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THE ESSENTIAL MAGAZINE OF ASTRONOMY

MARCH 2012

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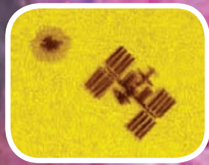

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ST-8300 Image of Vdb142 by Peter Clausen

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SKY & TELESCOPE

March 2012

VOL. 123, NO. 3

TOM DAVIS

On the cover: The Sun's first light may have shone in a cloudy, star-studded region like this one.

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Robert Naeye
Spectrum

Is Astronomy's Golden Age Over?

PEOPLE FREQUENTLY LOOK BACK in time to a purported Golden Age, when their national or cultural group was at the height of its power and prestige. If you ask a professional astronomer or planetary scientist in the U.S. or Europe to name the Golden Age in their field, the truthful answer would be "right now."

Thanks in large part to government investment in space telescopes, interplanetary missions, and major ground-based facilities such as America's Kitt Peak National Observatory and the European Southern Observatory, the astronomical and planetary sciences have advanced human knowledge of the universe by leaps and bounds over the past several decades.

Consider exoplanets. Just 25 years ago, we didn't know of a single planet orbiting a star other than the Sun. Today, the confirmed count exceeds 700 (including a potentially habitable superearth, see page 14), and NASA's Kepler mission has identified more than 2,300 strong candidates. In our solar system, we have detailed knowledge of all the major planets and their moons. Were it not for the government investment in astronomy and related sciences, our current knowledge of the universe might be where it stood in the early 1970s.

Whether government investment in astronomy is a judicious or wasteful use of public resources is debatable, although astronomical-related projects constitute only a minuscule sliver of the budgetary pie, and leadership in science and technology is essential for any nation's economic health. But one fact is not in doubt: economic and political forces are converging into a perfect storm, producing what looks like will be a precipitous downsizing in government support for astronomical projects in the U.S. Unless the economic and political climate changes drastically, the coming decade will witness the potential closures of major national facilities such as Kitt Peak or Cerro Tololo, no new flagship planetary missions, and very few space telescope launches other than perhaps Webb (and nothing specifically to follow up Kepler's discoveries).

But this issue's articles about Epsilon Aurigae give me some reason for optimism that the Golden Age might continue in spite of the perfect storm. Astronomical research isn't going away completely, and as the four amateur sidebars explain, more and more people will be able participate in different types of research. And with the demonstrable success of projects such as Citizen Sky and crowd-sourced data-mining projects such as Galaxy Zoo and Planet Hunters, more professionals will be motivated to tap the enormous potential of citizen scientists. Maybe the rapid rate of discovery will continue, but with different types of partnerships achieving different kinds of results.

Robert Naeye
Editor in Chief

Another Astronomical Origin for *Frankenstein*?

The article by Olson *et al.* in the November 2011 issue on the origin of the story of *Frankenstein* (page 68) was an interesting read. No doubt Mary Shelley deserves the credit for her classic tale, but I can't help wondering if she had read Copernicus's *De Revolutionibus*. In the treatise's Preface and Dedication to Pope Paul III, Copernicus writes

> But even if those who have thought up eccentric circles seem to have been able for the most part to compute the apparent movements numerically by those means, they have in the meanwhile admitted a great deal which seems to contradict the first principles of regularity of movement. . . . They are in exactly the same fix as someone taking from different places hands, feet, head, and the other limbs — shaped beautifully but not with reference to one body and without correspondence to one another — so that such parts made up a monster rather than a man.

Maybe some more sleuthing is in order?

David Sattinger
Tucson, Arizona

Visual Observers' Creds

The News Note "Past Meets Future at AAVSO's Centennial" (*S&T*: January 2012, page 20) gives the impression that visual observing no longer has a place in variable-star astronomy. We disagree with this assessment, and the AAVSO is firmly committed to the support and encouragement of visual variable-star observing and its use in astronomical research.

The research community has made it clear to us that visual data for many variable stars still have scientific value, and that visual observing should continue. Professional astronomers who use AAVSO visual data in their own work gave their support during the AAVSO's General Meeting, and many more make regular use of our visual light curves for both research and teaching. One of the most important products of visual observing — the centuries-long observing records for some stars — is unique: you cannot turn the clock back and obtain instrumental data. Continued visual observation of these stars is vital for the future study of their long-term behavior.

Visual observing also remains a low-cost and low-technology means for all astronomers to participate in meaningful scientific data collection; it provides this opportunity to a far larger global community than digital observing alone possibly could. It has also been proven as a gateway for young people to become involved in astronomy.

We think that visual and digital observers each have their own strengths that should be put to the best and most productive use. We also think that there remains more than enough valuable work for visual observers to do that ensures they can make important contributions to science while doing what they love. The AAVSO will continue to support and encourage all observers, visual and otherwise, to make their own contributions to the good work that we all believe in.

Matthew R. Templeton
Science Director, AAVSO
Mario Motta
President, AAVSO
Arne A. Henden
Director, AAVSO

Editor's Note: *For more on photometry and the AAVSO's visual Citizen Sky project, see the article sidebars on pages 20 and 26.*

Planetarium Workshop

I was very interested in the photograph of Allyn Thompson in the November issue (page 20). I believe he was standing with his telescope on the ground level of the planetarium in New York City.

In the late 1950s I enrolled in the night course for telescope-mirror making at this planetarium. I commuted once a week from Montclair, N.J. In spite of my efforts, the course ended before I was ready to figure my 6-inch mirror into a parabolic shape (the difficult part!). They were kind enough to finish it for me. I picked the mirror up later and had it aluminized.

Several years ago I tested the mirror using the Foucault method described in Thompson's book, *Make Your Own Telescope*. It was right on.

Art Siegel
New Hartford, Connecticut

Look to the Nitrogen

I wish to comment on Emily Lakdawalla's article on NASA's new Mars rover Curiosity and the search for life (*S&T*: December 2011, page 22). The very first thing that investigators should look for, on Mars or any other planet, is a nitrogen cycle. Nitrogen is an essential component of all DNA, RNA, and proteins. Its unique properties provide the glue — or, perhaps more aptly, "Velcro" — that holds DNA in a spiral helix yet allows the helix to partially unzip for duplication or RNA transcription.

On Earth, a major abiotic system for nitrogen fixation is the combination of an oxygen-nitrogen atmosphere and lightning. This combination produces nitric acid, which on the ground is neutralized by metal oxides and carbonates to form nitrate ions that plants can use as a nitrogen source. Some microorganisms also produce nitrate directly in an oxygen-nitrogen atmosphere without the need for abiotic sources. For example, the bacterium *Pseudomonas radicicola* forms nodules on the roots of some plants, particularly legumes. This is a symbiotic relationship: *Pseudomonas* supplies nitrate,

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and the plant returns sugar.

If there is no life on Mars today, it may mean there's no nitrogen cycle. And if there never was a stable, long-lived nitrogen cycle — long enough for life to emerge — there probably never has been life on Mars.

Donald Simons
Wilmington, Delaware

No Bok Globule

I've been a long-time fan of Sue French. Her extensive knowledge of the night sky and her persuasive writing style always inspire me to go out and look up at the sky. The first thing I read in *Sky & Telescope* is her column. However, in the January issue (page 54) she described the keyhole in NGC 1999 as a Bok globule, and recent scientific reports suggest that there's actually nothing in the keyhole.

Byungsoo Kim
Yongin, South Korea

***Editor's Note:** The reader is correct: ground and space observations have indeed shown that the so-called globule is in fact not a physical object. It may be a gap in the gas and dust, formed by an outflow from the nearby star V380 Ori. Our thanks to the reader for pointing out this discovery.*

For the Record

✷ *The Moon is new at 2:39 a.m. EST on January 23rd, not January 22nd as stated on page 43 of the January 2012 issue. For a list of past errata, please go to* **SkyandTelescope.com/Errata**.

75, 50 & 25 Years Ago

Roger W. Sinnott

March 1937

Nova in Cassiopeia? "In the early morning hours of October 5, 1936, the writer was photographing the [spectrum of] Gamma Cassiopeiae [with] the great 69-inch telescope of the Perkins Observatory near Delaware, Ohio. . . . He was at once impressed by the fact that the star seemed to be unusually bright. . . . If Gamma Cassiopeiae should turn into a nova it would probably become a spectacle unparalleled in astronomical history."

It didn't, and today we know that novae, unlike Gamma Cas, are exploding white dwarfs. But Ernest Cherrington, Jr., had just discovered a new class of hot, rapidly rotating variable star.

March 1962

Infrared Frontier "Some of the most interesting questions of astrophysics can be answered by observations of the infrared spectra of stars. Hitherto, the progress of infrared astronomy has been handicapped by insensitive detectors and by the absorption of our atmosphere. . . .

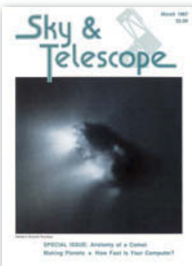
"[Steward Observatory's Aden B.] Meinel said, 'Infrared astronomy therefore needs much larger telescopes as well as more efficient detectors.' . . . As a first project, the construction of a 10-foot infrared dish has been suggested, the probable cost being $100,000."

Not for 15 years would Meinel's dream be fully realized when the European Southern Observatory's 3.6-meter (11.7-foot) reflector came online. A few years later, new infrared array detectors marked a further breakthrough.

March 1987

Test of Computer Speed "[The Savage] benchmark's calculations [for testing computer accuracy] are quite similar to the use of trigonometric functions in orbital or celestial mechanics problems. . . .

"Many people consider the IBM PC-AT family of computers the most powerful of the personals, and this is borne out when applying the Savage benchmark. An 8-MHz 80286 processor . . . [runs it] in just 54 seconds."



T. S. Kelso's article proved wildly popular, and it brought a flood of timings from readers, some of whom used supercomputers. The program code listed in the article runs in 0.0015 second on a typical PC today.

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

What Happened on the Moon?!

Generations of astronomers grew up assuming that, as in the title of an old science-fiction tale, "Nothing Ever Happens on the Moon." But in the scene here, something dramatic happened in geologically recent times to create an utterly unMoon-like terrain about 3 km (2 miles) long.

Located in the foothills south of the Apennine Mountains, "Ina Caldera" first drew attention in photos taken from the Apollo 15 orbiter in 1971. But never has it been seen in such stark detail as in this recent image from NASA's Lunar Reconnaissance Orbiter.

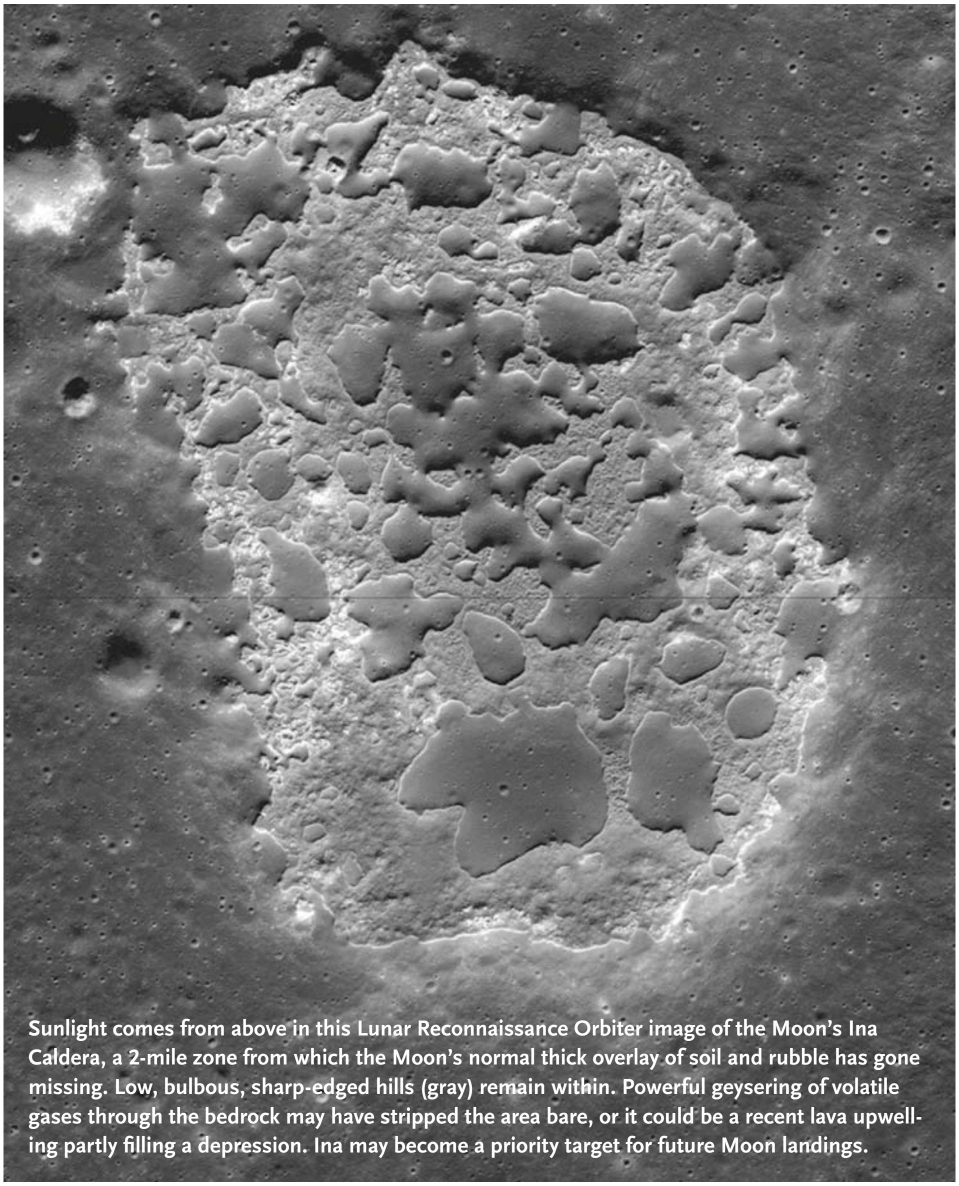
We're looking at an area of bright, cleaned-off substrate below the surrounding terrain. At first look, something seems to have stripped away the lunar regolith — the dark gray blanket of loose rocks, rubble, and dust that covers the Moon almost everywhere — exposing a lighter, blocky surface up to 250 feet (80 meters) lower down. That's a lot of regolith to get rid of. Many low, blobby hillocks of old, cratered surface remain raised within the bare zone. These are sharply edged by cliffs with slopes as steep as 40°, as if their edges were eaten away by the bright area. The whole structure sits atop a much larger, low volcanic dome.

One theory is that the bright floor collapsed from below and recently flooded with lava, which then mostly drained away. Another theory is that powerful outgassing through porous bedrock blew away the regolith, perhaps in many episodes. Such outgassing appears to have happened at places on Mercury. Perhaps volatiles such as carbon dioxide or water remain deep in the Moon and occasionally blow free.

How young is Ina? The bright floor has very few craterlets, its details remain sharp, and its minerals show none of the usual space weathering by micrometeorite impacts, cosmic rays, and solar radiation. Previous age estimates of as little as 1 to 10 million years are challenged by a few craterlets that do show up in the high-resolution LRO images. Still, Ina must have formed just yesterday compared to the rest of the Moon's ancient geology.

A few similar features are known or suspected elsewhere on the Moon, such as the floor of Hyginus Crater not far north (last month's issue, page 50). Could big, violent outgassings happen even now?

Even before LRO, Ina was known to researchers and amateur Moon watchers, though at much lower resolution; it's item



Sunlight comes from above in this Lunar Reconnaissance Orbiter image of the Moon's Ina Caldera, a 2-mile zone from which the Moon's normal thick overlay of soil and rubble has gone missing. Low, bulbous, sharp-edged hills (gray) remain within. Powerful geysering of volatile gases through the bedrock may have stripped the area bare, or it could be a recent lava upwelling partly filling a depression. Ina may become a priority target for future Moon landings.

NASA / LRO

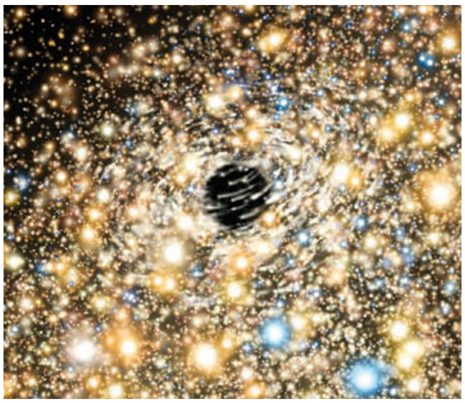
99 in Charles Wood's Lunar 100 list (*S&T:* August 2007, page 47, with finder photo). It sits in Lacus Felicitatis just north of Mare Vaporum at latitude 18.65° north, longitude 5.30° east. The shallow, D-shaped depression is detectable with an 8- or 10-inch telescope in excellent seeing under just the right (very low) lighting conditions.

Super Black Holes: New Records, if Real

In December a team of astronomers made news worldwide by announcing two black holes that seem to be the biggest ever directly "weighed." Such giants would make trouble for the standard relationship between galaxies and their central black holes. Lost in the coverage was the fact that, as the researchers make clear in their December 8th *Nature* paper, the measured masses are so uncertain that there's a chance neither hole is anything special.

The two objects reside in the centers of the giant elliptical galaxies NGC 3842 and NGC 4889, each a central member of a galaxy cluster. The team, led by Nicholas McConnell and Chung-Pei Ma (University of California, Berkeley), used the Gemini North and Keck II telescopes in Hawaii to determine how fast stars in the galaxies' innermost regions whirl around the centermost point. That reveals the gravitational force of the unseen central object.

For NGC 3842's central monster, the team found a mass between 7 and 13 billion Suns. For NGC 4889 the range was bigger, 6 to 37 billion Suns. Those ranges are only "one sigma," meaning that statistically, there's a 68% chance that the true value lies within the range and a 32% chance that it's outside even those wide limits.

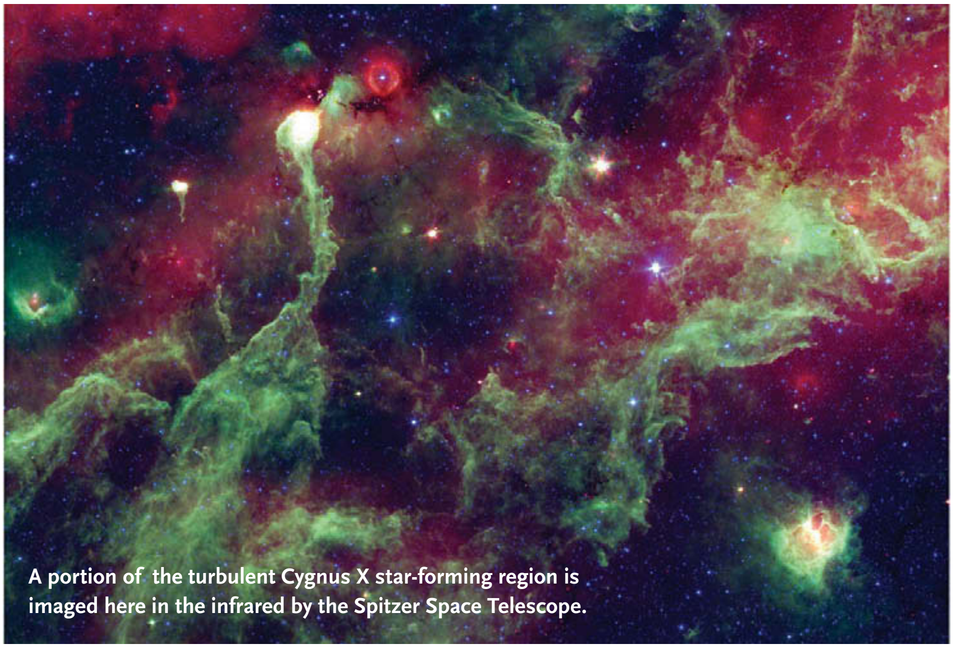


GEMINI OBSERVATORY / AURA/ LYNETTE COOK

This illustration, issued with a Gemini Observatory press release and published around the world, is symbolic at best. Even in the star-dense center of a galaxy, each star is thousands of astronomical units from its nearest neighbor, while a 10-billion-solar-mass black hole would be 400 a.u. wide — tiny by comparison.

By comparison, the previous heavyweight black-hole champion is the one at the center of M87 in the Virgo Cluster. A study in early 2011 put its mass between 6.2 and 7 billion Suns (one sigma).

The wide uncertainty for the new black holes comes from the fact that they're roughly five times farther away: more than 300 million light-years. That's near the current technological limit for mass measurements using gas or star swarms moving around a galaxy's central object. In their spectral studies, the astronomers had to include the combined star-glow out to about 1,000 light-years (1 arcsecond) from the center. Hence the wide error bars.



A portion of the turbulent Cygnus X star-forming region is imaged here in the infrared by the Spitzer Space Telescope.

NASA / SPITZER SPACE TELESCOPE

Another Origin for Cosmic Rays

Where do cosmic rays come from? These superfast particles, discovered a century ago bombarding Earth's upper atmosphere, were long a mystery. In recent years astronomers have found evidence that they're accelerated to their high energies by magnetic fields compressed in the expanding shock fronts of supernova remnants. Now there's even better evidence that some cosmic rays come from another proposed birthplace: magnetic shock fronts in turbulent star-forming regions, caused by stellar winds.

In supernova remnants, astronomers have had solid confirmation only for the high-energy acceleration of electrons. But most cosmic rays are protons (or heavier atomic nuclei). So Isabelle Grenier (Paris Diderot University and CEA Saclay) and her colleagues turned the Fermi Gamma-ray Space Telescope to the star-forming region Cygnus X, a tumultuous complex of nebulae about 4,500 light-years away behind Gamma Cygni in the center of the Northern Cross. Here the team detected a diffuse glow of extremely high-energy gamma rays (up to 100 GeV) coming from inside a superbubble, a giant cavity in the nebula's gas blown out by stellar winds from many young, hot stars. The gamma radiation seems to arise from high-energy protons hitting atoms of gas or other particles inside the bubble. With energies averaging much greater than cosmic rays near Earth, these protons seem to be freshly accelerated and still near their place of origin.

They're probably held inside the bubble by the maelstrom of twisted magnetic fields expected in the colliding stellar winds, Grenier says. Over time some will leak out and join the cosmic-ray particles pervading the Milky Way, sometimes reaching Earth.

A Massive Young Star Declares Itself

The odd little bipolar nebula Sharpless 2-106 in Cygnus is a challenge object even for visual observers with 16-inch telescopes under dark skies. It stands revealed below in unprecedented glory, thanks to imaging in five near-infrared colors and in hydrogen-alpha emission by the Subaru and Hubble telescopes.

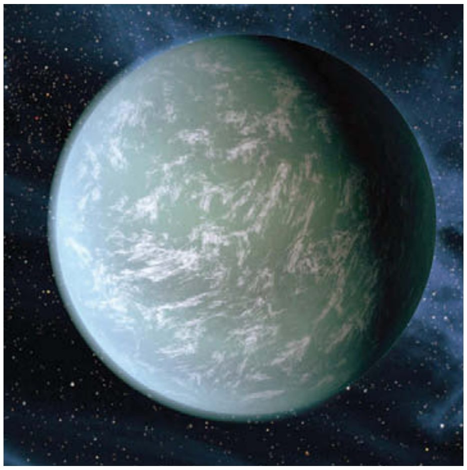
Hidden behind the dust lane at center is a massive new *B*0 star that recently emerged from its birth cocoon. Bipolar jets from the star's immediate surroundings have blown two opposite voids, whose walls ripple with cascading turbulence. The walls are best seen in red H-alpha emission, color-coded blue here. The star, which presumably has about 15 times the mass of the Sun, is in its final stages of formation and will soon settle down onto the main sequence, the adult stage of stellar life. It's located behind the brightest glow of scattered light near the center of the central dust lane. The view here is roughly 2 light-years wide.

HUBBLE / SUBARU

Kepler Finds a Potentially Habitable World

It could be a friendly, rocky super-Earth with six times Earth's surface area for creatures to swim and roam upon. Or it could be a gassy mini-Neptune with no real surface at all. But the planet Kepler-22b, announced by NASA in December, is likely at least to have pleasant temperatures — good for oceans, rainfall, and Earth-style biochemistry. It basks comfortably in the habitable zone of a *G*5 star slightly dimmer and cooler than the Sun 600 light-years away in Cygnus, in the Kepler spacecraft's fixed field of view. Kepler measured the planet's diameter — 2.4 Earths — by how much starlight it blocked during transits.

The planet orbits with a year 290 Earth days long. That is very large compared to the orbits of most of the 2,326 planet candidates Kepler has found so far. Most of these are roasters that orbit much faster and closer to their stars, which is why they were discovered first. Only now is Kepler accumulating a long enough data span to catch and confirm transits of slow orbiters farther out, with the kinds of temperatures where you might be able to step out of a spaceship and walk around in shirtsleeves.



NASA-AMES / JPL-CALTECH

An artist's concept of Kepler-22b, which is 2.4 times as wide as Earth. If it has Earth's composition (unknown as yet), its surface gravity would be a daunting 3 gs.

Astronomers don't yet know the mass of this new find nor, therefore, its density and composition. A mass determination might begin to emerge this summer, once Cygnus is high in a dark sky and spectrographs can watch for the star's expected slow radial-velocity wobble.

The Kepler science team trumpeted Kepler-22b as the mission's first confirmed planet occupying the habitable zone of its host star. The key here is "confirmed"; many additional pleasant-temperature candidates are waiting in the wings.

Kepler finds planets by staring at roughly 150,000 stars from 9th to 15th magnitude in an area of sky covering 105 square degrees — about the area your fist covers at arm's length. Every 30 seconds the craft measures all the stars' brightnesses to extreme precision, nonstop. When a planet crosses the face of one of these stars from our point of view, it registers as a slight dip in brightness. The Kepler team doesn't consider a candidate viable until three transits are seen. And

GOTO

A new sky over Wyoming

Gillette Wyoming is in the heart of America's new energy future. Surrounded by coal, natural gas, and oil reserves, as well as plentiful wind power, it sends out energy resources to the rest of the country. And it will soon be sending out astronomy education resources as well. The Campbell County School District Planetarium in Gillette is the first American CHRONOS II HYBRID installation. Its director, Paul Zeleski not only has an ambitious goal of creating HYBRID planetarium programs for others' use, but also of producing students who are proficient in the production skills which will be used in tomorrow's world.

This project to put students in the planetarium driver's seat began with a total renovation to the district's 30-year old planetarium equipment. In addition to the CHRONOS II HYBRID with SP2-HD video projection, full audio, lighting, and even laser light show equipment was put under a brand new dome. 68 new custom-made seats now fit under the 9 meter diameter dome.

The next step in the equipment upgrades will add 68 touchscreen devices at each armrest, where students may be quizzed by the instructor, scan and search for more information about topics on the dome, and with specially-created software even enable them to control the sky from their own seats. GOTO CHRONOS II HYBRID and the rest of the technology and integrated software programs at Gillette have set a new standard for modern educational planetariums. This planetarium will both inspire and educate. At Gillette, not even the sky is the limit!

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it's not "confirmed" until ground-based follow-ups can determine its mass or at least, as in this case, an upper mass limit.

Recording three passages by Kepler-22b, each just 7½ hours long and spaced nearly 10 months apart, required a bit of luck. The spacecraft noted the first transit on May 15, 2009, just a few days after it started taking data in earnest. The third came just before Christmas 2011, just prior to a two-week "safe mode" event when the spacecraft took itself offline. "If there had been any change in when these occurred, we would have missed them," says Kepler principal investigator William Borucki. "So we think of this as our Christmas planet — it was a great gift."

Some 80% to 95% of Kepler's candidate planets will probably turn out to be real, science team members expect. Deputy leader Natalie Batalha says 207 of the candidates so far are considered "Earth-size" (no more than 1¼ times Earth's diameter) and another 680 are classified as "super-Earths (1¼ to 2 Earth diameters).

Meanwhile, 48 planet candidates of all sizes now orbit far enough out to be in their stars' habitable zones. Of these, 10 appear similar to Earth's diameter, though five of these are considered suspect. Two, three, or more planets orbit 367 stars, about 20% of those where any transiting candidates have been detected at all. "The parameter space is spreading," Batalha says. "We're pushing to smaller planets and longer orbital periods." Some even appear to be smaller than Earth. Just as this issue was going to press, Kepler scientists announced a five-planet system in which two are nearly identical in size to Earth (0.87 and 1.03 Earth radii). Batalha says we can expect another big release of candidate planets soon.

Borucki is hoping that NASA will provide the funds to keep Kepler going past its nominal 3½-year mission, which ends late this year. Most of Kepler's target stars have shown more microvariability than expected (*S&T:* October 2011, page 12), which adds noise to the data. This means the spacecraft will need to observe for several additional years to identify all the Earth-analog transiting planets in its search zone, as was originally intended.

More on the Pinwheel Supernova

Amateur telescope users kept a close watch last summer and fall on Supernova 2011fe in M101, the Pinwheel Galaxy off the Big Dipper's handle. The supernova brightened in late August, maxed out at magnitude 10.0 in mid-September, and faded in the following months. It was the nearest and brightest Type Ia supernova since 1972; M101 is just 21 million light-years away.

Some fresh science results are out. The discovery team, the Palomar Transient Factory group, caught the supernova remarkably early, when it was still only magnitude 17.2. They have extrapolated back and determined that the star exploded just 11 hours before. This makes it by far the earliest-caught Type Ia explosion.

Another group, led by Peter Nugent of Lawrence Berkeley Laboratory, finds that the progenitor star was a carbon-oxygen white dwarf, exactly as theorists expected. In a Type Ia explosion, a close companion star is thought to pour matter onto a white dwarf until the dwarf becomes overloaded, starts to collapse, and undergoes a complete thermonuclear explosion that fuses nearly all of its material into heavier elements. Some unfused oxygen from near the white dwarf's surface was measured flying away from the explosion at 20,000 km per second (45 million mph).

Sensitive radio and X-ray observations show no evidence of the blast interacting with surrounding material, such as the putative companion star might have blown off in earlier ages. Nor do pre-explosion images show any progenitor star. These findings rule out a luminous red giant or other highly evolved star for the companion. Analysis of the supernova ejecta, and its overall brightness, indicate that the companion was not another white dwarf spiraling in and merging, either.

That leaves a main-sequence star, or perhaps a mildly evolved subgiant, as the white dwarf's feeder object — a valuable data point for sorting out what actually happens in these crucial explosions (*S&T:* November 2011, page 14). Type Ia supernovae are of special interest because they're the best "standard candles" for measuring large cosmic distances without relying on redshifts. ✦

On September 18th the supernova in M101 was magnitude 10.2, still about at its peak. For this image, Albert van Duin in the Netherlands used a homemade 16-inch f/4 Newtonian reflector for 39 minutes of exposures with a QSI 583wsg CCD camera.

An End

After 200 years of mystery, Epsilon Aurigae is surrendering its secrets to an organized professional-amateur campaign.

Robert Stencel

For many decades the bright star Epsilon Aurigae has confounded astronomers. Every 27 years, for a period lasting at least 18 months, the 3rd-magnitude star strangely dips to nearly 4th magnitude, but with no visible companion star to be seen. Something must be passing in front of the primary star, but that eclipsing object has remained an enigma since astronomers first noticed Epsilon Aurigae's varying brightness in the 1820s.

Hoping to solve this stellar mystery, astronomers eagerly awaited the latest eclipse, which lasted from August 2009 to July 2011. Armed with superior telescopes and detectors, professional and amateur astronomers collected an unprecedented array of high-quality measurements that seem to finally provide a consistent description for this most troubling of systems.

Subject to the usual caveats, such as an imprecisely known distance (about 2,000 light-years), astronomers

in Sight

S&T illustration by Casey Reed

ENIGMATIC BINARY **This illustration of the Epsilon Aurigae system is an update of the one that appeared in the May 2009 issue. Information from the recent eclipse changed our picture of the system in subtle ways. The system consists of an *F* star that shines with the intensity of about 30,000 Suns, making it appear at 3rd magnitude despite its 2,000-light-year distance. Evidence for an eclipsing disk was circumstantial in 2009, but is ironclad today, though the disk no longer appears to be warped. Observations have also bolstered the idea that a very hot and massive *B* or *O* star lurks inside the disk, but the disk material is thick enough that it hides this star from our view.**

have long known that the visible star is an *F*-type star that outshines our Sun by about 30,000 times. It's a bit hotter than the Sun (7500 Kelvins versus 5750 K), but is chemically quite similar.

But what about the dark eclipsing object? In 1965 Su-Shu Huang (Northwestern University) theorized that a huge brick-shaped object was the culprit. Using new infrared detectors during the 1982–84 eclipse, Dana Backman (NASA/Ames Research Center) and his collaborators demonstrated the presence of a large, relatively cool 500-K body in the system, suggesting some kind of disk. During the 2009–11 eclipse, my graduate student Brian Kloppenborg and I employed Georgia State University's CHARA Array on California's Mount Wilson to image the star using interferometry. Our pictures have proved unequivocally that an opaque, elongated disk is indeed causing the eclipse.

A low-density disk must have a high-mass object in the center in order to remain gravitationally intact, so there must be some kind of star embedded within the disk. Using the International Ultraviolet Explorer satellite in 1979, Margherita Hack (University of Trieste, Italy) found a clue when she took the first ultraviolet spectrum of Epsilon Aurigae. She argued that the system's unexpectedly high ultraviolet brightness requires a relatively massive star inside the disk.

But what kind of star is it, and what is the disk made of? Professional and amateur astronomers gathered extensive new lines of evidence during the 2009–11 campaign. Nearly every modern astronomical method was called into service: interferometric imaging, spectroscopy in multiple wavelength bands, optical and infrared photometry, polarimetry, and computer simulations of disk physics. The resulting clues have given us a partial solution to Epsilon Aurigae's mysteries, but vexing questions still remain.

Imaging the Disk

By conducting interferometric imaging of Epsilon Aurigae with the Michigan Infrared Combiner (MIRC) on the CHARA Array before, during, and after the eclipse, our observing team detected a long, thin disk causing the eclipse by covering nearly 50% of the *F* star. Rarely in astrophysics can we be so certain of a conclusion, but the pictures don't lie.

More importantly, the images allow us to estimate the disk's dimensions relative to the *F* star's measured 2.3-milliarcsecond diameter: The disk is at least 12 milliarcseconds in length by 1.1 milliarcseconds in vertical thickness. We can convert those angular sizes to astronomical units (1 a.u. is the average Earth–Sun distance) if we know the distance. The estimated 2,000-light-year distance is far enough to be difficult to measure by modern methods, including parallax measurements made by the European Hipparcos satellite. Adopting the result from the late astrometry expert Peter van de Kamp (Swarthmore College), the distance is 1,890 ± 100 light-years. This suggests that the *F* star is about 1.3 a.u. wide, while the disk is at least 7 a.u. across and about 0.6 a.u. thick.

CATCHING the Light

Jeff Hopkins

Amateur observations combine to piece together the Epsilon Aurigae puzzle.

Around 1980 Vanderbilt University astronomer Doug Hall, and later Russ Genet, encouraged me to get started in photoelectric photometry. By early 1982 I was willingly pulled into doing photometry of the upcoming 1982–84 eclipse of Epsilon Aurigae by Arizona State University astronomer Paul Schmidtke and Robert Stencel, known affectionately as Dr. Bob. I have been observing this star system ever since. I found I could do real science from my backyard with my 8-inch telescope, and as a senior engineer with Motorola I could fairly easily build my own photomultiplier-tube-based UBV (ultraviolet, blue, and visual) photon counting system.

CHARLIE HOPKINS

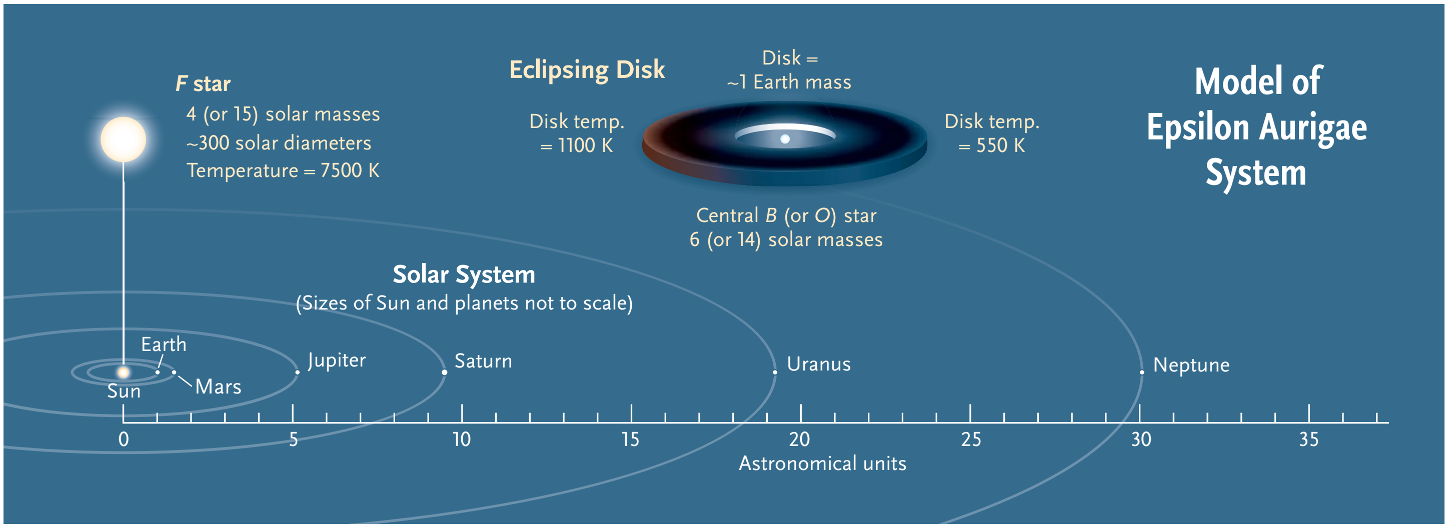
Arizona amateur Jeff Hopkins has taken photometric data of Epsilon Aurigae since the early 1980s. In this photo, he is holding his self-made UBV photon-counting photometer.

Together, Dr. Bob and I headed the 1982–84 eclipse campaign. It was very successful, with several dozen contributing members from around the world. This was before personal computers became easily available, and well before the internet. Almost all communication was via ground mail.

The primary method of obtaining eclipse data was photoelectric photometry. Simply put, stellar photoelectric photometry measures a star's brightness. To enhance the data's value, astronomers use filters to see how that brightness changes in specific wavelength bands. During Epsilon Aurigae's 1980s eclipse, the UBV bands were most popular. Even though small observatories started to contribute spectroscopic data during the 2009–11 eclipse, more observers still submitted photoelectric photometry. Observers expanded in the recent eclipse to the R band (red) and the near-infrared I, J, and H bands. A big surprise this time around has been the high-quality V-band data submitted by observers using only a DSLR camera on a tripod, since DSLRs were never constructed with photometry in mind (*S&T*: April 2011, page 64).

Over the course of the 2009–11 campaign, Dr. Bob and I have published 24 newsletters and created a comprehensive website, as well as an active and useful Yahoo forum. Twenty-five observers from around the world submitted more than 3,700 observations during the eclipse. Some of our most prolific observers were Des Loughney from Scotland (209 observations), Gerard Samolyk from Wisconsin (649), and Richard Miles from England (306). I submitted 565 observations from my Hopkins Phoenix Observatory in Arizona, still using the original UBV photometer I built in the 1980s.

Despite the impressive quality and quantity of data from the recent campaign, Epsilon Aurigae is still not ready to give up all of its secrets. Most eclipsing binary systems produce clean light curves. But Epsilon Aurigae's light curves can be quite confusing. With most eclipsing binaries, it's easy to calculate when one star begins to eclipse the other, or when the eclipse ends. But that's not the case with Epsilon Aurigae. The giant eclipsing body is an elongated disk rather than a

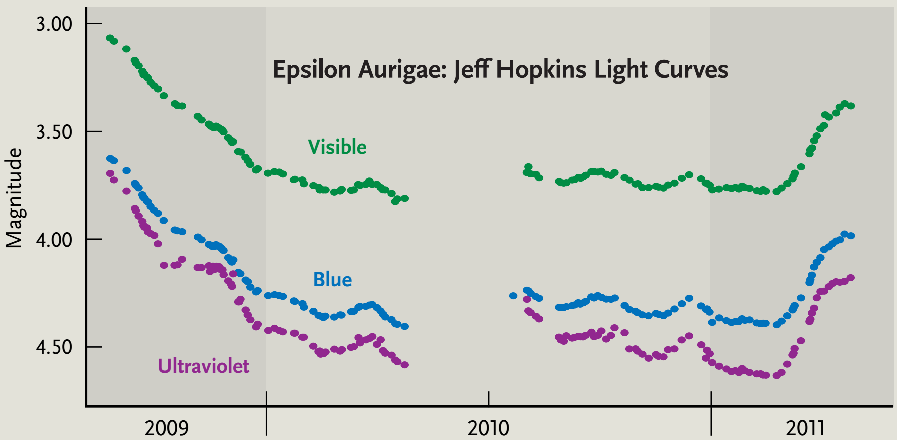


S&T: CASEY REED / GREGG DINDERMAN

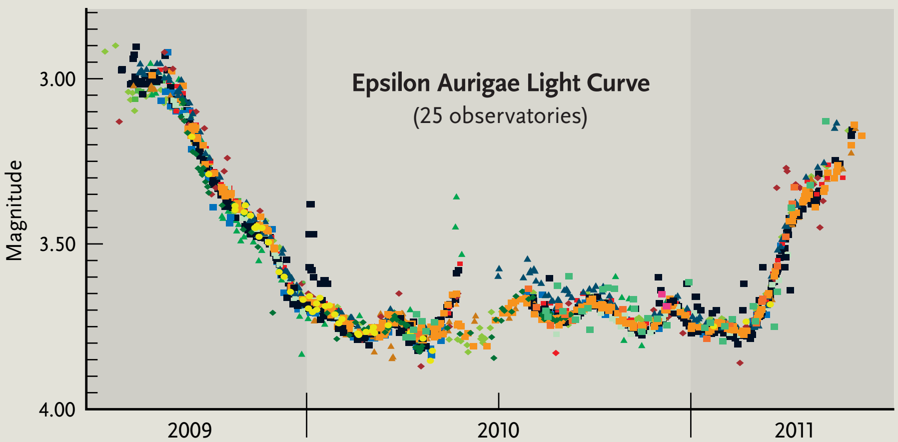
SOLAR SYSTEM VS. EPSILON AURIGAE Using data from the latest eclipse, astronomers have conceived this model for the Epsilon Aurigae system. The system consists of two stars, a highly evolved *F* star that is visible at all times, and a smaller but hotter and more massive *B* or *O* star that is hidden inside a relatively thick circumstellar disk. When that disk passes in front of the *F* star from our perspective, the *F* star dims by nearly a full magnitude.

sphere. As the eclipse was nearing its end, egress started off fine and then halted about halfway to fourth contact. To confuse matters further, a mysterious pseudoperiodic, out-of-eclipse brightness variation appears in all bands. The system is still enigmatic despite our collective efforts. Perhaps more of the mystery will be solved in 2036.

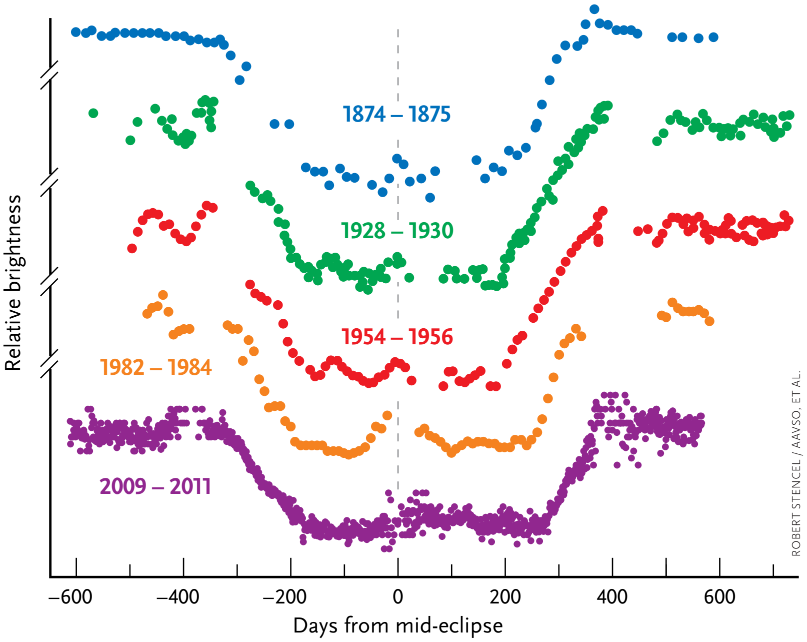
***Jeff Hopkins** runs the Hopkins Phoenix Observatory near his home in Phoenix, Arizona.*



Jeff Hopkins recorded Epsilon Aurigae's brightness in the U (ultraviolet), B (blue), and V (visible light) bands. The star exhibited similar brightness variations at all three wavelengths, but the eclipse is deeper in the U band than in the V band. The gap in the light curves occurred in the late spring and early summer of 2010, when Epsilon Aurigae was too low in the nighttime sky to record high-quality data.



Jeff Hopkins assembled photometric V-band data from 25 observers in many different countries to create this light curve of Epsilon Aurigae's recent eclipse. The data clearly shows a pronounced dimming lasting nearly two years. But the detailed variations reveal considerable variability during the deepest part of the eclipse, perhaps due to the uneven thickness of material in the occulting disk.



CHANGING LIGHT CURVES These light curves from visual data show Epsilon Aurigae's behavior during the five most recent eclipses. The curves show the same general trends from eclipse to eclipse, but they're not exact copies of one another. It's unlikely the stars have evolved much since the 1874–75 eclipse, so most of the variability probably comes from changes in the disk.

Equally important, we can deduce the two stars' relative velocities from our measurements, which provide a key to the individual masses. Brian Kloppenborg is doing this work as a part of his Ph.D. thesis.

The various observations constrain the orbit of the two stars around a common center of gravity, but even now the mass of the visible *F* star remains uncertain — in some models it's around 4 Suns and in others it's as high as 15. Prior to the latest eclipse, many astronomers favored the high-mass interpretation. But by measuring the relative motions of the visible *F* star and disk, we're accumulating evidence that the *F* star is only 60% as massive as its companion. This result clearly favors the lower

DECIPHERING the Disk

Robin Leadbeater

Amateur spectroscopy helps resolve the eclipsing object's motion.

Robin Leadbeater poses with the Celestron C11 and LHIRES spectrograph that he uses to take data of Epsilon Aurigae. His spectroscopic observations of Eps Aur and other systems have demonstrated that amateurs are capable of making fundamental contributions in a field once thought to be solely the province of professionals.

Changes in an eclipsing binary's brightness can sometimes tell us the diameter of the eclipsing object. In the case of Epsilon Aurigae, interferometric imaging actually allows us to see the object's silhouette.

Yet for this system, the eclipsing object's internal structure and the physical properties of its constituent material remain hidden. The object (now known to be a disk) is not totally opaque: A translucent halo surrounds its optically thick region, which leaves its spectral signature on light passing through it from the companion *F* star during an eclipse. By repeatedly measuring spectra during the eclipse, we can build up a detailed picture of this outer material, slice by slice, as it slowly glides past the star.

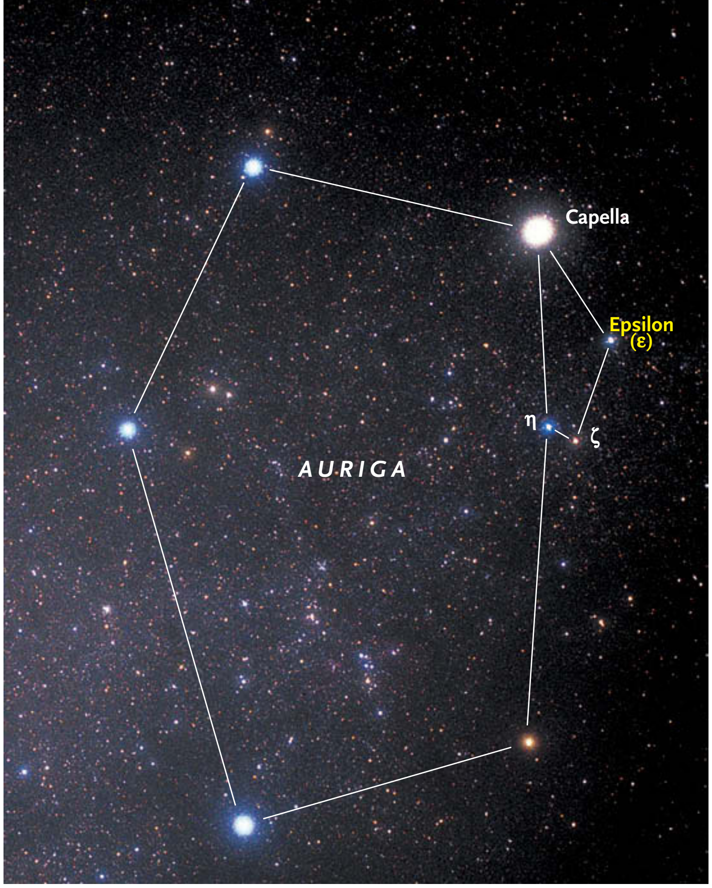
Since the 1980s eclipse there have been significant advances in the technology available to amateur spectroscopists. Sensitive electronic imagers have replaced film and amateurs have recently developed spectrographs capable of resolving spectral lines just a few hundredths of a nanometer wide, sufficiently high resolution for pro-am collaborations such as the Epsilon Aurigae campaign. As a result, amateurs contributed more than 800 spectra during the most recent eclipse.

While some observers covered the complete optical spectrum looking for signs of the disk, others concentrated on measuring the evolution of specific lines known to show changes during eclipse, using the highest resolutions. For this project, I modified my LHIRES spectrograph, extending its range into the far red to cover a potassium absorption line at 769.9 nanometers. This line is absent from the companion *F* star's spectrum, so any changes are attributable to the eclipsing disk's properties.

The potassium line was measured at infrequent intervals during the previous eclipse by professional astronomers David Lambert and Scott Sawyer, and it was thought that more intensive study of this feature during the 2009–11 eclipse might reveal more of the disk's structure. My goal was to take spectra at 0.03-nm resolution at weekly intervals throughout the eclipse, a sixfold increase in time resolution compared with that achieved by anyone during previous eclipses.

end of the *F* star's mass range, indicating that it's a highly evolved giant (a post-asymptotic-giant-branch star), possibly on its way to puffing off its outer envelope to form a planetary nebula, and eventually leaving a white dwarf behind. In this scenario, the *F* star initially had more than 6 solar masses, but it transferred a significant fraction of its mass to the unseen companion.

Infrared spectroscopic observations suggest that the disk is made of a variety of solid materials, but it's dominated by particles generally larger than those submicron-scale bits floating in interstellar space, and perhaps resembling volcanic hail. Several other new lines of evidence indicate substructure in the disk, possibly due to interactions among asteroid-size objects or perhaps from tidal kicks when the two stars reach their closest approach during each orbit.



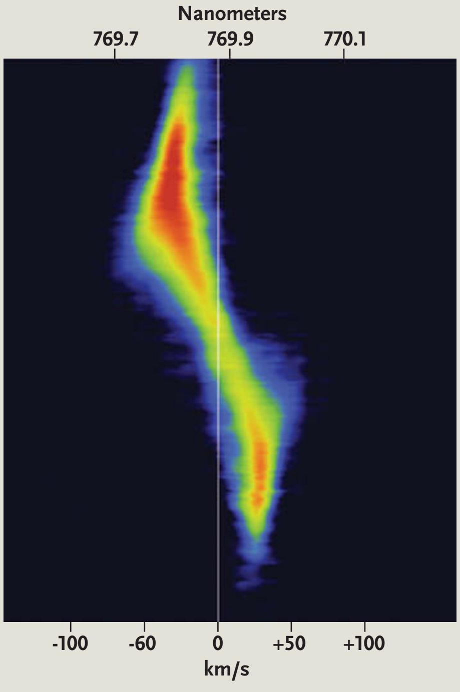
EASY-TO-FIND STAR Thousands of people in many different nations observed Epsilon Aurigae during the recent eclipse. They were aided by the fact it's bright and very easy to find, even in moderately light-polluted skies. Look for 1st-magnitude Capella and go from there. Auriga is high in northwestern evening skies this time of year.

Although my observatory is located in the wettest corner of England, I recorded more than 250 spectra, despite the weather's best attempts to thwart me. When a storm put my observatory temporarily out of action, I avoided a potential gap by shipping the modified instrument to Germany, where amateur Lothar Schanne continued the measurements.

My spectral data shows the evolution of the 769.9-nm line during the eclipse. The line's wavelength moved from red to blue, passing above and below where it would be if the material were at rest. The eclipsing disk's movement along our line of sight is causing these shifts, telling us that the material in its leading half is moving away from us, while the trailing half is coming toward us. These motions imply that the disk is rotating and almost edge-on from our point of view.

The absorption line actually appeared some months before the system's brightness started to drop. Indeed, this line's appearance was the first evidence that the eclipse was beginning. The absorption from the disk was still detectable spectroscopically in late 2011 despite the system's brightness having returned to normal levels during June. This lingering potassium absorption might be the last sight we get of the disk until its return in 2036.

The detailed changes in the line's shape and intensity give us deeper insights into rotation speeds and densities in different parts of the disk. Together with similar data collected by amateurs for other spectral lines, observations of this potassium line should allow us to define the nature of the eclipsing disk more precisely.



Robin Leadbeater's image shows how the contribution of the eclipsing disk to the potassium line in Epsilon Aurigae's spectrum changed between March 2009 (bottom) and November 2011 (top). Warmer colors signify increased absorption. The line began redshifted from its expected position (central white line). As time passed the wavelength shifted toward the blue. These changes arise due to the disk material's motion away and toward Earth. Software developed by amateur spectroscopist Christian Buil generated this image.

***Robin Leadbeater** directs the Three Hills Observatory in Wigton, England. He has compiled a full list of amateur Epsilon Aurigae spectra at **www.threehillsobservatory.co.uk/epsaur_spectra.htm**.*

The Star Inside the Disk

Astronomers have collected a remarkably wide range of spectra during the eclipse campaign, many from "amateurs" using commercially available spectrographs (their data is essentially professional quality, so I hesitate to call these scientists "amateurs"). By monitoring the neutral potassium line near 769.9 nanometers, British amateur Robin Leadbeater has provided some of the most immediately useful results (see page 22). Robin re-created the classic results reported by David Lambert (McDonald Observatory) during the 1980s eclipse, but Robin could provide more extensive coverage over time with his backyard telescope. He discovered step-like increases in the strength of the potassium line as the disk eclipsed the *F* star. Robin and I interpret this behavior as further evidence for disk substructure, possibly rings or density waves.

Robin, along with accomplished amateurs in Europe and North America, have performed equally important optical monitoring of the hydrogen-alpha spectral line at 656.3 nm. Hydrogen is by far the most abundant element in most stars, and H-alpha is the strongest hydrogen spectral line at visible wavelengths. Epsilon Aurigae's H-alpha line exhibited dramatic changes in absorption and shape,

THE ECLIPSE IMAGED ***Facing page, top left:*** **These dramatic images taken from the CHARA Array, an interferometer on Mount Wilson near Los Angeles, unambiguously resolve Epsilon Aurigae's visible *F* star and a dark disk crossing in front of it right on cue — during the latest eclipse. These extremely high-resolution observations have proved what many astronomers have long suspected — that the eclipsing object is a disk. But the structure's composition, mass, and origin remain unknown.** ***Bottom left:*** **In this room astronomers match the light path lengths from the CHARA Array's six telescopes to submicron precision.** ***Far right:*** **The foreground dome houses one of the six 1-meter telescopes that comprise the CHARA Array. The dome for the famous 100-inch Hooker Telescope looms in the background.**

GETTING Good Vibrations

Gary Cole

Monitoring the polarization of Epsilon Aurigae's light is helping to peel away

We say light is "polarized" when its rays have different properties in different directions. The most recognized case is linear polarization, when all the wave vibrations occur in one plane as the light propagates. Polarization is created by strong magnetic fields or photons scattering off electrons, but it only becomes measurable when the source is asymmetric or partially obscured. Measuring polarized light with the technique of polarimetry is challenging because most starlight is only slightly polarized.

GARY COLE

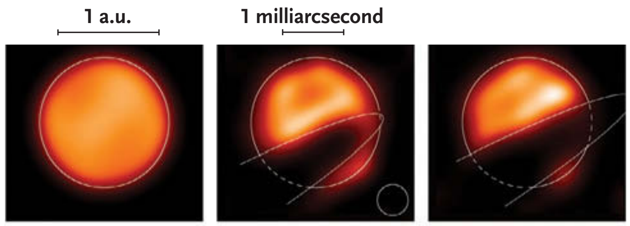
Gary Cole stands next to his automated Celestron telescope that he uses to take polarization data of Epsilon Aurigae and other stars.

I've had a longstanding interest in polarimetry, but it was a conversation with Robert Stencel at the 2009 Society for Astronomical Sciences meeting that started me on a serious pursuit of this technique. Epsilon Aurigae's polarization had first been studied during the 1982–84 eclipse, and Dr. Bob encouraged me to repeat those observations in the upcoming cycle. Previous measurements had left some doubt as to the source of the effect and whether or not it would reappear.

I constructed my instrument from a Celestron C8 optical tube, photometric filters, and an SBIG ST-402 CCD camera. It's a dual-beam imaging polarimeter, which is a standard professional design with a calcite analyzer prism and a rotatable wave plate. It creates two images for every star, and the brightness ratios of the star pairs in four images taken at different polarization angles reveal the magnitude and direction of polarization to a precision limited only by the number of photons collected.

The instrument is mounted piggyback on my C14, which locates the targets and guides during exposures. In addition to Epsilon Aurigae, I observe a collection of standard stars to verify calibration.

Looking at data taken between August 2010 and May 2011, it's apparent that something was modulating Epsilon Aurigae's polarization on a timescale of about 60 days. The graph of these data shows V-band observations taken on 115 nights. The error in the nightly measurements, primarily due to photon noise, is about 0.05%. The polarization varied from about 2% to 2.5% over this period. The base value is due to polarization by magnetically aligned interstellar dust and is consistent with historical measurements of this star; the remainder is eclipse related. I obtained similar results in the B (blue) and R (near-infrared) bands. The final pulse of polarization ended with a precipitous falloff at the same time that third contact appeared in the light curve. This behavior is similar to the pat-



R. STENCEL / GEORGIA STATE UNIV.

S&T: ROBERT NAEYE

MIKE SIMMONS

the system's secrets.

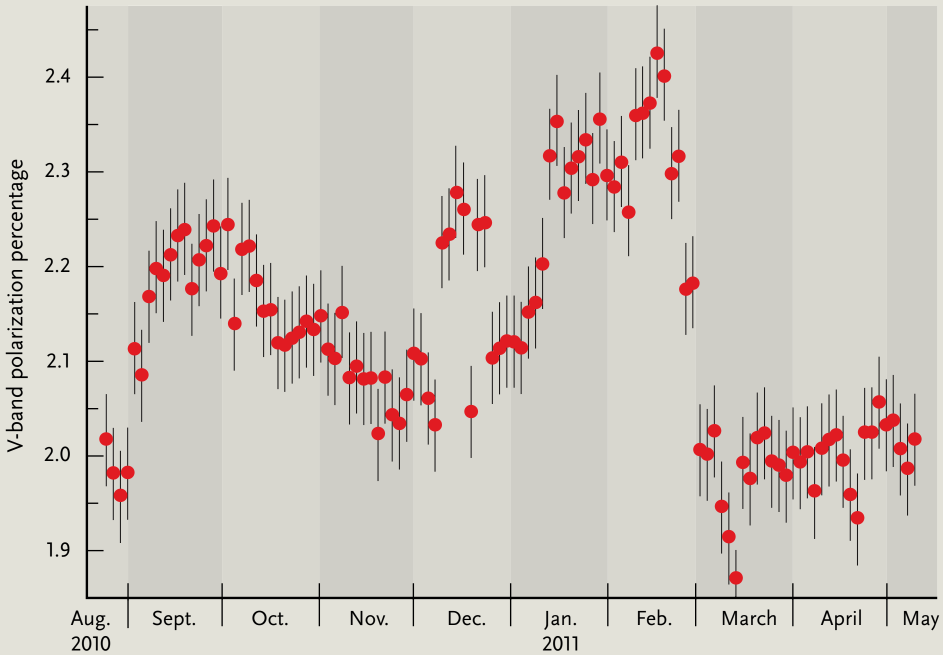
tern seen 27 years ago. These results suggest that something associated with the eclipsing disk is causing the polarizing effect.

Post-eclipse observations with my upgraded C14 polarimeter have shown that polarization has remained near the historical interstellar level through the end of 2011. Although the primary eclipse has ended, the project is not yet over. Results from the 1980s eclipse showed additional activity for several years following the main event. I look forward to resuming monitoring in the coming observing seasons, and to continuing the collaborations I've developed during the project.

My results show that polarimetry is a natural area for pro-am collaboration, because neither poor seeing nor urban light pollution prevent the acquisition of high-quality data. Many bright stars, including massive, rapidly rotating *Be* stars such as Beta Lyrae and P Cygni, are known to have polarimetric variations, but few have been subjected to extended time-series studies. This is an area open to amateur investigation. Give it a try!

***Gary Cole** operates the Starphysics Observatory near Reno, Nevada.*

Epsilon Aurigae: Gary Cole Polarization Measurements



S&T: GREGG DINDERMAN, SOURCE: GARY COLE

During the recent eclipse, Gary Cole has demonstrated that amateurs can take high-quality and scientifically valuable data on the polarized light from stars such as Epsilon Aurigae. Cole's data show the degree to which Epsilon Aurigae's polarization varied over the course of nearly a year. The increases and decreases in polarization are probably caused by variations in the density of free electrons in the eclipsing disk.

probably related to activity around the *F* star and disk material absorbing light from that star. We'll learn more as we further scrutinize the data.

In addition to optical spectra, advances in infrared spectroscopy have enabled more consistent monitoring of eclipse phases. Using the SpeX instrument on NASA's Infrared Telescope Facility atop Mauna Kea, our group was able to re-create a classic observation showing the emergence of carbon monoxide (CO) absorption after mid-eclipse. This observation is significant because it provides evidence that the nearby *F* star's intense radiation is stripping volatile (easily vaporized) compounds such as CO from the disk — similar to what we see when comets approach the Sun. The *F* star must be changing CO's state from solid to gas — which we observe when the heated, trailing portion of the disk swings into view after mid-eclipse.

We also discovered that the helium 1083.0-nm spectral line appeared strong immediately after mid-eclipse, when we were observing the disk's central regions. The helium line persisted for several months. Solar and stellar astronomers have long recognized the helium line's significance as being diagnostic of hot plasmas at about 100,000 K. At this extreme temperature, helium can produce hard (high-energy) ultraviolet light and soft (low-energy) X rays. Finding this feature in a disk's center implies a massive, energetic central star, probably spectral type *B* or *O*, that is potentially accreting matter and heating that material to high temperatures. The strength of the line tells us that huge numbers of ions are being produced locally and are accreting onto a hot and massive central star.

Computer simulations suggest the accreting gas needs to be replenished, perhaps from colliding asteroids inside the disk, or from capturing some of the gas in the *F* star's stellar wind. The *B* or *O* star that's accreting this gas must be very hot and massive, but its diameter is tiny compared to the swollen *F* star, and it's the huge disk — not its central star — that's clearly causing the eclipse.

UNITING the Stargazers

Aaron Price

A global amateur campaign puts the "science" back in "citizen science."

The Citizen Sky project is a focused effort by the American Association of Variable Star Observers (AAVSO) to coordinate observations of Epsilon Aurigae's 2009–11 eclipse and also promote amateur use of the data they collected. Funded by the National Science Foundation, the project was designed for those new to variable-star science and amateur astronomy.

Citizen Sky has more than 4,000 registered participants, approximately half of whom claim little or no prior experience in astronomy. About 450 participants submitted more than 8,000 observations to the campaign. Of these, about 7,000 were visual observations (naked-eye, binoculars, or telescope); the others are photometric measurements taken at various wavelengths with digital detectors (CCDs, DSLRs, photoelectric photometers).

AAVSO

Citizen Sky organizers gathered at the California Academy of Sciences in September 2010 to conduct a workshop for Epsilon Aurigae observers. Aaron Price is at the far left. The "V" is for *Vstar* software.

The large amount of visual data is particularly impressive. When combined, the measurements can achieve a precision better than a typical single photometric observer — although photometry, when done correctly, will always be more precise than observing by eye. In addition, the visual data extend the AAVSO's Epsilon Aurigae archive to more than 21,480 observations (of all types), covering eclipses back to 1842. This century-plus record allows for superb long-term study.

All of the Citizen Sky data is stored in the AAVSO's database, which is one of the most used in the world. Epsilon Aurigae light curves have been plotted at the AAVSO website almost 14,000 times in the last year alone. Astronomers download the raw data more than once a week so they can do their own analysis, making it one of the top 10 most popular stars on the website (which has data on more than 16,000 stars).

But Citizen Sky's goal is to expose participants to the entire scientific process, not just data collection. The project has organized teams to work on mini-projects such as his-

Challenges for Theorists

Historically, photometry revealed most of what we knew about Epsilon Aurigae. Thanks to the organizing efforts of Jeffrey Hopkins (see page 20) and the American Association of Variable Star Observers (see the sidebar below), we have thousands of new observations spanning the optical part of the spectrum. These data define a light curve (a graph of how Epsilon Aurigae's brightness changes over time) of the current eclipse that is far better than any obtained during previous eclipses.

The light curves show several trends that reveal how the eclipse's overall shape and duration constrain the disk's length. Smaller variations superposed on the light curves indicate either disk substructure and/or large-scale bulk motion of gas around the *F* star. The eclipse light curve is asymmetric about mid-eclipse, with egress light rising much more quickly than it faded during ingress. This argues for an asymmetric disk, seen in spectroscopic indicators too, which probably results from differential heating by the hidden star. The disk's leading side is colder, denser, and more opaque than the evaporating trailing side. The interferometric images also suggest the ingress side is slightly thicker than the egress side.

An area of burgeoning amateur contribution involves polarimetry — the measurement of the orientation of light's oscillations. Anyone familiar with polarizing sunglasses knows that some surfaces and even parts of the clear daytime sky vary in brightness depending on the rotation of the polarizing lenses. This effect was used by Jack Kemp (University of Oregon) during the 1982–84 eclipse, and more recently by Kemp's former student Gary Henson (now at East Tennessee State University) and by Nevada amateur Gary Cole (see page 24) to detect strong variations in the polarization of light from Epsilon Aurigae during the eclipse.

Listen to a **BONUS AUDIO INTERVIEW**

To listen to an audio interview with author Robert Stencel, visit SkyandTelescope.com/EpsAur.

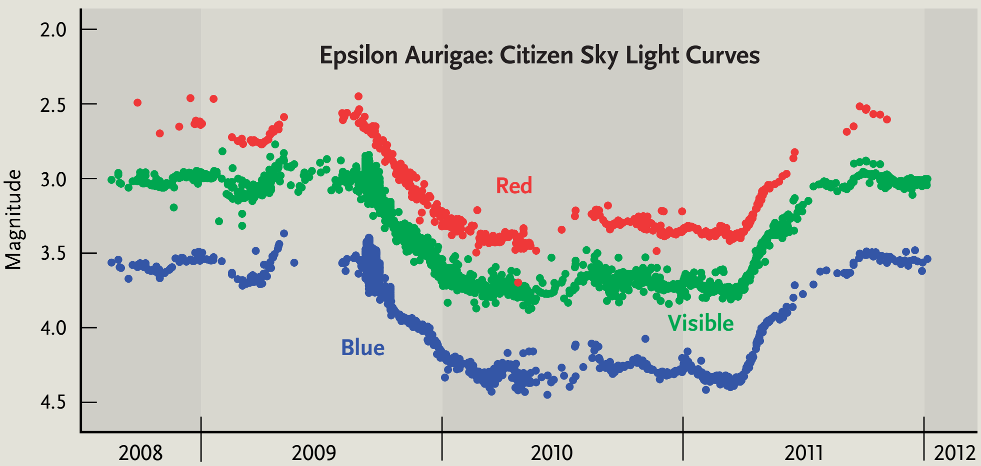
torical reviews of the literature, building statistical software, and analyzing observational data. Teams dedicated to outreach have even produced a documentary film and written a rock song about the project. You can watch a trailer of the film at **http://kck.st/epAur** and hear the song at **http://bit.ly/vM2ktU**.

Another team developed procedures, tutorials, and spreadsheets for how to acquire accurate and calibrated photometry using consumer-level DSLR cameras. Many variable stars, including Epsilon Aurigae, are too bright for regular telescopes but are perfect for affordable DSLR cameras. With such a camera, anyone can help professional astronomers by obtaining very precise measurements of these bright stars (*S&T:* April 2011, page 64). No telescope is needed.

We will publish results from these projects in a summer 2012 special edition of the *Journal of the AAVSO*, a professionally peer-reviewed astronomical journal. More information on all these projects is available at **Citizensky.org**.

Aaron Price *is the Assistant Director of the AAVSO and was the co-creator of the Slacker Astronomy podcast. His research interests involve cataclysmic variable stars, statistics of large variable-star datasets, citizen science, and how people interpret scientific visualizations.*

After compiling thousands of visual observations from the global Citizen Sky program, the AAVSO assembled these light curves of the recent Epsilon Aurigae eclipse in the B (blue), V (visible light), and R (near-infrared) bands. All three clearly show the deep eclipse, but also small-scale variability, especially during the extended "bottom" of the eclipse. The AAVSO also has J-, H-, and U-band light curves available at its website.



AAVSO / MATTHEW TEMPLETON

These oscillatory changes may relate to disk substructure or even accretion by the central star, or to asymmetries in the *F*-star's atmosphere. Nadine Manset and her colleagues at the 3.6-meter Canada-France-Hawaii Telescope have monitored the eclipse using optical spectropolarimetry. These data provide the unique ability to examine polarization of light in wavelengths in and out of spectral lines, and so they explore changes due to opacity in the system. Polarimetry, like all these lines of data, is providing grist and challenges for the theorists.

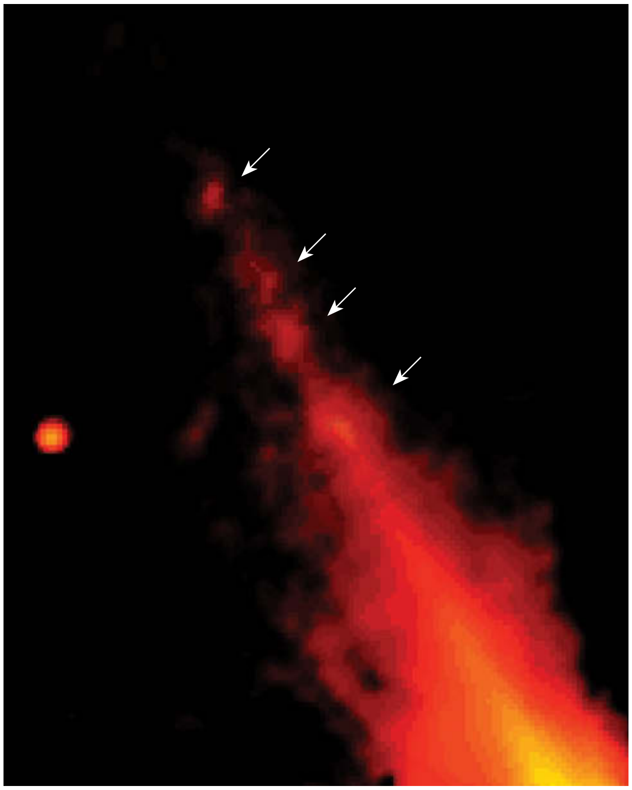
What Comes Next?

Putting all the pieces together, astronomers have developed the current model: a lighter but more evolved *F* star is in mutual orbit with a heavier but disk-shrouded *B* or *O* star. This system resembles a classical Algol-type interacting binary system, with an evolutionary history once described as the Algol Paradox: How did the lighter star become more evolved? Answer: the star that was born with more mass transferred some of its material to its companion, reversing the initial mass ratio.

The unique characteristic of Epsilon Aurigae is that the eclipses provide a tomographic or CAT scan of a circumstellar disk, and the disk itself is in a transitional or debris-disk phase, not unlike the famous disk around Beta Pictoris, where colliding small bodies are generating large quantities of dust. In past models, a huge "infrared star" was required to produce optical spectra changes during eclipse. The atmosphere of the observed disk can now fulfill this role. Astronomers used to think a high-mass supergiant star was needed to account for the brightness of Epsilon Aurigae despite its great distance. A post-red-giant star can now account for this property. The nature of post-red giants has only been explored in detail in the decades since the last eclipse. Such stars may represent the distant future of the Sun, and are far more common than supergiant stars.

Although the recent eclipse is fading into memory, the bonanza of data is providing researchers both ample constraints for checking the current model and inspiration for how to design observations that can confirm ideas without waiting another 27 years for the next eclipse. Forthcoming facilities such as the James Webb Space Telescope (infrared) and the Expanded Very Large Array (radio) may be able to pursue some interesting measurements of the disk. Key among the goals in these studies is pinpointing the disk's age and evolutionary state, and whether there might be high levels of activity such as the central star's accretion of disk matter. The *F* star itself is an important part of the study. Does it have an active atmosphere or giant convective cells, flares, or even a strong stellar wind?

The next eclipse is forecast to start in 2036, but you can enjoy out-of-eclipse variations of Epsilon Aurigae's light next time you see the star riding in the evening sky. Post-eclipse observations are still needed — this star retains its capacity to surprise. Like much of the "dark matter" in the universe, we're beginning to catch glimpses of the hidden side of the lives of binary stars. ✦



NASA / PAUL KALAS

DEBRIS DISK Hubble Space Telescope observations clearly resolve clumps (arrowed) and uneven structure in the debris disk orbiting the young star Beta Pictoris. The disk consists of dust from colliding asteroids and comets. The eclipsing disk in the Epsilon Aurigae system appears to have similar substructures.

INTERFEROMETRY

Interferometry is a technique that uses the combined beams of multiple, widely spaced telescopes in order to achieve the effective resolution of a telescope with an aperture as big as their overall spacing. Georgia State University's CHARA Array on Mount Wilson is capable of achieving just under one-thousandth of one arcsecond of resolution (called a milliarcsecond), which amounts to resolving a parking space seen at the Moon's distance. Epsilon Aurigae's visible *F* star is just over 2 milliarcseconds across.

Robert Stencel *is professor of astronomy at the University of Denver and Director of the Chamberlin and Mt. Evans Observatories. He authored the pre-eclipse article on Epsilon Aurigae that appeared in the May 2009 issue of* S&T.

Finding the Sun's Lost Nursery

ROBERT ZIMMERMAN

Astronomers are trying to understand the cluster where the Sun was born 4.6 billion years ago.

Determining the environment in which our Sun was born is helpful for finding out whether our galaxy can produce other stars and planetary systems similar to our own. It will also teach us a lot about star formation, the universe's most essential building block. And above all, it will help us fill in the blanks in our solar system's history. Finding out the Sun's birthplace would in many ways be like an adopted child discovering the identity of his birth parents. The past would no longer be an unknown, but an event we could study and learn from.

The problem with finding that birthplace is the simple

STELLAR NURSERY According to recent research, the Sun was born in an environment similar to NGC 281 in Cassiopeia, seen here in a combined Chandra (purple) and Spitzer (red, green, and blue) image. The central cluster, IC 1590, contains hundreds of stars that formed about 3.5 million years ago. All of the surrounding gas will eventually be incorporated into stars or blown away by stellar winds, ultraviolet radiation, and supernova shock waves. An open cluster of gravitationally bound stars will be left behind, but its members will someday disperse, leaving little or no trace of their birth environment.

NASA / CXC / CFA / S. WOLK; INFRARED DATA: NASA / JPL / CFA / S. WOLK

fact that the Sun was born approximately 4.6 billion years ago in a cluster buried inside a giant molecular cloud. That cloud no longer exists and the cluster has either dispersed entirely or the Sun has wandered very far from it. Moreover, the Sun's birth took place in a different part of the Milky Way Galaxy, which itself has evolved significantly over time as it has absorbed other dwarf galaxies.

Thus, identifying the Sun's birthplace is essentially like trying to find a mote of dust that has been tossed into a pile of dirt. The dust exists, but it would be exceedingly difficult to separate it from all the other dirt particles around it.

Despite these challenges, astronomers are beginning to pin down a few key facts about the womb that produced our Sun. These parameters are even pointing to one particular open star cluster, M67, as a place where the Sun might have been born. "Though there are arguments both for and against it," notes Bengt Gustafsson (University of Uppsala, Sweden), "the possibility could be appealing."

The Sun's Birth Cluster

For much of the 20th century, astronomers favored the idea that single, isolated stars such as the Sun formed

GENTLE STARBIRTH The dark nebulosity is the Taurus Molecular Cloud. With a distance of "only" 450 light-years, it's one of the closest and most widely studied stellar nurseries. Astronomers once thought the solar system formed in a similar cloud, but the latest evidence suggests it formed in a more crowded environment.

HISAYOSHI KATO

in relatively benign environments similar to the Taurus Molecular Cloud (TMC), which has no supermassive stars and where stars don't crowd together into tight clusters. Astronomers assumed that if one or more supermassive stars were too close, pumping out a lot of energy and then exploding as supernovae, the environment would have been too hostile for the solar nebula to coalesce. Similarly, if the birth cloud had been too densely cluttered with stars, the solar system would have had trouble forming. Because scientists thought that a new star would remain in its cluster for billions of years, there was more than enough time for a nearby star to venture close enough to disturb and even destroy a budding solar system.

This assumption was reinforced by the ease of investigating the TMC, only 450 light-years away. Not only was this the place where the first T Tauri baby stars were discovered, the inability of astronomers to see into dust clouds prior to the launch of infrared space telescopes meant that the TMC was one of the few places where these baby stars could actually be observed. These fortuitous circumstances encouraged astronomers to use this cloud and its isolated stars as the poster child for the Sun's birthplace.

The only kink in this theory was the presence in meteorites of short-lived radioactive isotopes such as aluminum-26 and beryllium-10. The most likely source of aluminum-26 is a long-gone supermassive star, whose internal nuclear reactions would have created the element. The star subsequently went supernova, spewing the aluminum into the young solar nebula.

Because astronomers doubted that our baby solar system could have survived such a nearby supernova, they looked for and found other methods for creating aluminum-26. This conclusion was bolstered by the fact a supernova could not have produced beryllium-10 itself — it required other formation processes as well.

One proposed solution was cosmic rays coming from either outside the solar system or from flares produced by the young and energetic Sun. When these cosmic rays smashed into the solar nebula they generated aluminum-26 and beryllium-10 in a process called *spallation*. With this new scenario, astronomers could model the formation of both the Sun and these short-lived isotopes in a benign environment like the TMC.

But the 2003 discovery of iron-60 (the decay product of another short-lived isotope) complicated the situation. Found in several primitive chondrite meteorites — material surviving from the solar system's earliest period — this isotope could only have gotten into these rocks if a nearby supernova had chemically "polluted" the solar system. "We now had this kind of difficult situation," explains Fred Adams (University of Michigan). "You needed two sources, both a spallation source and a supernova source."

Moreover, new research in the 1990s showed that

OPEN CLUSTERS VS. GLOBULAR CLUSTERS

Star clusters come in two basic varieties: open and globular. Open clusters, the subject of this article, generally consist of several hundred to tens of thousands of stars that formed together inside a stellar nursery. The stars in most open clusters are relatively young, perhaps a few million to a few tens of millions of years old. M67's estimated age of more than 3 billion years makes it a rare geriatric open cluster.

Globular clusters also consist of stars that formed together, but the globulars orbiting the Milky Way are "fossils" of starbirth that took place more than 10 billion years ago. Moreover, most globulars have significantly larger stellar populations than open clusters. Some of the most cherished globulars in the night sky can boast of hundreds of thousands of members, and a few, such as Omega Centauri, may contain several million stars. Some astronomers have proposed that Omega Centauri is the surviving core of a dwarf galaxy that was cannibalized eons ago by the much larger Milky Way Galaxy.

TAD DENTON / ADAM BLOCK / NOAO / AURA / NSF

HUBBLE HERITAGE TEAM (AURA / STSCI / NASA)

dense open clusters were less dangerous to starbirth that previously thought. The new data suggested that stars in open clusters generally disperse quickly, in only a few million years. Shortly after a star and its planetary system form, the star drifts out of its crowded birthplace, freeing it from the danger of later damaging close encounters.

Consequently, astronomers developed an entirely different scenario for the Sun's birthplace. Rather than forming in a sparsely populated molecular cloud like Taurus, the solar nebula coalesced in a cluster embedded in a large stellar nursery similar to the Orion Nebula, packed with stars and supermassive behemoths that periodically went boom and seeded the solar nebula with some of those short-lived isotopes. Meanwhile, spallation processes created other isotopes such as beryllium-10.

Astronomers have also used the present size and shape of our solar system to make some estimates about the Sun's long-gone birthplace. For example, a cluster can be too crowded and dense. Too many close neighbors would have perturbed the orbits of the objects going around the Sun, forcing them into highly elongated orbits. Though the planets go around the Sun in near-circular paths, many distant transneptunian objects have orbits that show evidence of disturbance, with a significant percentage beyond 50 astronomical units tracing orbits with high eccentricities and inclinations. These unusual orbits suggest a rough limit to the density of the birth cluster, just crowded enough for its stars to distort the orbits of the outer Kuiper Belt objects but not dense enough to disturb the orbits of the planets themselves.

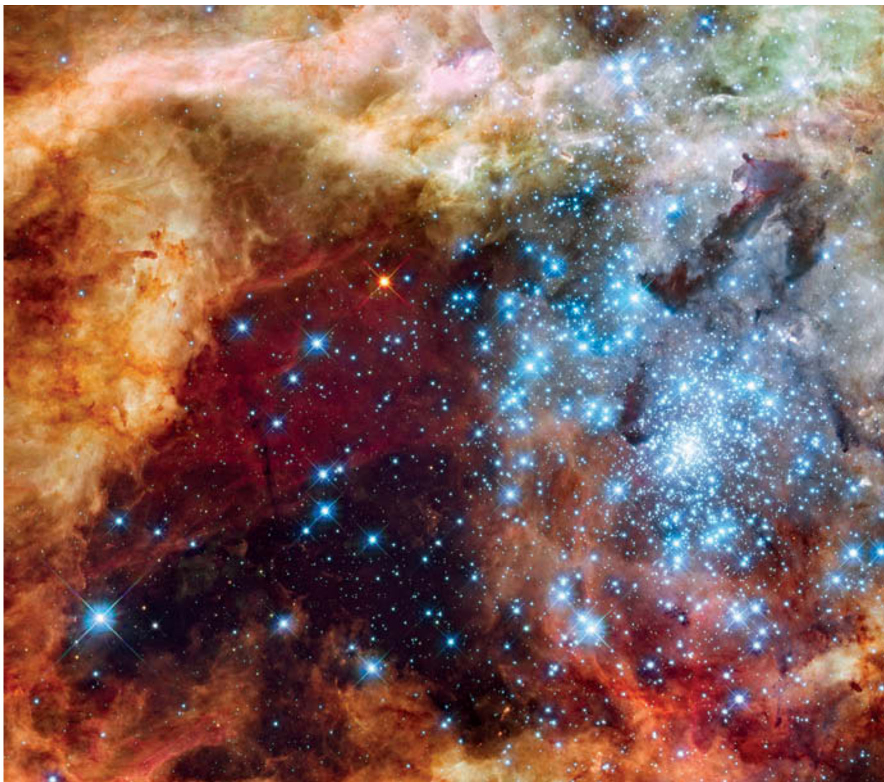
These and other constraints thus suggest to astronomers that the Sun's birth cluster should have had between 1,000 and 5,000 solar masses and approximately 1,000 to 10,000 stars, with a radius between 3 and 10 light-years. The distances between stars meant that no stellar encounters occurred closer than 400 astronomical units while the Sun was a member of the cluster. The cluster must also have had at least one giant star with approximately 25 solar masses that would have gone supernova from as close as ⅓ light-year and early in the Sun's formation process.

Locating that Cluster

Now that we have a vague idea of what the Sun's birth cluster should have looked like 4.6 billion years ago, can astronomers find either the cluster itself or its remains?

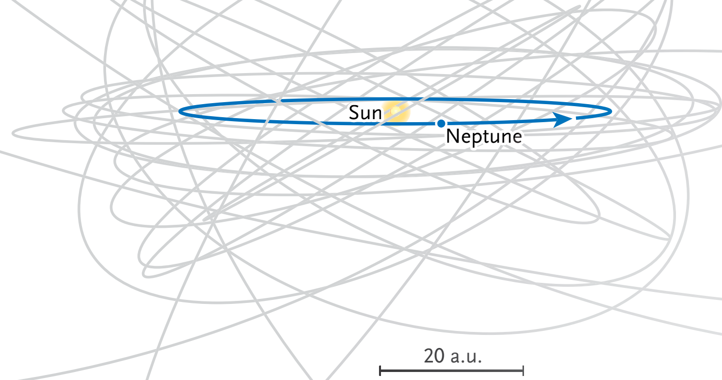
In principle, one could try to extrapolate the Sun's orbit backward around the Milky Way's center and try to locate stars with comparable orbits. As the birth cluster dispersed, some of the Sun's siblings — formed at the same time — would follow somewhat similar orbits. By identifying these stars, astronomers can trace their orbits back in time until they all come together at their mutual birthplace.

Simon Portegies Zwart (University of Amsterdam, the Netherlands) has started this work, calculating that the Sun has orbited the Milky Way's center 27 times since the galaxy's formation. Zwart then estimated that, based on the estimated size of the original cluster, about 10 to 60 of the Sun's siblings should still lie within 320 light-years of our solar system.



NASA / ESA / F. PARESCE (INAF-IASF) / R. O'CONNELL (UNIV. OF VIRGINIA) / WFC3 OVERSIGHT COMMITTEE

TOO CROWDED This Hubble Space Telescope image shows the dense cluster R136 in the heart of the Tarantula Nebula. This cluster contains too many massive stars to be a close analog of the Sun's birth environment.



PERTURBED ORBITS Many of the small bodies orbiting the Sun beyond Neptune have highly inclined and/or eccentric orbits. Theoretical calculations have shown that gravitational perturbations from a star passing no closer than 400 astronomical units of the newly formed Sun could have thrown these objects into these orbits. But fortunately, the star did not approach close enough to disrupt the inner solar system. These facts indicate that the Sun was born in a tightly packed cluster, but not too tightly packed.
S&T: GREGG DINDERMAN / SOURCE: CANADA-FRANCE ECLIPTIC PLANE SURVEY

Identifying these stars is a daunting task, to say the least. Not only are they difficult to distinguish from the millions of other stars in the sky, finding stars with the right orbits will unfortunately require far more precise measurements of stellar motions than those currently available. Only when the European Space Agency launches Gaia around 2013 will astronomers be able to begin locating these siblings (*S&T:* March 2008, page 36).

One way to narrow the search is to look for nearby *G*-type stars that also have a chemical make-up similar to the Sun's, since all the stars that formed in the same birth cluster should generally be alike chemically. Finding such solar twins is far less challenging and has been a major research effort for decades (*S&T:* July 2010, page 22).

M67: The Possible Birth Cluster

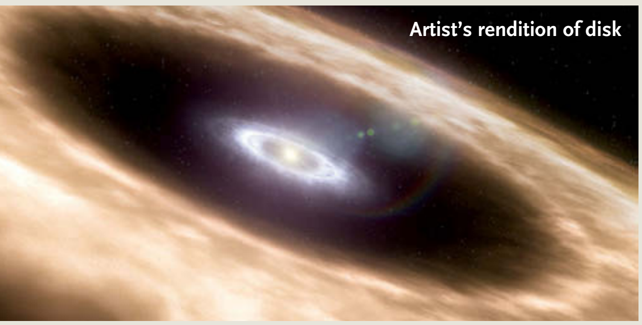
Surprisingly, this is where M67 has become a center of attention. Located in Cancer about 3,000 light-years away, this unusual open cluster has an estimated age of around 4 billion years, making it one of only a handful of open clusters in the Milky Way thought to be that old.

Despite its unusually high age, M67 is slowly dying. In its 17 estimated orbits around the galactic center, tidal forces have elongated the cluster and created a tail pointing perpendicular to the galactic center, while drawing off a significant percentage of its stellar population. All told, M67 is thought to have lost about 80% of its stellar mass since its formation, leaving it with about 1,400 stars today.

Open clusters normally disperse quickly — within

Planets Walk Crooked after Cloud Crashes

OUR SOLAR SYSTEM is quite orderly — all the planets orbit the Sun in the same direction and roughly the same plane — but the same doesn't always hold true for exoplanets. Some alien worlds follow highly elongated, tilted orbits or even revolve backward compared to their stars' rotations. These systems don't jibe with standard theories of planetary formation, which describe bodies coalescing from protoplanetary disks that spin the same way their stars do to conserve angular momentum as molecular clouds collapse. But such models deal with systems forming in isolation, and since most stars (including the Sun) are probably born in clusters, that scenario doesn't quite fit.



ESO

Following up on previous studies of what a cluster environment can do to forming planets, Ingo Thies (University of Bonn, Germany) and colleagues recently suggested that planets can form with off-kilter orbits if they suffer cloud fender-benders in crowded stellar nurseries.

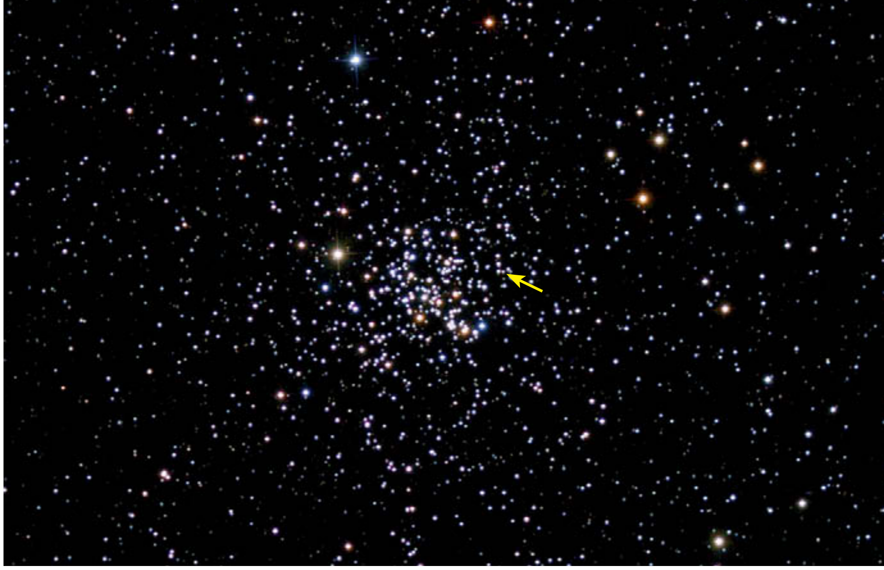
The team simulated how gas accretes onto protoplanetary disks around stars that interact with dense gas in the cluster. They found that the accreted gas forms an annulus that later combines with the existing protoplanetary disk, tilting the disk's inclination even to the point of retrograde (backward) rotation. Accretion can also create chemically distinct regions in the resulting disk and speed up planet formation by radially compressing the original material, increasing its density.

Planets that have already formed aren't immune to these effects, either. In a system modeled off the Sun's four outer planets, gas flowing toward the star crosses planetary orbits and causes the planets to migrate inward to between 0.5 and 4 astronomical units, the team found. Eccentric and unstable, the orbits don't last long and one or more planets are kicked out entirely, leaving the Jupiter-mass planet in a tight orbit around the star. Such interactions could explain the surfeit of hot Jupiters discovered in exoplanet searches.

Reality might not be so simple, notes Matthew Bate (University of Exeter, England). Existing planets could accrete new material and grow into higher-mass planets or even brown dwarfs. Simulations by Bate and his colleagues of accretion onto embryonic protostars also suggest that adding gas while the star is still forming can misalign a disk, too.

S&T *assistant editor* ***Camille M. Carlisle*** *authored last month's cover story on imaging black holes.*

POSSIBLE BIRTH CLUSTER M67's stars have a similar age and chemical composition as the Sun, leading to speculation that the Sun was once a member of this magnitude-6 open cluster in Cancer. The arrowed star is a near-identical solar twin. But M67 revolves around the galactic center in a more highly inclined orbit than the Sun, and it has probably orbited fewer times, casting serious doubt on this scenario. Nevertheless, M67 serves as an excellent stellar laboratory for studying the type of cluster in which the Sun was born. For a finder chart of M67, see page 45.



GREG PARKER / NOEL CARBONI

approximately 10 million years — but astronomers think M67 has survived for several billion years because it orbits the galactic center in a somewhat high-inclination trajectory, reducing the amount of time it's exposed to the dense regions in the galactic plane that could pull it apart. At the moment, M67 is 1,350 light-years above the plane, at what is thought to be its maximum galactic altitude.

M67 is also interesting because of its overall chemical composition. "The photometric and spectroscopic evidence as compiled so far indicates that the cluster has a very similar chemical abundance to that of the Sun," says Mark Giampapa (National Solar Observatory).

Because the cluster has an age and chemical abundances similar to the Sun, astronomers have used it as a laboratory for studying the Sun itself. For example, an earlier study by Giampapa of solar-like stars in M67 gave a rough statistical idea of the range of long-term magnetic activity for *G*-type stars such as the Sun (*S&T:* March 2009, page 35).

Similarly, in 2009 Gustafsson and a team of Swedish astronomers took a close look at a handful of solar-type stars in M67, picking one in particular for a detailed chemical analysis. They discovered that this star is more like the Sun than any previously studied near-solar twin. "That's astonishing, because when we compare the Sun to the most solar-like stars in the solar neighborhood, they're usually more different from the Sun than this solar twin is in M67," says Gustafsson.

The fact that M67 contains such a solar twin, and happens to also have an overall age and chemical composition similar to the Sun, is provocative. Also intriguing is that the cluster's size matched the expected size of the Sun's birth cluster rather well, both now and in the far past.

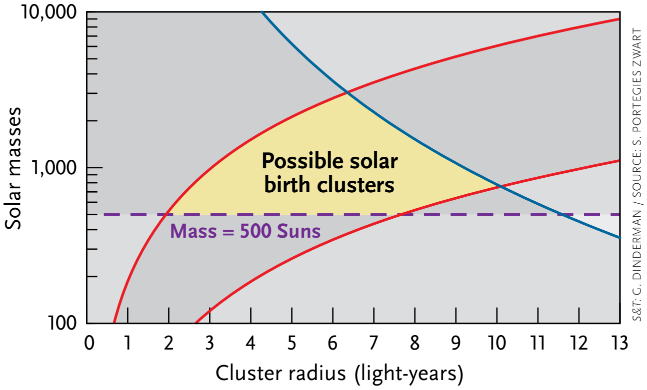
Finally, the cluster's orbit shares one similarity with that of the Sun. Though the Sun's orbit lies almost exactly in the galactic plane, whereas M67's orbit has a much higher inclination, if you were to look down at the galaxy from above, the orbits would look rather similar. In other words, some evidence suggests the unlikely possibility that the Sun once belonged to this now-distant cluster, and could even have been born there.

The Sun's Birth

Here's the possible scenario. About 4.5 billion years ago, M67 would have been embedded in a giant molecular cloud. The cluster contained many baby stars, including the Sun itself, as well as a handful of hot, supermassive *O* and *B* stars pumping energy into the cloud. The big guys eventually went supernova and threw short-lived isotopes into the mix. Then, in one of M67's seventeen passes through the galactic plane, the Sun would have drifted free; the gravitational force of nearby stars and clouds confined it to the galactic plane so its new orbit never rose more than 261 light-years above or below the galactic plane.

As alluring as this scenario may be, it remains a remote and unlikely possibility, even to Gustafsson. For one thing, the Sun has orbited the galactic center perhaps as many as 27 times, and M67 perhaps as few as 17. Moreover, the Sun and M67 have different orbital inclinations. If the Sun came from M67, its orbit was somehow yanked from M67's high-inclination orbit into a low-inclination orbit that matches the galactic plane nearly perfectly. "This seems a bit contrived," notes Gustafsson.

There are age discrepancies as well. Though age estimates for M67 can be as old as the Sun's 4.6 billion years,



S&T: G. DINDERMAN / SOURCE: S. PORTEGIES ZWART

CLUSTER CONSTRAINTS **Various factors limit the nature of the Sun's birth cluster. The Sun had to form within the red lines for the solar system to have its current configuration. Very-low-mass clusters below the purple line would not have produced a star as massive as the Sun. A cluster above the blue line would hold itself together during the Sun's lifetime. But this is not a stringent limit; the Sun could have formed in such a cluster and then escaped.**

NASA / C. R. O'DELL / S. K. WONG

NASA / ESA / J. BALLY (UNIV. OF COLORADO) / H. THROOP (SWRI) / C. O'DELL (VANDERBILT UNIV.) (4)

ORION NURSERY **The central region of the Orion Nebula (M42), imaged on the left in a Hubble Space Telescope mosaic, is one of the nearest star-forming regions. The Sun may have formed in a similar nebula, which contains several thousand young stars that are mostly low in mass. But several supermassive stars in the nebula's center (the Trapezium) will eventually go supernova. The most massive star, Theta^1 Orionis C, is literally destroying nearby protoplanetary disks (small images on the right) by blasting them with ultraviolet radiation. The small Hubble images of individual disks show tadpole-like tails pointing away from Theta^1 — the result of photoevaporation.**

more recent and accepted ages range from about 3.8 to 4 billion years. Because the Sun is about 4.6 billion years old, if these new age estimates are correct, M67 would not have yet existed when the Sun was born. But as Giampapa notes, "Cluster age estimates are often controversial." One recent study gives M67 an age range of 3.5 to 4.8 billion years, whereas another, based on a study of lithium abundances in solar twins, yields 3.21 to 4.42 billion years.

Also, star-forming giant molecular clouds are routinely found in the plane of the galaxy in its spiral arms. If M67 formed in one of these clouds, how did it end up having such a high-inclination orbit? "We basically don't know," says Adams. "That's an open question."

One far-out explanation is that M67 is the remnant of a captured dwarf galaxy. "I think it is possible," muses Gustafsson, "but there are many arguments against it. I would certainly not draw that conclusion on the basis of the existing data."

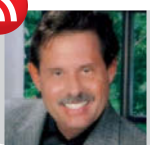
Finally, and most importantly, the Sun and its several thousand sibling stars from its birth cluster are just a tiny handful out of the 400 billion stars in the Milky Way. After 27 galactic rotations, these stars would have been scattered widely throughout the galaxy. To track them down and then extrapolate their orbits backward to M67 seems rather implausible, to say the least.

Even if M67 is not the Sun's birthplace, however, it remains an excellent laboratory for gleaning more information about the cluster where the Sun was born. "Even if the Sun did not come from M67," says Gustafsson, "the fact that the first M67 solar twin that we scrutinized, and possibly more of its solar-like stars, have a very similar composition to the Sun would tell us that maybe the Sun formed in a similar and dense environment."

A closer study of M67's other solar twins will allow astronomers to answer many questions about the formation of stars like our Sun. Moreover, a careful tally of M67's stellar population "would give us a census of what the Sun's original neighborhood was like," notes Giampapa. "How did nearby supernovae and novae and even very luminous stars influence the Sun as it formed?"

Such work would tell us how that neighborhood shaped our solar system and the planet we live on. It might tell us why our planet was conducive to the origin and development of life. It also might help us quickly find other similar systems, with their own planets, in a similar environment. In other words, study M67 and you might find out what the Sun's birthplace was like. And that in turn will tell us a great deal about why our solar system ended up as it did. ✦

Listen to a **BONUS AUDIO INTERVIEW**



To listen to an audio interview with astronomer Mark Giampapa of the National Solar Observatory, visit SkyandTelescope.com/Birthplace.

S&T contributing editor ***Robert Zimmerman*** *writes regularly about space, astronomy, politics, and history on his website,* ***http://behindtheblack.com****.*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A Different Pathway to the Stars

Astronomy outreach could benefit from the Czech approach: city-funded observatories.

Peter Foukal & Štěpán Kovář

Public access to telescope viewing in the U.S. and Canada is mainly through amateur groups and college observatories. But locating such venues and coordinating with their schedules can be difficult when a family wants to view the Moon or Jupiter on short notice. A recent trip to the Czech Republic showed me (PF) another pathway to the stars.

This small central-European nation has a unique network of 44 municipally financed public observatories. Currently, 24 of these are professionally staffed and offer lecture facilities, exhibit space, and even some planetariums. My Massachusetts town has trouble budgeting for a library, so how do small Czech towns manage to fit professional astronomers into their priorities?

The story began in the town of Pardubice, near Prague, where the enlightened local aristocrat Baron Arthur Kraus founded an observatory in 1912. Its fine 150-mm Merz refractor was used partly for regular solar observations, but its main aim was to provide astronomy instruction for the town's citizens.

The baron's enthusiasm encouraged the founding of the Czech Astronomical Society in 1917, and his observatory was a start. But the network's first major element was the Štefánik Observatory on Petřín Hill in Prague, built in 1928. This impressive structure, set in a beautiful park overlooking the capital, has always been a popular attraction for citizens and tourists. More than 33,000 annual visitors enjoy daily viewing of the Sun and nighttime celestial sights through its four main telescopes, which include a

This page: The public observatory in Vsetín (population about 29,000) was built in 1950. Its main equipment is a pair of co-mounted Zeiss refractors of 200- and 130-mm aperture (*facing page*). About 8,000 visitors each year, including many students, attend open nights and talks.

EMIL BŘEZINA

pair of co-mounted 200- and 180-mm Zeiss refractors.

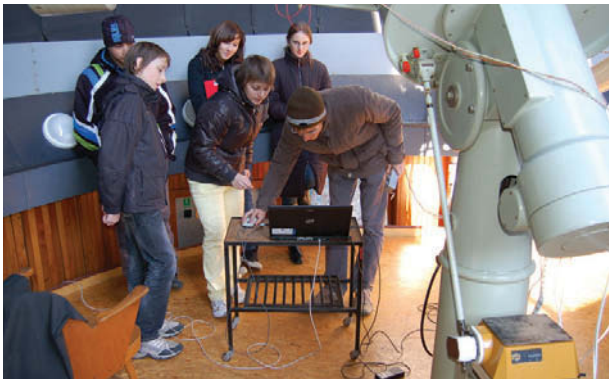
Another facility was founded in České Budějovice in 1937, which was followed by one in 1938 in the smaller town of Tábor. These early installations provided easy access to the wonders of the night sky for everyone, and they also served as a nucleus for amateur clubs. Between the two World Wars, Czechoslovakia was an industrialized democracy and astronomy was recognized as an important element in the education of its citizens.

But most of the observatories were built after World War II. The communist government thought that astronomy instruction would help combat the Church's influence. It didn't, but the idea provided funding that helped build Czech amateur astronomy. After 1948 the number of observatories grew rapidly. Once Sputnik was launched, amateur-astronomer tracking of Soviet satellites provided another funding source.

To achieve success, observatories need to be staffed by competent and enthusiastic personnel. My recent visit during a regular evening viewing session impressed me. Besides our group, two families with small children listened intently in the dark dome as the astronomer on duty showed lovely views of Epsilon Lyrae, M13, and a comet. He explained the separation of the Double Double's close components, the likelihood of collisions between the globular's densely packed stars, and the probable origin of the periodic comet. The children asked good questions. This memorable evening cost about $1 per person.

The backgrounds of the observatory staff range from undergraduate astronomy majors to Ph.D. astronomers. So this network provides a significant source of employment for university astronomy graduates. Some amateur programs in turn produce research candidates. One of them, Kamil Hornoch, won the Astronomical Society of

EMIL BŘEZINA



LIBOR LENZA

High-school students study the Sun with the 150-mm Zeiss coudé refractor at the public observatory in Valašské Meziříčí. The 11 staff members welcomed 26,000 visitors in 2011.

the Pacific's 2006 Amateur Achievement Award for his discoveries of dozens of novae in other galaxies. He's now a professional astronomer.

In parallel with the public observatory network, Czech amateurs maintain scores of private observatories, many involved in vigorous research programs. For example, the Czech Astronomical Society's Section on Variable Stars and Exoplanets maintains the international database on exoplanet transit observations. Members also account for about 20% of the worldwide observations of such transits. Other Czech amateurs have contributed significantly to studies of the apsidal motion of close binaries.

I (PF) built my own small observatory in a seaside community near Boston, where hundreds of visitors have enjoyed viewing. Examining the Sun, Moon, or planets through an eyepiece provides a sense of drama and immediacy not matched by viewing Hubble images on a computer screen. I have boxes of enthusiastic letters from schoolchildren to prove it. So why are there so few municipal observatories in the U.S.?

The mistaken belief that astronomy is impossible from light-polluted towns is partially to blame. Many do not realize that the best objects for small telescopes can be viewed perfectly well even from downtown Manhattan. Inadequate funding is another often-cited barrier. But many suburban taxpayers accept $50-million price tags for high schools with elaborate athletic facilities.

Would it be unreasonable to build a $49-million high school and set aside $1 million to build and endow the operation of a professionally staffed community observatory? It's a matter of priorities. Czech schools rank above their American counterparts in international comparisons of science and math skills. ✦

***Peter Foukal** is a solar physicist whose publications include cover articles in* Nature, Science, *and* Scientific American. *He is currently preparing the third edition of his graduate text* Solar Astrophysics. ***Štěpán Kovář** is a software and systems engineer with IBM in Prague. He is past president of the Czech Astronomical Society.*

New Product Showcase

▼ **IMAGING ON AUTOPILOT** CCDWare announces the latest iteration of its popular imaging control program, *CCDAutoPilot 5.0* (Basic package: $95, Professional edition: $295). This PC program automates all aspects of CCD astrophotography for an entire evening's activities with a user-friendly point-and-click interface. Not only does the program control your camera and telescope mount, it can also control electronic focusers, instrument rotators, observatory domes, and weather sensors. More than just an imaging automation program, *CCDAutoPilot 5.0* provides tools to measure key imaging system parameters, such as exposure offsets for color filters, and even suggests guiding parameters to produce the best images possible. See the website for additional details and register to download a free 60-day trial of *CCDAutopilot 5.0* Professional edition.

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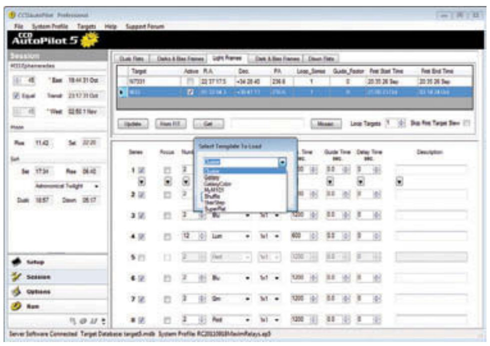

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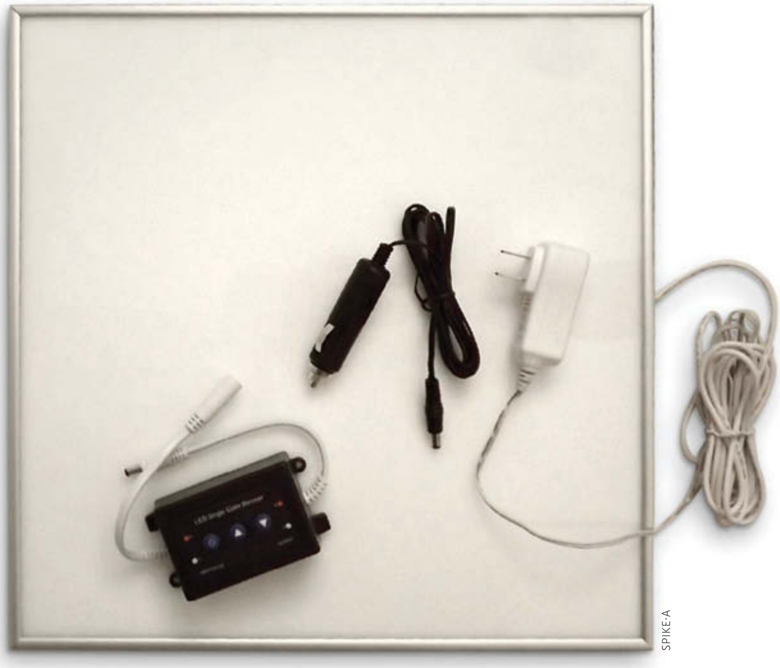
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▲ **INSTANT FLAT-FIELDS** The new Spike-a Flat Fielder ($199.95) makes recording flat-field calibration frames a snap. This acrylic panel uses edge-lit LED lights with multiple layers of diffusion material to achieve uniform illumination of approximately 1% variation on telescopes up to 12 inches. It works with both CCD and DSLR cameras to remove vignetting and dust motes from your raw images. Each unit comes complete with a 110-to-12-volt DC power adapter, a 12-volt cigarette-lighter adapter, and an LED dimmer control box. Larger custom sizes are also available.

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SBIG OFF-AXIS GUIDER SBIG announces an accessory that adds self-guiding to its popular ST-8300 CCD camera. The new OAG-8300 Wide Field Off-Axis Guider ($1,495) uses a 7-element relay lens system that places the guide camera to the side of the main imaging camera and filter wheel while adding only ¾ inch (19 mm) of back focus to the entire imaging package. The unit attaches in front of the filter wheel and also acts as a 0.7× focal reducer that effectively doubles the guide camera's field of view. The guide-camera attachment can also be rotated in 90° increments. Designed specifically to work with SBIG's new ST-i Planet Cam and Autoguider, you'll need to verify its compatibility with other guiding cameras. Special limited introductory price: $995.

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Multitudes of Stars

Which constellations contain the most naked-eye stars?

GREAT ASTRONOMICAL BRIGHTNESS is a wonderful thing — just take a look at the majestic spectacle of Venus and Jupiter approaching each other in early March (see page 48). And dazzling Sirius is always a joy to behold when it's high in a dark sky.

But now I want to talk about Sirius when it's struggling to appear through bright twilight and even daylight. Then we'll let twilight fade, seek a dark sky, and appreciate the beauty of fainter stars — in large numbers.

AKIRA FUJII

The numerous faint stars of the Milky Way run left of dazzling Sirius into northwestern Puppis, which fills the left side of this photo.

Sirius before sunset. As long as you know exactly where to look, Venus is easy to see with your unaided eyes in broad daylight when it's near peak brightness and high above the afternoon Sun — as it is this spring.

But how many people have seen stars with their unaided eyes while the Sun is above the horizon? The eagle-eyed 19th-century astronomer J. F. J. Schmidt reported seeing zero-magnitude stars several minutes before sunset. And one sharp-visioned friend of mine has seen Arcturus right at sunset.

Sirius shines at magnitude –1.4. Can someone with typical vision see it without optical aid in daylight? I've succeeded a few minutes before sunset, locating it first in a finderscope and then lining it up with a treetop. If sky conditions are good, why don't you try for yourself?

Of course the best time to try this observation is when Sirius is near the sky's meridian, the highest it gets. When does Sirius stand on the meridian at sunset for observers around latitude 40° north? Near the end of March.

Bright stars versus many stars. We know that March evenings are a time of bright stars. Most of the stars that shine at 1st magnitude or brighter are in the western sky in the departing constellations of winter. But the spring stars Regulus and Arcturus are in the east — soon to be joined by Spica.

Now, however, let's imagine we're at a site with a dark sky. Instead of thinking about brightness, let's turn to number. Which constellation has the most stars fairly easy to see with the unaided eye?

The practical answer for observers at mid-northern latitudes would be rich Orion and Taurus, which both have 60 stars brighter than magnitude 5.25. But suppose we were far enough south to see certain constellations high above the horizon, so that they weren't significantly dimmed by atmospheric extinction. Which constellation would have the most stars brighter than our limit?

The answer is Centaurus, with 79. But none of Centaurus is above our map's horizon now. Neither is Cygnus, tied for second in the ranking with 70 stars. But Puppis, the other number-two constellation, is now at its highest due south, with most of its stars above the horizon at latitude 40° north.

The river continued. Last month I discussed the celestial river Eridanus, which is well placed for observation at nightfall if you're reading this in February or late January. Only four of Eridanus's stars are brighter than magnitude 3.5 — not much for a stream 130° long. (That estimate of its winding length comes from the great early-20th-century astronomy writer William T. Olcott.)

But in our ranking by number of easily visible stars, Eridanus comes in fourth, ahead of admittedly smaller Orion and Taurus. There are 61 stars brighter than magnitude 5.25 in Eridanus. ✦

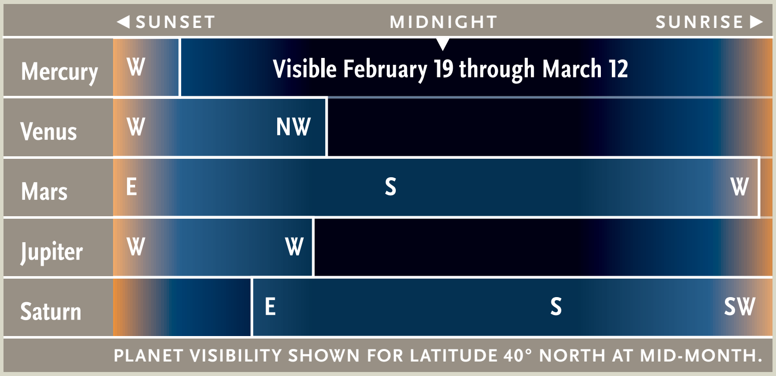
Fred Schaaf welcomes your comments at fschaaf@aol.com.

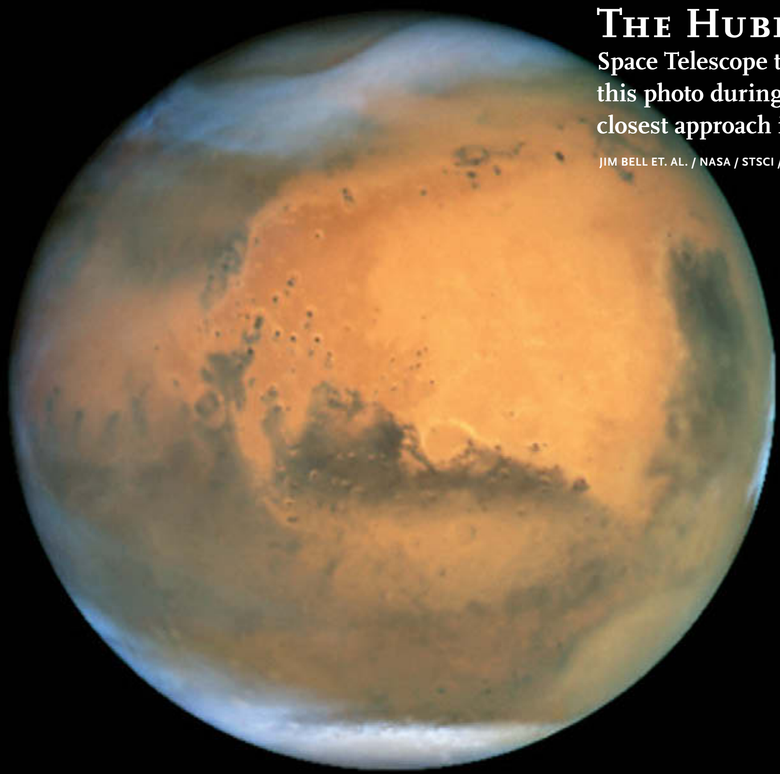
March 2012

MOON PHASES

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

PLANET VISIBILITY





The Hubble Space Telescope took this photo during Mars's closest approach in 2003

JIM BELL ET. AL. / NASA / STSCI / AURA

Feb. 25 – Mar. 3 DUSK: The six or seven brightest objects in the night sky are all visible 45 minutes after sunset from mid-northern latitudes; see page 48.

Feb. 28 – Mar. 10 DUSK: Mercury is at least 10° above the western horizon a half hour after sunset.

Mar. 1–8 ALL NIGHT: Mars shines its biggest and brightest for this year. It's at opposition (opposite the Sun in the sky) on March 3rd and closest to Earth on the 5th. See the November issue, page 50, for a guide to observing Mars through a telescope.

6, 7 EVENING: The Moon hangs right of Regulus on the 6th and well to Mars's lower right on the 7th.

8 FULL MOON (4:39 a.m. EST).

10 LATE EVENING: The Moon forms a nice triangle with Spica and Saturn once they're well up by 10 or 11 p.m.

10–24 EARLY EVENING: Look for the zodiacal light starting about 80 minutes after sunset from dark locations at mid-northern latitudes. It's a huge pyramid of light in the western sky passing through Venus, Jupiter, and the Pleiades.

11 DAYLIGHT-SAVING TIME begins at 2 a.m. for most of the U.S. and Canada.

12, 13 EVENING: Venus and Jupiter pass each other just 3° apart; see page 48.

14 LAST-QUARTER MOON (9:25 p.m. EDT).

20 SPRING BEGINS in the Northern Hemisphere at the equinox, 1:14 a.m. EDT (10:14 p.m. on the 19th PDT).

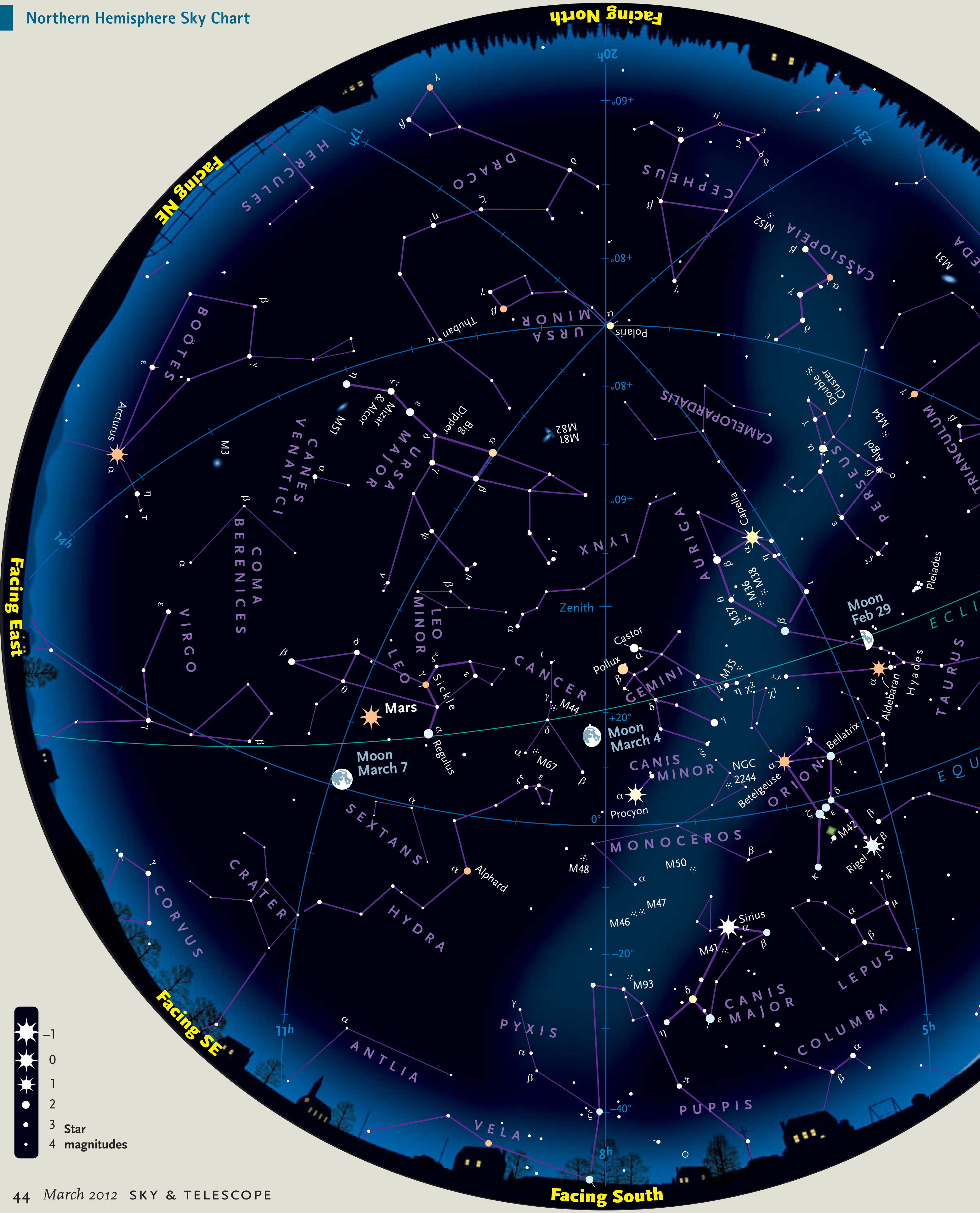
22 NEW MOON (10:37 a.m. EDT).

23 DUSK: A very thin crescent Moon should be visible from North America 8° to 10° above the western horizon a half hour after sunset. Keep it in view as the sky darkens and the Moon sinks toward the horizon.

25–27 DUSK: The waxing crescent Moon is near Jupiter on the 25th, near Venus and the Pleiades on the 26th, and right of Aldebaran on the 27th; see page 49.

30 FIRST-QUARTER MOON (3:41 p.m. EDT).

See SkyandTelescope.com/ataglance for details on each week's celestial events.


Facing North
Facing NE
Facing East
Facing SE
Facing South
20h
17h
23h
14h
11h
8h
5h
+60°
+80°
+60°
+40°
+20°
0°
–20°
–40°
Zenith
DRACO
HERCULES
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M3
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M51
M81
M82
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M31
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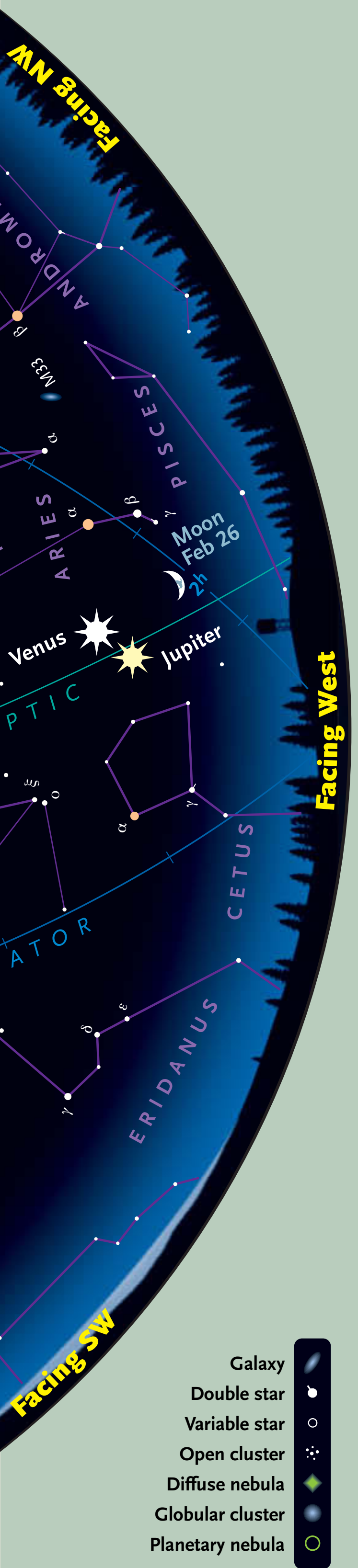
Double Cluster
M34
Algol
PERSEUS
TRIANGULUM
LYNX
AURIGA
Capella
M36
M37
M38
Pleiades
Moon Feb 29
ECLIPTIC
TAURUS
Hyades
Aldebaran
COMA BERENICES
VIRGO
LEO MINOR
LEO
Sickle
Regulus
Mars
CANCER
M44
M67
Castor
Pollux
GEMINI
M35
Moon March 4
Moon March 7
CANIS MINOR
Procyon
NGC 2244
Betelgeuse
Bellatrix
ORION
EQUATOR
M42
Rigel
MONOCEROS
M50
M48
SEXTANS
HYDRA
Alphard
CRATER
CORVUS
M47
M46
Sirius
M41
CANIS MAJOR
M93
LEPUS
COLUMBA
PYXIS
ANTLIA
PUPPIS
VELA
–1
0
1
2
3
4
Star magnitudes



Using the Map

WHEN

Late January	Midnight
Early February	11 p.m.
Late February	10 p.m.
Early March	9 p.m.
Late March	Dusk

These are standard times.

HOW

Go outside within an hour or so of a time listed above. Hold the map out in front of you and turn it around so the yellow label for the direction you're facing (such as west or southeast) is at the bottom, right-side up. The curved edge is the horizon, and the stars above it on the map now match the stars in front of you in the sky. The map's center is the zenith, the point overhead. Ignore all parts of the map over horizons you're not facing.

Example: Rotate the map a little so that "Facing SW" is at the bottom. Nearly halfway from there to the map's center is the constellation Orion. Go out, face southwest, and look halfway up the sky. There's Orion!

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

Watch a SPECIAL VIDEO

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

Binocular Highlight: The Crab's Treasures

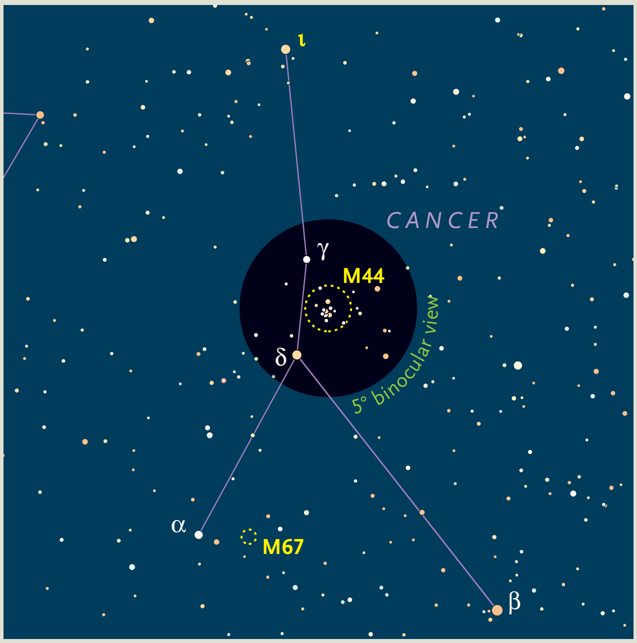
Cancer is such an indistinct constellation that you would hardly expect it to house a pair of Messier objects and an attractive binocular double. Yet that's exactly what we find within its crabbed confines.

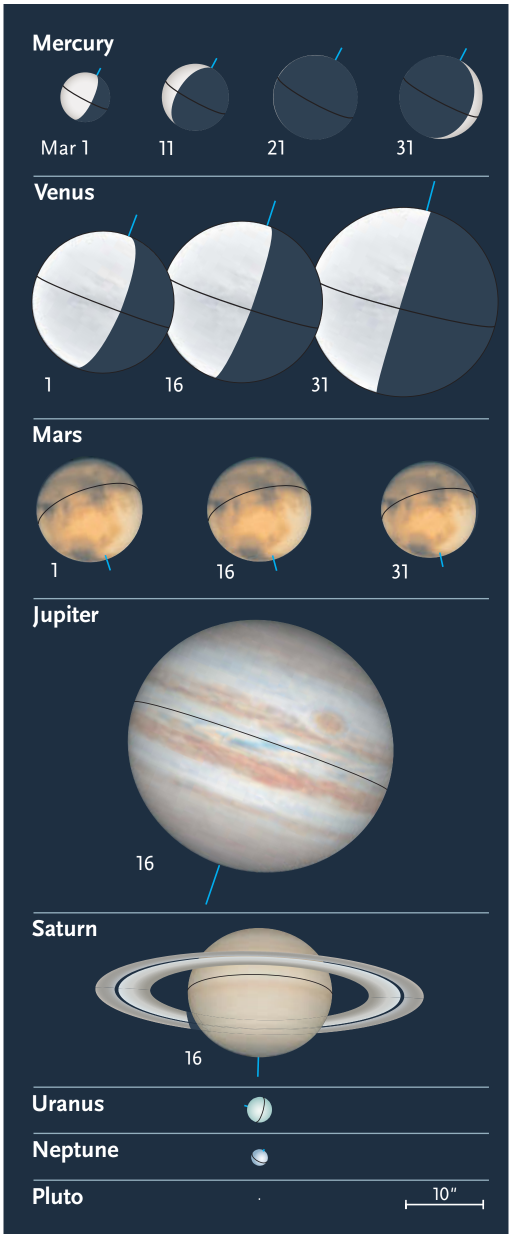
Among the many Messier open clusters, only the Pleiades (M45) are more striking than the Beehive, **M44**. The cluster is plainly visible to the unaided eye under moderately dark skies, and it's a treasure in binoculars of any size. I find the view in my 10×50s to be particularly pleasing — the magnification is sufficient to break open the main grouping, while the field of view is expansive enough to include nearby Gamma (γ) and Delta (δ) Cancri. M44's heart is a quartet of stars shaped like a miniature version of the constellation Corvus. These are bracketed by stellar arcs to the north and south, and in all I count roughly two dozen prominent stars, mostly ranging from 6th to 8th magnitude.

South of M44, and only 2° west of Alpha (α) Cancri, lies **M67** (see page 36). Not exactly a showpiece, M67 is nonetheless an easy binocular find. My 10×50s show it as an elongated haze oriented northeast to southwest. The northeast extremity is marked by a prominent 7.9-magnitude foreground star, while the southeast edge of the cluster is reinforced by an unresolved mass of somewhat brighter cluster stars. I was never able to convincingly resolve M67, though it definitely has a grainy appearance.

Finally, the Crab offers up a pleasing binocular double. **Iota Cancri** consists of a 4th-magnitude primary and 6th-magnitude secondary with a scant 31″ between them. I'm able to split the duo with my 10×50s, but the disparate brightness of the component stars makes this a challenge. ✦

— *Gary Seronik*



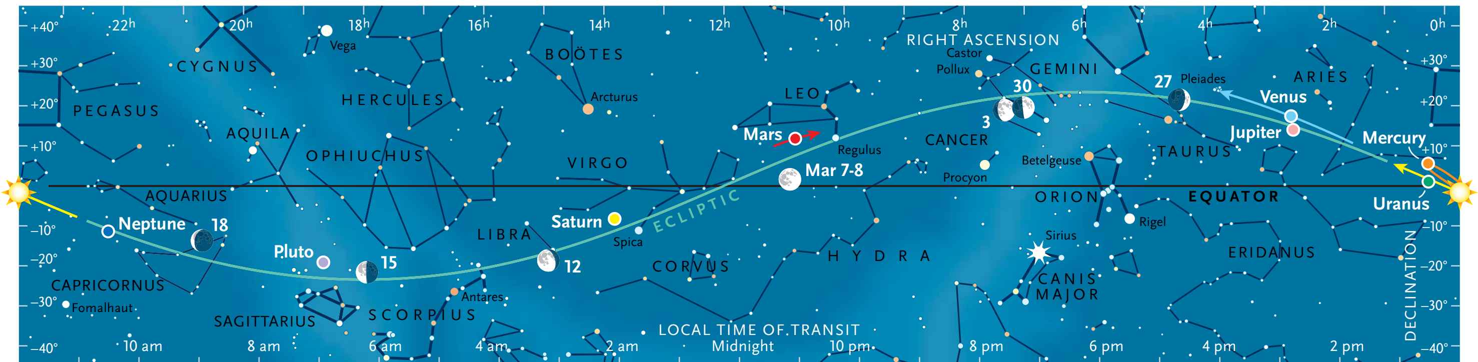


Sun and Planets, March 2012

	March	Right Ascension	Declination	Elongation	Magnitude	Diameter	Illumination	Distance
Sun	1	$22^h\ 48.5^m$	–7° 35′	—	–26.8	32′ 17″	—	0.991
	31	$0^h\ 38.6^m$	+4° 10′	—	–26.8	32′ 01″	—	0.999
Mercury	1	$23^h\ 50.7^m$	–0° 11′	17° Ev	–0.9	6.4″	66%	1.043
	11	$0^h\ 19.3^m$	+5° 18′	16° Ev	+0.8	8.7″	23%	0.774
	21	$0^h\ 02.4^m$	+3° 56′	4° Ev	—	10.9″	1%	0.614
	31	$23^h\ 38.2^m$	–1° 00′	16° Mo	+2.3	10.8″	11%	0.623
Venus	1	$1^h\ 30.7^m$	+10° 36′	44° Ev	–4.3	18.4″	64%	0.907
	11	$2^h\ 11.9^m$	+15° 13′	45° Ev	–4.3	20.0″	59%	0.833
	21	$2^h\ 52.8^m$	+19° 17′	46° Ev	–4.4	22.0″	54%	0.757
	31	$3^h\ 33.0^m$	+22° 39′	46° Ev	–4.5	24.5″	49%	0.680
Mars	1	$11^h\ 09.8^m$	+9° 56′	174° Mo	–1.2	13.8″	100%	0.676
	16	$10^h\ 47.8^m$	+11° 53′	163° Ev	–1.1	13.7″	99%	0.685
	31	$10^h\ 31.5^m$	+12° 53′	144° Ev	–0.7	12.6″	97%	0.740
Jupiter	1	$2^h\ 19.4^m$	+12° 54′	56° Ev	–2.2	36.1″	99%	5.466
	31	$2^h\ 43.0^m$	+14° 53′	32° Ev	–2.1	34.0″	100%	5.804
Saturn	1	$13^h\ 51.3^m$	–8° 35′	132° Mo	+0.4	18.4″	100%	9.022
	31	$13^h\ 44.9^m$	–7° 54′	163° Mo	+0.3	19.0″	100%	8.757
Uranus	16	$0^h\ 15.2^m$	+0° 54′	8° Ev	+5.9	3.3″	100%	21.057
Neptune	16	$22^h\ 14.4^m$	–11° 30′	24° Mo	+8.0	2.2″	100%	30.904
Pluto	16	$18^h\ 39.0^m$	–19° 14′	76° Mo	+14.1	0.1″	100%	32.415

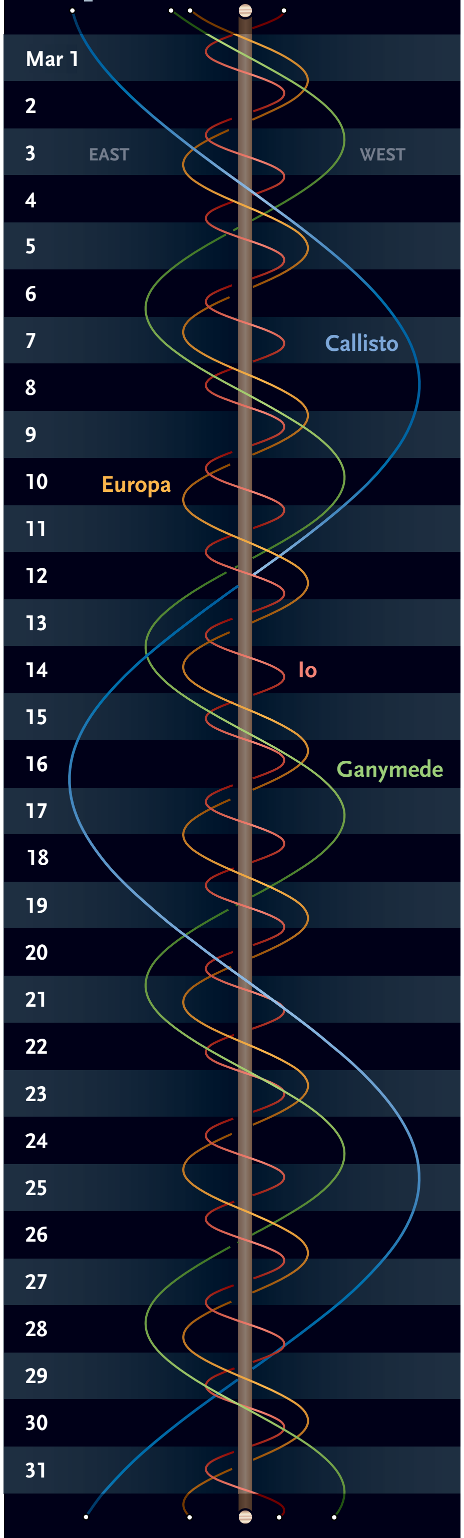
The table above gives each object's right ascension and declination (equinox 2000.0) at 0^h Universal Time on selected dates, and its elongation from the Sun in the morning (Mo) or evening (Ev) sky. Next are the visual magnitude and equatorial diameter. (Saturn's ring extent is 2.27 times its equatorial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

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



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

Jupiter's Moons



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.

A Great Month for Planets

All five classical planets are prominent on March evenings.

The first half of March is an amazing time for viewing planets. Nightfalls feature Venus and Jupiter, the two brightest, passing each other high in the west. Mercury has a superb greatest elongation below them early in March, right when Mars is at opposition and closest approach. And Saturn rises to join the action later in the evening.

From February 25th through March 3rd, the six or seven brightest objects in the night sky are visible 45 minutes after sunset at mid-northern latitudes. In addition to the Moon, these include Mercury, Venus, and Jupiter in the west, Mars in the east, and Sirius in the south-southeast. And if you live below latitude 35° north, you can also see Canopus, the seventh-brightest object, low in the south.

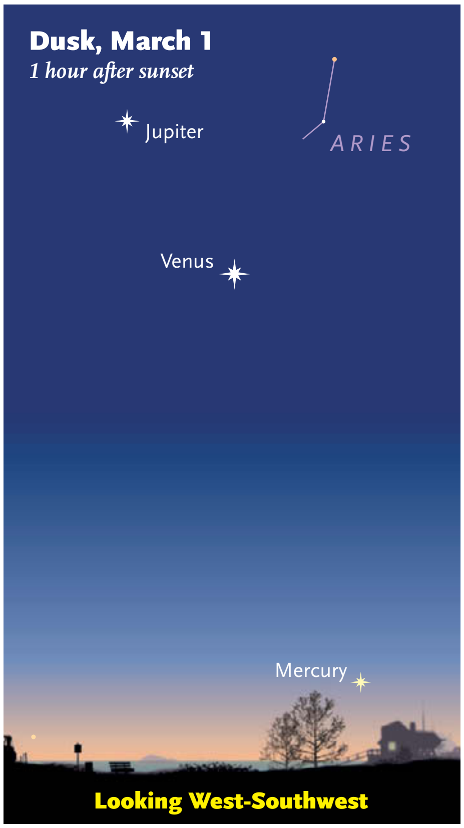
Dusk

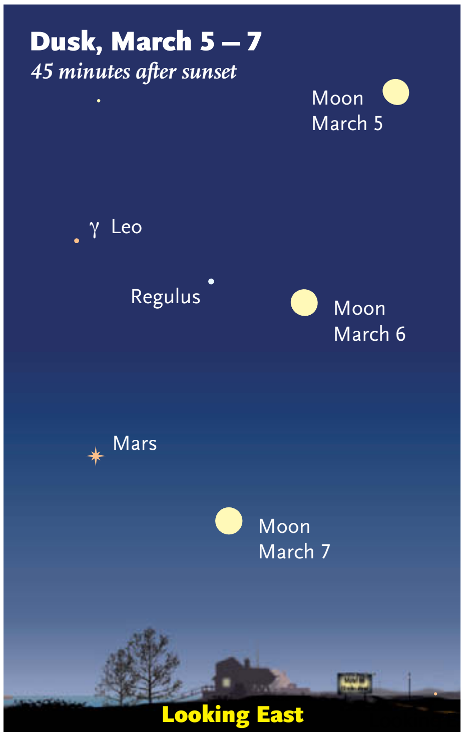
Mercury is the lowest and farthest west in early March's parade of bright planets. Start looking for it a half hour after sunset about 30° below and a little to the right of already-bright Venus. On March 4th, Mercury reaches a greatest elongation of 18° almost directly above the Sun and doesn't set until the sky is fully dark. But Mercury fades very rapidly after that, dimming from magnitude –0.5 to +0.5 in just 5 days. By March 13th it's magnitude +1.9, too faint to see in bright twilight without optical aid.

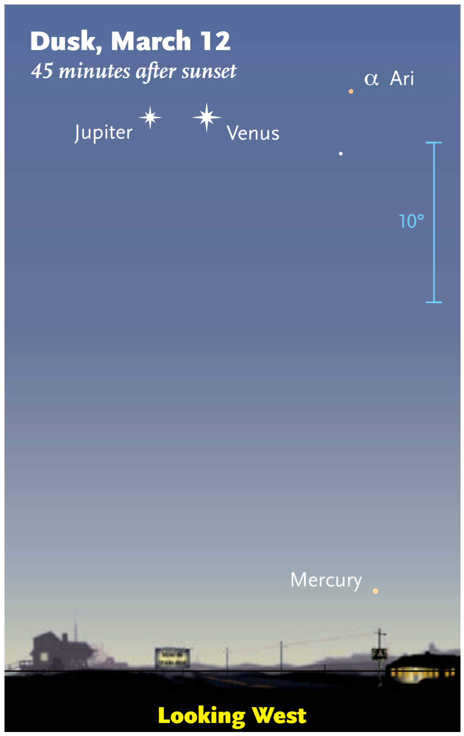
Dusk and Evening

Venus and **Jupiter** form a spectacular pair in the west all month from sunset until mid-evening or later. As March opens, Jupiter (magnitude –2.2) shines 11° upper left of blazing Venus (magnitude –4.3). They're a good third of the way up the sky in late twilight.

By March 9th the gap between these two brightest planets shrinks to less than



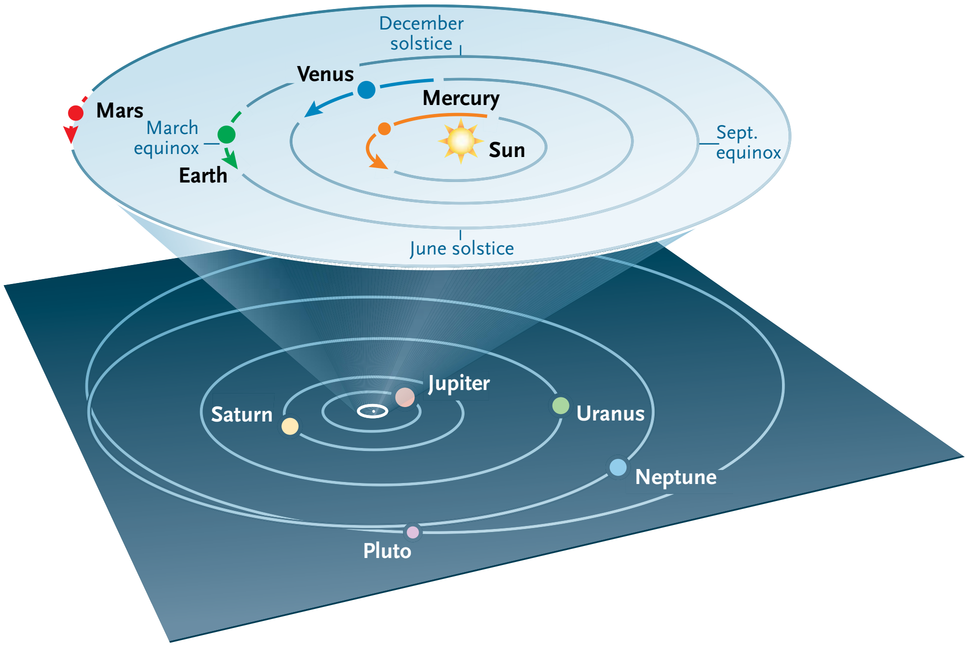




These scenes are drawn for near the middle of North America (latitude 40° north, longitude 90° west); European observers should move each Moon symbol a quarter of the way toward the one for the previous date. In the Far East, move the Moon halfway.

ORBITS OF THE PLANETS

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

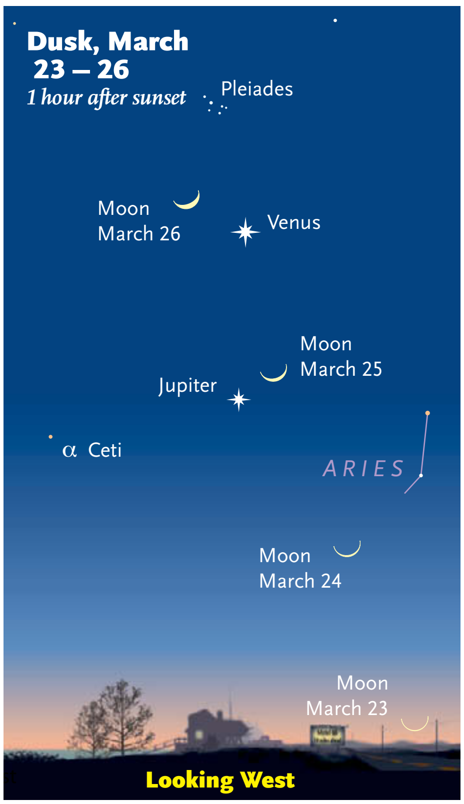


5°. Observers in the Americas see them about 3° apart from March 12th through 14th. The lustrous duo doesn't set until almost 4 hours after the Sun. Telescopes show Jupiter 35″ wide and the 58%-illuminated disk of Venus 20″ wide.

While Jupiter appears ever lower, fainter, and smaller during March, the opposite is true of Venus. On the American evening of March 26th, Venus reaches its greatest elongation of 46° east of the Sun. It shines well over 40° above the horizon at sunset for most of the U.S. This is Venus's highest showing of its entire 8-year apparition cycle.

DUSK TO DAWN

Mars comes to opposition with the Sun on March 3rd and so rises in the east as the Sun sets. Fire-colored Mars glares at magnitude –1.2 in early March, just a little dimmer than Sirius. Due to its markedly elliptical orbit, Mars is closest to Earth on March 5th, two days after opposition. Mars is then 63 million miles from Earth, and its disk appears 13.9″ wide.



Opposition occurs shortly after Mars reaches aphelion (February 15th), its farthest from the Sun in space. So this is the most distant Mars opposition since 1995 — though only slightly farther than the oppositions of 2010 and 2014.

Mars's small apparent size makes it all the more important to observe the planet when it's high in the sky: around the middle of the night. See page 50 of the November issue for a Mars guide.

Mars burns in south-central Leo, chasing fainter Regulus across the sky each night. Mars's swift retrograde (westward) motion helps it rapidly gain ground on Regulus. The gulf between the two dwindles from 15° to 5½° during March.

Saturn rises about 4 hours after sunset on March 1st but only about 1 hour after the Sun on March 31st. Like Mars, Saturn is retrograding toward a 1st-magnitude star — in this case, Spica. But Saturn, being far from the Sun and slow-moving on the sky, only narrows this gap from 7° to 6° during March. Saturn brightens marginally, from magnitude +0.4 to +0.3, and telescopes show its disk growing to 19″ and its rings narrowing slightly.

Uranus, and **Neptune** are too close to the Sun to observe in March. **Pluto** is marginally observable just before dawn.

MOON AND SUN

The **Moon** is near Regulus on March 6th, near Mars on March 7th, and forms a line and triangle with Spica and Saturn on March 10th and 11th. The waxing lunar crescent is strikingly close to the upper right of Jupiter at nightfall in eastern North America on March 25th. On the 26th, when Venus reaches its greatest altitude, the Moon hangs to Venus's upper left with the Pleiades above.

The **Sun** arrives at the March equinox at 1:14 a.m. EDT on March 20th (10:14 p.m. on the 19th PDT). This is when the Sun crosses the equator heading north for the year, marking the start of spring in the Northern Hemisphere and autumn in the Southern Hemisphere. ✦

To see what the sky looks like at any given time and date, go to SkyandTelescope.com/skychart.

Enigma of the Ashen Light

Help astronomers solve this enduring mystery of Venus.

For more than three centuries, many telescopic observers have reported a faint glow emanating from the nightside of Venus. One of the oldest unsolved riddles in planetary astronomy, the so-called *ashen light,* is puzzling because this cloud-shrouded planet has no satellite capable of reflecting sunlight to illuminate its nightside the way that sunlight reflected by Earth produces the appearance of "the old Moon in the new Moon's arms."

There is a common link, however, between earthshine on the Moon and the ashen light of Venus. They are both phase-dependent and only become conspicuous at large phase angles. The ashen light is seldom reported when Venus is more than 30% illuminated and is usually seen only when the crescent phase is viewed against a dark sky. At such times Venus must be viewed at a rather modest altitude above the horizon, so image quality is almost invariably impaired by atmospheric turbulence.

Although some observers have described the color of the ashen light as purple, blue, and even green, reports of a warm, ruddy hue are far more common. Visual perceptions of the color of faint light sources are notoriously unreliable. A pronounced shift in the sensitivity of the dark-adapted eye toward the blue end of the spectrum, known as the *Purkinje effect*, causes a faint source of red light (such as the glowing ember of a distant cigarette) to be perceived as green. Most observations of the ashen light using color filters suggest that it really is brightest in the red region of the spectrum.

The appearance of the ashen light of Venus is frequently compared to earthshine on the crescent Moon. The apparent surface brightness of the sunlit lunar crescent is about 2,500 times greater than the earthlit portion of the Moon. The intensity of sunlight reflected by the cloud canopy of Venus is about 60 times stronger than the reflected light of the crescent Moon, producing intense glare that makes observing the planet's adjacent nightside extremely challenging.

Many authorities dismiss the ashen light as an optical illusion. Skeptics find it hard to believe that the phenomenon has not been recorded in images or spectrograms obtained with large Earth-based telescopes, let alone by the various spacecraft that have orbited Venus.

It cannot be denied that the human eye–brain combination has an insidious tendency to fill in or complete the figure of a crescent. Prospective observers of the ashen light have been strongly encouraged to eliminate this visual cue by hiding the crescent behind an occulting bar inserted at the focal plane of an eyepiece. Malleable 15-amp fuse wire is the ideal material for constructing such a device because it's easy to form a semicircular kink that matches the curve of the planet's terminator.

Your telescope can also be a source of deception. The dazzling brilliance of Venus's sunlit crescent severely taxes the color correction of achromatic refractors. The French astronomer André Danjon cautioned that the purple halo of chromatic aberration can convincingly mimic the appearance of the ashen light. Nor are reflectors immune. Light diffracted by the spider supports of the secondary mirror of a Newtonian or Cassegrain reflector can also produce the appearance of a glow on the planet's nightside.

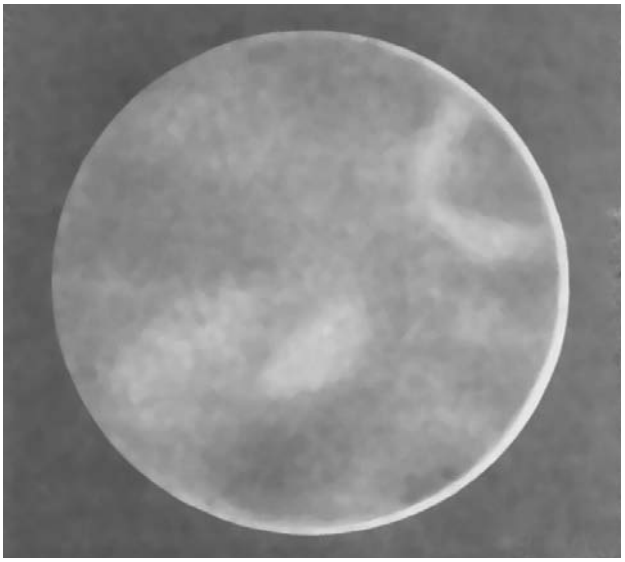
Veteran Venus observers such as Richard Baum have characterized the ashen light as "a rare phenomenon, seen with difficulty and even then uncertainly." An exhaustive review of the British Astronomical Association's observational archives, which span more than a century, has led Richard McKim, director of the British Astronomical Association's Mercury and Venus Section, to conclude that the phenomenon is real but only appears sporadically:

> *Sometimes the ashen light is visible for many days in succession, as in 1940, 1953, 1956, and 1957. At other times, despite excellent observing conditions, it remains elusive... Its visibility must therefore depend upon conditions in the Venusian atmosphere rather than upon the altitude of Venus in terrestrial skies.*

Although most accounts of the ashen light describe a uniform, structureless glow, some observers have remarked on its patchy or mottled appearance. In 1949 three experienced observers in the United States independently reported that only one-third of "the dark face glowed over an area in the form of a biconvex lens, with

The waxing crescent Moon, Venus, and Jupiter made a dramatic spectacle in the evening twilight of December 1, 2008. This year, Northern Hemisphere observers will be treated to the best spring apparition of Venus since 2004. The month preceding June's transit will be an unusually favorable opportunity to observe the ashen light.

S&T: DENNIS DI CICCO



The ashen light is often described as a uniform glow emanating from the nightside of Venus. However, many observers have reported an irregular, dappled appearance similar to this 1932 drawing by Robert Cheveau using 7 ½-inch refractor.

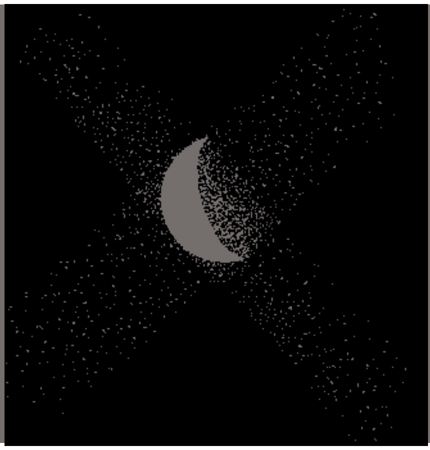
one surface along the terminator and the other some way within the dark limb." Several observers at widely separated locations in Britain independently reported that the ashen light was unusually conspicuous on the evening of March 17, 1953. One commented on its "slightly brownish, mottled" aspect, while another was struck by the "filmy, granular look" of a "coppery" glow that he suspected might be caused by "a confusion of tiny bright spots." Others have described wavy arcs of light and random scatterings of bright dots. These reports of structure are difficult to reconcile with the notion that the ashen light is invariably an optical illusion.

If the ashen light is a real but transient phenomenon, what mechanism could produce it? Prior to 1962 the glow of intense auroral displays seemed to be the most plausible explanation. Terrestrial auroral displays occur when charged particles emitted by the Sun are captured by the Earth's magnetic field and interact with rarefied gases high in the atmosphere. It was widely suggested that the closer proximity of Venus to the Sun would subject it to almost twice the flux of solar corpuscular radiation, but in 1962 the Mariner 2 spacecraft revealed that Venus lacks an appreciable magnetic field. In any event, there doesn't appear to be any correlation between the reports of the ashen light and the level of solar activity or solar-wind events.

Others have suggested that the ashen light might be an analog of the terrestrial airglow or permanent aurora that occurs at extremely high altitudes in Earth's atmosphere. This phenomenon occurs when atoms ionized by solar radiation during the day slowly release radiant energy throughout the night as they return to their ground states. Instruments aboard the Russian Venera 9 and Venera 10 orbiters detected a glow in the visible region of the spectrum on the nightside of Venus emitted when single atoms of oxygen recombine to form diatomic molecules of oxygen. Although this oxygen airglow fluctuates in brightness by a factor of three, it has been estimated that even at its brightest it is about 40 times too faint to be visible through a telescope of modest aperture.

A far more intense and even more variable oxygen airglow is emitted at a wavelength of 1.27 microns in the near-infrared. Almost a thousand times stronger than the visible-wavelength oxygen airglow, this emission has been studied with large ground-based telescopes equipped with sensitive infrared detectors. The brightest sources at this wavelength are well-defined patches measuring 1,000 to 2,000 kilometers in diameter. At the opposite end of the spectrum, sudden, dramatic brightening of Venus's night side at far-ultraviolet wavelengths was detected on several occasions by NASA's Pioneer Venus Orbiter during the 1980s. However, neither the near-infrared nor the far-ultraviolet emissions would be visible to the human eye, so their relationship to the ashen light is certainly questionable.

Flashes of lightning illuminating the clouds above the nightside of Venus have been proposed as an explanation for the ashen light. During the 1970s, American and Russian spacecraft recorded radio noise that was widely interpreted as evidence of lightning discharges, but definitive proof only came in 2007, when the magnetometer aboard the European Space Agency's Venus Express Orbiter detected the short, intense electromagnetic pulses that are the characteristic signature of lightning. Gathered over a three-year period, these data suggest that lightning on Earth and Venus is similar in strength and frequency at similar altitudes. On Venus, lightning is more prevalent during the day than at night and occurs more frequently at low latitudes, where the solar energy input to the planet's atmosphere and resulting convection are strongest. But in order to be visible from Earth as the ashen light, it has been estimated that 1,000 flashes per second would be required to illuminate the clouds on the nightside of Venus, a figure about 10 times greater than the observed frequency.

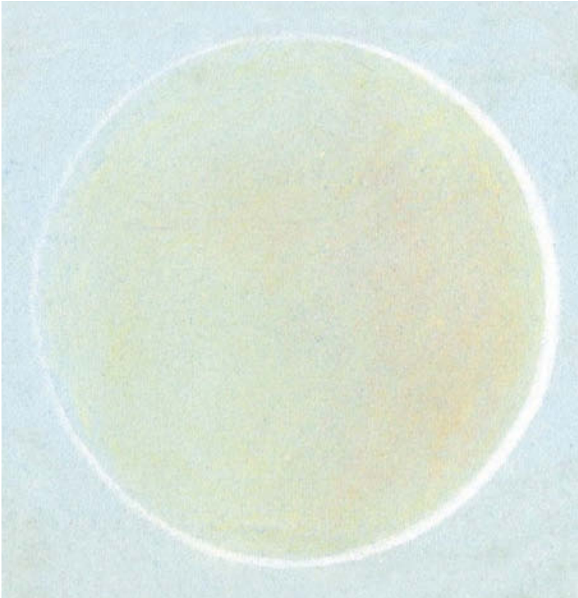


EWEN A. WHITAKER

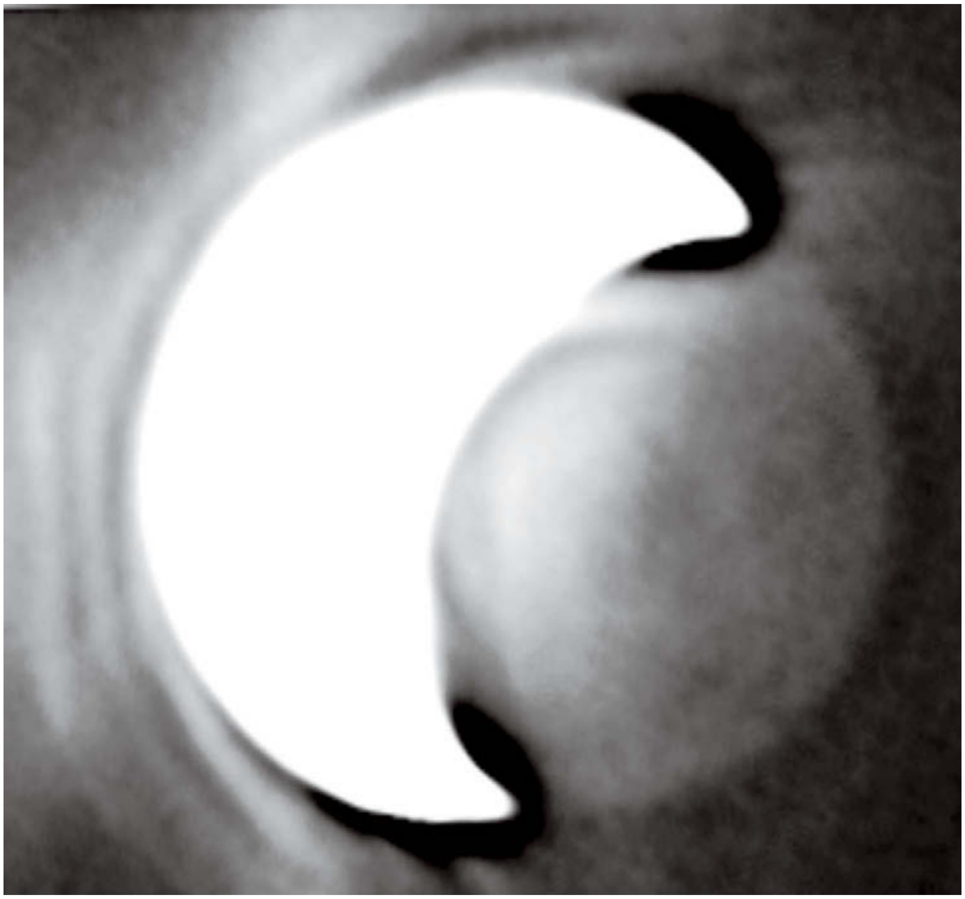
Diffraction spikes from secondary mirror supports in some reflecting telescopes are enhanced when superposed on the planet's nightside. Many spurious reports of the ashen light are attributable to spider diffraction. Refractors, Maksutov-Cassegrains, and Schmidt-Cassegrains will not produce these illusory appearances.

Six years ago, Fred Taylor of the Atmospheric, Oceanic, and Planetary Physics Group at Oxford University proposed a straightforward explanation for the ashen light. According to Taylor, the opacity of the cloud structures observed in recent years by Venus Express is sufficiently low that the dull red thermal glow of the planet's surface, which bakes at an ovenlike 800°F (430°C), might occasionally penetrate the atmosphere and become dimly perceptible at visible wavelengths. Absorption and light scattering by the aerosols in Venus's atmosphere are weak at visible and near-infrared wavelengths, allowing the dim glow of the planet's surface to vary depending on the presence or absence of intervening clouds of greater opacity. Taylor says that "it seems not unreasonable to expect a fully dark-adjusted observer to be able to see the glow from the surface of Venus under good viewing conditions." Descriptions by telescopic observers of the ashen light's ruddy hue as well as the dappled appearance or partial visibility of the nightside are certainly consistent with this notion.

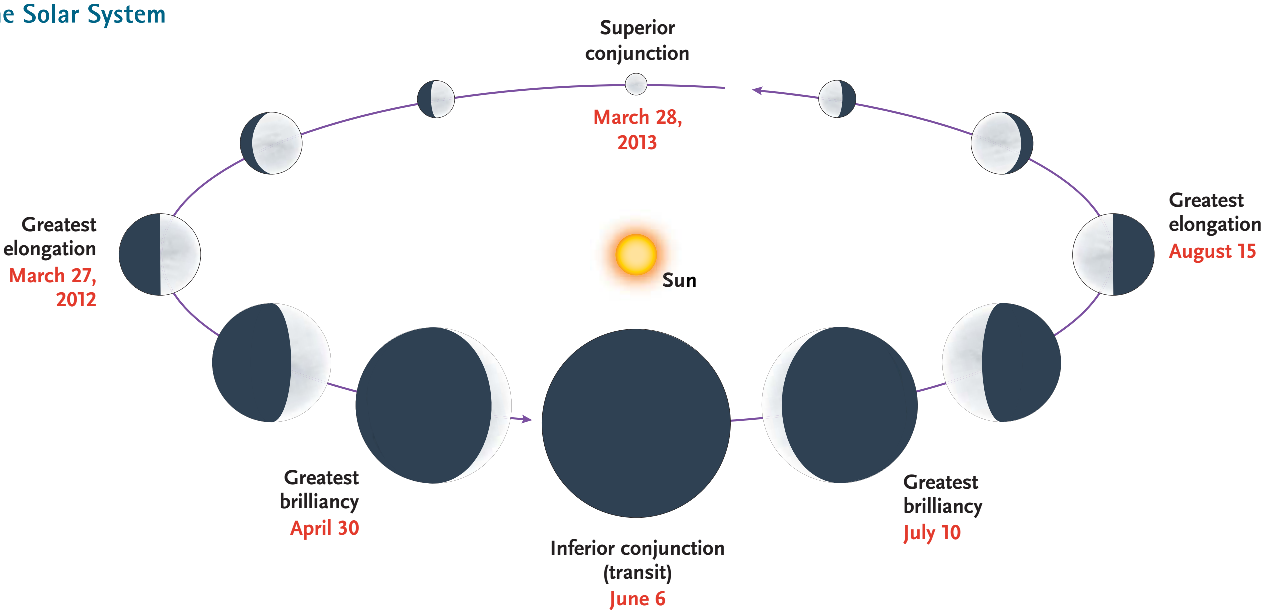
Taylor's hypothesis calls to mind an extraordinary observation of the ashen light in broad daylight made in 1962 by a pair of graduate students at the University of Arizona who went on to become two of the leading planetary scientists of their generation. Dale Cruikshank and William K. Hartmann had been observing Venus near inferior conjunction with a 12.5-inch Newtonian



This sketch by Dale Cruikshank depicts the appearance of the nightside of Venus appearing ruddier than the background sky during a daylight observation in 1962. This intriguing observation by a seasoned observer and eminent planetary scientist lends credence to the notion that the thermal glow of the planet's torrid surface may occasionally be visible to telescopic observers.



In May 2004, the French amateur Christophe Pellier imaged Venus at a wavelength of 1-micron in the near-infrared region of the spectrum. Although the crescent was only 19% illuminated, it appears much fatter because it was drastically overexposed in order to record the thermal emission from the planet's nightside. Although these images bear an uncanny resemblance to descriptions of the ashen light by visual observers, the wavelength is impossible for the human eye to detect.



For Northern Hemisphere observers, Venus will be unusually well-placed in the evening sky throughout the spring of 2012. The best opportunities to observe the ashen light will occur between late April and the middle of May. *S&T:* LEAH TISCIONE

reflector for several days. "We were quite familiar with the appearance of Venus from day to day, usually at about the same time of day," Cruikshank recalls. "Since the ashen light sighting came unexpectedly as part of a long series of observations, we were pretty certain of its reality." In this instance the ashen light did not appear brighter than the brilliant sky background, but was perceived as a coppery or bronze hue inside the cusps of the crescent that contrasted with the surrounding azure sky.

While the reality of the ashen light remains controversial, Cruikshank strongly encourages amateurs to continue monitoring Venus's night hemisphere:

> *We can adopt the principle that many phenomena of Venus are time-variable, and that the observations made by professional astronomers with their sensitive techniques do not cover enough of a time base to have caught the elusive ashen light. It then seems reasonable that amateurs, if suitably equipped with sensitive instruments on moderately large telescopes, can play a role in solving the mystery of the ashen light because they can devote a large amount of time to getting the observations.*

As recently as the 1980s, astronomers discovered that the clouds of Venus are partially transparent at several near-infrared wavelengths, making it possible to image deep cloud decks and even the planet's surface. While images of the sunlit portion of Venus at a wavelength of 1 micron (1,000 nanometers) are virtually featureless because they record sunlight reflected by high-altitude clouds and hazes, images of the planet's nightside at this wavelength record thermal emissions from the surface with surprising clarity. Venus's appearance in this narrow spectral window broadly correlates with its topography, the cooler highlands appearing dark and the warmer valleys bright.

In 1991 a team of French astronomers using a 42-inch telescope at the Pic du Midi Observatory obtained the first 1-micron images of the surface features of Venus. Thirteen years later French amateur Christophe Pellier managed to duplicate this feat. Using a 14-inch Schmidt-Cassegrain, a monochrome webcam, and a 1-micron infrared filter, Pellier imaged the nightside of Venus glowing right through the planet's clouds in May 2004, when Venus appeared as a 19%-illuminated crescent. Uncertain whether his equipment would be up to the task, he was taken aback to see the thermal glow from the nightside of Venus appear on the monitor after an exposure lasting only a few seconds. Inspired by Pellier's success, dozens of other amateurs have since captured near-infrared images of the planet's topography (*S&T:* October 2010, page 72).

Although these images bear a striking resemblance to depictions of the ashen light by visual observers, they record Venus in a region of the spectrum that is invisible to the human eye. But they should entice imagers to monitor Venus's nightside in visible wavelengths to record any appearance of the ashen light. The addition of an infrared-blocking filter to exclude wavelengths longer than 800 nanometers and exposures of several seconds under a dark sky should capture the phenomenon if it is present at the time.

Late this spring, Venus will be well placed in the evening sky for observers in the Northern Hemisphere. With remarkably powerful imaging capabilities now in the hands of so many amateur astronomers, the solution to one of planetary astronomy's most enduring mysteries may finally be within our grasp. ✦

Although S&T *contributing editor* ***Thomas Dobbins*** *is a skeptic when it comes to Bigfoot and the Loch Ness Monster, he became a true believer in the ashen light following his only sighting of the phenomenon 27 years ago.*

Dennis di Cicco

2 Scopes for an Active Sun

After several years in the doldrums, solar observers once again can rejoice: the Sun is active.

After an unexpectedly long snooze as solar cycle 23 wound down and cycle 24 began, the Sun is once again an exciting target for observers. While following the daily evolution of sunspots with a telescope equipped with a safe white-light filter is a fascinating way to keep tabs on solar activity, the real excitement comes from observing with a special filter that transmits a narrow slice of the spectrum centered on the red wavelength of hydrogen-alpha light at 656.3 nanometers. At this wavelength the Sun reveals constantly changing prominences dancing along the solar limb, some of which can extend tens of thousands of kilometers into space. And if the filter transmits a slice of the spectrum less than an angstrom (1 angstrom = 0.1 nanometer) wide (the narrower the better), the Sun's disk can appear filled with intricate detail around active regions on the solar surface.

In late 2011 I followed solar activity for several months with two Coronado telescopes that we borrowed from Meade Instruments for this review. The SolarMax II 60 and SolarMax II 90 are, respectively, 60-mm f/6.6 and 90-mm f/8.8 refractors made exclusively for hydrogen-alpha, or H-alpha for short, solar observing.

Both SolarMax II scopes isolate the H-alpha wavelength with an internal etalon and a separate blocking filter located near the eyepiece. The blocking filter for the 60-mm scope is permanently mounted in a 90° diagonal, making the diagonal a required part of the setup. Although the 90-mm scope is also available in this configuration, the version I tested is made for "straight through" imaging with a larger blocking filter mounted in the focuser drawtube, so it can be used with or without a diagonal.

The basic SolarMax II telescopes are specified as having a bandpass of less that 0.7 angstrom. They are also available with a so-called double-stacked option that narrows the bandpass to less than 0.5 angstrom, providing even greater visual contrast in the detail seen on the solar disk. The double-stacked scopes have a second etalon mounted in front of the telescope objective. The scopes I tested were double-stacked models, and I tried them with and without the second etalon. More about this in a moment.

Each SolarMax II telescope is supplied with a clamshell mounting ring fitted with a projection-type solar finder. Although the double-stacked scopes are relatively compact, they are also rather heavy for their apertures; the SolarMax II 60 tipping the scales at 7.6 pounds (3.4 kg), and the 90 at 21.6 pounds (9.8 kg). The 60 can be used with a heavy-duty photographic tripod, but the 90 needs a much more substantial mount. Although I was satisfied using the 90 on my aging Vixen Great Polaris DX mount, I consider it about the minimum mount suitable for seri-

Coronado SolarMax II Hydrogen-Alpha Telescopes

U.S. prices: SolarMax II 60 starting at $1,499
SolarMax II 90 starting at $3,599
Meade Instruments, 27 Hubble, Irvine, CA 92618
949-451-1450: www.meade.com

ALL IMAGES ARE BY THE AUTHOR

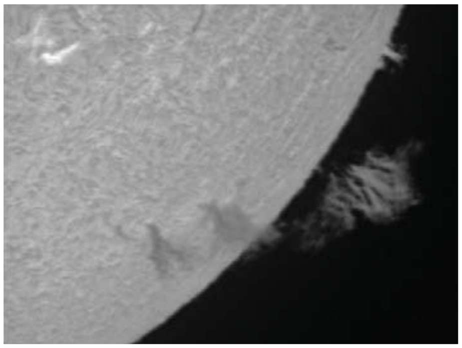
ous observing with this scope. To get the best experience with either scope, you'll want a tracking mount with slow-motion controls.

Even if you're new to H-alpha solar observing, the SolarMax II scopes are easy to use. With the single-etalon models, you simply focus the Sun in the eyepiece and adjust a lever on the side of the telescope tube until solar features display the greatest image contrast. The "sweet spot" showing the greatest contrast moves across the field of view as you adjust the lever. While I could find a setting that showed the overall solar disk to advantage, I generally adjusted the lever so that the point of maximum contrast was centered in the eyepiece field and then used my mount's slow motions to move the portion of the solar disk of interest to this point.

The double-stacked scopes work the same way as the single-etalon models, except that you also have to tune the objective-mounted etalon after adjusting the internal one. Since the double-stacked images are a little dimmer, it really helps to block as much stray light as possible from entering your eye.

When the double-stacked scopes were properly tuned, the views were nothing short of spectacular. Even a rather minimally spotted Sun often showed sinuous dark filaments crossing the solar disk and dramatic prominences, some of which visibly changed in a matter of minutes. (If you want to see how the Sun looks right now in H-alpha light, check out the GONG Network at **http://gong.nso.edu**, where a global system of telescopes keeps constant vigil on the Sun with images and movie loops that are updated every minute.)

SolarMax II scopes have helical focusers. While these offer precise adjustment, especially for photography, it took some time for me to adapt to them for visual observing, since I'm used to pinpointing the sharpest image by quickly "racking" back and forth through the focus point. This is especially true at the H-alpha wavelength, which is near the eye's limit of visibility. The relatively slow action of the helical focuser, coupled with a small amount of backlash in the units I tested, meant that it often took some finessing to get the visual focus set right.



Last November 22nd the author used the SolarMax II 60 and a DMK video camera to image a solar filament straddling the Sun's limb. It appears dark against the Sun's surface, but becomes a bright prominences when seen against the sky.

I had very good results using both scopes in the double-stacked configuration with a DMK video camera. But my colleague Sean Walker, who has considerable experience imaging with H-alpha scopes, notes that equally good results are possible with the single-etalon configuration since the image will be brighter and you can use image processing to achieve the boost in image contrast that visually occurs with the double-stacked setup.

In the world of telescopes, aperture is king, and at the outset of my review I fully expected to spend more of my "leisure" time observing with the SolarMax II 90. But that ended up not being the case. The grab-and-go portability and more-relaxed mounting requirements of the smaller SolarMax II 60 were two reasons that I often chose it, but there was another reason that's less obvious. You tune the second etalon on the double-stacked scopes by turning a ring mounted on the front of the etalon. With the smaller scope I could easily reach up and do this while comfortably looking into the eyepiece. But with the larger scope I'd need arms like an orangutan. It's really a two-person job to fine tune the 90's front-mounted etalon.

Overall, I really enjoyed the SolarMax II scopes. Each clear day as the rising Sun crested the trees bordering our office parking lot, I'd check the GONG Network to see what was happening. If something looked interesting, I'd grab the 60 and head outside for a firsthand look. It emphasized just how easy it is to use these scopes for H-alpha observing on a moment's notice.

---

*Senior editor **Dennis di Cicco** has been patiently waiting several years for the Sun to wake up and solar activity to return to exciting levels.*

The Coronado SolarMax II telescopes, pictured here in the double-stacked configuration explained in the accompanying text, offer outstanding views of solar activity. They are very easy to operate even for those new to hydrogen-alpha observing.

WHAT WE LIKE:

Crisp, detailed hydrogen-alpha views

Easy to operate

WHAT WE DON'T LIKE:

Relatively heavy for their size

Richard Tresch Fienberg

Tiny Tracker: The Vixen Polarie

U.S. price: $429, not including optional polar-alignment scope
Vixen Optics, 1023 Calle Sombra, Unit C
San Clemente, CA 92673
Phone: 949-429-6363, www.vixenoptics.com

At last year's Northeast Astronomy Forum in Suffern, New York, some of the biggest attractions were, as usual, literally the biggest attractions: huge Dobsonian reflectors, several giant astrographs, and a bevy of heavy-duty equatorial mounts (*S&T:* August 2011, page 34). But some of the loudest buzz at the trade show was caused by one of the smallest new products on display there: Vixen's Polarie camera tracker. Company representative Brian Deis didn't even have a working prototype on hand — just a mockup. Nevertheless, many of the attendees who looked it over walked away saying the same thing: "I can't wait to get one!"

About the size of a paperback novel and weighing only 1½ pounds (0.7 kg), Polarie turns a standard photographic tripod into a motorized tracking mount for a DSLR or smaller camera. It's not the first product to do so, but it's the smallest, lightest, and least expensive camera tracker that I've seen. If you already have a DSLR, a tripod, and a ball head, you're only a Polarie away from being able to shoot wide-field astrophotos anywhere you travel without having to lug around lots of gear. The device runs for hours on two AA batteries, adding to its convenience, and inside the battery compartment is a little switch that sets the motor turning one way in the Northern Hemisphere and the other way in the Southern.

Deis brought a pre-production sample of the Polarie to the Oregon Star Party in late August, and he let me take it to Chile on *Sky & Telescope's* southern-observatories tour in September. He says it differs from the production model only in the finish of the case; the innards are identical to what customers will get with the production models. I played with the device under the spectacular southern sky, shooting exposures of the Milky Way and constellations up to 5 minutes long with my Canon EOS T3i DSLR

WHAT WE LIKE:

Compact, elegant design

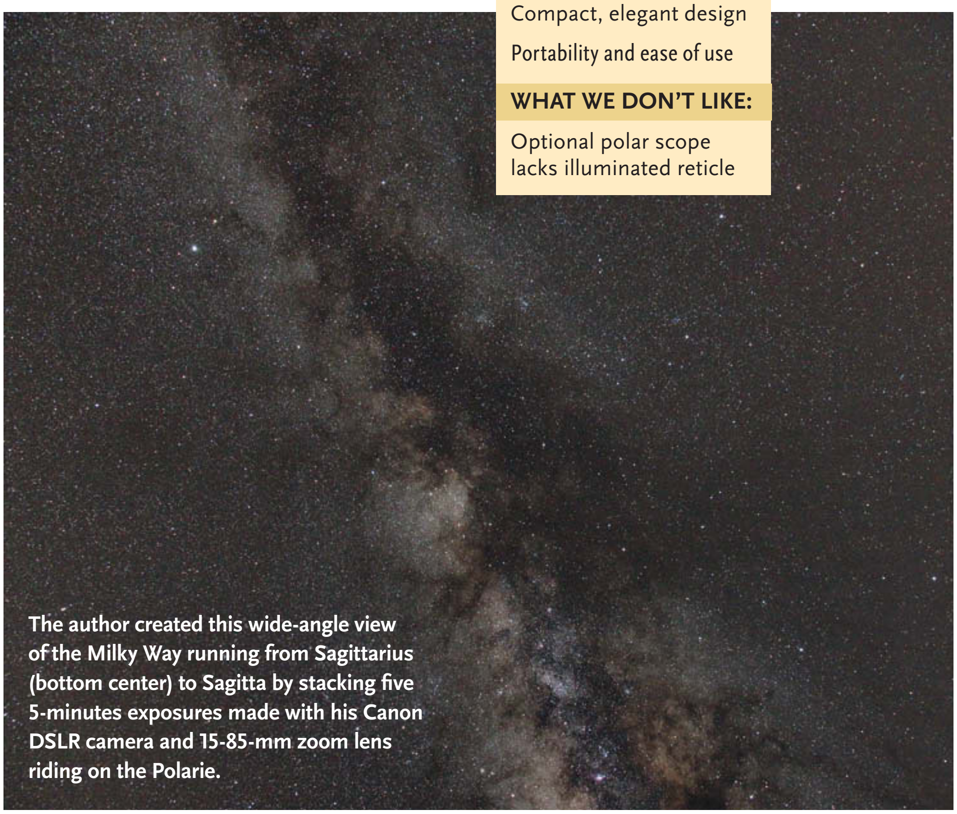
Portability and ease of use

WHAT WE DON'T LIKE:

Optional polar scope lacks illuminated reticle

The Vixen Polarie is a pocket-size, go-anywhere tracking platform that mounts to a photographic tripod and can carry cameras weighing as much as 3.4 pounds

S&T: SEAN WALKER



The author created this wide-angle view of the Milky Way running from Sagittarius (bottom center) to Sagitta by stacking five 5-minutes exposures made with his Canon DSLR camera and 15-85-mm zoom lens riding on the Polarie.

EXCEPT WHERE CREDITED, ALL IMAGES ARE BY RICHARD TRESCH FIENBERG

A peep sight built into the tracker's body (at upper right in this view) is adequate for rough polar alignment when the Polarie is used for short exposures with wide-angle lenses. For more precise alignment there's an optional polar-alignment scope ($249), which is pictured here and described in the accompanying text.

The power dial glows red when the direction of rotation is set for the Northern Hemisphere; green for the Southern. There are fixed drive rates for solar, lunar, and sidereal tracking as well as a ½-sidereal rate for starscape photography, which minimizes the apparent motion between the sky and landscape. The "light bulb" setting turns on a backlight for the polar-axis elevation indicator (shown below).

The tracker's polar elevation can be roughly set using the built-in inclinometer, which is calibrated to read the observer's latitude. The Polarie is powered by two AA batteries or an optional external supply that connects via a mini-USB plug.

and a 15-85-mm zoom lens.

Polarie attaches to any tripod with a standard ¼-20 threaded bolt. Obviously, the sturdier the tripod, the better. I travel with a Manfrotto carbon-fiber tripod that's both robust and lightweight. For rough polar alignment, you tilt the tripod head back till an indicator on Polarie's side points to your latitude, then turn the head till the Polarie is facing due north or south, depending on which side of the equator you're on. In case you want to set up during the day, Polarie comes with a magnetic compass; at night, of course, you just aim toward the pole star (in Chile, that's magnitude-5.5 Sigma Octantis).

To refine the polar alignment after nightfall, you look through a peep sight on one corner of the Polarie and adjust the tilt and azimuth of the tripod to center the pole star in the field. That's good enough for wide-angle astrophotography — my 5-minute exposures showed no sign of trailed stars. If you plan to shoot at telephoto focal lengths, though, you'll want even better polar alignment, and for this purpose Vixen offers an optional polar scope similar to the one made for its Great Polaris telescope mounts.

To use the polar scope, you unscrew a cap on the back of the Polarie and remove the camera mount (a metal disk with a spring-loaded ¼-20 bolt at its center) from the front of the device after loosening two thumbscrews. This reveals a hole through the center of the tracker, and you just slide the polar scope in through the back till it fits snugly. It's easy to see the polar star field when looking through the eyepiece, but the scope lacks an illuminated reticle, and under the pitch-black Chilean sky, I couldn't see the lines indicating where to put Sigma Octantis so that Polarie would be truly aligned on the celestial pole. Shinning a red flashlight obliquely into the front of the polar scope showed the reticle lines, but I lost sight of faint Sigma; I suspect using a flashlight will work okay in the north when aligning on Polaris, which is much brighter.

The Polarie doesn't come with a ball head, which you'll need to aim your camera toward any part of the sky you choose. If your ball head has a $\frac{3}{8}$-16 threaded hole, which many do, you'll need a tripod thread adaptor to mate it with the ¼-20 bolt on the Polarie. I was concerned that the thumbscrews holding the Polarie's camera mount on the tracker body might slip under the weight of my DSLR and lens, but they held fast. Vixen says the Polarie can carry up to 3.4 pounds (1½ kg), which should be fine for most cameras and lenses but rules out any thought of attaching a telescope.

A dial on the Polarie lets you switch between four drive rates: sidereal, solar, lunar, and ½ sidereal. That last rate has become popular for those who like to capture wide-angle shots of the night sky over terrestrial landscapes, as it strikes a balance between trailed stars and blurry foregrounds. Eclipse photographers with telephoto lenses will appreciate the solar and lunar rates. An LED indicates which rate you're using, and it lights up red if the Polarie is turning in the right direction for the Northern Hemisphere and green for the Southern.

Vixen definitely has a winner here. Polarie makes long-exposure constellation photography easier than ever, especially for anyone who has to travel to dark skies. I can't wait to get one! ✦

Visit us at www.SkyandTelescope.com/skytel/beyondthepage for more product reviews.

Former Sky & Telescope *editor in chief* ***Richard Fienberg*** *is currently the press officer for the American Astronomical Society.*

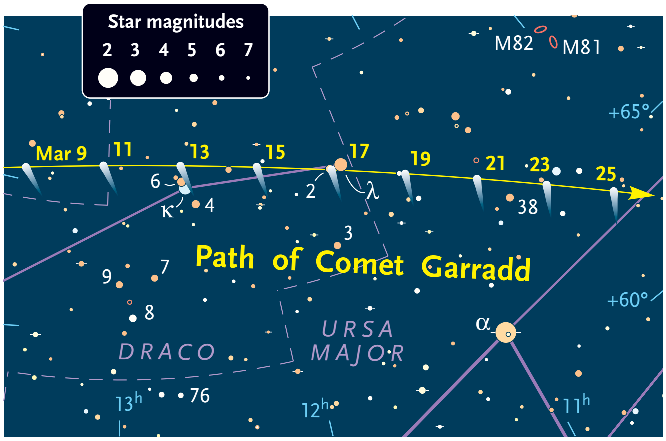
Comet Garradd Returns Anew

The comet that won't quit is back in view for binoculars and small scopes.

It's the little fuzzball that could. Comet C2009 P1 (Garradd) has remained a nice, 7th-magnitude telescopic sight since last August. In December it finally descended into the evening twilight, while rising into better view before dawn (*S&T:* November 2011, page 52). Now it's in good view late at night and, if predictions hold, should be brightening just a bit.

As February begins and most readers receive this issue, the comet is still near the Keystone of Hercules. It's well up by 2 a.m. and very high in the east before the first light of dawn. On the morning of February 3rd it skims ½° past the globular cluster M92 (magnitude 6.5). For this event, plan to go out about two hours before your local sunrise, after moonset.

After that date, the moonlight encroaches further. The Moon is gone again at comet-viewing times during the second half of February, when the comet is making its way across the arched back of Draco. During this period it's still best

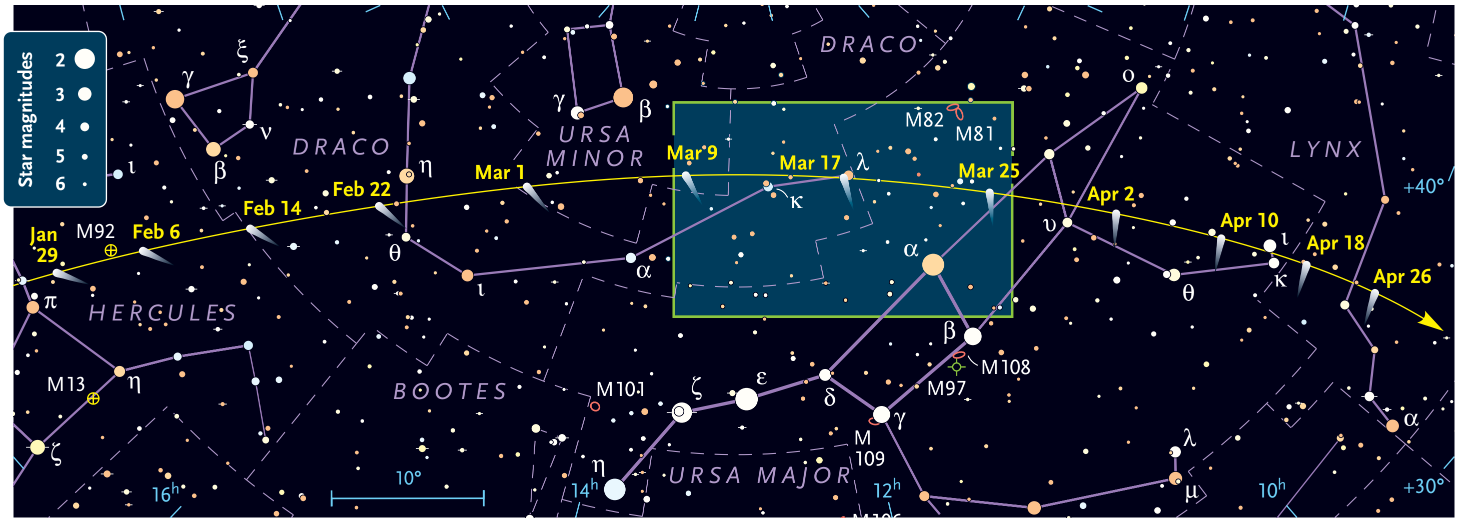


Asteroid Occultations

• On the night of March 10–11, a 9.7-magnitude star in Orion will be occulted by fainter 57 Mnemosyne along a path crossing the U.S. from Delaware to southern California. The star should be blotted out for up to 7 seconds within several minutes of 4:19 March 11th Universal Time.

• On the morning of March 28th, 6.8-magnitude 14 Virginis will be occulted low in the west-southwest by small 823 Sisigambis along a path from New Mexico to central California. The star should vanish for no more than 1.6 seconds within several minutes of 11:23 UT.

Finder charts and full details are at **www.asteroidoccultation.com/IndexAll.htm**.



Comet Garradd's position is plotted at 0:00 Universal Time on the dates indicated. This falls on the afternoon or evening of the previous date in North America (at 7 p.m. EST, 4 p.m. PST). Stars are plotted to magnitude 6.5 on the lower chart and to 7.5 on the blowup at upper left, which covers the March dark-of-the-Moon period. The comet tails point away from the direction of the Sun.

seen in the late night or early morning.

But by the time its moonless weeks in March roll around (roughly March 9th through 27th), Comet Garradd is in Draco's tail north of the Big Dipper, and nicely high starting as soon as the evening grows fully dark. This period is covered by the blowup chart at far left. On March 11th the comet is at its farthest north, declination 71°. On the night of March 16–17 it passes about ¼° by the tail star of Draco, 3.8-magnitude Lambda Draconis. During this period it should start to fade a bit.

Moonless evening skies in April run from about April 8th through 25th, with Comet Garradd glowing even higher overhead. On the night of April 13–14 it threads the gap between Iota (ι) and Kappa (κ) Ursae Majoris, the stars of Ursa Major's forepaw. But the comet is dimming, perhaps down to magnitude 8, as it moves farther away from both Earth and the Sun. It will never come back.

Comet Garradd changed appearance little as the months went by last fall. Austrian astrophotographer Michael Jäger shot this view on November 19th. The blue gas tail and whiter dust tail were angled 60° apart.

Comet Garradd hangs around so long because it really is a slow mover, with an orbit entirely outside that of Mars. At its December 23rd perihelion it was 1.55 a.u. from the Sun. When closest to Earth on March 5th, it's 1.27 a.u. from us. Clearly it's an intrinsically large comet that would have been a much greater spectacle if it had come closer to the Sun and Earth. ✦

Minima of Algol

Feb.	UT	Mar.	UT
3	13:22	3	5:36
6	10:11	6	2:25
9	7:01	8	23:15
12	3:50	11	20:04
15	0:40	14	16:53
17	21:29	17	13:43
20	18:18	20	10:32
23	15:08	23	7:21
26	11:57	26	4:11
29	8:46	29	1:00
		31	21:49

These geocentric predictions are from the heliocentric elements Min. = JD 2452253.559 + 2.867362E, where E is any integer. Derived by Gerry Samolyk (AAVSO), they reflect a slight lengthening in the star's period that seems to have occurred in early 2000. For more information and a comparison-star chart, see **SkyandTelescope.com/algol**.

Lunar Occultations

In the first few days of March, the dark limb of the waxing Moon occults three 3rd- to 5th-magnitude stars for observers in various parts of North America.

• Early on the evening of March 1st, the Moon occults 5th-magnitude 114 Tauri for most of the eastern U.S. and southern Ontario. Some times for the star's disappearance: Toronto, 7:47 p.m. EST; Atlanta, 7:18 p.m. EST; Chicago, 6:23 p.m. CST.

• Later that same night, the dark limb covers 3rd-magnitude Zeta Tauri for the Northeast and much of the Midwest. Some times: Toronto, 1:25 a.m. EST; Washington, DC, 1:36 a.m. EST; Chicago, 12:39 a.m. CST; Winnipeg, 12:16 a.m. CST.

• The following night, March 2–3, the Moon's limb occults 4.1-magnitude Nu Geminorum for most of eastern and central North America. Some times: Montreal, 12:15 a.m. EST; Washington, DC, 12:29 a.m. EST; Atlanta, 12:49 a.m. EST; Chicago, 11:21 p.m. CST; Kansas City, 11:34 p.m. CST, Edmonton, 9:32 p.m. MST.

For maps and timetables, see **www.lunar-occultations.com/iota/bstar/bstar.htm**.

The Southern Main

A small area in Puppis teems with clusters and nebulae.

So Argo, rising from the southern main,
Lights with new stars the blue ethereal plain;
With favouring beams the mariner protects,
And the bold course, which first it steer'd, directs.
— Erasmus Darwin, *The Botanic Garden*

THE ANCIENT AND IMMENSE Ptolemaic constellation Argo Navis represented the great ship sailed by Jason and the Argonauts on their legendary quest for the Golden Fleece.

Nicolas Louis de Lacaille found vast Argo unwieldy when making up his 1763 star catalog *Cœlum Australe Stelliferum*, commenting that it had more than 160 stars visible to the unaided eye. To deal with this, Lacaille gave Greek letter designations to Argo's brightest stars. Then he assigned uppercase and lowercase Roman letters to each of three sections of Argo. Thus the catalog has one star designated "a" in Argo's stern, another on its keel, and yet a third upon its sails.

Today, Lacaille's three subdivisions parade the sky as the officially recognized constellations of Puppis (the Stern), Carina (the Keel), and Vela (the Sails), while Argo Navis has been swept from the celestial vault into the dustbin of abandoned star figures.

Let's confine our tour to the Stern of the dissected ship and begin with the delightful open cluster **Messier 93**, located 1.5° northwest of yellow Xi (ξ) Puppis. In a moderately dark sky, M93 is a bit of fluff to the unaided eye, while 14×70 binoculars show two easily visible stars and a few faint ones against a misty backdrop. In my 105-mm refractor at 17×, the cluster is rich in faint stars and looks like a glittering creature with two bright shining eyes. At 47× it metamorphoses into a celestial moth, whose body stretches east-northeast from the eyes. Wings unfold east and south, and forelegs curve north of the body. Why a moth instead of a butterfly? Moths fly at night, of course. About 60 stars create our sparkling lepidopteran, while 11 stars west of his body plump up M93 to a diameter of 22′.

Clusters and Nebulae in Puppis

Object	Type	Mag(v)	Size	RA	Dec.
Messier 93	Open cluster	6.2	22′	7^h 44.5^m	–23° 51′
NGC 2482	Open cluster	7.3	12′	7^h 55.2^m	–24° 15′
Trumpler 9	Open cluster	8.7	5′	7^h 55.7^m	–25° 53′
NGC 2467	Emission nebula	8.0	16′ × 12′	7^h 52.5^m	–26° 26′
Haffner 18	Open cluster	9.3	5′	7^h 52.7^m	–26° 23′
Haffner 19	Open cluster	9.4	2′	7^h 52.8^m	–26° 17′
NGC 2453	Open cluster	8.3	5′	7^h 47.6^m	–27° 12′
NGC 2452	Planetary nebula	11.9	31″ × 24″	7^h 47.4^m	–27° 20′

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

***Right*: Argo Navis represented the ship that carried the heroes who stole the Golden Fleece. It was the biggest constellation before it was carved into pieces in the modern scientific era.**

S&T: LEAH TISCIONE

Model-telescope-maker Barry Crist imagines a different critter inhabiting M93. The densely packed core stars form a shape that reminds him of a giraffe. My 130-mm refractor at 67× shows a fat U of stars, open to the northeast, that forms the giraffe's back and legs. The giraffe's neck attaches to the southern side of the U and stretches eastward, while his nose points south.

Obviously suffering from a case of the late-night munchies, New York observer Joe Bergeron claimed that M93 "closely resembles a partially eaten pizza. Clearly visible are two leftover pieces, while stray bits of peppers and mushrooms are scattered about the pan of this mystical cosmic spectacle."

M93 is roughly 400 million years old, ancient enough to sport several red-giant stars — including our moth's eyes. Can you see their amber glow?

Returning to Xi and then moving 1.5° east-northeast takes us to the open cluster **NGC 2482**. My 105-mm scope at 87× shows 40 faint to very faint stars gathered in bunches that comprise a loose, irregular group about 12′ across. The cluster is quite attractive in my 10-inch reflector at 115×. Its many members have a small brightness range and are arranged in several spidery arms. The cluster is accented by a triangle of 8th-magnitude field stars off its northeastern side and a deep-yellow gem of similar brightness at its opposite edge.

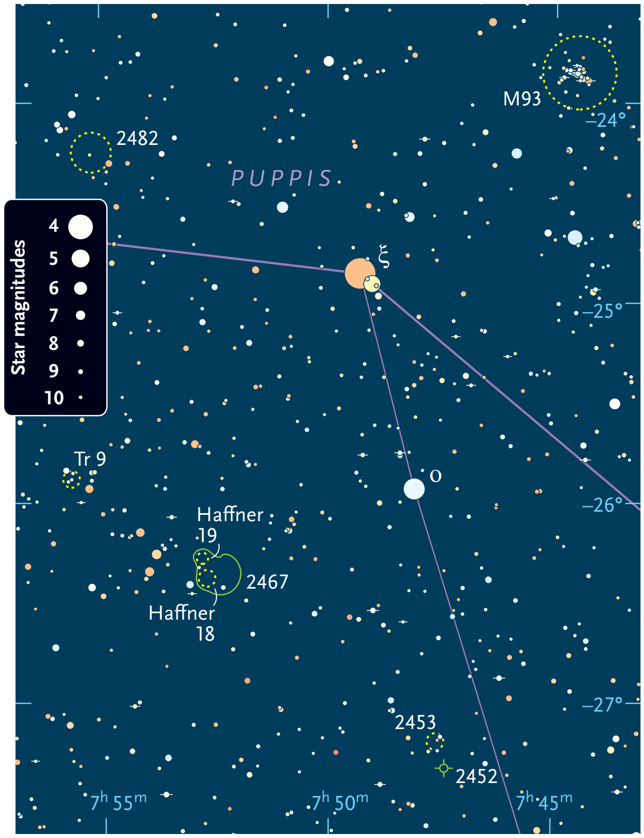
While M93 and NGC 2482 appear close together on the dome of the sky, they're not especially close in space. M93 is 3,400 light-years away from us while NGC 2482 is a thousand light-years more distant.

Sweeping 1.6° southward, we come to the remote open cluster **Trumpler 9**, an additional 3,000 light-years distant. Through my 105-mm refractor at 87×, it shows only 14 stars, the brightest in a wedge that points west.

There are four stars west of the wedge that seem to form a "1" (the numeral one) when viewed through an erect-image telescope. Together, the wedge and the numeral look like "> 1." So I call this combo the Greater Than One asterism. The bright star at the base of the "1" shines with a rich golden hue. In the inverted view of my 10-inch reflector, a few additional stars turn the asterism into a "12."

An impressive nebula-cluster complex rests just 54′ southwest of Trumpler 9. William Herschel discovered the brightest part of the nebulosity, **NGC 2467**, with his 18.7-inch reflector on December 9, 1784. His description reads: "Large, almost round, 6′ or 7′ in diameter, entirely milky, a pretty large star not far from the center; a very curious appearance."

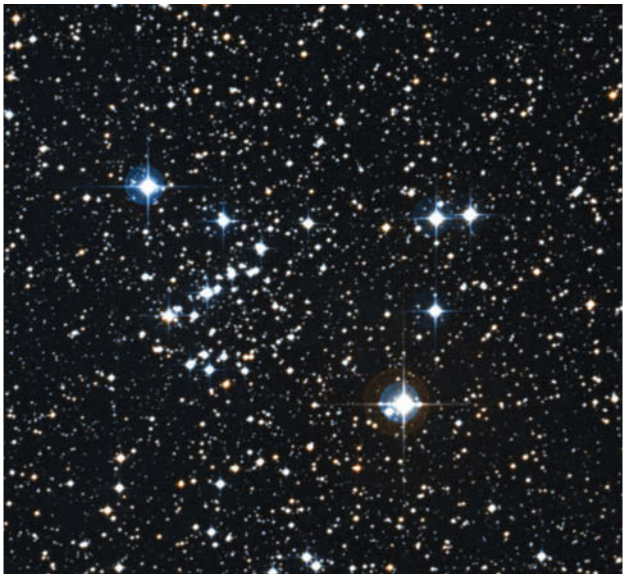
Through my 105-mm refractor at 17×, NGC 2467 is an obvious hazy patch harboring a prominent star. The nebula looks very nice at 87×. The star is cocooned in the northern part of a bright patch of nebulosity that



All the targets in this article are an easy star-hop from Messier 93, which is shown on the all-sky chart on page 44.

POSS-II / CALTECH / PALOMAR OBSERVATORY

The brightest stars in Messier 93 are red giants.

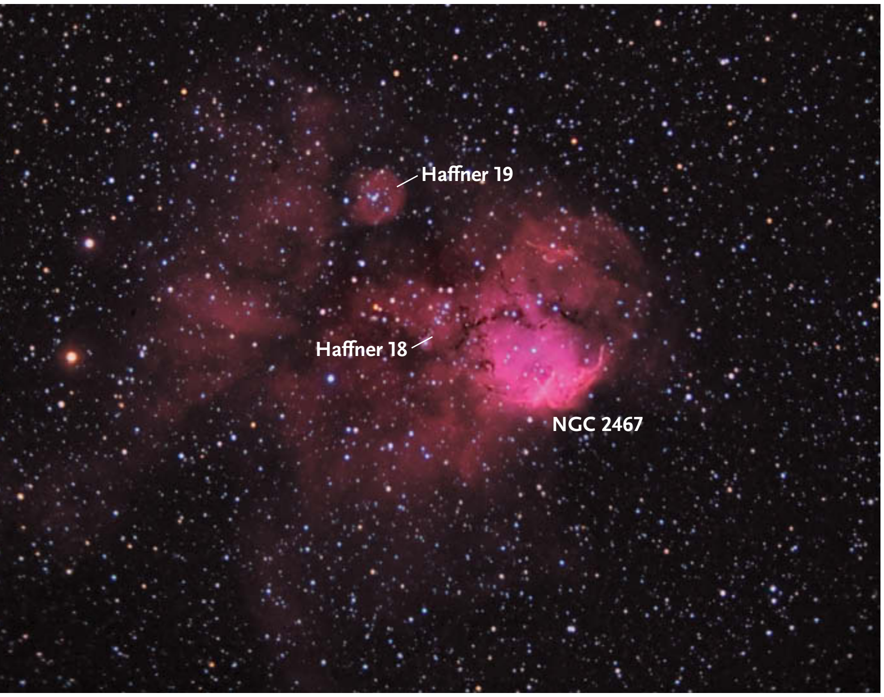


POSS-II / CALTECH / PALOMAR OBSERVATORY

This photo shows why the author calls Trumpler 9 the Greater than One cluster.

stretches 6′ east-west and 4¾′ north-south. Fainter mist extends the nebula to 9′ east-west and 7′ north-south, and there's a brighter, mostly detached band extending eastward from its northern edge. These gauzy scarves of mist are beaded with a dozen faint stars.

This nebula sprawls across 45′ in deep images, and as a whole, it's known as Sharpless 2-311.



This 40′-wide image of the huge nebula Sharpless 2-311 by California astrophotographer Jim Thommes combines exposures through standard color filters and a hydrogen-alpha filter. The brightest part of the nebula is called NGC 2467.

In 1957 the German astronomer Hans Haffner identified two star clusters in the complex, now known as **Haffner 18** and **Haffner 19**. Haffner 18 was subdivided into three star bunches: Haffner 18a (northwest), Haffner 18b (south), and Haffner 18c (northeast).

In my 105-mm scope at 87×, the eastward-reaching band of nebulosity captures the territory of Haffner 18a and 18b, but they appear starless. Only Haffner 18c surrenders any stars, and then merely a half dozen. Haffner 19 is 6′ north in the same field of view, showing a small, round, bright nebula with a blot in the center that suggests a knot of stars. At 122× the knot is resolved into three "stars," but the brightest one still looks like a composite. A fourth star appears on the south-southwestern edge of the nebula. At 203× the bright star divides into at least two components. The nebula enfolding Haffner 19 is probably a Strömgren sphere, a region that has been completely ionized by the intensely hot (spectral type *B*1V) star in the cluster's heart.

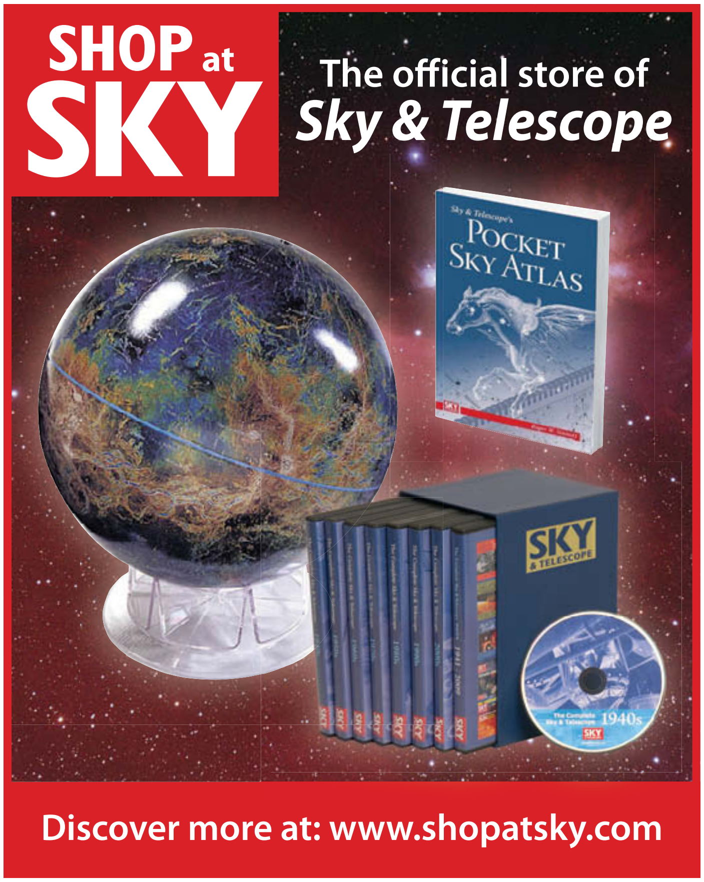
Ionization fronts powered by massive stars embedded in the NGC 2467 complex are plowing through the region's gas and dust, compressing it and triggering ongoing star birth. NGC 2467 and the Haffner clusters are extremely youthful, just 1 million to 2 million years old. Complicating the scenario, some sources place all three objects about 20,000 light-years away, while others put them at significantly different distances despite their apparent connection.

Now we'll slip 1.3° southwest to the open cluster **NGC 2453**. At 47× my 105-mm refractor shows three stars in a row crossing a 3′ hazy patch, the brightest star on its northwest edge. Three very faint stars also fleck the haze, and boosting the magnification to 153× adds several more. Many faint suns decorate the cluster through my 10-inch scope at 115×, their densest concentration huddled against the row's southeastern half.

NGC 2453 shares the field of view with the planetary nebula **NGC 2452**, which dangles 9.6′ south of the cluster's brightest star. My 105-mm scope at 87× shows the planetary as a small round spot marking the pointy end of a skinny kite that it forms with three stars just south of the cluster. At 153× I suspected a small brighter spot in the disk's southern edge, which was confirmed at 174×. Through my 10-inch reflector at 115×, NGC 2452 is slightly oval and dimmer in the center.

If you have a large telescope, see if you can tell that the nebula is not fully annular, but rather has bright north and south rims. NGC 2452 is one of the few planetary nebulae that may be physically related to the open cluster that's near to it on the dome of the sky. ✦

***Sue French** observes the deep sky from her semi-rural backyard in upstate New York. She always welcomes questions and comments at scfrench@nycap.rr.com.*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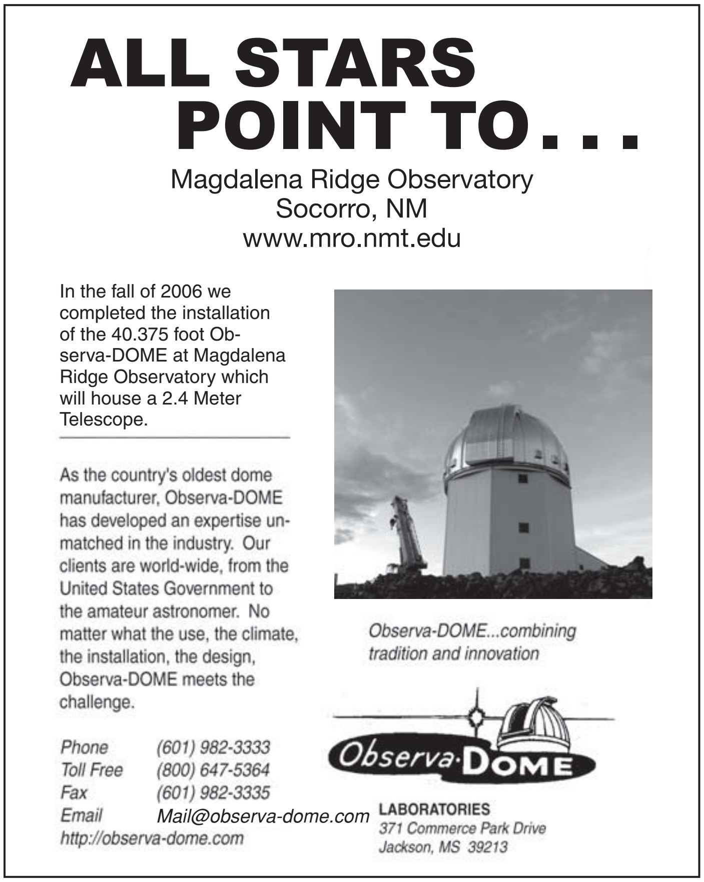
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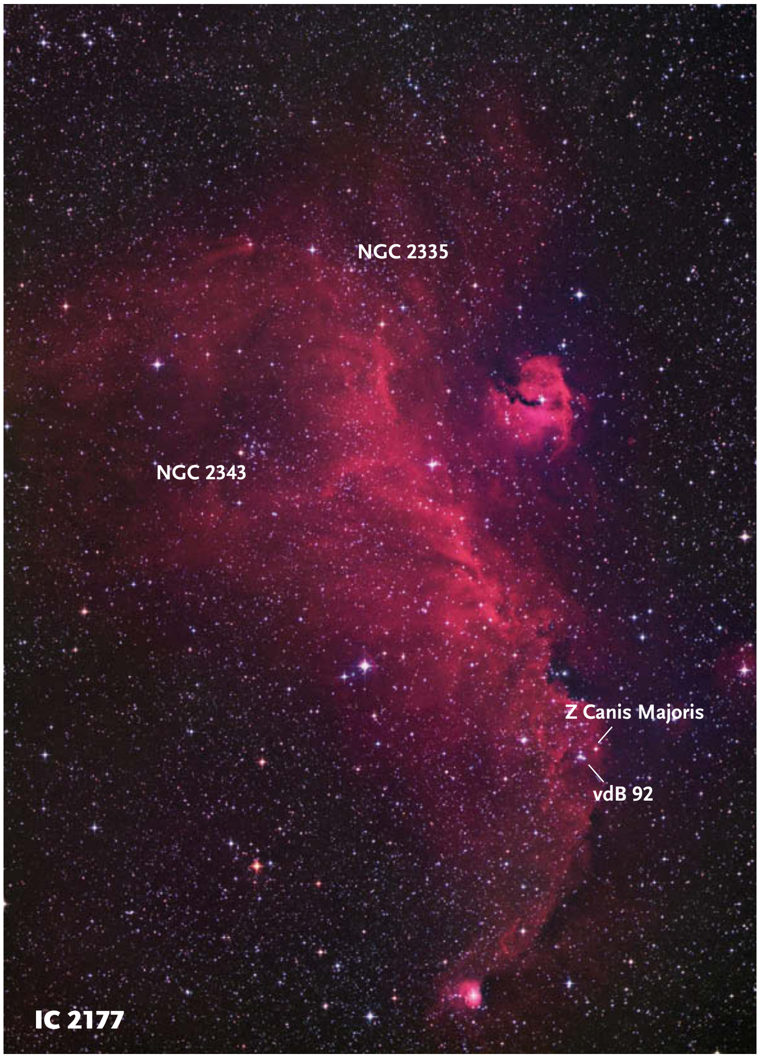


ROBERT GENDLER

Sharpless 2-308 is a large shell surrounding the 7th-magnitude Wolf-Rayet star EZ Canis Majoris, as shown on the facing page. It's faintly visible when viewed unfiltered in my 18-inch, and an O III filter transforms this nebula into a beautiful 35′ bubble. The sharpest contrast is along a 25′ western border, where weak filamentary structure is visible. At the south end of this long arc, the rim curves east, crossing directly through a triangle of 7.5, 8, and 9th-magnitude stars. Then it dims as it passes just south of 3.9-magnitude Omicron^1 Canis Majoris. The shell is difficult to follow in the southeast, but it can be picked up again on the eastern edge of the rim. From this point the border continues directly north, where material pools up on the north end in a brighter 10′ circular patch. The interior has a very light filling of gauzy nebulosity, with EZ CMa residing at the center.

NGC 2359 is my favorite Wolf-Rayet shell and a great target for any scope equipped with an O III filter. The central region has a high surface brightness and is visible at just 13× in my 80-mm finder. With my 18-inch, the bubble spans 5′ and the brighter western rim gives a crescent appearance. Three 11th-magnitude stars lie along the north portion of the rim, and the 11.4-magnitude Wolf-Rayet star HD 56925 is just northwest of center. Careful viewing may reveal irregularities in the rim and interior lacy filaments.

Two dramatic wings or horns that extend from the central bubble are the source of the popular nickname "Thor's Helmet." Most prominent is a fairly bright 9′

Exotic Objects in Canis Major

Object	Type	RA	Dec.
Sharpless 2-308	Wolf-Rayet shell	6^h 54.2^m	–23° 56′
NGC 2359	Wolf-Rayet shell	7^h 18.5^m	–13° 13′
Z Canis Majoris	Star with jet	7^h 03.7^m	–11° 33′
VY Canis Majoris	Star with jet	7^h 23.0^m	–25° 46′

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

appendage attached at the south end of the bubble. It first angles southwest and then bends to the west, thinning out into a long ribbon. A thicker wing is attached at the north end and streams to the northwest. In addition, look for a third fainter strip of nebulosity that begins on the north end and flows 10′ due east.

Stellar Jets and Exotic Stars

Z Canis Majoris is a unique pre-main-sequence binary system consisting of an FU Orionis star and a young Herbig *Be* star still embedded in a dust cocoon. Since the 1970s astronomers have followed its erratic behavior and outbursts as it evolves in fits and starts toward the main sequence. Most recently, Z CMa brightened from 10.5 to 8.5 magnitude in a February 2011 outburst.

Z CMa resides along the southwestern edge of IC 2177 (the Seagull Nebula) in a strange star field with a very uneven distribution of stars due to obscuring gas and dust. Van den Bergh 92, a small group of a half-dozen bright stars, is just 3′ southeast.

I had an opportunity to observe Z CMa using Jimi Lowrey's monster 48-inch Dobsonian last year from Fort Davis, Texas. At 488× and 813×, Z CMa appeared as a 9th-magnitude yellowish star with a fairly bright nebulous appendage that gently curved 40″ to the west before fading at the tip. The jet appeared slightly bowed out to the north with a thickness of only 5″. I have seen this filament faintly through my 18-inch scope. However, its visibility may depend on the current brightness of the variable star.

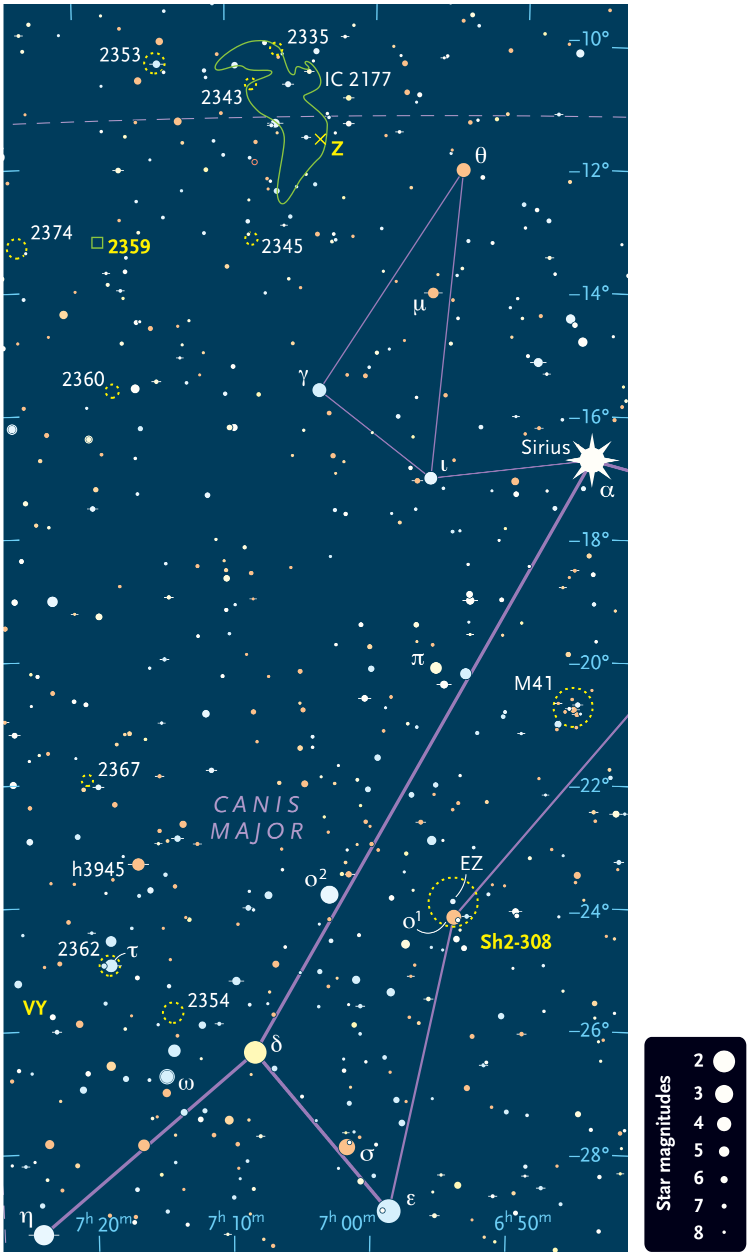
The red hypergiant **VY Canis Majoris** is one of the largest and intrinsically brightest stars in our galaxy. Roughly 2,000 times the solar diameter, it shines with nearly 500,000 times the Sun's luminosity. VY CMa is encased in a small, irregular reflection nebula consisting of ejected material from earlier, high-mass-loss outbursts. The intriguing visual target is a small tail or jet that has been likened to the Nike "swoosh" logo.

VY CMa appeared slightly fuzzy or soft when I viewed it at 175× in my 18-inch, like a star that won't focus in poor seeing. Bumping the magnification to 285×, I clearly saw a tiny orange disk surrounding a brighter center, and I was startled to find a short tail extending out from the star. The best view was at 325× — the central star was cleanly resolved within a very small, 4″ halo, and the attached jet extended about 8″, curving slightly to the west-northwest. In Lowrey's 48-inch, the jet appears as a shiny blue-white saber attached to the orange star. At the other extreme, I wonder what's the smallest scope that can show this tail? ✦

Steve Gottlieb observes the deep sky from dark sites in California and around the world. He welcomes comments and questions at steve_gottlieb@comcast.net.

Sharpless 2-308

DEAN SALMAN



Telescope Economics

To build or to buy? The answer to that perennial question has changed throughout the years.

For diehard ATMs, building telescopes is a way of life. But for others, the decision about whether or not to make a scope often hinges on economics. Will I save money building my own? The question turns up regularly in online forums and in my e-mail in box. Before the emergence of the large-scale commercial telescope industry about 40 years ago, the answer was a definite "yes!" But throughout the years the increasing abundance of low-cost imported Dobsonian scopes, and the escalating expense (and scarcity) of telescope-making supplies, has made it reasonable to wonder if it's still possible to save a few bucks by going the home-made route. The prevailing conventional wisdom says "no," but my own experiences suggest the answer isn't as simple as that.

To get to the bottom of the matter, I scoured the astronomy marketplace and gathered all data I could readily find. I priced mirror blanks and mirror-making kits, secondary mirrors, focusers, finders, plywood, aluminizing services, and so on, to assemble data that were accurate and up-to-date. I also surveyed commercial telescopes to find the going rates for Dobsonians. The distillation of that research is presented in the accompanying graph.

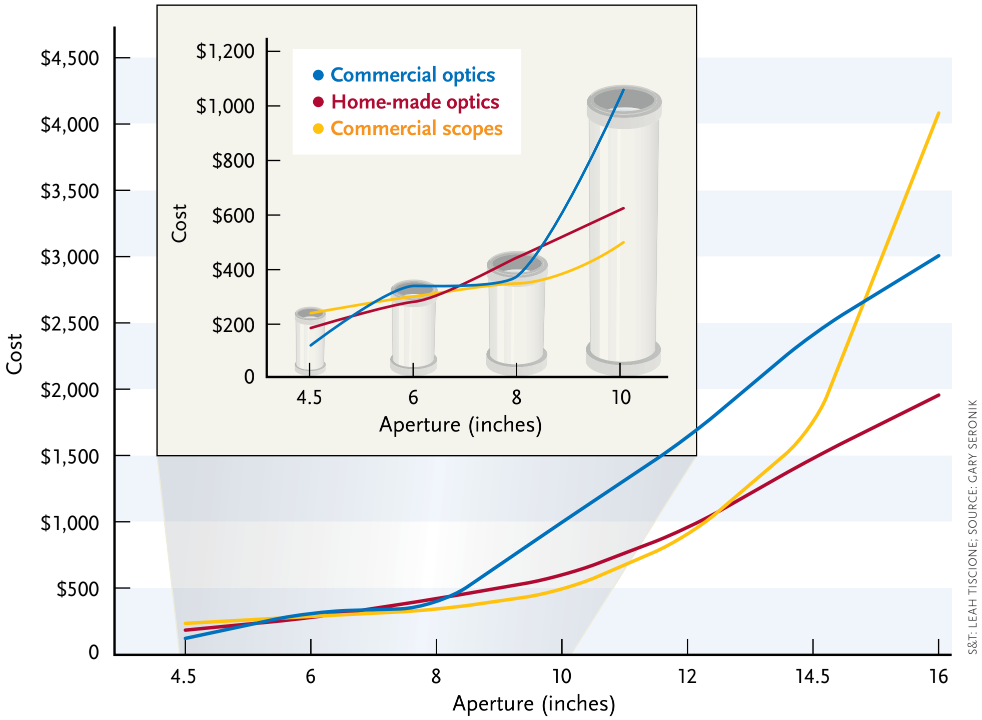
The author's 12¾-inch Dobsonian reflector (pictured here under the watchful eye of Sam) was built for less than $700, demonstrating that it's still possible to save a considerable amount of money if you make your own primary mirror and take care when choosing components such as focusers and finders.

As the data make clear, the build-or-buy question can't be answered with a simple yes or no. Look at the plots showing the costs of purchased Dobsonians versus ones made by grinding your own mirror. The two lines track closely across a range of apertures, with store-bought coming out slightly cheaper than home-built in some popular sizes. But an interesting thing happens when we move up to a 12-inch scope — the two lines begin to diverge by increasingly greater amounts. So yes, you can clearly save money by making your own Dobsonian, but probably only if you attempt an instrument bigger than 12 inches. This tidy summary, however, is only the big-picture perspective — some interesting economic information hides in the details.

One conspicuous feature of the graph is the sudden upward spike in the price of manufactured scopes larger than 12 inches. This reflects the bimodal nature of the current telescope market. Most commercial Dobsonians are either imported, low-cost, mass-produced units (which mostly have apertures of 12 inches or less), or low-volume, domestic instruments with big price tags. Were it not for the made-in-China scopes, building your own would be a money saver pretty much across the board.

Another piece of information graphically presented is that it's much easier to save money if you grind your own primary mirror than if you buy one that is ready-made. Indeed, buying a mirror will generally mean spending considerably more than simply purchasing an entire commercial instrument. Again though, once you get to large apertures, even building with a commercial primary becomes viable, but it never matches the savings realized by making your own mirror.

Before you finalize your build-or-buy decision, keep in mind that my analysis is based on averages and assumptions. As such, the graph mostly illustrates broad trends.



As this graph illustrates, the relative cost associated with building your own Dobsonian from scratch, building one utilizing commercial optics, and purchasing one outright, changes considerably as the aperture increases. Although there are only slight differences in costs for the smaller scopes, commercially made instruments in the highly popular 8- and 10-inch size are generally less expensive than home-built. But for large apertures, the economics favor home-built instruments.

A great deal depends on the specific choices you make. For example, the cost of building your own scope can change significantly if you opt for an expensive focuser instead of a budget model, or by selecting a premium diagonal mirror in place of a more economical one. Similarly, as anyone who peruses the ads in this magazine knows, there is a considerable range of prices among commercial scopes. In other words, once you decide on a specific aperture, you still have to do your research and apply your own selection criteria to what's available.

One item the graph doesn't show is that the build-it-yourself route offers the greatest *potential* for saving money. Commercial scopes are, more or less, an all-or-nothing proposition — you usually buy the scope as it comes. But when you make your own, you can do a good deal of scrounging and opportunistic purchasing. It's often possible for a group to buy ATM supplies in bulk to save money, and it's common for club members to have extra parts they're willing to sell for cheap.

You can also defer some purchases for later. For example, you might start off by equipping your scope with an inexpensive focuser or peep-sight finder, and then upgrade later as money allows. Keep this in mind when tracing the do-it-yourself line on the graph — it's the "fuzziest" one of all.

At the end of the day, however, making your own telescope isn't purely a decision about economics. I feel the knowledge gained from the experience and the potential for customization are two of the best reasons to give it a try — a telescope you make yourself really and truly is *yours*. And there's no denying the pleasure in being able to say, "Yes, I built it myself — mirror included!" I think most ATMs would agree, that's priceless. ✦

S&T contributing editor ***Gary Seronik*** *is a long time ATM and penny pincher with an armada of home-built scopes to call his own. Some of these are featured on his website,* ***www.garyseronik.com****.*

Targeting *the* International

This orbiting outpost is within reach of anyone with a camera.

Thierry Legault

When imaging solar and lunar ISS transits, Thierry Legault uses a Takahashi TOA 130 (pictured above) and TOA-150 refractors, and a Canon EOS 5D Mark II DSLR mounted on a heavy-duty video tripod. The camera operates in rapid-fire mode, recording four frames per second. Unless otherwise credited, all images are courtesy of the author.

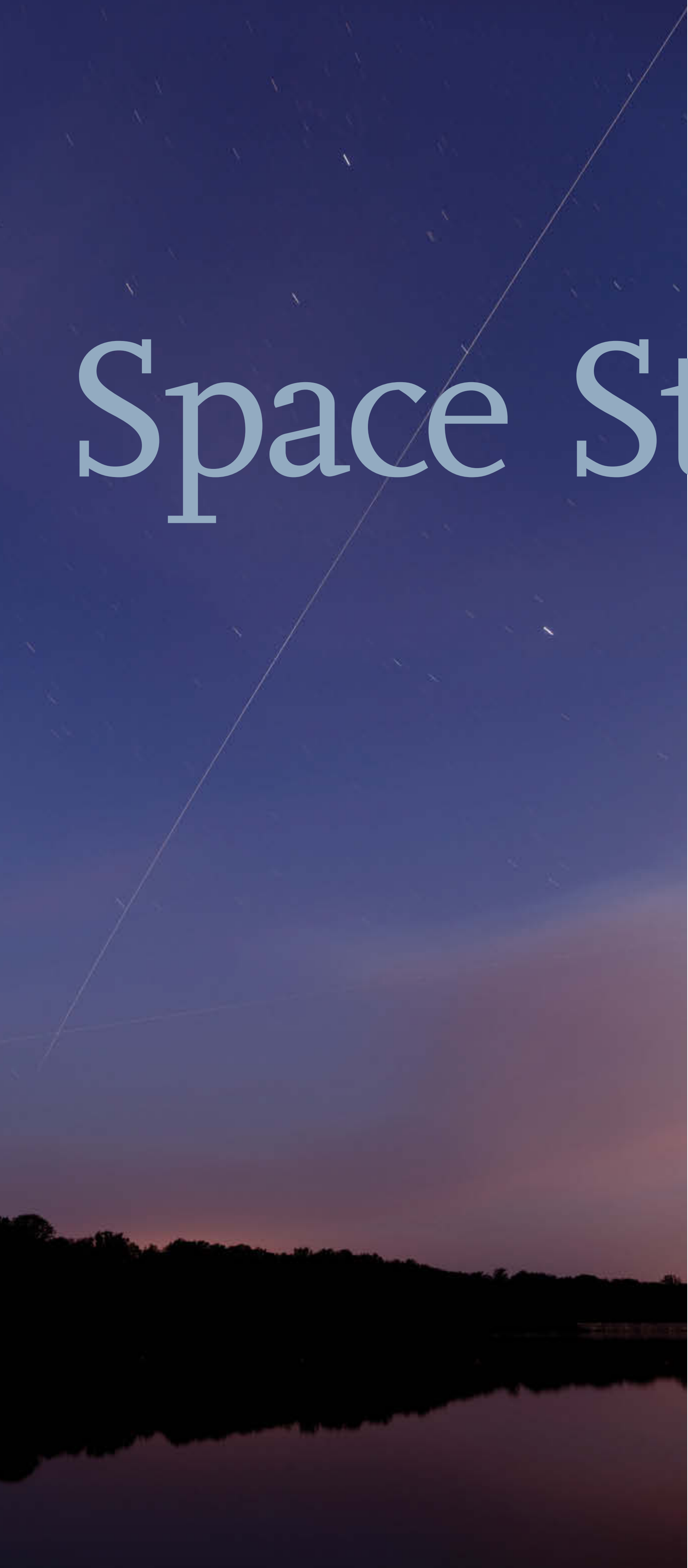
Of the hundreds of satellites that race overhead each night, none are as big as the International Space Station (ISS), and few rival its visibility. This permanent human outpost soars about 240 miles (385 km) above our heads, and it is so large that it invites amateurs with modest astrophotographic equipment to try their hand at capturing it in detail. There are several ways to image the ISS, each with its own set of challenges and results.

Orbital construction of the ISS began in 1998 and slowly continued for the next 13 years until the final pieces were delivered in mid-2011. Weighing nearly 500 tons, the station spans roughly the size of a football field. Massive solar panels compose the majority of its visible structure, along with large white radiators that form its most reflective parts. Until July 2011, NASA's Space Shuttle ferried most of the crews and supplies to and from the ISS, but those responsibilities are now performed by Russian spacecraft, as well as unmanned European and Japanese cargo ships. Typically, a crew of six astronauts occupies the ISS's 4,300 square feet of living space.

From Earth, the station's apparent speed is similar to high-altitude aircraft, racing by at around 1.2° per second near the zenith. Its orbit is inclined 51.6° above the equator, making the ISS visible from anywhere in the world with latitudes less than 65°. Areas at latitudes close to 51° north or south benefit from numerous ISS passes per month, while observers living near the equator can only see a few.

Whizzing along at the fantastic speed of 17,200 mph (about 7.7 km per second), the ISS takes only 91 minutes to complete a single orbit. The best opportunities to observe it during a favorable pass are when the Sun is approximately 4° to 20° below the horizon. When the Sun is higher, the sky is too bright, making the ISS difficult to spot. When the Sun is too far below the horizon, the station is effectively invisible.

The ISS always travels roughly west-to-east, but its



T. LEGAULT / E. RIETSCH

Space Station

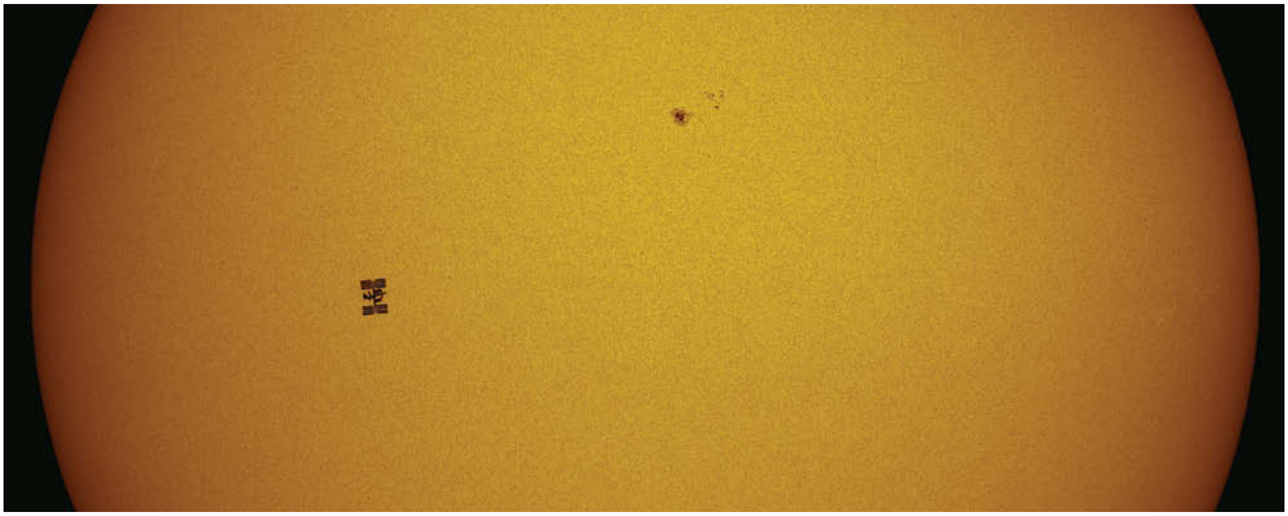
Go to SkyandTelescope.com/Legault to watch some of Thierry Legault's International Space Station flyby videos.

precise direction varies each pass. For example, it may rise in the west-southwest, and disappear toward the east-northeast. Culmination (the highest position in the sky during the pass) also varies; a simple rule of thumb is that the lower the station culminates in your sky, the farther away it is. Fortunately, we don't have to calculate the visibility and trajectory ourselves; specialized websites including Heavens Above (**www.heavens-above.com**) and Calsky (**www.calsky.com**) can alert you to favorable passes.

Wide-field photography

Twilight ISS passes from horizon to horizon last about five minutes, and are easily captured using any DSLR or point-and-shoot digital camera capable of exposures of several seconds or longer. Preliminary tests should be performed to determine your camera's best shooting parameters. The Space Station is so bright that there's no need to use high ISO settings or lenses with fast f/ratios. Use a remote cable release or the camera's self-timer to avoid shaking the camera at the beginning of your exposure. Set the lens focus at infinity by using a distant landscape feature, or the Moon, Venus, or Jupiter if they are visible in the sky. Composing the view so that the path of the flyover includes the foreground will make the photograph more interesting.

Left: **Twilight shots are a good way to begin capturing the ISS. Here the orbiting outpost crosses the summer triangle of Altair, Deneb, and Vega shortly before dawn. Legault captured this view with a Canon EOS 5D Mark II DSLR camera and 24-mm lens.**

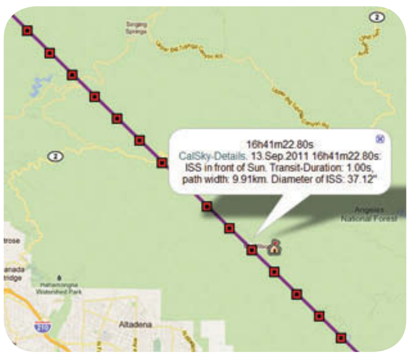


ISS transits of the Sun are only visible within a thin track on the ground, and last less than one second. Using the setup shown on page 70, the author captured the silhouette of the ISS as it zipped in front of the Sun on May 22, 2010, from Niederbipp, Switzerland.

Solar and Lunar Transits

Even if you don't see it, the ISS also passes overhead in the daytime sky. If you plan ahead, you can occasionally see the Station passing in front of the Sun. But you must plan your observing extremely carefully — solar transits last less than *1 second* when the Sun is higher than 35° above the horizon. The transit duration decreases to roughly ½ second when the Sun is higher than 60°. Moreover, these durations are applicable only if you are close to the center of the visibility path, which is less than 12 miles (20 km) wide. For a transit of ½ second, this width decreases to less than 3 miles (5 km), but you'll benefit from the larger apparent size of the ISS, which at these times approaches roughly one arcminute.

The chances of seeing a solar transit from your backyard are extremely low. If you want to increase your chances of experiencing an ISS solar transit, you'll have to travel. Both Heavens Above and CalSky can predict the ground track where ISS transits will be visible, so use these websites to plan your imaging location. Avoid dense forests, busy roads, and private property. That said, I find scouting areas to be a big part of the adventure of shooting ISS transits. In addition to a map of the transit visibility zone, a good GPS unit for precisely determining your location is a must.



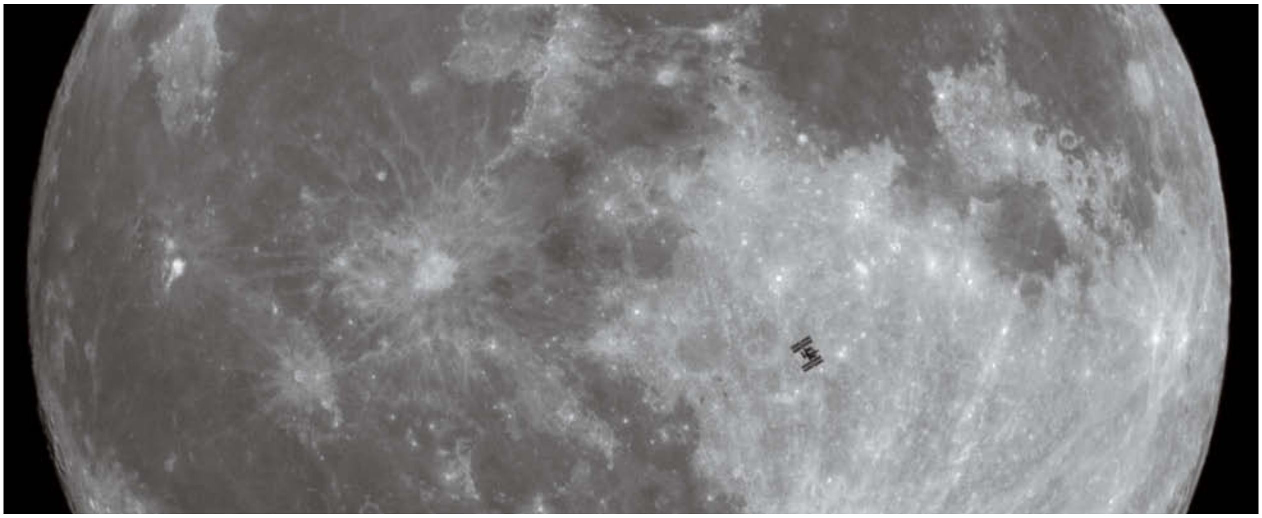
The author uses CalSky (www.calsky.com) to accurately plot the center of the visibility path of an ISS solar transit. For this particular event, the ISS achieved an apparent diameter of 37.12 arcseconds.

Once you choose a spot to set up, you may attract the attention of the local population and even the authorities: keep this article with you, it may help to explain what you intend to photograph. In all the numerous places where I have set up to shoot ISS solar transits, I have never encountered problems, just curious people.

Obviously, photographing an ISS solar transit requires the same safety precautions as any other observation of the Sun. I prefer to use a full-aperture filter made with AstroSolar Safety Film manufactured by Baader Planetarium, which provides the best performance-to-price ratio. This filter material is available in two versions, but for imaging ISS solar transits, I recommend the "brighter" photographic-density (3.8) version to allow using short exposures. Indeed, one of the difficulties of solar ISS transit photography is the apparent motion of the ISS. To "freeze" the station and avoid motion blur, I recommend exposures shorter than 1/1,000 second. Even using such lightning-fast exposures, the ISS moves almost 2 arcseconds during a 1-second transit. Short exposure times also help freeze atmospheric turbulence, which is usually worse during daytime due to the ground heating up by solar radiation.

Transits can also be photographed through solar hydrogen-alpha filters, though the relatively low transmission of these filters leads to longer exposure times than desired. A tracking mount isn't mandatory to obtain good results, but it will free you up to concentrate on other tasks instead of constantly having to keep the Sun in the center of your camera's field of view.

Whatever the type of instrument or camera you use, focus your camera on sunspots or solar granularity before the transit. The brevity of the event means that a high-quality cable release is an absolute necessity. Set the



Lunar transits by the ISS occur much more frequently than solar transits, offering more opportunities to catch one. The same telescope used to record solar transits will work just as well for lunar transits, though no special filters are required.

camera in continuous shooting mode, with the middle of your image sequence corresponding to the calculated time of the transit.

Your choice of cameras and shooting mode will dictate how many successful frames you'll capture during the crucial moments. DSLRs vary in the rate they can shoot continuous frames. For example, in RAW mode, which records the highest-quality uncompressed data, the Nikon D3s can record 9 frames per second (fps) for 5 seconds before filling up the camera's image buffer, while the Canon Rebel XS (1000D) can record only 1.5 fps for 4 seconds. In JPEG mode, rapid-fire image sequences will be longer before filling the buffer (and may not even fill the bugger with some camera models), but the quality of the images is noticeably lower. If you choose to shoot in JPEG mode, adjust the compression, sharpness, and contrast parameters to obtain the best results.

Even with a high-end reflex camera, an image sequence lasting just 4 or 5 seconds doesn't give a wide margin to account for timing discrepancies. Use an accurate time source. I use a Casio radio-synchronized watch. Common GPS units generally display the time with an error often exceeding 1 second.

Another alternative is to use the video mode of a DSLR (if available), or an astronomical video camera such as those manufactured by Lumenera, the Imaging Source, Point Grey Research, or Basler. The overall pixel count of video images will be less than that of a DSLR, but you'll be able to begin recording your video well before the transit.

Regardless of the type of camera you use, you should adjust the exposure time and ISO (or gain settings when using video) by referencing the histogram function in your camera or recording software so that the solar disk is bright but avoids saturation. Higher ISO or gain values increase noise in your images, and respond less favorably to sharpening. Because your target is moving between frames, the images cannot be stacked to reduce noise.

To record the full solar disk on the image, your telescope's focal length (in millimeters) should not exceed 100 times the shortest dimension of your camera's sensor. For example, when using a camera with an APS-C sensor measuring 15-by-22 mm, you should use a focal length no greater than 1,500 mm. A full-frame sensor (24-by-36 mm) can comfortably fit the entire solar disk on the detector using focal lengths up to 2,400 mm.

Lunar transits present many similarities with solar transits, except there's no danger to your vision or equipment while recording the event. The apparent diameters of the Moon and the Sun are the same, so the focal-length rule above is also applicable. However, a quarter or a crescent Moon can be aligned with the large dimension of the sensor, allowing you to increase the focal length a little bit. Of course, the briefness of the transit requires the use of short exposures, and because the Moon is much fainter than the Sun, you'll need to significantly increase the ISO

Emmanuel Rietsch extensively modified the author's equatorial tracking mount to enable variable-speed tracking and wireless controls. Note the additional finderscope with attached camera used to autoguide on the ISS. Another useful accessory is a flip-mirror, which helps the author precisely align the main telescope and guidescope.

setting or video gain to freeze the Space Station's motion.

A lunar transit can occur anytime: at twilight as well as in the middle of the night or even in full daylight. Depending on the circumstances, the ISS will appear as bright as the Moon's surface (or even brighter) if it's illuminated by the Sun, or as a dark silhouette if it's in Earth's shadow.

For good results, careful preparation (including study of the weather forecasts), and mastery of your equipment will pay large dividends.

High-Resolution Imaging

Taking high-resolution pictures is perhaps the most challenging way to photograph the ISS, and prior experience with planetary imaging is extremely advantageous. Despite an apparent size close to that of Jupiter or Venus during zenithal passes, the Space Station's great speed makes it exceedingly difficult to keep on your camera's sensor, particularly when using long focal lengths.

I suggest practicing airplane imaging in the daytime. When first attempting to track fast-moving targets, use a well-aligned finderscope with a clearly visible reticle. Loosen the axes of your mount and try to manually track airplanes passing at high altitude. If you can keep them within your sensor's field of view during a significant part of the run, then you should be able to succeed when shooting the ISS. Dobsonian mounts with smooth axes are useful for manually tracking the ISS, although the German amateur Dirk Ewers obtains very nice images with an equatorial mount. Until recently, the motorized systems of most equatorial or altazimuth mounts could not adequately track the ISS, but Software Bisque's mounts controlled by *TheSkyX* are notable exceptions.

My solution to the high-speed tracking problem was to have my friend Emmanuel Rietsch modify my Takahashi EM-400 German equatorial mount by replacing most of the internal electronics and motors, and incorporating

THIERRY LEGAULT / EMMANUEL RIETSCH

Capturing high-resolution views of the ISS will push your telescope and tracking abilities to their limits, but the results can be worth the effort. This close-up series of the Space Station clearly resolves the large solar panels that provide power to the outpost. Also visible is the Space Shuttle *Endeavour*, which was docked for its last visit on May 29, 2011.

Each Space Station pass presents observers a series of rapidly changing perspectives. The same techniques used to capture the ISS can be used to record any orbiting spacecraft. When NASA's Space Shuttle (shown here) was in service, it was a popular target for satellite chasers.

THIERRY LEGAULT / EMMANUEL RIETSCH

wireless controls. Additionally, Rietsch wrote a custom program to enable autoguiding on the target using a tandem-mounted finderscope equipped with an autoguider camera. He has recently adapted a less-expensive Orion EQ-G mount with similar features.

Use of these modified mounts requires them to be set up as if the axis of the ISS pass is the axis in which to align the mount. Thus, calculating the elevation and east/west offset of this imaginary polar axis is required for each ISS pass.

The best cameras for high-resolution ISS imaging are without a doubt the high-speed video cameras mentioned above, though a DSLR or a compact camera in video mode is also usable. The modules and the radiators on the ISS are white and reflect sunlight extremely well, so exposures shouldn't exceed a few milliseconds. The solar panels on the ISS are orangish and are often nearly invisible.

Any telescope can resolve the ISS, though larger-aperture instruments will produce a brighter image at longer focal lengths. The only guide with regard to the telescope's focal length is to amplify it as much as possible, within the limits of your tracking abilities. Focus on a bright star, planet, or the Moon before an ISS pass. When using Schmidt-Cassegrain telescopes, be aware of focus changes while tracking the ISS across the sky due to shifting of the primary mirror. A good mirror-locking system is mandatory to achieve the best results.

Once you've successfully recorded an ISS transit video, simply scan through the frames to find a series of several consecutive images that could potentially be stacked to improve the image's signal-to-noise ratio. Just as with planetary imaging, noise is the enemy, and sometimes noise can be confused with real details, especially if you aggressively sharpen your image — even up-sampling the image can cause confusion. I tend not to use much sharpening to avoid over-interpeting my results.

Catching satellites adds yet another level of interest to our hobby. And using the tips described in this article, you can image detail on many satellites orbiting Earth, including discarded rocket stages and even the Hubble Space Telescope. ✦

French amateur astronomer ***Thierry Legault*** *is world renowned for his high-resolution images of the planets and satellites. Visit his website at* ***www.astrophoto.fr****.*

Sean Walker
Gallery

▶ **GALAXY ON EDGE**

Al Kelly

Edge-on spiral galaxy NGC 891 in Andromeda presents a thick dust lane that's visible in large telescopes.

Details: *Celestron CGE 1400 Schmidt-Cassegrain telescope with Orion Parsec 8300C CCD camera. Total exposure was 5⅙ hours.*

▼ **THE COLORFUL HELIX**

Lynn Hilborn

The Helix Nebula, NGC 7293 in Aquarius, displays radial clumps of material ejected from its dying central star.

Details: *TEC 140 refractor with FLI MicroLine ML8300 CCD camera. Total exposure was 5 hours through Astrodon Hα and O III filters.*

WISPS WITHIN VIRGO

Fabian Neyer

This deep exposure reveals faint and rarely seen cirrus nebulosity that resides in the Milky Way in the direction of the Virgo Cluster of galaxies. **Details:** *Borg ED101 refractor with SBIG STL-11000M CCD camera. Total exposure was more than 36 hours through Baader Planetarium color filters.*

◂◂ AUTUMN METEORS

Sebastian Voltmer (2x)

While photographing panoramic nightscapes, French amateur Sebastian Voltmer captured two bright bolides within minutes as they pierced the tranquility of the night over Spicheren, France, on the evening of September 28, 2011. **Details:** *Canon EOS 5D DSLR camera with 16-mm lens. Each photo is a panorama consisting of multiple images.*

Gallery showcases the finest astronomical images submitted to us by our readers. Send your very best shots to gallery@SkyandTelescope.com. We pay $50 for each published photo. See SkyandTelescope.com/aboutsky/guidelines.

MOONRISE ECLIPSE

Arne Danielsen

The Moon rises while departing Earth's shadow as seen from Oslo, Norway, during the total lunar eclipse of December 10, 2011. **Details:** *Canon EOS 5D Mark II DSLR camera with 70-to-200-mm zoom lens at 200 mm. Single one-second exposure at ISO 400.*

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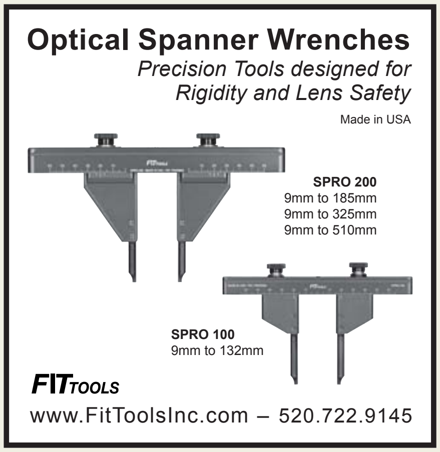

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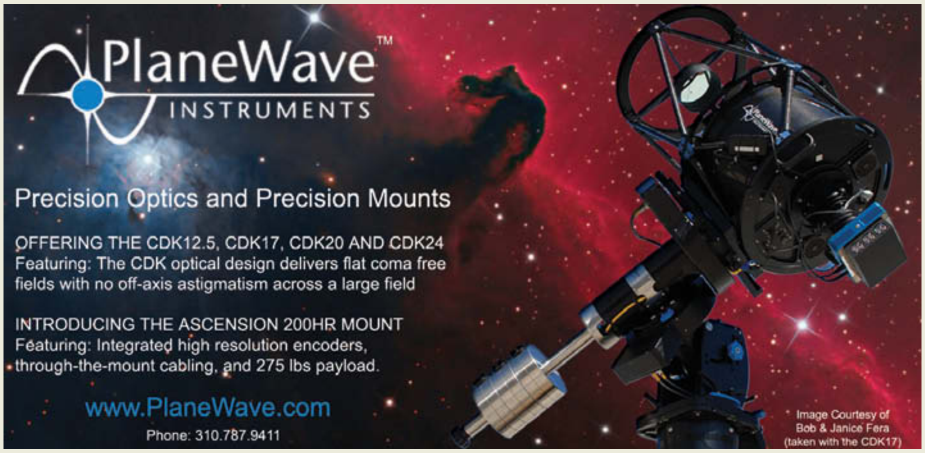

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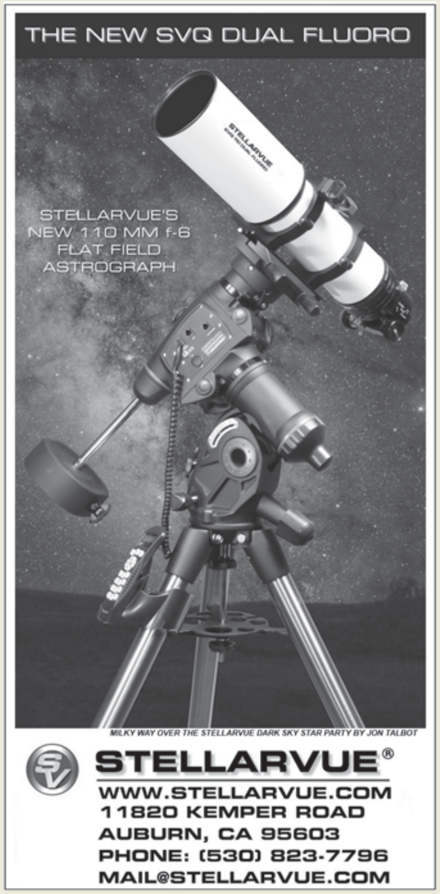

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My Interest in Stars Coalesces

Observing a comet as a young boy triggered the author's interest in astronomy.

Comet Arend-Roland

LOWELL OBSERVATORY

On a clear night when I was in second grade, my dad took me for an outing I never forgot. I was told we were going to a place where it was so dark we could see the stars. Driving only a mile or so, we were away from neighborhood lights, and in the twilight waited for the deepening darkness. We buttoned our jackets and hiked along a short trail, arriving at the vista of a small lake. It was early spring and at first I was more interested in listening to frogs than watching the stars. A star here and there popped into visibility. Already immersed in a croaking crescendo from nearby water-logged friends, we were soon bathed by starry pinpoint lights.

There was little light pollution in the Empire, Oregon sky of the mid-1950s. The Milky Way's sheen was easy to see. But as twilight faded, the grand prize was hanging affixed, a bright comet that couldn't be missed. It appeared as a beacon in the growing blackness, head up, halfway between the treed horizon and the zenith. I wondered what the tail was made of and how it could be so bright. By itself, the dark sky with its myriad of glistening diamond stars would have been splendid enough, but on this night, the comet spectacle was the centerpiece. Other brilliant stars were mere wallpaper to the comet image from that evening, steadfast against their twinkling visage.

The frogs continued their monotonous tome. When I moved or stepped on a twig, they turned quiet in my vicinity. But not for a moment did they consider the highlight afar. They all missed out on what surely would've been the visual capstone of their lives. But their brains and sensory apparatuses, wired only to watch for nearby intruders, weren't equipped to consider a distant visitor. How many people pay attention to a comet's apparition? How often do we behave as frogs and not lift our chin to enjoy a star?

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Diverted by a splash for only a moment, my gaze then returned upward and I almost gasped. My attention was riveted by the chunk of brightness glued to heaven. One might have guessed it would barrel on through, gone in a flash. But it was a piece of space reality, hanging there still, loitering in the air as a stationary airplane laughing away the tug from gravity.

Dad packed me up in his old GMC cruiser and I bombarded him with questions all the way home. I watched the comet for a few more nights, but couldn't see it nearly as well. There were also complications with school bedtime hours. The comet's brightness dimmed, rains moved in, and pretty soon it was gone. I had hoped to watch it longer, but reality sometimes gets in the way.

Later, I figured out, as the only bright comet from that time, we had observed Comet Arend-Roland after it rounded the Sun. I've seen many more comets since, but I have yet to view a comet as gloriously real as in the spring of 1957. Months later, Sputnik launched another cosmic paradigm shift, but for me, the comet of 1957 was how the stars began to provide a special appeal. ✦

Jim Higgs is a semi-retired human resources consultant who has held executive positions in several high-technology companies. He continues active involvement in amateur astronomy (when it's clear) from Portland, Oregon. He is nearing publication of a book titled Through a Childhood Lens.