The Amazing Story of Neptune's Discovery p. 28

SKY & TELESCOPE

THE ESSENTIAL MAGAZINE OF ASTRONOMY

JULY 2011

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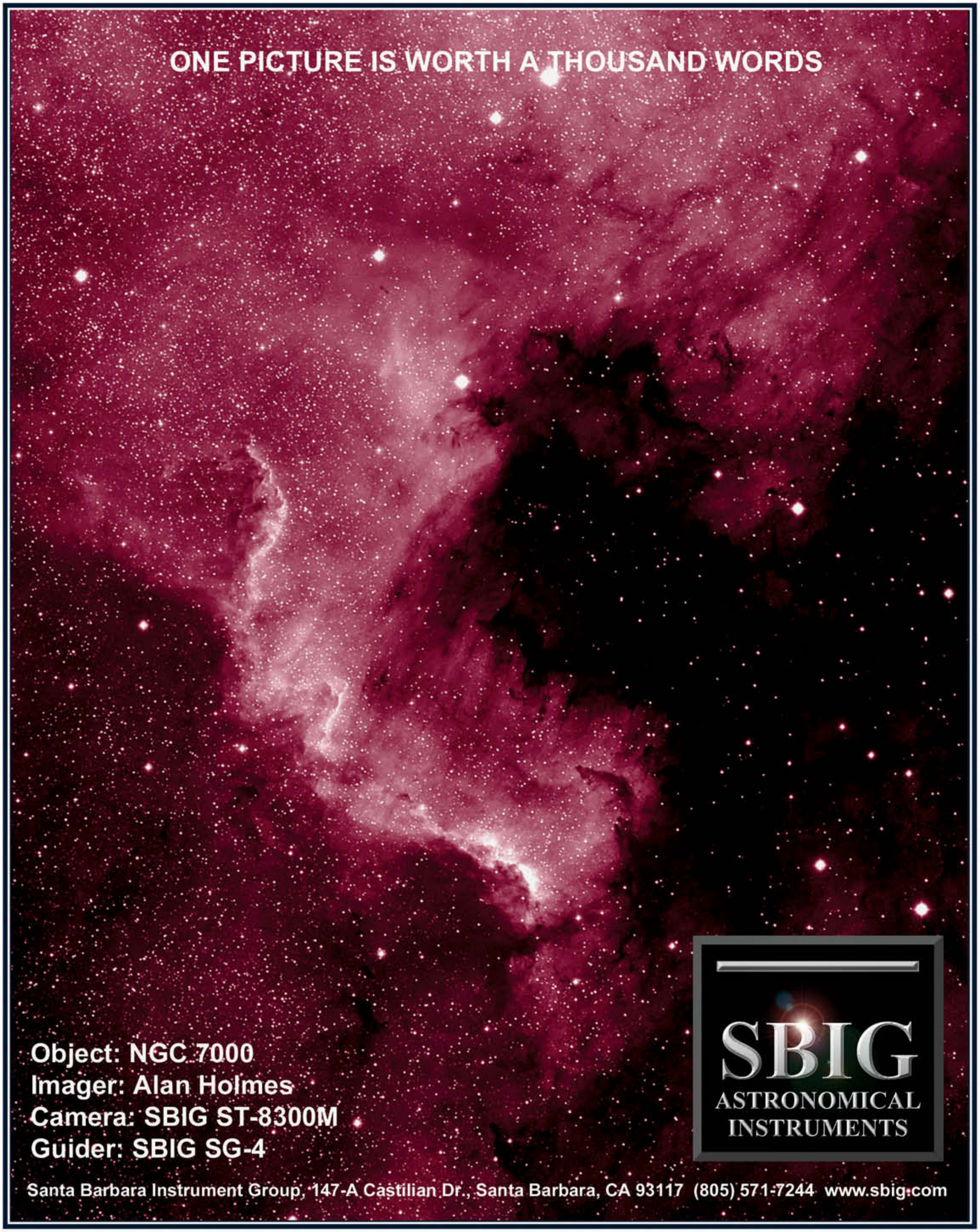

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July 2011

VOL. 122, NO. 1

On the cover: Artist Ron Miller portrays an erupting volcano on Jupiter's moon Io, the solar system's most volcanically active world.

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ROGELIO BERNAL ANDREO

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My Town,Our Planetarium # 175

GOTO

A Green Projector for a Green City

Kumamoto Japan, on Kyushu, the southernmost of Japan's large islands, is a beautiful, green, and very historic city. Blessed with abundant water, the environment is rich with natural and man-made wonders, such as the Kumamoto Castle. Recently, the Kumamoto City Museum asked GOTO INC to replace its older GOTO projector with the new CHRONOS II HYBRID planetarium system. The new CHRONOS II's gorgeous starry sky, brilliant sun, moon, planets, and very realistic 10,000,000 micro-star Milky Way is synchronized with a 4Kx4K fulldome video sky for a completely immersive GOTO HYBRID Planetarium™ experience.

Visitors to the planetarium will now enter the 16 meter dome, sit in one of 180 comfortable new seats and take virtual trips into Kumamoto's past and its future. The new barrier-free seating arrangement, new digital audio, and a newly re-paneled dome screen help to make this truly a wonderful upgrade. And, since the CHRONOS II uses only LED's as its light source, the Kumamoto planetarium will also do its part to keep the city green.

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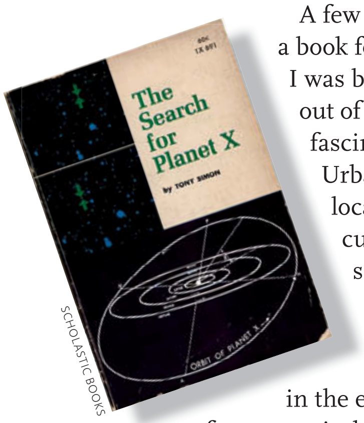
Neptune, Droid App, and Astrotourism

EVERYBODY GETS INTO astronomy in a different way. For me, I can point to two seminal events from my childhood. When I was about 6, my parents bought me a cheap Monolux refractor for Christmas. Despite its wobbly mount, I vividly recall finding Jupiter from an Acme grocery-store parking lot. I was thrilled to see stripes on the planet, and four moons perfectly lined up. That sight was seared into my memory banks and remains there to this day.

A few years later I read *The Search for Planet X* by Tony Simon, a book for children about Clyde Tombaugh's discovery of Pluto. I was blown away by the idea that a Kansas farmboy right out of high school could discover a planet. But I was equally fascinated by the earlier chapters, which told the tale of how Urbain Le Verrier and John Couch Adams predicted the location of an unknown planet by using mathematical calculations. That narrative taught me the predictive power of science, and really turned me onto astronomy.



SCHOLASTIC BOOKS

With its intoxicating blend of sheer genius, missed opportunities, and international rivalry, I still find Neptune's discovery to be the most compelling story in the entire sweep of astronomical history. If you're a student of astronomical history, you're undoubtedly familiar with the tale. But Renée James's and Bill Sheehan's article on page 28 brings fresh insight, such as the fact that despite the audacious brilliance of Le Verrier's work, he wouldn't be able to get his paper published in today's leading planetary-science journal. I *really* hope the skies are clear later this year so I (and all of you!) can see Neptune when it comes very close to its discovery position. If you take photos, send them to us!

On a different topic, when we released our first application for Apple mobile devices (SkyWeek) a few months ago, we were flooded by requests asking when we were releasing a Droid version. I'm very pleased to announce that the Droid version of SkyWeek is now available, and it's free. We also made our Apple version free of charge. If you own the right kind of device and haven't downloaded SkyWeek yet, check it out and spread the word.

Finally, I wanted to invite you to join *S&T* for some exciting travel opportunities. Working with Spears Travel, I'm leading an astronomically themed tour of northern Chile this September. Next year we'll be working with Insight Cruises. We're running a trip to Hawaii to see the June transit of Venus. In November, we're running both a land tour and a cruise to Australia to see the total solar eclipse. See the ads on pages 57 to 59 for more details.

Robert Naeye
Editor in Chief

SKY & TELESCOPE

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The Essential Magazine of Astronomy

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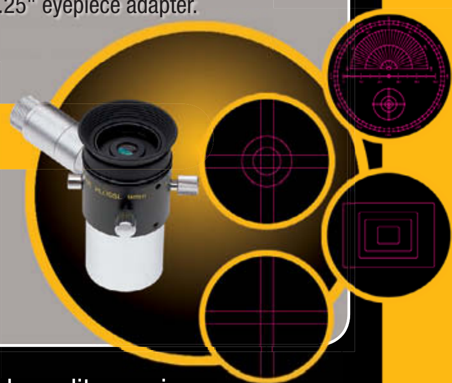

These specialty eyepieces are very useful for astrophotographers or for observers making astronomical measurements. Their etched reticle patterns are internally red illuminated to stand out against a dark sky.

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Stargazing Network?

I am a 38-year-old man who loves the night sky. I also have muscular dystrophy and use a wheelchair full time. I am very interested in a binocular tripod, as well as a telescope, but I am unsure how to proceed since I am sitting down at all times and have limited hand strength. Perhaps you could share my information with your readers, and we could start a network. I am sure that I am not the only wheelchair user who loves the sky!

Patrick Moeschen
Salem, New Hampshire
pmoes@comcast.net

Binocular Sights

Thank you for featuring Hugh Bartlett's "Binocular Sights for City Nights" series in *Sky & Telescope*. As a longtime amateur astronomer who lives in an apartment off a busy highway in suburban Los Angeles County, I've been looking for just such a guide.

Since hauling my telescope downstairs to a sidewalk next to cars and trucks whizzing by at 60 mph and spewing out pollutants doesn't exactly entice me outside on a nightly basis (hats off to all sidewalk astronomers), most of my observing occurs on the balcony with 8×42 or 10×50 binoculars. I observe small chunks of sky, but it usually beats being street-side. Bartlett's offerings include some of the brighter Messier objects actually visible in bad light pollution (too many binocular astronomy guides claim you can see objects from the city that just aren't visible) and an intriguing array of asterisms that I'd never before considered, as well as bright double stars. With more of us being deprived of decent views of the night sky, I hope such features become more common in the magazine.

Chris Boyd
Redondo Beach, California

Rapid Sampling

I enjoyed Jesper Sørensen's article on fast versus slow optics back in the November 2010 issue ("Fast or Slow?" page 72), especially as I am contemplating the purchase of yet another telescope. However, the requirement that an object span at least two image pixels in order to be resolved simply reflects the fact that anything smaller than a pixel will appear as a featureless point of light; it is not an example of the Shannon–Nyquist theorem.

Rather, this theorem states that a time-varying signal must be sampled with an interval less than ½*f* between samples in order to unambiguously detect frequencies as large as *f* — you have to sample fast to pick up rapid wiggles. If you want to pick up frequencies of, say, one kilohertz, you have to sample at least twice per millisecond.

An equivalent condition applies to certain types of imaging, in which rapid sampling in the image-reciprocal space is required in order to detect rapid intensity variations in the image. An example of this is magnetic resonance imaging, in which data is, in effect, collected in the image-reciprocal space.

This distinction is important to people who practice medical imaging and signal processing, though it does not alter the conclusions of Sørensen's article.

Richard G. Spencer
Baltimore, Maryland

Super Moon Suits Up

My 11-year-old granddaughter Victoria has a school project for which she has been tracking the Moon for the past several weeks. On March 19th, my daughter took Victoria and the rest of the family out to see the Moon at its closest approach to Earth. When she pointed to the Moon and told the children that this was called the Super Moon, the youngest, Patrick (age 4) asked, "But where is its cape?" I thought your readers might get a chuckle from this, as I did.

Thomas F. Brennan
New Castle, Delaware

Exploring Exoplanets

Professor John A. Johnson did an outstanding job in laying out the various criteria used in exoplanet hunting throughout his article "The Stars That Host Planets" (April issue, page 22). For example, I've probably done literally hundreds of fits — not to be confused with the graphic format "FITS" used by professional astronomers — using the fourth-order Hermit algorithm for 55 Cancri. But until reading Johnson's article, I had never considered the iron-to-hydrogen ratio of 55 Cancri and its impact on the formation of giant planets in that system.

I was pleased that Johnson pointed out that red dwarfs are the best targets for searching for low-mass exoplanets. I did not know, until reading the article, that high-precision Doppler shifts were being measured in the infrared instead of the visible part of the spectrum. This makes perfect sense and is surely a much more efficient method than the painstaking task of trying to measure Doppler shifts of *M*-type stars in the visible part of the spectrum. This is something that I plan on looking into further.

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.


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All in all, Johnson's article is one of the best articles that I have read on the search for exoplanets. It just goes to show you that every time I read *S&T* I learn something new.

Eric F. Diaz
Indianapolis, Indiana

Dark Ages Query

The term "Dark Ages" seems confusing and misleading, so I would like some clarification. The "End of the Cosmic Dark Ages" article (May issue, page 26) states that when the "Dark Ages" began, the universe had cooled to 3000 kelvins.

If we had been there to observe it, this would have been almost white hot, with radiation probably coming from all directions. And even if the universe had cooled to 1000 kelvins, it would still be red with visible light. I assume "Dark Ages" is therefore just a metaphor for "Not Ionized." Is this correct or am I missing something here?

Barry McElmurry
Vista, California

Editor's note*: Astronomers have not precisely defined the beginning of the "Dark Ages," but they generally refer to this period as the epoch between the time that the cosmic microwave background redshifted into the infrared and the time when the first stars formed. Nothing was producing visible light during the Dark Ages, which lasted several hundred million years. The definition is quite anthropocentric.*

For the Record

✵ *M85's companion galaxy is NGC 4394, not NGC 4293 as stated in the caption to the photo on page 59 of the May issue.*

✵ *The famed optics maker Alvan Clark was misspelled as "Alvin" Clark on page 8 of the May issue.*

75, 50 & 25 Years Ago

Roger W. Sinnott

July / August 1936

New Comet "On the morning of May 15 a telegram was received at the Harvard Observatory . . . from Leslie C. Peltier of Delphos, Ohio, asking for verification of an extremely slow moving ninth magnitude comet. . . .

"The fact that Peltier's Comet will be visible to the naked eye during the latter part of July and into August is good news. . . . Not since Halley's Comet reappeared in 1910 has a naked eye comet of any consequence been visible."

It was Peltier's fifth comet find. His name would be added to five more.

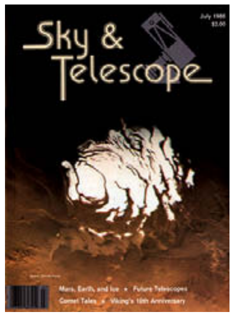
July 1961

Cloud Satellites "The discovery of two faint, cloudlike objects circling the earth at the same distance as the moon has been reported by the Polish astronomer K. Kordylewski, at Krakow Observatory.

"His find is the result of many years of searching, based upon the idea that the most likely locations for additional satellites are the Lagrangian points of the Earth-Moon system."

Kordylewski's naked-eye sightings of two dust clouds near the gravitationally stable L_5 point, 60° behind the Moon, electrified the astronomical world. Each appeared as a luminous patch a little fainter than the gegenschein, and he saw them several times since 1956 from dark mountain stations in Czechoslovakia. However plausible they seemed, numerous attempts by amateur and professional astronomers to confirm them met with mixed success. By the end of the decade, both optical and radar studies essentially ruled out their existence.

July 1986



New Aten Asteroid "On March 4th Carolyn and Eugene Shoemaker discovered one of the rarest types of asteroid known. This new object, 1986 EB . . . takes less time to circle the Sun than Earth does."

Only five other Aten-class asteroids were known, starting with Eleanor Helin's discovery of 2062 Aten itself in 1976. Today, the number of known Atens exceeds 650.

For astronomy news as it breaks, see SkyandTelescope.com/newsblog.

Hubble Constant, Dark Energy Refined

NASA / ESA / STSCI / A. RIESS AT AL.

NGC 5584 in Virgo has become an important step on the cosmic distance ladder. It contains 250 Cepheid variable stars studied in detail with the Hubble Space Telescope, yielding a very accurate distance of 72 million light-years. And in 2007 it hosted a Type 1a supernova — helping to calibrate the supernova distance scale for galaxies much farther away.

Edwin Hubble announced evidence that the universe is expanding in 1929, in the age of flappers and bootleg gin. But long into the Space Age astronomers couldn't agree on how *fast* it's expanding. About all they could tell for certain was that the cosmic expansion rate — the "Hubble constant" — was somewhere between 50 and 100 kilometers per second per megaparsec.

The Hubble Space Telescope was funded, built, and named with a prime goal of pinning down the Hubble constant. The intended method was the same as astronomers had been using from the ground: measure the distances of galaxies by the brightnesses and periods of their Cepheid variable stars, then match these distances to the galaxies' observed redshifts (how fast they're receding from us).

This Hubble "key project" improved the value less than hoped; stubborn uncertainties remained. As of 2001 the project's best efforts put the expansion rate of today's universe (called H_0) at 72 km per second per megaparsec with an uncertainty still as large as ± 8. More enticing results soon started coming from "precision cosmology" studies of the cosmic microwave background radiation, especially by NASA's WMAP satellite, which launched in 2001. Last year WMAP scientists announced that, if you assume the geometry of space is flat and dark energy works like Einstein's cosmological constant (as seem likely), then H_0 is 71.0 ± 2.5. This becomes an even better 70.4 ± 1.4 when combined with other findings.

But astronomers have pressed on with direct measurements that involve fewer assumptions. In 2009, a team led by Adam Riess (STScI) using Type Ia supernovae to measure galaxy distances came up with 74.2 ± 3.6. In 2010 another study, based on gravitational-lensing geometry by a distant galaxy cluster, came up with 72.6 ± 3.1, though this involved similar assumptions to WMAP's.

Now the Cepheid specialists have surged back nearly to the front of the pack. Based on more than 600 Cepheids in eight galaxies that recently displayed Type Ia supernovae, Riess's team has announced a refinement of its own: to 73.8 ± 2.4.

This matters. The Hubble constant in today's universe, and its changes through cosmic time, are the keys to knowing the universe's nature, history, and fate.

In particular, the new Cepheid study gives improved distances to eight well-observed Type Ia supernovae. These help astronomers calibrate similar supernovae seen in the distant past, which trace how the cosmic expansion rate has changed over time. And this in turn refines our picture of dark energy — the unknown effect that, about 5 billion years ago, began to overpower gravity and cause the cosmic expansion to start accelerating.

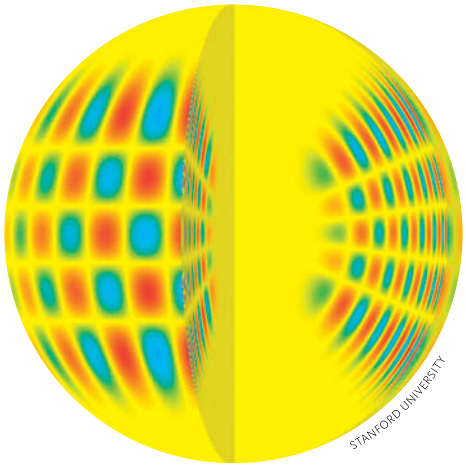
The refinement is enough to rule out a recently proposed alternative to dark energy: that large, unseen voids in the very distant universe affect the expansion rates we observe.

The study also slightly refines dark energy's "equation of state," finding a value of $w = -1.08 \pm 0.10$. This strengthens the growing assumption that its value is exactly –1, making dark energy a property of space itself (rather than something *in* space), like the "cosmological constant" Albert Einstein proposed nearly a century ago.

Big Kepler Bonus: Precision Stellar Physics

NASA's Kepler spacecraft has been making so much news with its abundant discoveries of small exoplanets (May issue, page 12) that its other bonanzas are going mostly unnoticed by the public. But Kepler is working a quiet revolution in variable-star astronomy. All sorts of things turn up when you can rapidly measure the brightnesses of 150,000 stars to a ten-thousandth of a magnitude or better in an unbroken series for months on end.

In particular, Kepler is turning "asteroseismology" into a booming field. Similar to Earth seismology, this technique uses slight oscillations on a star's surface to probe conditions throughout the star's interior. As was first seen in the Sun, a variety of acoustic waves — pure tones — resonate continuously throughout a star like vibrations ringing in a bell. As sound waves go, they're very low frequency. In the Sun's case their periods range from 1.5 to 20 minutes per cycle. They can express themselves as tiny, harmonic variations in a star's total brightness. By teasing them apart and analyzing them, astronomers can often determine a star's diameter, mass, and other properties with greater precision than by any other method.



A computer model of one mode of the many acoustic waves that resonate through the interior of the Sun

So get ready for what some are calling a "golden age for stellar physics." Led by William Chaplin (University of Birmingham, U.K.), a team of five-dozen scientists has found 500 Kepler stars with oscillations clear enough to accurately determine the stars' diameters and masses. Less than a dozen such stars were available before Kepler and its smaller European predecessor, CoRoT. "These new observations allow us to measure the detailed properties of stars at an accuracy that wasn't possible before," says coauthor Steve Kawaler (Iowa State University).

There are surely more to come. The 500 finds came from a sample of only 2,000 solar-type stars in Kepler's view that were tracked for a month, using a special spacecraft mode that measured their brightnesses once per minute (versus the usual twice per hour).

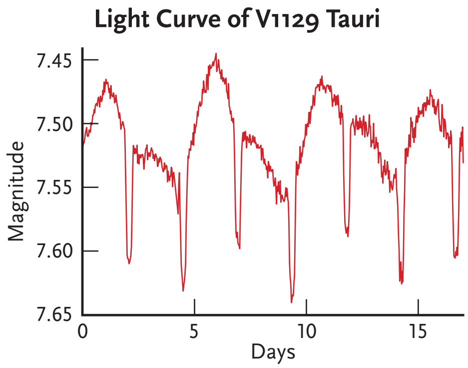
And there was a surprise. The 500 stars turn out to have diameters closely matching theorists' predictions — but their masses are generally a little less than expected. Once these observations are melded with estimates of the stars' ages (now in progress), the results should refine models of exactly how stars form, burn, and age.

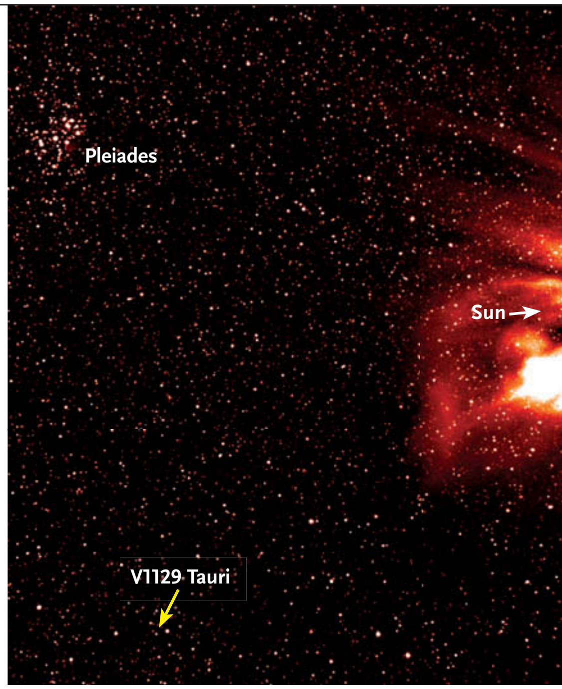
Variable Stars Behind the Sun

Kepler isn't the only spacecraft that's moonlighting in the variable-star business. Who would think that a solar observatory could create top-quality light curves of variables as much as 38 magnitudes fainter than the Sun?

That's what an innovative project is doing with data from NASA's two STEREO solar satellites. Each carries a Heliospheric Imager (HI) that looks for faint wisps of solar wind in wide fields off to the Sun's side. "We realized that the stability of the HI cameras could also be used to monitor variations in the brightness of stars," says Danielle Bewsher (University of Central Lancashire, U.K.). "To date, 893,000 stars have passed through the HI-1 field of view alone, producing an unexpected resource that is currently being data-mined."

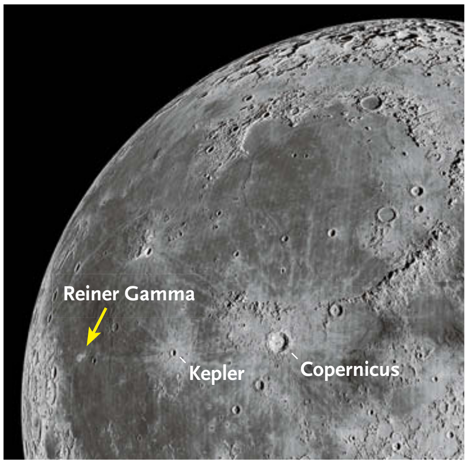
In a first look at the data, the project found 122 new eclipsing binary stars alone. "STEREO's ability to sample continuously for up to 20 days, coupled with repeat viewings from the twin spacecraft during the year, makes it an invaluable resource for researching variable stars," says team member Karl Wraight (Open University, U.K.). STEREO can see stars as faint as magnitude 12 and can measure bright ones with enough precision that the data could reveal asteroseismology pulsations and transits by exoplanets.





D. BEWSHER / K. WRAIGHT / NASA / STEREO

NASA's twin STEREO spacecraft are imaging the thin gas where the Sun's corona fades away to become the solar wind. As an unexpected bonus, the cameras also steadily record the brightnesses of many thousands of background stars. For example, STEREO's light curve of V1129 Tauri shows that it's a grazing eclipsing binary and also has large starspots that change the system's brightness by about 0.1 magnitude as it revolves.



NASA

Reiner Gamma is easy to spot with a backyard telescope near the edge of Oceanus Procellarum.

New Insights on Lunar Swirls

The next time the Moon is full or waning, take a good look with your telescope at Reiner Gamma in Oceanus Procellarum. This conspicuous bright smudge is the best-known example of the "lunar swirls" that have baffled planetary geologists for decades.

"Swirls remain one of those big unanswered questions in lunar science," says Catherine Neish (Johns Hopkins University Applied Physics Laboratory). Lunar scientists have long speculated that they're related to variations in the "space weathering" of the lunar surface. Exposed material darkens over long ages due to high-energy radiation and micrometeorite bombardment. That's why rays splashed from a young crater look bright against the older terrain they land on.


NASA

The mysterious lunar marking Reiner Gamma itself is only about 20 miles (35 km) wide, but narrow surface swirls extend far to the upper right and lower left of this frame. This view was captured by Lunar Orbiter 4 in 1967.

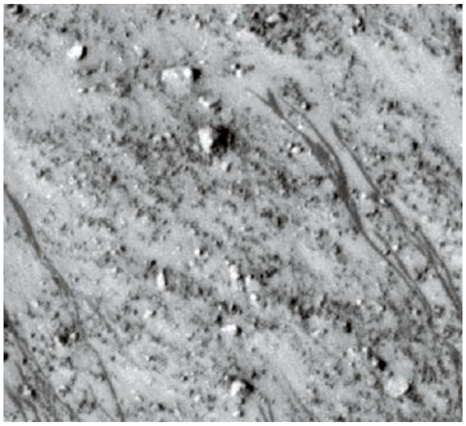
The mystery deepened when Apollo spacecraft found strong magnetic fields directly over the swirls. In 1980 Lon Hood and C. R. Williams (University of Arizona) suggested that patchy, localized magnetic fields are shunting solar-wind plasma away from the bright areas, slowing the weathering. Others have proposed that the swirls arise from the gaseous comas of impacting comets — but in that case there ought to be more of them. Or maybe cometary gas magnetized the surface — but calculations suggest that a thin surface layer can't become magnetized strongly enough to create the observed anomalies.

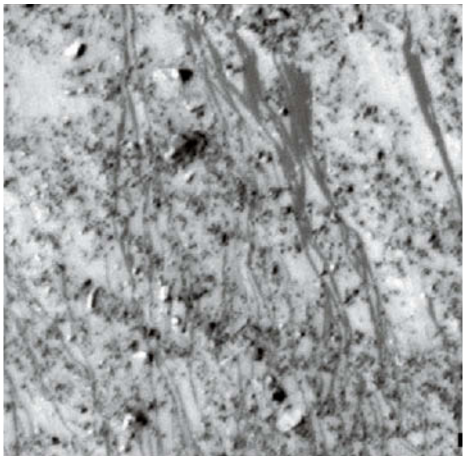
Recent missions to the Moon — particularly NASA's Lunar Reconnaissance Orbiter (LRO), India's Chandrayaan-1, and Japan's Kaguya — have amassed a formidable store of new observations. So far these are saying a lot about what the swirls are not. Counts of tiny craterlets show that they're not freshly exposed surfaces. LRO's laser altimeter shows that they're not lumpy or elevated. Radar scans show no differences in surface roughness. Infrared maps reveal no thermal anomalies.

One promising idea, put forward last year by Ian Garrick-Bethell (University of California, Santa Cruz) and two colleagues at Brown University, takes a different tack: the swirls are continually brightened with replenished toppings of very fine dust, levitated electrostatically from elsewhere.

The Lunar Surveyor missions in the late 1960s sent back TV images showing thin layers of microscopic dust particles hovering a few feet above the lunar surface, especially around local sunrise and sunset, presumably due to static-electric charging. There's still no explanation why this happens. But once lofted, these ultrafine particles can be moved around by electric fields created within the localized magnetic bubbles. This could remove dust from some places and deposit it in others. The dusty topcoat would have to be at least a foot thick, based on recently published calculations. But they can't be thicker than about 30 feet (10 m), notes Garrick-Bethell, because the swirls' bright lanes show no vertical relief in low-Sun-angle images.

What caused the magnetic anomalies themselves is still a mystery.




NASA / JPL / UNIV. OF ARIZONA (2)

These two images of the same terrain, taken by Mars Reconnaissance Orbiter in May and August 2009, show the rapid appearance of dark flow marks on the slope of Asimov Crater. The scene is about 250 feet (80 meters) across.

New Sign of Water Flowing on Mars?

Starting more than a century ago, telescopic observers have often seen a "wave of darkening" that spreads down from the shrinking Martian polar caps during the local spring and summer. Early observers thought they were seeing the seasonal green-up of Martian vegetation, a notion that persisted into the 1960s until spacecraft observations ended all such hopes.

But admit it: we're still captivated by the idea that liquid water might flow somewhere on Mars even now.

A decade ago NASA's Mars Global Surveyor spotted relatively fresh gullies snaking down walls of a few Martian craters. Was water leaking from subsurface strata in cliff walls? It's still not clear how the gullies form, but the thinking now among planetologists is that dry avalanches of rubble and frozen carbon dioxide are responsible for the currently active gullies.

But there's a new indication that liquid water may flow elsewhere during Martian summer. The super-resolving HiRISE camera on the Mars Reconnaissance Orbiter (MRO) has seen rivulet-like markings form, grow, and fade in the planet's south temperate latitudes. These "transient slope lineae (TSLs)," as they've been dubbed by Alfred McEwen (University of Arizona) and his colleagues, could be formed by brine containing enough salt to depress its freezing point by more than 100°F (50° to 60°C), the group claims.

Strengthening the case, many of the flow-like features have come and gone in a matter of months. At least 15 sets of TSLs have been seen to change over time. They darken the surface when they appear and then gradually lighten.

"These flows may advance a little near the warmest time of each day," McEwen writes, "or they may advance by greater amounts on some days but not others."

Unlike the gullies seen by Mars Global Surveyor, these new finds occur only along Sunward-facing slopes, and they form only during the relative warmth of midsummer. Why they're found only at latitudes 32° to 48° south is unclear. It's also a puzzle where and how brines could be stored so near the surface.

McEwen and others have targeted particularly rich TSL fields for repeated looks with HiRISE and a sensitive spectrometer during the coming southern summer.

Martian Atmosphere May Come and Go

One way that Mars is *very* different from Earth is that its atmosphere is mostly something (carbon dioxide) that can freeze out on the ground, leaving a partial vacuum above. MRO's radar has discovered 12,000 cubic kilometers of frozen CO_2 under the surface, about as much CO_2 as is in the atmosphere today. This suggests that the thickness of the Martian atmosphere may change severalfold over the roughly 100,000-year warm and cold cycles that are caused by periodic changes in the planet's axial tilt and orbital eccentricity. ✦

David Grinspoon

The State of Alien Affairs

The author reflects on the results of Denver's recent E.T. commission election.

S&T: PATRICIA GILLIS-COPPOLA; UFO: ©ISTOCKPHOTO.COM / AUGUSTINC

SINCE I WROTE the column in last November's issue (page 20) about Denver's Extraterrestrial Affairs Ballot Initiative, several readers have asked me what happened. The result was mixed. The measure did not pass, which helps restore my faith that an educated populace can collectively make good decisions, including rejecting the notions that secret alien technology is here on Earth and that urgent diplomatic measures are required of city governments to prepare for imminent alien contact.

On the other hand, it received 31,108 votes, or 18%. What were those people thinking?

Maybe some of them didn't actually read the full ballot initiative, but felt that it's about time that we take a less provincial view of our existence in the vastness of the cosmos. Fair enough. And surely some were amused by that goofy initiative, which seemed like a joke at the end of the ballot. It was actually quite a relief after voting for numerous national and state offices, complex tax measures, and constitutional amendments, to find a final ordinance requiring "...the creation of an extraterrestrial affairs commission to help ensure the health, safety, and cultural awareness of Denver residents and visitors in relation to potential encounters or interactions with extraterrestrial intelligent beings or their vehicles..." An alien commission? Rock on!

But one has to assume that a significant portion of the 18% knew what they were voting for and chose it anyway. What's wrong with that?

I don't find it impossible that intelligent extraterrestrials could travel to Earth. And I can easily imagine the possibility of long-lived intelligences with unpredictable intentions, behavior, or capabilities. Signs of contact, especially unintentional on their part, might seem very strange and difficult for humans to interpret. Certainly we should explore our solar system and remotely probe others, and we should remain on the lookout for alien artifacts and engineering.

So I try to keep an open mind. But whatever you think about the existence of intelligent extraterrestrials, it's also quite plausible that we haven't been visited, and most of what has been cited as evidence is the result of wishful thinking. We have to be wary of our biases here.

I have seen several things in the sky that I cannot explain. My interpretation of these sightings is not that I have witnessed alien activities. I don't have proof that reinforces this impression. I have a high level of confidence in my scientific intuition even while I recognize that it's not an infallible guide.

I have attended meetings of UFO enthusiasts, and I often agree with their opening statements, which usually involve an assertion of the immensity of the universe and the absurdity of positing that we are alone in this vastness. But they lose me when they start describing their evidence, which is often highly anecdotal or subject to less-exotic interpretations. The proponents of alien encounters very much want to believe. I think most of us do. Personally, I would love it if some wise aliens would show up and tell us the secret to long-term global survival with advanced, planet-changing technology. I feel the lure of belief in my mind and heart, and I want to see as clearly as I can through that reality distortion field. Maybe we all want to believe, but for some of us that makes it harder, not easier. ✦

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*Noted book author **David Grinspoon** is Curator of Astrobiology at the Denver Museum of Nature & Science. His website is www.funkyscience.net.*

Where the H

ROSALY LOPES

lot Stuff Is

Volcanism takes a variety of forms on other worlds.

VOLCANIC ERUPTIONS are among nature's grandest spectacles, and thanks to interplanetary spacecraft, we can see signs of current and past activity on other worlds. Volcanic plumes rise hundreds of kilometers from the surface of Enceladus, lava lakes up to 200 kilometers (120 miles) across are bubbling away on Io, and Mars's Olympus Mons rises nearly three times higher than Mount Everest.

But our spacecraft catch only a glimpse in time of the geology of other worlds. Unless volcanoes are constantly erupting, we would have to be very lucky to catch one in the act. For example, only a small number of Earth's 600 active land volcanoes are constantly on the go. Stromboli in Italy may take the prize, erupting almost continuously for at least 2,000 years.

Most of our world's active volcanoes are hidden under the sea, dotting the boundaries of tectonic plates. Earth is the only known body to have plate tectonics. This is probably due to the planet's size and crustal thickness. If the crust is too thick relative to a planet's size, plate tectonics can't get started. If the crust is too thin, it might break up into so many pieces that it will form a jumbled mess. Earth appears to be at the "Goldilocks" point for plate tectonics.

Even though many of Earth's volcanoes form near plate boundaries, other worlds clearly show that volcanoes can exist without plate tectonics. Volcanoes represent a body's effort to rid itself of internal heat. That heat can either be left over from a body's formation, or in the case of Io, the result of some external force. The variety of features we see on other worlds demonstrates that volcanic activity can manifest itself in a multitude of ways.

Remarkably, many extraterrestrial volcanoes look like their terrestrial cousins, though few resemble the steep, foreboding Mount Doom of *Lord of the Rings.* Depending on the lava's composition, eruptions can be gentle or violently explosive. Sometimes lava pours out onto a planetary surface and just spreads out, forming flat plains such as the lunar maria. Fluid basaltic lavas often build up shield volcanoes, such as those in Hawaii and Iceland. On explosive volcanoes such as Arizona's Sunset Crater, the fragments of lava that landed close to the vent built a relatively small but steep-sided cone. The combination of lava flows and explosive eruptions over long periods builds the tallest volcanoes, such as Mount Fuji in Japan.

A volcano's shape provides clues about the type of eruption and magma. Explosive volcanoes on Earth usually erupt silicon-rich lavas (andesites) rather than sodium-rich basalts. Using remote sensing to relate a magma's composition to eruption type is important for planetary studies, because sending human field geologists to distant worlds is a daunting proposition that lies far in the future.

Volcanoes on the Moon and Mercury

Our Moon once had vast oceans of liquid lava, but today it's volcanically dead — its last eruptions occurred about a billion years ago. Analysis of rocks from various maria show that their lavas were very fluid basalts that spread relatively quickly to cover vast areas; it would have been an amazing sight! But there were no Mount Dooms on the Moon, only a few small cones and domes, probably formed in short-lived eruptions of alternating lava and ash.

Apollo astronauts returned rock samples with intriguing glass beads, formed when tiny droplets of magma erupted into cold space, froze, and then fell back to the surface. What caused some lunar eruptions to be explosive

VENUS VOLCANO ILLUSTRATION: ESA / AOES MEDIALAB

SUNSET CRATER: USGS; STROMBOLI: ©ISTOCKPHOTO.COM / AZ DIENSTLEISTUNG; MOUNT FUJI: ©ISTOCKPHOTO.COM / RSSFHS

EARTH ***Top:*** **Japan's 3,776-meter (12,389-foot) Mount Fuji is a classic volcano that has formed from both explosive eruptions and lava flows.** ***Center:*** **Stromboli, off the coast of Italy, is a 926-meter peak that has been erupting almost continuously for at least 2,000 years.** ***Bottom:*** **Arizona's 340-meter-high Sunset Crater is a cone volcano that formed by a series of small explosive eruptions.**

when mare activity appears to have involved outpourings of fluid lava? Most likely, small pockets of gases (particularly sulfur and carbon monoxide, traces of which are found on the glass beads) propelled the magma into lava fountains perhaps similar to those in Hawaii.

Mercury and the Moon look superficially alike, with impact craters dotting their surfaces. But Mercury has no maria covered by vast expanses of lava. The question of Mercury volcanism remained open until recent results from NASA's Messenger spacecraft. Like the Moon, Mercury volcanism appears to have been both explosive and effusive. Scientists have identified an irregular depression surrounded by a diffuse halo of bright material northeast of Rachmaninoff basin, interpreted as an explosive volcanic vent. Messenger entered Mercury orbit in March 2011, so we can expect the story of the innermost planet's volcanic history to slowly reveal itself.

Venus: Land of Volcanoes

Volcanic materials cover at least 90% of Venus's surface. Sinuous channels thousands of kilometers long run across plains formed by lava flows. The lavas must have been extremely viscous to flow such long distances. They may be ultramafic lavas, whose high magnesium content makes them very fluid. Such lavas erupted on Earth millions to billions of years ago. When Venus had active volcanism, the planet must have been even more hellish than it is today.

How recently were Venus's volcanoes active? The surface has relatively few impact craters, so it must be young. In the late 1970s, NASA's Pioneer Venus spacecraft measured a steady decrease in sulfur dioxide (SO_2) above the cloud tops. An earlier massive volcanic eruption could have pumped large amounts of SO_2 into the atmosphere and by the late 1970s the SO_2 was slowly breaking down.

More recently, some exciting results emerged from Europe's Venus Express orbiter. The spacecraft's Visible and Infrared Thermal Imaging Spectrometer (VIRTIS) measures how much energy the surface radiates at a wavelength of about 1 micron. Fluctuations across the

LEFT: S&T: SEAN WALKER; RIGHT: NASA / GSFC / ARIZONA STATE UNIV.

THE MOON ***Far left:*** **Vast outpourings of lava covered the lunar maria roughly 4 billion years ago, including Mare Crisium on the Moon's northeastern limb. One of the Moon's smaller maria, Mare Crisium is about 555 kilometers (345 miles) across.** ***Near left:*** **These two volcanic cinder cones in the Lacus Mortis region, imaged at high resolution by NASA's Lunar Reconnaissance Orbiter, are only about 1.5 kilometers across at their bases.**

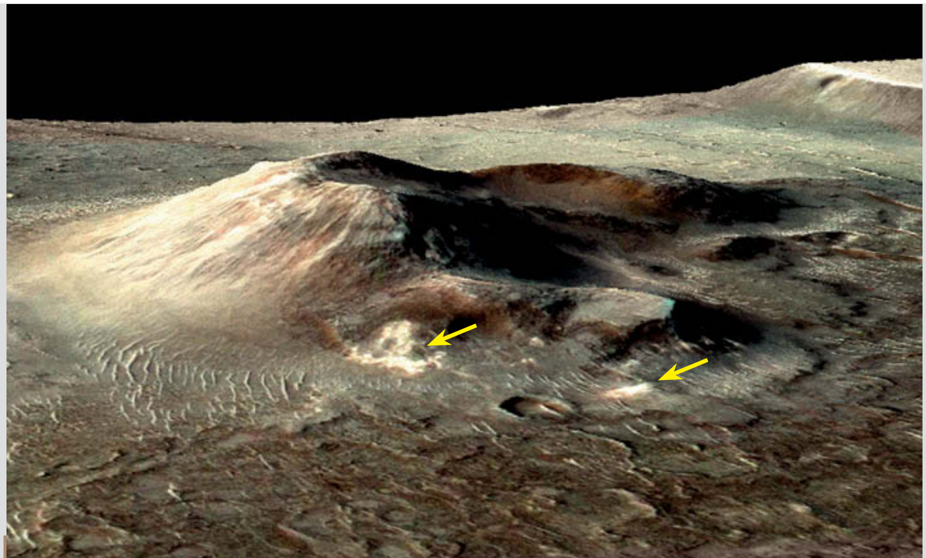
NASA / JHU-APL / CARNEGIE INSTITUTE OF WASHINGTON

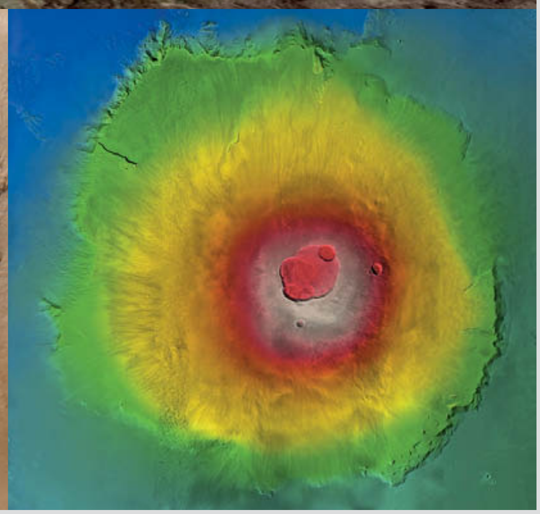
MERCURY **Flyby images such as this one from NASA's Messenger spacecraft resolved the long-standing question of whether Mercury ever had volcanism. The noncircular depression at upper right is a 20-km-wide volcanic caldera surrounded by lighter-colored volcanic deposits. Now that Messenger is orbiting Mercury, scientists will study Mercury's volcanic history in more detail.**

surface relate to variations in chemical composition. When scientists correlated VIRTIS data with Magellan radar images and topographic data of the surface, they found that three areas, Imdr, Themis, and Dione Regiones, are anomalously bright. Taken together, these results indicate relatively recent lava flows (*S&T:* July 2010, page 20). The fact that these flows are so pristine is evidence that they are considerably younger than most others on Venus, possibly 250,000 years old or younger — a blink of an eye in geologic time.

This finding fuels the debate of whether Venus was catastrophically resurfaced between 300 million and 1 billion years ago. Proponents of the hypothesis argue that volcanoes covered most of the surface relatively quickly with molten flows that buried or destroyed any preexisting craters. Since then, volcanism has not occurred and only occasional impacts have changed the surface. The fact that VIRTIS data shows several young flows is inconsistent with this idea, but it doesn't pound a nail in the

MARS





The Red Planet was at one time a volcanically active planet, with giant volcanoes that dwarf those on other planets. But as Mars's interior cooled, activity has dwindled to the point where the planet shows no signs of current volcanism. *Top:* This false-color perspective image of the volcanic cone Nili Patera is derived from images taken by NASA's Mars Reconnaissance Orbiter. The cone is about 5 kilometers across, and it features two areas of hydrothermal deposits (arrowed) in the foreground, evidence of recent activity that might be indicative of potential abodes for microbial life. *Bottom left:* NASA's Mars Global Surveyor acquired this image of the isolated volcano Apollinaris Patera. The number and sizes of impact craters on the flanks suggests that the 5-km-high volcano was probably last active about 3 billion years ago. *Bottom right:* This false-color image from the European Space Agency's Mars Express orbiter shows 24-km-high Olympus Mons, the largest mountain in the solar system. The colors represent different elevations on this ancient shield volcano. Rising magma from a hot spot in Mars's interior formed Olympus Mons. Because of Earth's moving plates, similar hot spots on our planet produce chains of volcanoes.

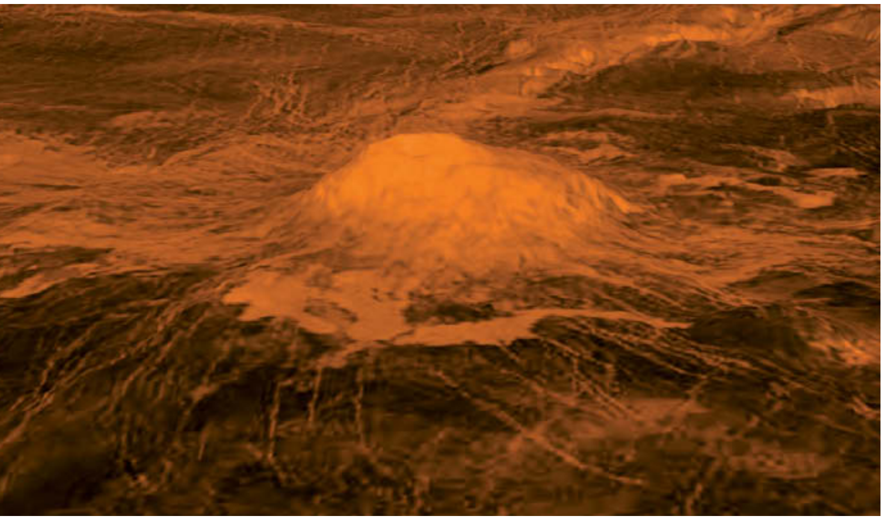
NILI PATERA: NASA / JPL-CALTECH / MSSS / JHU-APL / BROWN UNIVERSITY
APOLLINARIS PATERA: MALIN SPACE SCIENCE SYSTEMS / NASA; OLYMPUS MONS: ESA / DLR / FU BERLIN / GERHARD NEUKUM

coffin either. Defenders of catastrophic resurfacing argue that it's unnecessary for all volcanism to have stopped. The debate goes on.

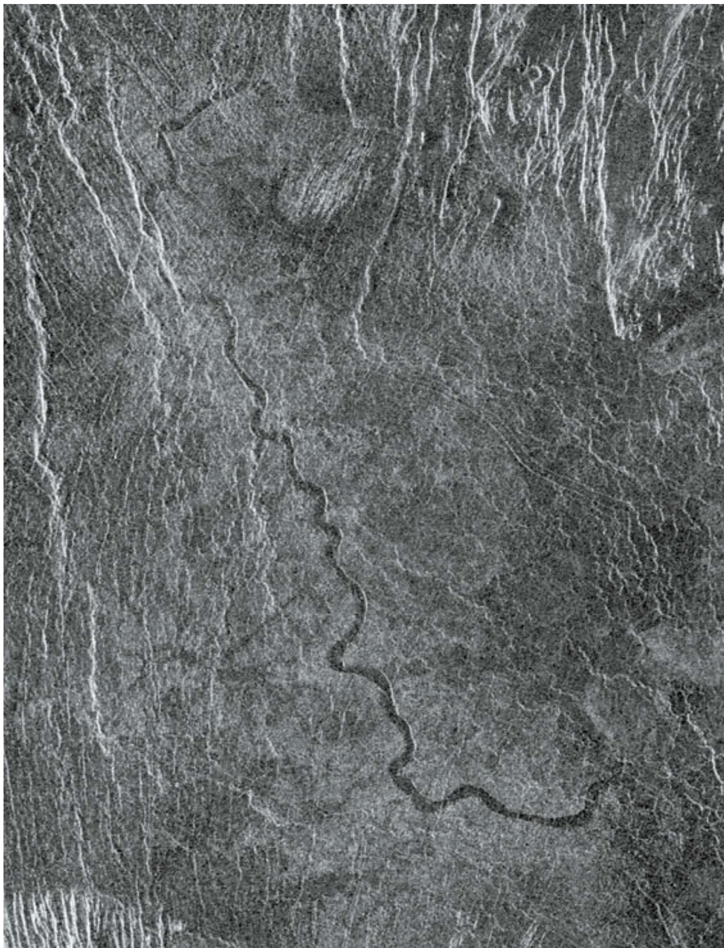
Towering Volcanoes on Mars

Mars features enormous shield volcanoes, vast plains of lava flows, numerous lava channels, domes, cones, and considerable evidence of explosive volcanism. Olympus Mons is the solar system's largest volcano, standing 24 km high. Its 600-km-wide base would cover Arizona. Measurements from various orbiters and landers show that most Martian volcanic deposits are similar to terrestrial basalts and andesites. NASA's rovers Spirit and Opportunity found plenty of evidence of volcanic rocks and even ash — the layers Spirit found at the Columbia Hills resemble ash fall or ash flow deposits.

Despite widespread volcanic features and multiple spacecraft studying Mars, we have not found any conclusive evidence for current volcanic activity. But there's plenty of evidence of recent volcanism. Analysis of Martian meteorites show that the most recent of these rocks crystallized out of lavas about 170 million years ago, young in planetary terms. High-resolution images from Europe's Mars Express orbiter show few impact craters over some volcanic areas, leading geologists to conclude that some of the lava flows are less than 2 million years old. It's possible that Martian volcanism is not yet dead.

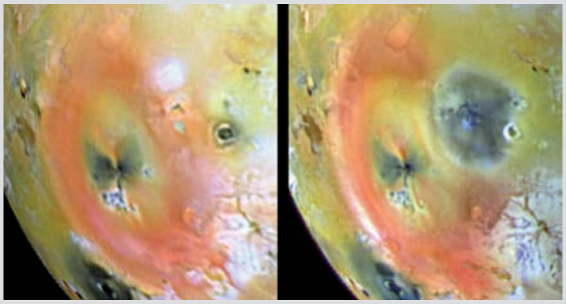


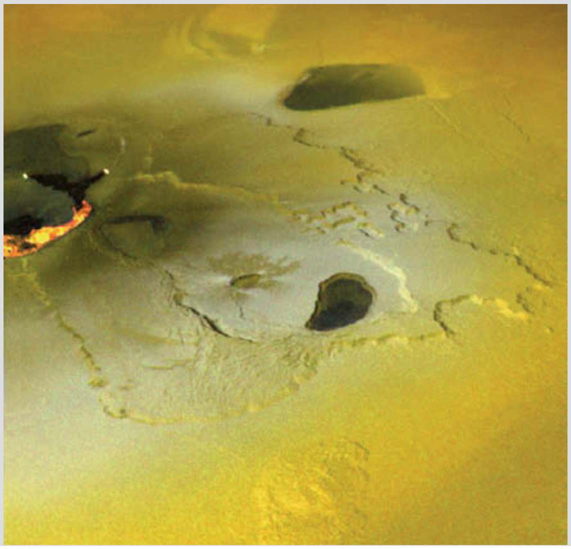
NASA / JPL-CALTECH / ESA



NASA / JPL

VENUS **The surface of Venus is largely covered by lava flows and other volcanic features. *Above:* Magellan's radar instrument provided the data to produce this topographic map of the volcanic peak Idunn Mons and its surrounding region. Recent infrared measurements from Venus Express showed that the flows in this region are younger than the surrounding terrain, strongly suggesting that Idunn Mons was recently active. *Right:* This mosaic from Magellan's radar shows a 200-km-long segment of a sinuous channel carved by flowing lava many millions of years ago. Lava must be extremely viscous to carve such a long channel.**





The innermost of Jupiter's four Galilean moons, Io is the solar system's most volcanically active world due to its complex tidal interactions with Jupiter, Europa, and Ganymede. All of these Io images were taken by NASA's Galileo orbiter. *Far left:* A plume from Pillan shoots 140 km (87 miles) into space. Io's volcanoes eject material at speeds of 1 to 2 km/second (2,200 to 4,400 mph). *Above:* The dark volcanic flow from Amirani is 250 km long, making it the solar system's longest known active volcanic flow. Whitish sulfur-dioxide-rich plume deposits circle Amirani's vent. *Above right:* In just 5 months, the dark volcanic flow from Pillan (upper right) covered an area the size of Arizona. Material vented by Pele created the large orangish ring. *Far right:* Galileo caught the giant Tvashtar caldera (upper left) in the act of erupting.

NASA / JPL / UNIVERSITY OF ARIZONA (5)

Measurements of methane (CH_4) gas are also intriguing. The atmospheric methane concentration is only a few parts per billion, so ground-based measurements from Earth are particularly challenging. But the presence of methane is very significant, because chemical processes in the Martian atmosphere destroy the gas, so its lifetime is less than a few hundred years — indicating that something is replenishing it.

Recent data confirmed the presence of methane and showed that it's concentrated in particular locations (*S&T:* April 2009, page 20). The source could be either volcanic gas or biological activity. While many scientists view volcanic gas as more likely, the degassing implies that hot magma still lies below the surface. If there is heat, there could be liquid water, and possibly microbial life. We look forward to future missions, such as NASA's Mars Science Laboratory (also named Curiosity), a Mini-Cooper-size rover that carries instrumentation capable of detecting methane at the level of a few parts per billion. In 2016 the European-led ExoMars orbiter will study trace gases in the Martian atmosphere and how they vary with time.

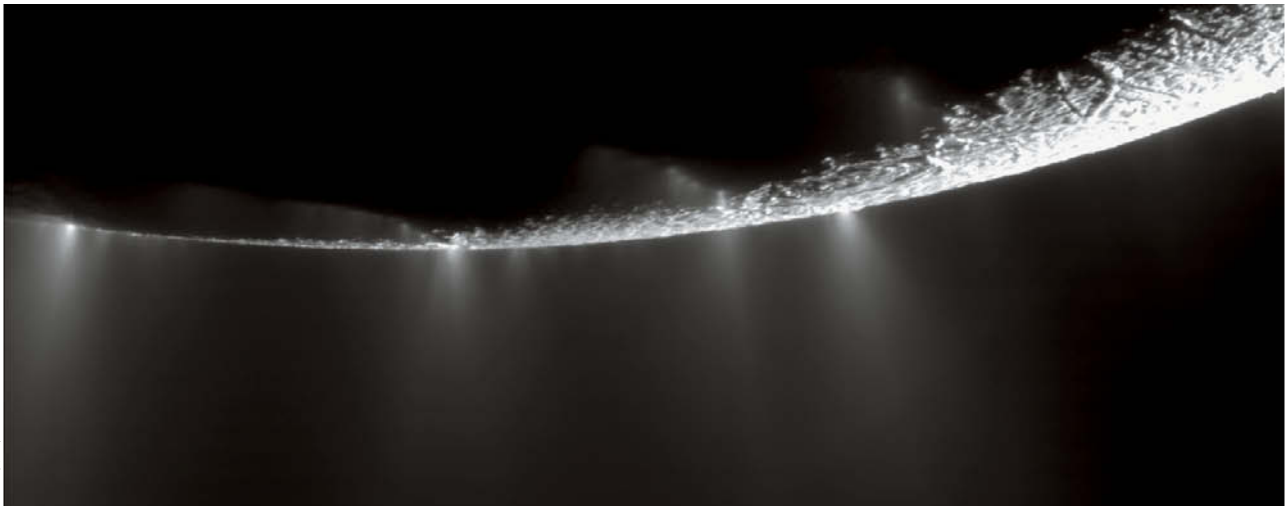
Frenetic Volcanism on Io

Jupiter's large moon Io is the most volcanically active body in the solar system. Io is just 5% larger than our Moon. If it had been left alone, it would have cooled and formed a thick crust long ago. But Jupiter's gravity pulls on Io so strongly that it creates a tidal bulge. The moons Europa and Ganymede distort the bulge as they pull it toward them. This tidal friction generates heat, which keeps Io's interior molten. Remarkably, scientists predicted Io's volcanism on the basis of these orbital interactions before the 1979 Voyager 1 flyby revealed Io's frenetic volcanic activity. NASA's Galileo and New Horizons spacecraft, and ground-based observations, have since revealed many more active volcanoes; we now know of nearly 200 and undoubtedly there are many more.

Most of Io's volcanoes are caldera-like depressions. Loki, about 200 km across, is the largest caldera in the solar system. Io's volcanoes rarely build structures such as shield volcanoes or domes, but long lava flows are common. The largest active flow field in the solar system reaches some 250 km from Amirani. Io's impressive lava flows are possibly similar to continental flood basalt lavas on Earth, such as the Columbia River basalts in the northwestern U.S. These terrestrial lavas flowed tens to hundreds of millions of years ago. Studying Io's volcanism thus gives us a window into Earth's past.

Io's surface is nearly entirely covered by SO_2 frost, which condenses from spectacular volcanic plumes, some of which rise several hundred kilometers high. The last spacecraft to fly by Io, New Horizons, captured remark-

NASA / JPL / SPACE SCIENCE INSTITUTE



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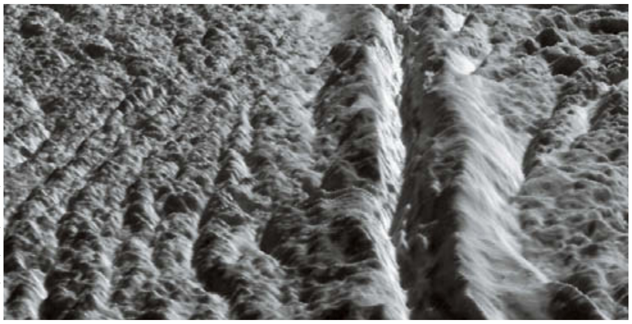


NASA / JPL / SPACE SCIENCE INSTITUTE

ENCELADUS ***Top:*** **Cassini images several jets shooting into space from cryovolcanoes near the south pole. The jets are rich in water ice and laced with organic molecules. About 30 jets have been identified to date.** ***Above left:*** **This perspective view shows Damascus Sulcus, one of the "tiger stripes" that are the sources for Enceladus's volcanic activity. The two parallel ridges are 100 to 150 meters high and the trough between them is about 200 to 250 meters deep.** ***Above right:*** **Icy particles shooting out from Enceladus form Saturn's tenuous E ring, imaged here by Cassini.**

able images of the plume over Tvashtar.

We still don't know the composition of Io's magma. Temperatures at active hot spots provide the best clues to magma composition, since the temperature at which different types of magma melt depends on their composition. Galileo measurements of Pillan showed temperatures of about 1500°C, too high for basalt (basalts on Earth rarely exceed 1200°C). More recent calibration of these data lowered the temperature to around 1300°C, still unusually high for basalts but possible in some circumstances. Io's magmas might be ultramafic, similar to those suggested for Venus and ancient Earth, or basalts.

The Exotic Cryovolcanoes

In the icy moons of the outer solar system, materials erupt that would be frozen solid at their normal surface temperatures. For this so-called *cryovolcanism* to occur, the body must have interior liquid water (probably with other constituents such as ammonia) that can rise to the surface to erupt. Spacecraft have detected possible cryovolcanic features on several icy satellites, but active cryovolcanism has only been confirmed on Saturn's medium-sized moon Enceladus.

The discovery of active volcanic plumes on Enceladus was one of the most exciting of NASA's Cassini mission, though it was not entirely unexpected. Enceladus's surface appears smooth and young, with few impact craters; it's also highly reflective, indicating that it's covered with pristine ice dusted with fresh materials. As Cassini flew through an extended plume on July 14, 2005, its instruments detected water vapor, methane, and carbon dioxide, as well as heat over one of the long parallel rifts ("tiger stripes") in the south polar region. Images revealed spectacular plumes originating from the tiger stripes, which are about 2 km across and up to 130 km long.

Enceladus is embedded in Saturn's tenuous E ring, which is replenished by fine particles ejected by the plumes. The plume material is being shot out at about 60 meters per second (135 mph). The plumes are probably linked to subsurface reservoirs of liquid water, though their depths remain unknown. These reservoirs could be potential abodes for life because they have biology's key ingredients: heat, liquid water, and organic compounds.

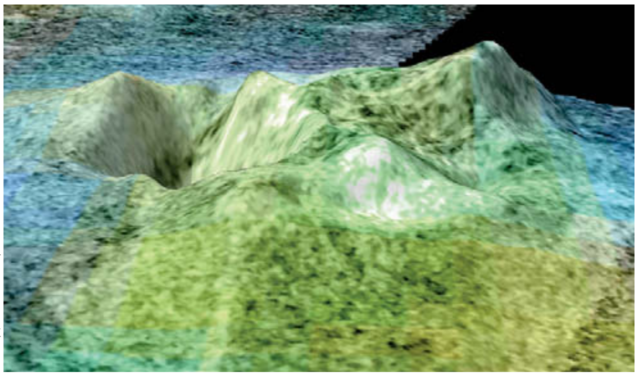
LISTEN TO AN AUTHOR INTERVIEW

To listen to an interview with author Rosaly Lopes, visit SkyandTelescope.com/volcanoes.

Scientists are debating the existence of cryovolcanism on Saturn's largest moon, Titan. Some flow-like features appear to be rivers of methane. But recent analysis of radar data shows the topography of the Sotra Facula region. A 1-km-high mountain lies next to a deep pit and flow-like features. There are no river channels nearby that could have created these flows, the pit is not circular like an impact crater, and the mountain is isolated and not part of a chain. This combination of features is difficult to explain with fluvial or other nonvolcanic activity. Although the debate goes on, Titan could be yet another world where heat and liquid water coexist. Thanks to volcanism, the conditions for life may occur even in the frigid environments of the outer solar system.

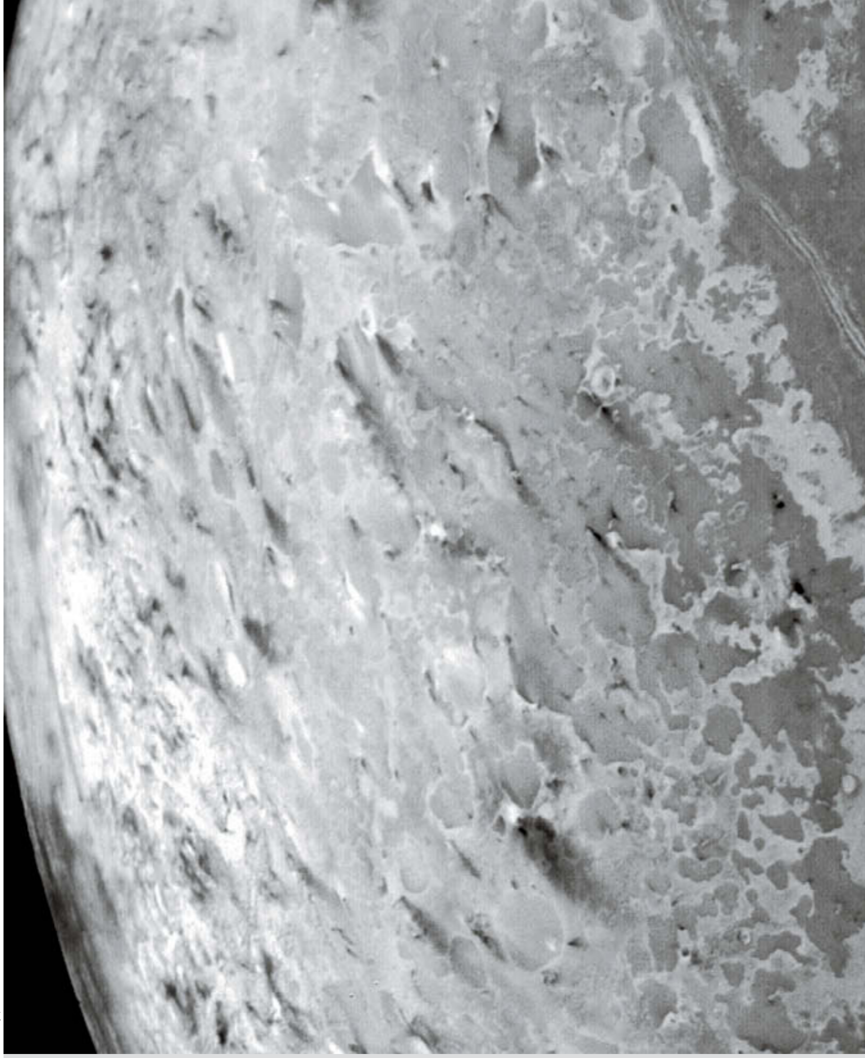
Seeing new worlds up close helps us better understand our own. We can use other worlds as "volcano laboratories" to understand what happens if conditions are vastly different from those on our home planet. Thanks to interplanetary missions, we now know that volcanism can occur in the absence of plate tectonics, in worlds where the magma is water rather than molten rock, and where surface temperatures and pressures are much higher or lower than Earth's. As we explore new worlds such as Pluto and asteroids, we may find more volcanoes, maybe some that erupted in the distant past, maybe some that are currently active. And as we learn more about exoplanets, we may learn that some sustain volcanism due to tidal heating or other processes. Stay tuned! ✦

Planetary volcanism expert ***Rosaly Lopes*** *is a Senior Research Scientist at NASA's Jet Propulsion Laboratory. Her fifth book,* Volcanoes, *was published in January as part of the Oneworld Beginnner's Guide series.*



NASA / JPL-CALTECH / UNIVERSITY OF ARIZONA

TITAN This false-color, vertically exaggerated perspective image is based on Cassini infrared and radar data. It shows a 1-km-high peak in the Sotra Facula region that is probably a cryovolcano.

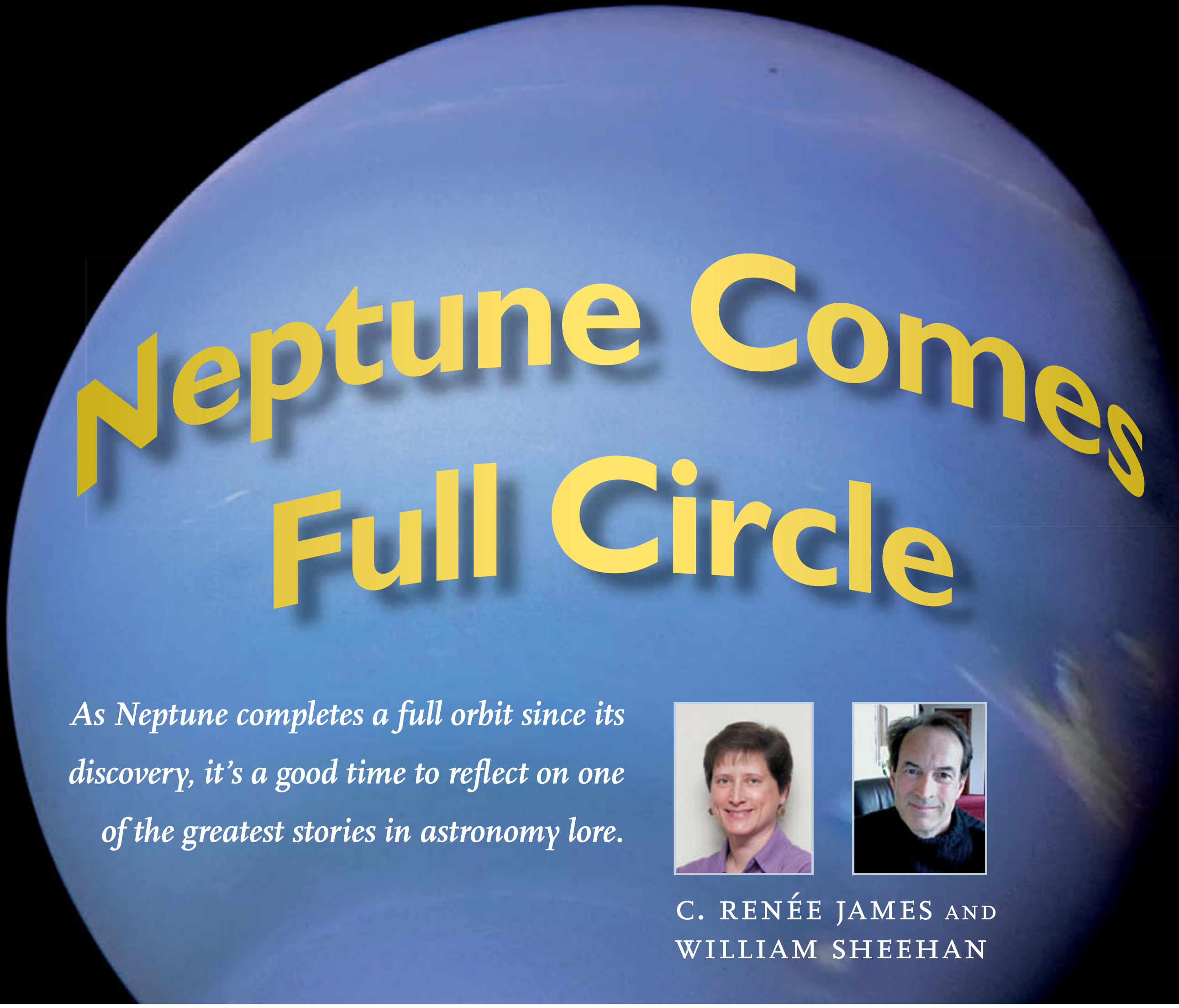


NASA / JPL

TRITON NASA's Voyager 2 spacecraft took this image of the south polar region of Neptune's large moon Triton during its 1989 flyby. Scrutiny of Voyager images revealed about 150 dark streaks, some more than 150 kilometers long. They appear to be wind-blown plumes venting from patches of dark nitrogen-rich ice, perhaps driven by nothing more than the energy of sunlight.

Sunlight-Driven Volcanism

When Voyager 2 flew by Neptune's large moon Triton in 1989, its pictures showed dark streaks that originate from rising geyser-like plumes. Scientists think the plumes are produced when sunlight penetrates a transparent surface layer of frozen nitrogen. Dark, carbon-rich impurities a few meters below the surface absorb and trap the sunlight. Sunlight this far from the Sun is feeble (only $1/900$ the amount received by Earth), and warms Triton's surface to only –235°C (–391°F). But this minimal amount of heating is enough to vaporize the icy nitrogen near the surface. The ice expands and then explodes into the near-vacuum of space, forming the plumes. If this model is correct, active plumes on Triton are a side effect of sunlight rather than an internally driven process — demonstrating yet another example of nature's creative ability to produce different styles of volcanism.



NEPTUNE IMAGE COURTESY NASA / JPL; PROCESSED BY DANIEL MACHÁCEK

Neptune Comes Full Circle

As Neptune completes a full orbit since its discovery, it's a good time to reflect on one of the greatest stories in astronomy lore.

C. RENÉE JAMES AND WILLIAM SHEEHAN

THE NARRATIVE of Neptune's discovery is a staple in introductory astronomy classrooms. An exciting tale of competing mathematicians and observers in a heated race, it's heralded as the triumph of celestial mechanics. Depending on one's nationalistic preference or personal predilection, the tale sometimes portrays certain figures as good guys, bad guys, or bumbling idiots, occasionally with a dose of insidious conspiracy. The Neptune story continues to shape the landscape of astronomical predictions, one complete Neptunian orbit after the planet's discovery.

As far as we Earthlings are concerned, Neptune rang in its New Year on September 23/24, 1846. At just past midnight local time, Johann Galle, acting on calculations just received from Urbain Le Verrier in Paris, spotted the predicted planet through the Berlin Observatory's 9-inch Fraunhofer refractor, resulting in graduate student Heinrich d'Arrest's exclamation, "That star is not on the map!"

We now know that Galle was not the first to record Neptune. In fact, Galileo Galilei could have made the discovery in 1613, when on two successive nights he noted that two stars in his field of view moved farther apart. But too busy with other matters, such as mapping sunspots, he never followed up. Also, Neptune was spotted — but never recognized — over the next two centuries by astronomers great (John Herschel) and obscure (Johann von Lamont), always hiding in plain sight like a great cosmic Waldo. The planet is not flashy (it maxes out with a magnitude of 7.8), but its bluish disk is easily noticeable with enough scrutiny.

It's just as well that serendipity never struck either Galileo or later accidental observers. According to the February 1847 *Monthly Notices of the Royal Astronomical Society,* Neptune's continued nondiscovery preserved for the years 1845 and 1846 "an importance which belongs to no period except that of the announcement of the theory of gravitation and of the publication of the *Principia*."

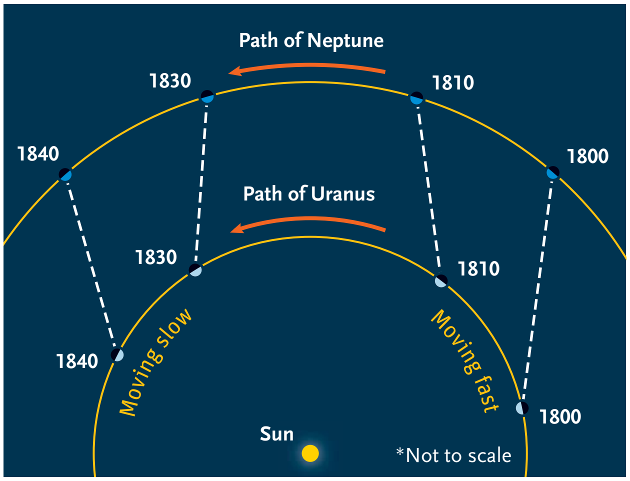
The discovery of Neptune is more than just a compelling story. It was epic.

Brian Sheen, director of the Roseland Observatory in Cornwall, England, has studied this historical episode in detail. He goes even further: "Neptune was totally unique. This sort of discovery will *never* be made again."

A Tale of Two Astronomers

To understand why Neptune's 1846 discovery is so special, we have to go back a few decades. In 1821, when French mathematical astronomer Alexis Bouvard published revised tables of Jupiter, Saturn, and Uranus, he realized something was askew in the outer solar system. For the previous few years, Uranus seemed to be moving faster in its orbit than it should, and Bouvard presciently suspected that an unknown planet might be responsible. For a brief period, in 1829–30, the tabular and observed positions of the planet matched, but thereafter the planet began to lag behind its calculated pace. Was something awry in Newton's clockwork universe?

To hunt down an unknown planet from its gravitational perturbation on a known world is anything but straightforward. Mathematical astronomers were used to making *pre*dictions — not *retro*dictions. Thanks to Kepler, they could easily predict a planet's motion given the elements of its elliptical orbit. Newton's theory of gravitation allowed for small corrections based on the perturbations of other planets, provided only that the timescale isn't too far into the future. But even in the hands of a skilled mathematician (and a supercomputer), the long-term effects of three-body interactions inevitably turn very ugly.



S&T: LEAH TISCIONE

ABERRANT BEHAVIOR William Herschel discovered Uranus in 1781, 40 years before it overtook and passed Neptune in their respective orbits. In the decades before 1821, Neptune was "ahead" of Uranus, and its gravity slightly accelerated Uranus's motion around the Sun. After 1821, Neptune's gravity essentially "pulled back" on Uranus, causing it to slow down. Uranus's aberrant motion was noticeable to astronomers of the early 1800s, and it proved to be the vital clue that led to Neptune's discovery.

To understand the Uranian peculiarities, though, one had to divine the cause from the effects. Few 19th-century mathematicians had the skills to grapple with such a complex problem, and only two were compelled to tackle it: Urbain Jean Joseph Le Verrier and John Couch (pronounced "Kootch") Adams.

The French

Alexis Bouvard (1767–1843) was the first astronomer to recognize anomalies in Uranus's orbit; and he presciently suggested they might be due to the gravitational perturbations of a more distant planet. Paris Observatory director François Arago (1786–1853) felt enough confidence in this possibility that he assigned the task of computing this planet's position to the brilliant mathematical astronomer Urbain Jean Joseph Le Verrier (1811–1877). Le Verrier spent a year wrestling with exceedingly complex calculations. Modern-day astronomers express the deepest level of respect for Le Verrier, who managed to tease out Neptune's position to within 1° despite not knowing the planet's distance, eccentricity, or inclination, and not having the benefit of computers. Le Verrier enjoyed some measure of luck, but nobody can deny that his prediction led directly to the discovery of the solar system's eighth planet, assuring his rightful place in the pantheon of astronomy immortals.

PORTRAITS: PARIS OBSERVATORY (3); FLAG: ©ISTOCKPHOTO / AYZEK

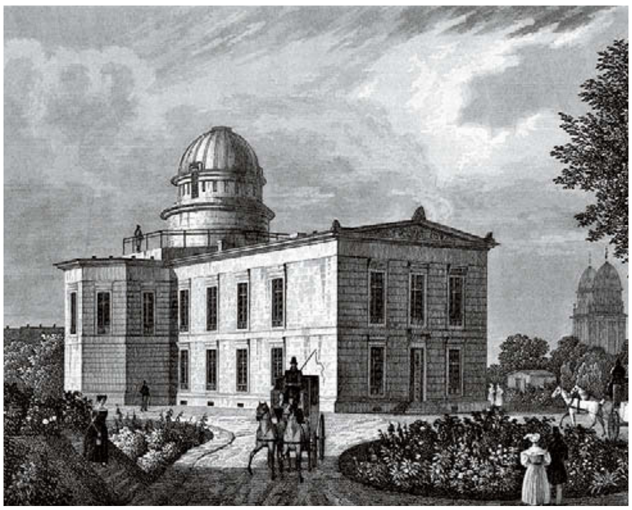
The British

Working independently, John Couch Adams (1819–1892) essentially duplicated Le Verrier's achievement, but with less confidence and precision. He lacked Le Verrier's credentials and was a man of shy disposition. He never published his results, meaning few astronomers were aware of his work. George Biddell Airy (1801–1892) served as Astronomer Royal at the time of Adams's work. Airy felt enough confidence in the young man's prediction, and its similarity to Le Verrier's published prediction, that he asked Cambridge University Observatory director James Challis (1803–1882) to search for the planet. Challis has been unfairly portrayed as a bumbler for his failure to identify Neptune, despite having seen it twice. But he was observing an extremely crowded star field without the benefit of a modern star chart. Adams never expressed any bitterness over the British failure to discover Neptune, and he and Le Verrier later established a lifelong friendship.

AIRY & ADAMS: S&T ARCHIVE; CHALLIS: THE ROYAL SOCIETY; FLAG: ©ISTOCKPHOTO.COM / HERREID

In June 1845, François Arago, then the director of the Paris Observatory, assigned this problem to Le Verrier (whose 200th birthday was celebrated on March 11, 2011). In other words, it was Le Verrier's *job* to publish something tangible about Uranus's peculiar motions.

For Adams, working out a new planet's position was sparked by a chance look at an 1832 "Report on Progress in Astronomy" by Cambridge University astronomer George Biddell Airy, who became Astronomer Royal at the Greenwich Observatory in 1835. Airy made only a one-sentence reference to the "difficulties" of Uranus at the end of a lengthy annual report for the British Association for the Advancement of Science, but it was enough to trigger the curiosity of the precocious undergraduate student.



ASTROPHYSICAL INSTITUTE POTSDAM

BERLIN OBSERVATORY Neptune was discovered in 1846 at the Berlin Observatory, which had been built just 11 years earlier. In 1913 the observatory was moved to Babelsberg, a suburb southwest of Berlin.

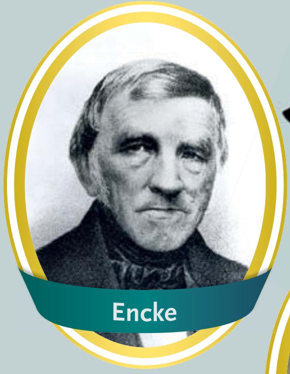
The stage was set. Le Verrier approached the problem with the French penchant for order and system. Indeed, he seems to have been an order-obsessed individual, who later entered politics as a deputy for his native *département* of La Manche as a member of the right-wing "Friends of Liberty" Party. When he succeeded Arago as Director of the Paris Observatory in 1854, he proved to be so authoritarian that he was eventually overthrown by his staff.

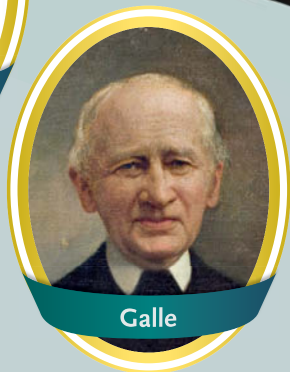
Unfortunately, before Le Verrier and Adams could understand what was behind Uranus's aberrant motion, both had to make key assumptions about the mystery object, such as an orbit within the same plane as Uranus. This was a reasonable (and correct) assumption, given that all the planets known at that time stay close to the ecliptic. But another crucial assumption was distance. Here, the two mathematical astronomers had to lean uncomfortably on the semi-empirical Bode's Law, a rather dodgy formula just a shade away from numerology, which had somehow worked for the first seven planets and the asteroid belt (see "Bode's Law," page 34). According to this "law," the unknown planet's distance from the Sun would be 38.8 astronomical units (about twice Uranus's). Neptune's actual distance, however, is 30.1 a.u.

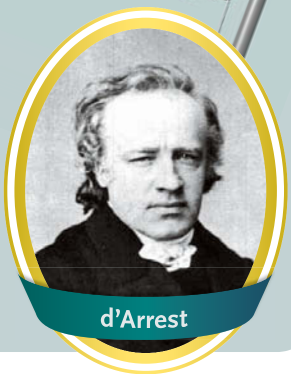
These days, the scientific community would resoundingly veto such makeshift assumptions. In fact, the submission guidelines for *Icarus,* the leading journal of planetary sciences, specifically state that it "does not

The Germans

Johann Franz Encke (1791–1865) was director of the Berlin Observatory when Le Verrier's letter arrived on September 23, 1846. Encke approved the immediate search for Le Verrier's predicted planet. Johann Galle (1812–1910) sighted Neptune *within one hour* of beginning the hunt for Le Verrier's planet, becoming the first person to see Neptune and recognize he was looking at a new planet. Graduate student Heinrich Louis d'Arrest (1822–1875) assisted Galle on this momentous occasion, suggesting that Galle consult a newly published star chart of the region near the Aquarius/Capricornus border. The pictured flag is that of the Kingdom of Prussia, home of the Berlin Observatory.







PORTRAITS: ASTROPHYSICAL INST. POTSDAM (3); FLAG: ©ISTOCKPHOTO / AYZEK

publish papers that provide 'improved' versions of Bode's Law, or other numerical relations, without a sound physical basis." Had Adams and Le Verrier been working in the 21st century, their predictions never would have found their way into a peer-reviewed journal!

In July 1846, Le Verrier had carried through the assigned project, and had dotted every i and crossed every t of his immense set of calculations to arrive at and publish a position for the mystery object, placing it near what was then the Aquarius/Capricornus border.

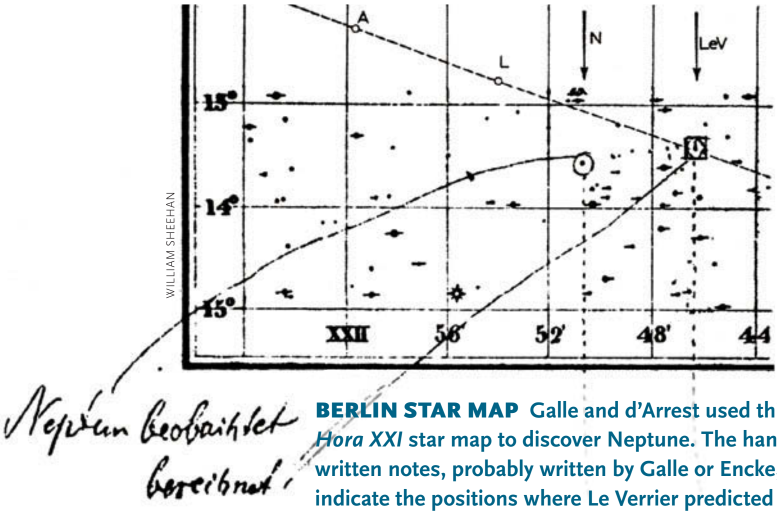
The British Search Founders

Meanwhile, across the English Channel, a far less tidy story was playing out. In ignorance of Le Verrier's work, Adams worked alone on the problem in his spare time. Unfortunately, neither Cambridge University Observatory director James Challis, nor Airy, felt any sense of urgency about the work of a young man who, apart from being a recent graduate, was essentially an unknown quantity in the field of mathematical astronomy. In contrast to Le Verrier, an established astronomer and an intimidating figure, Adams possessed an extremely timid personality that failed to make a strong impression on others. A fellow student later remembered him as "a rather small man, who walked quickly, and wore a faded coat of dark green."

Further hindering Adams's progress were his social skills — or lack thereof. Likely suffering from Asperger syndrome, Adams was a perfectionist who was prone to self-doubt and who obsessively reworked his calculations and stumbled awkwardly through personal encounters. For example, instead of following standard protocol to

WILLIAM SHEEHAN

DISCOVERY TELESCOPE **Johann Galle discovered Neptune using this beautiful 9-inch Fraunhofer refractor, which is currently on display at the Deutsches Museum in Munich.**



WILLIAM SHEEHAN

BERLIN STAR MAP Galle and d'Arrest used this *Hora XXI* star map to discover Neptune. The handwritten notes, probably written by Galle or Encke, indicate the positions where Le Verrier predicted the new planet and where Galle found it.

prearrange a meeting with Airy, one of the busiest civil servants in England, Adams simply dropped by the Greenwich Observatory unannounced in October 1845 and was, to his puzzlement, turned away. He left a sketchy, single-page summary of his calculations in Airy's mailbox.

His prediction at that time put the planet within 1.5° of where it really was. Not surprisingly, no one in England bothered to look.

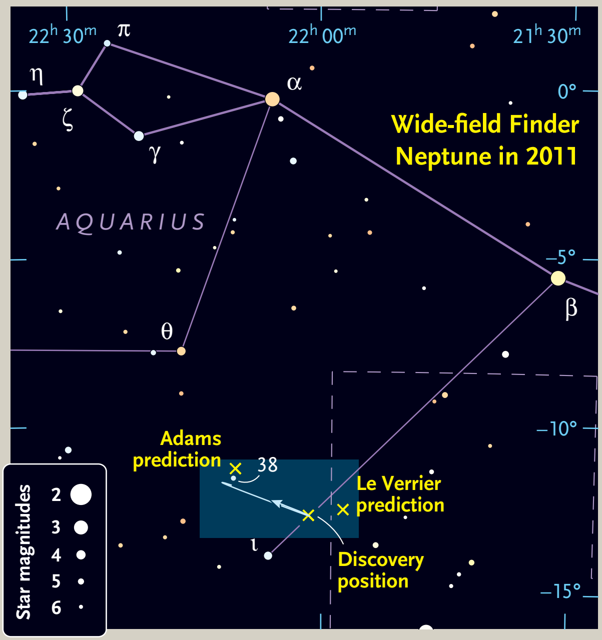
Nine months later, after Le Verrier had published his predictions, Adams — by now aware of the competition — was *still* revising his calculations. He was justifiably uncomfortable with the assumptions he was forced to make (including the distance from Bode's Law) and was juggling a bewildering number of equations while trying to solve for eight or nine unknowns. He refused to publish his computations until he had arrived at a final answer. He never would, primarily because he never could.

But now Airy was aroused. He was struck by the near coincidence between Le Verrier's published and Adams's still-secret positions. In July 1846 Le Verrier had put Neptune within just 2.5° of where Adams's 1845 calculations had done so. Contrary to later criticism, Airy seized the moment and delegated to Challis the task of hunting down the object telescopically.

Challis had Cambridge's excellent 12-inch Northumberland refractor, but his method was slow and plodding. He plotted stars night after night in a wide zone of sky

Relive Neptune's Discovery

Despite Le Verrier's confidence in his calculations published on July 1, 1846, he had no initial success motivating anyone to search for his theoretical planet — not even in France. Not until September, when he wrote to German astronomer Johann Galle at the Berlin Observatory, did he receive an enthusiastic response. Galle persuaded his director, Johann Encke, to allow the search for Le Verrier's planet. Though Encke was hesitant at first, perhaps he was in a better mood than usual because it was his birthday. "Let us oblige the gentleman in Paris," Encke finally consented.

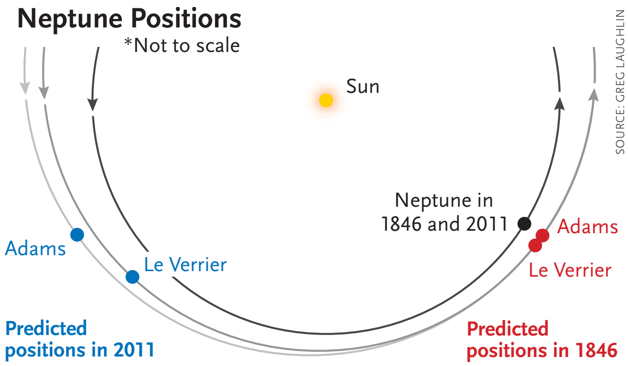


On September 23/24, 1846, the theoretical planet lay along the ecliptic near celestial longitude 325°, very close to Saturn. Galle, assisted by graduate student Heinrich Louis d'Arrest, began scanning the stars for a small disk using the observatory's magnificent 9-inch Fraunhofer refractor. No planets were apparent, so he abandoned that approach, and changing tactics, decided to rummage through the star charts in a cabinet outside Encke's office.

As far as they knew, the best atlas was a generation out of date and insufficient for their search. But d'Arrest had a flash of inspiration. Why not browse the Berlin Academy's new charts that were just being published? They soon found what they were looking for: *Hora XXI*. This map contained the correct field of stars and had been published earlier that year. D'Arrest later recalled what happened next:

> We ... went back to the dome, where there was a kind of desk, at which I placed myself with the map, while Galle, looking through the refractor, described the configurations of the stars he saw. I followed them on the map one by one, until he said: and then there is a star of the 8th magnitude in such and such a

PREDICTED POSITIONS This illustration compares Le Verrier's and Adams's predicted positions of an eighth planet with Neptune's actual location. The two mathematical astronomers assumed (due to Bode's Law) that the unseen planet orbited farther from the Sun than Neptune's actual distance. As a result of this mistaken assumption, their 2011 predictions are far off.



around Le Verrier's position (using an ephemeris calculated for him by Adams!) hoping — eventually, when he got around to following up — to find one that moved from one night to another. If he had possessed an authoritative map he could have saved himself the trouble. On August 4 and 12, 1846, he actually recorded Neptune, but failed to recognize it. Challis has often been painted as a bumbler because of this oversight. But a glance at the types of crowded star fields he was observing makes his oversight more forgivable.

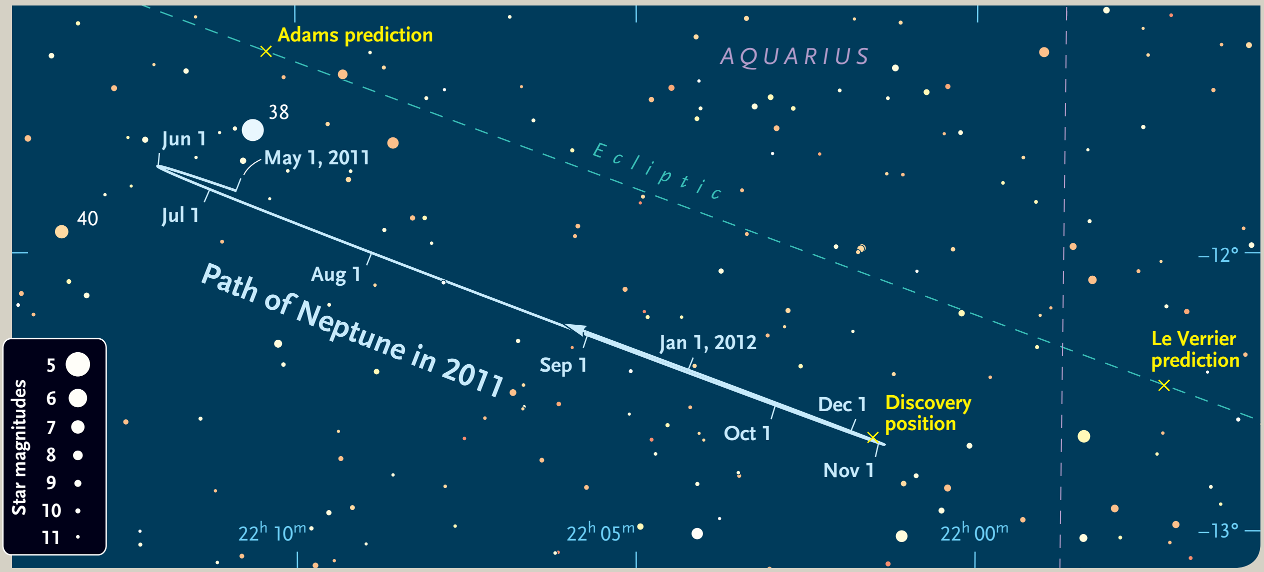
A Planet Found

Galle and d'Arrest were not to face Challis's ordeal. They possessed an excellent star chart of the region just published by the Berlin Academy that had not yet been sent to other observatories. It allowed them to settle quickly on a dot that didn't belong (see "Relive Neptune's Discovery" below). At 8th magnitude, Neptune was found about a degree from Le Verrier's calculated position. Observations the following night confirmed the expected motion for a planet beyond Uranus. On September 25th Galle fired off a congratulatory letter to Paris informing Le Verrier that "the planet of which you indicated the position actually exists." At the Paris Observatory, François Arago captured the achievement in a glorious phrase, announcing that Le Verrier had "discovered a world with the tip of his pen."

position, whereupon I immediately exclaimed: "THAT STAR IS NOT ON THE MAP!"

Galle and d'Arrest found Neptune about a degree from Le Verrier's calculated position. On July 12, 2011, the planet will complete its first full orbit of the Sun since the night Galle laid eyes on it 165 years ago. As Neptune retrogrades among the stars this year, it makes several passes of the same star field in which it was discovered. It came close to its discovery position on February 11th, but Neptune was lost in the solar glare. It will come close again on October 27th and November 22nd.

Amateurs who point their telescopes to these crowded star fields will have the sensation of traveling back in time to the dome in Berlin, to relive one of the most momentous events in the history of astronomy. They may well ask: What will our own world be like when this distant planet, orbiting slowly in its cold solitude, returns for a second time to the place of its birth as an object of human awareness?



BODE'S LAW

Developed in the 1700s, and sometimes known as the Titius-Bode Law, this "law" is actually just a mathematical formula to describe the relationship between the distances of planets from the Sun. Each planet is assigned a number (n) derived from a geometric progression, where n = 0 for Mercury, 0.3 for Venus, 0.6 for Earth, 1.2 for Mars, and so on. Then the distance to the Sun is given simply by $a = 0.4 + n$.

This formula works astonishingly well for most planets in the solar system, even predicting the existence of the asteroid belt before the discovery of Ceres. But this apparent success is a mere coincidence. Neptune is 29% closer to the Sun than the law predicts, and astronomers have found no evidence of relationships similar to Bode's Law in other planetary systems.

Planet	n	Prediction (0.4 + n)	Actual
Mercury	0.0	0.4	0.39
Venus	0.3	0.7	0.72
Earth	0.6	1.0	1.00
Mars	1.2	1.6	1.52
Ceres	2.4	2.8	2.77
Jupiter	4.8	5.2	5.20
Saturn	9.6	10.0	9.54
Uranus	19.2	19.6	19.2
Neptune	38.4	38.8	30.1

The discovery received its due accolades, dominating headlines throughout the Western world.

But the British felt great shame for having been scooped by the French. Modern-day scholar Robert W. Smith (University of Alberta, Canada) reports that "even in the 1890s, the rancor over the discovery of Neptune smothered a move to give Airy a burial in Westminster Abbey." After all, claimed his critics, he had obviously not taken Adams's first calculations seriously enough.

If the British were angry at Airy, the French were irate. Soon after the discovery, Airy assembled documents disclosing that Adams had been working on the same problem, and had come to a similar conclusion a year earlier. The French saw a British conspiracy to steal credit for a discovery that rightfully belonged to them. The French press vigorously defended Le Verrier's priority to such a degree that John Herschel would complain in his diary, "These Frenchmen fly at one like wild cats!"

Sheen has a more political take on the matter: "The fuss over the British claims was more to do with the Battle of Waterloo in 1815, when the British and the Berliners (Prussians) joined forces to beat the French." The French public reacted bitterly when it became widely known that Le Verrier had not won the assistance of French observers to look for the unknown planet and had to enlist the help of the Berlin Observatory. The fact that France had few suitable instruments was also humbling.

Adding to the modern debate was the mysterious decades-long disappearance of the so-called Airy file, which contained all the British documents about the entire affair. Some scholars suspected a cover-up by the Astronomers Royal (a case of "who shall rid me of this meddlesome file"). The reality was perhaps not quite so sinister. The documents were found in the personal papers of Olin Eggen, the right-hand man of Richard van der Wooley (who served as Astronomer Royal from 1956 to 1971). Eggen had removed the file from the Greenwich Observatory in the mid-1960s, ostensibly to write biographies of Airy and Challis. Eggen died in 1998, and left no account of why he kept the papers for so long, so we'll never know his motives.

Those of us "in more enlightened times" are often amused by the vehemence of the Neptune controversy. But as astrophysicist Greg Laughlin (University of California, Santa Cruz) points out, "Being first is very important, and so the struggle for priority is no small deal. Fame through priority of discovery can propagate forward."

A case in point is 61 Cygni. Serious amateurs and professionals know this star because Friedrich Wilhelm Bessel first measured its parallax in the 1830s. Virtually nobody hears about Thomas Henderson, who measured the parallax for the closer and more interesting star Alpha Centauri, but who failed to publish his results first, or Wilhelm Struve, who did so for more distant Vega.

In the case of Neptune, Robert W. Smith points out, "This was one of the greatest triumphs in the entire history of science. This is why the stakes were so high." It is also why the discovery of Neptune continues to fascinate us, a full Neptune orbit later. ✦

Send Us Your Neptune Photos

Shoot Neptune when it comes very close to its discovery position this October and November, and submit your best image to SkyandTelescope.com/community/gallery/submit. We will feature a selection of the best and most innovative images at SkyandTelescope.com/Neptune. Most camera-and-lens combinations will reveal 8th-magnitude Neptune with an exposure of 10 seconds or less. Show us your creativity!

JOHN BOUDREAU

Frequent S&T *contributor* ***C. Renée James*** *is an associate professor of physics at Sam Houston State University and author of the book* Seven Wonders of the Universe That You Probably Took for Granted.

S&T *contributing editor* ***William Sheehan*** *is currently working on a book on Neptune with Robert Smith and Craig Waff, and a film with Dutch filmmaker Maarten Roos. He authored the article about Saturn's ring spokes on page 50.*

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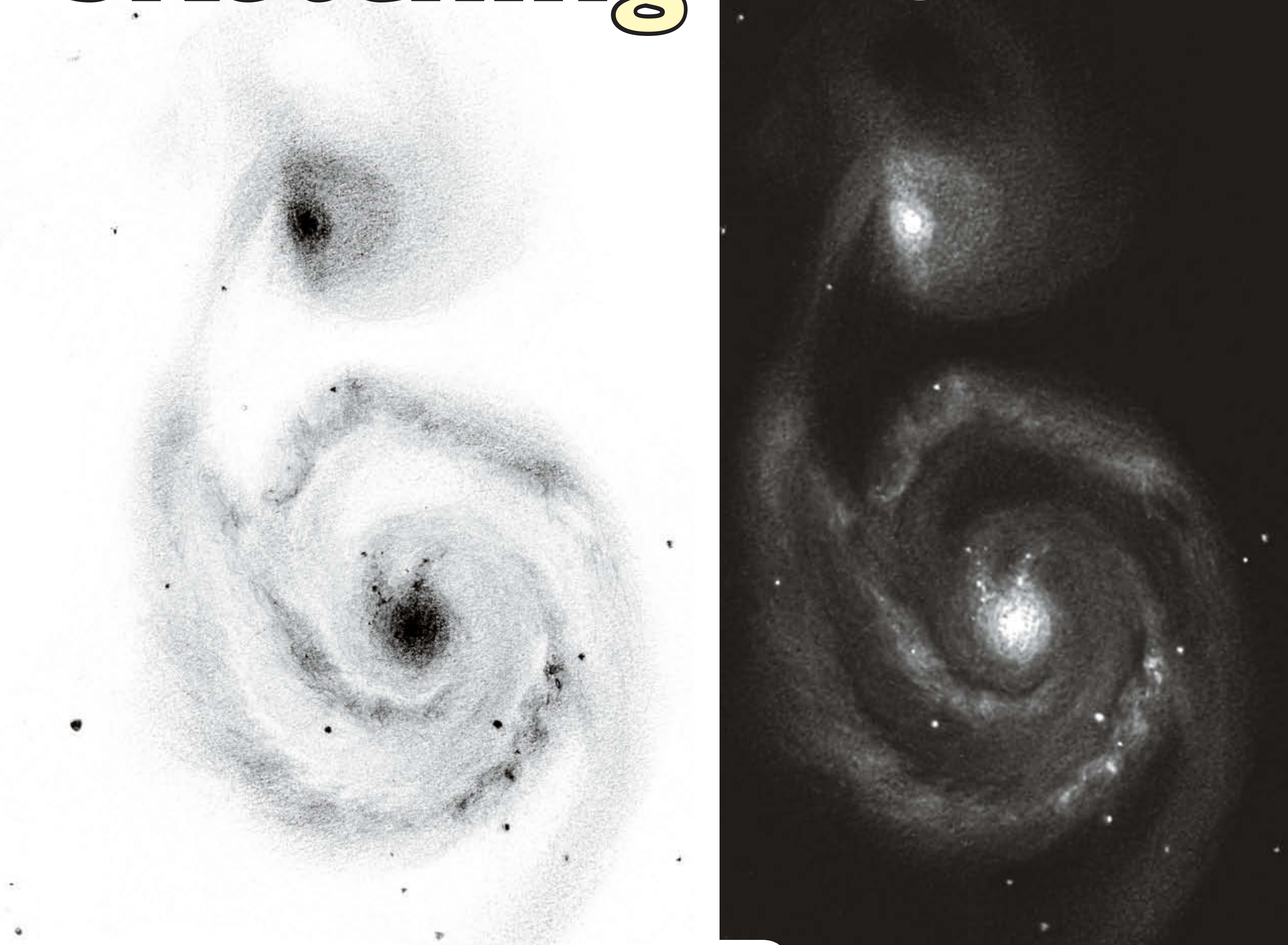
Sketching M51



For seeing all that's detectable in the eyepiece, nothing beats the discipline of sketching.

HOWARD BANICH

My quest to make the best possible drawing of what I could see in M51, the Whirlpool Galaxy in Canes Venatici, began on an exceptionally dark and steady Oregon night in May 2006. I was out with my 28-inch alt-azimuth Newtonian reflector. At high power I was utterly blown away by M51's internal detail, and I made a quick drawing of just the inner spiral arms. Unfortunately, making a complete sketch of the interacting pair of galaxies at such a level of detail required more patience than I had at the time.

During the next three years, however, the project remained nagging in my mind. Scientific sketching has become almost a lost art; the camera began taking its place in all the sciences more than a century ago. Compared to sketching, photography was far more precise, objective, detailed, fast, and easy. But scientists lost something when they put down their pencils. Never do you *see* with such penetration and insight as when you are rendering a subject accurately by hand. The great naturalists, anatomists, mechanics, architects, and others of the 18th and 19th centuries were all shaped by this essential skill.

Astronomy and sketching have a particular affinity. For planetary observing, cameras did not surpass the eyeball until quite recently. And even now, visual observing outdoors in the dark is all about pushing the eye and brain to work at limits where they don't often go.

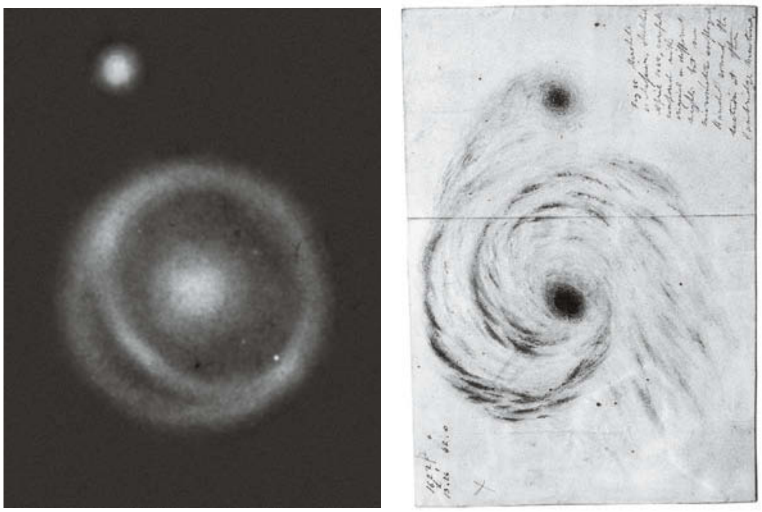
In July 2009 I got my act together and tackled M51 again. The result is the rendering presented at far left. I built it up over seven hours of observation, spread over my six nights of best seeing in 2009 and 2010, in an attempt to record everything in the galaxy and its companion that I could make out with my 28-inch scope.

The Sketch

I used magnifications from 250× to 800× during sketching, with 400× generally giving the best view. I needed excellent skies to fully exploit these high powers, which is why only six nights over the course of 12 months are rolled into the sketch. After each observation I took sky-darkness readings with a Sky Quality Meter; these ranged from 21.25 to 21.73 magnitudes per square arcsecond. (A sky with zero artificial light is often assumed to be magnitude 22.0 per square arcsecond.) The two observing sites I used during the sketch are at 4,400 and 7,600 feet altitude.

Because I built up the sketch gradually using direct and averted vision at various magnifications, it doesn't represent what I saw at any one time. To see all the detail presented here in one glance would take an all-time great night or a much larger scope.

AT THE LIMIT OF VISION **On the far left is the author's original pencil sketch. The inverted version at near left was slightly modified in *Photoshop Elements* to make the contrast more realistic. North is up, east is left.**



PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY OF LONDON, 1833

ARMAGH OBSERVATORY

EARLY SKETCHES **The brain, unlike the camera, is wired to see patterns in fragmentary data — often to the point of seeing patterns that don't exist (in data of all kinds!). *Left:* John Herschel drew M51 as a split ring in 1833, observing with his 18-inch speculum-metal reflector. Accordingly, Lord Rosse at first also saw a split ring in his 72-inch. Can you? *Right:* Rosse later got the basic spiral pattern correct, but in this 1845 sketch, he fudged details.**

The sketch is not unbiased. After I drew M51's general shape and familiar details, I looked at high-quality photos for subtle features to hunt. I considered these details confirmed if I had three definite averted-vision sightings of them within a few minutes. Because vision at the ragged edge of detection is tricky business, I then attempted to "see" the same detail elsewhere in the view. Such false-positive sightings were rare, increasing my confidence in what I recorded.

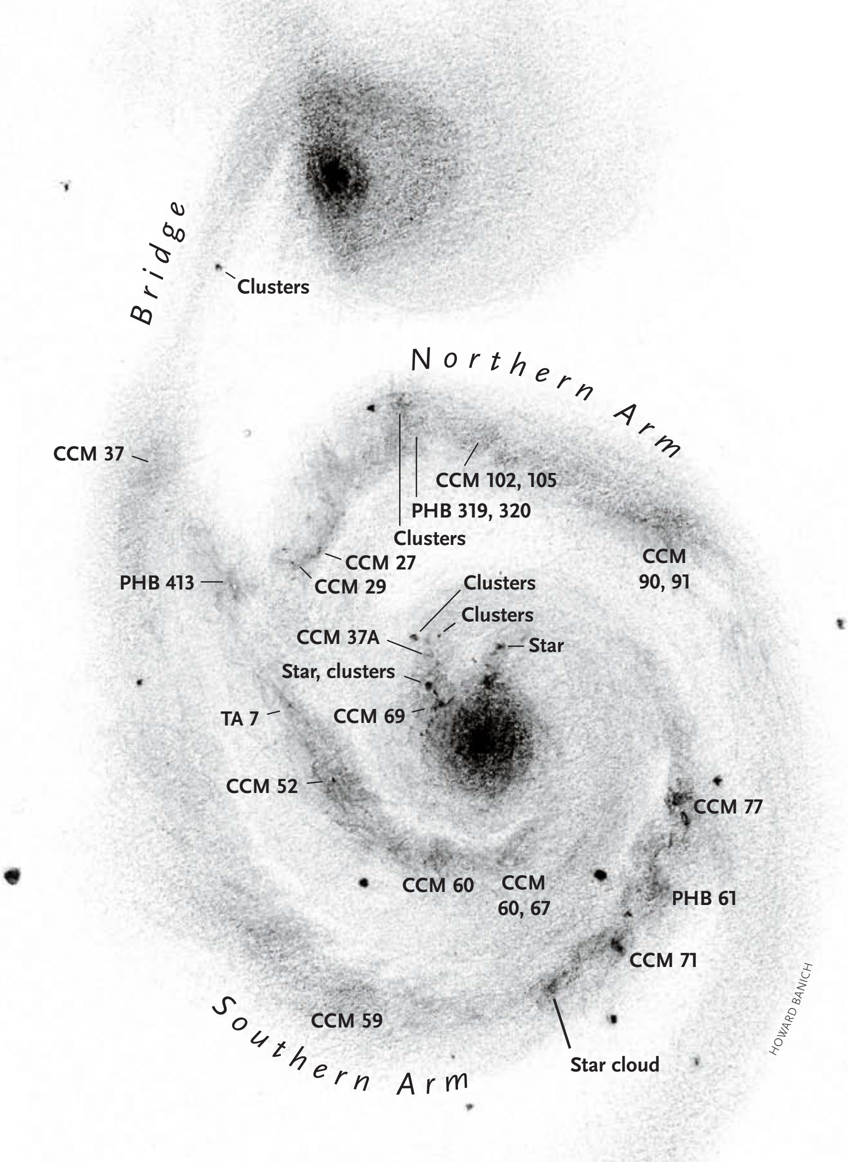
Layers of Detail

Looking at historical observations, and using my own experience of sketching M51 and its companion galaxy, I've come to think of this iconic scene as having three layers of successively deep visual detail.

The first layer consists of simply being able to see the galaxies' cores. Charles Messier saw only one when he discovered M51 in 1773. His collaborator Pierre Méchain discovered the second nucleus in 1781 — the heart of the companion galaxy we now call NGC 5195.

The second layer is M51's large, dim disk of spiral arms. William and John Herschel, with their big reflectors in the late 18th and early 19th century, didn't see the spiral arms as such. To them the disk was a bifurcated ring surrounding the core, as in John Herschel's 1833 drawing above, which he made while using an 18-inch speculum-metal reflector. It required Lord Rosse's 72-inch speculum-mirror telescope in 1845 for anyone to finally recognize the spiral arms, the first recorded in any galaxy.

Lord Rosse was also the first to see detail within the arms and the famous bridge of material between the two



DEEPER-SKY OBJECTS Labeled here are some of the features the author visually identified in M51. Most are combinations of emission nebulae (HII regions), bright young star clusters, and larger stellar associations.

galaxies. These details represent the third and most difficult layer, which extends even deeper to the tidal spray of material around NGC 5195.

Here's an examination in detail.

Layer 1: The Galactic Cores

At first glance both cores look rather similar. As an entire galaxy, M51 is brighter than NGC 5195, but M51's magnitude 9.0 includes the spiral arms. The core of NGC 5195 is slightly more condensed (concentrated toward its center), so even though this galaxy's total magnitude is listed as 10.5, it stands out nearly as well.

The core of M51 is mostly round, but that of 5195 is slightly elongated, as if has a stubby central bar. Even a 6-inch scope under modest suburban light pollution will show that the companion has a sharper, more pointlike nucleus and a sharp cutoff line into darkness running north-south just east of center.

Layer 2: Shape of the Spiral Arms

As you study the pair through an 8-inch scope in a reasonably dark sky, you'll start seeing traces of M51's larger disk. Photographic images of the graceful spiral arms draw us to the eyepiece, so be careful about preconceptions affecting what you see.

For example, what might we see if we didn't know about "spiral nebulae" at all? John Herschel didn't, and even though his sketch of M51 showing a bifurcated ring looks odd today, go out some clear night, forget about spiral arms, and try to see the ring.

It's not hard. Lord Rosse saw Herschel's ring until his second round of observing with his new 72-inch in April 1845, and he had previously been observing M51 for years with his 36-inch scope. But then, the ring was what he *expected* to see.

With your own preconceptions in check, you may notice that the two main arms aren't perfectly symmetrical and that they seem not to reach quite to the core. Also note that the Northern Arm has a sharp kink where it's closest to 5195. Where the Northern Arm continues west past the kink, it's remarkably straight before it starts to bend toward the south. The Southern Arm has a similar but weaker kink farther along.

Now look at the largest blank areas between the arms, inside the two kinks, and you'll notice that both are slightly on the eastern side.

Interestingly, just as the kinks in the two arms are roughly opposite each other, so are the greatest concentrations of emission nebulae ("HII regions" of ionized hydrogen) and star clusters. The two brightest inter-arm wisps also mirror each other.

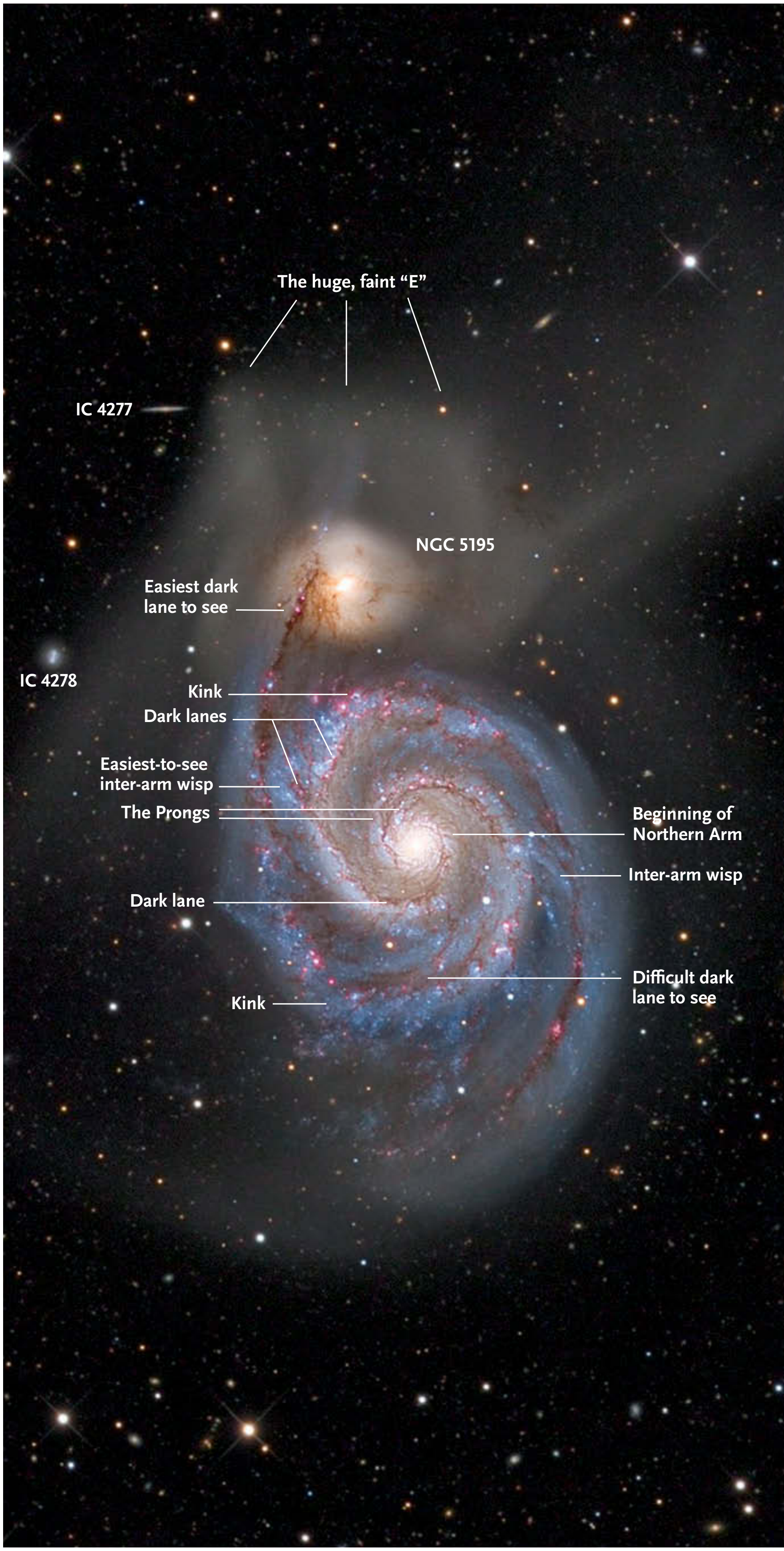
Layer 3: Spiral Arm Details

Detail within the spiral arms consists of HII regions, star clouds, star clusters, and dark lanes of dust and gas. All these are challenging to detect; to see them you'll need a dark sky, a large scope, and good averted-vision skill. If you notice any lumpiness in M51's spiral arms, your scope is big enough to dig to this layer more seriously.

Let's start at the north edge of M51's core, at an area I call the Prongs. This is where the Southern Arm begins. The Prongs are two extensions from the core pointing north and curling slightly west like a two-finger peace sign. They're the easiest detail of this layer to see. The space between them is part of the dark lane that hugs the inner edge of the Southern Arm.

The Prongs are home to several small, starlike condensations. In steady seeing I can see them at 400× or more

WHY PHOTOGRAPHY WON Using a 20-inch Ritchey-Chrétien telescope (smaller than the author's 28-inch Newtonian), Russell Croman made this image from three hours of filtered exposures with an SBIG STL-11000XM CCD camera from Mayhill, New Mexico. The labels are the author's comments on visual features.



RUSSELL CROMAN

as tiny stellar pinpoints that flicker in and out of visibility. These are huge, star-rich HII regions and a few faint Milky Way foreground stars.

More difficult to see, but related to the Prongs, is the beginning of the Northern Arm. It closely hugs the west side of the core.

The southwest side of the Southern Arm has the most easily seen HII regions and star clusters. Along with the starlike points in the Prongs, these were among the first spiral-arm details I saw in 2006.

More HII regions and clusters are near the kink of the Northern Arm, but they're slightly more difficult. Dark lanes are a distinctive feature of M51 photographically, but visually they were the most difficult details to spot with certainty. As in other galaxies, they generally line the arms' inner edges. The easiest dark obscuration to see is the one that causes the sharp north-south cutoff just east of the nucleus of 5195.

The connecting bridge between the two galaxies is also one of the more difficult features. The brain easily assumes that the Southern Arm extends to 5195, but truly *seeing* a continuous band of material is tricky even with a big scope. Are you really sure you've seen the bridge?

Even fainter than the bridge is the big, wide spray of gravitationally perturbed stars west and north of 5195. The whole thing resembles a big, vague capital E with its prongs pointing north — not much smaller than the disk of M51 — but this requires an extremely transparent sky.

Equally difficult is the outer end of the Northern Arm as it fades away far southward. How far can you follow it?

Extra Credit

Finally, two tiny, faint IC galaxies lie in the distant background not far from NGC 5195. Although they're unrelated and exceedingly difficult, they're part of the scene and make inviting targets. I saw IC 4278 with difficulty as a small, roundish puffball. IC 4277 was even more challenging. It shows up in photos as a small edge-on galaxy, but visually detecting the faint smudge of its core requires patient use of averted vision and exact knowledge of its location. Top-notch sky conditions are needed to detect either galaxy, and if you're successful they add a hard-won depth to M51's glorious field of view. ✦

***Howard Banich** has geeked out on spiral galaxies since 1966 and made his first sketch of M51 in 1974. He's waiting optimistically for a perfect night to continue sketching, and in the meantime invites email at howard.banich@nike.com.*

Double Stars of Summer

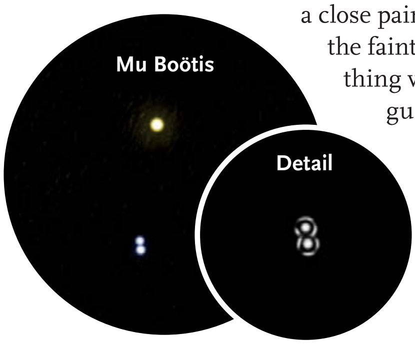
The summer sky has an abundance of double and multiple stars.

JAMES MULLANEY

DOUBLE STARS are the underappreciated gems of the night sky. They appear simple yet display an endless variety of tints, magnitudes, separations, and configurations. And unlike other deep-sky wonders, they're easy to locate and view even when the sky is hazy, moonlit, or light-polluted.

From the thousands of summer doubles that are visible to even the smallest telescope, let's pick out a few distinctive systems — some well-known, others less so.

Mu (μ) Boötis: Among the amazing hoard of double stars to be found in Boötes is this neat triple system. At low power it appears to be a bright star with a distant, fainter companion. In good seeing, a magnification of 100× or higher shows that the fainter star is itself a close pair. The primary is tinted yellow, and the fainter stars are orange. There's something very alluring about this trio that's guaranteed to keep you coming back to it again and again!



All three stars are part of one vast system. The close pair has a well-determined orbital period of roughly 250 years, and the primary lies at the same distance (120 light-years) and is drifting through space in the same direction.

Zeta (ζ) Coronae Borealis: Here's a pretty bluish white and greenish white pair which, for reasons I've never understood, is seldom observed. Its spacing is just right to be pleasing in small telescopes, yet it's close enough to be attractive in 12-inch (300-mm) apertures, which typically spread wide, bright doubles unduly far apart, and saturate their delicate hues with too much light. Avid double-star observer Sissy Haas describes this system as "a lovely close pair of vivid stars." The two suns almost certainly form a physical pair, as they're drifting though space together.

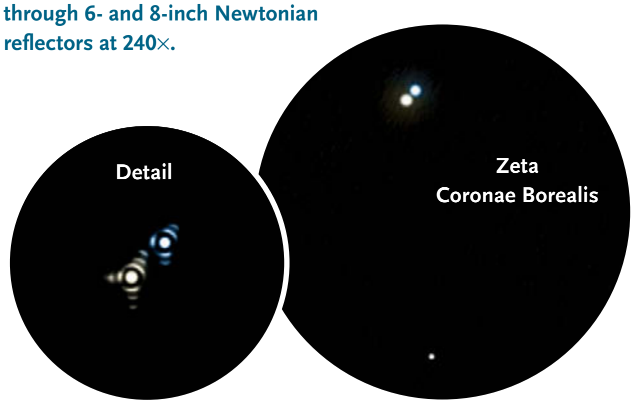
Kappa (κ) Herculis: This is another neglected duo, but in this case it's easy to see why. It must compete with the intensely hued showpiece double Rasalgethi (Alpha Herculis) and the magnificent Hercules Cluster (Messier 13). But this striking, roomy, yellow-and-garnet combo is well worth seeking out no matter what size scope you use. It looks its very best to me as viewed in a 6-inch reflector at 50×. If you haven't yet seen it, you'll be delighted!

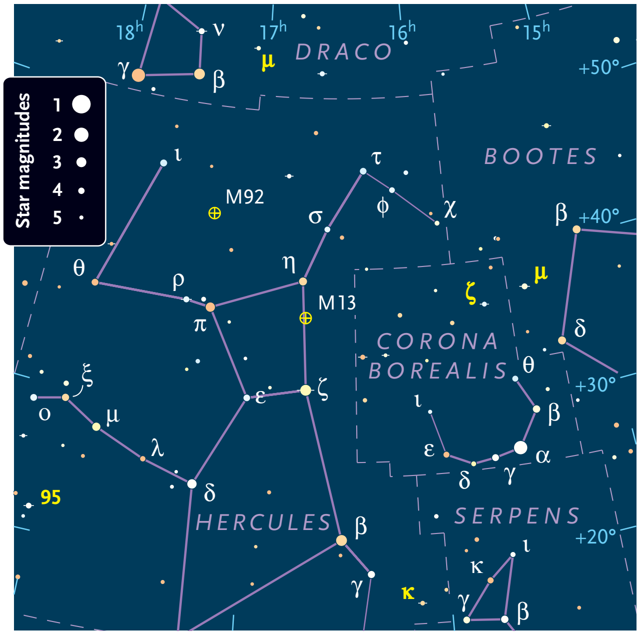
Unlike the systems we've seen so far, this is an *optical double* — an unrelated pair of stars that only appear to be close to each other — rather than a gravitationally bound *binary star*. The brighter star is roughly 390 light-years away, compared to 470 light-years for the fainter star.

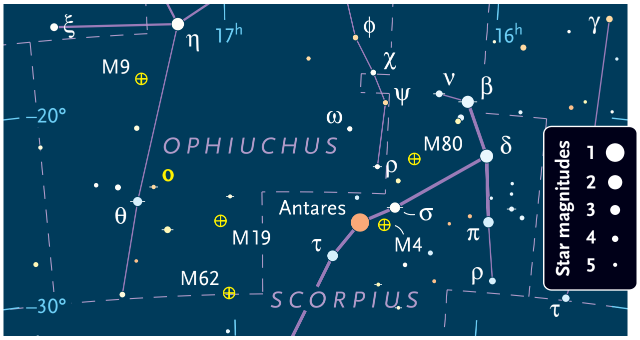
Mu (μ) Draconis: Here we find a cozy identical-twin binary that's neatly resolved in a 5-inch scope at 100×, while lower magnifications show the components apparently touching each other! This slowly orbiting pair has been described as a miniature of famed Castor in Gemini — but it's fainter by many magnitudes, and both stars are yellowish rather than bluish-white like Castor's.

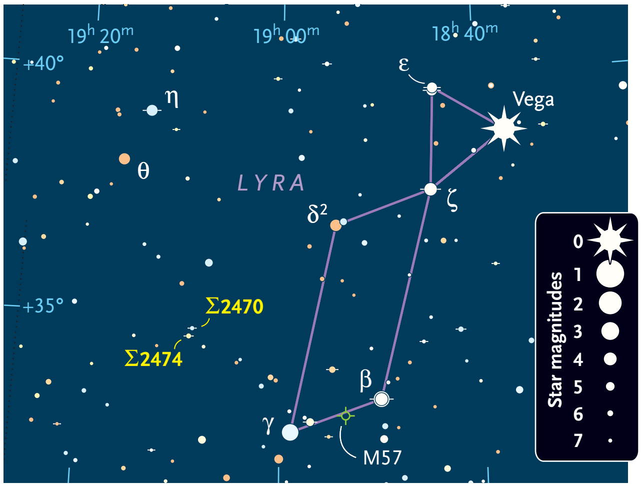
Omicron (ο) Ophiuchi: This neglected binary star is lost among Ophiuchus's swarm of globular clusters

All sketches here were prepared by Arizona stargazer and graphic artist Jeremy Perez. They represent the views through 6- and 8-inch Newtonian reflectors at 240×.









and other deep-sky wonders. Its striking pale-orange and clear-blue components are nicely spaced and a sweet sight in scopes as small as a 60-mm refractor at 30×. If this binary were situated in a less prolific constellation, it would definitely be considered a showpiece pair.

95 Herculis: This lovely pair is one of my all-time favorites due to its subtle but amazing hues. They were described as "apple-green and cherry-red" by the great early-19th-century stargazer William H. Smyth — and so they appear to me. The reaction I've had showing this object to other observers (both beginning and experienced) once they've taken time to really examine it is: "Wow. The colors are real!" Yet, not everyone sees them this way. One description from the past calls the stars "beryl and sardonyx!" While a nice easy pair in any scope, its exquisite tints are perhaps at their best when seen in

Some Nice Summer Double Stars

Name	Mag.	Sep.	PA	RA	Dec.
μ Boo AB	4.3, 7.1	109″	171°	15^h 24.5^m	+37° 23′
BC	7.1, 7.6	2.3″	6°		
ζ CrB	5.0, 5.9	6.3″	306°	15^h 39.4^m	+36° 38′
κ Her	5.1, 6.2	27″	13°	16^h 08.1^m	+17° 03′
μ Dra	5.7, 5.7	2.4″	8°	17^h 05.3^m	+54° 28′
ο Oph	5.2, 6.6	10″	353°	17^h 18.0^m	–24° 17′
95 Her	4.8, 5.2	6.3″	256°	18^h 01.5^m	+21° 36′
Σ2470	7.0, 8.4	14″	268°	19^h 08.8^m	+34° 46′
Σ2474	6.8, 7.9	16″	263°	19^h 09.1^m	+34° 36′

a 6- or 8-inch scope at 50× to 100× (again, not too widely separated, and not too much nor too little light).

It's important to look directly at double stars to see their tints — using the color-sensitive cone cells at the center of your eye —instead of using the averted vision that's so helpful for glimpsing faint deep-sky wonders.

Σ2470 and Σ2474: Most stargazers are familiar with the famed Double-Double (Epsilon Lyrae), but this little-known wonder, also in Lyra, is the Double-Double's double! Lying southeast of Epsilon (ε), the components of this multiple system are both fainter and wider than its namesake. It consists of two similarly bright double stars set 10′ apart (compared to Epsilon's 3.5′). Both have nearly identical separations and position angles, while Epsilon's pairs are at right angles to each other.

With such a wide separation, these duos are unlikely to form a true quadruple system, as Epsilon does. But as one observer put it, "What a display of symmetry in nature!" A 4-inch scope at 16× shows them nicely, and the view improves with aperture, as long as the magnification isn't cranked up too high. Struve 2470 (Σ2470) looks white and pale blue, while Struve 2474 (Σ2474) is yellowish and ruddy in hue. ✦

James Mullaney is coauthor with Wil Tirion of The Cambridge Double Star Atlas *and* The Cambridge Atlas of Herschel Objects.

A Crack Between the Worlds

The time between day and night is magical.

WE'VE ALL HEARD or read how mysterious twilight is supposed to be. In *The Teachings of Don Juan*, Carlos Castaneda calls it the crack between the worlds. But when was the last time you actually went out and experienced twilight for yourself?

If you live at middle or high northern latitudes and observe between late May and late July, when twilight is longest, you will have plenty of time to explore it. What can you do then? Several things — the best of which is watching the sky beautifully darken and ever so slowly bring forth the stars.

Slow fade to the Scorpius hour. Our all-sky map on page 44 shows the heavens as they look around 11 p.m. (daylight-saving time) in early July and dusk in late July — a time we can call the Scorpius Hour. This year that sky is dominated by two bright triangles. The first is the famous one called the Summer Triangle — though it doesn't reach its highest in late twilight until September. It's formed by zero-magnitude Vega, which is high in the east at the Scorpius Hour, together with 1st-magnitude Altair and Deneb below it.

LAURENT LAVEDER

At dusk in July 2011, 1st-magnitude Saturn low in the west-southwest forms a second triangle together with marginally fainter Spica about a dozen degrees to its left and zero-magnitude Arcturus high above them.

Only one other point of light shines at 1st magnitude or brighter besides the five stars and one planet that form these two triangles. That's Antares, the brightest star in Scorpius. It resembles the planet Mars (Ares) in its orange hue — hence its name, meaning Rival of Ares.

The pattern of Scorpius is a double curl that looks much indeed like the outline of a scorpion. It is also like a toppled-forward letter S — S for Scorpius — set like a blazing monogram on the tablecloth of fading twilight that covers the round table of the sky. Too bad that bright Scorpius is quite low in the south for most of the industrialized world, even at this its prime hour.

I remember seeing Antares on the rim of a little dell one night in North Dakota. The star's ruddiness was enhanced by green Northern Lights resting peacefully nearby, filling the whole sky after a rousing display.

What else to do with twilight. After Antares appears, your sky should grow dark enough for you to see the Big Dipper in the northwest, Cassiopeia in the northeast — and maybe Leo setting north of west while the Great Square of Pegasus rises north of east. But there are other things to do around that time.

Look for special twilight glows and shadows in the sky: Earth's shadow, crepuscular rays, the "purple light," and noctilucent clouds (see **www.atoptics.co.uk**).

With a Sky Quality Meter or by checking limiting magnitude, compare different stages of twilight to different degrees of light pollution. How far from the center of a big city must you go at night to have your sky reach a darkness equivalent to that at the end of nautical twilight, when the Sun is 12° below the horizon?

Here's one final activity to try during twilight: observe bright double stars in your telescope. How do the hues of colorful doubles appear when the sky is still a little light? Is it easier to detect the challenging, reputedly green companion of Antares outside the big star's glare if you observe in twilight? ✦

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

Sky at a Glance

MOON PHASES

SUN	MON	TUE	WED	THU	FRI	SAT
					1	2
3	4	5	6	7	8	9
10	11	12	13	14	15	16
17	18	19	20	21	22	23
24 / 31	25	26	27	28	29	30

PLANET VISIBILITY

	◀ SUNSET	MIDNIGHT	SUNRISE ▶
Mercury	W	Visible June 22 through July 24	
Venus		Very low by late July	NE
Mars			NE E
Jupiter		E	SE
Saturn	SW W		

PLANET VISIBILITY SHOWN FOR LATITUDE 40° NORTH AT MID-MONTH.

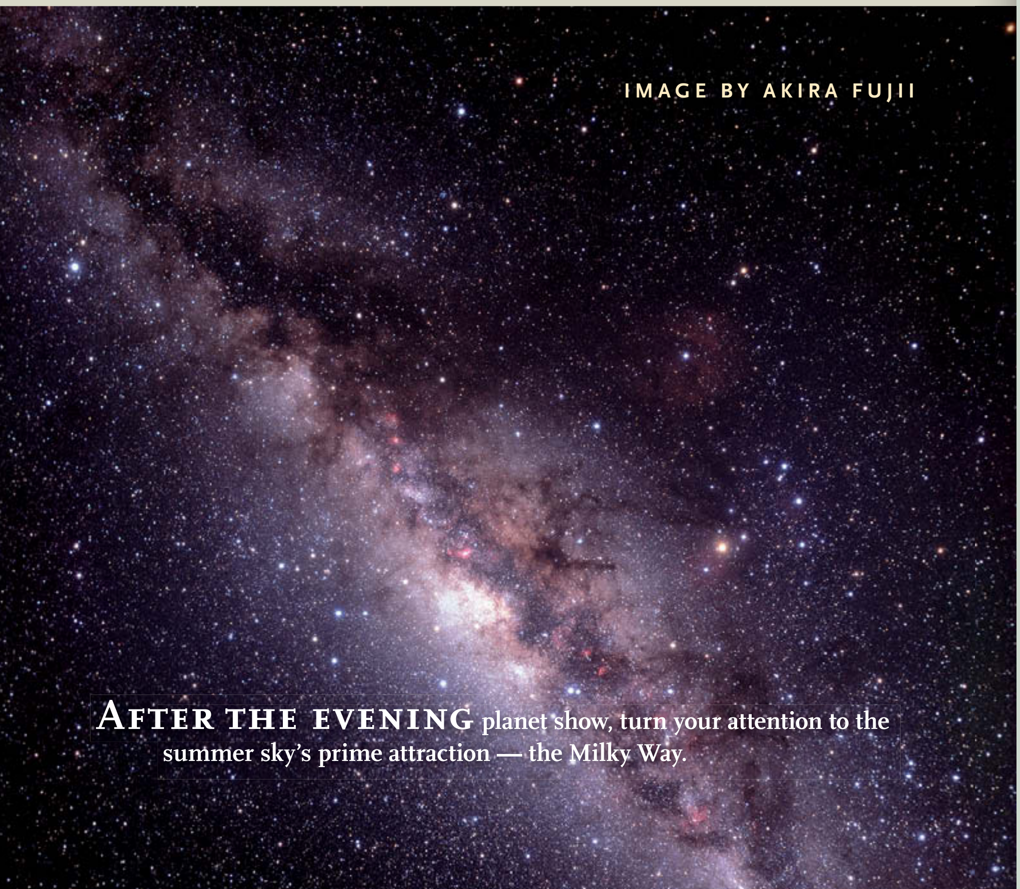


IMAGE BY AKIRA FUJII

AFTER THE EVENING planet show, turn your attention to the summer sky's prime attraction — the Milky Way.

July 2011

1 NEW MOON (4:54 a.m. EDT). A slight partial solar eclipse is theoretically visible just above the horizon from a small, remote section of ocean off the Antarctic coast. But it's unlikely that there will be a break in this area's perennially stormy weather.

1–19 DUSK: Mercury is fairly well placed for observers at mid-northern latitudes — about 8° above the west-northwestern horizon a half hour after sunset.

2 DUSK: North Americans may be able to spot a very thin crescent Moon to Mercury's lower left a half hour after sunset. Bring binoculars.

3–4 DUSK: The crescent Moon is left or upper left of Mercury and below Regulus, as shown on page 48.

4 EARTH is at aphelion, farthest from the Sun for 2011, at a distance of 94,512,000 miles (152,102,000 km). That's just 3.3% greater than its minimum distance.

6–8 EVENING: The Moon passes below Saturn and Spica.

8 FIRST-QUARTER MOON (2:29 a.m. EDT).

11 EVENING: Antares is 2° or 3° below the Moon.

12 HAPPY BIRTHDAY NEPTUNE! (See page 28.)

15 FULL MOON (2:40 a.m. EDT).

23 LAST-QUARTER MOON (1:02 a.m. EDT).

23, 24 DAWN: The waning Moon shines near Jupiter.

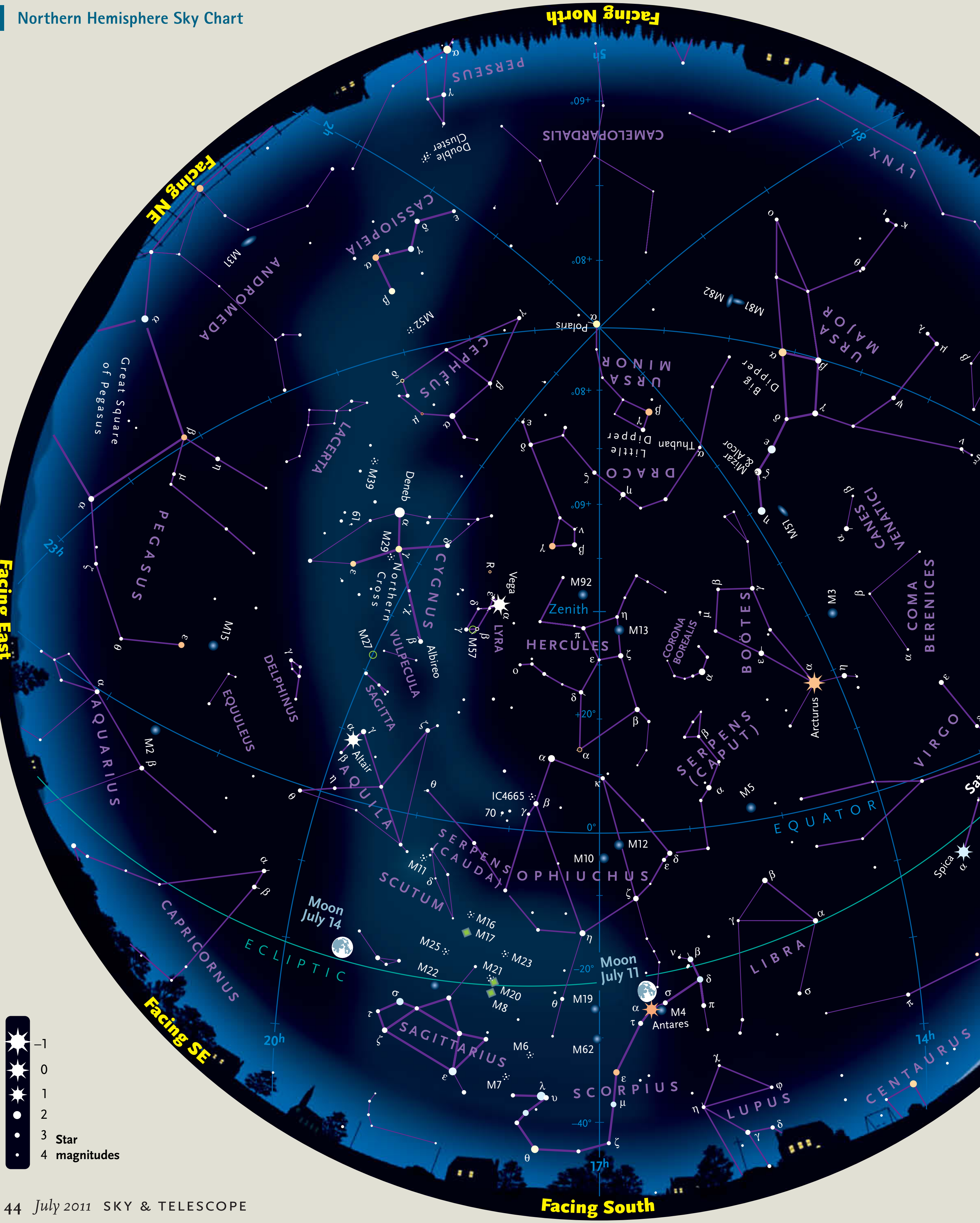
25, 26 PREDAWN: The Moon is near the Pleiades and Hyades, as shown on page 49.

27 DAWN: Faint Mars is 2° or 3° lower left of the Moon for North America. The Moon occults (passes in front of) Mars for parts of South America and the Pacific Ocean, mostly during daylight hours.

28–30 NIGHT: The weak Southern Delta Aquarid meteor shower peaks around these nights.

30 NEW MOON (2:40 p.m. EDT).

See SkyandTelescope.com/ataglance for details on each week's celestial events.


Facing North
Facing NE
Facing East
Facing SE
Facing South
PERSEUS
Double Cluster
CAMELOPARDALIS
LYNX
CASSIOPEIA
M31
ANDROMEDA
M52
Polaris
M81
M82
URSA MAJOR
Big Dipper
CEPHEUS
URSA MINOR
Little Dipper
Thuban
Mizar & Alcor
DRACO
Great Square of Pegasus
LACERTA
M39
Deneb
61
CANES VENATICI
M51
PEGASUS
M29
Northern Cross
CYGNUS
Vega
LYRA
M57
M92
Zenith
HERCULES
M13
CORONA BOREALIS
BOÖTES
M3
COMA BERENICES
M15
M27
VULPECULA
Albireo
DELPHINUS
EQUULEUS
SAGITTA
Arcturus
VIRGO
AQUARIUS
M2
Altair
AQUILA
SERPENS (CAPUT)
M5
IC4665
70
EQUATOR
SERPENS (CAUDA)
M12
M10
OPHIUCHUS
Spica
M11
SCUTUM
CAPRICORNUS
Moon July 14
M16
M17
ECLIPTIC
M25
M23
M22
M21
Moon July 11
LIBRA
M20
M8
M19
M4
Antares
SAGITTARIUS
M6
M62
M7
SCORPIUS
LUPUS
CENTAURUS
2h
8h
23h
20h
14h
17h
+60°
+80°
+40°
+20°
0°
–20°
–40°
–1
0
1
2
3
4
Star magnitudes

Using the Map

WHEN

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

*Daylight-saving time.

HOW

Go outside within an hour or so of a time listed above. Hold the map out in front of you and turn it around so the yellow label for the direction you're facing (such as west or southeast) is at the bottom, right-side up. The curved edge is the horizon, and the stars above it on the map now match the stars in front of you in the sky. The map's center is the zenith, the point overhead. Ignore all parts of the map over horizons you're not facing.

Example: Rotate the map so that "Facing West" is at the bottom. About two-thirds of the way from there to the map's center is the orange-tinted star Arcturus. Go out, face west, and look two-thirds of the way up the sky. There's Arcturus!

Note: The map is plotted for 40° north (the latitude of Denver, New York, and Madrid). If you're far south of there, stars in the southern part of the sky will be higher and stars in the north lower. Far north of 40° the reverse is true. Saturn is positioned for mid-July.

Watch a SPECIAL VIDEO

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

Binocular Highlight: Ophiuchus Globulars

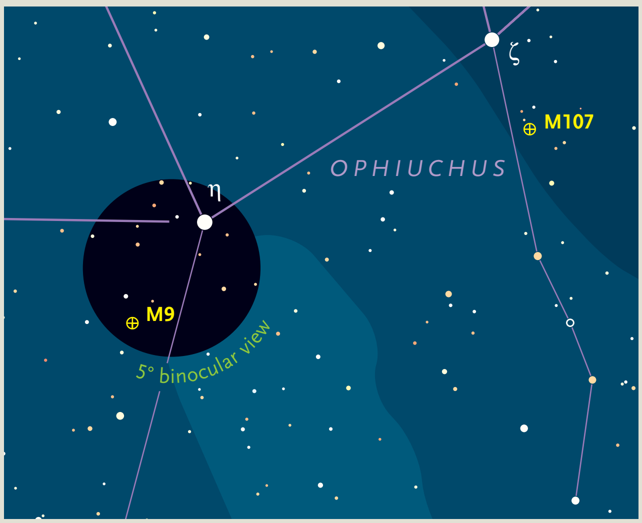
Ophiuchus is a big constellation mostly made up of 3rd- and 4th-magnitude stars. However, due to its size and proximity to the heart of the summer Milky Way, it's home to no fewer than seven Messier objects — all globular star clusters. Only Sagittarius, the constellation that contains the galactic center, has as many Messier globulars. While most Ophiuchus globulars have been highlighted here previously, two have not: M9 and M107.

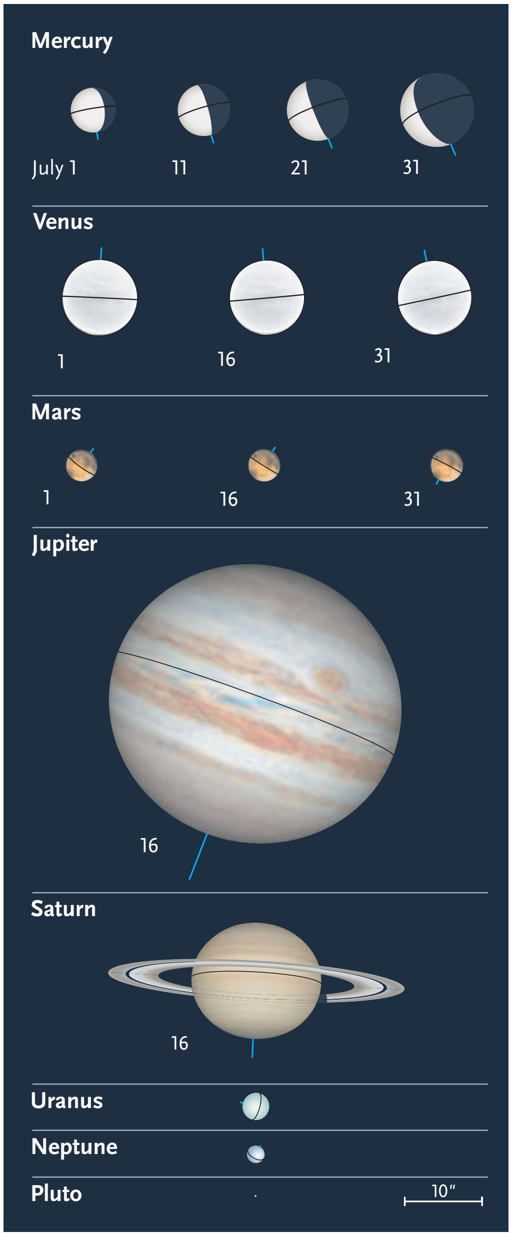
Both clusters can be tricky to see; fortunately, each shares a binocular field of view with a reasonably bright star. Let's begin with **M9**. Start your search at 2.5-magnitude Eta (η) Ophiuchi. If you place the star at the 1 o'clock position, M9 will appear at 7 o'clock. You'll have to look carefully though — the cluster may not jump out at you immediately. In my 15×45 image-stabilized binoculars, M9 appears obviously nonstellar, though less so in my 10×50s. If you're using 7× binos, identifying M9 will be more challenging. I find that using averted vision (looking slightly to one side of the object) helps bring out some of the fuzziness that distinguishes the globular from field stars.

Although it too glows at magnitude 7.8, **M107** is slightly more difficult to see than M9. Fortunately, M107's position is relatively easy to pinpoint. You'll find it a half binocular field south-southwest of 2.5-magnitude Zeta (ζ) Ophiuchi, and directly below a small right triangle of 7th-magnitude stars. In my 10×50s and 15×70s, M107 shows as a tiny, round glow. But unlike most other globulars, this one lacks a strongly condensed nucleus, making it a difficult find in light-polluted skies.

Although I wouldn't call either cluster easy, I am able to glimpse them in my 10×30s. ✦

— *Gary Seronik*



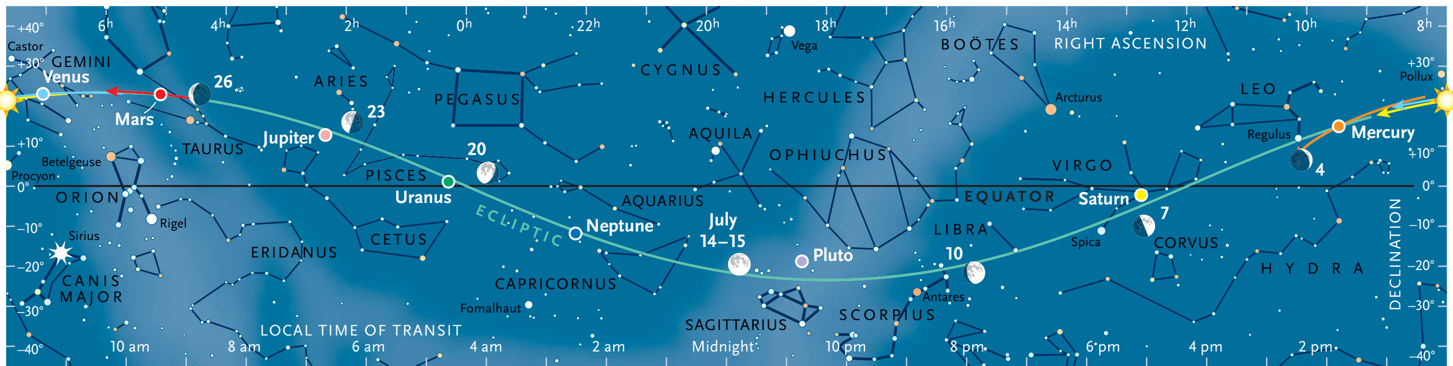


Sun and Planets, July 2011

	July	Right Ascension	Declination	Elongation	Magnitude	Diameter	Illumination	Distance
Sun	1	6^h 37.8^m	+23° 09′	—	–26.8	31′ 28″	—	1.017
	31	8^h 38.9^m	+18° 26′	—	–26.8	31′ 30″	—	1.015
Mercury	1	8^h 00.8^m	+22° 23′	19° Ev	–0.5	5.8″	75%	1.153
	11	9^h 03.4^m	+17° 38′	25° Ev	0.0	6.7″	59%	0.996
	21	9^h 46.1^m	+12° 26′	27° Ev	+0.4	8.0″	43%	0.842
	31	10^h 06.3^m	+8° 22′	23° Ev	+1.1	9.5″	26%	0.705
Venus	1	5^h 42.4^m	+23° 09′	13° Mo	–3.9	9.9″	98%	1.677
	11	6^h 35.7^m	+23° 22′	10° Mo	–3.9	9.8″	98%	1.699
	21	7^h 28.9^m	+22° 26′	7° Mo	–3.9	9.7″	99%	1.715
	31	8^h 21.1^m	+20° 25′	5° Mo	–3.9	9.7″	100%	1.726
Mars	1	4^h 20.2^m	+21° 22′	32° Mo	+1.4	4.2″	97%	2.224
	16	5^h 04.9^m	+22° 56′	36° Mo	+1.4	4.3″	96%	2.183
	31	5^h 49.3^m	+23° 42′	40° Mo	+1.4	4.4″	95%	2.133
Jupiter	1	2^h 11.6^m	+12° 00′	64° Mo	–2.2	37.1″	99%	5.313
	31	2^h 27.0^m	+13° 12′	89° Mo	–2.4	40.5″	99%	4.873
Saturn	1	12^h 42.7^m	–1° 53′	92° Ev	+0.9	17.4″	100%	9.552
	31	12^h 48.3^m	–2° 36′	65° Ev	+0.9	16.6″	100%	10.036
Uranus	16	0^h 17.3^m	+1° 03′	109° Mo	+5.8	3.6″	100%	19.736
Neptune	16	22^h 10.3^m	–11° 52′	143° Mo	+7.8	2.3″	100%	29.193
Pluto	16	18^h 23.6^m	–18° 52′	162° Ev	+14.0	0.1″	100%	31.093

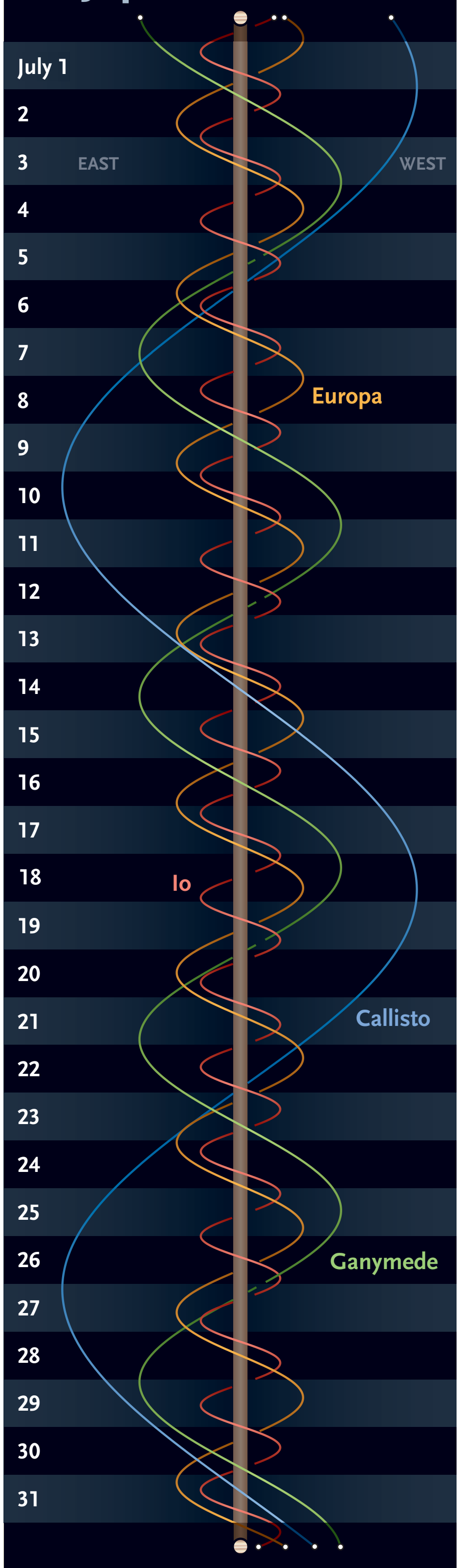
The table above gives each object's right ascension and declination (equinox 2000.0) at 0^h Universal Time on selected dates, and its elongation from the Sun in the morning (Mo) or evening (Ev) sky. Next are the visual magnitude and equatorial diameter. (Saturn's ring extent is 2.27 times its equatorial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

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



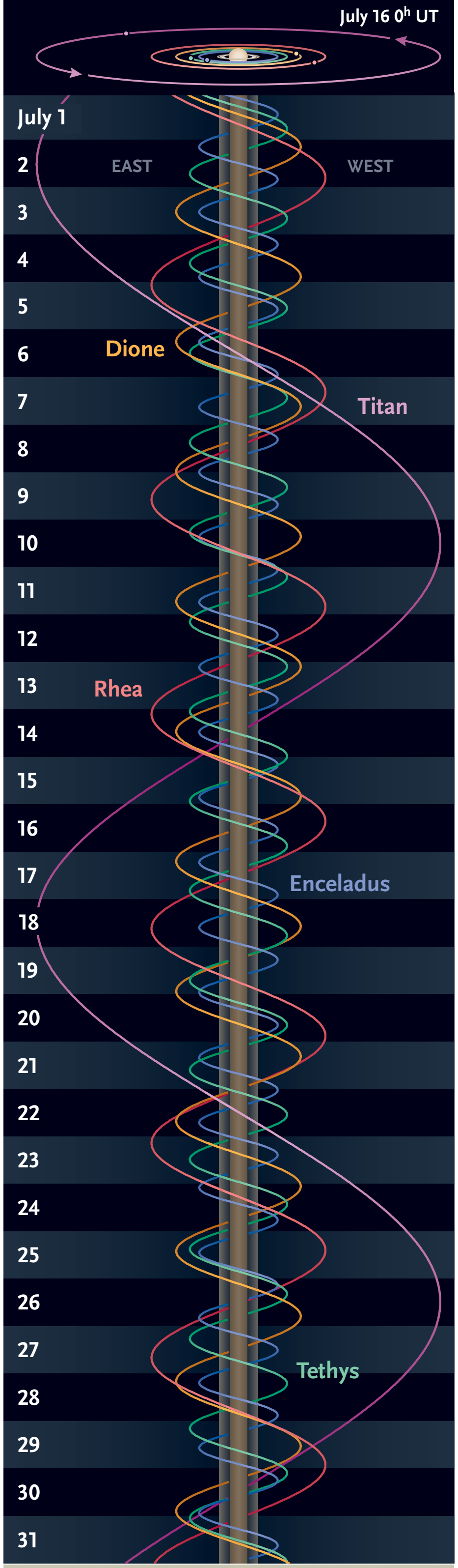
The Sun and planets are positioned for mid-July; the colored arrows show the motion of each during the month. The Moon is plotted for evening dates in the Americas when it's waxing (right side illuminated) or full, and for morning dates when it's waning (left side). "Local time of transit" tells when (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.

Jupiter's Moons



The wavy lines represent Jupiter's four big satellites. The central vertical band is Jupiter itself. Each gray or black horizontal band is one day, from 0^h (upper edge of band) to 24^h UT (GMT). UT dates are at left. Slide a paper's edge down to your date and time, and read across to see the satellites' positions east or west of Jupiter.

Saturn's Moons



The wavy lines represent five of Saturn's satellites; the vertical bands are Saturn's globe and rings. Each gray or black horizontal band is one day, from 0^h (upper edge of band) to 24^h UT (GMT). The ellipses at top show the actual apparent orbits; the satellites are usually somewhat north or south of the ring extensions.

Fred Schaaf

Two at Dusk and Three at Dawn

July's planets are at their best in twilight.

Two bright planets shine at dusk this July. For the first three weeks of the month, Mercury is fairly easy to spot low in the west-northwest shortly after sunset. And Saturn shines far to Mercury's upper left, remaining above the horizon all evening.

Jupiter rises around the middle of the night but shows best in a telescope at the beginning of dawn, burning partway up the southeastern sky. Look for lesser Aldebaran and even-dimmer Mars well to Jupiter's lower left. And not long before sunrise, Venus rises in a bright sky very low in the east-northeast.

DUSK AND EVENING

Mercury puts in a moderately good apparition for viewers at mid-northern latitudes in July. Until the 20th, you can spot it roughly 5° above the west-northwest horizon around 45 minutes after sunset.

Mercury shines at magnitude –0.5 as the month begins. It passes through M44, the Beehive Star Cluster, on the evening of July 6th, but in the bright sky down low even a telescope won't show the cluster properly.

By greatest elongation on the 20th, Mercury's 7.8″ globe is 44% illuminated and has dimmed to magnitude +0.3. After that the planet rapidly fades and drops from view. On the 26th, however, binoculars may show 1.4-magnitude Regulus about 3° northeast of 0.8-magnitude Mercury. Look early.

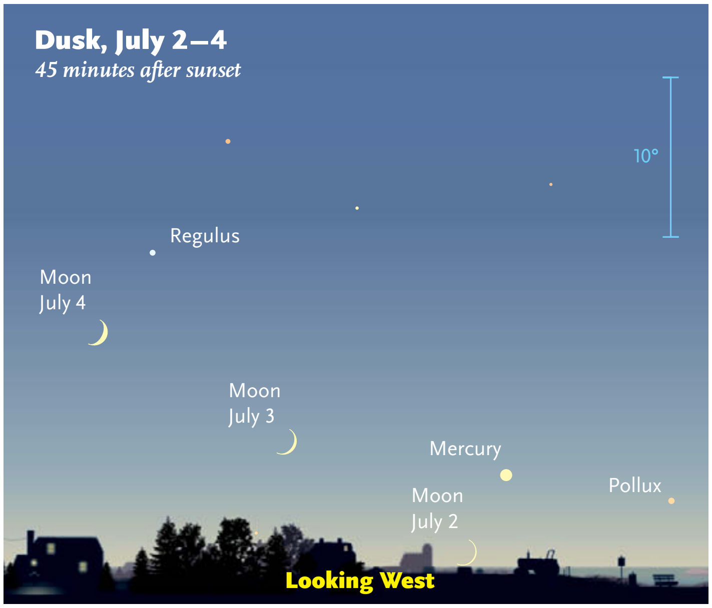
Saturn, in Virgo, glows at magnitude +0.9 about a third of the way up the west-southwest sky as the stars come out in twilight. Don't confuse it with marginally fainter (and much more twinkly) Spica more than a dozen degrees to Saturn's left. Saturn starts the month with the 3rd-magnitude double star Gamma (γ) Virginis (Porrima) only about ½° to its upper right, but the ringed world is now starting to move slowly away from the double. Gamma Vir consists of two nearly identical stars currently 1.7 arcseconds apart.

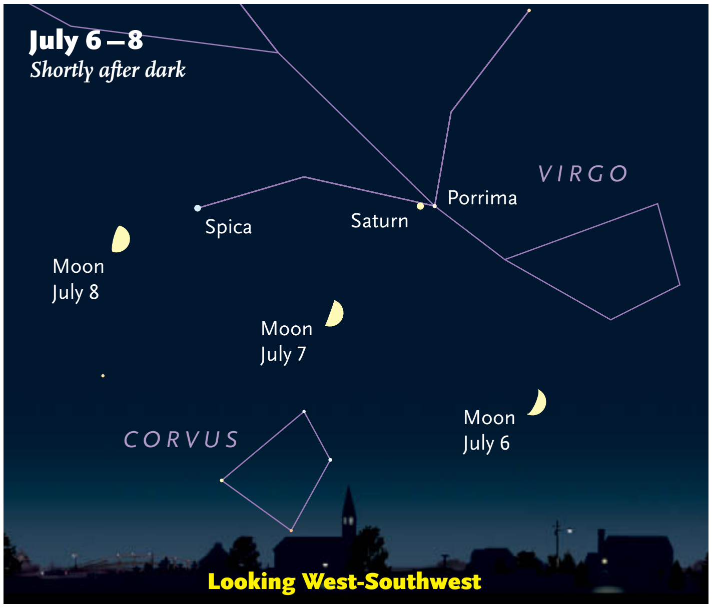
Telescopic observers should study Saturn as early as possible each evening, while it's still high. Saturn's rings are now opening back up a trace, from a 7° to 8° tilt. The planet is at *quadrature* (90° east of the Sun) on July 3rd, so all month the shadow of the globe on the rings is most prominent, enhancing the system's 3-dimensional appearance.

LATE NIGHT

Uranus and **Neptune** rise before the middle of the night, but they're best observed in the predawn hours. For charts, see **SkyandTelescope.com/uranusneptune**. On July 12th Neptune completes its first orbit around the Sun since its discovery in 1846, as discussed on page 28.

Pluto was at opposition on June 28th, so it's best sought around midnight using the chart on page 64.





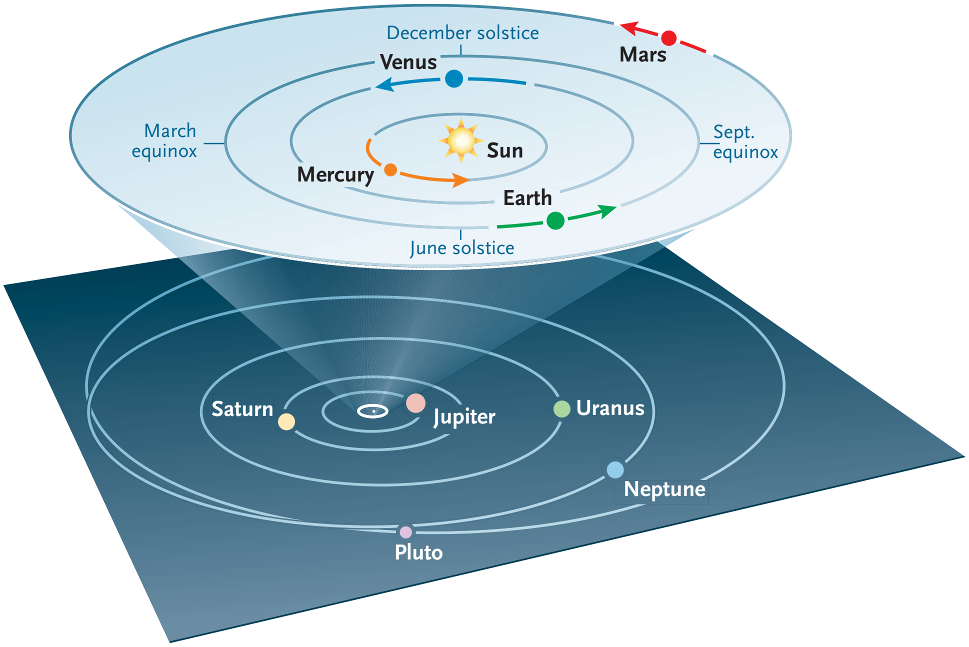
PREDAWN TO DAWN

Jupiter, in southwestern Aries, rises about 2 a.m. (daylight-saving time) as July opens and around midnight as the month closes. The giant planet brightens from magnitude –2.2 to –2.4 in July, and its apparent diameter grows to 40″. Jupiter is quite high in the southeast by dawn.

Mars, in Taurus, rises in the east-northeast before dawn's light begins. It shines at a mediocre magnitude +1.4, noticeably dimmer than nearby Aldebaran (magnitude +1.0), and telescopes show it as a miniscule blob just 4″ wide.

From June 30th through July 4th Mars passes through the outskirts of the Hyades about 5° north of Aldebaran. On the 8th Mars pierces north through the ecliptic plane (two days after Venus does the same). On the mornings of July 25th and 26th the orange-yellow world lines up between Taurus's horn tips, Beta and Zeta Tauri. By month's end it's on the verge of entering Gemini.

Venus rises about an hour before the Sun as July starts, and only about a half hour before as July ends. Although the planet shines at a brilliant magnitude –3.9, it will become hard to find low in the very bright east-northeast sky as the month progresses.



ORBITS OF THE PLANETS

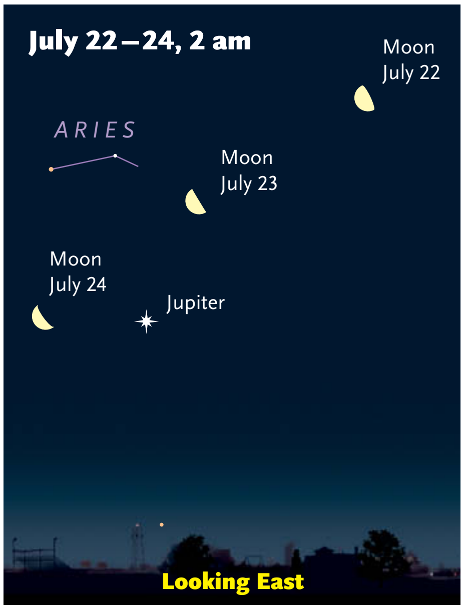
The curved arrows indicate each planet's movement during July, as if you were looking down on the solar system from the constellation Ophiuchus. The outer planets don't change position enough in a month to notice at this scale.

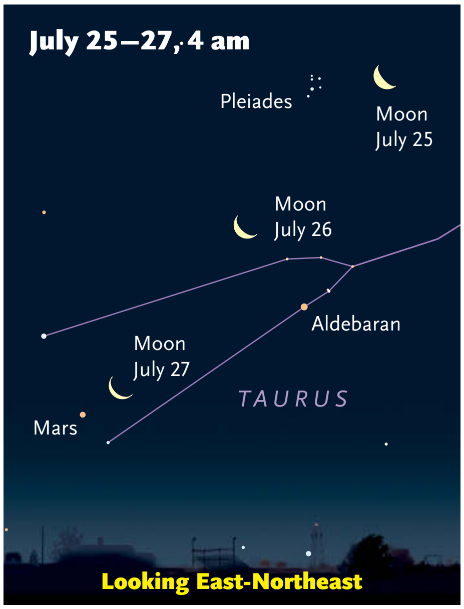
MOON, SUN, EARTH

A very slim crescent **Moon** may be visible in North America about ½ hour after sunset on July 2nd. Look lower left of Mercury, as shown on the facing page. A thicker lunar crescent is lower left of Regulus on July 4th. The Moon reaches first quarter and forms a triangle with Saturn and Spica on the evening of July 7th. The waxing gibbous Moon glows close above Antares on the evening of July 11th. The last-quarter Moon is upper right of Jupiter before dawn on July 23rd and left of the planet on the 24th. The waning crescent is right of the Pleiades on July 25th, upper left of Aldebaran on the 26th, and close to the upper right of Mars on the 27th. The Moon occults Mars this morning over much of South America and parts of the South Pacific.

The **Sun** experiences a tiny partial eclipse on July 1st barely above the horizon in a remote and stormy section of the ocean between Africa and Antarctica. Although no human is likely to see the event, this eclipse presages bigger things to come: it's the first solar eclipse of a new saros series (number 156), which will continue for 1,226 years.

Earth is at aphelion, its farthest from the Sun, on July 4th. The centers of the two bodies are then 94,512,000 miles (152,102,000 km) apart, 1.67% greater than their average distance. Ironically, this is close to the hottest time of year at mid-northern latitudes. ✦

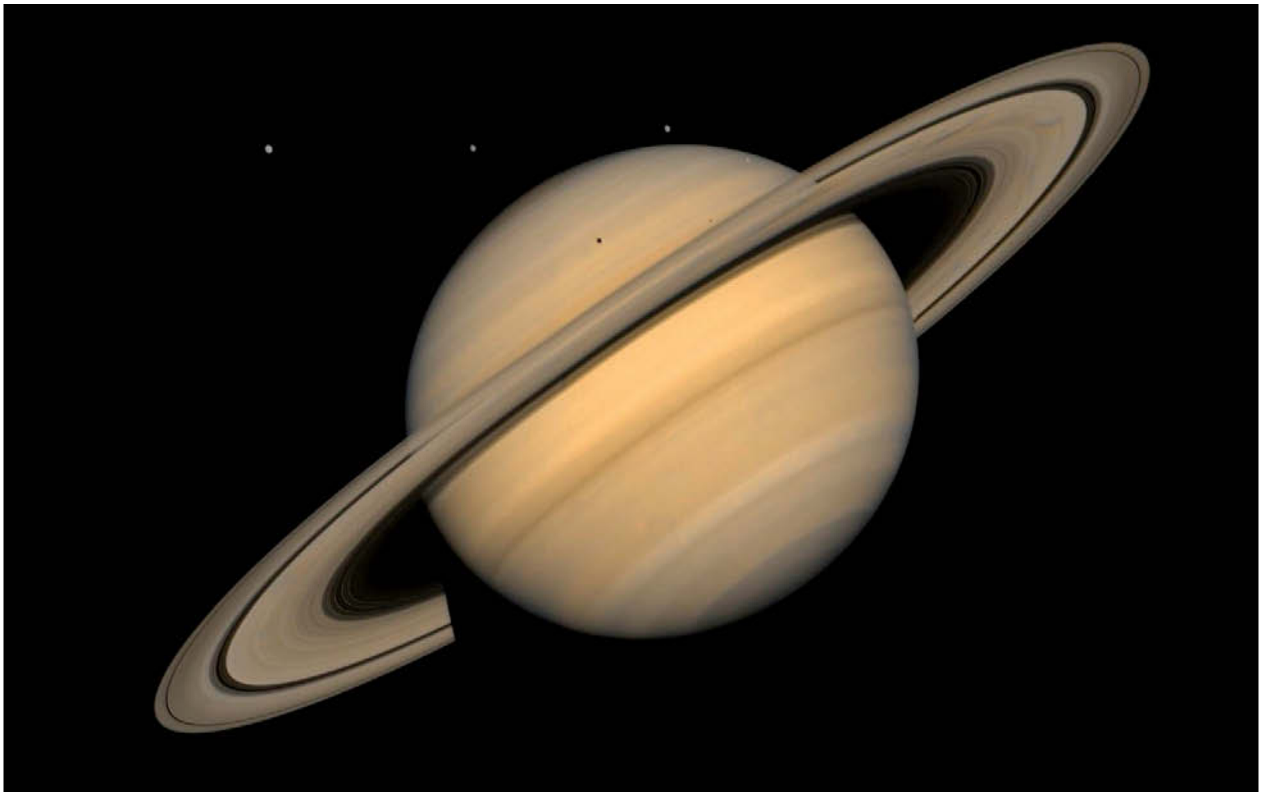




William Sheehan

Ring Spokes Return

Visual observers have seen elusive details in Saturn's B ring for more than a century. Can you spot them?



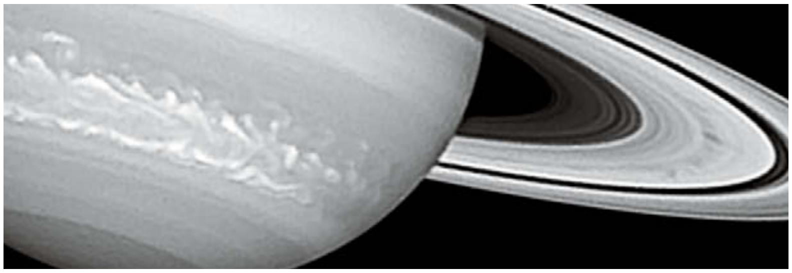
NASA / JPL / USGS

When NASA's Voyager 2 spacecraft flew by Saturn in November 1980, it captured hundreds of images of the rings. Many pictures, including this one, revealed dark spokes in the B ring, confirming nearly a century of observations by visual observers.

When NASA press releases mention radial markings known as spokes in Saturn's B ring, they consistently claim that they were discovered thanks to the Voyager 1 spacecraft flyby in November of 1980. But the fact is that observers on Earth first detected the spokes in what was arguably the last important discovery in planetary astronomy to be made visually.

In 1887 Charles-Émile Stuyvaert provided the first credible reports of spokes in the B ring. Using the 15-inch Cooke refractor at the Royal Observatory of Belgium in Brussels, Stuyvaert made numerous sketches of dusky radial streaks in the B ring, which he called "striae." In January 1888 James E. Keeler made a single ambiguous but suggestive drawing of spokes in the B ring by using the newly inaugurated Lick 36-inch refractor.

Few reports of radial markings in Saturn's ring system were noted in the 20th century until 1977, when Stephen James O'Meara, a volunteer observer using the 9-inch Clark refractor at Harvard College Observatory, began to observe them. O'Meara was inspired by the legendary 1850s studies of Saturn and its rings by W. C. Bond, G. P. Bond, C. W. Tuttle, and Sidney Coolidge, who used the recently commissioned 15-inch Merz refractor at Harvard College Observatory. O'Meara was eager to follow in their footsteps and pursue "a long-term systematic study of something on Saturn," he recalls.



NASA / JPL / STSCI

The Hubble Space Telescope targeted Saturn on March 12, 2011, revealing fine details within the North Tropical Zone storm, as well as numerous spokes throughout the B ring. Go to **www.skyandtelescope.com/saturnmovie** to see an animation of several frames of this series captured over the course of two hours.

At the suggestion of Harvard astronomer Fred Franklin, O'Meara began visually estimating the brightness of Saturn's A ring for comparison with photometric measurements, in hopes of confirming its suspected variability. He also started to systematically look for possible variations in the B ring. Thus he came to note occasional radial dusky bands that he dubbed "spikes." Franklin was supportive of O'Meara's work, but also perplexed. Astronomers had always assumed that gravitational forces alone could account for all the ring features, so radial markings ought not to exist at all. Ring particles move in Keplerian orbits; those closer to the planet orbit faster than more distant ones, so radial features should quickly smear out, an effect known as Keplerian smear.

And yet radial markings clearly exist — at least some of the time. When NASA's Voyager probes encountered Saturn in 1980 and 1981, both captured hundreds of images of the faint, shadowy fingers radiating across the B ring. Scientists named the features "spokes" due to their resemblance to spokes in bicycle wheels. Movies assembled from Voyager images revealed spoke features 6,000 kilometers (3,700 miles) long. But scientists couldn't determine exactly how they form.

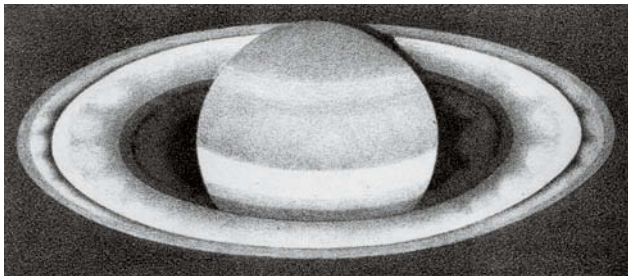
Scientists have long suspected that spoke locations are tied to the rotation of Saturn's magnetic field. Spokes orbit Saturn for a few hours, at the same rate as the axial rotation of the planet's magnetic field, before shearing out with their broad ends facing Saturn as electromagnetic forces gradually lose their grip and gravitational forces reassert control. Because spokes appear bright in spacecraft images of the backlit rings (due to forward scattering), some of their particles must be similar to those in smoke or aerosols, with diameters of only a few thousand angstroms (millionths of an inch).

The spokes are transient and appear to vary with the planet's seasons. Saturn's axial tilt of 26.7° means its polar regions are alternately plunged into darkness or exposed to sunlight for nearly 15 years at a time. These seasonal effects are augmented by the swath of shadow cast by the rings on the globe, which blocks sunlight from the tropical and temperate regions for long intervals.

Geraint Jones (then at the Max-Planck-Institut für Sonnensystemforschung) and his collaborators developed a promising formation theory in 2006. They realized that the spokes appear radial to us only because they're foreshortened. When reprojected from a viewpoint over one of the poles, they appear tilted — generally in the direction expected from Keplerian shear, but occasionally oriented backwards. According to Jones and his colleagues, lightning in Saturn's upper atmosphere produces electrons that are channeled along the planet's magnetic field lines from the storm's location. Upon encountering the rings, the electron beams ionize tiny ring particles to produce a levitating sheet — a "spoke." The shape of the initial spoke depends on the shape of the thunderstorm.

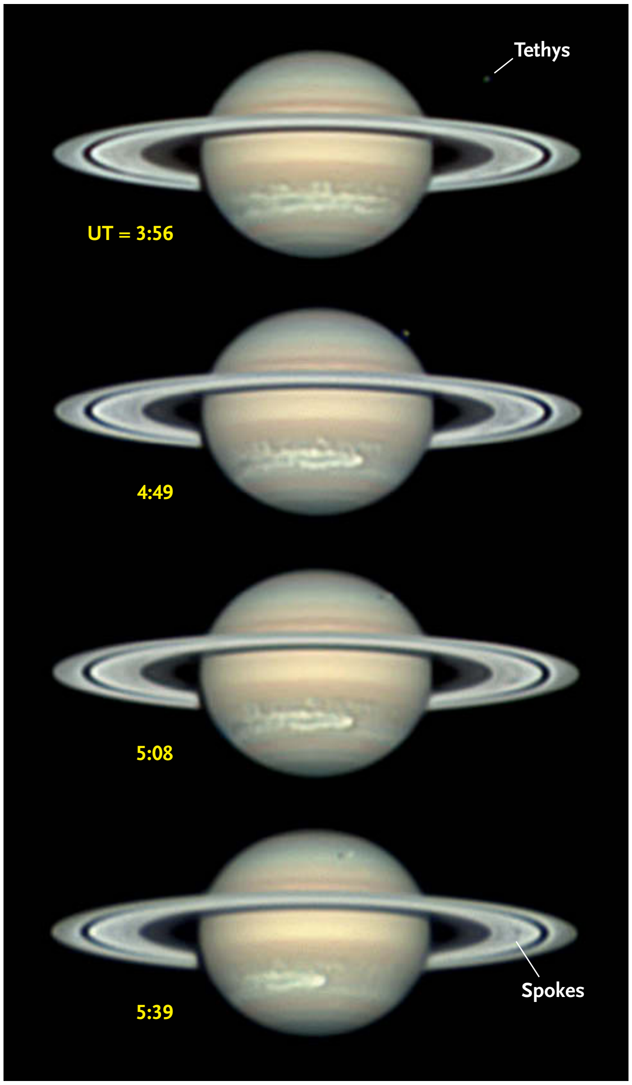
This theory elegantly explains why spokes appear preferentially in Saturn's midnight-dawn sector. The density of ions in Saturn's ionosphere depends on the intensity of solar radiation, resulting in a near-dawn minimum which allows the electron beams to propagate most easily to the rings. Rapid changes in the spokes over hours can also be explained by the average duration of Saturnian thunderstorms. In the part of the B ring where spokes appear, the ring particles are orbiting almost in lockstep with the planet's rotation, at the Saturnian equivalent of geostationary orbit. The fact that spokes appear at specific magnetic longitudes is accounted for because a thunderstorm at a given longitude on Saturn always produces a spoke at a fixed longitude on the rings at that distance from the planet. Thunderstorms at lower latitudes produce spokes closer to Saturn whereas at higher latitudes they "map" onto locations farther out. Because of the geometry, only thunderstorms occurring between latitudes +43° to +52°, and –38° to –46° are able to map onto the B ring.

To observers used to assuming that Saturn's globe is a bland and quiescent version of Jupiter, where major spots are rare enough to receive eponymous names such as Hall's Spot of 1876, Hay's Spot of 1933, and Botham's Spot of 1960, it may come as a surprise that the planet is actu-

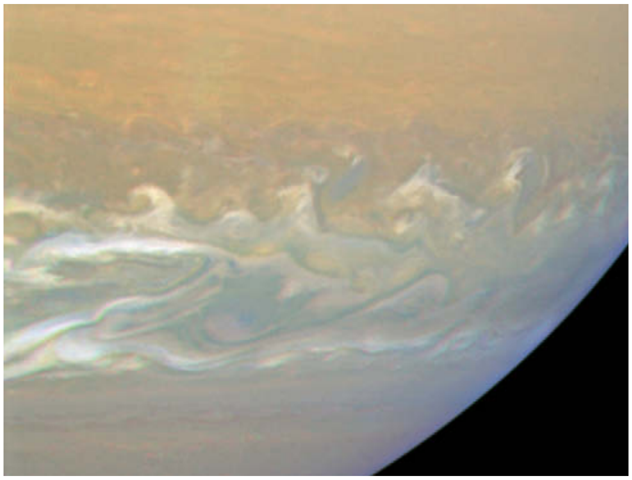


CHARLES-ÉMILE STUYVAERT

While observing the ringed planet in 1887, Charles-Émile Stuyvaert made numerous drawings such as this example depicting dark areas within the rings he dubbed "striae." He used the 15-inch Cooke refractor at the Royal Observatory of Belgium.



DON PARKER



NASA / JPL / SPACE SCIENCE INSTITUTE / SEAN WALKER

Above: **NASA's Cassini orbiter captured this close-up of the North Tropical Zone storm. The disturbance displays complex swirls larger than Earth, where constant flashes of lightning are thought to occur, producing the spokes seen in the B ring.**

Left: **Amateurs have recorded spokes throughout the current apparition. Note the spokes appearing on the sunrise ansae of the ring system in this detailed series of images by Don Parker of Coral Gables, Florida, on the evening of March 23, 2011.**

ally subjected to frequent violent storms. The relatively muted appearance of most Saturnian features compared to those of Jupiter is mainly attributable to lower temperatures prevailing on Saturn, where gases such as ammonia condense at greater depths. In addition, fierce wind speeds of up to 1,100 miles (1,800 km) per hour on Saturn cause storms to rapidly spread out and dissipate. Thus, there is no true analog to Jupiter's Great Red Spot there. But increased surveillance of Saturn in recent years has revealed that major spots and disturbances are more common than previously thought. Indeed, as this *S&T* issue goes to press, a major North Tropical Zone (NTrZ) storm has been underway for several months and now completely encircles the globe.

In contrast to Jupiter, which has virtually no axial tilt, Saturnian storm activity appears to be seasonal, and is affected at least in part by seasonal radiation in the two hemispheres as the planet orbits the Sun.

The result is that Saturnian storm activity — and thus according to the thunderstorm theory, spoke formation and visibility — is increasing as spring progresses in the northern hemisphere. It's unknown if the spokes will truly disappear at the height of Saturnian summer. NASA's Cassini orbiter is currently in an equitorial orbit, unable to view the spokes again until May 2012 at the earliest, making amateur observations particularly valuable.

The next few years will be interesting. This year and next are the best times to observe spokes. Already imagers are confirming one of O'Meara's early findings that the spokes appear most intense on the morning ansa and become sporadic and weak on the evening ansa. Will visual observers begin adding their own reports of spoke sightings, as O'Meara did in the 1970s? Observing these low-contrast features can be extremely challenging. Judging by the spokes' visibility in amateur images, color filters may increase your chances of detecting them. They appear most pronounced in images recorded through a red filter in excellent seeing conditions.

For a July Lunar Libration diagram, check out SkyandTelescope.com/skytel/beyondthepage.

Saturn's northern hemisphere has been tilted toward Earth since the Saturnian equinox of August 2009. Thunderstorms occurring in latitudes +43° to +52° within the current NTrZ storm should continue to give rise to spokes. It would appear that there is no better time than the present to hunt for these ghostly apparitions. ✦

S&T *contributing editor* ***William Sheehan*** *is an avid planetary observer whose latest book,* A Passion for Planets, *is due for release this fall. He coauthored the article on page 28.*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New Product Showcase

▶ **STARS OF THE NORTH** Ashland Astronomy Studio's new "Stars of the Northern Hemisphere" poster ($16.95) will familiarize you with the stars and constellations visible from North America, Europe, and Asia. This 36-by-24-inch poster plots more than 2,400 stars on three separate panels, showing the circumpolar constellations, the winter constellations, and the summer constellations, as well as close-up charts of the Pleiades and Hyades clusters. Each constellation and named star is labeled, and hundreds of stars that host known exoplanets are marked. A legend along the bottom of each panel displays the month that each constellation is highest in the sky at local midnight.

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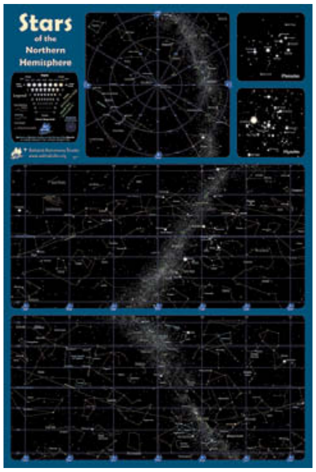

ASHLAND ASTRONOMY STUDIO (2)

ED TRIPLET Barska's new Magnus 80ED refractor ($599) offers color-free performance at an affordable price. The Magnus 80ED features an 80-mm f/7 air-spaced triplet objective with one element made of extra-low-dispersion glass that reduces color fringing to nearly imperceptible levels. Its dual-speed 2-inch Crayford-style focuser combined with an included 90° erect-image 2-inch diagonal makes the scope ideal for both astronomical and terrestrial viewing. Each scope comes complete with a tripod mounting bracket, a 1¼-inch adapter, and an 8-to-24-mm 1¼-inch Plössl zoom eyepiece, as well as a foam-lined hard carrying case.

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▶ **ITALIAN RC** Officina Stellare's full line of Ritchey-Chrétien telescopes is now available to U.S. customers. Its new series of Pro RCs (Ritchey-Chrétien astrographs) offers three levels of options, allowing you to customize the telescope at the time of purchase. Each Pro RC features your choice of primary and secondary mirrors made with regular or low-expansion optical glass and protected aluminum coatings. A carbon-fiber truss-tube assembly with three fans behind the primary mirror aids in temperature regulation of the optics. A built-in two-element field flattener guarantees pinpoint stars across the field of today's largest CCD cameras. Base models include two Losmandy-style removable dovetail mounting plates. Additional accessories are available at the time of order; see the website for details and a list of dealers.

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Australian Eclipse 2012

E. AUSTRALIA · NOVEMBER 8TH – NOVEMBER 15TH, 2012

Let *Sky & Telescope* help you get the most out of the eclipse and the glories of Down Under. Join us November 8–15, 2012 for a swing through Australia, astronomy-style.

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See beyond the obvious. We'll orient ourselves in Sydney, enjoying its fresh vibe and hear the latest on Australian astrophysics research from University of Sydney astrophysicist Julia Bryant, Ph.D. Then off to Australia's astronomy corridor. We'll visit "The Dish" at Parkes and the Siding Spring Observatory at Coonabarabran (Astronomy Capital of Australia).

North to Cairns, with suspense building. While we're in the neighborhood, we'll unwind with a visit to the Great Barrier Reef. After the eclipse, if you'd like to move on to Uluru, the wine country, wildlife viewing, and beyond, we can make your concept a reality. *S&T* is poised to assist you to extend and customize your journey with pre- and post-packages as you wish.

Map out a robust intellectual adventure. Reserve now, and join kindred spirits in a timeless moment. Visit http://www.insightcruises.com/SolarEclipse

SKY & TELESCOPE

DAY 1: Nov. 8

Arrive Sydney

Upon your arrival at Sydney Airport, you'll be met by your guide for a City Tour of Sydney, including a tour of the Sydney Opera House, a refreshing stop at Bondi Beach, and a view of the historic Rocks area. In early afternoon, we'll relax on a luncheon cruise of Sydney Harbor, then check in to The Four Seasons Hotel of Sydney. We'll have an early dinner at a local restaurant, and call it an evening.

Lunch provided.

FOUR SEASONS Hotels and Resorts

DAY 2: Nov. 9

Free day in Sydney

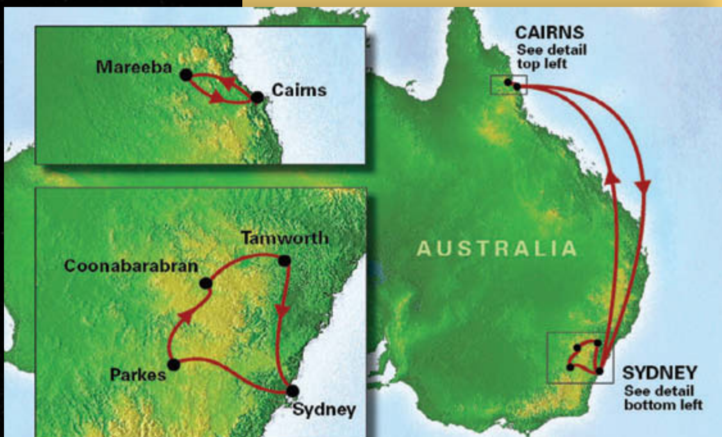
Enjoy a day at leisure on your own. We highly recommend the Royal Botanic Garden (with its famous flying foxes), The Art Gallery of New South Wales, and the Taronga Zoo — excellent options all within easy walking distance from our hotel.

Breakfast provided.

DAY 3: Nov. 10

Travel to Parkes

Wake up Sydney hotel
Breakfast, 7am
Check-out/leave hotel at 8:30am
Arrive Parkes hotel, 4:30pm
(lunch en route at a resort)
Dinner in Parkes hotel
(Country Comfort Inn), 5:30pm
Depart hotel 7:30pm for night-time
Southern sky observing
Night-time Southern sky observing at 8pm
(weather permitting)
Back at hotel in Parkes at 10pm
Spend night in Parkes hotel






Today we head out to Australia's astronomy corridor. We'll traverse the UNESCO World Heritage Site Blue Mountains, preserved because of their unique mix of rain forest, blue mists, golden red sandstone escarpments, eucalyptus forest, and canyons. We'll pause in Katoomba to take in the view of The Three Sisters, and head into Central New South Wales for lunch in a country town. Our journey continues through picturesque farmland, arriving at Parkes in late afternoon. We'll have a relaxing dinner and take an informal first look at Southern Hemisphere skies.

Breakfast, lunch, and dinner provided.

DAY 4: Nov. 11

Visit Parkes Observatory

Wake up in Parkes hotel
Breakfast, 7am
Check-out/leave hotel at 8:30am
Arrive Parkes Observatory 9am
Lunch at Parkes Noon to 1pm
Leave Parkes 1:15pm
Arrive hotel in Coonabarabran at 4:30pm
BBQ dinner at Coonabarabran hotel (Matthew Flinders), 5pm
Depart hotel 7:30pm for nighttime observing
Night-time Southern sky observing at 8pm (weather permitting)
Back at hotel in Coonabarabran at 10pm
Spend night in Coonabarabran hotel

This morning we head up the Newell Highway to the Australia Telescope National Facility, Parkes Observatory: The Dish. While we can't enter the observatory building itself, we'll receive exclusive briefings on the radio astronomy work executed with the 64-meter parabolic dish, and learn about Parkes' role in the Apollo 11 Moon landing, and other Apollo missions. Punctuated by the rumbling and whine that signals the movement of the dish, we'll wrap up our visit with lunch at The Dish Cafe (Elvis recommends the scones) and memorable photo ops.

After lunch it's onward to Coonabarabran, Astronomy Capital of Australia. With luck, we'll see emus, and with a lot of luck, we may spy kangaroos and koalas in the landscape. 5pm-ish we'll check in to our classic country motel, and unwind over a poolside barbeque. After dinner, we'll go to a local commercial observatory, and beneath a canopy of stars, tour the southern sky with a Siding Spring astronomer.

Breakfast, lunch, and dinner provided.

DAY 5: Nov. 12

Visit Siding Spring Observatory

Wake up in Coonabarabran
Breakfast, 7am
Check-out/leave hotel at 8:30am
Arrive Siding Spring, 9am
Depart Siding Spring, Noon
Sandwiches on bus
Arrive Tamworth Airport 3:30pm
Depart for Cairns at 5pm
Arrive Cairns 10:30pm
Check into hotel (Shangri-La) at 11:30pm

Wake up in Coonabarabran to the sound of parrots and kookaburras. We'll have a simple country breakfast, and head into Warrumbungle National Park. We head through eucalyptus forests, past the World's Largest Solar System Drive to Siding Spring Observatory, Australia's premier optical astronomy center, atop Mt. Woorut. Get the scoop on cutting-edge tools and exploration at the Australian Astronomical Observatory with an exclusive briefing, and visit some of the dozen other observatories on site.

We're off, then, through New South Wales' "New England" region, headed to Tamworth and our transfer to Cairns, Queensland, and our base at the Shangri-La Hotel.

Breakfast, lunch, and dinner provided.

DAY 6: Nov. 13

The Great Barrier Reef

Breakfast in Shangri-La, 7am

All aboard at 8:30am for a Big Cat Green Island Reef Cruise. On a smooth-sailing catamaran, we head for the Great Barrier Reef World Heritage Area, one of the Seven Natural Wonders of the World. On a 6,000-year-old coral cay, Green Island National Park's tropical vine forest is home to 60 species of birds. Offshore in the surrounding reef live green and hawksbill turtles, clams, fish, stingrays, and a diversity of creatures.

Your cruise includes five hours on Green Island, a semi-sub coral-viewing tour, the choice of a glass-bottom boat tour or snorkelling equipment for the day, a fish feeding display, lunch, and self-guided island walks. The Big Cat cruise ends at 5pm with a transfer back to our hotel in Cairns.

You're on your own for dinner, but our hotel is right on the water, downtown Cairns. Every imaginable food option, and price range, from dozens upon dozens of restaurants, is within a 10-minute walk. For those tuckered out by snorkeling all day at The Reef, either the fancy Aisan Fusion restaurant, or the water front full-service cafe, both on the property of the Shangri-La, are fine choices!

Breakfast and lunch provided.

DAY 7: Nov. 14

ECLIPSE DAY ... at Dawn

Choices choices! Early this morning we leave the Shangri-La for our pre-selected eclipse viewing site options.

Option One: On the Beach
You can settle in at our gorgeous beach selected for weather and viewing prospects, positioned above the high-tide line for the entire eclipse experience, with exclusive use of an ocean-front cafe. We'll have a breakfast buffet going before, during, and after the eclipse ... just a 30-second walk down from the water's edge and equally "distant" to your camera equipment. We have rooms booked right next door in a charming, tropical motel ... a place to store your equipment or recharge your batteries.

Options Two and Three: In The Outback
You can choose to head to the statistically sunniest spot in the Outback, on the dry side of the Great Dividing Range. Once there, you have two options:

- Observe on the ground at a site in the Outback
- Hop into a hot air balloon in Mareeba (guaranteed to the first 45 people who book; any unused by the first 45 will be assigned to people in the order in which they book) optimizing our position for eclipse viewing "on the fly."

Tonight, join us for an eclipse celebration reception, by the sea, followed by a sit-down dinner of regional foods.

Data for our approximate viewing sites:

The Beach
Total duration is 2 minutes and 0.2 seconds.

Event	Local Time	Alt.*
1st contact:	5:44:40.8 AM	1˚
2nd contact:	6:38:26.6 AM	14˚
Mid eclipse:	6:39:26.7 AM	14˚
3rd contact:	6:40:26.8 AM	14˚
4th contact:	7:40:13.5 AM	28˚

The Outback – Balloon launch site:
Total duration is 1 minute and 40.2 seconds.

Event	Local Time	Alt.*
1st contact:	5:44:54.8 AM	1˚
2nd contact:	6:38:44.0 AM	14˚
Mid eclipse:	6:39:34.1 AM	14˚
3rd contact:	6:40:24.2 AM	14˚
4th contact:	7:40:13.1 AM	28˚

For those not ballooning, we'll head north a few clicks:
Total duration is 1 minute and 58.8 seconds.

Event	Local Time	Alt.*
1st contact:	5:44:38.6 AM	1˚
2nd contact:	6:38:15.3 AM	13˚
Mid eclipse:	6:39:14.7 AM	14˚
3rd contact:	6:40:14.1 AM	14˚
4th contact:	7:39:48.1 AM	28˚

*Alt. – Atltitude of the Sun over the horizon

DAY 8: Nov. 15

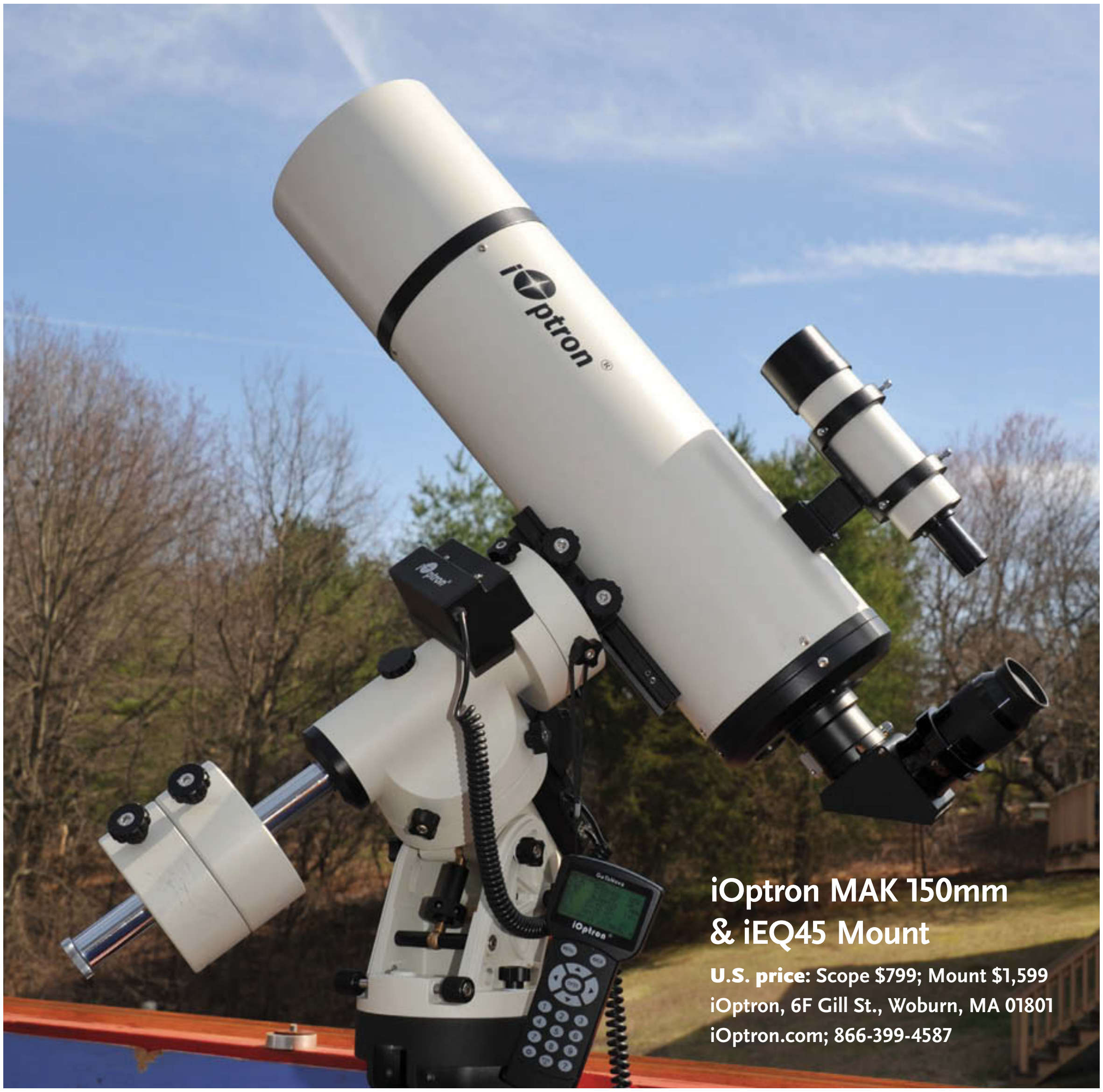
Fly Home

Check-out/leave Cairns hotel, 10am
Fly home from Cairns; arrive LAX 7pm, Nov. 15

Dennis di Cicco

iOptron's New 6-inch Mak & German Equatorial Mount

These recent additions to the iOptron family of telescopes and mounts are aimed at serious observers and astrophotographers.



ALL PHOTOS TAKEN BY S&T: DENNIS DI CICCO

iOptron's new MAK 150mm Maksutov-Cassegrain telescope and iEQ45 German equatorial mount are superbly matched and provide stable, high-magnification views of the Moon, planets, and brighter double stars. All images are by the author.

SINCE LANDING ON the astronomical scene in late 2007, iOptron has continually introduced products aimed at an ever-more sophisticated audience. And two of the latest — a 150-mm (6-inch) Maksutov-Cassegrain telescope and a mid-weight German equatorial mount — are clearly designed for serious observers and astrophotographers. As our bitter New England winter begrudgingly gave way to spring earlier this year, I spent several weeks testing both products, which were on loan for this review.

My colleague and long-time Mak enthusiast Gary Seronik has reminded me more than once that 6-inch Maks strike a balance between aperture and thermal performance, since larger-aperture Maks often require impractically long times to acclimate to changing ambient temperatures. All of my testing was done with the iOptron MAK 150mm housed in my backyard observatory and when temperatures remained relatively stable. As such, thermal issues were not a problem, and the very subtle heat plume I could sometimes detect rising from the light baffle during early evening in out-of-focus star images did not affect in-focus views.

The scope is a Rumak design, meaning that the secondary mirror is a separate optical element glued to the inside of the strongly curved Maksutov corrector, rather than being a spot aluminized directly on the corrector's surface. This gives optical designers an additional degree of freedom, which can be used to produce a scope with better color correction, a flatter field, and, most importantly, better off-axis star images. The iOptron MAK 150mm does indeed deliver excellent star images across the field.

Several years ago I tried a similar-looking 6-inch Maksutov marketed out of Asia that had equally good optics but was hobbled by a sloppy focusing system. That's not the case with the iOptron model. In addition to having a dual-speed focuser with a very light touch, the MAK 150mm's focuser has an internal preload that makes focusing very precise. The preload also makes images return to the same spot following the slight image shift that occurs when you reverse the focusing direction. This is a nice feature for anyone doing high-magnification recording with webcams and other imaging devices with small detectors.

As with all compound telescopes that focus by changing the separation between their primary and secondary mirrors, the MAK 150mm's effective focal length depends on the location of the focal point, and it increases as you move the focus to a point farther outside the tube. My typical configuration for visual observing included a 2-inch star diagonal (pictured on the facing page) and, with 1¼-inch eyepieces, an adapter that required the focus to be a bit farther out. At this location I measured the effective focal length as 2,095 mm, yielding about f/14, with a working aperture of 145 mm and a central obstruction of 57 mm. These values are all well within expected limits.

This scope excels for observing the Moon, planets,

The MAK 150mm features a dual-speed focuser with a very light touch. In addition to offering precise focusing at high magnifications, an internal preload keeps images in the same position when reversing the direction of either focusing knob.

MAK 150mm

What we liked:

First-rate image quality

Precise dual-speed focusing

What we didn't like:

Beefy tube requires heavy-duty mount

iEQ45 Mount

What we liked:

Excellent stability & load capacity for its weight

Accurate polar-alignment system

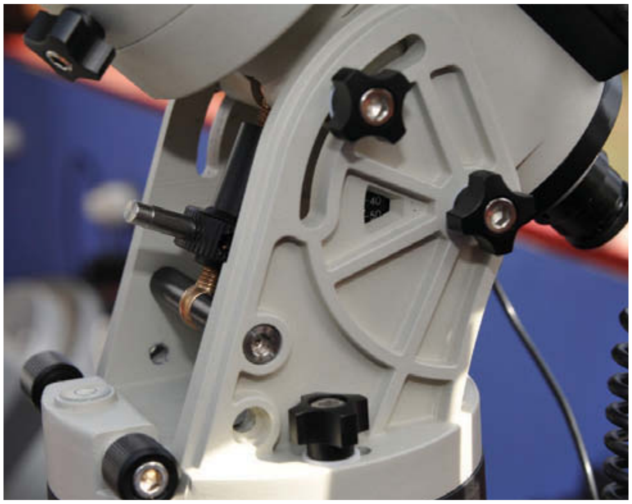
Excellent Go To performance

What we didn't like:

Slow response during keypad entry

Limited astronomical data shown on hand control

For more information about these products go to iOptron.com.



Compact and lightweight, the base of the mount's equatorial head has fine-motion controls for setting the altitude and azimuth of the polar axis. Combined with the built-in polar-alignment scope, they make short work of achieving accurate alignment in the field.

Although relatively easy to learn, the hand control has a rather sluggish response to keypad entries (see the accompanying text for details). The eight-line display shows an abundance of information about the mount, but only limited astronomical data for objects contained in the internal database.

As soon as the scope's electronics establish a GPS link, they create a graphic display showing where Polaris (or Sigma Octanis in the Southern Hemisphere) should be positioned on the polar-scope reticle to achieve accurate polar alignment. The position is referred to the face of an imaginary clock (thus the odd "time" displayed) as well as being inverted for the view in the polar scope. The author tested this system extensively and found it to be highly accurate.

and brighter double stars. With Jupiter slipping into trees on my western skyline and Saturn hanging low in the southeast during the evening, I spent much of my time exploring the Moon and hunting down interesting double stars, with magnifications as high as 420× (using a 5-mm eyepiece) when the astronomical seeing would permit. I particularly enjoyed the views at 210× and 350× with the new 10- and 6-mm Tele Vue Delos eyepieces reviewed in last month's issue, page 58. That said, it's worth noting that the scope's long focal ratio is very forgiving of eyepiece design, and I also had very good views with much older Plössl and orthoscopic eyepieces, and even lowly Kellner eyepieces delivered pleasing views.

Overall, I'm very impressed with the quality and performance of the MAK 150mm. In normal use with the included 8×50 finder and metal dew shield, the scope weighs about 17 pounds (almost 8 kg). As such, users will want a solid mount, particularly if they plan to do a lot of high-magnification observing. I found the scope ideally matched to iOptron's new German equatorial mount, so read on.

iEQ45 German Equatorial Mount

The next time I need a reminder that I shouldn't judge a product based on early impressions, I'll just think back to my experiences with iOptron's new iEQ45 mount. I was very taken with the mount as I set it up and checked out its impressive set of features. That enthusiasm, however, was ratcheted back a few notches when I started testing it at night. But my initial impressions returned as my testing gave way to simply observing. Here's why.

The iEQ45 is well engineered and manufactured, and it has numerous subtle features that make it one of the most portable mounts in its class. For example, the counterweight shaft stores inside the declination housing, and since the whole equatorial head weighs only 25 pounds (11 kg), the mount is extremely easy to carry as one piece. It comes with interchangeable dovetail saddles that accept scopes with either Vixen or Losmandy-D dovetail plates. The main electronic module is permanently attached to the polar-axis housing, and it takes only seconds to connect the hand control and cable for the declination motor. The mount runs on 12 volts DC and it comes with a universal AC adapter as well as a power cord fitted with a standard "car" plug.

The mount has a bubble level, fine-adjustment controls for altitude and azimuth positioning, a latitude scale, a built-in polar scope, and a very nice polar-alignment routine. Here's how it works. Within a minute or so of powering up the mount, the electronics automatically acquire a GPS link and the hand control displays a graphic image of where you should position Polaris on the polar scope's illuminated reticle to achieve proper polar alignment. You then make the necessary adjustments using the mount's fine-motion controls for altitude and azimuth, and you're done. From start to finish the process can take as little as three to four minutes.

I checked the reticle's scale and its concentricity with the polar shaft's axis of rotation and found both to be spot on. Combined with the graphic display, it made the alignment process very accurate, as well as intuitive. This is a great system for people who set up the mount in the field and want precise Go To performance as well as accurate tracking for astrophotography.

At this point things couldn't have gone

All electrical connections for the iEQ45 are made via this module permanently attached to the polar-axis housing. Not shown is the LED illuminator for the polar scope's reticle, which plugs into the "reticle" port on the module.

This snapshot of the waxing gibbous Moon was made with a full-frame Nikon D700 DSLR. As described in the text, the MAK 150mm's effective focal length depends on the location of the focal point outside the telescope tube. For this image, the camera body with a 2-inch nosepiece was placed directly into the scope's 2-inch adapter, yielding an effective focal length of 1,950 mm and f/13.

more smoothly, and I turned my attention to testing the mount's performance. The good news? The mount is remarkably stable for its weight; Go To accuracy is commendable, even when executing "meridian flips" and switching between observing in the eastern and western halves of the sky; and the drive's periodic error is only about 19 arcseconds *before* training the electronic periodic-error correction.

The bad news? I found several aspects of the hand controller somewhat annoying. Foremost is the need for slow and deliberate keypad entries. If you're accustom to rapidly entering data on a keypad (picture a teenager tapping out a text message on a phone), you'll need to slow down to use this mount. I found myself having to verify each entry by looking at the display. Adding to this is a menu structure that, while relatively intuitive, is lengthy, and you generally start from the beginning of the menu each time you want to enter a new object or command.

At first I found this frustrating, but in reality much of my annoyance arose from testing the mount rather than observing with it. As such, I was constantly making keypad entries and hopping from object to object. It was only when I settled into "observing" mode and spent more time looking in the eyepiece than fiddling with the keypad that my attitude changed.

When observing, the only time that the lagging keypad response was noteworthy was when I used the direction keys to move around the field of view, since the scope would continue to move for a fraction of a second after I stopped pressing a key. With high slew speeds, this would cause me to overshoot my target. The simple fix is to select another speed, which you do by pressing a single digit key.

I could nitpick other aspects of the mount's hand control, but this would unfairly detract from what I consider to be an excellent mount. After all, the things that are really important — fast and precise polar alignment, excellent stability, accurate tracking, great Go To performance — are all there with the iEQ45. And these features, especially the stability, made high-power observing with the MAK 150mm a very pleasant experience.

The iEQ45 is rated for telescopes weighing up to 45 pounds (20 kg). There's nothing magic about this value, it's simply the weight above which the manufacturer feels the mount's stability becomes compromised. I tested it with several telescopes, including a long-focus 4-inch refractor, and loads up to about 30 pounds (50 pounds with counterweights), all with excellent results. For many years my workhorse portable German equatorial mount has been a Vixen Great Polaris DX. The iEQ45 is equally portable, has twice the load capacity, adds Go To pointing, and outperforms the Vixen in every way, all for not much more than the cost-adjusted price I paid for the Vixen. In my mind that makes the iEQ45 an excellent value. ✦

It comes as no surprise to his friends that Sky & Telescope *senior editor* ***Dennis di Cicco*** *can enter data on a telescope hand control far faster than he can compose a text message on his cell phone.*

See Pluto in 2011

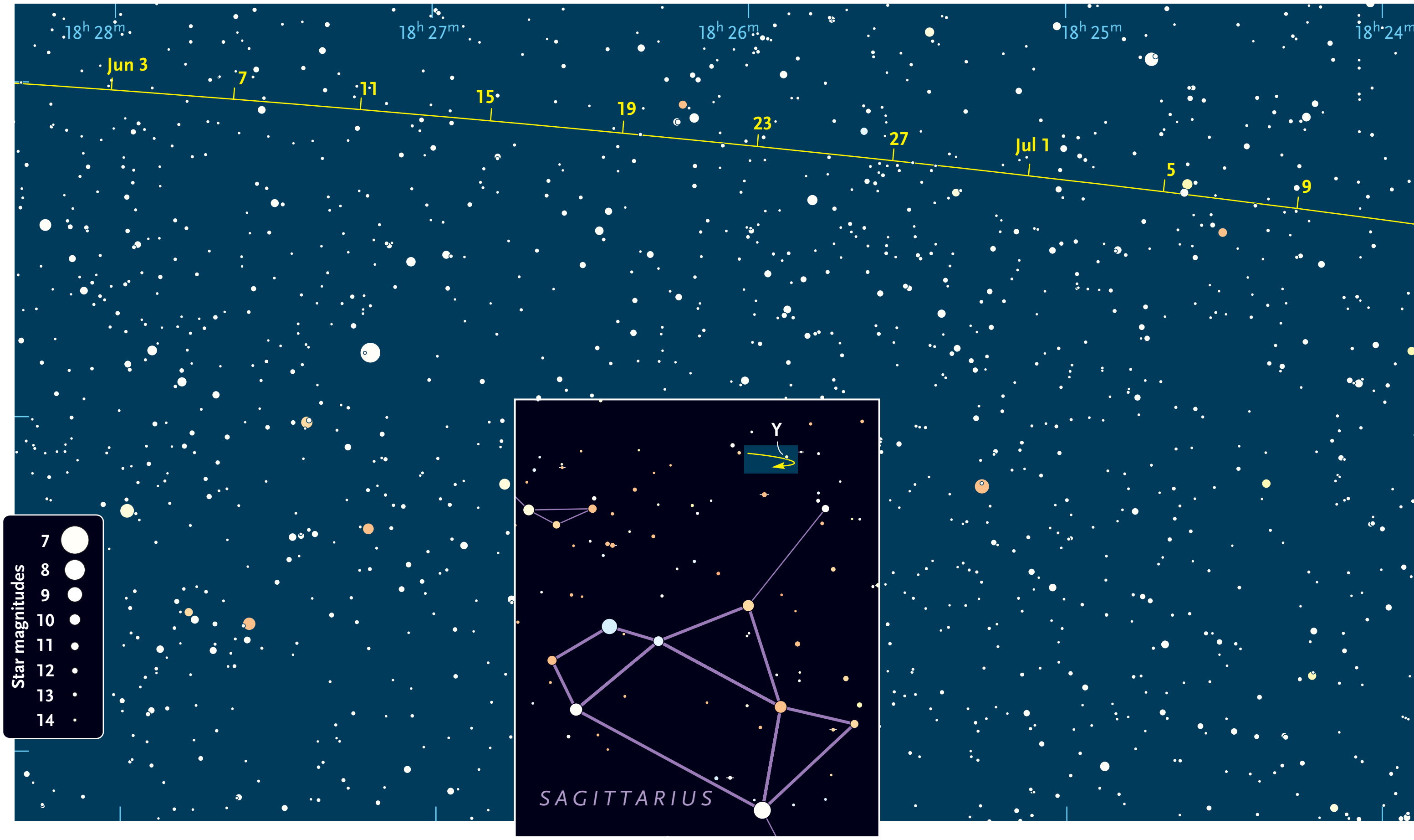
However you classify this faint flicker, spotting it is a real accomplishment.

Every year like clockwork, editors of *Sky & Telescope* debate whether to print a finder chart for Pluto. For the last few years the decision has always been "Okay, but this is the last time. We won't run it next year — no way!"

Why would we turn a cold shoulder on an innocent hunk of rocky ice whose travels we've plotted for decades? It has little to do with the 2006 decision by the International Astronomical Union (IAU) to demote Pluto from official "planet" status. We have various opinions on how Pluto should be classified, but nobody likes the IAU's current, sloppy definitions, according to which Pluto is a dwarf planet but not a planet.

It's not that there's any shame in being a dwarf — after all, astronomers often use common words in strange ways. For instance, the great majority of stars, including our own Sun, are classified as dwarfs. That's pretty odd, especially considering that the next step up is a subgiant. (Imagine walking up to an average-sized stranger and asking "Excuse me, are you a dwarf or a subgiant?") But nobody denies that a dwarf star is a star. So why isn't a dwarf planet a planet?

Whatever you call it, Pluto is still unique and historic. In some ways it's more special now than when Clyde Tombaugh discovered it in 1930. Back then it was an odd man out — a misfit, with its eccentric orbit and absurdly small size. Now it's the prototype of an entire huge class: the Kuiper Belt objects. And it's the only one of them that you can see in a medium-large backyard telescope.



The problem with plotting Pluto is that it's moving farther south in the sky, and crossing the densely-packed star fields of the Sagittarius Milky Way. Moreover, it's fading gradually, from its peak magnitude of 13.6 at its 1989 perihelion to roughly 14.0 now. That makes it a real challenge from mid-northern latitudes . . . but we don't have the heart to abandon it yet.

You'll need to pick a clear, moonless night when western Sagittarius is near its highest in the southern sky. An 8-inch scope should suffice under dark skies, but you will probably need at least 10 or 12 inches of aperture to see it from a typical suburb. Pluto also demands high magnification, good seeing, and lots of hard work.

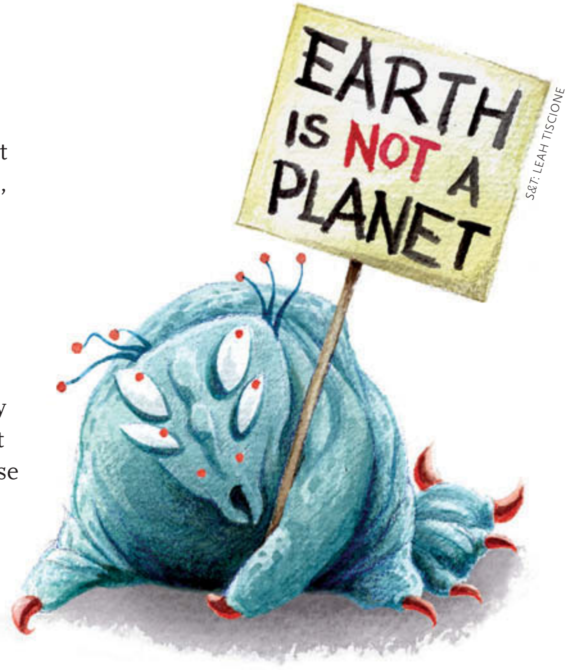
On the large chart, the ticks on Pluto's path are for 0^h UT on the dates indicated. This is on the afternoon or evening of the previous date for American time zones. Interpolate between tick marks to put a pencil dot on Pluto's track for the time and date you plan to look for it.

Outdoors, start by using the little inset chart to locate the yellow star Y Sagittarii, which varies irregularly between magnitude 5.5 and 6.1. Then switch to high power and carefully star-hop your way from there to your pencil dot.

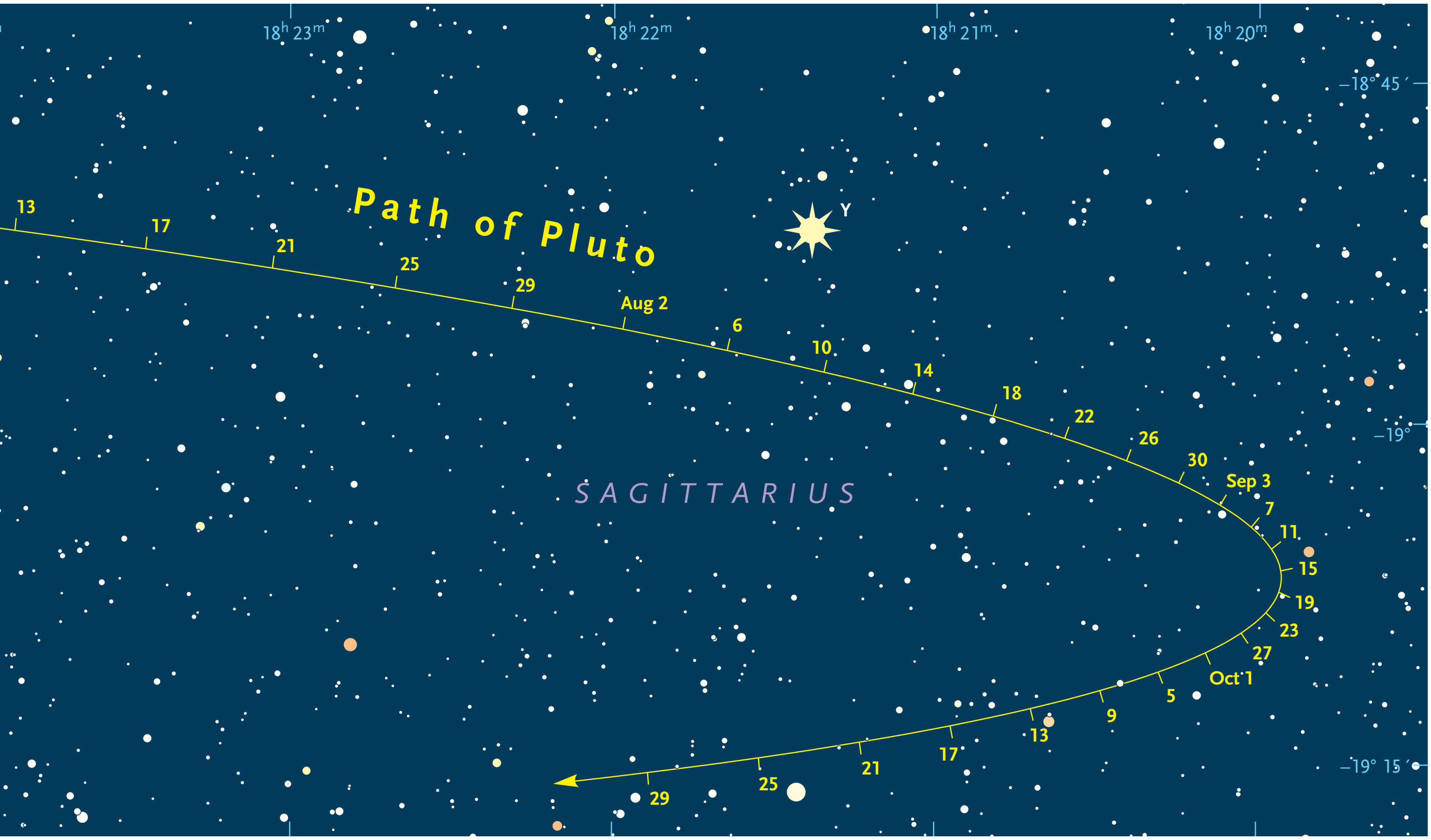
The chart shows stars to magnitude 14.5, significantly fainter than Pluto. But stellar databases this deep are notoriously unreliable, so you can't be 100% sure that a 14th-magnitude blip is Pluto just because it's not plotted as a star on the chart.

Locating Pluto with a Go To scope is little help, because this area of the sky is so rich in faint stars. Even at 200× or higher, there will probably be several blips near the center of the field of view. How can you know which of them is actually your target?

The only way to be absolutely certain is to sketch the suspect's position with respect to neighboring stars, then come back on the next clear night. If your object is indeed Pluto, it will have moved.



And once you've invested that much effort, you will truly have made Pluto your own. Despite all the charts and automated assistance in the world, there's no substitute for old-fashioned patience and persistence. ✦



Mad for the Night

The Butterfly Cluster floats in an amazing deep-sky field.

The stars drop down in their blue dominions
To hymn together their choral song:
The child of earth in his heart grows burning
Mad for the night and the deep unknown.
— Æ (George William Russell), *Breaghy*

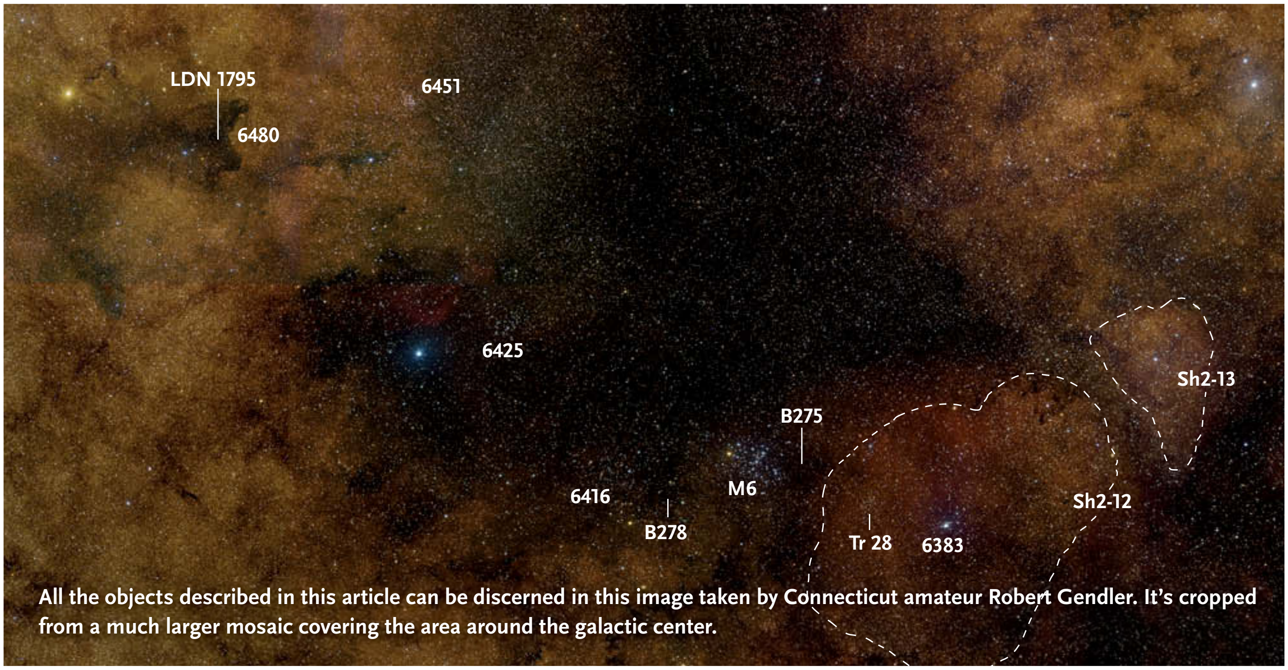
As amateur astronomers, we're often stirred by the grandeur of the night sky, especially at this time of year when the riches of the southern Milky Way gracefully overstride the evening sky.

One starry domain where deep-sky wonders abound is the realm of the splashy open cluster **Messier 6**, the Butterfly Cluster. In a dark transparent sky, M6 is a naked-eye hazy patch one-third of the way from Gamma (γ) Sagittarii to Epsilon (ε) Scorpii. Through 15×45 image-stabilized binoculars, I count 20 stars in an oblong grouping about 20′ long. At the northeastern end, the group's brightest star is the red giant BM Scorpii, a semiregular variable with a period of 2.2 years and a visual-magnitude range of 5½ to 7. BM Sco is decidedly yellow-orange through my 105-mm refractor at 28×, in dramatic contrast to the glitter of blue-white gems that adorn the cluster. At least 30 mixed bright and faint stars gather in an 18½′ × 5½′ core, and outliers expand the group to about ½°. Bumping the magnification up to 76× reveals a teeming throng of well over 100 stars.

The brilliant beadwork of M6 is strung in loops and lines that make it easy to envision outlines of fanciful figures. The cluster's namesake butterfly may have debuted in the 1923 popular astronomy compendium *Splendour of the Heavens*, where M6 is described as "somewhat irregular in shape, with a central rib of stars, and resembles a butterfly with open wings."

M6 was discovered by the Sicilian astronomer Giovanni Battista Hodierna, who listed it in 1654 in a booklet titled *De Admirandis Coeli Characteribus* (On the Wonderful Features of the Heavens). M6 was included among his "nebulosae," objects that appear nebulous to the unaided eye but reveal stars through a telescope. Hodierna's sketch of M6 appears to have 20 stars.

California amateur Kevin Ritschel finds the area neighboring M6 worthy of careful study. With a 110-mm



All the objects described in this article can be discerned in this image taken by Connecticut amateur Robert Gendler. It's cropped from a much larger mosaic covering the area around the galactic center.

GEORGE GREANEY

This photo on hypered color film captures the huge nebula Sharpless 2-12 and brighter but smaller Sharpless 2-13 to its northwest (upper right). Messier 6 is near the left edge, and the dark nebula Barnard 275 lies between M6 and Sh 2-12.

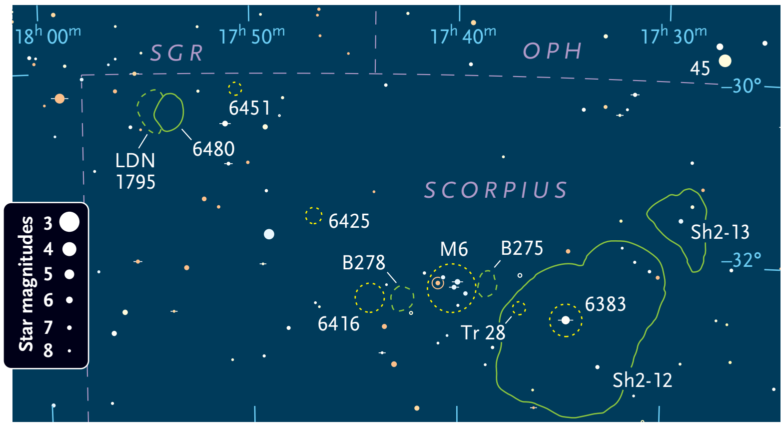
refractor and a wide-field eyepiece giving 24×, Ritschel notes, "Dark nebulae straddle both sides of the cluster like cosmic saddlebags, **Barnard 278** to the east and **Barnard 275** to the west." He remarks that the contrast between M6 and these nebulae is quite striking.

Turning my 105-mm scope at 87× toward each dark nebula, I find B275 blacker in the center and more discrete, while B278 is larger with inky tendrils creeping toward M6 and **NGC 6416**, the loose cluster nudging its eastern side. NGC 6416 displays three 9th-magnitude stars, 15 faint stars, and some very faint stars in 15′.

Inconspicuous in a small telescope, the open cluster **Trumpler 28** sits ½° west-southwest of B275. Through my 10-inch reflector at 68×, Tr 28 is an 8′ gathering of 25 moderately faint stars with an arc of three 9th- and 10th-magnitude suns in its northwest quadrant.

Trumpler 28 is named for Robert Julius Trumpler, who included it in his 1930 *Lick Observatory Bulletin* on open clusters. It was the 28th anonymous object in Trumpler's list of 334 clusters. The description reads, "Fairly dense group of stars 11–14m with well defined outline but slightly unsymmetrical." The bulletin lead to Trumpler's name being associated with the cluster, but he mentions its previous inclusion in Edward Emerson Barnard's 1927 *Photographic Atlas of Selected Regions of the Milky Way*. It appears there on Plate 24, and the accompanying text calls it "a small cluster, 8′ in diameter, with few stars."

Sweeping another ½° west-southwest takes us to **NGC 6383**. This cluster is dominated by a 6th-magnitude spectroscopic binary, its components in such tight embrace that they're distorted into ellipsoids. Both stars are spectral type O7V, placing them among the bluest stars in the sky. Stars with earlier spectral types aren't any bluer because their extra energy is in the invisible ultraviolet.




PETER VASEY

Messier 6 is a modest collection of young, blue stars dominated by a red giant in its northeast corner.

I see NGC 6383's bright star and a few faint ones over a little smudge through my 15×45 binoculars. My 10-inch scope at 68× shows about 10 stars closely guarding their lucida, like an underpopulated version of the Tau Canis Majoris Cluster (NGC 2362). A detached surround of additional stars swells the cluster to 20′.

NGC 6383 sits at the heart of the large, faint emission nebula **Sharpless 2-12**, which is difficult to discern from my northerly latitude. Kevin Ritschel (110-mm refractor) and fellow Californian Robert Ayers (8-inch refractor) found that both O III and hydrogen-beta filters provide good views. Both observers say that Sh 2-12 commingles with **Sharpless 2-13** to its northwest, and Ritschel notes that the latter is slightly fan shaped and brighter than its companion. Sh 2-12 and Sh 2-13 are about 80′ and 40′ across, respectively.

Trekking 1.6° east-northeast from M6 takes us to the curious cluster **NGC 6425**. Through my 105-mm scope at 17×, it's a moderate-size grainy patch making the southwest corner of a 25′ trapezoid with three stars, magnitudes 5, 8, and 8½. The cluster's most obvious star is nestled in its center. At 87× NGC 6425 boasts 21 stars of similar magnitude, and it appears decidedly triangular, with the triangle's sides 8′ to 10′ long. A tiny equilateral triangle formed by the central star and two dimmer suns rests on the western edge of a starless void lurking within the cluster.

Just south of the Sagittarius border, **NGC 6451** is a lovely cluster through any telescope. In my 105-mm refractor at 28×, it's a pretty diamond-dust cluster about 7′ across with brighter chips at the west and northeast edges. At 87×, 30 faint to extremely faint stars gather in a sparkly group elongated northeast-southwest. Seen though my 10-inch scope at 219×, NGC 6451 is a very unusual-looking cluster containing a large, very fat Y that's almost devoid of stars. About 30 faint stars are sprinkled around the Y and define its edges, while a dozen additional stars fill out the group. A little fuzzy spot flecked with a few pinpricks of light clings to the south-southeastern branch of the Y, like a touch of dust on an ebony table.

Our final targets are the dark nebula **LDN 1795** and background star cloud **NGC 6480**. California amateur Steve Waldee calls the combination "exquisite" in his 120-mm refractor, while Georgia amateur Dave Riddle says it's prominent even in his 11×80 finderscope and "may be one of the finest dark nebulae visible in small telescopes."

On June 27, 2008, Riddle's impressive digital sketch representing the view of LDN 1795 through his 18-inch scope was featured on the Astronomy Sketch of the Day at **www.asod.info/?p=1074**. He describes the nebula "as either a horse's head or the head of a Great Dane." LDN 1795 overlays a rich Milky Way star cloud, and where the dark nebula abruptly ends in the west, the star cloud NGC 6480 stands forth in sharp contrast. John Herschel discovered NGC 6480 in 1837. The catalog of Herschel's observations from the Cape of Good Hope reads: "An extraordinary bright nebulous portion of the milky way, on a black ground, very large; an angle taken where there is a star 12th magnitude." The coordinates in our table are for this defining star. ✦

Sue French *welcomes your questions and comments at scfrench@nycap.rr.com.*

The Realm of the Butterfly Cluster

Object	Type	Mag(v)	Size	RA	Dec.
Messier 6	Open cluster	4.2	30′	17h 40.3m	–32° 16′
Barnard 275	Dark nebula	—	13′	17h 39.0m	–32° 20′
Barnard 278	Dark nebula	—	15′	17h 42.7m	–32° 19′
NGC 6416	Open cluster	5.7	18′	17h 44.3m	–32° 22′
Trumpler 28	Open cluster	7.7	8′	17h 37.0m	–32° 28′
NGC 6383	Open cluster	5.5	20′	17h 34.7m	–32° 35′
Sharpless 2-12	Emission nebula	—	80′	17h 34.3m	–32° 39′
Sharpless 2-13	Emission nebula	—	40′	17h 29.0m	–31° 30′
NGC 6425	Open cluster	7.2	10′	17h 47.0m	–31° 31′
NGC 6451	Open cluster	8.2	8′	17h 50.7m	–30° 12′
LDN 1795	Dark nebula	—	26′ × 12′	17h 54.7m	–30° 31′
NGC 6480	Star cloud	—	25′	17h 54.6m	–30° 26′

Angular sizes 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.

Secondary Considerations

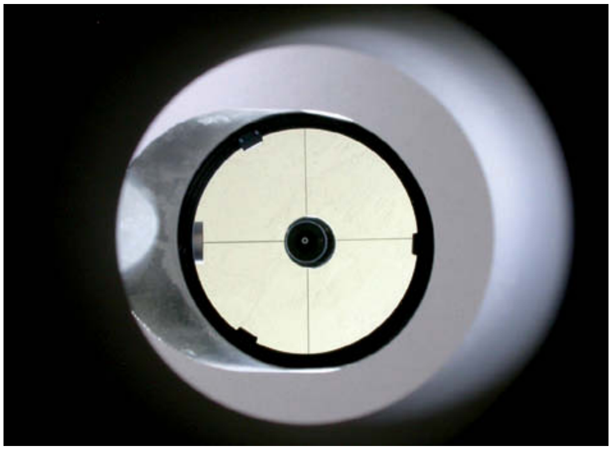
Aligning a Newtonian's diagonal mirror is not as difficult as many think.

IF ONLINE DISCUSSIONS are a gauge, then collimation of a Newtonian telescope is a major source of confusion and anxiety. Newcomers in particular often find themselves drowning in minutiae, or bewildered by contradictory advice.

Let's step back and consider job #1 of collimating a Newtonian. What we want to do is aim the optical axis of the eyepiece at the center of the primary mirror and aim the optical axis of the primary mirror at the center of the eyepiece. That's it. And collimation would be trivially easy if the only components involved were the eyepiece and primary mirror. The presence of the secondary mirror complicates things, but only slightly.

To understand the role of the secondary, imagine it as a hole in a piece of cardboard placed between your eye and the primary mirror. The hole needs to be large enough for us to see the entire primary, and its circumference needs to be concentric with the outer edge of the primary.

Because the secondary is just a piece of flat glass, incorrectly positioning it won't introduce aberrations. In other words, contrary to some material on the internet, a misaligned secondary mirror doesn't produce astigmatism, coma, spherical aberration, or a stock market crash. All a secondary does is reflect light from the primary to the eyepiece.



GARY SERONIK

A Newtonian reflector's secondary mirror introduces complexity into the task of aligning the scope's optics, but not as much as some people think. Placing a piece of white paper on the tube wall opposite the focuser makes it easier to see what adjustments are required when you look into the focuser, as shown here.

How do we make sure that the secondary is doing its job? Simply put a collimating cap (a dust cap with a small hole punched in its center works) in the focuser, rack the focuser out to its typical position, and have a look. Check that the entire primary mirror is seen reflected in the secondary and that the primary's outer edge appears concentric with the outer edge of the secondary. If this isn't the case, make the necessary tweaks to the secondary's adjustment screws.

But what about the dreaded secondary offset you may have heard about? If you satisfy the conditions above, you needn't worry about it. A secondary is offset from the primary's optical axis to make the illumination profile at the focal plane concentric with the eyepiece's field of view. Fast primaries (f/5 and under) need more offset than slow mirrors (f/7 and greater). But illumination drop off is less of a problem than many people think, and as long as your secondary mirror is big enough to show the whole primary mirror and a little extra, offsetting it from the optical axis won't make a big difference at the eyepiece.

It's helpful to remember that we're dealing with two issues: collimation and illumination. Collimation involves the alignment between the eyepiece and the primary mirror, whereas adjustments to the secondary mirror mainly affect field illumination. That's why when I collimate my scopes, I finish by tweaking the secondary to get the alignment exactly right — I trade an imperceptible shift in the illumination pattern for precise collimation. That might strike some as heresy, but I get better alignment this way because I make the final adjustments while looking in my collimating cap. There's no temptation to settle for "good enough," because I walked back and forth to the primary's adjustment knobs for the umpteenth time. The real proof of this method is the fact that it works. Of course, if you enjoy fussing with secondary offset, focuser tilt, and so forth, that's your choice — it's just not necessary. ✦

*Contributing editor **Gary Seronik** has built numerous telescopes, several of which are featured on his website, www.garyseronik.com.*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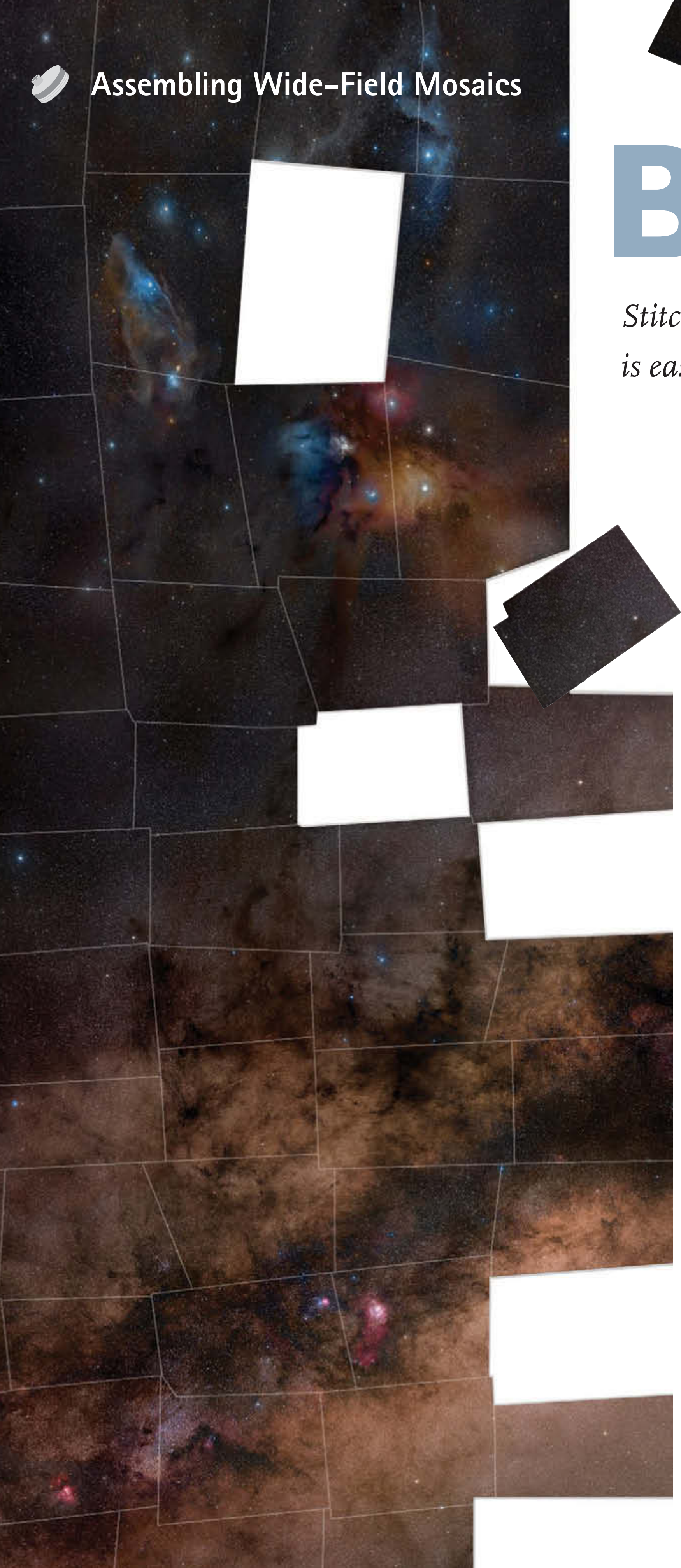

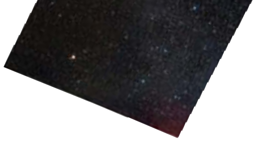

Building

Stitching together seamless mosaics is easy with this multi-platform software.

Photographing wide-field vistas of the night sky is a rewarding experience, since a virtual panorama of targets awaits us each clear evening. Although we can record the sweeping vistas using wide-angle camera lenses on a CCD camera, these lenses lack the resolution of telescopes and specialized astrographs. But we can have the best of both worlds by shooting overlapping images with a telescope and seamlessly stitching them together on a computer to create high-resolution, wide-angle mosaics.

Mosaics allow us to craft compositions of much larger fields of view than what telescopes can cover in a single frame. Likewise, mosaics are an excellent way to create images with higher resolution than what other optics and cameras can deliver in one-frame compositions covering the same field of view.

Since a mosaic doesn't have to stop at any given number of frames, we can build as large a field as our skies allow. Once we've mastered the technique, the sky is truly the limit.

Plan of Attack

One of the most important tasks when starting a mosaic is the planning. You can do this by using any planetarium software that allows you to define your camera and telescope's field of view. Whatever you use to plan your total field, make sure you allow at least 10% to 15% overlap between frames so that you have enough stars common to adjacent frames for registration purposes.

Nearly as important as planning your composition is to calibrate your data with excellent flat-field calibration frames. Although some variations in your images can be corrected before stitching the panels together, the process

Recording and assembling huge mosaics of the night sky is a worthy challenge for astrophotographers who want to increase their camera's field of view to reveal wide-scale structures only hinted at in narrow fields. Rogelio Bernal Andreo explains how to seamlessly assemble high-resolution vistas, such as this region encompassing Sagittarius and Scorpius, using the program *PixInsight* (http://pixinsight.com).

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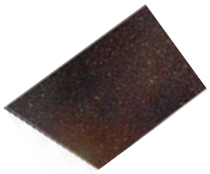
Mosaics in PixInsight

Rogelio Bernal Andreo



is much easier when you begin with excellent data.

Once you've recorded your data and are ready to put it together, you can choose from several computer programs that can stitch your fields together. *RegiStar*, *MaxIm DL*, and *Photoshop* are popular choices. I suggest avoiding any panorama-making applications, because these are generally optimized for daylight panoramas, and often don't do a good job registering astroimages.

Although each application has its strengths and weaknesses, I prefer *PixInsight* (**http://pixinsight.com**) due to its excellent registration accuracy and background matching — key to building mosaics — as well as its ability to stitch frames together seamlessly while the data is in a linear state, which as we shall see, gives us certain advantages. *PixInsight* (171 euros at press time) covers every function from image calibration to the final mosaic.

Mosaic Strategy

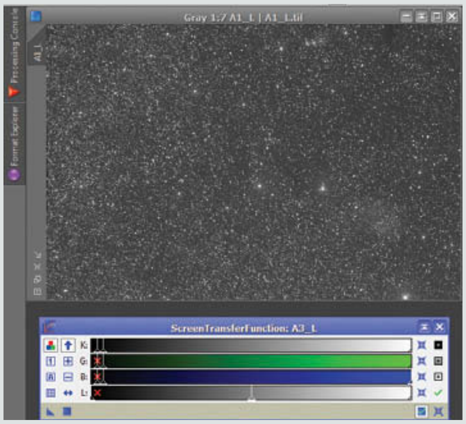
Unless you record your images with a one-shot color camera or you're building a monochrome mosaic, you will have a different set of data for each filter. In this article I create an LRGB mosaic, so I have four filtered sets of data per frame. I prefer to first stitch together the luminance images, and then register the red, green, and blue images to this master.

Once our original frames have been calibrated (again, good flat-fielding correction is extremely important), my first step is to crop off any edges that are not common to all exposures caused by dithering or misalignment between data recorded on multiple nights. Because my images are 32-bit linear (unstretched) format, the visible range of the image is likely compressed near the black point of the histogram. In order to see the brightness range of the image — and therefore be able to discern the areas to remove — I use *PixInsight*'s Screen Transfer Function (STF) dropdown process (Process / Intensity Transformations / Screen Transfer Function) to stretch the image preview on the screen. Click the "A" tab to auto-stretch the preview. The STF stretch does not actually modify the data; it only makes it visible on the monitor. I keep this tool open throughout the mosaicing process so that I can stretch the previews after each step and examine the results. Once the image has been screen-stretched, I use the Dynamic Crop tool (Process / Geometry / Dynamic Crop) to crop each panel.

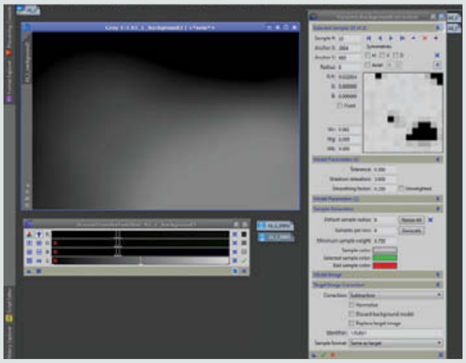
Next I remove any light-pollution or uneven-illumination gradients. This is possibly the most critical step for creating a seamless composition, so I spend as much time as necessary getting it right. *PixInsight*'s Background Modelization process is one of the most sophisticated gradient-removal tools available, particularly the Dynamic Background Extraction tool, or DBE (Process / Background Modelization / Dynamic Background Extraction). Gradient removal deserves an entire article, but for now one of the best ways to see whether we're effectively removing gradients is by examining the background model generated by the DBE tool. You can learn more about this at: **http://pixinsight.com/videos/DBE_M42_Example/en.html**.

Once I have removed the gradients from each of my stacked frames, I register and stitch them together to create my luminance mosaic. I do this by opening the Star Alignment tool (Process / Image Registration / Star Alignment) and changing the working mode to Register/Union – Mosaic. I also check the Generate Masks and most importantly, the Frame Adaptation check-boxes. Frame adaptation analyzes the images and makes the necessary linear adjustments for a seamless background when the frames are stitched together. I also increase the RANSAC tolerance parameter in Star Matching to a value of 6 or higher. After these settings, I select one of my luminance frames as the Reference image, and register any of the other two frames by dragging the blue triangle in the bottom-left of the window and releasing it over the image I want to register.

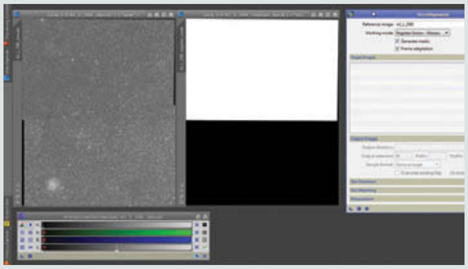
When I finish the Star Alignment process, I should have a new image with the two frames nicely registered and frame-adapted. If Star Alignment failed to register the images, I can limit the registration process to a preview selection, within just the overlapping areas from the



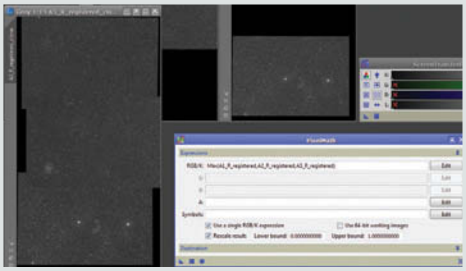
SCREEN STRETCH: *PixInsight* is an astronomical image-processing suite that includes functions for data calibration and stacking, as well as many advanced post-processing routines, while keeping the data in a linear, unstretched format. Because the data is kept linear, computer monitors can't display the entire brightness range. To display a "stretched" preview after each process, you can use the Screen Transfer Function and click the "A" button, and keep the tool open for later use.



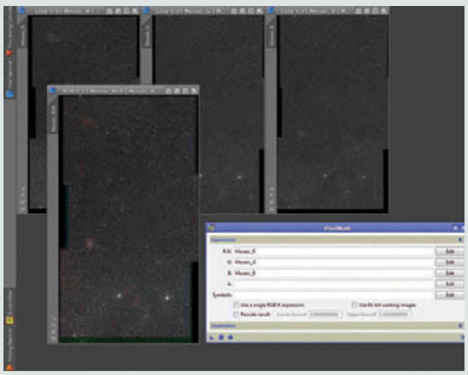
GRADIENT REMOVAL: Suppressing any light pollution or uneven-illumination gradients is critical before stitching together mosaic frames. The author uses the Dynamic Background Extraction tool on each frame, and examines the background model generated to ensure he has properly identified areas to correct before subtracting it from his image.



REGISTRATION: Aligning overlapping frames using the Star Alignment tool is quick and easy. Chose one of the frames as the reference image, and simply drag the triangle at the bottom left of the process window over another image to combine it with the first frame. Repeat this for each additional frame, using the new stitched image as the reference until the luminance mosaic is complete.



STITCHING FRAMES: After registering each of the red, green, and blue frames, each can be stitched together using Pixel Math to create the mosaic's color channels. Pixel Math requires input of a short line of code (shown in the Expressions dialog).



COLOR COMBINE: With the red, green, and blue images assembled, use Pixel Math to combine them into a color image by assigning each channel to its proper position and unchecking the boxes at the bottom of the window. You should also expand the Destination and change the color space to RGB color.

See more of Rogelio's work at blog.deepskycolors.com.

images I'm trying to register. I do this by right-clicking the image and selecting the Mode / New Preview option, then simply clicking at the top-left of the preview area and dragging the cursor to the bottom-right of the area. This tells Star Alignment to only look in this area when searching for star matches, simplifying the registration process.

If the overlap appears seamless in one place but not in other areas, this is due to improper gradient removal or poor flat-field calibration. Although I can later address this using the masks generated by Star Alignment, it's best to go back to the gradient-removal process and refine my DBE parameters, making sure the background model generated corrects the frames properly in all overlapping areas.

Once I have two frames stitched together seamlessly, I repeat the process, this time using the new stitched image as the reference to register the remaining frame. Star Alignment will then generate an image with the three frames nicely registered and integrated.

Integrating Color Data

Once I've completed my luminance mosaic, I crop and remove any gradients from each of the red, green, and blue stacked frames, then register them to the luminance. As before, I use Star Alignment, but this time I change the working mode to Register/Union – Separate, and use the luminance mosaic as the reference image. I also limit the Star Alignment to a defined preview area, and register one frame at a time. For example, if the red images are called R1, R2, and R3 respectively for each frame of the mosaic, I start registering only R1 and define a preview area in the luminance mosaic covering the area where R1 will go, and so on for the other red frames.

This will generate three red images that align nicely with the luminance mosaic, but are black where the other panels will go. I take these newly registered red frames and add them together into one red mosaic using Pixel Math (Process / Pixel Math). When the Pixel Math window opens, I type Max(r1,r2,r3) in the RGB/K line, where r1, r2, and r3 represent my three registered red images. This is the equivalent of blending the three images using the "Lighten" layer blending mode in *Adobe Photoshop*. When I'm done with the red frames, I repeat the registering and pixel-math processes with my green and blue frames.

I'm now left with four mosaics: one per color channel, and the luminance image. As all are still in linear-stretch form, I simply combine the data as if they were single stacked frames that had just been calibrated. I do this with the Pixel Math process again, this time unchecking the "Use a single RGB/K expression" button, and assigning each mosaic to its proper RGB color channel. The luminance image will be added momentarily.

After creating the RGB image, I need to balance the colors. This is very easily done in *PixInsight* by first running Background Neutralization (Process / Color Calibration / Background Neutralization). I follow this with the Color Calibration tool located in the same process menu. Often, the default values in both processes work quite nicely.

After color balancing the RGB image, I perform a non-linear stretch on both the RGB and luminance images. Once I am happy, I then integrate the Luminance channel with the RGB data using the LRGB Combination tool (Process / Color Spaces / LRGB Combination). Now the mosaic is ready for further processing needed to generate the final picture to print or upload to my website.

If you've never assembled a mosaic before, the first few times it may be a bit intimidating. But once you get the hang of it, it's all a matter of practice, like everything else in this hobby. But the benefits are worth the extra effort. You can create sweeping portraits of vast swaths of the night sky. Happy mosaicing! ✦

***Rogelio Bernal Andreo** records his stunning mosaics from rural locations in California.*

After integrating the luminance image with the RGB data, you can crop, stretch, and sharpen the image in *PixInsight* until you're happy with the final result. This mosaic of three frames reveals IC 443 and surrounding nebulae near the borders of Gemini and Orion. The author recorded it with a Takahashi FSQ-106EDX astrograph and SBIG STL-11000M CCD camera.

▸ **FACE-ON CLOSE-UP**

Al Kelly

The face-on spiral galaxy IC 342 in Camelopardalis appears riddled with pinkish star-forming regions, though its overall appearance is distinctly reddened due to intervening dust within our Milky Way Galaxy.

Details: *14-inch Celestron CGE 1400 Schmidt-Cassegrain with Orion Parsec 8300C CCD camera. Total exposure was 3⅓ hours at f/6.7.*

▾ **THE BURNING HEART OF SCORPIUS**

Ivan Eder

Straddling the border of Ophiuchus and Scorpius, this striking group of dark, emission, and reflection nebulae is known collectively as the Rho Ophiuchi cloud complex.

Details: *Modified Canon EOS 5D Mark II DSLR with 200-mm lens at f/4. Total exposure was 57½ minutes from Windhoek, Namibia.*

▲ **APOGEE AND PERIGEE**

Pedro Ré

The Moon's varying apparent size is striking when a photo of the particularly close perigee of March 19th (*left*) is compared to a photo taken at apogee on June 6, 2009.

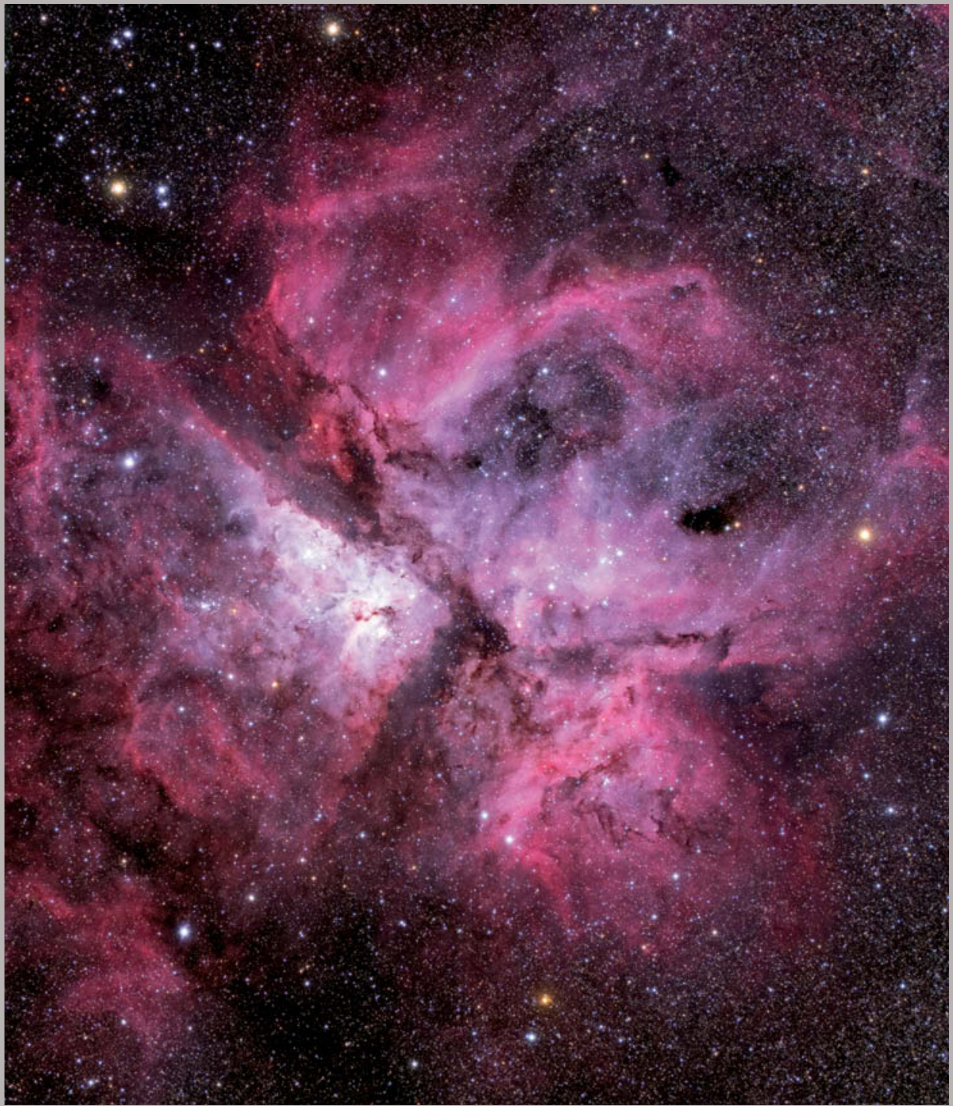
Details: *Takahashi FS-128 refractor with Canon EOS 350D DSLR camera. Each image is a stack of 10 frames.*

► **SHOWPIECE OF CARINA**

José Joaquín Pérez

The Carina Nebula (NGC 3372) is the brightest nebula in the sky. Visible from the Southern Hemisphere, this huge star-forming region is home to one of the most luminous stars known, Eta Carinae (left of center), which erupted around 1840 to become the second-brightest star in the night sky.

Details: *Astro-Physics 140EDF4 refractor with SBIG STL-11000M CCD camera. Total exposure was almost 8 hours through Baader Planetarium color filters.*



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▸ RISING GALAXY

P. K. Chen

The center of the Milky Way rises over Jade Mountain (Yushan) in Taiwan.

Details: *Canon EOS 450D with a 15-mm lens. Total exposure was 5 minutes.*

▾ RESPLENDENT SWORD

Fabian Neyer

This exquisitely detailed photograph of the Sword of Orion reveals the famous Horsehead Nebula (Barnard 33) and the Great Orion Nebula (M42), as well as many faint emission and reflection nebulae that permeate the region.

Details: *Borg 101ED refractor with SBIG STL-11000M CCD camera. Four-panel mosaic totaling over 60 hours of exposure through Baader Planetarium hydrogen-alpha and color filters.* ✦

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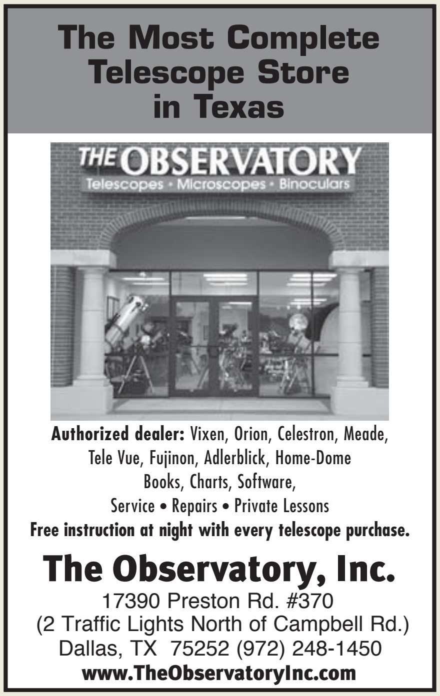

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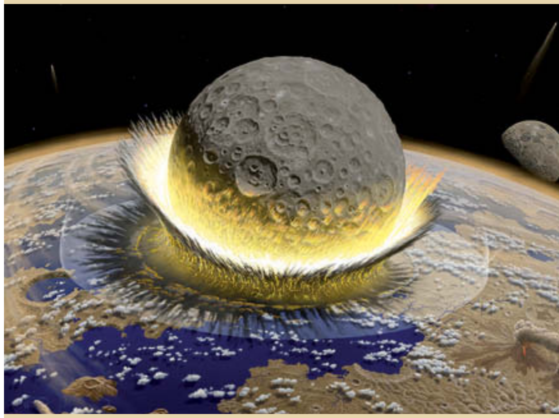

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Singing to the Bugs

The author worked through a sweltering Arizona summer to buy his first telescope.

Like many people involved in our hobby, I became interested in astronomy as a child. I learned to identify the planets and constellations in grammar school, and eventually decided I wanted a closer look at them. By the time I started high school, I had set my sights on a very fine telescope made by a local optician named Max Bray. All that stood between me and that beautiful instrument was several hundred dollars. Sufficiently motivated, in the summer of 1974, I looked for a way to earn the money.

I soon found my first summer job thanks to my older brother, who worked part-time at a local plant nursery. My task was simple: water the trees. The nursery had hundreds of saplings in 55-gallon barrels. Six days a week, eight hours a day, I walked from barrel to barrel, giving each tree its daily allotment of water.

This was a summer job in Phoenix, Arizona. As you can imagine, Phoenix can get a little warm in the summer; 110°F (43°C) in the shade isn't unusual. Unfortunately, there was very little shade among the saplings, so I didn't even have that small comfort. And the owner of the nursery, Mr. Baker, had some unusual rules for his employees, one of which was that male workers were not allowed to wear short pants unless their legs were "prettier" than the legs of his teenage daughters. At least I would never suffer from sunburned knees.

It goes without saying that the job was not intellectually stimulating. Finding new ways to exercise my imagination was essential for maintaining my sanity during those long, baked days. I talked to bugs. I made up songs and sang them to the bugs. I counted the leaves on ficus trees and had deep philosophical conversations with lizards. Above all, I continually reminded myself of all the amazing things I would be able to see once I had the money to buy that telescope. At $1.35 an hour, it would take about eight weeks. My star-struck eyes fixed firmly on the prize, I moved from tree to tree, water hose in hand, singing to the bugs.

The dismal summer finally came to an end, and the telescope was mine. It did not disappoint. My first view of the rings of Saturn took my breath away, and the brilliant optician Max Bray became a lifelong friend.

Would the view through that telescope have been as precious if I didn't have to work so hard for it? Probably. But the memory of watering those trees and singing to the bugs as I dreamed about the stars still brings a smile to my face. And I still look at the stars. ✦

__Andre Bormanis__ lives in Los Angeles and is working on the upcoming Disney TV series Tron: Uprising. *He has also written for* Star Trek: Voyager *and* Star Trek: Enterprise.


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