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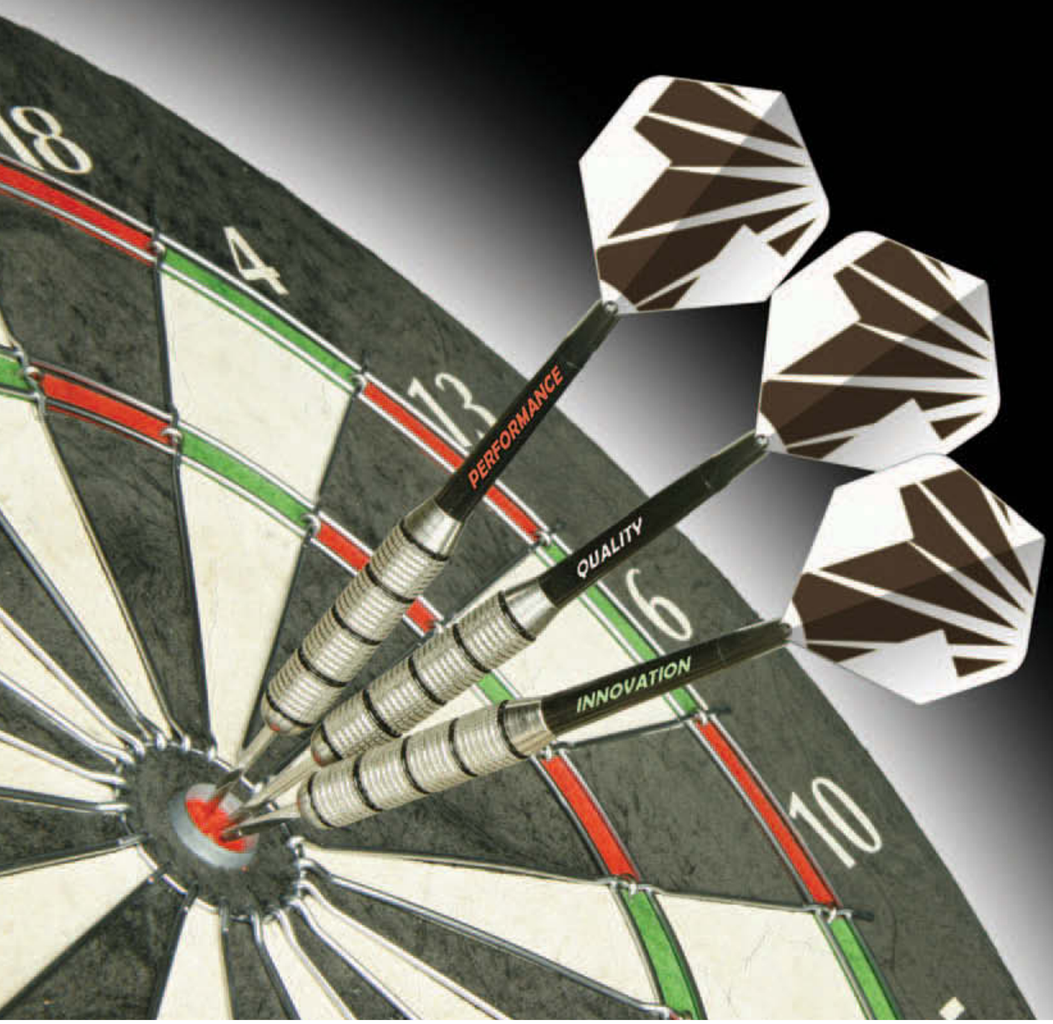

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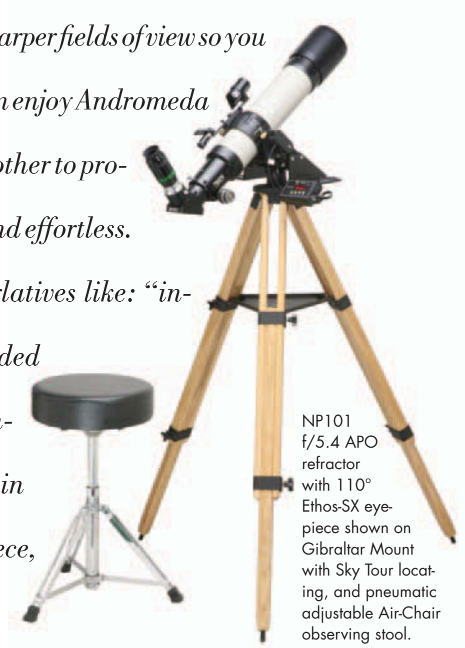

NP101 f/5.4 APO refractor with 110° Ethos-SX eyepiece shown on Gibraltar Mount with Sky Tour locating, and pneumatic adjustable Air-Chair observing stool.

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SKY & TELESCOPE

November 2013 VOL. 126, NO. 5

On the cover: Voracious black widow pulsars come back from the dead only to eat their stellar mates.

COVER: CASEY REED

FEATURES

OBSERVING NOVEMBER

S&T TEST REPORT

ALSO IN THIS ISSUE

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We're looking forward to heading out to the desert for a couple of days to do some imaging of Comet ISON. If you do the same, email us (support@skywatcherusa.com) your best shots and we'll put them up on our web site.

Comet ISON & Chile Tour

AS I WRITE these words in mid-August, my *S&T* colleagues and I are gearing up for Comet ISON. This month's issue contains Joe Rao's insightful analysis of how often great comets grace our skies (page 30). We also have maps in the Sun, Moon & Planets and Celestial Calendar sections that tell you exactly where and when to look. Our next issue will have a lot more information about ISON and comets in general, and our special annual editions *Beautiful Universe* and *SkyWatch* will also contain comet coverage.

I really, really wish I could look into a crystal ball and tell you how bright the comet will be at its peak. But in reality, we probably won't know for certain until late November or early December, after ISON reaches perihelion and begins moving into the dawn sky. Only then will we know how effectively the Sun's intense heat is ablating ice and dust from the comet's nucleus, which will ultimately determine the comet's appearance. Anybody who tries to give you definitive brightness predictions months in advance is either playing the hype game or doesn't understand the unpredictable nature of comets. At the time of this writing, ISON has not brightened as much as expected, so prospects for a glorious display seem to be dimming. But I'm not giving up hope just yet.

The internet is clearly well suited for rapidly changing news stories such as comet apparitions. I encourage you to frequently check **skypub.com/ISON**, where we will post regular updates, photos, and predictions, along with opportunities for amateur involvement.

Switching gears, *S&T* is once again partnering with Spears Travel for an astronomically themed tour of Chile. The trip will run from March 27 to April 4, 2014, and will include a tour of Cerro Tololo Inter-American Observatory (pictured at left), at least four nights of observing with Chilean amateur astronomers, and numerous trips to beautiful natural and cultural sites. Having been to Chile three previous times, I can assure you it will be a *great* trip.

S&T: ROBERT NAEYE

If you live in the Northern Hemisphere and have never been south of the equator, you owe it to yourself to check out southern sky spectacles such as the Magellanic Clouds (and their many associated deep-sky objects), the incredible globular cluster 47 Tucanae, and the glittering Jewel Box Cluster. For more details and an itinerary, visit **www.skypub.com/chiletour**. ✦

Robert Naeye
Editor in Chief

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

Choice for a New Era

In 1974, the city of Cottbus, Germany opened Raumflugplanetarium "Juri Gagarin." It celebrated the Soviet space pioneer, and welcomed visitors into its 12.5 meter dome to see the wonders of space. Over the years, thousands of students and families enjoyed the sky and the wonderful stories the staff could tell about it. But of course in the past 4 decades, the Soviet era ended and new technologies developed.

The Cottbus planetarium director, Gerd Thiele, is also president of the GDP, the German-speaking association of planetariums. As such, he and his team had the opportunity to see many examples of planetariums, to speak with colleagues, and to learn all about the realities of new systems. He did his homework regarding the fabulous capabilities of the new HYBRID systems, but also asked about real world issues such as long-term operational and maintenance costs, spare parts availability beyond the 10 years that some companies now offer, a strong European service and support system, and ultimately, the lifetime costs of systems.

The GOTO CHRONOS II HYBRID offered what he was looking for. He found a fulldome system that he really liked in RSA Cosmos, and after several European scouting trips, he chose RSA Cosmos to supply his future digital system and theater integration services. And after seeing a demonstration of a GOTO opto-mechanical sky in his own dome, he knew that the CHRONOS II was the right choice. This opto-mechanical projector was much more accurate and energy conserving than his old machine, has a more comprehensive control system, and a gorgeous sky.

And so on June 19, 2013, Europe's first GOTO CHRONOS II HYBRID planetarium opened to rave reviews. It won't be the last! Already, another CHRONOS II HYBRID opening is scheduled this fall, and more are to follow. Each one is making the choice of the GOTO CHRONOS II HYBRID to begin a new era for their planetarium. When does your planetarium's new era begin?

Cottbus Planetarium Director Gerd Thiele (left), RSA Cosmos president Benjamin Cabut (center), and GOTO INC president Nobutaka Goto (right)

* Photos by RSA Cosmos

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Call for Small-scope Observers

I am sending this letter to call for more volunteers for my double-star observing project (*S&T*: September 2012, page 68). The well-known Dawes formula predicts the aperture you'll need in order to resolve a stellar pair with a specific separation, but there's some controversy over the best way to calculate the needed aperture when the stars have different magnitudes. Instead of tackling that controversy head-on, I'm compiling observations for specific double stars in order to find empirically what works and what doesn't.

You can see the project and what has been found so far by typing the URL **http://bit.ly/14dVKSU** into your web browser. But while I have many (well appreciated!) volunteers, I need even more. The task is daunting: we need as many observations as we can get, and from as many observers as possible, to confirm the smallest aperture that splits 51 different test pairs. We might need as many as 50 such confirmations for each pair. I especially need observers with small telescopes, less than 100 mm in size. Volunteers don't need to do any measuring or have experience in double-star observing — they just need to take a look at the pair and see whether or not their aperture shows two distinct stars instead of one. The difficult parts are giving up time you could use to observe something more glamorous and catching pairs when they are still up in the sky. But this project could make history, so I'm not ashamed to ask for your help.

Sissy Haas
823 Reamer Avenue Ext.
Greensburg, Pennsylvania 15601
has103@comcast.net

Astronomy Exports for the Future

I was very interested in Robert Naeye's June Spectrum column on fostering astronomy in developing nations (page 6). When I read it I was about to go to the rural southeast town of Nueva Guinea, Nicaragua, where I serve on the board of a school that I helped found called Colegio Cristiano Manto de Gracia. We are trying to develop a solid math and science curriculum, and I was traveling there to host a star party. I purchased a small (114-mm) reflector to take down, too, which I left for the students to use.

We had two clear nights to look through the scope and had about 100–125 people attend. While the main attraction was looking at Saturn with its rings, we also enjoyed views of the young crescent Moon and Venus. I love hearing the excitement when someone sees Saturn's rings for the first time — you don't even need a translator to understand it! I also did a short presentation on the Milky Way and had a scale model of the inner solar system. I hope that this will spark a lifelong interest in learning for some of the students. Children in Nicaragua are hungry for anything from the U.S., so why not export science and math instead of pop culture?

You might ask yourself, how do you get word out about a star party in a rural farming town in the middle of the Central American rain forest? Facebook of course!

Bret Dahl
McKinney, Texas

Einstein and the Telescope

Thank you for the wonderful account of Einstein's intersection with amateur astronomer and telescope maker Zvi Gezari (June issue, page 32). One question: the article never indicates whether Einstein ever observed anything through the telescope Gezari built for him. Is there any evidence that Einstein spent time under the stars with his new scope?

Brian Peterson
Lexington, South Carolina

Editor's Note: *There's no record that Einstein ever used the telescope, but neither is there a reason to think he didn't use it at least once. We simply don't know.*

The story of Einstein's telescope brought back some wonderful memories I have of Zvi Gezari. During the 1950s I was also a member of the Optical Division of the Amateur Astronomers Association of New York, and I remember Zvi well. He was dynamic and outspoken, and he held strong opinions that he shared readily and often. I last saw him at Stellafane in the late 1960s, and he was as outspoken and dynamic as ever. He never mentioned his gift to Einstein, and reading about it reminded me of his generosity and the old Optical Division's far-reaching effects.

Although some parts of the telescope Zvi made might indeed have come from war-surplus materials, they most likely would have been of American origin. We all scrounged bits and pieces from the surplus dealers on New York's Canal Street, and metric components were not unusual. The equatorial mount was fabricated from aluminum castings designed by Richard Luce, who was chairman of the Optical Division and a retired mechanical engineer. I machined a mount of the same size from Dick's castings, as well as a larger size, and I still use both on occasion.

As a footnote: the inscription "TMML" on the mirror may mean "Telescope Mirror Making Lab," the grinding and polishing areas separate from the machine shop.

Francis J. Manasek
Norwich, Vermont

Fighting the Dew

I thoroughly enjoyed reading Rod Mollise's article on combating dew formation on observing gear (July issue, page 30). Dew has long been a bane to amateur astronomers. I have long sought a dew-removal solution like the battery-powered heat guns he mentioned. Until this article, I had no idea such devices even existed. Thank you for showing me the light!

Keith Stanley
Charleston, Illinois

Write to Letters to the Editor, *Sky & Telescope*, 90 Sherman St., Cambridge, MA 02140-3264, or send e-mail to letters@SkyandTelescope.com. Please limit your comments to 250 words. Published letters may be edited for clarity and brevity. Due to the volume of mail, not all letters can receive personal responses.

As a newbie to observational astronomy, I found Mollise's piece "Dew Busting" most informative. I have a dew shield for my Celestron 9.25 Schmidt-Cassegrain and Kendrick heater strips in my equipment bag, but Mollise's advice will certainly spare me a lot of heartache in the future.

David Davidson
Atlanta, Georgia

For the Record

✷ *The spectrum labeled "Comparison star" on page 26 of the September issue should instead be "Comparison spectrum." The spectrum is an emission spectrum from an arc lamp, a low-density gas-filled tube through which a current is run to excite atoms.*

✷ *The planetary nebula shown on page 58 of the August issue is NGC 6751, not 6571 (5 and 7 are transposed). The nebula is correctly identified on the previous page and in the table. Also, Teutsch J1906.4–0647 should be Teutsch J1906.3–0647. For all errata in 2013 issues, see* **skypub.com/errata**.

75, 50 & 25 Years Ago

Roger W. Sinnott

November 1938

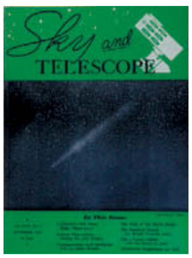
Wavy Meteors "At Harvard College Observatory Dr. Fred L. Whipple found oscillations in meteor trails that could in many cases be traced to the action of the camera and not the meteor. . . . Vibrating at 1/ 20th of a second one camera produced like fluctuations in a meteor trail. . . .

"Since the vibrations occur at a constant rate they act as a graph on which the meteor plots its speed. The accuracy is almost as great as can be obtained when the meteor is timed by a rotating shutter. The method has the advantage that many meteor trails already photographed on Harvard patrol plates can now be measured for velocity."

Whipple was famous for innovative techniques. Another time he determined the distances of meteors by measuring the extent to which their tracks were out of focus, compared to stars, on telescopic photographs!

November 1963

Lost Comet "This winter may see the recovery of a faint periodic comet lost for over half a century. This is Comet Tempel-Swift, discovered in 1869 by the German amateur Wilhelm Tempel. . . . It was reobserved on three later returns to perihelion, in 1880, 1891, and 1908. No one has seen it since.

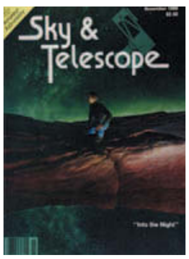


"What happened to this comet has now been explained by B. G. Marsden, Yale University Observatory, from his calculations with an IBM 7090 computer. Close approaches to Jupiter in 1911 and 1913 increased the orbital period of Tempel-Swift to 6.0 years. . . . By unlucky accident, this placed the comet always behind the sun at perihelion. Observations were impossible until further approaches to Jupiter in 1935 and 1946 lengthened the comet's period."

Tempel-Swift remained lost through 1963, leading Marsden and others to devise better prediction methods by considering the effect of outgassing from the comet itself. The MIT Lincoln Laboratory's automated LINEAR telescope finally swept the comet up by accident in 2001. It is now called Comet Tempel-Swift-LINEAR.

November 1988

Solar System's Edge "Although it has been five years since Pioneer 10 crossed the orbit of Pluto . . . scientists expect that the spacecraft will soon reach another milestone, when it ceases to ride the flow of the solar wind and enters interstellar space."



Telemetry from Pioneer 10 was expected to show it leaving the heliosphere when the spacecraft reached about 50 astronomical units from the Sun. But it didn't. Then in 1998 Voyager 1 overtook Pioneer 10, and it's now 125 a.u. out. In 2012 Voyager 1 signaled it might be nearing the edge — but it will take some time to be sure.

SUN | Weakest Solar Cycle in a Century

The Sun overslept its typical 11-year sunspot cycle, and since it finally woke up (a year late), it's given the weakest performance in 100 years.

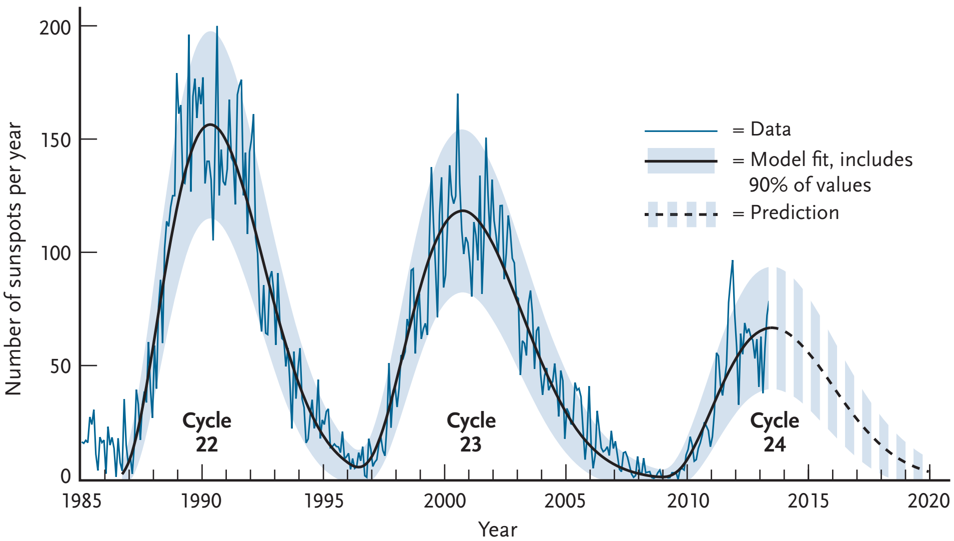
Three scientists, David Hathaway (NASA/Marshall Space Flight Center), Giuliana de Toma (High Altitude Observatory), and Matthew Penn (National Solar Observatory) presented possible explanations of the Sun's odd behavior at July's meeting of the American Astronomical Society's Solar Physics Division in Bozeman, Montana. But their ideas sparked a lively debate.

All three agreed that the Sun has followed its normal pattern of activity, but to a much smaller degree. A cycle starts with the Sun's magnetic field weak and dipolar — like a giant bar magnet. Our star rotates fastest at its equator, and this differential rotation wraps the magnetic field lines like rubber bands around the solar surface. The magnetic tangles that result usually produce sunspots, prominences, flares, and coronal mass ejections.

But this time, the normally frenetic activity was muted. "Not only is this the smallest cycle we've seen in the Space Age, it's the smallest cycle in 100 years," Hathaway says.

The latest cycle is also oddly asymmetric. The Sun's north pole has led the cycle since 2006, with the south pole lagging behind. The hemispheres aren't always in sync, but usually any asymmetry resolves in a year or so. "We don't know why this is lasting for so long," de Toma says.

Despite Cycle 24's weakness, it could be part of the Sun's normal variation. Hathaway and de Toma cited records showing weak cycles at the turn of the 19th and 20th centuries. Perhaps the solar cycle tapers every 100 years or so in what's known as the *Gleissberg Cycle*. But it's not easy to establish the existence of a cycle that turns



The number of sunspots has decreased over the past few decades, with the current cycle (Cycle 24) shaping up to be only half the strength of the cycle that peaked around 1990.

S&T: LEAH TISCIONE; SOURCE: DAVID HATHAWAY / NASA MSFC

SPACE WEATHER | Radiation Belts Powered Locally

Space physicists have confirmed that electrons in the heart of the Van Allen radiation belts surrounding Earth are accelerated to relativistic speeds by a local kick of energy, rather than by riding an electromagnetic tsunami that starts far out and then crashes inward.

Scientists discovered the Van Allen belts 55 years ago using the United States' first artificial satellite, Explorer 1. The belts' charged particles are trapped, forced to spiral up and down along magnetic field lines at tremendous speeds.

Scientists have struggled to understand how the belts' electrons are accelerated to relativistic energies. Two competing theories emerged in the 1990s. The tsunami idea holds that solar storms force electrons from the outer magnetosphere inward, where stronger fields closer to Earth pump up their energy. The local idea envisions electrons accelerated in place, drawing their energy from electromagnetic waves in the solar wind.

Launched last August, NASA's two Van Allen Probes follow each other around Earth in looping 9-hour orbits that repeatedly plunge them through the radiation belts (*S&T*: December 2012, page 12). The probes had been on the job for less than two months when, on October 9th, electrons in the belts experienced a sudden energy surge. Measurements show that the intensity built up right in the heart of the magnetosphere and only later spread to particles farther out.

As Geoff Reeves (Los Alamos National Laboratory) and colleagues detail online July 25th in *Science*, the local acceleration is probably caused by very low-frequency radio waves in the solar wind. These waves amp up the electrons through a resonance akin to repeatedly pushing someone on a swing to reach thrilling heights.

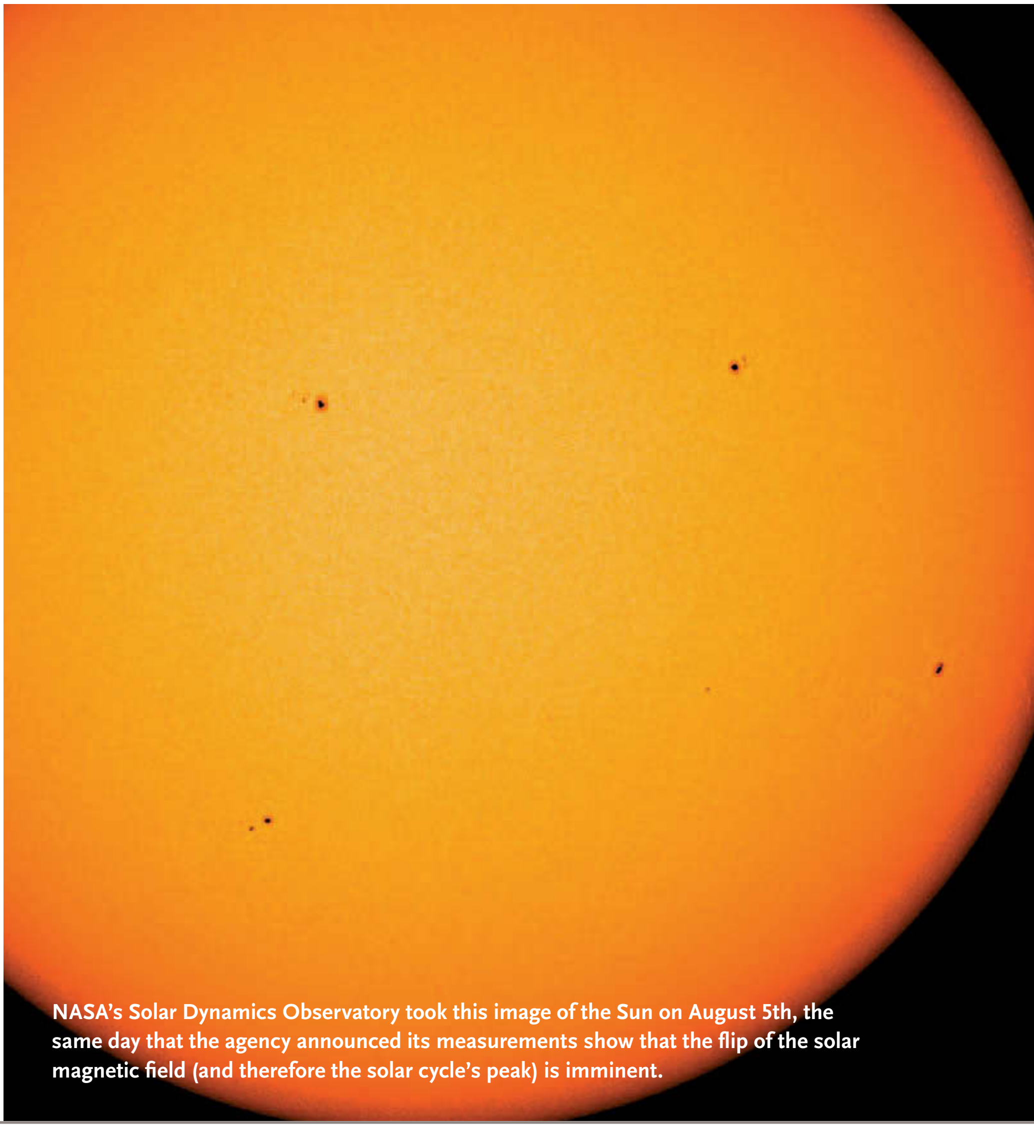
■ **J. KELLY BEATTY**

over on such a long timescale, much less what causes it. “Certainly I don’t understand how it works,” Hathaway admits.

Penn offered another, more catastrophic option: sunspots might die out. Using spectra to measure sunspots’ magnetic fields, his team found that the magnetic field strength in sunspots is waning. Once the magnetic field grows weak enough, sunspots will stop appearing on the photosphere, even though the solar magnetic cycle will continue.

But Penn acknowledges that other studies don’t all see the same trend: de Toma’s measurements, for example, show no change with time. De Toma was even able to reproduce Penn’s results by excluding small sunspots, suggesting Penn’s trend might result from the way his team selects their samples.

Despite the controversy, scientists are already trying to predict the strength of Cycle 25, expected to peak in 2024. Penn anticipates a wimpy cycle if sunspots’ fields continue to weaken. Hathaway is instead focused on the *meridional flow*, the flow of magnetic flux from the Sun’s equator to the poles. A stronger flow would help strengthen weak polar fields, but so far meridional flows have been completely absent in Cycle 24. Despite their different methods, Penn and Hathaway expect the same: the next cycle will be the weakest yet.
■ **MONICA YOUNG**



NASA’s Solar Dynamics Observatory took this image of the Sun on August 5th, the same day that the agency announced its measurements show that the flip of the solar magnetic field (and therefore the solar cycle’s peak) is imminent.

NASA / SDO / HMI

BLACK HOLES | Snack Swinging Through Galactic Center

The gaseous snack inbound for our galaxy’s supermassive black hole (June issue, page 23) might be starting to swing around the beast. Called G2, the mystery object was discovered in 2011 dive-bombing toward the black hole. It appears to have about 3 Earth masses in gas, but scientists debate whether it’s merely a cloud or hides a young enshrouded star.

Astronomers had forecast that G2’s closest approach to the black hole would occur around September 2013. This spring, Kim Phifer (University of California, Los Angeles) and colleagues pushed that estimate back to March 2014 after analyzing Keck observations spanning June 2006 through August 2012.

Now Stefan Gillessen (Max Planck Institute for Extraterrestrial Physics, Germany) and his colleagues think they’ve spotted a turnaround. Observations done this April with the Very Large Telescope in Chile show a shift in part of G2’s emission: instead of being entirely redshifted — which means the emitting object is moving away from us along our line of sight — a fraction of the diffuse gas is now blueshifted. That implies that the front-most bit of gas has swung around the black hole and begun moving back toward us after its closest approach.

That doesn’t mean the March 2014 estimate is off. Although G2’s compact “head” is roughly 100 Earth-Sun distances wide, its diffuse part is stretched across 10 times that distance. Gillessen’s team estimates that only 7% of the cloud had swung around the black hole when they observed in April. The main chunk of gas is therefore still en route.
■ **CAMILLE M. CARLISLE**

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

IN BRIEF

Under stress, asteroids are fragile. Naomi Murdoch (Institut Supérieur de l'Aéronautique et de l'Espace, France) and colleagues simulated asteroid soil with 3- to 4-mm balls placed between two cylinders. The inner cylinder rotated and dragged the balls with it, and when it reversed direction in 1 *g*, only the innermost balls were jerked. But in microgravity aboard a parabola-flying jet, the forces rippling out disturbed the distant balls, too — more like the behavior expected from a fluid. The pseudo-soil result suggests that spacecraft landing on asteroids could trigger long-distance avalanches, the team reports in an upcoming *Monthly Notices of the Royal Astronomical Society*. The study will help mission planners predict surface behavior for NASA's upcoming OSIRIS-REx, which will collect samples from asteroid 101955 Bennu.

■ MARK ZASTROW

Far-out exoplanet imaged. Using the Subaru telescope on Mauna Kea, Masayuki Kuzuhara (National Astronomical Observatory of Japan) and colleagues have spotted what may be one of the lowest-mass exoplanets ever found by direct imaging. The object orbits a whopping 44 astronomical units from its Sun-like host star GJ 504, better known as 59 Virginis. An unusually blue spectrum and cool, 500-kelvin temperature suggest that the companion's atmosphere is relatively cloud-free, unlike most gas giants, the team reports in the September 1st *Astrophysical Journal*. But the planet's mass is still debated: if the host star is a few billion years old instead of the few hundred million that the discoverers predict, the planet would have had time to cool to its present temperature even if it's a brown dwarf.

■ SHARI BALOUCHI

DANA BERRY / SKYWORKS DIGITAL, INC.

STELLAR | Dead Stars Caught Colliding

This artist's conception portrays two neutron stars at the moment of collision. New observations confirm that colliding neutron stars probably produce short gamma-ray bursts.

Although astronomers haven't found a smoking gun for the violent collision of two neutron stars, two new studies contain a strong whiff of gunpowder.

Merging neutron stars are a hypothetical culprit for the brilliant but brief high-energy flashes called short gamma-ray bursts (GRBs). GRBs are the signal of powerful jets and fall into "long" and "short" categories. Long GRBs last longer than 2 seconds and are probably created by massive stars when their cores collapse to form black holes. Short GRBs are thought to come from the merger of two neutron stars, or a neutron star and a black hole.

The merger would be no elegant affair. As two neutron stars spiraled in for their final approach, they would cover about 50 kilometers every millisecond, says Daniel Kasen (University of California, Berkeley, and Lawrence Berkeley National Laboratory). "That's like a carnival ride that takes you around the city of Berkeley 1,000 times a second," he adds. The whirling would yank material off the stars' surfaces and fling it out into space, where it might be joined by more stuff ejected as a hot wind blowing off the merged object. The debris should be a mixture of heavy metals (such as gold and platinum) and radioactive waste, he says.

The radioactivity should cause a faint glow known as a *kilonova*. Recently, Kasen and Jennifer Barnes (same affiliations) determined that this glow should show up more in the near infrared than in the optical, where astronomers had been looking.

When NASA's Swift spacecraft detected the short burst GRB 130603B on June 3rd this year, two teams set out to find the theorized kilonova. Using the same Hubble Space Telescope observations taken nine days after the burst, Edo Berger (Harvard-Smithsonian Center for Astrophysics) and colleagues and Nial Tanvir (University of Leicester, UK) and colleagues independently found a near-infrared source where the GRB went off. If the infrared emission was just from the burst's afterglow, it should have faded away before then.

Tanvir's team also grabbed a second set of Hubble observations about 30 days after the burst, when the kilonova should have faded away. Sure enough, it was gone.

It's possible that the observed signal was just the burst's regular afterglow. But that would require the burst to have changed its fading behavior somewhere along the way, which is unlikely. The simplest explanation is that Hubble indeed caught a kilonova's signature.

"If this interpretation is correct, we have finally witnessed how many of the heavy elements in the universe were created, which would be very exciting," Kasen says.

Tanvir says any alternatives have to be really unusual. "It would certainly be a surprise if it turned out to be something else." ✦

■ CAMILLE M. CARLISLE

Search for Intelligent Worlds

To find extraterrestrial intelligence we should look for engineered exoplanets.

HUMANS HAVE CERTAIN qualities that distinguish us from other life: levels of abstract reasoning, awareness of past and future, and the ability to intentionally alter environments. This inventiveness enabled our species to weather the last ice age and populate nearly the entire planet. But do we have enough of these skills, on the necessary scale, to continue to thrive?

We have global influence but lack global control. We now dominate many of Earth's "natural" systems, and scientists have identified many accelerating global changes that may threaten the future of our civilization. Unlike most challenges our race has faced, these new self-imposed hurdles are inherently planetary in nature and will require globally coordinated responses. Our future survival hangs on the need to perceive and act on this scale.

Just in the nick of time, we may be starting to develop a kind of "planetary intelligence" that would enable us to anticipate, perceive, and respond to survival threats on a global level. The rapidly coalescing, technologically interconnected global *noosphere* (pronounced "new-oh-sphere," a term coined in 1922 by Pierre Teilhard de Chardin to mean "sphere of human thought") of trade and communication has some properties of an emerging consciousness. As in a primitive nervous system, information is sensed and exchanged through complex networks, and the global system reacts in various ways. Through us and our technology, the biosphere is arguably developing a global mind that may soon be able to fend off asteroid strikes and climate catastrophes.

©BIGSTOCKPHOTO / MIKE KIEV

Our survival may depend on refining and amplifying these tendencies. Britain's Astronomer Royal Sir Martin Rees, in his book *Our Final Hour*, gives civilization a 50% chance of surviving the next century. Others have described a kind of 21st-century bottleneck whereby our exponentially increasing technological prowess will either destroy our civilization or insure its long-term survival. This bifurcation may be a feature of technological civilizations in the galaxy. Many may be short lived but some could be nearly immortal. If so, our search for other intelligences is a search for survivors of the same kinds of challenges we currently face.

Over the long run planets are changing, unreliable homes, so some long-lived civilizations might not be confined to a single world. Others may engineer their planets. We're beginning to observe exoplanet atmospheres, so when our abilities improve, we should be on the lookout for signs of deliberately altered environments. How would we recognize these "noosignatures"?

We can imagine how we would terraform worlds or fix climate problems on a future Earth. If our descendants are still here and want to maintain their civilization, let alone a thriving biosphere, they will intervene to prevent future ice ages and, eventually, the Venus-style runaway greenhouse that will despoil Earth if left to its own devices. If an exoplanet has a strange climate that is being controlled by seemingly unnatural atmospheric compounds such as chlorofluorocarbons, that should grab our attention. Or if we find a world with a suspiciously unusual day-night pattern of brightness, we might suspect planetary engineering with mirrors or surface alteration. Of course, we can't really predict the actions of super-advanced intelligent aliens, so we can at best make reasonable guesses and be prepared for surprises. ✦

David Grinspoon *is Baruch S. Blumberg Chair of Astrobiology at the Library of Congress. Follow him on Twitter at @DrFunkySpoon.*

The Black Widows

A mysterious group of stellar corpses resurrect themselves by sucking life from their companion stars.

Roger W. Romani

Man-made particle accelerators have grabbed headlines recently with the discovery of the Higgs boson. But astronomers know that even more powerful accelerators lurk out there in the cosmos. The particles produced by these celestial accelerators give off high-energy radiation detectable with NASA's Fermi Gamma-ray Space Telescope. In our galaxy, spinning neutron stars called pulsars are the most prominent sources of this radiation. Beyond the Milky Way, accreting supermassive black holes that shoot jets straight at us (called blazars) are the most common luminous gamma-ray sources.

But the most mysterious sources have been a handful of bright gamma-ray-emitting objects not identified with either class. Astronomers have proposed several explanations, from distant galaxies to nearby clumps of annihilating dark matter, but no model has convincingly described all the sources.

New discoveries are shedding light on this mystery, implying that some of these gamma-ray sources are a special type of neutron star, a "black widow pulsar" that vaporizes its companion. Surprisingly, this discovery comes not from the high-energy space telescope that originally detected the sources but from standard ground-based telescopes, which can catch the visible light from the companion star's evaporation. In fact, the evaporation is not just visible, but dramatic — in a few cases amateur-class equipment can record the effects of these cosmic accelerators' death rays.

NO ORDINARY PULSAR

Like other millisecond pulsars, a black widow is a neutron star spun up to hundreds of rotations per second by stealing material from a stellar companion. The pulsar's wind blasts the companion, eventually whittling it down to a few hundredths the Sun's mass. The two stars are also very close together: about 0.01 astronomical unit, or less than one-thirtieth Mercury's distance from the Sun.

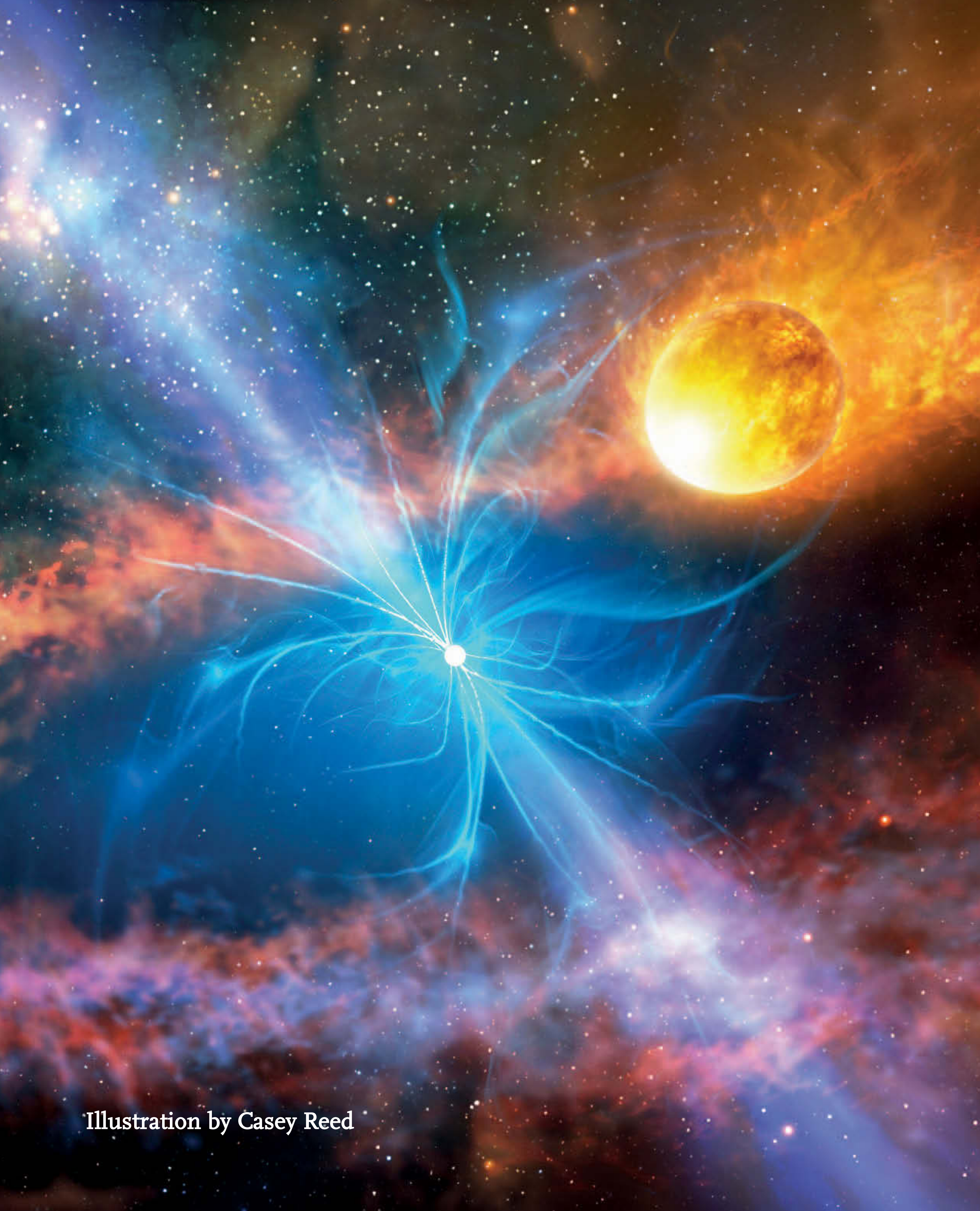
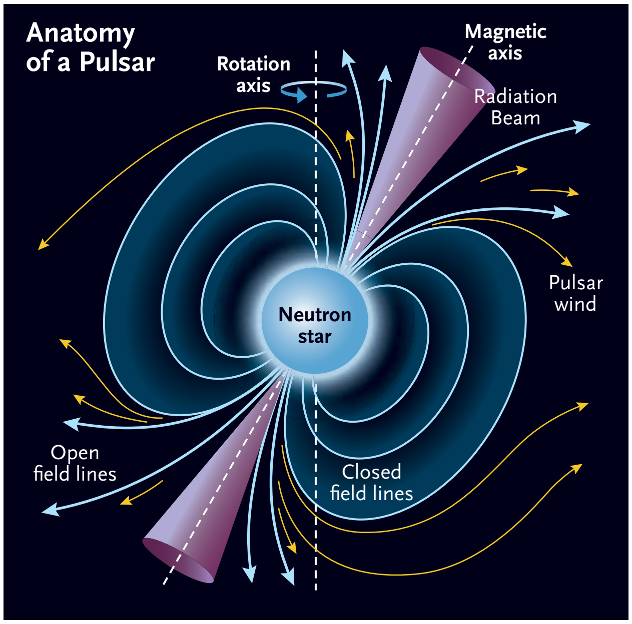


Illustration by Casey Reed



S&T: LEAH TISCIONE

STELLAR LIGHTHOUSE A pulsar is a spinning neutron star that beams radiation along its magnetic axis. Because the pulsar's magnetic axis doesn't line up with its rotational axis, the beam looks like brief, periodic flashes to us as it swings in and out of sight.

Death and Transfiguration

When a massive star explodes as a supernova, its core collapses to a 30-kilometer-wide neutron star with 100 trillion times the density of water. Often this collapsed core is threaded by an ultra-strong magnetic field and spins at periods less than 0.1 second. This field and spin conspire to boost charged particles to nearly the speed of light in acceleration zones above the star's magnetic poles. As these particles traverse the star's magnetic field, a small fraction of their energy converts to beams of radiation, with the remainder streaming out as a relativistic wind.

We have detected such beams for nearly 50 years as they sweep past Earth as the neutron star rotates. They often come in the form of brief radio flashes, like stellar lighthouse beacons. Although we detect most pulsars as radio sources, very energetic pulsars can emit across the electromagnetic spectrum, with particularly strong pulses in the gamma-ray band. All pulsar beams advertise the presence of powerful particle accelerators, but gamma-ray beams mark the most powerful pulsars of all.

Of course, this power isn't free. Over time, a pulsar's spin slows and the accelerator weakens. For the first 1,000 years or so, the relativistic particle wind can power a bright nebula, such as the Crab (M1). The gamma-ray beam can remain active for about a million years. After 10 to 100 million years, the energetically unimportant but easily detected radio pulses fade away, too. The neutron star languishes in the pulsar graveyard, cooling to a black cinder of obscurity.

But some pulsars get a second life. If the pulsar forms in a binary system, the binary companion may evolve enough after millions or billions of years to transfer matter to the long-quiet neutron star. The accreting material impacts the stellar corpse and spins it up to periods of a few milliseconds, restarting the particle accelerator and radiation beams.

When Don Backer (University of California, Berkeley) and his colleagues found a radio source pulsing at 1.6 milliseconds in 1982, the news rocked the world of high-energy astrophysics. The object spun 20 times faster than the Crab pulsar, which was the fastest pulsar then known. And with no sign of a recent supernova, the pulsar puzzled many astronomers: how could it be so energetic, spinning at 642 rotations per second in solitary splendor? It must have been resurrected somehow, but where was the binary companion that "fed it up" to such a short period, giving it rebirth?

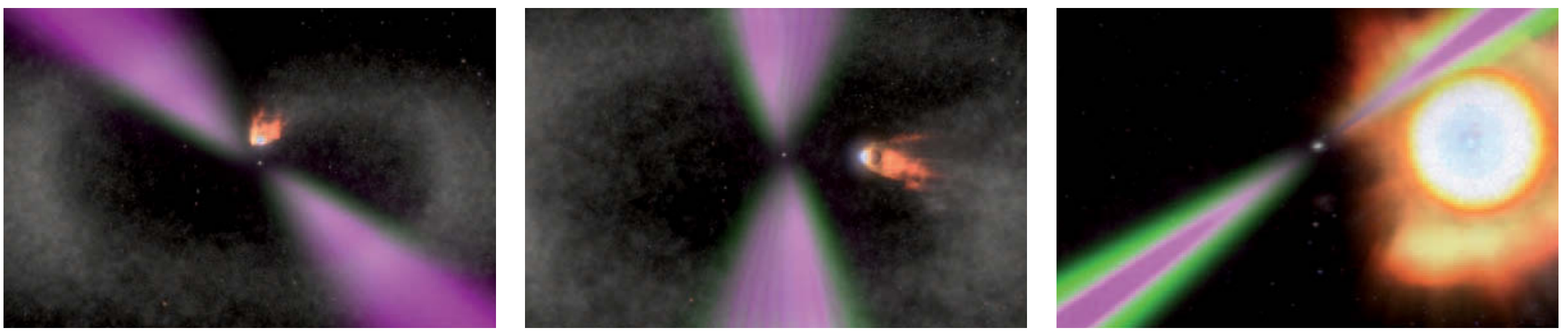
A Black Widow's Appetite

A likely solution to this puzzle was provided in 1988 when Andrew Fruchter and his colleagues (then all at Princeton

SANDBLASTING

The pulsar's wind eats away at the companion star, ripping off the outer layers (red and orange) and heating the "day" side (white and blue). (The third and fourth illustrations zoom in on the companion's blasted sides.) As the stars orbit each other, the companion alternately shows its day and night sides to us, making it appear to brighten and fade.

CRUZ DEWILDE / NASA GODDARD SPACE FLIGHT CENTER (6)



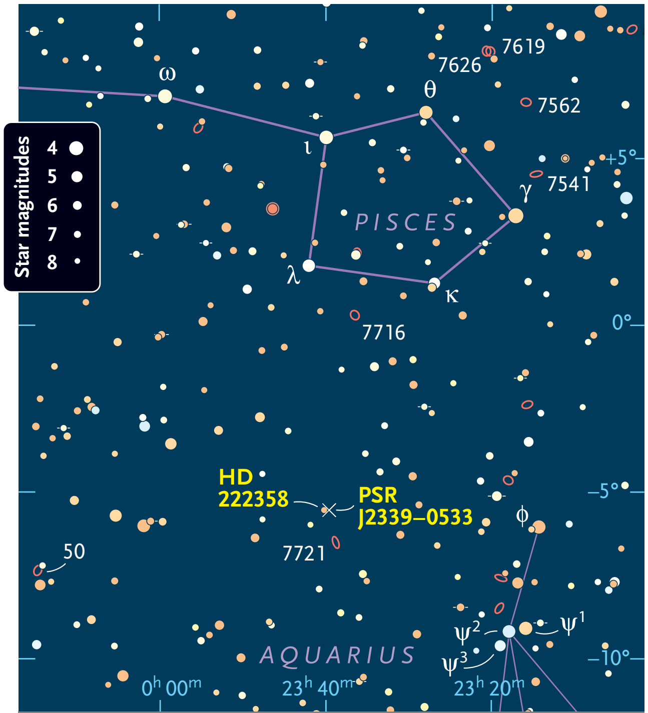
University) discovered PSR B1957+20. This millisecond pulsar is in a 9.2-hour binary orbit with a very-low-mass companion. Remarkably, the high-energy pulsar wind seems to be heating and expanding this companion, driving matter off its surface and whittling it down to a substellar mass (*S&T*: July 1995, page 13). The energetic millisecond pulsar, with cosmic ingratitude, is evaporating the companion that resurrected it from the pulsar graveyard. The popular moniker "black widow," invoking the female spider reputed to eat its mate after completing reproductive interaction, has stuck for such binary pulsars.

This black widow and the pulsar found in 1982 were discovered via their radio signals. This is unsurprising because radio telescopes are extraordinarily sensitive and therefore highly effective for pulsar surveys. But the dense, ionized gas flowing from an evaporating star can scatter or absorb radio waves. Indeed, J1957 exhibits radio eclipses, when the pulsar's companion lies between us and it and the neutron star's radio pulses must pass through the companion's evaporation wind. Black widow pulsars can thus hide behind the gas streaming off their doomed mates.

Uncovering Shy Widows

In the 25 years since the discovery of the J1957 system, astronomers have found only two other black widows in the Milky Way's galactic plane. We have detected several more in globular clusters, but the large distances and high crowding in clusters have made these pulsars difficult to study.

The launch of Fermi in 2008 changed all this. The black widows, and other particularly powerful millisecond pulsars as well, have been spun up to such short periods that their particle accelerators can produce gamma rays that show up brightly in Fermi's detectors. Searches with radio telescopes for pulsations at the positions of these gamma-ray sources have been very productive. In some cases, we have even found a pulsar in gamma rays without radio confirmation, using massive computer searches to test many trial periods for pulsations. Together, these efforts have already turned up more than 120 nearby energetic pulsars.



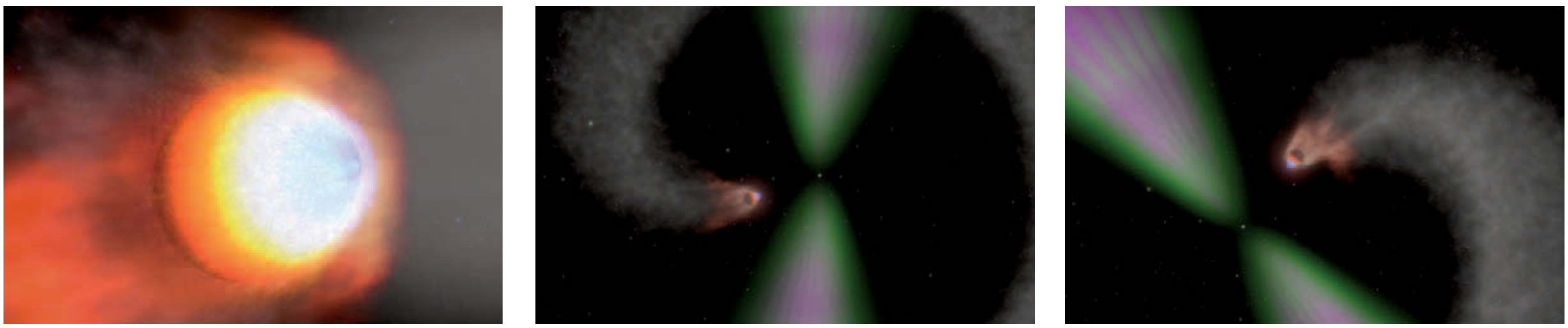
S&T: GREGG DINDERMAN

An Autumn Challenge

With the right equipment amateurs can detect the dramatic contrast between the pulsar-heated and cool sides of a black widow's companion. PSR J2339–0533 is near the Pisces-Aquarius border and nicely situated above the treetops during October and November evenings for those in mid-northern latitudes.

J2339 varies by three magnitudes over the course of its 4.6-hour orbit, reaching a peak magnitude of about 18. You'll need at least a 10-inch aperture and a CCD to catch the appearance and disappearance of the superheated companion.

The star is 3 arcminutes west of the 7.6-magnitude star HD 222358. Start observing an hour or two before peak so that you can follow the brightening and fading. For those wanting to estimate the phase, the more exact period is 0.1930983 day and maximum occurred at Julian Day 2456566.4952 (September 30, 2013, 23:53 Universal Time).



This pulsar haul includes 20 black-widow-type binaries. Why so many? Unlike the radio emission, the energetic gamma-rays can punch right through the companion wind, even if the star is violently evaporating. Given this strong gamma-ray signal, astronomers are motivated to check the source repeatedly in the radio, increasing the odds that they will catch a thin patch in the wind and detect the radio pulses when the pulsar is "in the clear." Without the gamma-ray signal, an astronomer surveying the radio sky would see nothing and move on. Thus, the Fermi gamma-ray sky survey provides a treasure map for pulsar hunters, saying "dig here."

Despite this success, a half-dozen sources out of the 250 brightest gamma-ray emitters had not been identified with blazars, pulsars, or their ilk. For the past couple of years my colleagues and I have been chasing down these mysterious sources. They are steady emitters, not varying over days or even years, and they have high-energy gamma-ray spectra, very characteristic of pulsars. But repeated radio searches see nothing, and computer studies of the gamma rays find none of the pulsations from young, energetic pulsars that they're designed to reveal.

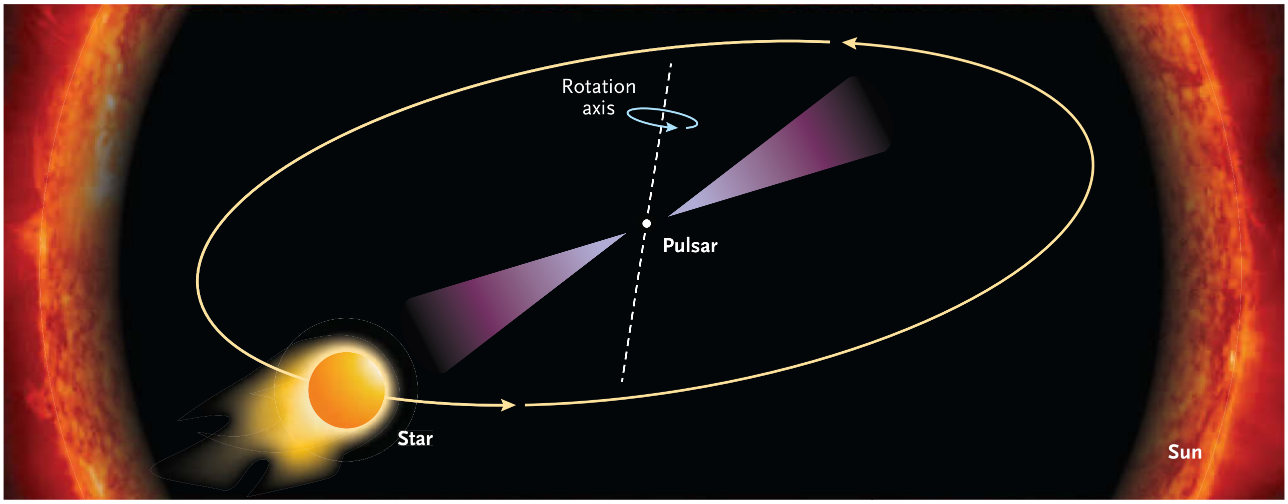
We have begun to suspect that these sources may be black widows in very tight orbits, with the pulsar buried deep in the companion's wind. The radio pulses may seldom or never make it through, leaving the pulsar virtually undetectable at radio wavelengths. Two recent discoveries support this story, and they show that the key is to look for the companion star. The relativistic pulsar wind is largely invisible — unless it hits something. In a black widow binary, the accelerated particles slam into the companion, heating it to a very high temperature. As the companion orbits the pulsar, we alternately see the bright, white-hot heated side and the faint, redder backside.

This is a distinctive signature, but finding such stars is not so easy. The same energy that lets gamma rays penetrate a pulsar wind makes them impossible to focus with mirrors, so Fermi instead "images" the gamma-ray sky by tracking the matter-antimatter particle pairs the photons make inside its detector. However, these tracks provide only limited angular resolution. Even a well-localized gamma-ray source might have a position anywhere in a patch of sky the size of the full Moon. If one is searching a galactic field for a faint variable source, there could be as many as 100,000 stars to check in that region! Thus it's not surprising that those discovered are in sparse fields well off the galactic plane or sources where other clues, such as from X-rays, help us zoom in on possible pulsars.

HOW MANY BLACK WIDOWS ARE OUT THERE?
The number of black widow pulsars found in the galaxy is growing rapidly. Currently there are about two dozen, with more discoveries on the way. The majority of these finds came thanks to NASA's Fermi Gamma-ray Space Telescope.

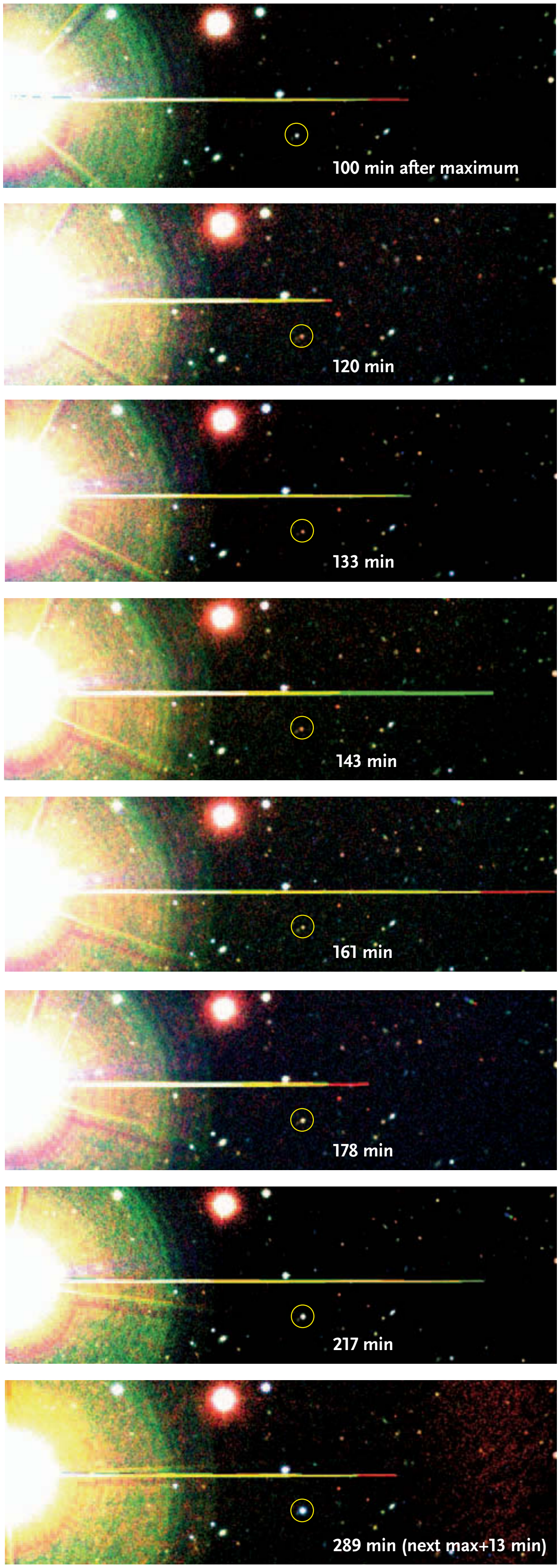
Two Black Widow Candidates at the Pulsar Frontier

The first success was for the Fermi source known as 2FGL J2339.6–0532. After Albert Kong (National Tsing Hua University, Taiwan) and his colleagues noted a variable star in the same region as the gamma-ray signal, we chased it down with a variety of telescopes to show that it is indeed the strongly heated companion to an invisible object spewing out more than 10 times the Sun's energy (probably as a pulsar wind). With the 10-meter Hobby-Eberly Telescope in Texas we obtained spectra throughout the 4.6-hour orbit. The source gave us a lesson in stellar spectroscopy, sweeping through the classes



S&T: LEAH TISCIONE

TINY BUT POWERFUL The black widow pulsar system J1311–3430 would fit inside the Sun. The orbit, companion star, and Sun are shown roughly to scale in this illustration, but the pulsar is much smaller than depicted here.



ROGER W. ROMANI (8)

TWO-FACED STAR These composite images from the 3.5-meter WIYN Telescope on Kitt Peak show the varying brightness and color changes of J2339's companion star (circled). The magnitude-7.6 HD 222358 is the brilliant star on the left.

from *F* (at about 7000 kelvin, when the heated side was in view) to *M* (at less than 3000 K, when seen from the back) in only two hours. This dramatic change is also visible in the companion's varying color throughout the orbit, shown at right.

This object turns out to be optically the brightest pulsar-heated binary known, with a peak magnitude of just under 18. To monitor the binary orbit we observed it with a 0.6-meter telescope at the Stanford University teaching observatory, where we clearly detected it through much of the orbit in 5-minute unfiltered exposures as it varied by three magnitudes. The star is easily found 3 arcminutes west of the magnitude-7.6 star HD 222358. Well-equipped amateurs with 10-inch-plus telescopes and sensitive CCD cameras should be able to detect this super-heated companion appearing and disappearing in a single observing session (see "An Autumn Challenge," page 19).

Perhaps even more spectacular is the recently discovered heated companion identified with the gamma-ray source 2FGL J1311.7–3429. This object varies by 4 magnitudes (from magnitude 20 to 24) with an unprecedented period of 94 minutes. In addition to the sinusoidal fading and brightening, it produces mysterious flares that increase the object's brightness up to magnitude 18. The companion's front surface has been heated to about 12,000 K — *B*-type-star temperatures. It's both intriguing and sobering to realize that as the heated face passes in and out of sight, we are witnessing the death throes of the companion as it suffers intense bombardment by the accelerator's wind.

After we identified the binary period for these two gamma-ray sources, other astronomers detected the millisecond pulses in both gamma-rays and radio, confirming their black widow nature. But the radio confirmation proved very difficult, with pulses so deeply buried in the companion's wind that they appear in only a few percent of the observations, when the wind fortuitously cleared. Such buried pulsars are unlikely to appear in any radio sky survey, so we needed Fermi to point to these sources.

Thus the Fermi treasure map continues to mark the sites of celestial-accelerator gold. With the first unidentified sources already proving to be two of the most extreme black widow pulsars known, we are eager to see what other accelerator surprises we can mine from the mysterious gamma-ray sky. ✦

***Roger W. Romani** is a physics professor at Stanford University and a member of the Kavli Institute for Particle Astrophysics and Cosmology. He is also a member of the Fermi mission's science team and studies neutron stars, black holes, and other high-energy objects.*

The Most Powerful Telescope Ever Built

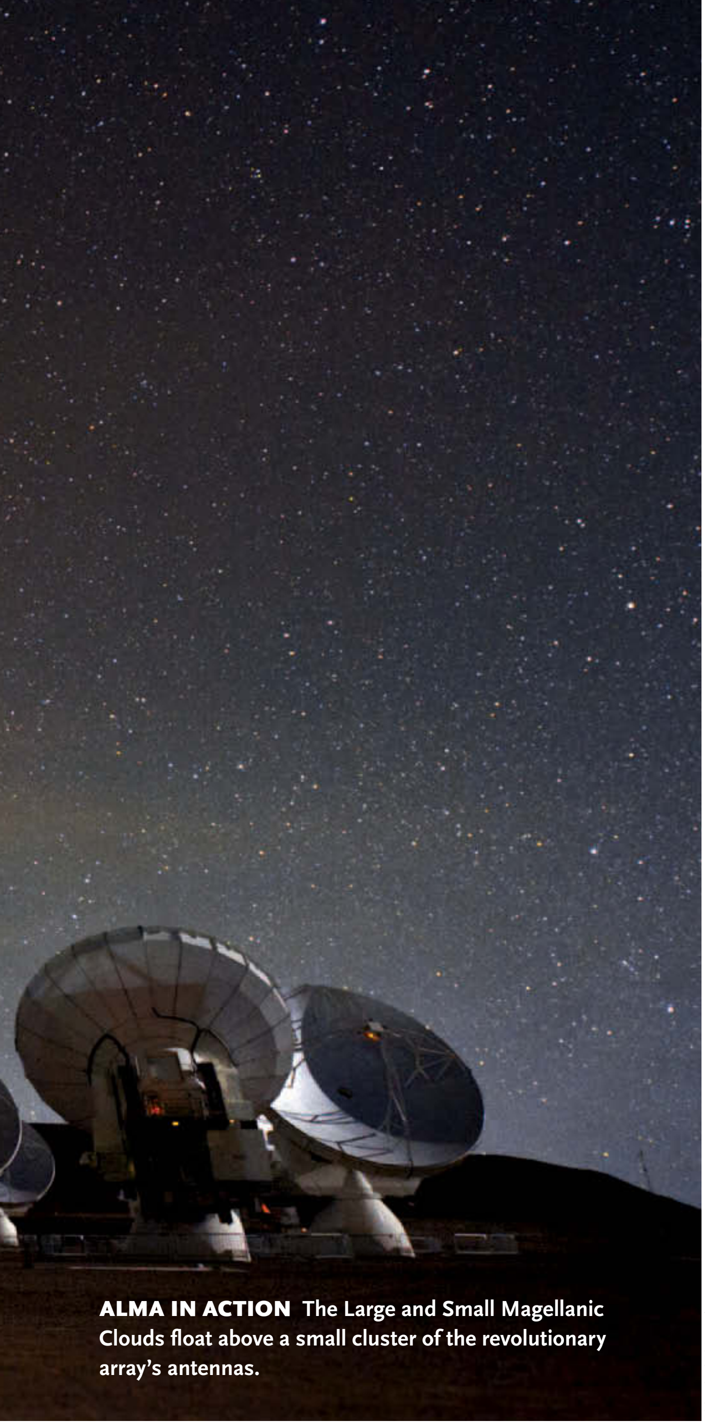
ALMA's cutting-edge technology promises to unveil our cosmic origins.

Monica **Young**

Most of the things we see in the visible universe — blazing stars, the planets they host, and the galaxies they inhabit — were born in frigid clouds of gas just a few tens of degrees above absolute zero. The deepest interiors of these clouds are largely invisible to X-rays, infrared light, or radio waves. But they give up their secrets at submillimeter and millimeter wavelengths, the little-known region of the electromagnetic spectrum squeezed between the longest infrared wavelengths and the shortest radio waves.

To explore this terra incognita, astronomers are building the Atacama Large Millimeter/submillimeter Array (ALMA). Perched at an elevation of 5,050 meters (16,600 feet) on the Chajnantor Plateau in Chile's Atacama Desert, ALMA sits above 49% of the atmosphere's pressure and 95% of the water vapor found at sea level. The thin, parched air is practically transparent to millimeter waves.

By the end of 2013, ALMA's 66 dishes will dot the plateau as far as 16 km apart. The fifty-four 12-meter antennas and twelve 7-meter antennas will work together to produce images up to 20 times sharper than previous (sub)millimeter telescopes, capturing details as fine as 6 milliarcseconds across. That's 10 times sharper than the Hubble Space Telescope's visible-light images. The gains in sensitivity are even greater, as much as 100 times better than telescopes observing at similar wavelengths.



ALMA IN ACTION The Large and Small Magellanic Clouds float above a small cluster of the revolutionary array's antennas.

ESO / CRISTOPH MALIN

To put it plainly, nothing on this scale has ever been done before.

"When you improve sensitivity or resolution by a factor of 10 or more, you almost guarantee you'll discover things you haven't seen before," says Lars-Åke Nyman, head of ALMA science operations.

Even the partially built array blows other submillimeter telescopes out of the water. For comparison, the Submillimeter Array on Mauna Kea consists of eight 6-meter dishes. Where SMA took hours to collect images and spectra of a faint faraway galaxy named BR 1202–0725, ALMA, observing with just a quarter of the full array, returned more detailed results within *minutes*.

"Astronomers get almost lyrical about how fantastic the data are," Nyman says of the results so far. "It's just getting better and better."

Building a **Revolution**

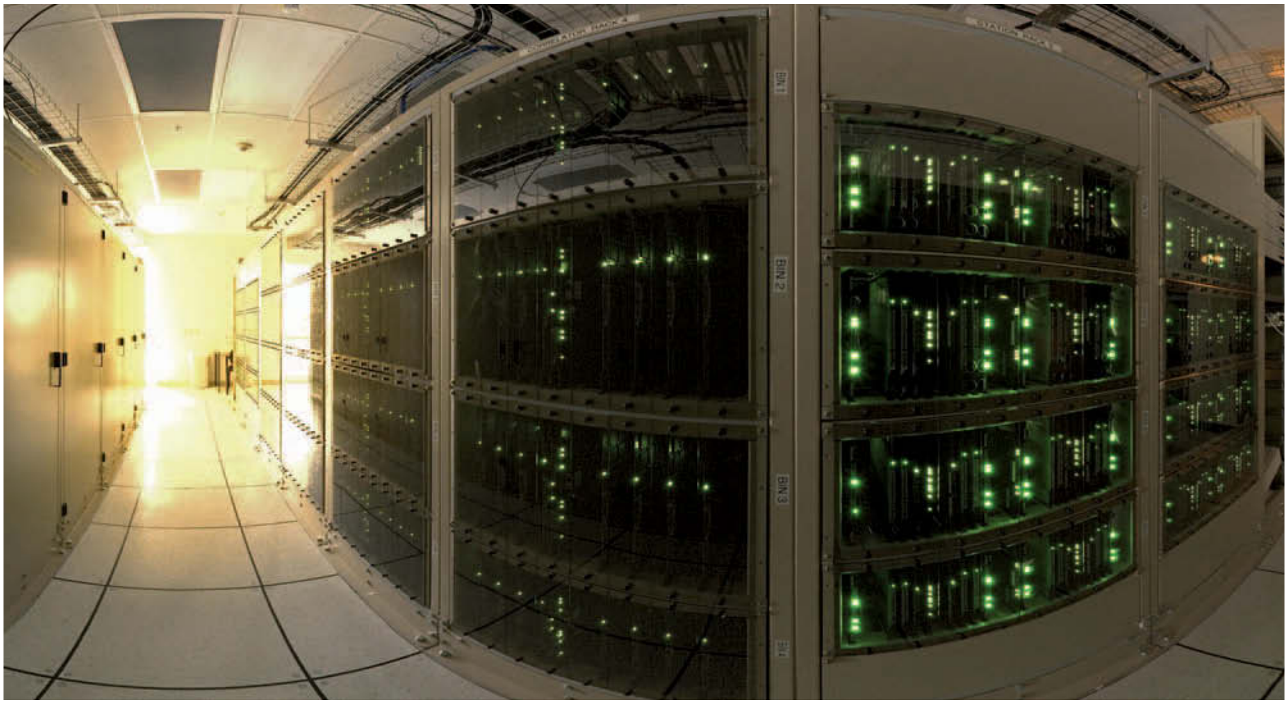
At the close of the last century, several groups around the globe realized the potential of the unexplored (sub-) millimeter wavelengths, and a flurry of planning ensued. The concept for a giant array solidified when these groups joined forces. In 1997 the U.S. National Radio Astronomy Observatory and the European Southern Observatory, in cooperation with Chile, combined previous designs into a plan for as many as 64 dishes atop the Chajnantor Plateau. This number was reduced to 50 as the National Astronomical Observatory of Japan joined the project with a proposal for 16 closely spaced dishes, which help ALMA image large-scale structure. Other international partners signed up, too, including Taiwan and Canada.

Every element of ALMA represents a major feat of engineering and international collaboration, but such leaps forward don't come cheap. ALMA is the largest and most expensive ground-based telescope currently under construction; the finished array will have cost its investors $1.4 billion in total to build.

North American, European, and Japanese companies designed and built the antennas, sometimes with quite different approaches, but always meeting the same strict specifications. The dishes are the most precise ever made, built to withstand gusty winds, extreme temperature variations, and the odd thunder- or snowstorm, all while maintaining their parabolic shape to within 25 microns, roughly the thickness of a hair. Two heavyweight transporters, fondly named Otto and Lore, lug the 100-ton antennas into place, positioning each dish on a concrete docking pad with millimeter precision.

HIGH-ALTITUDE WORK A technician, bundled up against the unforgiving environment, works at the Array Operations Site at 5,050 meters. Time spent at this elevation is limited due to health concerns.

ALMA (ESO / NAOJ / NRAO) / CARLOS PADILLA



ESO

Each of ALMA's dishes will eventually be equipped with 10 of the most sensitive receivers ever built. In principle, they work like AM/FM receivers, but they detect much higher frequencies. Liquid helium cools the superconducting electronics to –269°C (–452°F), just 4°C above absolute zero, almost eliminating electronic noise. Once all the receivers are installed, each dish will detect wavelengths from 0.3 to 9.7 millimeters (950 to 31 GHz, a span of five octaves).

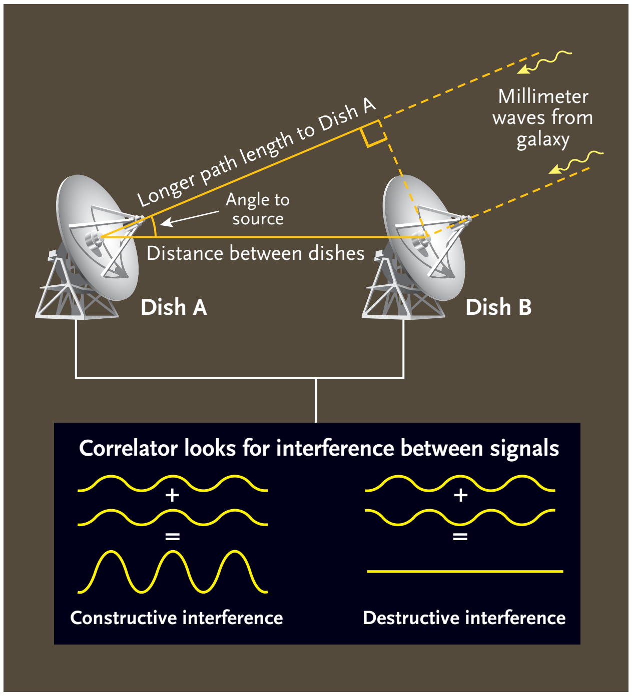
A *correlator*, a specialized supercomputer that performs 17 quadrillion operations per second, matches the wavefronts arriving through optical fibers from each pair of antennas. That's a few million times faster than the average desktop computer, a feat necessary to efficiently craft images via interferometry (see page 25).

Alwyn Wootten, the North American ALMA project scientist, flew down to oversee the first six months of ALMA's installation. The initial results he witnessed demonstrated the observatory's promise. "It was pretty amazing. With just five antennas, we could already make an image far beyond what had been done before. That really brought it home to me."

ALMA's first light in 2011 produced images unprecedented in their sharpness and sensitivity, even with only a fraction of the array online. Since then, ALMA has busily

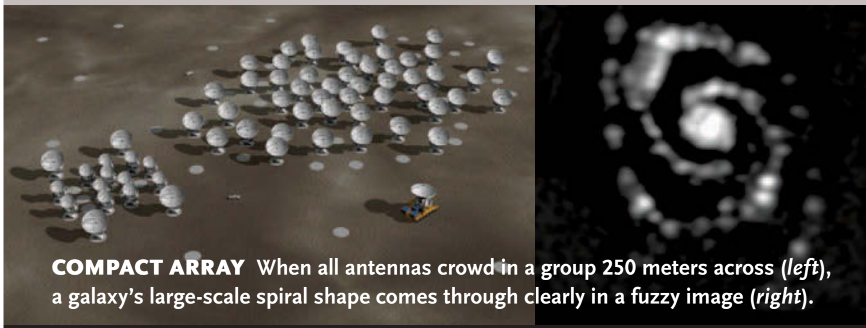
SUPERCOMPUTER ***Above:*** **ALMA's main correlator receives data from up to 64 antennas. These days a typical desktop computer has four processors — the correlator has 134 million. It needs that many to combine celestial signals from up to 2,016 different antenna pair combinations.** ***Below:*** **Originally called the Atacama Compact Array, the 16 dishes (four 12-meter and twelve 7-meter) of the Morita Array enable ALMA to image large-scale targets such as nearby galaxies and star-forming regions.**

ALMA (ESO / NAOJ / NRAO) / R. HILLS

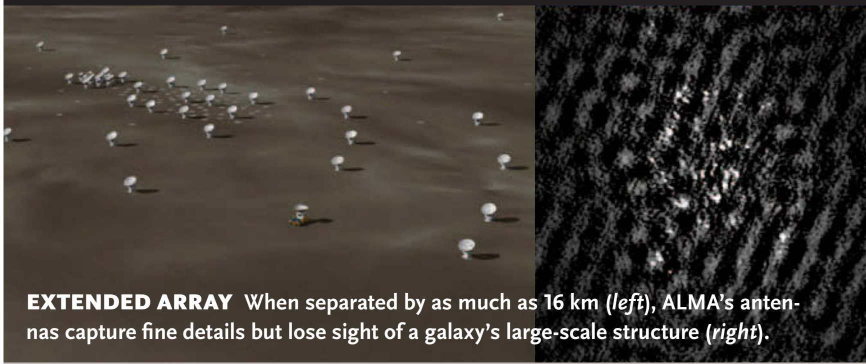


S&T: LEAH TISCIONE

ALMA (ESO / NAOJ / NRAO) (4)



COMPACT ARRAY When all antennas crowd in a group 250 meters across (*left*), a galaxy's large-scale spiral shape comes through clearly in a fuzzy image (*right*).



EXTENDED ARRAY When separated by as much as 16 km (*left*), ALMA's antennas capture fine details but lose sight of a galaxy's large-scale structure (*right*).

HOW DOES INTERFEROMETRY WORK? In this diagram, millimeter waves from a galaxy travel to two ALMA dishes, some of them taking the slightly longer path to Dish A rather than to Dish B. Each dish's receiver converts the light waves to electronic signals that travel along optical fibers to a specialized supercomputer. This correlator sees that Dish A's signals are slightly out of phase with Dish B's. Working backward from the interference, the correlator calculates the time difference, which corresponds to the difference in path length, and thus the angle to the source. That calculation gives the angle from one direction; combining information from various pairs of antennas gives a more accurate source position.

BEASTS OF BURDEN ALMA's 100-ton antennas are designed to move into multiple configurations. Two transporters (Lore is pictured here), themselves weighing 130 tons each when empty, lug the antennas into position using millimeter precision.

ALMA (ESO / NAOJ / NRAO)

ALMA: More Than the Sum of Its Parts

Imagine having pupils as big as an ALMA radio dish, each one about the height of a four-story building. That's what you would need to see images as sharply at millimeter wavelengths as you do in visible light. But ALMA will see even better, using interferometry to mathematically combine the signals from all 66 dishes into images up to 10 times sharper than Hubble's visible-light images.

How does it work? The diagram at the upper left shows how a computer uses the time difference between signals coming from a pair of dishes to infer the location of the source and construct its image. The resulting picture is as sharp as if one giant dish as wide as the two dishes' separation were doing the work.

As the dishes move farther apart, the image sharpens. A separation of 16 kilometers, ALMA's maximum baseline, would allow two dishes to resolve details as fine as 6 milliarcseconds — the typical angular width for a naked-eye star. Achieving the same resolution with a single antenna would require a dish 16 kilometers wide.

But two small dishes aren't really the same as a single large one. They miss a lot of information because they don't catch the photons falling in the area between them. Even as two widely separated dishes capture the finest details, they lose the large-scale structure — losing sight of the forest for the trees.

"What an interferometer sees better than anything else is sharp edges," explains Alwyn Wootten. "Extended structure, which has no sharp edges, does not produce any flux on long baselines."

ALMA addresses this problem by placing some dishes closer together rather than farther apart. A set of twelve 7-meter and four 12-meter dishes named the Morita Array bunch together to capture the large-scale structure in neighboring galaxies and dust clouds. Not only can the 7-meter dishes squeeze into more compact configurations, but the four 12-meter dishes also function as single-dish telescopes to add information on the widest scale.

FIRST LIGHT While still under construction, ALMA imaged the Antennae Galaxies. Whereas Hubble captures the blue-white light of newborn stars, ALMA sees the amber glow of their birthplaces: cold, dense clouds of molecular gas. This image was produced using only 12 antennas, but ALMA will equal or exceed Hubble resolution once the full array is online.

(NRAO / AUI / NSF); ALMA (ESO / NAOJ / NRAO); HST (NASA, ESA, AND BRAD WHITMORE (STSCI))

Early Results

ALMA has already captured several stunning — and sometimes surprising — images, all taken using less than half the full array. Here's a sampling of ALMA's early science results:

• Previous telescopes had spotted a spherical shell around the red giant star R Sculptoris, but ALMA revealed the fine detail hidden within. The star's winds, spiral-shaped in cross-section, show the first evidence of an unseen stellar companion.

• A sharp view of Fomalhaut's massive dust ring suggests the presence of two shepherding planets, each with less than three times Earth's mass.

• ALMA spied two narrow gas "bridges" crossing a large gap in the disk surrounding the young star HD 142527. These bridges provide strong evidence for two gas-giant planets sweeping up material during a key stage in planet formation.

• ALMA for the first time directly imaged the snow line around another star, TW Hydrae. The line, which marks the spot where carbon monoxide gas freezes solid, corresponds roughly to where smaller icy bodies such as comets and dwarf planets begin to form.

• Millimeter-size dust grains discovered inside a brown dwarf's disk suggest that stars' smaller cousins can spawn their own planets.

• Galaxies that were furiously forming stars when the universe was only 1 billion years old suggest that just 500 million years after the Big Bang, the cosmos had already assembled large reservoirs of cold gas and dust, ready to be formed into stars.

• ALMA captured a high-resolution view of the cold, dense gas clouds surging out of Sculptor Galaxy (NGC 253). In a feast-to-famine move, the galaxy's plethora of newborn stars is pushing out the very gas that would otherwise form more stars.

revealed stellar embryos, prebiotic molecules, and rare, faraway galaxies bursting with stars — each discovery shedding a little light on our beginnings.

Before There Were **Stars**

The hot blaze of stars belies their origins in vast, cold clouds of gas and dust. ALMA penetrates the veil to detect dense knots that could one day evolve into stars. In fact, the mammoth telescope will be the first with enough resolution to witness gas collapsing under its own weight: the very first step in forming a star.

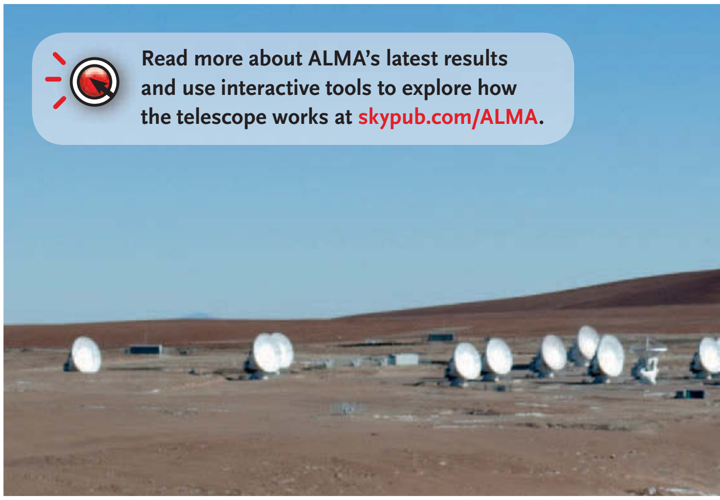
"ALMA looks not at the stars themselves but at the gas and dust, at how you first assemble stars, and how this material is then affected by stars that form," explains Leonardo Testi, the European ALMA project scientist.

By peering inside star-forming clouds, astronomers can determine what the future stellar population will look like in terms of its mass and spatial distribution, chemical composition, and magnetic properties. These differ from one cloud to another, but it's unclear why. "These are important questions to understand because they, in some sense, shape the evolution of the universe," says Testi.

"Even in its 'early science' phase, ALMA is completely changing the way we think about how stars form," says Jill Rathborne (Australia Telescope National Facility). She and her colleagues, among the first astronomers to use the array, directed 25 antennas toward the fetal star cluster G0.253+0.016, dubbed the Brick.

There are no stars to light the Brick's dark mass. Instead, cold gas and dust swirl around dense, pre-stellar embryos. Previous telescopes saw those embryos as amorphous blobs, but Rathborne's observations resolve individual clumps that could one day become stars, nestled among an intricate web of gaseous filaments.

"The analysis will keep us busy for many years to come," says Rathborne. And she emphasizes that these results are only an early sign of ALMA's potential. "We are on the cusp of an amazing revolution. When fully



operational, ALMA will completely revolutionize our understanding of how stars are born."

Of Stars and **Planets**

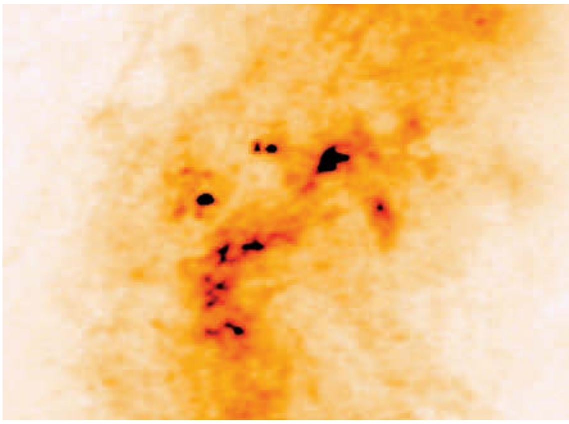
Studies of planet formation can expect a similar transformation. Planets take shape around stars that have just ignited inside their dusty cocoons. Unlike previous interferometers, ALMA will resolve the inner regions where rocky planetesimals form.

How these planets grow is still a mystery. Small dust grains easily stick together, but once they reach a certain size, collisions are as likely to destroy the clumps as to grow them. Even if they survive intact, friction between the dust and gas ought to drag the larger dust particles into the star. Yet somehow, the dust must stick together in ever-larger clumps to form huge numbers of planets.

ALMA's high-resolution images may solve this paradox. When Nienke van der Marel (Leiden University, the Netherlands) and her colleagues pointed 21 antennas toward the young star Oph IRS 48, they uncovered the first evidence of a so-called *dust trap*. Theorists had suggested that eddies swirling in the circumstellar disk could confine dust grains, giving them a chance to stick together. The new observations back up this theory, though Oph IRS 48's dust trap is too far out to form planets. (It's more likely forming dwarf planets like those in the Kuiper belt.)

In addition to detecting dust traps, ALMA can see disk gaps carved by condensing gas giants and could even resolve the protoplanets themselves. Stars still outshine their companions at millimeter wavelengths, but the contrast is more favorable than in visible or infrared light.

ALMA's fine spectral resolution offers another perspective on planet formation. Many of the chemical building blocks of life are made in and around stars before planets even take shape. "So the big question is, how and where do these molecules form? And can they be transported to forming planets?" asks Ewine van Dishoeck



JILL RATHBORNE / CSIRO / JCMT / ALMA(ESO / NAOJ / NRAO)

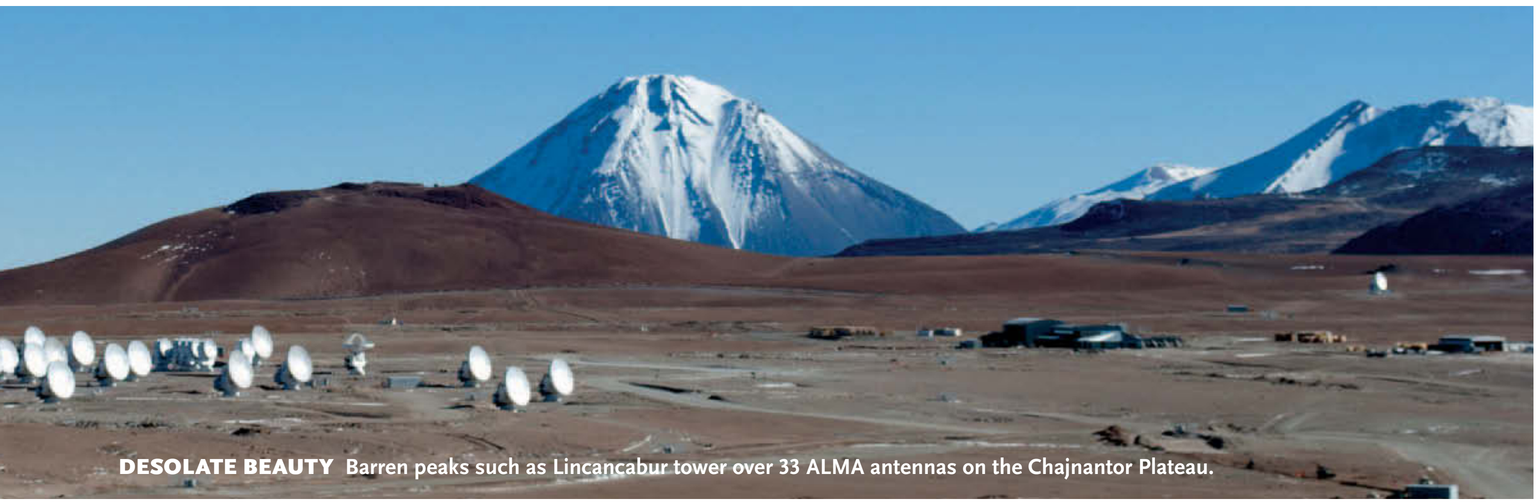
THE BRICK Dense clumps of gas and dust nestle among a frigid weave of filaments in the Brick, a molecular gas cloud near the galactic center that could one day turn into a massive cluster of stars. The full 3-mm image, a portion of which is shown here, has revealed more than 50 stellar embryos so far.

(Leiden Observatory, the Netherlands), who has been heavily involved in planning ALMA for the past 20 years.

"The space between the stars is basically a big vacuum. A particle meets another particle maybe once every 10,000 years," van Dishoeck explains. Yet the number and complexity of interstellar molecules continues to surprise astronomers, and ALMA is revealing ever more intricacy.

For example, the spectrum of the young binary IRAS 16293–2422 in Rho Ophiuchi, a nearby star-forming region, revealed the simple sugar glycolaldehyde (*S&T*: December 2012, page 16). This discovery of a "building block of life" caught the media's attention, though it's unclear how a prebiotic molecule floating in interplanetary space would settle on a planet's surface. One possibility is that these molecules hitch a ride on icy bodies, such as planetesimals or comets, that later crash-land on a planet.

Glycolaldehyde is but one chemical found in the surprisingly rich data set — astronomers weren't even able to identify all the lines they saw, van Dishoeck says. Chem-



DESOLATE BEAUTY Barren peaks such as Lincancabur tower over 33 ALMA antennas on the Chajnantor Plateau.

ALMA (ESO / NAOJ / NRAO) / J. GUARDA (ALMA) ists will have to go back to the lab before astronomers can sort out all the molecules that ALMA is detecting.

"We were so delighted when we saw the first data, that even with just 16 antennas, ALMA was already an order of magnitude more sensitive than any of the existing data we had on this source," van Dishoeck adds. "That was just an eye-opener. Wow! Now we can see how far the chemical complexity can go."

From the Near to the **Very Far**

The same sensitivity that's so effective for zooming in on star and planet formation can be trained on the most remote galaxies. Though just-ignited stars reveal their presence by emitting at wavelengths largely outside of ALMA's range, the expanding universe redshifts that emission into ALMA's territory.

In the early universe, stars were forming more rapidly than ever before — or since. At the same time, supermassive black holes lurking in galactic centers were also growing at tremendous rates. There's no obvious reason why the two should develop at the same pace, yet they did. Understanding why might help explain galaxy evolution.

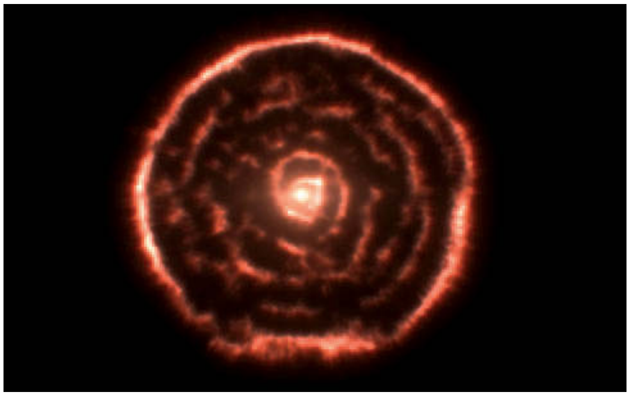
Carol Lonsdale, head of the North American ALMA Science Center's User Support Group, used the array to study star formation in 49 faraway galaxies whose central black holes are guzzling gas at enormous rates. Observing these galaxies would have been infeasible with previous telescopes, but ALMA took only 90 seconds to detect most of the targets, each several billion light-years away.

Galaxies with extremely active black holes often host super-starbursts that manufacture stars at a stupendous rate of 1,000 per year, much faster than any nearby galaxies and exceptional even in the distant universe. But the galaxies Lonsdale observed have slowed production, forming less than a few hundred stars per year.

"We're catching these galaxies at a crucial moment in time, right when everything's coming together," Lonsdale explains. All starbursts must come to an end, and the ALMA observations might be seeing the turn of the tide. Further observations from ALMA and other telescopes will probe just how much the flourishing central black holes disrupt the surrounding star-forming factories.

ALMA (ESO / NAOJ / NRAO)

FIRST MOVE An antenna operator checks that all is well as a caravan moves the first ALMA dish to the high-elevation site.



ALMA (ESO / NAOJ / NRAO)

STELLAR SPIRAL Previous telescopes had spotted a spherical shell around the red giant star R Sculptoris, but ALMA revealed the spiral rose hidden within. The aging star circles an unseen companion; the motion winds up R Scl's stream of ejected gas.

The Once and **Future ALMA**

"We've been working on ALMA for so many years, thinking it would be a revolutionary instrument," says Testi. "Finally this is coming true. The data from ALMA are really a step beyond what we had before."

Now ALMA is in the middle of a second cycle of observations, with at least 32 antennas in the main array, as well as nine 7-meter and two 12-meter antennas in the Morita Array. By the beginning of the third observation cycle (currently scheduled for June 2014), all 66 antennas will be in use.

And much more is in store for this observatory. Wootten is working with ALMA engineers and astronomers to expand the array's wavelength range. The upgrades will increase sensitivity to water molecules in nearby forming planetary systems, as well as to molecular spectral lines from the universe's first galaxies.

ALMA will also conduct very long baseline interferometry (VLBI), combining forces with other submillimeter arrays worldwide to image the tiniest details, such as the silhouette of the supermassive black hole hiding in the Milky Way's center (*S&T*: February 2012, page 20). Although ALMA outpaces other submillimeter telescopes, keeping existing facilities open will be key for VLBI.

Even with only a fraction of its antennas operational, ALMA has already proven its worth as the most expensive ground-based telescope. Now astronomers all over the world are poised for full operation, which is bound to transform our understanding of the visible universe. ✦

S&T *web editor* ***Monica Young*** *eagerly awaits the coming ALMA revolution.*

How Often Do Bright Comets Appear?

With Comet ISON approaching, it's natural to ask how often truly great comets grace our skies.

Joe Rao

THE HYPE OVER Comet ISON will soon reach fever pitch. Discovered in September 2012 and christened almost immediately as "The Comet of the Century," ISON's best showing is expected to come in mid-December as it pulls away from its exceedingly close Thanksgiving Day brush with the Sun and emerges into view in the eastern sky during the dawn hours of early December (see page 50).

If ISON evolves into the head-turning object that we all hope it will, the public and the media will undoubtedly ask how often such a bright naked-eye comet appears. It's a question that has been asked many times before, but depending on what source you consult, you can find a variety of answers.

As a young boy just getting started in astronomy, one of my favorite books was *New Handbook of the Heavens,* by Hubert J. Bernhard, Dorothy A. Bennett, and Hugh S. Rice. In the chapter on comets, the authors write: "At least 15 to 20 comets per century are visible to the casual observer, and, on an average, four wondrous ones appear every 100 years. These cause so much excitement that it is hard to escape notice of them."

But in a 1974 collection of astronomy essays, the prolific author Isaac Asimov offered this rather pessimistic assessment: "The twentieth century has had rather poor luck with comets. In 1910 we had Halley's Comet returning and that was pretty spectacular but since then there has been scarcely a comet visible to the naked eye and certainly nothing spectacular."

Long-time *S&T* columnist George Lovi offered a rather sanguine forecast on the possibility of seeing a bright comet in his May 1990 *Rambling Through the Skies* column: "During Halley's recent (1986) visit, I told people it wouldn't be the spectacular sight so many anticipated. However, I did venture the consoling prediction that we would see a prominent comet within 10 years or so. This has been the case during my lifetime: at least one good comet per decade."

In anticipation of ISON's impending apparition, I decided to see if I could provide a more definitive answer to the question of just how often we might expect to see a bright naked-eye comet.

What Constitutes a "Bright" Comet?

For this survey I examined all comets that have appeared since the beginning of the 20th century on up to the pres-

GERALD RHEMANN

ent time. Here are my own definitions for two specific varieties of comets:

Common comets are only visible with optical aid or dimly with the unaided eye. The vast majority of periodic comets — whose orbits are well known and have been observed more than once — fall into this category. These comets quietly come and go and are known only to enthusiastic amateur astronomers who make a concerted effort to hunt them down with good binoculars or telescopes. Generally they are unimpressive to the eye, usually appearing as nothing more than faint fuzzballs, even in large telescopes.

Great comets are set apart from other comets as being stupendously bright and/or fantastically structured, perhaps developing a tail that stretches a quarter of the way or more across the sky. Such a comet can rival the brightest stars and planets. And in very rare cases, a great comet might become so bright that it becomes briefly visible during the daytime.

Only great comets can qualify as bright comets, yet in the same token, many bright naked-eye comets do not necessarily qualify as "great" comets. For this survey, I will establish a very high standard in case ISON lives up to all of its hype.

Light Blight

Another mitigating factor is light pollution, which over the last 40 years has metastasized across our landscape and muddied the celestial waters. To be detected visually from most large cities and their immediate suburbs today, a comet's head or coma cannot be much fainter than 2nd magnitude (the brightness of Polaris and Orion's three belt stars). Sadly, city dwellers now need to relocate to a rural viewing site to fully appreciate the splendor of a potentially great comet, which when subjected to urban skyglow usually ends up becoming reduced to just a dimly glowing fuzzy blob with only a hint of a tail.

In addition, satellite technology has made us aware of comets that have briefly flared to magnitude zero or brighter as they arrived at perihelion. The Solwind, SolarMax, and SOHO satellites have revealed a number of such objects in recent years. But they were en route to or receding from the Sun, which meant they were usually very difficult to see, so I did not include them.

The table on the final page lists all the comets that appeared from the beginning of the 20th century up to the present and that attained a brightness of at least magnitude 2.0. My chief references are *The Bright Comet Chronicles*, compiled by comet observer John E. Bortle (**www.icq.eps.harvard.edu/bortle.html**), and *Cometography.com*, by Gary W. Kronk (**http://cometography.com**).

Twenty-five bright comets have appeared during the past 112 years. That's an average of one about every 4.5 years. Of course, they didn't appear precisely at 4.5-year intervals. In fact, during mid-October 1911, Comet Beljawsky was visible simultaneously with Comet Brooks in the western sky during late evening twilight. Imagine . . . two bright comets for the price of one! In contrast, there was a 14-year drought between Comet Skjellerup-Maristany in 1927 and Comet de Kock-Paraskevopoulos in 1941.

The Tail Wags the Comet

Eleven of the 25 comets in my sampling attained negative magnitudes. Yet even a relatively bright comet can still end up being rather difficult to see if we view it at a very low altitude; its light becomes significantly attenuated by haze that perpetually hangs within several degrees of the horizon. Viewing a comet against a bright twilight sky can also noticeably diminish its overall appearance, especially its tail.

The physical appearances and behaviors of comets are as varied as the appearances and behaviors of people; no two are alike. And probably the most important factor in determining whether a comet can be branded as a prominent object is its tail(s). Depending upon the amount of material present in a comet and upon the closeness of its approach to both the Sun and Earth, the tail might be almost nonexistent or it might not develop at all. But some comets have sprouted extensive tails.

I still remember a cold Saturday evening in early January 1986 that drew tens of thousands of people to Jones Beach on Long Island, N.Y. Local astronomy clubs set up telescopes for the general public in order to observe Comet Halley, then low in the western sky. I brought my 10-inch Dob and used low power to provide a nice wide-field view. The line of people who patiently waited for a look was incredibly long, but after peering through the eyepiece and seeing only a small nebulous patch with a starlike center, virtually every person asked the same question: "Where's the tail?" One nonplussed woman seemed to speak for everyone when she exclaimed, "What good is a comet if it doesn't have a tail?"

So in judging how impressive a comet is supposed to look to the average person, the tail is what makes or breaks the comet.

Caste of Comets

Taking into account brightness, appearance of the tail, how high in the sky, and proximity to twilight versus a dark sky, I grouped my 25 comets into three categories:
Showstoppers: A comet so striking or impressive that it calls attention to itself; even a casual observer will stop and say: "Oh my, look at that!"
Showpieces: A comet that attracts wide attention or admi-

The Best Comets Since 1901

Great January Comet 1910

Magnitude +2.0 or brighter January 13–27
This comet was visible in daylight on the 17th as a snowy-white object with a tail 1° long. It quickly moved northward and became a stupendous object for the Northern Hemisphere. By January 30th, a sweeping tail stretched out to about 50° in length.

Halley 1910

May 6–27
After perihelion, it evolved into an increasingly large and imposing object in the eastern morning sky. On the morning of May 19th, after the Moon had set, the tail was seen to stretch for 120° — two-thirds of the way across the sky!

Ikeya-Seki 1965

October 15–31
This showstopper was a member of the Kreutz family of sungrazing comets. It was the brightest comet of the 20th century, visible in full daylight within a few degrees of the Sun. Japanese observers said it appeared "10 times brighter than the full Moon." During the last week of October a long twisted tail, resembling a wispy searchlight beam above the eastern horizon, stretched for at least 25°. The nucleus split into three pieces.

West 1976

February 18–March 8
At perihelion on February 25th, this comet could be glimpsed in the late-afternoon sky with the naked eye. Moving into the morning sky, a spectacular tail developed, boasting no less than five components by March 8th, the longest being a dust tail measuring 30° in length. It was described as "a fantastic fountain of light" in the May 1976 *S&T*. A disruption of the nucleus resulted in four fragments.

Hyakutake 1996

March 19–April 4
It came to within 0.1018 a.u. of Earth on March 25th, the intrinsically brightest comet to pass so close to Earth since 1556. It could be observed almost directly overhead during the predawn hours, shining as bright as zero magnitude and against a dark sky sporting a tail that approached 100° in length. John Bortle calls it "One of the grandest comets of the millennium!"

McNaught 2007

January 6–25
This comet reached its peak brilliance on January 13th and 14th, when many could easily spot it in broad daylight just by blocking the Sun with a hand. The comet then moved into the evening skies of the Southern Hemisphere, unfurling a gigantic fan-like tail containing a number of luminous bands, eventually reaching a maximum length of 35° on the 23rd.

To read author Joe Rao's descriptions of the Showpiece and Garden Variety comets, visit **skypub.com/brightcomets**.

ROBERT MCNAUGHT

S&T ARCHIVES / MARTIN GROSSMANN

S&T ARCHIVES

S&T ARCHIVES / WILLIAM LILLER (HARVARD COLLEGE OBSERVATORY)

ALAN DYER

ration, though perhaps not quite that of a showstopper.
Garden variety: A comet that is unexceptional in the sense that it either faded very rapidly or didn't "stand out" compared to a showstopper or showpiece. Showstoppers or showpieces can be considered "great" comets, but garden variety comets cannot.

Two comets fell just short of making the cut: Comet Wilson-Hubbard in 1961 and Comet Holmes in 2007. The latter unexpectedly flared in less than two days from magnitude +17 to +2.5 during October 23-24. It appeared more like a nova to the unaided eye; a moderately bright yellow star in Perseus.

Some readers might take me to task in my categorization of a few of these comets. Some might think Comet Ikeya-Seki was unworthy of being called a showstopper because it was always low to the horizon from mid-northern latitudes and was difficult to see east of the Mississippi River because of a persistent spell of hazy weather. Yet in the January 1966 *S&T* (page 52), Leif J. Robinson noted of Ikeya-Seki: "Not since 1910 have amateur astronomers around the world enjoyed such a splendid cometary sight!"

Some might argue that Comet Hale-Bopp or Comet Bennett should be considered showstoppers as opposed to showpieces. I happen to be of a certain age that gave me a chance to see Comets Bennett, Hale-Bopp, and West all under optimal conditions, and I have always felt that Bennett surpassed Hale-Bopp. The only thing that Hale-Bopp had over Bennett was that it could be seen by a very large audience during convenient evening hours whereas Bennett was relegated to the predawn morning sky. Should Hale-Bopp qualify as a showstopper because so many people saw it? One can argue either way, but if it were somehow possible to see both comets side by side at their best, I honestly think Bennett would have been the overwhelming choice. Comet West was a stunningly beautiful "chrome sword" hanging down from the sky and easily beats out both Bennett and Hale-Bopp for showstopper status.

To this end, I can only say that everyone's personal preferences are subjective opinions that cannot be "right" or "wrong." As the translated Latin maxim states, "In matters of taste, there can be no disputes."

Wrong Place at the Right Time

Occasionally, even when a comet puts on a great show, you might not be able to see it because its zone of visibility is chiefly confined to those regions either south or north of the equator. For example, observers living in Australia or southern Africa completely missed out on Comet Hyakutake's incredibly long tail in 1996, yet they had ringside seats when showstopping Comet McNaught's own prodigious tail dominated their western evening sky in late January 2007 while northerners were more or less shut out.

In fact, comets in 1917, 1927, 1941, 1947, and 1948 were at their best chiefly for those living in the Southern Hemisphere. For this reason, there were no really fine and bright comets available from the Northern Hemisphere from 1912 through 1956. Ironically, 1911 and 1957 were years that featured *two* bright comets.

"There can be seemingly long stretches without any spectacular comets being seen, but that by no means necessarily implies absolutely none occurred," adds Bortle. "Random selection in apparition circumstances can indeed prove to be very cruel at times." Sometimes, unfortunately, that's the way it goes with comets.

Final Evaluations

Let's go back to our three original sources and see how their statements regarding the frequency of bright comets hold up compared to what has actually occurred since 1900.

WHAT MAKES A COMET BRIGHT?

How bright a comet becomes depends on several factors. Among them is the size and composition of the icy clumping of cosmic rubble that forms the comet nucleus. This part of a comet, usually only a few miles across, is gradually warmed by the Sun's heat and expels gas and dust into space, often in distinct jets. A comet's activity increases rapidly as it draws closer to the Sun; the brightness typically varies (roughly) as the inverse fourth power of its solar distance.

But just as important is the comet's distance from Earth. A comet of average size can appear stupendously large and bright if it passes very close to Earth. A case in point is Comet Hyakutake in 1996. Coming to within 9.5 million miles of Earth, it reached zero magnitude and was accompanied by a nearly 100° tail. But if Hyakutake had approached no closer than Comet Hale-Bopp (122 million miles), it would have appeared no brighter than magnitude +6. Conversely, if Hale-Bopp had passed Earth as closely as Hyakutake, it would have blazed at magnitude –6 (3 times brighter than Venus) with a tail stretching across the entire sky!

Showpieces


Eclipse Comet

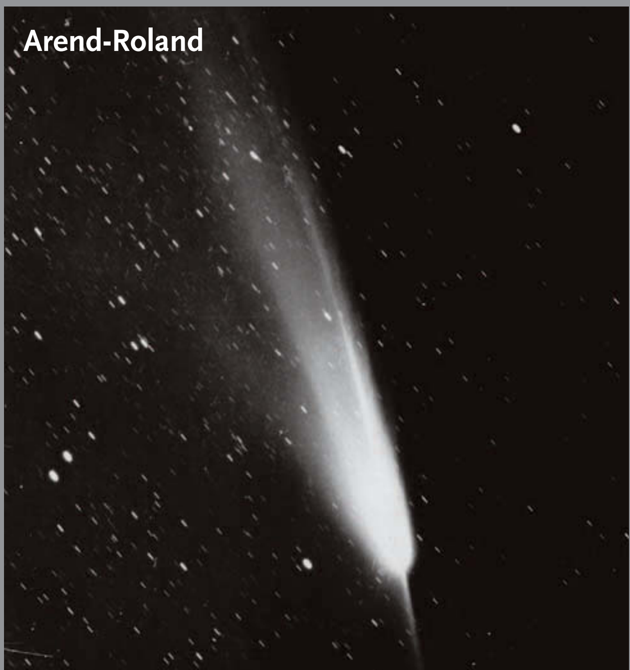
S&T ARCHIVES


Hale-Bopp

S&T: DENNIS DI CICCO


Lovejoy

YURI BELETSKY / ESO


Arend-Roland

S&T ARCHIVES / LOWELL OBSERVATORY


Seki-Lines

ALAN MCCLURE / INTERNATIONAL DARKSKY ASSOCIATION


Bennett

S&T ARCHIVES / J. U. GUNTER

New Handbook of the Heavens suggested 15 to 20 comets are visible per century, with four of them described as "wondrous." In the 20th century there were 23 bright comets and if we limit the term "wondrous" solely to showstoppers, there were five that appeared. All things considered, both values are reasonably close to the numbers quoted in the *Handbook*.

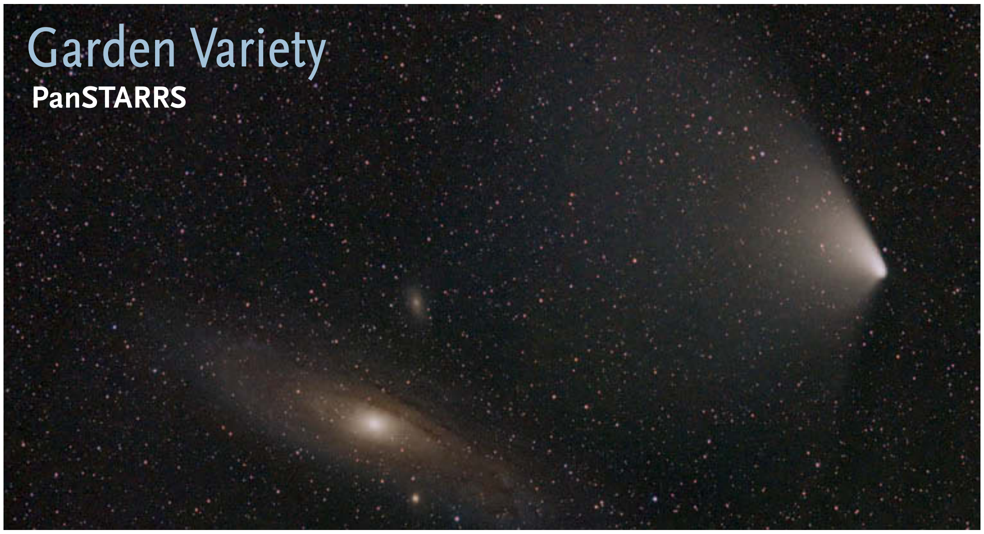
How about Isaac Asimov's gloomy assessment? He stated in his book that since the appearance of Comet Halley in 1910 that there had been — in his opinion — a paucity of naked-eye comets, none of which were in any way dazzling or eye-catching.

As it turns out, although the book (*Asimov on Astronomy*) was published in 1974, it was actually based on a compendium of essays that he had written from 1959 to 1966. Although Halley's 1910 appearance made my showstopper list, consider that the next showstopper didn't come along until 55 years later, with the appearance of Comet Ikeya-Seki. In addition, I've already mentioned the dearth of bright comets visible from the Northern Hemisphere through much of this timespan. With these facts in mind, we can better understand Asimov's negative appraisal.

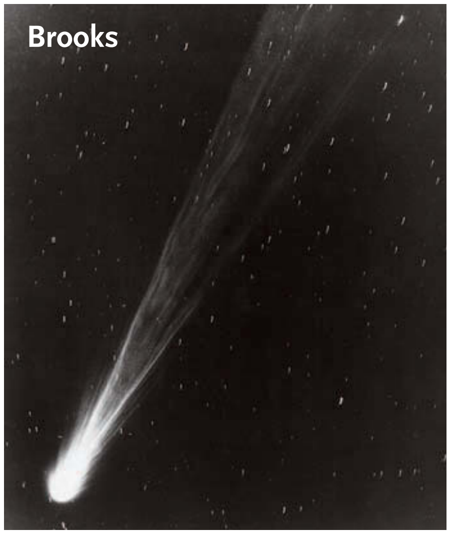
As for George Lovi, he commented in 1990 that during his lifetime at least one good comet had appeared per decade. If we take into account both showstoppers and showpieces, there were 13 such comets in the 20th century, which certainly can be classified, at least from Lovi's perspective, as "good" (if not "great"). That's an average of one every 7.7 years, which is well within his prescribed frequency of at least one good comet per decade.

Sadly, Lovi passed away in February 1993, but his 1990 forecast proved to be prophetic: just six years later, showstopping Comet Hyakutake put on a glorious display.

For more descriptions of bright comets, and to vote for whether you think Comet ISON will be a showstopper, showpiece, or garden variety comet, visit skypub.com/brightcomets.



S&T: SEAN WALKER



S&T ARCHIVES / WILLIAM DUNCAN MACMILLAN (YERKES OBSERVATORY)

S&T ARCHIVES / HAUTE PROVENCE OBSERVATORY / LIÈGE INST. OF ASTROPHYSICS

ALAN MCCLURE / INTERNATIONAL DARK-SKY ASSOCIATION

Comets Reaching at Least Magnitude +2.0: 1901–2013

Designation	Name	Perihelion Date	Peak Magnitude	Category
C/1901 G1	Viscara	1901 April 24	–1.5	Showpiece
C/1907 L2	Daniel	1907 September 4	+1.5	Garden Variety
C/1910 A1	Great January Comet	1910 January 17	–4.0	Showstopper
1P/1909 R1	Halley	1910 April 20	0.0	Showstopper
C/1911 S3	Beljawsky	1911 October 10	+1.5	Garden Variety
C/1911 O1	Brooks	1911 October 28	+2.0	Garden Variety
C/1917 F1	Mellish	1917 April 11	+1.5	Garden Variety
C/1927 X1	Skjellerup-Maristany	1927 December 18	–6.0	Garden Variety
C/1941 B2	de Kock-Paraskevopoulos	1941 January 27	+2.0	Garden Variety
C/1947 X1	Great Southern Comet	1947 December 2	0.0	Showpiece
C/1948 V1	Eclipse Comet	1948 October 27	–3.0	Showpiece
C/1956 R1	Arend-Roland	1957 April 8	+1.0	Showpiece
C/1957 P1	Mrkos	1957 August 1	+1.0	Garden Variety
C/1962 C1	Seki-Lines	1962 April 1	–2.5	Showpiece
C/1965 S1	Ikeya-Seki	1965 October 21	–15.0	Showstopper
C/1969 Y1	Bennett	1970 March 20	+0.5	Showpiece
C/1970 K1	White-Ortiz-Bolelli	1970 May 14	+1.0	Garden Variety
C/1973 E1	Kohoutek	1973 December 28	–3.0	Garden Variety
C/1975 V1	West	1976 February 25	–3.0	Showstopper
C/1983 H1	IRAS-Iraki-Alcock	1983 May 21	+1.5	Garden Variety
C/1996 B2	Hyakutake	1996 May 1	0.0	Showstopper
C/1995 O1	Hale-Bopp	1997 April 1	–0.5	Showpiece
C/2006 P1	McNaught	2007 January 12	–5.0	Showstopper
C/2011 W3	Lovejoy	2011 December 16	–1.0	Showpiece
C/2011 L4	PanSTARRS	2013 March 10	+1.5	Garden Variety
C/2012 S1	ISON	2013 November 28	?	?

A Proliferation of Comets

In trying to assign a value for the frequency of appearances of bright comets, we can only base that number on the law of averages. But because comets can come and go at random, there will be intervals when the wait between exceptionally spectacular comets will be shorter or longer than what the averages suggest.

During the 20th century, the average for the appearance of a showstopping comet worked out to be once every 20 years. Yet, as I noted earlier, at one point we went 55 years without seeing any showstoppers. Conversely, over the last 48 years, we have been blessed with no less than four showstoppers — an average of one every dozen years or so. It might not seem that way, but we're living in a time when there has been a veritable proliferation of bright and spectacular comets.

The stage is now set for Comet ISON. Will its performance be worthy of the fifth showstopper in less than a half century? We'll all know the answer in the weeks ahead. Stay tuned. ✦

A five-time Emmy-nominated broadcast meteorologist at News 12 in Westchester, N.Y., ***Joe Rao*** *has been an assiduous amateur astronomer for more than 40 years. He was bestowed the Astronomical League's prestigious Walter Scott Houston Award in 2009.*

Dennis di Cicco

Oculus All-Sky Camera

Ever wonder what's happening in the night sky when you're not looking? Here's a way to find out.

Starlight Xpress Oculus All-Sky Camera
U.S. Price: $1,095
Available from dealers worldwide
www.sxccd.com

ALL PHOTOGRAPHS BY THE AUTHOR

IT'S HUMAN NATURE that fuels my enthusiasm for testing new products. But that same human nature also makes some of these products intrinsically more interesting to me than others. And this is the case with the new Oculus All-Sky Camera from the venerable CCD-camera maker Starlight Xpress in the U.K.

Ever since reading about the Smithsonian Astrophysical Observatory's Prairie Network in the March 1970 issue of this magazine, I've been captivated by the idea of photographically patrolling the night sky. But this was too expensive for most amateurs to attempt in the days of film-based astrophotography, and I expect it was the reason no commercial patrol systems were then available.

That, however, has changed in the low-cost-per-shot digital age, and today there are several commercial systems for snapping pictures of the night sky. What makes the Oculus All-Sky Camera stand out is its excellent performance-to-price ratio. The camera's 1.45-megapixel Sony monochrome SuperHAD ICX205AL CCD offers high sensitivity (too high, in fact, to be used with the supplied lens for daytime imaging). It also has very low dark current and antiblooming to prevent unsightly image artifacts on bright objects. The Oculus produces 2.8-megabyte, 16-bit FITS images that capture all of the CCD's dynamic range. This image format is also compatible with all programs for processing and analyzing astronomical images.

The camera I borrowed from the manufacturer for our review came with a 1.55-mm f/2 fisheye lens that creates a 180° circular image. But Starlight Xpress's Terry Platt also loaned me a 2.5-mm f/1.2 lens that is now shipped standard with the camera (the 1.55-mm lens will remain an option). Although the 2.5-mm lens loses a little of the sky around the horizon (where most of us have some obscuration), it has much better imaging performance, especially for stars. I clearly preferred this lens for my tests.

The Oculus camera is a small, weatherproof module designed to remain outdoors 24/7. After several nights using the temporary arrangement pictured opposite, I mounted the camera on a permanent pole attached to the outside wall of my backyard observatory. The camera still looked and performed like new after more than five months of continuous exposure to wind, rain, and the blistering heat served up by one of New England's hottest summers on record. My only word of caution is that any permanent mounting should allow relatively easy access to the camera, since dust, pollen, spider webs, residual spots from raindrops, and the occasional bird poop needs to be cleaned from the camera's acrylic dome now and then.

The Oculus uses a USB 2.0 connection to a computer for its power and data transmission. There's a separate 12-volt DC input to power the camera's dew heaters (an AC-powered adapter comes with the Oculus). Although running these heaters is optional, they are a must for dewy conditions. They also help remove raindrops quickly after a storm. I left them on continuously.

The camera's USB 2.0 cable is only 10 feet (3 meters) long, and it was too short for my permanent mounting arrangement. Because the maximum recommended length for a USB 2.0 cable is about 16 feet, adding a 6-foot extension cable to the Oculus still wasn't enough for my setup. Instead, for greater separation between the camera and computer, Starlight Xpress recommends connecting the camera to a *powered* USB hub, which itself can be at least 16 feet from the computer via another USB 2.0 cable. Although this arrangement worked fine for me, it also meant keeping the powered hub only 10 feet from the camera, which placed it outside (and needing weatherproofing).

My best solution was to use a so-called USB 2.0 active repeater cable. I purchased a 33-foot repeater cable for $21.95 from **sewell.com** (part number SW-29419). It worked like a champ, and allowed a distance of more than 40 feet between the camera and computer. Some USB 2.0

Despite a brilliant, 85%-illuminated gibbous Moon on the morning of May 28th, the Oculus camera with the 1.55-mm fisheye lens captured a short meteor trail flashing in the author's eastern (left) sky.

The author tested two lenses with the Oculus camera, which can use any C-mount video lens. He preferred the 2.5-mm f/1.2 lens (at left with a homemade light shield), which now comes standard with the camera.

Right: **The Oculus camera comes with a spare acrylic dome, an AC power supply for the dew heaters (see text for details), software CD-ROM, and a hard-shell, foam-fitted carrying case.**

WHAT WE LIKE:

Compact all-weather construction

Scientific-grade image data

Continuous night-sky monitoring

WHAT WE DON'T LIKE:

Occasional issues with software (see text for details)

This composite picture assembled from full-frame images made with the 2.5-mm lens shows some of the brighter meteors captured during last August's Perseid shower.

repeater cables work better than others, but I can certainly recommend the Sewell cable for the Oculus.

The software provided with the Oculus is both a strength and weakness of the system. One of its strengths is that it was easy to install and run on all six computers I tried. These included a very old Windows XP desktop that I dredged out of storage (it hadn't even been turned on since the last Bush administration) and a modern netbook computer running 64-bit Windows 7 professional.

Another of the software's strengths is its simplicity. With minimal referencing of the manual, I had images streaming from the camera only moments after installing the program. And I mastered most of its basic functions in about a half hour. It's easy to take and automatically save up to 1,000 sequentially numbered frames. The software also enables turning all of these frames into an AVI-format movie. Each morning I'd watch the movie from the previous night's images, and then pull any original frames of interest for detailed analysis and processing.

Although the software is robust and never crashed when I left it running unattended, the program was rather temperamental if I tried having it run the Oculus in the background while using the computer for other tasks. It also wanted to be left alone when automatically acquiring a sequence of images — I couldn't use the program to process one image while the camera was taking another.

The only other handicap I encountered with the software was its 1,000-frame limit. Since the optimum exposure in my suburban sky was about 30 seconds, the 1,000 frames only lasted for about 8 hours of sky patrolling. This was fine for short summer nights, but as winter approached I was wishing for a greater frame limit.

But it's easy to run the Oculus with most programs designed for astronomical cameras, since it looks to the outside world like a standard Starlight Xpress SXV-H9 camera. For example, the Oculus was plug-and-play compatible with *MaxIm DL* (version 5.23).

I really like the Oculus All-Sky Camera. It's become a morning ritual after a clear night for me to head to the computer and watch the AVI movie. Airplanes, flaring satellites, occasional meteors, and passing clouds (it's true, some do spontaneously form over my observatory) are all part of the whirling starry vista. My wife calls it reality TV for geeks. I couldn't agree more. ✦

Over the years, senior editor ***Dennis di Cicco*** *has built several photographic systems for patrolling the night sky. Despite one being outrageously dangerous, he's lived to tell about it.*

▸ **COMET OBSERVING PACKAGE** From Explore Scientific comes the new Bresser AR102S Comet Edition telescope and binocular package ($449.95). The AR102S is a 102-mm f/4.5 doublet achromat in an ultra-short 20¼-inch (51.4 cm) tube assembly, with a built-in internal mirror diagonal that makes collimation simple. Its 2-inch focuser includes a 1.25-inch adapter, and with the included 20-mm 70° Series eyepiece, the AR102S produces a generous 3° true field of view. The scope comes complete with a sturdy alt-azimuth mount with an adjustable-height metal tripod and backpack. Also included is a pair of WA 7×50 binoculars with its own carrying case. The binoculars feature long-relief eyepieces comfortable for viewing with eyeglasses. Both the telescope and binoculars are ideal for observing comets, or sweeping extended nebulosity and star fields within the Milky Way. See the manufacturer's website for additional details.

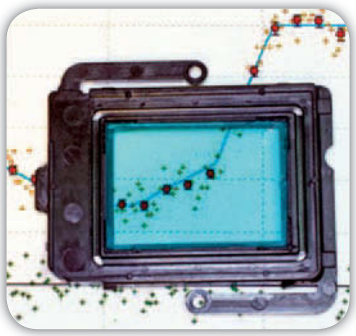
Explore Scientific
621 Madison St., Springdale, AR 72762;
866-252-3811; explorescientific.com

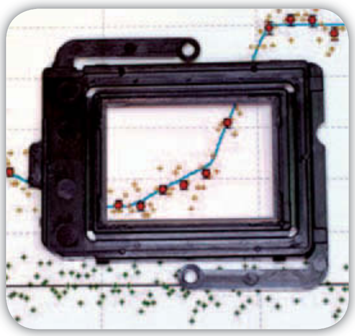
▴ **PLANETARY CAMERA** From ZW Optical comes the ASI120MM ($329.95), a new high-speed video camera designed for astrophotographers. The ASI120MM features the highly sensitive MT9M034 monochrome CMOS detector with a 1,280×960 array of 3.75-micron pixels. This USB-2.0 camera is capable of recording 35 frames per second at full resolution, or up to 215 frames per second of uncompressed video with on-chip ROI. Additionally, the camera can operate in 12-bit format and can function as an autoguider for your deep-sky imaging needs with its built-in ST-4 autoguider port. The camera comes complete with USB-2.0 and ST-4 guiding cables, a 1.25-inch nose-piece adapter, a CD with camera drivers and control software, and a removable fisheye lens.

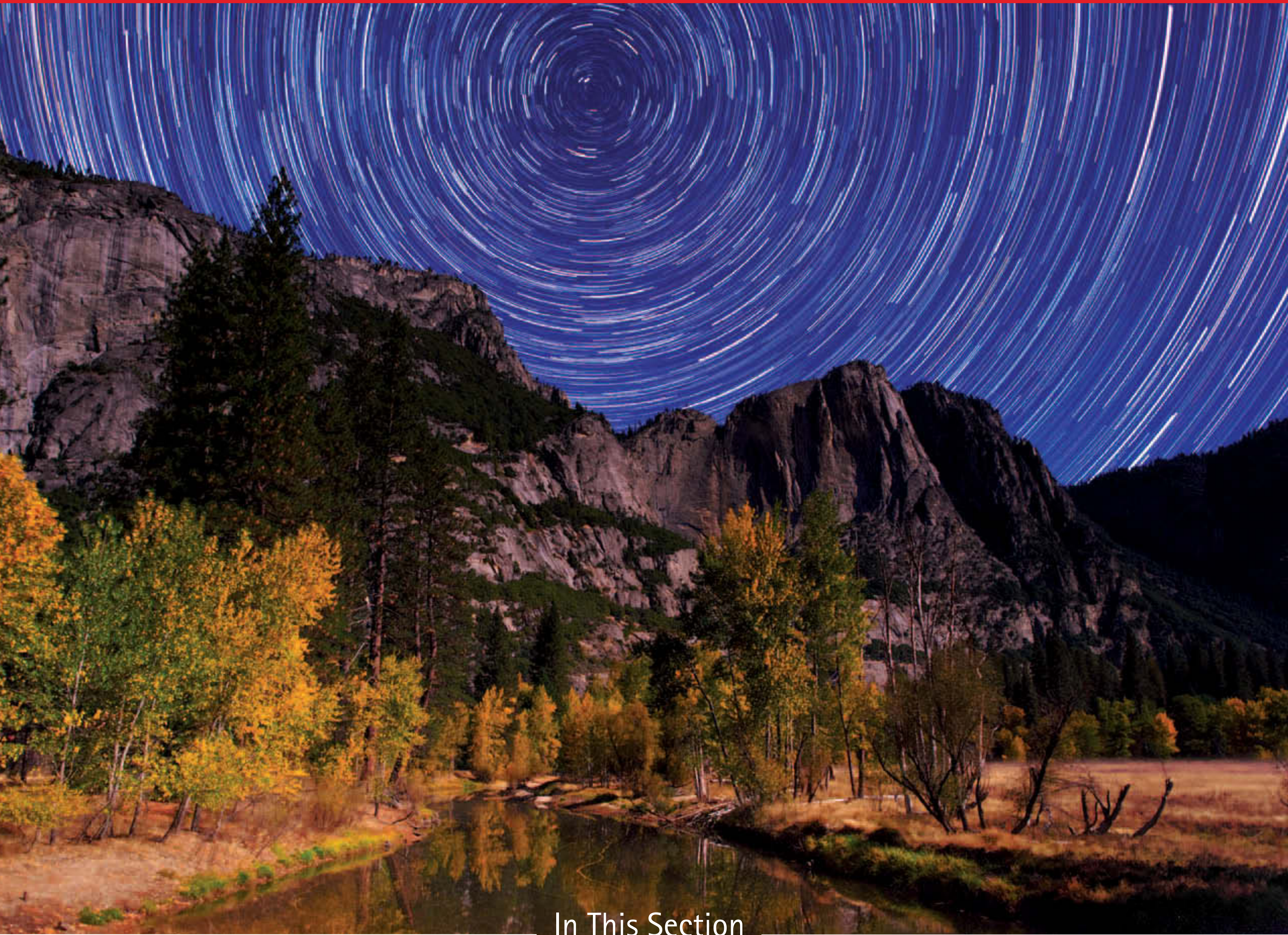
ZW Optical
Available in the U.S.A. from High Point Scientific
442 Route 206, Montague, NJ 07827, 800-266-9590;
www.highpointscientific.com

▾ **ASTRODON DSLR** Premier filter manufacturer Astrodon teams up with DSLR aficionado Hap Griffin to offer the Astrodon Full Spectrum Modification Service ($320 plus shipping). This service replaces both the stock IR-blocking filter and front filter used for dust protection in your Canon DSLR with an AstrodonInside AD40D Clear Filter to enable the use of any astronomical or photographic filter with your camera (July issue, page 68). Now you can take advantage of the full spectral sensitivity offered by the CMOS sensors in Canon DSLR cameras and shoot infrared photography, normal daytime pictures, or hydrogen-alpha nebulosity under moonlight. With the AstrodonInside filter, the camera's autofocus and viewfinder remain perfectly calibrated. Note that additional filters will be required in the optical path for proper photographic color balance depending on your target. The service requires shipping your camera to Hap Griffin for modification and voids any manufacturer warranty.

Hap Griffin
www.hapg.org







In This Section

PHOTOGRAPH: BABAK TAFRESHI / TWAN

Stars shine above a moonlit November landscape in California's Yosemite National Park.

Sky at a Glance

NOVEMBER 2013

2–15 **DAWN:** The zodiacal light is visible in the east 120 to 80 minutes before sunrise from dark locations at mid-northern latitudes. Look for a tall, broad pyramid of light leaning to the right, with Mars near its apex.

3 **DAYLIGHT-SAVING TIME ENDS** at 2 a.m. for most of the U.S. and Canada.

A HYBRID SOLAR ECLIPSE traverses the Atlantic Ocean and equatorial Africa. The partial phase is visible over a large area, including eastern North America. See page 51.

6 **DUSK:** Venus shines about 7° lower left of the waxing crescent Moon; see page 48.

11–28 **DAWN:** Mid-northern observers should be able to spot Mercury well above the east-southeastern horizon 45 minutes before sunrise.

17, 18 **DAWN:** Comet ISON, perhaps now visible to the unaided eye, passes close to Spica; see page 50.

EVENING: The just-past-full Moon shines right of Aldebaran and the Pleiades on the 17th and left of Aldebaran on the 18th.

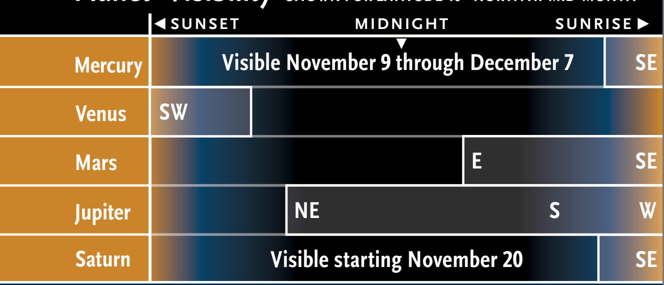
22 **DAWN:** Comet ISON is level with Mercury and 5½° to the planet's right.

25, 26 **DAWN:** Saturn is less than 1° from much brighter Mercury. Comet ISON may be visible far below them a half hour before sunrise; see page 49.

29 **DAWN:** Spica shines to the lower left of the waning crescent Moon. The Moon goes on to occult (hide) Spica during broad daylight in North America, but the Moon's thin crescent will be very difficult to locate without a Go To telescope.

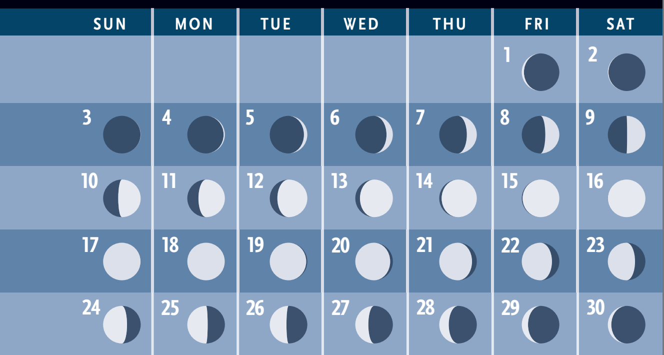
Planet Visibility

SHOWN FOR LATITUDE 40° NORTH AT MID-MONTH



Moon Phases

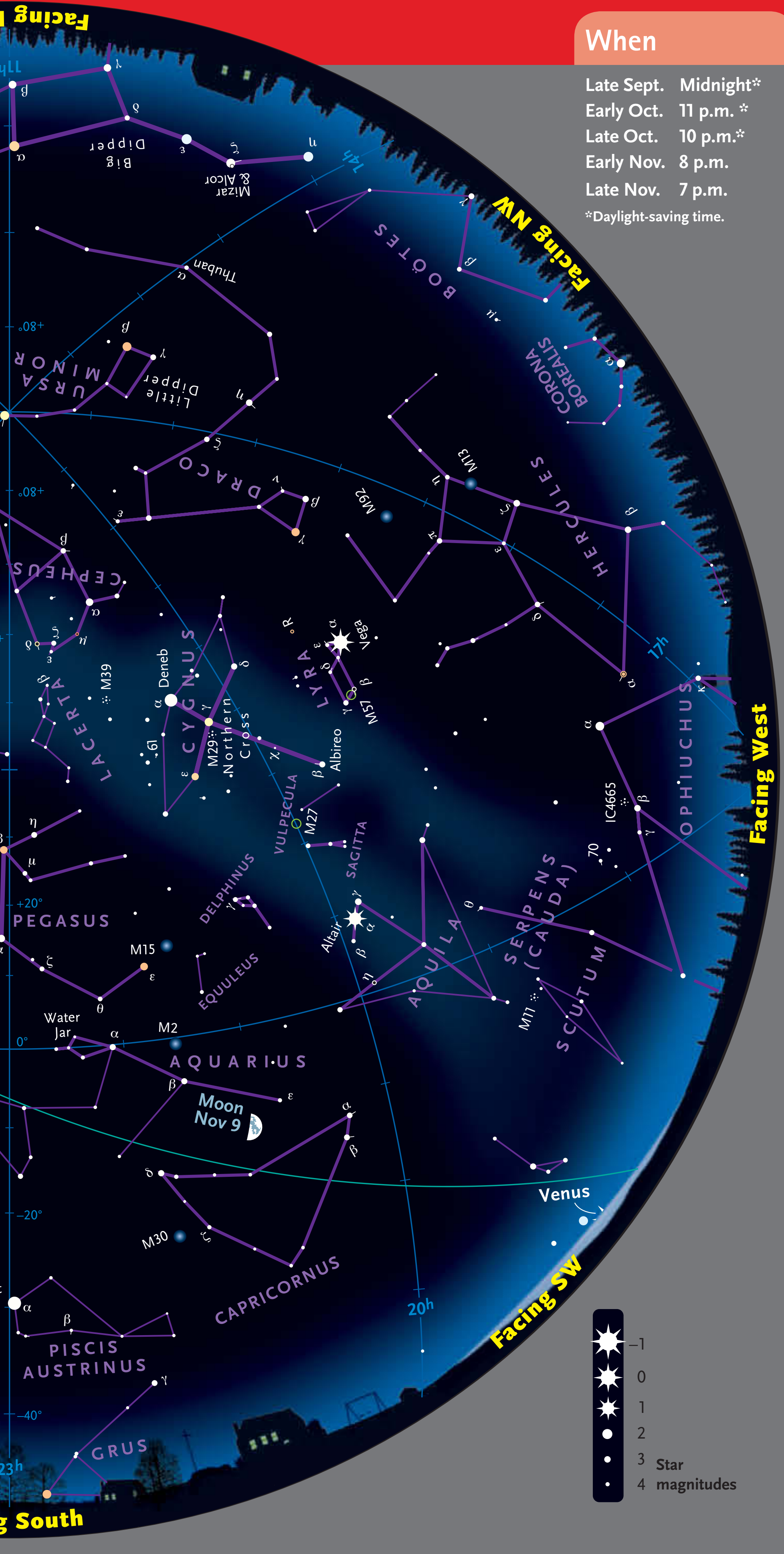
New	November 3	7:50 a.m. EST	First Qtr	November 10	12:57 a.m. EST
Full	November 17	10:16 a.m. EST	Last Qtr	November 25	2:28 p.m. EST



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 Sept.	Midnight*
Early Oct.	11 p.m. *
Late Oct.	10 p.m.*
Early Nov.	8 p.m.
Late Nov.	7 p.m.

*Daylight-saving time.

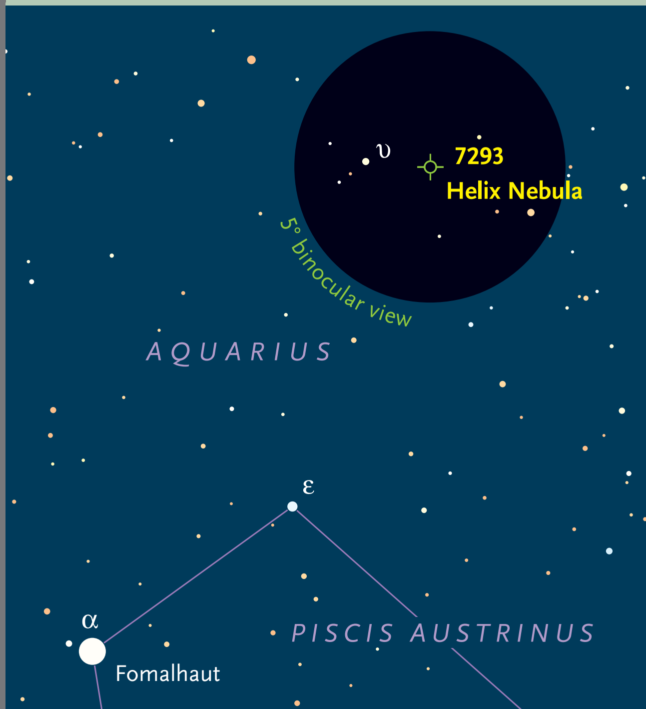
A Ghost in Aquarius

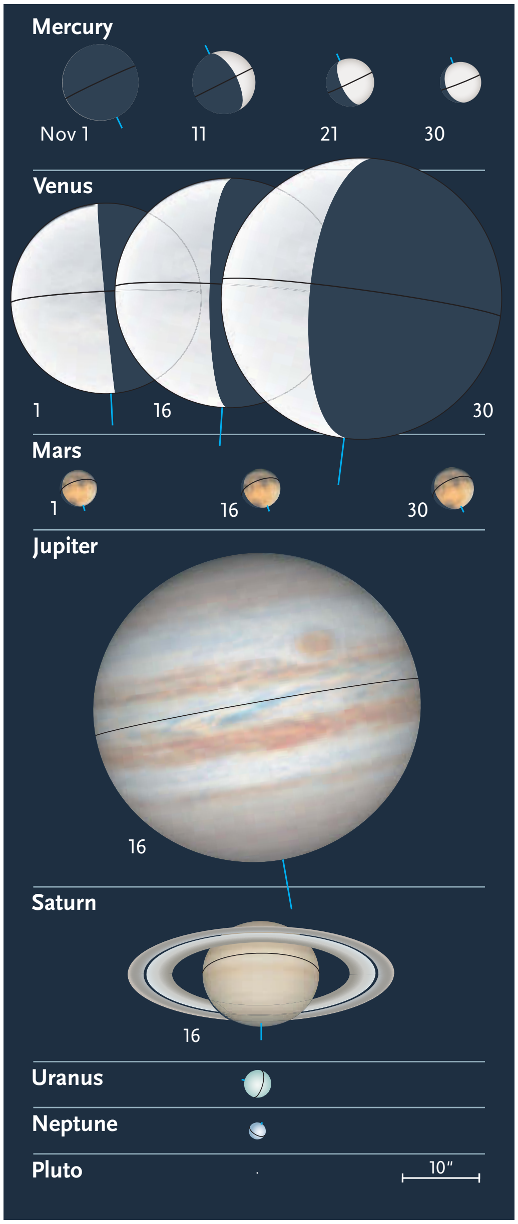
Planetary nebulae are perhaps the most challenging class of deep-sky object for binocular users. With only a handful of exceptions, they're very, very small at typical binocular magnifications. To make matters worse, most planetary nebulae are also faint. But one planetary that seems to defy the norm is the **Helix Nebula**, NGC 7293, in Aquarius.

When you look at the Helix Nebula's stats, you can be forgiven for expecting it to be a piece of cake. After all, it's about half the apparent size of the Moon (nearly 18′ across) and glows at magnitude 7.3. Easy, right? Not so much. Ironically, it's the nebula's huge size that makes it so difficult. The magnitude tells us how bright the Helix would appear if all its light radiated from a single, starlike point. But take that same illumination and spread it out to cover 18′, and you can begin to appreciate the problem. The nebula's surface brightness is very low, and that's what makes it tricky to detect.

Having said that, the low magnification of binoculars actually helps keep the Helix's light tightly concentrated. As a result, I'm able to sweep it up under dark skies with my 10×30 image-stabilized binoculars. The nebula pops in and out of view, but it's definitely there. My 15×45 image-stabilized binos make relatively easy work of it — the extra magnification and aperture render the Helix as a modest, evenly illuminated disk of ghostly light.

To try your luck with the Helix, begin by hopping from brilliant Fomalhaut up to Epsilon (ε) Piscis Austrini. From there, jump north 6½° to 5th-magnitude Upsilon (υ) Aquarii. Scan for the nebula 1° west-southwest of Upsilon. ✦



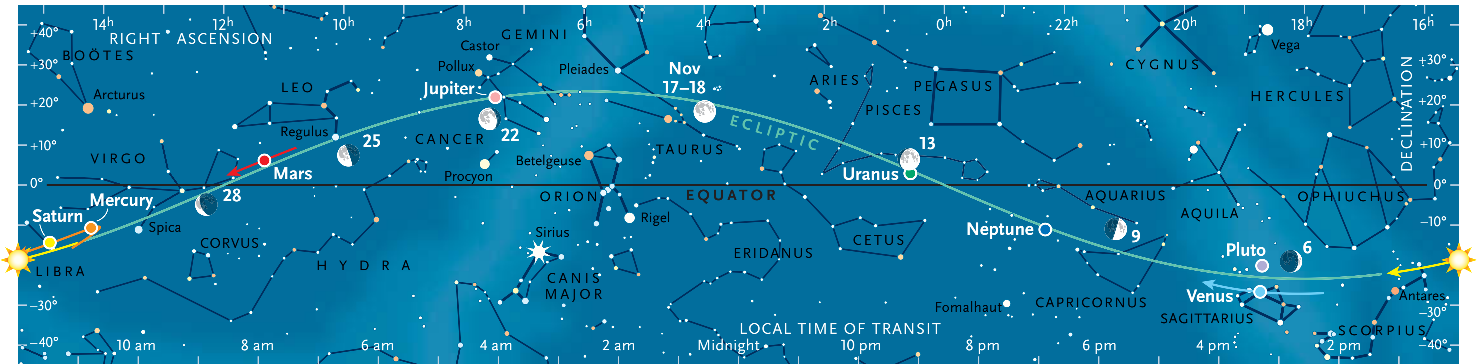


Sun and Planets, November 2013

	November	Right Ascension	Declination	Elongation	Magnitude	Diameter	Illumination	Distance
Sun	1	$14^h\ 24.6^m$	–14° 21′	—	–26.8	32′ 14″	—	0.993
	30	$16^h\ 23.8^m$	–21° 36′	—	–26.8	32′ 26″	—	0.986
Mercury	1	$14^h\ 31.2^m$	–15° 44′	2° Ev	—	10.0″	0%	0.672
	11	$14^h\ 03.2^m$	–10° 25′	16° Mo	+0.3	8.2″	28%	0.815
	21	$14^h\ 31.7^m$	–12° 35′	19° Mo	–0.7	6.3″	69%	1.070
	30	$15^h\ 20.2^m$	–16° 57′	16° Mo	–0.6	5.4″	87%	1.251
Venus	1	$17^h\ 39.8^m$	–27° 00′	47° Ev	–4.5	24.9″	50%	0.670
	11	$18^h\ 23.2^m$	–27° 05′	47° Ev	–4.7	28.1″	44%	0.594
	21	$19^h\ 02.0^m$	–26° 15′	45° Ev	–4.8	32.1″	38%	0.519
	30	$19^h\ 31.1^m$	–24° 52′	43° Ev	–4.8	36.7″	31%	0.454
Mars	1	$10^h\ 46.8^m$	+9° 26′	59° Mo	+1.5	4.9″	93%	1.921
	16	$11^h\ 18.7^m$	+6° 17′	66° Mo	+1.4	5.2″	92%	1.798
	30	$11^h\ 47.1^m$	+3° 24′	72° Mo	+1.2	5.6″	91%	1.674
Jupiter	1	$7^h\ 27.6^m$	+21° 54′	108° Mo	–2.4	41.3″	99%	4.772
	30	$7^h\ 24.3^m$	+22° 04′	138° Mo	–2.6	44.8″	100%	4.402
Saturn	1	$14^h\ 46.4^m$	–13° 50′	5° Ev	+0.5	15.3″	100%	10.855
	30	$14^h\ 59.9^m$	–14° 50′	21° Mo	+0.6	15.4″	100%	10.788
Uranus	16	$0^h\ 33.5^m$	+2° 50′	135° Ev	+5.7	3.6″	100%	19.324
Neptune	16	$22^h\ 18.4^m$	–11° 16′	99° Ev	+7.9	2.3″	100%	29.814
Pluto	16	$18^h\ 40.8^m$	–20° 15′	46° Ev	+14.2	0.1″	100%	33.223

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

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



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

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

Fred Schaaf

Spring Stars in Fall

You can time-travel by staying up until dawn.

. . . O Wind,
If Winter comes, can Spring be far behind?
— Percy Bysshe Shelley, *Ode to the West Wind*

The early 19th-century English poet Shelley had considerable interest in science in general and astronomy in particular. But I'm not quoting Shelley because of his astronomical connections. I want to explain how we can provide a literal, astronomical answer to the question that ends his famous ode — by observing, at least off and on, through an entire November night.

Fall to spring in a single night. If we see the stars of winter climbing November's evening skies in the east as autumn's stars move on in the south and west, can the stars of spring be far behind? To find the answer, stay up until — or wake up before — the first light of dawn. You will probably want to do that anyway to look for Comet C/2012 S1 ISON, which may — or may not — become brilliant as it falls past bright stars and planets into the sunrise this month.

Let's start right after a November sunset. The first stars that come into view, still rather high in the western sky, are Vega, Deneb, and Altair. They make up the "Summer Triangle" — a bit of a misnomer for this September-peaking asterism.

By around 9 p.m. (standard time) in November, the Great Square of Pegasus is on or just past the meridian, the Andromeda Galaxy is near the zenith, Cassiopeia is at its highest in the north, and Orion has just cleared the east horizon.

I don't know where you live. But if I stay out in my New Jersey backyard until midnight in November, when not just Sirius but all of Canis Major has cleared the southeast horizon, I might suddenly notice that frost has silently, magically joined me as an observing companion.

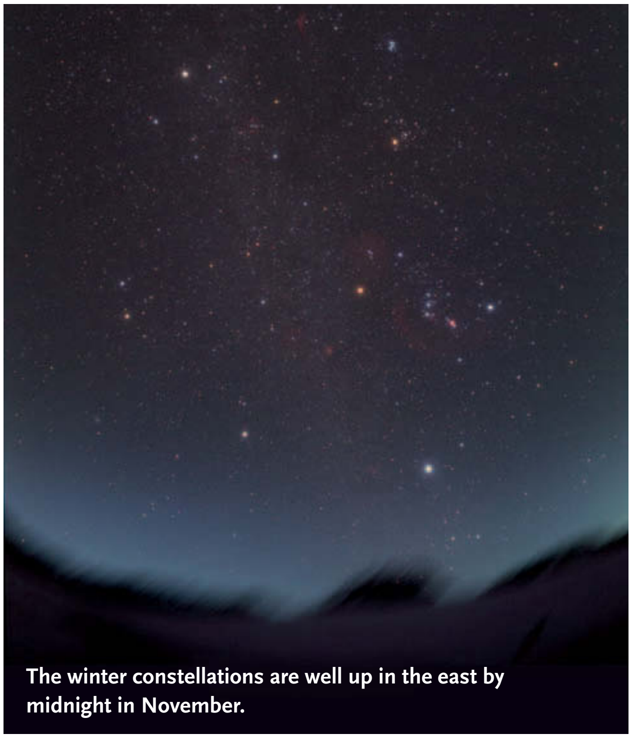
Can spring stars be far behind? You might want to catch a few hours of sleep after midnight, but be sure to be out again by 5 a.m. That's when you'll see "all the morning stars sing together." The Big Dipper will be wheeling high in the northeast, pointing its handle to Arcturus, the Spring Star, from which you can drive the spike (straight line) to Spica — and, just after mid-month, to Comet ISON near Spica.

How different — and fresh — it is to see our old spring friends such as Arcturus and Spica (and Corvus!) coming up before dawn at this time of year. Some of us are familiar with this experience from being out at this time to look for mighty Leonid meteor showers in certain years.

Leo is indeed striding toward the meridian at this time. I remember seeing him up there on a November dawn when I was in 6th grade in 1966 and witnessed the start of what was to become one of the most intense Leonid storms in history. My best meteor that morning was a half-Moon-bright fireball that hurtled so fast down the southwest sky it took my breath away.

I also remember, 35 years later, when I saw Leonid rates briefly hit 1,000 per hour as morning twilight came on. And even when dawn brightened enough to show color in the landscape, I still saw beyond a fellow observer's head three brilliant Leonids at one time. They fell through the almost faded-out form of Orion as he touched the low western treeline with Sirius to his left.

The stars of winter and spring, in the midst of autumn, are what you will surely see if you get up before dawn this month. Let's hope we also see a comet as memorable as a splendid Leonid display. ✦

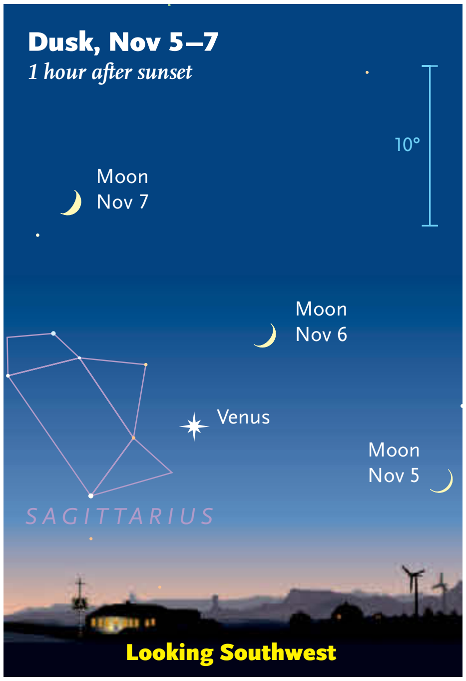


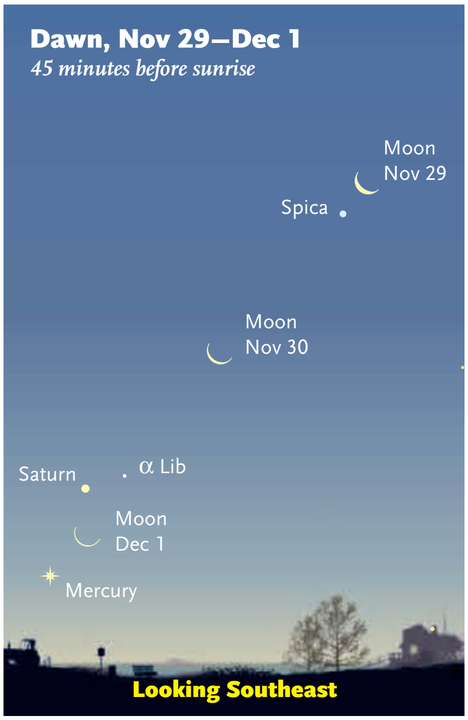
The winter constellations are well up in the east by midnight in November.

AKIRA FUJII

Five Bright Planets & One Comet

All the classical planets and a promising comet should be visible this month.





What a rich and strange month November will be! An unusual hybrid (total-annular) solar eclipse crosses the Atlantic and parts of Africa on November 3rd, including a slight partial eclipse visible at sunrise from the Eastern Seaboard. Venus and Jupiter are in fine view during dusk and late evening, respectively, and both planets improve throughout November.

Mars rises in the small hours of the morning and is high in the southeast by dawn. First Mercury and then Saturn appear low in the dawn sky later in November, and they have a close conjunction on the 25th and 26th.

Most exciting of all, this is the month when Comet C/2012 S1 ISON may become visible — and conceivably even impressive — to the unaided eye. However bright the comet turns out to be, we know that it will have a close conjunction with Spica and pass both Mercury and Saturn before plunging stunningly near the Sun in the sky and in space on November 28th, Thanksgiving Day in the U.S.

DUSK & EARLY EVENING

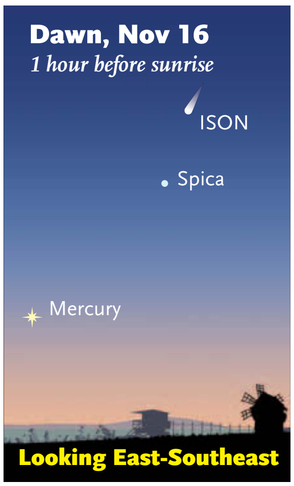
Venus is nearing the peak of its evening apparition for northern observers, but that's not saying much this year. Even at its highest in early December, Venus will be just 19° above the southwest horizon a half hour after sunset for observers at latitude 40° north. Although the planet attains a greatest elongation of 47° from the Sun on November 1st, it's also very near its farthest southern declination then. In fact, on November 6th it's slightly farther south (–27° 10′) than it has been since 1930.

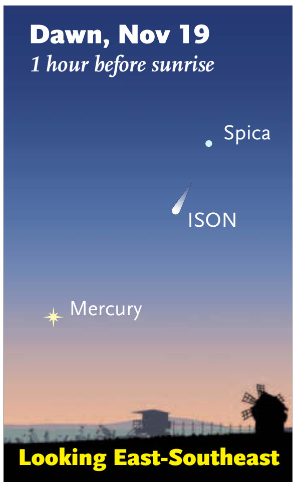
Venus brightens from magnitude –4.5 to an awesome –4.8 during November. Venus's crescent is equally exciting through telescopes, slimming from 50% to 31% lit while its tip-to-tip diameter increases from 25″ to 37″.

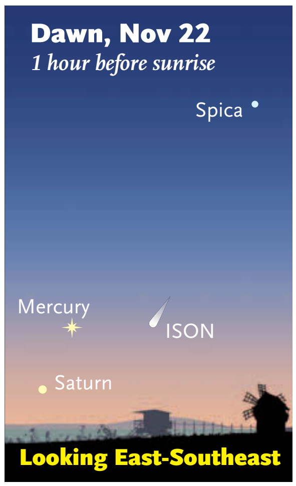
Neptune is near its highest in the south at nightfall, and **Uranus** follows about two hours later. They're in Aquarius and Pisces, respectively. See last month's issue, page 50, for finder charts.

EVENING & NIGHT

Jupiter, in Gemini, rises about 10 p.m. daylight-saving time on November 1st and about 7 p.m. standard time on November 30th. Jupiter brightens from magnitude –2.4 to –2.6 this month, and its creamy, banded orb swells from 41″ to 45″ wide.



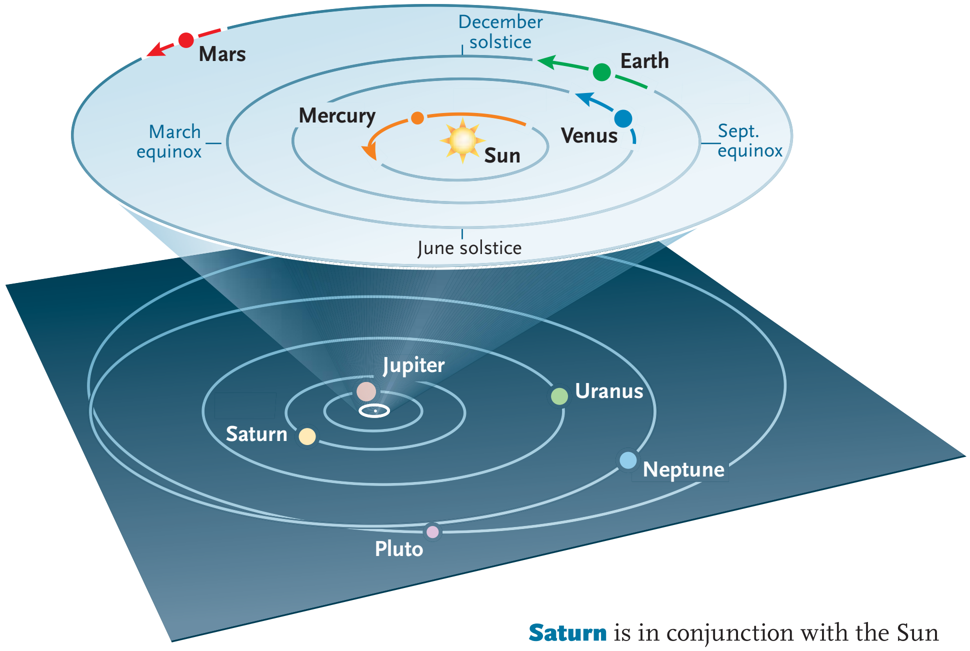




Fred Schaaf

ORBITS OF THE PLANETS

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



Jupiter halts direct motion (eastward against the starry background) on November 7th, so it remains about 7½° from Pollux all month, forming a dogleg with Pollux and Castor. Toward the end of the month it starts edging westward toward Delta Geminorum (Wasat). On November 9th, Jupiter goes through its ascending node, passing north of the ecliptic, the plane of Earth's orbit, for the first time in six years.

Mars comes up around 2:30 a.m. daylight-saving time on November 1st and around 1 a.m. standard time on November 30th. The Red Planet finally starts brightening significantly, kindling from magnitude +1.5 to +1.2 in November. Through a telescope, you can see its tiny disk grow from 4.9″ to 5.6″ wide. Mars starts November in south-central Leo and moves into western Virgo, ending the month not far northeast of Beta (β) Virginis.

DAWN

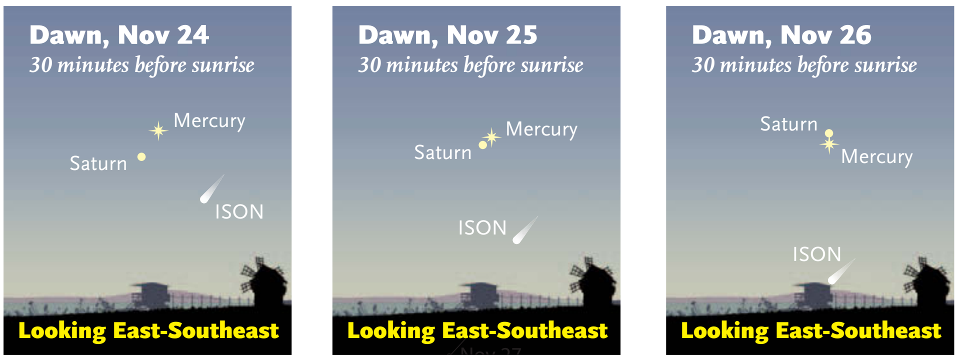
Comet ISON races from Leo across Virgo and Libra into Scorpius this month. It's a good 52° from the Sun on November 1st, so it's already quite high in the south-southeast at the first sign of dawn in early November. But it appears quite a bit lower — and probably brighter — each morning as it approaches its rendezvous with the Sun on November 28th. See page 50 for finder charts and details.

ISON passes quite close to Spica on November 17th and 18th, and about 5° from Mercury and Saturn on the 23rd and 24th.

Mercury passes through inferior conjunction with the Sun on November 1st. It appears significantly higher and brighter each morning after that, becoming visible to the unaided eye around November 9th. It shines at magnitude +0.8 that morning, brightens to –0.7 by the 20th, and remains essentially this bright into early December. This is Mercury's best morning apparition of 2013 for mid-northern latitudes.

Saturn is in conjunction with the Sun on November 6th and doesn't become easily visible to the unaided eye low in the dawn until the last week of November.

Mercury reaches greatest elongation from the Sun on November 18th. After that it appears lower each morning, while Saturn, below it, appears a little higher. The two planets pass each other around 1^h UT on November 26th when they're just 0.3° apart, but they're about twice that separation by the time they rise in the Americas. That morning Saturn shines at magnitude +0.6, just one-third as bright as Mercury. If you can get a reasonably steady view through a telescope, Saturn will appear much more impressive: 15″ across at the equator and more than twice that if you include the rings, compared to Mercury's slightly gibbous 5.6″ disk.



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. For clarity, the Moon is shown three times its actual apparent size. Comet ISON will probably appear fainter than shown, and may be invisible without binoculars.

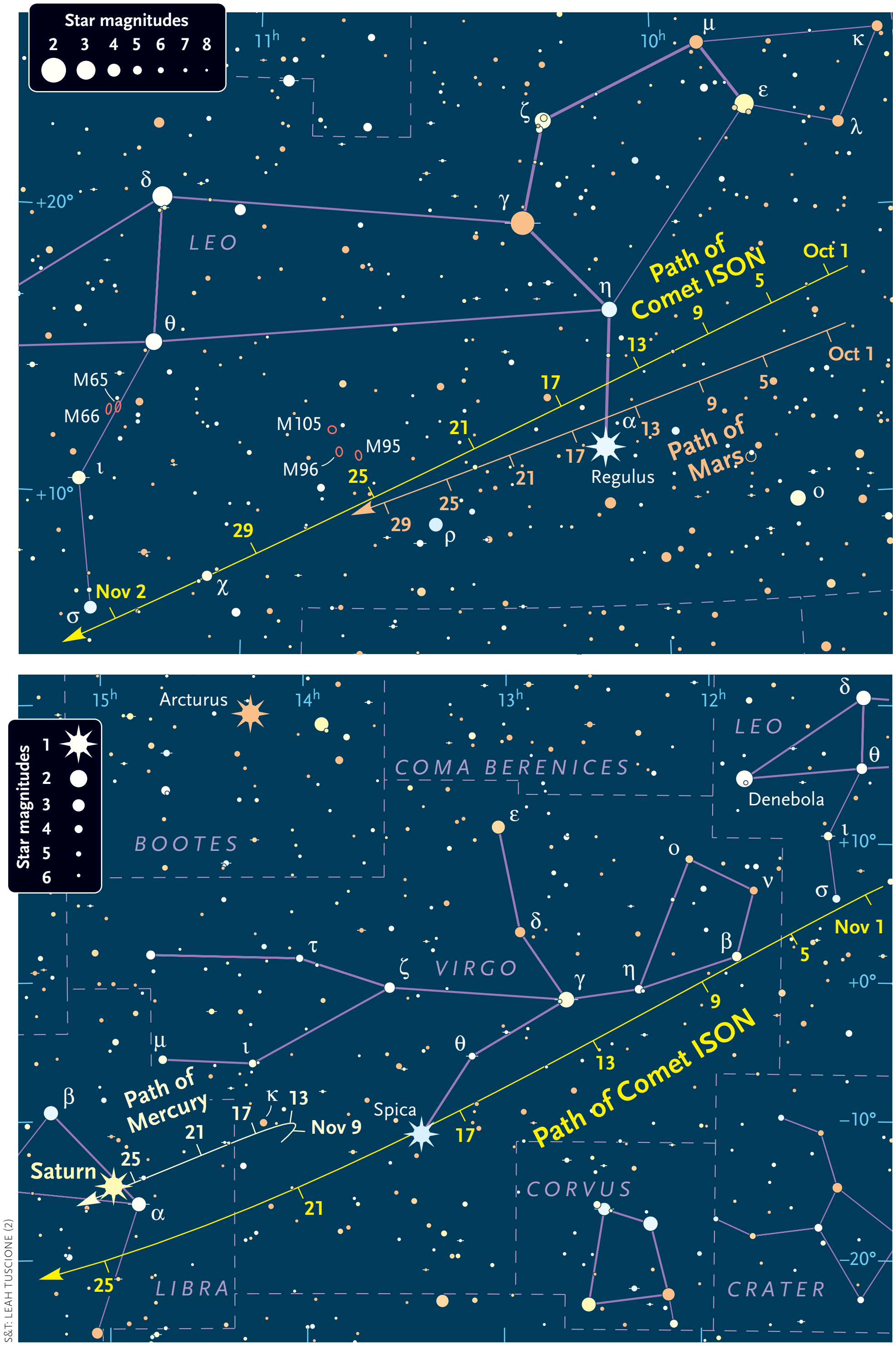
SUN & MOON

The **Sun** experiences the aforementioned hybrid eclipse on November 3rd; see page 51 for details.

The waxing crescent **Moon** is upper right of Venus on November 6th. The waning crescent is right of Mars on the morning of November 27th. The Moon occults (hides) Spica around 11:30 a.m. CST November 29th in North America, but the 14%-lit crescent will be very hard to locate less than 45° west of the Sun in the daytime sky. ✦

As Comet ISON Nears. . .

Will it become a great comet? A pathetic dud? Or something in between?



S&T: LEAH TUSCIONE (2)

For Comet ISON, now speeding sunward across Leo and Virgo in the morning sky, a moment of truth is approaching. That moment is perihelion day, November 28th (Thanksgiving in the U.S.), when the comet will whip around the Sun less than one solar diameter from the Sun's surface.

The heat will roast the surface of the comet's icy nucleus to 2700°C (4900°F), hot enough to melt iron. Moreover, the comet will be inside the Sun's Roche limit, where the Sun's tidal effect will overpower the nucleus's weak self-gravity. So the nucleus will be pulled apart into a line of rubble if it doesn't have enough tensile strength to resist the tidal stretching. Combine that with the violent broiling and outgassing — and no one knows what will come out the other side of perihelion to climb up the eastern dawn sky in the first half of December.

As we wait for these developments, however, you can watch the incoming comet with a telescope — maybe — as it draws closer to the Earth and Sun during October and much of November.

Comet ISON (C/2012 S1) spent June, July, and much of August hidden in the Sun's glow after, disturbingly, not brightening at all from January through May. It was still a pathetic magnitude 15.5 when lost from good sight at the beginning of June; it should have been almost two magnitudes brighter by then. When observers recovered it low in the dawn in mid- and late August it was about magnitude 14.0,

Comet ISON's path against pre-dawn stars in October (*top*) and November. Ticks mark 0:00 Universal Time every four days. (To change UT to Eastern Daylight Time, subtract 4 hours. To get Eastern Standard Time, subtract 5.) Put pencil dots on the positions of Mars and ISON for the date and time you'll observe. (Dawn begins about 90 minutes before sunrise). In October, Mars is your best starting point for star-hopping to the comet's exact location among faint stars.

NASA / ESA / HUBBLE HERITAGE TEAM (STSCI / AURA)

The Hubble Space Telescope captured Comet ISON last April 30th when it was still 3.9 astronomical units from the Sun and failing to brighten on schedule. The visible tail here is only about 40 arcseconds (70,000 miles) long. This is a composite view; the telescope imaged the stationary background stars and galaxies in two colors, then tracked the moving comet in a single color (shown white).

still two magnitudes below the original forecast that had it turning into a grand spectacle.

Anything could still happen. ISON's nucleus is not very big as comets go: less than 3 miles (5 km) in diameter. At perihelion there's certainly a good chance that it will come apart. A disintegration that late in the game would be good news for eager skywatchers, because a swarm of rubble would expose more icy surface to the solar broiling. The more gas and dust that are released, the longer and brighter the comet's tail will be in the following days and weeks. The prototypes for a big post-breakup brightening are the spectacular Comet West in 1976 and Comet Lovejoy in 2011 (see page 30).

On the other hand, if the nucleus breaks up long before perihelion, the debris will spread out and perhaps become too diffuse to see at all.

Inward Trajectory

The maps at left show the comet's path in October and November as it crosses Leo, then Virgo, in the pre-dawn sky. By chance the comet travels nearly along the ecliptic during this time. If its weakening was just a passing phase from which it recovers, it should brighten from about magnitude 9 on October 1st to 8 on October 15th, 6 on November 1st, and 3 on November 15th. You may find that it's much fainter.

By another coincidence, Comet ISON tracks right alongside Mars during October. Planet and comet will remain within 2° of each other from September 25th through October 23rd as they speed eastward against the stars. They appear closest in the sky (0.9°) on October 17th and 18th, after passing their closest in space (0.07 a.u.) on the 1st. Then the falling comet gains speed and pulls away sunward.

On the morning of October 15th, Mars happens to be passing Regulus by 0.9° while ISON is just 1.1° on Mars's opposite side — a possible photo opportunity.

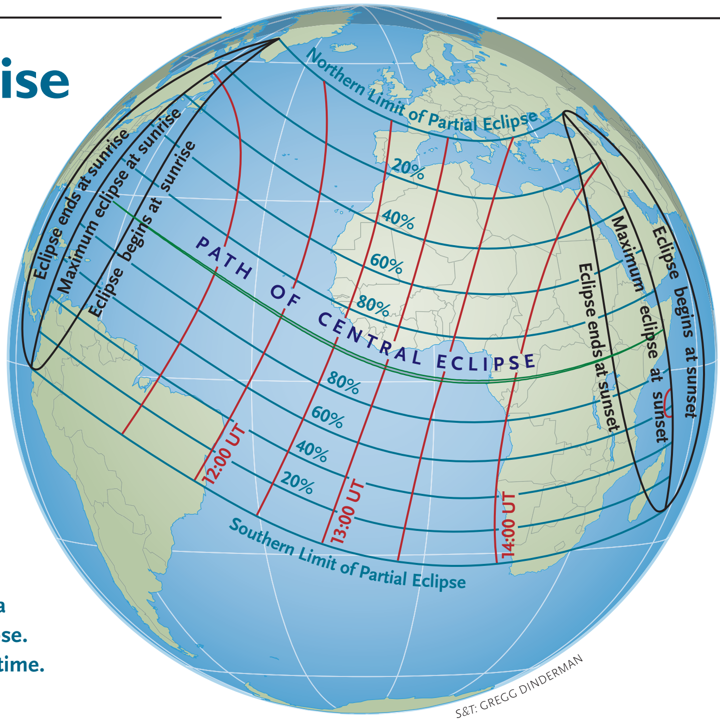
On the morning of November 7th, the comet is about 0.4° south of Beta (β) Virginis, magnitude 3.6. On November 18th it passes less than 1° from Spica. And finally in November, see its configurations with Saturn and Mercury low in the dawn on pages 48–49. The comet symbols there are highly exaggerated. Probably.

Partial Solar Eclipse at Sunrise

The Sun will undergo a borderline annular/total eclipse on November 3rd: barely annular after sunrise over the western Atlantic, then barely total for the rest of the way, including across equatorial Africa to sunset.

A partial eclipse can be seen from much more of the globe, as shown here — barely including North America's Eastern Seaboard at sunrise.

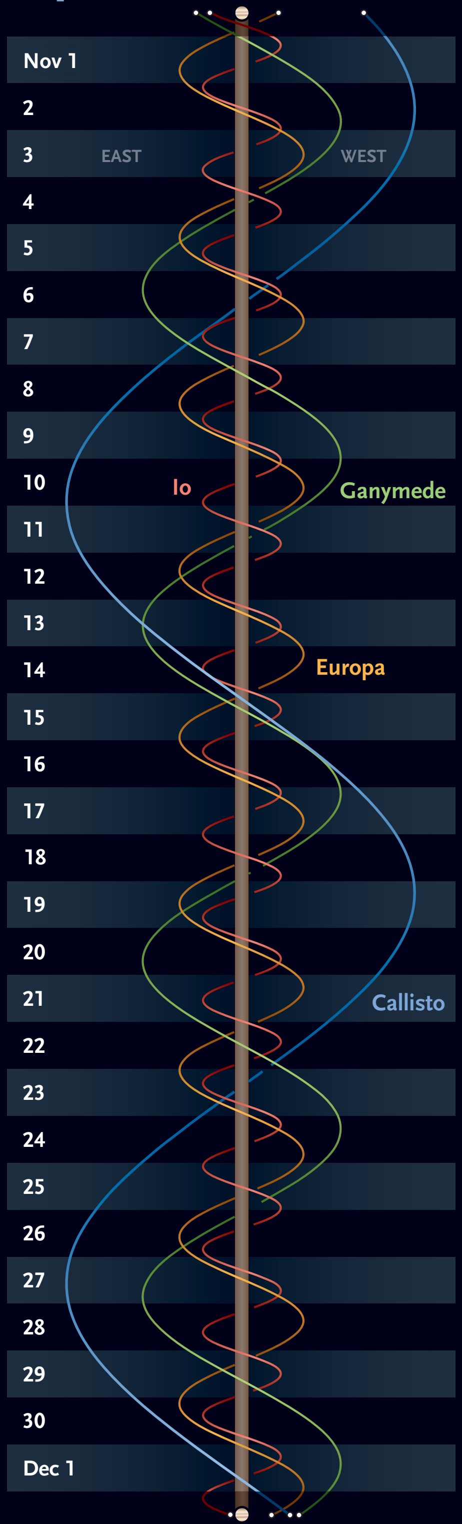
For viewers from New Brunswick to Florida, only a small nick will be missing from the Sun's lower left limb when the Sun rises over the east-southeast horizon. The nick will diminish and disappear within minutes. This last trace of the partial eclipse will theoretically be detectable right at sunrise from as far west as Alabama, Ohio, and northern Labrador, but you'll need a flat horizon and binoculars or a telescope with a safe solar filter over the front. No matter where you are, always use a proper solar filter for looking at the bright Sun. For more information, including links to timetables for many cities, see **skypub.com/nov2013eclipse**.



S&T: GREGG DINDERMAN

On November 3rd, solar-filter users across a wide swath of the world can view a partial eclipse of the Sun. Red lines indicate the Universal Time of deepest eclipse. The blue lines tell the percent of the Sun's diameter the Moon will cover at that time.

Jupiter's Moons



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

November Meteors

The strange Taurid meteor shower is active all the way from mid-October (or earlier) to late November. The meteors are debris from Periodic Comet Encke. They intercept Earth at a relatively low velocity, but even so they often blaze brightly, indicating unusual size. Only about a half dozen Taurids are normally visible per hour at best, but spectacular Taurid fireballs sometimes make up for the shower's low rate. The Taurids are also unusual among meteor showers in being active from dusk to dawn.

If you see a fireball during these weeks, it's almost certainly a Taurid if its direction of flight, traced far enough backward, leads to southern Aries in October or the vicinity of the Pleiades and Hyades in November.

The shower seems to have two distinct radiants. The Southern Taurids are most active in late October and early November, giving way to the Northern Taurids by mid-November.

The more famous Leonid shower falls on the bright nights of November's full Moon; it's due to peak on the morning of the 17th. Even in dark-sky years under ideal conditions, the Leonid shower now produces only about 20 meteors visible per hour. Long gone are its historic displays of 1998 to 2002.

Jupiter and Its Moons

During November Jupiter climbs up into good view in the eastern sky before midnight, shining in Gemini near Castor and Pollux.

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

Listed on the facing page are all the interactions in November between Jupiter, its shadow, and the satellites and their shadows. A 3-inch telescope is often enough for watching these.

Jupiter itself enlarges from a respectable 41″ to 45″ wide in November as it approaches its January 5th opposition. Here are the times, in Universal Time, when its Great Red Spot (actually pale orange-tan) should cross Jupiter's central meridian. The dates, also in UT, are in bold:

October 1, 2:35, 12:30, 22:26; **2**, 8:22, 18:18; **3**, 4:13, 14:09; **4**, 0:05, 10:00, 19:56; **5**, 5:52, 15:47; **6**, 1:43, 11:39, 21:34; **7**, 7:30, 17:26; **8**, 3:22, 13:17, 23:13; **9**, 9:09, 19:04; **10**, 5:00, 14:56; **11**, 0:51, 10:47, 20:43; **12**, 6:38, 16:34; **13**, 2:30, 12:25, 22:21; **14**, 8:17, 18:12; **15**, 4:08, 14:04, 23:59; **16**, 9:55, 19:51; **17**, 5:46, 15:42; **18**, 1:38, 11:33, 21:29; **19**, 7:25, 17:20; **20**, 3:16, 13:12, 23:07; **21**, 9:03, 18:59; **22**, 4:54, 14:50; **23**, 0:46, 10:41, 20:37; **24**, 6:33, 16:28; **25**, 2:24, 12:20, 22:15; **26**, 8:11, 18:07; **27**, 4:02, 13:58, 23:54; **28**, 9:49, 19:45; **29**, 5:41, 15:36; **30**, 1:32, 11:27, 21:23; **31**, 7:19, 17:14.

November 1, 3:12, 13:07, 23:03; **2**, 8:59, 18:54; **3**, 4:50, 14:46; **4**, 0:41, 10:37, 20:32; **5**, 6:28, 16:24; **6**, 2:19, 12:15, 22:11; **7**, 8:06, 18:02; **8**, 3:57, 13:53, 23:49; **9**, 9:44, 19:40; **10**, 5:36, 15:31; **11**, 1:27, 11:22, 21:18; **12**, 7:14, 17:09; **13**, 3:05, 13:01, 22:56; **14**, 8:52, 18:47; **15**, 4:43, 14:39; **16**, 0:34, 10:30, 20:25; **17**, 6:21, 16:17; **18**, 2:12, 12:08, 22:04; **19**, 7:59, 17:55; **20**, 3:50, 13:46, 23:42; **21**, 9:37, 19:33; **22**, 5:28, 15:24; **23**, 1:20, 11:15, 21:11; **24**, 7:06, 17:02; **25**, 2:58, 12:53, 22:49; **26**, 8:44, 18:40; **27**, 4:36, 14:31; **28**, 0:27, 10:22, 20:18; **29**, 6:14, 16:09; **30**, 2:05, 12:00, 21:56.

These times assume that the spot is centered at about System II longitude 203°. If it's not following predictions, it will transit 1⅔ minutes early for every degree of longitude less than 203°, or 1⅔ minutes later for every degree greater than 203°.

Any feature on Jupiter appears closer to the central meridian than to the limb for 50 minutes before and after transiting. The higher the planet, the better the seeing. A light blue or green filter boosts the contrast of Jupiter's reddish, orange, and tan markings somewhat. ✦

The Moon • November 2013

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

S&T PHOTO: DENNIS DI CICCO

Phases

NEW MOON
November 3
12:50 UT

FIRST QUARTER
November 10
5:57 UT

FULL MOON
November 17
15:16 UT

LAST QUARTER
November 25
19:28 UT

Distances

Perigee
November 6, 9h UT
227,025 miles
diam. 32′ 43″

Apogee
November 22, 10h UT
251,931 miles
diam. 29′ 28″

Librations

Petrov (crater)
November 10

Mare Australe
November 12

Jenner (crater)
November 13

Gibbs (crater)
November 15

Minima of Algol

Oct.	UT	Nov.	UT
3	10:27	1	2:35
6	7:15	3	23:24
9	4:04	6	20:12
12	0:53	9	17:01
14	21:42	12	13:50
17	18:30	15	10:39
20	15:19	18	7:28
23	12:08	21	4:17
26	8:57	24	1:06
29	5:46	26	21:55
		29	18:44

Phenomena of Jupiter's Moons, November 2013

Date	UT	Event
Nov. 1	2:29	III.Tr.E
	12:56	I.Ec.D
	16:27	I.Oc.R
Nov. 2	10:11	I.Sh.I
	11:13	II.Sh.I
	11:23	I.Tr.I
	12:24	I.Sh.E
	13:36	I.Tr.E
	13:40	II.Tr.I
	13:51	II.Sh.E
	16:21	II.Tr.E
Nov. 3	7:25	I.Ec.D
	10:54	I.Oc.R
Nov. 4	4:39	I.Sh.I
	5:45	II.Ec.D
	5:50	I.Tr.I
	6:53	I.Sh.E
	8:04	I.Tr.E
	8:18	III.Ec.D
	10:47	II.Oc.R
	11:20	III.Ec.R
	13:09	III.Oc.D
	16:20	III.Oc.R
Nov. 5	1:53	I.Ec.D
	5:22	I.Oc.R
	23:08	I.Sh.I
Nov. 6	0:17	I.Tr.I
	0:31	II.Sh.I
	1:21	I.Sh.E
	2:31	I.Tr.E
	2:55	II.Tr.I
	3:09	II.Sh.E
	4:16	IV.Ec.D
	5:36	II.Tr.E
	7:04	IV.Ec.R
	15:16	IV.Oc.D
	18:41	IV.Oc.R
	20:22	I.Ec.D
	23:49	I.Oc.R
Nov. 7	17:36	I.Sh.I
	18:45	I.Tr.I
	19:02	II.Ec.D
	19:49	I.Sh.E
	20:59	I.Tr.E
	22:26	III.Sh.I
Nov. 8	0:00	II.Oc.R
	1:26	III.Sh.E
	3:05	III.Tr.I
	6:13	III.Tr.E
	14:50	I.Ec.D
	18:17	I.Oc.R
Nov. 9	12:04	I.Sh.I
	13:12	I.Tr.I
	13:49	II.Sh.I
	14:18	I.Sh.E
	15:26	I.Tr.E
	16:09	II.Tr.I
	16:27	II.Sh.E
	18:49	II.Tr.E
Nov. 10	9:18	I.Ec.D
	12:44	I.Oc.R
Nov. 11	6:32	I.Sh.I
	7:39	I.Tr.I
	8:18	II.Ec.D
	8:46	I.Sh.E
	9:53	I.Tr.E
	12:17	III.Ec.D
	13:12	II.Oc.R
	15:20	III.Ec.R
	16:50	III.Oc.D
	20:01	III.Oc.R
Nov. 12	3:47	I.Ec.D
	7:11	I.Oc.R
Nov. 13	1:01	I.Sh.I
	2:06	I.Tr.I
	3:08	II.Sh.I
	3:14	I.Sh.E
	4:20	I.Tr.E
	5:22	II.Tr.I
	5:46	II.Sh.E
	8:03	II.Tr.E
	22:16	I.Ec.D
Nov. 14	1:39	I.Oc.R
	15:07	IV.Sh.I
	17:58	IV.Sh.E
	19:29	I.Sh.I
	20:33	I.Tr.I
	21:35	II.Ec.D
	21:43	I.Sh.E
	22:47	I.Tr.E
Nov. 15	1:09	IV.Tr.I
	2:23	III.Sh.I
	2:24	II.Oc.R
	4:32	IV.Tr.E
	5:25	III.Sh.E
	6:42	III.Tr.I
	9:51	III.Tr.E
	16:44	I.Ec.D
	20:06	I.Oc.R
Nov. 16	13:57	I.Sh.I
	15:00	I.Tr.I
	16:11	I.Sh.E
	16:25	II.Sh.I
	17:14	I.Tr.E
	18:34	II.Tr.I
	19:04	II.Sh.E
	21:15	II.Tr.E
Nov. 17	11:12	I.Ec.D
	14:33	I.Oc.R
Nov. 18	8:26	I.Sh.I
	9:27	I.Tr.I
	10:39	I.Sh.E
	10:52	II.Ec.D
	11:41	I.Tr.E
	15:35	II.Oc.R
	16:16	III.Ec.D
	19:21	III.Ec.R
	20:27	III.Oc.D
	23:39	III.Oc.R
Nov. 19	5:41	I.Ec.D
	9:00	I.Oc.R
Nov. 20	2:54	I.Sh.I
	3:54	I.Tr.I
	5:08	I.Sh.E
	5:44	II.Sh.I
	6:08	I.Tr.E
	7:47	II.Tr.I
	8:23	II.Sh.E
	10:28	II.Tr.E
Nov. 21	0:09	I.Ec.D
	3:27	I.Oc.R
	21:22	I.Sh.I
	22:20	I.Tr.I
	23:36	I.Sh.E
Nov. 22	0:08	II.Ec.D
	0:35	I.Tr.E
	4:46	II.Oc.R
	6:21	III.Sh.I
	9:24	III.Sh.E
	10:16	III.Tr.I
	13:25	III.Tr.E
	18:38	I.Ec.D
	21:53	I.Oc.R
	22:14	IV.Ec.D
Nov. 23	1:14	IV.Ec.R
	7:15	IV.Oc.D
	10:43	IV.Oc.R
	15:50	I.Sh.I
	16:47	I.Tr.I
	18:04	I.Sh.E
	19:01	II.Sh.I
	19:02	I.Tr.E
	20:58	II.Tr.I
	21:41	II.Sh.E
	23:39	II.Tr.E
Nov. 24	13:06	I.Ec.D
	16:20	I.Oc.R
Nov. 25	10:19	I.Sh.I
	11:14	I.Tr.I
	12:33	I.Sh.E
	13:25	II.Ec.D
	13:28	I.Tr.E
	17:56	II.Oc.R
	20:15	III.Ec.D
	23:20	III.Ec.R
	23:59	III.Oc.D
Nov. 26	3:11	III.Oc.R
	7:35	I.Ec.D
	10:47	I.Oc.R
Nov. 27	4:47	I.Sh.I
	5:40	I.Tr.I
	7:01	I.Sh.E
	7:55	I.Tr.E
	8:20	II.Sh.I
	10:09	II.Tr.I
	10:59	II.Sh.E
	12:50	II.Tr.E
Nov. 28	2:03	I.Ec.D
	5:13	I.Oc.R
	23:15	I.Sh.I
Nov. 29	0:07	I.Tr.I
	1:30	I.Sh.E
	2:21	I.Tr.E
	2:42	II.Ec.D
	7:05	II.Oc.R
	10:19	III.Sh.I
	13:23	III.Sh.E
	13:45	III.Tr.I
	16:54	III.Tr.E
	20:32	I.Ec.D
	23:40	I.Oc.R
Nov. 30	17:44	I.Sh.I
	18:33	I.Tr.I
	19:58	I.Sh.E
	20:48	I.Tr.E
	21:38	II.Sh.I

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

Friends

Cassiopeia offers bountiful gifts to stargazers.

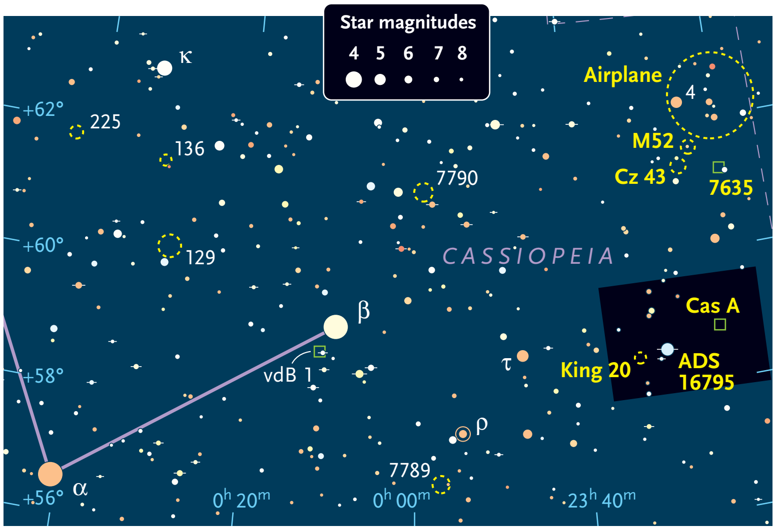
The stars are friends of mine. To lofty height,
When falls the sombre canopy of night
Upon a slumb'ring world, my spirit flies
And treads with them the highway of the skies.
— Richard Herbert Mann, *Friends of Mine*

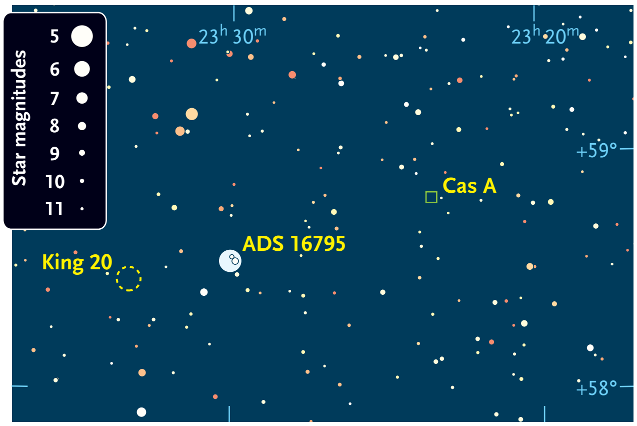
Many of us claim friends among the stars and eagerly greet them as they slowly come forth in deepening darkness. One of the best-loved and mostly widely recognized star patterns is the familiar M shape of Cassiopeia's brightest stars that is now suspended high in the north.

Clusters, Asterisms, Stars & Nebulae in Western Cassiopeia

Object	Type	Mag.	Size/Sep.	RA	Dec.
M52	Open cluster	6.9	16′	23^h 24.9^m	+61° 36′
Airplane	Asterism	4.1	1°	23^h 20.0^m	+62° 21′
Cz 43	Asterism	—	14′	23^h 25.8^m	+61° 19′
NGC 7635	Emission nebula	~10	16′ × 6′	23^h 20.7^m	+61° 12′
ADS 16795	Multiple star	4.9 – 13.0	0.3″ – 231″	23^h 30.0^m	+58° 33′
King 20	Open cluster	9.5	6.0′	23^h 33.3^m	+58° 28′
Cas A	Supernova remnant	—	4.7′ × 3.9′	23^h 23.5^m	+58° 49′

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.





Not all the stars we cherish are visible to the unaided eye. I'm quite fond of open clusters, and Cassiopeia bears a particularly beautiful one in its western reaches, **Messier 52**. A line from Alpha (α) through Beta (β) Cassiopeiae points straight to it, and the reddish orange star 4 Cassiopeiae hovers 41′ due north of the cluster.

From my semirural home in upstate New York, M52 is readily visible through 12×36 image-stabilized binoculars as a fairly bright hazy patch with a conspicuous star on its western edge. My 105-mm (4.1-inch) refractor at 87× shows a wonderful swarm of 50 faint to very faint stars about 12′ across. The distribution of stars is patchy, but there is some concentration toward the center. Through my 10-inch reflector at 115×, I count 80 stars in a 15′ cluster whose rim is frayed with scraps and strings of stars.

The prominent star at M52's edge doesn't belong to the cluster, whose brightest members shine at magnitude 10.5. This youthful cluster's stars have a mean age of 51 million years and lie 4,600 light-years away from us. Including the faint stars of its corona, M52 has a diameter of 23.3′ and about 890 probable members, according to a study published in *Astronomy & Astrophysics* (Pandey et al., 2001).

Ruddy 4 Cassiopeiae marks the eastern wingtip of an asterism that Massachusetts amateur John Davis calls the **Airplane**. Through my 105-mm scope at 17×, I see six stars outlining a thin, double-convex lens, which represents the plane's wings. Five additional stars curving northward form what Davis calls "the rest of the fuselage and swept-back tail fin of the aircraft." The bright red beacon of 4 Cassiopeiae must be the navigation light on the plane's port wing. The Airplane has a wingspan of

MICHAEL FULBRIGHT

A medium-power telescopic field of view encompasses the rich open cluster M52 at upper left, the asterism Czernik 43 to its south, and the Bubble Nebula (NGC 7635) to its west-southwest.

1° and is made up of stars ranging in brightness from magnitude 5.0 to 9.4.

Czernik 43 rests 19′ south-southeast of M52. According to the 1966 catalog of Polish astronomer Mieczyslaw Wojciech Czernik, this group is 14′ across and has 106 stars. My 130-mm refractor at 23× displays a splash of pinpoint stars. At 63× about 20 faint stars are loosely scattered across roughly 12′ of sky. A reddish orange, 9th-magnitude star sits on the group's northwestern edge, and a yellow-white, 8th-magnitude star nuzzles its northern edge.

A 2008 paper by Gracjan Maciejewski and Andrzej Niedzielski in *Astronomische Nachrichten* indicates that Czernik 43 is a chance alignment of physically unrelated stars — an asterism rather than a true cluster.

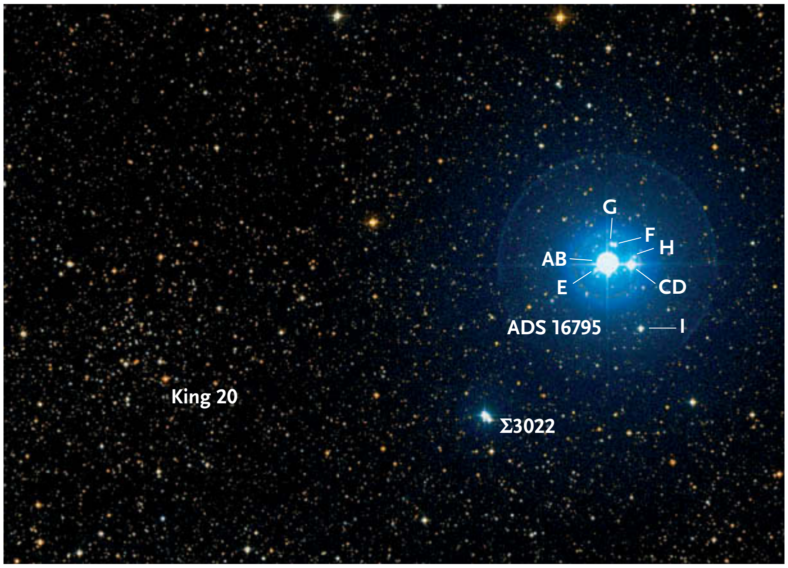
Sprawled 38′ southwest of M52, the emission nebula **NGC 7635** is faintly visible in my 130-mm refractor at 37× when I use an O III filter. This diaphanous band of light tilts north-northwest, with a 7th-magnitude star off its western flank and a 9th-magnitude star near its center. At 63× I can spot the nebula without a filter, and it's rather nice with a narrowband nebula filter. The south-southeastern tip is bracketed by a 9th-magnitude star on one side and a triangle of 10th- and 11th-magnitude stars on the other. Another 11th-magnitude star is pinned to the nebula's eastern flank, between the two 9th-magnitude stars. The nebulosity covers about 14′ × 4′ and is brightest near the central star, especially to its north and east.

Earlier this year, contributing editor Ken Hewitt-White featured views of NGC 7635 as seen through larger telescopes. He was even able to detect part of the involved shell that gives NGC 7635 its nickname, the Bubble Nebula (January issue, page 65).

Next we'll move south to the multiple star **ADS 16795**, whose blue-white primary star resides 2.2° west of golden Tau (τ) Cassiopeiae and shines at the same magnitude. The system is listed as having 10 components in the online version of the *Washington Double Star Catalog*, as shown on the following page. At 17× my 130-mm scope shows components A and C. F and G appear as a single star, as do Ia and Ib. Star E joins the scene at 117×, while F and G become separately visible. Star H looks exceedingly faint at 164×, but is easier to see at 234×. My 10-inch reflector at 166× shows all of the same stars and adds D, which is closely hugging C. The B component is lost in the glare of the primary star, and Ia and Ib remain blended into a single star.

The components of this multiple were discovered by several different observers and have different common designations. However, all but the distant Ia/Ib pair, which is ADS 16792, share the ADS 16795 designation from Robert Grant Aitken's 1932 catalog.

The open cluster **King 20** is 26′ east and a shade south of ADS 16795. It's visible as a little fuzzy spot in my 105-mm refractor at 17×. A magnification of 127× shows that



This colorized plate from the Palomar Sky Survey shows the major components of the multiple star ADS 16795, the charming double star Σ3022 to its southeast, and the loose open cluster King 20 to the east of that.

Components of ADS 16795 & 16792

Comp.	Mag(v)	Sep.	P.A.
AB	4.9, 9.3	0.8″	356°
AC	4.9, 7.2	76″	269°
AE	4.9, 11.3	40″	117°
AF	4.9, 10.6	67″	338°
AG	4.9, 11.1	67″	347°
FG	10.6, 11.1	11″	73°
AI	4.9, 9.9	231″	207°
CD	7.2, 9.1	1.4″	215°
CH	7.2, 13.0	26″	338°
Ia,Ib	10.4, 10.8	0.3″	287°

this misty patch is overlaid by four faint stars in a lop-sided kite shape plus one very faint star near the bottom of the kite. Many extremely faint stars precipitate from the haze at 213× through my 10-inch scope. The kite flies through the southern half of the cluster, which appears about 5′ across.

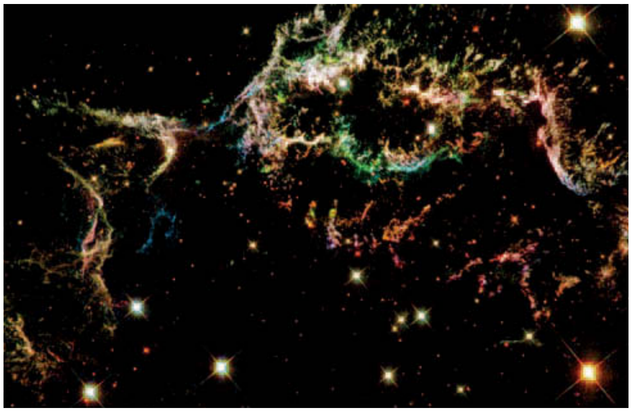
Recent studies grant King 20 about 116 members, an age of 160 million years, and a distance of approximately 5,700 light-years.

For those who like a real challenge, try **Cassiopeia A**, located 54′ west-northwest of ADS 16795. In 2009 a friend asked if this supernova remnant is a visual target. I said that I didn't think so, but I'd check. I was stunned to learn that William Gates, author of a series of supernova-remnant articles in *Amateur Astronomy* magazine, found its northern arc to be immediately and continuously visible through his 9.25-inch Schmidt-Cassegrain with an O III filter at 94×. Trying this myself, I find the best views through my 10-inch scope come with a narrowband filter at either 115× or 166×. The faint band of light appears almost straight and about 2½′ long running east-south-east to west-northwest. A 13th-magnitude star guards its western end. My 15-inch reflector at 79× shows a brighter dot in the band's center.

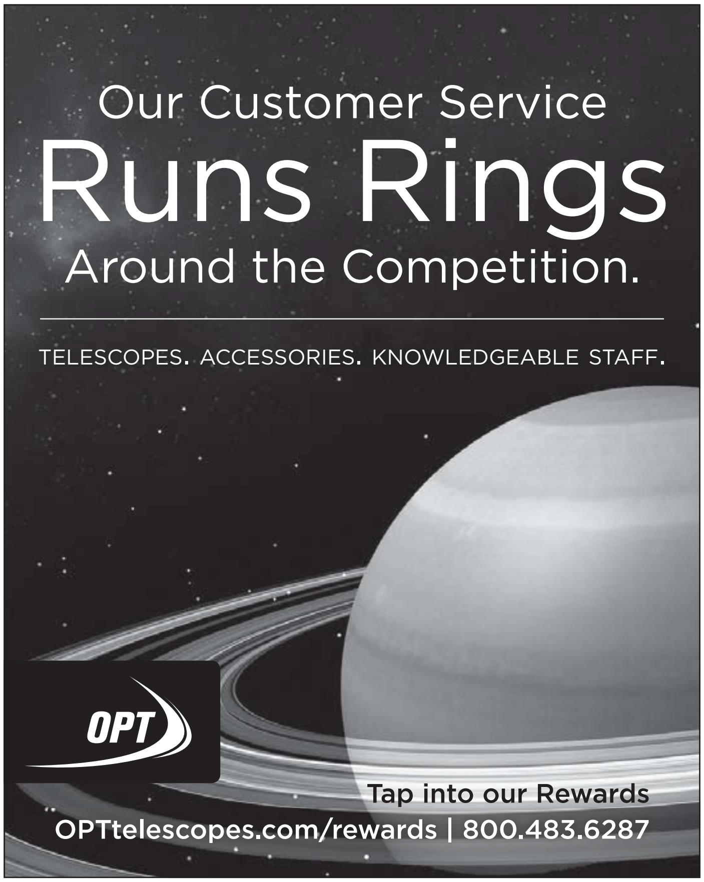
To pinpoint this scrap of Cas A, note that the brightest stars in the immediate area form a nearly equilateral triangle with sides about 4′ long. The triangle sits northeast of our target and points toward it. If you draw an imaginary line from the middle of the triangle's northeastern side through its southwestern point and then keep going for 1¾ times that distance, you'll land right on the nebulous arc.

The supernova that created Cas A probably should have graced our sky in the second half of the 17th century. William B. Ashworth, Jr. suggested that John Flamsteed saw the supernova as a 6th-magnitude star in 1680. Flamsteed cataloged the star as 3 Cassiopeiae, but no star that bright is seen in its position today. Other astronomers think this is unlikely because the lost star's position is offset from the center of Cas A by 6′ to 10′.

Why did the supernova go unnoticed — assuming that Flamsteed's observation was spurious? Some studies indicate that the supernova was a Type IIb resulting from the core collapse of a red-supergiant star. Such supernovae quickly rise and fade in brightness and might be missed during a spell of cloudy skies. Its light may also have been heavily cloaked by dust that the massive, dying star ejected in the late stages of its life. ✦



This Hubble Space Telescope image shows the northern arc of Cassiopeia A in false color, using red, green, and blue to represent emissions from sulfur, hydrogen, and oxygen, respectively.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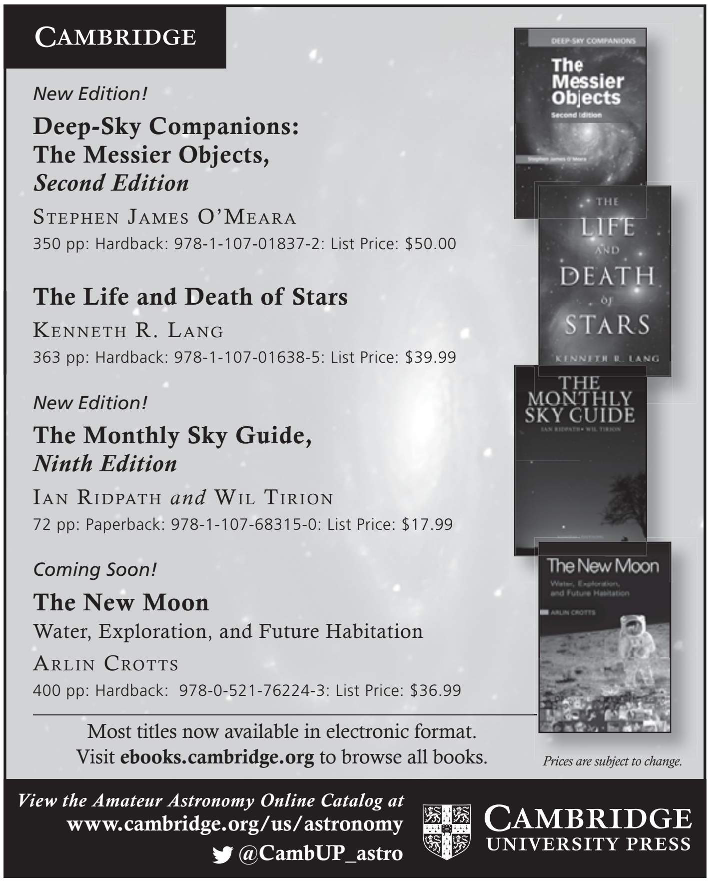
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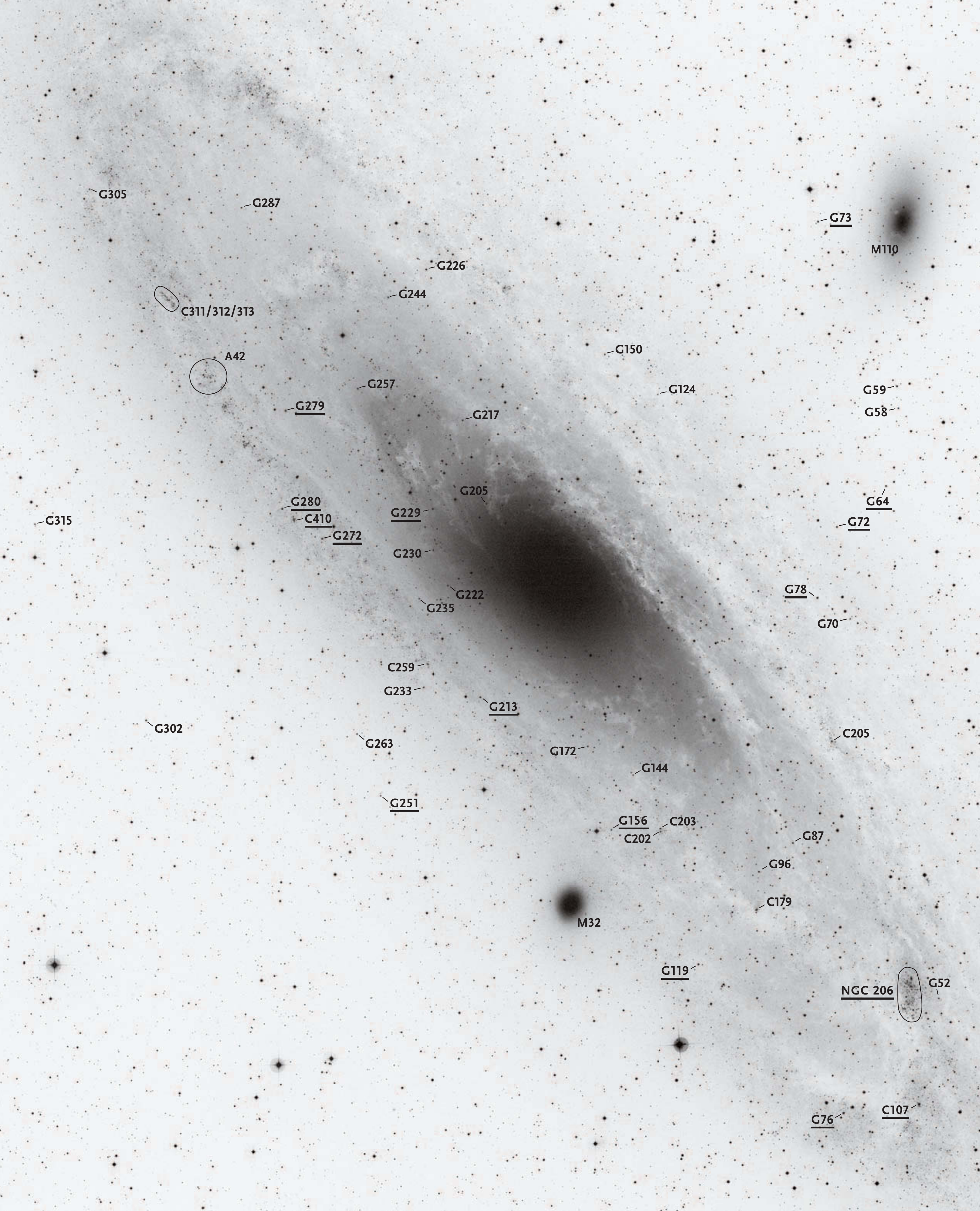

G305
G287
G73
M110
G226
G244
C311/312/313
A42
G150
G257
G124
G59
G58
G279
G217
G205
G64
G280
G229
G315
C410
G72
G272
G230
G78
G222
G235
G70
C259
G233
G213
G302
C205
G263
G172
G144
G251
G156
C203
C202
G87
G96
C179
M32
G119
G52
NGC 206
C107
G76

Exploring Messier 31

Backyard scopes can reveal dozens of star clusters in the Andromeda Galaxy.

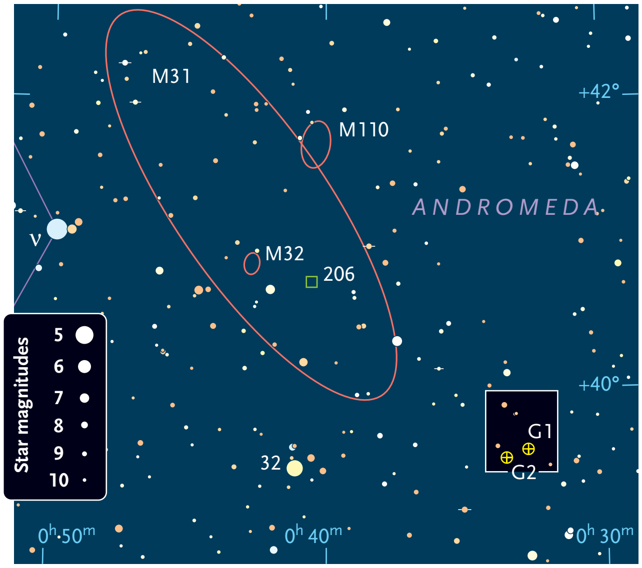
In his November 1979 *Deep-Sky Wonders* column, Walter Scott Houston described amateur observations of M31's globular star clusters. I have been sporadically hunting them ever since, and I've learned that excellent seeing and high power are more important than aperture when trying to see details in these tiny objects. So far, my 16-inch f/4.5 Newtonian has revealed the 40 globular clusters, 10 open clusters, and two stellar associations that are labeled on the chart on the facing page. My fellow Canadian stargazer Guy Mackie has observed 18 of these with his 12.5-inch scope, and several are visible with an 8-inch scope.

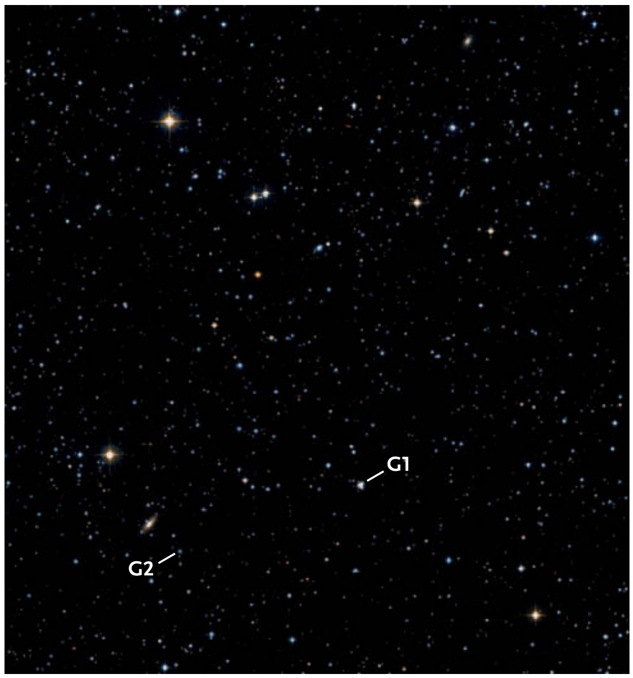
At magnitude 13.7, **G1** is by far the brightest globular cluster in M31 — and indeed, it's the most luminous globular in the entire Local Group. Like the Milky Way globular Omega Centauri (and others), G1's stars vary considerably in age, so many astronomers suspect that it's actually the core of a captured dwarf galaxy.

Use the star chart and image at right to star-hop to G1, which lies well outside M31's visible disk. The giant globular appears obviously non-stellar through my 8-inch Newtonian at 61×, and at 348× I can occasionally glimpse the two foreground stars on G1's western edge. Mackie's 12.5-inch at 264× shows a "condensed core with soft halo," and the halo looks as large as Saturn's disk in my 16-inch at 261×. While you're in the area, seek out G1's junior partner **G2**, which is 2 magnitudes fainter.

Now let's search M31's visible disk, starting near its southwestern end with the huge stellar association **NGC 206**, which is visible in 4-inch refractors and prominent through an 8-inch scope under dark skies.

With a 10-inch telescope, 14.2-magnitude **G76** is the easiest globular to find because it lies within a distinctive Cassiopeia-like asterism near NGC 206. Observers are always delighted when I show them G76 in their own telescopes. I once saw G76 with my 8-inch at 348× on a



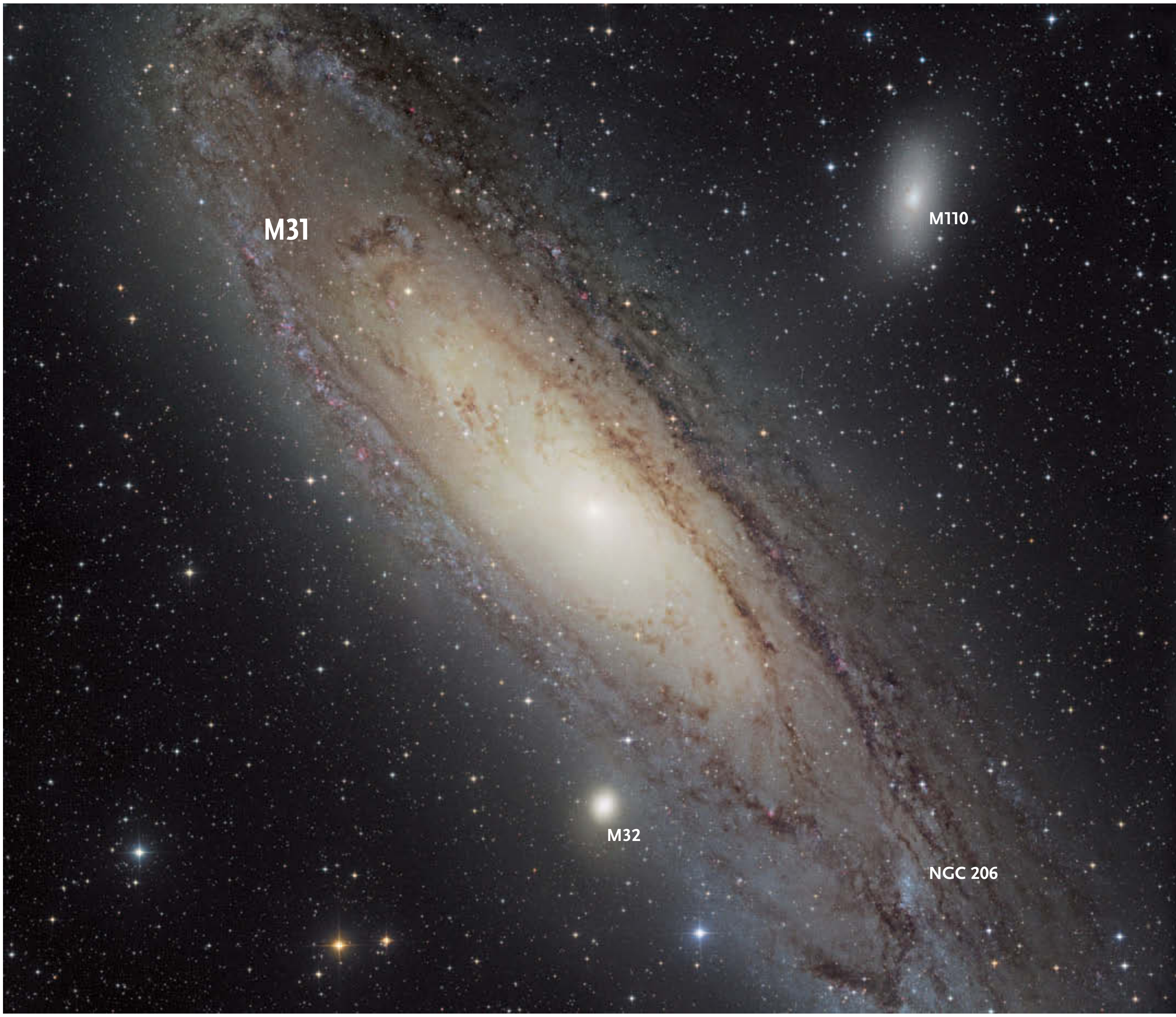


POSS-II / CALTECH / PALOMAR OBSERVATORY

Right: **The giant globular cluster G1 appears non-stellar even at fairly low magnification. But its much fainter and smaller cousin G2 appears just like a star even through large backyard telescopes.**

Facing page: **All the objects observed with the author's 16-inch Newtonian are labeled on this photograph. Objects also observed with Guy Mackie's 12.5-inch have underlined labels. The nomenclature comes from the 1981 *Atlas of the Andromeda Galaxy*, by Paul W. Hodge. Labels starting with G, O, and A stand for globular clusters, open clusters, and stellar associations, respectively.**

POSS-II / CALTECH / PALOMAR OBSERVATORY



STEFAN HEUTZ / STEFAN BINNEWIES / JOSEF PÖPSEL

Color photographs reveal a great deal about the morphology of galaxies. The elderly stars of the central regions appear yellowish, associations of young, hot stars are blue, and H II regions are pink.

night with excellent transparency and very good seeing, but that was about my 20th try with that aperture! G76 is only 3.6″ in diameter, but that's larger than most. Using my 16-inch on a superb night I wrote that "G76 has a huge halo at 522× with a stellar core." I wrote this after a night of viewing many fainter globulars, most of them mere sparks, so "huge" is a relative term.

With my 16-inch at 366×, the open cluster **C107** appears stellar with direct vision, but it swells into a tiny fuzzball with averted vision. From there, let's star-hop northeastward along the M32 side of the Andromeda Galaxy. The open cluster and H II region **C179** is a small smudge at 229×; two faint and starlike globular clusters, **G96** and **G87**, are neighbors.

Open clusters **C202** and **C203** lie only 16″ apart. The northern one, C203, is bright and stellar, whereas C202 is fainter and quite extended. Adjacent **G156** can be seen despite its proximity to a 9.3-magnitude star. At magnitude 15.6, this was the faintest globular that Mackie found with his 12.5-inch. At 316× he logged it as an "averted vision fleck of light."

Skipping 35′ northeast, I reach my favorite high-power field in the galaxy. It features the large H II region and open cluster **C410** bracketed by two of the easiest globular clusters: **G272** and **G280**. In my 16-inch at 366×, oval C410 is elongated 2:1 and exhibits a slight central brightening; a glimmer of a star appears repeatedly on its eastern side. G272 is magnitude 14.7 and 3.4″ in diameter. I called it the Blinking Globular — I can only see the stellar core with direct vision, and I can only see the halo with averted vision. G280 is magnitude 14.2, but is only 2.7″ in size. Its stellar core is brighter than G272's. Only on the steadiest nights did G280's tiny halo make it seem larger than the similar-magnitude star beside it.

At 4.9″ in diameter, **G279** is second to only G1 in size, but it's only magnitude 15.4. This is rather faint to be teasing out detail with my 16-inch, but at 366× G279 appears larger than adjacent stars. Direct vision shows an extremely faint stellar core, but the stellaring is invisible with averted vision.

The galaxy's northeastern end features an open cluster trio, **C311/312/313**. Together they form an extremely faint band, elongated 6:1. There's a hint of mottling with my 16-inch at 366×. My club's 25-inch Dobsonian working at 227× separates out C311, the southernmost cluster, as a large knot.

A group of globulars lies near M31's core: relatively easy **G235** and **G222**; fairly difficult **G230**; and difficult **G229**, **G257**, **G205**, and **G217**. The bright core looks daunting on photographic guide charts, so I avoided hunting these globulars for decades. However, I've learned that this area looks far brighter on images than it does at the eyepiece. All of these globulars appear starlike except G229. The 25-inch at 318× revealed a very faint core in G229's fairly large dim halo.

There are fewer noteworthy objects on the M110 side of the Andromeda Galaxy. **G73** is interesting because it may be in orbit around M110 rather than around M31. **G58** is rather faint and small — only magnitude 15.5 and 2.3″ in diameter — but on two nights I logged it as "soft" in comparison with very close **G59**, which is much brighter but stellar. On a superb night during 2008's exceptionally quiet Sun (which should decrease airglow, thus giving a darker sky), **G35** and **G72** also looked slightly swollen in comparison to similar-magnitude stars.

Very easy **G78** is part of an asterism resembling the Greek capital letter sigma (Σ). G78 is the same magnitude as G76 and G280. In my 16-inch at 366×, G78 has a stellar core in a substantial halo. Its neighbor, 15.9-magnitude **G70**, is the faintest globular revealed by my 16-inch.

The many other clusters plotted on the charts all appear stellar in my scope, but I viewed most only at 203× or 229×. A few might blossom into fuzzies on an excellent night that enables a high-power view.

On a very memorable night (September 14, 1999), the rare combination of excellent seeing and transparency allowed me to glimpse blue-supergiant stars in NGC 206 with my 16-inch and an orthoscopic eyepiece giving 261×. I had been waiting for the perfect night to attempt these massive young stars, whose intrinsic luminosity is 250,000 times that of the Sun!

Four or five brighter Milky Way stars lie in front of NGC 206. But behind them perhaps eight stars flickered in and out of visibility at the limit of vision. I carefully checked four similar-sized areas immediately surrounding NGC 206, and I didn't see any stars at the edge of vision in those areas. So I'm confident that most of these glimmerings were indeed some of the 70-odd blue supergiants that are so prominent in color photographs of NGC 206. After my observation I carefully examined a photograph that showed eight particularly bright blue stars, matching my observation. So the brightest stars in the Andromeda Galaxy are within the grasp of a 16-inch telescope on a perfect night! ✦

---

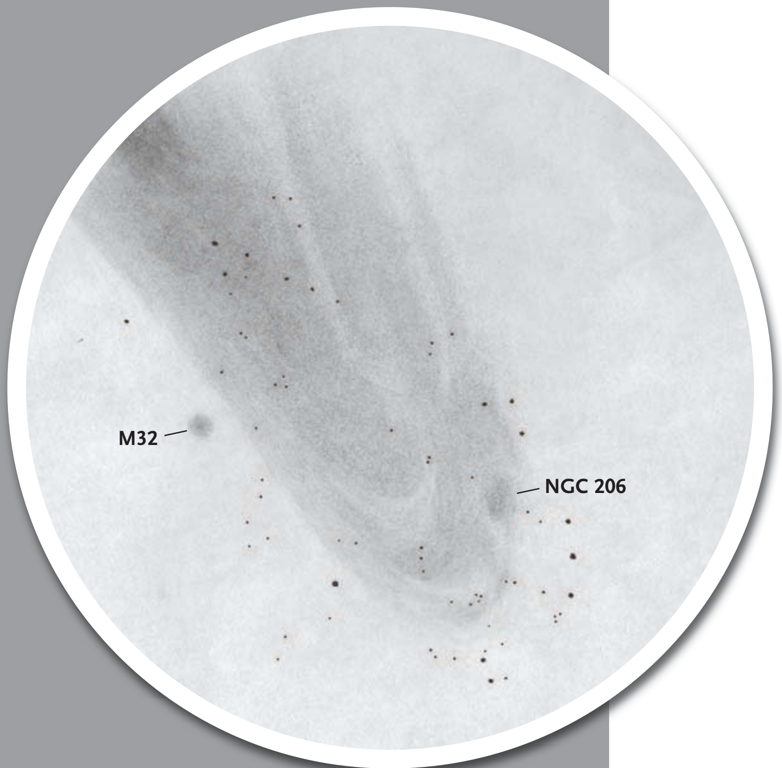
*The gegenschein and zodiacal band are occasionally visible from **Alan Whitman**'s backyard observatory in British Columbia's Okanagan Valley.*

M31's Large-Scale Structure

M31's spiral arms are quite difficult to discern because the galaxy is tilted just 12.5° to our line of sight. The strongest clues to a visual observer are the two dust lanes that are particularly prominent between M31's core and the satellite galaxy M110. See how far you can trace them in each direction — an exercise that depends more on the quality of your skies and your skill as an observer than on the aperture of your telescope.

Guy Mackie's sketch below shows how much is possible with a 12.5-inch scope; he traced the inner arm looping back toward M32 and discerned intricate structure in the outer arm southwest of NGC 206.

— Tony Flanders



A Porter-Inspired Dob

A stumble in the dark led to a scope built for comfort and performance.

Connecticut ATM Edward Amarante is someone who feels that necessity is the mother of invention. The truthfulness of that maxim was made painfully clear to him at the 2011 Stellafane convention in Springfield, Vermont, when he fell from a stepladder while observing with his 12½-inch f/6 Dobsonian. "Hobbling home from that misadventure, I had all the motivation I needed to build a scope that would eliminate any chance of a repeat performance," Ed recalls.

Stellafane, as it turned out, supplied inspiration as well as motivation. "I was always very intrigued by the Russell Porter turret telescope, majestically situated on Breezy Hill," Ed explains. "I particularly liked the scope's roughly stationary eyepiece." Seeking to marry this feature with the smooth motions and simplicity of his Dob, Ed set to work planning a new observing rig based on his 9.25-inch Schmidt-Cassegrain optical tube assembly.

ALL PHOTOS BY THE AUTHOR

A moment of observing misfortune at the annual Stellafane telescope-making convention in Vermont led Ed Amarante to design and build this mount for his 9.25-inch Schmidt-Cassegrain telescope. It features an eyepiece that remains at a fixed height.

The challenge was to design a mount that would be easy to set up and comfortable to use. As the accompanying photos show, Ed's Porter-inspired Dob has much in common with traditional Dobs, including bearings made with Formica laminate riding on Teflon pads. But it also features an eyepiece height that remains constant, regardless of where the scope is aimed, because the eyepiece is located at the center of rotation for the altitude bearings. The eyepiece position only changes in azimuth during use. "Seated comfortably, I can observe the sky from the horizon to the zenith and sweep about 45° in azimuth without moving my chair," Ed writes. "It's a real game changer when it comes to viewing enjoyment and ease."

Ed's mount has several clever features that make it easy to transport and set up in the field. "I didn't want to be fussing with screws and nuts in the dark," he says. The mount breaks down into easy-to-manage components that assemble quickly thanks to cam-lever clamps that fasten the four vertical struts to the base and the rocker box. The mount's three legs also telescope in for easier transport.

Ed equipped the mount with digital setting circles, but they upped the ante when it came to construction accuracy and rigidity. The parts of the mount requiring strength are made from solid oak, while the main scope bearings and the ground board are double thicknesses of oak-faced plywood. Each tripod leg is three lengths of ¾-inch-thick solid oak held together with screws and glue.

Construction accuracy was largely a matter of taking time. As Ed cautions, "With some digital setting circles, the two axes of motion have to be precisely orthogonal to each other." Achieving this with wood components can be a challenge and requires careful techniques. Ed cut the bearing circles on a router table with the circles rotating on a pin. Those same holes for the pin are used for positioning the setting circle's shaft encoders, ensuring that they are properly located at the exact centers of rotation.

The mount's unconventional appearance invites curiosity from fellow observers, some of whom wonder about

Top**: Clever cam-lever clamps firmly lock four struts that connect the top and bottom of the scope's mount. *****Below:***** Ed's "Porter-inspired Dobsonian" combines the smooth motions of John Dobson's telescope design with the famed Porter turret telescope's convenient eyepiece position. The result is superb observing comfort.**

its stability. As Ed points out, "It actually has a footprint similar to many commercial tripods and the center of mass is positioned directly over the azimuth bearing, resulting in a very stable configuration."

It's no accident that the result of Ed's careful design and construction is a telescope that is easy to transport and set up and is a real pleasure to use. "I'm now able to enjoy the hobby that I love in complete comfort," he reports. Plus, no more cursed stepladders!

Readers wishing to contact Ed directly can reach him at **acruiser1942@aol.com**. ✦

Contributing editor ***Gary Seronik*** *is an experienced telescope maker and observer. He can be contacted through his website,* **www.garyseronik.com**.

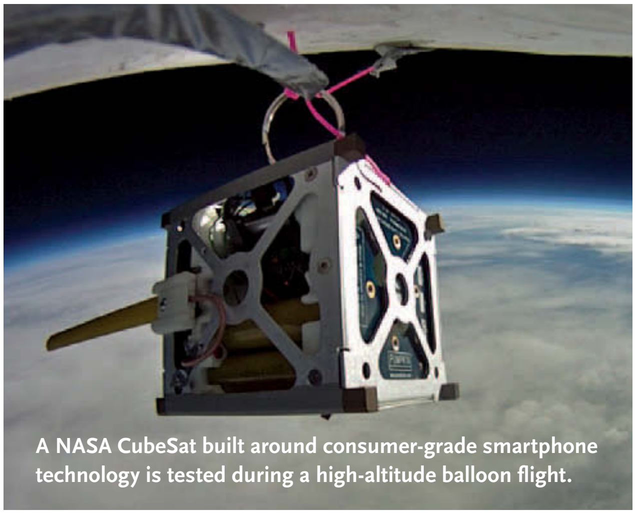
Amateur Space Exploration

Tim DeBenedictis

CubeSats are paving the way for public entry into orbit.

Conducting astronomy from beyond Earth's atmosphere has long been the exclusive province of NASA and other governments' space agencies. But that's changing. Thanks to advances in electronic miniaturization and the development of private spaceflight, it's now possible for universities and small companies to orbit their own satellites. For no more than the budget required to construct a large amateur observatory, anyone can launch a satellite capable of performing useful science. Within the next decade, it may even be possible for amateur groups to conduct space exploration from beyond low-Earth orbit.

The technology behind small satellites known as CubeSats was pioneered in 1999 by Bob Twiggs (then at Stanford University) and Jordi Puig-Suari (California Polytechnic State University). Realizing that most rockets carry payloads into orbit with hundreds of pounds (or more) of excess lift capacity, Twiggs wondered if it would be possible to piggyback smaller satellites onto those rockets. He also wondered if small satellites could survive in orbit long enough to produce useful results.



A NASA CubeSat built around consumer-grade smartphone technology is tested during a high-altitude balloon flight.

The answer to both questions is a resounding *yes*. The original engineering work done at Stanford and Cal Poly has evolved into the current CubeSat standard, which defines the size, shape, and mass constraints for these new "citizen satellites." The smallest CubeSats, called 1U, are 10 centimeters (4 inches) on a side, with a mass of 1.33 kilograms (3 pounds) or less. Larger 2U and 3U CubeSats are also possible with lengths of 20 and 30 centimeters and masses up to 2.66 and 4.0 kg, respectively.

To date, nearly 100 CubeSats have been launched, with a success rate of around 75%. About half of the failures are due to the launch vehicle not reaching orbit. Most of the remaining failures are attributable to communication or power-system problems in orbit. Although this success rate is a little bit lower than that of much larger satellite launches, it has been achieved with remarkably smaller budgets. Quite likely the combined cost of all CubeSat missions to date is less than that of a single commercial communications satellite launch.

What Can You Do With CubeSats?

So far the mission objectives of most CubeSats flown have fallen into three categories: performing scientific, research, developing new space technologies, and serving educational and public-outreach goals. Some examples

The CubeSats (left to right) TechEdSat, F-1, and FITSAT-1 drift past the International Space Station's solar panels moments after their deployment on October 4, 2012, from the Japanese Small Satellite Deployer mentioned in the accompanying text.

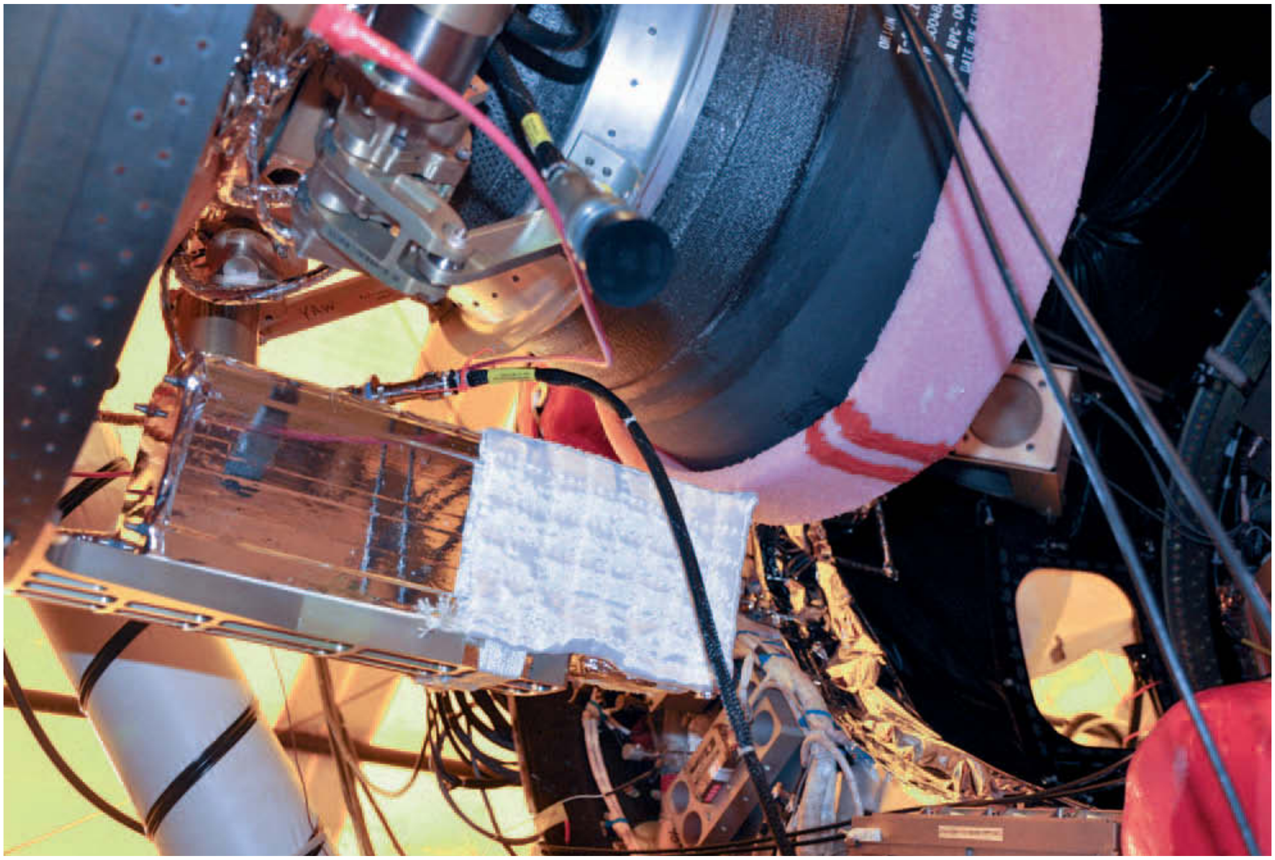
of CubeSats in the science category include Stanford's 3U QuakeSat 1, launched in 2003 to provide space-based detection of electromagnetic signals thought to be precursors of earthquakes. NASA's GeneSat-1, launched in 2006, was a self-contained biology laboratory that studied the effects of exposure to the space environment on *E. coli* bacteria. The Radio Aurora Explorer (RAX), developed at the University of Michigan, was launched in 2010 to measure plasma formations in the ionosphere known to disrupt communications with orbiting spacecraft.

CubeSats whose primary missions are to develop new space technologies include NanoSail-D2, a 3U CubeSat deployed in early 2011 that successfully deployed NASA's first solar sail in orbit. MAST, the Multi-Application Survivable Tether, was developed by Tethers Unlimited and launched in 2007. It was a trio of 1U CubeSats connected by a 1-kilometer-long tether. The middle CubeSat was supposed to crawl up and down the tether, taking pictures to examine the tether for damage caused by space debris. The mission achieved only partial success due to difficulties with tether deployment and ground communication. The CanX-2 mission, launched by the University of Toronto in 2008, was more successful and became the first CubeSat to change its orbit using a cold-gas thruster.

The third category of CubeSat missions is primarily educational. Some student CubeSats are never intended to fly — just building a functional satellite for the price of a used car can be a tremendously satisfying and rewarding project on its own. (Any telescope makers who spend more time crafting their instruments than looking through them can probably relate to this!)

Among the more unusual satellites in this category is South Korean artist Hojun Song's CubeSat, which caries high-wattage LEDs intended to blink Morse-code messages transmitted to it by amateur radio operators on the ground. A similar concept was demonstrated by Japan's FITSAT-1, which was released from the International Space Station in 2012 and flashed LEDs over the U.S., Europe, and Japan.

Finally, I'd be remiss not to mention my company's entry into the educational CubeSat category. SkyCube is



The Poly Picosatellite Orbital Deployer allows CubeSats to hitch a ride on rockets carrying other payloads. Here it's attached to the aft end of a Taurus XL rocket before launch from California's Vandenberg Air Force Base.

scheduled for launch later this year and, if successful, will be the first crowd-funded satellite to reach orbit. It will broadcast 120-byte "tweets" from space on a frequency of 915 MHz. SkyCube will also capture VGA-resolution images of Earth, which sponsors can request using their smartphones. At the end of its 90-day mission, Sky-Cube will inflate a 3-meter balloon and become visible to the naked-eye as it de-orbits via atmospheric drag, thereby avoiding the buildup of space debris.

Getting Into Orbit

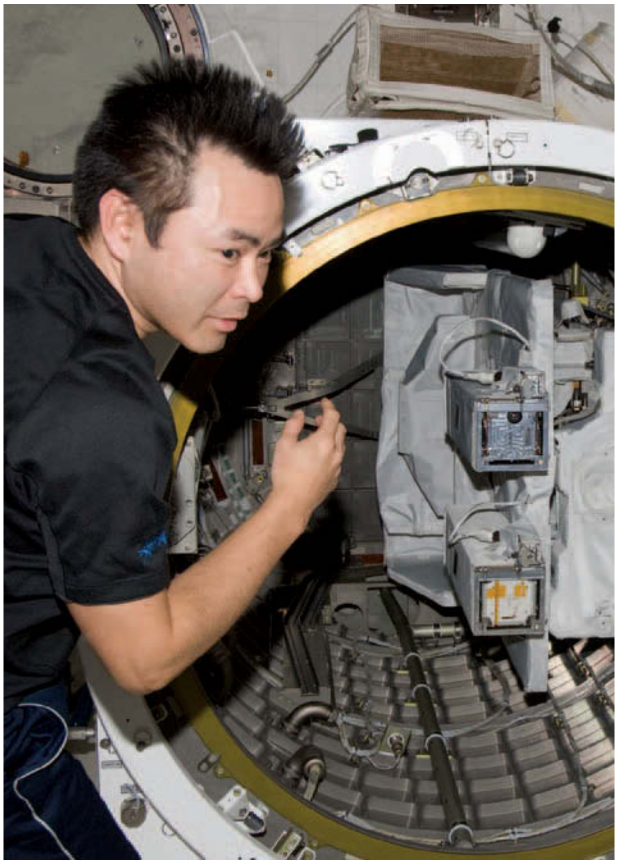
There are currently two methods of deploying Cube-Sats in space. The first is piggybacking on the launch of a much larger satellite. Once the primary payload is deployed, secondary payloads are ejected from spring-loaded devices called P-PODs (Poly-Picosat Orbital Deployers), which place them in orbits that gradually drift away from the primary payload. The majority of CubeSats have been launched this way.

The second and newer method of deploying CubeSats is to release them from the International Space Station (ISS). This is done with the Japanese Small Satellite Orbital Deployer that was brought to the ISS in July 2012. Releasing CubeSats from the ISS can cost significantly less than piggybacking them on a launch vehicle, but they have the limitation of orbiting relatively near the ISS.

A CubeSat piggyback launch costs about $100,000 for a single 1U satellite, and double or triple that for 2U and 3U satellites. ISS deployments cost about half as much. There are a number of commercial launch providers, as well as brokers who specialize in placing small payloads on launch vehicles and assisting with the various complex regulations.

Although $100,000 is a significant sum of money, it's a lot less than the tens of millions of dollars required for a dedicated launch vehicle. In the future, "nano-launchers" capable of lifting an individual CubeSat into orbit directly from Earth's surface, or from a high-altitude aircraft or balloon, may reduce launch costs by another order of magnitude. Unfortunately, NASA's Nano-Satellite Launcher Initiative was recently canceled, but that has opened the doors to private development.

NASA provides an opportunity for educational institutions to launch CubeSats for free, called ELaNa (Educational Launch of Nanosatellites). To qualify, a CubeSat project needs to be sponsored by an educational institution based in the U.S., a NASA research center, or a nonprofit organization. NASA reviews ELaNa proposals annually, and it accepted 33 out of 43 submitted in 2012.



Aki Hoshide, a flight engineer for Expedition 33 aboard the International Space Station, readies a pair of CubeSat launchers in the airlock of the Kibo laboratory module prior to the satellites' deployment on October 4, 2012.

As of now, however, only eight ELaNa CubeSats have been launched. Several years may elapse between the date that an ELaNa proposal is accepted and when the CubeSat is deployed, but it's hard to beat a free ride into orbit!

CubeSat Hardware

CubeSats are largely made from off-the-shelf electronics and aluminum frames that can be built with common machine-shop equipment. Space-grade solar cells are available at low cost from Spectrolab, the division of Boeing that produces large panels for the ISS and other spacecraft.

Many vendors offer standardized CubeSat kits and components that help prospective mission planners avoid reinventing the wheel. These kits include basic items required for all CubeSat missions, including computer-processor boards, electrical-power systems, and radios. They also offer optional components such as high-resolution cameras, Sun- and star-trackers for determining the satellite's orientation, and magnetorquers for actively orienting a satellite using Earth's magnetic field.

With commercially available components, the hardware budget for a minimal 1U CubeSat might run about

CubeSat Launch Providers

This list includes U.S. and foreign launch-service providers that have demonstrated at least one successful CubeSat deployment to orbit.

NASA CubeSat Launch Initiative
www.nasa.gov/directorates/heo/home/CubeSats_initiative.html
NASA's CSLI provides opportunities for small satellite payloads to piggyback on upcoming rocket launches. It also manages the Educational Launch of Nanosatellites (ELaNa) program that provides free launches for qualifying missions.

Orbital Sciences Corporation
www.orbital.com/SpaceLaunch
Developed the Pegasus, Minotaur, and Antares launch vehicles, which have delivered small satellites to orbit since 1990.

SpaceX
www.spacex.com
The first private launch provider to successfully deliver cargo to the International Space Station. The company launches secondary nanosatellite payloads but does not deal directly with any CubeSat smaller than 3U (see the listing for Spaceflight Services below).

Spaceflight Services
www.spaceflightservices.com
Provides frequent flight opportunities from multiple launch providers, including SpaceX and Orbital. It is a subsidiary of Andrews Space, SpaceX's preferred launch reseller for payloads smaller than 3U.

ISIS Launch Services
www.isispace.nl/cms/index.php/products-and-services/launches
The independent launch-services subsidiary of Netherlands-based Innovative Solutions in Space. It offers regular piggyback launch opportunities on a variety of launch vehicles.

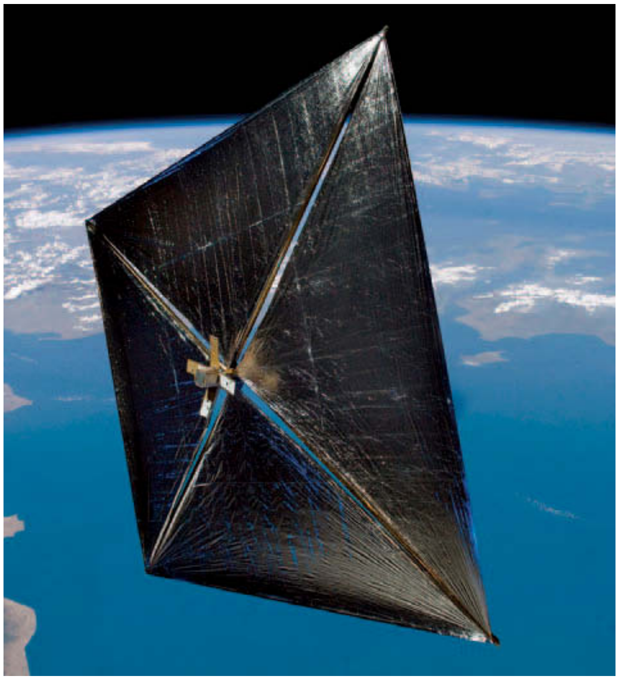
NanoRacks
www.nanoracks.com
Coordinates CubeSat deliveries to, and deployments from, the International Space Station.

Eurockot Launch Services
www.eurockot.com
Launches satellites into LEO for institutional and commercial satellite operators from the Plesetsk Cosmodrome in northern Russia.

California Polytechnic State University CubeSat Project
www.cubesat.org
An international collaboration of universities, high schools, and private firms that provides launch opportunities for small satellites.

University of Toronto Institute for Aerospace Studies
www.utias-sfl.net
The UTIAS Space Flight Laboratory offers regular launch opportunities for CubeSats and nanosatellites using primarily Russian and Indian launch vehicles.

Earth2Orbit
www.earth2orbit.com
Brokers launches for international clients on Indian launch vehicles.



Top: **Students and engineers hold a pre-launch briefing in California's Mojave Desert for a suborbital launch of the Prospector P-18D rocket. It carried four CubeSats designed to gather data for orbital missions that will launch in 2014.**

Above: **An artist's rendering of NASA's NanoSail-D2 deployed in January 2011. It tested a method of de-orbiting CubeSats using atmospheric drag on a low-mass, high-surface-area sail.**

$30,000. Building everything yourself is one way to reduce costs, but then the tradeoff is engineering time. Hojun Song's CubeSat was built from recycled parts over a period of six years for a total hardware budget less than $1,000. Its launch last April on a Russian Dnepr rocket cost a hundred times more.

CubeSat developers are often asked if temperature extremes and radiation will destroy circuit boards. The answer to both questions, at least for CubeSats in LEO, is no. Because CubeSats are exposed to darkness and sunlight repeatedly during their roughly 90-minute orbit of Earth, their internal temperatures are typically between 0° and 60°C (32° to 140°F), and well within the range of electronics engineered to industrial-temperature standards. Cold temperatures are more of a worry for batteries, which may stop working when frozen. But running a high-power device such as a radio will keep batteries warm, and many commercial CubeSat power systems come with battery heaters.

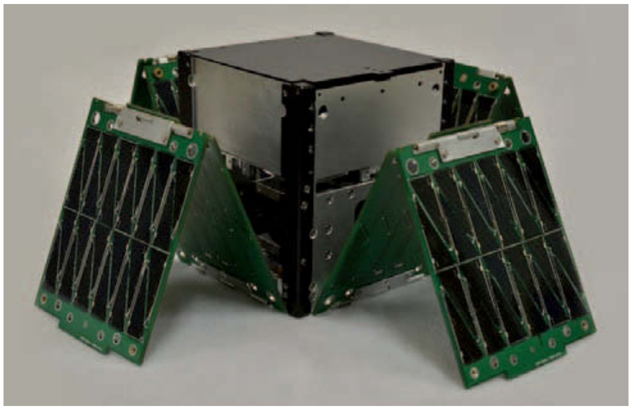
The radiation environment in LEO is not terribly different from that on the ground, since Earth's magnetic field traps most high-energy particles in the Van Allen radiation belts at altitudes of 4,000 km and higher. This is why ISS astronauts do not require heavy radiation shielding to survive for many months in orbit. If CubeSats eventually reach into the Van Allen belts or beyond, then radiation hardening of the satellites may become a more significant issue.

Testing CubeSat hardware prior to launch is also an important step. Most launch providers specify thermal vacuum, vibration, and shock criteria that a CubeSat must meet. In addition to protecting the CubeSat itself, these criteria ensure the safety of the launch's primary payload. Since access to test equipment can be challenging, most launch brokers provide assistance with this process.

CubeSat Communications

Once in orbit, most CubeSat missions need to communicate with the ground. In an age of global high-speed internet communication, it's easy to think that CubeSats can simply plug into an existing satellite-communication network. This, unfortunately, is not the case. Most CubeSat missions so far have communicated with their own ground stations, using their own frequencies, antennas, and protocols. In 2007 the European Space Agency's education office began a collaborative effort, called GENSO (the Global Educational Network for Satellite Operations, **www.genso.org**), to provide a worldwide network of CubeSat ground stations. But this network has yet to materialize in a significant way.

The amateur-radio community has many decades of experience listening to satellite transmissions. Ham operators can detect CubeSat transmissions with radio gear costing a few hundred dollars. These amateurs have provided important data for CubeSat missions, and a coor-



SCOTT CUTLER / SOUTHERN STARS

The author's company, Southern Stars, built this crowd-funded CubeSat, known as SkyCube. Scheduled for launch this year, its solar panels will unfold once the satellite is deployed.

dinated effort in this area would be helpful for the future.

The small size of a CubeSat's solar panels limits the amount of power they can generate. This, in turn, limits how much power the satellite's radio can transmit. A 1U CubeSat, completely covered with space-grade solar cells, generates about 1½ watts of power, averaged over many orbits. A typical CubeSat radio might consume 8 watts when broadcasting at full power. As such, it must be powered down for most of each orbit, or set to broadcast only in a low-power "beaconing" mode. Even when passing over a ground station, a CubeSat's 8-watt broadcast limits the data rates to around 9,600 bits per second — old dial-up modem speeds.

NASA's recent TechEdSat mission carried an Iridium data modem designed to communicate with the existing constellation of Iridium communications satellites. This novel approach neatly sidestepped the problem of ground communications by plugging into an existing satellite-communication network. But regulatory issues have prevented TechEdSat from fully utilizing its Iridium data modem. So for the time being, CubeSat communications are a challenge and an area where the amateur-radio community can make important contributions.

Space Debris (and Other Regulations)

Space debris is a problem that NASA takes seriously. Although the chance of a direct collision between two active satellites is very low, it has happened. The big danger is that the many hypervelocity fragments resulting from a rare collision could destroy other satellites, cascading into an ever-larger problem.

CubeSat Hardware Vendors

Here's an alphabetical list of leading commercial CubeSat hardware and electronic-component suppliers that offer flight-tested materials.

Andrews Space
andrews-space.com

Offers an extensive set of high-end components for small spacecraft, including avionics, reaction wheels, control-moment gyros, and integrated satellite simulators.

Astronautical Development
www.astrodev.com/public_html2

U.S.-based developer of low-cost, high-quality radios for CubeSats. Provides radios for Boeing's Colony 2 CubeSat standard. Also develops custom structures, processor boards, electrical-power systems, and other CubeSat components.

ClydeSpace
www.clyde-space.com

Leading vendor of CubeSat components, specializing in power subsystems, batteries, and solar panels. Also develops systems for attitude determination and control.

GOMSpace
www.gomspace.com

Provides CubeSat components for low-cost science and commercial proof-of-concept missions. Products include power systems, radios, computers, cameras, attitude determination and control systems, and software.

Innovative Solutions in Space
www.isispace.nl

Based in the Netherlands, ISIS offers CubeSat structures, radios, antennas, attitude determination and control systems, power systems, and solar panels.

Pumpkin
www.cubesatkit.com

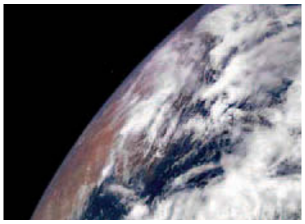
The first commercial American CubeSat hardware vendor, and considered by many to be the industry leader. Manufactures off-the-shelf hardware and software for nano-satellites that conform to Cal Poly's CubeSat specifications.

Tethers Unlimited
www.tethers.com/Products.html

Supplies advanced component technologies for CubeSats, including solar arrays, de-orbit systems, and water-electrolysis propulsion mechanisms.

Fortunately, Earth's atmospheric drag provides a natural solution, at least in LEO. This drag causes satellite orbits to decay and the satellites to eventually burn up harmlessly as they reenter the atmosphere. Drag affects small objects much more than large ones. Tiny CubeSats often have lifetimes of several weeks or months, and they are required to have a maximum orbital lifetime of less than 25 years.

The Federal Communication Commission (FCC) requires a thorough review of orbital debris for CubeSat missions before issuing a radio broadcast license. NASA's Johnson Space Center provides free software to assist in performing this review. Furthermore, because of security issues, the National Oceanic and Atmospheric Administration requires a review of all CubeSat missions that will image Earth's surface in any way. It's wise to contact these government agencies early on in the process of developing a CubeSat mission, because you don't want to be pulled off a launch vehicle because your paperwork is not in order! The Cal Poly CubeSat Project provides an excellent overview of the licensing process at **www.cubesat.org/index.php/documents/developers**.



The ESTCube-1, built by Estonian students, snapped this view of North Africa last May.

Into the Future

Despite their challenges, CubeSats have demonstrated that students, small companies, and even individuals can accomplish space missions that previously required the budgets of telecommunications giants or national governments. What might the next 10 years hold?

One possibility is even smaller satellites. Bob Twiggs is currently advocating "matchbox" satellites, which could be deployed by the hundreds from a 1U container at a cost of only a few hundred dollars each. Zach Manchester's KickSat project is an example. The concept of owning and operating your own satellite for less than $1,000 is tantalizing. Experience shows that such things should be possible with current technology. But the important question remains as to what useful science can be done with such small satellites.

The U.S. Air Force Academy is currently developing FalconSAT-7, a 3U CubeSat that will deploy a 20-cm "photon sieve" diffractive telescope capable of imaging Earth's surface at 1.7-meter resolution from an altitude of 450 kilometers.

At this year's Northeast Astronomy Forum (NEAF) in New York, senior editor Dennis di Cicco conducted a 20-minute video interview with author Tim DeBenedictis about his plans to launch a CubeSat later this year. To watch the video, go to skypub.com/cubesat.

Although no dedicated communications network for CubeSats currently exists, transmissions from these satellites are within range of low-cost ham-radio antennas (pictured) and receivers.

MIT planetary scientist Sara Seager is developing ExoplanetSat, a CubeSat to monitor individual stars for exoplanet transits (see **skypub.com/seagerinterview**). This is similar to NASA's Kepler mission, but at less than 1% of the cost. And if ISS deployments and nano-launch initiatives succeed in lowering launch costs by another order of magnitude, it might be possible to orbit a 6U, 12U, or 24U satellite for the same cost as a 1U or 3U launch today. Scientific payloads such as Seager's would scale accordingly.

Various proposed CubeSat propulsion technologies suggest another possibility. Aerojet Rocketdyne offers a hydrazine thruster for CubeSats that is capable of boosting a 1U payload in LEO to escape velocity. Although no current launch providers allow secondary payloads to carry explosive propellants (for safety reasons), this may change as nano-launchers are developed.

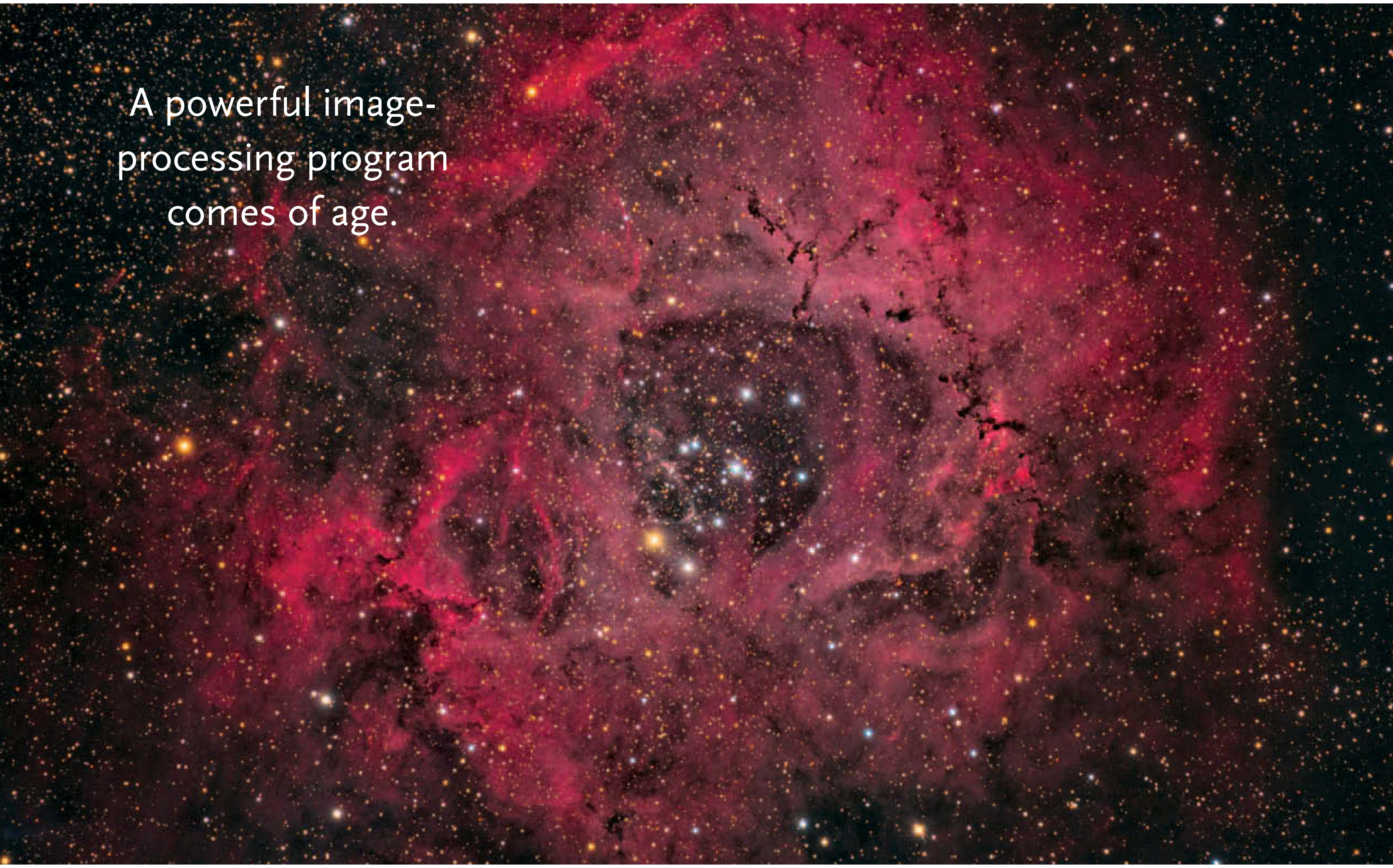
Even more exotic propulsion systems have been proposed. Tethers Unlimited offers a water-electrolysis propulsion system that uses sunlight to electrolyze water into hydrogen and oxygen fuel, which is burned in microbursts to gradually raise or alter a CubeSat's orbit. Since water is inert when the CubeSat is launched, this avoids the propellant restriction. In August 2012, MIT researchers announced the development of coin-sized ion thrusters that could provide long-term, continuous thrust to CubeSats for many months at a time. These developments could lead to such milestones as the first amateur-operated space telescope, or a CubeSat mission to orbit the Moon, or perhaps an interplanetary CubeSat to impact a near-Earth asteroid.

Whatever the future holds, it's clear that CubeSats have opened exciting avenues to individuals and small groups. For the first time in the history of amateur astronomy, the sky is no longer the limit. ✦

*Space enthusiast **Tim DeBenedictis** heads Southern Stars, the company behind the highly acclaimed* SkySafari *and* SatelliteSafari *apps for Apple and Android mobile devices.*

Insight into PixInsight

A powerful image-processing program comes of age.



Many astrophotographers use a host of image-processing software (mostly *Adobe Photoshop*), often because no single software package has all the tools necessary to get the job done. That philosophy changes with Pleiades Astrophoto's *PixInsight Core*. Developed for astro-imagers by astro-imagers, *PixInsight* contains the tools to take your astrophotos from your camera all the way to gorgeous final results, as done with this richly detailed image of the Rosette Nebula. All photos are courtesy of the author.

Warren Keller

Astrophotographers should take note: there's a relatively new player in the world of deep-sky image processing. No, it's not the latest from Adobe, nor is it a major update from any of the big names in astronomy software. It's Pleiades Astrophoto's *PixInsight* (**http://pixinsight.com**), a powerful image-processing program by Spanish software developer Juan Conejero.

PixInsight began in 2004 as limited-edition freeware. It evolved into the mature commercial product *PixInsight Core* by 2007 with help from many contributors in both the amateur and professional astronomy communities. The program is available for Windows, Mac OS X, Linux, and FreeBSD operating systems, but as of the release of version 1.8 Ripley, *PixInsight* is available only in a 64-bit version. That enables it to take advantage of the multi-core processors of modern computers, which is necessary to run the program's intensive algorithms.

As a full-featured image-processing suite, *PixInsight* is capable of handling all your deep-sky astrophotography processing needs, from calibrating and stacking

FITS images to the final touches of sharpening, deconvolution, and selective adjustments often done in more generic photography software. The program is structured much like an operating system, which permits users to develop their own processing modules using the C++ programming language and to submit them to the parent company for possible inclusion in the program in future releases. More than 125 cutting-edge processes and scripts created exclusively "for astro-imagers by astro-imagers" are already included, with more offered online or with each update.

The software's user interface offers a dizzying array of drop-down menus and submenus, and navigation would be daunting without the aid of adequate documentation. Although the official help file is somewhat spotty as of this writing, a wealth of useful information exists in mouseovers, appearing as the cursor passes over process dialogs. Another fantastic resource is the *PixInsight* user forum (**http://pixinsight.com/forum**), where the latest tutorials are often shared. Nearly every successful *PixInsight* user owes part of his mastery to the video tutorials of Harry Page (**www.harrysastroshed.com/pixinsighthome.html**); viewing these before delving into the program will greatly reduce any confusion and is highly recommended.

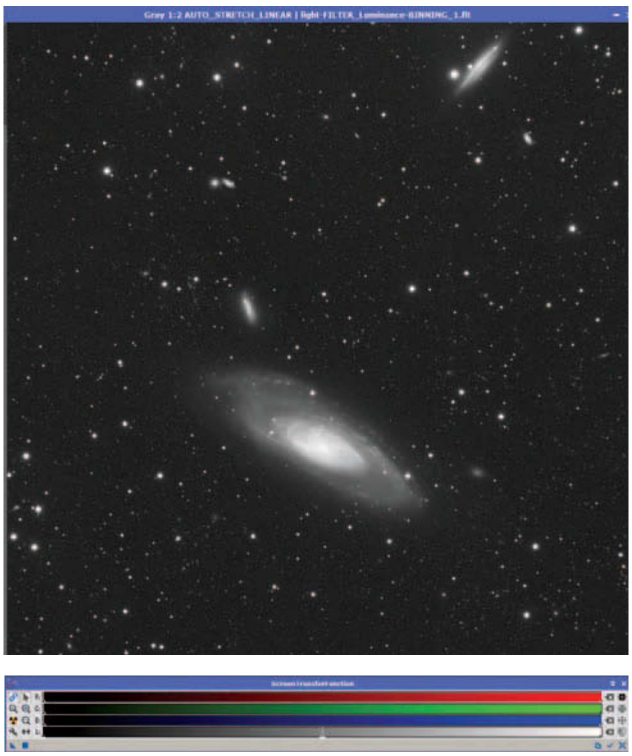
Salient Features

Unlike other image-processing programs, *PixInsight* often generates a new image for certain processes, such as star masks, or stacking results. This quickly accumulates many open files on your desktop as you perform each step in your workflow. The program manages these files using multiple Workspaces, and lets you save your workflow as a Project (FILE / Save Project). Projects preserve each of the open images, and also save each step performed during processing sessions.

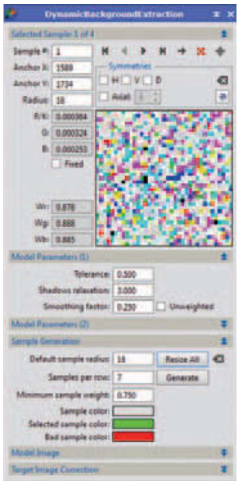
Another useful feature is the Process Console. This command-line display window shows the progress of each process, along with other pertinent information. The dialog opens with each process you activate, and you can keep it open by clicking the blue square "Stick" button in the top right of the window. Each process dialog has a New Instance, indicated by the blue triangle at the bottom-left corner of each tool window. When you drag a New Instance onto an open image, the process is applied; when you drag it to the desktop, a process icon is created. Rather than opening processes with their default settings via the pull-down menu, you can use saved New Instances to open them with the last settings used. This is extremely helpful in providing quick access to your own custom settings. You can save an entire chronological workflow of New Instances and load them during processing sessions.

PixInsight's calibration, alignment, and stacking algorithms are all grouped into the Batch Preprocessing script (SCRIPT / Batch Preprocessing) written by Kai Wiechen and Juan Conejero, which enables all steps of preprocessing to be performed in a single pass. Activating this action script opens a window that allows you to select your bias, dark, flat, and light exposures. When selected, the script automatically organizes the data by filter, camera binning, and exposure. It then calibrates, aligns, converts color camera files, and integrates (stacks) your dozens of images into completed master files saved in a directory of your choice, ready for additional processing.

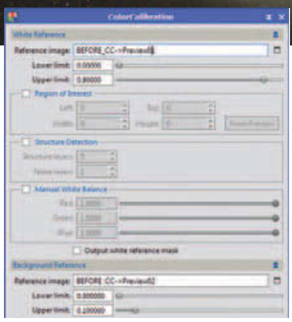
Seasoned imagers are aware that a 16-bit astronomical image displayed in the linear state is generally of poor quality. Most astronomical processing software is incapable of giving a good look at how the data will appear after a nonlinear stretch has been applied. You must wait to address problems such as gradients, color imbalance, and noise until after the nonlinear stretching of the histogram reveals them. *PixInsight*'s Screen Transfer Functions (STF) however, are a game changer. Users are able to repair images before they are stretched. With STF AutoStretch engaged (IMAGE / STF Autostretch), each image shows a preview of the stretched data, enabling you to see and reduce gradients, adjust the color balance, and apply noise reduction while your actual data remains in a linear state.



***PixInsight* contains a wide selection of tools essential for processing deep-sky images such as this one of M106. Its ScreenTransferFunction enables you to stretch the display of 16-bit data so you can see an image's faintest and brightest areas simultaneously to identify and correct problems such as light-pollution gradients, vignetting, and color bias.**



Above: **The DynamicBackgroundExtraction tool permits you to carefully model the background sky in your photos *(lower right)* which can then be subtracted from the image *(lower left)* to correct gradients before additional processing.**



Above: **Once gradients and field illumination are addressed in an image, you can then establish a natural color balance using the ColorCalibration tool. Note how the outer spiral arms of M106 become a pleasing bluish color against a neutral sky background (*right*) after application of the tool.**

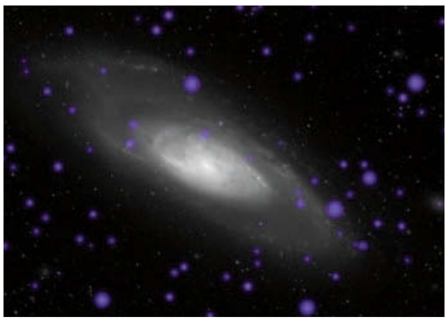
The tools of choice to reduce light-pollution gradients and vignetting in *PixInsight* are the BackgroundModelization processes (PROCESS / BackgroundModelization). These powerful tools can automatically generate samples of relatively neutral background sky (AutomaticBackgroundExtractor), or you can manually select your own in the DynamicBackgroundExtraction tool. The manual method is the preferred choice for fields that have a preponderance of nebulosity. Both do a fabulous job of neutralizing gradients.

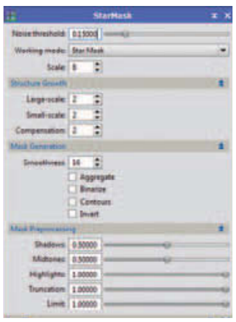
Wavelets: More than Sharpening

Much of the selective processing in *PixInsight* is accomplished using Wavelets. Wavelets are signal-processing algorithms that you can use to deconstruct an image into separate components called layers or planes. These wavelet layers isolate objects by their structure size. For example, one plane is assigned to small stars, another for larger nebular or galactic structures, and so on. Once you isolate these layers, you can enhance or otherwise adjust them independently. Manipulation of image data via wavelets is one of the primary foundations of *PixInsight*.

The software tackles color balance with the ColorCalibration tool (PROCESS / ColorCalibration). With it you can achieve natural color after establishing even-field illumination. Although many imagers use the *G2V*-star calibration method as their white-balance reference, ColorCalibration is distinctly different. The process uses wavelets to isolate stars and analyze all of the spectral types present in the image in order to create the white reference. Spiral galaxies may also be used as an alternative white reference — the reasoning being that these galaxies provide an excellent sampling of all stellar classes. In addition to the white reference, the process also uses a background reference defined by the user for its calculation.

Another of *PixInsight*'s unique and powerful tools is HighDynamicRangeMultiscaleTransform (PROCESS / MultiscaleProcessing / HDRMultiscaleTransform). It's best reserved for use after nonlinear stretching. Essentially, the push of a single button can recover structure that might otherwise require several iterations of work in other programs. Galaxies and nebulae with high dynamic range (such as M101 and M42) often appear featureless in the brightest areas once the faint regions are stretched





Left: PixInsight's **StarMask tool uses wavelets to isolate stars and generate a separate mask file, enabling you to process them separately from your main target.**

Left: The HDRMultiscaleTransform tool will recover detail in the brightest areas of galaxies, nebulae, and globular clusters with a single click of your mouse that would otherwise take many steps to accomplish in other programs.

Below: Using Wavelets in *PixInsight* isolates the small- and large-scale structures in your photos, including stars, spiral arms of galaxies, or tiny details in nebulae.

into visibility. The tool utilizes wavelets to isolate these brighter regions, so that their dynamic range can be compressed to recapture and enhance subtle detail, including dust lanes.

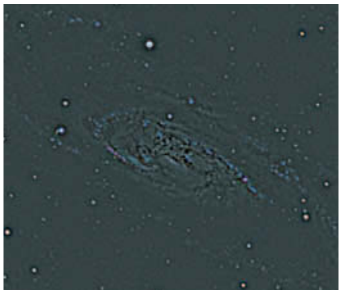
Although most astrophotographers are familiar with *Photoshop* masking techniques to isolate and independently alter aspects of an image, *PixInsight*'s wavelet-based StarMask tool (PROCESS / MaskGeneration / StarMask) is unique in that it effectively selects only stellar features. Once a star mask is applied to an image, the stars may be concealed or revealed for further processing. This may include color saturation, or the Morphological-Transformation tool (PROCESS / Morphology / MorphologicalTransformation) to shrink their size to better reveal faint nebulosity in crowded star fields.

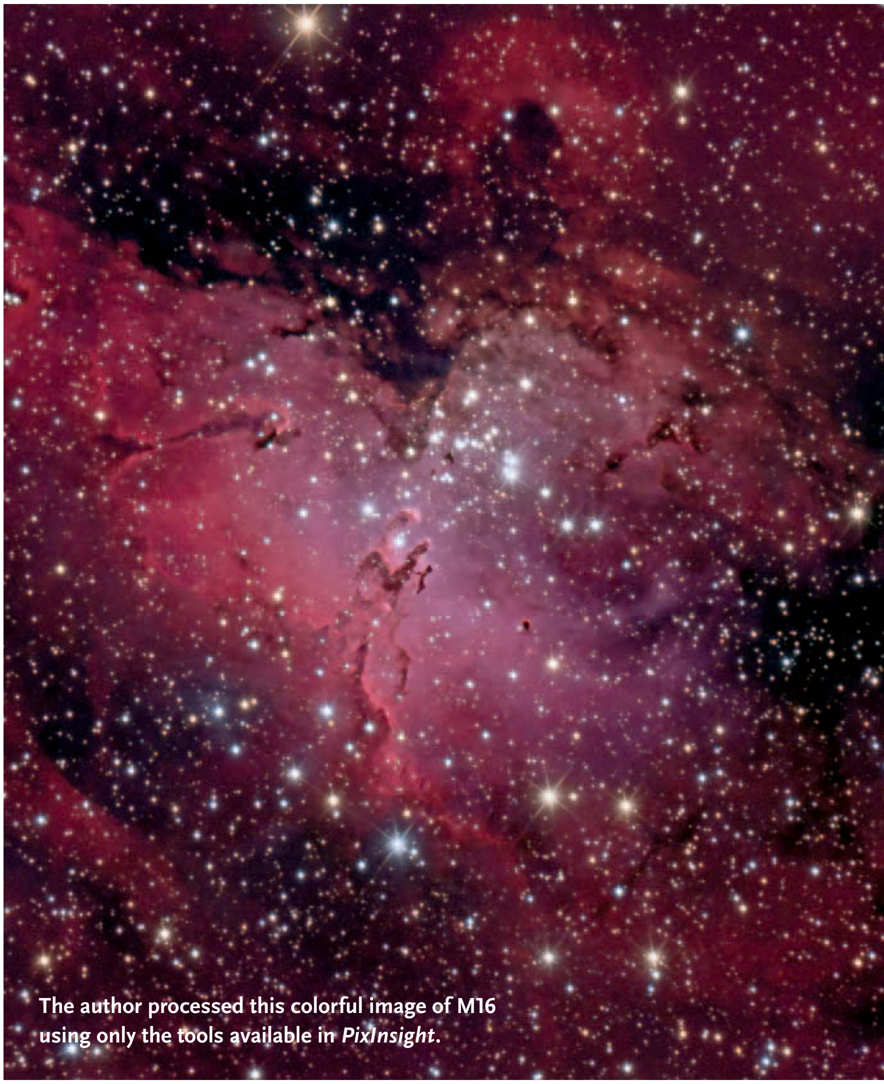
And of course, *PixInsight* includes many CCD-specific image-processing commands familiar to veteran imagers, including PixelMath and deconvolution, and Unsharp-mask sharpening. PixelMath (PROCESS / PixelMath) is used to blend two versions of an image together, which among other things can reduce the aggressive effects of sharpening.

In addition to those processes, *PixInsight* offers advanced tools such as GradientMergeMosaic (PROCESS / GradientDomain / GradientMergeMosaic) to assist in the construction of multiple-pane mosaics (*S&T:* July 2011, page 72).

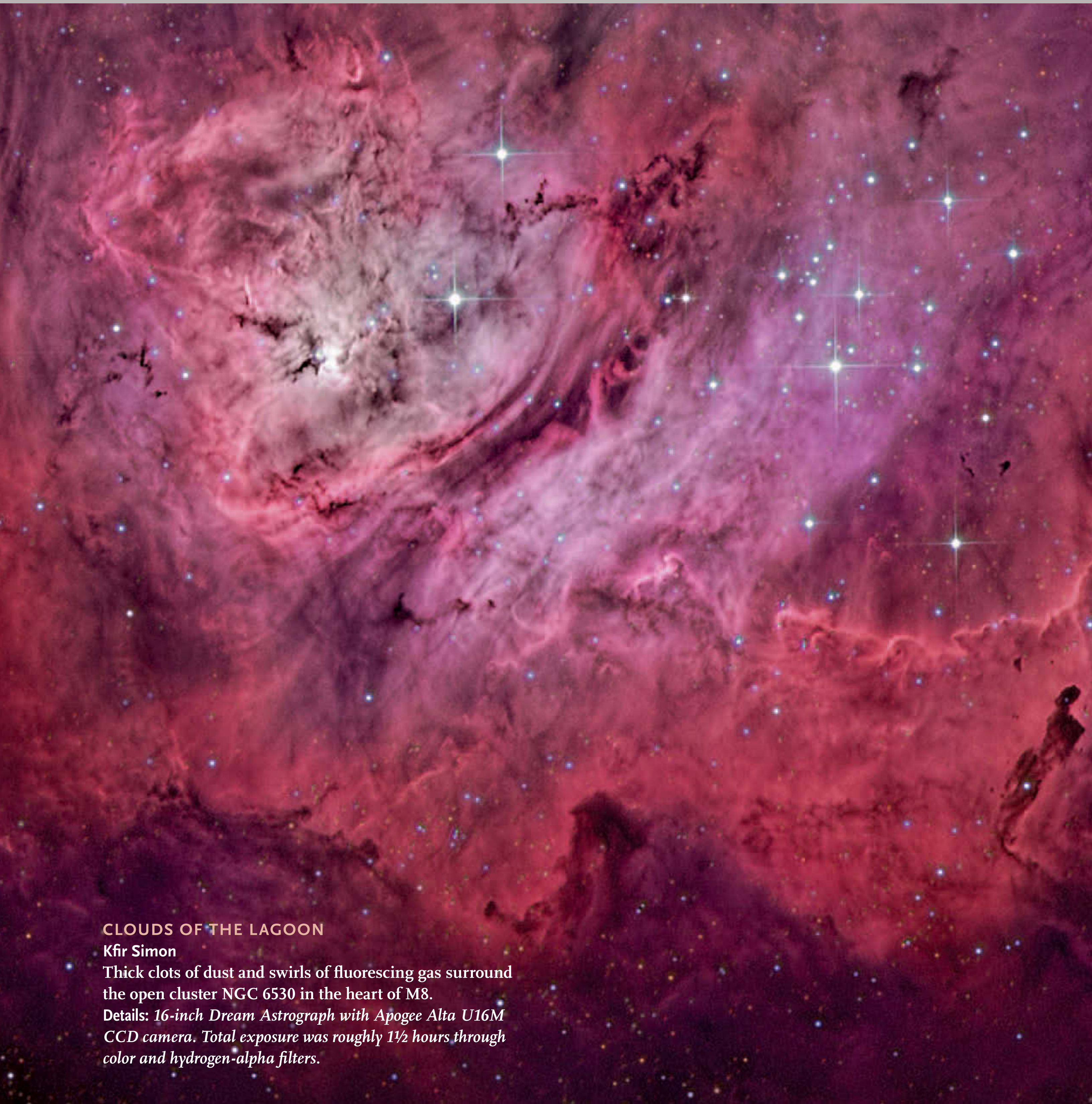
Like most astronomical software, *PixInsight* is not an easy program to master, and there are far too many powerful functions to cover in a single article. Quality tutorials such as those mentioned earlier offer the keys to the kingdom, significantly smoothing out the steep learning curve. Even if you're relatively new to image processing, you will likely desire an advanced post-processing program at some point along your path. Today, two roads diverge in the forest of image processing — one marked *Photoshop*, the other *PixInsight*. After *Photoshop*'s two decades of dominance in the field, many imagers are choosing to take the road less traveled, and traffic on that road is growing rapidly. ✦

***Warren Keller** offers a video tutorial detailing the use of PixInsight available at **www.ip4ap.com**. Visit **www.billionsandbillions.com** for more of his deep-sky astrophotos.*





The author processed this colorful image of M16 using only the tools available in *PixInsight*.



CLOUDS OF THE LAGOON

Kfir Simon

Thick clots of dust and swirls of fluorescing gas surround the open cluster NGC 6530 in the heart of M8.

Details: *16-inch Dream Astrograph with Apogee Alta U16M CCD camera. Total exposure was roughly 1½ hours through color and hydrogen-alpha filters.*

▲▲ **WARPED SPIRAL**

Brian Peterson

The bright spiral galaxy NGC 5033 in Canes Venatici presents observers with diffuse spiral arms and an overly bright core that hint at a past merger with another galaxy.

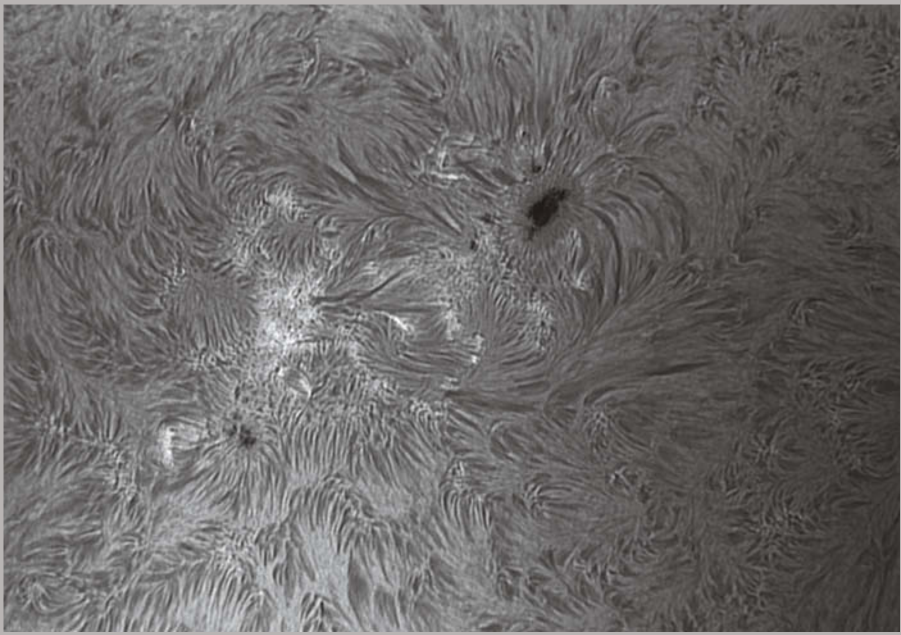
Details: *Starizona Hyperion 12½-inch astrograph with SBIG STL-11000M CCD camera. Total exposure was 7 hours through color filters.*

▲ **FACE-ON GALAXY**

Al Kelly

Located in the Virgo Cluster of galaxies, M61 is a barred spiral that displays many pinkish star-forming regions in this deep-color image.

Details: *Celestron CGE 1400 with Orion Parsec 8300C CCD camera. Total exposure was 3 hours.*



◀ **CHURNING SPOT**

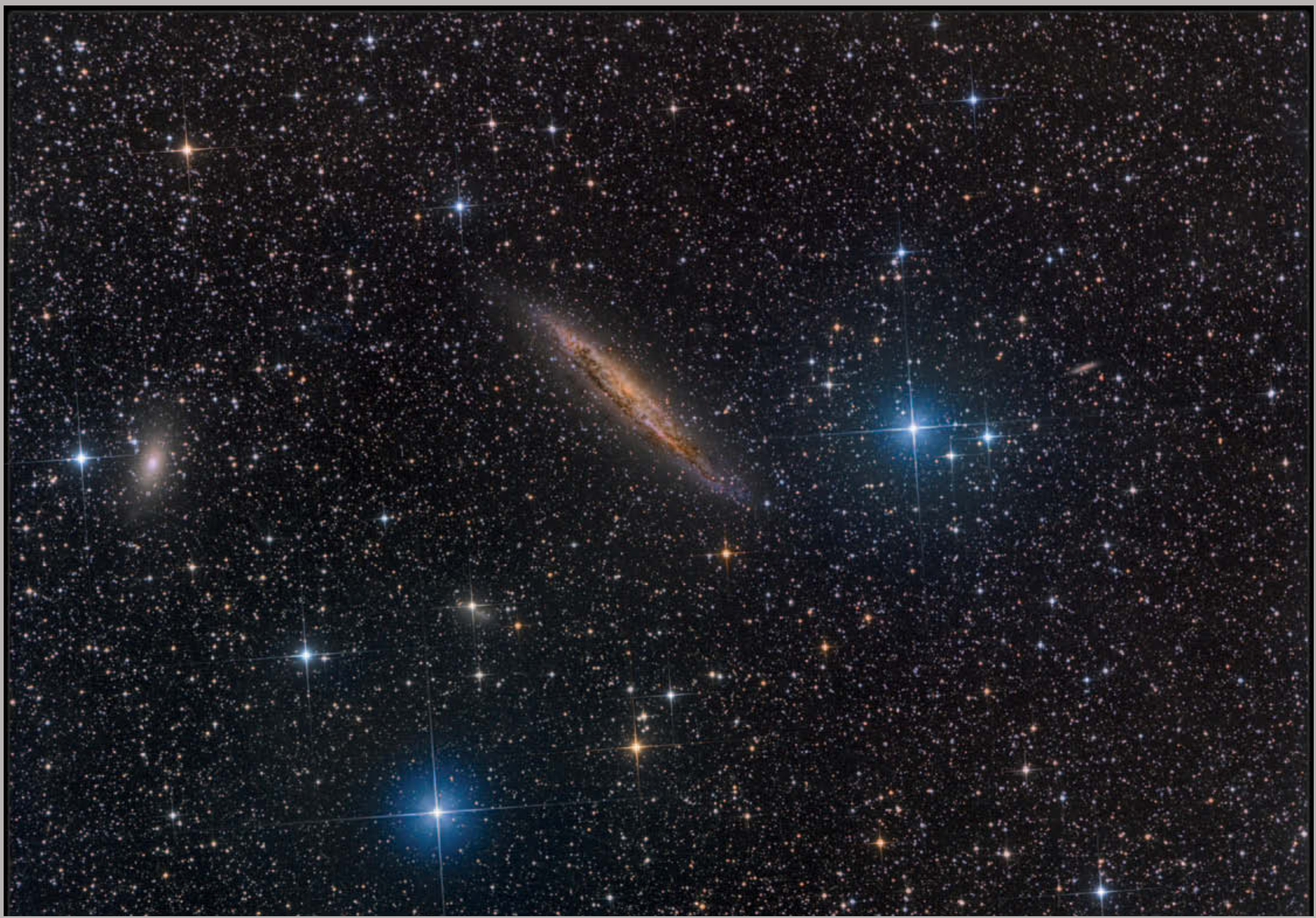
Emiel Veldhuis

Sunspot AR1793 is surrounded by thin filaments and frothing plasma. **Details:** *Modified Coronado P.S.T. with 130-mm objective and Imaging Source DMK31AU04.AS high-speed video camera. Stack of multiple frames recorded on July 19th.*

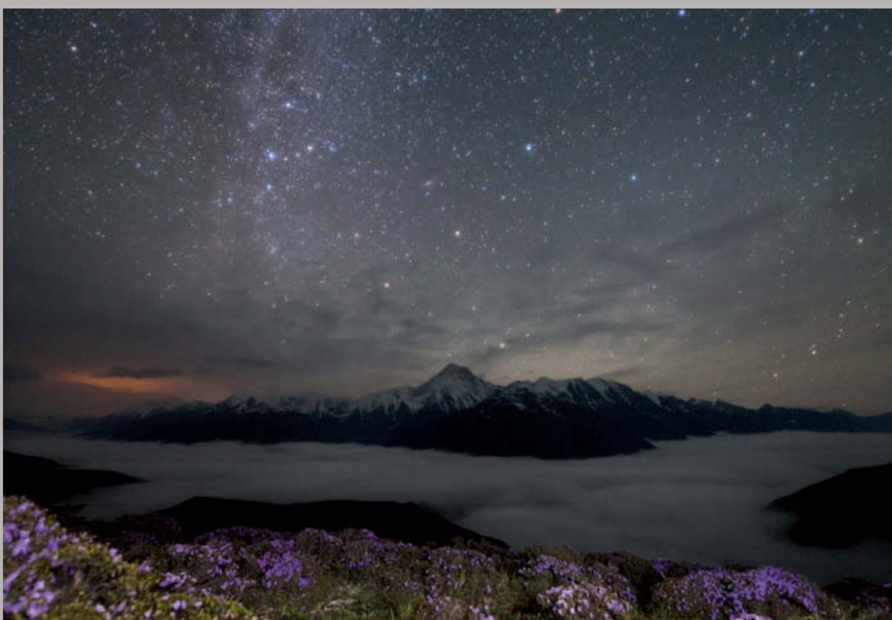
▼ **NGC 4945**

Kfir Simon

Between the moderately bright blue stars Xi^1 and Xi^2 Centaurus (right and bottom left, respectively) resides the nearby galaxy NGC 4945, an 8th-magnitude spiral with prominent dust lanes. **Details:** *16-inch Dream Astrograph with Apogee Alta U16M CCD camera. Total exposure was 2 hours through color filters.*



GALACTIC PELICAN
Frank Sackenheim
The famous Pelican Nebula, IC 5070, is an ionization front illuminated by young, energetic stars within a vast molecular cloud in Cygnus.
Details: *Takahashi FSQ-106EDX astrograph with SBIG ST-8300 and QSI 583 CCD cameras. Total exposure was 15 hours through narrowband filters.*



◂ **MOUNTAINTOP MILKY WAY**
Jeff Dai
Cassiopeia and the northern extent of the Milky Way rise over Mount Gongga, the tallest peak of the Daxue Mountains in China's Sichuan province.
Details: *Canon EOS 5D Mark II DSLR with 50-mm lens. Total exposure was 77 seconds at ISO 2500.* ✦

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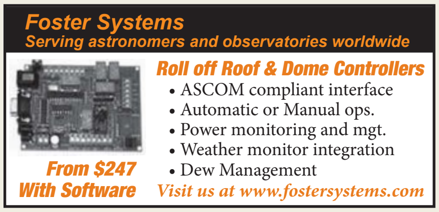

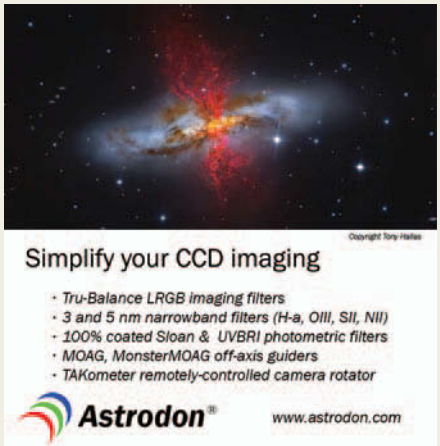

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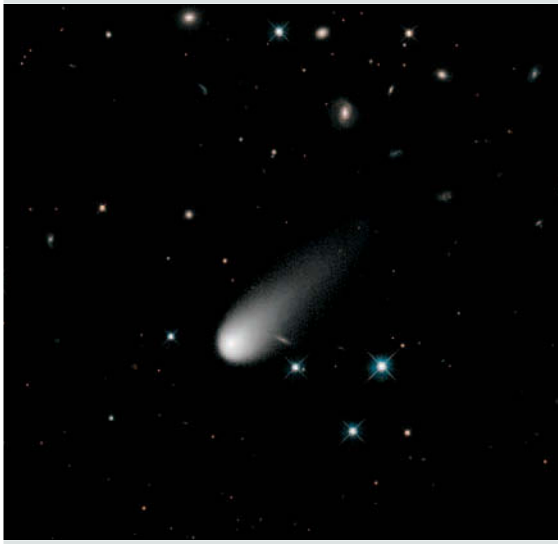

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Frank Ridolfo

Let's Re-Name Astronomy Day

We need a catchier name, and more of them.

S&T: LEAH TISCIONE

ASTRONOMERS CHERISH our yearly day of public notoriety: Astronomy Day. But there's a problem: the name "Astronomy Day." Let's face it, to most people this has all the appeal of, say, Botany Day (sorry, no offense intended toward botany enthusiasts). We need a better name, and we need more of them as well. We need names that immediately grab the public's attention and invoke a sense of mystery, wonder, and curiosity — names that will cause the public to flock to our events.

Therefore, I propose that the astronomy community adopt the following new events (with glamorous names) to augment our traditional (and plain vanilla) Astronomy Day.

Manned Space Flight Appreciation Day: We acknowledge the value of human space travel by launching the entire U.S. Congress on a deep-space mission to the distant Oort cloud of cometary debris.

"Where is Everybody?" Day: We ponder the question first posed by Enrico Fermi regarding why we have yet to encounter advanced alien civilizations. We can celebrate this event almost any time, with the exception of June, July, and August, when everybody shows up at my beach cottage.

End of the World Day: We celebrate the fact that last year's predictions of the end of the world failed to materialize. We would also use this joyous occasion to acknowledge this year's predictions regarding next year's demise of our world.

Ye Old Universe Day: We commemorate the age of the universe, now thought to be 13.8 billion years based on the latest results from Europe's Planck mission. We will celebrate this event on the 138th day of each year (May 18th in non-leap years).

"Where Am I?" Day: We celebrate the wondrously bizarre laws of quantum mechanics that govern the subatomic realm. This name corresponds to the famous double-slit experiment in which a single photon can be found in two different places at the same time. This is actually not as strange as it seems. It's just the quantum mechanics version of multitasking — something we humans do each day without any concern over violating the rules of logic or common sense.

Forget Me Not Day: We fondly remember Pluto's former glory days. Pluto may no longer be a planet, but it's still in our hearts and will never be forgotten. As to the members of the International Astronomical Union who voted to demote the beloved Pluto from planetary status, what where you thinking? It will take decades of "Forget Me Not" days to undo the harm.

Null Hypothesis Day: We recognize the confounding aspects of the null hypothesis test of statistics; wherein a postulated hypothesis is deemed to be true when the null of the hypothesis is proven to be false (or something like that). Apparently, only tenured mathematics professors fully understand the concept. This day may or may not have astronomical significance, depending on the nature of the hypothesis, or the nature of the null hypothesis (or something like that).

Surely, these days will draw crowds like never before — like moths attracted to a flame. As PR experts have long known, the success of any campaign is greatly dependent on how you name a thing. ✦

***Frank Ridolfo** is a retired nuclear engineer living in Bloomfield, Connecticut. He spends his time contemplating the mysteries of the cosmos as well as the mystery of what day of the week it is.*

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