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THE ESSENTIAL GUIDE TO ASTRONOMY

# SKY & TELESCOPE

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# October 2015 VOL. 130, NO. 4


**On the cover:**
The Orion Nebula is the nearest star-forming region to Earth and contains thousands of stars.

PHOTO: NASA / ESA / M. ROBBERTO / HUBBLE SPACE TELESCOPE ORION TREASURY PROJECT TEAM

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ESO / PETR HORÁLEK

## OBSERVING OCTOBER



## S&T TEST REPORT



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  Peruse additional images to help you navigate the area around NGC 7006.

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  Dive into sites of massive star formation in your night sky, and watch the process in action.

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## Photo Gallery

*Image by Brendan Walsh*

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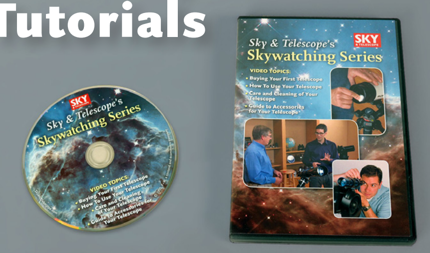


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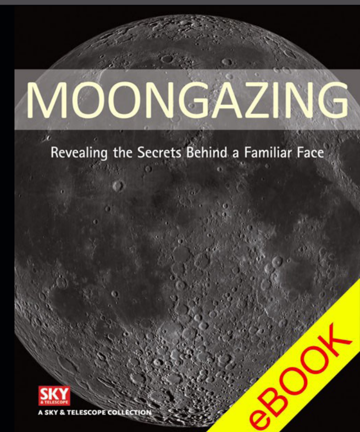


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**ONLINE PHOTO GALLERY**

Astrophotographer Slawomir captured this close-up of the Carina Nebula. The brightest star, Eta Carinae, is one of the most luminous and most massive stars known.

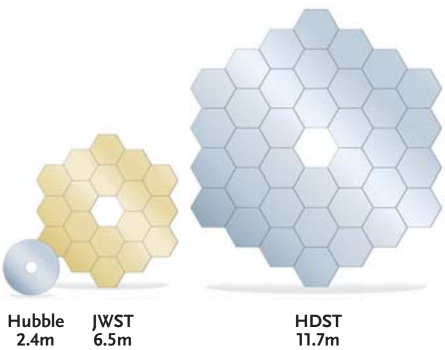
Peter Tyson
**Spectrum**

# A Super Hubble

IN EARLY JULY, a group of astronomers released a report championing a single bold idea. It's a proposal that, in my opinion, ranks up there with President Kennedy's 1961 challenge to put a man on the Moon "before the decade is out."

The notion is to build a space telescope so big, so sensitive, and so technologically advanced that it might enable astronomers to answer some of the grandest questions we've ever asked: Are we alone? Do Earth-like planets with breathable air exist elsewhere? Are they, in fact, common? How did life emerge in the cosmos in the first place?

The group that wrote the report knows whereof it speaks. It is the Association of Universities for Research in Astronomy, or AURA. A consortium of 40 U.S. institutions and four international affiliates, AURA, among many other things, conducts science operations for the Hubble Space Telescope (HST) and for the upcoming James Webb Space Telescope.




**How the primary mirror of the HDST stacks up against those of Hubble and James Webb**

C. GODFREY (STSCI)

In short, AURA's study calls for a High Definition Space Telescope, a sort of "super Hubble." With its 12-meter (39-foot) segmented primary mirror, the HDST would be 100 times more sensitive to faint light than HST is and provide views five times as sharp. You can download the AURA report here: **hdstvision.org/report**.

Parked a million miles from Earth in a gravitationally stable location, the HDST would also have devices — a coronagraph and perhaps also a star shade — that would so effectively block a star's blinding glare as to allow astronomers to directly image exoplanets orbiting that star. (See page 16 for our story on where such direct imaging of extrasolar planets stands today.)

More importantly, such a telescope could, in principle, characterize the atmospheres of nearby exoplanets. Detecting an abundance of water vapor, oxygen, methane, and other organic compounds sheathing an exoplanet might very well signal an active biosphere on its surface.

I think the HDST idea merits serious consideration. The hurdles are many and huge: For this project to reach fruition would take decades of painstaking effort, the development or perfection of entirely new technologies, sustained political will, and many billions of dollars.

But just imagine knowing, with a high degree of certainty, that another Earth exists out there, perhaps with beings as or more intelligent than we are. What would that understanding do to our worldview? To our sense of self as human beings? To our hubris? ✦

*Editor in Chief*


**SKY & TELESCOPE**

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**The Essential Guide to Astronomy**





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# Introducing the Apogee Aspen

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Main image: The Horsehead Nebula in Orion (IC 434) courtesy of R. Jay GaBany (www.cosmotography.com)
This image was produced with a RCOS half meter telescope, an Apogee 16 megapixel camera and Astrodon E-Series filters. Exposure times: 720 minutes Luminance, 270 minutes Red, 270 minutes Green, 270 minutes Blue and 420 minutes h-alpha (all 1X1).

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## The Herschel Sprint

After some 15 attempts over 20 years, I've had my fill of Messier Marathons. Thanks to Mark Bratton (*S&T:* Apr. 2015, p. 34), the Herschel Sprint will be my replacement. Ideally I'll tackle it on April 9th next year, to match the lunar conditions Herschel faced in 1785. As Bratton points out, the transit-instrument constraint severely restricts the time I can spend on each object, but it might help recreate the excitement that the Herschel siblings felt on that historic night.

***Paul Dawson***
*Olancha, California*

## Moon Over Stonehenge

Let's be honest: most astronomy-club logos are dull and unimaginative. When's the last time you saw one fit to grace the bumper of a lime green AMC Gremlin? So when I set out to help a group of 6th graders in San Anselmo, California, design their club's insignia, I was determined that it would be thrilling. It would inspire wonder and a sense of adventure.

Inspiration seemed close at hand. Only a few blocks away, in the town square, stands a statue not of a Civil War hero but of San Anselmo's most famous son, Yoda. What says "astronomy" better than a 3-foot-tall green space alien with pointy ears? Alas, the idea was a false start. Copyright issues aside, the power of Yoda's personality overwhelmed the insignia — making it look more like an advertisement for a comic-book convention than the emblem for a grade-school astronomy club.

Just when all seemed lost, I happened across an image that fired my imagination. While preparing for the Apollo 17 mission in 1972, astronaut-geologist Harrison "Jack" Schmitt asked renowned space artist Robert McCall to design a

GORDON READE

NASA

mission patch depicting the Moon over Stonehenge. McCall's design was ultimately rejected, but Stonehenge symbolizes mystery and our quest to understand the universe. What could be better? With the help of a graphic artist, the design above soon emerged, and it was all I had hoped for. So, Dr. Schmitt, my 6th-grade students and I thank you for your idea!

***Gordon Reade***
*Palo Alto, California*

***Jack Schmitt replies:*** *Actually, I think that the San Anselmo 6th graders' design for their astronomy-club insignia is much better than Bob McCall's. It captures even more of the significance of Apollo and of Apollo 17, the most recent mission of human exploration to the Moon.*

## Taking the Measure of Light Pollution

Jan Hattenbach's "Surveying Skyglow" (*S&T:* May 2015, p. 34) advocates that we measure light pollution. Bravo! That's good old empirical science. Surveys will help map our world's light at night and prepare us for the next step: to match those surveys with the incidence of human disease. Light pollution — the misuse of light at night — is not just about sea turtles, migrating birds, or better astro photos. It's about us. Time is of the essence.

***Bob Guzauskas***
*West Palm Beach, Florida*

I belong to a group called Dark Skies, Inc., in the Wet Mountain Valley of south-central Colorado. We have a 15-year history of public education about nightscape preservation and have completed many projects that retrofit unshielded lighting fixtures with shielded ones. In February 2014, we began taking quarterly sky-quality measurements (SQMs) at 10 locations within the boundaries of our adjoining two towns, Westcliffe and Silver Cliff. We knew our efforts had to be paying off but were very surprised when our annual average SQM reading came in at magnitude 21.2 per square arcsecond — not far from the 21.6 that corresponds to a naturally dark starry sky with a limiting visual magnitude of 6.4!

But the real value came last summer. One of our members noted that the International Dark-Sky Association has a program for certifying towns as an International Dark Sky Community. And we'd already accomplished most of the criteria, except for getting Westcliffe and Silver Cliff to pass lighting ordinances and collecting letters of support. Our ongoing education efforts really paid off for both situations: the town councils unanimously passed outdoor-lighting ordinances, citing the need to protect the dark-sky heritage and to stimulate astro-tourism. And our call for letters of support produced more than 115 letters, emails, and Facebook "likes" from our combined population of just 1,100.

In just three months, the IDA's board unanimously approved our application, and we became the ninth International Dark Sky Community. Since then we've been contacted by other groups wanting to know how we did it. So we've developed a website (**http://bit.ly/FormDarkSkyGroup**) that details not only our story but also the hard-learned lessons on changing mindsets, dealing with elected officials, educating the public, and more.

***Ed Stewart***
*Westcliffe, Colorado*

## Naming Names on the Moon

I very much enjoyed Andrew Livingston's article on Giambattista Riccioli and the naming of lunar features (*S&T:* May 2015, p. 26). However, his point that astronomi-

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cal considerations played hardly any role at all in the naming of three craters along Mare Nectaris for Christian figures is mistaken. It was almost inevitable that Riccioli, a 17th-century Jesuit, would name a crater "Catharina." Saint Catherine is one of the traditional patron saints of scientists in general and astronomers in particular. In Orthodox icons, she is frequently depicted with an armillary sphere, a quadrant, or some other piece of astronomical equipment.

Bishop Theophilus, contrary to the article, is not a Catholic saint, and indeed he's remembered as the persecutor of the much-loved Saint John Chrysostom. So it is unlikely that naming a crater for him would earn many "points with the Church." Instead, Theophilus and his canonized nephew, Saint Cyrillus, are on the Moon for an impeccably astronomical reason. In the late 300s, Theophilus published a century-long list of accurate Easter dates based on the 19-year-long Metonic cycle; in the early 400s, Cyrillus published a 110-year-long list. This Easter *computus* remained an active topic of astronomical research into the 1800s, and consequently the revered "giants" of this field — Theophilus, Cyrillus, Dionysius Exiguus, and Beda — were all assigned craters by Riccioli.

***Norman Hugh Redington***
*Cambridge, Massashusetts*

***Andrew Livingston replies:*** *I'm very grateful to Mr. Redington for pointing out the Easter connection, and I'd be delighted if he or anyone else can identify the man with the many eyes on the left of page 31. But there's no denying the "S." in Riccioli's label "S. Theophil." The Coptic Church considers him a saint, and he still appears in some lists of current Roman Catholic saints, even though historian Edward Gibbon described him as far from saintly: "a bold, bad man, whose hands were alternately polluted with gold and with blood." And Riccioli couldn't have been too impressed either with Theophilus and Cyrillus's wholesale destruction of classical learning — but, as elsewhere, he prudently left things open to interpretation. As for Saint Catherine, usually shown with the wheel of her martyrdom, she is the patron saint of a long list of professions from lawyers to wheelwrights. But astronomy? Here the official patron is Saint Dominic, for whom there's no crater on the Moon.*

## For the Record

✷ *July issue, p. 38: The biblical citation in Nick Kanas's article on celestial frontispieces should be Isaiah 40:26.*

# 75, 50 & 25 Years Ago

*Roger W. Sinnott*

**September-October 1940**

**Dark Matter** "[A very interesting star] is Harvard Variable 10302, located in one of the dark patches of nebulosity that abound in Sagittarius. [It is] a Cepheid-type variable [with] an absolute magnitude of –1.5. Since the observed median apparent magnitude is 14.2, the star should be 45,000 light years from the sun. . . .

"When measured, however, H. V. 10302 was found to have the unusually large color index of about $+3^{m}.0$, which is comparable to the colors of the very red N-type stars. . . . The extreme redness of the star indicates that it lies in a region of the Milky Way that is heavily obscured by fine dust particles. . . . When the obscuration is allowed for, the star is found to be only 2800 light years away.

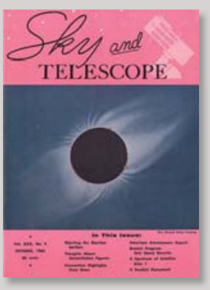
"This investigation is but one phase of a larger program to determine the distribution of dark matter in space, and thus to aid in solving the problem of the size and structure of the Milky Way system."


*What gives Henrietta Swope's report such a modern ring is her reference to "dark matter." Today this term has a far grander meaning in cosmology. So much dark matter is needed to explain, gravitationally, the observed structure and distribution of galaxies in the universe that theorists believe it must consist of exotic subatomic particles that permeate everything.*

**October 1965**

**Warping Harness** "Arthur S. Leonard . . . well-known satellite observer and optical designer from Davis, California, [exhibited his unobstructed] 'Yolo' reflector (named after the county in which he lives). What a strange-looking telescope! . . .

"At the eyepiece end of the main body is an 8-inch spherical mirror of 192 inches focal length. Tilted 3° 04′ from being perpendicular to the incoming starlight, this primary reflects the image to a 6-inch mirror of the same focal length. Mounted in a harness to warp its figure, the secondary reflects light back through the main body and out of the adapter tube. . . ."



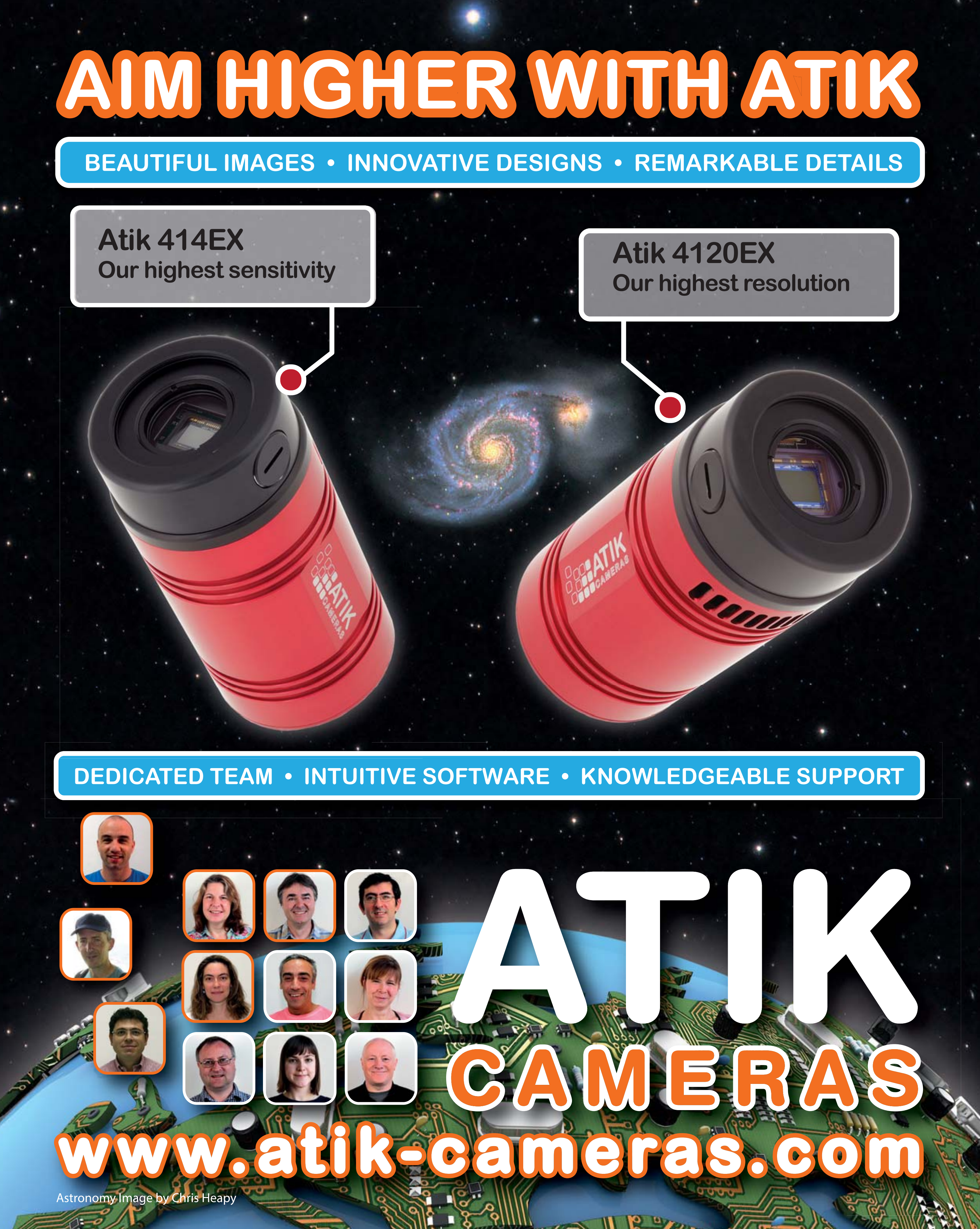

*Art Leonard's novelty at the 1965 convention of the Western Amateur Astronomers had far-reaching consequences. A mechanical engineer, he'd worked out the math for how a mirror deforms under stress — and then designed a harness to do so precisely. Twenty-five years later, when warping harnesses were used in figuring the mirror segments for the Keck telescopes, its scientists credited Leonard with pioneering the warping technique.*

**October 1990**

**Close Encounter** "The Whirlpool galaxy, M51, and its unusual companion, NGC 5195, apparently brushed each other only 70 million years ago. Computer simulations by Sethanne Howard (Georgia State University) and Gene G. Byrd (University of Alabama) show that the companion actually skimmed the edge of the larger system's disk. . . .

"The companion currently orbits M51 with a period of about 500 million years and an inclination to the plane of the disk of 50° or so. The smaller galaxy is spiraling in toward the larger one; the two should merge in less than three more orbits. . . ."


*Recent modeling efforts do favor this scenario (that is, several encounters with the smaller galaxy in an eccentric orbit). These also show that a single close pass of two stray galaxies, under the right conditions, can create most of the features seen in the M51 system.*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# MISSIONS I New Horizons Reaches Pluto

**On July 14th,** NASA's New Horizons spacecraft flew through the Pluto system, culminating a 5-billion-kilometer, 9½-year-long journey. The piano-size spacecraft came as close as 12,500 km (7,750 miles) from the dwarf planet's surface at 11:50 Universal Time, zipping past at 13.8 km (8.6 miles) per second.

Flight controllers at Johns Hopkins University's Applied Physics Laboratory in Laurel, Maryland, report that the spacecraft performed flawlessly. Results from its seven instruments were not sent all at once but instead will trickle back in compressed form through mid-November. Then the entire data set will be sent again without compression throughout 2016.

Pluto's diameter is close to 2,370 km (1,475 miles), slightly larger than previous estimates and also just a bit more than Eris's 2,336 ± 12 km. Spacecraft images resolved Pluto's mottled landscape into a wonderland of bright and dark regions.

Nitrogen and methane ices cap the north polar region, while a concentration of frozen carbon monoxide exists in the western half of a large, heart-shaped region that's been provisionally named Tombaugh Regio. Dark regions elsewhere might be dominated by carbon-rich compounds. The dwarf planet's tenuous nitrogen atmosphere extends at least 1,600 km (1,000 miles) from its surface.

NASA / JHU-APL / SWRI

*Left:* New Horizons took this view of Pluto on July 13th. The bright, prominent, heart-shaped area has been provisionally named Tombaugh Regio, to honor Pluto's discoverer. *Right:* A view of Charon, taken the same day, shows unexpected geologic diversity and a dark-stained polar cap.

A frozen plain (dubbed Sputnik Planum) shows no craters at all, so this surface can't be more than 100 million years old — and it's likely much younger — having been resurfaced by some unknown process. How such a small world has remained geologically active for 4½ billion years remains a mystery.

Meanwhile, 1,200-km-wide Charon has a pronounced, reddish-black stain at its northern pole that might be a veneer of methane molecules captured from Pluto's escaping atmosphere and converted by radiation over time into complex hydrocarbons. Craters, fractures, and relatively smooth plains appear elsewhere. One gash crosses the mid-northern latitudes and appears to be longer and much deeper than Earth's Grand Canyon.

Next month's issue includes detailed coverage of New Horizons' historic flyby.

■ **J. KELLY BEATTY**

# LUNAR I Moon's Mysterious Twilight Clouds from Comets

**Using measurements** by NASA's Lunar Atmosphere and Dust Environment Explorer (LADEE) spacecraft, Mihály Horányi (University of Colorado, Boulder) and colleagues have revealed the distribution, origin, and size of clouds of dust particles that float above the Moon's surface at dawn and dusk.

These dust clouds were discovered in 1968, when NASA's last robotic lunar lander, Surveyor 7, took images of a strange twilight glow along the lunar horizon. The glow comes from light scattering off fine dust particles.

LADEE's measurements reveal that the dust cloud is much closer to the Moon's surface and less dense than previously thought. They also confirmed the dust's origin: comets. LADEE recorded an asymmetric dust cloud instead of a circular one along the Moon's day-night line. If the dust is coming from asteroids, as was originally thought, then the resulting impacts would produce a much weaker and more symmetric cloud, due to the particles' near-circular orbits as they move inward toward the Sun. In addition, the team also found that the cloud increases in density during annual meteor showers, which generally come from comet debris, the team reports in the June 18th *Nature*.

These observations rekindle the debate about what causes the dust to levitate and hang about the terminator line in the first place. The most generally accepted theory, *static levitation*, points to changes in charge: shaded areas become negatively charged when the solar wind bombards the surface with electrons, whereas sunlit areas become positively charged by the Sun's photons displacing these electrons. Once an area becomes charged, the dust particles begin to leap about, attempting to get away from their like-charged neighbors. The Moon's terminator would thus be whipped into a chaotic frenzy.

■ **ANNE MCGOVERN**

# MISSIONS | Lander Philae Phones Home . . .

**After seven months** of electronic hibernation, Philae awakened on the surface of Comet 67P/Churyumov-Gerasimenko in mid-June and resumed contact with its handlers on Earth.

When last heard from, early on November 15, 2014, the European Space Agency's washing-machine-size lander had survived an unexpectedly rough-and-tumble arrival on the comet's surface (*S&T:* Feb. 2015, p. 12). Its transmissions ended prematurely, after only 57 hours, because Philae had wedged itself in a heavily shadowed location that offered little direct sunlight to recharge its onboard batteries.

But the comet's changing solar geometry eventually provided much more sunlight, enough to revive Philae's basic functions. About 85 seconds of telemetry, relayed via the lander's comet-orbiting mother ship, Rosetta, reached Earth on June 13th at 20:28 Universal Time. Then the lander inexplicably went silent again, despite multiple attempts to restore contact, until a 22-minute-long communication session on July 9th. This second contact confirmed that Philae is receiving commands, one of which was to transmit measurements from its radar sounder.

Philae appears to be in good shape despite its extended shutdown. More than 8,000 packets of data are stored in the craft's mass memory, which, when finally relayed to Earth, should reveal details about the comet's activity during the few days prior to when the lander last phoned home. Philae can only transmit these data when Rosetta is within its line of sight.

The mission team also hopes the renewed transmissions will help them triangulate the landing site's exact location, which remains unknown. More importantly, Philae woke up in time to perhaps add important ground-zero measurements of the nucleus' activity surge as Comet 67P neared perihelion on August 10th.

■ **J. KELLY BEATTY**

# . . . and Rosetta Spots Sinkholes on its Comet

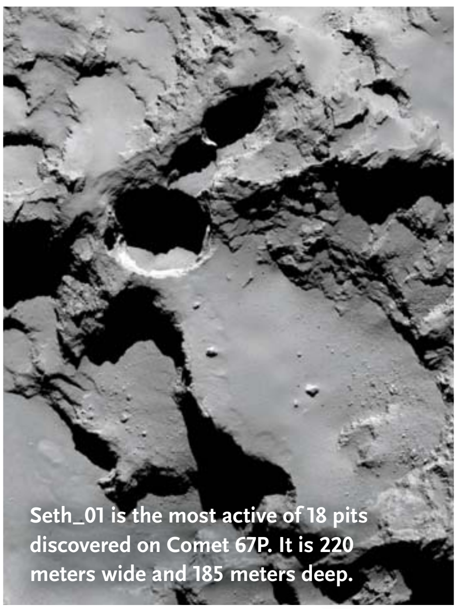
**The spacecraft orbiting** Comet 67P/Churyumov-Gerasimenko has found 18 holes in the nucleus. (And no, mission planners didn't think to pack golf clubs.)

ESA's Rosetta spacecraft has been orbiting Comet 67P since August 2014 (*S&T:* Aug. 2014, p. 20), gathering observations of the funny-looking nucleus, which is shaped rather like a dog's head. The observing campaign has turned up the new 18 pits. They're not the first holes seen on comet nuclei, but they are the first that look like this. The pits tend to cluster together in small groups, and they range from 50 to 310 meters (160 to 1,020 feet) wide. Some pits are cylindrical and deep; others are shallow. The deep ones seem to be "active," with dusty jets spewing from their walls or floors. The deepest one reaches more than 200 m below the surface.

The holes can't be from erosion, because erosion wouldn't create such nicely circular holes. And outbursts from the nucleus exhume only a thousandth as much material as a typical large, active pit would have expelled.

Instead, Jean-Baptiste Vincent (Max Planck Institute for Solar System Research, Germany) and colleagues think the pits are sinkholes. Somehow, the team writes in the July 2nd *Nature,* cavities form beneath the comet's surface. Once the cavity's ceiling becomes too thin to support its own weight, it will collapse, creating deep, circular pits like those observed. The collapse would expose fresh material in the pit's sides, which would then partially sublimate away and fill the pit with debris. That would explain both why deep, cylindrical pits seem to be active and why quiescent pits have had their sides eaten away and their bottoms filled with rubble. But *why* the cavities form remains unclear.

■ **CAMILLE M. CARLISLE**



Seth_01 is the most active of 18 pits discovered on Comet 67P. It is 220 meters wide and 185 meters deep.

VINCENT ET AL. / NATURE PUBLISHING GROUP

# BLACK HOLES | Too Big for its Britches

**The supermassive** black hole CID-947 is at least 10 times too massive for its host galaxy, raising questions about how closely galaxies and black holes actually coevolve.

On average, a supermassive black hole has a mass 1⁄100 to 1⁄1000 that of its host galaxy. This consistent relationship has led astronomers to suspect that a black hole's growth and that of its host galaxy are intertwined.

But shining at us from a mere 2 billion years after the Big Bang, CID-947 has ⅛ its galaxy's mass. To look like black hole–galaxy systems we see today, the galaxy would have to grow by maybe another factor of 10, without the black hole growing at all, Benny Trakhtenbrot (ETH Zurich, Switzerland) and colleagues report July 10th in *Science*. If so, that would suggest that black holes and galaxies don't grow in lockstep; instead, black holes evolve quickly and their host galaxies follow. Other observations have also hinted at this independent evolution, but uncertainties in all the results make it difficult to know for sure. Read the behind-the-scenes discovery story at **http://is.gd/cid947.**

■ **SHANNON HALL**

## GALAXIES | Dark Galaxies Suffuse Coma . . .

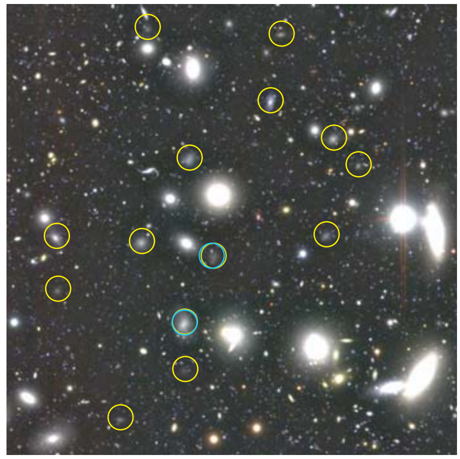
**Late last year,** astronomers reported a weird find: 47 "dark" galaxies mingling with the other denizens of the Coma Cluster (*S&T:* Mar. 2015, p. 12). Now another team has discovered a whopping 854 of these faint, fluffy, and hard-to-explain objects in the same cluster.

Even ordinary galaxies contain a lot of dark matter, which makes up about 83% of the universe's mass. But the dark galaxies discovered within the Coma Cluster contain even more of the exotic and invisible stuff, up to 98% of their total mass.

The galaxies are incredibly dim, making them difficult to pick out even with advanced instruments. Yet despite their lack of stars, most still span roughly the size of the Milky Way. Only dark matter could hold this diffuse collection of stars together in the collision-prone environment of a crowded galaxy cluster.

Jin Koda (Stony Brook University) and colleagues found the dark galaxies by poring over archival images from the 8.2-meter Subaru Telescope. Astronomers haven't seen so many of these objects elsewhere, suggesting that the crowded cluster environment strips star-forming gas out of these galaxies, leaving only dark matter behind, the team reports in the July 1st *Astrophysical Journal Letters.*

■ **MONICA YOUNG**



NAOJ

This color composite of Subaru images shows some of the newly discovered "dark" galaxies, circled in yellow. Blue circles highlight two galaxies discovered late last year. The image above covers less than 1% of the studied area.

## . . . and Mystery of Dust-Poor Early Galaxies

**New submillimeter** observations reveal low levels of dust in nine early galaxies. The result is in line with previous predictions, but it does highlight a problem with some observers' calculations.

Peter Capak (Caltech) and colleagues used the ALMA array, with other optical and infrared data, to look at nine galaxies shining at us from about a billion years after the Big Bang. The astronomers detected dust emission from only four of the nine galaxies, but detected a form of ionized carbon known as [CII] in all nine.

As the authors explain in the June 25th *Nature*, the presence of all this ionized carbon suggests a low level of dust. Carbon likes linking up with other elements to form molecules, so it doesn't hang around by itself for long. But with few heavy elements to bond with, and with minimal dust around to protect the carbon atoms from the ionizing influence of ultraviolet radiation — which is pouring out from the young stars in these nascent galaxies — the normally rare [CII] has become fairly concentrated.

The implication is that these galaxies have amounts of dust similar to that in the Small Magellanic Cloud (SMC). That's unsurprising: dwarf galaxies likely undergo star formation in on-and-off fits, so they'll take longer to build up dust.

Interestingly, two of the team's galaxies have similar amounts of dust to A1689-zD1, the remarkably dusty galaxy that raised eyebrows earlier this year (*S&T:* June 2015, p. 14). But A1689-zD1 existed 300 million years before these galaxies. What counts for a "moderate" amount of dust a billion years after the Big Bang is "challenging" only 700 million years after the Big Bang, says Veronique Buat (Astrophysics Laboratory of Marseille, France). Perhaps in general dust buildup was slow, but some galaxies jumped the gun and got dusty fast.

Dust warmed by starlight is usually the dominant source of a galaxy's infrared emission, a fact astronomers exploit to estimate the rate of starbirth in distant galaxies. If there's less dust in early galaxies, then the particular correlation used to calculate the starbirth rate in an individual galaxy will give an estimated rate that's too high. But the assumption probably has much less of an effect on estimates of star formation across cosmic time, because most stars form in less luminous galaxies that we already assume have very little dust. And studies that assume a galaxy's dust properties are similar to the SMC's (such as *S&T:* Feb. 2014, p. 10) appear okay as well.

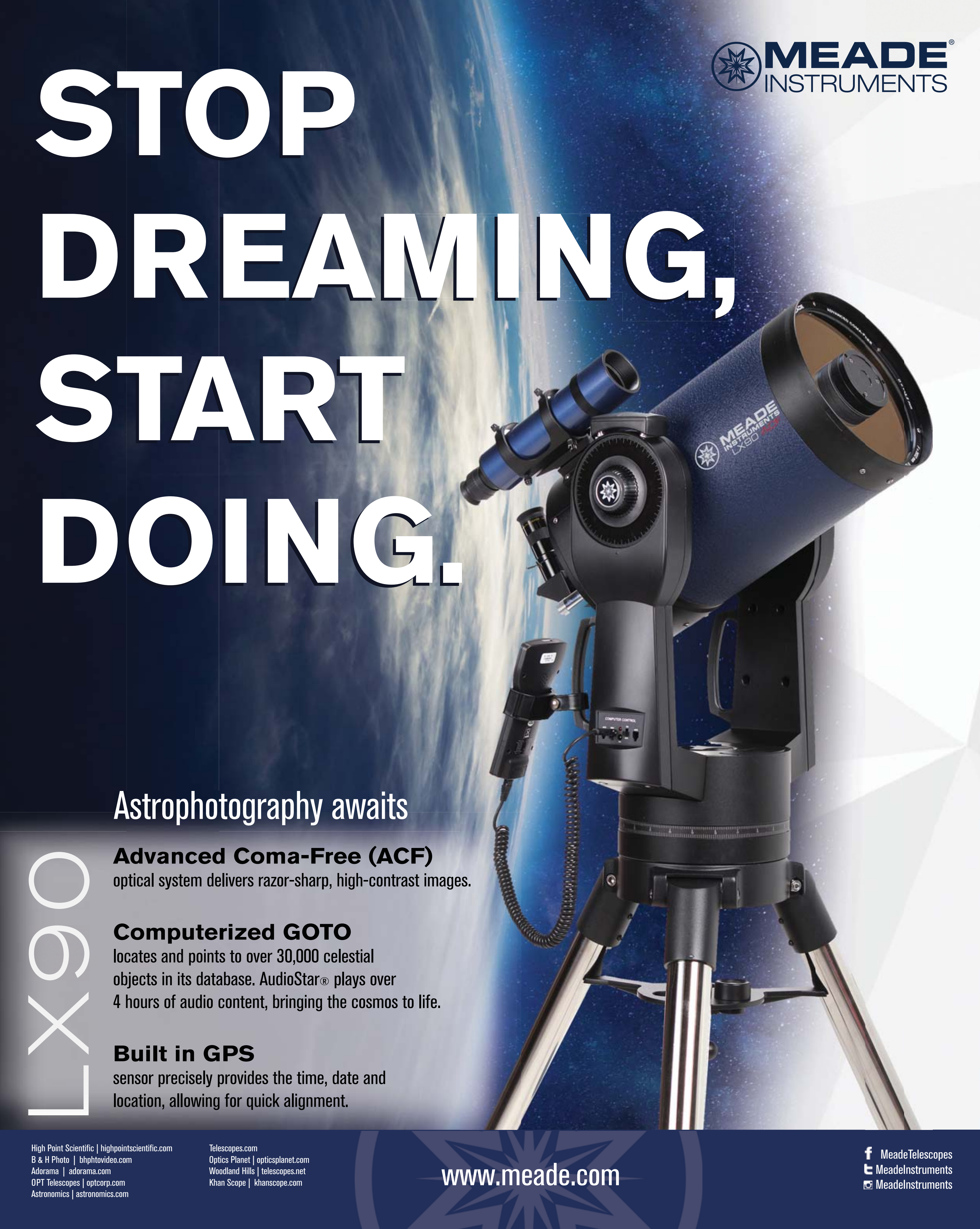
■ **CAMILLE M. CARLISLE**

## EXOPLANETS | Planet with a Tail

**Astronomers have confirmed** that the exoplanet Gliese 436b is trailing a gigantic, coma-like cloud behind itself in its orbit. Gliese 436b has about the mass and size of Neptune but orbits its red dwarf star in just 2.6 days. In 2014, astronomers watched Gliese 436b pass in front of its host star in ultraviolet (UV) light and found that the star stayed dim long after the planet had ostensibly finished transiting.

David Ehrenreich (Geneva Observatory, Switzerland) and colleagues have now confirmed that observation. The team studied the planet's transit in a specific UV spectral line called Lyman alpha, which is associated with hydrogen. The astronomers thus found that the planet blocks more than 50% of the host star's UV light, whereas it blocks less than 1% of its visible light. The result suggests that the planet is trailing a gigantic, comet-like tail of hydrogen behind itself that continues to block starlight after the main transit, the team writes in the June 25th *Nature*. Read more and watch a video of the system at **http://is.gd/436btail**.

■ **JOHN BOCHANSKI**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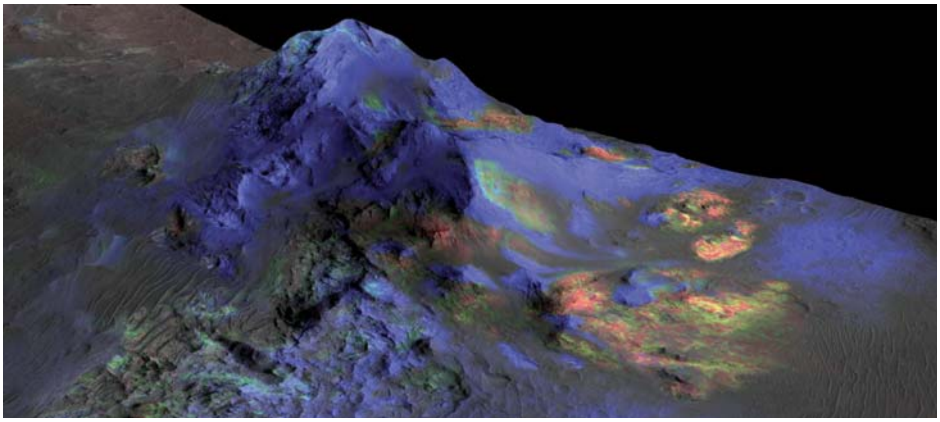
# MARS | The Glint of Martian Glass



NASA / JPL-CALTECH / JHUAPL / UNIVERSITY OF ARIZONA

Scientists have found deposits of impact glass (green) preserved in several Martian craters, including Alga (crater's central peak shown above). Also detected are the minerals pyroxene (purple) and olivine (red). The color-coded composition information from NASA's Mars Reconnaissance Orbiter is shown over a terrain model based on observations, but with the vertical dimension exaggerated by a factor of two.

**Scientists have detected** glass in several Martian craters, created by the fierce heat of impacts that melted these parts of the Red Planet's surface.

Mars is pockmarked with craters, but thus far planetary scientists haven't definitively found impact glass there. They have seen glass in general, though: a huge deposit lies in the north polar sand sea and across the northern plains, covering some 10 million square kilometers (4 million square miles). But that glass likely came from ancient, explosive volcanism.

Kevin Cannon and John Mustard (both at Brown University) combined lab work and spacecraft observations to find the newly identified impact glass. Researchers can differentiate between glass and minerals based on how the material absorbs certain wavelengths of light. So Cannon whipped up a rock-powder recipe similar to Martian dirt, then fired it to create glass. With the pseudo-Martian glass in hand, he determined the material's spectral pattern.

Then the team looked for this signal in several impact craters observed by NASA's Mars Reconnaissance Orbiter. Their homemade computer algorithm successfully teased glass's signature out of the spectroscopic mess of many of the craters. The glass also matches up well with other features interpreted as impact-spurred, sometimes even following the sharp margins of melts (such as in Alga Crater) or staying confined to a melt's thin draping across the surface (as in Ritchey Crater), the team reports June 5th in *Geology*.

"This is pretty cool," says Briony Horgan (Purdue University), who codiscovered the northern glass deposit. Detecting glass's spectral signal is a major challenge: glass is partially translucent, so it doesn't absorb light well. On the other hand, iron-bearing minerals like olivine and pyroxene — which also appear in the craters — absorb a lot more light, producing absorption bands that are much deeper and easier to recognize. "Because they absorb so much more light than glass, their signature tends to swamp out the glass signature," she says.

Glass is an intriguing find because, since it forms by very rapid cooling, it's good at entombing biosignatures, Cannon explains. "If the impact melt cooled slowly, it would cook any kind of organic matter trapped inside," he says. Plus, glass is friendlier to microbes, with weaker chemical bonds than rock, making it easier for microbes to tunnel inside.

Less exotically, scientists could use this type of spectral analysis to find many other kinds of minerals on Mars, or on other bodies, and to better understand the range of materials impacts produce.

■ **CAMILLE M. CARLISLE**

## IN BRIEF

**Exoplanet or Illusion?** An analysis of stellar activity casts doubt on whether Kapteyn b, a supposed super-Earth circling in its star's habitable zone, is real. Kapteyn b is one of two exoplanet candidates around Kapteyn's star, an old, cool red dwarf (*S&T:* Sept. 2014, p. 14). Astronomers detected it using the radial velocity method, which looks at the small blue- and redshifts in starlight created as the star and planet move around their common center of mass. But starspots and other activity can mimic this effect. Paul Robertson (Penn State) and colleagues found Kapteyn b's orbit is "worryingly close" to an integer fraction of the star's rotation period. They conclude in the June 1st *Astrophysical Journal Letters* that the exoplanet isn't real. But other astronomers are unconvinced, and the planet's existence remains disputed.

■ **EMILY POORE**

**Hot Jupiter Stratospheres Explained?** When present in an atmosphere, radiation-absorbing molecules create an inversion layer, with the temperature first decreasing, then increasing, with altitude. This happens because certain molecules at the top of the atmosphere absorb radiation, keeping the middle parts cool. In the solar system, compounds like ozone and methane do the job, but they are too flimsy to withstand the heat in a hot Jupiter's stratosphere. Using the Hubble Space Telescope, Korey Haynes (NASA Goddard) and colleagues found tantalizing traces of the heavy-duty absorber titanium oxide on the hot Jupiter WASP-33b, as reported in June 20th's *Astrophysical Journal*. Astronomers had hoped this molecule could explain the inversions seen on hot Jupiters (*S&T:* May 2014, p. 18), but until now no one had detected it. If confirmed, this detection would be the first definitive correlation. ✦

■ **ANNE MCGOVERN**

# The Next Blue Dot


Astronomers are working to directly image alien Earths, with several promising space missions in development.

Ruslan Belikov & Eduardo Bendek

**In 1990,** at the request of Carl Sagan, NASA engineers turned Voyager 1 toward the inner solar system and commanded its telephoto camera to take a picture of Earth from a distance of 6½ billion kilometers (4 billion miles). This produced the famous "pale blue dot" image of our home planet, which Sagan likened to "a mote of dust suspended in a sunbeam."

With many billions of Sun-like stars in our Milky Way, it's natural to ask whether there are other "blue dots" like ours — stable, hospitable, and teeming with life. The search for Earth-like planets and extraterrestrial life is one of the most fundamental and noble pursuits in all of science. Such a discovery would prove to be a major milestone of our civilization, on par with the Apollo landings on the Moon.

We have taken the first steps in that quest. NASA's Kepler mission and ground-based searches have already detected several roughly Earth-size planets in the temperate "habitable zones" of their respective stars. But we have not yet been able to directly image them or search their spectra for chemical signs of life (*biomarkers*) like oxygen, methane, and liquid water.

Many exoplanet astronomers and instrumentalists are working hard to accomplish this goal. Standing on the shoulders of the previous planet-detection efforts, we are now gearing up to image potentially habitable worlds directly. Depending on how close the nearest Earth-like planet exists, we might be able to capture its image between 5 and 20 years from now.

## Observational Limitations

As of this writing, close to 2,000 confirmed planets are known — more than 5,000 if all of Kepler's planet candidates are included. Almost all of them have been found by one of three indirect methods: radial-velocity (Doppler) detections, transit photometry, and microlensing. A handful of these discoveries are the right size and distance from their stars to be potentially habitable worlds.

To be suitable for life as we know it, such a planet would have at least three observable characteristics:

- A diameter roughly 0.5 to 1.5 times that of Earth, to enable a rocky surface with an atmosphere.
- An orbit in the star's *habitable zone,* to enable liquid water to exist on the surface; for Sun-like stars, this corresponds to an orbital radius of about 0.8 to 1.8 astronomical units.
- The presence of multiple biomarkers in the atmospheric spectrum; for example, an atmosphere containing oxygen, methane, and water vapor could not be easily explained without life.

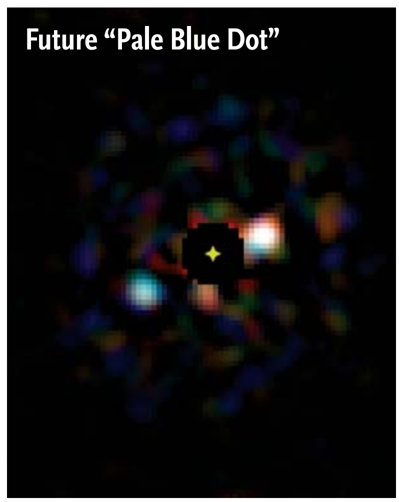
Planets satisfying the first two requirements are commonly referred to as "potentially habitable," while the third would establish a "likely inhabited" planet. Thanks to Kepler's rich trove of discoveries, a statistical picture is starting to emerge about how often stars host potentially habitable planets. Most of astronomers' latest estimates range from about 20% to as high as 50%. This implies the existence of tens of billions of potentially habitable planets in our galaxy alone — every person

**A PLETHORA OF WORLDS** By some estimates, the Milky Way is home to as many planets as its hundreds of billions of stars. Astronomers are trying to determine how many of these might be like Earth.

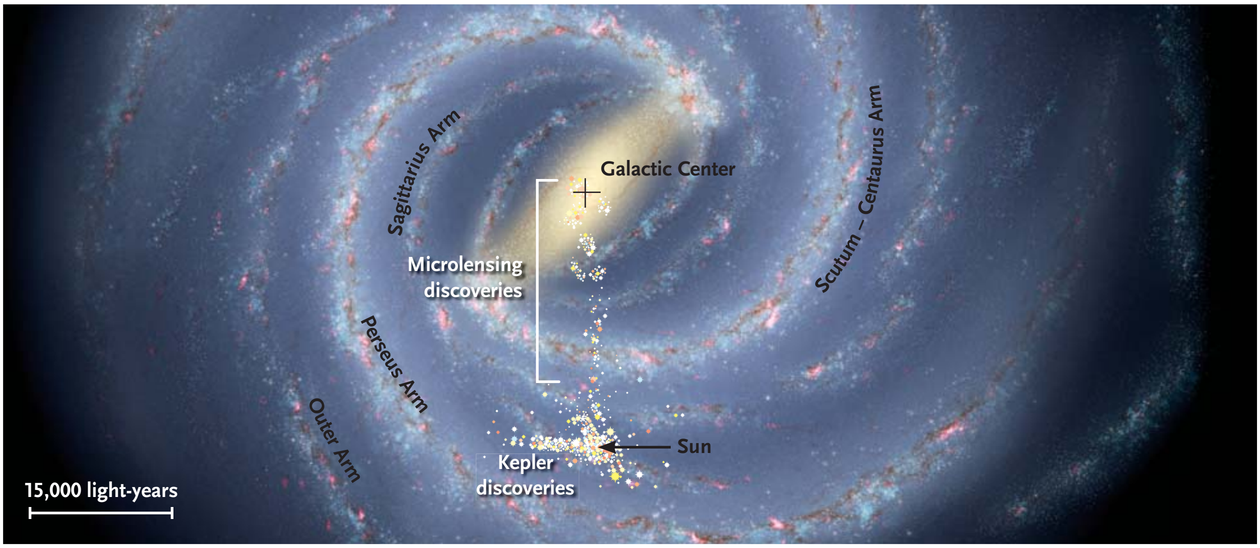
ESO / PETR HORÁLEK

**PAST AND FUTURE** *Left:* When Voyager 1 looked back toward Earth in 1990, from 6½ billion km (4 billion miles) away, our world barely registered as a slightly bluish blip less than a pixel wide. *Right:* During the next two decades, astronomers hope to master the technology to reveal other "pale blue dots," like the one in this simulated image of planets orbiting a distant star (hidden by mask).


NASA / JPL-CALTECH




JARED MALES & RUSLAN BELIKOV




DATA: NASA; MILKY WAY MAP: ESO

**SCANNING THE GALAXY** Virtually all the thousands of known exoplanets were found using one of three methods: radial-velocity measurements (dots nearest Sun), microlensing observations, and transits recorded by NASA's Kepler spacecraft.

alive on Earth can have at least one to call his or her own!

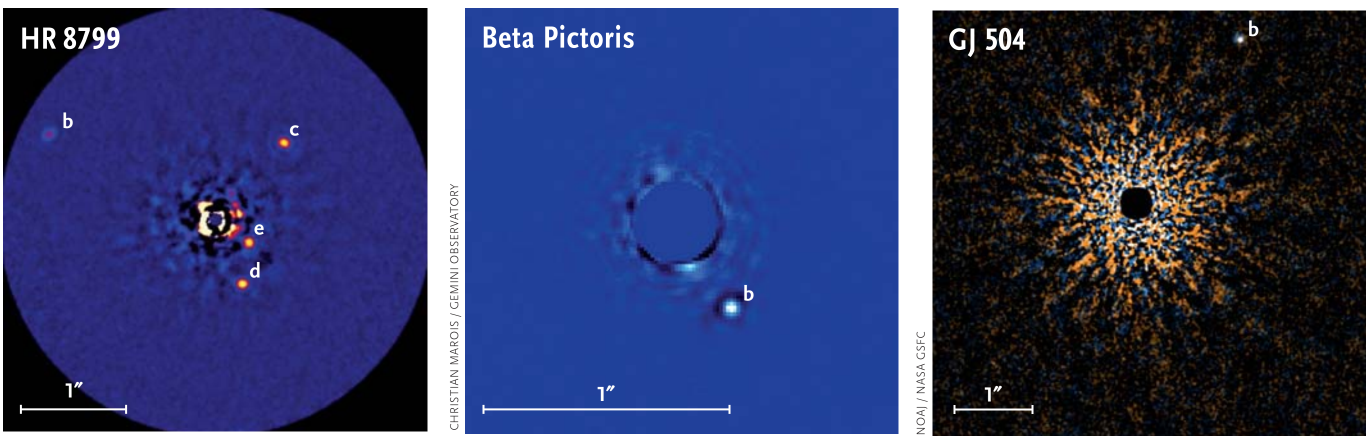
However, despite the phenomenal success of Kepler and other searches to date, planet hunters have been stymied by two key limitations. First, we don't yet have a way to obtain the spectra of small exoplanets (though in the coming decades we expect that to change). Second, current methods are not particularly good at detecting potentially habitable planets around the *nearest* stars.

For example, the transit method (which Kepler uses) misses 199 out of every 200 Earth-like planets around Sun-like stars because a planet's orbit must be inclined very little, almost precisely edge-on to our line of sight, to be detected. As a result, since detections are rare, all of Kepler's planets lie hundreds or thousands of light-years away.

Meanwhile, the radial-velocity method can and does probe the nearest stars, but it doesn't yet have the sensitivity needed to detect potentially habitable planets around Sun-like stars, and it's blind to planets with face-on orbits. Consequently, we've only detected planets around a small fraction of stars in our immediate galactic neighborhood — even though we expect most of those stars to have planets.

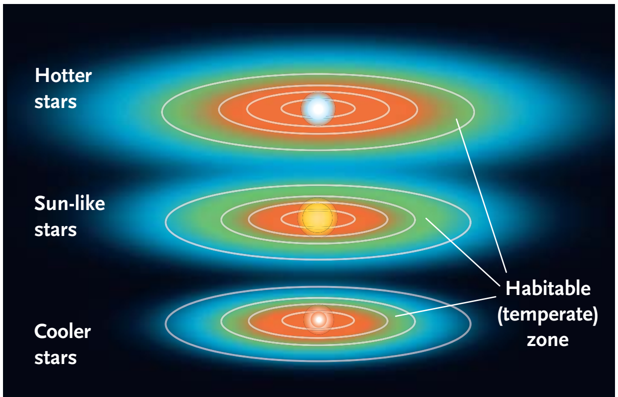
## Direct Imaging of Exoplanets

Since about 2008, a new planet-detection method has been gaining prominence: direct imaging. Astronomers use one of several starlight-suppression techniques to block a star's bright light in order to directly image the planets around it as small dots. While other detection methods will continue to improve and play key roles in the future of exoplanet science, direct imaging is the only conceivable means to perform a complete survey of any nearby star's potentially habitable planets and to obtain their spectra. If we want to find the nearest planet with



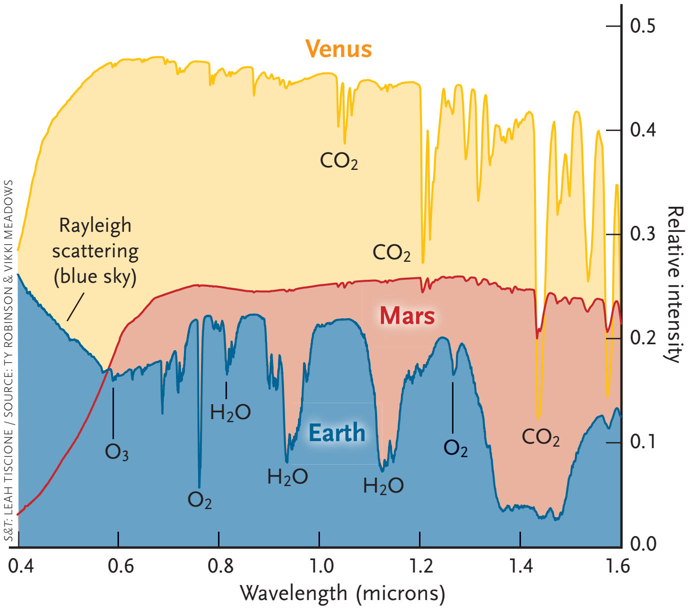

NRC-HIA / CHRISTIAN MAROIS / KECK OBSERVATORY; CHRISTIAN MAROIS / GEMINI OBSERVATORY; NOAJ / NASA GSFC

**FIRST FINDS** During the past decade astronomers have successfully imaged several exoplanets orbiting their host stars. Most are young giant planets still hot and glowing from their formation. In each of these images, the central star itself has been masked out.




**JUST RIGHT** Astronomers hope to find Earth-like planets in the *habitable zones* of nearby stars, temperate regions where water can exist in liquid form. The hotter the star, the more distant this zone lies from the star.

NASA AMES




S&T: LEAH TISCIONE / SOURCE: TY ROBINSON & VIKKI MEADOWS

**SPECTRAL CLUES** These simulated spectra reveal that "biomarkers" (such as atmospheric oxygen and water vapor) are prominent on Earth but missing on Venus and Mars. The detailed spectra from large space observatories will be able to resolve these signatures. Smaller spacecraft should still be able to differentiate between an "Earth" and a "Venus."

life on it, direct imaging is arguably the only way to do it.

At least nine planets have been directly imaged to date, and dozens of other detections are possible planets. In every case thus far, and for the foreseeable future, any direct image of an exoplanet will be a spatially unresolved dot — just as images of stars are unresolved — because the planet's tiny disk is orders of magnitude smaller than the diffraction (resolution) limit of even the largest telescopes.

Yet even though we have no hope of resolving continents, oceans, or polar caps on an Earth-like exoplanet with foreseeable technology, the amount of science we can infer from that unresolved dot is remarkable. For example, we could record the planet at different times and then fit a Keplerian orbit to its observed positions around the host star. This, together with the star's characteristics, establishes whether the planet is in the habitable zone.

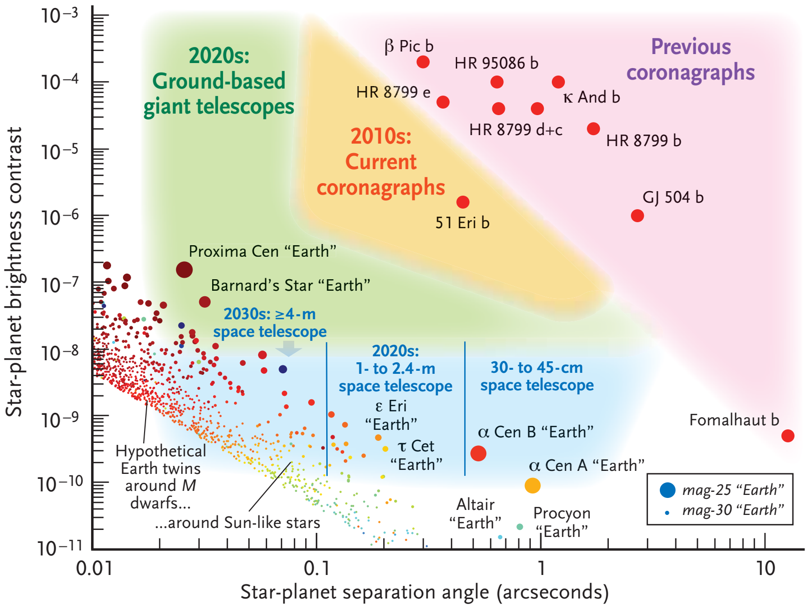
Although we can't use direct imaging to estimate the planet's size (as the transit method does) or its mass (as the radial-velocity method does), both can be inferred with some confidence from the planet's brightness and spectrum — or from just its color. Imagine the discovery of a pale blue dot in the habitable zone of some nearby star. It could be either a small "Earth" or a larger "Neptune." However, if the planet also appears 10 billion times dimmer than its star, then it would have to have an impossibly low *albedo* (reflectivity) to be the size of Neptune. Thus, by elimination, only a small rocky world would fit all the observations.

We can attempt several other observations with direct imaging. Watching a planet's brightness and polarization vary as it moves through different phases (crescent, gibbous, and so on) during each orbit can reveal the presence of clouds or oceans. Short-term periodic brightness variations might disclose the length of the planet's "day," while chaotic and annual brightness variations give information about weather and seasons, respectively.

Arguably the most exciting and powerful characterization that direct imaging enables is recording the spectrum of the planet's atmosphere. It's now possible to perform spectroscopy indirectly, by observing a planet at different wavelengths during transits or eclipses involving its star (*S&T:* May 2014, p. 18). However, these methods only work with a small fraction of transiting planets, and they're not very sensitive to Earth-like planets around Sun-like stars, in which case direct-imaging spectroscopy might be the only viable option.

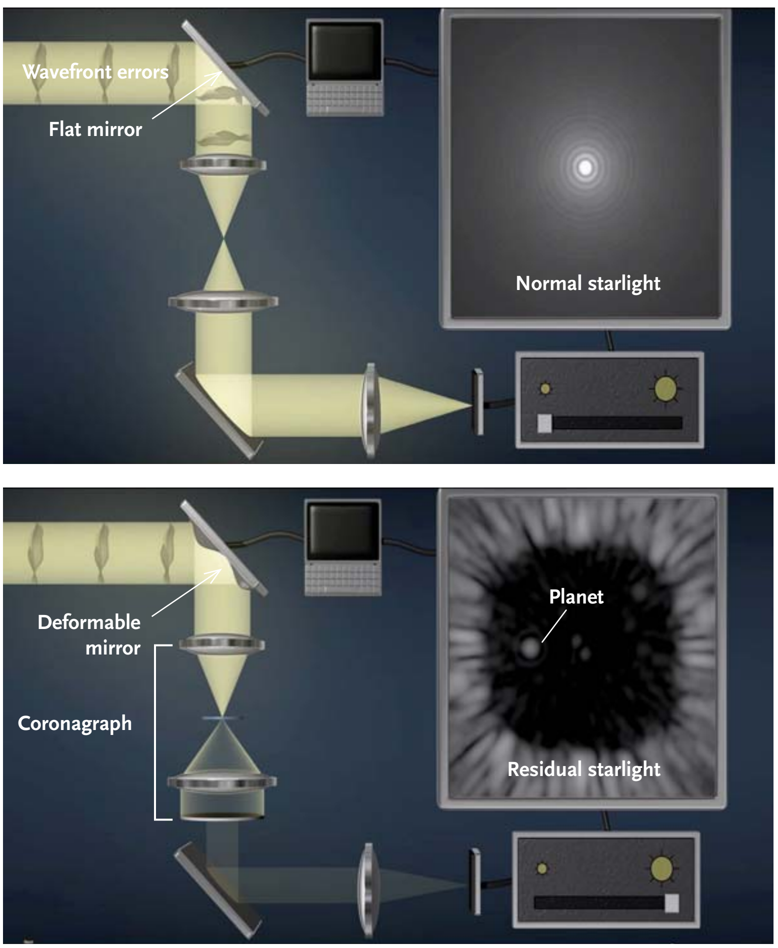
Key to the compositional characterization of Earth-like exoplanets is the detector's *spectroscopic resolution* — that is, how finely the detector can subdivide the observed wavelengths. Space-based missions proposed in the next decade or so might be limited to only 10 spectral channels for potentially habitable worlds before signal noise becomes prohibitive. But even three-channel color imaging is sufficient to differentiate a "Venus" or a "Mars" from an "Earth." A white planet would indicate either an opaque cloud cover (like that surrounding Venus) or a snowball planet. An orange hue would suggest photochemical atmospheric haze similar to Titan's. With 70 spectral channels, we can detect oxygen and water in the atmosphere of an Earth-like exoplanet and a plethora of other features.

Furthermore, if a planet has a relatively cloud-free atmosphere, its atmospheric pressure can be deduced by noting how blue the planet appears, because deeper,




R. BELIKOV / E. BENDEK / O. GUYON

**BIG-PICTURE PERSPECTIVE** The capabilities of present and future high-contrast instruments determine the types of exoplanets they can image. A sampling of the worlds imaged to date occupies the upper-right corner. Circles at lower left indicate Earth "twins" in the habitable zones of every nearby star out to 65 light-years. The colored regions show how the detection ability of current ground-based technology compares with that of ever-better space-based imagers in the future.




NASA / JPL-CALTECH (2)

denser atmospheres will exhibit more Rayleigh scattering and cause a bluer color. This density can, in turn, be used to infer whether the planet is capable of sustaining liquid water on its surface. There will, of course, be ambiguities, but even low-resolution spectroscopy is good enough to establish the diversity of exoplanet atmospheres and to pave the way for the higher-resolution spectroscopy required to look for more definitive biomarkers.

## Direct-Imaging Technology

Two key challenges complicate any attempt to directly image a potentially habitable planet: *contrast* (how faint the planet appears compared to its star) and *angular separation* (how close it is to the star). As shown in the plot at left, the brightness contrast is roughly $10^{-7}$ to $10^{-9}$ for Earth-like planets around *M* dwarf stars such as Proxima Centauri or Barnard's star; about $10^{-10}$ for those around Sun-like stars such as Alpha Centauri, Tau Ceti, or Epsilon Eridani; and about $10^{-11}$ for those around intensely bright, early-type stars such as Procyon and Altair.

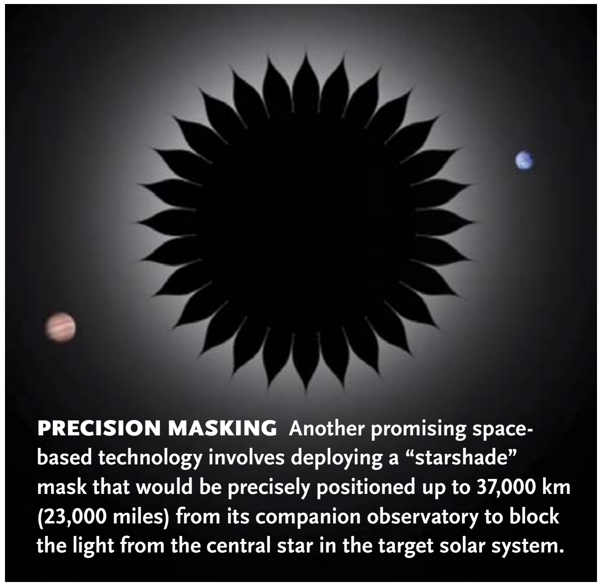
Meanwhile, the angular separation of the habitable zone ranges from about 0.1 to 1 arcsecond for the nearest few dozen Sun-like stars — but the separation is only about a tenth of that for the nearest few dozen *M* dwarfs. It's like trying to detect a firefly buzzing around a searchlight from many miles away.

Generally speaking, direct imaging of potentially habitable worlds requires contrasts of a billion or better and, except for a few of the nearest stars, a diffraction limit close to what modern telescopes can reach. Remarkably, instrument concepts exist that achieve these levels of performance, with laboratory demonstrations very close to success and getting better every year. The two methods likely to attain these high-contrast thresholds involve "internal coronagraphs" and "external starshades."

Internal coronagraphs utilize specially designed optics and masks to suppress a star's inherent brightness. They are essentially much more advanced versions of the coronagraph that Bernard Lyot invented in 1931 in order to see the Sun's corona. The basic principle is the same: a mask, placed at one of the telescope's focal planes, blocks the star but not its planets.

However, complications arise because of the wave nature of light: diffraction causes concentric *Airy rings* in the image of the star, which are not blocked by the mask and are still millions of times brighter than the planet. So additional optics and masks must be used to suppress all of the starlight, including the Airy rings. Another complication is that slight optical imperfections cause starlight to leak through the coronagraph, obscuring planets. Modern

**BEATING THE GLARE** To detect faint exoplanets, future space observatories will utilize coronagraphs that block the star's light with a combination of adaptive optics and special masks to suppress diffraction from the star.



**PRECISION MASKING** Another promising space-based technology involves deploying a "starshade" mask that would be precisely positioned up to 37,000 km (23,000 miles) from its companion observatory to block the light from the central star in the target solar system.

NASA / JPL-CALTECH (2)

coronagraphs use adaptive optics and deformable mirrors to remove these slight aberrations.

The starshade alternative suppresses starlight by blocking the star before its light ever reaches the telescope. A specially designed mask placed far in front of a space telescope — perhaps 30,000 km away! — would block the star's light. For this to work, the telescope must stay precisely positioned within the starshade's shadow, a level of formation flying that will be challenging but not impossible to achieve. Even then, starlight will diffract around the edges of the starshade, creating a bright spot right in the center of the shadow — where the telescope is. Specially shaping the edge of the starshade can suppress this diffraction effect, known as "Poisson spot" or "Arago spot," and this challenge has sparked a lot of innovation among mission designers.

Since there's no practical way to keep a starshade that's thousands of kilometers away in space precisely aligned with a specific point on Earth, ground-based telescopes can only use internal coronagraphs. However, starshades are, in principle, compatible with any space-based telescope positioned beyond Earth orbit.

Both methods have advantages and disadvantages, and conceivably both will be used in future efforts. Either way, an important tool in high-contrast imaging is "post-processing" of the images, which can typically boost their contrast by a factor of 10 or more. Sometimes image processing used alone, without a coronagraph, can achieve good results.

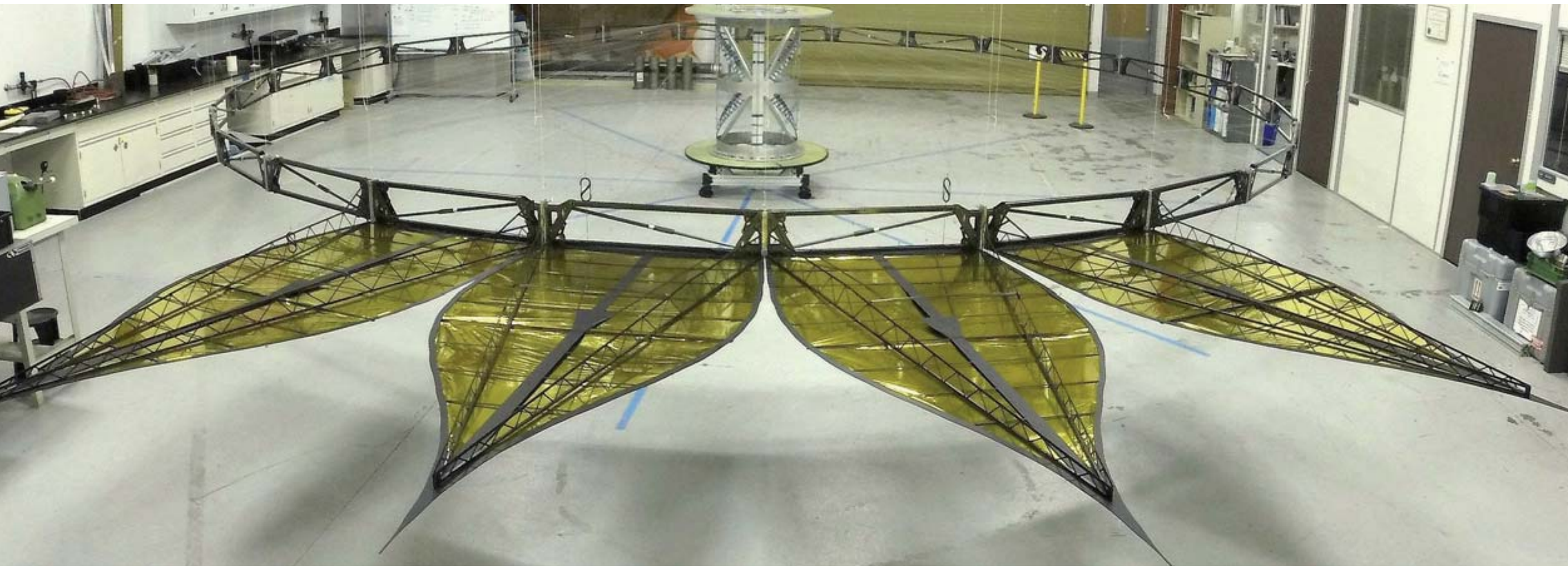
## Direct Imaging Instruments and Missions

As the contrast performance of direct-imaging technologies improves, so does the capability of ground- and space-based telescopes. High-contrast coronagraphs on ground-based telescopes have already recorded direct images of numerous young, hot exoplanets far from their stars (well outside their habitable zones). The next generation of these instruments, collectively known as "extreme adaptive optics," is currently pushing the performance envelope. Examples include Project 1640, Subaru Coronagraphic Extreme Adaptive Optics (SCExAO), Gemini Planet Imager (GPI), and Spectro-Polarimetric High-contrast Exoplanet Research (SPHERE). Some of these are capable of directly imaging mature giant planets such as a "Jupiter" in a star's habitable zone, but they can't quite pick out smaller, potentially habitable worlds.

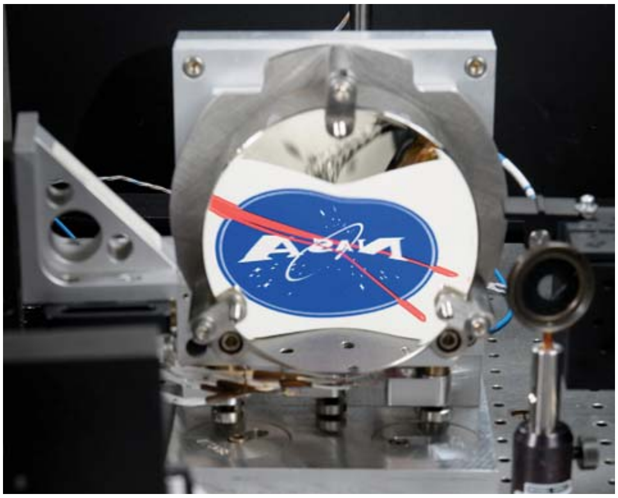
The next big leap in ground-based, high-contrast imaging will come from powerful coronagraphs attached to extremely large telescopes (ELTs). Terrestrial observatories are fundamentally limited by Earth's atmosphere to detecting exoplanets with a contrast of no better than about $10^{-8}$ with respect to their host stars. But a 30-m aperture will offer unprecedented angular resolution, so observers should be able to probe directly the tiny habitable zones of a small sample of *M* dwarf stars whose potentially habitable planets are brighter than the $10^{-8}$ contrast threshold. This capability complements that of space-based missions, which can achieve better contrast (because there's no atmosphere in space) but will likely not be large enough to achieve the extremely small angular resolution of their ground-based counterparts.

We've mentioned *M* dwarfs a few times, with good reason. They comprise most of the stars in the galaxy, and they have very long, stable lifetimes. But they also pose certain obstacles to habitability.

For example, because these stars are relatively cool, their habitable zones are close in. A planet orbiting close to its *M*-dwarf primary is likely to be tidally locked, so its sunward half will always be very hot and its shadowed



NASA / JPL-CALTECH



NASA / DOMENIC HART

**NEW TECHNOLOGIES** ***Above:*** **This test model, constructed at NASA's Jet Propulsion Laboratory, allows astronomers and engineers to experiment with four of the 28 petals that a fully deployed starshade mission would require.**

***Left*****: An aspheric mirror, used in a type of coronagraph called Phase-Induced Amplitude Apodization, distorts light in a way that enables detectors to record images of a star without Airy rings — so all light from the star can be easily blocked.**

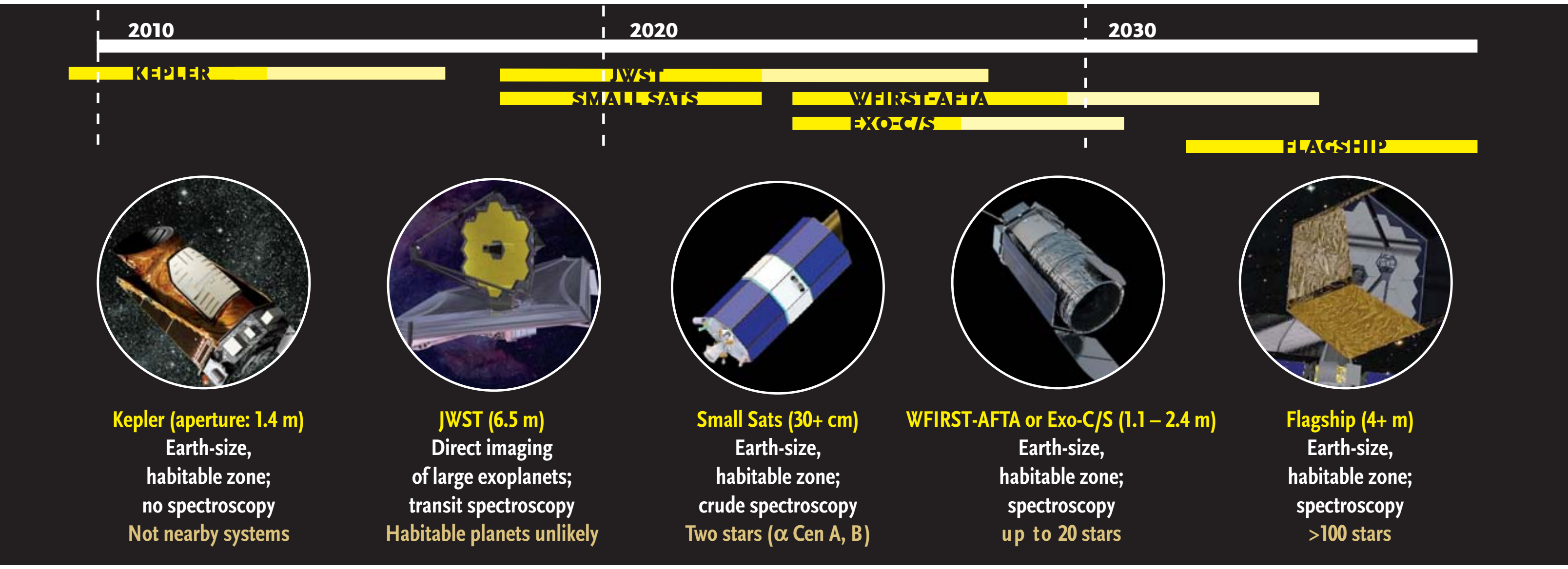
half very cold. This geometry might leave just a thin habitable "twilight zone" along the day-night terminator, from which the star always appears close to the horizon. If the atmosphere is thin, it might freeze onto the planet's dark side. If it's quite dense, fierce winds might continually blow from the day side toward the night side in order to distribute heat and equalize the planet's overall temperature. In addition, *M* dwarfs are quite active, and their X-ray flares might repeatedly sterilize any close-in planet. Despite these obstacles, ELTs or future advances in transit spectroscopy should be able to establish whether *M* dwarfs remain good breeding grounds for habitable planets.

Direct imaging from space, on the other hand, will enable us to look for potentially habitable planets around Sun-like stars (spectral types *F, G,* and *K*), which don't have these possible obstacles to habitability. The forthcoming James Webb Space Telescope (JWST) will have direct-imaging capability and will also utilize the transit method (and transit spectroscopy in particular) for exoplanet studies. However, its coronagraph is not powerful enough to spot small, tightly bound exoplanets.

Thus, the first direct image of a potentially habitable planet around a Sun-like star will probably come from another space mission. Among the possibilities is NASA's next proposed "flagship" mission, called WFIRST-AFTA (Wide-Field Infrared Survey Telescope – Astrophysics Focused Telescope Assets), and mission planners are developing a high-performance coronagraph for it. While this spacecraft's planned objectives don't include looking for potentially habitable planets, a recent simulation suggests that it would have a 50:50 chance of detecting one anyway. A report on this mission can be found at **wfirst.gsfc.nasa.gov**.

NASA managers have also commissioned studies for two smaller, less-expensive missions, one equipped with a coronagraph (Exo-C) and the other with a starshade (Exo-S). Simulations predict that Exo-C might discover two potentially habitable planets and Exo-S four of them, along with many large exoplanets. The Exo-S study also looked at the feasibility of flying a starshade in formation with WFIRST-AFTA. Both studies were completed this year, and summaries are found at **exep.jpl.nasa.gov/stdt**.

Another exciting possibility, perhaps achievable by the end of this decade, is launching a small space observatory to search for planets around Alpha Centauri A




**THE WAY FORWARD** Kepler has shown the potential of using space-based observatories to discover exoplanets. But true understanding of these worlds will only come when future technology allows astronomers to image them directly and to study their compositions using spectroscopy. Current and planned missions are shown, as well as concepts not yet approved by NASA.

and B. Since they're only 4.4 light-years from Earth, both stars have habitable zones roughly 1 arcsecond in radius, considerably wider than those of other Sun-like stars or *M* dwarfs in our vicinity. So a smaller, less expensive space telescope — equipped with an objective only 30 to 45 cm across and a state-of-the-art coronagraph — could directly image planets around either star. The main challenge is to suppress the starlight of both stars instead of just one. We and our team are developing the technology to do just that, and we've recently proposed a mission called Alpha Centauri Exoplanet Satellite (ACESat).

One of these various missions might directly image the first potentially habitable planet and perform the low-resolution spectroscopy that would give us tantalizing suggestions of its ability to sustain life. The next step would be to loft a larger space observatory capable of surveying the nearest few hundred stars for habitable planets and of taking high-resolution spectra with dozens of wavelength bands. The exoplanet community has been studying several of these flagship mission concepts, with an eye toward launching one perhaps two decades from now (see the box at lower left for one such concept).

## Dreams of a Space-based Megascope

**Even though** its launch is still years away, astronomers are already looking beyond the James Webb Space Telescope for the kind of space-based observatory that could truly revolutionize astronomical research in the future. A recent study sketches out the rationale for a gigantic High-Definition Space Telescope (HDST) that could undertake this quest. Its mirror would be at least 12 m (39 feet) across.

According to the report, issued by the Association of Universities for Research in Astronomy, this mega-telescope and its coronagraph would search for planets around the roughly 600 stars that lie within 100 light-years of Earth and conduct spectroscopic scans for signs of life on or around them. The HDST would also make extraordinary breakthroughs in the study of black holes, dark energy, and cosmic evolution. Learn more at **hdstvision.org**.

## A Moment in Time

What would an image of an alien Earth look like? Spotting that "pale blue dot" around another star would have enormous implications not only for astronomy but also for everyone on Earth. Its discovery would no doubt transform our worldview, inspire kids to become scientists, and reinvigorate public interest in space science and exploration. The spectrum of a "likely inhabited" planet could revolutionize biology and theories of how life arose on Earth. Such an image would also reveal the next frontier beyond the solar system and sow the seeds for what might ultimately prove to be our civilization's greatest triumph: the era of interstellar exploration.

In all the countless generations of people over the millennia, many have wondered if we are truly alone or if other worlds like ours exist elsewhere. Out of all those generations, we are privileged to be the one that finally stands on the verge of answering this age-old question. ✦

***Ruslan Belikov*** *and* ***Eduardo Bendek****, scientists at NASA's Ames Research Center, specialize in the technology of exoplanet imaging and are the lead investigators for the proposed Alpha Centauri Exoplanet Satellite.*

# Making Massive Stars

Monica Young

*Researchers are refining the recipe for some of the brightest stars in the night sky.*

**As autumn settles in,** Orion once more begins its journey into northern night skies. Its massive stars give shape to winter's night: red and supernova-ready Betelgeuse; blue giant Bellatrix; the blue-white supergiant that dominates the Rigel triple-star system; and windy supergiant Saiph. And tucked within this most recognizable of constellations is the Orion Nebula, the nearest birthplace of massive stars — those with more than eight times the mass of the Sun.

Yet massive stars' visibility from Earth is deceiving; they are actually few and far between, making up fewer than 1% of all stars in the Milky Way. In part, this is because the behemoths live their lives fast and furious, running out of fuel and blowing up into giants before lower-mass stars even start fusing hydrogen in their cores. But it's also because making massive stars poses challenges not faced by smaller stars.

Even before massive stars can form, the cards are stacked against them. Most clumps of dust and gas will fragment into smaller pieces. And even if a giant clump manages to stick together, the bright star it creates harbors the clump's own destruction. Massive stars' powerful winds and, more importantly, their intense radiation destroy the molecular gas cloud they call home, pushing away the very gas that feeds them.

Yet somehow, instead of falling to pieces or blowing themselves apart, some stars manage to grow to giant size. How do massive stars persevere amidst the forces of creation and destruction?

**ORION'S STARS** Lying 1,300 light-years from Earth, the Orion Nebula (shown here in a Hubble close-up) is home to the nearest massive forming stars.

NASA / ESA / M. ROBBERTO / HUBBLE SPACE TELESCOPE ORION TREASURY PROJECT TEAM

*Facing Page*: This stunning vista reveals Orion from head to toe and shows massive stars from birth to death. Dark molecular clouds swirl amongst the constellation's stars, and Orion Nebula is clearly visible. Photographer Rogelio Bernal Andreo also used a narrow hydrogen-alpha filter to pick out Barnard's Loop, a red crescent of ionized hydrogen gas. These might be the glowing remains of long-ago supernovae, lit up today thanks to the intense radiation from young massive stars.

## Puzzled Theorists

All stars begin their lives cocooned in clouds stuffed full of molecular gas. At 30 to 300 light-years across, these giant molecular clouds typically host a few hundred particles per cubic centimeter. That density makes for a better vacuum than the best one created on Earth, yet it's enough to block visible light and, depending on which part of the cloud you're looking through, infrared too.

Theorists find it easy to make low-mass stars within these clouds. James Jeans formulated the simplest model in 1902, where thermal pressure, gas molecules' heat-generated buzz, resists gravity until the clump is roughly the mass of the Sun. Only then does gravity win for a while, driving the inward fall of gas until hydrogen fusion ignites and the star once more resists collapse.

But by the time a low-mass star has ignited fusion, high-mass stars have already run out of fuel. In fact, while the Sun took about 50 million years to form, a star with the mass of 15 Suns will "turn on" in just 60,000 years. These stars are burning brightly long before they've achieved their final masses, so their intense radiation ought to push out inflowing gas and dust. The push of photons, known as radiation pressure, threatens to reverse the accretion flow before the star can reach more than 20 solar masses.

"Obviously, nature found a way to overcome these problems," says Floris van der Tak (Netherlands Institute for Space Research and University of Groningen, The Netherlands). "We just aren't quite sure how it did that."

Three ideas have been advanced to answer that question, boiling the answer down to when a star gathers its bulk. Does a star hoard all its mass before the core begins to collapse? Does gas continue to flow in during collapse? Or, in an option that sidesteps massive star formation altogether, do lower-mass stars collide and merge?

The latter proposal, introduced by Ian Bonnell (University of St. Andrews, UK) and colleagues at the turn of this century, eliminates both threats facing massive star formation. Since stellar collisions would join two fully formed lower-mass stars, radiation pressure never becomes an issue during formation. Moreover, giant molecular clouds' tendency to fragment into lots of smaller pieces isn't a hindrance, it's a plus: with more stars around, there's a greater chance for collision.

Still, for collisions to happen stars must exist extremely close together from birth. Though rare, this isn't impossible — young star clusters might have the required high densities at their centers, or two stars may form in already close orbits.

The eclipsing binary MY Camelopardalis is one probable example of a close stellar pair just about to merge. Born in the young cluster known as Alicante 1, this system contains two *O*-type stars spinning around each other every 1.2 days, each in turn hiding the other from Earth's view. The stars themselves are already 38 and 32 times the Sun's mass.

Javier Lorenzo (University of Alicante, Spain) and a team of professional and amateur astronomers measured this system's brightness changes as well as the velocities of its stars. The extremely short orbital period, combined with the stars' high masses, suggests that the two are in contact, their surfaces touching and mixing. Simulations predict an imminent merger: the stars should combine into a single beast with more than 60 times the Sun's mass in less than 2 million years.

The imminent merger confirms that the process can happen. But it also appears to be rare and perhaps only explains the most massive of stars.

## Ordered Collapse or Chaotic Accretion?

Since mergers of lower-mass stars aren't the (whole) answer, theorists tend to turn toward two other possibilities: gathering mass either before or during collapse.

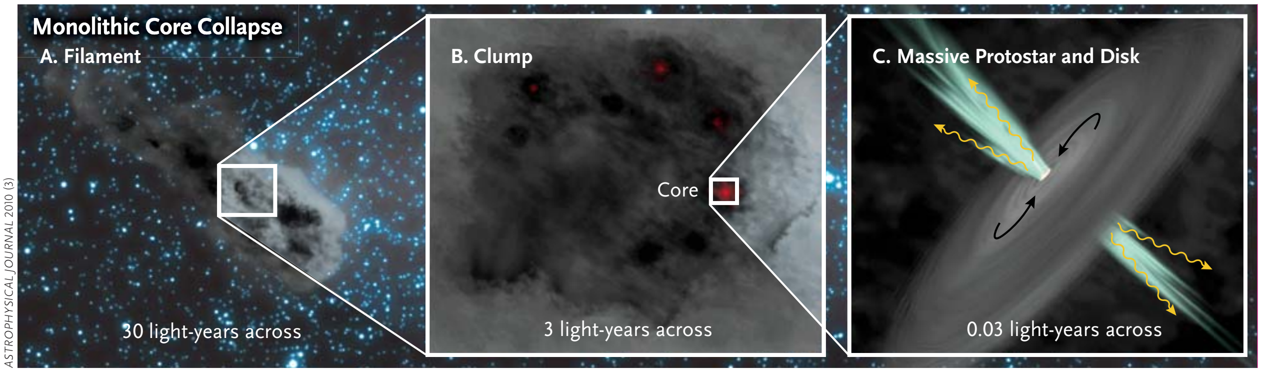
The first option, *monolithic core collapse,* scales up low-mass star formation. In analogy to their smaller brethren, massive protostars host correspondingly massive accretion disks. The disk itself could be opaque enough to protect inflowing gas from radiation's intense pressure, and disk-powered jets could also carve out cavities that serve as an escape route for the star's photons. But massive stars don't just double (or quadruple) the low-mass recipe. Making giant clumps also requires extra ingredients, such as roiling turbulence and constricting magnetic fields, which prevent fragmentation into smaller initial pieces.

In the alternative model, *competitive accretion,* the cloud does fragment into many smaller seeds, but rather than exist within isolated cores, feeding on gas from their immediate surroundings, these seeds draw their mass from the entire cloud. Most seeds will form low-mass stars, but bigger seeds will ultimately collect more mass, following the maxim "the rich get richer." Even more important is "location, location, location": stellar seeds born in regions rich with gas will grow faster and more massive than those born in sparser regions.

Competitive accretion naturally explains why massive stars tend to be found in clusters rather than on their own, as well as in the centers of those clusters, where the star-forming cloud would have had the densest gas reservoir.

But while monolithic collapse results in gas flows through a massive, puffy disk, accretion in the competitive scenario isn't nearly so tidy. Gas flows in from all sorts of directions, and if an accretion disk forms at all, it will never grow very large due to encounters with nearby forming stars. The messy accretion flow may never become opaque enough to protect against the protostar's intense radiation, says Jonathan Tan (University of Florida).

Despite their differences, distinguishing between monolithic collapse and competitive accretion isn't easy.




S&T: LEAH TISCIONE, SOURCE: CARA BATTERSBY ET AL. / *ASTROPHYSICAL JOURNAL* 2010 (3)

**MONOLITHIC CORE COLLAPSE (A) A filament arises in a turbulent giant molecular cloud, and within the filament, a clump of gas begins to collapse. (B) The clump contains dense knots of condensing gas called cores. (C) At the center of each core, gas flows onto the protostar in an ordered way, via an accretion disk that spans several thousand astronomical units. The opaque disk protects inflowing gas from the protostar's intense radiation. Photons instead escape through the cavities carved out by fast-flowing gas jets, so the star can continue to grow even after it ignites fusion.**

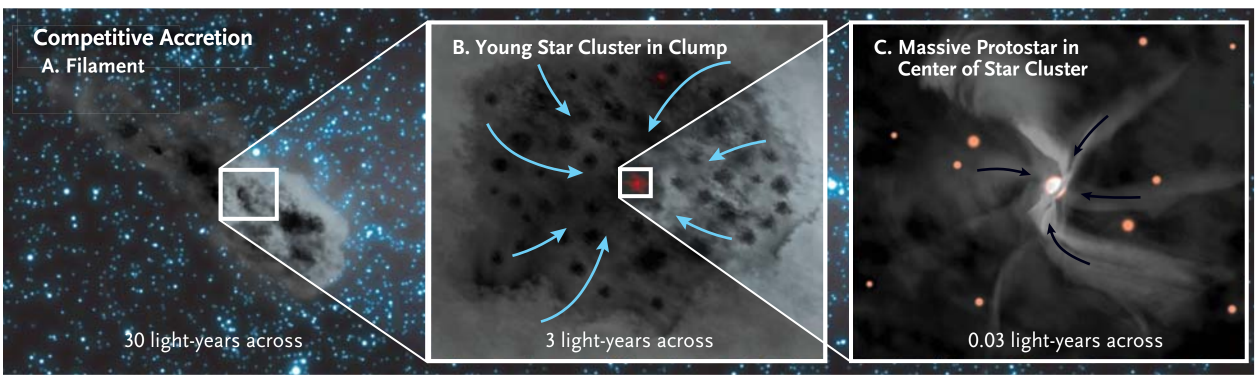
Not only do massive stars form in the blink of an astronomical eye, but also, because ignition occurs while the stars are still growing, any changes hide behind a veil of dust and gas — a veil made thick by the high density of their surroundings. In addition, massive stars are so rare that there are no nearby examples. While the closest star to the Sun, Proxima Centauri (part of the Alpha Centauri triple system) is only 4 light-years from Earth, the nearest massive protostars lie 1,300 light-years away.

One thing that would support the idea of monolithic collapse is massive accretion disks around forming stars. Even if the disks themselves can't be seen, astronomers can look for the powerful, disk-powered outflows that light up surrounding gas at radio and infrared wavelengths. Astronomers have discovered a number of these powerful outflows, evidence that so far leans toward the tidier scenario of monolithic collapse, Tan says.

For example, the nearest massive protostar, a future *B*-type star known as Orion Source I, sports an X-shaped wind flowing off its accretion disk. (Go to **http://is.gd/massivestars** to watch this wind flow in a movie made from two years of observations.) Astronomers have also spotted narrower jets emitted from more than a dozen massive protostars.

Andrés Guzmán (University of Chile and Harvard-Smithsonian Center for Astrophysics) and colleagues took a closer look at another protostar, the future *O*-type star dubbed G345.4938+01.4677 (G345 for short), using the Atacama Large Millimeter/submillimeter Array (ALMA) high in Chile's Atacama Desert. They spotted not just narrow jets, but also a massive, rotating disk-like structure surrounding the protostar.

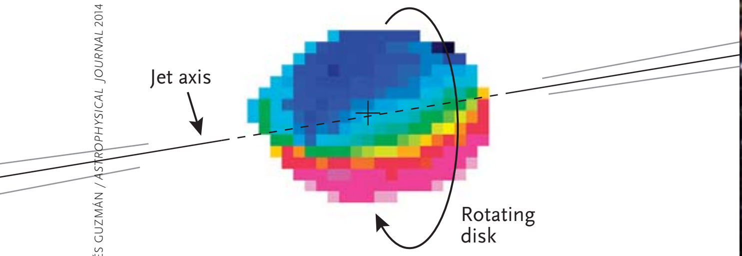
The rotating structure spans roughly 3,000 astronomical units (a.u., the distance between Earth and the Sun), making it ten times larger than the typical protoplanetary disk feeding a low-mass protostar. But the fast, narrow jets suggest a more typical disk is hidden deep inside. Alongside these signs of ordered accretion,




S&T: LEAH TISCIONE, SOURCE: IAN BONNELL / MNRAS 2001 (3)

**COMPETITIVE ACCRETION (A) Clumps of gas condense within a cloud. (B) But in competitive accretion, gas continues to flow in from great distances as the cloud fragments into many low-mass "seeds." Only a few of these, preferentially the largest seeds that form in the cluster's center, will ultimately grow into massive stars. (C) The massive protostar continues to compete for gas, drawing from the whole molecular cloud. Gas flows in from every which way, disrupting ordered accretion, and close encounters with other stars (whose accretion flows are not shown here for simplicity) may truncate any accretion disk that manages to form.**

ANDRÉS GUZMÁN / ASTROPHYSICAL JOURNAL 2014




**PROTOSTELLAR DISK** **ALMA detected emission from sulfur dioxide gas revolving around the protostar G345. Gas is colored by its velocity in this image: on one side, gas is moving away from us (red), while on the other side gas is coming toward us (blue). In other words, this blob of accreting gas, which spans 3,000 times the distance between Earth and the Sun, is clearly rotating.**

the team observes the harsh effects of the protostar's radiation on the surrounding environment. Combined, the team's observations provide direct evidence that an accretion disk can survive the birthing of a massive star.

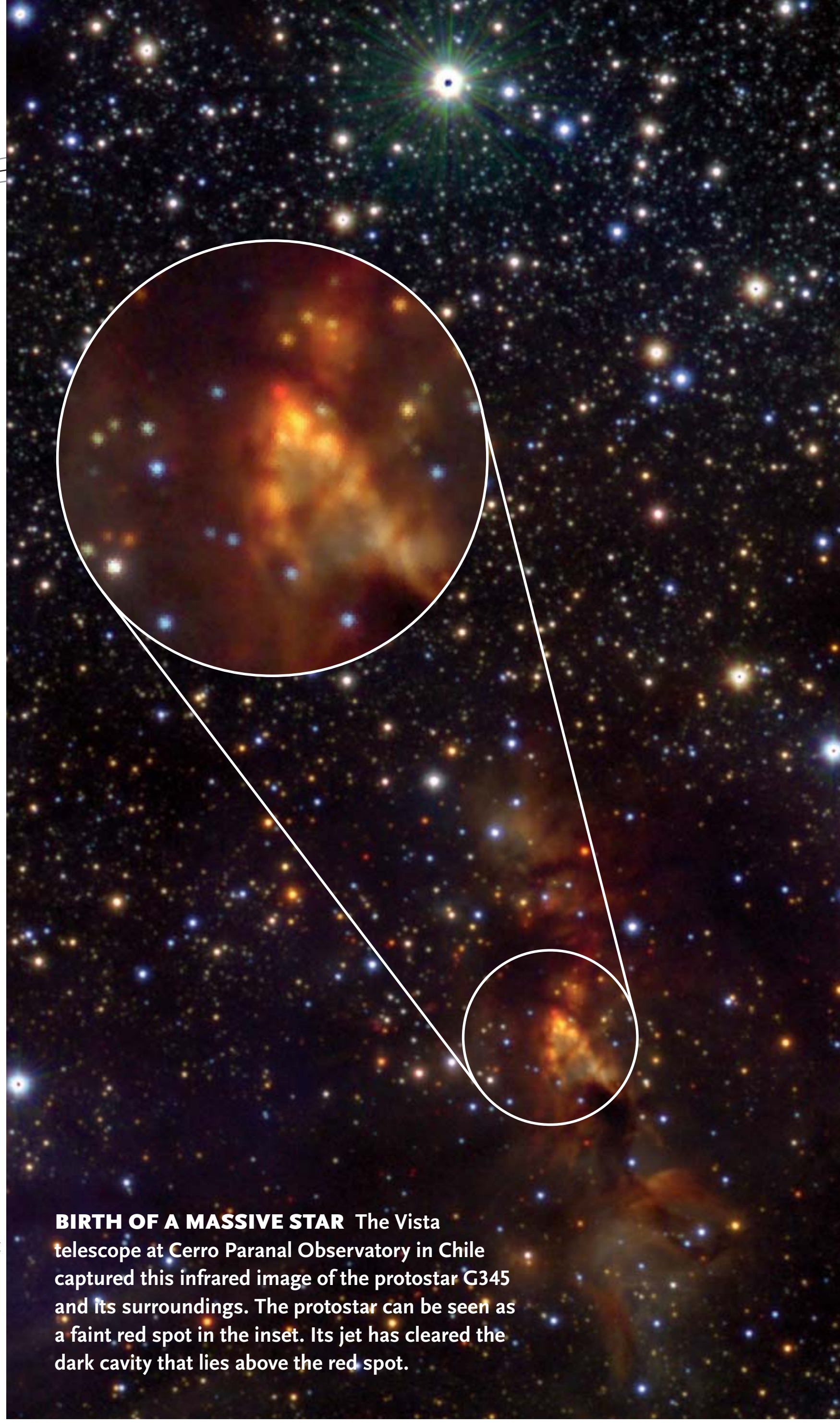
Even though monolithic collapse seems to have the upper hand at the moment in explaining the birth of massive stars, the debate isn't over yet. "Monolithic collapse is quite successful . . . maybe up to 15 to 20 solar masses," van der Tak says. But, he adds, the most massive stars may need more extreme models. "Perhaps there is room for each of these theories."

## Collapsing Cores

Gravity's role in star formation appears straightforward: balance thermal pressure then drive collapse. And in the dense, collapsing pockets within a giant molecular cloud, astronomers such as Alyssa Goodman (Harvard University and Harvard-Smithsonian Center for Astrophysics) have found that the gas indeed remains placid.

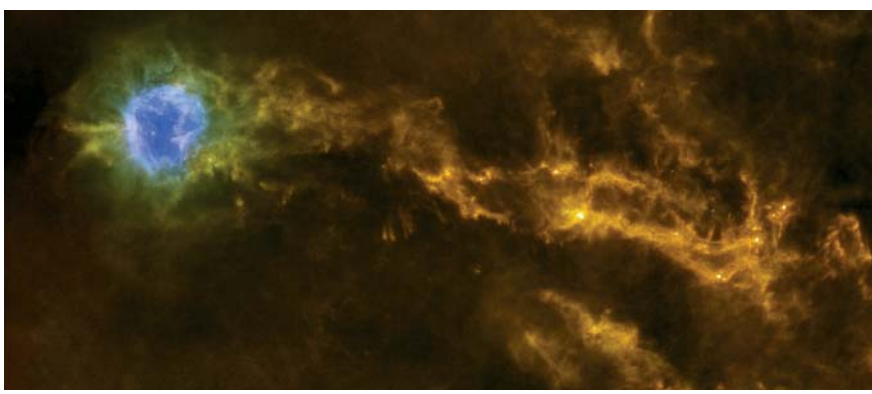
"We called them 'islands of calm in the turbulent sea,'" says Goodman. That is, the collapsing cores exhibit only small thermal motions, even if the surrounding gas sloshes turbulently about.

But gas doesn't always collapse in a spherical way. Even solely under the influence of gravity, gas will form filaments. If that seems strange, take a look at any cosmological simulation, where gravity shapes the universe's mass into a similar filamentary cosmic web. (Though in star formation, turbulence and magnetic fields also have a role to play in shaping filaments.)



**BIRTH OF A MASSIVE STAR** **The Vista telescope at Cerro Paranal Observatory in Chile captured this infrared image of the protostar G345 and its surroundings. The protostar can be seen as a faint red spot in the inset. Its jet has cleared the dark cavity that lies above the red spot.**

SOURCE: ALMA OBSERVATORY (2)



**STRANDS OF STARS** **The star-forming region IC 5146 contains cold gas that glows gold in this far-infrared image from Herschel Space Observatory. About 45 gravitationally bound stellar seeds, some which appear as bright spots, are mostly strung along the main filament (left), where dense gas is under collapse. The amethyst glow at left comes from the Cocoon Nebula, a stellar nursery with a recently formed massive star at its center.**

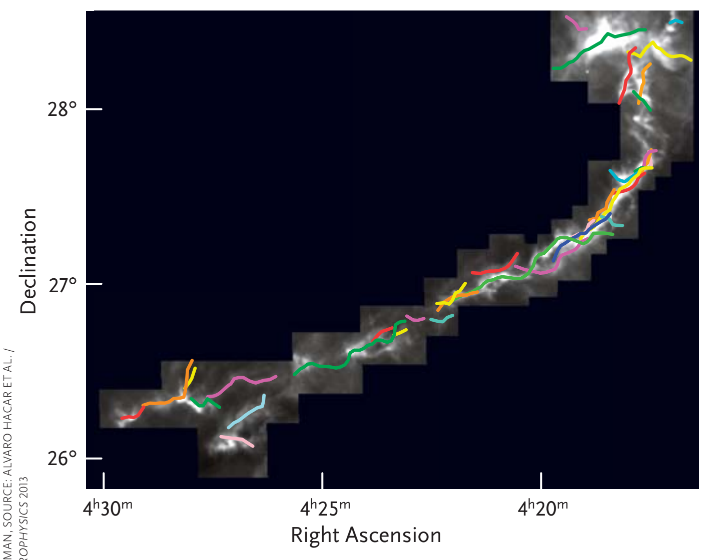
ESA / HERSCHEL / SPIRE / PACS / D. ARZOUMANIAN

It's within filaments that denser star-forming cores materialize. In fact, almost a century ago, the gifted observer Edward Barnard compiled a catalog of "dark markings on the sky" and noted there must be a connection between the "vacant lanes" (filaments) and the bright nebulae lit up by adolescent stars.

Modern instruments, capable of measuring molecular motions within these dense clouds at high resolution, are revealing the complexity of that connection. In a star-forming region in Taurus (*S&T:* Feb. 2005, p. 90), Alvaro Hacar (University of Vienna, Austria) and colleagues used the Five College Radio Astronomy Observatory in Massachusetts to look more closely at the filaments named L1495/B213, which together stretch 30 light-years long. They found that these filaments, like rope, can be split further into shorter fibers, each spanning a light-year or so. Only some of these cylindrically collapsing fibers condense further into sphere-shaped star-forming cores roughly one-third light-year across.

"If you want to know what the hottest, newest, craziest thing in star formation is, it's this," Goodman says. But, she cautions, studies of filaments, fibers, and cores all have vastly different resolutions, making it difficult to form a cohesive picture. "We don't have a case yet where it's all connected."

Though the Taurus cloud is a low-density environment that churns out correspondingly low-mass stars, astronomers have since discerned filaments' rope-like structures in a variety of star-forming regions. That includes G035.39-00.33, a dark cloud with complex filamentary structure and several massive stars-to-be. At a distance of almost 10,000 light-years, this dense cloud isn't easy to observe, but Jonathan Henshaw (University of Leeds, UK) and colleagues resolved several fibers entwined within a larger filament.




*S&T:* GREGG DINDERMAN, SOURCE: ALVARO HACAR ET AL. / *ASTRONOMY & ASTROPHYSICS* 2013

**THE FIBERS WITHIN** **Alvaro Hacar and colleagues studied the motions of gas within two filaments, dubbed L1495 and B213, in the Taurus star-forming complex. The team identified 35 distinct fibers within the rope-like filament.**

Simulations suggest that the level of complexity in these nested structures may be even higher than what current technology allows us to observe. As Hacar says, "perhaps we are just scratching the surface."

## A Complete Recipe for Massive Stars

While astronomers are still deciphering the details of cloud collapse, it's clear that gravity rules condensation into not just well-behaved, spherical cores, but also a complex hierarchy of filaments and fibers. Turbulence and magnetic fields further complicate this picture.

"There's turbulence in galaxies, there's no way around that," says Adam Leroy (Ohio State University). Leroy studies the effects of turbulence in the Sculptor Galaxy (NGC 253) and other galaxies bursting with star formation. Turbulent flows are bound to arise during many processes, including but not limited to major galaxy mergers (*S&T*: Sept. 2015, p. 16). And as gas churns randomly this way and that, the sloshing affects the size and density of forming filaments.

Realistically accounting for turbulence in simulations has resulted in perhaps the most important theoretical advances in star formation over the past few decades. A high degree of turbulence appears to be a necessity in forming massive stars, especially in the monolithic collapse model: turbulence gives molecules an extra boost of energy, so gas clumps can grow larger before gravity dictates their collapse.

Turbulence also plays a role in increasing density within a cloud, creating the right initial conditions for massive stars. "Big waves of supersonic material crash into each other, and if the waves are bigger and stronger then very dense pockets will form," Leroy says.

Though important early on during cloud collapse, turbulence dissipates as the cloud condenses further into star-forming fibers and cores. Magnetic fields, on the other hand, are thought to remain with cores. Since the presence of strong magnetic fields limits the long-range and chaotic gas flows required for the competitive accretion model, cores with strong fields are more likely to collapse monolithically.

In a recent test of magnetic fields' role, Tan and colleagues used ALMA to measure spectral lines emitted from molecules within four gas clumps, chronicling the motions of up to 100 Suns' worth of mass in each clump. The team found indirect evidence for strong magnetic fields: even the most massive clumps of gas maintain their hefty mass despite not having enough thermal or turbulent pressure to withstand gravitational collapse. Magnetic fields are the only missing ingredient that could provide the necessary support.

But this evidence is indirect, testament to the fact that magnetic fields are exceedingly difficult to measure. That

DIGITIZED SKY SURVEY 2

isn't to say measurements are impossible: for example, strong magnetic fields can split a spectral line into multiple lines at slightly different wavelengths (known as the Zeeman effect), and the direction of a cloud's magnetic field will influence the polarization of light passing through it, which astronomers can then measure.

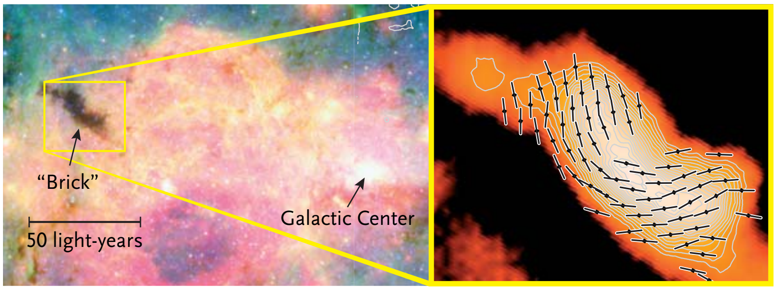
The problem is that magnetic fields suffuse the sparse gas that floats between stars and star-forming clouds. In that drifting, low-density gas, the magnetic field is weak but well aligned. So if astronomers observe the magnetic field in a collapsing cloud, their view would also include the gas between Earth and the cloud. Chances are this interstellar gas will dominate their measurements and perhaps even give a false sense of what the magnetic field looks like within the cloud.

But astronomers never shy away from a challenge. Thushara Pillai (Max Planck Institute for Radio Astronomy, Germany) and colleagues zeroed in on two of the darkest infrared shadows along the galactic plane. Dubbed the Brick and the Snake, these clouds lie 12,000 and 27,000 light-years from Earth, respectively.

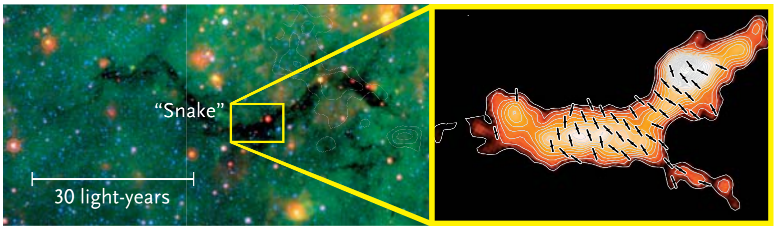
Though the shadows are dark in the infrared, they glow gently at even longer wavelengths. Dust grains, especially well-aligned ones on the clouds' surfaces, polarize this radiation as it escapes. Pillai's team used archival data from the James Clerk Maxwell Telescope and the Caltech

ESO / APEX / A. HACAR ET AL. / DIGITIZED SKY SURVEY 2

**IN ANOTHER LIGHT** **The L1495/B213 filaments of cold, dense gas are just shadows in the visible-light Digitized Sky Survey image (*above*), but they glow gently at submillimeter wavelengths (*left*).**

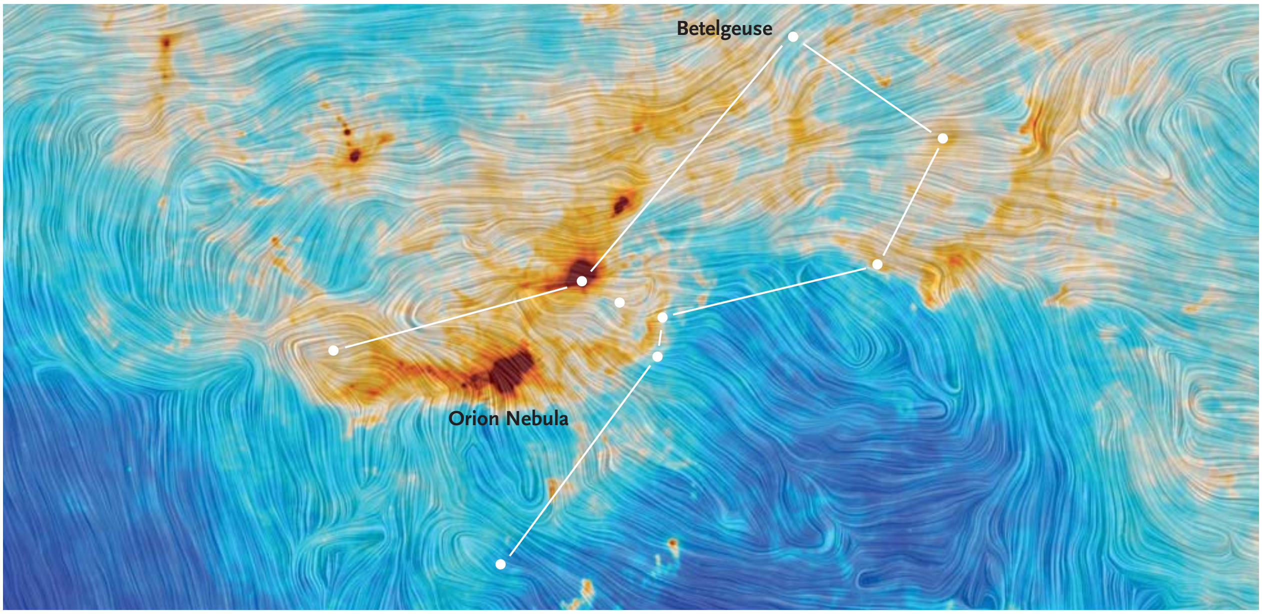



T. PILLAI & J. KAUFFMAN, SOURCES: SPITZER GLIMPSE & MIPSGAL IMAGES, CSO HERTZ DATA




T. PILLAI & J. KAUFFMAN, SOURCES: SPITZER GLIMPSE & MIPSGAL IMAGES, JCMT SCUPOL DATA

**BRICK & SNAKE** **Two dense molecular clouds known as the Brick (*top*) and the Snake (*bottom*) show up as dark shadows in Spitzer images (left), silhouetted against a background of mid-infrared emission from warm dust and gas. But the clouds glow at submillimeter (top right) and far-infrared wavelengths (bottom right). The polarization of this long-wavelength radiation showed Pillai's team how the magnetic field is oriented: parallel to the Brick filament and perpendicular to the Snake filament.**




ESA / PLANCK COLLABORATION

**MAGNETIC EFFECT** The Planck satellite's exquisite view of polarized light in the Orion molecular clouds reveals the effect of large-scale magnetic turbulence on star formation. The color scale shows emission from dust: blue represents sparse regions while red reveals dense clumps (the most prominent clump is the Orion Nebula). The texture represents the direction of the magnetic field, which becomes disordered near areas of star formation.

Submillimeter Observatory to measure this polarization. These estimates showed — more directly this time — the strong magnetic fields that support these massive clumps against fragmentation.

Pillai's team also saw that the magnetic field aligns with the cloud's filaments — magnetic field lines are either parallel or perpendicular to the filaments. In a much larger survey that includes the entire Milky Way plane, the Planck satellite team studied polarization toward three low-mass star formation regions and found the same result: magnetic fields tend to align with or against filaments.

These observations might reveal filaments' magnetic history. "When the magnetic field is strong, matter is preferentially channeled along magnetic field lines, the path of least resistance," explains Doris Arzoumanian (Space Astrophysics Institute, France). So any emerging structures form perpendicular to magnetic field lines.

When turbulent motions instead dominate over the magnetic field, Arzoumanian continues, the gas flows turn into shock waves that crash against the magnetic field lines and compress the field. The areas of stronger field restrain material and form filaments aligned parallel to the magnetic field lines.

Though astronomers have long suspected that magnetic fields are important in forming stars, observations proving their role have been difficult to carry out, and only recently have simulations begun to include magnetism's full complexity. But all that's beginning to change. With theoretical advances, as well as the public release of Planck polarization data and ALMA's continually improving polarization capabilities, astronomers are beginning to puzzle out the part that magnetic fields play.

## Destroy to Create

Massive stars thrive in the hostile environment they create, their existence echoing Pablo Picasso's famous words: "Every act of creation is first of all an act of destruction." Astronomers have made great progress in understanding that creation by penetrating the high-density shroud that veils massive star formation. They're beginning to discern the complex, nested structures involved in protostellar collapse, as well as the importance of magnetic fields.

Still, many questions remain, most of them centering on just how much massive stars follow in the footsteps of their lower-mass brethren. ("I might have an answer for that if you would ask me in a couple of years and we got our ALMA time," Alvaro Hacar jokes.) Massive star formation clearly differs from that of low-mass stars in important ways, and while theorists have largely incorporated turbulence into simulations, their work with magnetic fields — determining their role in shaping filaments, controlling collapse, and balancing turbulence and gravity — is still very much in progress.

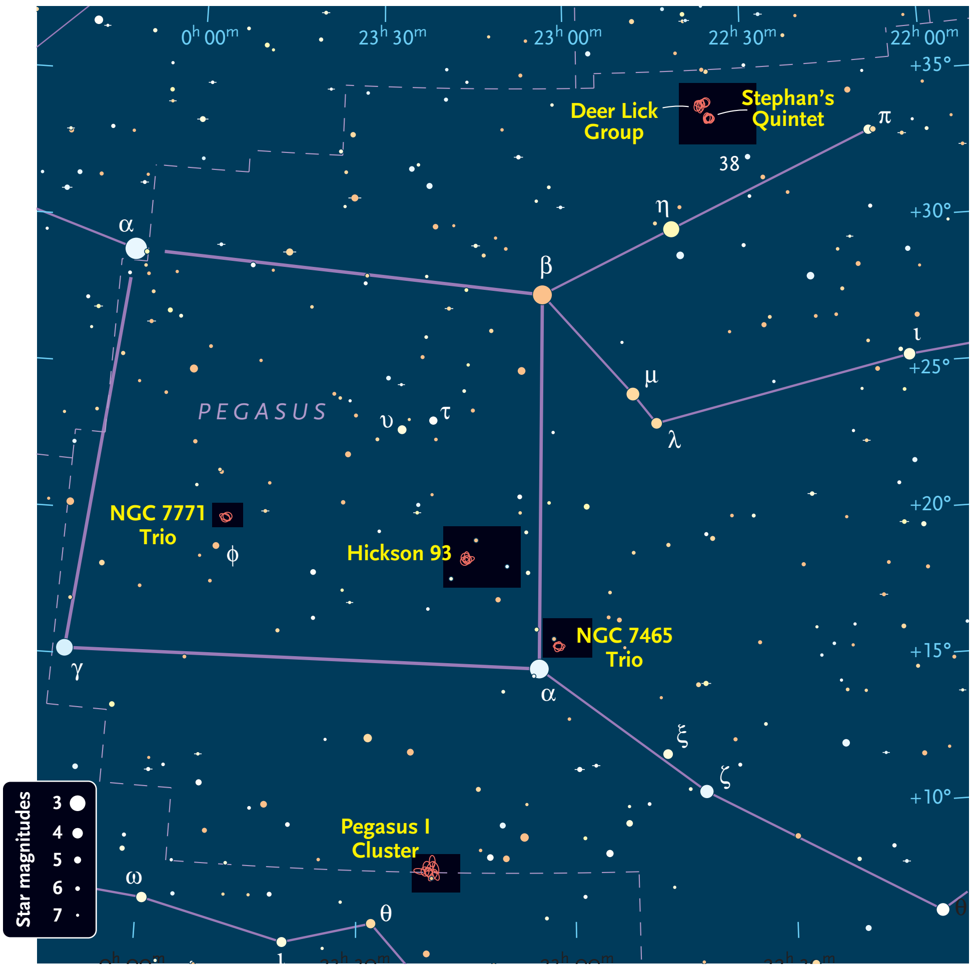
Until astronomers can figure out the proportion of star formation's essential ingredients, the recipe for the most massive stars remains a secret. It's a good thing our galaxy continues to cook them up. ✦

*S&T Web Editor* ***Monica Young*** *enjoys watching cooking shows, especially the celestial one above our heads.*

# A FEW of MY Favorite Things

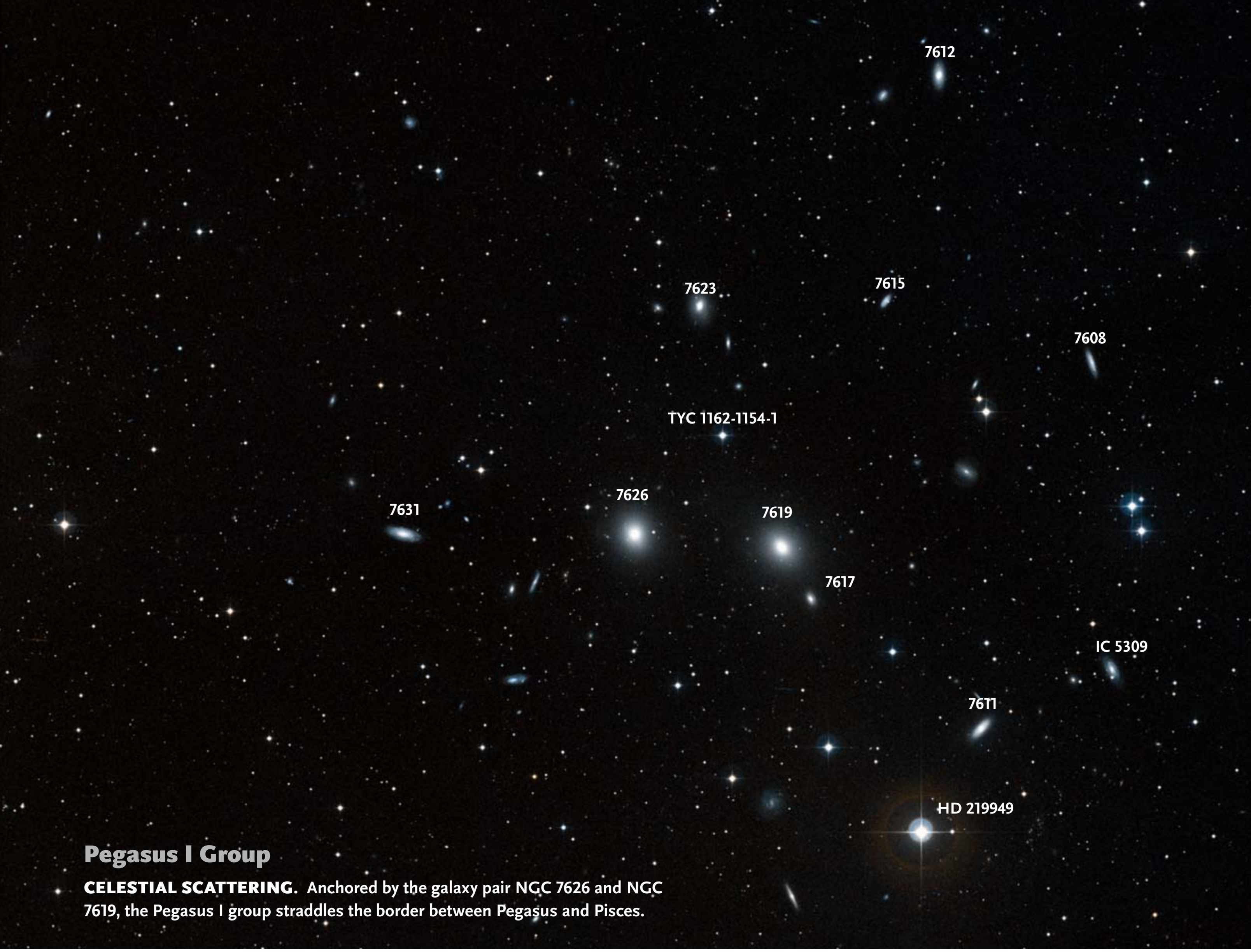
Ted Forte

**A sense of wonder and a good imagination will aid you in this tour of Pegasus galaxy groups.**




**Less than a century ago,** astronomers were still not convinced that there existed galaxies beyond our own. The known universe consisted of our Milky Way; all of what are now known to be external galaxies were thought to be clouds of gas or clusters of stars within it. Armed with modern knowledge, today's observer sees these faint, nebulous smudges very differently than preceding generations, with an added sense of wonder and awe. Isolated galaxies become objects of unimaginable dimension, and groups of galaxies suggest impossibly vast structures. We are privileged to perceive these groups for what they actually are, which makes observing them great fun.

Among the stars of Pegasus, the Winged Horse, are some of the fall sky's best galaxy groups for backyard observers. This tour concentrates on objects that should be detectable in a 10-inch telescope from reasonably dark skies, but larger scopes and darker skies will, of course, reveal more. Perhaps the most enthralling thing about observing galaxy groups is that they contain many levels of challenges. No matter your experience, location, or scope size, there will be a limit to your level of detection. Pushing that limit is what deep-sky observing is all about.

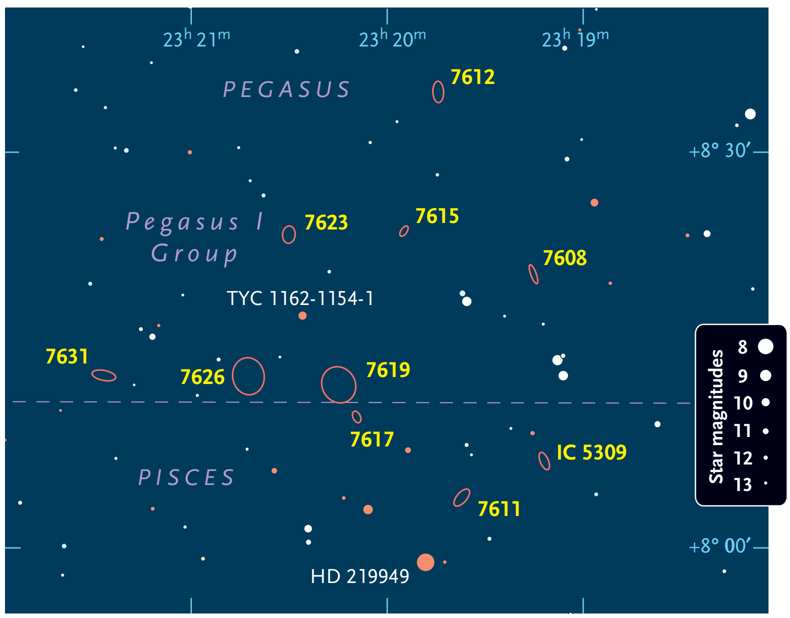



**Pegasus I Group**

**CELESTIAL SCATTERING.** Anchored by the galaxy pair NGC 7626 and NGC 7619, the Pegasus I group straddles the border between Pegasus and Pisces.

POSS-II / STSCI / CALTECH / PALOMAR OBSERVATORY

The table that accompanies this article gives an estimate of difficulty based on an experienced observer using a 10-inch telescope in a Bortle Class 4 sky (see *S&T:* Nov. 2014, p. 62). Such a sky is described as transitional between rural and suburban environments with a naked-eye limiting magnitude between 6.1 and 6.5. On this scale, a 1 is easy and a 7 probably isn't visible. The estimate is meant to offer a relative assessment of difficulty, but don't let it discourage you from trying even the most difficult objects. The only true assessment of difficulty will come from your own best attempt at detection. The magnifications listed are a recommended starting point. You will benefit, of course, from varying your magnification to suit your own circumstances.




## The Pegasus I Group

Straddling the Pegasus–Pisces border, the galaxy grouping dominated by **NGC 7619** and **NGC 7626** is sometimes called the Pegasus I group. The brightest 10 galaxies here are part of a larger group of about 39 galaxies. The four or five brightest members are visible in an 8-inch scope, while larger scopes reveal a rather crowded field of galaxies. To find the group, look for a slightly lopsided keystone asterism of 5th-magnitude stars 9° south-southeast from Alpha (α) Pegasi. Placing that asterism in the northwest quadrant of your finder scope should center the galaxy group.

NGC 7619 and 7626 are both large elliptical galaxies that lie 173 million light-years and 161 million light-years away, respectively. Their apparent angular separation is just 9′, with NGC 7626 nearly due east of NGC 7619. They show as similarly sized oval patches in the eyepiece, fairly uniform in brightness except for their small, nearly stellar, cores. Another 11′ east lies the spiral galaxy **NGC 7631**, an elongated oval blur with a brighter elongated center. This east-west line of three galaxies is the most striking feature of the Pegasus I group.

In a wide-field eyepiece, my eye is drawn across the invisible border of Pisces to the third brightest galaxy of the group, **NGC 7611**, about 12′ southwest of NGC 7619. It appears quite extended, with a brighter, noticeably circular core. A magnitude-6.9 star, HD 219949, shines 5.5′ to its southeast. Approximately the same in apparent size, but considerably fainter, is the neighbor almost 7′ to the northwest, **IC 5309**. This fairly tight spiral galaxy is very challenging in a 10-inch scope, but was no problem in my 18-inch. **NGC 7617** is closer to NGC 7619, just barely inside the boundary of Pisces, and is a smaller companion to the giant elliptical. NGC 7617 is an intermediate class of galaxy called a *lenticular*: it's disk-shaped like a spiral, but without the characteristic spiral arms or active star formation. NGC 7617 is also very challenging target in a 10-inch scope; look for a tiny spot of nebulosity about 3′ south-southwest of the circular glow of NGC 7619.

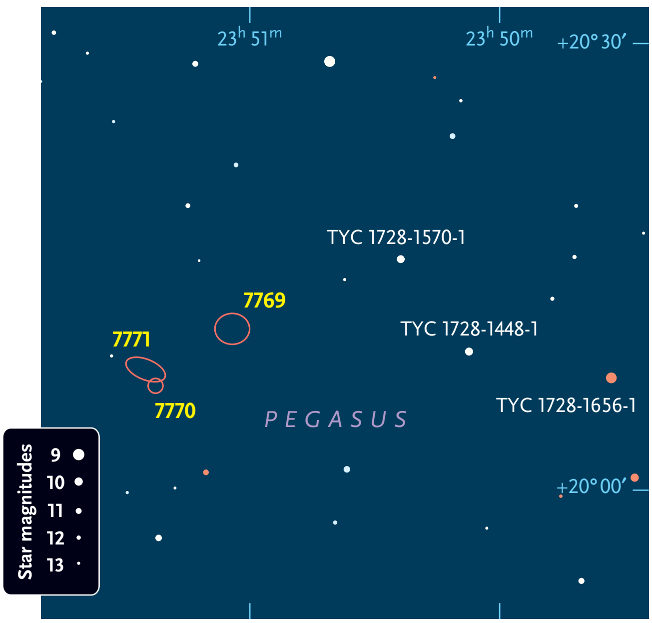
**NGC 7623**, which rivals NGC 7611 in brightness, lies about 11′ north of the prominent NGC 7619–NGC 7626 pair. Use the 10th-magnitude star, TYC 1162-1154-1, shining between the pair and NGC 7623, as a waymark. The galaxy shows an oval glow, brighter toward the center, stretching north-south. To the west of NGC 7623 are two very challenging targets. **NGC 7615** is a 15th-magnitude oval spot that will push a 10-inch telescope to its limit. Its neighbor, **NGC 7608**, while larger and brighter in listed magnitude, has considerably lower surface brightness and may not be detectable at all.

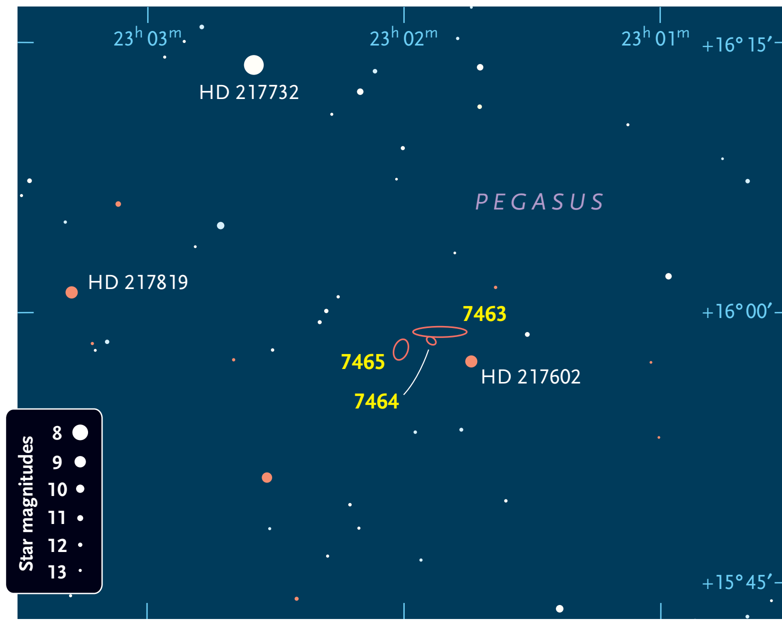
**NGC 7612**, which lies about 15′ northwest of 7623, marks the northern extent of the Pegasus I group. It's an elongated lenticular galaxy with a bright core.

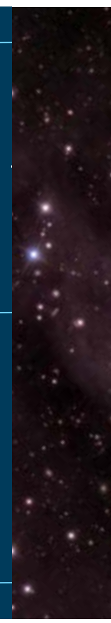
Several more galaxies become visible in the Pegasus I cluster with larger aperture; a 25-inch scope should detect at least 20. At any aperture, meticulous dark adaptation will help you reach fainter magnitudes. So, too, will a number of techniques and practices for seeing deep, such as employing a black hood to block any extraneous light. Learn to use your averted vision; in time it will become automatic. Movement helps your eye detect faint patches of light, so try rocking the scope or sweeping the area. Experiment with different magnifications. Keep your optics clean and well collimated. Stay comfortable, stay hydrated, and rest often. Above all, remain positive and persistent, and never assume an object is too difficult to attempt its observation.

## Beyond Pegasus I

**NGC 7769**, **NGC 7771**, and **NGC 7770** make a nice trio of galaxies located about a degree north-northwest of



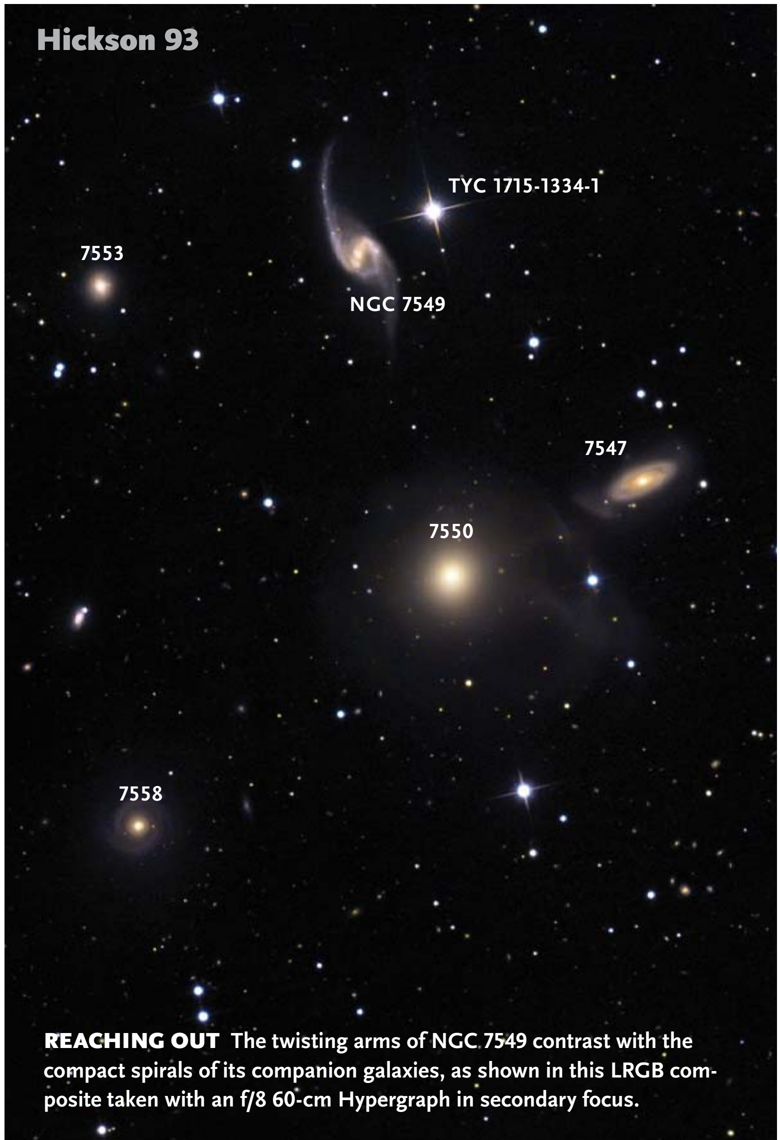
Phi (φ) Pegasi. On the west side of the trio, NGC 7769, displaying a circular halo around a luminous core, is the brightest in the group. NGC 7771 appears nearly as bright but is more elongated with a bright bar-shaped central feature. I have detected the pair in a 5-inch telescope. NGC 7770 is in contact with 7771 but is much more difficult to see, appearing as a very faint nebulous spot surrounding a stellar nucleus.

A similar trio featuring a bright pair with a faint companion lies 1° northwest of Alpha Pegasi and about 2.5′ from an 8th-magnitude field star, HD 217602, that interferes just a bit with observations. The brightest in the group is **NGC 7465**, a luminous oval halo that intensifies toward its center. Northwest of NGC 7465 is the rather elongated spiral, **NGC 7463**, a thin, uniformly bright stripe of light. Its faint companion, **NGC 7464**, is the dimmest and most difficult to observe of the group.

## Hickson Groups

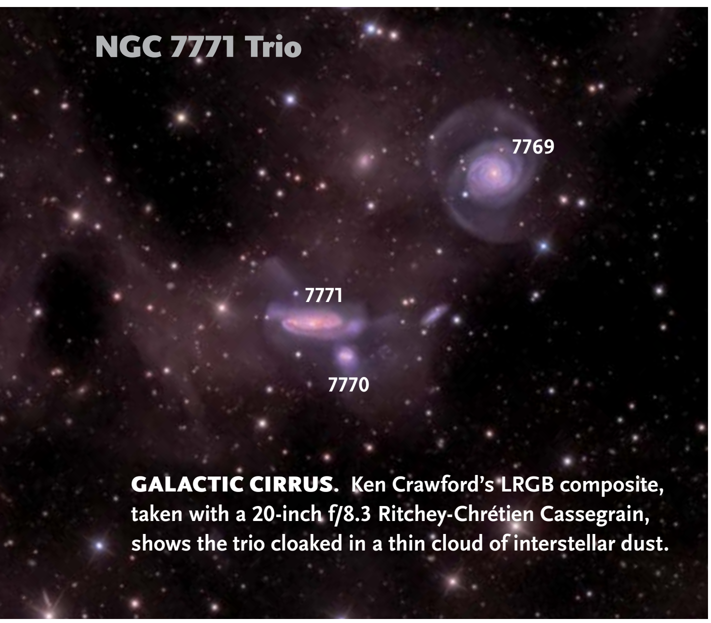
Canadian astronomer Paul Hickson compiled a list of 100 compact galaxy groups in 1982. These so-called Hickson Groups of four or more closely associated galaxies often show interaction among members. Favorite targets of amateur astronomers, many of the groups are quite challenging and often appear as no more than faintly detectable, undifferentiated blobs at low or moderate power. Yet some of the groups can be separated into their individual members even with 10 inches of aperture.

Pegasus contains seven Hickson groups. One of the more accessible is Hickson 93 (also cataloged as Arp 99) in the southwest corner of the Great Square. **NGC 7550**, the largest and brightest member, shows as distinctly round with a vivid core. Look for two stars, magnitude 6.5 and 6.7, about 1.5° apart; NGC 7550 is midway

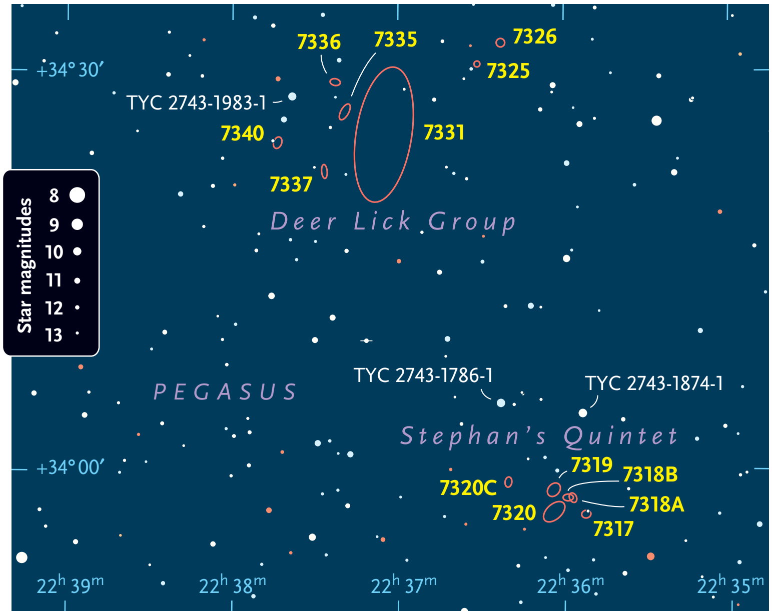


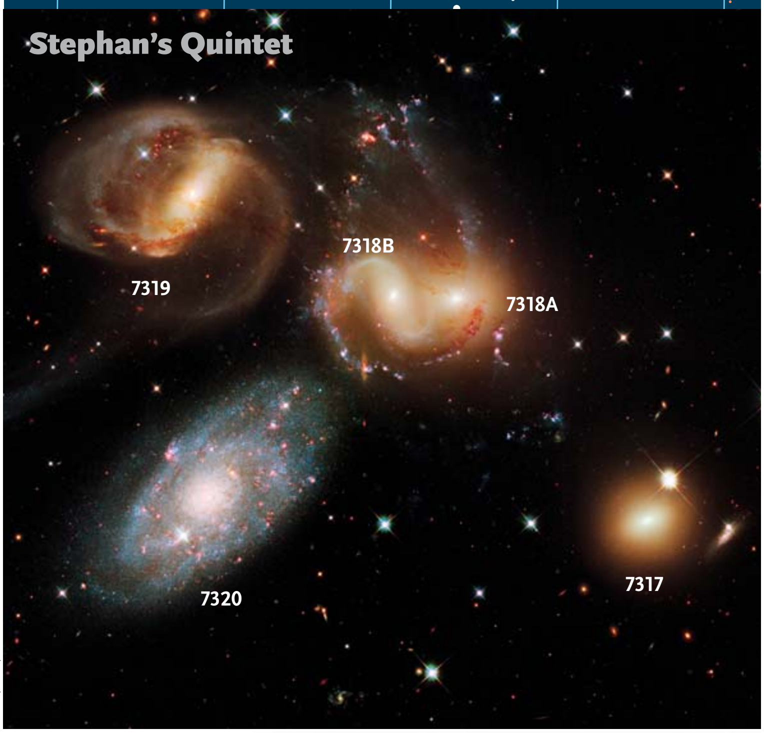

**REACHING OUT** The twisting arms of NGC 7549 contrast with the compact spirals of its companion galaxies, as shown in this LRGB composite taken with an f/8 60-cm Hypergraph in secondary focus.

JOSEF PÖPSEL / STEFAN BINNEWIES




**GALACTIC CIRRUS.** Ken Crawford's LRGB composite, taken with a 20-inch f/8.3 Ritchey-Chrétien Cassegrain, shows the trio cloaked in a thin cloud of interstellar dust.




NASA / ESA / HUBBLE SM4 ERO TEAM

**INTERLOPER** The crystalline blue of NGC 7320 contrasts dramatically with the burnished glow of the interacting galaxies, showing it to be an outsider. *Right:* Uwe Glahn's sketch of Hickson 92, made at the eyepiece of an 8-inch f/4 Newtonian reflector, gives an idea of the group's appearance when viewed with moderate aperture in good seeing.

between them, 4.5° northeast of Alpha Pegasi. Detectable in a 10-inch, it's easily seen with larger apertures.

The other four members of Hickson 93 are more challenging. Look about 3′ to the west of NGC 7550 for the elongated glow of **NGC 7547** and 5′ north for the smaller **NGC 7549**. An 11th-magnitude star shines about 1′ to the west of NGC 7549. The final two member galaxies, **NGC 7553** and **NGC 7558**, are extremely challenging. I wasn't able to detect NGC 7558 with my 18-inch scope, and NGC 7553 seems to be at the extreme limit of detection even at that aperture. You shouldn't be deterred by my experience, though; you never know what's actually visible in your own circumstance until you look.

The most famous Hickson group in Pegasus, perhaps the most famous of the entire catalog, is better known as *Stephan's Quintet*. Discovered in 1877 by Édouard Stephan, four of the five Quintet galaxies comprise a well-studied compact galaxy group, caught in the act of merging and catalogued as Hickson 92 (Arp 319). Movie buffs might recognize the group as the heavenly characters that open Frank Capra's holiday classic, *It's a Wonderful Life*. The contorted shapes of these galaxies bespeak violent collisions and make for interesting imagery.

Locating Stephan's Quintet is most easily accomplished by finding the much larger spiral galaxy **NGC 7331**, which lies northeast of the group. First, imagine a line connecting Eta (η) and Pi (π) Pegasi, the stars marking one of the forelegs of the winged stallion. Then look for two stars, HD 212988 (magnitude 6) and 38 Pegasi (magnitude 5.6), angling northeast from the center of that line. NGC 7331 lies 2° 20′ northeast of 38 Pegasi, at about twice the distance that separates the two stars. Its spiral is very elongated and angled nearly north-south. Using its long axis as a guide, adjust your view one eyepiece field south and a half field west. Stephan's Quintet is just 30′ to the south-southwest of NGC 7331, along the imaginary line connecting the spiral galaxy to 38 Pegasi.

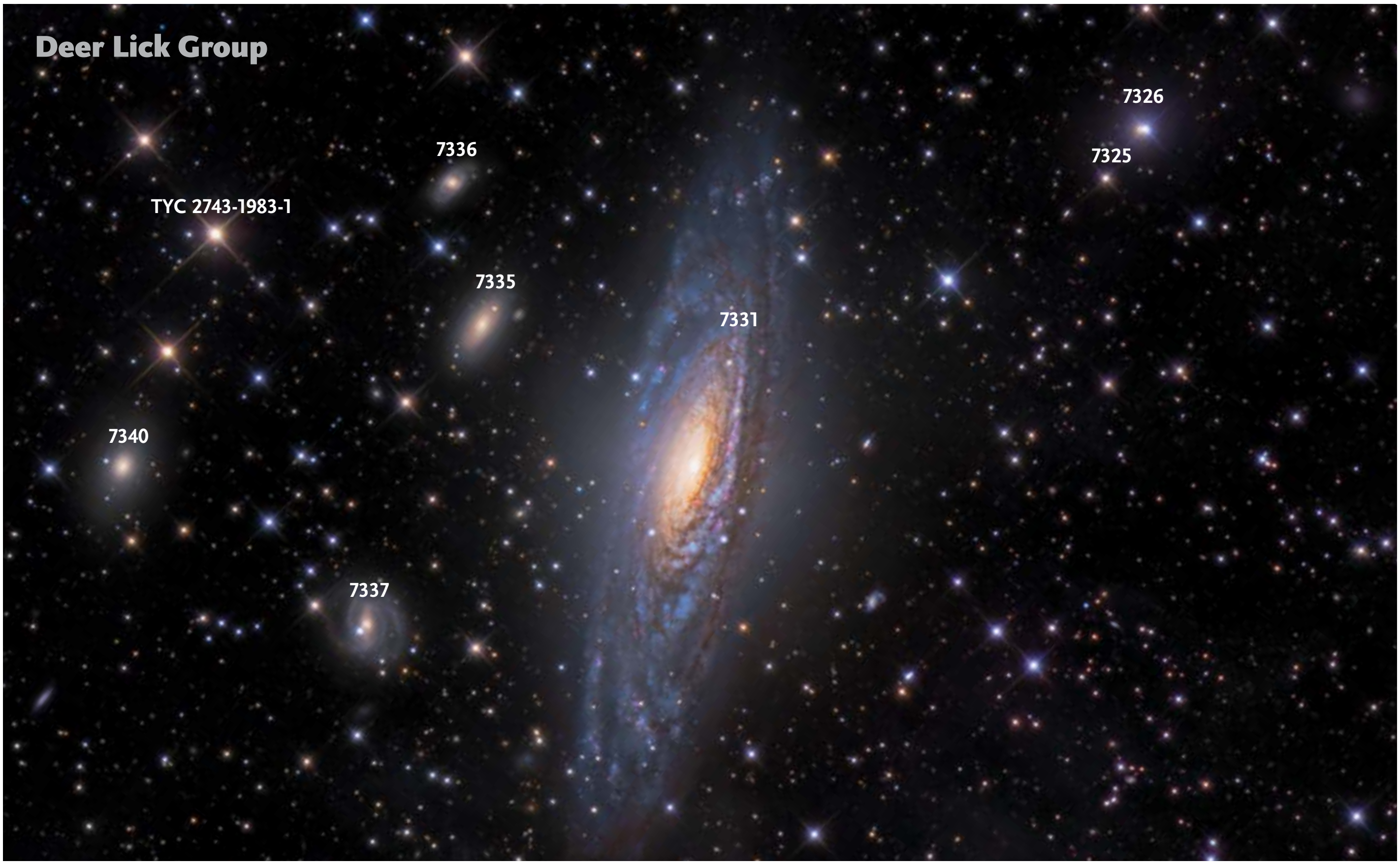
The brightest and largest member of Stephan's Quintet, **NGC 7320**, is a foreground object that isn't a true member of the Hickson association. In the eyepiece, it shows as a large, smooth oval that — to my eye — appears a bit dimmer than the interacting pair, **NGC 7318A** and **NGC 7318B**, about 1.5′ to the northwest. This overlapping pair appears as a single object: a distorted oval with a slightly more visible center. Very large scopes may detect two separate objects here, or at least a distinctly binary core. The southwest corner of the group is occupied by **NGC 7317**, which appears as a small hazy spot of nebulosity paired with a star of about 13th magnitude. **NGC 7319** is the faintest of the five components of Stephan's Quintet. It's an evenly lit elongated glow angled

Visit SkyandTelescope.com/observing/pegasus-galaxy-groups to download more observing files.

## Finding My Favorite Galaxy Groups in Pegasus

| Object | Mag (v) | Size | RA | Dec | Diff | Power |
|---|---|---|---|---|---|---|
| NGC 7317 | 13.6 | 48″ × 46″ | 22h 35.9m | +33° 57′ | 5 | 135× |
| NGC 7318A | 13.4 | 1.1′ × 1.0′ | 22h 35.9m | +33° 58′ | 5 | 135× |
| NGC 7318B | 13.1 | 1.6′ × 0.8′ | 22h 36.0m | +33° 58′ | 5 | 135× |
| NGC 7320 | 12.6 | 2.2′ × 1.2′ | 22h 36.1m | +33° 57′ | 4 | 120× |
| NGC 7319 | 13.1 | 1.6′ × 1.0′ | 22h 36.1m | +33° 59′ | 5 | 135× |
| NGC 7320C | 15.5 | 35″ × 29″ | 22h 36.3m | +33° 59′ | 7 | 135× |
| NGC 7326 | 15.8 | 46″ × 20″ | 22h 36.4m | +34° 33′ | 7 | 120× |
| NGC 7325 | 14.9 | 57″ × 38″ | 22h 36.6m | +34° 30′ | 6 | 120× |
| NGC 7331 | 9.5 | 10.5′ × 3.4′ | 22h 37.1m | +34° 25′ | 3 | 35× |
| NGC 7335 | 13.4 | 1.3′ × 0.5′ | 22h 37.3m | +34° 27′ | 5 | 135× |
| NGC 7336 | 14.5 | 0.8′ × 0.4′ | 22h 37.4m | +34° 29′ | 6 | 80× |
| NGC 7337 | 14.4 | 1.0′ × 0.8′ | 22h 37.4m | +34° 22′ | 7 | 135× |
| NGC 7340 | 13.7 | 0.9′ × 0.6′ | 22h 37.7m | +34° 25′ | 5 | 120× |
| NGC 7463 | 13.2 | 2.6′ × 0.6′ | 23h 01.9m | +15° 59′ | 5 | 135× |
| NGC 7464 | 13.3 | 31″ × 28″ | 23h 01.8m | +15° 58′ | 3 | 80× |
| NGC 7465 | 13.6 | 2.2′ × 1.8′ | 23h 02.0m | +15° 58′ | 3 | 135× |
| NGC 7547 | 13.7 | 1.0′ × 0.4′ | 23h 25.1m | +18° 58′ | 6 | 80× |
| NGC 7550 | 12.2 | 1.5′ × 1.3′ | 23h 15.3m | +18° 58′ | 3 | 50× |
| NGC 7549 | 13.0 | 2.8′ × 0.8′ | 23h 15.3m | +19° 02′ | 6 | 135× |
| NGC 7553 | 14.7 | 42″ × 32″ | 23h 15.6m | +19° 03′ | 6 | 135× |
| NGC 7558 | 14.9 | 52″ × 43″ | 23h 15.6m | +18° 55′ | 7 | 135× |
| IC 5309 | 13.7 | 1.3′ × 0.6′ | 23h 19.2m | +08° 07′ | 6 | 135× |
| NGC 7608 | 14.2 | 1.5′ × 0.4′ | 23h 19.3m | +08° 21′ | 7 | 80× |
| NGC 7611 | 12.5 | 1.5′ × 0.6′ | 23h 19.6m | +08° 04′ | 4 | 135× |
| NGC 7612 | 12.8 | 1.6′ × 0.7′ | 23h 19.7m | +08° 35′ | 5 | 135× |
| NGC 7615 | 14.3 | 50″ × 18″ | 23h 19.9m | +08° 24′ | 6 | 120× |
| NGC 7617 | 13.8 | 0.9′ × 0.7′ | 23h 20.2m | +08° 10′ | 6 | 135× |
| NGC 7619 | 11.1 | 2.5′ × 2.0′ | 23h 20.2m | +08° 12′ | 3 | 35× |
| NGC 7623 | 12.9 | 1.4′ × 1.0′ | 23h 20.5m | +08° 24′ | 5 | 135× |
| NGC 7626 | 11.1 | 2.5′ × 2.1′ | 23h 20.7m | +08° 13′ | 3 | 35× |
| NGC 7631 | 13.1 | 1.7′ × 0.7′ | 23h 21.4m | +08° 13′ | 5 | 135× |
| NGC 7769 | 12.0 | 3.2′ × 2.7′ | 23h 51.1m | +20° 09′ | 3 | 135× |
| NGC 7770 | 13.8 | 51″ × 45″ | 23h 51.4m | +20° 06′ | 5 | 135× |
| NGC 7771 | 12.3 | 2.5′ × 1.2′ | 23h 51.4m | +20° 07′ | 4 | 120× |

The difficulty score ranges from 1 (easy) to 7 (undetectable) as described in the main text. 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.




KEN CRAWFORD

**STRANGER** NGC 7331, some 46 million light-years away, fronts a dense galaxy group that lies more than six times more distant from us than the 10th-magnitude spiral.

northwest-southeast. The faintest member of Hickson 92 is the much more difficult **NGC 7320C**, which lies about 4′ east-northeast of the main group. It takes a lot of aperture to detect this tiny 16th-magnitude spot.

## Outside the Quintet

A trail blaze on the path to Stephan's Quintet, NGC 7331 also anchors its own galaxy grouping. It's accompanied by several faint companions that are popular with deep-sky observers trying to push the envelope of visibility. The group has picked up the popular moniker, the *Deer Lick Group*, presumably in honor of Deer Lick Gap, North Carolina, where author Tom Lorenzin made a particularly successful observation of its members. The fainter galaxies are often erroneously referred to as satellites, but they're unassociated with NGC 7331, which, at about 46 million light-years distant, is much closer to us (the fainter galaxies are at least six times farther away).

The brightest companion, **NGC 7335**, is about 3.5′ to the northeast of the center of NGC 7331. It's elongated at a similar angle to its larger neighbor and has a slightly more visible core. **NGC 7337** is 5′ southeast of NGC 7331 and is involved with a star close alongside. The pair looks a bit like a double star in the eyepiece. **NGC 7340**, 8′ east of NGC 7331, and **NGC 7336**, which is 2′ north of NGC 7335, are both barely detectable spots of nebulosity. The very challenging **NGC 7325**, small, faint, and round, sits about 8′ northwest of NGC 7331. The ultimate challenge here, perhaps, is the detection of **NGC 7326**, which lies another 3.5′ northwest of NGC 7325. I needed my 30-inch telescope to detect it.

## Your Best Tools

It's a happy circumstance that, in some directions, modest telescopes can encompass several external galaxies in a single field of view. The significance of this is more fully appreciated when we contemplate the true nature of those faint smudges of light. Armed with modern knowledge, we're fortunate to perceive a much grander cosmos than could astronomers of earlier centuries. Allowing yourself to enjoy that privileged vantage point will enhance your observing experience, so remember to bring your imagination and sense of wonder to the telescope. They just may be the best tools you have as an observer. ✦

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*Contributing Editor **Ted Forte** observes from his home near Sierra Vista, Arizona. He pens a monthly astronomy column for his local newspaper, the* Sierra Vista Herald.


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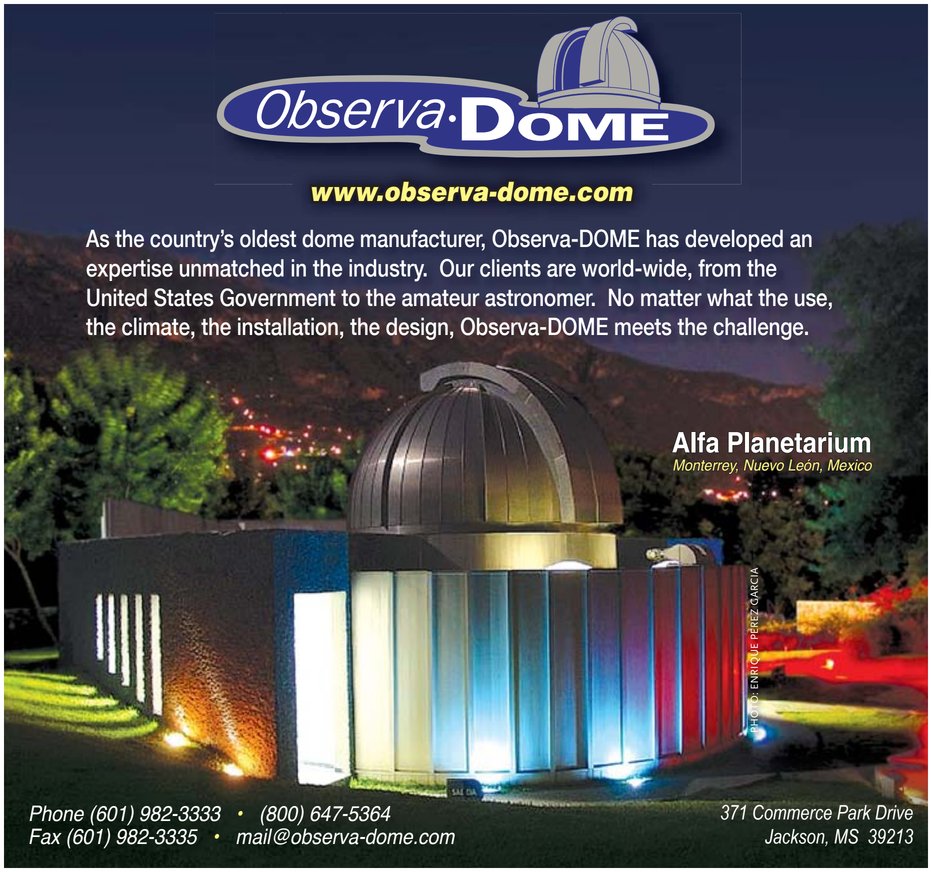
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## In This Section



**PHOTOGRAPH: NASA / ESA / HUBBLE SPACE TELESCOPE**

**Tucked away in eastern Delphinus, the globular cluster NGC 7006 offers a challenge for visual observers; see page 57.**

## OCTOBER 2015

**1–2** **LATE NIGHT:** The waning gibbous Moon shines in the Hyades when it rises in the east. The Moon occults Aldebaran for western North America near dawn on the 2nd; see page 49.

**8** **DAWN:** The crescent Moon, Venus, and Regulus form an irregular triangle approximately 20° above the eastern horizon, with Mars and Jupiter glowing 4° apart to the lower left.

**9** **DAWN:** The Moon forms a triangle with Mars and Jupiter, with Venus and Regulus blazing above.

**11** **DAWN:** Binoculars may reveal the tiny light of Mercury left or upper left of the thin crescent Moon very low in the east before sunrise.

**11–25** **DAWN:** The zodiacal light is visible 120 to 80 minutes before sunrise from dark locations at mid-northern latitudes. Look east for a tall pyramid of light stretching up toward Gemini with Venus, Mars, and Jupiter in its base.

**12** **NIGHT:** Algol shines at minimum brightness for roughly two hours centered at 10:01 p.m. PDT (1:01 a.m. October 13th EDT); see page 51.

**15** **NIGHT:** Algol shines at minimum brightness for roughly two hours centered at 9:50 p.m. EDT.

**17, 18** **DAWN:** Mars gleams less than ½° from Jupiter.

**21–22** **PREDAWN:** The moderate Orionid meteor shower is active in the hours before dawn.

**24–26** **DAWN:** The triple lights of Venus, Jupiter, and little Mars shine above the eastern horizon. Jupiter and Venus are less than 2° apart, with dimmer Mars just 3° below them.

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

◀ SUNSET — MIDNIGHT — SUNRISE ▶

| | |
|---|---|
| Mercury | Visible beginning October 8; E |
| Venus | E; SE |
| Mars | E |
| Jupiter | E |
| Saturn | SW |

### Moon Phases

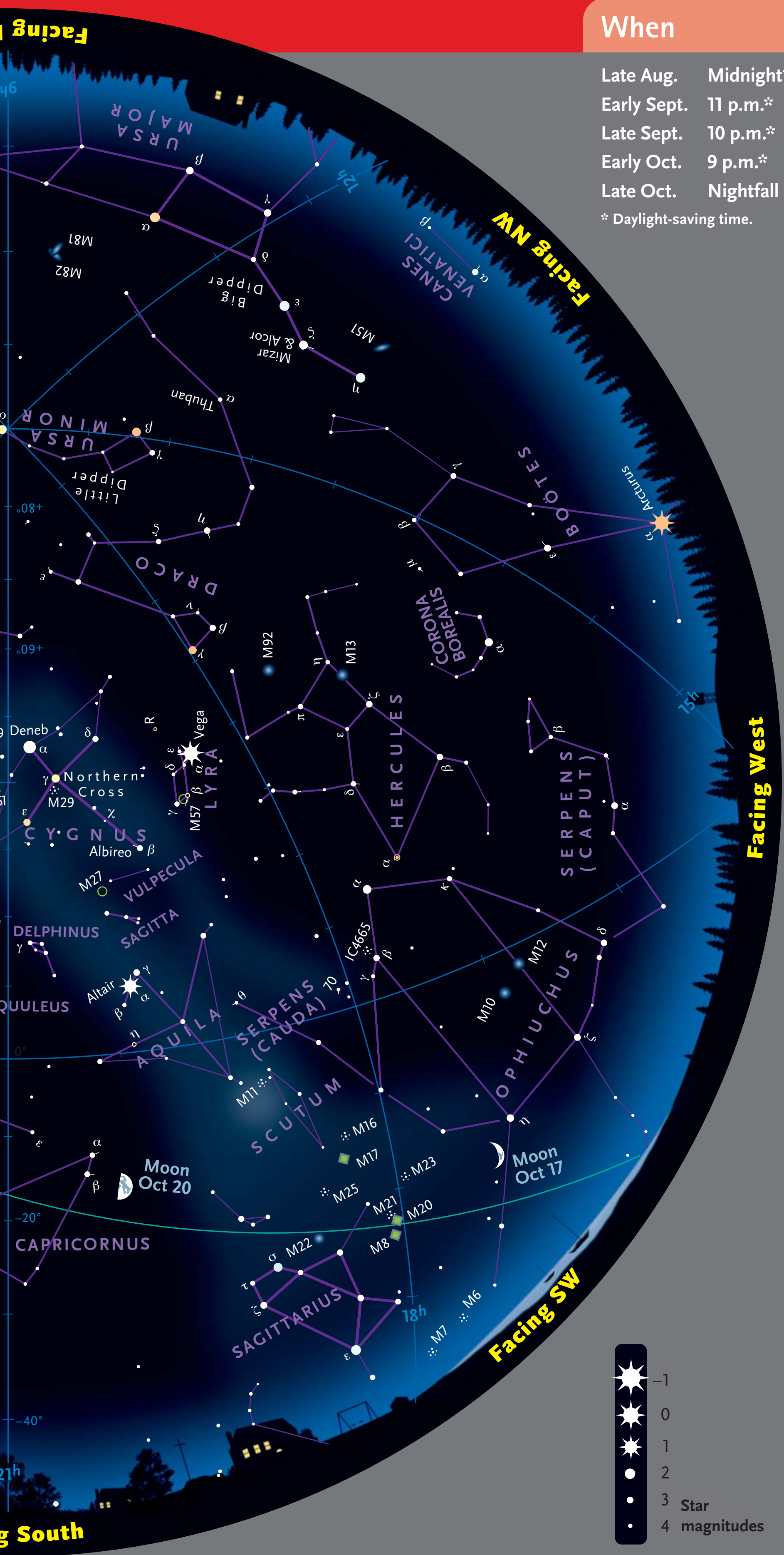
| | |
|---|---|
| Last Qtr October 4 5:06 p.m. EDT | New October 12 8:06 p.m. EDT |
| First Qtr October 20 4:31 p.m. EDT | Full October 27 8:05 a.m. EDT |

| 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 | 31 |

## Using the Map

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

EXACT FOR LATITUDE 40° NORTH.




## When

| | |
|---|---|
| Late Aug. | Midnight* |
| Early Sept. | 11 p.m.* |
| Late Sept. | 10 p.m.* |
| Early Oct. | 9 p.m.* |
| Late Oct. | Nightfall |

* Daylight-saving time.

Gary Seronik

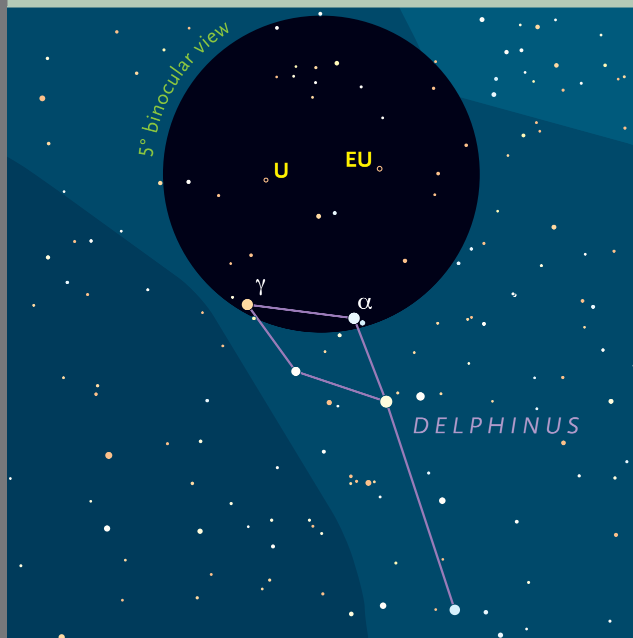
Binocular Highlight

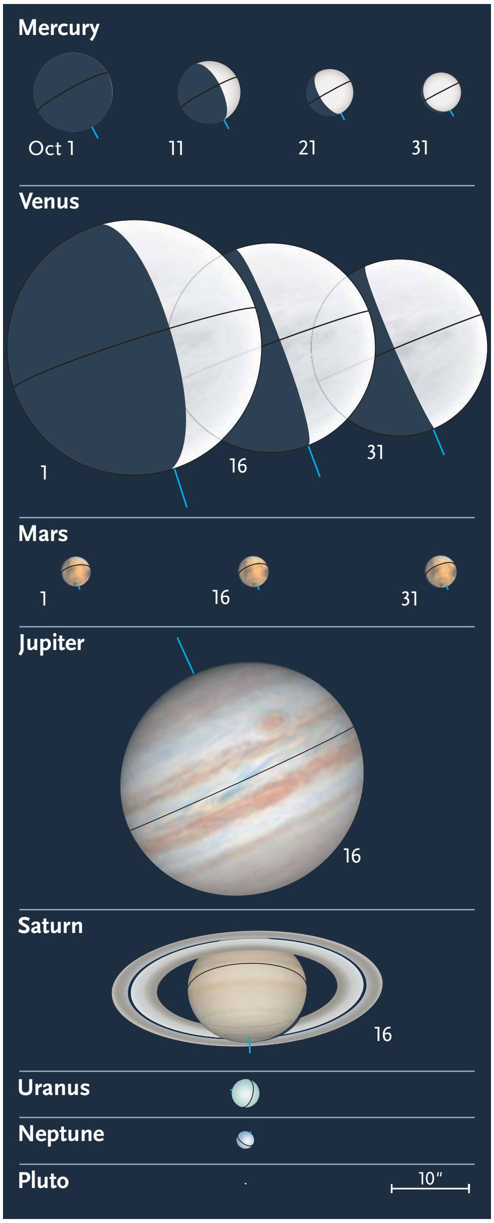
# Two Delphinus Variables

**One of the sky's** most distinctive small constellations is Delphinus, the Dolphin. Its shape is easy to visualize, consisting of five stars that range in brightness only from magnitude 3.6 to 4.4. Yet despite lying next to a rich swath of Milky Way, Delphinus is surprisingly devoid of binocular deep-sky treasures. But that's not to say the Dolphin has nothing of note. Indeed, it possesses two fine binocular variable stars: **U** and **EU Delphini**.

Both stars are categorized as small-amplitude, pulsating red giants and sit together in the same, easy-to-locate binocular field. Just north of Gamma (γ) and Alpha (α) Delphini lies a pair of 6.2- and 6.8-magnitude stars. Proceed about half that distance north again from the pair, and you come to U and EU, separated by roughly the same spacing as Gamma and Alpha. U is the easternmost of the two variables and ranges in brightness from a peak of magnitude 5.5 to roughly two magnitudes fainter, over a period of about 1,160 days. Neighboring EU isn't quite as dramatic in its brightness swings. It erratically changes from magnitude 6 to 7 but does so over period of 62.7 days. Since neither star dims beyond magnitude 7.5, both remain within easy binocular reach all the time.

But you should take all the numbers given here with a grain of salt — no two cycles are exactly the same. Sometimes the stars brighten a little more than average, sometimes a little less. Their luminosity curves also have lots of subtleties. U Delphini, for example, tends to dim quickly then slowly brighten, with lots of little peaks and valleys along the way. But that's the fun of variable stars. It's difficult to know from night to night exactly what they will do! ✦



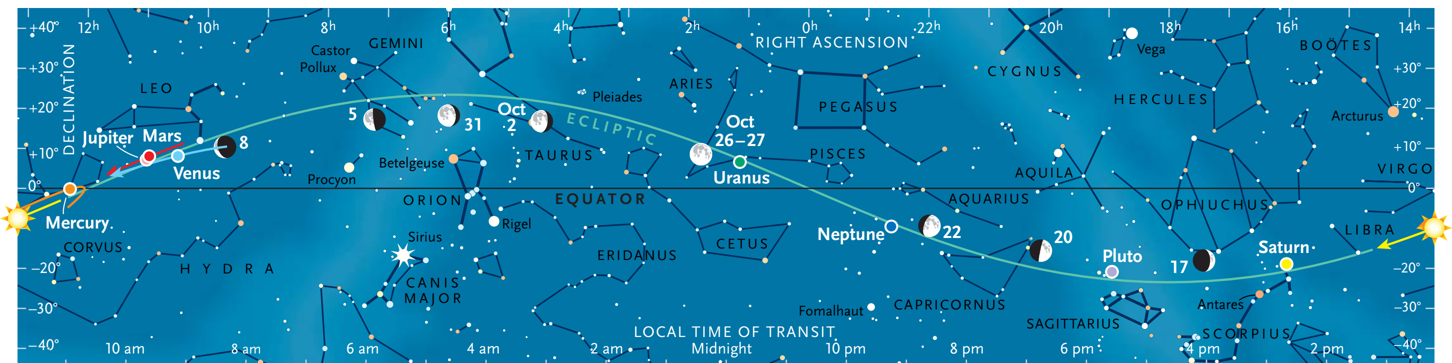



## Sun and Planets, October 2015

| | October | Right Ascension | Declination | Elongation | Magnitude | Diameter | Illumination | Distance |
|---|---|---|---|---|---|---|---|---|
| Sun | 1 | $12^h 26.8^m$ | –2° 53′ | — | –26.8 | 31′ 57″ | — | 1.001 |
| | 31 | $14^h 18.7^m$ | –13° 51′ | — | –26.8 | 32′ 13″ | — | 0.993 |
| Mercury | 1 | $12^h 20.0^m$ | –4° 43′ | 2° Mo | — | 10.2″ | 0% | 0.658 |
| | 11 | $12^h 04.4^m$ | +0° 24′ | 16° Mo | +0.3 | 8.1″ | 29% | 0.830 |
| | 21 | $12^h 40.6^m$ | –2° 09′ | 17° Mo | –0.9 | 6.1″ | 73% | 1.103 |
| | 31 | $13^h 38.7^m$ | –8° 31′ | 11° Mo | –1.0 | 5.2″ | 93% | 1.304 |
| Venus | 1 | $9^h 40.6^m$ | +10° 33′ | 43° Mo | –4.7 | 33.0″ | 35% | 0.505 |
| | 11 | $10^h 12.2^m$ | +9° 13′ | 45° Mo | –4.6 | 28.8″ | 42% | 0.578 |
| | 21 | $10^h 48.0^m$ | +7° 02′ | 46° Mo | –4.6 | 25.5″ | 48% | 0.653 |
| | 31 | $11^h 26.3^m$ | +4° 06′ | 46° Mo | –4.5 | 22.9″ | 53% | 0.729 |
| Mars | 1 | $10^h 23.5^m$ | +11° 25′ | 34° Mo | +1.8 | 3.9″ | 97% | 2.388 |
| | 16 | $10^h 58.5^m$ | +8° 00′ | 39° Mo | +1.8 | 4.1″ | 96% | 2.306 |
| | 31 | $11^h 32.7^m$ | +4° 27′ | 45° Mo | +1.7 | 4.2″ | 95% | 2.209 |
| Jupiter | 1 | $10^h 49.9^m$ | +8° 26′ | 27° Mo | –1.7 | 31.4″ | 100% | 6.272 |
| | 31 | $11^h 11.3^m$ | +6° 19′ | 51° Mo | –1.8 | 33.0″ | 99% | 5.977 |
| Saturn | 1 | $15^h 56.1^m$ | –18° 36′ | 54° Ev | +0.6 | 15.7″ | 100% | 10.561 |
| | 31 | $16^h 08.4^m$ | –19° 15′ | 27° Ev | +0.5 | 15.3″ | 100% | 10.879 |
| Uranus | 16 | $1^h 07.9^m$ | +6° 29′ | 176° Ev | +5.7 | 3.7″ | 100% | 18.987 |
| Neptune | 16 | $22^h 36.5^m$ | –9° 40′ | 135° Ev | +7.8 | 2.3″ | 100% | 29.248 |
| Pluto | 16 | $18^h 55.2^m$ | –21° 04′ | 81° Ev | +14.2 | 0.1″ | 100% | 33.111 |

**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-October; 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

# Legends in Three Directions

## The stars of the October sky spell out a trio of ancient tales.

**For many lands** in Earth's northern temperate zone, October is the month of painted leaves. Few sights in nature can match the wonder of the changing colors of the fall foliage, especially in places like New England, where the hues are most varied, bright, and vivid.

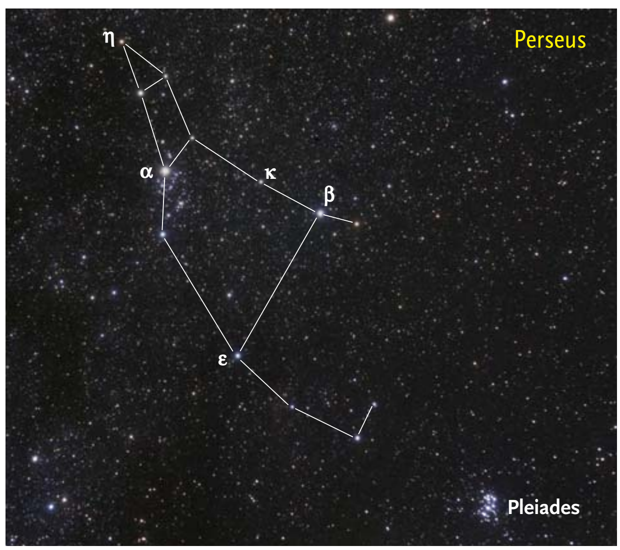
Yet the stars of October evenings are even more the stuff of which legends are made. At this time, you can see the stars of the greatest star-myth of Western (European) culture and greatest star-myth of Eastern (East Asian) culture, both high in the sky. And low down you can see the stars of one of the greatest of Native American star-myths — the one that offers an explanation for the marvelous color change of fall leaves.

**The myth of Perseus, in the northeast and east.** Six constellations help tell the Perseus tale: Cepheus and Cassiopeia (king and queen), Pegasus (winged horse), Andromeda and Perseus (chained maiden and hero), and Cetus (officially whale, but traditionally sea monster). The legendary figures of these constellations glimmer in our imaginations as we observe them on October evenings — though at the time of our all-sky map (page 42), Cetus lies right on the east-to-southeast horizon with one star, Alpha (α) Ceti, not quite risen.

There are visual and scientific realities of these constellations as captivating as the characters and story of the classical Perseus myth. They include the prominent naked-eye patches of M31 (the Andromeda Galaxy), the Double Cluster of Perseus, and the Alpha Persei Cluster — plus the more challenging naked-eye deep-sky objects M34 (open star cluster in Perseus), NGC 752 (open star cluster in Andromeda), and M15 (globular star cluster in Pegasus). And the constellations of the Perseus myth contain the three most important prototype variable stars: the eclipsing binary Beta (β) Persei (Algol), the long-period variable Omicron (ο) Ceti (Mira), and the Cepheid variable, Delta (δ) Cephei. Algol represents the severed head of monstrous Medusa — a mythological figure who seems to be known to more of my college students these days than even Perseus or Andromeda.

**The myth of the weaving maiden and the cowherd, high in the west and southwest.** Depending on the source, the woman at work is either Vega or the entire pattern of Lyra; the cowherd (or prince in some versions of this East Asian legend) is either Altair or the compact straight line of three stars, Gamma (γ) (Tarazed), Alpha (Altair), and Beta Aquilae (Alshain). The two figures are celestial lovers, separated from each other for neglecting their heavenly duties. It's the "river" of the bright Milky Way that separates Vega and Altair, and therefore these lovers, all year long — save for "the seventh night of the seventh moon" (usually celebrated in early August) when they cross a bridge of magpies and are together for just one night. If Vega is imagined to be the lady herself, the greater pattern of Lyra is her loom. For amateur astronomers, this instrument, which supposedly spins out celestial tapestries, is even more marvelous for offering Epsilon (ε) Lyrae (the Double Double) and M57 (the Ring Nebula).

**The myth of the hunters pursuing the bear, low in the northwest.** Various Native American tribes see a bear in the bowl of our Big Dipper. The tail of Ursa Major holds three hunters of the bear: Robin (Alioth); Chickadee (Mizar), who carries a pot (Alcor); and Moose-Bird (Alkaid). Following these in a continued curve are the additional hunters Pigeon, Blue Jay, Horned Owl, and Saw-Whet Owl, represented by Gamma (Seginus), Epsilon (Izar), Alpha (Arcturus), and Eta (η) Boötis (Muphrid), respectively. The Boötes foursome sets as the bear circles under the North Star, but circumpolar Robin, Chickadee, and Moose-Bird stay up to kill the bear, whose blood splashes red the breast of Robin and then, down below, the foliage of October. ✦




AKIRA FUJII

# A Climax of Conjunctions

Three bright planets converge in grand groupings at dawn.

**Can we possibly top** the spectacular planetary pairings earlier in this "Year of the Conjunctions"? October may feature 2015's most *complexly* beautiful planetary arrangements of all — though we must get up before sunrise to see them.

At dusk this month, the only bright planet visible is Saturn, shining low in the southwest. But before and during dawn, three planets — Venus, Jupiter, and Mars — converge after the last and brightest of them, Venus, passes Regulus. Mars brushes less than a half degree from Jupiter. Then, for the final event in an epic series of close conjunctions, Venus comes to within one degree of Jupiter. That's also when Venus, Jupiter, and Mars contract into what will be arguably the finest tight trio of bright planets we'll see for many years. And well below these three planets, after the first week of October, we get a good view of a fourth — Mercury.

## DUSK

**Saturn** appears above the southwestern horizon about 45 minutes after sunset in October, but little more than 10° high as seen from around latitude 40° north. That's not high enough to allow a sharp image of the planet's globe and rings in a telescope, but binoculars will provide a good view of Beta (β) Scorpii as Saturn tracks north of it this month, passing only ⅔° from the double star between October 23rd and 27th. The ringed planet starts the month setting 2½ hours after the Sun in eastern Libra, but ends it setting less than 1½ hours after the Sun in western Scorpius.

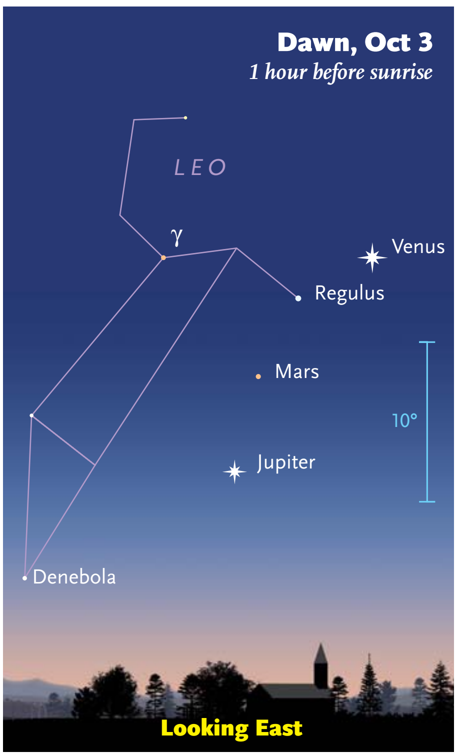
## NIGHT

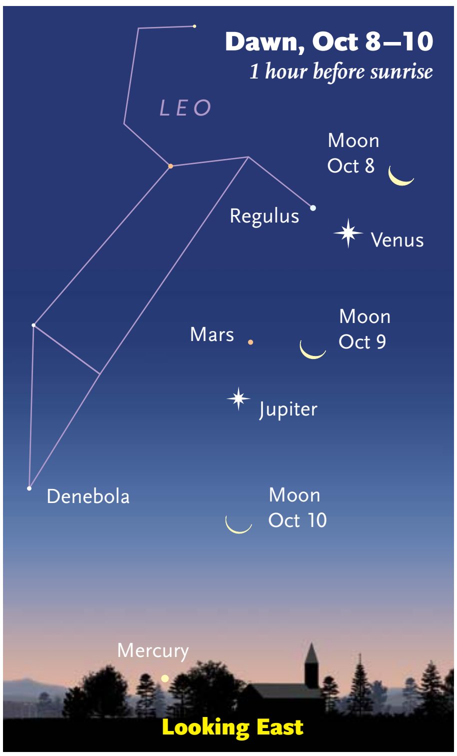
**Pluto** is best seen right after full darkness falls. Use the finder chart at **skypub.com/pluto2015** to locate the 14th-magnitude world as it approaches Xi² ($\xi^2$) Sagittarii.

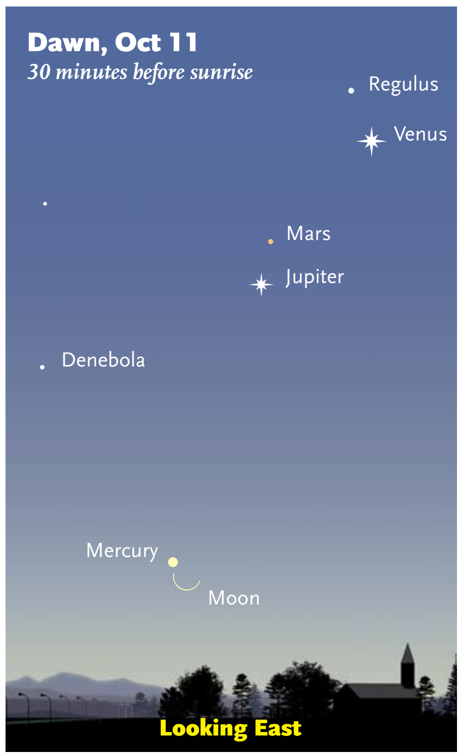
**Neptune**, fading a trace to magnitude +7.9 in Aquarius, is highest in the south in the middle of the evening. **Uranus**, peaking at magnitude +5.7 in Pisces, reaches opposition on the night of October 11–12 so is highest in the middle of the night all month. The apparent diameter of Uranus is now 3.7″, Neptune's only 2.3″. Finder charts for both are at **skypub.com/urnep**.

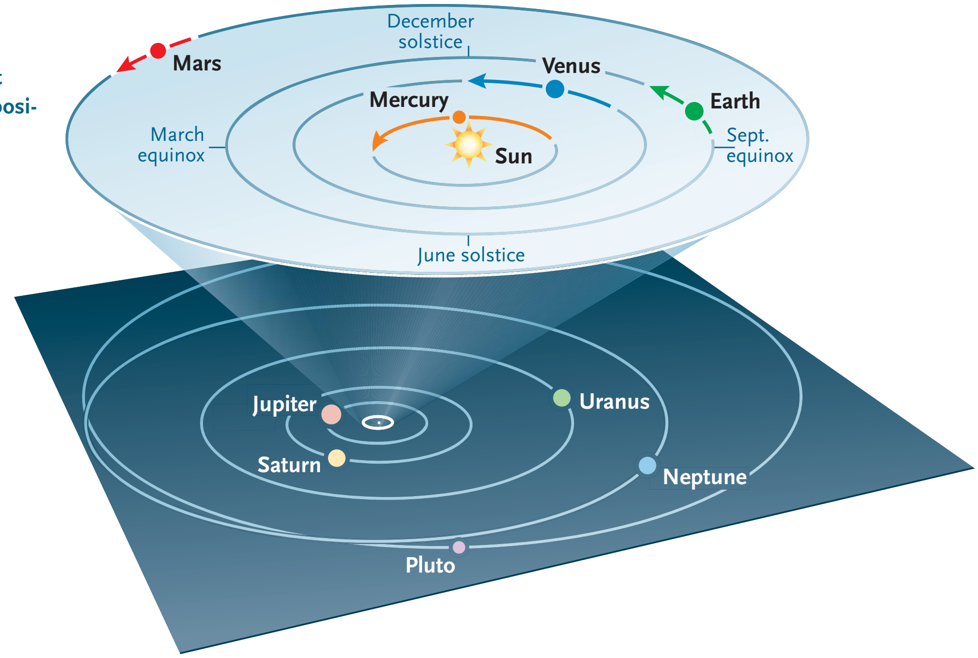
## DAWN

**Venus**, Regulus, **Mars**, and **Jupiter** — in that order from top to bottom — start






### ORBITS OF THE PLANETS

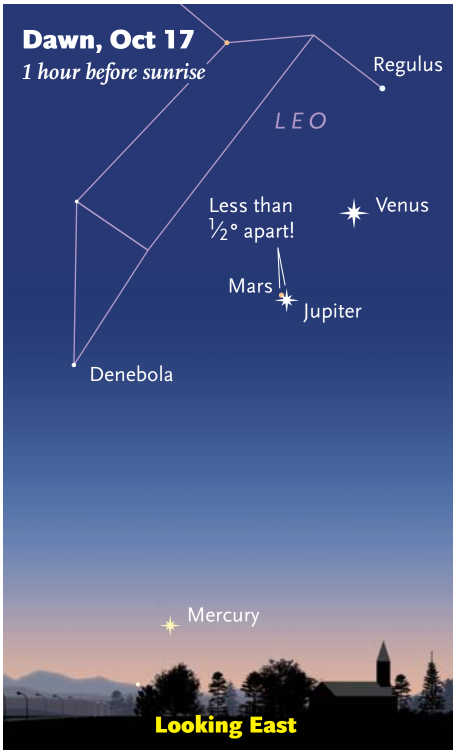
**The curved arrows show each planet's movement during October. The outer planets don't change position enough in a month to notice at this scale.**

October almost evenly spaced in a beautiful curve extending from about 30° to 15° altitude in the east an hour before sunrise.

In the pre-dawn hours of October 8th, the crescent Moon forms a compact triangle with Venus and Regulus approximately 2½° apart. They're still that close the next morning, when the Moon forms a second tight triangle with Mars and Jupiter only about 10° below Venus and Regulus.

On October 17th and 18th, magnitude +1.7 Mars shines less than ½° from magnitude –1.8 Jupiter, with Venus less than 7° to their upper right. In the same medium-power telescopic field of view, Jupiter appears almost exactly 8 times wider than Mars.

On October 25th and 26th, Venus blazes just 1.1° from Jupiter. This is the last in the current series of Venus–Jupiter conjunctions, one that closely resembles the 3–2 B.C. series that may have been the appearances that became known as the Star of Bethlehem. Venus has dimmed a bit from magnitude –4.7 at October's start to –4.5; on these mornings of conjunction, however, it still greatly outshines Jupiter.




October 26th is also the day Venus reaches greatest elongation from the Sun (46° W), rising just short of 4 hours before our star. The planet's globe may not appear half-lit in a telescope until several days later; check each morning. Venus's apparent diameter shrinks from 33″ to 23″ during October — Jupiter's grows from 31″ to 33″ in the same period — while Venus's phase thickens from 34% to 53% sunlit.

But Venus and Jupiter have additional close company during their conjunction. On the morning of the 26th, the circle containing Venus, Jupiter, and Mars is only about 3½° in diameter. The three travel as a "trio" — within a 5° circle — all the way from October 22nd to the 29th. In the final days of the month, Mars moves away from Jupiter, with Venus in hot pursuit. Venus soon catches Mars, glowing less than 1° from the Red Planet from November 2nd through 4th.

**Mercury** brightens rapidly early in the month and may first be visible about 1° above or upper left of the slim crescent Moon on the 11th, when the duo reaches an altitude of about 8° a mere forty minutes before sunup. Mercury is less than 20° below Jupiter at this time, but the gap between them grows as the month progresses.

Mercury reaches greatest western elongation on the 16th, when it rises at the very start of astronomical twilight. By the final week of the month, the tiny planet brightens to magnitude –1 but descends quite low into the sunrise.

## MOON PASSAGES

The Moon pairs spectacularly with Venus and Regulus on October 8th, and on the 9th it forms an equally splendid triangle with Jupiter and Mars. Just before sunrise on October 11th, the slim lunar crescent can be spotted just below Mercury. The waxing crescent Moon is upper left of Saturn on the evening of the 16th. ✦

# The Fickle Draconids

Watch for slow, unusual meteors that may show up on October 8–9.

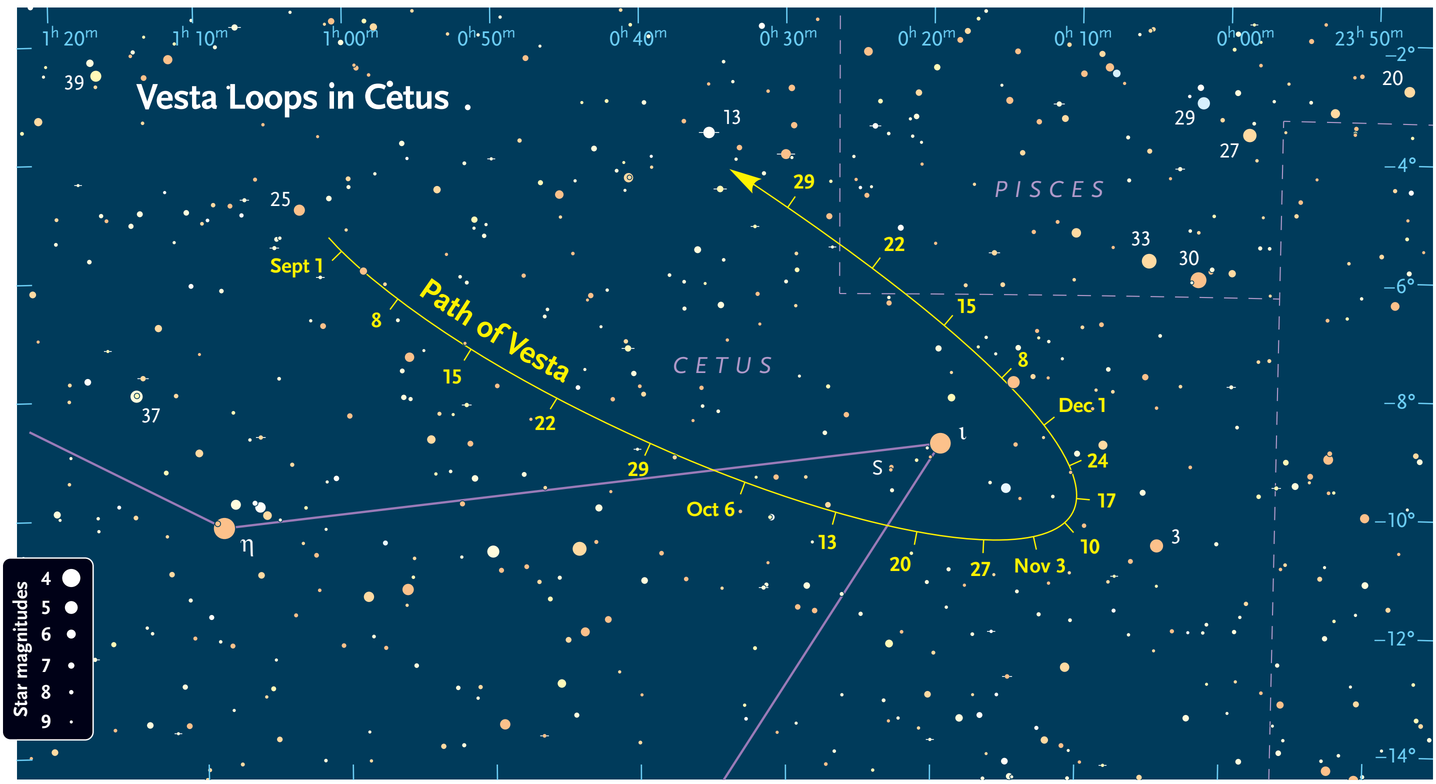
**Some meteor showers** are as regular as the seasons, but the Draconids of early October are wildly variable. Most years nothing happens. But in 1933 and 1946 the Draconids produced two of the great meteor storms of the last century. Some other years have produced lesser displays, with zenithal hourly rates (ZHRs) of 20 to more than 500 meteors visible per hour by an ideally situated observer.

In 2011, bright moonlight and the shower's erratic reputation resulted in only spotty amateur data. Too bad; the few counts that the International Meteor Organization received suggest that the ZHR hit 300 that year. Working independently, Josep Maria Trigo-Rodríguez (Institute of Space Sciences, Spanish National Research Council) concluded that the ZHR exceeded 400 per hour and that Earth passed in rapid succession through three dense streams of particles. Two of the streams were predicted to exist; the third was a surprise. A Draconid fireball over Spain rivaled the brightness of the gibbous Moon in the sky.

Then in 2012 came a swarm of unusually faint Draconids detected by radar.

The Draconid particles are shed by Comet 21P/Giacobini-Zinner, a short-

A fireball from no known radiant lit up Canada's Banff National Park at 1:30 a.m. on December 20, 2014, while Brett Abernethy had his camera on a tripod, its shutter open, and its f/2.8 lens pointed toward Orion and Sirius. He was hoping to catch an aurora. When the Sun is behind clouds it gives them a silver lining; the meteor lined them with blue.



period comet that currently rounds the Sun about every 6.6 years. Most displays have happened in years close to the comet's perihelion; the comet last passed nearest to the Sun in February 2012. That would suggest not much will happen in 2015. But you never know.

Nor is the timing of a possible shower very predictable. Recent activity suggests that if we see anything this year, its brief peak could arrive anytime from $21^h$ Universal Time on October 8th (Thursday afternoon in North America) to $14^h$ UT on the 9th (midday Friday).

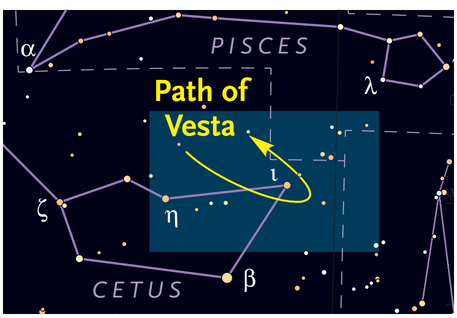
The shower's radiant is at the head of Draco, which is circumpolar. The radiant is highest in the evening, rather than in the morning as for most showers, so start watching at dusk. The Draconids appear exceptionally slow-moving as meteors go — partly because they are catching up to Earth from behind, and also because their short-period orbit means they don't fall sunward from very far out.

This year we'll have no problem with moonlight; the Moon is a waning crescent.

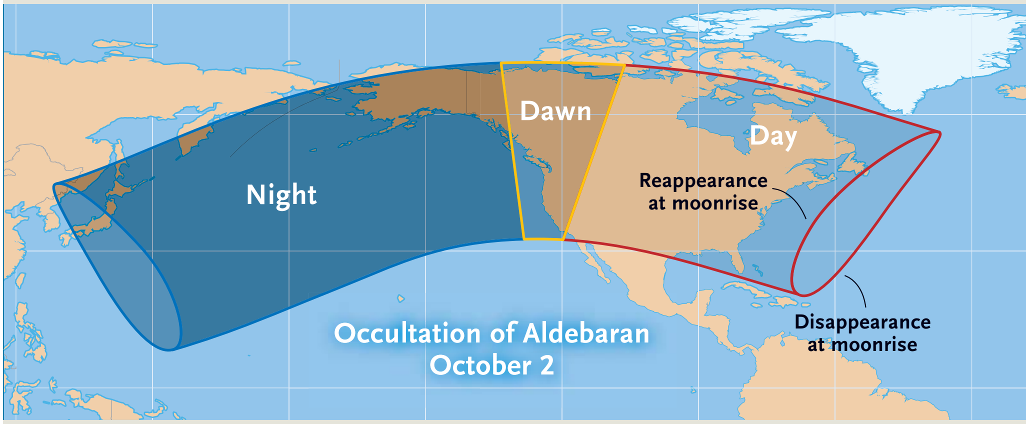
---

**Vesta, the brightest asteroid,** isn't getting much attention lately — not since NASA's Dawn spacecraft dumped it in 2012 and flew away to take up with Ceres, which Dawn is now orbiting and becoming ever more photographically entranced with.

But Vesta remains the leading asteroid date for amateurs. It's easy to see in binoculars at magnitude 6.2 for a couple weeks around its September 29th opposition, and it's still as bright as 6.8 on November 1st, 7.5 on December 1st, and 8.0 at the end of the year. On its path at left, the ticks are for 0:00 Universal Time.




# A Blue-Sky Occultation




**On the morning of October 2nd, the newly risen waning crescent Moon occults Aldebaran for most of North America in daylight, and for the West Coast as dawn brightens before sunrise. (The dividing lines between day, dawn, and night are drawn for the center of the occultation, halfway between disappearance and reappearance.)**

**Have you ever seen** the Moon occult a star in the clear blue sky of a sunny day?

For the second time in two months, the Moon will cover 1st-magnitude Aldebaran for parts of North America. The Aldebaran occultation of September 4–5 was written up in last month's issue, page 51. The one coming up on the morning of October 2nd will be rather different.

First, it happens well after sunrise for most of the continent. Westerners are the exception; most of them will see the Moon cover Aldebaran while dawn is brightening. Along much of the West Coast, it won't quite be sunrise even when Aldebaran reappears out from behind the Moon.

Second, the Moon will be waning gibbous, 74% sunlit. When the Moon is waning, an occulted star disappears on the bright, sunlit limb and reappears from behind the dark limb. The bright limb's glare will be greater than during September's occultation, when the Moon was last quarter, so it will interfere a little more with Aldebaran's orange firespark in the last seconds before the star snaps out.

Most important will be the clarity of your daytime sky. If the sky is hazy blue-white, the Moon itself may be hard to spot. Once you've got it, though, even a small telescope is likely to show the 1st-magnitude star, especially if you switch to medium-high power (see *S&T*: Oct. 2014, p. 36).

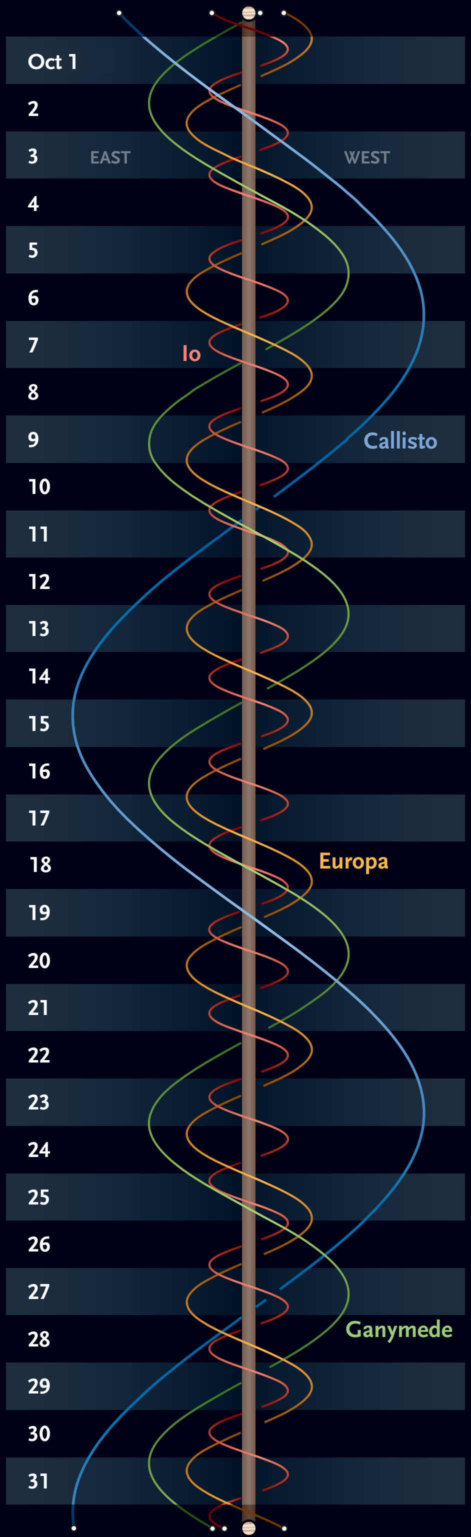
Aldebaran will snap back into view from behind the Moon's invisible dark limb up to an hour or more later.

Here are some predicted times; all are a.m.: Montreal, *disappearance* 9:56, *reappearance* 10:52 EDT. Central Massachusetts, *d.* 10:00, *r.* 10:56 EDT. Toronto, *d.* 9:56, *r.* 10:55 EDT. Washington DC, *d.* 10:03, *r.* 11:00 EDT. Atlanta, *d.* 10:09, *r.* 11:01 EDT. Miami, *d.* 10:32, *r.* 10:56 EDT. Winnipeg, *d.* 8:35, *r.* 9:41 CDT. Chicago, *d.* 8:53, *r.* 9:55 CDT. Kansas City, *d.* 8:53, *r.* 9:54 CDT. Austin, *d.* 9:18, *r.* 9:43 CDT. Edmonton, *d.* 7:14, *r.* 8:23 MDT. Denver, *d.* 7:41, *r.* 8:44 MDT. Vancouver, *d.* 6:02, *r.* 7:17 PDT. Berkeley, *d.* 6:17, *r.* 7:17 PDT. Los Angeles, *d.* 6:39, *r.* 7:15 PDT.

Interpolate between cities near you to estimate the times for your location. Set up early; the Moon and star won't wait. Detailed timetables for western locations where the sky will be somewhat dark are at **lunar-occultations.com/iota/bstar/1002zc692.htm**. (The table has three long sections: disappearance times, reappearance times, and the cities' coordinates.)

In the West, also watch for occultations of Hyades stars, 4th magnitude and fainter. Timetables for the brightest Hyades, for sites where the sky may be sufficiently dark, are at **lunar-occultations.com/iota/bstar/bstar.htm**.

## 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.

When Christopher Go shot this image on June 12th, Jupiter was visible in evening twilight, so its more brightly lit side faced west. Now that Jupiter shines before dawn, we see its celestial eastern side catching sunlight the best. (South here is up.)

# Action at Jupiter

**Dawn breaks** relatively late in October, especially because most of us are still on daylight-saving time. That's good for Jupiter followers. Early dawn finds Jupiter moderately well up in the east — amid Venus, Mars, and Regulus, as told on page 46. But we are still seeing Jupiter on the far side of the solar system from us, so it appears only about 32 arcseconds wide.

Even so, any telescope shows Jupiter's four big Galilean moons. Binoculars usually show two or three. Identify them using the diagram at left.

All the October interactions between Jupiter and its satellites and their shadows are listed on the facing page.

And here are the times, in Universal Time, when the Great Red Spot should cross Jupiter's central meridian. The dates, also in UT, are in bold. (Eastern Daylight Time is UT minus 4 hours.) Detecting the Red Spot when Jupiter is this small and low is an accomplishment. Good luck!

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

These times assume that the spot is centered at about System II longitude 230°. Features on Jupiter appear closer to the central meridian than to the limb for 50 minutes before and after transiting. A light blue or green filter slightly increases contrast and visibility of Jupiter's reddish and brownish markings.

**Double shadow transits.** On Sunday morning October 18th, Ganymede and Io will *both* be casting their tiny black shadows onto Jupiter's face from 10:42 to 12:08 Universal Time (6:42 to 8:08 a.m. EDT, 3:42 to 5:08 a.m. PDT).

A week later, on Sunday morning October 25th, another double shadow transit of Ganymede and Io will run from 12:36 to 14:53 UT (6:36 to 8:53 a.m. MDT, 5:36 to 7:53 a.m. PDT).

Ganymede's shadow is the larger and more visible of the two. That's because Ganymede is 5,262 km (3,270 miles) in diameter, while Io is only 69% as wide and therefore presents only half as much surface area to block sunlight.

# Asteroid Occultations

**On the morning of October 5th,** telescope users from Georgia through central Texas can watch for a 9.1-magnitude star in Cancer to be occulted by the faint asteroid 675 Ludmilla for up to 2.2 seconds. The star will be low in the east-southeast.

**Late on the night of October 16–17,** observers along a narrow track running from northern Ohio to southern California can watch for 215 Oenone to occult a 9.0-magnitude star at the Cetus-Pisces border for up to 3.6 seconds. If you're near the east end of the track, the star will be very low in the southwest.

**On the evening of October 29th,** 415 Palatia should occult an 8.2-magnitude star in Capricornus along a line from southern California through southern Wyoming for up to 4.5 seconds. The star will be low in the southwest.

For maps of the shadow tracks with predicted times, and finder charts for the stars, go to **asteroidoccultation.com/IndexAll.htm**. For how to time these events and where to report your times, see **asteroidoccultation.com/observations**. Video recording yields the desired accuracy; see "Equipment" on that page.

For advice and help, join the International Occultation Timing Association (IOTA) discussion group at **groups.yahoo.com/neo/groups/IOTAoccultations**. ✦

## Minima of Algol

| Sept. | UT | Oct. | UT |
|---|---|---|---|
| 3 | 1:39 | 1 | 17:46 |
| 5 | 22:28 | 4 | 14:35 |
| 8 | 19:17 | 7 | 11:23 |
| 11 | 16:05 | 10 | 8:12 |
| 14 | 12:54 | 13 | 5:01 |
| 17 | 9:42 | 16 | 1:50 |
| 20 | 6:31 | 18 | 22:39 |
| 23 | 3:20 | 21 | 19:27 |
| 26 | 0:09 | 24 | 16:16 |
| 28 | 20:57 | 27 | 13:05 |
| | | 30 | 9:54 |

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.

## Phenomena of Jupiter's Moons, October 2015

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

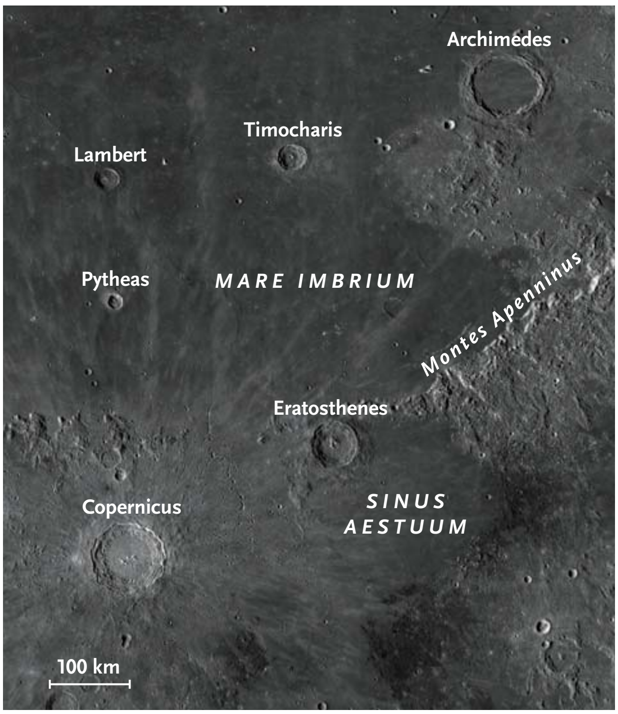
Every day, interesting events happen between Jupiter's satellites and the planet's disk or shadow. The first columns give the date and mid-time of the event, in Universal Time (which is 4 hours ahead of Eastern Daylight Time). Next is the satellite involved: **I** for Io, **II** Europa, **III** Ganymede,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

# A Corner of Imbrium

In just one telescopic view, you can retrace more than 4 billion years of lunar history.

**Most "Exploring the Moon" columns** describe a single type of lunar landform, such as basin rims, crater floors, rilles, or mare ridges. Yet when looking through a telescope's eyepiece, you don't see just one feature in isolation but rather everything in that portion of the Moon. The fun then comes in deciphering which processes created the different landforms you see — and in what sequence.

In fact, this is the stratigraphic approach that legendary astrogeologist Eugene Shoemaker and his colleagues developed in the late 1950s, when modern mapping of the Moon began in preparation for the Apollo landings. Stratigraphy is based on the *law of superposition,* namely, the rock units on top must be younger than the ones below. For example, sometimes craters sit atop other features and therefore are obviously younger. More often, however, a crater's deposits — secondary craters, rays, or other ejecta — define the overlap relationships.




The array of features in the southeast corner of Mare Imbrium holds the key to understanding the region's geologic history. For example, why does Archimedes have truncated rim deposits and a flat, lava-covered floor?

Shoemaker first applied this stratigraphic interpretation to the southeast corner of the Imbrium basin, stretching from Copernicus to Archimedes. And it's a good starting point for budding lunar explorers to learn to read the Moon's history, because it's well placed, dramatic, and reveals a fascinating story.

## A Big, Ancient Splat

Start your observational investigation with a broad overview, looking over the entire Imbrium region. You'll see an oval outline of mountain chains that surround and contain **Mare Imbrium**. The Alps, Caucasus, Apennine, and Carpathian ranges are the remnant rim of the giant Imbrium impact basin, which formed about 3.85 billion years ago when a huge asteroid collided with the Moon. Because its lava-filled interior and mountainous rim cover so much territory, this basin must be one of the oldest lunar features.

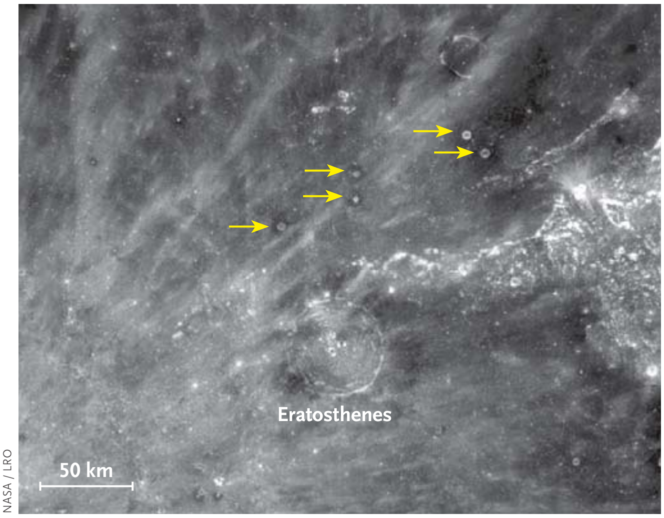
But what did that primordial projectile smash into? Some pre-Imbrium material is visible at the edges of the eyepiece view. For example, the lower-right corner of the photo at left shows hints of old craters that were smashed through, covered, and bulldozed by Imbrium ejecta that flowed across the land like an immense mudslide. These ruined features are the oldest landforms visible in this area.

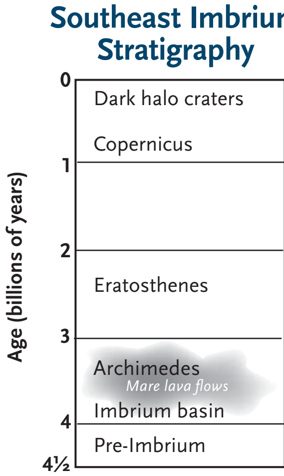
What happened after this enormous basin formed is clear: it filled with mare lava flows. But a question that careful visual observations solved was: *when* did those flows erupt? Shoemaker recognized that the crater **Archimedes**, 81 kilometers (50 miles) across, provides critical clues about the sequence of events after the basin's creation.

Although Archimedes' rim is relatively fresh, its outer deposits of ejecta have been completely covered by Mare Imbrium's lava flows. Shoemaker reasoned that the basin's formation erased all previous topography in the impact zone. Then lavas erupted repeatedly and flowed across the basin's floor. Later, Archimedes and other craters formed on this fresh lava plain. Later still, another round of Imbrium lavas flowed across the surface, surrounding and covering the ejecta from Archimedes.

*Contributing Editor* ***Charles A. Wood*** *(www2.lpod.org) is coauthor of the book* 21st Century Atlas of the Moon.

Charles A. Wood




**This timescale illustrates the sequence of events described in the text. You can create a similar stratigraphic timeline for any area you observe carefully on the Moon.** CHARLES A. WOOD

**With the Sun shining directly down on the lunar landscape, the rim of Eratosthenes is nearly invisible. Not far to its north are a series of small pits called *dark halo craters* (arrowed) that punched through a bright crater ray from Copernicus.**

Magma must have also risen up along fractures underlying Archimedes, explaining how mare lava partially filled the crater's floor and buried its central peaks.

Shoemaker noticed that the 59-km-wide crater **Eratosthenes**, which interrupts the Montes Apenninus, has small secondary craters and faint rays visible at full Moon on the nearby plains of Mare Imbrium. So Eratosthenes must have formed after the last lava flows in this area. Moreover, because it maintains some rays (which erode away rather quickly), it's probably younger than other craters on Mare Imbrium that lack ray patterns.

Are any nearby craters likely to be younger than Eratosthenes? There's one obvious candidate: **Copernicus**. Based on the brightness and extent of its rays and secondary craters, 96-km-wide Copernicus is the youngest large landform in this area. Its ejecta clearly lie atop those of Eratosthenes. Ages determined by counts of small craters superposed on Copernicus' wide apron of debris indicate that this impact occurred 800 million to 1 billion years ago. This is ancient by Earth standards — but relatively recent for events on the Moon.

Finally, are any features in this southeast Imbrium quadrant even younger than Copernicus? Many small craters a few kilometers in diameter appear younger, because they display crisp rims that would have been smoothed and eroded over time.

But can we use the law of superposition to *prove* that they're younger than Copernicus? Yes! During full Moon, point your telescope to the tract of mare just north of Eratosthenes. They're a challenge to see, but under high magnification you might notice about a half-dozen dark splotches. At the center of each is a 3- to 5-km-wide impact crater gouged into bright ray material from Copernicus. These small pits, known as *dark halo craters,* excavated underlying mare lavas and spread them as pulverized debris on top of the ray.

Within this eyepiece-wide view of southeast Imbrium, a careful observer can identify landforms created during 4 billion years of lunar history, from battered pre-basin ruins to very young dark halo craters cutting through bright rays. Using the benchmarks explored here, now have a look at every other feature in the field of view and try to decipher where it fits in this lunar sequence. ✦

## The Moon • October 2015

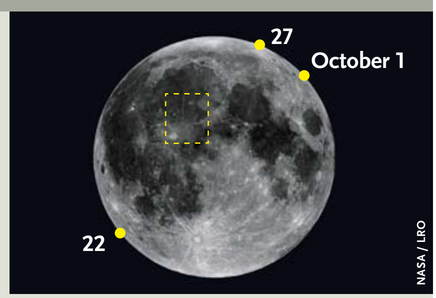
### Phases

**LAST QUARTER**
**October 4, 21:06 UT**

**NEW MOON**
**October 13, 0:06 UT**

**FIRST QUARTER**
**October 20, 20:31 UT**

**FULL MOON**
**October 27, 12:05 UT**




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

### Distances

| | |
|---|---|
| **Apogee** 252,518 miles | **October 11, 13ʰ UT** diam. 29′ 40″ |
| **Perigee** 222,739 miles | **October 26, 13ʰ UT** diam. 33′ 3″ |

### Librations

| | |
|---|---|
| **Byrd (crater)** | **October 1** |
| **Short (crater)** | **October 22** |
| **Mare Humboldtianum** | **October 27** |

# Millions Together

## The stars gather close in the southern wing of Cygnus the Swan.

*Burning our hearts out with longing*
*The daylight passed:*
*Millions and millions together,*
*The stars at last!*
— Æ (George William Russell), *Night,* 1904

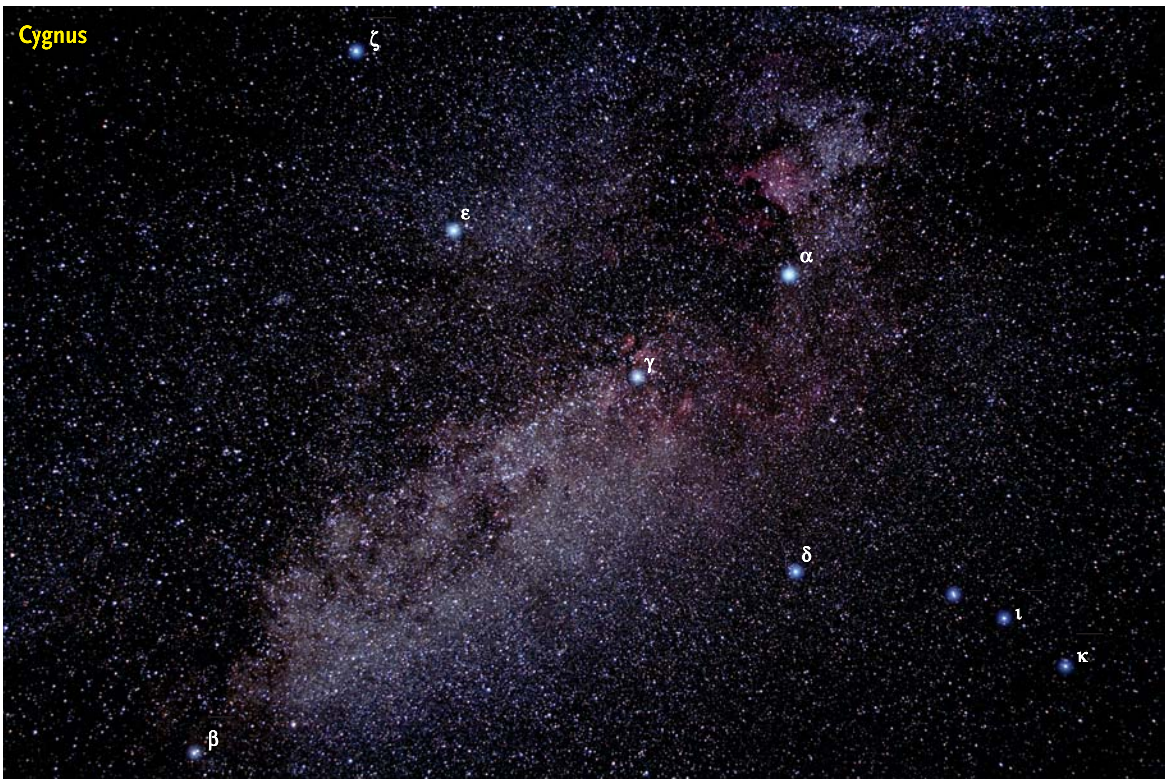
**How large would** a telescope have to be to show you a million stars? Many variables are involved, but the short answer is: not very big. There are more than a million stars 11th magnitude or brighter, but you'd have to peruse the entire celestial sphere to spot them. Under dark skies, you could see them in a 3-inch scope. Tens of millions of stars are within the grasp of a 10-inch scope.

The stars are most densely crowded along the plane of our galaxy, where there are as many as 150,000 stars in one square degree of sky. Most of them are far too faint to reach with a backyard telescope, but we can appreciate them with our mind's eye. The region near the bend of Cygnus the Swan's southern wing is one of these high-density regions, as well as the place where we'll start this month's sky tour.

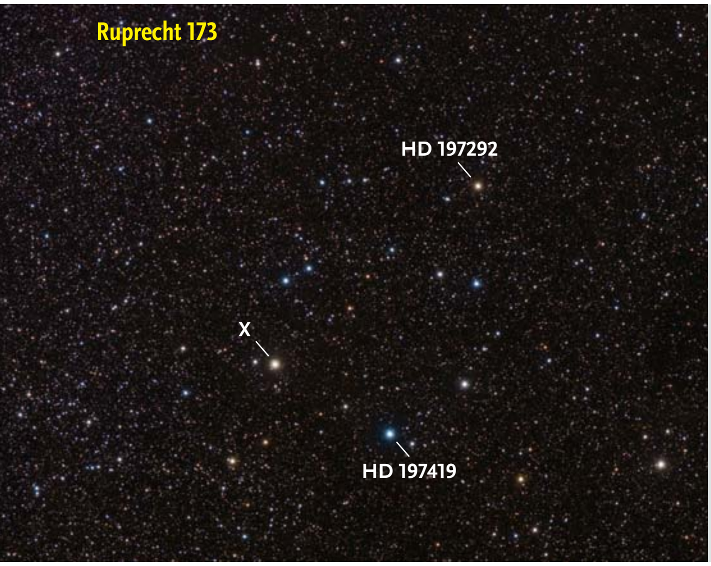
Golden-hued Epsilon (ε) Cygni marks the wing's bend and serves as a starting point for our explorations. A quintet of little-known star clusters hovers north of Epsilon, but in such a crowded star field it's not surprising that listings for size and position differ among various catalogs. This makes it even more intriguing to discover what we can see for ourselves.

We'll begin with **Ruprecht 173**, a large cluster located 1.8° north-northwest of Epsilon. Ruprecht clusters are named for Czech astronomer Jaroslav Ruprecht, one of the authors of the *Catalogue of Star Clusters and Associations* (1958, 1970), its supplement (1982), and related works.

Through my 130-mm refractor at 23×, I see Ruprecht 173 dominated by a 22′ circlet of stars, magnitude 6.5 and fainter. The easternmost star is **X Cygni**, a Cepheid variable star with a period of 16.4 days and a magnitude range of 5.9 to 6.9. X Cygni and a 7th-magnitude star




DAN LESSMAN




BERNHARD HUBL

## The Stars of Cygnus

| Object | Type | Size | RA | Dec. |
|---|---|---|---|---|
| Ruprecht 173 | Open cluster | 40.0′ | $20^h$ $41.7^m$ | +35° 33′ |
| X Cygni | Variable star | — | $20^h$ $43.4^m$ | +35° 35′ |
| Ruprecht 175 | Open cluster | 15.0′ | $20^h$ $45.4^m$ | +35° 31′ |
| Ruprecht 174 | Open cluster | 9.0′ | $20^h$ $43.4^m$ | +37° 01′ |
| Dolidze 47 | Open cluster | 5.0′ | $20^h$ $41.7^m$ | +36° 37′ |
| DoDz 11 | Open cluster | 13.1′ | $20^h$ $51.0^m$ | +35° 50′ |
| Dolidze 45 | Remnant cluster | 16.2′ | $21^h$ $10.8^m$ | +37° 34′ |

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.

north of the circlet's western edge emit a golden glow. A wide W of five stars sits southwest of the circlet, and 40 to 50 fainter stars are loosely scattered about, forming a group with indefinite borders that's only slightly more prominent than the starry background. The catalog in *Star Clusters* (Brent A. Archinal and Steven J. Hynes) gives this cluster a diameter of 40′, while *Sky Catalogue 2000.0* (Alan Hirshfeld and Roger W. Sinnott) lists 50′.

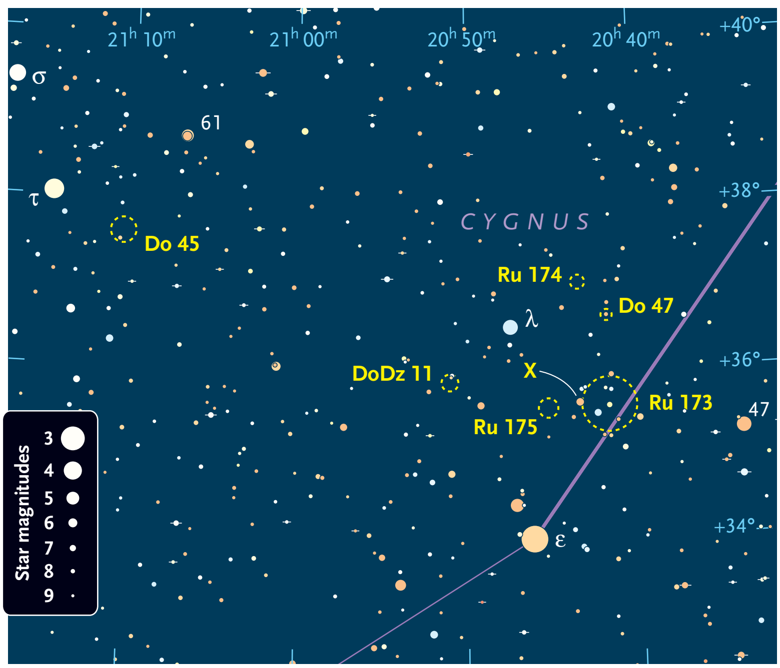
Sharing the field of view with Ruprecht 173, **Ruprecht 175** is a very granular haze overlaid by several stars magnitude 9 and fainter. Boosting the magnification to 91×, Ruprecht 175 displays about 20 moderately bright to faint stars over a dim, patchy haze roughly 8′ across. This corresponds fairly well to the 9′ size given in *Sky Catalogue 2000.0*, but according to *Star Clusters*, Ruprecht 175 spans 15′.

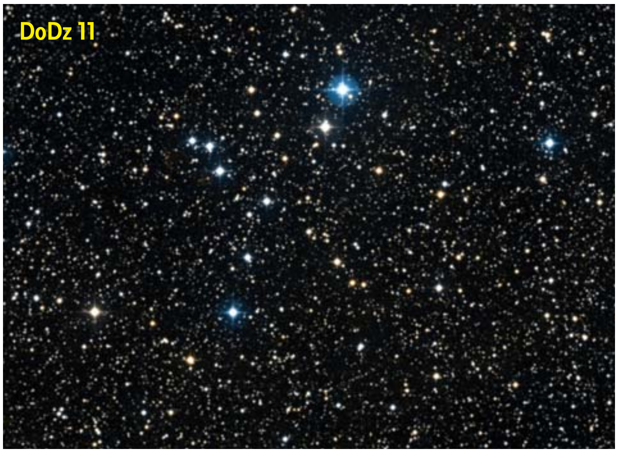
A 1998 paper in the *Astronomical Journal* further complicates the cluster situation. Canadian astronomer David G. Turner proposes that Ruprecht 175, X Cygni, and the southernmost part of Ruprecht 173 may form a physically related group. He gives the sizes of Ruprecht 175 and Ruprecht 173 as 9′ and 50′ × 30′, respectively.

**Ruprecht 174** also inhabits this area of the sky, 57′ west-northwest of Lambda (λ) Cygni. My 130-mm scope at 48× shows a grainy patch of mist just south of a 10th-magnitude star, with a few extremely faint stars involved. At 91× I see 15 faint to very faint stars over unresolved haze about 6′ across. With my 10-inch reflector at 187×, I count 37 moderately faint to very faint stars gathered into a 7½′ × 4½′ oval, tipped northeast. A more densely concentrated region stretches northeast from the center. A relatively bright, trapezoidal group of several stars, including the 10th-magnitude one, rests atop the cluster.

The position for Ruprecht 174 given in this article's table is from the 2013 catalog of Nina V. Kharchenko and colleagues.

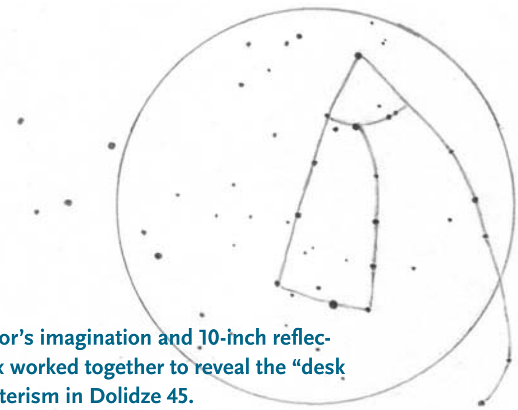
A half degree southwest of Ruprecht 174, we find **Dolidze 47**, named for Georgian astronomer Madona V. Dolidze. Unlike many candidate open clusters, the Dolidze groups weren't proposed due to their visual appearance. In the course of her spectral studies of stars at Abastumani Astrophysical Observatory, Dolidze noticed groups of hot young stars with similar apparent brightness and other groups with a seemingly cluster-like distribution of spectral type and brightness (main-sequence). Despite this promising-sounding method of discovery,






POSS-II / STSCI / CALTECH / PALOMAR OBSERVATORY


POSS-II / STSCI / CALTECH / PALOMAR OBSERVATORY



The author's imagination and 10-inch reflector at 68x worked together to reveal the "desk lamp" asterism in Dolidze 45.

many Dolidze groups are probably not true clusters.

Through my 130-mm refractor at 23×, Dolidze 47 shows only five stars. The three brightest form a 2.9′-long curve decreasing in brightness (magnitudes 8 to 10) from east-southeast to west-northwest. A faint star sits north-northwest of the brightest star, and another dwells south of the dimmest star in the arc. At 63× the southern star is double, and the total star count scores 15. The brightest star, SAO 70387, gleams gold at the cluster's heart. At 91× I count 20 stars in a 7′ × 5′ oval, including a meandering tail of stars dangling from the west-southwestern end.

Dolidze 47's size is listed as 5′ in *Star Clusters* and 11′ in the online *Catalog of Optically Visible Open Clusters and Candidates* (Wilton Dias and colleagues, **astro.iag.usp.br/ocdb**). The Kharchenko catalog classifies Dolidze 47 as an open cluster remnant, the residue of a cluster whose stars have mostly dispersed, leaving only high-mass members behind.

Sweeping 56′ southeast from Lambda brings us to **Dolidze-Dzimselejsvili 11**, one of the star groups found by Madona Dolidze and Galina N. Jimsheleishvili. The questionable transliteration of the name most astronomical catalogs use is Dzimselejsvili, thus the clusters are abbreviated Dolidze-Dzim or simply DoDz. DdDm designates the one planetary nebula discovered by the pair.

Pinpointing DoDz 11 is problematic because its cataloged size ranges from 3′ to 14′, and its center position differs by several arcminutes. I'll simply describe what I saw in the area with my 130-mm scope. At 37× a dozen stars trace out a 7¼′-tall X with the brightest star, magnitude 8, at the northwest end of one crossbar. Several faint stars are scattered in and around it. A magnification of 63× reveals about 30 stars gathered into a 10′ clump with indefinite borders. This corresponds fairly well to the size and position updated in 2006 by deep-sky researcher Mathias Kronberger. His values are listed in the table.

And now for the question many folks ask: "How do you pronounce those names?" According to linguist Carl Masthay, who can read Georgian script, Dolidze and Jimsheleishvili are approximately pronounced DOE-lee-dzeh and JEEM-sheh-LAY-shvee-lee. The capitalized syllables are very mildly stressed.

You'll find another Dolidze cluster 56′ west-southwest of Tau (τ) Cygni. When I first observed **Dolidze 45**, I noted that there wasn't a convincing group in the position plotted in my atlas, but a more interesting gathering of stars sat off its eastern side. I later discovered that the *Catalog of Optically Visible Open Clusters and Candidates* identifies the more prominent collection as Dolidze 45. My 130-mm scope at 37× unveils about 20 stars, the brightest tracing out a north-south arch that takes two right-angle bends, first west and then north, halfway down the arch's eastern side. My 10-inch reflector at 68× discloses 46 stars within the given 16.2′ size of the cluster, and it fills out the peculiar shape so that it looks something like a desk lamp to my eye. Two of the stars I use to imagine my desk lamp actually lie outside the cluster's southwestern rim. I think it makes an adorable asterism. How about you? ✦

Ken Hewitt-White

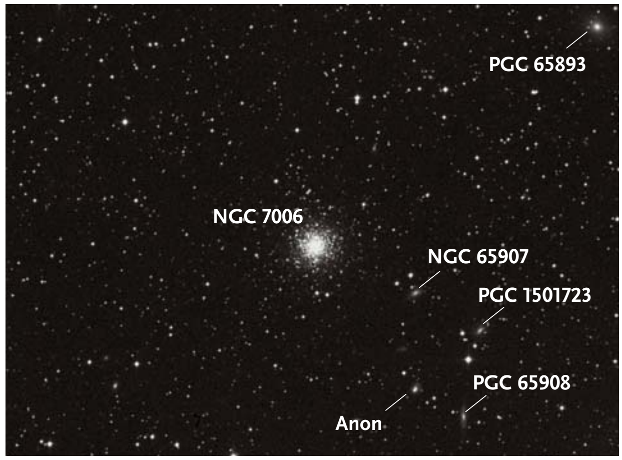
# Small Globular, Tiny Galaxies

## The area around NGC 7006 in Delphinus is interesting and challenging.

**Adrift in the galactic** boondocks 135,000 light-years away, **NGC 7006** is the second most distant globular cluster easily visible in amateur telescopes. The 10.6-magnitude outlier is no showpiece, but it's easy to locate 3½° east of 4th-magnitude Gamma (γ) Delphini. In turn, NGC 7006 is a handy hopping-off point to some nearby faint galaxies — a few of them barely beyond the outskirts of the cluster. My descriptions below stem from observations made with two large Dobsonians over the past several years.

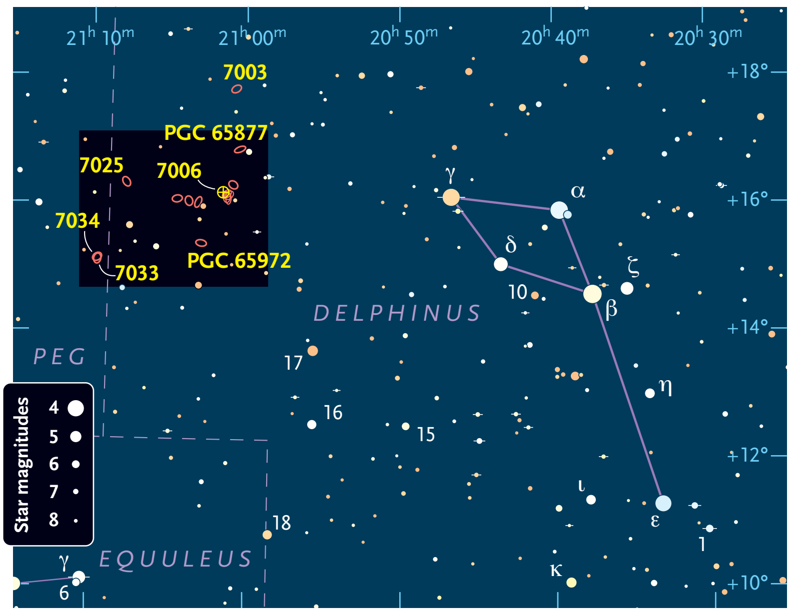
First, the globular. Resolving NGC 7006 into stars is no easy exercise. The brightest cluster members are magnitude 15.6, and most of the rest are much fainter. All those dim dots are packed into a sphere spanning less than 4′ of sky. On a concentration scale ranging from 1 to 12, NGC 7006 is class 1 — extremely dense. In my 17.5-inch f/4.5 reflector at 83×, I see only a little hazy ball that gradually brightens towards the middle. A 14th-magnitude double star of about 15″ separation lies near its southern edge.

The view improves subtly with increased magnification. At 222× in my 17.5-inch scope, the cluster's broad, bright middle grows granular, and my averted vision perceives a slightly mottled halo that includes some peripheral pinpoints. They might be field stars conspiring to make NGC 7006 appear larger than it really is, but at 285×, my perception of resolved stars includes three or four across the core. I've also aimed a friend's 20-inch f/5 Dobsonian at NGC 7006. To my delight, the bigger telescope working at 363× delivered at least partial resolution.




POSS-II / CALTECH / STSCI / PALOMAR OBSERVATORY

Resolving the tight globular cluster NGC 7006 into individual stars is a challenge even with a big scope. At 83× with 17.5 inches of aperture, the cluster displays as a hazy ball, brightening toward the center. A close study of the region southwest (lower right) of the globular reveals a dim quartet of galaxies.




## Heading North

Now for the galaxies. The obscure specimens around NGC 7006 are classic "faint fuzzies" visible only in larger apertures at dark observing sites. If you're up for a challenge, let's ferret out the tough stuff!

I begin by nudging the scope 12′ northwest of the globular to 14.2-magnitude **PGC 65893**. Thanks to a relatively favorable surface brightness, this tiny elliptical at 222× is not difficult to detect — though it's a mere mote of mist less than 1′ in size. Two 11th-magnitude stars glimmer 2.5′ northwest of the galaxy.

Less than ¾° north-northwest of NGC 7006 lies 13.7-magnitude **PGC 65877**. This face-on spiral, barely 1′ across, is another puny patch. The scene is saved by an attractive, low-power triple 8′ to the galaxy's west-southwest: the 6.7-magnitude primary star, HD 199941, is

Visit SkyandTelescope.com/observing/going-deep-delphinus/ for more on deep-sky Delphinus.

accompanied by a 9.2-magnitude star 70″ northeast and a 10.0-magnitude star almost 3′ south-southeast.

Almost 1° farther north is the 13.0-magnitude face-on spiral **NGC 7003**. Measuring 1.1′ × 0.8′, this pale haze to my eye looks elongated in a ratio of 2:1. At 222× I note a 15th-magnitude star hugging the galaxy's eastern edge. At lower powers, the combination seems comet-like: the star acts as the comet's nucleus while the elongated galaxy is its tail.

## Dropping South and East

Let's reverse our steps, dropping southward past our cluster starting point — but not by much. Less than ½° southeast of NGC 7006 is a 6.9-magnitude orange-red variable star, HD 200393. Just 6′ northeast of that glaring beacon is the 14.2-magnitude spiral galaxy **PGC 65982**. At 285×, I see the 0.6′ × 0.3′ wisp plus a 15th-magnitude star immediately eastward.

From PGC 65982 we head east for ⅓° past a 12th-magnitude star (and past galaxy PGC 66006, which I've inexplicably overlooked!), to 14.2-magnitude **PGC 66034**. Measuring 1.6′ × 1.1′, this galaxy at 222× is marginally better than PGC 65982. A 10th-magnitude star glares 6′ southwest. Images of this wee wisp reveal not one galaxy but two — the interacting systems displaying tidally distorted arms.

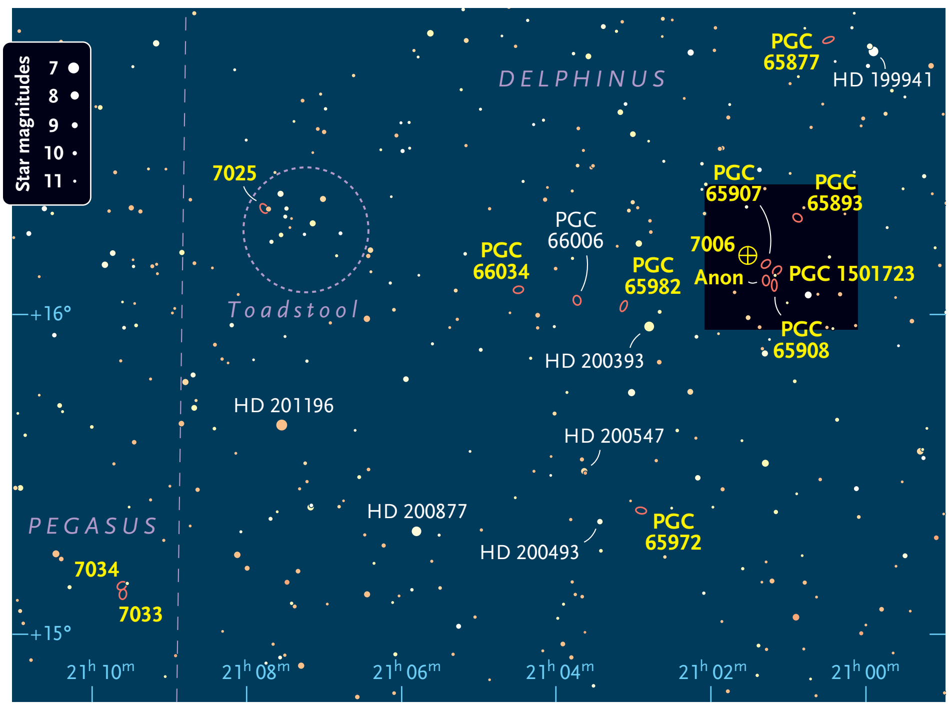
Slightly more than ½° south of the orange-red variable mentioned earlier is 14.0-magnitude **PGC 65972**. I need 285× just to identify this 0.5′ × 0.3′ blur, but the surrounding field is nice. 13′ northeast of the galaxy is an 8.7-magnitude golden-yellow star, HD 200547, that sports two 11th-magnitude companions, about 25″ and 35″ southeast. And only 9′ east-southeast of the object is a 9.1-magnitude blue star, HD 200493, with three 14th-magnitude attendants along its north side, each about 30″ from the primary. A pretty sight!

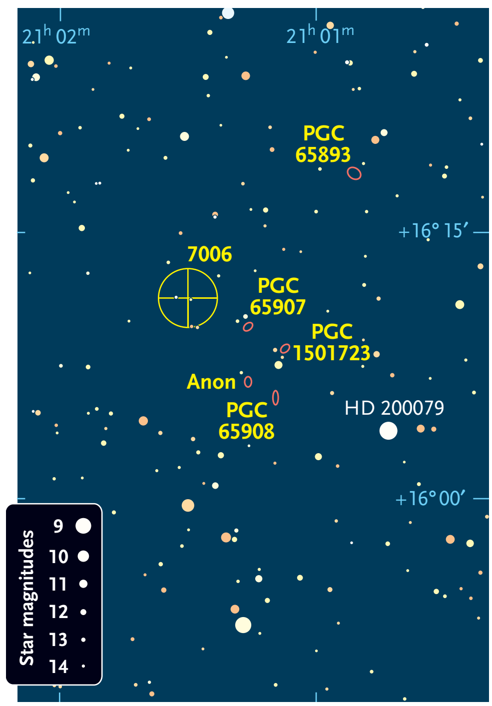
From that pretty multiple star, I slowly drift 1½° east-southeastward past 6.6-magnitude HD 200877 to 14.2-magnitude **NGC 7033** and 13.8-magnitude **NGC 7034**, galaxies 1.5′ apart. (The pairing is 2¼° south-east of the globular cluster NGC 7006.) Each galaxy is elongated and measures approximately 1′ in its long dimension. NGC 7033 points north-northeastward to the slightly bigger and brighter NGC 7034, which, in turn, aims at an 11th-magnitude star 1′ northwest. These basic details — and little else — show at 285×.

We now push 1¼° north-northwestward, past a 6.3-magnitude star, HD 201196, to **French 1**. This ¼°-wide asterism, nicknamed the Toadstool, is formed by a dozen 9th- to 12th-magnitude stars. On its east edge is the brightest galaxy in my survey: 12.8-magnitude **NGC 7025**. The face-on spiral measures 1.9′ × 1.3′, elongated northeast-southwest. At 83×, it's a miniscule patch almost in contact with a 9.7-magnitude star 40″ west. At 222×, NGC 7025 is elliptical, diffuse, and brighter in the middle.

## Beside the Globular

From the Toadstool, it's a 1½° hop back to our starting point, NGC 7006. Compared to all the fuzzy stuff, the little globular actually looks impressive! And it leads



*Galaxy hunter **Ken Hewitt-White** takes a special interest in groups of galaxies that lie virtually in the same line of sight as globular clusters.*

## Diving Deep Off the Nose of the Dolphin

| Object | Mag. (v) | Surface Brightness | Size | RA | Dec. | PA | Notes |
|---|---|---|---|---|---|---|---|
| NGC 7006 | 10.6 | — | 3.6′ | $21^h\ 01.5^m$ | +16° 11′ | — | glob. cluster |
| French 1 | — | — | 13.0′ | $21^h\ 07.4^m$ | +16° 18′ | — | The Toadstool |
| **Heading North** | | | | | | | |
| PGC 65893 | 14.2 | 13.5 | 0.8′ × 0.6′ | $21^h\ 00.9^m$ | +16° 18′ | 55.0 | not difficult |
| PGC 65877 | 13.7 | 13.5 | 1.1′ × 0.9′ | $21^h\ 00.4^m$ | +16° 52′ | 112.3 | not difficult |
| NGC 7003 | 13.0 | 12.7 | 1.1′ × 0.8′ | $21^h\ 00.7^m$ | +17° 48′ | 115.0 | elongated |
| **Dropping South and East** | | | | | | | |
| PGC 65982 | 14.2 | 12.2 | 0.6′ × 0.3′ | $21^h\ 03.1^m$ | +16° 02′ | 15.5 | high SB |
| PGC 66006 | — | — | 0.9′ × 0.7′ | $21^h\ 03.7^m$ | +16° 03′ | 14.5 | overlooked! |
| PGC 66034 | 14.2 | 14.7 | 1.6′ × 1.1′ | $21^h\ 04.5^m$ | +15° 05′ | 100.0 | double system |
| PGC 65972 | 14.0 | 11.8 | 0.5′ × 0.3′ | $21^h\ 02.9^m$ | +15° 23′ | 80.0 | high SB |
| NGC 7033 | 14.2 | 13.1 | 0.8′ × 0.5′ | $21^h\ 09.6^m$ | +15° 07′ | 4.1 | 1st of pair |
| NGC 7034 | 13.8 | 13.3 | 1.1′ × 0.6′ | $21^h\ 09.6^m$ | +15° 09′ | 121.0 | 2nd of pair |
| NGC 7025 | 12.8 | 13.6 | 1.9′ × 1.3′ | $21^h\ 02.9^m$ | +16° 20′ | 49.4 | best in show |
| **Beside the Globular** | | | | | | | |
| PGC 65907 | — | — | 0.6′ × 0.4′ | $21^h\ 01.3^m$ | +16° 10′ | — | not difficult |
| PGC 1501723 | — | — | 0.6′ × 0.4′ | $21^h\ 01.1^m$ | +16° 08′ | — | more difficult |
| PGC 65908 | — | — | 0.8′ × 0.3′ | $21^h\ 01.7^m$ | +16° 06′ | — | challenge! |
| Anon | — | — | — | — | — | — | star in front |

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.

me to something easily found yet challenging to see: a compact clump of four teensy galaxies right beside the cluster. The quartet lies almost halfway between NGC 7006 and a 7.8-magnitude star, HD 200079, about 13′ to the southwest.

The image on page 57 shows a combination of smudges and stars forming a squat parallelogram whose north-south dimension spans approximately 3′. There's one smudge per corner, except on the southeast corner where a 14.2-magnitude star substitutes for a galaxy slightly off the mark. An 11.4-magnitude star dazzles on the parallelogram's west side, and numerous 13th- to 15th-magnitude stars are scattered around the figure. The four fuzzies, each under an arcminute in size, blend in with the starry crowd.

A 3′-long line from the globular passes through a 13.8-magnitude star to **PGC 65907** on the northeast corner of the parallelogram. The galaxy forms a roughly 30″-wide equilateral triangle with the 13.8-magnitude star and a 12.9-magnitude star. I can hold the target steadily at 285×. Slightly more than 2′ in the same direction is **PGC 1501723**, on the northwest corner. It, too, forms a 30″-wide triangle with a 13.6-magnitude star eastward and a 14.4-magnitude star south-southeastward. (The previously mentioned 11.4-magnitude "dazzling" star lies only 30″ farther.) This dimmer galaxy is hard to hold, but definite at 285×.

Continuing clockwise around the parallelogram brings us to the southwest corner marked by **PGC 65908** — or maybe not. I've never made a firm sighting of this strongly elongated ghost in my 17.5-inch scope. When conditions are ideal, I can detect the 15th-magnitude stars flanking the target but not the galaxy itself. However, I'm fairly confident I've glimpsed it in my friend's 20-inch Dob at 363×.

The galaxy near the parallelogram's southeast corner is slightly mysterious. Our photo reveals that the object, labelled **Anon**, is almost obliterated by a 13th-magnitude star superimposed on its southeast side. In my telescope at 285×, I see only a star that seems unnaturally large and blurry. The effect is similar in the 20-inch at 363×. Eagle-eyed observers with larger Dobsonians might discern the galaxy itself and thus confirm the faint foursome beside NGC 7006. ✦

 Gary Seronik

# A Grab&Go Starter Scope

*This 5-inch, altazimuth reflector is both versatile and well made.*

## Vixen R130Sf Reflector & Porta II Mount Package

**U.S. price:** $399
Vixen Optics
1050 Calle Amanecer Ste C
San Clemente, CA 92673
vixenoptics.com

THE PERFECT beginner's telescope. What does it look like? How much should it cost? Telescope manufacturers have wrestled mightily with these questions for years. Aim for a very low price point and you end up with the much (and rightly) maligned department-store trash scope. Or, produce something with a host of quality features and watch customers blanch at the price, then rush to the mall to buy a trash scope. The sweet spot can be elusive. And yet, many manufacturers do offer decent starter telescopes at reasonable prices. The Astronomers Without Borders OneSky instrument I reviewed in the February 2014 issue (page 60) is a good example. Could the Vixen telescope featured here be another? Superficially, the two have much in common — both are basic 5-inch Newtonian reflectors on altazimuth mounts. Most significantly though, both aim to deliver a lot of bang for the buck.


**The Vixen R130Sf Newtonian reflector OTA is matched with the company's Porta II altazimuth mount for an attractive and appealing combination. It's potentially a fine beginner's scope or a portable secondary instrument for experienced observers.**

ALL PHOTOGRAPHS BY GARY SERONIK

The Vixen package in this review consists of two components: the R130Sf 5-inch, f/5 optical tube assembly (OTA), and the Porta II altazimuth mount. (Either can be purchased separately.) The OTA is nicely finished and features all-metal construction, with the exception of the focuser, which is mostly plastic. Together, the mount and scope add up to a strikingly attractive combination at an affordable price. But would the pairing's performance match its potential? We put it through its paces to find out.

## Initial Impressions

The scope and mount arrived in separate boxes and in excellent condition. There was very little to put together, as both components essentially come fully assembled. To complete the mount, all you have to do is attach two slow-motion-control knobs (one for each axis), unfold the aluminum tripod, and affix the accessory tray. For the OTA, simply place the finder in its holder and slip it into the fitting on the tube. Attach the OTA to the mount via Vixen's dovetail bracket system, tighten the lock knob, and you're good to go. Or so I thought.

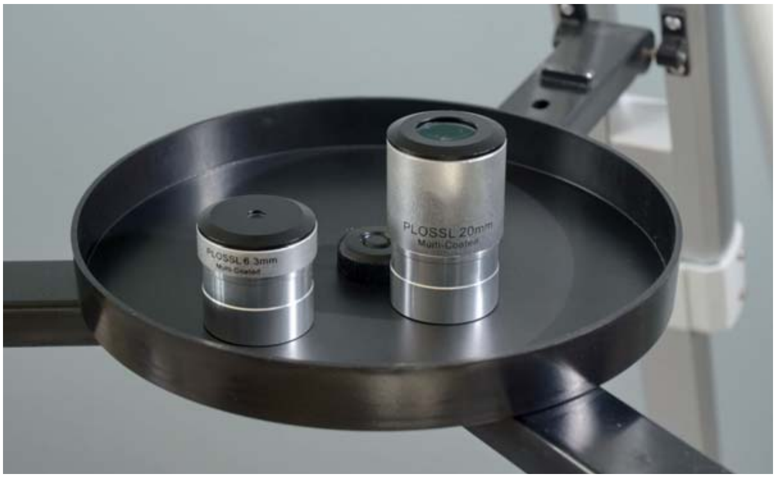
I decided to give the scope a quick daylight test drive — always a good idea with a new instrument. I put an eyepiece in the focuser, aimed at a distant building, then racked the focuser out, then a bit more, still more, and then . . . I reached the end of its travel and yet the image was still fuzzy. I pondered the situation briefly and then did what people like me rarely do — I consulted the manual. It turns out focus can only be reached for visual use by threading the included 2⅛-inch-long eyepiece adapter onto the top of the focuser barrel (though it's unnecessary for photography). That's because the focal plane of the R130Sf resides unusually far (some 5¾ inches) outside the tube. This makes the OTA several inches shorter than it would otherwise be, resulting in a more compact unit. It also means the secondary mirror has to be on the larger side since it lies farther from the focal plane, where the converging cone of light from the primary mirror is wider. The diagonal in the R130Sf measures 1.85 inches on its minor axis, which represents a 37% linear obstruction — fine for general observing, but larger than ideal for viewing low-contrast planetary detail.

The telescope comes with two nice Plössl eyepieces: a 20mm model that produces 33× and a generous 1½-degree-wide field of view, and a 6.3mm unit for 104×. Both have metal housings and barrels, and multicoated optics. Although an additional medium-power eyepiece would be nice, the two Plössls included offer a reason-

| WHAT WE LIKE: |
| --- |
| Excellent optics |
| Useful set of quality accessories |
| Attractive fit and finish |
| **WHAT WE DON'T LIKE:** |
| Poor documentation |
| Imprecise focuser |
| Mount prone to vibration |

***Left:*** **Weighing less than 20 pounds including the mount, the R130Sf is a breeze to transport and set up for a night of observing.**

***Bottom:*** **The heart of the R130Sf Newtonian reflector is a high-quality 5-inch-diameter primary mirror, shown here in its adjustable cell.**





able range of capabilities. The 20mm model serves well for finding objects and for viewing large clusters, while the 6.3mm eyepiece yields enough power to show good detail on the Moon and planets. Also included is the previously mentioned finderscope — a high-quality 6×30 unit on an easy-to-adjust, spring-loaded dovetail bracket.

## Documentation Woes

As is common with many, many telescopes, the Vixen package suffers from poor documentation. It's a mystery to me why so little emphasis is placed on a good instruction manual — especially with a telescope that's likely to find its way into the hands of beginners. The 8-page booklet that comes with the scope covers three OTAs (including the R130Sf), but is partially in Japanese. The Porta II comes with its own 16-page manual, which does a decent job of explaining the mount's functions.

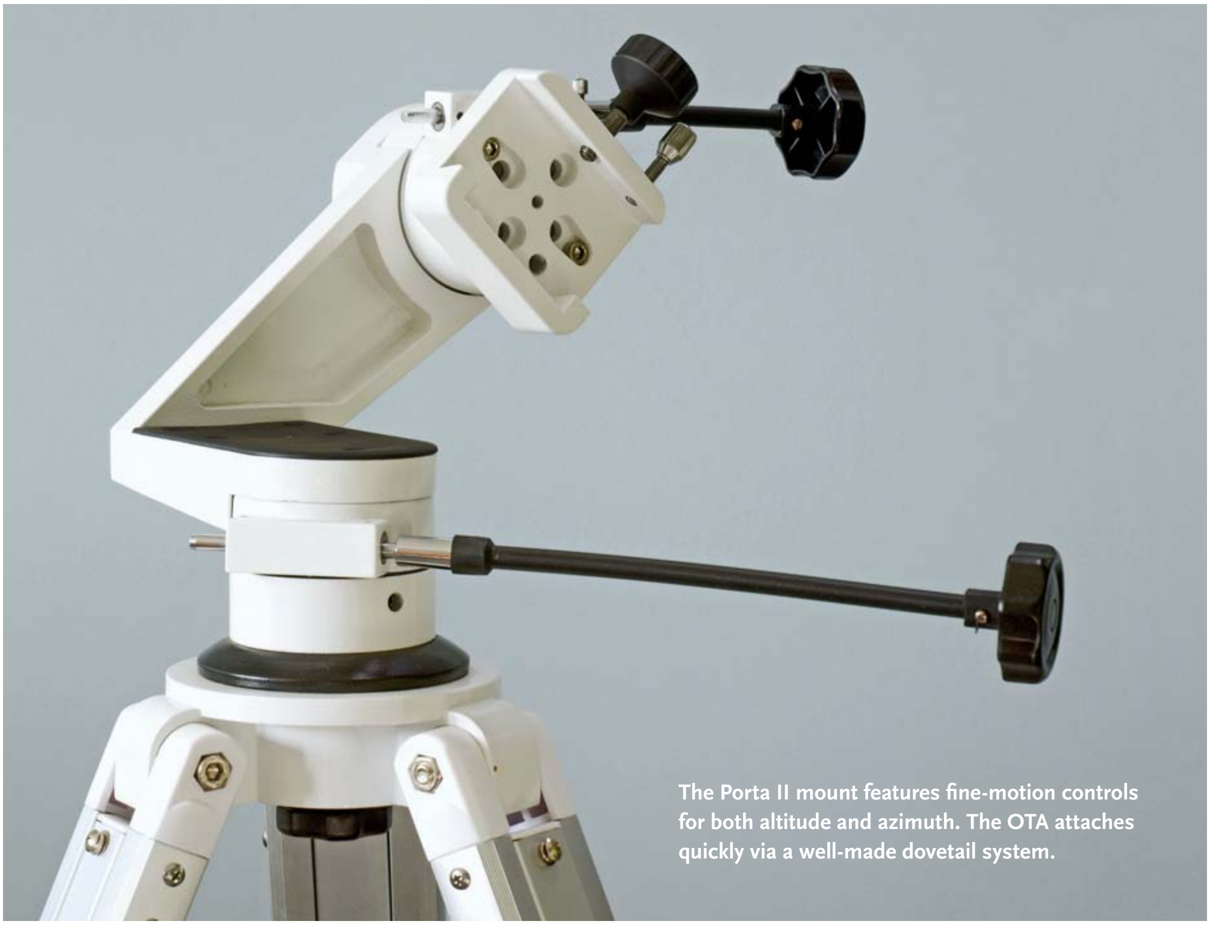
The collimation instructions are brief, unhelpful, and suffer from numerous translation mishaps. You can download better (though still flawed) instructions from the Vixen Optics website. And as it turns out, knowing the basics of collimation would prove handy since our test scope arrived with both mirrors out of alignment. Worst off was the secondary mirror, which was positioned too far toward the front of the tube. Its adjustment screws were locked down so tight I feared I might break my Allen wrench trying to budge them.

Aligning the primary mirror was no picnic either. Although its center is marked to make matters easier, a collimation tool isn't provided. And before you can make any adjustments, you have to remove a metal cover from the back of the mirror cell — something not noted in the instructions. Once that's done, you're presented with three pairs of push-pull adjustment screws. These require both a Phillips head screwdriver and an Allen wrench (but of a different size than the one used for the secondary mirror). It's as if the scope's designers genuinely believed that collimation, once set at the factory, would never again need to be touched. However, as time-consuming as it was to get the mirrors aligned, they stayed that way for the duration of my evaluation.

## In the Field

Preliminaries out of the way, it was finally time to give the scope a proper test drive. The R130Sf and Porta II

***Top:* Included with the R130Sf are 20mm and 6.3mm Plössl eyepieces that provide a useful range of magnifications. A handy accessory tray attached to the tripod leg brace provides plenty of room for additional eyepieces and accessories. *Middle:* Unlike the dim, difficult-to-aim finderscopes found on many "budget" telescopes, the R130Sf includes a very nice 6×30 unit on a superb, easy-to-adjust bracket. *Bottom:* Concealed under a metal cover plate (not shown) are the primary mirror's collimation screws. Both a user-supplied Phillips head screwdriver and Allen key are required for the adjustments.**



The Porta II mount features fine-motion controls for both altitude and azimuth. The OTA attaches quickly via a well-made dovetail system.

combination is so lightweight (19.4 pounds combined) that setting it up for a night under the stars is a breeze. Lining up the finder was a snap thanks to its spring-loaded bracket. With the tripod legs fully retracted, the eyepiece is at a comfortable height for seated viewing.

Aiming the scope is intuitive and straightforward. I simply grabbed the back end of the scope and moved it to where I wanted to look. The mount has fine-motion controls on both axes, so precisely centering a target and tracking were both easy. You can adjust the tension of both motions with a supplied Allen key, neatly hidden under a rubber cover on the mount. That's a nice touch — you never have to worry about not having the right tool with you. You can also loosen the tube ring clamps to rotate the OTA to a more convenient focuser position, and fine-tune the tube's balance.

The winter constellations were still high in the evening sky when I began my evaluation, so I chased down a few favorite double stars. First up was Castor, with its magnitude 1.9 and 3.0 components separated by 4.2 arcseconds. In the 6.3mm eyepiece, splitting the duo was no trouble at all. Next, something more challenging — Rigel. Even though the component stars are farther apart (9.4 arcseconds), Rigel is a much trickier double because of the brightness difference between its 0.3-magnitude primary and 6.8-magnitude secondary. I was able to fish the companion star out from the glare of its bright host without too much trouble. On another night, the crescent Moon beckoned. I swept up and down the terminator and saw all kinds of fine detail sharply presented. More impressive was the scope's ability to render low-contrast lunar features, including the domes Arago Alpha and Beta, in Mare Tranquillitatis.

Tucked away under a rubber cover are two Allen keys. The small one is for adjusting the tensions of the altitude and azimuth motions, while the larger key fits the screws that allow reorienting the mount's dovetail plate.

Although the views the scope delivered indicated good optics, I couldn't resist centering Polaris in the high-power eyepiece for a quick star test. The scope produced closely matching intra- and extra-focal images, confirming the primary mirror of the Vixen is of very high quality. I was impressed. In short, the scope delivered everything a good 5-inch reflector is capable of. I have no complaints about the quality of the images the R130Sf presented.

## An Imperfect Gem

As rewarding a performer as the Porta II and R130Sf combination is, I did experience some frustrations that cropped up particularly when I was observing with high magnification. I found the gearing of the rack-and-pinion focuser to be a little too crude for the scope's fast f/5 focal ratio. Often, I'd go from just a little inside focus, to a little outside, and back again without being able to nail focus exactly. The solution turned out to be a minor modification. I simply unscrewed the eyepiece adapter, added a couple wraps of Teflon (thread seal) tape to the threaded fitting on the top of the focuser, then reattached the adapter. This allowed me to tweak the focus by unscrewing the eyepiece adapter a turn or two, transforming it into a fine-thread helical focuser. It worked very nicely.


**The rear of the telescope tube can collide with the mount's tripod legs when the scope is aimed at altitudes higher than 75 degrees. Vixen offers an optional extension pillar to alleviate this problem.**

**A few wraps of Teflon tape applied to the threaded fitting on the top of the focuser allows the eyepiece adapter to serve as a fine-thread helical focuser.**

The mount generally performed well, with vibrations dampening out in two or three seconds when the tripod legs were fully retracted. But if there was any kind of breeze, the Porta II was prone to quivering, causing the image in the eyepiece to maddeningly dance around. Likely this is due to the cantilevered design of the single-arm fork, which offsets the scope's mass about 5 inches from the center of the mount's azimuth axis.

Another design-related problem crops up when your target has an altitude greater than roughly 75 degrees. In those situations, the back end of the OTA can collide with the tripod legs. You can orient the tube so that it sits between the legs, but that usually means repositioning the whole telescope — mount and all — and is a workaround at best. A better solution is the optional SXG "half-pillar" extension Vixen offers for the Porta II.

## Bottom Line

Shortly after I received the scope, *S&T* Equipment Editor Sean Walker asked for my initial thoughts. I wrote back: "I'm impressed by the quality of the optics — the mirror is very good, as are the eyepieces. On the down side, the mount is more jiggly than I expected. Not a problem at low power, but for planetary observing it can be frustrating. The other issue is the plastic focuser, which makes precise focus at high magnification a challenge. Overall, though, I enjoyed using the scope and was pleased with what Vixen put together for the money."

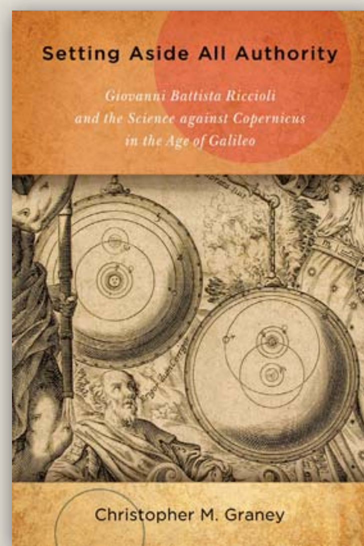
After spending several additional weeks using the instrument, my initial impressions stand. Would I recommend it to a friend as a first scope? Yes — but with the caveat that they get a copy of Terence Dickinson's *NightWatch* to serve as a substitute manual. So equipped, a newbie would find the scope rewarding for all kinds of observing, from sweeping the Milky Way to detailed close-ups of the Moon and planets. For non-beginners, the R130Sf and Porta II combination has a lot to offer as a grab-and-go scope. It's lightweight and quick to set up, yet with optics good enough to satisfy experienced eyes. ✦

*Contributing editor **Gary Seronik** scans the skies from his home near Victoria, BC, Canada, and can be contacted through his website:* ***garyseronik.com***.



# Science vs. Science

## *Setting Aside All Authority: Giovanni Battista Riccioli and the Science against Copernicus in the Age of Galileo*




**Christopher M. Graney**
**University of Notre Dame Press, 2015**
**288 pages, ISBN 978-0-268-02988-3, $29.00, paperback.**

Like many historians of modern astronomy, I first encountered Giovanni Battista Riccioli's *Almagestum Novum* (*New Almagest*) through the writings of John Flamsteed. The *New Almagest* (1651) was the book against which Flamsteed formed his earliest ideas about mathematical and observational astronomy. Perhaps because of the role he assigned to it — a treatise to challenge rather than embrace — I've taken some of the more dismissive readings of the *New Almagest* at face value. Riccioli is often portrayed as just this side of foolish: swayed by religion, he denied the rationality of Copernican heliocentrism and promoted instead Tycho's hybrid geocentrism (not Ptolemy's strict geocentrism, but a system in which the Sun and Moon orbit the Earth while the planets circle the Sun). Moreover, he made this foolishness obvious in the *New Almagest*, a treatise filled with unconvincing anti-Copernican arguments.

In *Setting Aside All Authority*, Christopher Graney argues that though Riccioli was a Jesuit, he wasn't hampered by Catholicism. In the *New Almagest*, he summarized 126 arguments (49 favoring heliocentrism, 77 against), but dismissed any depending solely on religious tenets. This left two substantive challenges to heliocentrism, the first concerned with motion, the second with annual parallax and its implications for star sizes. Riccioli's support for geocentrism stemmed from the Copernican inability to respond to these challenges. It was never a matter of "religion vs. science" but rather "science vs. science": existing empirical evidence pointed to geocentrism as the more rational system.

Graney leads us through a fresh translation of the *New Almagest* to explain Riccioli's logic. First, following Tycho, Riccioli noted a lack of evidence for what we now refer to as the Coriolis effect. If the Earth orbits the Sun, the effects of its motion through space should be observable during dropped-ball experiments. That they weren't (the mathematics weren't sorted out until the 19th century) troubled him. Even more troubling, however, was a second issue: star size. As the Earth moves through its orbit, stars should increase and decrease in magnitude, and their relative positions should change, yet no one had detected this annual parallax. Perhaps the parallax was too small to be observed, but that could be true only if stars were extremely distant from Earth. If that was so, the stars needed to be gargantuan to have the apparent diameters observed by astronomers. (Theories of diffraction and resolving power would eventually show stellar disks to be spurious, but measurable diameters were accepted as fact in the 17th century.) Even using the smallest possible diameter, an ordinary star was calculated to be as broad as the Earth's orbit — an absurdity. Copernicans had no good explanation for what they, too, considered an improbability; while Riccioli could defend his position with carefully executed telescopic measurements, they were forced to invoke the glory of God to justify the immense size of the stars.

The arguments of both Riccioli and Graney are complicated and subtle. Even so, I had little difficulty following them, thanks to Graney's lucid prose and clear diagrams. If you think you know Riccioli, or if you want to know him better, pick up this book. Graney's re-reading of the *New Almagest* is absolutely convincing, and *Setting Aside All Authority* is sure to become the standard text on the "science vs. science" debate between Riccioli and the supporters of heliocentrism. ✦

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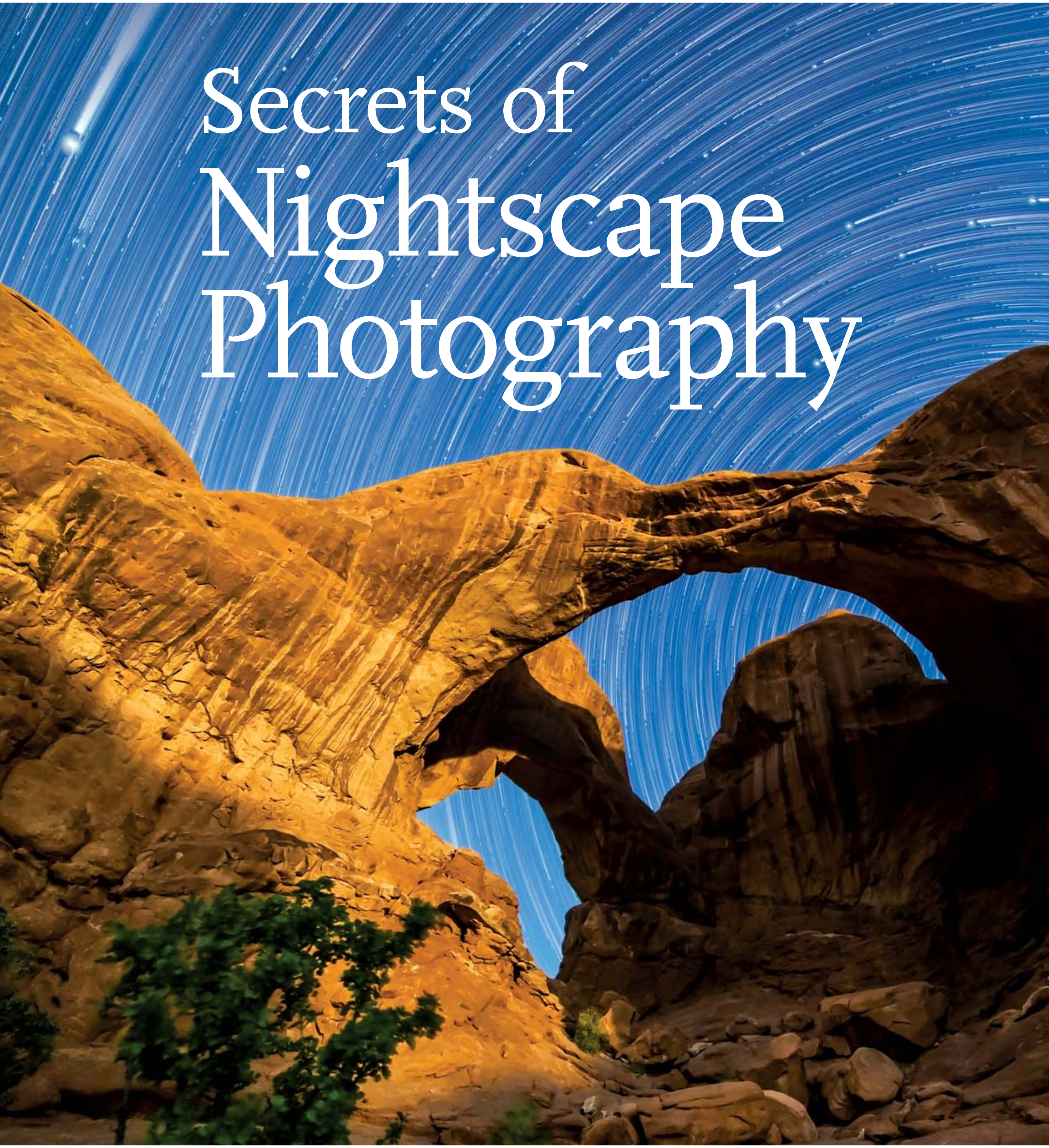
S&T *Observing Editor* ***S. N. Johnson-Roehr*** *enjoys reading almost as much as she enjoys sketching sunspots.*

# Secrets of Nightscape Photography



Alan Dyer

## Here are some essential tips for shooting the night sky above picturesque landscapes.

**For decades, astrophotography gurus** advised newcomers to start with simple camera-on-tripod shots before graduating to the advanced task of shooting celestial targets through telescopes. This was meant to teach the limits of normal photographic techniques; targets in the night sky are almost always faint and require long exposures to record adequately. But without tracking to counteract Earth's rotation, you were limited to only a few seconds or so before trailing compromised your shot. Next, you'd get a tracking mount and continue from there.

What those guides didn't account for is the power and simplicity of digital single-lens reflex (DSLR) cameras. These allowed astrophotographers to discover the beauty of nightscape photography as a unique pursuit in itself. Now many devote all their nights — indeed their careers — to shooting nightscapes exclusively using the simplest of equipment.

While a lot of complex gear isn't necessary to become involved in nightscape photography, securing great results comes from learning how to get the most out of your equipment. Here are some of the "trade secrets" that can help you record breathtaking results yourself.

### Low-Noise Cameras

Your choice of camera is arguably one of the most important factors for nightscape photography. And while you might already own a DSLR, look carefully at its specifications before assuming you've got that base covered. The most important camera specification in a good nightscape camera isn't the highest number of megapixels but rather its ability to produce low-noise images.

There are two paths to achieving this goal. The first is simply to buy a new camera. Manufacturers are always improving the firmware that performs the internal processing of images, as well as incorporating the latest low-noise sensors. Cameras that are more than four or five years old will often produce noisier images at comparable ISO settings than the newest models, even when other specifications look similar.

When shopping for this new camera, look for one with large pixels. While some top-end cameras these days offer upwards of 36- to 50-megapixel arrays, full-frame chips with 20 to 24 megapixels will generally perform better for astrophotography. In these cameras, each photosite (pixel) is about 6 microns across, which inherently produces less noise than smaller pixels. This is because, just as with telescope aperture, larger pixels collect more light than small ones do.

The best nightscape cameras tend to be "full-frame" models with a 24-by-36-mm CMOS sensor. By comparison, typical 20-megapixel APS-format or "cropped-frame" cam-

**FLOODLIT** Unlike deep-sky imagers, nightscape photographers welcome moonlit nights! The Moon illuminates the foreground in natural light while turning the star-filled sky deep blue. The author shot the scene above in Arches National Park, Utah, using the Canon EOS 6D DSLR, 14-mm lens, and intervalometer pictured at right.

ALL PHOTOGRAPHS BY THE AUTHOR

**EXPOSURE GUIDE** Use your camera's Histogram feature to judge exposure. Shoot so that the levels spread out toward the right (seen above at right) rather than concentrate to the left. This ensures good detail in the shadowed areas with a minimum of noise.

eras use pixels of just 4 microns or smaller, yielding more noise in a similar exposure. A cropped-frame sensor with 6-micron pixels shouldn't have more than 15 megapixels.

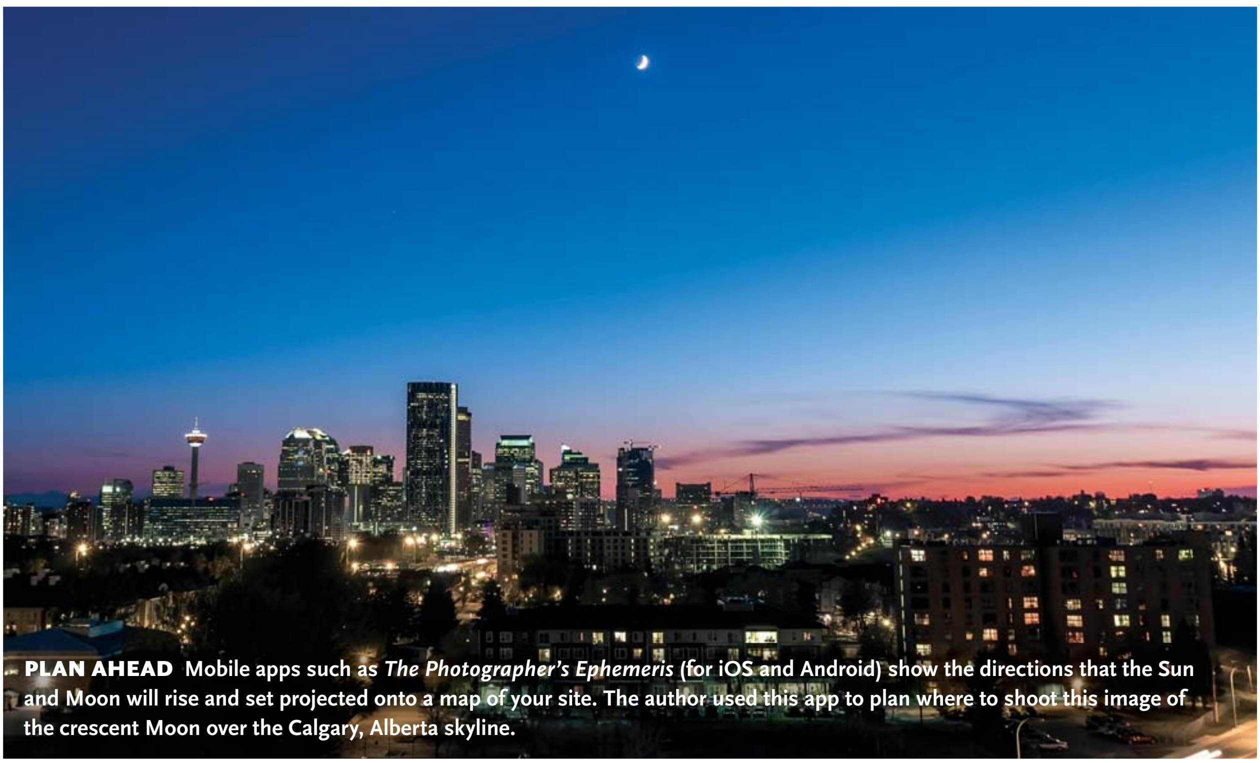
## Fast Lenses

The second way to take low-noise nightscape images is to increase your photon-collecting efficiency by using fast, high-quality lenses. Wide-angle lenses in the 14- to 24-mm range are the most popular for shooting nightscapes. A lens with a maximum aperture of at least f/2.8 or lower is essential.

The slow, f/4 to f/5.6 "kit" zoom lenses that often come with a new camera are fine for shots in twilight or under bright moonlight, but they will fail to record the Milky Way well in an untracked image. Spend some time on photography-review websites to research your lens before buying. You'll want one with excellent edge correction in addition to having a fast f/ratio.

## Shooting Sequences

One accessory besides a tripod that's essential to shooting most nightscapes is an intervalometer. This is a



**PLAN AHEAD** Mobile apps such as *The Photographer's Ephemeris* (for iOS and Android) show the directions that the Sun and Moon will rise and set projected onto a map of your site. The author used this app to plan where to shoot this image of the crescent Moon over the Calgary, Alberta skyline.

programmable gadget that will fire your camera's shutter automatically for as many images as you like, as long as you want, and spaced at the time interval you desire. Intervalometers are readily available from your camera manufacturer and third-party suppliers.

## Expose to the Right

Once you've got your equipment and begin shooting the night sky, nothing will improve your images more than following this edict: expose to the right. This means to use the histogram function in your camera as a gauge to adequately expose your image. You want the histogram to spread across the entire graph — not peak far to the left (underexposed) side. Although you can boost the brightness of your photo in processing later, doing so will also increase noise. If you are seeing artifacts such as banding and a "glow" at the edge of the frame, your images are underexposed.

On dark, moonless nights, don't be afraid to shoot at ISO 6400 or "wide open" at f/2 if that's what it takes to get a well-exposed image.

## The 500 Rule

Shooting longer exposures can also help avoid underexposed, noisy images. But camera-on-tripod nightscapes are usually limited by "the 500 rule." This is the longest reasonable exposure before sky rotation introduces noticeable star trails, and it can be roughly determined by dividing 500 by the focal length of your lens.

For example, to avoid star trails when shooting with a 24-mm lens, an exposure should be no longer than about 500/24 = 20 seconds. Keeping exposures under that limit while still exposing to the right on dark nights often demands fast f/ratios and high ISO speeds (1600 and up).

## Shoot RAW

To produce the best photography of any kind, always shoot in RAW format. Only RAW images preserve the full range of 14-bit data recorded by the camera's sensor. Saving in Jpeg (JPG) format converts these images into 8-bit files, which greatly reduces tonal range. This throws away half your image quality, information that can never be retrieved later. Don't shoot JPGs just to save space — memory cards and storage space are now relatively inexpensive.

## To Calibrate or Not?

Most high-end digital cameras offer a menu option called Long Exposure Noise Reduction (LENR). Turning LENR on forces the camera to take a "dark frame" immediately after the main exposure with the shutter closed. A dark frame is an image of the noise generated by your camera that is then subtracted from the previous image, which reduces speckling in the result.

I recommend using LENR, particularly on warm summer nights, because a large component of the noise in a dark frame is thermal signal. However, using LENR isn't practical when shooting a sequence of images to be stacked into star trails or turned into a time-lapse movie. The time the camera takes to shoot the dark frames will introduce large gaps in star trails or jumps in the motion of the stars.

A way around this is to take dark frames separately at the end of a shoot. They can then be subtracted from your images later when processing your images.


**WIDE LENS** Fast "prime" lenses — ones with fixed focal lengths — are the favorites of nightscape photographers. No-frills manual lenses, such as the Rokinon 14-mm f/2.8, provide excellent optical quality and fast speed at affordable prices.

**PROCESS RAW** *Adobe Camera Raw* in *Photoshop* and *Adobe Photoshop Lightroom* offer many powerful tools to help process your nightscape photos, including vignette reduction, noise reduction, and the ability to recover details in the shadows and highlights independently.

## Digital Darkroom

The most important step in processing nightscape images is to first "develop" your RAW files. I use the *Adobe Camera Raw* plug-in within *Photoshop* to process all my RAW files. An alternative is *Adobe Photoshop Lightroom*. Its Develop module is identical to *Adobe Camera Raw*.

*Camera Raw* and *Lightroom* include many tools specifically designed to correct common optical problems in DSLR images. For example, both have tools that correct vignetting in wide-angle images. The latest versions include powerful tools that can reduce chromatic aberration in some camera lenses and noise-reduction tools that are among the best in the business.

The beauty of processing RAW images is that no pixels are permanently altered in the process. All your changes are recorded in a small .XMP text file (or, in the case of *Lightroom*, in its internal database), permitting you to return to the image at any time and readjust it.

## Smart Filters and Layers

For most nightscape photography, *Camera Raw* or *Lightroom* will provide all the processing power you'll need. But for more advanced processing, you might need the layering and masking tools available in *Adobe Photoshop* and its companion program *Adobe Bridge*.

*Photoshop* provides many features for editing your images, but two that are particularly useful for astrophotography are smart filters and adjustment layers.

To apply smart filters, convert the base image into a "smart object" by selecting Filter > Convert for Smart Filters. Or when in *Adobe Camera Raw*, shift-click the Open Image button to open the file as a smart object from the start. Once it opens in *Photoshop*, if you double-click on the smart object layer the image opens again in *Adobe Camera Raw*, allowing you to rework its settings if needed.

Once your base image is a smart object, you can use any processing filter, applying any of them as smart filters that can be reopened and altered at any time.

You can apply corrections to brightness, contrast, and

**STACKING STAR TRAILS** *Advanced Stacker Actions*, a plug-in program for *Adobe Photoshop*, works directly with RAW files for the highest-quality results, while offering a choice of stacking effects like this Long Streak Trails option. The actions also produce a PSD file with many useful layers to facilitate additional processing later.

color balance by using adjustment layers (Layer > New Adjustment Layer). These never alter the original image. Instead, each adjustment is performed on an image layer that you can rework at any time.

## Star Trails

If a star trail nightscape is your goal, there are two ways to do this. The first is simply to shoot one long, multi-minute exposure at a low ISO speed. While this time-tested method works well, it demands that everything goes perfectly during that one long exposure.

Another star trail image method is to "shoot short and stack" — that is, take many shorter images and stack them all together later. While there are free programs that can accomplish this, I like to use *Advanced Stacker PLUS*, a plug-in addition to *Adobe Photoshop* that works directly with RAW files. You call up the actions from within *Photoshop*'s File > Automate > Batch command to stack a folder of images, all while applying a dark frame.

Creating star trails by shooting hundreds of short exposures has an additional advantage: the same images can also be used to create a time-lapse movie. I'll cover some basic time-lapse techniques in an upcoming issue.

Between the wonderful cameras and lenses now available, and the many software options at our disposal, we can do much more to create stunning nightscapes than we could just a few years ago. A camera-on-tripod setup isn't just a beginner's tool but a powerful means to spend a lifetime shooting the sky at night. ✦

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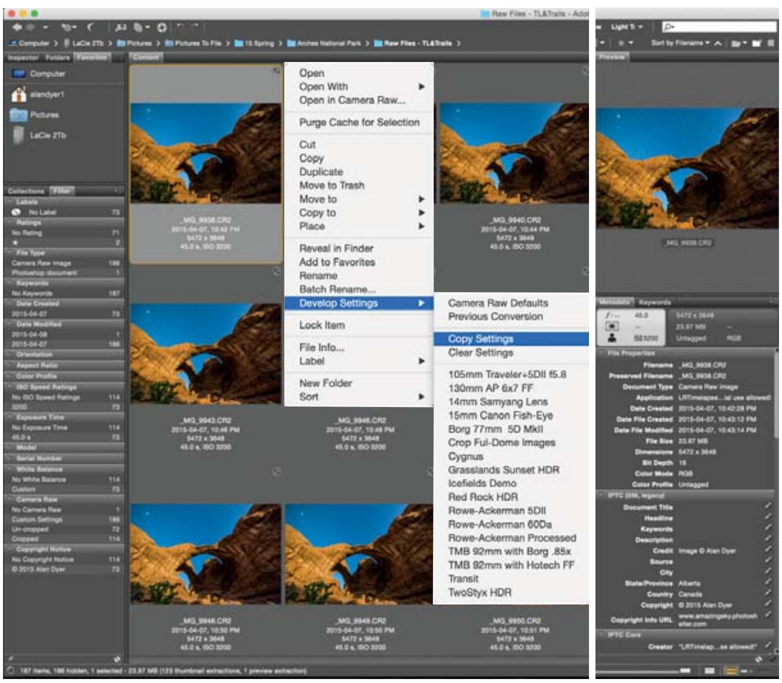
*Contributing editor **Alan Dyer** is author of the eBook* How to Photograph & Process Nightscapes and Time-Lapses ***(amazingsky.com/nightscapesbook.html)***.




**BATCH PROCESSING** You can process an entire folder of star-trail images with *Adobe Photoshop Lightroom* or *Adobe Bridge*. Start by processing a single photo. Then right-click on that frame and select Develop Settings > Copy Settings. Next, select all the other RAW images in the folder, and right-click to select Develop Settings > Paste Settings. In moments, all your frames will be identically processed.

# Meet Leah

*This 16-inch reflector is a marvel of craftsmanship and engineering.*

SOME PEOPLE LIKE TO name their telescopes. As Wichita, Kansas ATM Tom Fairbanks explains, "I have two beautiful daughters, but despite my pleas, my wife wouldn't agree to name either of them Leah. One day, as I sat looking at my telescope, it occurred to me that since I was solely responsible for bringing this baby into the world, I could name it whatever I wanted — Leah it would be." In this case, the name not only suits the elegance of the telescope, but it also serves as a humorous (and painfully true) acronym: Large Expensive Astronomical Hobby. But Leah is much more than a clever name — she's also a pretty amazing telescope.

A professional electrical engineer and hobbyist woodworker, Tom was up for something more challenging than a plain-Jane Dobsonian for his first scope. "After searching the internet for ideas, I found a few images of the split-ring design," he recalls. "It had that cool look I was going for and offers the advantage of being a true equatorial mount." This was important because he wanted an instrument that would be suited to computerized pointing and tracking. Of course, such a mount is considerably more complex and difficult to build than a Dob; doubly so for a first-time builder.

TOM FAIRBANKS

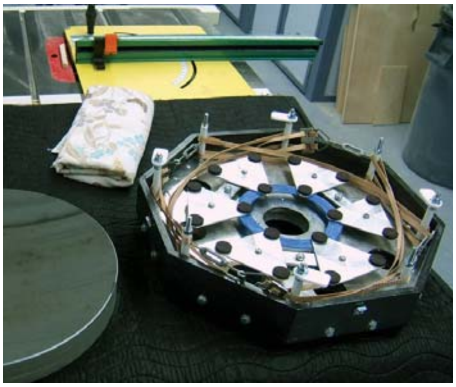
This 16-inch, f/4.2 Newtonian rides on a split-ring mount — a configuration that originates with Russell Porter, designer of the famed 200-inch Hale Telescope. The 16-inch features a rotating upper cage and computer-controlled go-to pointing.

To ensure that he understood the design in detail, Tom built a ¼-scale model as a first step. This exercise demonstrated a few important consequences of the split-ring configuration. As Tom recalls, "while playing with the model, I realized that the eyepiece could not remain fixed and needs to be able to rotate to any side of the tube." The model also showed that the mount's bearings would have to cope with both radial and axial forces, and that a traditional Dobsonian-style sling mount used for supporting the primary mirror wouldn't suffice for all the scope's various orientations.

To solve the first of these issues, Tom decided to equip Leah with a rotating upper cage so that the eyepiece could easily be orientated to the most comfortable viewing angle. "For the upper cage assembly, I settled on thin, interlocking rings of plywood kept in position by small rollers originally made for a sliding shower door," Tom says. One of the cage's best features is that the rotation is friction-controlled — there's no need to clamp or unclamp anything to change the eyepiece position.

Leah's 2-inch-thick, 16-inch f/4.2 primary mirror sits on a conventional 18-point flotation cell. Nothing unusual about that. What is clever, though, is how the mirror is supported laterally. Instead of a Dobsonian's single sling, Tom's cell incorporates what he calls a "quad sling system" — essentially four individual slings arrayed around the mirror's circumference. Each one supports part of the load in turn as the orientation of the scope changes. Turnbuckles allow the tension of all four slings to be adjusted and ensure the mirror remains exactly centered in the cell.

Critical to the scope's success was the quality of the bearings used in the mount. Tom's initial choice of go-kart axle bearings proved to be unsuitable. In the end he



TOM FAIRBANKS

One of the telescope's novel features is its "quad-sling system," which provides lateral support for the primary mirror in its 18-point-flotation cell.

opted for heavy-duty units he found on an internet surplus site. "It took some time to rebuild the mount to accommodate the new bearings, but wow was it worth it!" he says. With the scope moving smoothly, the next step was to add motors for go-to pointing and tracking. Each axis utilizes a servo motor assembly and encoder, along with a controller unit and wireless hand pad — all sourced from Sidereal Technology (**siderealtechnology.com**). He chose Software Bisque's *TheSkyX Serious Astronomer Edition* software to aim the scope. "The intricacies of gearing, clutches, and getting it all mounted probably consumed more time than any other phase of this project," he notes. "But to my surprise, the scope moved at my command the very first time I pushed the buttons!"

Tom is passionate about the technology behind Leah — indeed, for him it's one of the main attractions of amateur astronomy. "However, I still enjoy the great views the scope offers," he says. "One night at a recent star party, I was looking at the Swan Nebula and was amazed by the sharpness of the image and by how much it looked just like a swan. There is so much to see. Leah and I plan to venture out every chance we get."

Readers interested in learning more can e-mail Tom at tomnet@cox.net. ✦

*Contributing editor **Gary Seronik** is an experienced telescope maker and observer. Contact him about your own ATM projects via his website, **garyseronik.com**.*

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**SCORPION'S STINGER**
**Klaus Brasch**
The stars Shaula and Lesath (left of center) mark Scorpius' stinger. The quartet of red nebulae are, from upper left, NGC 6357, 6334 (Cat's Paw), tiny 6302 (Bug), and IC 4628 (Prawn).
**Details:** *Canon EOS 6D DSLR camera with a 135-mm lens and IDAS LPS-V4 nebula filter. Total exposure: 8 minutes.*

### ◄◄ CLASSIC DUMBBELL

Jaspal Chadha

Sometimes called the Apple Core, the Dumbbell Nebula (Messier 27) in Vulpecula marks an expanding shell of clumps and wispy matter shed by a dying star roughly 10,000 years ago. This colorful view was captured despite the light pollution of London, England.
**Details:** *Altair Astro RC250-TT V2 astrograph, QHYS CCD camera, and Chroma Technology filters. Total exposure: 95 minutes.*

### ◄ DEEP DUMBBELL

Fred Herrmann

For a different take on the same object, this extremely deep composite image reveals faint waves of matter outside the main shell. The Dumbbell lies about 1,400 light-years from Earth.
**Details:** *PlaneWave Instruments CDK14 astrograph, SBIG STXL CCD camera, and five filters. Total exposure: 80 hours.*

### ▲ GRANDEST GLOBULAR

Jérôme Astreoud

The immense globular cluster Omega Centauri (NGC 5139) tops any observer's list of "must view" southern-sky objects. Located 15,800 light-years away and 150 l-y across, it boasts some 10 million stars and appears as a soft glow to the unaided eye.
**Details:** *Takahashi Epsilon 210mm Newtonian astrograph, Canon EOS 7D CCD camera at ISO 800, and Baader filter. Total exposure: 42 minutes.*

▲ **A DIM "BRIGHT" NEBULA**

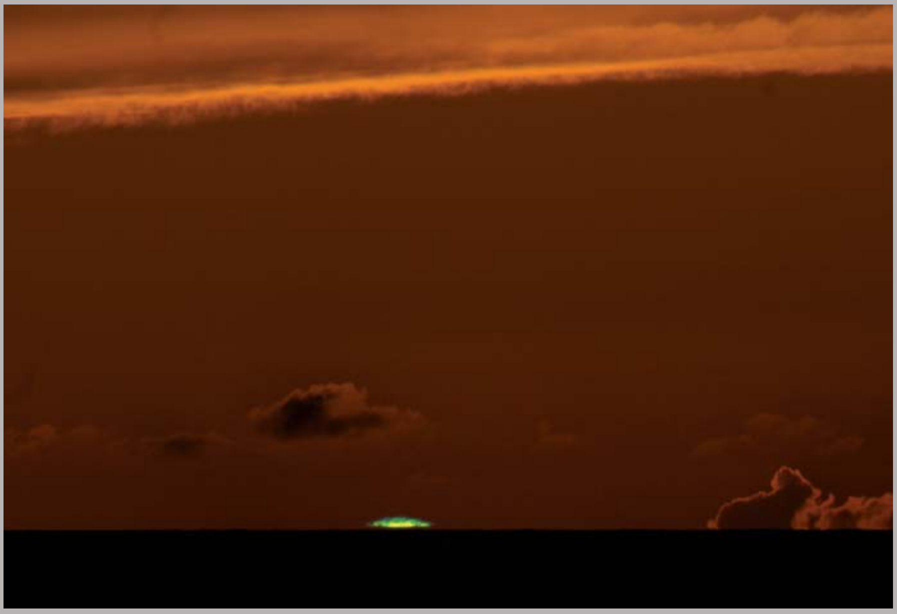
Dan Crowson

Lynds Bright Nebula (LBN) 270, between Deneb and Sadr in Cygnus and centered here, is actually quite dim. Framing it are brighter glows from LBN 273, 274, and 292.
**Details:** *Astro-Tech AT90EDT apochromatic refractor and SBIG ST-8300M CCD camera with LRGB filters. Total exposure: 4 hours.*

► **ELUSIVE GREEN FLASH**

Eusebio Rufián

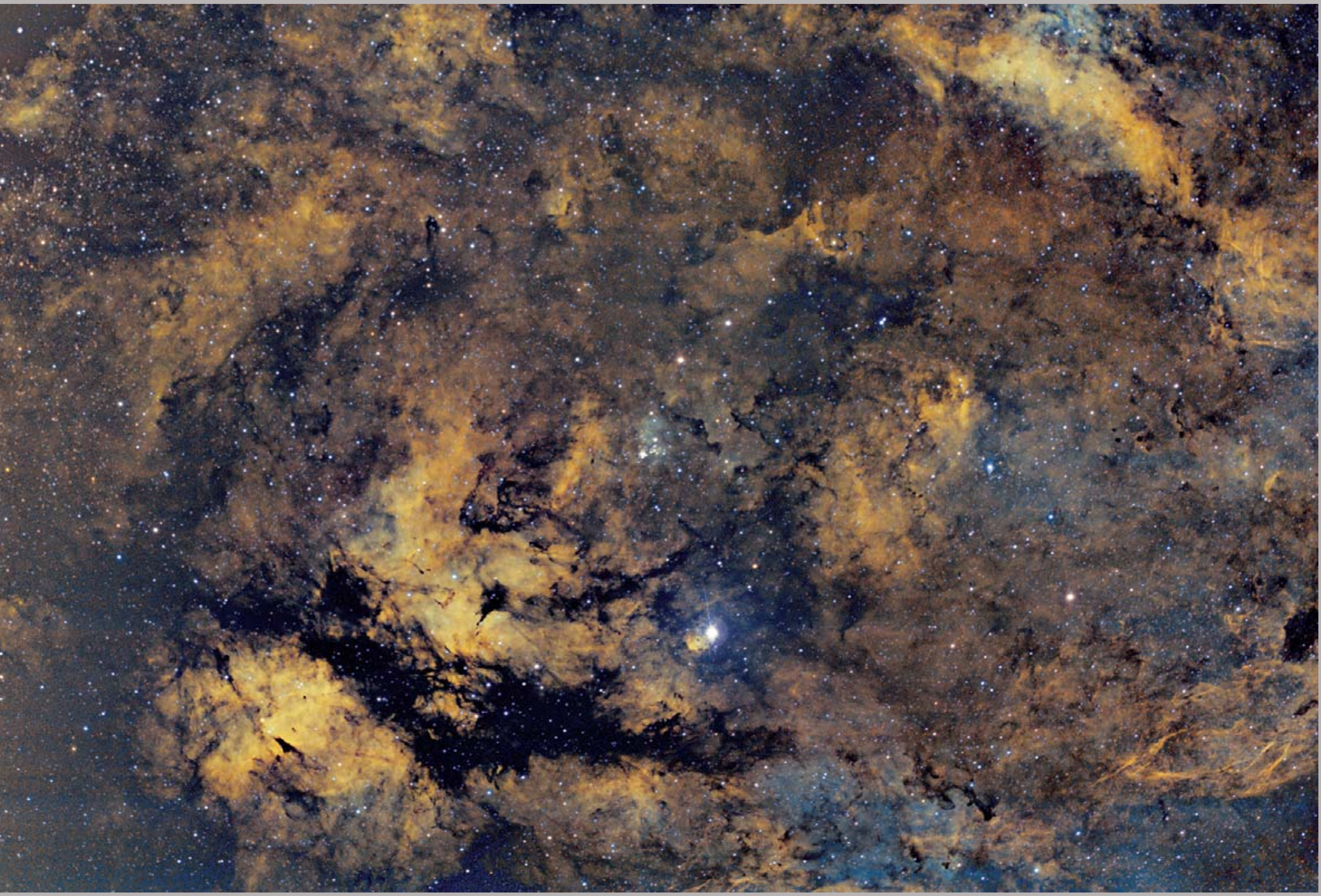
A final glint of emerald green (caused by differential refraction in the atmosphere) is all that remains of the setting Sun as seen from Cadiz, Spain, on September 14, 2014.
**Details:** *Orion EON 110mm ED apochromatic refractor and Nikon D100 DSLR camera used at ISO 200. Exposure: 1⁄4000 second.*



THE FLOWER OF CEPHEUS

**Chuck Manges**

Delicate blue-hued wisps from the Iris Nebula (Caldwell 4) surround the open cluster NGC 7023 at its center. The nebula reflects light from the 7th-magnitude star SAO 19158.
**Details:** *Astro-Tech AT65EDQ astrograph and QHY9M CCD camera with LRGB filters. Total exposure: 4.9 hours.*



▲ **SMALL CLUSTER, BIG BILLOWS**

Robert Fields

To the eye, NGC 6910 is a tiny cluster of stars in Cygnus. But long-exposure images bring out the extensive nebulosity that surrounds it. This "Hubble palette" view combines light from ionized sulfur, twice-ionized oxygen, and hydrogen alpha. **Details:** *Takahashi FSQ-106ED apochromatic refractor and SBIG STL-11000M CCD camera with narrowband filters. Total exposure: 10 hours.*

▶ **OCTOBER'S "FALSE DAWN"**

Dale Cupp

A pristine sky over Arizona's Mount Lemmon revealed the zodiacal light very clearly before dawn on October 2, 2014. **Details:** *Canon EOS Rebel T2i DSLR camera and 18-to-55-mm zoom lens set to 18 mm. Exposure: 45 seconds.* ✦

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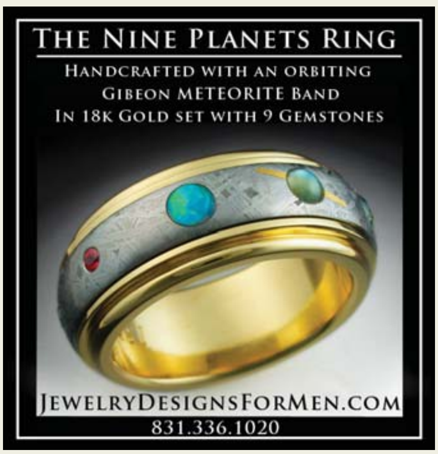



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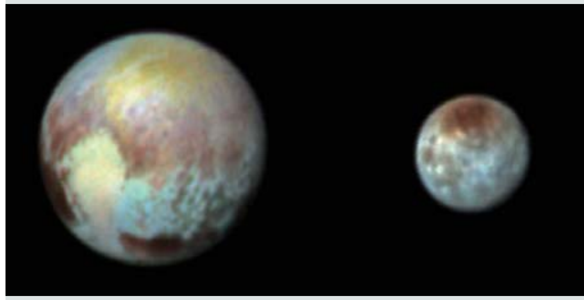

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# The Great Watering Hole

*What have we lost with the dilution of sci.astro.amateur?*

I STOPPED IN AT sci.astro.amateur (s.a.a.) the other day for old times' sake. What was once a very busy newsgroup is now a quiet Google group. It was like returning to a familiar neighborhood after a long absence and finding almost everyone you once knew had moved away and many stores had been boarded up. For those of us who jumped onto the internet in the mid-90s, the original s.a.a. was an essential cyberspace stop.

Back then, it was terribly addictive: once drawn into a thread, you were hooked for good or ill. And no matter the issue, you could count on a passionate debate. Best way to collimate an SCT? Hot topic! How big a central obstruction is too big? Flame war! No subject was too benign to generate outrage and spark a lively exchange. A lot of it was vacuous and needlessly vitriolic, but wasn't it fun?

True, s.a.a. was also a favorite hangout for a herd of notorious trolls. But as numerous as they were, the trolls did manage to post on-topic once in a while. More importantly, they were outnumbered by spectacularly generous and experienced individuals who seemed to have no end of patience for helping a steady stream of newbies who inadvertently stumbled into the fray. Most of all, what made s.a.a. great was that virtually everyone seemed to stop in once in a while to chat. It was the Great Watering Hole of amateur astronomy.

Today, there are plenty of places to discuss your favorite astro topics online. In fact, there might be too many. Cloudy Nights, Facebook, Google+, IceInSpace, Twitter, Yahoo Groups, and many other networks host specialized groups and forums. If your interest is Newtonian reflectors, there's a forum for that. SCTs? Forum for that. Sketching? Forum. Lunar observing? Check. And so on. Only a dedicated curmudgeon could see so much variety as a bad thing.

ABBEY LOSSING

But at the risk of fitting that unflattering profile, I have to say that I miss having a single online clubhouse where everyone hangs out. What we've lost is the ease with which different perspectives come together and ideas cross-pollinate. It seems each of us has found our tribe, and now we're content to exist on tiny islands of thought. Sure, you could read more than one forum — I regularly check in on a half dozen myself — but who has the time to look at enough to really sample a broad cross section of our wonderfully diverse hobby?

Is there a Great Watering Hole anywhere today? As self-serving as this might sound, I'm going to say you're looking at it right now. Yes, this and other magazines provide a common point of contact for amateur astronomers. In these pages you see the entire spectrum of the hobby represented month after month. And while no print publication can hope to match the interactivity and immediacy of online forums, magazines do allow us to dip into a common well of ideas and draw from it what we will.

This magazine is a shared experience — something that has grown increasingly scarce in our media-saturated, multi-platform electronic age. The inevitable march of progress might have overtaken s.a.a., but I for one am glad that we at least still have *this* watering hole. ✦

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*__Gary Seronik__, an S&T contributing editor, kept himself busy for this issue. See his Binocular Highlight on page 43, his test report on page 60, and his Telescope Workshop column on page 72.*

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