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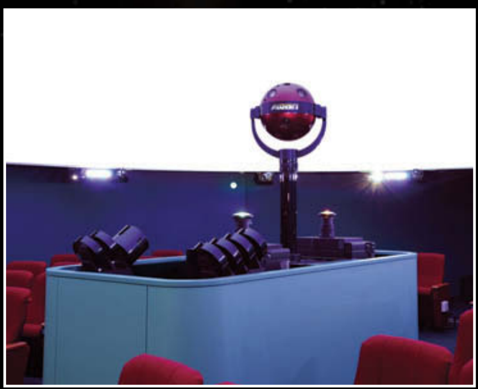

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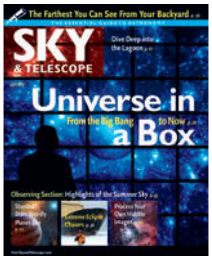
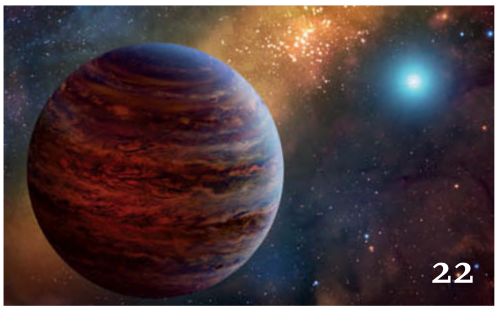


On the cover: Cosmic history plays out on the NASA Ames Hyperwall as Joel Primack looks on.

PHOTO: BRETT CASADONTE; SIMULATION: CHRIS HENZE

FEATURES



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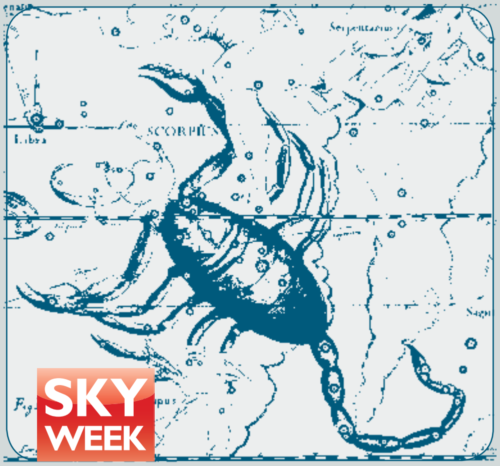

JOHANNES HEVELIUS

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Moving Forward in E-Media

S&T HAS RECENTLY taken big steps to help us take advantage of all the wonderful opportunities that exist in the rapidly evolving electronic media environment.

First, I have the pleasure of introducing you to our new Web Editor: Monica Young. Monica interned at *S&T* in March and officially joined our staff on April 2nd. In addition to reporting on science and other areas of astronomy, she will lead the way as we upgrade our website. Expect to see significant improvements in the months ahead in the design and navigability of our home page, and you can look forward to exciting new content as well.

Monica hails from Edina, Minnesota. She graduated from the University of Pittsburgh with degrees in English writing and physics. Monica then moved to Boston University, where she earned a Ph.D. in astrophysics in 2011. She has also done research at the Harvard-Smithsonian Center for Astrophysics and postdoctoral work at Penn State University. Monica observed distant quasars with NASA's Chandra X-ray Observatory, the European Space Agency's XMM-Newton X-ray observatory, and other telescopes to help unravel the complexities of how supermassive black holes accrete matter.

"Working at *S&T* has been my dream job for years, so I'm thrilled to be here!" says Monica. "This is an especially good time to join a great group of editors and designers as the magazine moves to embrace new media."

Second, as I promised a few months ago, *S&T* is now available on Apple iPads. If you're a current print subscriber enjoying your free digital edition of *S&T* on a desktop or laptop computer, you can now get a **free iPad edition** by downloading the *Sky & Telescope* app at the iTunes App Store. To download and read the iPad issues, simply use the same e-mail and password you use to access the desktop version. If you're a print subscriber who has not yet signed up for the digital desktop edition but who wants to access the free iPad edition, go to our website and sign up for a free digital subscription by entering an e-mail and password. Then go to iTunes and download our app. If you're not a print subscriber, a monthly iPad subscription is $3.99 per issue ($2 off the U.S. newsstand price); a year's subscription is $37.99. Digital issues include links to bonus audio interviews, videos, and image galleries.

Finally, our *SkyWeek* television show, hosted by associate editor Tony Flanders, has experienced a dramatic increase in audience reach to over half the U.S. market, with a presence on 121 PBS stations. Look for it between PBS programs or by visiting **skyweek.com**. We are thrilled by the success of this major outreach effort and thank our sponsors, Meade and Software Bisque.

Robert Naeye
Editor in Chief

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Founded in 1941 by Charles A. Federer, Jr. and Helen Spence Federer
The Essential Guide to Astronomy

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Looking Up

Normally my 9-year-old son has only a passing interest in anything that doesn't involve video games or sports with a ball. The February pairing of the Moon with Jupiter and Venus was a wonderful exception. While in the drive-through at McDonald's with the third-grade basketball team, we saw a glowing crescent Moon that seemed to be almost touching Venus, which was blazing like a spotlight. One of the kids actually spotted Jupiter (about 15° above Venus) before I could point it out. The next night we stood on the front porch and saw the Moon almost touching Jupiter this time, with Venus below, closer to the horizon. The night after, my son actually took *me* outside to enjoy the triplet. Seeing the Moon make its path amongst those glowing sky markers was the most spectacular demonstration of real-time celestial mechanics I've seen, not least because of the responding glimmer in my son.

David Blythe
Louisville, Kentucky

Change in Scope

In the February Letters section, Mr. Gotsch bemoaned the changes in *S&T*'s cover banner from the two previous designs (which I also liked). The editor noted that there have been only three changes in the cover since the original of 1941. There was a subtle change that came with the second banner that I've always wondered about. In my article, "Structural Considerations for Telescope Makers," in the June 1976 issue (page 423), I touted the stiffness and strength advantages of triangles over parallel beams in open tubes. The Serrurier Truss is such an example. Prior to my article, the Newtonian telescope drawn on the magazine's cover used the parallel-beam arrangement. When the second banner debuted — inside the magazine in July 1978, on the cover in January 1980 — the parallel tube Newtonian became a triangle-truss design. Any connection there?

John Brooks
Lake Shastina, California

Editor's note: *Although Mr. Brooks's article is a classic still cited today by amateur telescope makers, the switch to the parallel-beam arrangement in the magazine's logo was not a result of his article per se but rather a response to the widespread move by astronomers to the triangle-truss design. When* S&T *was founded in 1941, the parallel-beam design was popular — think Mt. Wilson's 100-inch, which was at that time the largest telescope in the world. But starting with the 200-inch Hale Telescope at Palomar in 1948, the truss model soon superseded the parallel beam. The new logo, besides showcasing a better structural design, was also easier to reproduce on small scales, such as along a book's spine. Still, it's correct to say that the logo's scope was patterned after the Serrurier Truss, which was by then the design of choice for big observatory telescopes and some amateur ones as well.*

Mystery Star Still Mysterious

Robert Stencel's excellent article explaining the Epsilon Aurigae mystery was unclear to me on one point. The evident asymmetry of the occulting disk is said to be due to uneven heating by the *hidden* star. The disk revolves around the hidden star, so heating from that source should be fairly even. Heating by Epsilon, on the other hand, would be asymmetric and would account for the trailing edge of the disk (the edge rotating away from Epsilon) being hotter than the leading edge.

This was a fascinating detective story which beautifully illustrates how science works.

Roy L. Robinson
Los Altos, California

Editor's note: *The reader is correct: "hidden star" referred to the* F *star being eclipsed, not the* B *star inside the disk. Our apologies for the opaque description.*

Eclipse Shooting

I found a close resemblance between aspects of Dennis di Cicco's solar eclipse photography experience (*S&T*: April issue, page 72) and my own. I've also tried the "bipod" approach, such as propping the lens of my still camera on a wall, but since 2006 I've switched over to HD video imaging. That year I used my Sony HDR FX1-E camcorder to record totality in Libya. I was so impressed by the wealth of detail (after stacking multiple video frames and processing the average) captured with a focal length of just 54 mm that I gave up DSLR activities completely.

The huge advantage of video is that it grabs lots of images rapidly with incredible resolution with respect to the real focal length. In 2010 on Easter Island I captured a 6th-magnitude star with an 8.5-mm focal length in stacked images of totality. Although DSLR cameras provide finer contrast transitions because of their superior color depth (12- or 14-bit data compared to camcorders' 8-bit images), the significant cut in equipment weight alone makes camcorder shooting worthwhile.

Friedhelm Dorst
Witten, Germany

New Observing Section

I just wanted to say I love how you have linked together all of the observing articles under the red band. It makes locating the individual articles much easier. Please convey my thanks to Pat Gillis-Coppola and the editorial staff for a wonderful change to an already great magazine!

Craig McGinty
Colorado Springs, Colorado

Scoff at "Screen Scanners"

I belong wholeheartedly to the visual observing sect that Malcolm Brown described in his sociological satire of the amateur astronomer tribe (*S&T:* April issue, page 86). Looking at an image of

M35 on a computer screen is like looking at a photo of your wife when she is standing right beside you: bring your 10x50 binoculars outside and see the beauty of nature as it *really* is.

Peter Gibbons
Carrigrohane, Cork, Ireland

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For the Record

✷*In the shell diagram on page 29 of the April issue, Mercury's core comprises the two yellow layers, not just the innermost sphere.*

✷*In the April News Notes (page 16), the caption of the top planetary lineup should say the exoplanets are from the Kepler-20 system, as the labels indicate.*

✷*On page 56 of the April issue, the planetary nebula Abell 33 is incorrectly labeled Abell 31 on the star chart.*

For a list of past errata, please go to SkyandTelescope.com/Errata.

75, 50 & 25 Years Ago

Roger W. Sinnott

July 1937

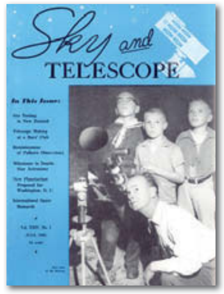
Bananas in the Sun "We can calculate the number of bananas the sun must consume daily in order to keep going. . . . By a curious coincidence, this figure is almost exactly equal to the mass of the earth. . . .

"Substitute coal, kerosene, or illuminating gas for the bananas. Since the caloric value of these commodities is at most three or four times higher than that of bananas, it follows that if combustion were the source of solar energy, the sun would burn to ashes within a few thousand years. There is no evidence of replenishment of fuel from without. No ordinary chemical reaction could maintain solar heat. . . . Hence astronomers still search for more powerful energy sources and theorize about sub-atomic chemical reactions that involve the hearts of atoms."

Soon after solar expert Donald H. Menzel wrote this cheeky editorial, astronomers determined the real source of the Sun's energy: nuclear fusion.

July 1962

Age of the Galaxy "The Milky Way galaxy is probably much older than the oldest stars observed today, according to S.S. Kumar of the Smithsonian Astrophysical Observatory. He believes it may have been formed some 32 billion years ago. . . . [The globular clusters M3 and M5] may be 26 billion years old according to A.R. Sandage."



Galaxy ages were eventually capped near 15 billion years after Arno Penzias and Robert Wilson discovered the cosmic background radiation in 1964.

July 1987

M31's Heavy Heart "John Kormendy (Dominion Astrophysical Observatory) has been studying the inner cores of galactic nuclei using the 3.6-meter Canada-France-Hawaii Telescope atop Mauna Kea in Hawaii. This site is blessed with remarkably good seeing, and the telescope can resolve images 0.5 arc second across. Thus the velocities of stars can be measured very close to the bright core of a galaxy's nucleus. This, in turn, reveals the amount of mass contained within the nucleus' innermost regions.

"Of the 100 or so galaxies Kormendy is studying, M31 shows the strongest evidence for a supermassive black hole. About 10 million solar masses of material is crowded into a volume no larger than 5 light-years across."

Work by Kormendy and others helped dispel the decades-long doubt that supermassive black holes lurked in galactic centers.

DARK MATTER | "Train Wreck Cluster" Causes Stir

NASA / ESA / CFHT / CXO / M. J. JEE

This composite image from Hubble, the Canada-France-Hawaii Telescope, and Chandra shows the cluster Abell 520. Its hundreds of galaxies (bright orange blobs) are poorly associated with dark matter (blue) mapped by weak gravitational lensing. Hot X-ray-emitting gas appears green.

New Hubble images have sparked heated debate on the nature of dark matter in Abell 520, a gigantic merger of several galaxy clusters 2.6 billion light-years away.

Andisheh Mahdavi (San Francisco State University) first mapped the cluster's dark matter distribution with weak gravitational lensing in 2007. Based on the gravitationally distorted shapes and orientations of galaxies in the far background, his team determined, surprisingly, that the dark matter's location doesn't match where the cluster's galaxies are.

"There are a few disturbing possibilities to explain the data, none of which is comfortable or a sure bet," says Mahdavi. Perhaps the most disturbing is the possibility that, somehow, dark matter was stripped away from some of the cluster's galaxies and formed a cloud of its own. That would contradict a key characteristic of dark matter that's been observed in many other ways: it does not interact with ordinary matter or with itself except by gravity. No known force should be able to grab hold of it to strip it off a galaxy.

Recent Hubble Space Telescope images both confirm and undermine the team's initial result. In a new study from Mahdavi's group, the massive "dark core" at the cluster's center still appears to be devoid of galaxies. But Douglas Clowe (Ohio University) and his colleagues used Hubble to observe Abell 520 with multiple short-wavelength filters for a longer total exposure that netted twice the light. These observations revealed more galaxies, and less dark mass, in the supposedly unpopulated dark matter cloud.

Clowe's group cautions that its results are still preliminary. When Mahdavi and his colleagues ran their own preliminary analysis of the same data that Clowe's group studied, they found no disagreement with their previous results. The jury is still out on what is happening in this unusual cluster.

■ **MONICA YOUNG**

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

MISSIONS | WISE Eye on the Infrared Sky

NASA / JPL / UCLA

On March 14th the team operating NASA's Wide-field Infrared Survey Explorer (*S&T:* December 2009, page 26) released the spacecraft's final all-sky atlas and catalog. The map is a composite of more than 18,000 images, and the catalog contains roughly 560 million individual objects, with roughly equal numbers of stars and galaxies. Also included are thousands of the Milky Way's diffuse nebulae and more than 150,000 objects (mostly asteroids) in our solar system. Moving objects are removed from this mosaic image, although some residuals remain: Jupiter appears as the red dot near the page number.

Data from three of WISE's four infrared detectors make up this image. Turquoise is near-infrared light at a wavelength of 3.4 microns, mainly from stars and galaxies. Green and red represent mid-infrared emis-

LUNAR | The Moon's Mysterious Birth . . .

New findings show that Earth and the Moon have identical isotopic ratios of titanium, which may be a problem for the widely accepted "big splat" lunar-formation hypothesis.

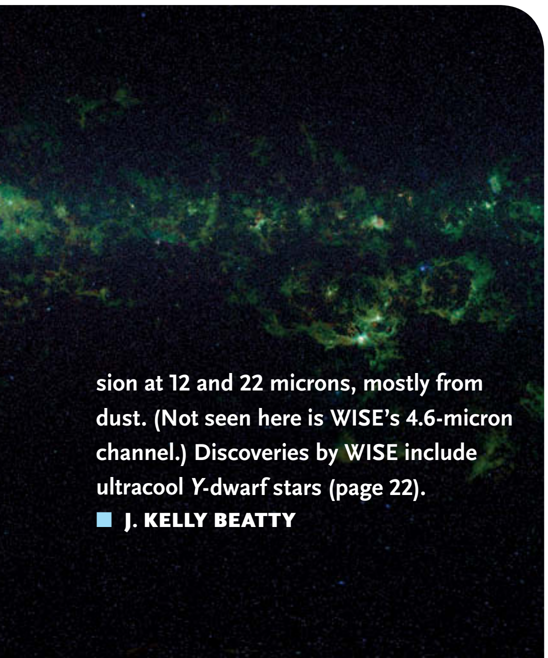
Most planetary scientists agree that the Moon was born when an object the size of Mars (sometimes called Theia) struck the infant Earth with a titanic glancing blow. Some of the debris, primarily from the impactor's mantle, then coalesced into our large satellite. But lunar and terrestrial rocks have long been known to have the same ratios of oxygen's three isotopes, suggesting that both came from the same original body.

Now cosmochemist Junjun Zhang (University of Chicago) and her colleagues have added another conundrum to this picture. In a recent *Nature Geoscience* paper, the team showed that the ratio of two titanium isotopes, Ti-47 and Ti-50, is likewise a dead match — identical to four parts in a million — in samples from the Moon and Earth.

Moreover, Zhang points out, the two bodies have the same isotopic ratios of tungsten, an important elemental tracer for silicate rocks. Tungsten-182 is created by the radioactive decay of hafnium-182. To get the tungsten ratios to match in addition to those of titanium and oxygen, the interiors of Theia and primordial Earth would have had to evolve the same way.

Some researchers have suggested that Theia originated in an orbit much like Earth's before it struck, explaining the similarity, but that's not the currently favored view. It's possible that the Moon took a few hundred years to pull itself together, time in which material could have sloshed back and forth between the just-hit Earth and the Moon-forming disk, as Julien Salmon and Robin Canup (Southwest Research Institute) reported at this year's Lunar and Planetary Science Conference. Or maybe a somewhat different impact sped up the proto-Earth's rotation enough to make the world itself fission into the Earth and Moon, Zhang and her colleagues speculate.

■ **J. KELLY BEATTY**



sion at 12 and 22 microns, mostly from dust. (Not seen here is WISE's 4.6-micron channel.) Discoveries by WISE include ultracool *Y*-dwarf stars (page 22).

■ **J. KELLY BEATTY**

. . . And Facial Secrets

If you've ever wondered why almost all the dark lunar maria face Earth and the farside is covered almost entirely by highlands, an *Icarus* study by planetary dynamicists may have the answer.

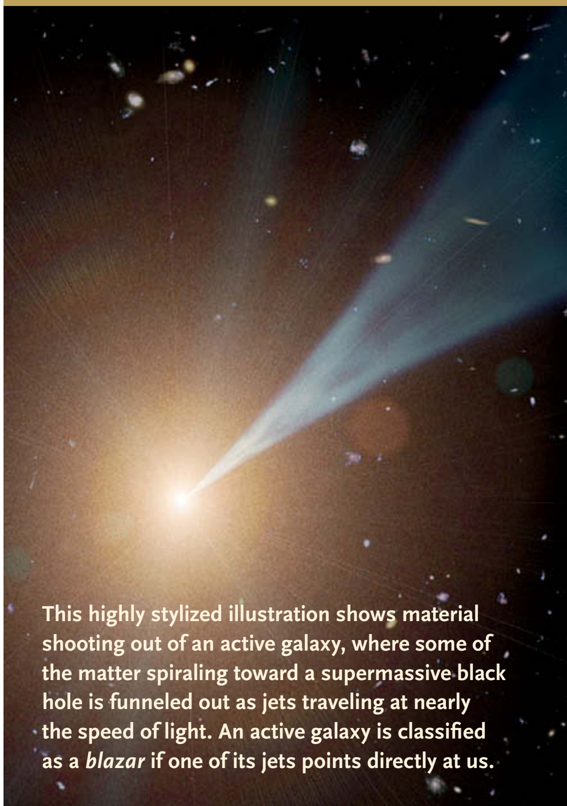
The Moon's globe is slightly oblong, like a football. One of the football's ends points straight at us and is crowded with lava-topped maria. The long axis points at us because, after the Moon formed, Earth's strong tidal forces created flexing and internal friction that gradually slowed the lunar spin.

But which end came to face Earth was a matter of how quickly the Moon's rotation slowed down. Maria are denser than highlands. If the despinning had been relatively rapid, the odds of the "Man in the Moon" facing us would have been about 50/50. But the slowdown was very gradual, so the odds favored the heavier end getting stuck facing us by about 2:1.

Still, geologists aren't really sure which came first — the tidal spin-down or the formation of the maria. And other factors might have weighted the hemisphere coin toss, too, such as a big whack relatively late in the game or even a wholesale redistribution of the lunar crust.

■ **J. KELLY BEATTY**

PHYSICS
Distant Galaxies Hint at Exotic Particle



This highly stylized illustration shows material shooting out of an active galaxy, where some of the matter spiraling toward a supermassive black hole is funneled out as jets traveling at nearly the speed of light. An active galaxy is classified as a *blazar* if one of its jets points directly at us.

NASA / JPL-CALTECH

High-powered jets beaming at us from distant galaxies may hint that the faithful photon is actually fickle. The speculative claim, by an Italian team looking at high-energy emission from blazars, is that gamma-ray photons coming from close to a galaxy's central black hole may switch between being photons and an exotic, as-yet undetected particle that goes beyond the Standard Model of particle physics.

These "axion-like particles," or ALPs, are hypothetical, low-mass particles that interact rarely with matter. As defined by theory, ALPs can turn into photons (and vice versa) in a strong magnetic field, like that in a blazar's core. An accretion disk in the core feeds a central black hole with material laced with magnetic fields, and high-powered jets shoot out along the magnetic fields sticking out

Continued on page 18.

Continued from page 17.

along the black hole's rotation axis. The jets can stretch thousands of light-years. ALPs should pass pretty much unmolested through the sea of photons suffusing both that inner region and the cosmos at large.

Oscillating photons aren't a new idea, ALPs are just the current flavor in favor. In 2007 a trio of physicists suggested ALPs to solve a problem. Many of a blazar jet's highest-energy gamma rays shouldn't survive the journey from the blazar to us. They should collide en route with the lower-energy photons filling space. But astronomers can see a blazar's most energetic gamma rays too well, leading the physicists to suggest that gamma rays oscillate between being photons and ALPs during their long voyage.

The new study looks at what happens to gamma-ray photons in the extreme environment near the accretion disk, not on the longer blazar-to-Earth voyage. Inside the blazar's core they should collide with a dense sea of visible and ultraviolet photons and, as in intergalactic space, be blocked more than they are. Gamma rays oscillating into ALPs could explain how these photons get out. When the ALP hits another magnetic field later on — perhaps that of the Milky Way — it could flip back, allowing us to observe it, Fabrizio Tavecchio (Astronomical Observatory of Brera, Italy) and his colleagues suggest.

Data from the planned Cherenkov Telescope Array, a ground-based gamma-ray observatory, and scheduled upgrades to the DESY ALPS particle-physics experiment in Germany, could reveal if photons do change their stripes.

■ CAMILLE M. CARLISLE

SECOND LIGHT | Bino Scope Opens Sharp Eye

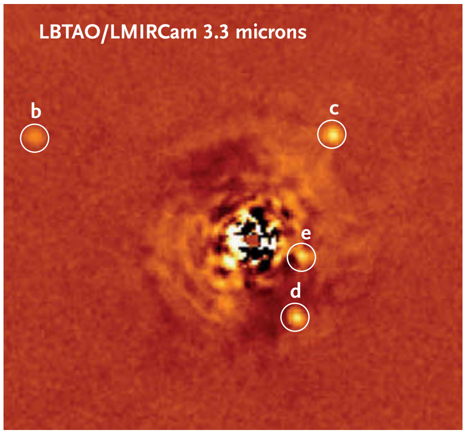
New images from the Large Binocular Telescope atop Arizona's Mount Graham show that the two-eyed leviathan is finally on its way to producing the observations it was made to do.

The LBT consists of twin 8.4-meter telescopes on the same mount. A state-of-the-art adaptive-optics secondary mirror has now been installed on one, sharpening its angular resolution tenfold. When both scopes have their adaptive optics and are linked interferometrically to work as a single aperture, the LBT's resolution will increase by another factor of three, to a total of tenfold better than Hubble's, says LBT director Richard Green.

This payoff has been long delayed. The twin telescopes saw first light in 2005 but only acquired the first adaptive-optics system last fall. Its key piece is an ultrathin secondary mirror, 0.91 meter wide and only 1.6 mm thick, with 672 tiny magnets on the back that deform its figure in a precisely controlled way 1,000 times per second. These deformations counter the distortions caused by atmospheric blurring. The result is a telescope that can see almost as sharply as if it were in space — within various limits.

Building and transporting the secondary mirrors posed a major challenge, and a couple of them broke. While awaiting them, LBT managers have used regular, rigid secondary mirrors to observe.

Among the shots from the newly sharpened side is this one (*above*) of the planetary system around the young star HR 8799, one of only a handful of exoplanet systems directly imaged. The brightness of the four giant planets at 3.3 microns wavelength suggests they



ANDREW SKEMER / UNIV. OF ARIZONA

The HR 8799 planetary system shows up clearly as seen in a narrow infrared band centered on 3.3 microns, an emission wavelength of methane common in gas-giant and cool-brown-dwarf atmospheres. This is the first time the innermost planet, HR 8799e, has been imaged at this wavelength. The star is masked out at center.

may be covered by patchy clouds, similar to those on Jupiter and cool brown dwarfs (page 22).

The images certainly whet the appetite. The single upgraded scope's performance seems at least as good as that of the 10-meter Keck scopes atop Mauna Kea in Hawaii, which are considered the best-performing of the world's advanced adaptive optics systems, says Ben Zuckerman (UCLA), who codiscovered three of HR 8799's planets in 2008.

The LBT was built by a collaboration of U.S., German, and Italian institutions. When light waves reaching the two scopes are combined wave for wave, the pair has the light-gathering power of a single 11.8-meter instrument and the image sharpness of a 22.8-meter scope.

■ CAMILLE M. CARLISLE

SCOPES | Projects Make Headway on Ground and in Space

Despite the austere funding climate, threats to older observatories, and deep cuts in the proposed NASA planetary science budget, there's some good news about powerful astronomical instruments.

• NASA's Kepler mission has received a 4-year extension, carrying it through September 30, 2016. The spacecraft has already spotted more than 2,300 exoplanet candidates since it began watching about 150,000 stars in Cygnus and Lyra in 2009. However, unexpected microvariability in star brightnesses, particularly for highly

Continued on page 20.

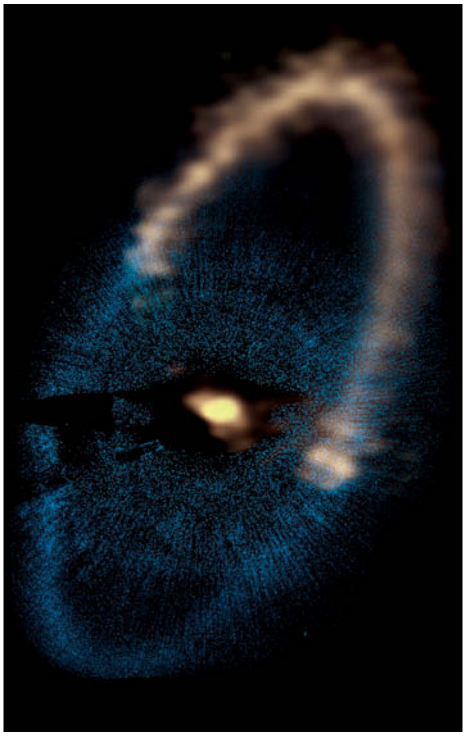
Continued from page 18.

convective, dim dwarf stars, has made Kepler's work harder: coaxing out signatures for Earth-size planets in Earth-like orbits requires seven or eight successive transits, not just the planned three.

• The first new science results are out from the Atacama Large Millimeter/submillimeter Array (ALMA) in Chile, and they're worth bragging about. These observations reveal the debris ring around the star Fomalhaut in exceptional detail. Only 15 ALMA antennas contributed, but even so "it's as if you're witnessing the type of breakthrough image first provided by the Hubble Space Telescope," says Paul Kalas (University of California, Berkeley), who has used Hubble to study the Fomalhaut system. The dust disk's sharp edges suggest the star may have two small planets shepherding the gigantic ring into shape. When all 66 of its dishes come online, ALMA will be by far the world's most powerful astronomical instrument studying the radio-infrared boundary.

• Groundbreaking for the 24.5-meter Giant Magellan Telescope (GMT) began with a bang on March 23rd. Crews blasted the top off Cerro Las Campanas in Chile, beginning the removal of 3 million cubic feet of rock from the mountaintop to make room for construction to start. Meanwhile, progress remains on track for the rival Thirty Meter Telescope (TMT) on Mauna Kea and the 40-meter European Extremely Large Telescope (E-ELT). All three of these observatories should be open for business in about 10 years' time. ✦

■ **J. KELLY BEATTY & CAMILLE M. CARLISLE**



ALMA: A.C. BOLEY ET AL. / NRAO / AUI / NSF; HUBBLE: NASA / ESA / P. KALAS ET AL.

The narrow dust ring around Fomalhaut lies about 135 astronomical units from the star (largely masked out at center) and is 13 to 19 a.u. wide. By comparison, Neptune is 30 a.u. from the Sun. Yellow at top is the new ALMA image; blue is an HST image.

IRON PLANET I March Madness on Mercury

Scientists announced a slew of results from NASA's Messenger probe at the Lunar and Planetary Science Conference in March, building on their growing understanding of the mysterious Mercury (*S&T:* April issue, page 26).

The results include an exquisite altimetry map of the planet's northern hemisphere (*shown below*). The laser altimeter zapped the surface eight times per second with a near-infrared beam, providing more than 10 million elevation measurements in the past year. The pulses reveal a broad, pronounced depression encircling the north pole, covered with thick volcanic layers that emerged from the interior early in Mercury's history. As Maria Zuber (MIT) and her colleagues reported online March 21st in *Science*, this broad lowland may have flipped into its current polar perch when Mercury's spin axis reoriented early on.

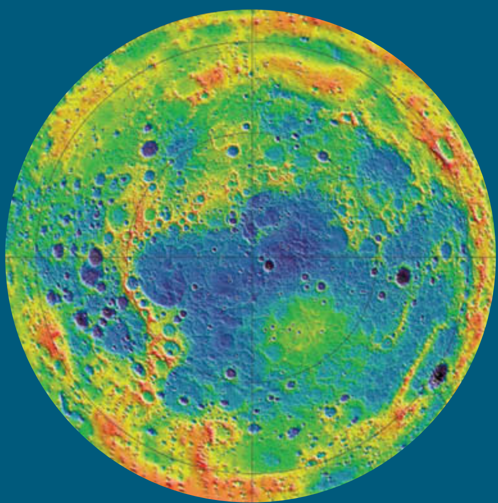
Another topographic oddity involves the giant, 1,000-mile-wide Caloris Basin, Mercury's largest impact feature. Inexplicably, part of the floor of Caloris stands higher than the rim. Zuber has a hunch the bulge might be related to global stress, caused by contraction of the young planet's crust as the interior cooled.

Painstaking study of Mercury's gravity field also suggests that there must be a dense solid layer — iron sulfide ("fool's gold") seems most likely — sandwiched between the mantle and core. This layer would explain both why the planet's magnetic field is weaker than it should be, given its giant iron core, and why the combined crust and mantle have such high rotational inertia without containing a lot of dense metals.

Lastly, evidence has increased for water ice hidden in shadowy polar craters. Early observations suggest that the ice isn't lying exposed on the shadowed surface; temperature models show that it could be stable a few inches below the surface. According to neutron-spectrometer team leader David Lawrence (Johns Hopkins Applied Physics Laboratory), if water ice *is* there, it's either buried under a thin insulating layer or some other hydrogen-bearing compound is mixed in with it, perhaps hydrocarbons, which would explain its dark appearance.

In April, Messenger fired its engine to brake into a more circular orbit, meaning that images and other measurements of Mercury's southern hemisphere could get nearly as good as those of the northern hemisphere.

■ **J. KELLY BEATTY**



NASA / JHU APL / CIW

The large, low-lying plain around Mercury's north pole appears blue on this topographic map of the planet's northern hemisphere (pole at center, equator at outer edge). Oranges and reds are about 3 miles (5 km) higher than blues and grays.

Misfit Stars

Illustration by Casey Reed

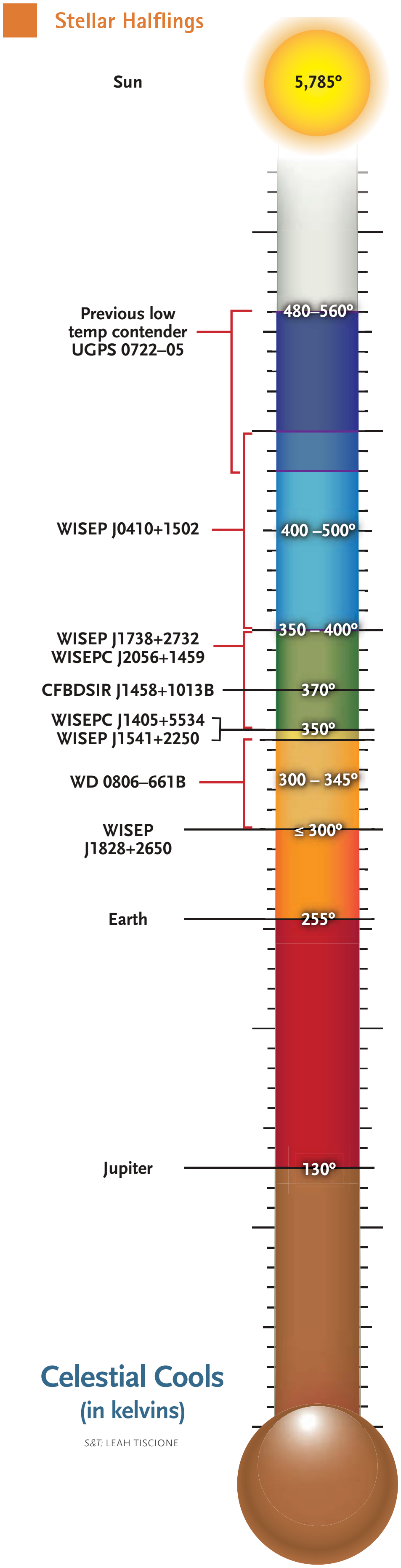
Kristina Grifantini

Half planet, half star, newly discovered brown dwarfs are only as warm as a summer's day on Earth, defying definition even as they tempt astronomers with new insights.

Beyond our skies, dim starlike objects the size of Jupiter float overhead, relatively close but, until recently, entirely invisible to our prying eyes. These brown dwarfs — often dubbed "failed stars" — never quite realize their potential for full starhood. Unable to shine like normal stars, they are destined to cool and darken. This past year, thanks to NASA's Wide-field Infrared Survey Explorer (WISE) mission and other observatories, astronomers have confirmed a bevy of the coldest brown dwarfs ever found. The chilly, enigmatic worlds share features with both low-mass stars and gas giants, and they promise to give insight into the mysterious origins of both.

For whatever reason, brown dwarfs form with too little mass to sustain nuclear fusion. Stars with 75 or more Jupiter masses have enough matter to continually fuse hydrogen into helium, releasing energy for millions or billions of years at steady temperatures. Brown dwarfs don't reach this mark: like regular stars, they can fuse the heavy form of hydrogen called deuterium, but they quickly consume that fuel and ultimately glow faintly with the heat left over from the gravitational collapse that birthed them. With no other lasting internal energy source of their own, brown dwarfs simply cool down as they age, radiating dimly at infrared wavelengths difficult for astronomers to detect amidst the background heat from other sources, such as Earth's atmosphere and the telescope we're using to observe them.

Researchers first theorized the existence of brown dwarfs in the 1960s and later thought they might account for a significant fraction of dark matter. We now know this is probably not the case, though the number of brown dwarfs likely approaches the number of regular stars. After the first brown dwarfs were confirmed in 1995, more than 1,000 have been spotted, with the coldest ones having surface temperatures as cool as 300 kelvins (80°F). Thanks to the pressure exerted by electrons and atomic nuclei, most brown dwarfs have approxi-



Celestial Cools (in kelvins)

S&T: LEAH TISCIONE

mately the same diameter as Jupiter. Adding mass to a brown dwarf would make it denser, not larger.

To categorize brown dwarfs, astronomers extended downward the stellar classification system of *O, B, A, F, G, K*, and *M*, which groups stars based on their observed spectra and temperatures. Beneath the *M* class (which consists of mainly stars, although this group includes the youngest, hottest brown dwarfs) are the *L* dwarfs, slightly older and cooler brown dwarfs between 2400 K (3860°F) and 1400 K (2060°F). *L* dwarfs eventually cool down to the *T* class, with atmospheres containing traces of steam, methane, and ammonia and at temperatures ranging from 1400 K down to 500 K (440°F). Whatever their temperature, many brown dwarfs' atmospheres have lithium (normally burned off during nuclear fusion), which is one way astronomers are able to pinpoint these stellar wannabes.

All brown dwarfs gradually fade at rates dependent on their mass, and end up in the coolest category, the *Y* class. These dwarfs show far more methane and ammonia in their atmospheres and potentially have water ice and salt clouds. They eventually reach Jupiter's temperature of around 130 K (–225°F). But the faint, long-infrared wavelengths of these older, ultra-cool *Y* dwarfs have been notoriously difficult to detect observationally. It wasn't until last year that the first eight *Y* dwarfs were discovered, six of which were found through the WISE mission.

The Search for Cold, Dark Beacons

WISE, launched into Earth orbit in December 2009 and retired in February 2011, snapped images every 11 seconds at four different mid-infrared wavelengths to map the entire sky. Scientists processed the data with automated software, pinpointed brown dwarf candidates, and used facilities such as NASA's Spitzer Space Telescope and the Keck Observatory in Hawaii to obtain photometry and spectra.

Last August, two papers announced that WISE researchers had found more than 100 new brown dwarfs, including the mission's first six confirmed *Y* dwarfs. These six objects are all relatively close, from about 10 to 30 light-years away. The coldest of these *Y* dwarfs, named **WISEP J1828+2650**, is only as warm as Earth on a summer's day: 300 K.

The temperatures of the eight new *Y* dwarfs fall somewhere between stars and planets, making the cutoff between the two categories unclear.

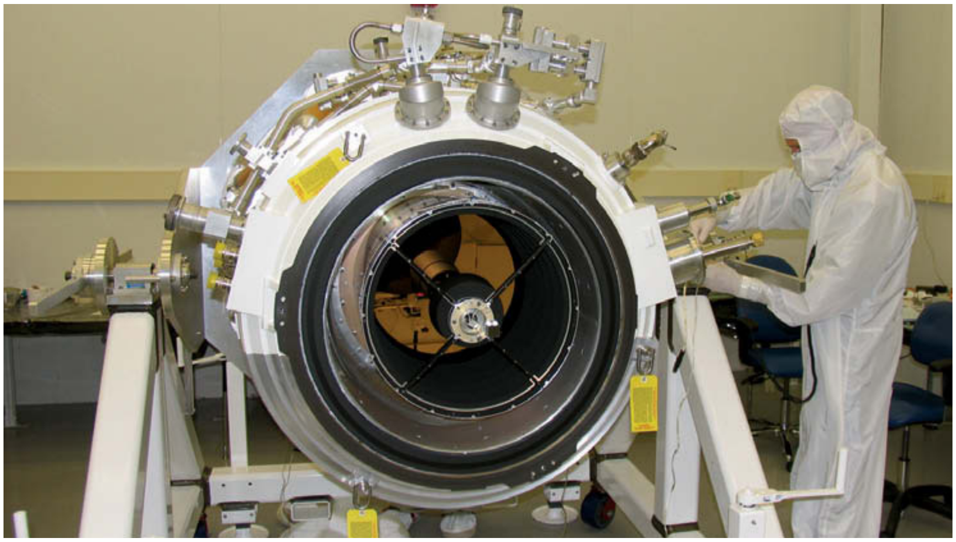
UNITED LAUNCH ALLIANCE

"That's just a glimpse of things to come," says J. Davy Kirkpatrick (IPAC-Caltech), lead author of one of the WISE papers. These ultra-cold brown dwarfs would appear 100 million times fainter than our Sun at the infrared wavelength of 1.2 microns if placed next to it.

One limitation of the new WISE data, however, is that all six *Y* dwarfs are isolated. Finding more in groups or near other objects would provide clues about their ages, masses, and other details.

"Right now we have 1,600 candidates in our list and we're not done searching the WISE data," says Michael Cushing (University of Toledo), lead author of the other WISE paper. While the bulk of the team's work will be completed in the next couple of years, scientists will be mining this dataset for decades.

Although WISE has been the most fruitful effort so far in finding ultra-cold brown dwarfs, two other groups spotted *Y*-dwarf candidates first, by looking for companions to particular stars. Last year, American and European researchers using the Keck II Telescope in Hawaii announced they had found a binary



NASA

INFRARED EXPLORER *Left:* WISE launched from Vandenberg Air Force Base in California on December 14, 2009. *Above:* WISE in a Logan, Utah clean room. Its primary mirror is coated with gold.

system containing an object, **CFBDSIR J1458+1013B**, that was only 370 K (210°F) — the temperature of boiling water (*S&T:* June 2011, page 12).

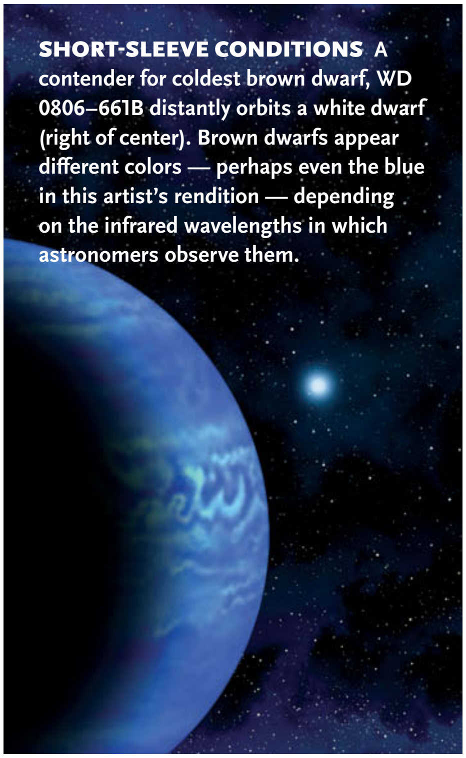
"These things are in our backyard, within 50 light-years of Earth," says Michael Liu (University of Hawaii), lead author of the J1458 paper. "Before this year, the coolest known object was estimated to be around 520 K," he says. "We're trying to map the sequence of changes along the way of low-mass stars to colder brown dwarfs to form a complete picture of these objects."

The eighth potential *Y* dwarf comes from another 2011 announcement. **WD 0806–661B** is 63 light-years away and, at roughly 325 K (125°F), it's a contender with WISEP J1828 for the coldest brown dwarf. Kevin Luhman (Penn State University) and colleagues were observing a white dwarf with Spitzer when they noticed the faint object orbiting the white dwarf at a large distance.

WD 0806B is a mystery. With only about seven times the mass of Jupiter, it's below the technical mass limit of about a dozen Jupiters that allows a brown dwarf to fuse deuterium. On the other hand, astronomers think that gas giants form in disks around stars no farther out than 100 a.u., yet this cold object orbits at a staggering 2,500 a.u. from its white dwarf companion. "You don't expect a gas giant to be out this far from a star unless something weird happened and its orbit was radically changed," says Luhman.

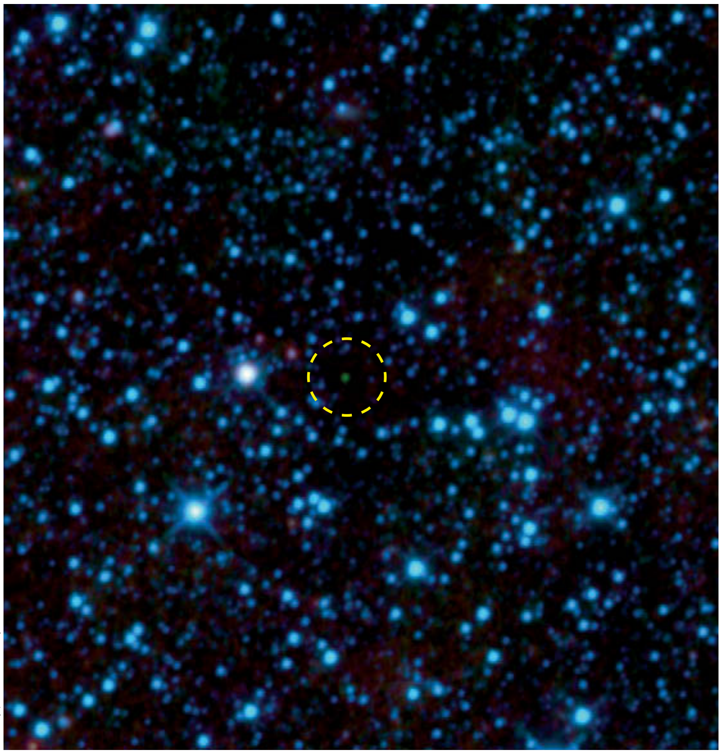
Codiscoverer Adam Burgasser (University of California, San Diego) says it doesn't really matter what it's called. "I'm less concerned about labeling something a planet or a brown dwarf — the important result is that this is a very cold object and its atmosphere is unique."

Despite the lack of a spectrum, WD 0806B's infrared luminosity suggests that it has the right temperature for a *Y* dwarf. It's hard to estimate the ages and distances of the free-floating WISE brown dwarfs, but because this object is paired



SHORT-SLEEVE CONDITIONS A contender for coldest brown dwarf, WD 0806–661B distantly orbits a white dwarf (right of center). Brown dwarfs appear different colors — perhaps even the blue in this artist's rendition — depending on the infrared wavelengths in which astronomers observe them.

JANELLA WILLIAMS



NASA / JPL-CALTECH / UCLA

NEEDLE IN A STELLAR HAYSTACK The green dot (circled) in this composite infrared image marks WISEP J1828+2650, currently the coldest known free-floating brown dwarf. A thermometer on this failed star's visible surface would read a lower temperature than that measured by a thermometer stuck in a person's mouth. J1828 is located in the constellation Lyra. The blue dots are a mix of stars and galaxies.

with a white dwarf whose age and distance are well known, Luhman says the team has been able to determine characteristics such as mass more easily.

These new discoveries are blurring the observational line between planets and brown dwarfs. If a cool object is found alone and giving off faint light of its own, most astronomers would call it a brown dwarf. But there are exceptions, such as free-floating, Jupiter-mass "orphan planets" thought to have been ejected from planetary systems (June issue, page 16). Astronomers may be forced to give up on mass and location clues alone and try to differentiate brown dwarfs from planets by inferring how these objects formed.

Planet-like Stars

Most theories suggest brown dwarfs originate not as planets do, but as stars do, from clouds of gas and dust that gravitationally collapse to form a dense core. But this process favors the formation of objects massive enough to sustain hydrogen fusion. With brown dwarfs, something must interrupt that formation process. The disturbance could be a larger, passing object that either steals material from the growing stellar embryo or flings the embryo out of the system before it can gather enough matter to sustain hydrogen fusion. Alternatively, the brown dwarf's formation may be triggered by turbulence in a nebula — such as a shock wave passing through — where there's too little mass to condense into a full star without a kick of this kind.

But others speculate that brown dwarfs could form similarly to large gas-giant planets, coalescing within a disk around a star before being ejected from the system to float freely in interstellar space. "Maybe it all happens at once, even in the same star-formation region," says Kirkpatrick. "How exactly you get to brown dwarfs may have many different routes."

"The WISE objects are fascinating, but they're old and don't give many clues about their formation mechanism," says Cathie Clarke (University of Cambridge, England). She adds that looking into star-forming clouds will help us understand how such cold, dense, hybrid objects form.

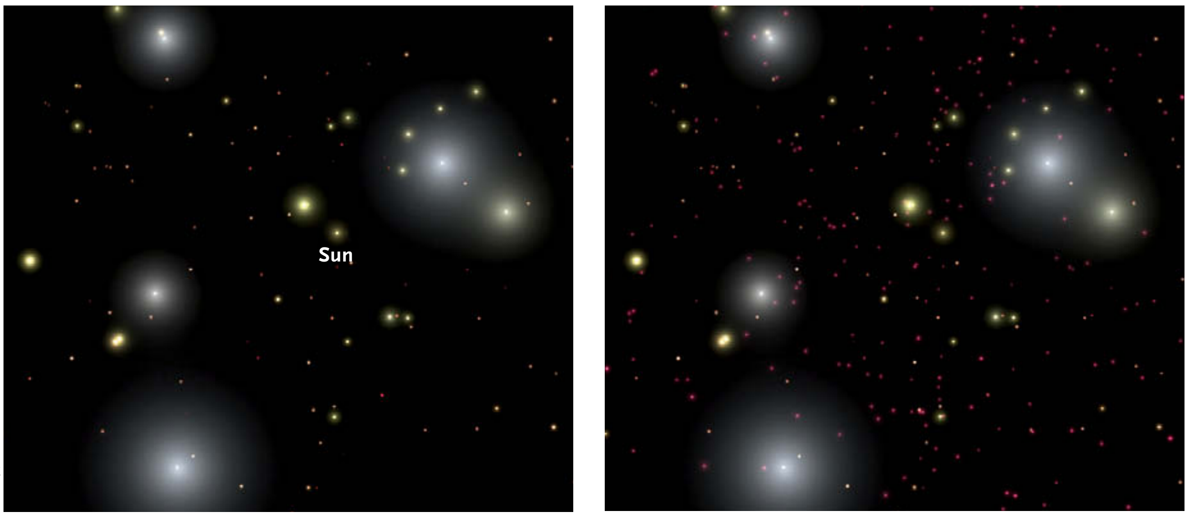
Clues to brown dwarf formation are likely to come with the international Atacama Large Millimeter/submillimeter Array (ALMA), a network of dishes currently being assembled in Chile that's touted as the world's largest astronomical project. The telescope, projected to be completed by 2013, will have 66 antennas in all, giving it a resolution sharper than the Hubble Space Telescope.

"ALMA is designed to look in the environments in which brown dwarfs are forming," says John Bally (University of Colorado, Boulder). There is a lot of interest in using ALMA to focus in on the formation of brown dwarfs, and astronomers hope that the telescope will play a major role in sorting out questions about *Y* dwarfs, he says. "It's very well suited for the study of low-luminosity objects."

Although the older *Y* dwarfs will provide a more complete picture of a brown dwarf's life cycle, they may also be helpful in another area of study. Because their temperatures drop to almost as cold as Jupiter's 130 K, *Y* dwarfs may turn out to be proxies for exoplanet atmospheres. The coldest known brown dwarf is 300 K, the same temperature Jupiter would have if it was 1 a.u. from the Sun, but researchers think they'll find colder examples with atmospheric conditions similar to the solar system's gaseous planets.

Some young exoplanets have been directly imaged, such as the Beta Pictoris planet and four planets around HR 8799 (page 18), but the majority of exoplanets are detected indirectly when they pass in front of their stars or cause a slight wobble in the star's position as they orbit. And the reflected glow from gas giants is usually washed out by the bright light from their nearby stars, making it difficult to study the planets' atmospheres. Because *Y* dwarfs are often alone rather than near other stars, astronomers can observe them directly and without an interfering glare, making their atmospheres easier to study than those of similar-sized exoplanets.

"Brown dwarfs are the simplest case," says Kirkpatrick. "If we get the models right, we can better compare those to the



NASA / JPL-CALTECH

DWARFS GALORE
The stars in these illustrations of the solar neighborhood aren't real: they're based on what astronomers expected to see before and after the WISE mission. The far left image shows known stars (white and yellow) and brown dwarfs (red). The near left picture shows the additional brown dwarfs expected in WISE data.

All in the Family

Although brown dwarfs have a wide range of masses, they are always about the size as Jupiter. Shown here (left to right) are the Sun (facing page), a low-mass *M* dwarf star, an *L* dwarf, a *T* dwarf, a *Y* dwarf, and Jupiter, plotted to scale. The visible-light colors of the brown dwarfs are chosen for an age of 1 billion years, except for the *Y* dwarf: since *Y* dwarfs have only been detected in infrared, the purple is an artistic choice.

***L* dwarfs:** ● The youngest brown dwarfs. Bright and warm, they glow at around 1700 K (2600°F). Compared with *M* dwarfs, *L* dwarfs have less titanium oxide and vanadium oxide in their atmospheres but more sodium, potassium, and water.

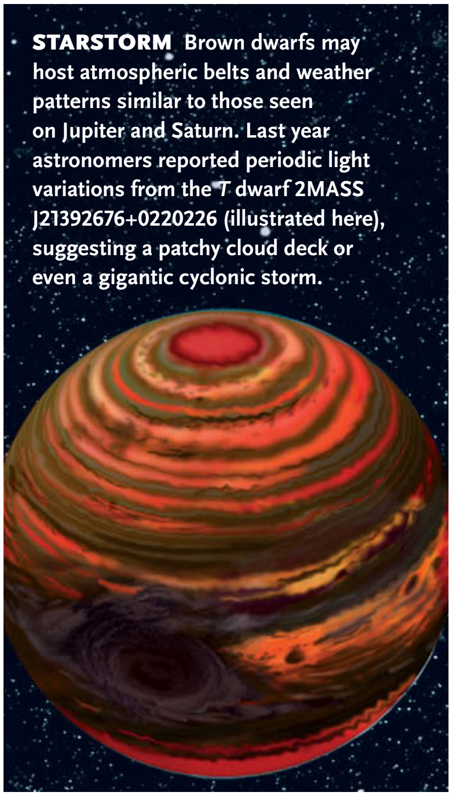
***T* dwarfs:** ● Middle-aged and cooler, these failed stars come in around 1200 K (1700°F) and have methane in their atmospheres.

***Y* dwarfs** ● The coolest of the cool. Water, ammonia, and methane characterize their atmospheres. Effective temperatures are less than 500 K (440°F).

S&T: GREGG DINDERMAN

exoplanets. We're just beginning to see hints of how diverse these cold atmospheres can get."

"These are basically stars that have ice in their atmospheres," adds Burgasser.



STARSTORM Brown dwarfs may host atmospheric belts and weather patterns similar to those seen on Jupiter and Saturn. Last year astronomers reported periodic light variations from the *T* dwarf 2MASS J21392676+0220226 (illustrated here), suggesting a patchy cloud deck or even a gigantic cyclonic storm.

JON LOMBERG

The *Y* dwarfs likely host some combination of methane, water, and ammonia gases, as well as both solid and liquid forms of water and salts. Some models suggest that these molecules could form clouds or belts like those seen on Jupiter and Saturn, which could show up as brightness variations as the dwarf rotates. Burgasser is part of a collaboration to monitor several sources for clues about brown dwarf atmospheres and weather.

There may be millions of ultra-cold brown dwarfs with ice-friendly temperatures and possibly even water cycles, according to Burgasser. But water cycles on *Y* dwarfs wouldn't look like Earth's because of the lack of solid surfaces. Instead of forming bodies of liquid water, molecules in *Y* dwarfs might circulate in the atmosphere while changing from gas to liquid to ice as they rise, then back to gas as they sink, he says. He adds that this scenario is highly speculative, since "we basically have never had those kinds of atmospheres to study before."

"There could be some atmospheres where floating life could actually form," Kirkpatrick muses, echoing an idea popularized by writers such as Arthur C. Clarke and Carl Sagan. "It's not out of the realm of possibility."

In addition to their fascinating atmospheres, *Y* dwarfs may hold hints of their past surrounding conditions. "One of the consequences of not fusing hydrogen is that brown dwarfs retain a record of the chemical abundance of the environment in which they formed," says Burgasser. Brown dwarfs, unlike the Sun, are fully convective, meaning material all the way down to the core is dredged up to the cloud tops, revealing the entire object's composition. This information would not only provide a glimpse into dwarfs' long-gone nurseries but it would also be useful to astronomers curious about environments in the early universe when the first stars formed. "These brown dwarfs would be relics of this period," he says.

As astronomers uncover more of these dim star–planet hybrids around us, it may turn out that *Y* dwarfs are among our closest neighbors, useful atmospheric laboratories, and ancient record-keepers waiting to tell us more about the universe. ✦

***Kristina Grifantini** is a science journalist based in Cambridge, Massachusetts. She won the 2010 American Astronomical Society's Solar Physics Division Popular Writing Award for her March 2009* S&T *cover story "Solar Impact."*

Universe on Fast Forward

STEFAN GOTTLÖBER / LEIBNIZ-INSTITUT FÜR ASTROPHYSIK POTSDAM

Supercomputer modeling is transforming cosmology from an observational science into an experimental science.

JOEL R. PRIMACK
& TRUDY E. BELL

OLD-FASHIONED STAR projectors show the changing night sky, acquainting planetarium visitors with constellations and planetary motions. Modern digital projectors can also show the locations of distant galaxies, and can even reveal their three-dimensional distribution in the cosmos by allowing the viewer to fly through intergalactic space.

But that's not nearly good enough for cosmologists — scientists who work to understand the composition, structure, and evolution of the entire universe. With the enormous power of the fastest supercomputers in the world, we now can model the three-dimensional evolution of the universe, from shortly after the Big Bang all the way to the present.

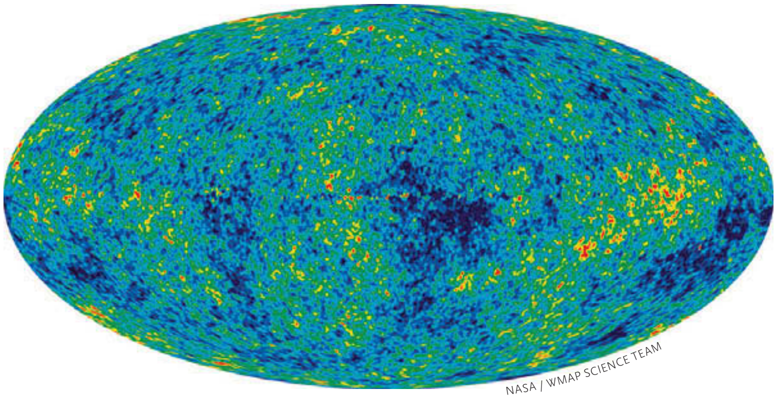
The computational power of supercomputers is literally transforming cosmology into an experimental science. Through supercomputer simulations, astronomers now can change the physical assumptions and see how the predictions change when, say, stars explode or galaxies collide. Simulations — along with stunningly beautiful visualizations of the results — let astronomers explore the universe in unprecedented detail, revealing insights not previously accessible. Even more powerfully, simulations allow astronomers to run an astrophysical process forward in sped-up time, and to make predictions that can be tested by observations of the real universe. In short, high-performance simulation now has joined theory, observation, and laboratory experimentation as another pillar of the modern scientific method.

The latest and best supercomputer model of the evolution of the universe is called "Bolshoi," after the Russian word for "big" with the connotation of "great" or "grand." The Bolshoi simulation has allowed us to test the agreement between our modern cosmological theory and the observed structure of the universe, both nearby and very far away. As we look farther out in space with our best telescopes, we are looking further back in time. As far as we can tell, the Bolshoi simulation's predictions agree perfectly with the best observations.

Joel Primack, one of the authors of this article, and Anatoly Klypin (New Mexico State University), are co-leaders of the Bolshoi project. Many other cosmologists are also involved. Scientific papers based on the Bolshoi simulation are now appearing in the *Astrophysical Journal* and other leading peer-reviewed journals.

Although not the first project to model the evolution of the universe, Bolshoi is better than previous cosmological simulations, including the path-breaking 2005 Millennium simulation, for three reasons: the improved accuracy and precision of its input data from observational measurements, the power and speed of NASA's Pleiades supercomputer and the computer codes used, and the detailed analyses of the Bolshoi outputs that are being made available to the worldwide astronomical community.

EVOLVING UNIVERSE ***Facing page, left to right:*** **These frames from the Bolshoi simulation depict the universe at redshifts of 10, 3, 1, and 0, which correspond to cosmic ages of 490 million years, 2.2 billion years, 6 billion years, and 13.7 billion years (today). The bright areas have high densities of dark matter. As the far left frame shows, Bolshoi's early universe has only a modest degree of lumpiness in the distribution of matter. But the subsequent frames demonstrate how gravity, acting over billions of years, gathers matter into long filaments that surround immense voids. Galaxies are concentrated along the filaments, clusters at the nodes.**

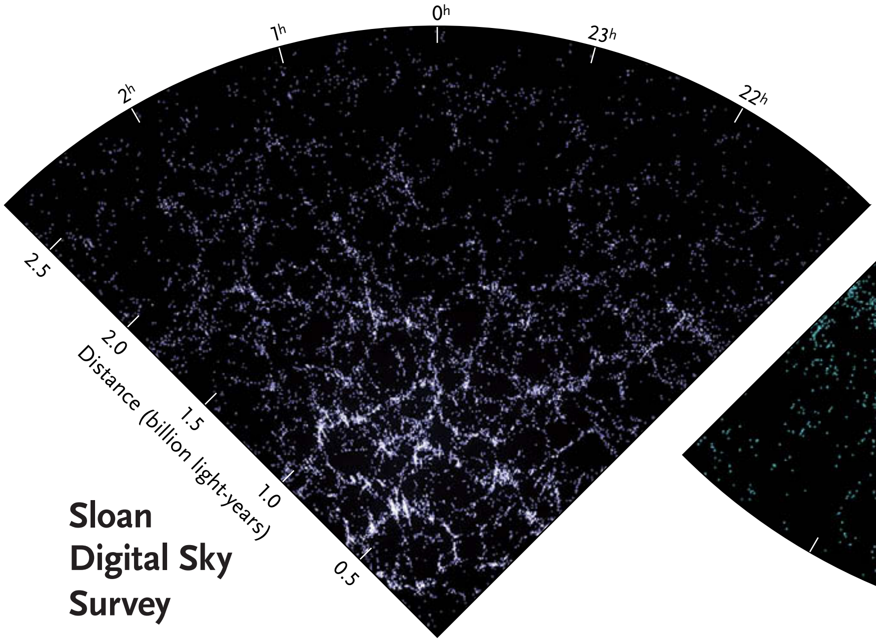


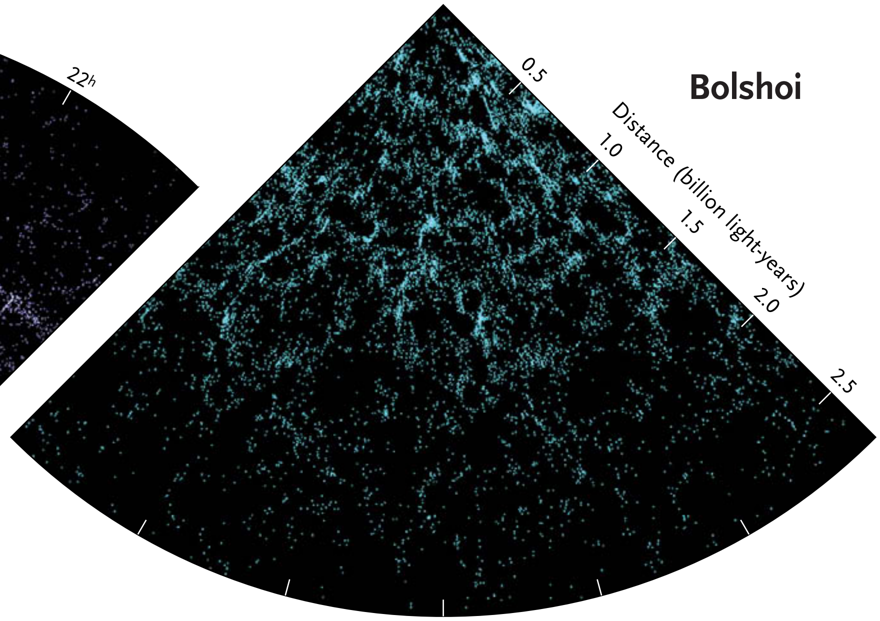
NASA / WMAP SCIENCE TEAM

INITIAL CONDITIONS According to standard cosmological models, the early universe experienced a period of inflation. This rapid growth spurt left behind slight variations in the density of matter. This lumpiness shows up as subtle warm (red) and cool (blue) spots in the cosmic microwave background (CMB), as revealed here in the seven-year dataset from NASA's WMAP satellite. Bolshoi and other cosmological simulations show how the CMB's higher-density regions served as "seeds" for the emergence and evolution of cosmic structure such as clusters of galaxies.

NASA / AMES RESEARCH CENTER

DIGITAL WORKHORSE A large team of scientists performed the Bolshoi simulation on NASA's Pleiades supercomputer at NASA's Ames Research Center near San Jose, California. Bolshoi ran on 13,824 processors, making it roughly equivalent to 7,000 dual-processor Apple MacBook Air laptops. It used 12 terabytes of random-access memory, which is more than 1,000 times the RAM of high-end laptops. The simulation took the equivalent of 18 days over several months in 2009.





N. MCCURDY (UC-HIPACC) / R. KAEHLER, R. WECHSLER (STANFORD U.) / M. BUSHA (U. ZURICH) / SDSS

REALITY CHECK As this comparison shows, Bolshoi's predicted distribution of dark matter halos closely matches the observed distribution of visible galaxies in the Sloan Digital Sky Survey. Although the two images differ in their details, they are virtually identical statistically, which gives scientists a valid reason for optimism that Bolshoi is accurately portraying how the universe actually evolved. Each wedge spans a quarter of the way around the sky and looks out to about 2.8 billion light-years.

Well-Tested Theories

As with simple or complex computer programs, the quality of the results output by a cosmological simulation depend both on the accuracy of the observational data used as input and the accuracy of the laws of physics used to specify the computational process. The laws of physics are the rules, if you will.

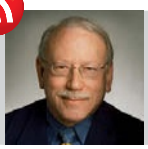
For Bolshoi, the equations of Albert Einstein's general theory of relativity are the rules for letting the supercomputer simulation unfold its model universe forward in time. This well-tested theory describes the behavior of space, time, and gravitation. Bolshoi is also based on the widely accepted and well-established modern theoretical framework for understanding the formation of the universe's large-scale structure: the Lambda Cold Dark Matter cosmology (abbreviated ΛCDM), based on the Cold Dark Matter theory devised by coauthor Primack and his colleagues in 1983-84.

In simplest terms, ΛCDM posits that right after the Big Bang, the universe rapidly inflated in size. This cosmic inflation vastly magnified tiny, random fluctuations in energy that existed at every point in space. These *quantum fluctuations* left matter and energy unevenly distributed throughout the universe. Assuming that the dark matter is cold — that is, that in the early universe it consisted of particles that moved much slower than the speed of light — then gravity caused high-density regions to coalesce into halos (clouds) of dark matter and ordinary atomic matter (which physicists call baryonic matter, because most of its mass comes from *baryons* — protons and neutrons in atomic nuclei). And these halos ultimately gave rise to galaxies and clusters of galaxies.

The Greek letter Lambda (Λ) is the symbol that Einstein gave to the *cosmological constant*, a possible property of space itself that represents a repulsive force that he thought could compensate for the attraction of gravity and permit a static universe. Einstein later called the cosmological constant his biggest blunder after Edwin Hubble showed that the universe is actually expanding. But now the evidence is extremely strong that there really is a cosmological constant — or something very much like it called dark energy. The Bolshoi simulation assumes that the dark energy is just Einstein's cosmological constant.

The ΛCDM cosmology also predicts that large-scale structure in the universe grows hierarchically through gravitation: repeated mergers of smaller dark matter halos create bigger ones. The principal purpose of the Bolshoi simulation is to compute and model the evolution of dark matter halos — thereby rendering the invisible visible for astronomers to study, and to predict visible structures that astronomers could then seek to observe. We also hope that the Bolshoi simulation may shed light on the exact nature of dark matter and dark energy, which remain unknown.

BONUS INTERVIEW and VIDEOS



To listen to an audio interview with coauthor Joel Primack, and to watch videos of the Bolshoi simulation, visit skypub.com/bolshoi.

Where the Data Come From

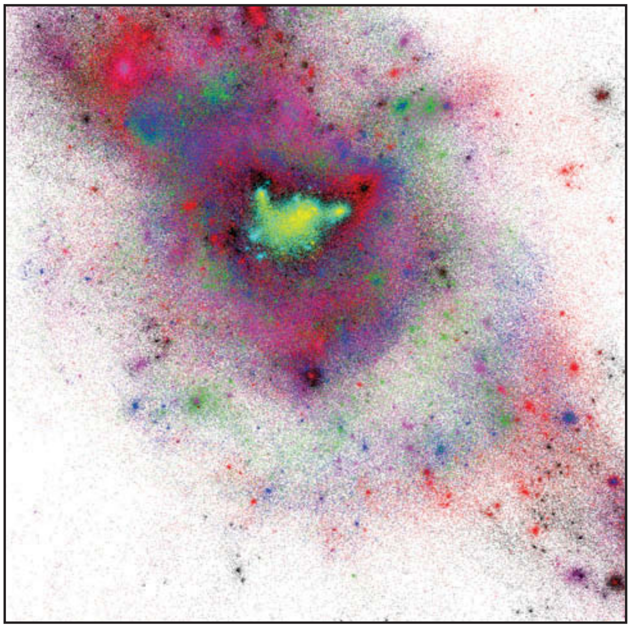
So the Bolshoi cosmological simulation unfolds from Lambda Cold Dark Matter cosmology and general relativity. The observational input data are the most accurate known: the cosmological parameters measured from the heat radiation remaining from the Big Bang and the observed distribution of galaxies and galaxy clusters.

The cosmic microwave background radiation was discovered by accident in 1964 by Bell Laboratories physicists Arno Penzias and Robert Wilson. Princeton University cosmologists Robert Dicke, James Peebles, and David Wilkinson quickly realized that the background hiss detected by Penzias and Wilson was the cosmic microwave background that George Gamow and his colleagues had predicted in 1948 would be left over after the universe had cooled over billions of years from a hot Big Bang.

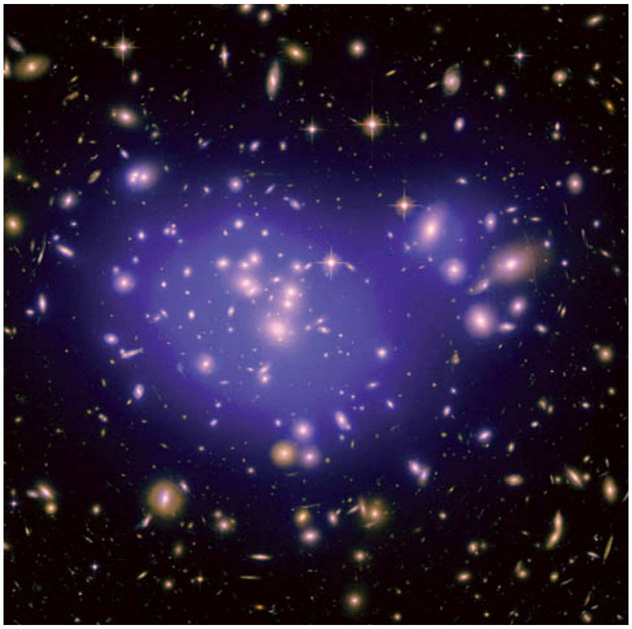
ΛCDM predicts how unevenly matter and energy had to be distributed so that a slightly lumpy early universe could form galaxies and clusters of galaxies, and even larger cosmic structures such as superclusters and enormous voids where few galaxies are found. In 1989 NASA launched the Cosmic Background Explorer (COBE) satellite to see if the cosmic microwave background indeed showed the slight differences in temperature that models of such a lumpy early universe predicted. In 1992 the COBE team announced that it had indeed seen the predicted tiny “anisotropy” (unevenness) in the distribution of temperatures in different directions. Six years later, two independent teams reported observations of Type Ia supernovae showing that the universe’s expansion has been accelerating for the past several billion years. That acceleration suggests the presence of dark energy.

As the observational evidence has steadily improved, it has also become increasingly consistent. Now all the different methods of measurement show that about 73% of the cosmic density today is dark energy and about 22% is cold dark matter. Only about 5% is ordinary baryonic matter — and only about 0.5% is visible as stars or gas.

NASA’s Wilkinson Microwave Anisotropy Probe (WMAP), launched in 2001, has been crucial in these precision measurements. WMAP and other observations definitively determined the age of the universe (to within 1% accuracy) as 13.7 billion years. More important, over the past decade, WMAP has produced high-resolution maps, meticulously plotting in fine detail the temperature and other characteristics of the cosmic microwave background across the entire sky. Analyses of the tiny variations in this primordial radiation have revealed a wealth of information about the universe’s history, structure, and composition. The slight temperature differences in the microwave background correspond to regions in the early universe that were slightly warmer and cooler, and thus less dense and more dense. As the early universe expanded, gravity vastly magnified the effects of those density variations, giving rise to the now-famous cosmic web — long filaments of galaxies surrounding immense

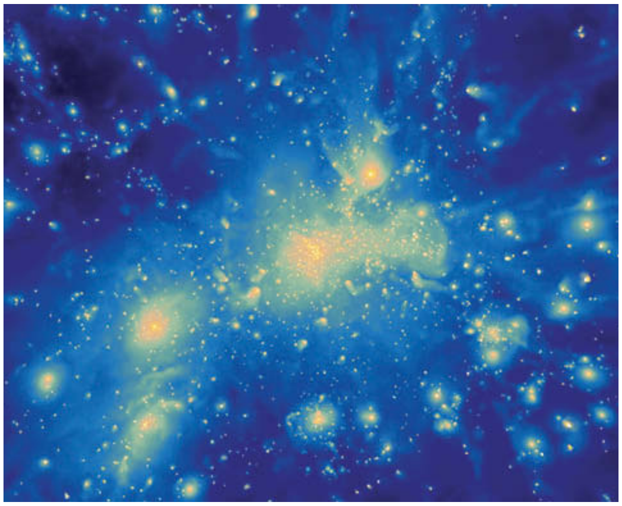


ANATOLY KLYPIN / STEFAN GOTTLÖBER



NASA / ESA / ERIC JULLO (JPL), ET AL.

CLUSTERS SIMULATED AND REAL ***Left:*** **This multicolored, ultrathin slice of the Bolshoi simulation is about 23 million light-years across and 7 million light-years thick. The close-up view shows complex structure of dark matter in and around a cluster of galaxies. Yellow dots denote were dark matter is moving fastest (exceeding 1,000 km/second), black dots the slowest (50 km/second).** ***Right:*** **This composite Hubble Space Telescope image shows the inner region of the galaxy cluster Abell 1689, 2.2 billion light-years away in Virgo. By measuring how the cluster has gravitationally lensed the light of background galaxies, astronomers can roughly map the distribution of dark matter, which is shaded purple. The right image is comparable in scale to the central bright region of the left image.**



Y. YEPES (UNIVERSIDAD AUTÓNOMA DE MADRID) / K. RIEBER (POTSDAM)

GAS DENSITY This frame shows gas distribution in a massive cluster from BigBolshoi, using the same initial conditions but treating the baryons separately from dark matter. For more Bolshoi images and videos, visit http://hipacc.ucsc.edu/Bolshoi.

voids that are seen clearly in large-scale galaxy surveys such as the Sloan Digital Sky Survey.

In 2008 the WMAP team released its WMAP5 data set, a five-year run of cumulative measurements of the detailed structure of the microwave background combined with the most reliable ground-based observations. The Bolshoi simulation is based on the cosmological parameters of WMAP5. Moreover, WMAP5 is completely consistent with a later data set released in 2010 called WMAP7, which is based on cumulative results of WMAP's first seven years, plus additional ground-based observations.

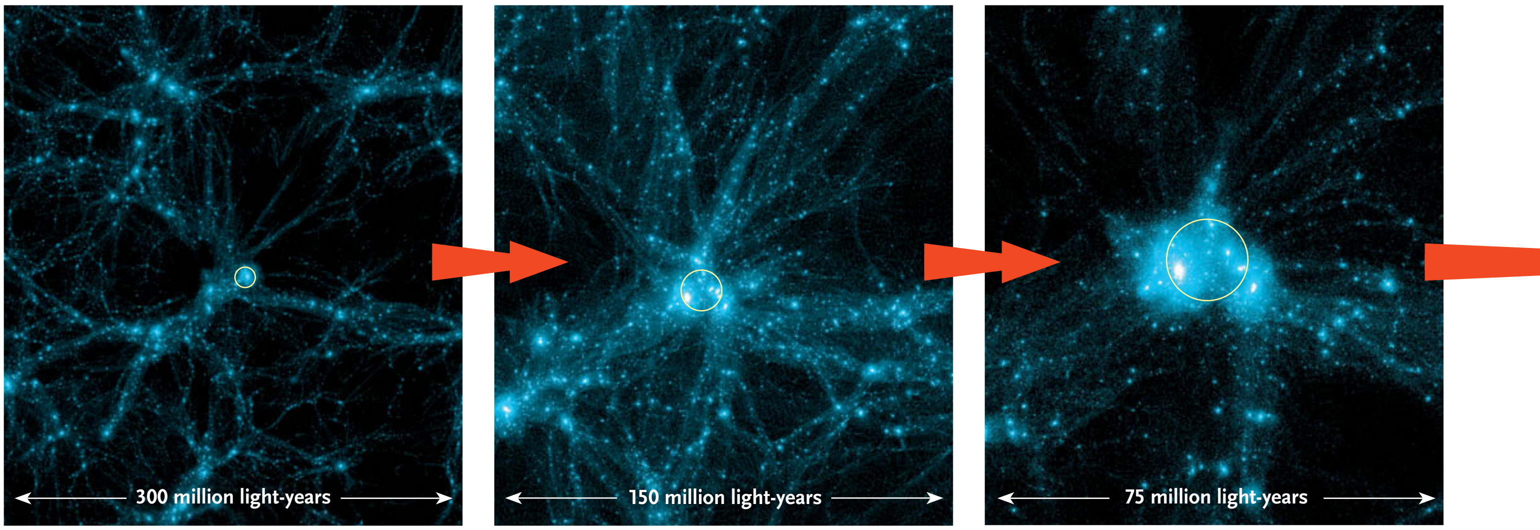
Universe in a Box

Just as many sciences seeking to understand large populations rely on analyzing a smaller representative sample of a population, the Bolshoi simulation modeled a smaller random representative volume of the universe. Specifically, it computed the evolution of a cubic volume measuring about 1 billion light-years on a side today, a volume that would contain millions of galaxies, all forming and subsequently residing in dark matter halos.

The Bolshoi simulation was run on the Pleiades supercomputer at NASA's Ames Research Center near San Jose, California, ranked in November 2011 as the seventh fastest supercomputer in the world and the third fastest in the United States. It was a monumental effort, funded by grants from NASA and the National Science Foundation. The full Bolshoi computation took 6 million CPU hours. Its software, developed by Anatoly Klypin, was a code called Adaptive Refinement Tree (ART), which achieved a resolution of just 5,000 light-years — quite fine compared to the enormous volume simulated. For comparison, the Milky Way's visible disk is about 100,000 light-years across, and its dark matter halo is about 2 million light-years across.

The Bolshoi simulation clock was started about 24 million years after the Big Bang. No supercomputers were needed to simulate what happened before then, because the fluctuations in cosmic density were still small, so simpler calculations could do an accurate job. The Bolshoi simulation then followed the evolution of 8.6 billion particles, all gravitationally interacting with one another. Each particle represented about 200 million solar masses (about 1/5,000th the mass of the Milky Way's dark matter halo) — including baryonic and dark matter.

During the simulated evolution of the universe, the supercomputer captured gigantic tables of numbers that correspond to three-dimensional "snapshots," equivalent to frames of a giant 3-D movie. Each snapshot contains about 400 gigabytes of data, preserving all the particles and their motions at that moment. Analyses of these snapshots — resulting in tables of the properties of all the dark matter halos at 180 different times from the Big



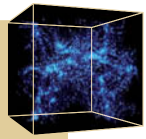
ANATOLY KLYPIN (NEW MEXICO STATE UNIVERSITY) (5)

Bang to the present, and charting how the halos at earlier times merge to form those at later times — are now accessible to astronomers worldwide, allowing them to explore the three-dimensional ΛCDM model of the universe and study how dark matter halos, their galaxies, and clusters of galaxies coalesced and evolved.

For example, the simplest way to associate galaxies with the dark matter halos uses a method called halo abundance matching (HAM), in which more luminous galaxies are associated with halos in which the dark matter particles are moving faster. Such an association is in accord with observations, which show that both spiral and elliptical galaxies are more massive and brighter if their constituent stars are moving faster.

Halo abundance matching allows the Bolshoi simulation to predict the likelihood of finding galaxies of various luminosities at various separations. These predictions are in excellent agreement with observations, unlike predictions based on the Millennium simulations. Moreover, the high resolution of the Bolshoi simulation allows astronomers to predict the abundance of large galaxies (such as the Milky Way) also having nearby companions as bright and as massive as the Large and Small Magellanic Clouds. The predictions say that about 71% of big galaxies have no such bright companions, 23% have one, 5% have two (like the Milky Way), and 1% have three or more. These predictions from the Bolshoi simulation are again in excellent agreement with observations. The success of these and other comparisons of the Bolshoi predictions with observations are confirming our general picture of how cosmic structure has evolved.

Several groups of astrophysicists around the world are working to use the full Bolshoi dark-matter-halo merging history to model the evolution of galaxies, taking into account the transformation of gas into stars, the accretion of gas by supermassive black holes, and the effects of the energy thereby released.



HOW DO WE KNOW DARK MATTER EXISTS?

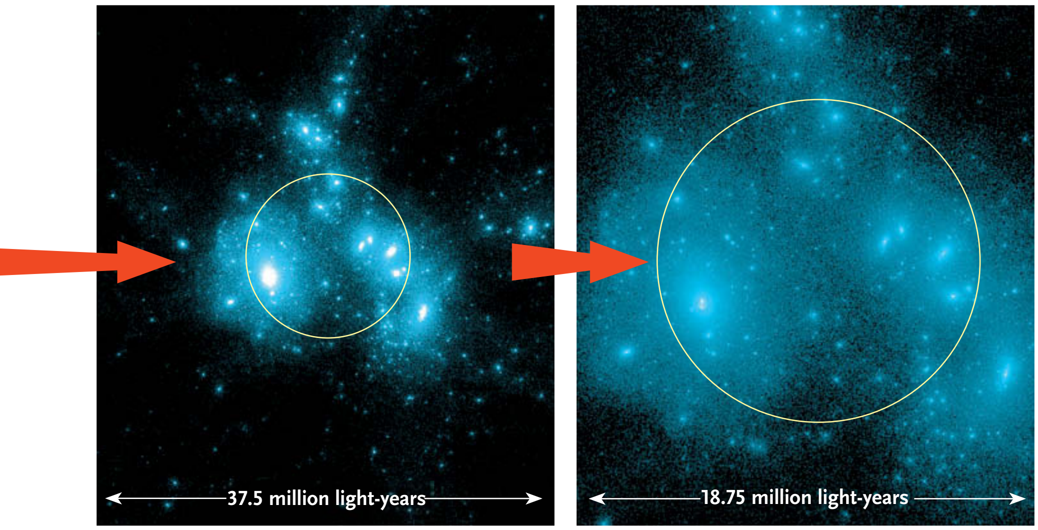
Astronomers observe cold dark matter not only through its effects on cosmic expansion but also through its gravitational influence on smaller scales, by measuring the speeds of stars and gas moving in galaxies or of galaxies moving in clusters, or by measuring the bending of light around galaxies and clusters. All of this evidence shows that dark matter makes up most of the mass of galaxies and clusters.

But Wait, There's More

The Bolshoi simulation, run in 2009 and analyzed in 2010-11, was the first of a suite of separate simulations run on NASA's Pleiades supercomputer.

A second simulation, known as BigBolshoi (or MultiDark), was run in 2010 with the same number of particles, but in a volume 4 billion light-years across — four times bigger on each side than Bolshoi, and thus 64 times larger in volume. Although lower in resolution than Bolshoi, BigBolshoi predicts the properties and distribution of galaxy clusters and other very large structures in the universe. Its results will help with projects, such as the Baryon Oscillation Spectroscopic Survey (BOSS), which are attempting to determine the properties of dark energy by measuring the universe's expansion history.

In autumn 2011, a third, higher-resolution simulation called miniBolshoi was started on Pleiades to model the formation and distribution of many small regions (a few tens of millions of light-years across) altogether containing hundreds of Milky Way-mass galaxies, with enough resolution to model the tiniest observed dwarf satellite galaxies. After improving the simulation code, we expect to finish miniBolshoi in 2012. By obtaining good statistics on the variations of galaxies' dwarf-satellite populations, we hope to shed light on why large galaxies seem to be surrounded by fewer satellite galaxies than predicted. If the predictions do not agree with observations, perhaps



ZOOMING IN Bolshoi allows cosmologists to zoom in and view how matter is organized at different size scales. Bolshoi's predictions can then be compared to astronomical observations. These boxes are all about 50 million light-years thick, but range in size (*left to right*) from 300 million light-years wide to only 18.75 million light-years across. The dense blobs are dark matter halos; the smallest halo in the right image would host a galaxy the size of our Milky Way.

alternatives to the standard ΛCDM theory might be required. For example, the dark matter particles might interact with themselves rather strongly, even though they interact only gravitationally and perhaps weakly with familiar baryonic matter.

A New Experimental Science

Up to now, cosmology has been a historical and purely observational science. Like geology and paleontology, the object of historical science is to reconstruct the history of the universe, Earth, and life from evidence millions or billions of years old. A geologist or paleontologist can analyze a rock fragment or bone chip in a lab. But geology and paleontology are notoriously difficult, because our dynamic Earth destroys much earlier geological evidence. After all, few individual organisms turn into fossils, which is why we find so few fossils.

To study the universe, astronomers are mostly limited to receiving and analyzing the spectrum of electromagnetic radiation emitted by objects eons ago (although they also receive information from cosmic rays and neutrinos, and probably someday gravitational waves). Almost all the radiation ever emitted at all wavelengths is still traversing the universe. Astronomers now possess three key tools to understand those "fossil" photons: great telescopes and instruments on the ground and above the atmosphere to capture those photons, sufficiently clever theories to explain what they show, and powerful supercomputer simulations to construct cosmological models based on those observations and theories.

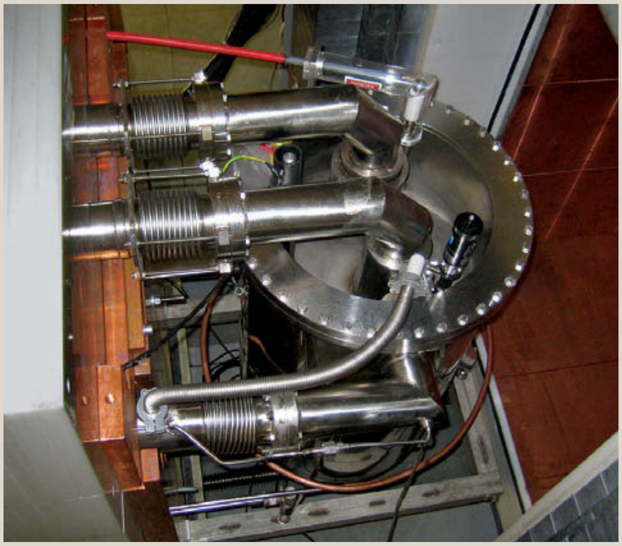
The Search for Dark Matter

Physicists expect that dark matter is some sort of elementary particle, like every other form of matter. If this particle does not interact through the strong nuclear force and is electrically neutral, it would interact with ordinary matter only weakly, like neutrinos. Such hypothetical dark matter particles are called "weakly interacting massive particles," or WIMPs.

If WIMPs are the dark matter, vast numbers of them are traveling right through Earth, just as neutrinos are, although WIMPs are much more massive. Many physicists are looking for these particles in super-sensitive experiments in deep underground laboratories, to shield them from cosmic rays. A few of these experiments show hints of WIMP detections. The evidence isn't convincing yet, but such experiments are rapidly increasing in sensitivity. They will either discover the WIMP or else rule out the popular candidate particles in the next few years.

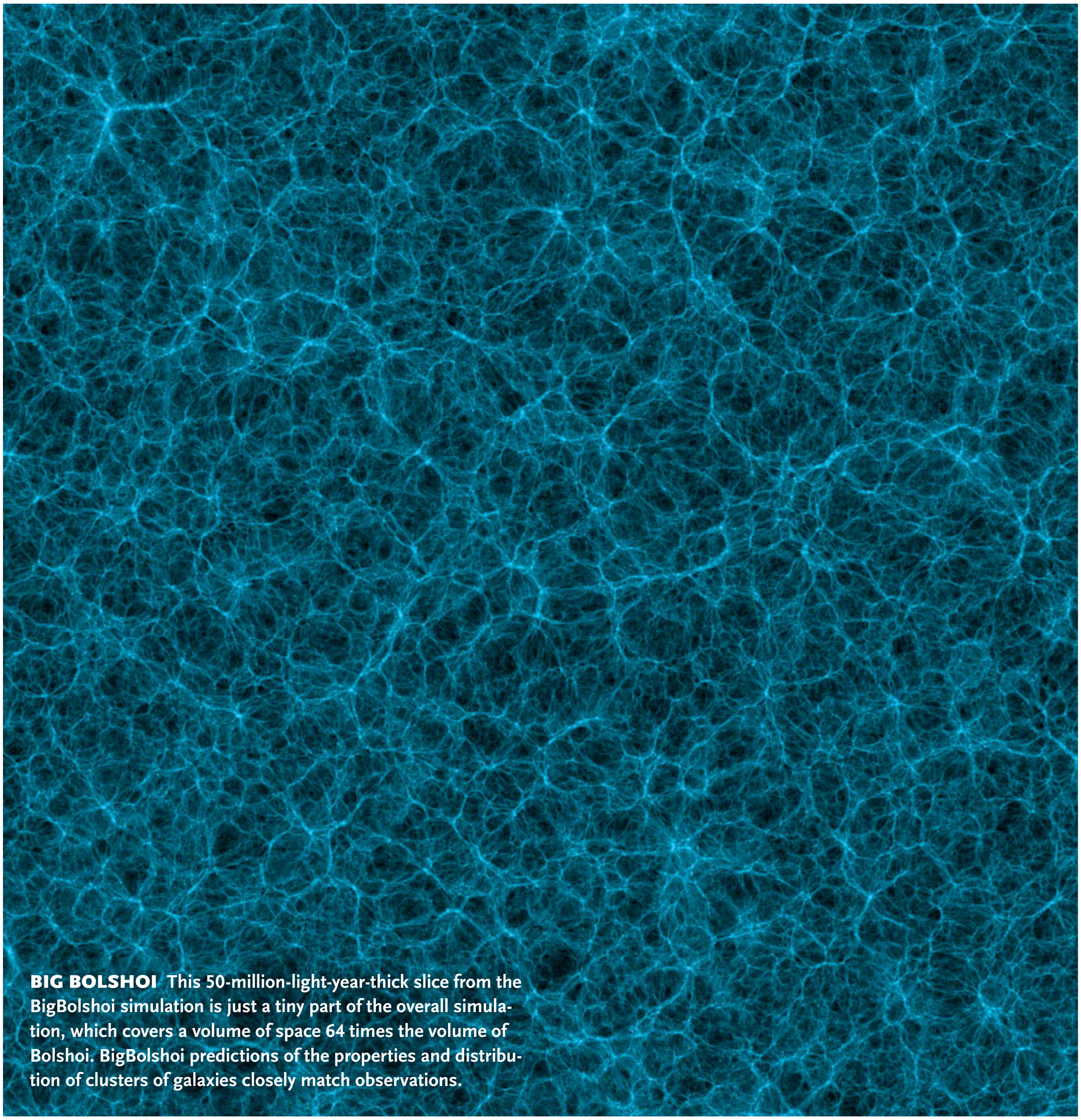
It's also possible that the dark matter particle will be discovered indirectly. For example, in galaxy dark matter halos, WIMPs can annihilate with one another, producing high-energy gamma rays among other things (*S&T*: April 2009, page 22). NASA's Fermi Gamma-ray Space Telescope is looking for such gamma rays. WIMPs can perhaps be made in energetic proton collisions at the Large Hadron Collider in Switzerland, where they would escape the detectors without interacting — but the missing energy and momentum would show that they had been created. This has not yet been seen. But even if such evidence starts appearing as the LHC particle-collision energy is increased, that would not prove that such particles are the dark matter unless we discover through direct or indirect detection that dark matter particles have the same mass.

The race is on to discover what the universe is mostly made of. Whoever discovers the nature of dark matter will surely win the Nobel Prize. — *Joel R. Primack*



XENON COLLABORATION (2)

THE SEARCH XENON, an international collaboration led by Columbia University physicist Elena Aprile (above), is one of several teams trying to detect dark matter directly in underground experiments. The team's detector is in the left photo.



BIG BOLSHOI This 50-million-light-year-thick slice from the BigBolshoi simulation is just a tiny part of the overall simulation, which covers a volume of space 64 times the volume of Bolshoi. BigBolshoi predictions of the properties and distribution of clusters of galaxies closely match observations.

STEFAN GOTTLÖBER/ LEIBNIZ-INSTITUT FÜR ASTROPHYSIK POTSDAM

Supercomputers are essential tools in the scientific process. Cosmologists can't literally drag a big chunk of the universe into a lab and run tests on it, so they need to use computers to perform their experiments. By re-creating how the universe evolved from a time shortly after the Big Bang, and visualizing each snapshot in detail, supercomputer modeling is allowing astronomers to explore how subtle changes in initial conditions and hypothesized physics affect subsequent cosmic evolution, and to make predictions they can test with future observations of the real universe. In essence, through cosmological simulations, astronomy is becoming an experimental science. ✦

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S&T *contributing editor* ***Trudy E. Bell (www.trudyebell.com)*** *is Senior Writer for UC-HiPACC. She is the author of 19 bylined feature articles that have captured top journalism awards, including the 2006 David N. Schramm Award of the American Astronomical Society. She has written a dozen books.*

The Quest for

DEAN REGAS Travelers cross the globe in search of the moment when the Moon devours the Sun.

This was it: August 1, 2008, eclipse day. Skies were partly cloudy over the vast Chinese desert — the worst possible scenario for those without immense reserves of inner calm. Scott and Michelle Gainey had crossed the Pacific Ocean and the Gobi Desert, arriving at a remote western province called the Xinjiang Uygur Autonomous Region to witness a total solar eclipse, the most spectacular astronomical phenomenon — if the clouds would only go away.

Avid travelers, the Gaineys had always wanted to visit China, and the occurrence of a total solar eclipse provided a perfect excuse. Though not astronomers by profession, the couple first bonded over their mutual passion for the subject as members of the Cincinnati Astronomical Society, and even exchanged vows under the dome of the Cincinnati Observatory.

The eclipse tour brought them to amazing sites, such as the Old City of Shanghai, Taoist and Confucian temples, and the Mogao Caves. They were even granted special access to the archaeological dig of the Terra Cotta Warriors; while other tourists remained on the viewing platforms, their group walked among the excavated model soldiers. "At the time," Scott says, "this was perhaps more important to me than the eclipse."

As they traveled, Scott broke the language barrier to distribute safe solar-viewing glasses to people in the local community. Through his improvised astronomy outreach, Scott and the tour group distributed 100 filters, starting him on a trend of utilizing eclipses as the ultimate teachable moment.

Eclipse day was chaotic. The narrow path of totality crossed a desolate plateau near the Mongolian border. Cars, trucks, and buses full of eclipse chasers from around the globe appeared like mirages out of the desert. Various groups, apprehensive about the cloud cover, scurried across the plateau in pursuit of better conditions. Amid the commotion, the Gaineys sat patiently on Persian rugs under a canvas tent, watching the comings and goings of their concerned cohorts.

As totality approached, the Gaineys could feel the crowd's anticipation building. "High anxiety," Michelle called it. But then the clouds parted and there it was: a perfect black hole in the sky. The disk of the Moon blotted out the Sun and the eerie glow of the corona contrasted stunningly with the surrounding clouds. "I was planning to look for all of the effects, the shadow bands and prominences," Michelle recalls. "But all of that flew out of my mind and I was just lost in it. Gaga, really."

SCOTT & MICHELLE GAINEY

A TEACHABLE MOMENT The 2008 total solar eclipse provided the perfect opportunity to reach out to the local public in China. Scott Gainey and the tour group broke the language barrier to distribute 100 safe solar-viewing glasses.

FROM TOP LEFT, CLOCKWISE: ANTARCTICA SUNSET: LUIGI BORSCHIN; PATAGONIA ECLIPSE: DAVID MAKEPEACE; TERRA COTTA WARRIORS: SCOTT & MICHELLE GAINEY; SUN ILLUSTRATION: © BIGSTOCK.COM; ANTARCTICA PHOTOGRAPHERS: BABAK TAFRESHI; CHINESE PERFORMERS: SCOTT & MICHELLE GAINEY; SOLAR VIEWER: D. MAKEPEACE; PATAGONIA ECLIPSE: D. MAKEPEACE

Totality

SCOTT & MICHELLE GAINEY (2)

PERFECT BLACK HOLE The clouds parted just in time for Scott and Michelle Gainey to watch the Moon swallow the Sun over the Gobi Desert. Howling erupted around them as thousands of onlookers shared in the same brief reverie. *Inset:* The Gaineys enjoyed dinner at a traditional Chinese theater, one of many cultural experiences they shared on their way to the eclipse site.

A great howling erupted from the thousands of onlookers as the Moon's disk covered the Sun. People were dancing, singing, shouting, crying. To the Gaineys, the years of planning and the long journey across the globe all led up to this brief moment of exhilaration shared with total strangers. Scott took a moment to tell himself, "This is really happening."

And then it was over — too soon, always too soon. A couple nearby, veteran eclipse chasers, had brought their own music to play, and they danced and twirled around long after the Sun re-emerged. Everyone was so happy to have seen the eclipse. And just like that, the Gaineys were hooked. "As soon as it was over," says Michelle, "we knew that this was for us. We're going to do this again."

Starting the Chase

The Gaineys are now members of a group of people who make it their purpose in life to see eclipses. They set aside money for astronomy-themed travel and plan vacations around astronomical events. They travel to the far corners of the globe for a glimpse of the greatest show from Earth. They are called eclipse chasers.

Eclipse chasers come from a wide variety of backgrounds. In 1995, 17-year-old Babak Tafreshi made an arduous 1,500-kilometer (930-mile) overland journey from his home in Tehran, Iran to the Afghanistan border to experience a mere 14 seconds of totality. Though tantalizingly brief, this eclipse, and the journey to witness it, hooked him. "From that moment, there was something about this phenomenon that attracted me," says Tafreshi. He wrote about his experience for *Nojum*, an Iranian astronomy magazine.

Babak Tafreshi

Four years later, another total solar eclipse came to Iran. "Although Iran is a large country, it was such a rare occurrence to have two eclipses so close together," Tafreshi says. After successfully viewing his second total solar eclipse, he began to document the experiences of his new hobby by collaborating on a decade-long video project.

"It's such a unique form of travel," Tafreshi says. "And each eclipse reveals its own insights." Since being bitten by the eclipse bug, Tafreshi became an editor at *Nojum* (1997–2007), an *S&T* contributing photographer, a board member of Astronomers Without Borders, and a 2009 co-recipient (with Carolyn Porco of NASA's Cassini mission) of the Lennart Nilsson Award for scientific photography. He also founded The World at Night (**www.twanight.org**), an international organization that helps create and exhibit photographs and videos of the night sky.

Meanwhile, Tafreshi's travels continued. On June 21, 2001, Tafreshi traveled to the unspoiled wilderness in central Zambia. Together with the seasoned German adventurer Gernot Meiser, he trekked an hour away from the nearest village to witness what he calls "one of the best eclipses I have seen."

"I really felt how nature reacts to this powerful natural phenomenon — birds flying to nests, a sudden bizarre silence, and insects jumping out to celebrate the brief night," Tafreshi recalls.

Afterward, Tafreshi and Meiser hiked in Kafue National Park in Zambia, enjoying the wilderness and the dark skies before returning home. Before sunrise one morning, Tafreshi was setting up a shot of the Magellanic Clouds. "I found a big, photogenic rock to place in the foreground," Tafreshi remembers. "I started to illuminate it with a flashlight to take the exposure when I noticed two bright dots reflecting on the rock. Then the whole rock started to move toward me."

The "rock" turned out to be a hippopotamus, the most dangerous large animal in Africa. With no time for thought, Tafreshi ran to the safety of camp, the still-exposing camera in hand.

On the Icy Bottom of the World

In 2003 Tafreshi's travels took him to the opposite extreme when he voyaged to Antarctica aboard a Russian icebreaker. The first eclipse to be viewed from the most forbidding continent, the expedition was as expensive as it was rare: more than $25,000 per person. Fortunately, Tafreshi found a sponsor, fellow Iranian eclipse-chaser Hamid Khodashenas. Tafreshi's job was to document the entire journey through one of the least traveled locations on Earth, as well as to manage the photo shoot during the brief moments of totality.

Sailing from Port Elizabeth, South Africa, the passengers were an international community — 100 people from 15 countries. The ship traversed the ice over many months, making several stops at Antarctic islands rarely visited by humans. Tafreshi discovered that the difficult journey to reach the narrow eclipse centerline in such an isolated and exotic location naturally united diverse groups of people.

This was no pleasure cruise but a working expedition in cold, harsh conditions. Several passengers suffered major injuries during severe storms before the ship reached the calm Antarctic waters. Ice cracks, hidden by snow, posed another danger once the passengers ventured out from the ship. Helicopters were available to ferry injured passengers back to the ship for urgent care, but sending anyone back to civilization was not an option — the next transport to the area would arrive six months later.

On eclipse day, November 23rd, the captain rammed the vessel into a thick shelf of ice. When the crew deemed the landing spot safe, the chasers bounded down, wearing their warmest parkas and mingling with the penguins. Icebergs stood above a stark, white landscape, and a colorful horizon ringed their temporary beachhead. Despite some clouds, the eclipse experience was spectacular.

"I can safely say that the penguins had absolutely no reaction to the eclipse," Tafreshi notes. The humans felt otherwise. They were standing on the icy bottom of the world, slowly drifting with the entire Southern Ocean below them. "It was like walking on a different planet."

The Eclipse that Demanded to be Seen

David Makepeace is a video producer and director in Toronto, Ontario, whose many eclipse chases have earned him the nickname "The Eclipse Guy." He witnessed his most recent total eclipse on July 11, 2010 from a remote outcrop on the Patagonian steppe. But that was Plan C.

Plan A was to sail on a clipper ship from Tahiti into the path of totality. When the cruise line canceled the trip with only months to spare, Makepeace scrambled to book Plan B. That involved flying to El Calafate, a small mountain town in southern Argentina, in order to catch a charter plane that would fly along the Moon's umbral shadow.

On the way, Makepeace added a stopover in Peru to hike the Inca Trail and experience Machu Picchu. Drawn

HAMID KHODASHENAS

THE KAPITAN KHLEBNIKOV Babak Tafreshi stands in front of the Russian icebreaker that ferried an international group of 100 eclipse chasers from the southern tip of Africa to Antarctica.

HAMID KHODASHENAS

PENGUIN PARTY **Tafreshi and the other eclipse chasers walked freely in Antarctica among the emperor penguins, who paid them (and the eclipse) no mind.**

to Peru's mystical allure, Makepeace wanted to hike the same path the ancient Incas took to reach their city in the mountains. He relished the challenge of the four-day trek. Despite his fear of a deadly fall, the experience of walking a path cut into massive cliff faces through the heart of the Peruvian jungle was exhilarating. "Don't look down," Makepeace recommends.

The final day of the hike was grueling, mentally and physically. His group passed a shrine of piled stones where people had left offerings, including pieces of chocolate. When Makepeace asked about the shrine, his guide made up a story, saying it was a spot sacred to the Incas. Makepeace later learned the truth — it was a marker erected at the spot where a hiker had fallen to his death.

At last his group took the final steps of the Inca Trail, came over a ridge, and beheld the city. Exhausted and awestruck, Makepeace stepped through the Sun Gate into what seemed like a vision arising out of the mists. The ancient ruins of Machu Picchu lay before him framed by verdant peaks and steep drop-offs. "This was not meant to be an easy stroll," says Makepeace. "You are meant to be changed by this arduous journey. Along the way I came to understand the Incan reverence for the Sun."

DAVID MAKEPEACE

MACHU PICCHU **David Makepeace stands near the Sun Gate entrance after an arduous trek to the ancient Incan ruins.**

His transcendent Peruvian adventure came to a sudden halt after he descended from Machu Picchu. At the town below the ruins, Aguas Calientes, Makepeace went to an internet café and received what he calls "the worst e-mail of my life." There would be no charter plane in El Calafate. Flight canceled, no explanation, no viewing of the eclipse that was only two days away.

Cursing his luck (and the tour company), Makepeace decided to continue the journey and see what might lie in El Calafate. He flew to southern Argentina in the dead of winter. Conditions were dark, snowy, cold, and windy, with no apparent prospects of seeing the eclipse. "What the hell am I doing here?" he asked himself.

He commiserated with other stranded eclipse chasers, and together they hatched a plan. The eclipse would not be visible from town, which lay in the easternmost extent of the path of totality. The Sun would set behind the Andes Mountains before totality occurred. But a group emerged with an impromptu plan: take four-wheel-drive buses up the slopes to gain elevation, and perhaps see the final glimpses of totality. The Sun would be extremely low in the sky, at a location that had been cloudy the previous two weeks. Statistically, this was the worst place along the path of totality to see the eclipse.

"There was no other choice," says Makepeace. "At that point I would have paid the last dime I had to see this thing." This was Plan C.

Two buses equipped with tire chains picked up the chasers at a local hotel. Each bus carried 20 to 25 people up a crude, snowy path to the desolate mountaintop, where the facilities resembled a lonely military outpost. A large, canvas tent protected the chasers from the wind, and a satellite TV played the World Cup final. Snow was blowing in a howling gale around them, and the air was bitter cold. But the sky was crystal clear. “The conditions were absolutely ideal,” Makepeace recalls. “I couldn’t believe it — we were actually going to see it!”

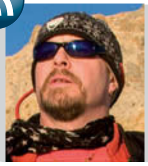
Makepeace observed the rapid approach and retreat of the Moon’s shadow across the distant hills and valleys. With the Sun only a few degrees above the horizon at totality, the corona and the entire sky were bathed in an ethereal golden hue for 2½ minutes.

“Through all of the hardships and stress, I almost believe that this eclipse demanded to be seen,” says Makepeace. An eclipse chaser often negotiates with the universe, never knowing with certainty what will happen on eclipse day or on the winding road there. Even with the best-laid plans, it comes down to living in the moment.

TO THE ANDES Four-wheel-drive trucks took an impromptu tour group up a crude mountain path for a chance to view the eclipse above the Andes Mountains.

DAVID MAKEPEACE (2)

Watch a BONUS VIDEO



To see David Makepeace’s footage of the Antarctic and Patagonian eclipses, visit skypub.com/eclipsechasers.

What’s Coming Up

For those looking ahead, the date August 21, 2017 stands out. This is the next total solar eclipse visible in the United States. But why wait? This year, there will be a total solar eclipse visible in Australia and the South Pacific on November 13th (April issue, page 68). The moon’s umbra will fall along the northeastern tip of Australia, crossing the Gulf of Carpentaria, so this is a perfect chance for a South Pacific cruise or a trip to the Land Down Under.

Experienced eclipse chasers have seen it all. They’ve traveled to every continent to marvel at totality, and they’ve also met agonizing defeat at the hands of capricious clouds. They’ll tell you all about it. In fact, swapping eclipse stories is their favorite pastime. Their descriptions of awe-inspiring successes and painful missed opportunities reveal the real story — witnessing the Moon’s struggle to block out the Sun may be exhilarating, but getting there is half the fun. Chasing eclipses is more than a job, or even a deep-rooted passion: it’s a way of life. ✦

***Dean Regas** is the Outreach Astronomer for the Cincinnati Observatory in Cincinnati, Ohio, and cohost of the television program* Star Gazers. *He can be reached at **dean@cincinnatiobservatory.org**.*

TOTALITY Shouts of joy rang out in the crystal-cold air as David Makepeace viewed the eclipse just moments before sunset.

CANON USA

▲ **CANON'S RETURN** Canon has announced the successor to its long-discontinued 20Da, a DSLR optimized specifically for astrophotography. The new Canon EOS 60Da ($1,499) features an 18-megapixel APS-C detector with roughly 4-micron-square pixels and an improved infrared-blocking filter that transmits up to three times more hydrogen-alpha light than other Canon DSLR cameras. This modification enables users to record the reddish hydrogen-alpha nebulosity prevalent in the night sky. The camera incorporates enhanced noise reduction and increased ISO speeds up to 6400, expandable to 12,800. Additional features include a 3-inch flip-out vari-angle LCD screen for easy viewing when attached to a telescope. The EOS 60Da's Live View mode is equipped with Canon's silent-shooting feature that eliminates shutter-induced vibration. Each purchase includes an AC adapter kit, rechargeable battery, and RA-E3 Remote Controller adapter.

Canon USA
Available through select dealers
www.usa.canon.com

▼ **QUICK-RELEASE BRACKET** FAR Laboratories has developed the Lyra Double Double Mounting System (LDDMS), a universal bracket designed to easily swap your finderscope or other small optics from one telescope to another. The LDDMS uses bungee cords with snap buckles to secure your small scope to the bracket, and another longer bungee to secure both to a larger telescope tube. The bracket includes holes to permanently mount the unit to your telescope, and is adjustable to fit most small telescopes. The mounted scope can then be precisely aligned by using the four alignment screws, and the LDDMS also includes two screw-in "eyes" for use as a peep-sight finder. The LDDMS is available in a variety of colors starting at $69.95. See the manufacturer's website for additional options.

FAR Laboratories
P.O. Box 25, South Hadley, MA 01075-0025
800-336-9054 www.dynapod.com


S&T: SEAN WALKER

CLASSIC SKY APP X04 Studios presents *Classic Sky Map* ($4.99), an intuitive planetarium app for the Apple iPod Touch, iPad, and iPhone. *Classic Sky Map* presents an interactive sky with thousands of the brightest stars, as well as the Sun, Moon, and planets. Clicking on a constellation makes a classical illustration of the chosen constellation appear. The app automatically creates star charts customized to your current location, and offers easy access to options such as live tracking, which matches the sky to the direction you hold your Apple device. You can also activate a night-vision mode or change the observation time and horizon skyline.

X04 Studios Inc.
www.x04studios.com
Available from the App Store

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.

In This Section

PHOTOGRAPH: ROBERT GENDLER

The Lagoon Nebula is amazingly complex and utterly magnificent.

OBSERVING

Sky At A Glance

7/1–7 **DAWN:** The Pleiades, Jupiter, Venus, and Aldebaran (top to bottom) form a nearly straight line low in the east an hour before sunrise; see page 48.

4 **EVENING:** Earth is at aphelion, its farthest from the Sun for the year, around 11 p.m. EDT.

8–10 **DAWN:** Look for Aldebaran just 1° right or lower right of dazzling Venus.

14 **DAWN:** The waning crescent Moon is lower right of the Pleiades and upper right of Jupiter.

15 **DAWN:** The thin crescent Moon forms a tight, spectacular quadrangle with Venus, Jupiter, and Aldebaran in the Americas. The Moon occults (covers) Jupiter before sunrise in most of Europe and after sunrise in much of Asia; see page 51.

16: **DAWN:** The very thin Moon is 1° to 3° upper right of 3rd-magnitude Zeta Tauri low in the east an hour before sunrise in North America.

21 **PREDAWN OR DAWN:** Io's shadow falls on Jupiter's eastern limb at 3:51 a.m. MDT (4:51 CDT), just before Europa's shadow eaves Jupiter's western limb. Europa itself appears on Jupiter's face southwest of Io's shadow.

24 **EVENING:** The waxing crescent Moon forms a quadrangle with Saturn, Spica, and Mars.

28 **DAWN:** Io and Europa both cast their shadows on Jupiter from 4:45 to 5:33 a.m. PDT.

Planet Visibility

	◀SUNSET	MIDNIGHT	SUNRISE▶
Mercury	W	Visible June 4 through July 7	
Venus			NE E
Mars	SW W		
Jupiter			NE E
Saturn	SW W		

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

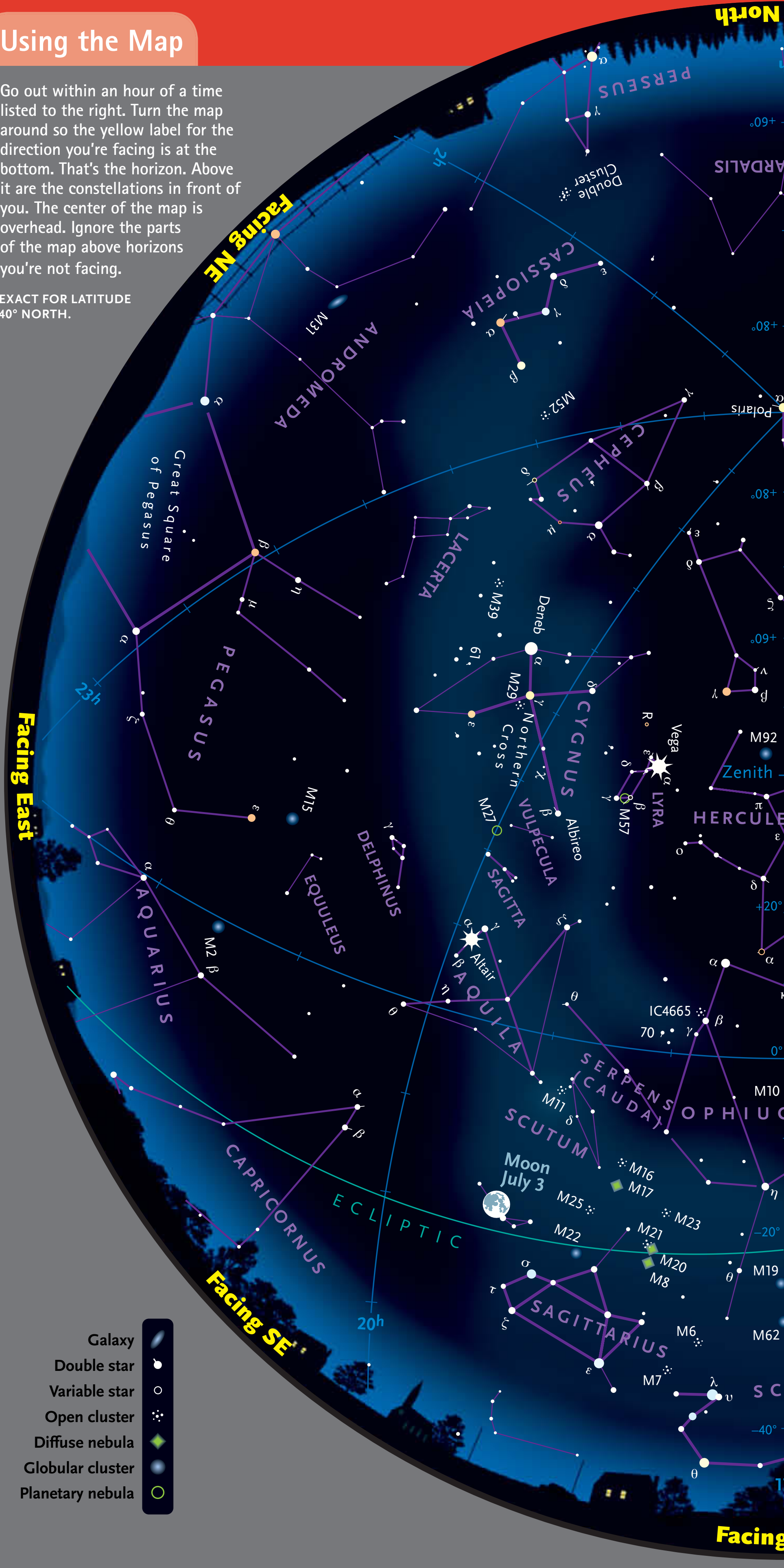
Moon Phases

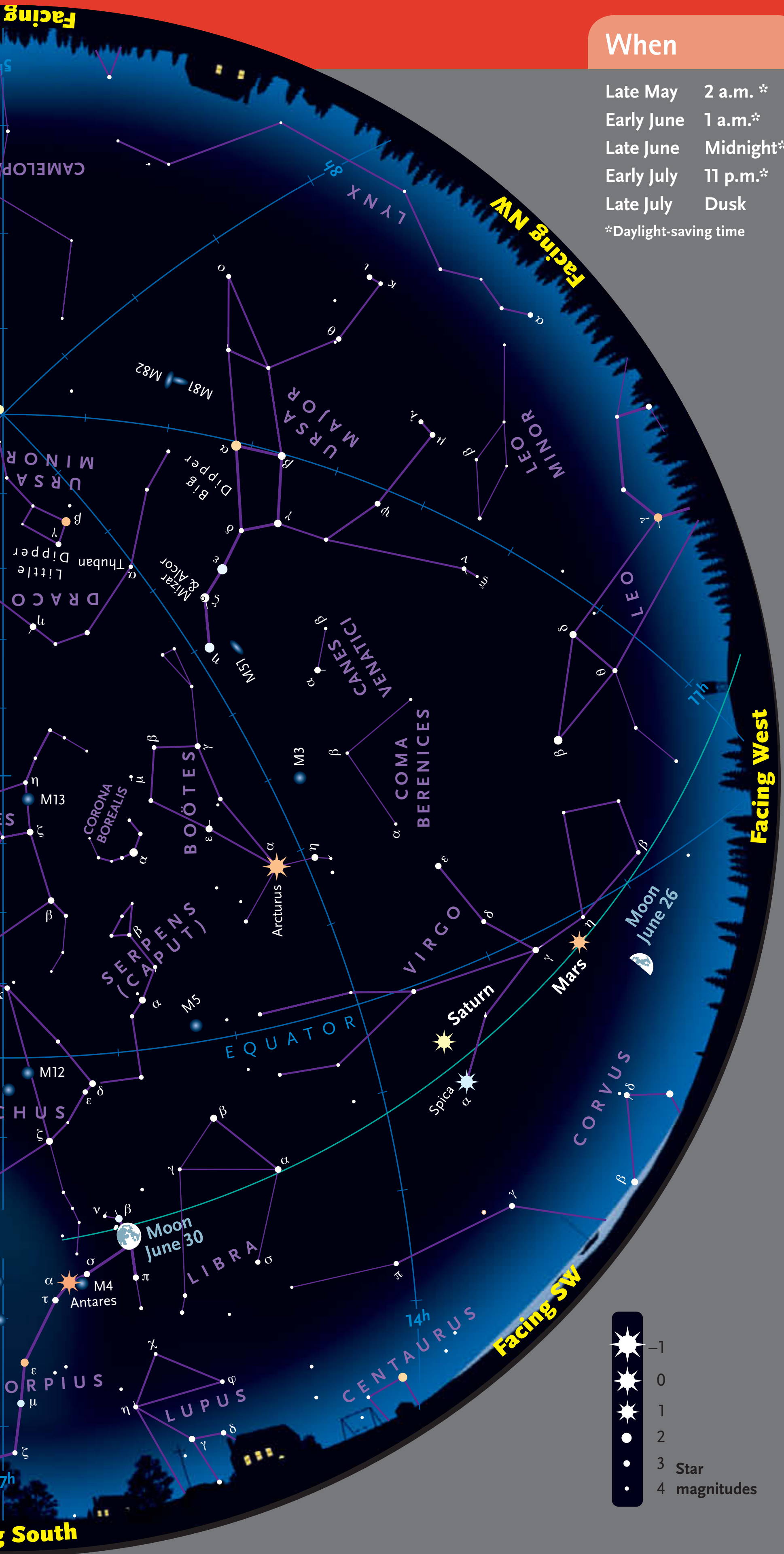
SUN	MON	TUE	WED	THU	FRI	SAT
1	2	3	4	5	6	7
8	9	10	11	12	13	14
15	16	17	18	19	20	21
22	23	24	25	26	27	28
29	30	31				

Using the Map

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

EXACT FOR LATITUDE 40° NORTH.





When

Late May	2 a.m.*
Early June	1 a.m.*
Late June	Midnight*
Early July	11 p.m.*
Late July	Dusk

*Daylight-saving time

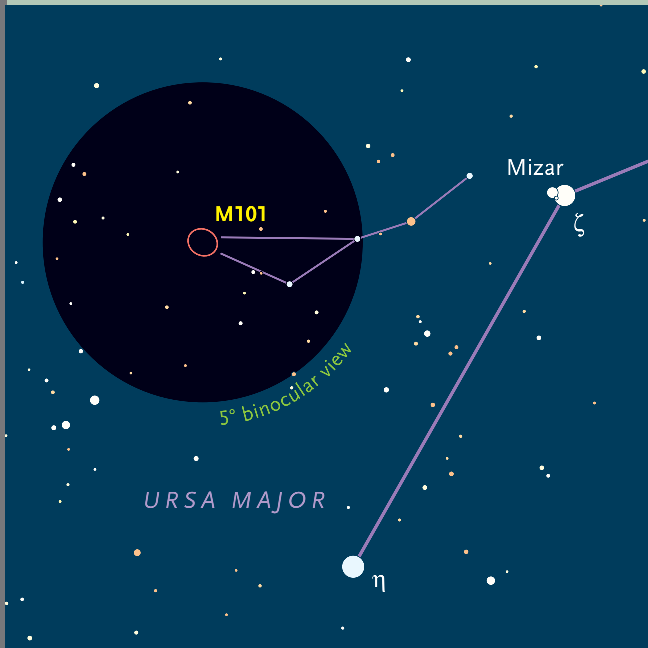
Binocular Highlight

M101: A Bear of a Galaxy

In the December 2011 issue of this magazine (page 38), I described five factors that determine whether a given object will be visible in binoculars. The most important of these is the target's brightness, but #2 on the list is how dark your skies are. This consideration is crucial when it comes to successfully sighting the face-on galaxy **M101** in Ursa Major, the Great Bear.

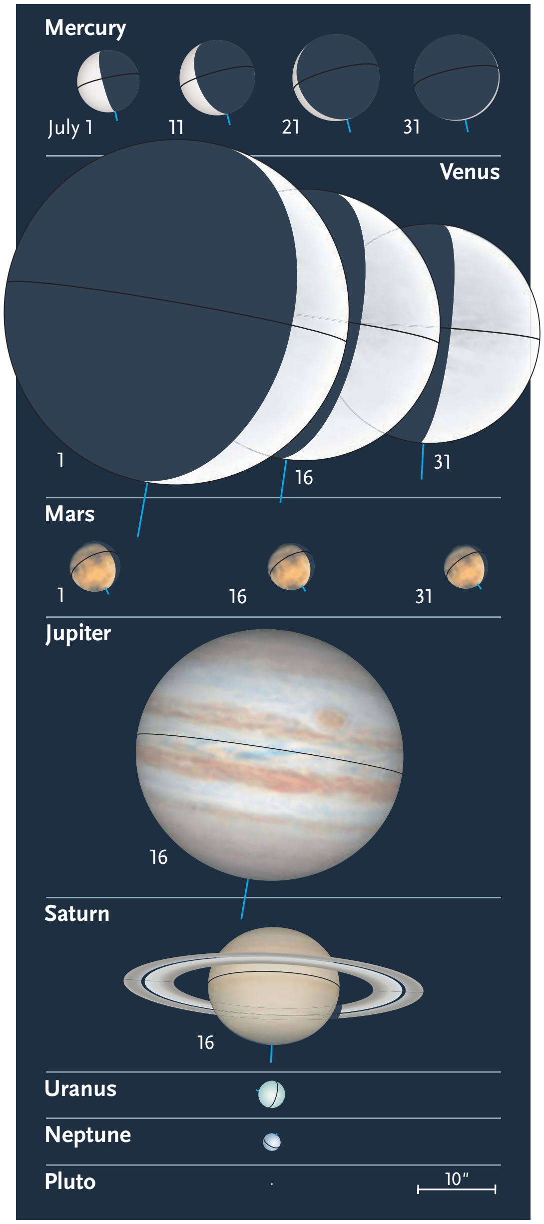
M101 is listed at magnitude 7.5, but because its glow is spread over a fairly large area, it readily blends into a light-polluted sky. Fortunately, locating the galaxy's field is reasonably straightforward. Start with well-known double star Mizar (Zeta Ursae Majoris), the middle star in the Big Dipper's handle. From there, follow a string of four 5th- and 6th-magnitude stars that extends eastward from Mizar. When you get to star #4, turn northeast — M101 completes an isosceles triangle with stars #3 and #4. Do you see it?

I went hunting for the galaxy early one March evening when it was still quite low, emerging from the light dome cast by a nearby town. In my 15×45 image-stabilized binoculars I could perceive M101 as a fairly large, round, evenly lit glow. But when I used my 10×30s, I had no luck. Later that same night, I tried again when the galaxy was overhead and in a darker part of the sky. In my 10×30s, M101 was a challenge, but it was visible about half the time, popping in and out of view. I have observed M101 from pristine skies, and under those conditions, those same 10×30s reveal it with little difficulty. With this galaxy, sky conditions make all the difference. ✦ — ***Gary Seronik***



Watch a SPECIAL VIDEO

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

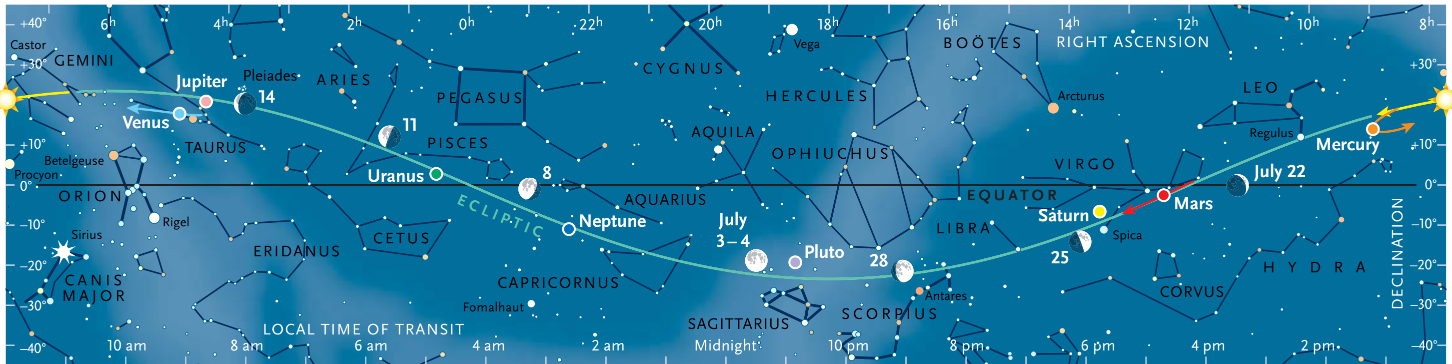


Sun and Planets, July 2012

	July	Right Ascension	Declination	Elongation	Magnitude	Diameter	Illumination	Distance
Sun	1	$6^h\ 40.9^m$	+23° 06′	—	–26.8	31′ 28″	—	1.017
	31	$8^h\ 41.8^m$	+18° 16′	—	–26.8	31′ 31″	—	1.015
Mercury	1	$8^h\ 30.1^m$	+19° 08′	26° Ev	+0.4	8.1″	41%	0.832
	11	$8^h\ 54.3^m$	+15° 17′	23° Ev	+1.2	9.8″	23%	0.688
	21	$8^h\ 48.9^m$	+13° 19′	13° Ev	+3.2	11.3″	7%	0.597
	31	$8^h\ 22.3^m$	+14° 27′	6° Mo	+5.0	11.1″	2%	0.604
Venus	1	$4^h\ 25.8^m$	+17° 30′	32° Mo	–4.6	44.7″	16%	0.373
	11	$4^h\ 38.1^m$	+17° 28′	39° Mo	–4.7	38.1″	26%	0.438
	21	$5^h\ 01.2^m$	+18° 10′	43° Mo	–4.7	32.6″	34%	0.511
	31	$5^h\ 32.0^m$	+19° 05′	45° Mo	–4.6	28.4″	41%	0.587
Mars	1	$11^h\ 55.2^m$	+0° 59′	79° Ev	+0.9	6.6″	89%	1.417
	16	$12^h\ 24.4^m$	–2° 29′	73° Ev	+1.0	6.1″	89%	1.523
	31	$12^h\ 56.0^m$	–6° 05′	67° Ev	+1.1	5.8″	90%	1.621
Jupiter	1	$4^h\ 09.0^m$	+20° 12′	35° Mo	–2.0	34.0″	100%	5.806
	31	$4^h\ 33.6^m$	+21° 10′	58° Mo	–2.2	36.0″	99%	5.480
Saturn	1	$13^h\ 27.5^m$	–6° 26′	103° Ev	+0.7	17.6″	100%	9.461
	31	$13^h\ 31.0^m$	–6° 55′	76° Ev	+0.8	16.7″	100%	9.954
Uranus	16	$0^h\ 31.9^m$	+2° 39′	105° Mo	+5.8	3.6″	100%	19.774
Neptune	16	$22^h\ 18.9^m$	–11° 08′	141° Mo	+7.8	2.3″	100%	29.198
Pluto	16	$18^h\ 32.5^m$	–19° 24′	164° Ev	+14.0	0.1″	100%	31.288

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

Fred Schaaf has authored 13 books on astronomy. Fred Schaaf

An Abundance of Riches

Summer evenings offer an amazing variety of sights.

July and August are the heart of summer. The mention of summer may make us think not only of heat but long days and short nights. We need to remember, however, that days are getting shorter from June's summer solstice onward, and the rate of shortening increases rapidly from late July through August.

As a result, earlier nightfalls partly offset the seasonal progression of the constellations. In other words, if we go out a few hours after sunset in August we'll find the constellations advanced only slightly from their July positions because darkness falls earlier and we catch sight of the stars earlier. That's reflected in this magazine's all-sky maps, which look surprisingly similar for July, August, and even September.

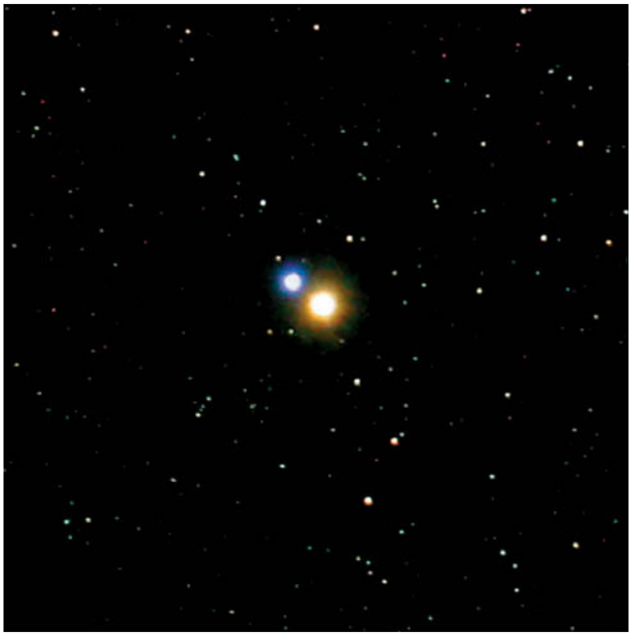
Might we get bored with this scene? Fortunately, no other evening sky offers prime views of so many different types of celestial objects. Let's call this the Summer After-Dusk Sky. And let us, in this column and next month's, explore it by class of object.

Asterisms and bright stars. These days, the most prominent and popular large asterisms other than the Big Dipper may be the Summer Triangle (Vega, Altair, and Deneb) and the Teapot of Sagittarius. I say "these days" because both of these asterisms seem to have been invented, or at least popularized, in the last 50 years. They're both nearing the meridian, where they'll be highest, in the Summer After-Dusk Sky.

Vega, Altair, and Deneb are all 1st magnitude or brighter. Summer evenings certainly can't rival winter's skies for number of very bright stars. Still, these three are joined by Spica, Antares, and extra-brilliant Arcturus. And this summer 1st-magnitude Saturn and Mars accompany Spica. Winter's Rigel and Betelgeuse are famous for their contrasting colors. But Vega has a distinct bit of blue to many observers, Antares is decidedly orange-yellow, and Arcturus has a unique champagne or ginger-ale hue.

Red stars — and green? If we seek with optical aid stars that are more intensely or interestingly colored, the Summer After-Dusk Sky may have more of the best ones than any other.

Moderately high in the northeast now is Mu Cephei, which might be the most popular very red star of all. Modest telescopic aid shows the color well (it varies with the star's varying brightness) and proves that Mu deserves its famous title: Herschel's Garnet Star.



JOHANNES SCHEDLER

Albireo is the classic color-contrast double star.

In addition, the two stars with the most famous — though controversial — claims to greenness are almost their highest on July evenings. With a very low-power telescope (or even binoculars) can you detect a supposed pale green to Beta Librae (also known as Zubeneschamali)? Then there's what some people feel is the vivid green of Antares' companion. This star can be seen in medium-size telescopes but is typically lost in the mighty primary's big fire unless the atmosphere is quite steady. The companion's color has been attributed to its contrast with the nearly ruddy Antares. But some observers have noted it as green on those rare, brief occasions when it emerges from behind the Moon about five seconds before Antares does.

Color-contrast heaven. Of course, there are breathtaking color-contrast doubles for small telescopes at all times of year. But is any time and sky as rich in them as this Summer After-Dusk Sky? You could begin with Albireo (Beta Cygni) and Rasalgethi (Alpha Herculis), two of the color-contrast pairs that are very high in this sky.

More to come. Next month we'll explore other kinds of double stars — plus the star clusters, nebulae, and even galaxies available in the Summer After-Dusk Sky. ✦

Planet Pairings Morning & Eve

Venus meets Jupiter at dawn, and Mars approaches Saturn at dusk.

This July, dusk and dawn each present us with a pair of beautiful planets near a 1st-magnitude star. At nightfall the planets are Mars and Saturn, with Spica near Saturn. At daybreak the worlds are Venus and Jupiter, accompanied by Aldebaran — with the Hyades and Pleiades gloriously nearby.

DUSK

Mercury begins July shining in twilight at magnitude +0.5, about 8° high in the west-northwest 45 minutes after sunset (as viewed from 40° north latitude). This is only a day after Mercury reached its greatest elongation of 26° from the Sun, but Mercury was at its highest for mid-northern observers a week before that — and brighter too. Mercury fades and loses altitude rapidly during the first week of July, and it reaches inferior conjunction with the Sun on July 28th.

EVENING

Mars and **Saturn** are roughly a third of the way up the southwestern sky as twilight fades in early July. Mars dims a little from magnitude +0.9 to +1.1 during the month, and Saturn dims from +0.7 to +0.8, leaving it only slightly brighter than its near neighbor, 1.0-magnitude Spica.

Through the telescope Mars has dwindled to only 6″ wide, while Saturn's globe is 17″ wide. Saturn is at quadrature (90° east of the Sun) on July 15th, so this month we see Saturn being sunlit from a little to the side — making it appear especially three-dimensional in telescopes. The shadow of the globe on the rings is particularly noteworthy.

The most exciting thing about Mars and Saturn in July, however, is how the gap between them shrinks all the way from 24° at month's start to just 8° at month's end. Mars begins July in extreme western Virgo but treks almost halfway across this longest constellation of the zodiac during the month. Meanwhile, Saturn creeps to about 4½° from Spica. Mars will glide *between* Saturn and Spica for a wonderfully tight grouping in mid-August.

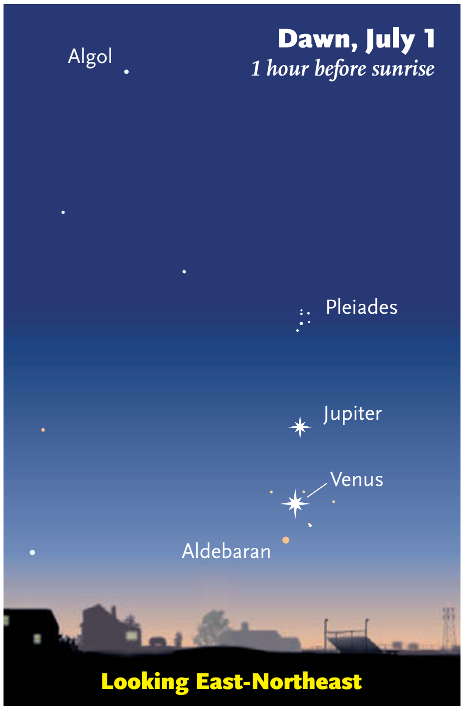
By the way, Mars crosses southward over the celestial equator on July 4th and southward over the ecliptic on July 24th.

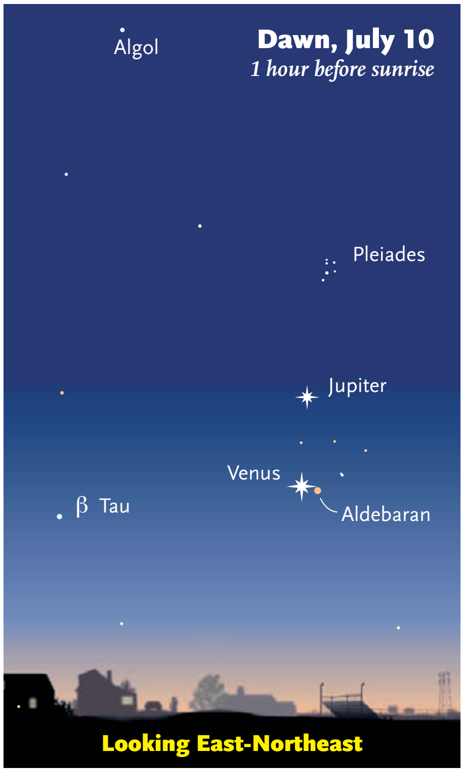
PREDAWN

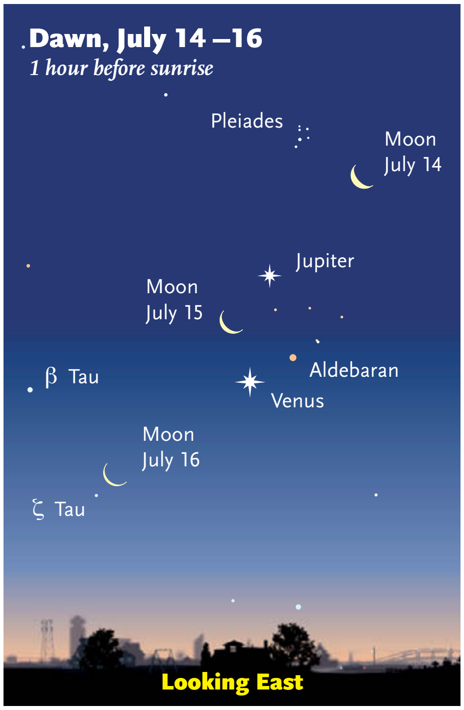
Uranus is in northwestern Cetus very close to Pisces, and **Neptune** is in Aquarius. Both are high enough for good telescopic viewing before the sky brightens; see **skypub.com/urnep** for finder charts.

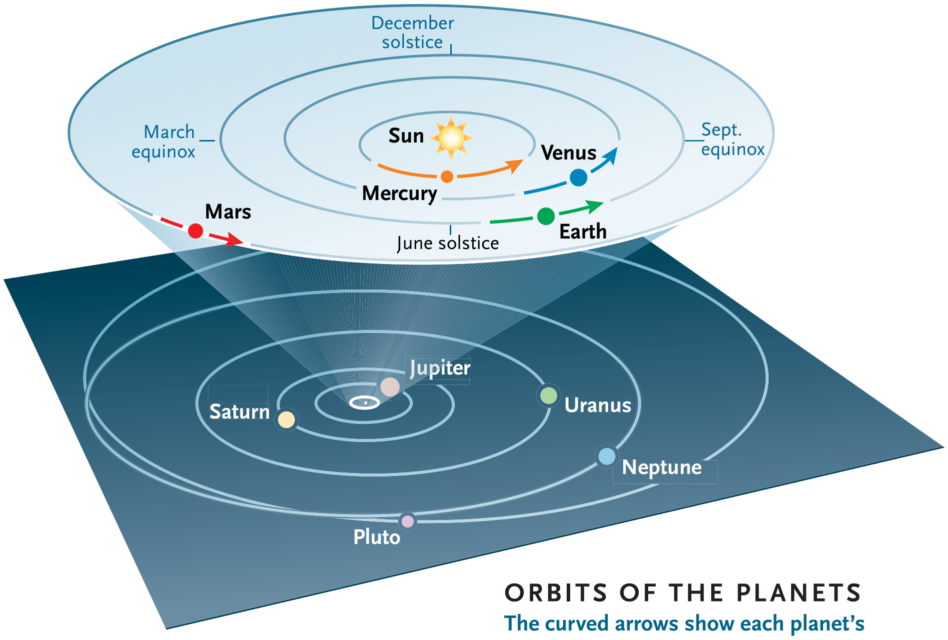
DAWN

Venus and **Jupiter** put on a show that should not be missed, even though it's









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

only visible before July's frightfully early sunrises.

Venus and Jupiter start July only 4.8° apart low in the east-northeast before daybreak. Venus is at its brightest during the first three weeks of July, blazing at a searing magnitude –4.7. Jupiter shines less than one-tenth as bright, around magnitude –2.1.

Venus is near the end of its retrograde loop, temporarily parked in the midst of the giant Hyades cluster. Jupiter is moving slowly eastward, drawing close enough to have this "quasi-conjunction" with Venus. (A quasi-conjunction is when two celestial objects come within 5° and then pull apart without ever passing each other.)

On July 1st, Venus is about 12° high and Jupiter about 16° high as seen at mid-dawn, 45 minutes before sunrise. By July 31st the two are much higher and farther apart, at altitudes of 27° and 40° in mid-twilight.

If you go out a little earlier in the dawn on July 1st, you'll see Venus and Jupiter as part of an amazing, nearly vertical, compact line of objects: Aldebaran at bottom, Venus 2½° above Aldebaran and in the midst of the Hyades, Jupiter 5° above Venus, and the Pleiades 6° above Jupiter.

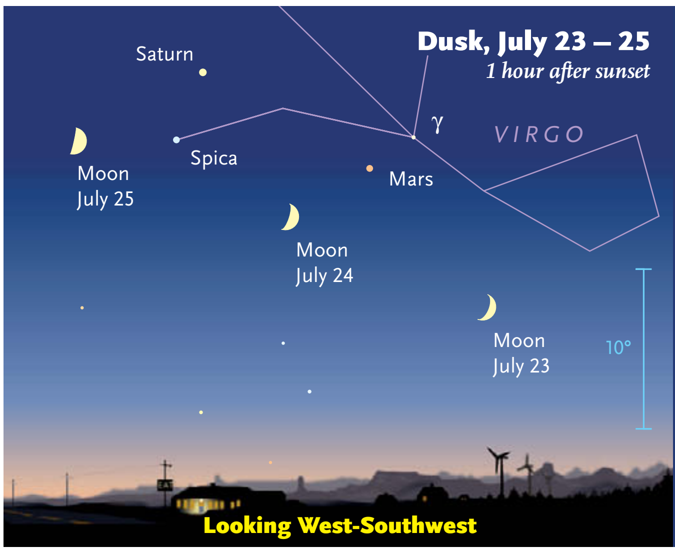
Venus is just 1° from Aldebaran from July 8th to 10th. But by the end of July, Venus has sped a full 14° away from Jupiter and the face of Taurus (the V formed by Aldebaran and the Hyades), and is nearing Zeta Tauri, the southern horn-tip of the Bull. By July 30th, Jupiter has crept to its closest approach to Aldebaran, 4.7° from the 1st-magnitude star.

In telescopes, Jupiter's fully lit disk grows from 34″ to 36″ wide in July, while Venus dwindles from 45″ to 28″ as its illuminated portion waxes from 16% to 41%.

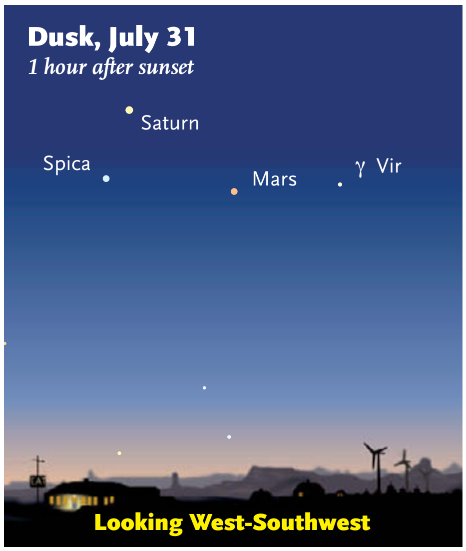
MOON AND EARTH

At dawn on July 14th the crescent **Moon** is right of the Pleiades and well upper right of Venus and Jupiter. The next day, many European observers see the Moon occult Jupiter. Then, at the American dawn of July 15th, the waning lunar crescent forms a dramatic compact triangle with Venus and Jupiter, and Aldebaran adds a fainter fourth corner. On July 24th and 25th, the waxing lunar crescent poses with Mars, Saturn and Spica.

Earth is at aphelion (farthest from the Sun in space) around 11 p.m. EDT on July 4th, when the centers of these bodies are 94,506,000 miles apart. ✦



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.



The Rise of R Draconis

Follow this Mira-type variable star brightening over the Little Dipper.

In the northern sky these evenings, Draco the Dragon arches high over the upward-floating Little Dipper. In the midst of this familiar scene, near a little flattened-W asterism that's easy to spot in binoculars or a finderscope, pulses a classic red variable star of the Mira type. It's currently rising toward maximum brightness.

R Draconis usually cycles from about magnitude 12.4 to 7.6, though in the last six years it has peaked as bright as 6.7 and as faint as 8.6. Its next maximum should come July 12th, predicts the American Association of Variable Star Observers (AAVSO). Its pulsation period averages close to 8 months, so expect it to keep peaking during the summers of even-numbered years for some time to come.

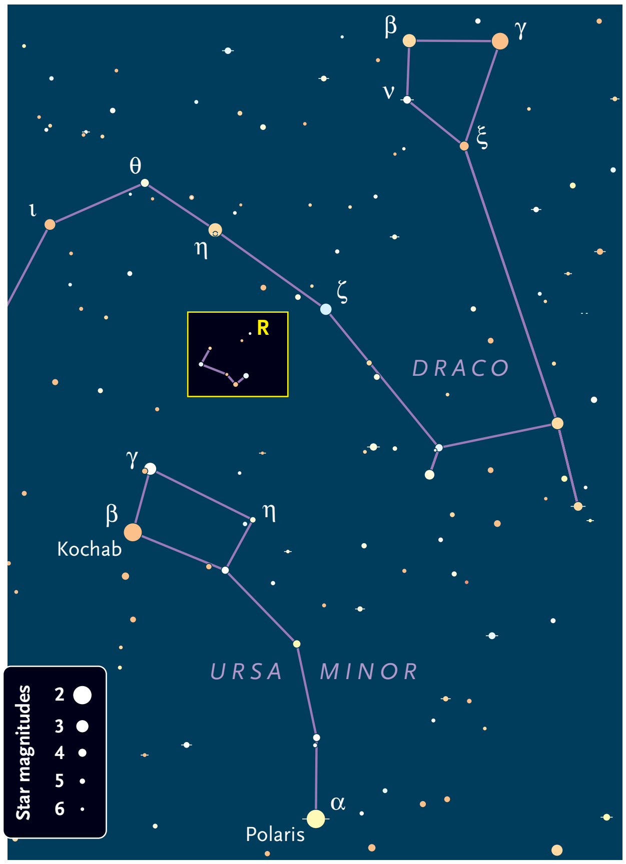
The charts below have south up, the way the scene currently appears in the northern sky with binoculars.

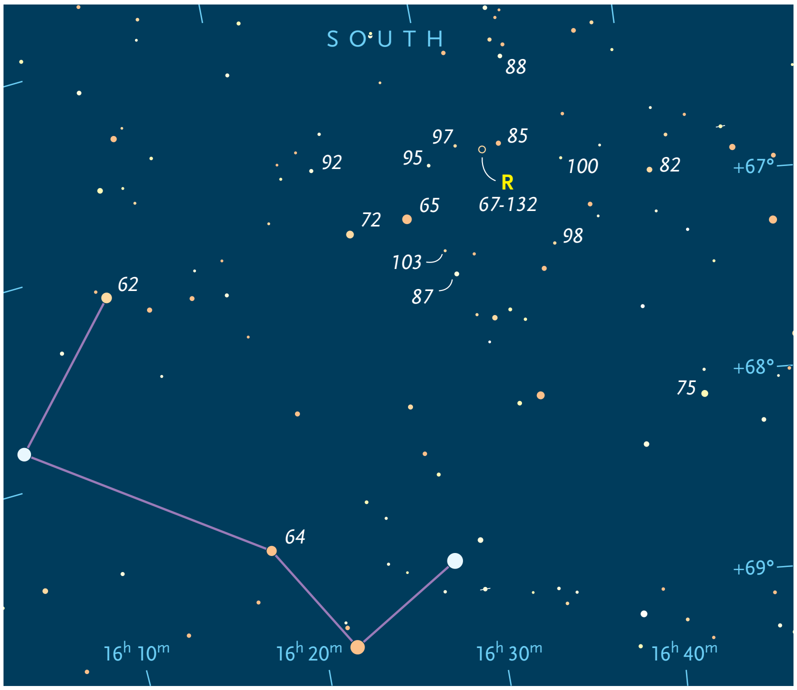
On the close-up chart, find two comparison stars that look just a little brighter and just a little fainter than the variable. At the eyepiece, judge where the variable lies between them in terms of brightness.

For instance, you might decide that R Draconis looks like its brightness is 3/5 of the way from the "85" star to the "92." The usual way to write this in your observing notebook is *85 3 V 2 92*, meaning the variable (V) is 3 arbitrary steps fainter than the magnitude-8.5 star and 2 of the same steps brighter than the 9.2. Later indoors you can do the arithmetic to arrive at magnitude 8.92 for your estimate. Round this off to 8.9.

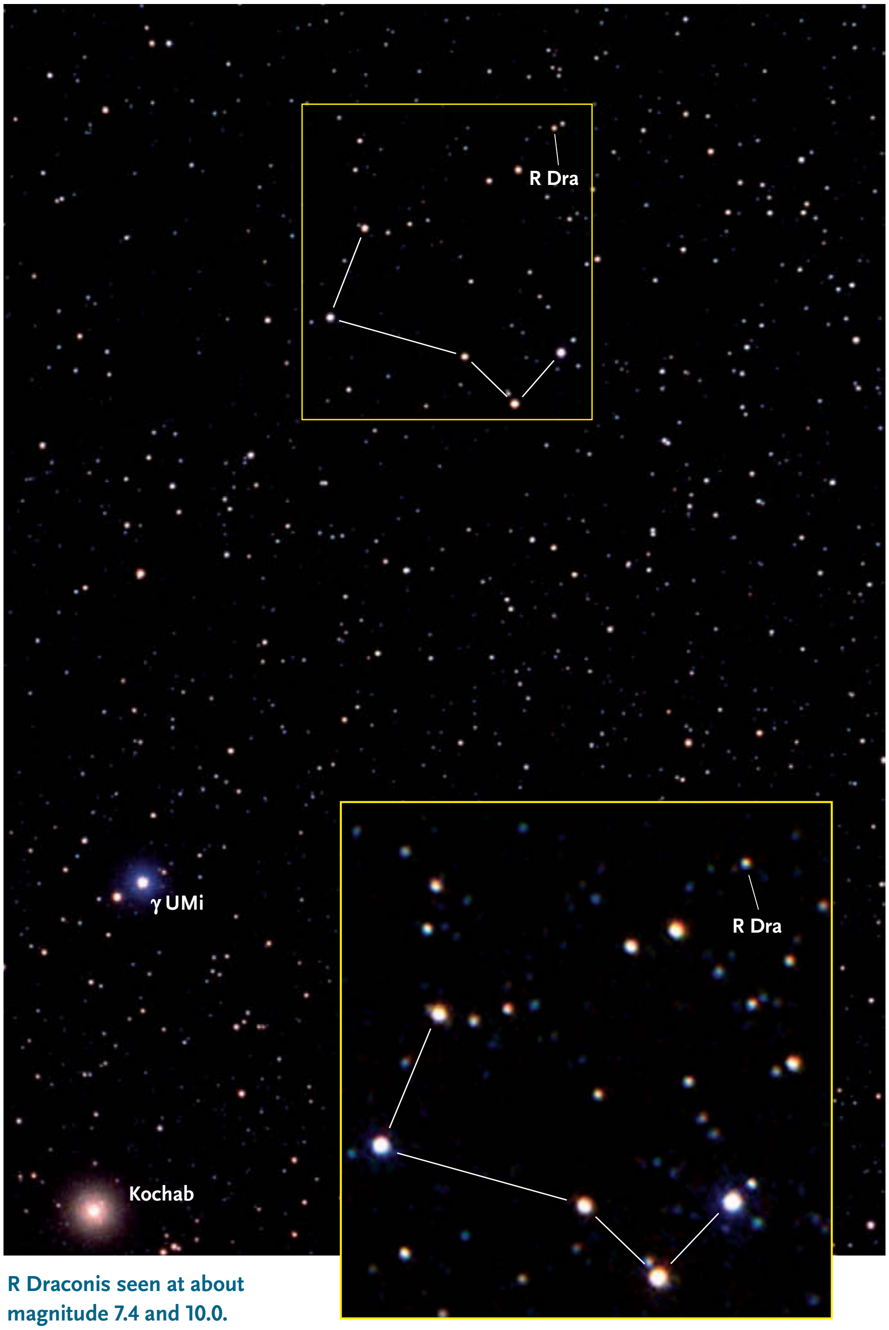
Visual estimates by different observers in different circumstances usually show several tenths of a magnitude of scatter. Even so, Mira stars like R Dra have such a large range (typically 5 magnitudes) that they're very well characterized by the vast numbers of eyeball estimates in the century-spanning AAVSO International Database.

The variability of this particular star was discovered in 1876 by the Norwegian astronomer C. T. H. Geelmuyden in Oslo — appropriate for a star so far north.





Left: The Little Dipper and Draco are shown as they appear when you face north on June and July evenings. The box around R Draconis shows the field of the comparison-star chart above, where star magnitudes are given to the nearest tenth with the decimal point omitted. Magnitudes are courtesy AAVSO. North is down (toward Polaris) on both charts, the way this part of the sky is oriented in summer when viewed with the naked eye or binoculars.



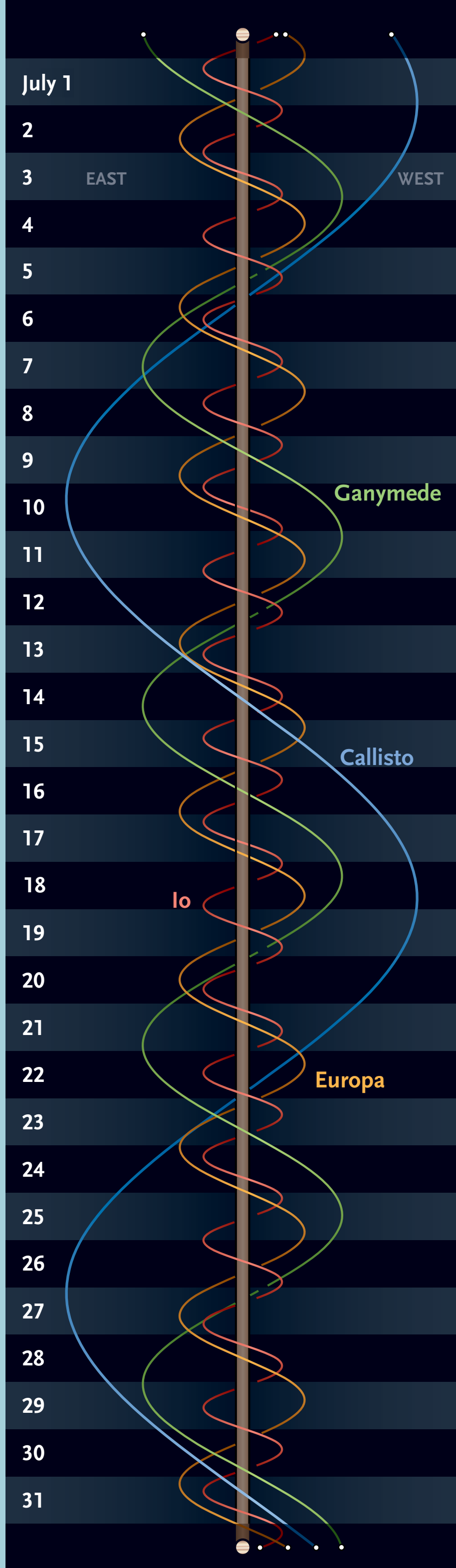
R Draconis seen at about magnitude 7.4 and 10.0.

Jupiter Occultation for Europe, Asia

On the morning of July 15th, the waning crescent Moon will occult Jupiter as seen from most of Europe and parts of Asia. Jupiter will slowly disappear behind the Moon's bright limb, then reappear from behind the dark limb up to an hour or more later.

To find the times for your location, and the altitudes of the Sun and Moon at these times, go to **transit.savage-garden.org/en/occultations/?id=17**, click your location on the map (within the purple occultation zone), then the "Submit" button, then scroll down.

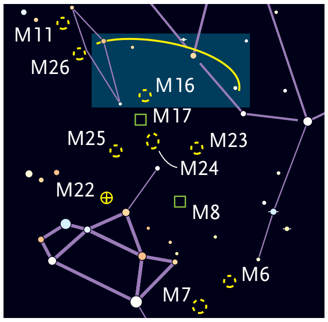
Jupiter's Satellites



Melpomene Over Sagittarius

Try for this shallow-sky target over a summer deep-sky playground.

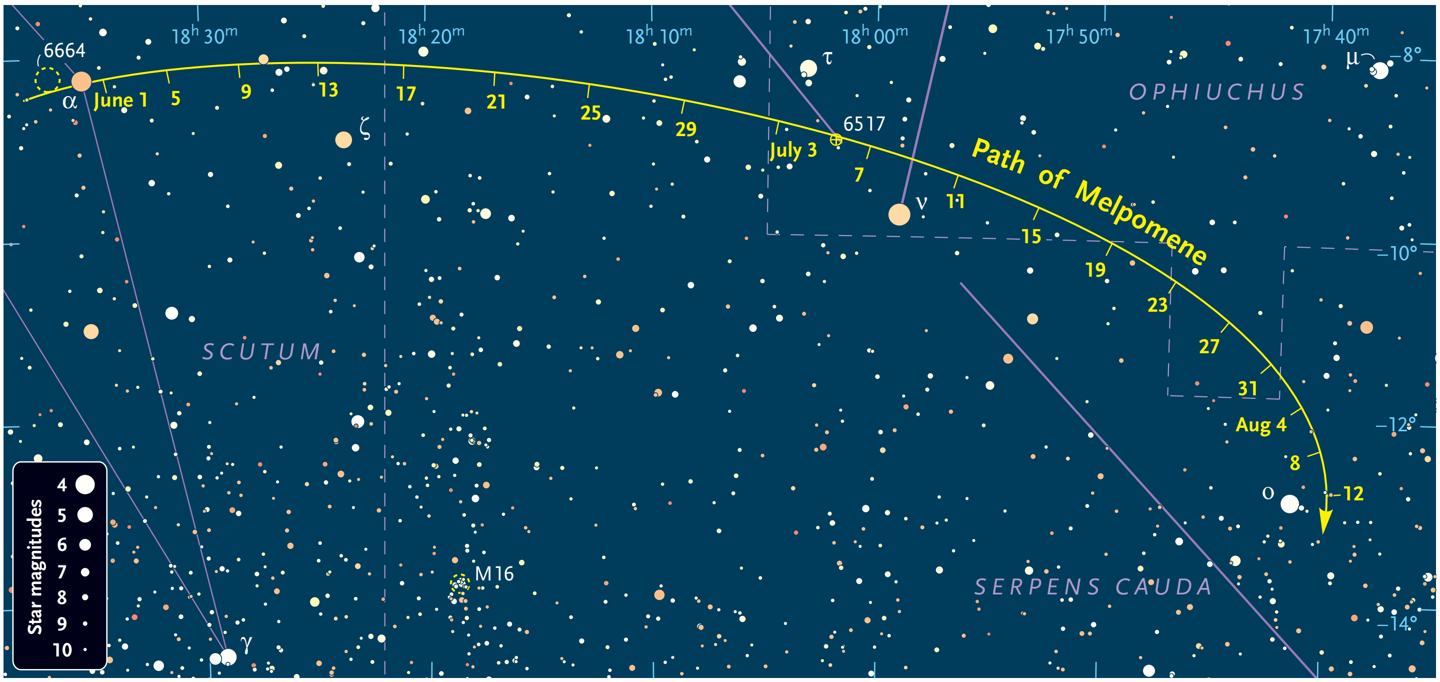
When you're hunting for a faint telescopic target, does a rich star field make it easier or harder to find? Many people say harder, such as when 14th-magnitude Pluto was crossing the thick summer Milky Way in recent years (see last month's issue, page 52). But I find it easier. The more faint little starry triangles and quadrilaterals I have to guide my way, the better I can narrow in on the precise point where the item is supposed to be.



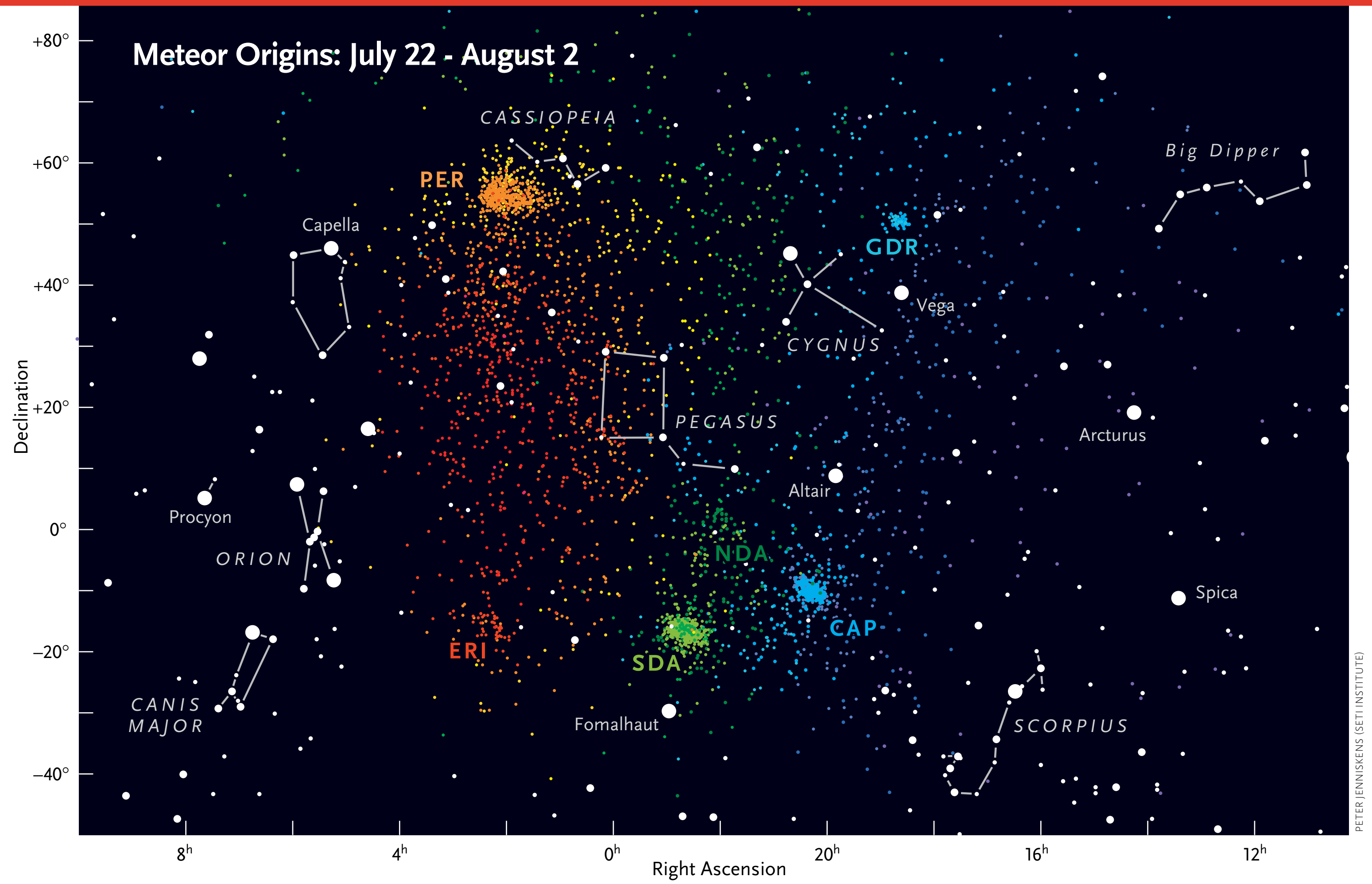
Of course, this requires a *really* good map to compare with your eyepiece view — one that shows everything your target might be confused with. When newbies get frustrated trying to find things, it's usually because they're using an inadequate map or don't know the necessary tricks for matching a map to the finderscope's field of view. See the quick summary of these tricks in the April issue, page 52, or in more depth at **skypub.com/charts**.

Good maps are your most crucial observing tool after a telescope. You would be crazy to deprive yourself of them. Excellent, detailed sky atlases are readily available on paper (see the text in the red bar at the top of the previous page), as software for custom printouts (allowing you to make either correct-reading or mirror-reversed printouts, to match the view in your finderscope and/or telescope), or for live display right at the scope on a laptop, tablet, or phone.

The map below shows stars to magnitude 10.2 in an area of Scutum, Serpens Cauda, and Ophiuchus north of the Sagittarius Teapot. Crossing this field from June through August is the main-belt asteroid 18 Melpomene. Named for the Greek muse of tragedy, it's a loose solar-system fragment about 100 miles (160 km) wide. With this map, you can take a side trip from the region's deep-sky wonders to follow Melpomene all season. It starts June at magnitude 9.8, bright enough to be visible through a 70-mm telescope in all but the most light-polluted skies. It brightens to 9.4 around opposition in late June, then fades back to 9.8 by August 1st.



Take this chart out with your scope to log a new object. The asteroid 18 Melpomene will appear between magnitude 9.4 and 9.8 in June, July, and August. Stars are plotted here to 10.2. The ticks on the asteroid's track show its position at 0h Universal Time on the dates indicated (which falls on the afternoon or evening of the previous date in the Americas). Interpolate to put a pencil dot on the track for the date and time when you'll go looking.



July Meteors: Out of the South

If you think summer meteors, most people think of the rich Perseid shower. It peaks around the morning of August 12th every year in the midst of vacation season.

But meteor action happens all summer. In July, meteor activity picks up after a slow first half of the year. As shown on the all-sky map above, several July showers have radiants (perspective points of origin) clustered in the late-evening southern sky. Taken together, these increase the chance that any meteor you see on warm July nights will be flying out of the south.

The map shows the individual radiant points of 3,875 meteors videorecorded last July 22nd through August 2nd by the CAMS and SonotaCo wide-sky video networks. If two cameras spaced about 25 to 60 miles apart both record a meteor's path against the starry background, it becomes possible to triangulate and reconstruct the meteor's actual three-dimensional path through the atmosphere. This in turn yields the radiant (usually elsewhere far across the sky) for this single meteor: the direction it came from in distant space.

CAMS is the NASA-supported Cameras for Allsky Meteor Surveillance project in California. SonotaCo is a network of 25 amateur astronomers operating 100 wide-field video cameras in Japan. These projects, and the automated data-reduction programs that have been developed for them, are revolutionizing knowledge of meteor showers, as we'll describe in an upcoming issue. Many new minor showers are being discovered, some of them remarkably well defined and not so minor. Some are variable or temporary, coming and going from year to year.

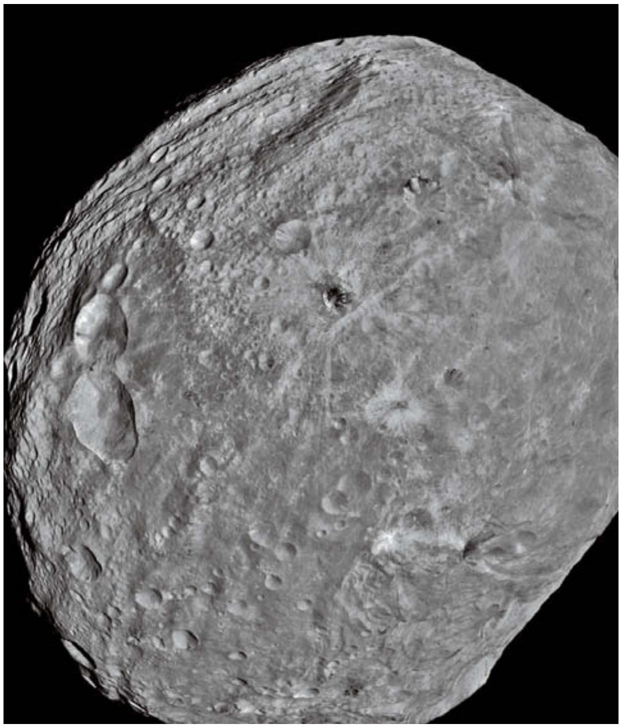
The colored dots are the radiants (perspective points of origin) for 3,875 individual meteors recorded in 3-D by the CAMS and SonotaCo video networks from July 22nd through August 2nd last year. The colors indicate the meteors' speed: blue the slowest, red the fastest.

On the map, the morning sky is center-left (rich in fast sporadic meteors) and the evening sky is center-right. Peaking in late July are the long-lasting Southern Delta Aquariid and Alpha Capricornid showers (SDA, CAP). The Northern Delta Aquariids (NDA) are just starting. Early Perseids are already ramping up. Unknown until recently were the slow-moving Gamma Draconids (GDR) coming out of the north. The fast Eta Eridanids run from about July 20th to August 20th before dawn.

The Moon is full on the nights of July 3rd and August 1st this year. ✦

Spy the Smallest Worlds

Track down the brightest asteroids in the solar system.



NASA / JPL-CALTECH / UCLA / MPS / DLR / IDA

As of mid-April, there were 583,767 asteroids with known orbits, yet only a few thousand of them come within the visual range of amateur telescopes. These remnants of our solar system's formative stages usually appear along the ecliptic, frequently revealing themselves as short streaks in long-exposure photographs. The nearest asteroids are often discovered shortly before closest approach, so this article should prepare you for these surprise visitors.

Asteroid observations date back to January 1, 1801, when the Italian priest Giuseppe Piazzi discovered Ceres. Ceres has an orbital inclination of 10.6° and lies between the orbits of Mars and Jupiter. Ceres will reach magnitude 6.9 this December. Ceres at this opposition is outside the range of what most observers can see with their naked eyes, but it provides one of three opportunities this year to view a main-belt asteroid with minimal optical aid.

***Above*: NASA's Dawn spacecraft took this image while orbiting Vesta. Visual observers can hunt down this world and the other bright asteroids later this year.**

Another opportunity involves Pallas, which was discovered in 1802 by German astronomer Heinrich Wilhelm Olbers. Although smaller than Ceres, Pallas can reach magnitude 6.4 at its very brightest. Pallas reaches opposition on September 24th in Cetus, though at magnitude 8.3 it will be too faint during this opposition to be seen with the naked eye.

Five years after discovering Pallas, Olbers found Vesta. Although Vesta is considerably smaller than Ceres, it reaches a magnitude of 6.4 in early December, putting it barely within naked-eye reach for anyone with good eyesight and a moderately dark sky. Ceres, Vesta, and Pallas are generally regarded as the only asteroids ever visible with the naked eye. NASA's Dawn spacecraft is currently studying Vesta in unprecedented detail (*S&T:* November 2011, page 32). Dawn is scheduled to leave Vesta in August 2012 for an encounter with Ceres in February 2015. Check **www.skypub.com/asteroids** for finder charts to these bright asteroids. Page 52 of this issue has a finder chart for the asteroid Melpomene.

In 1918 Japanese astronomer Kiyotsugu Hirayama realized that many asteroids have very similar orbits, which led to classifications of families within the main belt. Most main-belt asteroids are thought to be small bodies that were prevented from accreting into a single body by Jupiter's powerful gravity. They are the survivors that didn't end up hitting a planet, crashing into the Sun, or being ejected from the solar system.

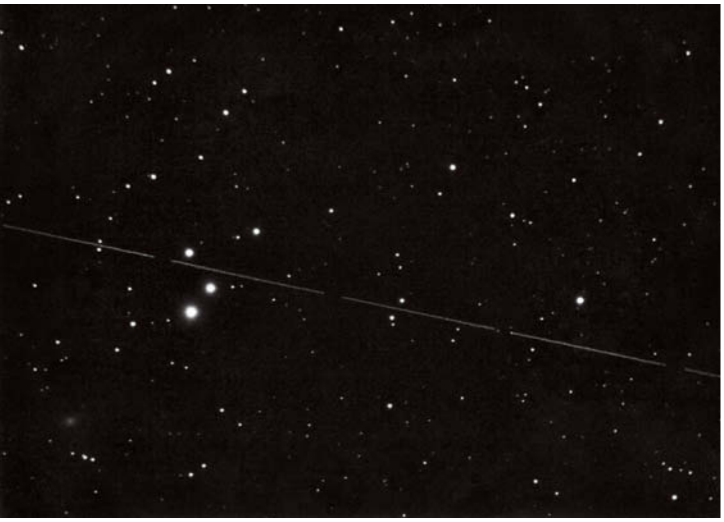
Because asteroid orbits are precisely known, amateurs with small telescopes or binoculars can hone their observing skills by finding and tracking these tiny points of light. Practicing these activities may inspire you to observe, image, and even hunt for much fainter objects.

Perhaps the most interesting asteroids for visual observers these days are near-Earth objects (NEOs), asteroids with orbits that occasionally take them extremely close to Earth. Our planet is regularly buzzed by NEOs and a few have made headlines recently, such as 2005 YU_{55}, which passed only about 200,000 miles (320,000 kilometers) from Earth in late 2011. This was so close that observers looking through backyard telescopes could detect movement as they watched. Although it was only magnitude 11 at its brightest, observing 2005 YU_{55} and similar NEOs passing closer than the orbit of the Moon is simultaneously very exciting and a little bit scary.

Visual observations of main-belt asteroids require good charts as well as the patience to observe the same location over a period of days to detect an object's motion with respect to the stars. CCD imagers have the advantage of being able to "see" motion (typically about an arcminute per hour) in main-belt objects much easier. Long-exposure images can show asteroids trailing against the surrounding star field. If you develop a long-term interest in asteroids, then it's worth spending time on internet forums interacting with others who do it regularly.

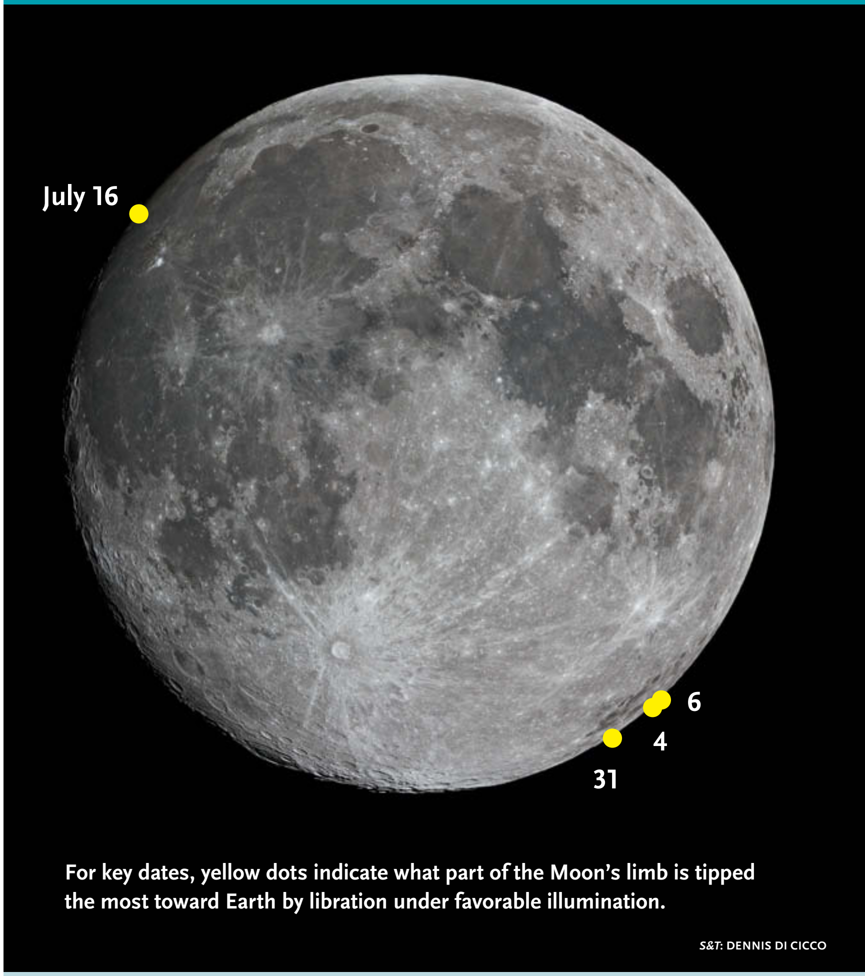
Unlike comets, newly discovered asteroids are not named for the person who found them. A new object is typically tracked for several oppositions, which can take years or even decades. When its orbit is sufficiently well known it will be given a permanent designation, and the discoverer is invited to assign a suitable name based on a set of International Astronomical Union guidelines.

Amateurs are still finding new asteroids and comets, though automated professional surveys now sweep up the majority of new discoveries. Still, computer-searching algorithms sometimes overlook moving objects. It's always worth checking your star maps and images carefully, since you never know what may be lurking within them. ✦



Senior editor Dennis di Cicco captured near-Earth object 2005 YU_{55} shortly before its closest approach on November 8, 2011. Each streak represents 45 seconds of exposure recorded with a 16-inch Schmidt-Cassegrain telescope and an SBIG ST-8300 CCD camera.

The Moon • July 2012



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

S&T: DENNIS DI CICCO

Phases

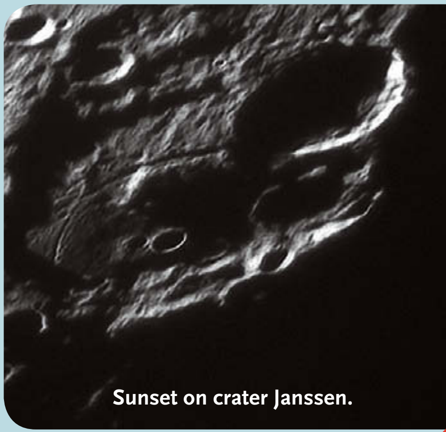
July 3	July 11	July 19	July 26
FULL MOON	LAST-QTR MOON	NEW MOON	FIRST-QTR MOON
18:52 UT	1:48 UT	4:24 UT	8:56 UT

Distances

Perigee	July 1, 18^h UT
227,832 miles	diam. 32′ 35″
Apogee	July 13, 17^h UT
249,724 miles	diam. 29′ 44″
Perigee	July 29, 8^h UT
229,754 miles	diam. 32′ 19″

Librations

Oken (crater)	July 4
Furnerius (crater)	July 6
Gerard (crater)	July 16
Lyot (crater)	July 31



S&T: SEAN WALKER

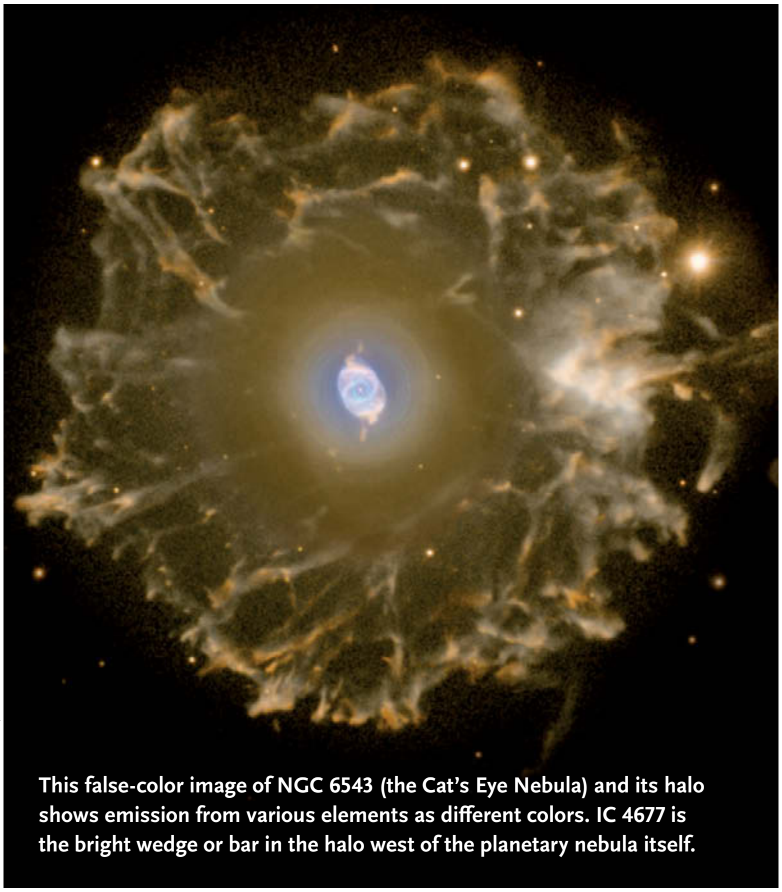
Sunset on crater Janssen.

By Draco's Scaly Folds

Some remarkable objects lie near the north ecliptic pole.

Where with vast convolution Draco holds
The ecliptic axis in his scaly folds.
— Erasmus Darwin, *The Botanic Garden,* 1791

Penned by the remarkable British polymath Erasmus Darwin, these lines direct us to the sky's north ecliptic pole, enwrapped in the great bend of Draco that starts behind the Dragon's head. The ecliptic is the Sun's apparent yearly path through the constellations of the zodiac, and the north ecliptic pole pierces the dome of the sky 90° north of the ecliptic. The NEP dwells at the center of a huge circle traced out by the north celestial pole as Earth's axis executes a leisurely wobble that takes 25,800 years. Currently, Earth's North Pole points very nearly at Polaris, making it our pole star. The next time the north celestial pole will be so close to a naked-eye star is about 3,000 years from now, with 5th-magnitude 31 Cephei as the pole star.



NORDIC OPTICAL TELESCOPE / ROMANO CORRADI (ISAAC NEWTON GROUP OF TELESCOPES)

This false-color image of NGC 6543 (the Cat's Eye Nebula) and its halo shows emission from various elements as different colors. IC 4677 is the bright wedge or bar in the halo west of the planetary nebula itself.

While you might think the north ecliptic pole wouldn't be a very exciting target, it shares a telescopic field with one of the sky's most enchanting planetary nebulae. **NGC 6543**, also known as the Cat's Eye Nebula, peers at us from a spot just 9.6′ west-northwest of the NEP.

NGC 6543 is found halfway between the stars Omega (ω) and 36 Draconis. Through my 130-mm refractor at 37×, I see a distinctive snake-like pattern of 9th- to 11th-magnitude stars that slithers northward for 32′. The serpent's eastern eye is a small blue-green disk with a bright center. The view changes dramatically at 164×. The nebula looks boxy, with rounded corners and a slightly darker center. One diameter of the box (north-northeast to south-southwest) is longer than the other. Almost overwhelmed by the brightness of the planetary, the central star is visible only when I direct my gaze to a position that makes the nebula look dimmer. As judged by the distance between two field stars, I estimate a span of about 20″ for the Cat's Eye. At 234× subtly complex brightness variations tease the eye.

The Cat's Eye Nebula is a visual treat through my 14.5-inch reflector. At low to medium power, it displays a compelling sea-green hue, while at high magnification it's wonderfully intricate. Deep images of NGC 6543 show a complicated helical configuration, but my visual impression is considerably different. At 276× I see a bright oval ring running east-southeast to west-northwest crossed by a slightly fainter, somewhat longer ring perpendicular to it. This structure overlays faint nebulosity that fills the outer loops of the rings and the crooks between them, while a small region around the central star is a bit darker. A fairly obvious bar of nebulosity sits 1.8′ west of NGC 6543. It appears about ½′ long, with a 15th-magnitude star ½′ off its east-northeastern end. This bar bears the designation **IC 4677**. In images showing IC 4677, you can see that it's the brightest part of a 5′ halo surrounding the Cat's Eye. The halo looks like a splash pattern formed when the Cat's Eye was dropped into the celestial sea.

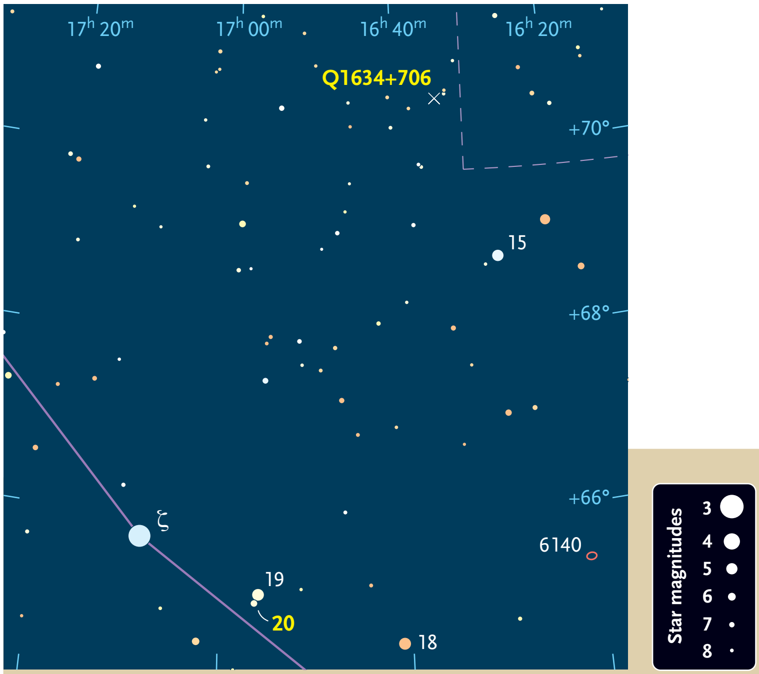
Two rather interesting double stars lie along the western leg of Draco's grand hairpin curve. The brighter pair is **Eta (η) Draconis**, with a 2.8-magnitude primary harboring an 8.2-magnitude companion 4.8″ to the southeast. Double-star maven Sissy Haas, author of *Double*

Stars for Small Telescopes, enthusiastically endorses this splendidly mismatched duo as having "Fantastic contrast for the separation!" You could split a 4.8″ pair at about 100× if its stars were evenly matched, but the great difference in magnitude between the stars of this pair calls for a substantially higher magnification. Through my 130-mm scope at 234×, the bright, yellow primary is fairly widely split from its pallid little attendant.

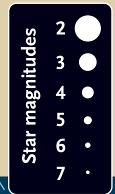
The second pair is **20 Draconis**, whose components are very similar in brightness at magnitudes 7.1 and 7.3. The advantage of having nearly equal magnitudes is offset by the snugness of these tightly knit components, which are currently hovering near the maximum apparent separation of 1.2″ for their 420-year orbital cycle. Thus I can see 20 Draconis split by a hair at the same power I used to split Eta Draconis. To me, the slightly brighter star appears white, while the companion hugging it from the east-northeast looks yellowish.

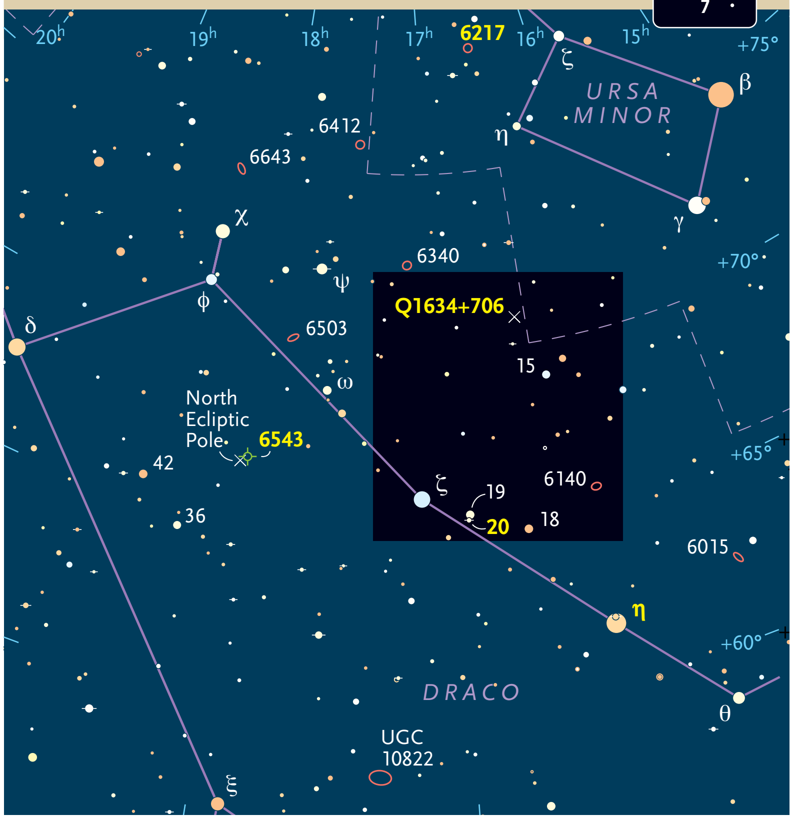
One question I'm often asked at public star parties is, "How far away can you see with that thing?" This led me on a search for the most distant object that I could easily show off in my 10-inch reflector. The quasar **Q1634+706** at magnitude 14.4 was my choice. To find it, look 1.9° north-northeast of 15 Draconis for a north-south pair of 8th-magnitude stars 2′ apart. Just to their east, you'll find six 11th- to 14th-magnitude stars that outline a 4′-tall U. The quasar is the bottom (southernmost) "star" in the U.

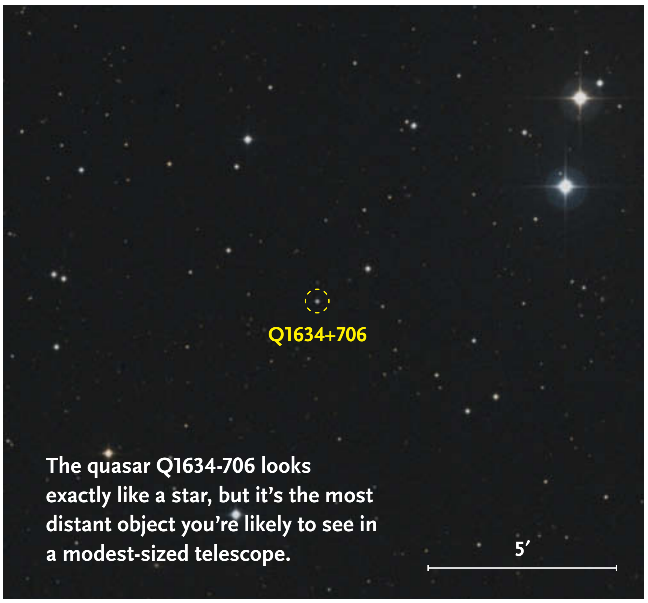
How far away is Q1634+706? That's a bit complicated to answer for such a distant object. The most commonly used measure in popular literature is light-travel distance, the distance the object's light traveled to get to you. But light-travel distance doesn't tell us how far away the quasar was when it emitted the light you see. That distance



Most of the objects discussed in this article are bright, and can be located easily using the wide-field chart below. The quasar Q1634+706 is a different story. To find it, use the chart above to star-hop to the tight pair of 8th-magnitude stars very near the quasar, then switch to the photograph at lower left.





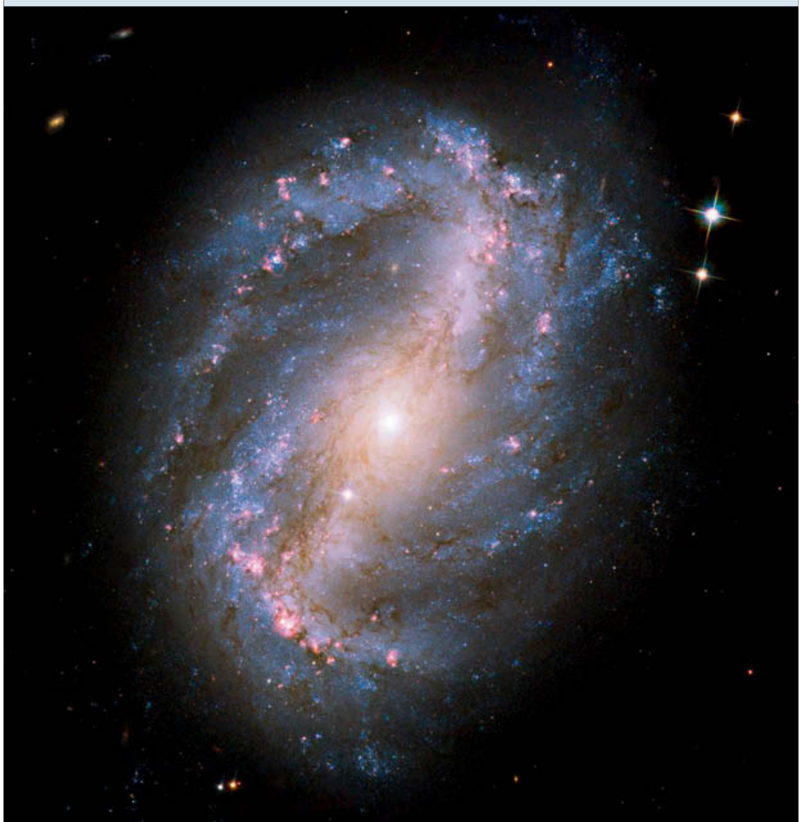


The quasar Q1634-706 looks exactly like a star, but it's the most distant object you're likely to see in a modest-sized telescope.

Assorted Delights in Draco and Ursa Minor

Object	Type	Mag(v)	Size/Sep	RA	Dec.
NGC 6543	Planetary nebula	8.1	22″×19″	$17^h\ 58.6^m$	+66° 38′
IC 4677	Part of planetary halo	15	44″×23″	$17^h\ 58.3^m$	+66° 38′
η Dra	Double star	2.8, 8.2	4.8″	$16^h\ 24.0^m$	+61° 31′
20 Dra	Double star	7.1, 7.3	1.2″	$16^h\ 56.4^m$	+65° 02′
Q1634+706	Quasar	14.4	—	$16^h\ 34.5^m$	+70° 32′
NGC 6217	Galaxy	11.2	3.0′×2.5′	$16^h\ 32.7^m$	+78° 12′

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.



NASA / ESA / HUBBLE SM4 ERO TEAM

This Hubble Space Telescope image shows that NGC 6217 is a splendid example of a barred spiral galaxy.

could be quite small. Imagine a photon being emitted by a quasar when the universe was young and objects were closer together. Because the universe is expanding, space keeps expanding in front of the photon, giving it a longer distance to travel. A quasar with a light-travel distance of 12 billion light-years couldn't possibly have been 12 billion light-years away when the light was emitted — the observable universe wasn't that big then.

Neither does light-travel distance tell us how far away the quasar is now. Space between the photon and its source also kept expanding during the photon's journey. Determination of distance "now" depends on what model of the universe we use. According to some common parameters, if you observe Q1634+706, you can say that you're seeing an object whose light took 8.6 billion years to reach us or that you're seeing an object that's now 12.9 billion light-years away.

Light-travel distance and "distance now" are almost identical for objects less than 2 billion light-years away.

Sweeping north into Ursa Minor, we come to the splendid galaxy **NGC 6217**. It makes an isosceles triangle with the stars Eta (η) and Zeta (ζ) in the Little Dipper's bowl. Even at 17× in my 105-mm refractor, the galaxy is easily visible as a small oval glow floating above (north of) a large asterism of fairly bright field stars. At 87× NGC 6217 displays a star-like nucleus and leans north-northwest. Two 11th-magnitude stars point toward it from the northwest.

NGC 6217 shows off its pretty, barred-spiral structure through the 10-inch scope at 115×. The galaxy's major axis is adorned with a long, broad bar. A sharply curved arm emanates from the north-northwestern end of the bar and accents the eastern flank of the galaxy's oval glow for about half its length. The opposed arm starting at the other end of the bar is less well-defined, shorter, and more gently curved. A small, bright, round core pins the center of the bar and enfolds a minuscule nucleus. Just beyond the core, a faint star is superposed on the south-southeastern stretch of the galaxy's bar.

NGC 6217 was the first celestial object imaged by Hubble Space Telescope's Advanced Camera for Surveys (ACS) after it was repaired in 2009. This impressive galactic star-city is roughly 80 million light-years away, a next-door neighbor compared to quasar Q1634+706. ✦

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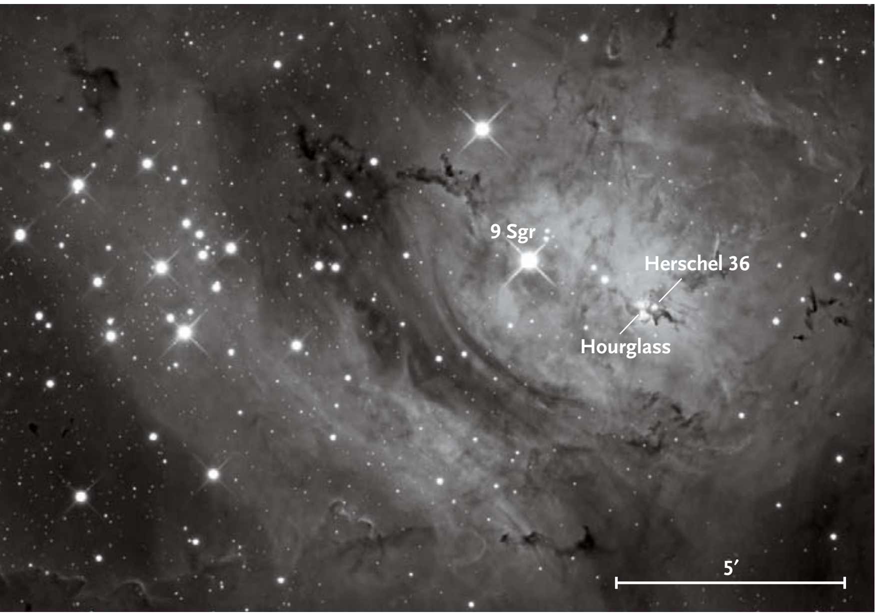
Diving into the Lagoon

This famous nebula deserves many hours of study.

DESPITE BEING 5,000 light-years distant, elongated Messier 8, the Lagoon Nebula, is one of the first objects that catches the eye when scanning the summer Milky Way. Various 17th- and 18th-century observers are credited with "discovering" this nebula, but its obvious naked-eye glow must have been known since prehistoric times. At latitude 50° north, where M8 is always low in the sky, my 8-inch Newtonian at 61× and 116× without a filter reveals the prominent curving dark lane between M8's two main lobes.

The tiny Hourglass is the brightest patch of nebulosity within this showpiece. It's found in the oval western lobe 3′ west-southwest of the 5.9-magnitude *O*6 radiative monster star 9 Sagittarii. The Hourglass glows from the ultraviolet stimulation of the 10th-magnitude *O*7 star Herschel 36 immediately to its west. Herschel 36 is probably as luminous as 9 Sgr, but it's heavily reddened and dimmed by dust.

To the north of the two main masses, my 8-inch also reveals a faint nebulosity elongated east-west just south of the 7.7-magnitude star HD 164865 (see the wide-field image on the next page).



ADAM BLOCK / MOUNT LEMMON SKYCENTER / UNIVERSITY OF ARIZONA

This close-up of the Lagoon Nebula's central region is shown in black and white with the red channel suppressed to emphasize the features that are visible through a telescope's eyepiece without a filter.

The loose open cluster that was born within the nebula displays about 40 of its more than 100 known members. Anthony Moffat, an expert on massive stars, gives the earliest spectral type of these stars as *O*5, implying that the cluster is only 2 million years old.

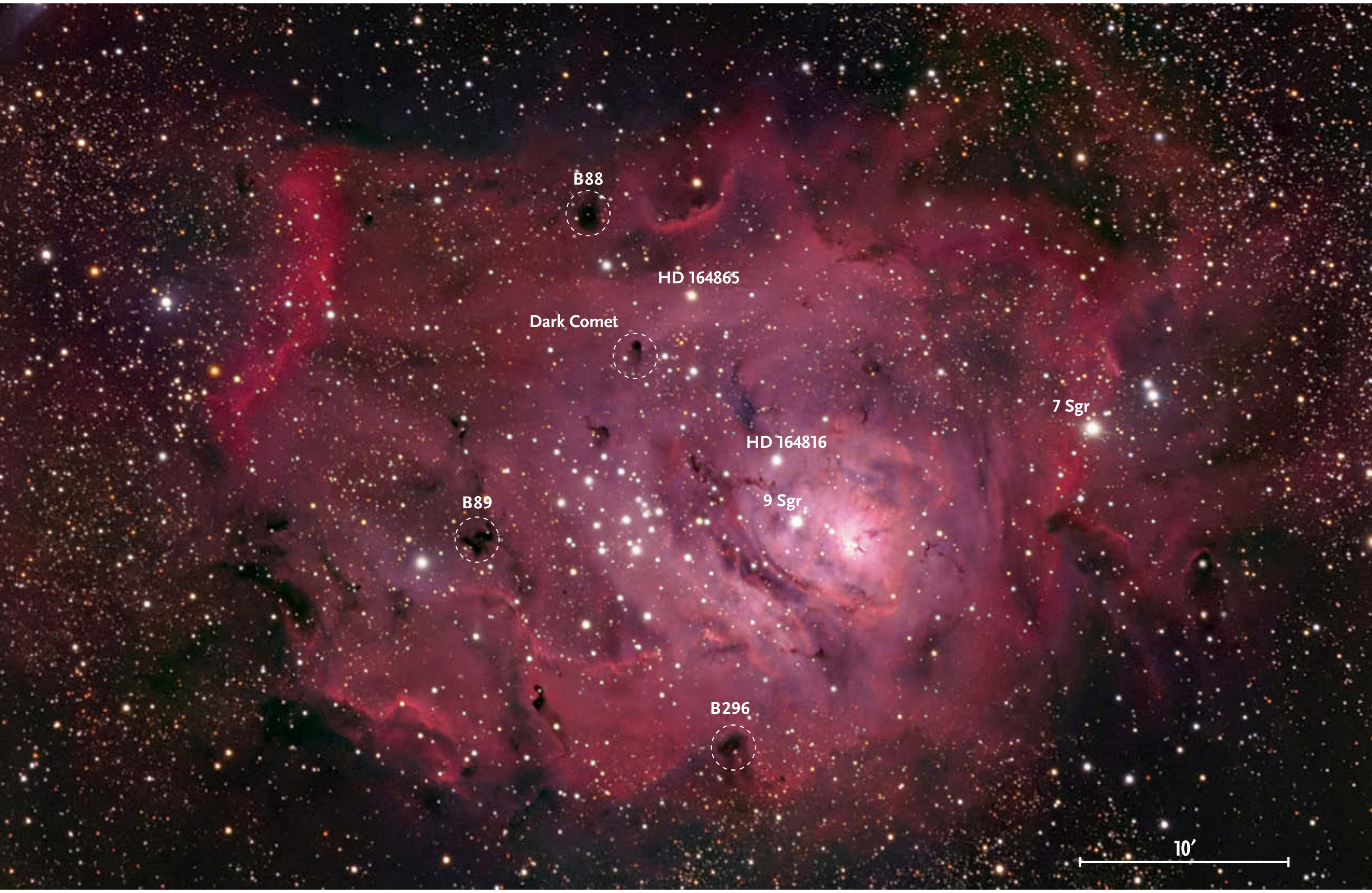
From Australia, where M8 appears overhead, fellow amateur Tony Buckley's 14.5-inch Dobsonian showed me a small dark nebula on the northern edge of the central star group at 136× using an O III filter.

In 2003 I was privileged to explore the Lagoon through the Chaco Observatory's 25-inch Dobsonian. The observatory is in Chaco Culture National Historical Park, which protects important archaeoastronomy ruins in northwestern New Mexico (May issue, page 26). It's also a superb high desert dark site where three segments of the Milky Way cast shadows! The telescope and its dome were donated by the founding director, John Sefick.

In May 2003 the 25-inch Dob showed me Burnham's Dark Comet 3.5′ southeast of HD 164865, ending my 23-year quest to see this captivating little dark nebula. It was probably first described in *Burnham's Celestial Handbook* (page 1581), where it's misidentified as Barnard 88. Several authors have repeated Burnham's error, but E. E. Barnard's *Atlas of Selected Regions of the Milky Way* clearly shows that Barnard 88 is a larger and darker spot near the northern edge of the nebula.

On two nights in June 2003 I undertook a detailed survey of the Lagoon Nebula using the observatory's 25-inch with freshly washed mirrors, an O III filter, and the monochrome photos in *Burnham's*. At 226× I saw a bright filament in the main dark channel, along the channel's northwest bank and parallel to it. The filament runs southwestward from a pair of 11th-magnitude sparks located halfway along the channel. I also detected a small, low-contrast dark nebula immediately west of the Hourglass, but I saw no more than a vague suggestion of an hourglass shape.

The rest of my survey was done at 113×. The main dark channel opens out to a wider dark knot at its southwestern end; at the opposite end the channel opens into a large dusky area. This may be the "lagoon" after which



HUNTER WILSON

This wide-field photo can be viewed both by white light during the day and red light at night. Its relatively muted tones show the nebula's true visual appearance better than deeper exposures do. The reddest areas are the ones most enhanced by nebula filters.

the nebula is named. Images show that from this dusky lagoon a narrow dark river meanders into the western lobe, but I saw only a thin intrusion.

I saw a low-contrast darker area about 3′ south of the cluster's central clump of diamonds, between two bright stars that are aligned east to west. I could trace a long dark streak that runs north-northeast to south-southwest about 4′ east of the cluster's core; the distinctive squiggle near its middle is B89. In M8's southeastern section, about 9′ south-southwest of B89, the big scope revealed a long, thin dust cloud embellished with an 11th-magnitude gem at its midpoint. This 11th-magnitude star marks the southwestern corner of a pentagon-shaped asterism of similarly bright stars.

There's an obvious triangular dark indentation south of M8's bright eastern lobe. The triangle is most opaque at its northern tip and along its northwestern side. Barnard designated this 6′ × 1′ "narrow black strip" as B296.

The bright western lobe of nebulosity has three dusky areas along its curved western edge: a large one off the southwestern tip which is enclosed by faint emission nebulosity, a smaller one in the middle which is also enclosed by a nebulous loop, and a very large elongated and diffuse one to the northwest. This broad dark area is bordered on its southeast by a very bright streak, and it's separated from a dark nebula farther east by a band of bright nebulosity.

A fairly prominent absorption nebula lies about 3′ north-northeast of the 7th-magnitude star HD 164816. From this dark nebula a mottled and star-filled area extends all the way to the Dark Comet.

Faint billows of emission nebulosity are visible between M8's bright western lobe and 5.4-magnitude 7 Sagittarii, and more faint billows lie north of that star. ✦

***Alan Whitman** was volunteer director of Chaco Observatory and its astronomy outreach program in 2003.*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Dennis di Cicco

The Paramount MX

The latest German equatorial telescope mount from Software Bisque brings a new level of sophistication to robotic astronomy.

FROM MY PERSPECTIVE as a reviewer, the new Paramount MX from Software Bisque is a little bit of a paradox. On one hand, it's a very nice German equatorial mount so outwardly classic in its execution that even instrument maker Joseph Fraunhofer, who proposed the design almost 200 years ago, would instantly recognize the MX for what it is were he alive today. On the other hand, buried beneath its surface is a technology so sophisticated that the mount's performance is beyond anything Fraunhofer could have dreamed possible.

The dividing line between what a German equatorial mount can do in theory and what the MX does in practice is almost nonexistent. Much of this performance is due to the software supplied with the MX, and that's one thing that helps set this mount apart from any of the other beautifully engineered German equatorial mounts made today. This software includes *TheSkyX Professional,* Software Bisque's flagship planetarium program, and *TPoint,* a spinoff of the computer code Patrick Wallace developed to control the pointing and tracking of some of the world's most advanced professional telescopes.

The Paramount MX easily handled 70 pounds of gear, including this 12-inch f/3 Riccardi-Honders astrograph. The author helped Arne Henden test this scope for the American Association of Variable Star Observers's next-generation photometric survey.

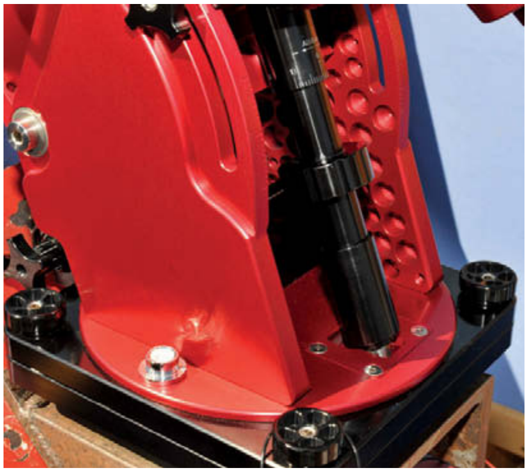
I don't have room to even list all the features of the Paramount MX and its software, let alone describe them in detail. There is, however, lots of information on the **bisque.com** website, and after extensively testing the MX we borrowed for this review, I have no reason to dispute a word of what's claimed for these products. That's not to say that the MX doesn't come with a few caveats, as I learned while using the MX in my suburban-Boston backyard observatory last winter and spring.

You Can Take it With You

The Paramount MX is Software Bisque's first mount designed to be portable. In addition to an optional field tripod ($2,000), it has a polar-alignment bore scope ($295) that threads into the MX's polar axis. I didn't test this setup, but I know from past experiences that well-made polar scopes can quickly assist users in achieving alignment in the field that is accurate enough for even demanding imaging applications. Furthermore, the MX's precision altitude and azimuth adjustments will make easy work of nudging the MX to get the polar scope properly targeted on the sky.

The MX without its counterweight shaft tips the scales at 50 pounds (23 kg), which makes it relatively easy for one person to handle. My setup involved an optional base plate ($180) that I attached to one of my observatory piers. The MX simply connects to this plate with four hand knobs. I was amazed to find that I could remove and replace the mount on this base plate and maintain polar alignment to within an arcminute or two. This would be a huge benefit for someone who wants to set up a permanent pier but needs to remove the mount between observing sessions.

The downside to using the MX in the field is its 48-volt DC power requirement. The mount comes with an 80-watt universal AC adapter, and Software Bisque recently introduced a 48-volt rechargeable battery ($600) that will power the mount for "many night's operation between charges." Although I mainly ran the MX with its AC adapter connected to house current, I also successfully tried the AC adapter connected to an inexpensive AC inverter (rated for 100 watts) plugged into my car's 12-volt power outlet.



Precision-calibrated adjustments for the MX's azimuth and altitude make quick work of accurately polar aligning the mount whether you are using the optional polar-axis bore scope or software that comes standard with the mount.

The MX's hand box is very basic, offering four programmable slewing speeds for the joystick control (which looks like a large button in this view). A built-in red LED map light is operated by the rocker switch just below the author's thumb. The pending release of software for Apple's iPhone, iPod Touch, and iPad will let these devices wirelessly control the mount's Go To pointing.

What we liked:

Precision mechanical construction

Extraordinary pointing and tracking accuracy

Exceptional integration with included software

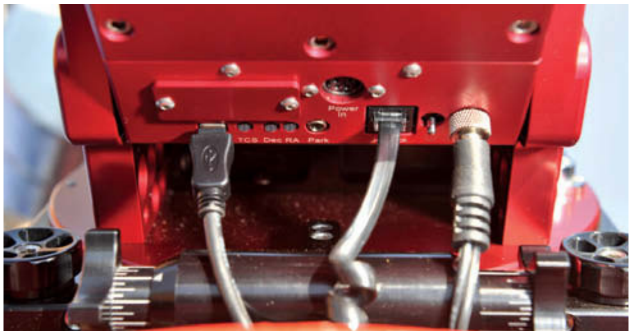
What we didn't like:

Although the mount's basic operation is easy to learn, mastering all of the MX's features is time consuming

You can run the mount without it being attached to a computer, though you won't find this capability highlighted in the MX's literature. You'll have to live with a default sidereal tracking rate and no Go To pointing, but you can still slew the mount around the sky with its joystick hand controller, and the auto-guider input still works. Leaving the computer home may strip away most of the MX's brainpower, but in reality you'll still be left with a better portable German equatorial mount than any marketed to previous generations of amateur astronomers and astrophotographers. Furthermore, Software Bisque has announced plans to soon release a basic version of *TheSky* for Apple's iPhone, iPod Touch, and iPad, which will allow wireless control of the MX's Go To pointing and other basic functions without a separate computer connection.

The Real Brains of the Operation

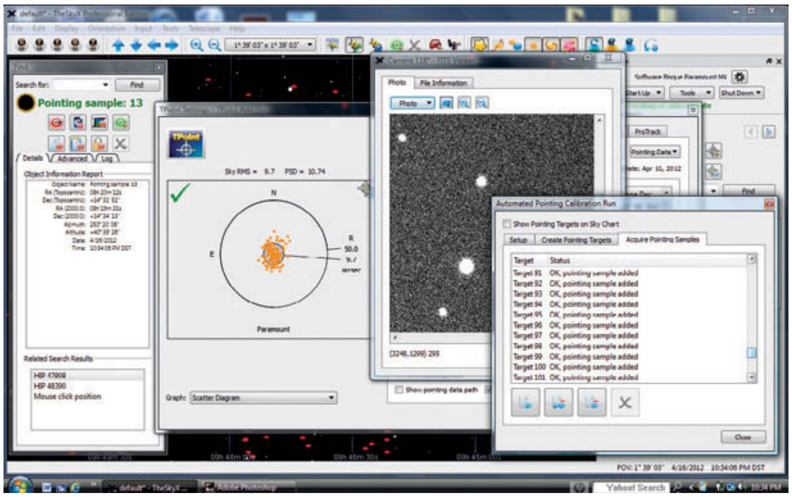
The power of the MX is unleashed when the mount is connected to a computer. Any relatively modern Mac or Windows PC should do. Initially I had some concern that my 4-year-old, run-of-the-mill HP laptop running Windows *Vista* wouldn't be up to the task, mainly because of its older graphics capabilities. But it worked just fine. Its low-resolution display (1,280 by 800 pixels) got rather crowded with dialog boxes at times, but never to the point



Internal cables and a variety of electrical connections on the MX's telescope saddle (*top*) and polar-axis housing (*above*), as well as provision for additional internal cabling, enable users to set up imaging systems without wires dangling from a telescope.

of being a handicap. People using the MX in an observatory should consider a computer with dual monitors: one for the various dialogs and the other for the sky chart.

Controlling the MX via *TheSkyX* planetarium software is very straightforward. You set up the program to display your sky overhead, select any object (night or day), and a single mouse click slews the MX (and whatever is mounted on it) to the object and begins tracking it. This



As explained in the accompanying text, the low-resolution display on the author's 4-year-old laptop computer became crowded with dialog boxes at times, but never to the point of being a problem while controlling the mount.

includes most Earth-orbiting satellites, which is impressive and a whole topic unto itself.

With the exception of the satellite-tracking feature, the click-and-point aspect of the MX is certainly nothing new. There are many Go To telescopes and planetarium programs that can be coupled to do the same thing. Indeed, you can use *TheSkyX* to control most of today's popular Go To telescopes. Where the MX rises above the others is its powerful integration with the software and, of course, its precision. I'll get back to these in a minute, but first a few words about *TheSkyX*.

I don't know if anyone has compiled a list of all the planetarium programs available today, but the number has to be staggering. Recently I tallied more than 60 made for smartphones alone! Very few, however, can challenge *TheSkyX* for top billing on any list. And there are good reasons why. *TheSkyX* is the current manifestation of planetarium software that Steve Bisque introduced as *The_Sky* in the early 1980s. Three decades and untold man-years of development have created a program so rich in features that I can't imagine any one person knowing how to use them all. Simply put, if you're an amateur astronomer and you can think of something that you'd like to do with planetarium software, then you can probably do it with *TheSkyX*. This includes controlling an entire observatory.

The downside of this vast resource is the learning curve that goes with it. Although I have dabbled with dozens of planetarium programs, I had never become proficient with any of the computer-based ones before starting this review. As such, I decided to keep a record. My first night easily had me up and running with *TheSkyX* and the basics of using it to control the MX. But I had logged a bit more than 20 hours sitting in front of the computer alone or with it attached to the MX before I stopped keeping records because the learning curve had begun to flatten out. Your mileage may vary depending on your level of computer savvy and what features of *TheSkyX* you delve into. For example, I spent more than 30% of my learning curve focusing on the advanced features of *TPoint*. And while I expect that most MX owners will use this program, you can learn its basic functions relatively quickly.

In a nutshell, *TPoint* is the computer power driving the MX's precision pointing. After mapping as few as six stars, *TPoint* can compensate for problems such as polar-alignment errors to deliver Go To pointing that will always center targets within your telescope's field of view. *TPoint* will also tell you how far off your polar alignment is and the number of "ticks" on the MX's adjustment knobs you need to make to achieve accurate alignment.

That's just the simple stuff. Deeper down, *TPoint* can create advanced mathematical models that compensate for a multitude of pointing "errors" involving everything from telescope flexure to atmospheric refraction. A *TPoint* feature called ProTrack uses these models to feed a continuous stream of tiny corrections to the MX's drive motors

TPoint **software supplied with the MX offers unprecedented tracking accuracy. This view of the famous Whirlpool Galaxy, M51, is a stack of thirteen 10-minute unguided exposures made through the Sky-Watcher Quantum 120-mm f/7 refractor reviewed on page 34 of last month's issue.**

(both right ascension and declination) that deliver unprecedented tracking accuracy over extended periods. This is the stuff that would have made Fraunhofer's head spin.

There are several ways to map stars with *TPoint* and the MX. I started out using a simple crosshair eyepiece and stars that I manually selected from the *TheSkyX's* graphic display. The MX slewed my telescope to the star, I centered it on the crosshair with the joystick controller, and I mapped it with a mouse click. The more stars mapped the better. I typically used three dozen stars with this manual method, and that was enough to deliver pointing accuracy on the order of 15 arcseconds. Yep, you read that right, 15 *arcseconds*. That means that the MX wouldn't just center Jupiter in the eyepiece, it could actually pinpoint which quadrant of Jupiter's disk I wanted. But wait, it gets better.

The MX, *TheSkyX,* and *TPoint* can work as a team when you have a CCD camera attached to your scope. The whole *TPoint* calibration can be automated from the selection of stars, to the taking of images, to mapping where the scope is pointed. With the setup shown on page 64, I automatically mapped about 125 stars in less than an hour. (Trees and clouds are no problem, since the software simply ignores "misses.") This gave a mind-boggling pointing accuracy better than 10 arcseconds and allowed ProTrack to make 20 back-to-back 10-minute unguided exposures with every one a keeper. If I hadn't done it myself, I'm not sure I'd believe it could be done!

If you have a permanent setup, you can probably go many months before an update of a *TPoint* calibration would be beneficial — any given model should work well from night to night as long as you don't make major changes to your equipment setup. Furthermore, you don't even need to "sync" the MX on a celestial target to use *TPoint's* accuracy from one observing session to the next. The mount has a built-in homing position that is accurate to better than 1 arcsecond. As such, just powering up the mount and homing it puts it in accurate sync with the sky anytime day or night. This is particularly valuable for remote setups, since the mount can be easily synced after power interruptions or computer glitches without the need for a person being present.

On several occasions I used this feature to surprise visitors. In the middle of the day I'd open the observatory roof, connect my laptop to the MX, and power everything up. I'd home the MX, click on a bright star on *TheSkyX's* display, and let the MX head off to its target. When the mount stopped slewing, and without ever checking the view myself, I'd tell my visitors to look into the eyepiece. I wish I had a camera to capture their expressions as they looked up from the telescope — showing people stars in a daytime sky, not to mention the ease of doing it, obviously made it seem as if I was flirting with magic.

Is there a downside to using *TPoint*? Apart from the learning curve that goes with exploiting the full potential of the software, the only one I can think of involves human nature and the polar-alignment features. It's extraordinarily tempting to use *TPoint* and the MX's altitude and azimuth adjustments to aim for polar-alignment perfection, especially since the first iteration of the process can often get you within 3 or 4 arcminutes of the celestial pole. But stifle the urge unless you really feel there's a need to have better alignment (and I'm open to people telling me why they would). In my case, trying for sub-arcminute polar alignment was like chasing ghosts — changes in my steel pier and the MX itself due to thermal expansion and contraction varied the polar alignment by about an arcminute during nightly temperature variations. How I discovered that is a story for another time.

The folks at Software Bisque have spent years perfecting robotic observing with their various programs and telescope mounts. The Paramount MX currently stands at the pinnacle of the company's success. Whether your interest is robotic gathering of research data or pretty astronomical images, and whether your telescope is in your backyard or on another continent, the MX can do it. And even if you're "old school" like me and enjoy being with your equipment while observing, the MX offers an experience that won't soon be forgotten. Please pardon the pun, but the MX is an incredible gem. ✦

If S&T *senior editor* ***Dennis di Cicco*** *wasn't sure exactly where the north celestial pole was before working on this MX review, he's convinced he knows where it is now.*

A Go To Binocular Chair

This homemade rig combines viewing comfort with utility.

There's deluxe, and then there's *deluxe*! Take a moment to imagine the ultimate binocular setup. If you let your imagination run wild, you'd probably come up with big binos and a comfortable way to use them while seated. And wouldn't Go To capability be nice? If that describes your dream binocular rig, then you have a lot in common with California ATM Norman Butler.

His binocular setup features a motorized chair with computerized Go To pointing. Although he can attach almost any binoculars to the chair, he most often cruises the sky with 15×80s. Like many ATM projects, this one began when inspiration met opportunity.

"I had a brief conversation with a wheelchair-bound binocular enthusiast a couple of years ago," Butler recalls. "He mentioned how nice it would be to sit in a comfortable chair, push some buttons, and let a computer find the astronomical objects for him. That planted the project's idea in my mind."

The first task was to find a suitable chair, and that's when opportunity knocked. "One day as I was taking out the trash, I spotted a discarded Ikea recliner," Butler notes. "It appeared to be in excellent condition, though substantial modifications were unavoidable."

Many homemade bino chairs pivot as a whole, like a dentist's chair, which places the observer's feet uncomfortably high up when the binos are aimed at the zenith. Instead, Butler decided to accomplish the altitude motion by making only the back of the chair recline. Comfort is enhanced with a footrest made from an old ironing board.

The chair's azimuth axis has a heavy-duty 17½-inch-diameter ball-bearing swivel (purchased on eBay), sandwiched between a pair of wooden tabletops. This base has a leveling mechanism made from three pipe flanges attached to threaded pipe segments. Leveling is achieved by screwing the flanges in and out as needed.

By chance, Butler discovered a square, steel frame that was also discarded in the trash. He modified it for the binocular support that is attached to the chair's back. "When I found that part, I realized the telescope-making gods were really with me on this project," he joked. Another piece of the puzzle is a counterweight mechanism to balance the chair for the observer's weight. Regular barbell weights and pipe fittings provide this adjustment.

The chair's drive system uses pairs of motors from Celestron NexStar 4SE telescopes. "I salvaged one set of motors from an old telescope, and I purchased another set from Celestron," Butler explains. "When they're wired in series, they become dual-torque monsters."

The altitude motors drive a plastic-coated, ⅛-inch stainless-steel cable, which moves the back of the chair up and down. The azimuth motors drive a gear (also salvaged from the NexStar telescope). The motors are controlled with the NexStar's computerized hand unit, and everything is powered by a rechargeable battery pack.

When Butler arrives at his observing site, setup proceeds much as it would for a NexStar telescope. The chair is leveled with its back set vertical, and the footrest is pointed north. After initial alignment on the sky, the bino chair is ready to roll. "With the touch of a button the bino chair slews to my target," Butler reports. "I sit comfortably viewing while the chair tracks the sky. Other times I just enjoy effortlessly scanning while slewing the chair with the hand controller. I usually hang a thermos of coffee on one of the armrests, pausing to take a sip or two while viewing. That keeps me going all night long." Now that's comfort!

If you want to learn more about Butler's bino chair, you can contact him at p.namron@yahoo.com. ✦

NORMAN BUTLER

Norman Butler's computerized Go To binocular chair provides comfortable views with his 15×80 binoculars. The setup was built without the benefit of a fully equipped machine shop — many of the parts were salvaged or purchased at a hardware store.

A creature of comfort, contributing editor ***Gary Seronik*** *also pens this magazine's Binocular Highlight column. He can be contacted through his website,* ***www.garyseronik.com****.*

Processing Your Own Hubble Images

You can explore the Hubble Legacy Archive to create your own imaging masterpieces.

ROBERT GENDLER

MICHAEL A. STECKER

Astrophotographer Robert Gendler explains how anyone with a computer and an internet connection can navigate the Hubble Legacy Archive (HLA) to download and process data to produce images such as this colorful mosaic of M42, the Orion Nebula. All astronomical images are based on observations made with the Hubble Space Telescope, and obtained from the HLA. Unless otherwise credited, all images are courtesy of the author.

STAYING ACTIVE IN astrophotography can be challenging. There may be long stretches of time when weather conditions or work schedules don't cooperate. Rather than shelving the hobby, though, imagers have creative ways to stay productive and develop their processing skills. One exciting project is to explore the Hubble Legacy Archive (HLA) and produce beautiful pictures.

The HLA (**http://hla.stsci.edu**) was conceived in May 2006 as a joint project by the Space Telescope Science Institute (STScI), the Space Telescope European Coordinating Facility (ST-ECF), and the Canadian Astronomy Data Centre (CADC). Its primary aim is to transform the previous archive of individual Hubble observations into a user-friendly, science-ready archive of easily retrievable data products.

Thanks to the HLA, you can access calibrated Hubble Space Telescope data within seconds, rather than the hours or days that it used to take. The HLA also has an organized retrieval mechanism for different archive products, along with a "footprint" service that allows users to specify a point or area of sky and see what Hubble data is available. The new system's format allows your computer to display Hubble data like a sky atlas with an interactive display rather than an observation list. Currently, the HLA is compatible with *Mozilla Firefox*, *Safari* (version 5), *Internet Explorer* (version 7 and 8), and *Google Chrome*.

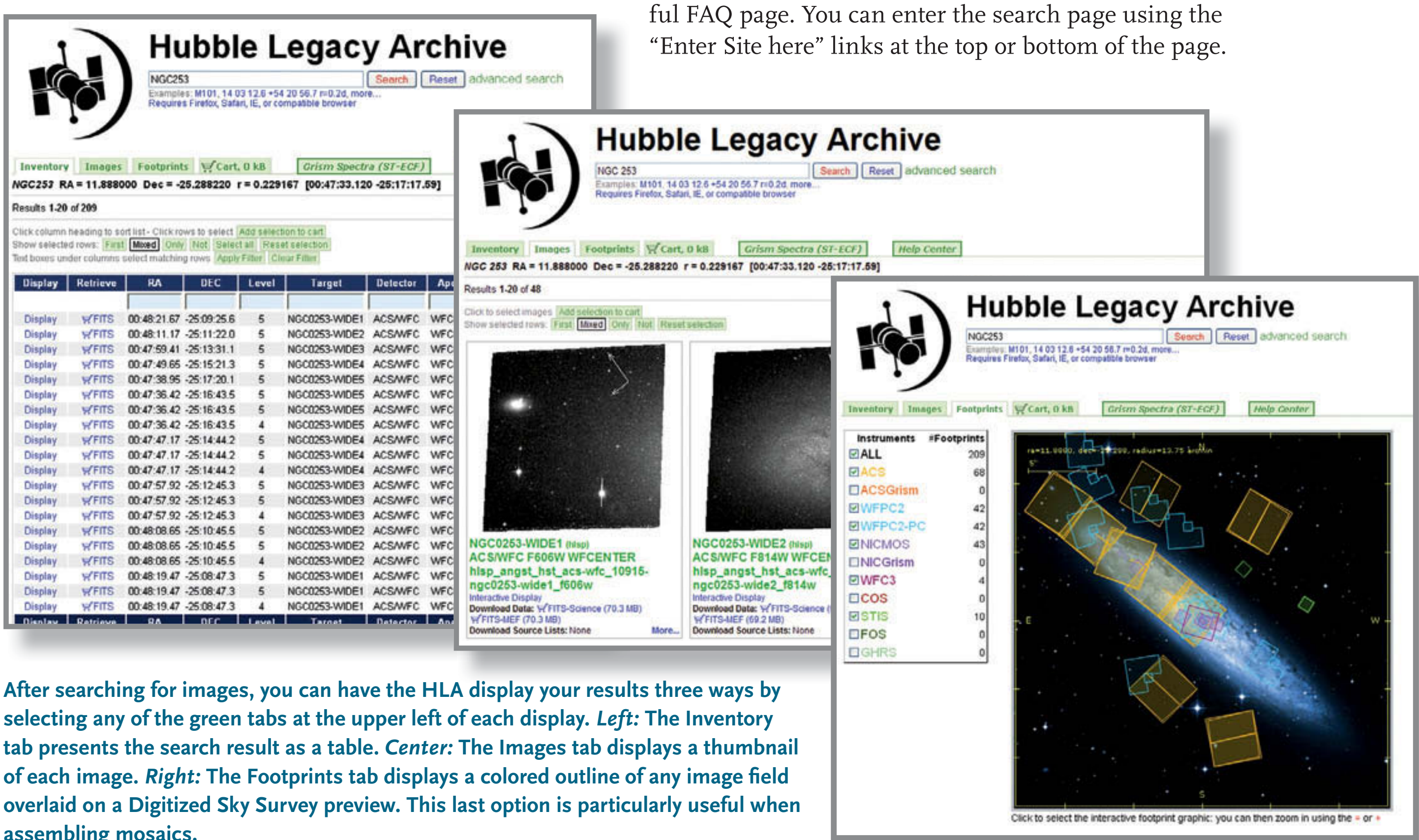
Before you delve into the HLA in search of images to assemble, it's important to remember that the vast majority of Hubble images are not recorded to produce "pretty" color pictures. The pictures we all see are usually made at a later time from data that scientists originally acquired to study certain physical processes or objects.

Astronomers take Hubble images with a variety of detectors and filters, but many of these combinations are unsuitable for making pretty pictures. The detectors I've found most useful for color images include WFPC2 (Wide Field and Planetary Camera 2), WFC3 (Wide Field Camera 3), and the ACS (Advanced Camera for Surveys). The best wideband filters to produce color images are F435W, F439W, F450W, F555W, F606W, F675W, F702W, F791W, and F814W. Narrowband filters often used are F437N and F502N (O III), F656N (H-alpha), F658N (N II), and F673N (S II). The numerical designation refers to the central passband of the filter in nanometers.

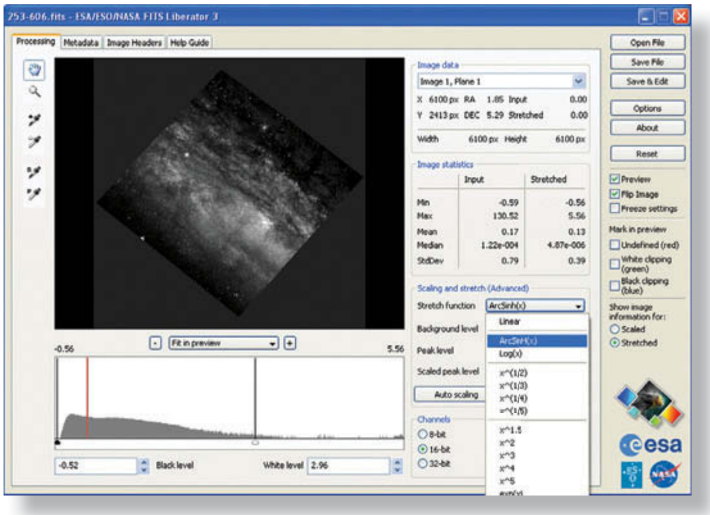
It's possible to create approximately true-color images from Hubble data only if three wideband exposures exist, and the filter passbands are close to the red, green, and blue sensitivity of the receptors in our eyes.

Navigating the HLA

Although the HLA appears daunting at first blush, retrieving data is relatively straightforward. When you first log on, the main page explains all the data currently available within the HLA archive. It also lists recent updates and provides multiple links to an extremely helpful FAQ page. You can enter the search page using the "Enter Site here" links at the top or bottom of the page.



After searching for images, you can have the HLA display your results three ways by selecting any of the green tabs at the upper left of each display. *Left:* The Inventory tab presents the search result as a table. *Center:* The Images tab displays a thumbnail of each image. *Right:* The Footprints tab displays a colored outline of any image field overlaid on a Digitized Sky Survey preview. This last option is particularly useful when assembling mosaics.



The free software *FITS Liberator* shown above provides users with an intuitive program that enables them to set the background and highlight levels of any FITS image. It includes a selection of preset stretch functions for displaying an image's entire dynamic range. Once you're satisfied with the results, you can save the image as a 16-bit TIF file to combine with other filtered images in programs such as *Adobe Photoshop*.

From there, you can start the search process by simply entering an object or the right ascension and declination coordinates into the search box.

Just below the search box is a list of search examples. A detailed tutorial page will open if you click the "more…" link, which explains many ways to search for particular objects. This tutorial is well worth reading because some data sets require special search parameters. Clicking the advanced-search hot-linked text allows you to specify the observing instrument (ACS, WFPC2, WFC3, etc.), spectral elements, and so on.

Below the search examples are tabs that provide basic ways to view the results of your search. Beginning at the left is the Inventory tab, which shows the results in a table format. Clicking on a column heading sorts the search results based on the chosen heading, such as detector, filter, or exposure time.

Next is the Image tab, which shows preview images. The site annotates each preview with exposure information such as the target name, instrument, and filter. It also has specific links that allow you to add the datasets to a cart for later download. Alternatively, one can simply right-click on the "download data" link and choose the "save target as" option to download the image. An interactive-display function allows you to zoom and pan the image before downloading it.

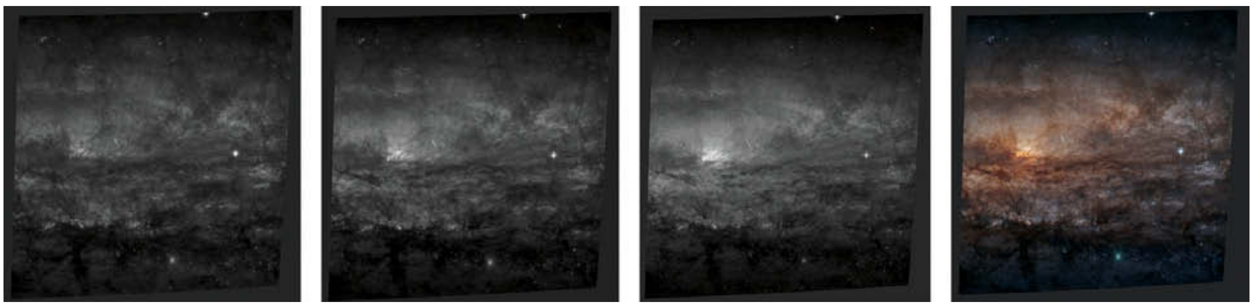
The third tab is Footprints, which brings up an interactive display of the various fields of each instrument data set overlaid on a Digitized Sky Survey (DSS) color composite of the imaged area. The Footprints display allows you to zoom and pan to view the outline of available data and it lets you select or de-select detectors graphically.

The last tab is Cart, which contains multiple data sets you've selected for download as compressed files grouped by target. There are some proprietary data sets that may not be directly available through the HLA but that can be retrieved through another download method. An archive account is required to retrieve these proprietary data sets, but this is relatively simple to set up.

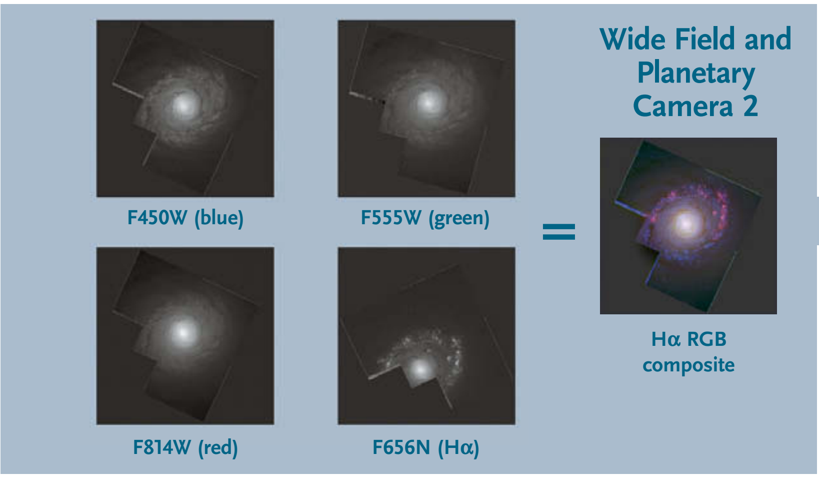
Liberating Software

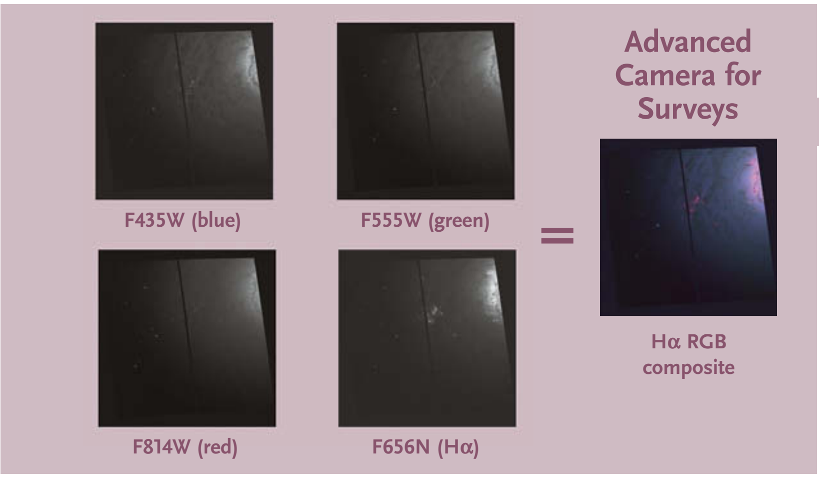
All unprocessed data available on the HLA are saved in FITS (Flexible Image Transport System) format, the standard format for astronomical images. Once your selected files are downloaded, they require processing to produce a color image.

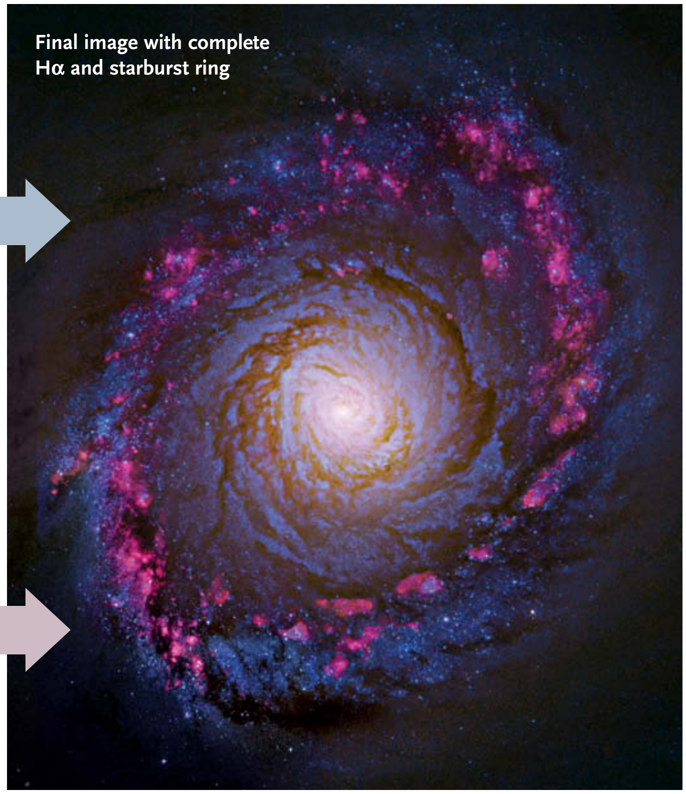
Previously, traditional graphics programs such as *Adobe Photoshop* could not open FITS files. Specialized astro-imaging software can manipulate these images, but there is another option for working with Hubble data: *FITS Liberator* (**www.spacetelescope.org/projects/fits_liberator/**). Developed by imaging scientists at the European Space Agency, the European Southern Observatory, and NASA, this free program was initially released in 2004 as an add-on component of *Photoshop*. It gave amateur astronomers the ability to manipulate professional astronomical data that was previously usable only by the scientific community. Today, *FITS Liberator* is a stand-alone program that no longer requires *Photoshop*.



Once you've stretched each of the FITS files, combining them into a color image is a straightforward process in most programs. This series of observations of the inner region of the galaxy NGC 253 is a rare complete set of wideband observations from Hubble's ACS camera. Each color channel was stretched using similar settings in *FITS Liberator* before final assembly in *Adobe Photoshop*.







Assembling mosaics of Hubble observations requires software that accurately registers astronomical images. The WFPC2 and ACS instruments recorded these two sets of observations *(left)* of the inner portion of galaxy M94 in Canes Venatici. The author aligned each image using *RegiStar* and then stitched them together before combining them into a color image *(above)*.

Using *FITS Liberator* is both intuitive and easy. Once you open an image, the program's primary function is to establish the picture's background and peak levels, and it compresses its dynamic range to show the brightest and faintest details simultaneously. My goal in *FITS Liberator* typically involves applying one of the stretch functions to boost shadow and mid-level data while avoiding burning out the highlighted regions. Under the Stretch function tab you'll find a list of presets, including logarithmic functions such as ArcSinh(x) and Log(x), as well as root functions. Each preset's effects depend on the image. The default stretch is linear, which is a good choice for data sets having low dynamic range, such as planet images. I find that the ArcSinh(x) preset typically produces the best results on high-dynamic-range images.

After settling on a preset stretch function, I'll adjust the sliders in the histogram window to refine the black and white points. You can also manually set background and peak levels by using the eye-dropper tools to the left of the image preview, or automatically by clicking on the auto-scaling button.

Another tool in *FITS Liberator* that I have found particularly useful is the reset button, which returns the image to its default settings if I need to start over. Checking the Freeze settings box recalls the previous settings when you open the application, which may be helpful for processing similar data sets. I keep the bit depth at the default value of 16. My final task is to save the stretched result as a 16-bit TIF file that I can then open for additional adjustments in *Photoshop*.

Visit skypub.com/hstprocessing for a gallery of beautiful Hubble images processed by Robert Gendler.

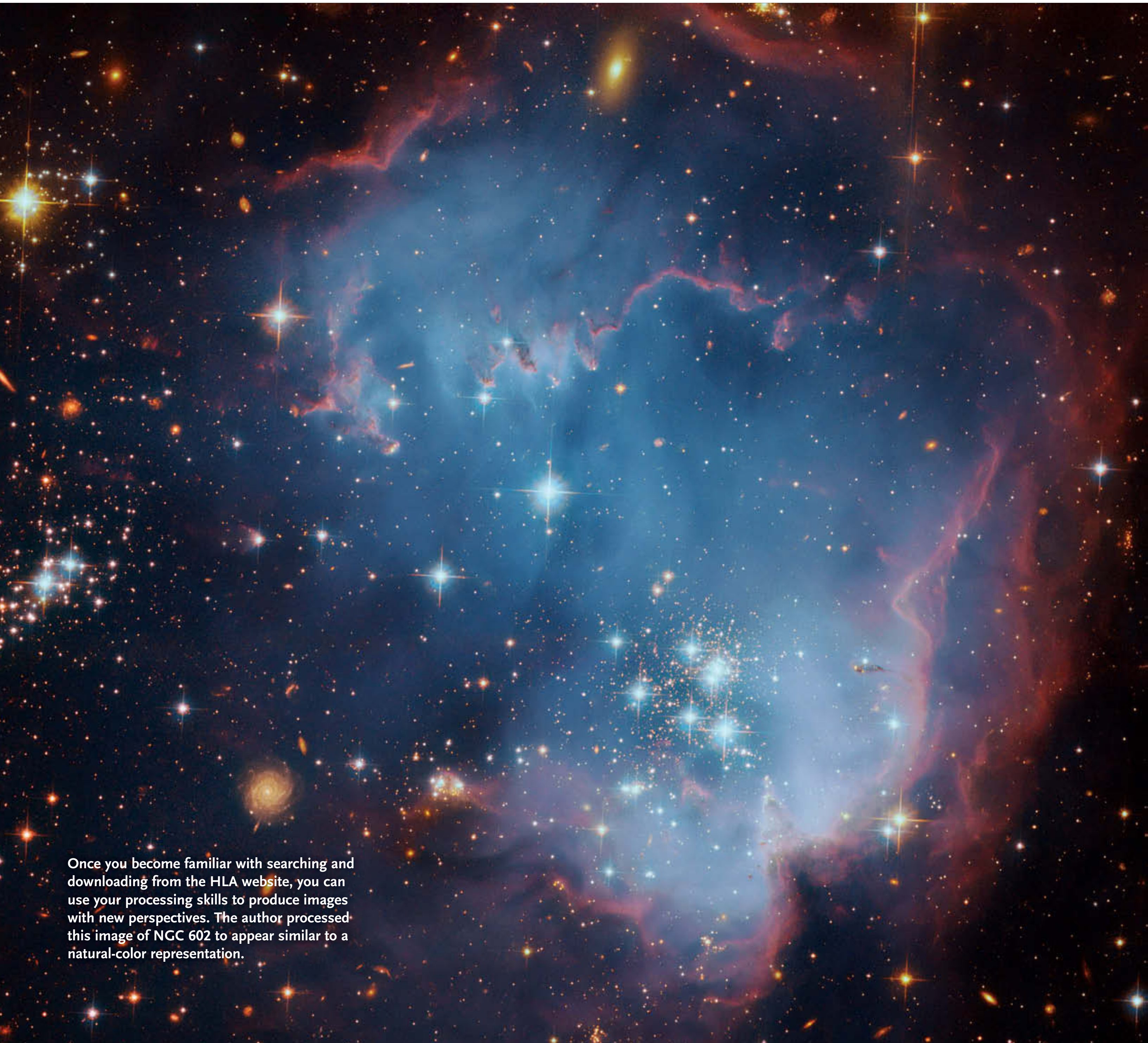
Creating a Color Image

As noted earlier, it's rare for a complete set of color data to exist for any one object. A simple rule of thumb for making a color image is to assemble the filtered images in chromatic order — the shortest wavelength is designated as the blue channel, the middle wavelength the green channel, and the longest wavelength assigned to the red channel. An ideal filter set for a pleasing tri-color image would be F435W (blue), F606W (green), and

F814W (red). A corresponding narrowband image made with the F656N (Hα) filter is particularly beneficial for galaxy images, since the F814W filter does not detect H II regions well. Often only two filtered channels are available for a given detector, such as F435W and F606W, or F606W and F814W, because scientists planned the observations for photometric measurements of stellar populations.

To make a tricolor image from these data sets, we need to somehow create the third channel. There are several ways to do this. We can assign the longest wavelength to red and the shortest to blue, and then average these two channels to make a substitute green channel. Alternatively, you can use a single-filtered data set for two color channels. An example would be if you have F435W and F606W; you can either average the two to create the missing color channel, or duplicate the F606W data set and use it as both the green and red channels.

Often a combined exposure within a given data set is labeled a "detection" on the HLA. This is considered a "white light" combination image, representing the sum of all the available filtered exposures for that observation. In this situation I sometimes use the detection exposure



Once you become familiar with searching and downloading from the HLA website, you can use your processing skills to produce images with new perspectives. The author processed this image of NGC 602 to appear similar to a natural-color representation.

This detailed observation of interacting galaxies NGC 2207 (left) and IC 2163 is a mosaic assembled from three overlapping observations captured with Hubble's WFPC2 instrument.

as the missing color channel. These strategies can often work surprisingly well in producing a pleasing tricolor image, though some two-channel combinations work better than others.

To achieve an even color balance between the individual channels in my final color composite, I often apply the same stretch to each filtered image in *FITS Liberator*. This helps when combining similar wideband exposures. If the data use different exposures or are a mix of wideband and narrowband images, I usually need to balance the results in another program.

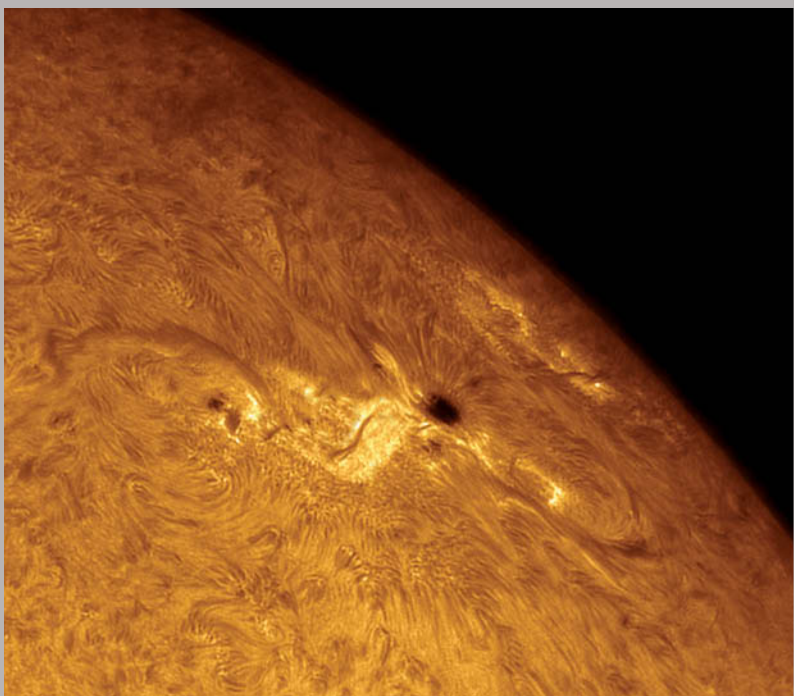
Once you prepare and save the individual color channels as 16-bit TIF files, you can assemble the final tricolor image in the graphics program of your choice. I prefer preparing the individual channels in *Photoshop*, then assembling the RGB composite in *MaxIm DL* (**www.cyanogen.com**). I often return to *Photoshop* to make any final tweaks.

Many of the images I've created from the HLA are mosaics, because a single data set is typically incomplete. Objects may not be centered on the detector or, in the case of the WFPC2, the composition may be awkward due to the odd shape of the camera's field. Fortunately, it's common to find overlapping data sets that can be stitched together to form a complete image.

Mosaics pose specific challenges because overlapping data sets having three suitable color channels are rare. Another problem when combining data sets from different HST instruments is having to deal with different pixel scales. In such cases I use the program *RegiStar* (**www.aurigaimaging.com**) to align images with different scales. When stitching together images for a color mosaic, I suggest stretching the data in *FITS Liberator* first, then registering the individual segments to one another using *RegiStar*. Save each registered section and then assemble the segments of each color channel in *Photoshop*. You should complete your final adjustments and blending of the overlapped segments before flattening the individual layers and assembling the final color composite.

The Hubble Legacy Archive is an extraordinary repository of fully calibrated, ready-to-use Hubble imaging data. This resource offers unprecedented opportunities to assemble images using exceptional astronomical data that were previously available only to professional astronomers. Creative strategies and approaches will empower the adventurous imager to expand the potential of this great reservoir of data for years to come. ✦

*Contributing photographer **Robert Gendler** mines the Hubble Legacy Archive from his home office in Connecticut.*



▲ **GRAND-SCALE VAPOR TRAILS**

Jerry Lodriguss

The Anomalous Transport Rocket Experiment (ATREX), launched from Wallops Island off the Virginia coast, released chemical tracers that appeared as luminous white clouds along the U.S. East Coast on the morning of March 27, 2012.

Details: *Canon EOS 550Da DSLR camera with 18-55 mm lens at 18 mm. The exposure was 20 seconds at ISO 3200.*

◄ **SOLAR ACTION**

Eduard Garcia-Ribera

Sunspot AR 1429 displayed numerous filaments as it approached the solar limb on March 14th.

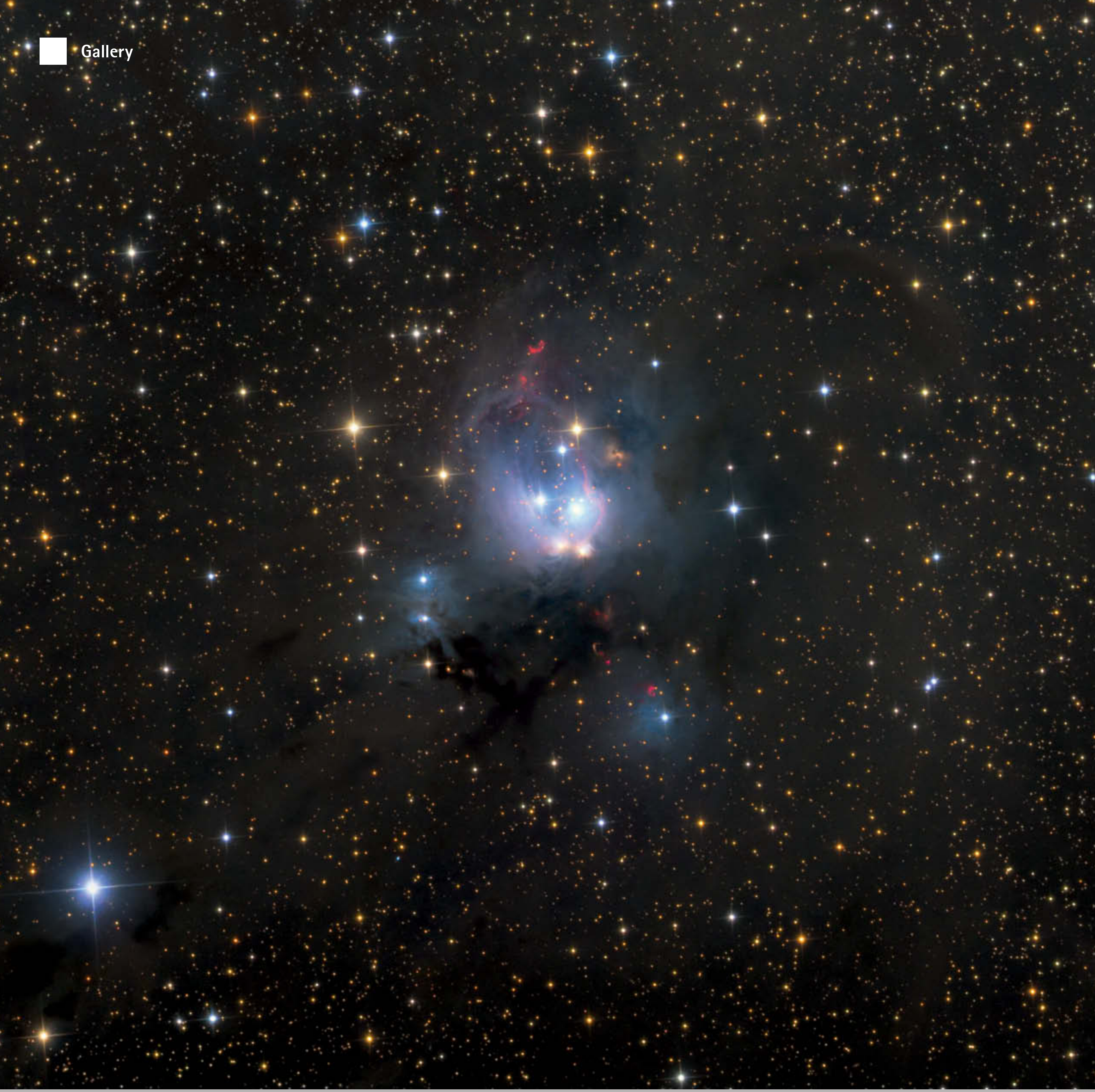
Details: *Lunt Solar Systems LS100THα solar telescope with Imaging Source DMK 31AU03.AS video camera. Stack of hundreds of frames processed in* RegiStax 6.

Visit skypub.com/gallery for more of our readers' photographs online.

▲ **OLD MOON IN THE ARMS OF THE NEW**
Jamie Cooper
The subtle beauty of earthshine was on display on March 24th when Jamie Cooper captured this photo from Northampton, England.
Details: *102-mm IKHAROS ED refractor with Canon EOS 550D DSLR. Composite of multiple exposures.*

► **CAPE COD CONJUNCTION**
Chris Cook
The crescent Moon joins brilliant Venus and fainter Jupiter above the Nauset Lighthouse in Eastham, Massachusetts, on the evening of March 26th.
Details: *Canon EOS 5D DSLR with 24-70 mm zoom lens. Exposure time was ½ second at ISO 640.*

▼ **MORNING VISITOR**
Amirreza Kamkar
The crescent Moon passes Venus as seen from the desolate landscape of the Maranjab Desert in Iran on the morning of March 1, 2011.
Details: *Canon EOS 500D DSLR with 15-mm fisheye lens at f/2.8. High-dynamic-range composite of multiple exposures ranging from 1⁄30 second to 4 seconds.*



STARBIRTH IN CEPHEUS

Ken Crawford

The picturesque complex NGC 7129 in Cepheus presents a plethora of clouds — including opaque dark, bluish reflection, and pinkish emission nebulae — as well as the brownish dust that permeates the entire region.
Details: *RCOS 20-inch Ritchey-Chrétien telescope with Apogee Alta U9000 CCD camera. Total exposure was more than 10 hours through Astrodon color filters.*

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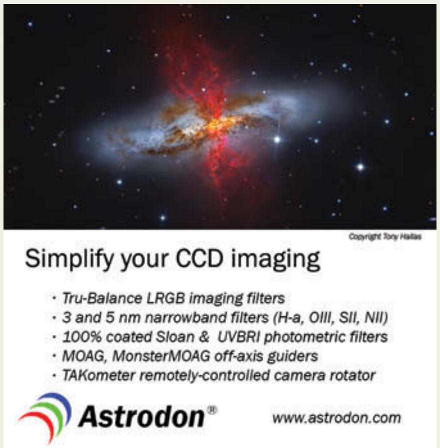

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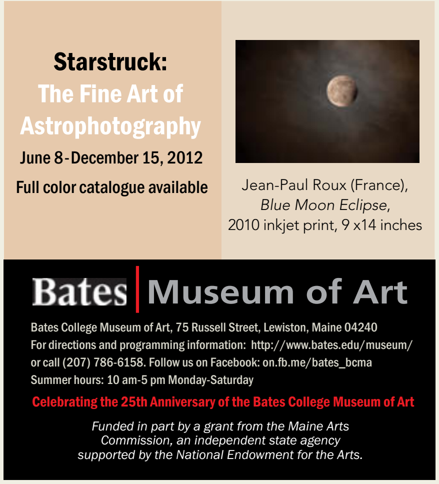

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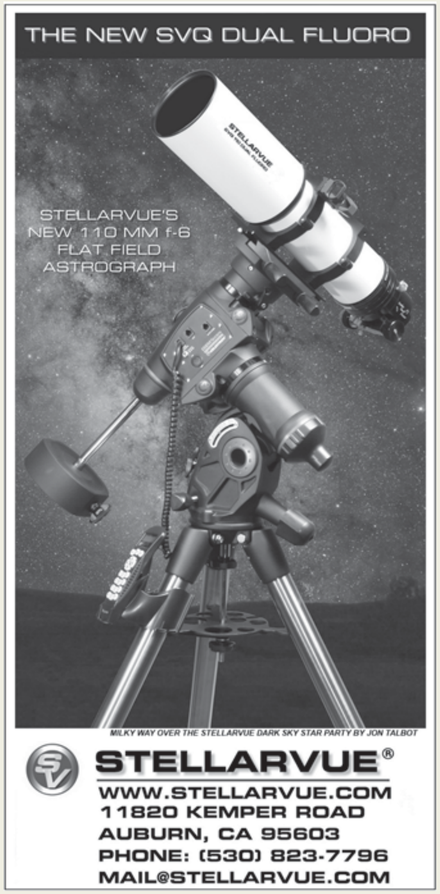

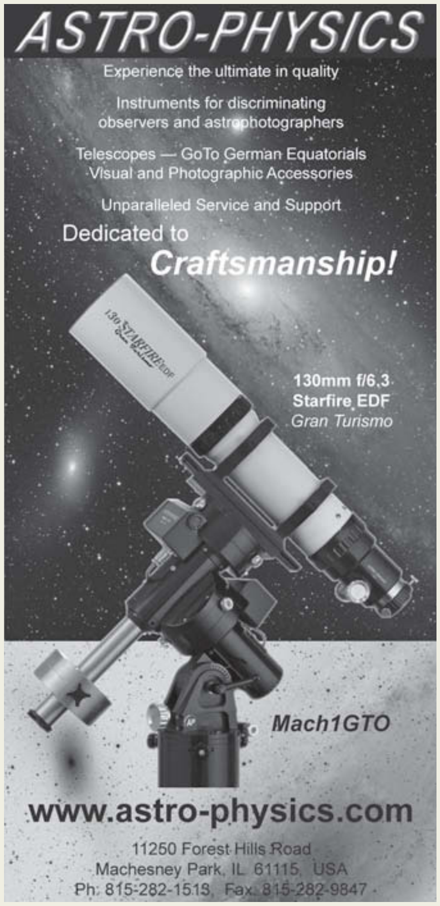

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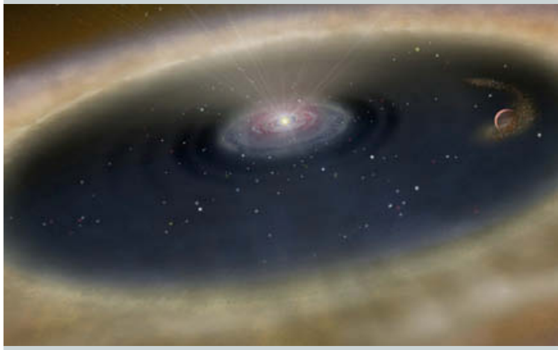

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Dave Dickinson

An Open Letter to 2117

What will the world be like for the next transit of Venus?

DANIEL GUIDERA

Greetings from 2012. I'm a backyard astronomer who is eagerly gearing up to observe the last transit of Venus in front of the Sun in our century. Ever since Jeremiah Horrocks observed the first fleeting passage of our nearest planetary neighbor in 1639 (January issue, page 64), we haven't missed an opportunity to view a transit. We've taken risks, traveling worldwide in an effort to measure the scale of the solar system and catch a glimpse of the black-drop effect (June issue, page 28). In 2012 we're even pointing our instruments at distant stars to catch transits of worlds orbiting them.

The transit of Venus is now more of a curiosity than a source of scientific understanding. Still, events that happen on such long timescales make us step back and wonder. What sort of world will exist over a century from now when the next transit of Venus occurs?

I won't attempt to make predictions as to just what sort of innovations you have; past futurists imagined travel by jetpacks or pneumatic tubes but missed mundane innovations such as laptops and e-mail. I can tell you that we're proud of achievements such as putting astronauts and telescopes in orbit, and we wonder if the Higgs boson really exists. Maybe you'll look back on our ideas as follies.

We also grapple with the growing pains that come with living in the early 21st century. Many still die of starvation and treatable diseases, and most of our 7 billion souls don't have access to quality education or medical care. Do you still wrestle with these problems, or do you face issues that we cannot foresee?

How we'd love to know how the human drama played out when the next transit of Venus approaches in 2117. What were the challenges of the 21st century and how did you conquer them? As a backyard astronomer, I love that the night sky connects me to the immensity of time as well as space. It's been said that a civilization that ceases to wonder soon ceases to be, and I suspect that if you're reading this, you still share our ancestors' will to explore the universe.

I wonder what methods you'll use to record the 2117 transit. In 2012, digital cameras and telescopes with hydrogen-alpha filters are all the rage, and I'll be one of many hoping for clear skies to use instruments that Horrocks could only dream of. What amazing technology will be available to you in 2117? I suspect that children in 2117 will still make pinhole projections of the Sun showing a tiny black dot transiting its face, just as humans have done since that first recorded transit in 1639.

It humbles me to think that just as there was a first, there shall be a last planetary transit documented by humanity. If you're reading this, then that already gives our generation a glimmer of hope that we somehow found a way to do the hard work of planning ahead so that a far-off generation can gaze upon the shadow of Venus crossing the face of the Sun anew and wonder of those generations past. ✦

Dave Dickinson (www.astroguyz.com) *is a science teacher, writer, and backyard astronomer in Hudson, Florida.*


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