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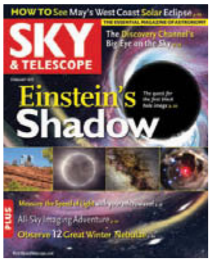
SKY & TELESCOPE

February 2012

VOL. 123, NO. 2



On the cover: Gas and dust swirling into a supermassive black hole won't hide the beast from the Event Horizon Telescope.

ILLUSTRATION; *S&T*: LEAH TISCIONE
INSETS FROM LEFT TO RIGHT: EDWIN L. AGUIRRE & IMELDA B. JOSON, *S&T*: DENNIS DI CICCO, NICK RISINGER, H. BOND / STSCI

FEATURES

THIS MONTH'S SKY

ALSO IN THIS ISSUE

S&T: DENNIS DI CICCO 1994

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TV & Free Digital Subs

At *S&T*, we're always looking for new ways to spread the word about astronomy. At the same time, video has become vital to learning and an integral part of the web experience. As part of our core mission, *S&T* has launched a major new video initiative, building upon the popularity of our website's Weekly Sky at a Glance section and our free *SkyWeek* app.

We're working with Powderhouse Productions of Somerville, Massachusetts, to record weekly episodes about what's up in the night sky. Written and hosted by associate editor Tony Flanders and named *SkyWeek* (after our app), these episodes will be available in 1-, 3-, and 5-minute segments. The 1- and 3-minute versions started to air in late November on several public television stations. The episodes air during the gaps between the regularly scheduled programming. The 5-minute version will be posted every week on our website at **skyandtelescope.com/skyweek**.

"I've had more fun writing and hosting *SkyWeek* than anything else I've done in my last five years at *Sky*," says Tony. "I love showing and explaining the glories of the night sky at public star parties, and this TV program is like a star party for the entire country."

We want to extend a special thanks to our sponsors Meade Instruments and Software Bisque, whose generous support helped make *SkyWeek* possible. We also want to thank Powderhouse and our former editorial intern Shweta Krishnan, who is now using her video talents at Powderhouse to help launch this project.

Speaking of Shweta, she has produced an entertaining and informative video celebrating *S&T*'s 70th anniversary. The video features interviews with current members of the editorial and art staffs, and former editors. We discuss the history of *S&T*, what it's like to work at *S&T*, and what we're planning for the future. If you haven't seen it yet, I welcome you to check it out by visiting **skyandtelescope.com/70Years**.

Last but certainly not least in importance, I'm very excited to announce that starting with this issue, all *S&T* print subscribers can sign up for a free digital subscription to *S&T* by visiting **SkyandTelescope.com/SubscriberServices**. A digital sub will allow you to receive the magazine a few days before it arrives in the mail (or perhaps weeks if you live in an area with slow or inconsistent mail delivery), and to quickly link to the various websites and bonus content that we provide in many of our articles. We are also working feverishly on an electronic edition of *S&T* optimized for iPads and other tablet computers, and that should be available in the near future.

Robert Naeye
Editor in Chief

SKY & TELESCOPE
Founded in 1941 by Charles A. Federer, Jr. and Helen Spence Federer
The Essential Magazine of Astronomy

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Worries about Webb

I found the December Focal Point, "Why We Should Build Webb" (*S&T*: December 2011, page 86), problematic. Yes, the Webb will be a fantastic instrument when/if it gets built and launched, but it will cost more than *five* times the original planned budget. It is devouring many other worthy astronomy and space-science missions. Is it a good idea to reward a project so low-balled and mismanaged? Dr. Hammel states that to finish and operate the Webb, NASA will have to "reallocate $3.6 billion over the next 12 years." Last I checked, $3.6 billion bought a flagship planetary mission, such as the Cassini-Huygens mission or a large chunk of the proposed Jupiter Europa Orbiter, or several smaller projects. NASA's budget is not a zero-sum game, but it's close enough for practical purposes.

On an unrelated note, I recall this year that when you published your finder chart for Pluto, there was some speculation in the article that you may not continue to do these every year. For me they are extremely appreciated. I am an old "star-hopping" guy and I used your chart both last year and this year to find Pluto for the first time in my decades of stargazing using my unguided, no DSC 16-inch Dobsonian. I'll do it on an annual basis as long as you publish the chart.

I've had a continuous subscription of *S&T* since June of 1968, when I was 10 years old. Thanks for your fine publication.

Tom Richter
Austin, Texas


S&T: LEAH TISCIONE

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Editor's Note: *We plan to continue publishing the yearly Pluto finder chart. For additional discussion of Webb's complications, see the January 2010 issue (page 8) and the March 2011 cover story about the Decadal Survey.*

The Quest for Jupiter's Shadow

Theoretically, all light sources can produce shadows. Shadows produced by celestial lights such as the Moon and Venus are well-known, but recently (just before my 15th birthday) I decided to try for something harder: photographing a shadow cast by Jupiter. On November 2, 2011 at around 1 a.m., just after the October 29th opposition, I was able to do just that.

I succeeded in this crazy idea at Parc du Mont-Mégantic, under +6 magnitude skies, a three-hour drive east of Montreal. With the help of my mentor, Sébastien Gauthier, I designed and built a modified equatorial sundial so that I could shoot longer exposures to capture more light and thus improve my chances of photographing the shadow. Among the equipment used were his Losmandy Gemini-8 mount, his Nikon D700 DSLR, and a 60mm macro lens kindly lent to us by Nikon Pro Services Canada.

On the night of November 1st, my father and I drove to Mont-Mégantic. By midnight we had set up the equipment and polar aligned, powered, and focused it. It was windy, below freezing, and I could hear the local wolf pack coming nearer and nearer. . .

I took three photographs to prove that


LAURENT V. JOLI-COEUR

Jupiter could indeed cast a shadow. The first one, a five-minute exposure at ISO1600 with an in-camera dark subtraction, was taken to capture the shadow. The gnomon's shadow was clearly visible on the projection screen when I stretched the image. This wasn't enough to prove it was Jupiter's, however. To do so, I slightly moved the mount in right ascension for the second exposure, expecting the shadow to move sideways. And it did. The third and final exposure was taken in a region of the sky far away from Jupiter. As the last image showed no sign of the gnomon's shadow, I concluded that the only possible explanation for the shadow in the first two images was Jupiter!

This experiment was a great adventure, a highlight in the seven years I've been an astronomer.

Laurent V. Joli-Coeur
Montreal, Canada
www.youngastronomer.com

Bring Back the Banner

The cover of the November 2011 issue, celebrating 70 years of *Sky & Telescope* history, made me wonder when and why it came to be that the long-enduring cover banner ("Sky" in partial script font, with a telescope icon) was changed to the red square with only the magazine's name in block letters.

The distinctive magazine cover did go through a few changes, but for the most part it retained its distinctiveness in spite of those changes. But my observation is that the current cover banner does not have the distinction it once had.

Regardless, I remain a loyal and contented subscriber to *Sky & Telescope* magazine.

Ken Gotsch
Bridgeton, Missouri

Editor's Note: *The magazine has had only three cover banners since its founding in 1941. The original, which you refer to, was a combination of the banners from the two magazines that joined to form* Sky & Telescope: The Sky *and* The Telescope. S&T *dropped that banner in January 1980 because, frankly, it looked like the magazines of a bygone era — at a time when American culture considered "old-fashioned" to be a really bad thing. The staff was concerned that the 1941 logo was losing us potential new readers.*

The current red block banner began in January 1991 as part of the first serious campaign to increase newsstand sales, as publisher Bill Shawcross wrote in that issue. The newsstand distributor for the campaign insisted on a cover banner that met certain specs for newsstand visibility; hence the current banner was born.

Viscous?

I'm worried about the use of "viscous" in the article "Where the Hot Stuff Is" (*S&T*: July 2011, page 20). Both the text and one of the image legends claims that only extremely viscous lavas could explain the long flows. But highly viscous lava flows hardly anywhere, by definition. In fact, it's the extremely viscous lavas that often block volcanic channels and are blown out during explosive eruptions.

In sum, wouldn't lavas of extremely *low* viscosity be the best explanation for the long flows?

Ken Vines
Horrabridge, Devon, England

Editor's Note: *The reader is correct. The sentence should have read "This means that the lavas must have been very fluid, to allow them to flow such long distances."*

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

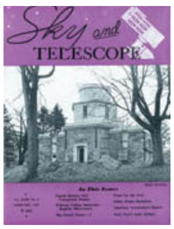
75, 50 & 25 Years Ago

Roger W. Sinnott

February 1937

Trailblazing Optics "An interesting and instructive visit to the U. S. Naval Observatory in Washington, D. C. was made by members of the Amateur Astronomers Association. . . . [We saw] the forty-inch Aplanatic Telescope, . . . [The primary mirror's] curve is not a parabola, but a hyperbola."

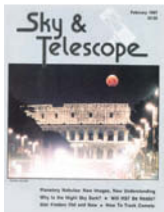
In writing their trip report, Grace Scholz and Robert Cox could hardly have guessed that most of today's largest reflecting telescopes share the Ritchey-Chrétien design.



February 1962

Space Fluff "An Aerobee-150 rocket called the 'Venus flytrap' was successfully fired from White Sands Proving Ground. . . . For nearly four minutes, while the rocket attained its maximum altitude of 168 kilometers and descended to 116, the 'flytrap' collectors were subject to micrometeorite bombardment. . . . Dr. Hemenway reported . . . three types of particles [were caught] that did not appear on the laboratory or control surfaces. They are dense spheres with sharp edges, ranging in size down to a few tenths of a micron or less; irregular submicron particles; and extremely irregular pieces of 'fluff.' "

Curtis L. Hemenway of Dudley Observatory pioneered studies like this one, but the origins of many micrometeorites remain puzzling.



February 1987

Far, Far Away "One of the most troublesome problems astronomers face in studying planetary nebulae is determining their distances. Various methods now in use disagree by factors of two to four. . . . [My team's] baseline radio images have already produced extremely accurate and detailed radio brightness distributions for these nebulae. . . . Two to three years from now we will repeat these VLA observations, figure the rates of angular expansion, and compute the distance to each nebula."

Planetary nebula distances found by Yervant Terzian (Cornell University) and his team's technique are among the most accurate known.

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

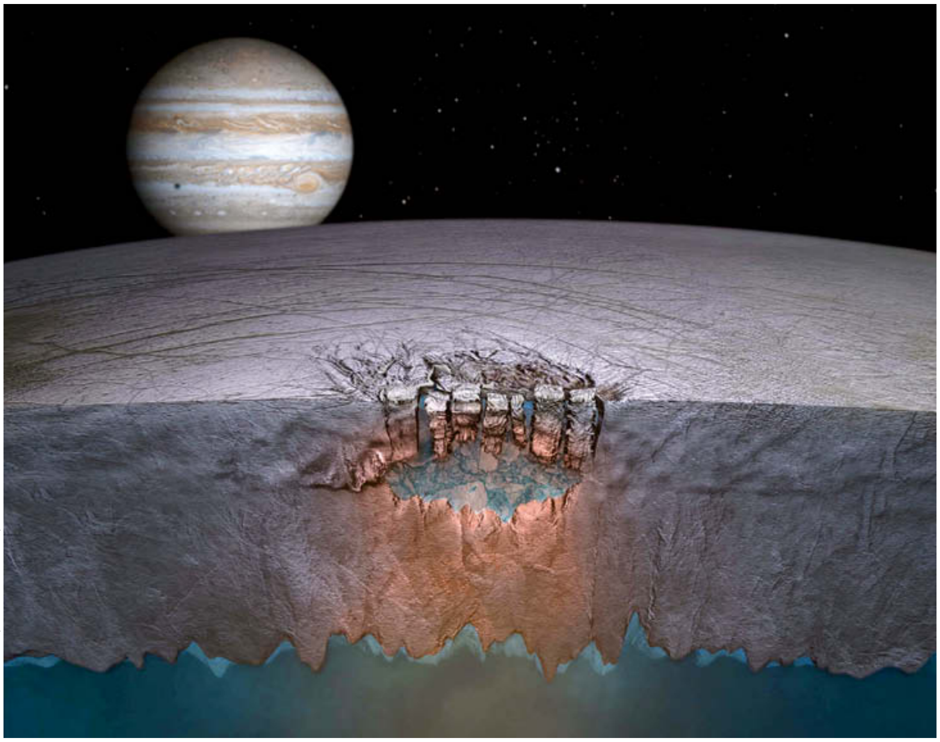
Active Lakes in Europa's Icy Crust

Inside the thick ice crust of Jupiter's moon Europa, well above the deep ocean far beneath, large lakes of water may sometimes crack apart their icy lids and wreak havoc with the surface. A new study concludes that Europa's strange "chaos terrains" stem from the breakup and refreezing of ice over extensive pools of water — one of them with the volume of North America's Great Lakes — just a mile or two down.

Water and ice are nothing new on Europa. Planetary scientists have long concluded that a deep ocean hides beneath the moon's mostly smooth, cracked-lined surface. But no one had a good explanation for the chaos terrains. These are rugged areas of jumbled ice, raised domes, and sunken depressions up to hundreds of kilometers wide. Astronomers first got a close look at them in the late 1990s with NASA's Galileo Jupiter orbiter. The images "made us step back and wonder what's going on," says Geoffrey Collins (Wheaton College), a planetary scientist and Europa researcher.

Particularly troublesome was the question of how to create the relatively high domes, such as those seen in the region called Conamara Chaos. They average some 700 feet (200 meters) tall, much higher than expected if they resulted from water emerging or plumes of warm ice pushing up from below — the two main competing theories.

The new model, set forth by Britney Schmidt (University of Texas at Austin) and her colleagues, draws on observations of Earthly ice activity, especially formations over subglacial volcanos and the breakup patterns of ocean ice shelves undermined by warmer currents.



BRITNEY SCHMIDT / DEAD PIXEL VFX / UT-AUSTIN

In this artist's depiction, a tidally heated warm spot in Europa's crust forms a subsurface lake that fractures and crumbles the overlying layer as it melts and refreezes.

In Schmidt's scheme, deep regions of Europan ice become buoyant compared to their surroundings, due to warming by the tidal flexing that happens as Europa orbits Jupiter. The warmer ice forms into plumes that push up through the thick shell. As a plume nears the surface, its pressure on the overlying brittle ice causes this ice to melt. The meltwater becomes what on Earth is called a *perched lake:* a lens-shaped body of water between ice above and below. The trapped water creates new cracks and widens old ones in the overlying layer, which seems to be just a couple of kilometers thick. Eventually the ice breaks up into big bergs surrounded by crushed chunks.

"You never have liquid water on the surface," says Schmidt. "As those big, strong icebergs move around, they can break up all the weak ice in between, which can fill with water — still not liquid [on top], but filled with water." The percolating water enriches the rubbly material with salty contaminants, giving it a different mineralogical signature than the cleaner ice elsewhere. Eventually the perched lake and overlying rubble refreeze.

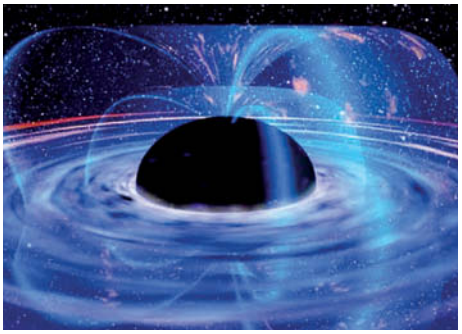
The strength of the new scenario is this: water takes up less space when liquid than when solid, so the melting of the lake causes the surface above to collapse, like in the Thera Macula region, whose rough-and-tumble terrain lies about 2,600 feet (800 m) below the surrounding ice plains. When the rubble and lake refreeze, the expanding ice "gives you the extra boost needed to pop that surface back up into a dome," Schmidt explains.

"It is a very convincing model," concludes Europa expert Robert Pappalardo (Jet Propulsion Laboratory). "It seems to explain a wide variety of observations."

One observation the model explains is why the ice in chaos regions is contaminated with compounds that seemingly came from below. And circulation between Europa's various layers is important not just for what comes up, but what goes down. The latter has implications for whether life could exist in Europa's deep ocean. The cycling of ice could provide a way for oxidants created on the surface to reach the depths and provide the energy flow necessary to drive biological processes. Says Tori Hoehler (NASA/Ames Research Center), "I think this really impacts the way we consider habitability on Europa."

NASA / JPL / UNIV. OF ARIZONA

Ice blocks, depressions, and jumbled terrain cover Conamara Chaos on Europa. In this color-coded image from Galileo, white is ice dust from a distant impact, rusty brown indicates contaminants that have emerged from below, and turquoise marks relatively old ice plains. The frame is about 19 miles (30 km) wide.



NASA

An artist's highly symbolic representation of the Cygnus X-1 black hole and its X-ray-hot inner accretion zone.

Cygnus X-1, Exactly

Backyard telescope users seeking to spot a stellar-mass black hole, or the next closest thing, have one good option: Cygnus X-1, which is locked in a close, 5.6-day orbit with a 9th-magnitude blue-giant star visible halfway down the Northern Cross. A 3-inch scope and the right chart will do the trick. The star's powerful X-ray companion became the first and best black-hole candidate starting in 1972. It has been studied intensively ever since.

For four decades, however, astronomers were unable to determine the hole's exact nature, because the system's distance remained stubbornly inexact. As of 2011 the best distance measures still ranged from 5,800 to 7,800 light-years.

Now we have a much better value. Using very-long-baseline interferometry, a radio-astronomy team led by Mark Reid (Harvard-Smithsonian Center for Astrophysics) measured the system's tiny trigonometric parallax due to Earth's annual motion around the Sun. Their parallax measurement, 0.539 ± 0.033 milliarcsecond, yields a distance of 6,070 ± 300 light-years, more than a threefold improvement.

Plug that distance into previous studies, and the black hole's mass comes out to be 14.8 ± 1.0 Suns. That means its event horizon is close to 90 km (56 miles) across. The mass of the blue-giant companion comes out to 19 ± 2 Suns.

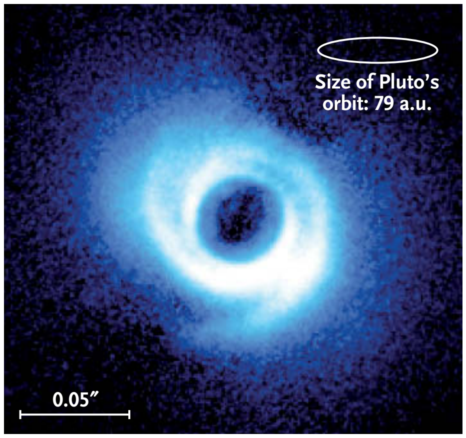
In addition, the hole's spin of more than 800 revolutions per second works out to be more than 95% of the maximum spin possible (defined as the event horizon rotating at essentially lightspeed). This is faster than could result from the hole accreting matter from its orbiting companion. It must have had a high spin at birth.

The new distance also allowed the group to find the system's space velocity with respect to its surroundings: a mere 21 km per second. This means it received little or no kick from a supernova explosion, supporting a theory that the parent star collapsed to form the hole directly, with no supernova fireworks involved.

A Young Star's Spiral Arms

The tally of confirmed extrasolar planets just crossed 700, and NASA's Kepler mission has announced another 1,700 likely ones awaiting follow-up. But even today, no one really knows the details of how planets form. Computer models indicate that the process is complex and confusing. The big picture is clear enough: as an interstellar cloud collapses under its own gravity, it organizes itself into a central star containing most of the mass, circled by a big disk of gas and dust containing most of the angular momentum. But exactly how does the disk then birth planets? Researchers have good ideas backed by ever-more-sophisticated simulations. But they don't know what the process actually looks like.

Remarkable new images from the Subaru Telescope provide a glimpse. In the image below, the masked-out central star is SAO 206462, a 9th-magnitude



NAOJ / SUBARU

Two spiral arms emerge from the dusty disk around SAO 206462 (masked out at center). This image, acquired by the Subaru Telescope using its HiCIAO adaptive-optics system, is the first to show such features clearly.

solar-type star 450 light-years away in Lupus. It's estimated to be just 9 million years old. Surrounding it is a dusty disk about 1 arcsecond across, which at that distance is roughly twice the size of Pluto's orbit. The disk, nearly face-on, sports two "wings" arcing outward. Such extensions have been seen around other young stars, but never this clearly. The image is a credit to Subaru's 8.2-meter aperture, its adaptive-optics imager, and the stable, rarefied air over Mauna Kea, Hawaii.

Carol Grady (Eureka Scientific) unveiled the image in October at a NASA-hosted conference dubbed Signposts of the Planets. The arms hint that one or more massive young planets are disturbing the disk from the inside. "Detailed computer simulations have shown us that the gravitational pull of a planet inside a circumstellar disk can perturb gas and dust, creating spiral arms," Grady explains. "Now, for the first time, we're seeing these dynamical features."

Modeling indicates that a single planet could create two arclike extensions, but in that case they would be symmetrical. The arms extending from SAO 206462 are not, suggesting that two planets are in play.

Grady and her team note that processes unrelated to planets could also be creating the spiral arcs. So now the search is on to detect the young planets directly, by the infrared glow they may be emitting.

The Oddly Magnetic Moon

Our Moon must have had a complicated childhood. No simple scenario of what happened to it works, and we can add newly refined magnetic data to the mess. Modern precision dating of Moon rocks from the Apollo program indicates that lunar magnetic fields were present well after theory says the Moon's internal dynamo should have died out.

Two new papers offer explanations. The problem is keeping the Moon's interior molten and convecting after it should have cooled and hardened. That cutoff date was around 4.2 billion years ago, according to models of the Moon's evolution. Yet magnetic traces pop up in lunar rocks that are hundreds of millions of years younger.

Magnetism doesn't have to come from a core dynamo. Impact-created plasmas could create local, short-lived fields lasting about a day, perhaps enough to magnetize rocks. But there are too many magnetized rocks for that scenario to be convincing.

In one new idea, the spin axes of the Moon's early liquid core and the mantle were askew from each other. If the two layers rotated differently, precessing with respect to each other due to tidal forces from the then-nearby Earth, the liquid could have remained stirred up.

Another theory stirs the core by moving the mantle in a different way: by smacking it with impacts big enough to knock the Moon out of synchronous rotation. "The large impacts that we need in our model to make a dynamo were present around 4 billion years ago," says coauthor Michael Le Bars (Aix-Marseille University, France). The hits came within about 100 million years of one another, he notes, and each could have created a temporary dynamo lasting 2,000 to 8,000 years.

NASA / JPL / USGS

Some of the Moon's lava-filled impact basins show nicely in this mosaic of images taken by NASA's Galileo spacecraft as it flew past on its way to Jupiter. Researchers studying three of the basins seen here, Serenitatis, Humboldtianum, and Crisium (near 8 o'clock, top center, and 6 o'clock) suggest that the impacts that created them could have restarted the Moon's internal magnetic dynamo.

Pluto and Eris: Neck and Neck

The final results are in from the November 2010 occultation of a 17th-magnitude star in Cetus by Eris, the distant dwarf planet that seemed to surpass Pluto for size after it was discovered in 2005.

The result: It's now a dead heat.

Only three observatories managed to record the occultation, but that was enough. Eris has a diameter of 1,445 miles (2,326 km) with an uncertainty of just 0.5%, say Bruno Sicardy (Paris Observatory) and his team. That's assuming Eris is spherical.

Pluto, as best we can tell, is between 1,430 and 1,490 miles wide. In Pluto's case, occultations of stars can't reduce the uncertainty because Pluto's tenuous atmosphere muddies the exact timing of when a star winks out and reappears. We won't know Pluto's girth for sure until the New Horizons spacecraft flies by in July 2015.

Eris, however, is still the King of the Kuiper Belt in terms of mass. Both it and Pluto have satellites, whose orbits reveal the masses very accurately. Eris is a good 27% heftier and denser. "The only plausible way is if Eris contains substantially more rock in its interior than Pluto," explains Mike Brown (Caltech), who led the team that discovered Eris. "In fact, the amount of extra rock that Eris contains is about equal to the mass of the entire asteroid belt put together."

Given its 19th-magnitude brightness,

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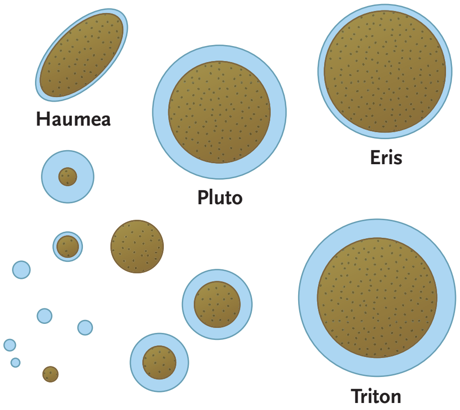


SOURCE: MICHAEL BROWN (CALTECH)

All Kuiper Belt objects with known densities are shown in cutaway, assuming that they consist of rock (brown) and ice (blue). Although Eris and Pluto are nearly the same size, Eris is 27% denser. Compositionally, Pluto may be more like Neptune's captured giant moon Triton.

the new, smaller Eris must have an incredibly reflective surface — literally as white as snow, or whiter. Astronomers already knew that Eris was covered with white frozen methane, but the occultation result pushes the reflectivity to an even greater extreme: 96%. Over time an icy surface should darken due to cosmic radiation and micrometeorite impacts. The only good explanation is that Eris generated a thin methane atmosphere when it last reached perihelion (in the late 1600s). Then, as Eris edged farther back outward from the Sun to its present distance of 97 a.u., those wisps froze out as a blanket of fresh frost no more than a few centuries old. It can't be more than inches thick.

If there's anything left of that atmosphere, the occultation didn't detect it. Sicardy's team reports an upper limit of about 1 nanobar — one-billionth the pressure of Earth's atmosphere and about 10,000 times more tenuous than Pluto's.

Expanding Universe: Credit Where Due

The one-sentence version of history says Edwin Hubble discovered the expansion of the universe in 1929, by comparing his measurements of galaxies' distances to their redshifts. That's why his name is on the Hubble Space Telescope.

Another bit of once-sentence history is that Georges Lemaître, a Belgian priest and mathematician, is "the father of the Big Bang." In the 1920s he and Alexander Friedmann proved that the equations of Einstein's general relativity require the universe to be either expanding or contracting, not standing still. In the 1920s no one believed this was actually happening, including Einstein. That's why Hubble's discovery just a few years later was a world-shaker.

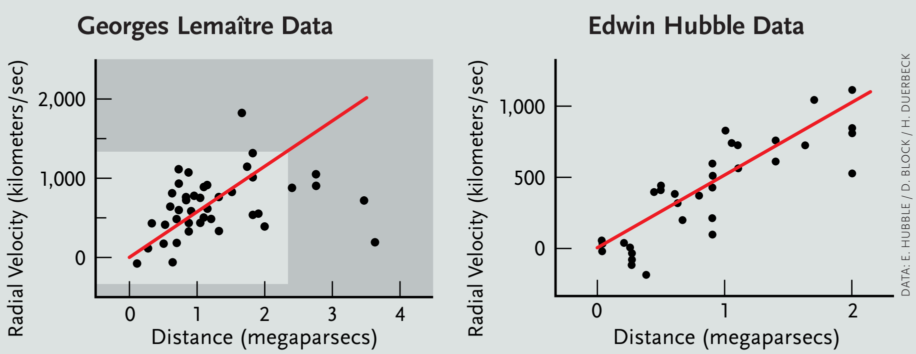
But history is rarely simple, and now it turns out that Lemaître deserves some credit for confirming his own theory.

Several history sleuths have unearthed an obscure paper by Lemaître from 1927, two years before Hubble's announcement, in which he correlated galaxies' measured redshifts with rough distance estimates based on their apparent sizes and brightnesses. The graph below plots the data he used, in the form of a "Hubble diagram." Its scattered dots barely show a trend at all, but they were enough for Lemaître to propose possible cosmic expansion rates of 625 and 575 km per second per megaparsec — history's first stabs at the "Hubble constant."

Hubble's clearer Hubble diagram in 1929 used his own better distance measurements of galaxies, based on his work measuring the brightnesses of their Cepheid variable stars. In Hubble's diagram, the distance-redshift correlation shows clear statistical significance, though he too announced a Hubble constant that was much too high: 530 km/s/Mpc.

Lemaître was not one to pick priority fights. In 1931 he passed up a chance to call attention to his 1927 work, saying in a newly discovered letter, "I did not find it advisable to reprint the provisional discussion of radial velocities which is clearly of no actual interest...." Looking at the graph, one might agree.

Still, first is first. Could there someday be a Lemaître Space Telescope? ✦



DATA: E. HUBBLE / D. BLOCK / H. DUERBECK

CATHOLIC UNIV. LOUVAIN / CARNEGIE INST. OF WASHINGTON

In 1929 Edwin Hubble published his history-making plot of galaxies' distances versus redshifts *(top right)*. But two years earlier, Georges Lemaître had already found signs that faraway galaxies recede faster than near ones. At top left is a modern plot of the data he used. Ignore the lines; just look at the dots. The trend is vaguer in Lemaître's plot, but it seems real. (The lighter box in Lemaître's graph is the area covered by Hubble's.)

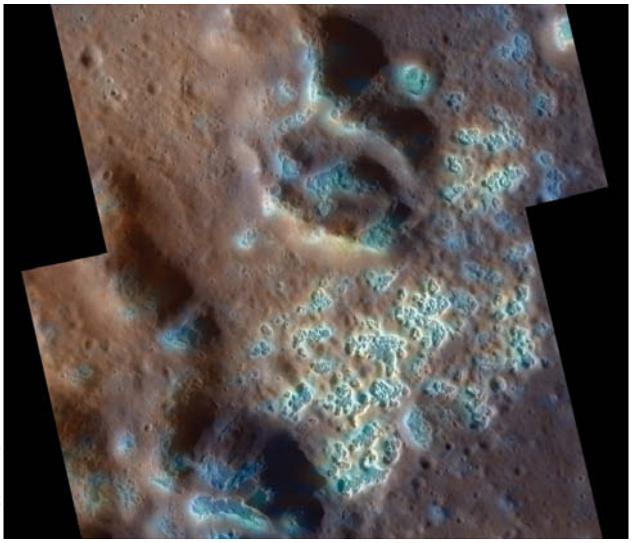
My Apologies to Mercury

The innermost planet is a lot more interesting than the author realized.

For decades I underestimated you. In the August 2011 issue, I callously lumped you in with the Moon, writing that you're both "dead" in an unflattering comparison with our solar system's more active and beautiful orbs.

In lectures, articles, books, and street-corner rants I confidently described you as interesting mostly in comparison with other rocky and senescent orbs. Your story served as a cautionary tale of "don't let this happen to your planet." Furious impacts during formation left you with only a metallic core and a flimsy mantle of battered, desiccated rocks from which all of the active and biogenic "good stuff" (water, sulfur, carbon, etc.) was driven off to regroup peacefully elsewhere in the solar system in clouds, ices, oceans, or rocks.

You were a topic of forensic planetary investigation — the time and manner of your death was of interest mainly to planetary-formation theorists. But you were not a place where very much would be happening today, save the knocking about of surface atoms by energetic solar particles.



PITS ON MERCURY This enhanced-color Messenger image of Mercury shows mysterious pits (whitish blue) known as hollows that may have formed from vaporizing solid materials.

NASA / JHU APL / CARNEGIE INST. OF WASHINGTON

I was at least partially wrong. Mercury is still the outlier at the dense, scorched inner end of our planetary system; vast areas are indeed ancient and cratered. But by giving Mercury its first comprehensive exam, NASA's sharp-eyed Messenger spacecraft has found things that should not be there. The hot little rock/metal dynamo has been ignoring our theories all along and harboring areas of dynamic change and renewal.

Many of Mercury's craters are dotted with clusters of small rimless hollows, not old enough to be dented with later craters. What's happening isn't exactly clear, but by analogy with similar pits on Mars, it seems that surface material is vaporizing. Perhaps these are widespread deposits of sulfur-rich rocks. If so, what are they doing there? We teach in cosmochemistry class that sulfur is among the most volatile elements, and has no place on such a scorched world. Mercury would have flunked Cosmochemistry 101.

But in science at least, reality rules, so it's our textbooks that flunk Mercury's lessons.

I was taught the rules of planetary chemistry by the geniuses who figured them out. My Ph.D. advisor John Lewis derived the theory of "equilibrium condensation," which gave us our understanding of which type of matter forms at what distance from the Sun: rock and metal in close where it's hot, ice and gas far from the Sun. Mercury's surface should therefore lack material that easily vaporizes.

Our minds want to impose order, to find the simple, underlying patterns beneath the surface of the unruly universe. Chemistry pointed toward a well-ordered solar system but physics came along and jumbled everything up. When protoplanets grew almost to planet size, they were tossed around in a mosh pit of mutual gravitation. The clean chemical seating chart was trampled on and some metal and rock were thrown far from the Sun and some ice and water-rich rock was sprinkled throughout the crowd. Perhaps sulfur ended up plentiful on Mercury where we all know it does not belong.

We planetary profs will recover from the indignity, and our newer texts will surely be less wrong. That the Mercurian surface is also mercurial — and surprisingly lovely — reminds us that we have only begun to explore our solar system. Someday our descendants will know if any of our precious ideas endured the relentless bombardment of real data. ✦

*Noted book author **David Grinspoon** is Curator of Astrobiology at the Denver Museum of Nature & Science. His website is **www.funkyscience.net**.*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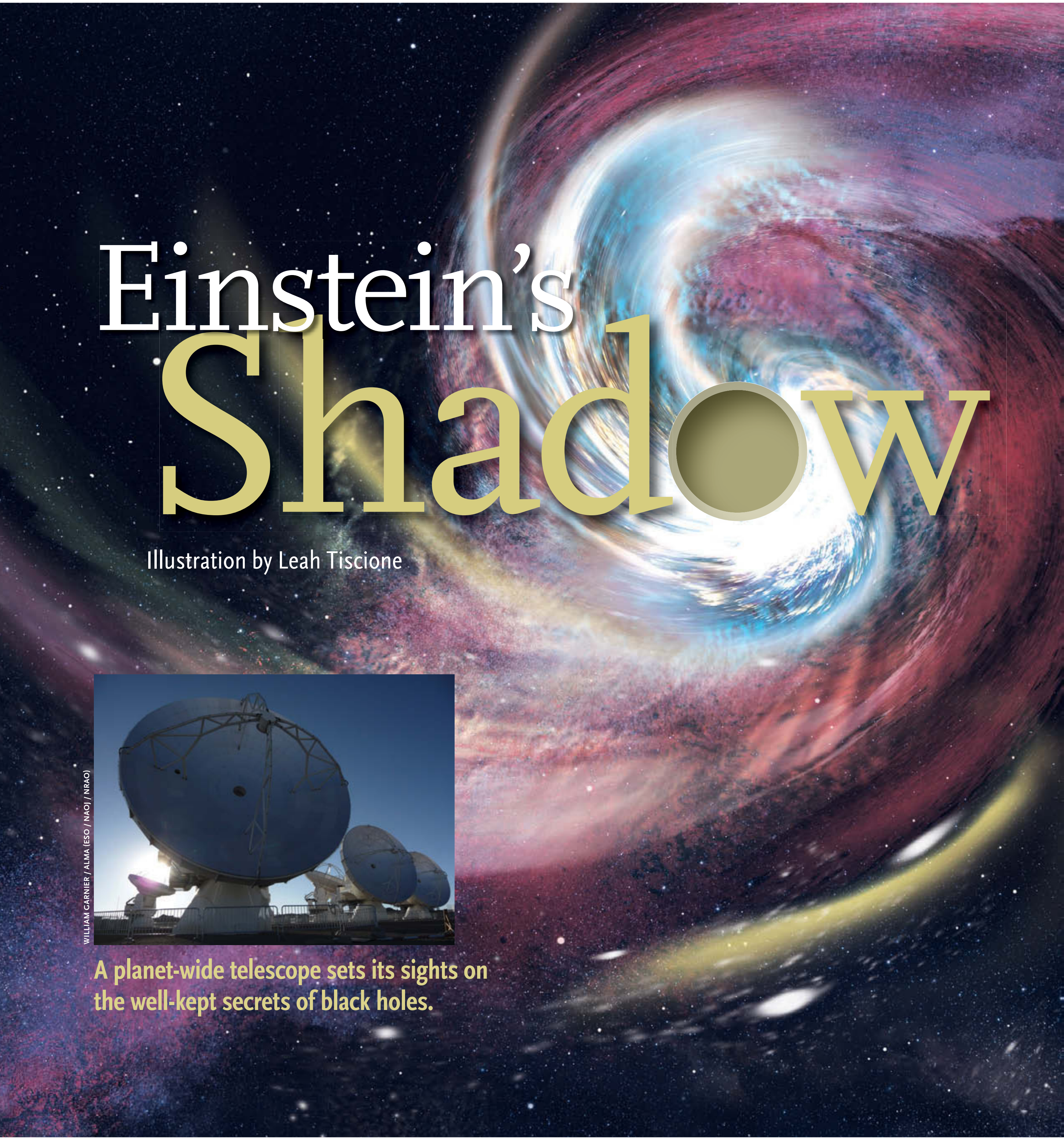


Einstein's Shadow

Illustration by Leah Tiscione

WILLIAM GARNIER / ALMA (ESO / NAOJ / NRAO)

A planet-wide telescope sets its sights on the well-kept secrets of black holes.

Camille M. Carlisle

These days, black holes are about as common as dust bunnies.

Millions of them dot the Milky Way's disk in stellar binary systems, gorging on material from their companion stars. Supermassive beasts lurk in the cores of most large galaxies and may even influence their hosts' formation and evolution.

But even though black holes appear to be just about everywhere, we've never actually seen one. That might seem a moot point, considering they swallow light. Nevertheless, as excellent as the circumstantial evidence is for their existence, black holes may not look how we think they do. Nor does current evidence prove the veracity of general relativity (GR), Einstein's theory of gravity that predicts — much to its creator's horror — the formation of these compact massive objects. We don't even know for certain that relativity's description of spacetime, and black holes, is correct: GR has never been tested in strong gravitational fields like those created by gargantuan black holes.

All that may be about to change. Astronomers across the world are joining forces to create the Event Horizon Telescope (EHT), a network of radio observatories that will stretch from the South Pole to Hawaii and southern Europe. These antennas will work together like a single planet-sized dish, peering into galactic hearts to study what happens near the event horizon, the closest distance light can approach before a black hole's gravity drags it so deep inside that we can no longer see it falling in. The EHT should unmask black holes, revealing how they feed and grow. More important, it will put everything we know — or think we know — about gravity to the test.

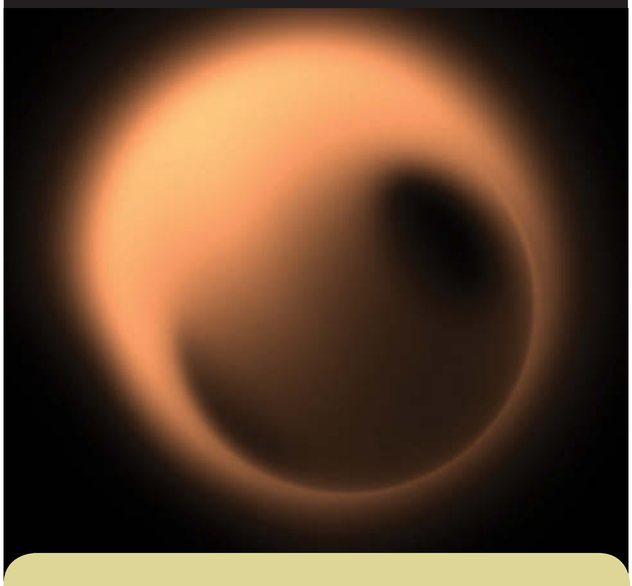
The Silhouette

So far GR has passed every test, from explaining delays in satellite signals to predicting the orbits of neutron stars (*S&T:* August 2010, page 28). But Newtonian mechanics also passed many tests in the two centuries between its publication and Einstein's theory of gravity. And physicists are well aware that GR fails to describe the microscopic realm, where they have to turn to quantum mechanics. The question is, how far can GR be pushed?

To answer this question, astronomers must probe where Newtonian mechanics breaks down: the innermost stable circular orbit, or ISCO (*S&T:* May 2011, page 20). The ISCO is the closest path material can follow around a black hole without falling in. But even though material inside the ISCO may still lie outside the event horizon, that material will eventually plunge into the black hole, no matter how fast it's going.

"Newton would look at that orbit and say 'That's crazy,'" says EHT project leader Sheperd Doeleman (MIT Haystack Observatory). There's no ISCO in Newtonian gravity: as long as material stays outside the object it's circling, it will continue to orbit, without spiraling in. But in GR, a black hole's gravitational potential is proportional to $1/r^3$ (r is the distance between the black hole and an orbiting particle) instead of the $1/r$ of Newtonian theory — which means the well sinks a whole lot more near the black hole in GR than Newtonian theory predicts. This effect overwhelms even the centrifugal energy of orbital motion. Circular paths become unstable, and like a penny in a coin vortex, material plunges past the event horizon.

CAPTURING THE BEAST Famously camera-shy, black holes may finally reveal themselves to astronomers' careful gaze in the next decade. This simulated image shows what our Milky Way's central black hole might look like to the Event Horizon Telescope, with the silhouette created by the extreme bending of light from accreting matter around the object.

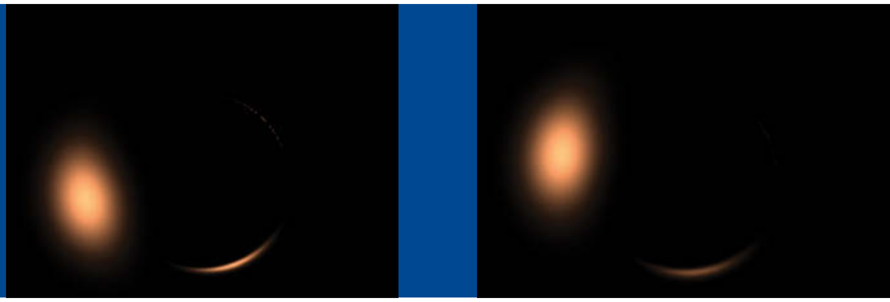


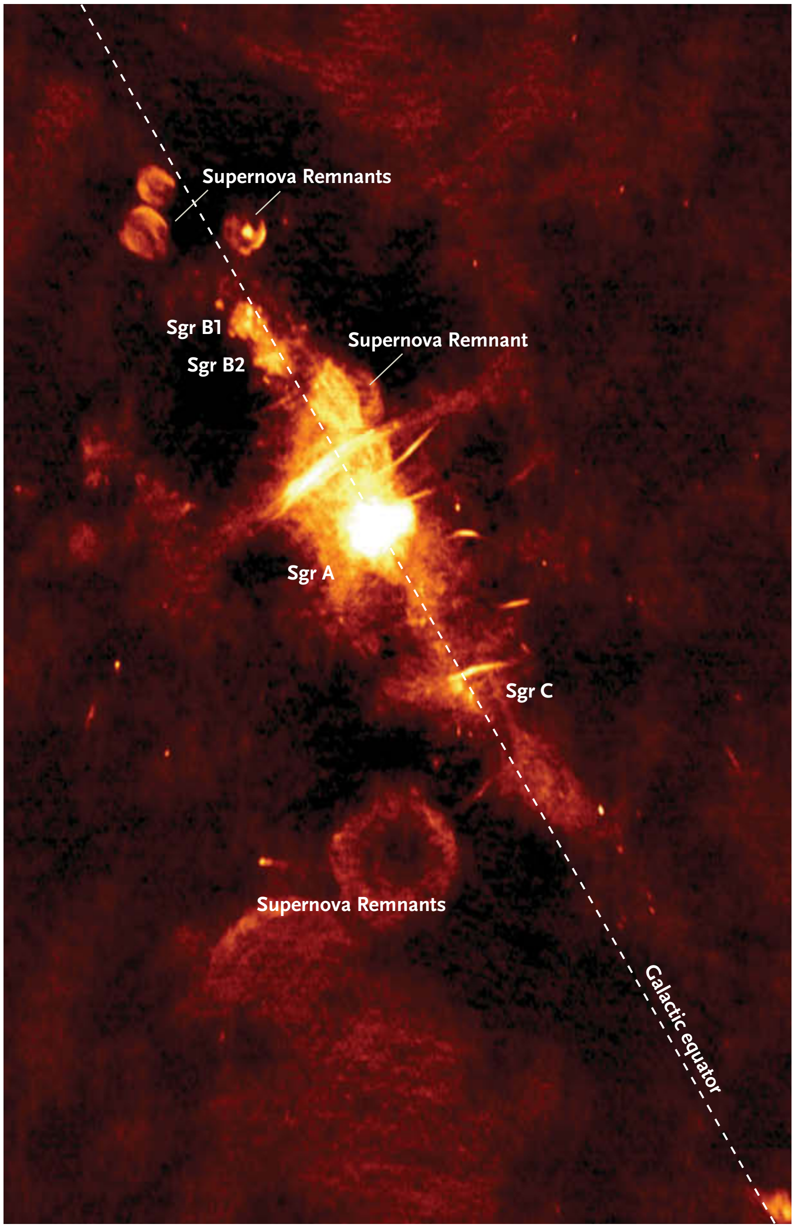
AVERY BRODERICK (UNIV. OF WATERLOO & PERIMETER INST.) / ABRAHAM LOEB (HARVARD-SMITHSONIAN CFA)

WHAT IS A BLACK HOLE?

A black hole is an object that is so massive and compact that it creates an inescapable, four-dimensional pit in spacetime. *But* a black hole is not made of matter: it doesn't have a hard surface. From the inside, a black hole is a cosmic whirlpool, an object made of warped spacetime, whose outer "edge" is the event horizon. From the outside, though, a black hole can be completely described with just three numbers: its spin, mass, and electric charge. Generally there's no overall charge, so charge can be ignored, reducing the variables to two.

VIEWING ANGLES Depending on how the accretion disk around our galaxy's central black hole is tilted to our line of sight, light from an orbiting hot spot could be lensed in a variety of ways. This sequence moves from looking down at the disk from above to seeing it from its side, with the spot behind the hole. The strength of the black hole's gravity determines how light bends near the event horizon.





NAMIR KASSIM (NAVAL RESEARCH LABORATORY) ET AL.

A SINGULAR NEIGHBORHOOD Although gas and dust obscure the Milky Way's center in visible light, its innermost parts show clearly in this radio image made using data from the NRAO's Very Large Array. The diagonal orientation results from the Milky Way's disk (Earth's orbit around the Sun is inclined to the galactic plane). Inside the Sgr A region hides the black hole known as Sgr A*.

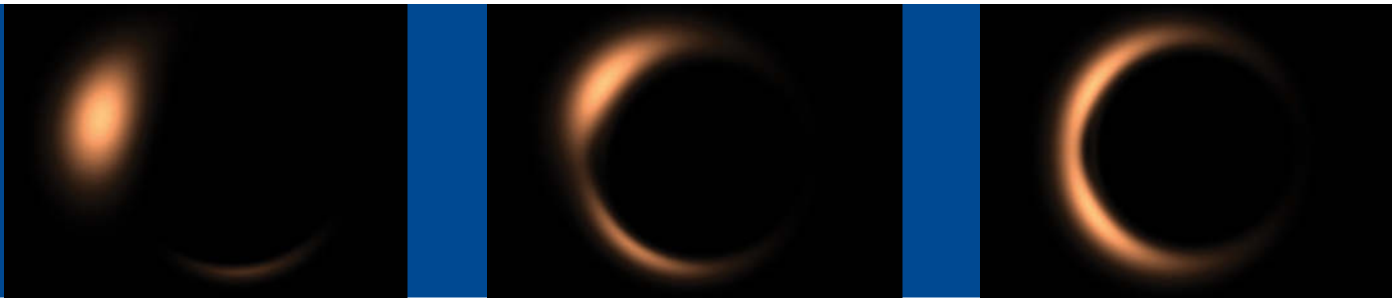
GR simulations make specific predictions about how the near-ISCO environment should appear to EHT scopes. If a disk of gas and dust surrounds a black hole, the event horizon should look like a dark silhouette, surrounded by the glow of accreting material and framed with streaks of light. The silhouette effect happens for two reasons. First, light is fighting to survive. The black hole sits in the midst of glowing accreting material heated by friction and gravitational acceleration. But toward the disk's center, light has to struggle to escape the indentation the black hole makes in the fabric of spacetime. As a photon loses energy, its wavelength becomes longer, until it's stretched to infinity and right out of existence.

The second and prevailing reason for the silhouette effect is what happens to radiation emitted by material on the event horizon's far side. The black hole blocks this light from our direct view, but it gravitationally lenses this radiation to curve around the central object to where we can see it, creating a darker center. The lensed light should form long streaks around the silhouette, looking rather like the diamond ring of a total solar eclipse — except in this image the light is emitted at radio wavelengths, not optical. While this radiation is gravitationally redshifted by the time it reaches us, the effect is insubstantial: a photon originating from the ISCO with a wavelength of 1.06 mm arrives at Earth at 1.3 mm.

These processes create what looks like a shadow but isn't. And how streaks stretch around the silhouette depends on how the black hole's gravity lenses light near the ISCO — which depends on what kind of gravity astronomers are dealing with. If observations reveal unforeseen phenomena (such as bizarre silhouette shapes), it could indicate that Einstein's theory breaks down in strong gravity.

Images also depend on how matter accretes onto black holes. Material falling in radially (that is, without orbiting) onto a nonspinning black hole would create a symmetrical image with a central "shadow." But if the accreting material is orbiting the black hole, the image will appear asymmetrical because material moving toward us looks brighter due to relativistic effects.

That's all in theory. While theorists have constructed excellent models over the past three decades of what goes on around black holes, they need observations to confirm



A. BRODERICK (UNIV. OF WATERLOO & PERIMETER INST.) / A. LOEB (HARVARD-SMITHSONIAN CFA)

them. As Abraham Loeb (Harvard-Smithsonian Center for Astrophysics) explains, “It would be very instructive to see, for the first time, how nature does it in reality.”

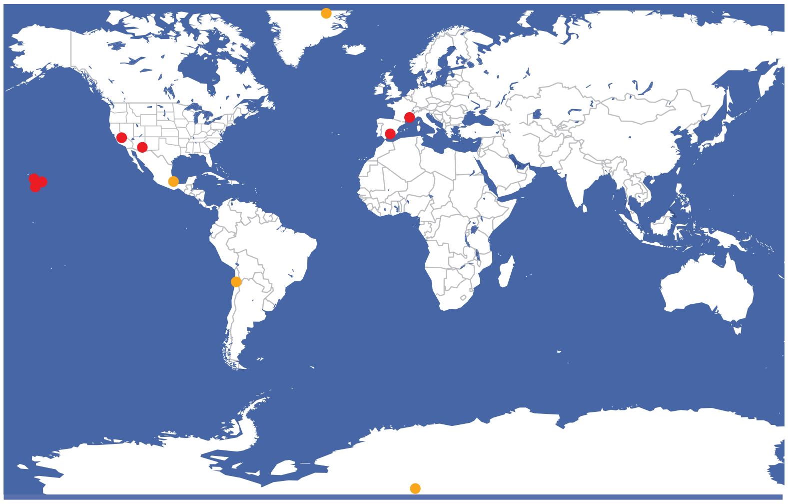
Acquiring Target

The EHT’s first target is Sagittarius A* (abbreviated Sgr A* and pronounced “A-star”), the supermassive black hole candidate at the center of our Milky Way. Measurements by UCLA and Max Planck Institute astronomers have pegged our galaxy’s beast at roughly 4 million solar masses by measuring the orbital motions of stars in the galactic center. At 26,000 light-years’ distance, Sgr A*’s event horizon will appear 53 microarcseconds wide. That’s about the size of a poppy seed in Los Angeles seen from New York City. Even so, Sgr A* has the largest apparent event horizon of any black hole candidate.

Astronomers plan to zoom in on this minuscule target with a technique called Very Long Baseline Interferometry. VLBI combines observations from radio telescopes far away from one another into a single enhanced image, just as though astronomers had used one big dish that spanned the distance between the scopes. Because a telescope’s theoretical resolution improves as its diameter increases, VLBI dramatically improves observing capabilities. The diameter of a “virtual” radio telescope stretching from Hawaii to Chile, for example, has the same resolution as that of a single dish 9,450 kilometers (about 5,870 miles) wide. Astronomers at different locations must observe simultaneously, but they can combine their observations to create a single, cohesive picture.

In 2007 EHT astronomers led by Doeleman observed Sgr A* using a three-station VLBI array that combined the Arizona Radio Observatory’s 10-meter Submillimeter Telescope (ARO/SMT), a 10-meter element of the Combined Array for Research in Millimeter-wave Astronomy (CARMA) in California, and the 15-meter James Clerk Maxwell Telescope (JCMT) atop Mauna Kea. Observing in the 1.3-mm (230-GHz) band, the astronomers detected structure in the ionized gas right around Sgr A* at a distance of roughly four times the size of the event horizon (*S&T:* March 2010, page 14).

But astronomers don’t yet know what that structure is. “You can’t reconstruct the image from only three telescopes,” says Doeleman. “So I know there’s something compact there, I know there’s something about the size of the event horizon, but I can’t tell you exactly what it looks like. To do that, we have to extend the VLBI to more telescopes.”



S&T: GREGG DINDERMAN

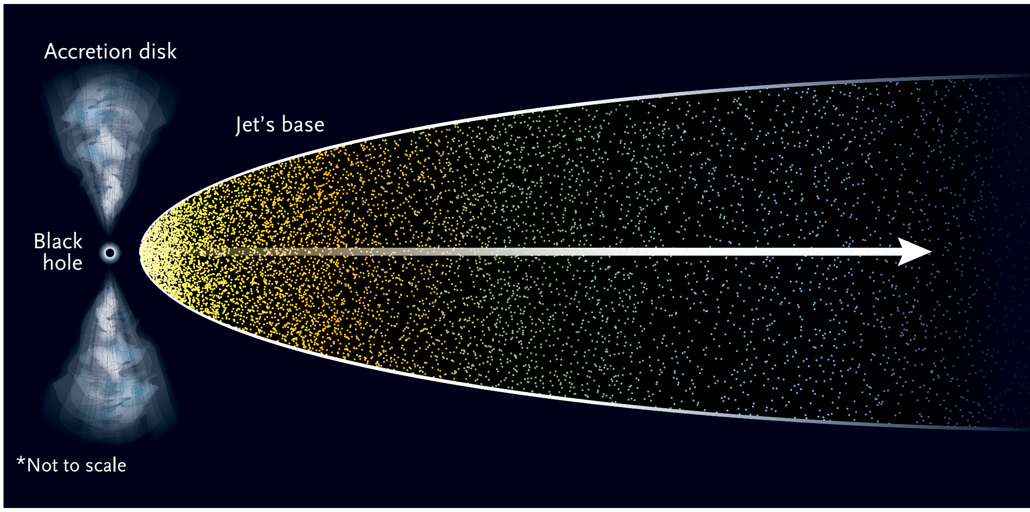
ALL OVER THE MAP **Capturing a black hole takes a planet-sized telescope — or a planet covered in telescopes working together. Shown are the various international sites participating, or expected to participate, in Event Horizon Telescope observations.**

The observations constrained Sgr A*’s angular size to 37 microarcseconds, which translates to a physical diameter of about four-tenths of an astronomical unit (a.u.). You’ll notice that that number is smaller than the event horizon’s size: Doeleman and his colleagues think the Sgr A* source may be a bright spot in an accretion disk or a jet that is slightly offset from the unseen black hole.

In April 2009 the astronomers added a second CARMA scope and spotted a flare in Sgr A* that appeared between the second and third observing days. This variability matches similar activity seen in other multiwavelength campaigns, bolstering the claim of event-horizon-scale structure. VLBI measurements also show that the Milky Way’s central black hole probably doesn’t spin very fast and that its accretion disk is more edge-on than face-on from our vantage point.

Violence Unmasked: M87

EHT astronomers also want to tackle the center of M87. This giant elliptical galaxy lies roughly 52 million light-



THE HEART OF THE MATTER STREAM Deep inside the elliptical galaxy M87, a supermassive black hole creates a high-speed jet that shoots from the galaxy's center. Recent observations suggest the jet indeed begins at a fixed point; everything shown here hides in the jet's bright core (shown below).

S&T: LEAH TISCIONE

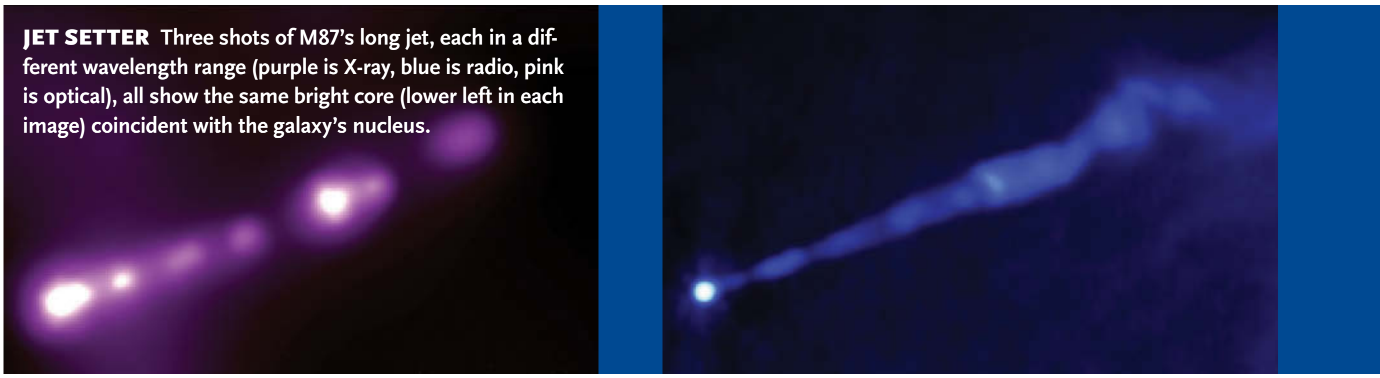
years away, 2,000 times farther than Sgr A*. Astronomers think that a 6.4-billion-solar-mass black hole (more than 1,000 times more massive than Sgr A*) lurks in M87's core. A black hole of that extreme mass would have an event horizon roughly 135 a.u. wide, just larger than the Kuiper Belt. But at M87's distance, the event horizon's angular size would be less than 8 microarcseconds — amazingly small, and yet this tiny horizon is the second largest candidate after the Milky Way's black hole. Lensing effects may make the accretion disk's inner edge appear larger, too, between 34 and 54 microarcseconds.

M87 is also fascinating because its core emits incredible amounts of radiation. Such active galaxies can produce 1 trillion times the Sun's energy, all in a region smaller than our solar system. Many active galactic nuclei shoot jets of plasma into intergalactic space (*S&T:* April 2010, page 20); M87's single visible jet stretches 5,000 light-years long.

Last September Japanese scientists not involved with the EHT reported VLBI measurements suggesting that M87's jet begins at a fixed point 14 to 23 times the event horizon's diameter from the black hole. That distance is surprisingly small: previous studies of jets that point straight at Earth had suggested separations thousands of times larger. But M87's jet is somewhat sideways from Earth's point of view, so the Japanese astronomers could see how the stream's bright, unresolved base changes location with wavelength, appearing to narrow in on the black hole's location. The team observed at six wavelengths from 2 to 43 GHz using an array of 10 antennas stretching from Hawaii to the Virgin Islands. With that span they could resolve details 400 times finer than Hubble can in optical light. Resolution at EHT wavelengths should be several times better and should allow radio astronomers to directly image both the jet's origin and accretion flow around the black hole.

M87 is a particularly attractive target because its light output varies on a much longer timescale than Sgr A*. Why these sources vary isn't definitively known. Fluctuations may be caused by "hot spots" in the accretion disk, which appear to flare as they approach us.

These structural changes during observing runs will smear images, reducing resolution and making it more difficult to image a black hole's silhouette. But high-frequency VLBI should be able to resolve changing structure from orbiting hot spots by capturing snapshots over short time intervals. Source signals can then be summed to reflect how the structure changes with time. Watching these changes will allow EHT astronomers to time hot-



JET SETTER Three shots of M87's long jet, each in a different wavelength range (purple is X-ray, blue is radio, pink is optical), all show the same bright core (lower left in each image) coincident with the galaxy's nucleus.

X-RAY: NASA / CXC / MIT / H. MARSHALL ET AL.; RADIO: F. ZHOU, F. OWEN (NRAO), J. BIRETTA (STSCI); OPTICAL: NASA / STSCI / UMBC / E. PERLMAN ET AL.

WILLIAM GARNIER / ALMA (ESO / NAOJ / NRAO)

MANY EYES MAKE LIGHT WORK The Atacama Large Millimeter/submillimeter Array (ALMA) is taking shape in the northern Chilean desert. Only a fraction of the planned 66 antennas appear in this photo.

spot orbits, and because hot spots are close to the black hole, their orbits move through relativistic anomalies not described by Newtonian gravity. By clocking these orbits, observers can test predictions of spacetime's structure near the ISCO.

"I honestly think that the real gold mine will be the non-imaging observations in which we monitor the time variability of Sgr A*," says Doeleman. By timing "blob" orbits near the ISCO, the team can also estimate the black hole's spin by comparing the measured orbital period with the predicted one to see if the monster's spin is speeding up disk rotation. It is these orbits, even more than the silhouette, that will determine how closely Einstein's predictions match reality.

What's Next

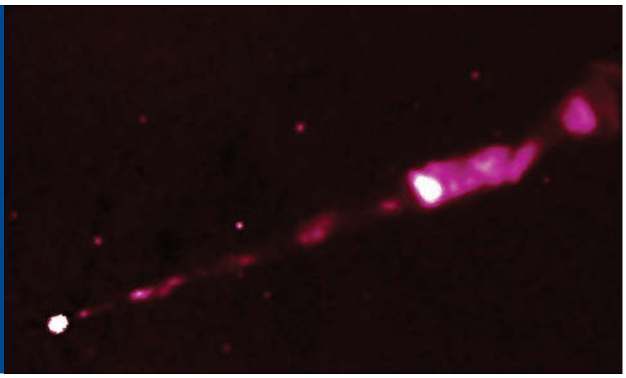
The EHT project has made great strides in the last few years, but there's still a long road ahead. With more than a dozen contributing institutes in Asia, North America, and Europe, the astronomers have many details to iron out.

One detail is the installation of masers — devices that use stimulated microwave emission from atoms to keep time. Because the EHT will combine observations conducted simultaneously around the world, accurate clocks are essential: the masers lose only a second over 100 million years. But some facilities' masers need maintenance, and others don't even have one yet.

Telescope modifications and various measurements also have to be made. To properly reconstruct the observations back at Haystack Observatory — Doeleman's home base and EHT headquarters — astronomers need to know each observing site's location to within a couple of feet. Such exactitude can take hours to calibrate, and earthquakes and spreading tectonic plates change site locations over time.

Achieving finer resolution will be the key to success. EHT astronomers plan to improve resolution in part by moving to shorter wavelengths. They're particularly focused on the 0.8-mm (345-GHz) band which, along with 1.3 mm (which Doeleman's team used in 2007 and 2009), is one of two main atmospheric windows in the millimeter/submillimeter range.

The challenge with 345 GHz is weather. Atmospheric



THE EVENT HORIZON

You don't have to be Einstein to calculate the radius of a black hole's event horizon. In 1783 British natural philosopher John Michell predicted the existence of "dark stars" using Newtonian mechanics. He described an object that was compact enough that light particles leaving its surface would be slowed and then pulled back down by the star's gravity. Although photons don't actually slow down as Michell and others hypothesized, the formula for calculating a star's critical radius remains the same. For a nonspinning black hole, the event horizon's radius is $R=2GM/c^2$ where G is Newton's gravitational constant and c is the speed of light.

TEAMWORK Members of the Event Horizon Telescope project (plus one eavesdropper: the author is in the back row) gathered at the MIT Haystack Observatory in January 2010 to hash out their strategy. Doeleman stands third from left in the back row.

water vapor can interfere with observations at this wavelength, making "high and dry" site conditions crucial. Astronomers have had some success with monitoring water-vapor fluctuations during observations and subtracting the effects from data later. EHT scientists also plan to use the Atacama Large Millimeter/submillimeter Array (ALMA), a network of 66 radio telescopes being assembled in northern Chile. Although ALMA has only about a third of its dishes in place it has already released its first images and begun an observing program. Astronomers will soon use the array to look at how Sgr A*'s behavior changes at different wavelengths, and the EHT team has already received international funding to phase ALMA with the global network.

ALMA is a "change in the firmament of VLBI," says Doeleman. Quite possibly the largest astronomy project in history, when completed it will have a resolution of less than 20 milliarcseconds at 345 GHz. If the EHT team can combine ALMA with seven to ten other antennas, astronomers should achieve an angular resolution of 20 *micro*arcseconds or better, clearly revealing Sgr A*'s silhouette.

EHT astronomers are hoping for a final list of stations committed to the project by 2015. During that time more facilities will come online, including the Large Millimeter Telescope (LMT), a joint American-Mexican project east of Mexico City that achieved first light last summer and has already signed onto the endeavor.

Meanwhile, observations are coming closer to revealing the secrets of black holes. Many astronomers are confident in the EHT, and the project received a thumb's up from the Astro2010 Decadal Survey. "We have the necessary technology and it was demonstrated to work on a smaller-scale project," says Loeb. "I think it's likely that the project will be successful."

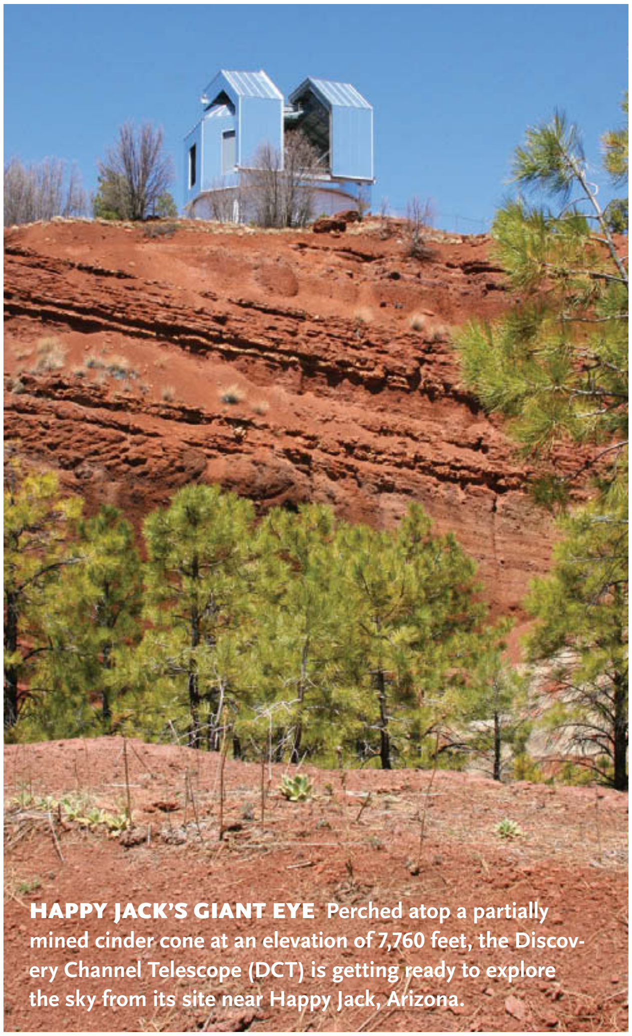
Doeleman agrees. Advances in VLBI and our understanding of galactic centers make it almost certain that astronomers will directly image black hole silhouettes within the next decade, he says. And as new instruments come online, radio astronomers will want to observe at these wavelengths for a variety of projects, making observation time harder to come by in the future. *Now* is the time for the EHT, says Doeleman. "We should be bold." ✦

***Camille M. Carlisle** is a former* S&T *intern who recently returned to the staff as assistant editor. This article is based on work from her MIT master's thesis, "Heart of Darkness."*

Lowell's New Discovery Machine

The Discovery Channel Telescope will bring the exploration of the universe to the public on a global scale.

Edwin L. Aguirre
& Imelda B. Joson



HAPPY JACK'S GIANT EYE Perched atop a partially mined cinder cone at an elevation of 7,760 feet, the Discovery Channel Telescope (DCT) is getting ready to explore the sky from its site near Happy Jack, Arizona.

ALL IMAGES COURTESY OF THE AUTHORS UNLESS OTHERWISE CREDITED

High on the summit of an ancient cinder cone some 65 kilometers (40 miles) southeast of Flagstaff, Arizona, engineers and technicians are putting the final touches on a state-of-the-art telescope designed to combine scientific research with educational outreach. Called the Discovery Channel Telescope (DCT), the $53-million facility is a joint venture between Lowell Observatory and the Discovery Channel.

The telescope's "first light" is expected to take place in May 2012, followed by a period of commissioning, early science, and full operations in 2012–13. With a primary mirror measuring 4.3 meters (14 feet) in diameter, the DCT will become the fifth largest telescope in the continental United States, behind the Large Binocular Telescope (counting it as a single facility), the Hobby-Eberly Telescope, the MMT, and the 200-inch Hale reflector. If telescopes in Hawaii are included, it becomes the ninth largest in the U.S.

"Lowell astronomers will use the DCT to explore the outer solar system, characterize the nature of comets, study planets around other stars, and examine star formation and evolution in the Milky Way and other nearby galaxies, among numerous other projects," says Lowell Observatory director Jeffrey Hall.

Clark Bunting, president and general manager of Discovery Channel, says the DCT aims to bring that newfound knowledge to more than 400 million households in over 200 countries. As he explains, "We are uniquely positioned to be able to share these discoveries on-air, online, and in schools around the world."

Discovery Communications Inc., which owns the Discovery Channel, is producing a documentary film

FLAGSHIP TELESCOPE Lowell Observatory director Jeffrey Hall poses next to the DCT's optical support structure in this May 2011 photo.

OPTICAL CONFIGURATIONS The DCT will be equipped with an instrument cube at the telescope's Ritchey-Chrétien focus. Provisions also exist for attaching very large and heavy fixed instruments at the Nasmyth platform at far right, or small special-purpose ones at the Cassegrain focal station.

on the making of the telescope that will air in June 2012. Researchers from Lowell and its partner institutions will use the DCT data for analysis and publication in scholarly journals, and the Discovery Channel has first rights to educational use of the telescope data for its programming. Because the telescope won't be open to the general public, DCT science will be incorporated into Lowell's outreach programs, both at its visitor center in Flagstaff and on-line.

MIRROR & SUPPORT ***Below:*** **The DCT's 4.3-meter primary mirror received a fresh coat of aluminum in January 2011. Aluminum has high reflectivity and it also satisfies the scientific requirements of the DCT's instrumentation.** ***Right*****: DCT engineers work on the primary mirror's cell inside the auxiliary building at Happy Jack.** ***Far right*****: A system of actuators mounted on the mirror cell will help maintain the primary mirror's precise shape and position as the telescope slews across the sky. This view shows some of the mirror's 36 lateral support rods and pistons arranged along the cell's edge. They will keep the mirror centered in the cell. The circular holes are for the mirror's 120 axial support-rod assemblies, which are designed to gently "poke" the mirror to correct for any changes in its surface figure.**

BILL DEGROFF / DCT PROJECT

A Unique Partnership

The DCT's history dates back to 2003, when John Hendricks — founder and chairman of Discovery Communications Inc., and a member of the Lowell Observatory Advisory Board — first proposed that Discovery be part of Lowell's plans to build a 4-meter-class telescope. Discovery Communications contributed $10 million to the telescope's construction, while the Hendricks family contributed $6 million through its foundation. The observatory's sole trustee, William Lowell Putnam, grandnephew of founder Percival Lowell, together with then-observatory director Robert Millis, committed Lowell Observatory to completing the telescope with funds from the Percival Lowell Trust.

Lowell Observatory astronomers surveyed the atmospheric quality of a number of sites around northern Arizona. They selected a site in the Coconino National Forest, near a U.S. Forest Service Ranger Station called Happy Jack, which is 7,760 feet (2,365 meters) above sea level. Happy Jack offers some of the steadiest and darkest skies in the Southwest. Typical seeing is 0.9 arcsecond on average with a naked-eye limit close to magnitude 8.

On July 12, 2005, Lowell and Discovery broke ground at the Happy Jack site. From that point on, Lowell proceeded steadily to completing the main observatory building in 2007 and the dome in 2009. By 2010 workers had

finished installing the mount and the primary mirror was delivered safely to the site. In January 2011 the mirror received its reflective aluminum coating. It was installed in its support cell in July and was successfully integrated with the telescope mount in August. Meanwhile, DCT engineers have been conducting final tests of the mirror-support control software and electronics systems.

Once operational, the DCT will augment the research being conducted with Lowell Observatory's 1.8- and 1.1-meter reflectors at the Anderson Mesa dark-sky site east of Flagstaff. The observatory's original 24-inch Alvan Clark refractor on Mars Hill in Flagstaff, which Percival Lowell used to study Mars, is now utilized for public education.

Telescope Features

At the heart of the DCT is the $6.5-million primary mirror made of ultra-low-expansion glass, which was molded into a single 100-millimeter- (4-inch-) thick meniscus in 2005 by Corning in Canton, New York. After years of polishing and figuring, the 3,040-kilogram (6,700-pound) mirror blank was completed in 2010 by the University of Arizona's College of Optical Sciences in Tucson.

To ensure that the thin, flexible mirror will maintain its precise shape regardless of where the telescope is pointing, the DCT will use an active-optics system (AOS) to support the primary in its 9-ton mirror cell. Through a complex system of 120 axial and 36 lateral actuators, the AOS will automatically adjust the mirror in real time during observing to keep the mirror's surface figure to within four-millionths of an inch (0.1 micron).

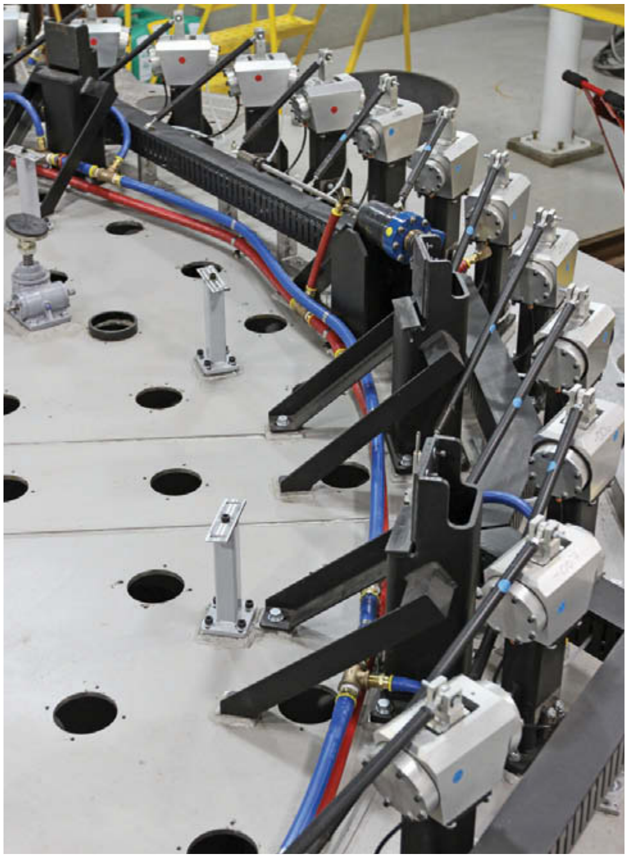
The DCT's 1.4-meter secondary mirror will be mounted in a specially designed vacuum-support structure that connects to the upper ring of the telescope truss. This "tip-tilt" piston structure allows the secondary to be positioned in tandem with the primary to keep the entire optical system properly aligned.

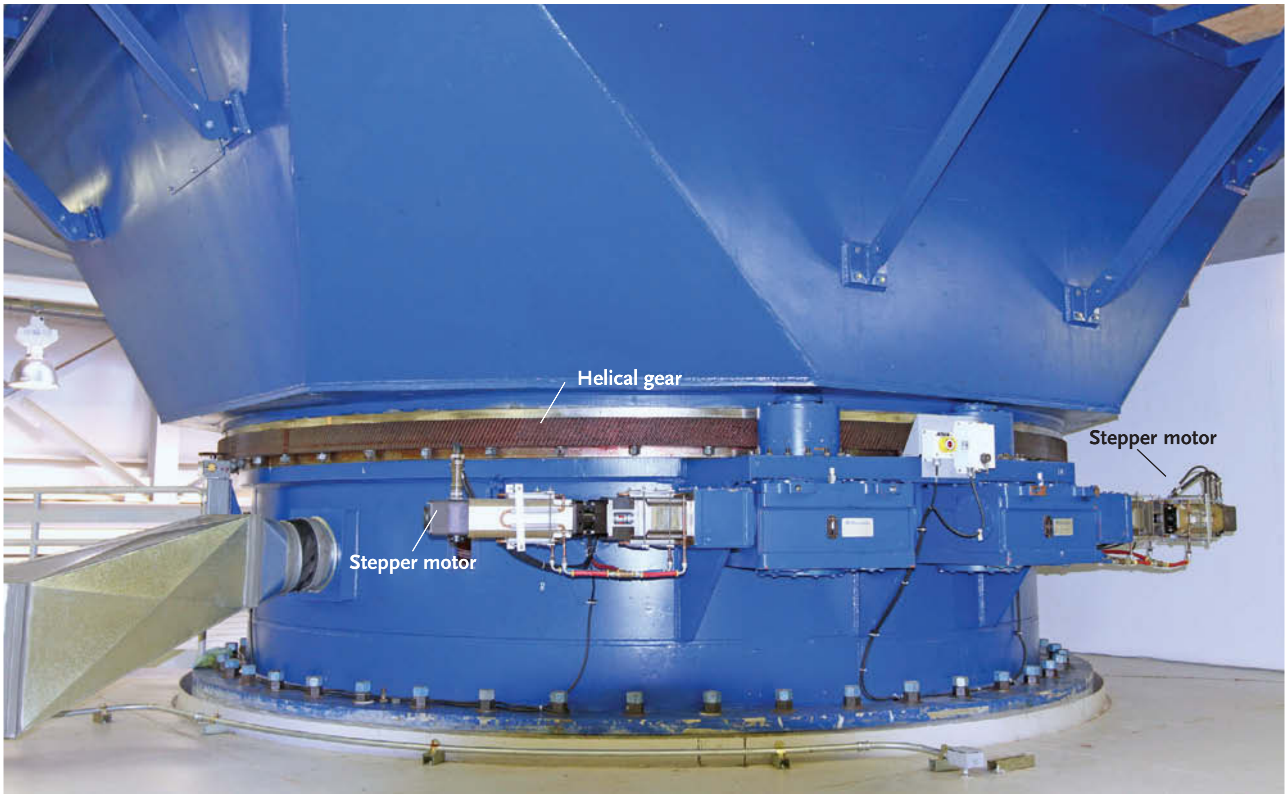
A Versatile Instrument Cube

Lowell designed the DCT to ultimately accommodate four different optical configurations: an f/6.1 Ritchey-Chrétien (RC) focus mode with a 0.5° field of view; an f/2.3 prime-focus mode with a 2° field; and f/6.1 Nasmyth and bent Cassegrain focus modes. The RC configuration will be the first to be implemented during the telescope's commissioning phase.

With the primary mirror and its cell in place, engineers began testing the telescope's optical performance using a test camera at prime focus. This will be followed by the installation of the secondary mirror and testing at the RC focus in early 2012.

Engineers designed an instrument cube with deployable fold mirrors to be mounted at the DCT's RC focus





CARRYING THE LOAD The entire telescope assembly and its massive altazimuth yoke mount is supported by a pedestal that sits atop a heavily reinforced concrete pier buried deep into the mountain's volcanic rock. This view of the yoke's pedestal and base shows two of the four counter-torqued stepper motors and the helical gear that will drive the 140-ton DCT in azimuth.


MINDRUM PRECISION

SECONDARY MIRROR The 1.4-meter replacement blank for the DCT's secondary mirror, made of fused quartz, was successfully "lightweighted" in the spring of 2010. This special machining process involved cutting out circular and hexagonal pockets from the blank's backside, reducing its overall weight to about 230 kilograms (500 pounds).

to allow Lowell astronomers to switch between up to five instruments on the various ports of the cube within one minute. Physically removing and installing instruments from a telescope is time consuming and can make a telescope go off-line for several nights. But the DCT's instrument cube will offer observers access to a variety of instruments and wavelengths on any given night. The ability to quickly change instruments makes the telescope ideal for rapidly following up transient phenomena such as supernovae and gamma-ray bursts.

"The ability to have such a suite of instruments available on Lowell's own telescope should greatly speed up the rate at which staff scientists are able to gather the wide variety of data needed to test theories, make new discoveries, and stimulate new theories," says Jim Emerson (Queen Mary, University of London), leader of the U.K. consortium that developed the 4.1-meter VISTA survey telescope now operating in Chile. "The DCT has obviously been very carefully designed and built, and once the inevitable teething problems are resolved, it will prove to be a great success. I look forward to seeing its first publications appear in academic journals."

Science with the DCT

The Discovery Channel Telescope's workhorse instrument during its early operations will be the Large Monolithic Imager, or LMI. This camera, which is being developed through a U.S. National Science Foundation grant, features a single CCD sensor with 15-micron pixels in a 6,100-pixel-square array. With a field of view of 12½ arcminutes square, the LMI will enable astronomers to obtain near-simultaneous deep optical imaging and high-precision photometry of target objects.

Also in development is the NASA-funded Near-Infrared High Throughput Spectrograph, which Lowell astronomer Henry Roe will use to perform a comprehensive spectral survey of Kuiper Belt objects (KBOs) orbiting the Sun beyond Neptune. Spectral information is currently available for only a handful of KBOs, but this survey will yield detailed data for some 350 objects, greatly expanding our understanding of the Kuiper Belt's structure, composition, formation, and evolution.

A third instrument, the DeVeny Spectrograph, which is currently being used with Lowell's 1.8-meter Perkins Telescope at Anderson Mesa, will be mounted on the RC cube to provide optical spectroscopic capabilities as part of the DCT's first-light instrument suite.

In addition to the KBO spectral survey, the DCT's initial science objectives will include comet observations. Lowell astronomer David Schleicher will use the telescope to determine the composition of cometary nuclei, the processes that drive activity when they are far from the Sun, and the relationship between short-period comets and KBOs in order to gain new insight into our solar system's formation and evolution.

Lowell astronomer Deidre Hunter will employ the DCT's imaging and spectroscopic capabilities to carry out an ultra-deep survey of dwarf galaxies to answer fundamental questions about the structure and evolution of individual galaxies as well as galaxy clusters and large-scale structures. Hunter's work will focus on the star-formation history of dwarf galaxies to help us understand their stellar populations and, by extension, the composition and nature of the larger, more massive elliptical galaxies they are thought to create through mergers. These observations will address the fact that stars can be seen forming at the edges of dwarf galaxies where the gas density is assumed to be too low to form stars. These results will help researchers investigate the nature and mass of dark-matter halos, the total amount of luminous and nonluminous material in the universe, and long-term cosmic evolution.

Lowell astronomer Phil Massey will use the DCT to study the mass–luminosity relationship for hot, massive *O*- and *B*-type stars. He will tackle this by imaging and taking the spectra of stars for which good mass measurements can be obtained, such as eclipsing binaries in nearby Local Group galaxies. With solid data for both mass *and* brightness, Massey hopes to determine which of the mass–luminosity theories is correct, and nail down one of the most fundamental properties of massive main-sequence stars.

Bumps on the Road

The DCT project did not encounter smooth sailing all the way. In May 2009, the secondary mirror — which was originally scheduled for completion that summer — suffered a major setback when the mirror blank developed an irreparable fracture due to excessive tooling force on the mirror's backside during the last phase of the "lightweighting" procedure. Lightweighting involves grinding out a honeycomb pattern on the backside prior to polishing and figuring to make the mirror lighter, stiffer, and more thermally stable.

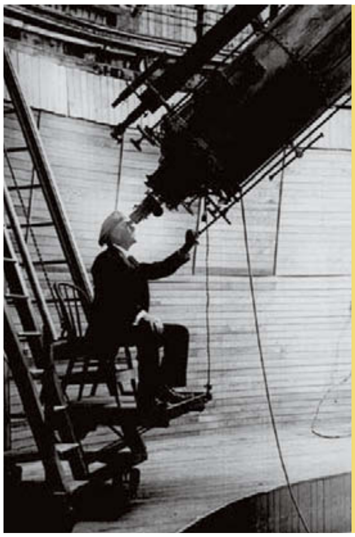
The DCT project team had to purchase a replacement blank and start the lightweighting process from scratch. Fortunately, the second mirror proved to be a success, and the lightweighted blank underwent final polishing and figuring last spring. The completed mirror was slated for delivery to the Happy Jack site last autumn for aluminizing. It will be integrated into the telescope in early 2012.

"There will certainly be bumps on the road as we finish final assembly and begin testing," says Hall. "So far, the facility and telescope components have come together exceptionally well, thanks to the hard work and dedication of Lowell's DCT team. They are building the future of Lowell Observatory, and it's looking spectacular." ✦

Former S&T *editors* ***Edwin Aguirre*** *and* ***Imelda Joson*** *have been visiting major astronomical observatories around the world since 1985. You can read about their adventures in "Edwelda's Universe" at* ***http://home.comcast.net/~edwelda****.*

BONUS INTERVIEW AND PHOTOS

To read an interview with Lowell Observatory director Jeffrey Hall and see more photos of the Discovery Channel Telescope, visit SkyandTelescope.com/DCT.



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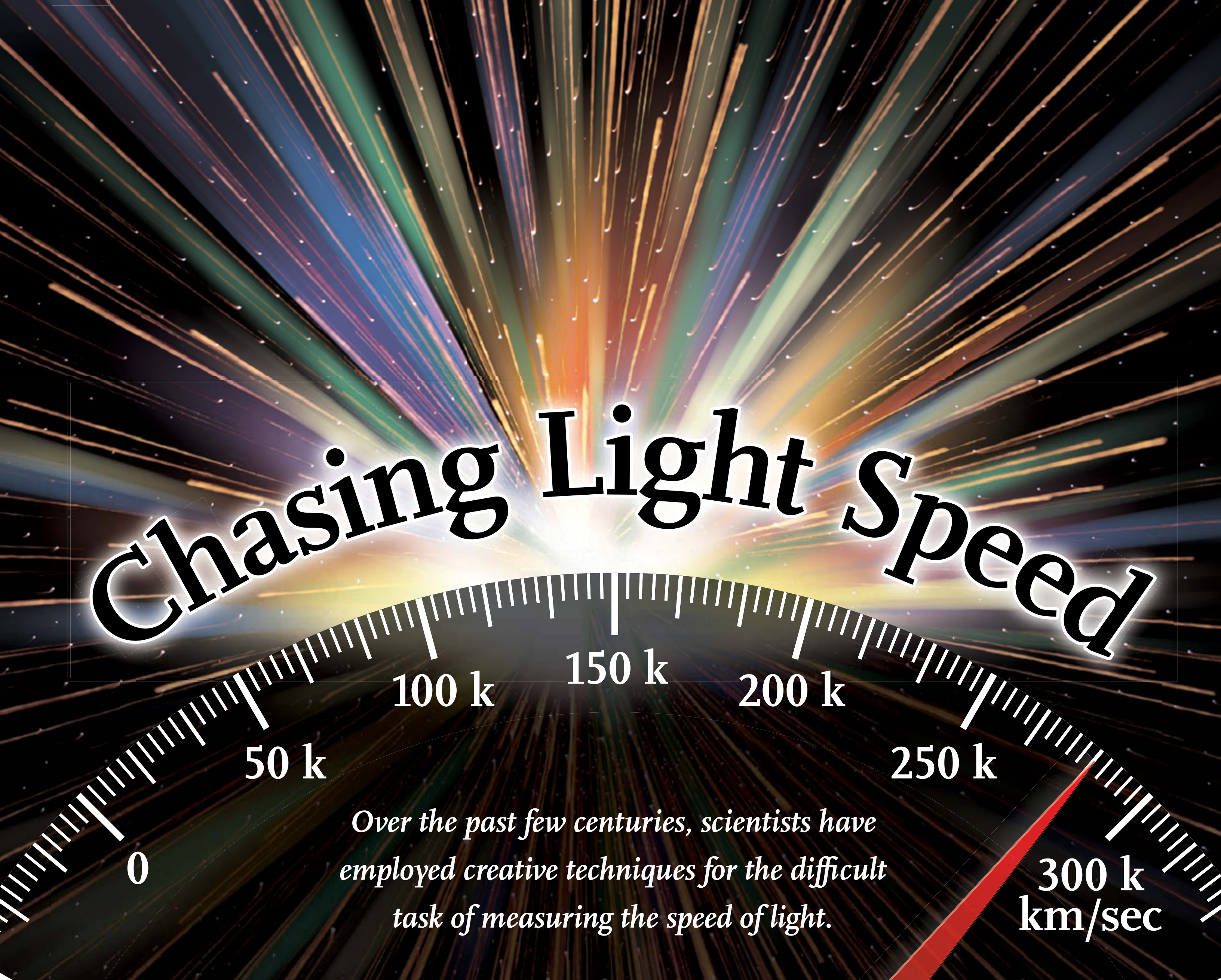
THE PARTNERS

Lowell Observatory is a Flagstaff-based private, non-profit research institution founded by Boston astronomer Percival Lowell in 1894. The Discovery Channel is a satellite and cable TV network headquartered in Silver Spring, Maryland, that produces documentary programming focused mainly on science, technology, adventure, and history.



Chasing Light Speed

Over the past few centuries, scientists have employed creative techniques for the difficult task of measuring the speed of light.

MUHAMMAD ALI once boasted that he was so fast he could switch off his overhead light at night and then be in bed before the room got dark. Comparisons with the rapid motion of either light or sound are commonly invoked to conjure up an impression of extraordinary speed. The high velocity of fighter jets, for example, is often measured relative to the speed of sound. Yet even sound waves take about 0.02 second to cross a small room. This interval would allow a light beam to traverse the Atlantic Ocean.

Indeed, we can no better envisage the immense expanses that light crosses in space than in comparison to the fleeting instants it requires to cover familiar, everyday distances. It has thus always been important for astronomers to know the exact value of light speed to help chart the mind-boggling vastness of the cosmos. With this motivation, astronomers have actively participated in the effort to measure the speed of light.

According to Albert Einstein's special theory of relativity, information cannot move faster than light in a vacuum, so that objects far from each other are effectively separated by time as well as space. Even our view of the Moon is out-of-date; we see it not in its current form but as it was 1.28 seconds ago. But only across the enormity of deep space do time delays in light transit become significant. Radio signals from NASA's Voyager 2 probe took more than four hours to reach Earth during its Neptune flyby. Far-flung quasars offer cosmologists the chance to peer back in time more than 10 billion years.

S&T: GREGG DINDERMAN / ISTOCKPHOTO: KAZUHIKO YOSHINO

Einstein's special relativity equation $E = mc^2$ expresses the velocity of light by the letter *c* (possibly from *celeritas*, Latin for "speed"). His celebrated formula equates mass to its energy equivalent. Yet aside from its obvious relevance to astronomy and space travel, *c* is also embedded in the workings of electromagnetism and atomic structure. Since these fundamental laws dictate the course of chemical reactions and the fine-tuned mechanisms of biology, scientists in many disciplines began to realize the universal significance of *c* long before Einstein's time. As a consequence, it became increasingly important to know the speed of light very accurately.

Early scholars were endlessly intrigued by the nature of light and understandably baffled by its extreme speed, which defied their best attempts at measurement. Many thinkers simply assumed that light speed must be infinite. Perhaps this untouchable and seemingly magical entity did not actually need to travel at all. Was light somehow instantaneously perceivable from afar?

TOM GALE

In the early 1600s, Galileo Galilei made many determined attempts to detect the motion of light beams. His strategy was logical, though in hindsight it seems quaint. Galileo and an assistant each carried a lamp to a hill. Galileo opened a shutter on his lamp to let out a beam of light. Upon seeing this light, his assistant immediately uncovered his own lamp. Galileo timed the appearance of his colleague's signal, which gave him a round-trip light-travel time between the hills. Despite having tirelessly rehearsed the process to minimize human error, he could not detect any delay in the arrival of his colleague's light beam other than what could be attributed to the timing of slothful human reflexes. Destined to failure, Galileo's experiment nevertheless showed that light traveled at least 10 times faster than sound. Many theorists, however, saw this as further proof of light's infinite speed.

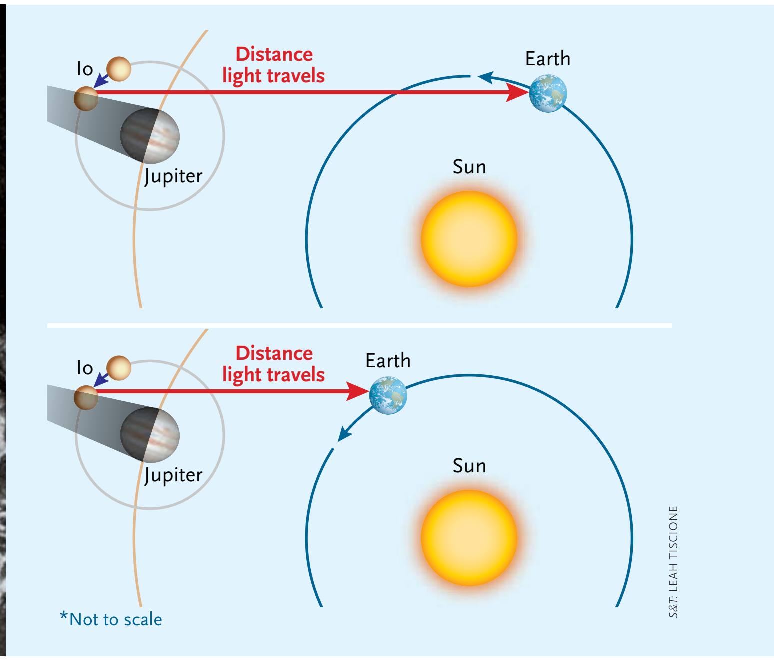
Perplexing Io

The 17th century witnessed a surge of seafaring for which accurate timekeeping was vital to determining longitude — a tricky problem for ships out of sight of land. Working at the Danish Uraniborg Observatory in 1671, Ole Rømer decided to test Galileo's claim that telescopic observations of Jupiter's moons could be used to precisely keep time. Fast-moving Io dives into Jupiter's shadow every 42.5 hours with clockwork regularity. Astronomers could time these eclipses even when looking through primitive telescopes. To everyone's surprise, Io appeared to enter eclipse several minutes earlier or later than predicted. This was disappointing news for navigators and downright puzzling for astronomers.

Rømer continued his observations in Paris the following year under the guidance of Jean-Dominique Cassini. The young Dane soon noticed that Io's eclipses followed a 13-month cycle, occurring ahead of schedule around the time of Jupiter's opposition and lagging behind when the giant planet was seen in twilight skies and laying farthest from Earth. Rømer brilliantly concluded that this anomaly had nothing to do with Io's orbit but was instead a consequence of its reflected sunlight taking varying time intervals to reach us, depending on how Earth and

ECLIPSING IO Danish astronomer Ole Rømer (1644–1710) demonstrated that changes in the timing of Io's eclipses behind Jupiter are due to the extremely fast but finite speed of light. As the illustration shows, eclipses seemingly occur "late" (*top*) or "early" (*bottom*) depending on where Earth and Jupiter are located in their orbits. Because the size of the solar system was unknown in Rømer's era, he could not use this technique to measure the speed of light to any degree of accuracy.

AIP EMILIO SEGRÈ VISUAL ARCHIVES / BRITTLE BOOKS COLLECTION



Jupiter were situated. When the Jovian system lay closest, light was simply reaching observers more quickly, making eclipses occur early. When near conjunction, Jupiter's light had to extend its journey to cross Earth's orbit which, according to Rømer's timings, took around 22 minutes.

Nobody at the time knew the size of Earth's orbit and so, unfortunately, the Paris team's data couldn't be translated into a reliable value of light speed. But Rømer had demonstrated for the first time the extreme but finite nature of the speed of light.

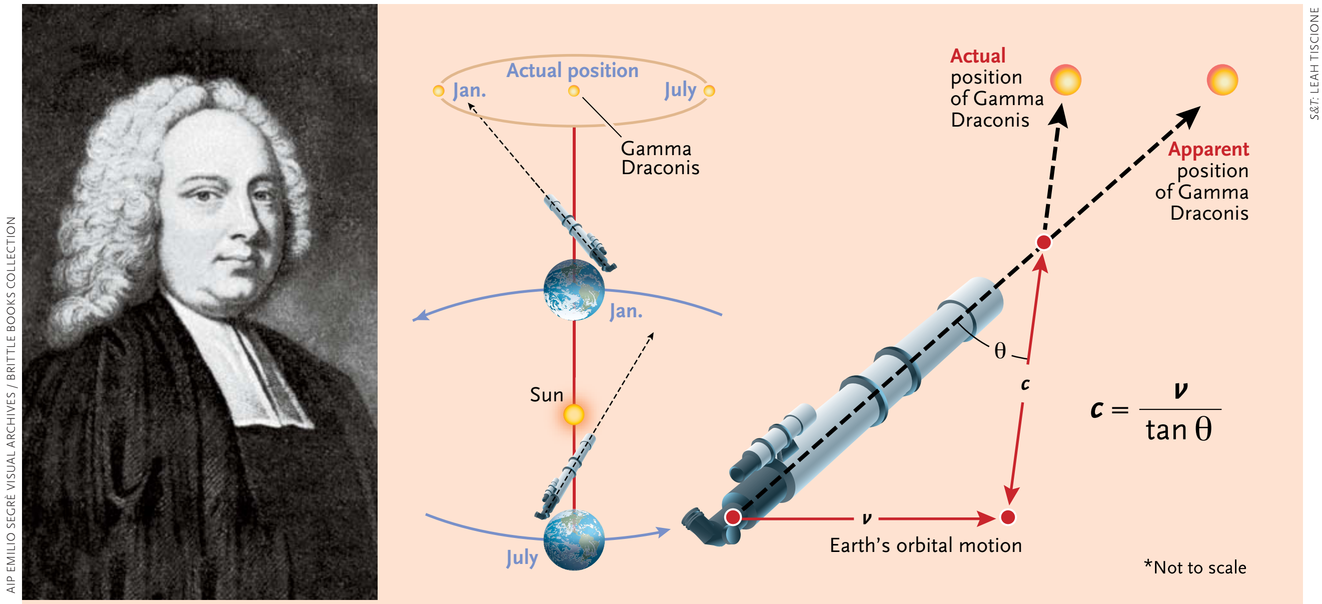
Round in Circles

As with many steps forward in science, serendipity lent a helping hand in the next determination of light speed. In 1725 Oxford University astronomer James Bradley was trying to detect the parallax shift of suspected nearby stars as Earth orbited the Sun. Such an observation would offer long-sought proof of Copernicus's heliocentric model of the solar system.

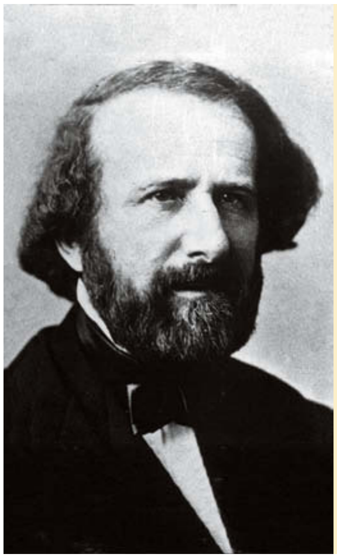
Bradley tracked the position of Gamma Draconis over the coming months. The 2nd-magnitude star appeared to follow a circular path but moved in a completely different direction than he expected and by a much bigger amount. Other stars Bradley monitored behaved similarly, each tracing out an inexplicably large ellipse in the sky some 41 arcseconds in diameter. Clearly, this was not parallax; it was unthinkable that all stars lay at the same distance, or were close enough to cause such huge shifts.

A few years later, while aboard a sailing boat in a moderate wind on the River Thames, Bradley noticed that the vane at the top of its mast shifted direction slightly whenever the boat turned. This seemed odd because the wind direction remained unchanged. The sailors explained to the puzzled Bradley that the boat's changes in direction were causing the shifts. Suddenly, the idea dawned upon Bradley that if light has a finite speed, Earth's motion around the Sun should have a similar effect on the apparent direction of approaching starlight. The timing and magnitude of his observed star shifts now made perfect sense. They didn't depend on Earth's position but instead resulted from its movement at right angles to the incoming starlight. Just as a person running through a rainstorm must tip an umbrella forward to stay dry, so our planet's orbital motion slightly skews the observed angle at which the light rays are perceived to arrive at Earth.

Using high-school-level trigonometry and a recently improved estimate of Earth's orbital velocity, Bradley announced that light travels 10,210 times faster than Earth moves around the Sun. This figure overestimates light speed by just a little over 1%. Though not the observation Bradley was seeking, his discovery of stellar aberration conclusively demonstrated Earth's motion within the solar system.



STELLAR ABERRATION While sailing on the River Thames in 1728, James Bradley (1693–1762) realized that the reason why distant stars appear to shift position during the year is due to Earth's motion around the Sun (*left*), which causes the aberration of starlight (greatly exaggerated in the diagram above). Using the observed angular shift of Gamma Draconis's position (θ = 0.006°) and the best available value for Earth's orbital speed around the Sun, Bradley used basic trigonometry to calculate how fast light travels between the Sun and Earth (*right*). His result of 8 minutes and 12 seconds was only 7 seconds shorter than our modern value, a remarkable achievement that helped him earn a promotion to the post of England's Astronomer Royal in 1742.



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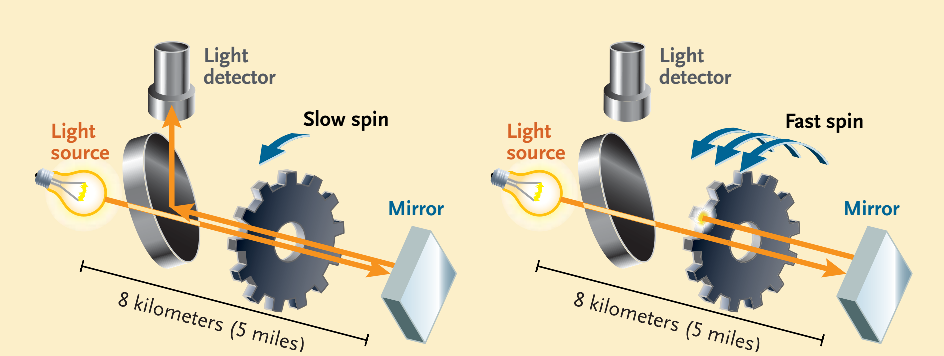


S&T: LEAH TISCIONE

THE REVEALING REVOLVING WHEEL French physicist Armand Fizeau (1819–1896) conducted a light-speed experiment that was simple in principle, but difficult in practice. By shining light through an electric-powered toothed-wheel whose rotation rate he could vary, he measured the speed of light to within 4% of our modern value. He also proved that light speed varies depending upon the medium in which light travels.

Wheel of Fortune

Before long, many physicists were eager to confirm the value of light speed from ground-based experiments. By the mid-1800s, simple electric motors allowed the speed of light to be measured over terrestrial distances for the first time. Scientists soon realized that a major obstacle to measuring light's motion in one direction lay in the impossibility of instantaneously relaying a signal between the synchronized clocks of two separated observers.

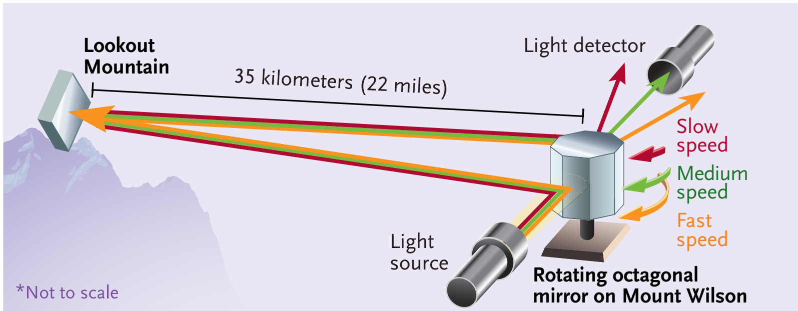
With this in mind, French physicist Armand Fizeau designed an apparatus to reflect a light beam back to its source from a mirror 8 kilometers (5 miles) away, cunningly negating the need for a second timing device. Inventor and fellow Parisian Paul-Gustave Froment assembled the required machinery and centered the experiment around one of his recently devised direct-current brush motors.

Setting the beam to shine between the fine teeth of a rotating wheel, Fizeau saw light pulses return through the same aperture when the wheel rotated slowly. When the wheel was spun faster, a tooth blocked the returning flash. Faster still, and it passed back through the cog's adjacent gap. By controlling the wheel's speed, Fizeau could measure the round-trip journey time of each light pulse. The rapid rotatory speed and, above all, the consistently smooth running of the motor were essential for the experiment's success. Though Fizeau's initial results overestimated *c* by about 4%, he went on to show that light travels slower in water and glass than it does in air, dispelling centuries-old ideas about the nature of light.

Evaporating Ether

In the 1920s the Prussian-born American physicist Albert Michelson carried out an ingenious refinement of Fizeau's experiment, featuring a rotating mirror. Michelson had earned global acclaim four decades earlier while teaming up with Edward Morley in a search for the elusive ether. Theories of the day deemed that light, as a wave, needed a medium for its transferral, just as sound is propagated by air and seawater conveys ocean breakers. By applying interferometry (a technique related to that used by today's astronomers to improve resolving power at major observatories, see page 23), they sought to detect Earth's motion through the hypothetical ether.

But much to everyone's puzzlement, the Michelson-Morley experiment failed to provide evidence for the



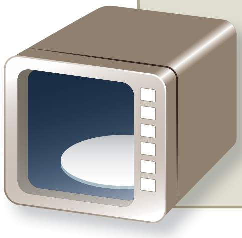
S&T: LEAH TISCIONE

AIP EMILIO SEGRÈ VISUAL ARCHIVES / MICHELSON COLLECTION

MOUNTAIN TO MOUNTAIN Albert Michelson (1852–1931) conducted speed-of-light measurements in the 1920s on two southern California mountaintops. He bounced light off a rotating octagonal mirror to a mirror 35 kilometers away, which reflected the light back. By varying the rotation speed of the octagonal mirror, much as Fizeau had varied the speed of his wheel, Michelson measured the speed of light to be 299,796 ± 4 km/sec. Michelson's experiment was often plagued by smoke from nearby fires. Nevertheless, he essentially measured the correct speed, since the modern value of 299,792.458 km/sec falls with the experimental uncertainty of his result.

MEASURE THE SPEED OF LIGHT AT HOME

You can repeat Louis Essen's great experiments of the late 1940s with many microwave ovens. Remove the turntable and find two locations where a stationary dab of butter melts the fastest. These locations are *antinodes*, the locations where the microwave amplitude is highest. Measure the distance between these two spots, which is half the wavelength of the microwaves. Multiply that distance by two to obtain the wavelength (λ), and then multiply that number by the microwave oven's frequency (f) as specified on the back of the oven or in the owner's manual (usually 2.45 gigahertz). Because $c = f\lambda$, this simple calculation will yield the value of c. If you perform this experiment carefully enough, you can measure c to within 5% of its actual value.



S&T: GREGG DINDERMAN

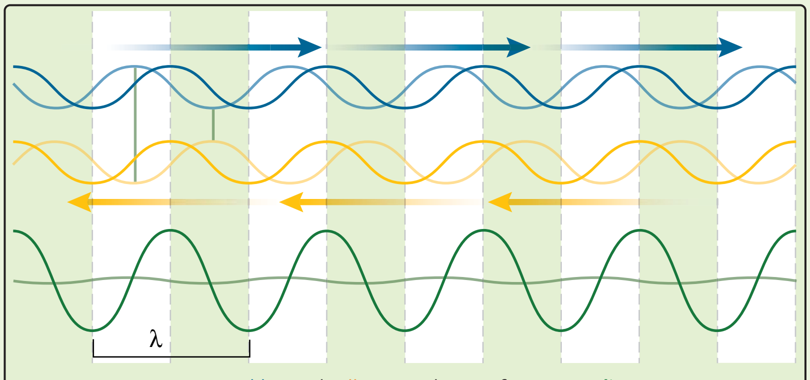
ether — one of the most important negative results in the history of science. By demonstrating that light's speed appears the same no matter how an observer is moving, they paved the way for Einstein's formulation of special relativity. Michelson won the 1907 Nobel Prize for Physics for this and other achievements.

Measuring the speed of light had preoccupied Michelson throughout his life. Returning to the problem in the 1920s, when he was past the age when many would consider retirement, he realized that a longer light path length was essential for minimizing error. Michelson sited his light source and a small, rapidly rotating octagonal mirror on Mount Wilson in California's San Gabriel Mountains, home to Mount Wilson Observatory. He stationed a second mirror on Mount Lookout, some 22 miles (35 km) distant. The clean air of high altitude minimized atmospheric absorption. He varied the speed of the rotating mirror, much as Fizeau had done in his earlier experiment. Meticulous to the last, Michelson had surveyors rigorously determine the baseline length to an unprecedented precision of about a centimeter.

Unfortunately, his painstaking observations over three years were plagued by a frustrating series of setbacks. Smoke from wildfires played havoc with the visibility of the beam. Worse still, a strong earthquake halfway through the data-collection period may have slightly altered the baseline length. Despite these obstacles, Michelson's calculated speed of light (299,796 ± 4 km/sec) turned out to be more accurate than any measurements obtained previously or in the subsequent 25 years.

In Light of War

The imminence of World War II prompted a flurry of research into radar technology, resulting in a wealth of new laboratory equipment for investigating light and radio waves. Having previously pioneered the use of vibrating quartz crystals for time measurement, British physicist Louis Essen, working with A. C. Gordon-Smith, could generate microwaves of very specific frequencies. By setting up standing waves (similar to the sound-wave harmonics of musical instruments) in cavities of precisely measured sizes, Essen calculated the speed of light more accurately than ever before: 299,792.5 km/sec. His value was some 16 km/sec higher than that obtained by most previous optical methods, so it raised many skeptical eyebrows. But Essen was a diligent experimentalist. Repeat



Two opposing waves (blue and yellow) combine to form a **standing wave** (green) whose maximum amplitude occurs when the crests of the opposing waves line up

S&T: LEAH TISCIONE

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NAILING IT Experiments conducted after World War II by British physicist Louis Essen (1908–1997), working with A. C. Gordon-Smith, gave us our modern value of the speed of light. Essen combined microwaves (blue and yellow) inside a cavity of precisely known dimensions (to within 0.8 micron) to produce standing waves (green). Essen measured the frequency (f) of these waves to high precision. The precisely measured size of the cavity established the wavelength (λ) of the standing waves. Essen could then apply the well-established equation $c = f\lambda$ to determine that c is 299,792.5 ± 3 km/sec. Subsequent experiments have refined Essen's results only slightly.

NASA / ESA / HOWARD BOND (STSCI) / HUBBLE HERITAGE TEAM (STSCI / AURA) (3)

OPTICAL ILLUSION These Hubble Space Telescope images, taken from May 20 to December 17, 2002, show what appears to be a ring-shaped nebula expanding faster than the speed of light. But it's not. The central star, V838 Monocerotis, emitted a bright pulse of light in February 2002. This starlight reflected off surrounding interstellar dust, creating a light echo. Because the starlight is reflected at an angle almost directly toward Earth, the light echo brightens material that lies successively closer to Earth along our line of sight, creating the illusion of superluminal motion. Other examples of superluminal motion have also proven to be due to geometric effects.

experiments verified his original *c* value, which became the international consensus for decades to come.

Only with accurate knowledge of *c* could radar, which transmits radio pulses and then detects the rebounding rays, successfully pinpoint the distance and motion of target objects. Today, civil applications of radar include air-traffic control, the satellite-mediated Global Positioning System, and, perhaps less popularly, police speed traps. Radar allows astronomers to measure the distances to nearby solar-system bodies, particularly valuable for potential Earth-impacting asteroids.

Unbreakable?

By the 1980s the speed of light was known with such accuracy that it was chosen as a way of defining the meter itself — now fixed as a light beam's traverse in a vacuum during $1/299{,}792{,}458$ of a second. Yet occasionally, deep-sky time-lapse images show nebulae or jets apparently expanding or moving faster than light speed. Hubble Space Telescope images of V838 Monocerotis, for example, show a rapidly expanding ring that appears to cheat Einstein's laws. In fact, such anomalies invariably prove to be optical illusions — a geometric effect caused by material moving at an angle almost directly toward Earth at near-light speed. In V838 Mon, a stellar outburst occurred amidst stationary clouds of gas, and the pulse of light successively illuminated more distant zones of the nebula. This light-echo effect gives the impression that the gas itself is moving superluminally.

Light echoes were first observed telescopically around GK Persei, a bright nova that erupted in 1901. Even before the outburst had faded, Dutch astronomer Jacobus Kapteyn correctly interpreted what everyone was seeing.

The superluminal muon-neutrino result reported by the Gran Sasso National Laboratory's OPERA team in September 2011 is an anomaly that has yet to be verified. The experiment involved firing neutrinos from CERN (near Geneva, Switzerland) through 740 km of rock toward the Italian lab. The team measured the neutrinos arriving an average of 60 nanoseconds earlier than if they had traveled at the speed of light. Many eminent scientists, including the OPERA team itself, have expressed doubts, insisting that some unaccounted-for source of systematic error must have skewed the particles' measured flight times. Attempts to replicate the unprecedented findings will be spearheaded by Fermilab near Chicago. The implications posed by a reproducible result, however unlikely, ensure that the physics community and public will await the new data with bated breath.

Despite such occasional claims to the contrary, it seems that the greater the sophistication of experiments, the more the reams of evidence accumulate suggesting that nothing can outpace a light beam in a vacuum — just as Einstein predicted. Thanks to the dedication of those who helped measure one of nature's most elusive constants, we've been able to learn much more about the scale of our universe. ✦

Tom Gale, Ph.D., is a freelance astronomy writer from North Somerset, U.K. He lectures on chemistry for University College London's Language Centre and is currently on sabbatical at Nazarbayev University in Astana, Kazakhstan.


STELLARVUE

▼ **ELITE ASTROGRAPH** Officina Stellare now offers the Veloce RH 200 ($7,995), an ultrafast-focal-ratio astrograph. The RH 200 is a 200-mm (8-inch) f/3 Riccardi-Honders astrograph made to accommodate the largest CCD cameras. The optical design consists of a full-aperture corrector plate combined with a Mangin primary mirror and 2-element corrector lens, yielding a 60-mm fully illuminated photographic field. Three fans behind the primary mirror rapidly cool the telescope to ambient temperature, while the carbon-fiber optical tube and CNC-machined structural components allow the telescope to retain focus over large temperature ranges. The RH 200 includes a custom zero-image-shift manual focuser, retractable dew shield, and two Vixen-style dovetail mounts.

Officina Stellare
Available in the U.S. from Oceanside Photo & Telescope
918 Mission Ave., Oceanside, CA 92054
800-483-6287; www.optcorp.com

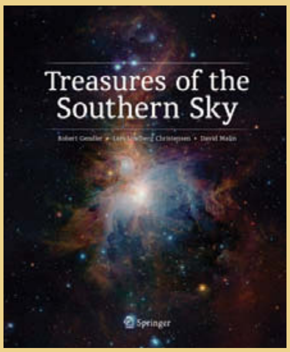
S&T: DENNIS DI CICCO

▲ **STELLAR FOCUSERS** Stellarvue now carries its own series of heavy-duty precision focusers for its line of refractors. The SVF25 (starting at $265) is a dual-speed rack-and-pinion focuser with a clear aperture of 2½ inches and 3½ inches of travel. Each unit is fully rotating and is threaded to accept the company's SFF7-25 and SFF25 photographic field flatteners. The SVF25 directly replaces most focusers on current Stellarvue refractors, and additional adapters are available for other telescope models. Each version comes with both 2- and 1¼-inch eyepiece adapters that have non-marring compression rings. A model having 3 inches of clear aperture (SVF30 for $399) is also available for use with the larger Stellarvue photographic field flatteners. See the company's website for additional specifications.

Stellarvue
11820 Kemper Rd., Auburn, CA 95603;
530-823-7796; www.stellarvue.com

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

SOUTHERN SPLENDORS *Treasures of the Southern Sky* (by Robert Gendler, Lars Lindberg Christensen, David Malin) is a photographic anthology of deep-sky objects south of the celestial equator. The book also celebrates the history of southern astronomy with an engaging narrative of key contributors to southern-sky exploration. Informative text provides the reader with intriguing facts about each of the featured objects. Arranged by season, the objects span the gamut from the most celebrated to the obscure. The stunning full-color reproductions were captured with a wide selection of telescopes ranging from coauthor Robert Gendler's personal equipment all the way to the Hubble Space Telescope.
Springer, 190 pages, ISBN 978-1-4614-0627-3.
Available from Springer, www.springer.com



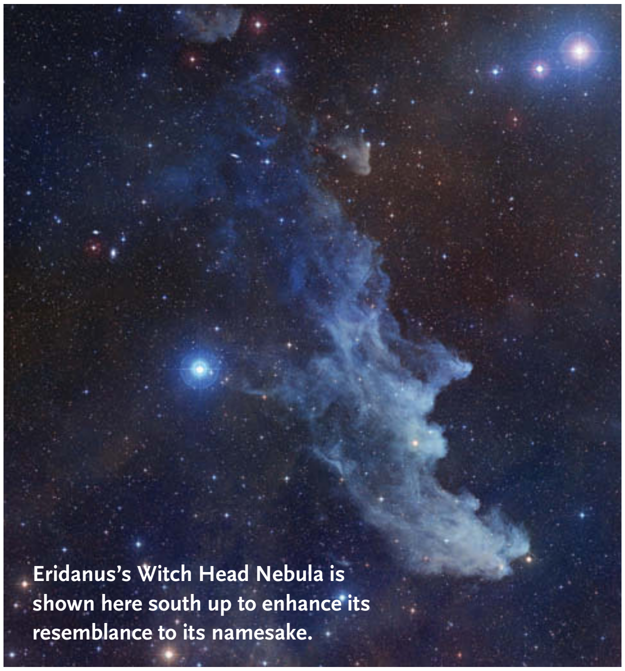
SPRINGER

Run, River, Run

A mighty watercourse meanders down the night sky.

There's a river in the sky other than the Milky Way of legends. It flows incredibly far — about one-third of the way across the sky — when and where it's entirely above the horizon. What's more, this river begins at an incomparable starting point, near Orion's brightest star.

The name of this stellar stream? Eridanus.



POSS-II / CALTECH / PALOMAR OBSERVATORY / NASA / NOEL CARBONI

Eridanus's Witch Head Nebula is shown here south up to enhance its resemblance to its namesake.

Where the river flows. Eridanus is the longest constellation in the north-south direction. The official boundaries stretch all the way from the celestial equator about 1½ hours west of Orion's Belt down to declination –58°, not far from the Small Magellanic Cloud.

Let's start at the northern end. The pattern begins with Beta Eridani, or Cursa. This 2.8-magnitude star is only 3° northwest of Rigel, Orion's brilliant forward foot. The name Cursa comes from an Arabic title meaning "the foremost footstool of al-Jauza," al-Jauza being Orion. Not far from Cursa is IC 2118, the photographically lovely Witch Head Nebula. Under superb conditions, the Witch Head is visible as a dim strip of glow in binoculars. It's a reflection nebula thought to be lit up from afar by mighty blue-white Rigel.

From Cursa, the river first flows westward about 2 hours of right ascension, then turns south, back east, and south again. Finally, a long stretch runs southwest, eventually ending with Alpha Eridani, or Achernar, the night sky's 9th-brightest star.

The name Achernar is from an Arabic phrase meaning "end of the river." But that name originally belonged to Theta Eridani, now called Acamar — an alternate transliteration of the same Arabic phrase. At declination –40°, Acamar is about as far south as the ancient Greeks could see, and that's where the traditional constellation ended. When Europeans sailed south of the equator in the 16th century, they extended the constellation and transferred the name Achernar to a different and brighter star.

Marvels along the meanders. Acamar is a superb double star, white suns shining 8″ apart at magnitudes 3.4 and 4.5. If you want a double star farther north, try lovely yellow and blue-green 32 Eridani, just south of the celestial equator. There's also Omicron^2 Eridani, a triple star 16.5 light-years away that includes the easiest white-dwarf star to observe. Even closer is orange Epsilon Eridani, just 10.5 light-years away and a famous target in the quest for planets and life beyond our solar system.

In a dark sky I've seen the dim stars of Eridanus glitter by the dozens along those shining curves that meander away from Orion. And I once woke from a dream in which I must have been at a more southerly latitude, with a magically enhanced view of Eridanus's full length twinkling.

Try checking out Eridanus for yourself. Next month, I'll have some surprising statistics to support how many-starred Eridanus really is.

Which river is it? Eridanus is the only accepted constellation whose name is neither a translation of the thing it represents (Leo = lion, for instance) nor a character from Greek mythology. It's the name of a river — but which one? Some think it's the Euphrates (the Babylonians called the city near its mouth Eridu). The Nile, Earth's longest river, runs north. Which way does Eridanus run? If south, then it might be the Mississippi, which runs uphill in the sense that its mouth is farther from the equatorially bulging Earth's center than its source is. ✦

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

MOON PHASES

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

PLANET VISIBILITY

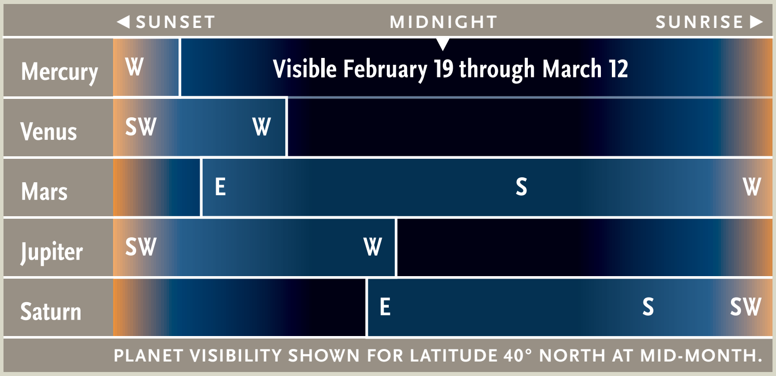


IMAGE BY PETE LAWRENCE

THE MOON WAS 1½ days old for this conjunction with Mercury over England on March 11, 2005.

February 2012

Jan. 13 – Feb. 20 NIGHT: Asteroid 433 Eros is within 30 million km of Earth and readily visible in small telescopes; see page 52.

Feb. 1 EVENING: The waxing gibbous Moon shines between the Pleiades and Hyades.

7 FULL MOON (4:54 p.m. EST).

9 EVENING: Mars rises to the left of the waning gibbous Moon around 8 p.m. (for North America). See page 48.

9–23 EARLY EVENING: The zodiacal light is on excellent display from dark locations at mid-northern latitudes. Look west starting about 80 minutes after sunset for a huge, tall pyramid of diffuse light centered on the line connecting Jupiter and Venus.

11 EVENING OR NIGHT: Algol is at its minimum brightness for roughly 2 hours centered on 10:50 p.m. EST (7:50 p.m. PST).

12, 13 DAWN: The Moon is 2° to 3° lower right of Spica on the 12th and well to Saturn's lower left on the 13th.

14 LAST-QUARTER MOON (12:04 p.m. EST).

21 NEW MOON (5:35 p.m. EST).

22 DUSK: An ultrathin, 1-day-old crescent Moon floats to the right of Mercury very low in the west a half hour after sunset. Bring binoculars.

23, 24 DUSK: The waxing Moon climbs rapidly toward Venus.

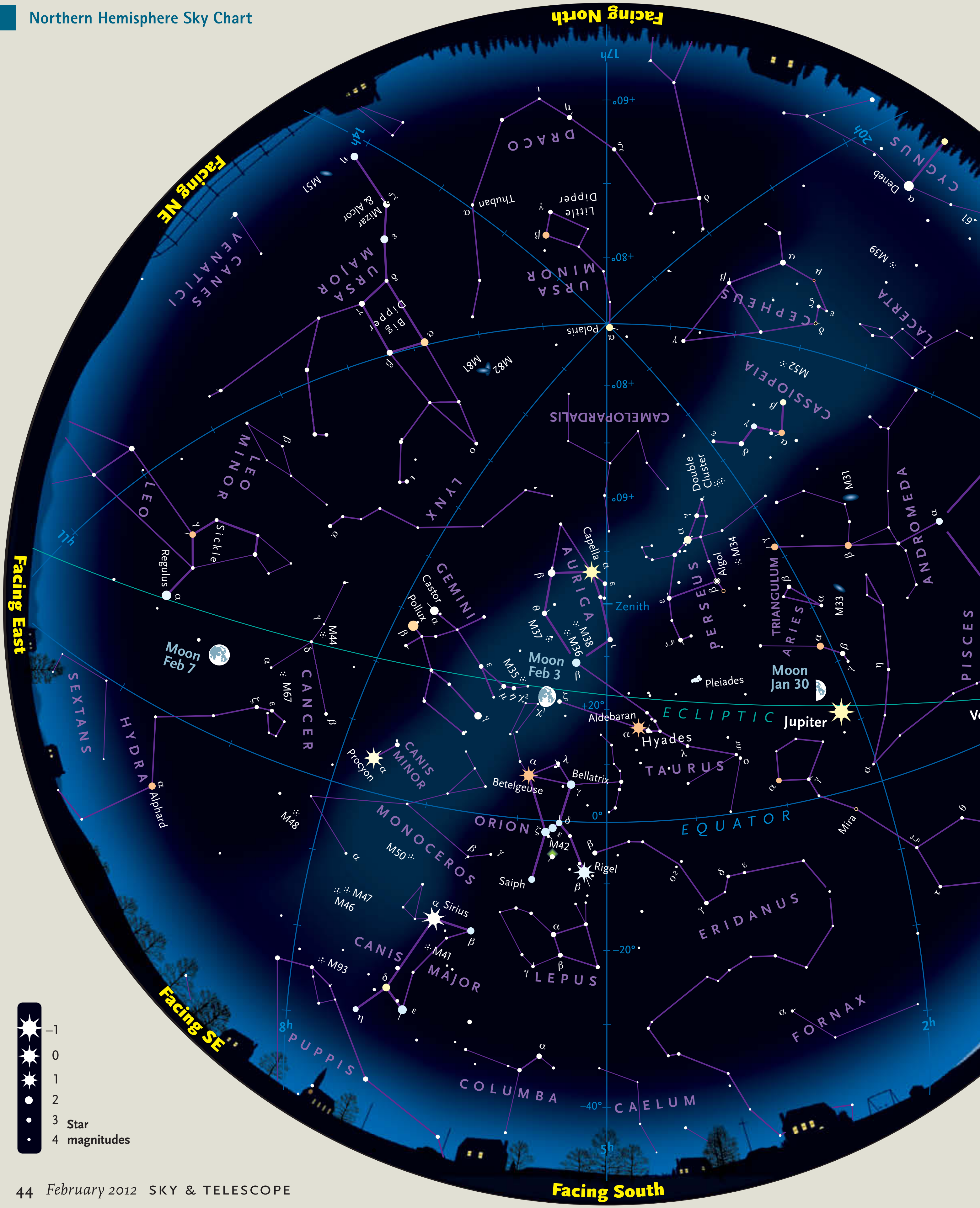
25, 26 DUSK AND EVENING: The Moon pairs spectacularly with Venus on the 25th and Jupiter on the 26th; see page 49.

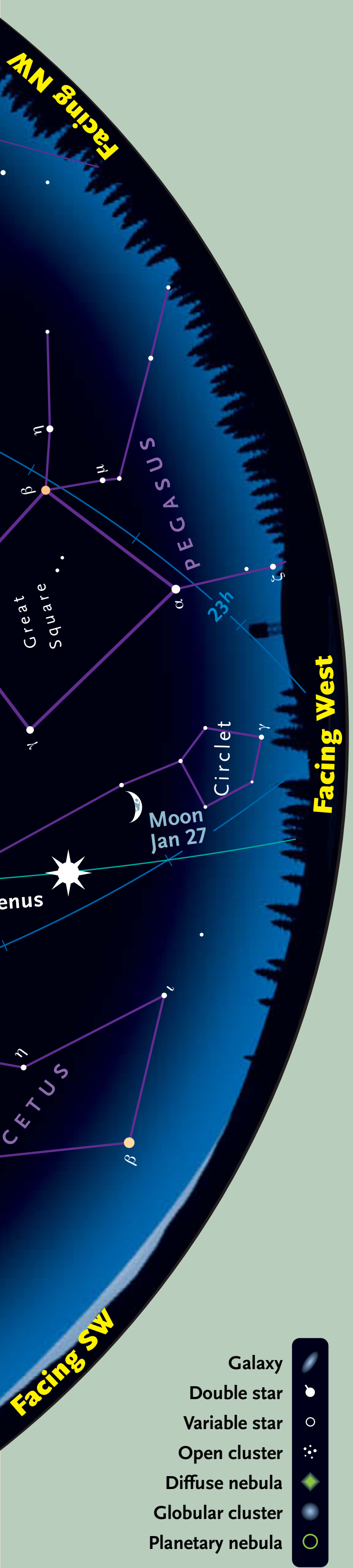
28, 29 EVENING: The Moon is near the Pleiades on the 28th and the Hyades on the 29th. Best in binoculars.

Feb. 28 – Mar. 10 DUSK: Mercury is more than 10° above the western horizon a half hour after sunset. This is Mercury's best evening apparition in 2012.

29 FIRST-QUARTER MOON (8:21 p.m. EST).

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


Facing North
Facing NE
Facing East
Facing SE
Facing South
DRACO
Thuban
Little Dipper
URSA MINOR
Polaris
URSA MAJOR
Big Dipper
Mizar & Alcor
M51
CANES VENATICI
M81
M82
CAMELOPARDALIS
CEPHEUS
CYGNUS
Deneb
M39
LACERTA
CASSIOPEIA
M52
Double Cluster
M31
ANDROMEDA
TRIANGULUM
M33
ARIES
PISCES
PERSEUS
Algol
M34
LEO MINOR
LYNX
LEO
Sickle
Regulus
AURIGA
Capella
Zenith
M37
M36
M38
GEMINI
Castor
Pollux
M35
Moon Feb 3
Moon Feb 7
Moon Jan 30
Pleiades
ECLIPTIC
Jupiter
Aldebaran
Hyades
TAURUS
M44
M67
CANCER
SEXTANS
HYDRA
Alphard
CANIS MINOR
Procyon
Betelgeuse
Bellatrix
ORION
EQUATOR
Mira
M48
MONOCEROS
M50
M42
Rigel
Saiph
ERIDANUS
M47
M46
Sirius
CANIS MAJOR
M41
M93
LEPUS
PUPPIS
COLUMBA
CAELUM
FORNAX
+60°
+80°
+20°
0°
–20°
–40°
17h
14h
20h
11h
8h
5h
2h
–1
0
1
2
3
4
Star magnitudes



Using the Map

WHEN

Late December	11 p.m.
Early January	10 p.m.
Late January	9 p.m.
Early February	8 p.m.
Late February	7 p.m.

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.

Example: Rotate the map a little so that "Facing East" is right-side up. Two-thirds of the way from there to the map's center are the twin stars Castor and Pollux. Go out, face east, and look two-thirds of the way up the sky. There are the Twins!!

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

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: Messier's Best

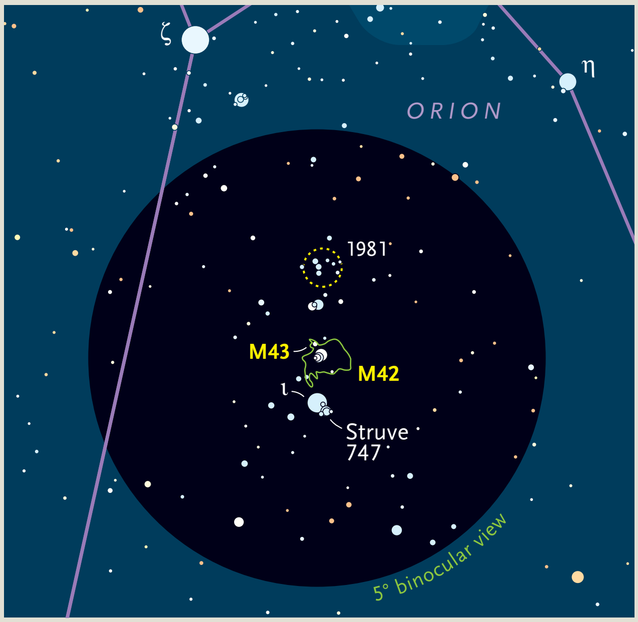
The Sword of Orion must surely rank as one of the finest binocular sights in the entire sky. In a tight 2½° field of view we find two Messier nebulae (**M42** and **M43**), a fine open cluster (NGC 1981), an attractive, tight binocular double (Struve 747), and a sprinkling of additional, prominent stars. But does M42 rank as the best Messier of all?

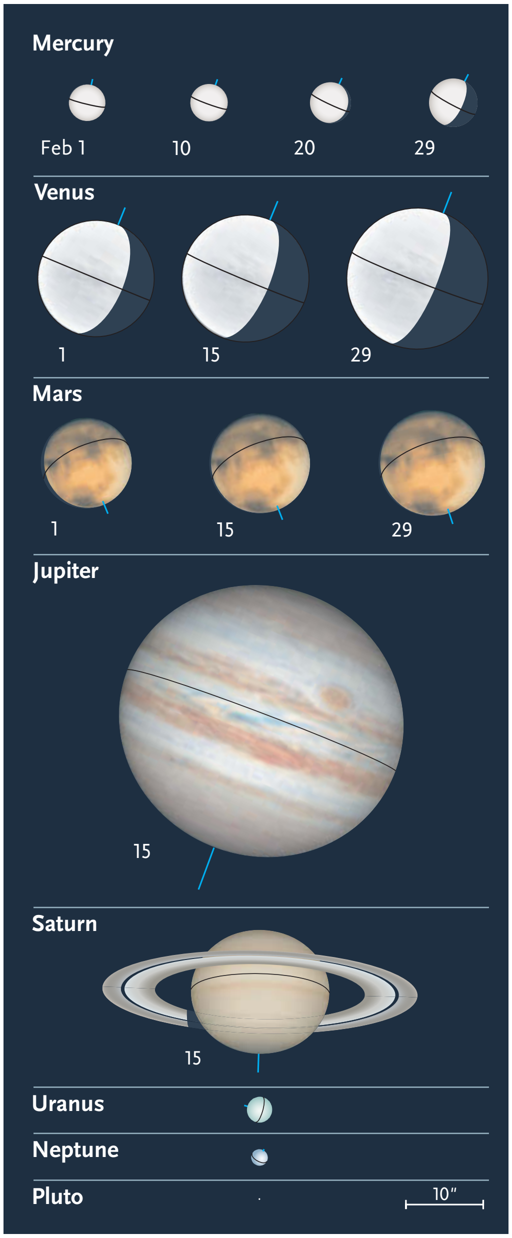
The Orion Nebula is near the top of every binocular observer's best-of list, but is it more entrancing than the Pleiades (M45), or the Andromeda Galaxy (M31)? That's a real apples and oranges and cantaloupes comparison! It terms of pure visual impact, I might give the Pleiades a slight edge over the Orion Nebula, but you can't view M42 in isolation — and the splendor of the whole picture is undeniable. It's a tough call.

Regardless, the Orion Nebula is a wondrous binocular sight, glowing like a pale, upturned rose in late bloom. Even under city skies, the core of the nebula is a snap to see in my 10×30 image-stabilized binos. From a dark location, M42 is absolutely enchanting, with few rivals anywhere in the sky. And nestled within the nebula's luminous heart lies the unresolved 5th-magnitude spark of the Trapezium grouping, along with neighboring Theta^2 (θ^2) Orionis paired with a 6th-magnitude star just to the east.

After taking in M42, nearby M43 can hardly fail to be an anticlimax. And it is. Here the challenge is seeing the nebula at all. Under good skies I can make out M43 as a dim little haze surrounding 4.6-magnitude 42 Orionis. M43 doesn't add much to the overall scene, but then again, it really doesn't have to. ✦

— *Gary Seronik*



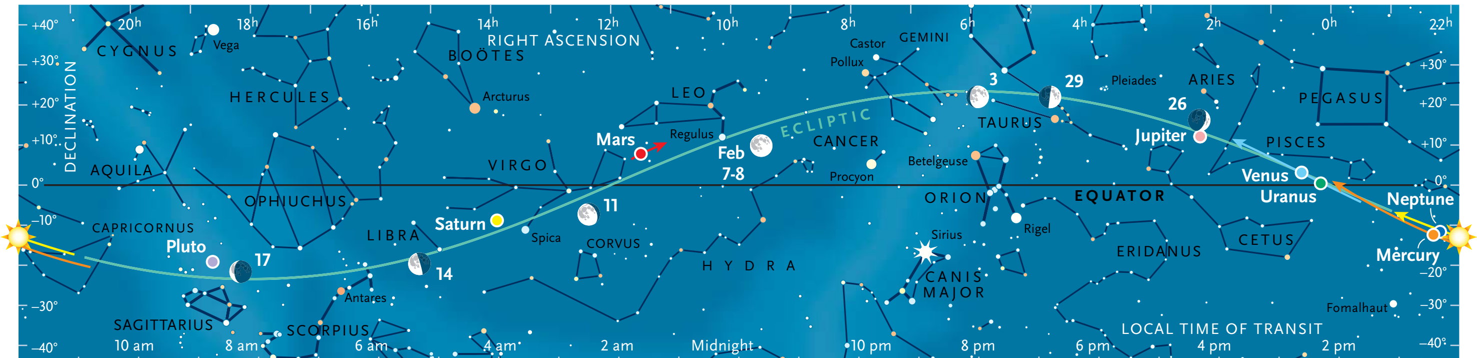


Sun and Planets, February 2012

	February	Right Ascension	Declination	Elongation	Magnitude	Diameter	Illumination	Distance
Sun	1	$20^h\,55.2^m$	–17° 22′	—	–26.8	32′ 28″	—	0.985
	29	$22^h\,44.8^m$	–7° 57′	—	–26.8	32′ 17″	—	0.991
Mercury	1	$20^h\,39.2^m$	–20° 31′	5° Mo	–1.1	4.8″	99%	1.414
	10	$21^h\,42.0^m$	–15° 54′	3° Ev	–1.6	4.9″	100%	1.381
	20	$22^h\,50.7^m$	–8° 35′	10° Ev	–1.3	5.3″	93%	1.266
	29	$23^h\,45.6^m$	–0° 59′	17° Ev	–0.9	6.3″	70%	1.070
Venus	1	$23^h\,29.2^m$	–4° 19′	40° Ev	–4.1	15.1″	74%	1.106
	10	$0^h\,07.6^m$	+0° 23′	41° Ev	–4.1	15.9″	71%	1.047
	20	$0^h\,49.4^m$	+5° 35′	43° Ev	–4.2	17.1″	68%	0.978
	29	$1^h\,26.6^m$	+10° 06′	44° Ev	–4.3	18.2″	64%	0.914
Mars	1	$11^h\,38.6^m$	+6° 29′	139° Mo	–0.6	11.8″	96%	0.793
	15	$11^h\,29.1^m$	+7° 50′	155° Mo	–0.9	13.1″	98%	0.717
	29	$11^h\,11.3^m$	+9° 48′	173° Mo	–1.2	13.8″	100%	0.677
Jupiter	1	$2^h\,02.6^m$	+11° 19′	81° Ev	–2.3	39.2″	99%	5.034
	29	$2^h\,18.7^m$	+12° 50′	57° Ev	–2.2	36.2″	99%	5.452
Saturn	1	$13^h\,52.6^m$	–8° 50′	102° Mo	+0.6	17.6″	100%	9.448
	29	$13^h\,51.4^m$	–8° 36′	131° Mo	+0.4	18.4″	100%	9.035
Uranus	15	$0^h\,09.3^m$	+0° 15′	37° Ev	+5.9	3.4″	100%	20.857
Neptune	15	$22^h\,10.1^m$	–11° 54′	5° Ev	+8.0	2.2″	100%	30.985
Pluto	15	$18^h\,36.4^m$	–19° 17′	47° Mo	+14.1	0.1″	100%	32.844

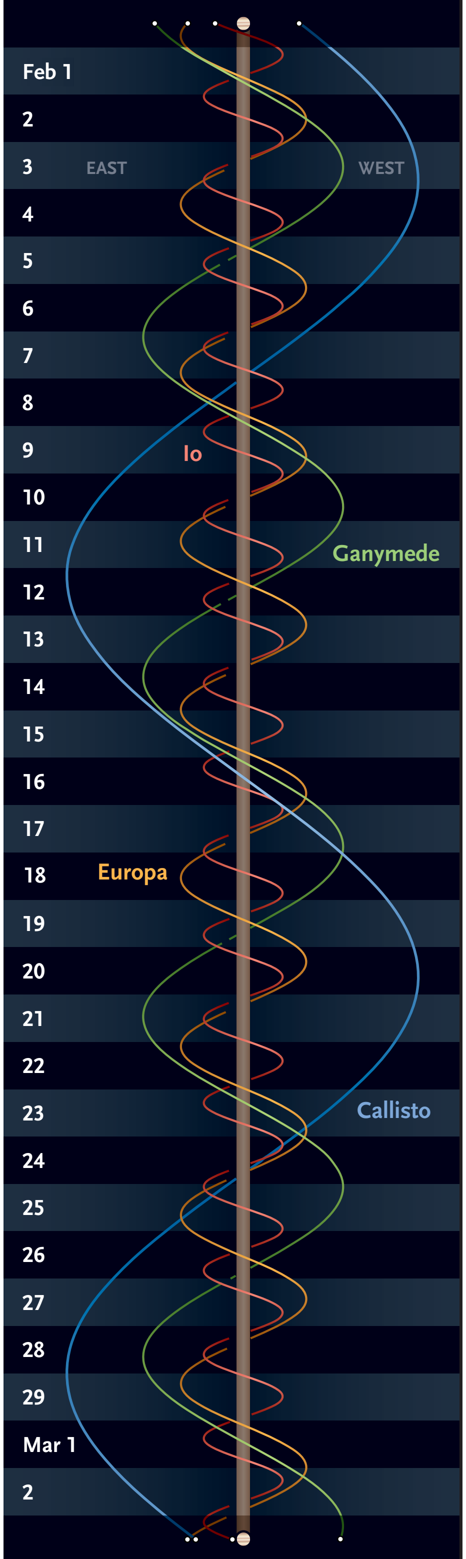
The table above gives each object's right ascension and declination (equinox 2000.0) at 0^h Universal Time on selected dates, and its elongation from the Sun in the morning (Mo) or evening (Ev) sky. Next are the visual magnitude and equatorial diameter. (Saturn's ring extent is 2.27 times its equatorial 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-February; 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 February. "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 0ʰ (upper edge of band) to 24ʰ 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.

Early Evening Convocation

The four brightest planets are visible after sunset in late February.

THE SKY AT DUSK is dramatic at the beginning of February, and it becomes increasingly thrilling as the month progresses. In the southwest, dazzling Venus and Jupiter start the month 40° apart and end it 12° apart. Mars, approaching maximum brilliance, rises now in early evening. In the final week of February, Mercury is also bright, albeit low in the west at dusk.

Jupiter remains visible for most of the evening — then sets in the west shortly after Saturn rises on the opposite side of the sky. By dawn, Mars has sunk low in the west-southwest or west, while Saturn still shines fairly high in the south or south-southwest.

DUSK AND EARLY EVENING

Jupiter floats high above **Venus** in the southwest sky at dusk on February 1st. But by month's end the gap between them shrinks to hardly more than a fist-width at arm's length — close enough to draw the gaze of even the most casual skywatcher.

Venus keeps appearing higher as the weeks pass. The interval between sunset and Venus-set increases from about 3¼ to 3¾ hours during February for skywatchers at 40° north latitude. Meanwhile Jupiter, upper left of Venus, keeps setting earlier as February progresses — around midnight at month's start and 10:30 p.m. at month's end. Venus brightens from magnitude –4.1 to –4.3 during February, while Jupiter dims slightly, from magnitude –2.3 to –2.2.

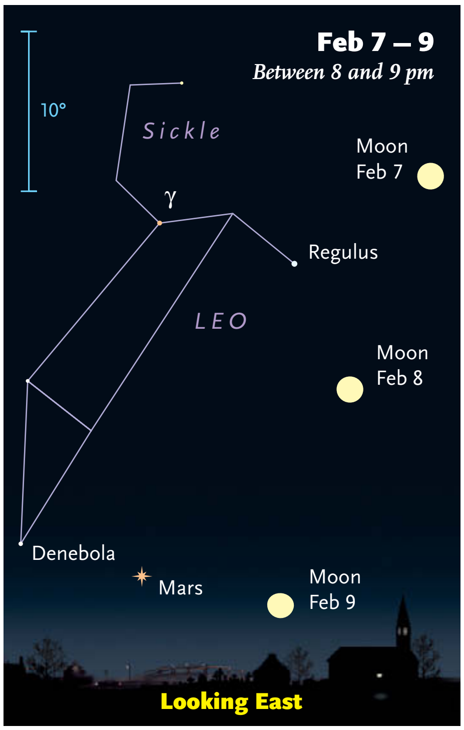
Telescopes show Jupiter high in the south-southwest at dusk as February opens, its round disk potentially rich with detail, though a fairly modest 39″ wide (36″ by month's end). Venus grows to half of Jupiter's apparent diameter by the close of February, while its phase shrinks to less than ⅔ illuminated.

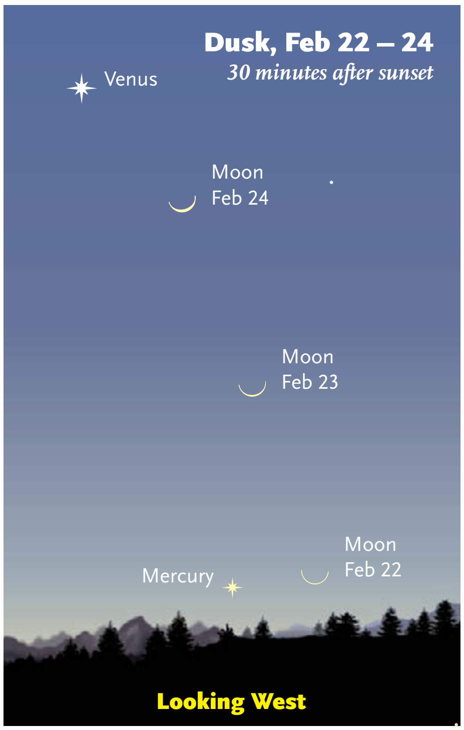
On the American evening of February 9th, telescopes at medium to high magnification should show the tiny blue-green disk of 5.9-magnitude **Uranus** just ⅓° south of dazzling Venus. **Neptune**, Uranus's fellow ice giant, is at conjunction with the Sun on February 19th and therefore unviewable all month.

Mercury slips up into view at dusk late in February, shining around magnitude –1 and setting about an hour after the Sun by February 22nd. To find it, look less than three fist-widths at arm's length lower right from Venus.

EVENING TO DAWN

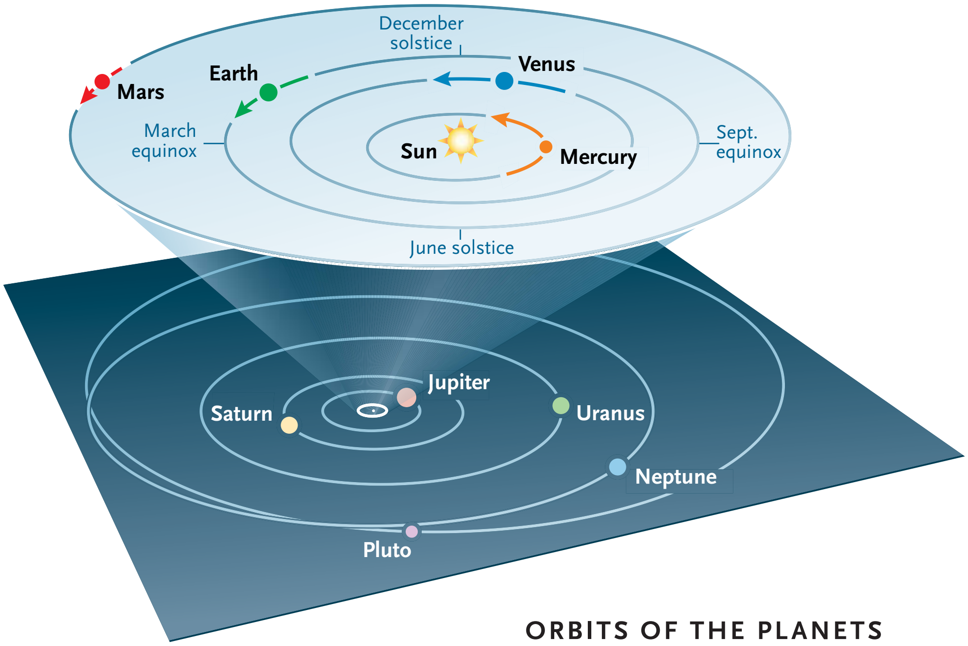
Mars makes a dramatic entrance to the early evening sky. The fire-colored planet roughly doubled in brightness during January, and it doubles again in February, kindling from magnitude –0.5 to –1.2. Equally marvelous is how its retrograde motion helps its rise-time back up by two and a half hours during February, from





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

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



ORBITS OF THE PLANETS

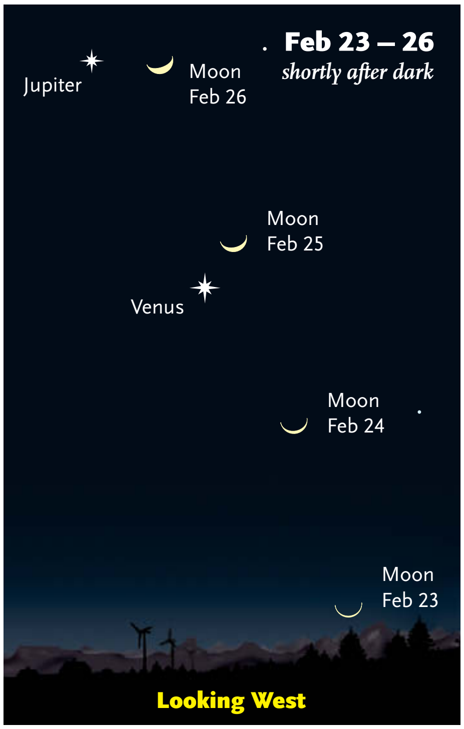
The curved arrows show each planet's movement during February. The outer planets don't change position enough in a month to notice at this scale.

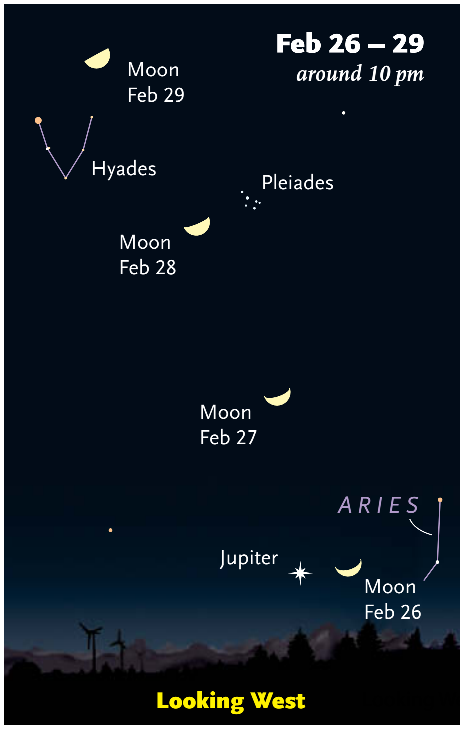
8:30 to 6:00 p.m. — right after sunset. Mars starts the month south of Leo's tail, rising about 8½° lower right of Denebola (Beta Leonis). The planet's retrograde motion (westward relative to the stars) brings it within 16° of Regulus, Leo's heart, during the course of the month.

Mars will reach opposition to the Sun on March 3rd and its closest approach to Earth on March 5th. Unfortunately, Mars is at aphelion (farthest out in its orbit) on February 15th, so Mars won't come very close to Earth during this apparition. Even so, the apparent diameter of the Martian globe increases from 11.8″ to 13.8″ in February — almost equal to its maximum of 13.9″ in early March. You should be able to glimpse considerable detail on Mars through a good telescope on a good night. Mars reaches its highest in the south, and is best in a telescope, shortly after midnight this month.

Saturn, in western Virgo, comes up around 11:30 p.m. at the opening of February but two hours earlier at the close of the month. Saturn will reach opposition to the Sun in mid-April, so in February the planet is brightening — from magnitude +0.6 to +0.4. That's about halfway in brightness between Arcturus and Spica. Saturn begins retrograde motion on February 8th, starting a hike back toward Spica, about 7° from Saturn.

As February begins, Saturn's gorgeous rings are tilted at a temporary maximum of more than 15° from edge-on, then close slowly for the next 5 months. Saturn is highest in the south around 5 a.m. at the beginning of February, 3 a.m. at the end of the month.





MOON PASSAGES

The **Moon** shines to the right of Mars on the evening of February 9th. At dawn on February 12th look for the lunar crescent close below Spica and farther to the lower right of Saturn.

After New Moon, the waxing lunar crescent climbs closely and beautifully past three planets at dusk. On February 22nd a very thin Moon sliver is right of Mercury. On February 25th a much thicker lunar crescent is quite close to the upper right of Venus. They're just 3° apart as seen from eastern North America — quite a spectacle! The next evening, the Moon shines to the right of Jupiter. ✦

A Lunar Volcanic Crater

Few large volcanic craters are visible on the Moon… except this one.

For generations, observers have debated the origin of lunar craters. Were they formed by impact or volcanism? Since the 1960s, the evidence has become overwhelming that the vast majority of craters on the Moon and every solid body in the solar system have an impact origin. Vast fields of mare lavas clearly show that volcanism was also a major lunar process, but other than small pits on mare domes, the features we commonly call craters were not formed by volcanism. Except for one.

JAXA / MOTOMARO SHIRAO

The unusual crater Hyginus stands out as the only substantial lunar crater lacking an elevated rim, leading geologists to suspect a volcanic origin. This oblique view facing south from Japan's Kaguya spacecraft reveals collapse pits along Rima Hyginus.

Even die-hard advocates of impact origins think that **Hyginus** is a volcanic crater. This 11-kilometer-wide rimless pit resides at the juncture of the two arms of a rille known as Rima Hyginus, in the east end of Sinus Medii. The fact that Hyginus lacks an elevated rim differentiates it from impact craters, and its association with rilles unambiguously links it to internal lunar forces. U.S. Geological Survey cartographers in the late 1960s noted another likely volcanic manifestation: a faint mantle of dark material surrounding Hyginus. Recent radar investigations of the material indicate that it's most likely a very thin pyroclastic or ash deposit. This is strong evidence for the interpretation that Hyginus is a volcanic structure.

You can see the morphological evidence — Hyginus has no rim, is at the juncture of two rilles, and is surrounded by dark material — quite easily in the eyepiece of a small telescope. Understanding the eruption mechanism requires detailed mathematical modeling of the physical processes of an eruption. Lionel Wilson and his colleagues at Lancaster University in the U.K. have now done that. Their model takes into account the 23 pits that lie mostly along the western limb of Rima Hyginus. Like Hyginus Crater, these are rimless depressions, and the fact that many have diameters wider than the average rille width of 3 km means that they must have formed *after* the rille.

Based on studies of small pyroclastic eruptions on Earth, and the formation of lines of pit craters in Hawaii, Wilson and his colleagues propose this sequence of events: a 240-meter-wide vertical sheet of magma called a dike moved upward and horizontally from the mantle. The dike presumably followed lines of weakness associated with the formation of Imbrium Basin. The rising dike produced upward pressure that slightly uplifted the surface above. An elongated depression known as a graben formed where surface rocks collapsed between two parallel faults, creating Rima Hyginus. The dike stalled, however, and none of its magma erupted onto the surface.

Some of the dike's magma spread laterally (becoming a

This high-resolution image by amateur Wes Higgins resolves the series of collapse pits along Rima Hyginus.

mass of igneous rock known as a *laccolith*) about a kilometer below the surface, eventually swelling to a diameter of roughly 10 km. Gas pressure built up at the top of the laccolith, fracturing overlying rocks. This allowed carbon dioxide gas and pyroclastic debris to erupt over the surface. The explosive release of gas and ash created a vacant space underground, so the overlying material collapsed to form Hyginus Crater. The pyroclastic debris is still seen today as the dark material around Hyginus. Gas flowed along the top of the dike to enhance the eruption, and the decrease in pockets of gas along the dike led to additional collapses, creating the 23 pits along the rille.

This complex scenario might not be the only explanation for what we observe, though the group's model is generally consistent with morphological constraints and known eruption physics. The long dikes were required to account for the rille's two arms, and the laccolith was necessary to provide a void for the collapse that formed Hyginus. Yet the estimated volume of the pyroclastic deposit is about the same as the volume of Hyginus Crater, which formed by removal of the magma that made the ash. The volume of the 23 pits is nearly the same as the calculated volume of gas that escaped.

An intriguing additional consideration is that the high-resolution narrow-angle camera on NASA's Lunar Reconnaissance Orbiter has recently imaged very small depressions and smooth surfaces on the floor of Hyginus. These are thought to be very young (millions rather than billions of years old) and raise the question of whether volcanic gases are still escaping from Hyginus. ✦

To get a daily lunar fix, visit contributing editor ***Charles Wood's*** *website:* ***lpod.wikispaces.com***.

The Moon • February 2012

Phases

Full Moon	February 7, 21:54 UT
Last quarter	February 14, 17:04 UT
New Moon	February 21, 22:35 U

Distances

Perigee	February 11, 19^h UT
231,619 miles	diam. 32′ 4″
Apogee	February 27, 14^h UT
251,345 miles	diam. 29′ 32″

Librations

Volta (crater)	February 9
Pascal (crater)	February 11
Oken (crater)	February 24
Demonax (crater)	February 26

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

S&T: DENNIS DI CICCO

A Rare Flyby of Eros

The granddaddy of near-Earth asteroids brightens to magnitude 8.6.

The first near-Earth asteroid ever discovered was 433 Eros in 1898. It made history then, in part by enabling the first accurate measurement of the astronomical unit and hence the scale of the solar system. It made history again in 2000 and 2001, when NASA's NEAR-Shoemaker probe took up orbit around it and then descended to its dusty surface.

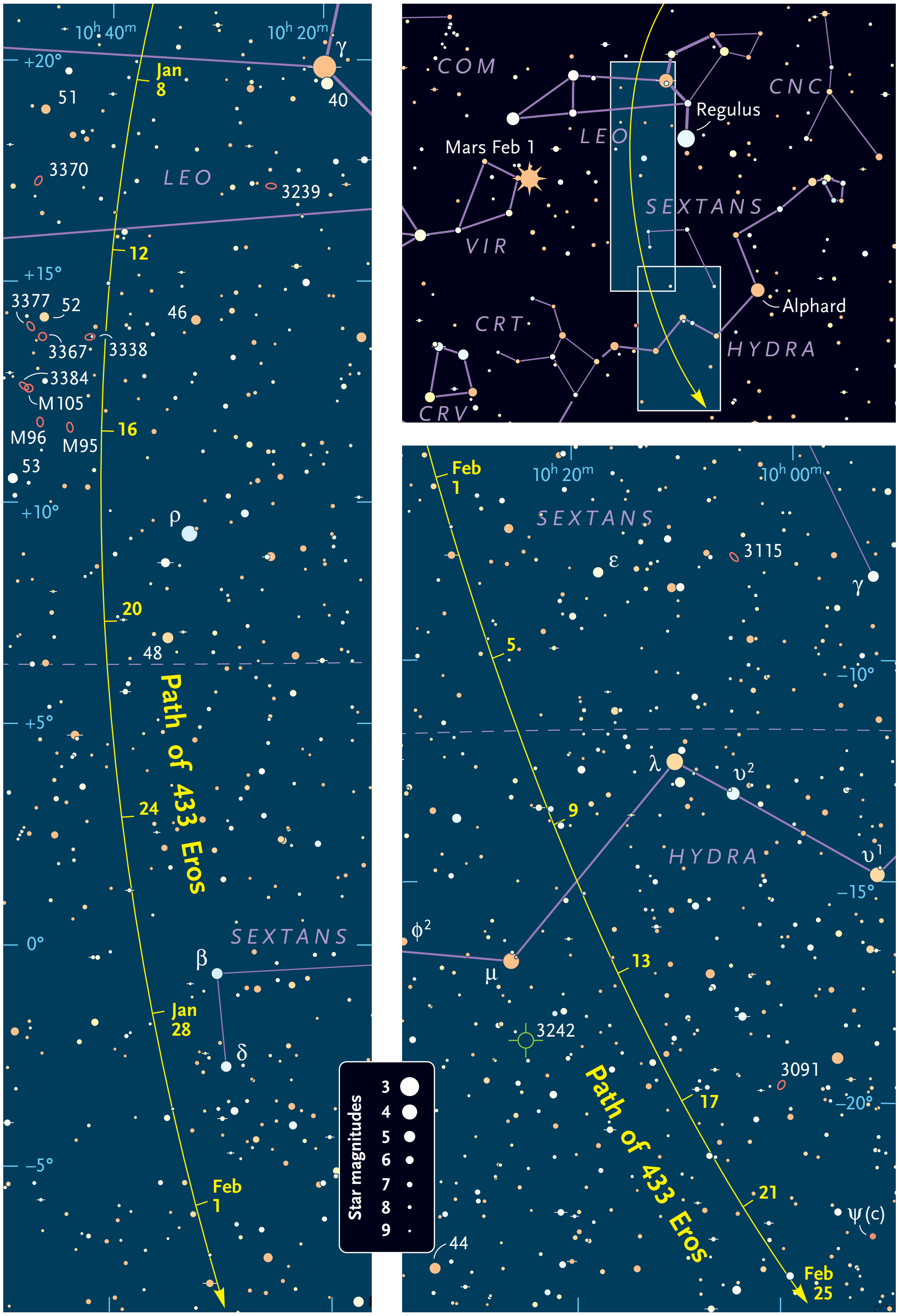
The finder charts here show its path across Leo, Sextans, and Hydra this season. It brightens from magnitude 9.2 on January 12th to 8.8 on the 18th, then 8.6 from January 25th to February 13th. It fades back to 9.0 by February 25th. Eros is closest to Earth on January 31st, though not very close as near-Earth asteroids go: 0.18 a.u., or 70 times the Moon's distance.

On the top-right chart, the blue rectangles show the areas of the larger charts. On these, the ticks on Eros's path mark its position at 0:00 Universal Time on the indicated dates (which is 7 p.m. EST on the previous date).

Eros is the second-largest near-Earth asteroid, after 1036 Ganymed, measuring 21 × 7 × 7 miles (34 × 11 × 11 km). This is its closest approach since January 1975. It next comes this close in January 2056.

NASA / JPL / JHU APL

The NEAR-Shoemaker spacecraft took this image of slowly tumbling Eros from a range of 1,100 miles on February 12, 2000. The color is approximately correct.



Action at Jupiter

February finds Jupiter already west of the meridian at dusk, so observe it right away while it's still high.

Even the smallest scopes show Jupiter's four big Galilean moons. Binoculars usually show at least two or three. Identify them with the diagram on page 47. Listed below are all their interactions with Jupiter's disk and shadow during February.

Here are the times, in Universal Time, when Jupiter's Great Red Spot should cross the planet's central meridian. The dates (also in UT) are in bold. The Red Spot appears closer to the planet's central meridian than to the limb (edge) for 50 minutes before and after these times: **February 1,** 7:30, 17:26; **2,** 3:22, 13:18, 23:13; **3,** 9:09, 19:05; **4,** 5:01, 14:57; **5,** 0:52, 10:48, 20:44; **6,** 6:40, 16:36; **7,** 2:32, 12:27, 22:23; **8,** 8:19, 18:15; **9,** 4:11, 14:07; **10,** 0:02, 9:58, 19:54; **11,** 5:50, 15:46; **12,** 1:41, 11:37, 21:33; **13,** 7:29, 17:25; **14,** 3:21, 13:16, 23:12; **15,** 9:08, 19:04; **16,** 5:00, 14:56; **17,** 0:51, 10:47, 20:43; **18,** 6:39, 16:35; **19,** 2:31, 12:26, 22:22; **20,** 8:18, 18:14; **21,** 4:10, 14:06; **22,** 0:02, 9:57, 19:53; **23,** 5:49, 15:45; **24,** 1:41, 11:37, 21:32; **25,** 7:28, 17:24; **26,** 3:20, 13:16, 23:12; **27,** 9:07, 19:03; **28,** 4:59, 14:55; **29,** 0:51, 10:47, 20:43.

These times assume that the Great Red Spot is centered at System II longitude 173°. If it's elsewhere, it will transit 1^2/3 minutes late for every 1° of longitude greater than 173°, or 1^2/3 minutes early for every 1° less than 173°.

Markings on Jupiter appear a little more contrasty through a blue or green eyepiece filter. The larger your scope, the darker the blue or green can be; you want enough light to see fine details clearly, but not so much that you lose visual details to glare (overexposure). And try several magnifications to find one that shows the most given the current seeing. Too high a power and you'll lose things in the overmagnified blurring.

And keep looking. More and more flickers of features come out with protracted scrutiny. ✦

Minima of Algol

January	UT	February	UT
3	0:19	3	13:22
5	21:09	6	10:11
8	17:58	9	7:01
11	14:47	12	3:50
14	11:37	15	0:40
17	8:26	17	21:29
20	5:15	20	18:18
23	2:05	23	15:08
25	22:54	26	11:57
28	19:43	29	8:46
31	16:33		

These geocentric predictions are from the heliocentric elements Min. = JD 2,452,253.567 + 2.867321*E*, where *E* is any integer. Derived by Marvin Baldwin (AAVSO), they are based on 17 timings collected from 1999 to 2003 and on the star's average period during the previous 35 years. For a comparison-star chart, visit SkyandTelescope.com/algol.

Phenomena of Jupiter's Moons, February 2012

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

Every day, interesting events happen between Jupiter's satellites and the planet's disk or shadow. The first columns give the date and mid-time of the event, in Universal Time (which is 5 hours ahead of Eastern Standard Time). Next is the satellite involved: **I** for Io, **II** Europa, **III** Ganymede, or **IV** Callisto. Next is the type of event: **Oc** for an occultation of the satellite behind Jupiter's limb, **Ec** for an eclipse by Jupiter's shadow, **Tr** for a transit across the planet's face, or **Sh** for the satellite casting its own shadow onto Jupiter. An occultation or eclipse begins when the satellite disappears **(D)** and ends when it reappears **(R)**. A transit or shadow passage begins at ingress **(I)** and ends at egress **(E)**. Each event is gradual, taking up to several minutes. Predictions courtesy IMCCE / Paris Observatory.

Orion's Golden Shield

Remarkable clusters and nebulae encircle the giant's torso.

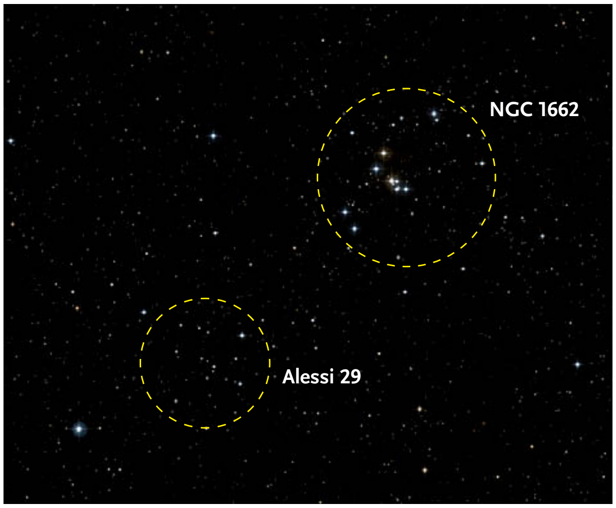
His sword hung gleaming by his side,
And, on his arm, the lion's hide
Scattered across the midnight air
The golden radiance of its hair.
— Henry Wadsworth Longfellow,
The Occultation of Orion

LAST MONTH we explored some of the amazing deep-sky wonders in the environs of Orion's gleaming sword. Now let's set our sights a bit farther north, starting in the mighty Hunter's shield, which is often portrayed as a golden lion pelt draped over Orion's outstretched arm.

We find an aptly seasonal Valentine's Day treat 1.8° west-northwest of Pi^1 (π^1) Orionis, atop Orion's shield. The open cluster **NGC 1662** is a heart-shaped beauty you could share with someone special.

My 130-mm (5.1-inch) refractor at 23× shows 22 stars in NGC 1662, all but four outlining a stylized heart with a loop where the lobes meet. The cluster's two brightest stars have a yellow hue; one ornaments the loop and the other shines at the top of the heart. The four loop stars belong to the multiple star h684, and a dimmer, fifth component becomes visible at high powers.

The light from this Valentine heart has traveled about 1,400 years to reach your eyes, starting approximately two centuries after the feast of St. Valentine was established.



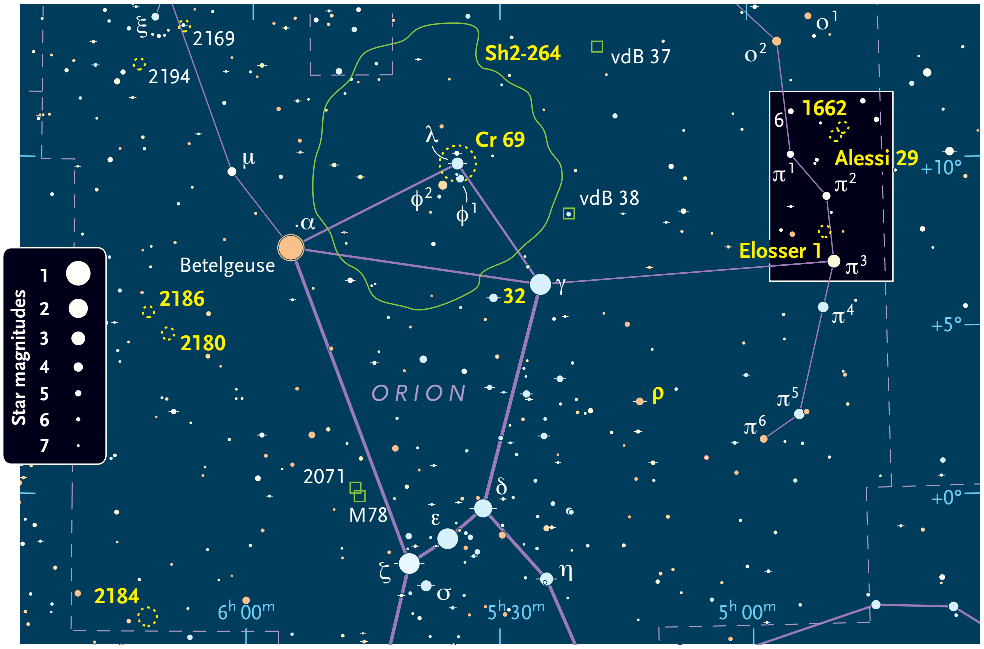
POSS-II / CALTECH / PALOMAR OBSERVATORY

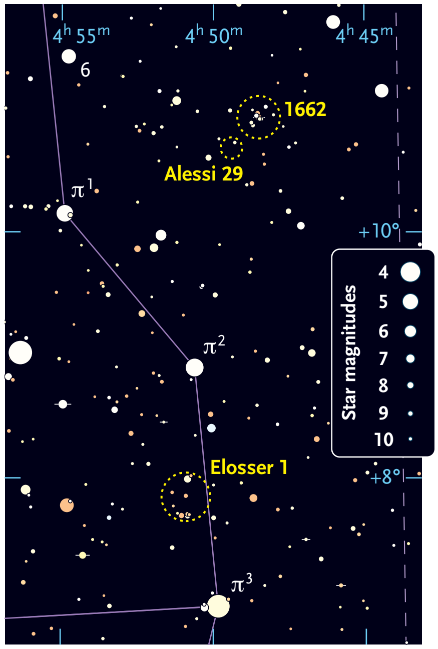
Just southeast of NGC 1662, we find the possible open-cluster remnant **Alessi 29**, discovered by Brazilian amateur Bruno Sampaio Alessi. Open-cluster remnants are the residue of clusters that lost their gravitational grip on most of their original members and have been pared down to more stable multiple systems. Such remnants are difficult to identify unless they have enough members to show a telltale spectral sequence indicating their former glory as part of a larger group.

Visually through my 130-mm scope at 63×, Alessi 29 is a teardrop of 13 stars magnitude 9.7 and fainter. The glistening teardrop is 9½′ long and appears to be falling from the northeast.

The bright, eye-catching asterism **Elosser 1** sits halfway between Pi^2 and Pi^3 Orionis and just east of an imagi-

POSS-II / CALTECH / PALOMAR OBSERVATORY





nary line connecting them. In the mirror-reversed view of my 130-mm refractor, Elosser 1 is a J of 13 stars hooked around a golden 9th-magnitude star. The brightest stars in the top and bottom of the J glow yellow and orange, respectively. At 63×, 15 faint stars are visible within the J, filling it out into an egg shape 21′ long.

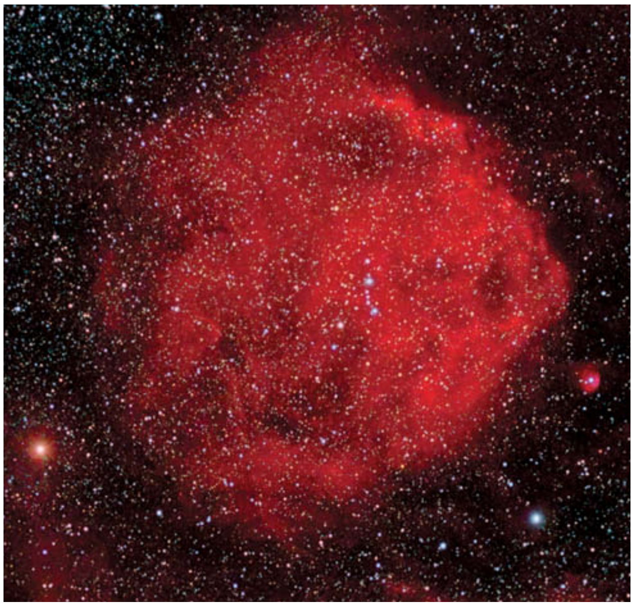
North Carolina amateur David Elosser chanced upon this group while observing with his 4-inch refractor. It's now listed in the Deep Shy Hunters' asterism catalog at **tech.groups.yahoo.com/group/deepskyhunters**. Elosser points out that the two star triangles at the southern end of the group seem to form "an old fashioned rocket ship."

Let's work our way away from the shield to the pretty double star **Rho (ρ) Orionis**. My 105-mm refractor at 87× shows a bright, golden primary with a much dimmer companion 6.9″ to the east-northeast.

The more equal and tighter pair **32 Orionis** is pinned to Orion's western shoulder. Both stars look white through my 130-mm refractor, the attendant watching its 4.4-magnitude primary from the northeast. Separated by only 1.3″, the components are split by a hair at 164× and nicely split at 234×.

The position of Orion's head is marked by **Lambda (λ) Orionis** and the other bright stars of the loose cluster **Collinder 69**. Lambda is a double star with blue-white, 3.5- and 5.5-magnitude components separated by 4.9″ and split in my 105-mm refractor at 87×. At low power, Collinder 69 covers about 1° and shows about 45 bright to faint stars in the 105-mm scope and 55 in the 130-mm scope.

If you visualize Collinder 69 as Orion's head, then the giant is a pinhead. But **Sharpless 2-264**, the 6½°-wide emission nebula surrounding the cluster, gives him a swelled head. Although Sh 2-264 is quite faint, Lowell Observatory's Brian Skiff found it "straightforward" with the unaided eye, and California amateur Robert Ayers has spotted it through 7×42 binoculars. Also in California, Kevin Ritschel observed the nebula with filter-aided eyes. Ritschel mounted a pair of 2-inch hydrogen-beta filters in holes cut into a shallow box, and he held the box up to his face like a mask. This not only helped him combat light pollution, but also kept stray light from reflecting off the back of the filters.



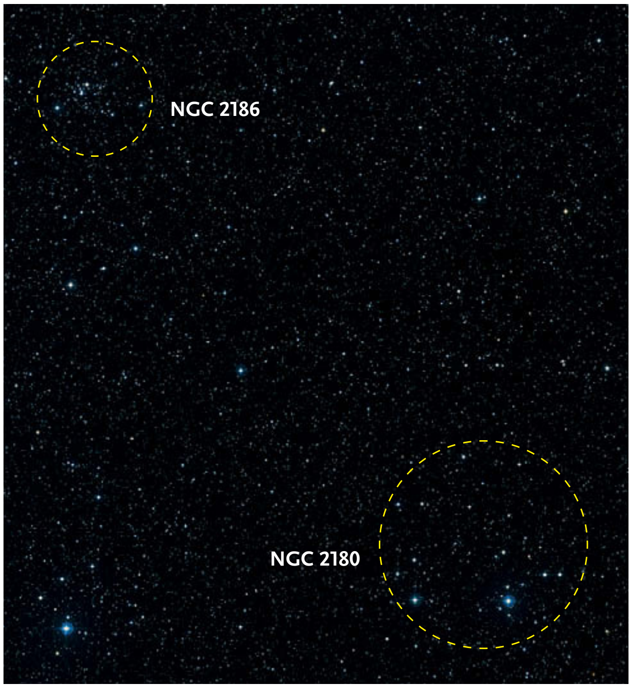
S&T: SEAN WALKER

The bright stars of Collinder 69 lie at the center of the huge nebula Sharpless 2-264 (shown above). Note also the nebulosity around Betelgeuse in the lower-left corner and the small, bright nebula van den Bergh 38 near the right margin.

Clusters, Doubles, and a Nebula in Northern Orion

Object	Type	Mag(v)	Size/Sep	RA	Dec.
NGC 1662	Open cluster	6.4	20′	4^h 48.5^m	+10° 56′
Alessi 29	Cluster remnant?	—	10′	4^h 49.4^m	+10° 41′
Elosser 1	Asterism	—	21′	4^h 50.9^m	+7° 51′
Rho Ori	Double star	4.6, 8.5	6.9″	5^h 13.3^m	+2° 52′
32 Ori	Double star	4.4, 5.8	1.3″	5^h 30.8^m	+5° 57′
Cr 69	Open cluster	2.8	70′	5^h 35.0^m	+9° 56′
Sh 2-264	Emission nebula	4.0	6.5°	5^h 36.3^m	+9° 58′
NGC 2186	Open cluster	8.7	5.0′	6^h 12.1^m	+5° 28′
NGC 2180	Open cluster	—	22′	6^h 09.8^m	+4° 49′
NGC 2184	Open cluster	5.8	33′	6^h 11.7^m	–3° 36′

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



POSS-II / CALTECH / PALOMAR OBSERVATORY

Sh 2-264 is too big to fit in the field of my refractors, even at lowest power. But I've been able to detect the nebula by sweeping a telescope across it and watching for edge effects, where the brightness of the nebula ends and gives way to a darker, nebula-free background. This works best with a hydrogen-beta filter, but a narrowband nebula filter can also help.

Collinder 69 is an extremely youthful cluster — only 5 million years old and 1,400 light-years distant. The cluster and its surrounding nebula are part of the Orion Complex, a vast array of nebulae and youthful stars that engulfs most of the constellation.

Now we'll leap over to a few open clusters in eastern Orion. The first is **NGC 2186**, found two-fifths of the way from 8 Monocerotis to Betelgeuse. My 130-mm refractor at 37× displays a small hazy patch flecked with two stars. At 117× the southern star becomes a close pair, the northern one gleams yellow, and a half-dozen faint stars emerge. NGC 2186 is an attractive cluster in my 10-inch reflector. At 70× the brighter stars are crowded by many sparkly pinpoints of light. At 118× the yellow star closely guards a distinctive line of stars trailing northward from the pair. Together they dominate the northeastern region of a 20-star wedge tapering southwest for 4½′. The yellow star is thought to be a giant of spectral type G0 and a true member of the cluster.

At low power, NGC 2186 shares the field of view with the open cluster **NGC 2180**. Through the 130-mm refractor at 23×, I see an 8th-magnitude star surrounded by a bunch of faint suns in a starry field. At 63× the faint stars seem to form a hook wrapped around the bright one, as though they were trying to yank it offstage to the east. The hook is about 8½′ long and 4½′ wide, but it's only the south-southwestern part of a splashier group of 55 stars spanning 20′.

The split personality of NGC 2180 is reflected in the various catalogs and atlases that include it. Some show the cluster as a small group centered on the 8th-magnitude star, while others have it as a much larger group centered farther northeast. Our table reflects the size and position from the *2005 Catalog of Open Cluster Data* (Kharchenko *et al.*).

Our final target, **NGC 2184**, is larger and showier than its neighbors to the north. It lies 8.4° south of NGC 2180 and 34′ west-northwest of a deep-yellow, 5.8-magnitude star. The 130-mm scope at 23× shows a loose collection of 30 stars, magnitude 7.8 and fainter, splashed across 32′. A lopsided pie wedge of four bright stars dominates the southeastern side of the cluster, all but the faintest one in shades of yellow. The middle star in the arc of the pie crust is the lovely double **Struve 874** (Σ874), its 8th-magnitude primary closely attended on the north-northwest by a 9th-magnitude companion. Some of the cluster's lesser gems also glitter with yellowish hues.

In the 1973 *Revised New General Catalog* (Sulentic *et al.*), NGC 2184 was deemed nonexistent because Jack Sulentic couldn't verify it on the 1950s *National Geographic Society – Palomar Observatory Sky Survey* prints. However, clusters are sometimes overwhelmed by field stars on deep images, while our eyes do a better job of sorting them out. ✦

***Sue French** welcomes your questions and comments at scfrench@nycap.rr.com.*

A Junk-Shed Bino Mount

Dedicated ATM or hoarder? Sometimes it's hard to tell the difference.

ATMS ARE SCAVENGERS. We're constantly on the lookout for items to stash away for a sometime-in-the-future project. One fellow telescope maker sharing this junk-equals-potential-project mentality is Stu Favilla of Victoria, Australia. "My astro junk lives in a few boxes in the shed," he admits. "It consists of old 0.965-inch eyepieces, cheap, nasty, and trashy accessories, rotten masked-down finderscopes, and other dusty bits and pieces." Also residing in Stu's shed is his first telescope, an Amasco 60-mm refractor. This telescope's mount is a typical altazimuth assembly, and it turned out to be a valuable piece of saved junk when it came time for Stu to build a support for his 20×80 binoculars.

Like many bino users, Stu quickly concluded that an ordinary camera tripod wasn't going to be satisfactory. Such an arrangement positions the binoculars uncomfortably close to the tripod itself. "You'd need the contortion skills of an anaconda to aim at the zenith," he accurately notes. Figuring the Amasco could be part of the solution, Stu had to devise a way to modify the scope's altaz mount to carry his 20×80s. "The idea was to place something in the mount's yoke to attach the binocular to," he explains.

Australian telescope maker Stu Favilla fashioned this binocular mount for his 20×80s from junk he had accumulated over the years. The mount's main component was recycled from his first telescope.

STU FAVILLA (2)

Another trip to the shed yielded a solution in the form of a length of 60-mm-diameter PVC pipe to serve as a "dummy" telescope, on which the binoculars would ride piggyback. The 20×80s are held on the PVC tube by a pair of large hose clamps that loosely secure the objective lenses, and with a ¼-20 screw that passes through the tube and threads into the binocular's mounting post.

Although the mount was going to be assembled from spare parts, Stu didn't want the finished project to look like junk. To make a neat job of the tube, he scrounged a pair of plumbing end caps, which also allowed him to attached a counterweight (an old, galvanized pipe bushing) to the front of the assembly. For utility, he also attached the original scope's altitude fine-motion control bar and finderscope bracket (which holds a laser pointer) to the PVC tube. The finishing touch was to use some spare hardwood trim to extend the tripod legs to increase the eyepiece height of the binos.

So how does his junk assembly work? "It performs much better than I expected," he reports. "The mount is very stable for 20× binos, and sweeps beautifully in both axes. With the 20×80s held steadily, I get a wonderful, almost 3-D experience, and can hunt down numerous faint targets."

But fine views are only part of the experience for Stu — the other is philosophical. "The spirit of this project is really recycling," he explains. "I urge everyone to consider their consumption habits and to try making something from their accumulated astro junk — you just might be delighted by the results!"

Readers wishing to know more about Stu's bino mount can e-mail him at sfavilla@bigpond.com. ✦

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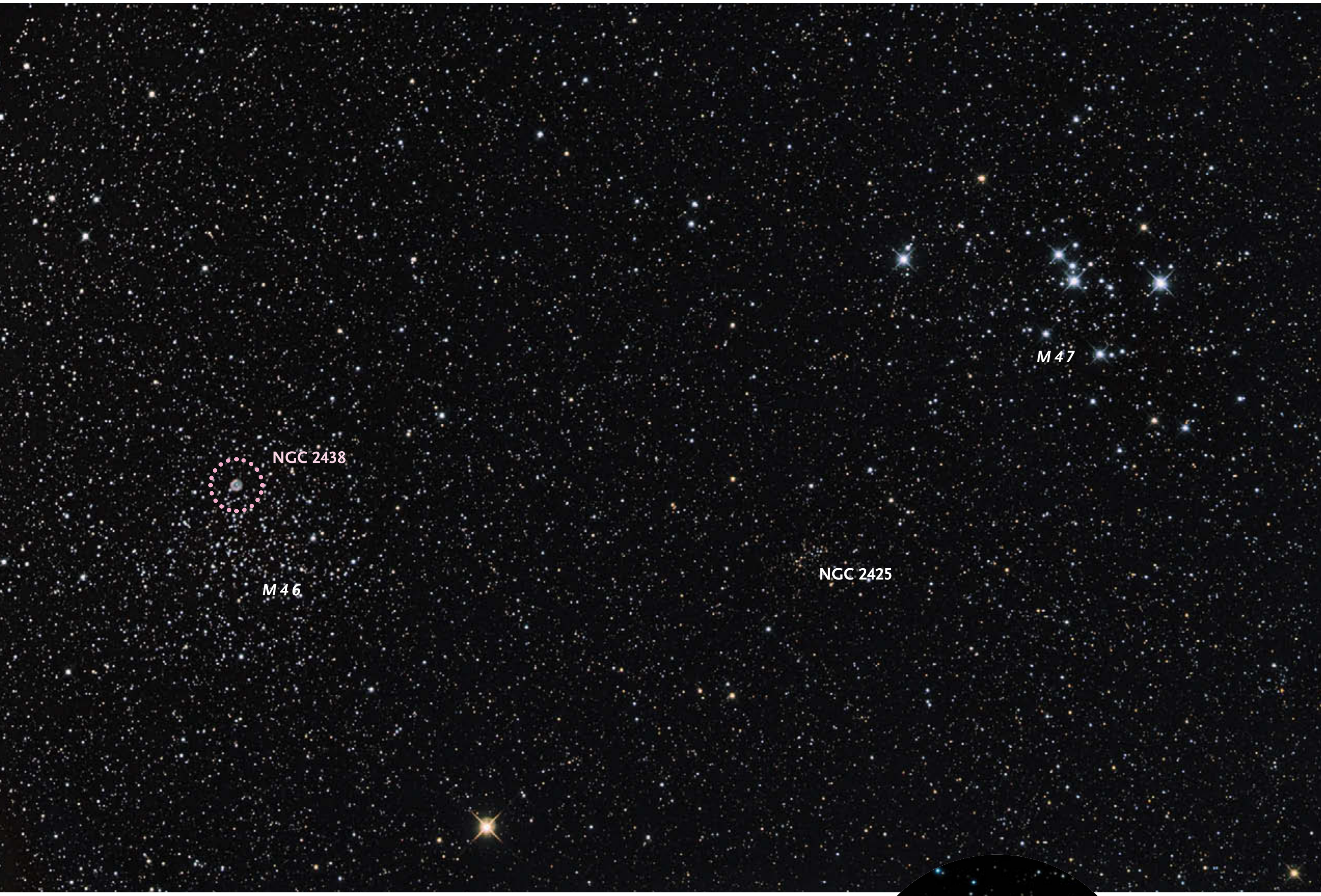
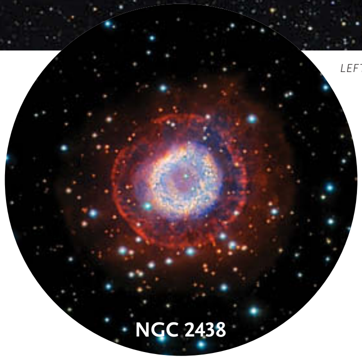
*Contributing editor **Gary Seronik** is a long-time hoarder and binocular observer. Some of his astro junk is featured on his website, **www.garyseronik.com**.*

A Dozen Winter



GREGG L. RUPPEL



LEFT: DANIEL LÓPEZ / IAC

Illusion: The open cluster M46, 1.3° from brighter M47 in northern Puppis, appears to hold the little planetary nebula NGC 2438. In reality, the nebula and cluster are unrelated.

Ted Forte

Planetaries

Winter is my favorite observing season. Winter nights start early, sparkle with bright stars, and sometimes display exceptional sky transparency and seeing. And it's a great time to track down planetary nebulae. Many marvelous examples dot the winter constellations.

Planetary nebulae are the beautifully symmetrical shells, rings, and sprays of glowing gas blown off by nearly every intermediate-mass star (those that began life with roughly 1 to 8 solar masses) as it ends its red-giant stage of life. Left exposed is the star's tiny, extremely hot core: a white dwarf in the making. The intense ultraviolet light from the hot central star excites the surrounding gas to fluoresce as it disperses.

Planetary nebulae are rare compared to stars only because they last briefly: typically just 10,000 years out of a star's entire lifetime. They're generally a fraction of a light-year to several light-years across. They take on many shapes — spheres, barrels, hourglasses, butterflies — sometimes with remarkably complex symmetric details that defy easy explanation.

Come with me on a tour of winter planetaries. We'll walk a circle around Orion to visit some of the season's best. You will use your entire eyepiece collection for this tour. Some big, dim planetaries need low magnification to tease them out of the background, while others invite you to pump up the power beyond any normal limits. Often you'll want to employ a narrowband filter such as an O III (pronounced "oh-three"), which is optimized to pass the blue-green wavelength of light emitted by doubly ionized oxygen atoms while suppressing most Earthly skyglow. Many planetaries emit most of their visible light at this wavelength.

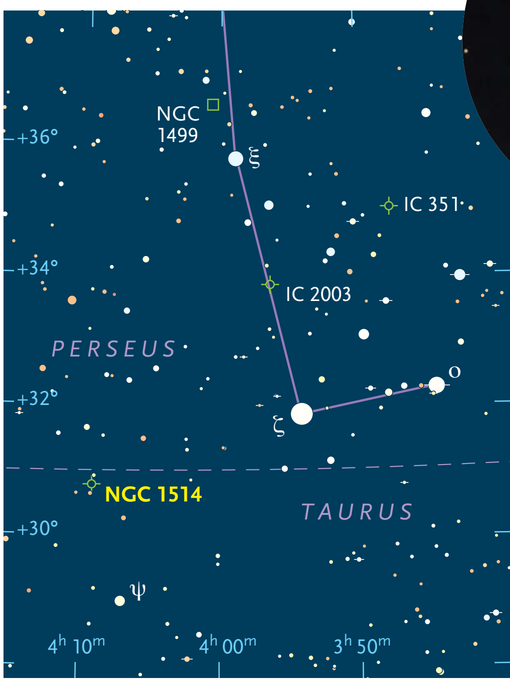
Nearly all the planetaries described here are plotted on both the *Pocket Sky Atlas* (which shows stars to magnitude 7.6) and the larger, deeper *Sky Atlas 2000.0* (stars to 8.5). Find them on your atlas using their right ascensions and declinations in the table on page 64. The two not plotted have finder charts here (to about magnitude 9.2) that will take you from a bright identified star to the object. If you do any deep-sky observing, you really need a good, detailed star atlas or its electronic equivalent.

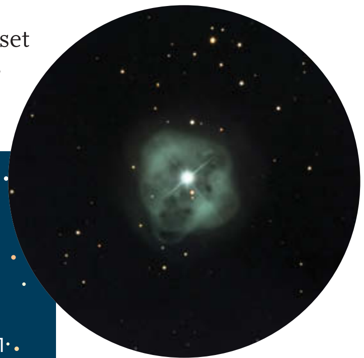
These deep celestial flowers are wildly varied.

Treasure Hunt

We'll start in Taurus with **NGC 1514**, the Crystal Ball Nebula. It lies 3.4° east-southeast of Zeta (ζ) Persei, the foot of Perseus near the Pleiades. Look for it nestled midway between two 8½-magnitude stars aligned north-south ¼° apart, as shown on the chart below. Mimicking its namesake, this object may help you to foretell the future — the future of your night's observing success. Its gossamer envelope requires a transparent sky to show itself well, so if you can see the nebulous shell around the 11th-magnitude central star fairly well, you're probably in for a good night.

An O III filter will help. Photos show a set of inter-looping shells, but visually you are apt to see it as just a round disk surround-





ABOVE: ADAM BLOCK / NOAO / AURA / NSF

In all images north is up and east is left. Except as noted, all were taken by observers using the 20-inch, CCD-camera-equipped telescope of the Advanced Observing Program at the Kitt Peak Visitor Center in Arizona.

ing the central star, even at high power.

The transparent delicateness of NGC 1514 may have been what convinced William Herschel that real nebulosity exists anywhere at all. Before he discovered this object in 1790, he was in the camp of those who supposed that all nebulae were swarms of faint stars. The Crystal Ball was the object that first shook his belief in that assumption.

Moving south — clockwise around Orion — "Cleopatra's Eye" is a nickname for **NGC 1535** in Eridanus. The name is attributed to Sky Tools creator Greg Crinklaw, who, seeing the oblong inner ring, was reminded of the Egyptian queen's eye makeup. NGC 1535 is often likened to the Eskimo Nebula in Gemini, which we'll visit later. Both have a multilayered structure, high surface brightness, and tolerance for high power.

ADAM BLOCK / NOAO / AURA / NSF

Eridanus (described at length on page 40) is the sky's long river — reminiscent of the Nile on Earth, adding another aspect to the Cleopatra association. NGC 1535 lies on the banks of the river, 4° east of 3rd-magnitude Gamma (γ) Eridani, or Zaurak. Low power shows an extended circular haze around a bright central area. You'll need high power to isolate the central star and explore the more intricate structure, which is revealed in increments as your magnification increases.

An O III filter may allow you to spy the thinner glow farther out. Remove the filter to enjoy the Eye's bluish color.

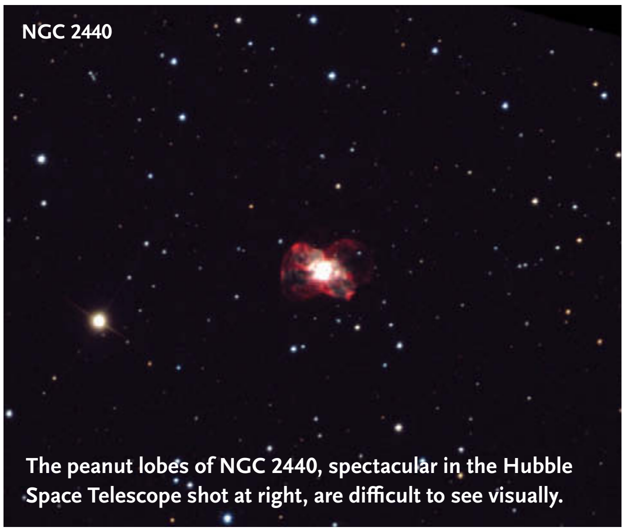
Moving east into Lepus, our next target is **IC 418**. It lies just under Orion, the same distance from each of Orion's feet. It's also about equidistant from Alpha (α) and Zeta Leporis above the Hare's back. Its appearance in Hubble Space Telescope images led to its moniker as the Spirograph. Through the eyepiece, however, another nickname is more descriptive: the Raspberry. It's a small, berry-like bauble through an 8-inch scope. In larger apertures its most remarkable feature is sometimes detectable: its raspberry tint. In my experience, most observers notice the slightly red or pink hue only if prompted. Perhaps the power of suggestion is at work, but I'm convinced that the red tint is real, having seen it many times. It's subtle at best; you're more likely to see blue or green.

IC 418 "blinks" — it seems to disappear when you look right at the central star, and absolutely blossoms when you look away to use averted vision. Many planetary nebulae exhibit this fun characteristic under the proper conditions. It's caused by the different sensitivity and resolution of direct versus averted vision. It's also a magical delight to those with a penchant for appreciating such things.

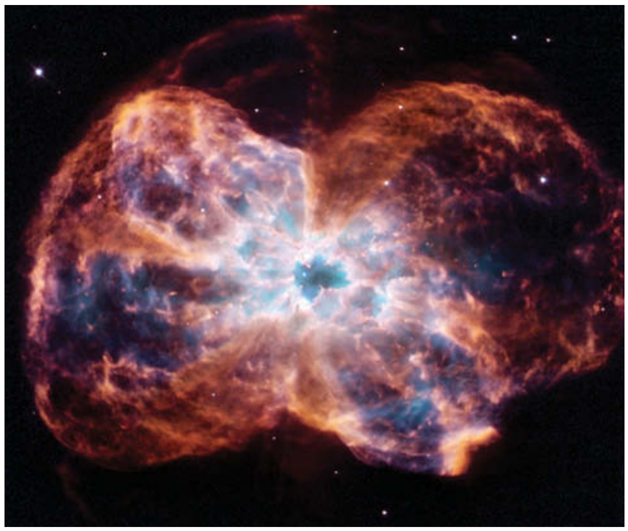
Our next stop is farther east in Puppis, where you can find the famous M46-M47 pair of open star clusters. M46 is the dimmer, eastern one, as shown on page 60. It's one of my favorite open clusters, and the presence of **NGC 2438** within it is the main reason. Despite appearances, the planetary isn't actually associated with the cluster. Although their distances are roughly similar, their radial velocities are different enough to rule out any association between them. But in the eyepiece they appear conjoined in a marvelous contrast, like a dust bunny in a jewel box.

There's more than one deception here. Not only is the nebula not really in the cluster, the bright centrally located star is not the central star of the planetary. The real central star is quite faint.

Planetary nebulae earn their cadre of fans by their wide variety of form, color, and brightness. Just 3½° south of M46 is **NGC 2440**. It presents a structure very different from the planet-like disks that inspired the "planetary nebula" name. The Hubble image below shows a dual-lobed hollow peanut. In an 8-inch telescope you're likely to see the brighter parts of it as a featureless, elongated blob with a brighter center. But there's more struc-

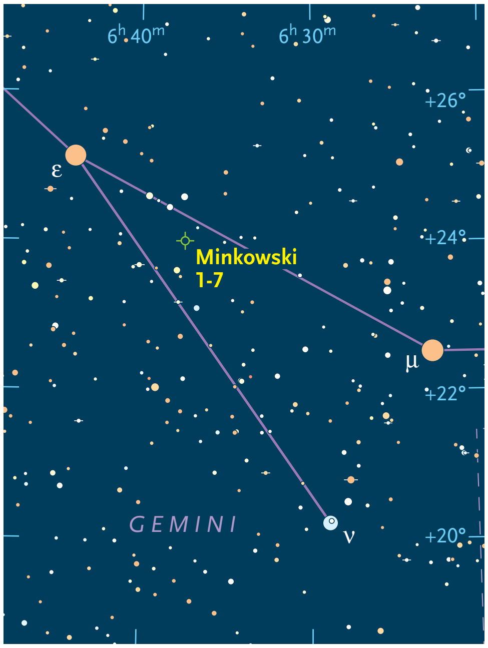


The peanut lobes of NGC 2440, spectacular in the Hubble Space Telescope shot at right, are difficult to see visually.


WIDE VIEW: JEFF CREMER / ADAM BLOCK / NOAO / AURA / NSF
HUBBLE PIC: NASA / ESA / K. NOLL (STSCI)

Abell 21 - Medusa Nebula

AL & ANDY FERAYORNI / ADAM BLOCK / NOAO / AURA / NSF



ture to be gleaned here. A nebula filter helps, especially with large apertures that provide more light.

Moving back north and a little west, Monoceros is home to **NGC 2346,** another example of planetary-nebula diversity. The bright central star is thought to be a merged "common envelope binary" in which one star is orbiting (temporarily!) within the tenuous outer layer of its bigger companion, with a period of 16 days. The star is variable, possibly due to dust clouds that sometimes obscure its light. Hubble publicists dubbed it the Butterfly Nebula, but it has also been known as the Hourglass Nebula (a name shared by other objects). Backyard observers will have difficulty seeing it as a butterfly; most will detect only the brighter inner area with the 12.5-magnitude central star. The object lies 0.6° southwest of the 4th- and 5th-magnitude star pair Delta (δ) and 21 Monocerotis, which are a 9° star-hop southwest from Procyon.

Gemini hosts a variety of planetaries, and we can take advantage of its current high elevation to test our skills on some challenging ones. Big **Abell 21** is best known as the Medusa Nebula. It's one of the easiest of the Abell planetaries but still poses a challenge due to its size (1/6°) and low surface brightness. Use low power and a nebula filter to detect the wispy half-disk of the Medusa. It's 5° due north of Beta (β) Canis Minoris (Gomeisa).

You'll have just the opposite problem with **Jonckheere 900** (PK 194-2.1) just below the Twins' feet. Its tiny disk (4″ wide) may appear too starlike to recognize. To complicate matters, a 12th-magnitude star just 12″ to the south can overwhelm the nebula — or give a binary appearance until you switch to high power to resolve the situation. A filter helps highlight the nebula while suppressing the star.

Objects in the catalog of Rudolph Minkowski are noted for being particularly interesting, and **Minkowski 1-7** is no exception. At first glance it's a rather ordinary, very dim disk, sized like an exceptionally faint ghost of Jupiter. But with careful study, see if you can detect the ragged edges along its long axis. A filter and high power help. M1-7 is just south of the line between Epsilon (ε) and Mu (μ) Geminorum, about a third of the way from Epsilon.

Near the Twins' bright heads lies a twin-like planetary. **NGC 2371–72**, the Gemini Nebula or Double Bubble, is a bipolar planetary that gained two NGC numbers because its discoverer, William Herschel, assumed it was two distinct objects. It is fascinating under high power. View it with and without a nebula filter; as with so many planetaries, each view will reveal unique details. The lobes run northeast-southwest and are about equal in size, but the southwest lobe is brighter.

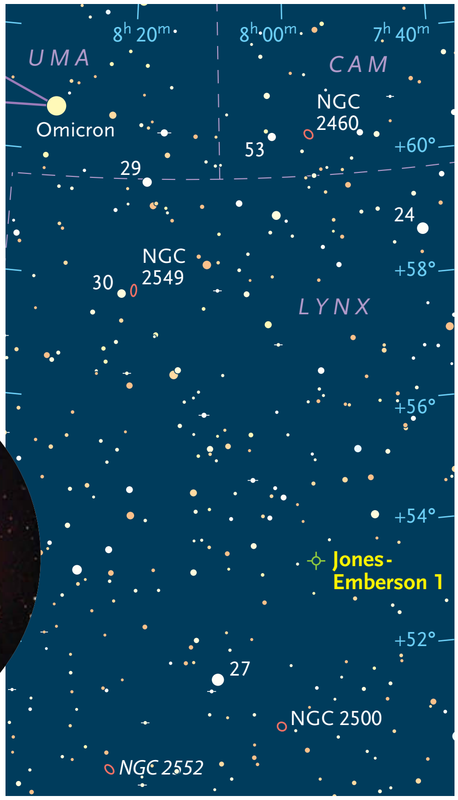
The most famous planetary nebula in Gemini, and perhaps in the winter sky, is the Eskimo Nebula, **NGC 2392**. It lies 0.6° southeast of the wide, unequal double star 63 Geminorum. The Eskimo gets its name from its appearance in deep photographs resembling a bright face in a furry parka hood. The multi-shelled bright part also

NGC 2346

DOUG MATTHEWS / CHARLES BETTS / ADAM BLOCK / NOAO / AURA / NSF

PETER & SUZIE ERICKSON / ADAM BLOCK / NOAO / AURA / NSF

PETER & SUZIE ERICKSON / ADAM BLOCK / NOAO / AURA / NSF



suggests a clown face; the nebula goes by that name as well. Its high surface brightness makes it visible even in small telescopes and through serious light pollution. An 8th-magnitude star, playfully named the Eskimo's Wife, lies a little more than 1′ north and lends a nice contrast. Look for their color difference.

The Eskimo can stand up to extreme magnification. When conditions allow, pump that power up and hold on tight, because you may be in for a "wow" moment. In my 18-inch scope I've been able to use up to 1,000× on the Eskimo! In large scopes the central star is obvious, and around it can be seen two bright rings with a darker ring between them. Smaller scopes show a pretty blue disk with hints of brightness variations.

Rebecca Jones and Richard Emberson discovered an object in Lynx, south of Ursa Major's nose, that has become known as the Headphones Nebula, a name suggested by David Kniseley. Images of **Jones-Emberson 1** do evoke that impression. It's quite large (7′) and has very low surface brightness, with two brighter arcs oriented opposite each other northeast-southwest. To search for this ghostly object wait for a night of excellent transparency and use low power, a filter, and perseverance.

If you enjoyed this tour, you'll be happy to know that I've skipped several interesting and wonderful objects that await your discovery in the winter sky. Be warned, becoming a fan of planetary nebulae can lead to a lifelong obsession. But m aybe that's not such a bad thing. ✦

Ted Forte is chair of the Astronomical League's Planetary Nebula Club.

USING A STAR ATLAS
A deep-sky observer needs to be adept at using star charts outdoors at the telescope. It's all a matter of simple tricks. Read how at SkyandTelescope.com/charts.

A Dozen Winter Planetary Nebulae

Name	Alt or Nickname	Const.	R.A. (2000.0)	Dec.	Mag.	Diam.	Central Star Mag.	Surface Brightness*
NGC 1514	Crystal Ball Nebula	Tau	$4^h 09^m 17^s$	+30° 46.6′	10.8	120″	9.4	20.9
NGC 1535	Cleopatra's Eye	Eri	$4^h 14^m 16^s$	–12° 44.4′	9.4	20″	12.2	15.6
IC 418	Spirograph Nebula	Lep	$5^h 27^m 28^s$	–12° 41.8′	10.7	14″	10.2	16.2
Jonckheere 900	PN G194.2+02.5	Gem	$6^h 25^m 57^s$	+17° 47.5′	12.4	12″	17.8	17.5
Minkowski 1-7	PN G189.8+07.7	Gem	$6^h 37^m 21^s$	+24° 00.6′	13.0	38″	13	20.6
NGC 2346	Hourglass	Mon	$7^h 09^m 23^s$	–00° 48.6′	12.5	60″	12.5	21.1
NGC 2371-72	Gemini Nebula	Gem	$7^h 25^m 35^s$	+29° 29.4′	11.2	72″	14.8	20.3
Abell 21	Medusa Nebula	Gem	$7^h 29^m 03^s$	+13° 14.8′	11.3	600″	16	24.9
NGC 2392	Eskimo Nebula	Gem	$7^h 29^m 11^s$	+20° 54.7′	8.6	47″	10.5	16.7
NGC 2438	PN G231.8+04.1	Pup	$7^h 41\ 52^s$	–14° 44.1′	11.0	66″	17.5	19.8
NGC 2440	PN G234.8+02.4	Pup	$7^h 41^m 52^s$	–18° 12.5′	11.5	54″	17.6	19.9
Jones-Emberson 1	PK 164-31.1	Lyn	$7^h 57^m 52^s$	+53° 25.3′	14.0	415″	16.8	26.6

* Magnitude per square arcsecond, averaged across the nebula. A first-rate dark sky has a surface brightness of about 21 magnitude per square arcsecond.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S&T: DENNIS DICICCO 1994

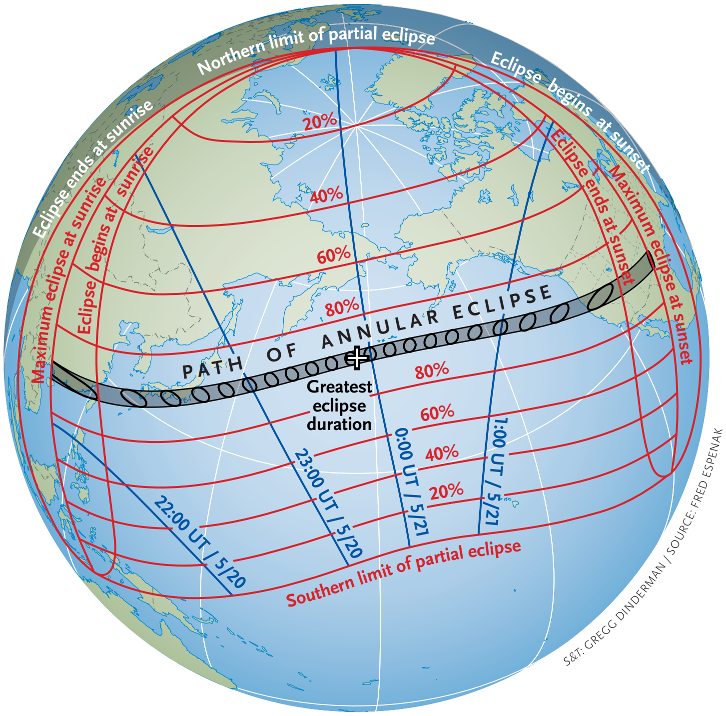
The western United States is the place to be for the upcoming eclipse on May 20th.

NEARLY TWO DECADES have passed since the last major eclipse of the Sun occurred within the United States. This long drought finally ends with an annular solar eclipse on May 20th. The Moon passes through the apogee point of its orbit just one day before this eclipse, so its large distance from Earth makes the Moon's diameter appear only 94% that of the Sun's. This results in a thick annular ring of sunlight surrounding the Moon at mid-eclipse and a rather broad path within which annularity is visible, ranging from 147 to 201 miles (237 to 323 km) in width.

While 88% of the Sun's surface area is blocked during annularity, the Sun will remain blindingly bright, mandating that everyone viewing the event must use the same precautions required to observe the Sun on any other day. In this respect, the midpoint of an annular eclipse is more like a partial than to a total eclipse.

Even at maximum phase the general illumination will approximate than of a bright overcast day — certainly nothing like the eerie twilight experienced during a total solar eclipse. Nevertheless, a clear blue sky will take on a much darker, richer tone than usual, making it possible for many observers to spot Venus shining at magnitude –4.3 about 23° east of the Sun, especially if they block the Sun with their hands while searching for the planet.

Other features to look for during this eclipse include the quality of the light around the time of annularity, which should appear silvery or metallic in character. During the deep partial phases and annularity itself, you



The path of next May's annular eclipse stretches from China to the western United States, but a partial eclipse is visible from anywhere within the shaded region on this map. Plotted lines let you estimate the maximum percent of the Sun's diameter covered, as well as the time this occurs, for any location where a partial eclipse is visible.

can look for eclipse images cast on the ground under leafy trees or formed by small apertures between your fingers. Such pinhole effects are often missed in the excitement of the eclipse but are well worth looking for.

The Annular Path

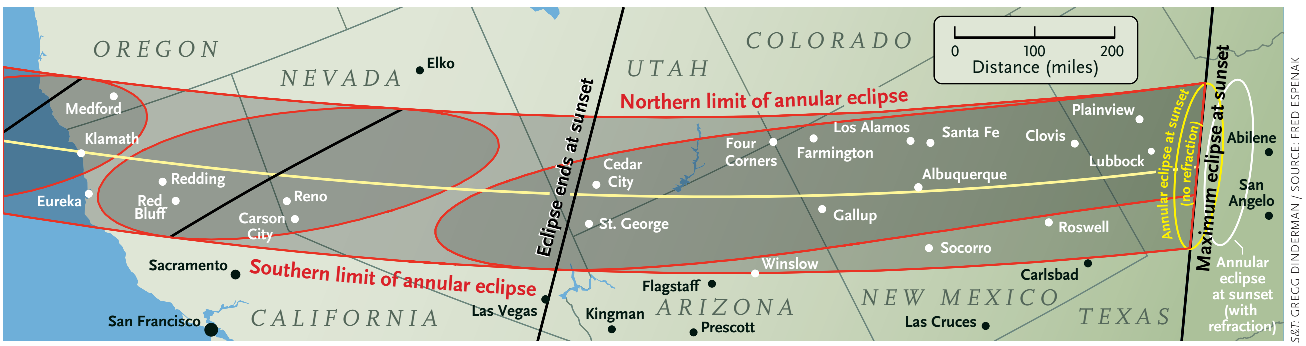
The last annular eclipse visible from the United States was on May 10, 1994. Many readers will recognize that the 18-year interval since then means that the upcoming eclipse is a member of the same saros series — a family of eclipses sharing very similar characteristics. The saros period is approximately 18 years 11 days and 8 hours, with the extra fraction of a day causing the central path of each succeeding eclipse to be displaced westward about one third of the way around the globe. Though the 1994 eclipse path was centered on North America, the middle of the 2012 path is located in the North Pacific Ocean.

The Moon's antumbral shadow begins its trek on the morning of May 21st along the coast of southern China in the Gulf of Tonkin. With a population of 7 million, Zhanjiang is the first major city in the path. The Sun is just 1° above the horizon during the 4-minute-long annular phase. The lunar shadow takes only a minute to travel 250 miles to engulf the cities of Guangzhou, Dongguan, Shenzhen, and Hong Kong. They all experience an annular eclipse with the Sun 5° high.

Continuing along its northeastward course, the shadow reaches Fuzhou and leaves mainland China, clipping northern Taiwan as it races across the East China Sea. Just 10 minutes into the annular track, the antumbra encounters the southern islands of Japan. Tokyo lies on the track's central line, where millions of inhabitants will experience an annular phase lasting 5 minutes with the morning Sun 35° up. After leaving Japan, the Moon's shadow faces a nearly 2-hour voyage across 4,000 miles of the North Pacific before its next landfall.

During its time at sea, the eclipse path reaches its midpoint where the shadow axis passes closest to the center of the Earth. This so-called instant of greatest eclipse occurs at 23:52:47 Universal Time on May 20th (May 21st local time). The annular phase is then at its maximum duration of 5 minutes 46 seconds.

After crossing the International Date Line, where the local time of the eclipse reverts to May 20th, the eclipse track passes south of Alaska's Aleutian Islands and gradually curves to the southeast as it heads for the Pacific coast of North America. The leading edge of the antumbral shadow reaches the rugged coastline of southern Oregon and northern California at 1:24 UT (6:24 p.m. PDT on May 20th). From the central line near Klamath, California, the Sun's altitude is 22° during the 4 minute 47 second annularity. Klamath lies on Highway 101, which offers access to the entire eclipse path along the Pacific coastline. This is critical to last-minute mobility should



The path of annularity in the western United States extends from the coastline at the California-Oregon border to northwestern Texas. Shaded ovals give "snapshot" representations of the Moon's antumbral shadow at approximately 5-minute intervals.

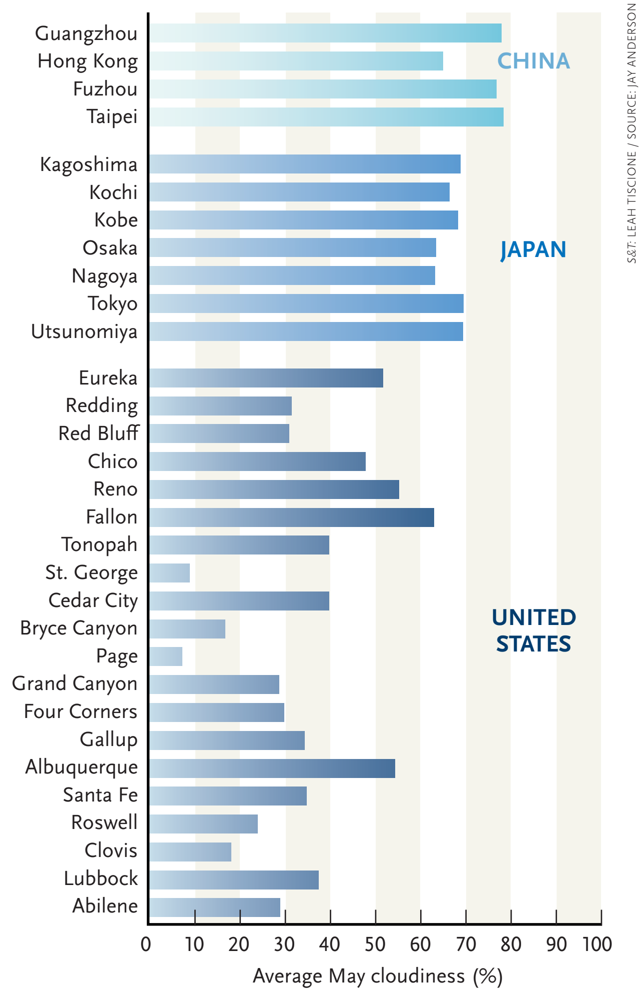
weather prove to be a contending issue on eclipse day. Farther inland in California, Red Bluff and Redding provide path access along Interstate 5.

As the shadow crosses from California into Nevada, the cities of South Lake Tahoe, Carson City, and Reno all lie in its path. The residents of Reno will experience 4 minutes and 25 seconds of annularity with the Sun 17° high. East of Reno, Interstate 80 allows access to the central line and the northern half of the eclipse path. Although much of eastern Nevada lies in the path, travel here will be more difficult on secondary roads. On the other hand, Interstate 15 out of Las Vegas travels north across the eclipse track into southwestern Utah, where St. George and Cedar City are in the path.

In Arizona, Interstate 40 east of Flagstaff enters the southern limit of the eclipse path and remains in it all the way across New Mexico and into Texas. At Albuquerque, which is on the central line, the duration of annularity lasts 4 minutes 25 seconds with the Sun 5° above the horizon. From a logistic standpoint, Albuquerque is an excellent location — Interstate 40 allows you to travel east or west along the path while Interstate 25 crosses the path in the north-south direction.

At the instant of mid-eclipse in Albuquerque, the antumbral shadow is shaped like an enormous deformed ellipse stretching more than 700 miles from Nevada to Texas, where its leading edge is already returning to space. Western Texas near Lubbock is a particularly interesting location for photographers because the annular phase will occur just before sunset.

When it ends at 1:36 UT (7:36 p.m. MDT), the Moon's shadow will have traveled along an 8,500-mile-long track in the span of 3½ hours. Most of the Northern Hemisphere from Asia across the Pacific to North America will see a partial eclipse. Only the easternmost parts of the United States and Canada will miss the show.



The percentage of cloud cover for selected locations in the western United States derived from two decades of data collected at ground stations around the time of maximum eclipse.

Weather Prospects

May is not a good time to start an eclipse in Asia, but it's a great time to end one in North America. With the beginning and middle of the shadow's track embedded in regions with a high frequency of cloud cover, this eclipse is tailor-made for U.S. observers.

Asia: In late May the annual southeast monsoon is entrenched over southern China, marked by high humidity, heavy cloudiness, and frequent rainfall. At Guangzhou, morning cloudiness averages 78%. Fortunately, the eclipse track straddles the coast of the South China Sea and weather prospects along the shore are a little better than those inland. Hong Kong has an average cloudiness of 65% at eclipse time.

In Japan the peak of the rainy season is still a month away and cloud coverage is about 10% lower than that over China. Climatological averages of cloud cover are fairly uniform along the Japanese track, between 60% and 70%, so site selection should rely on forecasts during the days

The upcoming event on May 20th will appear very similar to previous eclipses in saros cycle 128, since the geometric circumstances are almost the same. Fred Espenak captured this photographic sequence of the 1994 annular eclipse.

running up to May 21st.

United States: Where Asia offers no better than a 60% average cloud cover, values below 10% are found in several places between California and Texas. It's not a slam-dunk, however, as eclipse chasers will have to watch for clouds along the coast and over the higher mountain peaks.

The ups and downs of average cloud cover shown in the graph on the facing page reflect the influences of terrain. The general downward trend in cloudiness from California to Arizona and New Mexico is a result of mountains blocking the Pacific Ocean moisture. Within this trend are features associated with local topography: lower clouds in the Sacramento Valley (Redding, Red Bluff, and Alturas); east of Arizona's Kaibab Plateau (at Page); and over the Llano Estacado (Roswell and Clovis). At St. George, Utah, average cloudiness is under 10%, whereas Cedar City, 50 miles to the north, it's four times greater. St. George lies on the northern edge of the Mojave Desert while Cedar City lies against the wrong side of the 10,000-foot Markagunt Plateau.

Place your eclipse camp too close to the mountains and you risk being blocked by clouds that form on the peaks. The best sites will be on the eastern side of a flat, low-altitude valley or plateau with the mountains low down on the western horizon. There are many choices available.

Western Texas tends to be a little cloudier than Arizona, but the spectacle of a sunset annular phase will attract some eclipse chasers ready to accept the risk. Ultimately, there is no excuse for missing this eclipse — reliable weather forecasts are readily available for a week ahead.

While viewing the 2012 annular eclipse is a rewarding experience in itself, it also serves as a great training opportunity for the U.S.A.'s next total solar eclipse on August 21, 2017. ✦

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*Retired NASA astronomer **Fred Espenak** masters two eclipse websites (**eclipse.gsfc.nasa.gov** and **www.mreclipse.com**). Canadian meteorologist **Jay Anderson** has written about eclipse weather since 1979. Both have journeyed the world to confirm their predictions in person.*

Local Circumstances of Annularity

	Partial Begins	Annularity Begins	Annularity Ends	Partial Ends	Maximum Eclipse	Sun Altittude	Duration of Annularity
Arizona							
Chinle, AZ	18h 26m 05s	19:32:57	19:37:26	—	19:35:11	8°	04m 30s
Grand Canyon, AZ	18:25:12	19:34:01	19:37:18	—	19:35:39	10°	03m 17s
Page, AZ	18:24:14	19:32:11	19:36:42	—	19:34:27	10°	04m 31s
Tuba City, AZ	18:25:28	19:33:24	19:37:30	—	19:35:27	9°	04m 07s
Winslow, AZ	18:27:14	19:36:27	19:37:00	—	19:36:43	8°	00m 34s
California							
Chico, CA	17:13:19	18:28:19	18:31:43	19:37:28	18:30:01	19°	03m 24s
Eureka, CA	17:09:33	18:25:50	18:29:50	19:36:33	18:27:50	21°	03m 59s
Oroville, CA	17:13:54	18:28:54	18:31:54	19:37:40	18:30:24	19°	03m 00s
Paradise, CA	17:13:28	18:28:10	18:31:53	19:37:22	18:30:01	19°	03m 43s
Red Bluff, CA	17:12:16	18:27:12	18:31:20	19:36:59	18:29:16	20°	04m 08s
Redding, CA	17:11:31	18:26:21	18:30:56	19:36:30	18:28:38	20°	04m 35s
S. Lake Tahoe, CA	17:16:05	18:30:03	18:33:01	19:38:00	18:31:32	17°	02m 58s
Susanville, CA	17:13:18	18:26:56	18:31:38	19:36:19	18:29:17	19°	04m 42s
New Mexico							
Albuquerque, NM	18:28:24	19:33:39	19:38:05	—	19:35:52	5°	04m 26s
Artesia, NM	18:31:42	19:36:27	19:38:56	—	19:37:41	3°	02m 29s
Clovis, NM	18:29:54	19:33:39	19:37:35	—	19:35:37	3°	03m 56s
Farmington, NM	18:25:45	19:32:38	19:35:48	—	19:34:13	7°	03m 09s
Gallup, NM	18:27:11	19:33:34	19:37:58	—	19:35:46	7°	04m 24s
Hobbs, NM	18:32:02	19:35:41	19:39:09	—	19:37:25	2°	03m 28s
Las Vegas, NM	18:28:02	19:33:19	19:36:26	—	19:34:52	5°	03m 06s
Los Alamos, NM	18:27:25	19:33:06	19:36:33	—	19:34:50	6°	03m 28s
Portales, NM	18:30:09	19:33:47	19:38:00	—	19:35:54	3°	04m 13s
Rio Rancho, NM	18:28:09	19:33:27	19:37:51	—	19:35:39	5°	04m 24s
Roswell, NM	18:30:59	19:35:15	19:39:02	—	19:37:08	3°	03m 48s
Santa Fe, NM	18:27:48	19:33:13	19:36:46	—	19:35:00	5°	03m 33s
Santa Rosa, NM	18:28:59	19:33:29	19:37:27	—	19:35:28	4°	03m 59s
Socorro, NM	18:29:40	19:35:25	19:38:44	—	19:37:04	5°	03m 18s
Tucumcari, NM	18:28:52	19:33:36	19:36:16	—	19:34:56	3°	02m 40s
Nevada							
Carson City, NV	17:15:56	18:29:19	18:33:13	19:37:41	18:31:16	17°	03m 54s
Reno, NV	17:15:22	18:28:32	18:32:58	19:37:15	18:30:45	17°	04m 26s
Oregon							
Medford, OR	17:08:29	18:24:33	18:27:19	19:34:15	18:25:56	21°	02m 46s
Texas							
Andrews, TX	19:32:33	20:36:04	20:39:09	—	20:37:36	1°	03m 05s
Big Spring, TX	19:32:41	20:35:22	—	—	20:37:16	0°	03m 41s
Brownfield, TX	19:31:30	20:34:26	20:38:47	—	20:36:36	1°	04m 21s
Hobbs, TX	19:31:27	20:33:54	20:38:05	—	20:36:00	1°	04m 10s
Levelland, TX	19:31:00	20:34:03	20:38:23	—	20:36:13	2°	04m 20s
Lubbock, TX	19:31:03	20:33:55	20:38:08	—	20:36:02	1°	04m 13s
Midland, TX	19:32:58	20:36:26	20:39:05	—	20:37:45	1°	02m 38s
Odessa, TX	19:33:07	20:37:21	20:38:40	—	20:38:00	1°	01m1 9s
Plainview, TX	19:30:20	20:33:41	20:36:58	—	20:35:20	2°	03m 17s
Utah							
Cedar City, UT	18:22:24	19:31:21	19:35:52	20:36:59	19:33:36	11°	04m 31s
St. George, UT	18:22:59	19:32:17	19:36:30	20:37:52	19:34:23	11°	04m 13s

The local times (adjusted for daylight saving time where appropriate) for eclipse events are given for selected locations within the path of annularity.

For All the Night's Stars

NICK RISINGER

Only a handful of people have successfully undertaken the daunting task of imaging the entire night sky with enough resolution to reveal small deep-sky targets. Nick Risinger recounts his adventure traveling more than 60,000 miles in pursuit of his dream project. The mosaic of the Milky Way pictured above barely scratches the surface of his undertaking; visit http://skysurvey.org to immerse yourself in his masterpiece.

I'm at 6,200 feet in the Nevada desert capturing the first images of what will ultimately become a 37,440-exposure, 5,000-megapixel photograph of the entire night sky. It's 18°F and while I try to keep my mind off the wind chill, the gusts continue to push over the ridge. As the first camera shutter snaps shut, a fairly typical portion of space appears on my laptop screen: other suns millions of billions of miles away are scattered across the frame, too many to count. The sheer work of what lies ahead slowly begins to sink in and I shudder — though not from the cold.

A photographer's dream to image the entire night sky comes to fruition.

ALL IMAGES ARE COURTESY OF THE AUTHOR

Beginnings

As a young boy, I treasured our family vacations to the central coast of Washington state, where low tides unveil beaches more than a thousand feet wide that run for miles. I remember being mesmerized by the surf and the water stretching to the horizon. For a young mind, this was a very big place, and it was here that my understanding of nature's vastness began to take shape. Later, when I was about 10 years old, my family went to visit relatives in Sweden. As the speeding blur of the runway dropped away on takeoff and the many hours of flight ticked away — what felt like forever — I realized how much bigger the world must truly be. Then, in seventh grade, I watched the Eames's classic *Powers of Ten* documentary, and the bounds of the universe instantly swelled beyond comprehension.

For some, our reverence for the scale of our natural world tends to dull with age, but I count myself as one of a peculiar breed who find the opposite to be true. So when my passions for photography and space eventually converged, I knew the resulting creation would have to

SOFTWARE

MaximDL
Mount and camera control

IRAF
Up-scaling, registration, saturated pixel replacement, stacking, background modeling

SExtractor
Generation of object list

SCAMP
Cross reference position and distortion headers

Swarp
Reprojection and stitching frames

PixInsight
Combine color data, mid-tone transfer function, noise reduction

GIMP
Final assembly, curve and color saturation

HARDWARE

Camera
Finger Lakes Instrumentation MicroLine ML8300 (monochrome)

Lens
Zeiss Sonnar 85-mm f/2.8

Filters
Astronomik LRGB, Astrodon Hα Filters

Mount
Takahashi EM-11 Temma 2M

Laptop
Intel Core i7-820QM running Linux Fedora OS, 8GB RAM, 4-terabyte external storage drive

To keep equipment weight down and speed up assembly each night, the author and his father constructed a custom mounting bar (being held by the author) that distributed six CCD cameras with lenses at both ends of an equatorial mount.

convey the vast scope of the cosmos. As I figured it, only two kinds of astronomical photos were possible — ones that covered part of the sky and ones that covered *all of it*.

Naively choosing the latter, I set about planning the photo shoot of a lifetime. It was a journey that would ultimately take my father Tom and me 45,000 miles by air and 15,000 by land as we enjoyed countless day-lit vistas and even grander nighttime skies from the darkest corners of the western United States and South Africa. Travel was necessary, since capturing the full sphere of the night sky carried with it certain geographic limitations. For starters, large parts of the sky near the north celestial pole are not visible from southern latitudes and the same is true of the southern sky from northern latitudes. Likewise with the seasons, what may be overhead in summer is below the horizon in winter. Complicated by weather and Moon cycles, only narrow windows of opportunity were open each month, so thorough planning was critical.

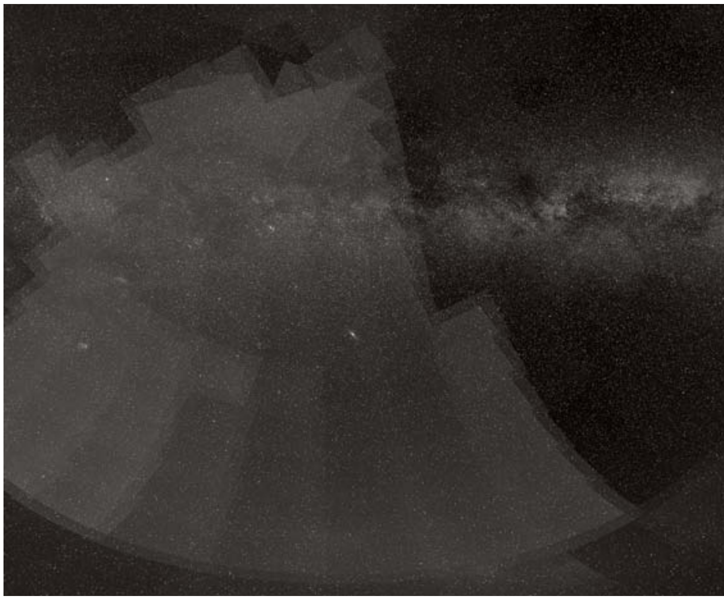
Choosing the Right Tools

Most of my project's decisions were dictated by the metric of speed, and finding the right tools to do the job was one such choice. One might assume that a big CCD sensor covering a wide view would be the natural tool for an all-sky survey, but it is rather the exposure time per area of sky that matters. By photographing with low-noise sensors, though smaller, I exposed the sky with shorter images, shaving away precious seconds, and ultimately many hours off the total time.

Efficiency between fields was also important. Rather than manually star-hopping from one constellation to the next and risk missing a piece of the puzzle, I divided the celestial sphere into 624 equally spaced areas and programmed their coordinates into my computer. I recorded these areas through six short telephoto lenses, each fitted with its own color filter and cooled CCD camera, all of which were controlled through a jungle of cables fed into a single laptop.

For the sake of portability during all the air-bound globe-trotting, I paid particular attention to how such a bulky collection of equipment could be secured with minimal weight. My solution was to construct a bracket that anchored three cameras to the topside of a computerized equatorial mount and the remaining three to the bottom in lieu of the traditional counterweight. This kept the entire package well under 100 pounds (45 kg), which proved to be a welcome feature for both travel and setup.

As our first trips to Nevada and Arizona got under-



way in March 2010, challenges popped up at nearly every turn, and I was constantly reminded of how little I initially knew about astrophotography. Terrestrial photographers rarely concern themselves with factors such as daylight saving time, polar alignment, or preventing a meridian flip that threatens to destroy half the equipment, but I suppose this is what gives astrophotography its charm — that perpetual task of keeping up with the motions of the heavens.

First Glimpse of Southern Skies

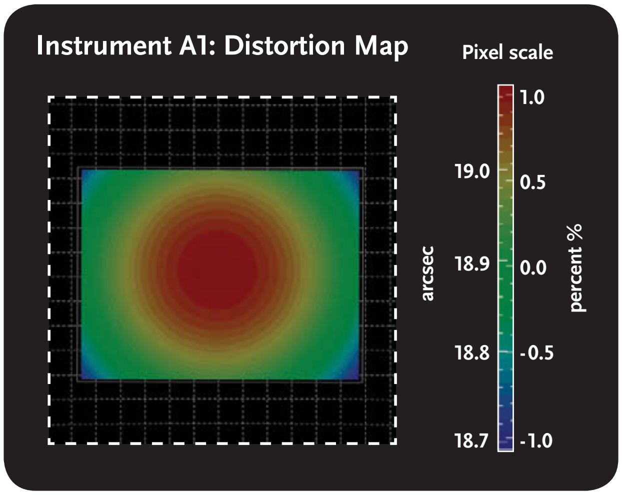
By mid-June 2010, with part of the Northern Hemisphere complete, the mission turned to the Southern Hemisphere, and it was in South Africa, not far from the South African Astronomical Observatory, where I caught my first glimpse of the southern Milky Way. Few words can adequately describe the sight of our galaxy's center perched straight overhead, so bold that I considered reading a book by its light! The Large and Small Magellanic Clouds were an equal treat, both luminous reminders that our galaxy is but one of many.

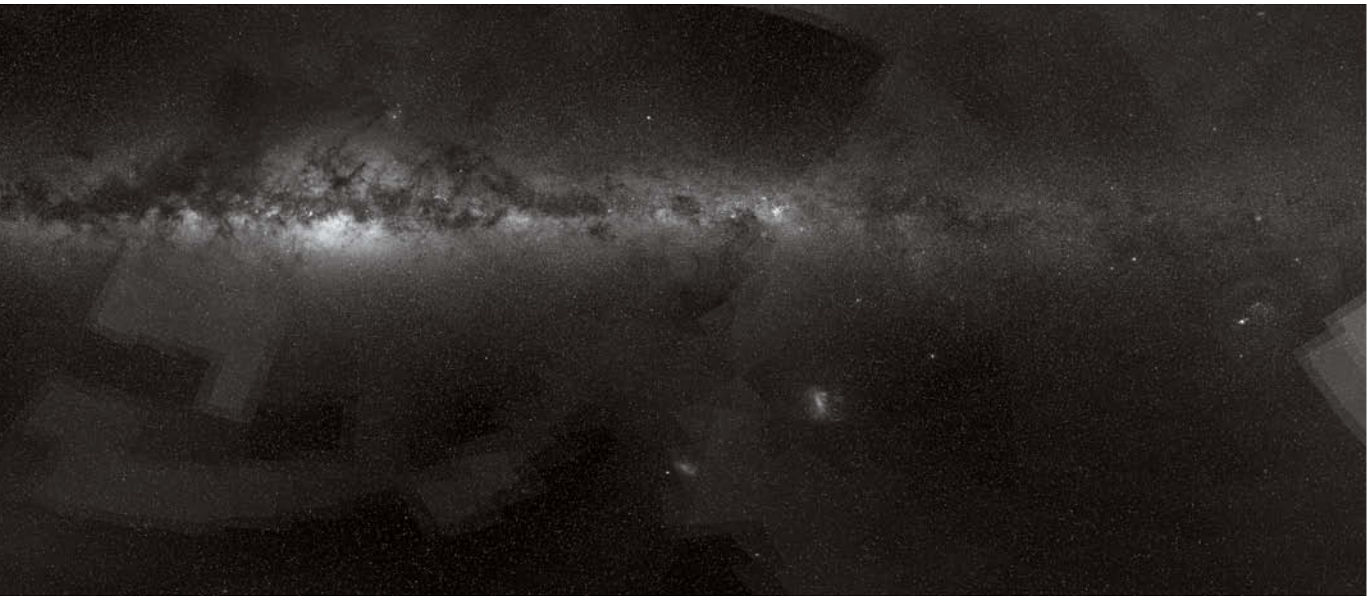
After three frigid weeks of winter in South Africa, we flew back to the States for some much enjoyed summer nights and familiar constellations. The process continued, and by Thanksgiving it was back again to South Africa to finish the Southern Hemisphere, followed by an earlier-than-expected return home thanks to favorable weather.

Finally, after far too many sleepless nights, our travel-weary bodies made the final push in Colorado as we snapped the last of the 37,440 exposures in January temperatures as low as –6°F. But the physical task was quickly exchanged for a mental one as the real work of making sense of so much data loomed like a dark cloud overhead.

What would normally be a manual process of calibrating, stacking, and stitching was impractical with so many

To take full advantage of dark skies each evening, all equipment needed to be set up and ready to go before twilight.





After months of recording tens of thousands of images, assembling an all-sky mosaic requires many additional steps not often considered in conventional astrophotography. Mapping lens distortion *(left)* and removing its effects as well as eliminating uneven sky glow *(below)* were just several of dozens of steps necessary to create a seamless all-sky mosaic.

exposures. Even simple tasks as mundane as moving a set of exposures from one folder to another had to be scripted, and off-the-shelf software programs were not up to the task of reducing so much data. The workflow therefore relied on a combination of professional tools. *IRAF* (**http://iraf.noao.edu**) performed up-scaling, registering, and stacking of the bracketed exposure sets followed by modeling of the backgrounds to eliminate gradients. *AstrOmatic's* suite of tools (**www.astromatic.net**) provided the astrometry that calculated the orientations and distortions from each lens and then eliminated them for a final stitching of the full sky. Although greatly simplified in summary, this process began in January 2011 and consumed *months* of processing time and four terabytes of storage. When finally completed, I was greeted by the photo I worked so hard to capture: a 5,000-megapixel view of the cosmos with our Milky Way stretching end to end.

The final result is visible today as a free interactive sky chart dubbed the Photopic Sky Survey (**http://skysurvey.org**). Visiting the site allows you to zoom in and pan around to any area of the entire sky in full color. Additional features let you toggle on the names of bright stars, the constellations, and accurate plots of the Sun, Moon, and planets.

People have congratulated me for following my dreams, perhaps without realizing how literally true this is, as the seeds of my project were in fact planted under fictitious skies. It wasn't until recently that I stumbled upon a video of John Dobson, best known for his pioneering low-cost telescope mount, whose words characterize the same nautical dream with more eloquence than mine ever could:

> "If you find yourself at sea in a small unlighted boat alone in
> the darkness of a cloudless night,
> and if you gaze into the darkness of the space between the stars,
> then keep wide awake.
> And if your mind is full of wonder and your heart is full of
> peace, there is a chance that you will understand."

***Above*: Once completed, the Photopic Sky Survey reveals expansive nebulosity often passed over by imagers for more picturesque targets, such as the faint reflection and emission nebulae at the upper right in the head of Scorpius. *Below*: Visit Nick's website to explore the entire Photopic Sky Survey in depth. Users can zoom in on the Milky Way, or scroll around the 360° interactive panorama with clickable labels of the bright stars, constellations, and deep-sky objects.**

Listen to an interview with Nick Risinger at http://skyandtelescope.com/photopicsurvey.

The solitary ring of these words hangs in the air, perhaps serving as a reminder of how our knowledge of the universe has been advanced time and again by those who studied the skies with lonely dedication. But then there are luminaries of history such as William Herschel who spent years scanning the heavens with help from his sister. I like that. After all, considering the many pastimes life has to offer, which ones are more meaningfully shared in the company of others than sitting under the stars? Thanks, Dad, for being there all those nights. ✦

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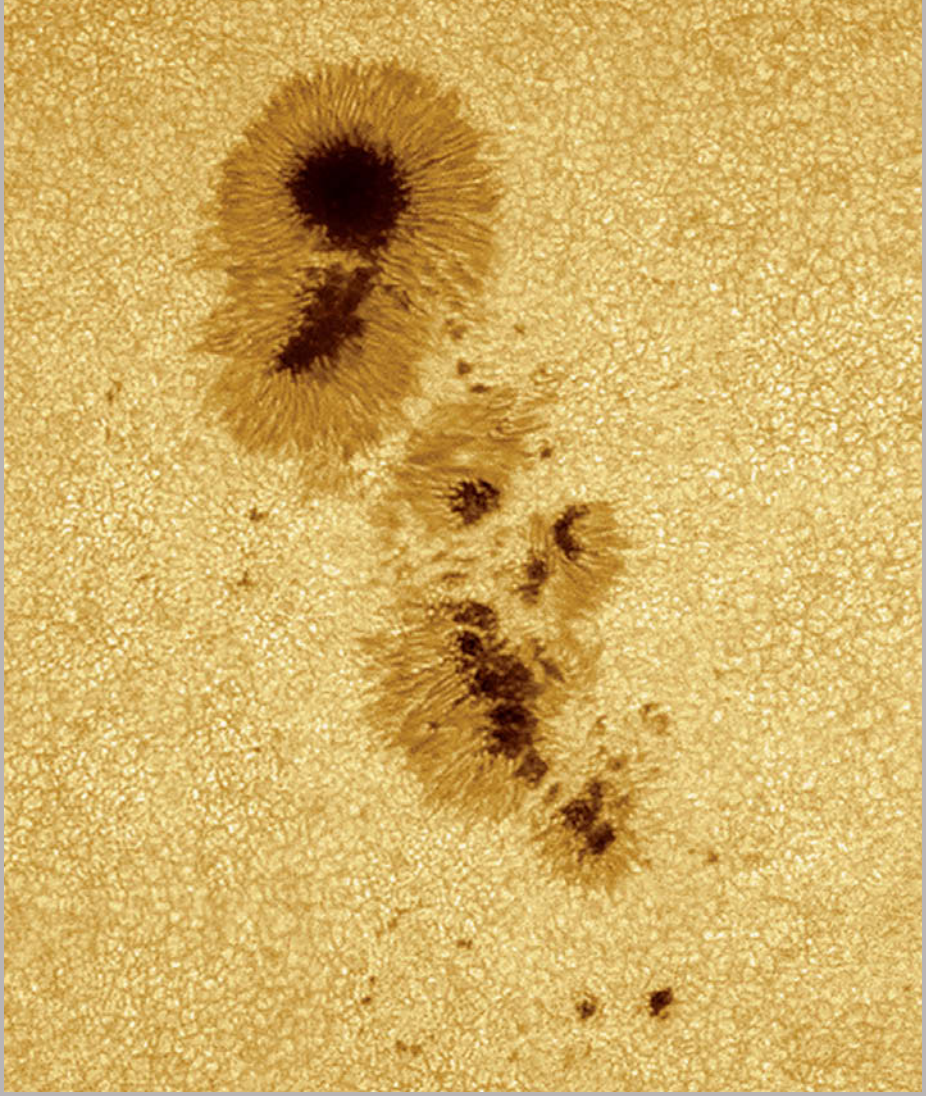
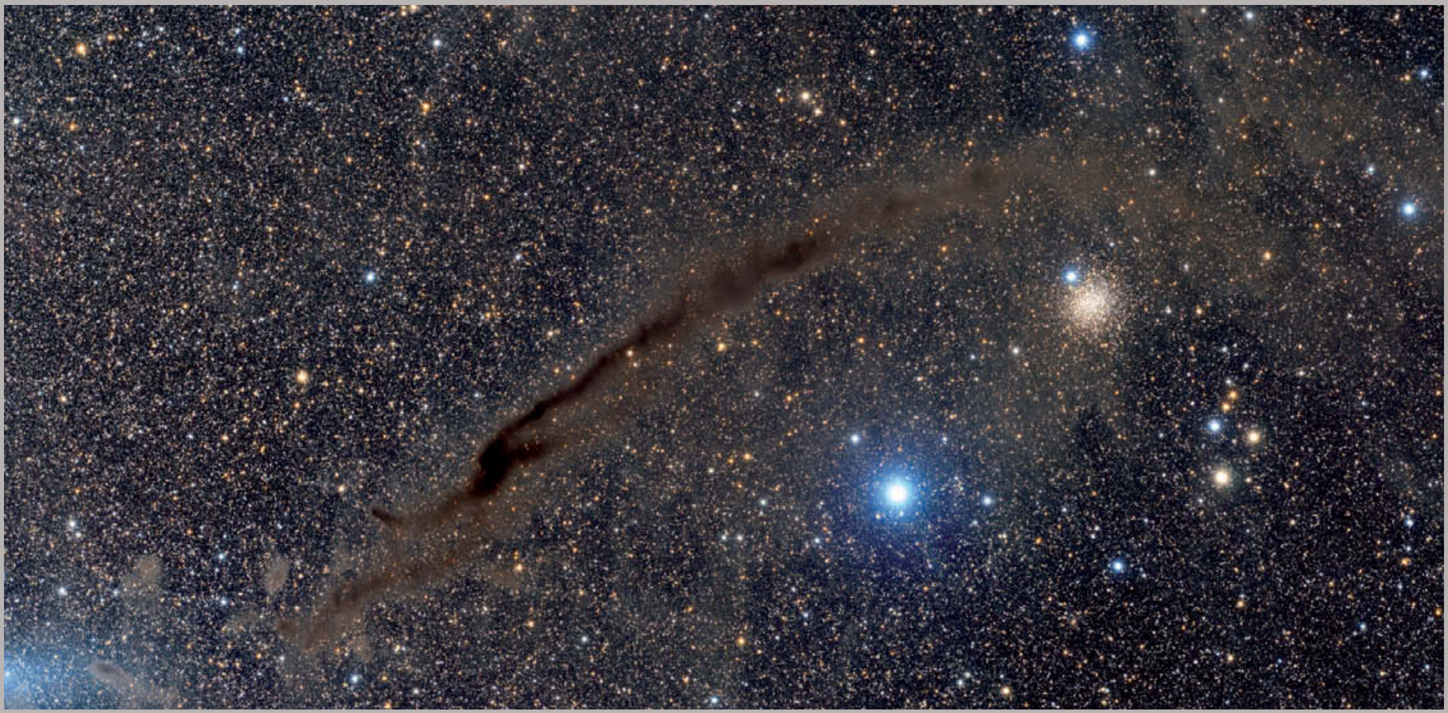
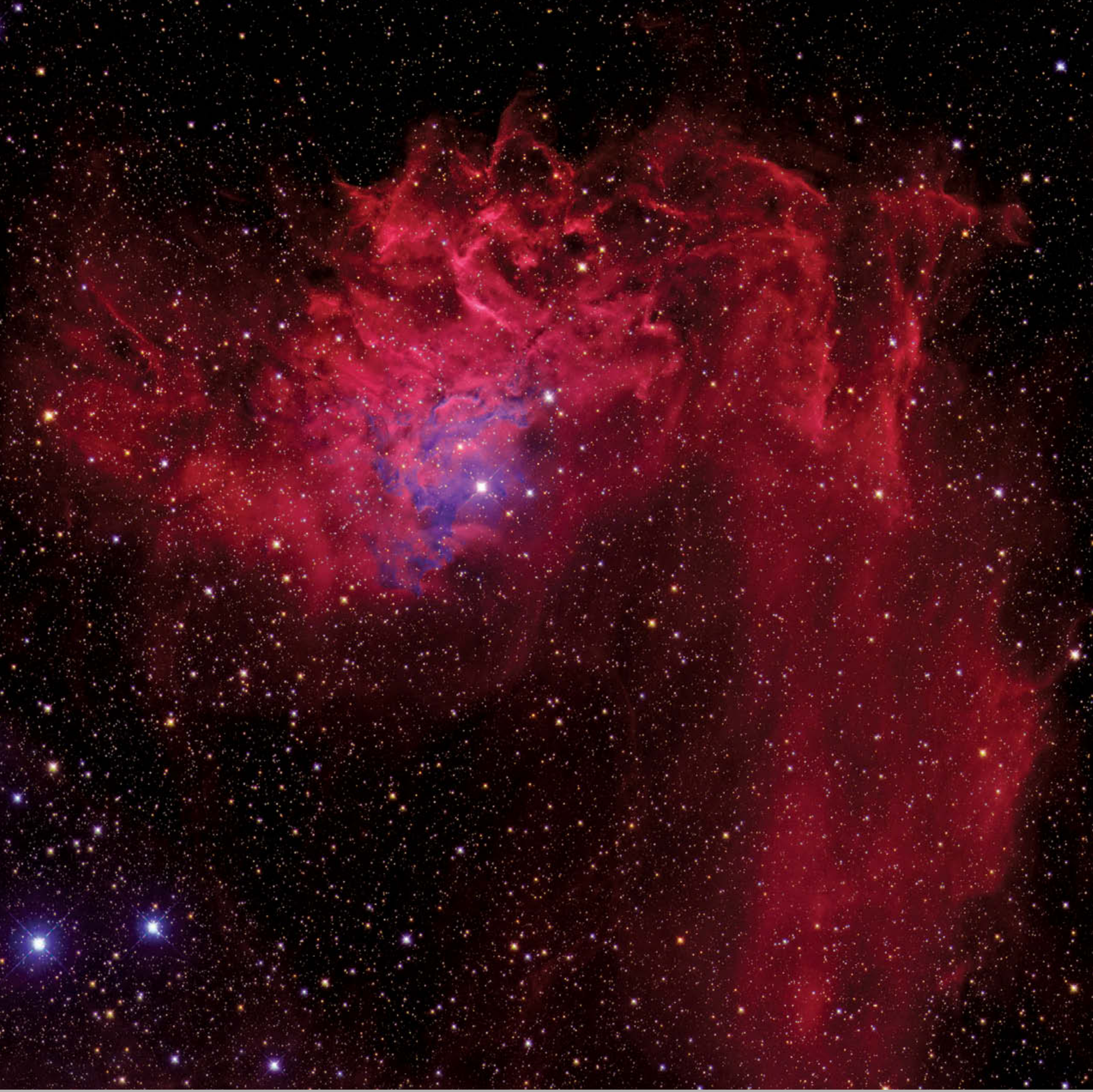
*A photographer, designer, and occasional speaker, **Nick Risinger** has presented his work at the Advanced Imaging Conference, Pixar, and numerous astronomy clubs.*



▸ **SPOT PARADE**
Alan Friedman
Active region 11263 put on a fine display as it marched across the solar disk early in August 2011.
Details: *Astro-Physics 10-inch F14.6 High-Resolution Maksutov-Cassegrain with Baader AstroSolar Saftey Film and Point Grey Research Scorpion video camera. Stack of multiple frames.*

▾ **THE DARK DOODAD**
Yuri Beletsky
The dust cloud known as The Dark Doodad in the southern constellation Musca appears to change opacity as is passes the blue star γ Muscae and globular cluster NGC 4372 at right.
Details: *Takahashi FSQ-106ED refractor with SBIG STL-11000M CCD camera. Total exposure was 51½ hours through color filters.*





▲ **THE FLAMING STAR**

Bob Holzer

IC 405 is a bright complex of pinkish emission and blue reflection nebulosity lit by the bluish star AE Aurigae.

Details: *Takahashi BRC-250 Baker-Ritchey-Chrétien astrograph with FLI PL16803 CCD camera. Total exposure was more than 40 hours through FLI color filters.*

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.

▶ **WINGED HELMET**

Paul Haese

Known as Thor's Helmet, NGC 2359 is a complex emission nebula in Canis Major. Its intricate appearance is due to strong stellar winds from a Wolf-Rayet star interacting with nearby molecular clouds.

Details: *GSO 8-inch Ritchey-Chrétien reflector with QSI 583wsg CCD camera. Total exposure was more than 22 hours through color filters.*

▼ **PLANET OF STORMS**

Glenn Jolly

Jupiter presented countless swirling storms to the patient observer throughout 2011.

Details: *Celestron EdgeHD 14 Schmidt-Cassegrain telescope with Point Grey Research Flea3 video camera. Stacked videos recorded through Astrodon RGB filters.*

▲ **AURORA BOLIDE**

Joe Bergeron

While recording faint aurorae on the evening of October 24, 2011, amateur Joe Bergeron of Binghamton, New York, managed to catch a bright bolide as it flashed through Taurus. **Details:** *Canon Rebel XS DSLR camera with 15-mm fisheye lens. Total exposure was 45 seconds at ISO 1600.*

▶ **SUNSPOT SUNRISE**

Jose Aguilar

In another sign that solar cycle 24 continues to intensify, the Sun rose on November 11, 2011, over Quezon City, the Philippines, with more than a dozen visible spot groupings. **Details:** *Canon 50D DSLR with 100-400-mm zoom lens and 2x tele-extender. Exposure length was 1/8000 at ISO 1000, f/36.* ✦

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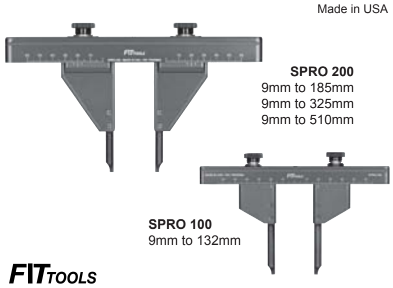

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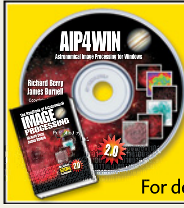

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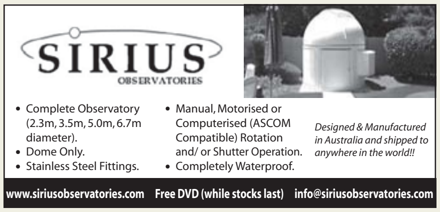

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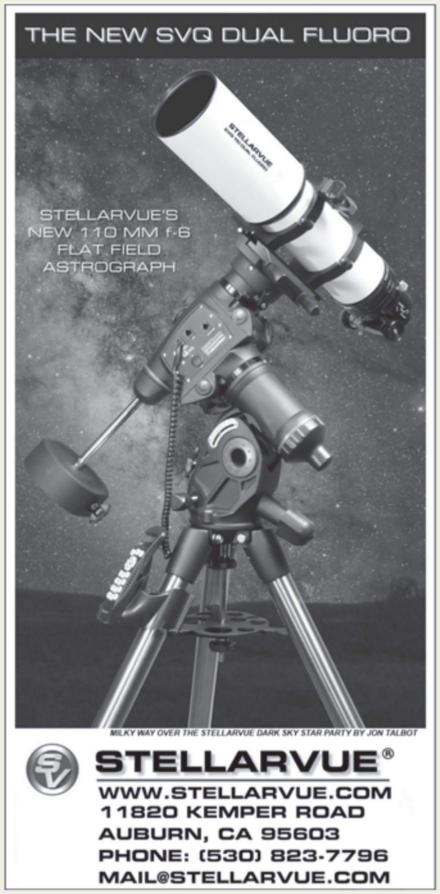

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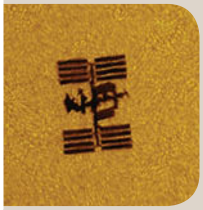
With major contributions from amateurs, scientists are close to figuring out the strange eclipsing binary Epsilon Aurigae.



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 Ted Rafferty

Galaxies in My Backyard

A retired professional astronomer is delighted by the advances in amateur equipment.

When I first became interested in astronomy in the early 1960s, I learned that most astronomy was done from the summits of remote mountains under extremely dark skies. That impression continued throughout my career as a professional astronomer, where I was involved with observing runs at mountaintop observatories such as McDonald, Lick, Kitt Peak, and Cerro Tololo.

Near the end of my career I was aware

TED RAFFERTY (3)

that amateur astronomers were taking some remarkable images, but I assumed they were from dark sky sites, with large telescopes and expensive cameras. When I retired I wanted to continue doing astronomy, but just for fun instead of for the science. I decided to try astronomical imaging, so I bought an inexpensive telescope and camera that were best suited for doing deep-sky imaging, with the plan of working out all the procedures from my backyard and then traveling to remote sites to do the "serious" imaging.

The instrumentation and computer software side of astronomical imaging proved as interesting to me as the resulting images. I think the statement "a telescope is never finished" is quite accurate, and I soon found myself often making improvements to the hardware and upgrading the software. Where possible, I built what I could myself. Upgrading the software was made easier by the abundance of available freeware. I found the quality of this freeware and the frequent upgrades an indication of how strong a commitment some people are making to amateur astronomy, which is a hobby that can get very expensive.

Besides the freeware, I found very useful information from the amateur astronomical community on the internet that allowed me to follow discussions by others with similar hardware and software or to start my own discussion thread. Many websites display astronomical images, which allowed me to learn about new possible targets besides the familiar Messier and Caldwell objects. Even better, friends made through these group sites have helped me climb the steep learning curve for imaging.

Amateur astronomy has changed a great deal since I was involved with it back in the 1960s and I was mostly unaware of those changes while working as a professional. I was certainly aware how computers were affecting the professional side of astronomy, but I didn't realize the profound impact they were also having on the amateur side. The other big change in amateur astronomy is the amazing amount of information and the exchanging of ideas that the internet has provided.

Though I was impressed by the advancements in instrumentation and

image processing, finding out I could take high-quality astronomical images from urban locations was my biggest surprise. I no longer plan to go through the trouble of going to remote sites; I will continue imaging from a location that, just a few years ago, I thought was completely unsuited for this purpose. Images taken with my own equipment clearly show that I, indeed, have galaxies in my backyard. ✦

***Ted Rafferty** is a retired astronomer who worked for the U.S. Naval Observatory in Washington, D.C. for 32 years.*

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