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DECEMBER 2014

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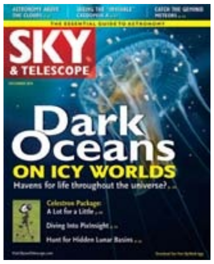
December 2014 VOL. 128, NO. 6



On the cover: Aquatic creatures might arise on other worlds in the depths below icy crusts.

PHOTO: ROB ROBBINS

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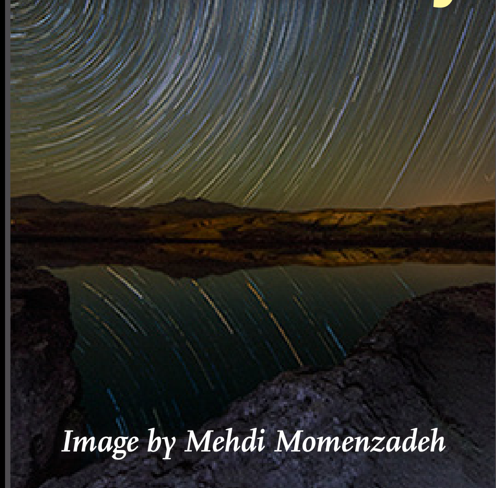

Image by Mehdi Momenzadeh

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Niels V. Christensen of Copenhagen, Denmark made this image of NGC 7635 on four clear nights during August of 2014.

Bullish on S&T's Future

IT'S HARD TO BELIEVE that this is my final issue as editor in chief of this venerable publication. Sometimes it seems like I just started my tenure, but that was way back in June 2008. This has been an exciting time to cover astronomy. The count of known exoplanets now exceeds 1,800. Computers, apps, and mobile devices have revolutionized amateur astronomy, and more and more people are taking great photos of the night sky. And amazingly, Opportunity keeps chugging along on Mars.

I want to briefly introduce my successor, Peter Tyson. Peter has been a science journalist for more than 30 years, starting at *Omni* magazine in the early 1980s and later serving 14 years as editor in chief of *NOVA Online*, the website of the PBS documentary science series, for which he wrote articles about astronomy and related fields. Peter will introduce himself more fully in next month's issue.

With Peter's background in multimedia, and with a staff of talented, dedicated editors and art personnel, I'm bullish on the future of *S&T*. Thanks to our former and current corporate owners, New Track and F+W, *S&T* remains financially sound despite the well-documented deteriorating business climate for publishing. F+W is encouraging us to reach new audiences through multimedia, so Peter and the staff will steer *S&T* in exciting directions while also maintaining the core values that have made it successful for 73 years. I deeply appreciate the fact that New Track and F+W management never asked us to dumb-down our editorial content. Moreover, they never pressured us to curry favor with particular manufacturers in a way that would compromise our editorial mission. They have always given us the support we needed to carry on *S&T*'s long-held traditions. Since acquiring *S&T* in January, F+W has improved our customer service and helped us modernize our website.

Most of all, I want to thank my editorial and art colleagues of the past six years for making my job *a lot* easier and more enjoyable than it might otherwise have been. These people include Alan MacRobert, Dennis di Cicco, Pat Coppola, Tony Flanders (who is also moving on), Sean Walker, Gregg Dinderman, Camille Carlisle, Monica Young, Leah Tiscione, Katie Curtis, and Casey Reed. I thank all of our regular contributors, especially Kelly Beatty and Roger Sinnott. I thank Peter Hardy and Lester Stockman in our ad sales department for helping to keep *S&T* healthy. And I thank all of our various business partners for their support.

To be honest, it has been stressful, frustrating, and challenging at times for my colleagues and I to operate in this rapidly changing media and business environment while also trying to preserve everything that makes *S&T* so valued by its audience. I hope you feel we have successfully walked this fine line during my 6+ years as editor in chief.

Robert Naeye
Editor in Chief

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and Helen Spence Federer

The Essential Guide to Astronomy

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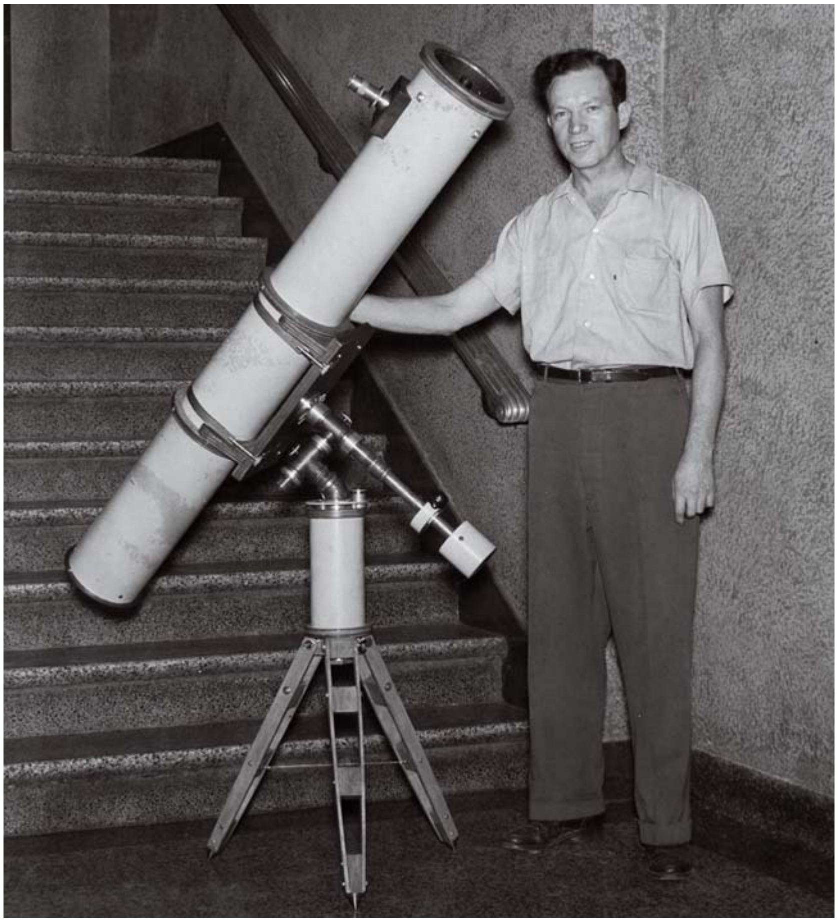
After some refurbishing, Allyn J. Thompson's famous scope still provides beautiful celestial views 67 years after his classic book appeared in print.



MODERN SCOPE: DENNIS DI CICCO; THOMPSON: *S&T* ARCHIVE

An *S&T* "Where's Waldo?"

I was reading my newly arrived July issue of *S&T* when I came upon Alan French's article, "Star-Testing Your Telescope" (page 68). Seeing the telescope pictured on the opening page, I exclaimed, "I know that telescope!" I jumped from my chair and ran (well, wobbled) to my home library and retrieved my old copy of *Making Your Own Telescope* by Allyn J. Thompson (Sky Publishing Corp., 1947). There, depicted in Plate I on p. iv in black and white, was the very same instrument that appeared in French's article.

I am delighted to see that this venerable representative of the legendary ATM's craftsmanship is not only alive and well but also still used, despite lacking Go To capabilities or even setting circles and a finderscope. I tried for five years, until I went away to college, to duplicate as best I could that very telescope. After graduation, life happened (as it tends to do), and I never resumed my telescope-making efforts. However, I still have the 6-inch mirror I ground and polished to an f/8 spherical surface by following the instructions in that book. It still gives me satisfaction to see how close I came to completing it. Seeing that the original model is still in use is like accidentally encountering an old friend after a long absence. It warms the heart.

Edward Novak
Waynesville, Ohio

Editor's Note: *Several sharp-eyed readers recognized the telescope pictured in the lead photograph of French's article as the 6-inch f/9 Newtonian reflector made by Allyn J. Thompson in the 1940s. (Thompson recommended f/8 in his book based on experience gained after making the scope.) A postal worker from New York City, Thompson described the construction of his telescope in a year-long series of monthly articles beginning in* Sky & Telescope*'s November 1944 issue. The articles were also the basis for Thompson's book. The book became an overnight classic, encouraging thousands of amateur astronomers to try their hand as telescope makers. Among them was the late John Dobson, whose ensuing adventures as a telescope maker influenced the current state of amateur astronomy.*

Following Thompson's death in 1955, his telescope was given to S&T*'s founder, Charles A. Federer, Jr. For many years the magazine's editors used it at local star parties, until it was retired and placed on display in the lobby of the magazine's headquarters in*

The Horsehead Nebula in Orion (IC 434) - This image was produced with a RCOS half meter telescope, an Apogee Alta U16M camera and Astrodon E-Series filters. Exposure times: 720 minutes Luminance, 270 minutes Red, 270 minutes Green, 270 minutes Blue and 420 minutes h-alpha (all 1X1).

Cambridge. In 2004 the staff presented it to senior editor Dennis di Cicco in recognition of his 30 years at the magazine and for his efforts to keep Thompson's book in print as a facsimile edition by Dover Publications. Di Cicco did minor restoration work on the scope, including returning it to the almond-color paint that he discovered beneath the battleship gray that had covered the scope for many decades. The scope is currently in 99% of its original condition. The reflector is an excellent performer optically and mechanically, and di Cicco still uses it for many observations, especially historically memorable ones such as Mars's close approach to Earth in late August 2003.

Alan French's article was both informative and well written, with clear, enjoyable descriptions. I look forward to future articles by him in the magazine.

Of course, what caught my eye immediately when I flipped to the article was the picture of Dennis di Cicco looking into the 6-inch Newtonian. As a pre-teen telescope maker, I tried to grind and polish a 4¼-inch mirror using the first volume of *Amateur Telescope Making* (edited by Albert G. Ingalls) as my reference guide. But the book confused me and, as I recall, I made nearly every mistake it described. Later, I acquired a copy of Thompson's fine book, which described what I needed to know in a manner understandable to me. I was then able to finish the mirror. That is a fond memory indeed.

Darryl Davis
Via e-mail

I enjoyed French's article, but I would like to make a minor correction to one of his descriptions. French states, "Double the aperture's diameter and your telescope collects four times as much light. But the Airy disk's angular diameter is halved, so the light is now concentrated in one quarter the area. The result is an Airy disk that is 16 times brighter."

A moment's thought reveals that this cannot be correct. The disk's *total* brightness increases only four times, because the aperture collects four times as much light. But what French said is true for the disk's *surface* brightness — the brightness per unit area, or the intensity. Although there's only four times as much light, it's compressed into one-fourth the area, so the intensity is 16 times greater when you double the aperture.

Domenic Quadrini
Wakefield, Rhode Island

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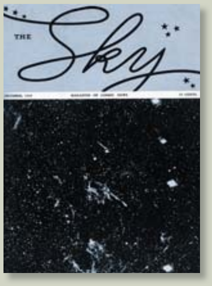
For the Record

✷ *September issue, page 52: The moon in front of Ganymede's shadow in the May 20th images by Christopher Go was wrongly identified as Io; it's Europa.*

✷ *October issue, page 76: We forgot to mention that the nebula shown is NGC 2170.*

75, 50 & 25 Years Ago

Roger W. Sinnott



December 1939

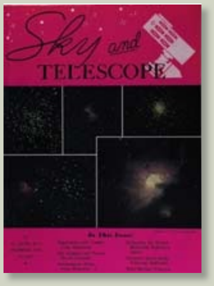
New Beginning "With the current issue, The SKY passes into the private management of Charles A. Federer, Jr. and his wife, Helen Spence Federer. Mr. Federer was formerly a member of the staff of the Hayden Planetarium, and is secretary of the New York Amateur Astronomers Association. Mrs. Federer has had charge of the Planetarium Book Corner for the past four years. . . ."

"Our best wishes go with the new management and editorship, with confidence that under the new arrangement the magazine . . . will fill a larger and larger field of usefulness. Clyde Fisher, Editor."

Within two years, The Sky *would merge with* The Telescope *to form the present magazine.*

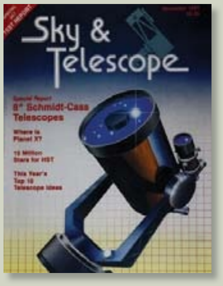
December 1964

Venus's Rotation "For three centuries astronomers have grappled unsuccessfully with the problem of finding the rotation period of Venus. Its cloud-laden atmosphere masks the true surface with a practically uniform veil, frustrating visual efforts to time the turning of the planet. Only one safe conclusion can be drawn from the bewilderingly contradictory visual determinations of rotation rate: most if not all are illusory. . . .



"Now, finally, radar astronomy offers an adequate tool. As reported in Hamburg [at the 1964 International Astronomical Union meeting], Venus rotates in a retrograde direction (from east to west, unlike the earth) in 247 days. The paper by I. I. Shapiro of Lincoln Laboratory, Massachusetts Institute of Technology, described results which he derived from data taken by the Arecibo Ionospheric Observatory's 1,000-foot radar telescope. . . ."

Now refined to 243 days, Venus's rotation is the slowest known in the solar system.



December 1989

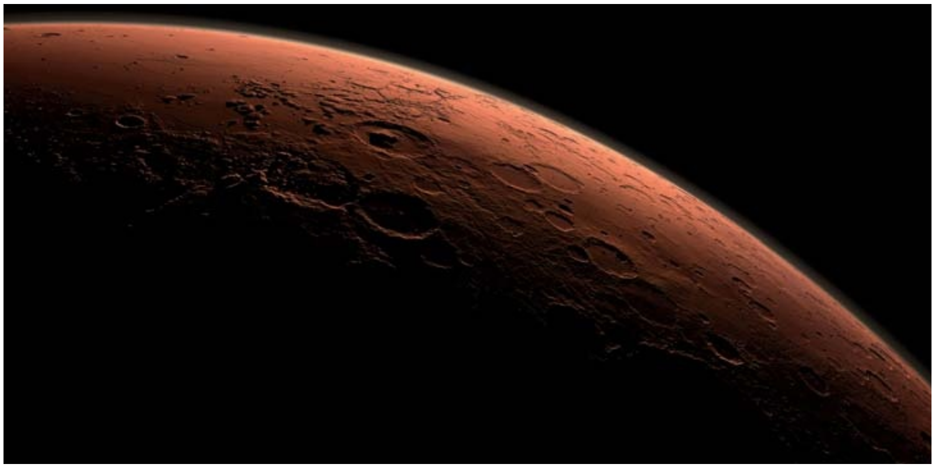
Image Fudging? "Optical astronomers may curse Earth's atmosphere because it degrades their images, but few seem willing to employ even simple methods to regain some of the lost information. 'Computerized image enhancement techniques have been used for years with great success in the field of radio astronomy, but are . . . often treated with distrust by optical astronomers,' writes Nigel Sharp (National Optical Astronomy Observatories). . . .

"[One] problem, says Sharp, is 'a distinct conservatism amongst optical astronomers.' Most 'prefer to take their image just as it comes from the telescope.' Anything else is seen as '"doctoring" the data.'"

But soon, amateur astronomers would marvel at the details on Jupiter and Mars they could bring out by stacking CCD images. Today, optical image processing is standard practice.

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

MISSIONS | Orbiters Reach Mars



NASA / JPL-CALTECH

Space around the Red Planet got more crowded in September, as two orbiters joined three already active there. The arrivals raise the number of operating missions at Mars to a record high of seven.

First came NASA's Mars Atmosphere and Volatile Evolution (MAVEN) spacecraft. After a 10-month, 711-million-kilometer cruise (442 million miles) that began last November 18th, MAVEN fired braking rockets for 33 minutes and slipped into orbit at 2:24 UT on September 22nd. Later rocket firings trimmed the spacecraft's initial polar orbit to a 4½-hour-long loop ranging from 150 to 6,200 km above the planet's surface.

MAVEN will study the Martian atmosphere and the charged particles, electromagnetic fields, and plasma waves racing by in the solar wind (*S&T*: Sept. 2014, p. 20). Over the next year, it will also drop five times to altitudes as low as 125 km to sample the uppermost wisps of the planet's tenuous air.

Mission scientists hope to answer a puzzle: how, when, and why did Mars evolve from its initially denser atmosphere and warmer climate to the bleak, frozen world seen today? One leading theory is that the solar wind stripped the atmosphere away. MAVEN's spectrometers will study whether atoms are escaping to space today and at what rate.

Two days after MAVEN, India's Mars Orbiter Mission (MOM) arrived on the scene. Launched last November 5th, MOM fired its braking rocket for 24¼ minutes and achieved Martian orbit on September 24th at 2:00 UT.

It was a historic day for the Indian Space Research Organization (ISRO). MOM (informally called *Mangalyaan*, Hindi for "Mars-craft") is India's first interplanetary explorer, and never before has a spacefaring nation successfully reached Mars on its first try.

The spacecraft utilizes the same basic design as ISRO's 2008 lunar orbiter, Chandrayaan 1, a cube-shaped structure about 1½ meters on a side with a mass of 1½ tons. The mission's primary objective is to show ISRO can design and operate a successful interplanetary spacecraft.

But MOM's instrumental payload, though modest, can potentially deliver important discoveries. A color camera will record the Martian surface. Also aboard is a Lyman-alpha photometer that will deduce the relative abundance of deuterium in the planet's uppermost atmosphere. A spectrometer will determine the abundance of atmospheric methane — a gas at the center of debate (*S&T*: Dec. 2013, p. 16) — down to parts-per-billion levels. Rounding out the payload are a thermal-emission spectrometer (for assessing surface composition and mechanical properties) and a mass spectrometer (for atmospheric composition).

■ **J. KELLY BEATTY**

MARS | Curiosity Reaches Its Mountain

On September 11th, NASA's Mars Science Laboratory rover reached the base of Aeolis Mons, informally known as Mount Sharp. The arrival comes two years into Curiosity's exploration of Mars (*S&T*: Nov. 2012, p. 20).

Like a kid who initially enters a toy store intent on buying only one game, the mission team has moved the rover here and there — even directing it *away* from the mountain for a time — to explore all the tantalizing geologic features near the landing site in Gale Crater. But now the rover has begun climbing into a cluster of mounds known as the Pahrump Hills. These lie in the Murray Formation, in the lowermost slopes of what will be a long climb. The formation is about 200 meters (660 feet) thick, reports rover mission scientist Kathryn Stack (JPL), potentially representing "millions to tens of millions of years of Martian history just waiting for us to explore."

Initially, the mission's 400-strong scientific team had planned to spend more time poking around the crater's floor. However, there's growing concern about holes and tears in the 0.75-mm-thick aluminum skin of Curiosity's six wheels. The damage first became obvious about a year ago, but a visual inspection last November showed a huge gash in the left front wheel (see image below).

In order to avoid undue wear and tear on the wheels, mission planners will redirect the rover away from the planned route, which investigated geologically interesting outcrops called Murray Buttes, and instead onto a shorter and presumably safer path. Orbital imagery shows few impact craters or layers in the alternate terrain, so it's probably relatively soft ground that will minimize wheel damage.

■ **J. KELLY BEATTY**

Curiosity's left front wheel shows multiple punctures and tears from rolling over angular stones along its path.

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STELLAR | Resolving the Pleiades' Distance . . .

A new radio interferometry measurement suggests that the distance to the Pleiades star cluster measured by the European Space Agency's Hipparcos satellite is decidedly wrong — and that ground-based astronomers had it right all along.

Open star clusters such as the Pleiades and Hyades are perfect proving grounds for models of stellar evolution, because their stars all have the same age and composition yet exhibit a wide range of masses. But for these models to work, it's critical that astronomers know the clusters' distances precisely.

A problem soon arose when astronomers released results from ESA's Hipparcos satellite, which gauged stellar distances using trigonometric parallax. Ground-based methods had consistently shown that the Pleiades (M45) lie about 435 light-years away. But according to Hipparcos, the cluster has a distance of just 392 light-years, supposedly with an error of less than 1%.

If the cluster really is 10% closer than everyone had thought, then its stars must be intrinsically dimmer than stellar models suggest. A debate ensued about whether the models or the spacecraft data were wrong.

Now Carl Melis (University of California, San Diego) and colleagues have seemingly put the matter to rest. In the August 29th *Science*, they report distance results derived using very long baseline radio interferometry. They claim to have nailed the distance at 444.0 light-years, accurate to within 1%.

If this result holds up, it's good news for the standard models of how stars work. But astronomers must try to understand why the Hipparcos observations misjudged the distance so obviously — and whether its entire database of stellar distances is suspect. By 2020 Gaia data should completely resolve any lingering aspects of the puzzling Hipparcos discrepancy.

■ **J. KELLY BEATTY**

. . . and Hybrid Star Spotted?

After nearly four decades of searching, astronomers might finally have found a Thorne-Żytkow Object (TŻO), a bizarre and, until now, purely theoretical star made in the merger of two stars.

This stellar hybrid forms in a rare interaction that crams a neutron star inside a red supergiant companion. The merger could result from the massive star swelling and engulfing the neutron star, or if the supernova that creates the neutron star launches that stellar core into its supergiant companion.

TŻOs have remained elusive because they should look nearly identical to ordinary red supergiants — except for their spectra. Unlike in normal supergiants, the convecting atmospheres of TŻOs dredge up thermonuclear products from the surface of the hot, embedded neutron star.

In a recent survey of stars in the Milky Way and Magellanic Clouds, Emily Levesque (University of Colorado, Boulder) and colleagues identified a TŻO candidate in the Small Magellanic Cloud by its unique chemical properties, the team reports in the *Monthly Notices of the Royal Astronomical Society*.

The candidate, HV 2112, initially appeared to be a lone *M*-type red supergiant, but with a mass much greater than the normal upper limit. The real clincher came in the form of HV 2112's spectrum, which showed lines from lithium, molybdenum, and rubidium in its atmosphere in a combination unique to the thermonuclear processes at work in TŻOs.

But a few features in HV 2112's spectrum don't match expectations, including the amount of lithium and heavy metals.

"We're calling [HV 2112] a 'candidate' for a reason," Levesque cautions. "Claiming that we've found a totally new model of star is an extraordinary claim, it requires extraordinary proof."

■ **MARIA TEMMING**

IN BRIEF

Powerful eruption wracks Io. A titanic volcanic eruption seen on August 29, 2013, was among the most powerful ever recorded in the solar system. The eruption followed two other, dimmer outbursts on August 15th and was captured simultaneously with the Gemini North telescope and the NASA Infrared Telescope Facility, both on Mauna Kea. The outburst probably involved a cluster of towering lava fountains spread over an estimated 83 square kilometers (32 square miles). The eruption's location — within a few degrees of 223° west, 29° north — is not associated with any previously recognized volcanic site. Team member Katherine de Kleer (University of California, Berkeley) says that the event unleashed an estimated 20 terawatts of energy, making it at least 10,000 times more powerful than the lava fountains spewed during the 2010 eruptions of Eyjafjallajökull in Iceland. The team's two analyses appear in the planetary science journal *Icarus*. Io is the most volcanic body in the solar system, with about 150 sites active now; the total site count is roughly 400.
■ **MARIA TEMMING**

Black Hole Trio Questioned. New data suggest that the recently discovered black hole triplet (*S&T*: Oct. 2014, p. 16) is really just a twosome. Joan Wrobel (National Radio Astronomy Observatory) and colleagues took a second look at the system, using data they had collected over a few years from the Very Long Baseline Array. The team was surprised to find that their data went much deeper, revealing an odd structure that seemed to link the two radio sources together. Wrobel's team now interprets the double signature as a single black hole shooting off jets; when the jets hit the interstellar medium, they form hot spots. Ergo, the two radio sources would not be two separate black holes, but two hot spots formed from the bipolar jets of a single black hole. Still, the results remain inconclusive, and the scientific debate is ongoing. Wrobel's team has already submitted a proposal for another round of observations.
■ **SHANNON HALL**


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Laniakea: Our Home Supercluster

Astronomers have mapped the cosmic watershed in which our Milky Way Galaxy is a droplet. This massive structure extends more than 500 million light-years and contains 100,000 large galaxies.

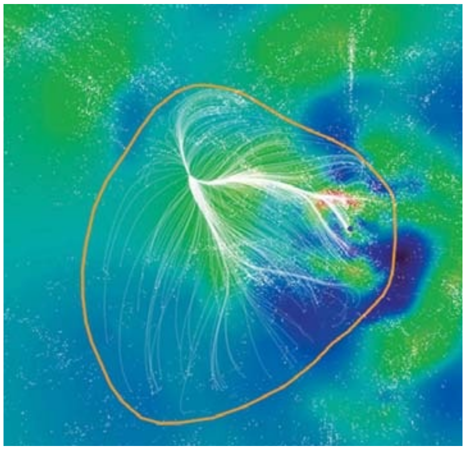
The work, published in the September 4th *Nature*, is the first to trace our local supercluster on such a large scale. It also provides a physical way to define what a supercluster is, by delineating it based on the motions of its member galaxies.

Researchers have been working out the gravitational structure in our local universe for decades. Based on work by Gérard de Vaucouleurs in the 1950s, astronomers have thought of our galaxy as being on the edge of the so-called Local Supercluster, a structure about 100 million light-years wide that's centered on the Virgo Cluster.

But astronomers have seen much larger structures in the universe, on the scale of several hundred million light-years. These maps have generally depended on calculating galaxies' 3-D locations based on their cosmological redshifts.

Brent Tully (University of Hawaii, Manoa) and colleagues have taken a different approach. They used galaxies' *peculiar velocities*, which are the galaxies' motions due to the local gravitational landscape. Galaxies fall toward or away from one another in this landscape; the Milky Way and many others seem to be moving toward the Great Attractor, a dense region in the vicinity of the Centaurus, Norma, and Hydra clusters about 160 million light-years away.

Peculiar velocities are on the order of a few hundred kilometers per second, whereas cosmic expansion velocities rise to several thousand km/s in the nearby universe, reaching 10,000 km/s roughly 130 million light-years out. (A galaxy recedes faster the farther away it is.) There's about 10–20% uncertainty in the peculiar velocity measurement for an individual galaxy. So only for nearby galaxies is the peculiar velocity high enough compared with the expansion velocity for astronomers to peg it confidently.



SDVISION INTERACTIVE VISUALIZATION SOFTWARE BY DP AT CEA/SACLAY FRANCE

A slice of the Laniakea Supercluster. The Milky Way is at the little blue dot toward the right-hand edge of the circled region (just below the reddish area, which is the Virgo Cluster).

The team found a way around this problem by using a technique called Wiener filtering. This algorithm allowed the team to essentially take a step back and look at the big picture, revealing the large-scale flow patterns created by galaxies' motions.

Last year, the team used this technique to map the local universe's web of filaments, clusters, and voids. Now, they've taken a closer look using their Cosmicflows-2 catalog, which contains more than 8,100 galaxies. The new catalog reveals where the flows merge and diverge, unveiling a gargantuan structure on whose periphery the Milky Way sits. The Great Attractor is a central valley in this newly demarcated watershed.

The team calls this huge supercluster Laniakea, from the Hawaiian *lani* (heaven) and *akea* (spacious, immeasurable).

The analysis also reveals other structures, including a separate supercluster called Perseus-Pisces and a distant concentration named Shapley about 650 million light-years away, toward which Laniakea is moving.

Finding out if our supercluster is only the elephant's trunk will require accurate distance measurements that reach three times farther than the current catalog.

■ **CAMILLE M. CARLISLE**

Find videos exploring our local cosmic structure at www.skypub.com/laniakea.

IN BRIEF

A Quasar Main Sequence? A new diagram is the closest astronomers have come to uniting quasars' diverse optical properties with what's actually going on physically. Building off decades of previous work by others, Yue Shen (Carnegie Observatories and Peking University, China) and Luis Ho (Peking University) looked at 20,000 quasars from the Sloan Digital Sky Survey and divided the sample based on two observed characteristics: the width of the hydrogen beta (Hβ) emission line and the strength of emission from singly ionized iron (Fe II). The resulting plot draws a "main-sequence wedge," reminiscent of the Hertzsprung-Russell diagram for stars (*S&T*: June 2014, p. 32). If, as the team concludes in the September 11th *Nature*, a wider Hβ line corresponds to a more edge-on disk and Fe II's strength is a proxy for the black hole's accretion rate, then the orderly diagram reveals a quasar's orientation and accretion rate, simply based on where the quasar lies in the plot. Paired with luminosity, the accretion rate also reveals the black hole mass. The correlations will require much more testing before they're confirmed.

■ **CAMILLE M. CARLISLE**

GRBs: A New Standard Candle? Two teams independently suggest that gamma-ray burst supernovae just might be "standardizable." At first glance, the supernovae that create long GRBs have irregular light curves. But when Zach Cano (University of Iceland) and a second, independent team comprising Xue Li and Jens Hjorth (both from University of Copenhagen, Denmark) analyzed separate sets of eight GRB supernovae, Cano found that the luminosity correlated with the light curve's width, while Li and Hjorth found that the luminosity correlated with the light curve's decline rate. The arguments are preliminary; the next step will be to successfully use GRBs as standard candles to confirm distances calculated with other tools.

■ **SHANNON HALL**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Astronomical Image by Sara Wager

TECHNOLOGY | Next-Gen Adaptive Optics

The Subaru Telescope has donned a new pair of glasses called Raven, a multi-object adaptive optics (MOAO) system that enables astronomers to correct for atmospheric turbulence over an unprecedentedly large field of view.

MOAO systems use multiple guide stars to monitor atmospheric changes in the field of view so that the system can correct in response. The first MOAO-enabled image was obtained in 2010 on the 4.2-meter William Herschel Telescope in the Canary Islands. The system was a successful technical demonstration, but it wasn't meant to do astronomical science.

Recently, a team led by David Andersen (National Research Council, Herzberg Institute of Astrophysics, Canada), Colin Bradley, and Olivier Lardière (both of University of Victoria, Canada) installed the Raven MOAO system on the 8.2-meter Subaru Telescope on Mauna Kea.

Raven has three sensors for tracking natural guide stars over a 3.5-arcminute field, each on a motorized "pick-off" arm; it also has a fourth sensor that's designed to work with the telescope's laser guide star. These state-of-the-art correction abilities enable the system to compensate for atmospheric turbulence using any stars in the field brighter than magnitude 14.

Raven also has two motorized pick-off arms for observing targets, each with a field of view of 4 arcseconds. These can also be pointed anywhere in the 3.5-arcminute field. Raven's deformable mirrors then sharpen the light from these two targets simultaneously and send the corrected images on through — in this case, to the telescope's spectrograph, enabling astronomers to take high-resolution spectra of two targets at the same time.

Raven's MOAO system delivers images with roughly 0.15-arcsecond resolution — better than the typical 0.5-arcsecond achievable without AO, but not diffraction-limited. The resolution is worse than the 0.05 arcsecond of Keck, which observes in near-infrared as Subaru does and is often the gold standard for AO results. But the new system's designers chose to create something that would work with Subaru's existing spectrograph, not produce the highest-resolution images possible.

Full-fledged MOAO instruments dedicated for long-term science investigation might have on the order of eight laser-guide-star sensors and 20 science pick-off arms, Andersen says. These systems will be crucial for the next generation of large telescopes, which will have huge multiple mirrors and require the ability to produce AO corrections over a wide field of view.

■ **JOHN BOCHANSKI**

GALAXIES | Galaxy Growth Still Mysterious

Spiral galaxy observations are shedding doubt on cosmic cannibalism's role in building up large galaxies.

Multiple studies have suggested that galaxies don't depend on major mergers to spur most of their star formation. But even minor mergers might not be major players. Writing in the July *Astronomy & Astrophysics*, Enrico Di Teodoro and Filippo Fraternali (both University of Bologna, Italy) studied 148 spiral galaxies and their environs. The results were surprising: 101 galaxies had no detectable companions, 15 had a massive companion, 6 had both massive and dwarf companions, and 26 had only dwarfs.

For the 32 spiral galaxies with dwarf companions, the team found that any future mergers would only provide each spiral with at most 0.28 solar mass of gas per year — approximately a fifth of the gas necessary to continue forming stars.

One alternative is that minor mergers could trigger star formation via tidal forces by compressing the gas that's already in the massive spiral. The impact on star formation from mixing up the spiral's own gas might be larger than the impact from gas injected into the spiral from the dwarf. Also, dwarfs likely add a lot of their own stars to the spiral.

■ **SHANNON HALL**

GALAXIES | Building Big Ellipticals' Cores

Two teams have tracked down seeds in the early universe that likely grew to become today's massive elliptical galaxies.

Modern, huge ellipticals have burned through their star-forming gas reservoirs and now sit quiescent. These galaxies likely grew from much more compact quiescent galaxies observed as they were 10 to 11 billion years ago (roughly at a redshift of 2). At that era, quiescent galaxies were actually the *smallest* galaxies around, roughly one-tenth the size of today's yet incredibly compact, with stellar masses greater than the Milky Way's.

But where did these compact cores come from? For the last year or so, astronomers have suspected the sources were recently discovered, compact star-forming galaxies at that same epoch, with sizes and masses similar to the compact quiescent galaxies.

Now, two teams have confirmed that the velocity of gas moving around inside several of these small star-forming galaxies matches the velocities of stars in the small quiescent ones. It's this gas that forms stars, so if the dynamics of the gas match the dynamics of the stars, that's a pretty good indicator that we're looking at the same type of beast at different ages.

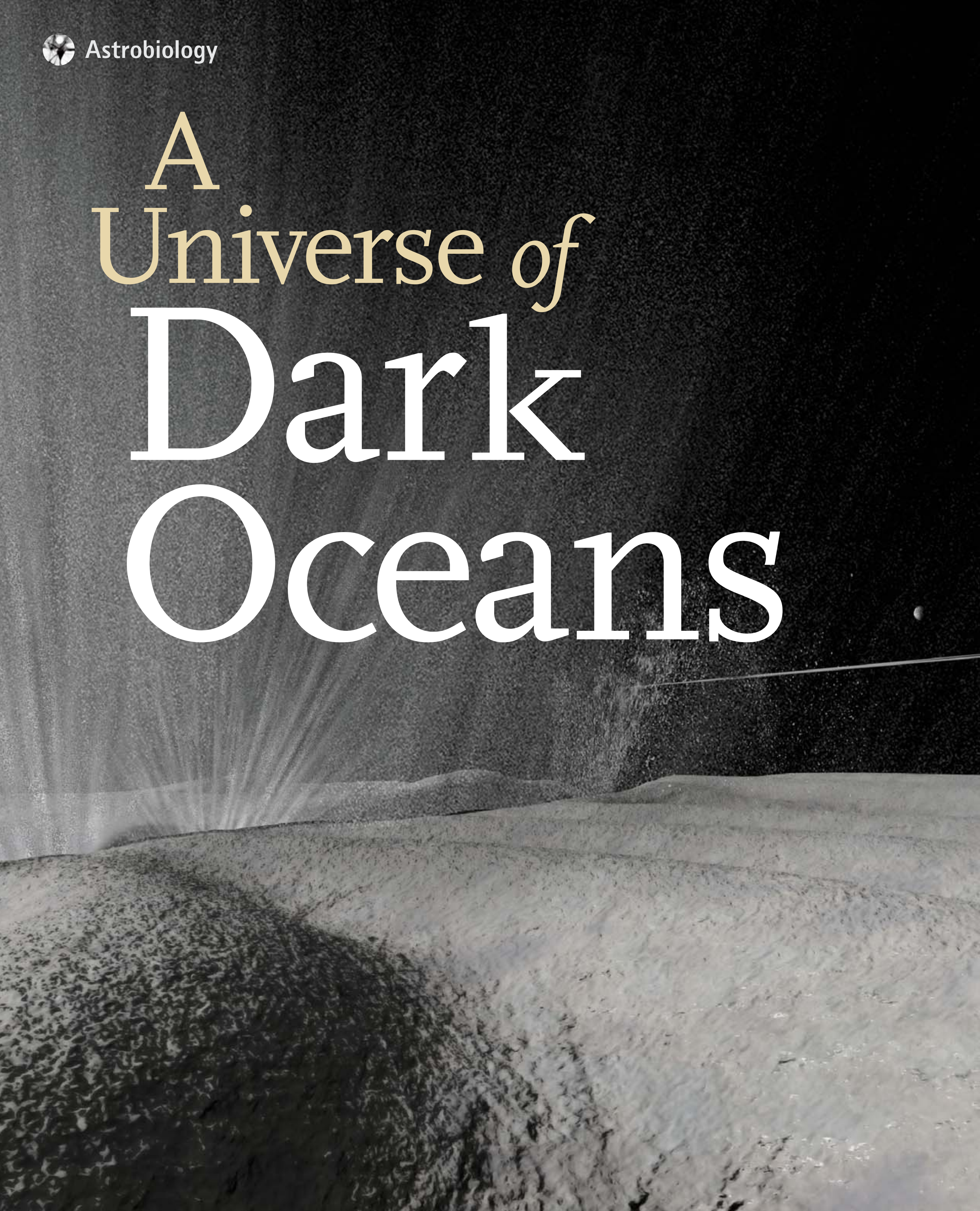
Both Guillermo Barro (University of California, Santa Cruz) and colleagues and Erica Nelson (Yale) and colleagues came to this conclusion using multiwavelength data for compact galaxies found in the GOODS and COSMOS surveys. The objects all have the right stellar masses and redshifts to be the precursors.

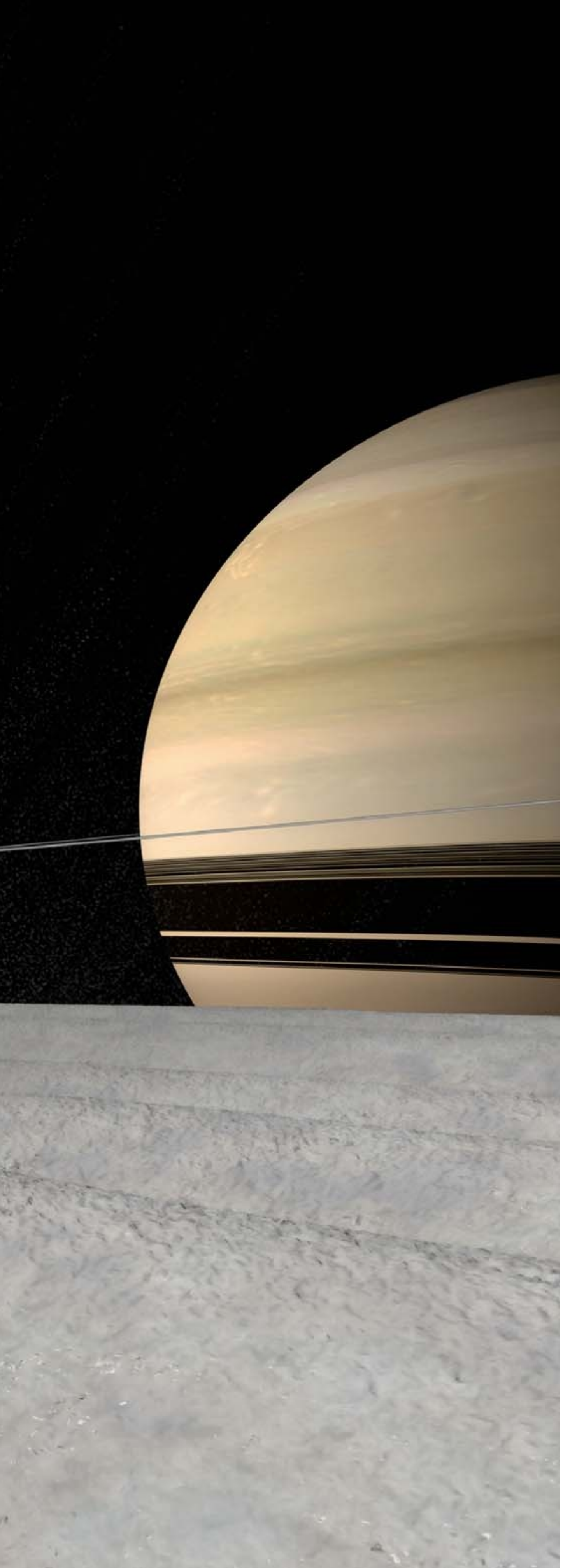
Assuming no more gas dumps down onto these cores, star formation will burn out in a few hundred million years. Feedback from supermassive black holes might exacerbate the quick death by removing gas, too. Barro's team found X-ray evidence for an active galactic nucleus (AGN) in 7 of the 13 galaxies it studied, while Nelson's team saw no sign of an AGN in the galaxy it analyzed.

This timeline puts the compact, star-forming galaxies right on track to become the small, quiescent galaxies observed. ✦

■ **CAMILLE M. CARLISLE**

A Universe *of* Dark Oceans





The icy bodies of the outer solar system might be teeming with life.

Caleb Scharf

THERE AREN'T MANY FIELDS like astrobiology. In the past I've even heard it called the science without anything to study. But the future has always been its strength; success in astrobiology will revolutionize our perspective on the nature of the cosmos, making Copernicus's decentralization of Earth seem like a prehistoric rite of passage.

A critical task for astrobiology is not just finding life elsewhere, it's finding life that's truly independent of terrestrial life. For example, if we find extant or extinct organisms on Mars, there's a good chance they'll be related to life on Earth — part of a genetic diaspora from microbe-laden planetary material thrown around the solar system by 4 billion years of asteroid impacts (*S&T:* Jan. 2007, p. 34). Either the Martians will be Earthlings or the Earthlings will be Martians. This remarkable discovery still would not help us determine the rate at which life emerges across the universe and the nature of its origins.

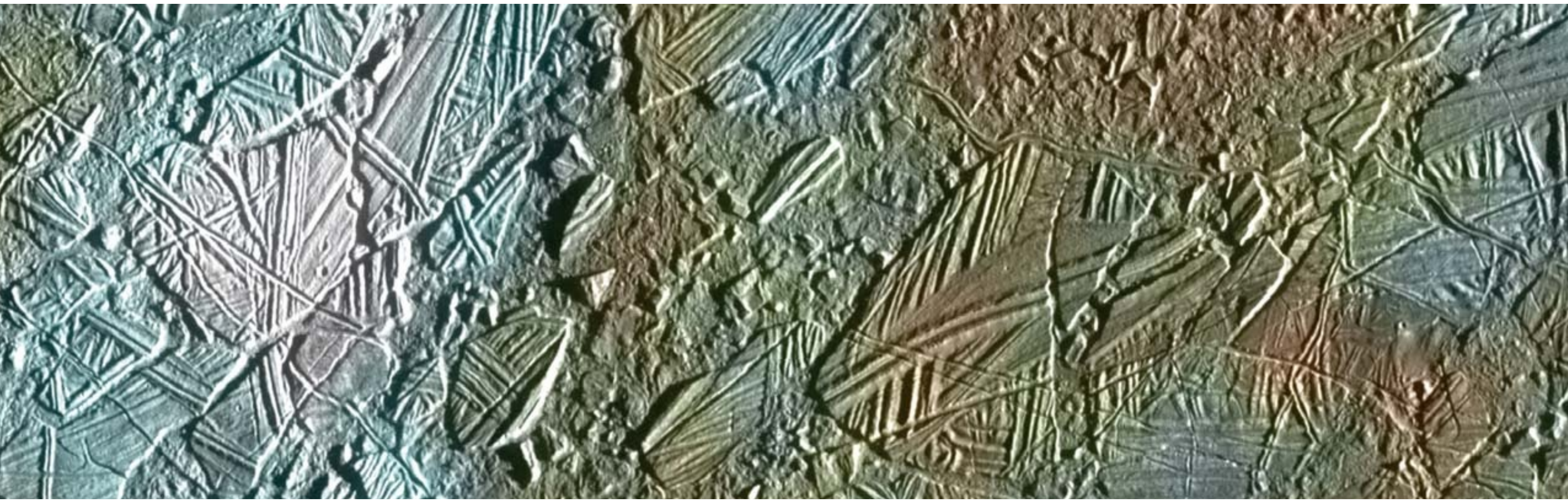
This is one reason why it's so important to use spectroscopy to measure chemical biosignatures in exoplanet atmospheres. But is there a chance to study in detail a truly separate strand of life much closer to home? There could be, deep within some of our most alien neighbors.

Dark, Fluid Realms

The icy moons of Jupiter and Saturn represent just the tip of the proverbial iceberg. Europa is the poster child. Its surface is frozen water at temperatures ranging from 50 to 110 Kelvin, with minimal cratering, suggesting an age of barely 50 million years. It's also crisscrossed by a tapestry of geographic features. Shallow ripples and cracks stretch for hundreds or even thousands of miles. Galileo images reveal plate-like zones and highly jumbled areas, and curious blushes of brownish reds and oranges. Galileo even detected an induced magnetic field around Europa, a clear signature of a conductive interior layer reacting to Jupiter's intense electromagnetic environment.

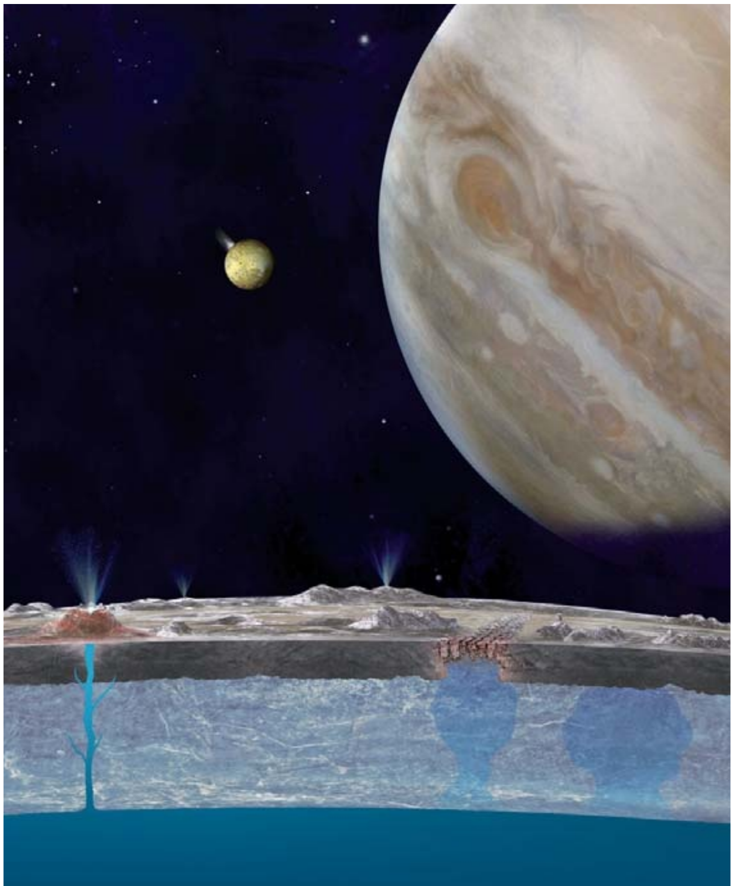
In late 2013, a team led by Lorenz Roth (Southwest Research Institute) announced it had pushed the Hubble Space Telescope's STIS instrument to its limits and discovered a remarkable plume of water vapor emanating from Europa's southern polar region. It's a very tricky observation, but there seems little doubt that when the moon is

THE GEYSERS OF ENCELADUS Artist Walter Myers portrays the powerful geysers erupting from the south polar region of Saturn's small moon Enceladus. The geysers contain water, salts, and hydrocarbons, strongly suggesting an ocean not far beneath the surface.



NASA / JPL / UNIVERSITY OF ARIZONA

CRACKED ICY CRUST NASA's Galileo orbiter returned this enhanced-color image of Europa's Conamara Chaos region. The broken cracks and ice blocks strongly suggest a constantly shifting crust akin to plate tectonics on Earth, indicating that the surface ice is overlying a water ocean. Spectra have revealed salts and organics on the surface, an encouraging sign for life.



NASA / JPL-CALTECH

BENEATH THE ICE This illustration depicts an ocean lurking not far below Europa's icy surface. Observations suggest that chloride salts from this ocean rise up through cracks and eventually make their way to the surface. Io and Jupiter are depicted in the background.

at the far point in its elliptical orbit (at apojove), it spews water into space. All evidence points to Europa having a global ocean of liquid water hidden below its icy crust.

And Europa is not alone. Its Jovian neighbor Ganymede also likely harbors deep liquid water, perhaps in multiple layers. At Saturn, geyser-spouting Enceladus — just 314 miles (504 km) across — may contain a subsurface sea at its southern polar region. Titan, with its thick atmosphere and seas of liquid hydrocarbons, is also a prime candidate for a deeper layer containing a vast water-dominated ocean. And transneptunian bodies such as Pluto and Eris likely host their own dark, fluid realms.

What causes and maintains these oceans? Europa has an iron center surrounded by a thick rock core, with its water layer on the outside. The heat of its initial formation has largely dissipated, but billions of years later the internal temperature is maintained by the radioactive decay of uranium, thorium, and potassium in the rock. In this way, Europa's warm core drives close to 200 gigawatts of power into the water's base — raising temperatures to around 250 Kelvin.

Like volcanically active Io, Europa also revolves around Jupiter in a mildly elliptical orbit — maintained by the pull of the other Galilean satellites. Changing gravitational-field gradients, or tides, work these moons like pieces of putty, and friction generates additional heat. For Europa, these forces may also generate internal, resonating Rossby waves that carry a thousand times the energy of frictional dissipation. Altogether, tides pump at least a trillion watts of additional power into this moon, raising internal temperatures to the levels needed for liquid water. In places such as the Pluto-Charon system, a history of tidal exchange and evolution could similarly promote the formation of an internal ocean.

Critically, a dose of ammonia and other compounds significantly increases the range of pressures and temperatures where dark oceans can occur. For example, add 30% ammonia by mass to a body of water and it'll freeze at around 175 Kelvin instead of 273 Kelvin (depending on the pressure), greatly reducing the energy budget needed to keep a subsurface ocean in its liquid state.

In 2013 astronomers Mike Brown (Caltech) and Kevin Hand (JPL) published Keck spectroscopic data of Europa with 40 times the resolution of Galileo's instruments. On Europa's trailing face (the side permanently downwind of the orbital motion), they discovered a coating of magnesium sulfate, along with sodium and potassium sulfates. The sulfur comes from Io's volcanoes, spewed into a torus of plasma surrounding Jupiter, and transferred to Europa. But the magnesium, sodium, and potassium once resided in a salty internal ocean — a briny mix that would taste (yes, literally) a lot like Earth's oceans. Enceladus's plumes include sodium salts and small amounts of methane, carbon dioxide, ammonia, and acetylene. And other icy bodies show surface evidence for impure water.

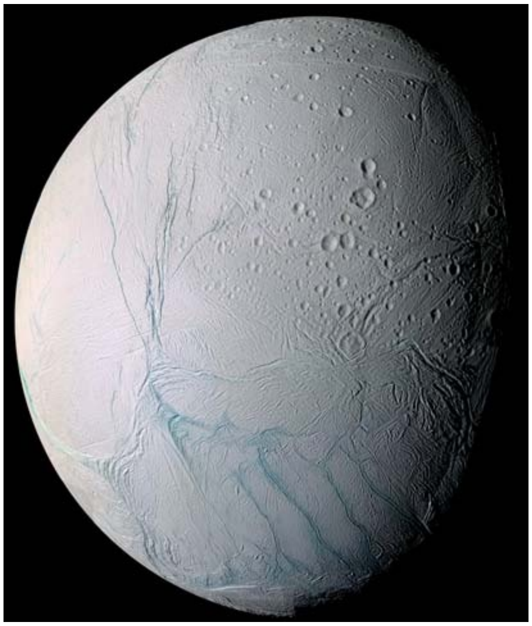
To better understand the configuration of dark oceans, researchers have built virtual planetary worlds that balance gravity, pressure, and internal heat to mimic conditions inside these icy bodies. Ganymede may be like a multilayered cake of different phases of ice and liquid. Titan may have a complex ocean that resides between a layer of water-dominated ice with its outermost hydrocarbon crust, and a deeper high-pressure water-ice zone. Recent Cassini data, including measurement of 10-meter tidal deformations and gravity variations, indicate that Titan's outer shell consists of icy material floating above a highly salty inner ocean. The ocean may decouple Titan's entire surface from the spin of its core — an extraordinary phenomenon seen in Cassini's Doppler ranging, where surface features have appeared to drift in their expected location over the years, not moving in synch with the moon's expected rotation.

The potential capacity of dark oceans in our solar system is astonishing. Adding up the estimates for known satellites yields a volume that could be *sixteen* times that of all Earth's oceans. And if we also consider transneptunian worlds, then radiogenic heating, tides from moons, plus insulating outer shells of frozen water, methane, and nitrogen, could create a total dark ocean volume more than that of all other liquid water in the solar system.

Splendid Isolation

Shortly after the Voyager 1 flyby in 1979, scientists realized that Europa's interior could harbor life. Not only is liquid water a critical agent in all known biochemistry, oceanographers had also begun finding complex ecosystems in the abyssal depths of Earth's oceans. Rich communities of chemosynthetic microbial life cluster around hydrothermal vents at mid-ocean ridges — living directly off the vents' mineral-rich spoils. These in turn support a startling number of tubeworms, shrimp, snails, crabs, and many other species. At ocean depths extending to more than 2.5 miles, where water pressure reaches hundreds of atmospheres, these organisms never see sunlight. They're entirely powered by the planet's geophysical and geochemical energy. A dark ocean in a distant world might offer an analogous habitat. If we find living organisms in Europa or Enceladus, then life in general could inhabit a vast swathe of the outer solar system.

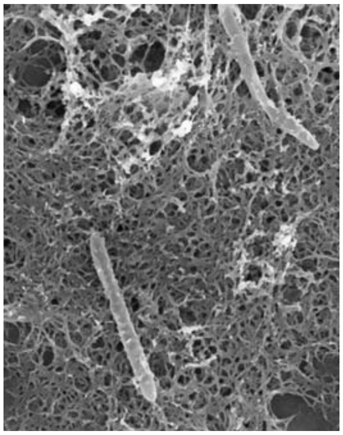
But would life in these places be truly independent and isolated? Careful simulation of the interplanetary dispersal of impact-ejected material suggests the answer is yes. Barely 1 in 10 million pieces of Earth or Mars material ends up impacting outer worlds such as Europa. The deep Jovian gravity well also means that any crumbs that make it to Europa will impact its surface faster than 44,000



BURSTING AT THE SEAMS ***Above:*** **This Cassini image shows geysers shooting water-ice particles dozens of miles into space from Enceladus's south polar region.**

ENIGMATIC ENCELADUS ***Left:*** **NASA's Cassini orbiter returned this portrait of Enceladus. Despite being only half as wide as Texas, the moon is at or near the top of the list of potential abodes for extraterrestrial life. The geysers have been imaged near the south pole, around the region of the "tiger stripes."**

NASA / JPL / SPACE SCIENCE INSTITUTE (2)



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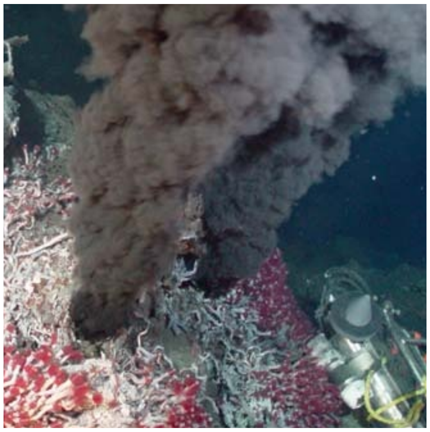
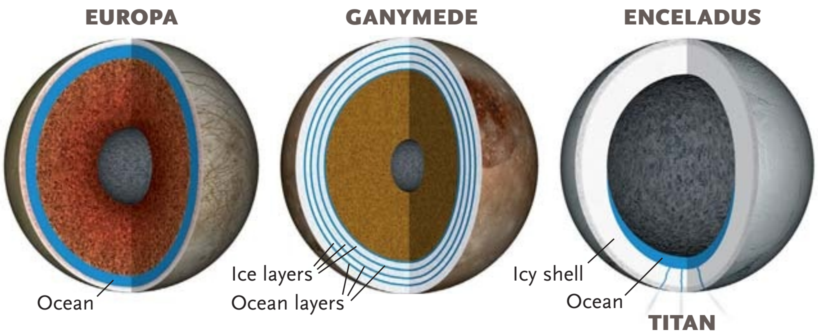
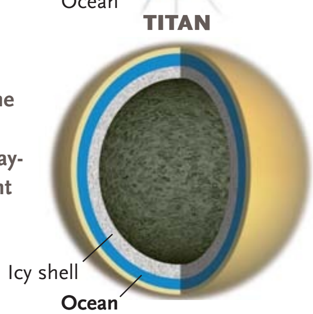


NOAA

DARK EARTH ECOSYSTEMS *Left*: Single-celled bacteria belonging to the species *Desulforudis audaxviator* survive more than a mile below Earth's surface in the complete absence of sunlight, oxygen, and organic compounds. The species has been around for millions of years by feeding on chemical food sources in the surrounding rock. *Right:* In the late 1970s, scientists discovered that the energy and minerals pouring out of hydrothermal vents on the ocean floor can sustain a wide variety of life forms despite a complete lack of sunlight. This image shows tubeworms surrounding a black smoker.





MOON INTERIORS These cutaway diagrams depict scientists' best current understanding of the interior structure of four moons of the outer solar system. All four exhibit strong evidence of liquid layers below their icy surfaces. Future missions might someday reveal whether these worlds harbor life.

S&T: GREGG DINDERMAN

Moon sizes not to scale.

Putative Oceans Compared

Object	Mean Ocean Thickness (km)	Crust Thickness Above Ocean (km)	Ocean Volume (billions of cubic km)
Earth	4	—	1.3
Europa	90	70	2.3
Ganymede	800 total	Multilayer	> 1.0
Enceladus	10	40	0.000012
Titan	230	200	14.5
Triton	160	170	2.4
Pluto	150	210	1.5
Eris	200	180	2.6

miles per hour (20 km/second) — more than enough to vaporize a rock and its contents into constituent atoms — an exceedingly efficient sterilization process.

On Europa's trailing orbital face, high-energy electrons also dump well over 100 rad of radiation per second — enough to give an exposed human a lethal dose in about 10 seconds. Even the hardiest, most radiation-resistant organisms on Earth will have their DNA denatured and broken up by this onslaught.

That radiation is bad news for human explorers, but good news for the deep ocean's biological isolation and chemistry. An ocean without oxygen might be a tough place for anything but the simplest and most slow-living organisms. But this same intense radiation at Europa's surface should generate a plethora of oxidants, including hydrogen peroxide and other compounds. Mixing these into the liquid interior can help drive the chemistry of a more complex biosphere.

Recently we've discovered more examples of terrestrial life forms that exhibit extraordinary survival skills suited to lonely conditions devoid of resources. For example, in 2008 scientists found a species of bacteria — *Desulforudis audaxviator* (or bold traveler, after a quote in Jules Verne's *Journey to the Center of the Earth*) — eking out an existence in water pockets that have been isolated for millions of years some 1.7 miles down in the rock of a South African gold mine. This single-celled organism not only exists in splendid isolation, it effectively lives off radioactive decay and rocks. When particle radiation from uranium and thorium in the surrounding environment splits water molecules, it produces free hydrogen for the bacterium to breathe, and sulfate compounds for consumption.

This remarkable biochemical trick doesn't prove that *D. audaxviator* started out in these water pockets, since its genetic makeup still comes from the same ancestral stock as the rest of Earth life. But some scientists have proposed that terrestrial life originated around hydrothermal vents or other parts of a deep biosphere — an option that would bode well for life starting up in dark oceans elsewhere.

Accessing the Oceans

Studying icy worlds and their watery depths in-situ is an exceedingly tricky business though. In 2022 ESA hopes to launch its JUpiter ICy moons Explorer (JUICE), targeting Ganymede, Europa, and Callisto — particularly Ganymede, the only moon with its own magnetic field. NASA's Europa Clipper is still at a concept stage for a 2025 launch; it would make at least 32 low-pass flybys of Europa, mapping it and applying an ice-penetrating radar, as well as trying to fly through and sample the southern water plume. Both missions are multi-billion-dollar affairs that will have to contend with hardware-damaging particle radiation and Jupiter's deep gravity well.

But aside from perhaps testing the contents of geysers, these missions won't venture into a dark ocean itself.

A Subsurface Antarctic Lake Teeming with Life

Like the icy worlds of the outer solar system, Antarctica also has isolated subsurface bodies of liquid water completely cut off from sunlight. Since these lakes were first identified in the 1990s, scientists wondered if they harbored life. As reported in the August 21st *Nature*, the answer is a resounding *yes*.

After careful preparations to avoid contamination, an international, multidisciplinary team including Brent Christner (Louisiana State University) and John Priscu (Montana State University) used a hot-water drill to bore down into Lake Whillans, a small body of water about 800 meters (0.5 mile) below the surface. The team brought up 30 liters (8 gallons) of water. Early analysis reveals 130,000 living cells per milliliter of lake water, a density roughly equivalent to that of deep oceans. Amazingly, the team has identified at least 3,931 distinct species of bacteria and archaea, meaning this cold, dark, nutrient-starved body supports a teeming ecosystem of life forms. Many of the species are related to previously known marine microbes that derive energy by breaking down minerals in rocks and sediment.

"The subglacial lake we studied is very different than the sub-ice oceans that presumably exist on the ice moons," says Christner. "But studies like ours have expanded the known boundaries of life on Earth, which are the conditions used to extrapolate the likelihood of life surviving elsewhere." — *Robert Naeye*

NASA EARTH OBSERVATORY

For that we'll have to wait for ideas that are barely off the drawing board: mole-like burrowing thermal drills and 'inchworm' robots to penetrate rock-like crusts of water — perhaps lobbed into the same cracks that are venting water into space. These concepts are being tested in relatively benign polar ice here on Earth, as engineers learn what it takes to operate in such extreme conditions.

This same technology could also be applied to descend into transneptunian worlds such as Pluto or Eris. Despite their distance (and even lower surface temperatures), without the intense radiation environment around Jupiter to damage hardware, these worlds might be equally attractive biologically isolated targets. Much like Europa, surface features and compositions can provide clues to the interiors. When NASA's New Horizons buzzes Pluto in July 2015, we'll perhaps learn more about its putative interior ocean.

The challenge to exploring such places is paralleled by the conceptual hurdle of acknowledging that stellar radiation may not be the only way to power living environments across the universe. Radiogenic heating and latent heat of formation represent key components of this energy budget, but tidal dissipation may be a critical factor in the long term. And that's where things get interesting, because tides are common, and are linked to the fundamental structures of planetary systems.

The tidal power warming Europa's interior is ultimately being drained from Jupiter's angular momentum, a flywheel carrying about 10^{33} joules. That's about the same as the total energy of photons emitted by the Sun in 100 days, or by a low-mass *M*-dwarf star in a couple of centuries. But Europa's drain is unlikely to ever exceed 10^{13} joules per second (ten trillion watts worth of power), so in principle Jupiter's angular momentum could power a dark ocean for at least a trillion years — far outlasting the Sun's main-sequence lifetime. This is contingent on other factors, such as maintaining the mean-motion orbital resonance between the Galilean moons, and whether or not any icy moon survives the aging Sun's inflated luminosity 5 billion years hence.

But if dark oceans exist in our solar system, they must exist across the cosmos. The enormous diversity of planetary-system architectures can give rise to all manner of situations where icy bodies are tidally flexed and warmed. If life can get started in Europa or Enceladus, it can surely get started in similar environments. Our galaxy could be full of isolated ecosystems inside icy moons and planets, many of which are kept liquid by radioactive isotopes, and tidal friction driven by nothing more than orbits and spins — truly the children of celestial mechanics. ✦

Caleb Scharf *is an astrophysicist and the Director of Astrobiology at Columbia University in New York. His latest book is* The Copernicus Complex: Our Cosmic Significance in a Universe of Planets and Probabilities. *He also authored* Extrasolar Planets and Astrobiology *and* Gravity's Engines.

Reviving Astronomy in a Small NATION

OSIRIS CASTILLO

After a tumultuous period when interest in astronomy virtually disappeared, the flame of astronomy has reignited in Nicaragua.

JULIO VANNINI When people think about astronomy in Latin America, images of dark Chilean skies often come to mind. The wonderful sight of the Milky Way's central bulge hovering overhead makes us dream about the treasures hidden among the countless stars. It's easy to forget that other Latin American nations have their own astronomy attractions and communities.

Such is the case of Nicaragua, one of the largest nations in Central America. And yet Nicaragua is tiny when compared to many other nations in the Americas. In fact, Nicaragua could fit comfortably *twice* inside the base of Mars's giant volcano Olympus Mons. With a history of civil turmoil and political unrest, it's easy to doubt

MAP: S&T: PATRICIA GILLIS-COPPOLA

that such a country could ever develop a serious interest in astronomy.

Please allow me to introduce you to the story of astronomy in my homeland, Nicaragua.

A Brief Historical Review

Before Christopher Columbus "discovered" Nicaragua in 1502 during his fourth voyage to America, indigenous tribes inhabited the region. In 1523 the Spanish traveler Francisco Hernández de Córdoba ventured down the San Juan River and sailed the calm waters of Lago Cocibolca, now known as Lake Nicaragua. After disembarking, the expedition's horses tasted the water and started to drink it. That earned the lake the title "sea of sweet water." It was there that de Córdoba founded the first Spanish settlement in the country: Granada, the town where I live.

In the following decades, warfare between the indigenous people and Spanish invaders left only a few settlements. The once thriving population of some 300,000 was reduced to only 30,000 survivors.

Nicaragua was a Spanish colony for nearly three centuries until her independence on September 15, 1821, the result of a joint effort with El Salvador, Honduras, Guatemala, Costa Rica, and Mexico. An attempt was made to integrate Nicaragua into the new Mexican Empire, and later it was a member of the Federal Republic of Central America. But that federation broke apart in 1838, with complete independence for its constituent states.

With their colonialist mindset, Nicaragua's authorities never considered it important to invest in education until the first half of the 20th century, when an increasing demand from the urban population began to be heard. Astronomy was included in the curriculum for middle- and high-school education. This worked reasonably well until a Minister of Education in the 1960s removed astronomy as a teaching subject because it was deemed unimportant for the nation's agricultural development. And with that, astronomy disappeared from schools for many decades.

The First Amateur Society

Inspired by the wonders of the sky, a group of scholars with knowledge of mathematics and physics created the Asociación Astronómica de Aficionados de Nicaragua (Amateur Astronomical Association of Nicaragua) on March 20, 1957. Armando Hernández (an engineer) served as president and Jaime Incer Barquero (an enthusiastic young man with a degree in pharmacy) served as secretary. With funding from the members themselves, the Asociación acquired a 6-inch Zeiss refractor and other equipment that served as the main tools for public outreach.

In late 1957 the society published *Cosmos*, a magazine that described the latest discoveries and provided general information about astronomy. Incer Barquero also wrote numerous articles about astronomy for local newspapers.

A few years later, the group teamed up with the elementary school Ramírez Goyena in the capital city Managua, where members installed the Zeiss refractor. The school became the nerve center for astronomical activities, and members gathered monthly to share knowledge and learn more about the skies.

In November 1958, Incer Barquero traveled to Chile to represent Nicaragua in the first major international astronomical meeting in Latin America. A year later, in October 1959, the Liga Iberoamericana de Astronomía (Latin American Astronomy League, or LIADA) was founded and Nicaragua officially joined the international fellowship of astronomers.

All Good Things...

Nicaragua in the 1960s and early 70s was the wealthiest nation in Central America, earning the reputation of being the "farm of Central America." With productive soils and a growing economy, the future looked promis-

JAIME INCER BARQUERO

Members of Nicaragua's original astronomy club, the Asociación Astronómica de Aficionados de Nicaragua, pose for this 1960 photo. Secretary Jaime Incer Barquero is in the center of the first row (wearing glasses).

S&T: ROBERT NAEYE

Author Julio Vannini, Jaime Incer Barquero, and *S&T* editor Robert Naeye stand inside the dome of the new Observatorio Neil Armstrong, located at the Pierre & Marie Curie School in Managua.

ing, especially for the growing astronomy community. The Asociación Astronómica had 100 members at its height, the large majority hailing from Managua due to the poor quality of roads at that time.

But then tragedy struck. On December 23, 1972, a powerful earthquake devastated Managua, destroying hundreds of flourishing businesses and killing and injuring thousands of people. International aid quickly rushed in, but the recovery was slow. Many astronomical society members left the country to look for a fresh start, and the group disbanded.

Then the political situation heated up. Many Nicaraguans felt discontent with decades of corrupt Somoza family members ruling as president, leading to a mass movement against the dynasty. A civil war ignited, costing the lives of some 50,000 people.

The conflict ended with the triumph of the Sandinistas over president Anastasio Somoza, forcing him to flee the country by airplane in July 1979. Most Nicaraguans thought this change would benefit the nation, and that the dream of freedom was coming true. It didn't take long for many to realize that the dream was exactly that — an illusion. A decade-long left-wing dictatorship was established. This sparked the Sandinista-Contra conflict, causing more death, economic recession, and a massive migration of families to other countries, mostly the U.S. and Costa Rica.

The vast majority of schools were transformed into political training facilities, and all chances of getting news of scientific advances from noncommunist nations were practically zero. Education was no longer a tool for seeding the mind with science, and the astronomy movement in Nicaragua came to an end.

A New Beginning

On February 25, 1990, after 10 years of Sandinista government and increasing international pressure, a new democratic government was established. Nicaraguans finally began to breathe the air of freedom, and things started to look promising for the revival of astronomy.

One of the last remaining original amateurs, Incer Barquero (who had become an authority in the fields of ecology, geography, natural science, and astronomy), began posting announcements of public astronomy lectures at the Pierre & Marie Curie Elementary School in Managua in 2001. Incer Barquero met Ricardo Amador, a young business management student with a serious interest in amateur astronomy, and together they embarked on the difficult task of reigniting interest in the general public. A couple of years later, they had a committed group of another 10 amateurs. One of them, Marlon Zambrana, was interviewed for the January 2004 *S&T* (page 80).

A new amateur society was founded in 2003 under the name of Asociación Nicaragüense de Astrónomos Aficionados (Nicaraguan Amateur Astronomers Association, or ANASA) (**www.facebook.com/anasa.carlsagan**). This group supported Incer Barquero's efforts and provided new energy, fresh ideas, and a commitment to revive the flame of astronomy. They contacted LIADA, who reinstated Nicaragua as an official member in 2007.

ANASA members organized many outreach projects, such as sidewalk astronomy and visits to schools and public venues. The group distributed materials, including a handbook for amateur astronomers and an astronomical calendar — both introduced during the 2009 International Year of Astronomy celebration. Members also wrote many articles for local newspapers.

Brothers in Arms

In 2007, during a regional physics conference held at the Universidad Nacional Autónoma de Nicaragua (UNAN)

Stargazers gather at the Observatorio Neil Armstrong. The observatory is open to the public every Friday night.

JULIO VANNINI

JULIO VANNINI

Residents of the town of Catarina gather to look at the Sun during Global Astronomy Month activities on April 1, 2012. Once rare, public stargazing activities are becoming increasingly common.

campus in Managua, the first official professional observatory was inaugurated. The observatory had humble origins, with a Celestron C8 telescope, an old SBIG CCD camera, and filters inside a medium-sized dome on the roof of a campus building. A creative group of investigators has put this modest equipment to good use, focusing on research topics such as stellar evolution, variable stars, and open cluster photometry. The staff also uses the facilities for public outreach and teaching.

With an ever-increasing interest in astronomy, existing groups are growing, covering all aspects of astronomy from amateur to professional. ANASA has teamed up with Astronomers Without Borders (AWB), a nonprofit group focused on mutual cooperation and exchange of knowledge and tools around the globe. ANASA membership is increasing, with more than 80 current people. From this group, a task force of 15 is performing public-outreach activities in other towns and cities. Some are even developing their own personal observatories, engaging in astrophotography, or making visual variable-star measurements. I personally had the opportunity to spread the word about ANASA at meetings held in Brazil, Costa Rica, and the U.S.

Other amateur groups have arisen. One of them, ASTRONIC, has an active role on several television stations and is running public observing sessions in Managua. Another new group in Managua, Astronomía Zona 2, is devoted to astrophotography. The group Viva León Observatory is conducting public and school activities in the city of León.

In 2012, during the celebration of AWB's Global Astronomy Month, I proposed that the Pierre & Marie Curie School participate in the International Asteroid Search Collaboration, which resulted in the first asteroid discovered by Nicaraguan students (*S&T:* June 2014, p. 26). This caused a science sensation in the school so intense that ideas of building a small observatory blossomed into a much more ambitious project.

We inaugurated the Observatorio Neil Armstrong (**www.facebook.com/ObservatorioNA**) on February 22, 2013. This facility, with its 10-inch Dobsonian, is open to the public every Friday night. Arrangements are being

Like other large cities, Managua suffers from significant light pollution, as demonstrated clearly in this photo taken in August 2014. Local amateur astronomers have started a public-awareness campaign that is just starting to bear fruit.

JULIO VANNINI

Numerous dignitaries, including Nicaragua's Vice President and the U.S. ambassador, attended the February 22, 2013 inauguration ceremony for the Observatorio Neil Armstrong.

JULIO VANNINI

made with other schools and the government to expand services. Workshops range from basic astronomy to more elaborate topics such as visual photometry and reporting. The observatory at UNAN-Managua has plans to upgrade its equipment and increase its efforts in many areas.

A Bright Future

The public is becoming increasingly aware of light pollution and many hotels are considering the added value of astro-tourism. The government branch dedicated to science and technology is showing an increased interest in astronomy as a cornerstone for improving education and is calling for meetings and public activities with participation of the amateur communities.

Nicaragua remains a small participant among the giants of astronomy. But we now have well-defined groups working together in spreading the word about amateur and professional astronomy. With dedication, patience, and sacrifice in the years to come, the growing amateur community will inspire an ever-increasing interest in the hearts and minds of young people for a better education. We're working hard to prepare the foundations for new generations to come, because we must invest in education, science, and technology. Any nation with no interest in these fields is doomed to fall further behind in its ability to provide a high quality of life for its citizens. ✦

Julio Vannini *(jvannini@gmail.com) serves as ANASA's president and as representative for the Nicaraguan amateur community in LIADA and Astronomers Without Borders. Visit his blog at* **http://ungaman.wordpress.com** *or follow him on Twitter @UngaMan.*

Managua's Mysterious Crater

At 23:04 local time on September 7th, residents of Managua heard a loud boom near the international airport and local air force base. The noise was quickly followed by ground shaking and the smell of burnt powder and tires. Within hours, Nicaraguan government officials reported a 12-meter-wide crater, which they attributed to a meteor impact.

This story quickly devolved into a worldwide media circus. Even supposedly reputable astronomy publications and websites bought the impact scenario hook, line, and sinker — without any skepticism of the official story. Some sources even speculated that the impactor was a fragment of asteroid 2014$_{RC}$, which flew by Earth at about the same time.

On September 9th, Julio Vannini reported in an e-mail: "No one saw a fireball. It was inside a military base with not a single surveillance video capturing the event, nor was anything seen from the airport. The government has been reluctant to search for meteorites, arguing that they have requested help from U.S. scientists for digging, search, and analysis."

The crater's origin was still a mystery at the time this issue went to press. It might have been formed by an accidental explosion on the air force base, which the Nicaraguan government is trying to cover up. Vannini concludes, "This is the time for opening the doors to a fair investigation. It's a good moment to educate our people about science."

— ***Robert Naeye***

Astronomy Above the Clouds

TOM GALE

The clement cloak of gas that enshrouds Earth is truly a wonder. The composition of our planet's unique atmosphere arises in part from a harmony of respiration and photosynthesis, performed by the organisms it shields from the deadly radiation and cold of space. Yet we skywatchers could be forgiven for harboring mixed feelings about this atmosphere. For the layers of gas above our heads distort the path of incoming light from space.

That's because the atmosphere is far from uniform. For example, adjacent air pockets can exhibit markedly different densities and turbulent motions. The overall consequence is that incoming light rays get refracted along a multitude of ever-changing pathways, as residual heat drives convection that ceaselessly churns up the nocturnal atmosphere.

Worse still, highly magnified images only serve to exaggerate the effects of atmospheric turbulence. Even on nights of relatively good seeing, we are usually plagued by the irksome shimmering of lunar craters and "boiling" star disks that jump around the telescopic field of view. Looking for delicate features in Jupiter's cloud belts can be somewhat akin to trying to glimpse the scales of a fish beneath a pond surface disturbed by a breeze.

In the last couple of decades, professional astronomers have tackled this problem with adaptive optics (AO), which quickly bend mirrors' surfaces to compensate for the chaotically changing, churning atmosphere above. But even with AO systems, observatory planners must still pursue the tried-and-tested solution: get above as much of the atmosphere as possible.

Early Risers

In his book *Opticks,* Isaac Newton insightfully penned that "the only remedy is a most serene and quiet air, such as may perhaps be found on the tops of the highest mountains above the grosser clouds." The higher the viewpoint, the better the seeing conditions generally become, a trend conclusively demonstrated during Charles Piazzi Smyth's expedition to Tenerife in 1856. There, the eccentric Astronomer Royal for Scotland, using a team of hardy donkeys, lugged a 7-inch telescope and other instruments to 10,700 feet (3,260 meters). Delighted by the sharp views he obtained and soon excited at the prospect of having a permanent mountain observatory built, Smyth recorded his observations in diligent detail in order to petition skeptical funding bodies back home.

Before Victorian times, there was no street lighting bleaching out the night sky, and so few thought to place the earliest astronomy centers anywhere but within easy reach of towns and universities. But by the late 19th century, light and soot spewed out by rapidly expanding industry soon drove more skywatchers to the mountains. When American

Seen from an airplane, La Silla Observatory in Chile looks forlorn against its cordilleran backdrop. At an elevation of approximately 7,800 feet, the site is one of many that astronomers have built in order to reach higher into the sky.

ESO

Into Thin Air

Astronomers' continual quest for optimal seeing conditions has ensured that leading observatories get built on ever-higher mountaintops.

PHOTO © UC REGENTS / LICK OBSERVATORY (2)

AN AMERICAN ICON Perched on Mount Hamilton, Lick Observatory was the world's first permanently occupied mountaintop observatory. Shown prominently here are the domes of the 36-inch refractor and 36-inch Crossley reflector, both installed in the late 1800s. *Inset*: The dome of the 120-inch Shane reflector, under construction in June 1951.

astronomers established the 36-inch refractor at Lick Observatory on California's Mount Hamilton (4,200 ft) in 1888, the site became the world's first permanently occupied mountaintop observatory.

Ever conscious of the advantages offered by high elevations, the solar astronomer and observatory pioneer George Ellery Hale was tempted by greater heights. He site-tested the lofty summit of Pikes Peak (14,115 ft) in Colorado as early as 1893 but, on practical grounds, eventually opted for Mount Wilson's modest elevation of 5,700 ft for the observatory he founded in 1904. Later to play host to the legendary 100-inch Hooker Telescope, Mount Wilson was key to developments in 20th-century astronomy, not least when Edwin Hubble used the 100-inch to discover that the Andromeda Galaxy was millions of light-years away, confirming it was an "island universe" separate from our Milky Way Galaxy.

THE OBSERVATORIES OF THE CARNEGIE INSTITUTION FOR SCIENCE COLLECTION AT THE HUNTINGTON LIBRARY, SAN MARINO, CA

HARROWING HAUL During transport up Mount Wilson, the tube for the 100-inch Hooker scope nearly fell off the road. Such scrapes are among the challenges of building at high elevation.

Rocky Retreat

Following the establishment of the iconic 200-inch Hale reflector on Palomar Mountain in 1948, clusters of domes rapidly sprung up atop other American summits. The 1950s saw the founding of the National Observatory at Kitt Peak (6,880 ft) in Arizona, while the much higher lava fields of Mauna Kea (13,750 ft) attracted their first big telescopes a decade later.

Each site marked an extra step away from encroaching light pollution and upward into the stable, moisture-depleted reaches of the upper atmosphere, a vital consideration for the increasingly important study of infrared wavelengths (see page 38).

Today, the Hawaii-based telescopes, including the leviathan twins of the Keck Observatory and the submillimeter-studying James Clerk Maxwell Telescope, are often crowned as the highest observatories on U.S. soil. But for that superlative we must instead turn to the Rocky Mountains. For in Colorado lies what was for several decades the highest optical telescope in the world: the Meyer-Womble Observatory. Named for both its designer and financier, the facility's modest windswept dome houses an impressive binocular telescope with two 28.5-inch aperture components. Coordinated by Robert Stencel (University of Denver), Meyer-Womble sits just below the summit of Mount Evans which, topping out at a breathtaking 14,260 ft, is one of the Rockies' highest peaks.

Long before optical telescopes arrived, a sinuous 14-mile access road to the summit attracted particle physicists keen to set up detectors at such an unprecedented elevation. Nobel laureate Arthur Compton's extensive cosmic-ray readings from the summit in the early 1930s confirmed that the detected number of cosmic rays increases with elevation. His data also helped reveal that the intensity correlated with geomagnetic latitude.

It wasn't long before Mount Evans set the scene for another landmark experiment. In 1939 the Italian emigrant physicist Bruno Rossi recorded the flux of muons, one of several subatomic byproducts generated when a cosmic ray collides with an atomic nucleus at the top of the atmosphere. Early measurements of these unusual particles showed them to be arriving at relativistic speeds. Since lab experiments had showed that muons at rest decay rapidly, the surprising abundance of muons that Rossi recorded at ground level proved that the particles' lifetime had somehow become prolonged. As he soon realized, this observation was a consequence and elegant demonstration of time dilation, a tenet of Einstein's special theory of relativity.

More recently, data from Meyer-Womble proved key to revealing the dusty, particulate nature of the mysterious eclipsing object in the enigmatic binary system Epsilon Aurigae (*S&T*: Mar. 2012, p. 18). Stencel harbors doubts about the future of small-scale, mid-latitude stations such as Mount Evans in a century gearing up for 100-foot apertures. But the site's rich scientific history, together with upgrading and reinforcement following storm damage in 2011, will help ensure that Meyer-Womble provides professional-grade astronomical data for years to come.

Asian Hideaways

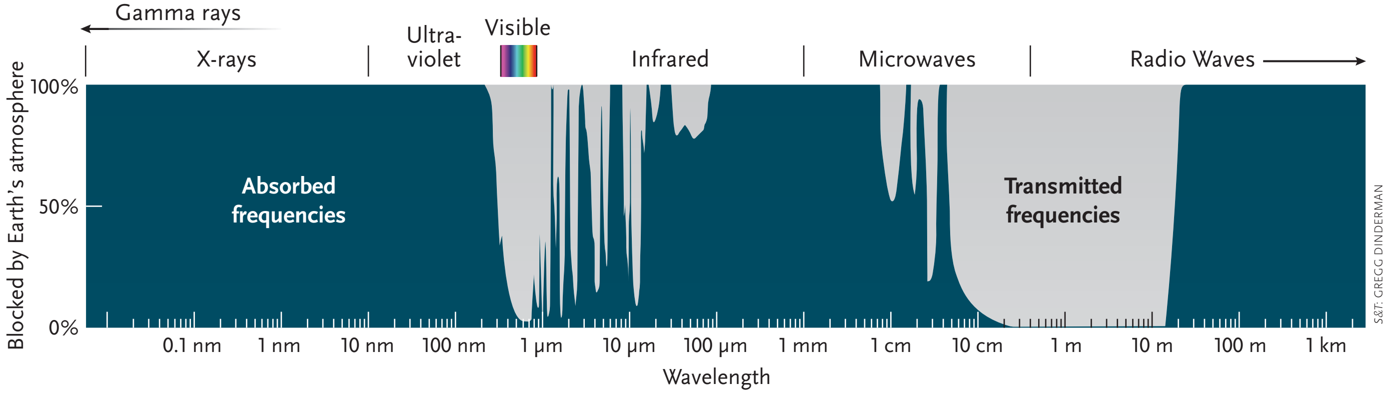
Although most cosmic rays arriving at Earth stem from the Sun, a handful have made a far longer journey. Astronomers studying these galactic and intergalactic cosmic rays often seek out observing locations farthest from the tightly clustered field lines at Earth's magnetic poles. Installations include the Pierre Auger Observatory in Argentina (4,500 ft) and the Major Atmospheric Gamma-ray Imaging Cherenkov (MAGIC) Telescopes on the Canary Island of La Palma (7,200 ft). Southeast Asia is arguably the region best placed for cosmic-ray astronomy, because it lies on Earth's magnetic equator. Here, terrestrial field lines sweep aside more incoming low-energy solar particles (up to 17 gigaelectron volts, or GeV) than anywhere else. This means that relatively few solar particles make it through to the atmosphere, enabling more of those from deep space to reveal themselves to detectors atop Doi Inthanon, Thailand's highest peak (8,400 ft).

"We don't detect the rays themselves," explains Alejandro Sáiz Rivera (Mahidol University, Thailand). "But the air shower of secondary particles includes neutrons. These don't make it down to sea level, but up at Doi Inthanon we pick up the signals of around 2 million neutrons every hour." Doi Inthanon is home to the group's Princess Sirindhorn station, near Chiang Mai. Despite the particles' cosmic sources, the neutron readings allow the team to indirectly detect solar storms: when the Sun releases a powerful flare toward Earth, the magnetic field carried by the flare deflects cosmic rays that would otherwise strike the planet. Sudden drops in the neutron count thus indicate disturbances in Earth's magnetosphere. Such signals picked up at Doi Inthanon, with its unusually high geomagnetic cutoff energy, complement those of the 11 neutron stations set up at polar latitudes to monitor space weather in an ongoing international venture named Spaceship Earth.

Elsewhere in Asia, the Indian Institute of Astrophysics sought to make the most of the even higher terrain in its own backyard — the Himalaya Mountains. Although much of the Indian subcontinent experiences a prolonged monsoon, the carefully chosen site on Mount Saraswati (14,760 ft) in the Hanle Valley of Ladakh lies in a rain shadow cast by the highest Himalayan peaks.

PIERRE-SIMON MANGEARD (2)

CATCHING NEUTRONS **The Princess Sirindhorn station in Thailand uses 18 tubes encased in polyethylene to detect neutrons created by cosmic rays hitting Earth's atmosphere. Inside lie tubes filled with a gas enriched in boron-10 and surrounded by lead. The lead emits subatomic particles (mostly neutrons) when atmospheric neutrons hit it, amplifying the signal. Deep inside, the boron isotope fissions when it captures a neutron, creating the detected signal. The 18-tube monitor weighs 36 tons, about 30 of which is the lead.**



PEEKING THROUGH THE GAPS Earth's atmosphere blocks many parts of the electromagnetic spectrum, allowing only certain wavelengths through (gray). Water absorbs many of the infrared wavelengths. The result is the transmission spectrum above. The spectrum and the transitions between wavelength ranges are approximate; there isn't a clear division between X-rays and gamma rays.

What's more, K2 and the other peaks of Pakistan's mighty Karakoram range dry out any rogue westerlies heading Hanle's way, which further reduces the humidity.

"We get just a few centimeters of rain per year and less than 20 cm of snow," explains Tushar Prabhu (Indian Institute of Astrophysics). The resulting dry, settled air at this elevation is a magical recipe for observational astronomy, routinely offering 0.8-arcsecond seeing conditions. Today, Hanle boasts the 2-meter Himalayan Chandra Telescope, which scours the ultra-dark sky at optical (about 0.4 to 0.8 microns) and near-infrared (0.9 to 2.5 microns) wavelengths, conducting studies that range from cloud movements in Venus's atmosphere to the behavior of cataclysmic variable stars, stellar evolution in open clusters, and the monitoring of supernova remnants.

High and Dry

The extreme elevation and arid climate of the Andes ensured that the world's longest mountain range was among the first to draw the attention of scientists seeking out the planet's optimal observing sites. Indeed, the first station at Chacaltaya was founded in the early 1940s, despite sitting at 17,160 ft. The station has long been remarkably accessible, requiring only a short approach road from the nearby Bolivian capital of La Paz. The highest observatory in the world for six decades, the Chacaltaya Astrophysical Observatory is a center for cosmic-ray research and now houses several experiments, including the Investigation on Cosmic Anomalies (INCA), which detects the secondary particles that gamma rays create when they strike Earth's atmosphere. Because the detec-

BARREN LAND The 2-meter Himalayan Chandra Telescope sits on the arid Mount Saraswati in India. The scope saw first light in 2000 and is one of the highest elevation observatories in the world.

RAKESH RAO / ASTROPROJECT

tor is at such a high elevation, it typically picks up a particle count 30 times higher than an experiment placed at half the elevation would for secondary particles generated by 16-GeV photons.

Other nearby parts of South America are almost perfect for optical and infrared astronomy, thanks to the icy Humboldt Current that flows northward along the continent's Pacific shoreline. Here, atmospheric moisture condenses out into fog banks that perpetually enshroud the coast. As a result, the region inland is one of the driest in the world — the Atacama Desert. There are towns near the Chilean coastal city of Arica where it rains less than once every decade, and a handful of villages where lifelong locals cannot remember ever having reached for an umbrella. The Atacama soil is so bone-dry that even highly water-soluble saltpeter can be dug from the ground as huge crystals — a valuable export commodity.

In fact, the infrastructure set up for mining has in part made the arid Atacama more accessible, enabling full exploitation of its dark-sky sites by establishing astronomical observatories in otherwise difficult and remote locations. The domes of Cerro Tololo, La Silla, and Cerro Paranal (all at 7200–8,700 ft), the last one home to the Very Large Telescope, are renowned for their world-class seeing conditions and ultra-transparent skies.

Now astronomers are setting up observatories higher than ever before in the Atacama.

Despite the health risks of working at Polarbear (17,030 ft; *S&T*: Oct. 2013, p. 22), ACT (also 17,030 ft), and the jungle of ALMA's 66 dishes (16,700 ft) on the Chajnantor Plateau, Tokyo University is reaching even higher. Planners boldly chose Cerro Chajnantor, a summit at a breathtaking 18,500 ft overlooking ALMA, for the University of Tokyo Atacama Observatory (TAO). At this elevation, atmospheric pressure is a mere 14.6 inches of mercury (495 millibars), less than half that at sea level. TAO will legitimately boast being the first operational telescope sited above half the mass of Earth's atmosphere.

The Tokyo project is spearheaded by a 1-meter optical/near-infrared instrument dubbed "mini-TAO." As a consequence of the extreme elevation, workers visiting Cerro Chajnantor must remain vigilant for symptoms of altitude sickness and not linger (see sidebar at right). These risks are now greatly minimized thanks to the recently established capacity to remotely operate the observatory.

Following its first light in March 2009, mini-TAO soon picked up a key emission line in the spectrum of interstellar hydrogen gas at 1.875 microns, a near-infrared band known as Paschen alpha (Pα). This detection, unprecedented by a ground-based instrument, would be impossible even from an Alpine summit due to blockage by the troublesome water vapor in Earth's atmosphere. Unlike visible light, Pα is hardly absorbed by interstellar dust, allowing astronomers to peek inside obscured parts of the Milky Way's most distant spiral arms. TAO research-

Elevation: The Silent Killer

Go hiking in the Rockies or shuffle between its ski lifts and you'll soon have to stop and catch your breath. Air pressure drops quickly as you ascend into the atmosphere (initially by 1 inch of mercury per 1,100 feet gained), so that each breath you draw harvests fewer oxygen molecules for your lungs. You might not feel the reduction in pressure but, as you climb, packets of plastic-wrapped food expand to bursting and bottles hiss when opened as they exhale compacted air.

Rise beyond 10,000 ft and your breathing becomes markedly faster. Your bloodstream's oxygen level drops and your rest pulse races as high as 100 beats per minute in an effort to compensate. You'll likely experience fatigue, headache, reduced appetite, or perhaps difficulty sleeping at night due to irregular breathing. These are all mild symptoms of altitude sickness and pass within a day or two if you rest and cease further ascent. Keep rising and ignore your body's warning signs, and life-threatening complications, including pulmonary or cerebral edema — the causes of countless mountaineering disasters — become very real threats.

In the construction and maintenance of mountain observatory sites, basing a core workforce at high elevation becomes unavoidable. "We have about 10 persons looking after the facilities," says Tushar Prabhu, referring to the Indian Astronomical Observatory (14,760 ft). Four engineers, stationed at the lower elevation of Leh (11,100 ft), visit the site to maintain the photovoltaic power supply, the telescope and its instruments, and the liquid nitrogen plant, as well as look after the computer network — "but only for 2 to 3 weeks at a stretch," he reassuringly explains. During observing sessions, however, many high-elevation observatories are now remotely operated from the comfort of lowland control rooms. The Indian Astronomical Observatory's satellite link with its headquarters down on the steamy plains of Bangalore means that only a minimal core of hardy, multi-tasking maintenance staff need endure the site's thin air and bitter winter temperatures that plummet to –15°F (–25°C).

Employers are all too aware that high elevation also compromises worker performance, skewing decision making and increasing the chances of accidents and costly mistakes. Michael Böcker (European Southern Observatory) reports that the attention spans and perceptual speed of staff are among the personnel traits most affected by high elevation. Even as early as 1923 the British physiologist Joseph Barcroft noted a similar finding during his fieldwork at Cerro de Pasco (14,100 ft) in Peru: "Judged by the ordinary standard of laboratory work, we were in an obviously lower category at Cerro . . . time was wasted there in trivialities and 'bungling' which would not occur at sea level."

Following medical research by John B. West (University of California, San Diego) and others, some high-elevation sites are now fitting oxygen enrichers to indoor working environments. By boosting the oxygen content in the air from its normal level of 21% to, say, 29%, confined work areas of the ALMA site at 16,700 ft can generate an oxygen pressure equivalent to an elevation of only 9,000 ft, which most people tolerate easily.

ers have since mapped the distribution of similar stellar nurseries in several dozen far-flung starburst galaxies. Understanding their star-forming habits will help shape new ideas about galactic evolution.

Excitingly, this is just the beginning: mini-TAO is merely intended as the observatory's pilot instrument. It will soon be joined by its bigger brother, the centerpiece 6.5-meter telescope already under construction and set for first light in 2017. Other projects are also in the works. Even as astronomers dream of larger mirrors and savvier adaptive optics systems for projects closer to sea level, it's hard to beat the conditions at these high-elevation sites. Astronomy the world over really is on the up. ✦

***Tom Gale** coordinates foundation-level chemistry teaching for University College London. A lifelong amateur astronomer, he is no stranger to high elevations himself and has climbed to 20,000 ft during snow treks in Nepal and Kyrgyzstan.*

Evade the Water

Infrared astronomy from the ground is hampered by absorption by compounds in Earth's atmosphere, particularly water vapor. The suitability of an observing site, particularly those tuning to submillimeter wavelengths, is often gauged from its Precipitable Water Vapor (PWV) value, the depth of liquid that would be obtained if all the gaseous water along the line of sight to the zenith could be condensed. PWV decreases with elevation and is sometimes less than 1 mm above the summit of Mauna Kea. During the deep winter darkness at hyper-arid, elevated regions of the Antarctic interior such as Dome C, the PWV falls below 0.3 mm, giving better than 50% transmission at 350 microns and other key far-infrared wavelengths.

Cerro Tololo Inter-American Observatory, as seen in 2004. The largest dome is for the 4-meter Victor M. Blanco scope.

DOUGLAS ISBELL AND NOAO / AURA / NSF

The World's Highest-Elevation Observatories

University of Tokyo Atacama Observatory (TAO)
Elevation: 18,500 ft
Location: Cerro Chajnantor, Atacama Desert, Chile
Wavelength Range: optical, infrared

Chacaltaya Astrophysical Observatory
Elevation: 17,160 ft (some experiments at 17,600 ft)
Location: Chacaltaya, Andes, Bolivia
Wavelength Range: gamma ray, cosmic rays

James Ax Observatory – Polarbear
Elevation: 17,030 ft
Location: Cerro Toco, Atacama Desert, Chile
Wavelength Range: microwave

Atacama Cosmology Telescope (ACT)
Elevation: 17,030 ft
Location: Cerro Toco, Atacama Desert, Chile
Wavelength Range: microwave

Shiquanhe Observatory
Elevation: 16,700 ft
Location: Ngari Plateau, Tibet
Wavelength Range: optical

Chajnantor Observatory – ALMA, APEX, QUIET, et al.
Elevation: 16,700 ft
Location: Chajnantor Plateau, Atacama Desert, Chile
Wavelength Range: millimeter, submillimeter

Chajnantor Observatory – ASTE, NANTEN2
Elevation: 15,750 ft
Location: Pampa La Bola, Atacama Desert, Chile
Wavelength Range: submillimeter

Large Millimeter Telescope Alfonso Serrano (LMT)
Elevation: 15,030 ft
Location: Sierra Negra, Puebla, Mexico
Wavelength Range: microwave

Indian Astronomical Observatory
Elevation: 14,760 ft
Location: Mount Saraswati, Ladakh, India
Wavelength Range: gamma ray, optical, infrared

Meyer-Womble Observatory
Elevation: 14,150 ft
Location: Mount Evans, Colorado, United States
Wavelength Range: optical, infrared

Yangbajing International Cosmic-ray Observatory
Elevation: 14,100 ft
Location: Yangbajain, Tibet
Wavelength Range: cosmic rays

Mauna Kea Observatory – Keck, Subaru, IRTF, et al.
Elevation: 13,750 ft
Location: Mauna Kea, Hawaii, United States
Wavelength Range: optical, infrared, submillimeter

High-Altitude Water Cherenkov Gamma-Ray Observatory
Elevation: 13,450 ft
Location: Sierra Negra & Pico de Orizaba, between Puebla & Veracruz, Mexico
Wavelength Range: gamma ray, cosmic rays

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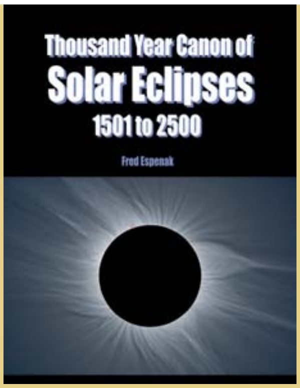

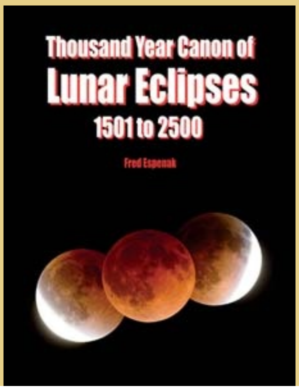

ECLIPSE COMPENDIUMS Astronomer and frequent *Sky & Telescope* contributor Fred Espenak releases two compendiums for eclipse chasers and researchers alike. *Thousand Year Canon of Solar Eclipses: 1501 to 2500* ($34.99, or $51.99 in 4-color print) is a comprehensive catalog of essential characteristics of each of the 2,389 solar eclipses occurring throughout this 10-century period. The book presents fundamental concepts of eclipse classifications, as well as statistical analysis of occurrences, including the location of greatest eclipse duration. Global maps of the path of visibility are carefully plotted and arranged 12 per page. 294 pages. *Thousand Year Canon of Lunar Eclipses: 1501 to 2500* ($34.99, or $51.99 in 4-color print) does the same for each of the 2,424 lunar eclipses occurring in the 10-century time frame. 298 pages, 8½ by 11 inches, paperback.

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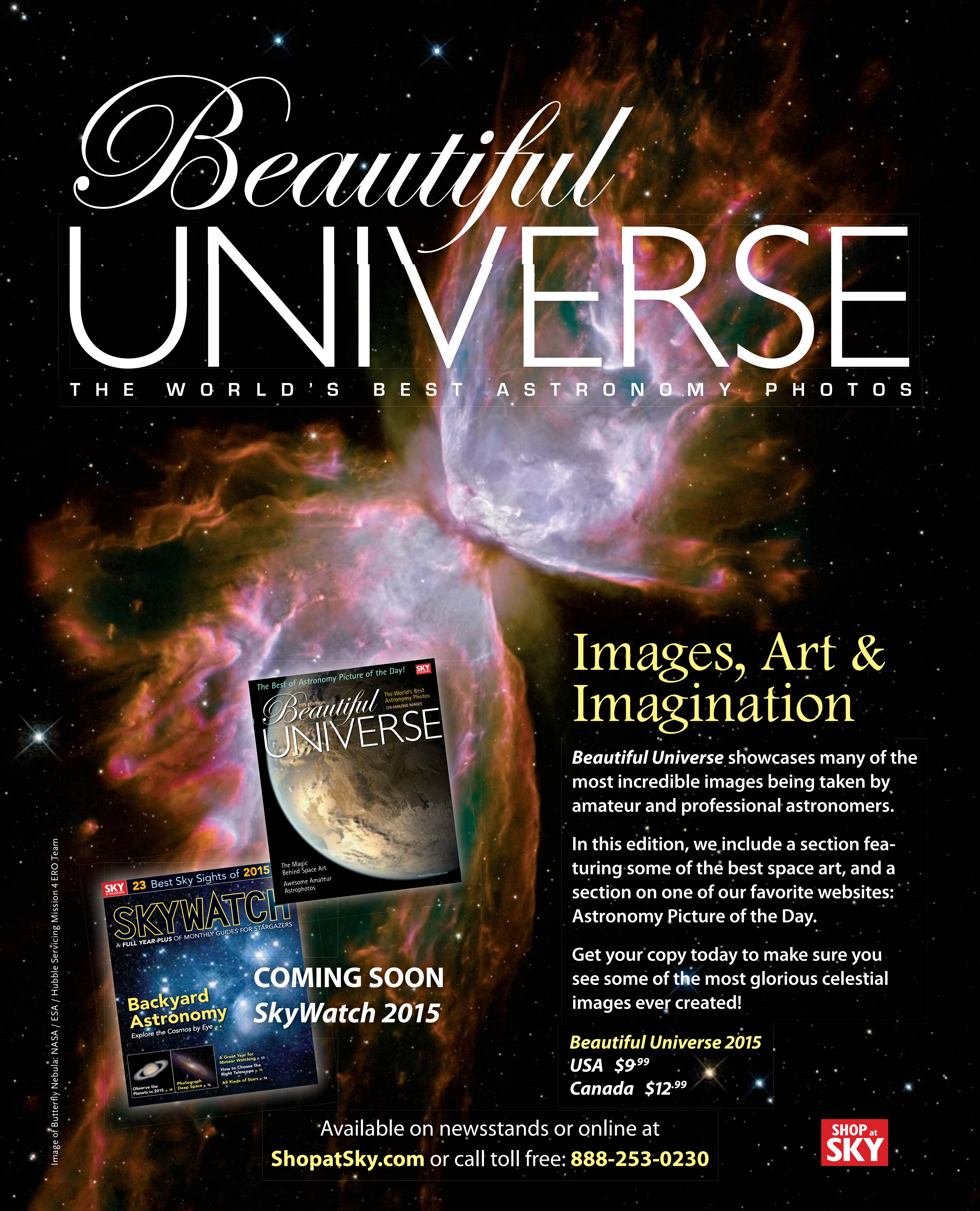
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In This Section

PHOTOGRAPH: AKIRA FUJII

This wide-field image shows the twin glow of the Double Cluster (page 47) to the southeast of Cassiopeia (page 56).

DECEMBER 2014

5 **EVENING:** Observers in the Americas can see Aldebaran very close to the almost-full Moon. Binoculars may also show some of the bright Hyades stars.

11, 12 **DAWN:** The waning gibbous Moon passes below Jupiter halfway up the southwestern sky.

13–14 **ALL NIGHT:** The Geminid meteor shower peaks this night. The best viewing will probably occur shortly before the last-quarter Moon rises around midnight; see page 51.

15 **EVENING:** Algol shines at minimum brightness for roughly two hours centered at 10:22 p.m. EST (7:22 p.m. PST); see page 53.

18 **EVENING:** Algol shines at minimum brightness for roughly two hours centered at 7:12 p.m. EST.

21 **THE LONGEST NIGHT OF THE YEAR** in the Northern Hemisphere. Winter begins at the solstice, at 6:03 p.m. EST (3:03 p.m. PST).

22 **DUSK:** An extremely thin crescent Moon floats to the right of Venus very low in the west-southwest shortly after sunset, as shown on page 49. This is a challenging observation; bring binoculars.

23 **DUSK:** Look for Venus well below the Moon.

24 **EVENING:** Mars shines to the left of the waxing crescent Moon.

28 **LATE EVENING:** Uranus is very close to the Moon, with an occultation visible in Japan and parts of the Arctic.

Planet Visibility
SHOWN FOR LATITUDE 40° NORTH AT MID-MONTH

	◀SUNSET	MIDNIGHT	SUNRISE▶
Mercury	SW	Visible in binoculars at month's end	
Venus	SW		
Mars	SW		
Jupiter		E	S SW
Saturn			SE

Moon Phases

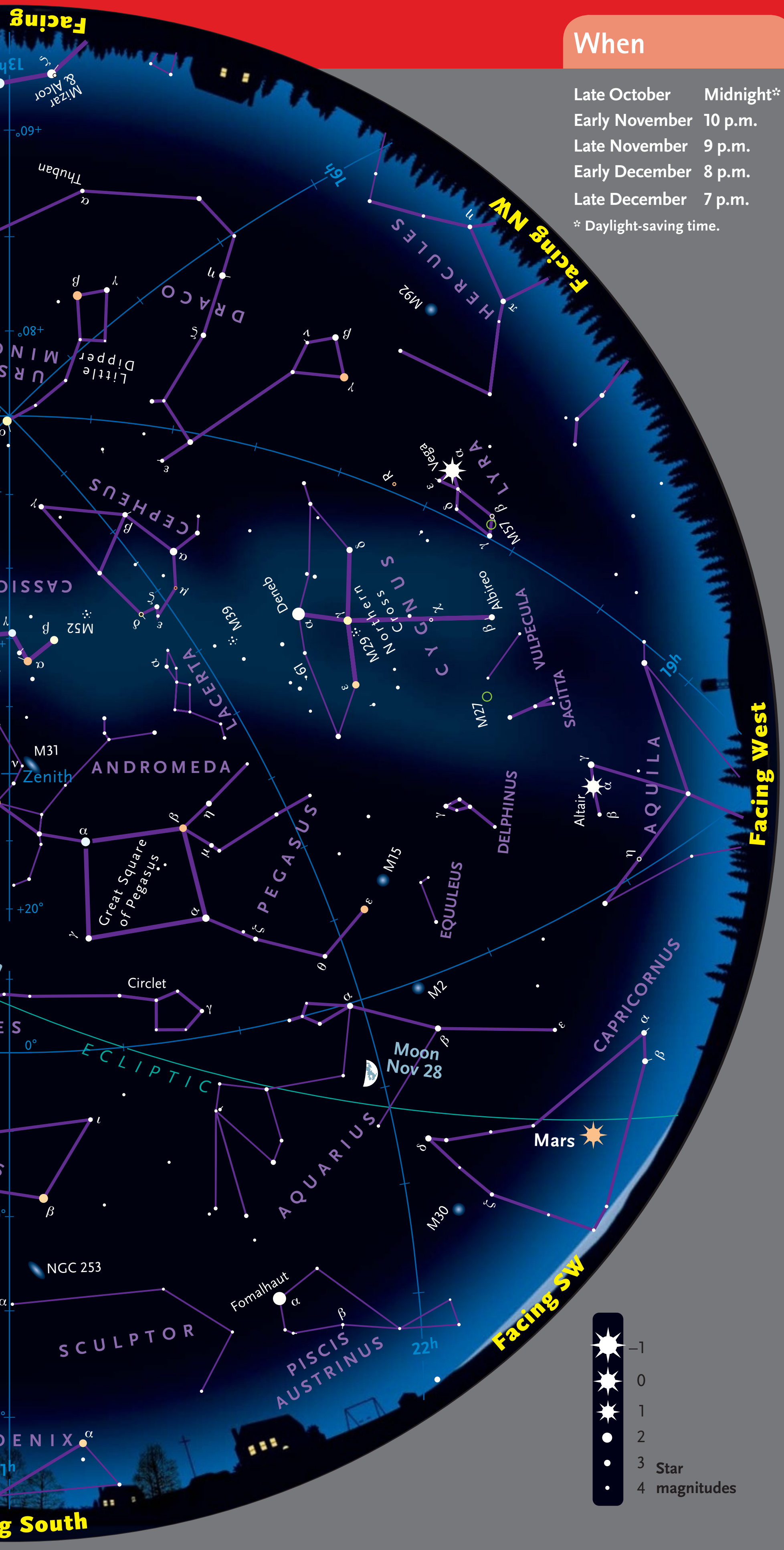
Full December 6 7:27 a.m. EST
Last Qtr December 14 7:51 a.m. EST
New December 21 8:36 p.m. EST
First Qtr December 28 1:31 p.m. EST

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

Using the Map

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

EXACT FOR LATITUDE 40° NORTH.



When

Late October	Midnight*
Early November	10 p.m.
Late November	9 p.m.
Early December	8 p.m.
Late December	7 p.m.

* Daylight-saving time.

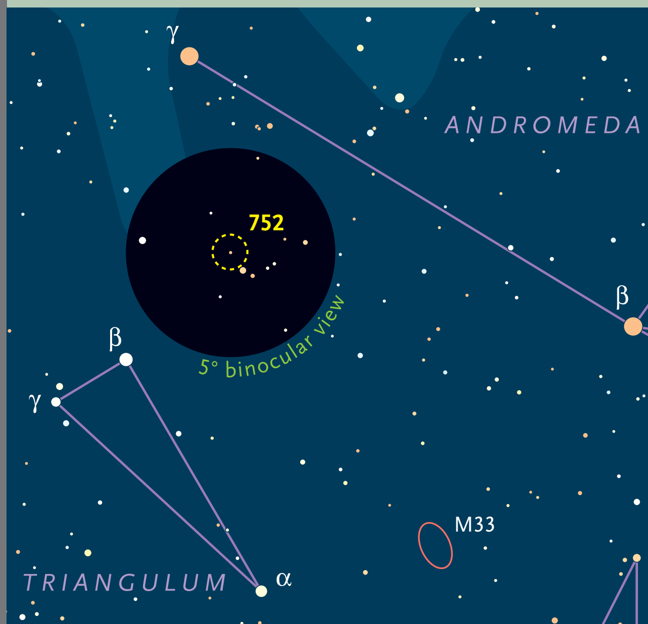
Andromeda's NGC 752

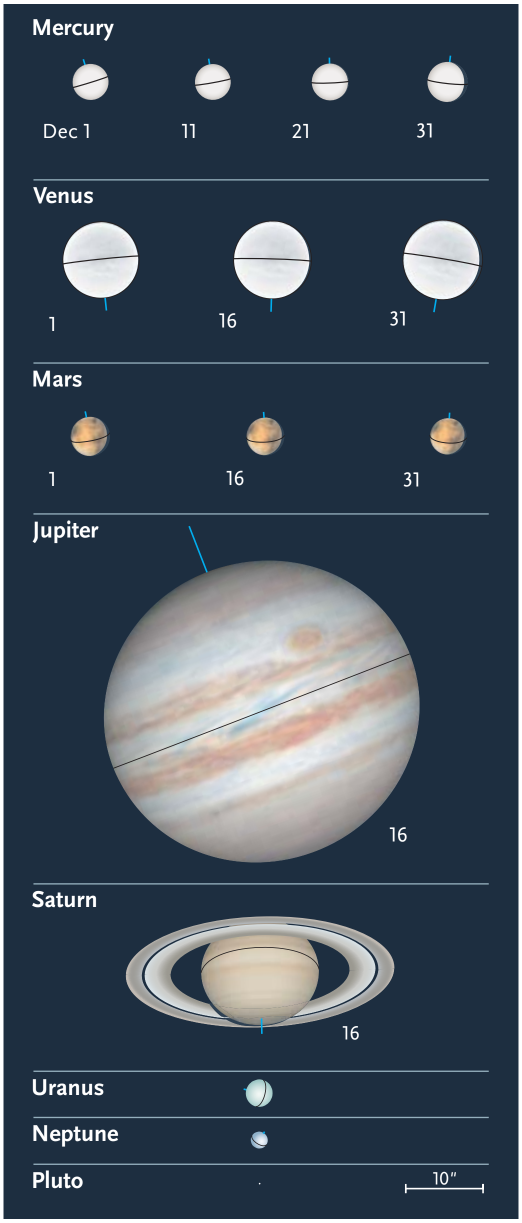
Andromeda . . . blank. Go ahead, fill it in. Andromeda Galaxy, right? Perhaps no constellation is more strongly associated with a single deep-sky object than Andromeda. And for binocular observers, that's doubly true — the Andromeda Galaxy (M31) is one of the finest targets in the sky. But the constellation has more to offer. Although nowhere near as famous as its galactic neighbor, the open cluster **NGC 752** is also a fine binocular sight.

The cluster is located about one binocular field south-southwest of 2nd-magnitude Almach, Gamma (γ) Andromedae. Alternatively, you could try my preferred route, which uses Gamma and Beta (β) Triangulum as pointer stars. Extend a line northward about 1½ times farther than the space between the stars to get to the cluster. No matter how you arrive, NGC 752 is an easy find under good skies.

In my 10×30 image-stabilized binoculars, NGC 752 has a spidery appearance with several curving rows of stars that converge toward the cluster's center. The two most prominent chains radiate eastward to form a sideways V, and a string of faint stars seems to define the cluster's northern edge. Overall, it's a fairly rich, large grouping with perhaps two dozen stars that pop into view. My 15×45s don't add much to the scene, but make the individual cluster stars easier to see.

Although NGC 752's discovery is often attributed to Caroline Herschel, it may in fact have been sighted first by 17th-century Italian astronomer Giovanni Battista Hodierna. Hodierna is perhaps best known for having made the earliest surviving drawing of the Orion Nebula. He made his deep-sky discoveries while surveying the sky for a never-completed star atlas. NGC 752 was likely one of his finds. ✦





Sun and Planets, December 2014

	December	Right Ascension	Declination	Elongation	Magnitude	Diameter	Illumination	Distance
Sun	1	$16^h 27.0^m$	–21° 43′	—	–26.8	32′ 26″	—	0.986
	31	$18^h 39.2^m$	–23° 08′	—	–26.8	32′ 32″	—	0.983
Mercury	1	$16^h 09.3^m$	–21° 17′	4° Mo	–1.1	4.7″	99%	1.436
	11	$17^h 16.4^m$	–24° 21′	2° Ev	–1.3	4.6″	100%	1.449
	21	$18^h 26.0^m$	–25° 18′	7° Ev	–0.9	4.8″	98%	1.404
	31	$19^h 36.0^m$	–23° 48′	13° Ev	–0.8	5.2″	92%	1.294
Venus	1	$17^h 06.1^m$	–23° 12′	9° Ev	–3.9	9.9″	99%	1.684
	11	$18^h 00.8^m$	–24° 10′	12° Ev	–3.9	10.0″	98%	1.665
	21	$18^h 55.7^m$	–23° 53′	14° Ev	–3.9	10.2″	97%	1.643
	31	$19^h 49.9^m$	–22° 24′	16° Ev	–3.9	10.3″	96%	1.617
Mars	1	$19^h 56.1^m$	–22° 10′	48° Ev	+1.0	5.1″	92%	1.827
	16	$20^h 44.4^m$	–19° 25′	45° Ev	+1.1	4.9″	93%	1.896
	31	$21^h 31.4^m$	–15° 53′	41° Ev	+1.1	4.8″	94%	1.965
Jupiter	1	$9^h 39.7^m$	+14° 46′	106° Mo	–2.2	39.8″	99%	4.951
	31	$9^h 37.1^m$	+15° 06′	137° Mo	–2.4	43.3″	100%	4.555
Saturn	1	$15^h 41.6^m$	–17° 41′	11° Mo	+0.5	15.2″	100%	10.913
	31	$15^h 55.3^m$	–18° 23′	38° Mo	+0.6	15.5″	100%	10.705
Uranus	16	$0^h 46.6^m$	+4° 16′	109° Ev	+5.8	3.6″	100%	19.671
Neptune	16	$22^h 27.9^m$	–10° 25′	71° Ev	+7.9	2.3″	100%	30.273
Pluto	16	$18^h 53.1^m$	–20° 41′	19° Ev	+14.2	0.1″	100%	33.710

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

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

The Sun and planets are positioned for mid-December; 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

Far As "Eye" Can See

Test your long-distance vision in December's skies.

Far as I can see, she loves me.
Her eyes, her eyes, her eyes are a blue million miles.
I look at her and she looks at me
And in her eyes I see the sea.
I don't see what she sees in a man like me
But she says she loves me.
Her eyes, her eyes, her eyes are a blue million miles.
— Captain Beefheart
Her Eyes Are a Blue Million Miles

Captain Beefheart (Don Van Vliet) was one of rock music's most eccentric songwriters. But some of his songs have lovely, straightforward, yet still imaginative lyrics. "Far as I can see" could also be heard as "far as eye can see" in Beefheart's song about the "blue million miles" of his wife's eyes.

How far the eye can see is a topic often on the minds of amateur astronomers. On clear December evenings, we can test our naked eyes' ability to see celestial objects at a marvelous variety of distances.

The nearest naked-eye star for northerners. Venus glows in the evening sky this month. When it's closest to Earth, as it will next be on August 16, 2015, it's still about 100 times farther from us than the Moon. Neptune, visible in evening twilight this month, is about 100 times farther still. The distances to even the nearest nighttime stars are vastly greater. The Alpha Centauri system is the closest to us, some 4.4 light-years away, about a quarter-million times farther from Earth than the Sun. But Alpha Centauri is only readily visible from the Southern Hemisphere and the tropics. The closest star visible at night for most of the world's population is Sirius, the brightest of all.

Sirius, which is almost twice as far from us as Alpha Centauri, rises about 9 p.m. as December starts and about 7 p.m. as December ends. It reaches its highest point around midnight on New Year's Eve.

Alpha Centauri is just 11% farther from Sirius than our Sun is, so Sirius would appear a little fainter to an observer in the Alpha Centauri system. But the marvelous thing is that the change in perspective would bring Sirius within 2° of Betelgeuse. Meanwhile, the distant stars of Orion would look almost the same as from Earth.

The farthest naked-eye open clusters and galaxies. At a distance of about 150 light-years, the Hyades Cluster in Taurus is the closest true star cluster to us. The Pleiades, also in Taurus, are about 440 light-years away. A third cluster to study with the naked eye, although better seen through binoculars, is the Alpha Persei Cluster, some 600 light-years from Earth.


AKIRA FUJII

Sirius, the brightest star in this image, appears near Orion in the sky, but appearances are deceiving. Sirius is 8.6 light-years from Earth, compared to more than 1,000 light-years for most of Orion's stars.

An increase in distance doesn't necessarily mean a decrease in visibility: NGC 869 and 884, which comprise the Double Cluster in Perseus, lie 6,800 and 7,700 light-years from Earth, respectively, yet glow bright in dark, clear skies. In good viewing conditions, naked eyes see the Double Cluster as a two-lobed fuzzy patch.

Galaxies lie at far greater distances than any readily visible star cluster. The closest external galaxies visible to the unaided eye from mid-northern latitudes appear not far from Perseus in the sky — they're M31 in Andromeda and M33 in Triangulum. At 2.5 and 2.7 million light-years, respectively, these galaxies are more than 300 times farther from Earth than the Double Cluster. M31 is easy for the naked eye in a reasonably dark sky. M33 offers a challenge to viewers unless the sky is very dark indeed.

Million-mile eyes. A million-mile-wide object can't fit into your eye — but its image can. What's the largest object that be seen with the naked eye? The Andromeda Galaxy, which is more than 150,000 light-years across. ✦

Jupiter Comes into Its Own

The King of Planets rises high before midnight in late December.

Each evening in December, Venus becomes a little easier to see after sunset. Late in the month binoculars may show Mercury not far to Venus's lower right. Much fainter Mars appears in the southwest in evening twilight and sets more than 3 hours after the Sun. Jupiter and Saturn rise earlier every night — Jupiter in the middle of the evening and Saturn in the small hours of the morning.

DUSK

Venus was so low after sunset in November that glimpsing it was a frustrating challenge. During the course of December, however, the interval between sunset and Venus-set increases from about 45 to 75 minutes when viewed at 40° north latitude, with the planet's sunset altitude increasing from 5° to 11°. That's enough improvement to make Venus, which shines at magnitude –3.9, reasonably easy to spot if the night is clear and you look for it just a few degrees above the southwest horizon starting a half hour after sunset. The globe of Venus grows only the tiniest bit in apparent size (from about 9.9″ to 10.3″), and through a telescope it appears as a small blurry dot in the turbulence low in the sky.

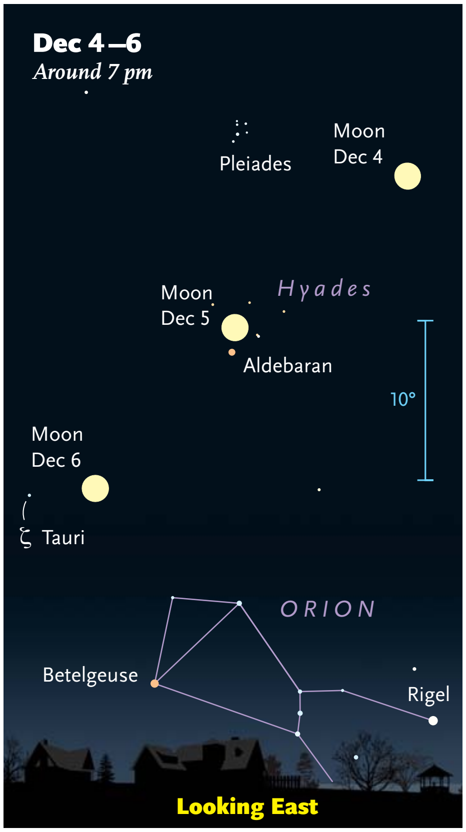
Mercury goes through superior conjunction with the Sun on December 8th. Late in the month, binoculars may show the little planet low in the evening twilight — it sets about 45 minutes after the Sun during the last few days of the year. When Mercury becomes visible in the dusk, it does so increasingly close to the lower right of much brighter Venus. By New Year's Eve Mercury shines at magnitude –0.8 and has pulled within 3.5° of Venus.

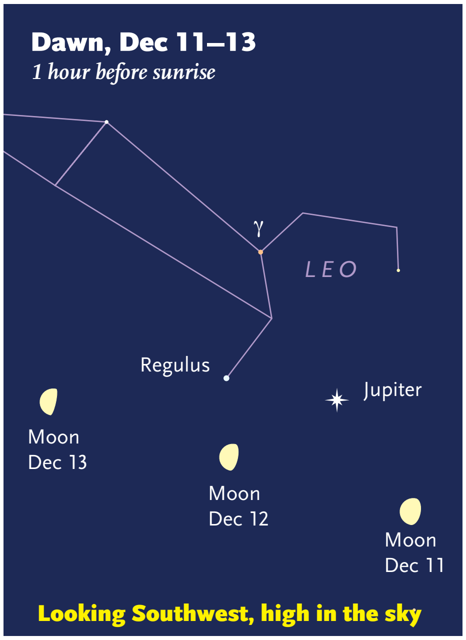
Pluto is 3° north of Venus on December 20th and a little more than 4° north of Mercury on December 25th, but it's far too dim to view in the bright sky even through large telescopes.

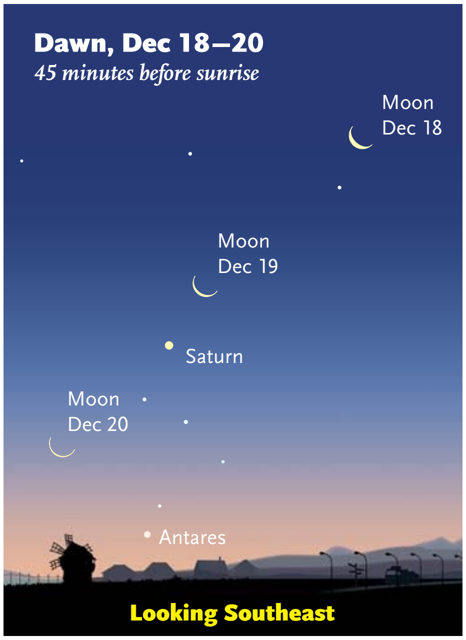
EARLY EVENING

For yet another month, **Mars** appears each night in the southwest as darkness falls and sets more than 3 hours after the Sun. Observers at 40° north latitude see Mars set at almost exactly the same time during the final month and a half of the year. That's within a few minutes of 8 p.m for those near the central meridian of a time zone. During December, Mars starts in easternmost Sagittarius and then glides most of the way across Capricornus. The planet dims a little — from magnitude +1.0 to +1.1 — and its disk now appears in most telescopes as a featureless orange dot less than 5″ across.

Neptune and **Uranus** are this month best observed at the end of evening twilight or, in the case of Uranus, a bit later. To access finder charts for these two



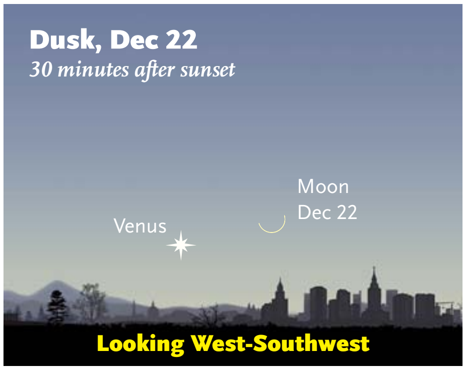


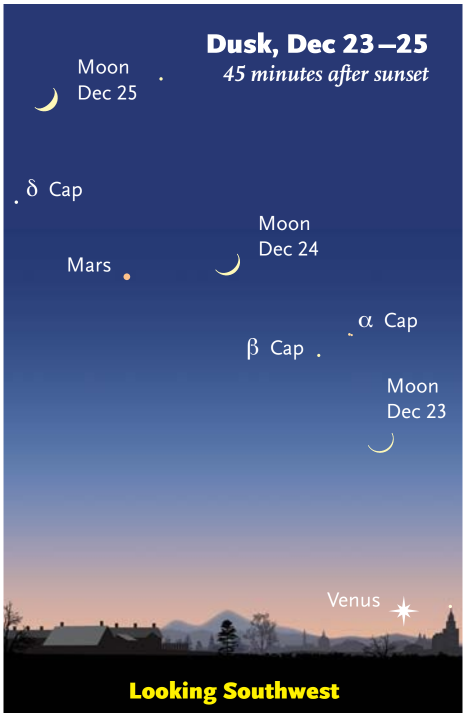


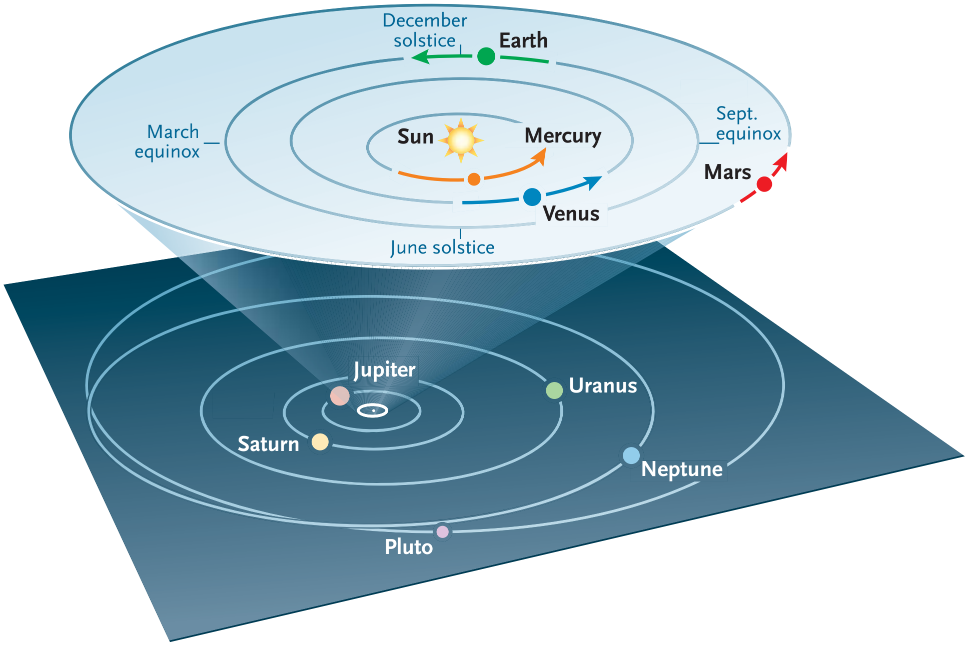
planets, see **skypub.com/urnep** or page 50 of the September issue.

MID-EVENING TO DAWN

Jupiter begins December rising around 10 p.m., but by month's end comes up at 8 p.m., when Mars is setting. Jupiter brightens from magnitude –2.2 on December 1st to –2.4 on January 1st. This happens while the giant planet lingers around its stationary point in westernmost Leo. Jupiter nudges in early December to a minimum separation of about 7° from Regulus. On December 9th, the planet halts its direct motion (eastward among the stars) and begins retrograde motion (westward back toward Cancer). Telescopes show the planet's banded orb enlarge from 40″ to 43″ during December. Jupiter reaches the meridian and is highest in the hours before morning twilight. It will be visible all night when it reaches opposition in early February 2015.







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

DAWN

Saturn comes up only about an hour before the Sun as December opens but more than three hours by month's (and year's) end. Saturn hangs low in the southeast as the sky begins to brighten. As the month progresses, the stars that mark the head of Scorpius and then, lower in the southeast, 1st-magnitude Antares, appear below Saturn. By month's end the planet is nearing the stars of the head — including the beautiful double star Beta Scorpii — and is preparing to leave Libra and enter Scorpius. This month sees Saturn at magnitude +0.5, and it's high enough by dawn for telescopes to provide fairly crisp views of its glorious rings. Their tilt grows slightly in December, from 24° to 24.5°.

SUN AND MOON

The **Sun** reaches the solstice at 6:03 p.m. EST on December 21st, marking the beginning of winter in the Northern Hemisphere and summer in the Southern Hemisphere.

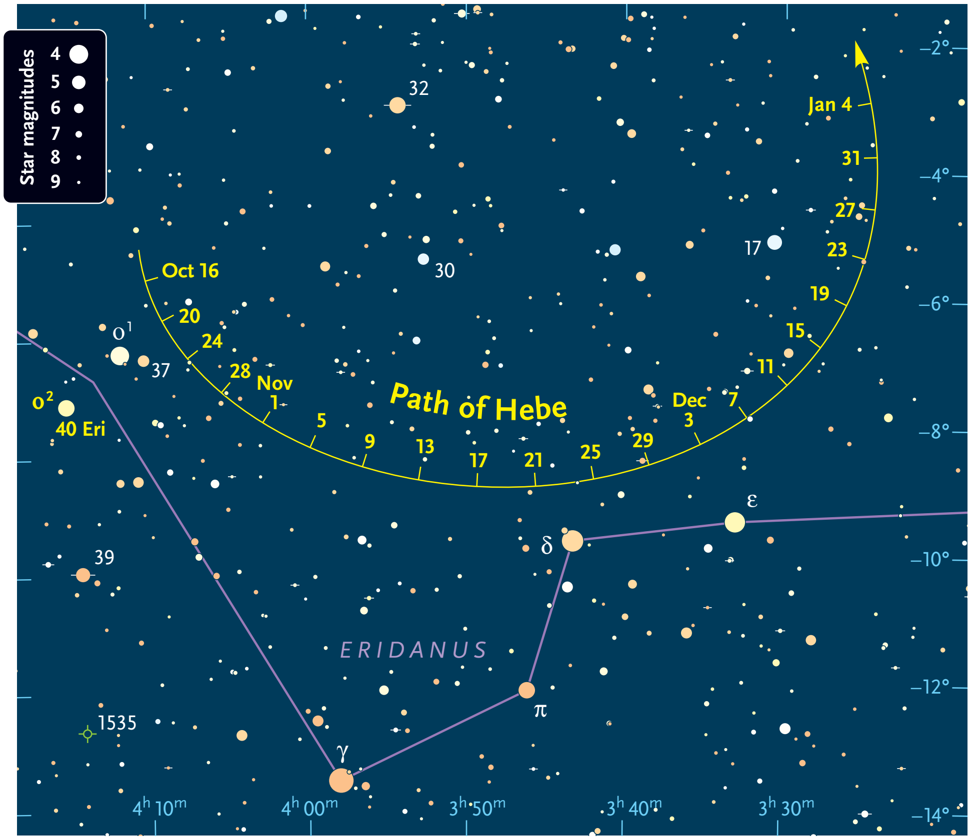
Observers in the Americas can see Aldebaran very near the almost full **Moon** on the evening of December 5th. Binoculars may also show the brightest Hyades stars surrounding the Moon. The waning gibbous Moon forms a largish right triangle with Regulus and Jupiter on the morning of December 12th. The waning lunar crescent is not far to Saturn's upper right at dawn on December 19th.

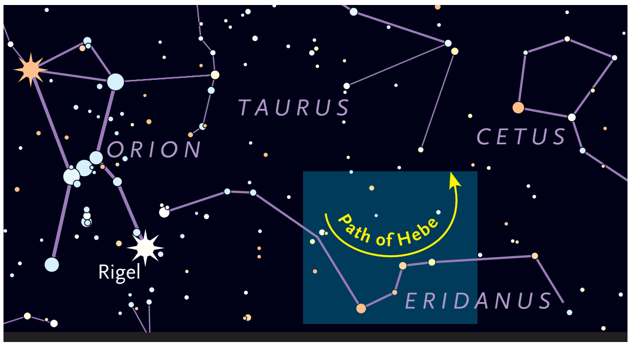
Back in the evening sky, a very young Moon shines to the right of Venus shortly after sunset on December 22nd. The waxing crescent is rather high above Venus on the 23rd, and it shines well to the right of Mars on Christmas Eve. ✦

Hebe and a White Dwarf

Two very different historic objects are currently a short star-hop apart.

Asteroids look alike through amateur telescopes, being featureless points of light. But as with stars, identical points of light can represent wildly different objects. Some asteroids are single, some are dumbbells or figure-8s, and some are true binaries with empty space in between. Some are loose rubble piles with a low overall density; others are solid rock and/or iron. Some are not really asteroids but dormant, dirt-sheathed comet nuclei. They're too small and far to tell by looking.





The date ticks on Hebe's path are plotted for 0^h Universal Time (on the evening of the previous date in the Americas). Interpolate to put a dot at the date and time you plan to observe, and star-hop there from Rigel. Hebe dims from magnitude 8.1 to 8.8 in late 2014, remaining a little brighter than the faintest stars plotted above (magnitude 9.2).

In the wastes of Eridanus west of Rigel these nights, 6 Hebe is moving through its retrograde loop. It shines at peak brightness (magnitude 8.1) from late October through mid-November and is still 8.8 at the end of December. The chart here, with stars down to magnitude 9.2, shows where to find it with a small scope or, if you're ambitious, good binoculars (especially if they're firmly braced).

Hebe was discovered in 1847 by a retired postmaster named Karl Ludwig Hencke, who had a small telescope in a rooftop observatory in what is now Poland. Hebe was Hencke's second asteroid find. His first was 5 Astraea in 1845, which he turned up only after 15 years of dogged asteroid hunting by carefully comparing his eyepiece views against star maps, often homemade. Professional astronomers had given up on discovering new asteroids years earlier, after finding none beyond the first four (Ceres, Pallas, Juno, and Vesta); those had been discovered in a flurry from 1801 to 1807. Hencke's two finds reinvigorated this pursuit, and it has continued to accelerate ever since.

Hebe is big as asteroids go, 120 miles (190 km) across. It's mildly irregular in shape judging by brightness variations during its 8-hour rotation, and it's unusually massive for its size. Its high density, 3.8 grams per cubic centimeter, indicates a solid rock-and-iron composition. In fact, Hebe is thought to be the source of up to 40% of the meteorites that survive to land on Earth, especially those with a high iron content. Hebe orbits very close to an unstable zone in the asteroid belt where fragments from impacts would be flung far and wide.

Hebe may also be double. On March 5, 1977, the asteroid-occultation timer Paul D. Maley observed what seemed to be a secondary blackout of a star by a small

companion, but there were no confirming observations. Not until 17 years later was the first asteroid satellite definitely found (little Dactyl orbiting Ida). Binary asteroids have since turned out to be fairly common.

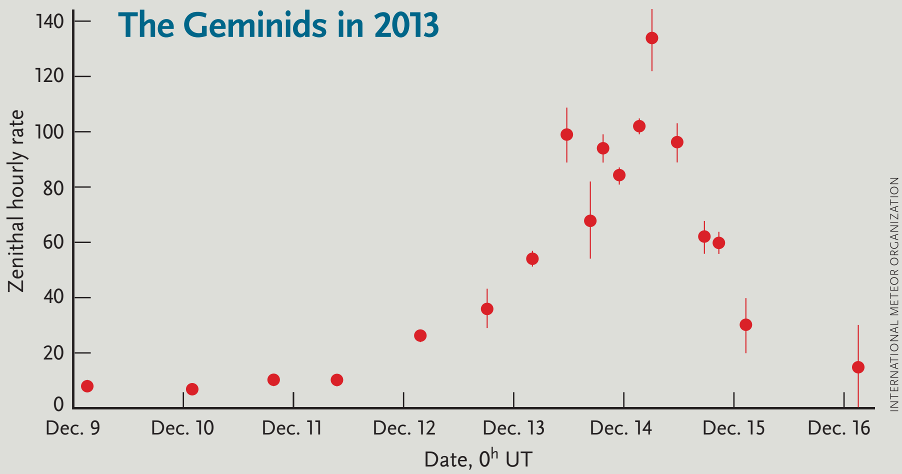
And the Easiest White Dwarf

As chance would have it, Hebe is passing near the 4th-magnitude star Omicron^2 (o^2) Eridani, labeled at the far left on the map. Also known as 40 Eridani, it's only 16 light-years away and is an intriguing triple star for amateur telescopes. The bright primary is a yellow-orange dwarf, type *K*1, somewhat smaller and dimmer than the Sun. It has a much fainter *white* companion, magnitude 9.5, located 83 arcseconds to the east. This in turn has an 11.2-magnitude red-dwarf companion 9″ to its north-northwest. They're named A, B, and C, respectively. B is not the closest white dwarf — the companions of Sirius and Procyon are nearer — but it's the only one that many amateurs are ever likely to see, due to its much wider separation from a much less brilliant primary.

I see it plain as day in my 6-inch reflector. Dimmer C close to B is not at all obvious in the 6-inch, but once I locate it, its reddish color definitely shows. Like many red dwarfs it is a flare star. Its occasional brief brightenings earned it the variable-star designation DY Eridani.

HIMMEL UND ERDE

Karl Ludwig Hencke, an amateur with a mission.



Despite the bright moonlight last year, amateurs around the world who followed the International Meteor Organization's standardized procedures counted 3,968 Geminids to produce this activity curve. The shower kept up a zenithal hourly rate of about 100 or more for nearly 24 hours, then, as usual, dropped off faster than it rose. The zenithal hourly rate is the number you would see per hour if there were no light pollution, allowing magnitude-6.5 stars to be visible, and if the shower's radiant were near the zenith.

Dodge the Moon for the Geminids

Some skywatchers fantasize about what it would be like if Earth had several big moons always coming and going — but not deep-sky observers, and certainly not meteor watchers. At a telescope's eyepiece you can at least shield the Moon's glare from your eye while looking for a faint cluster or galaxy, and you can use high power to lower the sky's apparent surface brightness. But a naked-eye meteor watcher under the Moon has a harder time avoiding its glare — and is stuck with the richest-field, highest-surface-brightness view of the sky ever possible.

We were mooned out for the Perseids last August, but the situation will be better for December's equally rich Geminid shower. On both of its peak nights, December 13–14 and 14–15, the shower is well under way before the last-quarter Moon rises. The nominal peak is supposed to come around 12^h Universal Time on the 14th, so both evenings should be good. The Moon won't rise until 11 p.m. to midnight on the night of the 13th (depending on your location) and an hour later the next night.

The Geminids' radiant, near Castor, rises pretty high by mid- to late evening, so by then the shower ought to be doing well. You may even see an occasional Geminid as early as nightfall. Any that appear so early, when the shower's radiant is still low in the east, will be graceful earthgrazers sailing far across the sky (August issue, page 64). Just be patient.

The Geminid meteoroid stream has been somewhat sorted by mass. Faint telescopic meteors reach their peak about a day ahead of the naked-eye count, and Geminids seen after maximum are often especially bright. If nothing but gravity were at work in interplanetary space, it's hard to imagine how this could happen. Solar radiation pressure, however, is also in play a little bit, and it affects small particles more than larger particles. Over the long run its effects add up.

If you'd like to be more than just a casual spectator, read how to make and report a scientifically useful Geminid count at **imo.net/visual/major**. You can be a part of creating the activity graph for 2014!

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.

Action at Jupiter

Jupiter rises high in the east by midnight in December, and it qualifies now as "big": growing from 40″ to 43″ wide this month. That's nearly as large as the 45″ equatorial diameter it will display near its February 6th opposition.

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

All the interactions between Jupiter and its satellites and all their shadows are tabulated on the facing page.

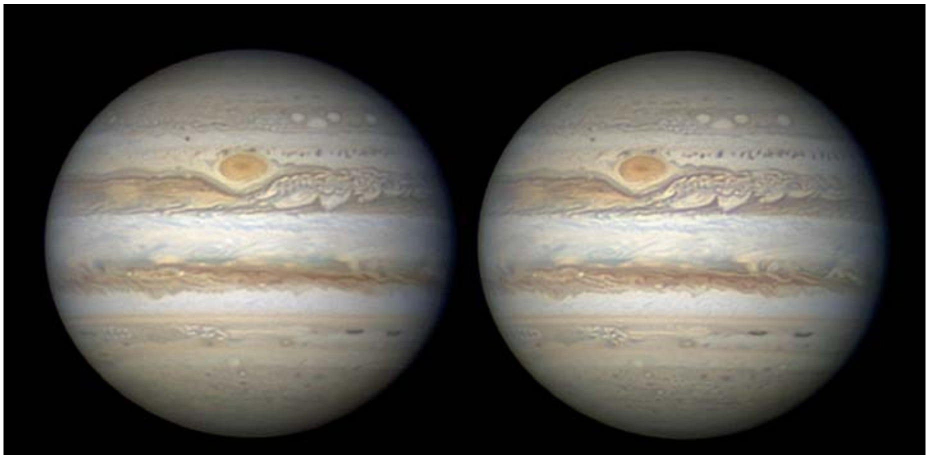
Moreover, we're now in a season of mutual eclipses and occultations among the satellites *themselves*. These events will continue until Jupiter sinks into the sunset next June. In December alone, 19 of them are in view from the eastern U.S. (though many of them involve only slight dimmings). For details, see **skypub.com/jovianmutualevents**.

Here are the times, in Universal Time, when the Great Red Spot should cross Jupiter's central meridian. The dates, also in UT, are in bold. Eastern Standard Time is UT minus 5 hours.

November 1, 1:14, 11:09, 21:05; **2**, 7:01, 16:56; **3**, 2:52, 12:48, 22:44; **4**, 8:39, 18:35; **5**, 4:31, 14:26; **6**, 0:22, 10:18, 20:13; **7**, 6:09, 16:05; **8**, 2:00, 11:56, 21:52; **9**, 7:48, 17:43; **10**, 3:39, 13:35, 23:30; **11**, 9:26, 19:22; **12**, 5:17, 15:13; **13**, 1:09, 11:04, 21:00; **14**, 6:56, 16:51; **15**, 2:47, 12:43, 22:38; **16**, 8:34, 18:30; **17**, 4:25, 14:21; **18**, 0:17, 10:12, 20:08; **19**, 6:04, 15:59; **20**, 1:55, 11:51, 21:46; **21**, 7:42, 17:38; **22**, 3:33, 13:29, 23:25; **23**, 9:20, 19:16; **24**, 5:12, 15:07; **25**, 1:03, 10:59, 20:54; **26**, 6:50, 16:46; **27**, 2:41, 12:37, 22:33; **28**, 8:28, 18:24; **29**, 4:19, 14:15; **30**, 0:11, 10:06, 20:02.

December 1, 6:01, 15:57; **2**, 1:52, 11:48, 21:44; **3**, 7:39, 17:35; **4**, 3:30, 13:26, 23:22; **5**, 9:17, 19:13; **6**, 5:09, 15:04; **7**, 1:00, 10:56, 20:51; **8**, 6:47, 16:42; **9**, 2:38, 12:34, 22:29; **10**, 8:25, 18:21; **11**, 4:16, 14:12; **12**, 0:07, 10:03, 19:59; **13**, 5:54, 15:50; **14**, 1:46, 11:41, 21:37; **15**, 7:32, 17:28; **16**, 3:24, 13:19, 23:15; **17**, 9:10, 19:06; **18**, 5:02, 14:57; **19**, 0:53, 10:48, 20:44; **20**, 6:40, 16:35; **21**, 2:31, 12:27, 22:22; **22**, 8:18, 18:13; **23**, 4:09, 14:05; **24**, 0:00, 9:56, 19:51; **25**, 5:47, 15:43; **26**, 1:38, 11:34, 21:29; **27**, 7:25, 17:21; **28**, 3:16, 13:12, 23:07; **29**, 9:03, 18:59; **30**, 4:54, 14:50; **31**, 0:45, 10:41, 20:36.

These times assume that the spot is centered at about System II longitude 228°. Features on Jupiter appear closer to the central meridian than to the limb for 50 minutes before and after transiting. A light blue or green filter slightly boosts the contrast of Jupiter's reddish, orange, and tan markings.



Jupiter was 42″ wide on March 4th when Damian Peach of Selsey, U.K., took these two images 17 minutes apart. South is up; the South Equatorial Belt remains wider than its northern counterpart. For each view, Peach stacked many de-rotated frames from several minutes of video taken with a Celestron 14-inch Schmidt-Cassegrain scope.

Lunar Occultations

Once in a while when you're out with the telescope, you may catch the Moon about to occult a star just by luck. Your odds are much better if you plan. Mark your calendar:

- **On the evening of November 26th** (Thanksgiving Eve), observers in the western U.S. can watch the dark limb of the waxing crescent Moon creep up to and snap out each component of the wide double star Beta Capricorni, magnitudes 3.1 and 6.1. Some times for the disappearance of the brighter star (Beta^2): San Francisco, 7:32 p.m. PST; San Diego, 7:31 p.m. PST; Salt Lake City, 8:37 p.m. MST.
- **On the evening of December 2nd**, the dark limb of the nearly full Moon occults Omicron Piscium, magnitude 4.3, for central and eastern North America except the southeast.

To see maps and timetables for both events: **lunar-occultations.com/iota/brstar/brstar.htm**.

Asteroid Occultations

More challenging are occultations of telescopic stars by pinpoint asteroids. The stars involved are much fainter (because such an event for any given star is very rare), and the ground track is narrow.

- **On the morning of December 11th**, a 9.1-magnitude star in Gemini will be occulted by faint 125 Liberatrix for up to 4 seconds as seen from a track running from southwestern Texas to southern California, with the star low in the west-southwestern sky. The occultation should happen within a few minutes of 5:31 a.m. PST.
- **On the morning of December 13th**, as seen from a track from southeastern Texas to northern California, 35 Leukothea will occult a 9.3-magnitude star at the Gemini-Auriga border around 3:18 a.m. PST.

For maps and details: **asteroidoccultation.com/IndexAll.htm**. ✦

Minima of Algol

Nov.	UT	Dec.	UT
3	3:07	1	19:17
5	23:56	4	16:06
8	20:45	7	12:55
11	17:34	10	9:44
14	14:22	13	6:33
17	11:11	16	3:22
20	8:00	19	0:12
23	4:50	21	21:01
26	1:39	24	17:50
28	22:28	27	14:39
		30	11:28

These geocentric (Earth-centered) predictions are from the heliocentric (Sun-centered) elements Min. = JD 2452253.559 + 2.867362*E*, where *E* is any integer. Courtesy Gerry Samolyk (AAVSO). For a comparison-star chart and more info, see SkyandTelescope.com/algol.

Phenomena of Jupiter's Moons, December 2014

Dec. 1	5:08	I.Ec.D
	8:39	I.Oc.R
	22:57	II.Sh.I
Dec. 2	1:23	II.Tr.I
	1:50	II.Sh.E
	2:27	I.Sh.I
	3:37	I.Tr.I
	4:16	II.Tr.E
	4:43	I.Sh.E
	5:53	I.Tr.E
	23:36	I.Ec.D
Dec. 3	3:07	I.Oc.R
	11:25	III.Ec.D
	15:03	III.Ec.R
	16:15	III.Oc.D
	17:48	II.Ec.D
	19:55	III.Oc.R
	20:55	I.Sh.I
	22:05	I.Tr.I
	23:01	II.Oc.R
	23:11	I.Sh.E
Dec. 4	0:21	I.Tr.E
	18:04	I.Ec.D
	21:20	IV.Sh.I
	21:35	I.Oc.R
Dec. 5	2:06	IV.Sh.E
	8:21	IV.Tr.I
	12:15	II.Sh.I
	13:05	IV.Tr.E
	14:38	II.Tr.I
	15:08	II.Sh.E
	15:23	I.Sh.I
	16:32	I.Tr.I
	17:31	II.Tr.E
	17:39	I.Sh.E
	18:48	I.Tr.E
Dec. 6	12:33	I.Ec.D
	16:02	I.Oc.R
Dec. 7	1:29	III.Sh.I
	5:04	III.Sh.E
	6:08	III.Tr.I
	7:05	II.Ec.D
	9:44	III.Tr.E
	9:51	I.Sh.I
	10:59	I.Tr.I
	12:08	I.Sh.E
	12:14	II.Oc.R
	13:16	I.Tr.E
Dec. 8	7:01	I.Ec.D
	10:30	I.Oc.R
Dec. 9	1:33	II.Sh.I
	3:51	II.Tr.I
	4:20	I.Sh.I
	4:25	II.Sh.E
	5:27	I.Tr.I
	6:36	I.Sh.E
	6:45	II.Tr.E
	7:43	I.Tr.E
Dec. 10	1:30	I.Ec.D
	4:57	I.Oc.R
	15:23	III.Ec.D
	19:02	III.Ec.R
	19:58	III.Oc.D
	20:21	II.Ec.D
	22:48	I.Sh.I
	23:38	III.Oc.R
	23:54	I.Tr.I
Dec. 11	1:04	I.Sh.E
	1:27	II.Oc.R
	2:10	I.Tr.E
	19:58	I.Ec.D
	23:24	I.Oc.R
Dec. 12	14:51	II.Sh.I
	17:05	II.Tr.I
	17:16	I.Sh.I
	17:44	II.Sh.E
	18:21	I.Tr.I
	19:32	I.Sh.E
	19:59	II.Tr.E
	20:37	I.Tr.E
Dec. 13	4:49	IV.Ec.D
	9:42	IV.Ec.R
	14:27	I.Ec.D
	15:21	IV.Oc.D
	17:52	I.Oc.R
	20:11	IV.Oc.R
Dec. 14	5:26	III.Sh.I
	9:02	III.Sh.E
	9:38	II.Ec.D
	9:48	III.Tr.I
	11:44	I.Sh.I
	12:48	I.Tr.I
	13:24	III.Tr.E
	14:01	I.Sh.E
	14:39	II.Oc.R
	15:04	I.Tr.E
Dec. 15	8:55	I.Ec.D
	12:19	I.Oc.R
Dec. 16	4:09	II.Sh.I
	6:12	I.Sh.I
	6:18	II.Tr.I
	7:02	II.Sh.E
	7:15	I.Tr.I
	8:29	I.Sh.E
	9:12	II.Tr.E
	9:32	I.Tr.E
Dec. 17	3:23	I.Ec.D
	6:46	I.Oc.R
	19:21	III.Ec.D
	22:54	II.Ec.D
	23:00	III.Ec.R
	23:36	III.Oc.D
Dec. 18	0:41	I.Sh.I
	1:42	I.Tr.I
	2:57	I.Sh.E
	3:16	III.Oc.R
	3:50	II.Oc.R
	3:59	I.Tr.E
	21:52	I.Ec.D
Dec. 19	1:13	I.Oc.R
	17:27	II.Sh.I
	19:09	I.Sh.I
	19:31	II.Tr.I
	20:09	I.Tr.I
	20:20	II.Sh.E
	21:26	I.Sh.E
	22:25	II.Tr.E
	22:25	I.Tr.E
Dec. 20	16:20	I.Ec.D
	19:40	I.Oc.R
Dec. 21	9:23	III.Sh.I
	12:11	II.Ec.D
	12:59	III.Sh.E
	13:23	III.Tr.I
	13:37	I.Sh.I
	14:36	I.Tr.I
	15:17	IV.Sh.I
	15:54	I.Sh.E
	16:52	I.Tr.E
	16:59	III.Tr.E
	17:01	II.Oc.R
	20:04	IV.Sh.E
Dec. 22	0:34	IV.Tr.I
	5:17	IV.Tr.E
	10:49	I.Ec.D
	14:07	I.Oc.R
Dec. 23	6:44	II.Sh.I
	8:05	I.Sh.I
	8:42	II.Tr.I
	9:03	I.Tr.I
	9:38	II.Sh.E
	10:22	I.Sh.E
	11:19	I.Tr.E
	11:36	II.Tr.E
Dec. 24	5:17	I.Ec.D
	8:34	I.Oc.R
	23:20	III.Ec.D
Dec. 25	1:28	II.Ec.D
	2:34	I.Sh.I
	2:59	III.Ec.R
	3:11	III.Oc.D
	3:29	I.Tr.I
	4:50	I.Sh.E
	5:46	I.Tr.E
	6:11	II.Oc.R
	6:50	III.Oc.R
	23:46	I.Ec.D
Dec. 26	3:01	I.Oc.R
	20:03	II.Sh.I
	21:02	I.Sh.I
	21:54	II.Tr.I
	21:56	I.Tr.I
	22:56	II.Sh.E
	23:19	I.Sh.E
Dec. 27	0:12	I.Tr.E
	0:48	II.Tr.E
	18:14	I.Ec.D
	21:27	I.Oc.R
Dec. 28	13:20	III.Sh.I
	14:44	II.Ec.D
	15:30	I.Sh.I
	16:22	I.Tr.I
	16:53	III.Tr.I
	16:57	III.Sh.E
	17:47	I.Sh.E
	18:39	I.Tr.E
	19:21	II.Oc.R
	20:30	III.Tr.E
Dec. 29	12:43	I.Ec.D
	15:54	I.Oc.R
	22:49	IV.Ec.D
Dec. 30	3:42	IV.Ec.R
	7:04	IV.Oc.D
	9:20	II.Sh.I
	9:59	I.Sh.I
	10:49	I.Tr.I
	11:04	II.Tr.I
	11:52	IV.Oc.R
	12:14	II.Sh.E
	12:15	I.Sh.E
	13:06	I.Tr.E
	13:58	II.Tr.E
Dec. 31	7:11	I.Ec.D
	10:21	I.Oc.R

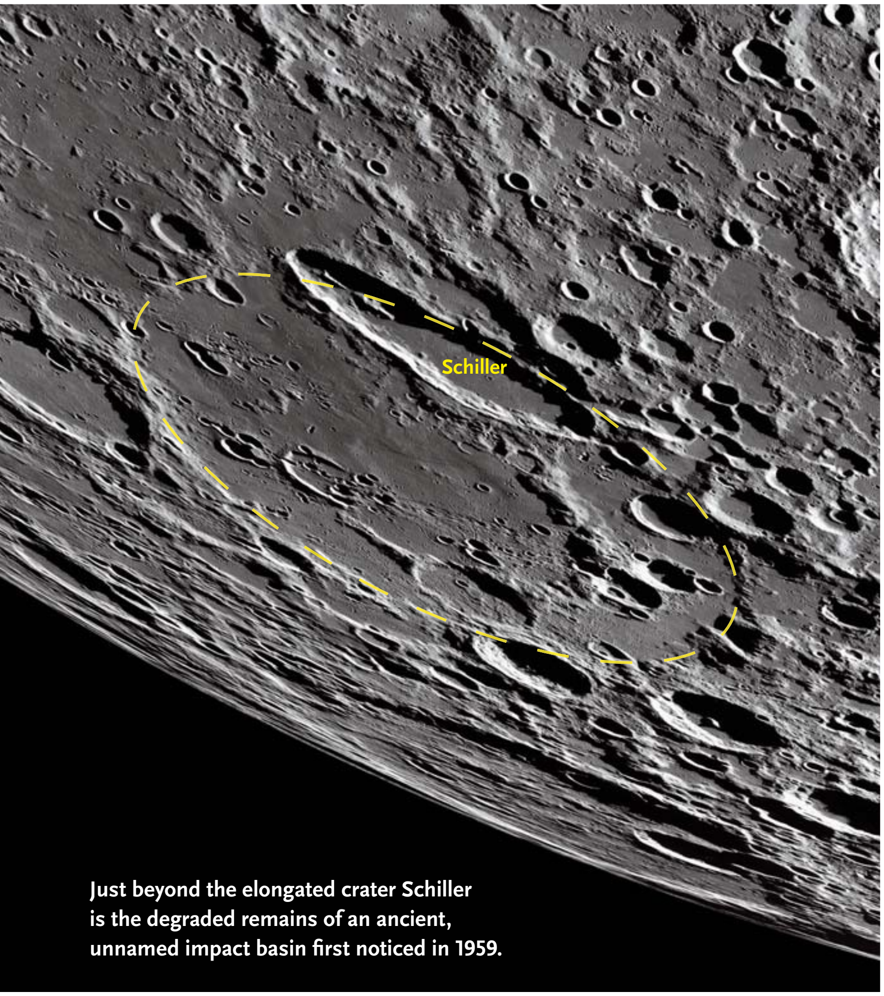
Every day, interesting events happen between Jupiter's satellites and the planet's disk or shadow. The first columns give the date and mid-time of the event, in Universal Time (which is 5 hours ahead of Eastern Standard Time). Next is the satellite involved: **I** for Io, **II** Europa, **III** Ganymede,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

Hunting for Lost Basins

Can you find hints of these buried features?

It seems odd that many of the biggest landforms on the Moon are often the most difficult to see. Massive impact basins such as the ones containing Mare Imbrium and Mare Nectaris are easily recognized due to their roughly circular expanses of smooth lava and surrounding mountainous rim arcs. But older basins tend to disappear.

The youngest and best-preserved lunar basin is **Mare Orientale**, but unfortunately its center lies just over the western limb, so we only occasionally glimpse strongly oblique views of its outer mountainous rings and dark mare lavas. Spacecraft images show that the Orientale basin has three or more concentric inner rings, like terraces in smaller crater walls, which surround a flattish central region. The Orientale basin contains a small central mare, with additional leaks of lava along the inside scarps of its rings.



Just beyond the elongated crater Schiller is the degraded remains of an ancient, unnamed impact basin first noticed in 1959.

NASA / GSFC / ARIZONA STATE UNIVERSITY

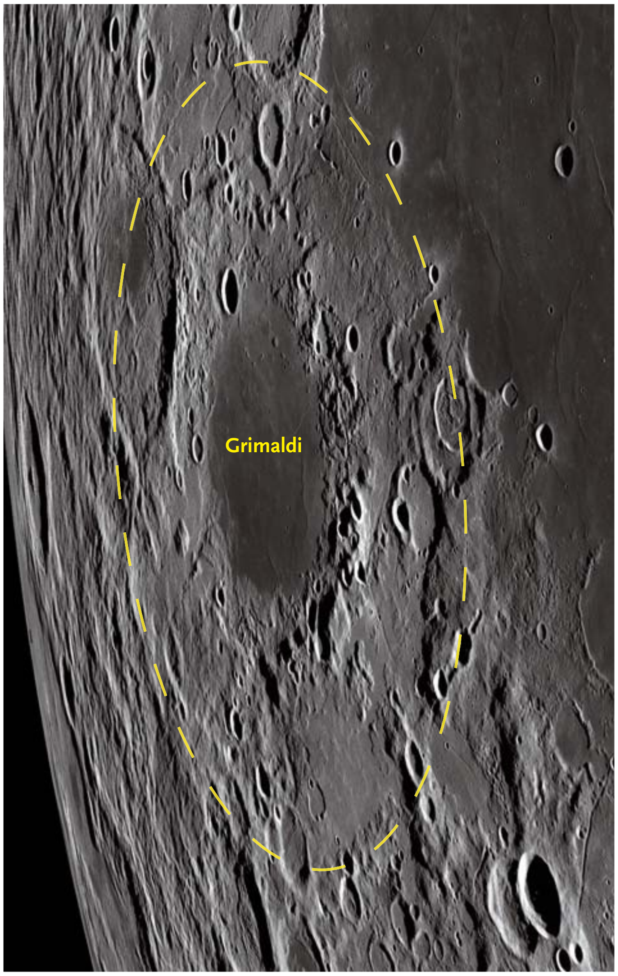
Scientists generally presume that most large lunar basins resembled Orientale when they formed, but that might not be the case. For example, the main rim of the relatively young Imbrium basin (which contains Mare Imbrium) is **Montes Apenninus**, which curves around just ¼ of the basin's circumference, and appears to have formed that way. Similarly, the 90° arc of **Rupes Altai** along the southwest rim of the Nectaris basin weakens and disappears in both directions.

The Imbrium basin has inner rings similar to those in Orientale, but they are largely covered by thick layers of mare lavas, with only a few emergent mountains (including **Mons Pico** and **Mons Piton**) and mare ridges possibly marking a ring location. Imbrium shows that not all newly formed impact basins necessarily had perfect bull's-eye patterns, and that subsequent events can bury and modify the original basin landscape.

Each large basin has its own peculiar history of formation and modification. **Mare Crisium** is surrounded by a nearly continuous ring of massive mountains, but they don't have the steep inward facing scarps of the Apennine and Atlas basin rims. Crisium, like Serenitatis and the other large basins, contains a hint of an inner ring that is detectable under low illumination. You can trace out subtle mare ridges that define the buried inner rings in Crisium, **Mare Serenitatis**, and **Mare Humorum**.

Older basins have shallower, discontinuous rims; their lava-covered floors are cratered by many subsequent impacts, and are lightened by rays and more extensive veneers of bright ejecta. Such old basins gradually disappear, making them an especially good observing challenge to find.

A small basin that most observers have seen but not recognized exhibits both a scarp-like rim and an unburied inner ring. Between **Schiller** and **Zucchius** in the Moon's southwest quadrant is a relatively flat-floored 208-mile-wide (335-km) basin that is often overlooked because of its more imposing neighbors. If you look closely, you'll observe both a basin rim that extends more than ¾ of the way around the central plain and a mountainous ridge that defines an inner ring. This structure is the only example on the lunar nearside of a basin whose size and morphology is common



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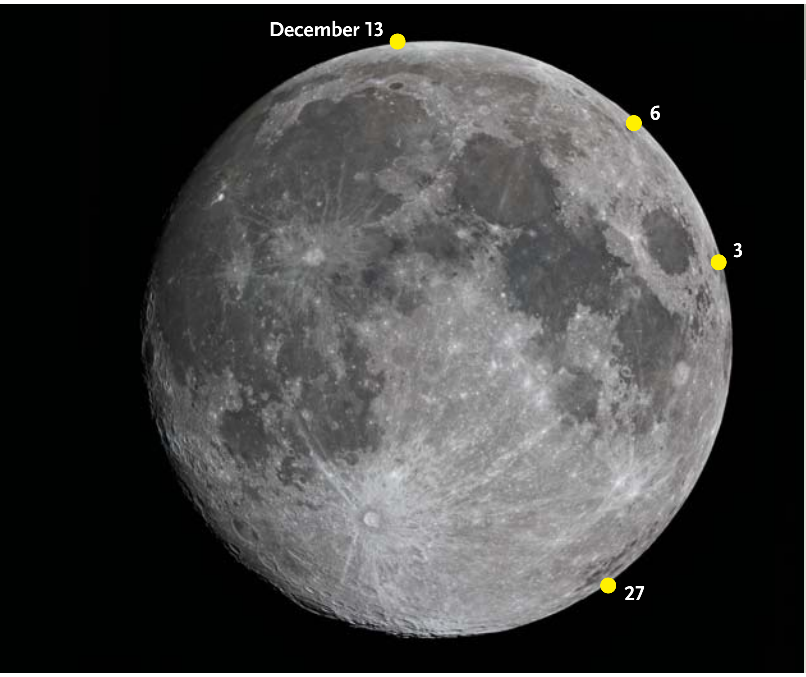
Although named as a typical lunar crater, Grimaldi is the flooded central ring of a larger impact basin whose outer rim is degraded by later cratering events.

on the lunar farside as well as on the rocky worlds Mercury and Mars.

Another unappreciated basin has a very conspicuous central lava deposit, but a basin rim and inner ring that are difficult to recognize. **Grimaldi** was named as a crater because the low ring that surrounds the central dark mare patch was mistaken for a crater rim. It's actually the inner ring of an impact basin whose northern rim was largely destroyed, but whose southern rim is just visible as the boundary between an inner, light-hued, smooth area and the rougher terrain beyond.

Some basins are so old and heavily modified that their existence is not completely certain. Since most nearside basins are named after the mare lavas they contain, it's generally presumed that every mare is contained within a basin. For the Serenitatis basin that's likely because **Montes Haemus** is probably the last remnant of the rim, whereas the **Serpentine Ridge** and other mare ridges within the basin may define its inner ring. But there is less evidence that impact basins underlie Mare Nubium, Mare Tranquillitatis, and Mare Fecunditatis. The next time you observe the Moon, see if you can find evidence for basin rims or mare ridge inner rings for these maria. ✦



S&T: DENNIS DI CICCO

The Moon • December 2014

Phases

FULL MOON
December 6, 12:27 UT

LAST QUARTER
December 14, 12:51 UT

NEW MOON
December 22, 1:36 UT

FIRST QUARTER
December 28, 18:31 UT

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

Distances

Apogee 251,395 miles	December 12, 23ʰ UT diam. 29′ 32″
Perigee 226,674 miles	December 24, 17ʰ UT diam. 32′ 46″

Librations

Cannon (crater)	December 3
Mercurius (crater)	December 6
Pascal (crater)	December 13
Mare Australe	December 27

The Starry Heavens

Clusters and nebulae abound in compact Cassiopeia.

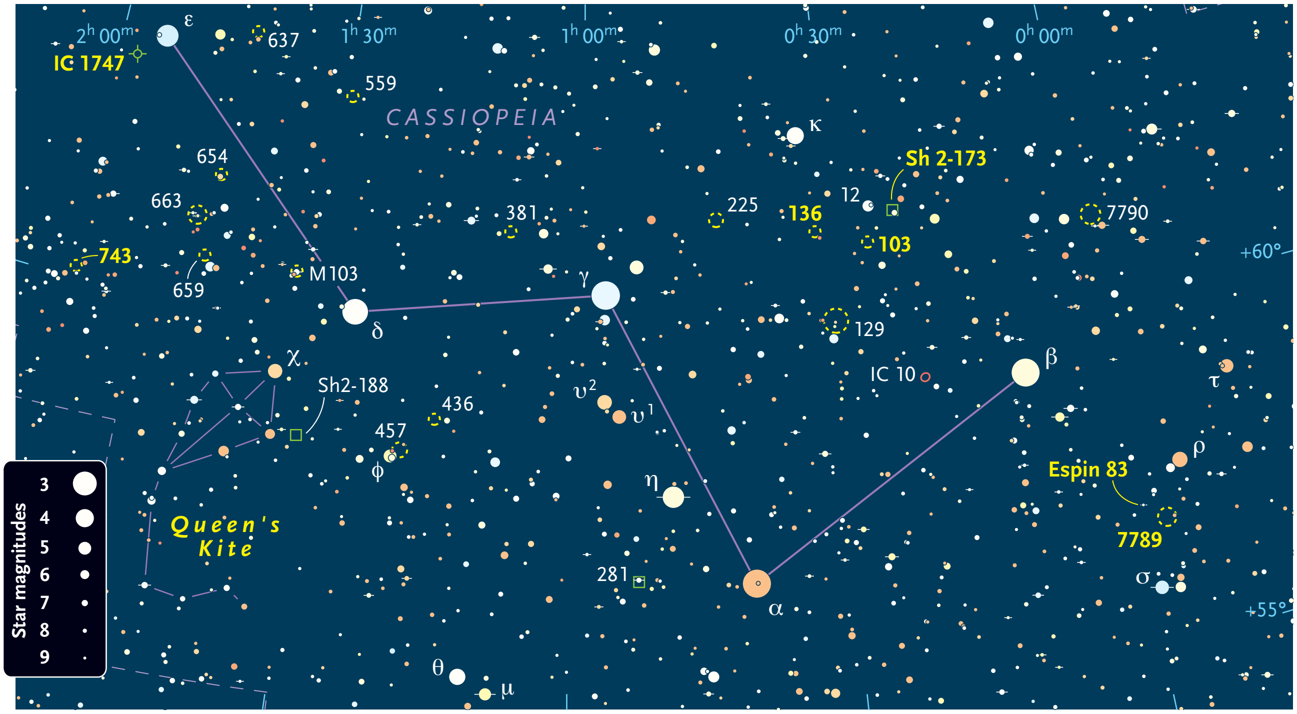
Ye quenchless stars! so eloquently bright,
Untroubled sentries of the shadowy night,
While half the world is lapp'd in downy dreams,
And round the lattice creep your midnight beams,
How sweet to gaze upon your placid eyes,
In lambent beauty looking from the skies!
— Robert Montgomery, *The Omnipresence of the Deity*, 1828

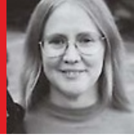
Several bright and shining eyes gaze down at us from Cassiopeia, and a wealth of lesser lights join them from their favored position along the crowded plane of our galaxy, where reigns the Milky Way in soft and misty splendor.

Many of the constellation's twinkling peepers are gathered into star clusters, with **NGC 7789** being one of the most beautiful stellar gatherings in our sky. The cluster shares a low-power field of view with the yellow hypergiant Rho (ρ) Cassiopeiae. A yellow hypergiant is a highly luminous supergiant that suffers prodigious mass loss, as well as occasional eruptions that dim the star with a cloak of ejected material. If Rho replaced our Sun, it would extend out beyond Mars to the inner edge of the asteroid belt.

NGC 7789 is easily visible through my 8×50 finderscope as a sizable, grainy glow. My 130-mm refractor at 23× unveils a beautiful cluster richly populated with pinpoint stars. An orange, 8th-magnitude star on the group's western fringe helps me assign an apparent diameter of 20′ to the cluster. NGC 7789 is stunning at 63× and reveals far too many stars to count, with the brightest weighing in at 10th magnitude. The fainter the stars, the more numerous they become, until they coalesce into a stippled haze in the cluster's teeming 12′ core.

NGC 7789 is a spectacular sight when viewed through my 10-inch reflector at 70×. Its panoply of stars is enchantingly filigreed with inky black threads that wind through the cluster. Off the group's northeastern side, the double star **Espin 38** displays a yellow-white primary with a ruddy companion to its west-southwest. The companion is a carbon star that varies from magnitude 9.9 to 12.7. Sometimes called Wildt's Red Star, after the German-American astrophysicist Rupert Wildt, this variable is currently near peak brightness. When I boost the telescope's magnification to 115×, NGC 7789's core stars seem





to be arrayed in a strange spiral pattern that unwinds clockwise from the center for more than 1½ turns.

Beta (β) Cassiopeiae, also known as Caph, lies halfway between NGC 7789 and the large emission nebula **Sharpless 2-173**, and 5th-magnitude 12 Cassiopeiae guards the nebula's east-northeastern edge. The inconspicuous star cluster Mayer 1 rests at the heart of the nebula, with a 7th-magnitude star marking its south-southwestern edge.

Through my 105-mm refractor at 47×, all I can see of Mayer 1 is a bent band of 10 stars. The brightest one is magnitude 9.5 and defines the cluster's center. These stars are entangled in a feeble glow that spreads southward to a 4′ trapezoid of 9th- and 10th-magnitude stars. The most prominent part of the nebula is a misty arc northwest of Mayer 1. A dark void between it and the cluster nicely delineates the arc's concave inner edge, and a pretty, reddish-orange, 7th-magnitude star adorns the outer edge. Very faint nebulosity weds this arc to the amorphous glow south of the cluster.

Although filters don't help much with the little refractor, a narrowband nebula filter works fairly well with my 10-inch reflector at 68×, expanding Sh 2-173 and emphasizing the dark gap between the arc and Mayer 1. Except for this fairly bright arc, the nebula's outer regions are vague. I'd guesstimate a maximum width of 18′ to 20′.

Czech astronomer Pavel Mayer introduced this cluster in a 1964 paper titled "List of Open Star Clusters in Emission Nebulae." It appeared in the journal *Publications of the Astronomical Institute of the Charles University* (*Acta Universitatis Carolinae. Mathematica et Physica*). The three clusters designated "Anon." (anonymous) in Mayer's list now bear his name.

Dropping ½° southward from 12 Cassiopeiae with my 130-mm refractor at 37×, I see a small, elongated, granular, fuzzy patch with two stars at its northeastern end. This is the open cluster **NGC 103**. At 102× ten stars emerge from the haze, and a half dozen stars scattered around them fill the group out to a diameter of 3½′. Through my 10-inch reflector at 187×, I count 30 stars within a diameter of 5′. Many are gathered into a bar that tapers southwest, and most of the rest form two drooping arms that sprout from each side of the bar's wide end.

NGC 136 sits just 46′ east-northeast of NGC 103. At 102× the 130-mm refractor readily shows a subtly flecked, diminutive patch of haze, though it does appear rather faint. The cluster spans 1¼′, and a very dim star dots its north-northeastern edge. NGC 136 is lovely through my 10-inch scope at 115×. It brings to mind a little mound of beach sand sparkling with minuscule grains.

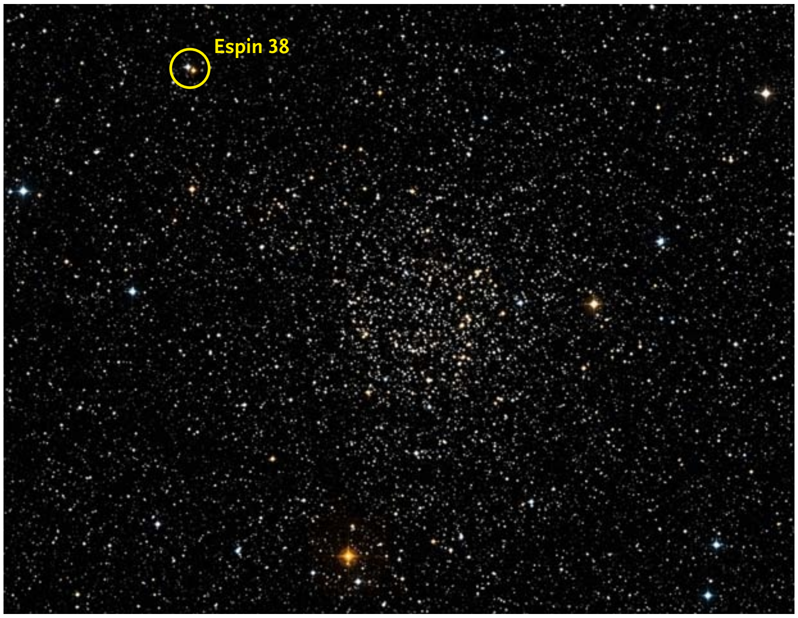
The **Queen's Kite** is a nice binocular asterism for those who live under skies compromised by outdoor lighting, and it's straightforward to locate near Delta (δ) Cassiopeiae. Dark skies or large binoculars reveal dim stars that may overwhelm the asterism's pattern.

The Queen's Kite is easily visible though 10×30 binoculars from my moderately light-polluted yard, even with a crescent Moon in the sky. The kite is topped by 4.7-magnitude Chi (χ) Cassiopeiae, and the rest of its stars are 6th and 7th magnitude. From Chi, the 2.2°-tall kite slants southeast, with each corner marked by a star. Additional stars lie along the kite's long sides, two in the east and one in the west, while another star marks the intersection

Clusters, Stars, and Nebulae in Cassiopeia

Object	Type	Mag(v)	Size/Sep	RA	Dec.
NGC 7789	Open cluster	6.7	25′	23^h 57.5^m	+56° 43′
Espin 38	Double star	9.8, 10.7	24″	23^h 59.1^m	+56° 58′
Sharpless 2-173	Emission nebula	—	25′	00^h 21.9^m	+61° 44′
NGC 103	Open cluster	9.8	5.0′	00^h 25.3^m	+61° 19′
NGC 136	Open cluster	11.5	1.5′	00^h 31.5^m	+61° 31′
Queen's Kite	Asterism	—	4.0° × 2.3°	01^h 37.8^m	+57° 23′
NGC 743	Open cluster	9.5	8.0′	01^h 58.6^m	+60° 09′
IC 1747	Planetary nebula	12.0	13″	01^h 57.6^m	+63° 19′

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



POSS-II / CALTECH / PALOMAR OBSERVATORY

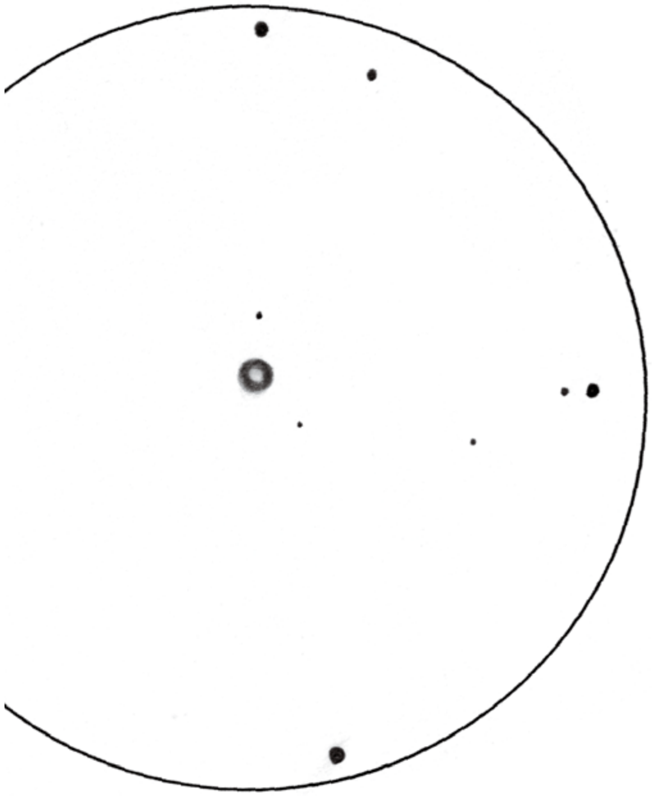
NGC 7789 is extraordinarily rich and old as open clusters go. The wide range of colors among its stars is due to the fact that many have evolved into red giants.

of the kite's crossbars. Below the kite's bottom, a solitary star starts the kite's tail, and farther south, four faint stars in an east-west zigzag complete it. The Queen's Kite is a product of the fertile imagination of Massachusetts amateur John Davis.

With my 105-mm refractor at 17×, sweeping about 4° eastward from Delta Cassiopeiae takes me to a rich star field 1½° across. The open cluster **NGC 743** is a small knot of stars nestled amid these brighter eyes. At 87× this is a distinctive cluster of 17 stars, 9th magnitude and fainter, in a 7′-wide group. Seven of the brightest stars make a broad, eastward-pointing V, and six stars within the V make a smaller capital D. In the northern arm of the V, the star closest to the point is the John Herschel double h1098 (HJ 1098). The 10th-magnitude primary has a 12th-magnitude companion 18″ to its north.

S&T: SEAN WALKER

The large emission nebula Sharpless 2-173 lies west-southwest of the bright, bluish star 12 Cassiopeiae.



Finnish stargazer Jaakko Saloranta sketched IC 1747 as seen through an O III filter on his 8-inch reflector.

Our last stop is the petite planetary nebula **IC 1747**, located 30′ southeast of Epsilon (ε) Cassiopeiae. At low magnification, it masquerades as just another star in an eye-catching, sinusoidal curve of 11th- and 12th-magnitude stars that runs east-northeast to west-southwest for 18′. In my 15-inch reflector at 102×, IC 1747 sheds its disguise, appearing fairly bright, small, and round. It's very nice at 216× — quite bright and softly annular with a fainter fringe. The nebula would span half the distance between two field stars that are 26″ apart. I couldn't see the 15.4-magnitude central star nor the brighter patches on the north and south rims of the annulus. Can you?

You don't need a 15-inch scope to enjoy IC 1747. Impressively, Finnish amateur Jaakko Saloranta could clearly see the annulus at 267× with an 8-inch reflector and an O III filter.

Williamina Fleming discovered IC 1747 in 1905 while she was classifying stars by examining photographic, objective-prism spectra. Her description reads, "Assumed to be the following and southern of two faint and difficult objects, which also appears somewhat hazy. The spectrum consists of a bright band having wave length of about 5000. Therefore, this object has been assumed to be a gaseous nebula." ✦

A Visual Guide to the Cassiopeia A Supernova Remnant

Howard Banich

Long thought unobservable, this important object displays surprising detail through medium to large backyard telescopes.

It was a dark and transparent night at the 2009 Oregon Star Party, and I was climbing the ladder to the eyepiece of my 28-inch scope, which pointed nearly straight up. I could already feel my spine tingle from awe and excitement. I was about to see Cassiopeia A for the first time, something that only a few other people had ever seen. This is what I wrote in my notebook after the observation:

"Holy smokes . . . it was immediately obvious at 105× with the UHC and O III filters, and then without filters! Seems like this should have an NGC or IC number. Chills went up my spine when I saw it — and I'm still genuinely thrilled. This is a lifetime observation for me. The supernova remnant seems to have a filamentary structure but it's only suspected with averted vision, plus it's nearly two objects in close contact. Wonderful, memorable object. 105× to 408×, 21.48 on my SQM (Sky Quality Meter)."

Until a month earlier, if I thought of Cas A at all, I considered it unobservable because of comments such as this excerpt from its Wikipedia entry: "It is extremely faint optically, and is only visible on long-exposure photographs." As the saying goes, don't believe everything you read on the internet!

Fortunately, the Fall 2009 issue of *Amateur Astronomy Magazine* included an article by Arizona amateur William Gates about observing Cas A through a 9.25-inch SCT equipped with an O III filter. So much for being "only visible on long-exposure photographs!" If Gates could see it with a 9.25-inch scope, surely I would have no trouble with my 28-inch under the superb dark skies of the Oregon Star Party. Even so, some of Cas A's unobservable aura still lingered as I was climbing toward the eyepiece. It was a fabulous moment when I first saw it.

What is Cassiopeia A?

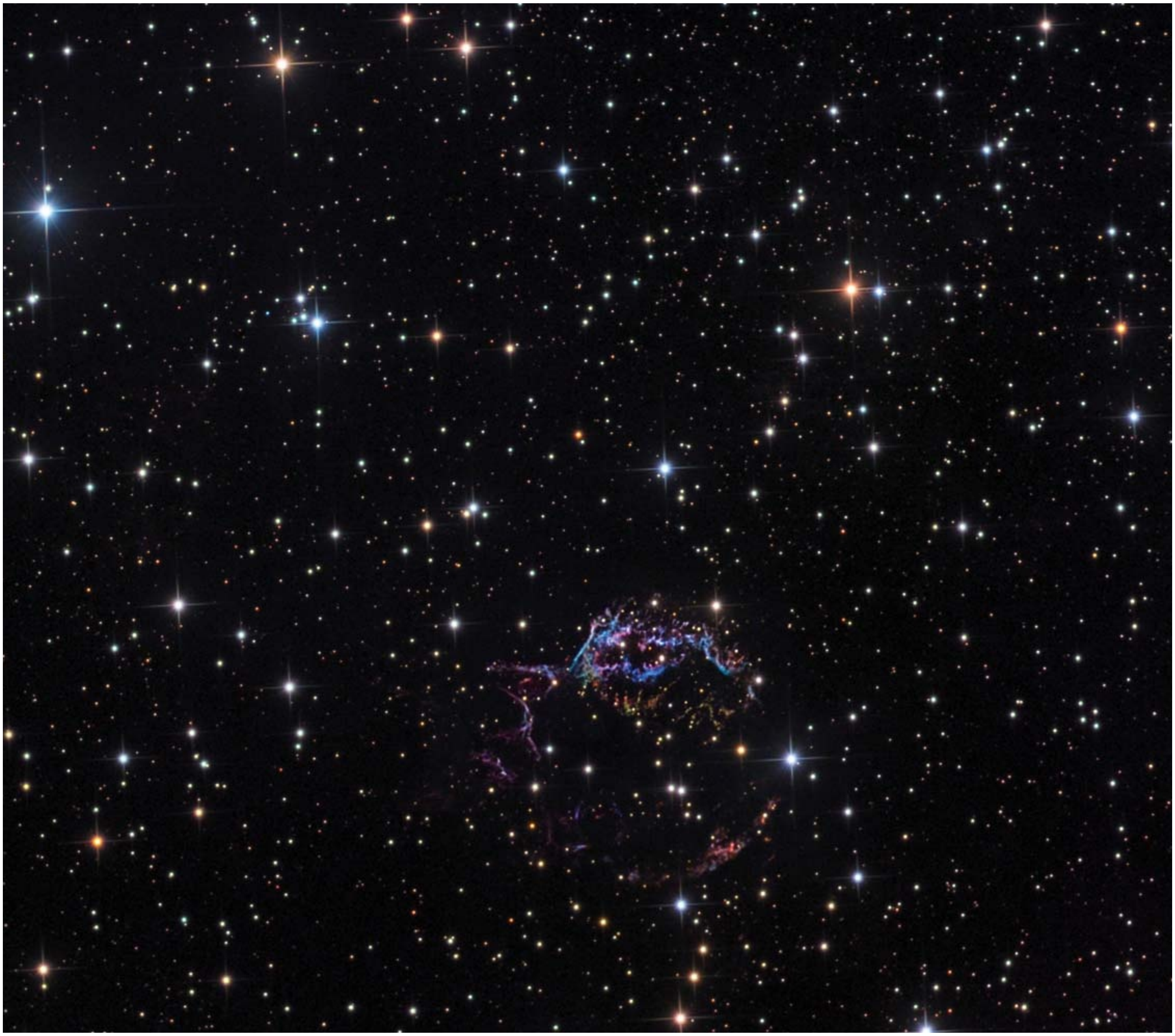
Approximately 11,000 light-years away lie the remains of a star that exploded as a supernova, now known as Cassiopeia A. Based on its current expansion rate, astronomers estimate that the light from the supernova should have reached Earth around 1667. You'd think it would have lit up the skies and been widely reported, but it seems to have escaped notice. It's been suggested that it may have been recorded in 1680 by John Flamsteed as the 6th-magnitude star 3 Cassiopeiae, but it seems more likely that the supernova was heavily veiled by the dust thrown off by its progenitor star in the millennia before it blew up.

What we see today are the remains of this exploded star along with surrounding material that the explosion swept up during its violent expansion. The matter caught up in the supernova shock wave now glows throughout the electromagnetic spectrum as a result.

All that's left of the progenitor star is a neutron star, although a recent study suggests it may be an exotic quark star (see **skypub.com/casa-quark**).

Visual Observations

Regardless of its historical visibility, the Cas A supernova remnant (SNR) is now about 13 light-years across, and it's the brightest radio source in the sky outside our solar



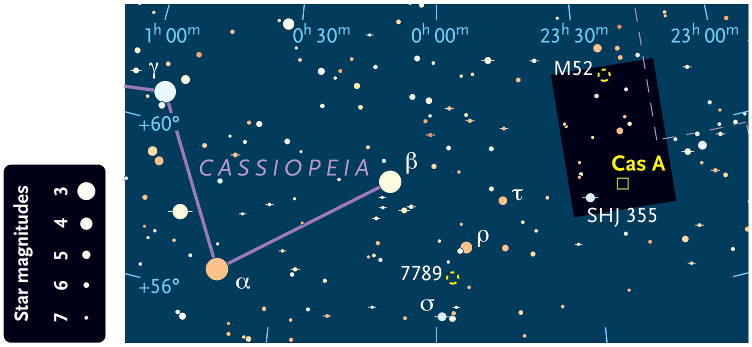
MAKIS PALAIOLOGOU / JOHANNES SCHEDLER / JOSEF PÖPSEL / STEFAN BINNEWIES

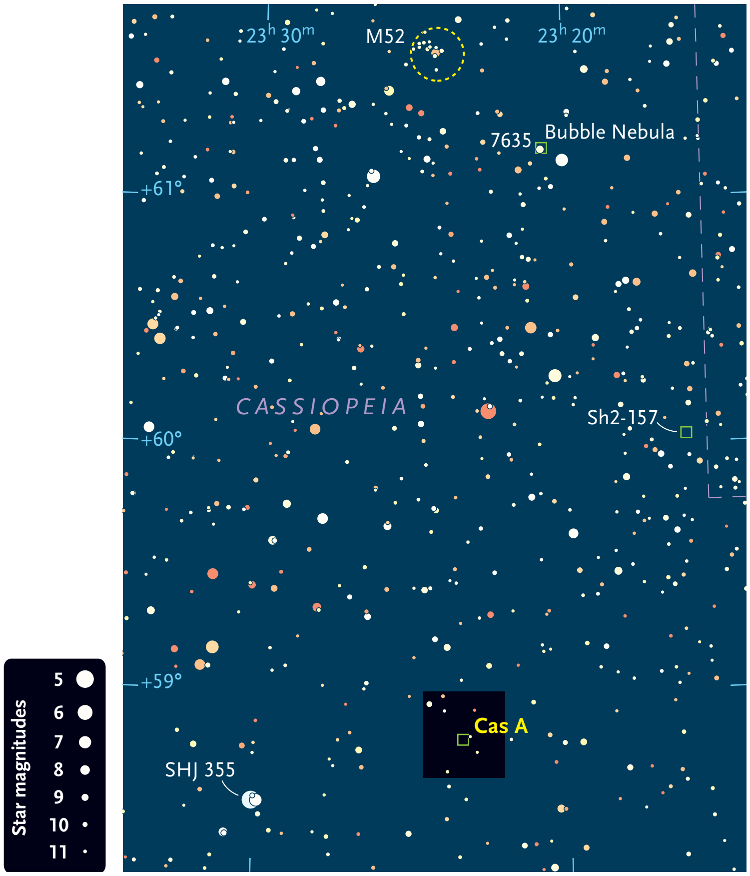
This stunning true-color image of Cassiopeia A required more than 8 hours of exposures on a 300-mm telescope. It's centered at right ascension 23^h 23.4^m, declination +58° 48^m and lies 0.9° west-northwest of the handsome multiple star SHJ 355, as shown in the chart on the next page.

system. Although visually rather dim, it's considerably brighter than you might expect for an object that was widely considered unobservable for so long. I estimate that the brightest part of the northern arc is approximately visual magnitude 14.0. It's about 4′ long, comparable to the bubble inside the Bubble Nebula, NGC 7635, which lies just 2.5° to its north. Narrowband and O III nebula filters enhance its visibility.

Since the 2009 Gates article, Cas A has been gaining increasing notice among visual observers, and growing numbers of observations are found online. The earliest observation I'm aware of was in 2007 by John Tatarchuk of Austin, Texas, using his 18-inch Dob. In any case, amateur observations are a relatively new thing. Cassiopeia A is plotted in the *Millennium* and *Uranometria* atlases as a radio or X-ray source, but it doesn't appear in any catalog of nebulous objects. This has contributed to its obscurity among visual observers for too long.

Because it's brighter than some NGC and IC objects, Cas A could have been discovered visually when these catalogs were put together in the 19th century. It was merely bad luck that nobody saw it back then, and it's interesting to imagine what observers such as the Herschels or Lord Rosse would have seen with their 18th- and 19th-century telescopes. More to the point, what can you see with your 21st-century telescope?






The author's initial 2009 sketch showed only the northern arc of Cassiopeia A.

The Northern Arc

The observations reported here were made with two Newtonian reflectors: my 28-inch and Jimi Lowrey's 48-inch, so they represent what can be seen in large apertures. But don't forget that Gates saw Cas A with his 9.25-inch SCT and an O III filter, so this isn't just an object for large amateur telescopes.

The first time you spot Cas A, you're likely to see the northern arc, which is by far the brightest part of the object. The northern arc has two main sections, although only the larger and brighter of these is visible in modest-sized scopes. If history is any guide, as more people become familiar with Cas A, some will see both parts of the northern arc with ever-smaller scopes. The sketch at lower left is my 2009 view of Cas A's northern arc.

I've become better acquainted with Cas A since then, with my best 28-inch observation so far coming from the 2011 Oregon Star Party. This was on a significantly darker and more transparent night than my first observation in 2009, and my observing notes read:

"OK! Best view yet of Cas A, but still no sign of the (southern) arc. I took out the Paracorr so there was minimal glass, and that very slightly boosted contrast of the nebulosity but didn't reveal the (southern) arc. At least not for tonight. I think I can see it from Steens Mountain under a great sky. I got the darkest of tonight's sky at 21.71 SQM, though. I used 220× and 355×, with 355× best with the (DGM Optics) NPB filter — the O III dimmed the SNR too much. I put an hour and a half into this observation."

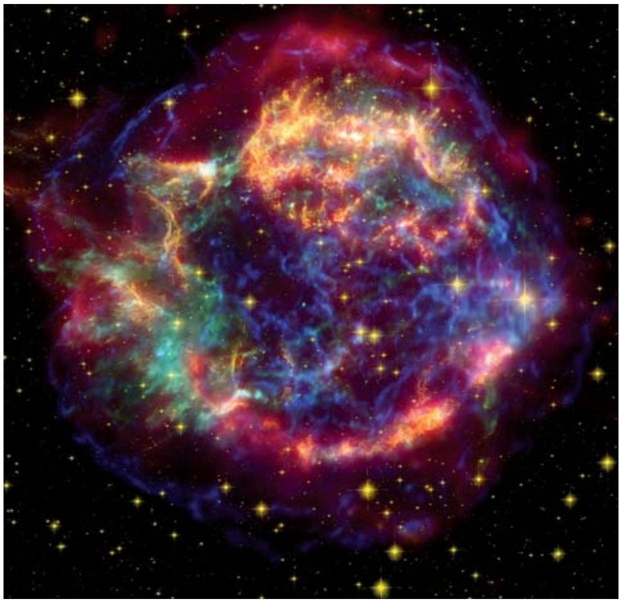
I've had similar views since 2011, but I haven't had the superior observing conditions needed to see if my hopeful speculation about seeing the southern arc with the 28-inch is correct.

In Lowrey's 48-inch, the northern arc was full of filamentary and mottled detail, as shown in the sketch on the facing page. I also saw what at first appeared to be a third segment of the northern arc.

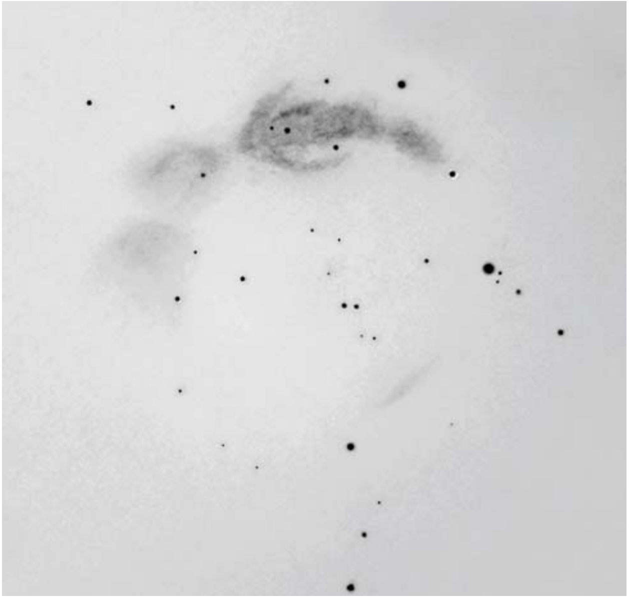
The Southern Arc

The brightest parts of the southern arc are extremely difficult to detect, and I've had no luck at all with my 28-inch so far. In November 2013, *S&T* contributing editor Steve Gottlieb and I visited Lowrey at his home in Fort Davis, Texas, and we observed together for several nights with Lowrey's magnificent 48-inch f/4 Newtonian. My primary target for this trip was the southern arc of Cas A, and I wasn't disappointed:

"AWESOME!! I finally saw a chunk of the southern arc!! Very faint, thin, with one bright spot I could see with extreme averted vision. The northern chunk is full of filaments and knots I haven't seen before using both the NPB and DGM O III filters. The O III gave a slightly more contrasty image with both the 10-mm and 8-mm Delos eyepieces. There was also a faint bit of the northern arc I hadn't seen before. Overall, Cas A looks like the Veil



NASA / JPL-CALTECH / OLIVER KRAUSE



***Left*: This false-color image of Cassiopeia A shows infrared light from the Spitzer Space Telescope as red, visible light from the Hubble Space Telescope as yellow, and X-rays from the Chandra X-ray Observatory as green and blue. *Right*: This detailed sketch combines elements of the author's views through his 28-inch scope with features seen only through Jimi Lowrey's 48-inch Newtonian.**

Nebula only 10 times farther away. 21.52 SQM."

As it turns out, the best distance currently available for the Veil Nebula, from the Far Ultraviolet Spectroscopic Explorer (FUSE) mission, is 1,470 light-years, placing Cas A about 7.5 times farther away. The guess of 10 times farther that's mentioned in my notes came about as we took turns at the eyepiece of the 48-inch telescope, and Gottlieb came up with what we agreed was an apt comparison. As wild guesses go, that was a pretty good one.

Much later, after comparing my sketch to photographs and the 3D model at **skypub.com/casa-3d**, it turns out we'd seen two parts of the southern arc. What I'd originally thought was a third part of the northern arc is actually the easiest part of the southern arc to see — it's the second puff of nebulosity off the western (left) end of the northern arc in my sketch. The area between them corresponds to the northwestern blowout area.

The bipolar blowout lanes are areas where the supernova blast was able to move with the least resistance; they were probably sculpted by a stellar wind from the progenitor star before it blew up. If you examine the multiwavelength image above, you'll notice streamers of material shooting out both the northwestern and southeastern blowout lanes.

The brightest portion of the southern arc is slightly in the foreground of the northwestern blowout area. Taking the axis of the blowout lanes as the north-south divide places what I'd originally considered the third segment of the northern arc as a physical part of the southern arc.

However, the real prize of the 48-inch observation was seeing an extremely faint wisp of the southern arc almost directly opposite the northern arc, as shown at the bottom of the sketch. This is the brightest segment of the southern arc in photos, and it has been my main target since 2009. Even though it required a 48-inch telescope and determined averted vision, it was a moment of joy to finally see it.

Spinning around the 3D model at **skypub.com/casa-3d** is not only instructive, but a lot of fun. (*Note*: At the time of this writing, the interactive model seems to be nonfunctional, but a movie on that site shows how it works.) This tool made it clear we saw two parts of the southern arc instead of only one. It also makes it apparent that the northern and southern arcs are the brightest parts of a 3-dimensional bubble as seen from our vantage point, and that Cas A looks very different from other perspectives.

A Visual Composite

My original sketch of Cas A through the 48-inch scope was made from memory right after coming down the observing ladder, so the drawing presented above is a composite made by blending the 48-inch sketch with my best 28-inch sketch, which was drawn at the eyepiece. The resulting drawing more accurately portrays what we saw through the 48-inch.

Although this effort falls short of what might be seen with hours of determined observations through the 48-inch over many nights, it may still represent the most detailed visual observation to date of the Cassiopeia A supernova remnant. The view really was reminiscent of what the Veil Nebula might look like from much farther away, and it was in every way a wonderful, memorable sight. ✦

***Howard Banich** can be reached by e-mail at howard.banich@nike.com. He would love to hear about any visual sightings of Cassiopeia A prior to 2007.*

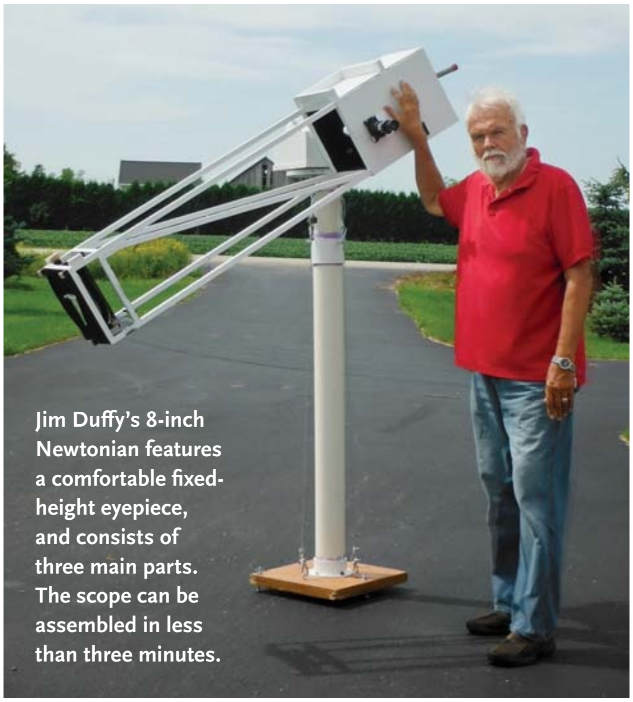
A Convenient Newtonian

A simple trick facilitates comfortable viewing with a fixed-height eyepiece.

TELESCOPES MADE TO ORDER. That promise is central to the allure of ATMing — you can have what you want, when you want it. So if you like to stand up straight while observing, you might decide to make something similar to Wisconsin ATM Jim Duffy's telescope. "My interest in astronomy dates from the 1940s when I used a 4-inch reflector with a cardboard tube," says Jim. "Now, after a 50-year career in computers and raising 14 children, I finally have time to get back into it."

Jim refers to his 8-inch f/7 reflector as his Porter Newtonian, after the famed scope on Breezy Hill in Springfield, Vermont. That scope was built by Russell Porter, who also designed the 200-inch Hale reflector on Palomar Mountain. Jim's scope shares several advantages with Porter's Springfield instrument. Most importantly, the eyepiece remains at a constant height regardless of where the telescope is aimed. Unlike the Porter version though, the focuser in Jim's reflector moves in azimuth with the rest of the optical tube.

A less obvious advantage shared by both scopes is that the optical tube's balance is unaffected by the eyepiece's weight. This potential for imbalance can be a real problem with conventional Dobsonians, especially those with apertures 8 inches and smaller. Comfort is another important benefit. "With Dobsonians, I'd often find myself bent over awkwardly — especially when observing objects near the horizon," Jim says. "That's not conducive to attentive, relaxed viewing."


Jim Duffy's 8-inch Newtonian features a comfortable fixed-height eyepiece, and consists of three main parts. The scope can be assembled in less than three minutes.

JIM DUFFY

Jim's scope achieves these advantages with a single, simple design twist: the focuser is positioned at the center of the altitude axis. Since this is also the scope's balance point, Jim needed to make the back end of his scope as lightweight as possible so that it wouldn't require a tremendous amount of counterweight. The focuser cage also had to be very sturdy. He used both 3/8- and 5/8-inch thick plywood for this component, and lightweight lengths of 3/4-inch hickory for the struts connecting the focuser cage to the mirror box.

Jim's mount is essentially Dobsonian technology placed on top of a 64-inch-high pier. The altitude bearings consist of PVC pipe flanges riding on Teflon, whereas the azimuth motion utilizes conventional Teflon-and-Formica bearings. The 4-inch-inside-diameter PVC pier is secured to a plywood base with a large pipe flange and four sets of tensioned guy wires. To balance the tube, he made a counterweight assembly from commonly available galvanized-steel plumbing components and barbell weights. The mount works smoothly and, as Jim notes, "I seem to have better control over the motions — in azimuth especially — probably from being positioned so close to the axes."

The telescope is comfortable and convenient to use. It breaks down into three 25-pound parts: the mount (including the pier), counterweights, and optical tube. This allows quick and easy field assembly. "It's a great improvement over my old, heavy Dobsonian," says Jim. "The pier support is solid even in the wind and I enjoy the mount's smoothness and ease of control."

Readers wishing to know more about Jim's telescope can contact him at scope@jfduffy.com. ✦

*Contributing editor **Gary Seronik** is an experienced telescope maker and observer. You can contact him via his website, **www.garyseronik.com**.*

Rod Mollise

ALL PHOTOS COURTESY OF THE AUTHOR

Celestron Package:

A Lot for a Little

An ensemble of Celestron equipment provides excellent visual and photographic performance.

AS ROBERT HEINLEIN used to say. "There ain't no such thing as a free lunch." That's usually true, but I *almost* feel like I got a free meal with Celestron's Edge 800 Schmidt-Cassegrain Telescope and VX mount. I found the combination of the advanced 8-inch SCT and inexpensive German equatorial mount (GEM) surprisingly capable, especially when equipped with Celestron's Edge f/7 reducer, off-axis guider, and StarSense auto-alignment system.

I have dreamed of an enormous SCT on a fork mount to ease me into my golden years. Unfortunately, I have to carry my scope to dark sites to do my best observing, and I really didn't want to haul a 14- or 16-inch telescope around. The more I thought about it, the more convinced I became that an 8-inch SCT was still the scope for me. Maybe my retirement scope should be a C8 of *a new type*, though, Celestron's Edge 800.

VX MOUNT **U.S. price:** $1,799 **www.celestron.com**

WHAT WE LIKE:

Excellent Go To accuracy

Tracking good enough for unguided 30-second exposures

Stable with an 8-inch SCT and accessories

WHAT WE DON'T LIKE:

Hand-control cable is too short

The included counterweight is too light for use with the telescope and heavy cameras or accessories

The author's Celestron 8-inch Edge SCT sits atop a VX German equatorial mount. The standard 9x50-mm finderscope is attached. A 12-pound counterweight is included in the package.

Different from other Schmidt-Cassegrains, the Edge includes a built-in corrector-lens system that both flattens the SCT's normally curved field and reduces coma, the blurring of stars at the field edge. For more on the Edge, see Dennis di Cicco's review of the Edge 1400 (*S&T*: Feb. 2011, p. 52). The Edge 800 is a scaled-down version of its innovative big sister.

I thought I'd purchase a new mount too — one that Celestron is pairing with the Edge 800, the Advanced VX. The VX's payload capacity is 30 pounds (14 kg), making it the company's smallest computer-equipped GEM. But it's well matched for a C8. Celestron currently offers the combination as a package for $1,799.

I purchased the telescope and mount last year, and they arrived in pristine condition. The tube came equipped with a 50-mm finder and a Vixen-format dovetail bar to fit the VX. *S&T* recently borrowed a StarSense and an off-axis guider from Celestron and shipped them to me to complete the package so I could write this review.

The box that contained the VX mount included the GEM head, a 2-inch steel-legged tripod, a single 12-pound counterweight, the NexStar Plus computer hand control, a cable for updating the mount's firmware, an instruction manual, the basic version of Software Bisque's *TheSkyX* planetarium software, and a DC power cord with a cigarette-lighter-style plug.

The Edge 800 is a striking pale green and the mount is impressively well finished for a GEM in this price class. I particularly appreciated the VX's large adjustment knobs, well-laid-out control panel, and big power switch that's easy to manipulate with gloved hands.

Visual Use

On my first clear night, I hustled the new scope out to my club's dark site. I didn't run into any problems assembling the mount or attaching it to the scope. After a little practice, most people won't need more than 10 to 15 minutes to set up the Edge/VX combo for visual use.

The big deal, though, was not how easy the scope and mount were to assemble, but how easy they were to transport. The package breaks down into easily manageable components that encourage me to use it frequently. At 14 pounds (6.4 kg) for the telescope, 17 pounds for the mount head, and 18 pounds for the tripod, I never had to strain. The telescope was quite stable on the mount with vibrations dying out in a couple of seconds.

A GEM must be property aligned on the celestial pole to track stars accurately. Polar alignment is simple for visual use. Remove the end caps from the VX's right ascension housing, turn the scope perpendicular to the mount's head to open up a hole in the declination axis, and then sight Polaris through the hollow polar bore. After these steps, the mount's Go To system will find objects with even the roughest polar alignment, though tracking will be poor.

A DSLR is attached to the Celestron off-axis guider. The autoguider camera is not part of the reviewed Celestron package.

Before the VX can locate objects, it must be Go To aligned. The first step is entering the time, date, time zone, daylight-savings time status, and location into the hand control. Most of these entries will be a one-time job because the mount is equipped with a battery-powered, real-time clock that keeps the date and time current.

There are several alignment options, but the most accurate is the two-star alignment. When you select that option, the VX will point at two stars it chooses from its database. After you center them in the finder and main scope, the hand control will ask if you want to add calibration stars. You may add as many as four, but I found three sufficient for excellent pointing accuracy.

Even at a magnification of 100×, anything I requested from horizon to horizon was in the eyepiece when the mount stopped. In the year that I've had the VX, it amazingly has never missed an object when I've been careful to do the alignment as outlined in the manual. The only problem I have encountered has been the 3-foot-long hand-control cable, which is a bit short.

The Edge f/7 Reducer

The addition of Celestron's Edge focal reducer converts the f/10, 2,000-mm-focal-length Edge 800 to an f/7, 1,400-mm-focal-length telescope that delivers lower powers and wider fields of view. The reducer is specifically designed to work with the Edge's built-in corrective lenses to preserve the scope's flat field. Although intended for astrophotography, I found the reducer very effective for visual use as well.

EDGE FOCAL REDUCER U.S. price: $299.95

WHAT WE LIKE:

Sharp stars to the field edge

WHAT WE DON'T LIKE:

Using larger imaging chips could pose a problem

The author imaged the Dumbbell Nebula (M27) through the Edge 800 setup. The picture is a stack of twenty 30-second unguided, prime-focus exposures using the Edge f/7 focal-length reducer.

For prime-focus deep-sky imaging, a focal reducer is highly desirable. The Edge reducer, which is optimized for small imaging chips, almost doubles the size of a telescope's field and cuts required exposure times in half. With my Canon DSLR, stars were sharp all across the frame.

Unguided Imaging

Since astrophotography was in my plan on a trip to the Chiefland Astronomy Village in Florida, I kept things simple. I shot through the SCT and reducer with my DSLR, but I didn't guide any exposures.

I mounted my Canon 60D camera to the scope with a standard prime-focus adapter threaded onto the Edge Reducer, which replicates the normal SCT threads. The only problem I ran into was balance. The VX's single counterweight was not heavy enough to balance the telescope in right ascension with the camera onboard. Fortunately, I had brought an additional 11-pound counterweight.

Because good tracking is critical for imaging, once the Go To alignment was complete, I performed the VX's All-Star Polar Alignment procedure. After centering a star I chose from the hand control's database, I completed the process by re-centering it again using the mount's altitude and azimuth adjusters rather than the hand control.

Preliminaries over, I sent the scope to M15 and began firing 30-second exposures. I shot twenty 30-second subframes of the globular. My stars were not quite round in all frames, but stacking these short exposures into a finished picture yielded pleasing images. What's amazing is that a beginner could have achieved similar results. I didn't do anything special; I just snapped away.

The Off-Axis Guider

If you want to go much beyond 30-second exposures, you'll need to guide the VX. Today, that's done with an autoguider camera that plugs into the VX's autoguide port. You could use a separate small telescope to provide guide stars for the camera to monitor, but flexure between the main scope and guide scope can cause trailed stars. Enter the Celestron off-axis guider (OAG).

When I opened the box containing the guider, my heart sank. There appeared to be a million adapter rings

OFF-AXIS GUIDER **U.S. price:** $249.95

WHAT WE LIKE:
Good construction quality with large, clear aperture
WHAT WE DON'T LIKE:
Camera and T-ring attach to off-axis guider with less-than-secure setscrews

and spacers. Luckily, the instructions for configuring the OAG for my setup were clear. Three setscrews attached the camera to the guider body. I prefer a more secure connection, but it caused no problems and I was impressed by the OAG's otherwise hefty construction and quality finish.

My pictures with the guider weren't award winners because I was imaging from my light-polluted backyard under a full Moon. And I did have one scare — when I began autoguiding at first, the guide camera didn't pick up a single star. It turned out that my autoguider wouldn't reach focus without an extension tube due to the presence of the Edge reducer. With the guider inserted into the tube from an old Barlow, the OAG worked well, keeping stars respectably round.

The StarSense AutoAlign Camera

Celestron's StarSense accessory mounts to the Edge's tube in place of the telescope's 50-mm finder and automates the Go To alignment process. The box contained a small

STARSENSE AUTO-ALIGN CAMERA **U.S. price:** $329.95

WHAT WE LIKE:
Completes a good Go To alignment in 3 minutes
WHAT WE DON'T LIKE:
The All-Star polar-alignment feature did not function

The Celestron StarSense camera takes the place of the standard 9x50-mm finder when used. This camera automates the Go To alignment process.

The author's image of globular cluster M15 consists of twenty 30-second, stacked, unguided, prime-focus f/7 exposures.

camera and a replacement NexStar hand control. Connect the StarSense controller in place of the original, hook the camera to one of the mount's Auxiliary ports, and you're ready to go.

I was skeptical that such a seemingly simple gadget would enable the VX to align itself. Nevertheless, it worked. I turned on the mount, entered the date, time, and city, and selected Auto Alignment. StarSense directed the mount to take images of star fields on both sides of the meridian. Despite a bright Moon, the camera was sensitive enough to acquire 40 to 100 stars every time. In only three minutes the StarSense indicated that the VX was aligned. We'd see about *that*.

I punched in M13. There it was near the center of the field of a 20-mm eyepiece at 100×. M57? Same. M3? Yep. Every single object from horizon to horizon was in the eyepiece. Go To accuracy seemed just as good as with alignments done the old-fashioned way.

Not that the StarSense was perfect. My eyes had difficulty with the display's small fonts. More significantly, the StarSense's All-Star polar-alignment routine didn't work. The results it yielded were inaccurate — it put the telescope degrees away from the celestial pole. I contacted Celestron technical support, who assured me they are working to make All-Star functional by the end of 2014. Even without All-Star, however, the StarSense was amazing. Not only did it align the VX as well as I could, it was just *so cool*.

The VX mount is not a caviar-class GEM, but it makes up for that with its low price, portability, and solid performance. Throw in the optically impressive Edge 800, the Edge Reducer, the off-axis guider, and the StarSense, and a novice — or an old hand — will be equipped with a system ready to take on almost any task for a price lower than I would have thought possible. ✦

S&T *contributing editor* ***Rod Mollise*** *writes an entertaining astronomical blog at* ***www.uncle-rods.blogspot.com***.

Digging into PixInsight

Get more out of your astrophotos with this powerful software.

Ron Wodaski

Astrophotography has always required thorough knowledge of the tools of the trade. This was true of film in the darkroom, and it's also true today with digital images. So choosing to learn a new or different tool isn't something to undertake lightly. But as imagers strive to produce great pictures, many have embraced a program that produces the cleanest results, enabling them to extract the most detail out of their images.

As one of today's better programs for image processing, *PixInsight* (**http://pixinsight.com**) has an enormous range of tools backed up by solid mathematics. Whether you're aligning dozens of exposures together or boosting the contrast range of your stacked result, the engine you don't see is every bit as important as the visible result. Producing high-quality images depends on good math, and *PixInsight* has excellent mathematical algorithms, making it worth your time to learn and use.

Digging In

PixInsight is a comprehensive image-processing package that includes a daunting number of tools, so finding your way around it the first few times might be confusing. Its

Above: **An astrophotographer's ability to pull the faintest details out of an image is often limited by how well the data is calibrated. *PixInsight's* powerful processes remove unwanted signal to produce the cleanest data, permitting you to reveal subtle details in your photos, like the delicate dust lanes in this high-resolution photo of NGC 3628. All images are courtesy of the author.**

greatest strength lies in its ability to produce smooth results while avoiding pitfalls such as “star bloat,” where stars become large and puffy due to tiny errors when stacking exposures reduces the resolution in your images.

I find that the best way to learn a program is by developing a basic workflow. My major steps when using any astronomical image-processing package follow this pattern: create master calibration files, calibrate, align, integrate (or stack), and finally do any corrections before final processing. Following this pattern will put you well on your way to mastering this complex but powerful program.

Each step has one or more tools to get the job done. These are called “processes” in *PixInsight* lingo. To open a process, select the PROCESS menu along the top, or hover your mouse pointer over the ProcessExplorer tab along the left edge of the window. Click on a process name to see additional documentation; double-click to open it.

There are two ways to apply a process in *PixInsight*. The first is by dragging the blue triangle at the bottom-left of each process window, known as the New Instance icon, onto a single image. The other is the Apply Global icon, which is the blue circle just to the New Instance icon’s right. Use this when working on a multiple images, such as when stacking many exposures.

Because 16-bit FITS files will always appear dark with only a few stars before you apply any contrast enhancement, you should perform an initial STF AutoStretch to display faint areas. Use it again to see the results of each process. It does not modify the image itself.

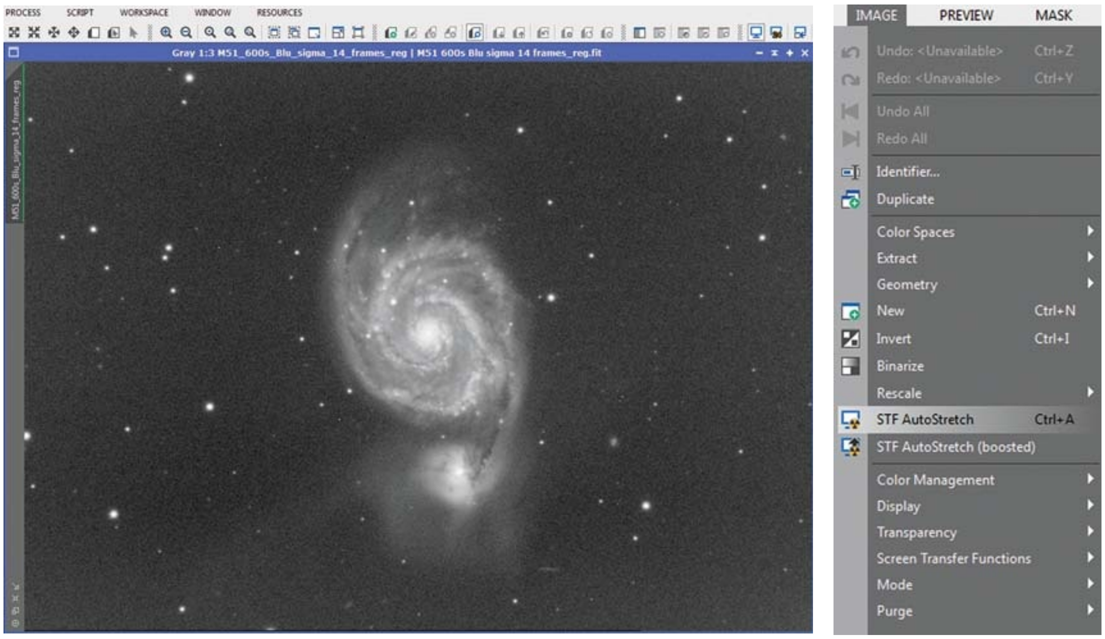
Making Calibration Masters

Due to the nature of deep-sky astrophotography, image calibration of some form is necessary to produce accurate science from long-exposure deep-sky images. Dark frames, bias frames, and flat-field images all must be applied to a set of images to remove imperfections and unwanted signal. Also, combining multiple calibration frames produces more accurate calibration master frames, which in turn contributes to a better result. You can accomplish this in *PixInsight* by using the ImageIntegration process found at PROCESS > ImageIntegration > ImageIntegration.

Begin by clicking the Add Files button, and select all the calibration files you want to combine into a master. Working with one type of calibration image at a time, different settings are required for each type of calibration master you generate. Note that output normalization occurs when making the master itself, and pixel rejection normalization is only used for the rejection algorithms.

When generating your master bias and dark frame

Author Ron Wodaski stands in front of the Tzec Maun Observatory in Cloudcroft, New Mexico. The dome houses a 1-meter Ritchey-Chrétien telescope used by students and researchers.



Use the STF AutoStretch function to better display your 16-bit images with enhanced contrast. The function is for display purposes only and doesn’t modify your image.

images, change the combination method to Average, the normalization to No normalization, and the Weights setting to Don't care (all weights = 1). Farther down in the Pixel Rejection (1) section, choose one of the rejection methods, but make sure to select No normalization. You can experiment with the different rejection algorithms to find which one works best for your data.

When you're ready, click the Apply Global icon to begin the process. In a few moments, your bias or dark frame master file will open on your screen, along with additional images of the low and high pixel levels rejected in the process. Close the rejected pixel images, and then save your master calibration file. Click the Clear button and repeat the process to generate the other master bias or dark frame.

Creating your flat-field master file requires slightly different settings; make sure to apply your bias master when calibrating flats, and include a dark frame if your flat-field exposures are longer than a few seconds. Use the same Average combination method, but change the output normalization to Multiplicative. In the Pixel Rejection (1) section, test different pixel-rejection tools to remove any cosmic ray hits or other unwanted signal from the integrated image, such as Percentile Clipping, or Winsorized Sigma Clipping. Finally, change the normalization setting to Equalize fluxes, then click the Global Apply button and save your result.

If you shot your target through color filters, you'll need to generate a master flat-field image for each filter used.

Calibrating Your Images

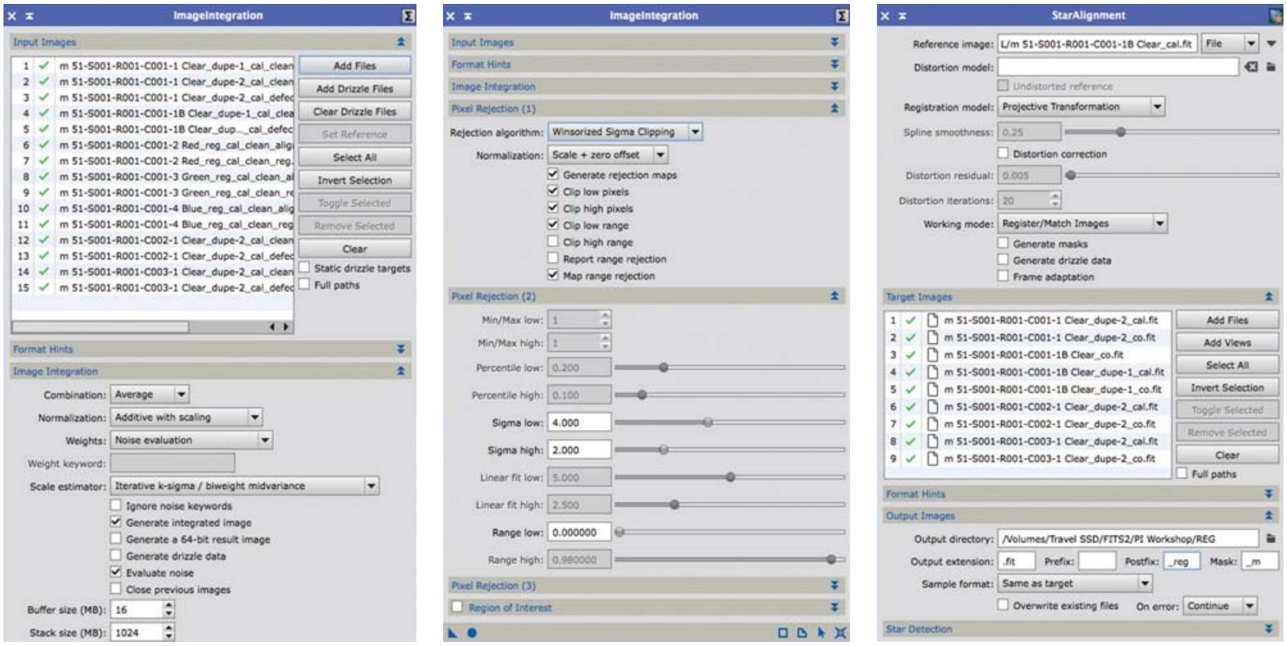
Now that you've made your calibration master files, it's time to apply them to your light images. Open the ImageCalibration window (PROCESS > ImageCalibration > ImageCalibration) and add all your light files that were taken with identical exposure length, binning, and temperature settings into the Target Frames section by clicking the Add Files button. Next, skip down to the Master Bias section and click the file folder icon to its right to find your master bias frame. Do the same for both the Master Dark and Master Flat sections until all your calibration images are in their proper section.

Now select where you'd like to save the calibrated files by clicking the file folder icon to the right in the Output Files section. You can also change the output extension, or add a pre- or postfix to the resulting file names.

You can leave any additional settings at the default value. Click the Apply Global icon to activate the process. If your images appear noisier than you expected after calibration, try checking the Optimize button and increasing the Optimize threshold level under the Master Dark section, and then repeat the process. You'll need to repeat the process on other image groups recorded at different sensor temperature settings, binning, and exposure lengths.

Star Alignment

Now that your light frames are all calibrated, it's time to align them all together before stacking. *PixInsight*'s Star



***Left*: Most of the image stacking to create your master calibration and light frames occurs when using the ImageIntegration process. When combining multiple dark and bias frames, select Average as the combination method, and No normalization. *Center*: The ImageIntegration process includes a number of excellent pixel-rejection algorithms. After selecting one based on the number of images you're combining, set the Normalization to Scale + zero offset, and adjust the Sigma low and Sigma high settings. To launch the process, click the blue circle at the bottom-left of the window. *Right: PixInsight*'s StarAlignment process allows users to register star fields accurately even when combining images captured at vastly different image scales.**

Alignment process is one of the most accurate alignment tools for registering star-field images, including photos taken at different focal lengths. This registration algorithm includes star detection, structure detection, a transformation matrix, hot-pixel rejection, and noise reduction. Many of these settings are tunable for especially tough cases. Begin by selecting PROCESS > ImageRegistration > StarAlignment.

Choose one of your calibrated images to be the reference to which you'll register all the others. You can work with open images (by selecting View) or unopened files by changing the option to File. Select your reference image by clicking the larger triangle to the far right. Next, click the Add Files button to the right of the Target Images section and add all the images to align (don't include the image you selected as the reference image). Specify an output directory in the Output Images section. Once again, click the Apply Global icon to activate this process.

Image Stacking

You can now combine (or stack) your aligned images by using the same ImageIntegration process you used to generate your master calibration frames, though you'll use different settings.

Open the process and click the Add Files button to select the files to combine. Next, choose a pixel-rejection algorithm that is suitable for the number of images you are combining. The best rejection method for your particular images is not always obvious. Use the table at the top of this page to help guide you on which rejection routine is most effective based on the number of images you're combining.

Rejection algorithms work best with normalized data, which means the program scales the values in a group of images so that they become comparable. Change the Normalization value in the Image Integration section to Additive with scaling. This is the output normalization, which is only used for the stacking portion of the stacking process. You must select the method for rejection normalization separately. Set the Normalization in Pixel Rejection (1) to Scale + zero offset, which will use the background levels in your images to calculate the proper rejection normalization.

As you gain more experience, you can alter the settings in the Pixel Rejection sections of the process. You can only adjust additional Pixel Rejection settings after you chose a rejection algorithm. Once selected, matching sliders become active in the Pixel Rejection (2) section. For example, when you select Winsorized Sigma Clipping, the Sigma low slider defines the limit for low outliers, and Sigma high defines the upper limit. Experiment with these settings to strike a balance between signal-to-noise ratio (or smoothness) and outlier removal aggressiveness. You can also use the Statistics process to examine the result of each setting; lower average deviation values are

Outlier Pixel Rejection

Number of Images	Pixel Rejection Method	Justification
1-2	No Rejection	Not enough images to identify outlier values.
3	Median	Outputs a file with middle pixel values. The result is noisier than averaging 3 images, but removes some outliers.
4-6	Percentile Clipping	Discards highest and lowest values and averages the rest.
8-14+	Winsorized Sigma Clipping	Determines standard deviations, better identifies outliers. Requires clean data with reasonably similar pixel values.
15+	Linear Fit Clipping	Fits each pixel stack into a straight line, best at identifying outliers. Works best with large number of images.

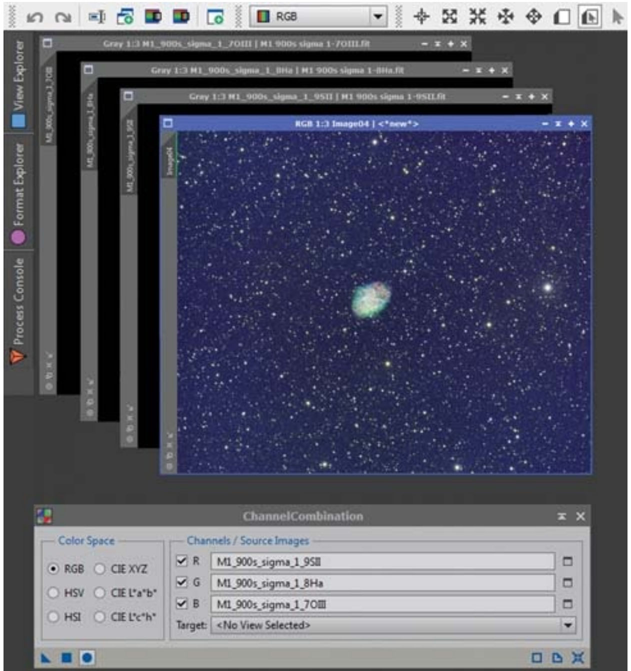
a good guide to success. But try not to overdo it: you don't want to get so aggressive that you begin to reject areas of your target object.

If the resulting stacked image is grainy or has rejected too much signal, consider the following suggestions. Change the values for high and low outlier removal. Use higher values to bring back details, and lower values to reduce graininess.

If the problem appears to be residual artifacts, decrease the Sigma low and Sigma high values to enhance outlier removal. This is especially important when creating flat-field master images from sky flats.

If your shoot monochrome images through color or narrowband filters, use the ChannelCombination process to quickly combine the stacked results into a color

After performing pixel rejection, carefully examine your result to make sure as many outlier pixels as possible were removed in the final stack. The image at left still includes unwanted signal after integration, but by increasing the Sigma low slider and lowering the Sigma high, these artifacts were successfully removed from the result at right.



Once your images are calibrated, stacked, and aligned, use the ColorCombination process to quickly create your master color image. Make sure to assign each filtered image to its corresponding channel.

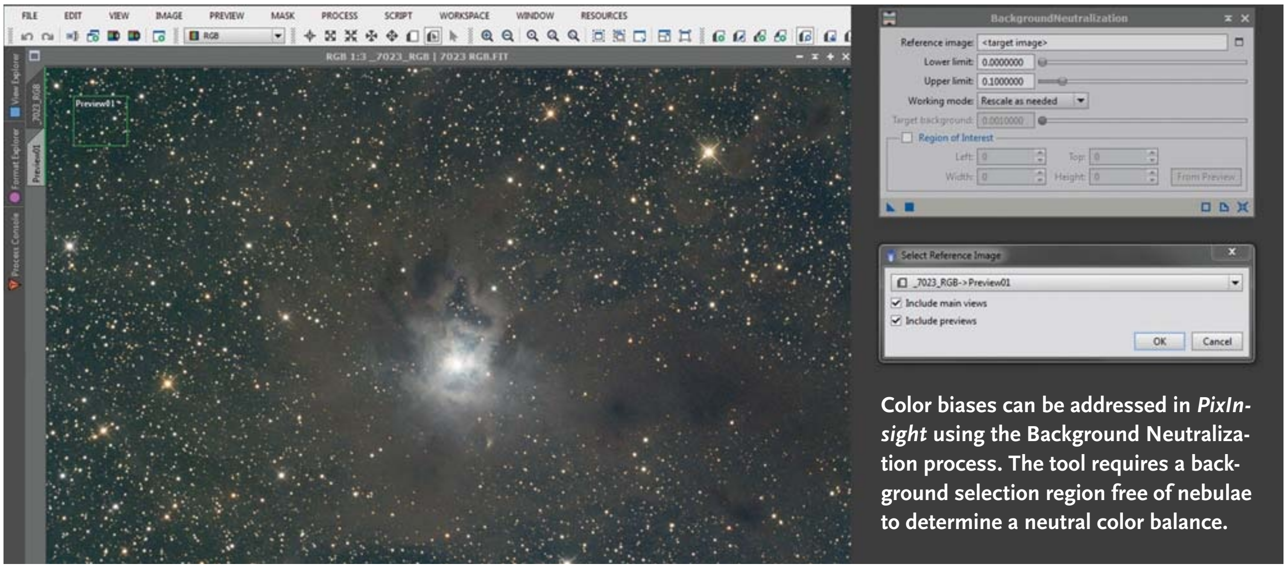
file. Once everything is combined, examine your result carefully to identify any issues that affect large portions of your images, such as color biases or gradients. *PixInsight*'s BackgroundNeutralization process (used on color images) will deal with channel color bias, and DynamicBackgroundExtraction (DBE) will clean up gradients in both color and monochrome images. An excellent tutorial on using these powerful tools appeared in the September issue on page 68.

After addressing any gradients, use the BackgroundNeutralization process to correct any color bias in your result. Select a portion of the true background as a reference by creating a new preview using the New Preview Mode in the toolbar along the top of the program window. Click and drag a rectangle of a background region in your image. It can be a small area, and a few stars are okay. Next, drag the New Instance triangle from the BackgroundNeutralization process onto the image to remove the color bias.

The ColorCalibration process is another useful tool for correcting color in your image. Use it after the BackgroundNeutralization process to establish good color balance on galaxies, star clusters, and other non-emission objects. Use the New Preview Mode to select your subject as the White Reference (to determine the white balance), and use your previously created preview as the background reference. Select each preview by clicking the file folder icon to the right of each Reference image line.

Now that everything is calibrated, combined, and cleaned up, you can move on to more conventional processing, including stretching the dynamic range, sharpening, and a host of other actions to produce your final result (*S&T*: Nov. 2013, p. 72). *PixInsight* includes many tools to do this, or you can simply take your image into another program of your choosing. *PixInsight's* tools are complex and can be daunting to master, but once you're comfortable with this basic workflow, your images will be sharp and free of unwanted signal, freeing you up to push your images to a higher level than ever before. ✦

Ron Wodaski is director of the Tzec Maun Foundation, which operates observatories in both hemispheres that are accessible to students and researchers alike. He is author of The New CCD Astronomy *and coauthor (with Russell Croman) of* The Zone System for Astro Imaging.

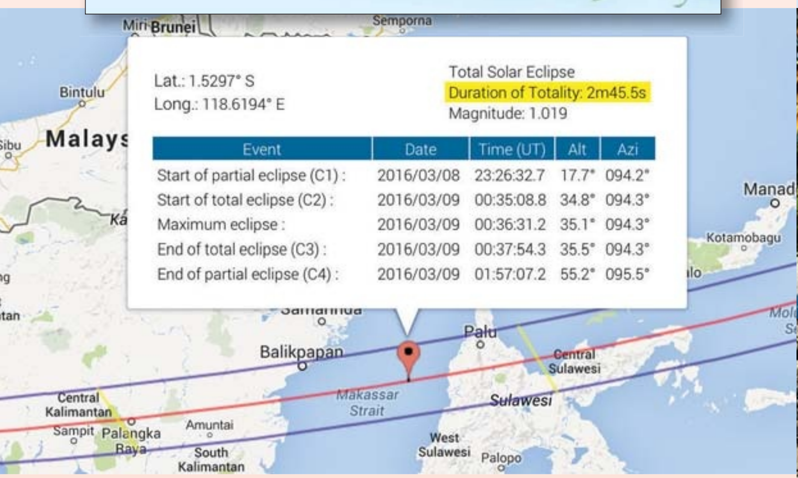


Color biases can be addressed in *PixInsight* using the Background Neutralization process. The tool requires a background selection region free of nebulae to determine a neutral color balance.

Sail roundtrip Singapore on Holland America Line's Volendam with *Sky & Telescope's* Bob Naeye, *Australian Sky & Telescope* editor Greg Bryant, and astronomers Dr. David Tholen and Dr. E.C. Krupp on the eclipse trip of a lifetime.

Join the fun and experience legendary Indonesia's cultures. You can explore Komodo, Bali, Lombok, UNESCO sites, and traditional cuisines all in the company of fellow eclipse buffs. When it's time to capture eclipse memories, tap *Sky & Telescope's* expertise. Reserve now for best cabin selection as this sailing is guaranteed to sell out.

While the full eclipse cruise is 16 days if you wish you can join the group after the initial Singapore departure and leave the cruise early, in Bali, spending as few as nine (9) days onboard.



Lat.: 1.5297° S
Long.: 118.6194° E

Total Solar Eclipse
Duration of Totality: 2m45.5s
Magnitude: 1.019

Event	Date	Time (UT)	Alt	Azi
Start of partial eclipse (C1) :	2016/03/08	23:26:32.7	17.7°	094.2°
Start of total eclipse (C2) :	2016/03/09	00:35:08.8	34.8°	094.3°
Maximum eclipse :	2016/03/09	00:36:31.2	35.1°	094.3°
End of total eclipse (C3) :	2016/03/09	00:37:54.3	35.5°	094.3°
End of partial eclipse (C4) :	2016/03/09	01:57:07.2	55.2°	095.5°

Add eight (8) hours to UT time for local time. I.e., the start of the total eclipse (C2) will be 8:35am.

Cruise prices vary from $1,999 for an interior stateroom to $8,299 for a Neptune Suite, per person, based on double occupancy. (Plus gov't taxes and fees, $329; booking service fee, $100; cruiseline gratuities, $11.50 per day; and Tour Leader gratuities, $100. For those attending our Program, there is a $1,075 fee. (The Program fee includes eclipse-viewing glasses, 13 seminars, a planetary debate, Q&As, and several receptions.) **Book by October 1st and save $300 per person on the Program fee.** For full terms and conditions please visit: InsightCruises.com/Sky-7

Dr. E.C. Krupp is an astronomer and Director of Griffith Observatory in Los Angeles. He received his M.A. and Ph.D. in astronomy at UCLA, where he studied the properties of rich clusters of galaxies as a student of Professor George O. Abell. He started his career at Griffith Observatory in 1970. Dr. Krupp has personally visited, studied, and photographed more than 2,000 ancient, historic, and prehistoric sites throughout the world and has led or supported 13 total solar eclipse expeditions and four annular eclipse efforts.

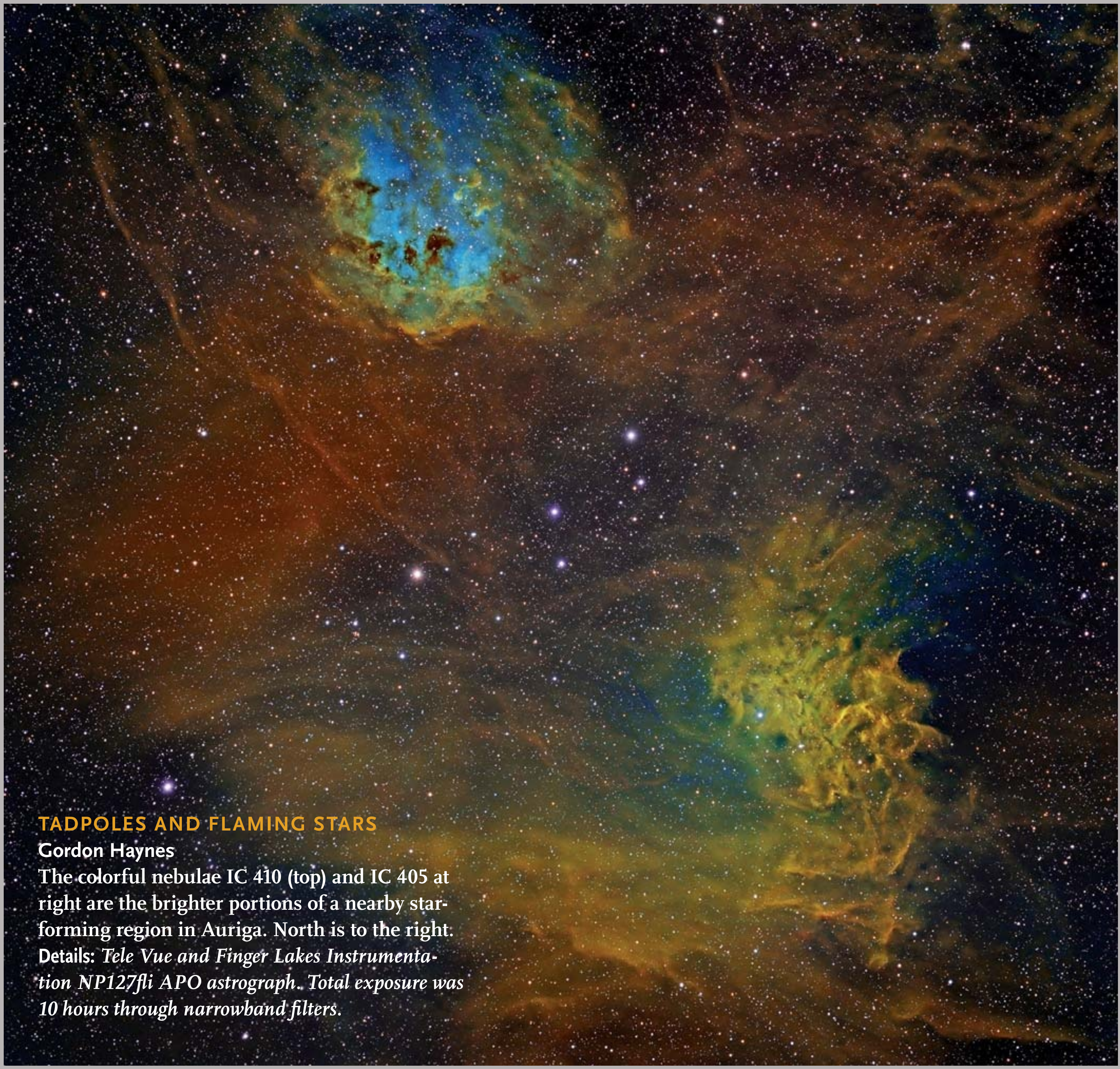
For more info: 650-644-5812 or Info@InsightCruises.com

Robert Naeye has been *Sky & Telescope's* Editor in Chief since 2008. Previously he was Senior Editor at *Sky & Telescope* and Senior Science Writer for the Astrophysics Science Division of NASA's Goddard Space Flight Center. Robert is the author of two books: *Through the Eyes of Hubble: The Birth, Life, and Violent Death of Stars* and *Signals from Space: The Chandra X-ray Observatory.*

Greg Bryant has been Editor of *Australian Sky & Telescope* since 2006 and a Contributing Editor to *Sky & Telescope* since 2001. He has also been involved with the publication of an Australian annual astronomy yearbook since the early '90s and science writing for the Australian Research Council's Centre of Excellence for All-Sky Astrophysics. A keen amateur astronomer for more than 30 years, Greg most recently teamed up with Insight Cruises for their successful 2012 Total Solar Eclipse tour in Australia. In 2000, the International Astronomical Union named asteroid 9984 Gregbryant in his honor.

David Tholen, Ph.D. is an astronomer at the Institute for Astronomy of the University of Hawaii (IfA), who specializes in planetary and solar system astronomy. Winner of the American Astronomical Society Division for Planetary Science's Urey Prize in 1990, Dr. Tholen and his students have discovered many near-Earth asteroids, the most famous being Apophis, which will make an extremely close approach to the Earth on April 13, 2029.

CST# 2065380-40



TADPOLES AND FLAMING STARS
Gordon Haynes
The colorful nebulae IC 410 (top) and IC 405 at right are the brighter portions of a nearby star-forming region in Auriga. North is to the right.
Details: *Tele Vue and Finger Lakes Instrumentation NP127fli APO astrograph. Total exposure was 10 hours through narrowband filters.*

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

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

▸ CROSSING ARCHES
Paolo Porcellana
The Sun often displays many prominences, but this fascinating double-loop was briefly visible along the solar limb on December 31, 2013.
Details: *150-mm home-built refractor with DayStar Quantum 0.5 angstrom solar Hα filter and Point Grey Research Chameleon monochrome video camera. Stack of multiple frames.*

◂ **DISTANT SPIRAL**

Al Kelly

Face-on spiral galaxy NGC 4535 in Virgo displays two well-defined spiral arms riddled with pinkish star-forming regions.

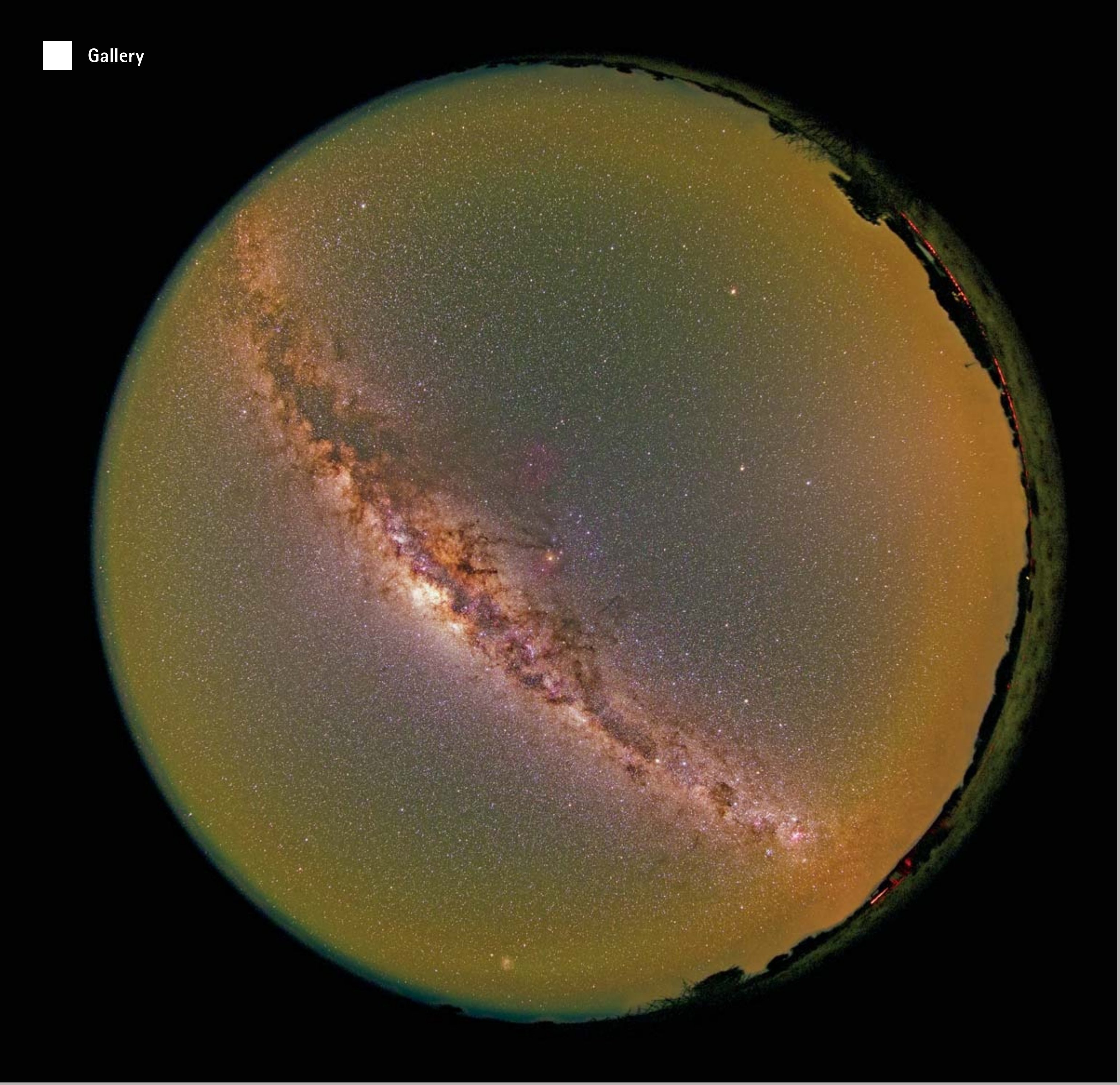
Details: *Celestron CGE Pro 1400 Schmidt-Cassegrain with Orion Parsec 8300C CCD camera. Total exposure was 5½ hours recorded at Johnson City, Texas.*

▾ **DISH REFLECTIONS**

Yuri Beletsky

Long star trails are reflected in the shiny dish of the decommissioned SEST radio telescope at La Silla Observatory in Chile. Farther in the distance is the dome for the 3.6-meter optical telescope.

Details: *Canon EOS 7D DSLR camera with 24-mm lens. Total exposure was 2 hours at ISO 1600.*



▲ **FISHEYE SKY**

Manuel Jung

The center of the Milky Way, including the colorful Rho Ophiuchi cloud complex in the middle, arches above Kiripotib Astrofarm in Namibia, while greenish airglow is visible along the horizon in all directions.

Details: *Canon EOS 6D DSLR with 8-to-15-mm zoom lens at 8 mm. Total exposure was 22 minutes at f/4.*

▶ **MOONRISE**

Anthony Ayiomamitis

The so-called "supermoon" of August 10th rises above the ruins of the 13th-century Medieval castle Fyllon on the Greek island of Euboea.

Details: *Takahashi FSQ-106N astrograph with Canon EOS 5D Mark I DSLR. Composite of three images, with exposures ranging between 1⁄25th and 1⁄50th second.*

▸ **KEMBLE'S CASCADE**

Greg Parker

This striking line of stars in Camelopardalis is a chance alignment spanning roughly 2½° and ending with the small open cluster NGC 1502 at lower-left.

Details: *Custom multi-lens imaging platform with Starlight Xpress SXVR-M26C CCD camera. Total exposure was 5 hours.*

▾ **DARK TOWER**

Robert Fields

The dusty tower known as LDN 1235 (center) also contains the reflection nebulae vdB 149 (left) and vdB 150 (right).

Details: *Takahashi FSQ-106N astrograph with SBIG STL-11000M CCD camera. Total exposure was 6⅔ hours through Astrodon color filters.* ✦

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Inside This Issue

Specialty astronomy equipment dealers and manufacturers are an important resource for amateur and professional astronomers alike — patronize our advertising dealers in this issue and enjoy all the benefits of their expertise.

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Actual number of copies of single issue published nearest to filing date: 16,312. H. Total (sum of 15f and 15g). Average number of copies each issue during preceding 12 months: 81,706. Actual number of copies of single issue published nearest to filing: 78,247. I. Percent paid. Average percent of copies paid for the preceding 12 months: 98.6%. Actual percent of copies paid for the preceding 12 months: 99.2%. 16. Electronic Copy Circulation: A. Paid Electronic Copies. Average number of copies each issue during preceding 12 months: 149. Actual number of copies of single issue published nearest to filing date: 99. B. Total Paid Print Copies (Line 15c) + Paid Electronic Copies (Line 16a). Average number of copies each issue during preceding 12 months: 63,516. Actual number of copies of single issue published nearest to filing date: 61,520. C. Total Print Distribution (Line 15f) + Paid Electronic Copies (Line 16a). Average number of copies each issue during preceding 12 months: 64,432. 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Stu's Last Lesson

In case of the unexpected, make it easier to distribute your astronomy possessions.

Stuart Forster (known to friends as Stu) was a mentor, educator, and one of the most highly regarded amateur astronomers in central New York. It came as a great shock in January 2011 when we learned of his sudden passing at age 55, having just retired from his medical practice to spend more time with his family, telescopes, and imaging software.

Although Stu's family appreciated his celestial activities, his familiarity with his equipment was his own. He had more than a dozen scopes, dozens of eyepieces and filters, six CCD rigs, two domes, 400 books, *S&T* back to 1964 . . . you get the idea. Stu was unique for the size of his collection, but the problem of dealing with specialized equipment when the unexpected occurs is one that all amateur astronomers risk sharing.

DAMIAN G. ALLIS

Ryan Goodson (New Moon Telescopes) and I have helped Stu's family sell his collection. As we have gone through this process, we've learned that you can make the lives of your family and fellow astronomers much easier by taking stock of what you own. If you weren't here tomorrow but your gear was, how much work would it be for someone else to deal with it? We recommend you consider the following:

1. Keep a list of *everything* and let someone know that this list exists and where he or she can find it.

2. If it's valuable, say so. If it can be thrown away, say that, too.

3. If you can't keep the original boxes, use containers to keep grouped items together. Stu kept Tupperware in business by placing complete sets of tools and components into labeled containers.

4. As you organize or modify your collection, take a picture of complete sets of similar objects, then add image labels and descriptions to your inventory. You instantaneously make a mountain a molehill.

5. Stu's collection was excessive in some respects, but he wasn't just an observer. He was the closest thing our region had to an equipment library where people could pick up a piece of astronomy equipment on loan, try it out, and bring it back (usually). Consider the possible future of your equipment.

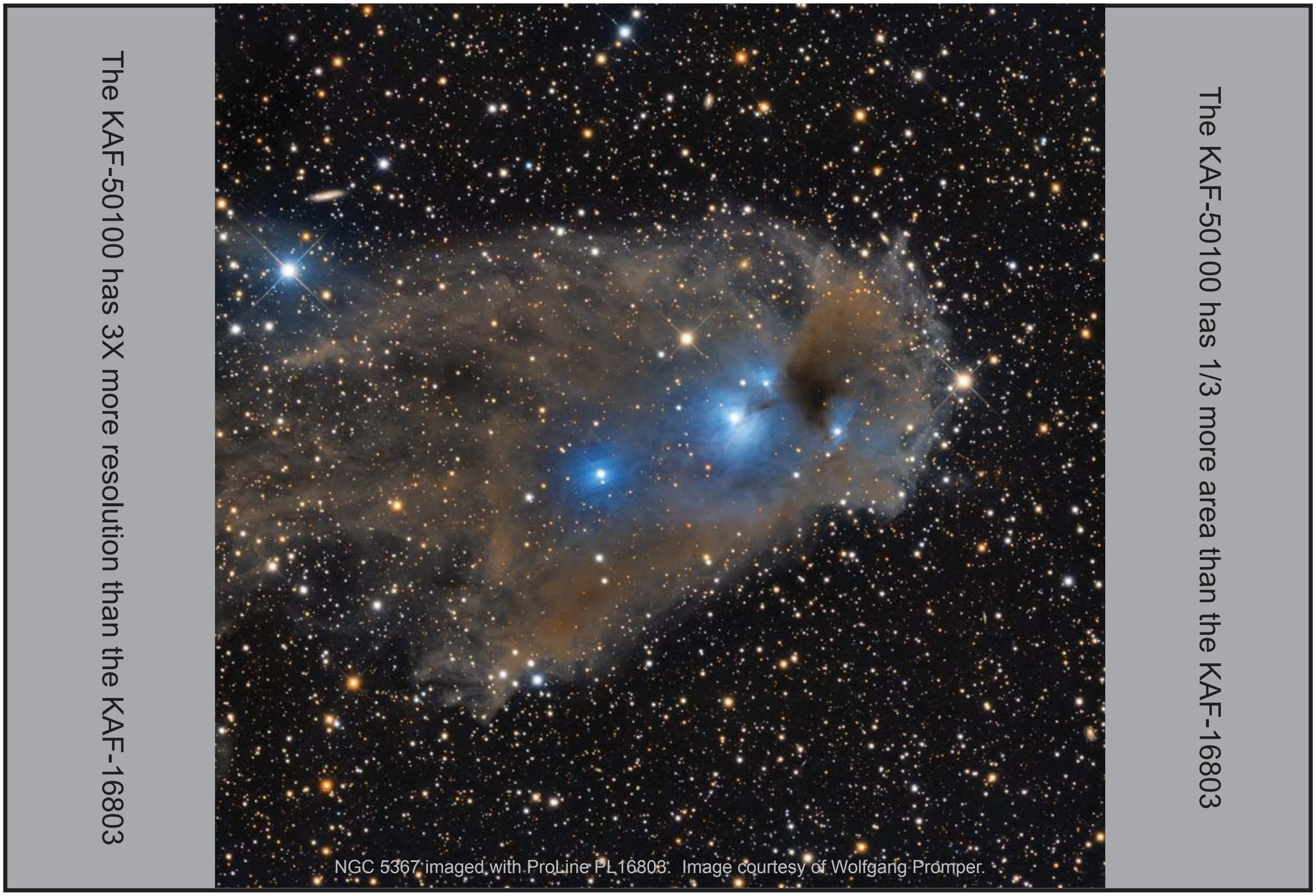
6. Join a club! Your local astronomy club is a support group for others who share your passion. It's also the first place your family can go to when they start selling stuff. We're happy to say that astronomy club members from all around central New York are putting Stu's gear to good use.

7. Be aware that proper distribution will not be easy. I posted announcements on several astronomy websites when I started selling Stu's equipment. I was sent take-down notices within hours because I wasn't selling my own stuff and didn't have seniority enough to post my announcement in the Classifieds section. Two years later, we're still sorting items and finding ways to sell them.

8. Keep books and magazines in the local area. See if your local public library or high school accepts donations (and offers tax write-offs).

If you have other helpful ideas, please find a way to add them to this list and let others know! ✦

***Damian G. Allis** is a research professor of chemistry at Syracuse University and a fellow with the Forensic and National Security Sciences Institute. He is director and co-organizer for CNY Observers & Observing (**www.cnyo.org**) and a 2014 NASA Solar System Ambassador.*



NGC 5367 imaged with ProLine PL16803. Image courtesy of Wolfgang Promper.

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