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M24 region imaged by Tony Hallas using a Tele Vue-NP101is refractor.

Tony Hallas, Renowned Astrophotographer, Returns to the Eyepiece

(from an unsolicited e-mail to David Nagler)

Hi David and Al,

Although I am still active in imaging, I have decided to go back to viewing and have taken possession of a new 24" f/3.85 Slipstream telescope from Tom Osypowski. You will be happy to know that I have acquired a treasure trove of Tele Vue eyepieces to complement this telescope, specifically: 26 and 20mm Nagler Type 5, 17.3, 14, 10, 6, 4.5mm Delos, Paracorr Type 2, and 24mm Panoptics for binocular viewing. After using a Delos, "that was all she wrote;" you have created the perfect eyepiece. The Delos eyepieces are a joy to use and sharp, sharp, sharp! I wanted to thank you for continuing your quest to make the best eyepieces for the amateur community. I am very glad that you don't compromise ... in this world there are many who appreciate this and appreciate what you and Al have done for our avocation. Hard to imagine what viewing would be like without your creations.

Best,
Tony Hallas

Tony with his Tele Vue eyepiece collection awaits a night of great observing at his dark-sky site.

SKY & TELESCOPE

April 2016 VOL. 131, NO. 4

On the cover: The lunar surface's low plains and rugged highlands mostly cluster in two different hemispheres.

PHOTOCOMPOSITE: BACKGROUND: TRENT M. HARE *ET AL.* / U.S. GEOLOGICAL SURVEY SCIENTIFIC INVESTIGATIONS MAP 3316; MOON: NASA GSFC / ARIZONA STATE UNIV.

FEATURES

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OBSERVING APRIL

S&T TEST REPORT

ALSO IN THIS ISSUE


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  As spring approaches, so does star party season. Find an event near you or submit your own!
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TOUR THE SKY – ASTRONOMY PODCASTS

Photo Gallery

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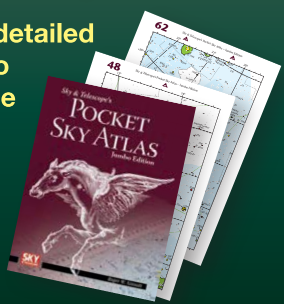

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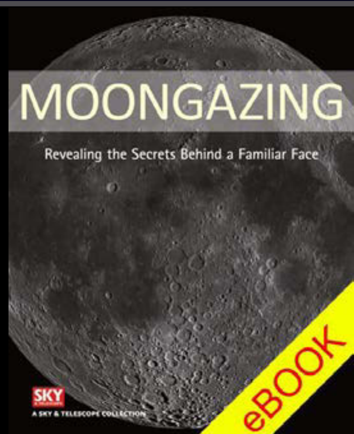

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ONLINE PHOTO GALLERY

Paul Swift spent two months composing a 10-panel narrowband mosaic of the Monoceros region.

Peter Tyson
Spectrum

An Ethos of Largesse

EACH OF US WHO enjoys going to star parties probably has a different reason why he or she most likes to attend. For many it will be the coal-dark skies. For others the camaraderie. For still others maybe the chance to try out a really big scope. (See Rod Mollise's feature article on page 34 for still other whys and wherefores.)

For my part, one of the qualities I most look forward to experiencing is the generosity of spirit.

A case in point was late Friday evening at Stellafane last August. Black-bottomed clouds marched across most of the sky over Breezy Hill in Springfield, Vermont. Many scopes I could see around me were covered up, their owners elsewhere. While a few folks did have their instruments at the ready, most were waiting for better conditions.

But one person was actively seeking openings overhead and encouraging anyone who cared to have a look to bend over his 5-inch scope — and quite a few did so. When someone asked if he thought it would clear, the man said, "We have enough sucker holes to keep us going." I could see his smile in the warm glow from my red flashlight.

DENNIS DI CICCO

Al Nagler at Stellafane, 2010

The man was Al Nagler, then celebrating six decades since his first visit to Stellafane in 1955. The guru of Tele Vue, who turned 80 years old in 2015, was as enthusiastic a participant as you'd want to find at this 80th iteration of the "Shrine to the Stars" convention. Most octogenarians would have been snug in their beds by that time of night. Not Al: too much magnanimous zest to bestow on interested bystanders.

Despite the general overcast, Al managed to pull M22 and M24 in Sagittarius into view and, a little later, the Great Globular Cluster in Hercules. He searched the sky; he swung his scope around; he switched eyepieces. He just wasn't going to take "no" for an answer. As a visitor peered at the E.T. Cluster that Al had just centered in his eyepiece, Al said, "It's upside down. See the eyes? It's very cute!"

Just before retiring for the night around midnight, Al glanced at the heavens and said, to no one in particular, "You're seeing the Milky Way against dark cloud. That's beautiful. You don't see that all the time."

Al Nagler exemplifies the selfless goodwill that abounds in amateur astronomy. This quality stood out for me as soon as I joined *S&T* in 2014 and began attending star parties and other events: those in our hobby are extremely *nice* people, and they like nothing more than sharing the beauties of the night sky with whoever wishes to see. ✦

Peter

Editor in Chief

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Astronomy from the Moon

Your "75, 50 & 25 Years Ago" column (*S&T:* Jan. 2016, p. 10) recalls an article from the January 1966 issue describing the potential advantages of a lunar observatory. While such a facility is still in the far future, telescopic astronomical research *has* already been conducted from the lunar surface. In 1972, Apollo 16 astronauts John Young and Charles Duke deployed a far-ultraviolet camera-spectrograph at their Descartes Highlands landing site. The 75-mm f/1.0 Schmidt instrument took photographs at a wavelength that is inaccessible to ground-based astronomers.

While on the lunar surface, the astronauts manually aimed the telescope — just as we amateurs did before the advent of Go To mounts. Among the astronomical objects photographed were Earth's upper atmosphere, nebulae, star clusters, and the Large Magellanic Cloud. When Young and Duke departed the Moon, they took a film cartridge that contained 178 exposed frames. But that first lunar telescope remains on the Moon to this day — perhaps "one small step" toward an eventual lunar observatory.

Frank Ridolfo
Bloomfield, Connecticut

NASA (2)

Apollo 16 astronauts set up a far-ultraviolet telescope on the Moon in 1972 *(left, foreground)* and used it to take images of auroral emissions on Earth *(right)* and other celestial targets.

It's All Relative

Thank you for the excellent articles on the intimate tie between general relativity and modern astronomy (*S&T:* Dec. 2015, p. 18 and p. 26). They inspired me to pull out my first *S&T* issue, June 1955, which was published just after Einstein's death. In it, George McVittie struggles to show "Why Should an Astronomer Study Relativity?" How times have changed!

Richard Stanton
Big Bear City, California

Write to Letters to the Editor, Sky & Telescope, 90 Sherman St., Cambridge, MA 02140-3264, or send e-mail to letters@SkyandTelescope.com. Please limit your comments to 250 words. Published letters may be edited for clarity and brevity.

Govert Schilling's wonderful article concerning the progress in the search for gravitational waves took me back to a tour I had of the LIGO facility in Hanford, Washington, in 2000. The researchers there had just achieved "first lock" (their version of "first light"), and I remember being impressed with the engineering feat required to create an interferometer on such a grand scale.

But after that visit I couldn't shake a gut feeling about it just being the wrong instrument for the task. After all, isn't LIGO really just a scaled-up version of the Michelson interferometer of 1887? And aren't all such investigations using this same basic technique (with the exception the Pulsar Timing Array folks)? It's like using a gauss meter to detect radioactivity. That meter might be very good and precise, but it's the wrong tool — you really need a Geiger counter. Am I wrong in thinking that researchers have yet to build their relativistic "Geiger counter" for gravity waves?

Jay Jiudice
Los Angeles, California

LIGO director Frederick Raab replies: *According to general relativity, the speed of light is constant and becomes the "ruler" for measuring space. A gravitational wave reveals its passing most simply by causing a phase shift in a beam of light crossing space. Whether it's radio emission from a pulsar or laser light in an interferometer, we measure the same effect — just on different scales of space and time. Simplicity never goes out of fashion in science. Interferometers of today, though complex devices operating at the limits of quantum mechanics and the atomic nature of matter, still allow us to measure such phase shifts of light in a way that can be verified simply.*

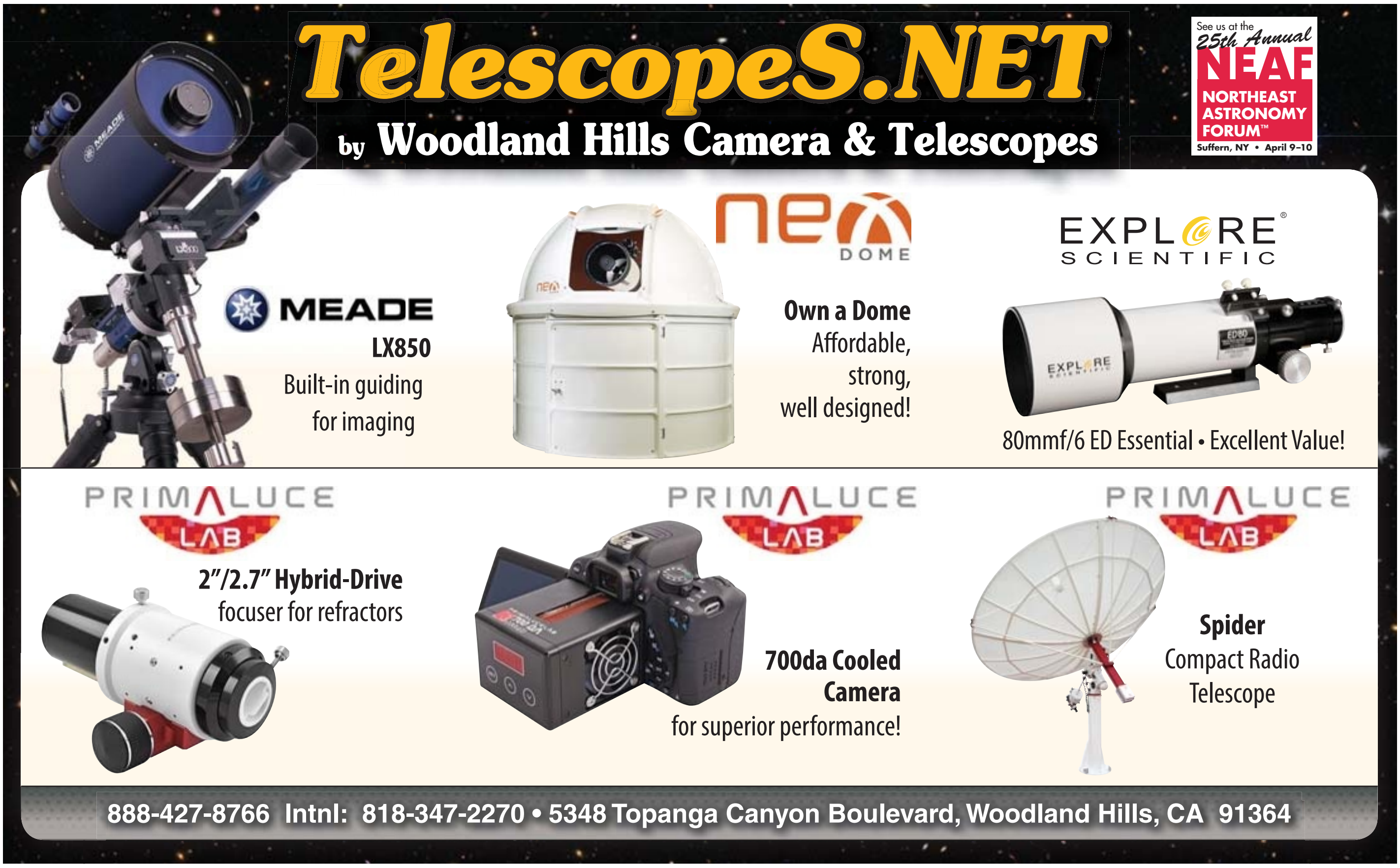
Govert Schilling mentions that radio astronomers are looking for tools to measure "longer, slower gravitational waves." Don't all these waves move at the speed of light?

Irene Kitzman
Tucson, Arizona

Camille Carlisle replies: *Yes, gravitational waves travel at the speed of light. "Slower" was a reference to their frequency — because the wavelengths are longer, a complete wave takes more time to pass by us compared with a shorter wave. We should have stuck with thinking of these as radio signals and used "lower frequency" instead of "slower" to avoid that ambiguity.*

A "Quiet" Superflaring Star

As Monica Bobra points out (*S&T:* Nov. 2015, p. 22), a solar superflare could have a dramatic impact on Earth and its inhabitants. Some solace can be found in the fact that, unlike our Sun, most flaring solar-type stars show strong emission lines due to ionized calcium — and the Sun doesn't. However, one of the first superflaring solar-type stars identified showed no such abnormal spectral char-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UNITED STATES

acteristics. Now designated MT Tauri, this superflaring star was identified by Mexican astronomer Guillermo Haro during a search in the Pleiades for flaring UV Ceti stars. (Later Stephen Naftilan and I found that it was actually a star far more distant than the Pleiades.)

Although Haro's team spent hundreds of hours observing this region of the Pleiades, they never saw MT Tauri in outburst again. Even so, that single event released about 1,000 times more energy than the largest solar flares. Perhaps it is the quiet stars that are the most dangerous.

Wm. Bruce Weaver
Monterey Institute for Research in Astronomy
Marina, California

Promoting Amateur Spectroscopy

It was great to see JTW Astronomy's L200 spectrograph included among your Hot Products for the year (*S&T:* Jan. 2016, p. 32). This instrument has enabled me to study *Be* stars and contribute to the database of their spectra (**basebe.obspm.fr**), all of which I find very rewarding. Considering the value of amateur spectroscopy to science, it would be great to have *S&T* provide more coverage of this topic — maybe equipment reviews but certainly more how-to articles. Just imagine the benefit if, say, half of all astroimagers contributed spectra!

Arnold de Bruin
Bussum, The Netherlands

Not-So-Rare "Earths"?

David Grinspoon's reminder to consider with caution the claims of SETI skeptics (*S&T:* Jan. 2016, p. 20) is timely and much needed. During the last 50 years, progress in astrophysics and astrobiology has steadily increased, not decreased, the probability of finding life to be common throughout the universe. Planetary systems, once considered the product of rare stellar encounters, are now accepted as quite ordinary. Water, once thought rare, is now found virtually everywhere we look, and the same is true for organic molecules. The Kardeshev scale categorizes the technological advancement of a civilization based on the amount of energy it consumes; we now replace that with a scale based on information.

I could go on, but it seems clear where science is placing the odds: toward favoring life and intelligence elsewhere. The SETI effort merits our support.

Mike Mortenson
Carmel, California

Brashear Telescopes Today

Thank you for the interesting article about the demolition of the Brashear factory (*S&T:* Jan. 2016, p. 68). It might interest your readers to know that Brashear is still in business, in Pittsburgh, as a unit of L-3 Communications. We continue to manufacture observatory-class telescopes, as well as a broad line of other precision optical systems.

Rich Colarco
L-3 Brashear
Colorado Springs, Colorado

For the Record

✷ *The stars labeled Beta and Zeta Tauri (*S&T*: Jan. 2016, p. 45) are actually Iota and Beta Tauri, respectively.*

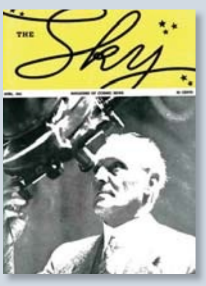
75, 50 & 25 Years Ago

Roger W. Sinnott

April 1941

Pluto's Name "There are [various claimants] to the prediction of Pluto, . . . but we mustn't forget that its name was prenatally assigned by [French astronomer] P. Reynaud in the same year (1919) that it was photographed (but not discovered) as a result of [William H.] Pickering's prediction.

"But back in 1898, the name Pluto was suggested for the newly-discovered asteroid 1898 DQ, or number 433. . . . W. T. Lynn, a prolific contributor to amateur British astronomy, [objected, noting this would honor] 'Pluto, the grizzly god, who never spares, who knows no mercy and who hears no prayers. . . .' A short while later [asteroid 433 was] named Eros."

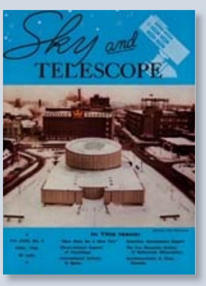


Columnist Roy K. Marshall liked to dig up obscure astronomical lore, much as Joseph Ashbrook did for the magazine in later years. Curiously, Marshall says nothing of Venetia Burney, the British schoolgirl now widely credited for naming Pluto.

April 1966

Life on Earth? "Harvard astronomer Carl Sagan has repeatedly opposed the widespread impression that the Mariner-4 closeup pictures of Mars last July are evidence against the existence of life on the red planet. . . . Dr. Sagan asks whether a similar series of pictures of the earth would show any traces of living things. . . .

"Several hundred thousand photographs of the earth have been obtained with Tiros and Nimbus meteorological satellites, and their resolutions range between 0.2 and 2.0 kilometers. [A marginal example] of human activity was noted on a Tiros-2 photograph . . . of a forest region near Cochrane, Ontario. There is a conspicuous grid of intersecting straight white lines



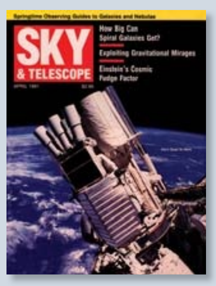
— logging swaths on which snow had recently fallen. [But, in general, if] hypothetical Martians had sent an exact duplicate of Mariner 4 to photograph Earth from the same distance, it could not have detected any sign of life."

April 1991

Starburst "There are many indications that NGC 1569, a small 11th-magnitude irregular galaxy in Camelopardalis, underwent a tremendously violent burst of star formation millions of years ago. Two decades of scrutiny have turned up 'twin' nuclei . . . as well as an arm of gas moving out from the center of the galaxy . . . [and] two additional gaseous arcs. . . .

"An unknown internal source must have sparked these energetic outbursts. Gravitational interaction with another galaxy seems unlikely because NGC 1569's nearest neighbor has been out of range for at least a billion years."

Well, maybe not. In 2008 Aaron J. Grocholski's team reported detecting individual red-giant



stars with the Hubble Space Telescope. Their brightnesses put NGC 1569 about 11 million light-years away, not 7 (as assumed earlier), thus within the IC 342 galaxy group. So past encounters with other galaxies are, in fact, likely.

STELLAR | Runaways' Telltale Shocks

Zeta Ophiuchi (blue star in the center of the image) and its accompanying bow shock, as seen at infrared wavelengths by the WISE space telescope.

NASA / JPL-CALTECH / UCLA

Astronomers have now found dozens of stars zipping through space at 30 kilometers per second (67,000 mph) or faster relative to their surroundings. These speedsters, called *runaway stars*, tend to be in isolated regions of the galaxy, though their paths often lead directly away from stellar clusters or even our galaxy's central black hole.

Astronomers had previously discovered about 20 of these stars, through pure luck. But now they have a new technique: searching for the bow shocks the stars create in interstellar gas and dust as they whiz through this material.

The star Zeta (ζ) Ophiuchi inspired the new approach. It's a hot, massive *O* star with a relative motion fast enough — roughly 24 km/s — to be "supersonic." As this massive star plows through space, astronomers discovered, its strong outflowing wind causes interstellar gas and dust to stack up in front of it, like the shock front of air that piles up ahead of a high-performance jet. This arc-shaped gas compresses, heats up, and shines with infrared light, emission that reveals both the mass and velocity of the star.

With Zeta Ophiuchi's example in hand, Grace Olivier (Case Western Reserve University) and colleagues decided to look for bow shocks in order to search for runaway stars. They turned to archival infrared data from the Spitzer and WISE space observatories and found more than 200 images of fuzzy red arcs. They then used the Wyoming Infrared Observatory's 2.3-meter telescope to look for the culprits behind 80 of them.

The team was surprised to find that "more than 95% of these bow shocks have a hot, massive, runaway candidate at their center," team member William Chick (University of Wyoming) said during a press conference January 5th at the American Astronomical Society meeting in Kissimmee, Florida. "It may be that our Milky Way is swarming with these hot runaway stars."

The team plans to extend its search to include the entire galactic plane. With more runaways spotted, the researchers will be able to trace the stars' motions backward in order to find the source of their accelerating kicks.

■ **SHANNON HALL**

MISSIONS | China's Dark Matter Probe in Orbit

On December 17th, China launched its first astrophysics payload. The Dark Matter Particle Explorer (DAMPE) will detect energetic particles known as cosmic rays, as well as gamma-ray photons from supernovae, pulsars, and other astrophysical sources — including, perhaps, elusive dark matter.

DAMPE is a collaboration among universities in Switzerland and Italy and the Chinese Academy of Sciences. (NASA is restricted from trading technology with China due to the 1976 International Trade in Arms Regulations, a key reason why China isn't a partner on the International Space Station.)

DAMPE joins the Alpha Magnetic Spectrometer and the Calorimetric Electron Telescope, both aboard the International Space Station, in taking the dark matter hunt to space. It's the first of a five-mission series, with the next two payloads — a quantum-communications satellite and an X-ray telescope — set to launch this year.

■ **DAVID DICKINSON**

BLACK HOLES | Magnetic Fields Near the Event Horizon

Astronomers have detected magnetic fields dancing in the skirts of the Milky Way's central black hole. The work is part of the Event Horizon Telescope (*S&T*: Feb. 2012, p. 20), a planet-spanning network of radio antennas aiming to "see" a supermassive black hole — or, rather, its telltale silhouette amid the glow of hot gas surrounding it like a superheated tutu.

Michael Johnson (Harvard-Smithsonian Center for Astrophysics) and other members of the EHT collaboration used telescopes in Hawai'i, California, and Arizona to peer into the inner sanctum of our galaxy's black hole, Sagittarius A*. With only three sites and a few nights' worth of observations, they couldn't reconstruct a complete image — instead of seeing the

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

MISSIONS | Japan's Akatsuki Finally Reaches Venus

Triumph is never sweeter than when following defeat. At 23:51 Universal Time on December 6th, Japanese Aerospace Exploration Agency (JAXA) engineers executed an innovative contingency plan to get the Venus Climate Orbiter, named Akatsuki, to its destination. The success came five years to the day after a main-engine failure caused the spacecraft to fly past Venus instead of going into orbit.

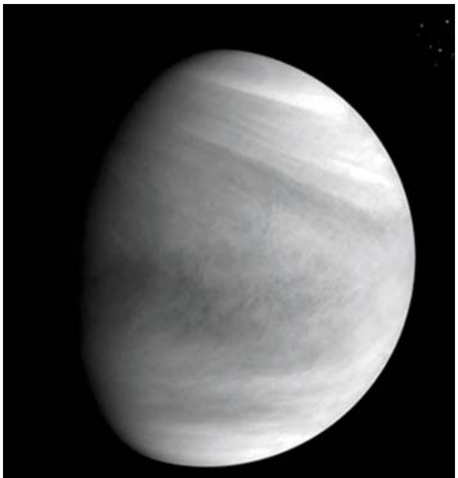
The spacecraft ran into trouble in 2010 when its main engine failed to execute a planned 12-minute firing. Telemetry analysis showed a pressure drop caused by a faulty valve in the main engine, which resulted in burning an oxidizer-rich mixture beyond normal limits. The failure overheated and destroyed much of the engine.

With the primary means of propulsion ruined, scientists and engineers scrambled to recover the mission while the spacecraft circled the Sun. Their solution: fire the craft's four reaction-control thrusters for more than 20 minutes at the next available opportunity to enter orbit around Venus. Engineers ran a series of short test burns in 2011, then placed the spacecraft in electronic hibernation to extend its life until the planned maneuver.

Akatsuki's successful arrival marks the first time the Japanese space agency has put a spacecraft in orbit around another planet.

The track is slightly wider-ranging than the one originally planned, which would have carried the spacecraft around Venus every 30 hours, with a closest approach of 300 km. The December burn instead placed Akatsuki in a 13.6-day elliptical orbit that brought it as close as 400 km to the surface. As this issue went to press, the JAXA team was planning a series of adjustments that would shrink Akatsuki's elliptical orbit to a period of 9 days, in time to start full science operations in April.

The six instruments aboard will probe Venus's atmosphere, measuring its rotation and convection. Researchers also hope to detect evidence for lightning using a high-speed imager. Viewing across radio, infrared, visible, and ultraviolet wavelengths, the payload will also record heat radiated from the surface — perhaps spotting active volcanoes, if they exist (*S&T:* July 2014, p. 16). A series of radio-occultation experiments will allow researchers to probe the atmosphere's depths as the spacecraft makes successive passes behind the planet as seen from Earth.



The Ultraviolet Imager aboard Akatsuki captured this image of Venus's swirling atmosphere on December 7, 2015, from an altitude of 72,000 km.

JAXA

■ **DAVID DICKINSON**

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whole elephant, they're only seeing an ear and a bit of trunk.

But those bits are good enough for them to deduce what's going on. The team detected *synchrotron radiation*, polarized light created by electrons corkscrewing along magnetic field lines. The polarized emission varied, and quickly, on roughly 15-minute time scales. That means the magnetic fields themselves, and the gas they interweave, are moving a lot.

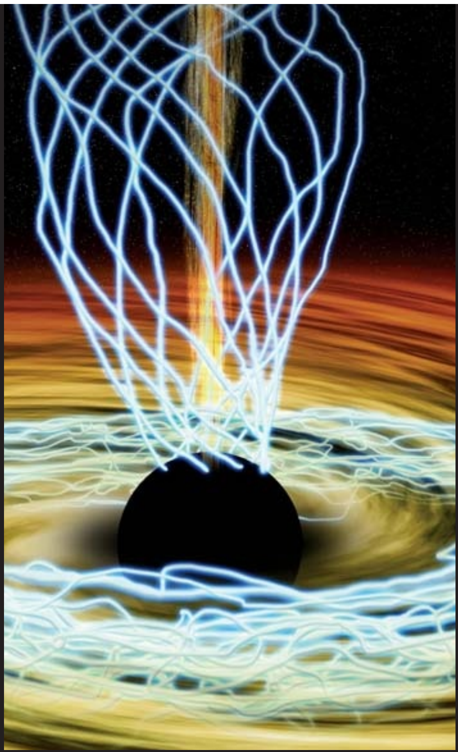
These changes only appear very close to the black hole. Essentially, the astronomers are seeing tangled, turbulent magnetic fields cavorting right near where gas takes its final plunge in past the event horizon.

The observations reveal structures on a scale that's only a half dozen times the black hole's radius, the team reports in the December 4th *Science*. To be able to detect these motions at this small scale is "really just amazing," Johnson sums up.

This result is great news for theorists, says Chris Reynolds (University of Maryland), who has spent his life working on black holes. It has taken decades to understand why gas in the accretion disk falls into a black hole at all — it should just orbit forever, because the gas is too tenuous for friction to slow it down. Astrophysicists realized that magnetic fields swirling around in the accretion disk would tug on the gas, pumping up the turbulence and robbing the gas of its angular momentum, allowing it to fall into the black hole.

"But it's all been very much in a theoretical domain," Reynolds says. The new EHT observations show that theorists have been on the right track. "It's honest-to-goodness measurements of a real black hole that are getting to the crux of this issue."

■ **CAMILLE M. CARLISLE**



M. WEISS / CFA

In this artist's conception, tangled magnetic fields (blue) surround and emanate from Sagittarius A*, the black hole at the center of our galaxy. The fields the Event Horizon Telescope team found are either in the disk or the jet (if the black hole has one — astronomers don't know).

GALAXIES | Aussie Amateur Finds Dwarf

Michael Sidonio's black-and-white discovery image of the dwarf galaxy NGC 253-dw2 (circled) reveals a small concentration of stars near the spiral NGC 253 (color image overlaid).

In October 2012 Australian amateur Michael Sidonio (a former captain of the country's "strongman" team) used his 12-inch reflector and FLI Proline 16803 CCD camera to record frames of the Sculptor Galaxy, NGC 253. All Sidonio wanted was a pretty image of this intermediate spiral galaxy, which lies about 11½ million light-years away.

But later he noticed a small, elongated smudge off to one side that wasn't plotted on any of his reference charts. His chance discovery triggered a succession of observations with ever-larger professional telescopes — culminating with Japan's 8.2-meter Subaru Telescope.

That little smudge, now designated NGC 253-dw2, turns out to be a dwarf spheroidal galaxy that the much bigger spiral galaxy is in the process of gobbling up via tidal disruption (as implied by its elongated shape). This straggler lies about 160,000 light-years from NGC 253, about as far as the Large Magellanic Cloud is from us and easily close enough to be held within NGC 253's gravitational death grip.

Cosmologists have often assumed that spiral galaxies grow and evolve by consuming lots of galactic small fry in their vicinity. But this big-fish-eats-small-fish paradigm, a key prediction of the standard cosmological framework, is in some distress (*S&T:* Sept. 2015, p. 16). For example, dwarf galaxies are scarce in the Milky Way's immediate neighborhood.

Thus, NGC 253-dw2 is an important find, as Aaron Romanowsky (San Jose State University) and nine coauthors — including Sidonio — detail in a forthcoming issue of *Monthly Notices Letters of the Royal Astronomical Society*. It provides a crucial observational test for the distribution of dark matter around the host spiral galaxy.

Another team has independently reported finding the dwarf galaxy in question. Elisa Toloba (Texas Tech University) and other observers spotted it in images taken between November 2011 and October 2014 with the Magellan Clay 6.5-m telescope in Chile.

■ **J. KELLY BEATTY**

STELLAR | Two Types of Binary

A new radio survey suggests that binary star systems come in two basic sizes: tight and loose.

John Tobin (Leiden Observatory, The Netherlands) and others used the Very Large Array's 27 antennas to study newborn stars in a nearby molecular cloud in the direction of Perseus. The team noticed that most of the young binary star systems in the cloud fall into two categories: they're either separated by less than 300 astronomical units or by a distance greater than 1,000 a.u.

"We think this is evidence that they form from distinct routes," Tobin said during a January 5th press conference at the American Astronomical Society's January meeting.

Stars are born in enormous clouds of gas and dust that collapse into clumps under the pull of gravity. As the clumps shrink, their outer regions flatten out into pancake-shaped disks. Meanwhile, deep inside, conditions eventually become hot and dense enough to ignite fusion, and a star is born.

But astronomers aren't sure how this process works with binaries. Tobin's team suggests that in the closer-packed systems, one star likely forms in its birth cloud's dense central core, while companion stars coalesce within the large gas disk encircling the forming primary star, much as planets do. But for the widely separated systems, each star might come together on its own, as part of the turbulent fragmentation of its parent cloud. Since most of the widely separated systems the team found are relatively young, the researchers speculate that these binaries drift apart over time.

■ **SHANNON HALL**

IN BRIEF

InSight Launch Postponed Until 2018. NASA's next Mars-bound mission, InSight (short for Interior Exploration using Seismic Investigations, Geodesy and Heat Transport), will not be launched this spring as planned. A vacuum seal in the lander's French-built seismometer developed a leak during a final round of thermal testing at Vandenberg Air Force Base in California. Mission managers decided that there wasn't enough time to make the needed repairs before the launch. Since the opportunities to send spacecraft to Mars occur during favorable orbital geometries that occur every 26 months, InSight won't get another chance to leave Earth until 2018.
■ **J. KELLY BEATTY**

Astronomers Predict a Supernova. Last year, Patrick Kelly (University of California, Berkeley) and colleagues announced the

EXOPLANETS | Kepler's Giant Candidates: Real or Not?

A new study shows that about half of Kepler's giant exoplanet candidates aren't real planets. That might sound surprising, but it's not: astronomers expected this result.

The *Astronomy & Astrophysics* study, by Alexandre Santerne (University of Porto, Portugal) and colleagues, followed up on potential giant planets detected by NASA's Kepler satellite, which over four years found more than 4,700 exoplanet candidates. Santerne's team conducted six observing campaigns with the 1.93-m telescope at Haute-Provence Observatory in France, looking for the worlds' tiny gravitational tugs on their stars. The instrument wasn't accurate enough to detect small planets, so the team focused on giants with orbits of less than 400 days.

The team observed 129 Kepler candidates. Of these, only 45 turned out to be bona fide planets. The rest were brown dwarfs (3) or multiple-star systems (63); for an additional 18 cases, the team could reject both these alternatives, but still don't know for certain what the signals are. Even if all 18 turn out to be planets, the study concludes, 51% of Kepler's giant potential planets would still not be real.

That's a lot higher than what previous studies have found. Most recently, Francois Fressin (Harvard University) and colleagues calculated a 20% false-positive rate for giant planets. But the high false-positive rate isn't that surprising, says Kepler data expert Timothy Morton (Princeton University).

"The reason this apparent false-positive rate from this study is so high is mostly because the Kepler team has been very generous with the last few data releases with what has been called a 'candidate'," Morton says.

Kepler mission scientist Natalie Batalha (NASA Ames) agrees. In the early years, she explains, the team automatically marked any potential planet more than twice Jupiter's diameter as a false positive. But Kepler couldn't always measure planet sizes with a high degree of accuracy. Moreover, the team worried that they were throwing away objects in the divide between planets and brown dwarfs. So the team stopped throwing out candidates based on size alone.

That decision increased the number of "fakes," but it enabled scientists to study how common brown dwarfs are compared with giant planets. In fact, Santerne's team found that "warm Jupiters," which are Jupiter-size planets no farther from their parent stars than Earth lies from the Sun, are 15 times more common than brown dwarfs in similar orbits. "That is the real news!" Batalha says.

The team also found that, once they removed false positives from the group, three distinct populations of giant planets emerged: hot Jupiters that orbit their star in a few days, temperate giants more like those in our own solar system, and a third type with orbits in between.

Morton is in the process of doing a wider-range calculation of the chance that any given planet in Kepler's list would turn out not to be real. He has already compared his calculations against Santerne's observations and finds that they match up. But he stresses that the Santerne results are specific to giant planets only — all indications are that the false-positive rate for smaller candidates is still low.

■ **MONICA YOUNG**

discovery of Supernova Refsdal, an exploding star in a faraway galaxy whose light had been split into four images on its way to Earth by an intervening galaxy's gravity (*S&T:* July 2015, p. 18). A flurry of computer simulations published immediately after the discovery predicted that another image would be found within one to several years, due to the effect of the lensing galaxy's home cluster, MACS J1149.5+2223. On December 11th, Kelly's team spotted the predicted fifth image of the exact same explosion, more than a year after Hubble caught the previous four images.

■ **MONICA YOUNG**

Exiled Exoplanet. Observations with the Gemini Planet Imager confirm that the giant body that orbits a distant 650 astronomical units from the star HD 106906 — more than 10 times Pluto's farthest point from the Sun — was probably flung there from closer in. Paul Kalas (University of California, Berkeley) and colleagues found that a Kuiper Belt–like ring of dust around the star is lopsided in its outermost parts: fat on one side and skinny on the other. Plus, the lonely planet's orbit is decidedly out of line with this disk, and the two should have formed in the same plane. Thus, Kalas says, "This whole system has been recently disturbed by some violent gravitational interaction." What that disturbance was is hard to say. The team reported the result December 1st at the Extreme Solar Systems III conference and in the November 20th *Astrophysical Journal.*

■ **MONICA YOUNG**

Hubble Peers into Exoplanet Clouds. Astronomers studying hot Jupiters have revealed when and how clouds form on these alien worlds. A couple years ago, observations suggested that hot Jupiters contained less water than expected in their atmospheres, potentially causing problems for planet-formation scenarios. Researchers pointed to obscuring clouds or a Titan-like haze to explain why the compound was missing (*S&T:* Mar. 2014, p. 14). David Sing (University of Exeter, UK) and colleagues have now confirmed this idea December 14th in *Nature*. They compared 10 hot Jupiters in visible and near-infrared light, and for each one "lacking" water, they also found spectral markers of clouds or haze. The study not only rules out dry hot Jupiters but also gives a guideline for assessing which atmospheres are clear. The results also suggest that cloud formation on these planets doesn't depend on temperature as clearly it does on brown dwarfs — the temperature-pressure balance might be a far more delicate one.

■ **MONICA YOUNG**

SPACE & SOCIETY | IAU Names Stars and Planets

Although it's the only recognized authority for naming stars, the International Astronomical Union has never bestowed a common name on a star. In December, however, following a wildly popular public contest, the IAU announced names for 14 stars and 31 planets that orbit them. For full details see **http://is.gd/IAUnames**.

■ **J. KELLY BEATTY**

Star Designation	Star Name	Planet Name *(Designation)*
14 Andromedae	Veritate*	Spe* *(b)*
18 Delphini	Musica	Arion *(b)*
42 Draconis	Fafnir	Orbitar *(b)*
47 Ursae Majoris	Chalawan	Taphao Thong *(b)* Taphao Kaew *(c)*
51 Pegasi	Helvetios	Dimidium *(b)*
55 Cancri	Copernicus	Galileo *(b)* Brahe *(c)* Lipperhey *(d)* Janssen *(e)* Harriot *(f)*
Epsilon (ε) Tauri	**Ain**	Amateru* *(b)*
Epsilon (ε) Eridani	Ran*	AEgir* *(b)*
Gamma (γ) Cephei	**Errai**	Tadmor* *(b)*
Alpha (α) Piscis Austrini	**Fomalhaut**	Dagon *(b)*
HD 104985	Tonatiuh	Meztli *(b)*
HD 149026	Ogma*	Smertrios *(b)*
HD 81688	Intercrus	Arkas *(b)*
Mu (μ) Arae	Cervantes	Quijote *(b)* Dulcinea *(c)* Rocinante *(d)* Sancho *(e)*
Beta (β) Geminorum	**Pollux**	Thestias* *(b)*
PSR 1257+12	Lich	Draugr *(b)* Poltergeist *(c)* Phobetor *(d)*
Upsilon (υ) Andromedae	Titawin	Saffar *(b)* Samh *(c)* Majriti *(d)*
Xi (ξ) Aquilae	Libertas*	Fortitudo* *(b)*
Iota (ι) Draconis	**Edasich**	Hypatia *(b)*

** These names are modified from the original proposals to be consistent with IAU rules.*

Preexisting, common star names are in bold.

MILKY WAY | Charting 70,000 Stars' Ages

Astronomers have mapped the ages of 70,000 red giant stars spanning our galaxy, ushering in a new era of galactic archaeology. Melissa Ness (Max Planck Institute for Astronomy, Germany) announced the new stellar catalog January 8th at the American Astronomical Society meeting in Kissimmee, Florida.

A fairly direct age measurement comes from starquakes, which create pulsations in brightness that change as the star ages. But such data is only available for a limited number of stars in the Kepler spacecraft's field of view, and the team wanted to date tens of thousands of stars using their compositions, determined by the APO Galactic Evolution Experiment (APOGEE) survey.

As stars like the Sun evolve into red giants, the roiling plasma of their outer convective layer extends its reach down to scrape the stellar core, dredging up just-fused elements and carrying them to the surface. Surface contamination reveals how long the red giant has been around.

So the team picked 1,475 stars observed by both Kepler and APOGEE. They then used them to "teach" a computer to look for a more indirect measure of age: stars' chemical footprints. Once the algorithm "learned" this chemical footprint from Kepler stars with known ages, the researchers set it loose on all the stars.

The results so far confirm that our galaxy's spiral disk formed from the inside out. The youngest red giants assemble along the galactic plane, encased by older stars. Farther from the galaxy's center, this younger "backbone" flares outward, away from the plane. These patterns are the hallmark of a disk that started small and grew slowly outward, like pancake batter first ladled onto the center then added to the edges.

■ **MONICA YOUNG**

SPACE & SOCIETY | NASA's Budget Boost

In December, Congress and President Obama approved funding for NASA to the tune of $19.3 billion for fiscal year 2016. That's almost $1.3 billion more than the agency received in FY2015 and $750 million above what it requested.

NASA's funding peaked at nearly 4.5% of the total federal budget in the Apollo era of the late 1960s. It dropped to 1% by the mid-1970s. Even with this latest increase, the current allocation is still less than 0.5% of the requested $3.999 trillion federal spending budget.

Nevertheless, "the best thing about this budget is that basically everything won," says Casey Drier (The Planetary Society). "But in terms of pure funding increases, the Space Launch System and the Planetary Science Division received some of the biggest increases."

The SLS is the next generation of heavy-lift rockets to take astronauts beyond low orbit to a near-Earth asteroid and eventually to Mars in the 2030s. SLS will receive $2 billion in FY2016. The first full-up SLS test might come in November 2018, and the first launch of a crewed Orion capsule as early as 2021.

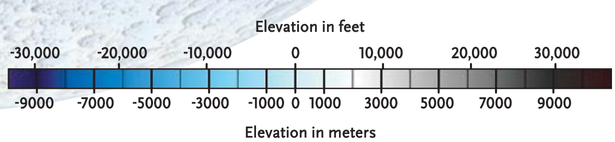
Meanwhile, the continuation of International Space Station operations will receive more than $5 billion — more than $1 billion above what NASA requested — and includes absorbing the commercial initiative for Boeing and SpaceX to develop crewed transport (which had been managed by NASA's exploration division).

But the most exciting prospects in the FY2016 budget come in planetary exploration. This division will receive more than $1.6 billion, about a quarter billion more than asked for. This boost will enable missions such as the Lunar Reconnaissance Orbiter and the current Mars rovers Opportunity and Curiosity to stay in operation. The development of a new Mars rover and a Europa mission, both set for the early 2020s, will also remain on track. In fact, the funding bill specifically requires the development of a Europa lander. ✦

■ **DAVID DICKINSON**

Our Two-faced Moon

Planetary scientists still don't know why one side of Earth's satellite looks so different from the other.

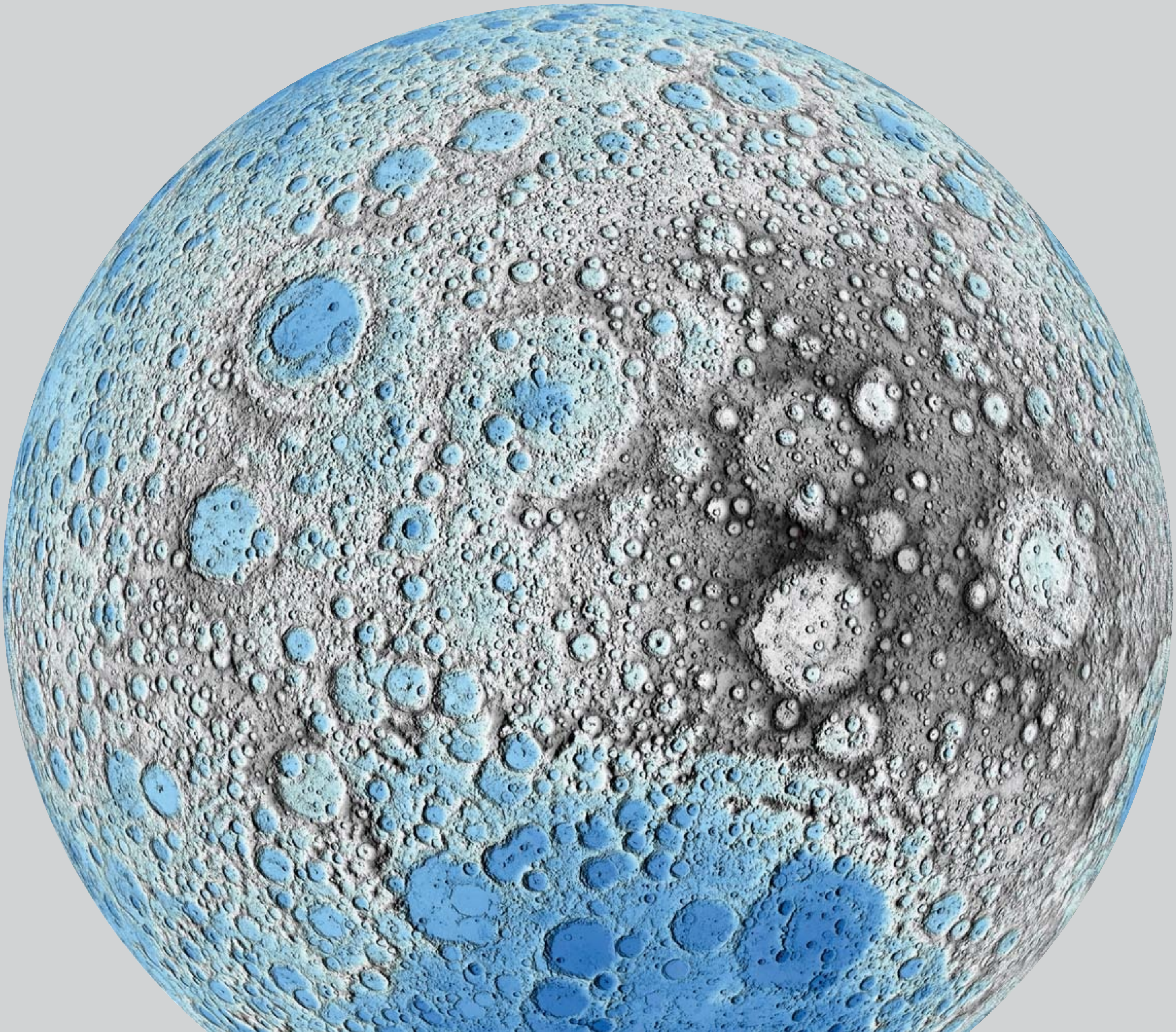


Paul D. Spudis

We've known for centuries that, as the Moon revolves around Earth, it shows us only one face. Before the Space Age, scientists could only speculate about the landscape hidden on the lunar farside. Informed expert opinion was that the farside probably looked similar to the nearside, with extensive low, smooth *maria* (Latin for "seas") set in rough, undulating highlands (*terrae*).

With the advent of spaceflight in the late 1950s, we finally saw the farside. That momentous event first occurred in 1959 thanks to the photographs captured by Luna 3, an automated satellite sent to the Moon by the Soviet Union.

Those first farside pictures were of poor quality and low resolution, but planetary scientists immediately realized that the near- and farsides are fundamentally different. The farside as seen from Luna 3 didn't show many of the dark maria (familiar to even the casual viewer) that are so widespread on the nearside. Except for a couple of small mare patches — including one patriotically dubbed "Sea of Moscow" by Soviet scientists and a dark, mare-filled crater named after rocket pioneer Konstantin Tsiolkovskiy — the farside appeared to be made up of mostly bright, rugged highlands, crisscrossed with rays



from several large, fresh craters. Subsequent Soviet and American robotic missions verified this initial discovery: the farside is composed almost entirely of the lighter toned, rough, and heavily cratered terrae, with limited exposures of maria.

Thus, we learned that the Moon possesses two hemispheres of distinctive character. This contrast is most obviously expressed by the distribution of dark mare deposits, but other differences (such as the distribution of certain elements) also exist. After more than five decades of study, we still do not fully understand how our Janus-like Moon developed its two faces — but we do have some clues that allow us to speculate on this dichotomy's meaning.

HIGHS AND LOWS The side of the Moon that faces Earth has broad lava plains across much of its surface. Yet the other side looks totally different: it's covered in rough highlands, with few lava plains. These false-color topographic maps are based on data from NASA's Lunar Reconnaissance Orbiter.

TRENT M. HARE ET AL. / U.S. GEOLOGICAL SURVEY SCIENTIFIC INVESTIGATIONS MAP 3316

"DARK SIDE" VS. "FARSIDE"

Although the Moon always points one face toward Earth, the whole lunar globe sees the Sun over the course of a lunar day. The Moon rotates on its axis once every 708 hours with respect to the Sun, thus putting half of its surface in darkness for 354 hours. The "dark side" is merely the nighttime hemisphere. If the dark side and farside were the same thing, we would never see lunar phases. The conflation of "dark side" with farside might have its roots in the cultural meaning of darkness as a synonym for "unknown."

The Lunar Maria

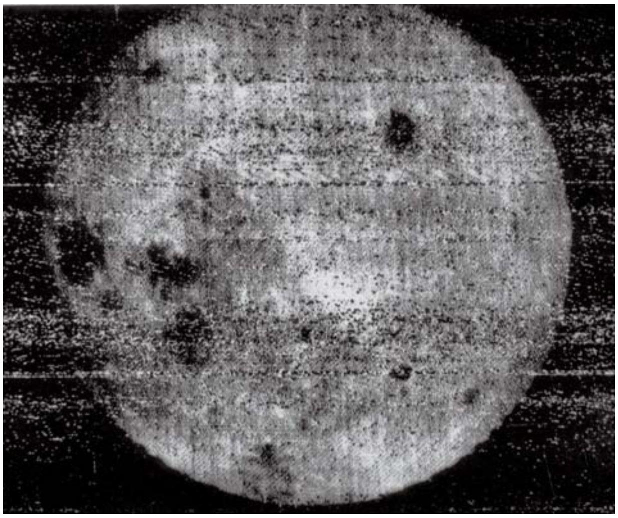
The Apollo explorations gave us a good understanding of the Moon's early history and evolution. We confirmed that the maria consist of ancient lava flows, which erupted onto the surface more than 3 billion years ago. These lavas arose when heat from the decay of radioactive elements deep within the Moon partially melted its magnesium- and iron-rich mantle, producing liquid rock that migrated upward toward the surface. This magma then erupted to form large deposits, similar to the massive sheets of lava that make up the Columbia River basalts in the western United States. Such eruptions can involve enormous volumes of magma and are called *flood basalts*.

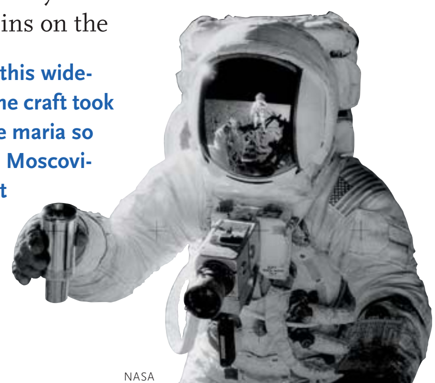
On the Moon, flood basalts fill gigantic impact features called basins. (By convention, planetary scientists define impact craters as basins when they are at least 300 kilometers across.) Some of these features are more than 1,000 km in diameter, as large as the state of Texas. The basins formed when asteroid-size bodies hit the Moon around 4 billion years ago, excavating large parts of crust and throwing ejecta across the surrounding highlands.

Basins create low areas and fractures in the crust. These fractures later allowed magmas to break through the surface and erupt onto it. The basins' low-lying interiors permitted these lavas to accumulate into stacks, pressing down on the crust and deforming the surface.

The infill of basins by mare lava is not a direct consequence of the impact. Instead, a significant length of time (hundreds of millions of years) usually elapsed between a basin's formation and its infilling by magma erupting from the deep interior.

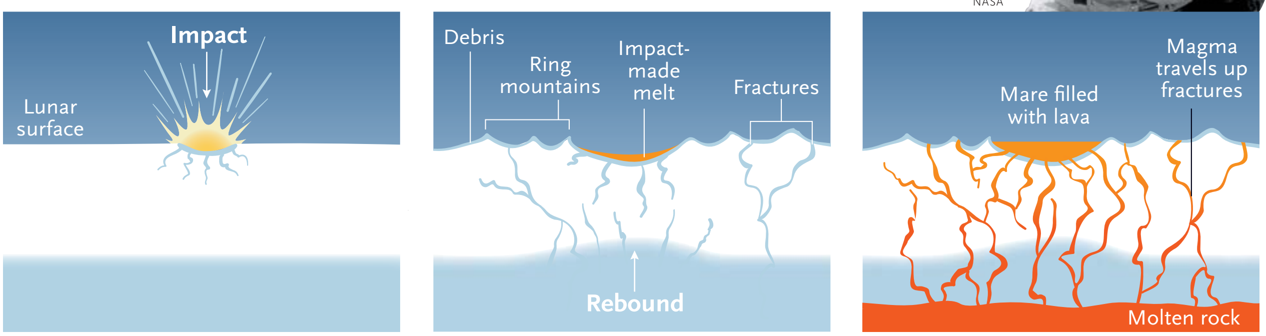
We have found impact craters and basins over the entire lunar surface, but not all basins are filled with lava — some are only partially covered, or not flooded at all. This is a critical point to note for understanding the origin of the hemispheric differences on the Moon: the abundance of maria on the nearside and their scarcity on the farside is *not* merely because there are fewer basins on the





NASA

FIRST LOOK AT THE FARSIDE ***Above:*** **In 1959, the Soviet spacecraft Luna 3 captured this wide-angle shot of the lunar farside. Although of poor resolution, this image and the other 28 the craft took revealed that the Moon's farside (the right three-quarters of the disk seen above) lacks the maria so familiar to observers from the nearside. In the image, the dark spot at upper right is Mare Moscoviense; the one lowest on the center left is Mare Smythii. The small dark circle at lower right with the lighter dot in the center is the crater Tsiolkovskiy and its central peak.** ***Right*****: Apollo 12 astronaut Alan Bean holds a container filled with lunar soil. (Crewmember Pete Conrad, who took this image on November 20, 1969, is reflected in Bean's visor.) Samples gathered by Apollo astronauts revolutionized the study of lunar geochemistry, and planetary scientists still use these samples to study the Moon's geologic history.**



S&T: LEAH TISCIONE (3)

HOW THE LUNAR MARIA FORMED **The Moon's lava seas formed in a multi-step process that spanned about a billion years. First, sometime between about 3.9 and 4.3 billion years ago, an asteroid slams into the surface, blasting out a basin even as the projectile is vaporized. The impact's shock waves fracture the underlying rock (left). The blast hurls debris into rings around the basin, while a small pool of shock-melted rock solidifies inside. Meanwhile, the rock beneath the basin rebounds upward, creating more cracks (middle). Much later — about 3.1 to 3.9 billion years ago — material heated and melted deep inside the Moon by radioactivity rises along the fractures as magma. When it reaches the surface, the lava fills the basin layer by layer to form a dark mare (right).**

farside. In fact, basins are (more or less) equally distributed over both near- and farsides. Some other factor must have caused the volcanic flooding of almost all the nearside basins and only a very few of the farside ones.

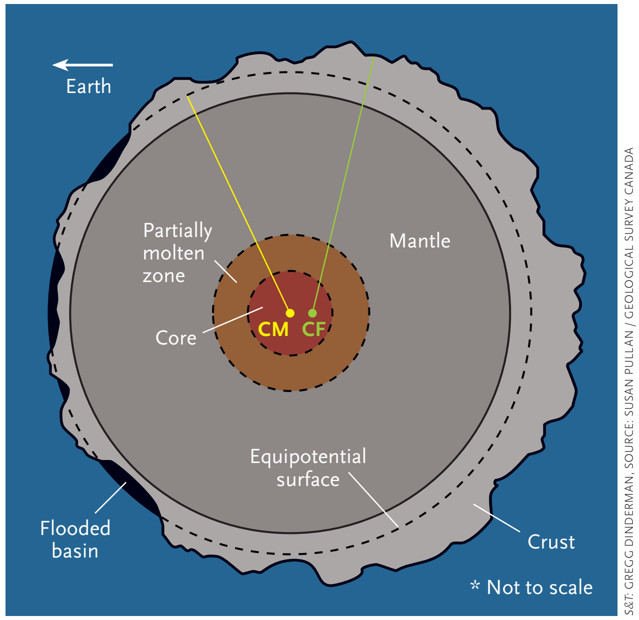
The Crust of the Moon

The lunar crust consists of aluminum- and calcium-rich rocks, similar to the terrestrial rock anorthosite. Anorthosite is made up almost entirely of one mineral: plagioclase, which has a relatively low density. Small rocks rich in plagioclase were first found in samples returned by Apollo 11. From this evidence and from looking at the highlands' topography and density, scientists concluded that the early Moon must have been nearly totally molten, covered by an ocean of magma in which low-density minerals floated to the top (forming an anorthositic crust) while denser, iron-rich minerals such as olivine sank to the bottom, ultimately becoming the mantle. It was this mantle that later partly remelted, through the slow release of heat by radioactive elements, to create the magmas that erupted as mare basalts.

The astronauts deployed long-lived instruments on the lunar surface, including seismometers that measured moonquakes. Study of these quakes showed that the Moon has a crust, a mantle, and possibly even a small metallic core. The lunar crust at the Apollo landing sites is between 35 and 40 km thick, similar to parts of Earth's continental crust. Interestingly, gravity data from orbiting spacecraft show that the crust on the farside is thicker than on the nearside, for reasons that remain unclear. In addition, the Moon's center of mass is offset from its geometric center by a couple of kilometers in the direction of Earth. This offset is probably what keeps the nearside visible and the farside facing away, because it would have forced the Moon's rotation and revolution periods to synchronize.

Armed with these findings, lunar scientists sought to explain the two faces' geologic differences. They first postulated that the difference in crustal thickness between the two hemispheres might explain why there are far more maria on the nearside. How would such a scenario work?

As mentioned, basalts are produced from the partial melting of the deep lunar mantle, forming bodies of liquid rock that are less dense than their surroundings and, therefore, buoyant. These liquids migrate upward along grain boundaries and cracks until they reach a point where they either escape to the surface and erupt or stop moving because the pressure from the overlying rock is no longer high enough to make them buoyant. Assuming all mare basalts came from the same "zone" of melting, scientists suggested that, because the crust is thinner on the nearside, the magmas could reach the surface there and erupt, but rising the same distance on the farside would still leave them below ground level.



LUNAR INTERIOR **The Moon's *center of mass* (CM) is offset from its geometric center (called the *center of figure*, CF) by about 2 km toward Earth. This offset led to the gravitational lockup that keeps the lunar nearside facing our planet.**

This explanation was attractive for a lot of reasons, especially as it unified several disparate observations into a generalized model that nicely explained a lunar mystery. But experience in science shows us that grand unifying theories are usually wrong — or, at best, incomplete. In this case, continued studies of the lunar samples returned by the Apollo missions demolished this *density equilibrium* idea. The composition of the liquid rock that filled maria changes from region to region, which means that the magmas' densities were different. That implies that, even *if* material all came from the same depth (unlikely), it wouldn't necessarily have risen the same distance. Thus, the contrast in the number of near- and farside maria can't merely be the result of magmas of similar densities rising to similar levels.

Lunar Heat

All the rocky planets contain radioactive elements that spontaneously decay into other elements, releasing radiation and generating heat. A classic example is the element uranium, half of which decays into lead over 4.5 billion years. Radioactive decay has been occurring inside the planets since they formed, and the heat that

A THIN VENEER

Although they can span hundreds of kilometers, maria are typically only a few hundred meters thick or less. They're usually thickest near basins' centers — sometimes reaching 2 to 4 km deep — and thinnest near the edges.

is generated partially melts the planets' interiors. The result is the generation of magma, which can cool slowly deep inside a planetary crust (a process called *plutonism*) or be rapidly pushed out onto its surface (volcanism).

Many different radioactive elements produce heat inside both Earth and the Moon. These elements are too large to fit into the crystal structures of the major rock-forming minerals. So as minerals crystallize from the magma, such elements tend to be left behind in the magmatic liquid that remains. On the Moon, this material has been given the name KREEP, which stands for potassium (K), rare-earth elements (REE), and phosphorus (P). We first discovered KREEP in Apollo 12 samples collected in Oceanus Procellarum, the largest expanse of maria. Because KREEP includes the radioactive, heat-producing elements uranium and thorium, a map of high radioactivity on the lunar surface is also a map of the KREEP content of different regions.

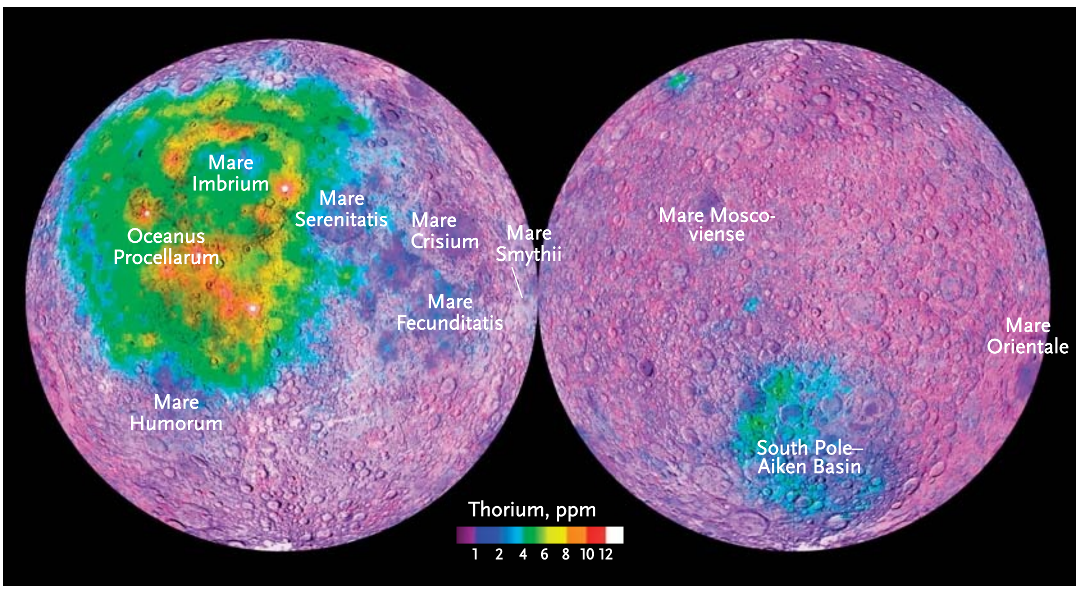
As shown by the 1998 Lunar Prospector mission, KREEP is not distributed evenly around the Moon. Instead, it's concentrated largely on the western nearside, within and around Oceanus Procellarum. A second, much lower concentration is found in the southern central farside, near the small maria on the floor of the South Pole–Aitken Basin, the largest (2,600 km) and oldest (perhaps 4.3 billion years) basin on the Moon. Because volcanism is driven by internal heat, scientists thought that high KREEP levels near the largest maria might mean that radioactivity had generated more heat in these places, resulting in the eruption of more lava. Higher KREEP abundances beneath the nearside than under the farside could explain why the Moon has two faces.

The difficulties in this case lie in two areas. First, the distribution of maria only partly correlates with high levels of radioactive elements. Although Procellarum is both very large and has lots of KREEP, other significant mare deposits occur in zones strongly *depleted* in such material. Such areas include both eastern nearside maria (such as Crisium, Smythii, and Fecunditatis) and some farside maria (Moscoviense and Orientale).

Second, the radioactive elements detected from orbit all occur within the topmost meter of the Moon's crust. Yet mare magmas are generated deep within the Moon, hundreds of kilometers lower. Any relationship between the surface and mantle compositions is likely to be both indirect and complex.

But even if the ultimate cause of the Moon's two-faced nature is a local enrichment of radioactive elements, this merely begs the question: why, then, are the heat-producing elements distributed unevenly on the Moon? There isn't a straightforward answer to this question, though some ideas have been proposed.

One recent paper suggested that since the surface of early Earth would have been molten after the impact that created the Moon, the radiant heat from this glowing sphere would have kept the Moon's nearside from cooling as quickly as the farside did. Such a temperature gradient between near- and farsides would supposedly lead to the creation of a chemical gradient, with a higher concentration of *refractory elements* (that is, those with high melting points, such as aluminum) on the farside. In this model, the thicker farside crust arises because



NASA

RADIOACTIVE MOON Spectra from the Lunar Prospector mission reveal levels of the radioactive element thorium on the lunar surface. Scientists think thorium, along with uranium and KREEP (potassium, rare earth elements, and phosphorous), helped melt the lunar interior, producing the magma that migrated to the surface to create the mare lava plains. But although the highest thorium concentrations appear in Oceanus Procellarum (orange and green area), maria locations don't necessarily match up with high radioactive levels.

RARE EARTH ELEMENTS

Rare earth elements are a group of metals that includes scandium, yttrium, and the 15 lanthanide elements (atomic numbers 57 through 71). They're used in many modern technologies, such as cell phones and hybrid-car batteries. In terms of abundance they're actually far more common in Earth's crust than gold, but they rarely exist in concentrations high enough to make mining economical.

PROFILE OF TWO FACES This mosaic from the Lunar Reconnaissance Orbiter's wide-angle camera shows the Moon centered at 300° east longitude.

NASA GSFC / ARIZONA STATE UNIVERSITY

that hemisphere initially had more refractory elements than the nearside.

But global maps of composition suggest that while regional differences do exist, they aren't primordial. Instead, these differences are the result of a complex history of impacts, mare flooding, and other geologic events that happened long after the Moon formed.

Another proposal is that the current near- and farsides were in a different configuration in the past and a large impact reoriented the Moon's spin axis, making the nearside mare dominated solely by accident. But even if such a scenario is true, it doesn't explain why there were two differing hemispheres to begin with.

A third idea proposes that a large "sub-moon" collided with the proto-Moon early in its history and plastered the farside with an additional rock layer as a "coating," creating the farside's highlands while at the same time "squeezing" that side's subsurface KREEP layer toward the nearside. Such an event does not align with our current understanding of how the impact process works. But even if it were feasible, there is no evidence that the Moon's farside contains any late-added, exotic rock types: farside compositions are similar (or identical) to those found globally around the Moon.

Thus, although these various scenarios can create double-faced Moons, all of the models proposed to date have a *deus ex machina* flavor, and science does not incorporate miracles into its explanations.

So we are left, at least partly, where we started. The Moon shows two faces, and the near- and farsides are different in many ways: maria vs. mostly highlands, thin crust vs. thick crust, and high levels of heat-producing elements vs. low levels of the same. These differences are probably related to differences in the lunar interior, some of which may date back to our satellite's formation. But we still only partly understand the history and processes involved in the evolution of the Moon. So why are the near- and farsides of the Moon so different? We don't know. ✦

Paul D. Spudis *is a planetary scientist specializing in lunar history and processes. He is the author of* The Value of the Moon, *being published in April 2016 by Smithsonian Institution Press. More at* ***www.spudislunarresources.com***.

Mapping the Universe's Ancient Sound Waves

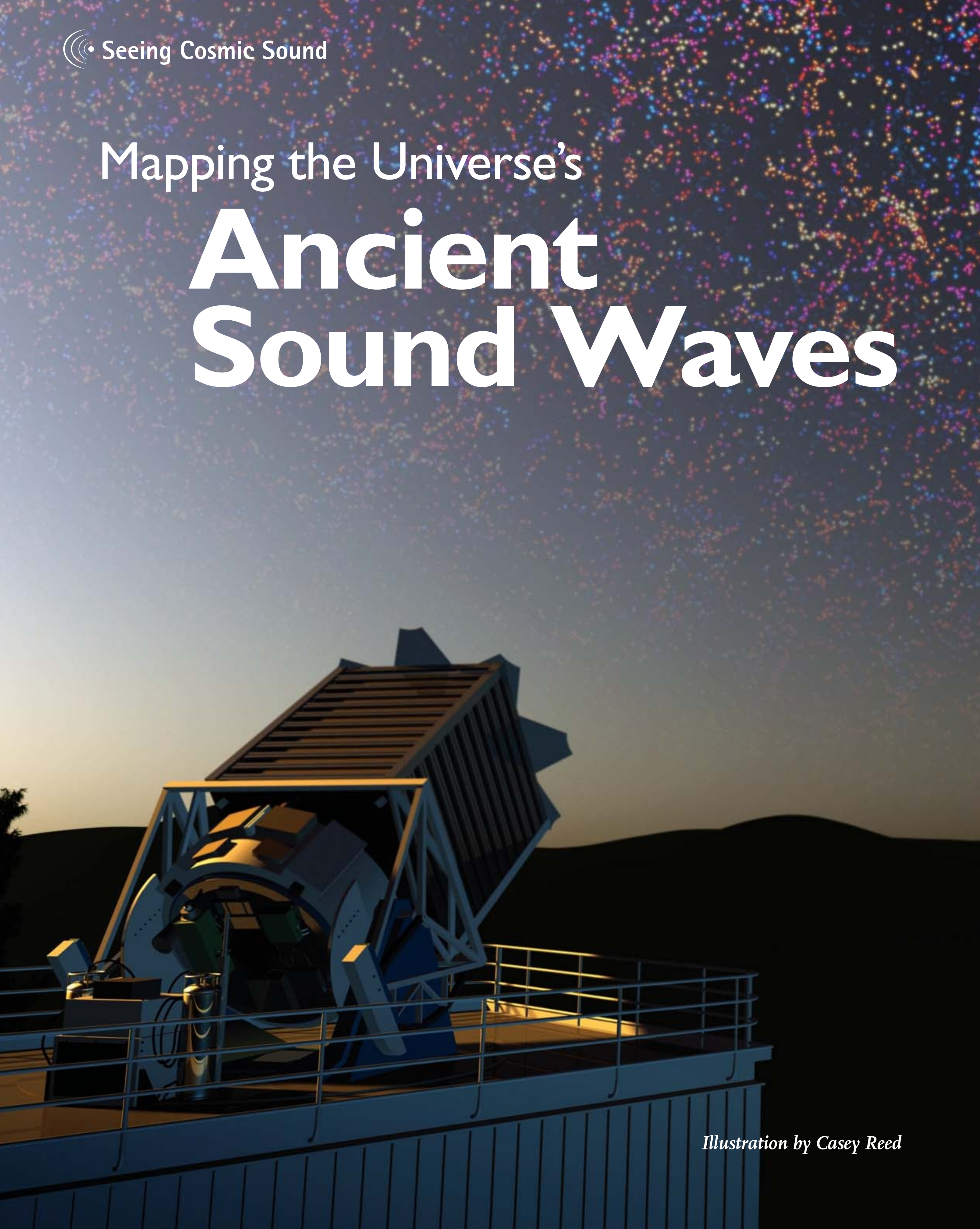


Illustration by Casey Reed

Astronomers are combing through the largest map of galaxies ever created to find the echoes of primordial sound waves.

Daniel Eisenstein In the Sacramento Mountains near Cloudcroft, New Mexico, the Sloan Digital Sky Survey (SDSS) has been charting the cosmic web of galaxies in the largest map ever created. Conceived of in the mid-1980s, the SDSS saw first light in 1998 and soon brought astronomy to mass-production mode. The collaboration now includes some 1,000 astronomers from more than 50 institutions worldwide, and they're tackling a grand goal: measuring the faint imprint of cosmic sound waves that reverberated throughout the universe during its first 380,000 years.

In 2014, SDSS announced a new map that charts the locations of 1.5 million galaxies within a volume equivalent to that of a cube 7.5 billion light-years on a side. This project is known as the Baryon Oscillation Spectroscopic Survey (BOSS), and it aims to shed light on the nature of dark matter and dark energy and the fate of the universe itself.

Sloshing in the Primordial Soup

Today's universe is filled with structure at cosmic scales — giant clusters, filaments, and walls of galaxies separated by voids as large as 200 million light-years across. This cosmic web doesn't come from recent interactions between galaxies — it arose in tiny density variations in the young, hot, and plasma-filled universe. By studying the arrangement of relatively nearby galaxies, cosmologists can reveal how those small, early seeds evolved over time.

In the theory of cosmic inflation, the universe expanded at a gigantic rate for a fraction of a second almost instantly after the Big Bang. The simplest model says the observable universe grew from a size 100 billion times smaller than a proton to roughly a meter across. But due to quantum uncertainties within inflation, some regions grew slightly differently than others. Portions that expanded a little less emerged from the inflationary period denser than average, while other parts came out somewhat sparser.

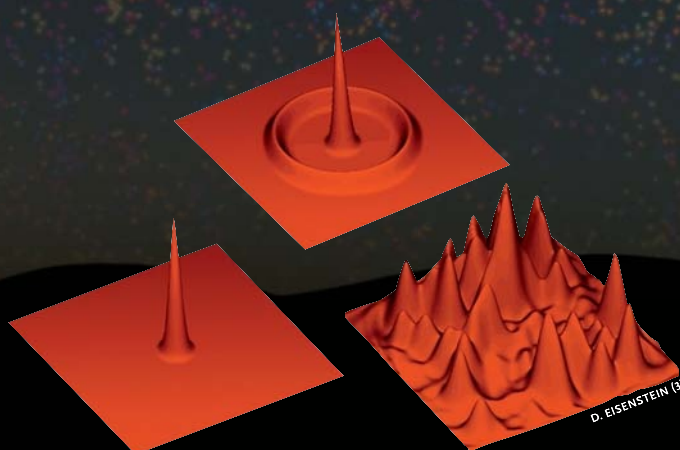
These initial density variations created the main actor of this story — sound waves. Even as inflation enhanced gravity-exerting clumps, the photons within those clumps produced enormous outward pressure. The opposing forces set particles and photons into motion in the form of sound waves. The end of inflation is similar to the popping of a balloon: the balloon's surface enforces a pressure difference, but once it breaks, the air inside expands and creates a sound wave that travels spherically outward.

Each region of the early universe created such a sound wave. Initially, those sound waves rushed about in the plasma-filled universe. There were no stars or galaxies yet in that dense, hot place. Electrons and nuclei couldn't separate far because of their electrostatic attraction, but it was too hot for them to settle down into atoms. Meanwhile, photons within the soup couldn't move far before scattering off an unbound electron.

In this tightly coupled system, pressure fluctuations (aka sound waves) carried electrons and nuclei along with them, leaving the dark matter unaffected. The primordial soup was so hot that the speed of sound reached 57% of the speed of light. Because scientists refer to protons and neutrons as baryons, these early sound waves are called *baryon acoustic oscillations*.

But as the universe expanded, it cooled. Eventually, 380,000 years after the Big Bang, atoms began to form. With no free electrons to scatter them about, the photons finally flew free; the neutral cosmic gas, no longer interacting with the photons, could no longer feel their pressure. The sound speed plummeted and the spherically outgoing waves stalled.

Over the first 380,000 years, the waves had traveled an enormous distance, and even after stalling, their effects expanded along with the universe. One such



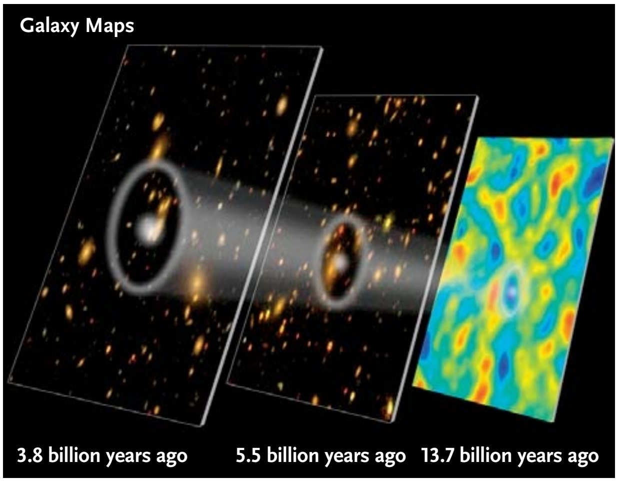
VISUALIZING SOUND WAVES A single disturbance *(left)* initiates a sound wave, like a rock dropped in a pond. And like a ripple on the pond's surface, that disturbance propagates outward *(center)*. In the early universe, each region of the universe initiated its own sound wave, and the resulting ripples overlapped *(right)*. Each ripple has a radius of 500 million light-years in today's universe, and overlapping ripples generate smaller (higher-frequency) overtones. To watch the animation, go to http://is.gd/cosmicsoundwaves.

MAPPING THE UNIVERSE *(Facing page)* This artist's conception shows the Sloan telescope, which charted more than a million galaxies, represented by colored dots, to reveal the imprint left behind by sloshing primordial plasma.

expanding spherical shell would have a radius of 500 million light-years today.

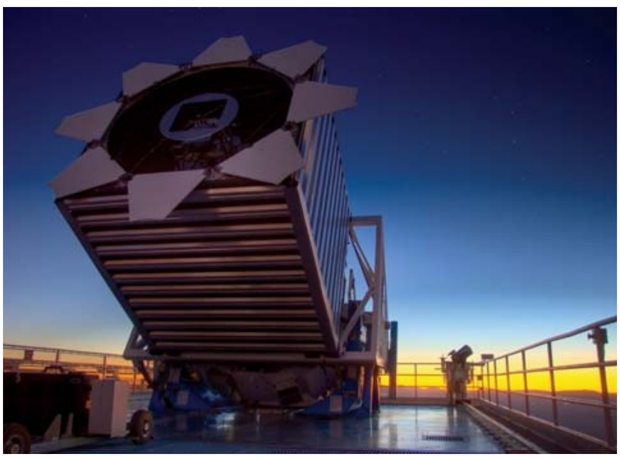
In 1970 Jim Peebles and Jer Yu, both working in the United States, and Rashid Sunyaev and Yakov Zel'dovich, both working in the Soviet Union, predicted that primordial sound waves would produce observable effects in today's universe, affecting the large-scale distribution of galaxies. But astronomers had to wait three decades for data collection methods to reach the extreme level of sensitivity required to see these effects.

Now, by precisely mapping the universe's galaxies and examining their arrangement in space, astronomers can finally study the imprint that primeval waves left behind. Galaxy maps hence serve as a time machine to study the earliest epochs of the universe.



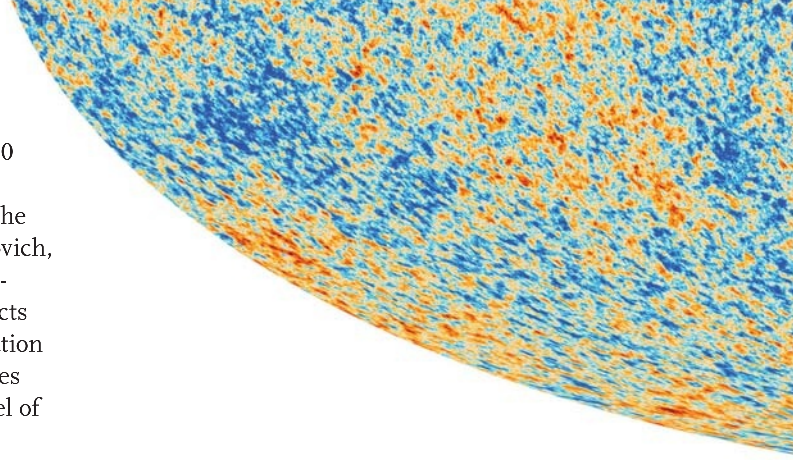
E.M. HUFF / SDSS-III TEAM / SOUTH POLE TELESCOPE TEAM / ZOSIA ROSTOMIAN

BARYON ACOUSTIC OSCILLATIONS Today, a pair of galaxies is most likely to lie 500 million light-years apart. This preferred distance (white rings, left) can be traced back in time to the cosmic microwave background (right), which immortalizes the sound waves that sloshed through the early universe.



DAVID KIRKBY

FROM DUSK UNTIL DAWN The Sloan Digital Sky Survey Telescope is a 2.5-meter f/5 Ritchey-Chrétien telescope with a 3-degree field of view. Rather than sitting enclosed in a dome, the telescope is protected by a wind baffle.



380,000 YEARS OLD The Planck satellite's full-sky image of the cosmic microwave background shows the universe as it existed during the age of recombination, when protons matched up with electrons and photons flew free. The inflation-enhanced temperature variations seen here (colder is blue, hotter is yellow and red) seeded the cosmic web of galaxies we see today.

Seeing Sound Waves

We observe primordial sound waves in two ways. The first method relies on sky maps that chart the temperature of the cosmic microwave background. Though the background looks nearly the same in all directions, precise maps show minuscule variations in temperature of a few parts in 100,000 due to the inflation-enhanced density fluctuations. These variations reveal a strong signature from primordial sound waves: just as ocean waves ripple sand, baryon acoustic oscillations resulted in hot and cold spots with a typical angular size of about 1 degree.

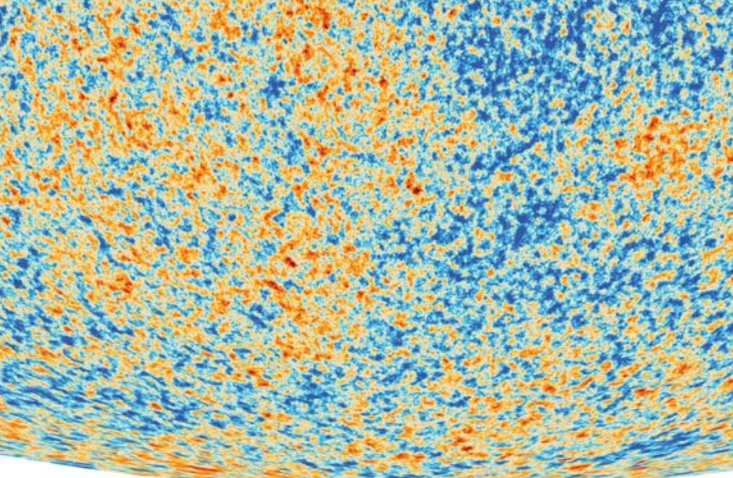
The radius of these sound waves' spherically expanding shells, 500 million light-years in today's universe, represents their fundamental length. As for a violin string, this length sets a fundamental tone as well as a series of higher-frequency harmonic overtones. The Planck satellite has by now produced exquisite observations of the harmonies present in the temperatures it measures, providing a beautiful and compelling validation of the theory of the early universe.

In the second method, astronomers measure sound waves' effect on galaxy clustering in the SDSS maps. Sound waves enhance the abundance of galaxies in a specific pattern: any given pair of galaxies is slightly more likely to be separated by 500 million light-years, rather than 400 or 600 million light-years. Though this can't be observed for an individual galaxy pair, the effect is detectable in large modern surveys with pairs from hundreds of thousands of galaxies. The detection of this statistical effect serves as a "standard ruler."

Mapping the Known Universe

To measure the standard ruler of baryon acoustic oscillations, astronomers must construct vast maps of the galaxies that are strewn across the universe like so many grains of sand. So how does SDSS actually make these maps?

The survey uses a custom-built 2.5-meter f/5 Ritchey-Chrétien telescope. A large secondary mir-

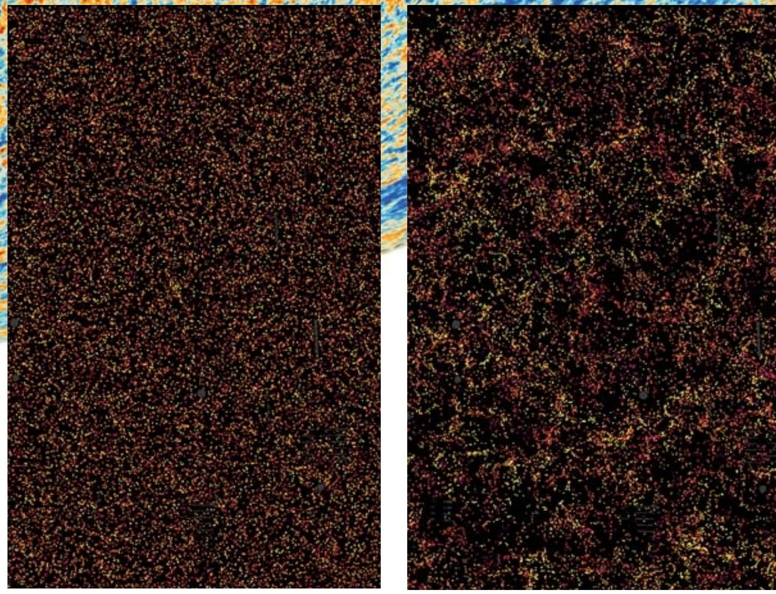


ESA / PLANCK COLLABORATION

ror and two correcting lenses supply a 3-degree field of view. While the primary aperture isn't large for a research telescope, the product of aperture and field of view enables the telescope to rapidly survey the sky.

The original SDSS project relied on two instruments that could each be mounted on the telescope in turn. The first was a large imaging camera, the largest digital camera of its day with 126 megapixels. Over the course of the survey, SDSS has imaged more than a third of the sky through 5 filters centered at 355, 469, 617, 748, and 893 nanometers. It has recorded 1.2 billion detections from 470 million unique objects. Roughly half of these are Milky Way stars; most of the rest are galaxies.

The second instrument was an optical spectrograph that takes an object's light and disperses it into a rainbow, allowing astronomers to measure the intensity in roughly 2,000 wavelength bands. The resulting spectrum may show absorption or emission at specific wavelengths, corresponding to properties of the atoms that are absorbing or emitting the photons. Astronomers can then compare these spectral lines to reference values and determine how fast the object is moving away from us.



D. EISENSTEIN / SDSS (2)

LARGE-SCALE STRUCTURE **Are galaxies distributed randomly in our universe? The answer is a decided "no." Randomly plotted points *(left)* contrast with an actual map of almost 50,000 galaxies at a redshift of around 0.5 *(right)*, whose light has been traveling for about 6 billion years to reach Earth. The right-hand image is about 3 billion light-years wide, 4.5 billion light-years tall, and 500 million light-years thick. Each galaxy is color-coded by its distance, with nearer galaxies yellow and farther galaxies purple.**

But though it's rich with information, spectroscopy is expensive in terms of exposure time. Because the spectrograph splits light into 2,000 or so bands rather than passing it through 5 large imaging filters, the instrument needs more time to collect enough light in each band. The telescope produced images in each filter in only 54 seconds, but a single spectrum typically requires 45 to 60 minutes. Moreover, a spectrograph capable of measuring

Measuring with a Standard Ruler

Finding ways to measure distance is one of the central problems in extragalactic astronomy. Though astronomers can use redshifts to sort galaxies by distance — a higher redshift means a galaxy's light has traveled a longer way through our expanding universe — redshift does not measure distance directly.

Standard phenomena provide other ways to measure distance. *Standard candles* are objects of known luminosity. If we measure their apparent brightness and know their intrinsic brightness, we can infer their distance. *Standard rulers* are objects of known size. We can infer their distances by their apparent size on the sky. This same concept explains why you can still judge distances even with one eye closed as long as you know how intrinsically big something is.

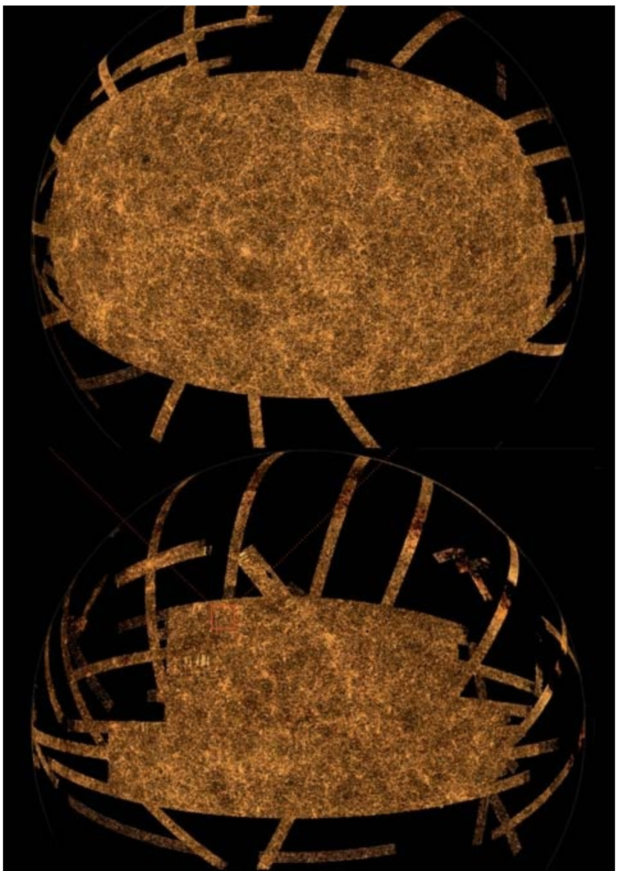
Accurate distance measures are vital to determining the universe's age and composition. For example, a universe that contains more matter will expand more and more slowly because of that extra matter's gravity. If you measure the redshift of an object in this universe, the distance to that object would be shorter than if the expansion had continued unabated. Said another way, a standard candle at a given redshift would appear brighter in a slowing universe than in a continually expanding one.

But it turns out that the universe isn't slowing down at all. In 1998 two separate teams of astronomers studying standard-candle supernovae concluded that faraway explosions appear unexpectedly faint for their redshift. The discovery was shocking: it means the universe's expansion is actually accelerating, probably driven by some repulsive force that acts only on the largest scales. Dubbed dark energy, this discovery, recognized by the 2011 Nobel Prize, presents one of the leading mysteries in modern physics.

Years ago standard candles revealed the presence of dark energy. Now the BOSS project is helping us to use the universe's primordial sound waves as a huge standard ruler to measure the properties of this mysterious repulsive force.

SPECTROSCOPY PLATES Engineers drilled 1,000 holes into every aluminum plate used in the BOSS survey, one hole for each observing target in a given field of view.

DAN LONG & THE SDSS COLLABORATION, WWW.SDSS.ORG



"ORANGE SPIDER" SDSS has imaged the sky north (top) and south (bottom) of the galactic plane. Light from Milky Way stars has been removed, revealing the cosmic web.

MICHAEL BLANTON / SDSS

all of the 200,000 objects that fall in a single 3-degree field of view would be enormously large and expensive.

To minimize the exposure time, SDSS uses a method call *multi-fiber spectroscopy*. The image of the sky comes to a focus at the same location where the imaging detector sat, a 3-degree field of view that spans about 2 feet in diameter. In place of the imager, observers place an aluminum plate with holes drilled at the location of the objects of interest. Each hole is plugged with an optical fiber, a flexible glass cylinder several meters long and a little thicker than a human hair. Once the light enters the tip of the fiber, it is trapped inside the cylindrical walls and routed to the spectrograph. Fed by the fibers, the spectrograph records a simple, two-dimensional picture with hundreds of simultaneous spectra.

The original SDSS used 640 fibers, each covering 3 arcseconds on the sky. For BOSS the facility upgraded to 1,000 fibers per plate, each capturing a field of view 2 arcseconds across, and new detector technologies and optics approximately doubled the instrument's throughput.

Since each 3-degree window of sky has a different arrangement of galaxies, a new aluminum plate must be drilled to 10-micron precision. Workers plug in the optical fibers by hand at the mountaintop, taking roughly an hour to prepare each spectroscopic plate. On long, clear winter nights, SDSS has recorded as many as 9,000 spectra.

SDSS astronomers rely principally on objects' color to decide which 1% of them should be pursued for spectroscopy. Galaxies vary in color depending in part on their redshift; BOSS focused on 1.5 million galaxies whose extremely red colors mark them as giant, faraway elliptical galaxies. These galaxies are typically a million times fainter than the unaided eye can perceive.

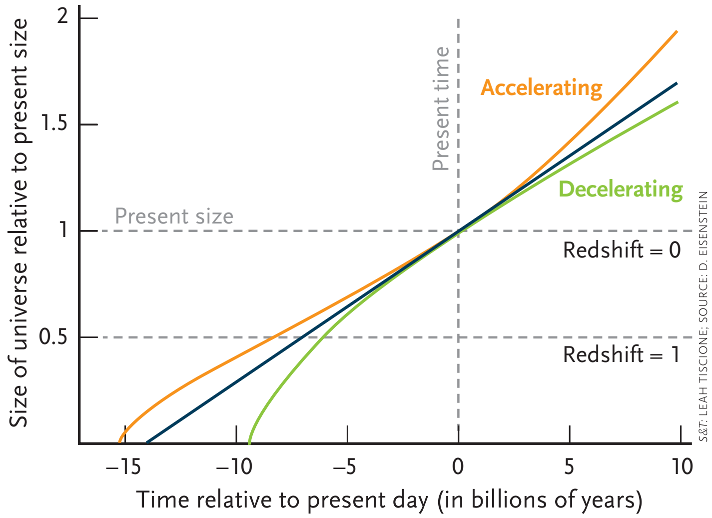
Plate after plate, night after night, and year after year, the survey built up to its full volume. With the release of the BOSS dataset in July 2014, roughly 2,500 plates had been drilled, plugged, and observed, resulting in a total of 2.5 million spectra for 2.2 million unique targets.

After SDSS collected the raw spectroscopic data, specialized software processed the output daily to produce final, calibrated spectra. The software then compared each galaxy's spectrum to a wide range of reference spectra to determine its redshift and distance. Then the data were ready for further analysis.

From Sound Waves to Cosmology

The SDSS BOSS survey mapped out galaxies at several different redshifts, determined the size of the primordial sound waves at each redshift, and calculated that redshift's distance. The results provide the most precise extragalactic distances ever measured.

Combining galaxy maps with a detailed view of the cosmic microwave background confirms a universe where normal and dark matter make up only 31% of the universe's total energy budget. Dark energy takes up the



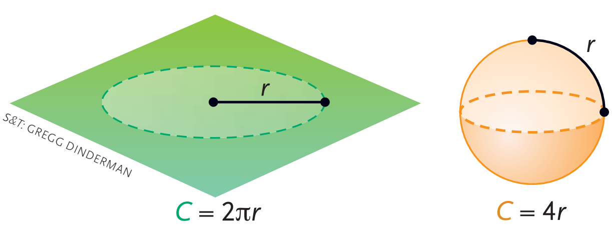
FROM SPECTRA TO COSMOLOGY *Left:* Astronomer Anne-Marie Weijmans, who is involved in a recently launched project mapping nearby galaxies, plugs in bundles of optical fibers. The fibers route incoming light to the spectrograph. *Right:* Determining how redshift relates to distance helps astronomers measure the universe's expansion. For example, in a universe whose expansion is accelerating, light from a galaxy at a redshift of 1 would take a longer time to arrive (traveling a longer distance) than in a constantly expanding universe.

remaining 69% and drives the ever-increasing expansion of spacetime.

The fact that these components sum to 100% is the hallmark of a flat universe. In general relativity, three-dimensional space can curve relative to our normal Cartesian expectations, with measurable effects. Cut a circle out of a piece of paper and it will have a circumference equal to 2π, or 6.3, times its radius. But that rule doesn't hold true for a circle shaped onto the surface of a sphere.

Consider Earth's curved 2D surface. Earth's equator forms a circle about 24,902 miles in circumference. But flying from this curved circle's center (the North Pole) to its edge (the equator) covers just 6,214 miles. In other words, the ratio of the curved circle's circumference to its radius is just 4, rather than 2π. By accurately measuring distances, we can determine that Earth's exterior forms a sphere without ever departing from its surface.

Watch animations that illustrate propagating sound waves and more at http://is.gd/cosmicsoundwaves.



FLAT VS. CURVED Cut a circle out of a piece of paper *(left)* and it will have a circumference equal to 2π multiplied by its radius. But for a circle shaped onto the surface of a sphere *(right)*, the circumference is just 4 times its radius. This simple geometrical concept can be applied to determine whether our 3D universe is "flat" or "curved."

In a similar manner, we can compare the circumference of sound waves seen in the microwave background to the sound waves' radius inferred from galaxy maps. We find that our 3D universe is indeed geometrically flat, in the same sense that a 2D sheet of paper is flat.

Comparing typical separations between galaxies over a range of redshifts further suggests that the density of dark energy remains approximately constant over time. The measurements show that as the universe doubles in size, the density of normal matter drops by a factor of eight — but the density of dark energy drops by no more than a factor of 1.5. That result agrees with predictions from the cosmological constant scenario, which suggests that dark energy comes from the energy of empty space and therefore remains constant in time and location.

Though BOSS results are in, SDSS is far from finished. A recently launched project will continue through 2020, exploring the Milky Way's history and dissecting nearby galaxies. Technological developments, such as the introduction of tightly packed fiber bundles for spectroscopy, will aid these studies.

But dark energy remains a powerful attractor of our scientific attention, even as it pushes the universe apart. SDSS will keep mapping the cosmos, broadening its reach to farther regions of the universe. Using spectroscopy of faint galaxies and hundreds of thousands of quasars, the extended BOSS project will continue to refine our understanding of this most elusive component of our universe, the faint echoes of the primordial sound waves. ✦

***Daniel Eisenstein** is a professor of astronomy at Harvard University. He has been involved in SDSS since 1998 and served as the director of SDSS-III.*

Big Fish, Small Tackle

Mathew Wedel

Grab your binoculars and drop a line in the deep pool of the Virgo Galaxy Cluster.

"Ask people who land huge fish with light tackle, why I do what I do," wrote West Coast observer Jay Reynolds Freeman, in an essay about hunting deep-sky objects with small telescopes. For amateur astronomers, there are no bigger fish than galaxies, and no lighter tackle than binoculars. There's something particularly satisfying about catching an object as grand as a galaxy in an instrument small enough to hold in your hands.

In addition to this reward, observing galaxies with binoculars shows you something about the universe. Galaxies are the building blocks of the cosmos, and in binoculars you can see them in their native habitat. Mostly that means they're isolated by vast gulfs of nearly empty space, but here and there you can find clumps of them. These galaxy groups and clusters are the first steps up a ladder that leads through superclusters, filaments, sheets, and walls composed of thousands or millions of galaxies, to the large-scale structure of the universe.

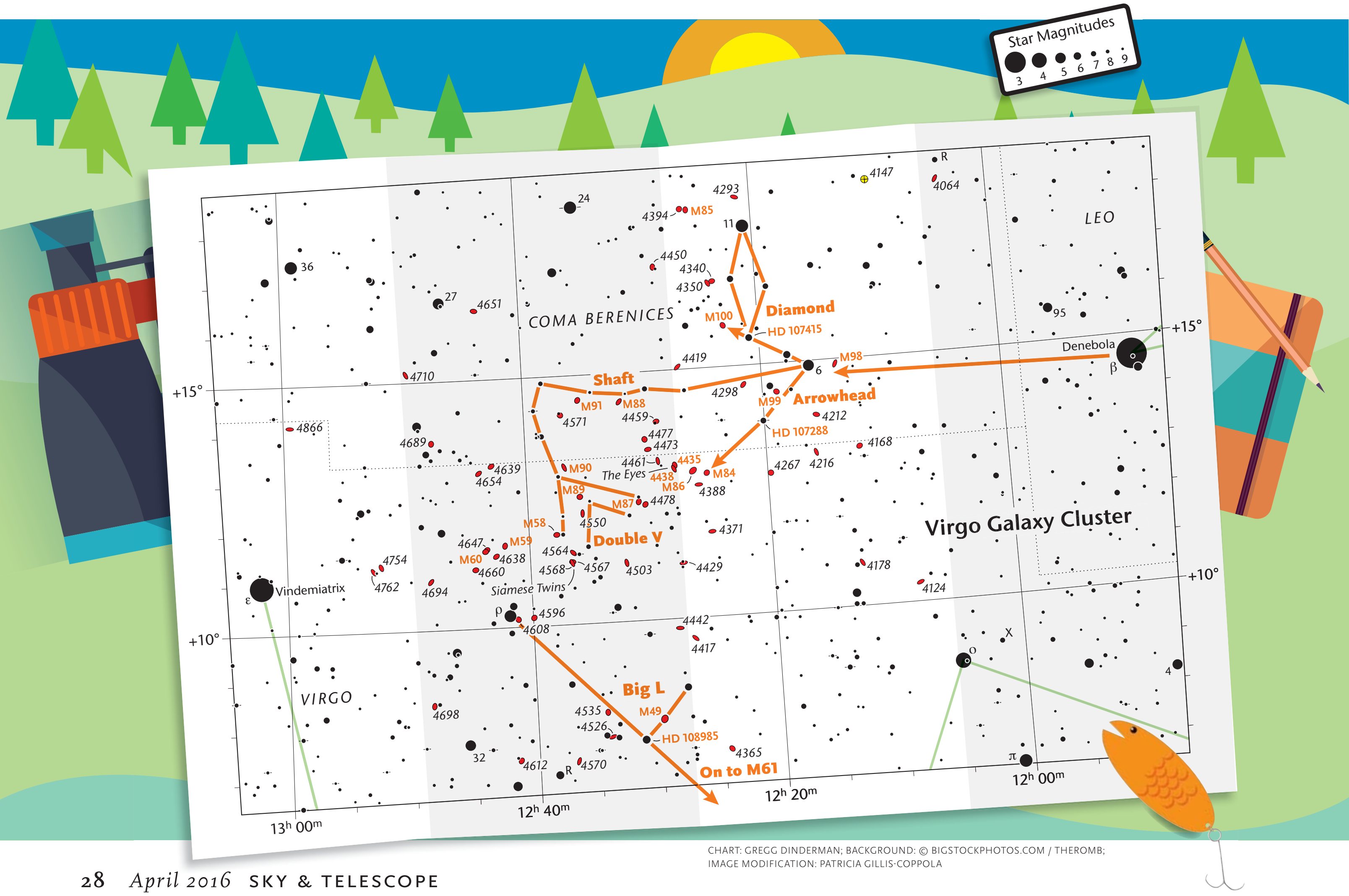
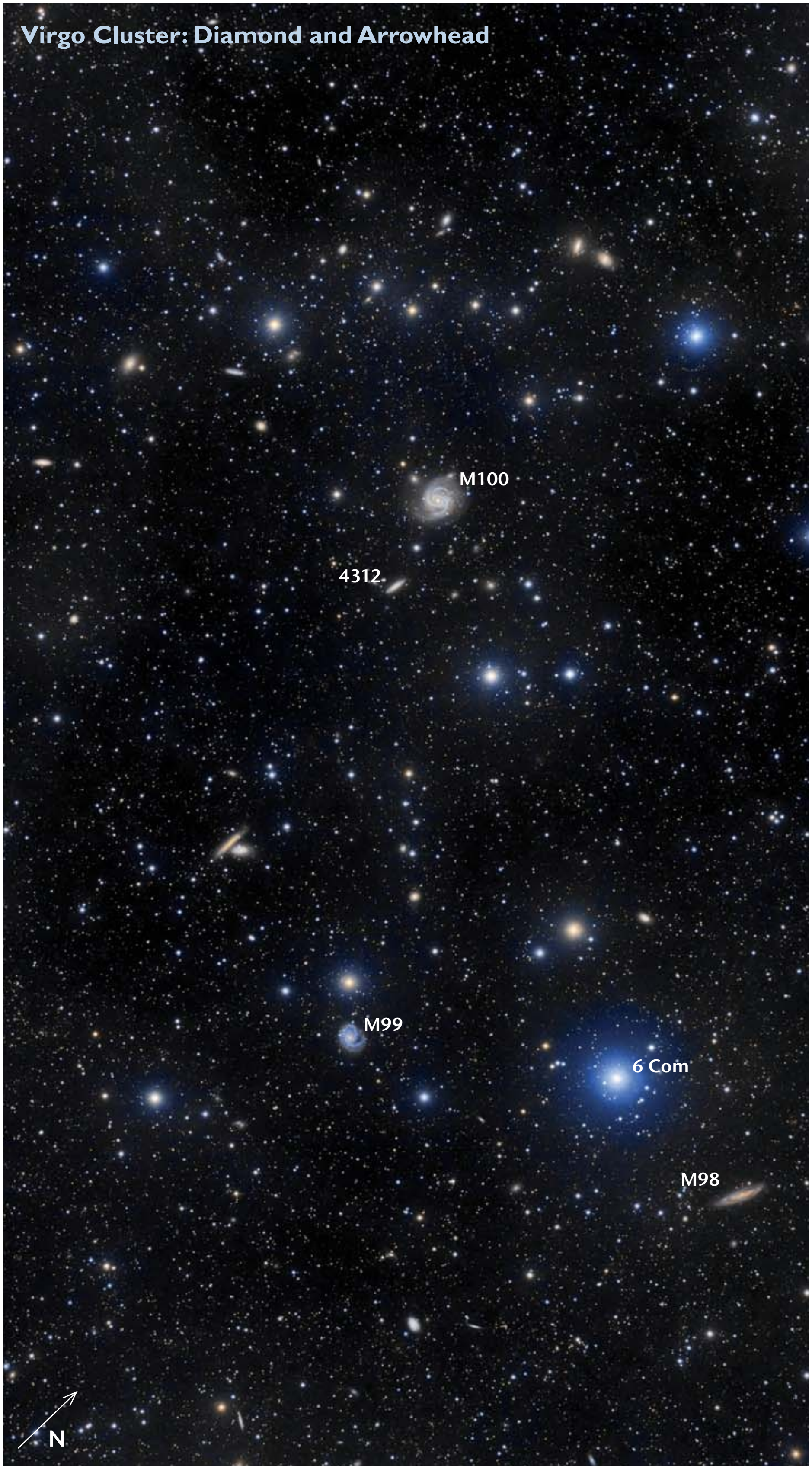


CHART: GREGG DINDERMAN; BACKGROUND: © BIGSTOCKPHOTOS.COM / THEROMB; IMAGE MODIFICATION: PATRICIA GILLIS-COPPOLA

DEEP-SKY FISHING HOLE The Virgo Cluster encompasses some 1,300 to 2,000 galaxies. Sixteen of those galaxies are Messier objects, discovered by Charles Messier and his colleague Pierre Méchain between 1771 and 1781.

ROGELIO BERNAL ANDREO



ROGELIO BERNAL ANDREO

ANCHOR STAR Fifth-magnitude star 6 Comae Berenices sits at the tip of an arrowhead asterism; use it as your home port while locating M98, M99, and M100.

Which brings us to the Virgo Cluster, a collection of more than 2,000 galaxies centered about 54 million light-years away. As the nearest large galaxy cluster, it has drawn the interest of both amateur and professional astronomers for almost a century. It also draws us in quite literally: our Milky Way Galaxy and the other galaxies of the Local Group are all moving Virgo-wards at 100–400 kilometers per second. It's another in a long line of Copernican reality checks — even our local galaxy club turns out to be a relatively small appendage of something much larger. But it makes for a dramatic demonstration at evening get-togethers: point boldly toward Virgo and announce to everyone present that on a cosmic scale, "we're headed thataway."

So, we're going to Virgo — in real life, with our binoculars, and in this article. Nothing has pushed my observing skills as much as going after galaxies with binoculars. They force me to use every trick in the book (see tip box, page 32). Access to dark skies certainly helps as well. Under clear, desert skies, I've seen all of the Virgo Messier galaxies in 10×50 binoculars. But even out there, some of them are tough, and I'm not always successful. A 15×70 instrument brings more aperture for catching and concentrating those photons, and more magnification for separating the galaxies from each other and from nearby stars. But whatever binoculars you have handy, give them a try — a few of the big elliptical galaxies should be detectable in almost any clean, serviceable instrument.

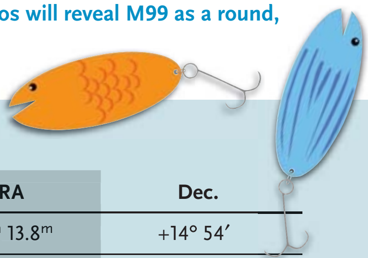
Of the thousands of galaxies in the Virgo Cluster, I'm focusing here on the 16 that are included in the Messier catalog. Most of them are in the northern reaches of the constellation Virgo, but a handful spill over into neighboring Coma Berenices. Several search strategies have been published for getting through the Virgo Cluster Messiers (a comparative list is available online at **messier.seds.org/more/virgo_obs.html**). Some use the galaxies themselves as landmarks. If you have the right combination of dark skies and visual acuity to make that work, I say go for it. I tend to stumble a bit myself in this area, so I use the pattern of foreground stars as a guide.

An easy starting point is the bright star Denebola at the tail end of the constellation Leo, the Lion. Scanning 7° due east will bring you to 6 Comae Berenices, which forms the tip of an arrowhead asterism a little less than 2° across. Three Messier galaxies lie in and around this triangle: **M98** is ½° west of 6 Comae, **M99** is 1° southeast, and **M100** is 2° northeast, just off the northern corner of the arrowhead. Of the three, M100, at a comparatively bright +9.3 magnitude and with no other bright sources nearby to interfere, should be easiest to see. Not only is M100 a good place to start a tour of the Virgo galaxies, it's also a good place to end — after your observing session is over, hit your favorite book, magazine, or website to study high-resolution images of this beautiful grand-design spiral galaxy.

M98 and M99 are both about half a magnitude dimmer than M100 and correspondingly harder to see. M99 is the brighter of the two, but it's located very near a 6th-magnitude star, HD 107170, and

SIGGI KOHLERT

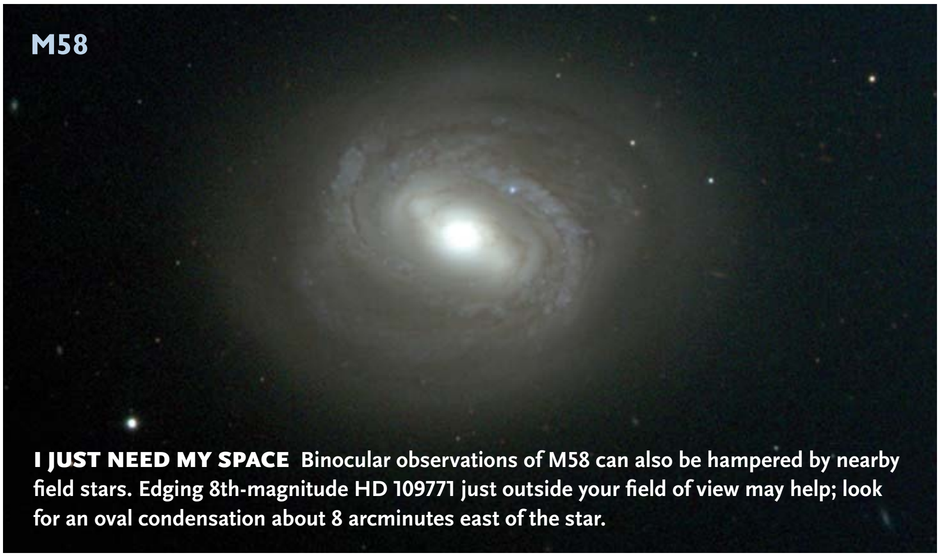
NEXT-DOOR NEIGHBOR In binoculars at low magnifications, 6th-magnitude field star HD 107170 may interfere with your view of M99. However, 15×70 binos will reveal M99 as a round, condensed patch of haze perched southwest of the star.



Gone Fishin'

Object	Galaxy Type	Surface Brightness	Mag(v)	Size	RA	Dec.
M98	Spiral	13.6	10.1	9.5′ × 3.2′	12^h 13.8^m	+14° 54′
M99	Spiral	13.2	9.9	5.4′ × 4.8′	12^h 18.8^m	+14° 25′
M100	Spiral	13.4	9.3	7.4′ × 6.3′	12^h 22.9^m	+15° 49′
M85	Lenticular	13.0	9.1	7.1′ × 5.2′	12^h 25.4^m	+18° 11′
M84	Lenticular	13.0	9.1	6.5′ × 5.6′	12^h 25.1^m	+12° 53′
M86	Lenticular	13.2	8.9	8.9′ × 5.8′	12^h 26.2^m	+12° 57′
NGC 4435	Barred spiral	12.5	10.9	2.4′ × 1.4′	12^h 27.7^m	+13° 05′
NGC 4438	Spiral	13.6	10.0	8.5′ × 3.2′	12^h 27.8^m	+13° 01′
M88	Spiral	13.0	9.6	7.0′ × 4.0′	12^h 32.0^m	+14° 25′
M91	Barred spiral	13.4	10.2	5.4′ × 4.4′	12^h 35.4^m	+14° 30′
M87	Elliptical	13.0	8.6	7.2′ × 6.8′	12^h 30.8^m	+12° 23′
M58	Barred spiral	13.1	9.7	5.5′ × 4.5′	12^h 37.7^m	+11° 49′
M89	Elliptical	12.5	9.8	5.1′ × 4.7′	12^h 35.7^m	+12° 33′
M90	Spiral	13.4	9.5	9.5′ × 4.5′	12^h 36.8^m	+13° 10′
M59	Elliptical	12.9	9.6	5.0′ × 3.5′	12^h 42.0^m	+11° 39′
M60	Elliptical	12.9	8.8	7.0′ × 6.0′	12^h 43.7^m	+11° 33′
M49	Elliptical	13.2	8.4	9.0′ × 7.5′	12^h 29.8^m	+08° 00′
M61	Barred spiral	13.4	9.7	6.0′ × 5.5′	12^h 21.9^m	+04° 28′

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.



I JUST NEED MY SPACE Binocular observations of M58 can also be hampered by nearby field stars. Edging 8th-magnitude HD 109771 just outside your field of view may help; look for an oval condensation about 8 arcminutes east of the star.

NOAO / AURA / NSF

at low magnifications it can be difficult to separate the two. M98 is off by itself, like M100, but it's fairly dim for a Virgo Messier galaxy, and I find it a challenging target under all but the best circumstances.

The northernmost star in the arrowhead, HD 107415, is also the base of a tall, narrow diamond, capped by 5th-magnitude 11 Comae Berenices. Just over 1° east-northeast of 11 Comae is **M85**, a large lenticular galaxy. M85 is the northernmost outpost of the Virgo Cluster, at least for observers using binoculars or small telescopes.

Now go back to the arrowhead asterism and follow a line from 6 Comae past HD 107288 (the bottom corner star) and on about 1½° to the large lenticular galaxies **M84** and **M86**. Of the two, M86 is the more easterly, as well as being larger and brighter. Out of all of the Messier objects, M86 has the highest blueshift — it's actually getting closer to us as gravity pulls it toward the center of the Virgo Cluster from the opposite side.

M84 and M86 comprise the western anchor of a famous line of bright galaxies called *Markarian's Chain*, which swoops off to the east and north. Should you attempt to catch the other members of the chain in your binoculars? Of course! The other members are spaced fairly regularly at intervals of ⅓°. If you see any of the non-Messier members of Markarian's Chain, the most likely will be **NGC 4435** and **NGC 4438**. This close couple is known as "The Eyes" for their eerie appearance in small telescopes. In binoculars they tend to merge into a single diffuse glow, but their combined light makes them a little easier to spot.

Now go back to the arrowhead asterism anchored at 6 Comae. This arrow has a crooked shaft that runs almost due east, composed of five 8th- and 9th-magnitude stars. The spiral galaxies **M88** and **M91** lie just southeast of the third and fourth stars in this line, respectively. M88 is one of the closest galaxies to us in the Virgo Cluster, at a "mere" 47 million light-years away. It's also strongly tilted to our line of sight, which helps concentrate its light. As a result, it's one of the brighter and easier members to pick up with binoculars.

The same cannot be said for M91. This barred spiral galaxy lies almost face-on to us, and at 63 million light-years it's one of the more distant Virgo Messiers. Both factors make it a challenging catch — M91 joins M98 as the Virgo objects that have foiled me the most often. If you do manage to spot it, consider this: the light that you're seeing left the galaxy only a couple of million years after the asteroid impact that wiped out the dinosaurs. Without that cosmic accident, we'd probably still be living in holes and trying not to get stepped on, instead of contemplating the universe.

At the end of the arrow we've been following, an arc of dim stars curves around to the south. Another gaggle of 8th- and 9th-magnitude stars in a nested double-V formation will help you spot four additional Messier galaxies. Easiest is **M87** at the west end of the larger V. M87 is the brightest galaxy in the Virgo Cluster, and not just from our point of view. This monster elliptical is legitimately huge, with an estimated mass of anywhere from 2 to 200 times that of the Milky Way, and a vast population of 12,000 globular clusters, compared to the Milky Way's 200 to 300.

The other three galaxies in this stretch, **M58**, **M89**, and **M90**, are all about one full magnitude dimmer. They're a varied bunch: M58 is a barred spiral; M89 is an elliptical; and

Best Deep-Sky Binocular Practices

These observing tips will help you see more with your binoculars no matter what the quality of your skies.

Go high in the sky. When objects are transiting, you'll experience less atmospheric interference. This helps even under dark skies, but it's crucial if there's light pollution.

Get comfortable. For observing well above the horizon, this usually means reclining or lying down. A chaise lounge, inflatable pad, sleeping bag or blanket thrown over a picnic table, or the hood of a car, or just on a clean, dry patch of grass — all of these can serve as observing "platforms."

Brace yourself. Or at least brace your binoculars against something. I've had good success using a monopod while reclining, trapping the far end between my feet. It may seem clunky, but it works, as will a parallelogram mount or binocular-go-round (*S&T:* December 2007, p. 92).

Be fanatical about dark adaptation. Hooded sweatshirts help. Pull the hood up around your face to block incident light. The hood helps pad the neck strap as well, if you use one.

Use averted vision, and be patient. Averted vision gives better results the longer you do it. This is where all these strategies start to reinforce one another: the more comfortable you are, the more likely you'll wait long enough for dark adaptation and averted vision to really pay off.

M90 is a peculiar spiral galaxy with diminished spiral arms but a recent burst of star formation in its core. Of these three, I find M58 the most challenging, as I sometimes struggle to separate the glow of the galaxy from the light of the 8th-magnitude star just to the west.

About 1° and 1.5° east of M58 lie the large elliptical galaxies **M59** and **M60**. M59 is about as bright as M58, but with no nearby bright stars to interfere, it's a slightly easier catch. M60 is easier still, at about half a magnitude brighter. M60 is only 5.5° west of Epsilon (ε) Virginis, or Vindemiatrix, the bright star that forms the northern "hand" of the Virgo constellation's stickfigure. Some observers prefer to "drop in" to the Virgo Cluster from Vindemiatrix — if you're one of them, feel free to run through this article in reverse!

Roughly 1.4° south of M59 is Rho Viriginis, a 5th-magnitude star at the top of an expansive L-shape that extends southwest over about 4°. About a third of the way along the bottom of the L, ½° northwest of HD 108985, you'll find **M49**, another giant elliptical galaxy. M49 rivals M86 and M87 in brightness, and each of these large ellipticals forms the gravitational center of one of the three major galaxy subsystems in the Virgo Cluster.

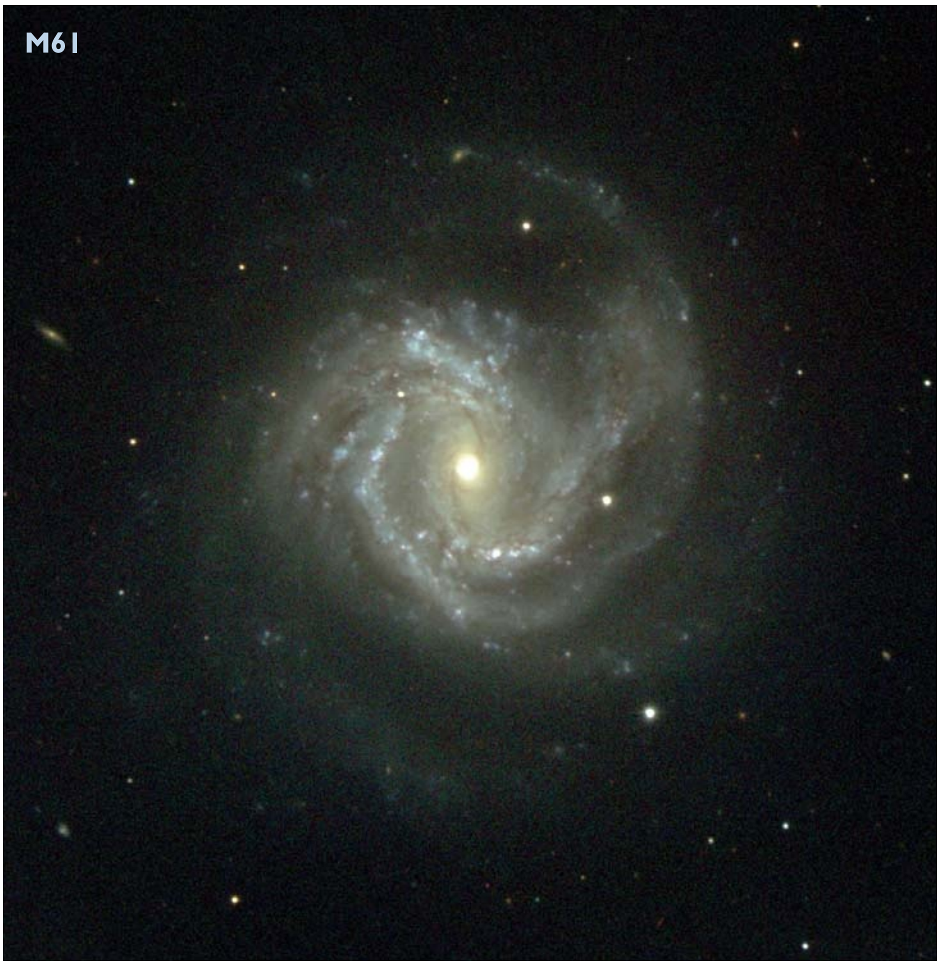
We have one more Virgo Cluster Messier galaxy to find. If you follow the vertical leg of the L asterism down from Rho, past HD 108985, and on another 4°, you'll come to **M61**, almost exactly halfway between 16 and 17 Virginis. M61 is a face-on spiral, but it contains an active galactic nucleus (AGN) that outshines its spiral arms, making it fairly easy to detect.

That's the end of the Messier galaxies in the Virgo Cluster, but we've really only hit the cluster's best and brightest. If you get through all of these with binoculars, grab your favorite atlas and see how many of the non-Messier NGC galaxies you can catch. And come back through with a telescope, especially to see the barred and grand-design spiral galaxies like M58 and M100. There's a lot to see and to think about in this part of the sky — now go have fun seeing and thinking! ✦

*Mathew Wedel chronicles his galactic fishing trips at **10minuteastronomy.wordpress.com**.*

SID LEACH

GRAY GLOW At magnitude 8.4, M49 might seem an easy target, but its surface brightness is only 13.2. Like many ellipticals, it appears as a subtle, soft patch of light in binoculars.



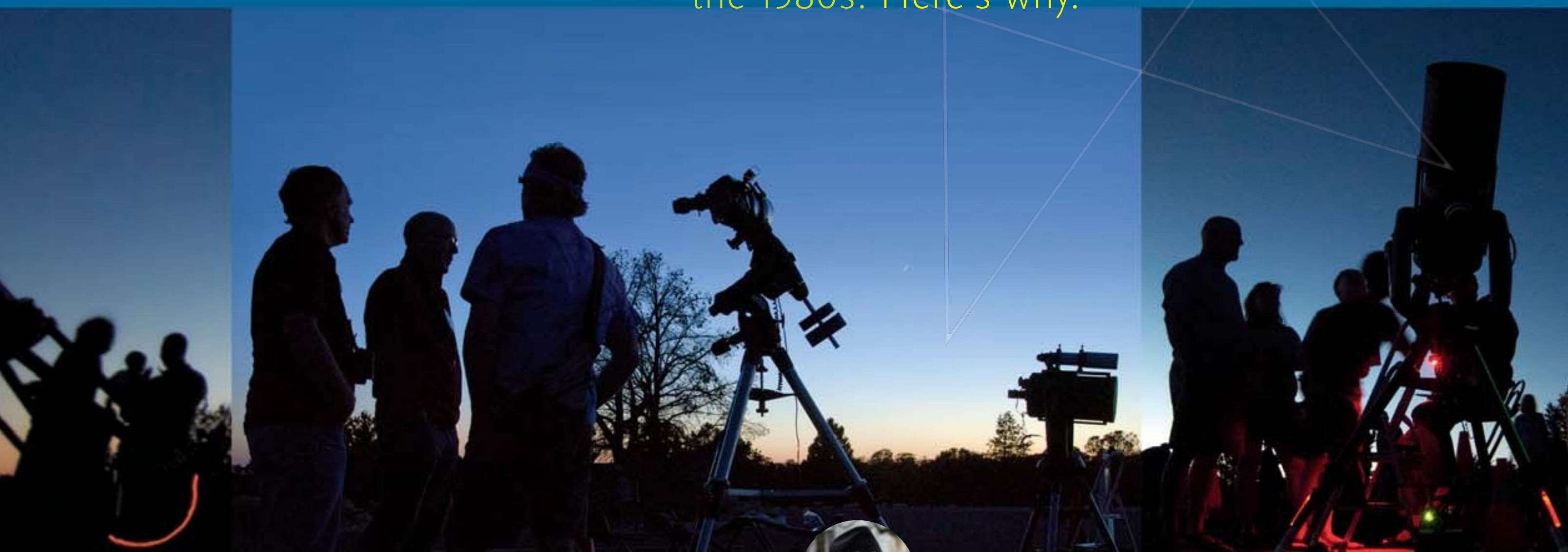
HILLARY MATHIS / N. A. SHARP / NOAO / AURA / NSF

FACE-TO-FACE ENCOUNTER M61, a target suitable for large binos, sits almost halfway between 16 and 17 Virginis. Look for a round condensation that brightens at the core.

Star Parties

in the 21st Century

Organized observing events have undergone explosive growth since the 1980s. Here's why.



I've been attending star parties since the 1970s, and in my opinion they're one of the best things about our avocation. I continually preach about them to beginners at my club and online. If you really want to experience amateur astronomy, I explain, get to a local, regional, or national gathering where amateur astronomers observe under dark skies.

Yet more than a few veteran stargazers have never attended a star party (or have stopped going). That's a shame, because these events are often more fun — and more productive — than observing alone in the backyard or even with friends at the local club's dark-sky observing site (if it's lucky enough to have one).

So here's some perspective on the star-party phenomenon as seen through the eyes of someone who has been to scores of them over the years.

Rod Mollise

Dark skies are the heart of the star-party experience. They aren't the only reason you'd drive a hundred — or a thousand — miles to attend one, but they're a *big* reason. Most of us put up with considerable light pollution in our backyards. A local club's observing site might be a bit better, but it's usually a compromise: far enough from the city to improve upon the backyard sky but close enough to make members' drives convenient.

Star parties, on the other hand, are held at locations as far from the light domes of major cities as possible. If you haven't been out under a truly dark sky lately, you might have forgotten what "dark" really means — how compelling the sight of stars in their multitudes can be. It's easy to identify the amateur astronomers who've never seen really good skies or haven't seen them in a while: they're the people staring at the sky above with open mouths as night falls. Even after nearly 40 years of star partying, I'm much the same. Gazing up at a pristine sky, I find myself thinking, "This is the way you're *supposed* to experience amateur astronomy."

GRAND CANYON NATIONAL PARK (3)

Do you really *need* dark skies to do astronomy? No, but they sure help. Good skies are obviously important for visual observers. The darker the sky, the dimmer and more distant objects you can see and the better they look. A good sky is also important for astrophotographers. Sure, digital processing makes it possible to produce acceptable images from light-polluted sites. But pictures taken out in the dark are easier to process, and the final result is almost always superior.

A good sky is the heart of the star-party experience, but that's just the start. Looking to add a new telescope or accessory to your observing arsenal? A star party is a better place to get an idea of what you want than online astronomy forums or dealers' websites. At a big event, there'll not only be acres of telescopes of every description to check out in person ("Wow, that 25-inch Dobsonian is much bigger than it seems in the pictures!"), but you can also talk to owners about the pluses and minuses of their setups. Most will be happy to discuss their gear with you and might even invite you to try it . . . or buy it. Swap meets are a feature at many events and a good way to obtain used equipment.

One of the best things about star-partying, more intangible than dark skies or astronomy gear, is the camaraderie. Sometimes I feel like one odd little duck. No one around me — other than my wife — cares about, much less understands, my obsession with the Great Out There. Internet discussion forums help, but it's still a relief to spend time with hundreds of people who love astronomy as much as I do.

GRAND CANYON STAR PARTY, ARIZONA **If you've become frustrated by the incessant pall of light pollution over your backyard, or if you're simply looking to spend some quality time with your telescope, there's nothing like the palpable excitement of waiting for darkness — *true* darkness — to envelop you at a local, regional, or national star party.**

In addition to finding yourself among friends (or at least folks who understand your obsession), you'll also learn something at star parties, both from the formal presentations and from just talking to and watching your fellow amateurs. How do I conquer the Herschel list of 2,500 deep-sky objects with a medium-size telescope? How do I bring out detail in galaxy pictures? How do I measure the separations of double stars? Even though I've been in astronomy for a half century, there's always *something* someone can teach me. There is no more important reason for attending a star party.

OK, star parties are great — for amateur astronomers. So what about your non-astronomer spouse or kids? For many of us, the expense of attending a distant major event means it takes the place of the year's family vacation. But with a little research it's easy to find a star party that will please everybody. If your bunch enjoys nature-oriented pursuits like camping, sightseeing, bird watching, or fishing, a star party might actually be better than heading off to Disney World. Moreover, larger gatherings almost invariably feature activities for non-astronomers.

S&T: J. KELLY BEATTY

FUN FOR ALL AGES If you're eager to attend a star party but your family is reluctant to join you, check the event's website to learn what kid-friendly activities or local sightseeing is available.

Where Should You Go?

If you're now resolved to try star partying or to try it again, where might you go? Which star party is right for you? The section below lists prominent events in the U.S. to help you decide. Talking with local astronomy club members or chatting online will also help. But let's at least try to narrow the choices.

Thinking most broadly, no matter how dark its skies, a site east of the Mississippi River will rarely — if ever — compete with a location in the West, and particularly in the desert Southwest. That's because of the East's humidity. Dry skies mean there's less moisture to scatter

Major Star Parties Across America

S&T: RICHARD TRESCH FIENBERG

WINTER STAR PARTY, FLORIDA KEYS

Eastern U.S.

❶ **Stellafane**, held near Springfield, Vermont, is the granddaddy of star parties, having gotten its start the 1920s. The emphasis is on telescope making, but there's plenty of observing, too. **stellafane.org**

❷ The skies don't get much darker east of the Mississippi River than they do at the **Almost Heaven Star Party**, held at Spruce Knob Mountain in West Virginia. This event features great facilities and great observing. **ahsp.org**

Southern U.S.

❸ One of the major events for southern star-partiers is the **Peach State Star Gaze**, held at the Deerlick Astronomy Village near Augusta, Georgia, well east of Atlanta. Expansive fields, great programs, and dark skies make up for rather spartan facilities. **atlantaastronomy.org/PSSG**

❹ The **Winter Star Party** is a snowbird's dream. Utilizing a Girl Scout camp in the Florida Keys, it provides an escape from the frigid north each February and offers a glimpse of the legendary Southern Cross. Space is limited, but amenities include (minimalist) bunkhouses, RV spaces, and plenty of room for tent camping. **scas.org/winter-star-party**

Midwestern U.S.

❺ It doesn't get much darker than the Michigan backcountry, and observing under excellent skies is the main course at the **Great Lakes Star Gaze,** held near Gladwin, Michigan. The site has provisions for RVs and camping, but if that's not your style there are motel rooms available in the area. **greatlakesstargaze.com**

❻ The **Nebraska Star Party** is not

any light pollution. Your telescope goes deeper.

So is a Southwestern star party set in a desert the top choice? Yes, if you live in the West. But for those of us who don't, those beautiful skies are far away. (I keep saying I'm going to get back to the marvelous Texas Star Party one of these days, but that drive of more than 1,000 miles has kept me away.) While I do think Easterners should trek to a big way-out-west gathering at least once in their amateur-astronomy careers, few of us have the time or money to do so often. That's OK — you and I both have star parties closer to home that can provide good skies and a great experience.

Besides, today there are actually things that weigh at least as heavily in my decision as sky quality. The older I get, the more important an event's *facilities* become. When I was in my 30s, I didn't mind tent camping next to my telescope and using a Porta Potti. Now, I choose an event with good amenities: a meal plan, decent cabins, real bathrooms, and showers. I'm willing to sacrifice considerable sky darkness for these. If I can't attend a star party comfortably, I'll opt for a motel room in the nearest town — or not go. If you like roughing it, fine. But if you're bringing the family, think hard about what awaits you.

What if the gathering you've chosen doesn't have good cabins or nearby motels? If you own a travel trailer or RV, you're all set. Almost all sizable events provide hookups (for a price). No RV? Then you can rent one, often for a price comparable to staying in a motel. The advantage is that you'll be onsite, where the action is, not miles away. You also won't have to worry about driving back to the motel if you're ready to call it a night before dawn, potentially disturbing fellow observers and breaking the event's "light rules" with your headlights.

Great Expectations

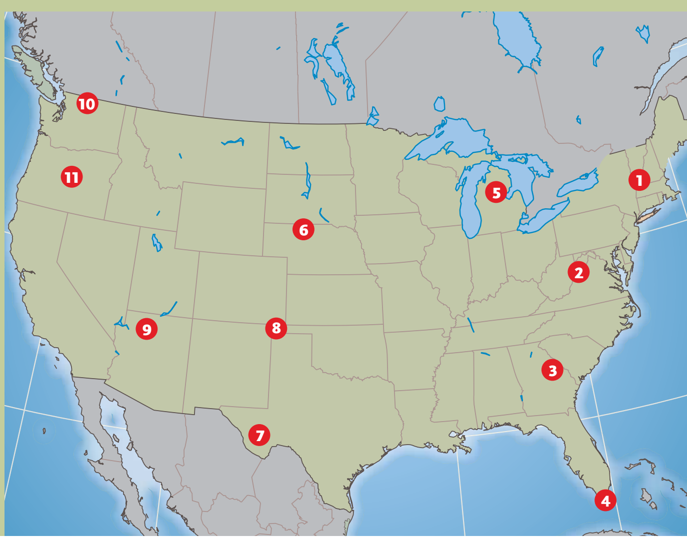
What's the star-party scene like in the second decade of the 21st century? I won't try to predict where star parties are going, but I attend enough events year in and year out to make some observations on what you can expect right now. Although star parties can be as different as snowflakes or the collections of telescopes on their fields, there are some common threads.

One given is "lots of people." The recent economic malaise seemed to diminish star-party attendance for a while, but my usual annual events rebounded, and most observing fields are again tending toward "jam-packed." I'll

THE CLUB SCENE

Virtually every medium-size city in the U.S. and Canada has an astronomy club, which typically maintains a location where members can observe under relatively dark skies. For a comprehensive list of clubs, go to skyandtelescope.com/astronomy-clubs-organizations.

just dark; its sky can also be quite dry. In that regard, this venue often has more in common with star parties in the West and Southwest than it does with Midwestern events. The site, a state park near Valentine, Nebraska, offers only primitive camping and RV spaces, but motels are nearby. **nebraskastarparty.org**



S&T: LEAH TISCIONE

Southwestern U.S.

7 Are there any western skies better than those of the famous (and huge) **Texas Star Party**? Maybe, but not much better, and few events can top the facilities of the TSP, which takes over the Prude (dude) Ranch near Fort Davis, Texas, home of McDonald Observatory. **texasstarparty.org**

8 It's a good thing that (somewhat primitive) bunkhouses are available at the **Okie-Tex Star Party**, since there are no motels nearby in tiny Kenton, Oklahoma. The trade-off is that this growing event boasts very dark southwestern skies. **okie-tex.com**

Western U.S.

9 Want a slightly different experience? Then try the **Grand Canyon Star Party**, which takes place in Arizona's iconic national park. You'll have plenty of opportunities for traditional observing in a beautiful setting, but the main event at GCSP is showing off night skies to park visitors. **www.nps.gov/grca/planyourvisit/grand-canyon-star-party.htm**

10 If you are more interested in a traditional star-party experience, the **Table Mountain Star Party** could be just the thing. While the event is held on a guest ranch at a remote site near Oroville, Washington, cabins and other services are available. It offers dark, dry skies at a higher altitude than you usually get at events in the eastern U.S. **tmspa.com**

11 While I am not normally one for roughing it at star parties, I might have to make an exception in the case of August's Oregon Star Party. Held at a mountain camp near Prineville, Oregon, amenities are basic: tent camping and portable toilets (meal service is offered). The draw here is observing at an incredibly dark site at an elevation of 5,000 feet. **oregonstarparty.org**

TABLE MOUNTAIN STAR PARTY, WASHINGTON

S&T: J. KELLY BEATTY

MUSIC MAKERS Even though dark-sky observing is the foundation of every star party, you'll encounter a variety of scheduled — and spontaneous — activities during the daytime as well.

take a chance on prognostication and say this trend will continue. Unless we can somehow reduce light pollution, more and more amateurs will abandon their backyards for dark skies at least occasionally. Bottom line? If you want to attend an event, register early or risk being left out.

What sort of telescopes populate today's observing fields? I still see plenty of big Dobsonian reflectors — but not as many as a decade ago. The most popular telescopes today seem to be Schmidt-Cassegrain telescopes (SCTs) and color-free apochromatic refractors (APOs). Most surprising to me is that the refractors seem to be overtaking the SCTs. That's probably because prices have fallen dramatically for APOs with apertures of 4 inches or larger, and also because these refractors are so capable of doing excellent astrophotography.

In fact, photography is once again "big" at star parties. These days, most amateur astronomers take pictures of the night sky with digital single-lens-reflex (DSLR) cameras rather than with astronomical-grade CCD cameras. DSLRs make it easy to produce color photographs of the sky. They're continuing to improve for that purpose with every new model, and they're very useful for terrestrial photography too.

For a few years having astronomy vendors at star parties seemed to be a thing of the past (probably due to the recession), but they're making a comeback at larger events, given what I've seen during the past year. It's so nice to be able to buy "in person" again — to look at and handle what you want rather than just click on a link on a website.

Almost everybody at star parties uses Go To computerized telescope pointing. Even observers who normally like doing things the old-fashioned way, "star-hopping" to objects with a finderscope and star atlas, tend to use computer-aided targeting at star parties. I want to see, rather than hunt, deep-sky objects when I get some precious hours under perfect skies.

GRAND CANYON STAR PARTY, ARIZONA

COMMON GROUND Star parties give you the chance to get to know amateur astronomers and the observing gear they use.

GRAND CANYON NATIONAL PARK

Amateur astronomy is not dying of old age. Yes, there's plenty of gray hair on our observing fields, but there always has been. These days I'm seeing plenty of young people, including whole families. Even more encouraging is the *gender* of those young astronomers. Women have long been an untapped resource for amateur (and professional) astronomy, and thank goodness that's changing. It's no longer unusual to see female observers of all skill levels peppering star-party fields. We still have a way to go in this regard, however, and a long way to go in bringing minorities into our avocation.

Finally, and most happily, the amateurs I encounter, even those doing serious projects, are *having fun*. That's what amateur astronomy is — or should be — all about. If star parties were only about tracking down faint fuzzies, I'd have purchased a piece of land out in the sticks long ago and saved myself some money. It's not. As the years have rolled on, I've discovered that it's the company of my fellow star-partiers that keeps me coming back.

So try a star party or two — or go back if you've been away for a while — and I believe you will agree. See you on the observing field! ✦

Contributing Editor "Uncle" ***Rod Mollise*** *spends much of every spring and fall at amateur astronomy events across the U.S. Read about his star-partying adventures and misadventures at* ***http://uncle-rods.blogspot.com***.

STELLAFANE, VERMONT

DENNIS DI CICCO

STAR-PARTY ETIQUETTE Most events have a set of rules designed to enhance the stargazing experience and safety for all concerned. For example, a red (not white) flashlight is a "must" for navigating after dark.

STELLAFANE, VERMONT

BIG SCOPES For many, regional star parties offer the chance to see the heavens through incredibly large reflecting telescopes.

DENNIS DI CICCO

What Should I Bring?

What you'll want to bring to a star party isn't much different from what you'd take to your club's dark site for an evening of deep-sky observing. But here are some additions and caveats:

- No matter what you bring, use a checklist to get it all into your vehicle. This is my number one rule. Don't be that legendary amateur who drove 1,500 miles to the Texas Star Party only to realize he'd left his eyepieces at home. Compose a comprehensive list of what you need, and don't check items off until they are packed in the vehicle.
- If you're using a telescope mount with complex electronics, test it thoroughly before leaving home. If possible, bring a backup mount (or camera or laptop computer) — just in case.
- Be ready for cold weather. A star party is not like your backyard. You'll be out under the night sky, standing stock-still for hours, with little protection from the wind. Even with temperatures only around 60°F, you can get awfully cold. Bring appropriate clothing, and layer it on.
- If you're camping, test your gear if you haven't used it in a while. Pitch the tent in the backyard to make sure you still know how, check the seams (still waterproof?), and make sure sleeping bags and air mattresses are still in good shape.
- Backups are fine, but backups of backups? No. Taking too much can be as bad as too little. Having to pack and repack tons of gear you don't use is no recipe for happy star partying.

In This Section

This Hubble/Chandra/Spitzer composite image shows dust clouds curling around the star cluster NGC 602; see page 57.
NASA / CXC / UNIV. OF POTSDAM / L. OSKINOVA ET AL., STSCI, JPL-CALTECH

Sky at a Glance

APRIL 2016

1–2 **NIGHT**: Algol shines at minimum brightness for roughly two hours centered at 9:09 p.m. PDT (12:09 a.m. April 2nd EDT, when Algol is setting).

9 **DUSK**: Look west-northwest after sunset for the next two weeks to enjoy Mercury's best evening apparition of 2016. The tiny but bright planet doesn't set until just after the end of twilight, depending on your latitude. This evening you'll find Mercury well to the lower right of the thin crescent Moon.

10 **AFTERNOON, DUSK**: The waxing crescent Moon occults Aldebaran this afternoon for telescope users across nearly all of North America; see page 50. By evening, the Moon is above Aldebaran and the Hyades.

16 **EVENING**: The waxing gibbous Moon shines 3°–4° below Regulus, the forefoot of Leo, the Lion.

17 **EVENING**: Find the blaze of Jupiter just 3° or so above the waxing gibbous Moon, near the hind foot of Leo.

20 **NIGHT**: The Moon hangs about 6° above Spica low in the southeast in twilight. Watch the nearly full Moon move closer to the blue-white star during the night. By dawn on the 21st, they're about 4° apart for North America.

22 **MORNING**: The predicted peak of the Lyrid meteor shower falls at 2 a.m. EDT. Observations of this typically weak shower will be hampered by the full Moon.

24 **LATE NIGHT**: The waning gibbous Moon forms an irregular quadrangle, about 10° wide, with Saturn, Mars, and Antares.

Planet Visibility

SHOWN FOR LATITUDE 40° NORTH AT MID-MONTH

	◀ SUNSET	MIDNIGHT	SUNRISE ▶
Mercury	W	Visible through April 27	
Venus		Visible through April 9	E
Mars		SE S	SW
Jupiter	SE	S W	
Saturn		SE S	SW

Moon Phases

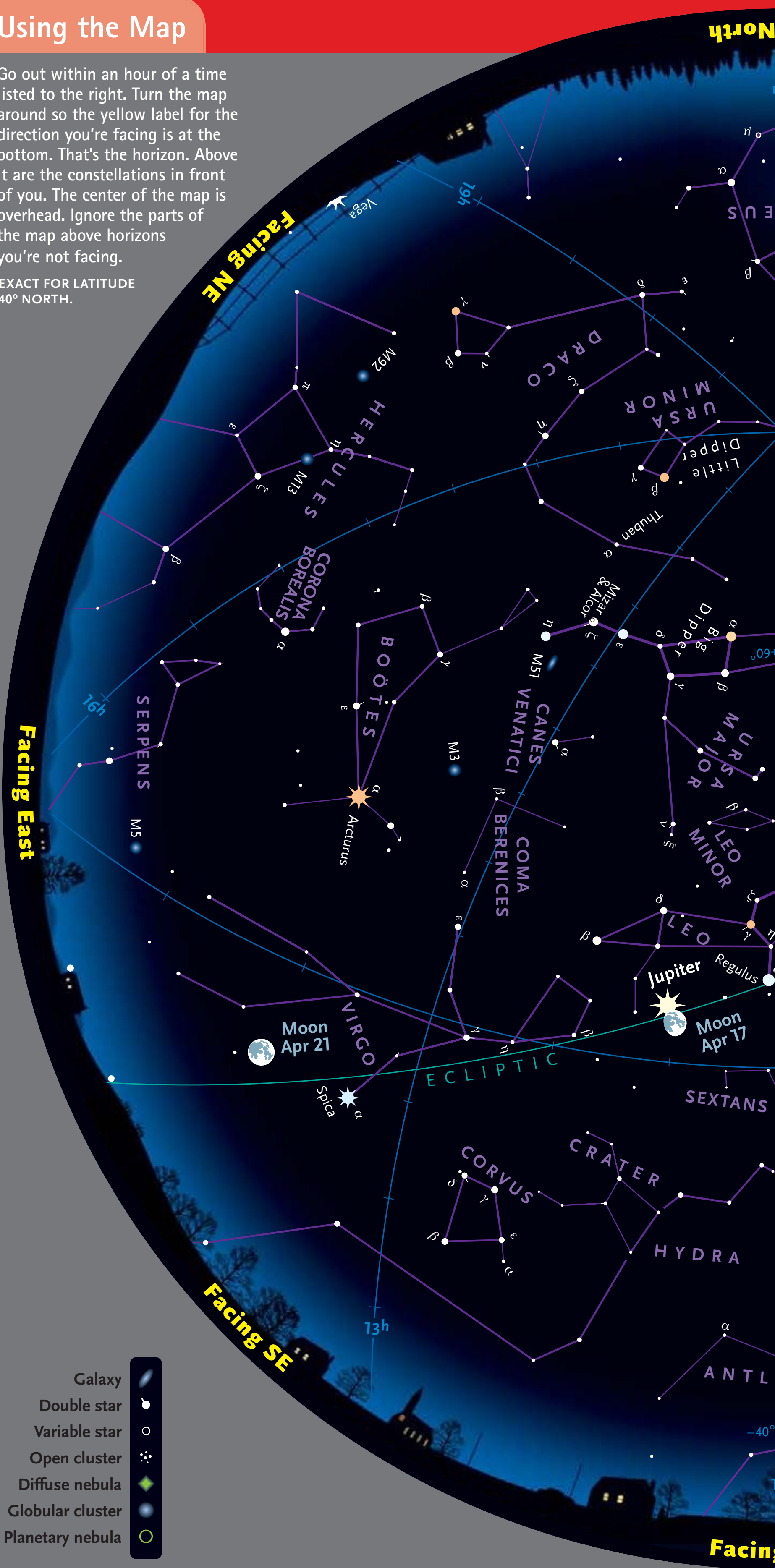
- New April 7 7:24 a.m. EDT
- First Qtr April 13 11:59 p.m. EDT
- Full April 22 1:24 a.m. EDT
- Last Qtr April 29 11:29 p.m. EDT

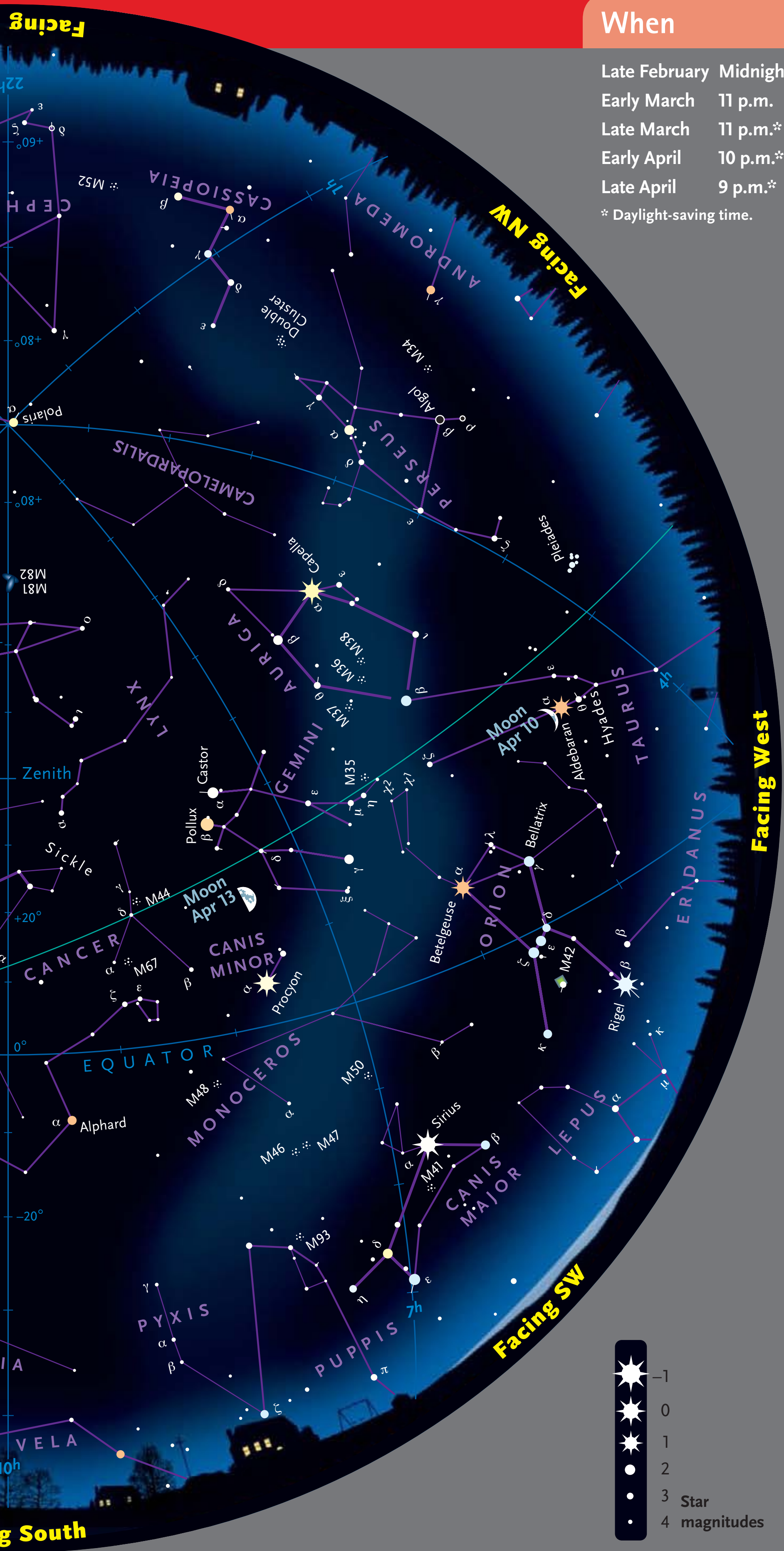
SUN	MON	TUE	WED	THU	FRI	SAT
					1	2
3	4	5	6	7	8	9
10	11	12	13	14	15	16
17	18	19	20	21	22	23
24	25	26	27	28	29	30

Using the Map

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

EXACT FOR LATITUDE 40° NORTH.





When

Late February	Midnight
Early March	11 p.m.
Late March	11 p.m.*
Early April	10 p.m.*
Late April	9 p.m.*

* Daylight-saving time.

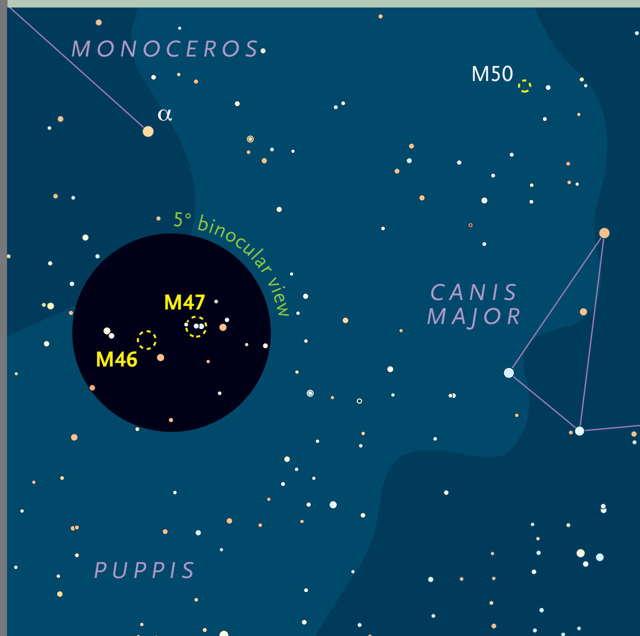
M46 & M47 In Puppis

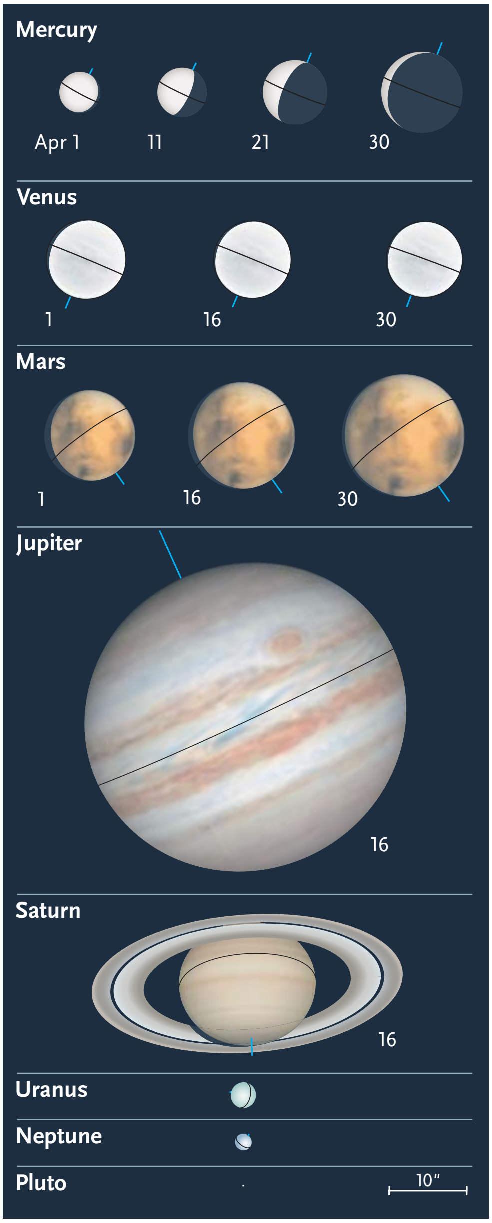
If there's one big category of deep-sky object that binoculars are best at showing, it's undoubtedly open clusters. While most globular clusters and galaxies more or less look alike in binos (with a few notable exceptions), just about every open cluster has its own character. They run the gamut from big, bright, and splashy, to small, dim, and hazy. You can sample some of this range by aiming your binoculars at the Puppis Messier pair, **M46** and **M47**.

From North American latitudes, Puppis itself isn't much to look at. Indeed, the easiest way to find M46 and 47 is to start from Canis Major. Draw a line from Beta (β) Canis Majoris through Sirius, and continue on for twice the distance between the two stars. That brings you to the cluster duo. Both objects comfortably fit in the same field of ordinary binoculars.

M46 and 47 are one of my favorite binocular pairings because each cluster is so distinct. The more obvious of the two is M47. Its brightest stars trace a conspicuous equilateral triangle with a clutch of fainter stars scattered about. It's a pretty sight, but somehow, the longer you look, the less impressive it seems. With M47, what you see is what you get.

By contrast, M46's beauty is subtle to the point of almost being elusive. It's a rich cluster, but its stars are much fainter than those in M47 — most are magnitude 10 or dimmer. As a result, even under good skies, my 10×30 image-stabilized binoculars show M46 as just a small, uniformly lit haze. I have to use my 15×45s to begin to tease out individual stars. And under light-polluted conditions, the cluster disappears altogether, even while neighboring M47 remains visible. ✦



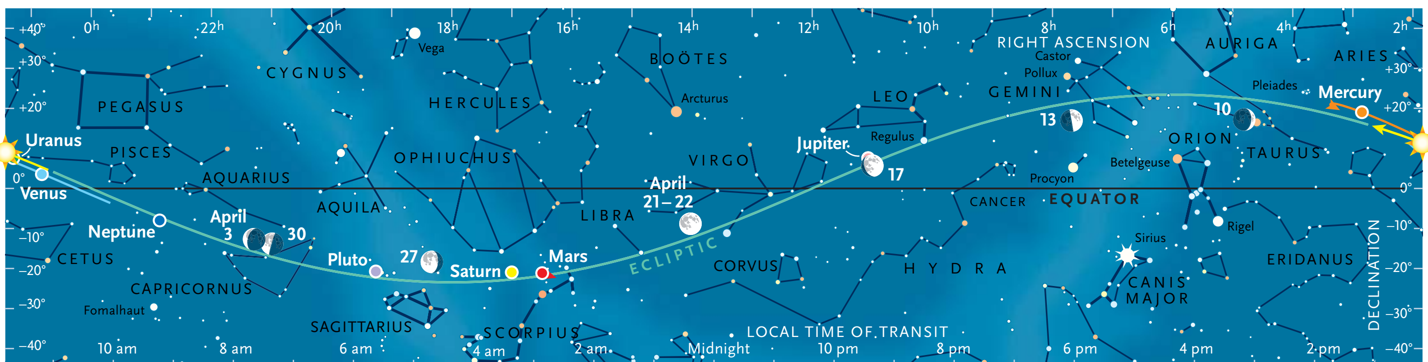


Sun and Planets, April 2016

	April	Right Ascension	Declination	Elongation	Magnitude	Diameter	Illumination	Distance
Sun	1	$0^h\ 42.2^m$	+4° 32′	—	–26.8	32′ 01″	—	0.999
	30	$2^h\ 29.8^m$	+14° 46′	—	–26.8	31′ 45″	—	1.007
Mercury	1	$1^h\ 13.8^m$	+7° 48′	9° Ev	–1.5	5.3″	94%	1.266
	11	$2^h\ 22.5^m$	+16° 08′	17° Ev	–0.8	6.4″	66%	1.056
	21	$3^h\ 09.2^m$	+20° 39′	20° Ev	+0.5	8.3″	31%	0.808
	30	$3^h\ 21.3^m$	+20° 46′	14° Ev	+2.7	10.5″	9%	0.639
Venus	1	$23^h\ 40.2^m$	–3° 44′	18° Mo	–3.8	10.3″	96%	1.615
	11	$0^h\ 25.6^m$	+1° 08′	15° Mo	–3.8	10.1″	97%	1.647
	21	$1^h\ 11.0^m$	+6° 00′	13° Mo	–3.8	10.0″	98%	1.674
	30	$1^h\ 52.5^m$	+10° 12′	10° Mo	–3.9	9.8″	98%	1.695
Mars	1	$16^h\ 21.8^m$	–20° 38′	124° Mo	–0.5	11.8″	93%	0.790
	16	$16^h\ 28.0^m$	–21° 16′	138° Mo	–1.0	13.9″	95%	0.673
	30	$16^h\ 23.6^m$	–21° 38′	152° Mo	–1.4	16.0″	98%	0.587
Jupiter	1	$11^h\ 07.8^m$	+7° 11′	154° Ev	–2.4	43.6″	100%	4.518
	30	$11^h\ 00.1^m$	+7° 54′	123° Ev	–2.3	40.9″	99%	4.817
Saturn	1	$17^h\ 00.6^m$	–20° 58′	115° Mo	+0.3	17.4″	100%	9.554
	30	$16^h\ 56.5^m$	–20° 49′	145° Mo	+0.2	18.1″	100%	9.187
Uranus	16	$1^h\ 16.9^m$	+7° 29′	6° Mo	+5.9	3.4″	100%	20.964
Neptune	16	$22^h\ 50.8^m$	–8° 13′	45° Mo	+7.9	2.2″	100%	30.655
Pluto	16	$19^h\ 14.0^m$	–20° 52′	99° Mo	+14.2	0.1″	100%	32.908

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

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



The Sun and planets are positioned for mid-April; 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

A Secret Flame

Find an individual hidden among the thousands.

And you would cause the sun to see your light
And then be shamed
You cover darkness with a thousand secret flames
With your love, oh my love, oh my love, my love...
— Michael Dunford and Betty Thatcher,
The Young Prince and Princess

In February's column, I discussed the desirability of observing a thousand stars and how to do it in the winter sky. This month, I look at the two sides — practical and mystical — of such observations. The mystical calls for us to see the stars as "a thousand secret flames."

A thousand secret flames. To imagine the stars as fire is a potent idea, even if the truth of it is that they're nuclear fires, producing energy by fusion. In the 19th century, scientists calculated that even an object as massive as the Sun could only burn for a few thousand years by any ordinary chemical reaction. The true nature of stellar fire was indeed a tremendous secret until the 20th century, when Einstein unlocked it.

Cloaks, both natural and artificial, keep the flames of the stars a secret. The scattering of blue by our atmosphere by day conceals the stars. The big reveal at nightfall is astonishing — as demonstrated by Isaac Asimov's story "Nightfall." That story illustrates Ralph Waldo Emerson's quote, "If the stars should appear one night in a thousand years, how would men believe and adore. . ."

But now the intermittent blankets of day, clouds, and bright moonlight are superseded in much of our world by the permanent covers of light pollution. It's up to us who care about the stars and sky to keep fighting to educate the public about the many and serious negative impacts of light pollution. If you aren't familiar with the International Dark-Sky Association, check out the organization and its work on light pollution at **darksky.org**.

A thousand suns to study. Although it may sound outrageous, I suggest that you try to observe a thousand individual stars or star systems, regardless of whether anyone has placed them on a list of visually pleasing double stars, or variable stars, or very red stars. Of course, the best place to start in sampling a thousand suns is with stars that are bright enough to see with the naked eye and therefore appear prominent, perhaps colorful, in the telescope. Record your observations of each star. Ideally, you should also learn facts about every star, to determine how each is an individual. And fortunately someone has done much of this fact collecting for you — retired professional astronomer Jim Kaler.

Kaler's website (**http://is.gd/kalerstars**) features portraits of individual stars. He regularly adds to the site and as of December 2015, the number of stars profiled had reached 892. Coincidentally, the catalog of the ancient Greek inventor of the magnitude system, Hipparchus, includes about 850 stars. These numbers approach 1,000, so you can see that it's possible to observe and study that many. If, however, observing 1,000 individual stars sounds too challenging to you, what should you do? Start with 100. You may find achieving the first 100 easier than you thought. And after that's accomplished, you're on your way to a thousand.

See the secret suns. A star can be a "secret flame" if its characteristics are unknown to you. You can learn the secrets of many a star before observing by consulting Kaler's site or other sources on your bookshelf or the internet. But be sure you don't let that knowledge remain un-visualized. If you do, it could easily wither away into dryness or be forgotten. But you won't forget the hidden realities of the stars once you've actually seen the individual stars themselves, burning in the sky. ✦

AKIRA FUJII

Four Fine Planets

April spreads a variety of sights along the ecliptic.

For much of April, Mercury shines prominently, low in the west-northwest, during evening twilight. Meanwhile, in the southeast, Jupiter beams bright during dusk, climbing to its highest in the south during the evening. Increasingly brilliant Mars and more subtle Saturn rise in late evening, just 7° to 9° from each other above Antares. Venus is mostly out of sight in April, buried deep in the sunrise.

DUSK

Mercury enjoys its highest apparition of the year for viewers at mid-northern latitudes, shining in the west-northwest in evening twilight. At the beginning of April, Mercury remains low, but it makes up for this by burning as brightly as magnitude –1.5. On April 18th, still at a bright magnitude 0, it reaches greatest elongation 20° east of the Sun and achieves its highest sunset altitude, 19°, for observers near latitude 40° north. If you look 45 minutes after sunset in mid-April, you'll find Mercury's vivid light still at least 10° high. And the speedy little world doesn't go below the horizon until just after the end of twilight.

At greatest elongation on April 18th, Mercury's globe appears about 7½″ wide and about 38% lit when viewed with a telescope. But Mercury then fades rapidly, dimming to magnitude +1.5 by the evening of April 25th. By the 28th, it's lost to our view, on its way to crossing the face of the Sun on May 9th.

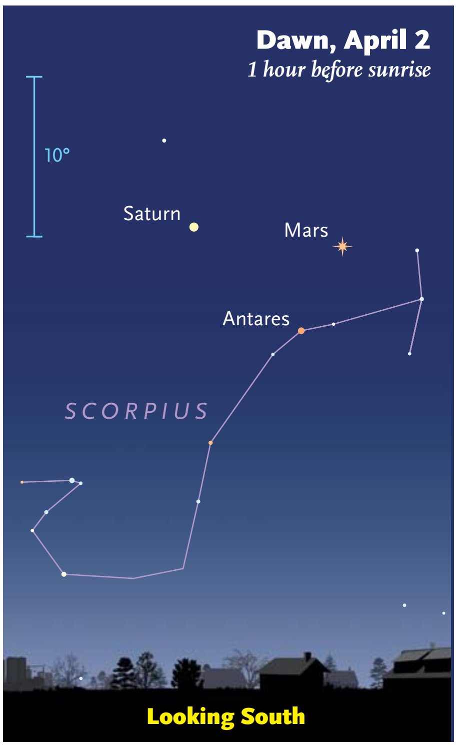
DUSK TO DAWN

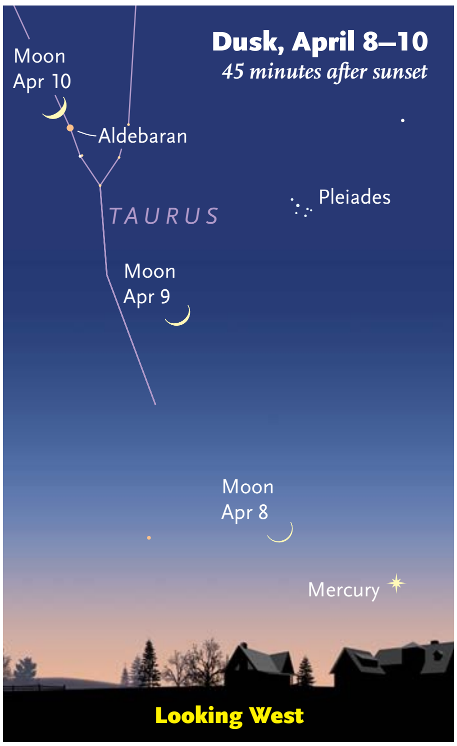
Jupiter reached opposition on March 8th and so remains big, bold, and visible most of the night throughout April. It fades a bit, from magnitude –2.4 to –2.3, with its apparent equatorial diameter shrinking from 44″ to 41″. But the giant planet reaches the meridian, where its telescopic image is steadiest, conveniently early in the night: around 11:30 p.m. on April 1st and before 9:30 p.m. on the 30th.

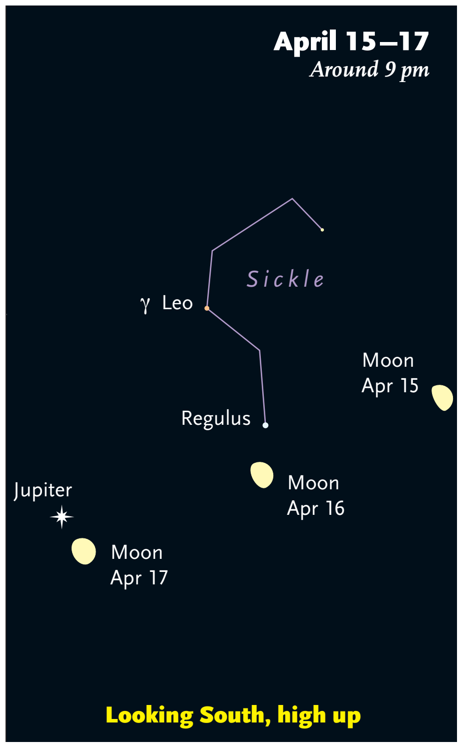
Jupiter moves slowly westward (retrograde motion) in southeastern Leo during April. On April 8th it passes just 7′ north of Chi (χ) Leonis. The 4.7-magnitude star's radiance is rivaled by that of the Galilean satellites of Jupiter, making Chi briefly seem like an imposter moon.

NIGHT

Mars and **Saturn** form a fascinating pair above Antares this spring. At the beginning of April, we have to wait until almost midnight for Mars to rise and about another 40 minutes for Saturn.

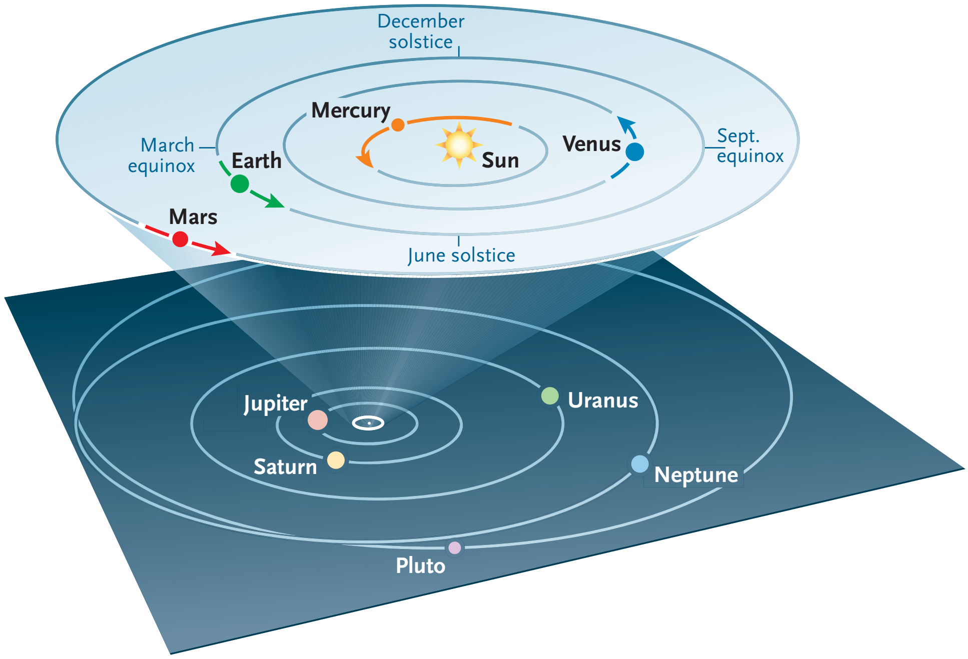






ORBITS OF THE PLANETS

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



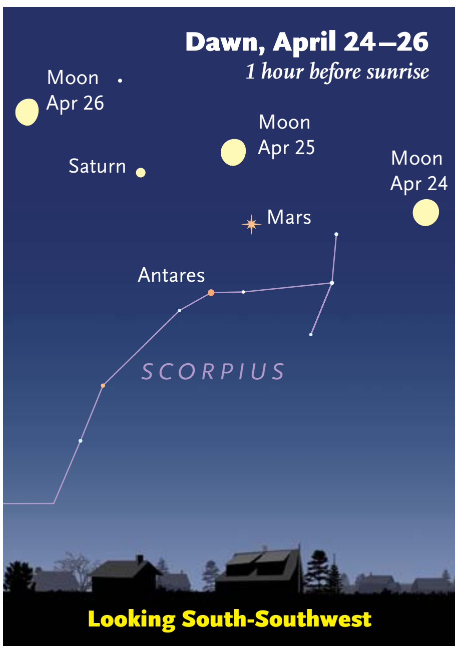
By the end of the month, however, Mars clears the horizon around 10 p.m., with Saturn appearing only about 30 minutes later. Being far south, though, they remain low long after rising for observers in mid-northern latitudes. Plan to observe them telescopically when they're at their best, near the meridian during the hour before dawn, around 5 a.m. as April starts and 3 a.m. as the month ends.

Saturn creeps west in front of the stars with retrograde motion and Mars moves east with direct motion, narrowing the gap between them from 9° to 7° this month — until just after April 17th, when Mars halts and begins its own retrograde motion, increasing the gap once more to 8°. The Red Planet spends April just over the border from Scorpius in Ophiuchus, the current home of Saturn, before crossing back into Scorpius in May.

Orange-gold Mars and golden-white Saturn will form remarkable triangles with Antares this spring and summer. Mars fantastically flames up from magnitude –0.6 to –1.4 in April, kindling to brighter by far than any star visible in the April night. Saturn brightens only slightly, however, from magnitude +0.3 to +0.2. Antares, somewhat variable, has an average brightness of +1.06.

The telescopic views of Mars and Saturn in April are exciting. Saturn's globe widens from about 17½″ to slightly more than 18″ wide. The planet's grand rings tilt a wide-open 26° from edgewise and measure 40″ across; see page 48 for more on observing Mars.

Even more notably, Mars swells from about 12″ to 16″ wide during the month. This is the largest Mars has appeared in a decade. But Mars will grow even larger as it reaches opposition on May 22nd and then as it makes its closest approach to Earth on May 30th.



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.

DAWN

Venus rises less than a half hour before the Sun this month and is unobservable past the morning of April 9th or so, depending on your latitude, air clarity, and eyesight.

Uranus is in conjunction with the Sun on April 9th and out of sight all month.

MOON PASSAGES

The **Moon** is a waxing crescent well to the upper left of Mercury in twilight on April 8th and occults Aldebaran during the afternoon of April 10th for all the contiguous United States and southern Canada; see page 50. The waxing gibbous Moon hangs below Regulus high in the south on the evening of April 16th and much closer to Jupiter the next evening. The waning gibbous Moon forms a rather compact triangle with Mars and Saturn at dawn on April 25th and a straight line with them the next morning. ✦

At Last, a Fine Mars Apparition

Mars moves into its best showing in a decade.

Mars has a reputation as one of the biggest disappointments in a telescope. It spends most of its time far from Earth, and it's a small planet to begin with. So it's usually just a tiny, shimmering fuzzball. Mars passes close to us only every 2.1 years around its oppositions, and even then it comes and goes fairly quickly. Moreover, because Mars has a rather elliptical orbit, many of its oppositions are relatively distant.

But now everything is coming together better than it has in 10 years.

We're currently on the upswing of Mars's 16-year cycle of oppositions near and far. By April 1st its globe in a telescope reaches an apparent diameter of 11.9 arcseconds, enough to show surface features fairly well in a sharp 4- or 6-inch telescope during excellent seeing. By May 1st Mars is 16.1″ wide, and when it tops out for the week around May 30th, its closest-approach date, it will appear 18.6″ across. Seen in a 200× eyepiece, that's like a ping-pong ball 7.2 feet (2.2 meters) away. Not bad.

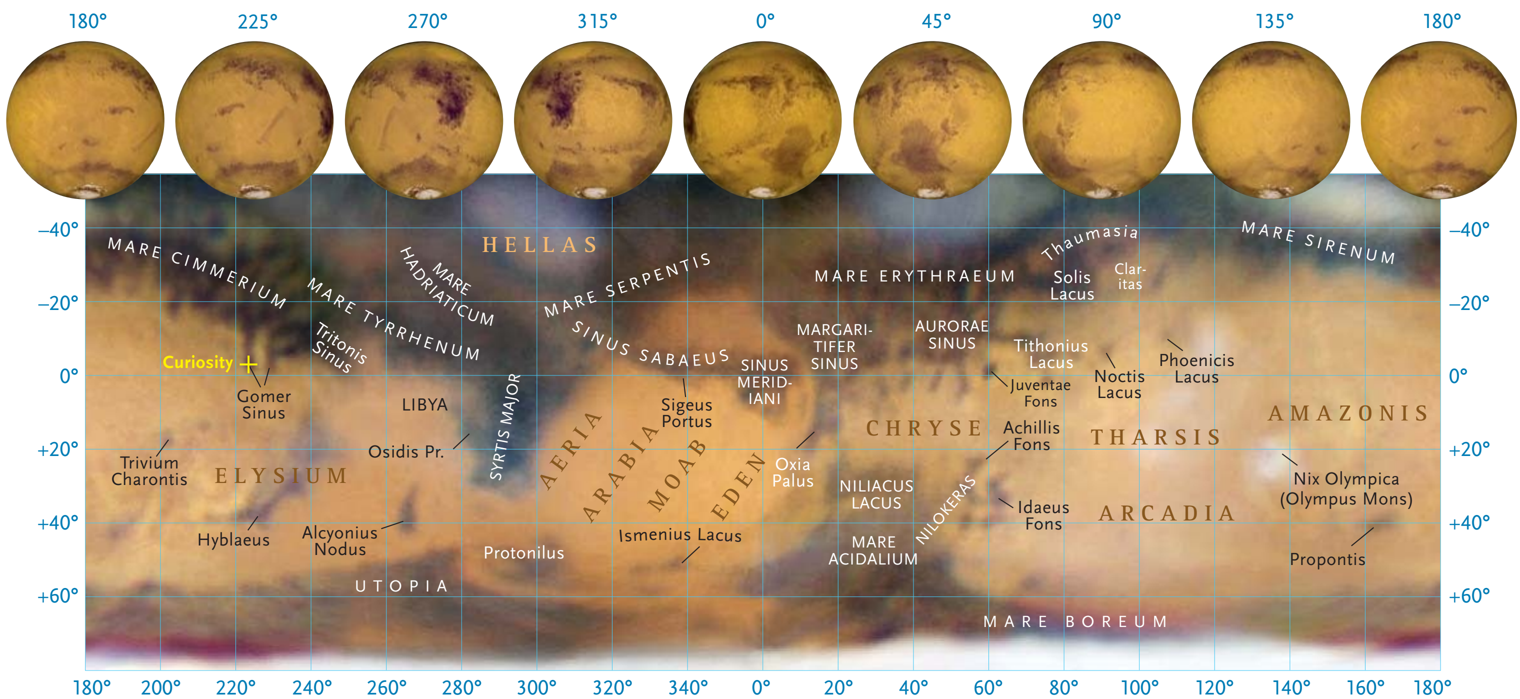
Opposition comes eight days earlier, on the 22nd, when Mars will shine at an almost Jupiter-like magnitude –2.1. Mars remains larger than 14″ all the way from April 17th to July 21st.

But there's a catch. This season Mars is fairly far south, in or near the head of Scorpius around declination –21°, so it will never get very high for those of us in the north temperate latitudes.

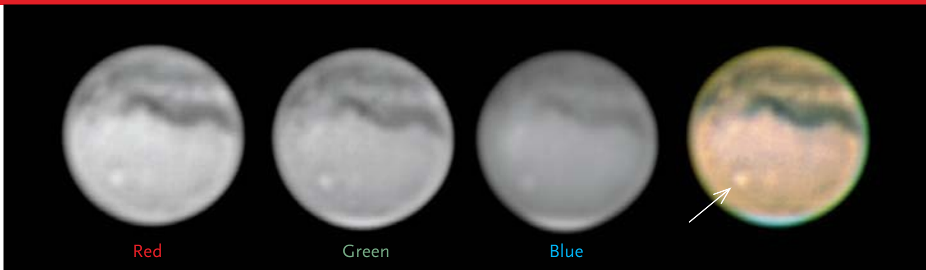
As always, give your telescope plenty of time to cool to the surrounding air temperature before expecting good views at high power. Observe often to catch nights of fine seeing. And spend lots of time watching for everything on Mars that is possible to glimpse; more comes out with time.

Here are some things to look for.

The polar caps. We see Mars nearly equator-on this season, with its north pole tilted only slightly into our view and the south pole tilted slightly away. Mars's northern hemisphere is currently in the height of its long summer (which runs from January 3rd to July 5th this year), so in April and May the North Polar Cap should already be very small and continuing to shrink. The Martian southern hemisphere is having winter, so the edge of the South Polar Hood of winter clouds may peek into view around the planet's southern limb. The southern cloud hood



Use this map to identify surface features you see. South is up, and Martian west longitude is labeled along the bottom. Damian Peach assembled the map from images he took in 2009–10. The globes, from Hubble images, are tipped about as Mars will appear this year. Each globe displays the central-meridian longitude that is directly below it on the map.



When moisture-laden winds blow up and over broad, high Olympus Mons, a stationary hood of clouds (arrowed) sometimes forms. The 19th-century Mars mapper Giovanni Schiaparelli named this bright spot Nix Olympica, "the snow of Olympus," though he knew nothing of its origin. It was pure coincidence that it turned out to be a mountain. Dark Mare Sirenum is above center. South is up in all images.

M. F. MOBBERLEY

should be larger but probably less brilliant white than the North Polar Cap. As always, tell celestial north and south in your eyepiece view by nudging the scope in the direction toward Polaris; new sky will enter from the view's north edge.

Albedo features. The Martian surface markings — the dark "maria" and bright "terrae," with their picturesque classical names given by Mars mappers in the late 19th and early 20th centuries — are merely differences in the average reflectivity (albedo) of the surface rock, sand, and dust. Windstorms sometimes move the dust, resulting in both seasonal and long-term changes. Syrtis Major, the most prominent dark marking, has undergone a dramatic, long-term widening since the 1950s. It also shows lesser seasonal changes in width: It tends to be widest in the northern hemisphere's midsummer, meaning now.

The area around Solis Lacus, sometimes called the "Eye of Mars," is notorious for changes in surface markings. So is the Elysium region.

Clouds and hazes. The Martian atmosphere is ever-changing. Look for white water-ice clouds and bluish limb hazes. Bright surface frosts also occur; these are hard to tell from clouds. As ice in the North Polar Cap sublimates through the northern summer, the atmosphere gains more water vapor and clouds become more frequent planet-wide.

Discrete clouds often recur at the same places, especially Hellas, Chryse, and Libya. The "Syrtis Blue Cloud" circulates around the Libya basin and across Syrtis Major; it's best seen when these features are near the limb. Viewing this bluish cloud through a yellow filter may cause Syrtis Major to appear distinctly green.

Orographic clouds sometimes form over windblown Martian mountains, like orographic clouds on Earth. Enormous Olympus Mons and the three other shield volcanoes of the Tharsis plateau are especially prone to them. So is Elysium Mons in Elysium on the planet's other side.

Limb brightenings ("limb arcs") are caused by dust and dry-ice crystals scattering light high in the Martian atmosphere.

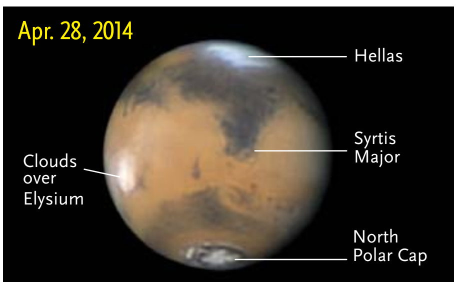
Morning clouds are bright, isolated patches of surface fog or frosty ground near the morning limb (the celestial east or "following" side). Fogs usually dissipate by midmorning as Mars rotates;

WHICH SIDE ARE YOU SEEING?

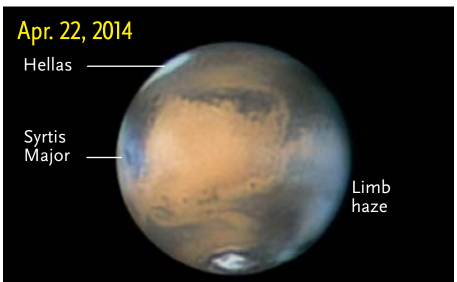
One side of Mars is fairly blank; the other is more feature-rich. To identify surface features you see in the eyepiece, you'll need to know what side of Mars is facing you.

To find out, enter the time and date when you plan to observe into our Mars Profiler, at **SkyandTelescope.com/marsprofiler**. Choose the correct orientation to match your telescope, and compare the map section you get you to the map and disks printed at left.

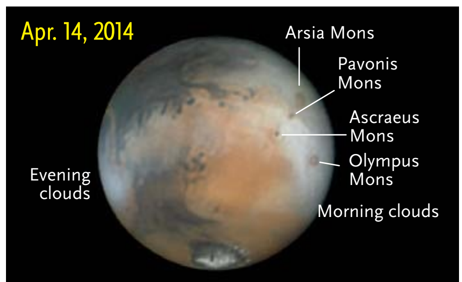
Out observing, you'll find that Mars presents nearly the same face from night to night. This is because the Martian day is only 38 minutes longer than Earth's. To see other parts of Mars, you have to observe at a different time of night, travel to a different longitude on Earth, or wait for a week or more to pass. If viewed at the same time of night from the same place, Mars takes somewhat more than a month to complete one retrograde (backward) "rotation."



This year the North Polar Cap is tipped into view a little less than seen here. The cap should again have shrunk to expose its dark collar. The vast Hellas Basin, south of Syrtis Major, often fills with clouds and frosts; when Syrtis Major faces us, Hellas is often mistaken for the South Polar Cap.



When Syrtis Major rotates to the limb, observers sometimes spot the "Syrtis Blue Cloud." It's presumably due to the blueing of hazes and low clouds near any limb, combined with the effect of an unusually dark background, rather than some chemical peculiarity of the cloud itself.



When the four great Tharsis volcanos aren't capping themselves with orographic clouds, they sometimes appear as the opposite: tiny ground-colored dots sticking up through a blanket of lower clouds. Amateur stacked-video imaging can bring out fine details like these that often escape visual observers.

DAMIAN PEACH (3)

frosts may persist for most of the day.

Evening clouds have the same appearance as morning clouds but occur on the planet's preceding limb.

Dust storms can occur in almost any Martian season, but they're uncommon during southern-hemisphere winter, meaning now. The critical diagnostic of a dust storm is a relatively bright patch moving and obscuring dark features that were previously well defined. Dust storms may change appearance from one night to the next.

For More Information

Jeff Beish offers his detailed rundown of this Mars apparition, with a calendar of what to watch for as the Martian seasons change through 2016, at **alpo-astronomy.org/jbeish/2016_MARS.htm**.

The next opposition of Mars will be even better. Mars will be at the peak of its 16-year opposition cycle, and when it's closest to Earth on July 31, 2018, it will be 24.3″ in diameter. That's nearly the maximum possible: 25.1″, which Mars attained in August 2003.

Crescent Moon Occults Aldebaran

A blue-sky event awaits your telescope on Sunday, April 10th. That afternoon the waxing crescent Moon will cover and uncover Aldebaran, the brightest star that it can ever occult. The occultation will be visible from all of the U.S. except Alaska and from all the well-populated parts of Canada. The Moon will be a 17%-illuminated crescent; you'll find it about 50° to the celestial east of the Sun. The fiery orange star will disappear behind the Moon's dark limb — invisible in daytime — then will reappear from behind the bright limb up to an hour or more later.

For easterners, the occultation happens in late afternoon or around sunset. Farther west, the local time will be earlier and the Sun higher.

Some predicted times: **Halifax:** *disappearance* 8:00, *reappearance* 8:56 p.m. ADT. **Montreal**, *d.* 6:47, *r.* 7:48 p.m. EDT. **Western Massachusetts**, *d.* 6:49, *r.* 7:54 p.m. EDT. **Toronto**, *d.* 6:39, *r.* 7:46 p.m. EDT. **Washington, DC**, *d.* 6:43, *r.* 7:55 p.m. EDT. **Atlanta**, *d.* 6:34, *r.* 7:49 p.m. EDT. **Miami**, *d.* 6:57, *r.* 7:50 p.m. EDT. **Chicago**, *d.* 5:25, *r.* 6:39 p.m. CDT. **Kansas City**, *d.* 5:11, *r.* 6:31 p.m. CDT. **Austin**, *d.* 5:07, *r.* 6:22 p.m. CDT. **Winnipeg**, *d.* 5:17, *r.* 6:13 p.m. CDT. **Denver**, *d.* 3:51, *r.* 5:11 p.m. MDT. **Edmonton**, *d.* 4:12, *r.* 4:36 p.m. MDT. **Vancouver**, *d.* 2:48, *r.* 3:28 p.m. PDT. **Berkeley**, *d.* 2:21, *r.* 3:37 p.m. PDT, **Los Angeles**, *d.* 2:21, *r.* 3:42 p.m. PDT, **Honolulu**, *d.* 10:29, *r.* 11:28 a.m. HST.

Asteroid Occultations

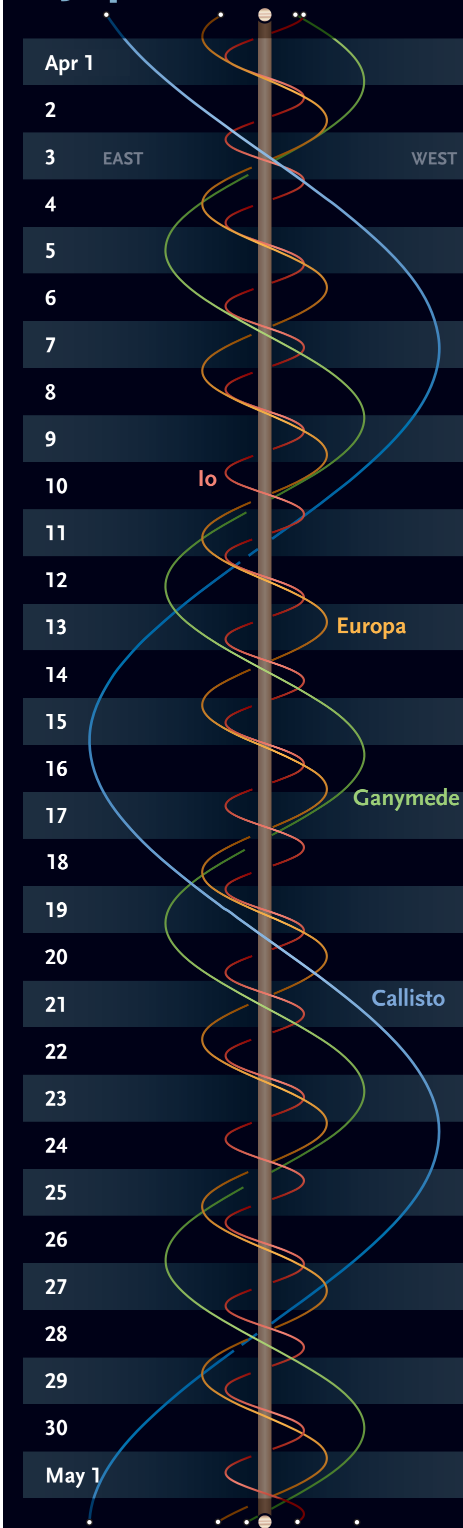
On the evening of April 1st, telescope users along a narrow path from Seattle to Mississippi can watch for a 9.3-magnitude star in the vicinity of the Pleiades to disappear for up to 6 seconds behind the invisibly faint asteroid 2892 Filipenko.

On the morning of April 5th, observers from Florida through North Dakota can watch for 216 Kleopatra (magnitude 12.7) to occult a 10.9-magnitude star in Libra for up to 12 seconds. Their combined light will drop by 2.0 magnitudes. Kleopatra is the largest M-class (metallic) asteroid and is about four times as long as wide. Accurate timings could help determine the actual shape of this strange object.

On the evening of April 12th, observers from north Florida to Seattle can watch for an 8.7-magnitude star at the Virgo-Leo border to be occulted for up to 4 seconds by faint 513 Centesima.

Maps, time predictions, and finder charts are at **asteroidoccultation.com/IndexAll.htm**. For how to time these events and where to report, see **asteroidoccultation.com/observations**. Videorecording yields the desired accuracy; see the "Equipment" heading on that page. For advice and help, join **groups.yahoo.com/neo/groups/IOTAoccultations**.

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.

Daily Events at Jupiter

As Jupiter recedes slightly from closest approach around its March 8th opposition, its apparent width shrinks from 44″ to 41″ during the rest of March and April — even as it climbs high into good view earlier in the night. By the end of April it's already transiting at nightfall.

Jupiter's four big Galilean moons are visible in any telescope. Binoculars almost always show at least two or three. Identify them using the diagram at left.

All the April interactions between Jupiter and its satellites and their shadows are tabulated below. Four **double shadow transits** occur on Jupiter in April. One happens when Jupiter is in view for central and western North America: on the morning of April 5th, from 2:37 to 3:19 a.m. PDT.

And here are all the times, in Universal Time, when Jupiter's Great Red Spot should cross the planet's central meridian. The dates, also in UT, are in bold. (Eastern Daylight Time is UT minus 4 hours.)

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

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

These times assume that the Great Red Spot is centered at System II longitude 234°. It will transit 1²/₃ minutes earlier for each degree less than 234°, and 1²/₃ minutes later for each degree greater. Features on Jupiter appear closer to the central meridian than to the limb for 50 minutes before and after transiting.

A light blue or green filter slightly increases the contrast and visibility of Jupiter's reddish and brownish markings; an orange filter helps darken the blues. ✦

Phenomena of Jupiter's Moons, April 2016

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

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

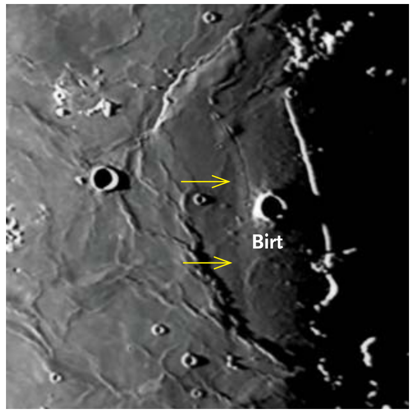
A Topographic Excursion

Curious features surround the Moon's iconic Straight Wall.

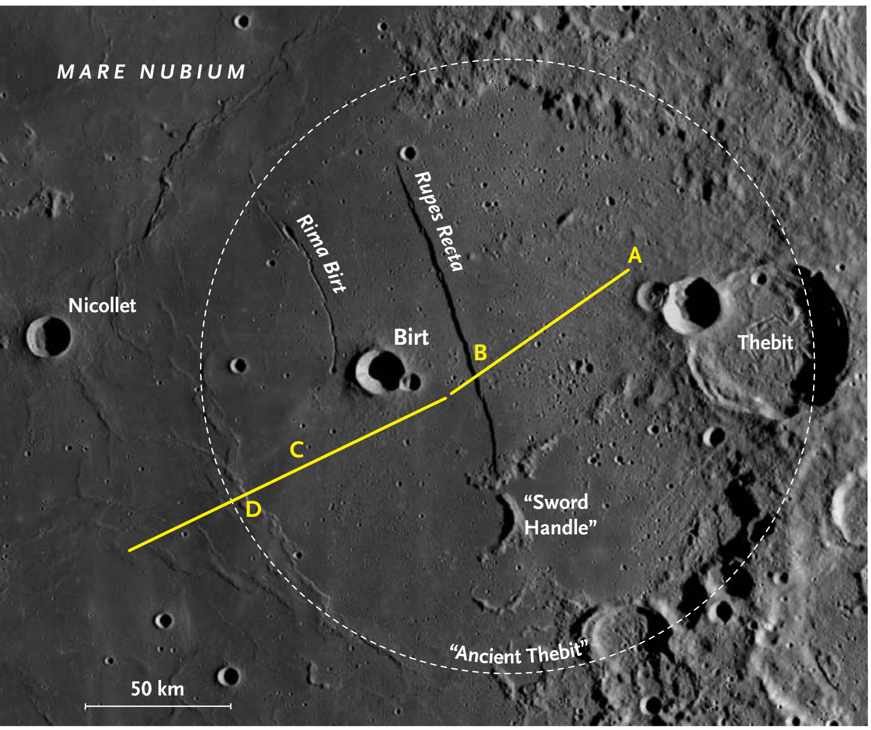
One of the Moon's best-known telescopic treats is the 115-kilometer-long Straight Wall. This striking feature, traditionally called the Railway by British observers, is now officially known as **Rupes Recta.** It casts a black shadow on the surrounding plain along the eastern shore of **Mare Nubium** around lunar sunrise, and it creates a distinct ribbon of brightness there at sunset.

This long, straight fault is such a focus of attention that observers often don't look closely at what else lies nearby. So I invite you to take a broader sweep of the area, especially when the terminator is just to the west near the 15-km-wide crater **Nicollet**.

With such low lighting, the first thing to notice is that the fault cuts the middle of a big "half crater," informally named Ancient Thebit, 200 km across. Its eastern edge is battered but still readily seen, with the younger crater **Thebit** (55 km) on its eastern rim. The western half of Ancient Thebit is missing, but low-angle lighting reveals curved wrinkle ridges that continue the arc of the missing rim. In my opinion, the Straight Wall is a fault that carried the crater's entire western half, and not just the lava plain, downward. Today the wrinkle ridges drape across the submerged rim.



Extremely low-angle sunlight reveals a subtle inflection in slope (arrowed) just west of the crater Birt. The Straight Wall, a fault scarp that's 115 km long and 400 m high, stands out dramatically in partial shadow at the terminator.



Interesting geologic features surround the well-known Rupes Recta (Straight Wall) on the southeastern shore of Mare Nubium. The straight lines correspond to the elevation profile at upper right on the facing page.

A profile across the floor of Ancient Thebit (marked from *A* to *D* in the image at left and plotted at upper right on the facing page) shows elevation differences that are otherwise undetectable. From *A* to *B*, the elevation gently decreases, and *B* marks the abrupt, 400-m drop of the Straight Wall. Surprisingly, over the next 60 km westward, the floor's elevation gently decreases another 400 to 500 m. At *C* there's an inflection in slope, where the floor nearly flattens out. And roughly 30 km farther west the profile rises about 200 m as it climbs over the mare ridges. This lava-draped western rim of Ancient Thebit is about 2 km lower than the eastern rim.

Similar altimetric traces over the nearby craters **Alphonsus**, **Alpetragius**, and **Arzachel** demonstrate that their western rims are about 1 km lower than their eastern ones. The tilts occur because all of these craters, as well as Ancient Thebit, formed on the outer margin of the inconspicuous Nubium impact basin. There the basin's ancient floor slopes downward toward its center, and consequently the crater rims do too. Ancient Thebit formed farther inside the basin, resulting in subsidence so extreme that it fractured along the Straight Wall and its western half dropped even more.

Let's go back to point *C* on the terrain's cross-section. Although the subtle change of slope isn't visible in the large Lunar Reconnaissance Orbiter image, the extreme

low-Sun view by Hong Kong amateur K. C. Pau (on the facing page) shows it beautifully. Note the change in tone from dark to light along a distinct north-south line almost paralleling the Straight Wall. A similarly delicate feature appears a bit farther north (out of the frame).

Surprisingly, this subtle slope change is depicted on a map in Edmund Neison's classic 1876 book *The Moon*. He accurately describes it as "a very gently sloping shallow valley . . . only visible with very great difficulty." I consider this feature to be an inflection valley: a slight but abrupt change in slope makes the elevated mare to the east face the setting Sun more directly and thus appear brighter than the flat mare to its west.

Detecting such slight slope changes by eye is difficult, requiring low illumination, good seeing, and high resolution. They're invisible or inconspicuous on LRO images, underscoring why we need both telescopic and lunar-orbiter views to discover and correctly interpret such subtle features.

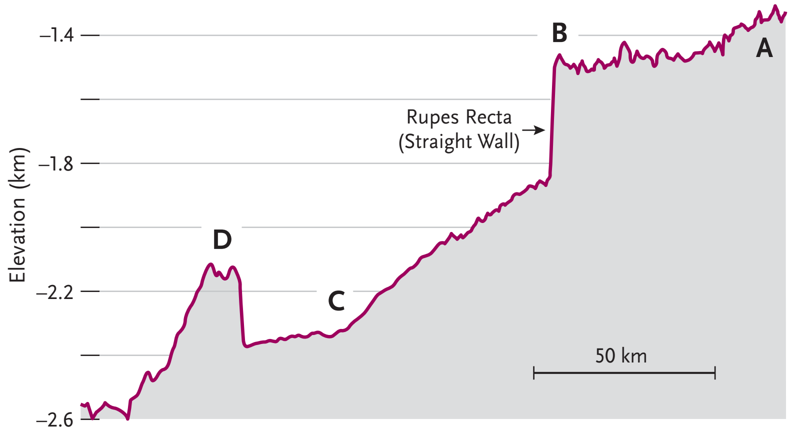
Other features very near the Straight Wall deserve your notice. Although well-enough known to have a name, **Rima Birt** is narrow and only just visible in my 4-inch refractor. And it's also challenging to classify. Like many sinuous rilles, it starts with a deep depression at the top of a low, 20-km-wide dome (on its south end). But this rille is not simply a channel made by flowing lava; instead, it consists of small, overlapping collapse pits. Dark-toned ash deposits surround both the deep depression and the rille itself — evidence that the pits were vents for volcanic eruptions.

Another peculiar characteristic of Rima Birt is the occurrence of deep pits at *both* ends, almost as if it had two starting points.

Based on the rille's location and its near parallelism to the Straight Wall, I suspect that these two features are related. Moreover, although part of the inflection valley is bounded by ash, that boundary extends far beyond the rille's southern terminus. To me, this implies that the stresses that caused the rille might have shaped the inflection valley as well.

Also famous to lunar observers is the "Sword Handle," a partial rim at the south end of the Straight Wall. The fault, though not evident, dropped the crater's western half into the Nubium depths. Just south of that is a much subtler arc of another partial crater rim.

The collapse that erased half of Ancient Thebit must have been a stupendous event. The down-dropped slab heaved and fractured, producing the Straight Wall and inflection valley we see today and providing subsurface conduits for the volcanic flows that triggered Rima Birt's line of pits — all good (if challenging) targets for you and your telescope. ✦



S&T: GREGG DINDERMAN; SOURCE: NASA

This elevation profile corresponds to the line from *A* to *D* on the facing page. *B* denotes the abrupt drop at Rupes Recta, and *C* indicates where the regional slope changes subtly on the floor of "Ancient Thebit."

AIRPHOTO / JIM WARK

Straight-line faults aren't unique to the Moon. This abrupt fault in western Montana created a prominent cliff, called the Chinese Wall, some 300 meters high.

The Moon • April 2016

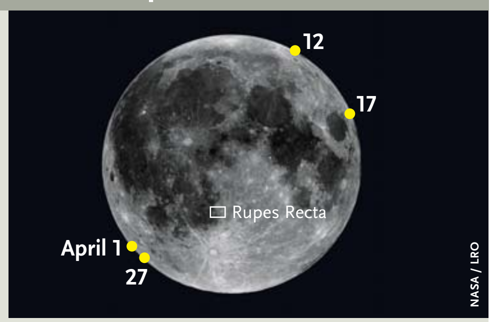
Phases

NEW MOON
April 7, 11:24 UT

FIRST QUARTER
April 14, 3:59 UT

FULL MOON
April 22, 5:24 UT

LAST QUARTER
April 30, 3:29 UT



NASA / LRO

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

Distances

Perigee	April 7, 18h UT
357,163 km	diam. 33′ 28″
Apogee	April 21, 16h UT
406,351 km	diam. 29′ 25″

Favorable Librations

Hausen (crater)	April 1
Mare Humboldtianum	April 12
Hubble (crater)	April 17
Baade (crater)	April 27

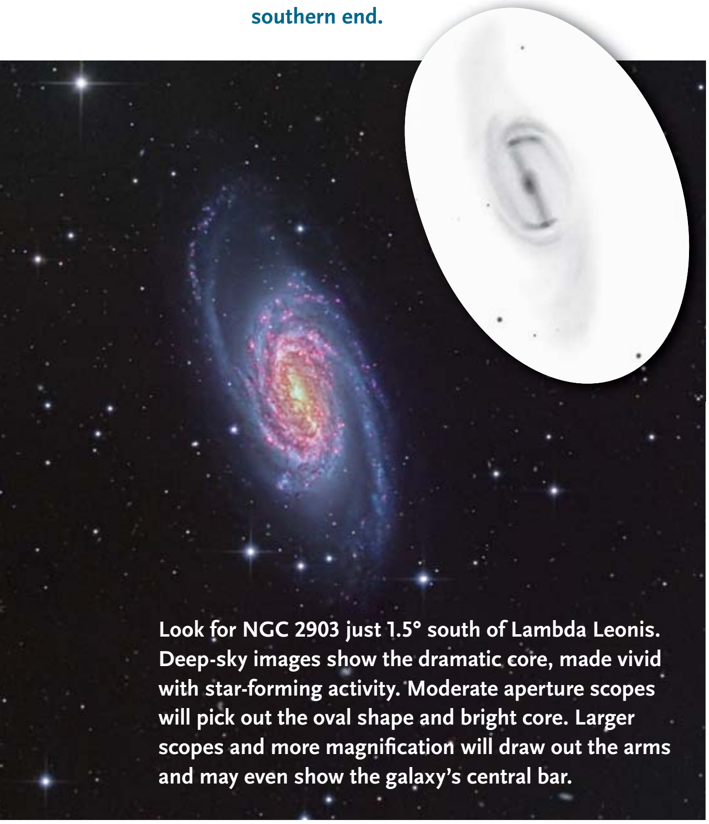
A Starry Sickle

Bright stars and strange galaxies hide in Leo's regal mane.

Where Leo waits King Sol in dog-days' reign
And Regulus shines diamond-like and bright,
When springtime wakes and summer smiles again
Till harvest moon beams yellow in the night;
Six suns, with four stars sparkling in its train,
Like question-mark which faces to the right.
Or secret symbol written clear and plain,
A starry sickle glitters in men's sight.
— Charles Nevers Holmes, *The Starry Sickle*, 1916

Our king of beasts, Leo, the Lion, reigns supreme on the all-sky chart at the center of this magazine, watching over his domain from a lofty position in the south. The map's north-south line slices right through a distinctive asterism known as the Sickle of Leo. The Sickle's highly curved blade is open toward the west, and diamond-like Regulus marks the end of its handle. We have a brilliant visual aid for finding the Sickle this spring. Jupiter, the king of planets, quite suitably shares Leo's lordly realm, sitting southeast of the Sickle. Although just a visitor to the kingdom, Jupiter well outshines Leo's royal stars.

The tip of the Sickle's blade is marked by Epsilon (ε) Leonis, and to its west-southwest we find the star Lambda (λ). Through my 130-mm refractor and a wide-angle eyepiece at 37×, yellow-orange Lambda shares the field of view with the spiral galaxy **NGC 2903**, which dangles 1.5° south of the star. The galaxy appears oval, twice as long as it is wide, and tipped a bit east of north.

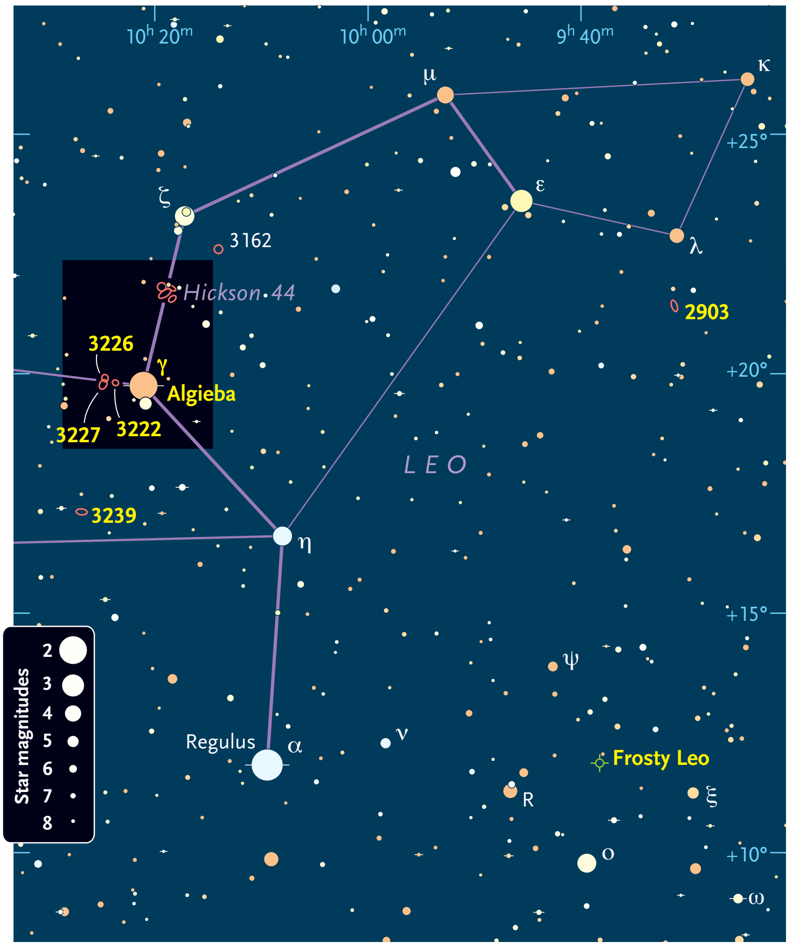


At 202×, Uwe Glahn's 14.5-inch reflector revealed the core, bar, and curving stretch of NGC 2903's spiral arms. Look for a wavy line of stars at the galaxy's southern end.

UWE GLAHN

Look for NGC 2903 just 1.5° south of Lambda Leonis. Deep-sky images show the dramatic core, made vivid with star-forming activity. Moderate aperture scopes will pick out the oval shape and bright core. Larger scopes and more magnification will draw out the arms and may even show the galaxy's central bar.

BILL SNYDER



It brightens toward a tiny core. Faint stars flank the galaxy's southern tip, the brighter one to the east. At 91× an ashen halo reaches a size of roughly 9½′ × 4′. A considerably brighter, mottled inner region covers about 5′ × 2½′, and its tiny core seems to be elongated. Boosting the power to 117×, the inner region looks quite patchy, and its core is definitely elongated. A faint star lies between the flanking stars, closer to the brighter one.

In my 10-inch reflector at 115×, NGC 2903 spans 10′. A slightly wavy line of four stars serves as a platform for NGC 2903's southern end, and a faint star huddles against the western side of the northern end. At 166× the core envelops a tiny, fuzzy nucleus, and the mottled region has brighter patches at its north and south ends. The northern patch becomes prominent at 213×, while the southern one is less pronounced. The core brightens toward the center, but no discrete nucleus is evident.

The brightest star in the Sickle's curve is **Gamma (γ) Leonis**, commonly known as Algieba, a delightful double star for any telescope. My 105-mm refractor at 68× reveals a striking pair of golden suns, the 2.4-magnitude primary watching over the 3.6-magnitude companion to its southeast.

Algieba's components form a true binary located about 130 light-years away from us. Preliminary orbital elements in the internet-based Sixth Catalog of Orbits of Visual Binary Stars give this pair an orbital period of 554 years, plus or minus 27 years. The apparent separation of the stars is currently 4.7″. If the preliminary elements are nearly correct, the separation will sluggishly crawl to a maximum of 4.8″ sometime in the early 2060s and then close to a cozy 0.2″ a few centuries from now.

Climbing 2.0° north-northwest from Algieba takes us to **Hickson 44**, a compact group of four galaxies spanning 18′ on the sky. Through my 130-mm refractor at 63×, NGC 3190 is easily visible as an elongated glow tilted west-northwest. NGC 3193 is dimmer and round. It hosts a bright center, and a 9.6-magnitude star nuzzles its northern border. At 91× NGC 3190 is about 3½′ long and one-quarter as wide. It holds a brighter, elongated center with a starlike nucleus. NGC 3193 measures about 1¾′ in diameter. NGC 3185 makes an appearance as a low-surface-brightness oval tipped southeast, and I can barely catch a trace of NGC 3187. At 117× NGC 3185 unveils a slightly brighter center. NGC 3187 presents a small, diaphanous wisp pointed at NGC 3190 that's seen only with averted vision.

Making the Curve

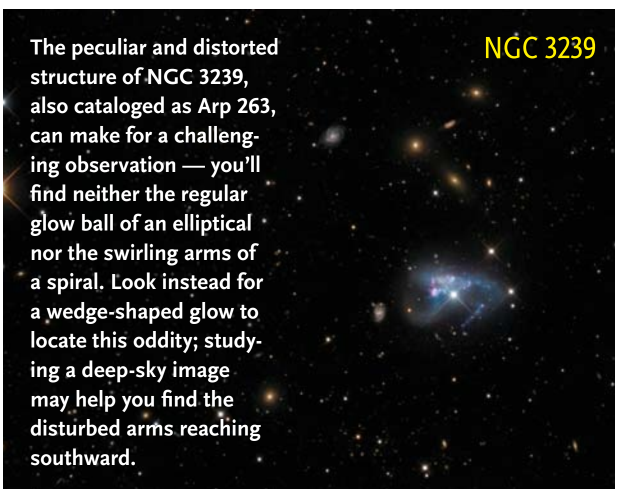
Object	Type	Mag(v)	Size/Sep	RA	Dec.
NGC 2903	Spiral galaxy	9.0	12.6′ × 6.0′	09h 32.2m	+21° 30′
Gamma Leonis	Double star	2.4, 3.6	4.7″	10h 20.0m	+19° 51′
Hickson 44	Galaxy group	10.9 – 13.4	18′	10h 18.0m	+21° 49′
NGC 3227	Spiral galaxy	10.3	4.1′ × 3.9′	10h 23.5m	+19° 52′
NGC 3226	Elliptical galaxy	11.4	2.8′ × 2.0′	10h 23.5m	+19° 54′
NGC 3222	Lenticular galaxy	12.8	1.3′ × 1.1′	10h 22.6m	+19° 53′
NGC 3239	Irregular galaxy	11.3	5.0′ × 3.6′	10h 25.1m	+17° 09′
Frosty Leo	Protoplanetary	11	28″ × 14″	09h 39.9m	+11° 59′

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.

My 10-inch reflector at 166× adds a stellar nucleus to NGC 3193, while my 15-inch reflector at 216× greatly prettifies Hickson 44, making features much easier to discern. The larger scope even teases out part of NGC 3190's dust lane, worn like a dusky ribbon upon the galaxy's south-southwestern flank.

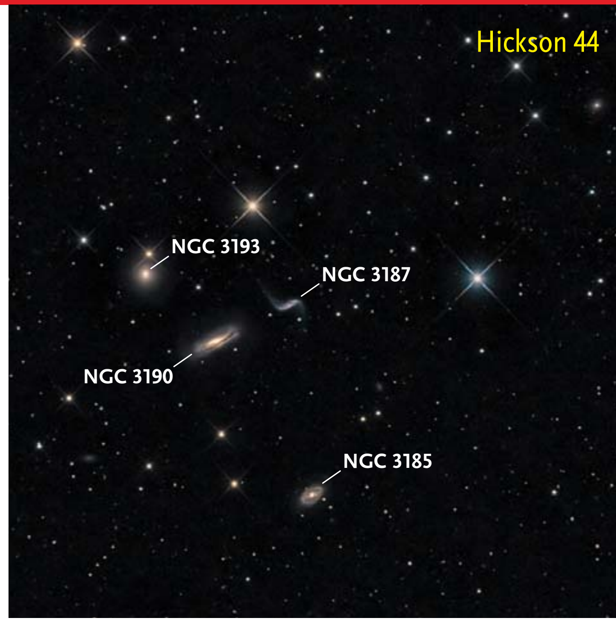
Interacting galaxies **NGC 3227** and **NGC 3226** reside 50′ east of Algieba, where my 130-mm refractor at 23× merely shows a moderately faint glow. At 63× it's evident that two galaxies exist here. Although the halos blend together, each harbors a small, distinct, brighter center. NGC 3227 is oval and tipped south-southeast. NGC 3226 balances atop (north of) its partner, with a halo canted northeast. Upping the magnification to 117×, the pair traverses about 4½′. NGC 3227 sports an oval core with a prominent, starlike nucleus, and NGC 3226 intensifies toward its center. **NGC 3222** now joins the scene, 13′ west of the duo. This little galaxy appears very dim and embraces a tiny, feeble nucleus. A faint star flickers in and out of view at NGC 3222's south-southwestern edge.

The remarkably strange galaxy **NGC 3239** perches 2.9° south-southeast of Algieba. My 130-mm refractor displays a 1¼′ wedge-shaped glow with a distracting 10th-magnitude star on its southwestern edge. The star makes an isosceles triangle with 12th-magnitude stars 2.4′ west and northwest. The galaxy extends farther westward when seen through my 10-inch scope at 166×, with a gauzy, tapering arm reaching out toward the western star. There's a brighter spot on the galaxy's edge, east of the 10th-magnitude star. My 15-inch reflector at 192× brings out a more subtle spot in the galaxy, north of the star, and a stubby barb of filmy light juts south-southwest from the brighter spot. A ghostly glow dwells beyond the galaxy about two-thirds of the way from the 10th-magnitude star to a faint star 5.6′ east-southeast. At 216× it becomes a petite north-south oval, the 15th-magnitude galaxy CGCG 94-42 (PGC 30585).



The peculiar and distorted structure of NGC 3239, also cataloged as Arp 263, can make for a challenging observation — you'll find neither the regular glow ball of an elliptical nor the swirling arms of a spiral. Look instead for a wedge-shaped glow to locate this oddity; studying a deep-sky image may help you find the disturbed arms reaching southward.

BOB FRANKE



SIEGFRIED KOHLERT

The four gravitationally bound galaxies that comprise compact group Hickson 44 offer a grand study for visual observers. NGC 3185 presents as an almost face-on spiral, while NGC 3190 is all but edge-on. NGC 3193 is a classic elliptical galaxy. The dimmest of the group, NGC 3187, is detectable in moderate scopes only because of its bright bar; you'll need aperture or images to see the glorious tails of its spiral arms.

Bizarre as my descriptions are, NGC 3239 appears even more peculiar in deep images, looking something like a lumpy, mirror-reversed π symbol. The most likely cause of its tortured appearance is thought to be a galaxy merger. NGC 3239's weird form has lent it the nickname the Loony Galaxy.

While galaxies are the main fare when it comes to deep-sky wonders in Leo, let's finish with a small dessert — the **Frosty Leo** nebula, 2.1° north of Omicron (ο) Leonis. Pointing my 10-inch scope at 166× toward the correct location, I see a slightly crooked, 15′ line of three bright stars very unevenly spaced and dressed in shades of yellow. The nebula sits 12′ south-southeast of the brightest star and just outside the southern corner of a 3′ isosceles triangle of faint stars. It's very small, bluish, and roundish with a nearly starlike center. My 14.5-inch reflector at 245× shows that Frosty Leo has a bright oval core and a relatively thin, fainter halo elongated roughly southeast-northwest. I estimate a length of ⅓′.

Frosty Leo is a protoplanetary nebula. When an aging star roughly the mass of our Sun exhausts its hydrogen fuel, it sheds its outer layers while its core contracts. The cocoon of cast-off material reflects light from the star, and we see a protoplanetary nebula. As the collapsing core grows hotter, it eventually warms the nebula enough to emit its own light, and a planetary nebula is born. Frosty Leo's name springs from its abundance of dust coated with crystals of water-ice. ✦

More Than Pretty Pictures

Coloring the Universe: An Insider's Look at Making Spectacular Images of Space

Travis A. Rector, Kimberly Arcand & Megan Watzke
University of Alaska Press, 2015
200 pages, ISBN 978-1-60-223273-0, $50.00, hardcover.

YES, PICTURES OF SPACE are beautiful, stunning even. But they're so much more than that. Telescopes let us see things we could never perceive on our own, and presenting those views is just as much science as it is art. That's the case laid out in *Coloring the Universe: An Insider's Look at Making Spectacular Images of Space*, by professional astronomer Travis A. Rector, visualization expert Kimberly Arcand, and Megan Watzke, press officer for the Chandra X-ray Observatory.

The term "pretty pictures," they write, is often used in a derogatory way to dismiss astronomical images as nice but not useful. Worse, sometimes the concepts of "false" color or Photoshop modifications confuse us into believing the images aren't real. But once you learn what goes into making an image and how to read the science contained within, you'll discover a new appreciation even for the Hubble Space Telescope's well-worn Pillars of Creation.

The authors assume no previous knowledge. Starting from first principles, they outline how cameras and telescopes work (and the crucial differences between these instruments and the human eye), as well as the basics of color theory. Step by methodical step, they review the data, colors, and even composition that go into an image. Only in the last two chapters does everything come together into a bigger picture, so to speak.

This back-to-basics approach may be mildly frustrating, but it's also enlightening. I knew Hubble's breathtaking vistas worked in its favor with public opinion, but I didn't realize the extent to which ground-based observatories followed suit, dedicating time and funds to similar legacy archives of space images.

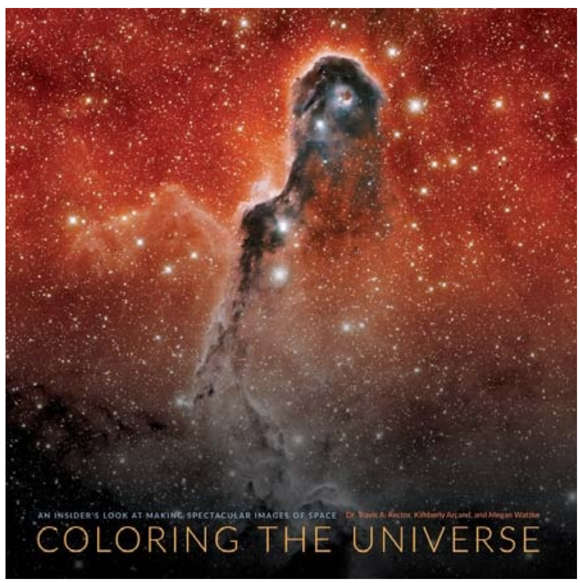
And when reading about a topic I fully understood, such as the differences between broadband and narrowband filters, I memorized the authors' analogy (finding the sound of the violin in an orchestral piece) in case I need to explain the same concept at a public observing night. I also found that the authors used just the right amount of physics, such as their brief explanation of atomic transitions that introduces narrowband filters.

Even if you find yourself skimming the text, you won't skip over the images. This is a coffee table book, and it's beautifully done, just as suited to paging through as it is to a thorough read. Each image illustrates a concept, from the primary mirror in Hawai'i's Gemini North Telescope to composite views of dense gas globules floating in a sea of interstellar hydrogen.

Often, the authors pair two images to demonstrate the effect of color choice for a particular narrowband filter or to show color contrasts. With two images demonstrating the three-dimensional effects of the Hubble color palette, it becomes clear why some people wonder if the space telescope flies out to the targets it observes. And the book closes with a fun gallery of *pareidolia*, the astronomical equivalent of finding shapes in the clouds.

This book isn't intended for the advanced astrophotographer. But for the uninitiated, and especially for anyone who's ever been suspicious of images that look nothing like what you see through your scope, this book's a good addition to your library. ✦

*S&T Web Editor **Monica Young** has always appreciated the power of a pretty picture.*



 Johnny Horne

An Imaging Ensemble
from Starlight Xpress

Starlight Xpress Trius-SX814C, Mini Filter Wheel with OAG, & Lodestar X2 Autoguider

U. S. price: Camera, $2,995; filter wheel, $425; and Lodestar X2, $649. Available from www.sxccd.com and dealers worldwide.

The Starlight Xpress Trius-SX814C camera configured with the SX Mini filter wheel with its integral off-axis guider and Lodestar X2 guiding camera attached.

ALL PHOTOS BY THE AUTHOR

IT'S EASY TO SEE why some astrophotographers prefer one-shot color CCD cameras. Rather than taking a series of exposures through various filters and combining them to form a color image, one-shot cameras serve up a color image almost from the get-go, requiring only a quick conversion from the camera's native format to full RGB color. It's the same convenience enjoyed by astrophotographers using DLSR cameras for deep-sky astrophotography.

WHAT WE LIKE:

Extremely low-noise images

Easy to use

WHAT WE DON'T LIKE:

No mechanical shutter

A new one-shot color camera from Starlight Xpress, the Trius-SX814C, offers more versatility than other color cameras I've tested. This compact, lightweight CCD camera features a 9.19-megapixel Sony ICX814 chip with a 3,388 × 2,712 array of 3.69-micron pixels forming an active imaging area measuring 12.5 × 10 mm.

These small pixels make the camera especially attractive to astrophotographers with fast, short-focal-length refractors, camera lenses, or short-focus Newtonians. In addition to its small pixels, the camera has very low noise characteristics. So little noise, in fact, that you can often forgo the need of dark-frame calibration.

The Trius-SX814C is a relatively small cylinder measuring 2¾ inches in diameter and 2⅝ inches long, so its size and weight (1 pound) shouldn't produce balance issues in most imaging configurations. There's an external cooling fan that supplements the unit's regulated thermoelectric cooling (TEC). Its CCD chamber is sealed with a fused silica window and purged with argon to prevent condensation from forming on the cooled chip.

One particularly nice feature of the Trius design is an integrated 3-port USB 2.0 hub at the rear of the camera. This helps reduce the number of cables connected to your host computer. I took advantage of the hub to connect a Lodestar X2 autoguider and a filter wheel so that only a single USB 2.0 cable ran from the camera assembly to my laptop. The camera is powered by 12 volts DC and includes a universal AC adapter. A "Y" coax power cable feeds the camera and exterior cooling fan. The camera can function as an auto guider and includes a 6-pin port to interface with your telescope mount.

Both cameras come with the control software *SXV_HCOL_USB*, which provides all the necessary functions of image acquisition, as well as post-processing functions such as calibration and stacking. While it functions adequately, it is proprietary to the Trius and will not, for example, open FITS images acquired with the camera using other software. Starlight Xpress also recommends Stark Labs *Nebulosity 4* (**stark-labs.com**), and *MaxIm DL* (**cyanogen.com**). I tried each during my testing though preferred the latter two that I have more experience with.

Mini Filter Wheel and Lodestar X2

Whether you're a fan of monochrome or one-shot color cameras, a good autoguider is an essential accessory when shooting deep-sky targets, and the Lodestar X2 autoguider didn't disappoint.

Like the Trius, the Lodestar X2's highly sensitive monochrome Sony ICX829 CCD detector produces extremely low-noise images, which permitted me to easily locate suitable guide stars with exposures of 2 seconds or less on all the instruments I paired it with. Like the Trius, the guider doesn't have a shutter. Its 752 × 580 pixel array measures 6.47 × 4.81 mm.

The Lodestar X2 has a versatile, compact design that can be used with most any guidescope or off-axis guider. The camera's outside diameter is precisely 1¼ inches, which fits in any standard telescope focuser. Furthermore, the front aperture includes C-mount threads, permitting a rigid connection to the off-axis guider (OAG) built into the Starlight Xpress Mini Filter Wheel that I tested. While a filter wheel isn't a necessary component when paired with a color camera, it is useful for shooting with specialized filters that block light pollution. The filter wheel can also function as a mechanical shutter; more on this in a moment.

The Trius includes an assortment of cables for use with the camera's internal USB mini hub, and an autoguider cable for using the SX-814C as a guide camera. A unique "Y" coax splitter powers both the camera and its external cooling fan.

The Lodestar X2 C-mount threads are convenient for attaching the guider to conventional camera lenses with standard C-mount adapters, thus creating an effective, freestanding autoguider and imaging setup.

Power for the Lodestar X2 comes from its USB 2.0 connection to the host computer (or Trius hub), and an RJ-12 cable is supplied to interface the guider with your mount. One note of caution here: the pin-out arrangement for the guiding interface cable is wired opposite to what has become the de facto standard on most telescope mounts, so it's important to use the RJ-12 cable supplied with the Lodestar. Other ST-4 compatible cables won't work with Lodestar X2. This is a touch ironic since the Lodestar cable is actually wired the same as the RJ-12 cables that have long been a standard in the telephone industry – it is the ST-4 cables that are different despite their now wide acceptance in the telescope world.

A small LED on the rear of the Lodestar housing lights up green when the guider is powered up and briefly blinks red when sending guiding corrections to your telescope mount.

The back end of the Trius includes a 6-pin RJ-12 autoguider port, a USB 2.0 port to connect the camera to your laptop, and a 3-port USB mini hub that allows users to connect up to three additional accessories, including a filter wheel, an autoguider camera, or the company's Active Optics guiding unit.

While not an essential component for color cameras, the Mini Filter Wheel accepts five 1¼-inch-format filters in threaded cells. One space could be blocked in to be used as a mechanical shutter for the imaging chip.

The Lodestar X2 autoguider includes internal C-mount threads, which permit it to be attached to the mini filter wheel OAG, or it can easily be inserted directly into any standard 1¼-inch eyepiece focusers on most guide scopes.

The effectiveness of the Lodestar X2 is best described by the ease in which I located guide stars with the filter wheel's OAG. The Starlight Xpress 1¼-inch Mini Filter Wheel and OAG is a five-position filter wheel that accepts conventional 1¼-inch filters in threaded cells. The 5⅞-inch-diameter filter wheel housing is 1⅛ inches thick and includes female T-threads on its front and back ports. It comes with its own USB 2.0 cable and software. The OAG is an integral part of the filter wheel and cannot be removed.

The OAG has no independent adjustments to help with the selection of guide stars beyond a single motion that slides the pick-off prism radially within the field of view. There is no side-to-side adjustment of the prism. The OAG has two long locking screws with convenient knurled knobs. One secures the position of the pick-off prism while the other locks the focus position for the autoguider camera.

Initially, this seemed to be a limiting factor in the OAG design, but locating guide stars with the Lodestar X2 turned out to be effortless. The camera's sensitivity allowed multiple guide star choices in the field with exposures of one or two seconds. During my tests, this wasn't the case most of the time but *every* time. Sufficiently bright guide stars appeared on a very smooth, noise-free background sky everywhere I pointed even without applying dark-frame calibration. Quite simply, the Lodestar X2 was the best autoguider I've ever used.

At the Telescope

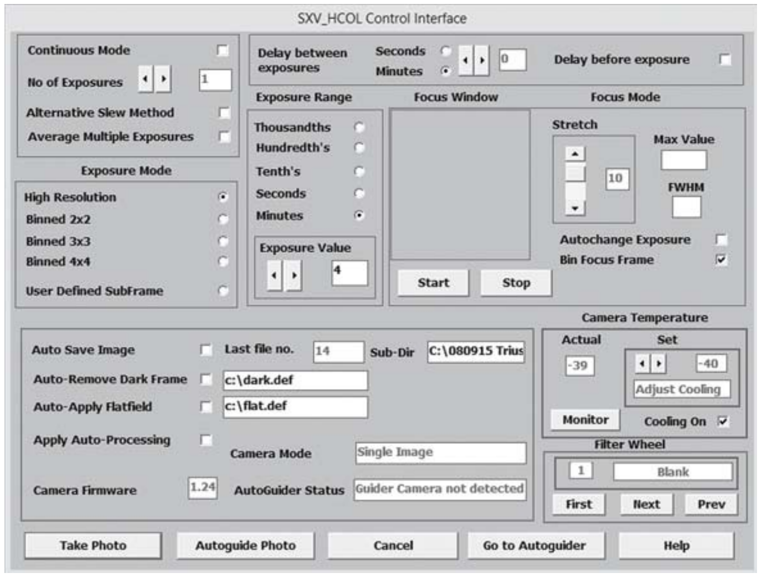
I tested the Trius-SX814C with a 102-mm f/6.9 William Optics refractor and at the f/4 Newtonian focus of my 12½-inch classical Cassegrain reflector. I also tried it attached to a Nikon 300-mm f/2.8 camera lens with a T-thread-to-Nikon-lens adapter. But due to the limited backfocus of the lens, I wasn't able to use the filter wheel and OAG in this arrangement.

The camera's compact size, small pixels, and cylindrical shape make it particularly well-suited for use with fast "Hyperstar" systems now available for some Schmidt-Cassegrain telescopes.

Imaging with the Trius-SX814C, Lodestar X2, and filter wheel with OAG was pleasantly straightforward when I was shooting with either telescope. The back focus required for the camera and OAG was shallow enough to allow me to reach focus on my Newtonian with its low-profile focuser. The camera reached its set cooling temperature of 20°C below ambient quickly and was stable in less than five minutes. Using the camera's highly sensitive binning modes was helpful when composing targets and rough focusing. Fine focus is achieved by observing the full-width half-maximum readout and moving the focus to a star's peak value. A full-resolution image takes about 7 seconds to download.

Once initially configured, the system provided the

An integral off-axis guider on the Mini Filter Wheel accepts any of the company's current autoguider cameras with a threaded C-mount interface. The knob at top locks the focus for the guide camera, while the lower knob secures the pick-off prism's position.



Left: **Due to the extremely low-noise characteristics of the Sony ICX814 CCD detector, dark-frame calibration is virtually unnecessary. This image of M20 was captured with a 12½-inch f/4 Newtonian for a total exposure of 50 minutes, and was processed without dark-frame calibration. Only a few dozen hot pixels can be seen in the final result.** ***Above:*** **Included with the camera is the manufacturer's control software** ***SXV_HCOL_USB*****, which controls the primary functions of the camera, autoguider, and filter wheel.**

most straightforward and quickest setup time of any deep-sky astrophotography configuration I have used. Even swapping the Trius-SX814C, Lodestar X2, and the OAG between the small refractor and the Newtonian meant little down time. I was into an imaging run in record time. The sensitivity of the Lodestar X2 guider was a big part of the quick setup, since the search for suitable guide stars fast and easy.

Dark Calibration, or Not?

The low noise in the Trius-SX814C and the camera's regulated, two-stage TEC cooling means that what few hot pixels are produced in most exposures can be removed using pixel-rejection algorithms when stacking sub exposures. The hot pixels would also be mitigated by dithering a number of exposures. (Dithering involves moving the telescope slightly between exposures so that spurious signal is averaged out when star images are registered and combined into a single result.) Indeed, the manual for the Trius-SX814C states that dark frames subtracted from exposures of 10 minutes or less may in fact *increase* noise in the final image.

I shot a series of dark frames for my test exposures with the camera, but I was still impressed by how little noise was present in 5- and 10-minute exposures without being processed with the dark frames. Furthermore, I typically ran the camera temperature at -20°C, though the cooler can operate as much as 40°C below ambient air temperature and further reduce thermal noise.

All in All

My takeaways from shooting with the Trius are an appreciation for its ease of use and its smooth, low-noise results. Veteran deep-sky astrophotographers know that a single 5- or 10-minute exposure is only the beginning of a picture; the "clean" look of each exposure taken with the Trius-SX814C makes the final result more rewarding. The camera was very sensitive for a chip with small pixels and a Bayer filter matrix on the CCD array.

While the lack of a mechanical shutter in both the Trius and Lodestar X2 cameras was never a problem for me, it could be seen as a shortcoming for astrophotographers interested in remote imaging. Yet a partial solution is to put an opaque "filter" one of the filter wheel's slots, which can then function as a mechanical shutter for the main camera.

The trio comprising the Trius-SX814C, Mini Filter Wheel with its OAG, and Lodestar X2 autoguider made for an easy-to-use total package. The extremely low-noise Sony detectors can eliminate a time-consuming process at the telescope, allowing you to record more light images each night. Astrophotographers choosing any one or a combination of these products will be rewarded by a well-designed system that makes the road to high-quality color deep-sky astrophotography much easier. ✦

North Carolina photojournalist ***Johnny Horne*** *has taken pictures for* The Fayetteville Observer *for 43 years and has been imaging the night sky since age 12.*

◄ **ELECTRONIC ALIGNMENT** iOptron announces the PoleMaster ($299), an electronic polar finder scope that helps you quickly and easily achieve near-perfect polar alignment. The PoleMaster is a small optic with an integrated camera that attaches in front of the polar finder scope on most iOptron equatorial mounts. Once installed, the unit functions in conjunction with the included *PoleMaster* PC software, which quickly plots your polar star field and marks where the true polar axis is, allowing you to adjust your alignment until you are within 30 arcminutes. Its optical alignment can be calibrated to match the true rotational axis of your mount. *PoleMaster* connects to Windows PCs via a Mini USB cable. Be sure to select the proper adapter for your mount when ordering.

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

▼ **OBSERVING AID** Universe2go unveils its personal planetarium device ($99), which combines your Apple or Android smartphone with an innovative viewer that projects constellation lines, star names, and other useful data over your real view of the sky. This interactive viewer works in conjunction with the *Universe2go* planetarium app by simply inserting your device into the viewer, which then projects your smartphone screen over your field to match the star patterns, to produce an "augmented reality" experience. The app plots roughly 120,000 stars, as well as the complete Messier and NGC catalogs, and includes over 3 hours of descriptive information. See the manufacturer's website for additional details.

Universe2go
+49-0-8191-94049-61; universe2go.com

▲ **GO TO MAK** Orion Telescopes & Binoculars introduces the StarSeeker IV 150mm GoTo Mak-Cass Telescope ($999.99). This compact 5.9-inch f/12 Maksutov-Cassegrain telescope has enough aperture to provide satisfying views of the Moon and planets, as well as many deep-sky objects. The telescope rides upon a single-arm alt-azimuth Go To mount with dual optical encoders, allowing users to slew to objects or move the telescope by hand without losing the Go To alignment. The StarSeeker IV hand controller features an extensive database of more than 42,000 celestial objects, including stars, double stars, galaxies, nebulae, star clusters, and more. The telescope includes a 2-inch visual back with a 2-to-1¼-inch adapter, a 90° star diagonal, 23- and 10-mm wide-field 1¼-inch eyepieces, and an Orion EZ Finder II reflex sight.

Orion Telescopes & Binoculars
89 Hangar Way; Watsonville, CA 95076
800-447-1001; oriontelescopes.com

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

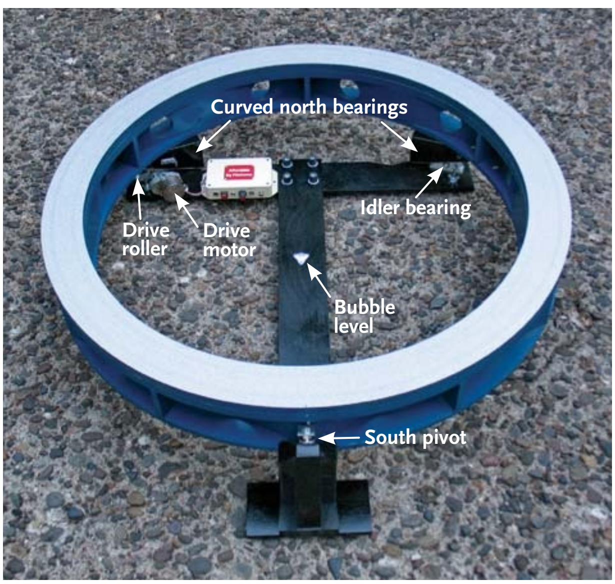
Oltion's Equatorial Platform

This low-profile mount provides motorized tracking for large-aperture scopes.

I'VE LONG FELT the ideal deep-sky machine is a big-aperture scope on an equatorial mount. Sure, most of us adapt readily enough to pushing our Dobsonians along to keep a target in the eyepiece, but there's no denying that it's much nicer to be able enjoy the view without the fuss.

Thanks to the advent of equatorial platforms, we can luxuriate in hands-free observing without the weight and bulk of a regular German equatorial mount. But the problem with many platforms is they usually add several inches to the height of the eyepiece. That sounds minor, but it can be the difference between needing a ladder or not — and that's a big deal.

Over the years this magazine has featured several equatorial platforms, but I can't recall seeing one as minimalist and low-profile as this unit by Oregon ATM Jerry Oltion. Many readers will recognize Jerry's name; he's contributed several innovative ideas to these pages over the years. So, I wasn't surprised to see him come up with such an elegant equatorial platform to carry his 20-inch Dobsonian and 12½-inch bino scope, which was featured in the January 2015 issue, page 68.



JERRY OLTION

Oltion's minimalist equatorial platform provides motorized tracking without adding significant weight or eyepiece height. The mount's stepper motor and electronics were purchased online.

"I'd been thinking about building an equatorial platform for my big scopes, but I didn't want to add much height to them, nor did I want yet another bulky, heavy component to carry around and set up," Jerry says. That desire fuelled his imagination. "I began by figuring out what parts of the mount were absolutely necessary, and then leaving out the rest."

Jerry took his cue from the flex-rocker concept pioneered by fellow Oregon ATM Mel Bartels and others. (See *S&T:* August 2004, pg. 133 for more.) In a flex scope, a Dobsonian's traditional rocker box and base are replaced with a ring and low-profile rocker assembly that allows the altitude and azimuth bearing points to lie atop one another, reducing the need for stiff, heavy components. The resulting lightweight configuration adds minimal height to the eyepiece position when pointed towards the zenith. Jerry realized that the same principle could work for an equatorial platform. The ground ring provides plenty of stiffness — the flex equatorial platform merely holds the bearings in the right place.

"A project like this isn't nearly as difficult to build as some would have you believe," he notes. But there are a few tricky bits. As the photos here illustrate, Jerry's minimalist platform consists of three main subassemblies. First there is the flex ring, which served as the scope's original base. Next is the T-assembly that holds the mount's bearings and drive motor in position. Last is a pair of wooden arcs that functions as the mount's north-axis bearing runners. The arcs attach to the underside of the flex ring via pairs of smooth rods that slide into matching sockets, and ride on matching bearings (one drive bearing, one idler) on the platform base.

The specific angles for the south pivot point and bearing surfaces depend on latitude. "It occurred to me as I was building the platform that the design lends itself to easy modification for different latitudes and/or scope sizes — just change the curve of the runners and the south pivot point's distance from the edge of the ring" Jerry says. "A person could have several sets of runners and pivot mounts for various latitudes and scopes."

Although you can derive the dimensions and required angles for the platform mathematically, Jerry took a different approach. "I wound up figuring out the proper

JERRY OLTION

The mount's T-assembly is shown with the flex base ring removed. Note the pair of arc segments that mount to the underside of the scope's base ring.

curve empirically by suspending the base ring from a rope, pinning the south pivot point into place, and tracing on a piece of cardboard the arc created by moving the ring," he explains.

The finished platform adds only seven pounds to the scope and four inches to its eyepiece height. But even that would be excessive if the mount was flimsy or didn't track well. So how does it perform? "Like it isn't even there," Jerry says. "The scope feels just as stable as ever with no extra settling time or detectable play — the only real difference is that objects stay centered in the eyepiece for up to 50 minutes at a time. And I have to remember not to nudge the scope along."

To read more about Jerry's low-profile equatorial platform, visit his website at **www.sff.net/people/j.oltion/flexeq.htm**. ✦

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

Do you have a telescope or observing accessory project *S&T*'s readers would enjoy reading about? Get featured in Telescope Workshop by e-mailing your idea to Equipment Editor Sean Walker at *swalker@skyandtelescope.com*.

Choosing a Camera

MANY CHOICES With so many cameras to choose from today, how can beginners decide which one best suits their needs?

The question isn't which is best, but which is best for your goals.

IT'S NEVER BEEN a better time to take up astrophotography. A good amateur image today would have been award-winning and groundbreaking only 10 years ago, and a half century ago no one would have believed it was a real photograph — because even shots from professional observatories were inferior. Advances in optics, mounts, and cameras have all contributed to the golden age of imaging we live in today, but the technology can be bewildering to the newcomer.

This article isn't about *which* camera to buy but rather attempts to explain the buzzwords and performance metrics used to evaluate camera models today. There's no such thing as the "best camera" on the market. The real best camera is constrained not only by your budget but also by your imaging goals (what you intend to shoot) and which optics you'll be pairing it with. Matching a camera to your glass is just as important as other criteria when choosing a camera. So let's have a closer look.

Telescopes 101

Although most people associate a telescope with the concept of magnification, the main purpose of a telescope or camera lens is actually to gather light. The bigger the opening, or *aperture,* the more light can come in. This is the first principle of photography — no matter which camera you choose, more light is always a good thing.

Regardless of whether we're talking about a camera lens, refractor, reflector, or catadioptric, we measure an optics ability to collect light by its aperture. This is simply how wide the front opening is that lets in the light (or the size of your primary mirror).

Magnification is determined by your optics focal length. Less magnification makes the image smaller but brighter. Think of light as sand pouring out of a bag. In 5 minutes of exposure time you only get so much sand, and you can make a big, wide, but thin pile of sand, or a small but deep pile of sand. Deep piles of sand (more light) produce brighter images and an improved signal-to-noise ratio. If you want a wide *and* deep pile of sand, you have to expose longer or get a bigger aperture with the same focal length.

The next important metric in understanding a scope or lens is its *focal ratio,* usually indicated by the designa-

for Astrophotography

Richard S. Wright, Jr.

tion f/ and a number. This is determined by dividing the optical system's focal length by its aperture. The focal ratio is a geometric indicator of how much light is delivered to the detector (be it a digital sensor or your eyeball) per unit area of the focused image, and a key point when selecting a camera later. Optics are called "fast" if the focal ratio is about f/5 or lower or "slow" if it's f/7 or higher. Where to draw the line between fast and slow optics is somewhat subjective, but the key takeaway is that fast optics deliver more photons per pixel.

One interesting consequence of this is that an image of, say, the Horsehead Nebula will be just as "bright" with an 80-mm aperture at f/4 as it would be with a 300-mm f/4 setup. The focal ratio is the unifying factor, and it works across all optics as a concrete metric of how long you'll need to expose for a target signal per pixel for a given subject.

Pixel Performance

So how does all this apply to camera selection? The detectors in digital cameras, regardless of whether they are CCD (charge-coupled device) or CMOS (Complementary metal-oxide semiconductor), have an inherent sensitivity to light. A chip that's not very sensitive would have less than stellar performance with a slow focal-ratio system.

Two things measure the light sensitivity of an imaging sensor. The first is *quantum efficiency*, or QE, which simply conveys how efficiently the chip converts photons into electrons. A detector with a QE of 100% would turn every single photon received into an electronic signal. On the other hand, a QE of 50%, which is typical for a consumer-grade detector, converts only half of the light reaching it into an electronic signal.

A detector's QE is not the entire story — the size of its pixels is also very important. Large pixels have more surface area for collecting photons and converting them into electrons (which are subsequently read out as your image). Additionally, the size of a pixel is figuratively the size of the bucket that holds electrons generated by the light. So a bigger pixel holds more electrons *and* has a larger surface area for collecting them. Today's race to achieve ever-smaller pixels is a race toward doom when it comes to low-light photography. However, this isn't to say you should always avoid small pixels, as is the case in planetary video cameras.

Another important factor with pixel size is what's

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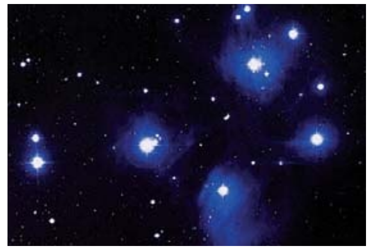
known as the full-well capacity. This specifies how many electrons each pixel can hold. A camera with small pixels might have a full-well capacity of 10,000 ADU (analog-to-digital units — how many electrons can be registered), while a larger pixel might have one of 100,000. In addition to the effective sensitivity, this affects the dynamic range. Do you want to record bright stars and faint galaxies or nebulae in the same exposure without saturating? You need a large full-well capacity for this.

Read Noise

Read noise is one more important metric to consider for getting good images with any digital camera. This is noise introduced by the process of reading the image off the chip. The key to pulling faint details out of deep-sky images of nebulae, galaxies, and comets is getting those details to register higher than the read noise from your camera. While you can stack many shorter exposures to get an effectively longer exposure, you can't pull out faint details unless those details are above the read noise. No amount of stacking will rescue them.

Cooled CCD or DSLR?

Here's something that perplexes many beginners: astronomical deep-sky CCD cameras always include some form of cooling of the sensor, yet DSLR cameras (and the majority of planetary video cameras) do not. Why is that? First, understand that cooling a chip does not make it more sensitive. Cooling reduces *thermal noise*. Heat will "jiggle" loose electrons, and these will register as light signal in your sensor. You can reduce this somewhat

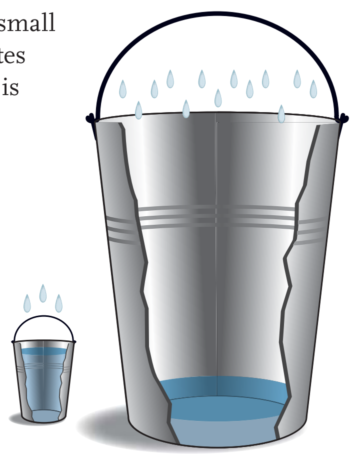


IMPROVING TECHNOLOGY Today's digital cameras and high-quality commercial optics allow amateurs to produce images that were simply unimaginable a few decades ago. This deep image of M45, the Pleiades *(left)*, was captured with a 200-mm-aperture telescope and Canon 5D DSLR camera. Compare that to the photo above, shot on film with the 60-inch reflector at Mount Wilson Observatory in 1995 — considered a good result at the time.

with what's called dark-frame calibration, but a dark frame (taken with no light striking the detector) also has thermal noise. So the cooler the chip is when exposing, the less thermal noise is generated. Commercial DSLR cameras do not include cooling because they weren't designed to make the extremely long exposures required for deep-sky astrophotography.

In general, a cooled camera will give you much cleaner (less noisy) images than an uncooled camera can. While the gain from uncooled to cooled is huge, the benefit of deep cooling does start to drop off after a bit. The gain going from 20°C to 30°C below the ambient temperature is not as great as the initial drop to reach 20°C below ambient. So don't lose any sleep if getting that extra –10° is going to break your budget.

Some of the newer imaging chips (particularly those produced by Sony) do not require dark-frame calibration at all. They're rated as having extraordinarily low thermal signal after some moderate cooling, often as little as one electron over a period of a lengthy exposure! This small of a thermal signal creates negligible noise, so this is a significant advantage.



CATCHING PHOTONS The pixels in your camera can be thought as buckets; small pixels capture fewer photons than large ones, and will fill up (saturate) much faster than a sensor with large pixels. *S&T:* LEAH TISCIONE

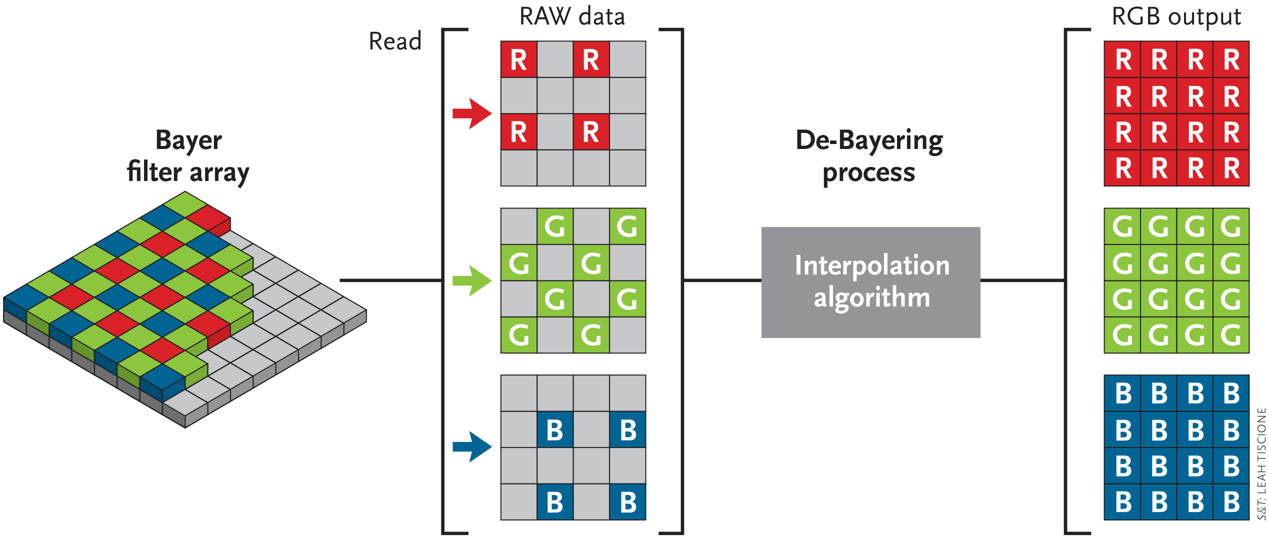
Color or Mono?

Color chips are really the same as monochrome chips, with the only difference being that they're topped by a thin, multicolored layer called a Bayer filter. This is a grid of microscopic filters with one red, green, or blue filter (in a ratio of 25%, 50%, and 25%, respectively) over each pixel on the detector. The sensor still records a monochrome image, but it's then processed with interpolation algorithms to create a full-resolution color image.

There are advantages to adopting a color workflow versus the monochrome/filtered workflow in astro-imaging, but one factor to consider is that the Bayer matrix reduces the effective QE of the chip. For example, "red" pixels do not receive 100% of the red light because of the Bayer filter, and so the base QE is effectively reduced. The QE of color sensors is generally much lower than that for monochrome detectors, so the former work best with fast focal ratios. You might have to work very hard to get good results from most DSLRs with f/10 optics on deep-sky objects, compared to using a monochrome detector matched with high-efficiency color filters.

Determine Your Goal

An obvious consideration when contemplating a camera purchase is what you want to shoot with that camera. For imaging the planets, Sun, and Moon, the hands-down winners these days are the CMOS-based video cameras. The biggest advantage of modern CMOS chips is the readout speed, critical to the planetary imaging technique of recording large video streams and stacking the sharpest frames. However, super-fast readout speeds aren't warranted unless you have optics that can deliver enough light to the sensor — not to mention a computer that can handle high data-transfer speeds.



COLOR OR MONOCHROME Color imaging sensors are actually monochrome chips with tiny color filters placed over each pixel (left). A special computer program known as a debayer filter separates the individually filtered pixels into their respective color channels (center), and then fills in the missing pixels in each color using an interpolation algorithm to create the final color result (right). Color sensors have lower efficiencies, so they generally work best with fast optics.

The choice of monochrome versus color in planetary photography is still an important decision. Monochrome cameras will generally be more sensitive, allowing shorter exposures and faster shutter speeds. And they are the best for lunar and solar imaging, which involve targets that are essentially monochrome.

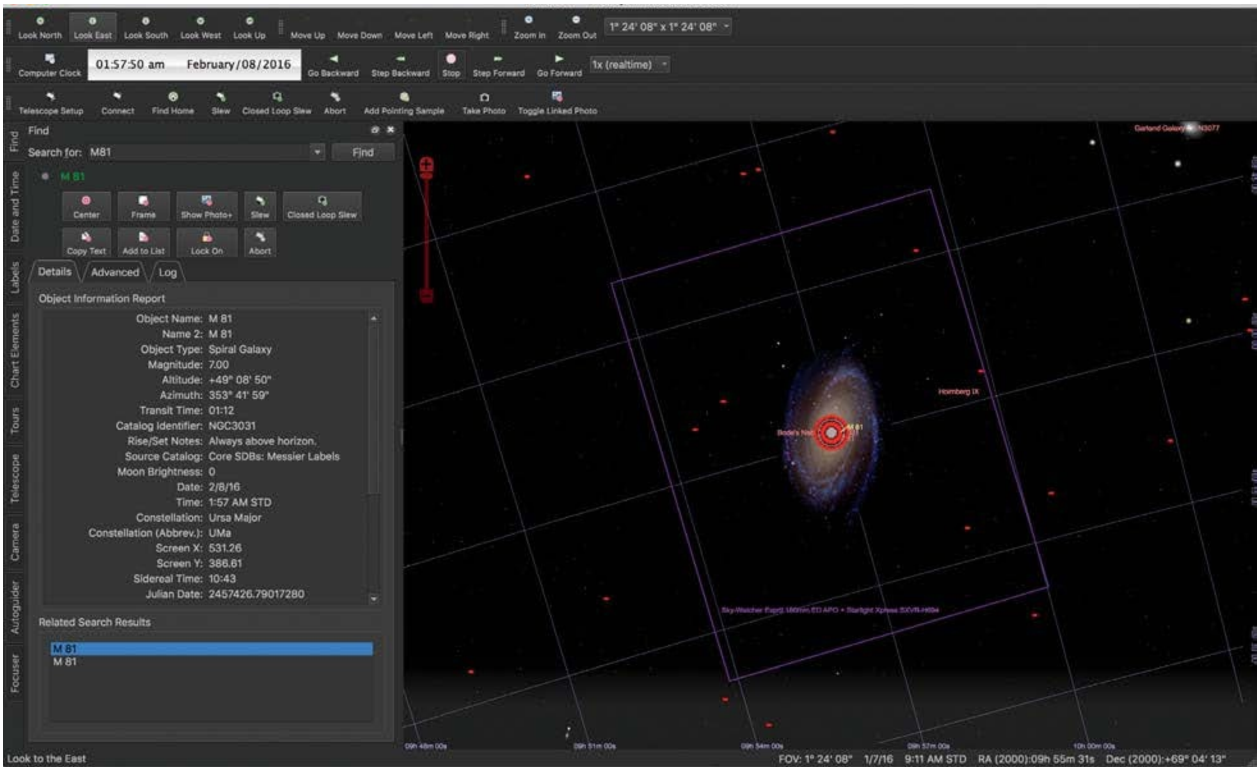
The decision isn't as straightforward when shooting the planets. Imagers regularly get phenomenal results using color cameras. Monochrome cameras with a filter wheel compromise your productivity, in that you'll have to change filters, process three different video streams, and then combine the results into a single RGB image later. Even so, this is the route to the very best data you can get out of your system. And monochrome cameras are a better choice if you intend to shoot the planets using specialized filters such as those that isolate ultraviolet, methane, or infrared wavelengths.

If your goal is deep-sky imaging, you'll want a larger chip (to record more of the sky) than most video cameras provide. You can use a planetarium program such as *TheSkyX* (**bisque.com**) to simulate the field of view of your potential optics-camera combination. (Full disclosure: I work for Software Bisque.) Experiment with the field of view of your telescopes or lenses to see if you can fit the objects you want to image in the frame of your desired camera. Is the object a tiny feature in the middle of a large field of stars, or will you need to mosaic multiple images together to cover the entire object?

If you are primarily limited to light-polluted skies, a good choice for deep-sky imaging is a monochrome camera equipped with narrowband filters.

When imaging through narrowband filters, there are few drawbacks for living somewhere without dark skies. You can even image during the bright phases of

ZOOMING IN While the focal length of an optic will determine the magnification of your target, the instrument's focal ratio determines the brightness of the image. This shot of the Horsehead nebula *(top)* was recorded with a 300-mm lens at f/4, while the bottom photo was captured with a 105-mm refractor at f/4.5 producing a nearly equivalent signal per pixel with higher resolution.



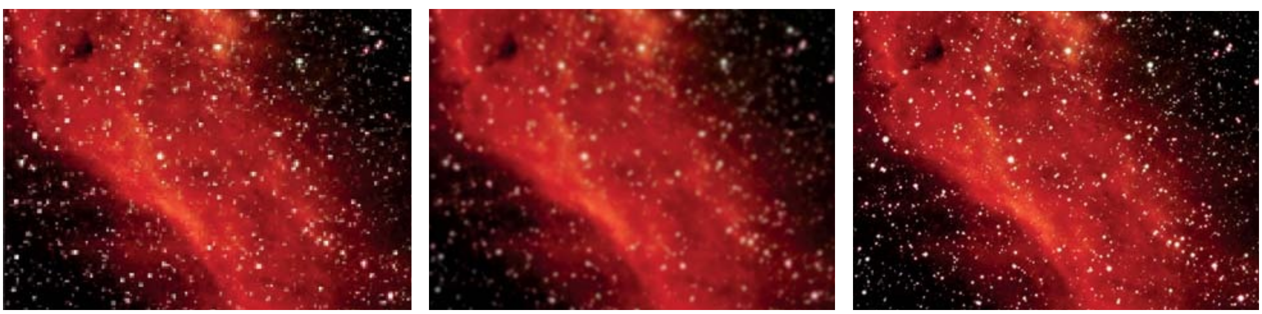
the Moon when most "natural" color imagers are out of business. But there is some penalty to shooting with narrowband filters. They block more light than broadband filters and require much longer exposures to achieve a comparable signal, so don't try this if you have high f/ratio optics or a mount that can't reliably guide for more than a few minutes.

Another boon for light-polluted skies is deep full-well capacity detectors. To get images from a light-polluted sky nearly as good as those taken from a dark sky, you have to image much longer. One of the primary impediments here is the skyglow, which adds considerable background signal to your images. In addition, the signal from deep-sky fuzzy objects needs to be as high above the skyglow as possible, which means taking very long exposures that tend to saturate small pixels.

COMPUTER RESEARCH Planetarium software that includes field-of-view indicators for specific imaging detectors and telescope combinations can help you decide what type of astrophotography works best with the optics you already own.

Image Sampling

Finally, let's talk about sampling. Any optical system, whether it's a telescope or a camera lens, has an intrinsic resolving capability limited by diffraction (a physical limitation we can't beat). The smallest focused spot is called the *Airy disk*, which depends on the wavelength of light and the aperture of the optical system. Larger apertures have smaller Airy disks (sometimes called the spot size) and can theoretically deliver higher-resolution images. However, in most cases, the best resolution you



PROPER SAMPLING Matching your pixel size to your optics, known as sampling, is an important factor in achieving a great astrophoto. An undersampled image *(left)* will appear pixelated when zoomed in. Oversampling, caused by using a long focal-length telescope and a camera with small pixels *(middle)*, often results in fuzzy images, particularly when the atmosphere is turbulent. A properly sampled image *(right)* avoids both of these issues.

can obtain is limited by atmospheric turbulence, commonly called "seeing."

Small pixels are better suited than large ones to take advantage of a fast optical system. Conversely, a slow optical system would probably waste the potential resolution gain provided by smaller pixels (as well as having the disadvantage that less light is delivered to each small pixel).

In an undersampled image, there are too few pixels for the detail the optics and sky conditions could have delivered. Conversely, oversampling means you're using far too many pixels given the resolution capabilities of your optics or the sky conditions. A super-high-resolution camera will not really deliver more resolution than your optical system or the local seeing conditions can deliver; you just get a blurry mess that looks better only when you shrink it down in Photoshop. Better results are obtained with proper sampling in the first place. You can easily determine your sampling resolution with this formula: arcsec/pixel = 206.3 × pixel size / FL (mm). Typical "average" seeing is about 2 arcseconds.

Parting Thoughts

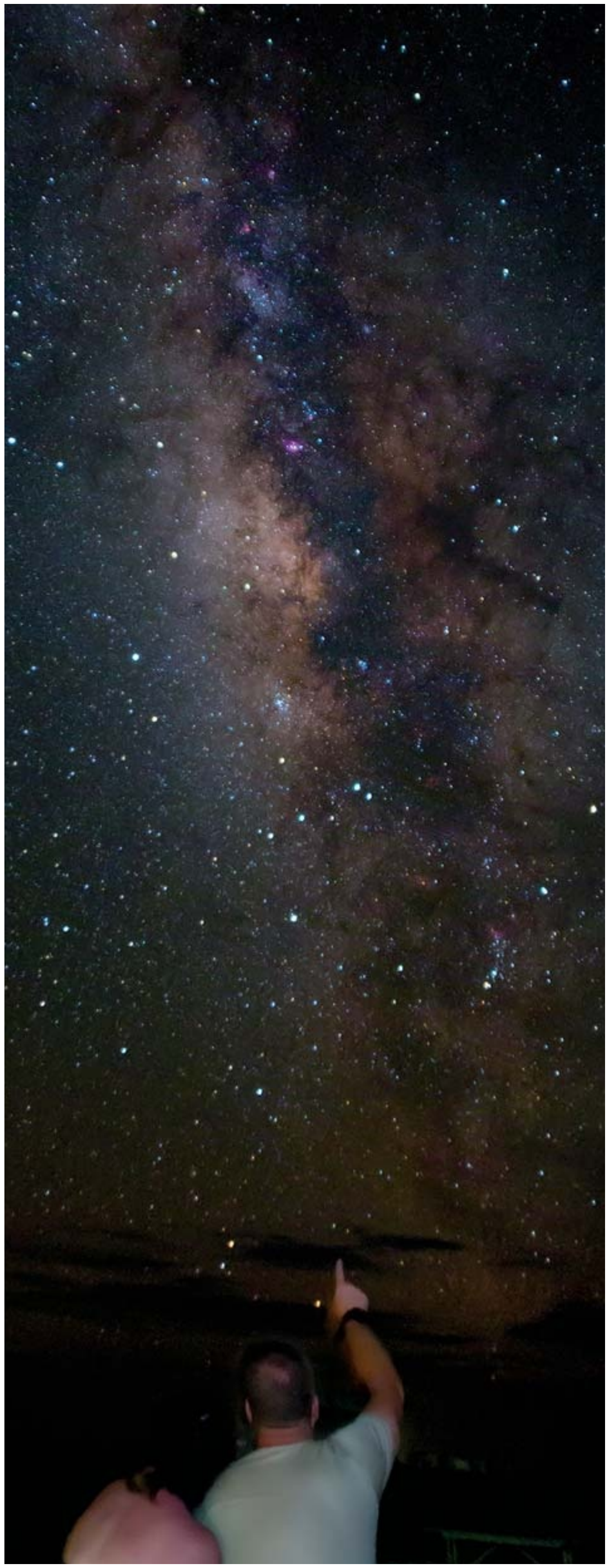
Selecting a camera for astrophotography shouldn't be done outside the context of the optics you'll use it with. In general, cameras with small pixels or color detectors perform well when paired with fast focal-ratio instruments. While you can certainly use a camera with big pixels on a fast optical system (which compensates for a lower QE detector and less-than-perfect guiding), they also perform very well on slower optics.

In addition to a camera chip's sensitivity, read noise is the limiting factor when stacking short exposures to reveal faint detail in deep-sky objects. Cooling provides a huge boost in performance, but don't obsess over really deep cooling if you're just getting started.

Finally, I've intentionally neglected to address the debate over CCD versus CMOS sensors. That's because there really is no debate, given the current state of the art. Both deliver great images and perform very well for astrophotography. CMOS has a definite edge in readout speed (great for video), while CCDs are more sensitive to ultraviolet and infrared wavelengths, though this won't be the case much longer. For normal deep-sky photography I would not let the choice of a CCD or CMOS detector be a deciding factor when choosing between two similar cameras.

Just remember, there is no single "best camera." Consider what you want to image, where you're imaging from, and how you're collecting the light. Using these criteria, you can evaluate a camera's specifications and suitability to your imaging goals. ✦

Richard S. Wright, Jr. is a senior software developer at Software Bisque by day and an avid astrophotographer by night, imaging deep-sky targets every clear night he can.



UNDERSAMPLING BENEFITS A DSLR with a wide-angle lens vastly undersamples the night sky, but it's relatively unaffected by atmospheric turbulence and tracking errors. This image was taken with a simple sky tracker (Sky-Watcher Star Adventurer) and a Canon EOS 5D DSLR with a 14-mm f/2.8 lens.

▶ COMPLEX CLOUD

Chuck Manges

Object 78 on Charles Messier's list (but discovered by Pierre Méchain) is an 8th-magnitude reflection nebula in Orion lit by two 10th-magnitude stars.
Details: *Celestron EdgeHD 11 Schmidt-Cassegrain telescope with HyperStar, QHY23M CCD camera, and LRGB filters. Total exposure: 99 minutes.*

▶ ▶ AGLOW IN PERSEUS

Bruce Waddington

Just 1,000 light-years away, NGC 1333 is a part of the Perseus Molecular Cloud and chock-full of newborn stars heavily shrouded in the nebula's dust. It glows with a total magnitude of 5.6.
Details: *PlaneWave 12.5-inch CDK astrograph, QSI 640ws CCD camera, and LRGB filters. Total exposure: 9.7 hours.*

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SPARKLING GEMS

Dan Crowson

The pretty open cluster Messier 103 (above) is easily found about 1° northeast of 3rd-magnitude Ruchbah (Delta Cassiopeiae, at right). Its stars include a 10th-magnitude red giant, seen near the cluster's center.
Details: *Astro-Tech AT90EDT apochromatic refractor with SBIG ST-8300M CCD camera and LRGB filters. Total exposure: 4 hours.*

DAYLIGHT COVER-UP

John Adams Hodge

The Moon's waning crescent, just 13% illuminated and challengingly dim, slid across the bright, gibbous disk of Venus during daylight for North American viewers on December 7, 2015.

Details: *Celestron C8 Schmidt-Cassegrain telescope and Canon EOS 70D DSLR camera. Exposure: 1/500 second.*

◀ **STREAMING GAS**

Gerald Rhemann

Comet Catalina (C/2013 US10) sported a stubby dust tail and a long, slender gas tail (tipped by the galaxies NGC 5363 and NGC 5364) when captured last December 20th in a two-frame mosaic.
Details: *ASA 8H astrograph and FLI PL 16803 CCD camera with LRGB filters. Total exposure: 31 minutes per frame.*

▼ **CAVE NEBULA**

Ron Brecher

Challenging to spot visually, Sharpless 155 (Caldwell 9) in Cepheus contrasts a red emission nebula, blue and yellow reflection nebulae, and colorful stars.
Details: *ASA 10N-OK3 astrograph and SBIG STL-11000M CCD camera with Baader Hα and RGB filters. Total exposure: 26 hours.*

▶ **FLAMING STAR NEBULA**

Van Macatee

Captured during 2015's Peach State Star Gaze, the IC 405 nebula surrounds hot, blue-white AE Aurigae. This erratic, 6th-magnitude variable is a runaway star.
Details: *Explore Scientific 102mm ES apochromatic refractor and modified Canon EOS T3i DSLR camera used at ISO 1600. Total exposure: 3.3 hours.*

◀ **RAISING THE BAR**

Ian Gorenstein

NGC 1530, a large barred spiral galaxy in Camelopardalis, displays two curving arcs and delicate dust lanes along its bar.

Details: *Celestron EdgeHD 14 Schmidt-Cassegrain telescope, Atik 460EXM CCD camera, and Astronomik LRGB filters. Total exposure: 5 hours.*

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GRAND HAVEN SKY

John Ensink

Haze moving in along the Lake Michigan shoreline adds drama — and some urgency — to this late-evening view of Orion and its environs captured on March 9, 2015.

Details: *Nikon D7000 DSLR camera at ISO 2500 with 11-to-16-mm zoom lens (used at 16 mm). Exposure: 15 seconds.* ✦

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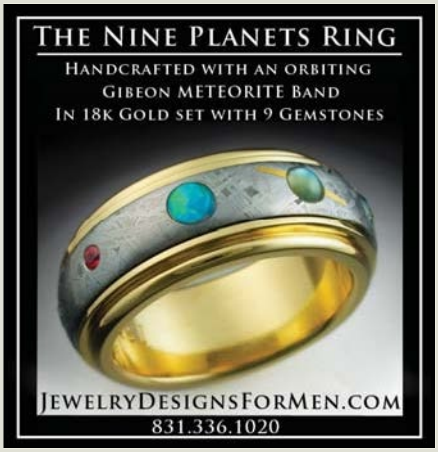

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Pluto Is Not the End

It's dangerous for NASA officials to imply we're done exploring the solar system.

When New Horizons flew past Pluto last summer, NASA Administrator Charles Bolden heralded it as "the capstone event to 50 years of planetary exploration," adding that the Pluto encounter "completed the initial survey of our solar system." NASA's science chief John Grunsfeld said, "There's very little *terra incognita* in our solar system today." These statements arise from an outdated view of our solar system — the hierarchical view of nine planets, with Pluto at the outer end, accompanied by a smattering of less-important bodies — and they threaten the future of NASA's solar system exploration.

How outdated? For starters, the Voyager encounters with the outer planets revealed the diversity and activity of their moons, many of them larger and more recently active than some planets. Among them are Europa, Enceladus, Titan, and Triton, each of them as worthy of a dedicated mission as any of the planets.

Then, of course, the discovery of large Kuiper Belt bodies unseated Pluto from planethood. We now know about thousands of solar-system objects beyond Neptune. Hundreds of them are large enough to be round, and their varying colors and albedos suggest that they're at least as diverse as the moons orbiting the giant planets.

In fact, this "third zone" of the solar system is almost certainly stranger than anything we've seen before. New Horizons' flyby of Pluto and Charon revealed bodies more varied than anyone had imagined. How weird do the other Kuiper Belt objects look? Pluto is not the end of the solar system; it's just the beginning of the *rest* of the solar system. The Kuiper Belt — contrary to what Grunsfeld said — remains almost entirely terra incognita.

Even within Neptune's orbit exist worlds we've barely touched. We now understand Uranus and Neptune to be a distinct class of planets from Jupiter and Saturn, and they have changed in the quarter-century since we visited them. We need to orbit our ice giants, probe them, and understand what they can tell us about similar-sized exoplanets.

As for those enticing moons, Voyager 2 managed only very distant, low-resolution views of Uranus' moons; Charon's surprisingly youthful surface makes me wonder how most of them truly look. And we don't know how time changes the appearances of these active, planet-circling worlds — Triton, Titan, Enceladus, Io, possibly Europa.

We have never visited any of the icy Trojans and Centaurs, populations roughly as numerous as the main-belt asteroids. Finally, missions like Rosetta and Hayabusa have shown us the dynamic nature of the solar system's tiniest bodies, and we'll likely never finish our reconnaissance of all those.

Each time we step a little farther into space, we see more, ask new questions, have new destinations to travel to. But it's a constant struggle to win support for federal funding for robotic exploration beyond Earth. So to have our space-science leaders imply that our work to explore the solar system is in any sense complete is hazardous. We're not done with the solar system. There's so much more to explore. ✦

NASA / JPL-CALTECH / T. PYLE (SSC)

Artist's concept of view from Kuiper Belt looking back towards the Sun

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