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THE ESSENTIAL GUIDE TO ASTRONOMY

SKY & TELESCOPE

JUNE 2015

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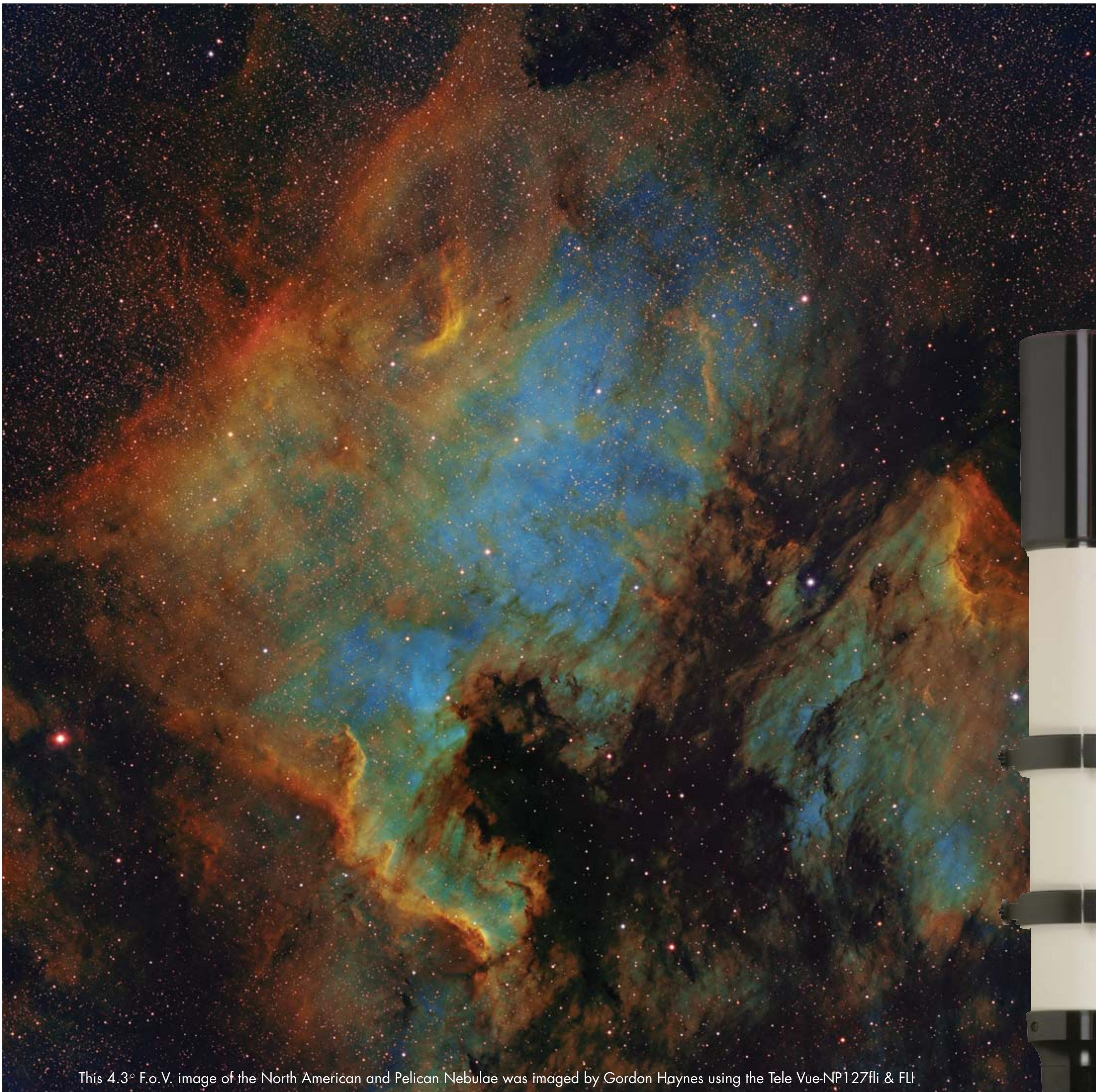

This 4.3° F.o.V. image of the North American and Pelican Nebulae was imaged by Gordon Haynes using the Tele Vue-NP127fli & FLI

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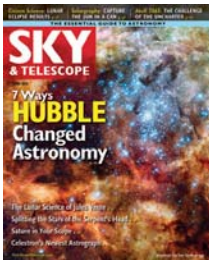

On the cover: The star cluster R136 in 30 Doradus is just one of the countless wonders the Hubble Space Telescope has shown to us.

PHOTO: NASA / ESA / F. PARESCE (INAF-IASF) / R. O'CONNELL (UNIV. OF VIRGINIA, CHARLOTTESVILLE) / WFC3 SCIENCE OVERSIGHT COMMITTEE

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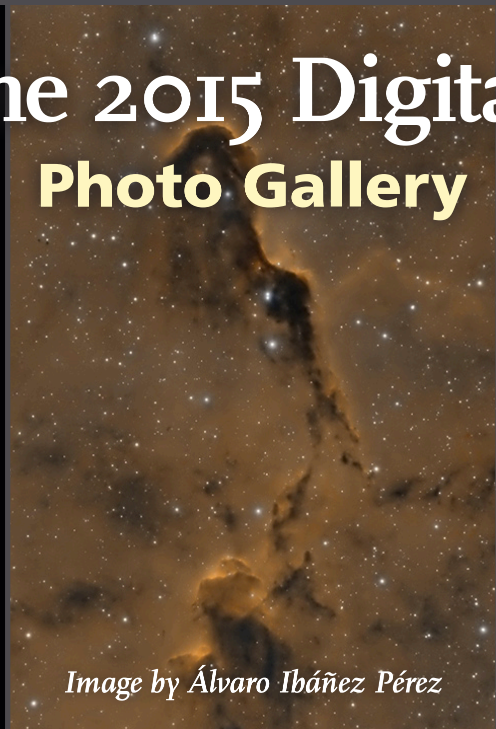

Image by Álvaro Ibáñez Pérez

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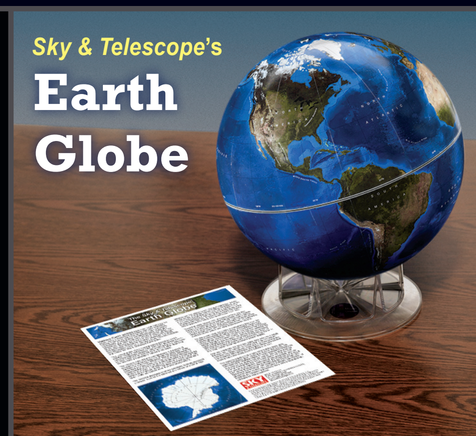

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March, April, and May

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ONLINE PHOTO GALLERY
Bob Gillette took this photo of nearby Centaurus A, capturing the dramatic dust lane that crosses the galaxy.

Take a Number

ONE OF THE THINGS I LOVE about astronomy is all the enormous numbers we blithely throw around. We use them, rely on them, wow ourselves with them, even as we fail in many cases to truly comprehend the magnitude each represents.

Take a few examples from this issue: A Chinese spacecraft discovers subsurface layers on the Moon thought be 2.5 to 3.3 billion years old (page 14). Sagittarius A*, the supermassive black hole at the heart of the Milky Way, has a mass of 4.3 million Suns (page 16). A galaxy cluster called Abell 2065 lies 1.1 billion light-years away (page 60).

We toss such figures around like so much confetti: 2.5 to 3.3 billion years ago? Sure. A mass of 4.3 million Suns? No big deal. A galaxy cluster 1.1 billion light-years away? What of it?

What of it? Think about that last one for a moment. How far away is 1.1 billion light-years? It's 6.5 x 10^{21} miles, or 6,500,000,000,000,000,000,000 miles. Can you really get your mind around that?

I feel reasonably comfortable with the idea of 3,000 miles, the rough distance across the continental U.S., having traveled it many times. I would even venture to say that I can *somewhat* grasp the concept of 239,000 miles, the rounded-up distance to the Moon. But 93,000,000 miles to the Sun? Forget it. You've lost me there, much less to Abell 2065. Maybe you're more adept with huge numbers than I am, but no one can wrap his or her brain around 1.1 billion light-years.

BOB FRANKE

The galaxy cluster Abell 2065 is 1.1 billion light-years away. And that's fine.

And that's okay.

I'm reminded of an incident in *The Snow Leopard*, by the late Peter Matthiessen. The writer is visiting a Buddhist lama at his isolated hermitage high in the Nepalese Himalaya. Because of crippling arthritis, the monk has not left his cliff-side haunt in eight years and may never again, yet he seems happy. Through an interpreter, Matthiessen asks him for his opinion on his apparent fate. The lama laughs, points dismissively at his lame legs, and says, "Of course I am happy here! It's wonderful! *Especially* when I have no choice!"

We amateurs regularly crunch colossal numbers because they help us get a grip on what we're dealing with way out there. But we have to admit to ourselves that they are so whopping as to be essentially absurd. All we can really do is shake our heads and smile. We have no other choice. A billion light-years? It's wonderful! ✦

Editor in Chief

SKY & TELESCOPE

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In Praise of Astrophotography

It was great to see Robert Gendler's timely article, "Composing the Universe" (*S&T*: Jan. 2015, p. 70). This discussion seems long overdue in the astrophotography community.

Whenever I look at an image, whether it's an astrophoto or a street photo, the first things I ask myself are, "What is the photographer saying to me? What is he or she saying about himself or herself?" Unfortunately, with most astrophotos the only thing being said is, "I am someone who has mastered complex technology." Then I turn the page on yet another image of M31.

There is so much more that can be communicated, and by adopting some of Gendler's suggestions about composition, visual flow, and balance, it's possible to create an inspirational, individual expression of the wonders of our universe.

Steve Irvine
Georgian Bluffs, Ontario

Remarkable Thin-Moon Sightings

If you are still interested in reporting the observations of "opposing crescents," I used an 8-inch telescope to observe the new Moon crescent on February 19th at 1:29 p.m. Mountain Standard Time from Tucson, Arizona. The previous morning, February 18th, I saw the old lunar crescent at 6:47 a.m. from Mount Lemmon, not far from Tucson, also telescopically. That time interval works out to be 30 hours 42 minutes.

My previous record, an interval of 33 hours 49 minutes, was in January 1996, when we observed the youngest new Moon at that time. But I hadn't seen anything shorter than that until this year.

Jim Stamm
Tucson, Arizona

A barely-there lunar crescent, just 16.7 hours past new Moon, as captured from Tehran, Iran, on January 31, 2014.

MOHSEN MIRSAEED

In 2013 and 2014, I tried to observe all waxing and waning crescents. I could see most of the visible ones except those with clouds or hazy dust at my horizon. One was on the evening of January 31, 2014, which I saw without optical aid when it was 16 hours 40 minutes past new. The previous morning, January 30th, using just my eyes I could see a waning crescent that was 18 hours 23 minutes from new. The time interval between these two sightings was just 35 hours 3 minutes!

Mohsen Mirsaeed
Tehran, Iran

Editor's note: *The previous record for well-documented naked-eye sightings of opposing lunar crescents was 35.7 hours, made in Hawaii on December 31, 1994, and January 1, 1995, by Stephen James O'Meara (*S&T*: May 1995, p. 105).*

Planet Earth's Predicament

I was gratified to see David Grinspoon's "The Big Payback" (*S&T*: Jan. 2015, p. 18). If anyone is capable of seeing Earth in planetary terms, it's astronomers, both professional and amateur. Although *S&T*'s circulation is relatively small, and astronomers make up a tiny fraction of the general population, the truth needs to be told whenever possible. And the truth is: The situation (both for ourselves and the biosphere) is very dire. Unfortunately, the current worldview has a stranglehold on the political process that could theoretically allow us to meet our numerous challenges in an intelligent manner. The prognosis is poor, in my estimation. Yet the truth (that is, accurate information) needs to be told, simply because we can. I'm glad that *S&T* is doing so.

Gordon Solberg
Radium Springs, New Mexico

David Grinspoon writes, "We're causing a mass extinction now," as he blames humankind. Yet the Smithsonian Institution estimates that 99.9% of all the species that have ever lived are extinct. Nothing is more natural than going extinct. The idea of humans being in such tight control of Planet Earth is quaint. Where I am now sitting was under a thick sheet of ice 20,000 years ago, and sea level was about 100 meters lower. Even the most ardent climate-change enthusiasts haven't argued that inconsiderate humans brought on the last Ice Age.

Grinspoon alludes to "developing a new global energy system that does not wreck the natural systems. . . ." (He doesn't tell us how this will work — but presumably he and other astrobiologists like to use electricity when the Sun isn't shining and the wind isn't blowing.) Then he calls for stabilizing the world's population, building a planetary defense system against impacts, and preparing for the eventual burnout of the Sun. As Grinspoon suggests, we are going to be quite busy.

John Wood
Concord, Massachusetts

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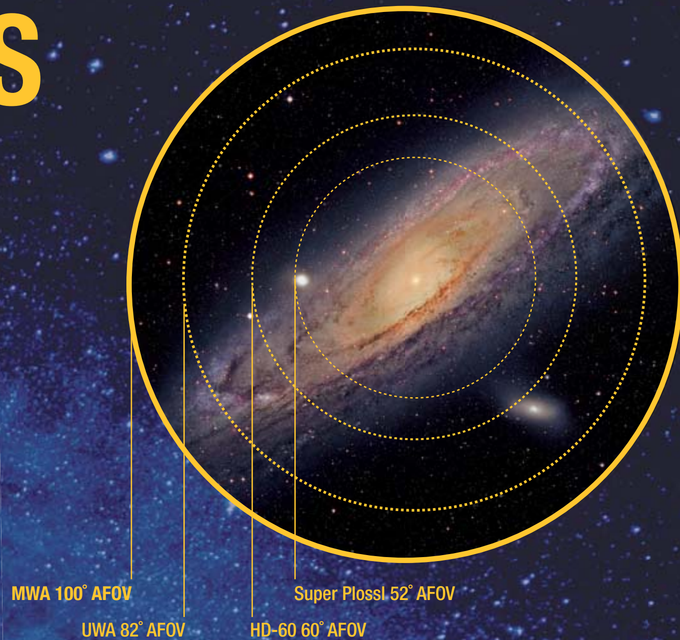

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As I began reading Grinspoon's article, I started to fear that *S&T*'s new management team had chosen to subtly enter the politically charged debate on man-made global warming. Then I reached the sentence referring to cyanobacteria "flooding Earth's atmosphere with poisonous oxygen" and realized that I had been snookered into taking the article literally. It was only then that I noticed the column's title, "Cosmic Relief," and concluded that Grinspoon was writing in the vein of Jonathan Swift's famous satire "A Modest Proposal." Well done!

The only thing he left out was a suggestion that, at some time in the distant future, our descendants will figure out a way to replenish the Sun's core with fresh hydrogen at just the right rate to prevent Old Sol from ever needing to initiate helium fusion. That would avoid the troublesome consequences of Earth being swallowed by the solar system's newly born red giant star. Of course, that would also deprive our galaxy of a potentially beautiful new planetary nebula — but, hey, you can't have everything.

Edward Novak
Waynesville, Ohio

Solar-Filter Clarifications

Sean Walker's review of DayStar's new Quark hydrogen-alpha solar filter (*S&T*: Nov. 2014, p. 38) states, "Optical designs with rear elements, such as the Petzval, and any oil-spaced objectives require a full-aperture energy-rejection filter for safe use." However, some Petzval telescopes, such as those made by Tele Vue, have rear elements 10 inches from the focal plane and therefore do not require such a filter. Nor are ours oil-spaced or cemented.

Also it's not the focal ratio of a fast refractor that permits "wide-field views of the Sun" but rather its focal length. This is why the 480-mm Pronto or TV-76 scopes, used with the Quark's amplifying optics and 21-mm back filter, permit a full-disk solar view. The TV-60 (360-mm focal length) might perform even better, since it yields a 0.8° field of view.

Al Nagler
Chester, New York

Editor's note: *Nagler is founder and CEO of Tele Vue Optics. Walker notes that the warning about Petzval designs was part of the manufacturer's literature.*

For the Record

✷ *The current orbital position angle of Sirius B (S&T: Mar. 2015, p. 50) is 78° (measured eastward, or counterclockwise, from north), not 282°.*

✷ *When viewing a nearly edge-on galaxy (S&T: Mar. 2015, p. 20), it's the increased surface brightness (not optical depth) that renders them easier to see than those tipped toward us with more open angles.*

75, 50 & 25 Years Ago

Roger W. Sinnott

May-June 1940

No Moving Cluster "When not properly accounted for, the effect of the solar motion may lead to a false conception of the true character of stellar motions. Such a misconception was recently brought to light by Dr. W. M. Smart of the Glasgow Observatory . . . who has convincingly disproved the notion that the stars of the Scorpius-Centaurus group form a moving cluster [like that] in Ursa Major, which includes five Dipper stars. . . . The apparent similarity in [the Sco-Cen stars'] velocities arises from a fortuitous reflection of the solar motion."

While moving at random and not gravitationally bound, the hot, young stars of spectral type O *and* B *in Scorpius, Centaurus, and Crux have astrophysical importance as the nearest* OB *association to our Sun.*

June 1965

Mercury's Day "Radar study of the planets has been an important activity of the Arecibo Ionospheric Observatory in Puerto Rico ever since its 1,000-foot radio-radar telescope went into operation in late 1963. . . . Recent results were

reported . . . by Gordon H. Pettengill and Rolf B. Dyce. . . .

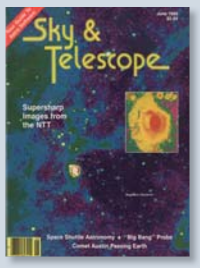
"The most startling result from this surveillance was a preliminary finding that the length of Mercury's day is 59 ± 5 of our days, and that the sense of its rotation is direct — from west to east like the earth's. Hitherto, most astronomers had accepted G. V. Schiaparelli's conclusion of 80 years ago that Mercury's day was equal in length to its year, that is, 88 Earth days. . . .

"One serious contradiction is raised by the radar rotation period. To experienced visual observers with suitable telescopes, Mercury has fairly conspicuous dusky markings, and a number of rather accordant maps of its surface have been drawn [assuming an 88-day rotation]. . . ."

The radar result proved the old maps were bogus. Mercury rotates once every 58.646 days.

June 1990

Galaxy Merger "The true nature of Arp 220, a peculiar 14th-magnitude galaxy in Serpens Caput, may finally be coming to light. For years astronomers have debated whether the system



is a Seyfert galaxy, as its bright, active core suggests, or a starburst galaxy, as its very strong infrared emission would indicate. . . .

"James R. Graham (California Institute of Technology) and colleagues made a very sharp 2.2-micron image using an infrared detector array on the 5-meter reflector atop Palomar Mountain. A special f/415 secondary mirror yielded an effective focal length of 2 kilometers. . . .

"The resulting image . . . shows two distinct sources barely 1 arc second apart [that] coincide with radio sources detected earlier at the Very Large Array. . . . This 'establishes beyond doubt that Arp 220 is the remnant of the merger of two galaxies,' says Graham, 'an event which triggered the ultraluminous phase now being witnessed.'"

The gravitational turmoil of this galactic merger seems responsible for the vigorous star-forming activity being observed there, and it might in some way explain a surprise finding in 2011, namely, that Arp 220 spawns a supernova every few months.

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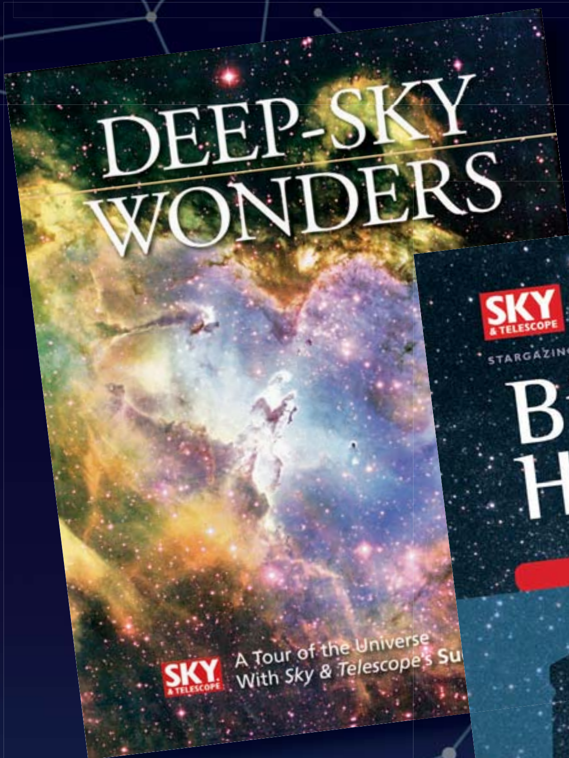

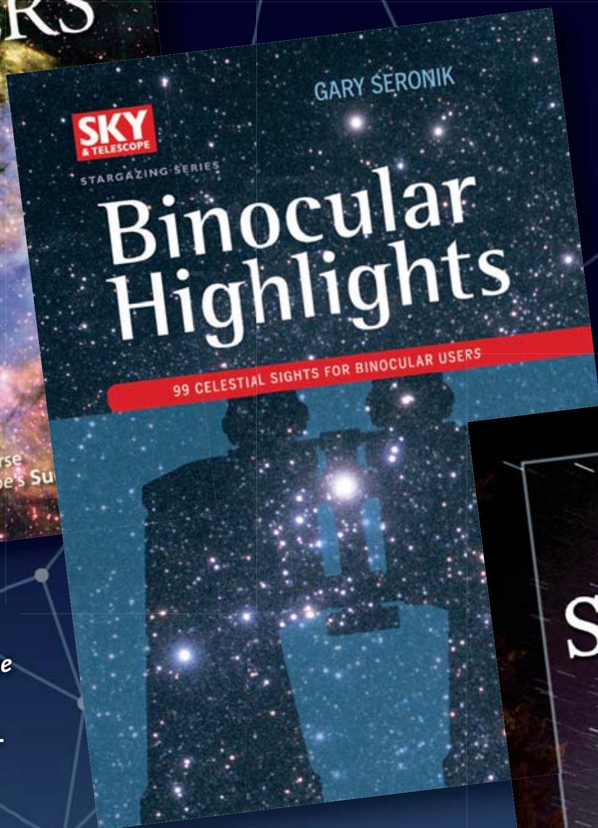

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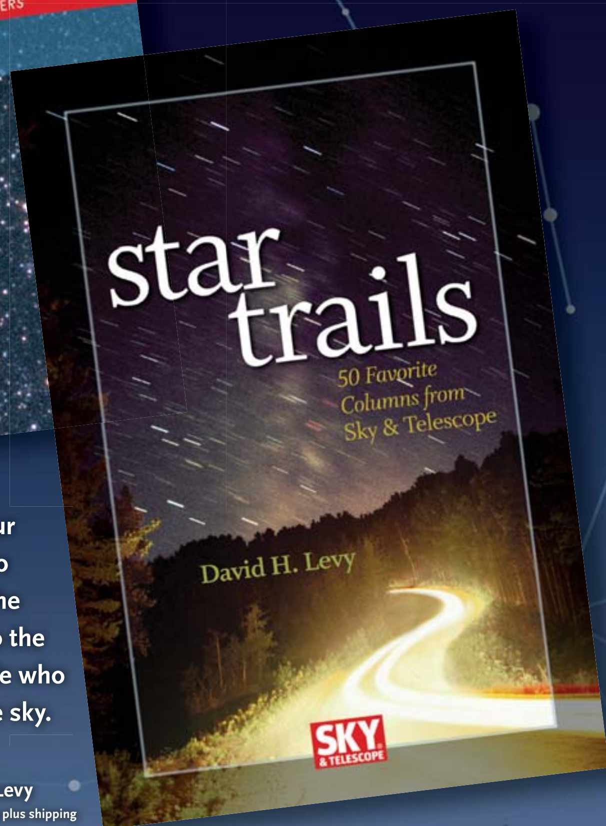

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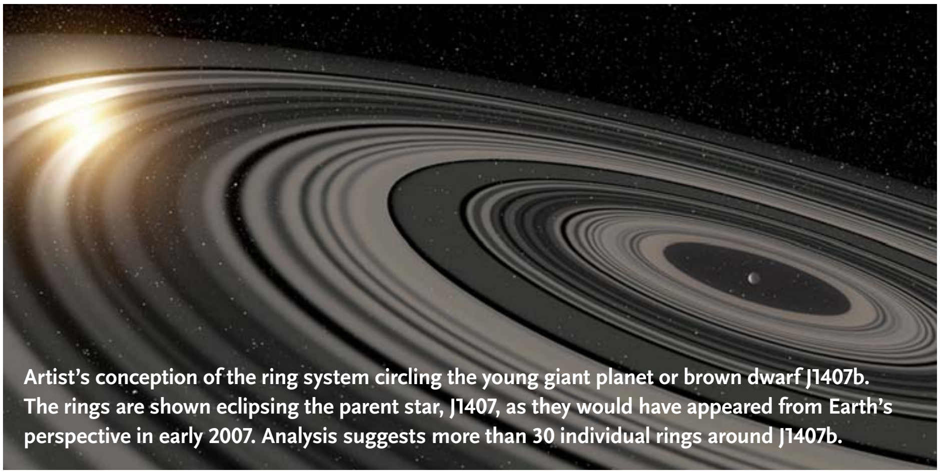

Artist's conception of the ring system circling the young giant planet or brown dwarf J1407b. The rings are shown eclipsing the parent star, J1407, as they would have appeared from Earth's perspective in early 2007. Analysis suggests more than 30 individual rings around J1407b.

RON MILLER

Astronomers have confirmed that the star 1SWASP J140747.93–394542.6 (hereafter J1407) seems to have a substellar companion with a gigantic ring system, inside which an "exomoon" might be forming — potentially the first detection of a satellite forming around an exoplanet.

Ring formation is thought to be fairly common for larger planets, as all of the outer solar system planets have rings. Furthermore, astronomers think that the giant planets' major moons formed in souped-up versions of these ring systems.

In 2012, Matt Kenworthy (Leiden Observatory, The Netherlands), Eric Mamajek (University of Rochester), and colleagues discovered one of these circumplanetary disks around the companion of the 16-million-year-old *K*5 star J1407. Kenworthy and Mamajek have now performed a new analysis of their original data, obtained by the SuperWASP planet search.

As the companion, named J1407b, passes between Earth and its host star, a rich and intricate eclipse pattern occurs, in contrast to the typical dips seen for a single companion. Reported in the February 20th *Astrophysical Journal,* the new analysis shows more than 30 separate ring structures, within a ring system spanning 1.2 astronomical units and having a mass on the order of 100 Moons. (Saturn's rings total roughly a thousandth the Moon's mass.)

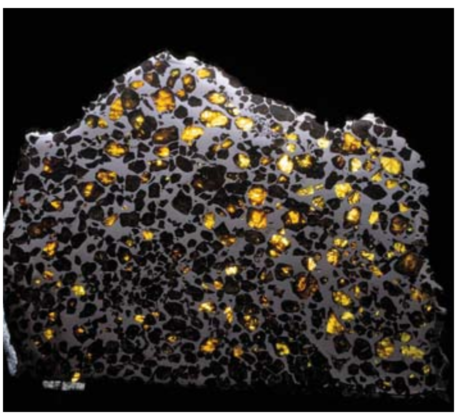
Perhaps even more exciting is the team's confirmation of one large, clear gap in the ring around J1407b, potentially carved out by a forming moon. The gap's size implies a satellite mass between that of Earth and Mars, with an orbital period of approximately two years.

Astronomers estimate that the orbital period of J1407b is about 10 years, but unfortunately they don't know exactly when the next eclipse will happen. "It could be tomorrow, next year, a few years, we don't know," says Mamajek. Amateur observations reported to the American Association of Variable Star Observers (AAVSO) have already ruled out some orbital periods, and the team encourages amateur astronomers to continue to help them monitor J1407. Such additional observations would help detect the next eclipse by the rings and also constrain the companion's period, size, and mass, as well as the size and mass of the rings. Find more info at **http://is.gd/j1407b**.

■ **JOHN BOCHANSKI**

Watch a video simulation showing the complicated light pattern the team observed as J1407b's rings passed in front of the star: http://is.gd/exomoondisk.

METEORITES | Long-Lived Magnetic Fields Left Their Mark


THE TRUSTEES OF THE NATURAL HISTORY MUSEUM, LONDON

The Esquel meteorite consists of gem-quality olivine embedded within an iron-nickel matrix.

The magnetic fields in the asteroid parents of two meteorites lasted hundreds of millions of years after our solar system's formation, an order of magnitude longer than expected, James Bryson (University of Cambridge, UK) and colleagues report in the January 22nd *Nature.*

The team studied the famous meteorites Imilac and Esquel, found in South America in 1822 and 1951, respectively. Both meteorites are pallasites, which come from the core-mantle boundary of a once-molten asteroid. When this molten conducting fluid inside the asteroid solidified, it locked inside itself an imprint of the magnetic field that existed at that time. This imprint also exists in the meteorites from the asteroid.

Using nanoscale imaging, the team looked at the physical structure of tetrataenite, an iron-nickel alloy, in each meteorite. Analogous to the way tree rings chronicle droughts and times of plenty,

STELLAR | Before They Were (Binary) Stars

Astronomers have taken a behind-the-scenes look at a set of dense gas clumps, catching a quadruple star system in the fleeting act of formation. Jaime Pineda (ETH Zurich, Switzerland) and colleagues report the observations in the February 12th *Nature*, and they add some much-needed evidence to the theoretical playing field.

It's easy to make multiples in theory. One idea is that a single star-forming clump might split into several, like fraternal twins in the womb. Another proposes that the disk of material that feeds a forming star might be gravitationally unstable, fragmenting and collapsing into another star that orbits the first. Some theorists have also suggested complex three-body encounters that can lead to stellar capture or a modification of existing partnerships.

But Pineda says these theories have a hard time explaining the formation of wide binaries, stellar siblings separated by thousands of astronomical units (a.u.). Instead, his observations point to a fourth option: fragmenting filaments.

Pineda's team used the Very Large Array in New Mexico to image radio waves emitted from ammonia molecules in the Perseus star-forming region. This radiation traces the presence of dense gas and reveals long filaments that have crumbled into four distinct clumps in a star-forming core called Barnard 5, which lies 815 light-years away. One of these clumps contains a well-known protostar, a star that hasn't yet ignited its core fusion. The other three clumps surround the protostar at distances ranging from 3,300 to 11,400 a.u.

The protostar and the three surrounding clumps each contain between a tenth and a third of the Sun's mass, based off the submillimeter-wavelength brightness as seen with the James Clerk Maxwell Telescope on Mauna Kea. The authors estimate that the clumps' gravitational collapse will take roughly another 40,000 years, so the stars' final masses will depend on how much gas they can collect in that time. Gas flowing along the filaments might continue to feed the growing clumps, or the individual masses could fragment further even as they continue to collect gas from their surroundings.

The clumps are smaller than what you might predict if you simply pit gravity's inward pull against the thermal motion of gas molecules. Instead, it looks like random flows of turbulence have broken up the condensations within this filament. Turbulent fragmentation isn't a new idea, but observational confirmation has only recently entered the realm of possibility, in part due to the VLA's massive upgrade in 2011.

■ **MONICA YOUNG**

---

the matrices of tetrataenite within Imilac and Esquel record changes of strength and direction of the magnetic field produced by their parent bodies over time — and the eventual shutoff of the field once each asteroid's core solidified.

These are some of the first observations of how an asteroid's magnetic field changes in time, notes planetary scientist Ben Weiss (MIT), who was not involved in the study. The measurements show that asteroid magnetic fields probably were generated a lot like that of Earth: by the motion of iron-rich fluid in a core that is turning solid. The motion would have been driven by the expulsion of iron-depleted material from the core as it "froze." Previous research assumed that convection in these bodies was thermally driven, like boiling water, which transfers heat with physical motion from a pot's bottom to top. However, the magnetic activity the two meteorites record lasted well beyond what thermally driven convection could have sustained.

■ **EMILY POORE**

IN BRIEF

Citizen Scientists Find "Yellowballs." Thanks to volunteers working with Zooniverse's Milky Way Project, astronomers have discovered a new signature marking a hidden phase of star formation. The project's aim is to find cavities carved out by the winds of newborn, massive stars. Before they emerge from their dusty cocoons, though, the not-yet-stars must grow from cool clumps of dense gas into ready-to-burn protostars, heating up their surroundings in the process. When a citizen scientist known by the username kirbyfood came across a mysterious fuzzy yellow thing and posted it in the Zooniverse forum, a professional astronomer tagged the object with the name #yellowball. Soon that identifier marked another 928 objects. Researchers think the yellowballs mark the in-between phase of transition from cool clumps of gas and dust to newly formed stars, Charles Kerton (Iowa State) and colleagues report in the February 1st *Astrophysical Journal*. Their yellow color comes from the combined glow of warm dust (red) and organic molecules (green) in false-color infrared images from the Spitzer Space Telescope.

■ **MONICA YOUNG**

Eta Carinae's X-ray Pulse. Ranking as the most massive, most luminous star within 10,000 light-years of us, Eta Carinae has baffled astronomers ever since it unexpectedly ejected a vast shell of matter in the 1840s. They now think it's actually a binary star whose components have roughly 90 and 30 times the Sun's mass. Recently, space observatories found that Eta Carinae creates strong X-ray outbursts every 5½ years, whenever the paired stars are closest in their highly elongated orbit, separated by only about 225 million km (140 million miles) — roughly Mars's distance from the Sun. Computer simulations by Thomas Madura (NASA Goddard Space Flight Center) and others suggest that the secondary's thin, high-speed stellar wind collides violently with the primary's slower, denser wind, creating a superheated shock boundary that generates a torrent of X-rays.

■ **J. KELLY BEATTY**

IN BRIEF

Dwarfs Nicked Oort Cloud. A red dwarf and its brown dwarf companion buzzed through the outer Oort Cloud some 70,000 years ago, Eric Mamajek (University of Rochester) and colleagues suggest in the February 10th *Astrophysical Journal Letters*. The team used a combination of position and motion data gathered by Adam Burgasser (University of California, San Diego) and others to simulate 10,000 orbits for the *M* dwarf WISE J072003.20–084651.2, called Scholz's Star. Of all those simulations, 98% had the star passing through the outer Oort Cloud. Its closest approach was probably between 0.6 and 1.2 light-years away (38,000 to 75,000 astronomical units), where it scraped the Oort Cloud. A second star, Gliese 710, has a more precisely calculated trajectory that shows it flying roughly 1.1 light-years from the Sun 1.4 million years from now. Theorists expect that stellar passes closer than 0.8 light-year happen roughly every 100,000 years.

■ **SHANNON HALL**

Chang'e 3 Landed on Lunar Layers. When China's Chang'e 3 spacecraft came to rest atop northern Mare Imbrium on December 14, 2013, it achieved the first soft landing on the Moon since 1976 (see page 54). The main spacecraft and its wheeled rover, called Yutu, each carried four instruments. Although Yutu traveled only 114 meters before suffering a mobility malfunction (*S&T*: May 2014, p. 12), its ground-penetrating radar system operated well. In the March 13th *Science*, mission scientist Long Xiao (China University of Geosciences and Macau University of Science and Technology) and colleagues report finding at least nine discrete rock layers extending to about 400 meters (0.25 mile) beneath the surface. Most are thought to be solidified lava or ash flows from regional eruptions that occurred 2.5 to 3.3 billion years ago. But the topmost pair, which together are about 4 meters thick, appear to be rubble thrown out when an impact excavated a nearby 450-meter-wide crater 27 to 80 million years ago.

■ **J. KELLY BEATTY**

GALAXIES | Dusty Galaxy in Early Universe

Astronomers have directly detected dust in a galaxy shining at us from only 700 million years after the Big Bang (redshift of 7.5). And given its mass, it's as dusty as a mature star-forming galaxy today.

Darach Watson (University of Copenhagen, Denmark) and colleagues explored the galaxy A1689-zD1 using ALMA and the Very Large Telescope (VLT). The galaxy is only bright enough to study because the galaxy cluster Abell 1689 gravitationally lenses A1689-zD1's light, magnifying it by more than nine times.

The optical light VLT detects from A1689-zD1 began as ultraviolet radiation, emitted by young, massive stars and was then stretched to visible wavelengths by the universe's expansion. Thus, the team can use the light to estimate the galaxy's mass in stars: 1.7 billion solar masses, a hundredth the Milky Way's stellar mass.

The optical spectrum from VLT and the dust emission detected by ALMA both suggest A1689-zD1's star-formation rate is at least a few times higher than the one-Sun-per-year rate of the Milky Way — not unusual for this cosmic era.

What is unusual is that the galaxy contains between half and a few times the ratio of dust to gas in the Milky Way. This value suggests the galaxy has already burned through half of its gas, only 150 million years after the universe's galaxies started churning out stars in earnest.

But because A1689-zD1 is only a hundredth as massive as the Milky Way, the little galaxy has only about a hundredth as much dust. It could have built up that dust by forming stars at a moderate rate for the last 150 million years, or perhaps it had an extreme "starburst" phase earlier and is now calming down. Per unit area, its star-formation rate is on par with many starburst galaxies, the authors note March 2nd in *Nature*. It's also consistent with upper limits calculated for other galaxies in the same cosmic era.

As in today's galaxies, most of the dust grains likely formed in the winds from old, swollen stars, or when massive stars went supernova. Because giant stars don't live long, there's no need to have a very old galaxy to see dust.

■ **CAMILLE M. CARLISLE**

BLACK HOLES | Midsize Candidate Found

Astronomers have discovered what appears to be a black hole of intermediate mass in the arm of NGC 2276, a spiral galaxy 100 million light-years from Earth. The source, called NGC-2276-3c, is shooting out a powerful radio jet 6 light-years long, with further radio emission extending out to 2,000 light-years. The black hole is potentially about 50,000 solar masses, Mar Mezcua (Harvard-Smithsonian Center for Astrophysics and Universidad de La Laguna, Spain) and colleagues estimate in the April 1st *Monthly Notices of the Royal Astronomical Society*.

Scientists know of only two credible black hole candidates in the 100 to 100,000 solar-mass range. One is in a galaxy 300 million light-years away, and the other is in the starburst galaxy M82. Their masses range from a few hundred to ten thousand solar masses. If proved legitimate, NGC-2276-3c "would be a rare and important find," says Roberto Soria (Curtin University, Australia).

There are several other cosmic objects that on first glance also appear to be intermediate-mass black holes (IMBHs), but that's because they are accreting material at unnaturally high rates, boosting their luminosity. Such objects are actually stellar-size, but they can also have powerful jets. If NGC-2276-3c were accreting at a rate far higher than normal, its mass could be smaller.

What's unclear is whether a stellar-mass black hole could support a radio jet steady enough to carve out the region seen around NGC-2276-3c. Black holes tend to cycle through different accretion states, but if stellar-mass black holes can truly sustain jet-powering super accretion, that would make the IMBH explanation for NGC-2276-3c less of a shoo-in.

■ **EMILY POORE**

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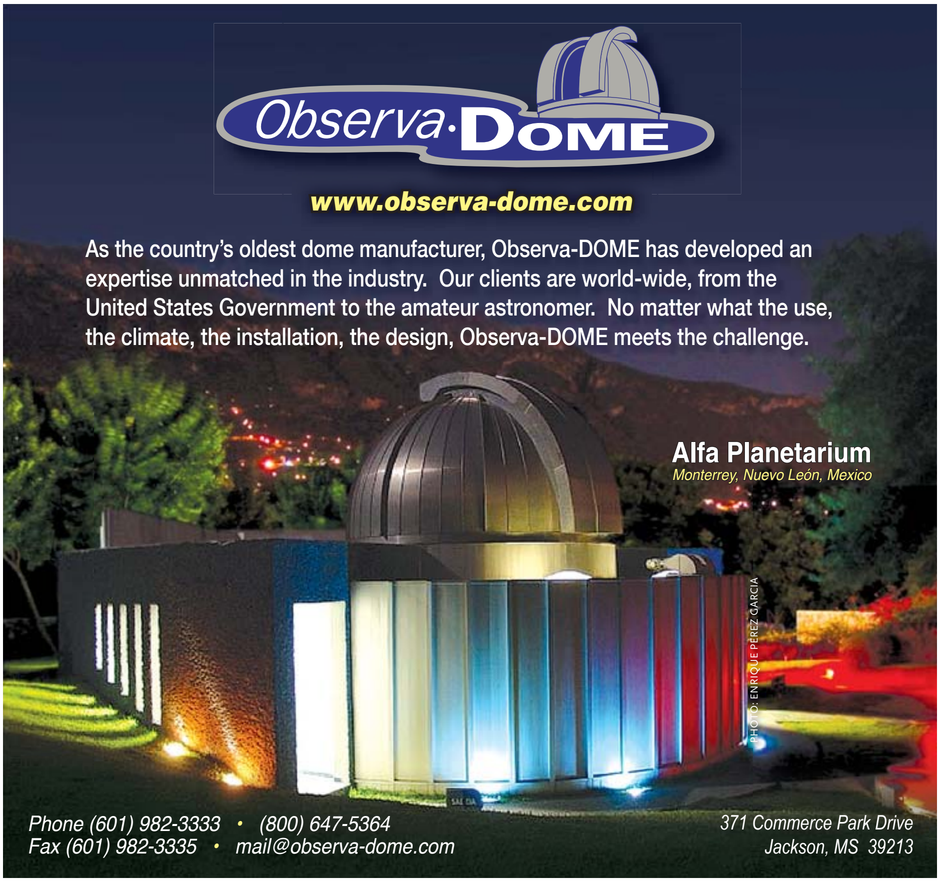

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BLACK HOLES | New Stars in the Shadow of Sagittarius A*

Observations suggest that several dozen low-mass stars, and eventually perhaps even planets, are forming just 2 light-years from our galaxy's supermassive black hole.

Theorists still don't understand how stars manage to coalesce around the Milky Way's central black hole, Sgr A*, which has a mass of 4.3 million Suns. The fierce gravitational field ought to rip clouds apart long before stars have a chance to form. And that's if the intense radiation from nearby stars in the galaxy's busy downtown doesn't blow the clouds apart.

Yet young, massive stars circle the behemoth. Previous observations show that massive stars have formed within a few light-years of the black hole as recently as 10,000 years ago.

Now Farhad Yusef-Zadeh (Northwestern University) and colleagues have added another layer to the mystery with their discovery of low-mass stars forming around the black hole, reported in an upcoming *Astrophysical Journal Letters*.

The astronomers used the Very Large Array to image what appear to be 44 protoplanetary disks, reservoirs of dust and gas that feed low-mass newborn stars. Intense ultraviolet radiation and stellar winds have shaped the cocoons around these objects into comet-like fuzzies, with bright heads and blown-back tails.

The disks sit in two clusters, lying 2 and 2.6 light-years away from Sgr A*, respectively. These clusters are both between 10,000 and 100,000 years old. Even though nearby stars' winds and intense radiation will steal mass from these disks, Yusef-Zadeh estimates they could have enough material left to form planets around the protostars.

The formation of low-mass stars suggests that, rather than a one-time formation event, stars are probably churned out continuously in our galaxy's center, says Andreas Eckart (University of Cologne, Germany). The galactic center has one of the highest star-formation rates in the Milky Way, so if this activity is long-standing, that makes theorists' conundrum more than a temporary curiosity.

Two scenarios exist for explaining star formation near the black hole, both of which use the black hole's pull to their advantage. In 2005, Sergei Nayakshin (University of Leicester, UK) and colleagues suggested that a cloud might break apart in the strong gravitational field, reassembling into a disk encircling the black hole. The disk could then form massive stars the same way that disks around stars form planets. That might explain why many young, massive stars encircle Sgr A* in two rings.

Last year, another method suggested by Behrang Jalali (University of Cologne, Germany) and colleagues suggested that molecular clouds on highly elongated orbits that pass very close to the black hole would *spaghettify*, compressing even as they stretch out along their orbit. That compression would in turn trigger star formation inside the clouds. A spaghettified, star-bearing cloud might explain the mystery object G2, which hurtled past Sgr A* last spring, the team proposed.

■ **MONICA YOUNG**

OBIT | Donald C. Parker, 1939–2015

Planetary imaging pioneer Don Parker passed away in Miami, Florida, on the evening of February 22nd from lung cancer. He maintained his razor-sharp intelligence, wit, and kindness to the end.

SEAN WALKER

Parker caught the astronomy bug at a young age. He built several telescopes during the 1950s, including an 8-inch f/7.5 Newtonian reflector that was featured in the November 1957 *S&T*. After serving as a medical officer in the U.S. Navy, he began a career in anesthesiology and resumed observing the planets, particularly Mars. He was a former director of the Association of Lunar and Planetary Observers (ALPO), where he became acquainted with Lowell Observatory astronomer Charles F. Capen. With Capen's encouragement and mentorship, Parker quickly rose to the forefront of amateur planetary photography. In 1988 he coauthored the book *Introduction to Observing and Photographing the Solar System* with Capen and fellow amateur Thomas A. Dobbins.

Parker continued to be a pioneer in planetary observing and imaging techniques, and he played a role in developing many of the methods used in digital planetary imaging today. He's also credited with the discovery of several features on Mars and Jupiter. Many of his 20,000-plus images have supported professional researchers at NASA, JPL, and other institutions, and he coauthored scores of papers in scientific journals, popular magazines, and news sites worldwide. In 1994, the International Astronomical Union named asteroid 5392 Parker in his honor for his contributions to solar system science. A frequent speaker at amateur conventions, he delighted audiences with his colorful and often self-deprecating humor. It was an honor to be his friend. ✦

■ **SEAN WALKER**


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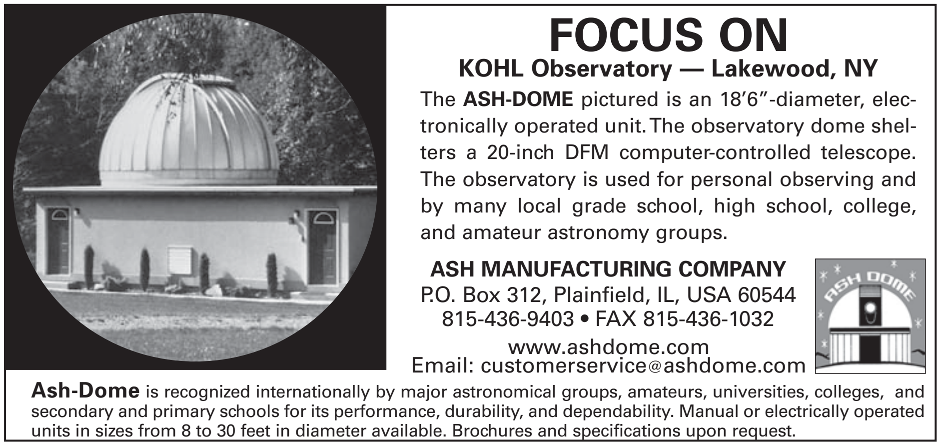
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Sidewalk Wisdom

Musing on a long-lost Asimov gem.

I LIVE ON CAPITOL HILL, a short walk from my office in the Library of Congress. It's a gentrified neighborhood of old Victorian houses, and you can often find all manner of valuable items left on the sidewalk.

Usually I don't find anything particularly enlightening, but one day recently I unearthed a treasure. In a mostly forgettable box of paperback novels and obsolete travel guides lay a textbook that caught my eye: *Psychology Today: An Introduction, Second Edition*, from 1972. Reflexively, I glanced at the front inside cover. At the bottom of a long list of contributing consultants, it read: "Chapter Introductions written by Isaac Asimov."

> *"It is as though we are at some stage of evolution between the multicellular and [the] multiorganismic."*
> – Isaac Asimov

Say what? Are you kidding me? No, the book was not kidding. I took that one home.

Each of the 34 chapters opens with a short, informal essay of roughly 500 words by the great science-fiction master and science writer. They are playful, irreverent, personal, often humorous, sometimes only loosely bound to the subject of the chapter, and always insightful. Asimov riffs on free will, the nature of consciousness, intelligence, morality, history, science fiction, and his famous three "laws of robotics" and how they relate to the questions of human psychology raised in the text.

In one of these micro-essays, Asimov brilliantly sums up one aspect of human existence. He is describing the different levels of biological organization and where we ourselves fit into the continuum of complexity. He starts with the viruses, which depend on living cells in order to function. Then there are the simplest cells, such as bacteria, and more complex cells with nuclei and various component parts. These complex cells can exist as free-floating individuals or loosely bound with others in various colonial arrangements. "Finally," says Asimov,

> cells can drown their individuality and abandon their free-living abilities in order to form a multicellular organism, which may be as simple as a flatworm, or as complicated as a giant sequoia, a whale, or a man.

But, he points out, the hierarchy doesn't end there. A multicellular organism, by itself, is generally as useless as a cell by itself. Such organisms need others to survive. All but the simplest reproduce sexually and therefore need a mate. Many are dependent for their survival on more complex social arrangements: a herd, a school, a flock, or, in our case, a tribe or society. Some, such as the social insects, have such tight interdependence with other individuals that they form what might be called superorganisms, and one may legitimately question whether individuality resides in the organism or the hive.

Just as we, as individual multicellular organisms, are each an exquisite arrangement of 37 trillion cells, with the whole being greater than the sum of its parts, so we cannot fully manifest our humanity, or survive for long, without forming larger associations, much as we might like to think we can. Asimov:

> As individual multicellular organisms ... we would be less willing to agree that a complex society or state is greater than the sum of the individual organisms making it up. We would be less ready to judge that it is a cheap price to give up our individualism to become part of a society. ... Yet the tug is there. It is as though we are at some stage of evolution between the multicellular and [the] multiorganismic.

It strikes me that the tension Asimov identifies here lies at the heart of many of our political, economic, and spiritual struggles. We are trying to work out how to thrive as individuals who also cannot exist without some larger cooperative order. But we're not insects, and we cannot subsume ourselves into the hive, the matrix, or the Borg. We need our individual freedom and creativity.

But now, in the Anthropocene as never before, we are confronted with the need to make smart, coherent, collective technological choices on a planetary scale in order to survive. It would not surprise me if someday we learn that intelligent technological species on other planets — if they exist — also have had to struggle with some version of this same evolutionary dilemma. ✦

David Grinspoon *is an astrobiologist and author at the Library of Congress in Washington, D.C. Follow him on Twitter at @DrFunkySpoon.*


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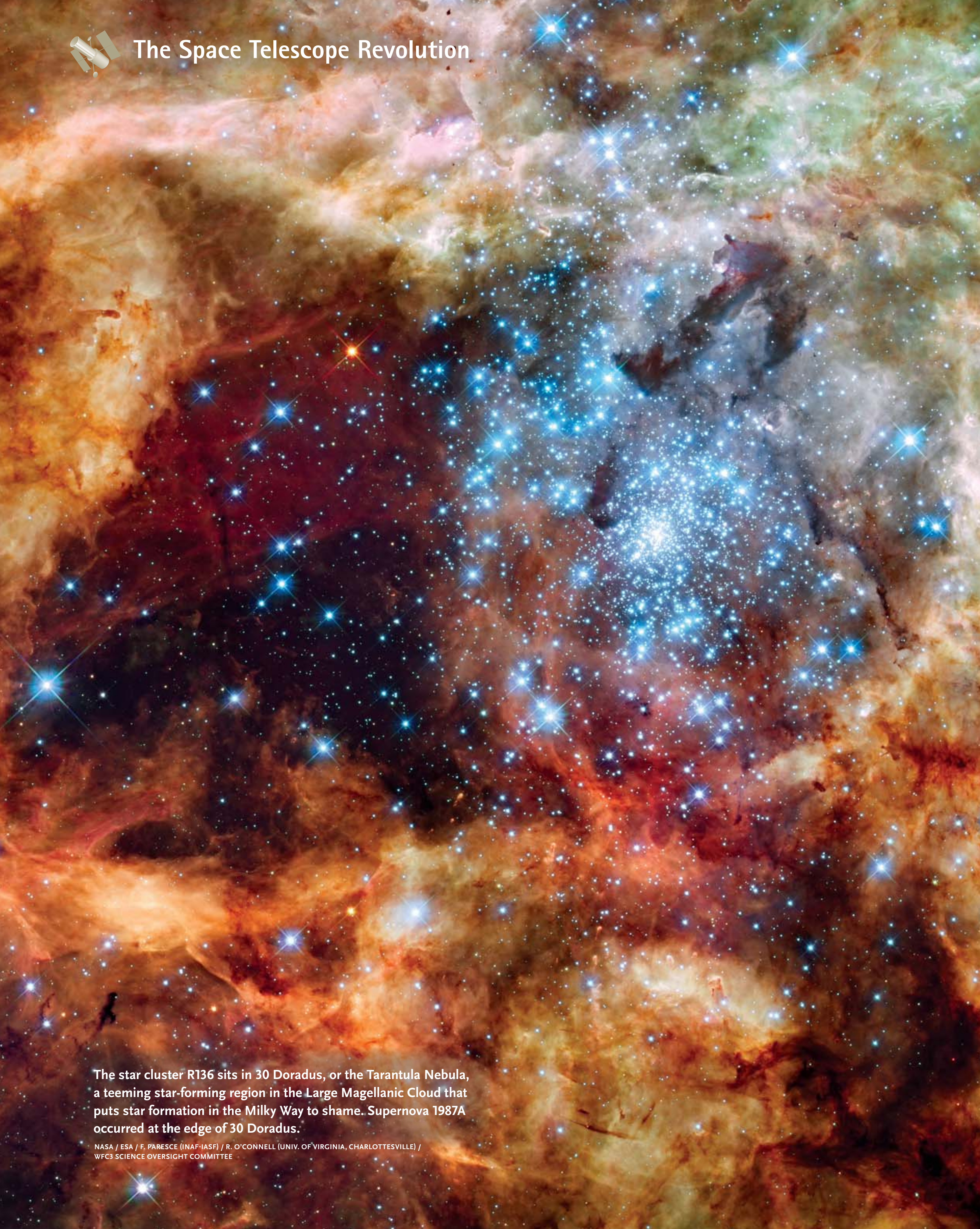

The star cluster R136 sits in 30 Doradus, or the Tarantula Nebula, a teeming star-forming region in the Large Magellanic Cloud that puts star formation in the Milky Way to shame. Supernova 1987A occurred at the edge of 30 Doradus.

NASA / ESA / F. PARESCE (INAF-IASF) / R. O'CONNELL (UNIV. OF VIRGINIA, CHARLOTTESVILLE) / WFC3 SCIENCE OVERSIGHT COMMITTEE

How HUBBLE Changed the Face of Astronomy

Govert Schilling

The first of the "Great Observatory" space telescopes transformed what astronomers knew — and didn't know — about the universe.

Many of today's astronomers were still in elementary school when the Space Shuttle *Discovery* carried the Hubble Space Telescope into orbit 25 years ago. Some weren't even born yet. To them, Hubble has always been around. Indeed, we've all grown familiar with the pretty pictures and revolutionary results of the most successful telescope in the history of astronomy. Even for veteran researchers, it's hard to remember how different the science of the universe looked before 1990.

It's also hard to remember that back then, many scientists were pretty skeptical about the space telescope, which traces its origin back to a 1946 (!) proposal by astronomer Lyman Spitzer (1914–1997). Over the years, Hubble experienced huge delays and cost overruns — some $2 billion in 1990 dollars had been spent by the time it finally left the launch pad, seven years overdue. Even worse, images revealed a small but fatal flaw in the 2.4-meter primary mirror soon after launch; it took until December 1993 for shuttle astronauts to install corrective optics.

But ever since, the Hubble Space Telescope has been a magnificent success story. The goals of its three original Key Projects — measuring the expansion rate of the universe, using distant Cepheids to probe the intergalactic medium, and carrying out a statistical survey of remote galaxies by taking pictures of random fields of view — were fully achieved and even surpassed. From planets to supermassive black holes, Hubble has revolutionized every single field in astronomy.

To celebrate the space telescope's 25th anniversary, let's take a look at seven ways in which Hubble turned the tables in our knowledge of the universe.

1. Solar System Surveillance

Until some 50 years ago, we basically didn't know our solar system neighbors. The 200-inch Hale Telescope at Palomar Mountain had provided us with some blurry photos that hardly beat the view through a small amateur telescope. Only with the advent of space exploration did we start to discover intricate details on the Martian surface, in Jupiter's cloud deck, and in the ring system of Saturn.

Hubble routinely takes high-resolution images of the other solar system planets. It had a front-row seat when Comet Shoemaker-Levy 9 slammed into Jupiter's atmosphere back in 1994. Ultraviolet observations — impossible from the ground — revealed auroras on Jupiter and Saturn, as well as the breakup products of cometary molecules. In addition, Hubble has discovered two new moons of Uranus, one of Neptune, and four of Pluto, and it found two distant Kuiper Belt objects that may serve as goals for NASA's New Horizons probe after it flies past Pluto in mid-July.

Today, amateur astronomers using image-stacking technology are also achieving incredible results in solar system observations, as are professionals using adaptive optics on large ground-based telescopes. Still, it's hard to match Hubble's high-resolution vigilance over our cosmic backyard.

2. Nurseries Unveiled

One of the first major science results from the Hubble Space Telescope was the discovery of protoplanetary disks (or *proplyds* for short) in M42, the Orion Nebula. Until then, nobody really knew how unique — or how run-of-the-mill — our own solar system might be. Ten years

NASA / ESA / J. CLARKE (BOSTON UNIV.) / Z. LEVAY (STSCI)

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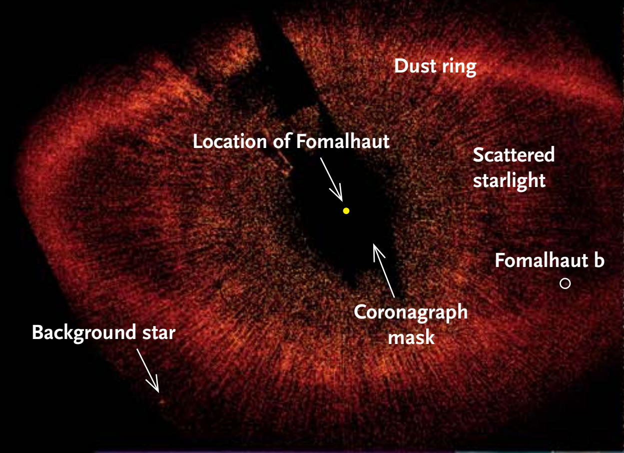
***Left*: This visible and ultraviolet composite image reveals an auroral oval on Saturn, where auroras can last for days. *Right*: Fragments from Comet Shoemaker-Levy 9 left impact marks in Jupiter's atmosphere in 1994, wowing astronomers.**



Above left: A dusty ring encircles the star Fomalhaut, potentially sculpted by a growing planet (circled). ***Above***: A view toward the galactic center, down to magnitude 30. Hubble monitored tens of thousands of stars for periodic dips in brightness, and astronomers identified potential hot Jupiters around several (circled). ***Far left***: These two cocoons in the Orion Nebula enshroud protoplanetary disks of dust and gas around embryonic stars. The disk in the lower image appears clearly as a green oval. ***Near left***: As they form, protostars eject jets along their poles, forming glowing patches called Herbig-Haro objects. Two pairs of jets appear in this image of the Carina Nebula: one at the very top, and the other at the top of the second-tallest "peak." ***Bottom***: The iconic Pillars of Creation in the Eagle Nebula, in infrared (*left*) and visible wavelengths. The infrared image cuts through all but the densest dusty gas and confirms that the pillars are gas that's hiding in the "shadow" of dense clouds at the pillars' tops. Those clouds shield the gas below from destructive ultraviolet radiation and stellar winds raining down from stars above.

earlier, the Infrared Astronomical Satellite had found compelling circumstantial evidence for the existence of dusty disks around young stars, but Hubble was the first to actually image proplyds in exquisite detail.

In fact, Hubble's spectacular views of stellar nurseries like the Orion Nebula, the Carina Nebula (NGC 3372), and the Eagle Nebula (M16) provided us with a much better understanding of the birth of stars and planetary systems. Using its near-infrared instruments — NICMOS and, after the last servicing mission in May 2009, Wide Field Camera 3 — the space telescope has peered into the dark cores of collapsing, dust-laden clouds. Its sharp vision revealed energetic bipolar jets from newly formed protostars, slamming into the surrounding interstellar medium. Hubble even discovered warps and gaps in circumstellar disks like the one around Beta Pictoris, hinting at the presence of planets.

Remember the famous Pillars of Creation found in the Eagle Nebula in 1995? Hubble found similar pillars in other stellar nurseries, all of them showing small-scale evidence of being eaten away by the energetic radiation of nearby clusters of hot, young stars. Over the past 25 years, we've seen the story of star formation turn from a sketchy note into a rich novel.

Of course, thanks to ground-based spectrographs and space-based instruments such as Kepler, we now know that planetary systems are the rule rather than the exception. Unsurprisingly, Hubble has also significantly added to our understanding of exoplanets: its transit observations have revealed the atmospheric constituents of hot Jupiters, and it even succeeded in directly imaging a protoplanet-like companion around Fomalhaut.

3. Restless Universe

Some three hundred years ago, Edmund Halley was the first to note that the "fixed stars" aren't fixed at all. Because of their motion through the galaxy, we see them move across the sky, albeit very slowly.

The *proper motion* of a distant star is much less conspicuous than that of a nearby one, for the same reason that a high-flying jet plane appears to move more slowly across the sky than a bird that wings right over your head. Little wonder that we don't notice the proper motions of stars beyond our local neighborhood.

But Hubble did just that. By comparing images of the Magellanic Clouds and the Andromeda Galaxy taken many years apart, astronomers were able to measure the tiny sideward motion of these galaxies with respect to the stationary background of distant, point-like quasars. As a result, we learned that the Magellanic Clouds are moving so fast that they can't be gravitationally bound to our Milky Way Galaxy — instead, they are first-time visitors (*S&T*: Oct. 2012, p. 28) — and that the Andromeda Galaxy really will collide and merge with the Milky Way a few billion years from now. By virtue of its eagle-eyed vision, the Hubble Space Telescope has turned our Local Group into a 3D stage, its main characters moving about in every direction.

On a smaller scale, Hubble monitored and measured the expansion of the debris from Supernova 1987A, showing how it slammed into gas that was blown away from the star prior to the explosion. It charted the development of light echoes around variable stars like V838 Monocerotis and RS Puppis. It revealed changes and motions in star-forming regions and in jets from the cores of distant galaxies. Over the past decades, our universe has become ever more dynamic.

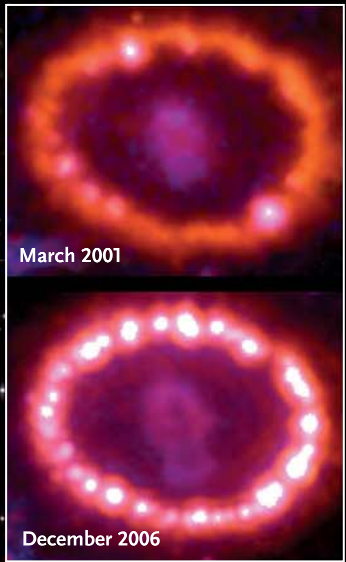
4. Galactic Secrets

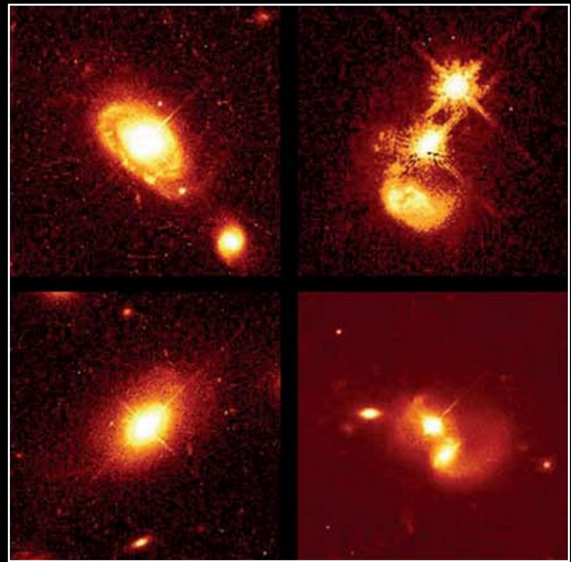
Pick up a popular astronomy book from the pre-Hubble era, and the chapter on galaxies is probably pretty speculative. Yes, they're out there in vast numbers, grouped together in clusters and superclusters, and they come in a variety of shapes and types: majestic spirals and barred spirals, puny irregular dwarfs and giant ellipticals. But back then, little was known about galactic evolution, quasars were still rather mysterious, and astronomers were not yet confident that supermassive black holes hid in the cores of most galaxies.

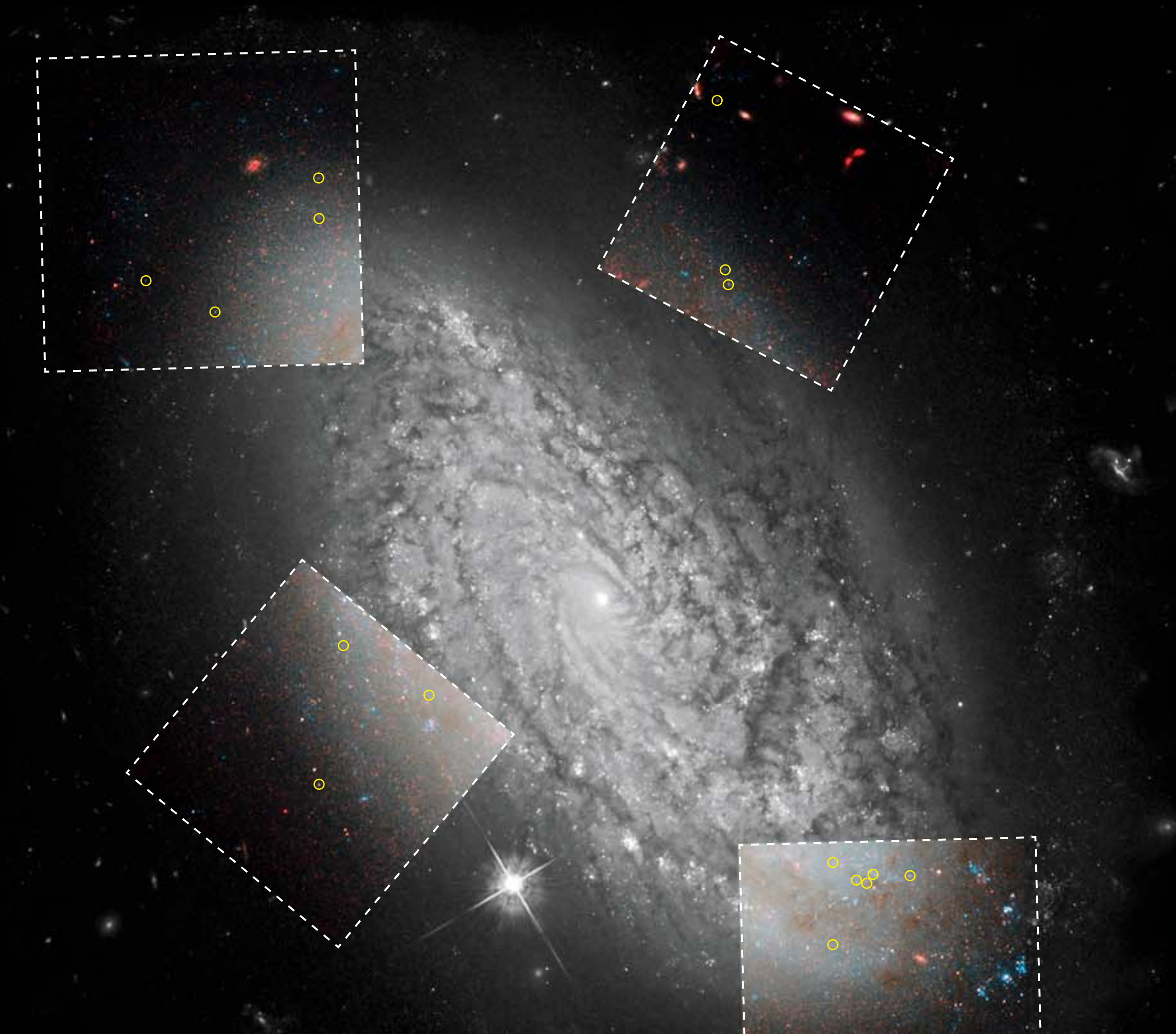
Since it launched, Hubble has observed thousands of galaxies, including many neighbors of our own Milky Way out to a few tens of millions of light-years. Not only did astronomers study individual nebulae, clusters, and giant stars in other galaxies, they also measured the bulk rotation in their cores. Over the years, it became clear that almost every galaxy harbors a supermassive black hole in its center. What's more, the space telescope helped reveal a tight correlation between the velocities of stars in a galaxy's bulge and the mass of the central black hole deep inside that bulge — evidence for "tandem" evolution of black holes and galaxies' stellar mass.

Hubble's high-resolution images of more remote galaxies, whose light took billions of years to reach Earth, also revealed galactic interactions, collisions, and mergers in the early universe. Wrecked spiral arms, warped disks, tidal tails — these cosmic traffic accidents confirmed the growing conviction that gravitational encounters explained some galaxies' unusual shapes. Astronomers also combined Hubble's observations with those from other instruments to find the infant cores of today's giant elliptical galaxies, which grew largely via mergers.

As for quasars: in its early years, Hubble confirmed that they are the active, star-like cores of extremely distant galaxies, powered by supermassive black holes. Astronomers discovered that powerful quasar winds and jets may even inhibit the inflow of gas into the galaxies, thus stalling large-scale star formation. Today, the space telescope's sensitive spectrographs also regularly use quasar light to study the intergalactic medium — one of the original Hubble Key Projects.







Astronomers used supernovae and Cepheids in distant galaxies, including several Cepheids in the spiral galaxy NGC 4258 (circled in inset boxes), to calculate the universe's expansion rate. This rate, called the Hubble parameter, constrains the nature of dark energy.

RS PUPPIS: NASA / ESA / HUBBLE HERITAGE TEAM (STSCI / AURA)-HUBBLE / EUROPE COLLABORATION; SN 1987A: NASA / ESA / P. CHALLIS AND R. KIRSHNER (CFA); QUASARS: JOHN BAHCALL (IAS) / MIKE DISNEY (UNIV. OF WALES) / NASA; NASA / ESA /A. RIESS (STSCI / JHU)

1995: R. WILLIAMS / HDT TEAM (STSCI) / NASA; 1998: R. WILLIAMS (STSCI) / HDF-S TEAM / NASA; 2004: NASA / ESA / R. WINDHORST (ARIZONA STATE UNIV.) / H. YAN (SPITZER SCIENCE CENTER / CALTECH); 2009: NASA / ESA / G. ILLINGWORTH (UCO / LICK / UC SANTA CRUZ) / R. BOUWENS (UCO / LICK / LEIDEN UNIV.) / HUDF09 TEAM; 2012: NASA / ESA / G. ILLINGWORTH, D. MAGEE, AND P. OESCH (UC SANTA CRUZ) / R. BOUWENS (LEIDEN UNIV.) / HUDF09 TEAM

***Facing page, far left*: The Cepheid RS Puppis illuminates its surrounding nebula. *Center*: Hubble recorded the shockwave from SN 1987A slamming into a previously ejected shell of material. *Near left*: These 1996 images reveal quasars' host galaxies, some of which (but not all) are colliding with other galaxies. Such images made explaining what triggers quasars more complicated. *Above*: Hubble took five deep fields: Hubble Deep Field (1995), Hubble Deep Field South (1998), Hubble Ultra Deep Field (2004 and 2009), and Extreme Deep Field (2012).**

5. Deep Fields

Arguably one of Hubble's most exciting results was obtained when the space telescope was trained on a tiny patch of "empty" sky in the Big Dipper in December 1995. A number of influential astronomers were against the idea (it would use up a lot of valuable observing time), but a few thousand faint galaxies showed up, many of them so remote that their light has taken more than ten billion years to reach us. In a sense, the space telescope was used as a time machine to provide cosmologists with a view of how the universe looked in its infancy.

Over the past 20 years, Hubble has taken several other "deep fields," in different parts of the sky, with more sensitive cameras, and in a wider variety of wavelength bands, culminating in the Extreme Deep Field and the Frontier Fields project (*S&T*: Jan. 2015, p. 20). Looking back to a few billion years after the Big Bang reveals irregular, clumpy galaxies smaller than today's, the primordial building blocks of the mature galaxies that currently populate the cosmos.

Hubble's infrared cameras play an important role in this field of cosmic archaeology: during its multi-billion-year-trip to Earth, the energetic ultraviolet light emitted by newborn stars in the very earliest galaxies is stretched all the way into the infrared by the expansion of the universe. As a result, some of the building blocks aren't even visible at optical wavelengths.

Deep-field studies revealed the history of star formation in the universe, which peaked some 11 billion years ago and has dwindled by a factor of 30 or so ever since. But Hubble's unique windows into the past also have posed puzzling questions about the unexpectedly fast growth rate of galaxies and their central black holes in the universe's first two billion years.

6. The Dark Side

The Hubble Space Telescope was named after pioneering cosmologist Edwin P. Hubble, co-discoverer of the expanding universe. Indeed, the space telescope's most important Key Project was to determine the age and expansion history of the cosmos, by carefully calibrating the astronomical distance scale. Before the space telescope, astronomers only knew that the Hubble parameter — a measure of the current expansion rate — was somewhere between 50 and 100 km/s per megaparsec (a parsec is about 3.26 light-years). Hubble narrowed in on just above 70 km/s/Mpc, although the results don't perfectly match the rate calculated from observations of the cosmic microwave background, which have pinned down the age of the universe at 13.8 billion years and the current expansion rate at 68 km/s/Mpc.

But Hubble's impact on cosmology turned out to be much larger than anyone could have foreseen. Observations of colliding clusters like the famous Bullet Cluster provided additional evidence for the existence of a mysterious "dark matter" in the universe — the data on galaxy dynamics and mass distribution within the clusters are hard to explain solely by the alternative gravity theory of Modified Newtonian Dynamics (MOND), which tries to explain the observations without unseen matter. Moreover, using the technique of weak gravitational lensing, where the shapes of thousands of background galaxies are slightly distorted by the gravity of intervening matter, astronomers are able to map out the distribution of dark matter, sometimes even in 3D.

Finally, Hubble played a key role in the study of distant Type Ia supernovae that led to the discovery, in 1998, of the accelerated expansion of the universe — one of the most intriguing astronomical finds of the past century. Apparently, another mysterious cosmic component, dubbed dark energy, is pushing empty space away from itself ever faster and faster.

7. The People's Telescope

There's one more way in which Hubble has forever changed the face of astronomy. In a very direct sense, it brought the universe into the living room — and into the classroom, for that matter. Largely thanks to the space telescope's stunning imagery, Hubble discover-

NASA / ESA / N. SMITH (UC BERKELEY) / HUBBLE HERITAGE TEAM (STSCI / AURA) / NOAO / AURA / NSF

This panorama spans roughly 50 light-years of the center of the Carina Nebula. The nebula's first stellar generation was born about 3 million years ago, and the nebula contains at least a dozen stars that are 50 times the Sun's mass or more. Ultraviolet emission from the young, massive stars eats away at the nebula.

ies made their way into newspapers, magazines, and TV shows, way beyond traditional science publications and programs. As a result, everyone knows Hubble. Everyone *loves* Hubble. And everyone marvels at the new, colorful, and awe-inspiring vistas of the cosmos it provides us with. Hubble has truly become "the people's telescope."

For amateur astronomers, the virtues of Hubble may be less evident at first sight. Novices who have been lured into the field by spectacular Hubble photos of planets, nebulae, star clusters, and galaxies may be unimpressed by the average view through a medium-sized amateur telescope and prefer "armchair astronomy" instead. Then again, astro-imaging technology has evolved to unprecedented levels, and amateurs may be inspired by Hubble to improve their own skills, as is evident from this magazine's monthly Gallery section.

Finally, the Hubble Space Telescope has returned astronomy to being a visual science. Professional astronomers used to be more interested in spectra and amassing data than in pretty pictures, but a new generation of scientists is no longer ashamed to concede that beautiful photos of the universe can be both captivating and scientifically valuable. Could it be because these younger astronomers have known — and loved — the Hubble Space Telescope since their elementary school days? ✦

Sky & Telescope *Contributing Editor **Govert Schilling** used many dozens of spectacular Hubble images in his latest coffee table book,* Deep Space.

What Comes Next?

Hubble is as powerful as ever, especially since the final Space Shuttle maintenance flight of May 2009. "Unless something breaks or Hubble is hit by a meteorite, we expect it to be operational well beyond 2020," says Kenneth Sembach, Hubble's mission head at the Space Telescope Science Institute (STScI). When the space telescope eventually dies, the plan is to attach a propulsion module to its back end, to enable a controlled atmospheric re-entry above the Pacific Ocean (instead of letting it make its own, less predictable way down).

Hopefully, by then Hubble will have been working for a couple of years with its infrared successor, the James Webb Space Telescope (JWST), due for launch in late 2018. But, says cosmologist Ivo Labbé (Leiden Observatory, the Netherlands), "Even though JWST is a fantastic machine, it won't have optical or ultraviolet capabilities. That's going to be a problem for a number of astronomical disciplines."

Some scientists are playing with the idea of refurbishing Hubble with a newer, bigger camera and — if necessary — with new gyroscopes and electronics, to further extend its lifetime. That would have to be done by a fully robotic mission: since the retirement of the Space Shuttle, astronauts can't reach Hubble anymore. According to robotic missions expert Frank Ceppolina (NASA Goddard), "It's not easy, but doable." The biggest hurdle, of course, would be money.

Meanwhile, STScI astronomers are studying concepts for what they call a High Definition Space Telescope (HDST), or "Hubble 2.0." HDST could have a segmented, deployable 12-meter mirror, be outfitted with cameras and spectrographs that cover the wavelength range from the near-infrared all the way into the UV, and leave the launch pad in the mid-2030s.

"This would be a truly transformational telescope," says Marc Postman (STScI). The multi-billion-dollar facility would serve the needs of both the astrophysics and the exoplanet communities. By spectroscopically studying Earth-like planets in the habitable zones of Sun-like stars, says Postman, "HDST will help us to answer one of the most fundamental questions we ever asked ourselves: are we alone?"

Measuring Earth's Shadow:

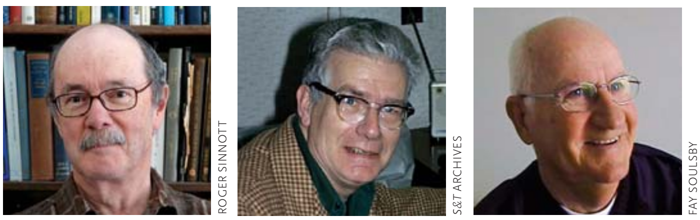
170 Years of Crater Timings

A very long-running lunar eclipse project reaches fruition.

Roger W. Sinnott

The last rim of the rayed crater Tycho (arrowed) was just about to cross the edge of Earth's umbra when Dennis di Cicco took this shot on the evening of November 8, 2003.

Maybe you have been one of them — a backyard astronomer, watch in hand, intently peering at a partially eclipsed Moon with a 2- to 8-inch telescope. You watch as a crater or small marking drifts up to, and then across, the edge of Earth's shadow. You note the time, realizing that you could be off by 20 or 30 seconds because the edge of the shadow is rather fuzzy. Crater timings may seem somewhat crude, but astronomers have made them this way for centuries. That's their beauty, and their potential value.



THE CURATORS *Left:* Roger Sinnott, a *Sky & Telescope* senior editor for many years. *Center:* The legendary *S&T* editor Joseph Ashbrook, who launched the project in 1956. *Right:* Byron Soulsby of Australia.

Last October, David Herald and I published a large database of these timings on the VizieR Service for Astronomical Catalogues operated in Strasbourg, France. Our data set holds 22,539 records of 26,685 individual timings, all made visually with small telescopes, during 94 total and partial lunar eclipses from 1842 through 2011. This is by far the largest collection of such timings that has ever been assembled.

Sky & Telescope readers can take special pride in contributing roughly half of these timings, starting almost 60 years ago. Editor Joseph Ashbrook solicited them from 1956 until his death in 1980, at which point I took over the magazine's crater-timing project. The rest were collected by Australian amateur Byron Soulsby, who cultivated his own worldwide network of crater timers and gleaned more timings from older literature. Especially important was a long series made by the noted lunar observer J. F. Julius Schmidt from 1842 to 1879, first in Germany and later at Athens Observatory in Greece.

When Soulsby died in 2009, David Herald (of the International Occultation Timing Association) and I merged and reformatted all these records. This vast collection serves as a check on just when lunar eclipses begin and end. It also helps us to assess some quaint theories about the size and shape of Earth's shadow.

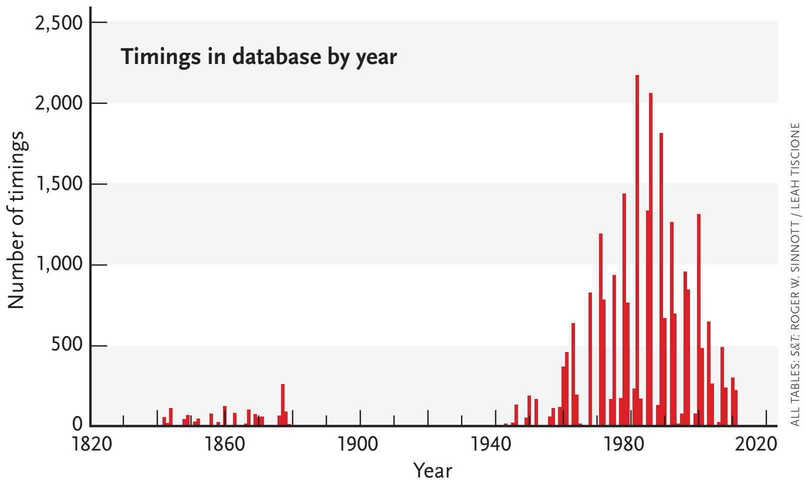
It's well established that Earth's atmosphere makes the umbra (the shadow's dark central portion) a little larger than would be expected for an airless Earth. So lunar eclipses always begin a few minutes early and end late. This effect was noticed as early as 1687 by French almanac maker Philippe de la Hire. To allow for it, modern publications such as the U. S. Naval Observatory's *Astronomical Almanac* routinely add 2 percent to the radius of Earth's umbra in their eclipse predictions.

But do careful timings by observers fully support this procedure? Is 2 percent the right value? No, in fact, as we'll see later in this article.

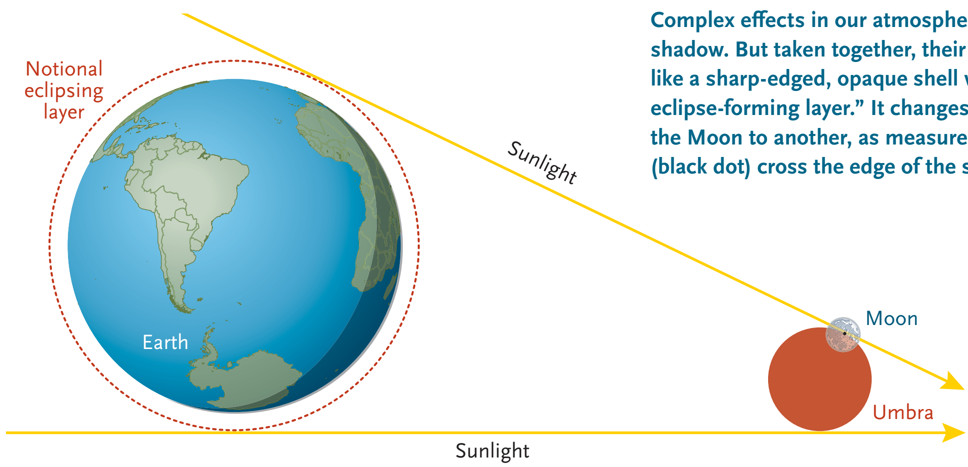
There are many further wrinkles. In a 1950 study of 33 lunar eclipses, Czech astronomers Jirí Bouška and Zdenek Švestka reported that the umbra was somewhat more swollen if an eclipse occurred within a few days after a meteor shower, presumably from extra meteoric dust in the upper atmosphere. Another 57 eclipses, studied in 1954 by František Link and Z. Linkova, appeared to confirm this finding. But Herald and I could find no such correlation in our much more extensive data.

We also checked to see if the umbra's size tracks the 11-year solar cycle in any way. That question suggested itself because, in a 1921 analysis of 150 eclipses by French astronomer André Danjon, the eclipsed Moon's brightness and color seemed to be tied to the solar cycle. In fact, Danjon devised his five-point *L* scale for rating an eclipsed Moon's brightness to aid further study of this effect. Alas, the database shows no solar-cycle correlation with the size of the umbra at all.

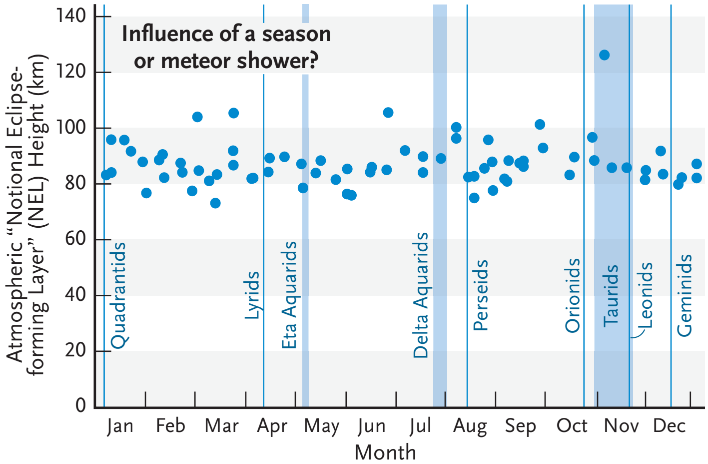
Left: **Johann Friedrich Julius Schmidt (1825–84) directed Athens Observatory for a quarter century and spent much of his career drawing, measuring, and mapping the Moon. He made 1,400 umbral timings from 1842 to 1879.**
Below: **Two great collections make up the 26,685 eclipse timings in the new database: those done by *S&T* readers, and a similar number, both modern and historical, independently gathered by Byron Soulsby of Canberra, Australia.**



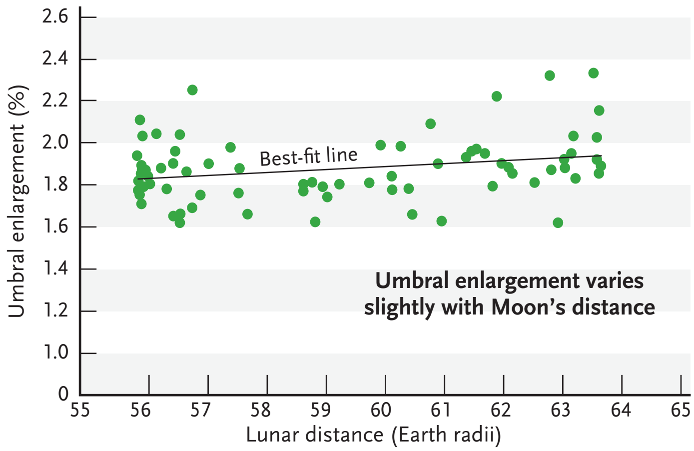
What about major volcanic eruptions? These can loft many cubic kilometers of dust into the Earth's stratosphere, where it spreads around the globe and persists for many months. Nine months after a huge eruption of Mount Agung on Bali, the Moon became as dim as a star of visual magnitude 4.1 during the legendary total eclipse of December 30, 1963. But the 615 crater timings *Sky & Telescope* received from that event show an umbra size quite typical of most other eclipses, bright or dark.

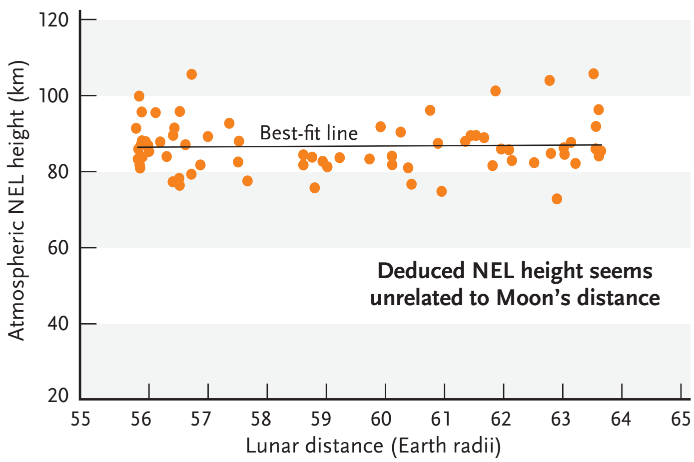


Complex effects in our atmosphere influence the edge of Earth's shadow. But taken together, their result is simple: the atmosphere acts like a sharp-edged, opaque shell with a particular depth, the "notional eclipse-forming layer." It changes depth slightly from one eclipse of the Moon to another, as measured by careful timings of when craters (black dot) cross the edge of the shadow's umbra.



Contrary to past reports, the atmosphere's eclipse-forming layer seems unaffected by the time of year or by the major annual meteor showers.





Middle: **The farther the Moon is from Earth, the more our atmosphere enlarges Earth's umbra compared to the size the umbra would have without the atmosphere. But this effect (the tilt of the best-fit line) is slight compared to the scatter from one eclipse to another.** ***Bottom:*** **Whatever causes that to happen, the height of the atmosphere's "notional eclipse-forming layer" (NEL) remains unaffected.**

The *Shape* of the Umbra

The most enduring oddity claimed for the umbra relates not to its size, but to its shape. For example, crater timings led French astronomer Guillaume Joseph Le Gentil to announce in 1755 that the umbra was larger north-south than it was east-west. But how could that be, given that Earth itself is "squashed" at the poles?

Then in the 20th century, a contrary supposed flattening of the umbra caught on. At various times Bouška, Link, Ashbrook, and Soulsby all reported the umbra to be wider east-west than it ought to be, even allowing for Earth's slight spread at the equator and the geometrical distortion in a converging light cone at the Moon's distance.

Following their lead, G. F. Schilling (Rand Corporation) wrote in the March 1965 *Journal of the Atmospheric Sciences* that a variation in the height of Earth's mesosphere (a zone from roughly 50 to 100 kilometers up) by latitude could explain the added oblateness of the shadow. Using measurements of noctilucent clouds as a guide, Schilling suggested that the mesosphere's height might vary from roughly 100 km at the equator down to 82 km at latitude 60° north or south.

Once again, however, the new database fails to agree. On average, the umbra appears as if an occulting layer 87 km thick uniformly surrounds the (oblate) Earth. This thickness, deduced from timings, does not vary in a predictable way with the position angle around the umbra — which is closely related to the latitude on Earth that accounts for a given piece of the shadow's edge.

Nor does it show any periodic or long-term trend over 170 years, despite the slow global warming that has happened during the last 100 years and especially the last 40. The timings do show the umbra to be oblate, but

The Online Data

The new crater-timing catalog is publicly available at **vizier.u-strasbg.fr/viz-bin/VizieR**, with the designation VI/140. It includes timings for the umbra contacting the Moon's limb as well as the ingress or egress of individual spots and craters. Each of the 22,539 records is accompanied by two calculated quantities: the percent enlargement of the umbra, and the NEL height that the timing implies for that point on the umbra's edge at that time.

Each record also shows the name of the individual or group who submitted it (a few are unknown). There are 764 names in all, including some people who made timings in their youth and went on to become well-known professional astronomers.

For a more detailed report on the database and the conclusions we draw from it, see "Analysis of Lunar Crater Timings, 1842–2011" by David Herald and Roger W. Sinnott in the October 2014 *Journal of the British Astronomical Association*, pages 247–253.

only to the extent expected from the known oblateness of Earth and the geometry of the shadow cone.

We call this atmospheric add-on to Earth's radius the "notional eclipse-forming layer" or NEL. We stress that this does not mean the atmosphere up to 87 km literally blocks sunlight traveling in a straight line past Earth toward the Moon. A combination of scattering, absorption, and refractive effects at many levels must be involved. The NEL is just a convenient concept for comparing, or predicting, lunar eclipses.

Should Predictions Be Revised?

A key finding from the new database is that crater timings disagree with the way in which *contact times* for lunar eclipses are predicted in the annual *Astronomical Almanac* (jointly published by the nautical almanac offices at the U.S. Naval Observatory and in the United Kingdom). Contact times are when the edge of Earth's umbra touches the Moon's edge, marking the start and end of the partial and total phases of a lunar eclipse. The *Astronomical Almanac* uses the 2-percent rule mentioned earlier, which goes back to a recommendation by American astronomer William Chauvenet in 1863.

Applying any constant percentage increase to the umbra's size overlooks, however, the fact that at some eclipses the Moon is near the far point of its orbit (apogee), while other eclipses occur with the Moon closer to Earth (perigee). As seen in the middle diagram on the facing page, crater timings "detect" this percentage problem, while the NEL method works equally well no matter where the Moon is in its orbit. Depending on which method is used, limb-contact predictions could easily differ by a minute or more.

Unlike the *Astronomical Almanac,* the French *Connaissance des Temps* uses a better prediction method recommended by Danjon in 1951. In effect, he adopted an NEL height of about 75 km. But his method, too, could be improved by a switch to the 87 km implied by the new database.

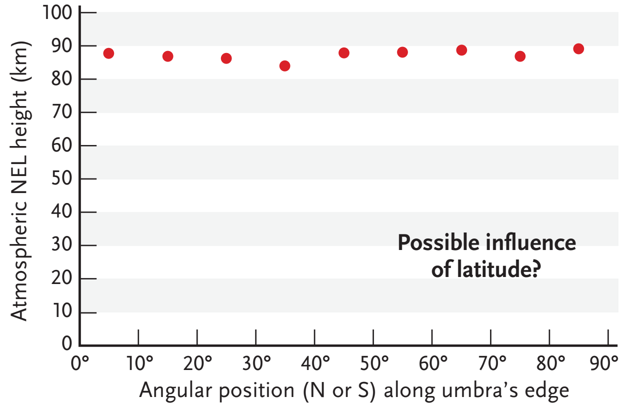
Keep in mind that our 87 km is the average for the 94 eclipses in our analysis. Certain well-observed eclipses have deviated from it — maybe not for the reasons suggested by past investigators, but deviated nonetheless.

For example, the 1,164 timings from the July 6, 1982, eclipse imply a height of 91 ± 1 km, while the 1,119 timings made on August 16–17, 1989, yield 82 ± 1 (where the uncertainties are one standard deviation from the mean; the 68% confidence level). These differences are statistically robust, but their cause remains unexplained.

Shortcomings

As with any crowdsourced inquiry, there are benefits in the sheer quantity of observations we received from dedicated volunteers, but there are caveats, too.

Observers have been asked on some occasions to use



Whether over the tropics or near the poles, Earth's atmosphere shows the same effective eclipsing height of about 87 kilometers (54 miles), within the statistical uncertainty of the database.

the steepest brightness gradient in the umbra's edge for making their timings (our preferred method), and at other times to use the mid-brightness between the umbra and penumbra on either side of the edge. The second method is especially problematic when one tries to time not craters, but the umbra's contacts with the Moon's limb. At first and last contact the Moon is wholly outside the umbra, while at second and third contact it is wholly inside. So an observer can't see the two brightness levels to judge their midpoint.

Observers agree more closely when timing the passage of small craters or spots across the umbra's edge. (Happily, 91% of the database timings are this type.) But even then, twilight or haze might throw timers off.

If the aim is to characterize the umbra at a *particular* lunar eclipse in hopes of understanding what makes the edge fuzzy, a specialized photometer or digital imaging technique would provide fodder for serious research. But if our interest lies, instead, in the visual response of the typical human eye, or in checking for possible cycles or long-term changes in the umbra — a fascination of past investigators — there's no substitute for visual timings spanning many decades or even centuries.

On September 27, 1996, a total eclipse of the Moon yielded 302 crater and contact timings sent in by readers. They indicate a higher than average eclipsing layer at that time, 92 ± 2 km.

This September 27th, one Metonic cycle later, a very similar total lunar eclipse will be widely seen during the evening throughout the Americas. The Moon may look dark, bright, or especially colorful as eclipses go. And no one knows if the umbra's size will correspond to the typical 87 km or something else. Only timings will tell. ✦

Senior Contributing Editor ***Roger W. Sinnott****, who joined the* S&T *staff in 1971, was amazed to see the Moon almost vanish from the sky during the predawn eclipse of December 30, 1963.*

The Science of Jules Verne's Fiction

Dean Regas

Nineteenth-century science and technology shaped two classic tales of imaginary spaceflight.

Under a Floridian sky, three astronauts boarded their metallic spacecraft. As throngs of well-wishers nervously looked on, at the awaited moment the crew blasted up, up into the warm, clear air — soaring toward the Moon. Flying where no human had gone before, they approached the cratered lunar surface, orbited around the silvery orb, and beheld the farside of the Moon. Then the spacecraft returned to Earth and plunged into the Pacific Ocean, where an American naval vessel gathered the intrepid astronauts and carried them safely back to the United States to be welcomed as national heroes.

This is the true story of the Apollo 8 mission, during which three American astronauts circumnavigated the Moon in December 1968. It also happens to be the plot of Jules Verne's 1865 science-fiction classic, *From the Earth to the Moon,* and his 1870 sequel, *Around the Moon.* A number of coincidences occur between this fantasy journey and the real-life mission undertaken a century later.

Apollo 8's recovery

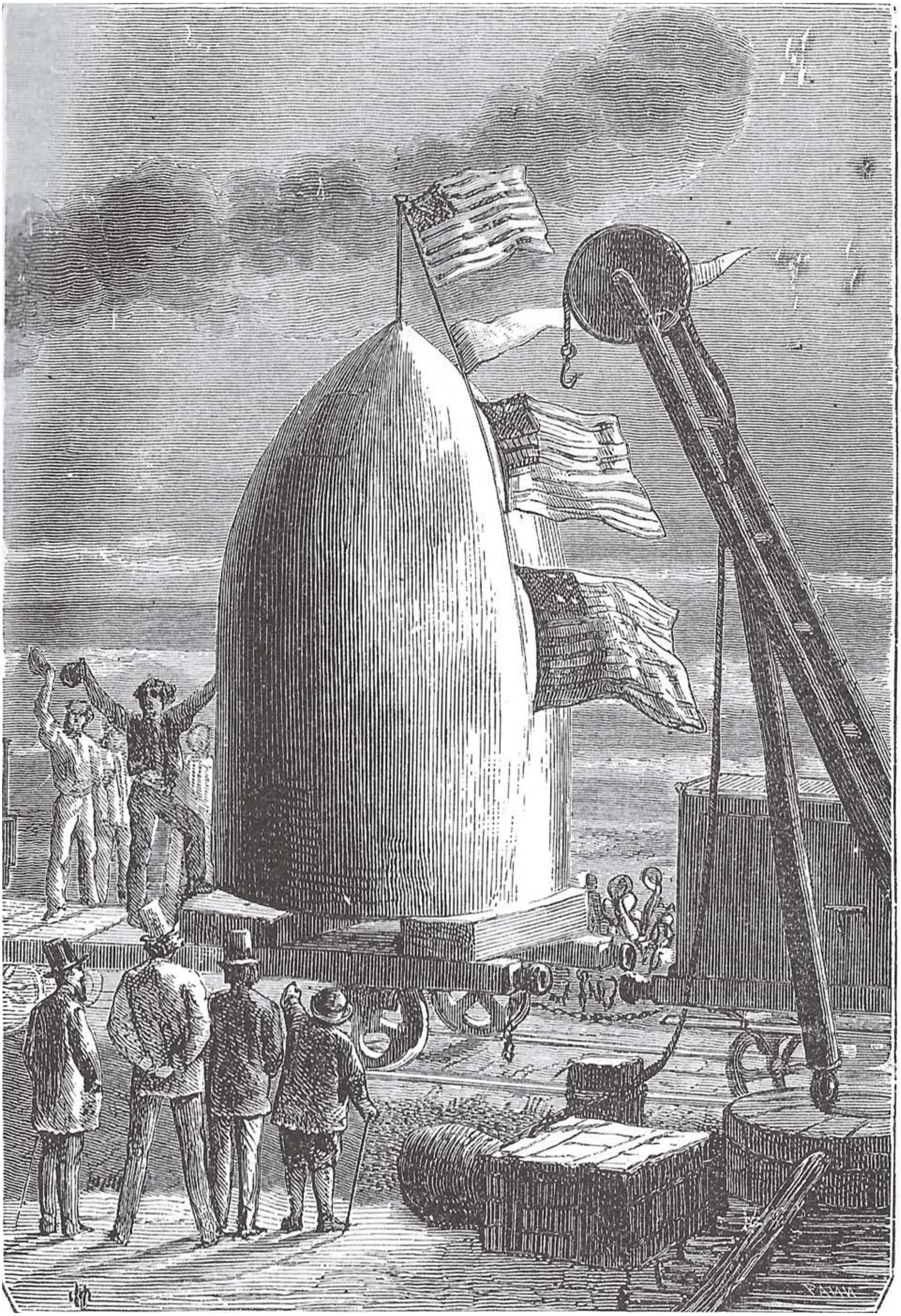
NASA

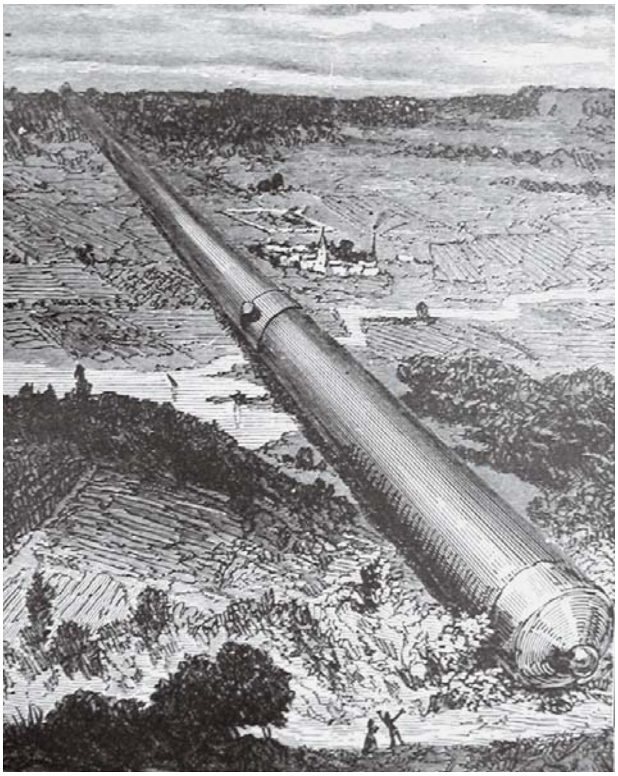
Verne's research on the latest astronomical discoveries, along with his familiarity with cutting-edge technology, allowed him to construct a realistic journey complete with comedy, drama, and education. Like Verne himself, the novels' adventurers were scientifically minded; they hypothesized, explained, and debated math, science, engineering, and astronomy throughout their journey. Today, 150 years later, Verne's science-fiction stories provide an illuminating window into 19th-century scientific knowledge.

The year is 1865, and Verne introduces the Gun Club, a fictional organization in Baltimore. The club's members (who possess, according to one account, "not quite one arm between four persons and exactly two legs between six") are artillery specialists who lament the end of the Civil War. So they must grudgingly turn their efforts to peaceful endeavors. President Impey Barbicane envisions a new course for the club and his country. "It is reserved for the practical genius of Americans to establish a communication with the sidereal world," he says. He proposes to shoot a cannonball at the Moon — and to hit it. After rousing applause he states, "I have the honor, my brave colleagues, to propose a trial of this little experiment."

With worldwide financial, moral, and spiritual support, the experiment begins. In order to reach the Moon, members of the Gun Club must build a monstrous cannon. They intend to fire it when the Moon is closest to Earth and directly overhead — something that can only occur between 28° north and 28° south latitude. After fierce lobbying (and ample name-calling)

Facing page: **The bullet-shaped projectile arrives at Stone's Hill, near Tampa Town in Florida. This and other engravings are reproduced from an 1886 printing of Jules Verne's *From the Earth to the Moon* and *Around the Moon* and provided by Jared Woodfill.**





To accelerate the projectile to high speed, the Gun Club's members build a mammoth cannon, Columbiad, that is 900 feet long.

from residents of Texas and Florida, Barbicane selects Tampa Town, Florida, as the project's base of operations. Soon the artillerymen construct a 900-foot-long cannon, called Columbiad, and load it with a mountain of explosives.

A century later, in 1958, engineers at the nonfictional National Aeronautics and Space Administration (NASA) also determined Texas and Florida to be well suited for America's rocket launches. If a rocket is propelled eastward from close to the equator, the added velocity of the spinning Earth will help it more easily break free of its gravitational pull and require less fuel. NASA managers likewise chose Florida over Texas as its principal launch site for orbiting satellites and for trips to the Moon and beyond.

In Verne's 19th-century rendition, the Gun Club initially plans for an unmanned mission. However, the inclusion of passengers is prompted by an audacious Frenchman named Michel Ardan, who arrives in Tampa Town demanding to fly in the projectile. In a typical Vernian twist, Barbicane and his rival, Captain Nicholl (an armor-plate magnate and foil to the Gun Club), agree to put aside their differences and join Ardan in a well-furnished bullet to be shot at the Moon. How they will return home is not fully discussed or detailed until they are en route.

In order to test the projectile, the Gun Club team practices with two small passengers: a cat and a squirrel. However, after the cannon fires and the ball falls back to Earth, only one emerges — the cat had feasted on the squirrel during the journey.

NASA engineers likewise tested their rockets with animals, specifically monkeys and mice, prior to launching human passengers. By then the space race was well under way, and in September 1968 (three months before Apollo 8) the Soviet Union's Zond 5 mission successfully flew a unique combination of tortoises, mealworms, flies, bacteria, plants, and seeds around the Moon and returned them safely to Earth.

Back in Tampa Town, it's launch day. Five million visitors have flooded into central Florida to witness the momentous event, which has to occur precisely at 10:48:40 p.m. The three explorers descend into the cannon and board their projectile. As the blastoff approaches, some in the crowd count *up*: ". . . thirty-eight! – thirty-nine! – forty! FIRE!!!"

Frankly, anyone shot out of such a cannon would be instantly killed. Verne knew this, and so he explains how the shock would be dampened with compartments of

NASA

Far left: **The projectile's interior is well appointed, with room for its crew of three and several animals. A bed of water under a wooden floor cushions the passengers during launch.** ***Left:*** **The liftoffs of Verne's fictional spaceship and of Apollo 8 both occurred in Florida.**

water. In truth, this would not have protected the astronauts. However, in the novel, the abrupt liftoff merely knocks the trio unconscious — though it kills one of the two dogs aboard (yes, they brought dogs).

When the crew regains consciousness, they reorganize their vessel and risk opening a porthole to dispose of the unlucky canine — which then tragically drifts next to them throughout the journey. In the novel, this open-door gamble works tremendously well, but in reality the extremely low pressure of space would vacuum the crew from the projectile.

Earth's Second Moon

Once above Earth's atmosphere, the crew faces a new crisis: a giant boulder hurtles into view. It narrowly misses their tiny craft but leaves the crew shaken. What *was* that thing? Barbicane concludes that it was Earth's second Moon.

In the mid-19th century, planet hunting had become all the rage. Neptune's discovery in 1846 let loose a mob of astronomers claiming the existence of new, unseen celestial bodies. Also in 1846, French astronomer Frédéric Petit claimed that two of his countrymen had observed Earth's second moon. Based on their accounts, Petit calculated its orbit and published his findings in 1861. Verne read this theory and seized upon it as a plot device in this novel. Barbicane even cites Petit as his source! (With 150 years of hindsight, however, Earth's second moon remains pure fiction.)

As Barbicane, Nicholl, and Ardan approach "the" Moon, they describe their observations of the lunar landscape in great detail. They spy deep craters and towering mountain peaks, radiating rays of debris, dark seas of rock, and deep rifts. The travelers then notice something is amiss: the projectile will not land on the lunar surface as planned but instead carry them to within a few miles of the Moon's north pole.

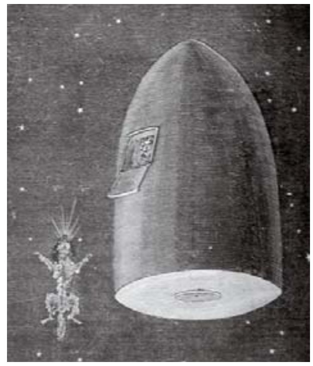
What had gone wrong — their math, aim, or velocity? It was that wayward rock, that "second moon," whose proximity and gravitational pull perturbed the course of the projectile. As the explorers realize this failure, they pass over the pole and are plunged into utter darkness.

The Farside (and Dark Side) of the Moon

The Moon is tidally locked to Earth. Therefore, from here we can only ever view one hemisphere of its surface. Not until 1959 did a robotic Soviet spacecraft, Luna 3, provide the first crude images of the unseen farside.

So what spectacular images would Verne dream up about the farside of the Moon — visions that would not be challenged for almost 100 years? Until this point of the story, Verne's descriptions were based on known science; however, the lunar farside was a great unknown in the 19th century.

The projectile reaches the Moon when it appears full



The force of the launch kills Satellite, one of two dogs aboard. So the passengers open a hatch to dispose of it. But the carcass floats alongside the craft en route to the Moon.

from Earth, so the farside is almost pitch black. Ardan expresses his disappointment: "Here is, however, a good opportunity lost of observing the other side of the moon." Yet it is not a complete loss. The warm glow from an erupting volcano illuminates its surroundings and gives the travelers tantalizing views of this *terra incognita*.

In the 19th century, scientists believed that volcanoes had formed the craters on the Moon. Earth's volcanoes

Freed of Earth's gravity, the three passengers and assorted animals float freely as the spacecraft coasts toward the Moon.

While coasting in darkness over the lunar farside *(left)*, the passengers endure extreme cold inside their capsule. But they warm quickly *(right)* once the capsule returns to sunlight.

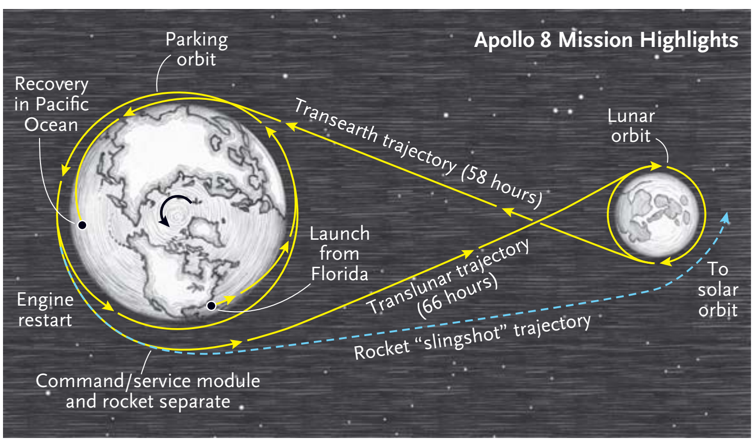
resembled the lunar surface from afar, and therefore geologists imagined innumerable volcanoes as the source of lunar craters. Verne's knowledge of current geological theories surely satisfied his science-minded followers.

The Apollo missions ultimately dashed any lingering faith in the volcano theory. Samples collected by its astronauts, along with spectrographic data from orbiting craft, prove that high-velocity impacts formed the vast majority of lunar craters. There are no active volcanoes on the Moon, though eruptions shaped the topography in the distant past. The large, dark, characteristically circular maria are in fact vast lava plains that partially filled basins excavated by titanic impacts. Billions of years later, these lava "seas" made ideal landing pads for the six Apollo missions that reached the lunar surface.

As Verne's astronauts continue around the farside of the Moon, a meteor streaks below them and explodes above the surface. The fireball brightens the lunar landscape momentarily, and the travelers are able to decipher what appear to be clouds, continents, seas, and forests. During the journey, Verne cites many scientists of the day who debated the existence of a lunar atmosphere. The three astronauts continue that debate and wonder if it was merely an illusion.

As it rounds the south pole, the projectile emerges into daylight. The travelers then observe the bleak, scarred landscape of the Moon's southern hemisphere. They see, "Nothing belonging to a living world — everything to a dead world, where avalanches, rolling from the summits of the mountains, would disperse noiselessly at the bottom of the abyss. . . . In any case it was the image of death, without its being possible to even say that life had ever existed there."

Buzz Aldrin, who in July 1969 became the second astronaut to walk on the Moon, expressed his awe and wonder about the beautiful but barren lunar landscape, calling it "magnificent desolation."



S&T: LEAH TISCIONE; SOURCE: NASA

Apollo 8's December 1968 flight to the Moon and back took 6 days. Its three-man crew orbited the Moon for 20 hours at an average altitude of 69 miles.

The inertia of Columbiad's projectile then carries the crew away from the Moon and returns them to Earth. The projectile streaks through the atmosphere like a shooting star and splashes into the Pacific Ocean. The Gun Club frantically scours the seafloor but later simply finds the projectile bobbing atop the waves, an American flag flapping from the top of its cone. The astronauts have returned safely!

Future Vision

The exciting circumlunar journey not only brings fame to the three explorers but also emboldens American scientists and engineers. Verne writes, "Since Barbicane's attempt, nothing seemed impossible to the Americans." The Gun Club helps to create the National Company of Interstellary Communication (NCIC) — a fictional forerunner of NASA — with a mandate to facilitate travel between the Earth and Moon, as well as to the planets and stars.

When founded in 1958, NASA likewise employed many former military scientists and engineers for the purely peaceful exploration of space. A decade later, NASA's Apollo team accomplished the herculean endeavor of sending astronauts first around the Moon and then, just months later, down to its surface. It was a golden age for American science and technology.

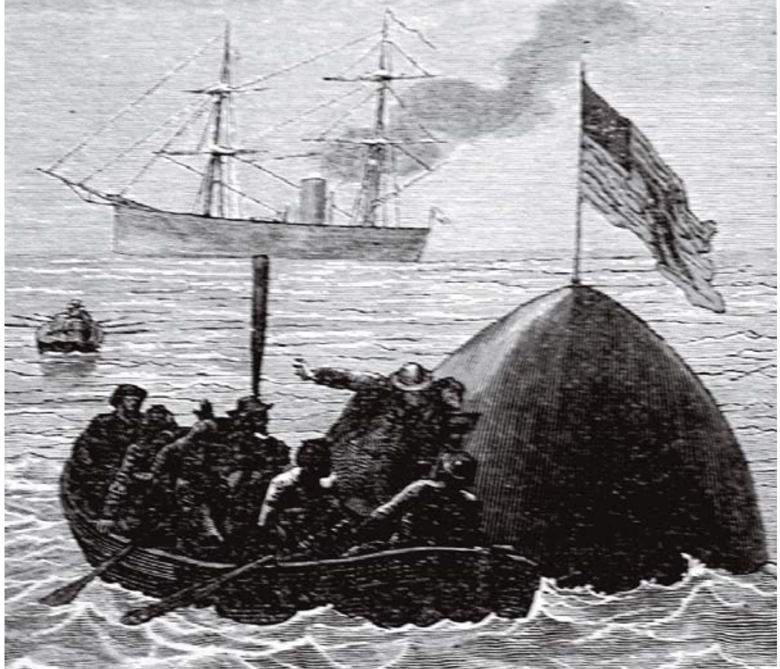
It's difficult to measure what impact the fictional writing of Jules Verne had on the real NASA missions that would follow. Surely many of the space agency's scientists, engineers, and astronauts nurtured their enthusiasm for space travel as children dreaming of what must lie beyond our Earth.

Neil Armstrong certainly felt a connection to Verne's adventure story. On July 23, 1969, returning home after he and Buzz Aldrin had completed their history-making moonwalks, Armstrong began his broadcast to Earth with these words:

> "A hundred years ago, Jules Verne wrote a book about a voyage to the Moon. His spaceship, Columbia [Columbiad], took off from Florida and landed in the Pacific Ocean after completing a trip to the Moon. It seems appropriate to us to share with you some of the reflections of the crew as the modern-day Columbia completes its rendezvous with the planet Earth and the same Pacific Ocean tomorrow."

Often the lines between science fiction and science fact become blurred. But, more interestingly and prosperously, they inspire each other. All new scientific discoveries are born in the imagination of dreamers. On this 150th anniversary of Jules Verne' epic journey, pick up a copy and see what you discover. ✦

Dean Regas is the outreach astronomer for Cincinnati Observatory and co-host of the bite-sized PBS astronomy program Star Gazers.



Apollo 8: Life Imitates Art

Verne's 1865 fictional trip around the Moon had several startling similarities to Apollo 8's circumlunar trip in December 1968. Both missions had a crew of three: Ardan, Barbicane, and Nicholl in the novel; Anders, Borman, and Lovell aboard Apollo 8. Verne's fictional projectile blasted off from Tampa Town, only 132 miles from NASA's site at Cape Canaveral. Verne's Columbiad fired its projectile at 24,545 miles per hour. Apollo 8 initially orbited Earth, and then rockets accelerated the capsule to 24,194 miles per hour toward the Moon. Neither craft had enough velocity to break free of Earth's gravitational pull; instead, both reached a point at which the Moon's gravity attracted them the rest of the way.

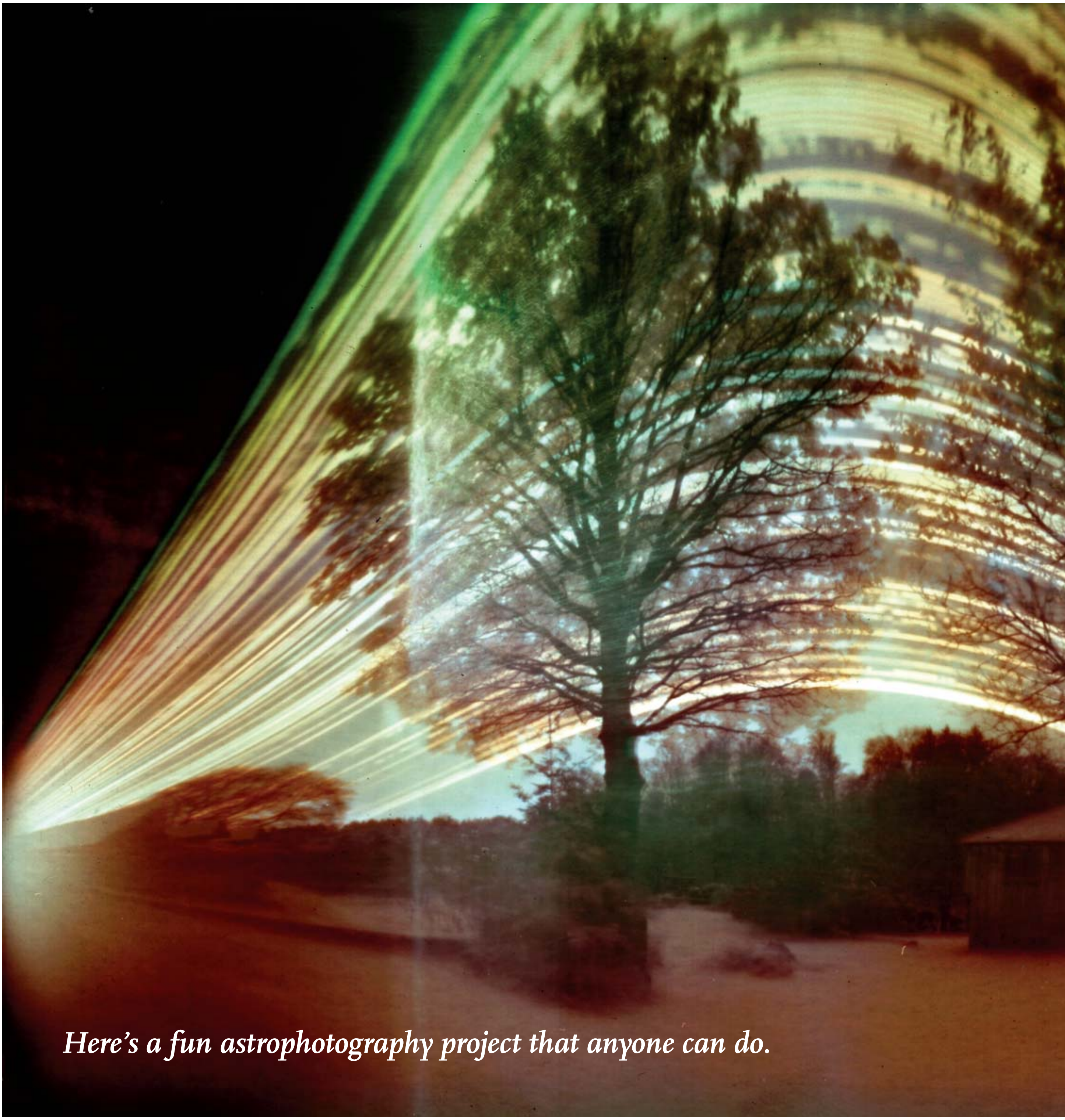
Verne's projectile then skimmed the lunar surface during a full Moon, which meant that Ardan, Barbicane, and Nicholl could hardly see anything when looking back at the "new" Earth. But Anders, Borman, and Lovell arrived during a waxing crescent phase. Consequently, after rounding the Moon, they were able to capture the timeless image of a "gibbous" Earth rising over the lunar landscape.

Verne's craft ultimately landed in the Pacific Ocean and was recovered by the *Susquehanna*, a vessel from the U.S. Navy. Apollo 8's capsule likewise dropped into the Pacific Ocean (5,000 miles from Verne's landing spot) and was recovered by the aircraft carrier *USS Yorktown*. Both capsules were constructed of aluminum — and both floated.

As the crew of Apollo 8 emerged onto the Moon's nearside, they saw a gemlike gibbous Earth rising over the bleak lunar terrain below them.

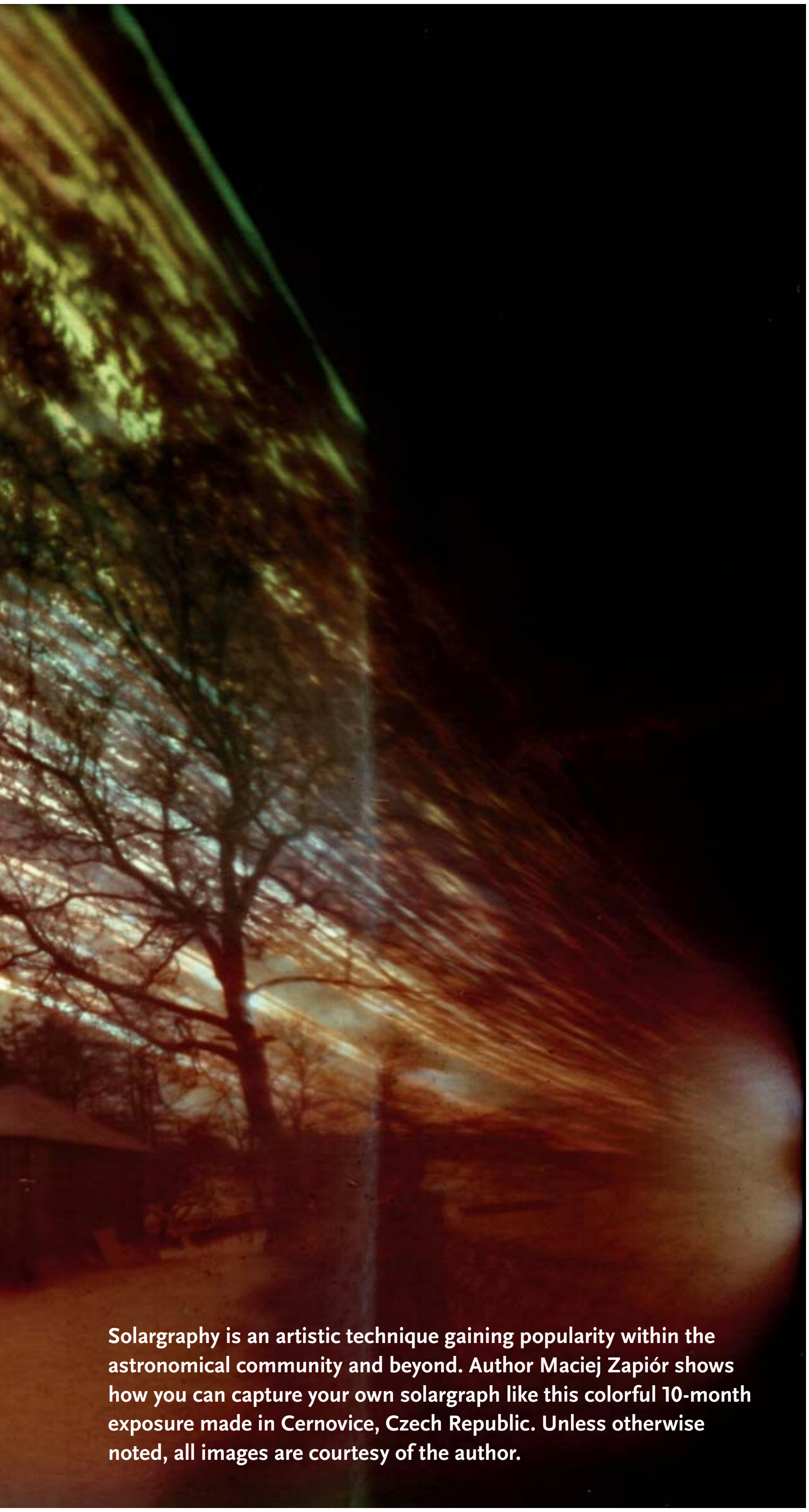
NASA

Catch the Sun



Here's a fun astrophotography project that anyone can do.

in a Can


Solargraphy is an artistic technique gaining popularity within the astronomical community and beyond. Author Maciej Zapiór shows how you can capture your own solargraph like this colorful 10-month exposure made in Cernovice, Czech Republic. Unless otherwise noted, all images are courtesy of the author.

The photos are eerie, almost otherworldly: A warped landscape with no signs of life. There are no people, no animals, and no cars in the street. All that's visible is the still landscape, crowned above by colorful traces of the Sun's path across the sky.

These photographs are known as solargraphs, recorded using the technique known as *solargraphy*. Their sole purpose is to capture the Sun's path over a long period of time with a foreground of your choice, for about a half-year exposure. The best part of this technique is it's cheap and easy to do, and it doesn't require an expensive camera, telescope, or even any developing chemicals.

What is Solargraphy?

Solargraphy is a modern take on pinhole photography, developed jointly by photographers Sławomir Decyk, Paweł Kula, and Diego López Calvín. They perfected this deceptively simple process as part of the Solaris 2000 project, which aimed to record the Sun's motions from various locations around the world.

The technique relies on two novel facts. The first is that light passing through a small hole is projected onto a surface, producing an image. This effect can often be seen during partial and total solar eclipses, when sunlight is filtered through dense leaves, projecting thousands of overlapping images of the eclipsed Sun on the ground below. The second fact is that even without exposure to developing chemicals, black-and-white photographic paper is still photosensitive. Incident light reacts with the paper, but at such a low level that developer and fixer chemicals are usually used to develop exposed paper into photographs.

The team discovered that affixing dry photographic paper to a pinhole camera enables photography without exposure to chemical baths, though obtaining an image requires extremely long exposure times, typically measured in months.

Assembling a Pinhole Camera

Recording a solargraph doesn't require any special photographic equipment. Besides the photographic paper, you can buy everything you need at a grocery store. First,

To record your own solargraph, you'll need a thin metal can or other waterproof container that can be sealed from extraneous light, black-and-white photographic paper, a pin or needle, scissors, a nail file, and black electrical tape.


The most important part of your pinhole camera is the pinhole aperture. Place it in the middle of your can, but be careful not to make the hole too big or else it will let in too much sunlight and overexpose your solargraph.


When inserting your photographic paper, be careful not to expose it to direct sunlight, and make sure its emulsion side is facing your pinhole aperture. Secure the paper to the inside of your camera on its four corners with small pieces of tape.


Seal the end of the can tightly with several layers of tape to ensure that no extraneous light gets into your pinhole camera. Also be sure to cover the pinhole aperture with a piece of tape until you're ready to begin the solargraph exposure.

you'll need to assemble your pinhole camera. This may be an aluminum beverage can or any other light-tight and weatherproof container. You'll need to be able to open and close the camera, so if you use a can, expand the opening using a can opener or a knife.

The next step is to make a tiny pinhole measuring 1 millimeter or smaller using a needle. The smaller the pinhole, the sharper the image produced and the longer you can expose your paper before overexposure, or "fogging" becomes a problem. The goal is to be able to take the longest exposure possible. Poking the hole from the inside of your can will allow you to easily file off any burrs, which will reduce vignetting in your final image.

Now that you have the pinhole camera ready to go, you'll need a sheet of photographic paper. You can find photo paper in photography stores, and many sources are available online. Although any brand can be used, the key is to use black-and-white photographic paper, which contains silver compounds that break down in the presence of light. Color photographic paper contains different compounds that do not react in the same way. In fact, black-and-white photographic paper will still work for solargraphy even if it's beyond its marked expiration date (and therefore cheaper).

Loading the paper into the camera doesn't have to be done in total darkness, but it's important not to expose the paper to direct sunlight. Perhaps the best method is to insert the paper by the light of a single dim bulb in the opposite corner of a room. Make sure to insert the paper with the light-sensitive side (the emulsion) facing the pinhole. Tape the corners to the inside of the can, to ensure changes in temperature or humidity won't curl the paper during its long exposure. Finally, close the can tightly using black insulation tape, to ensure that no other light enters into the can except through the pinhole aperture. Finally, cover the pinhole with a small piece of black tape as well.

Caution Before Exposing

Now your solargraph is ready to use. But before setting it up for its long exposure, it is *crucial* that if you plan to place your camera in a public location, you first attain any necessary permissions from property owners or local authorities. In early February, a pinhole camera affixed to a bridge in downtown Atlanta, Georgia, caused a major disruption that required disposal by a bomb squad!

Choose a spot where the camera will remain untouched throughout the entire planned exposure time. Affixing it to a stable structure is a good idea: you can attach the camera to a balcony, pole, railing, or tree.


Securely mount your pinhole camera so that it doesn't move at all during its half-year exposure. Also be sure to attain permission from the local authorities before mounting your camera in a public location.

You may want to aim the camera south to capture the Sun's entire path each day, or simply consider which direction will achieve the best composition between the Sun's path and the foreground. The camera's field of view is roughly 180° along the horizontal axis and 90° along the vertical axis. Once you've firmly attached the camera where it will stay for the next several months, remove the tape from the pinhole aperture and wait.

Although a solargraph exposure typically lasts 6 months, from solstice to solstice, you can practice with exposures as short as one month and use the trial to decide on the right exposure or direction for your desired result.

Scanning the Result

Once your exposure is complete, retrieve the camera and cover the pinhole with tape. You can then either scan the result yourself using your own flatbed scanner, or bring the camera to a local business that offers scanning services. Scan the image with at least 600 dots-per-inch resolution, and make sure you save it as a TIF, BMP, or PNG file. A word of caution here: do *not* attempt any pre-scan previews, because the scanner's bright light source adds more exposure to the image, which further reduces contrast and obliterates the less-exposed areas.

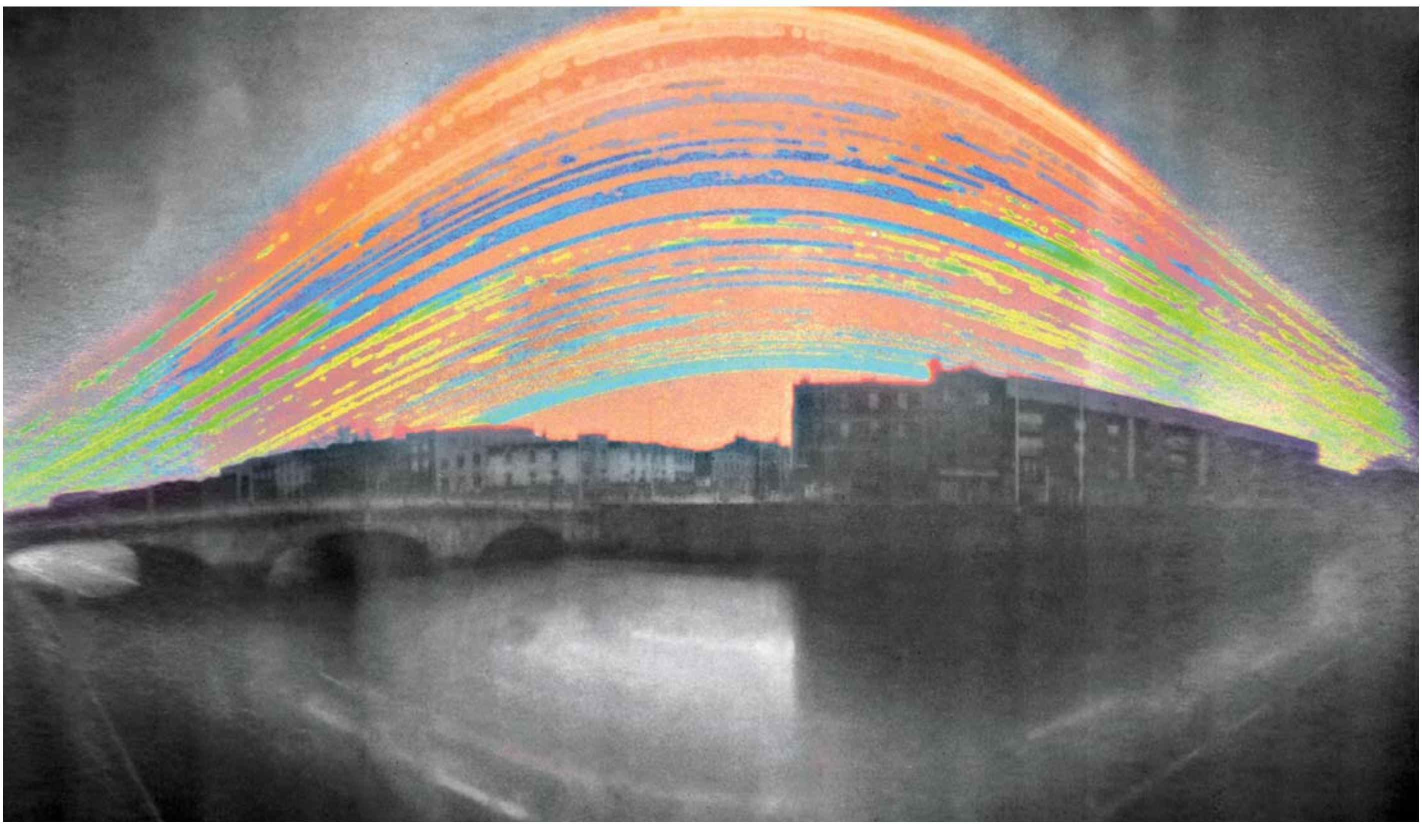
Now, your scanned photo reveals a negative, low-contrast, mirror-reversed image. Because exposure to light has "developed" the black-and-white paper in a way that its manufacturers never intended, the scanned image often displays unusual colors that are the result of random factors such as temperature and humidity interacting with the emulsion during the long exposure.

You can use any graphics program such as *Adobe Photoshop* (**adobe.com**) or *Gimp* (**gimp.org**) to invert the image from negative to positive, and also flip it so that it appears right-reading. Additional adjustments can then be performed to increase contrast and apply any color corrections to produce an image closer to natural color, or you can play around with the saturation and hue settings to really enhance the artistic aspects of the photo.

The Solargraph Unveiled

In the final solargraph, moving objects disappear due to the miniscule amount of light that passes through the

***Left*: Once your solargraph is completed, it will appear as a mirror-reversed, negative image. You can use most any image-processing software to flip the image and convert it to a positive, as well as perform any additional enhancements (below).**

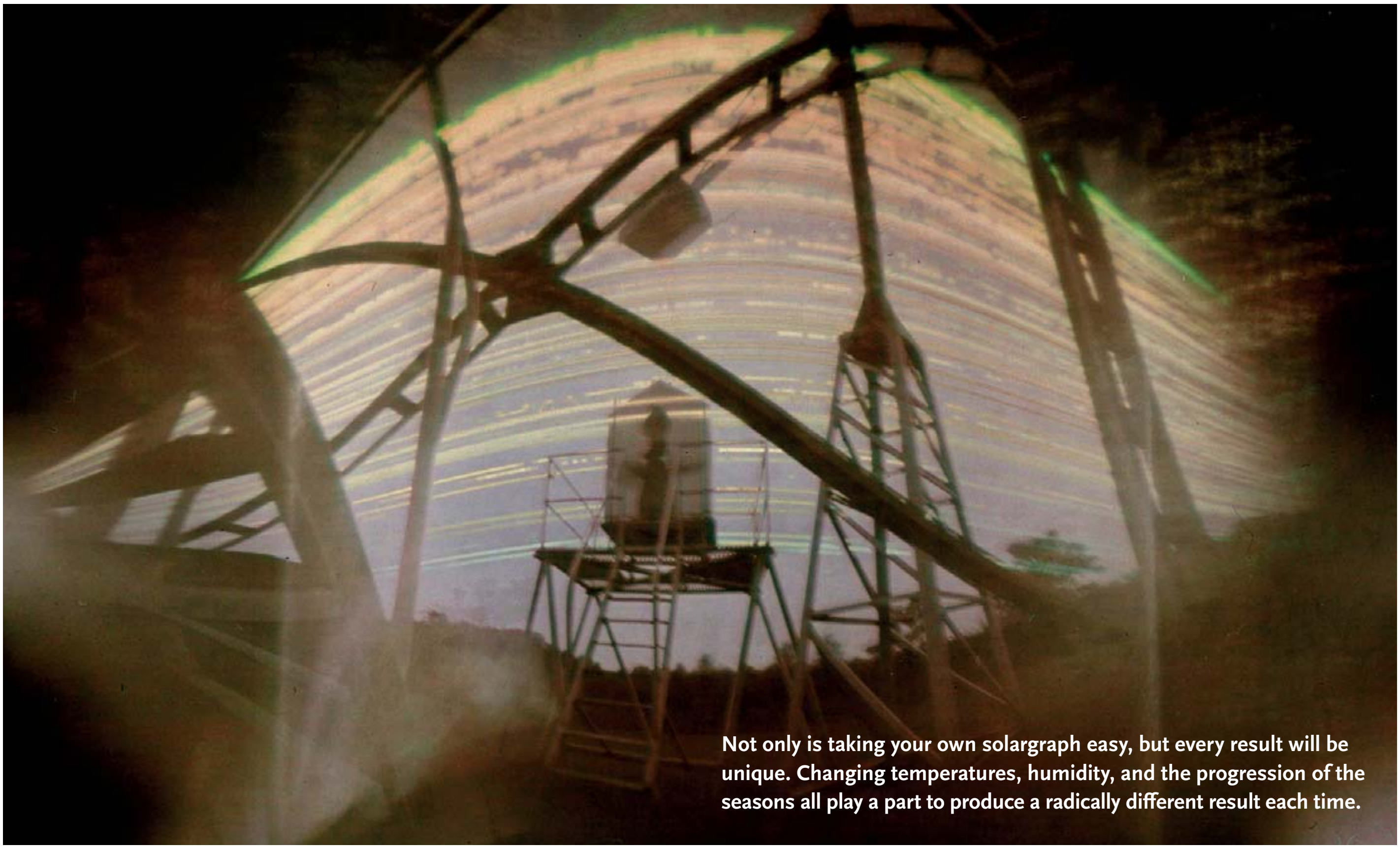


pinhole. The only motion a solargraph captures is that of the blazing Sun, represented as the many curved lines that mark the Sun's trails across the sky each day. Cloudy stretches of days will show as gaps between these trails, while partly cloudy days will record intermittent trails. The daily solar trails culminate at the same point on the meridian, but also illustrate how the sunrise and sunset points move along the horizon depending on the time of year. If you plan the exposure to begin on one solstice and end on the next, the resulting image will show all the possible positions of the Sun at your location. By comparing solargraphs taken at different latitudes, global variations in the Sun's altitude become clear.

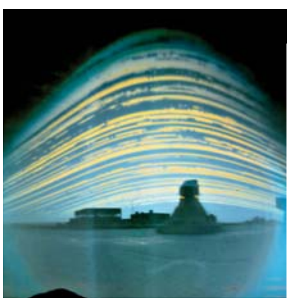
Just as solargraphy is an excellent project to teach about the axial tilt of Earth, the technique also gives us the opportunity to see what the world would look like if our eye could compress half a year into a single frame — phenomena occurring on astronomical time scales concentrated into a single picture. Solargraphs also capture hints of seasonal changes. Leaves appear ghostly, since they were only on the trees for a portion of the exposure. In the magical world of the solargraph, even shadows disappear — any object that's visible is lit on each side, as if the Sun illuminated it from all positions simultaneously.

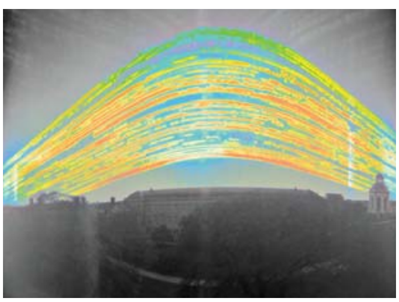
Solargraphy allows us to transcend our limited senses and notice what is usually imperceptible. Recording your own solargraph is easy and inexpensive, yet the results are surprisingly complex. Done well, a solargraph has undisputed educational value while offering the opportunity for a unique artistic approach to every result. ✦

__Maciej Zapiór__ would like to thank Viggo Hansteen and Andrew Murphy for assistance with some of the solargraphs in this article. Visit his website at **analemma.pl**.

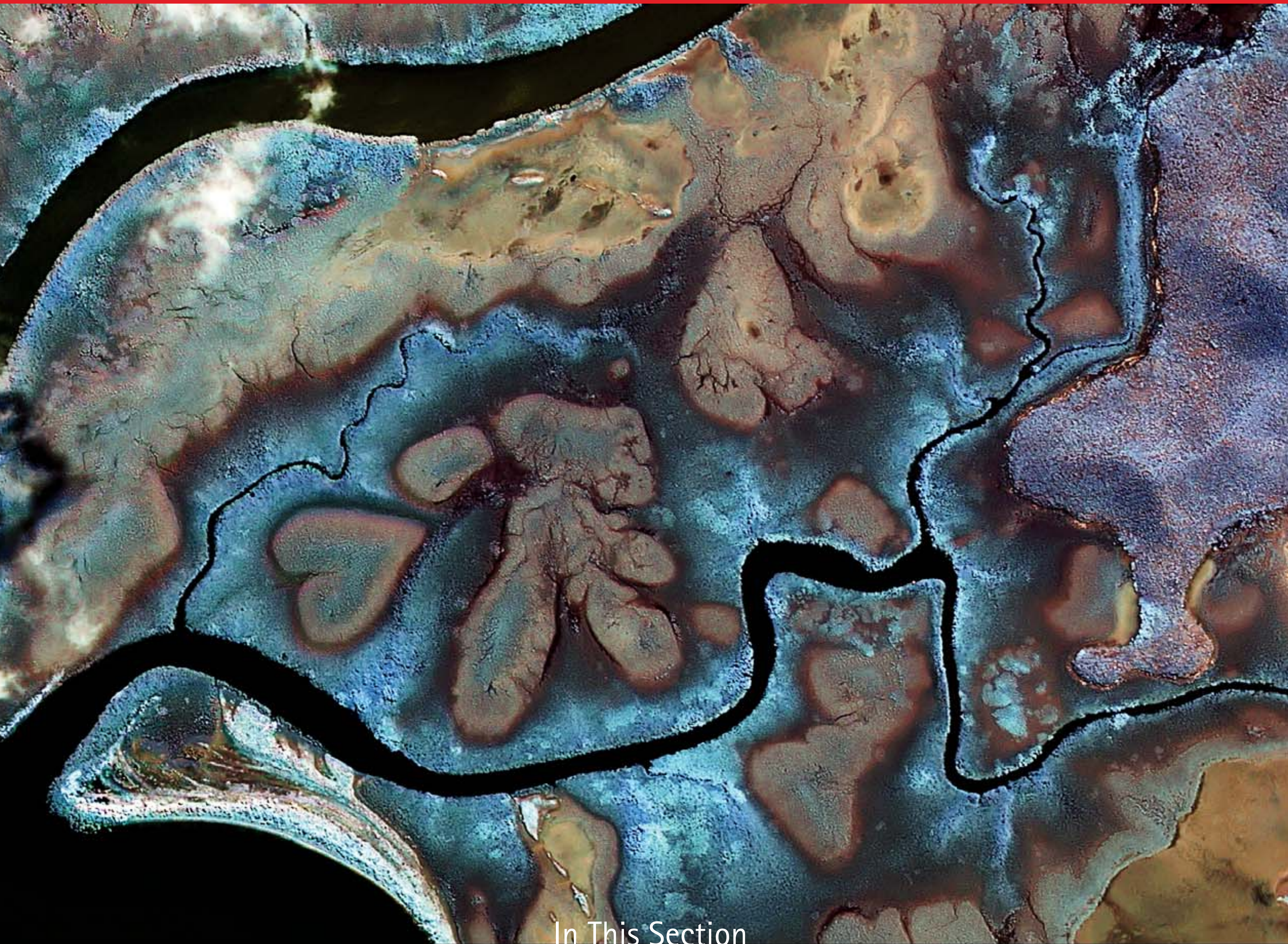


Not only is taking your own solargraph easy, but every result will be unique. Changing temperatures, humidity, and the progression of the seasons all play a part to produce a radically different result each time.





MACIEJ ZAPIÓR & DAWID GUZENDA



In This Section

PHOTOGRAPH: KARI / ESA

The Heart of Voh, shown at left in this false-color satellite image, is a naturally occurring feature in the mangrove swamps of New Caledonia.

JUNE 2015

1 **NIGHT**: Saturn is low in the southeast at dusk; the nearly full Moon shines a few degrees away. Watch through the night as the Moon draws away.

3 **NIGHT**: A double shadow transit occurs on Jupiter from 9:59 to 11:14 p.m. PDT (4:59 to 6:14 June 4th UT).

13 **DUSK**: Look west to see Venus and Jupiter, now just 10° apart. The Beehive Star Cluster (M44) gleams just below the brilliant light of Venus.

19 **EVENING**: Look below Venus and Jupiter for the thin crescent Moon.

21 **THE LONGEST DAY** of the year in the Northern Hemisphere. Summer begins at the solstice, 12:38 p.m. EDT.

21 **EVENING**: The waxing crescent Moon hangs about 5° left of Regulus, with Jupiter and Venus to the lower right.

25 **NIGHT**: Look for Spica about 4° southeast of the first quarter Moon, which sets after midnight.

27 **DUSK**: Venus is less than 2° from Jupiter for the next week. Watch each evening as they draw closer until their conjunction on the 30th.

28 **DUSK**: Find Saturn about 2° from the waxing gibbous Moon.

30 **DUSK**: After the Sun sets, look for Jupiter and Venus low in the west, just ⅓° apart.

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

	◄SUNSET	MIDNIGHT	SUNRISE►
Mercury		Visible June 22 through July 13	NE E
Venus	W NW		
Mars		Hidden in the Sun's glare all month	
Jupiter	W NW		
Saturn	SE	S	SW

Moon Phases

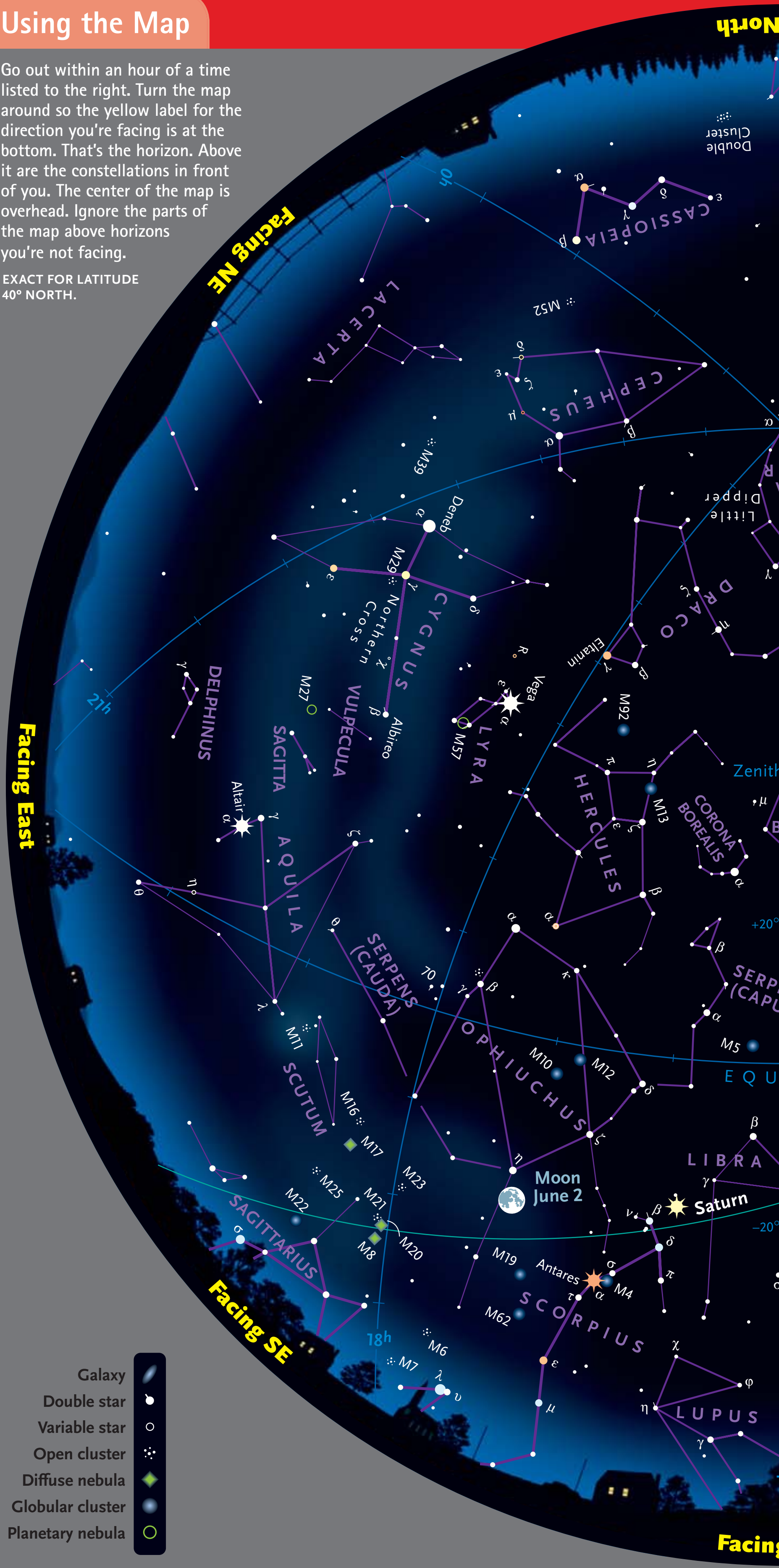
- Full June 2 12:19 p.m. EDT
- Last Qtr June 9 11:42 a.m. EDT
- New June 16 10:05 a.m. EDT
- First Qtr June 24 7:02 a.m. EDT

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				

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.

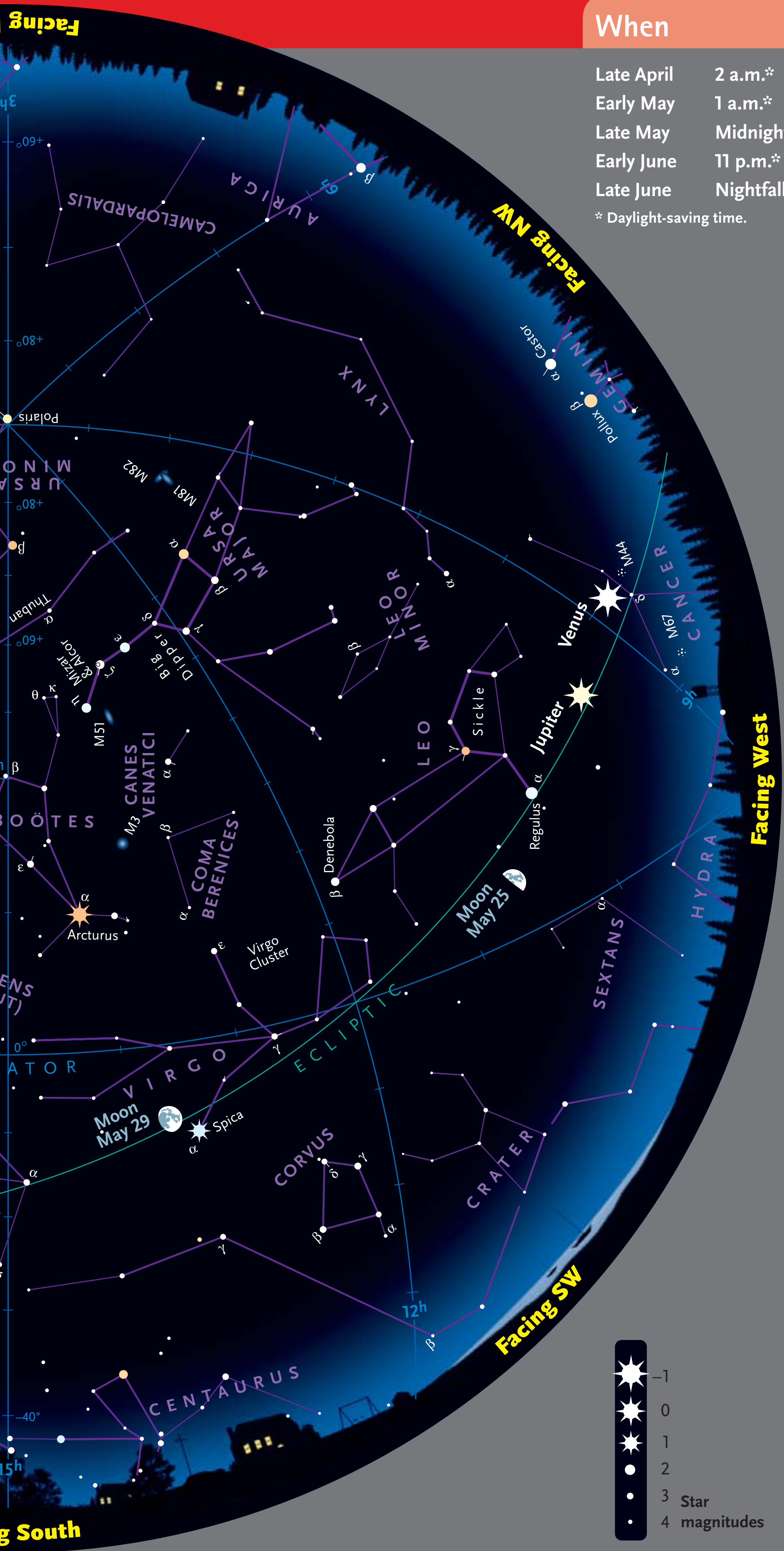
EXACT FOR LATITUDE 40° NORTH.



When

Late April	2 a.m.*
Early May	1 a.m.*
Late May	Midnight*
Early June	11 p.m.*
Late June	Nightfall

* Daylight-saving time.



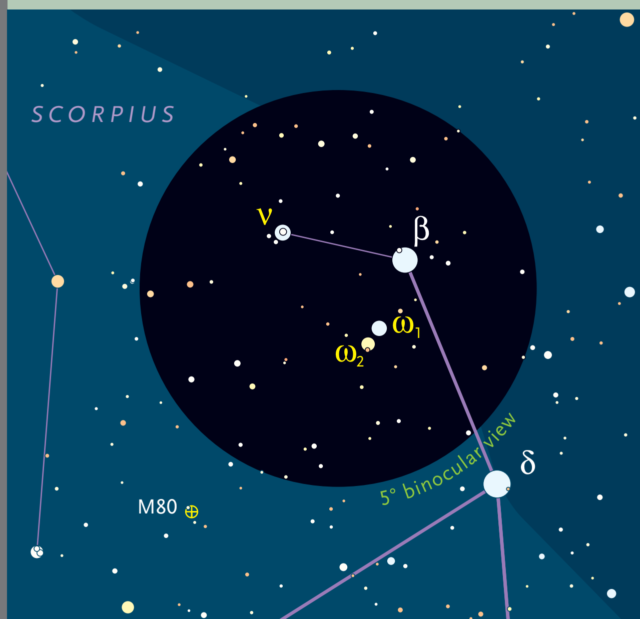
Beta Scorpii Doubles

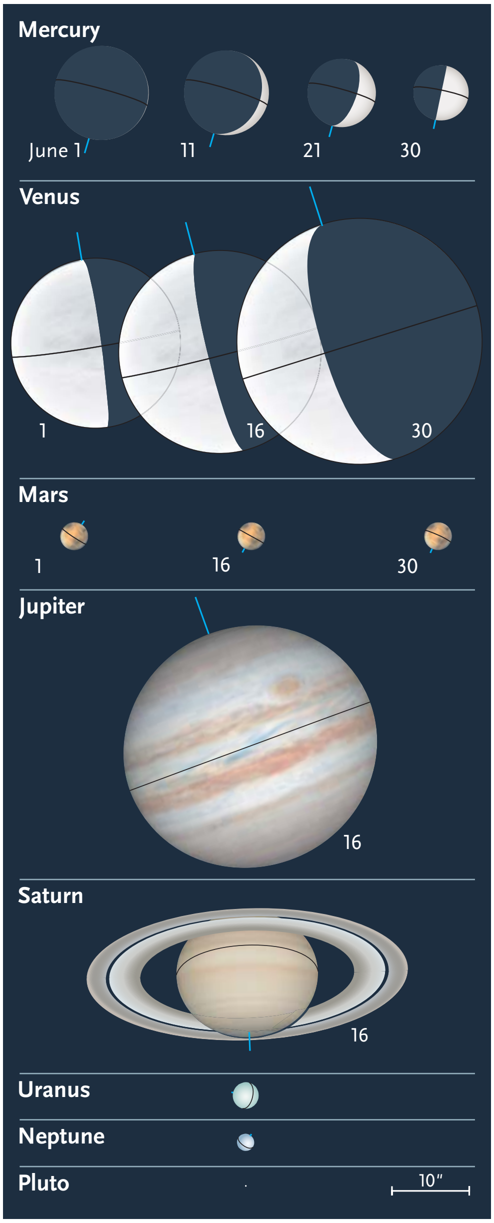
Scorpius features a wealth of interesting binocular targets for early summer nights. One region that is often overlooked includes 2.6-magnitude Beta (β) Scorpii. It forms an attractive triangle with two binocular double stars: **Nu** (ν) and **Omega** (ω) **Scorpii**. One is as easy as they come, the other is a serious challenge.

Compared with telescopes, binoculars have two significant limitations when it comes to observing double stars. First, typical binos operate at magnifications of 7× to 15×. That's great for wide-field views, but it's a bit of a handicap for most doubles, which often require plenty of magnification to split. The second disadvantage is that binoculars are most often hand-held, which significantly limits their resolution. Fortunately, you can buy or build a binocular mount. (A web search will turn up plenty of results, and my own website — **www.garyseronik.com** — has plans for putting one together.) In a pinch, you can simply use an L-bracket with a camera tripod.

Let's begin with Omega, the easy double. You'll have little trouble seeing both stars in this pair even with hand-held 7× binoculars. The stellar duo are separated by nearly 15 arcminutes. Do the two stars look the same brightness to you? At first glance, they probably do, but look a little longer. $Omega^1$ (the more northern star) is magnitude 3.9, while $Omega^2$ is a little fainter at magnitude 4.3.

Now for the tough pair, Nu Scorpii. Its components are much closer, only 41 arcseconds apart. Even worse, they are of unequal brightness, shining at magnitudes 4.2 and 6.6. To split this difficult pair, you'll need mounted binoculars that magnify 10× or greater. Give it a try — it can be done. ✦



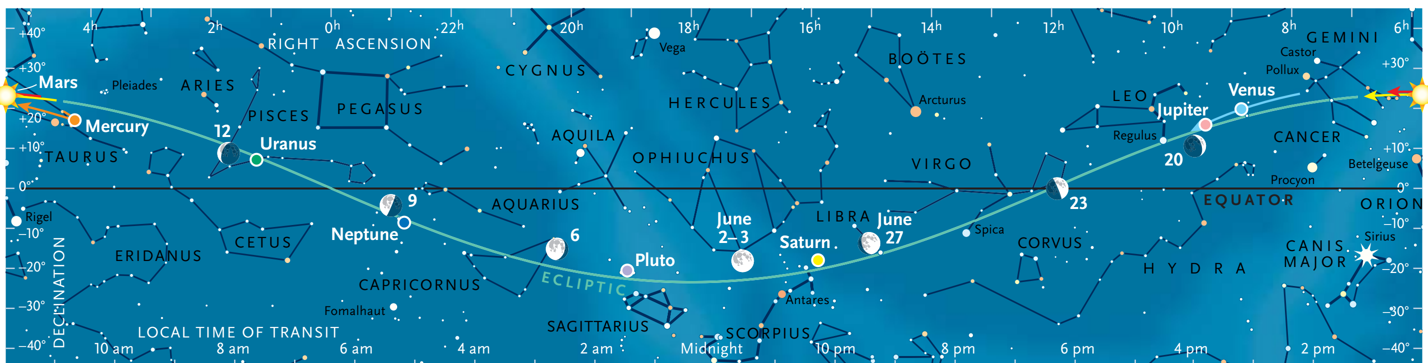


Sun and Planets, June 2015

	June	Right Ascension	Declination	Elongation	Magnitude	Diameter	Illumination	Distance
Sun	1	4h 33.5m	+21° 57′	—	–26.8	31′ 33″	—	1.014
	30	6h 33.6m	+23° 13′	—	–26.8	31′ 28″	—	1.017
Mercury	1	4h 26.7m	+19° 15′	3° Mo	—	12.2″	0%	0.549
	11	4h 12.8m	+16° 58′	16° Mo	+2.6	11.0″	10%	0.612
	21	4h 25.2m	+17° 45′	22° Mo	+0.8	8.8″	28%	0.760
	30	5h 01.5m	+20° 16′	22° Mo	–0.1	7.1″	49%	0.942
Venus	1	7h 50.8m	+23° 41′	45° Ev	–4.4	22.1″	53%	0.756
	11	8h 31.1m	+21° 15′	45° Ev	–4.5	24.7″	47%	0.675
	21	9h 06.3m	+18° 15′	45° Ev	–4.6	28.1″	41%	0.595
	30	9h 32.5m	+15° 18′	43° Ev	–4.6	31.8″	35%	0.524
Mars	1	4h 49.0m	+22° 56′	4° Ev	+1.5	3.7″	100%	2.546
	16	5h 33.7m	+23° 56′	1° Mo	+1.5	3.6″	100%	2.570
	30	6h 15.1m	+24° 08′	4° Mo	+1.6	3.6″	100%	2.583
Jupiter	1	9h 16.6m	+16° 46′	66° Ev	–1.9	34.6″	99%	5.690
	30	9h 35.3m	+15° 16′	43° Ev	–1.8	32.5″	100%	6.066
Saturn	1	15h 56.3m	–18° 11′	171° Ev	+0.1	18.5″	100%	8.978
	30	15h 48.7m	–17° 52′	141° Ev	+0.2	18.1″	100%	9.172
Uranus	16	1h 13.5m	+7° 06′	65° Mo	+5.9	3.5″	100%	20.406
Neptune	16	22h 45.8m	–8° 42′	105° Mo	+7.9	2.3″	100%	29.690
Pluto	16	19h 02.2m	–20° 38′	160° Mo	+14.1	0.1″	100%	31.936

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

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



The Sun and planets are positioned for mid-June; 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

The Magical Midnight Hour

Stay up late to see the summer skies at their best.

Midnight can truly be a magical time — for observing the heavens. That's especially true at the middle latitudes of the Northern Hemisphere in the month of June, when days are longest and prolonged evening and morning twilights reduce night to a minimum. In fact, if you live as far north as latitude 50°, there's no night at all in June, only twilight from sunset to sunrise. Even there, however, the sky is darkest at midnight (by which we mean more like 1 a.m. if you're on daylight-saving time, of course).

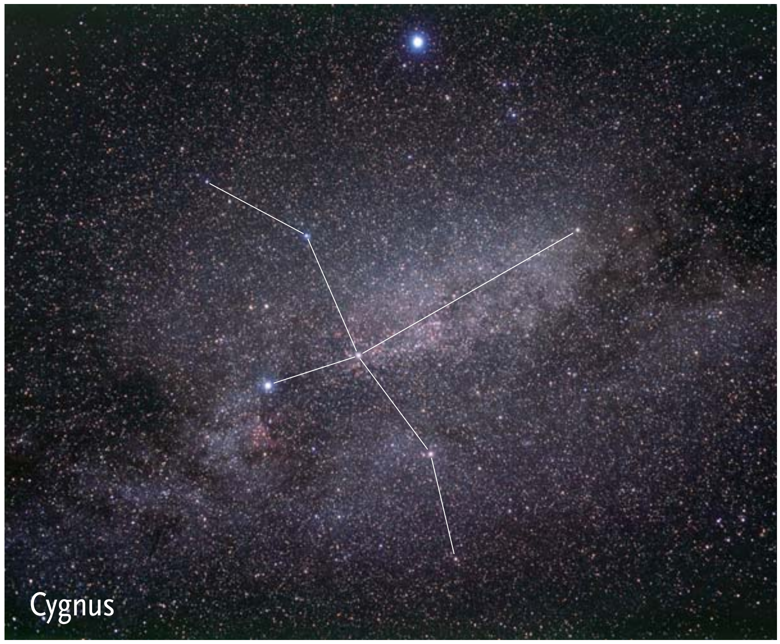
Do you want to observe the deep sky in your telescope as well as possible? Do you want to see as many stars as possible with the naked eye? If your answer to either question is "Yes," and you're located north of the tropics in June, then midnight is the best time for you.

Midnight as a refuge. Twilight is a beautiful state of the sky and much astronomy can be done in it. It should certainly be distinguished from the ugly, glare-blotched thing called "a light-polluted sky" that so many of us have to contend with at home these days. But even if you're very far from city lights, in June you won't see faint galaxies or nebulae, or a truly star-studded sky, until "'round midnight."

IDA (the International Dark-Sky Association) continues to declare various places in the world as dark-sky preserves of various sorts. Midnight is the temporal version of such refuges for all of us.

A foretaste of late summer's glories. For the past few Junes in this column I've insisted that we shouldn't move on too quickly to late summer's attractions, tantalizing as they are. I've said that we should explore and enjoy the constellations that are highest in the sky as dusk fades on June days, even if they're mostly rather dim: Libra, Serpens Caput, Corona Borealis, Hercules. Despite their overall faintness, these constellations offer to telescopic observers wonders like the double star Alpha (α) Librae (Zubenelgenubi), the spectacular globular clusters M5 (in Serpens Caput) and M13 (in Hercules), and several amazing variable and double stars in Corona Borealis, which for naked-eye observers also offers the 2nd-magnitude star Gemma and the attractive semi-circle pattern of its main stars.

But after you make these observations, hang in there (or rather out there) for the full dark of the middle of night. By then, the sky is in one of its most striking states, offering a foretaste of the glories we usually encounter in late summer when they're visible sooner after nightfall.



AKIRA FUJII

What's highest in the middle of June nights? Blue-white Vega, the queen star of summer, is nearing the zenith if you live around latitude 40° north. The entire Summer Triangle of Vega, Deneb, and Altair is high, with the iconic sights of those stars' constellations well-placed: M57 (the Ring Nebula) and Epsilon (ε) Lyrae (the Double Double) in Lyra; and Beta (β) Cygni (the splendidly colorful double star, Albireo), the North America Nebula, and Veil Nebula in Cygnus. Scorpius is on or just passing the meridian, and just behind it glows the central region of our Milky Way galaxy with its amazingly numerous deep-sky wonders.

What else is visible in the middle of June nights? This year, Venus and Jupiter have already set but Saturn is not far past the meridian. Spica is getting low in the southwest but Arcturus is still high. The Big Dipper's bowl, in the northwest, is about as high as the Little Dipper's. Cassiopeia is a little lower in the northeast, and M31 (the Andromeda Galaxy) is a bit to the lower right of Cassiopeia. The Great Square of Pegasus is rising, oriented like a huge diamond, just north of east. ✦

They Meet At Last

Jupiter and Venus come together in an epic conjunction.

During June, the two brightest planets, Venus and Jupiter, draw together in the west after sunset — and draw all eyes towards them. They end the month in a conjunction that's not only extremely close, but also truly epic in other respects.

The only other planet well up at nightfall in June is Saturn, but Mercury becomes visible low in the dawn late in the month.

DUSK TO LATE EVENING

Venus and **Jupiter** start the month 20° apart but appear 60 times closer together on June 30th. They spend an incredible eight evenings within 2° of each other in late June and early July. This is the middle event in a trio of Venus-Jupiter conjunctions that closely resembles the series that might have been the appearances of the Star of Bethlehem in 3–2 BC.

For observers around latitude 40° north, Venus starts the month a generous 35° high at sunset, setting about 3½ hours later in complete darkness. Those figures shrink to about 27° and less than 2½ hours by month's end — the day Venus and Jupiter are closest together. Jupiter has by then dimmed from magnitude –1.9 to magnitude –1.8, but Venus spends the month brightening from –4.4 to –4.6, just short of the peak brilliance it will reach in July. This means that during June, Venus grows from 10 times to 15 times brighter than Jupiter.

Venus makes an exciting journey on the way to its encounter with Jupiter:

On the American evening of June 1st, Venus, Pollux, and Castor are almost equally spaced in a compact, nearly straight, nearly horizontal line.

On June 6th, the bright planet reaches a greatest elongation of 45° from the Sun. But the "dichotomy" of Venus (when it appears half-lit in a telescope) can occur as many as 10 days before greatest elongation — so start watching for it in late May.

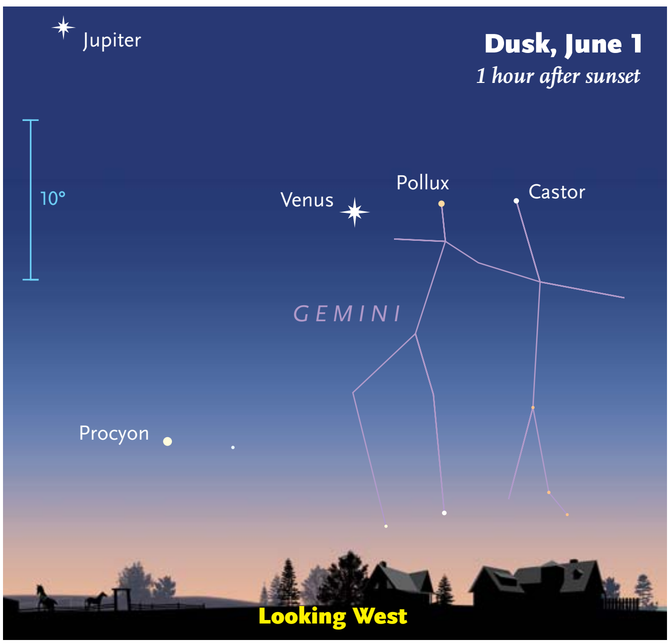
Venus then approaches M44, the Beehive Cluster, and on the American evenings of June 13th and 14th, it appears less than 1° of the cluster's center. Look for M44 lower left of Venus on the 13th, and below it on the 14th.

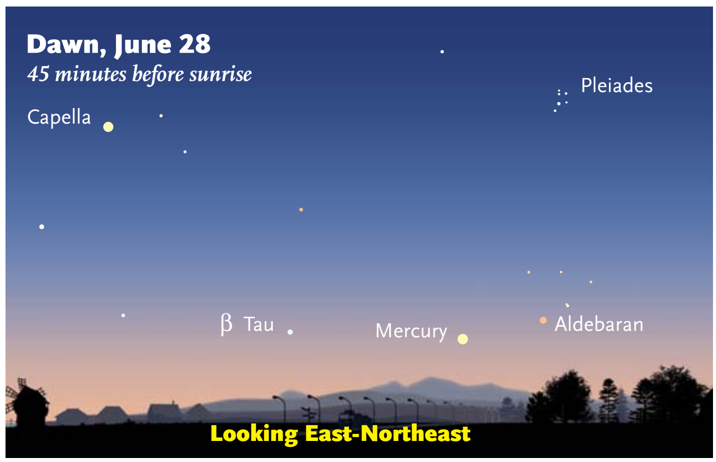
And on the 13th, Venus, Jupiter, and Regulus form a diagonal line of lights, nearly equidistant from one another.

The crescent Moon forms spectacular configurations with Venus and Jupiter on June 19th and 20th (see below).

In the final week of the month, the ever tighter and more majestic pairing of Venus and Jupiter seizes more and more public attention. These two lamp-like planets linger within 2° of each other for eight evenings starting on June 27th, and burn about 15° high in the west-northwest an hour after sunset on the final day of the month.

Venus and Jupiter are closest together on that American evening of June 30th, when the separation between them is only 0.3°. They'll fit together in a fairly high-

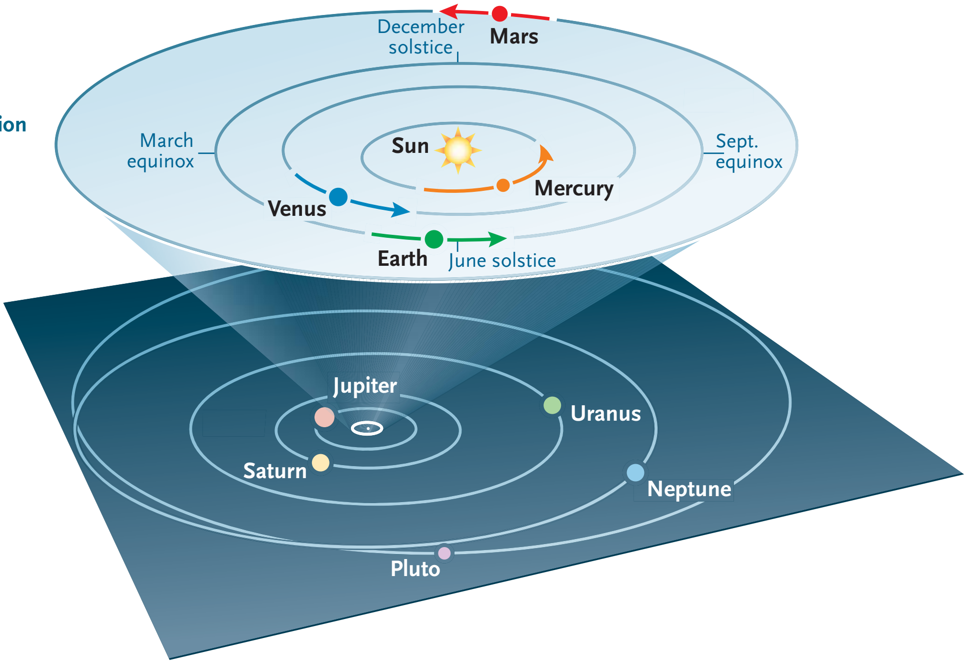




These scenes are drawn for near the middle of North America (latitude 40° north, longitude 90° west); European observers should move each Moon symbol a quarter of the way toward the one for the previous date. In the Far East, move the Moon halfway. The blue 10° scale bar is about the width of your fist at arm's length. For clarity, the Moon is shown three times its actual apparent size.

ORBITS OF THE PLANETS

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

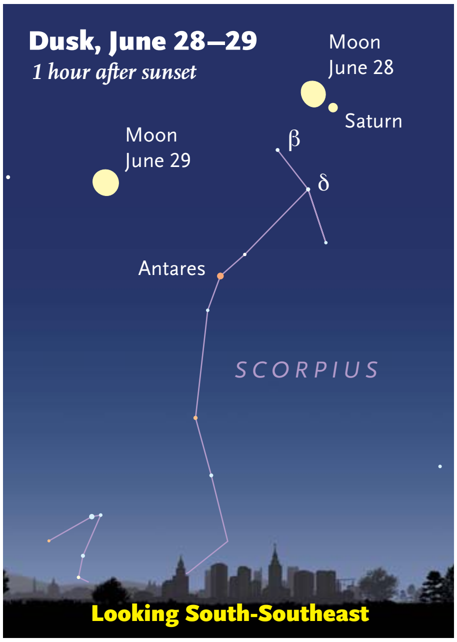


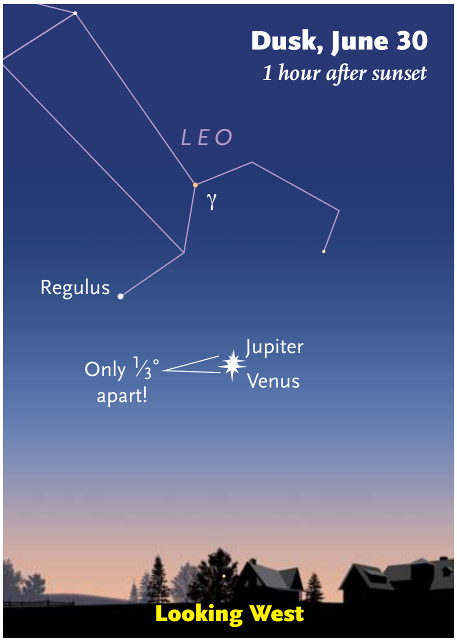
power telescopic field of view, with Venus — which starts the month only 22″ wide and ends it 32″ wide — essentially identical in apparent diameter to Jupiter! Their globes otherwise contrast dramatically, with dazzlingly clouded Venus only 34% lit and the far more dully clouded (but detailed) Jupiter 100% lit. Venus is currently 7.4 times closer to the Sun than is Jupiter, so Venus's surface is illuminated by the Sun 55 times as brightly! This is the same difference in surface brightness they'll display in your telescope.

FROM DUSK TO NEAR DAWN

Saturn was at opposition on May 22nd so in June is already visible in the southeast at nightfall, not setting until morning twilight. Saturn dims a bit — from magnitude +0.1 to +0.2 — as it retrogrades in eastern Libra, still only about 3° from the fine double star Beta (β) Scorpii. During the second half of the month, the ringed planet transits in the south in late evening before Venus and Jupiter set. This is the ideal time to observe Saturn's globe (more than 18″ wide this month) and its rings, which in June span more than 41″ and are tilted a wide 24° from edgewise.

Uranus and **Neptune** are still not very high at dawn's first glow (see **skypub.com/urnep** for a finder chart). **Pluto** reaches opposition in July.





DAWN

Mercury was at inferior conjunction on May 30th and now climbs gradually into the dawn. But even when Mercury reaches greatest western elongation from the Sun on June 24th, it brightens to only magnitude +0.5 and is only about 35% lit. Have a look for it that morning anyway; bring binoculars and scan low in the east-northeast as dawn brightens. Just 2° to Mercury's lower right will be slightly dimmer Aldebaran.

Mercury is a bit higher and brighter by month's end, but still only about 6° or 7° above the horizon around 45 minutes before sunrise.

Mars passes through conjunction with the Sun on June 14th, and so it's not visible this month.

SUN AND MOON

The **Sun** arrives at the solstice at 12:38 p.m. EDT on June 21st, commencing summer in the Northern Hemisphere and winter in the Southern Hemisphere.

The **Moon** is less than one day short of full when it shines less than 6° lower left of Saturn at dusk on June 1st. The waxing crescent Moon is directly below Venus at dusk on June 19th. Then, on June 20th, it glows farther left of Venus — but only about 6° lower left of Jupiter. The next night, the thickening lunar crescent is left of Regulus. At nightfall on June 28th, the waxing gibbous Moon is less than 2° upper left of Saturn. ✦

Saturn at Its Best

Saturn is closest in May and June, with its rings tipped wide open.

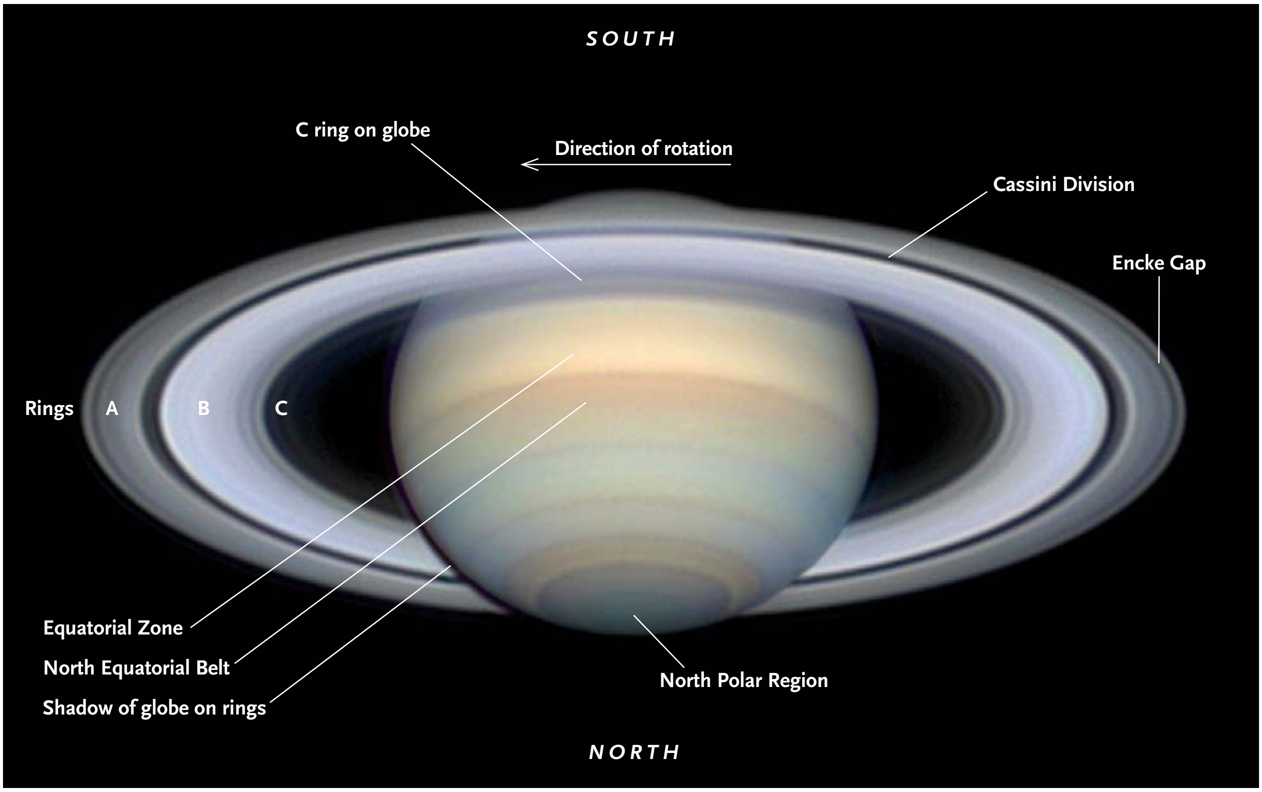
As Jupiter sinks westward through the hours of the night and through the weeks of late spring, Saturn comes up in the southeast to lure your telescope away.

Saturn reaches opposition on the night of May 22nd: about two weeks later than it did the previous year, as always happens. Throughout May and June Saturn remains essentially at its closest, biggest, and brightest for 2015. Shining just above the head of Scorpius, Saturn is fairly far south at declination –18°. (And it will be even farther south until 2021.) So you'll want to stay out late enough with your telescope for it to approach the sky's meridian and shine as high as possible. It's nearly there by 1 a.m. daylight-saving time on May 1st, 11 p.m. on June 1st, and in late twilight by July 1st.

All this time, Saturn shines strikingly bright at magnitude 0.0 or +0.1. It far outshines Antares, magnitude +1.0, twinkling some 10° to 13° below or lower left of it. Saturn's equator appears about 18.5 arcseconds wide in May and June, and the immense ring system spans 42″, quite a bit wider than Jupiter appears now.

And the rings are almost wide open! They're tilted from our line of sight by a trace more than 24°. This is the widest open we've seen the rings since 2005, which is why Saturn looks unusually bright to the naked eye this year. When the rings are edge on (as last happened in 2009), Saturn glows no brighter than Antares.

This high ring tilt means we get fine looks not only at the rings themselves, but at Saturn's equatorial latitudes, now completely exposed, and at the North Polar Region, which is tipped both into Earthly view and into Saturnian summer sunlight. (Saturn's equator is exactly aligned with the rings.) A challenge for imagers under the best conditions will be the Polar Hexagon, slightly darker and perhaps a bit greener than the rest of the North Polar Region. The finest amateur imaging can show that the Hexagon is indeed six-sided rather that round, even though this feature went undiscovered until the Cassini Saturn orbiter sent back shots from close up.



Saturn's rings were tilted 22.0° from our line of sight when Damian Peach took this extraordinarily fine image on April 27, 2014. At that time, Saturn's poles still bumped a little above and below the outer edges of the A ring. This year they don't. South is up in all images.

Rings Past Poles

Saturn's rings were tilted 25.0° last February 26th, enough to extend beyond Saturn's poles. The shadow of the globe fell well to the west on the rings behind (lower right of the globe here) but did not yet quite break the rings over the north pole (bottom). Cameras can bring out not just details but color contrasts better than the eye; note the whiteness of the icy rings compared to the yellowish planet. Darryl Milika and Pat Nicholas in Australia used a Celestron 14 scope and a ZWO ASI174MM planetary video camera for this image.

The tilt of the rings and Saturn's axis will increase only slightly in the next two years (with minor seasonal fluctuations), to a maximum of 27° in 2017.

As for those minor seasonal fluctuations, the tilt is currently *decreasing* very slightly, from 24.6° on May 1st to a minimum of 24.05° in mid-July. Normally that would be insignificant. But it's not *quite* enough for Saturn's south pole to start peeping above the outer edge of the A ring; that happens at ring tilt 24.0°. In the 2014 pictures at left and lower right, by comparison, the rings were tilted only 21° or 22°.

You may, however, detect something else around the sunlit north pole at this opposition. Before opposition, Saturn's globe always casts its shadow westward onto the rings behind it (to the left in south-up images like these). The width of the shadow visible next to the globe shrinks in the months and weeks as opposition approaches. Afterward, the shadow on the rings grows wider just off the globe's *eastern* edge. And around opposition itself this year, the north pole of the planet will cast its shadow northward just enough to break the outer edge of the rings barely above the pole.

This particular subtlety may be lost in the fuzz of atmospheric seeing on most nights. But Saturn is always a work of jeweler's art regardless. Here are more aspects to look for.

Markings on the Globe

Like Jupiter, Saturn is gas planet with banded cloudtops. But Saturn is not only smaller and farther than Jupiter, its markings are also more deeply veiled under high-altitude haze. Even so, my 6-inch reflector almost always shows some of Saturn's banding: the bright Equatorial Zone, the slightly darker North Equatorial Belt, and the dusky North Polar Region. Subtler banding is sometimes detectable in the mid-latitudes.

In late 2010 Saturn erupted with a record-breaking white storm at about 45° north latitude that became easy to see in amateur scopes. The planet's fast upper winds tore a turbulent trail of white clouds from the storm's active head that eventually ran completely around the globe. Might such a thing happen again, now that Saturn's northern hemisphere is approaching its midsummer?

Large scopes and sharp imaging more often show tinier white and dark spots: smaller round or oval storms, visible only during very steady seeing.

Rings Show Off

The smallest astronomical telescope should reveal the rings easily and the dark Cassini Division between the A and B rings with a little more effort.

The dusky C ring is more of a challenge where it appears against the dark-sky background. Its dark shading is easier to see where it crosses Saturn's bright face just inside the B ring. This season, the C ring in front of Saturn may seem especially noticeable. That's because it blends with a thin line of the rings' shadow extending into view at the same Saturnian latitude.

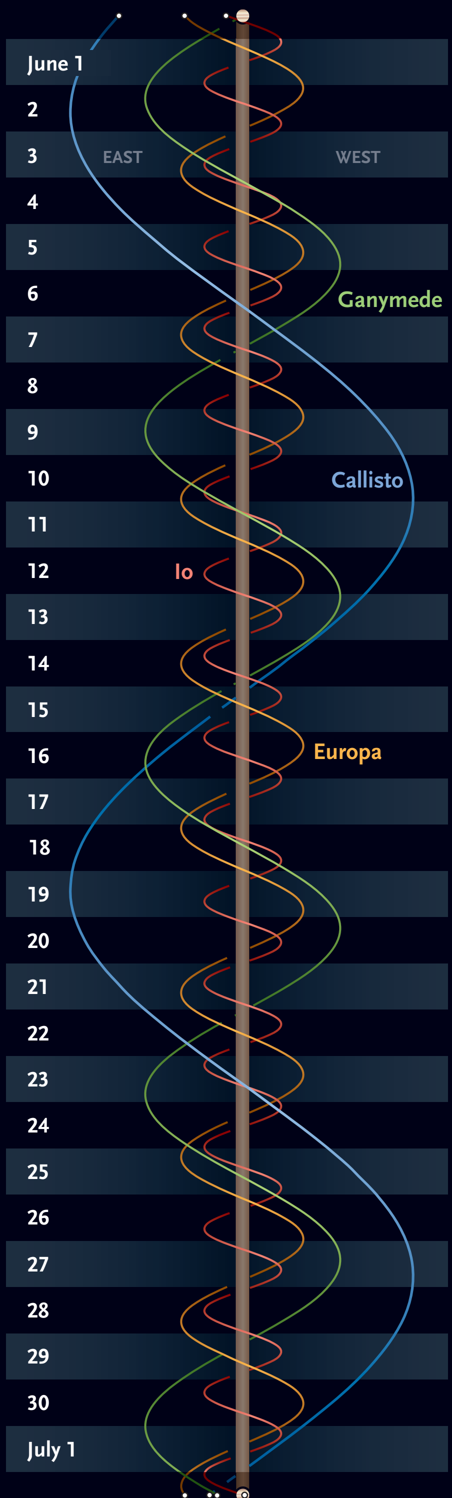
Seeing any further detail in the rings takes upwards of 200× on a high-quality 8-inch or larger scope on a night of top-notch seeing. On such rare nights I *think* I detect occasional flickers of Encke Gap with my 12.5-inch reflector.

Very subtle banding in the rings is also occasionally reported under near-perfect conditions. The fabled ring spokes, diffuse radial bands on the wide B ring, have even lower contrast, eluding all but the most experienced visual observers with large scopes. And usually they aren't there at all. Fortunately, stacked-video imaging has brought such elusive details within reach of backyard observers. To capture spokes if they're present, shoot short video clips no more than 90 seconds long to stack. Any longer and the rapid orbital motion of the ring material will blur away any spokes. And, be very careful not to overprocess your images or false features will creep in. This is more of a problem with Saturn than the other planets because of all the sharp lines between bright and dark that the rings add to the scene.

May 11, 2014 **May 15, 2014** **May 23, 2014**

The Seeliger effect, the brightening of the rings near opposition, is subtle in images. But visual observers who become familiar with Saturn notice it fairly easily. Opposition fell on May 10th in 2014. Trevor Barry in Australia recorded a series of images in the following days using a 16-inch reflector with a ZWO ASI120MM planetary video camera.

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.

You may also notice Saturn's bright surface through the Cassini Division — as opposed to black sky in the parts of the division off the planet's edge — at times when a sunlit part of Saturn appears through this narrow slot.

For several nights around Saturn's May 22nd opposition, watch for the *Seeliger effect:* a slight brightening of the rings with respect to the globe. This is caused by the solid ice particles in the rings backscattering sunlight more effectively than the cloudtops do.

Moon Dance

In addition, Saturn and its rings are surrounded by extra baubles: more moons for amateur scopes than orbit any other planet.

Even a 60-millimeter scope will usually reveal well-named Titan, half again as big as our Moon. A 6-inch will show the orange tint of Titan's thick photochemical smog, which hides this weird world's rainclouds, rivers, and lakes of liquefied natural gas.

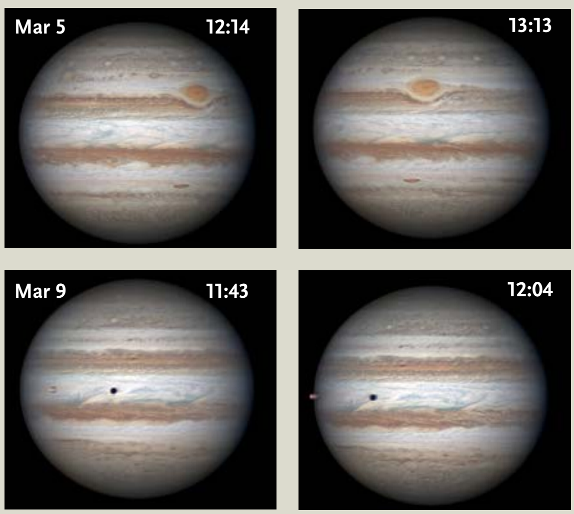
A SATURN GUIDE AT YOUR SCOPE

Our **SaturnMoons** app displays the nine largest satellites at any time and date, the rings' changing tilt, and background info by J. Kelly Beatty. Available from iTunes for $2.99.

A 4- or 6-inch scope will also show Iapetus, Rhea, Dione, and (with a little difficulty) Tethys. An 8-inch may occasionally catch fainter Enceladus closer in. My 12.5-inch shows Enceladus pretty regularly. You can identify the moons, or find exactly where to look for them, at any time and date using the interactive tool at **skypub.com/satmoons**. Or for handy use at the scope, get our SaturnMoons app for phones and tablets as described above.

And of course, take every opportunity to show Saturn to others! Countless amateurs remember a first view of Saturn as the door that opened for them the riches of astronomy.

Action at Jupiter



Jupiter sinks lower in the western dusk in June, so begin observing it with your scope as soon as you can spot it in twilight. Start from brighter Venus to its lower right. Jupiter is on the far side of the Sun from us, so it's near its minimum apparent size; it shrinks from 34″ to 33″ across its equator in June. But it still shows more illuminated area than any other planet,

Last March, a month past opposition, Jupiter's North and South Equatorial Belts were nearly equal on the side away from the Great Red Spot, but somewhat dissimilar on the Red Spot's side. South is up. The Moon casting its shadow in the bottom images is Io. Christopher Go of Cebu City, Philippines, took these images as part of his long-term monitoring of Jupiter. He uses a 14-inch Celestron Schmidt-Cassegrain scope with a Skyris 132M planetary video camera and de-rotates Jupiter before stacking frames.

Phenomena of Jupiter's Moons, June 2015

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

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

including Venus, which is currently only half-lit or a bit less.

Distant though Jupiter may be, lots is happening here. Any telescope shows Jupiter's four big Galilean moons. Binoculars often show at least two or three. Identify them using the diagram at far left.

All the interactions in June between Jupiter and its satellites and their shadows are listed in the table above.

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.)

May 1, 5:19, 15:14; **2**, 1:10, 11:06, 21:02; **3**, 6:58, 16:53; **4**, 2:49, 12:45, 22:41; **5**, 8:36, 18:32; **6**, 4:28, 14:24; **7**, 0:20, 10:15, 20:11; **8**, 6:07, 16:03; **9**, 1:59, 11:54, 21:50; **10**, 7:46, 17:42; **11**, 3:38, 13:33, 23:29; **12**, 9:25, 19:21; **13**, 5:17, 15:12; **14**, 1:08, 11:04, 21:00; **15**, 6:56, 16:51; **16**, 2:47, 12:43, 22:39; **17**, 8:35, 18:30; **18**, 4:26, 14:22; **19**, 0:18, 10:14, 20:09; **20**, 6:05, 16:01; **21**, 1:57, 11:53, 21:48; **22**, 7:44, 17:40; **23**, 3:36, 13:32, 23:28; **24**, 9:23, 19:19; **25**, 5:15, 15:11; **26**, 1:07, 11:02, 20:58; **27**, 6:54, 16:50; **28**, 2:46, 12:42, 22:37; **29**, 8:33, 18:29; **30**, 4:25, 14:21; **31**, 0:16, 10:12, 20:08.

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

These times assume that the spot is centered at System II longitude 224°. Features on Jupiter appear closer to the central meridian than to the limb for 50 minutes before and after they transit.

Lunar Occultation

On the evening of June 28th, when the waxing gibbous Moon is just 1½° from Saturn, the Moon's thin, invisible dark limb will occult (cover) the 4.1-magnitude star Theta (θ) Librae for eastern North America. The star is an unresolvably close binary, with equal 5th-magnitude components predicted to be 0.05″ apart. So the occultation could happen in two quick steps 0.1 or 0.2 second apart, depending on your location. Is this slow enough to see by eye? A past occultation of Theta Librae was reported to be non-instantaneous.

Some times of the disappearance: Montreal, 11:14 p.m. EDT; Toronto, 10:58 p.m. EDT; central Mass., 11:13 p.m. EDT; New York, 11:08 p.m. EDT; Washington DC, 11:00 p.m. EDT; Atlanta, 10:38 p.m. EDT; Miami, 10:48 p.m. EDT; Chicago, 9:36 p.m. CDT; Kansas City, 9:17 p.m. CDT; Austin, 9:06 p.m. CDT. ✦

More Lunar Landing Sites

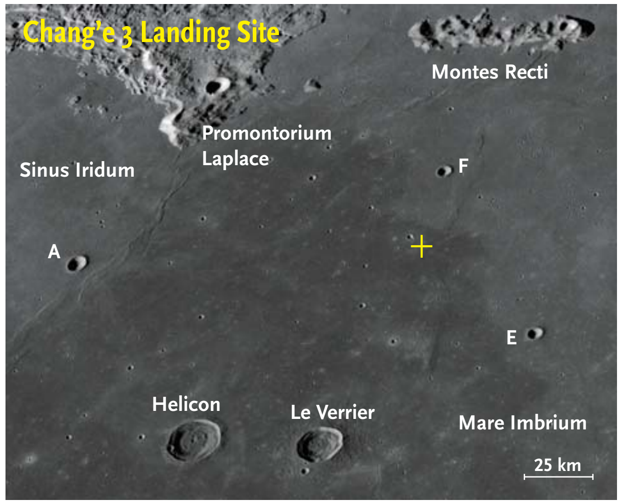
Recent space missions have left their mark on the Moon — by landing intact or crashing.

Humans naturally want to see where their famous predecessors have been. Some years ago, when traveling in Europe, I made sure to visit the National Observatory of Athens so I could view the location from which the great 19th-century observer Julius Schmidt (see page 29) observed the Moon. Lowell Observatory was likewise a required stop when I first visited Flagstaff, Arizona.

My quest extends to the Moon as well. Even though every landing or crash site for lunar spacecraft is too small to detect from Earth, I like to closely observe the landscapes of the landing areas.

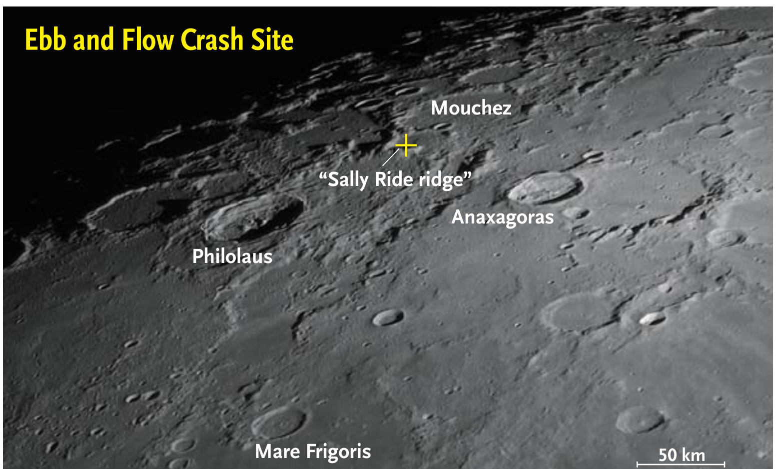
In the five years since I described early Soviet (*S&T*: July 2010, p. 51) and more recent (*S&T*: Feb. 2010, p. 51) lunar landing sites, four additional spacecraft have reached the surface of the Moon. Unlike early days of the space race, when missions often ended with accidental impacts, now a spacecraft's final orbits are usually planned for the impact to probe the lunar surface or simply to avoid historical landing sites.

Ebb and Flow, the two components of NASA's Gravity Recovery and Interior Laboratory (GRAIL) mission, collided with a ridge deep in the lunar northern hemisphere on December 17, 2012, while the Lunar Atmosphere and Dust Environment Explorer (LADEE) impacted on the farside on April 18, 2014. The fourth spacecraft to reach the Moon lately was China's Chang'e 3, which soft-landed with the self-propelled Yutu rover on northern Mare Imbrium on December 14, 2013.



NASA / ARIZONA STATE UNIV.

The Chinese lander Chang'e 3 and its rover, Yutu, dropped onto a nearly featureless stretch of northern Mare Imbrium in December 2013. This is a composite of Lunar Reconnaissance Orbiter images.



NASA flight controllers intentionally crashed the twin GRAIL spacecraft, Ebb and Flow, into a broad ridge informally named for the late astronaut-educator Sally Ride. Seen here in an image taken through a 14-inch telescope, the ridge is observable near the distinct far-northern craters Philolaus and Anaxagoras.

RICHARD BOSMAN

GRAIL was an inexpensive and conceptually simple mission that provided some of the most important data ever collected about the Moon. By tracking the exact distances between Ebb and Flow, mission scientists could calculate minute variations in the pull of gravity all around the Moon. These measurements led to detailed maps of the thickness of the lunar crust, better understanding of the subsurface structure of impact basins, and confirmation that the upper few kilometers of the highlands crust is hyper-fragmented.

When they finally ran low on fuel, these two small satellites followed their polar orbit on a final pass south to north over Mare Imbrium, across Mare Frigoris, passing near the crater Philolaus, and smashing at 6,100 km per hour (just over 1 mile per second) into an unnamed ridge. The mission team has proposed naming the ridge after the late Sally Ride, who was an inspiring astronaut,

*Contributing Editor **Charles A. Wood** (www2.lpod.org) also studies the cratering record of another moon, Saturn's Titan.*

Charles A. Wood

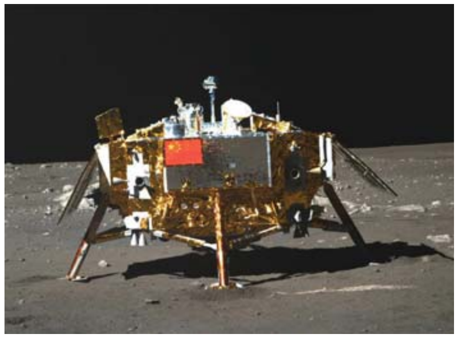
secondary-school educator, and GRAIL team member. (The International Astronomical Union will formally consider the request later this year.)

The ridge is inconspicuous but not too hard to observe. Start in familiar territory, the space between Sinus Iridum and Plato, and then shift your view poleward to the conspicuous fresh crater **Philolaus** (71 km wide) and just beyond that to shallow, rough-floored **Mouchez** (83 km). Between these two features lies **Sally Ride ridge**, which is probably a rim segment of an ancient crater adjacent to Mouchez. According to measurements from the Lunar Reconnaissance Orbiter's *QuickMap* path tool (*S&T*: Aug. 2014, p. 54), the ridge is about 40 km long and rises about 2½ km above its surroundings.

The landing site for the Chang'e 3 mission is easier to find. In this case start at the northwestern end of Mare Imbrium with the twin small craters **Helicon** (24 km) and **Le Verrier** (21 km). Now look halfway between Le Verrier and **Montes Recti** (Straight Range); that flat mare is where Yutu sits in its tracks, its carrier craft about 80 feet (25 meters) away.

The region is not quite featureless: a broad, slightly dark lava flow extends from the west to the Chang'e 3 landing area, whereas lavas to the east are slightly paler and older. Yutu's ground-penetrating radar has detected multiple layers — probably a sequence of lava flows and ejecta blankets — beneath the landing site (see page 14).

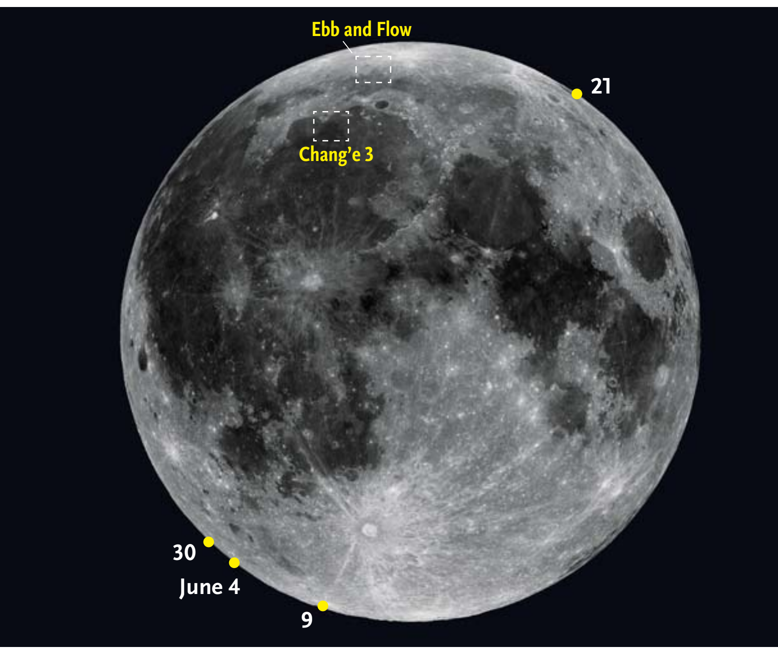
Observation of the LADEE crash site is impossible from Earth, even with the best telescopes, for it crashed onto the farside. Originally, the location was unknown, but LRO scientists discovered the small depression it made near the crater Sundman V in the Orientale Basin ejecta blanket. In fact, if you can see the large crater **Einstein** when libration along the western limb is good, the region beyond — almost visible —is the resting place for LADEE.



CHINESE ACADEMY OF SCIENCES

Chang'e 3 on the lunar surface, as seen by a camera on its rover, Yutu, on December 22, 2013. It was the first soft lunar landing since 1976.

The LRO team has done an excellent job tracking down most of the spacecraft that reached the Moon. Although all of the intact spacecraft and excavated craters are far too small to see from Earth (Ebb and Flow gouged out pits each about 5 m wide), it's fun to follow up your telescopic views of these regions with a trip to the LRO landing-site webpage (**featured-sites.lroc.asu.edu**) to see what only a future lunar tourist might be able to observe. ✦



NASA / LRO

The Moon • June 2015

Phases

FULL MOON
June 2, 16:19 UT

LAST QUARTER
June 9, 15:42 UT

NEW MOON
June 16, 14:05 UT

FIRST QUARTER
June 24, 11:03 UT

Distances

Perigee 229,728 miles	**June 10, 5h UT** diam. 29′ 38″
Apogee 251,116 miles	**June 23, 17h UT** diam. 32′ 17″

Librations

Cabeus (crater)	June 4
Hausen (crater)	June 9
Mare Humboldtianum	June 21
Vallis Baade	June 30

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

A Heaven Full of Stars

Split the Serpent's star systems into their colorful components.

Alone in the night
On a dark hill
With pines around me
Spicy and still,

And a heaven full of stars
Over my head,
White and topaz
And misty red;

Myriads with beating
Hearts of fire
That aeons
Cannot vex or tire;

Up the dome of heaven
Like a great hill,
I watch them marching
Stately and still.

And I know that I
Am honored to be
Witness
Of so much majesty.

— Sarah Teasdale, *Stars*, 1920

Although the starry sky is one of our great loves, most amateur astronomers don't think of stars as proper deep-sky objects. But why not? They certainly reside beyond the shallow sky (our solar ystem), and they're fascinating objects in their own right. For some remarkable stars that are now well-placed in our sky, let's visit Serpens Caput, the Serpent's Head. We might picture this celestial serpent as a speckled king snake, flecked with small stars and inhabiting a regal place in the lofty heavens.

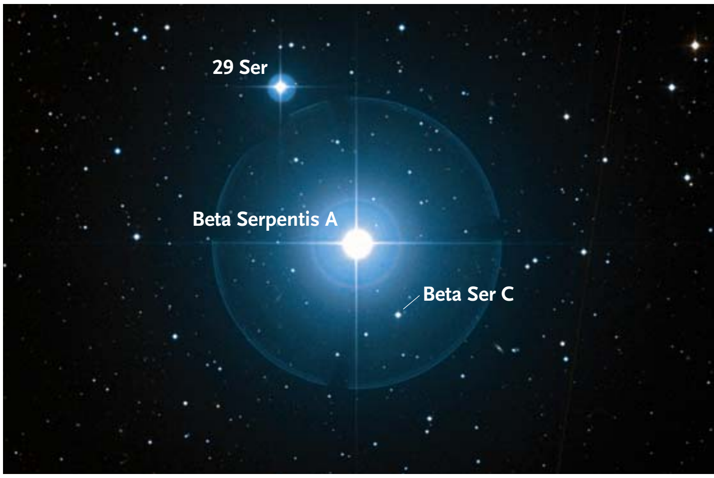
Unlike our Sun, most stars dwell in multiple star systems, making them the most popular stars pursued by skygazers. Multiple stars come in a variety of colors, separations, and magnitudes that heighten their allure. What better place to start this month's tour than the incredible system **Beta (β) Serpentis**, a probable quintuplet! And all five components are visible through a fairly small telescope.

In 1781 the famous observer William Herschel discovered the closest companion (**B**) to Beta Serpentis A, and he described the stars as "extremely unequal." The large magnitude difference begs a higher magnification than you might otherwise expect from the generous separation of 31″ between the stars. Nonetheless, the pair shows quite well through my 130-mm refractor at 48×, with the 10.0-magnitude companion west of its 3.7-magnitude primary. A third member (**C**) shares the field of view, lying a spacious 3.3′ south-southwest.

Far removed from the AB pair, component C may seem an unlikely companion. But on his website, *Stars*, (**stars.astro.illinois.edu/sow/sowlist.html**), astronomer and author Jim Kaler explains that these three stars keep pace with one another as they move through space. With Beta 155 light-years away from us, Kaler calculates that the C star is separated from the AB duo by at least 9,500 times the distance between the Earth and Sun, and it would take more than a half million years to orbit them once.

If this isn't impressive enough, consider component **D**. In a 2011 paper in the *Astrophysical Journal Supplement Series*, Ed J. Shaya and Rob P. Olling (University of Maryland) explain how they determined that some very wide star pairs "are either presently bound or were previously bound." Beta Serpentis AD forms one of these pairs.

Through the 130-mm scope and a wide-angle eyepiece giving 117×, I can fit star D in the field of view with the other components. This also reveals that D itself is a fairly close pair. The brighter star shines at magnitude 8.2, and its 10.7-magnitude attendant sits north-northwest. The D stars lie a whopping 27.4′ west-southwest of



POSS-II / STSCI / CALTECH / PALOMAR OBSERVATORY

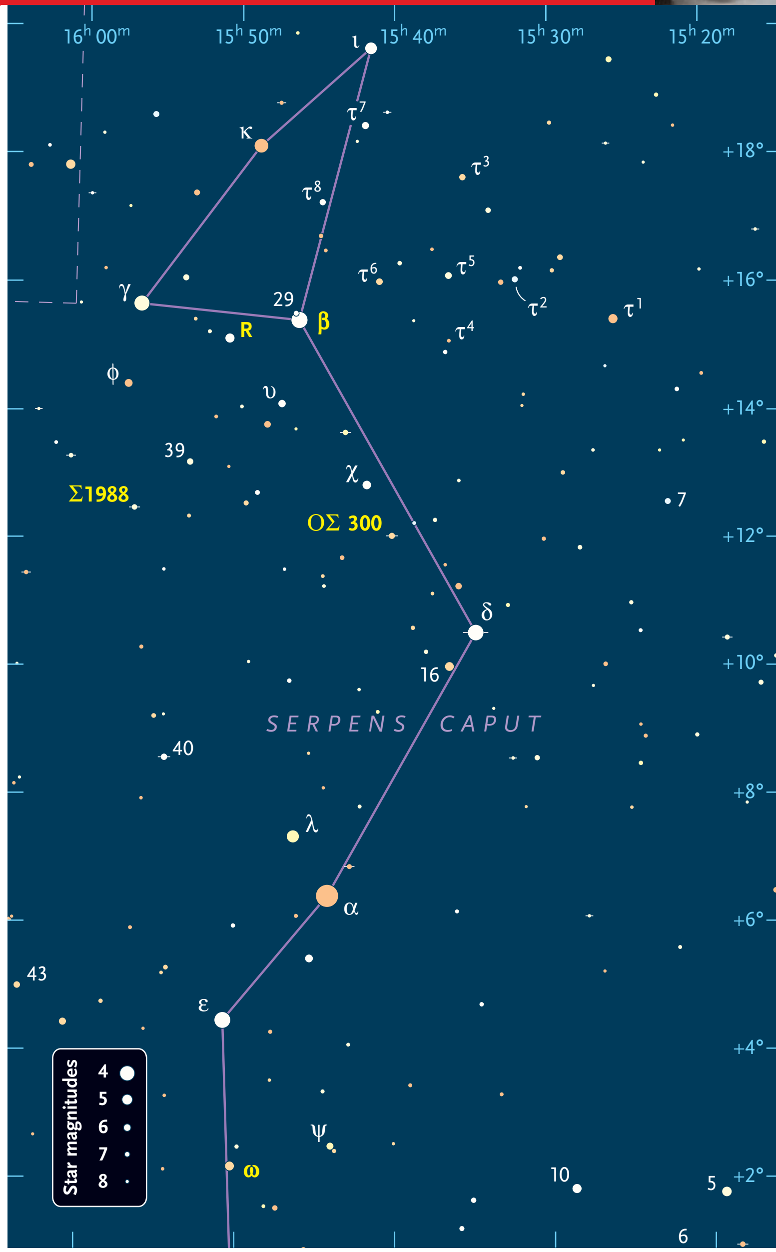
their primary. To me the quintuplet's colors appear: A, white; B, yellow-orange; C, undecided; Da, pale yellow; and Db, undecided. I can see all five stars together in my 10-inch scope at 68×. Star Db looks yellow-orange, but the color of star C still eludes me. What do you see?

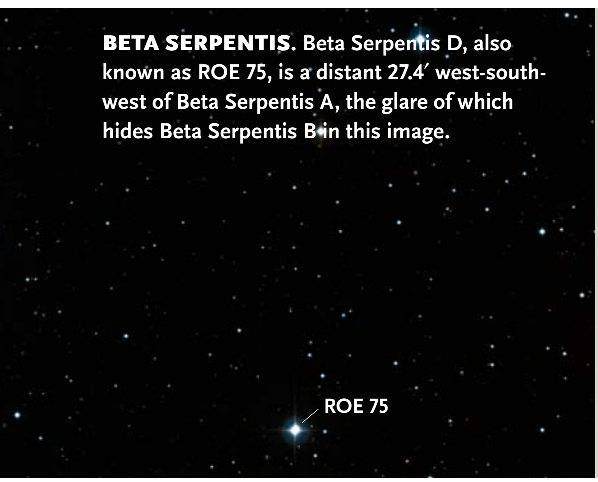
Kaler writes that if D actually orbits the ABC trio, it's separated from them by no less than 80,000 times the Earth-Sun distance, and it would take at least a million years to complete one journey around them. The D pair is also known as **ROE 75**, named for Syracuse University professor Edward Drake Roe Jr., who discovered it with his 6½-inch Alvan Clark refractor on May 20, 1911.

Variable stars also have a large following among amateur astronomers, and you'll find the noteworthy Mira-type variable **R Serpentis** 1.1° east-southeast of Beta. Mira variables are named for the prototype of their class, Omicron (ο) Ceti, which lies in the constellation Cetus. They are unstable red giant stars whose outer layers undergo slow, semiregular expansion and contraction.

R Serpentis has a magnitude range of about 5.2 to 14.4 and a period of approximately 356 days. This is a good time to start watching the star. Its rise to maximum is more rapid than its fall, and it's been on its way up since March. Based on performance over the last few years, the star should attain 8th magnitude sometime in June, and it will still grace our evening sky when it reaches a maximum of 6th or 7th magnitude in late July. As you follow R Serpentis, watch its color, which is deeper red when the star appears faint than when it's bright.

The variable star designation for R Serpentis is R Ser. You can use that name when visiting the AAVSO (American Association of Variable Star Observers) website **www.aavso.org** to learn more about the star. You can also create a variety of star charts for R Serpentis. The charts label nearby stars with their magnitudes so that you can track the rise to maximum over the next few months.





BETA SERPENTIS. Beta Serpentis D, also known as ROE 75, is a distant 27.4′ west-southwest of Beta Serpentis A, the glare of which hides Beta Serpentis B in this image.

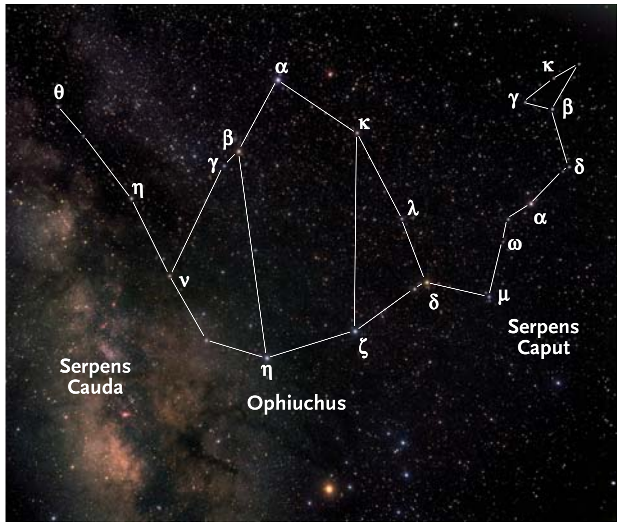
The Serpent's Stars

Object	Type	Mag(v)	Size/Sep	RA	Dec.
β Ser	Multiple star	3.7, 10.0, 11.0, 8.2	31″, 3.3′, 27.4′	$15^{h}\,46.2^{m}$	+15° 25′
ROE 75	Multiple star	8.2, 10.7	6.1″	$15^{h}\,44.4^{m}$	+15° 18′
R Ser	Variable star	5.2 – 14.4	—	$15^{h}\,50.7^{m}$	+15° 08′
Σ1988	Multiple star	7.6, 7.8	1.9″	$15^{h}\,56.8^{m}$	+12° 29′
OΣ 300	Multiple star	6.3, 10.1	15.3″	$15^{h}\,40.2^{m}$	+12° 03′
ω Ser	Exoplanet host	5.2	—	$15^{h}\,50.3^{m}$	+2° 12′

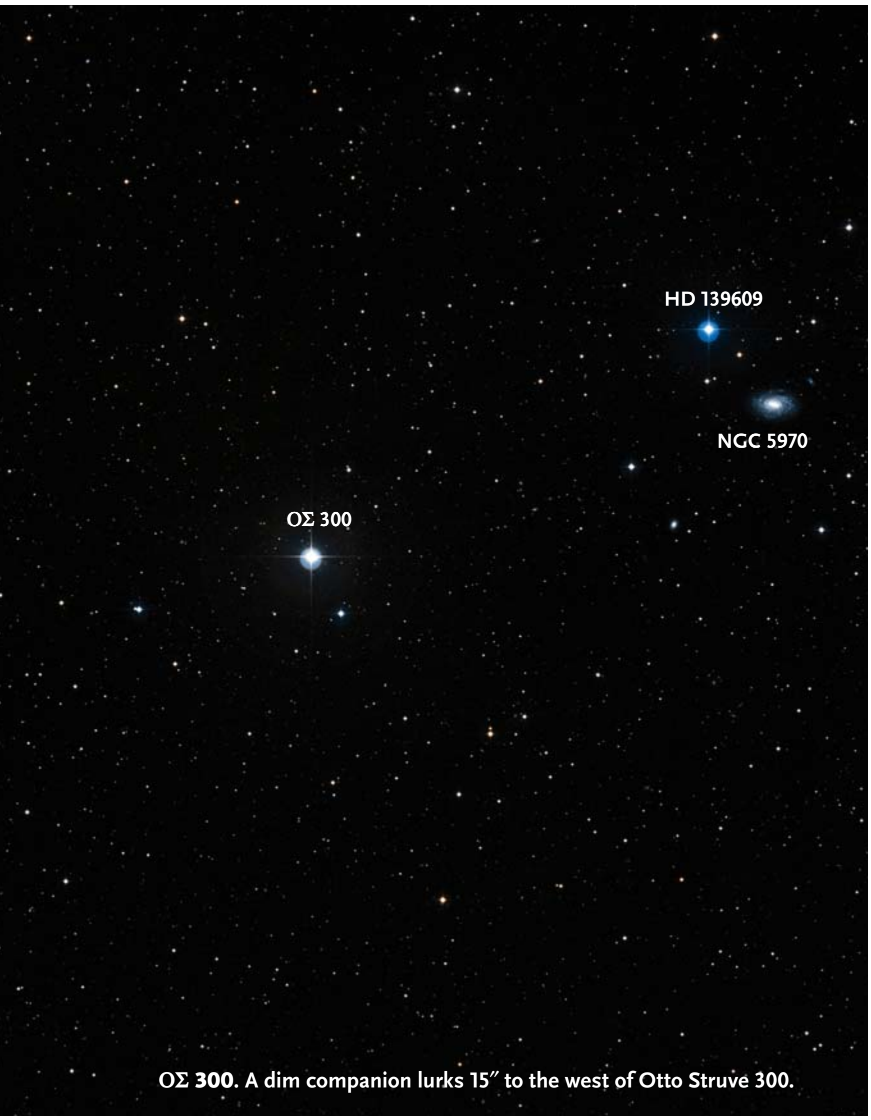
Angular sizes and separations are from recent catalogs. Visually, an object's size is often smaller than the cataloged value and varies according to the aperture and magnification of the viewing instrument. Right ascension and declination are for equinox 2000.0.

If we slide 1.1° southeast from 39 Serpentis, we come to a double star that's even tighter than the ROE 75 pair. The components of **Struve 1988** (Σ1988 or STF 1988) are only 1.9″ apart, but the fact that their magnitudes are nearly matched and not overly bright makes them fair game for small telescopes. They are barely separated through my 130-mm scope at 91× and offer a prettier picture at 102×. The primary looks pale yellow-white, while its slightly dimmer companion to the west-southwest appears yellow-white.

Struve 1988 is named for its discoverer, the distinguished German-Russian astronomer Friedrich Georg Wilhelm Struve, who was the founding director of Pulkovo Observatory near St. Petersburg, Russia. Sweeping 53′ south-southwest from Chi (χ) Serpentis will take us to a striking double star discovered by his son, Otto Wilhelm Struve, who succeeded his father as director of the observatory in 1862.



AKIRA FUJII



OΣ 300. A dim companion lurks 15″ to the west of Otto Struve 300.

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Otto Struve 300 (OΣ 300 or STT 300) is nicely split in the 130-mm refractor at 37× and presents a pleasantly contrasting pair. The deep-golden primary watches over a much dimmer companion 15″ to its west. I couldn't discern the companion's color, so I tried it with my 10-inch scope. The tint was still difficult to judge, but I decided to put my money on yellow-white. How about you?

Now let's plunge southward to **Omega (ω) Serpentis**, which at magnitude 5.2 is visible to the unaided eye in a moderately dark sky. Through my 130-mm scope, it simply shows a nice, deep yellow color, but it's what you can't see that makes this star special. Omega is known to harbor a planet, a giant at least 1.7 times as massive as Jupiter. Called Omega Serpentis b, this exoplanet rounds its sun once every 277 Earth days in a nearly circular orbit that's just a little larger than Earth's orbit. The star is a G8III yellow giant roughly 12 times as big across as our Sun and located about 260 light-years away from us.

Bun'ei Sato (Tokyo Institute of Technology) and colleagues detected this exoplanet using precise radial velocity measurements taken at the Okayama Astrophysical Observatory on top of Mt. Chikurin-Ji. In 2013 they reported their results in the *Publications of the Astronomical Society of Japan*. Since Omega Serpentis orbits the system's center of gravity, the resulting changes in the star's radial velocity (the speed of an object along the observer's line of sight) can tell us a lot about what's causing them. So when you direct your gaze toward Omega Serpentis, know that you're looking at a giant star accompanied by a giant planet.

Now that you've been introduced to these stars of white, topaz, and misty red, I hope you'll agree that a heaven full of stars has much to offer. ✦

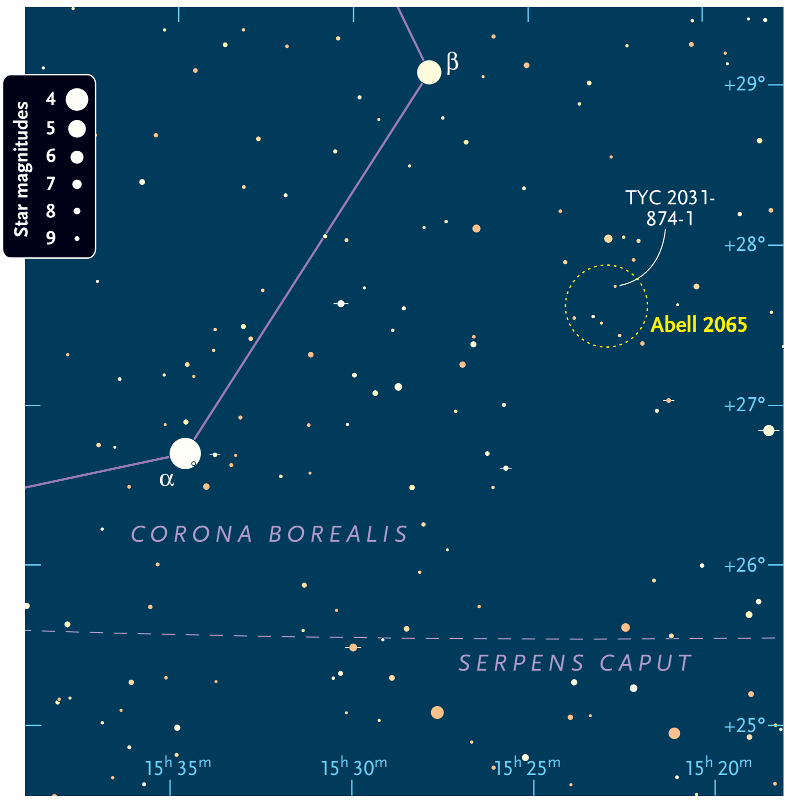
Abell Galaxy Cluster 2065

Follow this observer's guide to the Corona Borealis galaxy cluster.

Howard Banich

Nothing imparts the immensity of the universe quite as well as seeing a galaxy cluster in the eyepiece of your telescope, and at 1.1 billion light-years distant the exceedingly faint collection of galaxies that make up **Abell Galaxy Cluster 2065** do indeed look far, far away. As you might imagine, light that's traveled for over a billion years, from galaxies that appear as tiny, barely perceptible smudges, is a difficult yet remarkable sight to see.

AGC 2065 is a tough nut. Scopes that can barely see this faint need optimum observing conditions to have any chance to reveal the brightest member galaxies. Large scopes, however, will show multitudes of galaxies, most of which take averted vision to see, so the cluster has to be tackled in sections — and you still need great skies. This is a challenging object no matter how you slice it, and it takes a good deal of effort and time to come away with a satisfying observation.



Observations

My observations of 2065 were made over nine observing sessions in 2013 and 2014, totaling about ten hours. Due to poor spring weather, all my observations were made from June to August when 2065 was already in the western sky. I did get a couple of nights when my SQM (Sky Quality Meter) gave readings around 21.85, so I can't complain. Nonetheless, I'm eager to see 2065 on the meridian during an equally dark spring night.

I now think of the cluster in three sections — the core, and the areas to its north and south. Although the entire cluster fits into a low-power eyepiece field of view, you'll need to use high powers to see the individual galaxies well; this encourages observing the cluster in sections.

On an excellent night, the view at low power (130×) in my 28-inch f/4 Newtonian was still quite wonderful, though. The field of view was the very definition of "lumpy darkness" because none of the galaxies stood out by themselves, but together lent a subtle yet unmistakably irregular texture to the sky.

Magnifications from 408× to 605× showed individual galaxies well, with 476× generally giving the best views. I almost always use a Paracorr II, but removing it helped me see slightly deeper. I also used the Bob Franke photo shown here to find my way through the cluster — instead of a chart — because it showed exactly where

ALL IMAGES BY BOB FRANKE

to focus my averted vision. It also gave me an idea how small and dim each galaxy might appear.

When I started sketching 2065, my drawing took up a small corner in my observing notebook since I didn't think I'd see all that much. Over several nights it became clear that I needed to start over at a much larger image scale just so I could include all the galaxies I was seeing. The sketch also became a means of tracking my progress through the cluster as I found my way through it, galaxy by galaxy. It gradually became my personalized atlas of the region.

I should note that my sketch portrays the appearance of 2065 as I saw it with averted vision. It would take a much larger telescope than one with 28 inches of aperture to get a direct vision view that matches my sketch.

I've broken my observations into three sections — Central, Southern, and Northern — to present the cluster in manageable chunks, and to help you follow my observing process. Bob Franke's photograph, marked with rectangles, corresponds to these three sections of the galaxy cluster.

Three of the brightest foreground stars in the field of view were my starting points. Although they have relatively faint magnitudes, ranging from 10.7 to 13.3, they're the brightest objects in the central part of the cluster, and they line up right along its northwest edge.

Central AGC 2065

It's the central part of 2065 that produces the "lumpy darkness" effect at low power because it has the densest clump with the brightest galaxies. The most distinctive bunch forms a tight triangle. This was the first group that caught my attention, and because of that, I think of **PGC 54880** (magnitude 17.3), **MCG +05-36-022** (magnitude 15.7), and **PGC 54883** (magnitude 15.4) as the heart of 2065. Nearby **PGC 54876** is equal in magnitude to PGC 54883, making it one of the four brightest galaxies in the cluster.

PGC 54883 and MCG +05-36-022 are also designated as the galaxy pair [WLH2009] 947.

Every other galaxy in 2065 is fainter than magnitude 15.7. An experienced observer under dark skies with a good 8-inch scope might be able to see PGC 54883 or PGC 54876, the two brightest galaxies. MCG +05-36-022 and PGC 54891, which are just a few tenths fainter, might be possible as well. Given that the prize is billion-year-old photons, they're worth a try.

It bears repeating that unless you have a really big telescope all, or almost all, of the individual galaxies are visible only with averted vision. Each galaxy is not only faint, but also appears quite small — the cluster is a billion light-years away after all — and needs high magnification to be seen well.

Aside from being one of 2065's brightest galaxies, PGC 54876 is historically significant. In 1935 Milton Humason, an observer at Mount Wilson Observatory, measured its redshift as part of a study of galaxy clusters that helped extend the famous velocity/distance property of the universe, an important step toward our current understanding of its expansion.

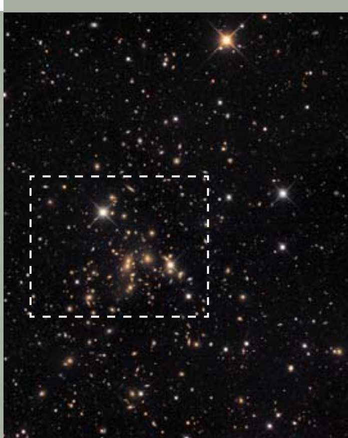
The faintest galaxy I've seen so far in the central group is **MAC 1522+2741G** at magnitude 17.5. On a night that would allow seeing a half magnitude deeper, the central part of the cluster should reveal another dozen galaxies.

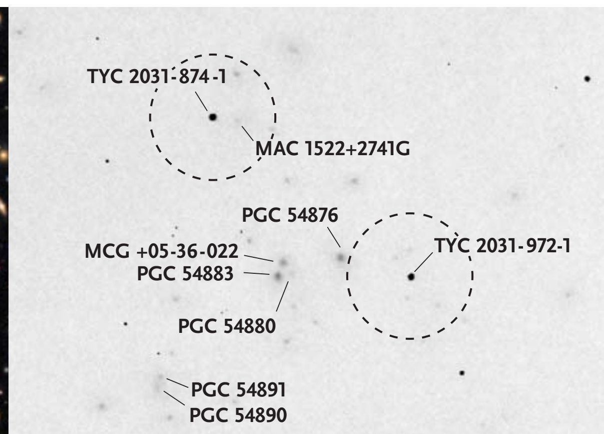
The Southern Section

As I moved away from the central group, it became surprisingly easy to lose my place in the cluster. It took several observing sessions to get comfortable knowing where I was; finding fainter foreground stars to use as reference points made this easier. The galaxies are

Central

Breaking the wide field into sections can help organize your Abell 2065 observations, most of which will be completed with a large-aperture telescope and averted vision.





Author's sketch of the central region. Hiding in the glare of the brightest foreground stars, the most difficult galaxies to see are within the two circles.

spread farther apart in the southern section but are still in good supply, and my eye wanted to organize them into curving chains and geometric shapes. Photographs show the galaxies gradually fanning away toward the south, and this was also the impression I got in the eyepiece.

One of the more difficult observations was of two galaxies nearly in contact, **PGC 54890** (magnitude 16.7) and **PGC 54891** (magnitude 15.7). I never actually saw them as truly separate galaxies, but rather as an extended blur. I had an even tougher time with **PGC 54894** (magnitude 16.4) and its companion, **SDSS J152245.11+273650.7** (magnitude 17.3). They appeared merely as a combined circular blur.

The Northern Section

There are a considerable number of galaxies to the north of the rich central area of the cluster. I found them easy to identify because they're more spread out, and several fairly prominent foreground stars helped pinpoint their location. Although this part of 2065 thins out faster than the southern section, it can be just as challenging.

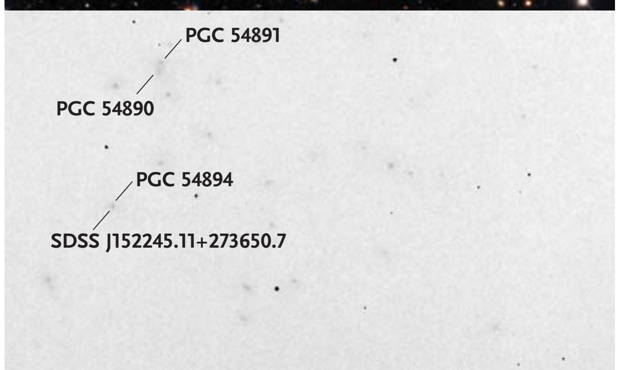
The brightest galaxy in this part of the cluster is **PGC 54868** (magnitude 16.0). All the other galaxies I saw in here were between magnitude 16 and 17. Interestingly, the faintest object I found in this area was **SDSS J152215.40+274657.0**, which although it looked a little fuzzy in the eyepiece is more likely a magnitude-17.8 star than a galaxy.

The Toughest Part

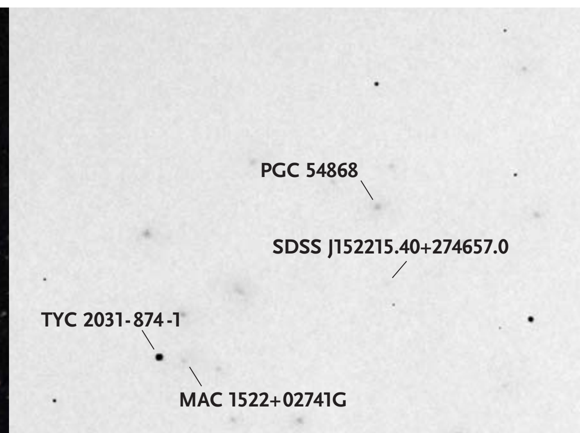
A handful of galaxies huddle around the two brightest foreground stars that mark the northwestern boundary of the central area of the cluster. Their location reduces the effectiveness of averted vision because this technique makes stars look brighter, too. On the most transparent nights, however, I could see many of these galaxies.

Southern

Author's sketch of the southern region of Abell 2065. It's easy to lose your way in this part of the cluster, so use the faint foreground stars as reference points to find your way in this deep field of faint fuzzies.



Northern



Author's sketch of northern region of Abell 2065. The bright foreground stars will allow you to star-hop more spryly in this part of the galaxy cluster.

Abell 2065 in Corona Borealis

Object	Type	Magnitude	Size/Sep.	RA	Dec.
PGC 54880	Galaxy	17.3	0.2′	15^h 22.5^m	+27° 43′
MCG +05-36-022	Galaxy	15.7	0.4′	15^h 22.5^m	+27° 43′
PGC 54883	Galaxy	15.4	0.4′	15^h 22.5^m	+27° 42′
PGC 54876	Galaxy	15.4	0.4′	15^h 22.4^m	+27° 43′
MAC 1522+2741G	Galaxy	17.5	0.2′	15^h 22.6^m	+27° 41′
PGC 54890	Galaxy	16.7	0.3′ × 0.1′	15^h 22.7^m	+27° 40′
PGC 54891	Galaxy	15.7	0.3′ × 0.2′	15^h 22.6^m	+27° 41′
PGC 54894	Galaxy	16.4	0.2′	15^h 22.7^m	+27° 37′
SDSS J152245.11+273650.7	Galaxy	17.3	—	15^h 22.7^m	+27° 37′
PGC 54868	Galaxy	16.0	0.3′	15^h 22.3^m	+27° 48′
SDSS J152215.40+274657.0	Star?	17.8	—	15^h 22.3^m	+27° 47′
MAC 1522+2745B	Galaxy	17.6	0.2′	15^h 22.6^m	+27° 45′
TYC 2031-874-1	Star	10.7	—	15^h 22.6^m	+27° 46′
TYC 2031-972-1	Star	11.6	—	15^h 22.3^m	+27° 43′

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.

Placing each star just outside the field of view made these observations possible. This was easier to do with a narrow field of view eyepiece.

Showing how effective this technique can be, the faintest galaxy I've seen so far in the entire cluster is **MAC 1522+2745B** (magnitude 17.6) which is right next to the brightest foreground star, **TYC 2031-874-1** (magnitude 10.7). The galaxies appearing closest to the star **TYC 2031-972-1** (magnitude 11.6) present similar difficulties. However you approach them, be prepared for an observing challenge.

Where's the Edge?

A deep, wide-field image centered on 2065 shows galaxies well beyond the obvious central concentration. So where's the edge of the cluster? There's no definitive answer, partly because 2065 is part of the Corona Borealis Super Cluster, a group of eight Abell galaxy clusters that are gravitationally bound and apparently in the process of condensing into a single super-duper galaxy cluster. In addition, there are non-related galaxy clusters near 2065 on the plane of the sky, making this a crowded area for faint galaxies. For the purposes of my observations I considered 2065 as being roughly 30 arcminutes in diameter — the apparent size of the Moon — because the cluster seems approximately this big visually.

Thoughts

Although the implication is there, published observations of 2065 usually don't mention the galaxy cluster's beauty and wonder. It takes intellect, imagination, and skill — common traits among visual observers — to see the beauty of something that's barely perceptible to the eye. The resulting wonder that can be mined from such an observation is an important aspect of astronomy and our humanity.

Without the research done by generations of dedicated astronomers, 2065 would only be a meaningless collection of small, faint smudges. Thanks to their work, we know that each of these smudges is a tremendous galaxy, that each galaxy is over a billion light-years away, all are gravitationally bound to each other, and 2065 will eventually form a single galaxy supercluster with seven other clusters. Wow.

One of the exquisite pleasures of visual astronomy is the contemplation of this knowledge while observing just one of AGC 2065's faint galaxies with your own telescope. Creating a personal connection with this stupendously distant part of the universe is just that easy, and just that difficult. ✦

Howard Banich *will be observing brighter objects for a while now, and invites e-mail at howard.banich@nike.com.*

 Alan Dyer

Celestron's Superfast Astrograph

Celestron's update of the Schmidt astrograph delivers super-sharp images across an expansive field. Is there a catch?

DEEP-SKY PHOTOGRAPHERS are a demanding lot. We'd like sharp optics with enough focal length to provide good detail in our deep-sky targets. But we also want wide fields for impressive images filled with nebulosity and stars. Oh, and we also want fast focal ratios, to keep exposure times short. And can we please have no star-distorting aberrations at the corners of the frame?

Celestron's new Rowe-Ackermann Schmidt Astrograph is designed to deliver on all those potentially conflicting counts. Think of it as a massive 620-mm-focal length "lens" with an astonishingly fast f/ratio of just f/2.2.

The Rowe-Ackermann Schmidt Astrograph

US price: $3,499.95.
Available from celestron.com and through dealers worldwide.

WHAT WE LIKE:
Pinpoint edge-to-edge star images
Fine focusing control
WHAT WE DON'T LIKE:
Significant vignetting with DSLRs
Required T-rings not supplied

Celestron's Rowe-Ackermann Schmidt Astrograph is a reconfiguration of its 11-inch telescope into a design dedicated to imaging at its f/2.2 prime focus. Unless otherwise noted, all photos are courtesy of the author.

With a full-frame DSLR camera it delivers a field of view of 3.3° × 2.2° but with a high-resolution image scale of 2.1 arcseconds per pixel, at least with the Canon EOS 5D Mark II camera I used for most of my testing. Using an image scale in that league, detail in deep-sky objects is likely to be limited by the seeing conditions at your site and not by the camera or optics. And yet the field of view is wide enough to encompass most large deep-sky objects, delivering the best of both worlds: high resolution and wide field.

The standout feature of Celestron's astrograph that attracts the most attention is its sheer speed. At f/2.2 it's possible to shoot deep images in just 3 to 5 minutes, great for assuring smooth, noise-free images. There is a price to pay, of course. Indeed, several. There's the actual cost. At $3,500 the Rowe-Ackermann is a serious financial commitment to deep-sky imaging. It is a dedicated photo instrument; it cannot be used visually.

The Rowe-Ackermann is also quite heavy. It's an 11-inch (28-cm) telescope, with a tube assembly 30.5 inches long that weighs 43 pounds (19.5 kg). That's a big tube assembly to heft onto a mount. Additionally its mount must be at least a middleweight model such as Celestron's CGEM DX or, better yet, their heavier CGE Pro. Along with sufficient counterweights to balance it all, you're looking at a total system weighing at least 150 pounds (68 kg). Consider that carefully if you don't have an observatory or other permanent setup.

A Different Kind of Astrograph

The Rowe-Ackermann Schmidt Astrograph is a modern reworking of the classic 5.5- and 8-inch Schmidt cameras Celestron produced in the 1970s and '80s. The original cameras' f/1.65 to f/1.5 focal ratios made them extremely attractive though difficult to use. You had to load individual chips of 35mm film inserted into custom film holders, all completely in the dark. Such was life in the dark ages of film.

The new Rowe-Ackermann does away with all that barbaric inconvenience. Optical designer David Rowe, who also helped develop astrographs for PlaneWave Instruments, created the initial design. Celestron then worked with optical designer Mark Ackermann to refine the final configuration.

In addition to its f/2.2 spherical primary mirror, the design incorporates a Schmidt corrector plate that eliminates image-blurring spherical aberration. At the prime focus is an additional four-element lens that corrects field curvature, critical for sharp images across the entire imaging plane.

The design certainly delivers as promised. When using the Canon DSLR with a 24 × 36-mm detector, stars were sharply focused pinpoints from the center out to the extreme corners of the frame. Indeed, I was impressed with just how tiny the star images were with

Key to the Rowe-Ackermann's optical performance is the four-element field-flattener lens mounted on the front corrector plate. Its cell is threaded for use with either of the two included camera adapter plates.

Each conical camera adapter plate threads onto the corrector lens cell and is itself threaded with either a 42-mm T-thread or a wider M48 thread for special wide T-rings. Screws for adjusting collimation are accessible through the slots, though some cameras may inhibit their accessibility.

Users will need to purchase the proper T-ring for their particular brand of DSLR camera. Full-frame cameras (those with a 24 × 36-mm detector) should be used with a wide M48 T-ring recommended to reduce vignetting as much as possible.

The body of most DSLR cameras inevitably juts into the light path, causing diffraction spikes on bright stars. Rotating the camera requires careful finger work to get at the lock ring on the adapter plate to loosen then retighten it.

The back cell includes the dual-speed Feather Touch focuser, fan vents for cooling the tube (and battery pack input), and two knobs for locking down the mirror once it is focused.

the Schmidt Astrograph, a function of its large 11-inch aperture yet relatively short focal length.

As such, precise focus is critical. The Astrograph comes with a custom Starlight Instruments 10:1 Feather Touch focuser that moves the primary mirror. The mechanism produced image shift of only a few arc-seconds as I racked the focus in and out. The focusing movement is extremely fine, important for such a fast instrument with a shallow depth of field.

The Astrograph comes with a small battery pack for eight AA batteries that plugs into a jack on the back of the instrument. This powers an internal fan that draws in outside air through filtered vents. This helps the tube cool down to ambient air temperature.

The tube is fitted with dovetail plates on both top and bottom using the Losmandy D-System standard.

An unprocessed raw image recorded with a Canon EOS 5D Mark II full-frame DSLR displays the level of vignetting introduced mostly by shadowing from the camera adapters and DSLR's mirror box. Note that the image is also flipped mirror-image.

These make it easy to attach the tube to most heavy-duty mounts, as well as a guidescope to the top of the tube using accessories from Celestron or third-party suppliers. The top of the tube also has two pairs of screw holes for attaching a bracket for a finderscope.

Also included with the Rowe-Ackermann are two camera adapter plates: one threaded to accept standard 42-mm T-rings, and the other with a wider 48-mm thread for special wide-aperture T-rings. The T-rings (not supplied) connect your brand of DSLR camera to the Celestron adapter plates.

A smaller 42-mm T-ring (the most common type everyone sells, including Celestron) will work fine with APS-format DSLRs with sensors 23 × 15 mm across. But to minimize vignetting with full-frame DSLRs, it's best to use a 48-mm T-ring. It is an essential piece of the system that can be hard to find. One was not included with the Astrograph, nor does Celestron offer one as an accessory. I ordered mine from Sky-Watcher USA. They offer "M48" T-rings for Canon, Nikon, and Sony cameras.

Options for shooting through a filter using a DSLR are limited. Doing so requires removing the flat optical window in front of the field flattener and replacing it with Celestron's 72-mm light pollution rejection filter ($499) made for the Rowe-Ackermann.

The included adapter plates are designed to connect a DSLR camera. Imagers with CCD cameras will need to devise extension rings to place the sensor 55 mm from the adapter plate flange, matching the distance to a DSLR sensor that the field flattener lens is optimized for.

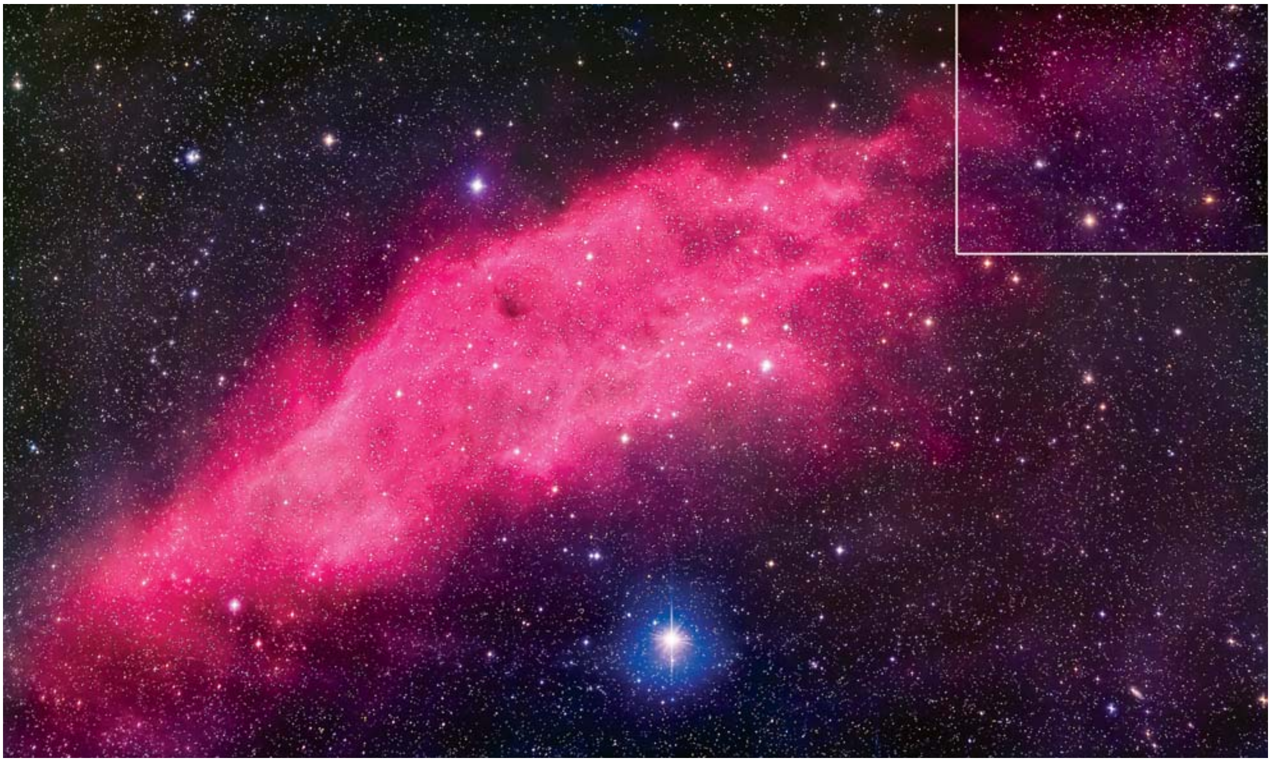
Shooting at Prime Focus

Whatever camera you choose, it sits at the prime focus, at the front of the instrument. This introduces a few caveats. For one, most DSLR camera bodies extend beyond the 4.5-inch-wide corrector lens and cell, intruding into the light path. This introduces asymmetric diffraction spikes around brighter stars.

Any CCD camera used with the Astrograph should ideally be lightweight and symmetrical, and no wider than 4.5 inches (11 cm). One-shot color cameras like Celestron's own Nightscape units would work well. Monochrome cameras with a filter wheel jutting out of the side of the camera will intrude into the light path.

Second, the presence of the camera extending several inches from the front of the instrument makes it impossible to use any manual focusing aids. In addition, the glowing LCD panel and lights on the back of a DSLR will illuminate any screen or white panel used to take flat-field frames, ruining these important calibration frames. Any lights on your camera need to be turned off or covered when imaging.

Another issue is that because the camera is looking at an image that has undergone just one reflection (off the primary mirror) all photos will be mirror-reversed.



A processed image of the California Nebula taken with the Canon 5D shows the generous 3.3° × 2.2° field. Bright stars, like Xi Persei at bottom, exhibit some diffraction spikes. This is a stack of five 5-minute exposures at ISO 400.

Zooming in on the extreme corner of a single raw frame used in the previous image reveals tiny star images right to the edges of the frame. The Rowe-Ackermann Schmidt Astrograph design succeeds in providing an extremely sharp starfield across a 36-mm-wide sensor.

While this is easy to fix later in processing, the flipped images can be disorienting when you're trying to frame faint or extended targets. Rotating the camera to frame a field requires swinging the tube down to access the camera. Loosening the large lock ring allows you to rotate the entire camera and adapter plate assembly. Like most finely threaded lock rings, It could occasionally bind up, i found, risking turning the entire lens assembly on the corrector plate. Making the adjustment is also unnerving as your fingers are millimeters away from the corrector plate. It was easiest to set the camera at a certain angle for the night and be done with it. That would certainly have to be the case for any remote imaging operation.

However, the main caveat to keep in mind is that the camera's position at the top of the tube necessitates operating the camera from a laptop running control software. You won't be able to look though a DSLR camera's optical viewfinder. Even if you could reach the camera, your head would get in the way!

As with any Schmidt telescope with its exposed corrector plate, the astrograph is prone to dewing. Plan to buy or build a dewcap.

Imaging Results

The Rowe-Ackermann's fast focal ratio makes it tempting to shoot loads of short exposures at high ISOs and not even bother with autoguiding. I did that on one test night, shooting a couple of dozen 60-second exposures at ISO 1600 with the mount just freewheeling. It worked fine. Stacking the results produced a smooth, relatively noise-free image.

I prefer to shoot deep-sky images at as low an ISO setting as is practical to minimize noise. Fortunately, even using ISO 400 required sub-frame exposures of no more than about five minutes for most targets. Stacking these produces a final image with little perceptible noise.

For exposures longer than a minute, most mounts will require autoguiding. Considering the investment in effort it takes to set up 150 pounds of mount, counterweights, and optical tube to get the Rowe-Ackermann going, attaching a small autoguider (it need only be a small CCD camera looking through a 50-mm finderscope) is not much more to ask. The computer needed to run most autoguiders has to be there anyway to run your main camera.

The Rowe-Ackermann's fast f/ratio has the advantage of keeping exposures short. The disadvantage is that, with DSLR cameras, the steep light cone creates a great deal of vignetting, especially on full-frame DSLRs. The edges of a DSLR sensor are partially blocked by the camera's mirror box, producing dark bands at the edges of the frame. This horizontal darkening combines with the circular vignetting introduced by the camera adapter (even with a wider M48 T-ring), as well as from the native vignetting originating in the optical design itself.

Celestron's instruction sheet claims a light fall-off to 78% 21 mm away from the center. That might be the case for the optical system itself, but in my real-world tests with an actual full-frame DSLR (the Canon EOS 5D Mark II) coupled with the M48 adapter, I measured a drop in brightness at the corners of the frame of about 1.8 f/stops on raw images. This is far more than I see with DSLRs used on slower optical systems, where the shadowing is confined just to the very edges of the field.

Users will need to shoot flat-field frames to compensate for the corner and edge darkening. Even then, I found that the difference in brightness from center to corners meant that images that were properly exposed at the center would be nearly 2 stops underexposed at the corners, potentially revealing noise again as flat-fielding and processing brings up the brightness of the corners.

CCD cameras with sensors mounted closer to the front of the camera body will fare much better, suffering far less vignetting (see image below), as will DSLR cameras with APS-format, cropped-frame sensors. It's a shame, though, to use the Schmidt Astrograph with anything less than a full-frame sensor, to make maximum use of its wide, flat field.

The upside is that the Rowe-Ackermann Astrograph produces amazingly sharp images over a wide field, in exposures that can be conveniently short. The downside is that creating great-looking images with DSLR cameras will take more work in processing than with slower instruments, to ensure the final image appears uniformly illuminated. ✦

Contributing Editor ***Alan Dyer*** *is author of the e-book* How to Photograph & Process Nightscapes and Time-Lapses, *available at* **www.amazingsky.com/nightscapesbook.html**.

The Rowe-Ackermann performs best with one-shot color CCD cameras, particularly those that utilize a compact, symmetrical body. Astrophotographer Jimmy Walker took this deep image of the Horsehead Nebula and Zeta Orionis with the Astrograph coupled with a Finger Lakes Instrumentation MicroLine ML-11003 CCD camera.

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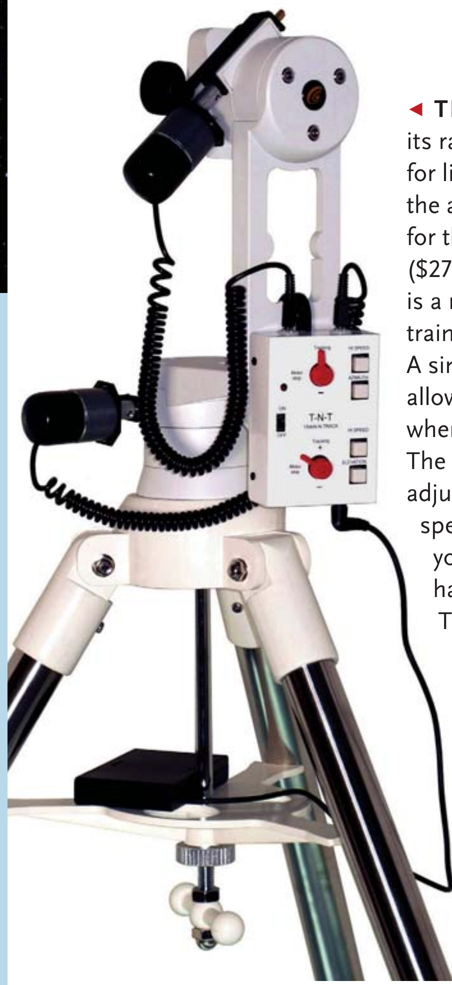

◂ **TNT DRIVES** JMI Telescopes expands its range of alt-azimuth tracking drives for lightweight telescope mounts with the addition of the Train-N-Track system for the Explore Scientific Twilight I mount ($279). The Train-N-Track (TNT) system is a motor drive system with adjustable or trainable tracking for alt-azimuth mounts. A simple 30-second training procedure allows the mount to track targets anywhere in the sky for 10 minutes or more. The TNT motor drive system includes adjustable speeds on both axes and high-speed centering. Its friction drives allow you to move the telescope around by hand without unlocking any clutches. The TNT system includes two easily assembled friction drive motors, the hand control box, and all hardware and cables, and it is powered by 8 AA batteries. TNT Motor Drives are also available for the Astro-Tech Voyager and Vixen Porta mounts.

JMI Telescopes
8550 West 14th Ave., Lakewood, CO 80215
800-247-0304; jmitelescopes.com

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Art from Science

Expanding Universe: Photographs from the Hubble Space Telescope

Edited by Nina Weiner, with contributions from Owen Edwards, Zoltan Levay, Charles F. Bolden, Jr., and John Mace Grunsfeld
TASCHEN, 2015
260 pages, ISBN 978-3836549226, $69.99, hardcover.

The word "by-product" usually doesn't have positive connotations. The disposal of manufacturing by-products can be expensive and dangerous, and when was the last time you gleefully dug into a meat by-product for supper? But as demonstrated by *Expanding Universe: Photographs from the Hubble Space Telescope*, it might be time to reconsider our relationship with secondary effects, at least those produced during the practice of astronomy.

As Govert Schilling notes (p. 20 this issue), the Hubble Space Telescope (HST) introduced many changes to the disciplines of cosmology and astronomy. But it also altered our view of the universe. We've seen great things — comet crashes, star births, galaxy collisions — and thanks to the Hubble imaging team at the Space Telescope Science Institute (STScI), we've seen them in luxurious, glorious color. Scientists don't use these public images directly, relying instead on spectral analyses and greyscale data. The magnificent and sometimes haunting images are a by-product of science, released to enlighten and educate, inform and inspire.

That *Expanding Universe* takes its cue from the art rather than science of the HST is clear from first glance. Not only are the images on and between the covers processed beautifully, but obvious care was taken with the book's design. The slick "high tech" aesthetic so prevalent in space science publications has been replaced with the look and feel of a classic folio. The use of the serif typeface Trajan for the essays only strengthens this impression. The main photo section is printed on a photo paper stock; glossy images of galaxies and nebulae are surrounded by black matte borders that protect the art from fingerprints and mimic the appearance of an album page. And at 11.8" × 11.8" and 260 pages, the book has a satisfying heft.

While this is an art book, science fans will also find something interesting here, particularly in Owen Edwards's interview with Zoltan Levay, STScI Imaging Lead. If you've wondered about the process of transforming raw data (3 to 5 gigabytes a day) into the striking photos we've come to expect, you'll enjoy reading this section. The book ends with a set of appendices that includes a distance ladder, glossary of terms, description of the HST's instruments, and biographical sketches of contributors to the volume.

The release of *Expanding Universe* was timed to coincide with the 25th anniversary of the HST's launch. As far as birthday presents go, you really couldn't ask for one more appealing or more appropriate. ✦

*S&T Observing Editor **S. N. Johnson-Roehr** loves reading even more than she loves astronomy.*

NASA / ESA / HUBBLE HERITAGE (STSCI / AURA) - ESA / HUBBLE COLLABORATION / H. BOND (STSCI / PSU)

Left: Cepheid variable star RS Puppis shines through a cloak of gas and dust. Right: Astronauts replaced all six gyroscopes in the HST in 1999.

Secondary Scheming

The optimum diagonal size depends on facts and preferences.

LIKE COLLIMATION, the correct size of a Newtonian reflector's secondary mirror generates a lot of discussion in online forums. Much of the resulting confusion arises from the fact that for a given telescope there's no single right answer. So, if you're trying to sort out what size is ideal for your scope, the best way to proceed is to separate fact from opinion and consider each independently.

Let's begin with the facts. First, there is a certain minimum size your scope's secondary mirror has to be. If it's undersized, you may find your 8-inch scope working like a 7-inch or smaller. Second, if the secondary is too big, it obstructs incoming light needlessly. That's undesirable because the image will be very slightly dimmer, and diffraction effects potentially reduce fine, low-contrast detail. And a bigger mirror will also cost more. Third, the larger the secondary mirror, the larger the region of the focal plane that receives light from the primary mirror's entire surface (the area referred to as the *fully illuminated field*). Fourth, diagonal mirrors come in a limited number of sizes, which means you may not be able to get one that precisely matches the size you desire.

GARY SERONIK

This small mirror causes big debates. But once you know some basic facts, it's easy to choose the optimum diagonal size for your scope and observing needs.

The first issue to settle is the minimum size your telescope requires. The smallest diagonal you should consider using is just big enough to deliver 100% of the light gathered by your scope's primary mirror to the center of the focal plane. You can calculate this by dividing L by f, where f is the focal ratio of the primary mirror, and L is the distance (length) from the center of the telescope tube to the focal plane. In the case of an 8-inch f/6 mirror, L is often about 9 inches. Dividing 9 by 6 yields a diagonal size of 1.5 inches. Now you have to decide if the minimum secondary is the right choice, or if a bigger one might be better. This is where we enter the realm of opinion.

In the good ol' days when most reflectors were f/8 or f/6, a popular rule of thumb stated that you should choose your diagonal to fully illuminate the center ½-inch of the focal plane. So if the minimum secondary size for your scope is 1.5 inches, you can satisfy that condition with a 2-inch diagonal mirror (1½ + ½). That approach still works, but for many of today's mirrors, which are often f/5 and faster, it will usually result in a secondary mirror that's bigger than necessary.

In my opinion, rather than worrying about the size of the fully illumined field, it makes more sense to choose your diagonal based on the amount of dimming at the edge of the field of a low-power eyepiece. When I make a telescope, I usually let images there lose about ½ magnitude — an amount that's far from obvious, especially as it's confined to the extreme field edge of only my lowest-power eyepiece. For all my other eyepieces, the drop off is much less, and sometimes even zero. How do you calculate the edge-of-field illumination? Easy. You can find several calculators online, but the best one is on Mel Bartels's website (**bbastrodesigns.com/diagonal.htm**).

Let's try an example: an 8-inch f/5 reflector with a 2-inch focuser and an L value of 9. Using the formula discussed earlier, we know that the secondary mirror for this scope should be no smaller than 1.8 inches. If we use the ½-inch rule, we would choose one with a 2.3-inch minor axis. Since secondary mirrors aren't commercially available in that size, you'd use the next size up — a 2.48- or 2.6-inch diagonal, depending on the vendor. However, if we allow the edge of field of a 2-inch, low-power eye-

S&T: CRAIG MICHAEL UTTER

To determine the necessary size of your secondary mirror, you need to know *L*. It is the distance from the center of the tube to the focal plane, where the eyepiece's field stop is positioned when the telescope is focused at infinity.

piece to drop ½ magnitude, we can use a 2.14-inch secondary — a full size smaller. But what if our scope only has a 1¼-inch focuser? Then we'd only need a 1.83-inch secondary — two sizes smaller than the ½-inch rule suggests.

The key point in all this is that for any given telescope, there is more than one correct solution. You may, for example, tolerate more (or less) edge-of-field dimming. Or perhaps you're planning a scope for imaging rather than visual use. In general, it's better to err on the side of choosing too big rather than too small. But once you take into account the facts, you can use your judgment to decide which size best satisfies your needs. ✦

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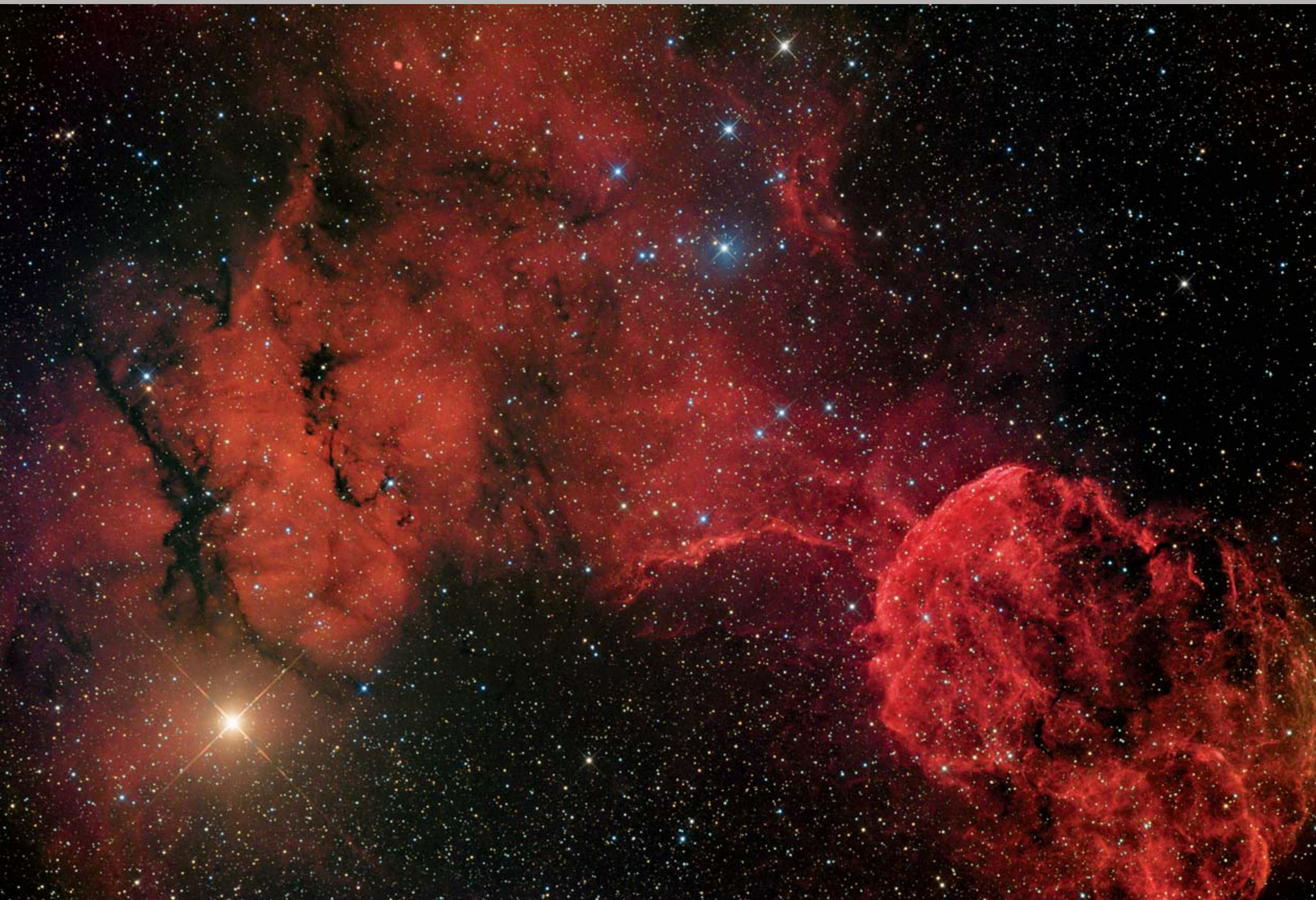
*Contributing editor **Gary Seronik** has additional information about secondary-mirror sizing on his website, garyseronik.com.*

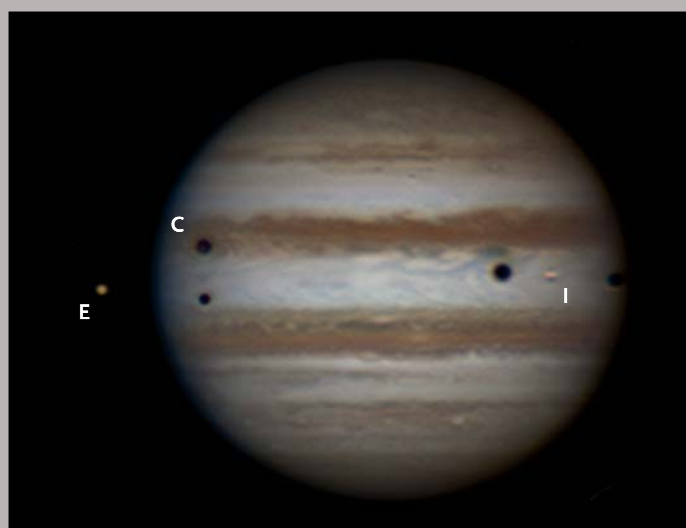
Do you have a telescope or observing accessory that *S&T*'s readers would enjoy knowing about? Get featured in Telescope Workshop by e-mailing Gary Seronik at gary@garyseronik.com.

Gallery showcases the finest astronomical images submitted to us by our readers. Send your best shots to gallery@SkyandTelescope.com. See SkyandTelescope.com/aboutsky/guidelines.



▲ **JELLYFISH ENCOUNTER**
Gregg Ruppel
The 3rd-magnitude star Mu Geminorum — known as Tejat Posterior (Castor's "back foot") — marks the way to the dim emission nebula Sharpless 2-249 and, at far right, the brighter Jellyfish Nebula (Sh2-248, part of supernova remnant IC 443).
Details: *ASA 10N astrograph and SBIG STL-11000M CCD camera with Astrodon GenII filters. Total exposure: 11 hours.*

► **TRIPLE TREAT ON JUPITER**
Efrain Morales
January 23, 2015, offered a rare event: the Galilean satellites Io (I), Europa (E), and Callisto (C) all cast their shadows on Jupiter's disk simultaneously for an all-too-brief 24 minutes.
Details: *Meade LX200ACF 12-inch telescope, Point Grey Research Flea3 CCD camera, and Astronomik filters.*



◀ **DELICATE STRUCTURE**

César Blanco González

Use of the "Hubble palette" — which assigns emission from hydrogen-alpha to green, oxygen ions to blue, and sulfur ions to red — reveals subtle colors and details in the North America Nebula (NGC 7000, at left) and Pelican Nebula (IC 5067/5070) in Cygnus. **Details:** *Takahashi FSQ-106ED astrograph, QHY8 and QSI 583ws CCD cameras, and Astronomik narrowband filters. Total exposure: 20¾ hours.*

▼ **PRETTY PLANET PAIRING**

Patricio Calderari

Bright Venus and dimmer Mercury, separated by just 0.6°, dramatically highlight the richly colored sunset seen on January 10th from Balduana, Switzerland. **Details:** *Nikon D800 DSLR with 70-to-200-mm zoom lens used at 200 mm. Exposure: 2 seconds at ISO 400.*

JUST PASSING THROUGH

James West

Timing was everything when the International Space Station quickly dashed across the lunar disk as seen on February 6th from Chandler's Ford in southern England.

Details: *Celestron EdgeHD 9.25 telescope and Canon EOS 70D DSLR camera. Composite of eight 1/1600-second images taken 0.15 second apart.*

TRIPLE CONJUNCTION AT SUNSET
Jacques Guertin
Venus, fainter Mars, and a 2-day-old crescent Moon provided a dramatic evening view for countless skywatchers in the Americas on February 20, 2015.
Details: *Nikon D800 DSLR camera with 28-to-300-mm zoom lens used at 98 mm and f/5.3. Exposure: 1⁄10 second at ISO 1000.*

▼ FAINT FIND IN DRACO
Thomas Henne
Lynds Bright Nebula 406, better known as the Laughing Skull Nebula, is a faint interstellar cloud that requires dark skies (in this case Austria) and patience to capture.
Details: *ASA 10N astrograph with Canon EOS 6D DSLR camera. Total exposure: 14.3 hours.*

▼▼ CASSIOPEIA'S GLOWING BUBBLE
Álvaro Ibáñez Pérez
The Bubble Nebula, NGC 7635, has been carved out of a larger interstellar cloud by strong radiation and stellar winds from the hot, massive, 9th-magnitude star at its center.
Details: *Teleskop Service 115 Triplet APO refractor and Atik 460EX CCD camera with Baader narrowband hydrogen-alpha and oxygen-III filters. Total exposure: 6.7 hours.* ✦

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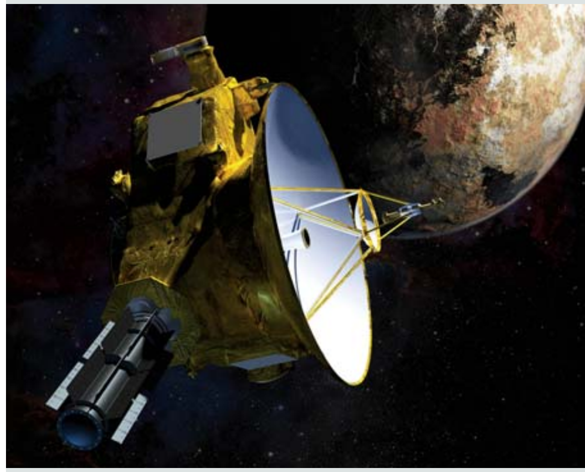

JOHNS HOPKINS UNIVERSITY APPLIED PHYSICS LABORATORY / SOUTHWEST RESEARCH INSTITUTE (JHUAPL/SWRI)

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In mid-July, New Horizons dashes by "dwarf planet" Pluto and its moons — a close encounter 85 years in the making.

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Kindling the Flame

A formative night at the Fels Planetarium

On a rainy Wednesday night in December 1965, when I was 11 years old, my father took me to the Fels Planetarium at the Franklin Institute in Philadelphia. This was a rare treat, as he worked overtime most nights to support our large and growing family. Only a small crowd had braved the weather, but the young lecturer rewarded those of us who had with a fascinating show.

Afterwards he invited everyone to accompany him to the rooftop observatory, cautioning that he could not open the roof because of the rain. Just a few of us accepted his offer; I think I was the only child in the group.

The lecturer described the Institute's 10-inch refractor and 24-inch reflector and answered a few questions. Then, noticing me, he handed me a diffraction grating mounted in a Kodak 35mm cardboard slide mount. He instructed me to hold it up to the light to see a rainbow.

I did, but wanting to impress him with what I had recently learned, I mentioned that it was amazing to think that they could derive the distances of far-off galaxies using a device such as this.

This had the intended effect. The man ran off and returned a few minutes later with a small stack of recent *Sky & Telescope*s. The mailing labels bore his name: Donald D. Davis. We spoke for a few more minutes — he was taking classes at nearby Drexel University, he said, and was building his own 8-inch reflector — and then my father and I left.

At Christmas a few weeks later, Santa gave me a subscription to the magazine. The cover of my first issue, December, had a picture of the great sungrazing comet Ikeya-Seki (C/1965 S1). I've had a subscription ever since, and I've read nearly every issue. Collectively, they have sustained my interest in astronomy through many more cloudy nights.

VICTORIA SEMYKINA

I saw Mr. Davis a few more times at the museum, but the crowds were large and we never spoke again. Later he had a summer astronomy program on the local public television channel. After that I never heard of him again.

In recent years I wondered what had become of him. The internet offered a few clues. A couple of articles mentioned his time at the Franklin Institute, and his year (1963) as president of the Rittenhouse Astronomical Society. In 1966, he became director of Montreal's new planetarium, which he wrote about for *S&T* (Apr. 1966, p. 196). He was mentioned again in the early 1970s in an article on a solar project at the science museum in Winnipeg. After that the trail went cold.

Then, earlier this year, I found an obituary online in a Winnipeg newspaper for a Donald D. Davis. He had died in 2004 at the age of 68. The obituary is short and doesn't mention any family or anything about astronomy. Besides where he lived, the only information is about "a series of cumulative health difficulties." I fear he may have had a hard life.

My daughter is nearly the age I was when I met Mr. Davis. I told her the story and then quoted Henry Adams: "A teacher affects eternity; he can never tell where his influence stops." She asked if this meant she had to be an astronomer when she grew up. I smiled and said no, but it did mean we needed to get out the telescope and look at Jupiter. ✦

__John I. McConnell__ is a Principal Program Manager at Microsoft, developing software for languages other than English. After graduating from MIT, he used his first paycheck to purchase a Celestron 8-inch telescope in 1975. He and his family live near Seattle.

In Memory

Donald C. Parker

Planetary Imaging Pioneer
(1939 - 2015)

"It's really kind of cool—when you're in a science and something all of a sudden falls into place that you don't expect. It's really neat. It's the thrill of the hunt. And you can come on over anytime, we never close... But remember, we don't do mornings."

– Don Parker

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