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JUNE 2013

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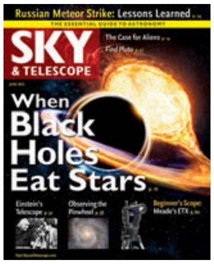
June 2013 VOL. 125, NO. 6



On the cover: When a star ventures too close to a monster black hole, the beast tears the ill-fated star apart.

ART BY CASEY REED

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Lift-off of NASA's High Resolution Coronal Imager (HI-C)
from White Sands, New Mexico on July 11, 2012.
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- **Star-Shredders in Action**
  Watch what happens when a black hole rips a star apart.
- **Einstein's Scope: A Gallery**
  See more images of Albert Einstein's only telescope.

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Image by Mick Hollimon

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Jerome Slagle shot Comet Pan-STARRS from the Griffith Observatory on March 10th. See more beautiful Pan-STARRS photos at our Online Photo Gallery.

Developing Astronomy in a Developing Nation

WHEN CONSIDERING potential growth areas for amateur astronomy, my mind quickly turns to developing nations. Amateur astronomy has been well established for a long time in economically advanced societies, but it has lagged behind in the poorer nations of the world.

With that idea in mind, I flew to the Central American nation of Nicaragua in late February. Nicaraguan amateur Julio Vannini, who I had previously met on a trip to Brazil (*S&T:* August 2010, page 6), invited me to attend the dedication of the Neil Armstrong Observatory at the Pierre & Marie Curie School (**www.eupmc.edu.ni**) in the capital city Managua. The school educates children from 1st grade through high school. Students are taught English starting in 1st grade and French in 2nd. Several Curie students recently discovered asteroid 2012 FE_{52} as part of the International Astronomical Search Collaboration.

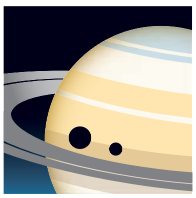
S&T: ROBERT NAEYE

Curie school principal Marta Zamora and five students.

The observatory currently houses a 10-inch Dob. That's not a particularly large scope, but a bigger one is in the works. Nicaragua's vice president and the mayor of Managua participated in the inauguration, as did ambassadors from the U.S., France, and Chile. The presence of these dignitaries signaled Nicaragua's realization that improved science education is essential for the nation's development.

On my final full day, I gave a talk to the Curie students about NASA's Mars rovers. At the end of my talk, the students deluged me with very perceptive questions (in English). Thanks to the tremendous efforts from staffers such as school principal Marta Zamora and amateurs such as Julio Vannini, science education is on an upward trajectory in Nicaragua.

Changing topics, I encourage all of you to read our special article by Eden Orion about Einstein's telescope (page 32). By sheer coincidence, Suvi Gezari, the granddaughter of the amateur astronomer who built the telescope for the iconic physicist, submitted her fascinating article about black hole tidal-disruption events around the same time Eden sent his article. It seemed only natural to run these two stories in the same issue!



Finally, check out our new *SaturnMoons* app for Apple mobile devices. This handy observing and information guide is available for just $2.99 from the iTunes Store. ✦

Robert Naeye
Editor in Chief

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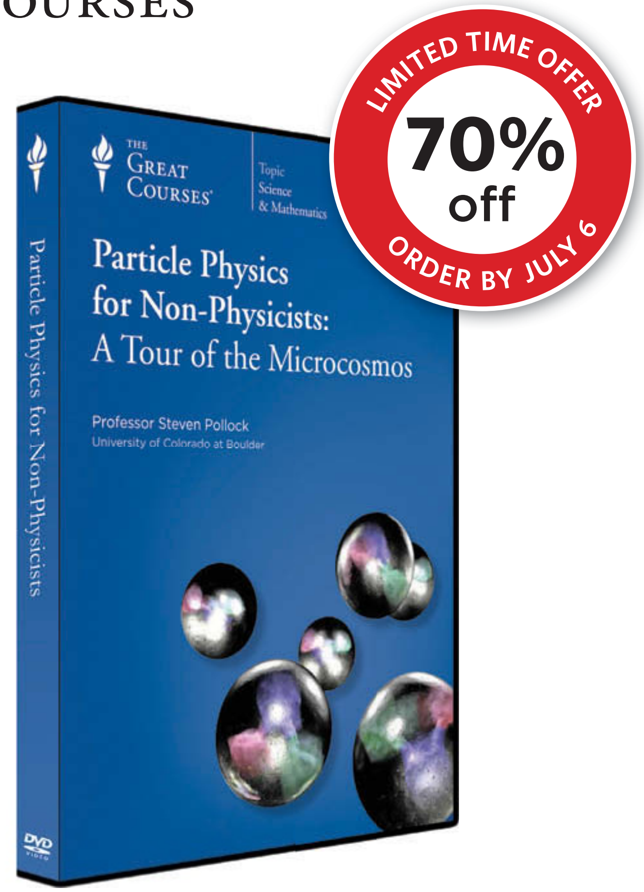

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Eclipse Humor

The similarity between Robert Naeye's eclipse photo in the March issue (page 6) and one I took in 1979 made me smile. Here in the Sacramento area, we were treated to a partial eclipse on a cloudy February morning that year. The clouds obscured the Sun but still contributed to a memorable photo, and the seagull flying through the shot made it even better.

Keeping in mind that it was the '70s, I titled the photo "Jonathan's View of the Sun after Taxes."

Alan Lampe
Folsom, California

ALAN LAMPE

Seen from Sacramento on February 26, 1979, a cloudy partial eclipse sparked some humor.

Splendors of Astrovideo

As a seven-year addict of video astronomy, I thoroughly enjoyed Rod Mollise's discussion of his observing experiences with this new technology (February issue, page 70). One aspect of video astronomy that Mollise didn't mention is its phenomenal effectiveness as an outreach tool. Not only does it bring lots of new wow-factor objects into play, it also allows you to discuss in depth a range of topics with a group instead of spending your time providing cursory individual guidance over and over.

For example, with videoastro the brilliant green of M27 shouts out the nebula's role in stellar recycling and element formation. Regions such as M8, M20, M17, and M42 introduce the star-formation story. If you shut off tracking, you can watch together the Moon drift across the screen as our planet rotates beneath. The possibilities are endless for engaging people in the wonders of the universe — and it's a joy to present, too.

Bill McDonald
Prescott, Arizona

Write to Letters to the Editor, *Sky & Telescope*, 90 Sherman St., Cambridge, MA 02140-3264, or send e-mail to letters@SkyandTelescope.com. Please limit your comments to 250 words.

Suffocating Underwater?

I have a question about the illuminating article on the *Hunley*'s sinking (February issue, page 26). In the forensic discussion, Stevenson writes that elevated carbon monoxide levels might have caused the crew to lose consciousness. What was the putative source of the carbon monoxide?

Steve Krasik
Salem, Oregon

Author's Note: *Carbon monoxide could have come from the candles used for illumination. In addition, carbon dioxide from the crew's respiration and lingering fumes from the recent painting of the interior would have stuffed up the air, too. But the crew had earlier tested how long they could stay underwater without replenishing their air supply: the candles went out after 25 minutes, and after two and a half hours all crew members felt the air getting thin and shouted "Up!" as if in one voice — no drifting off to unconsciousness there. Of course, in that instance they were deliberately testing the limits of the air supply and so were attuned to the changes taking place, not exhausted from an attack on an enemy ship. But what really happened remains a mystery.*

Aurora Reflections

I am writing to let you know how much I enjoyed your article on auroras (February issue, page 18). As a young boy I was always interested in space, the solar system, and what made it all work, but I never grew serious about the subject until I was 12 or 13, when I witnessed my first display of the aurora borealis while living on Long Island in the late 1950s.

I was on my way home shortly after dark one evening when I decided to take a shortcut that led me across a neighbor's property. As I was walking downhill looking at the ground, I began to see my shadow dancing around on the dark, dew-covered grass. Puzzled, I looked up and was flabbergasted to see pink, blue, and green curtains dancing across the sky. I dashed home as fast as my legs would carry me.

I banged on the kitchen door for my mom to let me in. I was stuttering and out of breath, and when she asked me what was the matter I took her hand and pulled her outside. "Look!" I said, pointing to the sky.

Calmly, she said, "Oh that's the aurora borealis, the northern lights."

We watched in amazement as patches of red and green appeared and disappeared across the sky. I made it a point there and then to get involved in astronomy.

Since then I've witnessed a few more auroras, two from upstate New York and one from Brooklyn in 2000 — the latter enjoyed with my wife from our backyard. My interest in amateur astronomy has only grown deeper over the years, but it still thrills me to the bone to see the lights that dance across the sky!

Brian Cassidy
West Melbourne, Florida

In Memoriam

I was saddened by the death of Sir Patrick Moore (March issue, page 16). I met Sir Patrick on several eclipse cruises, and he was always the life of the party. His British charm and wit were wonderful. He could also drink anyone under the table! I only regret never taking him up on the invitation to spend some time with him at Chelsea. An icon is gone forever.

Kent Blackwell
Virginia Beach, Virginia

75, 50 & 25 Years Ago

Roger W. Sinnott

June 1938

Solar System Age "For thousands of years man has gathered observations on the universe. His imagination has raced ahead of his eye, piecing the fragmentary data into a cosmic picture. . . .

"We now have reason to believe that the solar system has existed in a condition similar to its present state for about two billion years."

Ernest Cherrington, Jr. (Perkins Observatory) probably based his estimate on the known rate at which uranium decays in igneous rocks. Today's estimate is about 4.5 billion years.

Unrelated trivia item: The June 1938 issue had the very first News Notes department. It has run nonstop ever since.

June 1963

Channel 37 or the Cosmos? "Observing extremely faint radio noise coming from the depths of space is essential to the astronomer's new picture of the universe. . . . The conflict between the needs of American radio astronomers and commercial TV has recently become acute.

"At the Tucson meeting of the American Astronomical Society, Bernard F. Burke [of the Carnegie Institution said] . . . the immediate need for action stems from a station assignment in television channel 37 to Paterson, New Jersey. . . . [T]he handicap will be particularly severe for large antennas, such as the 300-foot dish of the National Radio Astronomy Observatory at Green Bank, West Virginia."

Lobbying by radio astronomers successfully blocked the frequencies 608–614 megahertz (channel 37) from use by over-air TV stations in the U.S. and many other nations. Only cable companies can use channel 37.

June 1988

Light Echo "Optical and radio astronomers share similar concerns about the degradation of their skies. Even the most casual stargazer near a city knows light pollution all too well. . . .

"Southern Arizona has become a model for other regions seeking to protect the sky around major observatories. On January 1st, the city of Tucson and surrounding Pima County outlawed the sale of mercury vapor lamps for outdoor purposes (a 1972 law made only their *use* illegal) and forbade certain types of outdoor advertising, including upward-directed illumination of billboards."

Tucson still spearheads the fight against urban light pollution. But 400 miles away is the Las Vegas strip, now the brightest spot on Earth's nightside that astronauts can see from space.

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

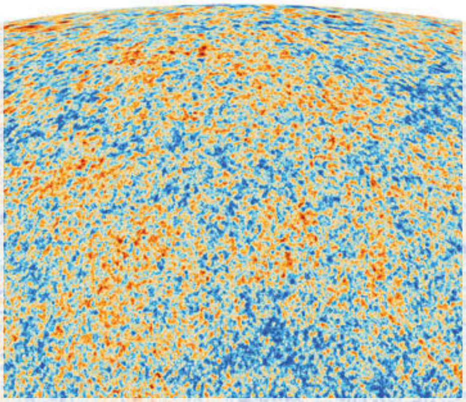
PLANCK | New Cosmology Results Announced

On March 21st scientists with the European Space Agency's Planck mission released their long-anticipated results from the spacecraft's first 15½ months of mapping the cosmic microwave background (CMB). Planck's high-resolution picture shows remarkable agreement with theoretical work, confirming that observations fit a simple cosmological model defined by just six parameters.

The graph below shows how temperatures fluctuate in patches of various sizes in the CMB, the radiation released 380,000 years after the Big Bang when the newborn universe cooled down enough to become transparent. The standard inflationary model makes specific predictions about what this graph should look like. Planck's observations (red dots) trace nearly perfectly this theory's predictions (blue line).

Combined with other measurements, Planck hones in on 13.798 billion years (give or take 0.037) for the universe's age, versus 13.77 billion from WMAP's 9-year results (April issue, page 12). Planck also lowers the fraction of the universe made up of dark energy, from 71.4% to 69.2%.

But Planck introduces a few surprises, notably its value for the Hubble constant. The Hubble parameter is the ratio of a galaxy's recession velocity to its distance and describes the rate at which the universe is expanding. Its value changes over time. Astronomers use various tactics to determine its present value, known as the Hubble constant. In the "local" universe, they use standard candles such as exploding white dwarfs or Cepheid variable stars. The current value for the Hubble constant based on local standard candles is 73.8 ± 2.4 km/second/megaparsec. The value extrapolated from Planck's CMB observations (combined with other measurements) is 67.80 ± 0.77 — somewhat in keeping with WMAP but definitely not with local measurements.



ESA / THE PLANCK COLLABORATION

The oldest light in our universe, the cosmic microwave background appears mottled in this slice of Planck's all-sky map. Created from nine frequency bands, the map shows temperature variations with the highest precision yet.

"I think this is one of the most exciting parts of the data that came out," says Planck scientist Martin White (UC Berkeley and Lawrence Berkeley National Lab). The fact that astronomers starting at opposite ends of cosmic history aren't calculating the same value for this fundamental parameter is going to attract a lot of attention, he says. It could signal a problem with the models or funky physics — even that the amount of dark energy somehow increases with time in a given volume of space.

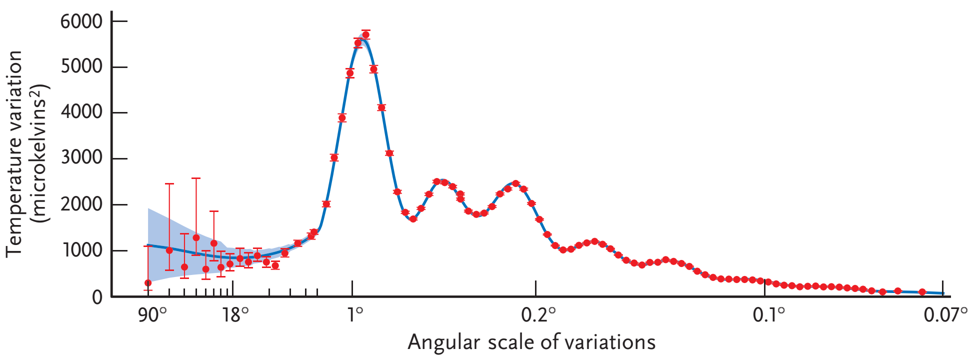
"That's a pretty radical thing to propose, and so this is not something that we should take lightly," White cautions.

Planck's results will be far-reaching — there are more than two dozen papers, and researchers have already started downloading data. Other noteworthy results:

- No extra neutrinos. According to the Standard Model of particle physics, there should be three flavors of neutrinos. Planck upholds that expectation.
- The universe isn't as uniform as expected. WMAP data hinted that the sky's northern and southern hemispheres don't look as much like each other (statistically speaking) as they should, and that there's an anomalous cold spot in the CMB. Planck upholds these results. Furthermore, researchers calculate slightly different values for the fundamental six parameters when they fit each half of the sky separately.
- The inflation model that best fits Planck's data performs worse for large patches of sky (below, far left in graph). That means temperature fluctuations in the CMB at the largest scales don't match what's expected as well as the fluctuations at small angular scales do.
- When inflation ended in the infant universe (roughly 10^{-35} second after the Big Bang), quantum fluctuations were bigger on large angular scales. These fluctuations served as seeds of large-scale structure. Inflation predicts this "tilt," and Planck upholds it beautifully.
- A map of the universe's matter distribution. Minuscule changes in the CMB caused by gravitational lensing allowed researchers to create the map. Nothing unusual, but it's a pretty neat survey shot.

The rest of Planck's results — including data on the polarization of CMB photons — will come out in 2014.

■ **CAMILLE M. CARLISLE**



CMB temperature variations are plotted against the angular scale of a patch on the sky. The blue line is the six-parameter cosmological theory, the red dots are Planck data. SOURCE: PLANCK COLLABORATION

MARS | An Ancient Habitable Oasis? . . .

The first full-depth hole drilled in a Martian rock by NASA's rover Curiosity has revealed what could be a former habitable environment, team scientists announced March 12th.

The drilled bedrock, named John Klein after a former deputy project manager, appears to lie in an ancient network of stream channels descending from Gale Crater's rim. By weight the rock is 20–30% smectite, a group of clay minerals that form in the presence of water. The water wasn't too salty, and the presence of calcium sulfates indicates it probably had a relatively neutral pH. All told, the results suggest that this region, called Yellowknife Bay, was once some sort of lakebed.

"We found a habitable environment that is so benign and supportive of life that, probably if this water was around and you had been on the planet, you would have been able to drink it," says project scientist John Grotzinger (Caltech).

How large, deep, or long-lived this lakebed was, the scientists can't say. They also can't give a good estimate of when it existed, although the ballpark estimate is 3 billion years ago. That's within a few hundred million years of when scientists think life arose on Earth.

Elements identified by one of Curiosity's instruments include oxygen, hydrogen, sulfur, and phosphorus. But what's whetted scientists' appetites (pun intended) is the hint of carbon and organic compounds. Because this is the drill system's first use, it's unclear whether the compounds are natural to Mars or residual contaminants, cautions Paul Mahaffy (NASA/Goddard Space Flight Center).

Carbon would be exciting because microbes could use it in their metabolism. What's also exciting is that the rock contains sulfur compounds in both oxidized and unoxidized forms. This combination could have created an "energy gradient," a chemical battery that could have powered primitive microorganisms.

None of these initial results means that microbes actually existed on Mars. The Curiosity team plans to drill again to confirm the findings, but they have to wait: technical problems required a rover reboot, delaying science operations, and solar conjunction blocked communication with the rover during much of April.

Once Curiosity finishes up at John Klein, it will head for Gale Crater's central mound (January issue, page 22). En route it will continue taking samples to check how rock compositions change on approach, which will hopefully help scientists determine the mound's origin.

■ **CAMILLE M. CARLISLE**

The first full-depth hole drilled on Mars by NASA's Curiosity rover. About 0.6 inch wide and 2.5 inches deep (photo is to scale), the hole is in a sedimentary rock called John Klein. Analysis of the heated sample revealed water, carbon dioxide, oxygen, sulfur dioxide, and hydrogen sulfide. The high-temperature water released is consistent with clay minerals.

NASA / JPL-CALTECH / MSSS

. . . and Front-row Seat for Comet Siding Spring

Comet Siding Spring (C/2013 A1) promises to put on a spectacular show in October 2014 — at least for the missions on and around Mars.

Robert McNaught discovered the comet on January 3rd this year using the Uppsala Schmidt Telescope at Siding Spring Observatory in Australia, just 10 days before a wildfire overran part of the observatory (April issue, page 10). The comet has a highly inclined, retrograde orbit that will come no closer than 1.4 astronomical units (130 million miles) to the Sun. It therefore won't come anywhere near Earth, but it will be very close to Mars.

Right now JPL's celestial dynamicists think the comet should miss the planet by about 74,000 miles (120,000 km), but there's still about a 1-in-10,000 chance of an outright collision. Closest approach will be on October 19, 2014. You can follow the comet's path using the orbit simulator provided by JPL's Horizons website at **http://1.usa.gov/15ME2m0**.

Mars and C/2013 A1 will race toward each other at 35 miles per second, and early estimates suggest that the comet's nucleus could be a whopping 30 to 40 miles across. Simulations by H. Jay Melosh (Purdue University) indicate that a collision would create a crater on Mars at least 6 miles deep and potentially several hundred miles across.

Hit or miss, the comet will look spectacular from the Red Planet. As calculated by small-body aficionado Bill Gray, the comet will approach Mars from the south and sweep into its northern-hemisphere skies over just a few hours.

"It probably won't reach the magnitude –8.8 shown in my ephemeris," he cautions. "Still, maybe it'll be bright enough (and suitably placed) for something on Mars to get a nice picture or two."

■ **J. KELLY BEATTY**

CRAB NEBULA
Mystery Flare in M1

The Crab is at it again. On March 3rd, NASA's Fermi Gamma-ray Space Telescope spotted a flare from the Crab Nebula (M1) that's three times greater than its average gamma-ray output. The Italian AGILE satellite also detected it. The flare faded over several days, ending around March 15th.

Since 2007 AGILE and Fermi have detected about a half dozen flares, the most fantastic in April 2011, when the Crab erupted in an outburst at least 30 times brighter than the nebula's norm. The 2013 flare is the brightest since that event; such flares put out 1,000 times more power than the Sun does at all wavelengths.

Astronomers still don't understand these events. The Crab Nebula is the remnant of a supernova seen in AD 1054. Inside it a pulsar spins 30 times per second and a hot, magnetized wind of electrons and positrons streams away from the pulsar, energizing the surrounding gas and making it glow.

Fermi team member Rolf Buehler (DESY Zeuthen, Germany) and his colleagues think this wind could be the flare culprit. Somewhere in the wind, magnetic fields might suddenly snap into new configurations, accelerating electrons that then emit gamma rays. These flares should originate within about one-third of a light-year from the pulsar and come from a region about the size of the solar system (about 1/10,000 the size of the nebula).

Attempts to nail down the flares' locations have failed. Gamma-ray telescopes have poor angular resolution, and observations in radio, infrared, and X-rays haven't detected conclusive signs of a flare. "At the moment we are all a bit mystified," says Buehler.

The irony: the Crab was once thought to be a steady emission source, and it's often been used to calibrate X-ray and gamma-ray observations. Detecting the variability has only become possible in the last five years or so with the advent of new instruments.

■ **CAMILLE M. CARLISLE**

Watch a NASA video about the Crab's 2011 whopper at **skypub.com/crabflare**.

IN BRIEF

Launched February 25th, two basketball-size Bright Target Explorer (BRITE) satellites are giving scientists new views of stars brighter than visual magnitude 4. Each BRITE satellite sports a 70-mm, f/2.3 lens with a 24° × 19° field of view, connected to an off-the-shelf Kodak KAI-11002 CCD. The international duo hitched a ride to orbit with the Indian Polar Satellite Launch Vehicle, on which rode several other experiments, including Canada's NEOSSat, the first space scope designed to search for hazardous near-Earth asteroids. Combined with work by the AAVSO and others, BRITE could help astronomers understand the evolution and internal workings of stars by revealing short- and long-term brightness variations.

■ **STEPHEN P. CRAFT**

Just days after launch, NASA's Van Allen Probes (formerly the Radiation Belt Space Probes, *S&T:* December 2012, page 12) discovered a third, temporary region of trapped high-energy particles in between Earth's two radiation belts, which also bear James Van Allen's name (he discovered them in 1958). The Van Allen Probes recorded the three belts last September, Daniel Baker (University of Colorado) and his colleagues reported online February 28th in *Science*. The third belt lasted for a month until a passing interplanetary shock wave disrupted it. During that month the outer belt also weakened and even disappeared for a week, and it's possible the third belt might have just been a split in the outer belt. Scientists don't yet know how or why it formed.

■ **J. KELLY BEATTY**

The faint X-ray flare Swift J1357.2–093313 came from a mysterious binary system, an international team reported in the March 1st *Science*. The system contains a red dwarf zipping around a black hole every 2.8 hours, one of the shortest periods ever recorded for a black-hole binary. Follow-up visible-light observations revealed that the system's brightness temporarily faded by up to 0.8 magnitude every few minutes, coming at progressively longer intervals over a roughly two-month span. That evolution suggests that whatever blocked the light was also moving away from the black hole over time.

■ **MONICA YOUNG**

Using simultaneous space-based observations from ESA's XMM-Newton and NASA's NuSTAR, an international team of astronomers says it has settled a long-standing debate over the nature of supermassive black holes' X-ray signals. Astronomers disagree over whether the X-rays come from the accretion disk or intervening clouds blocking our line of sight. Although seemingly esoteric, the debate determines whether astronomers can measure black holes' spins, which in turn can reveal how the objects grew (*S&T:* May 2011, page 20). In the February 28th *Nature*, the team argues the new observations are a slam dunk for the disk model, but the results don't convince skeptics, who say the analysis's assumptions undermine the claims.

■ **CAMILLE M. CARLISLE**

New ALMA observations hint that star formation spiked earlier than previously thought, Joaquin Vieira (Caltech) and his colleagues report in the March 14th *Nature*. The astronomers observed two dozen of the brightest sources in the South Pole Telescope survey in order to find galaxies furiously forming stars. Some of the starburst galaxies are the most distant ever discovered, forming 500 solar masses per year just 1 billion years after the Big Bang. (The Milky Way forms stars at a relatively paltry rate of 1 solar mass per year.) Astronomers think the first population of stars arose 600 million years before that, but they didn't expect star formation to be as vociferous at 1 billion years as the ALMA results suggest. ✦

■ **MONICA YOUNG**

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Cosmic Optimism

Our galaxy is likely to contain an increasingly large number of advanced civilizations.

IN PAST COLUMNS I've touched on how the accelerating changes happening on our planet compare to other dramatic chapters in Earth's history (*S&T:* October 2011, page 16), and the perspective we gain imagining the relics of our time after another 230-million-year galactic orbit has passed (April issue, page 16). Here, I'll consider the implications of this evolving view of time for SETI (the search for extraterrestrial intelligence).

A time-tested tool for discussing ET intelligent life is the Drake equation, which allows us to estimate the number of communicating civilizations (*N*) in our galaxy given knowledge about several astrophysical variables and educated guesses about others. We're rapidly learning the actual values of some factors that were wild guesses in 1961 when Frank Drake first framed the question this way. We now know that most stars have planets, and soon we'll know the frequency of potentially habitable planets.

Many discussions have concluded that regardless of the other variables, *N* hinges crucially on the value of *L*, the average lifetime of a communicating civilization. It's difficult to discuss the question of longevity without projecting our fears and expectations for our own future. The original SETI theorists Carl Sagan, Frank Drake, and their colleagues were greatly influenced by the Cold War threat of nuclear annihilation. Do all communicating civilizations blow themselves up after 100 years? If so, *L* will be a small number, around 100 years. Or do some civilizations transcend their primitive warlike tendencies and develop into a peaceful, mature, long-lived state lasting millions of years?

BIGSTOCKPHOTO.COM / MATKA WARIATKAS

But it's a mistake to assume that *L* is closely tied to our own longevity. Most acorns do not become trees, but a forest is dominated by trees. Our civilization may just be an acorn, but are there any trees in the galactic forest?

In the April issue I discussed the possibility that the current Anthropocene period could signal a planetary transition to a sustainable civilization. We're well aware of ways our technology could backfire on us, so technological intelligence surely isn't always conducive to long-term survival. But science and technology are giving us the ability to understand and predict our world. One can imagine reaching a stage where we have a deep understanding of nature, a deep self-understanding, an ability to forestall natural disasters such as asteroid impacts, and ultimately the capacity to spread out beyond the solar system to make our civilization invulnerable to any calamities on the Earth or Sun. Even if most civilizations at our stage are doomed to self-destruct, some small fraction could make the transition to quasi-immortality.

This possibility completely changes the equation. If this transition to immortality is possible, even if it's extremely unlikely, then the Drake equation is inappropriate for the phenomenon it seeks to explore. Why? Because it's a "steady-state" equation. The very definition of *L* as an average lifetime contains the implicit assumption that the total number of civilizations is constant, and they are created as fast as they are destroyed. In my view, there is no *L*, really, because I don't see the origin and destruction of technological civilizations as a steady-state phenomenon.

If just a tiny fraction of civilizations make it to this quasi-immortal state, then *N* is *increasing* over time and the galaxy must be increasingly permeated with intelligence. This is not an opinion, it's a calculation, and it leads me to what I call "cosmic optimism." I don't know if our long-term prospects are great, but I think the prospects for intelligence are great. So there is plenty of hope for the future of advanced civilizations. Whether we get to be a part of that future in the long run is up to us. ✦

David Grinspoon *is the Chair of Astrobiology at the Library of Congress. Follow him on Twitter at* **@DrFunkySpoon**.


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Star-Shredding Black Holes

Dormant black holes turn into ravenous beasts when renegade stars wake them from their slumber.


Suvi Gezari

The unlucky star that wanders too close to a supermassive black hole faces a catastrophic end. Initially, it bulges slightly due to tidal forces, just as Earth's oceans bulge in response to the Moon's gravity. Over the next half hour or so, increasing gravitational stress rips the star apart. Stellar remains spread in a wide spiral; the gas that isn't ejected at high speeds circles back to feed the black hole, glowing bright-hot before it disappears into its gaping maw.

The stellar remains not ejected at high speeds circle back, glowing bright-hot before they disappear into the black hole's gaping maw.

Astronomers first proposed that stars could become victim to tidal shredding by black holes in 1975, but it took two decades for astronomers to observe the first convincing candidates. In the past five years, two developments have substantially widened the discovery potential. First, we have found several events emitting light at optical wavelengths, where the next, most powerful surveys will soon scan the sky for transient and variable phenomena. And astronomers have also detected X-rays and radio waves from brief, spectacular jets that can form when the shredded star funnels into the black hole. These developments are guiding future searches for these rare events.

We can see black holes despite what their name suggests because when they devour a meal, they become beacons of light. Snared gas releases its gravitational potential energy as light and heat, rendering black holes visible even when they're billions of light-years away. In luminous *active galactic nuclei*, huge disks of gas feed supermassive black holes millions or billions of times the mass of our Sun. Such long-lasting meals can power jets of material traveling close to the speed of light and stretching a million light-years through space.

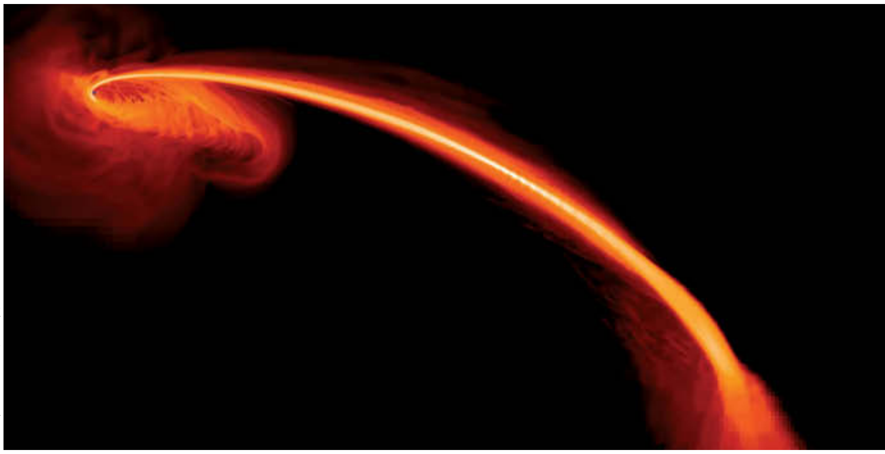
But active galaxies are in the minority — most galaxies' black holes hibernate, dormant for lack of fuel. Their presence can only be inferred by the rapid orbits of stars and gas clouds within their "sphere of influence," which extends out to 30 light-years for black holes 100 million times more massive than the Sun. Telescopes have resolved this sphere in 30 or so nearby galaxies, but in more distant galaxies we only see the slumbering leviathans if they wake for a bite to eat.

A Tidal Rip

Black holes shred stars using the same force that governs the tides. When the Moon's gravity pulls on Earth, it tugs harder on the nearside than on the farside: the nearside oceans feel a stronger pull than Earth's core, which feels a stronger pull than the oceans on the farside. As a result, Earth stretches into a slightly oblong shape, with high

Illustration by Casey Reed

Supermassive black holes sleep quietly in the hearts of distant galaxies. But they remain invisible only as long as there's nothing to eat. This illustration shows a rare close-passing star sacrificing itself to briefly reveal the black hole's presence.



NASA / S. GEZARI (JHU) / JAMES GUILLOCHON (UCSC)

SHREDDED STAR When a black hole shreds a star, the stellar remains stretch into a wide spiral, half circling back into the black hole and the other half flying out of the system at high speeds. This frame from a computer simulation shows the gas density around a black hole (black dot in left upper corner). See the full simulation at www.skypub.com/star-shredders.

tides on the sides facing and opposite the Moon. The same effect occurs when a star ventures too close to a black hole, but the pull on the nearside is so much stronger than on the farside that the tidal bulge literally tears the star apart.

The tidal tug-of-war pits the black hole's gravity against the self-gravity holding the star together. The match tips in the black hole's favor at a critical distance determined by the mass and size ratios of the black hole relative to the star. If our Sun approached a black hole a million times its mass, that critical distance would be half the Earth-Sun distance, or 0.5 astronomical unit (a.u.).

As the mass of the black hole increases, its tidal reach grows more slowly than its event horizon, the boundary from within which even light cannot escape. For a black hole with the mass of 100 million Suns, both the tidal reach and the event horizon extend to 2 a.u. Black holes this massive gulp their stars whole — the star passes through the event horizon before it ever feels a stretch.

But there's a loophole. Even at higher masses, it's possible for a black hole to shred rather than gulp a star — as long as the black hole is spinning. Einstein's general theory of relativity predicts smaller event horizons for quicker spins; the fastest-whirling have event horizons half the size of their nonspinning cousins. A spinning black hole could have a mass of up to 700 million Suns and still shred a Sun-like star outside its event horizon.

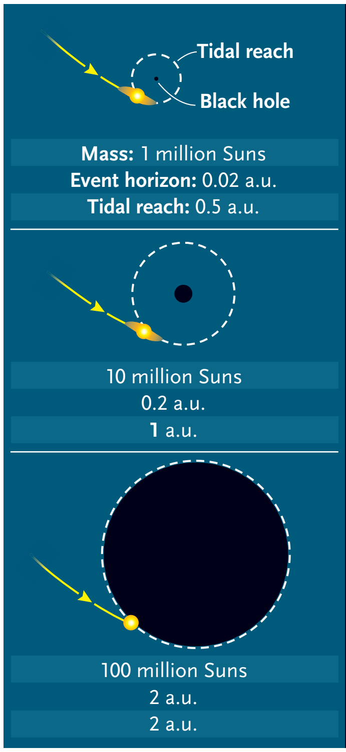
Astronomers have never directly measured a black hole's spin, though considerable indirect evidence suggests many do spin (*S&T:* May 2011, page 20). But we can definitively say we've found a spinning black hole if we observe a leviathan with more than 100 million solar masses rip apart and consume a Sun-like star.

Tidal-shredding events can also provide a smoking gun for intermediate-mass black holes (IMBHs) 1,000 to 100,000 times the mass of the Sun. Although there's some evidence that IMBHs lurk in the centers of dwarf galaxies and star clusters, their existence remains controversial.

IMBHs could shred objects much denser than stars, such as the stellar remnants known as white dwarfs. Although a supermassive black hole would swallow a white dwarf whole, an IMBH is small enough to tear a white dwarf apart while it still lies outside the event horizon. The shredding could trigger thermonuclear burning, causing an explosion similar to a Type Ia supernova. Direct evidence for the presence of an IMBH could come from a peculiar supernova in the center of a dwarf galaxy or star cluster.

Messy Meals

A black hole small enough to shred its meal outside the event horizon will gobble it down like a ravenous beast, flinging half the stellar debris out of the system at high speeds. The other half eventually spirals around, flaring



S&T: LEAH TISCIONE

Tidal Reach

A black hole's strong gravitational pull overcomes a star's self-gravity at a critical distance known as its tidal reach. But as a black hole's mass increases, its tidal reach grows more slowly than its event horizon, the radius from within which light cannot escape. So nonspinning black holes with masses above 100 million Suns will swallow stars whole.

as it falls into the gravitational well. More massive black holes tear stars apart at greater distances, so the stellar debris takes longer to fall in. This fall-back time can be used to "weigh" the central black hole. We estimate black hole mass by combining measurements of the changing brightness with simulations to determine how quickly the bound stellar debris returned to the black hole.

The number of stars passing near a central black hole ought to diminish over time. But the nucleus of a galaxy is a crowded place and random interactions between stars scatter stars into new orbits, replenishing the black hole's metaphorical cookie jar. Detailed calculations balancing these two processes estimate that a black hole will scarf down one star every 1,000 to 100,000 years.

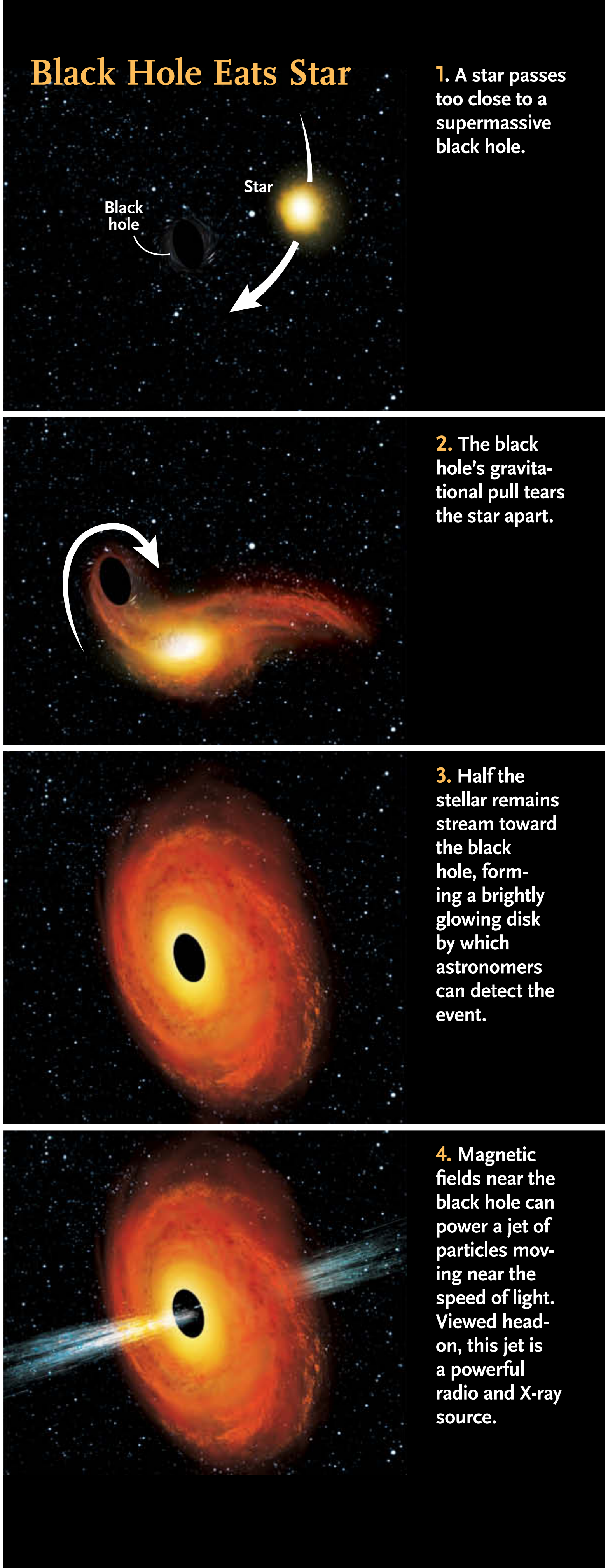
We can't wait around that long for a star to approach the supermassive black hole closest to home — the one lurking in the Milky Way's center. But later this year, we might see the next best thing, when our neighborhood bully is expected to tear into a passing gas cloud (see page 23). Moreover, we now have powerful telescopes surveying millions of galaxies over wide swaths of sky, guaranteeing that we'll see star-shredding action in the distant universe.

The Search Is On

Astronomers discovered the first candidate black-hole-shredded stars, dubbed *tidal-disruption events*, using the ROSAT satellite, which was launched in 1990 to survey the low-energy X-ray sky (100 to 2,000 electron volts). A decade after the launch, astronomers analyzing the satellite's vast database noticed several otherwise normal galaxies that had briefly flared in X-rays.

Follow-up observations from the Hubble Space Telescope confirmed these were not active galaxies — the central black hole had been truly dormant before the mysterious X-ray bursts appeared. And Chandra X-ray Observatory images taken 10 years after the initial flares showed that the X-rays had indeed faded away over time. In contrast to the theoretical research described above, calculations based on eight years of ROSAT observations show that a galaxy's central black hole might gobble a close-passing star every 100,000 years or so.

The Chandra and XMM-Newton X-ray satellites continue to find additional candidates with properties similar to the ROSAT-discovered flares. A black hole's brief, star-fueled feeding frenzy explains the rate and other properties of the X-ray flares. But their discovery years after the



Black Hole Eats Star

1. A star passes too close to a supermassive black hole.

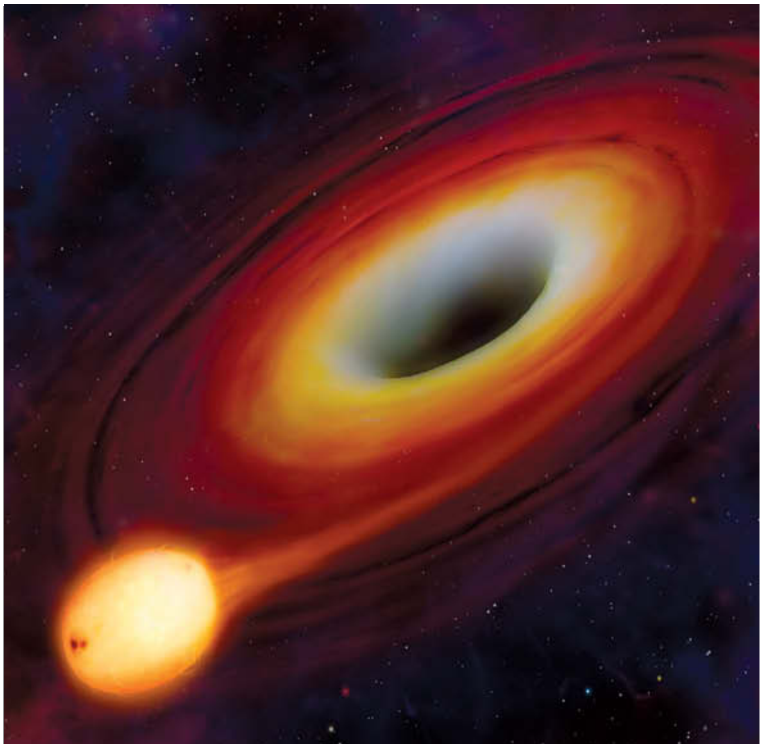
2. The black hole's gravitational pull tears the star apart.

3. Half the stellar remains stream toward the black hole, forming a brightly glowing disk by which astronomers can detect the event.

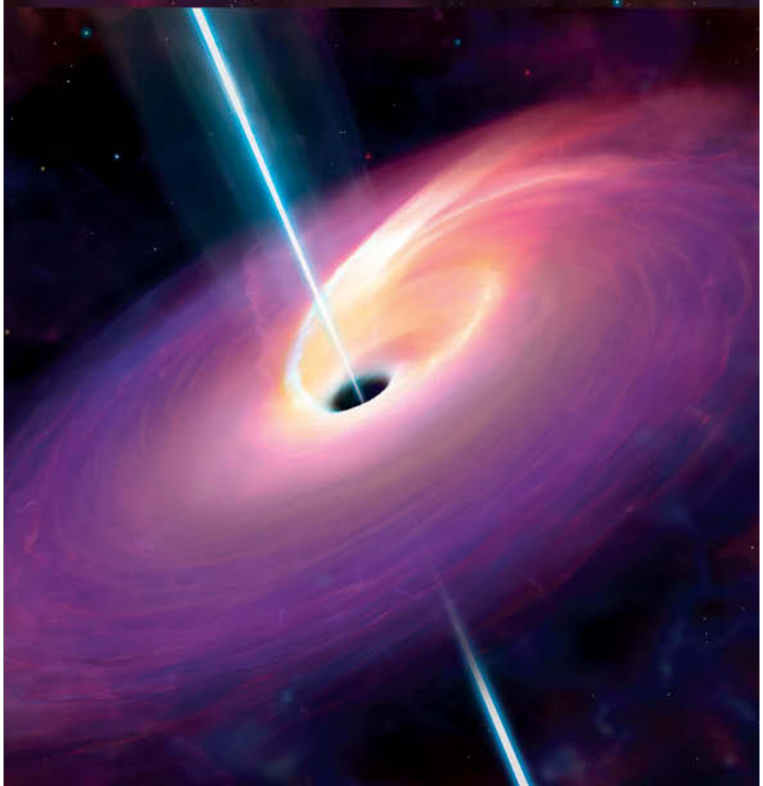
4. Magnetic fields near the black hole can power a jet of particles moving near the speed of light. Viewed head-on, this jet is a powerful radio and X-ray source.

S&T: LEAH TISCIONE (4)

> Powerful telescopes surveying millions of galaxies over wide swaths of sky guarantee that we'll see star-shredding in action.



STELLAR DISRUPTION Once a star passes within reach, a 1-million-solar-mass black hole takes only half an hour to tear it apart.



CONSEQUENCES The optical and ultraviolet flares occur many months later, after the stellar remains have spiraled inward. This artist's conception includes a relativistic jet powered by the gaseous disk.

UNIVERSITY OF WARWICK / MARK GARLICK (2)

initial outbursts limits further study.

Understanding these transient events requires catching them in action. When a supermassive black hole chows down on tidally disrupted debris, the temperature of the inspiraling gas can climb to 1 million degrees C (1.8 million degrees F). Most of the light is emitted as X-rays, but a tail of emission extends to longer, ultraviolet and optical wavelengths. The Galaxy Evolution Explorer (GALEX), a space telescope launched in 2003, observes ultraviolet radiation, which Earth's atmosphere blocks from ground-based scopes. NASA designed GALEX's wide-field imaging capability to study galaxies' star-formation history, but I realized we could use the wide-field instrument to search among hundreds of thousands of galaxies to find tidal disruption events as they happen.

GALEX repeatedly observed patches of sky over a three-year period to create images with long exposure times and deep sensitivity. My team examined these fields and identified three luminous ultraviolet flares coming from otherwise normal-looking galaxies. The same flares appeared simultaneously in visible-light observations taken as part of the Canada-France-Hawaii Telescope (CFHT) Legacy Survey.

Combining ultraviolet and visible-light information, we found the three flares came from gas glowing at temperatures greater than 50,000°C, almost 10 times as hot as the Sun's visible surface. The gas remained hot for the duration of the flare, which faded according to theoretical predictions for shredded stellar debris accreting onto a black hole. Chandra X-ray observations showed that the flares were faint in high-energy X-rays, so ongoing accretion in active galaxies can't explain these events.

A search of archival data from the Sloan Digital Sky Survey (SDSS), a visible-light study of more than a quarter

Before the star met its untimely end, it had already lost its outer layers, exposing its helium core.

of the sky, revealed two additional tidal-disruption candidates. In these events, flaring gas glowed at temperatures greater than 20,000°C. Their light faded in the same way as the transients discovered in the GALEX images, with the gas remaining hot over time. But the observations weren't frequent enough to estimate how long the flare took to reach its peak brightness, information that would have allowed us to estimate the black hole mass.

We discovered a sixth candidate by combining the GALEX survey with simultaneous observations from Pan-STARRS 1, a 1.8-meter telescope on the summit of Haleakalā, Hawaii, that scans the northern sky for visible-light transients. In June 2010 these telescopes caught a

To see video animations of star-shredding black holes, go to **skypub.com/star-shredders**.

flare at the center of a distant galaxy and monitored the outburst as it brightened to a peak a month later before fading away over the following year.

This time, we could model the changing brightness using tidal disruption simulations; we estimated a mass of 2 million Suns for the central black hole. More surprising was the nature of the star it had captured.

The stellar debris consisted of fast-moving helium stripped of its electrons — surprisingly, there was no accompanying hydrogen. This is odd, since stars are usually made mostly of hydrogen and only a little helium. Before it met an untimely end, this star had already lost its outer layers, exposing its helium core. Very massive and short-lived stars can lose their hydrogen envelopes through winds, but the host galaxy's stars are too old and long-lived for winds to be the culprit.

More likely, the star had lost its hydrogen envelope during a previous pass around the black hole (*S&T*: Aug. 2012, page 12). A star near the end of its life might have bloated into the red giant phase, which would have made it more vulnerable to tidal stripping. Other studies suggest this star was not one of a kind — red giants stripped of their hydrogen envelopes are likely to dominate the stellar population near a supermassive black hole.

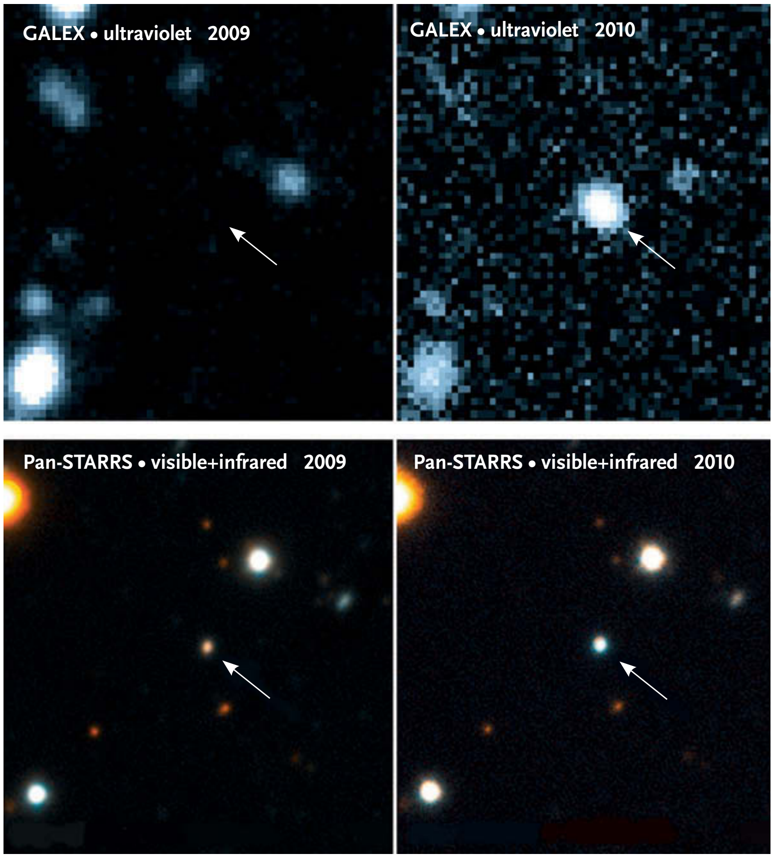
The Birth of a Jet

The discovery of Sw J164449.3+573451 in March 2011 heralded a major paradigm shift in the search for tidal-disruption events. At first astronomers mistook this flare for a gamma-ray burst whose X-ray glow ought to have lasted for minutes. But when the flare continued for more than a week, it became clear that this event was something completely different.

High-resolution follow-up images from the Gemini North Telescope on Mauna Kea, Hawaii, and the Very Large Array, a radio observatory in New Mexico, placed the flare within the host galaxy's nucleus. This position strongly suggests that the nature of the flare has something to do with the central black hole. The black hole's mass, estimated to be 10 million solar masses given the galaxy's size, is in the right range to tidally disrupt a star. And archival X-ray observations showed that it had been dormant before the flare occurred.

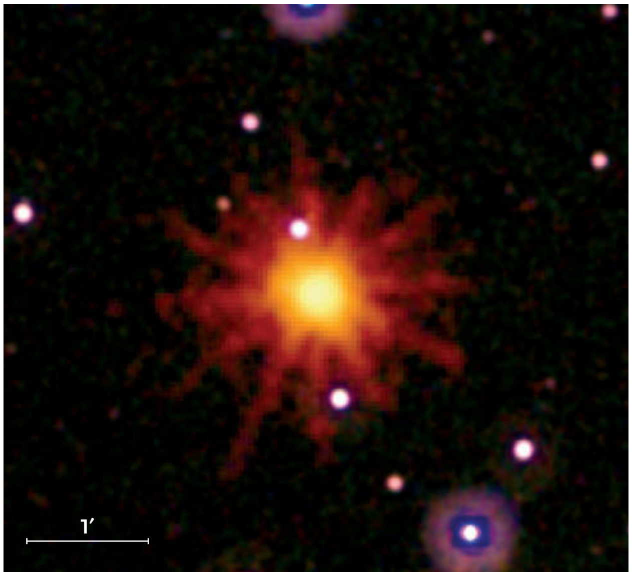
But that's where the agreement between theory and observation ends. Observations measured the flare's X-ray luminosity to be 100 times brighter than the maximum output allowed for a black hole of that mass. Above this maximum, the pressure from the radiation ought to blow away the accreting gas and shut off the flare.

One way to explain this apparent contradiction is if the shredded star fuels an ultra-speedy jet. Special relativis-



NASA / S. GEZARI (JHU) / ARMIN REST (STSCI) / RYAN CHORNOCK (CFA)

BEFORE AND AFTER The GALEX satellite and Pan-STARRS 1 telescope caught a flare in ultraviolet and optical light, respectively, from a galaxy 2.7 billion light-years away. The outburst shows the distinct signatures of a black hole tidally shredding a helium-rich star.



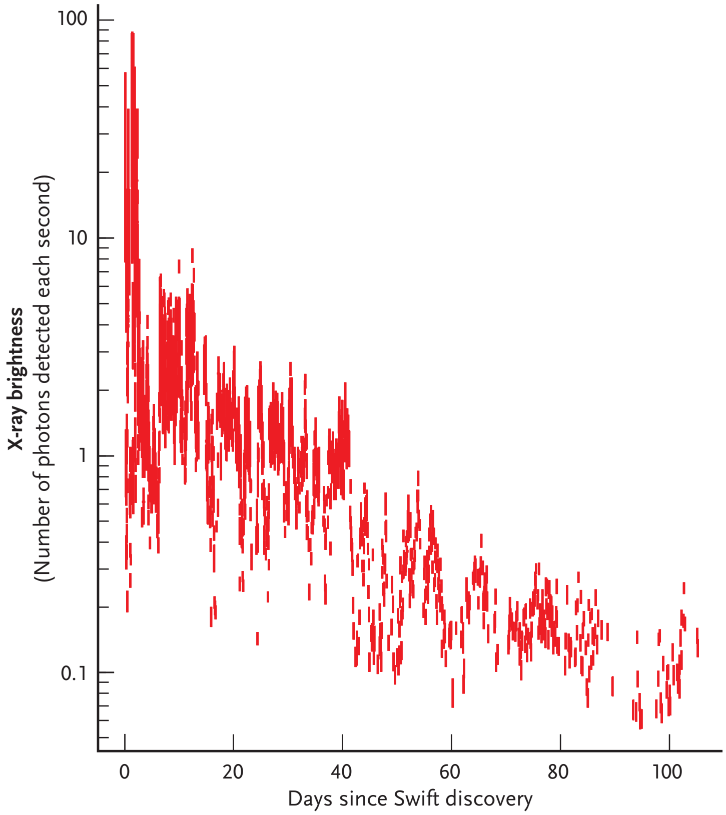
NASA / CXC / MIT / F. BAGANOFF, R. SHCHERBAKOV ET AL

TIDAL FLARE The Swift satellite spots an intense X-ray flare (yellow and red) from a tidal-disruption event known as Sw J1644. X-rays penetrated the heavy dust cover that hides the corresponding optical and ultraviolet light (white and purple) from view.

tic effects in the fast-flowing material would amplify the radiation observed. Rapidly brightening radio emission confirmed that material is indeed moving close to the speed of light, so the most likely explanation for Sw J1644 is that the inward-spiraling stellar debris from a tidal-disruption event powered a relativistic jet pointed our way.

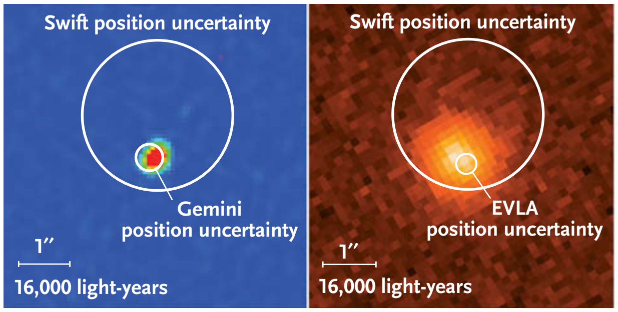
Do all shredded stars fuel jets? Probably not — we would have detected jet signatures in other tidal-disruption events had they been present. One barrier to forming jets is generating the necessary magnetic field; stellar magnetic fields aren't strong enough on their own. The field fueling Sw J1644's jet must have come from somewhere else, such as from instabilities in the newly formed accretion disk feeding the black hole. Astronomers continue to monitor Sw J1644 at radio wavelengths to watch what happens as the jet plows through the ambient gas surrounding the feeding black hole.

Unfortunately, corresponding optical and ultraviolet studies of the accretion disk are impossible because dust hides the black hole from view. But there are other ways of learning about the stellar debris as it swirls into the black hole. Rubens Reis (University of Michigan) reported in the August 2, 2012, *Science* the discovery of a 200-second



FADING LIGHT **Swift's X-ray Telescope observed Sw J1644 for three months after the first flare on March 28, 2011. The light faded over time as the black hole gobbled the shredded star.**

S&T: LEAH TISCIONE, SOURCE: NRAO / CFA / ASHLEY ZAUDERER ET AL



NASA / SWIFT / STEFAN IMMLER

LOCATING A FLARE **The Swift satellite's position uncertainty is too large to precisely locate the X-ray flare named Sw J1644. But the high-resolution Expanded Very Large Array image (*left*) located the simultaneous radio flare: it was coming from a distant galaxy's nucleus, imaged by the Gemini North Telescope in Hawaii (*right*). A nuclear outburst of this magnitude hints that the central supermassive black hole was involved.**

periodic signal in Sw J1644's light curve (*S&T*: Nov. 2012, page 14). This period corresponds to the orbit of material around the black hole, tantalizing evidence that ties the jet to the accretion of stellar debris.

Just two months after Sw J1644's discovery, a team led by Bradley Cenko (University of California, Berkeley) detected a similar event called Sw J2058. This time, observations show evidence of a flare both from the swirling stellar debris and from a relativistic jet, so astronomers will be able to study both processes in the same system.

The future is bright for transient searches. Several ground-based surveys are in the works, including the Large Synoptic Survey Telescope (LSST), which plans to photograph the entire available sky twice each week once it goes online early next decade. LSST could potentially discover thousands of shredding events per year. Astronomers have proposed additional surveys with wide-field X-ray telescopes, such as the eROSITA instrument to be launched in 2014 aboard a Russian satellite.

In just a few years, the hundredfold or so increase in number of detections will make it possible to study tidal shredding events en masse. We can then use the light from these feeding frenzies to weigh galaxies' central black holes over cosmic time and piece together the history of black hole growth.

Since visible light, radio waves, and X-rays each reveal a different view of the star-shredding process, following up on discoveries with observations across the electromagnetic spectrum will be key. Only then can we turn tidal-disruption events into cosmic laboratories, which provide our only direct view of the mysterious beasts slumbering in the hearts of distant galaxies. ✦

***Suvi Gezari** is an assistant professor in the Department of Astronomy at the University of Maryland, and has been on the hunt for star-swallowing black holes for over seven years.*

A Galactic Snack

SLEEPING BEAUTY NASA's Chandra X-ray Observatory peered into the Milky Way's center for two weeks to create this image, where red, green, and blue represent low, medium, and high-energy X-rays. Supernova remnants, pulsars, and hot gas all contribute to the X-rays seen here. The Milky Way's dormant black hole sits at the center of the bright, white cloud.

In April 2011 Stefan Gillessen (Max Planck Institute for Extraterrestrial Physics, Germany) was reviewing Very Large Telescope observations of the Milky Way's center when, to his delight, he saw something new.

For the last two decades, astronomers have watched stars zip around the dormant supermassive black hole lurking in the center of our galaxy, using near-infrared observations to penetrate the heavy cover of dust and gas. Those observations have pinned the black hole's mass at 4.3 million Suns. But in the 2011 observations, Gillessen saw something no one had noticed before, an object that showed up only at the longest near-infrared wavebands.

The MPI team estimated the object, named G2, radiates at 280°C (535°F), far too cool to be another star. Instead, their measurements show it's a dusty gas cloud with as much mass as three Earths, and it's speeding almost straight for the black hole. By the time G2 makes its closest approach in mid-September, it will be traveling at 6,300 kilometers per second (14 million mph), passing within 27 billion km of the black hole's event horizon. If the object really is a fluffy gas cloud, rather than a denser star, the black hole's tidal forces will rip it apart.

"The black hole is currently eating only a hundredth of a millionth of a solar mass per year," Gillessen explains. "The cloud will increase that rate by roughly a factor of 250. That's quite a reasonable snack for a black hole."

The Milky Way's central black hole is quieter than any other we can observe. It has relatively little fuel to feed on, so the passage of G2 will give astronomers a rare opportunity: potential front-row seats to the stirrings of a sleeping beast.

According to Gillessen's team, the black hole's gravity is already tidally stretching the cloud along its direction of travel. In the process, the cloud should eventually heat to more than 10 million degrees C, producing X-rays 30 times stronger than the occasional X-ray flares coming from the black hole's immediate surroundings.

Over the next 30 years or so, the cloud's gas will mix with the thin, ambient gas to feed the black hole a substantially greater diet than it's used to, perhaps eventually forming a jet that flies outward along its poles. "It would be extremely exciting if we could actually see how that jet developed," Gillessen notes. "That would teach us how these jets are formed, a process which is essentially unknown."

Not all scientists agree with the MPI team's optimism. "Our group has a very different interpretation," says Andrea Ghez (UCLA).

The UCLA group suggests that a star embedded in a dusty envelope explains the same data. Moreover, unlike the MPI group, the UCLA group does not detect spectroscopic evidence of the shape change expected if the object were a cloud instead of a star.

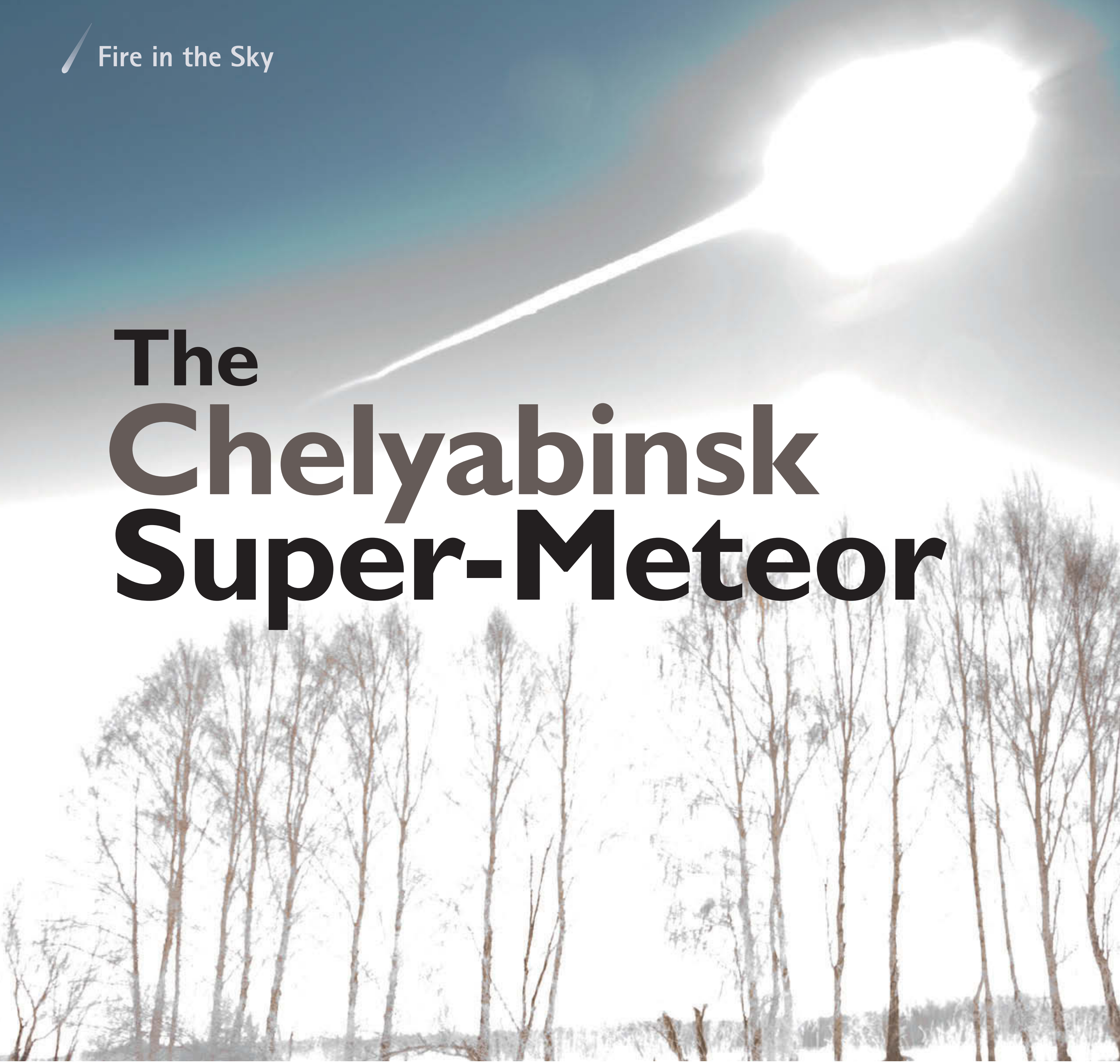
"I would bet that we are not going to see great fireworks later this year," says Ghez. "It's going to be just one more star making its closest approach to the black hole."

In fact, other stars have whipped by closer than G2's imminent passage. At these distances, stellar self-gravity wins out over the black hole's gravitational tug — a star would have to come over 100 times closer to risk being torn apart.

Gillessen doesn't dispute that G2's close-pass in September might be uneventful. "We might see nothing. You never know."

But Ghez herself adds, "We'll all have fun looking later this year."

— *Robert Zimmerman*



The Chelyabinsk Super-Meteor

Daniel D. Durda

Scientists are piecing together the story of the largest asteroid impact with Earth since 1908.

On February 15, 2013, the planetary science community was geared up for a big news story: the very close approach of asteroid 2012 DA_{14}. This event would remind the world of the potential danger of asteroid impacts.

Little did we know that Mother Nature had arranged a far louder wake-up call that morning. At 9:20 a.m. local time — just 16 hours before 2012 DA_{14} swept past Earth from the south — a small, westbound asteroid blazed through the dawn twilight over the Russian city of Chel-

9:21:35

MARAT AHMETVALEEV (2)

9:20:33

yabinsk. Dozens of dashcams captured the super-bolide, thanks to its occurrence over an urban area and the proclivity of Russian drivers to record their every move in order to protect themselves from fraudulent insurance claims. Videos posted on the internet captured the brilliant fireball and thundering sonic booms. And as reports poured in of shattered windows and damaged buildings, the reality set in around the globe that a meteor event can injure hundreds of people.

EYEWITNESS TO THE EXPLOSION

Marat Ahmetvaleev

I was taking pictures in a Chelyabinsk park with my Canon 5D DSLR camera on a freezing February morning. I leaned over to change the camera angle on the tripod to take another shot when suddenly I saw a bright flash with my peripheral vision. Initially it was small. My camera was aimed almost in the same direction, but I immediately turned it toward the object to take a picture.

At about the same time I started to hear a sound that resembled white noise with a slight rustle and crackle. The sound was barely audible but lasted for the meteor's entire flight. In the first seconds my heartbeat and breathing sped up, and my hands started to shake. When the flash's brightness peaked, I felt strong heat on my face, but it lasted just a split second. I also felt a strong pain in my eyes from the intense glare.

Then, two minutes after the flash, I heard a series of explosions — the sound was clear and powerful, reminiscent of drumbeats. The first explosion was very loud, and I felt a wave of sound. I felt no physical sensations or vibrations from concrete structures or roads because I was in an area with pine trees. Immediately after, I heard a series of bomb-like sounds, and many birds flew in all directions. My heartbeat, breathing, and tremors increased from the shock of this event.

Only after the series of explosions ended did I start to return to normalcy, and I was then able to set the correct exposures and camera angles to shoot a few panoramas showing residual traces of the meteor. The surrounding scene changed. It looked like the sky was bluer and more transparent. The Sun had already risen, but its brightness was like no typical morning Sun — it looked like the Sun at its zenith.

I had a hurricane of thoughts in those first few seconds, and not in the most positive way. One of my initial thoughts was the explosion of a nuclear bomb. Then, given the insane speed of the object, I thought it was something from outer space. Immediately I began to think of the consequences for all the people and all my relatives in the city. A few minutes later I heard an ambulance and a fire alarm, which accentuated my negative thoughts. Only after I contacted my family on the phone did I begin to calm down and take more photographs.

Marat Ahmetvaleev's website is http://marateaman.livejournal.com.

RIGHT PLACE, RIGHT TIME Marat Ahmetvaleev was taking photos of the Miass River, which runs through Chelyabinsk, when a small asteroid exploded in the eastern sky. Ahmetvaleev captured the spectacle at peak brightness (*above left*) and as the train of debris dissipated over the course of 25 minutes (*above* and *pages 26 and 31*).

MARAT AHMETVALEEV

9:33:01

Characterizing the Blast

After an initial flurry of speculation, scientists needed only a day or two to sort out the basic astronomical facts. With the media and public focused on the impending close pass of 2012 DA_{14}, and with Hollywood's penchant for depicting threatening asteroids with swarms of smaller fragments, many people immediately wondered if the Russian meteor was somehow linked to 2012 DA_{14}. That suspicion was quickly erased when astronomers determined that the parent meteoroid had an eccentric orbit typical of an Apollo near-Earth-asteroid (NEA). This is wildly different from DA_{14}'s more Earth-like and inclined path.

For a few brief moments the meteor literally outshone the Sun in Chelyabinsk's dawn sky. Using models that relate a fireball's mass to its peak brightness, Peter Brown (University of Western Ontario, Canada) estimates the meteor's peak at a whopping absolute magnitude of –28 (compared to the Sun's –26.7 apparent magnitude).

Regardless of an incoming object's size, most of the energy for creating a meteor's luminous head comes from the shock-heated air surrounding it. Baked to temperatures as high as a few tens of thousands of degrees, the air becomes ionized (it turns into a plasma) and glows similar to the way a flame or lightning bolt does. The Chelyabinsk meteor impacted the atmosphere at a typical NEA speed, in this case about 18.6 km/seconds (42,000 mph). The shock formed from a meteoroid entering the atmosphere at such a hypersonic speed is truly intense. The plasma just millimeters from the meteoroid's surface radiated enough heat to vaporize the intruder's outer skin. This vaporized material was swept away by the hypersonic air flowing past, forming a trail behind the object that eyewitnesses saw as a luminous train in the sky.

Some of the first quantitative verification of the event's energy came from its infrasound signature. Since 2001, the Comprehensive Nuclear-Test-Ban Treaty Organization (CTBTO) has operated a global network of 45 microbarograph arrays to monitor the atmosphere for the low-frequency (less than 20 hertz) "booms" of nuclear blasts around the planet. The network is also sensitive to natural infrasound sources, such as volcanic eruptions and large bolides. The concussive atmospheric blast from Chelyabinsk was picked up by 17 CTBTO microbarograph arrays, including stations as far away as Greenland and Antarctica.

Almost immediately the infrasound data, along with the thermal infrared signature measured by space-based instruments such as those on U.S. Air Force Defense Support Program satellites, confirmed the large size. Initial reports indicated an explosive equivalent of at least 100 kilotons of TNT, and it wasn't long before the estimates climbed to a few hundred kilotons. The last meteor blast approaching this energy occurred over Sulawesi, Indonesia, on October 8, 2009; infrasound data put that bolide disruption at about 50 kilotons. The estimates of the Chel-

CHELYABINSK REGIONAL BRANCH OF RUSSIAN INTERIOR MINISTRY / AP IMAGES

IMPACT CRATER? Russian police stand near a 6-meter hole in the ice covering Lake Chebarkul, 70 km (45 miles) west of Chelyabinsk. Scientists are still investigating whether a fragment of the bolide punched through the ice to create this hole.

VIEW FROM SPACE An instrument on the European Meteosat-9 weather satellite caught the vapor trail (short white streak) of the bolide as it disintegrated.

EUMETSAT

WHAT ABOUT COMETS?

A few percent of objects that impact Earth are comets or their dormant remnants. Because comets often approach our planet on orbits that can be far more eccentric and highly inclined than those of typical asteroids, comet impact speeds tend to be significantly higher than those of asteroids. Retrograde, long-period comets can impact as fast as 72 km/second (161,000 mph), much higher than the average 17 to 20 km/second speed of most asteroids. Because of these faster average impact speeds, a comet impact will generally cause much greater damage than the impact of an asteroid of the same size.

yabinsk event have now settled in at about 440 kilotons (although this number may yet be refined) — nearly 30 times the yield of the Hiroshima atomic bomb.

This is the most energetic confirmed asteroid impact with Earth's atmosphere since the megaton-scale Siberian Tunguska airburst on June 30, 1908. We estimate that explosions roughly the size of Chelyabinsk occur about once per century, whereas Tunguska-like impacts thankfully happen only once every few centuries or so.

Blown to Bits

The fireball's brightness and the energy of the terminal explosion enabled scientists to estimate the diameter of the meteoroid prior to entry: about 17 meters (56 feet). The 11,000-metric-ton object probably experienced numerous impacts in space before its fatal encounter with Earth, so it may have already had substantial surface and internal cracks. It was catastrophically crushed to bits by the increasing dynamic pressure of a Mach 60 entry from the vacuum of space into the dense lower atmosphere (see "A Different Kind of Explosion," page 31).

The impactor's disintegration 23 km high showered fragments over hundreds of square kilometers, with some of the largest pieces estimated to weigh nearly half a ton. Rapidly braked and badly broken by the dense lower atmosphere, many of the meteorites simply fell to the ground rather than "impacting" in the manner of a large-scale cratering event. Most of the smaller fragments hit the snow-covered ground with speeds no greater than the terminal speed of an object dropped from the same high altitude, thus they remained mostly intact and left only small "entry wounds" in the snow.

Although astronomers have no formal definition for the term "impact," we have an intuitive sense that the object has to strike the ground with a significant fraction of its pre-entry speed still dominating its motion. Asteroids that are large, very dense (metallic), or both do not appreciably sense the atmosphere from a deceleration point of view; they really do "impact" the ground at speeds greater than the speed of sound and blast out craters. The biggest pieces of this Russian meteorite may

PAVEL MALTSEV (2)

ROCKS FROM SPACE Despite the extraordinary event in the sky, recovered meteorites are rather ordinary: stony chondrites with a low iron content. ***Far left:*** Viktor Grokhovsky of the Russian Academy of Sciences committee on meteorites is leading the recovery efforts. Hundreds of fragments collectively weighing more than 100 kg have been found.

ASTEROID ART: MICHAEL CARROLL; STADIUM PHOTO: BERNARD GAGNON / WIKIMEDIA COMMONS

SCALE MODELS Artist Michael Carroll depicts asteroid 2012 DA_{14} (left) and the Russian impactor (right) inside Heinz Field, home stadium of the Pittsburgh Steelers. Neither asteroid was imaged at high resolution, but this artwork accurately portrays their sizes. It's a good thing Earth was hit by the smaller object.

have slammed into the ground with some remnant of their original entry velocity. One of the largest chunks apparently punched a 6-meter-wide hole through the ice covering Lake Chebarkul, about 70 km west of Chelyabinsk.

The meteorites recovered so far suggest that this object was an LL5-type ordinary chondrite, among the class of stony meteorites with low iron content that are the most common to fall on Earth. A similar chondritic body four or five times larger blazed through the Siberian sky in 1908, exploding with a force of 3 to 5 megatons and leveling more than 2,000 square kilometers of taiga (**www.skypub.com/tunguska**). The Chelyabinsk event was in many respects a mini-Tunguska.

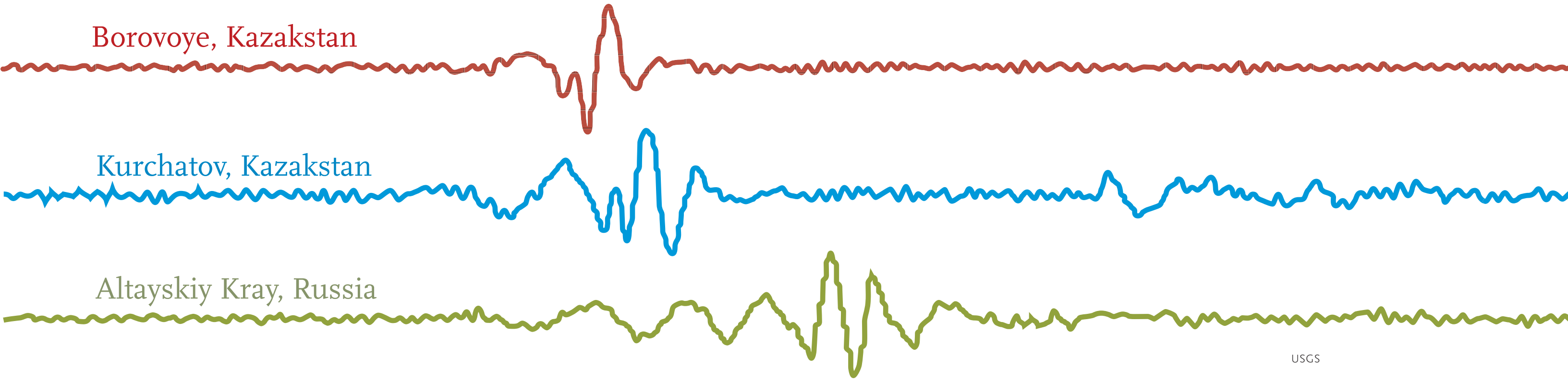
The video coverage of the bolide from many locations has enabled scientists to make a fairly robust determination of the asteroid's pre-entry orbit. By analyzing features such as the length and orientation of shadows from streetlight poles cast by the bolide, at least three different teams determined the 3-D trajectory of the terminal phases of the bolide's flight and backtracked that path into space, accounting for gravitational deflection as the asteroid approached Earth. Like several other recovered meteorites whose pre-impact orbits have been determined, this one moved along a fairly eccentric orbit with an aphelion comfortably in the middle of the main asteroid belt. Its orbital period was about 18 months.

The Human Impact

The shattered windows and collapsed walls throughout the 2,000-square-km area surrounding Chelyabinsk have provided a tangible example of the damage that even a relatively small NEA impact can cause. Had the explosion not occurred over a densely populated city of more than 1

ASTEROID OR METEOROID?

An *asteroid* is a small rocky or metal-rich object orbiting in space. A very small asteroid is often called a *meteoroid*. Although there is no formally adopted definition for the size dividing asteroids from meteoroids, for programmatic purposes NASA treats asteroids as objects detected telescopically in space before impact and meteoroids as objects that enter the atmosphere undetected. When a small object is plunging through the atmosphere, it's called a *meteor*. A piece of space rock that reaches the surface is known as a *meteorite*.



GROUND SHAKING Although the meteor exploded 23 km high, its shock wave produced ground motion equivalent to a magnitude-4.2 earthquake. These seismogram readings, in order of increasing distance, were all taken more than 620 km away.

million people, the event may have remained noteworthy only to the impact-hazard community. But the internet and airwaves were flooded with videos of the Sun-like fireball, recordings of thundering sonic booms, and images of bloodied faces due to flying glass — transforming the usually dispassionate, academic discussion of small asteroid impacts into a very real human story.

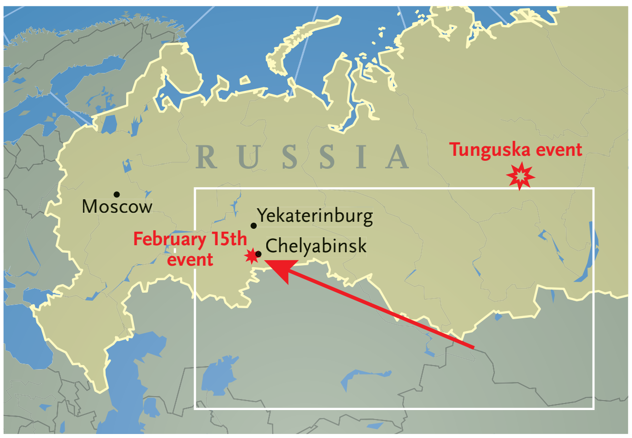
More than 1,500 people were injured and thousands more had to deal with blown-out windows in a Russian winter. Thankfully, no one was killed. In the grand scheme of things, it could have been far, far worse. If the meteoroid had penetrated the atmosphere on a steeper trajectory, instead of entering at a shallow 16° from horizontal, larger pieces might have made it to the ground intact, causing more damage, more severe injuries, and perhaps fatalities.

Some have wondered why astronomers failed to detect this object prior to impact. Interestingly, the meteoroid made its perihelion passage near the orbit of Venus just 6 weeks earlier, before approaching Earth from an apparent direction in the sky only about 20° from the Sun. Knowing the meteoroid's orbit and size, Bill Cooke (NASA/Marshall Space Flight Center) calculated that the object was

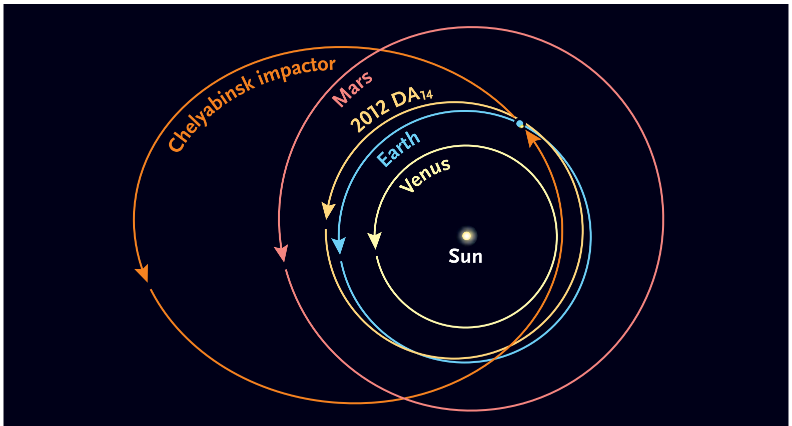
MIASS / WIKIMEDIA COMMONS

GROUND DAMAGE The shock wave from the object's rapid disintegration blew out windows and caused damage to buildings throughout the Chelyabinsk metropolitan area. Roughly 1,500 people were injured, mostly by flying glass.

GROUND ZERO These maps show the 254-km ground track of the Chelyabinsk meteor after it entered Earth's atmosphere above China's northwestern border with Mongolia. Studies of photos and videos indicate that the meteor was first seen when it was about 90 km above the ground. Its disintegration began about 11 seconds later at an altitude of 23 km (75,000 feet).

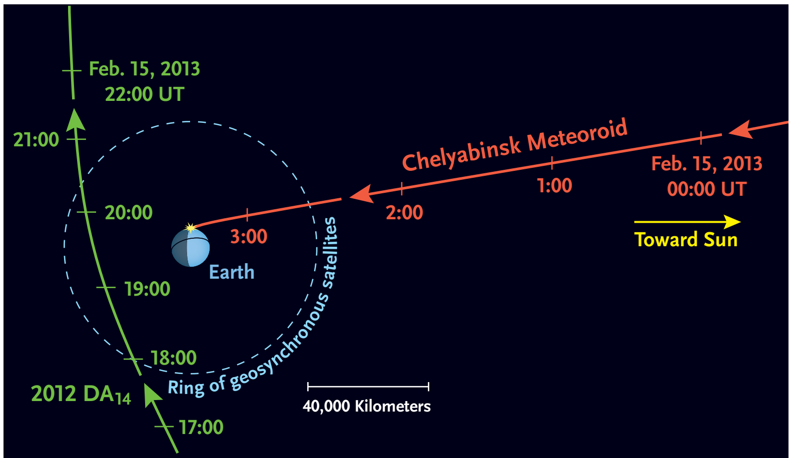


S&T: GREGG DINDERMAN (2)



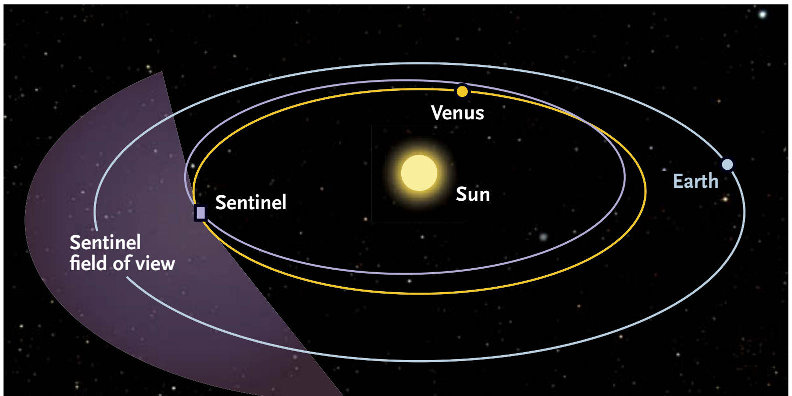
S&T: GREGG DINDERMAN

ORBITS The Chelyabinsk impactor had an eccentric orbit that carried it into the asteroid belt. Asteroid 2012 DA_{14} follows an orbit very similar to Earth's. DA_{14} will continue to have close encounters with Earth and may someday hit.



S&T: GREGG DINDERMAN

INCOMING! The Chelyabinsk impactor came from a different direction and about 16 hours earlier than 2012 DA_{14}, meaning that it was physically impossible for the two objects to be related. The Chelyabinsk meteoroid approached Earth from the direction of the Sun, which precluded any opportunity to observe it in the days prior to impact.



S&T: LEAH TISCIONE

SPACE SENTINEL Ball Aerospace and the B612 Foundation are partnering to build a privately funded wide-field infrared telescope known as Sentinel, which will be optimized to discover small asteroids in near-Earth space.

so faint that the largest asteroid survey telescopes, which can detect objects as faint as magnitude +24 under ideal dark-sky conditions, would not have seen it until just two hours before impact. But when Cooke included the fact that the meteoroid was in the daytime sky near the Sun in the days before impact, it became obvious that we never had a chance to see it coming.

What about future events of similar magnitude? Can we develop the capability to routinely detect such small objects and perhaps even have the technology in place to prevent their impact? And is it even worth the cost?

We do, of course, occasionally spot objects this size during close approaches in the course of our ongoing surveys. But those surveys are currently designed to meet the 1992 Spaceguard Survey Report goal of finding 90% of near-Earth objects larger than 1 km; they only serendipitously catch smaller objects during favorable viewing circumstances. With the Spaceguard goal now effectively achieved, we have eliminated most of the risk from global-scale, civilization-ending asteroid impact events during our lifetimes and the lifetimes of our grandchildren. We're now shifting attention to smaller potential impactors. But how do we decide how small is small enough?

To address these questions, NASA and the impact-hazard community have performed a cost/benefit analysis. How does the cost of detecting and preventing the impact of objects of a particular size match up against the cost of the damage and loss of life that would be incurred if one of those objects were to impact a populated area? Even though its impossible to assign a value to human life, scientists have done their best to weigh the tragic consequences from impacts of objects as a function of size, the frequency of such impacts, and the cost required to survey any given size of potential impactor to 90% completeness.

From these calculations, NASA's Near-Earth Object Program is focusing its efforts on finding 90% of the estimated 100,000 near-Earth objects larger than 140 meters across, using a number of ground-based telescopes either in operation now (such as those used by the Catalina Sky Survey, Spacewatch, and LINEAR) or in the development or planning stages (Pan-STARRS and LSST). Such a survey will also detect a fair number of smaller objects, but only a very small percentage of the estimated 80 million objects similar in size to the Chelyabinsk asteroid. Clearly, we have a lot of work to do.

While that search is ongoing using ground-based telescopes, several studies have concluded that a space-based wide-field infrared telescope would significantly speed things up. The nonprofit B612 Foundation and Ball Aerospace & Technologies Corporation are in the design and early development phase to build and operate just such a telescope with private funding (*S&T:* October 2012, page 13). Their Sentinel spacecraft, to be launched in 2017–18 and operated from my hometown of Boulder, Colorado, will survey near-Earth space from a Venus-like orbit around the Sun, which will significantly improve the efficiency of NEA discovery during its 6.5-year mission. Sentinel will survey 165 square degrees of sky every hour using its 5- to 10.4-micron infrared detector. Like its ground-based telescopic cousins, Sentinel will also discover many smaller NEAs down to 30 meters across, increasing the chance of cataloging some Chelyabinsk-size impactors long before their terminal approach.

Like the 1994 impact of Comet Shoemaker-Levy 9 into Jupiter's atmosphere, the Chelyabinsk event provided a particularly alarming wake-up call that we indeed live in a cosmic shooting gallery, and that asteroids, even tiny ones, pose a threat. The Russian meteor serves as a stark reminder that, behind the statistical analyses and numerical models, people going about their daily lives are the reason we're in the business of watching the skies. ✦

__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 Earth. He is also a member of the B612 Foundation's Board of Directors and an accomplished artist and pilot.

A DIFFERENT KIND OF EXPLOSION

The demise of the Chelyabinsk bolide was caused by a very rapid transformation of kinetic energy to heat and vapor. The first structural flaws to be exploited by the crushing pressure of entry caused some initial fragmentation that immediately increased the drag and pressure of the resulting pieces. This, in turn, made it easier for those pieces to break up, causing a rapid runaway disintegration.

The booms heard on the videos came from the ballistic shock of the entering object and its subsequent fragments (like an aircraft sonic boom), and the shock from the intense mass loss and vaporization associated with the terminal airburst. The fireball vapor expanded supersonically and produced an even more intense boom than the ballistic shock alone. Earth's atmosphere is quite thin and fragile compared to those of several other planets in the solar system, but it effectively shields us from impacts of house-size rocky asteroids such as this one, and even larger objects up to about 100 meters in diameter.

9:44:03

MARAT AHMETVALEEV

THE STORY OF

Einstein's Telescope

A telescope made specifically for the iconic physicist was long forgotten, but it has recently been brought back to life.

Eden Orion

EDEN ORION

A telescope made for Albert Einstein is now on display in Jerusalem.

One night in December 2007, I received a phone call from the Hebrew University in Jerusalem. The caller told me that he heard my lecture about telescope making, and asked me if I would be interested in fixing one of their old telescopes. "Who was the original owner of the telescope?" I asked.

"Einstein," the caller replied.

"Albert?" I inquired.

"Yes. It was his telescope," the man said. "He donated it to the university many years ago. He wanted Israeli kids to look through this telescope and discover the wonderful science of astronomy." The caller asked whether I could do this project.

I had already made several telescopes of various sizes, so I assumed I could do the job. After several meetings, I took on the project in early 2008. I went to the Joseph Meyerhoff Youth Center for Advanced Studies at the Hebrew University, where the telescope was kept. It was standing in the entrance hall on an equatorial mount. I saw that it was an 8-inch Newtonian reflector with a focal ratio of approximately f/8.

When I first opened the mirror cell, I didn't realize there was any mirror there at all. It was so dirty and dusty that it looked like it contained a thick aluminum blank. I asked permission to rinse it with water, but it took about 30 minutes before I could even tell that it was in fact a telescope mirror. The years in storage had left their mark, but the mirror was still in observing condition.

On the back of the mirror glass I found a hand-inscribed engraving: "Zvi Gezari TMML 1952, Optical Division, Jul – 15- 1952, Hyden Planetarium NY NY." Having seen this engraving, I began a journey to discover who this man was — Zvi Gezari, the maker of Einstein's telescope.

DANIEL AND WALTER GEZARI

DELIVERY DAY **Manhattan-based amateur astronomer Zvi Gezari (seated on right) delivered his handmade 8-inch Newtonian reflector to Albert Einstein on May 14, 1954, at the physicist's home on Mercer Street in Princeton, New Jersey. An unidentified Princeton University staffer is looking up the tube.**

The Telescope Maker

I learned that Zvi Gezari was born in Poland in 1910. In 1928 he emigrated to Palestine, where he joined the Mishmar Ha'Emek kibbutz. There, Gezari met his future wife Temima, a young American painter. After several years, Temima returned to the U.S. and Gezari began his engineering studies at the Technion (Israel Institute of Technology). Temima returned to Palestine in 1938, and in 1939 they married in Tel Aviv. Shortly thereafter they moved to the U.S., where Zvi and Temima built their family home on Long Island and had two sons, Daniel and Walter.

Zvi Gezari was a serious amateur astronomer who built an observatory next to his house. His son Daniel later became a senior astrophysicist at NASA's Goddard Space Flight Center in Maryland. Daniel's daughter Suvi also became an astrophysicist, and now works as an assistant professor at the University of Maryland (she authored the article on black holes beginning on page 16).

The telescope built by Zvi Gezari has many interesting characteristics. For example, the bolts on the optical tube were in inches, whereas the bolts on the mount were in metric units. The explanation came while I spoke with Gezari's relatives in Israel. They told me that the mount

THE GEZARIS
Top: **Zvi Gezari, the builder of Einstein's telescope, reads to his sons Daniel (right) and Walter circa 1953 in their Manhattan home.** ***Below left:*** **Zvi Gezari poses with his wife Temima sometime around 1969. Temima was a painter, sculptor, and educator who specialized in children's art; she lived to the age of 103.** ***Below right:*** **On the day Albert Einstein received his telescope, the great physicist met Daniel (right) and Walter Gezari, ages 11 and 9. Daniel later became a NASA astrophysicist; Walter developed businesses in medical equipment and marine technology.**

GEZARI FAMILY

RICHARD SOLO

ZVI GEZARI

was made with parts that came from German artillery used in World War II. From Gezari's point of view, it was an expression of Isaiah 2:4: "They will beat their swords into plowshares and their spears into pruning hooks."

Gezari was an industrial engineer, and president of the fabricating division of a major steel-pipe distributor firm. But his real love was astronomy and building telescopes. He first met Einstein in 1953 at a science conference in New Jersey. According to Daniel Gezari's recollections, when Einstein learned that Zvi Gezari was an amateur astronomer who ground mirrors and built telescopes, he said to Zvi, "I envy you."

"You envy me?" Gezari replied. "You're Albert Einstein! Why should you envy me?"

"Because you can build a telescope with your hands. I can't build anything with my hands," Einstein answered.

Gezari responded, "But you don't need to build a telescope, you can use any telescope in the world."

Einstein then confided that he had never looked through a telescope. "I've been invited to the dedication of several new observatories, but no one ever asked me if I wanted to take a look through the telescope."

Zvi said he'd be honored to make a telescope for him. Einstein replied that he couldn't possibly accept such a generous offer, and mentioned an experience he had when a company had wanted to give him a telescope but that it had resulted in a lot of publicity he hadn't expected. Gezari recalled that there was a high school being built in Israel in honor of Einstein (the Albert and Elsa Einstein School in Ben Shemen). Gezari said he would build the telescope for Einstein, and deliver it to him so he could use it, and that after he was finished he would make sure the telescope was donated to the Einstein School on Einstein's behalf. Einstein said he would certainly accept the offer if the telescope was later given to the school. So Gezari built the telescope over a period of about six months in the New York Amateur Astronomers optical shop in the basement of the Hayden Planetarium at the American Museum of Natural History.

ISRAELI ASTRONOMICAL ASSOCIATION

TEMPORARY HOME **Einstein's telescope was moved to the Williams Planetarium in Jerusalem in 1962, where it remained for several years until the building and all its contents (including the telescope) were transferred to the Hebrew University in Jerusalem. This photo, taken in 1965, shows members of the Israeli Astronomical Association.**

The Travels of a Telescope

On May 14, 1954, Zvi and his two sons loaded the telescope in their family station wagon and drove it to Einstein's house on Mercer Street in Princeton, New Jersey. After meeting the great scientist, they unloaded the scope and assembled it in Einstein's garden, and spent the afternoon at his residence. A number of photographs document the event, including pictures taken by the Gezaris and by reporters from the *New York Times* and *Herald Tribune*. These photos prove that the telescope found several decades later in Jerusalem was indeed Einstein's telescope. One can easily recognize Einstein and Gezari in these pictures.

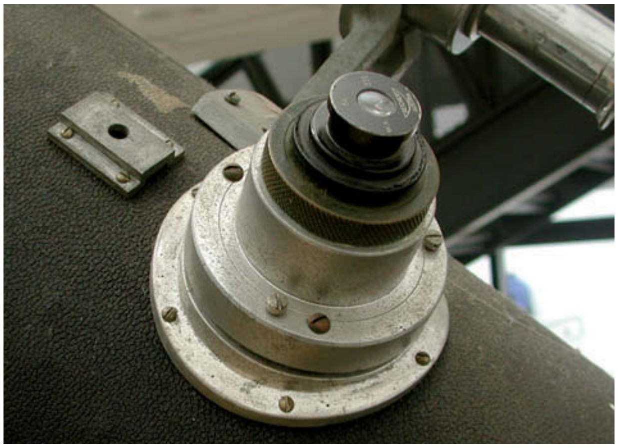
Daniel Gezari recently e-mailed me his recollections from that day:

> "Einstein was the most kindly and gentle person I have ever met. He spoke excellent English, but with a soft, strong German accent. He smiled easily and talked freely with us all, particularly with dad. The two of them seemed to hit it off quite well, possibly since both were Jews who had lived through the difficulties of post-World War I Europe.
>
> Einstein was very friendly to us boys and spent a lot of time with us that afternoon. We had brought him a tropical seashell as a gift, so he took us up to his study and took the top page of the work he was doing that day — with some very complicated tensor mathematics and comments in German on it — and

EDEN ORION

SUVI GEZARI

BACK IN BUSINESS **After years in storage, Einstein's telescope was restored to service by author Eden Orion. *Left*: Hanoch Gutfreund, chairman of the physics department at the Hebrew University (and former president of the university), cuts the ribbon at the Einstein Telescope inauguration ceremony in September 2008. *Right*: Zvi Gezari's granddaughter Suvi uses the telescope at the Joseph Meyerhoff Youth Center in Jerusalem. She authored this issue's cover story on black hole tidal-disruption events (see page 16).**



EDEN ORION (2)

TELESCOPE UP CLOSE ***Top*****: The 8-inch primary mirror was covered in grime before being cleaned.** ***Above*****: The helical focuser and nonstandard eyepiece are seen close up.**

> autographed it to us, signing it with his very familiar signature 'A. Einstein.' I was a kid, so I asked him, "Why didn't you sign it Albert Einstein?" He answered, "I only sign 'Albert' on checks."

As previously agreed, Einstein dedicated the telescope to the Einstein School in Ben Shemen, and the telescope was flown to Israel after the great physicist passed away on April 18, 1955.

The telescope was delivered to Ben Shemen as planned, and stayed there for several years. In 1962 the telescope was transported to the Israeli Astronomical Association's Williams Planetarium Building in Jerusalem. In a later legal proceeding, that building and all of its equipment — including Einstein's telescope — were transferred to the authority of the Hebrew University. Then the telescope was moved to the National Library in Jerusalem, where it seems to have been forgotten for several decades.

Eshel Ophir, a Hebrew University biologist and former head of the Science Oriented Youth Unit of the University of Jerusalem, discovered it in 2004 after being told by a technician that two old telescopes were sitting in the cellar. Only after comparing the reflector with photos from the Einstein Archives at the university did Ophir and his colleagues recognize it as Einstein's telescope.

Restoring the Telescope to Life

Having received the telescope for restoration work, I noted that it lacked the front spider assembly and that its helical eyepiece focuser was badly stuck. It took about two months in a bath of chemicals to release it. Then, using Vaseline as a lubricant, it operated smoothly again. The eyepieces found with the telescope were less than 0.975 inches across, too small to fit the original focuser, nor did they fit any modern 1¼- or 2-inch focuser. I thus had to machine a new insert for the focuser so it would accommodate modern 1¼-inch eyepieces. Since it lacked the spider and secondary flat mirror, I installed four new spider vanes and a Newtonian diagonal flat mirror according to calculations made from the initial measurements.

Since the telescope tripod and mount were made partly from World War II German artillery parts, it was quite heavy. I had to design a strong wheeled base that would enable us to move the scope easily for outdoor observations. I made this base from thick Baltic-birch plywood that absorbs vibrations during movement.

On the evening of June 17, 2008, we took the telescope outside to make a first-light observation. We saw beautiful images of lunar craters and Saturn's rings. On September 25th of that year, the Hebrew University celebrated the Einstein Telescope inauguration. Former university president (and current chairman of the physics department) Hanoch Gutfreund spoke of the adventures of Zvi Gezari and his telescope to a large audience of young and old listeners.

The telescope is currently kept at the Meyerhoff Youth Center in Jerusalem. The Center is dedicated to introducing children and teenagers to science, technology, and the scholarly world. During interactive lectures, laboratory sessions, and workshops, the staff translates advanced-level science and scholarly ideas into terms accessible to children and young adults. The students are taught to think and work like scientists, scholars, and engineers, and are thus exposed to the joys of curiosity, followed by research and the satisfaction of answering their own research questions. Einstein's telescope is an important educational tool. It's kept on display in the lobby in a special glass cabinet where everyone can see it. Due to its delicate condition, it is brought out and used only during special events. Then, students and adults stand in line in order to enjoy its unique optical qualities. ✦

Amateur astronomer and artist ***Eden Orion*** *lives in northern Israel. He organizes many astronomical activities for the public, including lectures, star parties, and telescope making for educational projects and institutes.*

To see more photos of Einstein's telescope, visit skypub.com/einsteinscope.

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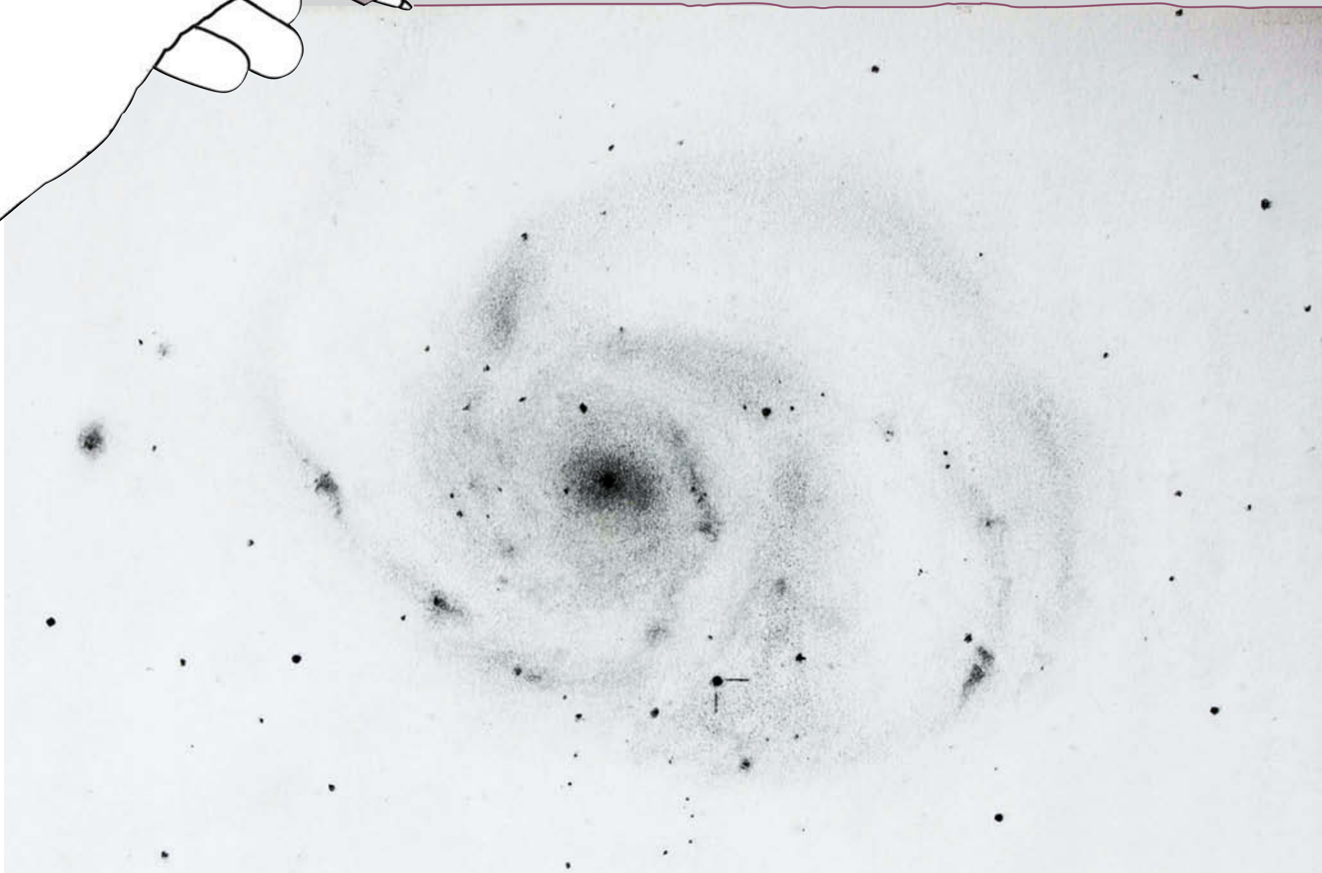
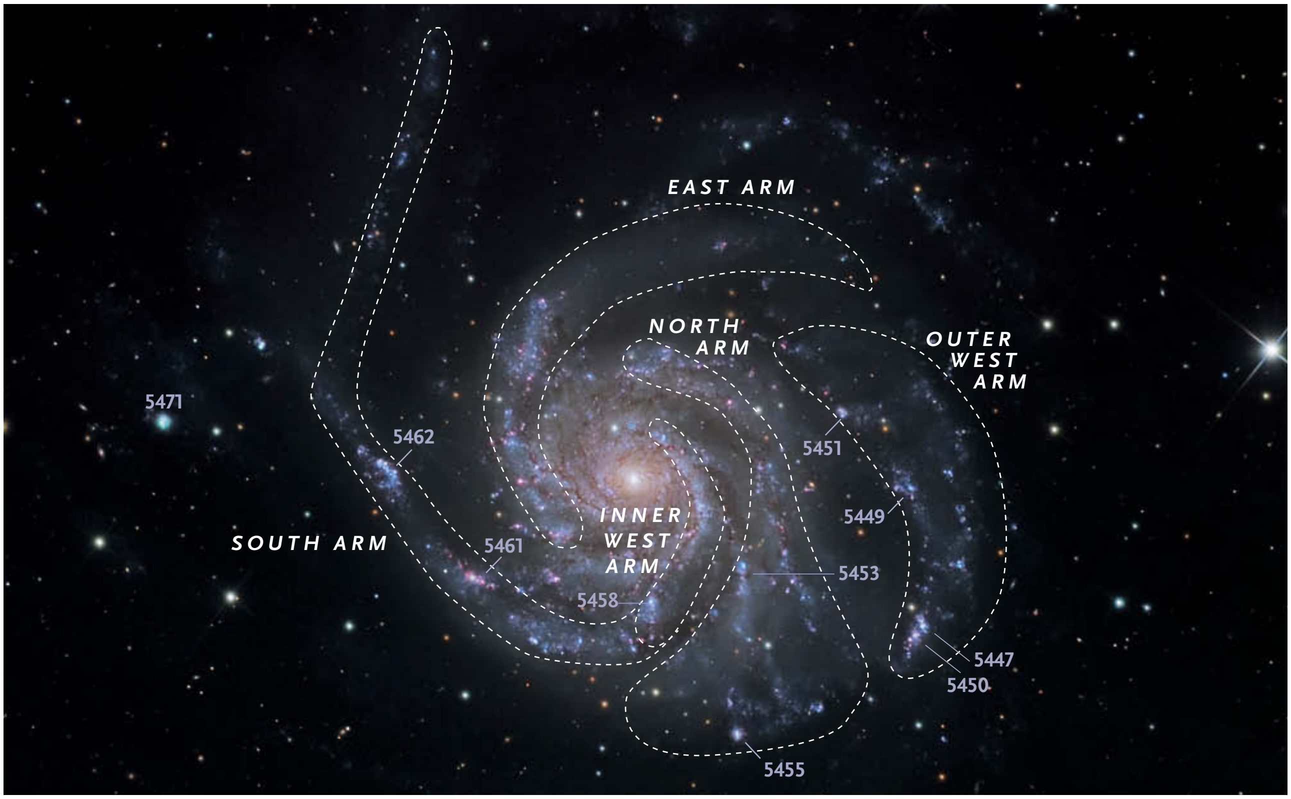
THE Determined Observer's Guide to M101

HOWARD BANICH



Few galaxies show as much detail as this dim, gigantic spiral does when viewed under dark skies.

HAND DRAWING: ©BIGSTOCKPHOTOS / JEREMY WEBSTER)



PHILIP PERKINS / WWW.ASTROCRUISE.COM

This splendid CCD image of M101 required almost 8 hours of exposures through a 12.5-inch telescope. NGC regions are labeled with their numbers, and the spiral arms are labeled as described in the text.

MY INTRODUCTION to Messier 101 was through Neale E. Howard's 1967 classic book, *The Telescope Handbook and Star Atlas*, where he described it as follows:

> An easy object for any telescope. Look for it just above the handle of the Big Dipper as the third vertex of a triangle in which the other two are Mizar and Alkaid. A spiral in large telescopes, you will probably see it as a large, pale object.

After four years of trying with a 3-inch f/15 Tasco refractor and my homemade 8-inch f/4 Newtonian, I finally spotted it on June 24, 1974, from my suburban Colorado front yard with the 8-inch. I made a quick sketch and wrote: "M101 was finally found, N. E. Howard is crazy."

If my skies had been darker, M101 would have been much easier to see, and Howard's description spot on. But like most observers, I lived and observed under light-polluted skies. M101 was my first lesson on how light pollution can render a deep-sky object invisible — or nearly so.

Unfortunately, M101 is even tougher to see now, because light pollution is worse than it was four decades ago. But I've recently had the good fortune to observe it under truly dark skies with my 28-inch f/4 motorized alt-azimuth Newtonian. I have currently spent nearly six hours observing and drawing this galaxy.

Facing page: **The author devoted seven sessions spread over the course of a year to sketching M101 at the eyepiece of his 28-inch telescope. The level of detail holds up well against the deep photograph at top.** **See page 40 for a labeled version.**

Unlike the much brighter M51, detail in M101 surrenders reluctantly; genuinely dark, transparent skies are essential. But as always, the more I observed and sketched, the more I saw. Practice really does help — and drawing even more so.

There is a potential pitfall, however. I'm familiar with M101's photographic appearance, and I have to be careful not to let that influence my observations. I'm always asking myself whether I'm really seeing a feature or just expecting to see it. Although my drawings are pencil renderings created in the dark with one eye closed while holding a dim red light between my teeth, I'm confident that only what I truly see ends up in my notebook.

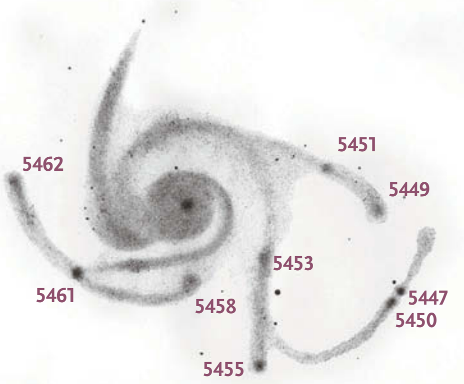
I will break down M101's features into three categories: easy, tough, and surprising. Your mileage will vary, of course. Even with identical equipment and observing conditions, different people often perceive things differently.

The features that I classify as "easy" were sometimes subtle but always apparent with direct vision. The "tough" features generally required at least some averted vision to see well, although over time I could glimpse some of them with direct vision. "Surprises" means just that. They needed the very best sky conditions and determined averted vision to detect or were not seen at all.

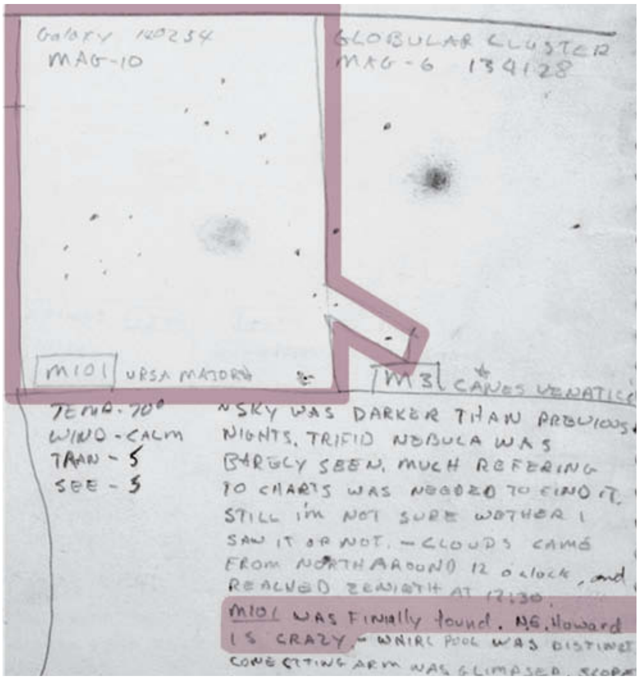
EASILY SEEN

N. E. Howard was right, of course. In a dark sky M101 is easy to see as a large pale object. That's how it appears through my 4-inch finderscope, and even in binoculars. But don't expect much if your skies are light-polluted.

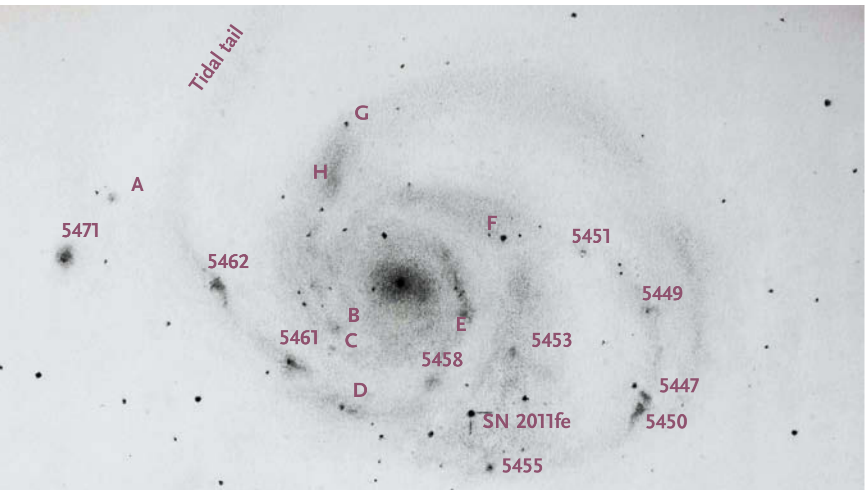
I noticed through my finderscope that M101 is a bit oblong. Through the 28-inch scope at low power (155×, a 5.5-mm exit pupil), the galaxy shows a fairly bright core with a small, much brighter nucleus surrounded by three stubby spiral arms and several H II regions. It appears lopsided because of the prominent southern spiral arm and the galaxy's dim western side. Handfuls of Milky Way foreground stars are scattered about.



Lord Rosse's assistant Samuel Hunter prepared this sketch in 1861 based on observations through the 72-inch Leviathan — a telescope much bigger but cruder than the author's.



The author's determination and attention to detail were already evident in this 1974 sketch, though his equipment and technique have advanced considerably since then.



NGC objects are labeled with their numbers, whereas other areas are labeled with the letters A through H. Each labeled area is actually a complex of many nebulae and star clusters; see skypub.com/m101 for details.

Placing these features on my drawing in correct relation to one another took the first 1½ hours of eyepiece time, for two reasons. Drawing a large, amorphous object is surprisingly difficult, and the more I drew the more I saw, tempting me to start drawing details rather than concentrating on proportion. But proportion really matters with large objects. So if you find yourself in this situation, stick with it until you're happy with your overall layout.

By this time I'd noticed that the three main spiral arms aren't stubby after all — and that there are more than three. The most interesting features are the 10 brightest regions within the spiral arms, all of which have their own NGC designations. Each is a mixture of numerous H II emission areas, star clusters, and star clouds. A UHC or O III filter shows the brightest H II areas with a bit more contrast — pretty cool considering that they're roughly 25 million light-years distant. But filters also obliterate the rest of the galaxy, so I didn't find them very useful.

The inner western spiral arm is the brightest, and it appears rather thin as well. The brightest segment is straight and appears to lie tangentially to and somewhat detached from the core. This arm loops around the southern part of the core and becomes tangled up with the beginnings of the southern and eastern spiral arms.

A couple of foreground stars near the core do a pretty good supernova impersonation, but in late August 2011 we were treated to the real thing with SN 2011fe, which was bright enough to see in 7×50 binoculars.

The core region is distinctly oval, and the better the seeing, the smaller the bright nucleus appears.

TOUGH TO SEE

Tracing the main spiral arms toward the center of M101 proved a challenge, because detail here has very low contrast. But along with the NGC regions, I could see knots of non-NGC H II regions and star clouds, along with several sharp bends within the spiral arms. Medium power helped increase contrast a little in this area. My best overall views of M101 on most nights were at 253× with a 3.5-mm exit pupil.

When the seeing was steady, I used 408× (a 2.0-mm exit pupil) to see that some of the H II regions had definite shapes and were interesting objects all their own. That's especially true of NGC 5447 and NGC 5450, which practically touch each other. They often appeared as one irregular object, and it took steady seeing to separate them well.

NGC 5462 also has a striking shape at high power in steady seeing, looking somewhat like the letter J.

The fairly prominent southern spiral arm is a spur off the inner western arm. It begins near NGC 5458 and contains two of the brightest H II regions: NGC 5461 and NGC 5462. The stubby northern arm, when it abruptly turns south, becomes quite faint and starts to spread out like a river delta. NGC 5453, the NGC region that I found most difficult to see, is located here.

As this faint branch of the stubby northern arm fans out, it starts blending with the southern arm and the fainter double outer western arm. I could see this clearly only after my first three or four observations. SN 2011fe appeared here in late August 2011 — it's indicated in the annotated drawing just above NGC 5455, which is at the southern limit of the delta area.

I also found this part of M101 to be particularly fascinating in Samuel Hunter's 1861 drawing, seen on the facing page. Hunter combined the western edge of the delta area and the brighter segment of the forked western arm into a single arm that loops in the opposite direction from the others. I saw them like this myself at times, so it's easy to understand why he drew them this way. It's an impressive drawing for someone who had no preconception of M101's photographic appearance.

The inner eastern spiral arm area near the core is diffuse, with a few subtle knots, and it's studded with the highest density of faint stars in M101 — all of which are in the Milky Way foreground. This area also happens to have the highest density of Cepheid variable stars, though none are visible through my scope.

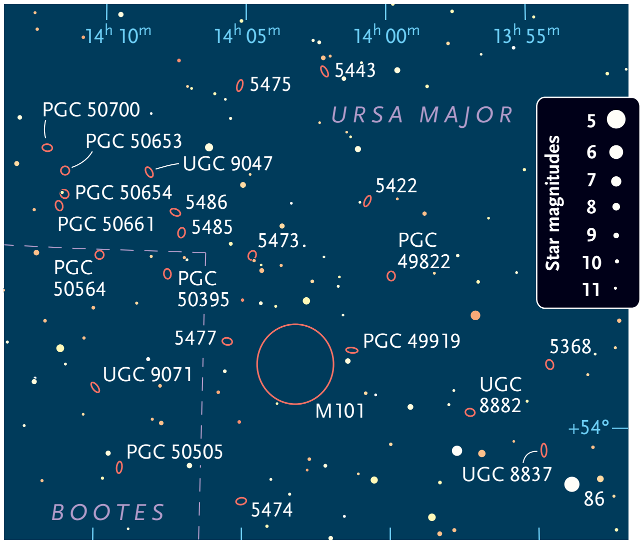
SURPRISES

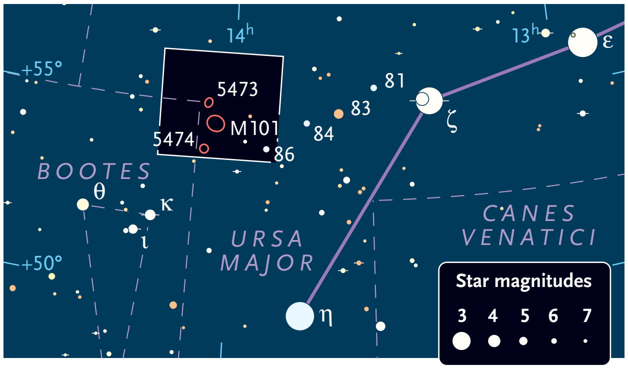
Deep images of M101 show that the end of the southern spiral arm has a long and faint tidal tail that takes a sharp turn to the northwest. I had no expectations of seeing this visually, but it was surprisingly easy with averted vision on the better nights. It extends a little farther than shown in my drawing — that's just where my notebook page ended. I saw it best at 253×.

The westernmost part of the forked outer western arm was similarly unexpected. At first all I could see were the bright H II regions NGC 5447 and 5450 together

ADAM BLOCK / NOAO / AURA / NSF

NGC 5474 is an extraordinarily asymmetric spiral galaxy, presumably due to gravitational interaction with M101.





This chart shows all galaxies near M101 with blue magnitudes of 15.6 or brighter.

with bits of the western arm's inner segment. But on one exceptionally good night (21.8 on my Sky Quality Meter), I could faintly see the curving, almost parallel traces of both forks, which suddenly made M101 look out of kilter in the east-west direction. It looked like the core was racing away to the east, bunching up the eastern spiral arms while stretching out the western arms. Before this, the core looked like it was bunching up the arms in the opposite direction, though not as dramatically.

I haven't been able to see the spur off the faintest part of the eastern spiral arm's northern extension, nor its connection to the forked outer western arm. I also haven't been able to see the innermost eastern spiral arm where it wraps right under the core. But I'll keep trying.

WHILE YOU'RE HERE . . .

If you can tear yourself away from M101, there's a nice bunch of NGC galaxies to the north, one each to the east and west, and one genuinely remarkable galaxy to the south: NGC 5474, shown at left. Actually, depending on your magnitude limit, you can see swarms of faint galaxies all around M101. ✦

Howard Banich *lives in Portland, Oregon, a hotbed of telescope makers and users despite its seemingly perpetual cloud cover. He welcomes questions at howard.banich@nike.com.*

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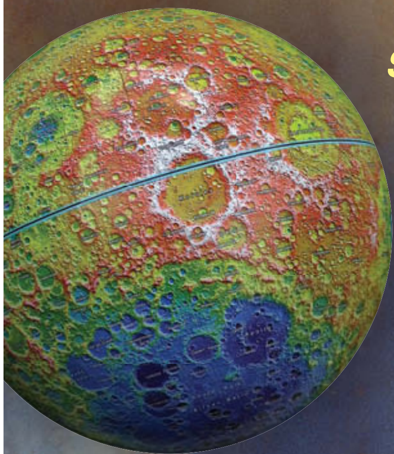

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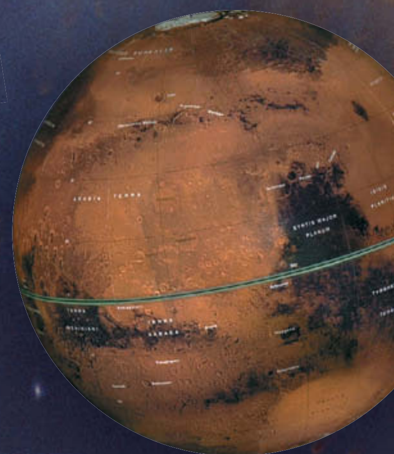

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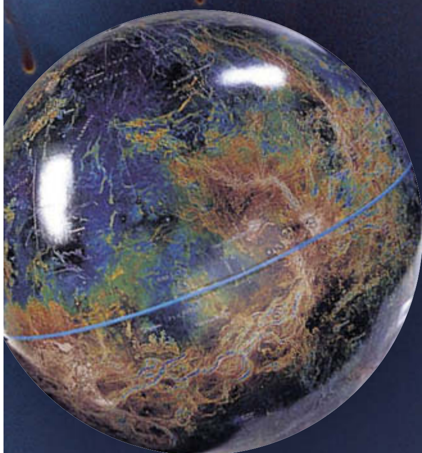

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In This Section

See page 38 for a guide to observing the magnificent Pinwheel Galaxy, Messier 101.

PHOTOGRAPH: NASA / ESA / STSCI / K. KUNTZ (JHU) / F. BRESOLIN / J. TRAUGER / J. MOULD / Y.-H. CHU

Sky at a Glance

1–13 **DUSK:** Look west-northwest 45 minutes after sunset for Mercury upper left of brighter Venus. This is Mercury's highest evening apparition of the year for northern observers. For observing Mercury even higher, in broad daylight, see page 51.

9 **DUSK:** Look for a very thin crescent Moon 6° to 8° below Venus shortly after sunset in North America. Bring binoculars.

10 **DUSK:** A more substantial but still delightfully thin crescent Moon floats 8° to 9° left of Venus.

18 **DUSK:** Mercury, dimmer now, shines 2.1° left of much brighter Venus.

EVENING: The Moon is left of Spica and well to Saturn's lower right; see page 49. The Moon occults (hides) Spica in parts of Africa.

19 **DUSK:** Mercury shines 1.9° lower left of Venus.

EVENING: The Moon is well to Saturn's lower left and closer to the right of the wide double star Alpha Librae (Zubenelgenubi). It occults Alpha Librae on the 20th in New Zealand.

20–21 **THE SHORTEST NIGHT** of the year in the Northern Hemisphere. Summer begins at the solstice, 1:04 a.m. June 21st EDT (10:04 p.m. June 20th PDT).

22–23 **ALL NIGHT:** The largest full Moon of 2013 rises around sunset on June 22nd and sets around sunrise on June 23rd. When it rises in the Americas on June 23rd it's nearly as large and as full.

Planet Visibility

SHOWN FOR LATITUDE 40° NORTH AT MID-MONTH

	◀ SUNSET	MIDNIGHT	SUNRISE ▶
Mercury	NW	Visible May 19 through June 21	
Venus	NW		
Mars		Visible with binoculars in late June	E
Jupiter	NW	Visible through June 3	
Saturn	S	W	

Moon Phases

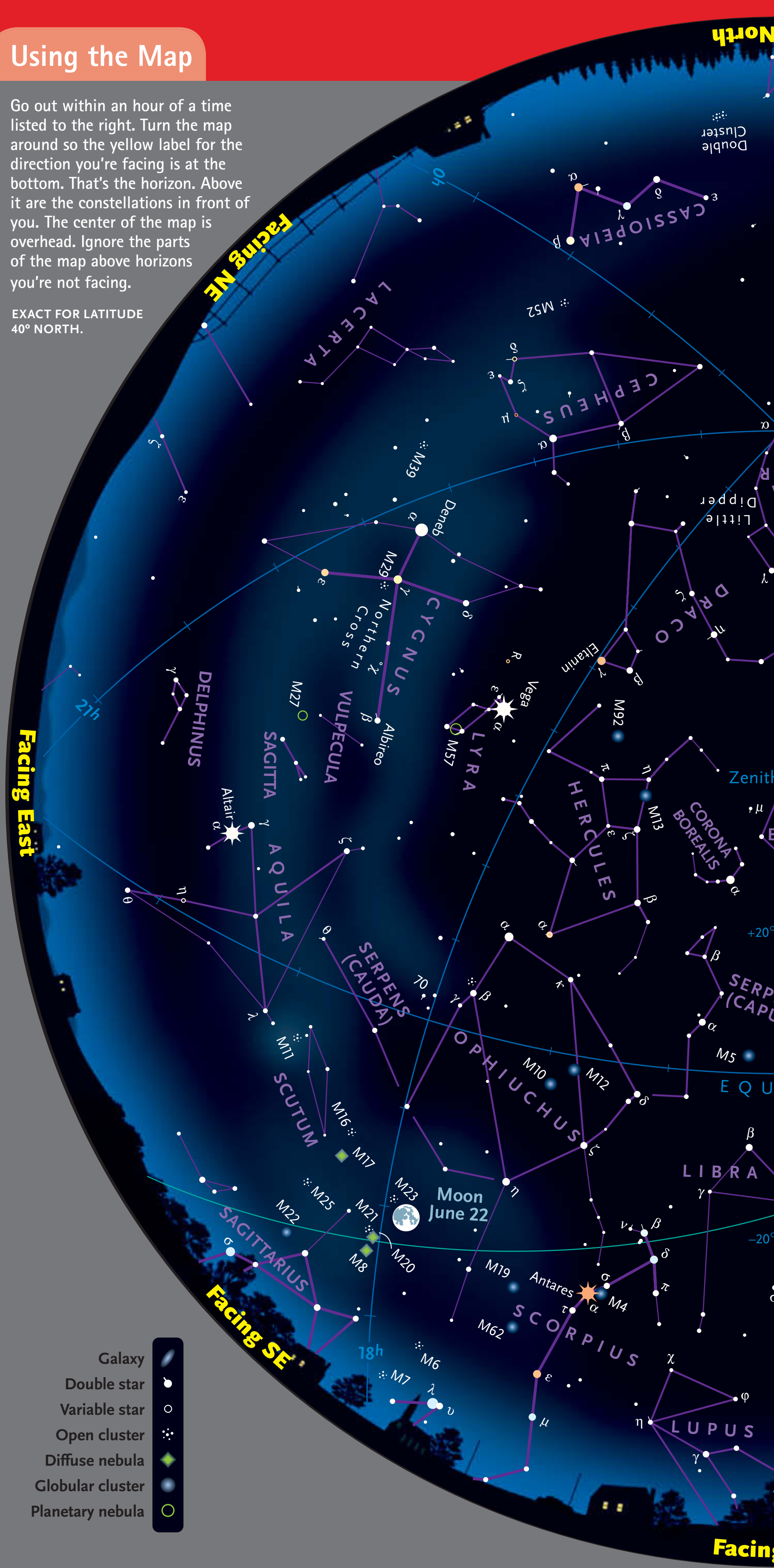
New	June 8	11:56 a.m. EDT	
First Qtr	June 16	1:24 p.m. EDT	
Full	June 23	7:32 a.m. EDT	
Last Qtr	June 30	12:54 a.m. EDT	

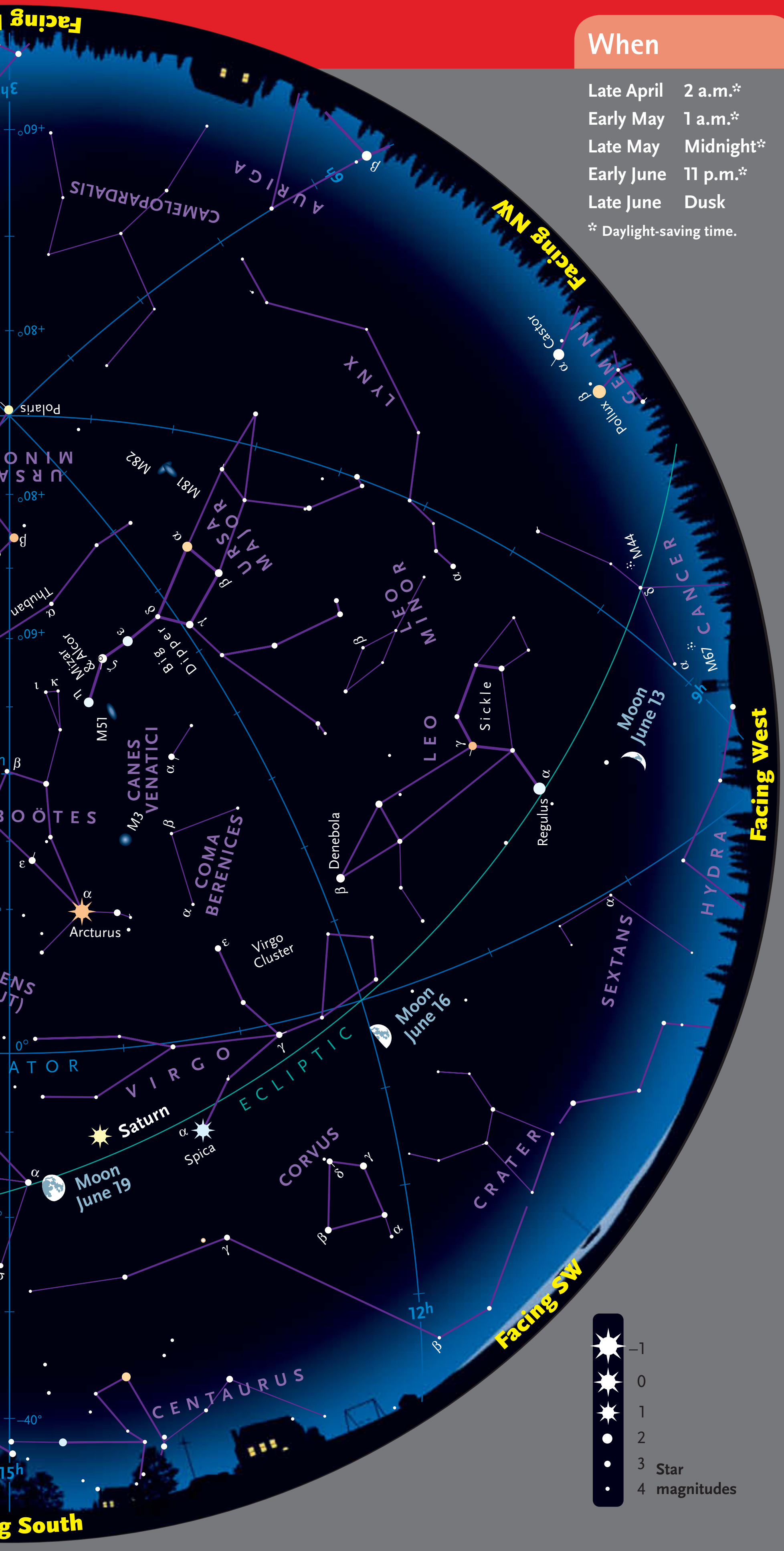
SUN	MON	TUE	WED	THU	FRI	SAT
						1
2	3	4	5	6	7	8
9	10	11	12	13	14	15
16	17	18	19	20	21	22
23 / 30	24	25	26	27	28	29

Using the Map

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

EXACT FOR LATITUDE 40° NORTH.





When

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

* Daylight-saving time.

Gary Seronik

Binocular Highlight

Around Antares

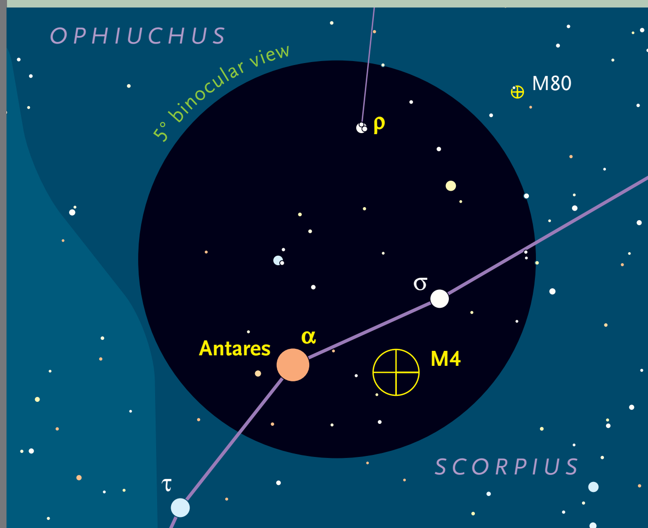
Scorpius is one of the most rewarding constellations in the entire sky — the more so the farther south you live. So bountiful is the harvest that you can enjoy a handful of targets without straying more than a binocular field from your starting point.

Let's begin our exploration of the celestial Scorpion with its leading light, 1st-magnitude **Antares**, Alpha (α) Scorpii. Antares is a red supergiant and one of the Milky Way's largest stars, spanning about 700 solar diameters. What's most striking about it visually, though, is its lovely golden-orange color. While this can be readily perceived without optical aid, the extra light grasp of binoculars helps enrich the star's tint. To make the color even more pronounced, try defocusing your binos slightly.

Shifting our gaze 3° north-northwest of Antares (and nipping over the border into neighboring Ophiuchus) we come to the lovely binocular triple star **Rho (ρ) Ophiuchi**. Rho shines at 5th magnitude, and its companions are both around magnitude 7, each lying a generous 150″ from the primary. That means seeing all three stars is a snap even in 7× binos. The stellar trio makes for a pretty little grouping.

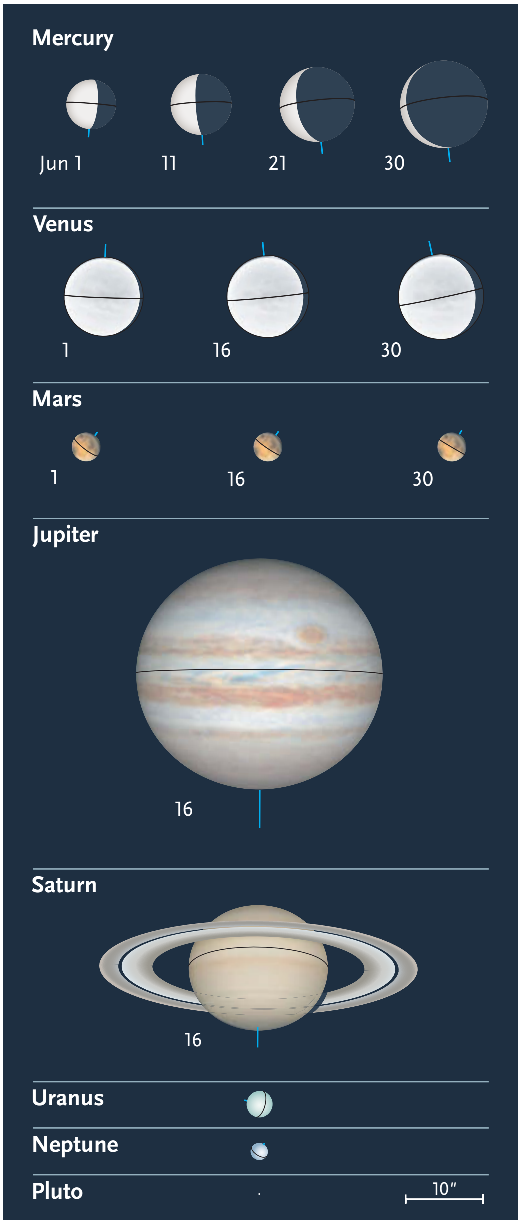
Finally, just 1⅓° west of Antares is the 5.4-magnitude globular cluster **M4**. For my money it's one of the most interesting binocular globulars. Partly that's because it's so near — only 7,200 light-years away. As a result, I can perceive a few cluster stars twinkling feebly against a fairly large background sheen of faint starlight when I view the cluster in my 15×45 image-stabilized binoculars under dark skies.

As a bonus, if you re-aim your binoculars slightly, you'll find that M4, Antares, and Rho Ophiuchi all fit comfortably together in a single field of view. ✦



Watch a SPECIAL VIDEO

To watch a video tutorial on how to use the big sky map on the left, hosted by *S&T* senior editor Alan MacRobert, visit SkyandTelescope.com/maptutorial.

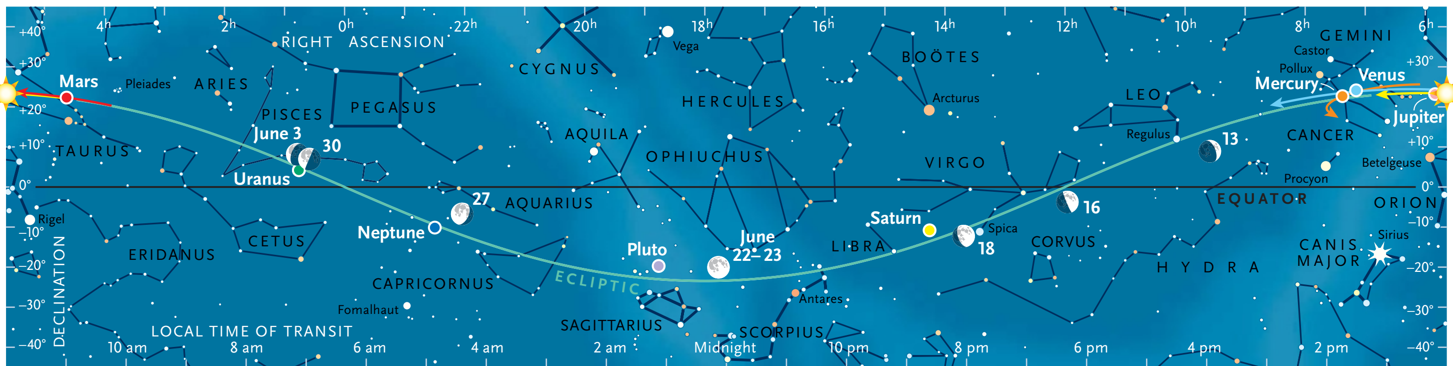


Sun and Planets, June 2013

	June	Right Ascension	Declination	Elongation	Magnitude	Diameter	Illumination	Distance
Sun	1	$4^h\ 35.5^m$	+22° 01′	—	–26.8	31′ 33″	—	1.014
	30	$6^h\ 35.7^m$	+23° 11′	—	–26.8	31′ 28″	—	1.017
Mercury	1	$6^h\ 04.2^m$	+25° 37′	21° Ev	–0.4	6.4″	63%	1.045
	11	$7^h\ 02.4^m$	+24° 05′	24° Ev	+0.3	7.9″	41%	0.852
	21	$7^h\ 33.7^m$	+21° 09′	22° Ev	+1.3	9.7″	23%	0.691
	30	$7^h\ 35.1^m$	+18° 43′	15° Ev	+3.0	11.3″	8%	0.594
Venus	1	$5^h\ 48.0^m$	+24° 16′	17° Ev	–3.8	10.3″	96%	1.627
	11	$6^h\ 41.6^m$	+24° 17′	19° Ev	–3.8	10.5″	94%	1.591
	21	$7^h\ 34.6^m$	+23° 08′	22° Ev	–3.8	10.8″	92%	1.550
	30	$8^h\ 21.0^m$	+21° 08′	24° Ev	–3.8	11.1″	91%	1.508
Mars	1	$3^h\ 52.1^m$	+20° 16′	10° Mo	+1.4	3.8″	100%	2.466
	16	$4^h\ 36.8^m$	+22° 18′	14° Mo	+1.5	3.8″	99%	2.464
	30	$5^h\ 18.8^m$	+23° 29′	18° Mo	+1.5	3.8″	99%	2.454
Jupiter	1	$5^h\ 34.2^m$	+23° 03′	14° Ev	–1.9	32.3″	100%	6.094
	30	$6^h\ 03.1^m$	+23° 13′	7° Mo	–1.9	32.2″	100%	6.131
Saturn	1	$14^h\ 17.1^m$	–10° 57′	145° Ev	+0.3	18.5″	100%	8.981
	30	$14^h\ 13.1^m$	–10° 43′	116° Ev	+0.5	17.8″	100%	9.342
Uranus	16	$0^h\ 45.0^m$	+4° 05′	73° Mo	+5.9	3.5″	100%	20.323
Neptune	16	$22^h\ 28.9^m$	–10° 14′	110° Mo	+7.9	2.3″	100%	29.628
Pluto	16	$18^h\ 44.6^m$	–19° 47′	164° Mo	+14.0	0.1″	100%	31.478

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

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



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

Fred Schaaf welcomes your comments at fschaaf@aol.com.

Fred Schaaf

The Northern Crown

This gem among constellations merits close scrutiny.

It's a little constellation, and usually only one of its stars is brighter than magnitude 3.7. It has no star clusters or bright nebulae, and none of its galaxies are visible in small telescopes. Even so, Corona Borealis, the Northern Crown, is a crowning glory of the June evening sky — and one of the prettiest, most remarkable constellations in the heavens.

Crowning glory. Corona Borealis appears at or near the crown of the sky, the zenith, for viewers at mid-northern latitudes. The summer solstice, when the Sun reaches nearly overhead at noon, might be considered the crown of the year. And that's when Corona Borealis is nearly overhead as long-awaited night finally falls on the longest day of the year.

Location, location, location. We always hear that's what makes a piece of real estate ideal. The piece of celestial real estate that's Corona Borealis certainly benefits from its place among the other constellations. Corona Borealis is right off the east shoulder of Boötes. It's just the right distance from Arcturus so that brilliant star draws our eyes to the Northern Crown without overwhelming it. Indeed, Corona Borealis lies along the line connecting Arcturus with Vega, the other dazzling star of June. These are the second and third brightest stars ever visible from latitude 40° north. (Sirius, the brightest, won't emerge from the Sun's glare until August.)

But it's not just location that makes the Northern Crown conspicuous. It is remarkably shapely, symmetric, and compact — a sightly semicircle formed by six major stars. Those stars are all of similar brightness except for one much brighter star, Alpha (α) Corona Borealis, which adorns the arc like a special gem.

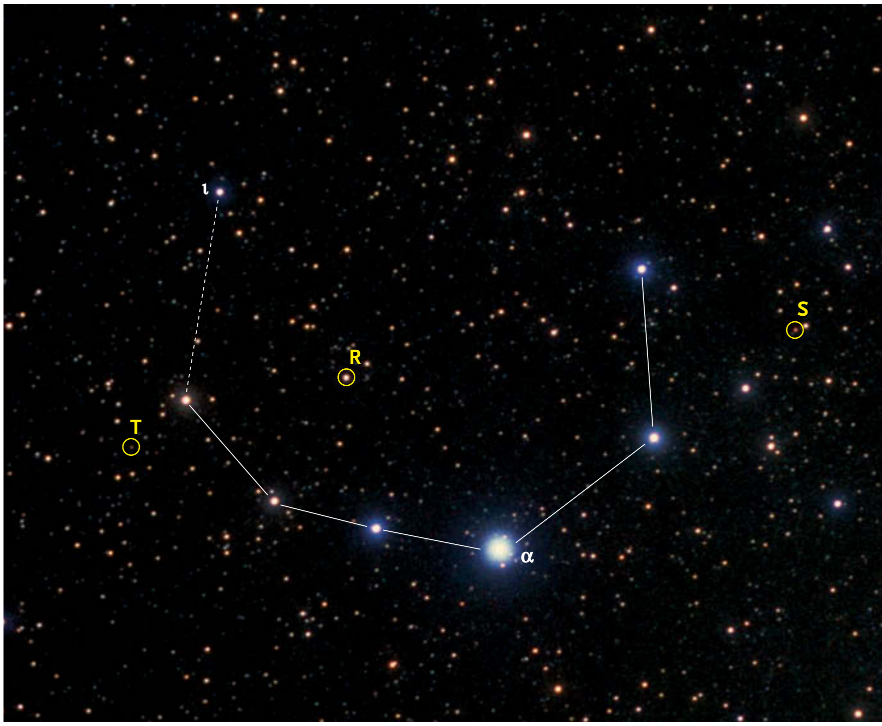
One of Alpha's names is in fact Gemma, Latin for "gem." Interestingly, however, this star is also often called Alphecca. That's derived from an Arabic root meaning "broken," presumably referring to the broken ring of stars. And indeed the pattern of Corona Borealis looks more like a broken ring if you add — as our all-sky map does — a seventh star, Iota (ι) Coronae Borealis.

The fade star. Corona Borealis has two stars that belong on the Top 20 list (maybe even the Top 10 list) of most interesting variables. They're R and T Coronae Borealis, affectionately called R CorBor and T CorBor by variable-star fans. Each is amazing in its own right, and they're also amazing opposites.

R CorBor is sometimes called the Fade-out Star. It's the most prominent example of a "reverse nova." R CorBor typically shines at 6th magnitude, standing out very well in binoculars. But every so often, unpredictably, the star's brightness plunges precipitously, dropping as dim as 12th to 15th magnitude in just a few weeks. After a few months — or occasionally much longer — a cloud of obscuring carbon that the star has emitted dissipates, and R CorBor returns to its original brightness.

By the way, another nearby variable star, S CorBor, varies between magnitude 5.8 and 14.1. That's fairly similar to the range of R CorBor. But S CorBor is just a typical long-period variable, like the much better known star Mira in the constellation Ceti. S CorBor doesn't linger long at its maximum brightness and has a period of 360 days. Its next peak is due in August.

Much more next month. Next month I'll talk about spectacular T CorBor, the Blaze Star. I'll also discuss Corona Borealis's attractive double stars. And I'll tell two legends inspired by the Northern Crown — both among the most touching and pretty of all star myths. ✦



AKIRA FUJII

Mercury Dances with Venus

The innermost planets appear together in twilight for most of June.

Venus burns bright but low in the west-northwest during evening twilight throughout June. Jupiter accompanies Venus at the start of June before sinking into the sunset, but Mercury remains visible near Venus for most of the month.

Saturn glows in the south at dusk. But no bright planets are visible at dawn until first Mars and then possibly Jupiter struggle into binocular view toward the end of June.

DUSK

Venus languishes low in June's long dusks. All month it's magnitude –3.8, the dimmest it ever becomes except when passing between Earth and the Sun. But that's still much brighter than any other planet, and Venus is high enough to spot easily with the unaided eye if the air is clear. For viewers around 40° north latitude, Venus is about 8° above the west-northwest horizon a half hour after sunset as June begins, and only a couple degrees higher than that by the end of the month.

Jupiter (magnitude –1.9) passes 1° from Venus on May 28th, but it appears farther below Venus and closer to the horizon each evening after that. It becomes invisible to the unaided eye around June 4th and through binoculars a few evenings later. Jupiter reaches conjunction on the far side of the Sun on June 19th.

Meanwhile, **Mercury** is enjoying what's arguably its best evening apparition of 2013 for viewers at mid-northern latitudes, appearing unusually high at dusk, with much brighter Venus to point the way. Mercury shines at magnitude –0.4 on June 1st, but it fades by almost 0.1 magnitude each successive evening.

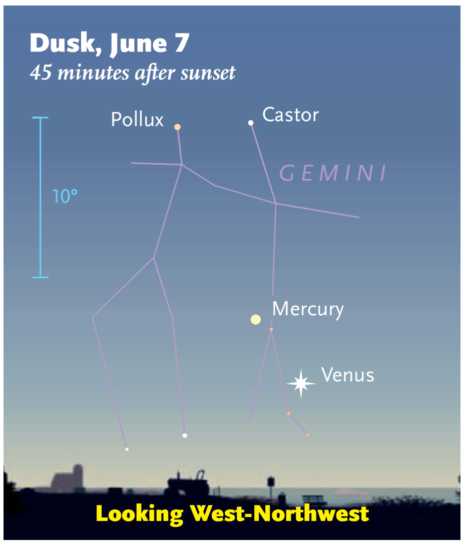
A half hour after sunset on June 1st, Mercury, Venus, and Jupiter form an almost straight 9° line with Mercury at upper left, Jupiter at lower right, and Venus almost halfway between them. The line lengthens 1° each evening as Mercury appears a little higher and Jupiter considerably lower. For an animation showing the planets' changing configuration, see **skypub.com/june2013planets**.

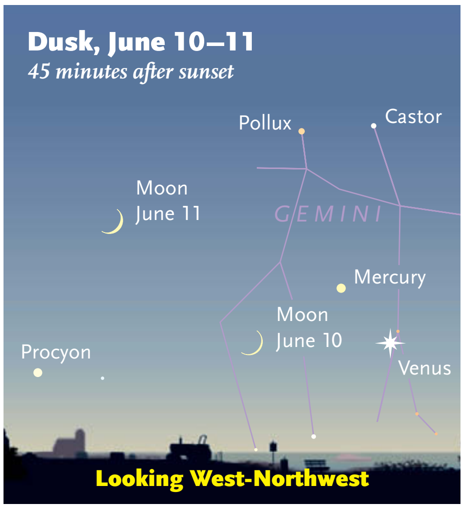
Mercury at first moves marginally up and away from Venus, reaching a temporary maximum separation of 5.0° on June 6th and 7th. But then Mercury begins returning down toward a spot somewhat left of Venus — slowly at first, and then increasingly rapidly.

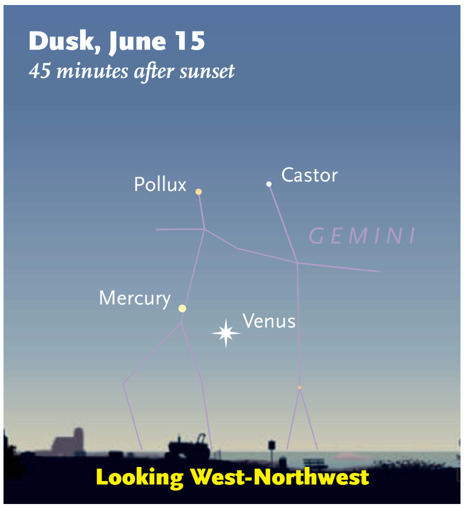
On June 12th Mercury reaches greatest elongation, 24° from the Sun. But by then it has already started to appear lower for northern observers due to the tilt of the ecliptic. On June 12th it's magnitude +0.5 and less than 40% illuminated: a thick crescent in a telescope.

On the evening of June 18th Mercury shines 2.1° almost due left of Venus. The planets are near their closest on the American evening of June 19th, with Mercury 1.9° lower left of Venus. By then Mercury has faded to magnitude +1.2, making it hard to see without optical aid in the bright twilight. But if you can catch the pair in a telescope when they're still reasonably high above the horizon, it will be fascinating to see Mercury's crescent 23% lit and 9.7″ from cusp to cusp not far from Venus, whose gibbous disk is 10.8″ wide, 92% lit, and much shinier than Mercury because it's more reflective.

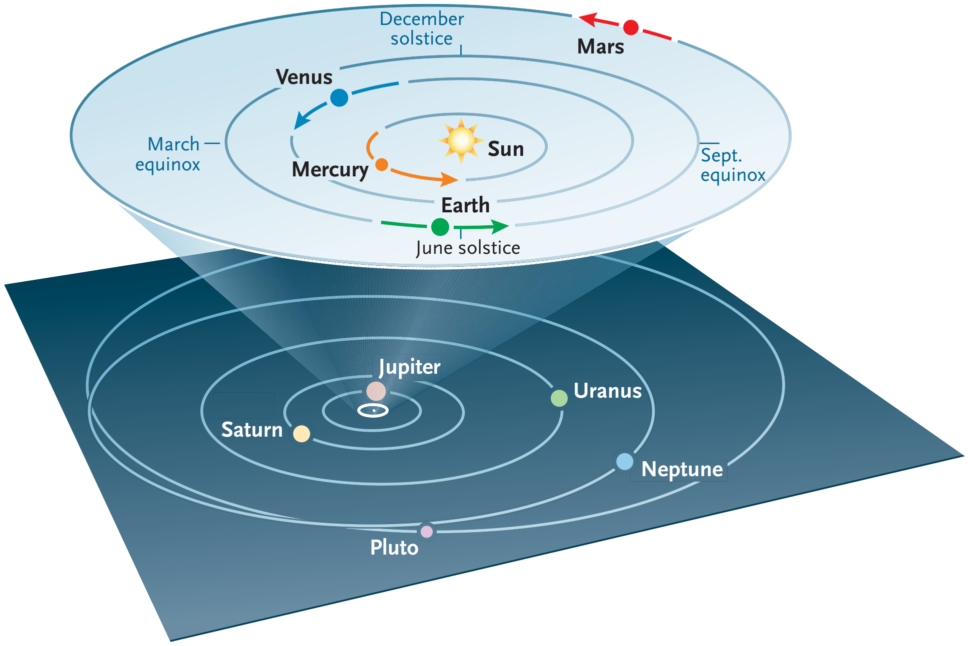
The easiest time to observe the planets telescopically is shortly after sunset, when Venus is obvious to the unaided eye. But







Fred Schaaf



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.

it's even better to catch them in the late afternoon, as described on page 51.

EVENING AND NIGHT

Saturn is near its highest in the south as night falls. The planet fades during June from magnitude +0.3 to +0.5, it shrinks a bit in a telescope, and its rings close up a tiny trace more. Yet Saturn is still Saturn — the telescopic showpiece of the solar system with those bright rings.

Viewers with binoculars can watch as Saturn slows its retrograde (westward) motion and pulls within ½° south of 4.3-magnitude Kappa Virginis at month's end. Naked-eye observers will find Saturn almost equidistant from Spica and Zubenelgenubi (Alpha Librae).

Pluto (magnitude 14.0, in Sagittarius) will be at opposition on July 1st, so it's at its highest in the south not long after midnight in June. See page 52.

First **Neptune** (magnitude 7.9, in Aquarius) and then **Uranus** (magnitude 5.9, in Pisces) rise in the middle of the night. Both are best viewed just before the sky begins to brighten. For finder charts see **skypub.com/urnep**.

DAWN

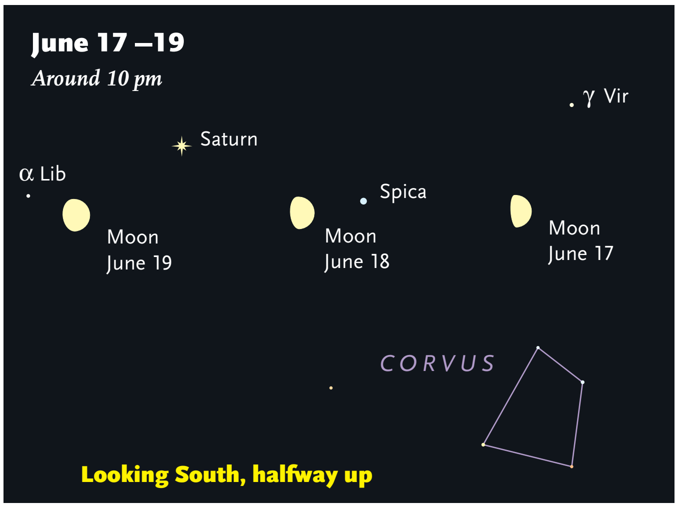
Mars is dim (magnitude +1.4), and it rises only about a half hour before the Sun on June 1st, making it hard to see even with a telescope. By month's end, however, it's more than 7° above the horizon a half hour before sunrise and visible through binoculars if the air is clear. Ten minutes later binoculars might conceivably show Jupiter poking just above the horizon.

SUN AND MOON

The **Sun** arrives at the solstice at 1:04 a.m. EDT on June 21st, inaugurating summer in the Northern Hemisphere and winter in the Southern Hemisphere.

On June 9th a very thin crescent **Moon** sets approximately 40 minutes after the Sun, about 6° to 8° below Venus for viewers in North America. On the 10th a thicker crescent floats 8° or 9° left of Venus, with Mercury also nearby.

On the American evening of June 18th the waxing gibbous Moon is not far left of Spica and well to Saturn's lower right. It's equally far to Saturn's lower left on the 19th, and fairly close to fainter Zubenelgenubi. The Moon occults (hides) Spica for parts of Africa, and it occults Zubenelgenubi for New Zealand and parts of Australia. ✦



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

Sighting the Solstice

Can you track the sunset point as well as your prehistoric ancestors did?

The word *solstice* comes from the Latin for "Sun stands still," and most astronomers think of it as standing still in declination: the Sun ceasing its northward movement as it creeps along the ecliptic past right ascension $6^h 00^m$ in June, then starting to return south.

True enough. But our distant ancestors saw the Sun standing still rather differently: as a part of their everyday landscape. So can you.

As the aligners of Stonehenge famously knew, the Sun rises and sets farther and farther north along the horizon through the winter and spring, slows down, stands still at the same setting point day after day around the solstice, and then begins to head back south — warning, in the hottest days of summer, of the winter to come.

How well can you track the Sun's setting point? Pick a fixed place from which to keep watch — a stone to sit on with a good westward view, or a mark on the ground, or a high, west-facing window. Starting weeks in advance, watch the Sun going down and sketch the mark points on or near the horizon: trees, buildings, mountains. They don't have to far away, but the closer they are, the more accurately you'll need to come back to the same viewing point day after day.

Mark on your sketch where the Sun disappears, and date it. Mark and date the new sunset point every few days.

How accurately can you determine the solstice date this way? It gets tricky as the Sun slows. One day before and after, if you're in the world's temperate latitudes, the setting point differs from the solstice setting point by about a half an arcminute! That's about 1/60 of the Sun's diameter and finer than the human eye's resolving power. Moreover, changes of atmospheric refraction add more than that much jitter from day to day.

So, keep doing it as the Sun moves back south. As it speeds up, the daily change will be easier to track. It will become easy to compare with the dates you marked while the Sun was heading north past the same points. Halfway between those dates is the solstice. That may be how ancient calendar calculators figured out the date.

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SOLSTICE AT STONEHENGE How well can you track the changing sunset point on your horizon through late spring and early summer? The project isn't necessarily monumental.

The Shortest Shadow

Here's another solstice project. Shadows are shortest and point true north every day at "local apparent noon." That's when the Sun crosses the meridian due south, halfway between sunrise and sunset, and it has little to do with noon by the clock. You can find its clock time on any date using a planetarium program or the *Skygazer's Almanac* that comes with our January issue.

Mark where on the ground the tip of a shadow falls at that moment. The shadow will shrink as summer solstice approaches, hold still for several days around it, and then begin to lengthen again, ever faster.

Again, don't expect high precision. Shadows cast by the Sun have fuzzy edges (penumbras) $\frac{1}{2}°$ wide, the Sun's apparent diameter. Around midday in June for mid-northerners, a shadow's penumbra is about 1/80 of its total length on the ground.

Alan MacRobert

Venus and Mercury in Daylight

When the two inner planets shine prettily to the naked eye, they're usually a mess telescopically, Mercury in particular. Mercury is obvious only when it's near the sunrise or sunset horizon, and low altitude means bad telescopic seeing.

So astronomers have always preferred to examine Venus and Mercury during the day. Venus isn't hard to find in a blue sky because it's so bright, but Mercury is tougher, unless your scope can point to its coordinates blind in the daytime.

We're now getting a good shot at Mercury in the afternoon sky, for two reasons: it's approaching a good eastern elongation (24° from the Sun on June 12th), and Venus is right nearby to guide the way.

Find Venus first. Set up your scope in late afternoon in the shadow of a building that blocks the Sun, so you can't accidentally sweep up the Sun and burn your eye. Using the appropriate chart below, measure Venus's distance from the Sun using the degree scale on the right edge, and eyeball the correct direction. That's where to look. Binoculars will help find Venus.

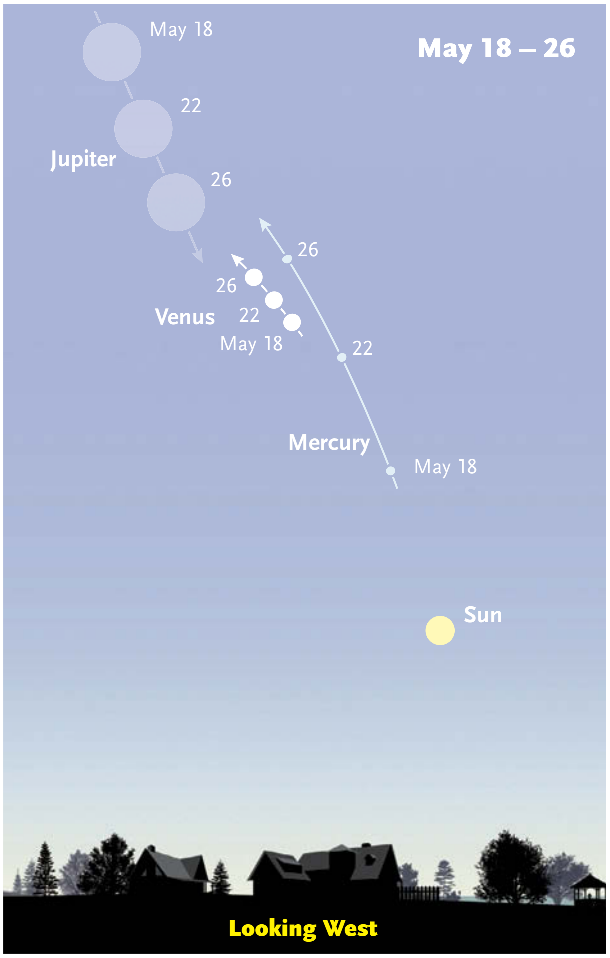
The charts are drawn for latitude 40° north. If you're far north or south of there, twist the sky view with respect to the horizon by the difference in degrees: clockwise if you're south of 40°, counterclockwise if north. This isn't precise but good enough.

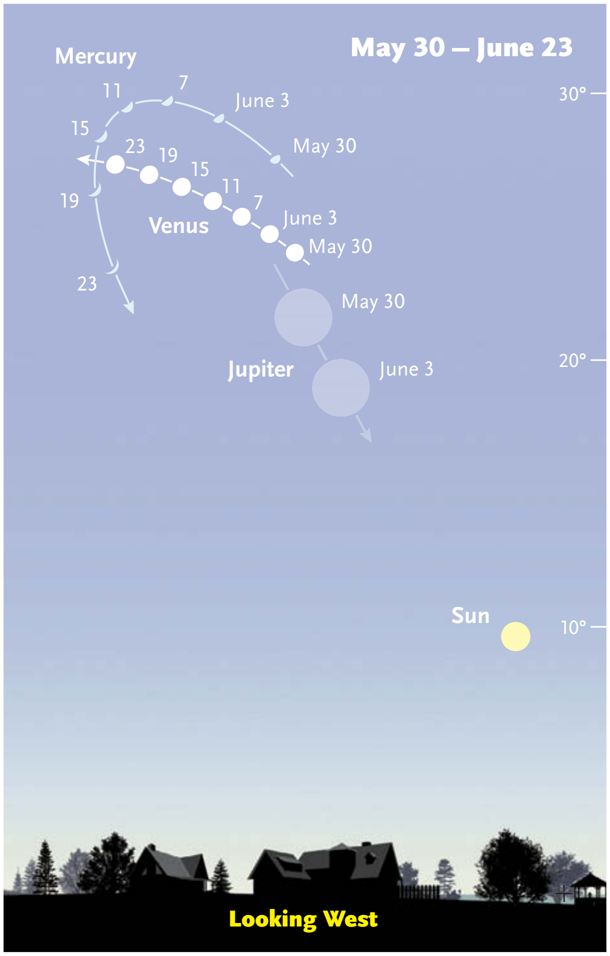
Also, the scene is drawn for an hour before sunset. Earlier in the afternoon, twist the sky a bit counterclockwise.

Venus in a blue sky shows in a good finderscope. Unfortunately, Venus isn't very interesting right now. It's small (11″) and almost round, since it's nearly on the far side of the Sun.

Mercury is another story. Find it from Venus on your date by measuring their separation on the chart. Mercury is waning and enlarging and becomes a crescent in late June. It's dim and dull gray: looking (as James Nasmyth put it in 1878) like zinc or lead compared to Venus's silver.

Jupiter is also in the scene, as it is when the planets shine low in twilight. Despite its size, Jupiter is tough telescopically in daylight. It's seven times farther from the Sun than Venus is, so its surface brightness is only about 1/49 as bright even though they have similar reflectivities (albedos). Look for a very dim thing deep in the blue. If Venus is silver and Mercury is lead, Jupiter is a gray ghost.





In daylight one hour before sunset, Venus, Mercury, and Jupiter are high enough to appear fairly sharp in a telescope. Here, each of their disks is shown magnified 270 times with respect to the altitude scale on the right (and with respect to the planets' separations from each other). Put pencil dots on their positions for your date. To find dim Mercury and Jupiter in the daytime, note their offsets from bright Venus.

Digging Up Pluto in 2013

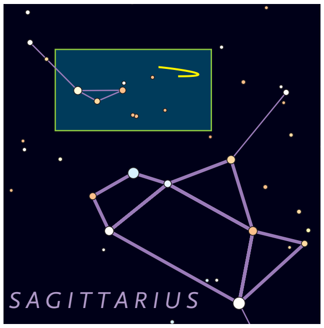
A little farther and fainter every year, remote Pluto continues to draw observers seeking to catch the only Kuiper Belt object that amateurs can ever see by eye without a truly giant telescope.

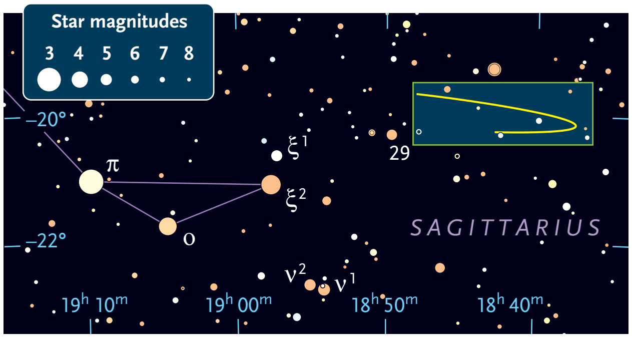
It's not easy. Pluto is magnitude 14.0 for a couple months around its July 1st opposition, only two-thirds as bright as it was around perihelion in 1989 (magnitude 13.6). Moreover, Pluto has been moving ever farther south. This year it's above the Sagittarius Teapot, off the lip of the Teaspoon near declination –20°. It won't bottom out until reaching nearly –24° in 2030. And it won't stop fading until it reaches magnitude 16.0 at aphelion in 2112. Mid-northern observers will never see Pluto better than it is now.

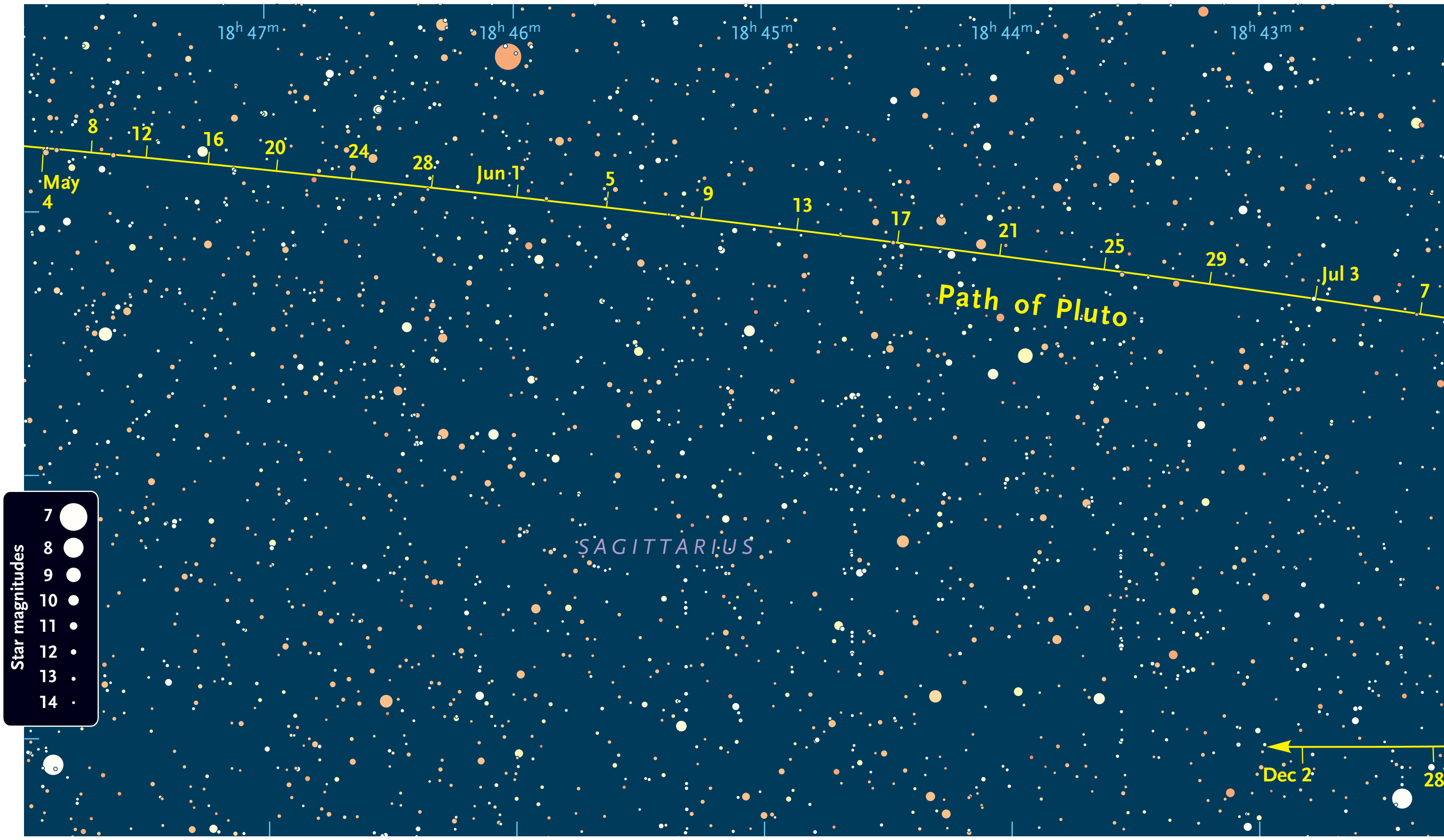
Under any but the darkest skies, you'll probably need at least a 12-inch telescope. On the chart below, ticks on Pluto's path mark its position at 0^h UT every four days. Interpolate between the ticks to put a pencil dot at the exact point on Pluto's path for the time you plan to hunt it.

The chart shows stars to magnitude 14.5. Palomar 8 is a small, 11th-magnitude globular cluster that's easy by comparison. Once you've star-hopped to Pluto's field at low power, switch to your highest power for working the final steps among the faintest specks to the position of your pencil dot.

To be sure that you've found the correct tiny glimmer, check back the next night to see that it has moved.





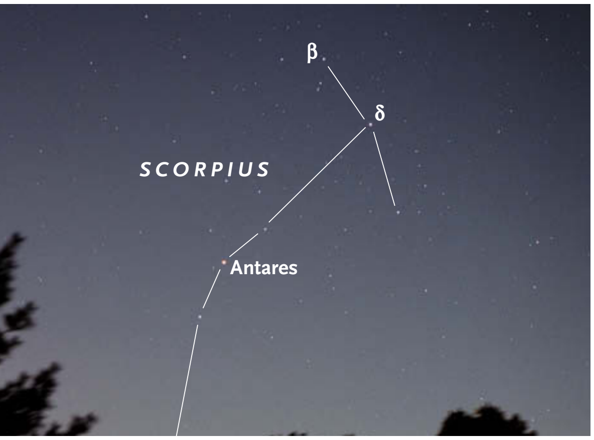


Lunar Occultation

If you're watching the waxing gibbous Moon through a telescope on the night of June 20–21, and if you're in eastern or central North America except for the deepest Deep South, you'll see the 4.8-magnitude star Kappa Librae creep up to the Moon's invisible dark limb and vanish. Some disappearance times: in western Massachusetts, 1:19 a.m. EDT; Washington, DC, 1:20 a.m. EDT; Atlanta, 1:23 a.m. EDT; Chicago, 11:56 p.m. CDT; Kansas City, 11:49 p.m. CDT; Winnipeg, 11:32 p.m. CDT; Denver, 10:31 p.m. MDT. ✦

Delta Sco Still Bright

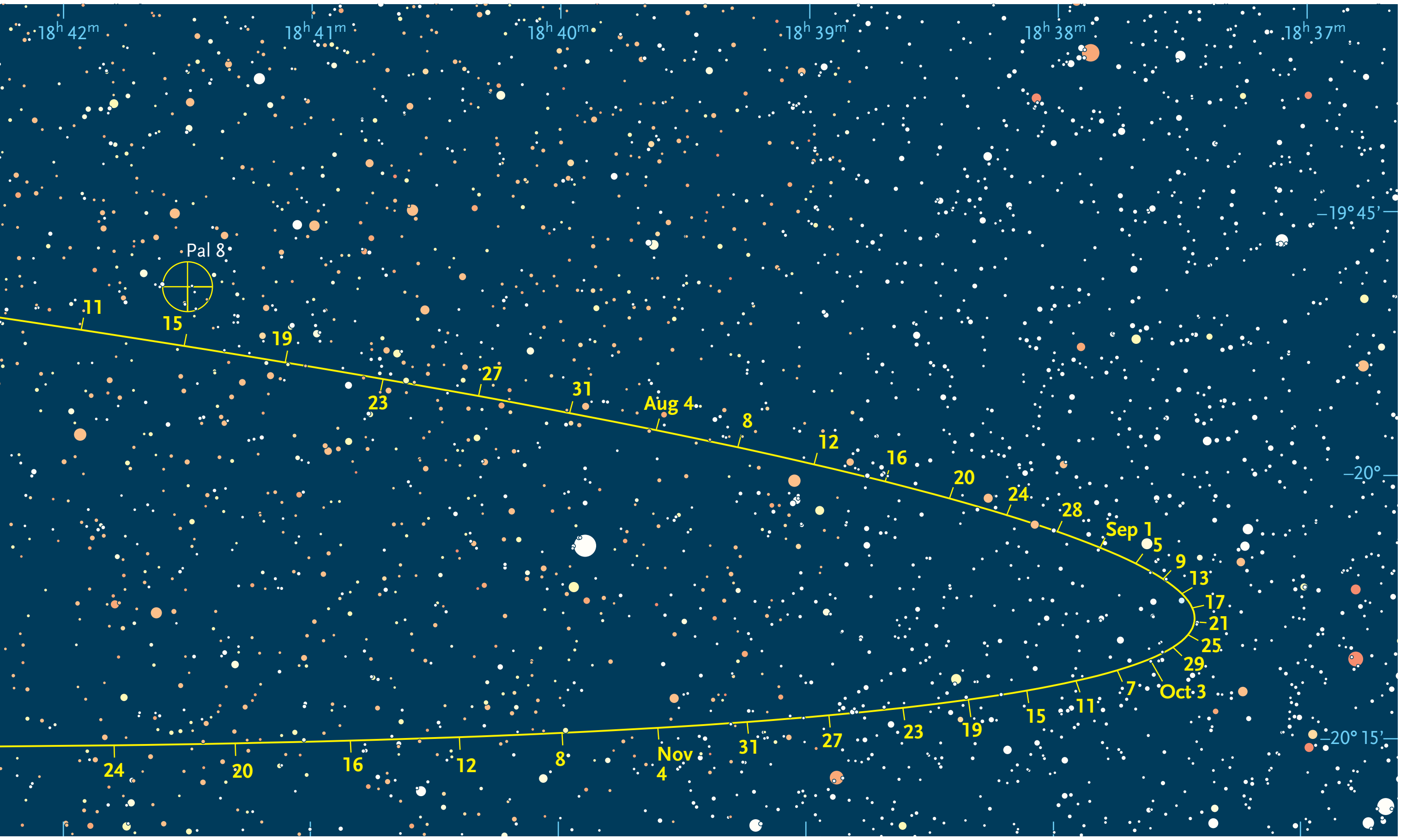
Thirteen years after it flared up in July 2000, Delta (δ) Scorpii remains brilliant at about magnitude 1.9, obviously outshining its former superior Beta (β). Sometimes it blazes even brighter. Estimate its magnitude using Beta, magnitude 2.6, and Antares, 1.1.



Asteroid Occultation

On the morning of June 12th, a 6.4-magnitude star east of Antares will wink out for up to 4 seconds along a track from Oklahoma across northwest Texas, southern New Mexico, and southern Arizona. The guilty party is the 13th-magnitude asteroid 332 Siri.

The star is unusually bright to be occulted by an asteroid, but there's a catch: the event (within a minute or two of 9:43 UT) happens low in the southwestern sky. For details, finder charts, and more asteroid occultations all year, see skypub.com/june2013siri. Also there are links to more info about asteroid occultations, how and why to time them, and connecting to the community of amateurs who are doing it.



Hunting Lunar Red Spots

Find these elusive silica-rich lavas.

Volcanism was once widespread on the lunar nearside, spewing forth the dark lava flows that created the maria we see today. Those lavas are similar to the most common lavas on Earth, the basalts that form the ocean floors. Nearly all volcanic rocks on the Moon are made of basaltic lava, whereas Earth has an exuberant variety of lava types. The motions of Earth's plates mix crustal rocks and water with basaltic magma inside the planet, producing a variety of volcanic rocks that are enriched in silica.

Silica-rich magma is more viscous than basaltic magma, and gases can't easily escape from it. The gas pressure builds up and can explosively erupt, spreading ash around the surrounding terrain. Viscous lavas by definition flow more slowly than basaltic ones, so they also build up steep-sloped volcanoes such as Mount St. Helens in Washington.

Plate tectonics did not occur on the Moon, so geologists didn't expect to find widespread silica-rich lavas. But some still appeared. This material built volcanic features different from the small domes and sinuous rilles found in the maria. The best known lunar silicic volcanoes are **Mons Gruithuisen Gamma** and **Mons Gruithuisen Delta** at the northwestern end of Mare Imbrium. These two stubby domes have unusually steep sides that are far brighter than mare domes — particularly at red wavelengths. This inspires the name "red spots" despite the fact that none actually appears red in the eyepiece.

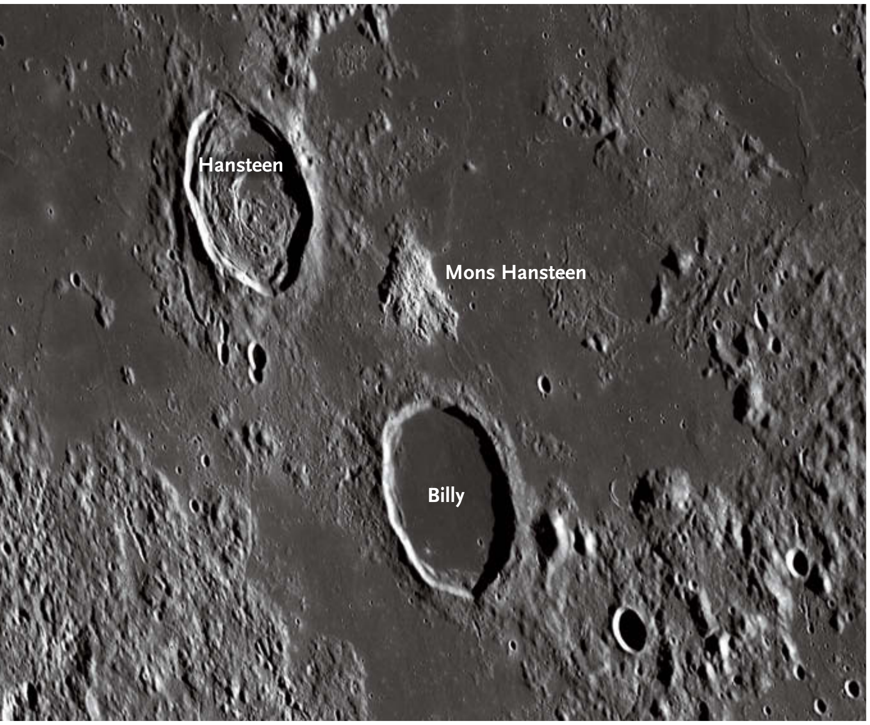
The steep sides and spectral redness suggest that the Gruithuisen domes were formed from silicic volcanic rocks, but it wasn't until last year that data from the Diviner radiometer onboard NASA's Lunar Reconnaissance Orbiter confirmed that theory. The observations suggest that red spots are made of viscous material similar to terrestrial granites or rhyolites, which are very different from easily flowing basalts.

Only a handful of red spots are known on the lunar nearside, and you can find them all with a small telescope. Not far from the Gruithuisen domes is the 40-kilometer-wide crater **Aristarchus**. Its southwestern rim and some of the surrounding ejecta are spectrally red. This information implies that when the impact blasted out the crater, a portion of the excavated material included a buried silicic mass. Geologists call this buried mass an *intrusion;* it's created when magma solidifies in the crust instead of erupting onto the surface.

Most other red spots are clustered around Mare Cognitum and Mare Nubium. All of these spots are in small, hilly areas older than the surrounding mare lavas. The easiest to find is **Mons Hansteen**, the Arrowhead. That nickname comes from its triangular shape, located near the craters Hansteen and Billy. The Arrowhead has a highly pitted surface, is brighter than its surroundings, and appears to be embayed by nearby lavas — meaning it is older than the surrounding lavas.

To the east is another informally named red spot, the 40-km-wide Helmet. That name comes from its appearance in south-up images as a rounded mass with spurs on its northern end that look like a neck protector and chin strap. The Helmet has two types of terrain, a slightly elevated plain that looks like an older mare surface, and a couple of distinct hills named Herigonius Pi and Eta. Both the hills and the plain are quite red spectrally (though not visually) and both appear to be residual pieces of an older

Mons Hansteen, the Arrowhead, is one of the few silicate-rich lava features visible on the Moon. This lunar mountain is easy to spot in backyard telescopes due to its pitted surface and its brightness compared with the surrounding maria.



NASA / GSFC / ARIZONA STATE UNIVERSITY (3)

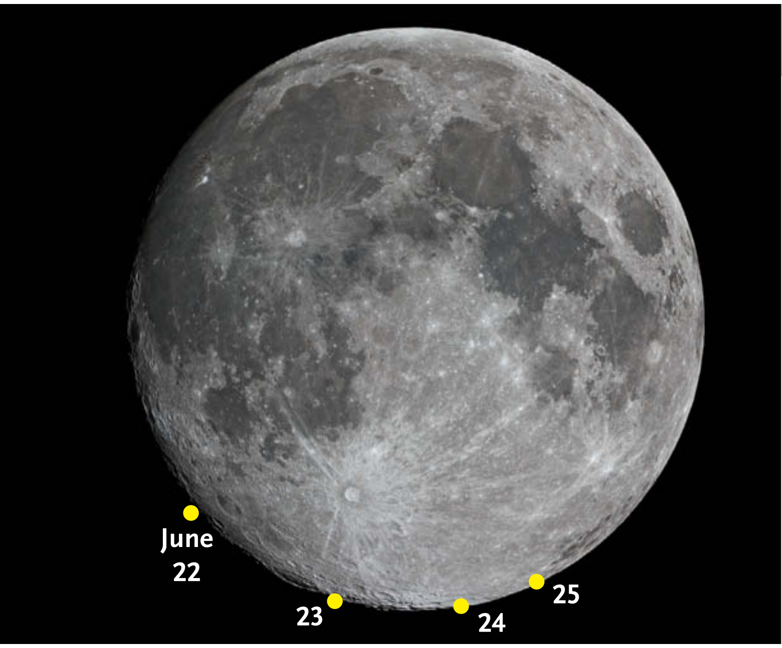
The volcanic domes Mons Gruithuisen Gamma (left center) and Delta (right) rise above the surrounding terrain.

terrain long since flooded by mare lavas.

The next region of interest includes the southern 50 km of **Montes Riphaeus**, which form a curved red spot that is apparently the rim of an (otherwise destroyed) ancient crater. Continuing eastward almost to **Alphonsus** is another small red spot near the crater **Lassell**. Just west of Lassell is an island of upland material informally known as the Lassell Massif, with two or three irregular pits at its southern end. Spectrally red material surrounds the pits, suggesting either that the pits are eroded impact craters that excavated the red material, or that they are small volcanic craters that erupted red ash.

As you look at these red spots, notice that they have different origins: at least two were made of red lavas that erupted onto the lunar surface (the Gruithuisen domes and Hansteen Alpha), whereas the others seem to have been excavated from intrusive layers by impact craters. In all cases the red material is older than the nearby maria. Perhaps before mare-type volcanism became pervasive, there was a period of silica-rich, non-mare volcanism. If so, that would suggest that lunar volcanism is more varied, and perhaps older, than indicated by the flat plains of the mare basalts. ✦

Roughly 8° east of Gassendi lies the odd lunar feature known as the Helmet. Much like other spectrally red spots, the Helmet is brighter and significantly more pitted than its surroundings.



S&T: DENNIS DI CICCO

The Moon • June 2013

Phases

NEW MOON	June 8, 15:56 UT
FIRST QUARTER	June 16, 17:24 UT
FULL MOON	June 23, 11:32 UT
LAST QUARTER	June 30, 4:54 UT

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

Distances

Apogee	June 9, 22h UT
252,579 miles	diam. 29′ 24″
Perigee	June 23, 11h UT
221,826 miles	diam. 33′ 28″

Librations

Vallis Inghirami	June 22
Le Gentil (crater)	June 23
Demonax (crater)	June 24
Pontécoulant (crater)	June 25

The First Plowman

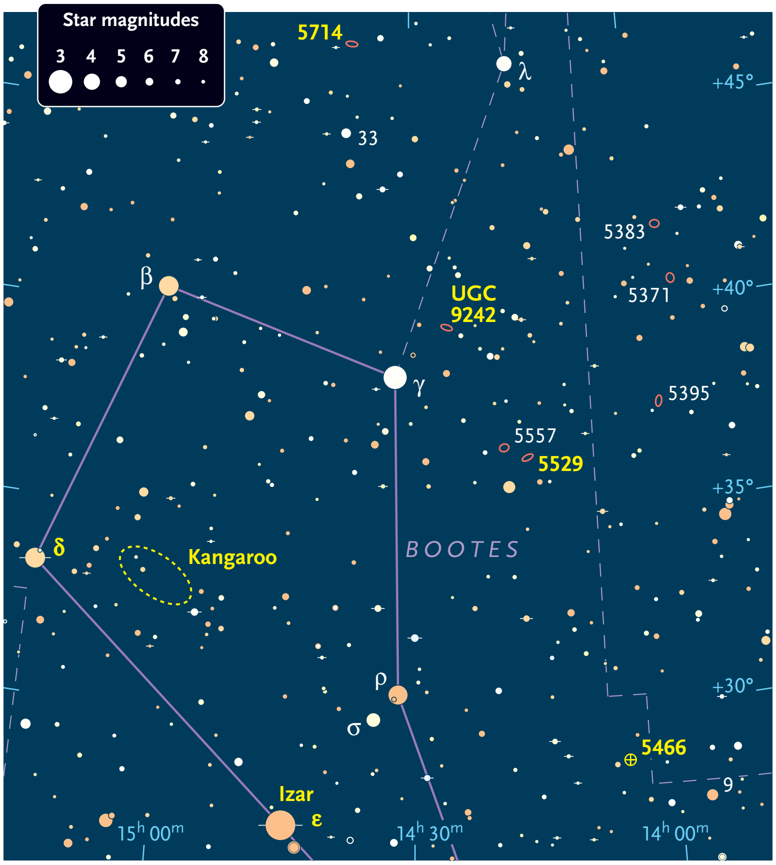
Boötes is home to one globular cluster and many great galaxies.

And next Boötes comes, whose order'd Beams
Present a Figure driving on his Teams.
— Marcus Manilius, *Astronomica*

The name Boötes is often said to come from a Greek term meaning "ox driver." According to some tales, Boötes invented the ox-drawn plow to make the cultivation of crops easier. Proud of her son's creation, the goddess Ceres had Boötes placed among the stars. We can also see his creation in the nearby asterism of the Big Dipper, which is called the Plough in the British Isles.

Have you ever wondered how to pronounce Boötes? One accepted pronunciation is bo-OH-teez. If you'd like to hear the names of the constellations spoken, visit *Sky & Telescope*'s guide at **skypub.com/constellations**.

We'll begin at **Delta (δ) Boötis**, a spacious double star whose components are widely parted by my 105-mm (4.1-inch) refractor at 17×. The deep yellow primary is a giant star with a spectral type of G8, and the pale yellow star following it across the sky is similar to our Sun. Despite the gulf between them, these stars form a true pair about 122 light-years away from us. Their angular separation on the sky tells us that they must be separated in space by at least 10 times the average Sun-Pluto distance.



Canadian amateur Dave Johns told me about a cute asterism he found 3.1° west of Delta. His **Kangaroo** spans 1.7° from nose to tail and makes a nice target for big binoculars or a small, wide-field telescope. My 18×50 image-stabilized binoculars show enough stars to see his shape, with the Kangaroo boinging his way east. My 105-mm scope at 17× nicely displays the 21 stars (magnitudes 7 to 11) that make up his outline. The Kangaroo's brightest star joins his foreleg to his body and shines with a golden hue.

Our next stop is the lovely double star **Epsilon (ε) Boötis**. It's commonly known as Izar, an Arabic word meaning girdle or loin cloth, denoting the star's position in its constellation figure. William Herschel discovered the pair in 1779, describing it as "a very beautiful object." He called the brighter star "reddish" and the fainter one "blue, or rather a faint lilac." Friedrich Georg Wilhelm von Struve bestowed the name Pulcherrima (Most Beautiful) on this double, calling its stars "very yellow" and "very blue."

Through my 105-mm refractor at 122×, I see Izar's snug primary and secondary as gold and white, respectively, which matches their spectral types of *K*0 and *A*0. However, many observers see the secondary as bluish, a common color-contrast illusion experienced when a yellow, orange, or red star is seen close to a fainter star that's not strongly colored. The companion star is only 2.8″ north-northwest of its primary, and you may need a magnification of more than 200× to separate them when the seeing (atmospheric steadiness) is poor.

Farther east we come to **NGC 5466**, the only globular cluster in Boötes. Look for it 1.5° northeast of the 6th-magnitude star 11 Boötis. Although the cluster has a ghostly surface brightness, I can detect it through 15×45 image-stabilized binoculars. The globular appears fairly large through my 130-mm refractor at 23×. I estimate that it would just fill the space between two field stars (8th and 9th magnitude) about ½° to the cluster's north-northwest and 8.4′ apart. A 7th-magnitude, yellow-orange star sits 20′ east-southeast of the cluster. At 102× NGC 5466 pres-

ents a slightly brighter core that's elongated north-south for 3¼′. The cluster remains fairly bright to a diameter of 5′ and then gives way to a gossamer halo. A few extremely faint stars pop in and out of view.

In my 10-inch reflector at 187×, NGC 5466 flaunts many chains of faint to very faint suns beading an unevenly bright haze, while isolated halo stars are set against a sable sky. Switching to my 15-inch reflector at 216×, NGC 5466 is a gorgeous, well resolved, and very loose cluster with ragged edges. Many stars of varied brightness grace the cluster, some of the brightest hemming the star-dappled core and molding it into a 5′ triangle pointed southwest. A line of several stars dangles from the globular's southwestern fringe and trends south-southeast.

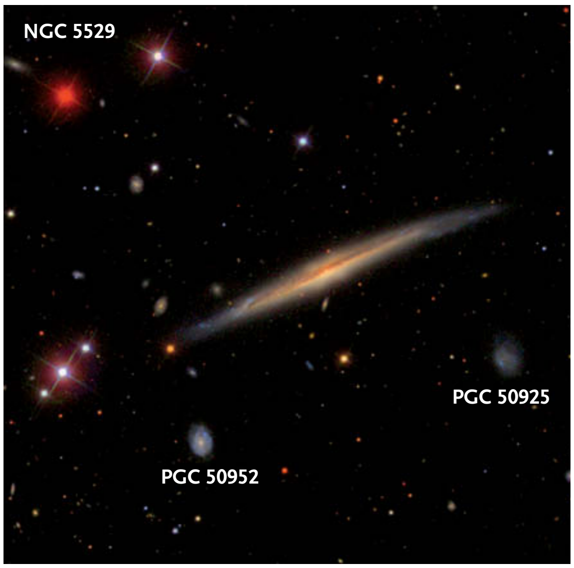
NGC 5466 is high above the plane of our galaxy, about 52,000 light-years from the Sun and 53,000 light-years from our galaxy's center. NGC 5466 sports a lengthy tail of tidal debris stripped from the orbiting cluster when it passed near the galactic center while plunging through the galaxy's disk. The tail's following arm extends at least 15° southeast, and the leading arm reaches across Canes Venatici and into Ursa Major. Part of the tail is kinky, and a 2012 study by Hanni Lux (University of Nottingham, UK) and her colleagues uses its peculiar structure to probe the shape of our galaxy's dark matter halo.

Now we'll call on the flat galaxy **NGC 5529**, which rests 52′ northwest of the 4.8-magnitude, yellow-orange star HD 125351. Flat galaxies are disk-like galaxies, seen edge-on, that appear at least seven times longer than wide.

NGC 5529 is faint, very slender, and grows brighter toward the center as seen through my 130-mm scope at 63×. It spans about 3′, running west-northwest to east-

southeast. NGC 5529 is nestled in a distinctive starfield that includes a short, three-star (magnitude 10.9 to 13.5) line near the galaxy's eastern tip and a large, six-star zigzag topped by a 10th-magnitude beacon west of the galaxy. Folks with 16-inch or larger scopes should look for the galaxy's thin dark lane and the two dim companion galaxies to the south (PGC 50952 and PGC 50925).

Large-scope enthusiasts may also like to try the more challenging flat galaxy **UCG 9242**, located 1.8° north-west of Gamma (γ) Boötis. Whereas NGC 5529 is nine times longer than wide, UGC 9242 is a needle-thin 17 times longer than wide. With my 10-inch scope at 89×, I can just see its very dim, elongated core sprouting short fainter extensions. A 13th-magnitude star is perched 1.3′ east-southeast of its center. At 115× I see only 1.3′ of this



SLOAN DIGITAL SKY SURVEY

Stars, Clusters, and Galaxies in Boötes

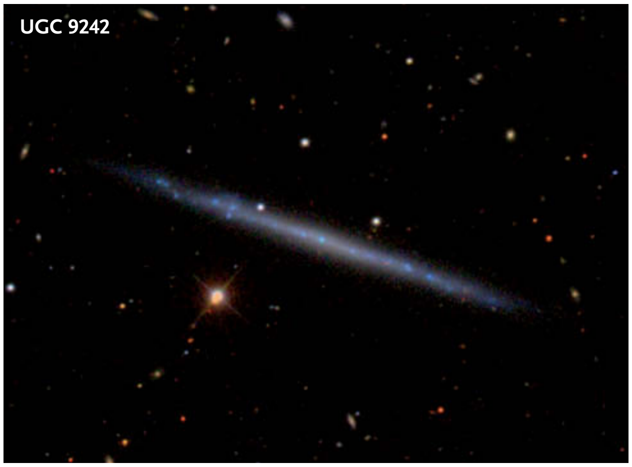
Object	Type	Mag(v)	Size/Sep	RA	Dec.
δ Boo	Double star	3.6, 7.9	109″	$15^h\ 15.5^m$	+33° 19′
Kangaroo	Asterism	—	113′ × 53′	$15^h\ 00.9^m$	+33° 09′
ε Boo	Double star	2.6, 4.8	2.8″	$14^h\ 45.0^m$	+27° 04′
NGC 5466	Globular cluster	9.0	9.0′	$14^h\ 05.5^m$	+28° 32′
NGC 5529	Flat galaxy	11.9	6.4′ × 0.7′	$14^h\ 15.6^m$	+36° 14′
UCG 9242	Flat galaxy	13.5	5.7′ × 0.3′	$14^h\ 25.4^m$	+39° 32′
NGC 5714 Sextet	Galaxy group	13.4–16.9	11.5′	$14^h\ 38.5^m$	+46° 39′

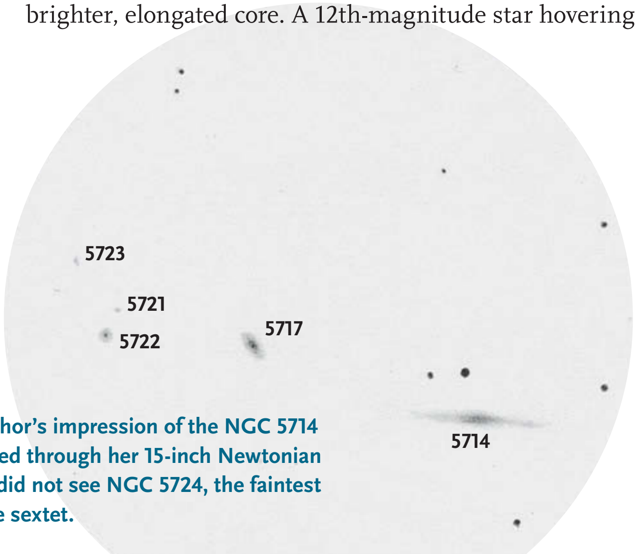
Angular sizes and separations are from recent catalogs. Visually, an object's size is often smaller than the cataloged value and varies according to the aperture and magnification of the viewing instrument. Right ascension and declination are for equinox 2000.0.

galaxy's 5.7′ length, a pin of light pointing east-northeast. Texas amateur Jimi Lowrey brought this superthin galaxy to my attention. How much of its length can you see?

We'll end our tour with a compact sextet of galaxies 1.9° west-northwest of 38 Boötis. In my 130-mm scope at 164×, I can barely see three of these faint galaxies with averted vision (that is, by looking a little off to one side of each object). **NGC 5714** (magnitude 13.4) is just a slightly elongated blur, while **NGC 5717** (mag. 14.4) and **NGC 5722** (mag. 14.7) show only their tiny cores as extremely faint spots. Two 13th-magnitude stars 5.2′ north-northwest of NGC 5722 point right to the galaxy.

Through my 10-inch scope at 166×, NGC 5714 becomes a 1½′ streak tipped a little north of east with a slightly brighter, elongated core. A 12th-magnitude star hovering



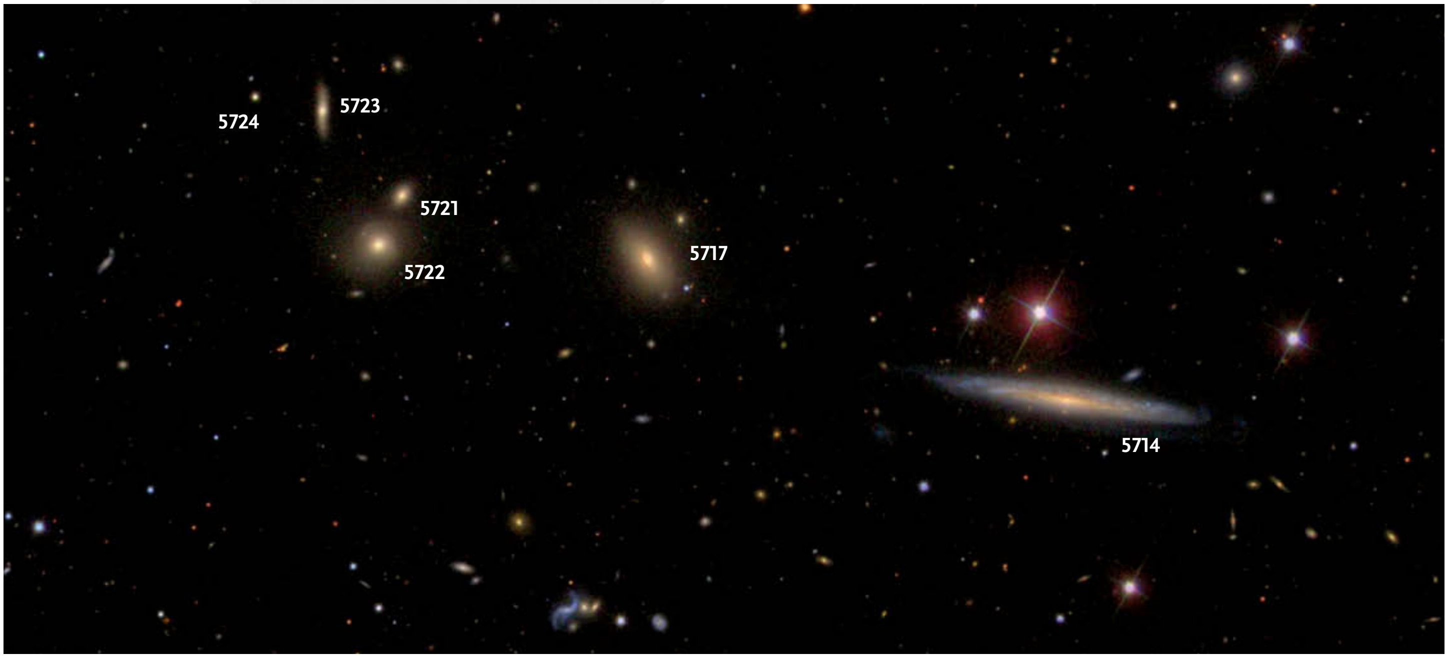


Here's the author's impression of the NGC 5714 sextet as viewed through her 15-inch Newtonian reflector. She did not see NGC 5724, the faintest member of the sextet.

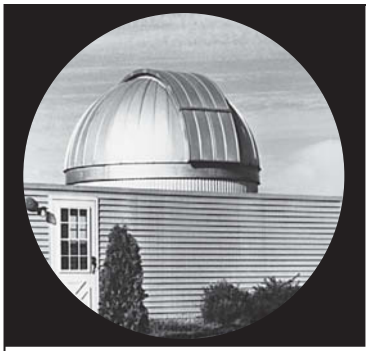
over the galaxy's northern flank guards a 13th-magnitude star to its east. This flat galaxy shares the field of view with NGC 5717 and NGC 5722. The former is a 1′ oval leaning northeast, which harbors a brighter core and starlike nucleus. NGC 5722 is small and round with an elusive, stellar nucleus.

My 15-inch reflector at 216× adds two fainter smudges to the group — **NGC 5721** (mag. 14.9) and **NGC 5723** (mag. 15.0). The final member of the sextet, **NGC 5724** (mag. 16.9), remained invisible to me. Can you spot it?

NGC 5717, 5721, 5722, and 5723 are each about 500 million light-years distant. NGC 5714 and 5724 are foreground galaxies 130 million and 260 million light-years away from us. ✦



SLOAN DIGITAL SKY SURVEY (2)



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The **ASH-DOME** pictured is a 12′6″-diameter, electrically operated unit. The observatory dome shelters a 10-inch, f/10 Dobbins telescope. The observatory is used for personal observing and by local amateur astronomy groups year-round.

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Gary Seronik

Return of the ETX

The ongoing saga of Meade's venerable Go To pioneer.

AH, THE MEADE ETX-90. Has a more famous telescope emerged in the past 20 years? I can't think of one. I remember the first time I got to play with an ETX. It was the autumn of 1998 and I had just moved to Massachusetts to begin working at *Sky & Telescope*. For the first weeks of my stay my apartment was furnished with a chair, a lamp, an air mattress, and the company's ETX-90. Talk about the bare essentials! My early nights with the ETX were a mix of pleasure and pain. The views were very, very good — nearly equal to those of my trusty Questar, another 90-mm Maksutov. But the ETX's neck-breaking finder, plastic mount, and balky motor drive were not exactly a joy.

Fast forward 15 years, and an updated ETX has arrived at my new home in Victoria, British Columbia. Pulling the telescope out of its fitted, hard-shell case made me feel like I was greeting a long-lost friend. The new telescope has many more features than the original and a remarkable price, but only time would tell if this reunion was destined to be a happy one.

Meet and Greet

The model we borrowed from the manufacturer for this review is the ETX-90 Portable Observatory. The fork-mounted Maksutov-Cassegrain telescope with its motorized Go To drive and AutoStar 497 hand control includes a heavy-duty field tripod (with its own padded carrying bag). The scope comes with 26- and 9.7-mm Plössl eyepieces, yielding magnifications of 48× and 129×, respectively. It also has a red-dot finder, a compass/bubble-level "eyepiece" alignment tool, the scope's carrying case, and a printed instruction booklet. In short, you get everything you need for a night of observing. (The regular ETX-90 package doesn't have the 9.7-mm eyepiece or the carrying case and lists for $399.)

At first glance the newest incarnation of Meade's popular ETX-90 Maksutov-Cassegrain looks strikingly similar to the original, which took the amateur astronomy world by storm when it debuted in 1996. Remarkably, this computerized Go To scope costs much less than the bare-bones, non-computerized original. ALL PHOTOGRAPHS TAKEN BY THE AUTHOR

Meade ETX-90 Telescope

U.S. price: $469 (for ETX-90 Portable Observatory package tested)
Meade Instruments
www.meade.com

True to its lineage, the current ETX-90 is pitched at beginners. A newbie's success often depends not only on how well the scope performs, but also on the quality of the instruction manual, which, in this case, is a mixed bag. The best sections are those describing the initial assembly and set up of the scope (complete with detailed color illustrations) and the various functions of the AutoStar hand controller. The information is, however, confusingly organized, and there are a few potholes that may cause a beginner some headaches. For example, a lengthy section describes the use of the compass "eyepiece" to orient the ETX to its home position (level, and pointed north). But there's no mention of the critical requirement of having the north-south axis of the compass lined up with the telescope tube. Is this obvious? Perhaps. But no more so than many other items that are covered in detail in the manual.

Another section of the manual that needs reworking is the appendix on basic astronomy. It contains several errors of fact, some dubious advice, and the general content and organization is poor. A bibliography of further reading material would have been a much better use of these pages.

Those criticisms aside, the instruction manual will enable most users to get up and running quickly. Setting up the scope is very easy — all you do is attach the ETX to its tripod, install six AA batteries, and plug in the AutoStar controller. Unlike the original ETX, the new model has its battery compartment on the top of the base, so it's no longer necessary to remove the scope from the tripod to change the batteries. Hurray!

The scope comes well-equipped with two eyepieces, a bubble-level/compass alignment tool, the AutoStar hand control, and a hard-shell case for the telescope. A heavy-duty tripod with a padded carrying bag is also included in the package.

Pointing the Way

It's amazing how far telescope electronics have evolved since the ETX debuted in 1996. All the original scope had was a slightly cranky motor drive that tracked at the sidereal rate. There was no hand control, and the scope had to be polar aligned for the tracking to work properly. You had to manually aim the scope at whatever object you wanted to look at. The new ETX, on the other hand, is a marvel of computerization. Decide what you want to see, push a few buttons, and voilà, when the scope stops slewing the object is in the eyepiece.

In spite of my less-than-optimal viewing site, the ETX-90's computerized pointing got off to a promising start the first night I took it out. I set up the scope on a west-facing balcony where the sky is largely obstructed by my apartment building. The scope's AutoStar controller initially suggested Deneb as an alignment star, which was then low in the western sky. The scope slewed to the star and I centered it in the eyepiece as instructed by the hand-control's

***Left*: The brains of the operation reside in the scope's AutoStar computer. In addition to controlling Go To pointing, the unit features a range of useful utilities and a database that includes more than 14,000 deep-sky objects and a similar number of stars.**

WHAT WE LIKE:

Full-featured AutoStar computer

Portability

Complete package

WHAT WE DON'T LIKE:

Noisy motors

Inconsistent Go To performance

***Above left*: A nice red-dot finder replaces the original ETX's optical finder. The unit-power device is well suited to the task of helping aim the telescope at bright alignment stars. In practice, once the telescope is set up, a finder is largely unnecessary. *Above right*: To assist AutoStar during initial setup, the telescope tube should be oriented level and pointed north. A handy bubble-level/compass "eyepiece" simplifies this task, especially if you observe from a location where Polaris isn't visible. *Left*: The ETX requires six AA batteries. Observers with easy access to an AC outlet should consider purchasing the optional AC adapter ($30), since fresh batteries will last only a few nights of moderate use.**

display. But I wasn't so lucky with AutoStar's picks for a second alignment star. I had to reject suggestion after suggestion because the stars were blocked from my view. Eventually the little computer picked another star that I could see in the west, Enif, the nose of Pegasus. When I centered that star and pressed the Enter button I got an "Align Successful" message. Alignment stars this close together are far from ideal, so I decided to make my first Go To target an easy one; the globular cluster M15, only 4° from Enif. After I selected M15 from the internal database, the scope made its short hop and put the globular in the eyepiece. But I was even more impressed when it next nailed the Andromeda Galaxy (M31) more than 45° from M15.

But on other nights, AutoStar would sometimes falter. There were times when the scope would do well with several targets in succession, and then miss a couple. For example, one evening after aligning on the stars Sirius and Rigel, the scope successfully made the long jump to Regulus, putting the star squarely in the 1° field of view of the 26-mm eyepiece. Yet it failed to pinpoint Betelgeuse, despite this star being much closer to the alignment stars.

Auto Super Star

AutoStar has far too many features to detail here, so I'll just highlight a few of my favorites. In general, AutoStar's Go To pointing placed targets in the field of view most of the time, though rarely dead center. When it did miss, it didn't miss by much — usually only by a degree or two — and for those occasions there's the nifty "spiral search" function. Pressing the Go To key a second time starts the scope slowly slewing outward in a boxy spiral until you spot the object, at which point you press the Mode key to stop the search. That's both handy and cool. I also made frequent use of the scope's "sleep" and "park" functions, which allow you to power down without losing your alignment for when you later return for more observing. Another feature that helps Go To pointing in a selected region of sky is AutoStar's "synchronization" function. Simply hold down the Enter key for 2 seconds after centering a target, and you'll get better Go To pointing in the area around that target. Suffice it to say, it's well worth your time to climb AutoStar's learning curve to get the most out of the ETX.

AutoStar also features guided tours of the sky. For example, after you've achieved successful alignment, AutoStar offers to show you a selection of "Tonight's Best," starting with easy targets and moving on to progressively more difficult ones. The tours I took were heavy on bright stars, which are interesting but hardly compelling sights in the eyepiece, and AutoStar would occasionally choose targets for which the ETX-90 is not particularly well suited because of their size or faintness.

Optics Plus

Although the ETX may have a computerized brain, at its heart is a Maksutov-Cassegrain optical system. The optics in my test telescope were acceptable, though not quite

***Facing page*: The ETX-90 has undergone several revisions since its launch in 1996. The latest version sports a few evolutionary changes (such as moving the battery compartment to the top side of the base), new features, and a much lower list price.**

as good as those in most of the ETXs I've used over the years. The optics were a bit undercorrected, which slightly softened my views of planets. While high-contrast targets such as lunar craters and stars were rendered crisply, subtle low-contrast features, such as Jupiter's cloud bands, were less prominent than I would expect for a scope with an 85-mm effective aperture (a measurement that I determined optically). The scope's collimation was dead-on, which was good since there's no user adjustment for this.

Two improvements to the new ETX made it substantially easier to use than the original. First is the focusing mechanism. I can't recall using a moving-mirror focusing system (found in virtually all modern Schmidt-Cassegrain and Maksutov-Cassegrain telescopes) that didn't display some image shift. My test ETX had none. There was, however, a quarter-turn dead spot when you reverse the direction you're turning the focus knob, which made precise focusing at high power a bit challenging.

The other improvement is the red-dot finder. It's much easier to use than the original, but it's still awkward to look through when the scope is aimed straight up. Although it's limited to bright objects, this is entirely acceptable for a telescope with Go To pointing. The only time I used the finder was to zero in on bright alignment stars, a task for which it's well suited.

Overall, the ETX performed capably, especially for its price. But like most complex devices, it has little annoyances. On the minor side, I found I was forever looking for somewhere to put the AutoStar hand unit. There's no holder for it, and it's too big to easily sit on the tripod spreader bar without sliding off and bungee jumping at the end of its cord. The cord's socket on the base of the scope is deeply recessed, making it difficult to reach the little release tab on the plug when you want to disconnect the cord and pack the scope in its storage case.

For me, the most annoying aspect of using the ETX-90 is its noisy motor drives, especially when the scope is slewing to a target. But even when the scope is simply tracking a target it sounds as if you're next to a busy fax machine. If the quiet of a country night is something that you cherish, this scope will disrupt the serenity.

The included heavy-duty tripod is very nice and has a tilting head for those rare occasions when you want to polar-align the ETX-90. It adds 13 pounds (6 kg) to the telescope's 9-pound heft, so the assembled scope is easy to move. The mount quickly dampens vibrations in about 2 seconds. While the view sometimes jiggled quite a bit when I was using the focusing knob, a set of vibration-dampening pads placed under the tripod legs helped considerably and are an accessory I highly recommend.

Conclusions

Overall the ETX Portable Observatory package has much to recommend it. The telescope has adequate optics and a capable Go To system. The AutoStar controller sports a host of useful functions and object catalogs while remaining simple enough that users will have little difficulty learning the basics.

Is the ETX-90 a good beginner's scope? It's not perfect, but it certainly has many features that the newbie will find useful and exciting. For more experienced observers looking for a portable scope, the ETX-90 could be a fine observing companion — especially if the Moon, planets, and double stars are your specialty. And it has to be said that the $469 asking price makes the package very enticing. To put that price into perspective, when the first AutoStar-equipped ETX-90 appeared in 1999, a comparable setup would have set you back more than $1,000, and that was in 1999 dollars! ✦

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*Contributing editor **Gary Seronik** is a telescope maker, user, and reviewer living in British Columbia. He can be contacted through his website: **www.garyseronik.com**.*

◄ **BUDGET EYEPIECES** Olivon Manufacturing Group rolls out its new 80° ED Wide Angle Eyepiece series. Each of these eyepieces incorporates extra-low-dispersion elements for color-free images, and every air-to-glass surface is multicoated to reduce light scatter and to produce sharp views across the entire visible field. Collapsible rubber eye guards and end caps are also included with each purchase. The 11- and 15-mm eyepieces are 1¼-inch format ($74), whereas the 16-, 20-, and 30-mm focal-length models are formatted for 2-inch telescope focusers ($190). See the manufacturer's website for a list of dealers.

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▼ **EYEPIECE TURRET** Baader Planetarium unveils an innovative observing kit for planetary enthusiasts. The Baader Classic Q-Turret and Eyepiece Set ($395) combines its new Classic Eyepieces series with a 4-position Q-Turret and 2.25× Q-Barlow in one convenient package. The Q-Turret ($85) is a 1¼-inch, 4-position click-stop eyepiece turret that enables observers to rapidly change magnifications with a simple twist of the unit. The turret's concave body is designed to add only a minimal 38 mm to your telescope's optical path, enabling it to be used with many Newtonian reflectors. The Classic Eyepieces set ($74 each) consists of 6-mm, 10-mm, and 18-mm Orthoscopic occulars with an unprecedented 50° apparent field of view, plus a matching 32-mm Classic Plössl. Each eyepiece is fully multicoated and includes integrated winged, folding rubber eyecups. The 32-mm Plössl also includes a slip-on eye guard extension tube to help place your eye at the optimum viewing distance. Also included is the 2.25× Q-Barlow ($69) with a removable, threaded lens cell that can be mounted directly to the barrel of the Q-Turret, or on any eyepiece barrel for a moderate 1.3× magnification boost. See the manufacturer's website for additional details.

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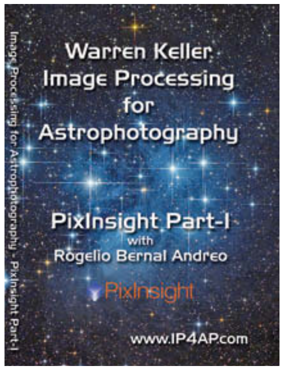

◄ **PIXINSIGHT TUTORIAL** Premier astrophotographers Warren Keller and Rogelio Bernal Andreo team up to bring you the latest video tutorial in the IP4AP series. "Image Processing for Astrophotography: PixInsight Part-1" ($69.95) is available for online streaming or as a DVD. It contains 2½ hours of information in 23 scripted *Adobe Flash* tutorials that will help familiarize you with the software *PixInsight*, a powerful and affordable alternative to *Adobe Photoshop* designed specifically for astrophotography. Part 1 of the series teaches you the basic steps needed to produce most types of deep-sky images, including tips on how to reduce, align, and combine all your data; correct for light-pollution gradients; and achieve natural color balance in all your images. More advanced techniques such as sharpening routines and non-linear stretching are also demonstrated to help you get the most out of your astroimages.

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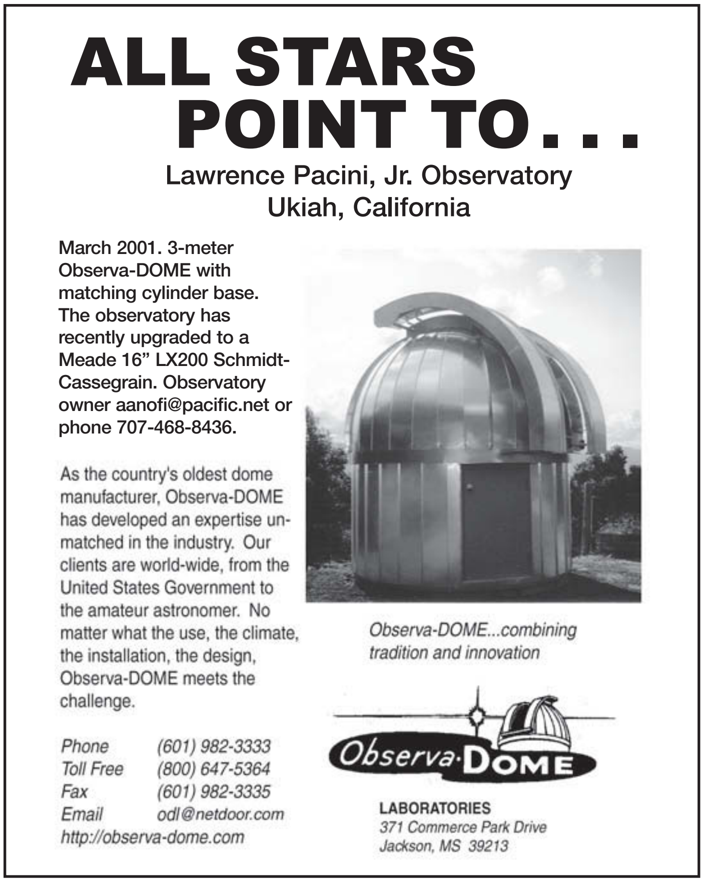
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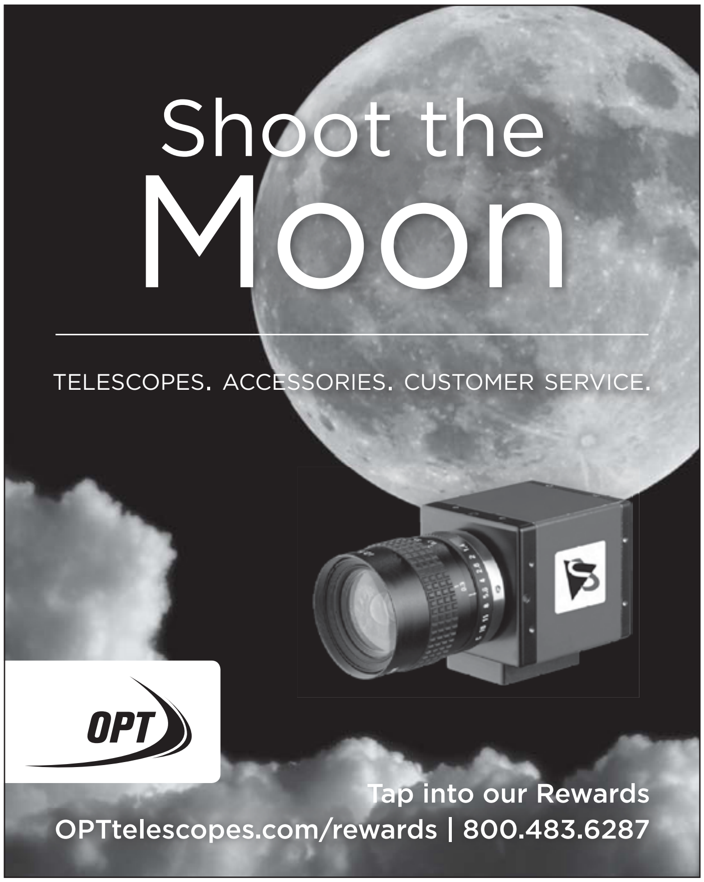
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A Nifty "Split-Pupil" Finder

This clever telescope sight is easy to make and a pleasure to use.

Many of my columns are devoted to making telescopes of one sort or another. But when it comes to enjoying a night under the stars, the scope is only part of the equation. Almost as important are the little extras that make the difference between pain and pleasure. Is there anything more frustrating, for example, than working with a lousy finder?

I've seen all kinds of sighting devices for telescopes, but few are as clever as the one built by Oregon ATM and science-fiction author Jerry Oltion. Jerry's "split-pupil finder" is as effective as it is simple. "It's really just a lens and a glow-in-the-dark arrow attached to a stick that holds them the correct distance apart," he explains. "The lens puts the arrow at infinity focus so it doesn't shift position against the stars when you move your head. It's the same principle behind Telrad-type finders." Jerry says he got the idea from his friends Chuck Lott and Craig Daniels, and that a very similar finder was described by Kansas City amateur Stanley B. Rowson in Albert Ingalls's November 1952 Amateur Scientist column in *Scientific American*.

Jerry suggests a lens about an inch in diameter with a focal length of 4 to 8 inches, though neither of these parameters is critical. Many telescope makers can find a suitable lens in their junk box, but another source is Surplus Shed (**www.surplusshed.com**). As the accompanying photos show, the finder is very simple. "Glue the lens to one end of the finder body and a glow-in-the-dark arrow to the other end positioned at the lens's focal point,"

The finder is a simple lens focused on a luminous pointer and is similar in concept to red-dot finders.

GARY SERONIK

JERRY OLTION

Jerry Oltion is shown using his "split-pupil" finder. He notes that it's best to position your eye just behind the lens and look over the top of it to see the sky and pointer arrow sharply focused.

Jerry explains. The finder works best if the arrow has a blunt tip, rather than a sharp one. You want the tip to be roughly the same height off the body of the finder as the center of the lens. Although Jerry trimmed the top off his plastic lens, it's okay to leave it round.

The finder's body is just a stick joined to a dowel with a strip of aluminum folded around the dowel and screwed to the stick. This provides friction-controlled altitude and azimuth motions for aligning the finder with the telescope. Jerry's finder has a base that fits into a dovetail bracket, but you can mount this lightweight device any way that suits your scope.

Using the split-pupil finder is straightforward, but several characteristics aren't immediately apparent. "If you put your eye about an inch behind the lens and look over its top, you'll see the sky and the pointer arrow sharply focused because your eye's pupil is large enough to simultaneously view both," says Jerry. "The beauty of this arrangement is that you're not losing any of the star's light through the lens — so the finder is good all the way down to the limiting magnitude of your sky."

Another nifty aspect of the finder is that you can adjust the brightness of the glow-in-the-dark arrow relative to the stars by just moving your head up and down to adjust the relative amount of light your eye sees from the sky and arrow. This lets you fine-tune your view.

Jerry's split-pupil finder is lightweight and easy to build, making it an ideal companion to an optical finder on a big scope or a great option for lightweight travel-scopes and small instruments. Readers can contact Jerry via e-mail at j.oltion@sff.net. ✦

*Contributing editor **Gary Seronik** is an experienced telescope maker with a taste for simple yet effective solutions. He can be contacted through his website,* ***www.garyseronik.com.***

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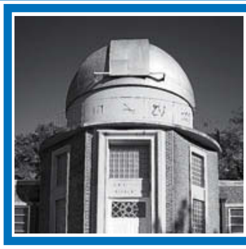

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A Sky & Telescope *editor answers your astronomy questions.*

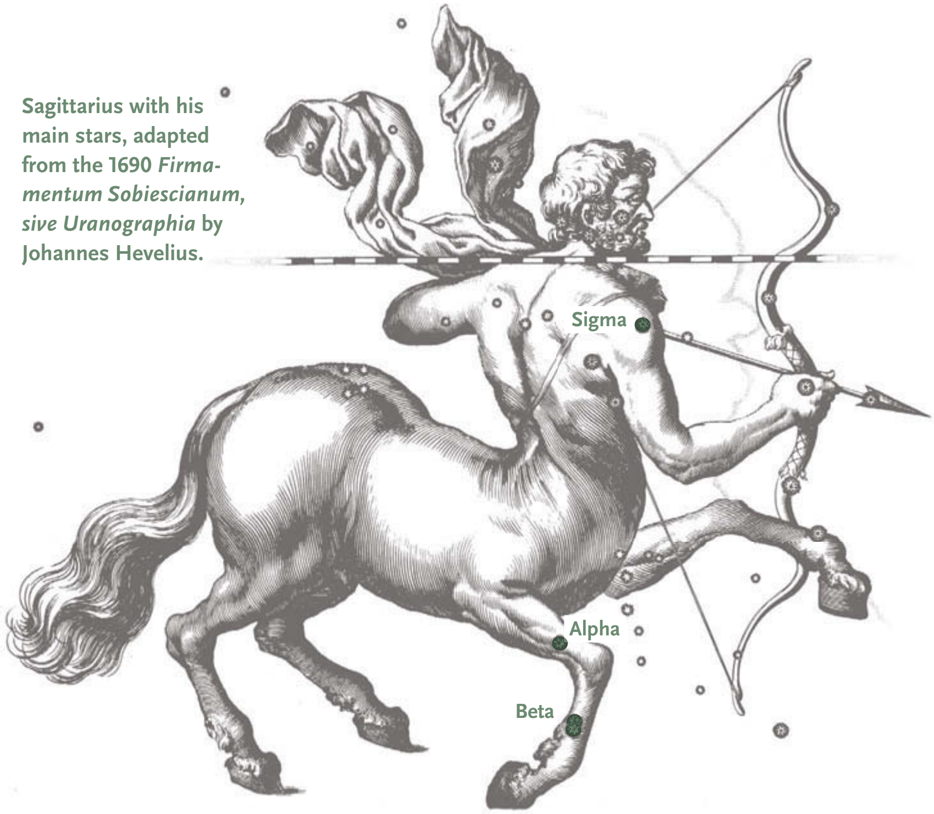
Flashes in the Sky

I was setting up to take pictures of the Orion Nebula last night, and I noticed a bright flash in the nebula for just a second. Could this have been the birth, or death, of a star?

—Daniel Lanctot
Central Village, Connecticut

Sorry. A supernova (the explosive death of a star) shines for weeks, not moments. As for a star being born, infant stars are notoriously variable — but on timescales of days to years.

Readers ask us about flashes among the stars all the time! What you may have seen was sunlight glinting off a flat surface on a rotating satellite. This happens a lot. It proved to be the explanation for the mysterious "Aries Flasher" in 1985, which excited the amateur-astronomy world with the possibility that a distant gamma-ray burster was giving off flashes of light. A project to watch Aries all night every night found more and more flashers, and not just in Aries. The satellite culprits were tracked down with a lot of detective work (*S&T:* June 1987, page 604). Though the mundane answer was a disappointment, the needs of the project helped to launch development of amateur CCD cameras.



Sagittarius with his main stars, adapted from the 1690 *Firmamentum Sobiescianum, sive Uranographia* by Johannes Hevelius.

Moons of Moons of Moons

Can a moon have a moon? If so, why don't we see any? Could Ganymede, for instance, have a natural satellite that we have yet to discover?

—Scott Hill, Tucson, Arizona

There's no limit to the possible hierarchy of orbits within orbits, as long as each succeeding pair of objects is close enough together to resist being pulled apart by the next object up.

For instance, the Sun orbits the center of the Milky Way, planets orbit the Sun, moons orbit planets, and spacecraft orbit our Moon. In principle, an escaped nut or bolt could orbit a spacecraft.

At each level, a satellite has to fit well within its host's *Hill sphere.* (You might appreciate the name.) This is where the gravitational force between the two is stronger than the influence of the next object up. The Hill sphere fits the space between the L_1 and L_2 Lagrangian points for any pair of orbiting bodies.

Earth's Hill sphere has a radius of about 1.5 million km (930,000 miles). That means our Moon could move about four times as far from Earth as it is now before it would come loose and drift away into its own orbit around the Sun.

In reality, over billions of years, slight perturbations and resonances can eventually pull apart objects that are as close as about ½ or ⅓ of the Hill radius.

Although most planets have big, obvious moons, none of the solar system's moons has a natural moon of its own — at least none big enough to find yet. Apparently, the hierarchical process that formed planets and then moons in the Sun's protoplanetary nebula broke down on finer scales.

Alpha Stars of Constellations

In Orion, Rigel is brighter than Betelgeuse. So how did Betelgeuse become "Alpha" Orionis?

—Bill Schultz, Cincinnati, Ohio

In his groundbreaking star atlas *Uranometria* (1603), the German astronomy buff Johann Bayer assigned Greek letters to stars in each constellation, and his letters have stuck ever since. Bayer often named a constellation's brightest star Alpha. But not always.

Bayer's method seems to have been to call the brightest star Alpha if it was *obviously* the brightest. Then he would name stars in his next brightness category "Beta" onward through the Greek alphabet, working from the head to the feet of the traditional constellation figure. Then he went one brightness category deeper and continued the lettering, going from head to feet a second time. His brightness categories were broad, encompassing more than a magnitude.

But some of his letters seem to make no sense at all. Alpha and Beta Sagittarii are a dim magnitude 4.0 and way down in the traditional Centaur's feet. The brightest star of Sagittarius, magnitude 2.0, got the letter Sigma.

Bayer apparently sometimes worked from poor notes. Alpha and Beta Sagittarii in his atlas are drawn huge and brilliant, a mistake only partially corrected by Johannes Hevelius in his later atlas, as seen at left.

Why RA and Dec?

In "right ascension," what's ascending? In "declination," what's declining?

—Eleanor Briggs, Kansas City, Missouri

Being an ancient science, astronomy is full of old quirks and conventions that must have made sense at one time.

The sky's equivalent of Earth's longitude and latitude has not been in wide use for very long. Until three centuries ago, astronomers mostly used astrology-friendly coordinates based on the ecliptic, the midline of the zodiac. You still sometimes encounter "ecliptic latitude and longitude" for the Moon, Sun, and planets.

Right ascension and declination are based instead on the celestial equator, the line in the sky above Earth's equator. So they're conveniently aligned with Earth's rotation. They came into wide use only with the invention of equatorial telescope mounts to track the sky's motion. Not until the early 1700s did John Flamsteed publish the first star catalog using RA and Dec in preference to the old ecliptic coordinates.

The term right ascension (*ascensio recta* in Latin) starts with an observer on Earth's equator looking east. There the celestial equator stands straight up from the horizon, and stars rise straight up all along the horizon. At the moment a star rises ("ascends"), a line at a right angle (*recta*) to this motion goes to the point on the equator rising at the same moment. The star's "right ascension" is read from this point on the celestial equator.

There was also "oblique ascension," referring to the point on the equator that rises at the same time as a star for an observer somewhere other than Earth's equator. The "ascensional difference" between right and oblique ascension differed not only for every star but every observer. Thankfully, oblique ascension passed into the dustbin of astronomical history.

Declination (*declinatio,* Latin for descent or the act of bending down) refers to descent from the sky's meridian. A star on the meridian is at its highest. As it descends from there, it traces out a line of declination — which is necessarily bent because it's a small circle, not a great circle (the exception being the celestial equator itself).

Sometimes things are born complicated and grow simpler rather than the other way around. ✦

Send questions to QandA@SkyandTelescope.com for consideration. Due to the volume of mail, not all questions can receive personal replies.

Watch Your Units

I am continually frustrated by the vagueness of Einstein's famous formula $E = mc^2$, energy equals mass times the speed of light squared, because the units of measurement are never given! We see "speed of light squared" and think "Wow, that's a big number!" But if c is measured in light-years per year, then c is 1, so E = m, and maybe one gram is just one erg of energy, which is just wrong or an H-bomb would barely go pop. Enlighten us please.

—Gerry Dyck, Assonet, Massachusetts

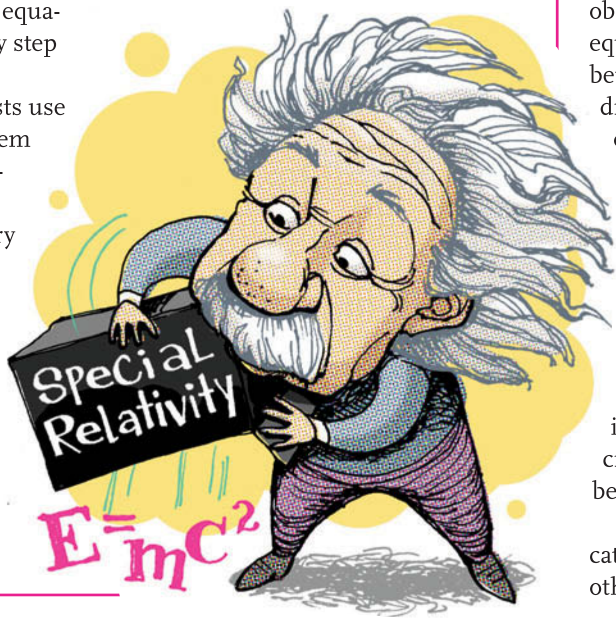
As every science teacher ought to teach, watch your units! As you point out, the number for any physical quantity must always include its units right alongside it — and they must be handled in equations exactly as variables are, every step of the way from start to finish.

To keep things simple, physicists use a single, internally consistent system for *all* units: either "cgs" (centimeters, grams, seconds), or "MKS" (meters, kilograms, seconds). Every other unit in physics breaks down into combinations of these three so-called *base units* — length, mass, and time — and in some cases four other base units that we'll skip here.

So, if on one side of $E = mc^2$ you give m in grams and c in centimeters/second, on that side of the equation you have not just numbers but also "grams × centimeters × centimeters / (seconds × seconds)." And sure enough, that string of base units *defines* the cgs unit of energy: the erg. Do it with kilograms and meters per second, and E comes out as the MKS unit of energy: the joule. Perfect! Too bad it goes unexplained.

Einstein discovered (in 1905) that $E = mc^2$ fell right out of his special theory of relativity, like a surprise jewel falling out of a box when he shook it — when you use consistent (i.e. cgs or MKS) units throughout.

So, matter and energy really are different incarnations of the same thing, equated by the speed of light. How weird is that?



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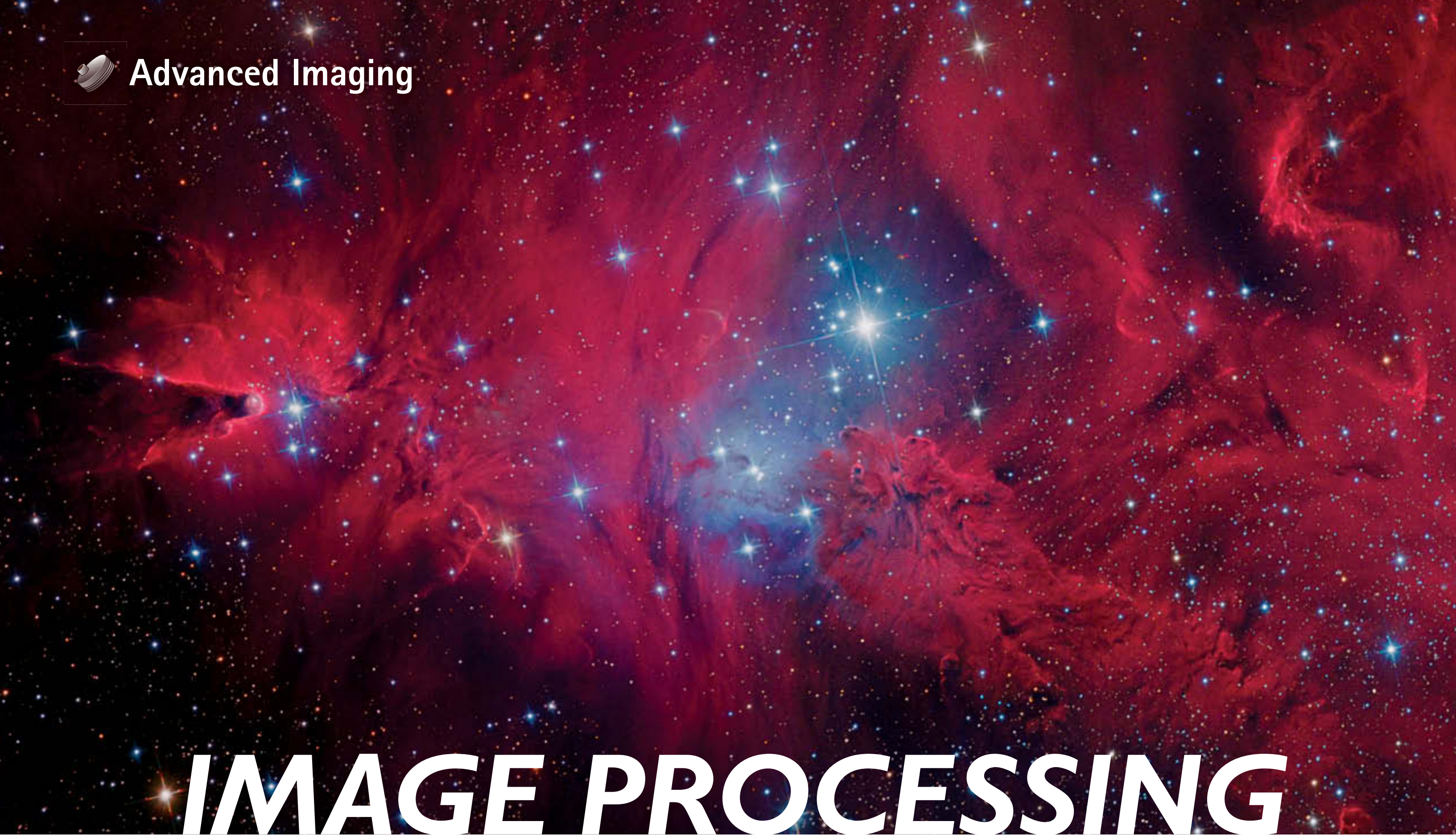


IMAGE PROCESSING *with* CCDStack 2

Improve your deep-sky images with this innovative program.

Bob Fera

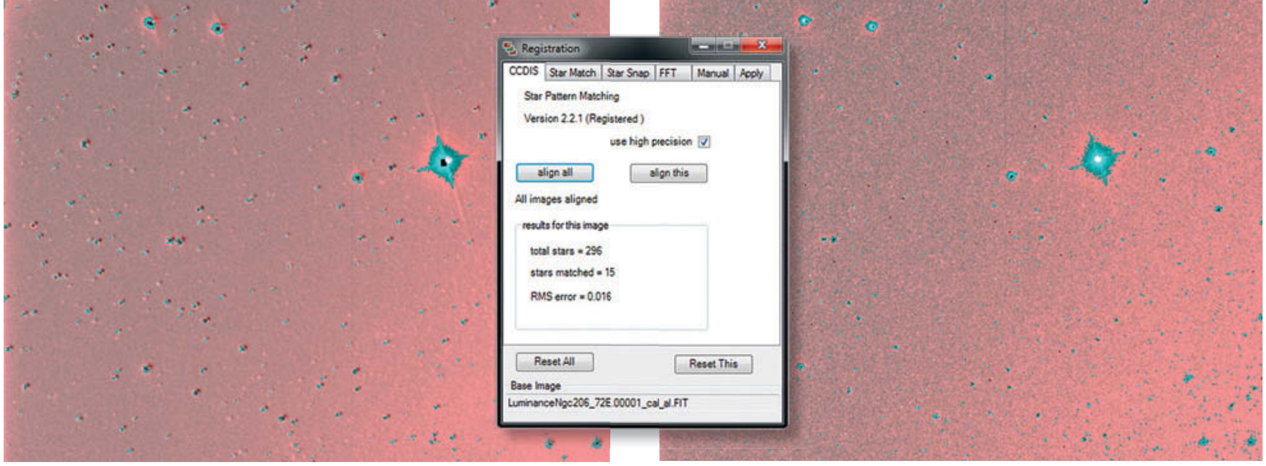
Of the myriad programs available today for processing CCD images, *CCDStack 2* is the choice of many seasoned imagers due to its intuitive user interface and various innovative "live" features. Veteran astrophotographer Bob Fera demonstrates his routine workflow using the software to calibrate, align, stack, and stretch his images to produce colorful portraits of celestial targets such as the deep photo above of the Cone Nebula. Unless otherwise noted, all photos are courtesy of the author.

Ask any experienced astrophotographer, and he or she will tell you that transforming a bunch of noisy sub-exposures into a colorful piece of art is no small feat. The process involves many steps using a variety of software packages, each with its own learning curve. For many imagers, the "art" happens in *Adobe Photoshop*. But before you can use a tool such as *Photoshop* to apply your personal touch to an image, your data must first go through a series of decidedly less sexy steps — calibration, alignment, and combination. And while these steps involve limited creative input, they are nonetheless critical to the final look of your picture.

Among the numerous programs for processing CCD data, I prefer CCDWare's *CCDStack 2* (**www.ccdware.com**) for PCs to calibrate, align, stack, and stretch my images into 16-bit TIFF files that are ready for the final tweaks in *Photoshop*. The program's strength lies in its intuitive user interface, as well as some "live" stretching features. *CCDStack 2* has worked well for me over the years and should provide you with a solid foundation for developing your own methods.

Image Calibration

Let's begin by preparing our calibration files. I always record several dark, bias, and flat-field images and combine these into "master" calibration frames to ensure that my final result is as clean as possible. This reduces any



After calibration, aligning your sub-exposures is easy in *CCDStack 2*. Simply open all the images to align, select Stack/Register, and the program automatically selects multiple stars to use as registration points. It also displays a type of "difference" between the base photo and each subsequent image that makes it easy to see when two images are out of register (*left*) and in alignment (*right*).

spurious artifacts in my calibration frames due to cosmic ray hits or other unwanted signals.

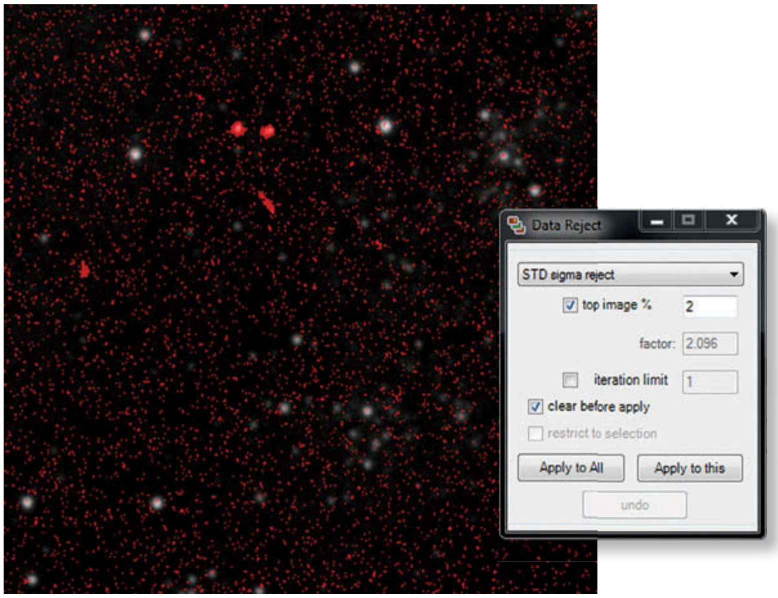
Start by opening the program and select Process/Create Calibration Master/make master Bias. The program will immediately open the last folder you used in *CCDStack 2*, so you may need to navigate to your calibration files folder. Once there, select all the bias frames that match the temperature you shot of your light frames. The Combine Settings window then opens, and allows you a few different ways to combine your biases into a "master" bias frame. I prefer to use the sigma reject mean method, and change the sigma multiplier to 2, and an iterations limit of 2.

In a few moments, your master bias frame is displayed. Simply save the result as a 16-bit FITS file, and repeat the same process to combine your dark frames by selecting the Process/Create Calibration Master/make master Dark.

Generating your master flat-field image is also similar, though the program will first ask you if you wish to dark/bias subtract each flat frame. If so, choose the master bias frame you've just created, and also the dark frame master that matches your flat-filed image. When you reach the Combine Method dialog, again choose sigma reject mean with a multiplier of 2 and an iteration value of 2. Make sure to repeat this routine for all your flats taken through various filters you shot through. Now that we have our calibration frames ready, let's tackle our raw data.

Open all of your individual exposures taken through one of your filters (if you use a monochrome camera with color filters). Next, select the pull-down menu Process/Calibrate. The Calibration Manager window opens, which will automatically find your master dark, bias, and flat frames if they were saved to the same folder you were working in previously. If not, click the "Dark Manager" button and navigate to your master frames. Once all of your master frames are selected, simply click the "Apply to all" button at the bottom left and in a minute or so, all of your images in this group will be calibrated. Save each of these calibrated images by selecting File/Save data/Included in the pull-down menu. A new window will open that allows you to add a suffix to your file title, to avoid overwriting your raw data. Select the 32-bit FIT float file option. Now you can repeat the same steps for each of your other filtered-image groups.

Now that all our images are calibrated, let's align each frame. If you have plenty of RAM on your computer and a fast processor, you can open all your calibrated exposures and align them all at once. If you have limited memory, you can perform your alignment in groups, but remember to select one image to be the "base" image that all the others will be aligned to. Make sure your alignment frame is the image visible, then select the Stack/Register pull-down menu, and the Registration window opens. *CCDStack 2* automatically detects multiple stars in your images, or allows you to select your own points to register



***CCDStack 2* is the only image processing program for amateurs that displays exactly which pixels in each image it determines will be ignored when combining sub-exposures using sigma-based data-rejection algorithms. The red spots on the image above are flagged to be rejected in a stack of 10 images.**

if you so choose. Once you've selected the alignment points, click the "align all" button at the bottom left, and in a few moments, each of your sub-exposures should be aligned properly. Before applying the alignment permanently, pan through each of your images to make sure each one worked properly. If so, click the Apply tab at the top right. The program offers a few resampling options to compensate for the sub-pixel shifting of each frame. I prefer Bicubic B-spline, but you can experiment to see what works best for your images. After the alignment is applied, save the results with a new suffix.

Data Rejection

At this point we have all our images calibrated, aligned, and ready to stack. Combining your sub-frames properly will dramatically increase the signal-to-noise ratio of your final image, while eliminating unwanted airplane and satellite trails and other random artifacts. In *CCDStack 2* this involves three steps: Normalize, Data Reject, and Combine.

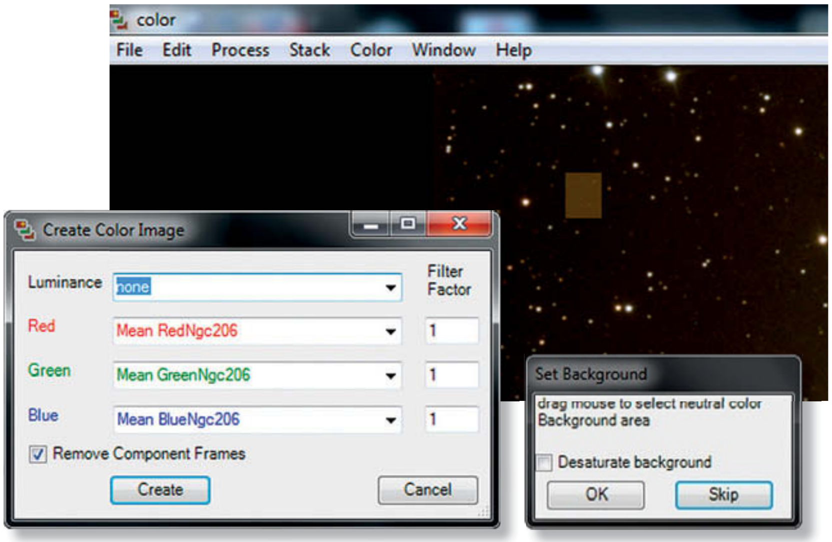
Normalizing your data mathematically compensates for variations in sky background and transparency, scaling all of your open sub-exposures to similar brightness values for corresponding pixels. This step is necessary to produce the best stacked result.

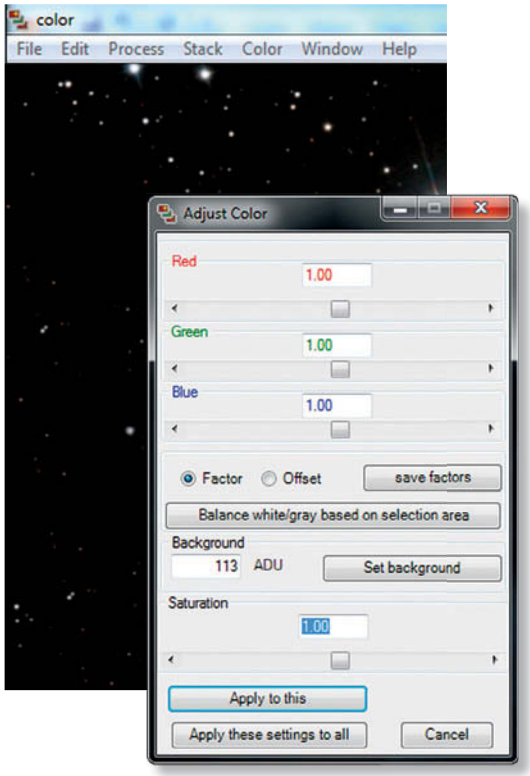
First open all the images taken with a single filter and Select Stack/Normalize/Control/Both. A small window opens that asks you to identify the background sky area. Simply click your mouse and pull a tiny rectangular selection around an area that will be a "neutral" background sky with no bright nebulosity, galaxies, or stars in your selection. For images where nebulosity permeates the entire image, try to find a region with the faintest nebulosity, or a dark nebula, as your background selection. After you've made your selection and clicked OK, the program will then ask you to select a highlight area. This will most likely be your main subject, whether it's a galaxy, nebula, star cluster, or comet. Make a selection around the brightest area and click OK. The Information window pops up and will display the calculated offset for each of your open images.

Next, we need to choose which method of data rejection to use. Data rejection identifies and removes undesirable artifacts in each of your individual images, replacing the offending areas in your final stacked result with the corresponding region from multiple unaffected sub-frames.

Choose Stack/Data Reject/Procedures and another new command window opens. Here we'll select the data-rejection algorithm from the pull-down list. I prefer to use the STD sigma reject, but you can experiment again to find what works best for your images. Check the "top image %" box, and set the value to 2, then click the "Apply to All" button. This can take a few moments, but when complete, the program will display all the rejected pixels in each of your sub-exposures as bright red. Now simply close the window and move on to the next step.

Now we're ready to combine our images into the final stacks. Once again, the program offers a number of ways





Combining filtered images to create a color composite is also straightforward in the program. Simply open your red, green, and blue (and optional luminance) images, and select Color/Create from the pull-down menu. A new window opens (*left*), where you will assign each image to its proper channel. When combined, another window opens that allows you to set a neutral background color (*above*). Next, the Adjust Color window appears (*right*), allowing you to set the white/gray levels, or input the offsets based on your filter/CCD camera combination.

Among the program's most innovative features is its ability to display "live" feedback when stretching an image to display both the faintest areas and brightest regions simultaneously. In the Adjust Display control window, simply move the DDP slider to the left and right to adjust your image, or change the background and maximum level display. None of these actions is applied permanently until your image is saved.

to do this. Refer to the internal help file to determine which suits your images best. I prefer mean combine, so I'll select Stack/Combine/Mean from the top pull-down menu. The software will then compute the mean value for each pixel in the stack of sub-exposures, while excluding the rejected pixels. This will give you the maximum signal-to-noise ratio in your final image. When completed, save the resulting image (File/Save Data/This), and again choose 32-bit FITS integer files. Close all files (File/Remove all images), and repeat the same steps for all like-filtered files.

Now we have master FITS files ready to combine into a color image. I prefer to process luminance images separately and then add them to the color result in *Photoshop*. Before combining any of the stacks, check them over carefully and address any gradients that may be affecting the individual stacks. *CCDStack 2* has a gradient removal algorithm that can be found in the pull-down menu Process/Flatten Background, which requires you to click areas in your image until they appear evenly illuminated.

Stretching and Deconvolution

Now let's stretch our luminance file using the Digital Development Process (DDP) feature. One of the software's most important features is its ability to do a "live" DDP on the displayed version of your file. First open your master luminance image, and select Window/Adjust Display, opening a window that displays sliders to adjust the Background, Maximum, Gamma, and DDP levels of the displayed image. You can now simply adjust each of the sliders until you're happy with the displayed result. The lower the DDP value is (when moving the slider to the left), the brighter the image becomes. I suggest keeping the image appearing slightly darker than how you'd like it to eventually look. This performs the bulk of the required stretching, but still leaves room for final tweaks in *Photoshop*. Once you get the image looking the way you want it, lower the Background value by around 50 points to avoid clipping the black level in your final image. Apply the display settings to your image with the pull-down option File/Save scaled data/This, and select TIFF 16 bit.

You can also sharpen your image using deconvolution to tighten up the stars and sharpen small-scale features. *CCDStack 2* has an excellent deconvolution routine called Positive Constraint that, when applied moderately, does a great job without introducing unwanted artifacts such as dark halos around stars. Select Process/Deconvolve. A new window opens, and a number of stars will appear with yellow + symbols over them. These are stars the program has selected to measure their point-spread function (PSF) to determine the strength of the deconvolution algorithm. You can also double-click on any stars you want the program to include in its calculations. Choose stars that are not saturated and are well defined (i.e. not embedded in nebulosity or within a visible galaxy). Next, select Positive Constraint at the bottom of the window, and set the number of iterations; I often use 30 to 50. Now click the "Deconvolve" button, and in a few minutes the

Visit www.skypub.com/excalibrator for an additional overview of the free PC software *eXcalibrator* by the author.


Subtle color variations and wispy details in targets such as the reflection/emission nebulae NGC 1973, 1976, and 1977 are easy to preserve and enhance using the tools found in *CCDStack 2*.

process is complete; save the resulting FITS file. You can apply the same DDP settings to the deconvolved image as you did to the original by switching to the unprocessed version and clicking on "Apply to all" in the Display Manager window. Save the deconvolved version as a scaled 16-bit TIFF to be combined with the color image later in *Photoshop*.

Color Combine

Finally, let's combine our red, green, and blue files into an RGB image. In order to accomplish this best, you first need to know the correct RGB ratios for your particular CCD camera, filters, and sky conditions when the images were recorded. Although there are several ways to measure these values once for your system, each data set also requires adjustments to be made for atmospheric extinction caused by the target's altitude when each series of color sub-exposures was taken. I prefer the free software *eXcalibrator* (**http://bf-astro.com/excalibrator/excalibrator.htm**) for determining an accurate color balance (see **www.skypub.com/excalibrator**). However, a simple method to get you started with approximate color balance in *CCDStack 2* is to normalize your red, green, and blue files to one another, and then combine the images at a 1:1:1 ratio. As described earlier, select a neutral background area, then the highlights. After normalization, select Color/Create from the pull-down menu. The Create Color Image window opens, where you can assign your filtered images to their respective channels. You can also incorporate your master luminance image here if desired, though make sure not to include the stretched luminance image. Click the "Create" button, and in a moment your combined color image will appear.

Immediately a small window called Set Background appears with your color file. If your image requires additional color adjustment, simply drag a box around a neutral background area and click "OK." You can perform additional background and highlight corrections using the Color/Adjust command in the pull-down menu.

When you're happy with the overall color image, you can stretch the result using the DDP slider and save the result for further adjustments in *Photoshop*, and include the stretched luminance image.

Performing these steps correctly provides a solid foundation upon which you can build and modify once you become familiar with all the tools available in *CCDStack 2*. Using the software's sigma-based data-rejection algorithms, live DDP, and a mild application of Positive Constraint deconvolution will give you a head start on your way to producing images that may one day appear in *Sky & Telescope*. ✦

***Bob Fera** shoots the night sky from his backyard observatory under the dark skies of Northern California.*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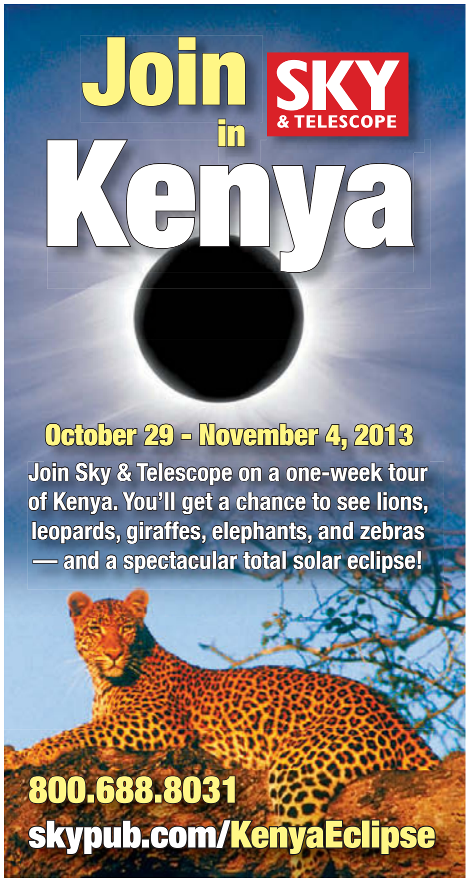
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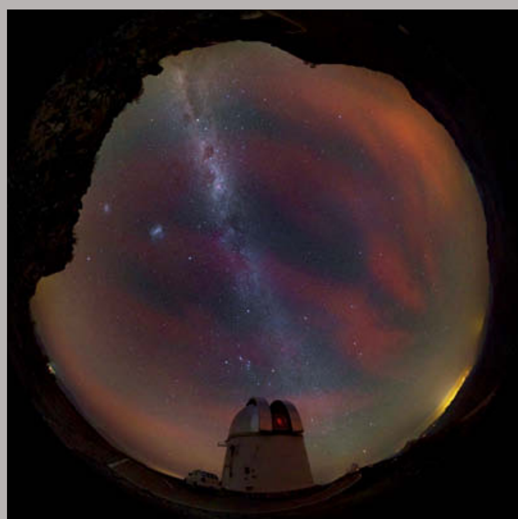
▲ **GUM NEBULAE IN VELA**
Gerald Rhemann
The large emission nebulae Gum 17 (center) and the smaller, brighter Gum 15 at top right are part of a huge nebulous complex permeating the southern constellation of Vela.
Details: *ASA astrograph H f/2.8 with FLI ProLine PL16803 CCD camera. Total exposure was 2⅘ hours through color filters.*

► **ATACAMA SKYGLOW**
Yuri Beletsky
The reddish bands seen stretching across the sky are due to a particularly strong airglow display that occurred over the Las Campanas Observatory in Chile last March 9th.
Details: *Canon EOS 5D Mark II DSLR camera with Nikkor 14-24mm zoom lens at f/4. Mosaic of 14 images, each exposed for 30 seconds.*

► ► **THE NORTHERN SHOW BEGINS**
Hap Griffin
Comet C/2011 L4 PanSTARRS made its evening debut for Northern Hemisphere observers on the evening of March 12th when it appeared only a few degrees south of the young crescent Moon.
Details: *Canon EOS Rebel XSi DSLR camera with 135-mm lens at f/5.6. Single 2-second exposure at ISO 800.*



▲ **PANSTARRS OVER THE VLA**

Alan Dyer

Comet PanSTARRS exhibited a broad, curved dust tail in this image captured over the Very Large Array radio telescope in New Mexico during the early evening twilight of March 17th.

Details: *Canon EOS 60Da DSLR camera with 50-mm lens at f/2.8. Total exposure was 25 seconds at ISO 400.*

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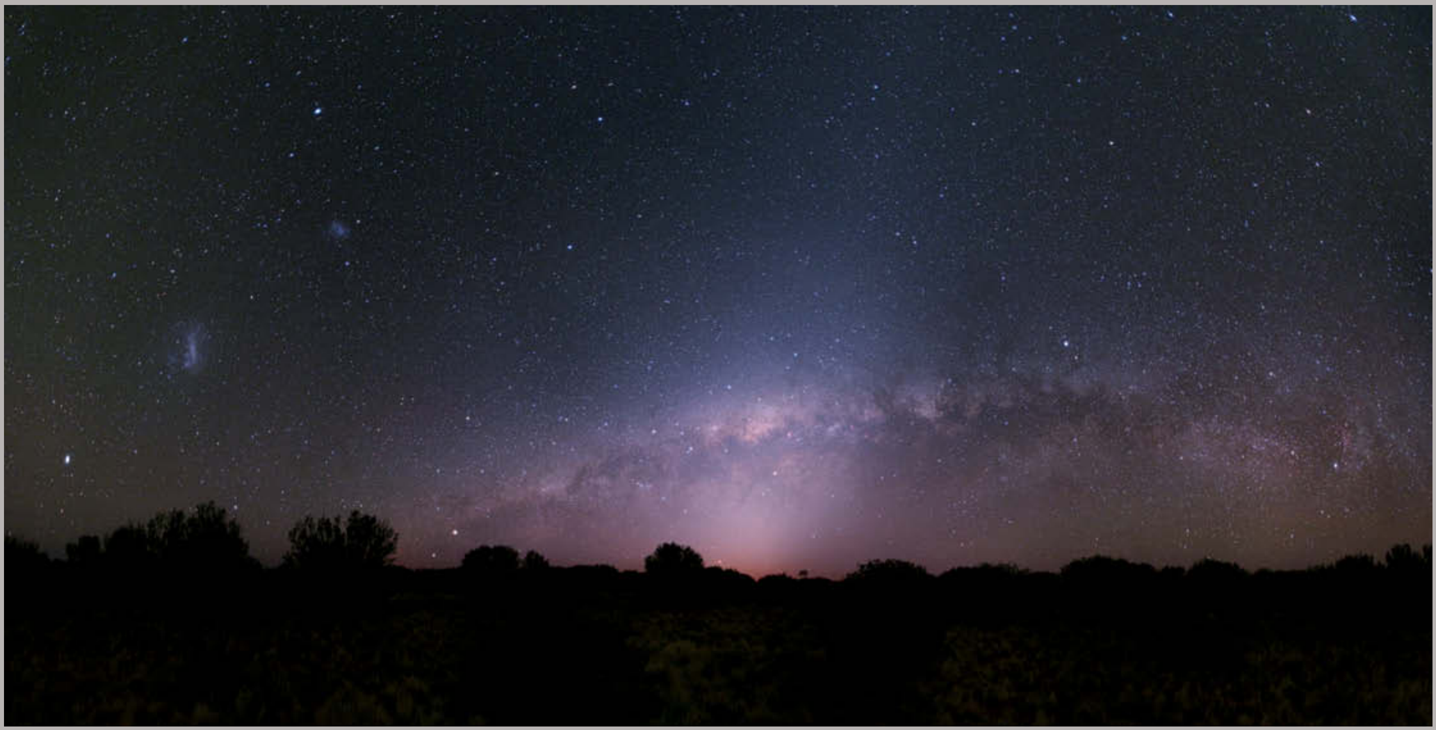

▲ **ZODIACAL DELIGHT**
Tunç Tezel
An exceedingly bright display of the zodiacal light juts diagonally across the Milky Way as seen from Uluru in central Australia.
Details: *Canon EOS 5D DSLR camera with 24-mm lens at f/2.5. Mosaic of 14 images exposed for 30 seconds each.*

◄ **LUNAR STREAKING**
Mariano Ribas
Argentinian amateur Mariano Ribas captured the International Space Station as it made a rare transit of the Moon seen from his home in Buenos Aires on the night of March 5th.
Details: *12-inch Meade LX 90 Schmidt-Cassegrain telescope at f/6.3 with Canon EOS Rebel T3i DSLR camera. Composite of 3 exposures of 1/1,250 seconds each at ISO 800.*

► **WIND IN THE SAILS**
José Joaquín Pérez
The colorful Vela supernova remnant, Gum 16, is the glowing debris from a massive star's cataclysmic demise seen 11,000 years ago. The explosion occurred some 800 light-years from Earth.
Details: *Astro-Physics 140mm f/7.5 Starfire EDF refractor with SBIG STL-11000M CCD camera. Total exposure was 7 hours through color filters.* ✦

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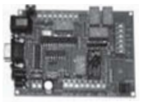

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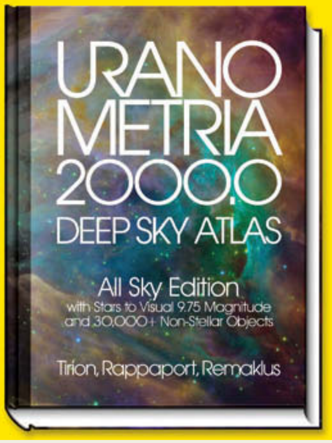

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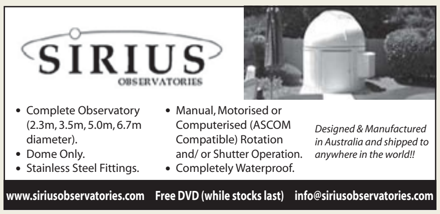

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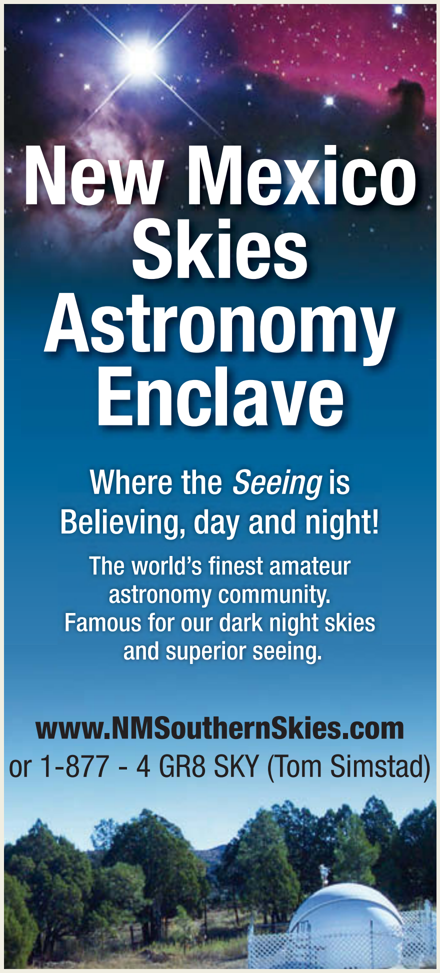

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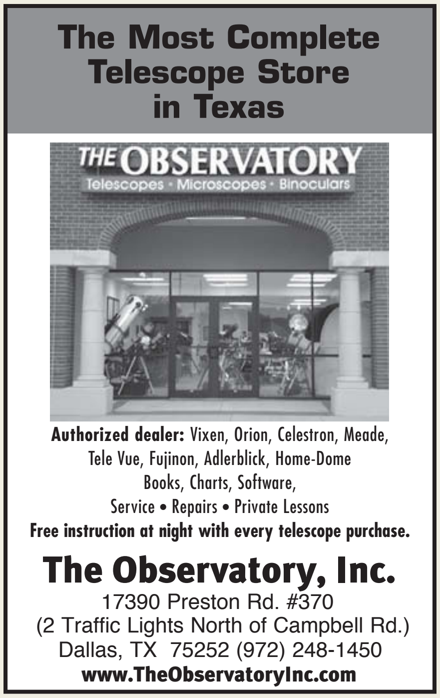

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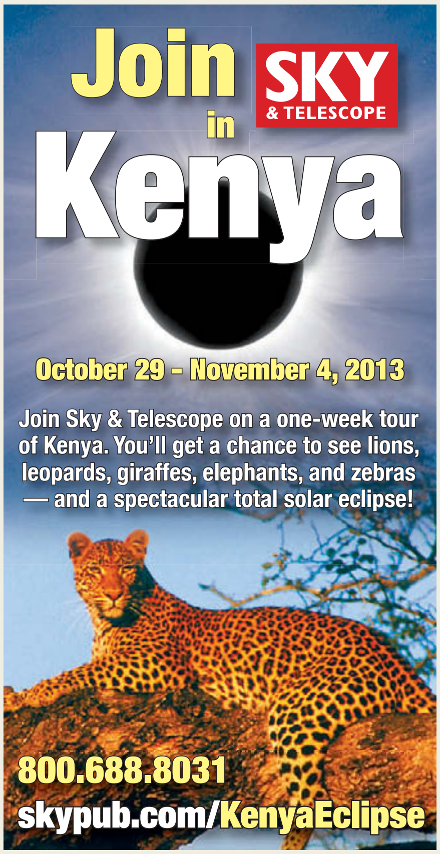

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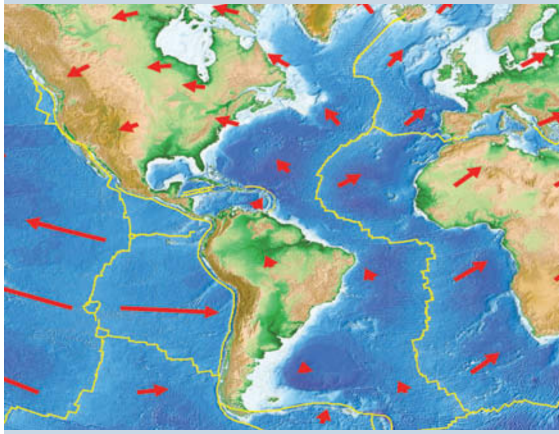

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Meteor Nights

After the Russian fireball, the author recalls his meteor-observing youth.

The recent Russian meteor explosion recalled to me the thrills of my own meteor-watching years as a teenager in suburban Long Island, during which I never saw anything as spectacular as the Chelyabinsk event. But even a single shooting star was a marvel then, something new, bright, and fast in the otherwise unchanging sky — a scratch against the perfect firmament. As every summer deepened into August, I looked forward to the bonanza of the mid-month Perseids.

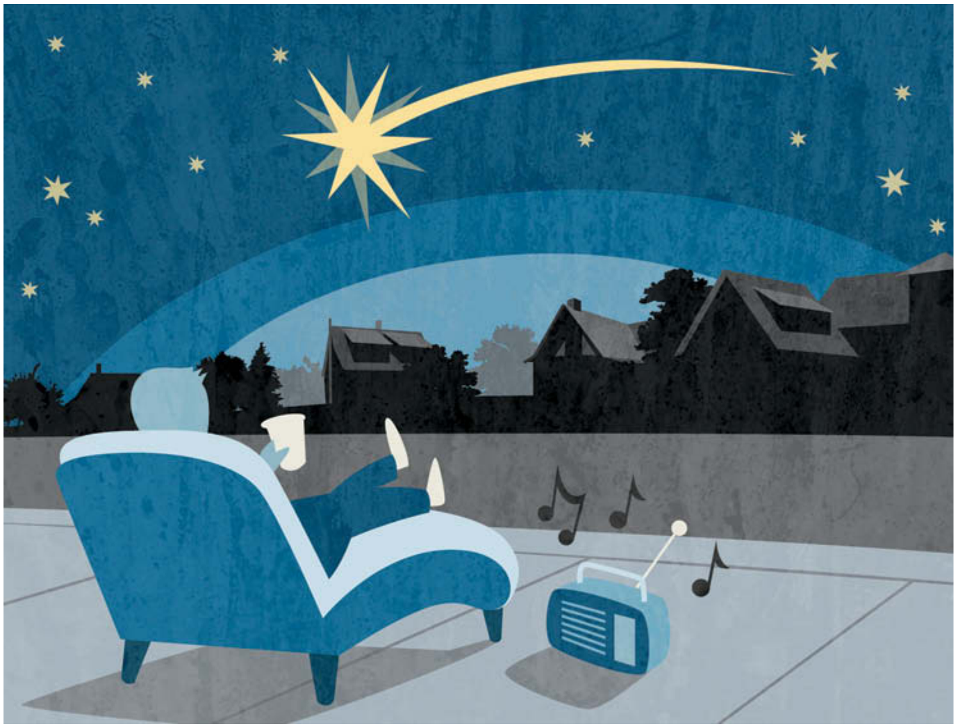
One night every summer for several years I brought a chaise lounge onto our front lawn, to the edge of the sidewalk. My transistor radio was tuned to WABC, the dominant New York pop station. It kept me company, and as the constellations rose, set, and wheeled through the night, so did famous radio jocks such as Cousin Brucie. In the evening hours passersby stopped and sometimes laughed when I explained what I was doing. After midnight the neighborhood fell silent, except for my radio, and the air dampened. I kept my eyes wide open, trying to take in all of Perseus and the surrounding northeast sky. I tallied every meteor on a yellow legal pad.

I can't say I saw many. On a clear, moonless night, an observer with good eyes may count as many as 60 Perseids in an hour. My best number, between 1:00 or 2:00 a.m. one very good year, was around 23. Some of these sightings may have been false positives: when I stared at the sky long enough, faint light-flickers started to bounce between the fixed stars, and my memory of the last flash and the hope for the next one conflated into a half-certain scintilla of a flare. My alertness waxed and waned, explaining why I might see three in five minutes and none for another 20.

My nights of patience were once rewarded generously by an undeniable fireball that streaked directly overhead, the recollection of which now suggests some of the terror that Chelyabinsk's citizens must have felt on February 15th. The meteor's passage was accompanied by a long, almost animal-like hiss. Although the fireball was not bright enough to substantially illuminate the sky, as it did at Chelyabinsk, the reverse image of the meteor's path remained shadowed on my retina for several minutes. I thought, too, that I might have seen the vapor trail gray-black against the night.

In those years *S&T* invited readers to submit their meteor counts, and not long ago, when looking through some back issues, I recalled that my name had once been included among the observers. On page 268 of the October 1969 issue, the Observer's Page published the list of contributors. There was my name: K. Kalfus, Plainview, N.Y. As compromised as my seeing conditions may have been, not to mention my observing skills, this was my first contribution to the advancement of science. It may prove to be my last, but like many people in Chelyabinsk, I continue to feel honored by my encounter with a celestial visitor. ✦

***Ken Kalfus** is the author of two collections of stories and three novels, including* A Disorder Peculiar to the Country, *a finalist for the National Book Award. His new novel,* Equilateral, *about a 19th-century attempt to communicate with Mars, was published in April.*



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