Imaging Technique: COMET FREEZE-FRAME p. 68

Observing the Urban Swan: CYGNUS IN THE CITY p. 58

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SEPTEMBER 2015

Total Eclipse of the Harvest Moon p. 26

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S&T Test Report: Big Binos p. 62

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September 2015 VOL. 130, NO. 3

On the cover: On September 27–28, a total lunar eclipse will (hopefully) wow observers across six continents — sorry, Australia.

PHOTO: AKIRA FUJII

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OBSERVING SEPTEMBER

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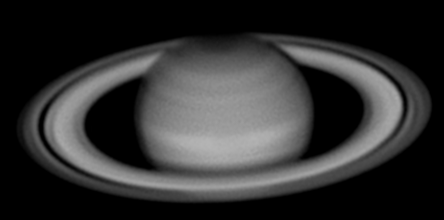

Image by Alessandro Carovana

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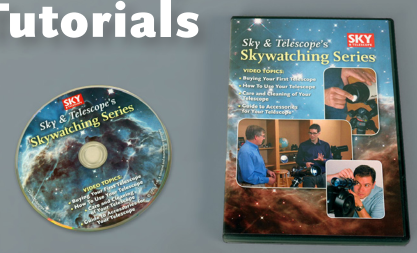

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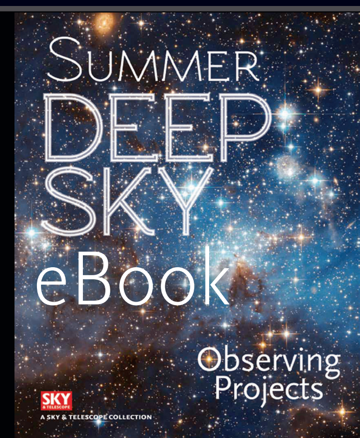

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ONLINE PHOTO GALLERY
Jeff Donaldson took a series of exposures to compile this H-alpha filtered image of the Whirlpool Galaxy (M51).

Taking the Bait

"THIS IS *REALLY* INSPIRING!" The moment my 20-year-old daughter Olivia uttered those words one night in May, I knew she was hooked. I had taken her and a friend to a hilltop outside Boston with a Meade 10-inch LightBridge Dobsonian.

First I dazzled them with the Moon, which, at less than two days from first quarter, pained the eye to look at through a 10-mm eyepiece. But those craters! The maria! The terminator! The girls were entranced.

Next I brought Jupiter and its four big moons into the field of view. "I can see the rings!" one of the girls murmured. She was referring to Jupiter's North and South equatorial belts, which were plainly visible. And the Galilean moons shone like jewels on a tiara — Callisto and Ganymede to the west, Io and Europa to the east.

But the evening's prize was yet to come. I swung the telescope around to the southeast and aimed the red dot finder into the light pollution dome capping downtown Boston. And there it was, hanging high above the city, shining where few stars could: Saturn. Through a 6-mm eyepiece, it looked at first glance like a white-chocolate-covered pretzel. The planet had reached opposition the night before, and its tilt of more than 24° from edgewise made the rings stand out distinctly. Perfect for setting that hook.

Saturn by cellphone

OLIVIA TYSON

"Oh my God," Olivia said while kneeling at the scope, head bent to the eyepiece. As she had done with the Moon and Jupiter, she immediately grabbed her smartphone and put its camera lens up to the eyepiece. Her friends *had* to see this! The phone's camera had trouble auto-focusing on the white pretzel instead of black space, but in the end Olivia nabbed it. While the result is as humble a shot of Saturn as you'll ever see, no photo of the ringed planet will ever mean more to her than that one.

"They've always been right there!" Olivia said later, musing on Jupiter and Saturn. Yes, indeed. "I've seen Saturn in books, but to *actually* see it!" Right on. "This makes me want to go to a star party. I can't imagine what you can see through a really strong telescope!" Hook, line, and sinker, friends.

Most of us in the hobby agree that passing the mantle to the next generation, and the next generation after that, is our duty, to help ensure a vibrant future for both amateur and professional astronomy. But what duty was ever such a pleasure to perform?

Have a memorable story about introducing a young person to astronomy? Please share it with us at **letters@SkyandTelescope.com**. ✦

Peter

Editor in Chief

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GOTO

Another GOTO first
A Triple HYBRID Planetarium!

On March 21, 2015, the Yokkaichi Municipal Museum reopened in Japan with GOTO INC's latest planetarium technology. The planetarium features a "CHIRON4○1 HYBRID SYSTEM", which in fact is a TRIPLE HYBRID SYSTEM. The 3 main elements of this system are：

(1) ***GOTO's most advanced opto-mechanical projector ever***. Yokkaichi's CHIRON4○1 is based upon the new CHIRON III projector. It has extremely high brightness LED illumination, and shows ***the intrinsic color temperature of 9,500 naked-eye stars down to magnitude 6.55***. It displays a Milky Way with more than 100,000,000 micro-stars down to magnitude 18, and accurate dark nebulae as well. All of these features are contained in a starball which is only 48cm in diameter!

2) ***VIRTUARIUM II, a fulldome digital video system using two 8K e-shift projectors*** – a first in the planetarium field.

(3) ***Digital Skyline System which produces immersive landscapes in the tilted theater using three high-brightness 4K video projectors***. The result is a scene across the front of the tilted dome which is ***10,000 pixels wide***, and which pulls audiences into beautiful scenes of earthly nature and space.
Since the city of Yokkaichi is a port city, the facility's name "Ginga Port 4○1" (Galaxy Port 4○1) is a natural. Daily voyages for the citizens of Yokkaichi into the Galaxy are now taking off!

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More Sketches, Please!

Articles such as "Edge-on Galaxies" (*S&T:* Mar. 2015, p. 20) are a great addition to the monthly columns by Sue French and others. One improvement would be to make use of more sketches instead of (or besides?) astrophotos. They are much more informative, especially when accompanied by information about the aperture of the instrument used and the limiting magnitude of the sky involved. For some fainter objects, long-exposure astrophotos do not do justice to the challenge of observing them visually. Also, giving the noble art of sketching more attention will hopefully inspire more people to give it a go. There are some really great sketching artists about, and with more of an equal distribution between astrophotos and sketches, the magazine will acquire more charm rather than losing it.

Esther Hanko
Purmerend, The Netherlands

EDITOR'S NOTE: ***Attention, sketchers!*** *Send your best astronomical renderings to gallery@SkyandTelescope.com (put "sketch" somewhere in the subject line), and if we get enough good-quality submissions we'll showcase them in a future issue.*

ALEXANDER'S ASTRONOMY SKETCHING

Australian observer Alexander Massey spent 3 hours at the eyepiece of his 17½-inch reflector to render all the detail in this sketch of the Ink Spot (Barnard 86) and the nearby star cluster NGC 6520 in Sagittarius.

Decades and Decades

After opening my April issue, I immediately read your editorial (p. 6) asking "Why have *you* saved your old *S&T*s?" Still on my shelf is the first issue, November 1941, which was printed during the height of World War II and cost all of 20 cents. That was before Sputnik, before eclipse chasing, and at a time when our local library had all of six books dealing with astronomy.

I became a subscriber in 1951, when I was in 9th grade, and now can proudly say I own every single issue. This is the magazine that sparked my lifelong interest in astronomy and, as a result, my becoming a planetarium director. One would be hard pressed to find a better reference source. Perhaps best of all, it put me in touch with individuals who share my passion and have become lifelong friends. I look forward to receiving every issue and hope you continue to publish this astronomical Bible for many more years.

William Speare
Clarks Summit, Pennsylvania

After reading Peter Tyson's Spectrum, I had quite a smile on my face! I too have saved all my issues of *Sky & Tel.* In fact, the July 1975 issue that he noted is the very first one I received after subscribing. And yes it is wonderful to go back and reread some of the old articles, do searches, and look at the telescopes and equipment of years gone by.

A short while ago, after noting the size of my issue collection, my wife suggested that I donate it to the local library (since I have the complete digital version anyway). I thought about it but could never do it. Those magazines had become part of me — but I only realized it after she asked about them!

Wayne Hodges
Arkell, Ontario

You don't throw away diamonds.

Steven Morris
Professor of Physics
Los Angeles Harbor College
Wilmington, California

Just wanted you to know that I beat out Dennis di Cicco and almost equaled Roger Sinnott. I got my first subscription to *S&T* in 1958, at age 13, as a Christmas gift from my father, a chemistry professor who wanted to encourage my interest in science. I can't be sure whether over the course of my 1967–91 Air Force career, which involved 13 moves, I received every single issue or sent in every renewal on time, but I'm now in my 57th year of reading and subscribing to *S&T.* I still have every issue that I received — the only magazine that I've accorded this honor.

Howard Ritter
Maumee, Ohio

I save mine for about a year. Then I take them to one of our club's public outreach events and set them out with a note: "Free — Take One!" The pile is always gone before the event ends. Perhaps one of those issues will encourage someone else to become interested in astronomy.

Greg Lewis
Clovis, California

One day in 9th grade, while we were supposed to be working on math problems, I noticed the robin's-egg-blue cover of *S&T*'s February 1966 issue on the magazine rack in my classroom. I picked it up and was amazed at the all-sky star chart in the back and the column entitled "Rambling Through February Skies" by Charles A. Federer. I had never seen anything like it before! Seeing my interest, my math teacher let me take the issue

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home and read it there. I later learned he was the faculty advisor for the school's astronomy club. In his later years, he gave me that very same February 1966 issue to keep — a memento I like to get out every February and look through.

Larry Black
Cedar Rapids, Iowa

I started my subscription in 1964, as a 13-year-old newcomer to astronomy, and now my 600+ issues nearly fill the bookcase I built to preserve them. The cover of the July 1964 issue pictures the lofty antenna of the Arecibo radio observatory in Puerto Rico, with its precarious catwalk some 450 feet above a huge metal dish below. Within a decade, as a senior astronomy major in college, I would be inching along that same catwalk during my summer internship at Arecibo — a step toward realizing my long-held dream to become a professional astronomer.

In the 1980s, on days off from teaching at the University of Massachusetts Dartmouth, I had the pleasure of working with the magazine's editorial staff on *Sky Catalogue 2000.0*. While not directly involved in *S&T*'s production, I did eavesdrop on the lively — often contentious — editorial meetings. These give-and-take sessions were the crucible of the high-quality reportage that remains a hallmark of the magazine.

Alan Hirshfeld
Newton, Massachusetts

I first read *S&T* in 1969. That's when I joined the Manchester [England] Astronomical Society, whose Godlee Observatory now has a near-complete collection back to the late 1940s. Published material is especially important to astronomical historians; digital data collections are too vulnerable to constantly evolving data-storage methods. In this respect, saved copies of *S&T* win hands down in providing a valuable timeline spanning an unprecedented period of astronomy and space exploration and in the development of both professional and amateur technology.

Kevin Kilburn
Manchester, United Kingdom

I've subscribed since 1976, and all the issues are placed in order on a "special" bookcase. Every time I browse these volumes, not only do astronomical facts resurface from the past, but I also relive moments and memories of my life. So this collection is like a "special" friend that has accompanied me for a long time (and will continue to).

Fabrizio Migliorini
Cernusco sul Naviglio, Italy

For the Record

✸ *July issue, p. 18: Walter H. Haas was 97, not 85, when he died in April.*

75, 50 & 25 Years Ago

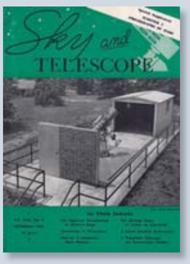
Roger W. Sinnott

September 1940
Telescope Nuts "Among the green-clad hills near Springfield, Vt., more than 300 telescope makers from widely-scattered sections of the country gathered on August 10th for their 15th annual convention and gab-fest at Stellafane. . . .

"Seven members of the New York Amateur Astronomers Association made the round trip in two chartered airplanes . . . On Sunday, the planes zoomed low over Stellafane, providing a great thrill for the occupants and the earth-bound watchers. . . .

"Acquaintances were renewed, while the younger amateurs gathered around Messrs. Porter, Ingalls, Everest, Pierce, and other sages in the art of grinding, polishing, and mounting a mirror. . . .

"The principal event . . . was the report of [Russell W.] Porter on the progress of the 200-inch telescope, for which he is consultant at Mt. Palomar. With the aid of slides of his own well-known cutaway drawings, Porter described many of the unique details of the new glass giant, which is scheduled for operation in 1942. . . ."



Barnstormers and the cast of sages aside, George V. Plachy could almost have been writing of Stellafane today.

September 1965
The New Mars "In a brilliant technological achievement that came off almost exactly as planned, Mariner 4 flew past Mars at a distance of 6,118 miles on July 14-15, after a 7½-month voyage of 325 million miles. This gave man his first close-up look at the solid surface of another planet . . . [and has] greatly changed some widely held ideas about Mars. . . .

"About 40 years ago, Percival Lowell was confident that his 24-inch telescope showed visible signs of great engineering works operated by intelligent beings on Mars. . . .

These sanguine hopes have long lost currency, and have been replaced by more guarded exobiological thinking. And now it appears that the Mariner evidence greatly restricts the probable scope of even this. . . ."

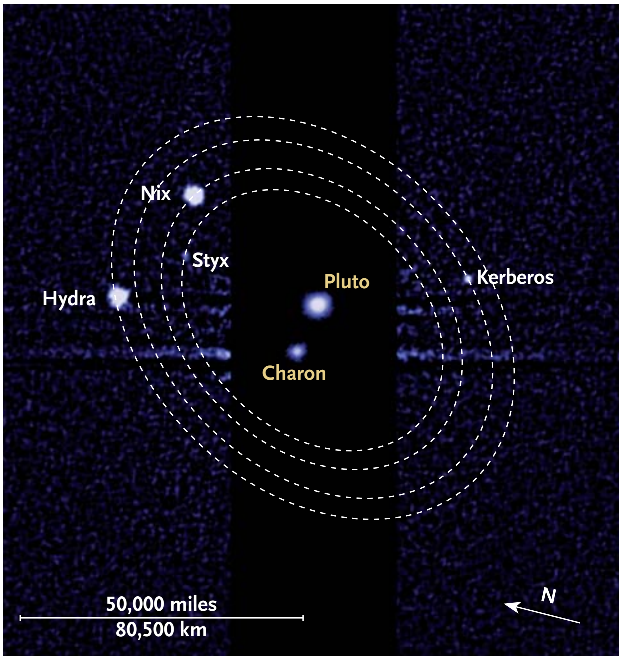
The magazine's special supplement presented 16 of the 22 grainy Mariner 4 images, which showed craters amid bleak landscapes and forever changed our perception of Mars.

September 1990
Hobbled Space Telescope "[Few] astronomers were prepared for the bombshell NASA dropped on June 26th. After struggling in vain for weeks to focus the telescope, spacecraft operators finally realized that something is fundamentally wrong with the optics. . . . Apparently the telescope suffers from a classic case of spherical aberration. . . . Once expected to give us eye-popping views of everything from nearby planets to distant galaxies, it now faces an 80-percent reduction in usefulness. . . .

"[The] faint-object camera can still do frontier work at ultraviolet wavelengths, where ground-based telescopes are blind. . . . But until a replacement for the wide-field and planetary camera [with corrective optics] arrives in 1993, what was supposed to be an astronomical Rolls Royce will perform more like a Hyundai."

Overnight the Hubble Space Telescope became the butt of puns, jokes, and cartoons around the world. But as Rick Fienberg foresaw in his bleak report, NASA's 1993 repair mission was a stunning success and the early problems are largely forgotten today.

SOLAR SYSTEM | Pluto's Perplexing Moons



NASA / ESA / M. BUIE

A composite of images taken in 2012 by the Hubble Space Telescope shows Pluto's five known moons (Pluto and Charon's brightness is reduced by a mask). The carefully balanced system depends on an orbital resonance to stay steady.

A study of Hubble Space Telescope images of Pluto and its moons, taken over the past decade, highlights the system's many oddities, Mark Showalter (SETI Institute) and Douglas Hamilton (University of Maryland) report in the June 4th *Nature*.

Pluto and its largest moon, Charon, form a binary system surrounded by four smaller moons: Styx, Nix, Kerberos, and Hydra. Planetary scientists have wondered how the four smaller moons, whose orbits are closely packed together, manage to avoid colliding. These moons experience variable gravitational pulls as Pluto and Charon move around their common center of mass. The result is a series of wiggles in the satellites' orbits. However, since the moons are so crowded together, any disruption could potentially push them within range of one another's gravity fields. Those tugs would further perturb their orbital balance.

The solution to this mystery appears to be a special three-body resonance. Hydra, Styx, and Nix's orbital periods are linked in ratios that prevent them from ever lining up in a row, which could permanently disrupt the system. Astronomers suspected for some time that resonances were at work, and Showalter and Hamilton have now confirmed their existence.

The Hubble observations also raise a new question about the system, with the discovery that Nix and Hydra are rotating chaotically, joining Saturn's moon Hyperion in that rare category. Most moons in our solar system orbit their planets synchronously: their spin rate is equal to their orbital period. This means that a synchronously rotating moon always points the same side at its host planet (as our own Moon does). Hyperion, and now Nix and Hydra, are bizarre deviations from this state; it is impossible to predict which of their sides will face their host planets and when.

"If you can imagine what it would be like to live on this body, it's a very strange world," Showalter says of Nix. "You would literally not know if the Sun is coming up tomorrow."

Scientists don't know what causes these chaotic rotations, but Showalter and Hamilton suspect that Nix and Hydra's situation might have to do with Pluto and Charon's binary configuration. The fluctuating dynamics could be throwing the moons into chaos.

Another new mystery lies in Kerberos's dark color. The rest of Pluto's moons are bright, and since Pluto and its satellite system were likely created from an impact event when something slammed into the protoworld that became the dwarf planet, the moons should all be made from the same material — and, therefore, be the same color. Kerberos's color could be a coincidence — "like when a kid goes to a birthday party and gets the last piece of cake" simply by luck, muses Scott Kenyon (Smithsonian Astrophysical Observatory) — or maybe not.

■ **ANNE MCGOVERN**

STELLAR | Helping Hand for

Astronomers might have new insight into the formation of Wolf-Rayet stars, massive stars stripped of their outer hydrogen layers. Researchers have suspected for years that these stars are the progenitors of Type Ib or Ic supernovae, whose light lacks the hydrogen spectral fingerprints typical of other core-collapse explosions. But how these stars form remains a lingering question.

Jon Mauerhan (University of California, Berkeley) and colleagues used infrared, optical, and X-ray instruments to observe an unusual Wolf-Rayet star, playfully dubbed Nasty 1 (official name NaSt1). While studying this star, the researchers were surprised to find a pancake-shaped disk surrounding it, instead of the usual fast-flying gas being ejected along the poles. The disk also emits X-rays.

DARK MATTER | Mapping the (Not-So-) Invisible

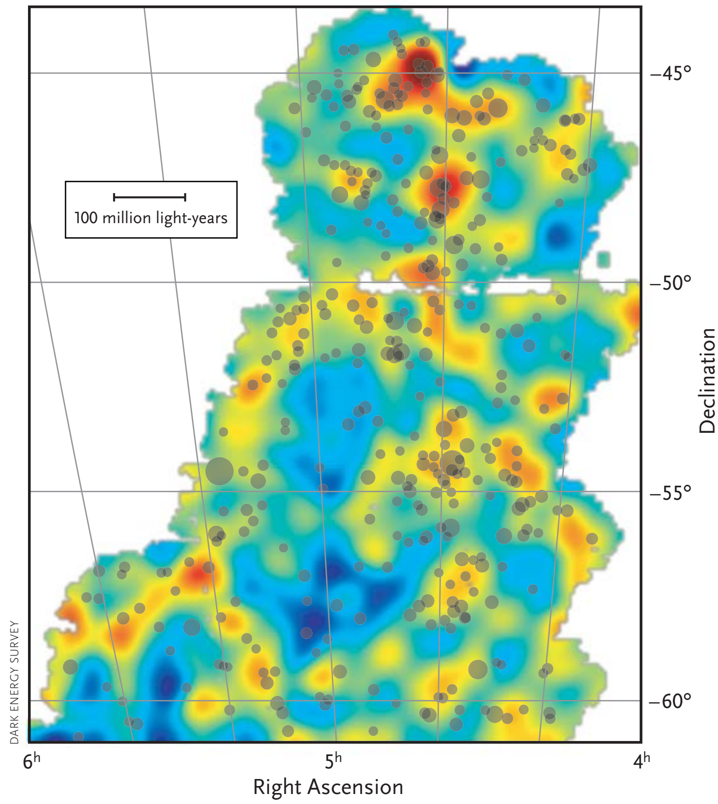
Two projects are mapping the distribution of dark matter in the universe, probing scales both large and small.

One, the Dark Energy Survey, is tackling the large-scale universe using the Dark Energy Camera (*S&T:* Jan. 2013, p. 15). The instrument is a 570-megapixel CCD camera that's in the process of surveying a huge, 5,000-square-degree swath of Southern Hemisphere sky.

Using preliminary data that covers just 3% of the full survey, Vinu Vikram (Argonne National Laboratory) and colleagues examined the shapes of more than 1 million faraway galaxies, whose light has traveled between 5.8 billion and 8.5 billion years to reach us. The team was looking for the smearing effect of intervening dark matter, which acts as a gravitational lens to magnify and distort distant galaxies' light.

Using the observed smearing, Vikram's team constructed a 2D dark matter map (shown at right) and plotted out how much dark matter lies along lines of sight within a 139-square-degree subset of the area. Generally, the observations support the picture of the universe as a cosmic spider web, with galaxy clusters strung along nodes and filaments of dark matter like so many caught flies. But clusters don't *exactly* trace the underlying dark matter distribution, because normal matter and dark matter follow different physical laws. The team posted the result May 7th on the open-access preprint site arXiv.org.

Working on a much smaller scale, Mathew Madhavacheril (Stony Brook University) and colleagues conducted a different study using the Atacama Cosmology Telescope to measure dark matter's smearing effect, not on the light from faraway galaxies, but on the most well-traveled light in the universe: the cosmic microwave background (CMB).



By measuring dark matter's smearing effect on galaxy shapes, the Dark Energy Survey mapped out the mysterious stuff's density over a large swath of sky. The color scale reflects dark matter density (red high, blue low); grey circles mark galaxy clusters — bigger circles represent larger clusters.

The team looked for sharp brightness changes in the CMB on arcminute scales, corresponding in this case to the few million light-years that an individual galaxy's dark matter halo spans. The astronomers found about 12,000 blips that matched up with galaxies listed in a Sloan Digital Sky Survey catalog. Each of these galaxies has a massive halo roughly 10 times that of the Milky Way, the team reports April 13th in *Physical Review Letters*.

Simply measuring the signal from individual galaxies' dark matter halos is an accomplishment — little has been done on these small scales before. The average dark halo's mass and concentration, as measured from the blobby composite image the team created, so far match what's expected from dark matter simulations. Researchers will apply the same technique to data obtained from the Advanced ACT polarization survey taking place between 2016 and 2018, which will cover 10 times the sky area. Eventually, Madhavacheril hopes to trace the growth of dark matter halos over cosmic time.

■ **MONICA YOUNG**

Wolf-Rayet Stars?

Both of these observations hint at a companion star. Astronomers usually assume that massive stars expel their outer layers as a stellar wind, an outflow of matter coupled with irregular ejections. But the typical mass loss from stellar winds might not be enough to produce as many Wolf-Rayets as we've observed; there are just too many of them relative to other, less-evolved massive stars. If a stellar companion is involved, however, it would pull on the Wolf-Rayet's loosely bound outer envelope, unraveling the star's outer hydrogen layer more quickly. The X-ray emission could be from the two stars' colliding stellar winds, the team suggests in the July 1st *Monthly Notices of the Royal Astronomical Society*.

■ **ANNE MCGOVERN**

IN BRIEF

New Ultra-Deep Star Catalog. Astronomers at the U.S. Naval Observatory have announced the first release of the USNO Robotic Astrometric Survey (URAT1). Begun in 2012, the effort encompasses about 228 million stars in the northern sky down to declination –15° and to about magnitude 19. This represents a nearly fourfold increase in the star count per degree of sky versus UCAC, the USNO's previous catalog. Each star's position has been pinpointed to within 5 to 30 milliarcseconds (0.005 to 0.03 arcsecond). URAT1 is available to users as catalog I/329 through the Strasbourg Astronomical Data Center: http://vizier.u-strasbg.fr.
■ **J. KELLY BEATTY**

Microwave Ovens Spark Radio Signals. After 17 years, researchers using the Parkes radio telescope in Australia have identified the culprit behind a mysterious type of radio signal: two on-site microwave ovens. Astronomers have suspected that the fleeting radio bursts, called *perytons*, were local: they only appear in Parkes data, and they appear equally bright at all 13 frequencies that Parkes observes — unlike point-like astrophysical sources, which are brightest at a single frequency. But the proof didn't come until Emily Petroff (Swinburne University of Technology, Australia) and colleagues installed a real-time radio interference monitor. In January, the telescope detected three perytons, just as the monitor picked up three signals at 2.3 to 2.5 GHz, the same frequency range that a microwave oven runs on. After extensive testing, the team discovered that when they opened a nearby oven's door prematurely during its cycle, the signal appeared. Thus, the perytons were likely caused by staff members who were too impatient to wait for their lunches to finish heating, the team reports in a paper posted to arXiv.org on April 9th. The perytons are different from fast radio bursts (*S&T*: Oct. 2013, p. 10), mysterious and powerful radio bursts with potential extragalactic origins. Read more at http://is.gd/perytonoven.
■ **SHANNON HALL**

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

EXOPLANETS | Super-Earth Volcanoes? . . .

The super-Earth 55 Cancri e is having hot flashes. Over the course of a year, the planet's infrared emission brightened almost fourfold, a huge and unusual variation that implies a temperature change of 1300K between 2012 and 2013.

Brice-Olivier Demory (University of Cambridge, UK) and colleagues dug this find out from a total of 85 hours of observations by NASA's Spitzer Space Telescope. The exoplanet takes only 18 hours to orbit 55 Cancri, and the observations covered the world both as it passed in front of, and was occulted by, its host star multiple times. During each occultation, the star blocks the planet's thermal emission (as well as its reflected light), which astronomers can then measure by its absence.

What Demory's team found was a change of almost 300% in thermal emissions between occultations measured in 2012 and 2013. That's no small blip — it signifies a corresponding temperature change from 1400 to 2700 kelvin (2100 to 4400°F).

Because 55 Cancri e's average temperature is so high, the planet's crust and mantle are probably weakened, if not wholly molten, the authors write in a paper posted March 10th to the preprint site arXiv.org. So the surface of this alien world might host volcanic activity, with ejecta plumes and even magma oceans. Big plumes could temporarily block the planet's infrared emission, explaining the drop to lower temperatures.

"This is a really exciting result," says Laura Kreidberg (University of Chicago). But the planet's temperature could also vary if a donut-shaped ring of material around the planet or the star hides some of the planet's infrared emission. "It's hard to say [which is the] likelier possibility. This planet is so completely unlike anything we have in the solar system that we don't know what to expect," she says.

In fact, both scenarios might be at play. Combining the two "has the potential to explain all the observations we have about this planet," Demory says.
■ **EMILY POORE**

. . . and Hot Jupiters: Cloudy or Clear?

Hot Jupiters' temperatures might predict their weather reports, not vice versa, a new analysis suggests.

Lisa Esteves (University of Toronto) and colleagues sifted through 4½ years of Kepler data to pick out 14 exoplanets that show clear brightness changes as they pass not only in front of, but also behind and next to, their host stars. By tracking the worlds as they moved through different phases, the astronomers worked out how much of each planet's light is reflected and how much of it comes from the planet's own heat.

The 14 exoplanets follow tight orbits around their host stars and are probably all tidally locked, showing the same face to their star at all times. So the team expected the hottest part of the planet's atmosphere to be smack in the middle of the side facing the star.

But, in six cases, it's not. In four hot Jupiters, where the average temperature hovers around "only" 2000 kelvin (3100°F), the bright spot is offset so that the planet's brightness peaks after its eclipse by the star. If the skies are clear on the part of the planet facing us during ingress, but clouds cover the side facing us during egress, starlight reflected off the clouds would shift the bright spot so that it appears after the eclipse.

On two other, hotter Jupiters, where average temperatures approach 3000K, the hotspot is offset in the opposite direction, peaking *before* the eclipse. The reason could be clear skies that enable us to see the planet's own glow as a hotspot offset toward the ingress side, the team reports in the May 10th *Astrophysical Journal*. But the other eight planets do not have offset hotspots, making it hard to know if clouds are the answer.
■ **MONICA YOUNG**

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IN BRIEF

Most Luminous Galaxy Discovered. Researchers using data from NASA's Wide-Field Infrared Survey Explorer (WISE) have discovered the most luminous galaxy to date. Dubbed WISE J224607–052635, this extremely luminous infrared galaxy (ELIRG) shines brighter in the infrared than 300 trillion Suns, likely powered by a supermassive black hole at its core that's a thousand times more massive than the one in the center of our Milky Way. J2246 is one of 20 ELIRGs reported by Chao-Wei Tsai (JPL) and colleagues in the June 1st *Astrophysical Journal* and has the highest redshift of the group: its light left it just 1.3 billion years after the Big Bang. ELIRGs are the brightest examples of hot dust-obscured galaxies, or hot DOGs (*S&T:* Dec. 2012, p. 14). Astronomers still debate how gargantuan black holes like the one in J2246 could have formed so early in the universe's history.

■ ANNE MCGOVERN

M31's Giant Gas Halo. Astronomers have detected a massive yet elusive nimbus of hot gas surrounding the Andromeda Galaxy. The gargantuan cushion extends out at least a million light-years, almost halfway to the Milky Way, Nicolas Lehner (University of Notre Dame) and colleagues report in the May 10th *Astrophysical Journal*. Astronomers have suspected that this kind of halo must surround most galaxies: observations only account for about 40% of the normal matter expected in galaxies (that's after accounting for dark matter), and simulations suggest that hot gas, both inflowing and outflowing, ought to envelop them. By observing 18 distant quasars whose light streams through the space where Andromeda's halo ought to be, the team detected the spectroscopic shadows that the halo's ions left on the quasar light. The measurements show that Andromeda's halo contains 3 billion Suns' worth of gas within 200,000 light-years and probably 10 times that amount out to a million light-years. In short, Lehner says, this study and an accompanying one of more distant galaxies have "essentially solved" the missing matter problem.

■ MONICA YOUNG

SUPERNOVAE | Type Ia, Two Ways

Two new studies confirm that the white dwarfs that explode as Type Ia supernovae can approach death on two different paths.

When white dwarfs accrete too much material, they burst through a strict weight restriction called the Chandrasekhar limit and trigger a thermonuclear blast deep inside themselves, self-annihilating in a Type Ia supernova.

For many years, astronomers have debated just how the white dwarf maxes out its mass. There are two scenarios: either it siphons gas from a "living" companion star until it just can't swallow any more (called the *single-degenerate model*), or it merges with another dead star like itself (the *double-degenerate model*). The growing sense is that white dwarfs probably die both ways.

Two papers in the May 21st *Nature* support this idea. In the first, Yi Cao (Caltech) and colleagues detected an ultraviolet pulse in light from the Type Ia supernova iPTF14atg that lasted for four days after the explosion. The authors propose the UV pulse arose when the exploding white dwarf's ejecta slammed into its companion star. The signal would then have disappeared once the ejecta engulfed the companion enough to hide the shocked gas created by the collision.

In the second study, Rob Olling (University of Maryland) and colleagues used archival observations from the Kepler mission to study three supernovae. Two of these supernovae (KSN 2011b and KSN 2012a) are clearly Type Ia; the third (KSN 2011c) is probably one. The team used the same theoretical predictions as Cao's team did to analyze their data and found no sign of ejecta slamming into companion stars.

Although Kepler doesn't look in UV (where Cao's team saw iPTF14atg's ejecta shock), Olling says that the telescope's sensitivity is so tremendous that, had there been a signal from material colliding with a companion star, his team would have seen it in visible light. Thus, the astronomers favor a dual white dwarf death as the origin for these three (likely) Type Ia events.

■ CAMILLE M. CARLISLE

STELLAR | Migrating Stars in 47 Tucanae

Observations of white dwarfs in a densely populated globular cluster confirm astronomers' expectations that stars migrate to a cluster's outskirts after losing mass.

Globular clusters are balls of very old stars organized by mass, with heavier, slower stars congregated near the middle and lighter, faster ones at the cluster's edge. Astronomers think that clusters organize themselves in this way via *dynamical relaxation*: when two stars interact gravitationally, the less massive star gets nudged farther out and is eventually expelled to the cluster's edges.

Using Hubble's Wide Field Camera 3, Jeremy Heyl (University of British Columbia, Canada) and colleagues have now caught this migration in action, by studying white dwarfs in the rich globular cluster 47 Tucanae. White dwarfs begin as the cores of stars like the Sun. When the stars hit the end of their fusion-powered lives, they shrug off their outer layers to reveal collapsed, planet-size cores, losing about 40% of their initial mass in the form of stellar winds. Because the stars lose so much mass, subsequent interactions with other stars should propel them outward from their initial positions over time.

White dwarfs cool as they age, and because hotter (younger) white dwarfs are brighter in ultraviolet wavelengths than cooler (older) ones, the researchers were able to estimate the cluster stars' ages and identify two major populations of white dwarfs. They found that the younger ones gathered near the center of the cluster, while the older ones were dispersed at the outer edges, exactly as expected. The result appears in the May 1st *Astrophysical Journal*. ✦

■ ANNE MCGOVERN


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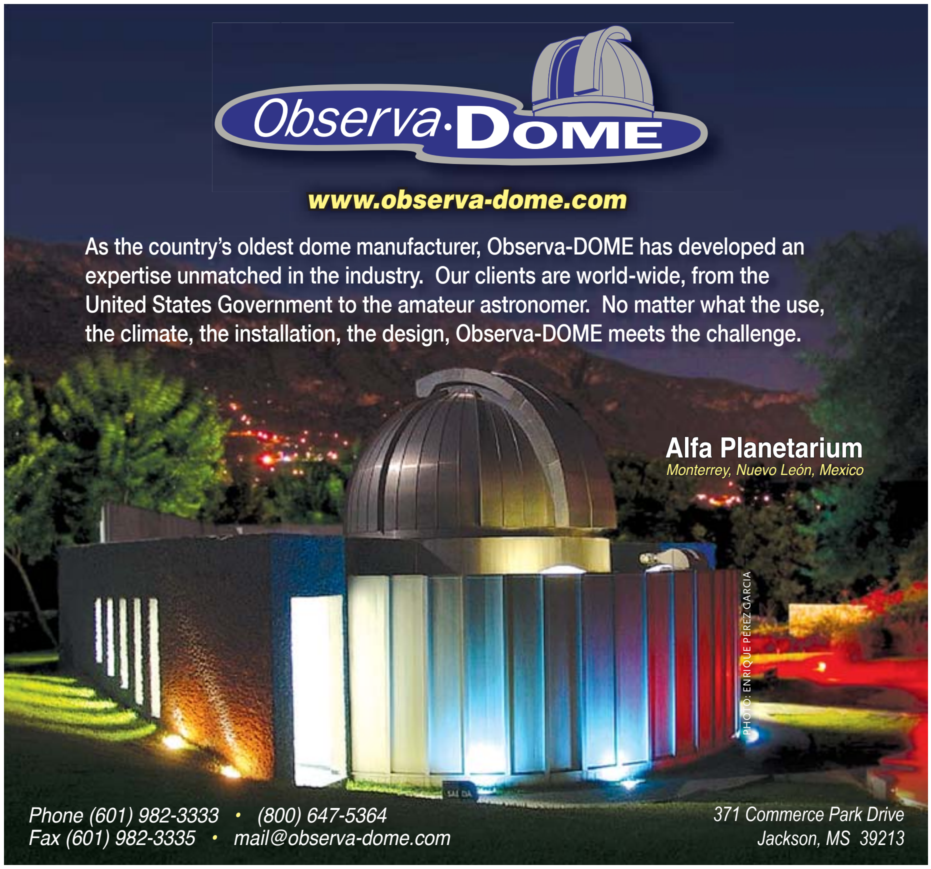
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How Galaxies Grow

Camille M. Carlisle

The universe's stellar metropolises rend, chew, and merge with one another. But how important are these encounters in creating the galaxies we see today?

Many of us have a rough-and-tumble view of galaxy growth. In this savage landscape, the rules are simple: eat or be eaten. Spirals tear up dwarfs and munch them like Fruit Roll-Ups. Big galaxies smash together and, in their cannibalistic fervor, gnash each other beyond recognition. Cosmic history can seem like the tale of galaxies playing a grim game of king of the mountain.

In the very early universe, when protogalaxies reigned and things were more of a mishmash, a riotous picture might have had some truth to it. But in their observations of the universe's past 10 billion years astronomers have found that, when it comes to how galaxies grow, the whopping crashes of whirligigs aren't as big a deal as you might think. The cosmos isn't the Wild West; many stellar cities don't land themselves in all-out brawls.

That hasn't always been the thinking. Astronomers have flip-flopped several times on how important mergers are in galaxies' evolution, says Pieter van Dokkum (Yale). In the mid-20th century, astronomers simply weren't thinking of mergers. Then, with the development of modern cosmology in the 1980s, the idea arose that these unions were the main driver of galaxy growth. And in the late 1990s and early 2000s, astronomers discovered that the most massive galaxies already existed within the universe's first few billion years, making some wonder if mergers even had time to play a role and if the whole cosmological framework was wrong.

MINOR SKIRMISH Arp 273 includes a spiral galaxy (top) that has had its arms pulled askew by a second, smaller galaxy about one-fifth its mass (bottom). The smaller companion perhaps dove through the larger one on an off-center trajectory, explaining the stretched spiral. The encounter likely triggered the clusters of newly formed stars (blue). A small orange core embedded in the spiral's outer right arm might be a third galaxy.

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

Today, we occupy some sort of middle ground. "I think everyone would agree that merging is a fundamental and important process," says Eline Tolstoy (University of Groningen, The Netherlands), "but I think we would disagree with each other about exactly how that manifests itself from one galaxy to the next."

Sorties and Wars

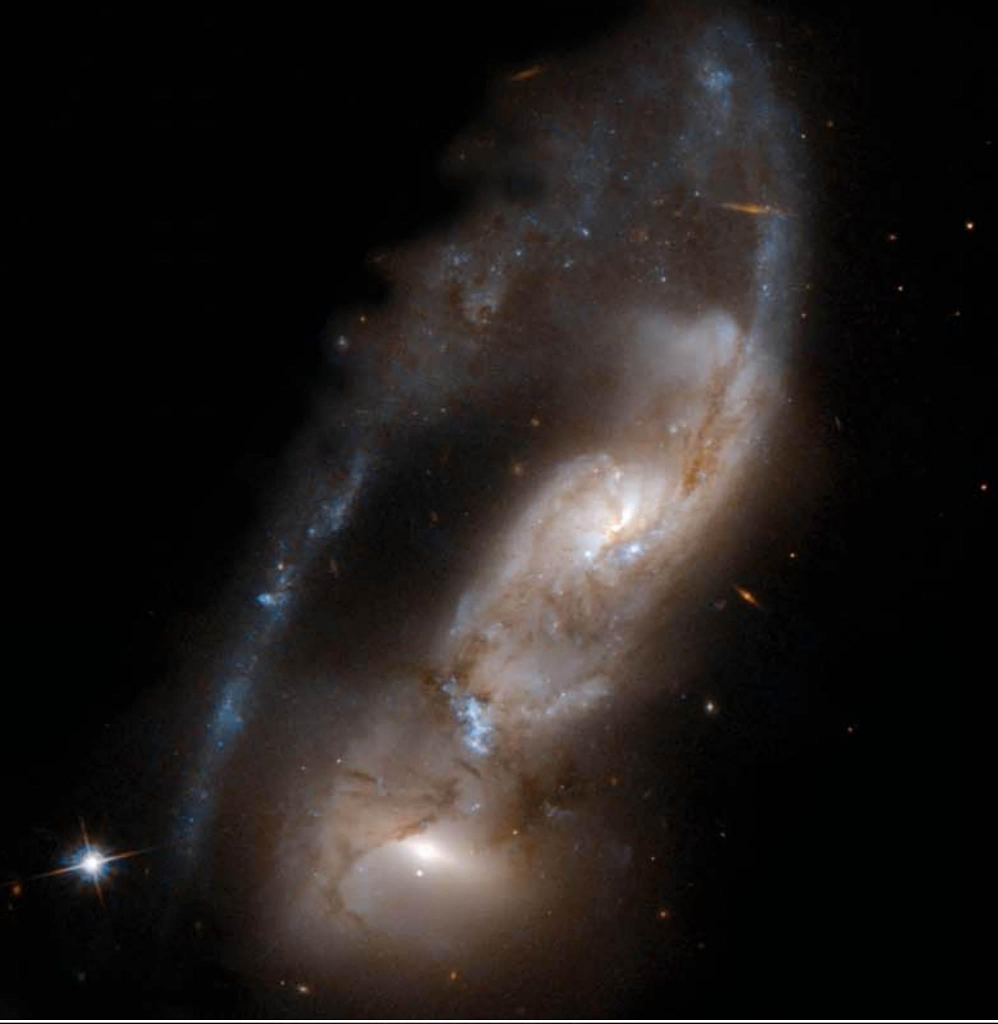
On the largest scales, cosmic structure looks like a sponge. Veins of dark matter, gas, and galaxies outline sparse voids. This spongy structure formed thanks to gravity, which exacerbated small blips in the nascent universe's density, pulling dark matter (which makes up most of cosmic particles) into a web of filaments and nodes. As this network coalesced, the first galaxies also formed, like coffee spilled on a cobbled floor, James Geach (University of Hertfordshire, UK) writes in his book *Galaxy: Mapping the Cosmos*. The sloshed coffee collects in the grooves between cobbles, much the same way the universe's pristine gas drained into gravitational valleys created by dark matter.

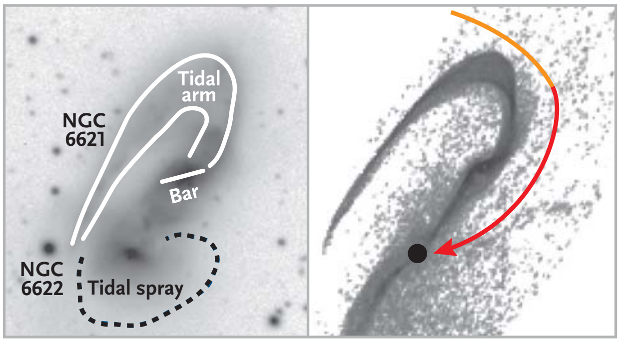
After that initial startup, galaxies continued to grow. For the first few billion years, they looked very little like the ones we see today — they were clumpy and turbulent, a hodgepodge of objects. Star formation ramped up, peaking across the universe about 10 billion years ago, during what astronomers call cosmic high noon. Then it dwindled, to less than one-tenth that rate today. Even so, about 95% of the stars shining now formed in the last 10 billion years, van Dokkum says.

GALACTIC CRASHES

Major and minor mergers have different effects on the galaxies involved. NGC 6621 and 6622, also known collectively as Arp 81 *(right)*, exemplify the interaction of two evenly matched systems: the encounter has torn both galaxies apart. On the other hand, the large spiral NGC 5754 *(below)* is five times more massive than NGC 5752 *(fuzz to its right)* and survived their recent encounter relatively unscathed. *Facing page:* William Keel (University of Alabama) and Kirk Borne (now at George Mason University) endeavored to reconstruct these systems' major tidal structures (labeled images) in simulations of the interactions. In the simulation diagrams, the big dot marks the center of the contender that looped around, and orbits are orange where they passed behind the other galaxy from our perspective.

NGC 5752/4 AND NGC 6621/2: NASA / ESA / HUBBLE HERITAGE (STSCI / AURA) & ESA / HUBBLE COLLABORATION / W. KEEL (UNIV. OF ALABAMA, TUSCALOOSA); SCHEMATICS: *S&T*: GREGG DINDERMAN, SOURCE: W. KEEL AND K. BORNE / *ASTRONOMICAL JOURNAL* 2003





Some — including those that make for the most breathtaking Hubble images — involve two large, well-matched adversaries, such as NGC 4038 and 4039, the Antennae Galaxies in Corvus. These *major mergers* happen when one contender is at most four times more massive than the other. Major mergers spur dramatic changes, creating a maelstrom of shock waves and turbulence in the galaxies' gas clouds that subsequently triggers star formation. Toward the end of the merger, the interaction can also drive a large amount of gas into the new galaxy's center, feeding the supermassive black hole (or holes) in the core and fueling a *starburst phase*, during which hundreds to thousands of Suns form per year for a few million years.

These mergers are spectacular, but they're not terribly common. In 2009 Shardha Jogee (University of Texas at Austin) and colleagues looked back 3 to 7 billion years ago at galaxies slightly smaller than the Milky Way. The team found that approximately two-thirds of these galaxies had suffered a merger, but only 16% had clearly been in a major duel. On the other hand, at least 45% had weathered a *minor merger*, a merger with a galaxy one-fourth to one-tenth the bigger one's mass.

Minor mergers often involve a big galaxy and a dwarf galaxy. They're more common than major ones because there are a lot of small galaxies in the universe and they tend to cluster around the larger ones, leaving themselves vulnerable to cannibalism.

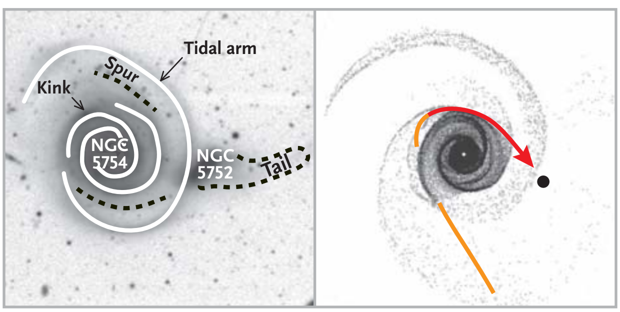
When the larger system is a spiral, a minor merger can warp its disk, creating pockets of star formation or puffing the pancake up and out. In some cases the merger barely leaves a mark. But the effect is hardly minor on the smaller contender: the encounter can devastate a dwarf, ripping it apart and glomming its pieces onto the rival's outskirts.

"The Milky Way wasn't really around yet, as we see it now," he says. Astronomers think that the types of systems present today — ellipticals, lenticulars ("lens-shaped"), spirals, barred spirals, and all the siblings in each of those groups — took shape between 6 and 10 billion years ago. So if we can track what's happened to stars over the last 10 billion years, we'll know how most of today's stars ended up where they are.

That's why a lot of the action — and the mystery — centers on cosmic high noon. Astronomers are fairly confident that smaller clumps of gas combined to build galaxies' early precursors. The question is what came next: how do you turn a galactic shantytown into a megalopolis?

Astronomers often tackle galaxy growth by looking at star formation, because star formation essentially *is* growth. To amass extensive stellar suburbs, galaxies need to build upon the finite resources they first incorporated. That means they need to either nab stars from elsewhere or find more gas to keep creating their own.

This sticking point is where mergers come in. When astronomers talk about mergers, they generally mean the interaction of full-grown galaxies after the universe's first couple billion years. But not all mergers are equal.



Building Big Galaxies

Conventional wisdom — at least, of late — is that the most massive of the melon-shaped galaxies called ellipticals form via mergers. These systems contain ancient stars moving along chaotic orbits, and they're also the heftiest stellar cities, easily 10 times more massive than the Milky Way. Astronomers don't see gargantuan ellipticals at cosmic high noon, but they do see compact, bulbous galaxies, with the stars deep inside packed as tightly as they are in today's leviathans. These *compact cores* can outweigh the Milky Way, even though they're only about

MORE THAN ONE WAY TO SKIN A GALAXY

Mergers aren't the only way galaxies interact. There are also encounters that aren't (or aren't exactly) mergers. These include a galaxy sucking in gas from the space around it, and *gravitational harassment* (yes, that's the technical term), when multiple high-speed passes in a crowded cluster leave a galaxy looking frazzled. In harassment and other near encounters, galaxies move past each other too quickly to grab hold and merge. But the galaxies can still end up looking not quite themselves. How common such processes are depends on how crowded a galaxy's neighborhood is, and who its neighbors are.

NASA / ESA / HUBBLE HERITAGE (STSCI / AURA) & ESA / HUBBLE COLLABORATION

DIFFERENT PEAS, SAME POD The galactic duo Arp 116 sits in the Virgo Cluster. The giant elliptical, M60, is roughly 10 times more massive than the spiral, NGC 4647, which is on par with the Milky Way. The galaxies lie roughly 10 million light-years from each other and make a nice pair in small telescopes. M60's stars rotate coherently, which might indicate that the galaxy has had a relatively merger-free history compared with other massive ellipticals.

a tenth the size. They began as small, star-forming galaxies that burned out early, leaving behind an aging stellar population eventually dominated by reddish dwarf stars.

Some astronomers think today's massive ellipticals started as these cores, then grew by stealing stars via minor mergers and using the captured stars to expand their borders. "If you combine those two things — that they didn't form a lot of new stars, but they've changed dramatically in how they look — they must have undergone mergers," van Dokkum says. "That, I think, is almost inescapable."

In addition, we know that mergers can create ellipticals. Simulations in 2007 by Frédéric Bournaud (now at CEA Saclay, France) and colleagues suggested that, after a galaxy has grabbed more than 30% to 40% of its initial mass from other systems, it will turn into an elliptical — regardless of whether its mergers were major or minor. And in a few billion years our own Milky Way is heading for battle with its sister spiral, the Andromeda Galaxy. Computer mockups of that merger indicate they'll combine to form a big, red elliptical (*S&T:* Oct. 2014, p. 20).

But things are never straightforward in galactic astronomy. Both simulations and observations also suggest that individual major mergers don't always destroy the combatants' disks. What matters is how gassy they are. Stars can steal angular momentum from one another via gravitational interactions, leading to helter-skelter layouts nothing like the initial, orderly pancakes. But gas dilutes this effect. If there's enough of it in the two galaxies — more than half of the contents, roughly — everything will inevitably settle down and create a disk. For major mergers, this might only have happened in the universe's first few billion years, when galaxies were particularly gassy.

In addition, today's lighter-weight ellipticals might have grown without outside help. The stars in these galaxies don't fly about randomly as they do in the biggest ellipticals; they seem to move together, rotating as a unit. The ordered motion, combined with other characteristics, suggests these systems form from really massive, star-forming galaxies, without much (if any) help from mergers. Astronomers have recently detected massive galaxies shining from 10 to 11 billion years ago that look poised to churn out enough stars to grow into big spheroids all on their own (*S&T:* Aug. 2015, p. 14). So there are likely at least two galactic breeds that can grow into the ellipticals we see today.

Spiraling into Confusion

For less massive (but still big) galaxies, including spirals like the Milky Way, the picture is even more opaque. These galaxies haven't increased in size much over the last 10 billion years, but they have increased a lot in mass — they're denser than they once were, and denser throughout, not just in certain spots. That's distinct from what astronomers see in the massive ellipticals, which are as dense in their centers today as they were 10 billion years ago.

This difference might arise because spirals and big ellipticals acquire their material differently. Thus astronomers suspect that, instead of assembling via significant mergers, spirals accrete gas steadily, with the material deposited at all radii and not just at the galaxies' edges.

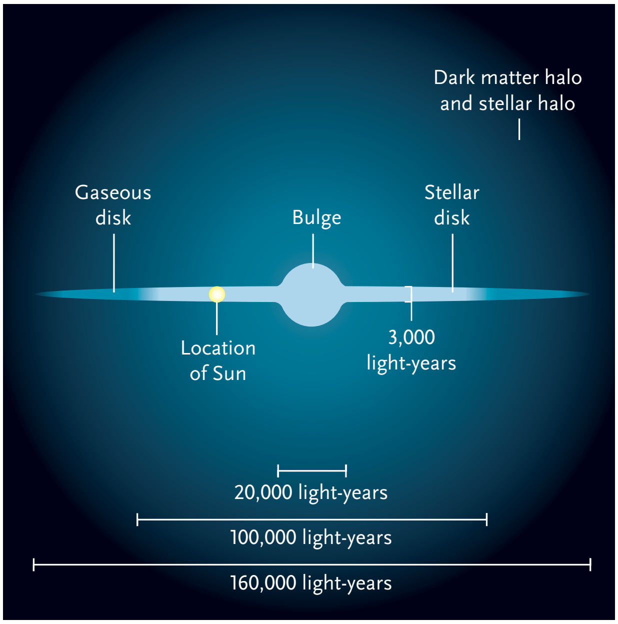
"That is the most obvious explanation," van Dokkum says. "That doesn't mean it's right, but it's the most obvious one," he adds, laughing.

The main mystery today is the role minor mergers play in spirals' evolution. In an intriguing study last year, Sugata Kaviraj (University of Hertfordshire, UK) looked at about 6,500 local spiral galaxies from the Sloan Digital Sky Survey and checked them for signs of disturbance. Since major mergers are unlikely to preserve disks in today's universe, he assumed that any disturbances — and the starbirth they induced — were from minor mergers. Given that, Kaviraj estimates that these tussles instigate roughly 40% of all the star formation going on in spirals. Coupled with a previous study he did of elliptical and lenticular galaxies, he argues that minor mergers might trigger around half of all star formation in today's universe. Other astronomers are less optimistic, suggesting that minor mergers might only ignite about 10% of the stars in a Milky Way–type galaxy.

Kaviraj thinks dwarfs spur starbirth by stirring up gas already in the larger galaxy. These spirals are "awash in gas," he says, but that gas needs compressing before it will spawn stars. "The dwarf essentially activates this gas into forming stars," he says. "What gas the dwarf itself brings into the system is pretty much irrelevant."

ANTENNAE GALAXIES The iconic pair NGC 4038 and 4039 represent one of the nearest and most recent galactic interactions. The two orange orbs are the original galaxies' cores. The dust (brown), young star clusters (blue), and hydrogen gas (pink) make for a beautiful but messy picture.

NASA / ESA / HUBBLE HERITAGE (STSCI / AURA) & ESA / HUBBLE COLLABORATION



S&T: LEAH TISCIONE

MILKY WAY IN BRIEF Edge-on schematic of our Milky Way Galaxy, with associated parts. Sizes are approximate.

Enrico Di Teodoro (University of Bologna, Italy) agrees that the gas in dwarf galaxies can't fuel the explosion in stars: in a study of 148 nearby spirals, he and Filippo Fraternali (also at Bologna) estimated that dwarf companions could supply at most one-fifth of the gas needed to sustain the average starbirth rate in the galaxies they observed. But he cautions that the gas in a spiral has to come from *somewhere*. Spirals generally only have enough gas to sustain a "normal" star-formation rate of one to two Suns per year for a few billion years at most. "If no fresh gas is supplied from the outside, spiral galaxies would have already exhausted their gas reservoir, and we would not observe star-forming galaxies in the local universe," he says.

Galaxies can also pull in gas directly from their surroundings, in a process called *cold-gas accretion*. Only relatively cold material can sink down deep into galaxies, cooling further until it can collapse to form stars. Astronomers think such accretion was particularly important in the early universe, when there was so much gas being channeled into galaxies that it could shove past their hot halos (which would normally stymie accretion). Simulation work by Dušan Kereš (now at University of California, San Diego) and colleagues in 2009, for example, argued that a galaxy that today has roughly 10 times the Milky Way's mass in stars built up most of that mass by accreting gas that's never been substantially heated.

Spirals' rotations, as well as how their rotation axes line up with the cosmic filaments they sit in, support the idea that these galaxies form through a more peaceful accretion of gas drawn in from their surroundings. And high-resolution simulations of the early universe also suggest that cold streams can directly connect to the edge of a galactic disk and feed the galaxy like a fuel line (see right). Because the gas is so diffuse and faint, observing such accretion is difficult in practice.

But there's the problem of semantics: when is an interaction a minor merger, and when is it cold-gas accretion? It's hard to tell when a clump of gas qualifies as a dwarf galaxy. Some astronomers draw the line based on whether the cloud sits in its own dark matter halo, as both dwarf and large galaxies do. But confirming such a halo poses its own challenges: astronomers are still debating whether a recent high-speed visitor to the Milky Way, the Smith Cloud, survived because of a magnetic sheath or because it has its own dark matter holding it together — and that gaseous object is a mere 40,000 light-years away, right in our backyard.

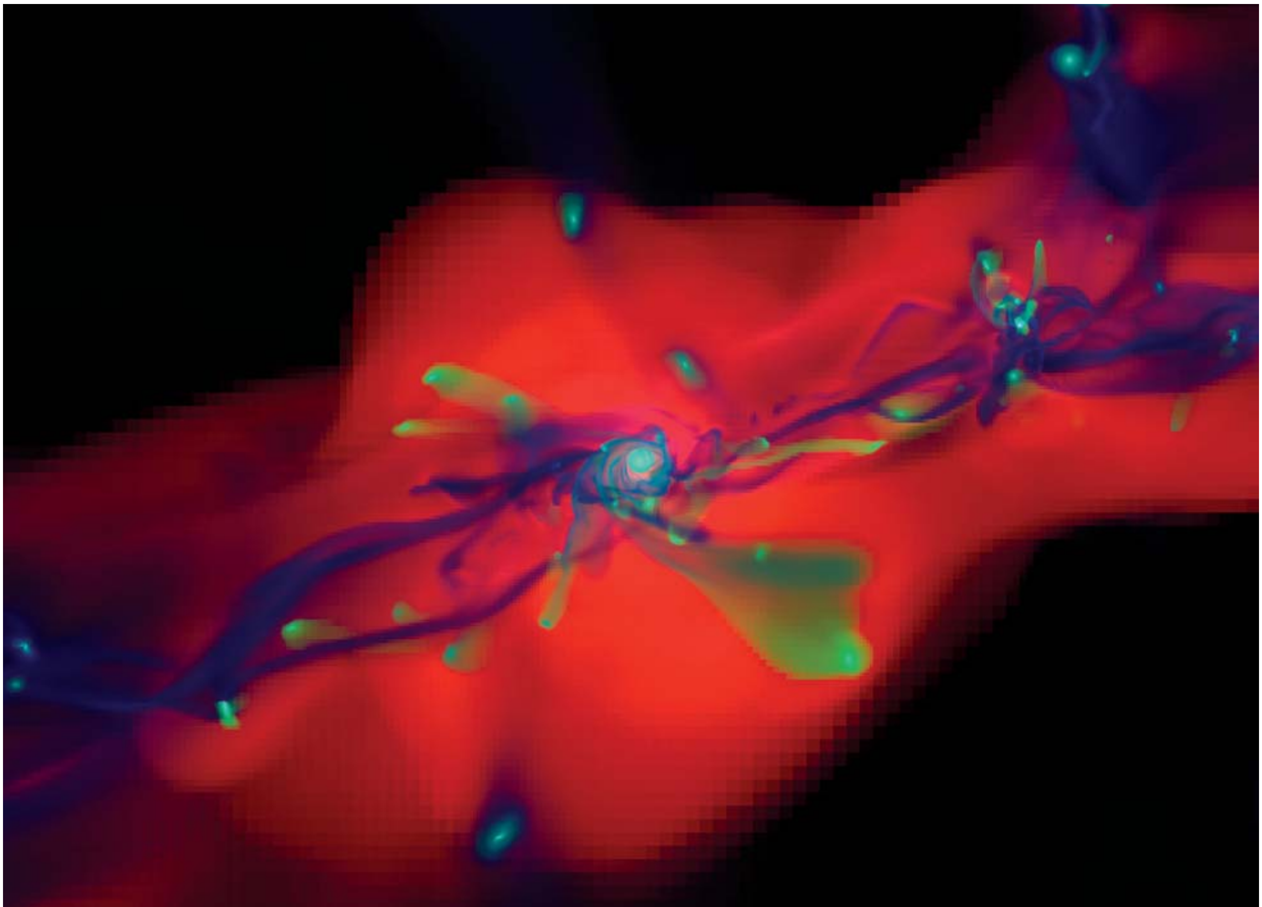
Going It Alone

Astronomers have other reasons to doubt mergers' role. The 2009 study by Jogee's team revealed that only a third (at most) of the stars being born 3 to 7 billion years ago were in visibly merging galaxies; instead, most new stars were lighting up in galaxies that weren't interacting. Other observations support this picture: many of the stars born in the last several billion years — and thus much of the growth that's happening — arise in quiet galaxies.

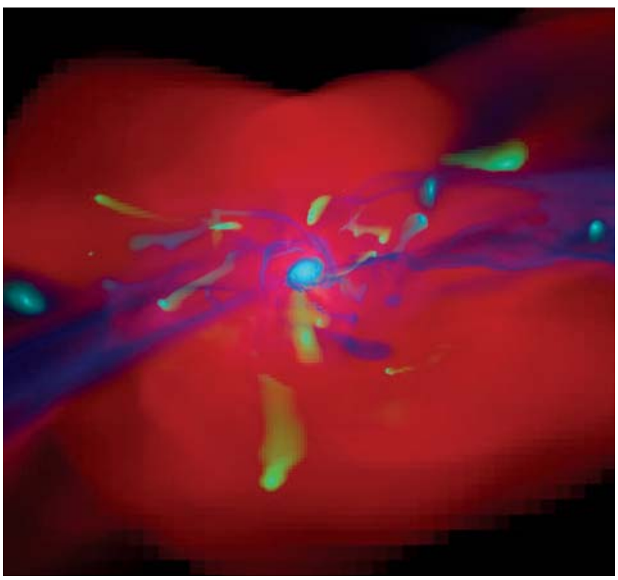
Another cause of suspicion is stellar halos. These gigantic clouds of old stars surround galaxies like the Milky Way, extending far beyond the spiral disk. Some astronomers predict that most of the halo stars come from dwarf galaxies the spiral has ripped up and eaten over time. Observers do see hints of stellar streams in the Milky Way's halo, including shreds of the dwarf Sagittarius, supporting this idea. And the Andromeda Galaxy is "a big mess," Tolstoy says, with a halo rich with substructures and clear evidence of a major accretion event. The merger debris could be from one of Andromeda's dwarf companions or another unidentified galaxy.

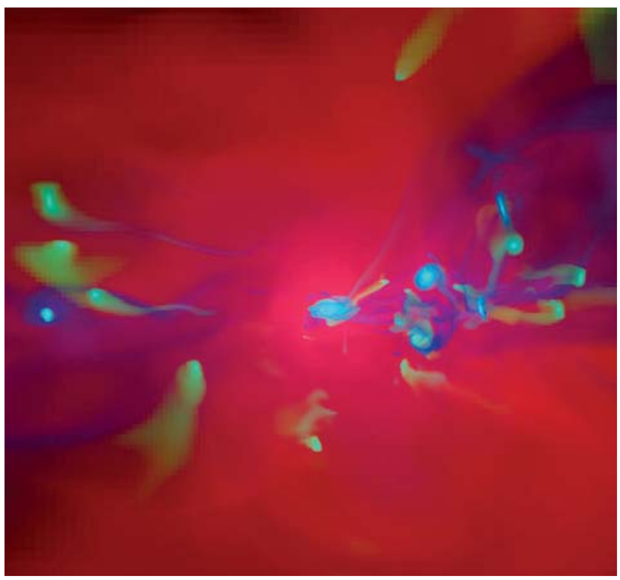
But a merger-made halo is hard to reconcile with the Milky Way's chemistry, Tolstoy warns. The halo stars astronomers have studied in detail have fairly pristine hydrogen-and-helium compositions, with low levels of heavy elements. The latter build up as stars die and seed the gas around them with things like carbon. The chemistry suggests that any consumed dwarfs had to have stopped forming stars after only a billion years, then merged with the Milky Way. "That becomes quite contrived," she says.

One unexpected turn comes from van Dokkum's team. The astronomers took a hard look at the nearby spiral M101, the Pinwheel Galaxy in Ursa Major. Using a compound instrument called the Dragonfly Telephoto Array, which combined eight Canon EF 400-mm f/2.8 telephoto lenses on a common mount, the team studied M101 down to a magnitude per square arcsecond of 32,



COLD-GAS SIMULATION In the universe's first couple billion years *(top)*, many protogalaxies grow by accreting cold gas along cosmic filaments (blue streams, forming galaxy in center). But as the gas falls into the gravitational well a galaxy sits in, the gas is shocked and heats up (red). At early times, the cold gas could push past the hot to accrete directly onto disks. But over time, the gas heats up and filaments become more diffuse, breaking up into smaller clouds that mix with the halo *(bottom left, 10 billion years ago, and bottom right, 7 billion years ago)*. Astronomers observe cold accretion onto the Milky Way today in the form of high-velocity clouds, potentially condensations from the galaxy's gaseous halo. One estimate puts this accretion rate just shy of one solar mass per year. To fuel the current starbirth rate, the Milky Way uses several times that amount of gas.





OSCAR AGERTZ (3)

similar to studies of the Milky Way's galactic family, the Local Group. To their surprise, the astronomers found *no* stellar halo.

If more spirals turn out to look like the Milky Way and M101, then galaxies might experience fewer mergers than astronomers think. But with only three big spirals studied at this depth, it's hard to say. "I have a completely open mind on this particular question," van Dokkum says.

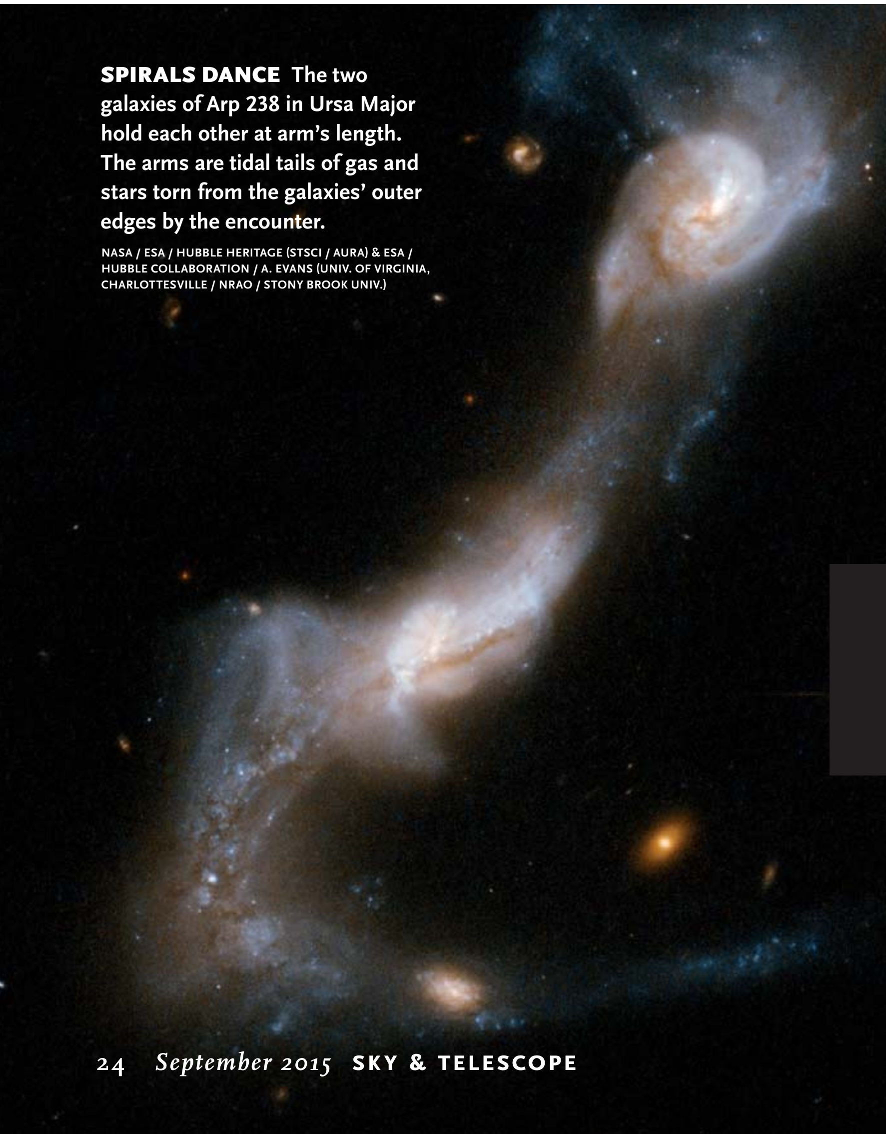
Making Sense of Mergers

Astronomers are investigating the true role of mergers in several ways. One is the work Kaviraj and others are doing, trying to determine observationally the impact minor mergers have across cosmic time. For that work, astronomers are looking to deep, large-scale projects, such as the Dark Energy Survey and the upcoming Euclid mission and Large Synoptic Survey Telescope.

There are also chemical and dynamical clues closer to home. Stars born together should have similar chemical makeups, revealing their common ancestry. A 5-year survey at Siding Spring Observatory in Australia, called GALAH (Galactic Archaeology with HERMES), is looking for these "chemical tags" in the Milky Way's halo stars, in order to identify debris from disrupted stellar clusters and dwarf galaxies. Similarly, ESA's Gaia spacecraft (*S&T:* Apr. 2014, p. 10) is hard at work compiling a detailed map of the Milky Way's stars and how they move. Preliminary Gaia data have turned up stars in the halo that do look like they've been snatched from elsewhere. But the data also suggest that our galaxy hasn't merged with anything larger than one-tenth its mass since its disk formed about 9 billion years ago. That would mean that between then and now, the Milky Way hasn't scuffled with anything bigger than the Large Magellanic Cloud.

Learning more about how the Milky Way grew will shed light on how relatively isolated galaxies evolve. And because most stars today are in Milky Way–type galaxies, understanding our galaxy and those like it will help us understand how important mergers have been in the universe overall. ✦

S&T *Science Editor* ***Camille M. Carlisle*** *might trump the universe's galaxies in snacking frequency.*



SPIRALS DANCE The two galaxies of Arp 238 in Ursa Major hold each other at arm's length. The arms are tidal tails of gas and stars torn from the galaxies' outer edges by the encounter.

NASA / ESA / HUBBLE HERITAGE (STSCI / AURA) & ESA / HUBBLE COLLABORATION / A. EVANS (UNIV. OF VIRGINIA, CHARLOTTESVILLE / NRAO / STONY BROOK UNIV.)

How Astronomers Watch Galaxies Age

It's hard to track galaxies across cosmic time. As astronomers study the universe at higher and higher redshifts, pushing farther back in cosmic time, they essentially take snapshots of what galaxies looked like at a particular moment. But these snapshots show an assortment of galaxies at different look-back times; they don't track the same set of stellar metropolises through their evolution across 10 billion years. Instead, astronomers have to connect the dots between epochs based on what they see.

"It's like having the fossil record: you see all these different animals at different times, but then you have to say, 'Okay, this dinosaur turned into this chicken,'" quips Pieter van Dokkum. In biology, scientists have genetic tools to help them understand the record. "We haven't quite found the DNA of galaxies yet."

Sans galactic DNA, astronomers often turn to mass as a proxy: they assume that the first, second, third, and so forth most massive galaxies today were also one of the first, second, third, and so forth most massive galaxies 5 billion or 10 billion years ago — in other words, they rank them by mass, and then use that rank as a sort of roll call to pick out the progenitors of today's galaxies across cosmic time. So long as galaxies don't on average hopscotch over one another in the mass pecking order, this trick works. Rank order is how astronomers determine that, compared with their appearance now, the progenitors of today's disk galaxies were fluffier but about the same size several billion years ago. In fact, disk galaxies' precursors seem to have a range of appearances about 8 billion years ago, from smooth or unstable disks to interacting systems.

September's Total Lunar Eclipse

Alan MacRobert

The whole western world can see the eclipse of September 27–28.

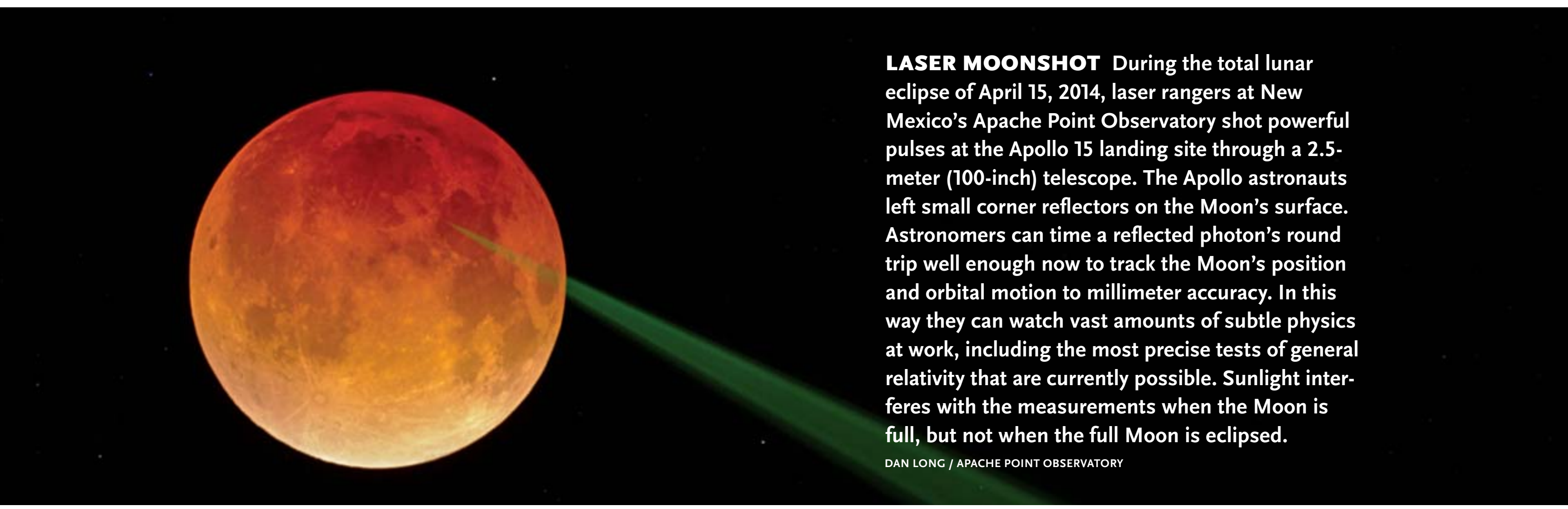
The current "tetrad" of four total eclipses of the Moon a half-year apart will end with a bang on Sunday evening, September 27th, for the Americas. Unlike last April's eclipse, which may not even have been precisely total (see the July issue, page 12), this one will carry the Moon through the umbra of Earth's shadow for a nice long hour and 12 minutes. Europe and Africa will see the eclipse happen on the local morning of the 28th.

Observers in eastern North America can watch every stage of the eclipse from beginning to end (weather permitting!), during convenient hours of late twilight or darkness with the Moon generally high in the sky.

Viewers in much of the American West will find the first partial stage of the eclipse already in progress when the Moon rises (due east) around the time of sunset. But even on the West Coast, the Moon will lift above the eastern horizon before totality begins. The map on the facing page, and the diagram and timetable on page 28, tell what to expect at your location and when.

This eclipse is unusual in one particular way. It's the *biggest* eclipsed Moon you'll ever see! The year's closest lunar perigee occurs just 59 minutes before mid-eclipse. The Moon (in Pisces) will appear 13% larger in diameter than it did when eclipsed last April 4th.

The events that happen to a shadowed Moon are more complex and interesting than many people realize. This eclipse, with its wide visibility, convenient evening schedule, and record size, is going to get a lot of publicity. So keep the following description handy for when family and friends ask you for the lowdown.



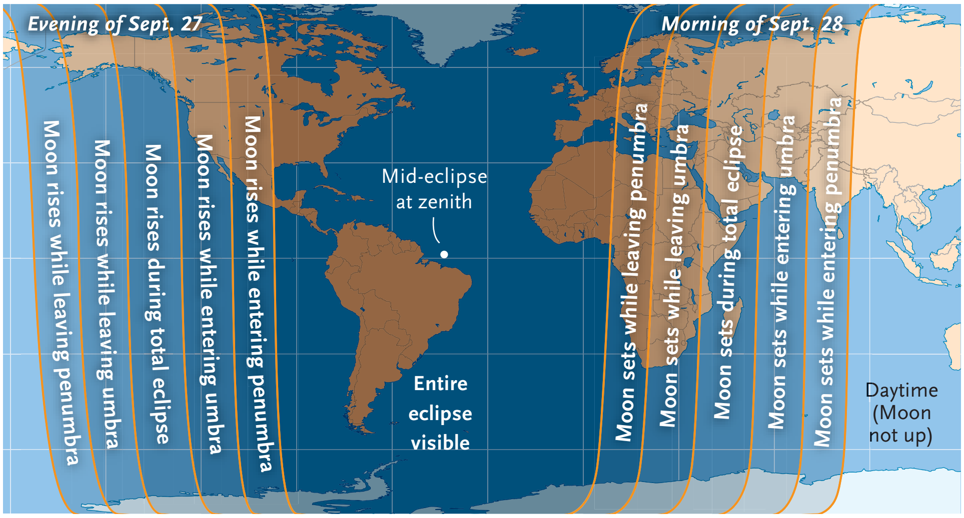
LASER MOONSHOT During the total lunar eclipse of April 15, 2014, laser rangers at New Mexico's Apache Point Observatory shot powerful pulses at the Apollo 15 landing site through a 2.5-meter (100-inch) telescope. The Apollo astronauts left small corner reflectors on the Moon's surface. Astronomers can time a reflected photon's round trip well enough now to track the Moon's position and orbital motion to millimeter accuracy. In this way they can watch vast amounts of subtle physics at work, including the most precise tests of general relativity that are currently possible. Sunlight interferes with the measurements when the Moon is full, but not when the full Moon is eclipsed.

DAN LONG / APACHE POINT OBSERVATORY

Stages of the Eclipse

A total lunar eclipse has five stages, with different things to watch for at each.

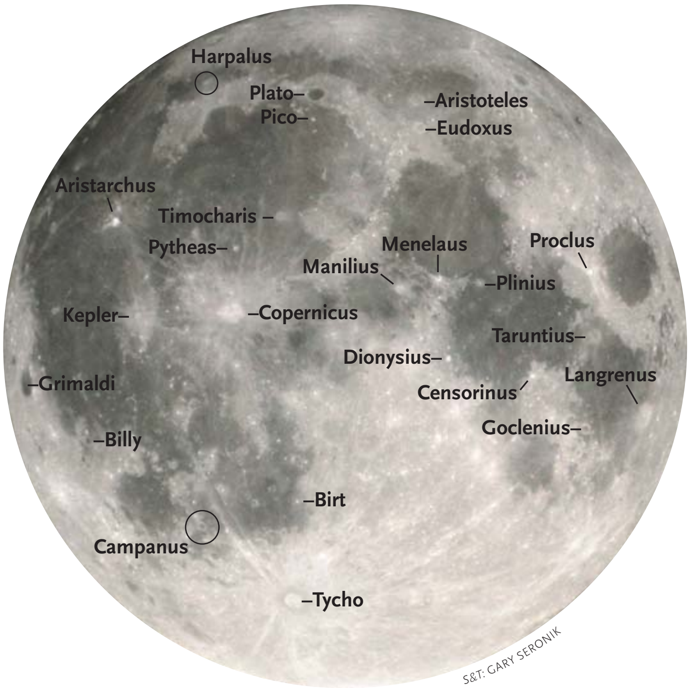
The first *penumbral* stage begins when the Moon's leading edge enters the pale outer fringe of Earth's shadow: the penumbra. But the shading is so weak that you won't see anything of the penumbra until the Moon is about halfway across it. During this eclipse, watch for a slight darkening to become apparent on the Moon's celestial northeast side: its left side as seen from North



S&T: LEAH TISCIONE

TWO ECLIPSES AGO ***Above:*** **Before dawn on October 8, 2014, Jeff McGrath shot the cirrus-hazed Moon through a 160-mm f/8 refractor at Stansbury Park Observatory Complex in Utah.**

WIDE VIEW THIS TIME ***Left:*** **For your location, check whether the Moon will rise (or set) during some stage of the eclipse. An eclipsed Moon is always full, so the Sun sets (or rises) at almost the same time on the opposite horizon. This means that a lunar-eclipse moonrise or moonset always happens in a very bright sky!**



CRATER TIMING GUIDE Craters and spots that stand out well during a lunar eclipse are identified here. Approximate times when the umbra's edge will cross them are listed at right.

America, its upper left side as seen from Europe.

The penumbra is the region where an astronaut standing on the Moon would see Earth covering only part of the Sun's face. The penumbral shading becomes stronger as the Moon moves deeper in.

The second stage is *partial eclipse*. This begins much more dramatically when the Moon's leading edge enters the umbra: Earth's inner shadow where the Sun is completely hidden. With a telescope, you can watch the edge of the umbra slowly engulfing one lunar feature after another (see the Crater Timings box on the facing page), as the entire sky begins to grow darker.

The partial phase will last just over an hour. As its end approaches, only a final bright sliver remains outside the umbra. By this time the rest should already be showing a dim, foreboding reddish glow.

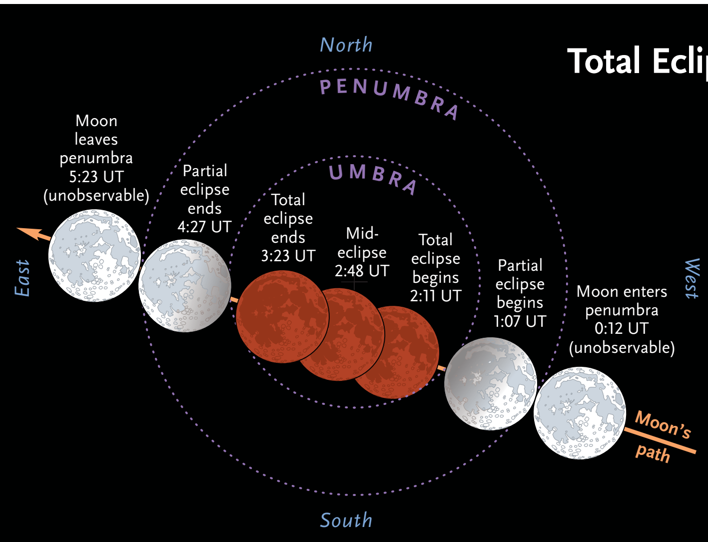
The third stage is *total eclipse,* beginning when the last rim of the Moon slips into the umbra. But the Moon won't black out: it's sure to glow some shade of intense orange or red. This red light is sunlight that has skimmed and bent through Earth's atmosphere, all around the edge of our globe, on its way to the Moon. In other words, it's light from all the sunrises and sunsets that ring our world at any given moment. An astronaut standing on the Moon would see the dark Earth thinly rimmed with brilliant orange from the Sun hidden behind it — brilliant enough to illuminate the lunar landscape around him an eerie red.

This umbral light can change a lot from one eclipse to the next. Two main factors affect its brightness and color. The first is simply how deeply the Moon goes into the umbra while passing through; the center of the umbra is much darker than its edges. At mid-eclipse this time, the Moon's south-southeastern edge will be only a quarter of a lunar diameter inside the umbra, so expect that side to be distinctly brighter than the rest.

The other factor is the state of Earth's atmosphere along the sunrise-sunset line. If the air is very clear, the eclipse is bright. But if a major volcanic eruption has recently polluted the stratosphere with thin global haze, a lunar eclipse will be dark red, ashen gray, or occasionally almost black.

In addition, *blue* light is refracted through Earth's clear, ozone-tinted upper atmosphere above the thicker layers that produce the red sunrise-sunset colors. This

Total Eclipse of the Moon, Night of September 27–28, 2015



Eclipse event	EDT	CDT	MDT	PDT
Penumbra first visible?	8:40 p.m.	7:40 p.m.	—	—
Partial eclipse begins	9:07 p.m.	8:07 p.m.	7:07 p.m.	—
Total eclipse begins	10:11 p.m.	9:11 p.m.	8:11 p.m.	7:11 p.m.
Mid-eclipse	10:48 p.m.	9:48 p.m.	8:48 p.m.	7:48 p.m.
Total eclipse ends	11:23 p.m.	10:23 p.m.	9:23 p.m.	8:23 p.m.
Partial eclipse ends	12:27 a.m.	11:27 p.m.	10:27 p.m.	9:27 p.m.
Penumbra last visible?	12:55 a.m.	11:55 p.m.	10:55 p.m.	9:55 p.m.

S&T: LEAH TISCIONE

ozone-blue light colors the Moon a bit near the umbra's edge. The result can be a subtle mix of changing blue, gray, purple, and even green.

Time-lapse videos may show large "flying shadows" in the umbra, caused by changing cloud-shadowing effects around the sunrise-sunset line as Earth turns and the Moon moves.

And then, as the Moon continues eastward along its orbit, events replay in reverse order. The Moon's edge re-emerges into sunlight, ending totality and beginning stage four: a partial eclipse again.

When all of the Moon escapes the umbra, only the last, penumbral shading is left for stage five. By about 30 or 40 minutes later, nothing unusual remains.

We'll have more than two years' wait until the next total eclipse of the Moon, on January 31, 2018. And that will be visible only from the Eastern Hemisphere and the western side of North America.

The previous tetrad of lunar eclipses happened in 2003–04. The next begins on April 25, 2032.

Uranus Again

During the eclipse of October 8, 2014, eleven days short of a year before this one, the Moon was only about 1° from 6th-magnitude Uranus. This time Uranus is about 15° to the Moon's east. But take a look during a quiet few minutes if the Moon is high in a dark sky at your location while the eclipse is still total. Use the finder charts on page 49. Uranus is 15 times larger than the Moon but, on this night, it's 8,000 times farther away. It will be magnitude 5.7. In the darkness of the total lunar eclipse, can you glimpse Uranus naked-eye? ✦

Although S&T *senior editor* ***Alan MacRobert*** *sees Earth totally eclipsing the Sun every clear evening from his house, he really wants to see it happening from Mare Crisium.*

Crater Timing Predictions

ENTRANCES Feature	UT	EXITS Feature	UT
Grimaldi	1:11	Grimaldi	3:31
Aristarchus	1:15	Billy	3:33
Billy	1:18	Campanus	3:37
Kepler	1:18	Tycho	3:38
Pytheas	1:25	Kepler	3:43
Copernicus	1:26	Aristarchus	3:45
Timocharis	1:28	Copernicus	3:51
Plato	1:30	Pytheas	3:53
Campanus	1:31	Timocharis	3:58
Aristoteles	1:38	Plato	4:04
Eudoxus	1:39	Manilius	4:05
Manilius	1:39	Dionysius	4:06
Menelaus	1:42	Menelaus	4:08
Tycho	1:43	Censorinus	4:11
Dionysius	1:45	Plinius	4:11
Plinius	1:46	Eudoxus	4:11
Censorinus	1:53	Aristoteles	4:12
Proclus	1:55	Goclenius	4:12
Taruntius	1:57	Langrenus	4:16
Goclenius	2:00	Taruntius	4:18
Langrenus	2:05	Proclus	4:20

Crater Timings Sought!

The size of Earth's umbra varies slightly from one eclipse to the next for reasons that are still unknown. For 170 years, careful observers have timed when the edge of the umbra crosses lunar markings during eclipses. In the June issue (page 28) Roger Sinnott told of the massive analysis that he and his colleagues did of the 26,658 timings that are on record since 1842. And he called for readers to make timings during this upcoming eclipse, especially because it offers a very similar repeat of the much-timed eclipse of September 27, 1996.

All you will need is a small telescope (use fairly high power), a timepiece that reads to the second, and a notepad and pencil.

Check in advance that your watch or device is accurately set to the second (for instance, at time.gov/widget). The idea is to time when the umbra's edge — defined as *where the shadow changes brightness most abruptly* — crosses a feature's center. Record the time to at least the nearest 5 seconds.

The photo at the top of the facing page labels some standard timing targets. The table above gives many rough predictions, so you don't get caught flat-footed. It's fine to skip some.

Please report your timings to Roger Sinnott at rsinnott@post.harvard.edu. We'll publish results in a future issue. You can become a part of lunar history.

Earth's Come & Go Moons

Astronomers are on the lookout for a smattering of tiny asteroids that get trapped as temporary moonlets around our planet.

Bruce Dorminey

The interplanetary space surrounding Earth and its Moon is vast, but it is not completely empty. We're regularly visited by near-Earth objects (NEOs) that go unseen, except by those observers who spend their nights looking for them.

Now a handful of planetary scientists is hoping to find a tiny subset of these NEOs that actually become Temporarily Captured Orbiters (TCOs) — "mini-moons" that are snared by Earth's gravity, linger in our vicinity for a few months or a few years, and then slip away.

The earliest known written mention of potential Earth-captured mini-moons came in 1913, when Clarence Chant, a University of Toronto astronomer, coordinated visual accounts of a dramatic North American meteor procession on February 9th of that year (*S&T:* Feb. 2013, p. 32). Chant noted that these objects were "probably in an orbit about the Sun, and that on coming near the Earth they were promptly captured by it."

To date, the only known mini-moon was the small asteroid 2006 RH_{120}. Likely only 3 to 7 meters across, this asteroidal fragment was discovered on September 14, 2006, with the Catalina Sky Survey's 0.68-meter Schmidt telescope on Mount Bigelow in Arizona (*S&T:* July 2007, p. 18). Dynamicists' reconstruction of its movement suggests that the interloper remained a tiny "second moon" for about a year.

Snared by Special Circumstances

If astronomers discovered one by accident, there surely must be others. The first computer modeling to offer a plausible mechanism by which these mini-moons could become bound objects was put forth by Mikael Granvik (University of Helsinki, Finland) and others in 2012. Their simulations indicated that on average these objects make about three complete revolutions around Earth and stay captured for only 9½ months. Only about 1% of them strike Earth.

STEALTHY COMPANIONS Astronomers estimate that, at any given time, Earth has up to 100 very small asteroids (at least 20 centimeters across) in temporary orbits around it.

Illustration by Dan Durda

It turns out that NEOs can only rarely become mini-moons. Those that do typically take up residency after passing through one of two gravitational "sweet spots" known as *Lagrangian points*. L_1 is situated about 1½ million kilometers (1 million miles) away from Earth in the sunward direction, while L_2 is at the mirror image location in the direction opposite the Sun. Any two-body system (Earth and Sun in this case) has five such points at which objects can remain in a stable configuration relative to the two bodies for long time periods.

To become mini-moons, objects must pass through L_1 or L_2 slowly — moving only 1 to 2 km per second (about 2,000 to 4,000 mph) with respect to Earth. (In contrast, uncaptured NEOs often zip by at tens of kilometers per second.) Then they "fall" into the *Hill sphere,* the dynamical netherland where our planet's gravitational influence exceeds that of the Sun. Earth's Hill sphere is about 1.5 million km in radius, some four times the Earth-Moon distance.

Granvik and his team estimate that, at any given time, there are probably about 100 mini-moons larger than 20 centimeters (8 inches) in diameter, a dozen at least 0.5 m across, and one or two larger than 1 m. An object the size of 2006 RH_{120}, at least 3 m across, might be captured only once every decade. Objects of 100 m or more might show up only once in 100,000 years.

"Mini-moons typically lie from one to roughly 10 lunar distances on crazy trajectories around Earth," said Robert Jedicke (University of Hawai'i), one of Granvik's coauthors. This distinguishes them from "pseudo moons" that sometimes come close to Earth and even share our planet's heliocentric orbital plane but are never gravitationally snared. In contrast, mini-moons are bona fide bound satellites — at least during the time they're captured.

Bits of the Early Solar System

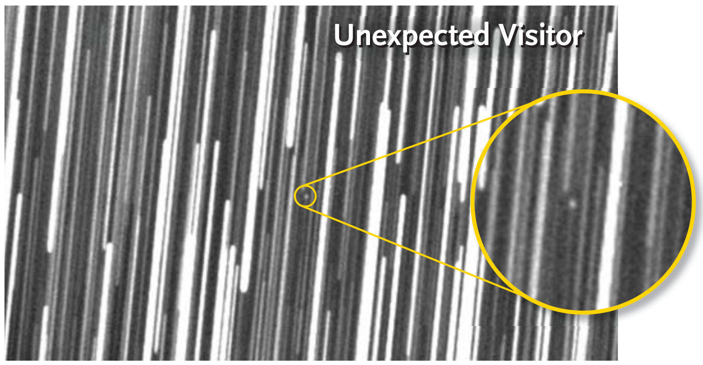
The starting point for all mini-moons is almost certainly the main asteroid belt, explains dynamicist William Bottke (Southwest Research Institute). Basking in sunlight, these main-belt objects heat up and then re-radiate that energy, creating subtle forces that cause them to move slightly and their orbits to evolve gradually. These gentle nudges, combined with the long-term gravitational influences of Jupiter and Mars, cause a small subset of asteroids to migrate inward to establish Earthlike orbits.

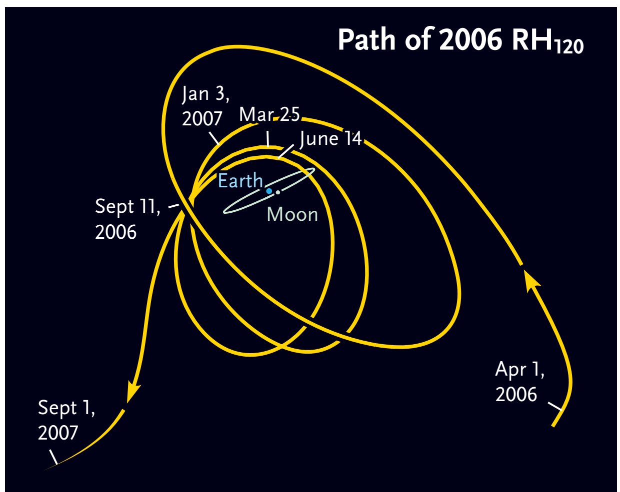
However, only a tiny fraction are moving in just the right direction and slowly enough to be captured. "Some objects may stay a year, some may stay 20 years," says Bottke. "They rattle around the Hill sphere with all sorts of trajectories until they find a way out. But it's a steady-state population; for every one that leaves, one enters. And although there's no restriction on size, over the next 100 years, we might only have one 20-meter mini-moon."

Once freed from the confinement of Earth's gravity, they continue on nearly Earthlike heliocentric orbits, with most unlikely to come close to Earth again for decades or even centuries.

Such small objects offer planetary scientists one of their best near-term hopes of bringing back a whole chunk of the pristine early solar system. What makes them attractive as targets is that, unlike a random NEO zipping quickly past Earth, these mini-moons are not only orbiting nearby but also traveling at much lower relative velocities than other asteroids. (In fact, for a time astronomers thought that slow-moving 2006 RH_{120} was actually a large chunk of spacecraft debris.)

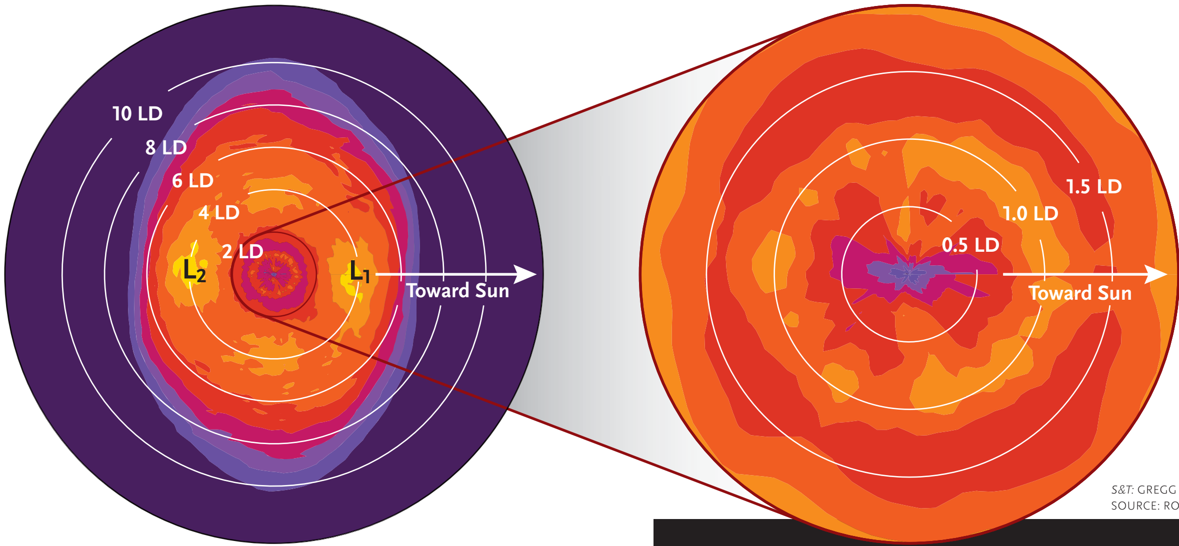
This means that future rendezvous missions would require relatively modest rocket propulsion to reach any given object and to return with samples of it — or perhaps to bring back the entire space rock. To get to a main-belt asteroid requires more powerful rockets than to get to some NEOs. And mini-moons offer the best economy of all, because they're relatively close by. One scheme involves having a spacecraft "parked" in geosyn-





Top: **Discovered by accident, the tiny asteroid 2006 RH_{120} was initially mistaken for a piece of space debris as it drifted slowly amid background stars. Peter Birtwhistle stacked 180 CCD images taken through his 0.4-m telescope to record the 19th-magnitude blip.** ***Above:*** **The little asteroid hovered near Earth for more than a year before slipping back into interplanetary space.**

S&T: GREGG DINDERMAN



S&T: GREGG DINDERMAN, SOURCE: ROBERT JEDICKE

Top-Down View

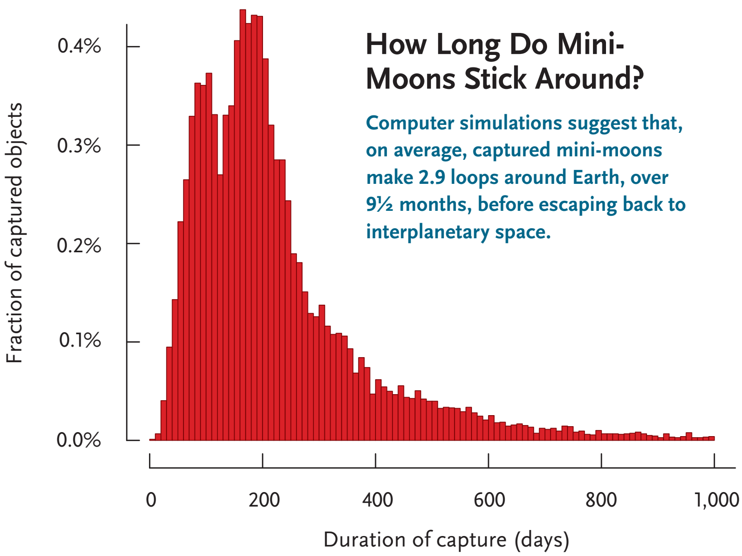
These plots show a computer simulation of the distribution of mini-moons near Earth averaged over time, with yellow denoting the highest likelihood. They are captured by Earth's gravity after slowly slipping through one of two Lagrangian points, labeled L_1 and L_2 at left. The enlargement at right shows that several objects could lie inside the Moon's orbit (labeled *1.0 LD*), but most are too small to detect even with powerful telescopes.

chronous orbit that could be dispatched on short notice to rendezvous with a captured object. Then it could retrieve the object wholly intact for transport as cargo back to Earth-based laboratories for analysis.

A Challenge to Find

Predicting that mini-moons exist is one thing, but spotting such small bodies is a very different matter. A 2014 analysis by Bryce Bolin (University of Hawai'i) and others concludes that the planned Large Synoptic Survey Telescope should be capable of discovering one of them per month, though it's not clear how they'd be flagged as mini-moons or tracked after discovery. Jedicke thinks to truly chart these objects' orbits and dimensions will require a dedicated space telescope.

To that end, in early 2013 he proposed dedicating one of two 2.4-m space telescopes, which the National Reconnaissance Office had recently donated to NASA (*S&T:* Sept. 2012, p. 15), to the detection of these objects from the Earth-Sun L_1 point. The 5-year effort he envisioned would perform a deep survey for objects throughout the solar system that were moving along the ecliptic plane. It would identify a wide array of objects beyond mini-moons: imminent Earth impactors, other NEOs, main-belt asteroids, comets, Trojans (objects that share Jupiter's orbit), Centaurs (renegades from the Kuiper Belt), and trans-Neptunian objects.



How Long Do Mini-Moons Stick Around?

Computer simulations suggest that, on average, captured mini-moons make 2.9 loops around Earth, over 9½ months, before escaping back to interplanetary space.

S&T: GREGG DINDERMAN, SOURCE: ROBERT JEDICKE

It seemed like a great fit at the time: NASA was seeking a target for its proposed Asteroid Redirect Mission (*S&T:* July 2013, p. 12), and mini-moons would be easy pickings, dynamically speaking. But ultimately space-agency managers cooled to the idea of using the donated space telescopes and also decided that the redirect mission would be designed to pluck a boulder from a largish NEO for astronauts to study, rather than to snare a whole small object. Besides, it's unrealistic to plan a spacecraft rendezvous with an object that hasn't been discovered yet.

Yet planetary researchers realize the immense scientific value of bringing an intact mini-moon back to Earth for study. They point to the celebrated case of 2008 TC_3, which to date is the only asteroidal object detected by observers before impacting Earth. Roughly 3 m across, it broke up in the atmosphere over the northern Sudanese desert, and search teams later recovered samples from the ground (*S&T:* Aug. 2009, p. 22). Although the impactor was never a mini-moon, its composition proved unusual.

"TC_3's meteorites are largely ureilites, a weird set of rocks from a body that melted and was then blown to smithereens a few million years after it formed," says geochemist Ed Scott (University of Hawai'i). "Some of its centimeter-sized samples contain totally different kinds of meteorites from very different main-belt asteroids. We still don't understand how it acquired them."

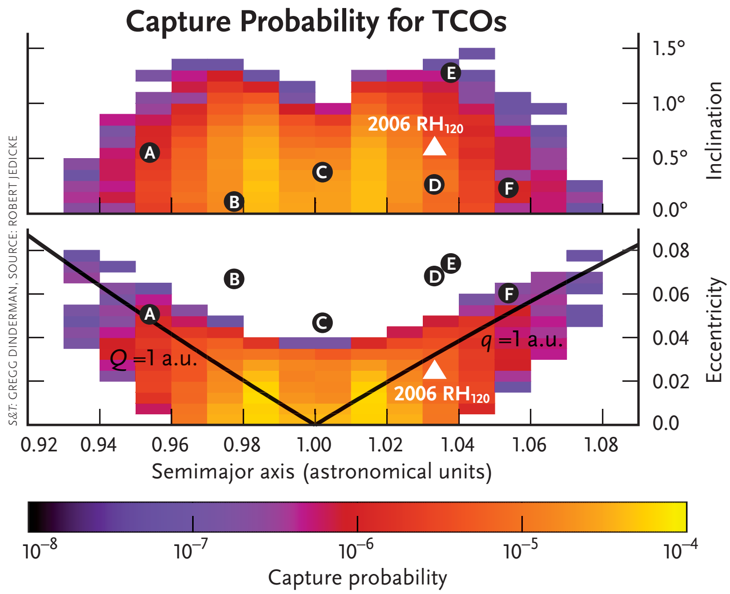
The hope is that small mini-moons might also have similarly interesting compositions. In fact, finding them on a regular basis would allow astronomers to spot and track potential Earth-impacting mini-moons well in advance. Were one predicted to slam into our atmosphere, researchers could set up a system to photograph, take spectra of, and measure a true bolide.

"With a month's notice, you could have people all lined up to observe the object coming through the atmosphere," says planetary scientist Clark Chapman (Southwest Research Institute). "You would know where it will hit, then have people find the fragments. The whole body of meteor spectra that sits in the literature could be reinterpreted with much more confidence. It would be TC_3 ten times over."

Some researchers, including Granvik, would like to use mini-moons to determine whether small asteroids have interiors that are more akin to rubble piles than monolithic pieces of space rock. This would have consequences for strategies to mitigate Earth impactors, as well as for future robotic and human missions to small asteroids.

But there's also more fundamental science at stake. "The way to understand how the solar system formed," says Jedicke, "is to bring back chunks of it that haven't been processed by tumbling through Earth's atmosphere or by surface weathering." The end result would provide what Jedicke terms a veritable set of "Rosetta stones" from which to unravel our solar system's earliest history.

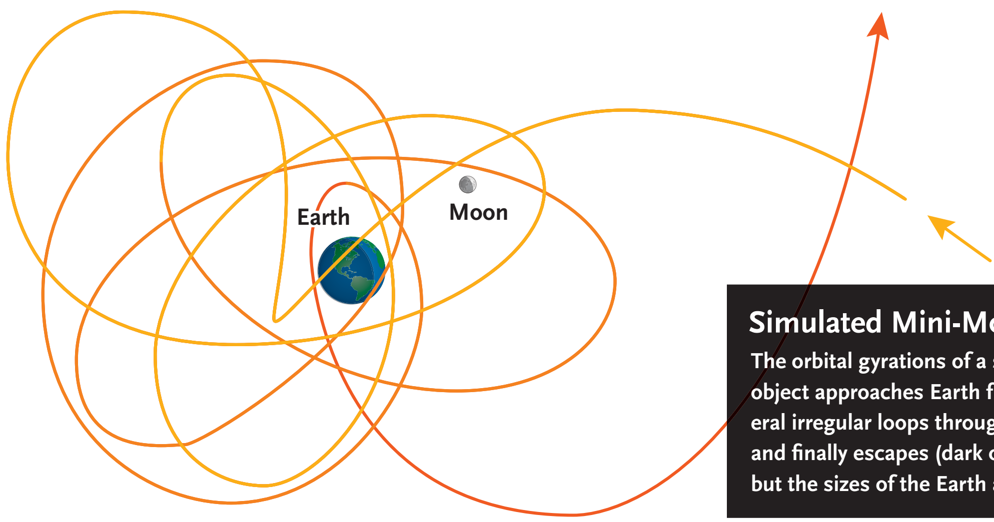
The first step is simply to find them. "Right now it's just theoretical, not a viable population," Jedicke admits. But the hunt is on — he's recently secured observing time on Japan's 8.2-m Subaru Telescope and its sensitive, wide-field detector called Hyper Suprime-Cam. Statistically,



In order to become captured, an asteroid must have an orbit very similar to Earth's, both in terms of its inclination (top panel) and eccentricity (lower panel). Color coding shows the probability of capture, with yellow denoting most likely, and the black lines indicate orbits with aphelia (*Q*) and perihelia (*q*) of 1 astronomical unit. Paired letters identify known asteroids whose orbits make them susceptible to capture, though none have been. Also shown is the pre-encounter orbit of asteroid 2006 RH_{120}, the only known mini-moon to date.

Jedicke figures he's got a 40% chance of finding a mini-moon during a single night and as high as 90% if he can squeeze in five nights of observations spread over a few months. "I've devoted a lot of time to understanding these objects," he says, and if the Subaru effort succeeds, he'll finally have a real mini-moon or two to work with. ✦

Science journalist ***Bruce Dorminey*** *is the author of* Distant Wanderers: The Search for Planets Beyond the Solar System *and a Forbes.com tech columnist. Follow him on Facebook, Twitter, and Google+.*



K. TERAMURA / UNIV. OF HAWAI'I

Simulated Mini-Moon Trajectory

The orbital gyrations of a simulated mini-moon begin as the object approaches Earth from the right (yellow line), makes several irregular loops throughout the Earth-Moon system (orange) and finally escapes (dark orange). Distances are shown to scale, but the sizes of the Earth and Moon are not.

The Case of the Missing M102

Did a false lead 232 years ago hide the truth about this "nonexistent" Messier object?

Michael A. Covington

For more than two centuries astronomers have referred to about 100 prominent star clusters, nebulae, and galaxies by numbers such as M31 and M42. These are from the Messier catalog, published in installments from 1771 to 1781 by the French comet-hunter Charles Messier. He was primarily documenting objects that could be mistaken for comets. Messier's own 13 comet discoveries have faded into history. But his list of non-comets was such a convenient tally of deep-sky objects for small telescopes that astronomers quickly adopted it and have used it ever since.

This part of the story is well known, but then the

PICK ONE Is the nonexistent "M102" actually NGC 5866 (below) and not M101 (left) as long thought? In deep images at the same scale they appear utterly different, but their bright cores look similar in small scopes.

M101: MASIL IMAGING TEAM; NGC 5866: MICHAEL COVINGTON

tale grows complex. Since Messier's time the Messier catalog has developed and matured, in several stages. It originally gave incorrect positions for some objects, and it failed to number the last few objects that Messier had noted. The catalog took its more-or-less accepted present form in the mid-20th century, when astro-historians added M104 through M110 and addressed the questionable identities of M47, M48, M91, and M102.

Most American reference books treat M102 as a duplicate observation of the galaxy M101, because M102's "discoverer," Messier's contemporary Pierre Méchain, later wrote that he had made this mistake. Many European observers, however, identify M102 with the smaller galaxy NGC 5866, and here I shall argue that they are probably right. My arguments parallel those of amateur astronomer Hartmut Frommert, who has analyzed the situation in detail, but I can offer some simplification.

Mistaken Identity

NGC 5866, as the Cambridge *Atlas of the Messier Objects* notes, is fainter than M101 (magnitude 9.9 vs. 7.7) but has a much greater average surface brightness (20.8 versus 23.7 magnitudes per square arcsecond). Both are visible in 10×50 binoculars under excellent conditions, and both are easier to see than some other Messier objects, such as M78 and M91. Thus, both should have been within reach of Méchain's and Messier's modest instruments.

In large telescopes or long-exposure photographs they look quite different: M101 is a huge, nearby spiral seen face-on, and NGC 5866 is a more distant galaxy appearing edge-on. However, their bright innermost areas are all that show in a small scope, and these can look similar as barely visible smudges. As amateur astronomer Richard Jakiel told me, NGC 5866 resembles the central part of M101 when a hazy sky or inadequate telescope hides the latter's big disk of spiral arms. My first casual attempt to see NGC 5866 was successful, with an 8-inch telescope, even though I was in town and the full Moon was in the sky. So I don't think it's too faint for Méchain to have seen and recorded.

Facing the Facts

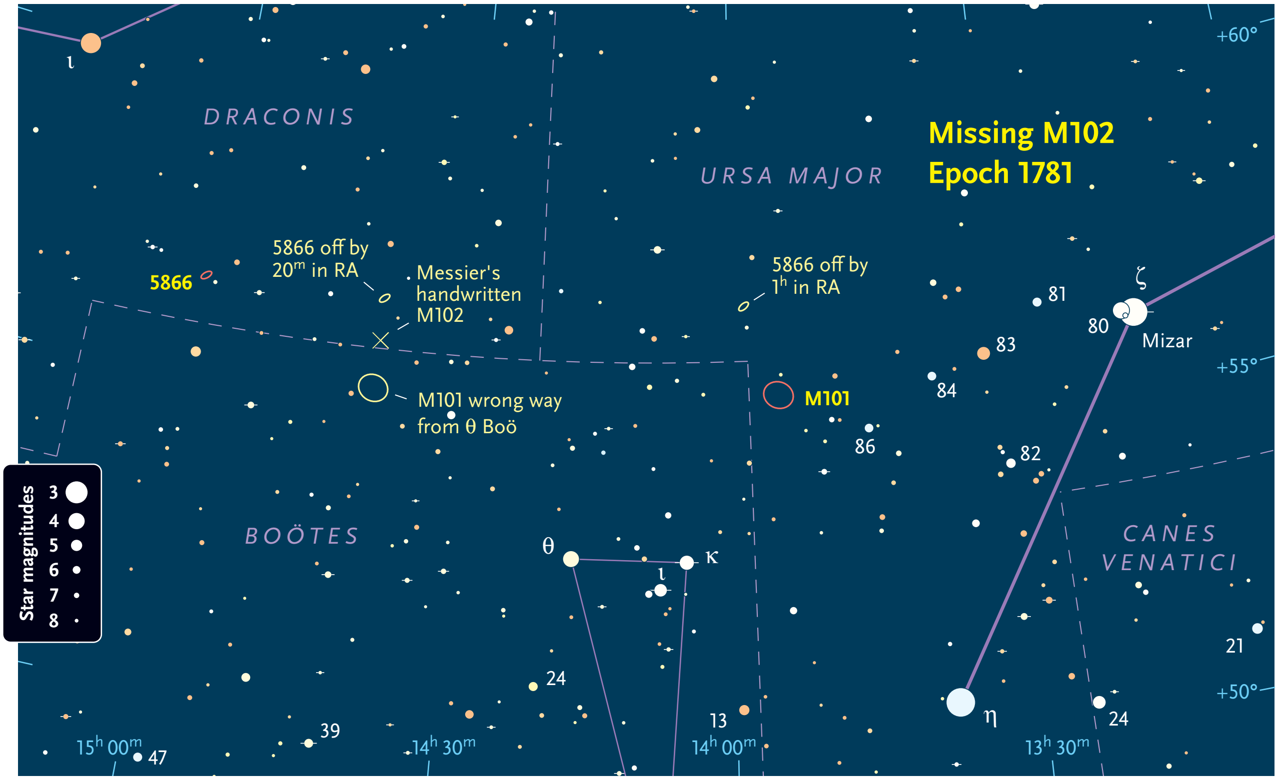
One must account for four facts: (1) Messier's description of M102; (2) an obvious typographical error in his description (the Greek letter omicron in place of theta); (3) Méchain's retraction, asserting that M102 was just M101; and (4) Messier's handwritten position for M102 in his personal copy of his catalog.

By themselves, (1) and (2) point clearly to NGC 5866; (3) does not, but I shall argue that it should not be taken at face value; and (4) is a puzzle for either theory, to which I shall propose a simple solution.

Start with Fact (1). In the final installment of his catalog, published in the French astronomical almanac *Connoissance des Temps* for 1784 (issued in 1781), Messier adds, at the end of his list, three objects that his colleague Méchain had found. Messier gives coordinates for only one of them. Here are his descriptions, in the original French; my translations follow:

Par M. Méchain, que M. Messier n'a pas encore vue.

By Mr. Méchain, [objects] that Mr. Messier has not yet seen:



101.
R.A. 13h 43m 28s (208° 52′ 4″) ["208" should read "205"].
Declination 55° 24′ 25″.
Nébuleuse sans étoile, très-obscure & fort large, de 6 à 7 minutes de diamètre, entre la main gauche du Bouvier & la queue de la grande Ourse. On a peine à la distinguer en éclairant les fils.
Nebulosity without a star, very obscure and rather large, from 6 to 7 arcminutes in diameter, between the left hand of Boötes and the tail of Ursa Major. Difficult to distinguish when the micrometer wires are illuminated.

102.
[No R.A. or declination given.]
Nébuleuse entre les étoiles ο du Bouvier & ι du Dragon: elle est très-foible; près d'elle est une étoile de la sixième grandeur.
Nebulosity between the stars ο Boötis and ι Draconis: it is very faint; close to it is a sixth-magnitude star.

103.
[No R.A. or declination given.]
Amas d'étoiles entre ε & δ de la jambe de Cassiopée.
Cluster of stars between ε and δ of the leg of Cassiopeia.

Here M101 and M103 are easy enough to identify. But the description of M102 is problematic.

Fact (2) is that in Messier's description of M102, "ο" Boötis must be a misprint for "θ" Boötis. Historians agree on this, because nothing else makes sense. In order for M101 and M102 to be confusable they must be fairly close together. Omicron (ο) Boötis is far away from M101 and from the other reference star, Iota (ι) Draconis. Theta (θ) Boötis, on the other hand, is a near neighbor of Iota Draconis, and there is no Greek-lettered star between them. It would be natural to describe an object as "between" Iota and Theta. It is not clear whether the misprint was on Messier's star chart or arose from a mistake by Messier or by the printers of the *Connoissance des Temps*.

Fact (3) is that, shortly after the catalog was published, Méchain retracted his observation of M102, stating that it was an error: a duplicate observation of M101.

The *Berliner Astronomisches Jahrbuch* for 1786, issued in 1783, contains a letter from Méchain, printed in German, announcing additional discoveries and asserting that M102 was a mistake. About M102 Méchain says the following (as quoted by Helen Sawyer Hogg in a 1947 article in the *Journal of the Royal Astronomical Society of Canada*; my translation follows):

> *Seite 267 der Connoissance des tems f. 1784 zeigt Herr Messier unter No. 102 einen Nebelfleck an, den ich zwischen ο Bootes und ι Drachen entdeckt habe; dies ist aber ein Fehler. Dieser Nebelfleck ist mit dem vorhergehenden No. 101 ein und derselbe. Herr Messier hat durch einen Fehler in den Himmelscharten veranlasst, denselben nach dem ihm mitgetheilten Verzeichnisse meiner Nebelsterne verwechselt.*

On page 267 of the *Connoissance des tems* [an older spelling] for 1784, Mr. Messier shows under No. 102 a nebula that I am supposed to have discovered between ο Boötis and ι Draconis; however, this is an error. This nebula is one and the same with the preceding No. 101. Owing to an error in the star charts, Mr. Messier has confused it in the list of my nebulae that was shared with him.

Méchain sent a similar but shorter letter to Berlin's French-speaking Académie Royale des Sciences et Belles-Lettres, which the academy published in French. It, too, refers to "an error in the star charts" but lacks the final clause attributing the mistake to Messier. Frommert speculates that the German editor and translator, the eminent astronomer Johann Elert Bode, added that clause.

Either way, this retraction does not make clear what the error was supposed to have been. Maybe Méchain himself was not sure. It is interesting to note that neither the *Connoissance des Temps* nor any other major French outlet ever published Méchain's retraction. Perhaps Méchain lost confidence in its accuracy.

Fact (4) is that in his personal copy of the catalog, Messier handwrote a rough position for M102, and it's not that of NGC 5866, M101, or any other galaxy or nebula. It is, according to Frommert, R.A. $14^h\ 40^m$, declination 56°. This point (in the coordinates for 1781) is plotted with an X on the chart at left. Messier's handwritten position shows that, at that time at least, he did not believe that M102 was a duplication of M101. But the position is imprecise; the declination is given only to the nearest degree, and the right ascension to the nearest 20 minutes.

A New View

If we had only Facts (1) and (2), we would be sure that M102 is NGC 5866. That galaxy is between Iota Draconis and Theta Boötis — about a third of the way from the former to the latter — and is the *only* galaxy in the area within reach of Méchain's small telescope. (See the star chart on the facing page throughout this section.)

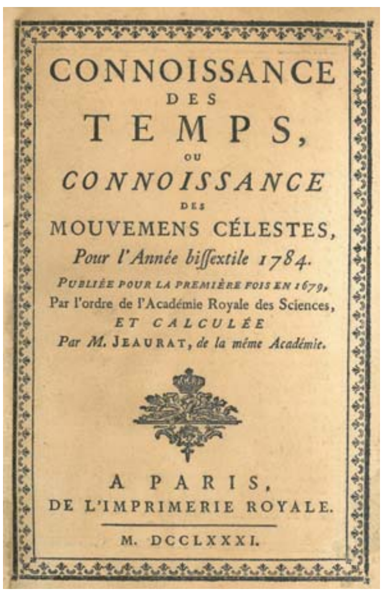
Fact (3) tells us that Méchain thought either he or Messier had mistaken two observations of M101 for two different objects. I don't think his correction should be taken at face value, however. I think the mistake was different than he thought.

A decade ago in these pages, Stephen James O'Meara argued forcefully that we should accept Méchain's retraction (*S&T:* March 2005, p. 78). O'Meara suggests that the second time Méchain observed M101, he measured its position relative to Theta Boötis and then he or Messier, when plotting it on a map, went the wrong way from Theta in right ascension, keeping the correct declination. That would give a position between Theta and Iota, different from the real M101, and once recognized, the error would justify Méchain's retraction.

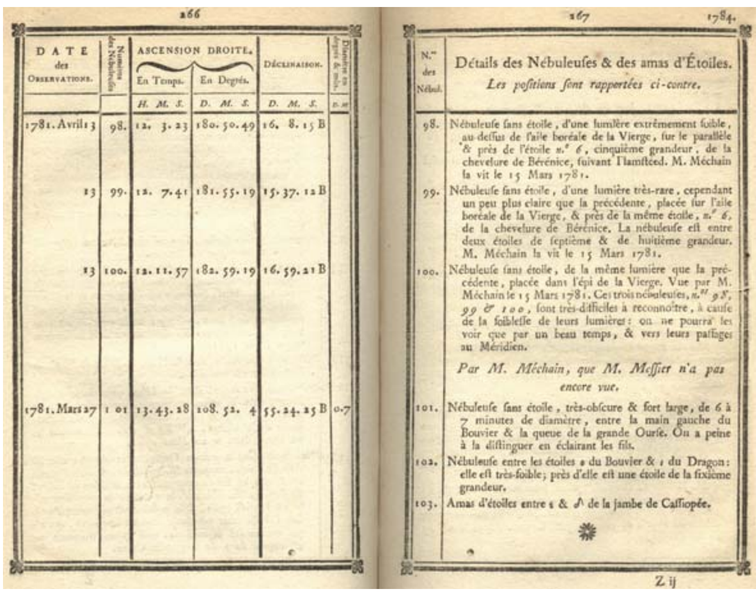
That assumes Méchain initially recorded a position measurement, and only later did he or Messier write the description mentioning Theta and Iota. If this is so, it is curious that Messier did not publish a right ascension and declination at all, not even approximately.

The description also mentions a sixth-magnitude star near the galaxy. No such star exists close to M101, but with NGC 5866, depending on how narrowly you interpret "sixth magnitude," you have your choice of several, including a magnitude-7.6 star very close indeed.

Most importantly, in his claim that M102 equals M101, Méchain attributes the duplication to "an error in the star charts" — indicating something wrong with the chart itself, not with someone's interpretation of a measurement. (A misprint of omicron for theta is not what he means here; that doesn't solve this part of the problem.) Since he names no particular atlas, we must suppose that he and Messier were working with a home-



CONNOISSANCE
DES
TEMPS,
OU
CONNOISSANCE
DES
MOUVEMENS CÉLESTES,
Pour l'Année biſſextile 1784.
PUBLIÉE POUR LA PREMIÈRE FOIS EN 1679,
Par l'ordre de l'Académie Royale des Sciences,
ET CALCULÉE
Par M. Jeaurat, de la même Académie.
A PARIS,
DE L'IMPRIMERIE ROYALE.
M. DCCLXXXI.



266

DATE des Observations.	Numéros des Nébuleuſes	Ascension Droite. En Temps.	Ascension Droite. En Degrés.	Déclinaison.	Diamètre en degrés & min.
		H. M. S.	D. M. S.	D. M. S.	D. M.
1781. Avril 13	98.	12. 3. 23	180. 50. 49	16. 8. 15 B	
13	99.	12. 7. 41	181. 55. 19	15. 37. 12 B	
13	100.	12. 11. 57	182. 59. 19	16. 59. 21 B	
1781. Mars 27	101	13. 43. 28	108. 52. 4	55. 24. 25 B	0.7

267 1784.

N.os des Nébul.	Détails des Nébuleuſes & des amas d'Étoiles. *Les poſitions ſont rapportées ci-contre.*
98.	Nébuleuſe ſans étoile, d'une lumière extrêmement foible, au-deſſus de l'aile boréale de la Vierge, ſur le parallèle & près de l'étoile *n.° 6*, cinquième grandeur, de la chevelure de Bérénice, ſuivant Flamſteed. M. Méchain la vit le 15 Mars 1781.
99.	Nébuleuſe ſans étoile, d'une lumière très-rare, cependant un peu plus claire que la précédente, placée ſur l'aile boréale de la Vierge, & près de la même étoile, *n.° 6*, de la chevelure de Bérénice. La nébuleuſe eſt entre deux étoiles de ſeptième & de huitième grandeur. M. Méchain la vit le 15 Mars 1781.
100.	Nébuleuſe ſans étoile, de la même lumière que la précédente, placée dans l'épi de la Vierge. Vue par M. Méchain le 15 Mars 1781. Ces trois nébuleuſes, *n.os 98, 99 & 100*, ſont très-difficiles à reconnoître, à cauſe de la foibleſſe de leurs lumières: on ne pourra les voir que par un beau temps, & vers leurs paſſages au Méridien.
	Par M. Méchain, que M. Meſſier n'a pas encore vue.
101.	Nébuleuſe ſans étoile, très-obſcure & fort large, de 6 à 7 minutes de diamètre, entre la main gauche du Bouvier & la queue de la grande Ourſe. On a peine à la diſtinguer en éclairant les fils.
102.	Nébuleuſe entre les étoiles θ du Bouvier & ι du Dragon: elle eſt très-foible; près d'elle eſt une étoile de la ſixième grandeur.
103.	Amas d'étoiles entre ε & δ de la jambe de Caſſiopée.

Z ij

IMCCE (2)

MYSTERIOUS OBJECT Astro-historians have long debated the particulars of several Messier objects. One of these is M102, listed here in Messier's catalog with two other bodies that "*M. Messier n'a pas encore vue*" ("Mr. Messier has not yet seen").

made chart. We know Messier created his own charts of comet paths, as did other astronomers of the time.

What I think happened is that Méchain or Messier used a chart on which one of the circles of right ascension was mislabeled by one hour. NGC 5866 and M101 differ in right ascension by almost exactly an hour, and in declination only slightly. A one-hour mistake in the right direction would make M102 seem to be a slightly imprecise duplicate observation of M101.

The most likely scenario, in my view, is that Méchain saw NGC 5866 but did not measure its position, only noting that it was between Omicron and Theta and close to a sixth-magnitude star. Later, he or Messier found this star field on a chart whose 15-hour circle was erroneously labeled 14, read off the rough coordinates, and noticed that these were close to (just a little more than 1° from) the coordinates of M101. Because this was not at all a precise measurement, Méchain would conclude that it was the same object.

A less likely alternative is that M102 was plotted correctly and M101 was plotted on a separate chart whose 14-hour circle was labeled 15. This, likewise, would make M101 and M102 come out with coordinates only a little more than a degree apart.

There remains Fact (4), Messier's handwritten position, which matches nothing at all. One possible explanation is O'Meara's, already mentioned — that a position measurement was "flipped" in right ascension relative to Theta Boötis. Another, offered by Frommert, is that NGC 5866's coordinates were misread due to a 5-degree (20-minute) error in labeling or reading right ascension on a map.

I think what Messier really did was much simpler. If Méchain never gave him a measurement for M102 — only a description saying it was between Theta and Iota — then all Messier could do was to look at his map and select a point midway between the two stars, and write down its position using very round numbers, choosing a right ascension circle marked on his map (14h 40m) and going up to what looked like the right declination (about 56°). That would at least give him something to compare to other people's reports and to use in planning his own observations.

PARIS OBSERVATORY LIBRARY (2)

PAIR OF STARS ***Left:*** **Charles Messier started publishing his famous astronomical catalog about a year after this portrait was painted circa 1770, when he was about 40 years old.** ***Right:*** **Pierre Méchain, who was 14 years younger than Messier, is depicted here in later life.**

A Matter of Choice

So I think it's probable, though not certain, that Méchain really saw NGC 5866, complete with the adjacent 6th- or rather 7th-magnitude star, and Messier may have seen it later when confirming the observation. Méchain's later impression that M102 was a duplicate of M101 was a mistake.

We will never have complete certainty, but I would rather add NGC 5866 to the Messier list as M102, with some remaining doubt, than leave it out. We accept other Messier objects that are at least as uncertain, such as M48 and M91. You are free to make up your own mind, but as for me — I finished observing the American Messier list almost 30 years ago — now I need to observe one more object. ✦

Michael Covington *is the author of* Astrophotography for the Amateur, Digital SLR Astrophotography, *and other books. By day he is a computational linguist retired from the Institute for Artificial Intelligence at the University of Georgia. He welcomes mail at* **astro@covingtoninnovations.com**.

FURTHER READING FOR THE CURIOUS

"Messier 102"
Hartmut Frommert
messier.seds.org/m/m102d. html

"The Missing Messier Objects"
Owen Gingerich
Sky and Telescope,
October 1960, pp. 196–199.

"Catalogues of Nebulous Objects in the Eighteenth Century"
Helen Sawyer Hogg
Journal of the Royal Astronomical Society of Canada, vol. 41 (1947), pp. 265–273.

The Messier Album
John H. Mallas & Evered Kreimer
Sky Publishing Corp., 1978.

"M102: Mystery Solved"
Stephen J. O'Meara
Sky & Telescope,
March 2005, pp. 78–79.

Atlas of the Messier Objects
Ronald Stoyan, Stefan Binnewies, Susanne Friedrich, and Klaus-Peter Schroeder
Cambridge University Press, 2008.


Summer Deep Sky eBook
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French astronomer Pierre Méchain discovered the great spiral galaxy M101 on March 27, 1781; see page 34.

In This Section

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Sky at a Glance

SEPTEMBER 2015

4 MIDNIGHT: The last-quarter Moon, just risen in the east with the Hyades, occults Aldebaran for viewers in eastern North America; see page 51.

10 DAWN: The waning crescent Moon shines between Venus and Mars low in the east.

11 DAWN: The thin crescent Moon passes less than 4° to the right or lower right of Regulus, below Mars and Venus.

DAWN: For the next two weeks the zodiacal light, or "false dawn," is visible in the east one to two hours before sunrise from dark locations at mid-northern latitudes. Look for a tall, broad pyramid of light extending up through Mars and Venus to Gemini.

18 EVENING: Look low in the southwest in twilight to spot the waxing crescent Moon less than 3° from Saturn. Antares twinkles 12° farther left.

22 NIGHT: Algol shines at minimum brightness for roughly two hours centered on 11:20 p.m. EDT (8:20 p.m. PDT); see page 50.

23 AUTUMN BEGINS in the Northern Hemisphere at the equinox, 4:21 a.m. EDT.

24 DAWN: Mars gleams less than 1° from Regulus for the next two nights. Look for them about 10° lower left of Venus.

25 EVENING: Algol shines at minimum brightness for roughly two hours centered on 8:09 p.m. EDT.

27 EVENING: A total lunar eclipse is visible throughout the Americas except Alaska and westernmost Canada. Europe and most of Africa see totality on the morning of the 28th; see p. 26.

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

Planet	◀SUNSET — MIDNIGHT — SUNRISE▶
Mercury	Hidden in the Sun's glare all month
Venus	E
Mars	E
Jupiter	Visible beginning September 7 — E
Saturn	SW

Moon Phases

Last Qtr Sept. 5 5:54 a.m. EDT

New Sept. 13 2:41 a.m. EDT

First Qtr Sept. 21 4:59 a.m. EDT

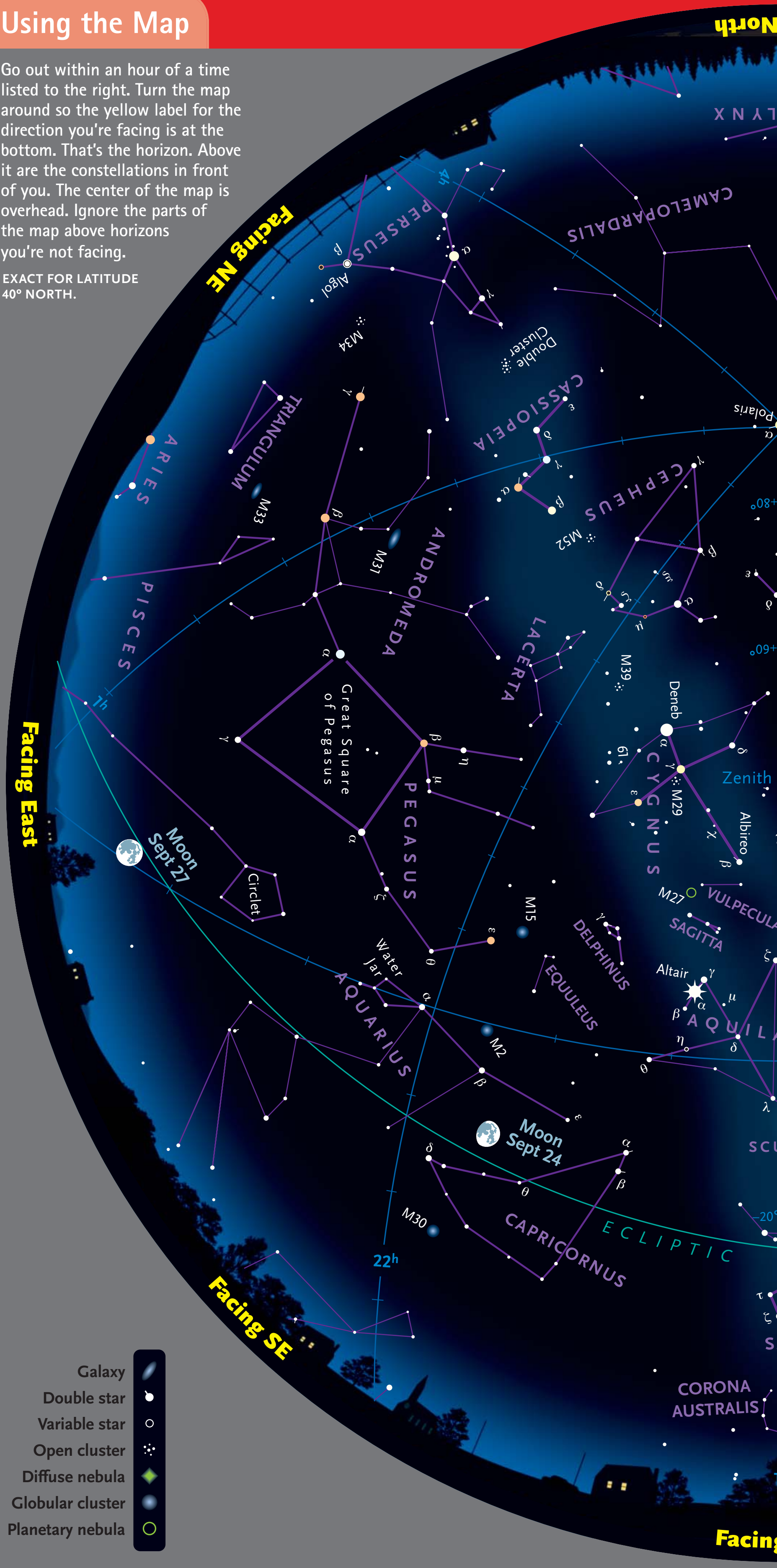
Full Sept. 27 10:50 p.m. EDT

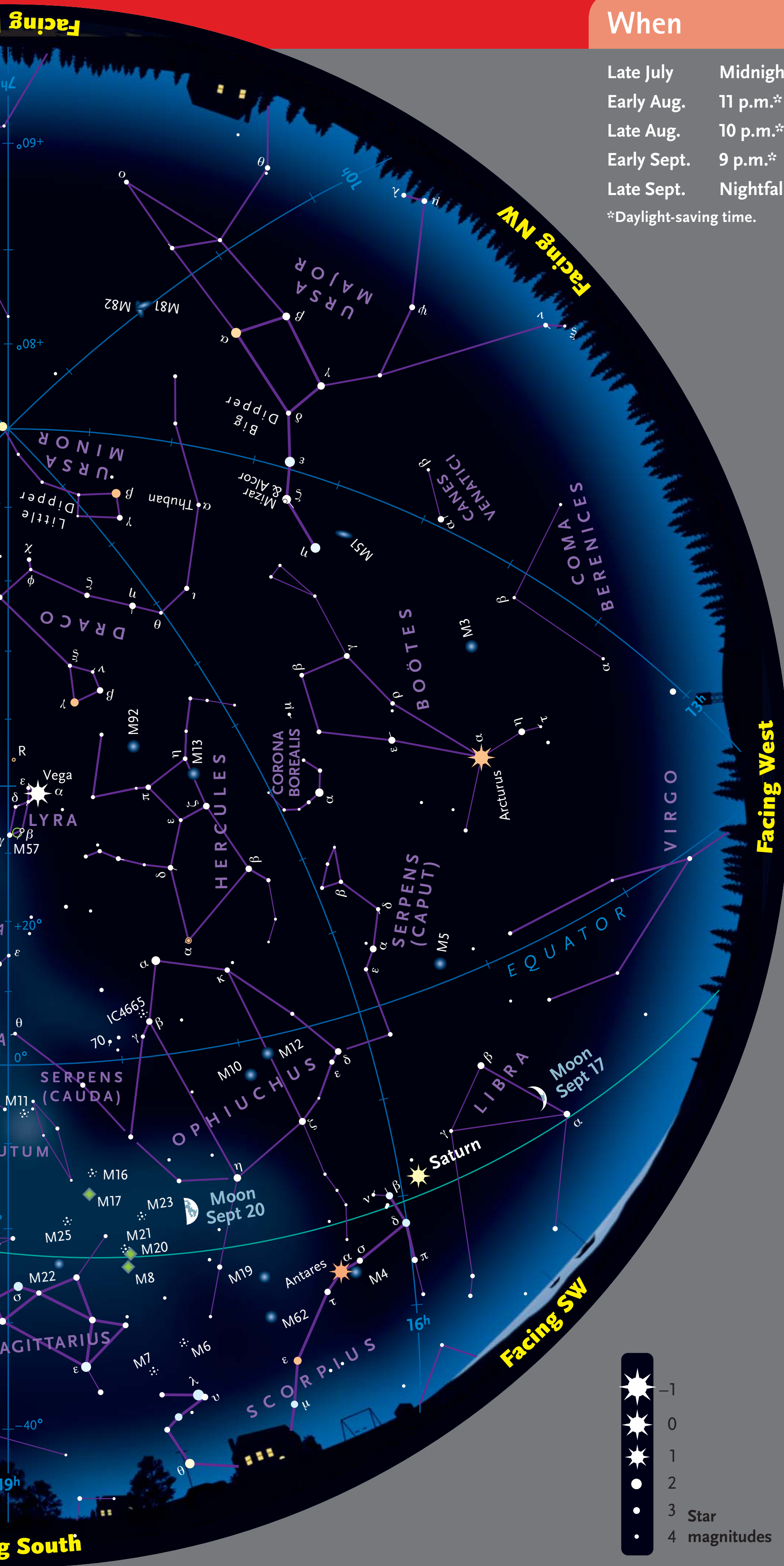
SUN	MON	TUE	WED	THU	FRI	SAT
		1	2	3	4	5
6	7	8	9	10	11	12
13	14	15	16	17	18	19
20	21	22	23	24	25	26
27	28	29	30			

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 July	Midnight*
Early Aug.	11 p.m.*
Late Aug.	10 p.m.*
Early Sept.	9 p.m.*
Late Sept.	Nightfall

*Daylight-saving time.

Gary Seronik

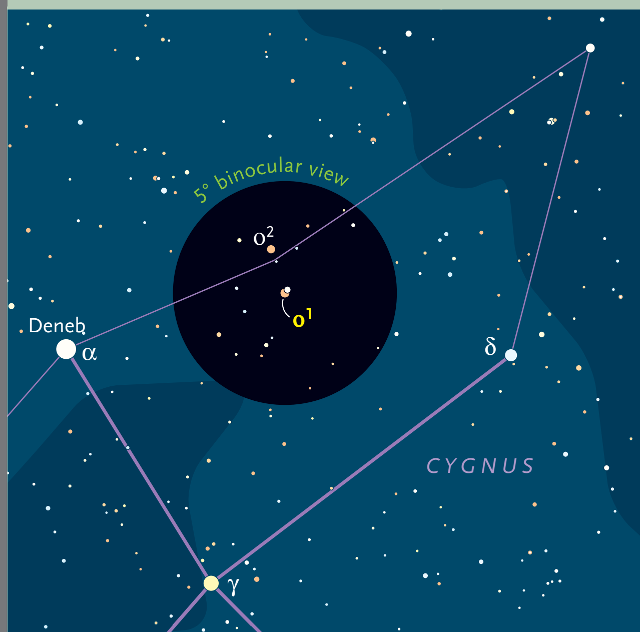
A Cygnus Double Delight

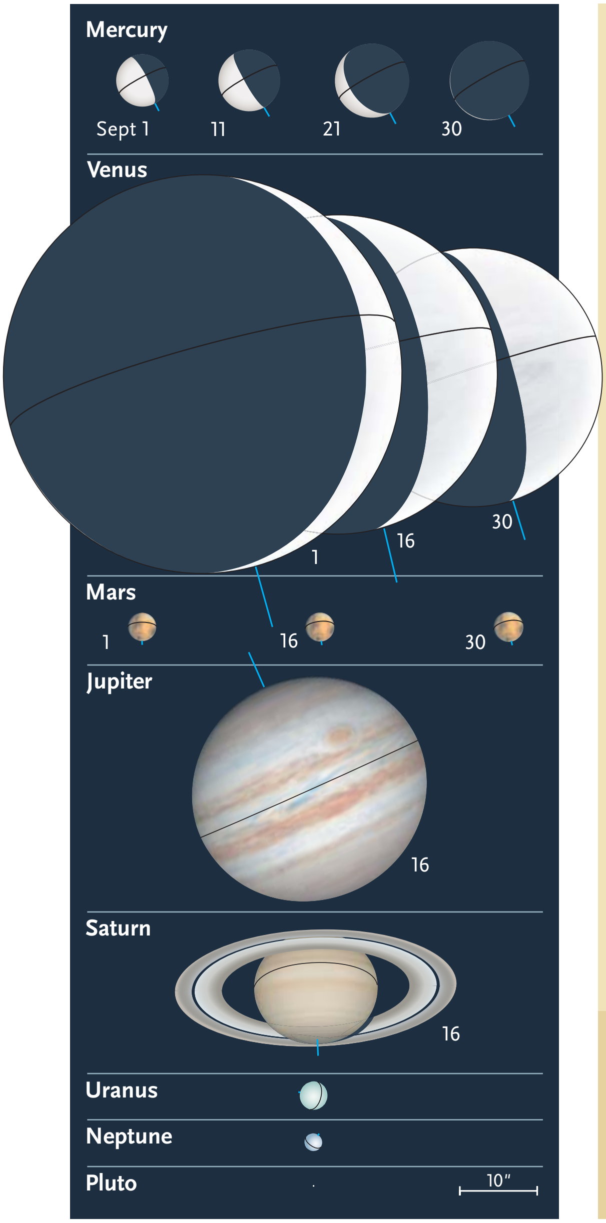
On mild summer nights I often settle into a reclining lawn chair with my binoculars to leisurely sweep the sky just to see what I can see. I particularly enjoy scanning up and down the Milky Way, especially the inviting stretch that runs through Aquila and north into Cygnus. Sometimes I stumble across something I've never noticed before, or rediscover an object I've long forgotten. It was on one of these casual sweeps I recently encountered the lovely double star **Omicron^1 (o^1) Cygni**.

What ingredients make for an attractive binocular double star? I prefer pairs that have component suns that are reasonably bright and close together, but not so close that they're impossibly difficult to split. It's also a bonus (albeit a rare one) if the stars have contrasting colors. Omicron^1 ticks all these boxes.

The double comprises the stars 31 and 30 Cygni. They check in at magnitudes 3.8 and 4.8, respectively, with a generous separation of 334 arcseconds between them. Seeing both components is easy even in 7× binos. But it's the double's contrasting colors that make it special. 31 (the brighter, eastern star) has a golden-orange hue, while 30 is a cool, bluish white. Indeed, they have one of the strongest color contrasts I've seen in binoculars. Even in my 10×30 image-stabilized binos the differing hues are noticeable. If you're having trouble seeing the colors, try defocusing slightly — this trick often helps reveal subtle tints.

Are you up for a challenge double? As it happens, 31 has another, faint (magnitude 6.9) companion 107 arcseconds to the south. I can readily see this little spark in my 15×45 image-stabilized binoculars, but can glimpse it only half the time in the 10×30s. How about you? For more on Cygnus, see page 58. ✦



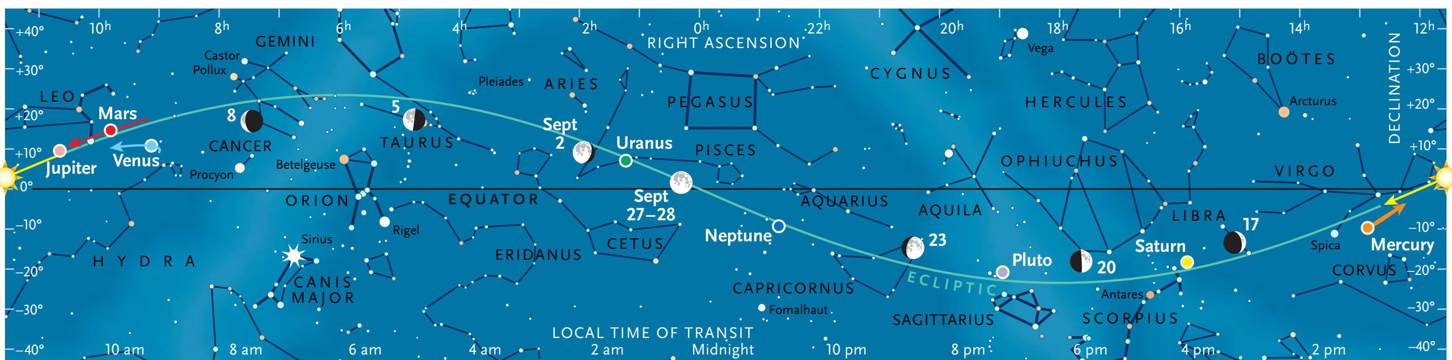


Sun and Planets, September 2015

	September	Right Ascension	Declination	Elongation	Magnitude	Diameter	Illumination	Distance
Sun	1	10^h 38.8^m	+8° 33′	—	–26.8	31′ 42″	—	1.009
	30	12^h 23.2^m	–2° 30′	—	–26.8	31′ 56″	—	1.002
Mercury	1	12^h 14.9^m	–3° 40′	27° Ev	+0.1	6.8″	60%	0.994
	11	12^h 44.7^m	–8° 25′	26° Ev	+0.3	8.0″	43%	0.843
	21	12^h 49.5^m	–9° 37′	18° Ev	+1.5	9.6″	18%	0.701
	30	12^h 23.7^m	–5° 26′	3° Ev	—	10.3″	1%	0.653
Venus	1	8^h 59.8^m	+9° 05′	24° Mo	–4.5	51.5″	9%	0.324
	11	9^h 00.7^m	+10° 25′	34° Mo	–4.7	44.7″	18%	0.374
	21	9^h 15.6^m	+10° 57′	40° Mo	–4.8	38.3″	27%	0.436
	30	9^h 37.7^m	+10° 38′	43° Mo	–4.7	33.5″	34%	0.498
Mars	1	9^h 09.5^m	+17° 33′	23° Mo	+1.8	3.7″	98%	2.510
	16	9^h 47.2^m	+14° 38′	29° Mo	+1.8	3.8″	98%	2.456
	30	10^h 21.1^m	+11° 39′	33° Mo	+1.8	3.9″	97%	2.393
Jupiter	1	10^h 25.8^m	+10° 46′	4° Mo	–1.7	30.8″	100%	6.396
	30	10^h 49.1^m	+8° 31′	26° Mo	–1.7	31.4″	100%	6.279
Saturn	1	15^h 47.9^m	–18° 04′	81° Ev	+0.5	16.4″	100%	10.107
	30	15^h 55.8^m	–18° 35′	54° Ev	+0.6	15.8″	100%	10.548
Uranus	16	1^h 12.2^m	+6° 56′	153° Mo	+5.7	3.7″	100%	19.081
Neptune	16	22^h 39.0^m	–9° 25′	165° Ev	+7.8	2.4″	100%	28.989
Pluto	16	18^h 54.8^m	–21° 00′	110° Ev	+14.2	0.1″	100%	32.587

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-September; 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

Stars for a Moonlit Night

A total lunar eclipse brings out a sky full of stars.

This column is normally dedicated to the stars. But the stars do cohabit the night sky with other celestial objects. And one such nighttime object radically affects the visibility of stars. It is, of course, the Moon.

Star-people vs. Moon-people. It sounds like a conflict in a science-fiction movie — but what I'm asking is how you see yourself: as a star-person or a moon-person? Do you enjoy exploring all the details of the brightest satellite in the solar system? Or do you like to travel and revel in the starry universe?

Most of us, of course, like both lunar and stellar observing. But September can be a frustrating month for would-be star (and deep-sky) observers due to the extra hours of bright moonlight cast into night by the Harvest Moon. I've written before about the Harvest Moon versus the late-summer Milky Way. But this year we have a special solution that opens to stargazers a wonderful window on the starry universe right in the midst of the night of the full Harvest Moon. The solution is a total lunar eclipse.

The magic — and manageability — of moonlight. Before we talk about this month's eclipse and its effect on the stars, however, let's get some things straight about moonlight.

First of all, we should never begrudge it. It's just too magical — even scientifically speaking. Moonlight covers everything like the finest of meshes. But consider some of the scientific facts about this seemingly mystical radiance. White paper in moonlight is about 2,000 times darker than black velvet in sunlight. On the other hand, the light of the full Moon is about 33,000 times brighter than Sirius. It is more than 2,000 times brighter than Venus when the planet is brightest (which Venus is, in this month's pre-dawn sky). Full moonlight is even about 1,000 times brighter than the combined light of all the nighttime stars. And it isn't millions of times dimmer than the Sun, just 400,000 times dimmer.

But there's good news for those of us who want to do some stellar observation while the Moon is in the sky. The first quarter Moon — a half-lit Moon — isn't half as bright, but only 1/11th as bright as the full Moon. This is due to the terminator and the many large shadows near it stretching down the Moon's central meridian at first quarter, as well as to the lack of a special kind of retro-reflecting that occurs from the lunar surface only very near full phase. Last quarter Moon is even dimmer than first quarter due to its higher proportion of the dark maria. The lunar light is half as bright as full Moon not 7 days before full (around first quarter) but a mere 2½ days before. This explains why observations of the stars and even extended deep-sky objects through telescopes are not as compromised by most phases of the Moon as people expect.

A lesson can be learned from meteor observers. They simply look for meteors in a direction away from the Moon or, if the Moon is especially bright, may block the direct moonlight with a tree, building . . . or even an umbrella. When it's raining moonlight (the grand Mare Imbrium is "the Sea of Rains"), use an umbrella or parasol — or would it be called a paralune?

The starry second nightfall of lunar eclipse. Weather permitting, the dimming of the Moon on the American evening of Sunday, September 27th, will be the 22nd total eclipse of the Moon I've seen in my life.

Among all its beauties, one of my favorites will be the awesome fall of a second, much deeper nightfall that occurs during it. Of course, you'll only experience this deeper night within night if you are at a site with minimal humanmade light pollution. ✦

CANSTOCKPHOTO.COM

Flames at Dawn

Look to the early morning for the best showing of bright planets.

The September sky holds only two bright planets at dusk: Mercury very low in the west-southwest for the first half of the month, and Saturn fairly low in the southwest all month. But at dawn, blazing Venus and emerging bright Jupiter, which formed a spectacular duo in the dusks of late spring and early summer, now loft into the eastern sky and prepare to converge again, this time with the much dimmer pairing of Mars and Regulus initially between them.

The total lunar eclipse of September 27th occurs in convenient evening hours for American observers — and during what is for many of us our least cloudy month; see page 26.

DUSK

Mercury sparks just above the western horizon in bright twilight for the first few days of the month. It reaches its greatest eastern elongation from the Sun (27°) on the 4th, shining at magnitude +0.1. But even then it sets only about 50 minutes after the Sun for observers around latitude 40° north, making for a challenging target. Binoculars help. Dimming Mercury gets lower each night, becoming lost from view after mid-month and going through inferior conjunction with the Sun on September 30th.

EVENING

Saturn comes into view at nightfall in the southwest in eastern Libra, but is less than 20° high for viewers at mid-northern latitudes. Its radiance dims from magnitude +0.5 to +0.6 this month, and the apparent equatorial diameter of its globe shrinks to 16″. The rings remain impressively tilted to 24.3°, however.

The interval between sunset and Saturn-set shrinks from 3½ to 2½ hours over the course of the month. The gap between Saturn and Beta (β) Scorpii also shrinks from 4° to 2° in September as the ringed planet, tracking eastward relative to the background stars, nears the border of Scorpius.

Pluto is best hunted in northeastern Sagittarius as soon as full darkness falls. For a finder chart for this 14th-magnitude world, see the July issue, page 52.

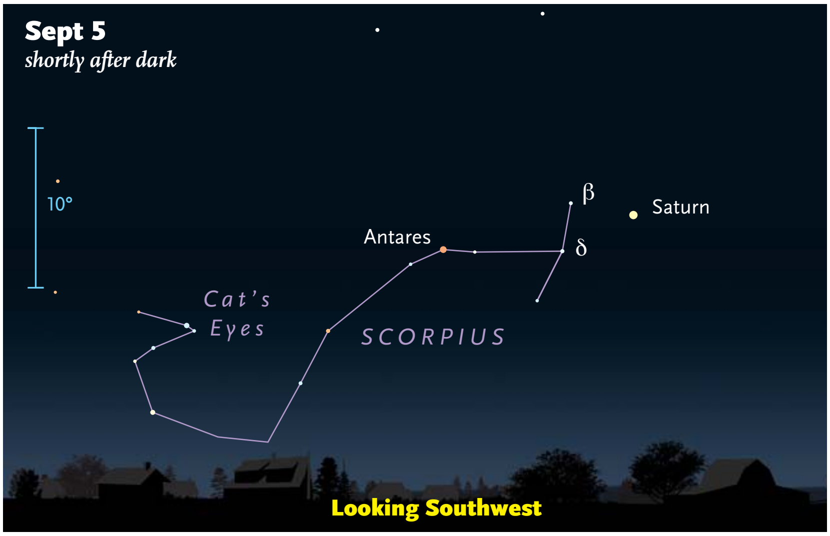
NIGHT

Neptune was at opposition on the American evening of August 31st, so in September it's visible almost all night, reaching its highest point around midnight daylight-saving time. The 8th-magnitude ice giant shines in Aquarius. Sixth-magnitude **Uranus**, in Pisces, is highest 2½ hours after Neptune. Finder charts for both are on page 49.

DAWN

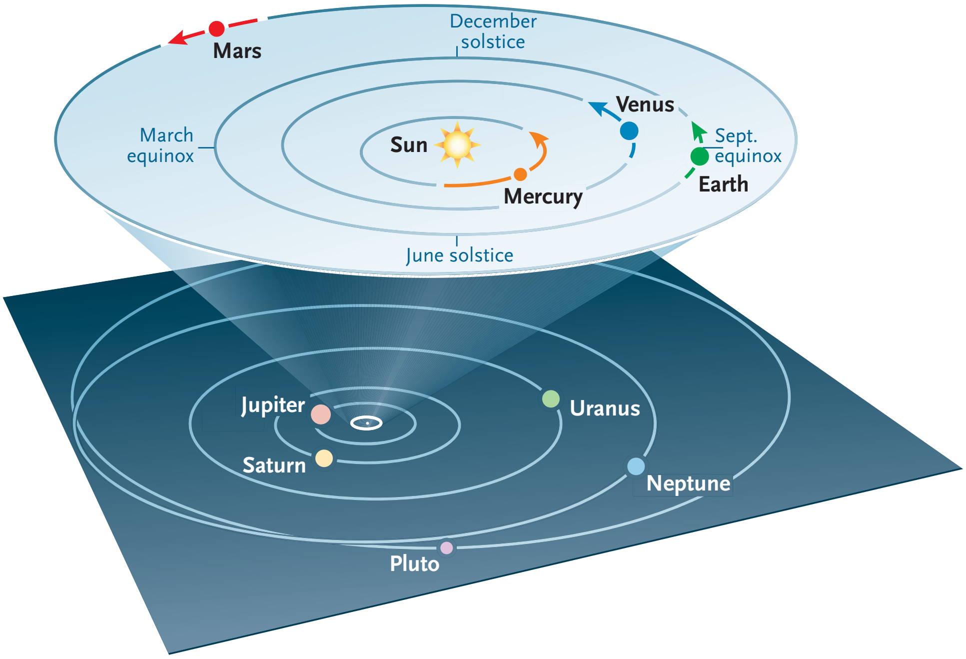
Venus climbs noticeably higher before dawn each week in September and burns brilliantly, with tremendously dimmer **Mars** about a fist-width at arm's length left or lower left of it. As the month progresses, **Jupiter** starts rising due east early enough before sunrise to become plainly visible about 20° lower left of Venus. And by late in the month, Mars passes close to Regulus; look for the pairing roughly halfway between Venus and Jupiter.

Venus flames to its greatest brightness of this apparition, magnitude –4.8, from about the 14th through 24th. The planet's disk shrinks from about 51″ to 33″ during



ORBITS OF THE PLANETS

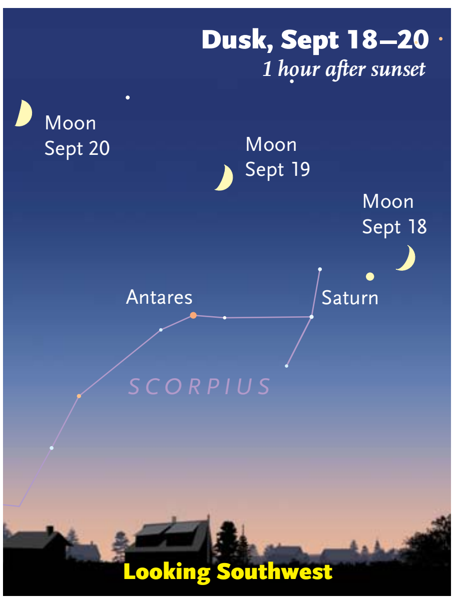
The curved arrows show each planet's movement during September. The outer planets don't change position enough in a month to notice at this scale.

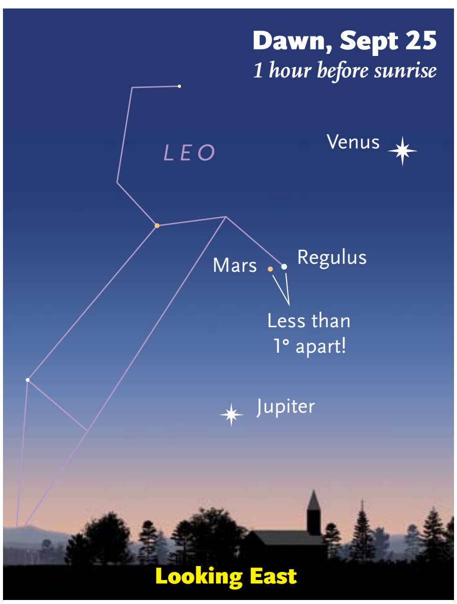


September, while its phase thickens from approximately 9% to 34% lit. Viewers around latitude 40° north see Venus rise less than 2 hours before the Sun at the beginning of the month but about 3½ hours before at month's end. It's almost 30° high an hour before sunrise on the last morning of the month.

Mars is as high as, or higher than, Venus through the first week of September. On August 29th, Venus passed 9½° south of Mars during a south-curving retrograde (westward) motion that continues through September 5th. For the rest of this month, Mars keeps its lead on Venus as they move eastward with direct motion against the background of stars. That motion carries magnitude +1.8 Mars to within 1° of magnitude +1.3 Regulus on the American mornings of the 24th and 25th, when the pair is equidistant from Venus and Jupiter. Their close approach accentuates the orange-gold of Mars and blue-white of Regulus.

Jupiter, at magnitude –1.7, is the last planet to rise in the morning, coming up less than half an hour before the Sun on September 1st but more than 2 hours before the Sun on September 30th. Around the latter date, Jupiter forms a beautiful curved line with Mars, Regulus, and Venus above it.





SUN AND MOON

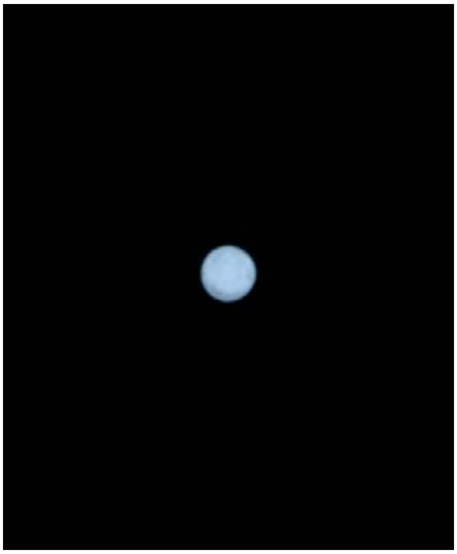
The **Sun** arrives at the equinox at 4:21 a.m. EDT on September 23rd, marking the beginning of autumn in the Northern Hemisphere and spring in the Southern Hemisphere. The Sun is partially eclipsed from parts of southern Africa and Antarctica on the 13th.

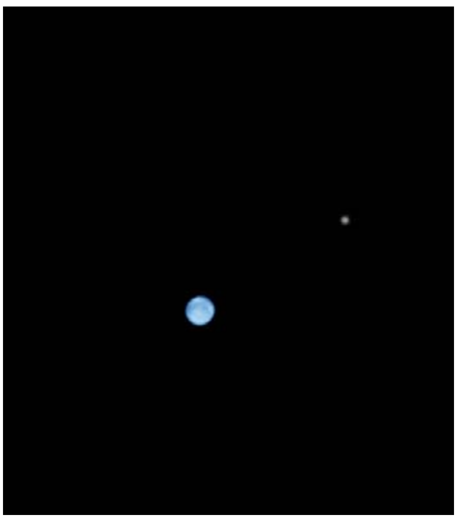
The **Moon** is totally eclipsed on the American evening of Sunday, September 27th, which is the European morning of Monday the 28th; see page 26. This full Moon is a Harvest Moon as well as the biggest of the year, with the year's closest perigee occurring less than an hour before the moment of full Moon.

The Moon is a slender waning crescent between Venus and Mars as the two planets rise in the east before dawn on the 10th. The next day, the Moon is to the right of Regulus and appears even thinner. Late in the dawn, and very low in the sky on the 12th, a subtle sliver Moon, less than a day from new, may be detectable to the lower right of Jupiter. The waxing crescent is close to and upper right of Saturn at dusk on the 18th. ✦

It's Uranus-Neptune Season

The haunters of the outer dark are returning.





When Uranus (top) and Neptune were high overhead at his Barbados location in September 2010, Damian Peach took these very sharp images with a Celestron 14-inch Schmidt-Cassegrain scope and a PGR Flea3 planetary video camera. They're shown at the same image scale. In the image of Neptune, its satellite Triton has been boosted in brightness to show clearly. This was not done for the nearly similar moons of Uranus. The colors are exaggerated but otherwise more or less correct.

Aquarius and Pisces wheel back into evening view as summer rotates westward toward its end, and within these watery constellations lie the solar system's twin outermost planets, dim and cold. Uranus and Neptune are four times wider than Earth and weigh in at 14 and 17 Earth masses, respectively. They qualify as "giant planets" not just by their size but by the fact that gas makes up a good fraction of their bulk. Yet each has only about a twentieth the mass of Jupiter.

You can say hello to them using a pair of binoculars; Uranus and Neptune now shine at an easy magnitude 5.7 and a tougher 7.8, respectively. A telescope at 100× or more resolves them into tiny disks, or at least slightly nonstellar blobs, 3.6 and 2.3 arcseconds wide.

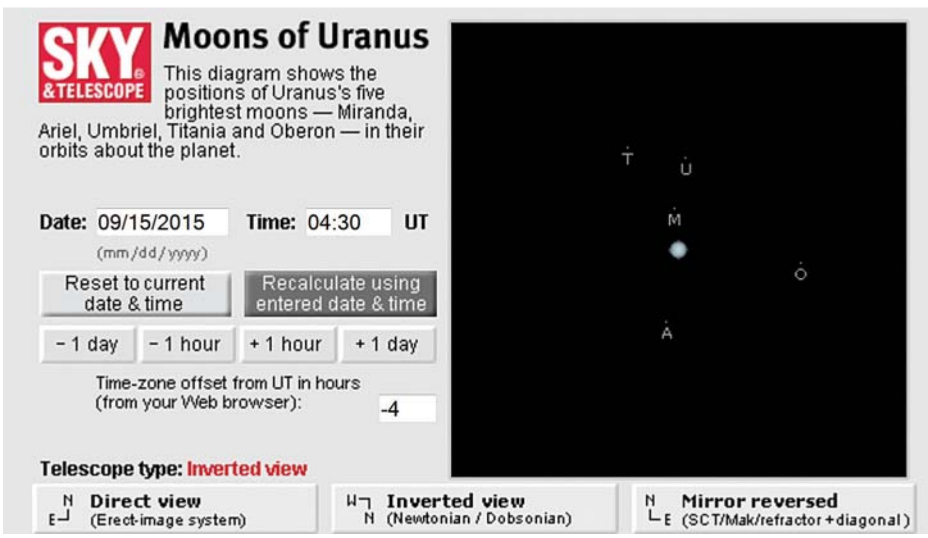
In August Neptune climbs fairly high by midnight (for observers at mid-northern). Uranus lags about two hours behind in reaching a good altitude, even though it's 16° farther north. Each month they get there two hours earlier, like the stars, because they're so far away and slow-moving. They appear about 40° apart this year; not since 1975 have they been so widely separated.

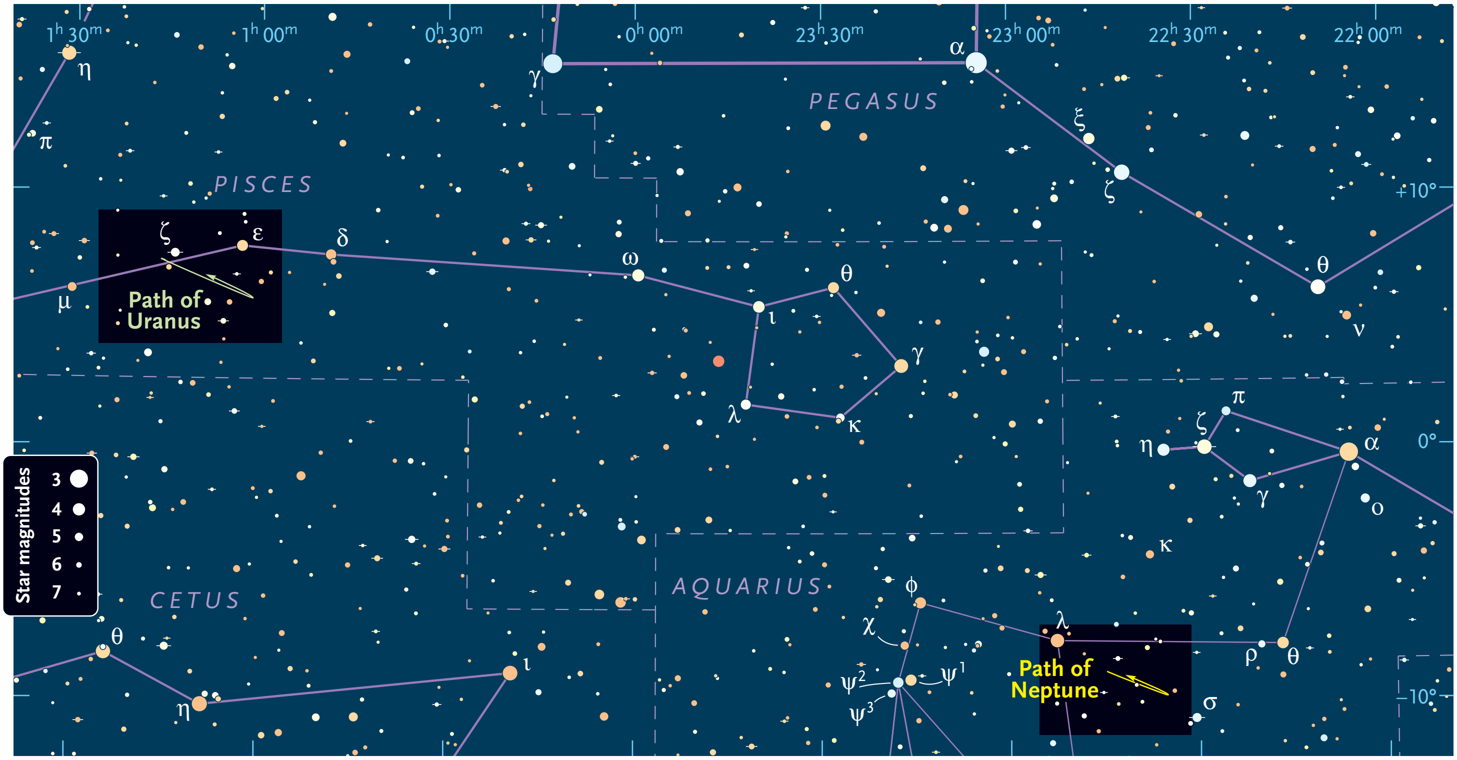
Neptune reaches opposition on the night of August 31st. Uranus follows on the night of October 11th.

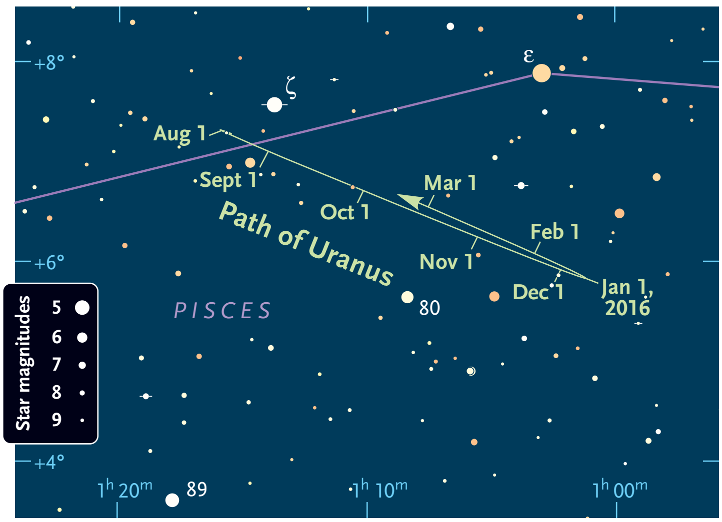
The big chart at right shows their locations below the Great Square of Pegasus. The black rectangles show the fields of the more detailed enlargements below.

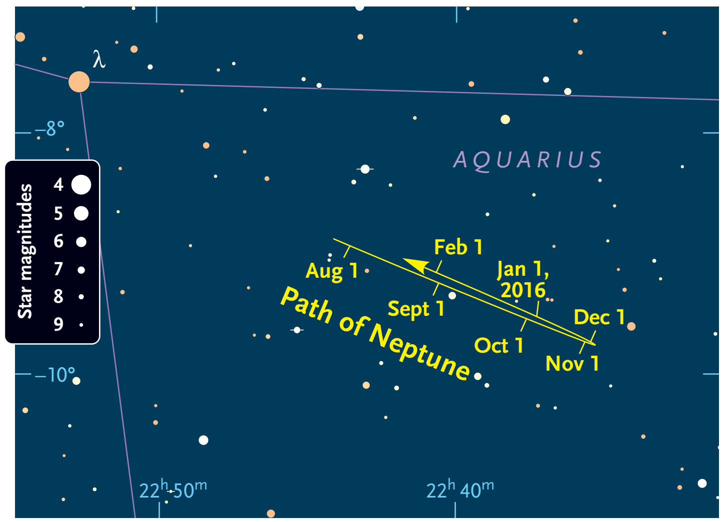
In addition to their similar sizes, masses, compositions, and appearances, another thing they have in common is that they're the solar system's only planets (by the current definition) that were *discovered* rather than always being known. William Herschel swept up Uranus by accident in 1781 with a homemade reflector in his back garden in Bath, England. Johann Galle discovered Neptune in a very deliberate search at Berlin Observatory in 1846, after Urbain Le Verrier predicted its position from unexplained gravitational tugs on Uranus.

Get convenient little charts for the brighter moons of Uranus and Neptune, as seen at any date and time, from skypub.com/neptunemoon and skypub.com/uranusmoons.









The Moons of Uranus & Neptune

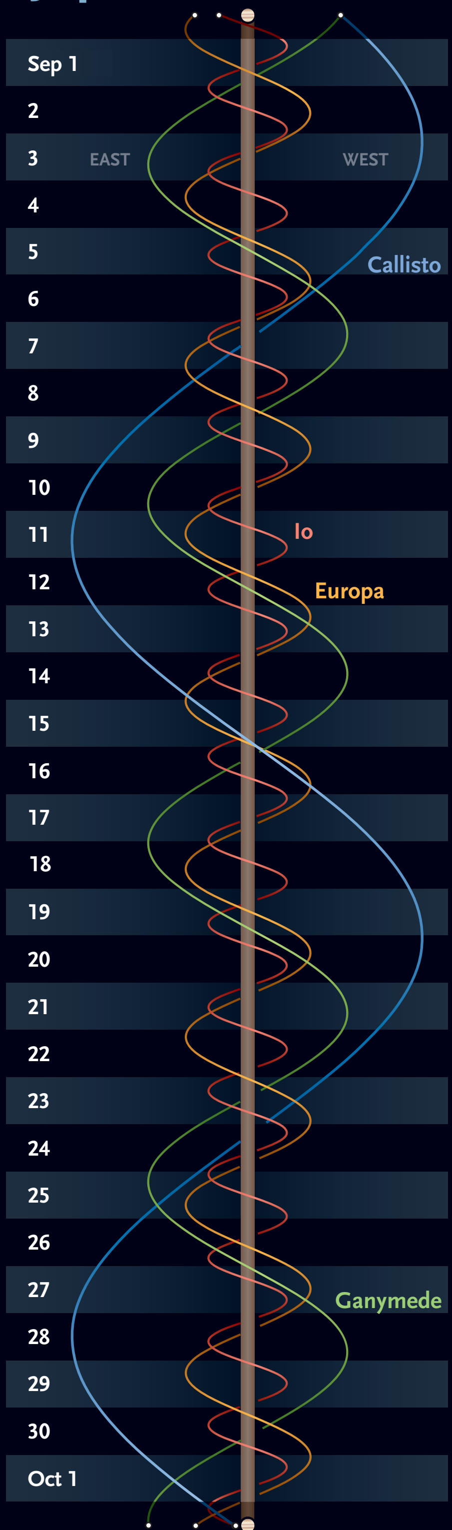
An 8- or 10-inch telescope gives you a shot at catching not just the two outer giants but some of their obscure satellites.

The least difficult of them is Neptune's one big moon, Triton. It's magnitude 13.5 when Neptune is near its mean opposition distance. That's brighter than Pluto, which Triton physically resembles. I'm almost always able to glimpse Triton repeatedly in my 12.5-inch reflector using 450× or more from my suburban location — if I've determined in advance where with respect to Neptune to look.

Uranus has four biggish satellites. Counting out from Uranus these are Ariel, Umbriel, Titania, and Oberon (the mnemonic is AUTO), at magnitudes 13.7, 14.5, 13.5, and 13.7, respectively (at mean opposition). But don't be fooled. I've had a hard time seeing any of them, probably because the glare from 6th-magnitude Uranus is enough to interfere pretty seriously. Try putting an occulting bar across the field stop of your highest-power eyepiece — a bit of

Above: The Great Square of Pegasus, just the bottom of which appears here, marks the way to the solar system's ice giants. On the closeup charts, stars are plotted to 9th magnitude — fainter than Neptune, and *much* fainter than Uranus.

Jupiter's Moons

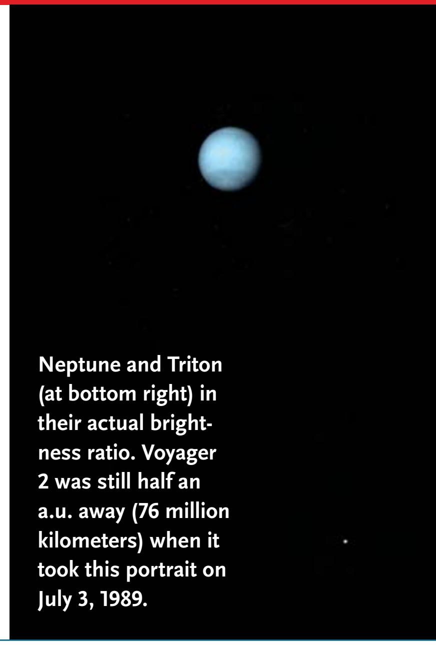


The wavy lines represent Jupiter's four big satellites. The central vertical band is Jupiter itself. Each gray or black horizontal band is one day, from 0^h (upper edge of band) to 24^h UT (GMT). UT dates are at left. Slide a paper's edge down to your date and time, and read across to see the satellites'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

aluminum foil across the field stop works — or just move Uranus slightly outside the edge of the view. Use your highest power.

How do you tell where the moons should be? Easy! For any time and date, use our little predictor apps at **skypub .com/neptunemoon** and **skypub.com/ uranusmoons**. Print out the little charts to use at the eyepiece. The size of the planet disk on each chart indicates the scale. Triton never strays more than 17″ from Neptune. Ariel remains within 10″ of Uranus, and Oberon remains within 50″.

Check back on following nights that the satellites are moving correctly, in case a faint background star has entered the field and is playing games with you.



Neptune and Triton (at bottom right) in their actual brightness ratio. Voyager 2 was still half an a.u. away (76 million kilometers) when it took this portrait on July 3, 1989.

NASA / JPL

Asteroid Occultations

If you're in the Florida Keys, the northern Bahamas, the northern tip of Yucatan, or parts of central Mexico, plan for an extraordinary asteroid occultation **on the morning of September 3rd**. Epsilon Geminorum, easily watched naked-eye at magnitude 3.0, will be occulted by faint 112 Iphigenia for up to three seconds before dawn begins. For the path map and time predictions, see the link below.

North Americans have several other, fainter asteroid occultations coming up:

On the evening of August 30th, telescope users from Arizona north through central Montana and parts of west-central Canada can watch for a 10th-magnitude star close to Altair being occulted by 12th-magnitude 849 Ara for up to 13 seconds.

On the evening of September 1st, observers near Vancouver, Seattle, and the coasts of Oregon and northern California can watch for Ara to occult *another* 10th-magnitude star close to Altair for up to 13 seconds.

Early on the evening of September 23rd, observers in southern and central New England, upstate New York, and possibly New York City may see a 10th-magnitude star in Serpens Cauda being occulted by 12th-magnitude 51 Nemausa for up to seven seconds.

For maps of the shadow tracks, with time predictions and finder charts for the stars, go to **asteroidoccultation .com/IndexAll.htm**. For how to time these events and where to report, see **asteroidoccultation.com/observations**. For human advice and help, join the discussion group at **groups.yahoo.com/ neo/groups/IOTAoccultations**.

Minima of Algol

Aug.	UT	Sept.	UT
2	12:44	3	1:39
5	9:33	5	22:28
8	6:22	8	19:17
11	3:10	11	16:05
13	23:59	14	12:54
16	20:47	17	9:42
19	17:36	20	6:31
22	14:25	23	3:20
25	11:13	26	0:09
28	8:02	28	20:57
31	4:51		

These geocentric predictions are from the heliocentric 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.

The Moon Occults Aldebaran

The Moon will cover 1st-magnitude Aldebaran every single month for the next few years, each time the Moon crosses Taurus in its monthly journey around Earth. But don't expect to *see* the occultations nearly so often. Each one will happen for only a fraction of Earth's surface, such as the zone on the map below. And on average around the year, only half of that zone will be twilight or darkness.

At magnitude +0.9, Aldebaran is the brightest star that the Moon ever crosses. The current series of Aldebaran occultations is creeping down the globe from north to south. Observers in the eastern U.S. and eastern Canada get their first chance late on the night of September 4–5.

Aldebaran will disappear behind the bright limb of the last-quarter Moon. Then as much as an hour later, it will reappear much more spectacularly from behind the Moon's dimly Earthlit dark limb. For North Americans, the Moon will be only recently risen in the eastern sky. The farther south and west you are, the lower it will be. Plan ahead.

Only the Northeast gets to see the star's disappearance. For this you'll need a telescope, because Aldebaran will be right next to the dazzlement of the sunlit lunar terrain just before it vanishes — looking in a telescope like a little orange fire on the Moon.

Its reappearance from behind the dark limb will be more widely visible: from as far south and west as Georgia and Wisconsin if you have a clear view right down to the east-northeast horizon.

Some times: at Toronto, *disappearance* 12:05 a.m. EDT, *reappearance* 12:40 a.m. EDT. Montreal, *d.* 12:05 a.m. EDT, *r.* 12:43 a.m. EDT. Boston, *d.* 11:57 p.m. EDT, *r.* 12:42 a.m. EDT. Washington DC, *r.* 12:38 a.m. EDT. Pittsburgh, *r.* 12:39 a.m. EDT. Atlanta, *r.* 12:35 a.m. EDT. Chicago, *r.* 11:39 p.m. CDT.

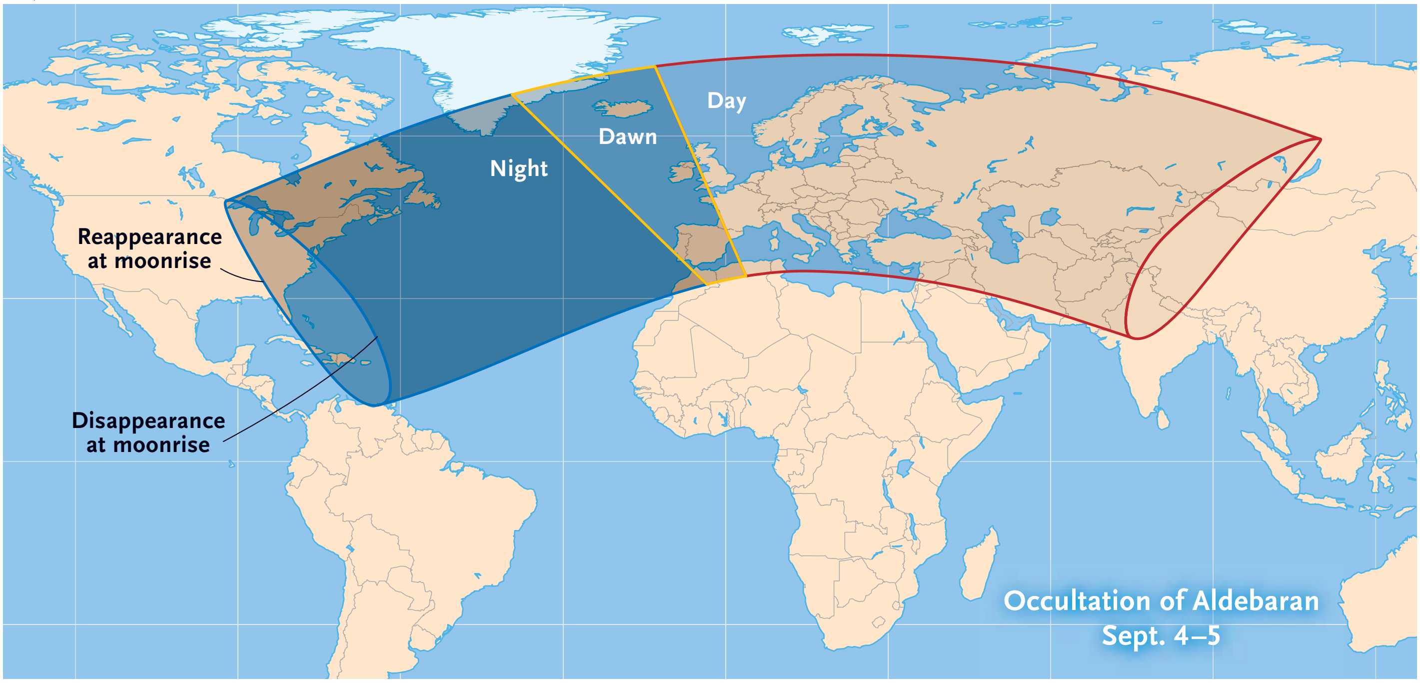
Los Angeles astrophotographer Michael Stecker captured this scene moments before the dark limb of the waxing crescent Moon occulted Aldebaran on April 10, 1997.

Timetables for many more locations in darkness or twilight, with the Moon's altitude at the time, are at **lunar-occultations.com/iota/bstar/0905zc692.htm**. Note that the document has three long sections: disappearance times, reappearance times, and the cities' coordinates.

Occultation reappearances are tricky! If you're not watching at exactly the right moment, the star can sneak back during a blink of your eye. So look up the time precisely, set your timepiece accurately, and watch steadily (even if your eye is watering) to catch it pop. ✦

The last-quarter Moon occults Aldebaran on September 4–5: late at night for parts of eastern North America, and in broad daylight on the morning of the 5th for most of Europe and central Asia. A telescope can show Aldebaran even in daylight. Its reappearance from behind the Moon's dark limb will be much more dramatic than its disappearance behind the bright limb.

IOTA / *S&T*: LEAH TISCIONE



The Ashen Light Redivivus

Modern research breathes new life into an enduring Venusian mystery.

For centuries, telescopic observers of the planet Venus have occasionally reported an elusive, if not illusive, glow on the nightside of the planet. This "ashen light," as it became known, resembles the faint Earthshine seen on the darkened portion of a nearly new Moon (*S&T:* July 2014, p. 54).

The literature on the subject is confusing. First, observations of the ashen light proper, in which the nightside appears *brighter* than the dark background sky, are often lumped with those where the nightside appears *darker* than the background sky. (The latter is a contrast effect.) Moreover, with an object as difficult to observe as Venus, illusions and optical effects abound: for instance, there is our well-known proclivity to "connect the dots" into complete figures, as well as the scattering of light by optical systems. (Observations made with reflecting telescopes are especially suspect, because of diffraction by secondary-mirror supports.)

Nevertheless, a handful of observations cannot be so easily dismissed, as Thomas Dobbins explored not long ago in this column's pages (*S&T:* March 2012, p. 50). Assuming that a real Venusian phenomenon might be involved, what can the physical explanation be?

In the case of the glowing dark side of the Moon, Earth's reflected sunlight is the explanation, as Leonardo da Vinci realized long ago. But Venus does not have a satellite, and while Earth would no doubt appear brilliant from Venus, its reflected light is far too feeble to produce such an effect. Many other explanations have been proposed over the years, some more ingenious than plausible — among them the notions that the inhabitants of Venus had set fires to clear forests or erected festal lights hailing new Venusian emperors!

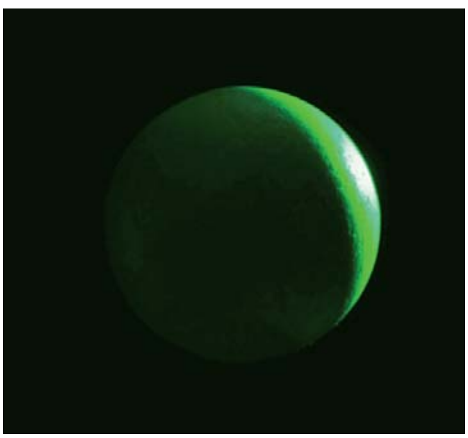
Less far-fetched was an 1872 proposal by Pierre de Heen suggesting that, since Venus is much closer to the Sun, auroral activity there must have intensity "the likes of which we can hardly imagine" and that this might account for the ashen light. His idea won support well into the 20th century, prompting Patrick Moore, in his 1956 classic *The Planet Venus,* to conclude that the theory "seems to be the best explanation."

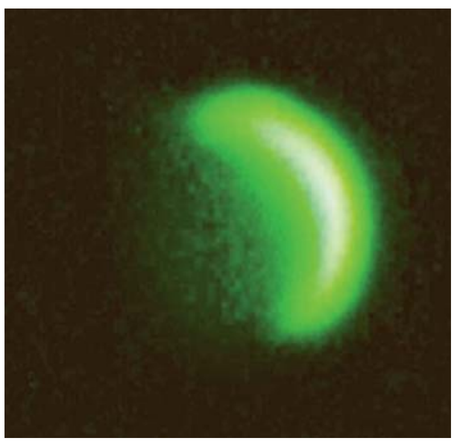
Credible Witnesses

At about that time, high-school students Dale Cruikshank and Alan Binder were working as summer assistants at Yerkes Observatory in Wisconsin. It was a dream job for anyone interested in the planets, and they enjoyed the opportunity to observe with the great 40-inch refractor, sometimes at night but regularly during the daytime when it wasn't needed for other research. Then Mercury and Venus proved to be the most rewarding objects.

They often noticed tantalizing surface detail on Mercury, as well as variable dusky bands on Venus, resembling those first photographed in the ultraviolet in 1927 by Frank Ross at Mount Wilson Observatory. The young students routinely observed Venus at 550× and 1200× through a Schott GG-14 yellow filter to reduce the telescope's stray (extra-focal) blue light.

On July 11, 1959, Cruikshank noted an unusual "halo" extending beyond the planet's cusps. This very faint





In May 2012 the authors photographed a simulated Venus through a green filter *(far left)* to mimic how it should appear telescopically — and then photographed Venus itself with the same camera and filter using an 11-inch telescope. The resulting stack of three images *(left)* reveals a subtle glow on the planet's nightside — but it's an artifact due to light leakage in the filter and extreme contrast enhancement.

glow remained visible even when the bright portion of Venus was occulted to reduce potential contrast effects. The glow was not detected the following two days, but on July 14th Cruikshank and Binder independently observed it. The glow remained sporadically visible on subsequent occasions.

Crucially, July 1959 was near sunspot maximum. Indeed, during the interval when they were seeing the glow around Venus's nightside, a number of powerful solar flares had been reported. Cruikshank and Binder's plot of the timeline of the occurrences of the halo and the big solar flares showed what seemed to be a tantalizing correspondence between the two.

Three years later, by then undergraduates, the two young observers followed their mentor, Gerard P. Kuiper, to the University of Arizona's new Lunar and Planetary Laboratory, where they wrote a brief paper titled "Solar Activity and Observations of the Nocturnal Luminescence of Venus." Kuiper suggested they withhold publication pending the results of sensitive spectrographic studies being planned by professional astronomers. Unfortunately, those studies yielded negative results, and a few months later NASA's Mariner 2 spacecraft discovered that, unlike Earth, Venus has no magnetic field. Since terrestrial auroras are intimately tied to Earth's magnetic field, it no longer seemed plausible that the ashen light — whatever it was — could be an auroral phenomenon.

There were no further developments until late 1975, when the Soviet Union's Venera 9 spacecraft studied Venus from orbit and detected oxygen emission lines in its nightside atmosphere. The lines, which appeared in both the visible and near-infrared parts of the spectrum, were later found to vary in brightness and to respond to changes in solar activity. In 1992, Cruikshank, by then a professional astronomer in Hawai'i, remained convinced that "strong outbursts of oxygen emission intensity might explain the reliable visual reports of the ashen light," and he wrote a paper encouraging amateurs to take up the quest with the high-quality equipment then becoming available.

YERKES OBSERVATORY

During the summer of 1959, planetary astronomer Gerard Kuiper (wearing tie) brought many budding, enthusiastic astronomers to the famed 40-inch refractor at Yerkes Observatory in Wisconsin. Among them were high-school students — and future astronomers — Alan Binder (second row, with eyeglasses), Ewen Whitaker (third row, far right), and Dale Cruikshank (top row, far right).

Fast-forward to the CCD era, when confirmations of elusive phenomena like the ashen light should have been forthcoming — were it real. But no digital image has ever registered it convincingly. A dim infrared glow due to the planet's superhot surface *has* been recorded, but that's in a spectral region inaccessible to visual observers and thus can't be identified with ashen light.

A Solar-Flare Trigger?

In 2012, we made a series of observations of the nightside of Venus in the months before its transit across the Sun. We had serious gear — Celestron 11- and 14-inch

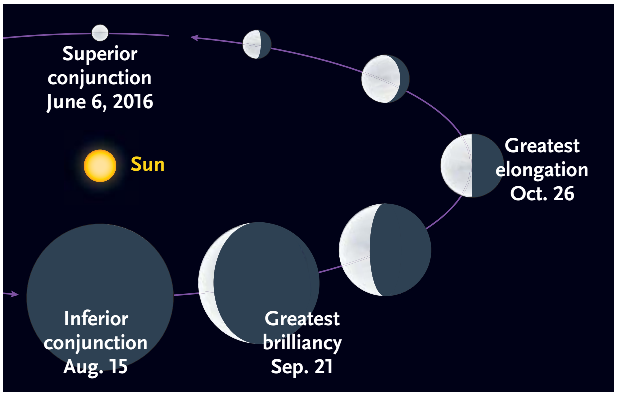
For up-to-the-minute information about solar flares and auroras (on Earth), check out spaceweather.com.

NASA / ESA

***Far left*: This sketch by Dale Cruikshank shows how Venus looked during a daytime observation in 1962. Note the mottled glow on the planet's nightside.**

***Left:* Astronauts aboard the International Space Station routinely see auroras. Red emission typically occurs higher up than green emission.**

Observers' next opportunity to search for ashen light comes early in September, when Venus appears in the predawn sky after inferior conjunction.



S&T: LEAH TISCIONE

Schmidt-Cassegrain telescopes and the 24-inch Clark refractor at Lowell Observatory — and we benefited from Cruikshank's advice and his narrow-bandpass filters. But we saw no hint of an ashen-like glow. Our disclaimer, however, is that during that time the Sun was fairly quiescent, with no strong flare activity — and this fact might be significant, in light of some suggestive recent research.

Working at Apache Point Observatory in New Mexico, astronomers Candace Gray and Nancy Chanover (New Mexico State University), Tom Slanger (SRI International), and Karan Molaverdikhani (University of Colorado) observed Venus spectrographically on four separate occasions between 2012 and 2014. Fortuitously, during each observing window an X-class solar flare — the strongest kind — was directed right at Venus. As Slanger reported at the 2014 meeting of the AAS's Division for Planetary Sciences in Tucson, "The results were amazing! There was a major solar storm in July 2012, producing an X-flare and huge coronal mass ejection that was directed right at Venus. We saw the brightest green line [of fluorescing oxygen atoms] that had ever been detected."

The green emission line wasn't detected after every flare but rather after only those that drove charged particles directly at Venus. While the planet lacks a global magnetic field, it does have an "induced" field, created when the Sun's magnetic field, embedded in the solar wind, becomes wrapped around the planet's ionosphere. There's also a long magnetotail extending out from the planet on the side opposite the Sun. So conceivably some kind of magnetic-reconnection process involving the solar wind is triggering auroral glows.

That's in keeping with results from ESA's Venus Express, which has shown that high-energy electrons are being channeled into the planet's nighttime atmosphere, where they excite oxygen atoms. Given the lack of a magnetic field, however, they're not channeled toward the poles (as occurs on Earth) but instead get dispersed. The result: auroras at all latitudes.

Based on these and other spectrographic results, Gray posits that the brightness and intensity of green-line emissions in the Venusian atmosphere likely depend on the strength of the solar flare, the depth in the planet's atmosphere at which the oxygen excitation occurs, and other as yet unknown factors.

Obviously there are chains of uncertainties here, but the auroral theory seems viable once again, providing a great opportunity for amateurs to take up the chase. If there are indeed Venusian auroras, can they be linked to X-flares and detected visually from Earth? If so, there might be something to the ashen light after all.

Like Cruikshank and Binder in 1959, persevering amateur observers armed with patience, attention to detail, and today's excellent equipment — as well as some luck — should take advantage of the current year's apparition of Venus to look for any hint of ashen light. The planet's thin crescent should be optimally placed in the morning sky during September and October.

Since major solar flare activity is likely to continue during this window, this might be a golden opportunity to finally snare the "Loch Ness of the solar system," as the ashen light has been referred to. Will you be the one to do it? ✦

*Contributing Editor **William Sheehan** is a veteran solar-system observer, historian, and author. An avid astro-photographer, **Klaus Brasch** took his first grainy Moon pictures in 1959 and now enjoys digital imaging from his backyard observatory in Flagstaff, Arizona.*

The Moon • September 2015

Phases

LAST QUARTER
September 5, 9:54 UT

NEW MOON
September 13, 6:41 UT

FIRST QUARTER
September 21, 8:59 UT

FULL MOON
September 28, 2:51 UT

Distances

Apogee September 14, 11h UT
252,565 miles diam. 29′ 20″

Perigee September 28, 2h UT
221,753 miles diam. 33′ 50″

Librations

Vallis Bouvard	September 9
Gauss (crater)	September 17
Cabeus (crater)	September 23

NASA / LRO

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

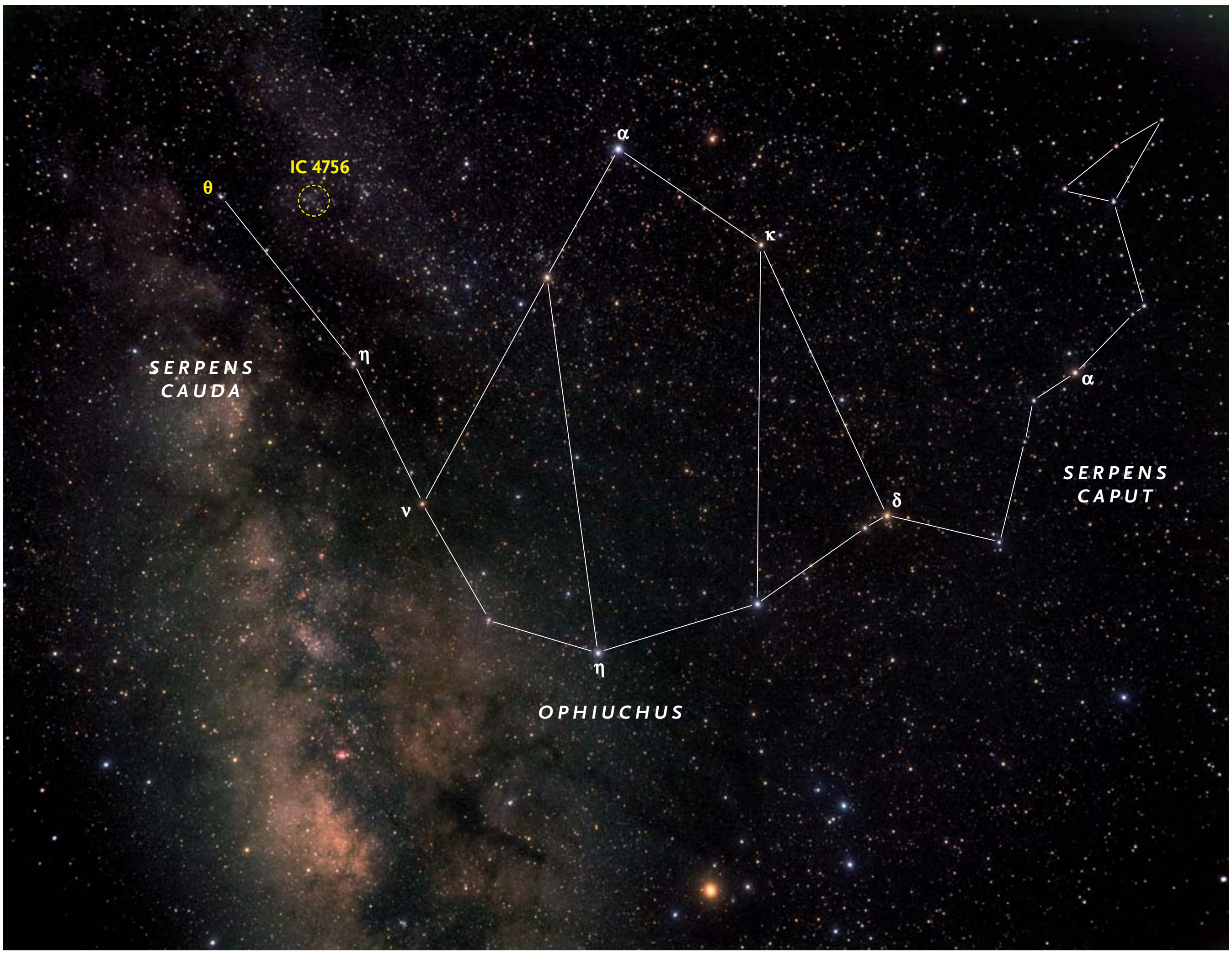
A Serpent's Tale

Look east of Ophiuchus for more starry discoveries.

Serpens, the Serpent, is the only one of the 88 modern constellations that's divided into separate pieces on the sky. Serpens Caput, containing this immense snake's head, is to the west of the Serpent Bearer (Ophiuchus), while Serpens Cauda, the beast's tail end, coils to his east. In June we perused some of the wonders in the west. Now let's see what tales the tail can convey about our deep sky.

The trailhead for our sky tour is the tip of the serpent's tail, **Theta (θ) Serpentis**, also known as Alya. Alya marks the bottom of an eye-catching, U-shaped asterism. The four stars that compose the U's sides are dressed in shades of yellow and gold, but Alya is arrayed in white. Through my 130-mm refractor at 23×, Alya splits into nearly matched components, with the companion resting east-southeast of its primary. To me, each star seems dusted with the merest touch of pale yellow. The 7.8-magnitude, red-orange star HD 175786 hovers north of the U's eastern side, adding another dash of color to the scene.

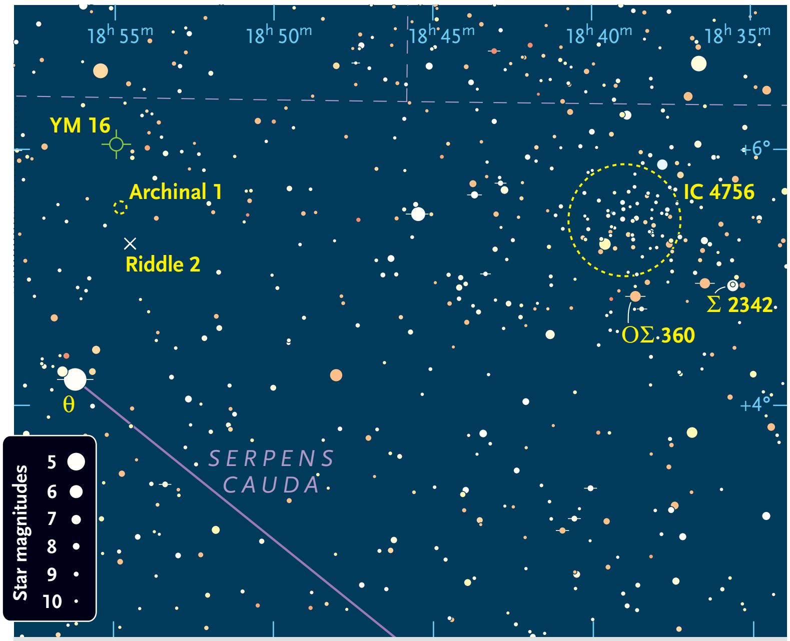
Each component of the Alya pair is about 1½ to 2 times the diameter and luminosity of our Sun. They're



AKIRA FUJII

believed to make up a physically bound pair. Author and astronomer Jim Kaler writes that the stars must be separated by at least 900 times the Earth-Sun distance. At that separation, he quips, "residents of a hypothetical 'earth' orbiting either one would see the other shine in their skies with the brightness of some 16 full Moons, allowing them to easily read their issues of the *Alya Gazette* at night."

Sweeping 4.5° west-northwest from Alya takes us to the sizable open cluster **IC 4756**, a very pretty sight when viewed through binoculars or a telescope with a wide field of view. My 130-mm refractor displays about 100 moderately bright to faint stars loosely scattered across 45′ of sky, with no tendency to grow more crowded toward the center. The group's leading light is a yellow, 6th-magnitude gem adorning the southeastern reaches of the cluster; however, it's not a true cluster member. A colorful, 8th- and 9th-magnitude star pair guards the cluster's west-southwestern border. The brighter star has a golden sheen, while its neighbor 2′ to the north-northwest gleams yellow.



Sights in Serpens Cauda

Object	Type	Mag(v)	Size/Sep	RA	Dec.
θ Ser	Double star	4.6, 4.9	22.3″	$18^h\ 56.2^m$	+4° 12′
IC 4756	Open cluster	4.6	40′	$18^h\ 38.9^m$	+5° 26′
ΟΣ 360	Double star	6.9, 9.1	1.7″	$18^h\ 38.7^m$	+4° 51′
Σ2342	Double star	6.5, 9.6	34.1″	$18^h\ 35.6^m$	+4° 56′
Riddle 2	Asterism	11.4	1.0′	$18^h\ 54.5^m$	+5° 16′
Archinal 1	Open cluster	—	1.5′	$18^h\ 54.8^m$	+5° 33′
YM 16	Planetary nebula	13	6.1′ × 5.0′	$18^h\ 55.0^m$	+6° 03′

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.

Thomas William Webb discovered IC 4756 and included it in his first edition (1859) of *Celestial Objects for Common Telescopes* under the listing for NGC 6633. He wrote, "Between it and θ, nearer the former, is a beautiful large cloud of stars, chiefly 8 and 9 mag., a nearer part, apparently, of the Galaxy: visible to the naked eye, and requiring a large field." Indeed, IC 4756 abuts a prominent branch of the summer Milky Way's misty river, which delineates the plane of the galaxy that we call home.

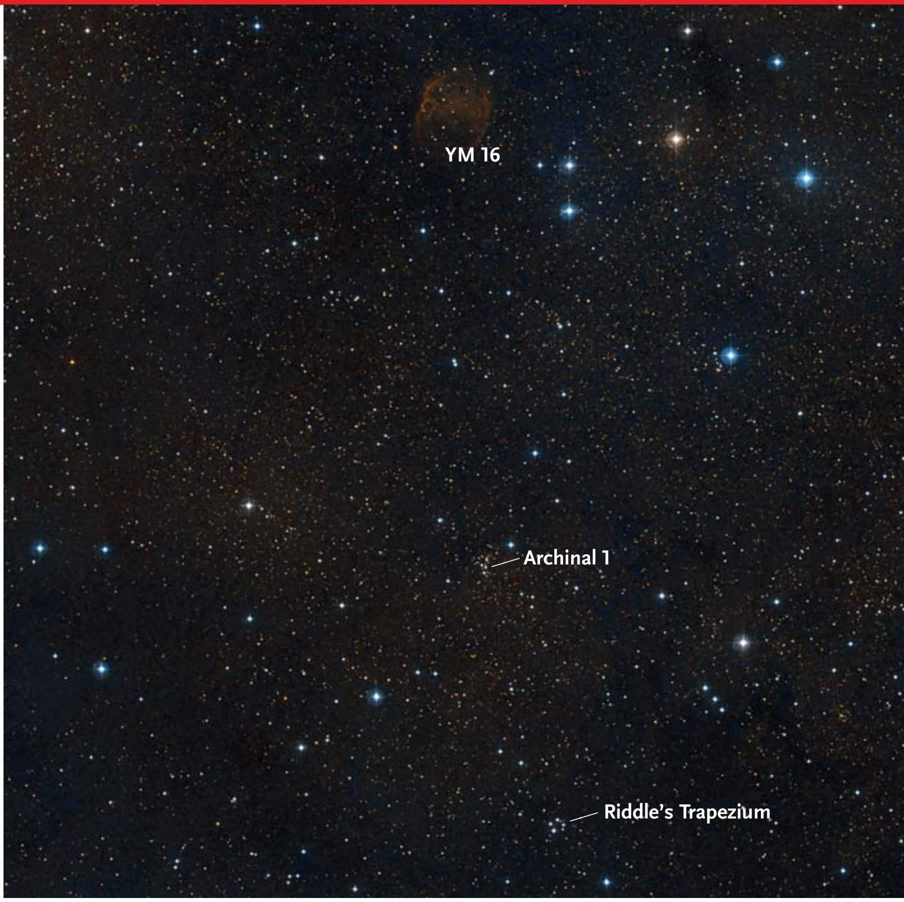
The bright, yellow-orange star dangling south of IC 4756 is **ΟΣ 360** (STT 360). Its designation tells us that it's one of the double stars discovered by Otto Wilhelm Struve, who succeeded his father, Friedrich Georg Wilhelm Struve, as director of Russia's Pulkovo Observatory in 1862. ΟΣ 360 is a close, unequal pair, hence it requires high magnification to split. The components are a scant 1.7″ apart and gleam at magnitudes 6.9 and 9.1. The companion makes its appearance west and a bit north of its primary when viewed through my 130-mm scope at 234×.

ΟΣ 360 forms a very shallow curve with two stars of similar magnitude to its west. The more distant one is a double discovered by the elder Struve, **Σ2342** (STF 2342). It's a very wide pair through the 130-mm refractor at 37×, with a white primary whose much fainter companion to the north looks yellow-white.

Now let's turn our attention to the region north of Alya, where a few little-known deep-sky wonders reside.

In 2003, Georgia amateur Dave Riddle reported a "trapezium-type asterism" to the Yahoo observer's group Amastro. He described it as a small ring of six stars about 1′ across. Its four brightest suns make a nearly perfect trapezoid. Trapezium-type systems were defined in the 1950s by Armenian astronomer Viktor Ambartsumian as multiple stars for which "the ratio of the greatest to least space distances between the components is less than three." The prototype is the multiple star system at the heart of the Orion Nebula.

In my 10-inch reflector at 43×, **Riddle's Trapezium** (Riddle 2) is a small fuzzy spot at first glance, but careful examination reveals three stars. The star at the trapezoid's western corner becomes faintly visible at 68×, and all four are obvious at 166×. I couldn't discern the other two ring stars, which feebly shine at about 15th and 17th magnitude. The brighter one might be visible through



POSS-II / STSCI / CALTECH / PALOMAR OBSERVATORY

Don Goldman captured the elusive nebulosity of Yerkes-McDonald 16 (YM 16) through a 16-inch Ritchey-Chrétien reflector; this image combines 6 hours 3-nm H-α and almost 11 hours of 3-nm O III exposures.

a 10-inch scope when observing conditions are good, but the seeing (atmospheric steadiness) was poor on the occasions that I observed this asterism. The trapezoid is also visible in my 130-mm scope. Three stars appear at 63×, and the fourth is reasonably easy to spot at 164×.

Just 17.6′ north-northeast of Riddle 2, we find the probable open cluster **Archinal 1**. It was discovered by Brent A. Archinal and introduced in the book *Star Clusters*, which Archinal co-authored with Steven J. Hynes (2003). They note that the cluster contains about 24 stars within a diameter of 1.5′.

Through my 130-mm refractor at 117×, Archinal 1 is a small misty patch sitting 2.2′ southeast of an 11th-magnitude star. One faint star dwells within the cluster's south-southeastern edge, and a couple more are intermittently visible. I suspected one additional star at 164×. With my 10-inch scope at 43×, Riddle's Trapezium and Archinal 1 share the field of view, but Archinal 1 looks considerably dimmer than its neighbor. At 299× there are three stars in a straight line, tipped slightly west of north, and a fourth star east-northeast of the line's center star. A fifth star is occasionally glimpsed. Even my 15-inch reflector didn't add much to the scene. I only spotted a few very faint stars among the brighter quartet.

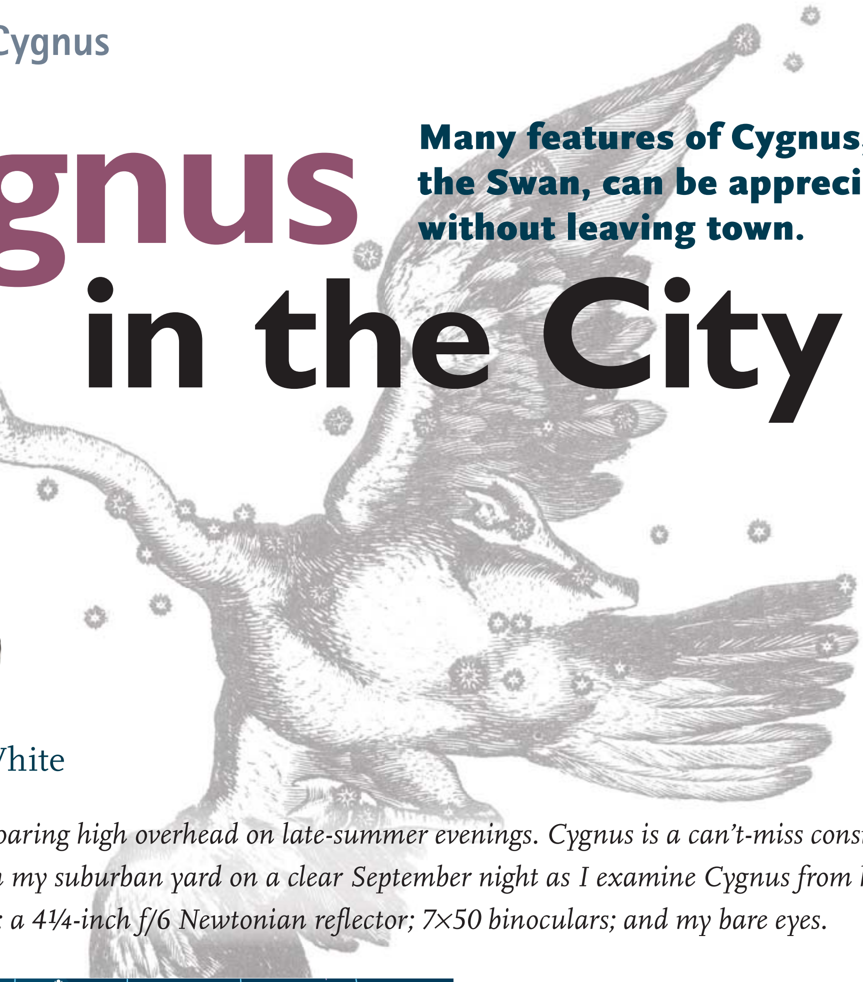
Where are the rest of those 24 stars? Richard Harshaw of Cave Creek, Arizona, managed to tease out a bunch of them with his 11-inch Schmidt-Cassegrain. He advises, "Folks, hit it with 400× or more. At that point a wonderful sprinkling of star glitter emerges from behind the four main stars." I know I'll give it a try. Will you?

Those who like a difficult challenge can try for the exceptionally faint planetary nebula **Yerkes-McDonald 16** (YM 16), 30′ north of Archinal 1. Through my 15-inch reflector at 79×, this phantom glow appears roughly 5′ across. It's defined mostly by diaphanous rims east-northeast and west-southwest of each other, like a set of parentheses. The west-southwestern rim is shorter and more tenuous. A barely perceived glow fills the area between them. The nebula is ensconced in a pie-wedge of 13th- and 14th-magnitude stars. The star at the wedge's point is northwest of the nebula, and the three stars of the pie crust lie off the opposite side. YM 16 is visible with a narrowband or hydrogen-beta filter, but an O III filter is detrimental. I prefer a filterless view.

When preparing this tour, years after visiting YM 16, I found that my logged description and eyepiece sketch don't tell the whole story. Images show that this planetary nebula is actually quite oval. A large portion of YM 16, southwest of what I'd detected, was completely invisible to me. This extends the nebula to a length of about 6′. I'd love to hear from readers who spot any part of this elusive nebula. ✦

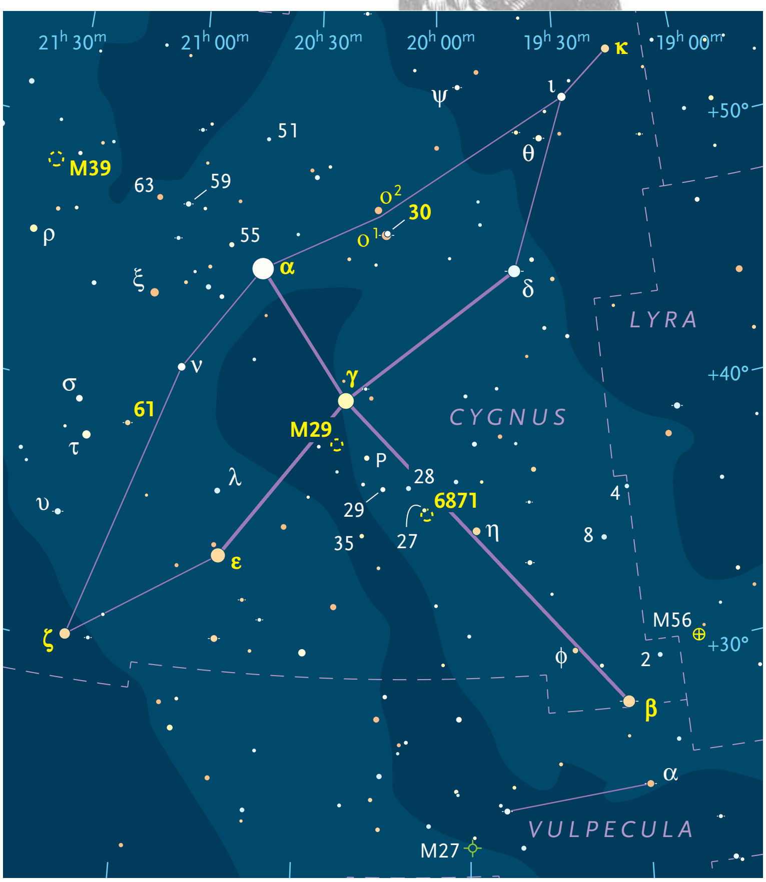
Cygnus in the City

Many features of Cygnus, the Swan, can be appreciated without leaving town.



Ken Hewitt-White

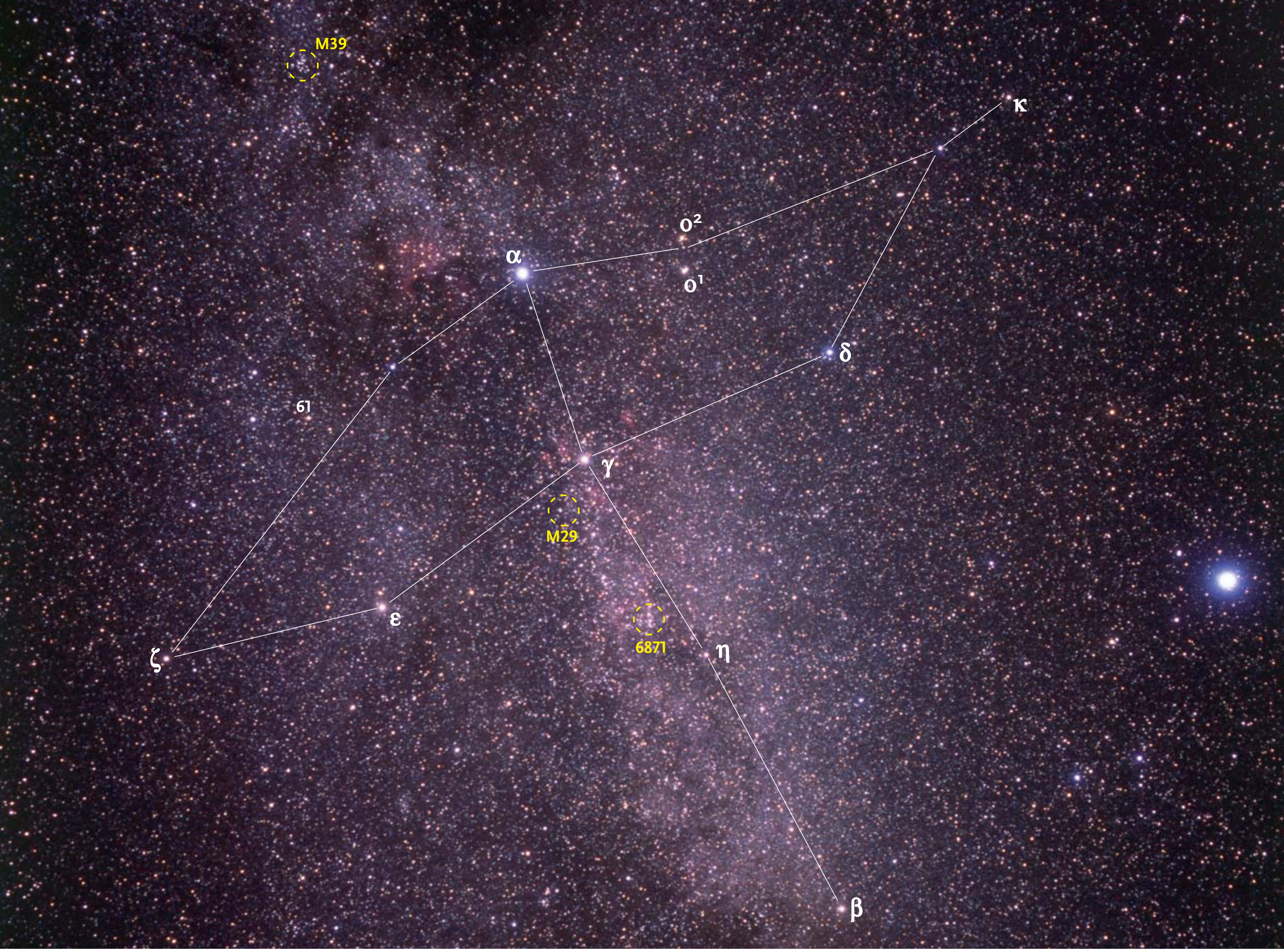
Oh, that heavenly Swan, *soaring high overhead on late-summer evenings. Cygnus is a can't-miss constellation, even amid city lights. Join me in my suburban yard on a clear September night as I examine Cygnus from head to tail with three small optical systems: a 4¼-inch f/6 Newtonian reflector; 7×50 binoculars; and my bare eyes.*



Sizing Up the Swan

Sixteenth largest of the 88 constellations, Cygnus covers 804 square degrees of celestial real estate. Within its borders are four dozen stars brighter than magnitude 5.0. Picking out the Swan is easy thanks to the **Northern Cross**, a five-star asterism inside the constellation that represents the bare bones of the bird. Like the iconic Big Dipper, the Northern Cross is an eye-catching star pattern in its own right. The Cross is large, measuring 22° by 16° (the Dipper is longer but not as wide), and it doubles as a basic, connect-the-dots skeleton of our feathered friend. To get the anatomy right, simply remember that the top of the Cross is the tail of the Swan.

The top, northeast, end of the Cross is marked by the blaze of 1st-magnitude **Alpha (α) Cygni**, whose name is Deneb ("tail"). At the southwest end is 3rd-magnitude **Beta (β)**, or Albireo, a word not easily translated, though the star clearly establishes the head of our long-necked flyer. Between Albireo and Deneb is 2nd-magnitude **Gamma (γ)**, or Sadr ("breast"). Southeast of Sadr is 2.5-magnitude **Epsilon (ε)**, or Gienah ("wing"). Northwest of Sadr is 3rd-magnitude **Delta (δ)**, which, oddly, has no common name. The row of Epsilon-Gamma-Delta outlines the leading edge of the Swan's wide-open wings. Outside the Cross, the wingtips are set by 4th-magnitude **Kappa (κ)** and 3rd-magnitude **Zeta (ζ)**. A scraggly arc of faint stars connecting Kappa, Deneb, and



AKIRA FUJII

Zeta delineates the wings' trailing edge.

The Northern Cross is far too broad to capture in the 7° field of my binoculars. However, I love focusing the glasses on the five main stars separately because each one exhibits its own color. The differences are subtle: Deneb gleams bluish-white while Delta Cygni seems pure white. Sadr is yellowish, Gienah shines an orange-yellow, and Albireo glows deep yellow. There are a few other colorful stars up there, too, which I'll cover later.

A slow binocular sweep along the spine of the Cross reveals the Milky Way, whose glittering band runs the length of the constellation. Observers outside the city limits probe the Cygnus Milky Way for its dim and delicate nebulas, but they're almost impossible to scrutinize in my suburban sky. What I describe below are Cygnus sights that beat city lights!

The Body of the Bird

Let's begin our tour at **Albireo**, more than 400 light-years from Earth and one of the most striking double stars in the heavens. The 3.4-magnitude yellow-orange sun and 5.1-magnitude blue sun, a generous 34″ (34 arc-seconds) apart, make a glorious combo in my 4¼-inch scope. I choose fairly low magnification to keep the components visually tight. By the way, this dazzling duo is not a true binary system. The stars are separated by roughly 10 light-years — too much for them to be gravitationally bound to each other.

Next, my attention turns to **Sadr**, approximately 1,800 light-years away. This central part of Cygnus is spectacular. My binoculars show Sadr encircled (on the sky, not in space) by a ragged wreath of at least a dozen stars ranging from magnitude 5.3 down to the limit of the glasses. In my little reflector at 22×, many additional stars almost fill the 2° field. The view includes three official open clusters, though to my eye it's all one big jumble of jewels. Channeling my inner Tolkien, I call this star-spangled region the *Ring of Sadr*.

Just outside my Ring of Sadr, 1¾° south-southeast of Sadr itself, is the open cluster **Messier 29**. A small,

JIM MAZUR

DIMMED BY DUST Intervening dust absorbs much of the light from M29, making an already sparsely populated open cluster appear even more so.

sparsely populated clumping some 3,700 light-years away, M29 barely registers in my 6×30 finderscope (this is the city, remember), but in the 7×50 binocs it materializes as a grainy smudge. My telescope, still at 22×, resolves the graininess into a compact array of stars less than 5′ (5 arcminutes) in diameter. Make that two arrays, for M29's six most prominent members are arranged in an opposing pair of stubby arcs, each one with three 9th-magnitude stars. Increasing the magnification adds only a few dimmer dots, thanks to my blanched night sky. However, I can't completely blame light pollution on M29's limited impact.

City glare also doesn't seriously harm my next treasure, the open cluster **NGC 6871**. Like M29, this underappreciated gem is a loosely bound group. And it's even farther away — at least 5,000 light-years, according to recent estimates. NGC 6871 glimmers almost 6° southwest of Sadr, and the "starhop" between them is a bit tricky. From Sadr, I hop along to the 5th-magnitude variable P Cygni, push on to similarly bright 29 Cygni, jog west to its twin, 28 Cygni, slide southward along a chain of faint stars curving into 5.4-magnitude 27 Cygni, then arrive at the cluster below. In my finderscope, NGC 6871 is underwhelming: a 12′-long bent line of exactly three wee stars, running approximately north-south.

But wait. The northernmost star looks blurry. My reflector at 50× morphs the mist into two nearly parallel star pairs: a 35″-wide northern duo of 6.8 and 7.3 magnitude, and a 20″-wide southern set of 7.8 and 8.7 magnitude. Together the four stars create a 2′-long quadrangle whose brightest star on the northwest corner sports a 9.6-magnitude companion. Several pale points are visible in and around the quadrangle. Farther down the cluster, the middle star in the bent line remains single, but the southern end splits into a pair of 7.8- and 8.8-magnitude stars 69″ apart. Not a bad cluster after all.

Behind the Tail and Along the Wings

From NGC 6871 we reverse our steps to Sadr and carry on to **Deneb**, a convenient launch point to my next destination. And the Swan's alpha star is itself worth a quick telescopic peek. In my low-power 2° field of view, the blue-tinted blazer, despite being over 2,600 light-years away, fairly gleams against the surprisingly rich Milky Way starfield. The view is gorgeous.

Next, the Milky Way provides some stellar stepping stones from Deneb to the open cluster **Messier 39**. I identify the route with binoculars first, then use my tele-

Selected Sights in the Swan

Object	Type	Mag(v)	Size/Sep	RA	Dec.	Distance
α Cygni (Deneb)	Supergiant	1.25	—	20^h 41.4^m	+45° 17′	2,600 l-y
β Cygni (Albireo)	Double star	3.4, 5.1	34″	19^h 30.7^m	+27° 58′	430 l-y
γ Cygni (Sadr)	Variable star	2.3	—	20^h 22.2^m	+40° 15′	1,800 l-y
Messier 29	Open cluster	6.6	10′	20^h 23.9^m	+38° 32′	3,700 l-y
NGC 6871	Open cluster	5.2	30′	20^h 06.5^m	+35° 47′	5,000 l-y
Messier 39	Open cluster	4.6	31′	21^h 31.9^m	+48° 26′	900 l-y
O^1 Cygni	Bright giant	3.8	—	20^h 13.6^m	+46° 44′	880 l-y
O^2 Cygni	Supergiant	3.98	—	20^h 13.3^m	+46° 49′	1,170 l-y
61 Cygni	Double star	5.2, 6.0	31″	21^h 06.9^m	+38° 45′	11.4 l-y

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.

scope's finder to hop from star to star. The 10°-long path trends east-northeastward via the 5th-magnitude stars 55 Cygni, 59 Cygni, and — halfway along — 63 Cygni. From 63 Cygni I continue almost directly east to the prize.

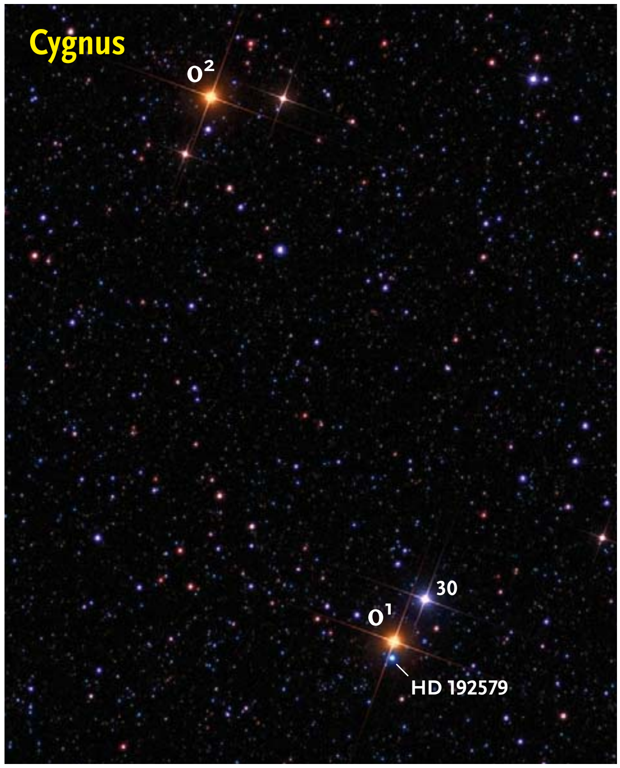
And what a prize. About 900 light-years away, M39 has more to offer than its far-off cousin, M29. The cluster shines at a magnitude of 4.6, is approximately ½° across, and presents a triangular shape. My 7×50 glasses pick up three 7th-magnitude stars forming the gently concave northeast side of the triangle, a slightly weaker star marking the triangle's southwest vertex, and numerous stars in between. In my small reflector, still at low power, I tally a dozen and a half cluster members, including a couple of tiny pairs. With increased magnification fainter pinpoints appear, including a profusion of Milky Way stars. Nice!

The Swan's western wing contains two 4th-magnitude stars 1° apart, aligned roughly north-south. In my binocs, the northern star, **Omicron^2 (o^2) Cygni**, also cataloged as 32 Cygni, glows red, while the southern star, **Omicron^1 (o^1) Cygni**, also known as 31 Cygni, is reddish-orange (see page 43). The latter is flanked 5.5′ to the northwest by bluish 5th-magnitude **30 Cygni**. The telescope at 22× captures the complete trio along with some faint stars around Omicron^2 plus a 7th-magnitude blue attendant 1¾′ south of Omicron^1. The stars in this pretty grouping aren't related. Omicron^2 is an estimated 1,170 light-years away. Omicron^1 is closer, about 880 light-years away, and its "attendant," HD 192579, at approximately 1,715 light-years, is most distant. The nearest beacon is 30 Cygni, 720 light-years from Earth.

The eastern wing features a true binary of historical interest. **61 Cygni** is dimly visible to the eye as a 4.8-magnitude star that forms a boxy figure with Deneb, Sadr, and Gienah. My telescope resolves the star into 5.2- and 6.0-magnitude orange suns 31″ apart. Just 11.4 light-years from Earth, 61 Cygni was the first star to have its parallax (and therefore its distance) measured, a feat accomplished in 1838 by German astronomer Friedrich Wilhelm Bessel at Königsberg Observatory. The object was already newsworthy 34 years earlier when Italian observer and founder of the Palermo Observatory Giuseppe Piazzi discovered that it possesses a remarkably fast motion (5″ per year) relative to the stellar background. An astonished Piazzi dubbed 61 Cygni the Flying Star.

HEIDI SCHWEIKER / WIYN AND NOAO / AURA / NSF

OLD BEAUTY The loose open cluster M39, some 900 light-years from Earth, is an estimated 200 to 300 million years old.



JERRY LODRIGUSS

WIDE DOUBLE With a separation of about 1°, Omicron^1 and Omicron^2 Cygni form a 4th-magnitude optical double.

So Long, Cygnus

My own astonishment is triggered whenever I compare Piazzi's Flying Star to brilliant Deneb. The famous Flying Star is one of the nearest star systems to Earth, yet it's a bit difficult to spot in my suburban sky. That's because its binary components are feeble orange dwarfs with only a tiny fraction the luminosity of our Sun. By contrast, distant Deneb is the 19th brightest star in the heavens. The white-hot supergiant is tens of thousands of times more powerful than our Sun. Talk about extremes!

There's more to Cygnus than just stars, but I'll save that for a darker night away from town. Meanwhile, keep flying, Big Bird. You always amaze me. ✦

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*Canadian observer **Ken Hewitt-White** imagines the constellation Cygnus as the ubiquitous Canada goose.*

 Sean Walker

Lunt Engineering 100 mm ED APO Binoculars

How do these premium 4-inch binoculars perform under the night sky?

ALL PHOTOS S&T: SEAN WALKER

Lunt Engineering 100 mm ED APO Large Format Binoculars

U.S. price: $2,490
Lunt Engineering USA
2520 N. Coyote Dr., Suite 110
Tucson, AZ 85745
luntengineering.com

Observing with both eyes can be a real treat, particularly when you're observing through two 4-inch apochromatic refractors. The Lunt 100 mm ED APO binoculars combine premium optics with interchangeable eyepieces that allow you to observe targets often reserved for telescopes.

BINOCULAR OBSERVING has always been a hit-or-miss experience for me. I'm very sensitive to optical misalignment, which can quickly spoil the advantage of observing with both eyes: my trouble with merging two images that are not perfectly aligned eliminates any benefit to the experience. That's why I prefer to try out a pair whenever possible before investing in them.

So when we borrowed Lunt Engineering's new 100 mm ED apochromatic binoculars from Woodland Hills Camera & Telescopes for review, I was certainly interested in how they would perform. The view through a good set of large binoculars is an experience like no other. When done properly, observing with both eyes can permit you to see to the very limits of your abilities.

The Lunt 100 mm ED APO Binoculars are marketed as premium binoculars built with the travelling amateur astronomer in mind. These heavy-duty binoculars would be as much at home on the deck of a battleship spotting tiny submarine periscopes during the day as they are under a dark, moonless night. The eyepiece ports are mounted at a 45° angle convenient for daytime observing, and they accept most 1¼-inch-format eyepieces in individual helical focusers, which really increase the unit's versatility for astronomical observing. At the Northeast Astronomy Forum last April, the company also introduced a version of the binoculars with 90° eyepiece holders.

The unit arrived double-boxed in custom-fitting foam with two 20-mm SWA eyepieces, along with an optional finder bracket and a unit-power multi-reticle finder. The last was a welcome addition, as it can be very difficult to accurately aim binoculars with eyepieces set at a 45° angle. Lifting the unit from the box, it felt every bit as heavy as its 14½-lb listed weight implied. It requires a heavy-duty mount. I did most of my testing on a Manfrotto studio tripod with a Universal Astronomics MacroStar head (**universalastronomics.com**) that held the Lunt 100s with ease.

The binoculars come with extendable lens shades, a built-in carry handle, and a tripod mounting base. There are two ¼-20 threaded sockets on either side of a ⅜-16 threaded socket supplied with a ¼-20 step-down adapter. Given the binoculars' hefty weight, I avoided using the step-down adapter.

Attaching the finder bracket and MacroStar L-bracket was easy, though if you intend on standing the binoculars on the objective end, you should remove the lens caps first: these threaded plastic caps are convex and don't sit flat against surfaces. Aligning the finder took just a minute or two, and I was ready to put the binoculars through some daylight tests immediately.

The Lunt 100s are virtually apochromatic — high-contrast targets in the middle of the field show only a hint of purple fringing, which becomes more pronounced towards the edge of the expansive 70° apparent field-of-view provided by the 20-mm SWA eyepieces. The optical alignment was very good, and I had no trouble merging the images. Viewing the siding on my neighbor's home showed some modest pincushion distortion.

The helical focusers can accommodate a wide range of eyepieces, and their collet-style locking mechanisms held everything in place and centered without any fuss. They also incorporate thick brass compression rings that won't mar your eyepiece barrels.

WHAT WE LIKE:

Large aperture

Unit-power finder and bracket

Accepts 1¼-inch eyepieces

WHAT WE DON'T LIKE:

Lens caps prone to scratching

The Lunt 100s include independent helical focusers that accept most any 1¼-inch eyepieces, and their inter-ocular distance ranges from 54 to 75 millimeters apart. Brass compression rings keep the eyepieces tightly centered.

Under the Stars

The crisp skies of late winter and early spring provided a wide variety of targets to really show off what is possible with what is essentially a pair of 4-inch short-focus refractors. The Orion Nebula, M42, showed extended nebulosity around the Trapezium, and I glimpsed hints of its bat-like appearance on a particularly dark night. Bright open clusters like the Pleiades filled the view with dazzlingly bright stars and a touch of nebulosity surrounding Merope. This cluster gave me the opportunity to evaluate the entire field of view carefully; with the included eyepieces, stars were nearly textbook perfect across roughly 75% of the field, though bright stars in the outer 25% of the field became elongated due to coma. This was noticeable only on very bright stars.

Internal baffling in the Lunt 100s is excellent. I observed the Moon from a thin crescent up through full phase, and I was never bothered by ghost images

Included with the Lunt 100s is a pair of SWA 20-mm 70° eyepieces, producing 27.5× magnification over a generous field.

or scattered light. The 20-mm eyepieces produce 27.5×, giving enough magnification to really show off cratered fields and rays, as well as the Moon's mesmerizing 3D appearance when Earthshine was present. A hint of color fringing was visible on the Moon, though mostly when it drifted towards the edge of the field.

While the view was nice with the supplied eyepieces, these binoculars really show off their abilities when used with high-quality eyepieces. I was able to test them for an extended period using a pair of Tele Vue's new 11-mm DeLite eyepieces (see below), which really added a new dimension to my experience.

With the DeLites, suddenly the Trapezium in M42 became four cleanly separated stars with tiny diffraction rings surrounding them. The globular cluster M13 in Hercules began to resolve into individual stars around its edges, and random star fields in Gemini became appealing in their own right, even without a showy target in field. Additionally, the 11-mm DeLites were extremely comfortable to look through, giving me an observing experience of the instrument "getting out of the way of the view."

What surprised me the most with the Lunt/DeLite combination were my views of Jupiter. Although the 11-mm DeLites provide only 50× magnification, this proved enough to show Jupiter and its moons with some tantalizing detail. Around opposition, Jupiter displayed its two dark belts as expected. But the Great Red Spot was also easy to recognize, and on several occasions I watched shadow transits of the Galilean moons. Once I even spotted Europa in front of the planet before it exited a transit. This might not impress some planetary aficionados, but keep in mind these were spotted with binoculars!

The Lunt 100s ability to accept most any 1¼-inch eyepieces allows you to match these premium binoculars with high-quality eyepieces. The 11-mm Tele Vue DeLite eyepieces seen above were a particularly good match for observing globular clusters and bright nebulae as well as the Moon and Jupiter.

Quick Look *by Dennis di Cicco*

Tele Vue's New DeLite Eyepieces

Tele Vue DeLite Eyepieces

U.S. price: $250
Tele Vue dealers worldwide

The DeLite eyepieces all have a generous 20 millimeters of eye relief and an adjustable eye guard that locks solidly in place with a twist of the lower textured-rubber collar. Their modest 47-mm barrel diameters make them ideal for bino-viewers, something that is often a problem for modern eyepiece designs that have bulging barrels.

DENNIS DI CICCO

YOU JUST KNOW that when one of the world's leading manufacturers of eyepieces unveils a new product line, it will spark a lot of interest among observers. And that's what happened last April when Tele Vue Optics made a surprise announcement introducing its new DeLite eyepieces at the Northeast Astronomy Forum (NEAF). Made to fit standard 1¼-inch focusers, the DeLites are currently available in focal lengths of 7, 11, and 18.2 millimeters, with more planned for the future that, according to company founder and CEO Al Nagler, will have focal lengths shorter than the 18.2-mm model.

Examining the field with the 11-mm DeLites, coma noted in the 20-mm SWA eyepieces was limited to just the very edge of field, perhaps due to the eyepieces' increased magnification and 62° apparent field. This let me enjoy observing the Moon and Jupiter almost to the edge of the field before having to re-center them.

While the views were enjoyable through most any eyepieces I used with the Lunt 100s, there is a practical limit to their versatility. The company claims that you can observe with these at over 100×, but there are some hurdles to overcome when using such high magnifications, as these would require eyepieces of 5-mm or shorter. Targets at 100× would need to be re-centered very frequently. Finally, such high magnifications are more likely to reveal any optical aberrations and misalignment that just aren't visible at the image scale you'd commonly use with binoculars.

I found the Lunt 100 mm ED APO binoculars to be extremely enjoyable to use, particularly when fitted with a pair of high-quality eyepieces. If you're in the market for premium large binoculars, consider giving these serious consideration.

*S&T Equipment Editor **Sean Walker** gets twice the enjoyment out of binoculars through astronomy and bird watching.*

The hefty weight of the unit requires a sturdy mount. The author used a Universal Astronomics MacroStar head, which held the view steady even at high magnifications.

While many of Tele Vue's recent eyepiece introductions have established new standards for the wide-field observing experience, the DeLites have far more modest specifications. With an apparent field of view (FOV) spanning 62°, the DeLites offer only a slightly wider FOV than Tele Vue's now-discontinued Radian eyepieces (57°), but smaller than the company's Delos eyepieces (72°). Indeed, were you only to look at the DeLites' specifications on paper, you might come away thinking that their most interesting attributes are simply the Tele Vue name and their $250 price tag (only a handful of the company's Plossl eyepieces retail for less than the DeLites).

What makes the DeLites special, however, comes from looking through them. And that's what I did after borrowing a set of the samples shown at NEAF for this review. I tried them with four scopes – a 12-inch f/4 Newtonian reflector fitted with Tele Vue's Big Paracorr coma corrector (reviewed in the April 2015 issue, page 72); a 12-inch f/5 Dobsonian; a 4-inch f/5.4 apo refractor, and a classic 6-inch f/9 Newtonian.

WHAT WE LIKE:

- Upholds Tele Vue's reputation for optical excellence
- Comfortable to look through
- Adjustable eye guard with locking collar
- Works with Dioptrx astigmatism corrector

As I've come to expect from all of Tele Vue's eyepieces, the DeLites offered superb views. Stars appeared as pinpoints across the entire field; there wasn't a hint of false color around even the brightest stars; and there was only a touch of pincushion distortion, meaning that round objects won't stretch into ovals as you sweep them across the field. Daytime views were contrasty and without a trace of color fringes even at the borders of high-contrast objects such as power lines seen against a bright sky.

These are the features everyone looks for in a quality eyepiece, but the DeLites offered something more – something that I also found remarkable about the Tele Vue Delos eyepieces (reviewed in the June 2011 issue, page 58). The DeLites are very easy to look through. You never get the feeling that you are struggling to get your eye perfectly aligned with the eyepiece. This comes as little surprise since Tele Vue acknowledges that the DeLite design evolved as a "smaller, more economical and lightweight version of the Delos." Even the name is a clever spin on a "lite" version of the Delos.

More so than even about their telescopes, observers tend to develop very strong feelings about their eyepieces, and I too have my favorites. While I certainly marvel at the views through many of today's incredible wide-field eyepieces, the bulk of my observing of the Moon, planets, multiple stars, and deep-sky objects is done at medium to high magnifications with tracking telescopes. As such, I'm well served with eyepieces that have a modest field of view. That's something to think about given that I can own the whole set of DeLites with their uncompromising 62° FOV for less than the cost of just one of some of today's premium wide-field eyepieces. ✦

***Dennis di Cicco** has been gazing skyward since the dawn of the Space Age.*

New Product Showcase

▲ **PANORAMA AUTOMATION** When iOptron rolled out its latest innovations at the Northeast Astronomy Forum in April, the iPano gigapixel mount head caught our eye. This robotic camera platform (introductory price: $999) supports large DSLR cameras and lenses and is designed to automate your ability to shoot extremely-large-scale panoramas. The iPano directly connects to most DSLR camera models and, with minor calibration, can automatically and precisely point and shoot as many overlapping frames as necessary to assemble your final gigapixel panorama. The unit weighs 7.3 lbs (3.3 kg) and bears a load of up to 11 lbs (5 kg), and it runs on lithium rechargeable batteries. The iPano accepts RS232 and RS485 inputs and also includes a built-in Wi-Fi connection.

iOptron
6F Gill St.,
Woburn, MA 01801
866-399-4587;
ioptron.com

▲ **QUICK RELEASE ADAPTER** Farpoint introduces the "D" Series Dovetail Camera Mount Quick Release Adapter ($55). This piggyback bracket connects any camera or accessory that uses a ¼-20 threaded mount to Losmandy D-size dovetail plates, allowing you to quickly reconfigure your telescope with secondary cameras, guide scopes, or other additional accessories. The adapter is manufactured from anodized aluminum and includes easy-grip knobs that can be operated while wearing gloves (dovetail plate not included).

Farpoint Astronomical Research
11358 Amalgam Way, Suite A1, Gold River, CA 95670
877-623-4021 or 916-671-5735; farpointastro.com

▲ **FSQ FOCUSER** Starlight Instruments announces the FTF3515-TAK FSQ106ED Feather Touch 3.5-inch Diameter Dual Speed Focuser Kit ($995). This rack-and-pinion focuser adds additional stability and precision to the legendary Takahashi FSQ-106ED astrograph. The focuser includes a custom-machined 3.5-inch drawtube with glare-resistant internal baffling and M98X1 female threads that allow users to directly attach Takahashi accessories. Each FTF3515-TAK focuser is tested to lift 18 to 20 pounds and is compatible with the Focuser Boss II electronic focusing kit.

Starlight Instruments
2380 E. Cardinal Dr., Columbia City, IN 46725
260-244-0020; starlightinstruments.com

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

Comet Freeze

Here's a great technique for stacking your comet photos in *ImagesPlus*.

Tim Jensen

Comets are rare visitors to our night sky. Often arriving with little warning, they put on a brief show and then slowly fade as they recede from the Sun. The brighter ones grab the public's attention, while amateurs grab their cameras. A bright comet is easy to shoot — simply point your camera or telescope at it, open the shutter for about 5 minutes, and you're pretty much done. Imaging the fainter ones can present an interesting challenge; they require much longer exposures to reveal any streaming ion or dust tails, which leads to more complex issues when assembling your image.

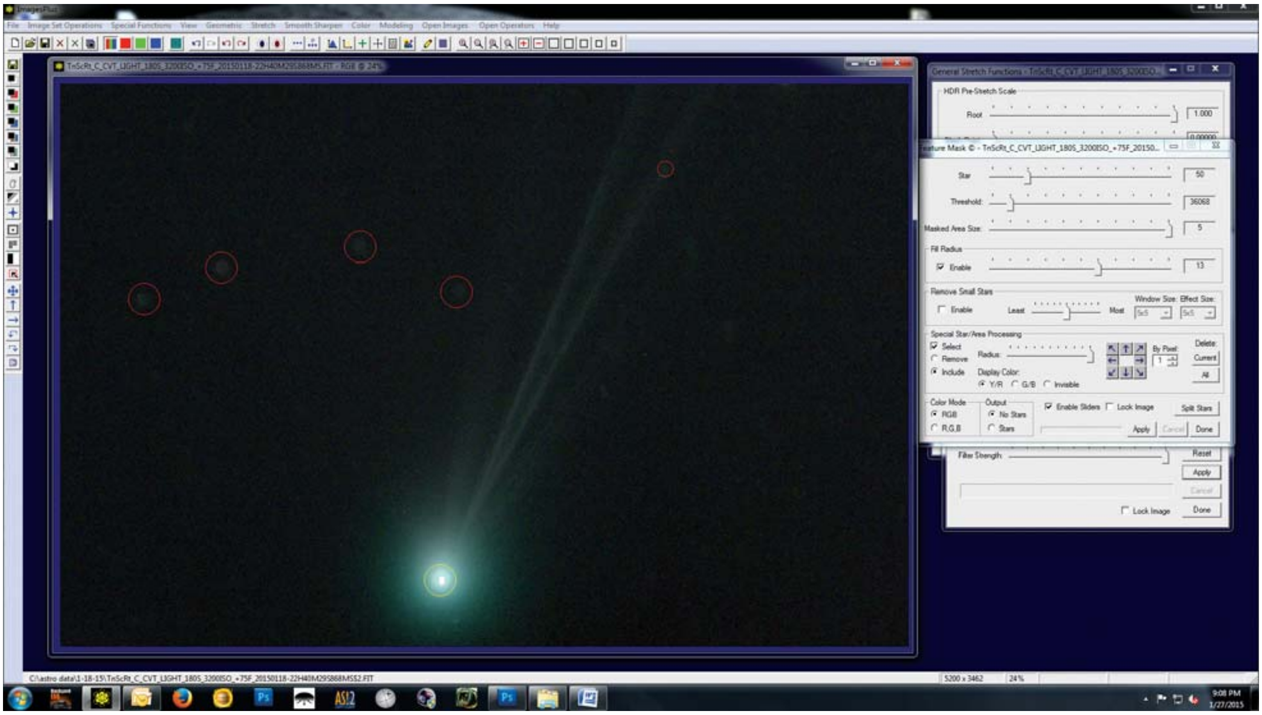
Perhaps the most appealing images of comets portray them as a brilliant greenish coma with a long, streaming tail that trails away against a field of sharp, round stars. But since comets move noticeably with respect to the stars in only a few minutes, long exposures tracked on the background stars are limited to only a minute or so before the comet begins to shift against the star field. The resulting photo often shows a nice star field with a blurry streak that was the comet as it moved during the exposure.

One fix to this issue is to guide on the comet itself with a separate guidescope. This produces a deep image of the comet surrounded by long streaks of trailed stars. So what can you do to get an image that has the best of both worlds: a deep, detailed comet with gossamer ion streamers against a perfectly tracked star field? My solution to this dilemma is to do both, and then combine the result using post-processing software. Here's how I do it with *ImagesPlus* (**mlunsold.com**).

Double Alignment

Part of the difficulty of freezing a typical comet's motion in deep photos is the fact that you need to take exposures tens of minutes long to bring out any ion or dust tails

LOVEJOY'S JETS Deep images of comets are surprisingly challenging to achieve. Because they move against the background stars, telescopic exposures are limited to just a minute or two before producing a trailed image. In the photo on page 68, author Tim Jensen has "frozen" the motion of Comet Lovejoy (C/2014 Q2) against background stars using images taken in mid-January with an Orion EON 110 refractor and Canon EOS T2i DSLR.
Above: Stacking many short exposures aligned on the moving comet produces a crisp, detailed view of the target. But some of its fainter details, including a wide dust tail, are hidden by long star trails. All images are courtesy of the author.



REMOVING STARS After stacking exposures in *ImagesPlus*, vestiges of the brightest stars might require additional masking to clean up fully. Use the Special Star/Area Processing option to isolate the comet's bright head so it won't be erased by the filter.

present. But as noted earlier, the target comet will trail in exposures longer than a minute or two. The solution is to shoot lots of short exposures that you'll later combine in two different ways: one registered and stacked on the comet, the other aligned and stacked on the background stars. Stacking many short exposures has the benefit of producing a deep image with signal comparable to a single long one.

The technique described below works on any DSLR or CCD images. (As with any deep-sky imaging, make sure to calibrate all your files before moving on to stacking.) To register your photos in *ImagesPlus*, select Image Set Operations > Align Files > Align Files – Translate, Scale, Rotate. This action first requires you to select the images you wish to combine. Navigate to the folder containing the files, and then hold down your control key and click on all the images you want to align, and press the Open button. Next, the Align TSR window opens, where you'll select a few options. Under Feature Selection Type, choose On Each Image, then select Translate Only under the Alignment Type section. Next, select the Common Point or Star and Reference Image in the Alignment Feature Selection area.

With all these settings chosen, move your cursor over to the first image displayed and click on the comet nucleus; the next image in the set automatically appears. Select the comet in each of your images until you're through the set. Once completed, the Align button becomes active at the bottom-right of the window; click it, and in a few moments all of your images will be aligned on the comet. Click the Done button.

Now let's align the images on the background stars. Open the same Align Files window as before, but this time select Translate, Scale, Rotate under the Alignment Type section, and Common Angle Defining Point or Star in the Alignment Feature Selection area. This time you'll need to click on two stars as your alignment points before the Align button becomes active. Click it, and in a few moments your second alignment set is complete.

Removing Stars

Once both sets of images have been aligned, you can stack each set together. Start with the comet-aligned

FLOATING FREE If everything goes as planned, at this stage you should have a deep comet image with only the faintest hint of trailed stars in the background.

images. Select the Image Set Operations > Combine Files/HDR Add... function, and select your comet-aligned files. When the command window opens, select Minimum as the Combination Method. This works great if the stars are well separated between each image. Often, however, the stars overlap a little bit, and you end up with some faint star trails in the combined image. They'll be easiest to see if you stretch the image using the Auto Stretch or Digital Development functions in the pull-down menu. I recommend Digital Development because you can control the aggressiveness of the tool and avoid an "overcooked" appearance.

You can remove these residual star trails using the Feature Mask © tool. Open it by selecting Special Functions > Mask Tools > Feature Mask © from the pull-down menu. When the tool window opens, increase the Star slider to about 50, and increase the Mask Area Size slider to 5. Click Enable under Fill Radius, and increase its value to about 15. Under the Special Star/Area Processing section, check the Select box, and move your cursor to the image and click the comet nucleus. Then click the Include button and expand the Radius slider to its maximum setting. This will exempt the comet nucleus from the mask. Finally, make sure to click the No Stars radio button under Output. Now press the Apply button, and in a few moments the last bit of star trails should be removed.

If the comet didn't move very much between your individual exposures, you may need to isolate it and remove the stars in each individual exposure before combining. This would require enhancing each aligned photo before removing the stars to bring out more of the comet. You can do this with Curves, Digital Development, or any of the tools found in the Stretch pull-down menu. Just remember, try not to be too heavy-handed — only enhance the comet slightly at this stage before stacking, or else the comet's head will become overexposed in the stacked result.

Generate the Star Field

Our next task is to make the star-field image. This is done using the same Combine Files/HDR Add... tool and settings used to create the comet-registered image. The stacked photo will have a trailed comet image, so you'll need to do some minor adjustments to the result. Open the stacked star-field image and stretch it to display its full dynamic range. You'll notice there's quite a bit of the comet left over in the image besides the trailed head; that shouldn't affect the final outcome.

Now we'll use the Feature Mask © tool with most of the same settings as we previously used for the starless comet result, with a few modifications. First, skip the Fill Radius section. In the Special Star/Area Processing section, click the Select box, then move your cursor to your image and click the middle of the trailed comet nucleus, and check the Remove button. Move the Radius slider all the way to the right, and finally choose the Stars button in the Output section. Now we're all set to hit the Apply button. When the tool is complete, save the result and we can reassemble the results.

TRAILED COMET ***Top:*** **To put the stars back into your image, first stack the set of images so they're registered on the star field. Your result will have a trailed comet. *Bottom:* Use the Feature Mask © tool to remove the comet's trailed head before recombining the star field with your comet image.**

Bringing It All Together

Because you're working with the same set of images, your comet image should already be accurately aligned to the star field image. *ImagesPlus* offers several options for combining the results, though my preferred routine is to use Special Functions > Combine Images Using > Blend Mode, Opacity, and Masks. In this tool you have the option to combine the images using average, median, or min (minimum) options. (My best results are often achieved with the Blend Mode set to Merge Split.) Adjust the opacity of the blend until it suits your tastes, and then click the Flatten button and you're pretty much done!

Comets are often challenging targets that require special attention to get the most out of your images. But having a robust set of tools in your image-processing arsenal can put you on course to take some of the most memorable photos of these rare and wonderful visitors to the inner solar system. ✦

Tim Jensen *is an avid astrophotographer and a research project supervisor at Swinburne Astronomy Online.*

Stilburn's Hyperbolic Newt

This coma-corrected telescope gives a sterling performance.

I'VE ALWAYS HAD great admiration for telescope makers who not only craft fine optics, but also have the talent to come up with new designs. Many of us can grind a decent mirror for a Newtonian reflector but couldn't even begin to concoct a new optical system. Similarly, there are computer jockeys who can crank out interesting telescope recipes but have never actually pushed glass — and a design isn't a *telescope* until it's actually built. ATM Jim Stilburn of Victoria, British Columbia, is one of the few that can do both very well.

Readers may recall Jim's previous effort, a 6-inch corrected Dall-Kirkham that was featured in the August 2013 issue (page 66). That telescope was the spark of inspiration for his newest creation, a 10-inch f/5 hyperbolic reflector. "My 6-inch provided tantalizing views at the Costa Rica Southern Sky Party, but it was only a matter of time before I came down with aperture fever," Jim says.

The first step in curing the fever was to sit down at the computer to start working up a design using *Zemax* optical software (**zemax.com**). Jim chose a 10-inch aperture for a full magnitude brightness gain over his 6-inch, and a focal ratio of f/5 for the sake of portability. But the coma inherent in a f/5 Newtonian troubled him. His solution was a design that utilizes a hyperbolic primary mirror with a matching corrector lens. "Having chosen the aperture and focal length, I was left with three degrees of freedom: the conic constant of the primary mirror, and the positions of the two corrector elements," he notes.

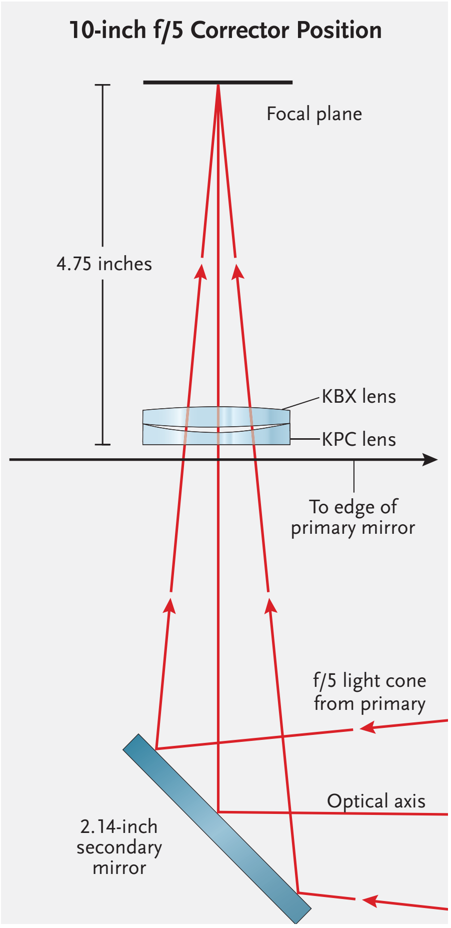
To achieve coma-free performance, Jim elected to make a primary mirror with a conic constant of –1.35 (which is "overcorrected" relative to the paraboloid used in a conventional Newtonian) matched with a 2-element, sub-diameter corrector lens. As he recounts, "After much brainstorming with *Zemax*, I realized that excellent field corrections could be obtained by including just two simple lenses ahead of the focal plane."

Jim added one additional constraint to keep the project manageable — the corrector had to utilize lenses purchased off-the-shelf. Experimenting with different lens types and spacings in *Zemax*, he ultimately settled on pairing a plano-concave lens with a double-convex element. Both parts were purchased from Newport (catalogue numbers KPC070 and KBX166, from **newport.com**) for a bit more than $100 and have broadband anti-reflection coatings. The lenses are mounted in a cell attached to the base of the focuser and positioned a fixed distance from the focal plane. The only drawback to this design is the distance to the focal plane requires a slightly larger diagonal mirror (2.14-inch minor axis), which gives a central obstruction of 23 percent.

As important as the rest of the telescope is, half the work went into grinding and figuring the primary mirror. "The most difficult part was making the mirror," Jim says. "But 'difficult' isn't quite the right word, because designing and making any part of a telescope is pure enjoyment." Fabricating the primary went smoothly and was accomplished with the same techniques used to produce a regular paraboloid, except, of course, for the extra work needed for the hyperbolic figure. Although a standard Foucault test would suffice, Jim prefers the simplicity of the Ross null test.

GARY SERONIK

Victoria, British Columbia, ATM Jim Stilburn has come up with another gem: a 10-inch f/5 hyperbolic reflector of his own design. The instrument is very portable and breaks down for airline travel.



S&T: LEAH TISCIONE

Readers interested in learning more can e-mail Jim at watoto1@gmail.com.

Whenever a newly completed telescope is used under the stars for the first time, it's a big moment. The anticipation is doubled when it's a telescope made with an untried design! So how did Jim's new creation work? "The scope met all my expectations: no coma, and pinpoint images to the edge of the field," he reports. "This is the second time that I have trusted *Zemax*, and the performance was exactly as it predicted."

Having had the privilege of observing with Jim's scope, I can attest to its quality. The views are sharp and aberration-free all across the field. It really is remarkable. And as fine a visual scope as it is, its flat, coma-free field also makes it a fine choice for astrophotography — something that I hope a motivated ATM/imager will prove in the future. ✦

Contributing editor ***Gary Seronik*** *can be contacted via his website,* ***garyseronik.com****.*

▲▲ **EXPLODING CIGAR**

Larry Van Vleet

Messier 82, the Cigar Galaxy, displays distinct bipolar jets of matter likely driven by supernovae in dense star clumps near the core. About 12 million light-years away, M82 is easy to find in Ursa Major.
Details: *PlaneWave CDK20 astrograph and Apogee U16M CCD camera using Astrodon hydrogen-alpha and color filters. Total exposure: 40 hours.*

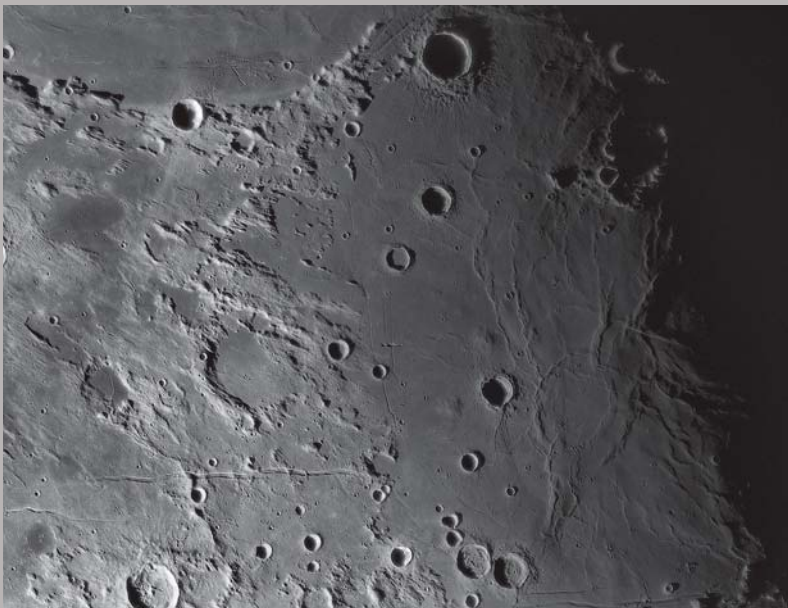
▲ **SATURN OPENS UP**

Alan Coffelt

When captured on May 3, 2015, a few weeks before opposition, Saturn showed off its wide-open ring system (south is up). The icy-white rings offer nice contrast with the pastel belts and zones on Saturn itself.
Details: *Celestron C11 Schmidt-Cassegrain with 2.5× TeleVue Powermate and ZWO ASI120MC color video camera. Total exposure: 12 minutes.*

ATTENTION, SKETCHERS! *Send your best astronomical renderings to gallery@SkyandTelescope.com (include "sketch" in the subject line), and if we get enough submissions we'll showcase them in a future issue.*

MAJESTIC EAGLE
Chad Binns
Made famous worldwide by the Hubble telescope's "Pillars of Creation" image, the Eagle Nebula (Messier 16) in Serpens reveals a wealth of detail in hydrogen-alpha light. **Details:** *PlaneWave CDK17 astrograph, SBIG STL-11000M CCD camera, and Baader Hα filter. Total exposure: 1 hour.*



◄ **ROUGH SEA OF TRANQUILITY**

Ross Sackett

Highly oblique lighting accentuates wrinkle ridges and rilles in western Mare Tranquilitatis and the curious circular set of ridges known as Lamont. The ragged Montes Haemus bound the region at left.

Details: *Celestron CPC Deluxe 1100 HD Schmidt-Cassegrain with ZWO ASI120MM-S video camera. Stack of 500 frames.*

▼ **GRANDEUR IN CORONA AUSTRALIS**

Fabian Neyer

NGC 6723 (a globular cluster that's 13 billion years old) and a trio of bright reflection nebulae (bluish NGC 6726–7 and small, orangish NGC 6729) punctuate a crowded field. The bright star is Epsilon CrA.

Details: *ASA 12N astrograph, FLI ML8300 CCD camera, and LRGB filters. Total exposure: 8.1 hours.*

REFLECTION IN A SALTY "SEA"
Majid Ghohoroodi
This pond, the only actual water in vast Namak ("Salt") Lake near Kashan, Iran, is big enough to mirror a large swath of the Milky Way (and distant light pollution) before dawn in late March.
Details: *Canon EOS 50D DSLR camera with 17-to-70-mm zoom lens used at 17 mm. Exposure: 30 seconds.*

▲ **NORTH AMERICA NEBULA**
Pat Darmody
This iconic namesake (note the distinct "Gulf of Mexico") is also designated NGC 7000. Broad and fairly bright, it glows in north-central Cygnus just a few degrees from Deneb.
Details: *Sky-Watcher Esprit 80 ED Triplet APO refractor, Canon EOS T2i DSLR camera, and Astronomik CLS-CCD filter. Total exposure: 42 minutes.*

► **DELICATE VEIL**
Gordon Haynes
The Veil Nebula, a bubble of faint nebulosity in Cygnus nearly 3° across, is what remains of a supernova that flared 5,000 to 8,000 years ago.
Details: *Tele Vue NP127 refractor and FLI ProLine 16803 CCD camera with Hα, O III, and S II narrowband filters. Total exposure: 8.8 hours.* ✦

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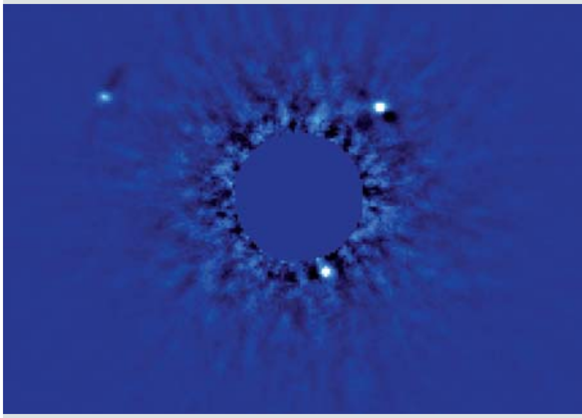

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Celestial Connections

The wonder of a journey that began long ago and far away ending in your eye

Many years ago I was a Visiting Fellow at Oxford University in England researching the origins of the Julian Period, on which the Julian Day count is based. I had the run of the Bodleian Library, with its fabulous collection of medieval astronomical manuscripts. Upwards of a thousand years old, these manuscripts written on sheep- or pigskin have endured the ravages of time and the occasional (literal) bookworm. Some are bound with twine and have ancient wooden boards as covers. I felt privileged to hold and study these venerable originals. A facsimile or digital copy just could not have evoked the same wonder at the durability of the written word or offered such a tangible link spanning almost a millennium.

One can say much the same of many astronomical phenomena. Everyone knows what a total solar eclipse looks like from the news or books. But it is quite another thing to actually experience a total solar eclipse yourself. You feel awe, even reverence. Watching the darkness approach and disappear with such speed, seeing the stars in the middle of the day, noticing the bewilderment of farm animals also witnessing the event — nothing can compare with it.

Similarly, watching a transit of Venus, which was I fortunate to do in both 2004 and 2012, is astounding. No photograph or news report could replace tracking that bullet hole as it migrated across the solar disk. (I hope my great-grandchildren observe the next transit in 2117. That would be a cosmic connection of a different sort, reaching across four generations.)

The strand of photons that reaches your eye from a distant galaxy such as M88 forms a tenuous yet actual link trillions of miles long.

MASIL IMAGING TEAM

But you needn't wait for a rare celestial event like an eclipse or transit to experience such a bond. In a sense it happens every time you look at the heavens with your naked eye or through a telescope. The thin stream of photons from distant stars and galaxies transfers energy from them to you across many light-years. It's not much energy, but it's an actual cosmic link across space and time. You are seeing and experiencing history in real time. What a privilege it is altogether to detect these few primordial messengers out of the myriad photons those stellar sources emitted into space long ago.

Nowadays we have CCD detectors that collect those original photon messengers and record copies for our eyes to observe. As magnificent as those images often are, we arguably lose something in the process, because that direct energy transfer from such deep-sky objects to us is broken — ironically, in the final fraction of an inch after traveling trillions of miles.

The difference between absorbing the energy from a copy rather than from the original stellar source is an ethereal but distinct one. It just isn't the same, just as it wouldn't have been the same years ago had I examined replicas of those medieval manuscripts rather than the very pages handwritten by anonymous scribes centuries before the advent of movable type. ✦

Ronald Lane Reese *is a Professor of Physics, Emeritus, at Washington and Lee University in Virginia and the author of* University Physics, *an introduction to calculus-based physics. He taught physics and astronomy for 40 years before retiring in 2011.*

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