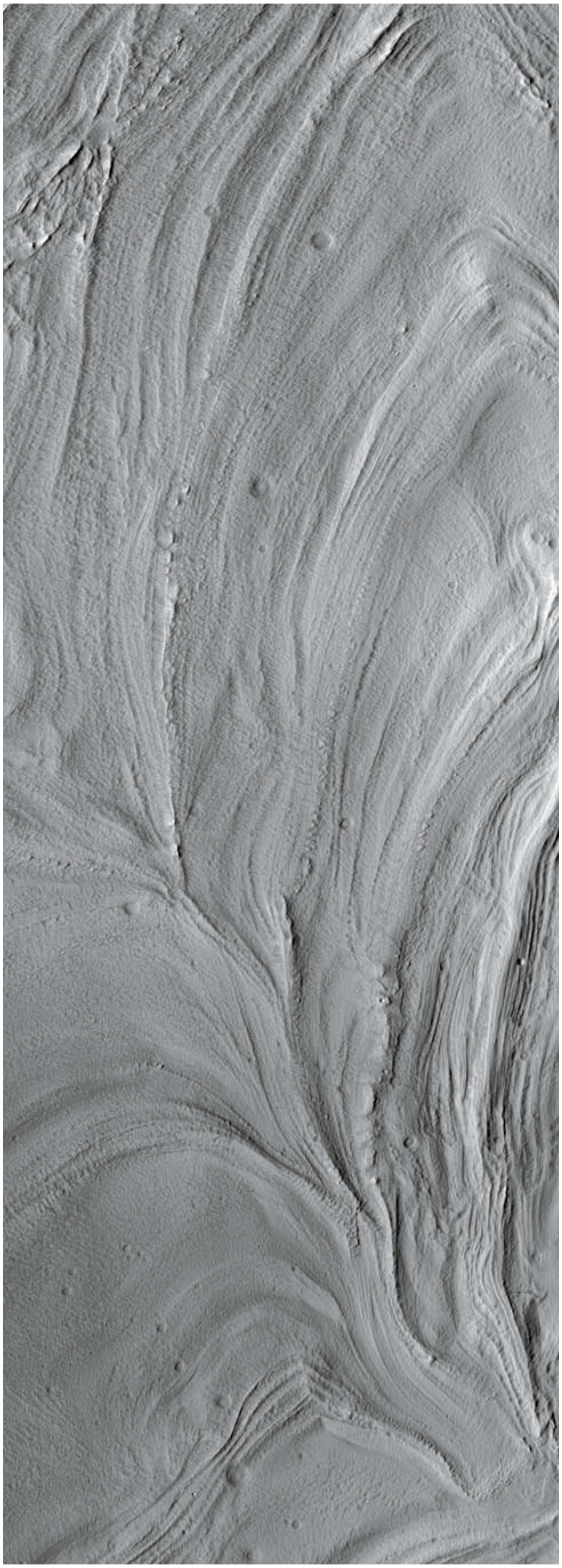


NASA / JPL-CALTECH / UNIV. OF ARIZONA / MAX PLANCK INST. / ADDITIONAL PROCESSING BY EMILY LAKDAWALLA



NASA / JPL-CALTECH / UNIVERSITY OF ARIZONA

SIGNS OF ICE ***Above*****: The Robotic Arm Camera on Phoenix Mars took this shot of a flat slab of water ice just centimeters below the surface.** ***Right*****: As on Earth, Mars's high latitudes often feature terrain shaped like polygons. Ice forms these polygons through complex processes involving the way water freezes, thaws, and exerts stress on its surroundings. This image was taken by the high-resolution camera (HiRISE) on Mars Reconnaissance Orbiter.**



NASA / JPL-CALTECH / UNIVERSITY OF ARIZONA

that melt at lower temperatures. The most recent work suggests that brines aren't needed; these gullies extend when, and only when, the uppermost layer of soil is at or above pure water's freezing temperature. But even if the gullies represent current sources of liquid water on Mars, they are transient, tiny, possibly salty trickles — hardly a paradise for life.

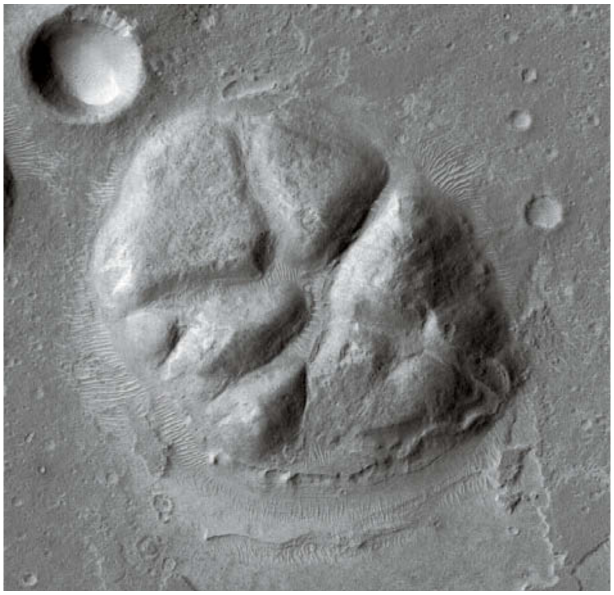
A Wetter Past

Ancient Mars differed considerably from modern Mars, and its relics are everywhere. Like the Moon and Mercury, Mars bears ancient, cratered terrain, largely confined to its southern hemisphere, that is scarred by huge numbers of overlapping impact craters. The craters bear witness to a time when the entire solar system suffered through an intense bombardment by wayward asteroids and comets (*S&T:* August 2011, page 20).

But look closely at the Moon, Mercury, and Mars, and you'll see the record of quite different histories. The Moon's cratered highlands have changed little since their formation. Mercury's cratered landscape has been flooded by countless volcanic eruptions and then wrinkled by planetary shrinkage. In contrast, Mars's southern highlands have been dissected by branching valleys.

At first glance, Mars's valley networks look like terrestrial river systems. But when scientists examined them closely in Viking imagery, they seemed geologically primitive. The valleys had few branches, and large areas lacked any valleys at all. Many geologists concluded that the networks were produced by infrequent releases of ground-

ICE FEATURES ***Left*****: This HiRISE image shows a glacial-like flow on the flanks of the giant volcano Arsia Mons.** ***Below*****: This image from MRO's Context Imager shows a 3-km-wide feature that closely resembles pingos found in Earth's Arctic regions. Pingos are mounds of ice covered by dirt and rocks.**



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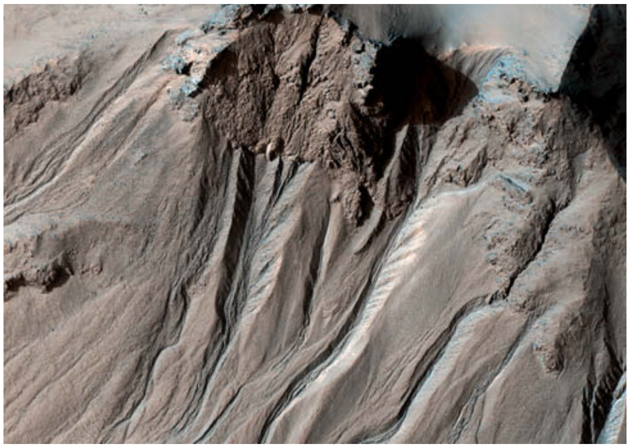
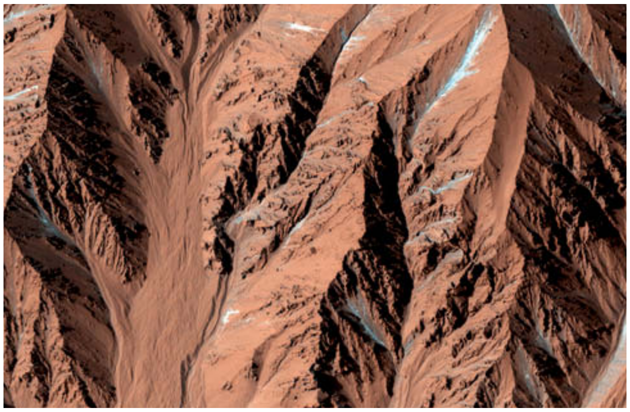




NASA / JPL-CALTECH / UNIVERSITY OF ARIZONA (3)

GULLIES High-resolution images taken from NASA orbiters have revealed numerous gullies on the Sun-facing walls of craters and canyons. Scientists are still debating their origin, but many geologists think they form when an aquifer of water bursts through a slope, creating a mini-avalanche of water mixed with sediments that flows downhill. These images come from HiRISE.

water. Perhaps the occasional large impact briefly thickened Mars's atmosphere, encouraging a few years' worth of greenhouse warming, rainfall, and runoff before the air thinned again, leaving Mars as cold and dry as before.

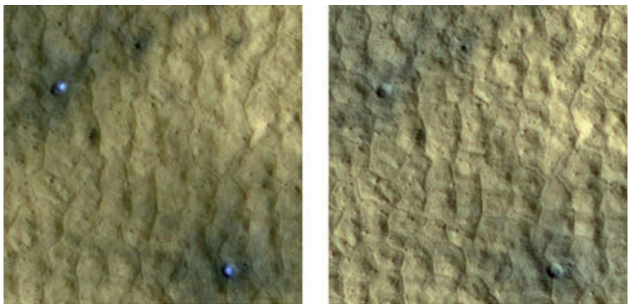
But new data have changed this view. Maps based on Mars Odyssey images show that the valleys link into densely branched drainage networks, with the smallest channels reaching right up to the divides between watersheds. Their complexity rivals Earth's river networks. Intriguingly, most valley networks appear to have formed within a narrow time span of perhaps 200 million years. And that 200 million years was relatively late — *after* Mars suffered most of its major impacts around 3.8 to 3.6 billion years ago. Something other than impacts was responsible for the warm world that spawned the valley networks.

Turning on the Water Cycle

Climatologists trying to explain a warm, wet early Mars run up against the "faint young Sun paradox." According to stellar-evolution models, the Sun should have been 30% fainter in its youth, while also producing more ultraviolet radiation that would have stripped away a carbon-dioxide-rich atmosphere. But if the valley networks actually formed late, after the major impacts, then they formed after the Sun had begun to burn brighter.

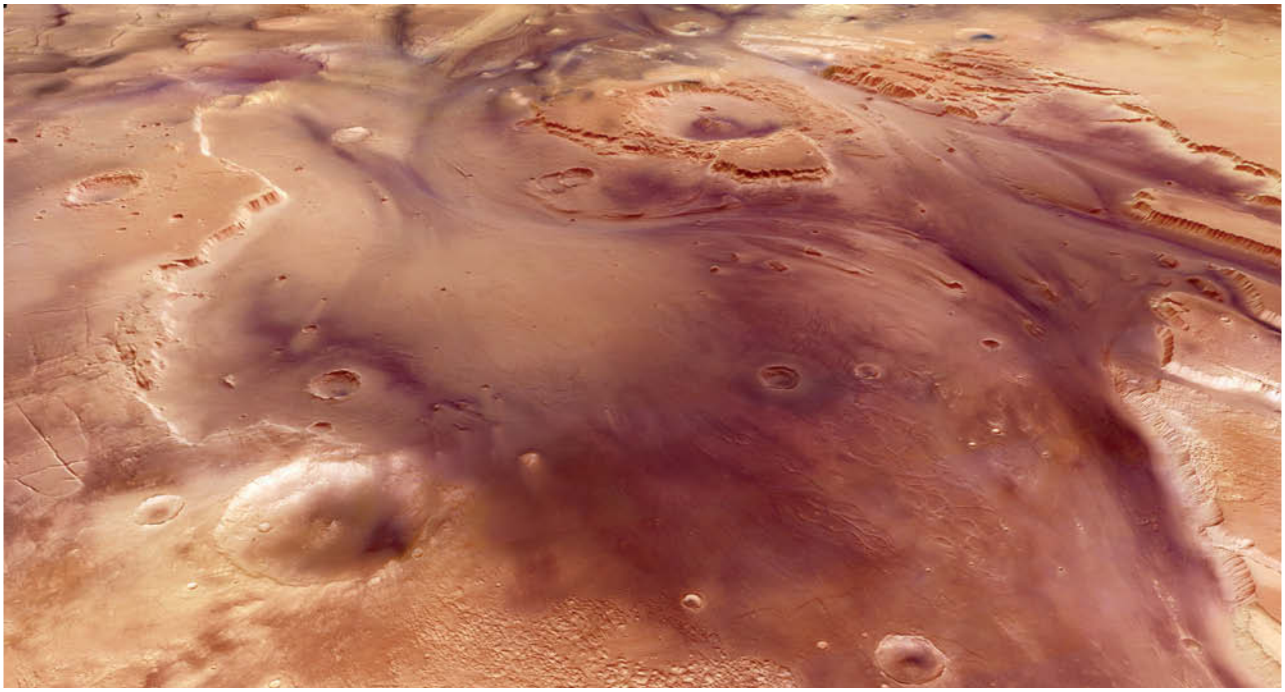
Mars's giant Tharsis volcanoes could have helped make Mars wet. The Tharsis region is a monstrous construct of overlapping volcanoes and lava flows that built up over billions of years. As impacts waned, volcanism stated to dominate Mars's geology. The boundary between these ages is thought to be about 3.8 billion years ago.

To see more images showing evidence for water on Mars, visit skypub.com/marswater.



NASA / JPL-CALTECH / UNIV. OF ARIZONA

DISAPPEARING ICE These two HiRISE images were taken 15 weeks apart in 2008. The *left* image shows two mid-latitude craters with freshly exposed ice (bluish spots). But the ice vaporized over time, leaving just dust behind on the crater floors (*right*). The craters are only 4 meters across and 50 centimeters deep.



ESA / DLR / FU-BERLIN / GERHARD NEUKUM

OUTFLOW CHANNEL After the river valleys dried up, Mars experienced occasional catastrophic floods, which carved deep, wide outflow channels such as Kasei Valles, imaged here by the high-resolution stereo camera on ESA's Mars Express orbiter.

Through Mars's middle age, volcanic eruptions pumped tremendous quantities of gases into the atmosphere, primarily water, carbon dioxide, and sulfur dioxide. These gases could have thickened the atmosphere just as a brightening Sun was warming Mars.

As Tharsis volcanoes were erupting, Mars's atmosphere grew faster than the Sun could destroy it. Water started to precipitate as snow or rain. Wherever it rained or the snow melted, running water wore away at Mars's soil. Water roiling with sediments quickly eroded environments that had been battered by impacts and decayed in hyper-arid conditions. The running water transported the sediment downstream. Water filled up craters such as Gusev and Gale to form lakes, and then they overflowed, flooding areas further downhill. Water eventually reached the great basin of the northern lowlands and perhaps even filled it up to form an ocean. And that's when a positive feedback cycle really got going. Basins full of water produced humid air that, when transported to higher elevations and cooler temperatures, dropped rain or snow.

NASA / JPL-CALTECH / ARIZONA STATE UNIVERSITY

RIVER VALLEYS Narrow, branching valleys are common in Mars's equatorial regions. The preponderance of evidence suggests they were carved by rainfall-fed rivers about 3.5 billion years ago. This image was taken by Mars Odyssey's THEMIS camera.

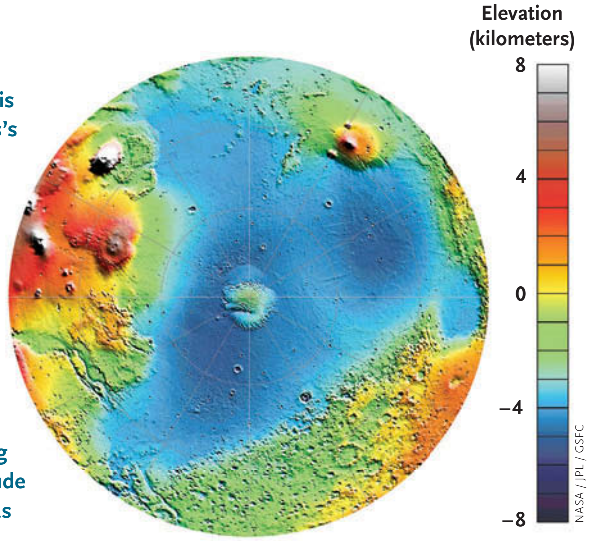
Did a northern ocean ever exist? There's circumstantial evidence for shorelines — breaks in slope — around the northern lowlands. Geomorphologists have also mapped delta-like deposits at the termini of valleys and found that most cluster at a common elevation — a sign that they all emptied into a single ocean. But many scientists remain unconvinced; the question of whether Mars ever had a long-lived northern ocean remains hotly debated.

Paradise Lost

Even if Mars was once a paradise, this hospitable environment has since been lost. Valley-network activity waned over time. Any magnetic field Mars may have had was lost once the core cooled and solidified, and the planet's early thick atmosphere was stripped away by the solar wind. The style of water erosion shifted from the valley networks to an entirely different kind of landform, the outflow channels. Outflow channels are enormous — up to 150 km wide and 2,000 km long — and must have been carved by catastrophic releases of massive quantities of water. They formed mostly during Mars's middle age, but a few have formed in geologically recent times.

Unlike valley networks, outflow channels probably required a frozen climate. A thick cryosphere of ground ice could have trapped and pressurized vast quantities of liquid water. An impact or an underground squirt of volcanic magma could have suddenly broken or melted a direct path to the surface for an underground lake's worth of high-pressurized water to traverse. This is particularly true in Mars's southern highlands; crater-forming impacts shattered the bedrock, leaving it highly porous, able both to store lots of water and to release it all at once in catastrophic floods. Such floods might have temporarily filled Mars's northern basin, but the water was short-lived. In just a couple of years, the water might have seeped back underground, froze, or evaporated into the atmosphere, where it precipitated back out as rain, snow, or ice and got locked up in the cryosphere again.

And yet NASA's rovers have found evidence that Mars continued to produce sedimentary rocks even after its warmer, wetter climate shut down. All of the sedimentary rocks seen by Spirit and most of those seen by Opportunity formed after Mars's most ancient, wettest age. Sedimentary rocks usually require some water to form. Many of Mars's sedimentary rocks contain minerals whose crystal structures include water molecules or hydroxyl (OH^-) ions. What could have deposited these sediments and then cemented them into place? The answer may have to do with Martian climate change.



NORTHERN PLAINS Scientists constructed this topographic map of Mars's northern hemisphere using data from Mars Global Surveyor's laser altimeter. It clearly shows the remarkably flat, low-lying plain that covers much of the north. Many dried-up channels near the equator lead directly into this basin, prompting many scientists to conclude that the blue, flat area was once an ocean.

Milanković Goes to Mars

Earth's climate shifts from warmer to cooler on tens-of-thousands-of-year swings known as Milanković cycles, named for Serbian scientist Milutin Milanković, who developed the idea in 1920s. Earth's axial tilt, along with the eccentricity and precession of its orbit, varies over a small range, which affects how much solar energy reaches Earth at different times in its seasons at different latitudes. Milanković cycles clearly influence Earth's climate; variations in isotopes of oxygen and carbon, plant activity, and the advance and retreat of glaciers all correlate strongly with the amount of solar insolation predicted by Milanković's theory.

Mars has even more extreme Milanković cycles. Mars's orbit can shift so that it's as much as 50% farther from the Sun at aphelion than at perihelion. And without the presence of a large moon to stabilize the orientation of Mars's rotational axis, at times the axis has been tilted nearly horizontal. In fact, Mars's current moderate axial tilt of only 25° is unusual. Mars spends more of its time with a relatively high tilt of 40° to 50°. During these

Will Curiosity Find Evidence for Life?

Many observers openly hope that Curiosity will spot fossil evidence for Martian life. Sadly, even if Mars once teemed with life, Curiosity is unlikely to spot it. For one thing, it has no instruments capable of observing individual microbe-sized fossils. Preservation is a problem, too; even on Earth, it's exceedingly rare to find evidence for ancient life in nearly 4-billion-year-old rocks.

On the other hand, because Mars's geology largely shut down eons ago, its ancient rocks are in much better condition than Earth's. Martian rocks have suffered comparatively little insult from heat or pressure since they formed. At Gale Crater, Curiosity is examining rocks as old as life on Earth. Those rocks record conditions that might have been warm and wet. They are the kinds of rocks that could preserve the ingredients from which Earth life must have been made.

Even in the likely event that Curiosity finds no evidence for life on Mars, it's studying rocks that changed little over billions of years and that record the geologic and climatic conditions under which terrestrial life got its start. There's nowhere on Earth we can do that. Our best hope for understanding what things were like when life started on Earth rests, ironically, on another planet. Although we're curious about Mars for its own sake, we're ultimately studying it because it's the best place to answer the question: how did we get here?

Curiosity at John Klein

NASA / JPL-CALTECH / MSSS

Eroding Mars's Atmosphere

Today's Martian atmosphere is enriched in deuterium, an isotope of hydrogen bearing a proton and a neutron, instead of the more common flavor of the element, which consists of a single proton. The most recent isotopic measurement, by Curiosity, shows a factor of five enrichment of deuterium. Light hydrogen more readily escapes the atmosphere than heavy hydrogen, so the deuterium enrichment tells us that Mars has lost most of its atmosphere over time. NASA's upcoming Mars Atmosphere and Volatile EvolutioN (MAVEN) mission, scheduled for a November 2013 launch, will help constrain exactly how much water was lost to the cosmos.

periods, most of the planet bakes in near-continuous sunlight for half of the year and hides in darkness for the other half. Polar caps can't exist under these conditions; instead, any year-round water ice forms within a band encircling the equator. Climate variations move Mars's reservoir of frozen water back and forth from the poles to the equator. From time to time, conditions may allow ground ice to flow more quickly than usual, creating some of the periglacial features at Mars's high latitudes.

Once in a great while, under marginal conditions barely more clement than today's, snowpack near the equator could melt to form short-lived flows of water. It may only occur during very brief intervals in the Milanković cycle, when Mars's axis is strongly tilted, its orbit is at its most eccentric, and when the equinoxes happen to line up with Mars's aphelion and perihelion. Then, and only then, for just a few weeks, a little water melts every day, trickles downward into the ground, and most likely freezes or vaporizes within the day.

Mars's loose windblown dust is rich in highly soluble minerals such as sulfates and salts. The brief wetting could dissolve those minerals, and then glue the sand grains together with mineral cement. Piles of dust and windblown sand became frozen in time, locked in the position they held that one time when Mars's crazy orbital gyrations briefly synced to create a transient climate where snow could melt. Many of the bright sulfate sandstones studied by Opportunity exhibit large crossbeds typical of such windblown sands.

NASA / JPL-CALTECH / MSSS

ANCIENT STREAMBED The Mastcam on NASA's Curiosity rover took this image of an ancient Martian streambed on September 14, 2012. This outcrop consists of sedimentary rock with rounded pebbles and gravel that were probably transported in fast-moving water.

Curiosity Follows the Water

Under the rare climatic conditions that permit snow to melt anywhere on Mars, Gale Crater is one of the places where you would expect to find water (*S&T:* November 2012, page 20). But melting water would've been an exceedingly rare event in a hyper-arid environment, happening only once every several millennia. Such an environment would not preserve evidence for ancient life, if such life ever existed.

Yet NASA's rover Curiosity has already found evidence for an even wetter environment. As Curiosity began its traverse across the floor of Gale Crater, it spotted rocks bearing rounded cobbles, too large to have been transported and rounded by wind. Those rocks must have tumbled in fast-moving streams. The first-drilled mudstones at the site named John Klein likely settled out of standing or very-slow-moving water. Many of the rocks have been wetted at least once since they solidified. Mineral-saturated groundwater passed through, leaving its mark in the form of gypsum-filled veins. Did that water come from above, seeping downward from a crater-filling lake, or did it well up from below when the rocks were deeply buried? The Curiosity team is working to answer that question.

The current thinking is that the lowest part of Gale's central mountain dates to the valley network era, when Mars was warmer and wetter. The upper part formed later, and probably consists of cemented windblown sands. The rocks in between recorded Mars's transition from hospitable to hyper-arid conditions. Gale Crater is thus a place whose rocks likely preserved evidence for every kind of climate that Mars ever had. As Curiosity climbs upward through Gale's stratigraphy, we hope its observations will verify or falsify our current understanding of Mars's past. ✦

***Emily Lakdawalla** is Senior Editor and Planetary Evangelist for The Planetary Society. Find her at **planetary.org/emily**.*
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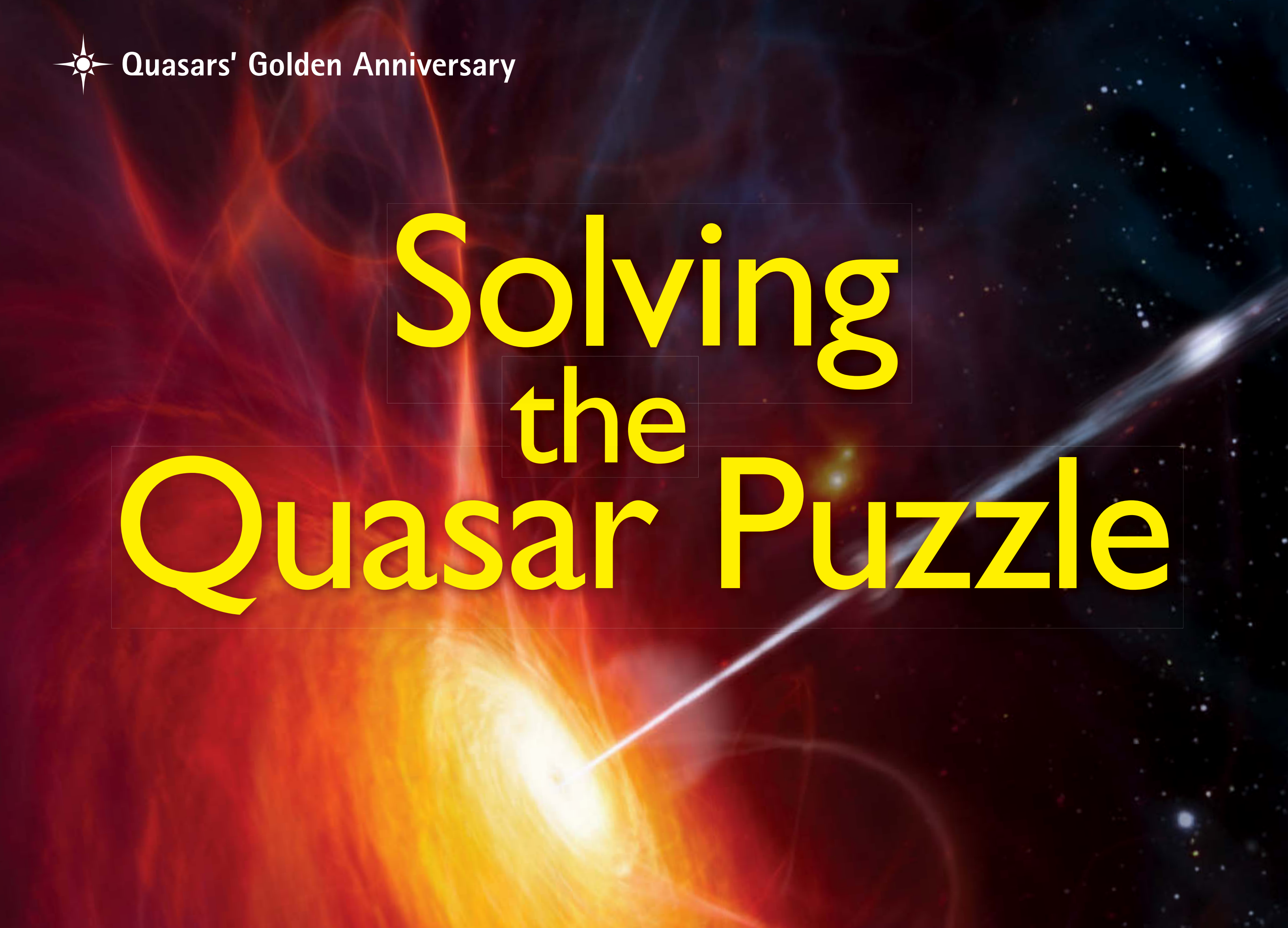


Solving the Quasar Puzzle

Fifty years ago, recently discovered "radio stars" began revealing their exotic secrets.

Bradley Peterson

Every so often a single observation changes how we perceive the universe. In 1610 Galileo pointed a refracting telescope at the sky to discover moons orbiting Jupiter, a view that helped boot Earth out of its central position in the solar system. Another revelation came in the 1920s, when Edwin Hubble observed variable stars in M31 and other "spiral nebulae," proving these fuzzy objects are independent galaxies lying outside our own — and extending the known universe far beyond the Milky Way Galaxy.

And 50 years ago, astronomy again changed forever when 33-year-old Caltech professor Maarten Schmidt measured the spectrum of a weird starlike object. Using the largest telescope in the world at the time, the famous 200-inch Hale Telescope at Palomar Observatory, Schmidt discovered that this "star" was not what it seemed. Three years later, Schmidt's discovery won him the cover of *Time* magazine, even as the community struggled to understand his and others' observations. Though not fully appreciated at the time, Schmidt's discovery would open the door to probing the universe's farthest reaches.

Finding a Match

The emergence of radio astronomy served as a prelude to the discovery of quasars. Development of radar during the Second World War led to the accidental detection of natural radio sources among the stars. In the decades that followed, radio telescopes mapped much of the sky. But understanding individual sources usually meant finding their counterparts in visible-light observations, a task easier said than done.

Radio telescopes were relatively crude tools until the late 1970s. Before the advent of highly precise interferom-

ILLUSTRATION: ESO / MARTIN KORNMESSER

etry, radio astronomers could obtain only a rough position for a given source. Identifying the visible-light counterpart out of a field of ordinary-looking stars and galaxies was challenging unless a strikingly unusual source coincided with the vague radio-source position.

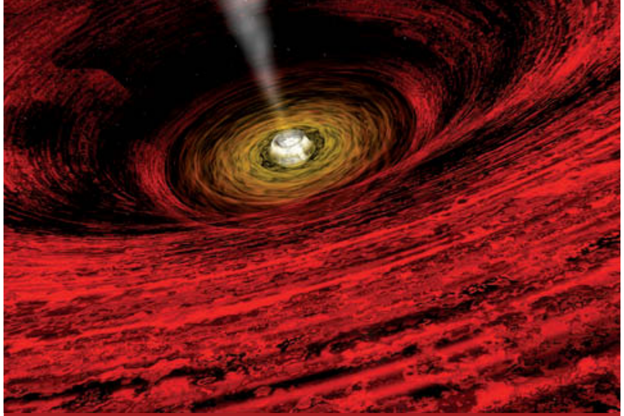
Astronomer Cyril Hazard pioneered a clever method of pinpointing radio sources: lunar occultations. A point of radio emission winks out almost instantaneously as the Moon crosses it, locating it on the arc defined by the Moon's leading limb. The re-emergence of the source on the other side or a second occultation with the Moon on a slightly different path defines a second arc; the intersection of the arcs precisely locates the radio source.

Hazard and his collaborators observed three lunar occultations of a radio source named 3C 273 (the 273rd source, ordered by right ascension, of the *Third Cambridge Catalogue of Radio Sources*) at the storied Parkes Radio Telescope in Australia. They located the source with sub-arcsecond precision. (Read more about Hazard's work at **skypub.com/3c273**.) Later observations showed it coincides with two visible-light sources: 3C 273 A seemed to be a wispy jet coming from 3C 273 B, a relatively bright, 13th magnitude starlike object. Unlike the pointlike appearance of stars in other photographs, 3C 273 B seemed to be immersed in a faint fuzz (*S&T:* June 1986, page 553).

Schmidt set out to explore the nature of these visible-light counterparts at Palomar Observatory. Armed with the precise position of the radio source, he applied astronomy's most powerful diagnostic tool: spectroscopy. But the visible-light spectrum he photographed only confused the situation. The spectral features of 3C 273 B were completely unfamiliar — nothing was where it was supposed to be.

NASA / ESA / GREG BACON (STSCI)

RELATIVISTIC BEAM Like stars, quasars appear pointlike in visible-light telescopes. This illustration shows the largest structures we can resolve directly: jets that fling material thousands of light-years from the black hole into intergalactic space at speeds approaching that of light.



APRIL HOBART / CXC

SO WHAT *IS* A QUASAR?

"Quasi-stellar radio sources," a mouthful that astronomer Hong-Yee Chiu abbreviated to "quasar," initially meant what it sounded like: a radio-wave-emitting pointlike object that looks just like a star in visible light.

But the term soon came to mean much more than that. "Quasar" now refers to a supermassive black hole millions or even billions of times more massive than the Sun, sitting at the center of a galaxy and guzzling gas from a surrounding disk. The central black hole, small in proportion to the disk that feeds it, hides in the center, as shown in the artist's impression above. The hot, whirling gas does most of the glowing — it outshines all the stars in the 100,000-times-bigger host galaxy. But if jets are present, blasting away along the black hole's polar axis, they emit radio waves and other radiation that can outpower even the disk. — *Monica Young*

After several weeks, Schmidt realized he was seeing a familiar pattern in the spectrum: the Balmer series of hydrogen lines. But it was shifted redward by 16%. Schmidt recounts his discovery on page 26.

A student recently asked, why wasn't 3C 273's redshift immediately obvious? After all, the pattern of emission lines is the same as that seen in spectra of star-forming regions and planetary nebulae. And these same lines had been seen in *Seyfert galaxies*, relatively nearby spirals with luminous cores that ultimately turned out to be quasars' somewhat fainter, underachieving cousins.

To understand why Schmidt's discovery was a major achievement, take a look at the original data on page 26. Schmidt had to photograph the spectrum, and in 1963 interpreting photographic spectra was more of an art than a science. Compare Schmidt's data, captured via the 200-inch Hale Telescope, to the modern version, obtained with a CCD detector on the much smaller 94-inch Hiltner Telescope. The weaker, low-contrast features immediately identifiable as emission lines in the CCD spectrum can hardly be seen in the photographic version; even the high-contrast lines appear spread out.

Faraway — and Bright

So why should a redshift of 16% come as a surprise? Astronomers already knew that the universe's expansion redshifts the spectral lines of objects at great distances, so that more distant objects appear to be receding from us more quickly. Even in the early 1960s, astronomers had seen distant clusters of galaxies with redshifts as large as 20%, higher than that of 3C 273.

But those clusters of galaxies didn't have 3C 273's intensity. More distant objects should look fainter, so if 3C 273 really lies 2 billion light-years from Earth, it would have to shine at least 40 times brighter than the most luminous known galaxy.

Moreover, Schmidt argued in his original paper that if the jet (3C 273 A) originated in 3C 273 B, it must stretch across 160,000 light-years. Even if it could somehow move at the speed of light, the jet would have to be 160,000 years old to have reached its current length; since it must move more slowly, it must be even older. If 3C 273 B always had the same brightness, the total luminous energy it would have radiated over that time would be more than that radiated from 100 million supernovae! Nevertheless, Schmidt maintained that "the most direct and least objectionable" explanation of 3C 273's redshift was that it was due to the cosmological expansion of the universe.

But a lot of astronomers were quite uncomfortable with such a tremendous amount of energy being generated for such a long time. The situation became even more difficult when astronomers watched individual quasars vary in brightness over days rather than months or years. The observations suggested something was generating a galaxy's worth of light from a volume less than a few light-days across, about the size of the solar system. What could create so much energy in so little space?

The Discovery

Until the 1960s, astronomers never had any doubt that all the sky's stars belonged to the Milky Way. But the nature of so-called "radio stars" puzzled astronomers. Radio telescopes had discovered these mysterious objects in the 1950s, and in 1960, Allan Sandage (Carnegie Observatories) identified one of them, named 3C 48, with a 16th-magnitude star. The star was like none of its kind, showing a peculiar visible-light spectrum with emission lines at unfamiliar wavelengths.

Other radio sources soon joined 3C 48. One of these was 3C 273, associated with a 13th-magnitude star. I measured that star's spectrum with the 200-inch Hale Telescope at the Palomar Observatory, only to find yet another strange spectrum with unrecognizable lines.

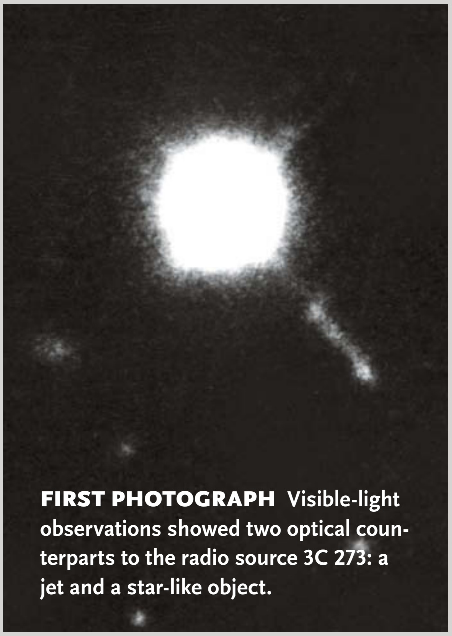
Six weeks later I was writing up my results when I looked again at the emission lines. It struck me that they showed a regular pattern: the lines toward the blue end of the spectrum were less intense and closer together. To check the pattern, I measured the position of each emission line and sure enough, I found they had the same intensity and spacings as the lines emitted by the hydrogen atom.

But to my astonishment, each line was shifted redward by a factor of 0.158. That redshift corresponds to an object moving away at 44,000 kilometers per second, or almost 16% the speed of light! Assuming the universe's expansion had redshifted the light, this redshift translated to a distance of 2 billion light-years.

Stars in our galaxy obey a speed limit of about 600 kilometers per second; beyond this limit, they would escape the Milky Way's confines. The corresponding spectral shift is 0.002. With a redshift 80 times larger, 3C 273 clearly couldn't be a nearby star. I knew it had to be some kind of galaxy-type object far away. That itself was a stunning realization, but that wasn't all. At that distance, the object would have to be incredibly luminous — a star that could outshine whole galaxies.

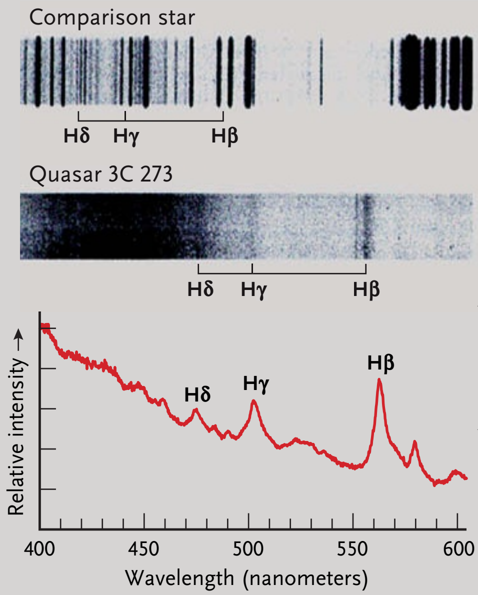
The objects that came to be called quasars were so extraordinary that some astronomers developed considerable opposition to my interpretation of their redshift. Intense debate lasted until new observations convinced most of the astronomical community that quasars really were faraway and hyperluminous — and nothing like stars at all.

— *Maarten Schmidt*



FIRST PHOTOGRAPH Visible-light observations showed two optical counterparts to the radio source 3C 273: a jet and a star-like object.

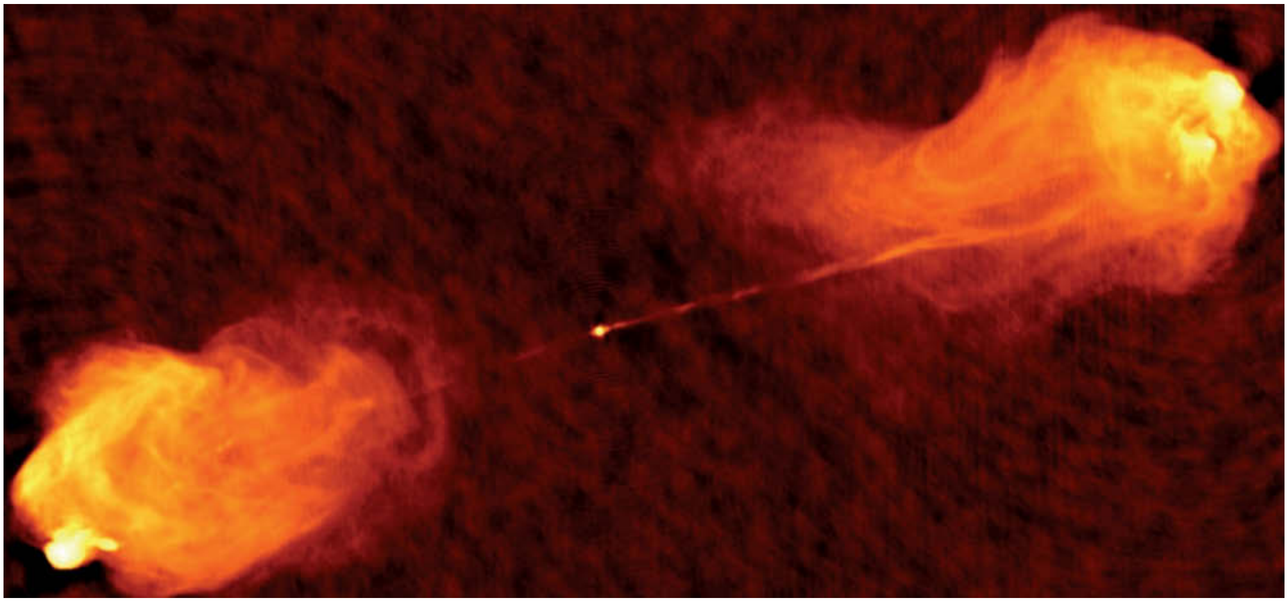
NOAO / AURA / NSF



M. SCHMIDT

KELLY D. DENNEY (OHIO ST. UNIVERSITY) / MDM OBSERVATORY

Top: This visible-light spectrum of a star shows dark lines where hydrogen in the stellar atmosphere is absorbing starlight. ***Above center:*** Maarten Schmidt's photographic spectrum of 3C 273 showed these same lines, but they were fuzzy and positioned at initially unfamiliar wavelengths. Schmidt later realized these lines were shifted toward redder wavelengths by 16%. ***Above***: A modern CCD spectrum of 3C 273 records the relative intensity at each wavelength, making even faint and spread-out lines easier to detect.



NRAO / AUI

RARE JETS Cygnus A (also known as 3C 405) is one of the nearest active galaxies, and one of the minority that produce spectacular radio-emitting jets. These streams of particles and radiation stretch 500,000 light-years end-to-end before they collide with intergalactic gas and fan out into giant lobes. The jets and lobes dwarf the galaxy, which doesn't appear in this radio image.

The daunting energy requirements led some astronomers to argue that quasar redshifts might be due to something other than cosmological expansion. Maybe quasars don't lie at such great distances after all, they suggested; maybe quasars are more-or-less local, say in the Local Group of galaxies.

Three alternatives would have allowed quasars to be local objects:

• Quasars could be local objects moving at speeds close to the speed of light.

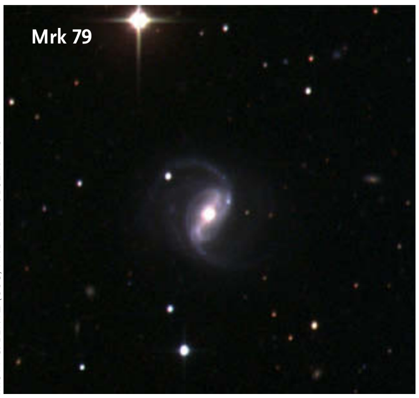
• Light from quasars could be gravitationally redshifted, having lost energy as it struggled to escape from a black hole's strong gravity.

• Quasar redshifts could be due to some as-yet-unidentified "new physics."

But these alternatives were questionable at best. If quasars were moving close to the speed of light, associated relativistic effects would make blueshifted quasars easier to detect than redshifted quasars, but none have ever been found. This largely discredited the notion that they could be local. And quasar light can't be gravitationally redshifted without resulting in a paradox of sorts: the large volume of low-density gas needed to produce emission lines would have to exist in a gravitational field so strong that it would compress matter to densities too high to form emission lines. The third alternative was mere conjecture, unsupported by any other evidence.

The redshift controversy raged for 15 years following Schmidt's discovery, until definitive evidence came in supporting the idea that quasars lie far outside the local neighborhood. In 1978 Alan Stockton (University of

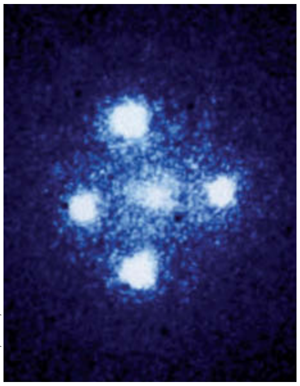
GEORGE SEITZ / ADAM BLOCK / NOAO / AURA / NSF



MISTY C. BENTZ (OSU) AND MDM OBSERVATORY

MISTY C. BENTZ (OSU) AND MDM OBSERVATORY

ACTIVE GALAXIES All of these galaxies host a feasting black hole, and they're all the same apparent brightness. But each step to the right takes a peek further back in time, showing a galaxy 10 times further away and therefore 100 times more luminous.



NASA / ESA / STSCI

EINSTEIN CROSS Gravitational lensing images like this one were among the first forms of evidence confirming that quasars lie at cosmological distances. Here a foreground galaxy (central object) acts as the lens. Its gravity bends the light from a background quasar 20 times more distant. The chance alignment produces four images of the quasar in a cross-like pattern around the galaxy.

Hawaii) showed that quasars are surrounded by normal galaxies with similar redshifts, and in greater numbers than expected by chance.

Further evidence reinforced quasars' extreme distances: Dennis Walsh (Jodrell Bank Observatory) led a team that identified the first quasar gravitationally lensed by a foreground galaxy, a phenomenon that could only be explained in a cosmological context. And in 1982 Todd Boroson and John Beverly Oke (Palomar Observatory) examined the fuzz around another well-known quasar, 3C 48 — fuzz that turned out to be its host galaxy's starlight.

Fueling Quasars

But if quasars' redshifts are cosmological, then there remains the question of their power source. Whatever it is, it has to generate a huge amount of energy in a small, solar-system-size volume.

Several astrophysicists — notably Yakov Zel'dovich and Igor Novikov in the Soviet Union and Edwin Salpeter (Cornell University) in 1964, and Donald Lynden-Bell (Cambridge University, UK) in 1968 — realized independently that the only feasible explanation is gas accreting onto a black hole millions of times the mass of the Sun. Though black holes can't emit light by definition, they become powerful beacons of light when they feed. As gas spirals into the gaping maw, it releases its gravitational potential energy as radiation across the electromagnetic spectrum.

By 1984 Martin Rees (Cambridge University, UK) had argued convincingly that any activity in a galaxy's nucleus would inevitably lead to the formation of a supermassive black hole. Even though direct observational proof remained elusive, astronomers tended to accept that accretion onto supermassive black holes powered quasars because this explanation was "the last man standing."

Ironically, the first strong evidence for the existence of supermassive black holes came not from quasars but from their inactive brethren. The whirl of gas and stars around the cores of nearby galaxies showed that nearly all massive galaxies host supermassive black holes in their cores. The only difference between a quasar and a normal galaxy is how much their central black holes have to eat.

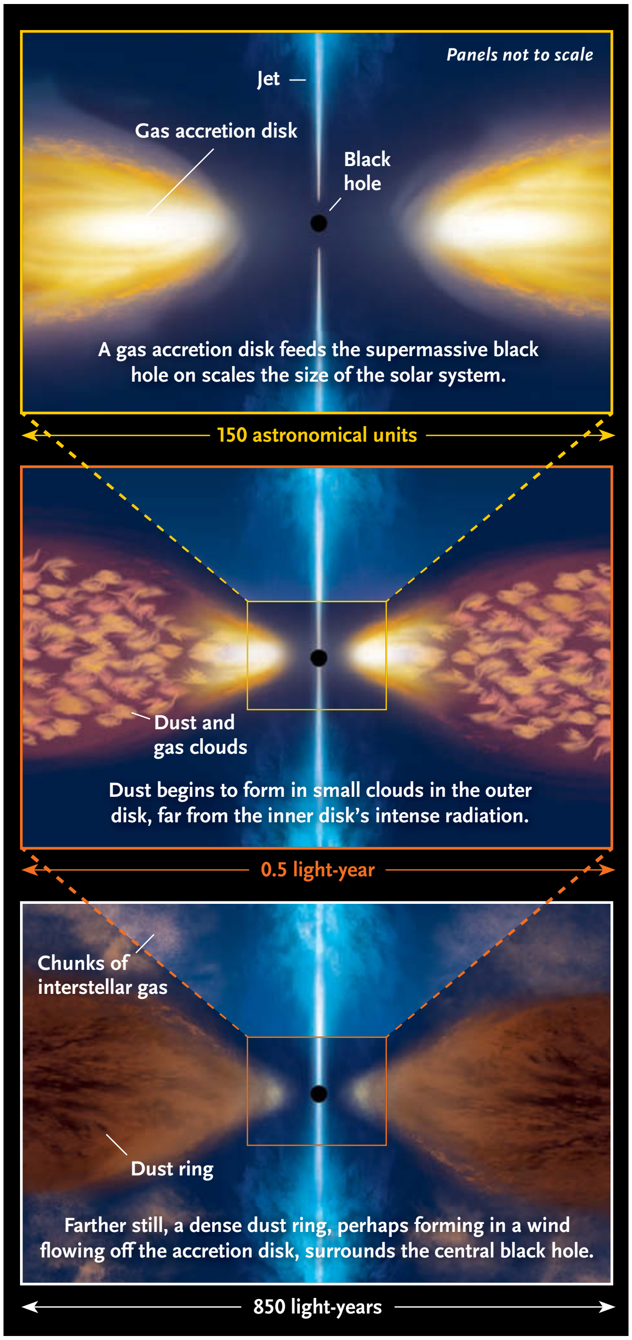
Building the Quasar Paradigm

Over the years, astronomers gradually began to piece together the story of quasars: how these exotic objects evolved over time and what they really look like. But before they could answer these questions, astronomers first had to find quasars — lots of them.

Initially, astronomers used radio emission to distinguish quasars from ordinary stars. The radio waves come from brilliant jets that blast their way out of the galaxy's center into intergalactic space. But astronomers soon realized that other properties, such as quasars' unusual spectra, variability, and X-ray emission, could also pick out these objects from a field of stars. In the process, they discovered that the more easily discovered "radio-loud" quasars represent only 5% to 10% of the population.

ESA / NASA / THE AVO PROJECT / PAOLO PADOVANI

VIEWING ANGLE This illustration shows an "edge-on" view of a quasar. A dusty shroud blocks most of the light emitted from the gas accretion disk surrounding the black hole.



S&T: LEAH TISCIONE

QUASAR, SIMPLIFIED These panels dissect one version of the current quasar model; each cross-section is an edge-on view at a different zoom level. The top panel zooms in to show the feeding black hole on a scale roughly the size of the solar system. The lower two panels progressively zoom out to show dust and gas structures on much larger scales.

By the early 1980s, various projects had discovered hundreds of thousands of quasars at ever-increasing distances. The Sloan Digital Sky Survey, a robotic recording of one-quarter of the sky, has found more than 120,000 during the past eight years. As the quasar census became more complete over time, a coherent picture of quasar evolution finally began to emerge.

Current theory says quasars grew in galaxy cores during the age of galaxy assembly, when the universe was only a few hundred million years old. The quasar population peaked after 3 billion years. But gradually, the supermassive black holes ran out of gas over the next few billion years, growing quiet in their old age.

In fact, quasars might have been the agents of their own destruction: their extreme luminosity heated the accreting gas to very high temperatures or even blew it out completely. The feedback starved the black hole of the fuel that once fed its youthful brilliance. All that remains of the quasars that dominated the universe 10 billion years ago are the now-dormant leviathans lurking in the centers of massive, nearby galaxies.

Though no telescope today can directly image the minute structure of quasars at vast distances, 50 years of research has yielded many indirect methods of finding out what these things look like. The basics are always the same: a gaseous accretion disk feeds a supermassive black hole. But the details are more difficult to discern.

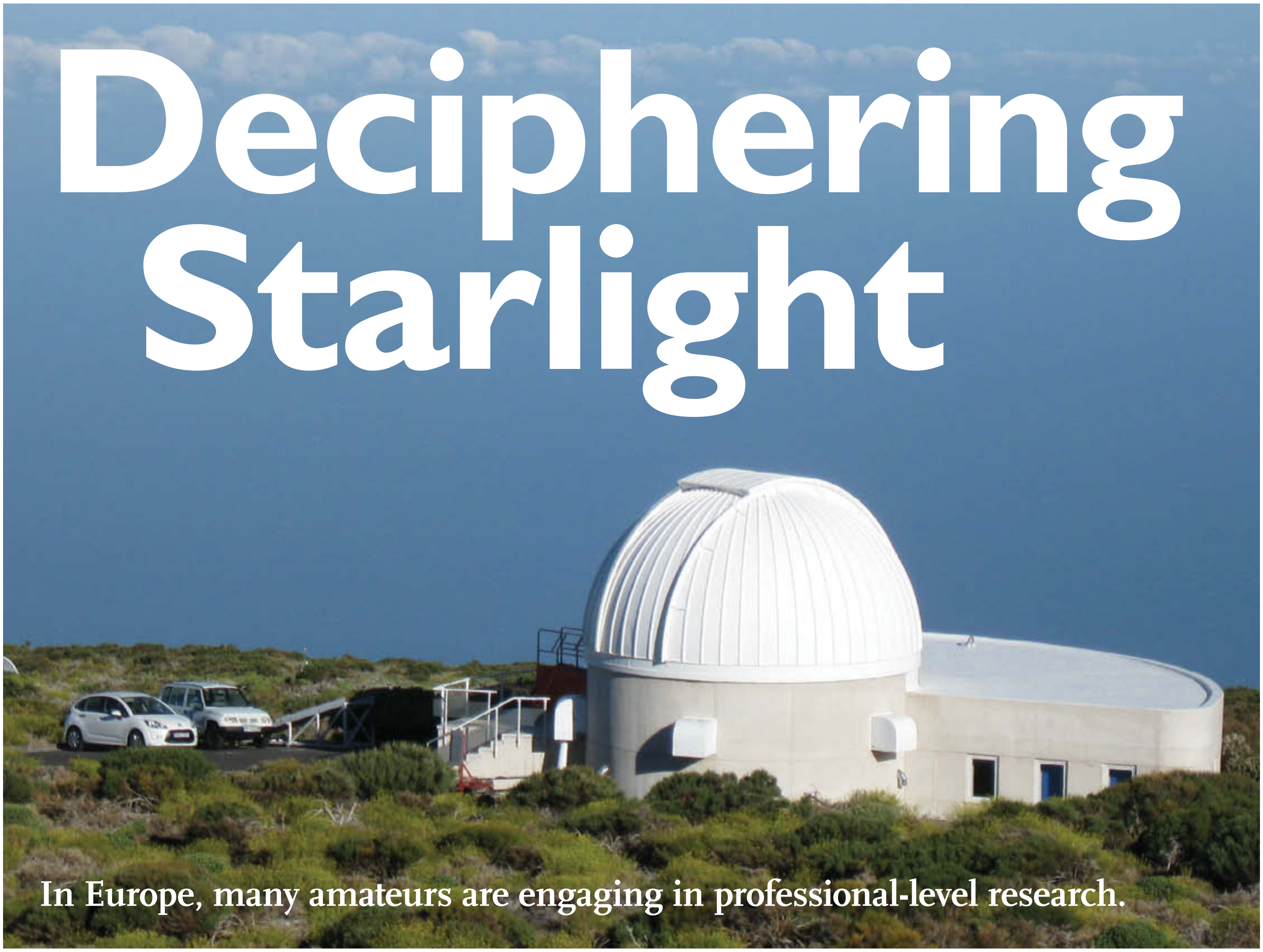
Observations suggest a dust-embedded region encircles some quasars, especially those with lower luminosities. The dust ring might be an extension of the accretion disk itself, or it might be related to winds flowing off the accretion disk. Either way, it must lie far from the harsh light and heat of the inner accretion disk if the dust is to survive. A quasar seen through this equatorial shroud looks very different from one seen directly — many of the key features by which we often recognize quasars, such as their broad emission lines, aren't directly visible. The presence of a dust shroud helps explain the variety of sources in the quasar population.

The current quasar model distills the great variety of quasar types down to three key parameters: the black hole's mass, how quickly gas feeds the black hole, and the angle at which we observe the system. Yet even after 50 years of research, quasars retain their mystery. We don't understand how black holes can grow to supermassive sizes so early, when the universe was only a few hundred million years old. Nor do we understand why some quasars emit intense radio waves and others do not. We still have only a meager understanding of quasars' inner structures and gas flows. And astronomers are actively debating how quasars influence and are influenced by their environment.

All I can conclude with certainty is that the next 50 years of quasar research are guaranteed to be as exciting as the first 50. ✦

Bradley Peterson *is professor and chair of astronomy at The Ohio State University, where he has pioneered innovative techniques to study the environments around the supermassive black holes that power quasars.*

Deciphering Starlight



In Europe, many amateurs are engaging in professional-level research.

CONVENTO GROUP / THOMAS EVERSBERG

Jan Hattenbach

An unusual group of tourists visited Tenerife in the Canaries this summer. These people were not attracted by the island's beautiful beaches and volcanoes. Instead, they came to work arduous night shifts on a professional 31-inch telescope, just to observe three inconspicuous stars in Cygnus. And each of these amateur astronomers was willing to shell out $1,300 for travel and to rent the telescope. "To these volunteers, working at a professional observatory is the greatest thing imaginable," says team leader Thomas Eversberg. "Yes, we're somewhat crazy, but what amateur astronomer isn't?"

Many amateurs would agree with this assessment. But why make amateur astronomy a costly and stressful exercise? It's supposed to be fun, right? Obviously, for some it means a lot more.

Studying Stellar Winds

The recent advent of professional survey telescopes has diminished the backyard observer's opportunity to contribute scientifically in certain areas, such as asteroid and comet discovery. But the emergence of inexpensive, high-resolution, off-the-shelf spectrographs is filling the gap. Even when coupled to modest-size telescopes, spectrographs can yield scientifically useful results by revealing a star's temperature, chemical composition, and prevailing physical conditions of atomic excitation and ionization.

Using the 31-inch reflector of the Institute of Astrophysics of the Canaries, Eversberg and his colleagues

NOT JUST A TOURIST SITE European amateurs flock to the island of Tenerife to use the 31-inch telescope housed in this dome. Owned by Spain's Institute of Astrophysics of the Canaries, the observatory sits at an elevation of 2,390 meters.

observe three Wolf-Rayet stars in Cygnus named WR 134, 135, and 137. Their photospheres are shrouded by dense gas clouds that move and rotate at high velocities. A visual observer won't notice anything unusual about these stars, but the clouds produce bright emission lines in the stellar spectra. By studying these lines, astronomers explore the connection between the stars' hidden surfaces and their powerful winds, and test for periodicities and random clumping in these winds.

"We're a textbook example of pro-am collaboration in astronomical spectroscopy," says Eversberg, who works for the German Space Agency in Bonn, but who does this spectroscopy research on a volunteer basis. Eversberg initiated the campaign with Anthony Moffat (University of Montreal, Québec). In 2009 they motivated amateurs to visit Tenerife to observe the periastron of the ultra-hot binary WR 140, the best-studied member of a class of objects called *colliding-wind binaries* (*S&T*: April 2011, page 28). The campaign yielded five times more spectra than a solely professional periastron campaign in 2001. With this amateur data, astronomers improved their knowledge of the system's mass, orbital period, and orbital inclination.

With colleagues from around the world, Eversberg and Moffat formed the ConVento group, comprising professionals and amateurs dedicated to stellar-wind phenomena (ConVento is Italian for "with wind"). ConVento members mostly use their own backyard observatories, but operating the professional facility on Tenerife has been the highlight of the campaign. "Our success in 2009 facilitated our proposal to acquire observation time for the 2013 campaign," says Eversberg. "Professionals know us now, and they know what we're capable of."

Catching One-Time Events

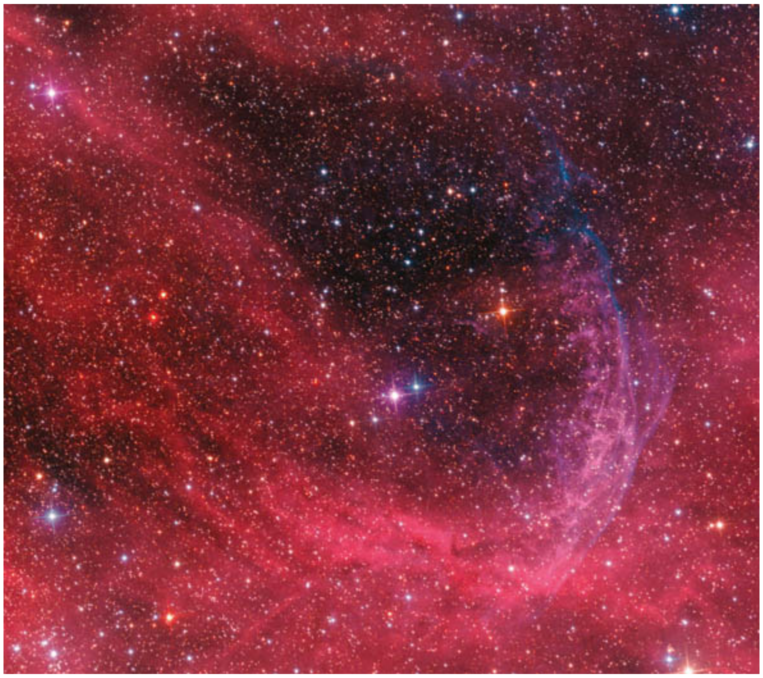
Professionals have access to the most advanced telescopes and instruments at the world's best observing sites, but they lack what amateurs possess in abundance — time. Long-term measurements, surveys, and monitoring require weeks or even months of telescope time, which are difficult to obtain at overbooked professional observatories. An 8- to 20-inch telescope coupled with an off-the-shelf spectrograph does the job just as well. Taking spectra of bright stars is possible even under light-polluted urban skies. And if you're clouded out one night, your colleagues will help out.

Spectroscopy has thus become a new and thriving field of "citizen science," especially among European amateurs. Though growing, the numbers are still comparatively small. "There are about 30 serious observers in France right now, with maybe another 100 people interested in the field," says Thierry Garrel, a member of the French Astronomical Ring for Access to Spectroscopy (ARAS), the most active amateur organization on the continent.

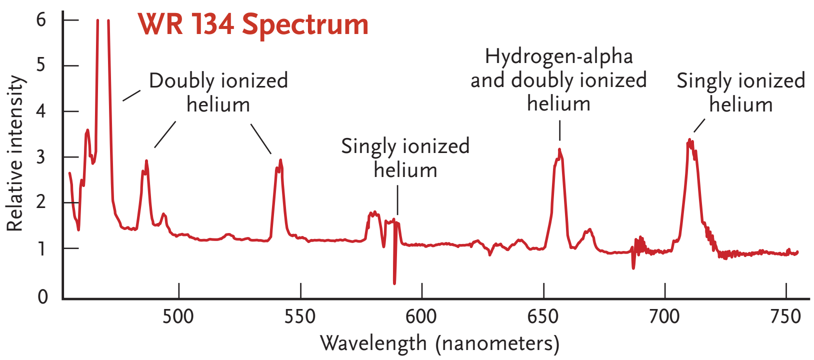
But those dedicated few are absorbed by their work. "Spectroscopy can be a dull exercise," says Eversberg.

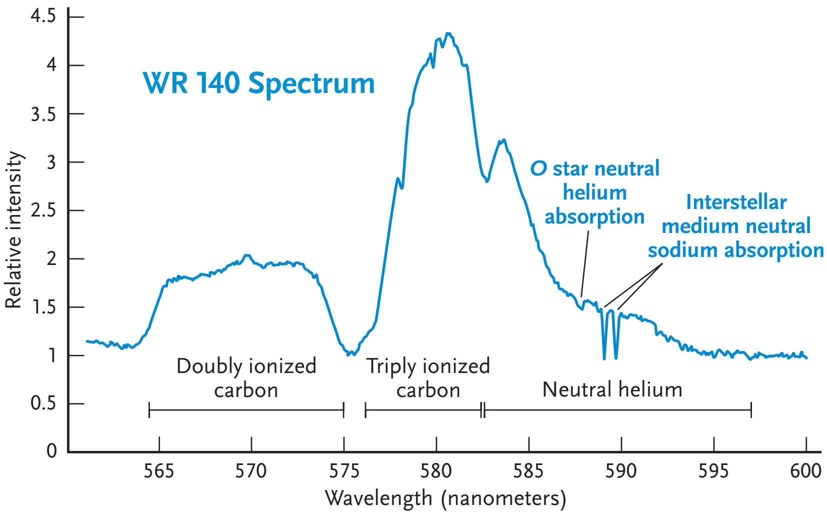
CONVENTO GROUP / THOMAS EVERSBERG (3)

AMATEURS GO PRO ***Top:*** **European amateurs have earned considerable observing time on this 31-inch professional reflector on Tenerife. They use it to take spectra of Wolf-Rayet stars and binary systems with energetic colliding stellar winds.** ***Center:*** **German astronomer Thomas Eversberg has coordinated this impressive amateur science campaign.** ***Bottom:*** **German amateur Daniel Weiss works in the observatory's control room.**



DON GOLDMAN





SOURCE: CONVENTO GROUP (2)

COLLIDING-WIND BINARY ***Above:*** **The ConVento group amateurs took this spectrum of WR 140, a binary system in which the winds from two massive stars (an *O* and a Wolf-Rayet star) are colliding. The spectrum was taken on November 24, 2008, when the two stars were at their closest approach.**

BLAZING STAR ***Top left:*** **This amateur astrophoto shows WR 134 (the bright reddish star at center) and its surrounding nebula, which is gas ejected by the star's powerful stellar wind.** ***Center left:*** **The ConVento amateur group used an echelle spectrograph to take this visible-light spectrum of WR 134. The data reveal various emission lines from hydrogen and helium.**

"You spend countless nights taking data for some other person to analyze, and worse, they're not pretty pictures, just graphs and numbers." But your reward isn't just finding your name on a scientific paper. As Eversberg points out, "Instead of taking the millionth image of the Orion Nebula, we're witnessing events that happen just once."

Consider long-period eclipsing binaries. Astronomers know of several dozen such systems, in which two stars periodically eclipse each other, but only a few have been fairly well studied. Their long orbital periods make them perfect for amateurs. The best-known example is Epsilon Aurigae, which went through its minimum from 2009 to 2011 as a dark cloud of gas and dust passed in front of the primary star. The previous eclipse occurred 27 years earlier, before amateurs had spectrographs. In the March 2012 *S&T,* British amateur spectroscopist Robin Leadbeater reported that more than 800 spectra taken by amateurs had been added to the wealth of data that now helps astronomers understand the strange eclipsing cloud. By observing the potassium absorption line at 770 nanometers, Leadbeater could see the eclipsing cloud months before it dimmed the star — and long after the official eclipse had ended.

Other long-period eclipsing binaries include AZ Cassiopeiae and VV Cephei, with orbital periods of 9.3 and 20.3 years, respectively. VV Cep is a prototype of variable binaries consisting of an aging supergiant and a hot dwarf star, whose spectra exhibit strong hydrogen and iron emission lines. These lines emanate from extended gaseous shrouds around the stars, and the way they evolve in time relates to wind patterns and velocities, and various stellar and orbital parameters.

With an eclipse of AZ Cas just concluded, Cezary Galan (Nicolaus Copernicus University, Poland) is urging amateurs to monitor the star through 2014. "A dense coverage with photometric and spectroscopic observations is needed," writes Galan on his website. "The long timescales of changes in AZ Cas demand the involvement of a large number of observatories to reduce the dependency on weather conditions and guarantee success during the important phases of the eclipse." As of early June 2013, amateurs had submitted about two-thirds of the 250 total spectra. "The interest in this campaign has significantly exceeded my expectations," says Galan.

Meanwhile, Darryl Sergison (University of Exeter, UK) is asking amateurs to spectroscopically monitor low-mass T Tauri stars to help astronomers gain a clearer picture of the environment around young solar-type stars and

PAOLO BERARDI

FRENCH SPECTROSCOPISTS Two French amateurs, Thierry Garrel (left) and Pierre Dubreuil, pose with their equipment at the 2012 amateur spectroscopy workshop in France. Most amateur spectroscopy is done with backyard telescopes such as these.

to characterize their various disk, accretion, and outflow structures. The study peaks in this autumn, but monitoring of three target stars began in late 2012.

The best example of a long-term project is the international *B*e stars campaign, which has been running for more than a decade. Approximately 20% of all *B*-type stars (which make up about 20% of all naked-eye stars) exhibit emission lines of hydrogen and sometimes helium and iron, which vary on timescales of hours to decades. Astronomers think the emission is caused by gas shrouds or disks ejected by the stars' fast rotation, which produces centrifugal forces at the equator that are strong enough to overcome gravity. But the spectral variability is poorly understood. Amateur spectra are critical. Astronomers in general have collected more than 72,000 spectra of about 600 different *B*e stars, but 29,000 of them (40%) have been taken by just 49 amateurs. Stored in the *B*e Star Spectra database, and maintained by amateurs and professionals alike, they have served astronomers in almost two-dozen publications.

For links to websites relating to amateur spectroscopy, visit SkyandTelescope.com/amateurspectra.

Becoming an Amateur Spectroscopist

Amateurs have many other interesting targets at their disposal, from novae and supernovae to passing asteroids and comets. All of these campaigns benefit from the emergence of off-the-shelf spectrographs. Just 10 years ago, amateurs lacked the instruments necessary for any high-resolution spectroscopic study unless they could build them by themselves.

Motivated by the desire to provide simple yet powerful instruments for amateurs to do serious research, in 2003 French amateur astronomers François Cochard, Olivier Thizy, Christian Buil, and Yvon Rieugné designed what was to become Lhires, a commercial high-resolution spectrograph for amateurs. Today, their company, Shelyak Instruments, offers instruments of all resolution classes at a variety of prices. Another European source comes

PAOLO BERARDI

TYPICAL SETUP This amateur setup shows a Celestron C5 coupled with a Shelyak Instruments Lhires III, a top-of-the-line, high-resolution spectrograph that sells for about $4,100. Lower-price spectrographs can also produce excellent scientific results.

from Jesús Rodríguez, Carlos Guirao, and Gerardo Ávila, engineers at the European Southern Observatory, and Vadim Burwitz, a professional astronomer at the Max Planck Institute for Extraterrestrial Physics in Germany. Their Club of Aficionados in Optical Spectroscopy (CAOS) has formed a collaboration with the German company Baader Planetarium to offer spectrographs to the amateur community.

But hardware is just one part of the story. How do you know if you have the necessary skills to be an amateur spectroscopist? “The technique is not self-explaining,” says Eversberg. Internet forums and newsgroups, such as those hosted by ARAS or the German Spektroskopie-forum, are crucial. Here, spectroscopy aficionados exchange knowledge on observation techniques and equipment, plan new campaigns, and discuss results. Most discussions are in English, allowing almost anyone to jump in.

European amateurs, with their different languages and cultures, have turned a seeming disadvantage into a virtue. Because national groups are small, international cooperation is essential. Every campaign includes people from all over the continent and, increasingly, the world. If you want to participate, please note that for data acquisition, it’s essential that you know how to manage your telescope and a CCD camera, because the spectrograph is just an additional part of your equipment. Also be aware that professional astronomers do most of the analysis because it usually requires specialized training.

Nevertheless, even in the internet age, nothing beats meeting fellow enthusiasts in person. Since 2004, European spectroscopists have gathered yearly at the Observatoire de Haute Provence in France for a one-week workshop. “To my knowledge, this is the only star party dedicated to spectroscopy,” says Thizy, who is one of the organizers. With more than 40 telescopes equipped with different types of spectrographs, it’s the best way to get in touch with the field and it’s participants, and beginners are always welcome. “Each year, we receive a growing number of guests, amateurs and professionals alike, and attendance is international,” adds Thizy. “If you have your own equipment, bring it. This is a very practical training session.” The 2013 workshop takes place August 1st to 6th.

“Within 10 years, spectroscopy has become a thriving field in amateur astronomy. It’s still small and highly specialized, but it enables amateurs “to go pro” like few others. And it’s growing. With equipment easily available and affordable, observation projects numerous, and increasing numbers of professionals requesting support, more pro-am collaborations will emerge in the future. Work will not run out; there is much more to discover. ✦

***Jan Hattenbach** is a freelance writer, amateur astronomer, and science communicator in Germany who recently took his first spectrum of a quasar.*

Resolution in Spectroscopy

Resolving power ($R = \lambda/\Delta\lambda$, with $\Delta\lambda$ the smallest distinguishable wavelength interval in a spectrum at wavelength λ), specifies what you can “see” with your spectrograph, as aperture does for telescopes. Values larger than 10,000 are considered “high,” which are necessary to reveal details of single lines and their time evolution. Simple slitless spectrographs reach less than 1,000 and are therefore considered to be low-resolution instruments. They don’t enable precise measurements of specific lines but are still highly capable instruments. Newcomers use them to learn about spectroscopy, but because high resolution limits the magnitude of reachable objects, some observers also employ them to study faint novae, supernovae, and quasars.

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An Astronomical Revival

In western North Carolina, philanthropists have revamped a former military satellite-tracking station, turning it into a leading hands-on astronomy education center.

Ashley Yeager

Deep in the Appalachians, two 26-meter radio dishes point skyward, listening to the cosmos. The original sounds they recorded were the transmissions of early missions to space. Later, they kept an ear on Soviet satellites during the Cold War. Then, there was silence. The telescopes and their smaller, 4.6-meter sibling sat shuttered, until one man recognized that the dishes could change the way students learn astronomy. Now the antennas, along with a family of newer, smaller telescopes, are again watching the sky, bringing the secrets of space to western North Carolina.

The telescopes are part of the Pisgah Astronomical Research Institute, or PARI, a nonprofit educational center where students can use real observing equipment to study astronomy, astrophysics, and engineering. “PARI is a place where we can give students a little hands-on experience to see if science and engineering are what they really want to pursue,” says PARI president Don Cline.

Now in its tenth year, the institute has acted as a hands-on laboratory for students, running programs such as SciGirls, Homeschool Day, and Climate and Space Science Camp, to show students that science can be a fun and even a realistic career. Through these programs and others, the institute hosts about 5,000 grade-school students each year and also sponsors five undergraduate interns each summer.

SPELLING OUT SCIENCE **Students (*above*) participating in one of the Space Science Lab sessions in August 2008 spell out the Pisgah Astronomical Research Institute’s acronym, “PARI.”**

"It's true joy to see students working at PARI," Cline says. He especially likes to watch them mature from nervously encountering a challenge to taking the steps to engineer the solution. "They come a long way and many things don't work out. There's noise and rust, and other issues that a book doesn't cover," he says. The students often have to figure out how to solve technical problems with instrumentation they wouldn't normally have access to at their schools.


RICHARD WRIGHT

Don Cline

The most characteristic features of PARI are the twin 26-meter radio telescopes. Students can use them to study pulsars or practice tweaking the placement of counterbalance weights to correct the mechanical equilibrium and precision of each antenna. A team has also connected the big dishes into an interferometer, a virtual telescope that combines the antennas' observations to achieve higher resolution than either dish can reach individually. With the improved view, the scientists hope to study the way the brightness of distant radio sources changes as dust and unseen clouds of gas in the Milky Way Galaxy pass between the sources and the radio dishes. The facility also has a cosmic-ray monitoring station, five weather and atmospheric stations, one of the most extensive collections of historical photographic plates in the United States, and 10 optical telescopes for students to use.

"I would recommend other students [do] internships or projects at PARI because it gives a glimpse at what onsite research is like," says Emma Taylor, a senior at Guilford College in Greensboro, North Carolina. She spent the summer of 2012 at the institute as a Cline Scholar, working on a calibration device for "Smiley." The 4.6-meter radio dish (painted with a big grin once meant to snub Cold War spy satellites, see page 40) is a remote-access radio telescope that high school and college instructors can log into from their classrooms and use to teach their students, in real time, about the hardware and software available to study space. It is symbolic of PARI's mission: a sophisticated scientific instrument made available to students and citizen scientists in a way that's fun to use.

Rising Again

PARI operates on an annual budget of $1 million, money that comes mostly from private donors, including Cline. He has gone to North and South Carolina universities looking for partnerships, and he and his colleagues have applied for and won several National Science Foundation grants to run research and education programs. Cline has even gone to Congress to ask for funding, all in an effort to raise the $40 million needed to operate PARI indefinitely. So far he and others have focused their fundraising on annual needs and are just beginning to think about an endowment, so the institute is not yet far along in reaching that $40 million goal.

"PARI is a great thing, one that I want to continue," says PARI science director Michael Castelaz. "But there's no certainty what will happen 5 to 15 years from now. The site and its development are still fragile."

But Cline says he isn't quitting. PARI's infrastructure is just too special to let go of again.

NASA officially opened the site in October 1963 as part of a network of satellite tracking stations, which sprang up throughout the country at the time to track unmanned and manned spacecraft. Then known as Rosman station, it was even one of the sites that transmitted Neil Armstrong's famous "one small step for [a] man" quote during the Apollo 11 Moon mission.

At about the same time in the '60s, Cline, a North Carolina native, was at the height of his business career. He first started working at Bell Labs in 1959 and then, in 1977, he left the company to form Micro Computer

IT'S NOT TAI CHI Students from T. C. Henderson Elementary School learn about lunar phases while one of the 26-meter dishes stands sentinel.

FROM SCRATCH High school students build circuit boards for their homemade radio telescopes. After construction and training, they took the scopes home to use during the school year.

FROWNS ARE FOR SISSIES Two high school students from North Carolina State University's Science House program grin over their circuits during a photonics workshop.

Systems with three fellow engineers. To honor his roots, he wanted to hire staff and technicians from nearby cities and towns. But when he recruited from the western North Carolina technical schools, the students came with book smarts but not the knowledge to "get their hands dirty and do real work to fix problems," Cline says.

As he and his partners were building the technology company, the space shuttle era was just beginning, and NASA's need to track satellites with the Rosman station was diminishing. In 1981 the space agency transferred ownership of the site to the Department of Defense (DOD), after which the military used the dishes to gather intelligence on Soviet satellite communications during the Cold War. The military operated the site for 14 years, and during that time it closed the Rosman station to the public. That restricted access gave off a very different vibe than during the site's NASA days, when people could come and learn about the projects being done there.

"People began to think this place was everything from an underground city to a secret submarine base," says Bob Hayward, an astronomer and educator at the site. "Some still do."

In the mid-1990s, military and government officials lobbied to permanently close the station, trading its operations to keep other North Carolina military bases open. The military shuttered the telescopes in 1995 and shifted control of the facility to the U.S. Forest Service. At the time, there was even talk of tearing out the radio dishes and bulldozing the buildings to restore the 200-acre site to its forested origins.

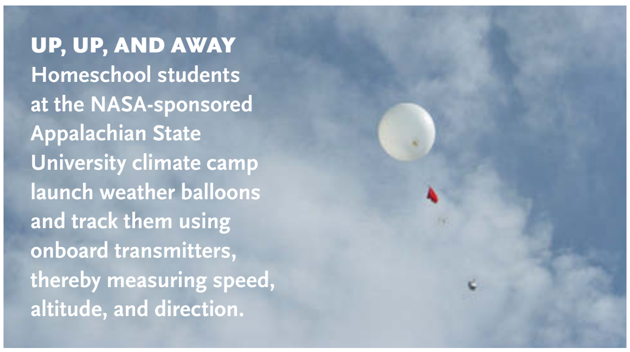
The remedial fixes, however, would have cost millions of dollars, money the Forest Service didn't have. So the site sat vacant — at least until Cline showed up.

Cline's interest in the site began when he heard about the two large satellite-tracking dishes while working with scientists at Appalachian State University in Boone, North Carolina, to develop their dark-sky observatory. Intrigued, he drove down to the site in 1995, soon after the telescopes were shuttered. At the time, the site and the equipment left there were worth $200 million. Cost wasn't the immediate issue, however: Cline took one look at the twin gargantuan, 340-ton radio telescopes and realized that he and others interested in astronomy education would have to bring scientists and students to the telescopes, not the other way around. The telescopes were just too monstrous to ever be moved.

Determined to acquire the site, Cline (who had already sold Micro Computer Systems) set up a nonprofit foundation in 1998 to begin raising money to purchase, revamp, and ultimately preserve the site for science, technology, engineering, and math ("STEM") education.

But purchasing the site required an act of Congress. Cline and his colleagues had to buy land along the French Broad River and then trade it to the U.S. Forest Service in return for the Rosman site. It took some lobbying and negotiation, but finally in 1999 the deal struck earned the group access to a 200-acre tract of land with several radio telescopes — including the two 26-meter dishes and Smiley — and a set of buildings nestled between two mountain ridges. It soon became clear to Cline and others that the ridges were ideal for optical telescopes and other science experiments.

Because the site had sat mothballed for so long, the telescopes and buildings needed millions of dollars of renovations, which Cline helped finance. All of this was done with the vision that PARI would be an educational lab for universities to partner with, an institute "all about STEM before the acronym even became popular," Cline says.



UP, UP, AND AWAY Homeschool students at the NASA-sponsored Appalachian State University climate camp launch weather balloons and track them using onboard transmitters, thereby measuring speed, altitude, and direction.

A Solid Foundation

While PARI's future may be fragile, its mission and infrastructure can't be matched in the southeast, says Mercedes Lopez-Morales (Harvard-Smithsonian Center for Astrophysics). "The site is one of the focus centers in the southeastern U.S. to attract young talent into astronomy, physics, and engineering fields," she says, crediting her own success as an exoplanet expert partly to PARI.

Lopez-Morales was one of the first students to come to the institute to do research, even before it officially opened. She had met Cline in 1999 when she was a graduate student in astrophysics at the University of North Carolina at Chapel Hill and was designing an experiment to study sets of variable and eclipsing binary stars. She had the equipment, the money, and the motivation, everything she needed to work on her thesis — except a dark spot to install her equipment. At Cline's urging, she came to PARI.

PARI was where Lopez-Morales truly learned to do science, and her work there eventually earned her a postdoctoral fellowship with famed planet hunter Paul Butler. He calls Lopez-Morales "one of the brightest lights among young astronomers," and thinks PARI is a wonderful site for young students who, as Lopez-Morales did, want to design and develop the skills to build their own experiments and astronomy equipment.

For her Ph.D., Lopez-Morales constructed her own robotic telescope, using an 8-inch Meade to monitor about 10,000 stars over three years. She watched them to look for variability, whether due to unknown eclipsing binary companions or for other reasons. Her research identified new low-mass, detached eclipsing binary stars and added precision measurements to astronomers' understanding of the relationship between the mass and radius of low-mass, main-sequence stars.

"Mercedes' project studying variable stars and dwarf binaries was, in some ways, a proto-Kepler mission," says Castelaz.

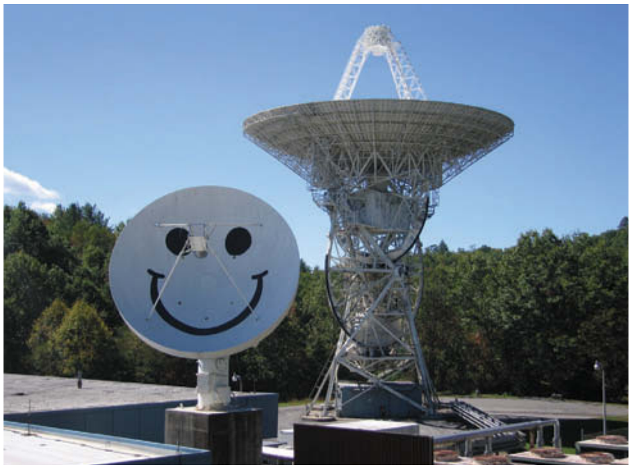
The research also showed how to address astrophysically interesting questions with a modest budget of $80,000 and using only equipment from the consumer astronomy market. Although this was not a new approach, it was the first time that a graduate student had assembled all the hardware, automated observing routines, and data analysis programs with only the help of PARI's staff.

Despite Lopez-Morales's, Taylor's, and other students' successes, critics still say that projects done at PARI are not "real astronomy" because they don't use data from one of the big astronomy facilities, Castelaz says. Clearly, the size and scale of the equipment at PARI is nothing like the telescopes at Kitt Peak in Arizona or on Mauna Kea in Hawaii — but the institute is not trying to be like those places. Instead, Castelaz says, PARI is training the technicians who will run those telescopes and the astronomers who will use them in the future.

For example, Taylor's project on Smiley ("the unofficial mascot of PARI," as she calls it) was to develop a new noise device that calibrates the intensities of sources observed with the telescope. The work is part of a larger project to make Smiley's data collection and analysis systems even more widely accessible to students and researchers. For Taylor, though, the work on the telescope and on a near-Earth object using one of the optical telescopes was what helped solidify her interest in astronomy and astrophysics.

"To the people who give a rip about education, PARI is a national treasure," says Alex Alexander, director of program advancement at the institute.

"It is a unique place in the world of astronomy, especially for young generations interested in hands-on scientific and technical work," Lopez-Morales says.



CANDID CAMERA PARI's iconic 4.6-meter Smiley radio telescope originally grinned at Soviet spy satellites. Smiley is completely dedicated to educational experiments via the internet and has been operated by thousands of teachers and students, some as far away as Australia. And yes, the smile is visible from orbit: see http://goo.gl/TMcO1.

Those young generations are the ones who are now linking the 26-meter radio dishes together and studying stars with and writing better software for Smiley. They're tracking meteors as part of NASA's All-Sky Fireball Network and continuing to upgrade the electronics and computer controls on all the research equipment at PARI. And they're the ones who will be able to delve deeper into astronomy and engineering and possibly earthquakes and ecosystems as Cline and Castelaz continue to convince more researchers to bring their projects to PARI. ✦

Ashley Yeager works in the news office at Duke University and is also a freelance science writer.

Recent PARI Undergraduate Projects

• Cline Scholar Emma Taylor (Guilford College, mentioned in the main article) developed and installed a new calibration source for the 4.6-meter Smiley telescope. She also determined the orbit of a near-Earth object. She's shown at left geared up to ascend via "bucket truck" one of the 26-meter antennas.

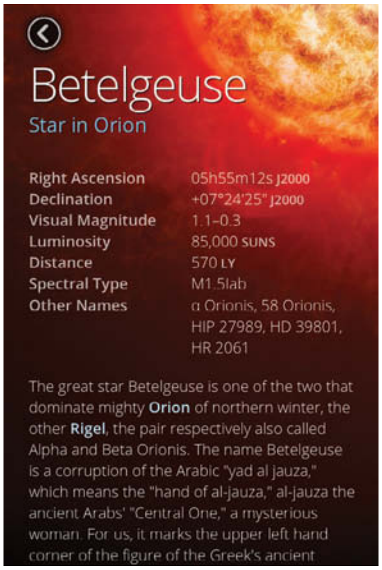
• Parks Scholar Menelik Zafir (Georgia State University) wrote a new software program for PARI's geomagnetometer.

• EMC Corporation Scholar Matthew Grimes (UNC-Asheville) upgraded the Smiley telescope's computer controls.

• NSF's National STEM Education Distributed Learning Scholar Rebekah David (UNC-Asheville) developed an interactive kiosk presentation that allows visitors to the North Carolina Museum of Natural Sciences in Raleigh to access PARI instruments and programs remotely.

• Joe Peters, Robert Picardi, and Lawson Smith (UNC-Asheville) helped commission PARI's interferometer. Their projects included development of a pointing model for the two 26-meter radio telescopes and detection of signals with new feedboxes.

• James Holtvedt, Nick Tarulli, and Matthew Burke (Western Carolina University's Kimmel School of Engineering) undertook the recommissioning of PARI's 12-meter radio telescope as their senior capstone project. The students analyzed the telescope's balancing needs and presented a paper recommending a solution. When fully operational, the telescope will survey the Milky Way at 22 GHz.



▲ **REAL SKY APP** Astrophotographer Nick Risinger teams up with Fifth Star Labs to produce *SkyGuide* ($1.99), an app for Apple mobile devices that shows you what's up in the sky. The app is based on Risinger's all-sky mosaic that he assembled from more than 37,000 images into a deep, seamless view of the Milky Way Galaxy (*S&T:* February 2012, page 70). *SkyGuide* automatically aligns itself to your surroundings using your device's built-in gyroscope and compass. Simply hold your device up and *SkyGuide* will match its display to the direction you're looking, revealing planets, stars, and nebulae in vivid color. Users can set the intensity of stars by dragging two fingers across the screen to best match their local viewing conditions. Touching any bright star or object opens a window with extensive historical and scientific information on the target. *SkyGuide* is compatible with the iPhone 4, 4S, 5, iPad 2, and iPod touch 4th generation and higher. See the Apple App Store for more information.

Fifth Star Labs
Available in the iTunes App Store

▼ **OBSERVING WEAR** Dark Skies Apparel announces the Observing Hood ($34.99), an oversized "monk" hood to help improve contrast and block stray light at the eyepiece, enabling you to see fainter objects even from suburban locations. Designed to drape over your head and encompass your telescope's eyepiece, the hood allows you to observe comfortably without the need to strain or squint to block stray light. It includes snaps to affix it around your neck. Each hood has a brushed cotton-denim exterior with a cotton-polyester blend lining.

Dark Skies Apparel
P.O. Box 56355 Chicago, IL 60656-0355
773-853-0416; www.darkskiesapparel.com

PLANETARY CAMERAS Celestron partners with high-end video camera manufacturer The Imaging Source to bring you the new Skyris planetary camera series (starting at $449.95). The Skyris 618M and 618C (monochrome and color) cameras feature a highly sensitive Sony IC618 CCD sensor with a 640 × 480 array of 5.6-micron pixels. The high-speed data transfer of USB 3.0 allows you to record up to 120 frames per second on bright subjects. Skyris incorporates a global electronic shutter and weighs only 3.6 ounces (102 grams). The camera is capable of recording in 12-bit mode and comes with a C-to-1¼-inch nosepiece, a 10-foot USB 3.0 cable, and Celestron *iCap* PC camera-control software. See the manufacturer's website for additional models in the Skyris series.

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

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

This September, Mars passes through the Beehive Cluster, which is pictured above.

In This Section

PHOTOGRAPH: ROBERT GENDLER

SEPTEMBER 2013

3–17 **Dawn**: The zodiacal light, or "false dawn," is visible in the east 120 to 80 minutes before sunrise from dark locations at mid-northern latitudes; see page 54. Look for a tall, broad pyramid of light with Jupiter near its apex.

5, 6 **Dusk**: Low in the west-southwest, look less than 2° below Venus for much fainter Spica.

8, 9 **Predawn**: Mars passes through M44, the Beehive Cluster in Cancer; see page 52.

8 **Dusk**: Venus shines spectacularly close to the thin crescent Moon in North America, with Spica nearby and Saturn to their upper left. The Moon occults (hides) Venus in southern South America.

9 **Dusk**: Saturn shines to the right of the Moon, with Venus to their lower right.

16–19 **Dusk**: Saturn shines less than 4° from Venus; see page 49.

22 **Autumn begins** in the Northern Hemisphere at the equinox, 4:44 p.m. EDT.

24 **Dusk**: Binoculars and telescopes should show Spica just ¾° below brighter Mercury very low in the west-southwest 15 to 30 minutes after sunset.

28 **Dawn**: Jupiter shines upper left of the thick waning crescent Moon, as shown on page 48.

Planet Visibility

SHOWN FOR LATITUDE 40° NORTH AT MID-MONTH

	◀ SUNSET	MIDNIGHT	SUNRISE ▶
Mercury	W	Visible with binoculars in late September	
Venus	SW		
Mars			NE E
Jupiter		NE	E
Saturn	SW		

Moon Phases

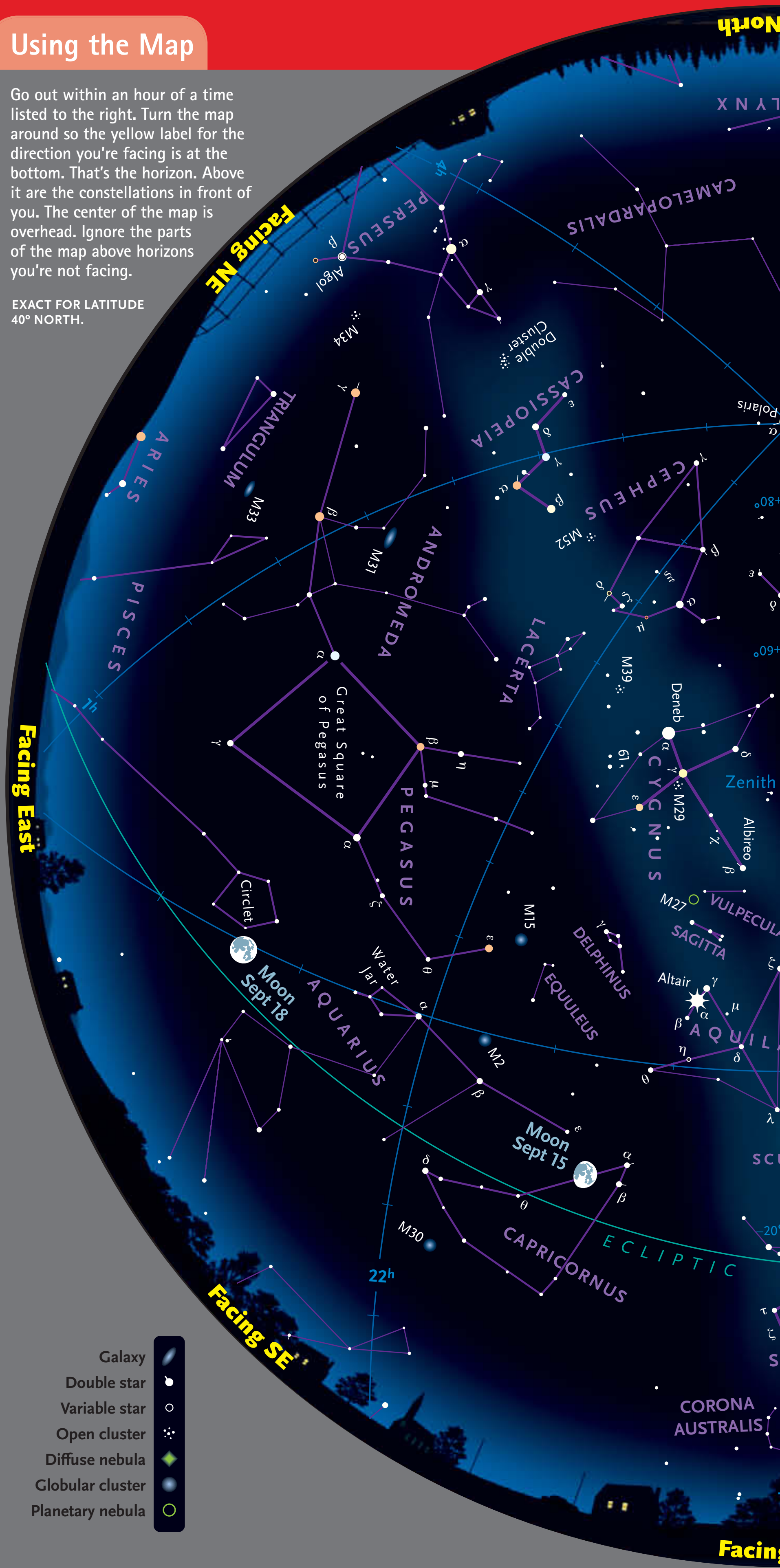
New Sept. 5 7:36 a.m. EDT	First Qtr Sept. 12 1:08 p.m. EDT
Full Sept. 19 7:13 a.m. EDT	Last Qtr Sept. 26 11:55 p.m. EDT

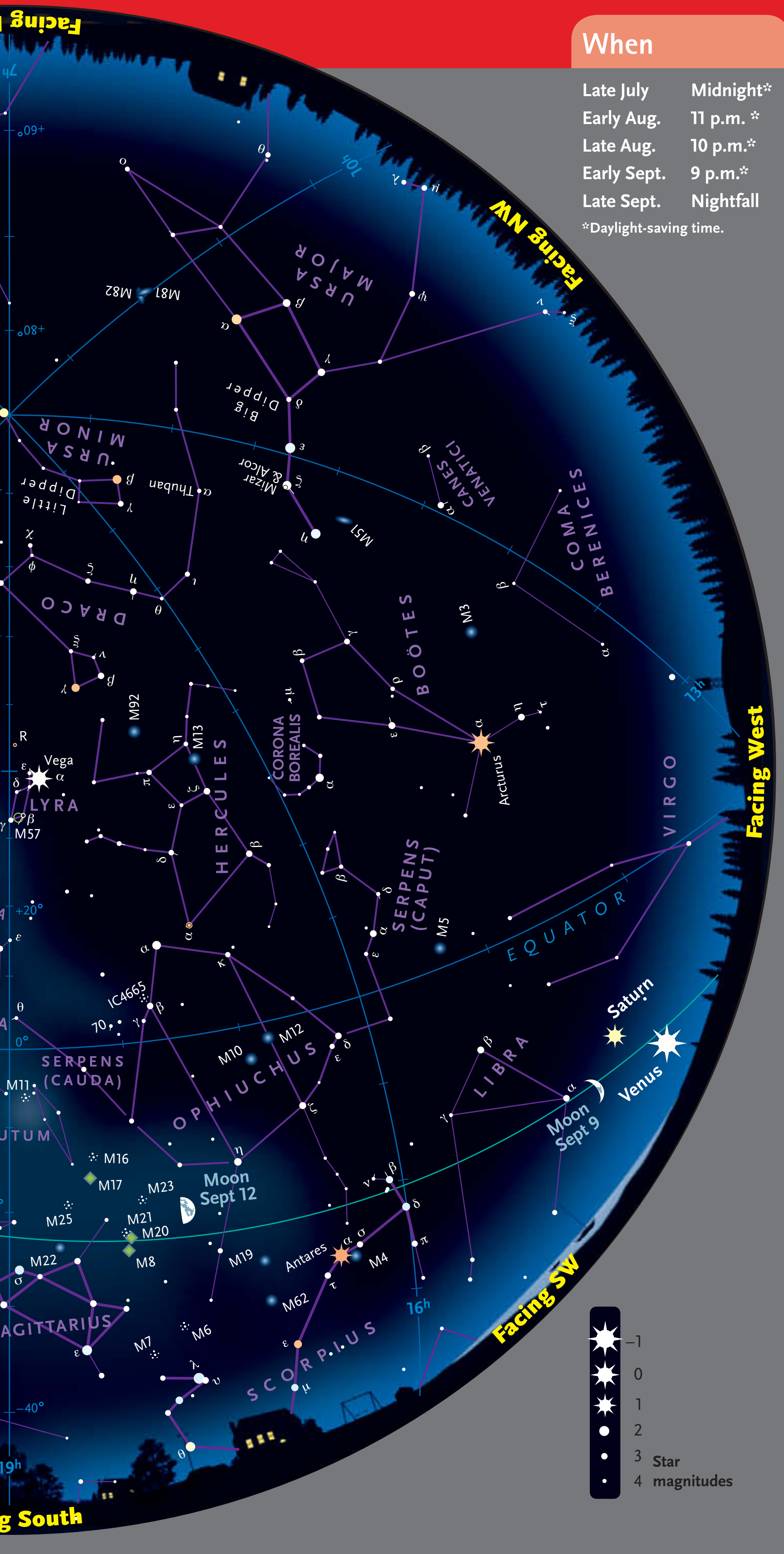
SUN	MON	TUE	WED	THU	FRI	SAT
1	2	3	4	5	6	7
8	9	10	11	12	13	14
15	16	17	18	19	20	21
22	23	24	25	26	27	28
29	30					

Using the Map

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

EXACT FOR LATITUDE 40° NORTH.





When

Late July	Midnight*
Early Aug.	11 p.m. *
Late Aug.	10 p.m.*
Early Sept.	9 p.m.*
Late Sept.	Nightfall

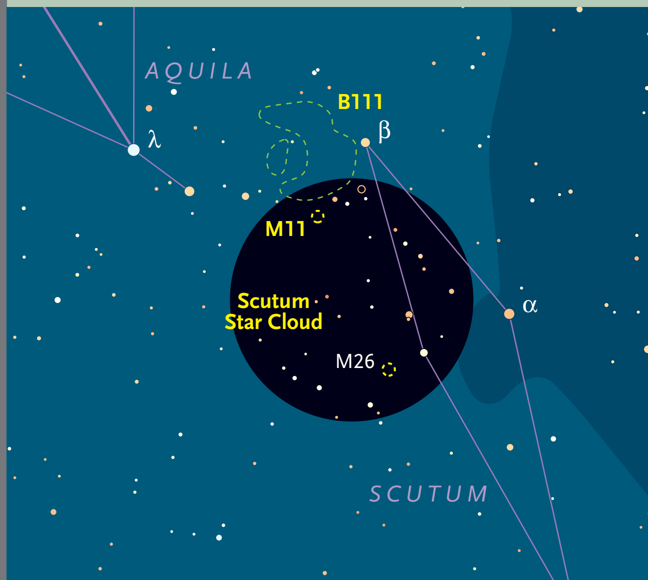
*Daylight-saving time.

Light and Dark in Scutum

Scutum is a tiny treasure chest of Milky Way delights — most notably Messier 11, the Wild Duck Cluster. Indeed, M11 is so well known that many observers fail to notice the constellation's other attractions.

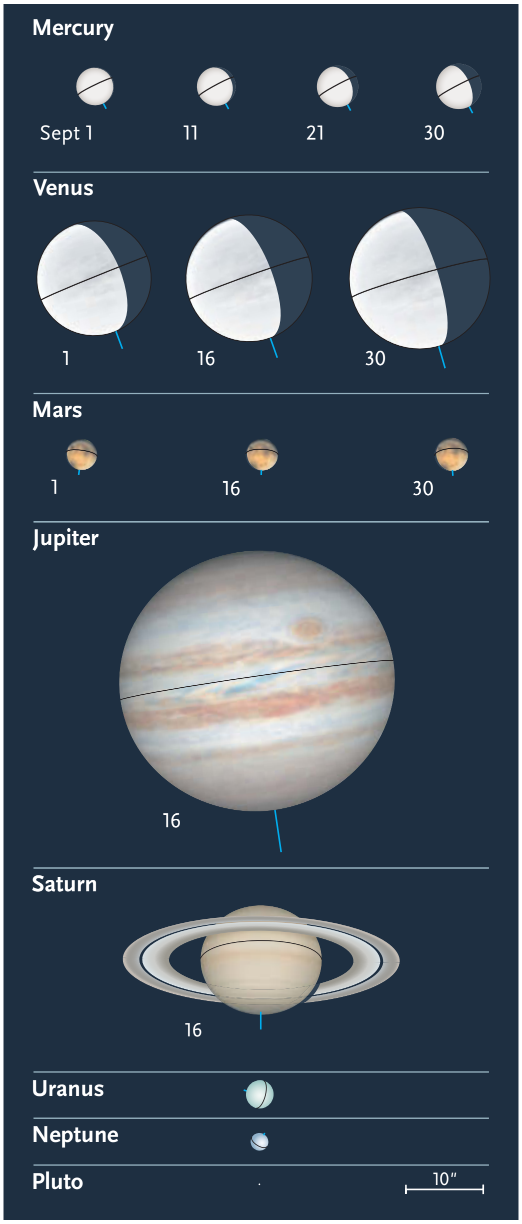
Let's give in to the inevitable and begin our tour by taking a moment to savor **M11**. I wrote about this binocular jewel in last September's column, so I won't dwell on it here except to say that it's not only a joy to behold, but it also serves as a good reference point for other deep-sky treasures. To appreciate the first nearby treasure, you'll have to reset your expectations from an object that's small and distinct (M11) to one that's large and amorphous. Look a little south and east of M11 for the shimmering expanse of the **Scutum Star Cloud**. Sweep back and forth and up and down to soak up the starlight and map the full extent of this delightful bit of Milky Way.

For our next target, you'll have to reset your expectations yet again — this time from viewing something luminous to seeking out darkness. The whole region near M11 is crisscrossed with dark nebulae. The cluster itself appears perched on the southern extremity of **Barnard 111** (B111), which delineates the Scutum Star Cloud's northern edge. The western limits of this star cloud are cut abruptly by a distinctly linear, unnamed tributary of the Great Rift, the dark lane that divides the Aquila Milky Way into two streams. Seeing the Scutum Star Cloud and its dark nebulae depends less on which binoculars you use than on your sky conditions. Dark, moonless skies are a must! ✦



Watch a SPECIAL VIDEO

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

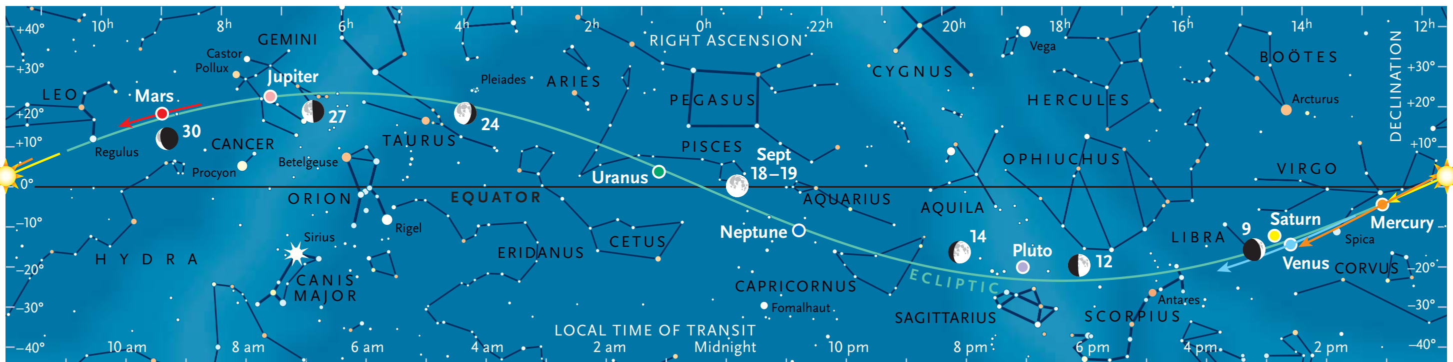


Sun and Planets, September 2013

	Sept.	Right Ascension	Declination	Elongation	Magnitude	Diameter	Illumination	Distance
Sun	1	$10^h\ 40.7^m$	+8° 22′	—	–26.8	31′ 42″	—	1.009
	30	$12^h\ 25.0^m$	–2° 42′	—	–26.8	31′ 56″	—	1.002
Mercury	1	$11^h\ 07.9^m$	+7° 07′	7° Ev	–1.2	4.9″	98%	1.375
	11	$12^h\ 10.4^m$	–0° 38′	14° Ev	–0.5	5.0″	91%	1.337
	21	$13^h\ 05.6^m$	–7° 51′	20° Ev	–0.2	5.4″	83%	1.253
	30	$13^h\ 50.7^m$	–13° 26′	24° Ev	–0.1	5.9″	75%	1.145
Venus	1	$13^h\ 05.8^m$	–7° 07′	39° Ev	–4.0	14.8″	74%	1.124
	11	$13^h\ 48.7^m$	–12° 00′	41° Ev	–4.1	15.8″	70%	1.053
	21	$14^h\ 32.4^m$	–16° 29′	43° Ev	–4.2	17.0″	67%	0.980
	30	$15^h\ 12.7^m$	–20° 01′	44° Ev	–4.2	18.3″	64%	0.913
Mars	1	$8^h\ 19.3^m$	+20° 37′	36° Mo	+1.6	4.1″	96%	2.292
	16	$8^h\ 58.3^m$	+18° 21′	41° Mo	+1.6	4.2″	96%	2.221
	30	$9^h\ 33.1^m$	+15° 52′	46° Mo	+1.6	4.4″	95%	2.143
Jupiter	1	$6^h\ 59.9^m$	+22° 36′	55° Mo	–2.0	34.8″	99%	5.664
	30	$7^h\ 18.1^m$	+22° 09′	79° Mo	–2.2	37.5″	99%	5.258
Saturn	1	$14^h\ 21.5^m$	–11° 43′	58° Ev	+0.7	16.1″	100%	10.343
	30	$14^h\ 32.0^m$	–12° 40′	33° Ev	+0.7	15.6″	100%	10.685
Uranus	16	$0^h\ 41.7^m$	+3° 42′	162° Mo	+5.7	3.7″	100%	19.083
Neptune	16	$22^h\ 21.7^m$	–10° 58′	160° Ev	+7.8	2.4″	100%	29.035
Pluto	16	$18^h\ 37.5^m$	–20° 07′	106° Ev	+14.1	0.1″	100%	32.223

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

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



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

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

Fred Schaaf

From the Milky Way to the Moon

September sports a famous full Moon and the last great views of our galaxy's hub.

In September skies, the brightest section of the Milky Way starts to roll away toward evening twilight. Of course, you'll need skies that aren't badly polluted by artificial light to see the Milky Way band. But when seeking the last weeks to view the star clouds, nebulae, and clusters in the direction of our galaxy's center, you also have to take into account a phenomenon almost as legendary as the Milky Way itself: the Harvest Moon.

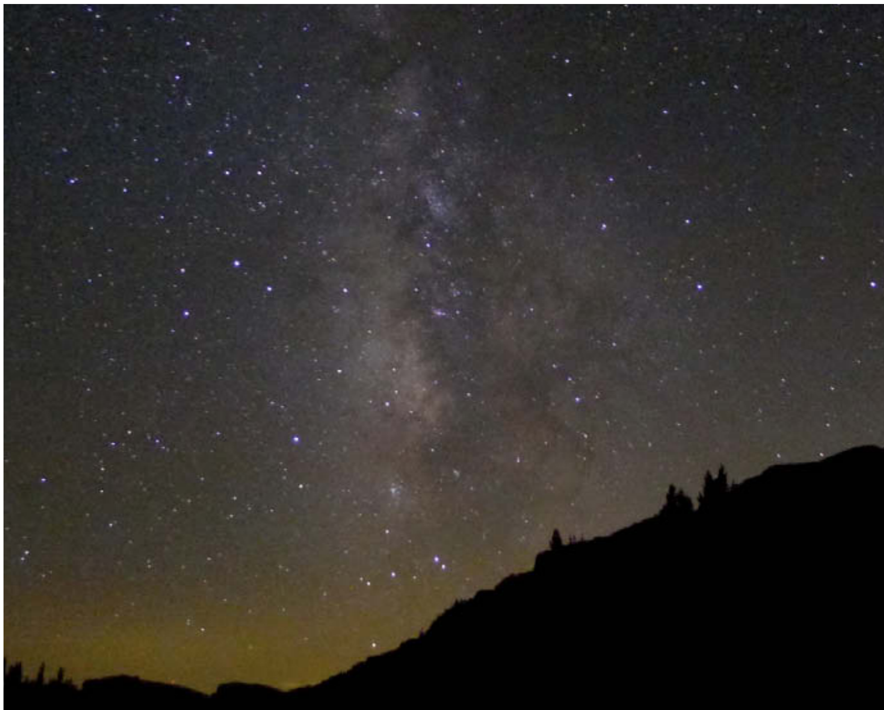
Moon versus Milky Way. The Harvest Moon is usually defined as the full Moon nearest to the beginning of autumn (in the Northern Hemisphere). In 2013 this full Moon occurs on September 19th, only three days before the equinox.

By late September, those of us at mid-northern latitudes will be disappointed to see the glorious Sagittarius-Scorpius Milky Way setting soon after nightfall. So this year, the prime nights to have the last really good looks at its marvels are those before the Harvest Moon begins to wash out the evening sky. These marvels include the big open star clusters M6 and M7, near the stinger of Scorpius; the Great Sagittarius Star Cloud, above the spout of the Sagittarius Teapot; and the bright nebulae M8 and M20 (the Lagoon and Trifid) above that.

There's another way in which early September is "clearly" the time to look at these wonderful sights. For many of us, summer skies are often thick with haze. But in much of the North Temperate Zone, September and October have the clearest and most transparent skies — perfect for the grand but delicate Milky Way glows.

All aboard for Milky Way Central. Carl Sagan once wrote about his fantasy of riding a train (or a spaceship filling the same role) that would take him out into our galaxy. He called it catching the "night freight to the stars." A similar fancy of mine is to imagine the middle of our galaxy as some kind of grand terminal for millions of transgalactic trains.

But the Harvest Moon phenomenon reminds me of another railroad analogy. The Moon is like a train that keeps arriving later and later; its eastward motion through the stars causes it to rise almost an hour later each consecutive night — on average. But for a few evenings before and after the Harvest Moon, the Moon seems to rise with much less delay due to the shallow angle of the zodiac with respect to the horizon. Around Harvest Moon, the Moon comes up only about a half hour later each evening for a viewer at mid-northern latitudes. The higher your latitude, the shorter the interval.



TONY FLANDERS

The Milky Way starts setting behind a ridge in California's Sierra Nevada mountains shortly after nightfall in September.

In most months, the Moon is gone from the early evening sky two or three days after it's full. But the bright Harvest Moon lights up the sky at nightfall for one or two extra evenings.

Like a lumbering old railway engine, the Moon's slow arrival above the horizon is an uproarious, enormous event. Its brightness is like a locomotive's headlight. Or maybe the moonlight washing out the Milky Way is the visual version of the Moon-train's blowing its whistle.

Not as bad as you think. Many deep-sky observers complain about the Moon's bright interference. But I've seen the dim Coma Star Cluster naked-eye around half Moon when the sky was very clear. And veteran amateur Steve Albers recently told me that he detected all of the Little Dipper's major stars (down to magnitude 5.3) when the Moon was full. So don't think that a bright Moon ruins everything but lunar and planetary observation. ✦

Close Encounters

Several celestial objects pass near to one another on the sky and in space.

At dusk Venus shines low in the west-southwest all September, experiencing conjunctions with Spica, Saturn, and the Moon. Mercury struggles into binocular view far to Venus's lower right in late September.

Jupiter rises in the middle of the night and is high by dawn. Mars, coming up three to four hours before the Sun, passes through the Beehive Star Cluster — a few weeks before its first close conjunction with still-faint Comet ISON.

DUSK

Venus appears no higher than it has for the past few months. Look for it low in the west-southwest while twilight is fading. However, it does brighten from magnitude –4.0 to –4.2 during September. Telescopes show its disk growing from 15″ to 18″, while its gibbous globe wanes from 74% to 64% sunlit.

About 45 minutes after sunset on September 5th and 6th, stargazers in the Americas can see 1.0-magnitude Spica twinkling less than 2° below Venus. On September 8th, the Americas enjoy a spectacular close pairing of Venus and the slender crescent Moon, with Spica still nearby. The Moon occults Venus shortly before or after sunset in parts of Brazil, Argentina, Uruguay, and Chile. Venus's last conjunction this month — though not a very close one — pairs it with fellow planet Saturn.

Saturn starts September 18° to Venus's upper left, but the gap between them closes rapidly. Their closest pairing occurs on the American evenings of September 17th and 18th, when +0.7-magnitude Saturn shines 3½° above much brighter Venus.

The ringed world is too low for good telescopic views unless the atmosphere is unusually steady. For viewers at 40° north latitude, Saturn sets 2½ hours after the Sun on September 1st but only 1½ hours after the Sun on September 30th.

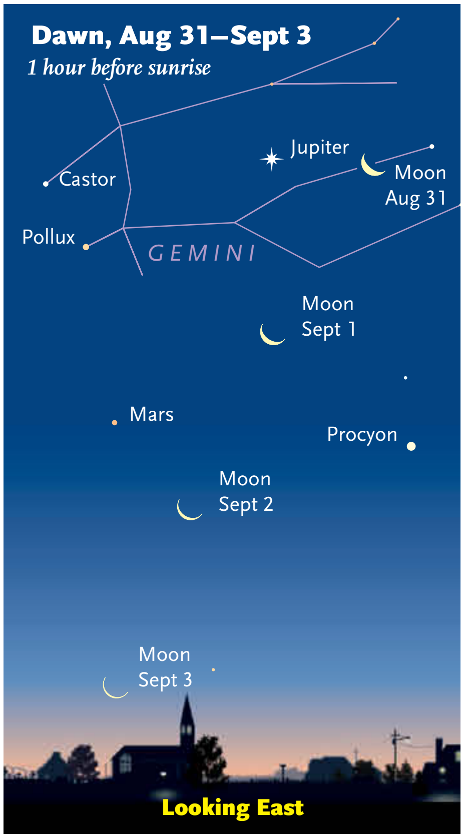
Saturn was in Virgo from June through August. It crosses back into Libra on September 1st and will remain in that constellation until 2015. Venus, by contrast, leaves Virgo on September 18th (Universal Time) and shoots across Libra and on into Scorpius in just three weeks.

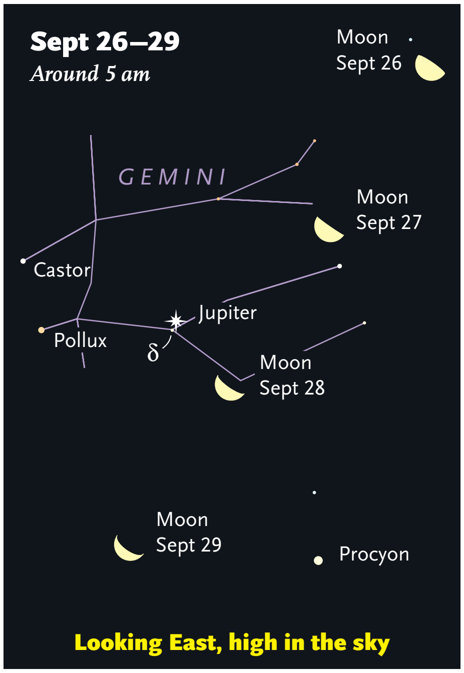
Mercury is barely above the horizon a half hour after sunset in late September, far lower right of Venus, for viewers at mid-northern latitudes. It will be tricky to spot even with optical aid. But you should try to view it on September 24th, when zero-magnitude Mercury is just ¾° above fainter Spica.

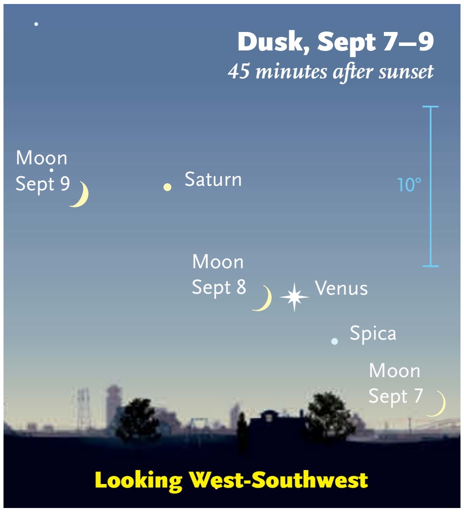
EVENING AND NIGHT

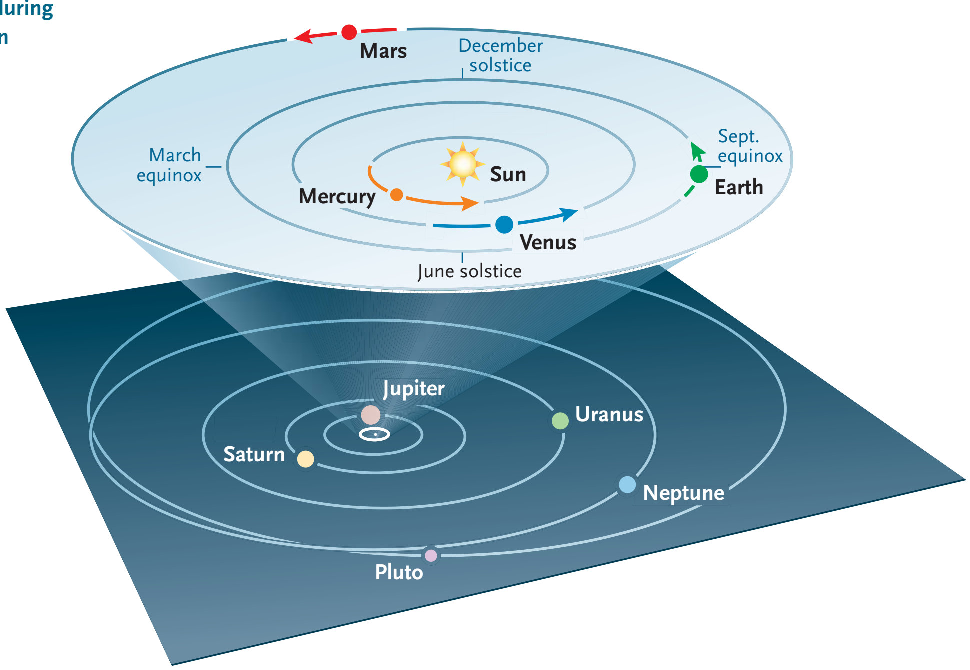
Pluto, glimmering at 14th magnitude in Sagittarius, is near its highest in the south just after evening twilight fades; see the finder chart in the June issue, page 52.

Neptune, magnitude 7.8 in Aquarius,









ORBITS OF THE PLANETS

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

is above the horizon at dusk but doesn't reach its highest until the middle of the night. **Uranus**, magnitude 5.7 in Pisces, reaches opposition on October 3rd, so it's best observed after midnight. See the finder charts for Uranus and Neptune at **skypub.com/urnep**.

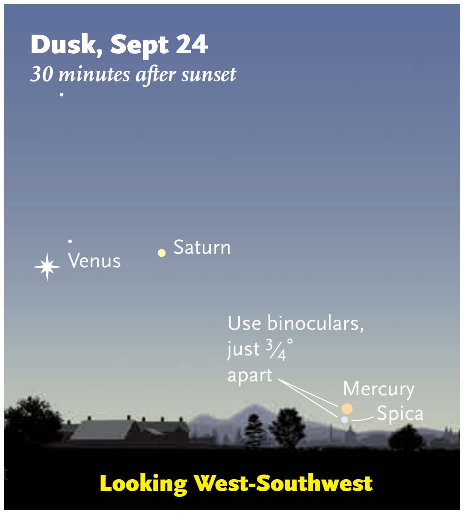
Asteroid **324 Bamberga** reaches opposition near the Circlet of Pisces on September 13th, when it's just 0.81 a.u. (121 million km) from Earth, closer to us than any other large main-belt asteroid ever comes. These close encounters occur only once every 22 years; see page 51 for details. I recall my excitement reading about such an approach in one of the first issues of *Sky & Telescope* I ever saw — 44 years ago.

DAWN

Jupiter rises sooner and sooner after local midnight (daylight-saving time) and is high by the beginning of dawn. Brightening from magnitude –2.0 to –2.2, the giant world treks east across central Gemini, ending September just ½° from 3.5-magnitude Delta Geminorum (Wasat).

Mars comes up around 3 a.m. all September and glows at a modest magnitude +1.6, with a disk barely 4″ wide. Nevertheless, it's fascinating to watch Mars's rapid flight from Cancer to Leo this month, including two notable conjunctions. The first is the Red Planet's passage through M44, the Beehive Star Cluster, best seen in the Americas on the mornings of September 8th and 9th (see page 52). Use optical aid to see the cluster clearly.

The second Mars conjunction is with a comet. With any luck, **Comet C/2012 S1 ISON** may brighten to 10th magnitude by late September, though the signs at press time aren't promising (see page 50). What's certain is that the comet passes 2.0° north of Mars on the morning of September 27th. The two bodies are also very close in space, with the comet just 0.07 a.u. directly "above" Mars (relative to the planet's orbit) on October 1st.



EARTH AND MOON

The waning crescent **Moon** is about equidistant from Jupiter, Mars, and Procyon at dawn on September 1st, nearly centered in their triangle. The Moon is well lower right of Mars the next morning.

Back in the evening sky, the waxing lunar crescent has a close conjunction left of Venus on the evening of September 8th and farther left of Saturn on the 9th. The full Moon on September 18–19 is called the Harvest Moon, since it's the full Moon closest to the equinox this year.

A thick waning lunar crescent shines lower right of Jupiter at dawn on September 28th and well upper right of Mars on September 30th.

The **Sun** arrives at the equinox at 4:44 p.m. EDT on September 22nd, crossing the equator southward to start autumn in the Northern Hemisphere and spring in the Southern Hemisphere. ✦

Comet ISON Approaches

The "comet of the century" was stuck at 16th magnitude when it hid out for the summer. Even so, good prospects remain for December.

GEMINI OBSERVATORY / AURA (3)

Comet ISON remained at about magnitude 16 from January through May before disappearing into the glare of the Sun. We won't get another look at how it's behaving until around the end of August. These images were taken with the 8.1-meter Gemini North telescope. The first two were taken in red light; the third has green and near-infrared added. Each frame is 2.5 arcminutes wide.

Newly discovered comets are always a bit mysterious and confounding in how they develop. That's especially true for new comets that become active very early, hinting of great things to come while they are still far from the Sun. In such cases, predictions of future glory often fall flat.

So what can we expect from **Comet ISON (C/2012)**, now approaching amid great expectations? It will swing close by the Sun at the end of November and climb up the dawn sky in December. Some have been billing ISON as "the comet of the century." Is there a chance that this *won't* be an embarrassment?

The excitement arises from the remarkably close Sun graze that the comet will perform at its perihelion on November 28th. It will fly less than one solar diameter past the Sun's visible surface, with the dusty ice of the comet's nucleus broiling violently. Despite the unknowns, past performances by sungrazing and sunskirting comets enable us to make a reasonable estimate of what's in store.

A comet usually brightens and fades by an inverse power law of its distance from the Sun. (Its brightness as seen by us also depends on its distance from Earth.) This has been true for all bright comets of the famous Kreutz sungrazing family that have survived their fiery encounters with the Sun, as well as for several others making close Sun passes. Comet ISON differs from most of these by being a dynamically "new" comet that has not experienced previous trips through the inner solar system. Such new comets often have surface deposits of low-temperature volatiles, mainly carbon dioxide and carbon monoxide, that vaporize far from the Sun and entice us with temporary early activity. Nevertheless, ISON shares many characteristics with ordinary sungrazers.

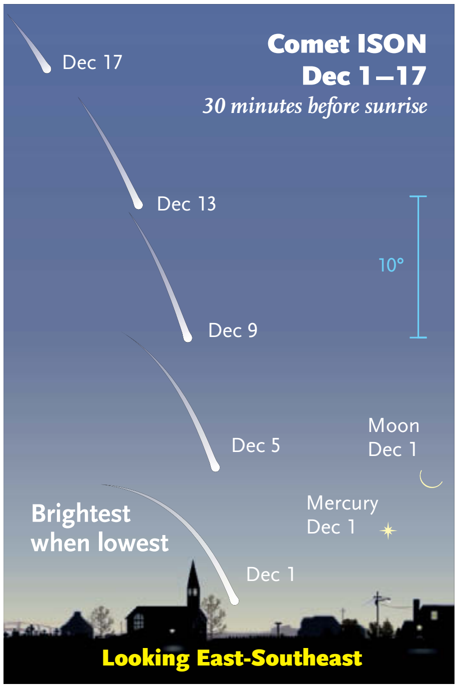
A close solar pass can disrupt and evaporate a comet's nucleus completely. The intrinsically faintest sungrazer to survive its brush with the Sun reasonably intact was Comet Ikeya-Seki in 1965. The long-tailed sungrazers seen in 1880 and 1887 experienced total disruption of their nuclei and dissipated completely within weeks after perihelion. The latest observations of Comet ISON suggest that it's intrinsically about as bright as those 19th-century objects, so the survival of its head much beyond November 28th is in question.

However, ISON is decidedly brighter than the recent Comet Lovejoy, which totally disrupted and, despite this or perhaps because of it, put on a spectacular long-tailed show for Southern Hemisphere observers at the end of 2011.

Extrapolating from those comets, here is the display I currently envision for Comet ISON at the close of this year.

The Forecast

From January through May, Comet ISON brightened hardly at all, remaining stuck at magnitude 16 or 15 and falling nearly



Although some of Comet ISON may be visible lying very low at dusk in December, the best viewing will be just before or during dawn.

Keep up to date with Comet ISON's developments at skypub.com/ison.

*Contributing editor **John Bortle** has been covering comet topics for S&T since 1967.*

John E. Bortle

two magnitudes behind early predictions. It became lost in twilight around the end of May and won't be back in view until the end of August.

So my forecast is that Comet ISON will develop more slowly in the autumn morning sky than initially thought. It won't reach naked-eye detectability until around the 10th of November, about three weeks before rounding the Sun. It will brighten steadily but not exceed 2nd or 3rd magnitude before disappearing into the morning twilight just a week shy of its November 28th perihelion. At that time a short, not particularly bright tail should trail the comet's intensifying coma.

On perihelion day the head of the comet may spike very briefly to around magnitude –6, brighter than Venus, next to the Sun. Experienced observers who use great precautions when looking for the comet close to the Sun may see it visually in the daytime sky as a fuzzy point. This grandeur will persist for only a matter of hours, as the comet will immediately begin to fade dramatically.

As ISON re-emerges in the dawn sky a few days after perihelion, its head will have faded to about 2nd or 3rd magnitude. But by now it will sport a brilliant, quickly straightening tail perhaps 10° to 15° long. This impressive tail will grow longer morning by morning, while the comet's head becomes ever less distinct.

The crescendo of the apparition will likely reach its peak between December 10th and 14th, when the comet will be best seen just before dawn after the Moon sets. Although little or perhaps nothing of the head will remain, the huge tail will loom in the eastern sky. Almost evenly illuminated over its length, this rapidly fading appendage could reach from southern Hercules to near the handle of the Big Dipper, spanning almost a quarter of the heavens as seen under good, dark observing conditions.

Will it be the "comet of the century"? If we're talking only about Northern Hemisphere observers, and since the century is only 13 years old, there's still a chance.

Bamberga at its 22-Year Peak...

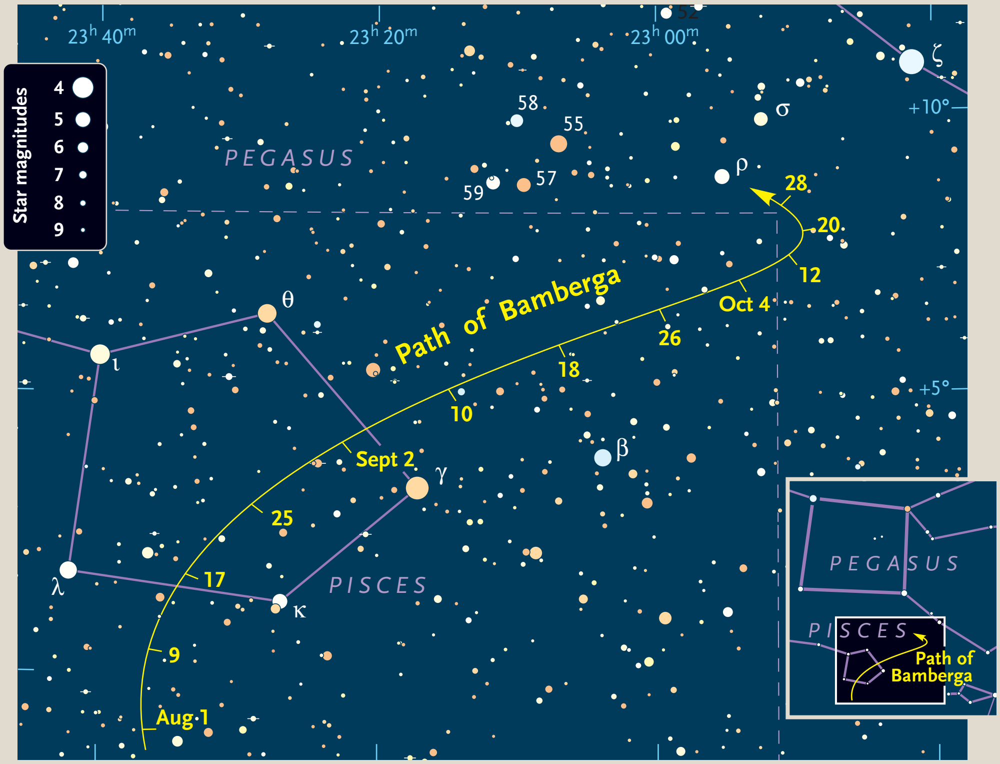
Orbital mechanics are simple in theory — it's all just gravity! — but from that simple root grow unexpected flowers of complexity and interest.

The main-belt asteroid **324 Bamberga** has a very ordinary orbital period of 4.395 years, but its unusually high orbital eccentricity (0.34) brings it closer to Earth than any other asteroid so large ever comes. With Earth's own orbital period being 1.000 year, Bamberga comes to an unusually close opposition from our viewpoint every 22 years. This happens again on September 13th.

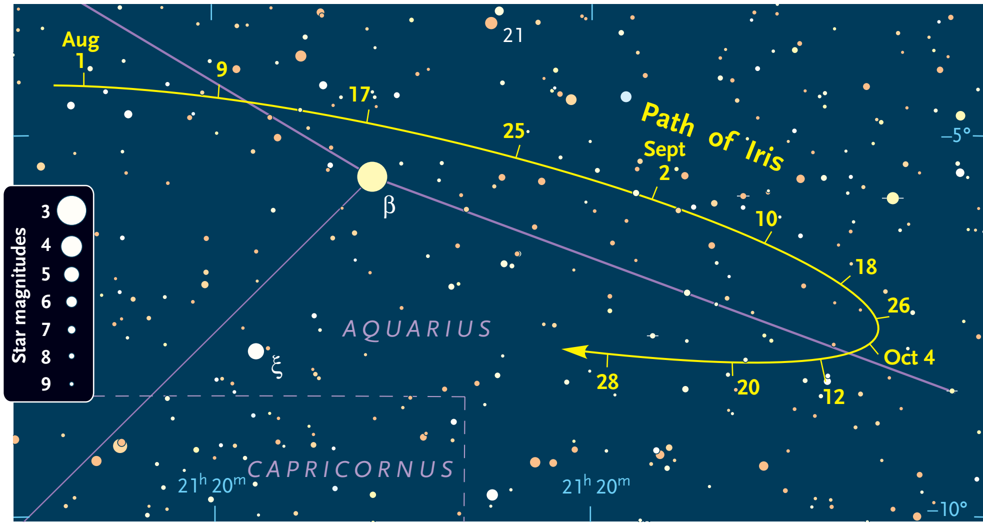
Bamberga is just 0.81 a.u. from us around that date, closer than the Sun is, and it will shine at magnitude 8.1 near the Circlet of Pisces. Bamberga would be even brighter — and probably would have been discovered earlier and received a lower number (Johann Palisa found it in 1892) — if it didn't have such a dark surface. It's a C-type, carbonaceous asteroid that reflects only 6% of the sunlight hitting it. It's about 230 km (140 miles) wide, making it the largest main-belt asteroid discovered so late and numbered so high. It's also the highest-numbered asteroid that's ever visible to most binocular observers.

Bamberga is magnitude 9.5 on August 1st, 8.4 by September 1st, 8.1 at opposition on September 13th, 8.5 October 1st, and 9.3 November 1st. It'll be a bit of a challenge in 10×50 binoculars, but it should be obvious with a 3-inch wide-field scope.

Longtime *S&T* columnist Fred Schaaf remembers a similar close Bamberga approach that happened two of its 22-year cycles ago. A forecast of that event in the August 1969 *S&T* was one of the things that snared him into astronomy, as he writes on page 49. Where will you be in 2035 and 2057? — *Alan MacRobert*

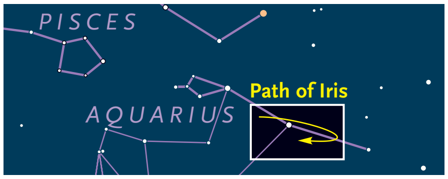


...and Iris at a Lucky Star



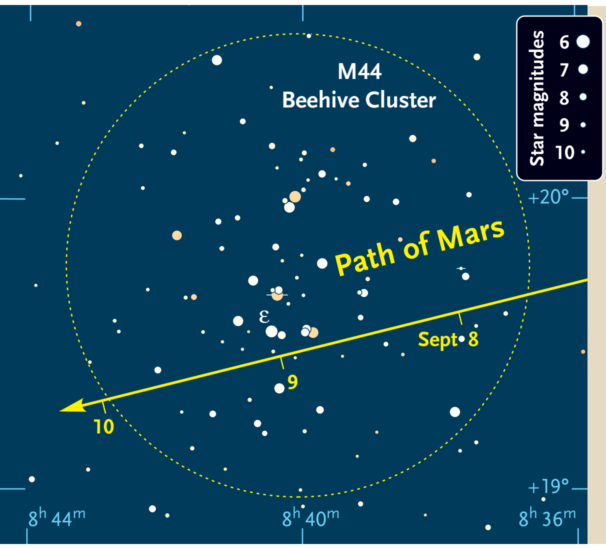
Although it was discovered much earlier and hence is much lower-numbered than Bamberga, **7 Iris** is similarly bright around its opposition this summer. It's located to Bamberga's west, looping around Beta (β) Aquarii or Sadalsuud — a name that may have meant "the luckiest of the lucky stars" in ancient Arabic, though the original context is lost.

Iris is the same size as Bamberga but has a much more reflective surface (albedo 28%), and this makes up for its being farther away. Iris is magnitude 8.3 on August 1st, 7.9 at opposition on



August 20th, 8.1 September 1st, 8.7 October 1st, and 9.2 November 1st. John Russell Hind discovered it in 1847.

And for a somewhat greater challenge, the asteroid 4 Juno (found in 1807) is about a magnitude fainter still, some 15° farther west. Use the finder chart for it on page 51 of last month's issue.



MARS BUZZES THE BEEHIVE

The big, familiar Beehive Star Cluster, M44 in Cancer, hosts a bright visitor on the mornings of September 8th and 9th. Mars is about 20° up in the east just before the start of dawn on those dates, high enough that binoculars will show the cluster's familiar beehive pattern with faint "bees" coming out of its top (north). Mars will be magnitude 1.6; M44's brightest star is magnitude 6.3.

With a telescope, can you see Mars's motion with respect to background stars before dawn grows too bright?

Jupiter's Moons

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

Alan MacRobert

Action at Jupiter

Jupiter in September is growing larger, nearer, and higher in the morning sky than it was in July and August. The best time to observe it telescopically to see what its belts, zones, and spots may be doing is in early dawn, when Jupiter is high up and the seeing sometimes grows very steady.

Any telescope shows Jupiter's four big Galilean moons. Binoculars usually reveal at least two or three, occasionally all four. Identify them with the diagram at left.

Listed below are all of the moons' many interactions with Jupiter's disk and shadow in September.

Jupiter's Great Red Spot is not an easy sight, since the planet grows from only 35 to 37 arcseconds wide in September. Here are the times, in Universal Time, when the Great Red Spot should cross Jupiter's central meridian. The dates, also in UT, are in bold:

September 1, 7:41, 17:36; **2**, 3:32, 13:28, 23:24; **3**, 9:19, 19:15; **4**, 5:11, 15:07; **5**, 1:02, 10:58, 20:54; **6**, 6:50, 16:45; **7**, 2:41, 12:37, 22:33; **8**, 8:28, 18:24; **9**, 4:20, 14:16; **10**, 0:11, 10:07, 20:03; **11**, 5:59, 15:54; **12**, 1:50, 11:46, 21:41; **13**, 7:37, 17:33; **14**, 3:29, 13:24, 23:20; **15**, 9:16, 19:12; **16**, 5:07, 15:03; **17**, 0:59, 10:55, 20:50; **18**, 6:46, 16:42; **19**, 2:37, 12:33, 22:29; **20**, 8:25, 18:20; **21**, 4:16, 14:12; **22**, 0:07, 10:03, 19:59; **23**, 5:55, 15:50; **24**, 1:46, 11:42, 21:37; **25**, 7:33, 17:29; **26**, 3:25, 13:20, 23:16; **27**, 9:12, 19:07; **28**, 5:03, 14:59; **29**, 0:55, 10:50, 20:46; **30**, 6:42, 16:37.

To obtain Eastern Daylight Time from UT, subtract 4 hours. These times assume that the spot is at System II longitude 201°. ✦

Minima of Algol

Aug.	UT	Sept.	UT
1	8:36	1	21:31
4	5:25	4	18:20
7	2:13	7	15:08
9	23:02	10	11:57
12	19:51	13	8:46
15	16:39	16	5:34
18	13:28	19	2:23
21	10:17	21	23:12
24	7:05	24	20:00
27	3:54	27	16:49
30	0:42	30	13:38

In September Algol is well up in the northeast by midnight. These geocentric predictions are courtesy Gerry Samolyk (AAVSO).

Phenomena of Jupiter's Moons, September 2013

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

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

Stalking the "False Dawn"

To see the elusive zodiacal light during September and October, you'll need dark, crystal-clear skies — and an alarm clock.

TUNÇ TEZEL

IDEAL LOCATION Even with twilight still evident, the zodiacal light competes with the center of the Milky Way in this November 2011 image taken minutes after sunset from Uluru (Ayers Rock) in Australia.

The most satisfying views of the cosmos can sometimes involve subtle, even furtive targets: tracing out the delicate whorls of the Orion Nebula, spotting dark rifts among the Andromeda Galaxy's gauzy spiral arms, or eyeballing a faint aurora. If that's what gives you observing pleasure, then make the effort to track down the faint glow known as the *zodiacal light*. This delicate, luminous pyramid, so named because it drapes across the zodiacal constellations along the ecliptic, extends upward from the horizon in the hours after sunset or before dawn.

Although the great observer Jean-Dominique Cassini spied it in 1683 and later detailed his observations in *Discovery of a Celestial Light Which Appears Within the Zodiac,* many earlier sightings and allusions to it exist. Ancient Persian and Arabic astronomers described "tall twilight" glows and "false dawns."

The source of this "subtle vapor," as Immanuel Kant termed it in 1755, is sunlight scattering off countless tiny flecks of dust drifting through the inner solar system. Imagine an enormous, swollen pancake of tenuous dust with the Sun at its center, and you'll have the right idea. Over the years many scientists have taken a stab at explaining this phenomenon — some more fanciful than others. My 45-year-old college astronomy textbook notes that it's likely due to a dusty tail that trails Earth as it orbits the Sun. (Not!)

Since the glow is brightest along the ecliptic, it's logical to assume that asteroids play a major role in its formation. That's what theorists thought in the mid-1990s, especially after the Infrared Astronomical Satellite (IRAS) and other space observatories detected several distinct dusty bands near the ecliptic derived from "families" of asteroids in orbits with similar inclinations.

In 2010, however, dynamicists led by David Nesvorný (Southwest Research Institute) decided to tackle the zodiacal light's origin from first principles. They modeled what would happen to dust released from various sources — asteroid collisions, comets arriving on random orbits from the Oort Cloud, and especially "Jupiter-family comets" (with orbital periods of less than 20 years) — and kept track of what went where. It wasn't enough to match the visible-light glow in the pre- and post-twilight sky, which comes mostly from particles inside Earth's orbit that scatter sunlight strongly in our direction. The model also had

to match the sizes and concentrations of dust lying outside Earth's orbit that various spacecraft had recorded.

At first, Nesvorný thought the best match would involve a mix of dust from asteroids (to match the glow's peak along the ecliptic) and comets from the Oort Cloud (to explain its vertical breadth). But the model provided a very different answer: virtually all the dust must come from short-period comets, with a small contribution from Oort Cloud comets. Moreover, all those Jupiter-family comets don't just sprinkle fairy dust along their orbits — more likely, they cough up pulses of debris by breaking up repeatedly, dozens of times, over their lifetimes.

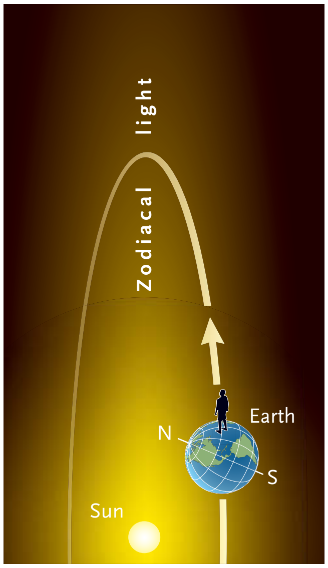
No more than 10% of the zodiacal dust can be from the asteroid belt. Some of it might be from interstellar space, as detailed by Brian May (astrophysicist and founding member of the rock group Queen) in his 2007 doctoral thesis, but the jury's still out on his contention: direct evidence for interstellar dust is more elusive, says Nesvorný.

Regardless of the sources, the diffuse zodiacal cloud has a total mass of perhaps 10^{19} grams, equaling the Martian moon Phobos. That's an awful lot of dust — enough to make the zodiacal light gleam brighter than the Milky Way. In fact, a mosaic of the region very near the Sun made in 1994 by the Clementine spacecraft reveals that the glow has an integrated magnitude of –8.5!

Needed: Your Darkest Dark

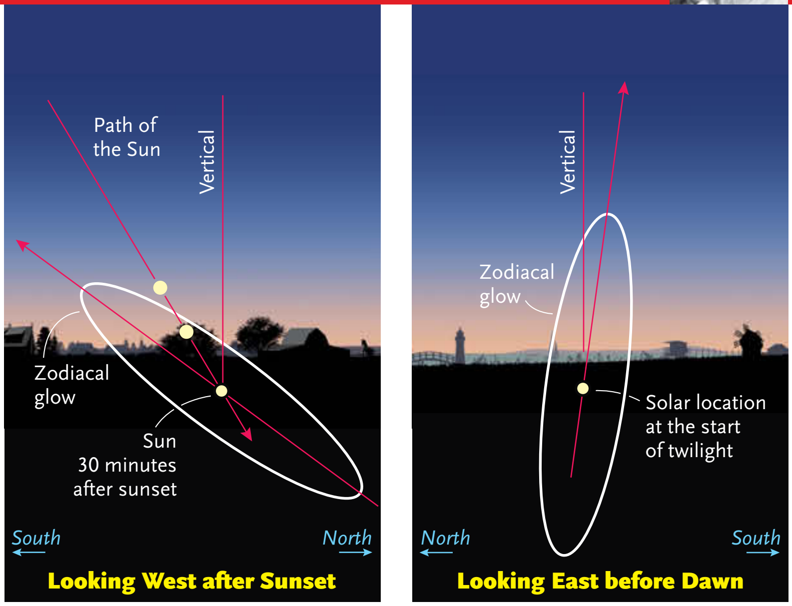
Yet spotting this luminous band by eye is anything but easy. Sadly, light pollution has made seeing the zodiacal light's eerie visage impossible unless the sky is truly dark. It wasn't always so challenging. "Up through the 1960s, it was possible to see the zodiacal light quite well even from the outer suburbs of many of the larger cities," notes veteran observer John Bortle. "From the rural areas only a bit more distant, it was a truly wonderful sight."

And it still can be — but you'll need to work for it. From mid-northern latitudes, the best



S&T: CASEY REED

SEEING THE GLOW The zodiacal light is caused by sunlight scattering off tiny dust particles in the inner solar system. It appears as a faint pyramid-shaped glow before dawn or after sunset.



S&T: LEAH TISCIONE

ECLIPTIC TILT From mid-northern latitudes, the zodiacal light is easiest to see in September and October before morning twilight. That's when the ecliptic is most nearly vertical in the predawn sky. Six months later, circumstances are reversed; the ecliptic stands nearly straight up as the Sun sets.

times to look are after sunset in spring and before dawn in autumn. That's when the ecliptic stands most nearly vertical as it rises from the western or eastern horizon, respectively. Summer is a poor time to look because twilight becomes so protracted, and winter is no better because the zodiacal light is projected against portions of the Milky Way that straddle the ecliptic.

During September and October, you'll need to venture outside before the first hints of twilight appear, about two hours before dawn. You must avoid the Moon, too, so plan on looking during the first half of either month. Transparent skies are a must, and give your eyes plenty of time to become dark-adapted.

Look for a tall, faint triangle of light that's relatively broad and brightest along the horizon (25° to 30° wide under the best conditions). The glow gradually tapers along a line tracing upward and slightly to the right through Leo, Cancer, and Gemini. Usually the narrowing finger fades from view roughly 60° up, though it actually continues along the ecliptic across the entire sky. Since the zodiacal light moves with the Sun, its visibility should become enhanced as dawn's twilight draws nearer.

Over the years observers have reported variations in the zodiacal band's brightness, shape, and color. There's anecdotal evidence that it becomes more obvious when the Sun is active and its disk is peppered with spots. Most likely you'll see it as a neutral, hazy white, though it might look tinged with red nearer the horizon (due to atmospheric scattering).

If you don't see it, blame your surroundings — and then seek darker skies. ✦

The Swan upon the Gale

Cygnus hosts both showpieces and little-known treats.

The swan upon the evening gale
Spreads his white wings above,
Capella gleams o'er hill and dale
Fair as the star of love.
— Leopold J. Bernays, *The Constellations*, 1839

Captivating Cygnus, the Swan, is so richly feathered with deep-sky wonders that you can barely swing a telescope without bumping into one. Time and again its wealth of celestial treasures entices us to delight in the seemingly endless sights laid before our questing eyes.

Let's launch our tour with the snug double star **Delta (δ) Cygni** at the bend of the Swan's northern wing. William Herschel discovered its dual nature in 1783. He described the stars as very unequal in brightness, with a "fine white" primary whose companion is "ash colour tending to red." The pair is barely split through my 130-mm (5.1-inch) refractor at 117× and still close at 164×. I see its components as white and yellow, the latter southwest of its bright neighbor. They orbit each other with a period of 780 years. This binary moves through space together with a 12th-magnitude star 63″ to its east-northeast, which is considered a likely member of this 165-light-year-distant system.

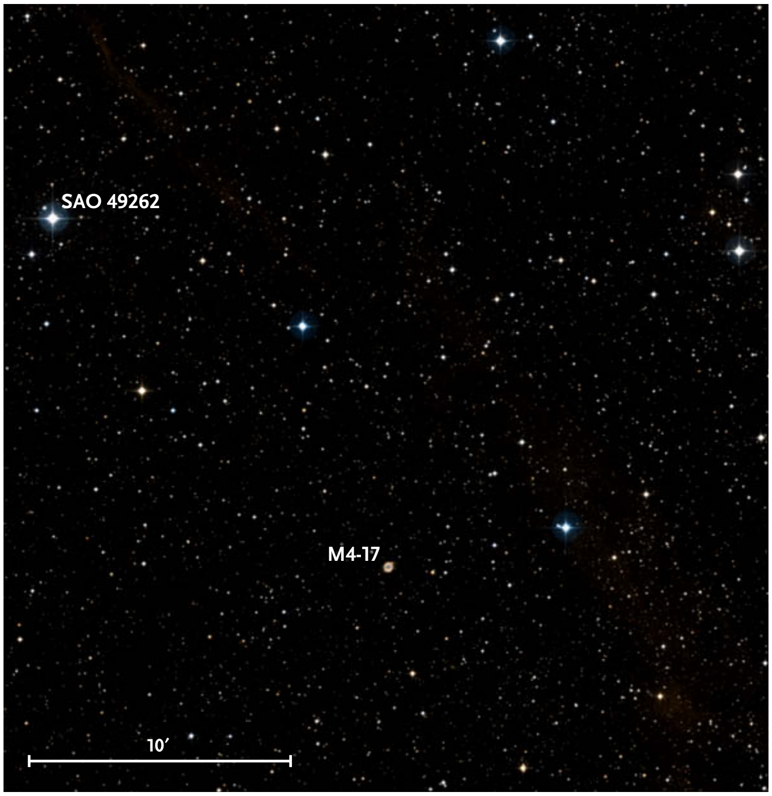
The pretty open cluster **NGC 6866** sits 3.5° east-southeast of Delta, and it's accompanied by an orange 7th-magnitude star 23½′ to its west. It's a nice, compact gathering of faint stars that stands out well in my 105-mm refractor at 17×. At 47× the concentrated center displays about 15 stars, while several rays and outlying patches add at least as many more. At 87× the borders are indefinite. But within a 16′-wide circle I count about 40 stars of 10th magnitude and fainter. My 10-inch reflector reveals at least 60 stars at 88×, and its 9×50 finderscope shows NGC 6866 as a small, fairly faint fuzzspot.

NGC 6866 is about 5,000 light-years distant. A study by Vladimir Frolov and colleagues in the May 2010 issue of *Astronomy Letters* identifies 267 member stars in a 40′ × 40′ square of the sky centered on the cluster.

Just 1° east-southeast of NGC 6866, the planetary nebula **Minkowski 4-17** (PK 79+5 1) makes a squat isosceles triangle with yellow, 7th- and 8th-magnitude stars 18′ northeast and northwest, respectively. My 130-mm scope at 117× discloses a small, extremely faint disk with averted vision. (Averted vision is the practice of looking a bit off to one side of a dim object to allow its light to fall on a more sensitive area of your eye's retina.) The nebula is weakly visible at 68× in my 10-inch scope with the help of an O III filter, and I can see a moderately small disk using direct vision with the filter at 115×. The O III filter becomes unnecessary at 213×, and the nebula morphs into a nice little annulus. Minkowski 4-17 looks as though it would cozily fit between a pair of stars 2′ to its west, which are 29″ apart.

German-American astronomer Rudolph Minkowski discovered nearly 200 planetary nebulae in the 1940s, more than doubling the number known at that time.

Golden **Omicron¹ (o¹) Cygni** makes a shallow arc with Delta and Deneb, the brilliant star that marks our



POSS-II / CALTECH / PALOMAR OBSERVATORY

These photographs are synthesized from red and blue plates of the Palomar Sky Survey. Each includes the nearest reasonably bright star to the object depicted. Stars are labeled with SAO numbers because many Go To telescopes use these numbers.

Stars, Clusters, and Nebulae in Cygnus

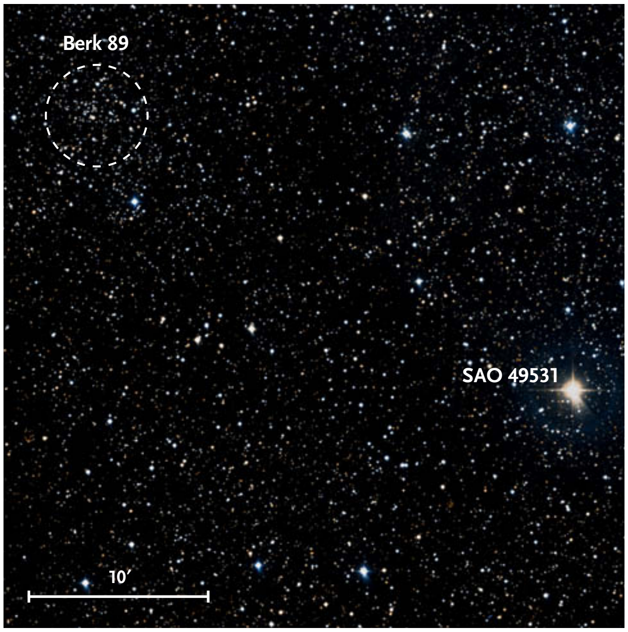
Object	Type	Magnitude (v)	Size/Sep.	RA	Dec.
δ Cygni	Double star	2.9, 6.3	2.7″	19^h 45.0^m	+45° 08′
NGC 6866	Open cluster	7.6	15′	20^h 03.9^m	+44° 10′
M4-17	Planetary nebula	13.7	23″ x 21″	20^h 09.0^m	+43° 44′
o^1 Cygni	Optical triple star	3.7, 6.9, 4.9	1.9′, 5.6′	20^h 13.6^m	+46° 44′
Berkeley 89	Open cluster	—	5.0′	20^h 24.5^m	+46° 02′
GN 20.43.9	Emission nebula	—	1.5′	20^h 45.6^m	+44° 15′
[G98] 171	Reflection nebula	—	1.0′	21^h 03.9^m	+50° 15′

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.

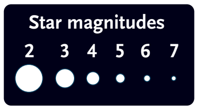
high-flying Swan's tail. Omicron^1 is an optical triple star. Although its components are a mere line-of-sight coincidence, they make a pretty trio through the eyepiece. Even 12×36 image-stabilized binoculars show the 5th-magnitude companion well to the northwest of the golden star and the 7th-magnitude companion one-third as far to the south. The trio is best seen at very low power through a telescope. In my 130-mm refractor at 23×, the three stars are spaciously separated. The brighter companion shines stark white, while the dimmer one has the sheen of a blue-white diamond.

Omicron^1 has a physical companion, but it's too close to be viewed through a telescope. However, you can detect indirect evidence of its duplicity because the components form an eclipsing binary. For 63 days of their 10.4-year orbital cycle, the smaller but hotter star hides behind its red giant companion, causing their combined brightness to drop from magnitude 3.73 to 3.89 — enough of a change to be detected by a dedicated variable star observer. The next eclipse occurs this year from October 9th to December 11th.

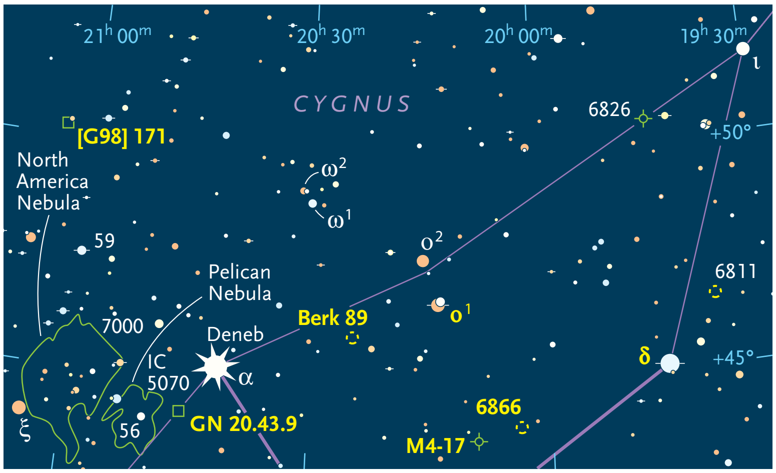
Berkeley 89 resides 2° east-southeast of Omicron^1 and has a deep-yellow 6th-magnitude star 29′ to its west-southwest. This stellar grouping all but hides itself in an opulent Milky Way star field. My 130-mm scope at 48× presents a very faint 4′ haze with a dim star pinning its

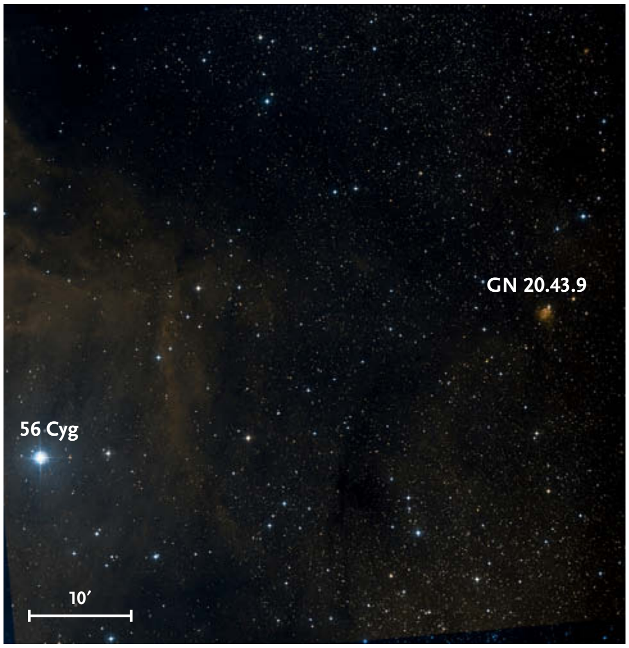


POSS-II / CALTECH / PALOMAR OBSERVATORY



To locate the fainter objects described in this article, use this chart to hop to the nearest plotted star, then use the appropriate Palomar Sky Survey photograph to hop from that star to your target.





POSS-II / CALTECH / PALOMAR OBSERVATORY (2)

center and slightly brighter ones anchoring the north and west edges. Three additional stars blossom at 102×, and the central star looks blurry, as though it's a blend of more than one star. These stars are probably foreground objects, since the group's brightest members are thought to be 14th magnitude. My 10-inch reflector at 68× shows five stars enmeshed in a misty patch 5′ across, while at 213× it pries a dozen stars from the haze.

A 2010 study in the *Monthly Notices of the Royal Astronomical Society* by Annapurni Subramaniam and colleagues finds that this is probably a true open cluster rather than an asterism, and if so it's roughly a billion years old and 6,700 light-years distant. At such an advanced age and with no dense core, Berkeley 89 must be losing its grip on its members, which are slowly merging with the local star population.

Next we'll call on the little-known blob of emission nebulosity **GN 20.43.9**. The "GN" in this name indicates that the nebula is listed in the *Atlas of Galactic Nebulae* (Thorsten Neckel and Hans Vehrenberg), and $20^h\ 43.9^m$ is its right ascension for equinox 1950.0. The nebula sits 1.3° southeast of Deneb and 49′ west-northwest of 5th-magnitude 56 Cygni. My 130-mm scope at 117× shows a 5′-tall kite of 10th- to 12th-magnitude stars flying north-northwest. A very faint drop of nebulosity dangles from the kite's brightest star, the one at its western corner. The drop is about 1⅓′ long, and a dim star lies just off its southeastern end.

GN 20.43.9 contains the young star cluster DBCL23, which is visible in narrowband infrared images. The cluster stars have blown out a cavity in the nebula, whose glowing walls now surround it.

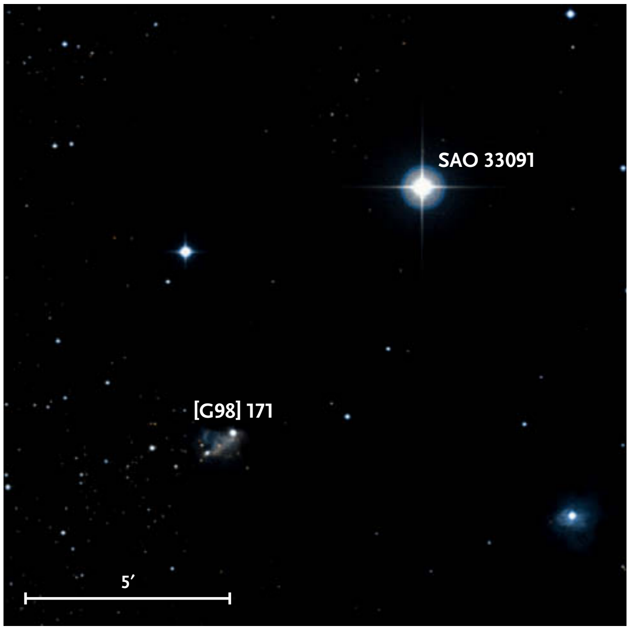
German amateur Reiner Vogel maintains a website (**www.reinervogel.net/index_e.html**) with some very interesting observing projects, including a tempting list of young stellar objects together with their associated nebulae. The variable star V1982 Cygni (magnitude 12.6 to 13.3) and **Gyulbudaghian 98-171** make up one pair that I chose to pursue.

To locate [G98] 171, climb 3° north from the 5th-magnitude star 59 Cygni to a curve of four 6th- and 7th-magnitude stars that's concave northeast and spans 1.4°. The easternmost star in the curve is deep yellow and hovers a scant 7.9′ northwest of the nebula. This star, a 9th-magnitude star 5.9′ east-southeast, and V1982 Cygni form a right triangle.

I first captured [G98] 171 with my 15-inch reflector. At 216× it was nicely visible as a bar of nebulosity stretching perhaps ¾′ southeastward from V1982 Cyg. The fact that I could see the nebula so easily in the larger instrument inspired me to look for it in my 10-inch. I was pleased to see its ghostly glow, which was vaguely discernible at a mere 88× but showed best at 187×.

The southwestern end of [G98] 171 harbors a star that's completely shrouded by a dense nebulous cocoon. I wasn't able to see this tiny nebulous knot, but Vogel spotted it with his 22-inch scope at 350×.

The hidden star and V1982 Cyg dwell in a V-shaped cavity excavated from the large dark-nebula complex to its west. A small cluster of about 50 stars is visible in infrared images. According to a 2006 paper in the *Astronomical Journal* by George Herbig and Scott Dahm, the stars have a median age of only 600,000 years and are roughly 2,000 light-years away from us. ✦



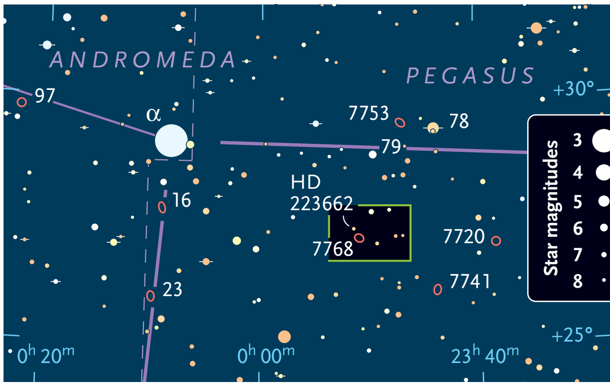
A Galaxy Group in Pegasus

Abell 2666 lies near the northeast corner of the Great Square.

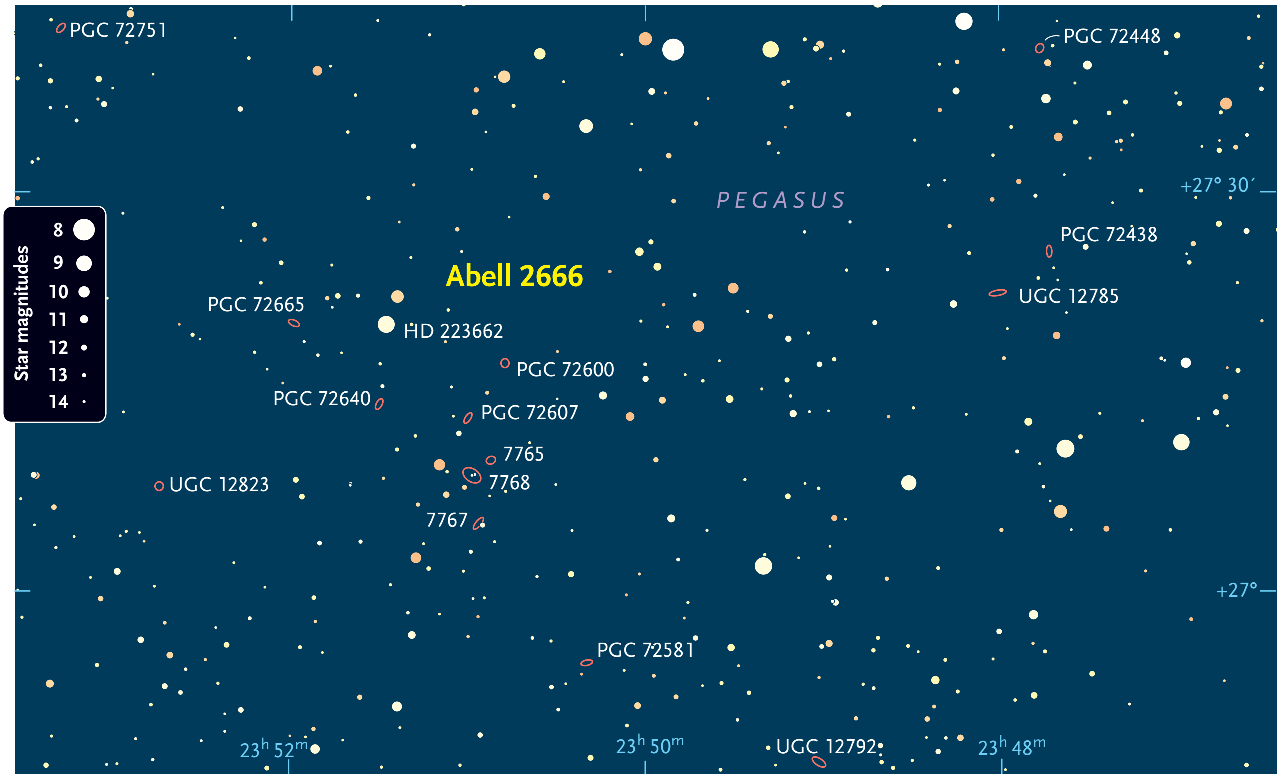
The galaxy cluster Abell 2666, roughly 300 million light-years away in Pegasus, is worth a good, long look. Employing my 17.5-inch f/4.5 Dobsonian at roughly 300× one perfect September night a few years ago, I identified 17 tiny cluster members. And there's more for the taking.

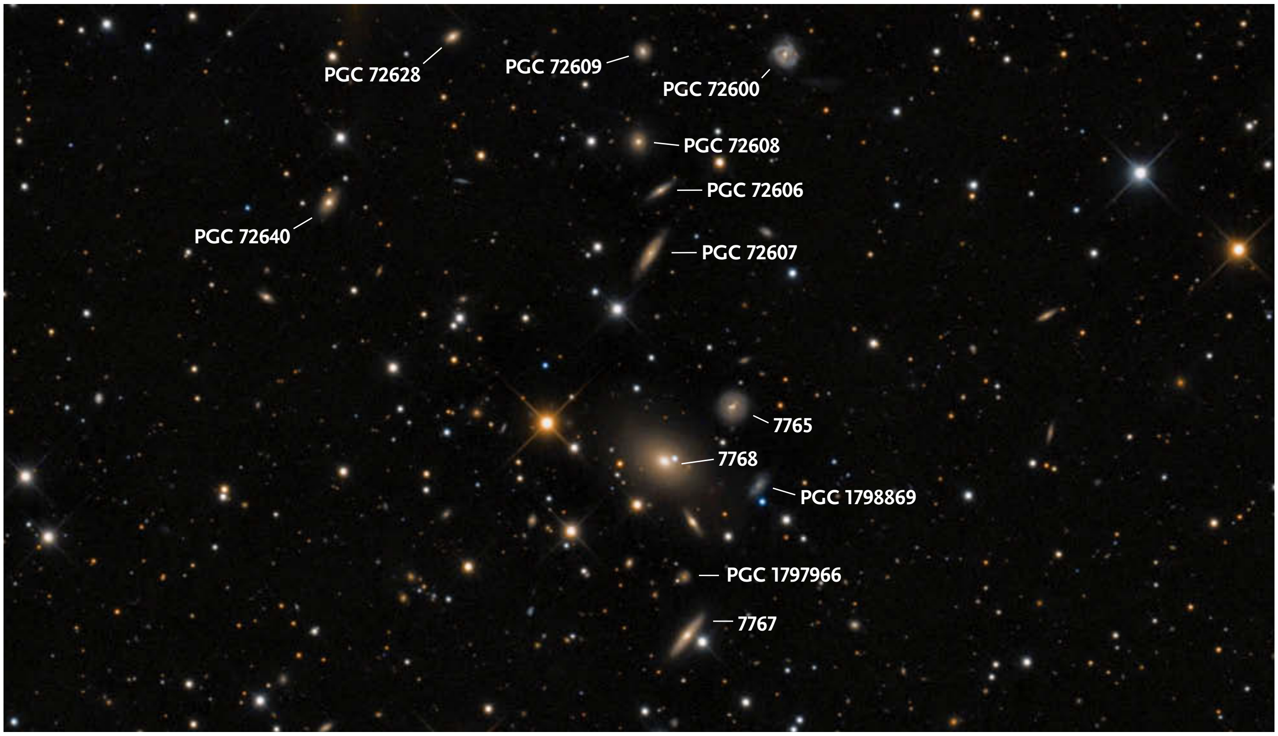
Abell 2666 is not difficult to locate. I began my star-hop at 2nd-magnitude Alpheratz (α Andromedae) at the northeast corner of the Great Square. From Alpheratz I swept slowly west 4° to 6th-magnitude 79 Pegasi, then turned south 1° to a wide triangle whose eastern vertex is marked by 8.1-magnitude HD 223662. From there I dropped southwest ¼° to the field of fuzzies.

Although the circular symbol for A2666 plotted in the second edition of the *Uranometria 2000.0 Deep Sky Atlas* spans 1¼° of sky, the core galaxies inside it form a ragged, north-south chain just 12′ long. My exploration began with the chain's prominent anchor galaxy and a smaller



This chart includes all galaxies listed in *HyperLeda* with blue magnitudes of 16.0 or brighter, corresponding roughly to visual magnitude 15.0. Additional galaxies are labeled in the photograph on the facing page, which covers this chart's central region.





BOB FRANKE

neighbor to its south. I continued with three "dim but doable" blobs northward, and finished by chasing down 12 toughies I call the "dirty dozen."

I quickly spotted the anchor, **NGC 7768**, less than 3′ west-southwest of a 10.8-magnitude star. Listed in Wolfgang Steinicke's online NGC/IC database at magnitude 12.3 and 1.6′ × 1.3′ in extent, this hefty elliptical appeared as a strongly condensed oval patch, oriented northeast-southwest, with a 14th-magnitude star superposed on its periphery northwest of center. However, I perceived so little of the galaxy's tenuous halo — even with averted vision — that a narrow gap existed between the galaxy and the star. Direct vision eliminated the halo entirely, reducing the galaxy to a fuzzy pinhead with the sharper but similarly bright point of light beside it.

The edge-on galaxy **NGC 7767** lies just 3.5′ south of that double dot. Listed at magnitude 13.5 and only 1.1′ × 0.2′ in size, NGC 7767 was a stubby but obvious streak slanted northwest-southeast immediately east of a 13th-magnitude star.

The trio of "dim but doable" members forms a shallow triangle north of the anchoring elliptical. I first drifted northwest of the anchor to 14.6-magnitude **NGC 7765**, just 0.7′ in diameter. From there I headed north to roundish 14.1-magnitude **PGC 72600**, west of the galaxy at the top of the chain. I then returned to NGC 7768 and nudged north again, this time past a 12.7-magnitude stellar landmark, to 14.7-magnitude **PGC 72607**. In photos this 1.1′ × 0.3′ edge-on galaxy aims at the nearby star, but even at high power it appeared spherical to me. A 13.7-magnitude star flickered roughly halfway between that galaxy and PGC 72600.

I spent most of my time identifying the "dirty dozen." Retracing my route from NGC 7768 northward past PGC 72607, I picked off **PGC 72606**, **PGC 72608**, and **PGC 72609** in a nearly straight line. (A right-angle turn west from PGC 72609 at the top leads to brighter PGC 72600, which I mentioned earlier.) Of these three galaxies, PGC 72606 was the most difficult. My averted vision picked it up very slightly west of the line joining PGC 72607 to PGC 72609.

Back to the anchor again. To its south-southwest I caught **NGC 7766** flanked by 13.4- and 14.8-magnitude stars. Between that smudge and NGC 7767 at the bottom of the chain I glimpsed **PGC 1797966**. I almost missed the exceedingly dim **PGC 1798869** barely 2′ west-southwest of the anchor. On an image from the Sloan Digital Sky Survey, I noticed a 14th-magnitude star 1′ southwest of this tiny mist plus a fainter star inboard that grazes the galaxy's edge. Seeing those pointer stars in the eyepiece enabled me to confirm my ghostly target.

I fished around for outliers, too. Trolling near the star HD 223662, I hooked **PGC 72628**, **PGC 72640**, and **PGC 72665**. Finally, I reeled in three tiny patches across 54′ of sky. **UGC 12823**, east of the core group, was the brightest of these. Southwest of the core, **PGC 72581** was the smallest and faintest. Farther southwest, **UGC 12792** appeared larger but paler than the easternmost galaxy. Good catches, all — yet other small fry slipped through my net. Next time! ✦

S&T *contributing editor* ***Ken Hewitt-White*** *loves to observe galaxies in the spring and fall.*

Dennis di Cicco

Stellarvue's New SVR102T Raptor APO

Even in today's crowded arena of 4-inch apo refractors, this scope stands out.

Stellarvue SVR102T Raptor Apochromatic Triplet

U.S. Price: $2,395

stellarvue.com

In addition to its excellent optical quality, Stellarvue's SVR102T apo refractor is noteworthy for its portability. The tube assembly and mounting rings weigh barely 10 pounds (4½ kg), less than half the weight of some 4-inch apos we've tested. It's pictured with the iOptron ZEQ25 mount mentioned in the text. All *S&T* photographs by the author.

If you've been reading our product reviews for a while, then you probably know that I enjoy testing refractors. It's not because I'm a "refractor guy;" at least no more than I am a Newtonian, Dobsonian, Maksutov, or Schmidt-Cassegrain guy. Rather it's the review process itself that I enjoy. There are no thick manuals to read, no complicated software programs to learn, no operating systems to master, no cables, and no power supplies. You get the idea. After a few optical measurements, reviewing a refractor involves mainly sitting at the eyepiece and observing, all in the name of work.

So it's no surprise that I was looking forward to reviewing Stellarvue's new SVR102T Raptor Apochromatic Triplet late last spring. Readers who attended this April's Northeast Astronomy Forum in New York likely saw the scope I tested prominently displayed at Stellarvue's booth. Company founder Vic Maris simply handed me the scope after the event so that I could bring it back to *Sky & Telescope* for this review.

As those who saw it know, the SVR102T Raptor is one very handsome telescope with its carbon-fiber tube and matching 9-inch-long retractable dew shield. The precision feel of the metal lens cap as I unthreaded it from the front end of the dew shield gave me an immediate clue to the overall quality of the scope's mechanical construction. All metal fittings are beautifully machined and have a high-gloss, black-anodized exterior finish. The matte-black tube interior has a pair of baffles to help block any light scattered off of the tube walls from reaching the scope's focal plane. There are also 16 additional baffles machined into the interior of the 2½-inch Feather Touch focuser. This precision dual-speed focuser, which has 3½ inches of drawtube travel, is a $400 option when ordered in place of the standard 2½-inch Stellarvue focuser. For those interested in optimizing the scope for astrophotography, you can purchase a dedicated field flattener ($319) that threads onto a 3-inch Feather Touch focuser available as a $500 option. The field flattener, however, was not yet available when I tested the scope.

Rounding out the SVR102T package are a pair of excellent-quality, hinged tube rings and a rigid-sided carrying case. Stellarvue offers optional Vixen- and Losmandy-style dovetail mounting bars, star diagonals, finders, and telescope mounts.

WHAT WE LIKE:

Superb optical quality

First-class mechanical construction

Lightweight and easily portable

WHAT WE DON'T LIKE:

Nothing that turned up during weeks of testing

The scope's three-lens objective has a center element made with Ohara's premium FPL53 extra-low-dispersion glass, and all six air-to-glass surfaces are broadband multicoated for maximum light transmission. The objective has a clear aperture of 101.5 mm and a focal length of 714 mm (my measurements).

Our review scope was equipped with a dual-speed 2½-inch Feather Touch focuser (a $400 option). This finely crafted unit features an engraved millimeter scale on the drawtube, which has 3½ inches of travel, and a compression-ring adapter with three locking thumbscrews.

The optical tube assembly with the Feather Touch focuser weighs 9 pounds (4 kg) and the tube rings add another 2 pounds. You can easily unscrew the focuser from the 20¼-inch-long tube, making the pieces small enough to fit inside airline carry-on luggage.

I did most of my testing with the SVR102T mounted on an Astro-Physics Mach 1 Go To German equatorial mount. But I also used it with iOptron's new ZEQ25 Go To mount pictured on the facing page. The latter made a particularly portable setup that I could easily carry around fully assembled, including the counterweight.

Under the Stars

Conventional wisdom holds that a 4-inch refractor is an ideal instrument for the Moon, planets, and binary stars. Unfortunately, the only planet visible in my evening skies was Saturn riding low in Virgo, where lousy atmospheric seeing hampered my attempts to push the scope to its limits. Nevertheless, at low and moderate magnifications the view was still impressive. Cassini's Division in the rings was always visible, and at times I was able to glimpse some banding on the planet's globe.

Lunar details were crisp and always seen with extremely high contrast. When using very high magnifications (occasionally approaching and sometimes exceeding 100× per inch of aperture), I saw no scattered light spilling over from the brightly lit rims of craters into their adjacent inky black shadows. I could have easily spent hours cruising the lunar terminator at 300× on just about any given night.

As good as these views were, my real test of the

The standard and optional focusers available for the SVR102T all unscrew from the main tube, enabling the resulting components to fit well within the limits set for airline carry-on luggage.

The Feather Touch focuser's drawtube has 16 sharp-edged baffles machined into its interior surface. Coupled with baffles inside the telescope tube, they eliminate any scattered light from reaching the telescope's focal plane, helping ensure high-contrast views.

The triplet objective has a center element made with FPL53 extra-low-dispersion glass. Broadband multicoatings on all air-to-glass surfaces make the lens appear almost invisible under normal lighting conditions, and they reflect just a hint of the brilliance from our studio flashes used to take this photograph.

SVR102T optics came while viewing binary stars. When I turned to these targets, it quickly became apparent that the scope had a truly first-class objective. Indeed, I can't recall ever using a 4-inch-class refractor with a better lens. Was the Stellarvue the best? Without the benefit of a side-by-side comparison, there's no way to make that judgment call. And even with such a comparison, at this level of optical quality, looking for differences among various telescopes would be splitting hairs at best.

The SVR102T showed virtually identical stellar diffraction patterns inside and outside of focus. Even at extremely high magnifications, stars snapped into such precise focus that there was never a question of when I reached the sweet spot. And at these magnifications, stars appeared as textbook-perfect Airy disks surrounded by a bull's-eye pattern of uniformly illuminated diffraction rings, which decreased in brightness outward from the Airy disk. There wasn't a hint of color fringes around bright stars. I can't imagine anyone finding fault with this scope's optical performance.

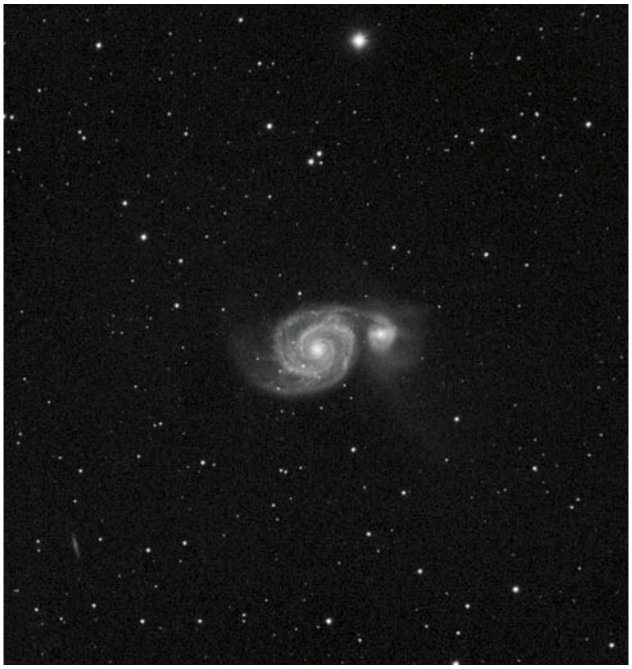
Looking Deeper

In an age when 12-inch and larger Dobsonian telescopes are common sights at even small star parties, most observers wouldn't classify a 4-inch aperture as the scope of choice for deep-sky observing. Nevertheless, a 4-inch refractor can still show a lot. Indeed, until the closing decades of the 20th century, most of the popular observing guides for amateur astronomers were based on observations made with refractors in the 4- to 6-inch range.

One evening after bouncing among a handful of Messier objects (mostly galaxies and globular star clusters), I decided to compare my views with the visual descriptions published by the late John H. Mallas in his classic *The Messier Album,* coauthored with astrophotographer Evered Kreimer. Based on a series of articles published in this magazine during the 1960s, Mallas's visual descriptions were often met with skepticism by other experienced observers of the day. Many felt the features he described were influenced more by photographs than by what he was seeing in the eyepiece of his 4-inch Unitron refractor. But on this particular evening my views not only nicely matched Mallas's description, I could sometimes eke out a few more details. This was especially true when I was looking at the cores of globular star clusters that showed better resolution at high magnifications than what Mallas suggested he saw.

That same evening I made a singular sighting that I came to fully appreciate only later. As mentioned earlier, I spent a lot of time viewing binary stars with the SVR102T, but I usually took the lazy-man approach and picked my targets from the modest selection of double stars listed in the database of the Mach 1's hand control.

The scope made short work of splitting all the double stars I examined with cataloged separations of 2 to 3



Although the dedicated field flattener planned for the scope was unavailable at the time of our tests, the SVR102T proved to be very capable for astrophotography. The image of the famous Whirlpool Galaxy (M51) at *left* is a 10-minute exposure with the SBIG STT-8300 camera reviewed in the July issue, page 62. June's waning gibbous Moon was captured with a full-frame DSLR camera and 2× Barlow.

arcseconds. Among them was 44 Bootis. The Mach1's database listed this pair of 5th- and 6th-magnitude stars as having a separation of 2.2 arcseconds. The components appeared tight, but were nonetheless cleanly split with the fainter companion appearing east-northeast of the primary. For the record, I made the observation with a Tele Vue 9-mm Nagler type 6 eyepiece teamed up with a 5× Powermate amplifier yielding a magnification of 400×.

This observation became more interesting later in the evening when I worked my way eastward to the famous Double Double in Lyrae. All four of its components were nicely resolved in a single view with a 14-mm Explore Scientific 100° eyepiece. But when I boosted the magnification to 400× to examine the close pairs, which I knew from memory were separated by about 2½ arcseconds, they appeared much more widely separated than 44 Bootis had been. The next day a little internet sleuthing uncovered an updated ephemeris for 44 Bootis suggesting that the separation is currently only 1.2 arcseconds. This value was confirmed by my colleague Roger Sinnott, who calculated the separation based on a modern orbit for the binary star system.

The SVR102T comes standard with a very durable, rigid-sided carrying case that holds the scope and a 2-inch star diagonal attached to the tube rings and dovetail mounting bar.

Given that the well-established Dawes limit for splitting double stars with a 4-inch telescope is 1.1 arcseconds, my ability to easily resolve 44 Bootis with the SVR102T is a testament to the scope's exceptional performance. I returned to 44 Bootis on several subsequent nights while reviewing the scope, but I was unable to resolve the star as well as the first night because of less-favorable atmospheric seeing. These nights served as a reminder of how important observing conditions are to achieving the optimum performance from any telescope. But it was also nice to know that when conditions are good, the SVR102T can perform to its theoretical limits. It really is an exceptional refractor. ✦

In July, senior editor ***Dennis di Cicco*** *celebrated his 50th anniversary of hunting down the globular star cluster M13 in Hercules by observing it with the same 60-mm Lafayette refractor he used for his original observation in 1963.*

A Good Rockin' Dob

This splendid telescope features a guitar maker's craftsmanship.

ONE OF THE THINGS I enjoy most about home-built telescopes is all the little touches that subtly describe the skills and personality of the scope's builder. Consider North Carolina ATM Terry McInturff. Terry is a talented guitar maker who has crafted instruments for some of the best-known players on the planet, including Eric Clapton and Jimmy Page. And little wonder — his guitars are beautiful. So, it's not surprising that his telescope is too.

"I have been an observer on and off since 1968, and recently I decided to build my first telescope," Terry recounts. He settled on a 10-inch f/6 Dobsonian with a primary mirror refigured by Optic Wave Laboratories. Where Terry's craftsmanship shines through is in the instrument's fine woodwork and superb finish — skills he honed during his 36 years of making guitars. "My knowledge of basic joinery, what glues to use, clamping techniques, and basic finish work definitely came in handy," he explains.

KAREN STACK

Master guitar maker Terry McInturff used his years of instrument-making experience to craft this attractive 10-inch f/6 Dobsonian.

Terry's background is also apparent in his choice of materials. The scope's secondary cage is made from a wooden drum shell, and there's another one in the scope's mirror box. "The ones I used are 12-inch-diameter, birch tom-tom shells," he says. "I just sanded and finished them the same way I did the rest of the scope."

Terry's focus is clearly on performance as well as looks. To ensure the primary mirror quickly cools to the ambient air temperature, the mirror box has a trio of fans (one blowing against the rear of the mirror, and two forcing air across its front surface). Appropriately, the fan speed selector is a Les Paul guitar pickup switch.

The scope's basic two-strut configuration was inspired by a design from Terry's ATM hero, the late Ron Ravenberg. "Setting up the scope is a breeze, thanks to Ravenberg's design," Terry reports. The struts are 2-inch-diameter aluminum tubes clamped in place with hand knobs made from rosewood. The tubes are stuffed with fiberglass to help reduce vibrations — a sharp rap against the upper tube damps in a second or less.

Among the neat features on Terry's Dob are the adjustable side-bearings for balancing the scope. Each side bearing has slots to accommodate a pair of bolts that pass through the mirror box and the side bearing. But he confesses that the idea was really borne of insecurity because he wasn't sure he'd get the balance point right for bearings fixed in one spot.

The Veil Nebula was Terry's first-light target. "The wow-factor was definitely there — both the eastern and western sections were nice and bright, and 52 Cygni looked like a sharp diamond," he says.

His observations are music to my ears, like rock music as played by, say, Eric Clapton. Readers wishing to learn more about Terry's scope can contact him at tcmzodiac@yahoo.com. ✦

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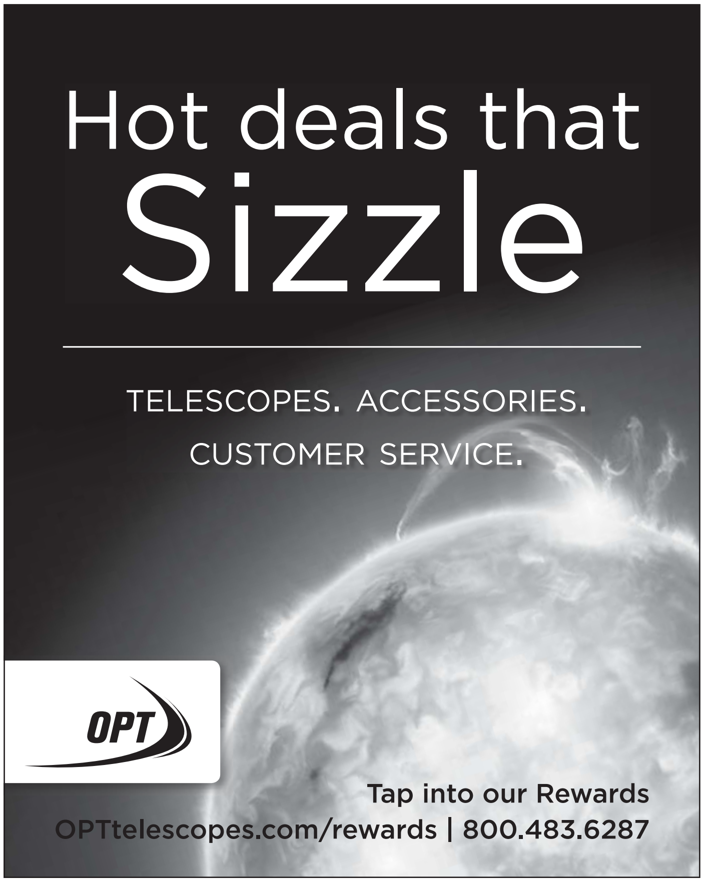
*Contributing editor and musician **Gary Seronik** has almost as many guitars as he has telescopes. He can be contacted via his website, **www.garyseronik.com**.*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Eyepieces:

Windows on the Universe

Understanding the basics will help you select from the cornucopia of modern eyepieces.

Alan French

WE LIVE IN A WONDERFUL TIME. As never before, today's observers and telescope enthusiasts are enticed by a fine variety of eyepieces — windows on the splendors of the night sky. The choices are so great that the eyepiece marketplace can be intimidating. And eyepieces are seductive. They're small, attractive, carefully crafted creations of glass and metal. You can easily fall under their spell.

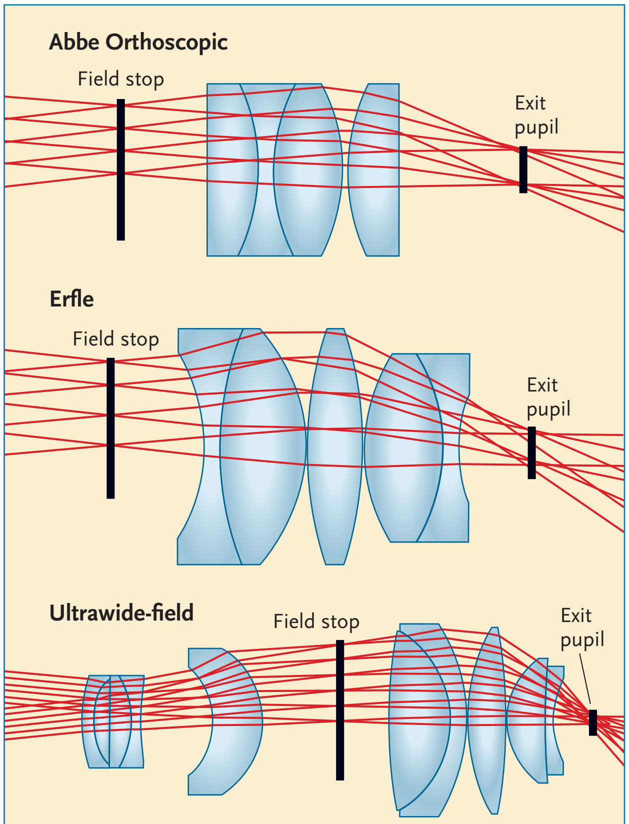
The heart of your telescope is the objective, the main light-collecting mirror or lens. Its diameter and quality largely determine what your telescope can reveal under ideal conditions. But your choice of eyepieces can greatly enhance your viewing, so let's take a look at eyepieces and their interaction with your telescope and eye.

The essential and familiar eyepiece characteristic is its focal length. Using the same units of measurement, a telescope's focal length divided by an eyepiece's focal length

ALL IMAGES S&T: DENNIS DI CICCO UNLESS OTHERWISE CREDITED gives the telescope's magnification. For example, a 6-inch f/8 reflector has a focal length of 48 inches (1,220 mm). Coupled with an eyepiece having a 25-mm focal length, the scope magnifies 49 times (1,220/25 = 49).

Another important eyepiece trait is its apparent field of view (AFOV), which has garnered much attention of late. AFOV is the angle our eye sweeps through as we scan from one edge of the field to the other. Simple eyepiece designs generally have 45° to 50° apparent fields.

Modern optical glass, the power of computers, and extremely efficient coatings that almost eliminate light loss at lens surfaces have opened new worlds to eyepiece designers. By allowing more optical elements to be added to an eyepiece design with little or no sacrifice in image quality, modern eyepieces can have apparent fields exceeding 100°. Instead of looking through a porthole, we can now view the universe through a picture window.



S&T: LEAH TISCIONE

For much of the 20th century, the preferred eyepiece for experienced observers was the 4-element Abbe orthoscopic with its roughly 45° field of view. Erfle eyepieces with five optical elements offered fields exceeding 60° but were poor performers on fast-focal-ratio reflectors that became popular beginning in the 1980s. Today, however, eyepiece designers have more freedom to add elements thanks to modern optical glasses and high-transmission coatings. The result is a new breed of ultrawide-field eyepieces exceeding 100° that perform exceptionally well on fast telescopes.

Eyepiece Fundamentals

A telescope forms a real image at its focal plane. If you point your telescope at the Moon while holding a piece of paper above the empty focuser, you'll see an image of the Moon formed on the paper. Move the paper in and out until you get a sharp lunar image and the paper will then be at the telescope's focal plane.

Knowing what happens at the focal plane helps us understand eyepieces. Let's consider one of my favorite deep-sky objects, the Veil Nebula in Cygnus. The entire Veil complex covers about 2¾° of sky. With a telescope of 600-mm focal length, the real image of the Veil spans almost 29 mm (1.14 inches) in the focal plane. Double the telescope's focal length to 1,200 mm, and the Veil appears twice as large, covering 58 mm (2.28 inches).

When you view a focused image in a telescope eyepiece, the focal planes of the eyepiece and telescope coincide. If you look into the bottom of a simple eyepiece, such as a Plössl, you'll see a sharp-edged ring, or field stop, located below the eyepiece's field lens. This field stop is positioned at the eyepiece's focal plane and sharply defines the edge of your view when you look into the eyepiece. The telescope focal length and diameter of the field stop's opening determine the true field of view (TFOV) — the amount of sky you see in the eyepiece. (The field stop lies between lenses in some complex designs.)

An eyepiece's barrel size limits the field stop's size. The maximum field stop diameter in 1¼-inch eyepieces is about 27 mm. With the 600-mm (focal length) telescope mentioned above, a field stop opening of 27 mm would reveal about 2.6° of sky, not quite enough to see the entire Veil at once. An eyepiece with a 2-inch barrel, on the other hand, allows a field stop up to about 46 mm, which is capable of showing 4.4° of sky and nicely framing the Veil. I speak from experience when I say that such a view is a lovely sight under dark skies.

In a telescope of 1,200-mm focal length, even a 2-inch eyepiece cannot show the entire Veil in one view. Furthermore, most eyepiece designs don't allow for field stops as large as their barrel diameters, and in many cases the maximum field-stop diameter is but a small fraction of the barrel diameter.

The true field of view in any eyepiece is determined by the diameter of its field stop and the telescope's focal length. As seen here, the field stop is often formed by the opening in a ring located ahead of the eyepiece's field lens. Some optical designs have field stops located between lens elements. The ultimate limit for the true field in any design, however, is set by the eyepiece barrel, which is why 2-inch eyepieces have become popular in recent years.

Apparent field is related to true field. Given two eyepieces of the same focal length, the one with a larger apparent field also has a bigger field stop and thus a wider true field. For example, using eyepiece specifications available on the internet, I found an 8-mm eyepiece with a 50° AFOV that has a field stop with a 6.5-mm opening, and another 8-mm eyepiece with a 100° AFOV that has a 13.9-mm field stop. The 100° eyepiece shows more than four and a half times the area of sky in a single view than the 50° eyepiece.

You can roughly determine the true field of an eyepiece/telescope combination by dividing the eyepiece's apparent field by the magnification. For a more accurate measure, you need the field-stop diameter. The true field, in degrees, is equal to the eyepiece's field-stop diameter divided by the telescope's focal length (both measured in the same units) and multiplied by 57.3.

A high-magnification eyepiece with a wide apparent field can provide an identical or larger true field than a low-power eyepiece with a narrow apparent field. As an example, there are 32- and 20-mm eyepieces that both have 27-mm field stops. The first has an apparent field of 50° and the second 80°. In a telescope of 1,200-mm focal length, the first will magnify 38× and the second 60×, but both will show identical true fields spanning 1.3° on the sky. The higher power is advantageous.

Magnification is often your friend. As magnification increases, the sky background darkens. A star's telescopic image is really a tiny disk, surrounded by faint rings. Up to a magnification where your eye begins to resolve this disk, star images remain tiny pinpoints, and the darker sky background will help reveal fainter stars.

With increasing magnification, extended objects such as nebulae are spread out as much as the sky background, so the image contrast does not change. Your eye, however, more readily perceives faint objects that cover more of your retina, making it seem as though contrast has increased. As such, enlarging a faint object generally makes it easier to see.

On a sunny day, arm your telescope with a low-power eyepiece and point it at the open sky or a brightly lit wall. Hold your eye far back from the eyepiece and note the small disk of light hovering above the eyepiece. This is the exit pupil. It's a tiny image of the telescope's aperture, and it has two important qualities: diameter and distance above the eye lens. When you observe, your eye's pupil should coincide with the eyepiece's exit pupil.

Magnification and telescope aperture determine the diameter of the exit pupil. Simply divide aperture by magnification to calculate the exit pupil's diameter. For example, an 8-inch (200-mm) telescope magnifying 50× has an exit pupil 4 mm in diameter (200/50 = 4). A nice shortcut for calculating the size of the exit pupil is to divide the eyepiece's focal length by the telescope's focal ratio.

Because the exit pupil is an image of the telescope's aperture, stopping it down is the equivalent of stopping down the telescope's aperture. This happens when the exit pupil's diameter is larger than your eye's pupil, a situation that can arise when using very low magnifications that produce large exit pupils. It turns out, however, that the resulting image is still the brightest possible at the

As explained in the text, the eye relief of an eyepiece is the distance between its eye lens and exit pupil. The exit pupil is the location where your eye's pupil needs to be to see the full field of view. Many people prefer eyepieces with a long eye relief, especially if they wear glasses while viewing through a telescope.

given magnification even though you're not using the full aperture of the telescope. There is no lower limit to the useful magnification of a refractor, but almost all reflectors and Cassegrain systems have central obstructions that limit their use with low magnifications.

Have your eyes been dilated during an eye exam? If so, you probably remember that your ability to see details suffered. I once took a pair of 7×42 binoculars, which have a 6-mm exit pupil, to my eye exam. With my pupils dilated, I could not get a sharp focus because a fully dilated eye doesn't work well. Our vision works best with smaller exit pupils (2 to 3 mm), which use only the central part of our eye's lens. This is another reason why higher magnifications (and thus smaller exit pupils) are an advantage.

Another important aspect of an eyepiece is its eye relief — the distance that the exit pupil is located above the eye lens. Longer eye relief is generally better, especially if you wear glasses while observing, since you'll need enough eye relief to place your eye at the exit pupil with your glasses on. If your eye is farther out than the exit pupil, you won't see the entire field of view. How much eye relief you need depends on your facial structure and your glasses. Eyepieces with long eye relief also tend to stay cleaner and are less prone to fogging up in cold conditions because your moist eye stays farther away from the cold eye lens. In the past, short-focal-length eyepieces (the high-power ones) usually also had very short eye relief, but modern designs tend to be much better in this regard.

Although an eyepiece's focal length is the fundamental property that determines the magnification it will deliver with a given telescope, it is only one of the factors today's observers must consider when making a purchase. The six eyepieces seen here all have approximately the same focal length, but their apparent and true fields (not to mention the costs) vary greatly.

Try Before You Buy

One thing that many people discover when seeking eyepiece advice from other amateur astronomers is that there are a lot of people who are passionate about their choices. Thus, I recommend trying the eyepieces you're considering purchasing. Amateur astronomers are generally happy to share equipment, and there are many star parties and conventions where you'll find all kinds of telescopes and eyepieces being used.

Trying eyepieces lets you decide which characteristics suit you, and what works best in your telescope. For example, I prefer more than 12 mm of eye relief, while others don't mind less. And today's ultra-wide apparent fields are not for everyone, especially if expense is a concern — those huge fields come at a price.

Most amateurs find that three eyepieces make a basic set. An eyepiece that gives a wide true field helps you find your quarry and enjoy large star clusters and nebulae. Another with a 2-mm exit pupil provides about optimum power for viewing many deep-sky objects. And a third giving a 1-mm exit pupil allows you to see the lunar and planetary detail that your telescope can reveal. But keep in mind that the steadiness of the atmosphere — the astronomical seeing — imposes limits on power. In my area of upstate New York, magnifications above 250× are rarely usable. In places blessed with excellent seeing, however, much higher powers can be wonderful.

Once you discover what you like to observe and become familiar with what your telescope can show, you'll probably want to expand your eyepiece collection. If deep-sky observing catches your interest, consider the widest apparent fields. Enticed by the planets? Consider eyepieces yielding exit pupils of 0.8 to 0.5 mm so that you can eke out the last bit of detail on nights of excellent seeing. Today there are also fine zoom eyepieces that allow you to set the perfect magnification.

Shiny new eyepieces will forever remain a temptation. And if you're searching for the perfect eyepiece, you won't be alone. But always remember that the best eyepieces are those collecting starlight, not dust. ✦

*Veteran telescope maker and observer **Alan French** is a familiar face at astronomical gatherings in the Northeast. He is married to Sue French, author of our monthly Deep Sky Wonders column.*

Piecing Together

Here's an easy technique for creating expansive images of the Sun and Moon using modest sensors.

Tim Jensen

Planetary imagers dream of shooting high-resolution photos rife with small-scale detail. Swirling clouds within Jupiter's Great Red Spot, or the enigmatic Encke Gap at the edge of Saturn's ring system, are two trophies we often search for when presented with a high-resolution planetary image. But capturing the same level of detail on full-disk images of the Sun and Moon requires a different approach. By the time you squeeze the entire object down to fit onto the modest detectors in today's planetary cameras, all that lovely detail is gone. The solution to this problem is to shoot multi-panel mosaics.

The advantage of making high-resolution mosaics is that the tiny details of your narrow field of view will be preserved in a final result. The drawback is that you have to take lots of images or videos and stitch them together to appear as one continuous image. Fortunately, there's a handy feature in recent versions of *Adobe Photoshop CS* that can make this stitching almost completely automated.

A Good Plan

Whether you're shooting the Sun through a 40-mm Personal Solar Telescope or lunar close-ups through a large reflector, plan your approach ahead of time to avoid gaps in your image. Few things are more disappointing than discovering when processing your images hours later that you missed a section of your target! Take the time to roughly calculate how many frames you'll have to record to completely cover the Sun or Moon with your particular setup. I suggest about a 50% overlap between each of your frames to ensure success. This should give *Photoshop* plenty of features to match between segments. When including the limb of your subject, position it so that it fills about ¾ of the field of view.

Also consider whether you'll be shooting with a polar-aligned mount or simply in alt-azimuth mode. Shooting your target with an aligned mount will allow you to shoot your mosaic tiles sequentially in right ascension and declination, ensuring you don't miss any regions in your final mosaic. This is still possible to do on an alt-azimuth mount, but keep in mind that your subject will appear to rotate as it arcs across the sky during your recordings.

The type of camera you use to shoot your mosaic is inconsequential to your final result, though the best lunar and solar images today are recorded using high-speed video cameras. These videos are then processed using specialized programs that combine the sharpest frames to produce a single image. Recent digital SLR camera models also allow you to record high-definition video that can be processed in the same way.

Once you've made your plans and are ready to shoot, choose a well-defined feature to establish focus, such as a distinct lunar crater at one end of the terminator or a dark sunspot. Take your time to sharpen the focus as much as possible. I often sweep through the telescope's focal point on the video screen a few times before I'm ready to record.

Finally, establish your exposure settings. The solar atmosphere and lunar surface present a wide range of brightness values, so some areas may be unavoidably overexposed, such as solar flares in the chromosphere or bright craters. Choose a region of your subject that is neither extremely bright nor dark as your mid-range value. Don't change these settings once you begin recording;

the Sun & Moon

Shooting large photographs of the Sun and Moon doesn't require a huge detector in your camera. Author Tim Jensen explains how with a little planning, you can capture and assemble mosaics of the Sun and Moon with small cameras and the Photomerge action in *Adobe Photoshop CS*. The image above was assembled from 25 individual tiles recorded with a Canon EOS T2i DSLR and a Celestron C14. All images are courtesy of the author.

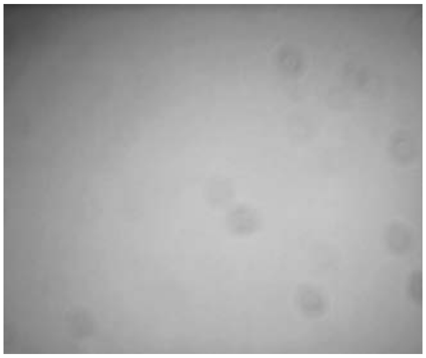
keeping them constant will give each overlapping frame the same brightness and tonality, and you'll avoid visible seams between each tile.

Once you begin recording your videos, make sure to capture an adequate amount of frames to guarantee you have plenty of sharp ones to stack. This can vary depending on your seeing conditions. I often record 2 to 3,000 frames per video to ensure a sharp result.

When moving from one mosaic section to the next, pick a feature that is about one-third of the way in from the edge you are slewing toward and move it until it's one-third of the way from the opposite edge.

Calibration Is Key

The biggest key to making an outstanding solar or lunar mosaic is recording a good flat-field calibration frame. Flat-field images record any optical defects in your system, such as dust motes or vignetting in your optical system. This calibration image is then divided into your raw image to cancel out these defects. Most planetary imagers skip this step when shooting close-ups of the planets because their target only covers a portion of the imaging chip, so dust motes or vignetting may be inconsequential to their final result. But when shooting lunar



***Far left*: Among the most important pieces required when stitching together seamless astrophoto mosaics are accurate flat-field calibration frames. This image records any dust donuts or vignetting in your optical system. The result is then mathematically applied to your raw images to correct these errors. *Near left*: The author solved the problem of shooting flats through solar filters by assembling a diffusing screen using a PVC pipe connector and a sheet of white plastic-bag material.**

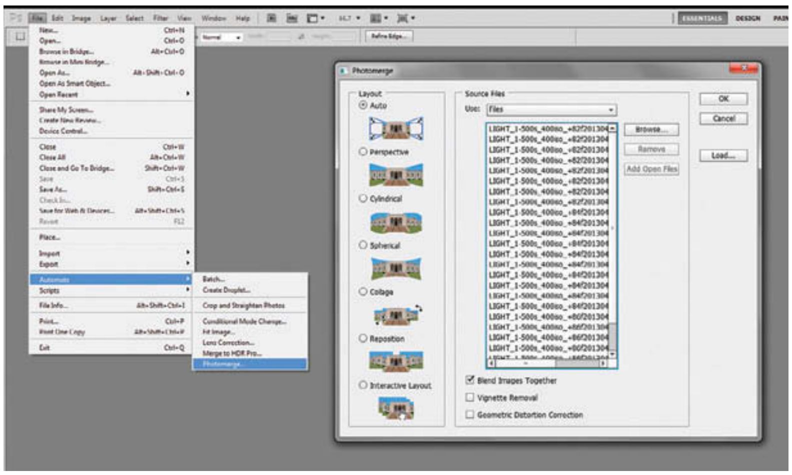
and solar mosaics, these defects need to be corrected to ensure a seamless result.

For flats to work properly, you need to shoot them with the exact same camera rotation and focus position as your mosaic tiles, so it's often easiest to shoot your mosaic tiles first, then record your calibration frames.

Shooting flat-field images for a lunar mosaic is exactly like capturing deep-sky flats. Simply point your scope at an area of the twilight sky that is fairly evenly illuminated and collect some video frames that give a well-lit, but not saturated, field of view. Most advanced video cameras and DSLRs have an option to display a histogram of the image being recorded. Try to expose your flat so the brightest areas peak at roughly 50% of the histogram. Once you're ready, simply record a video of a few hundred frames that you will then stack into your flat-field image.

Making a flat for solar hydrogen-alpha images is a bit trickier. It's nearly impossible to find a light source strong enough to shoot a flat through a solar filter. My solution is to use the Sun itself. By placing a diffuser in front of my telescope's objective, I can blur out details to create good flat-field images. You can use any white material as a diffuser as long as it's uniform and isn't completely opaque. A white garbage bag stretched taught over a plastic pipe large enough to fit over your telescope's objective makes a great diffuser that you can use whenever necessary. To use the diffuser, aim at a bland area of the chromosphere and place the diffuser over the telescope's objective. Then simply adjust your exposure as described earlier. The additional benefit to using a diffusing cap is that you can switch between shooting flats and lights in seconds.

Assembling your mosaic after stacking and calibrating the individual tiles is easy. Simply open *Photoshop*'s Photomerge function (File / Automate / Photomerge) and select all your images to combine. All that's left is to click the "OK" button and wait for the action to complete.

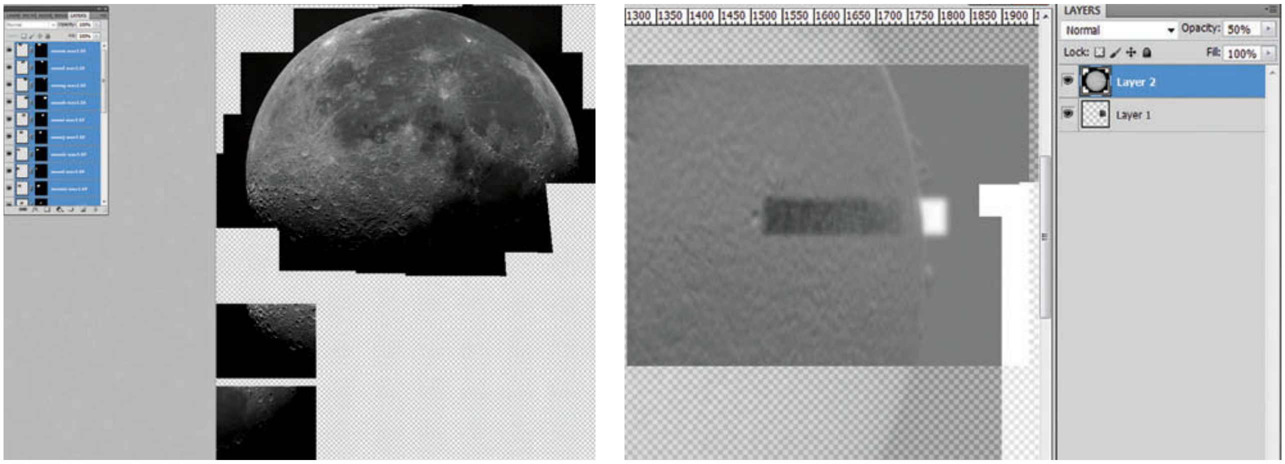


Putting It All together

Once that you've recorded all your videos and calibration frames, the next step is to stack each video to create the mosaic tiles. I prefer to use *AviStack 2* (**www.avistack.de**) to stack my videos, though all planetary-image processing programs have the ability to apply flat-field calibration frames. You may want to refer to your program's help section to read up on creating flat-field images, but each use a similar process — stack your flat-field video and save the result in the program's preferred format. Then load the flat-filed image into the calibration section of your preferred program. Now simply stack each of your mosaic videos with this flat loaded and it will be applied properly.

When you've completed the stacking process, combining the resulting mosaic tiles is extremely easy using the Photomerge function in *Photoshop CS3* or higher. Simply open the program and select File / Automate / Photomerge from the pull-down menu. A dialog window opens that first asks you to choose the files or a folder where your mosaic tiles reside. Click the Browse button and navigate to your images. Once you've located the mosaic tiles, select them all by clicking the first image at top, hold the shift key, and click the last image on the bottom.

Next, select the "Auto" button in the Layout column. Make sure the Blend Images Together box is checked, hit "OK," and let *Photoshop* run its magic. The program will align each image and organize them on a different layer, then create masks to blend them into the final mosaic. This can take several minutes and when it's done, you'll have a full mosaic image on the screen. If you had enough overlap between each tile, there should be no gaps visible in the final mosaic.



Left: **If the sharpness varies greatly between tiles or there was inadequate overlap, Photomerge may fail to register pieces of your mosaic.** ***Right***: **The easiest way to manually register tiles of a mosaic is to paste the missing piece into your image then change the layer blending mode to "Difference." Simply slide the tile into place using your mouse and keyboard arrow keys. It can be easier to identify where to move your tile if you lower the layer opacity to 50%.**

Occasionally, Photomerge does not recognize where a frame should be placed, and leaves it out of the mosaic. If that happens, you can manually insert the frame where it belongs. Open the missing frame, choose Select / All from the pull-down menu, then click your mosaic image and select Edit / Paste. The missing tile will appear in the middle of your mosaic. Select the Move Tool from the tools palette and drag the layer into roughly the proper position. You can then fine-tune the layer's position by opening the Layers window (Window / Layers) and changing the layer blending mode to Difference. At that point, simply move the layer into its final position with your keyboard's arrow keys. If the new tile is slightly rotated to the mosaic, you can adjust this by selecting Edit / Transform / Rotate. The layer will appear almost black when aligned. Once you've aligned this layer, change the blending mode back to Normal and select Layer / Flatten Image. At this point you can sharpen your result, adjust the color, or do any additional processing you'd usually do to create your high-resolution solar or lunar photos.

Once you've mastered these simple steps, creating large mosaics is a fun way to create full-disk, high-resolution images of the Sun and Moon. Even if you don't own a large telescope or multi-megapixel camera, you can still produce gorgeous panoramas of the brightest, most detailed objects in our solar system. ✦

Tim Jensen *is an avid astrophotographer and research project supervisor for Swinburne Astronomy Online.*

When you're satisfied all your mosaic tiles are properly in position, you can sharpen, colorize, or crop your image just as you would do to any other astrophoto. This 30-frame mosaic of the Sun was captured with the author's Coronado P.S.T. and a Point Grey Research Flea3 video camera.

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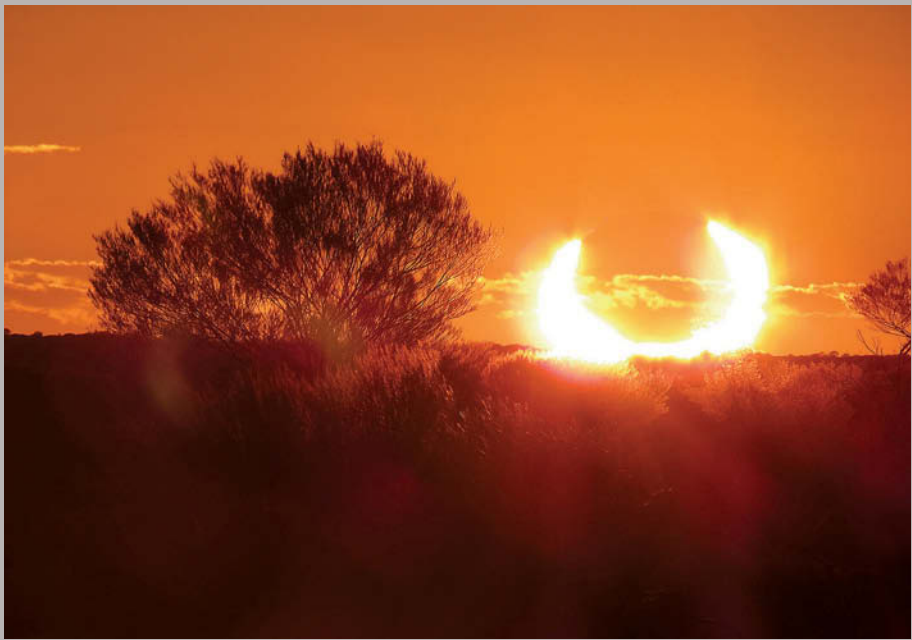


◀ **HORSESHOE SUNRISE**
Darrel Grant
Lucky observers in Australia were treated to an annular eclipse at sunrise on the morning of May 10th.
Details: *Canon PowerShot SX40 HS digital camera. Single exposure of 1⁄40th second from Illgararie, Australia.*

▼ **DEEP IN CENTAURUS**
Rolf Wahl Olsen
This exceedingly deep image reveals faint shells of stars that extend far beyond the familiar bright core and dust lane in active galaxy NGC 5128.
Details: *10-inch Serrurier Truss Newtonian with QSI 683wsg CCD camera. Total exposure was 120 hours recorded through Astrodon Generation 2 color filters.*

▲ **THE PENCIL NEBULA**

Kfir Simon

Nicknamed the Pencil Nebula due to its appearance in early photographs, NGC 2736 is a bright shock front from an ancient supernova.

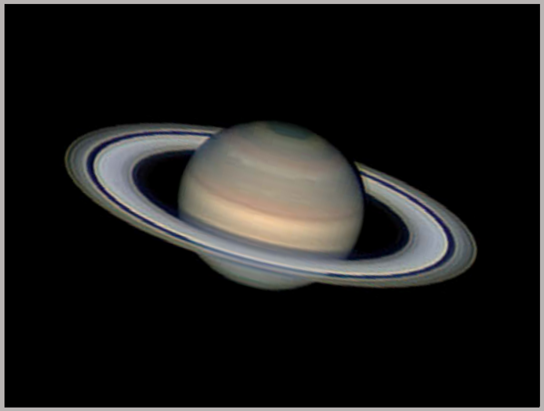
Details: *16-inch Dream Astrograph with Apogee Alta U16M CCD camera. Total exposure was 3 hours through narrowband and color filters.*

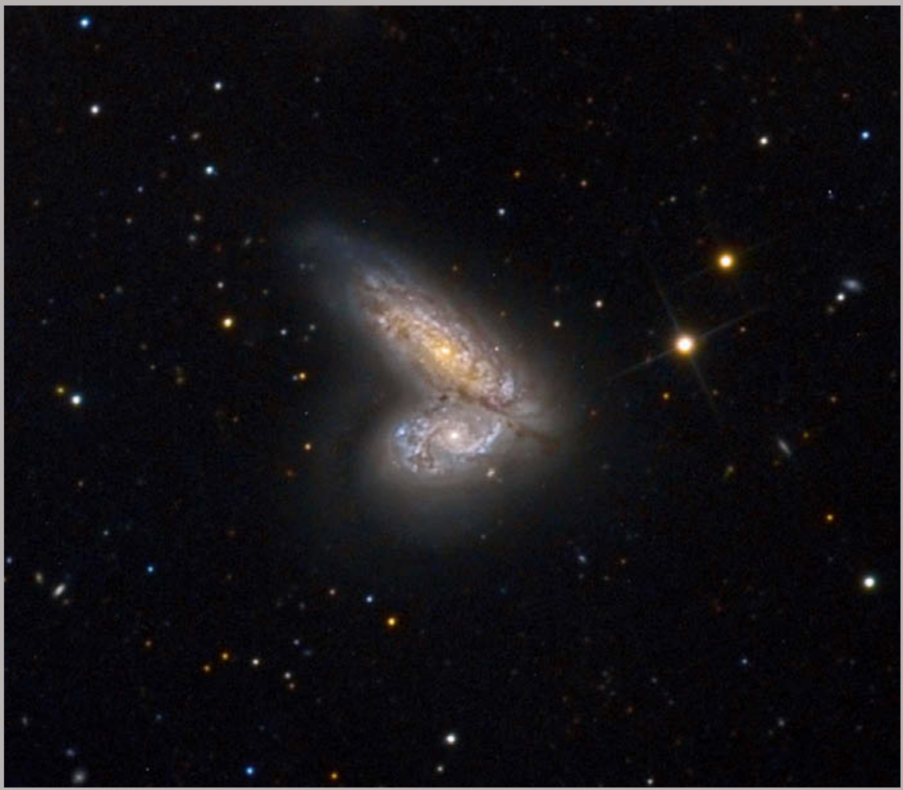
► **WIDE RINGS**

Christopher Go

Saturn shows off its amazing ring system with its dark Cassini Division and rarely seen Encke Gap visible near the outer edge of the B ring.

Details: *Celestron C14 Schmidt-Cassegrain with Point Grey Research Flea3 video camera. Stack of multiple frames on the evening of April 13th.*





▲ **RECEDING COMET**
Gerald Rhemann
As Comet C/2011 L4 PanSTARRS headed for the fringe of the solar system, it passed by the nebula NGC 7822 in Cepheus, presenting another photographic opportunity. **Details:** *ASA H f/2.8 astrograph with FLI ProLine PL16803 CCD camera. Total exposure was 24 minutes through color filters.*

◂ **GALACTIC BUTTERFLY**
Bruce Waddington
NGC 4567 and 4568 in Virgo are two dusty spiral galaxies in the process of merging roughly 60 million light-years away. **Details:** *PlaneWave Instruments CDK12.5 corrected Dall-Kirkham astrograph with QSI 640ws CCD camera. Total exposure was 5⅘ hours through color filters.*

Visit SkyandTelescope.com/gallery for more of our readers' astrophotos.

PANSTARRS ANTITAIL

Jérôme Astreoud

Near the end of May, Comet C/2011 L4 PanSTARRS passed through a chance alignment of its orbital plane with Earth's, revealing a long antitail pointing back toward the Sun. The bright star at bottom left is Polaris.

Details: *Canon EOS 7D DSLR camera with 200-mm lens at f/2.2. Total exposure was 18 minutes captured on May 30th.* ✦

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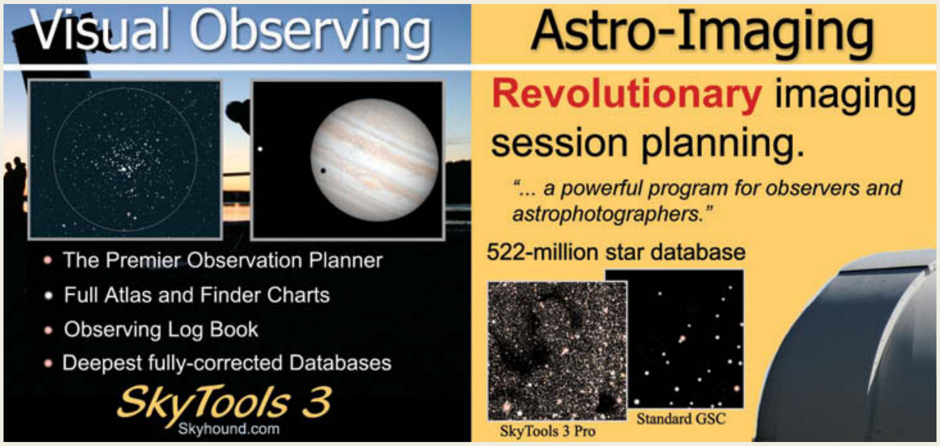

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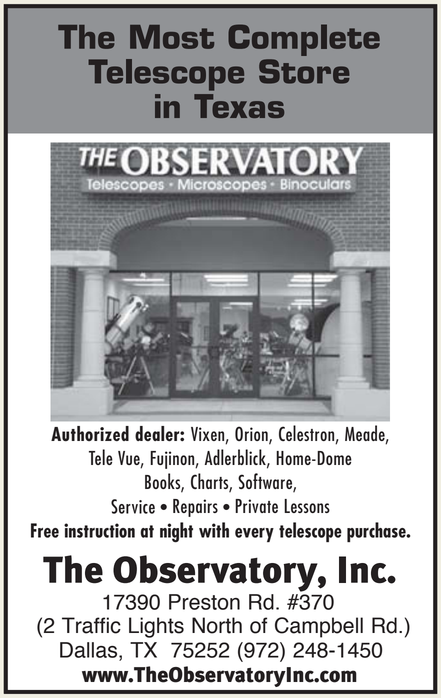

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IN THE NEXT ISSUE

The Great Supernova Race
In the race to discover supernovae, professionals have taken the lead, but amateurs are still playing a vital role.

Back to the Big Bang
By studying the oldest light in the universe, scientists are hunting for the fingerprints of inflation.

Amateur Eclipse Balloon Flight
An international team of amateur astronomers flew a balloon into the stratosphere to capture spectacular views of last November's total solar eclipse.

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The second installment of our Milky Way series covers the sky from Scutum to Cassiopeia.

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Why Chelyabinsk Endures

Months after the event, the author continues to watch the Russian meteor videos.

DAN PAGE

Are February's Russian meteor videos just another spate of already-forgotten disaster porn? Or do the clips offer something more, even months later?

For years, as I worked on a book about meteorites, I was steeped in the science of space rocks. I walked across Antarctic ice with scientists collecting meteorites, and I flew over a remote impact crater in Australia. Just now, I've been tossing a meteorite back-and-forth in my hands, turning my skin beet-red. It's difficult to comprehend the mindless violence of the cosmos. It got a lot easier when that semi-trailer-size meteor blew up over Chelyabinsk.

Angled shots of a snowy park, sounds of an explosion, white smoke in blue air, roadways bathed in the fireball's glare. Fascinated, I still watch those sublime scenes. Writer David B. Morris says that the sublime is that feeling for "qualities of wildness, grandeur, and overwhelming power, which, in a flash of intensity [can] ravish the soul with a sudden transport of thought or feeling." Surely the Russian meteor videos show us that very quality. They are epic, even on a laptop.

Then again, maybe for some they were mere movie-like spectacles, or, as Jon Stewart noted on *The Daily Show*, a glimpse into the hard-bitten Russian soul. One driver with a dashboard cam listens to the radio as the meteor swings over. He says nothing at all beneath such intense light.

Immanuel Kant believed that reason was a crucial part of the sublime; the mind can make sense of the experience. These videos remind us of our capacity to understand the universe and, specifically, to detect and deflect asteroids or, with warning, to evacuate potential impact zones. Reason can rescue.

The Chelyabinsk videos differ from run-of-the-mill disaster porn because they give us a special Kantian realization: Impacts are the only natural disasters we can actually prevent. Detecting city-killer asteroids is possible and worthwhile. Deflecting them won't require nukes but, in one scenario, white paint. (Uneven heating of dark and light surfaces would nudge the rock on a new trajectory.) Americans spend $40 billion a year on pizza. Surely we can afford to launch a mission with a paint brush. We learned in February that lives are potentially at stake. We can learn the lesson again by watching the footage.

That's why I find myself drawn to the most dramatic videos, agreeing with University of Arizona planetary scientist Tim Swindle that these clips record people's reactions to the bolide and not the bolide itself. They offer a human scale to the humongous, rock-strewn solar system. Two office workers dodge a shattering window. Students scream at the explosion that interrupted their class. Such moments make impact events "more believable," says Swindle.

So too do the scenes of the aftermath. Workers in parkas and hard hats repairing the city's heavily damaged zinc factory show that your workplace can be torn apart by a meteor explosion! Here's a picture of a man sweeping up glass. That's all, just a man sweeping up glass. The solar system tries to break us? We're awed. We get out a broom. And if we're smart, we'll spray-paint an asteroid. ✦

***Christopher Cokinos** is the author of* The Fallen Sky: An Intimate History of Shooting Stars, *and the forthcoming* Bodies, of the Holocene. *He teaches English at the University of Arizona.*

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