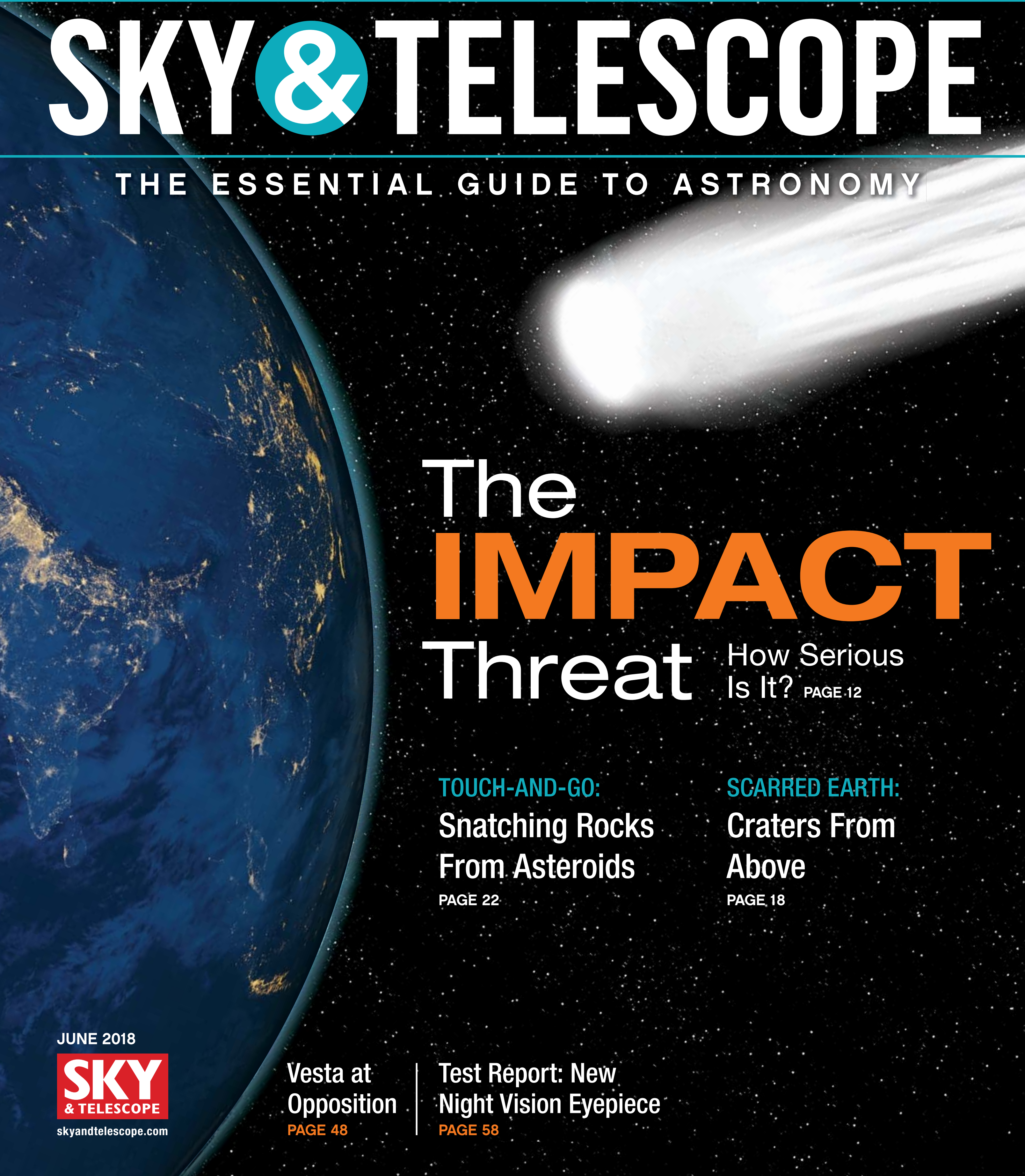
DEEP-SKY WONDERS: Colorful Doubles PAGE 54

TITAN TELESCOPES: The Legacy of George Ellery Hale PAGE 34

BINOCULAR TOUR: 15 Steps to Forever PAGE 64

SKY & TELESCOPE

THE ESSENTIAL GUIDE TO ASTRONOMY



The IMPACT Threat

How Serious Is It? PAGE 12

TOUCH-AND-GO: Snatching Rocks From Asteroids PAGE 22

SCARRED EARTH: Craters From Above PAGE 18

Vesta at Opposition PAGE 48

Test Report: New Night Vision Eyepiece PAGE 58

JUNE 2018

SKY & TELESCOPE

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CONTENTS

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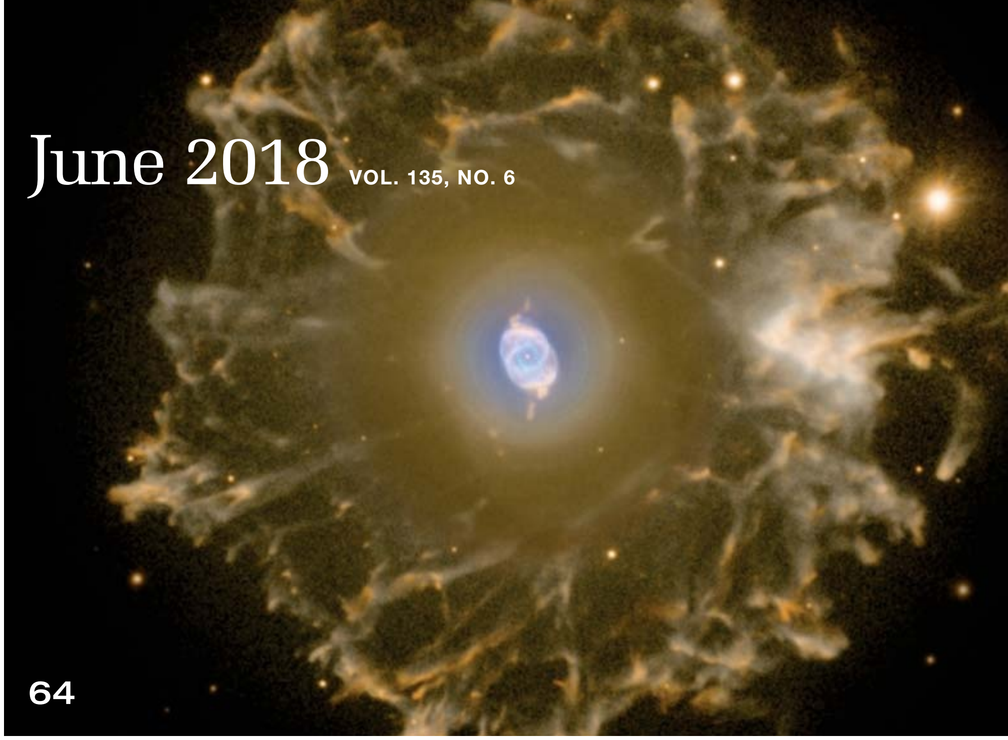
THE ESSENTIAL GUIDE TO ASTRONOMY



June 2018 VOL. 135, NO. 6

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ON THE COVER

Artist's concept of comet on collision course with Earth.

MARC WARD / STOCKTREK IMAGES / GETTY IMAGES; ROBERT SIMMON / NASA EARTH OBSERVATORY

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Heaven Sent

IT'S NOT OFTEN THAT we get to report on an astronomical discovery that benefits all humankind. The research we write about tends to be of the pure rather than the applied kind — a new gamma-ray burst detected, a fresh insight into dark matter, and so on.

This particularly holds true these days, when specialization is the order of the day, and many scientific results we astronomy editors cover, if not put in proper context, might go over lay readers' heads like a shooting star that fades in seconds. Try as we might to deliver them in clear, accessible prose, some feature articles even in *S&T* can feel arcane to those new to the field.

But for this issue, I had the pleasure of reporting a story whose most significant disclosure all human beings, no matter their age, nationality, education level, or scientific literacy, can appreciate in an instant.

The news is simply this: NASA-funded efforts have determined that no mountain-size asteroid or comet is on a trajectory to hit Earth for at least the next 100 years.

NASA / JEFF WILLIAMS

Even top NASA scientists could not have stated this with confidence as recently as 20 years ago. We just didn't know what might be lurking out there unfound. Now, after a diligent search that began in 1998, astronomers think we have effectively "retired the risk" of any object larger than a kilometer (0.6 mile) in diameter colliding with our world in the foreseeable future (see page 12).

Not that most people worry about such a calamity occurring. But in this time of uncertainty over our planet's fate as a result of our own doings, it comes as a relief to learn that at least one natural hazard — in fact, possibly the gravest of all, just ask the dinosaurs — has been, as one expert told me, "largely put aside by discovery."

Of course, we have lots more to learn about such immense space rocks and what they can do to us. See our articles about large meteor craters on Earth (page 18) — sober reminders of what *does* happen — and about two missions now en route to study and sample near-Earth asteroids (page 22).

Such work is important, because despite the reassuring news, it's always possible that one of our surveys could pick up a previously unknown comet, or an asteroid smaller than 1 km across that still packs a wallop, that might be making a beeline for Earth. We need to know as much as we can about these things in case we have to try to stop or divert one.

In the meantime, though, we can all breath just a little bit easier. Kudos to all involved in this achievement.

Peter

Editor in Chief

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A high-altitude balloon carrying the HyperSpectral Imager for Climate Science instrument is partially inflated with helium at sunrise in preparation for launch.

HYSICS TEAM/LASP

Up, Up, and Away

The article "Science in the Stratosphere" (*S&T:* Feb. 2018, p. 14) states that, to retrieve the telescope at each mission's end, the telescope detaches from the balloon, goes into free fall, and then parachutes down to a somewhat gentle landing. But what happens to the balloon? Does it somehow self-destruct, or does it just eventually fall back to Earth somewhere unguided?

Kurt Petersen • Sheboygan Falls, Wisconsin

Laura Fissel replies: *That is a really good question! When NASA sends a signal to separate the balloon from the parachute, it also fires explosive bolts that tear open a large seam in the balloon so that the helium can escape. The balloon therefore falls as well, usually landing a kilometer or so away from the telescope. It can't be used again, so NASA personnel just collect and remove it. But it's far better to recover the balloon from nearby than to have it land much later somewhere unexpected. You can imagine what a surprise it would be for anyone who saw the balloon land or happened to come across it later!*

Fissel's article on balloon astronomy took me back to a special evening 25 years or so ago. I was driving home and saw a bright, planet-like object in the twilight sky where no planet should be. It was getting dark, but I got out my telescope and pointed it at the mystery object, and there before me was a beautiful, teardrop-shaped balloon that was high enough to still be in sunlight. I could see the sun reflecting off the instrument package dangling beneath — a sight I've never seen since.

Scott Kardel • San Marcos, California

A New Era?

As a subscriber since college in 1987, I've rarely been tempted to write the editors. However, the Spectrum entitled "Rippled Fabric of Astronomy" (*S&T:* Jan. 2018, p. 4) has led me to raise a question about one of the key items in the article.

While the direct observation of a neutron-star merger in both light and gravity waves was indeed a historic event, it's not the first time we've "usher[ed] in an entirely new era of 'multi-messenger astronomy.'" Wouldn't this new era be more accurately dated to the detection of neutrinos and optical radiation from Supernova 1987A?

The great discoveries rarely fade with time, and I suspect Peter Tyson's mild hyperbole might end up being more true than the neutrino-linked supernova event of 30 years ago. I really enjoyed the comparison of light and gravity-wave detection for the same event as both hearing and seeing it, though I don't know what the neutrino equivalent would be — feeling it, perhaps?

Matt Cline
Anderson, South Carolina

Seeing in the Dark

I want to thank Alan Whitman for his article "Dark Clouds in Taurus" (*S&T:* Jan. 2018, p. 57). The number of people who can observe dark nebulae grows smaller every day due to light pollution. I had first learned of and planned to view the Taurus Dark Cloud complex a few months prior but didn't have a map good enough to find its nebulae. With Whitman's article in hand, I was able to try hunting them down in my 8×56 binoculars.

I found all the dark nebulae that he plotted by slowly sweeping back and forth, looking for a lack of stars. However, I could only catch glimpses of that inky black at the heart of a few dark patches. What really surprised me was how, when I put the binoculars down and simply gazed at the area with averted vision, I kept glimpsing those dark streamers.

I confirmed my naked-eye sighting by sketching where I was seeing the two streamers and comparing it to wide-field images. I credit my super-dark skies (limiting magnitude 7.5) and young eyes for making such an amazing discovery.

Scott N. Harrington
Evening Shade, Arkansas

Full Moon Fever

I once thought, as Dave Chapman does, that "if you do the math, you'll find that when February has no full Moons, then both January and March that year *must* contain two full Moons" (*S&T:* Feb. 2018, p. 84). Alas, this is often but not always the case, at least as reckoned in Universal Time.

In the year 2094, for instance, it's the months of January and April (not January and March) that feature two full Moons, and looking ahead to 2113, it's January and May that sport the two full Moons.

Also, it's possible for a February with no full Moon to happen in a year with only 12 full Moons (2067), which means that only one month (March in this case) gets two of them.

Bruce McClure
Norwood, New York

Braille Method

I'd like to point out that the extremely elongated shape of the recently discovered interstellar visitor 1I/'Oumuamua (*S&T:* Feb. 2018, p.10) is not all that unprecedented. In 1999, the spacecraft Deep Space 1 flew by the asteroid Braille and found it to consist of a long string of small rounded bodies. Several images of other small solar system bodies have shown them to be made up of two or more "lobes" connected together. The media reports of 'Oumuamua as being so unusual as to possibly be artificial are, indeed, "hyperbolic."

Alex Heydon
Ajax, Ontario

Kelly Beatty replies: *Yes, 9969 Braille is definitely elongated, and it conceivably might be a chain of connected fragments. But this little asteroid spins very slowly, every 226 hours, whereas the rotation period of 'Oumuamua is 8 hours. Such a highly elongated object rotating that fast can't hold together unless it's solidly bound as a whole — what geologists term "monolithic" — rather than a collection of pieces.*

A Family Affair

Surely *Sky & Telescope* is a family-friendly publication. Nevertheless, you might have added new meaning to the term with the January 2018 issue.

I refer to your plaudits for a telescope based on a design by John Dobson (p. 30); the citing of Harold F. Weaver as co-discoverer of Berkeley open clusters (p. 55); and mention of the Trumpler 2 cluster (p. 62), named after Lick Observatory's Robert J. Trumpler. It's a verifiable — albeit obscure — fact that these three people were matrimonially related, a consequence of choices made by two of Trumpler's daughters: Cecile, the eldest, married Weaver; Elizabeth Julie, the youngest, married R. Lowry Dobson, one of John's brothers.

If *S&T*'s editors had wished to highlight this familial conjunction, I suppose you could have urged readers to view the Berkeley and Trumpler clusters with a Dobsonian reflector.

Mark Gingrich
San Leandro, California

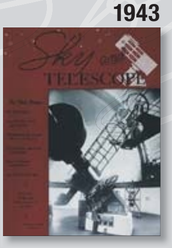
FOR THE RECORD

- Colorful sunrises and sunsets on Earth (*S&T:* Jan. 2018, p. 49) are caused by Rayleigh scattering of sunlight's blue wavelengths by air molecules.
- The 24°×24° field of view of the TESS cameras (*S&T:* Mar. 2018, p. 24) is equivalent to the area covered by nearly 2,100 full Moons.
- The images of Venus (*S&T:* Mar. 2018, p. 53, bottom caption) were obtained using a filter that transmitted wavelengths longer than 610 nm.

SUBMISSIONS: Write to *Sky & Telescope*, 90 Sherman St., Cambridge, MA 02140-3264, U.S.A. or email: letters@skyandtelescope.com. Please limit your comments to 250 words; letters may be edited for brevity and clarity.

75, 50 & 25 YEARS AGO by Roger W. Sinnott

1943



1968

1993

◖June 1943

Spiral Puzzle "It has been known for a long time that the spiral nebulae are in rotation. The radial velocities in spirals sufficiently inclined to the line of sight tell us that one edge is receding relative to the other, which is approaching us. Astronomers have been puzzled, however, as to the actual direction of rotation: are the spiral arms trailing behind or going on ahead? This question is important in theories of the origin and future of these galaxies. . . .

"Now Dr. Edwin Hubble, one of the foremost authorities on extragalactic nebulae, finds sufficient evidence in the famous Mt. Wilson collection of photographs to state . . . that probably all spiral arms are trailing."

The debate went on for decades, but today we know Hubble was mostly correct. A much-studied exception is NGC 4622 in Centaurus. Starting in 2002, work of a team led by Ronald J. Buta (University of Alabama) has shown that the outer tips of its arms actually do lead.

◖June 1968

Death by Supernova "Although in our galaxy Type II supernovae may occur as often as twice a century . . . most must be at such vast distances from us that their cosmic-ray flux would arrive highly diluted. Suppose, however, that . . . such a supernova explosion occurred within a few hundred light-years of the sun. . . .

"The possibilities have been explored by biochemist K. D. Terry of the University of Kansas and space scientist W. H. Tucker of Rice University. . . . The paleontological record clearly shows periodic mass extinction of large groups of animals (not plants). . . . It is calculated that since pre-Cambrian times 600 million years ago, perhaps four nearby supernovae caused radiation of 1,000 roentgens at the earth. . . ."

Notwithstanding today's wide acceptance that the Chicxulub impact killed the dinosaurs, nearby supernovae remain another viable threat to life on Earth.

◖June 1993

Evil Genius "Astronomers who enjoy Sherlock Holmes mysteries recently learned that they might have more in common with Prof. James Moriarty, master criminal, than with their hero — at least in the imagination of English storywriter Arthur Conan Doyle. Astronomer Bradley Schaefer has uncovered evidence that Moriarty is actually a thinly veiled fiction based on . . . American astronomer . . . Simon Newcomb. . . .

"Schaefer has also uncovered long excerpts copied from the detective stories in Mrs. Newcomb's hand. . . . She must have been pleased by the character who, in Doyle's words, [had] 'a brain of the first order' — in short, the only man smart enough to outwit Sherlock Holmes."

SOLAR SYSTEM

Amazing Storms, Jet Streams on Jupiter

NEW RESULTS PUBLISHED in the March 8th *Nature* show us the latest looks at Jupiter from NASA's Juno spacecraft, revealing details of the giant planet's atmosphere.

In a visually stunning result, Alberto Adriani (INAF Institute for Astrophysics and Space Planetology, Italy) and colleagues report the discovery of two sets of cyclones at the planet's poles.

The complex at Jupiter's north pole has a central, 4,000-km-wide (2,500-mile-wide) cyclone, with a ring of eight, regularly spaced storms of similar size around it. At the south pole, a central cyclone sits in the middle of an imperfect pentagon of five others, each between 5,600 to 7,000 km wide, or about half of Earth's diameter.

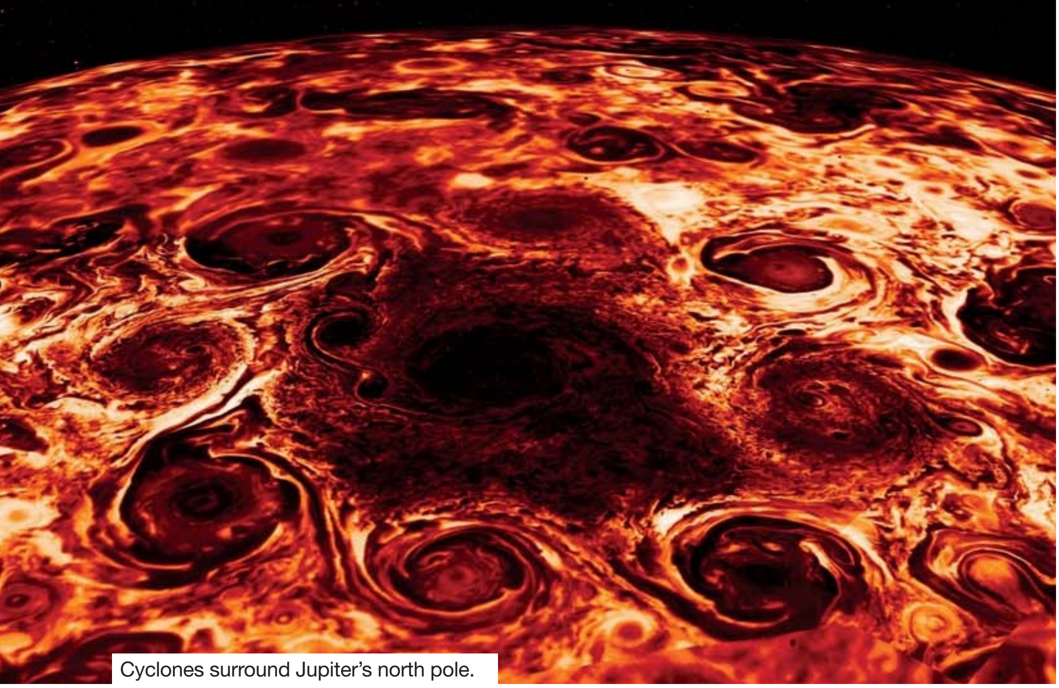
The individual storms rotate every 27 to 60 hours at hundreds of kilometers per hour. It's possible they drift around the central cyclones, but Juno observed little change over 7 months. The team doesn't know why the patterns remain stationary. It's also still unclear whether the cyclones formed at the poles or migrated there from elsewhere.

Additional work shows that the planet's jet streams reach some 3,000 km down, far deeper than many scientists expected. For comparison, Jupiter's weather layer — the part where sunlight is absorbed and clouds form — is only about 100 km deep. Deep jet streams favor a long-standing theory for Jupiter's atmosphere, in which the jet streams form a series of nested cylinders, like a roll of toilet paper that's been carved into a sphere (but fewer layers). Each latitude band corresponds to a different layer in the nest, with higher latitudes corresponding to deeper cylinders.

In the region dominated by the jet streams, the planet rotates differentially, turning more quickly at its equator than at its poles. But below the deep jet-stream layer, the planet appears to rotate more like a solid ball, which means the cylinder scenario may need some modification.

More results are forthcoming, including about widespread lightning, predominantly in the northern hemisphere. Still, questions linger — such as how deep the Great Red Spot goes — and await additional data.
■ CAMILLE M. CARLISLE

● For more results and images, visit https://is.gd/junosjupiter.


Cyclones surround Jupiter's north pole.

NASA / JPL-CALTECH / SWRI / ASI / INAF / JIRAM

COSMOLOGY

Signal from First Stars Suggests Primordial Chill

A SIMPLE EXPERIMENT has detected a signal from the very first stars. The observations may have intriguing implications for the nature of dark matter.

For years, astronomers have been trying to map the early universe's neutral hydrogen gas via its 21-cm radio emission. In particular, they want to see how the first stars' high-energy radiation heated this gas, ionizing bubbles that spread across the infant universe. Detecting the emission is difficult, as it has been redshifted to low radio frequencies and is often swamped by foreground signals. Nevertheless, several large radio arrays are getting close to detecting the emission signal.

Now, Judd Bowman (Arizona State University) and colleagues have turned the tables, using a simple setup to find early hydrogen via *absorption* instead. Ultraviolet light from the first stars would have altered the energy states of hydrogen atoms, knocking them out of balance with the cosmic microwave background (CMB). The hydrogen could then make itself known not by emitting 21-cm radio waves but by absorbing them from the CMB.

The team used a detector called the Experiment to Detect the Global Epoch of Reionization Signature (EDGES) in the radio-quiet Australian Outback. About the size of a large desk, EDGES contains few electronics and is extremely well calibrated to lower frequencies. As the team reports in the March 1st *Nature*, EDGES successfully detected hydrogen absorption by averaging the signal across the sky. The subtle dip in the radio spectrum is centered at a frequency of 78 MHz and corresponds to an epoch just 180 million years after the Big Bang.

But to scientists' surprise, the absorption observed was deeper than theory predicts, suggesting that the hydrogen gas in the early universe was unexpectedly cool.

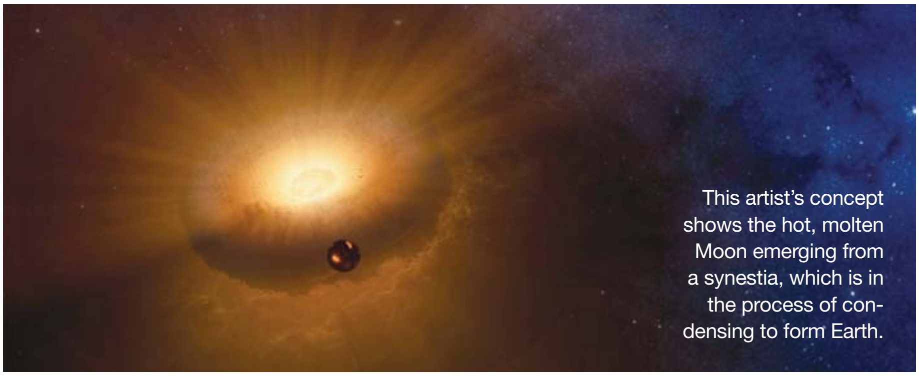
In a companion paper, Rennan Barkana (Tel Aviv University, Israel) argues that non-gravitational interactions with dark matter particles would have naturally cooled the gas. Based on the EDGES observation, Barkana predicts a relatively low mass for the dark particles — at most a few times the mass of a proton — and relatively low velocities. "These results indicate that 21-cm cosmology can be used as a dark-matter probe," he writes.

But first, Bowman wants to see the results repeated. "The next step in the scientific process is for another group using a different instrument to confirm our detection."

■ GOVERT SCHILLING

MOON

Giant Impact May Have Vaporized Earth to Make Moon



This artist's concept shows the hot, molten Moon emerging from a synestia, which is in the process of condensing to form Earth.

A NEW TWIST ON the giant impact theory posits that the Moon formed from Earth's vaporized remains after an epic collision.

Most planetary scientists agree that our Moon was created when a Mars-mass body delivered a glancing blow to Earth, launching large amounts of rock into an orbiting ring that coalesced to form the Moon.

However, problems have emerged with this scenario. For one, most of the Moon would have been made from the impactor's mantle, but measurements of isotopic ratios show that the Moon and Earth are made of exactly the same stuff. All other solar system bodies with known isotopic ratios have their own distinct signatures.

To address this inconsistency, Simon Lock (Harvard University) and Sarah Stewart (University of California, Davis) proposed a radical approach. They developed computer models last year showing that when two planet-mass objects collide, they could form a *synestia*. This mass of vaporized rock and metal takes the shape of a giant, spinning donut, which is connected to a metal-rich central bulge — the surviving core of the planet.

In the model, the Moon forms within the orbiting torus of the synestia. As the rock vapor cools, it begins to condense onto bits of solid rock, which gradually merge into a fully formed but still molten Moon.

The researchers' follow-up with colleagues, published online February 28th in the *Journal of Geophysical Research: Planets*, indicates that a synestia would have been the ultimate mixer, erasing chemical differences between the impactor and the impacted body. Moreover, this scenario explains the Moon's lack of volatiles, as the most easily vaporizable material would have remained in a gaseous phase rather than glomming onto the Moon.

So far, the synestia model has produced mixed reactions within the ranks of planetary scientists. Some of them welcome it as a potential fix for the limitations of the giant impact theory, but others remain skeptical.

■ JAVIER BARBUZANO

GALAXIES

Dwarf Galaxy Evicted Milky Way Stars

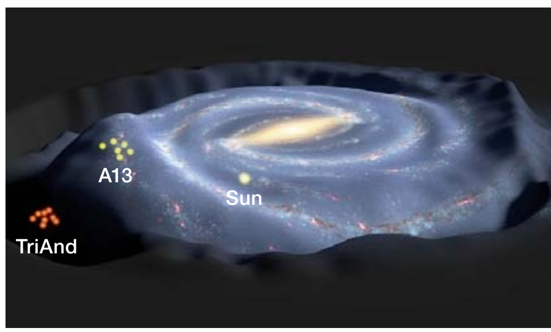
MOST STELLAR STREAMS in the Milky Way's halo are ghosts of dwarf galaxies past (*S&T:* Apr. 2017, p. 22), long ago torn into shreds after encounters with our more massive galaxy. Now, new research that appeared online February 26th in *Nature* shows that some of these stars might not be dwarf remnants at all — they might have come from the Milky Way's own disk.

Maria Bergemann (Max Planck Institute for Astronomy, Germany) and colleagues studied 14 stars in two halo populations, known as A13 and Triangulum-Andromeda (TriAnd), using the Keck I telescope in Hawai'i and the Very Large Telescope in Chile. After collecting the stellar spectra, the astronomers measured the abundances of elements heavier than hydrogen and helium. Unlike most of the stellar halo, these stars are rich in heavy elements, more akin to stars in the galaxy's disk.

Moreover, TriAnd and A13 have similar abundances to each other, implying a common birthplace — even though they're separated by 30,000 light-years.

Bergemann and colleagues simulated a possible origin scenario. The Sagittarius dwarf galaxy, now stretched into a thin stream that wraps around the Milky Way, careened into our galaxy several billion years ago. Such an interaction would have disrupted the Milky Way's disk and sent swirls of stars above and below the galactic plane.

■ MONICA YOUNG



▲ The A13 and TriAnd clouds are in the outer galaxy, roughly 15,000 light-years above and below the galactic plane, respectively.

SYNESTIA: SARAH STEWART (UNIV. OF CALIFORNIA, DAVIS) / NASA; A13 AND TRIAND: © T. MUELLER / NASA / JPL-CALTECH

STARS

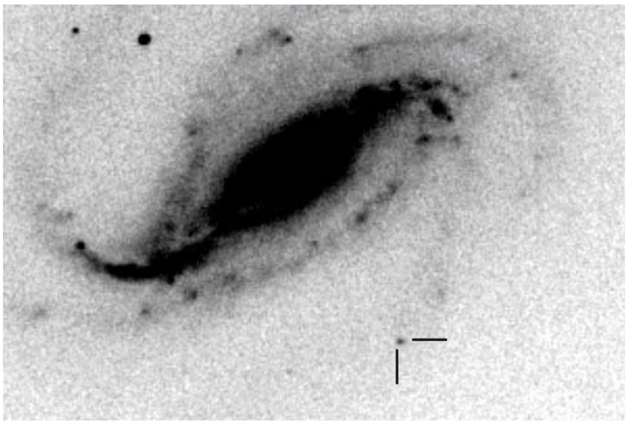
Amateur Captures Supernova's First Light

AN AMATEUR ASTRONOMER serendipitously captured the first flash of a supernova, providing the earliest glimpse of a stellar explosion.

On September 20, 2016, Víctor Buso was testing his new CCD camera in the observatory he had built atop his home in Rosario, Argentina. He pointed his 40-cm Newtonian toward the galaxy NGC 613, taking a series of 20-second exposures over the course of 1½ hours. While the first images didn't show anything unusual, Buso soon noticed that a pixel near the end of one of the galaxy's spiral arms had brightened — and was becoming brighter with every shot.

Buso contacted another amateur astronomer, Sebastián Otero, a member of the American Association of Variable Star Observers, who helped Buso send out an international call for follow-up. The February 22nd *Nature* article details the observations and their significance.

What Buso had captured was the *shock breakout*, the moment when the shock wave traveling outward from the collapsing core of the star breaks through the surface. The star's outer layers of gas heat up as they're ejected, brightening rapidly — in this case, at a rate of 40 magnitudes per day.



◀ This is one of a series of negative images showing the supernova at the moment of discovery: an initially faint object (marked by crosshairs) in the southern, outer regions of the spiral galaxy NGC 613.

The shock-breakout phase had been largely theoretical because, although astronomers had seen hints of the phenomenon, it had never been definitively detected at visible wavelengths. The shock wave only takes a few hours to break out of the star, and much of its immediate emission is at higher-energy wavelengths.

The Neil Gehrels Swift Observatory subsequently monitored the supernova's X-ray, ultraviolet, and visible-light emissions. Based on the discovery and follow-up observations, Melina Bersten (National University of La Plata, Argentina) and her team determined that the exploding object had been a star in a binary system, which had lost its outer layers of gas to its companion star, leaving behind a helium-dominated core. The progenitor, once about 20 times as massive as our Sun, had shrunk to 5 solar masses by the time it exploded.

Buso, who works as a locksmith, says the discovery brought him great joy. "Sometimes I wonder why I do this, why I put so many hours and so much passion into this. . . . Now, I have found the answer."

■ JAVIER BARBUZANO

IN BRIEF

Most Distant Super-Supernova

Astronomers have detected the most distant superluminous supernova, flashing from more than 10 billion years in the past. Mathew Smith (University of Southampton, UK) and colleagues found the exploding star as part of the Dark Energy Survey Supernova Program. The event, called DES16C2nm, has a redshift of 1.998 and, like others in its class, appears to be poor in hydrogen. When combined with 10 other superluminous events, DES16C2nm turns out to be part of a fairly uniform group. There's no sign that the supernovae's properties differ across cosmic time. The team expects that DES will be able to detect such supernovae from the last 12 billion years; upcoming facilities may push even further back in time. The results appear in the February 10th *Astrophysical Journal*.

■ CAMILLE M. CARLISLE

NASA 2019 Budget Proposal Cancels WFIRST

The White House's NASA budget proposal for fiscal year 2019 calls for the cancellation of the Wide Field Infrared Survey Telescope. The National Academies' 2010 decadal survey placed a top priority on the development of WFIRST to study dark energy and exoplanets. It moved from design study to formal development just last year, and the American Astronomical Society has released a statement rejecting the project's cancellation. However, the program was recently under external review to ensure it could deliver science at a reasonable cost, and findings upped the mission budget by $300 million. The FY19 budget request also cuts all funding for NASA's Office of Education, as well as for several Earth-observing missions, and shifts exploration focus to the Moon. It's worth noting, though, that many of these cuts were also requested in the 2018 budget proposal and ultimately weren't approved. For more details on the proposal, visit **https://is.gd/FY19budgetproposal**.

■ DAVID DICKINSON

Arecibo's Fate Decided

Beginning April 1st, the University of Central Florida (UCF) is taking over the operations and management of the Arecibo Observatory in Puerto Rico from the National Science Foundation (NSF), although NSF retains ownership. Arecibo had been threatened by funding shortfalls for more than a decade, as the NSF weighed its ability to both maintain existing facilities and invest in new ones. Late last year NSF solidified its plans to reduce its funding for Arecibo from the current $8 million per year to $2 million per year in 2022 while simultaneously seeking alternative sources of funding. Now, UCF leads a consortium that will provide support and technical personnel to manage the observatory, its research — including NASA's near-Earth asteroid observations, funded by an additional $3.6 million per year — and associated educational and outreach activities. UCF astronomers will receive some dedicated time on the radio dish, and observing time will also still be awarded to the larger astronomical community.

■ MONICA YOUNG

VÍCTOR BUSO & GASTÓN FOLATELLI

OBITUARY

Stephen Hawking, 1942–2018

▲ Stephen Hawking addresses a crowd at Northeastern University in 1991.

STEPHEN HAWKING, renowned and inspirational physicist, died on March 14th at the age of 76. He spent decades defying expectations and living a remarkably full life, and is survived by three children and three grandchildren.

Hawking was born on January 8, 1942, in Oxford, England. Though clearly gifted, he didn't apply himself in school until he reached college, where he studied physics and graduated with honors. He went on to graduate school at the University of Cambridge. It was then, at age 21, that Hawking was diagnosed with amyotrophic lateral sclerosis (ALS), a disorder that affects nerves in the brain and spinal cord, leaving muscles to weaken and waste away. Hawking was told at the time that he would have one, maybe two years to live.

Yet two years later, Hawking was feeling relatively well, engaged to be married to Jane Wilde, and casting about for a thesis idea. That's when he came across Roger Penrose's work on singularities. While his thesis focused on the Big Bang singularity, this interest naturally led him to black holes, which would occupy most of his career.

Even as ALS confined him to a wheelchair by the 1970s, Hawking began to contemplate the ideas behind the concept he's most famous for: *Hawking radiation*. In this process, black holes lose energy (and therefore mass) by interacting with virtual particles. The vacuum of space is not totally empty; virtual particles pop into and out of existence. These short-lived particles come in pairs that quickly recombine and annihilate, resetting the energy scorecard to zero. But near a black hole's horizon, tidal gravity pulls apart the particles, boosting their energy such that they survive and become "real." One is lost into the black hole and the other flies away, carrying the energy it has taken from the black hole's gravity — thus reducing the black hole's mass.

Hawking radiation is difficult, if not impossible, to observe but has huge implications for physics. If black holes radiate their mass away, that would destroy the information the mass once held — something quantum mechanics forbids. Even now physicists are struggling to understand the implications in their quest for a true unification of general relativity and quantum mechanics.

Hawking completely lost his ability to speak in 1985 and relied solely on a computerized voice system. It slowed his communication, but in 1988 he nevertheless published the best-selling and foundational *A Brief History of Time*, which walks through the origin and structure of the universe, space, and time with clarity and a good dose of wit.

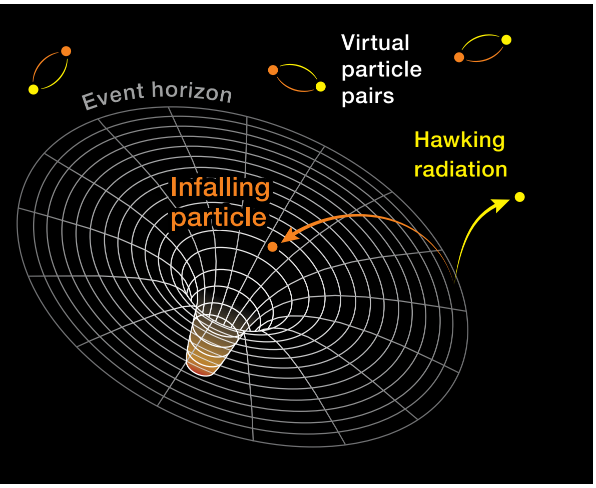
Hawking divorced Jane, his wife of 30 years, in 1995 and married his one-time nurse, Elaine Mason. He and Mason divorced in 2006. However, Jane and Hawking maintained a good working relationship, and Jane's autobiography, titled *Travelling to Infinity: My Life with Stephen*, resulted in the 2014 movie that celebrated Hawking's life, *The Theory of Everything*.

Although he continued his research on black holes, recent years saw Hawking turn his gaze toward humankind's future, motivated by concerns over our planet's long-term habitability. He advocated a push for the stars and helped launch Breakthrough Starshot (*S&T:* Aug. 2016, p. 12). At his 75th birthday celebration, he reminded attendees, "Remember to look up at the stars and not down at your feet. Try to make sense of what you see and wonder about what makes the universe exist. Be curious, and however difficult life may seem, there is always something you can do, and succeed at. It matters that you don't just give up."

■ MONICA YOUNG

● For more on Hawking's life, visit **https://is.gd/Hawkingobit**.

In Hawking's concept of black hole radiation, the lucky one of a virtual pair of particles produced near the event horizon (a black hole's "point of no return") may escape, appearing to radiate from the black hole itself.



HAWKING: KELLY BEATTY / S&T; ILLUSTRATION: GREGG DINDERMAN / S&T

Space Invaders

How grave is the threat that a giant asteroid or comet could strike Earth and do us serious harm?

In July 1994, Comet Shoemaker-Levy 9 spectacularly riddled Jupiter with immense chunks of its erstwhile self — a never-before-seen pummeling that grabbed the attention of astronomers and the public worldwide. By that time, most scientists had bought into the notion, first advanced in 1980, that an impact from another huge space object had wiped out the dinosaurs 65 million years ago. But the comet crash was a stark reminder that massive collisions still happen in our solar system today.

After first asking NASA to assess the threat, in 1996 Congress tasked the space agency with finding, within a decade, 90% of the estimated 1,000 near-Earth asteroids at least 1 km (0.6 mile) in diameter. NEAs are those asteroids with a perihelion of less than 1.3 astronomical units, that is, an orbit whose closest point to the Sun is under about 195 million km. And 1 km across is the minimum size that, if the object struck us, could potentially trigger a global catastrophe — unleashing a years-long winter, caus-

ing major crop failures, and conceivably ending civilization as we know it. (By comparison, the "dino killer" at the end of the Cretaceous was an estimated 10 km across.)

By 2011 asteroid-hunting surveys had met the legislative mandate, and today the census is closer to 95% complete. NASA's official catalog of NEAs 1 km or larger stands at 887 of an expected 934 (plus or minus 10 or so). Fortunately, not a single one is on a collision course with our planet.

In fact, the risk of civilization-ending catastrophe "has been largely put aside by discovery," says retired senior research scientist Alan Harris (formerly Jet Propulsion Laboratory), one of the leaders in this field. It's one of the great scientific achievements of our era.

The Missing 5%

Why does NASA feel confident that the total population of 1 km and larger NEAs is likely less than 950? Harris likens estimating their total numbers to keeping track of ducks in wildlife management. "You tag 'em and turn 'em loose, then you come back next year and you grab a bunch of them and see what fraction of them has tags," he says. "You know how many you tagged, so you just multiply back up to what you now estimate to be the whole population."

Within the past year, three separate population estimates of NEAs, one of them by Harris, all wound up with roughly similar numbers at all size ranges. "The three of us all agree within a factor of two or so all the way up and down the line," Harris says, including within a few percent at the 1-km-diameter size. "That gives me confidence that we're on the right track, because three different groups with three different sets of data all come up with about the same answer."

The "missing" 5%, the roughly 50 objects still lurking in the shadows, are thought to lie in resonant orbits with Earth. Imagine one on the far side of the Sun in an orbit that takes just as long as we do to go around our star — a 1:1 resonance. We'd never see it. "It simply would never get close enough to Earth to get into our detection window," says Paul Chodas (Center for Near Earth Object Studies, Jet Propulsion Laboratory). "But that's a narrow niche, and over time, if even just slightly outside that niche, it will eventually come by our planet and we will see it."

Outstanding Questions

We might know the size of the enemy's army, but uncertainties remain in understanding the combatants themselves. One is how to translate between the inherent brightness of an NEA (which usually is a mere speck in survey images) and the object's actual diameter and density. Planetary scientists start with the absolute magnitude *H*, the brightness a fully illuminated body would have if it were 1 astronomical unit from both the Sun and Earth. Then they assume a particular surface reflectivity (typically 14%) in order to convert *H* to a physical size. But not all asteroids are equally reflective.

Another ambiguity is the degree of impact damage by girth. As noted, scientists use 1 km as the lower size limit on what could provoke global climatic damage. "But we don't really know that for sure — maybe it's 2 km," says Harris. If that's the case, our chances are even better: There's maybe a tenth as many 2-km NEAs as 1-km ones, with a corresponding drop in the frequency that one might collide with us. Moreover, almost all of the remaining undiscovered NEAs lie in that 1-to-2-km size range. "That means our risk of global catastrophe is uncertain mostly by not knowing where that lower threshold is," Harris says.

EARTH: NASA; ASTEROIDS: THECRIMSONMONKEY / GETTY IMAGES

Where a monster space rock comes down is also critical. The Chicxulub impactor, which triggered the extinction of the dinosaurs (and much else) after smacking into the Caribbean off what is today the Yucatán Peninsula, struck thick sedimentary deposits rich in hydrocarbons and sulfur. Spewed into the atmosphere, the resulting soot and aerosols likely had a much more devastating environmental effect than if the intruder had hit, say, a mountain of granite in northern Canada.

Size Matters

They say no good deed goes unpunished, and in 2002, when it became clear that observing teams were well on the way to finding 90% of kilometer-size NEAs, NASA chartered a Science Definition Team (SDT) to look at what it would take to bring that 1-km threshold down even lower. Should we also ferret out those NEAs that, while not global threats, might still cause significant *regional* devastation and thus still pose a substantial risk to Earth's population?

The team's report, released in 2003, recommended discovering 90% of all NEAs larger than 140 meters (460 feet) in diameter — the size at which widespread regional damage could result. Last fall, a reconvened SDT recommitted to that same size threshold (see the full report at **https://is.gd/2017NASA_SDT**).

As it had in the 1990s, Congress went with the recommendation, setting the end of 2020 for the survey's completion. The decree did not come, however, with a substantial boost in funding, which the NASA community would have needed to meet that time constraint. Astronomers already know they won't reach the Congressional deadline.

For one thing, pinpointing the smaller objects is a significantly harder task. Not only is it easier to find the bigger ones, but as you go down in size the number of asteroids also increases exponentially. (It's different with comet nuclei, which, once they approach the Sun, don't seem to hold together for long if they're smaller than about 1 km.) Experts put the number of NEAs with a size of 140 m or greater at more than 24,000.

"It's one thing to suspect that size population, and it's another thing to actually go find them," says Lindley Johnson, who heads NASA's Planetary Defense Coordination Office. "We've got a ways to go."

Currently, we've found about 8,100 objects with an *H* of 22 or brighter, which corresponds to scientists' best estimate of the absolute magnitude of objects 140 m and larger. So they're about one-third complete. New wide-field surveys soon to come online, including the Large Synoptic Survey Telescope in Chile, will help locate many of the NEAs in this expanded census. But all ground-based systems, both professional and amateur, have limitations. First, objects this small can only be spotted during the week or so when they pass closest to Earth. Yet a given telescope on Earth's surface can only search the half of the sky roughly opposite from the Sun. The time it can be online is bounded, and weather and Moon interference can also affect survey performance.

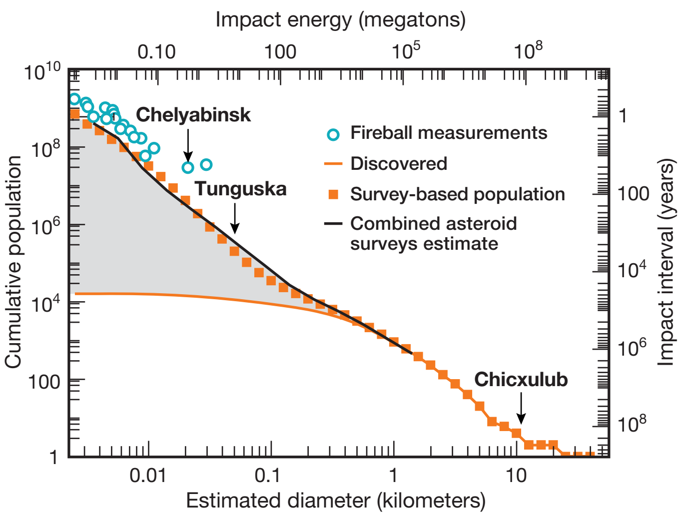
"You will only know if an impact is going to happen a matter of months in advance, and the best you can do is evacuate and things like that. You know, Bruce Willis just can't save us."

A telescope flown in space wouldn't have such constraints. "It is clear that if we want to get this catalog of NEAs completed in anything under several decades, we need to go to space-based capabilities," Johnson says.

Seeing in the Dark

One of the most promising proposals is NEOCam. (NEO stands for *near-Earth objects*, a term that also encompasses comets.) This space telescope would be "parked" at *Lagrangian point* L_1, a point of equilibrium between the respective gravitational tugs of the Sun and Earth that sits between the two bodies. "At L_1, we have a wide view of the volume of space surrounding the Earth's orbit, which is where NEOs that are the most likely to be hazardous spend much of their time," says Amy Mainzer (Jet Propulsion Laboratory). Mainzer is principal investigator both of NEOWISE, a highly successful asteroid-hunting mission now winding down, and of the proposed NEOCam.

Equipped with a 0.5-m telescope, NEOCam would scan the celestial sphere in the infrared, specifically the mid-



▲ **WHAT'S MISSING** After decades of searching, astronomers have found nearly all of the largest objects with diameters of 1 km or greater — and they're relatively rare. Supergiants like the Chicxulub impactor that struck 65 million years ago are rarer still. But a large gap (gray region) remains between what we've detected and what we expect exists for the smaller but still potentially hazardous bodies.

DEFENDING AGAINST A SPACE ROCK

"The foundational principle of planetary defense is **FIND THEM EARLY**," says Lindley Johnson, NASA's Planetary Defense Officer. Depending on the scenario and warning time, we have at least three methods we could consider to redirect or destroy a hazardous object on its way to a direct hit.

With significant lead time, we might use a *gravity tractor*. This is a spacecraft that would use the gravitational force created by its own mass to nudge an object off its Earth-targeting path. This method has not been tested, however, and we would need decades to build, launch, and undertake this type of mitigation.

A *kinetic impactor* would smash into the interloper at a high speed, transferring its momentum to the object. Ideally, this would change the object's velocity, causing its course to deviate enough for it to miss us. This one would require enough time for the craft to be built, launched, and travel to its target — a few years at minimum.

If the threat of impact was imminent or the rock was too large for these two methods to be viable, a *nuclear explosive device* might be the only option. We might have to deal with the fragments, but they'd have more localized effects.

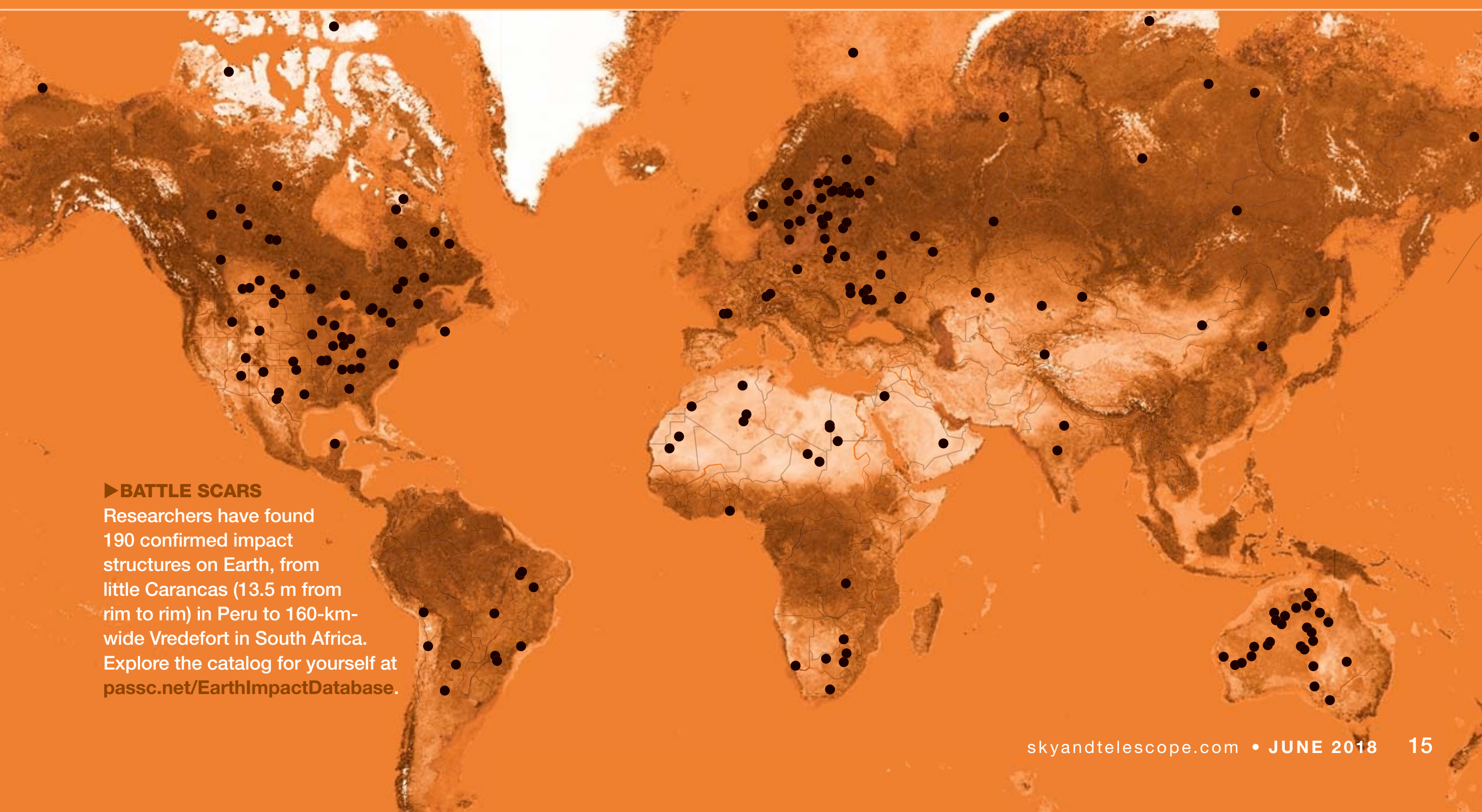
▲ **HOBA METEORITE** Due to its enormous weight (about 60 tons), the largest meteorite found on Earth, the Hoba iron meteorite in Namibia, still sits where a farmer discovered it in 1920. Scientists think it fell to Earth about 80,000 years ago.

SHORT- VS. LONG-PERIOD COMETS

Short-period comets originate in the Kuiper Belt out beyond Neptune's orbit and usually take 200 years or less to orbit the Sun. Long-period comets lie in the Oort Cloud, an extremely distant region hosting billions of comets. A single trip around our star could take a long-period comet 30 million years.

Estimated Diameter (m)
(NOT TO SCALE)

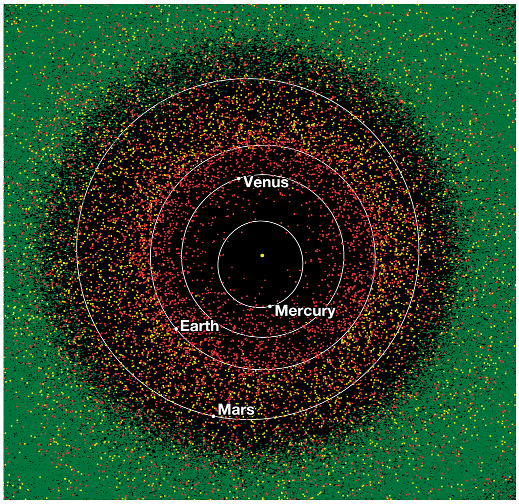
Total near-earth asteroids discovered as of March 15, 2018



▶**BATTLE SCARS**
Researchers have found 190 confirmed impact structures on Earth, from little Carancas (13.5 m from rim to rim) in Peru to 160-km-wide Vredefort in South Africa. Explore the catalog for yourself at **passc.net/EarthImpactDatabase**.

infrared wavelengths around 10 microns. While we humans can't perceive such wavelengths, asteroids — especially dark ones — are naturally brightest in this part of the spectrum, reradiating most of the sunlight they absorb in the mid-infrared, Mainzer says. NEOCam would detect NEAs at greater distances than ground-based telescopes can and at sizes smaller than 140 m. It would also help astronomers get a better handle on each NEA's size, orbit, spin rate, and other factors. This is useful not just for hazard management but also for more generally understanding asteroids, which serve as time capsules of solar system history and, someday, could be spacefaring resources.

NASA is currently assessing NEOCam's viability, but in the highly competitive environment of federally funded space missions, there's no guarantee it will fly. (NEOCam would cost the American taxpayer about $600 million to build and launch, Johnson told me.) "We are waiting to see what the future holds," Mainzer says.



◀ **DON'T PANIC** The positions of known asteroids in the inner solar system are plotted for May 1, 2018. The green dots are all numbered asteroids that do not approach Earth. The yellow ones represent those that approach our planet but don't cross its orbit. The red dots mark asteroids that cross Earth's orbit but don't necessarily closely approach our planet itself. Although the plot makes our neighborhood look claustrophobically crowded, remember that the space represented by this diagram is predominantly empty.

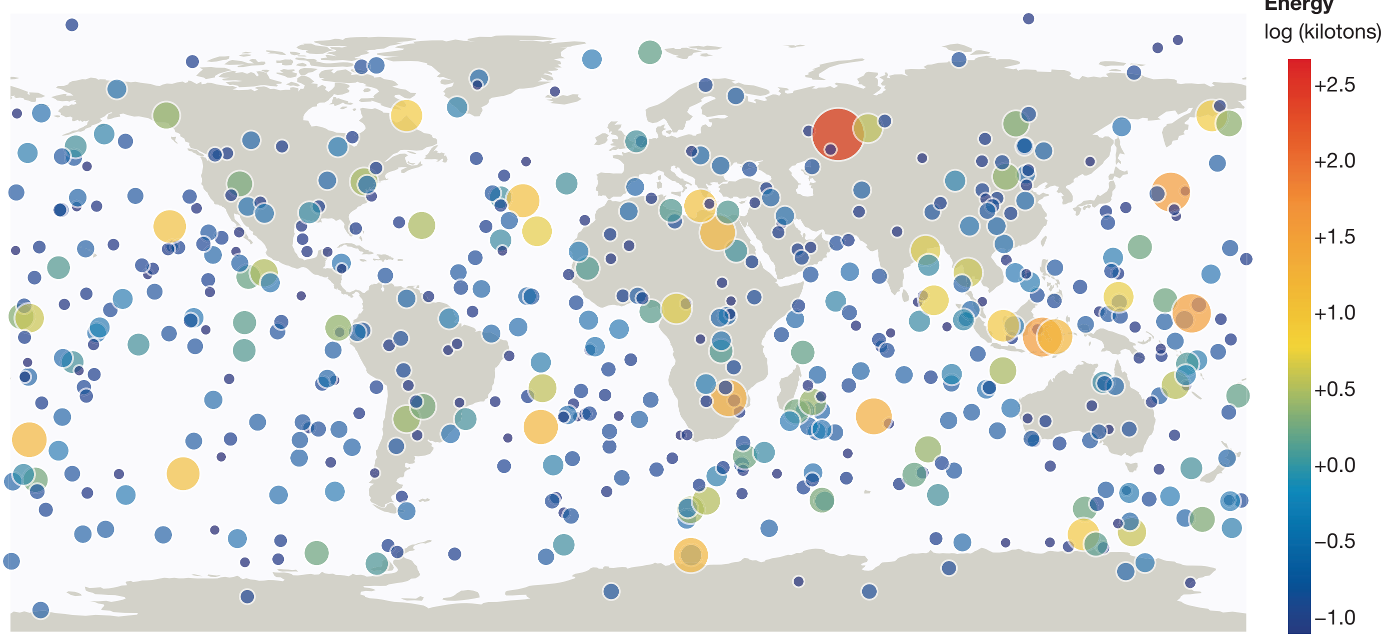
Getting Even Smaller

Earth's close encounters in the last century or so are a reminder that even modest-size objects can be dangerous. Thought to have been roughly 20 m in diameter, the meteoroid that exploded over Chelyabinsk, Russia, in 2013 injured more than 1,600 people and caused at least $30 million in damage. The so-called Tunguska event in 1908 involved an object more than twice as large, at around 50 m. Fortunately it exploded in the lower atmosphere over a sparsely populated area of Siberia, but the multi-megaton blast still flattened 2,000 square km of forest.

Both incidents are symptomatic of a small impact: While a large asteroid would punch right through the atmosphere and hit the ground intact, smaller rocks detonate high up. When they do so, they unleash damaging shock waves that can reach the surface. (Large asteroids would also generate shock waves.) If a Tunguska-size event happened over a big city, millions could die.

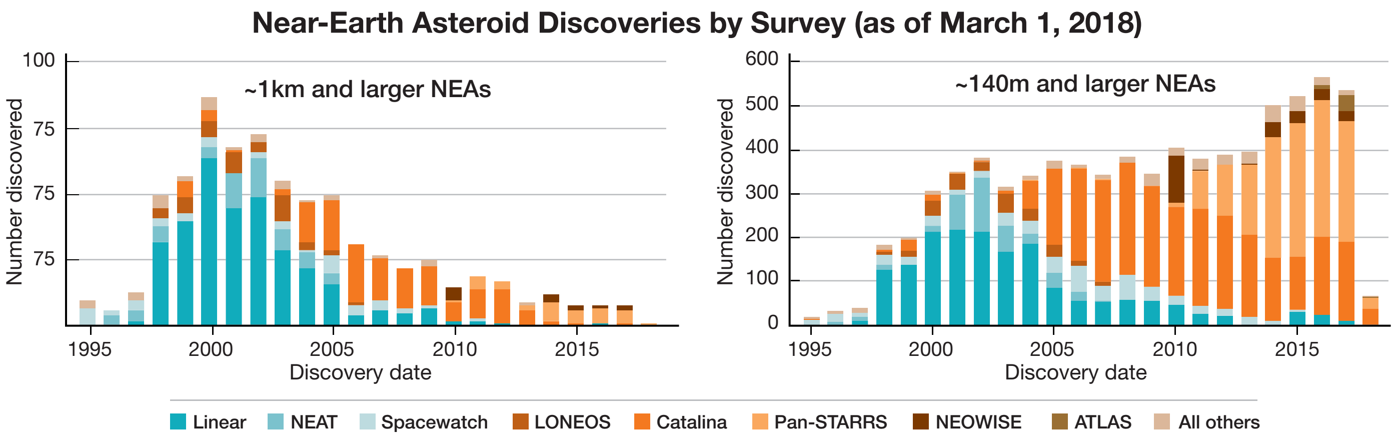
Fortunately, the chance of something like a Tunguska fireball exploding over a major city is slim, Harris says. "They only hit the Earth about once in a thousand years, and only one in 10 will hit a populated area, or maybe one in 20 or

Fireballs Reported by U.S. Government Sensors (April 1988 to February 2018)



▲ **BOMB-GRADE FIREBALLS** Between 1988 and 2018, U.S. sensors have picked up 735 bright fireballs, a subset for which we have geographic coordinates pinned down (shown). The large red dot marks the Chelyabinsk event.

ASTEROID POSITIONS: CNEOS; FIREBALL MAP: ALAN CHAMBERLIN (CNEOS / JPL-CALTECH / NASA)



▲ **TALLY UP** Observers have found roughly 95% of near-Earth asteroids that are 1 km or larger, with most of the discoveries made in the early 2000s (*left*). Now their focus is on finding objects 140 m wide and larger (*right*). Note the different *y*-axis scales.

GREGG DINDERMAN / S&T, SOURCE: ALAN CHAMBERLIN (CNEOS / JPL-CALTECH / NASA)

30." Our homegrown severe earthquakes, hurricanes, floods, and tsunamis are all more likely hazards, he says. "It comes down to just a very minor threat. How much of society's resources do you want to pile into that?"

The Comet Factor

Researchers' focus to date has been on the risk from asteroids (and to a lesser extent from short-period comets, those that come from the Kuiper Belt). This is wise: Asteroids that might pose an impact threat far outnumber comets.

But long-period comets, those that originate in the Oort Cloud, are typically huge — a km or more across — and arrive at much greater speeds relative to Earth than asteroids do. They also appear in our environs with little advance notice. "They're simply undetectable until they approach within the orbit of Jupiter or Saturn, so it's really not possible to see them with decades of warning," says Chodas.

It doesn't leave time, as we might have with known asteroids whose orbits we can calculate decades ahead, of using deflective or destructive methods to remove or lessen the impact (see sidebar page 15). "You will only know if an impact is going to happen a matter of months in advance, and the best you can do is evacuate and things like that," Harris says. "You know, Bruce Willis just can't save us."

The good news, again, is such icy rogues are very few and far between. Long-period comets pass close to Earth only 1% as often as NEAs do. "There are a lot fewer of them coming into the inner solar system, and, frankly, space is a big place," says Johnson. "I'm not saying that's not a hazard we have to deal with, but let's take care of the asteroids first, then hopefully future technologies will provide us better capability against the less-probable threat."

Telling It Like It Is

Beyond finding, cataloging, and even visiting comets and asteroids (see page 22), there's one more important piece: improving general awareness.

It's not inconceivable, for example, that an out-of-the-blue explosion in the sky like that over Chelyabinsk could spur acts of aggression or even war by governments that mistake them for attacks. For that reason, Johnson's office works closely with the U.S. Department of Defense to get details about atmospheric impacts out quickly.

The NASA community also strives to keep the public informed of the actual nature of the threat. This can backfire, particularly when talking about "run-of-the-mill" asteroids of the 1- to 10-m variety that regularly pass between Earth and the Moon. "Most of the close approaches we report on our website are astronomically close, but in human terms still very far away," Chodas says (see **https://cneos.jpl.nasa.gov**). "Yet the images that [news editors] post on their web stories often depict giant asteroids passing *extremely* close."

These mini ones, including the thousands of tiny objects that burn up harmlessly in the atmosphere every day, are just not the focus of the big NASA search efforts. "It's not that we don't need to pay attention to these impacts," says Linda Billings (National Institute of Aerospace), who is a consultant to Johnson's Planetary Defense Coordination Office. "We *are* paying attention. But these events, and NEO close approaches to Earth, are happening all the time." We just didn't know about them before we had robust systems in place to pick them up, as we do now.

Johnson concurs. "I do worry a little bit that we will have cried wolf one too many times, so to speak, and we will lose the ear of the public when one comes around that we really need to tell them about." It's true that we don't have to worry about these smaller objects, he says. "But we do need to keep an eye out and find what's out there, because one of these days there will be a bigger one that's going to impact us, and we just don't know when that is."

■ Among space rocks that strike Earth, *S&T* Editor in Chief **PETER TYSON** favors those he can hold in his hand, such as the Campo del Cielo meteorite he recently acquired.

Cataclysms from above

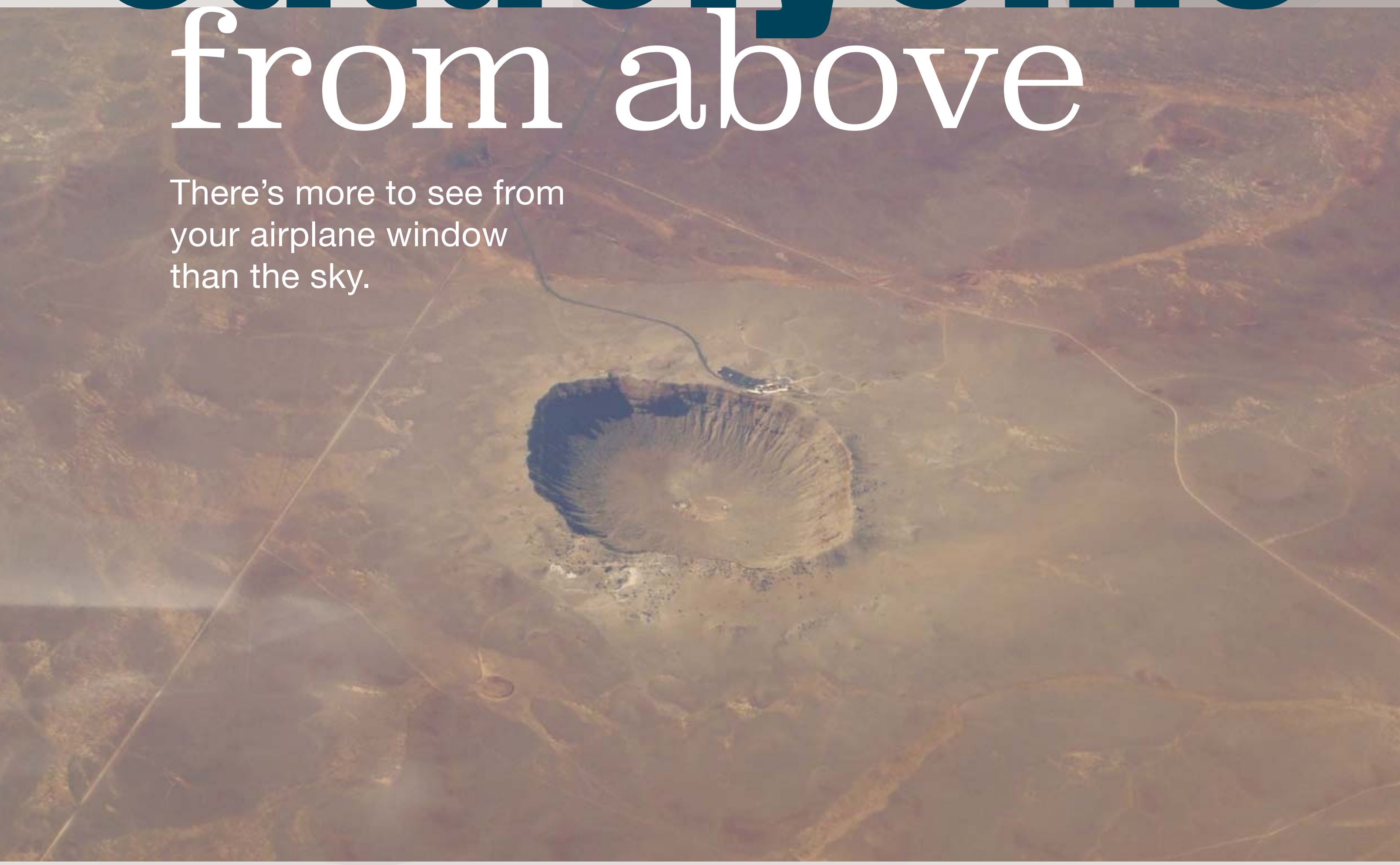
There's more to see from your airplane window than the sky.

As astronomers, we reach out to the universe. We point our telescopes and send spacecraft to discover what's happening Out There. When we look up at the aged face of the Moon, for example, we see the scars of the solar system's violent past. Impacts by asteroids and comets have blasted giant craters in planetary surfaces, and indeed continue to do so. Craters on our own planet, however, are few and far between, because our active world reshapes itself through plate tectonism, volcanism, and erosion.

But occasionally, a view out of an airplane window will remind astronomers and geologists that, sometimes, the universe reaches out to us!

In an effort to understand how the cratering process may work on other worlds, I have hiked in about 20 impact structures on Earth. Technically, I even live near one (the Chesapeake Bay isn't obviously shaped like a crater, but its impact origin was recognized about 20 years ago). But with a few exceptions, the view from the ground doesn't let you take in the overall structure. An aerial view is much better, and in fact many terrestrial impact structures were first discovered in aerial photographs or spacecraft views.

As a planetary scientist engaged in a number of projects — recently, for example, as a participating scientist in the Japanese Akatsuki mission at Venus — I am obliged to travel frequently. The international nature of space exploration means trips to lots of interesting places. Happily, I love flying. I always get a window seat, mostly for the geology (although it's the chance of seeing the aurora borealis that motivates



my taking a north-side window on eastbound transoceanic flights). Sometimes all I see is clouds. But very occasionally, I am rewarded by the view of an impact structure — a piece of terra firma scarred by the universe, right beneath me.

Perhaps the easiest crater to see is the most famous: Meteor Crater, just to the east of Flagstaff, Arizona. It helps that this part of the country is desert, with often clear skies. The 1-km-wide (0.6-mi-wide) crater actually lies on an air lane, one of the regular paths that planes are routed along. Although that might sound fortuitous, it can be excruciating. I can easily end up sitting on the wrong side of the plane to see the crater. Worse yet, I've flown right over, straining at the window to look straight down beneath the plane. But sometimes *there it is*, an isolated hole in the ground with a slightly raised rim. A good marker is the wiggly Canyon Diablo nearby, after which the meteorites associated with the crater are named. I have seen Meteor Crater while on cross-country flights (Baltimore to Los Angeles), but the best views I've had have been when flying out of Phoenix or Flagstaff.

◀ **CRATER FROM AFAR** This view from the southeast shows the narrow Canyon Diablo in the foreground. The crater rim and some of the rock layers needed a little unsharp masking to bring out detail.

Another southwestern U.S. structure is Upheaval Dome in southeastern Utah. Again, this 5-km-wide structure, with its distinctive rings of rock, can be seen from cross-country rides (e.g., Washington Dulles to Los Angeles). Even if you miss the crater, the beautiful upper reaches of the Colorado River nearby, with Lake Powell, buttes, and the strange features called *volcanic necks* — created when weathering and erosion eat away the rock surrounding a former volcanic feeder tube — mean there's plenty of stark geology to see.

The largest structure I've seen from the air is the 214-million-year-old Manicouagan Reservoir. Dammed water makes the subtle topography of this large, complex crater visible, forming a 70-km-wide, ring-shaped lake. In summer it's highlighted by the contrast of the dark waters against the trees around it, and in winter by the snow on the frozen surface, making it much brighter than the surrounding forest (see next page). The ring is even visible in the in-flight navigation map display on most airliners.

My most recent prize is El'gygytgyn. This mouthful is a 12-km-wide crater lake in Siberia that lies in an 18-km-wide crater, visible as a partial ring of hills around the water. Although flights from the U.S. East Coast to Japan usually cross mid- or south Alaska and follow the Kamchatka peninsula down, sometimes wind patterns force a more poleward track, pushing planes to fly just off the north coast of Alaska and down across Siberia. I caught a distant view once, but the contrast was rather poor and the perspective too foreshortened to be impressive. On a recent trip (Dulles to Tokyo Narita), however, I saw that we were going to pass close to the crater — but I was on the wrong side of the plane! Fortunately conditions were calm and the seatbelt sign was off, so I could get up and look through the window in the exit door on the other side.

So far I've photographed four craters from the air. I use a small digital camera with a decent zoom, but modern smartphone cameras are perfectly adequate. One challenge is that views are often hazy; boosting the contrast later in

◀ **METEOR CRATER** This lucky near-overhead view shows the crater's square shape, created due to weaknesses in the rock that existed before the meteorite hit. The road and parking lot of the visitor center appear at the top.

▶ **UPHEAVAL DOME** The structure of concentric rings formed as the rocks lifted up beneath the crater itself, which has been eroded away in the 170 million years since its creation.

ALL PHOTOS BY AUTHOR; BACKGROUND: NATCHA29 / GETTY IMAGES

▲ **MANICOUAGAN** The reservoir in summer *(top)* and winter. This feature is much larger than others the author has seen from the air. Often you don't have much choice when it comes to including foreground wings, but instead of lamenting, think of them as adding immediacy and scale.

▲ **EL'GYGYTGYN** A bright sheen reflects off the lake from the Sun, low in the sky at this latitude of 67° 30′ *(top)*. Clouds stream off the lake toward the north. A few tens of seconds later, the view has wheeled around to remove the glint and make the lake's shape a little clearer against the snowy landscape *(above)*. The lake is slightly off-center from the ring of hills which marks the crater.

Crater Bucket List

Clearwater Lakes: pair of craters (20 and 30 km in diameter) just to the east of Hudson Bay in Canada. The larger lake has a ring of islands that is actually a "peak ring," formed when the crater's central peak collapsed. Polar flights to Asia, or high-latitude routes to Europe, may catch it.

Bosumtwi: 10.5 km wide, Ghana. The closest I've come was when a taxi driver taking me to the Dulles airport was from a town 30 km from it. He was shocked when I told him the lake was formed by an impact!

Roter Kamm: 1-km-wide shallow structure in Namibia, overrun by sand dunes. Flights from the U.S. to South Africa may overfly this (as well as the beautiful Namib desert).

Gosses Bluff: the 4.5-km-wide ring of hills is actually not the rim but rather the eroded core of the uplifted central rocks in the crater. West of Alice Springs in Australia.

an image-processing program may be helpful (or even using a camera with an infrared filter). I try to take a few views. Sometimes the perspective changes nicely, and, depending on the Sun-feature-camera geometry, the lighting can change dramatically. This is especially the case for crater lakes, where sunglint can be strong, as with El'gygytgyn above.

Some craters that I'd love to see from the air, but haven't yet, are listed to the left. Maybe you'll have better luck! Paul Hodge's book *Meteorite Craters and Impact Structures of the Earth* is a great travel guide, and there are also several good resources on impact craters online — the most useful is the Earth Impact Database at **passc.net/EarthImpactDatabase**. Good hunting!

■ **RALPH LORENZ** is in the planetary exploration group at the Johns Hopkins Applied Physics Laboratory and worked for 27 years on the international Cassini-Huygens mission to Saturn and Titan. He is the author of *Dune Worlds* and the *Cassini-Huygens Owners' Workshop Manual* and does much of his writing on airplanes.

We've been to asteroids before. Several of them, in fact — flybys, orbital rendezvous . . . we've even touched down on two asteroids and brought back samples from one of them. But this summer, two robotic emissaries will usher in a new era of exploration when it comes to these small solar system bodies.

That's because these spacecraft, the Japanese space agency's Hayabusa 2 and NASA's Osiris-REX, will study two dark, primitive, near-Earth asteroids unlike any we've explored before. Many of the asteroids we've examined close up have been of just one type — the so-called S-type asteroids (S stands for *silicaceous*). These dominate the inner asteroid belt and may be the source of the most common stony meteorites we have in our museum collections, known as ordinary chondrites. But they only make up one-sixth of all the asteroids we know of. The majority belong to another, very important class: the carbonaceous C-type asteroids.

DARK ASTEROIDS Ryugu and Bennu's surfaces are about as black as toner cartridge powder.

C-type asteroids (and the alphabet soup of other, closely related dark spectral types) have, for the most part, escaped our exploratory escapades. But these carbon-rich bodies are some of the most pristine survivors we have from the solar system's early days. What little we know about their composition suggests that it's similar to the Sun, albeit without most of the hydrogen, helium, and other easily vaporized compounds. As such, we think they've changed very little since the planets formed some 4½ billion years ago.

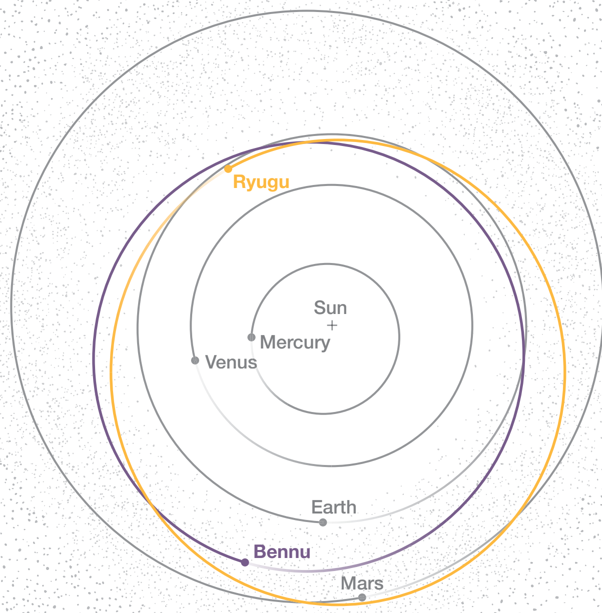
We're pretty sure we have plenty of meteorites from these types of primitive asteroids — the carbonaceous chondrites. But meteorites we collect here on Earth have complicated pasts and don't usually come with "Made in X" labels on them. Trying to decipher their origins is a little like trying to understand the detailed geologic history of eroded pebbles gathered from the bed of a stream flowing from a distant mountain range. Samples hand-picked directly from these asteroids, on the other hand,

TOUCHDOWN A brief touch is all NASA's Osiris-REX needs to gather priceless info on the solar system's building blocks. Japan's Hayabusa 2 will use a similar strategy.

would give us a rare look at the very material from which our own planet accreted, without ambiguity about its provenance and context. Planetary scientists thus hope that the small caches Hayabusa 2 and Osiris-REX bring back to Earth will reveal precious new information that even our vast collection of fallen meteorites cannot provide.

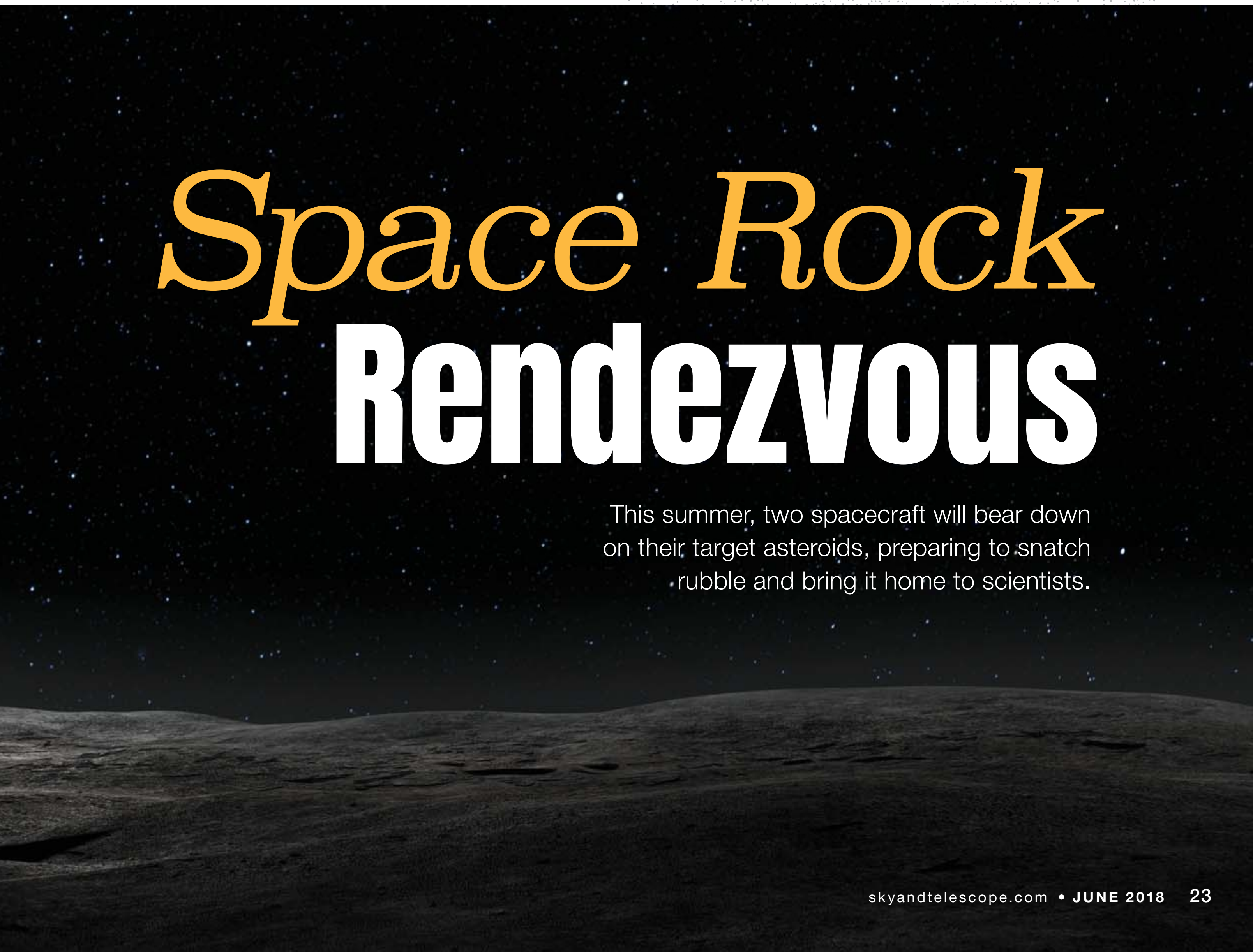
Petite and Primitive

The diminutive destinations of the Hayabusa 2 and Osiris-REX missions are, respectively, the near-Earth asteroids 162173 Ryugu (formerly designated 1999 JU_3) and 101955 Bennu (provisionally tagged as 1999 RQ_{36} when it was discovered). Scientists chose these targets not only for their compositions, but also because both are comparatively easy



▶ **ASTEROIDS AMONG US** Ryugu and Bennu's orbits nestle among those of the inner planets, shown here at their locations for July 1st. They are only two of the nearly 4,000 known asteroids whose orbits lie within that of Mars (see page 16 for an accurate plot of those bodies).

OSIRIS-REX: NASA GODDARD SPACE FLIGHT CENTER CONCEPTUAL IMAGE LAB; ORBITS: GREGG DINDERMAN / S&T



Space Rock Rendezvous

This summer, two spacecraft will bear down on their target asteroids, preparing to snatch rubble and bring it home to scientists.

to reach from an orbital mechanics perspective. Both follow moderately eccentric orbits that carry them away from the Sun to the distance of Mars and bring them just interior to Earth's orbit, crossing our planet's path in the process.

Ryugu is the larger of the two at just shy of a kilometer (0.6 mile) across. We don't know much about it, but ground-based telescopic observations of the asteroid reveal a 7.6-hour rotation period and a spectral marker in reflected sunlight that's characteristic of iron-bearing clay minerals. Since clays form in the presence of water, and Ryugu is a small, airless world without weather, the possible presence of clays suggests that Ryugu's larger parent body was heated just enough to melt at least some of the water ice it accreted along with rocky minerals as it formed. Hayabusa 2 may thus bring us a sample of early solar system materials that have been altered by ancient water.

With a mean diameter of 492 m (1610 ft), Bennu is about half the size of Ryugu. The asteroid passes close to Earth every six years, making Bennu simultaneously one of the most potentially hazardous near-Earth objects and the most accessible carbonaceous asteroid.

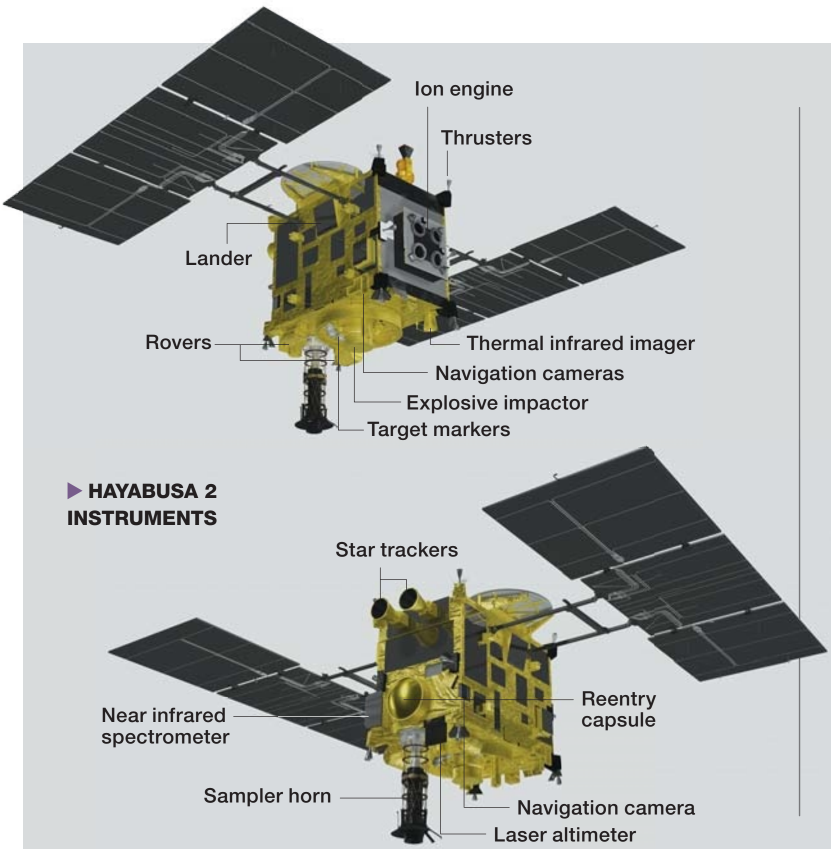
These close approaches have provided numerous opportunities for ground-based optical and radar observations, meaning Bennu is also one of the best-characterized near-Earth asteroids, with detailed assessments of its size, shape, and spin state. Its rapid, 4.3-hour rotation and top-like shape suggest that it's been spun up by solar thermal effects and possibly by tidal effects due to close encounters with Earth, both of which would cause loose surface material to migrate toward the equator. The radar observations also show evidence for at least one house-size boulder on the surface. Based on what the first Hayabusa spacecraft found at the near-Earth asteroid 25143 Itokawa, scientists expect to find plenty of rocks strewn across the landscape.

Long before Bennu evolved into its present orbit, it likely began life as part of a larger, 100-km-scale parent asteroid somewhere in the inner main belt 4.6 billion years ago. The mineralogy implied by its spectral properties suggests it has survived largely unchanged by geochemical processes since its initial assembly during the first several million years of solar system history. Based on detailed computer simulations, the fragment that became Bennu was likely knocked from its parent body between 700 million and 2 billion years ago and gradually found its way into near-Earth space through a combination of rotation-fed orbital drift and the giant planets' gravitational effects.

How do you design a sample-collection strategy when you don't know the surface's makeup or the size of its fragments?

Grab and Go: Carbonaceous Chondrite Takeout

The challenge for both missions is to rendezvous with, touch, and acquire samples from the surfaces of very small solar system bodies, bodies for which we have very little "hands-on" intuition. How do you design a sample-collection strategy when you don't know the surface's makeup or the size of its fragments, and in a microgravity environment that can turn even the simplest of everyday field geology activities into a quagmire of unexpected outcomes? Will you be sampling



▶ **HAYABUSA 2 INSTRUMENTS**

▶ **EXPLOSIVE ARRIVAL** On its final sampling run, Hayabusa 2 will drop an explosive impactor toward Ryugu (1) then dash to hide behind the asteroid's limb before the impactor detonates. As it flees, the mother ship will drop a camera satellite to watch the explosion (2). Once the explosion-sped projectile carves a crater in the asteroid (3), Hayabusa 2 will return to the site and briefly touch down (4-5). A projectile shot from its collecting horn will spray debris up into the spacecraft, where it will be caught and cached. A second later, Hayabusa 2 will take off (6).

fine dust, pea-size gravel, or the solid surface of exposed bedrock? Do you plan to scoop up a loose aggregate, drill into hardened rock, or blast the asteroid with a projectile and fly through the cloud of lofted debris? And how do you do any of these without endangering the spacecraft itself?

Fortunately, decades of observational and theoretical studies of asteroids and the findings from the pioneering missions that preceded Hayabusa 2 and Osiris-REX have taught us at least a little of what to expect when we arrive at Ryugu and Bennu. Every asteroid we've explored so far has had some sort of fragmented regolith on its surface, a layer of pulverized rock built up by millennia, even eons, of impacts by smaller asteroids. So we expect the surfaces of Ryugu and Bennu to be similarly littered with rocky samples just waiting to be nabbed.

Furthermore, because the asteroids are so small, their surface gravities will be very weak, making operations there more akin to the zero-*g* docking activities at the International Space Station than a hike across a dusty lunar plain. These considerations rapidly funneled mission planners toward sampling concepts that involved some form of a "touch-and-grab-some-gravel" approach.

HAYABUSA 2 AND RYUGU

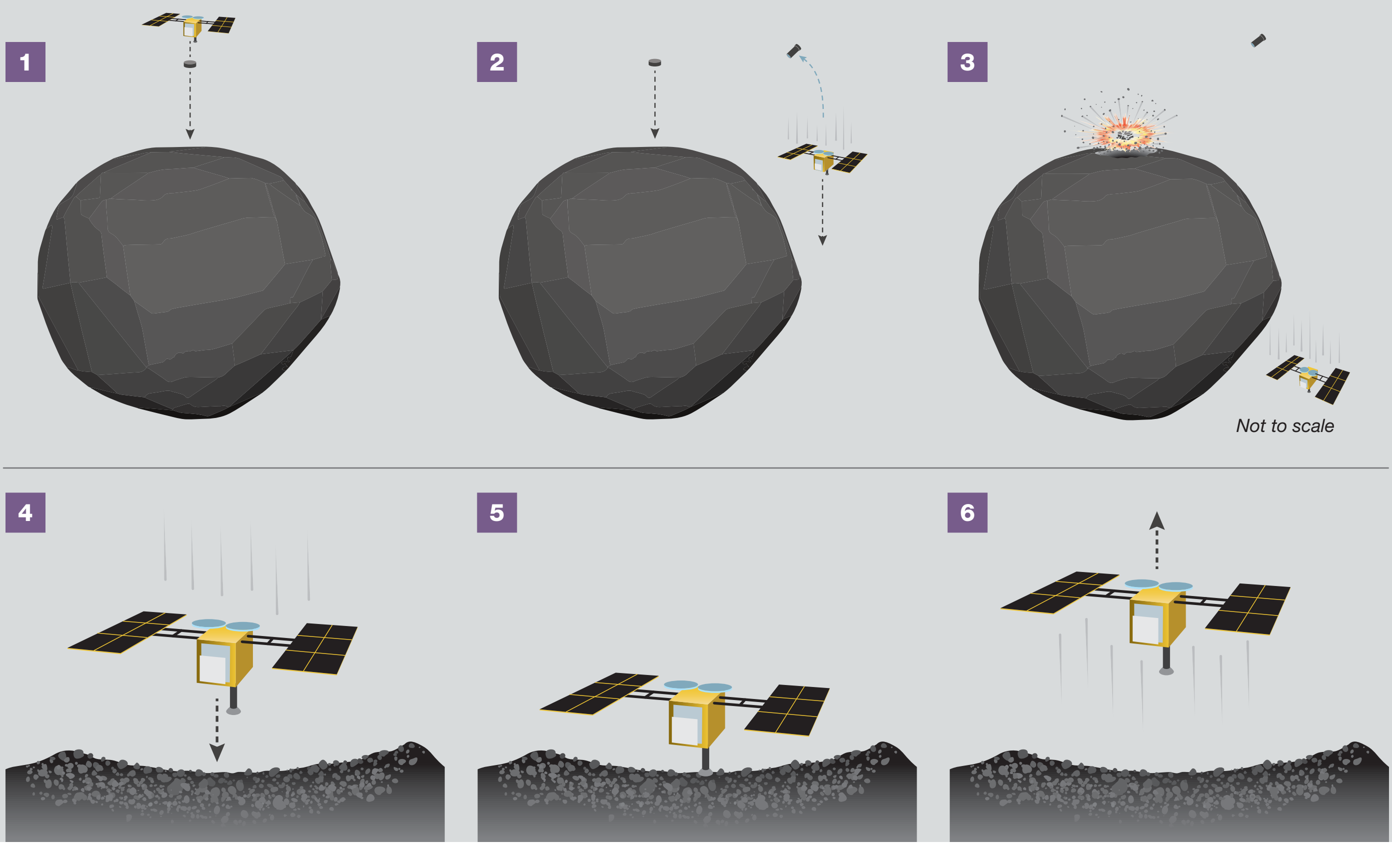
"Hayabusa" means falcon in Japanese, evoking great speed and precision flying. "Ryugu" refers to the magical Dragon Palace at the bottom of the sea, from which, in Japanese folklore, the hero Urashima Tarō returned with a mysterious treasure box.

While the overall design philosophy for both missions may be roughly similar (fly out to a primitive near-Earth asteroid, rendezvous with the target and study it for a while, select a good sampling site, collect the sample, and return it to Earth), the specific sampling strategies for each are different in their details.

Hayabusa 2 is the successor to Japan's plucky Hayabusa mission, which returned to Earth in June 2010 with tiny samples of Itokawa. Launched from the Tanegashima Launch Center on December 3, 2014, the Hayabusa 2 spacecraft employs essentially the same configuration as its predecessor, but with some novel technologies. The main body of the spacecraft itself is about the size of a refrigerator, adorned with two wing-like solar panel arrays that provide power for the spacecraft's instruments and ion engine.

After Hayabusa 2 arrives at Ryugu in June 2018, the spacecraft will gradually approach the asteroid over 18 months or so as the mission team studies its mineral composition, measures the temperature and thermal properties of its surface, and searches for the best location to sample. During this time the mother ship will deploy a small lander called the Mobile Asteroid Surface Scout, or Mascot, as well as three small, hopping rovers named Minerva-II.

HAYABUSA 2: JAXA; SAMPLING: GREGG DINDERMAN / *S&T*



The shoebox-size Mascot probe has its own camera, a multi-color microscope to closely examine the asteroid's surface materials, a radiometer to take Ryugu's temperature, and a magnetometer. Its battery should power a 16-hour or so investigation of the surface.

The Minerva-II rovers are direct descendants of the Minerva deployed toward Itokawa from the original Hayabusa but which unfortunately failed to actually reach the asteroid's surface. There are two types of hopper: one larger, eight-sided rover that's roughly 20 cm tall, and a second, hexadecagonal pair, each just 10 cm tall, or roughly the size of the palm of your hand. They contain their own cameras and other instruments similar to those on Mascot. Each probe has two DC motors inside that work together to "hop" the probes across the surface. Combined with Mascot, the rovers will reveal what the surface is like on a scale similar to what a human explorer would experience poking around as a field geologist, nicely complementing the global-scale observations the main spacecraft gathers.

Finally, the mother ship will descend toward the surface to collect its prize. A meter-long, metal sampling horn extends down from the spacecraft's underbelly. An aluminum contact sensor and collapsible metal skirt will sense the touchdown on Ryugu, setting off a sample collection process that will shoot a 1-cm-size tantalum projectile into the bit of surface inside the end of the sampling horn at a speed of 300 meters per second (700 mph). The ejecta from the little impact will travel up the horn and into one of three separate sample containers inside the return capsule. The edge of the sampling horn is also folded back under to create an inner rim designed to trap material that gets stuck in there when the horn touches the asteroid, as a backup in case the projectile sampling mechanism fails to fire (as happened on the original Hayabusa mission). There's no time to linger: Just one second after this sequence, the spacecraft will boost itself away from the asteroid to avoid tipping over.

The entire descent, sample, and ascent sequence will be repeated, up to a total of three times, filling all three sample containers with about 100 milligrams of regolith particles.

The final grab-and-go will be special, though. To uncover material unaltered by space-weathering effects, Hayabusa 2 will first shoot an explosive impactor toward the asteroid, accelerating a copper projectile enough to excavate a crater a few meters wide. The freshly exposed subsurface material will serve as the sample site. A small camera subsatellite will watch the cratering process unfold from about a kilometer way in space, taking an image every second for later downlink to Earth while the mother ship hides behind Ryugu. Once things are safe, the mother ship will again descend, sample, and dart away.

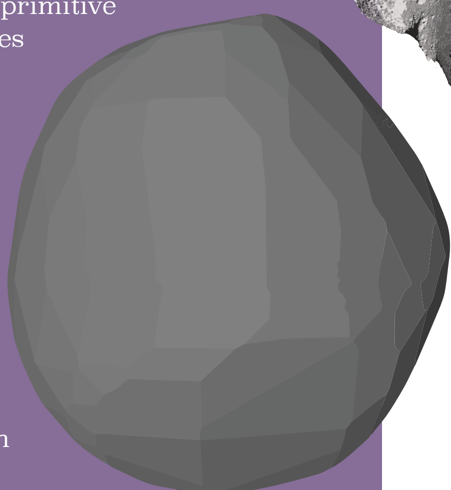
Once all three samples have been acquired, the sample container will be shut tight inside the return capsule with an aluminum seal that will protect any volatiles in the material from being vaporized by exposure to space's vacuum.

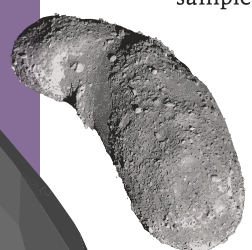
Major Types of Asteroids

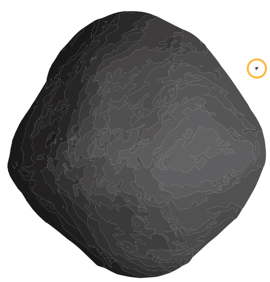
Figuring out just which types of meteorites come from the various types of asteroids observed in the main belt has been a Holy Grail of planetary science for decades. We put asteroids into taxonomic groups based on their colors, albedos, and the shapes and depths of absorption features in the spectra of sunlight reflected off their surfaces. We then attempt to interpret these spectral properties in terms of actual mineral compositions and, in turn, connect the dots to link them with the meteorite types we measure in our labs. But because space weathering alters the spectral properties of asteroids' surfaces, and because some asteroid types show few clearly diagnostic spectral features, this is easier said than done.

(In addition, the alphabetic designations and groupings can vary depending on who is doing the classifying.)

What we think we know is that the S-type asteroids are the source of the ordinary chondrites, which are the most common stony meteorites that fall on Earth. The primitive carbonaceous chondrites seem to be related to the C-type asteroids (and the other closely related types of dark asteroids like the Bs, Fs, and Gs). The predominate minerals we detect on the M-type asteroids appear to be metal, making these bodies the likely source of iron meteorites.







Size of spacecraft

◀ **SIZE AT A GLANCE** Ryugu is nearly twice as large as Bennu, and both are more rotund than kidney-bean Itokawa. The spacecraft icon shows the approximate size of Osiris-REX and Hayabusa 2.

RYUGU AND ITOKAWA: JAXA, BENNU: OSIRIS-REX TEAM / NASA / GSFC

In December 2019, Hayabusa 2 will depart Ryugu for its year-long journey back to Earth. Just a few hours from home in December 2020, the return capsule will separate from the main spacecraft before beginning its 12-km/s reentry through the atmosphere, ending with a parachute-assisted landing at the Woomera Test Range in Australia.

Not a Carbon Copy

In contrast to Hayabusa 2's adventurous multi-vehicle choreography and blast-and-go sampling, the Osiris-REX mission team chose a more conservative, single-spacecraft methodology. Having roared off its Cape Canaveral launch pad on September 8, 2016, the two-ton spacecraft begins its approach phase to Bennu in August 2018, during which time the operations and science teams will begin a search for small moons and any damaging dust that might orbit the asteroid, examine the surface, and refine their model of Bennu's shape.

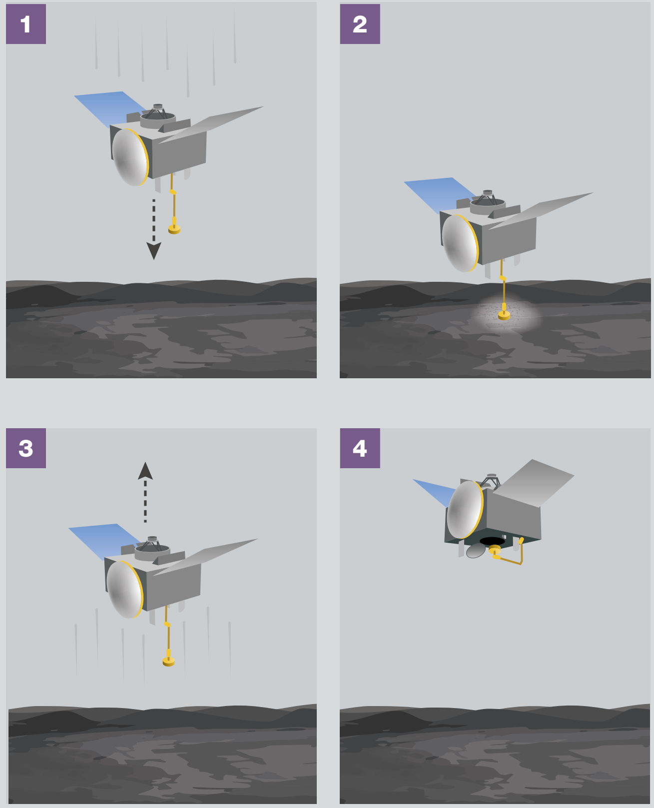
After a few tentative low-speed hyperbolic passes several kilometers from the asteroid and a couple months in an initial 1.5-km-high "practice" orbit, Osiris-REX will begin the detailed survey and reconnaissance phase of its mission in late February 2019. Its three-camera suite (including an 8-inch telescope) will map the asteroid, provide detailed context for the sample site, and monitor the progress of the sample acquisition itself. Meanwhile, a laser altimeter will produce a finely detailed topographic map, while three different spectrometers map the mineral, organic, and thermal lay of the land.

Near-Earth asteroids are literally gold mines in the sky: Not only do we think they contain precious metals, they also should have water that we can convert into spacecraft fuel.

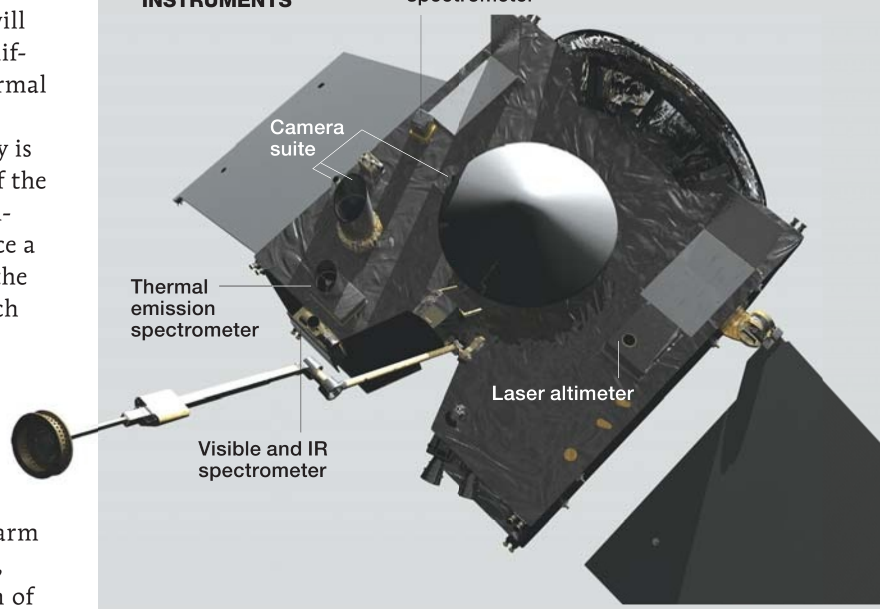
The Touch-And-Go (TAG) sample acquisition strategy is designed with both spacecraft safety and preservation of the sample's pristineness in mind. The microgravity environment makes extended spacecraft contact with the surface a risky venture, especially given that Osiris-REX is about the size of a walk-in closet and could easily tip over. So, much like their Japanese colleagues, the Osiris-REX team has opted for a similar slow descent, brief touchdown, and get-outta-Dodge plan of action.

This plan centers on the Touch-And-Go Sample Acquisition Mechanism (TAGSAM), an articulated arm that extends a few meters below the main structure of the spacecraft. At the business end of the arm is a large-dinner-plate-size annulus of fine metal mesh, which makes the instrument look like the combination of

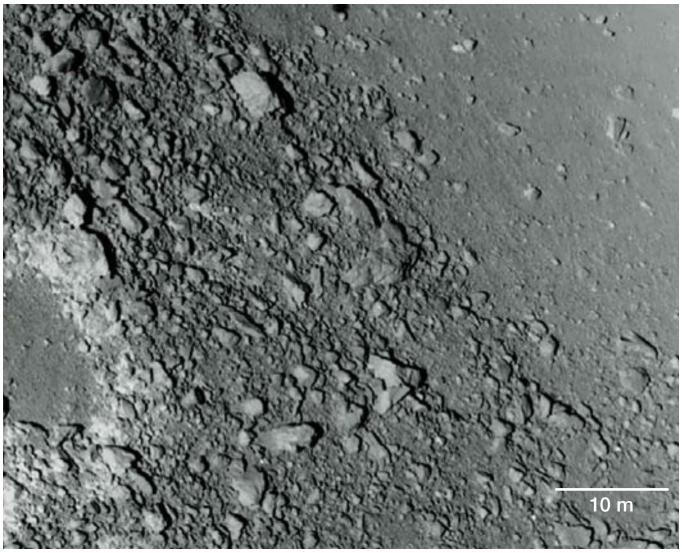
▼ **NASA'S STRATEGY** Expecting a rubble-strewn surface, Osiris-REX will forego projectiles when it touches down on Bennu (1). Once its sampling head is securely planted on the asteroid's surface, it will release a burst of nitrogen gas (2), kicking up dust and small pebbles into the instrument. A few seconds after touchdown, the spacecraft will lift off (3), stowing the sample in its return capsule on the craft's underbelly (4).



▼ **OSIRIS-REX INSTRUMENTS**



OSIRIS-REX: NASA; SAMPLING: GREGG DINDERMAN / *S&T*



▲ **ITOKAWA CLOSE-UP** Scientists expect Ryugu and Bennu to have rubble-strewn surfaces similar to what the first Hayabusa spacecraft found on Itokawa, shown here on November 9, 2005. The crater Komaba appears at left, and the smooth region upper right is MUSES-C Regio. Boulders in this area are generally a few meters wide.

a metal detector and a vacuum. Osiris-REX will edge up to Bennu and plant TAGSAM on the surface. As soon as the spacecraft senses proper contact, the instrument will spew out a stream of pure nitrogen gas, kicking up loose material and blowing it up into the TAGSAM head, thereby trapping small pebbles up to 2 cm in size. As a backup, engineers designed the TAGSAM contact pads to allow some regolith particles to stick there as well. Although this strategy will pick up regolith that's been exposed to space weathering, it does avoid the complicated multi-impact approach Hayabusa 2 will use.

Within seconds of collecting its sample, planned for July 2020, Osiris-REX will beat a comparatively hasty 0.7-meter-per-second (1.6 mph) retreat off the asteroid. Once the mission team has verified that the required 60 grams or more of carbonaceous regolith has been collected, the spacecraft will stow TAGSAM and its regolith sample in its sample return capsule. Osiris-REX will then begin a slow drift away from Bennu before initiating its return-to-Earth burn in March 2021. The sample capsule will plunge through the atmosphere over the Utah Test and Training Range west of Salt Lake City on September 24, 2023, marking the end of Osiris-REX's primary mission but just beginning the journey of discovery for the worldwide community of planetary scientists who will dig in to the gritty treasure from Bennu.

OSIRIS-REX AND BENNU

Osiris-REX is an acronym for Origins, Spectral Interpretation, Resource Identification, Security, and Regolith Explorer. The phrasing of the mission's science goals this way enabled the mission team to use a name that points to the Egyptian god Osiris, who spread knowledge of agriculture (and hence life) to the Nile Delta and also was king of the underworld — two roles that bring to mind asteroids' potential source of Earth's organics and the threat they pose to our planetary safety. "Bennu" was another Egyptian deity associated with rebirth.

Pushing Back the Frontiers

The samples returned from both of these groundbreaking missions and the new knowledge gained about their parent asteroids will not only finally tell us how the different flavors of carbonaceous chondrite meteorites are related to various types of dark asteroids. They'll also provide crucial steps forward in planetary science and exploration.

One of the most fundamental questions we have about the formation of our own home world is: Where did Earth's water and organic materials come from? Were they present in the material Earth itself formed from, or were they delivered to Earth after the planet was assembled?

For many years, scientists' favored answer was that Earth's water came from comets that had hit the planet early on, but as we've studied comets' compositions we've realized that the isotopes in their water don't match Earth's. Instead, our planet's water might be "native," carried in the rocks that stuck together to build our world up — the same rocks that endure today as asteroids. Finally getting our hands on samples plucked from the types of asteroids long suspected to be the most primitive building blocks of the terrestrial planets will go a long way to answering these questions.

In addition to their compelling scientific value, the near-Earth asteroids are literally gold mines in the sky: Not only do we think they contain precious metals, they also should have water that we can convert into spacecraft fuel, providing important in situ resources once we're routinely exploring and navigating the inner solar system.

Just operating in close proximity to Ryugu and Bennu is going to provide crucial knowledge that will come in handy as we expand our experience working in space beyond Earth. Hayabusa 2 and Osiris-REX are pioneers in helping us wrap our heads around the sometimes counterintuitive working environments we're going to encounter on the surfaces of these lumpy little worlds.

And of course, there's always the looming problem of what to do if an asteroid targets Earth. Although a civilization-ending hit is unlikely (see page 12), smaller rocks could come. An asteroid impact is a natural disaster that we can actually prevent, but only if we know more about the asteroids themselves and how they respond to our poking and prodding. So as exaggerated as it sounds, these missions might not only tell us about Earth's past — they could also help us preserve its future.

■ **DAN DURDA** is a principal scientist at the Southwest Research Institute in Boulder, Colorado, where he studies the evolution of asteroids and the effects of their impacts on one another and on Earth.

JAXA

Is that Star Blue or Green?

The *eXcalibrator* freeware program helps to take the guesswork out of color-balancing your deep-sky images.

As a child on car trips with my family, I often heard my parents ask this question about car colors: Is that blue or green? While driving my parents to a restaurant nearly 40 years later, from the back seat came the same question, "Is that blue or green?" I turned to my wife and said, "I can't believe they're still doing that." Today I engage in discussions about color relative to stars, galaxies, and nebulae instead of automobiles.

Several years ago, I shared an image of the open cluster M67 on an online imaging forum. A more experienced astrophotographer commented that the stars in the photo were too yellow, as open clusters usually have younger bluish stars. As the discussion continued, another imager, Wolfgang Renz, noted that M67 is a very old cluster, no longer dominated by blue stars. Using data from the Naval Observatory Merged Astrometric Dataset (NOMAD) catalog, he showed that the stars are mostly white or yellowish white.

This started my quest for a repeatable process to obtain consistent and reasonably accurate color balance in my deep-sky astrophotos. The journey eventually culminated in the development of the freeware program *eXcalibrator* for Windows (**https://is.gd/eXcalibrator**).

Color Is Complicated

When imaging the night sky, several factors affect the color of your results. First, the spectral sensitivity of different CCD and CMOS detectors varies greatly. Some are more sensitive to blue light, while others respond better to red or green light. This is true with both a monochrome camera (used with individual color filters) or a one-shot color camera (which incorporates tiny red, green, and blue filters over individual pixels).

▲ **TOO BLUE** There are many techniques to achieve a natural color balance in deep-sky photography, though most are subjective. This image of M31 in Andromeda was captured by the author and processed two different ways. The right side is balanced based on comparison to other images found online, while the left side uses *eXcalibrator* to establish color balance based on known star colors in the image.

UNLESS OTHERWISE NOTED, ALL PHOTOS COURTESY OF AUTHOR

Another variable is the combination of red, green, and blue filters used in all digital cameras to make the color result. Whether you're using a monochrome or one-shot color camera, these filters vary in their transmission curves and cutoffs. In some cases, the red, green, and blue passbands overlap. Other filter sets have distinct transmission gaps intended to reduce the effects of light pollution.

Additionally, several variables beyond your equipment can affect the color of your images. These include *atmospheric extinction* and transparency. The lower your target is in the sky, the more atmosphere its light travels through, which blocks an increasing amount of blue light. Hazy skies also block bluer wavelengths more than red, skewing the color in your result. Other effects are due to extraterrestrial factors such as dust in our galaxy, and even intergalactic gas and dust between your target and your camera. Finally, inconsistent image-processing choices, such as the normalization (the equalization of individual exposures) before stacking, can skew the final result.

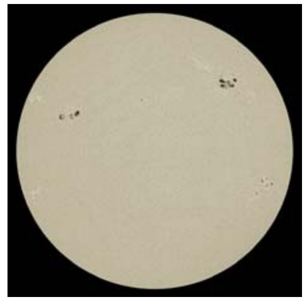
Color Correcting

Astrophotographers often rely on several methods to correct the color balance. Some are better than others. Often, an imager will look online to compare his or her image with those of others. This is perhaps the *least* reliable way of achieving accurate deep-sky color! Do a simple web search for M31, and you'll be presented with dozens of images of this showpiece galaxy, some bluer, others reddish. "Eyeballing" the color in your images this way might produce a pretty result, but it isn't very accurate.

One reasonable way to color-balance a galaxy image is to assume that the integrated light of a face-on spiral galaxy is white. This reasonable approach shows a galaxy with its intrinsic color. However, many galaxies, for example, IC 342, are seen through intervening dust within the Milky Way, which reddens its overall appearance. So using this intrinsic color assumption for IC 342 makes the foreground stars too blue.

Another common color-balancing technique is to set the background color in your image to a neutral gray. This works well for some images, though not if the field is filled with emission nebulosity or dust.

Some imagers even use the cumulative light of all the stars in a picture as a white-point average. This does work with some objects, if there is no intervening galactic extinction. For instance, the core of a globular cluster often makes a good white-point reference.



▲ **WHITE STAR** While our Sun is informally referred to as a yellow dwarf, it is really a white *G*-type main-sequence star (*G*2V). Amateur astronomers use other solar analog *G*2V stars as reliable white-point calibration targets.

Of all the techniques mentioned, using the color of stars in your images is a step in the right direction to achieve reasonably good color balance. But star colors vary greatly, depending on which direction you look. Stars in the arms of our Milky Way tend to be young and therefore blue. Looking to the galaxy's halo and bulge, you see more reddish stars. In fact, the general stellar population is mostly comprised of red dwarfs, so the true average color of stars skews toward the red end of the spectrum.

Solar Analog

Many amateurs, in their pursuit of an accurate color calibration method, rely on a technique that uses *G*2V spectral-class stars as a white-balance reference. Our Sun is a *G*2V star, and its light appears white to our eyes. Using this approach, you adjust the red, green, and blue exposures so that the *G*2V

▼ **DUSTY VEIL** One common technique used to color-balance galaxy photos is to assume their integrated light should be white. But some galaxies, such as the face-on spiral galaxy IC 342 seen below, are viewed through dust within the Milky Way. The integrated light balance technique *(left)* produces a nicely colored galaxy image. Using *G*2V-like stars as calibration sources in eXcalibrator results in an image of the galaxy reddened by dust, which blocks bluer wavelengths *(right)*.

SUN: SOLAR DYNAMICS OBSERVATORY / NASA

stars in an image appear white — if there are any G2V stars in the field.

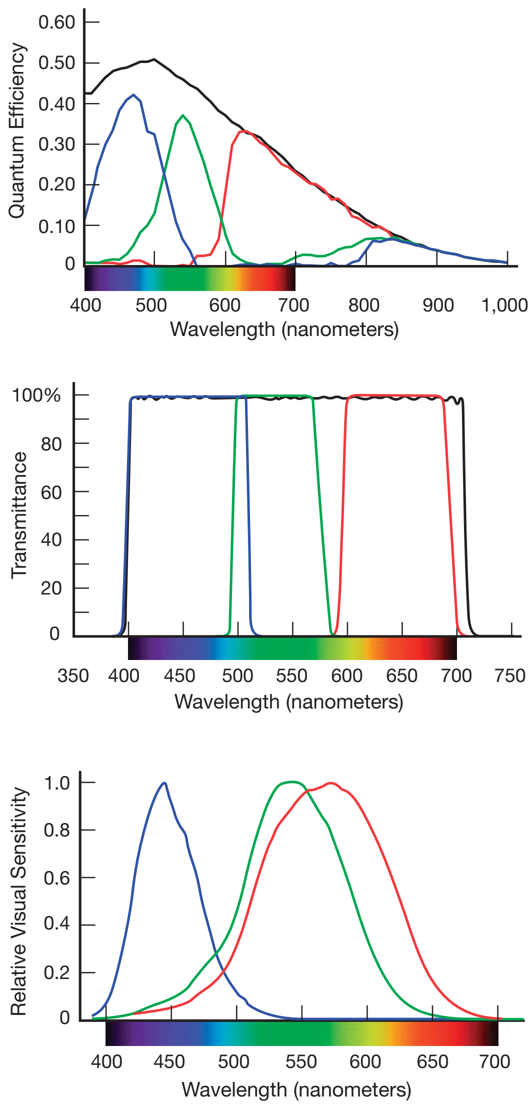
Using this singular calibration method still has problems. First, as mentioned earlier, there is no correction for the altitude of the target as it is imaged throughout a night or over several nights. It's particularly problematic when the target falls below about 40° above the horizon. Atmospheric dust scatters green light more than red, and blue more than green.

Secondly, G2V calibration doesn't account for the sky's variable transparency. As the night progresses, thin clouds might come and go. This can compromise the data for just one of the three color filters, throwing a meticulous G2V calibration scheme out the window. Still, this technique at least heads you in the right direction.

Continued research led to the work of amateur Bernhard Hubl and Mishca Schirmer of the Max Planck Institute for Astronomy. They use stars from the Sloan Digital Sky Survey (SDSS) database as white-balance reference points. They identified white (Sun-like) stars in their images to determine color correction.

This seemed like a reasonable solution. I liked combining a G2V-like calibration method with information from the image itself to color-balance. Additionally, this technique uses catalog data acquired by a professional survey. And so, with help from Hubl and Schirmer, *eXcalibrator* was born.

With the help of amateur Bruce Waddington, the program incorporates a linear regression (LR) routine to allow the use of stars of any color as calibration sources that reference the SDSS data. By obtaining nearly identical results, the LR routine reinforces the white-star color-balancing concept. The program also incorporates the AAVSO Photometric All-Sky Survey (APASS) data, fully automating color calibration in deep-sky images recorded with monochrome cameras and color filters.



▲ **SPECTRAL VARIABLES** While many outside factors can contribute to the color of your deep-sky astrophotos, none is as influential as the camera and filter you use to shoot through. The spectra above show the red, green, and blue spectral response curve of a KAI 11002 CCD detector *(top)* and the passbands of AstroDon Gen2 color filters. The bottom graph displays the spectral response of the human eye. Each camera and filter combination will produce different exposure times to achieve a natural color balance.

GREGG DINDERMAN / S&T (3)

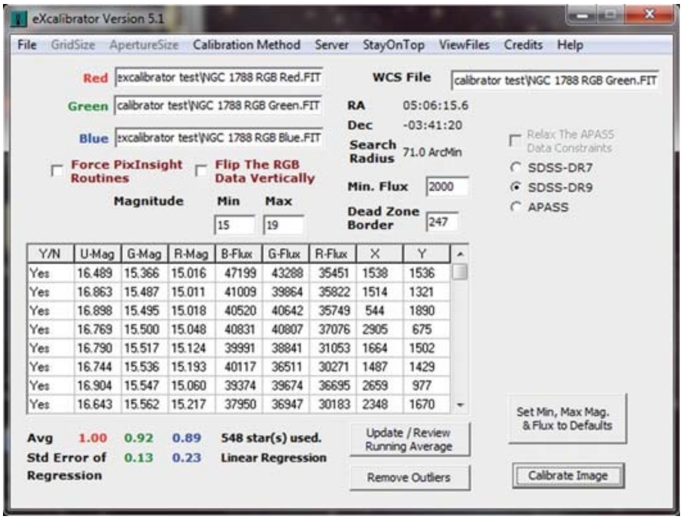
Putting *eXcalibrator* to Work

Contrary to Superman legend, the Sun is not a yellow star. When viewed near the zenith or from space, the Sun looks and photographs white. Measuring the color balance of the Sun with SDSS's u- (ultraviolet through blue), g-, and r-filter values yields (u–g) = 1.43 and (g–r) = 0.44. So *eXcalibrator* searches an image for stars with SDSS (u–g) and (g–r) values similar to the Sun's. The program uses the average values of the identified stars to determine the proper red, green, and blue scaling ratios for color correction.

With the LR routine, *eXcalibrator* only incorporates the green and red values from the SDSS or APASS data (most filters for amateur cameras block ultraviolet light). The program then computes a color correction by comparing the stars' colors in the image with their known color values from these databases.

There are two ways to utilize *eXcalibrator*. The first is to color-balance your data. To start, you first need to plate-solve one of your calibrated and stacked monochrome FITS images shot through a red, green, or blue filter, which can be accomplished with the Image Link function in *TheSkyX* (**bisque.com**) or online at **nova.astrometry.net**. This adds World Coordinate System (WCS) information to the FITS header that the program will then utilize to find suitable calibration stars in the image. The program also works on one-shot color images that have been split into their respective color channels and saved as FITS files.

Once one of the images has been plate-solved, load the red, green, and blue images into their respective boxes and also select the plate-solved image in the WCS File box. The program then employs the FITS WCS data to determine the center of the field of view, image size, scale, and rotation. Click Calibrate Image, and the program downloads SDSS or APASS data from the VizieR Catalogue Service. *EXcalibrator* then identifies stars that should be white and calculates the color adjustment. To obtain a larger sample, the LR routine also selects stars that are yellow and cyan in hue. When completed, the program presents you with the average weight of each color, which you then use when combining them in your preferred image-processing program.



NEBULOUS FIELD Using the stars as color balance calibration sources makes short work out of images filled with emission nebulosity, such as this shot of NGC 2261 in Monoceros.

▲ **EXCALIBRATING** Using *eXcalibrator* is easy. Plate-solve one of your color images and enter it into the WCS File section at upper right. Next, select each of your red, green, and blue frames in their respective lines at top left. Then simply click the Calibrate Image button at the bottom right, and in a few moments the scaled weight of each channel will be presented next to Avg at the bottom left of the screen.

Calibrating an Imaging System

The other way *eXcalibrator* can be used is to determine the exposure times for each filter taken with your particular equipment under near-ideal conditions. This is accomplished by taking two or three 5-minute exposures with each color filter with your scope pointed near the zenith. You calibrate, register, and stack those results, and then run the resulting images through the *eXcalibrator* process. The correction factors to adjust the red, green, and blue exposure times should be used when shooting future images. For example, calibrating one of my imaging systems produced RGB color ratios of 1.0, 1.12, and 1.20, respectively. So I shoot my individual R, G, and B exposures at 10, 11, and 12 minutes. Using these calibrated system values, my images should have a well-balanced natural color appearance.

By imaging under good transparency and taking care to avoid atmospheric extinction due to the altitude of your target, the final *eXcalibrator* R, G, and B correction factors should usually be close to 1:1:1.

▶ **GOLDEN CLUSTER** Globular clusters are another target that is thought to be a good white-point calibration object. But many of these star clusters are dominated by older, redder stars and are also seen through intervening dust in the Milky Way. The image of M10 at upper right presents a color image calibrated by assuming the core of the cluster is white, while the version at right used *eXcalibrator* to determine the cluster's color based on the spectral properties of known stars in the field.

Once you've calibrated your system, it's easy to integrate *eXcalibrator* into your own imaging routine. Here's my typical astrophotography workflow:

» Acquire the data for my imaging target.
» Calibrate, register, and combine the R, G, and B exposures.
» Plate-solve one of the stacked results.
» Run the R, G, and B images through the *eXcalibrator* process to determine the final color adjustment.
» Use the adjustment weights to assemble the color image.
» Continue with stretching and other processes to produce the final color image.

Even with a calibrated system, *eXcalibrator* will produce slightly varying channel weights in different data sets, because the program takes into account atmospheric extinction, transparency, and other variables that occurred when the images were acquired.

Using different camera and filter pairings, it's possible to adjust the color with *eXcalibrator* so that white stars appear white — an excellent way to consistently obtain good color in the initial tri-color assembly. By following through with consistent image processing, you can accurately compare different images and say, for example, "Galaxy A is bluer than Galaxy B."

If you agree that making white stars white will produce reasonable color in your astro-images, then hitch your wagon to *eXcalibrator* and take it for a ride. Color balance in astrophotography is ultimately a matter of personal taste. But being reasonably accurate from the get-go will add consistency to your results and make your later processing decisions easier.

■ **BOB FRANKE** is a retired software developer and avid astrophotographer. See more of his images at **bf-astro.com/index.htm**.

 by Steve Murray

A Crowded Life

A curious mind and an inventive spirit helped George Ellery Hale transform modern astronomy.

▲ **ASTRONOMER AT WORK** George Hale poses at his desk in the "Monastery," the quarters of staff and visiting scientists at Mount Wilson Observatory.

"Palomar Observatory is my favorite mount-top in the world," says Mansi Kasliwal (Caltech). She and her students use spectra obtained with the observatory's 200-inch Hale Telescope to study optical and infrared transients — supernovae, gamma-ray bursts, and black holes feeding on stars. The big reflector was the last telescope developed by George Hale, a scientist who made pioneering discoveries about the Sun, gave astrophysics some of its most powerful tools, and helped to shape both national and international scholarly institutions. It was a crowded life, and one that transformed modern astronomy.

George Ellery Hale was born June 29, 1868, into a wealthy Chicago family that encouraged his science interests. Hale's father, William Ellery Hale, helped his son during his youth and through his early career, providing him with tools and instruments. Hale's mother, Mary Scranton (née Brown) Hale, encouraged his creative development, sharing with him works of poetry, literature, and history during his formative years. His interests were diverse, taking him from the woodworking shop and laboratory he built with his brother, to observing the Moon and planets with a 4-inch Clark refracting telescope mounted on the roof of the family home when Hale was 14, to informally studying architecture with the Chicago architect Daniel H. Burnham. His inquisitive nature, supported by a family that encouraged intellectual

▶ **IMPRESSIVE INVESTMENT** At the invitation of university president William R. Harper, George Ellery Hale joined the faculty of the University of Chicago in 1892. During the hiring negotiations, Hale extracted a promise from Harper that the university would build a new observatory and install a great refractor within three years of his appointment. This photograph, taken by Frank E. Ross in 1925, shows the end result of Hale's deal. Funded in large part by Chicago businessman Charles Yerkes, the Yerkes Observatory was dedicated in 1897, five years after Hale joined the university. The great dome still houses the 40-inch telescope, the world's largest refractor.

robustness, served Hale well as he grew and moved on to study at the collegiate level.

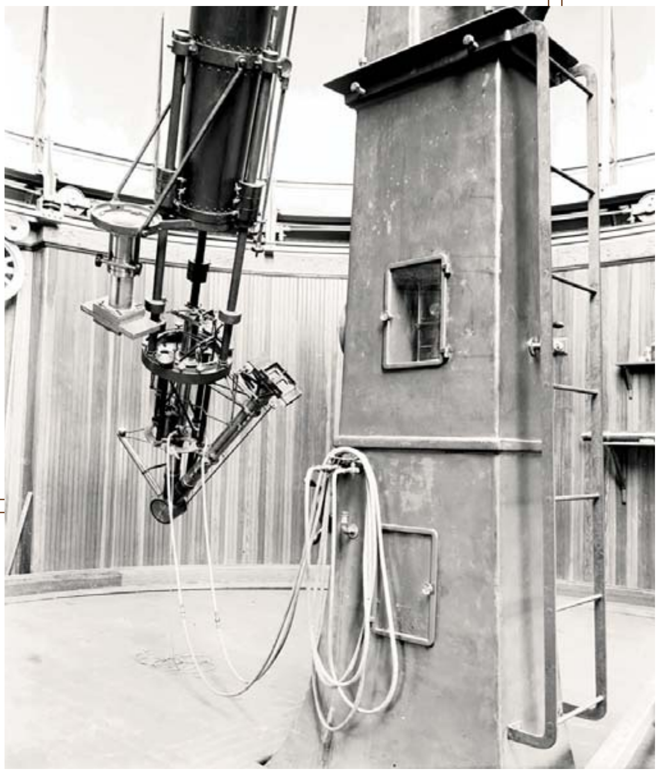
During Hale's student years at the Massachusetts Institute of Technology (MIT), he volunteered at the Harvard College Observatory. Edward Pickering, the observatory director, was an early believer in the "new" astronomy — studying the physical properties of stars rather than just their positions and movements — and their experience together likely influenced Hale's own ideas about the science. Hale's first technological contribution was the *spectroheliograph*, a device he invented to photograph the Sun at a single wavelength of light. With it, he determined that sunspots are vortices in the solar atmosphere, a discovery that formed the basis for his baccalaureate thesis.

Hale married two days after his graduation from MIT and, when he returned from his honeymoon, he set up a personal observatory at the family's Kenwood (Chicago) home with a 12-inch refractor, a gift from his father. He spent the next two years conducting research and teaching until he was recruited as a faculty member to the newly established University of Chicago in 1892. Hale wanted a bigger research telescope and hoped that the university might be a path to better equipment.

His interests were diverse, taking him from the woodworking shop and laboratory he built with his brother, to observing the Moon and planets . . .

The same year he joined the University of Chicago, Hale addressed a meeting of the American Association for the Advancement of Science (AAAS) in New York, where he learned that the University of Southern California had ordered two 40-inch lenses for a new telescope on Mount Wilson, California, but had been unable to complete payment on them. Hale instantly went to work on a plan to bring the lenses to the Midwest. With the help of University of Chicago president William Rainey Harper, Hale obtained money for the lenses and telescope construction from financier and transportation magnate Charles Yerkes.

UNIVERSITY OF CHICAGO / YERKES OBSERVATORY (2)



◀ **SOLAR STUDY** As part of the terms of his employment, Hale agreed to cede his own Kenwood Observatory, complete with 12-inch refractor, to the University of Chicago. This photograph, taken in the 1890s, shows Hale's spectroheliograph attached to the refractor.

▲ **HANDLE WITH CARE** The mounting and tube of the 40-inch refractor manufactured by Warner & Swasey Company were displayed at the Columbian Exposition of 1893 in Chicago before being installed in Yerkes Observatory. The telescope housing was put in place in the observatory in 1896. This image, taken in November of that year, shows construction workers hoisting the polar axis to the top of the mount.

UNIVERSITY OF CHICAGO / YERKES OBSERVATORY (2)

Hale appealed to Yerkes' ego by assuring him that his name would be on the largest refractor in the world. Displaying what would become lifelong confidence in his own plans, Hale began hiring a technical staff even before his financial support was confirmed.

Yerkes Observatory was established in 1897 in the village of Williams Bay on the north side of Geneva Lake, Wisconsin. To realize Hale's vision of "laboratories for optical, spectroscopic, and chemical work," an approach that would be repeated on Mount Wilson, the observatory was designed as more than a conventional telescope-and-dome facility. It was the ability to test chemical and physical processes in the laboratory, and to compare them with stellar observations, that eventually enabled so many of the astrophysics discoveries made with Hale's telescopes.

Hale's satisfaction with the new telescope only lasted a few years, however. Soon, he was planning for yet bigger instruments. More light-gathering capability was necessary for increased spectral line dispersion and a better chance of identifying chemical elements. By this time, Hale also shared the view of many astronomers that refractor telescopes had reached their practical limit, and that only reflectors could provide the apertures required for better spectroscopy. In 1894, William Hale had donated a 60-inch glass disk to the university to support his son's aspirations. He had urged the institution to provide a mounting for it as well, but the university had refused. While the elder Hale was still inclined to fund the entire effort, he died in 1898 and the disk was put into storage.

George Hale saw an opportunity again in 1902 when the Carnegie Institution of Washington was established with a $10 million gift from Andrew Carnegie. Hale was one of the original advisors to the philanthropic organization, which was intended to fund pure research projects. In June 1903, Hale tested the solar seeing at Mount Wilson. Pleased with his observations, he applied to the Carnegie Institution to finance a solar observatory on the mountain. When his proposal for a 60-foot solar observatory won approval from the institution, it was time to move to California. "I doubt that he ever intended to stay in Wisconsin permanently," says Dan Koehler (Yerkes Observatory). "For Hale, Williams Bay was no competition to Pasadena."

It All Comes Together

The initial Carnegie message of approval didn't commit funds to the Mount Wilson project. Hale nevertheless moved west in December 1903, using his own money and family loans. He had the Snow Solar Telescope shipped to Mount Wilson on loan from Yerkes and spent the winter setting it up. (He would later add a 60-foot and a 150-foot solar telescope — the largest in the world until 1962 — to the observatory's instruments.) He signed a 99-year lease for the observatory land in June 1904 and commenced moving his Yerkes colleagues to California. His confidence was again rewarded in December of that year when he finally received the Carnegie funding message. Hale resigned from Yerkes Observatory two weeks later.

1908 was a big year on Mount Wilson. Hale used a modified spectroheliograph to show that sunspots were magnetic, the first time that magnetic fields were identified on an extraterrestrial body. Later work would yield the Hale-Nicholson Law, which states that magnetic polarities in sunspots are symmetric across the solar equator and that polarities in each hemisphere switch from one sunspot cycle to the next — phenomena that are still being investigated today (*S&T:* Jan. 2018, p. 18).

> Hale was the ultimate networking specialist at a time when networking wasn't even a concept.

The 60-inch mirror that might have earlier found a home at Yerkes was installed in its telescope mount in December 1908 after four years of grinding and figuring by Hale's chief optical engineer, George Ritchey. It was the first major telescope to use a *coudé focus*, which sent light to a point outside the telescope, allowing astronomers to change instruments without disturbing the telescope's tracking. The design also featured a mercury-filled bearing system that supported 95% of the structure's weight. Successful operation of the 60-inch telescope effectively marked the end of refractors for research.

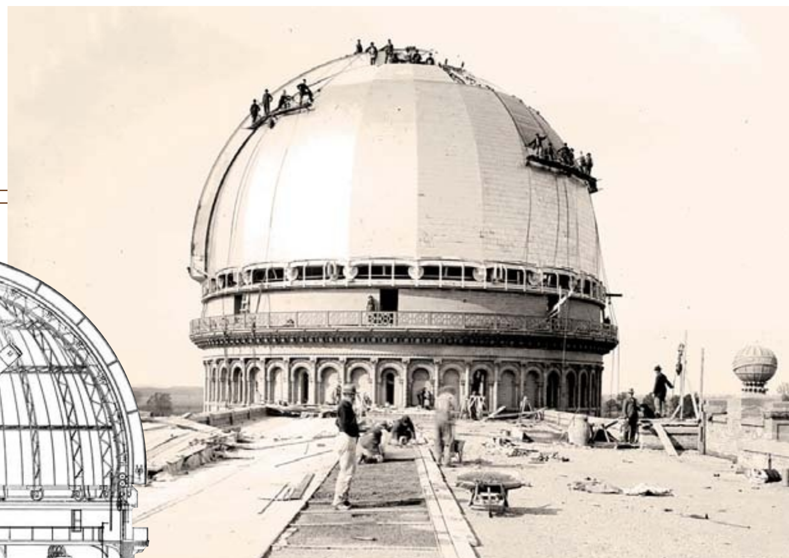
But Hale was planning for a bigger telescope even before the 60-inch reflector was completed. John Hooker, a Los Angeles business executive, amateur astronomer, and friend to Hale, offered to pay for the casting and grinding of a 100-inch disk, with the understanding that it would be the biggest telescope in the world and would be named after him. It was a risky commitment, as the 60-inch telescope hadn't yet been fully checked out, but Hale pressed forward in September 1906 with a disk order to the Saint-Gobain glassworks, the French company that had cast the 60-inch disk and the only operation willing to attempt a bigger one.

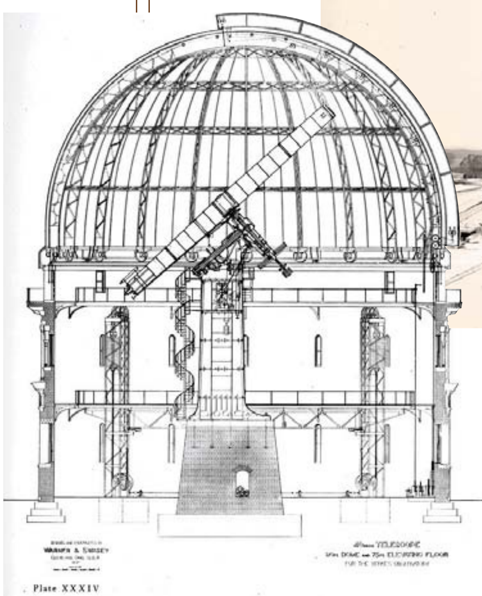
The first disk looked like a failure. It contained air bubbles, and Ritchey doubted it would withstand grinding and polishing. Saint-Gobain tried again with new methods and equipment, but without success. In desperation, Hale gambled that the original disk was salvageable and decided to have it completed over Ritchey's strong objections. The mirror was finished after seven years but, given their tensions over the mirror, so was the relationship between Hale and Ritchey (*S&T:* Oct. 2016, p. 66).

As before, Hale began the project boldly, but without sufficient financing: Hooker's money wouldn't cover critical components like the mount and housing, and other engineering difficulties raised the total price. Eventually, Hale had to convince Andrew Carnegie to supply another $10 million via the Carnegie Institution to complete the work.

First light for the 100-inch on November 1, 1917, came with some suspense. Several hours were needed for the mirror to adjust to ambient temperatures. Once the mirror had stabilized, however, it showed its true potential, and attendees realized that Hale had produced another "world's largest telescope."

Some of the most important work of 20th-century astronomy happened inside the Hooker dome on Mount Wilson. Edwin Hubble determined that Andromeda was a galaxy outside our own by measuring distances to Cepheid variables and established that the universe was expanding. A. A. Michelson used a 20-foot interferometer to make the first measurement of a star's diameter. Fritz Zwicky determined that the gravi-





▲ **TOPPING IT OFF** The great dome of Yerkes Observatory was tinned and cemented in the autumn of 1896.

◀ **MAKING PLANS** Telescope makers Warner & Swasey Company included this drawing of the Yerkes Observatory's 40-inch scope, 90-foot great dome, and 75-foot elevating floor in a 1900 circular describing their latest work.

UNIVERSITY OF CHICAGO / YERKES OBSERVATORY (2)

tational mass of galaxy clusters was far greater than expected from their luminosity, offering an early hint of dark matter. Walter Baade identified two types of Cepheid variables and, with that discovery, doubled the size of the universe calculated by Hubble.

The Hooker remained the world's largest telescope until 1949, when Hale beat his own record on Mount Palomar.

A "Type A" Astronomer

Hale's industriousness affected science far beyond the construction of telescopes. While still at the University of Chicago he founded *The Astrophysical Journal* with James Keeler in 1895, and he was a major driver in establishing the American Astronomical Society in 1899. In 1904 he founded the International Union for Cooperation in Solar Research, which later became the International Astronomical Union, and he played a major role in transforming the Throop Polytechnic Institute into the California Institute of Technology. In 1916, he was instrumental in creating the National Research Council to harness scientific expertise for national needs.

▼ **SUN SPOTTING** The Snow horizontal telescope (coelostat) was a gift to Yerkes Observatory from Helen E. Snow in memory of her father, George W. Snow. Hale transported the instrument to California in 1904 to make solar observations. The scope had a 60-foot (18-meter) focal length so was housed in a long building, next to which was built the 60-foot solar tower.

"I've been struck by the huge number of scientists living at the time that Hale corresponded with and knew personally. He was the ultimate networking specialist at a time when networking wasn't even a concept," says Koehler.

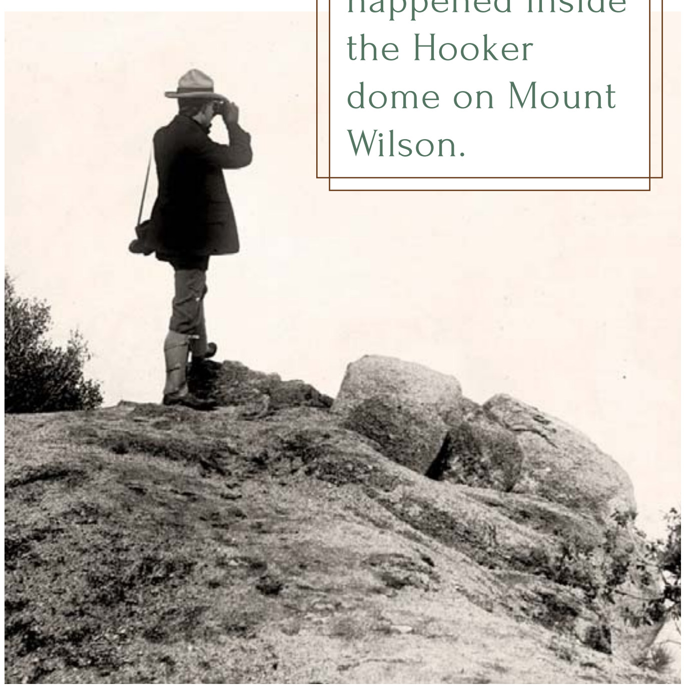
Over time, the frenetic pace took a toll. Hale had long suffered from headaches and bouts of depression. Worsening symptoms led to nervous breakdowns serious enough to make him decline meetings and spend repeated periods in sanitariums. Weakened by ill health, Hale resigned as director of the Mount Wilson Observatory in 1923. The next year, he built a small solar laboratory in Pasadena, where he did much of his scientific writing and planned for his next big telescope.

Hale was aware that light pollution from greater Los Angeles was a growing problem for Mount Wilson, and in 1928 he opened a new chapter in astronomy farther south in California with a $6 million award from the Rockefeller Foundation. His initial ambition was to build a 300-inch telescope on Palomar Mountain, north of San Diego. After being convinced that it would be too difficult to construct, however, he scaled his design back to 200 inches. Regrettably, the enterprise would stretch a decade beyond his life. Hale died on February 21, 1938, at a sanitarium, where he had been admitted a few months earlier after a stroke. He was 69 years old.

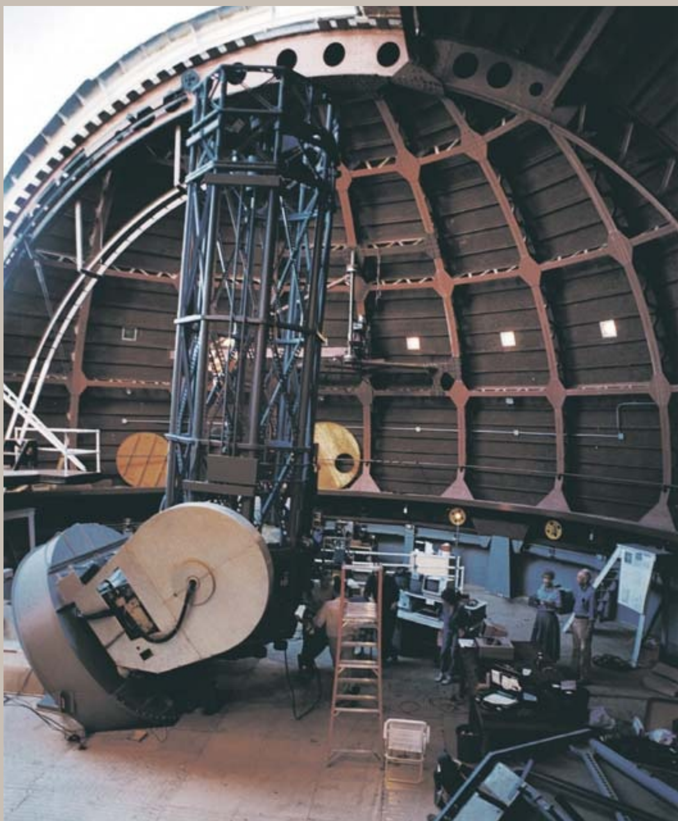
Sponsors named the new reflector at Palomar Observatory in his honor at its 1948

> Some of the most important work of 20th-century astronomy happened inside the Hooker dome on Mount Wilson.

▼ **MAN ON A MISSION** George Hale takes in the view from Mount Wilson, c. 1904.



UNIVERSITY OF CHICAGO / YERKES OBSERVATORY (2)



◀ **RECORD BREAKER** Mount Wilson's 60-inch scope saw first light on December 13, 1908. It was the world's largest functional telescope until the completion of the observatory's 100-inch scope in 1917.

▼ **HUMANS FOR SCALE** Two (unidentified) men stand on the unpolished 200-inch Pyrex mirror disk made by Corning Glass Works for the Hale Telescope at Palomar Observatory.

▼▼ **GIGANTIC GLASS** The 200-inch Hale Telescope dwarfed the crowd that gathered at Palomar Observatory on the occasion of the telescope's dedication on June 3, 1948.

60-INCH SCOPE: DENNIS DI CICCO / S&T; MIRROR DISK: UNIVERSITY OF CHICAGO / YERKES OBSERVATORY; 200-INCH TELESCOPE: PALOMAR OBSERVATORY / CALTECH dedication ceremony. The Hale Telescope saw first light in January 1949, and Edwin Hubble was the first astronomer to use it. With four times the light-gathering power of the Hooker, it remained the largest telescope in the world until 1975, when the Russian BTA-6 telescope (238 inches, or 6 meters) saw first light. Because the BTA-6 suffered from several design problems, however, many astronomers extend the Hale record to 1993 when the Keck Telescope began operation.

Time ultimately caught up with the telescopes at Williams Bay and Mount Wilson. The 40-inch refractor at Yerkes Observatory transitioned to a teaching tool after 1990; the observatory is scheduled to close permanently in October 2018. The last research project on the 60-inch Mount Wilson telescope ended in the mid-1990s. Although the Hooker Telescope was retired in 2015, Mount Wilson Observatory celebrated the famous reflector on November 1, 2017, the date of its centennial. Viewing opportunities through both telescopes on Mount Wilson are now available to the public (*S&T:* Sept. 2016, p. 22).

◀ **MR. MONEYBAGS** Andrew Carnegie's money played a pivotal role in the construction of Mount Wilson, funding the construction of Hale's dreams via the Carnegie Institution of Washington. This photo shows Hale and Carnegie in front of the steel dome of the 60-inch telescope, c. 1910.

Of all Hale's telescopes, only the 200-inch reflector is still used for research. Mansi Kasliwal has been working with it since she was a student at Caltech. "When you enter the main dome for the first time," she says, "you feel a part of something much bigger. You get a feeling of awe and inspiration and history that really leaves an impression. If you're a young student, it can change your life."

■ **STEVE MURRAY** is a freelance science and technology writer who stargazes from his home in San Diego, California. He'll travel anywhere to explore new observatories.

George Hale's Telescopes Today

All of Hale's telescopes are open for public visits at present. With the exception of the Hale reflector on Mount Wilson (still used for research), the observatories offer opportunities to stargaze through them, too.

Yerkes Observatory (https://is.gd/yerkes): The University of Chicago recently announced plans to close Yerkes Observatory. In the meantime, scheduled public tours are offered Monday–Saturday and are the only way to see the building interior and the 40-inch refractor. There's a nominal charge for the tour. Private group tours can be arranged on request. Because of its dated architecture, the building isn't handicapped accessible.

Public observing with the 40-inch refractor and 24-inch reflector (used by George Ritchey to test his design concepts) is offered monthly at selected times, weather permitting.

This Memorial Day weekend, Yerkes Observatory will host Starlight 2018, an event tied to Hale's 150th birthday. Speakers from Mount Wilson, Palomar, and Caltech have been invited to participate in the free event.

Mount Wilson Observatory (https://is.gd/mtwilson): Grounds are open daily, weather permitting. Two-hour docent-led tours are offered on weekends between April 1st and November 30th, with one-hour tours added between June and August. Private group tours are available with advance registration. There's a nominal charge for the tour. Visitors are free to take a self-guided tour with downloadable guide. Distances and hilly terrain limit access for individuals with health or mobility concerns.

In keeping with Mount Wilson's history of solar astronomy, free solar viewing is available to the public on weekends.

The famous 60-inch and 100-inch telescopes can be rented by groups for half- or full-night viewing sessions. The observatory also sets aside a number of ticketed evenings throughout the year for stargazing by individuals.

In honor of Hale's 150th birthday, Mount Wilson Observatory has planned a range of celebrations, beginning in May. Events include a photographic retrospective, a lecture series, a concert series in the 100-inch dome, and weekend open house activities with free nighttime observing (July or August).

Palomar Observatory (https://is.gd/palomar): Observatory grounds are open to the public daily, weather permitting, except December 24–25 and during some maintenance operations. Visitors can tour public areas on their own or participate in one-hour guided tours of the Hale Telescope on weekends, spring through fall. There's a nominal charge for tours, but they're free for youth and student groups. Some areas — including the Hale Telescope dome — are not accessible to mobility-impaired visitors.

UNIVERSITY OF CHICAGO / YERKES OBSERVATORY

1 EARLY MORNING: The waning gibbous Moon poses some 3° left of Saturn above the Teapot in Sagittarius.

3 EARLY MORNING: Look toward the east-southeast to see the Moon and Mars rising a little more than 3° apart.

10 EVENING: Venus and the brightest lights of Gemini form a shiny string of beads as they set toward the west, with Venus blazing on the left, Castor twinkling on the right, and Pollux almost exactly halfway between.

15 DUSK: Mercury emerges from the gloaming as it sets in the northwest. Binoculars will help coax this tiny world out of the glare of the setting Sun. Visibility improves throughout the month.

16 EVENING: Look toward Cancer in the west after sunset to see the thin sliver of the waxing crescent Moon about 8° from dazzling Venus, with the Beehive Cluster (M44) almost exactly halfway between.

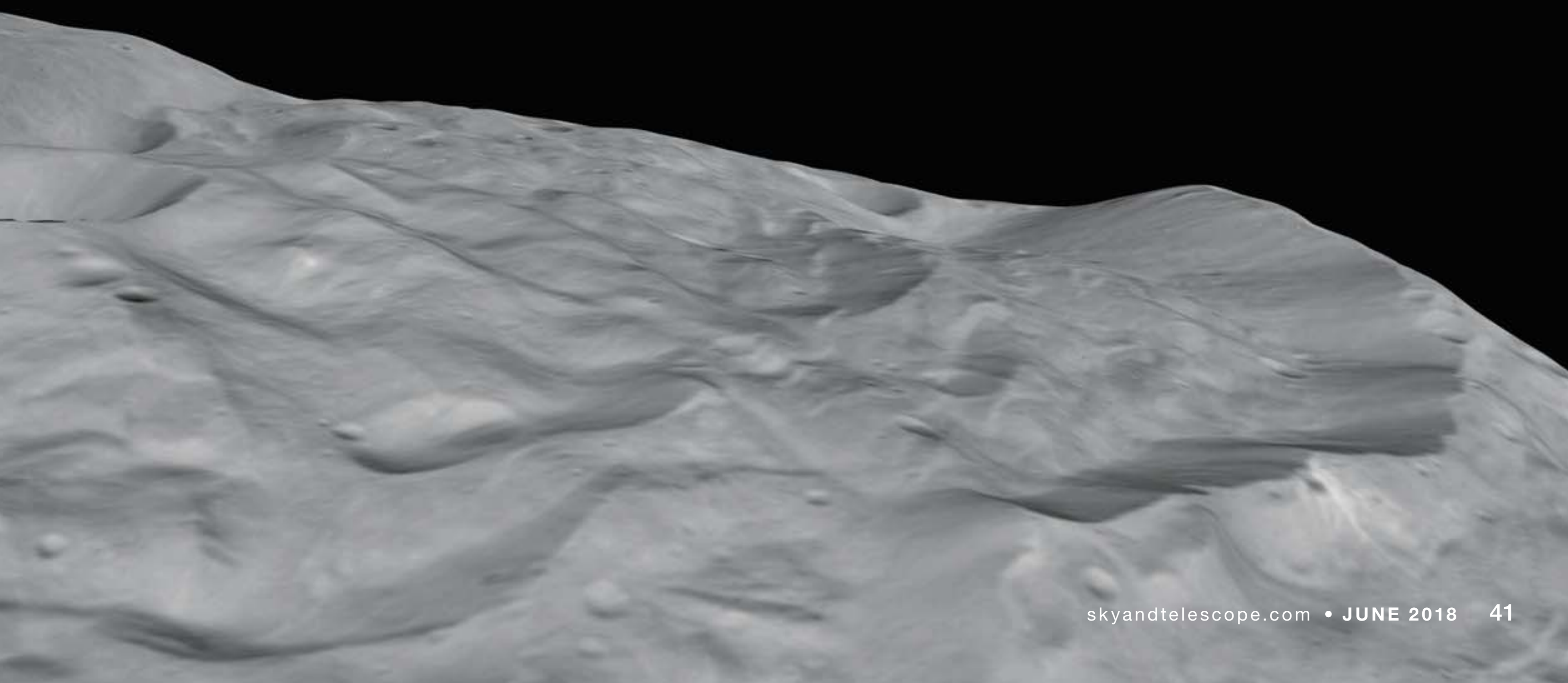
17 DUSK: The Moon leads Regulus by some 3° as they sink together in the west.

19–20 ALL NIGHT: Vesta is at opposition with the Sun and, at magnitude 5.3, visible throughout the night even to the naked eye at dark enough locations; see page 48. To find this minor planet, look just under 1° upper left of the halfway point along a line connecting Lambda (λ) Sagittarii (the top star of the Teapot) and Eta (η) Ophiuchi.

21 THE LONGEST DAY OF THE YEAR in the Northern Hemisphere. Summer begins at the solstice, 10:07 UT (6:07 a.m. EDT).

23 NIGHT: A waxing gibbous Moon and regal Jupiter share the spotlight in Libra, shining some 4½° apart.

27–28 ALL NIGHT: Saturn is at opposition to the Sun; see page 50. The planet, with its rings tilted at almost maximum extent, shines at magnitude +0.0. The full Moon is only about 1° away, but don't let that deter you from trying to spot this glorious planet.



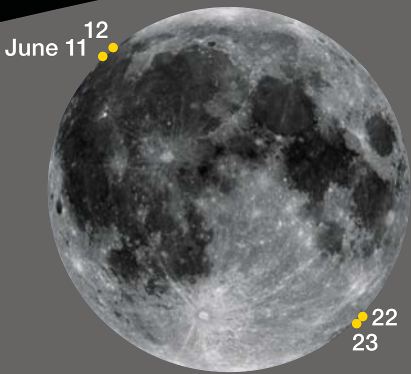
From an altitude of 2,700 km above Vesta's surface, NASA's Dawn spacecraft obtained this image of mountains at the asteroid's south pole that are several kilometers high (see page 48).

NASA / JPL-CALTECH / UCLA / MPS / DLR / IDA

JUNE 2018 OBSERVING

Lunar Almanac

Northern Hemisphere Sky Chart



Yellow dots indicate which part of the Moon's limb is tipped the most toward Earth by libration.

NASA / LRO

MOON PHASES

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

LAST QUARTER
June 6
18:32 UT

NEW MOON
June 13
19:43 UT

FIRST QUARTER
June 20
10:51 UT

FULL MOON
June 28
04:53 UT

DISTANCES

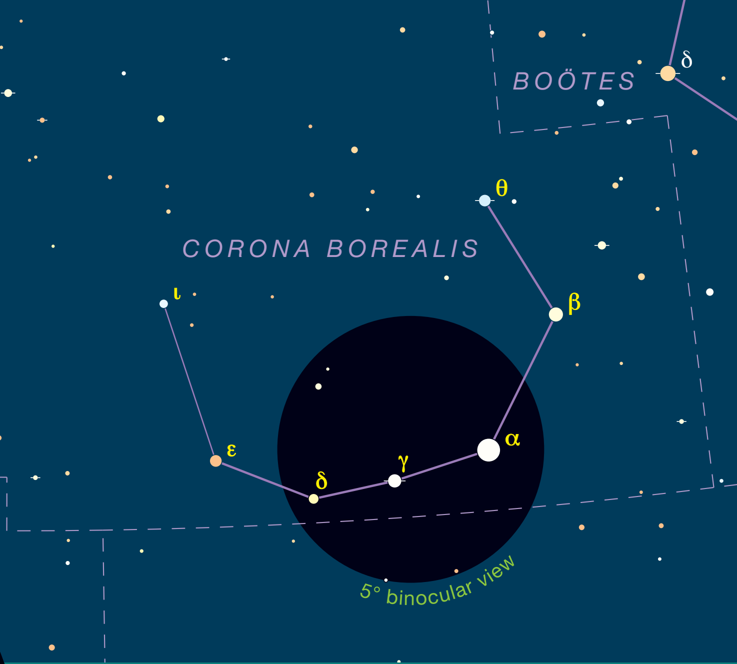
Apogee	June 2, 17^h UT
405,317 km	Diameter 29′ 29″
Perigee	June 15, 00^h UT
359,503 km	Diameter 32′ 14″
Apogee	June 30, 03^h UT
406,061 km	Diameter 29′ 26″

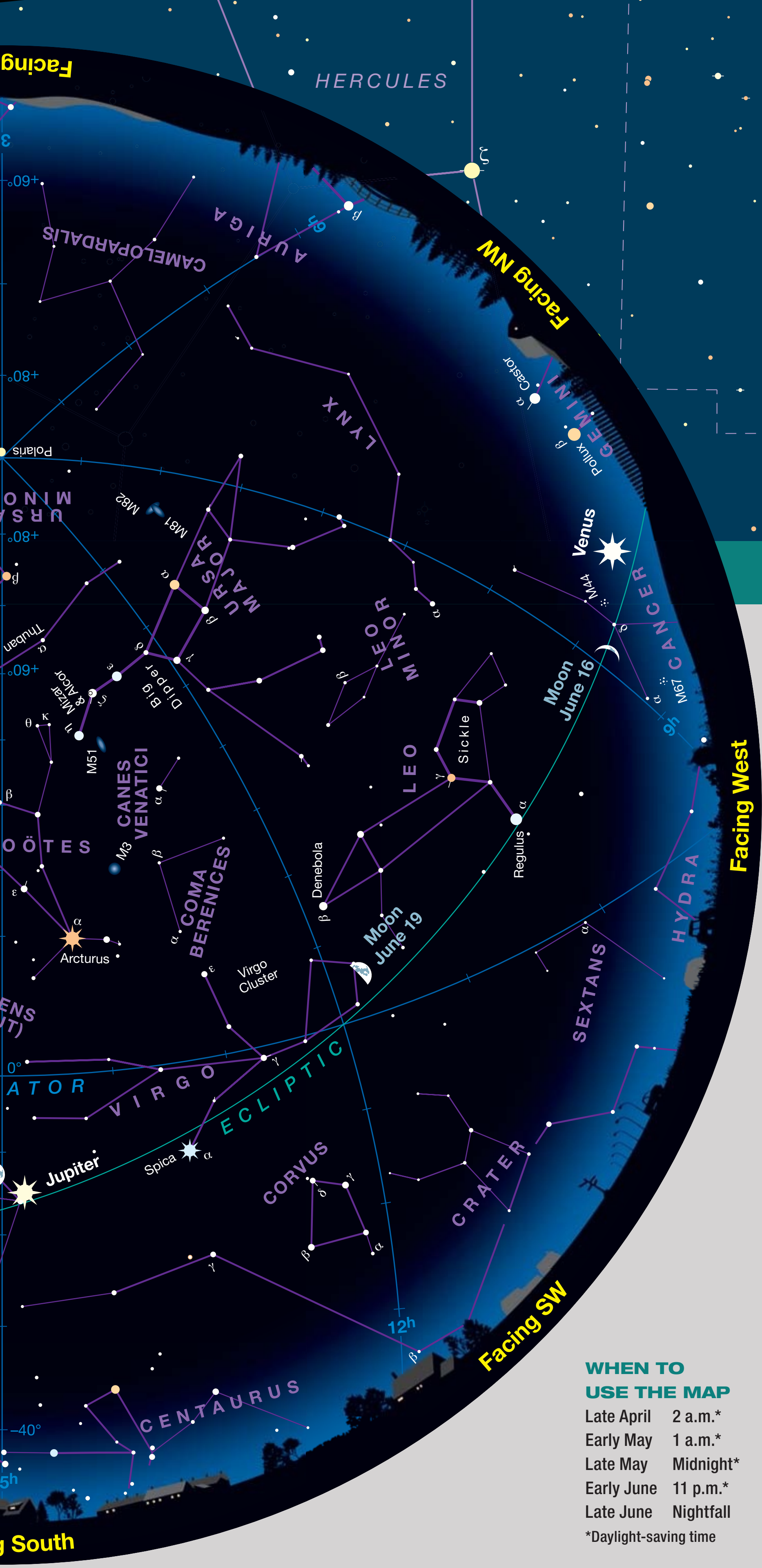
FAVORABLE LIBRATIONS

- Gerard Crater — June 11
- Xenophanes Crater — June 12
- Oken Crater — June 22
- Pontécoulant Crater — June 23

Planet location shown for mid-month

USING THE NORTHERN HEMISPHERE 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. The center of the map is overhead. Ignore the parts of the map above horizons you're not facing.





WHEN TO USE THE MAP

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

*Daylight-saving time

Binocular Highlight by Mathew Wedel

The Northern Crown

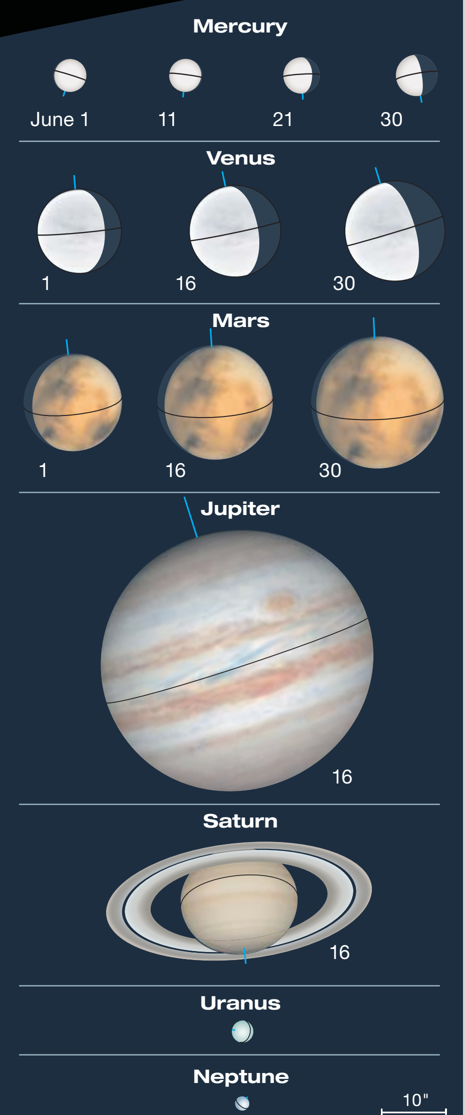
It's easy to fall into the perception that bright stars are nearby and dim stars are distant. That is in fact the assumption that many early astronomers made, before we could accurately measure the distances to the stars. Usually it's not true, though. In most constellations the visual magnitudes are all scrambled up, and distant giants often outshine nearby main sequence stars.

In Corona Borealis, the Northern Crown, the perception that bright equals nearby is mostly accurate: **Alpha (α) Coronae Borealis** is actually the closest, at 75 light-years, and the component stars around each arc are progressively more distant from Earth. On the longer, eastward arc, **Gamma (γ)** lies 146 light-years away, **Delta (δ)** at 170, **Epsilon (ε)** at 221, and **Iota (ι)** at 312. On the short western arc, **Beta (β)** is 112 light-years from us, and **Theta (θ)** is 380. There are a couple of wrinkles: With a visual magnitude of 4.6, Delta is actually slightly dimmer than both Epsilon and Theta, both of which are 4.1. And the great distance to Theta obscures the fact that it is intrinsically much brighter than all the rest. The other stars in the crown shine with luminosities 30 to 90 times that of the Sun, but Theta, a hot, young *B*-type star, shines with the brightness of 245 Suns.

The central crown asterism of Corona Borealis is also a handy ruler for angular measurements. The angular distance from Epsilon to Alpha is almost exactly 5° (5° 07′, to be precise), and the distance from Epsilon to Theta is 7° 00′. A lot of binoculars have true fields of view in that range, so you can use the stars of Corona Borealis to check up on manufacturers' claims, or just to get a feel for what 5° looks like.

■ MATT WEDEL has been too busy observing to think of anything clever to say about himself. Check back next month.

PLANET VISIBILITY: Mercury: visible at dusk after the 15th • **Venus:** visible at dusk • **Mars:** rises late evening, highest before dawn • **Jupiter:** visible at dusk, highest before midnight • **Saturn:** rises early evening, visible until dawn

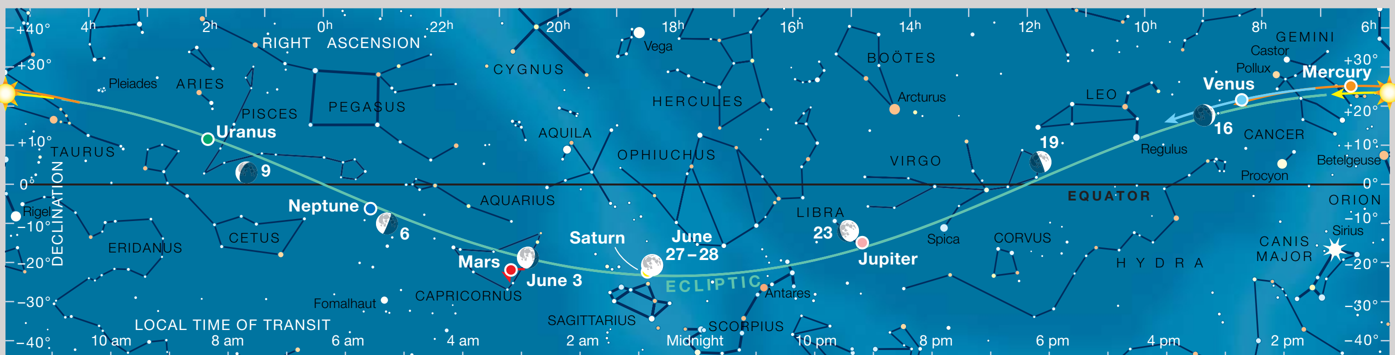


PLANET DISKS have south up, to match the view in many telescopes. Blue ticks indicate the pole currently tilted toward Earth.

June Sun & Planets

	Date	Right Ascension	Declination	Elongation	Magnitude	Diameter	Illumination	Distance
Sun	1	$4^h\ 34.4^m$	+21° 59′	—	–26.8	31′ 33″	—	1.014
	30	$6^h\ 34.5^m$	+23° 12′	—	–26.8	31′ 28″	—	1.017
Mercury	1	$4^h\ 08.1^m$	+20° 49′	6° Mo	–1.7	5.1″	97%	1.305
	11	$5^h\ 41.7^m$	+24° 48′	6° Ev	–1.7	5.2″	97%	1.303
	21	$7^h\ 10.2^m$	+24° 27′	17° Ev	–0.7	5.7″	79%	1.185
	30	$8^h\ 13.9^m$	+21° 23′	23° Ev	–0.2	6.5″	63%	1.040
Venus	1	$7^h\ 04.2^m$	+24° 31′	34° Ev	–3.9	13.1″	80%	1.271
	11	$7^h\ 55.1^m$	+22° 51′	37° Ev	–4.0	13.9″	77%	1.204
	21	$8^h\ 43.8^m$	+20° 11′	39° Ev	–4.0	14.7″	74%	1.134
	30	$9^h\ 25.4^m$	+17° 04′	40° Ev	–4.1	15.6″	70%	1.068
Mars	1	$20^h\ 32.8^m$	–21° 47′	125° Mo	–1.2	15.3″	91%	0.612
	16	$20^h\ 47.0^m$	–21° 57′	136° Mo	–1.7	18.0″	94%	0.521
	30	$20^h\ 50.9^m$	–22° 47′	149° Mo	–2.1	20.7″	96%	0.453
Jupiter	1	$14^h\ 53.0^m$	–15° 16′	155° Ev	–2.5	44.1″	100%	4.468
	30	$14^h\ 44.6^m$	–14° 46′	125° Ev	–2.3	41.5″	99%	4.746
Saturn	1	$18^h\ 32.2^m$	–22° 21′	153° Mo	+0.2	18.2″	100%	9.153
	30	$18^h\ 23.4^m$	–22° 29′	177° Ev	0.0	18.4″	100%	9.050
Uranus	16	$1^h\ 57.1^m$	+11° 24′	53° Mo	+5.9	3.4″	100%	20.474
Neptune	16	$23^h\ 10.8^m$	–6° 19′	98° Mo	+7.9	2.3″	100%	29.778

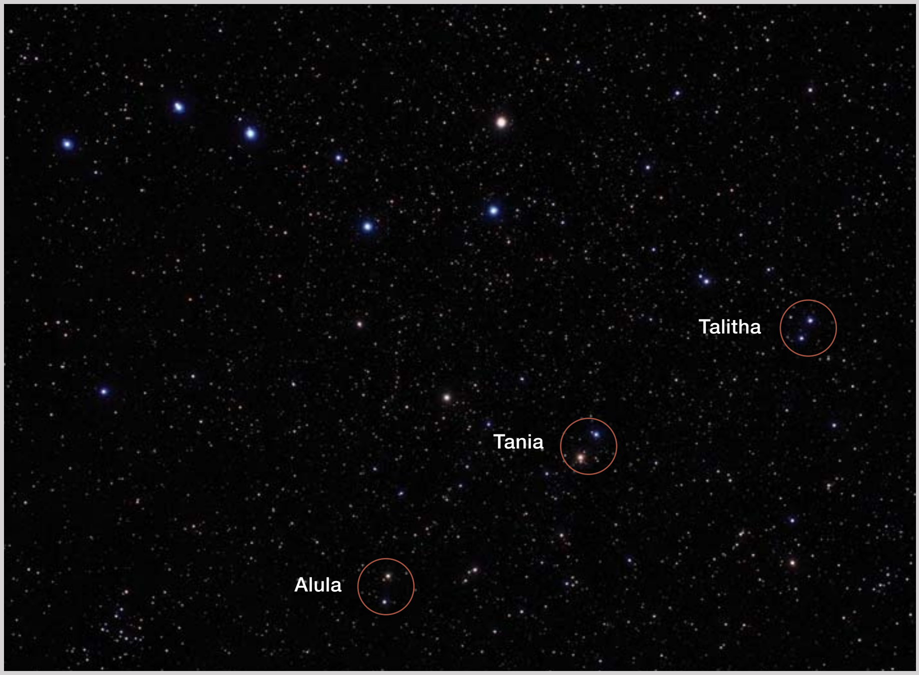
The table above gives each object's right ascension and declination (equinox 2000.0) at 0^h Universal Time on selected dates, and its elongation from the Sun in the morning (Mo) or evening (Ev) sky. Next are the visual magnitude and equatorial diameter. (Saturn's ring extent is 2.27 times its equatorial 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.



The Sun and planets are positioned for mid-June; the colored arrows show the motion of each during the month. The Moon is plotted for evening dates in the Americas when it's waxing (right side illuminated) or full, and for morning dates when it's waning (left side). "Local time of transit" tells when (in Local Mean Time) objects cross the meridian — that is, when they appear due south and at their highest — at mid-month. Transits occur an hour later on the 1st, and an hour earlier at month's end.

Leap With A Gazelle

This asterism is all about pairs of stars, and pairs within pairs.



One of the less famous asterisms of spring is nevertheless one of my favorites. Therefore, I'm going to devote this entire column to this single asterism whose name is derived from medieval Arabic lore: the "Three Leaps of the Gazelle."

Taking the three leaps of the gazelle. Between the Big Dipper and Leo shines a line of stars composed of three naked-eye pairs of similarly bright stars that belong to Ursa Major. Originally imagined as six gazelle footprints, the pairs are now often depicted as the three visible paws of the Great Bear (the fourth paw is hidden behind one of the other ones in drawings of Ursa Major).

The overhead leaps. The three stellar pairs are located at declinations of about +47°, +42°, and +32°, and thus a pair passes exactly or nearly overhead as seen from anywhere in the 48 contiguous states of the U.S. The doubles are at right ascensions of about 9^h, $10^h\ 20^m$, and $11^h\ 18^m$. From northwest to southeast, from front of the Great Bear to the back, the three pairs are Iota (ι) and Kappa (κ) Ursae Majoris (magnitudes 3.1 and 3.6); Lambda (λ) and Mu (μ) Ursae Majoris (magnitudes 3.5 and 3.1); and Nu (ν) and Xi (ξ) Ursae Majoris (magnitudes 3.5 and 3.8).

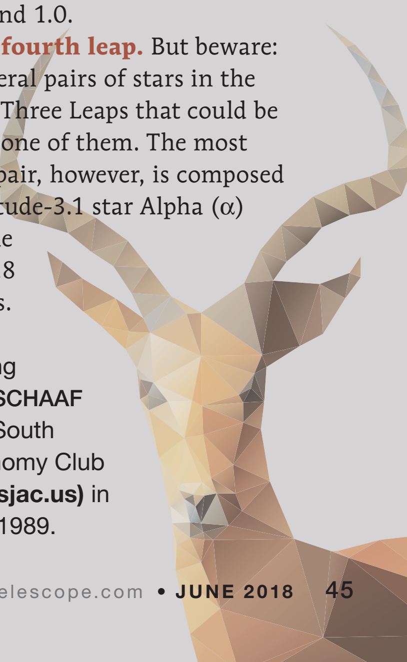
But the Arabs saw the leaps of the gazelle going the other direction, southeast to northwest: thus Nu and Xi Ursae Majoris are the footprints of the first leap. *Alula* means "first leap" or "first spring" in Arabic and hence these two stars are commonly called Alula Borealis and Alula Australis (the northern Alula and the southern Alula). *Tania* means "second," and so Lambda and Mu are known as Tania Borealis and Tania Australis, respectively. *Talitha* means "third" — however, only one of the two stars of the third leap, the northern star, Iota Ursae Majoris, gets called this, but without the "borealis" addition: It's just Talitha.

There doesn't seem to be an accepted proper name for Kappa Ursae Majoris. But Iota gained an additional name that was used quite a bit in recent decades: the strange-looking "Dnoces." This was later revealed as a new name coined by Gus Grissom for one of several navigational stars to be used on the fateful Apollo 1 mission. Dnoces is for America's first spacewalker, Edward H. White II: "Dnoces" is "second" spelled backwards. It's ironic that a star named "second" backwards is one already called Talitha, or "third."

Contrasts of the leap stars. The considerable contrasts in true nature between the members of each of the three pairs is fascinating because the stars in each pair are separated by only about 1–2° in the sky. A beautiful visual juxtaposition are the colors of Tania Borealis and Tania Australis, the former being an *A2* white or blue-white star, the latter an *M0* red (or very orange-gold) star.

Alula Borealis is about 400 light-years distant while Alula Australis is only around 26 light-years away. And Alula Australis is one of the most interesting double stars in the sky. The first double star whose orbit was determined, it has a period just shy of 60 years. Its two main components, Xi Ursae Majoris A and B, shine at magnitudes 4.4 and 4.9. They're currently about 2″ apart and separating rapidly. Xi UMa A and Xi UMa B (the two brightest lights in what turns out to be at least a five-star system) are also marvelously Sun-like, belonging to spectral classes G0 and G5, respectively. Xi UMa A has a luminosity, radius, and mass calculated to be 1.1, 1.0, and 1.0 that of the Sun, while the corresponding numbers for Xi UMa B are 0.7, 0.9, and 1.0.

The false fourth leap. But beware: There are several pairs of stars in the region of the Three Leaps that could be mistaken for one of them. The most outstanding pair, however, is composed of the magnitude-3.1 star Alpha (α) Lyncis and the magnitude-3.8 star 38 Lyncis.



■ Contributing Editor **FRED SCHAAF** founded the South Jersey Astronomy Club **(http://www.sjac.us)** in the spring of 1989.

AKIRA FUJII; GAZELLE: BLUELELA / GETTY IMAGES

To find out what's visible in the sky from your location, go to skypub.com/almanac.

Planets Aplenty

The planets are out in full force this month, and they are joined by an asteroid.

Saturn is at opposition, visible virtually all night long this month, as is the asteroid Vesta, shining slightly brighter than it has in decades. Venus is at its highest this year for mid-northern latitude observers after sunset. Mercury is much lower than Venus but still relatively high in evening twilight by month's end. Jupiter is visible almost all night long and still near its brightest. Mars, just one month away from perihelic opposition, rises in the late evening and flames up by a whole magnitude to rival Jupiter's brightness by the end of June.

DUSK AND EVENING

Venus attains its highest sunset altitude of the year on June 6th at almost 28° for observers around latitude 40° north. The planet starts the month setting more than 2½ hours after the Sun, but the interval is some 15 minutes shorter before the month is over.

Venus brightens from magnitude –3.9 to –4.1 in June. Its apparent diameter increases from about 13″ to more than 15″, and its phase decreases from 80% to 70%. The bright lights of Gemini, the stars Castor and Pollux, twinkle above Venus as twilight deepens. Venus is about 5° lower left of Pollux on June 5–9. On the American evenings of June 19th and 20th, Venus is on the outskirts of M44, the Beehive Star Cluster in Cancer.

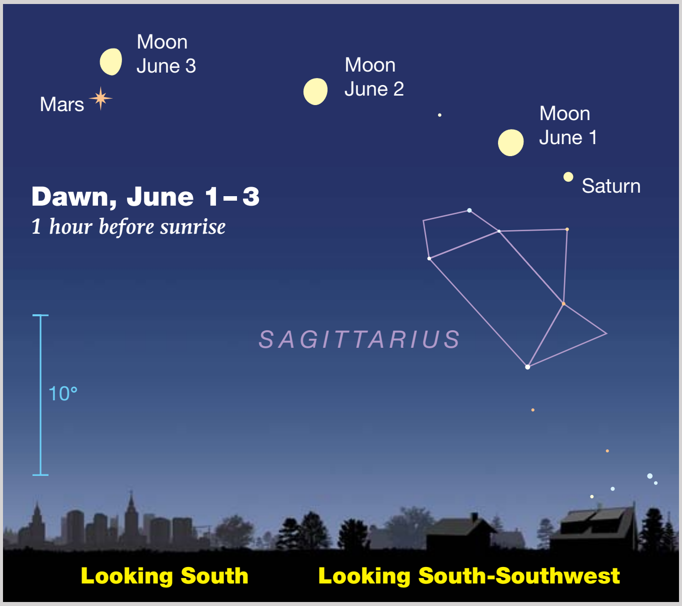
Mercury is at superior conjunction with the Sun on the night of June 5–6 but emerges into visibility low in the dusk by mid-month. By month's end Mercury sets 1½ hours after the Sun, dimming to a little brighter than 0.1 magnitude. It also grows to 6½″ wide and thins to less than ⅔ lit. Greatest elongation will occur on July 12th.

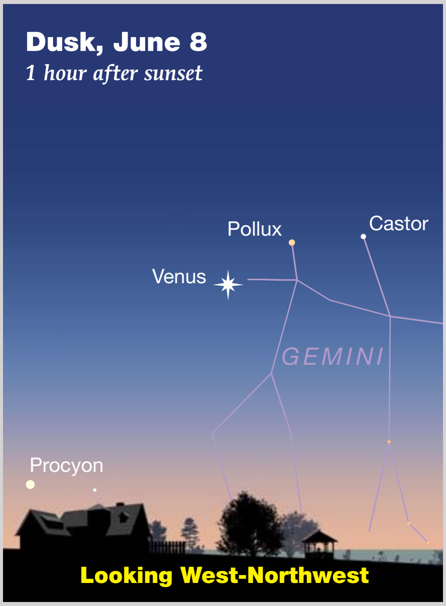
DUSK TO DAWN

Jupiter is already visible in the southeast at nightfall during June and is highest around 11 p.m. local time as the month begins and 9 p.m. as it ends. The giant planet dims from magnitude –2.5 to –2.3 during June, and its angular diameter decreases from 44″ to 41½″. But this is still prime observing season for Jupiter (see pages 50–51 for details about viewing the Galilean moons and the Great Red Spot). The huge world continues to drift westward relative to the stars of Libra in June.

ALL NIGHT

Saturn comes to opposition on June 27th, only half a day before the full Moon poses around 1° upper left of Saturn. Saturn brightens from magnitude +0.2 to +0.0 in June. Its globe is a little more than 18″ across. The glorious rings span a distance about 2½ times greater than the globe and are tilted 25.7° to our line of sight, almost the maximum possible. This month is the best for trying to see special Saturnian





▶ 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.

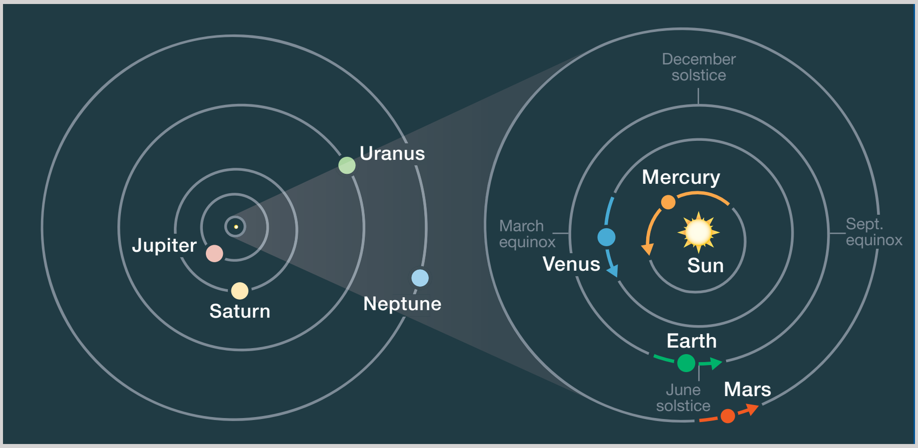
wonders, such as one of the planet's dusky polar caps or the narrow Encke Gap in the A ring out beyond the wide Cassini Division. The only problem with these observations for viewers at mid-northern latitudes is the lowness of Saturn in the southern sky. The planet still floats just above the Teapot of Sagittarius.

Asteroid 4 **Vesta** reaches opposition on June 19th and is not just visible all night long but is plainly visible with the naked eye at a reasonably dark location. This brightest of the asteroids reaches a peak magnitude of 5.3 this month, slightly brighter than it has been in decades or will be again until 2031. See page 48 for a finder chart and discussion.

EVENING UNTIL DAWN

Mars starts June less than two months away from its closest approach to Earth since 2003. How thrilling it is to see Mars brighten from magnitude –1.2 to –2.2 and swell from 15″ to more than 20″ wide in this one month. See the upcoming July issue for information on when and where to look for specific Martian surface and atmospheric features.

Mars rises around midnight as June begins and around 10:30 p.m. as the month ends. But the planet slows its eastward motion in Capricornus and then on June 28th halts and begins westward (retrograde) motion.



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

DAWN

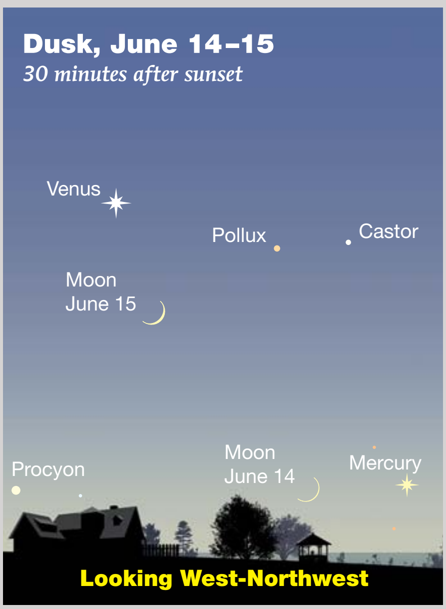
Neptune and **Uranus** get high enough to observe by morning twilight (see **https://is.gd/urnep** for a finder chart for these outer giants).

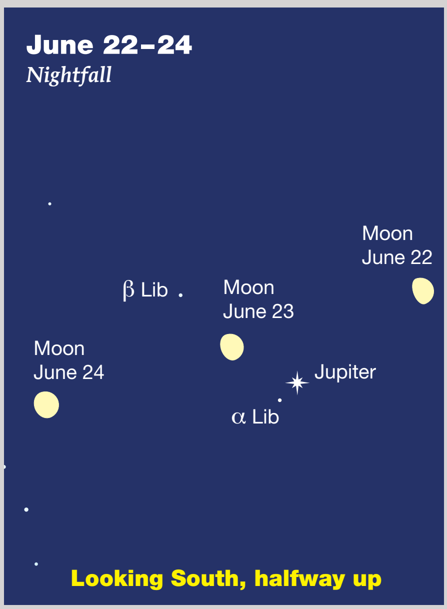
SUN AND MOON

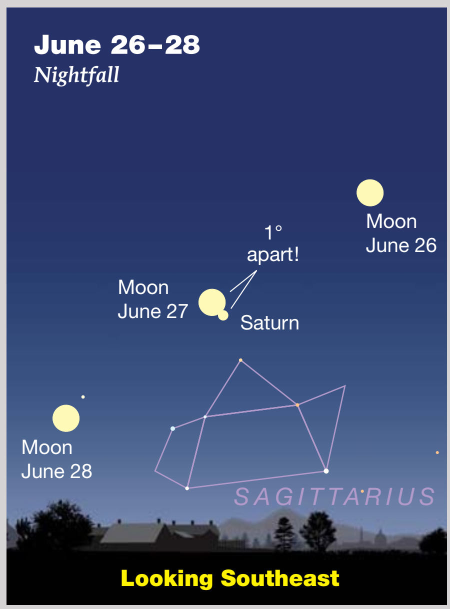
The Sun reaches the June solstice at 6:07 a.m. EDT on June 21st, starting summer in the Northern Hemisphere and winter in the Southern Hemisphere.

The waning gibbous **Moon** is a little more than 3½° left or upper left of Saturn at dawn on June 1st and 2½° above Mars at dawn on June 3rd. The very thin waxing lunar crescent is almost 8° to the left of Mercury, very low in the west-northwest a mere half-hour after sunset on June 14th. Bring binoculars to see Mercury in conjunction with the Moon. The next two evenings the crescent Moon is 7½° lower right of Venus and then again 7½° upper left of Venus. The waxing gibbous Moon is less than 5° upper left of Jupiter at nightfall on June 23rd. The almost-full Moon is only about 1° from Saturn at nightfall on June 27th. On the final American evening of June, Mars and the waning gibbous moon rise about 4½° apart.

■ **FRED SCHAAF** enjoyed an awesome, ultra-close conjunction of Mars and Saturn 40 years ago this month.







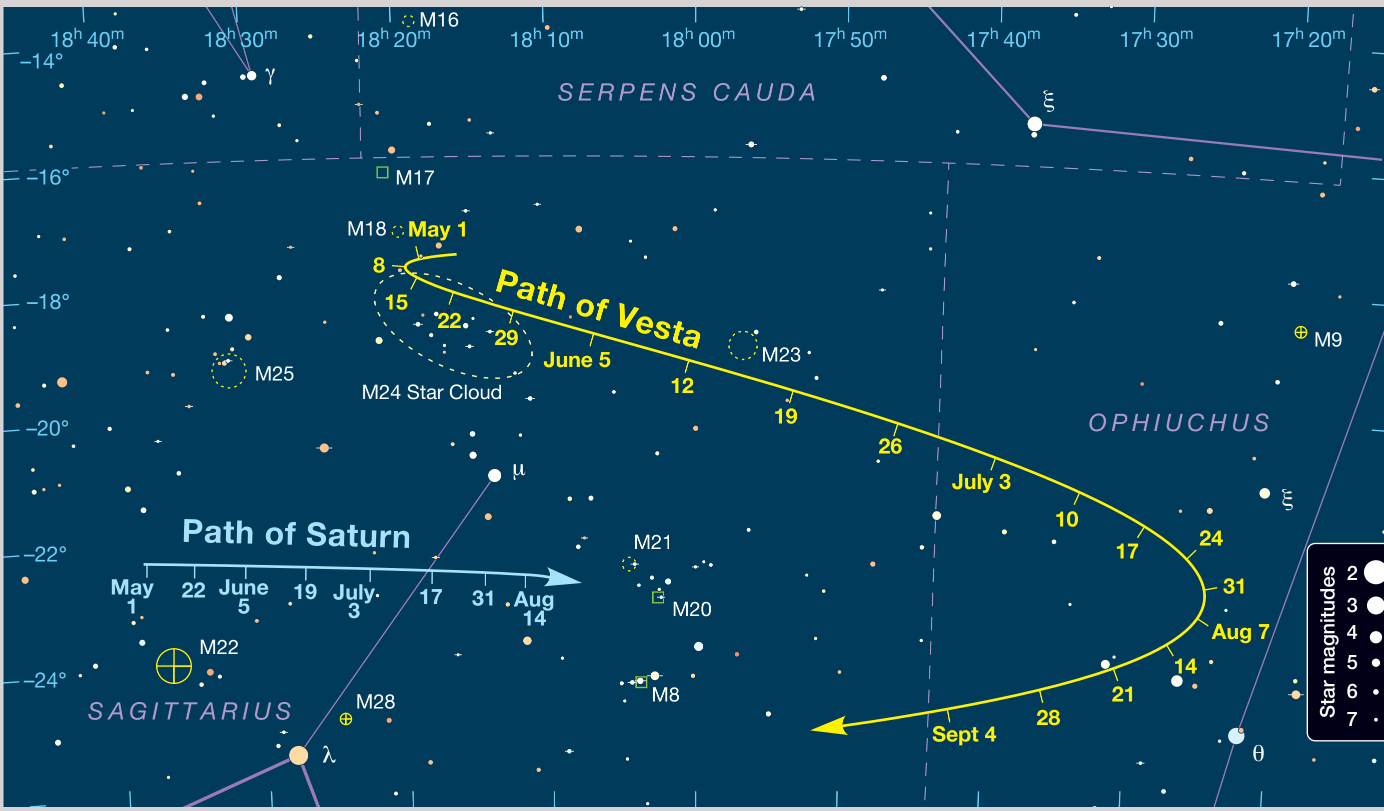
Vesta at Its Best

Asteroid 4 Vesta is closest this month, a lustrous light in the southern sky.

Vesta, the fourth-discovered asteroid, reaches opposition (opposite the Sun in the sky when viewed from Earth) on June 19th. Though neither the largest nor the most massive of the main belt asteroids, Vesta's the brightest of them all at opposition. This year No. 4 shines in Sagittarius at magnitude 5.3 and will be visible without optical aid under reasonably dark skies. It's a bit dimmer the rest of the month, ranging from magnitude 5.6 to 5.8, but still within reach of the naked eye under good skies. It's worth tracking during May and July as well, when it will be an easy binocular object.

There's something intrinsically interesting about observing asteroids — they're giant space rocks, after all — but the success of NASA's Dawn mission turned Vesta into a particularly compelling target. While the Hubble Space Telescope resolved some of its largest surface features in the 1990s, it wasn't until the Dawn spacecraft dropped in on Vesta in 2011 that scientists were able to study the asteroid in detail. Vesta's almost, but not quite, spherical; it's missing a good chunk out of its south pole. It's also differentiated, meaning it has a crust, a mantle, and a core, like Earth. This layering was predicted by spectral analyses pre-dating the Dawn mission, as well as by studies of meteorites thought to have originated

▼ Vesta's position is marked with a tick at 0^h UT every seven days. For North America, this time falls in the early evening (or late afternoon) of the previous date.



VESTA: NASA / JPL-CALTECH / UCLA / MPS / DLR / IDA

◀ Vesta's south pole, bottom, saw extensive damage during an impact event about 1 billion years ago. The tremendous troughs at the asteroid's equatorial region, which may have been caused by faulting from the impact, are about 10 kilometers across.

on Vesta (see sidebar at right), but spacecraft data helped confirm these theories. Vesta, mostly intact, fully differentiated, is unique among asteroids. That we can see it by simply looking up at the right part of the sky is neat, to say the least.

Where to Find It

Vesta's in a busy part of the sky this month, traveling through northwest Sagittarius, not too far north and then northwest of Mu (μ) Sgr. Zero-magnitude Saturn hangs out a few degrees below Mu, serving as a clear directional beacon. Vesta's a little, but not much, higher in the south than the ringed planet, and neither is ideally positioned for observers at mid-northern latitudes. This is the time to seek out those open southern horizons at your local star party.

In mid-May, Vesta doesn't clear the horizon until about an hour before midnight. It stands highest when it culminates around 4 a.m., reaching around 32°, so plan on some late nights or very early mornings. Observing (sleeping) conditions get a bit easier as Vesta approaches opposition. On June 19th, it rises a bit before sunset and stands about 21° high by the arrival of true darkness, about 10:30 p.m. local time. It's at 30°, its highest for the night, an hour after midnight. It drops lower as the morning ages, setting just as the Sun rises.

Sorting Vesta from its celestial neighbors might take time and will certainly be easier with optical aid, even when it's at its brightest. It will appear stellar in binoculars and small telescopes; very large apertures, say 10–12 inches or more, may show hints of the irregular disk. Vesta sports an angular diameter of 0.69″ for most of June, but seeing and transparency will affect the view, especially when the target is close to the horizon. Even if you can't resolve the disk, high-aperture observing can offer its rewards: Many observers report seeing color in Vesta through large scopes at high power. Descriptions range from pale yellow to pinkish rose.

Meet the Neighbors

Around the time of new Moon in mid-May, Vesta is 1° from the open cluster M18, drawing nearer to the M24 Star Cloud each night. There are plenty of stars in the area to complicate ID attempts, particularly as Vesta edges past M24 between May 15th and 29th (full Moon). But keep in mind Vesta's one of the brighter objects in the area. About 40′ southwest of M18, a *K*2 orange dwarf star (HD 167720) shines at magnitude 5.8. The brightest star in M24 is HD 167356, a 6th-magnitude peculiar *A* star. So Vesta has plenty of stellar company, but not much competition in terms of brightness.

In the week before opposition, look for Vesta in the vicinity of the broad open cluster M23. By the end of June and the next full Moon, Vesta will have crossed into the southern reaches of Ophiuchus. It remains a naked-eye object in the opening nights of July.

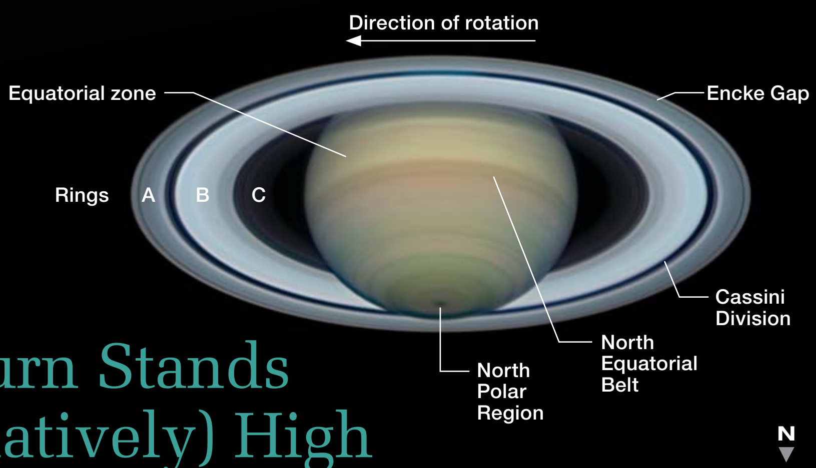
NASA / UNIVERSITY OF TENNESSEE

Ancient Asteroid Bits

The arrival of NASA's Dawn spacecraft at Vesta revealed intensive scarring on the asteroid's surface. Vesta's not-quite-spheroid shape is the result of a massive impact event about 1 billion years ago. The collision produced an approximately 500-km-wide crater, now named Rheasilvia, at Vesta's south pole. About 1% of Vesta's volume was displaced, with ejecta deposited in a 100-km ring around the impact basin and ½ million cubic miles of material sent into space.

About 5% of all meteorites we find on Earth come from the Rheasilvian impact. The mineralogy of Howardite-Eucrite-Diogenite (HED) meteorites, which resemble terrestrial igneous rocks, places them in this group. HED meteorites were first connected with Vesta in the 1970s, when scientists noted their infrared and visible spectra were similar to the asteroid's.

The image above shows three slices of HED meteorites as viewed through a polarizing microscope. The slices share a common mineralogy, but their dissimilar textures indicate that they originated in different parts of Vesta's crust and surface and crystallized at different rates. The slice on the left comes from a meteorite named QUE 97053, which was recovered from the Queen Alexandra Range of Antarctica. QUE 97053 is basaltic eucrite that formed in volcanic flows on the surface of Vesta some 4.4–4.5 billion years ago. The center slice comes from a cumulate eucrite that fell in Moore County, North Carolina, in 1913. Cumulate eucrites are similar to basaltic eucrites, but have oriented crystals. They're thought to have formed in the upper plutons of Vesta's crust rather than in surface flows. The slice on the right comes from a diogenite meteorite named GRA 98108, recovered from Graves Nunatak, Antarctica. Diogenites, which formed in magma chambers deep in Vesta's crust, are composed mostly of orthopyroxene and hypersthene, with smaller amounts of olivine, plagioclase, troilite, and chromite.



Saturn Stands (Relatively) High

SATURN ARRIVES AT OPPOSITION on June 27th, very close to the time of full Moon. On the night of June 27–28, the Moon and Saturn will only be about 1° apart. It's a pleasant scene, but to get the best binocular or telescopic view of the ringed planet, make plans to observe on the nights (weeks!) before and after opposition.

Last quarter Moon falls on June 6th, when Saturn rises about 1¼ hours after the Sun sets. By the end of twilight, Saturn's still low, only about 7° above the southeastern horizon. And that's the trouble for observers at northerly latitudes: Saturn stays low in the south. Shining just above the Sagittarius Teapot, Saturn's at declination –22°, about ½° farther south than it was at opposition last year. This southern creep continues until 2021, when the declination will begin to improve for northern observers.

On the night of June 6–7, Saturn eventually climbs to about 27° high, transiting about 2:30 a.m. local time. The sky starts brightening with morning twilight about an hour later, but that's still a sizeable window for some good looks. At new Moon on June 13th, Saturn is more than 10° high by the time full darkness falls, and about 27° high at 2 a.m. when the planet transits.

Saturn subtly brightens over the course of the month, reaching magnitude +0.0 by the 23rd. It dims again to +0.2 by the end of July, but that still makes for a bright light in the night sky.

▲ Saturn's rings were tilted 26.5° from our line of sight when Damian Peach captured this image with the 106-cm f/17 Cassegrain at Pic du Midi Observatory on June 11, 2017. Notice that Saturn's south pole was entirely occluded by the nearly wide-open rings. South is up.

Saturn's equatorial diameter shrinks ever so slightly during the same period, but we're talking a change of around one quarter of an arcsecond — it's essentially 18″ for all of June and July.

Radiant Rings

You won't notice much of a change in the tilt of Saturn's rings, either. They'll be open to 25.7° for June and 26.1° for July. That's not quite the maximum 27°, but still an almost ideal view. Small scopes will show the rings and in steady seeing can reveal the Cassini Division, the dark gap between the A and the brighter B ring. The ghostly C ring can be difficult to see even in images. Start searching at the points where the ring crosses the globe, then follow it across the face of the planet (if you can).

If you observe several days in a row, you might notice that the rings appear brighter around the date of opposition. This phenomenon is attributed to the *Seeliger effect* (sometimes called an *opposition surge*). Because the Sun is behind us, the shadows of the ice and dust particles that make up the rings are hidden. Sunlight hits the rings straight on, and the back-scattered light pumps up the brightness from our vantage point in the solar system.

Action at Jupiter

JUPITER IS NOW PAST opposition but is still visible in Libra for most of the night. It rises well before sunset, so it's already approaching its highest point by the end of twilight. It's about 35° high when it transits well before midnight on June 1st. By the 30th, it culminates about 40 minutes after sunset and sets about 2:30 a.m. local time. The observation window is shortening, but there's still about 4 hours of deep dark for Jupiter spotting at the end of the month.

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

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

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

DAMIAN PEACH / E. KRAAIKAMP / F. COLAS / M. DELCROIX / R. HUESO / G. THERIN / S. SPRINAU / S2P / IMCCE / OMP

These times assume that the spot will be centered at System II longitude 290°. If the Red Spot has moved elsewhere, it will transit 1⅔ minutes earlier for each degree less than 290° and 1⅔ minutes later for each degree more than 290°.

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.

The table below lists all the interactions of Jupiter with its satellites and their shadows for June. Scan for events when Jupiter will be visible in the evening for your time zone.

Phenomena of Jupiter's Moons, June 2018

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

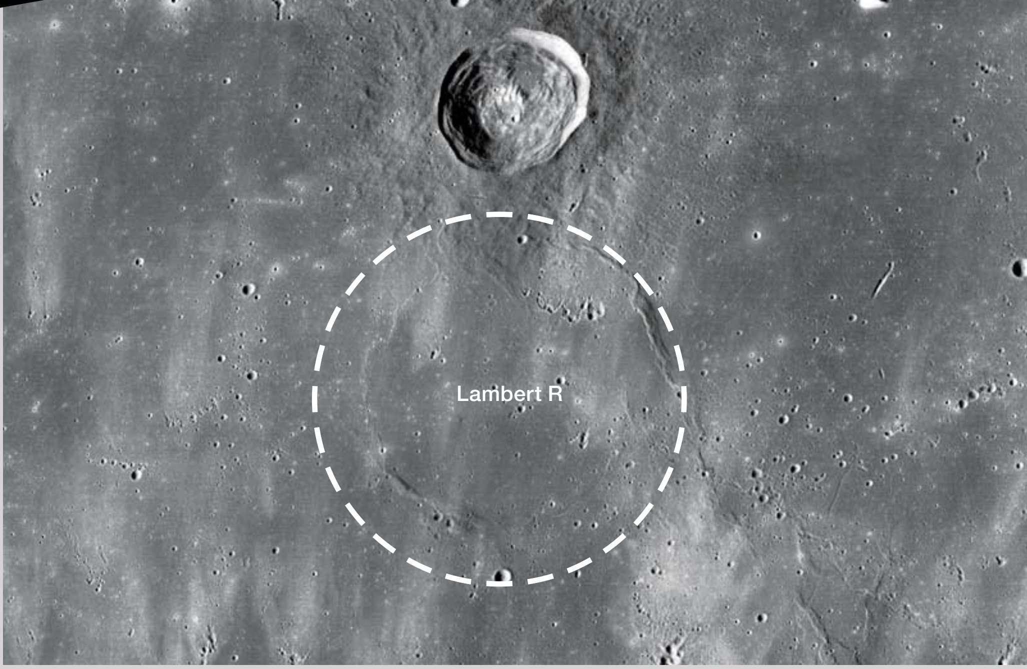
Every day, interesting events happen between Jupiter's satellites and the planet's disk or shadow. The first columns give the date and mid-time of the event, in Universal Time (which is 4 hours ahead of Eastern Daylight Time). Next is the satellite involved: **I** for Io, **II** Europa, **III** Ganymede,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

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.

Submarine Craters

Gravitational anomalies shed light on buried craters.



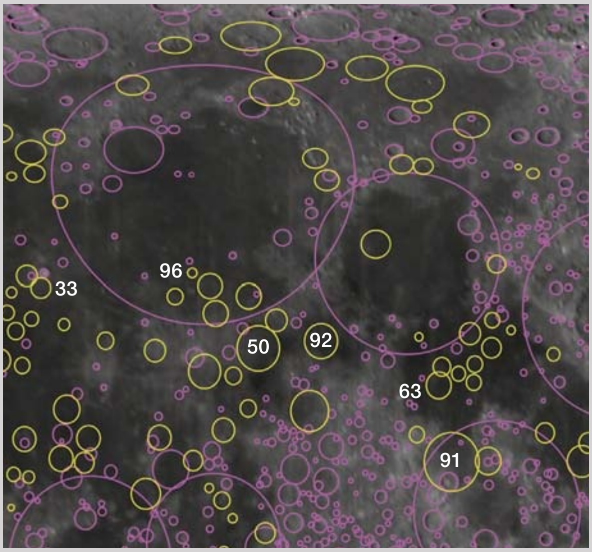
▲ Buried craters, including Lambert R, seen just south of Lambert, create gravitational anomalies picked up by NASA's GRAIL spacecraft.

Maria are the most conspicuous large features on the Moon. They have smooth surfaces, dark hues, and a general paucity of superposed impact craters. Most maria lavas erupted between about 3.8 and 2.5 billion years ago, lying within large impact basins whose rims are best seen at the curved **Apennine** and **Altai** mountain ranges. The ages of formation of the basins themselves are poorly known, but all are from earlier than about 3.8 billion years ago. The interval between basin excavation and the last lava flows in them is as much as 1.5 billion years. During that time, numerous impact craters must have formed on the basin floors and on the various individual flows of lavas that accumulated to form the maria we see today. Craters on top of the last flows are easy to spot, as their rays and other ejecta cross the maria; **Copernicus**, **Aristillus**, and **Kepler** are prominent examples. Other mare craters, such as **Lansberg**, **Eratosthenes**, and **Archimedes,** formed earlier than the last lava flows that covered their ejecta.

Additional craters have been almost completely buried by lavas, leaving just traces of their circular rims. A well-known example is 56-km-wide **Lambert R** (R for ruin) just south of Lambert in southern Mare Imbrium. Other such ghost craters occur in southern Oceanus Procellarum and elsewhere, and one just south of Plato has its own informal name: Ancient Newton. Some craters must have also formed on basin floors and early mare lavas but since then were completely submerged by lavas and are no longer detectable. That is, until now.

Alexander Evans, formerly at the Massachusetts Institute of Technology and colleagues have processed the extraordinary high-resolution measurements of lunar gravity obtained by NASA's Gravity Recovery and Interior Laboratory spacecraft (GRAIL) and discovered 104 circular gravity anomalies with no surface expressions. These features, which Evans and colleagues call Quasi-Circular Mass Anomalies (QCMA), occur within and near maria, and are interpreted as being due to craters that formed on an earlier surface of an impact basin that mare lavas later completely inundated. Their map shows locations of QCMAs in yellow and visible craters in pink.

Surprisingly, QCMAs have both mass excesses and deficiencies. The explanation of these differences relies upon the fact that the highlands crust excavated by basins has a relatively low density of 2.4 grams per cubic centimeter, whereas the density of lava flows that erupt onto basin floors is 3.2 g/cc. If a buried crater is filled by a lot of lava, it's likely to have a mass excess, and if

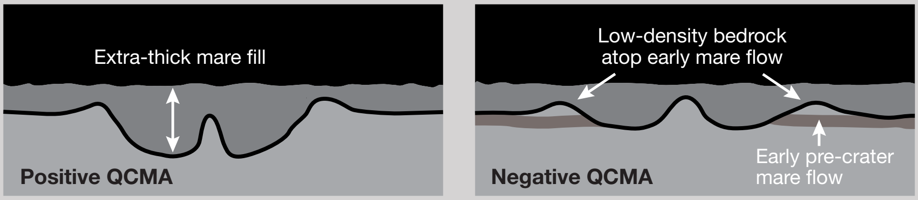


▶ This map of circular gravitational anomalies highlights visible craters in pink, while those with no visible surface features appear in yellow. The numbered regions are known buried craters that can be observed when sunlight strikes the area at a low angle.

LAMBERT R: NASA / GSFC / ARIZONA STATE UNIVERSITY; ANOMALIES: NASA / GRAIL / EVANS it has more highlands material, a mass deficiency. Consider a large, complex impact crater with terraced walls and an uplifted central peak that formed on the original floor of a basin. It would have excavated relatively low-density highlands material. Assume that late mare lavas surround a crater, overflow its rim and flood the floor, and continue to rise until completely submerging the crater rim. The thickness of the lava is greater inside the crater than outside because craters excavate material from below their surroundings. For example, the floor of a typical 100 km-wide crater extends about 3 km below the surrounding terrain. GRAIL measurements over the center of such a crater will show a positive gravity anomaly (more mass) compared to outside the crater due to a 3-km-thicker pile of high-density mare lavas inside. So QCMAs with positive anomalies are mostly large and probably formed on the original basin highlands floor.

Evans's group explains QCMAs with negative gravity anomalies as marking craters that formed into early mare lava flows, excavating through the lavas into the underlying lower-density highlands material. During the modification stage of crater formation, the uplift of the central peak and surrounding floor would create a crater infill of low-density highlands rocks fractured by the impact event. If this low-density floor material rose to the level of the surrounding pre-lava terrain, the thickness of subsequent lava fill inside the crater would be the same as outside and there would be no gravity anomaly or, if the highlands material rose higher, a negative one. Projectiles that impacted into thick mare deposits may not intersect the low-density highlands deposits at all and therefore not generate any gravity anomaly — these stealth-buried craters would be totally undetectable.

We can identify a few of the yellow circles on the QCMA map with known features. Number 63, in western Mare Tranquillitatis, is **Lamont**, a small dual-ring impact basin. Immediately to the south is larger QCMA #91 that underlies **Sinus Asperitatis**, a previously recognized buried crater or basin. And south of the Imbrium Basin rim are two other named features: #50 is **Sinus Aestuum** and #92 is **Mare Vaporum**, both thought to be small impact basins. All of these small basins have positive gravity anomalies, implying that they formed before lavas erupted in their areas. One final identified small feature is Lambert R (#96), which has a negative anomaly, meaning that it formed after lavas had erupted in its vicinity. That is quite likely considering that bits of its rim emerge above the surrounding Mare Imbrium lavas.

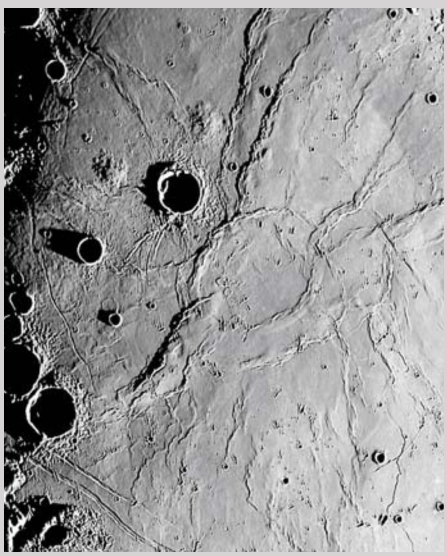


▲ Quasi-Circular Mass Anomalies (QCMAs) are categorized into two groups. Positive QCMAs (left) contain higher mass than their surroundings, which is thought to be due to mare lava flooding a crater that excavated deep into the underlying terrain. Negative QCMAs have a mass deficiency compared to their surroundings, implying a buried crater that formed in the low-mass early lunar highlands material.

Notice that there is only one QCMA within each of the impact basins Crisium, Nectaris, Humorum, Serenitatis, and the inner part of Imbrium. For all of these except Nectaris, the lavas are possibly so thick that submerged craters are totally encased in mare lavas and generate no anomalies.

It's surprising that large QCMAs occur in Mare Frigoris and Oceanus Procellarum where no underlying impact basins are thought to exist, and thus the mare thickness might be less than needed to completely cover crater rims. These are mostly negative gravity anomalies, but I would have thought that their large diameters and shallow Procellarum lavas would have caused most of the impacting projectiles to excavate into the underlying highlands materials. Perhaps Procellarum lavas are thicker than I imagine.

The detection of QCMAs is exactly what would be expected, and like most good discoveries raises more questions for investigation. Let me encourage you to observe a sequence of craters formed on and at different depths below the present mare surface. Start with **Copernicus**, which sits atop the latest lavas, then look at nearby **Eratosthenes** and **Archimedes**, whose ejecta are covered by lava flows. Next, search out Lambert R when the Sun illumination is low to see peaks of a rim that barely rise above the mare surface. And then look for a few of the submarine craters shown on the map. Number 33, which is just south of Aristarchus, is hinted at by low mare ridges. Further north, look for the big QCMAs in Mare Frigoris that seem to have no correlation with mare ridges at all.



▶ The crater Lamont is a completely buried impact basin that appears as a shallow system of circular ridges.

■ Contributing Editor **CHARLES WOOD** chairs the Lunar Nomenclature Task Group of the IAU's Working Group for Planetary System Nomenclature.

ANOMALIES: GREGG DINDERMAN / *S&T*; LAMONT: ROBERT REEVES

◀ If you find yourself under dark skies, try to spot Nu[1] and Nu[2] Coronae Borealis without optical aid. At magnitude 5.4 and 5.6 respectively, they're bright and far enough apart that you may be able to make the split with your naked eye.

Shining Jewels

Determining the colors of double stars — sometimes brilliant, sometimes subtle — can be tricky even for experienced observers.

Instead of being white, they often shine with a colored light, offering in their strange couples admirable associations of contrast, where the astonished eye sees wed emerald fires with those of ruby, topaz with sapphire, diamond with turquoise, or opal with amethyst, sparkling with all the nuances of the rainbow.

This charming description of double stars was penned by Camille Flammarion in his 1880 book, *Astronomie Populaire*. These glittering gems of the night sky are treasures that anyone with the desire to observe them can acquire.

When viewing stars, color perception is a peculiar and very individual thing. The ability to differentiate colors varies from person to person. Many men are colorblind to some degree. Women can generally distinguish finer shades of color, but they often perceive a greater color shift between one eye and the other. We all experience contrast illusions. When a deep yellow-to-red star sits next to one that's not strongly colored, we tend to see the companion as blue or green. These foibles only make each pair more personally our own. Let's visit some of this season's shining jewels and see what colors you detect.

We'll begin in the Northern Crown with **Nu[1] (ν[1])** and **Nu[2] (ν[2]) Coronae Borealis**. They're so widely separated they can be individually seen with the unaided eye if your sky is dark enough to spot their 5.4- and 5.6-magnitude glows. A pair of binoculars will easily reveal their colors. Through 12×36 image-stabilized binoculars, the separation between the stars is extremely wide. I see Nu[1], the northern star, as an orange ember, while Nu[2] shines a slightly yellower orange. As you might suspect with such a spacious relationship, the stars aren't physically related. Although they might be roughly the same distance away from us, somewhere in the vicinity of 600 light-years, they're moving in very different directions on the sky.

Just 1.6° west of Nu[1], **Sigma (σ) CrB** is a colorful but closer duo you can admire in a small scope. My 130-mm refractor at 37× shows an unevenly bright pair of close but cleanly split stars that both gleam yellow, the companion floating 7.4″ west-southwest of its primary. They lie 70 light-years away.

Next door in the Herdsman's upraised arm, we can procure a delightful two-for-one. **Kappa (κ)** and **Iota (ι) Boötis** are only 36′ apart, making their couplets accessible in the same field of view. The 130-mm at 23× shows Kappa as a close, yellow-white pair, with the 4.5-magnitude primary guarding a 6.6-magnitude companion to its west-southwest. Kappa is a visual binary, whose measure in 2016 placed the stars 13.1″ apart. Southeast of Kappa, Iota's stars vaunt greater color contrast, magnitude difference, and separation. Its 4.8-magnitude primary also glitters yellow-white, but the 7.4-magnitude companion north-northeast wears a nice golden hue.

On the opposite side of Corona Borealis, we find the constellation Hercules, home of the pretty double **Kappa (κ) Herculis**. The stars are quite similar in hue, the primary deep yellow while the companion shades a skosh more toward yellow-orange. They're widely split through the 130-mm scope at 23×, with the 6.2-magnitude companion north-northeast of its 5.1-magnitude primary. You'd suspect two bright stars only 27.3″ apart on the sky would be physically bound, but in this case, they're not. Kappa is merely an optical

▶ Color perception varies greatly from observer to observer. The author saw both components of Sigma Coronae Borealis as yellow through her 130-mm refractor at 37×. Jeremy Perez, observing with a 6-inch reflector at 240×, saw the secondary as a reddish purple.

CORONAE BOREALIS: POSS-II / STSCI / CALTECH / PALOMAR OBSERVATORY; SIGMA CORONAE BOREALIS: JEREMY PEREZ double, that is to say, a chance alignment of unrelated stars.

Also in Hercules, **Mu (μ) Her** can be seen as a triplet when the timing is right. In the 130-mm scope at 37×, the bright, yellow primary is mated to a much dimmer, orange spark west-southwest. The companion is a close pair (BC) with an orbital period of only 43 years. This June the 10.7-magnitude C component is an excruciatingly close 0.6″ north of the 10.2-magnitude B component. My 14.5-inch scope at 245× offers a kissing duo, each glimmering orange. Five years from now they'll have widened to 1.2″, presenting a much easier target. Is your seeing (image steadiness) good enough to wrest them apart?

Strolling down to the Scorpion we find another twofer in the guise of **Xi (ξ) Scorpii** and **Struve 1999** (Σ1999 or STF 1999). I most recently dropped in on these stars with my 105-mm refractor. At 36× Xi AC is a close, unequal pair with a yellow companion huddled northeast of its yellow-white primary. East-southeastward in the same field of view, the components of Σ1999 are more widely separated. Here the primary is deep yellow, while the companion to its east sparkles yellow-orange.

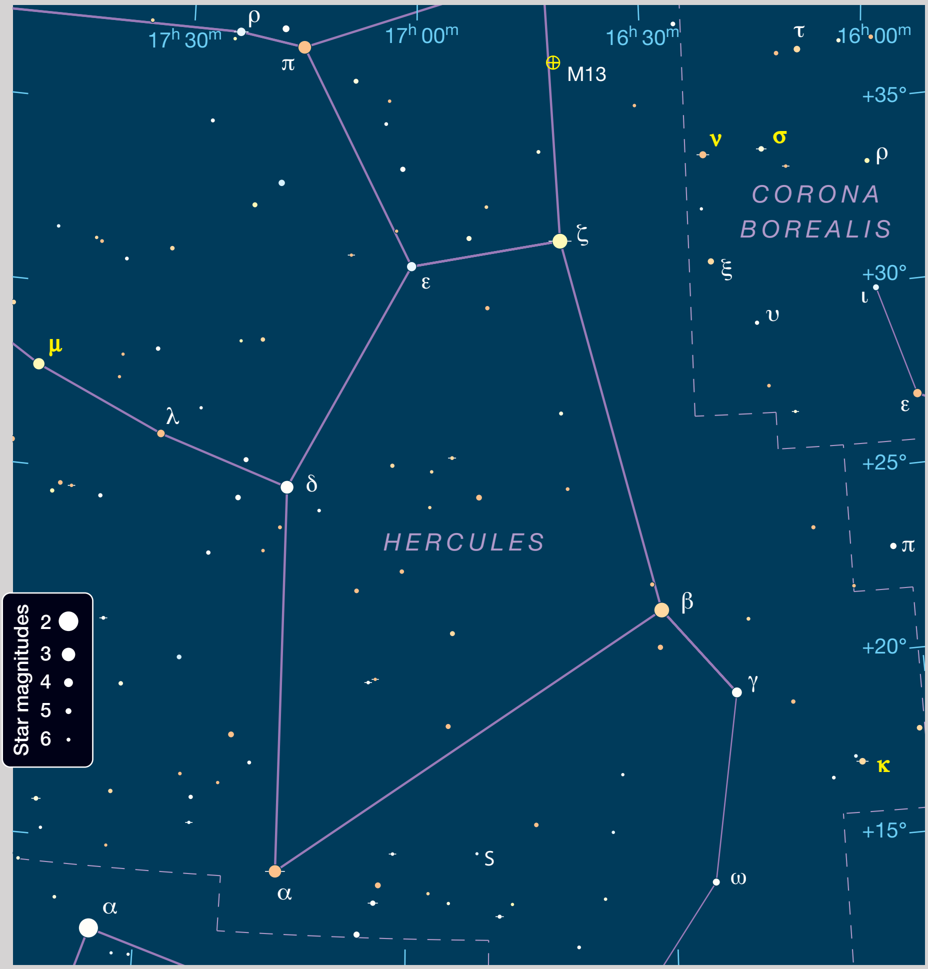
Xi Scorpii's primary has another companion (B) visible to backyard scopes, perhaps with some difficulty. Together they form a visual binary with a period of only 46 years, and B currently dwells a mere 1.1″ north and a bit east of the A component. Although I've split similar doubles at 203× with the little refractor, this pair only yields a shape that looks like a snowman — probably because it's fairly low in my sky where the image steadiness isn't as good. At 381× I get a hairline split during spells of good seeing. Unlike the custom for most doubles, the B designation belongs to the brighter of the two stars, but they look pretty equal to me.

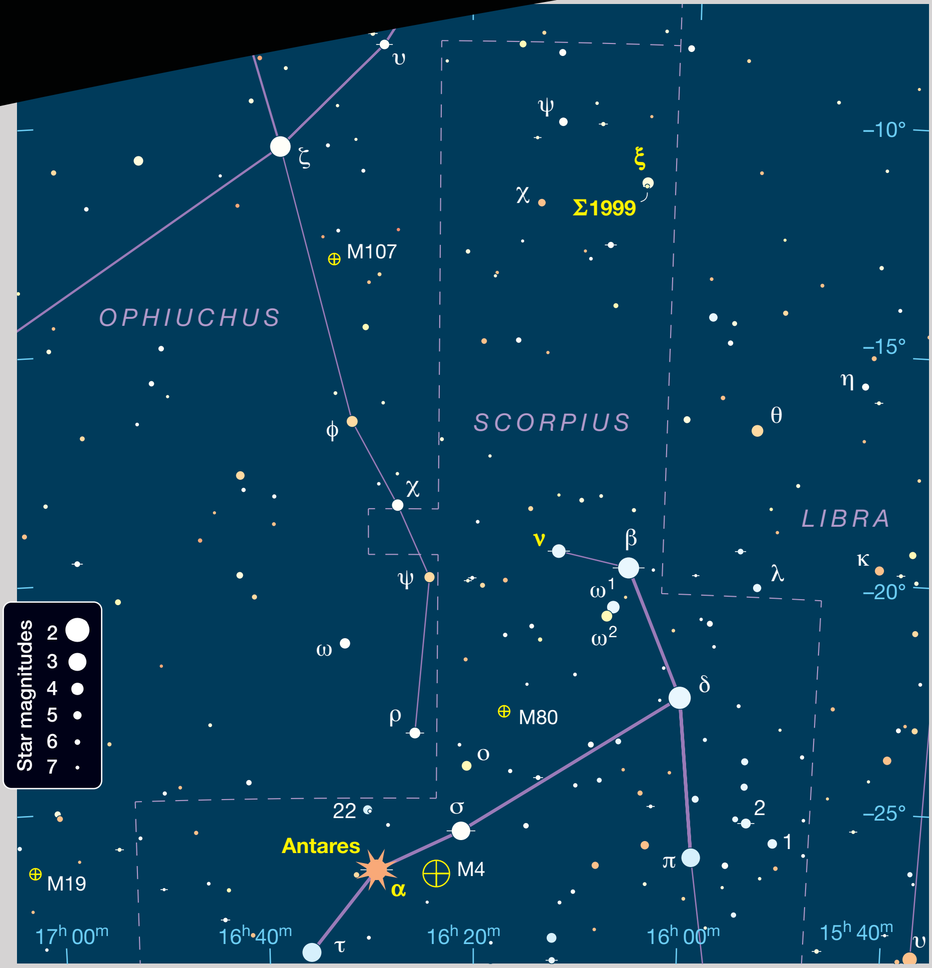
Nu (ν) Sco is an 8.3° drop south-southeast from Xi Sco and a lovely quadruple star through a telescope. In the 130-mm scope at 63×, three of the components are visible. The 4.4-magnitude primary has two companions 41.6″ to the north-northwest and 2.5″ apart.

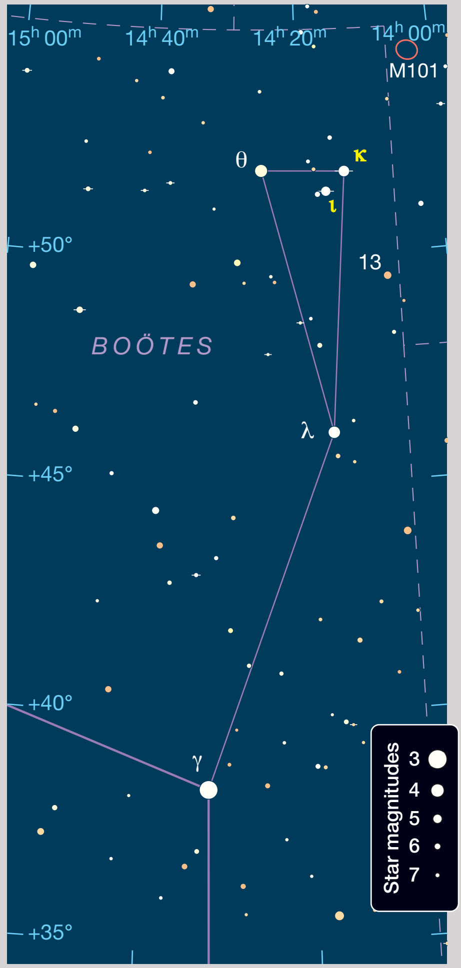
Early Summer Doubles

Object	Mag(v)	Sep	RA	Dec.
ν^1 and ν^2 CrB	5.4, 5.6	355″	$16^h 22.4^m$	+33° 48′
σ CrB	5.6, 6.5	7.4″	$16^h 14.7^m$	+33° 52′
κ Boo	4.5, 6.6	13.1″	$14^h 13.5^m$	+51° 47′
ι Boo	4.8, 7.4	38.8″	$14^h 16.2^m$	+51° 22′
κ Her	5.1, 6.2	27.3″	$16^h 08.1^m$	+17° 03′
μ Her A, BC	3.5, 9.8	35.5″	$17^h 46.5^m$	+27° 43′
μ Her BC	10.2, 10.7	0.6″		
ξ Sco AB	5.2, 4.9	1.1″	$16^h 04.4^m$	–11° 22′
ξ Sco AC	5.2, 7.3	7.6″		
Struve 1999	7.5, 8.1	12.1″	$16^h 04.4^m$	–11° 27′
ν Sco AB	4.4, 5.3	1.6″	$16^h 12.0^m$	–19° 28′
ν Sco AC	4.4, 6.6	41.6″		
ν Sco CD	6.6, 7.2	2.5″		
Antares	1.0, 5.4	3.2″	$16^h 29.4^m$	–26° 26′

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.





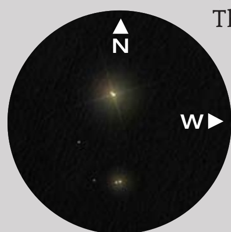


A magnification of 164× also pries apart the primary and a snug, 5.3-magnitude companion 1.6″ to its north. The light from Nu is somewhat reddened as it passes through interstellar dust on the way to our eyes. In addition, celestial objects low in the sky are seen through a longer column of air, and the resulting buildup of atmospheric haze and dust along our line of sight shifts their colors to longer wavelengths. Although A and B are blue-white stars while C and D are white, I often see them in hues of white to yellow. Spectral class isn't always a good indicator of what color to expect.

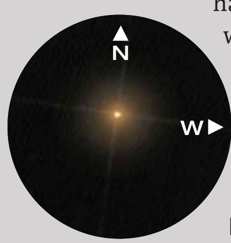
If any double star might be likened to Flammarion's pairing of emerald fire and ruby, the Scorpion's lucida, **Antares**, comes close. However, viewing them is a difficult task. Antares shines brilliantly at magnitude 1.0, hiding the 5.4-magnitude companion in its glare when the seeing isn't good. Yet even from my northerly location, I can sometimes split the stars with my 130-mm and 10-inch scopes at magnifications of 200× to 300×. While not as red as a ruby, Antares certainly does beam at us with a reddish orange tint, a fact reflected in its name, which means "like Mars," the red planet. Many observers, including myself, see the companion bedecked in green, but there are no green stars. A star that emits light most strongly in the green part of the spectrum also radiates enough balancing colors to make it appear white. When we see the blue-white companion as green, we're experiencing a color-contrast illusion — one that's hard to shake. It's quite a sight if you manage to split the stars!

Antares is a slowly changing visual binary with an indeterminate orbit. The online Washington Double Star Catalog put the stars 3.2″ apart in 2016, with the companion west of its primary.

As you can see, perceived colors can be affected by many things, so don't try too hard to get it "right." Just enjoy what you see. I find first impressions are often the best.



▶ Doubles Xi Scorpii *(top)* and Struve 1999 can easily be held in the same field of view. Many observers see these four stars as variations on yellow and orange, but Sissy Haas has reported Xi Sco as amber yellow and royal blue.



▶ Good seeing will help you split the difficult double Antares. Do you see a green companion snugged up to the red-orange primary?

JEREMY PEREZ (2)

■ Contributing Editor **SUE FRENCH** enjoys splitting double stars with telescopes large and small.


If you...
Lvoe a chalnelge you wlil lvoe atsphrotophgray
Are you an astrophotographer in waiting?
Capturing stunning pictures of the night sky is hugely rewarding. But there's more to astrophotography than just taking pictures - it's about optimising your equipment, tuning the tracking of your mount and bringing all the components together with a single control software. It's also about sharing the tips and tricks you pick up along the way, and showing friends and family the incredible images you've captured.
Our powerful cameras and intuitive software make astrophotography accessible without compromising on the freedom and flexibility you need to make your setup your own. After all, its up to you to find the best way to image with your equipment from your site.
Astrophotography can be a challenging hobby - it's not easy to capture faint objects hundreds of thousands, or even millions of light years away. That's why our beginner-friendly cameras and live-stacking software help to get you started on your journey. When you are ready, you can push yourself and your set up to the limit with our sensitive, cooled CCD cameras. Is it time you rose to the challenge?
ATIK CAMERAS
Guiding discovery
Image credits: Simon Großlercher

S&T Test Report by Dennis di Cicco

Image-Intensified Observing

The versatility of this new light-amplifying observing system just might make it a game-changer in the world of amateur astronomy.

The heart of the TNVC Night Vision System is a standard-issue PVS-14 monocular. It's seen here attached to a Tele Vue 18.2-mm DeLite eyepiece on the Sky-Watcher Dobsonian reflector reviewed in the April issue. The 4½-inch-long monocular weighs only 12 ounces, making it smaller and lighter than many modern eyepieces.

TNVC-Tele Vue Night Vision System

U.S. Price from: $3,260 ($4,255 as tested with white phosphor image tube and accessories for smartphone photography)

tnvc.com / televue.com

What We Like

Excellent versatility for astronomy

Connects to a wide range of Tele Vue eyepieces

Ease of capturing images with a smartphone

What We Don't Like

Legal restrictions for ownership and use

THE UNDERLYING TECHNOLOGY for modern image intensifiers has been around for a couple of decades. It has given us a variety of self-contained, palm-size devices capable of amplifying light more than 30,000 times, and this gives us the reasonable expectation that an image intensifier could make ordinary backyard telescopes perform like monster light buckets. As such, it's fair to ask why the current generation of image intensifiers hasn't played a greater role in amateur astronomy. If there's a simple answer to that question, I don't know it. But I do know that this could change, thanks to a recent collaboration between the Tactical Night Vision Company (TNVC) and Tele Vue Optics. The resulting night-vision system (picked as one of our 2018 Hot Products in last January's issue) proved to be the most impressive visual light-amplifying setup I've ever used.

For the record, I've dabbled with image intensifiers going back to the days of war-surplus equipment offered by Edmund Scientific in the 1960s. But the most useful device I've tried for astronomy was an "electronic eyepiece" called the I³ Piece and sold by Collins Electro Optics in the 1990s. It was based on a generation-three image intensifier (essentially the same basic technology in use today). I reviewed the I³ Piece in this magazine's February 1999 issue, and I ended up buying one but

ALL PHOTOS BY THE AUTHOR

only occasionally did visual observing with it. I found it more useful for video recording things like asteroid occultations and, when adapted to wide-angle camera lenses, meteor showers.

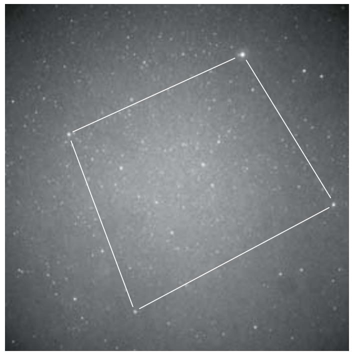
I was less than an hour into my first evening testing the TNVC night-vision system when it became clear to me that its adaptabilityg could run circles around the I^3 Piece.

The TNVC Night Vision System

At the heart of the TNVC system is an unmodified, standard-issue, military-grade PVS-14 Night Vision monocular. Several versions are available from TNVC, and I tested the TNV/PVS-14 L3 Gen3 Un-Filmed White Phosphor model. That's a mouthful for sure, but basically this unit uses technology that has between 15% and 20% greater light transmission and a phosphor viewing screen with a nearly neutral color compared to other generation-three image intensifiers. For readers interested in the technical details of, and differences between, various night-vision devices, I strongly recommend checking out the excellent material on the TNVC website (**tnvc.com**), especially the sections on technology, astronomy, FAQs, and the buyer's guide. The website also has detailed sets of technical specifications for the various monoculars.

Nighttime terrestrial viewing with the PVS-14 monocular is a jaw-dropping experience. The unit delivers a circular field of view covering about 40° at 1× magnification. Just the light from my suburban night sky is enough to render my backyard as if it were daytime when viewed through the monocular. Even more impressive was the terrestrial viewing under the inky black skies in the mountains of southern New Mexico. With only starlight illuminating the ground, the monocular showed surprising detail, albeit not with the same clarity as I had under my light-polluted skies back home in Massachusetts.

Turning the monocular to the night sky was equally impressive, with stars around 8th magnitude visible. Oddly, this result was about the same in Massachusetts and New Mexico, even though the naked-eye limit was very different for these two locations. Determining the exact magnitude limit with and without the TNVC monocular was challenging, in part because the monocular's enhanced red sensitivity gives a bigger apparent boost to red stars, which shine with light less sensitive to the unaided eye.



▲ From the author's suburban home west of Boston, pointing the PVS-14 monocular at the night sky revealed more stars than are plotted in *Sky & Telescope*'s *Pocket Sky Atlas*. The monocular alone shows a 1× field of view approximately 40° in diameter. It is seen here roughly centered on the Great Square asterism of Pegasus.

But there's another aspect of the monocular than makes the magnitude comparison difficult, and this goes for observing by naked eye or with a telescope. Visual observers use various techniques to eke out the faintest stars, with averted vision being the best-known method. But with the monocular the faintest stars on the phosphor screen are seen with direct vision, even if they did teeter at the edge of visibility because of atmospheric seeing and the image intensifier's scintillation — a peppering of point-like flashes that appear randomly, especially when the monocular's gain is turned all the way up.

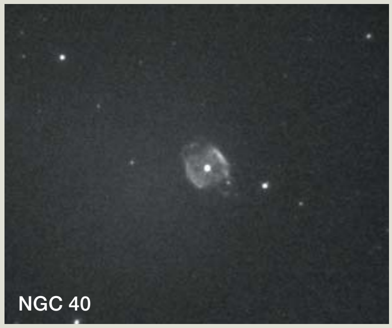
Perhaps a good way to illustrate the magnitude increase due to the monocular is through a pair of observations made from my backyard on a night of below-average transparency. At the time I struggled to see naked-eye stars

◀◀◀ In addition to the PVS-14 monocular, the system has available an adapter (center) that connects the monocular to any Dioptrx-compatible Tele Vue eyepiece and another adapter (left) that fits over the monocular eyepiece to connect it to Tele Vue's FoneMate smartphone camera holder (right).

◀◀ Much of the TNVC Night Vision System's versatility comes from its ability to use different Tele Vue eyepieces, thus offering the observer an easy way to vary the magnification. The author did most of his testing using eyepieces with magnifications ranging between 54× and 308× on the 18-inch Sky-Watcher telescope.

◀ The PVS-14 monocular is waterproof and powered by a single AA battery. The Duracell alkaline battery pictured here will run the monocular for about 50 hours at room temperature. The small knob above the battery compartment is the monocular's gain control, which the author usually had set to maximum for his tests.

▲ Adding to the adaptability of the system is a simple setup for capturing images seen in the night-vision monocular with a smartphone. Using a method explained in the text, the author made all the accompanying astronomical images with his Apple iPhone 6s pictured here.



▲ Planetary nebulae were excellent targets for the 18-inch telescope and TNVC Night Vision System. This is just a small sample of the many such objects the author viewed with the setup.

▲ These images don't do justice to the impressiveness of seeing large emission nebulae through the monocular equipped with a hydrogen-alpha filter. Stars are heavily suppressed because the filter blocks 99% of visible light. And as explained in the text, emission nebulae are only seen in the central part of the field because the filter goes off band at large viewing angles. Cygnus with its famous North America Nebula (top) is reproduced in color to show the approximate hue of the monocular's white-phosphor viewing screen. The shot of Orion (above) clearly shows Barnard's Loop, but the large nebulosity surrounding the celestial Hunter's head isn't apparent because of the filter's band shift away from the center of the field.

in the Little Dipper fainter than Polaris and the two at the end of the dipper's bowl, but the monocular easily showed more stars in the area than are plotted in *Sky & Telescope*'s *Pocket Star Atlas*. That's a gain in the ballpark of three-plus magnitudes. And it's also about the same gain I experienced when viewing the open star cluster M67 in Cancer with and without the monocular a few minutes later using the Sky-Watcher 18-inch Stargate Dobsonian reviewed in the April issue, page 58.

Speaking of telescopic observations, this is where the TNVC Night Vision system really eclipsed my experiences with the I³ Piece. The main reason is magnification. The I³ Piece has the fixed magnification equivalent of roughly a 25-mm eyepiece. The TNVC system, on the other hand, connects directly to any Dioptrx-compatible Tele Vue eyepiece and thus allows you to vary the magnification by simply switching eyepieces. And many of the objects seen to advantage with an image intensifier, such as small globular and open star clusters, planetary nebulae, and faint stars, are best viewed at higher magnifications than afforded by a 25-mm eyepiece. Indeed, I spent a great deal of time observing with the TNVC unit attached to a 7-mm eyepiece, which yielded more than 300× with the 18-inch scope.

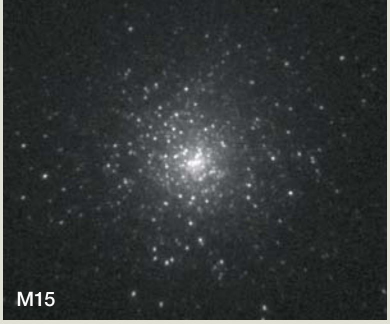
While the performance of the TNVC system was outstanding for the objects mentioned above, it was far less effective on diffuse objects such as nebulae and galaxies, with the exception of some hydrogen-emission nebulae that I'll mention later in this review. The issue here is one of contrast. While the TNVC amplifies the brightness of these diffuse objects, it equally amplifies the brightness of the background sky and as such does little to improve the contrast. In a truly dark sky, boosting the brightness of a telescopic view helps with the visibility of some faint nebulae and galaxies, but the effect is not nearly as profound as when viewing compact objects like planetary nebulae and anything involving resolvable stars.

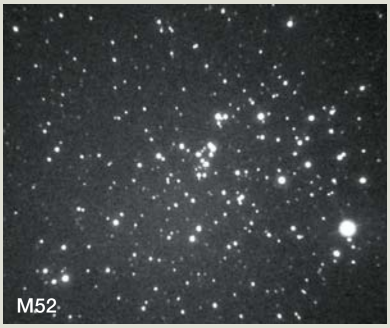
As much as I savor the "natural" view through a telescope eyepiece, the increased magnitude reach available with the TNVC system became almost addictive at times. This was especially true when I was hunting small star clusters. The increased number of stars visible was one reason, but the ease of seeing even the faintest stars with direct vision was equally appealing.

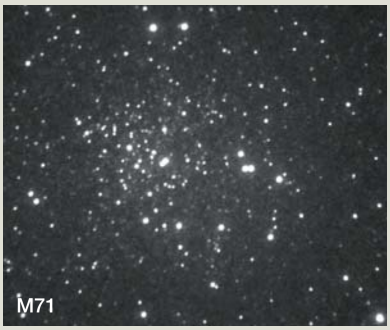
Smartphone Imaging

My past experiences trying to capture still images with the I³ Piece involved custom adapters and, at best, were only marginally successful. Not so with the TNVC system. An optional adapter couples Tele Vue's FoneMate directly to the monocular eyepiece, and because the phosphor screen is relatively bright, it's easily captured with a smartphone snapshot. But single exposures are rarely impressive, since they are degraded by noise and the image intensifier's scintillation mentioned earlier, which the eye/brain automatically averages out during visual use.

I don't know the features of every smartphone camera, but there's a very cool one available with my Apple iPhone 6s. When the camera's self-timer is activated, the result is not a single exposure, but rather a burst of 10 shots made in less than a second. For normal photography I'd select one good shot from the burst — when everyone had his or her eyes open, for example — and







▲ Globular and open star clusters are also excellent targets for the image-intensifier system, which showed stars at least two and sometimes three-plus magnitudes fainter than one sees by just looking through an eyepiece without the monocular attached to it.

delete the rest. But when shooting with the TNVC system I kept all 10 frames and later exported them for stacking with astronomical image-processing software. The results were remarkable, and the photos an order of magnitude better than those obtained with just a single exposure, even if they still fell somewhat short of the visual impression you get when looking through the TNVC monocular.

An Unexpected Treat

One of the most interesting experiences I had with the TNVC system is clearly biased by my long standing interest in the glowing clouds of hydrogen scattered throughout the Milky Way. It began one night at last year's Stellafane convention in Vermont when Tele Vue's founder, Al Nagler, handed me his TNVC monocular. "Here," he said, "check out the Milky Way." As I swept upward from Sagittarius to Cygnus I was dumbfounded to see amazingly faint hydrogen-emission nebulae almost magically appear as they crossed the center of the field. I'd looked for them in the past with the I³ Piece fitted to wide-angle camera lenses, but only the brightest ones were faintly visible. Al's trick had been to attach a narrowband hydrogen-alpha filter to the front of his monocular (and as I later learned through experimentation, the fast f/1.2 speed of the monocular's objective — the camera lenses I experimented with in the past were f/2.8 and slower). Because narrowband interference filters are only effective over a limited angle of view, the hydrogen nebulae were only seen in the center of the field (approximately 20° of the monocular's full 40° field), but watching them swim in and out of visibility as they swept through the field was part of this truly novel experience.

▲ After Tele Vue's Al Nagler treated the author to views of faint hydrogen-emission nebulae with a filter-equipped monocular (described in the text), the author made this plastic piece on a lathe to fit a 3-nm hydrogen-alpha filter over the objective of the monocular he tested. The setup was used for the pictures of Cygnus and Orion on the facing page.

There's Always a Caveat

As exciting as the TNVC Night Vision System is, ownership of one comes with a catch, and in this case it's legal. This level of night-vision equipment falls under the International Traffic in Arms Regulations (ITAR) regulatory regime. While U.S. citizens are free to own the TNVC monocular, it's a federal crime to send or take one out of the country without a proper export license issued by the U.S. Department of State. I knew this from previous experiences with night-vision equipment. But I was caught off-guard by a restriction spelled out in the paperwork I signed in order to borrow the TNVC device for this review — it's a violation of ITAR rules to allow any non-U.S. citizen to look through the device even here at home. You can read the details in the FAQ section on **tnvc.com**.

▲ As explained in the text, the night-vision system was not as effective for viewing many galaxies as it was for planetary nebulae and star clusters. This view of the Andromeda Galaxy through the monocular was not substantially better than what was visible without it.

It seemed a little awkward asking people if they were indeed U.S. citizens before offering them a look through the monocular, but even for the sake of a product review I'm not willing bend federal laws! Fortunately, all were citizens, and I could enjoy their gasps of amazement when they first took a peek through it.

■ As a partner in the MDW all-sky hydrogen-alpha survey project (**mdwskysurvey.org**), **DENNIS DI CICCO** was particularly excited to see glowing clouds of gas with this handheld device.

◀ BIG PIERS

iOptron now offers piers for observatories. The Permanent Pier is a 7⅛-inch diameter, ¼-inch-walled aluminum pier with an 8¼-inch-square top plate. Four side struts are welded between the pier tube and the base plate to eliminate side flexure of the tube assembly under heavy or off-center loads. Each Permanent Pier is capable of supporting loads of up to 163 kg (360 lb) and is available in three heights: 600-mm (23½-inches) for $448, 800-mm for $478, and 900-mm costing $498. Custom heights and adapters are available by special order at additional cost.

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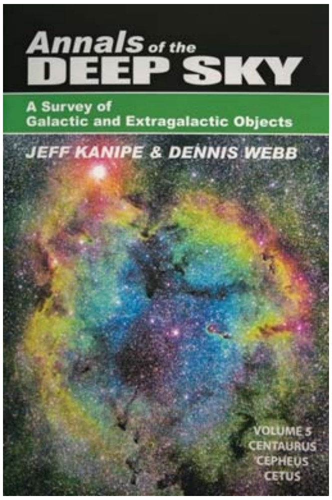

◀ CONTINUING COMPENDIUM

Willmann-Bell releases the 5th volume of *Annals of the Deep Sky: A Survey of Galactic and Extragalactic Objects* by Jeff Kanipe and Dennis Webb ($24.95). The series continues to be the most up-to-date and comprehensive observing guide available in the 21st century. Volume 5 features 206 illustrations, with current astrophysical profiles of the major stars and deep-sky objects paired with extensive historical and observational information. This fifth volume covers the constellations Centaurus, Cepheus, and Cetus, with deep-sky objects ordered by their distance from Earth. Softbound, 6 by 9 inches with 408 pages, ISBN 978-1-942675-09-9.

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SKYSAFARI 6 ▶

One of the most popular planetarium apps for Apple devices gets a big update. *SkySafari 6* (starting at $2.99) once again expands the usefulness of this popular app. Among its many new functions are a "Say It" feature that incorporates basic voice control to find and center objects, and "Tilt It" that uses your device's accelerometers to slew your Go To telescope. *SkySafari 6* includes 29 million stars down to 15th magnitude and the PGC catalog including 784,000 galaxies to 18th magnitude. Each of the stellar and deep-sky object catalogs is expandable with in-app purchases. Available in Basic, Plus, and Pro versions, each requires a device running iOS 8 or later and includes support for the Apple Watch. The Plus and Pro versions also incorporate Wi-Fi Go To telescope control and iCloud synchronization. An Android version is expected by mid-2018. See the manufacturer's website for a complete listing of features.

Simulation Curriculum
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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.*

Fifteen Steps to Forever

Use these well-known observing targets as incremental stepping stones into the cosmic past.

The concept of astronomical look-back time has always fascinated me. We see nothing in the sky as it is at this moment, but only as it was in the past, when the light left it. Even the Moon is 1.3 light-seconds away. Beyond the small compass of the solar system — 8 light-hours across at the orbit of Neptune — the look-back times swell into years, millennia, and eons. It's natural to wonder what was happening on Earth when the light we see now departed from celestial objects. In 2016 I wrote an article, "12 Steps to Infinity" (*S&T:* Dec. 2016, p. 24), covering a dozen objects in the winter sky and the corresponding events in Earth history.

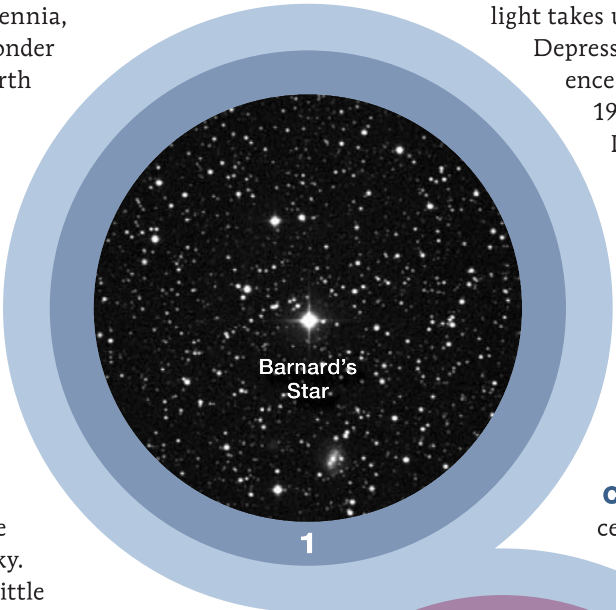
This article is a sequel and an expansion of the concept, encompassing 15 objects visible in the late spring and early summer sky. This time we'll start out a little closer, end up much farther out, and see a more diverse set of targets. We'll go fainter, too, down to almost 13th magnitude, so although many of the objects are binocular-friendly, you'll need a telescope to see them all. Whatever instrument you choose, for the duration of this tour it will be a time machine, and we will be chrononauts in the sea of time and space. Let's set sail.

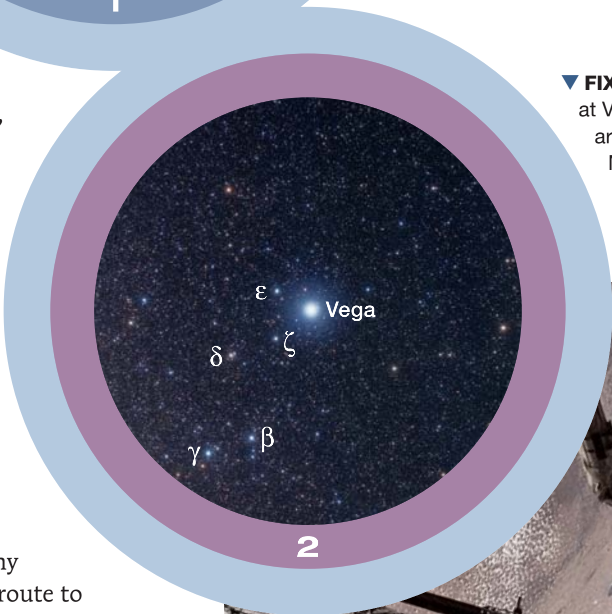
The closest star visible to observers at mid-northern latitudes is **Barnard's Star**, a red dwarf in the constellation Ophiuchus, the Snake Holder. Barnard's Star lies only 5.98 light-years away, meaning that the light we see now left the star in mid-2012. That was a huge year for astronomy and space travel. The rover Curiosity was en route to Mars, for a landing on August 6th. SpaceX sent the first of its Dragon capsules to the ISS, and Liu Yang became the first female taikonaut when she flew to China's Tiangong-1 space station. Like most amateur astronomers, I was excited about the annular eclipse of the Sun in May and the transit of Venus in June — both of which I was fortunate to observe.

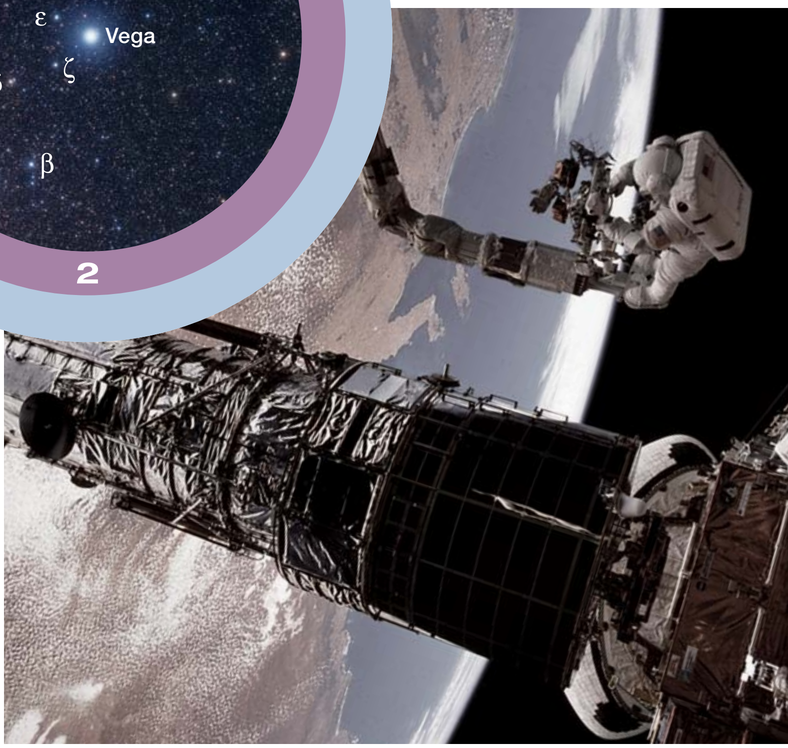
Our next step out is **Vega**, in Lyra the Lyre, an *A*-class main-sequence star lying almost exactly 25 light-years away. That's a nice round number, easy to remember, and a handy yardstick for our journeys to come. In 1993, Space Shuttle Mission STS-61 installed corrective optics on the Hubble Space Telescope, ushering in a new age of discovery that continues to this day. Ida and Dactyl were discovered to be the first known binary asteroid. Here on Earth, Keck I started science observations, becoming the world's largest telescope. And I graduated from high school.

Now we turn north, to the naked-eye double star formed by **Mizar** and **Alcor** in the handle of the Big Dipper. With distances of 78 light-years for Mizar and 82 for Alcor, their light takes us back to the late 1930s. Despite the Great Depression, astronomy was at the forefront of science. Clyde Tombaugh had discovered Pluto in 1930, New York's Hayden Planetarium and Los Angeles's Griffith Observatory both opened in 1935, and construction of the dome for the 200-inch Hale Telescope on Palomar Mountain started in 1936 (the telescope would not enter service until 1949). Excitement for the big telescope was high, thanks to Edwin Hubble's headline-making discovery of the expanding universe.

Four-and-a-half times farther out, at 288 light-years, lies the **Coma Star Cluster** in the constellation Coma Berenices. Now we're back to 1730, the year that

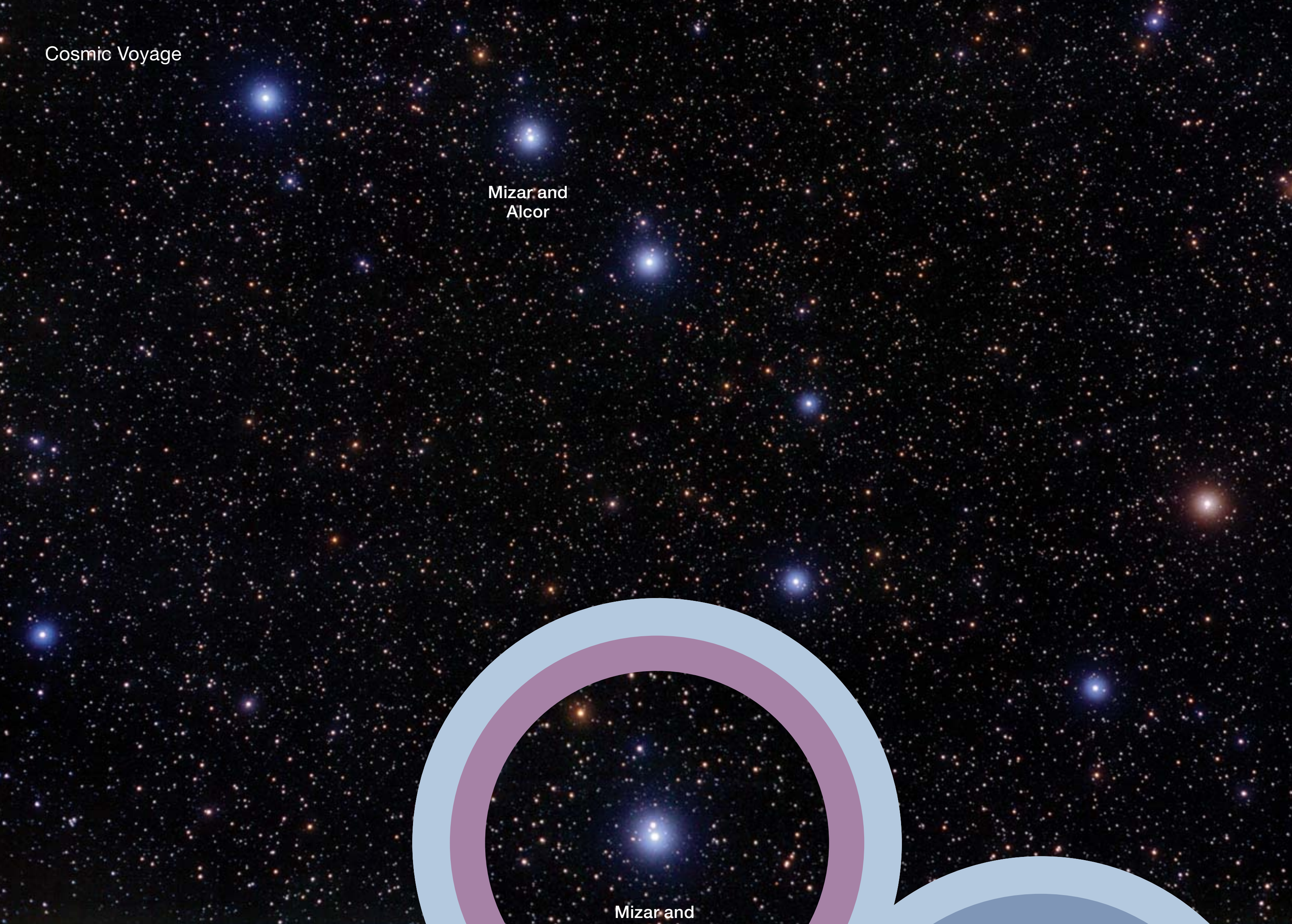






▼ **FIXING HUBBLE** When we look at Vega, we see light that left around the time astronaut Story Musgrave worked on fixing the Hubble Space Telescope on STS-61, what was to be the first of three repair missions.

ILLUSTRATION: LEAH TISCIONE / S&T; BARNARD'S STAR: POSS-II / CALTECH / STSCI / PALOMAR OBSERVATORY; VEGA: AKIRA FUJII; STS-61: NASA



Charles Messier was born. Astronomers had been using telescopes for more than a century, but reflecting telescopes and achromatic refractors were still decades away from being widespread. Serious observers used aerial telescopes, tubeless designs in which the objective lens and eyepiece were separated by dozens or hundreds of feet to reduce chromatic aberration. Aerial telescopes look cumbersome, but they were good enough to allow Giovanni Cassini to discover four moons of Saturn in the late 1600s and the ring gap that bears his name, the Cassini Division.

Far to the east of Coma, the brilliant double star **Albireo** sits at the head of Cygnus, the cosmic Swan, 430 light-years away. The light we see now left the stars in the late 1500s. In the last great age of pre-telescopic astronomy, the world wrestled with the heliocentric cosmology proposed by Copernicus. To challenge the Earth-centered views of Ptolemy was not only intellectually daring, but also mortally dangerous, given prevailing religious views. To resolve the question, Danish astronomer Tycho Brahe measured the courses of the planets with unprecedented accuracy — data that would allow Johannes Kepler to derive his laws of planetary motion in the early 1600s.

Brahe measured the skies more accurately than any before him, but people all over the world had been making similar observations for millennia — as our next few steps will demonstrate. The Antikythera mechanism was a Greek mechanical computer used to predict astronomical phenomena, from the first or second century BC. That's about the time that the Olmecs, Mayans, and other Mesoamerican cultures were devising astronomical calendars of stunning accuracy. To see light that has traveled since the last centuries BC, seek out **M57**, the Ring Nebula, in Lyra. From Earth, M57 sits only a little more than 6° from Vega, but at 2,300 light-years, it's almost 100 times as distant.

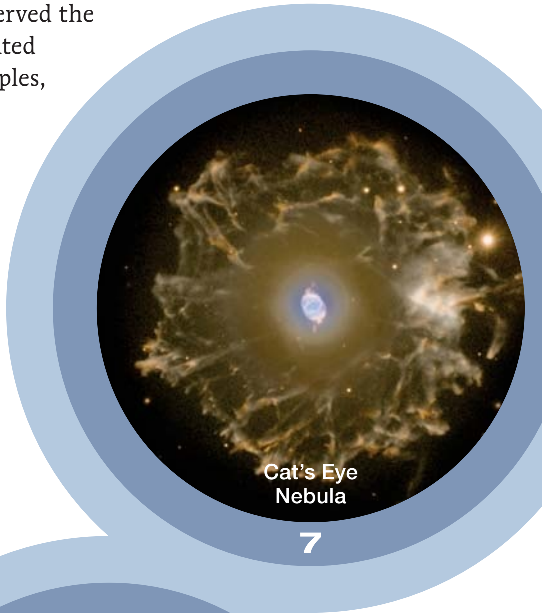
Our next stop is another planetary nebula, **NGC 6543** (Caldwell 6), the Cat's Eye Nebula in Draco, the Dragon. The Cat's Eye lies 3,600 light-years away, and its light comes to us from the Bronze Age. One of the most impressive astronomical artifacts to survive from that time is a sky disk from Nebra in Germany. A bronze disk 12 inches in diameter and inlaid with gold, the Nebra sky disk depicts the Sun, the Moon, and a star cluster (probably the Pleiades), and also marks the solstices.

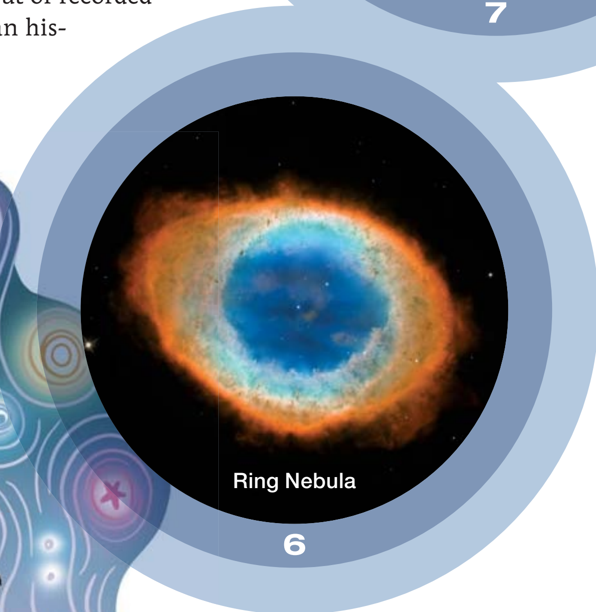
For our next step we will voyage far to the south, both geographically and celestially. **M8**, the Lagoon Nebula in Sagittarius, the Archer, is a stellar nursery, and one of only two star-forming regions visible to the naked eye (the other is the Orion Nebula, M42). The light we see now left 4,100 years ago, when the Great Ziggurat of Ur was being constructed in Mesopotamia (modern-day Iraq). The ziggurat was a temple to the moon god Nanna, and it embodies the importance of astronomical phenomena to the ancient Sumerians.

Sweep 21° northwest from M8 and look 2,100 light-years farther out, to **M11**, the Wild Duck Cluster, in the constellation Scutum, the Shield. At 6,200 light-years from Earth, M11 is one of the more distant open star clusters in the Messier catalog. Its light corresponds in age with what may be the oldest star map yet discovered, the Fuxi star map, from a Neolithic tomb in Henan, China.

Greece, Central America, Germany, Mesopotamia, China — ancient cultures across the globe not only observed the heavens, they consecrated that knowledge in temples, tombs, calendars, and even computers. We pause now at the edge of a gulf, both in the sky and in our own past. Until now, we've been observing stars, clusters, and nebulae in the adjacent spiral arms of the Milky Way. It's time to step out into the galactic halo, and out of recorded human history.

▼ **CALENDARS AND CHARTS** Light from these planetary nebulae embarked on its cosmic voyage around the time the Mayans were performing complex calendrical calculations and peoples of the Bronze Age were crafting the first star charts. Your binoculars or telescope won't reveal this level of detail, but bear these images in your mind while you observe.


Cat's Eye Nebula
7


Ring Nebula
6


Albireo
5

TUMULTUOUS TIMES
Light from the gloriously colored double star Albireo left at around the time the heliocentric model of the solar system was replacing the familiar geocentric model, Tycho Brahe took Johannes Kepler under his wing, and Galileo was soon to point his telescope skyward.

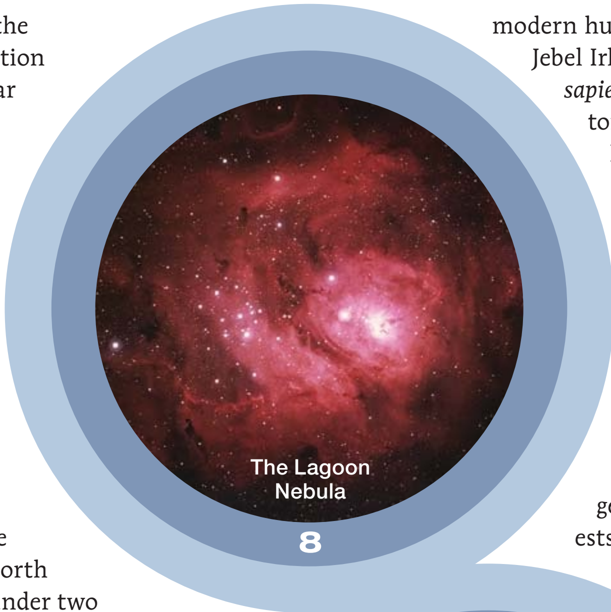
MIZAR AND ALCOR: AKIRA FUJII; COMA STAR CLUSTER: NASA / DONALD R. PETTIT; ALBIREO: STEFAN BINNEWIES / JOSEF PÖPSEL / CAPELLA OBSERVATORY; FIGURE: LEAH TISCIONE / *S&T*; RING NEBULA: NASA / ESA / C. ROBERT O'DELL (VANDERBILT UNIVERSITY); CAT'S EYE NEBULA: NORDIC OPTICAL TELESCOPE / ROMANO CORRADI (ISAAC NEWTON GROUP OF TELESCOPES, SPAIN)

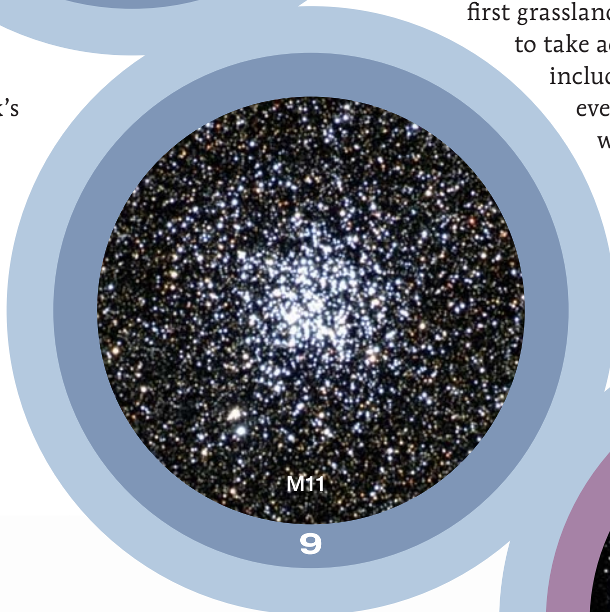
Soaring alone in the uncrowded constellation Hercules, the globular cluster **M13** shines down from a distance of 22,000 light-years. The softly golden light of M13 may look warm, but it comes to us from a time when Earth was anything but. Twenty-two thousand years ago the world was in the grip of an Ice Age glacial maximum. North Dakota was buried under two miles of ice, and glacial gouges can still be seen on boulders in New York's Central Park.

M13 is one of the closest and brightest globular clusters visible in the northern sky. At the other end of the scale, **NGC 2419** (Caldwell 25), the "Intergalactic Wanderer" in the constellation Lynx, is the most distant of the Milky Way's star clusters. Its look-back time of 275,000 years corresponds to the oldest evidence of anatomically modern humans. Both genetic dating and new fossils from Jebel Irhoud in Morocco have pushed the origin of *Homo sapiens* to 250,000 to 300,000 years ago. Our ancestors would share the world with other humans — Neanderthals, Denisovans, and tiny *Homo floresiensis* — until only 40,000 to 50,000 years ago.

Our last step took us 10 times farther out than the one before. Now we leap more than 100 times farther, to the Sombrero Galaxy, **M104**, in the constellation Virgo, whose light reaches us from across 31 million light-years. Thirty-one million years ago, Antarctica was separating from South America and Australia. This allowed cold water to circulate all the way around Antarctica for the first time, and it triggered a period of global cooling. Tropical rainforests contracted to a belt around the equator, and the first grasslands appeared. New animals evolved to take advantage of the open plains, including camels, horses, rhinos, and — eventually — a family of bipedal apes with a gift for making tools.

The spiral galaxy **NGC 5005** (Caldwell 29), in Canes Venatici, the Hunting Dogs, is our



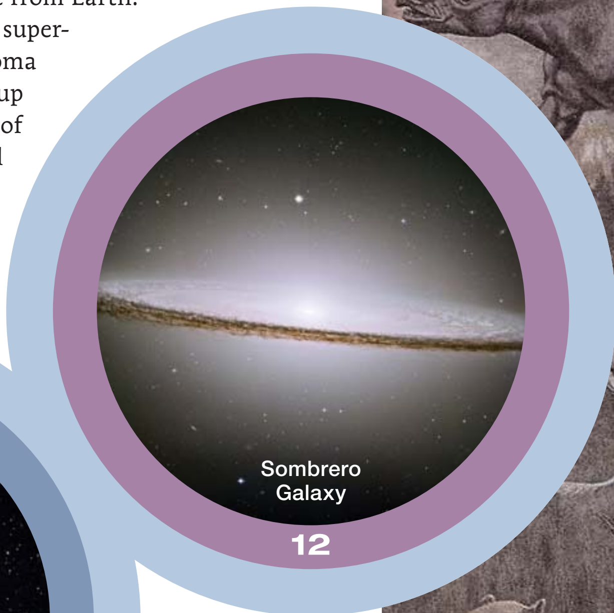


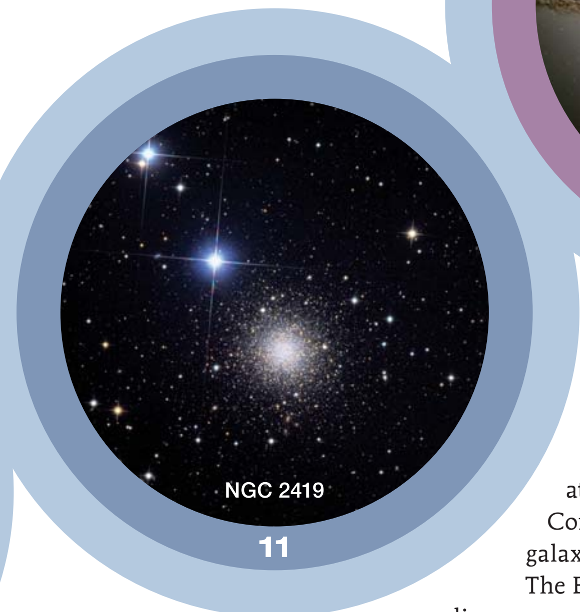
THE ICE AGE COMETH As you observe M13, imagine Earth as it was 22,000 years ago, when large sheets of ice covered much of Europe and North America and mammoths roamed in Mexico.

next stop. From approximately 69 million light-years away, its light has traveled to us from the end of the Age of Dinosaurs. Our mammalian ancestors had been mostly living in trees and burrows for 160 million years, but astronomy was about to reach down to Earth and reset the course of evolution. The impact of a 10-kilometer-wide (6-mile-wide) asteroid in what is now Mexico's Yucatán Peninsula collapsed global ecosystems, clearing the way for mammals and one surviving line of dinosaurs — birds — to take over the world.

Our last two targets were spiral galaxies not vastly different from our own. Now we venture out even farther, to visit the largest galaxy easily visible from Earth.

NGC 4889 (Caldwell 35) is a supermassive elliptical galaxy in Coma Berenices. The galaxy may be up to a thousand times the mass of the Milky Way, and its central black hole is an estimated 21 billion solar masses. This leviathan lurks 308 million light-years away, at the center of the Coma Supercluster of galaxies.

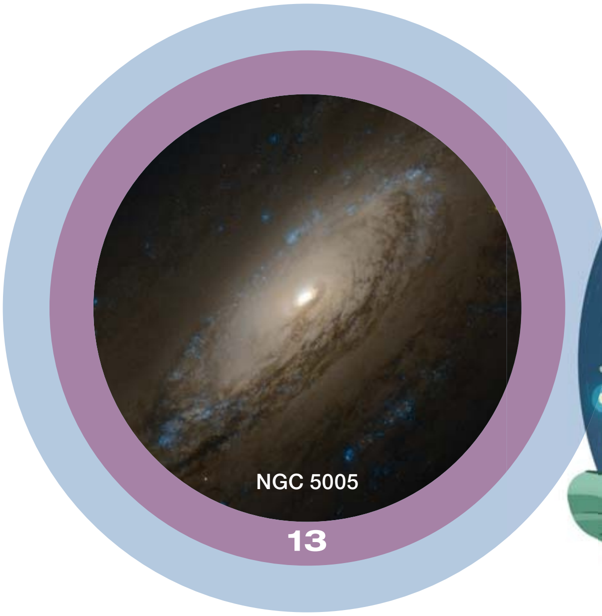




The Earth of 308 million years ago was dominated by coal swamps. High levels of atmospheric oxygen fueled the evolution of giants: dragonflies with 27-inch wingspans, millipedes 7 feet long, and amphibians the size of crocodiles. But the Carboniferous rainforest collapse of 305 million years ago led to global cooling and drying, conditions which would favor a new group of animals with drought-resistant scales and hard-shelled eggs. These were the first amniotes, the progenitors of all later reptiles, dinosaurs, birds, and mammals.

▶ **USHER IN THE SAVANNA** Thirty-one million years ago, which is how far back in time you are looking when you observe M104, grasslands first appeared and new animals, such as rhinos and horses, began to roam. In time, tool-wielding bipedal apes would join them.

LAGOON NEBULA: NOAO / AURA / NSF; M11: N. A. SHARP / REU PROGRAM / NOAO / AURA / NSF; M13: N. A. SHARP / REU PROGRAM / NOAO / AURA / NSF; GLACIER ILLUSTRATION: LEAH TISCIONE / *S&T*; NGC 2419: ADAM BLOCK / MOUNT LEMMON CENTER / UNIVERSITY OF ARIZONA; SOMBRERO GALAXY: NASA / ESA / THE HUBBLE HERITAGE TEAM / STSCI / AURA; OLIGOCENE: JAY MATTERNES / PUBLIC DOMAIN

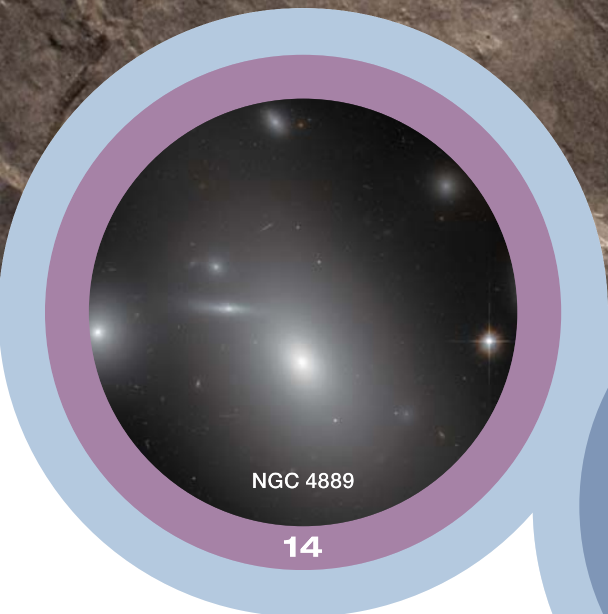


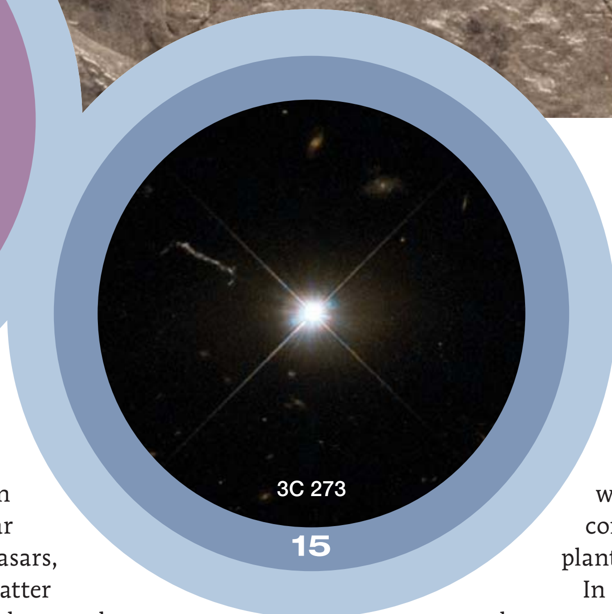
DINOSAURS' DEMISE **Few dinosaurs are as iconic as *Tyrannosaurus rex* of Late Cretaceous fame. When you point your telescope at NGC 5005, you look back 69 million years to the time of *T. rex*, just a little before an asteroid slammed into the Yucatán Peninsula and ended its reign.**

Fifteen Cosmic Steps

Object	Type	Distance (l-y)	Mag(v)	Size/Sep	RA	Dec.
Barnard's Star	Red dwarf	5.98	9.5	—	$17^h\ 57.8^m$	04° 41′
Vega	Star	25	0.0	—	$18^h\ 36.9^m$	38° 47′
Mizar, Alcor	Double star	78, 82	2.3, 4.0	14.4″	$13^h\ 23.9^m$	54° 56′
Coma Star Cluster	Open cluster	288	1.8	275′	$12^h\ 25.1^m$	26° 06′
Albireo	Double star	430	3.1, 5.1	34.4″	$19^h\ 30.7^m$	27° 58′
M57	Planetary nebula	2,300	9.7	70″ × 150″	$18^h\ 53.6^m$	33° 02′
NGC 6543	Planetary nebula	3,600	8.8	19″ × 350″	$17^h\ 58.6^m$	66° 38′
M8	Emission nebula	4,100	—	90′ × 40′	$18^h\ 03.8^m$	–24° 23′
M11	Open cluster	6,200	5.8	14′	$18^h\ 51.1^m$	–06° 16′
M13	Globular cluster	22,000	5.9	16.6′	$16^h\ 41.7^m$	36° 28′
NGC 2419	Globular cluster	275,000	10.4	4.1′	$07^h\ 38.1^m$	38° 53′
M104	Spiral galaxy	31 million	8.0	8.7′ × 3.5′	$12^h\ 40.0^m$	–11° 38′
NGC 5005	Spiral galaxy	69 million	9.8	5.8′ × 2.8′	$13^h\ 10.9^m$	37° 03′
NGC 4889	Elliptical galaxy	308 million	11.5	2.9′ × 1.9′	$13^h\ 00.1^m$	27° 59′
3C 273	Quasar	2.4 billion	12.0	—	$12^h\ 29.1^m$	02° 03′

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





▲ **MONSTER DRAGONFLIES** Fueled by an atmosphere rich in oxygen, gigantic creatures such as dragonflies with 27-inch wingspans evolved alongside millipedes 7 feet long. Can you picture such a world when you observe NGC 4889?

One more step remains: **3C 273**, in the constellation Virgo, the first quasar ever to be identified. As with other quasars, the light from 3C 273 is emitted by matter shredded to plasma in an accretion disk around the supermassive black hole at the center of a distant galaxy. The central black hole weighs in at around 1 billion solar masses. At 2.4 billion light-years away, 3C 273 is the most distant object easily visible in amateur instruments.

By now, you may be expecting that the Earth of 2.4 billion years ago was in the grip of climate change and mass extinction — and that expectation is correct. Life had already been up and running for over a billion years, but about 2.4 billion years ago photosynthesis by cyanobacteria produced the first oxygen atmosphere. The Great Oxygenation Event caused a mass extinction of microbes that could not tolerate free oxygen and precipitated a severe ice age that lasted almost 400 million years. In time, however, the oxygen atmosphere would lead to the evolution of complex, multicellular life: fungi, plants, animals, and us.

In this tour we've seen one of almost every important category of astronomical object, including a red dwarf, double stars, open and globular star clusters, planetary nebulae, a star-forming nebula, spiral and elliptical galaxies, and a quasar. Almost all of the deep-sky objects we visited are Messier or Caldwell objects, and that's the real moral of the story. A determined observer can learn a tremendous amount about the structure of the Milky Way and the universe beyond just by tracking down the Messiers and Caldwells and noting the distances to the various objects. It's a cosmic voyage on the grandest scale, and a quest I hope you'll continue.

■ **MATT WEDEL** collects time machines. So far, they only go in one direction, but he's working on it.

Art Gamble's G-Tracker

Simple. Elegant. Good Enough.

◀ Art Gamble uses his G-Tracker with one of his Art Swivel telescopes, featured in the April 2015 issue, p. 70.

WHEN I WAS INTO astrophotography, I used to spend half an hour or longer polar-aligning my telescope. Nowadays all I do is visual observing with a trackball scope, and polar alignment is a matter of figuring out more or less where north is and plopping the mount down sort of aligned with it. That degree of accuracy is plenty good enough to keep an object in the field of view for the amount of time I want to study it.

It would be nice if there were a simple, elegant way to make alt-azimuth mounts track with equal facility. Not necessarily perfect, but good enough.

Art Gamble, whose "Art Swivel" telescope was featured in our April 2015 issue, has figured out just such a device, and it's about as simple as you can get.

It looks a little like a barn-door tracker: two slabs of wood, a hinge, and a screw that slowly tilts one of the wooden slabs upward. In order to put the hand-knob close at hand while he's observing, Art added a flexible shaft made from two grease gun hoses. Since Art is a retired machinist, he also made a tracker out of metal. That one comes in two pieces and works more or less the same, using the back feet of the moving part as the hinge. A third design uses a strap hinge and might be the simplest of the lot.

To use the G-Tracker, as Art has dubbed it, you simply put it under the east leg of your tripod or under the east foot of your Dobsonian, and turn the knob attached to the screw. That side of your tripod or ground board rises upward, and your scope moves westward. If you're aimed anywhere near the meridian (the north-south line that runs directly overhead), your tracking is pretty much spot-on. The farther you stray to the east or west, the more your target takes a diagonal path through the field of view.

When that happens, place your object a little off-center and let it drift through center toward the other side of the field while you're tracking. Even near the horizon, that motion is much slower than having no tracking at all. Art reports, "With use, you learn how to position the object in the field to get the most viewing time. For the vast majority of the viewable parts of the sky the tracker works well."

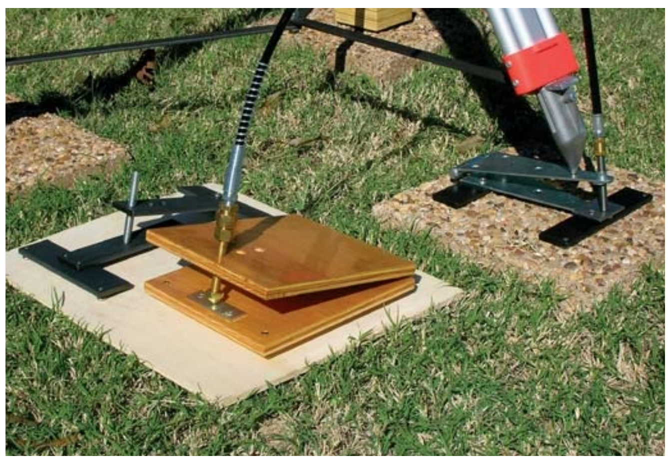
No, it's not perfect, but it greatly increases the amount of time your target stays in the field of view. As Art says, "This device is meant to be an aid to give you more time at the eyepiece; astrophotographers need not apply."

There are ways to improve its accuracy, though. If you're going to spend much time in a particular part of the sky, you can always adjust the mount so the east leg becomes the northeast leg, which corrects its aim for objects in the northeast or southwest; or make it a southeast leg, which helps in the northwest or southeast.

You can also raise the north leg of your tripod or ground board, bringing it closer to a true polar alignment. For

▶ The G-Tracker design lends itself to many different forms; three variations are shown here.

▶▶ The plywood version uses a piano hinge on one end and a metal plate on the other for the adjustment screw to rest on. Either round the end of the screw or use an acorn nut (as seen in the photo at near right) to produce a smooth motion.



ART GAMBLE (3)

SHARE YOUR INNOVATION

Do you have a telescope or observing accessory that *S&T* readers would enjoy knowing about? Email your projects to Jerry Oltion at j.oltion@gmail.com.

observers far north of the equator it would be difficult to raise it enough to help much, but as Art points out, "If you live in Ecuador, you've got it made."

At some point you have to stop and reset the screw or you risk tipping over your telescope. You can double your tracking time by raising the west side of your mount by that same height, starting out low on the east side and tracking through level to high. Art reports that "With the 30-inch spacing on my tripod feet I get about five minutes of tracking for each inch of travel turning the screw."

If you start an inch low and go until you're an inch high, that's ten minutes — plenty of time for most observations. It's a great improvement over no tracking at all. And that's the name of the game when it comes to ATM projects: *improvement*.

Art says, "I've been pushing Dobsonians around for decades and wish I'd thought of this long ago."

For more information, contact Art at **artgam1946@gmail.com**.

Contributing Editor **JERRY OLTION** appreciates "good enough" when it comes to tracking.

NGC 2023

Mark Hanson, S. Mazlin, W. Keller, R. Parker, T. Tse, P. Proulx (SSRO)

Often overshadowed by the Horsehead Nebula to its west (outside the frame at top), this colorful mix of blue reflection and reddish emission nebulae in Orion surrounds the young star HD 37903.

DETAILS: *RCOS 16-inch Ritchey-Chrétien telescope with FLI PL16803 CCD camera. Total exposure: 38 hours through Astrodon LRGB filters.*

◁ WHIRLPOOL OF STARS

Lloyd L. Smith

Messier 51 in Canes Venatici is an interacting pair of galaxies, with NGC 5195 (top) having recently passed near the large spiral NGC 5194. This interaction has produced the ghostly faint halo of stars extending well beyond the bluish spiral arms seen at left and upper right.

DETAILS: *RCOS 14½-inch Ritchey-Chrétien telescope with an SBIG STX-16803 CCD camera. Total exposure: 18 hours through LRGB filters.*

▽ WINTER HUNT

Brian Ventrudo

The winter constellations Canis Major and Orion (center) appear to chase Taurus (upper right) above Cathedral Rock near the dark-sky community of Sedona, Arizona.

DETAILS: *Nikon D750 DSLR camera with Tamron 15-to-30 mm zoom lens at 15 mm, and f2.8. Total exposure: 15-seconds at ISO 3200.*

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THE HEART OF HERCULES

Bob and Janice Fera

Abell 2151, the Hercules Cluster, contains some 200 spiral and elliptical galaxies roughly a half billion light-years distant.

DETAILS: *PlaneWave CDK17 astrograph with Apogee U16M CCD camera. Total exposure: 12.8 hours through Astrodon Gen2 LRGB filters.*

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A Feast for the Eyes

To the author, one indelible night of observing could hardly have been more delectable.

IF YOU'RE A GASTRONOME like I am, you know that you can recall the particulars of a superb meal even years later. Such can be true, too, with stargazing. One night about 15 years ago is a case in point. Prior to that evening, I'd been to the brink of photon starvation from lack of observing opportunities. But that night snatched me back with a smorgasbord of celestial delights.

At a quaint outdoor bistro in Casselman, Ontario called the Quarry, I sat down to a multi-course meal. With Venus hanging low in the west, the star-dappled sky overhead showcased such wonders as the Andromeda Galaxy, Orion Nebula, and Perseus Double Cluster. The patio was half-full of other hungry astronomers also sampling the heavenly cuisine and savoring the aroma of rural Ontario carried on the chill autumn breeze.

I was quite familiar with my waiter, a 10-inch Sky-Watcher Dob. But that night "he" had a fresh look to him, as if he'd just returned from vacation. In fact, his mirror of a face had just had a makeover at the skilled hands of Canadian ATM Normand Fullum.

I began with an appetizer of Neptune and Uranus on the half shell. They were exquisitely prepared as tiny disks of blue and green on a velvet background of deep space sprinkled with stars. I knew even then it was going to be a special evening.

Next came a wonderfully delightful soup, a southern-sky broth of stars with 2 Pallas, a bright, magnitude-7.6 asteroid just below Cetus, bobbing enticingly in it. After that I enjoyed a salad of tossed bright and dim comets in a creamy Milky Way dressing: Comet 2P/Encke was a large smear of diffuse light in Cygnus whose taste complemented the small bright nucleus of Comet Linear (C/2002 T7) in Perseus, itself a luscious comet even though it wouldn't ripen to magnitude 1 until the following spring. There was also a vague hint of Comet Linear-NEAT (C/2001 HT50) in Aries.

My appetite whetted, I now settled into the main course: a planetary entrée of cosmic proportions. Waiters paraded plate after plate of roast Saturn, with Mars and the Moon as side dishes, to diners across the patio. A to-die-for gravy of good seeing and transparency covered all the dishes, bringing out subtleties in the piquancy of each. Saturn's atmospheric bands and Cassini Division, with hints of the Encke Gap, presented ethereal flavor differences between globe and rings. Meanwhile, the sous-chef made the Moon's high mountains and deep craters more divine by brazing this large side dish with his binoviewer to add that 3D touch. All the while, the bartender kept my glass full of rare single-malt whisky.

I finished this unforgettable meal with a dessert of multiple stars: Sigma Orionis, a quadruple-star system in the same field of view with the triple-star system Struve 761.

Only late in the evening did I finally leave the Quarry, having dined on cuisine the likes of which I had not tasted in a long time. I promised myself I would do it again soon. May all of us regularly have such feasts. Bon appétit!

■ **TODD WEEKS** is a wildlife photographer living in the National Capital Region of Canada. An avid amateur astronomer, he has been an active member of the Ottawa Valley Astronomy and Observers Group since 2002.

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