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SKY & TELESCOPE

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On the cover: NASA's Cassini spacecraft has unveiled many of Saturn's dirty little secrets.

COVER: BJÖRN JÓNSSON / NASA

SKY & TELESCOPE (ISSN 0037-6604) is published monthly by Sky & Telescope Media, LLC, 90 Sherman St., Cambridge, MA 02140-3264, USA. Phone: 800-253-0245 (customer service/subscriptions), 888-253-0230 (product orders), 617-864-7360 (all other calls). Fax: 617-864-6117. Website: SkyandTelescope.com. Periodicals postage paid at Boston, Massachusetts, and at additional mailing offices. Canada Post Publications Mail sales agreement #40029823. Canadian return address: 2744 Edna St., Windsor, ON, Canada N8Y 1V2. Canadian GST Reg. #R128921855. POSTMASTER: Send address changes to *Sky & Telescope*, PO Box 420235, Palm Coast, FL 32142-0235. Printed in the USA.

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  See videos and photos from Cassini.
- **Planetary Migration with Greg Laughlin**
  Editor in Chief Robert Naeye interviews exoplanet expert.
- **Stonewall Jackson in the Moonlight**
  See more historical images depicting the Battle of Chancellorsville.

Photo Gallery

Image by Mick Hollimon

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Howard Bower captured the large and extremely faint supernova remnant Simeis 147 with 36 hours of exposure time. To see more fantastic shots, or to submit your own, see our online photo gallery.

The Russian Meteor: A Needed Wake-Up Call

LIKE THE REST OF THE WORLD, I was stunned by the February 15th asteroid breakup over Russia (page 10). Just the night before, I was talking to members of the Amateur Telescope Makers of Boston at our monthly meeting about the next day's flyby of asteroid 2012 DA_{14}. I got out of bed at 6:00 a.m. on the 15th and logged onto the internet to headlines that a meteor had exploded over the Ural Mountain region of Russia. For a minute, as I tried to clear my groggy head, I assumed this was just a particularly bright fireball.

But as I read news reports that people were injured, I quickly realized this was the real deal — a significant and watershed asteroid impact with Earth. I was stunned by the quality and quantity of dramatic videos, and felt relief that there were no reports of fatalities. I was *not* surprised when I saw quotes from leading experts that the Russian fireball and 2012 DA_{14} were going in different directions and were thus completely unrelated, but was astonished by the temporal coincidence.

Then, my professional self went into overdrive. By 6:10 a.m. I was sending and receiving e-mails from *S&T* colleagues about the need to cover this event quickly on our website. Shortly after driving to the office I wrote a story for our website, and later did a television interview with the local CBS affiliate. My colleagues helped me update the web article as more information and imagery poured in.

The *S&T* staff deeply regrets that people were injured, and we wish all of them a full and speedy recovery. I also feel badly that these unfortunate folks have to face a Russian winter with shattered windows and damaged buildings. But despite the human hardship, I see a silver lining in this asteroid breakup. The well-documented event, along with the very close 2012 DA_{14} flyby, serves as a wake-up call that humanity needs to view the asteroid impact threat as something more serious than fodder for mediocre Hollywood action flicks. The event over Russia was big enough that the entire world took notice, but not so large as to wreak death and destruction on a large scale (or potentially trigger an accidental nuclear war). Every government in the world is now keenly aware that Earth lies amidst a cosmic shooting gallery, and that it's possible for an asteroid to explode over its territory. I feel that my nation has so far done its part to discover threatening asteroids and characterize the impact hazard. Now it's time for the international community to come together to take the next logical steps in defending our planet. ✦

Robert Naeye
Editor in Chief

SKY & TELESCOPE
Founded in 1941 by Charles A. Federer, Jr. and Helen Spence Federer
The Essential Guide to Astronomy

Editorial Correspondence: *Sky & Telescope,* 90 Sherman St., Cambridge, MA 02140-3264, USA. Phone: 617-864-7360. Fax: 617-864-6117. E-mail: editors@SkyandTelescope.com. Website: SkyandTelescope.com. Unsolicited proposals, manuscripts, photographs, and electronic images are welcome, but a stamped, self-addressed envelope must be provided to guarantee their return; see our guidelines for contributors at SkyandTelescope.com.

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Phone toll free: 888-253-0230.

Subscription Rates: U.S. and possessions: $42.95 per year (12 issues); Canada: $49.95 (including GST); all other countries: $61.95, by expedited delivery. All prices are in U.S. dollars.

Newsstand and Retail Distribution: Curtis Circulation Co., 730 River Rd., New Milford, NJ 07646-3048, USA. Phone: 201-634-7400.

Bishop Museum's Voyage Continues

Many planetarians remember Bishop Museum, in Honolulu, Hawaii, as the creator of the NASA-sponsored "Explorers of Polynesia" planetarium show. It told the story of modern Hawaiians recreating migratory voyages around the Pacific in double-hulled sailing canoes. That show revealed some of the non-instrument navigational techniques which were developed using observations inside this planetarium 35 years ago.

Of course Bishop also features programs on modern astronomy and the discoveries atop Mauna Kea, but planetarium director Mike Shanahan continues to tell the story of Hawaiian voyaging to tens of thousands of visitors and residents annually. And the planetarium continues to train new Polynesian navigators to sail with a deep understanding of the sky and signs from Nature, but without compass or sextant; without maps or GPS.

Bishop Museum recently renovated the planetarium with a new dome, seats, audio, lighting, and GOTO CHRONOS II HYBRID projection and control system. The CHRONOS II star projector uses long-life LEDs to illuminate 8,500 perfect stars and a gorgeous Milky Way to put audiences "on the canoe" at sea, on a perfect night. And unlike older analog projectors, the digitally-controlled CHRONOS II is able to "jump" to any location on earth, at any time in the past, present, or future, in a matter of seconds rather than minutes or hours.

A synchronized fulldome video system adds enhancements to the CHRONOS II sky which can include coordinate lines, constellation figures, or even partial clouds (!) to aide in the realistic simulations used to teach navigation. The intuitive and ergonomically-designed GOTO HYBRID control console recently allowed Hawaii's master navigator to simply walk up and begin using it to teach his current class of Polynesian navigators!

GOTO INC is very proud to have used input from former Bishop Museum planetarium director Ken Miller and hundreds of other planetarium professionals in the design of the CHRONOS II HYBRID system. Ken joined GOTO INC 13 years ago, where he helps custom fit GOTO systems to users around the world.

Ken Miller (left) Mike Shanahan (right)

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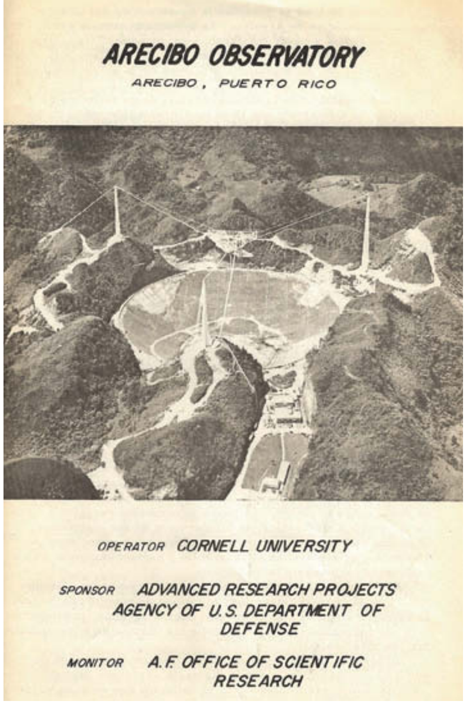
Spring Cleaning Brings Memories

I lived in Puerto Rico from the autumn of 1968 to the spring of 1971, when I was assigned to Ramey Air Force Base, northeast of Aguadilla. I took at least two trips up the tortuous roads that lead to the Arecibo Observatory to gawk and let some of the people who visited us gawk, too.

In cleaning out decades of memorabilia I came across a brochure we must have picked up on one of our visits to the observatory. It is a single sheet of 8½″ × 11″ paper printed to make four pages, comprising a cover, descriptions of the facility written in Spanish and English, and a sketch of the observatory's layout. Its configuration then was quite a bit different from what it is today. Note the project's sponsor and monitor: I wonder what they were doing down there in addition to the radio astronomy they conducted.

Gerald P. Hanner
Papillion, Nebraska

Editor's Note: *Ionospheric research. Arecibo Observatory was the brainchild of Cornell professor William E. Gordon, who wanted to study the ionosphere. The Defense Department's Advanced Research Projects Agency (ARPA, now DARPA) thought the observatory would be useful for tracking ion trails from missile exhaust. However, the military was also a primary sponsor of scientific research at the time, so it wasn't particularly odd for it to be involved with building an astronomical observatory — plus, NASA wasn't interested and the NSF couldn't afford it. Andrew J. Butrica wrote an in-depth account of Arecibo's history in his book* To See the Unseen: A History of Planetary Radar Astronomy. *You can read it online at* ***http://history.nasa.gov/SP-4218/sp4218.htm***.



GERALD P. HANNER

The Arecibo Observatory was officially a Department of Defense project until its transfer to the National Science Foundation in 1969.

In the Dark about Dark Matter

In his January 2013 cover story about dark matter (page 26), Dan Hooper mentioned the search for a grand unified theory (GUT), which reminded me of a four-line poem I wrote many years ago that had almost slipped from my mind:

He was the one with real true GUTS
He spoke them forth, no if's no but's
All thought out so long and well
All explained e'n heav'n and hell.

K. Rod Schultz
Ukiah, California

In his article Hooper informs us, "If the dark matter takes the form of particles that are between about 10 and a few thousand times as massive as the proton, then XENON-100 should be able to detect their impacts." This range limit on the mass exists because of a physical phenomenon known as *coupling*. For an intuitive understanding of coupling, imagine trying to hit a dried pea or a basketball with a baseball bat. Neither will go as far as a baseball, because both are outside the optimal mass range for energy coupling, bat-to-ball. The underground attempts at detection are looking for the particle-physics equivalent of home runs, those rare instances when dark and regular matter "connect."

Therefore, is it naïve to expect more detections when Earth is plowing into the dark matter halo? The flux of particles will be higher, yes, but the degree of coupling won't necessarily be. Coupling could instead be greater when Earth is moving *slower* with respect to dark matter than when moving faster, depending on the nature of the interaction. After all, slow-moving neutrons interact with nuclei more strongly than fast ones.

Peter Wilson
Phoenix, Arizona

Author's Note: *For most types of dark matter that we have hypothesized, the interaction strength (or coupling) between dark matter and nuclei does not depend significantly on how fast the dark matter particles are moving. So the variation in rate is just the result of the flux variations as Earth plows through space. In other, less-typical dark matter models, the interaction strength can go up with velocity, making the significance of the dark matter wind even more important.*

"Dark matter" and "dark energy" continue to remind me of the F_f of my student days, the "fudge factor" by which we multiplied our answer to make it match the answer in the book. Both the Ptolemaic and Newtonian systems were abandoned when observations did not agree with theory. Now once again we have a dispute between observation and theory. Of course, non-visible matter might still be identified, but that still leaves "dark energy" as a fudge factor. It seems to me that we need new theorizing.

Robert H. Irwin
Berkeley, California

Editor's Note: *What makes the evidence for dark matter so compelling to both research astronomers and physicists are the multiple, independent, and consistent lines of evidence. We see the effects of dark matter in how galaxies rotate, in how galaxy clusters are held together, in the growth of large-scale cosmic structure, and in the statistical pattern of microwave background temperature variations. Multiple lines of evidence exist for dark energy, too. Dark matter may indeed be a "fudge factor," but it's a unifying concept*

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that explains many disparate phenomena simultaneously — the hallmark of a robust scientific theory. Ongoing investigations will ultimately determine whether dark matter and dark energy actually exist.

Flash from the Past

At 16 years old, I was an extremely active amateur astronomer living near Pasadena, California. Early in the summer of 1969 my mother contacted Hale Observatories, and my friend Stephen Edberg (now at NASA's Jet Propulsion Laboratory) and I became volunteers at the Hale Observatory Library on Wednesday afternoons during the summer break. It was heady stuff for two 16-year-olds, but we rarely saw the staff astronomers. Only two took a few minutes out of their schedules to talk with us — Henrietta Swope and Halton Arp. I never forgot the experience. Roger Sinnott's "75, 50 & 25 Years Ago" column in the January issue (page 11) surprisingly had articles about both astronomers, and that coincidence brought back to my mind that wonderful experience from over 40 years ago. Thank you for the memories!

James Richards
Radcliff, Kentucky

For the Record

✷ *In the sky chart for microquasar SS 433 on page 38 of the March issue, the labels for 19 and 22 Aquilae are transposed.*

75, 50 & 25 Years Ago

Roger W. Sinnott

May 1938

Runaway Globular? "A newly discovered globular cluster, to be reported by Dr. [Harlow] Shapley in a current publication of the Harvard Observatory, may be intergalactic. . . . The system carries the number NGC 1841 and is only six degrees from the South Pole of the sky. . . . Before we can confidently place NGC 1841 far outside the ordinarily accepted bounds of the Galaxy we must discover and study its variable stars, if any, and not trust alone to the rather deceptive measures of angular diameter and integrated brightness."

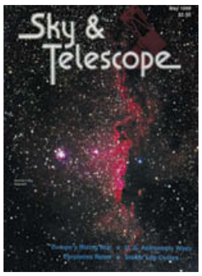
Left unsaid in this news item is that NGC 1841 lies about 14° from the Large Magellanic Cloud. Shapley thought the globular was much farther from us, but now we know that it belongs to the LMC's own family of globular clusters.

May 1963

Big Shrink "About 10 billion years ago, the Milky Way galaxy underwent a rapid collapse, shrinking to about a tenth of its former diameter and about 1⁄25 its thickness. This idea is due to three astronomers at Mount Wilson and Palomar Observatories: O. J. Eggen, D. Lynden-Bell, and A. R. Sandage. Their evidence consists of the observed motions and colors of 221 well-studied dwarf stars. . . .

"It is now known that metal-poor stars are older than metal-rich ones. Hence the older stars are those with highly elliptic, strongly inclined galactic orbits, while the younger ones move nearly in the galactic plane in circular orbits. . . ."

This finding of Eggen, Lynden-Bell, and Sandage is considered a classic of deductive reasoning. Astronomers now think the Milky Way formed from several smaller clumps combining and collapsing together, instead of just one as the trio first proposed.



May 1988

Light Echo "The first visible light echo ever seen from a supernova has been detected around SN 1987A by Arlin P. S. Crotts (University of Texas). This phenomenon is due to light from the explosion reaching us after illuminating, or 'echoing off,' interstellar clouds in the supernova's vicinity. . . .

"On March 4th, Crotts photographed two glowing arcs 32 and 47 arc seconds from the supernova . . . [that come] from clouds lying some 440 and 950 light-years, respectively, *in front of* the new star as seen from Earth."

The luminous arcs appeared just one year after the supernova itself. The likelihood of such echoes had been pointed out a few months earlier by Bradley E. Schaefer (now at Louisiana State University).

Learn more about the Russian meteor at skypub.com/RussianMeteor.

FIREBALL | Russian Meteor Wreaks Havoc

On February 15th a meteoroid exploded over Russia, creating this trail over Chelyabinsk in west-central Russia. The object detonated a couple of minutes before this photo was taken.

URAGAN.TT / WIKIMEDIA COMMONS

A meteoroid exploded over Russia on February 15th with the energy of an estimated 470 kilotons of TNT, the equivalent of about 30 Hiroshima bombs.

The bolide streaked through Russian skies at 9:20 a.m. local time and outshone the Sun. One minute 28 seconds later, shock waves from its deceleration and explosion collapsed structures and blew out roughly 100,000 square meters (1 million square feet) of windows. The meteoroid exploded almost directly above Chelyabinsk, an industrial city of about 1 million people. Damage varied widely, even within the same building: shock waves behave like bouncing balls, bludgeoning some surfaces and sparing others depending on how the waves are directed and how well they resonate with certain materials. More than 1,000 people were injured, mostly by flying glass.

Collected fragments are ordinary chondrites, stony meteorites that make up 85% of all meteorites recovered. Despite early reports that a fragment blasted a hole in the frozen Lake Chebarkul, about 80 kilometers (50 miles) west of Chelyabinsk, it's now unclear whether the fireball and the hole are actually related.

By an amazing coincidence, the impact occurred just 16 hours before the predicted closest approach of asteroid 2012 DA_{14} (February issue, page 51). But the two objects were moving in different directions — the asteroid south to north, the bolide east to west. Calculations put the outer end of the impactor's former orbit in the asteroid belt (see diagram below).

"This is *not* related to 2012 DA_{14}," says Peter Brown (University of Western Ontario, Canada). "This is perhaps the most certain aspect of the entire event."

Although 16 hours might seem a short period of time, Earth moves about 30 km per second (67,000 mph) through its orbit, meaning that in those few hours the planet traveled more than 1.7 million km.

Analyses by Brown and others suggest the meteoroid entered Earth's atmosphere at 18 km/s, a speed typical of near-Earth objects (NEOs). It entered at a grazing angle of 16° and burst at an altitude of 25 to 30 kilometers. Based on data from worldwide infrasound stations, about 20 seconds passed between atmospheric entry and the meteor's airborne disintegration. Given a chrondritic composition and the bolide's estimated energy yield, the original object had a mass of roughly 10,000 metric tons and was about 17 meters (55 feet) in diameter.

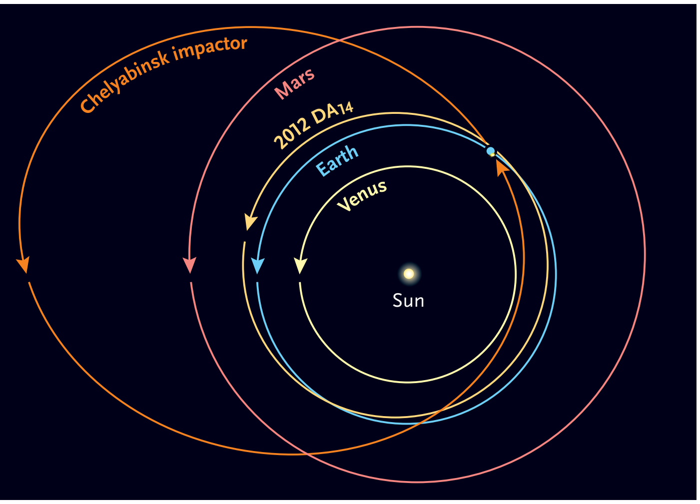
An event of this magnitude happens about once per century. It's the biggest known impact since the Tunguska event in 1908, which exploded with roughly 20 megatons a mere 8.5 km above the ground and flattened 2,000 square kilometers of trees in central Siberia. More recently, a bolide detonated over Indonesia in 2009, with an estimated energy of 50 kT.

Thankfully no one was killed by the Chelyabinsk event, but that's no guarantee for future safety. The one-two combo with

POSPEL A / WIKIMEDIA COMMONS

Shock waves from the meteor explosion damaged the roof of the Chelyabinsk Zinc Plant, which collapsed despite its steel beams.

Despite the extraordinary concurrence of their arrivals, the Chelyabinsk meteoroid and asteroid 2012 DA_{14} are unrelated objects. Calculations show the meteoroid came from much farther afield, with its orbit extending into the main asteroid belt.



S&T: LEAH TISCIONE, SOURCE: DAVE CLARK / PETER BROWN / PAUL CHODAS

2012 DA_{14} should serve as a wake-up call, experts say.

"It's one thing to talk in the abstract about blown-out windows, et cetera," says Dan Durda (Southwest Research Institute). "It's quite another to be reminded that there are very often people behind and under that shattered glass. *That's* why we care about these events and that's why it's worth the investment to survey for smaller NEOs and to plan for preventing larger impacts."

Besides the worldwide attention, the event has scientific value. "The major significance is that this is the first well-documented event which has clear ground-level effects," says Brown. "This will permit calibration of entry models for tens-of-meter-sized objects for the first time."

Such small objects are difficult to track. Of the near-Earth asteroids discovered so far, only about 35% are smaller than 100 meters across. Former NASA astronaut Ed Lu (B612 Foundation) estimates that we've only found 1% of objects the size of 2012 DA_{14}, which is about 50 meters wide. More details will appear in next month's issue.

■ **CAMILLE M. CARLISLE**

METEORITES | First-Ever Sample from Mercury?

STEFAN RALEW / WWW.SR-METEORITES.DE

This largest fragment of meteorite NWA 7325 weighs just over 100 grams and is about the size of a golf ball (the cube is 1 cm on a side). The moss-green color comes from a silicate mineral called diopside that's infused with chromium.

A clutch of meteorites from northwest Africa, known as NWA 7325, looks to be a near-perfect geochemical match to the surface of the innermost planet. All previous candidates for pieces of Mercury (called angrites and aubrites; *S&T*: April 2012, page 31) are close but imperfect matches to the surface composition found by NASA's Messenger spacecraft.

German meteorite dealer Stefan Ralew bought NWA 7325's 35 pieces in April 2012 a few months after they were found in the Moroccan desert. The fragments total 354 grams (12.5 ounces). The stunning green of their fusion crust, created by flash heating while diving into Earth's atmosphere, prompted Ralew to send samples to meteorite expert Anthony Irving (University of Washington).

Irving and his team found that the meteorite contains abundant magnesium and calcium but almost no iron — hallmarks of what geochemists think rocks from Mercury should be like.

Irving is trying to keep his enthusiasm in check. "NWA 7325 is tantalizing, and certainly more consistent with the Messenger results than either angrites or aubrites," he explains, "but we need a [spacecraft-returned sample] for 'ground truth'."

Shoshana Weider (Carnegie Institution of Washington), who has spent years studying Messenger's spectra of Mercury, is likewise cautious. The planet's surface seems to be rich in the silicate mineral enstatite, which is not obvious in NWA 7325. Also, there shouldn't be so much calcium. To explain these discrepancies, she and Irving agree that the meteorite might have been part of the bedrock deep below the surface, before a large impact sent it flying off into interplanetary space.

There are still many unknowns about these weirdly green space rocks. Tests are under way to determine their age and time in space before reaching Earth. So far Ralew isn't offering any of NWA 7325 for sale, to give researchers the chance to run the entire gamut of analytical tests.

■ **J. KELLY BEATTY**

SUPERNOVAE | Tipoff for Impending Death

A massive outburst might give astronomers a few weeks' advance notice of when certain giant stars will go supernova, Eran Ofek (Weizmann Institute of Science, Israel) and his colleagues report in the February 7th *Nature*.

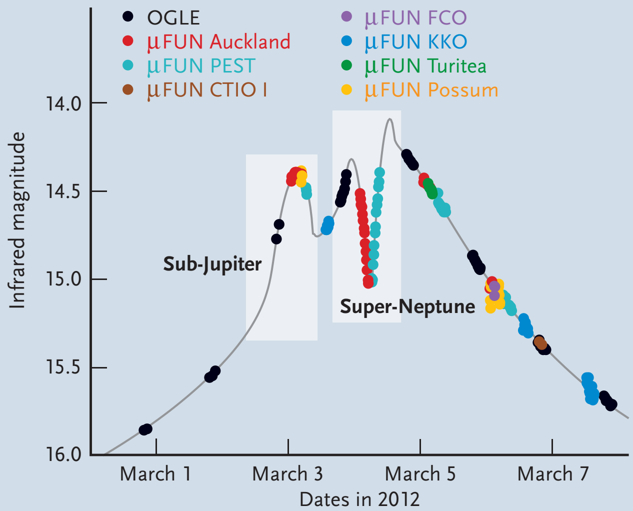
Forty days before it blew, the star that became SN 2010mc brightened and belched a massive amount of gas at 2,000 km/sec (4.5 million mph), more than twice the speed of the Sun's fastest wind. The star then exploded as a Type IIn supernova, distinguished from other core-collapse supernovae by its narrow hydrogen spectral lines.

After the star exploded, the expanding debris slammed into the previously ejected gas, leaving telltale signatures in the supernova's light curve and spectrum. Ofek and his colleagues used these signatures to estimate the mass of the pre-supernova outflow. The blow-off amounted to 1% of the Sun's mass, a great amount compared to typical stellar winds. Given the short period separating the two events, the authors estimate that there's a 99.9% chance the belch and supernova are related.

This process might be common to all Type IIn supernovae, which are thought to be the deaths of *luminous blue variables*, massive stars known for their eruptive events. A recent paper by Jon Mauerhan (University of Arizona) and his colleagues in the *Monthly Notices of the Royal Astronomical Society* examined SN 2009ip, which has a light curve remarkably similar to SN 2010mc. That star might have undergone a similar outburst less than two months before it died. But it cried wolf twice with previous flare-ups (in 2009 and 2010) before the final outburst (in 2012), so the first two events were likely from a different process.

■ **MONICA YOUNG**

PRO-AM | Amateurs Help Detect Distant Multi-Planet System



Observations by the Optical Gravitational Lensing Experiment (OGLE) in Chile (black dots) only track parts of a light curve resulting from a star lensing a more distant star. Amateur observatories at various longitudes around the world (other colors) caught more of it, revealing signs of two giant planets (boxed). SOURCE: OGLE / MICROFUN COLLABORATION

An international pro-am collaboration called the Microlensing Follow-Up Network (MicroFUN) has announced the second discovery of a multiple-planet system by the microlensing method. The group discovered a super-Neptune and sub-Jupiter by monitoring the brightening and fading of a *K* dwarf star 13,000 light-years away, halfway to the galactic center. Both planets reside beyond the star's snow line, the distance where water vapor in a forming system can condense into grains of ice.

Gravitational microlensing occurs when a passing foreground star temporarily magnifies a background star's light. A planet orbiting the foreground star can reveal itself by adding additional wiggles to the light curve. Microlensing is good for finding low-mass planets and also planets far from their stars, both of which are challenging for other techniques. But detecting exoplanets via microlensing requires close monitoring of millions of stars. And only amateurs can dedicate the near-continuous global coverage to capture the entire light curve when one of these events begins.

Founded in 2004, the MicroFUN collaboration consists of 23 observatories, 16 of them amateur-run. When a survey scope spots the start of a promising microlensing event, the other observatories follow up, ideally filling in the light curve without a break as Earth rotates through night and day.

"Even a bright lens will in most cases only reach a peak brightness of around magnitude 15 in the near-infrared," says Berto Monard, a South African amateur member of MicroFUN since 2006. "This is a faint, sometimes near-invisible, dot or smudge amidst a star region with thousands of brighter stars, on a CCD chip that shows a star field one-third the size of the full Moon."

As the graph above illustrates, amateur observations were crucial in detecting the complex dips that indicate the two new planets. Amateurs interested in joining MicroFUN can learn more at bit.ly/VXhaKh.

■ **MONICA YOUNG**

SUN | Astronomers Zoom in on Solar Hairs

Solar astronomers have effectively resolved the individual hairs on the Sun's hot head, an achievement that might help them understand why that head is so hot in the first place. Using a new instrument called the High-resolution Coronal Imager (Hi-C) borne on a sounding rocket, Jonathan Cirtain (NASA/Marshall Space Flight Center) and his colleagues took five minutes of images of the Sun's corona. The images' resolution is 150 kilometers (90 miles), so fine that the pictures reveal individual strands of plasma.

To put that in perspective: the ratio of the Sun's diameter to the smallest structure the images can resolve is about the same as the ratio of my height to the width of one of my hairs — roughly 1:9,000. (I have thick hair.)

Hi-C's resolution is six times sharper than the AIA instrument aboard NASA's Solar Dynamics Observatory, which heretofore had the highest-resolution view of the corona. Rocket flights are an inexpensive way to demonstrate that new technology works before investing in a long-duration mission to carry it, so the detection of such small structures is good for Hi-C as well as solar physics.

One reason astronomers want to see the corona in ever-higher resolution is because they don't understand why it's so hot. The corona blazes at roughly 2 to 4 million kelvin (3.5 to 7 million degrees F), a hundred times hotter than the chromosphere below it. The Sun's direct heat can't cause that, so something invisible must be carrying a lot of extra energy up and depositing it into the corona. The likely culprit is the release of energy from stressed magnetic lines of force, but researchers don't know the details of how that works (*S&T*: October 2012, page 16).

The plasma structures that Hi-C detected could be related to this energy release. The structures twisted and changed during the observations, suggesting the magnetic field is doing the same thing. Combining Hi-C's images with simultaneous observations by AIA and the Japanese Hinode spacecraft, Cirtain and his colleagues saw flares and temperature spikes up to 7 million kelvin as the structures unwound themselves, the team reported in the January 24th *Nature*.

Twisted, curved magnetic field lines carry energy, explains Gert Botha (Northumbria Uni-

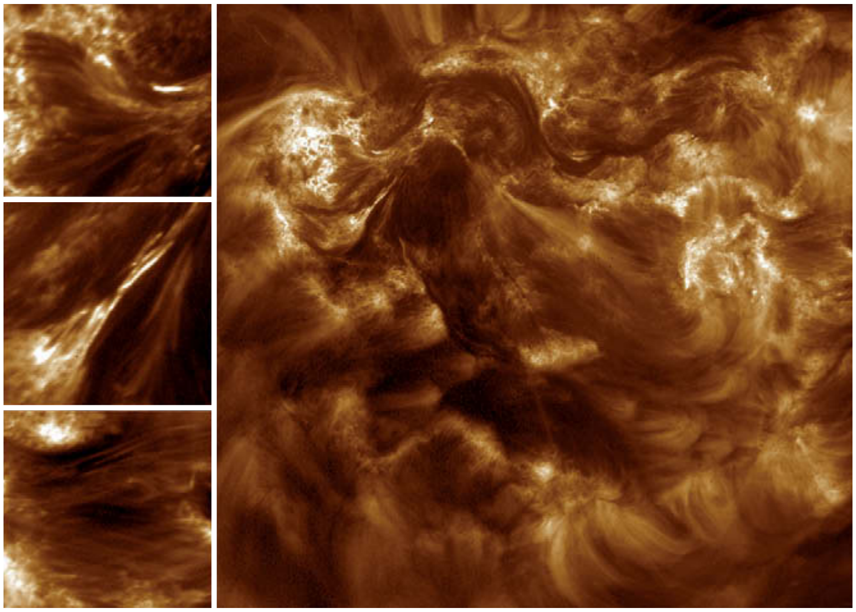
Watch plasma filaments writhe on the Sun: skypub.com/solarhairs.

versity, England), who studies structures similar to those Hi-C detected. As long as the structure is stable, nothing happens. But the writhing field lines don't want to be stable — like stretched rubber bands, they want to snap back into simple configurations. When they snap in a process called *magnetic reconnection,* the field lines break apart and reconnect into a lower-energy structure, releasing pent-up energy to heat the surrounding gas.

Solar physicist Peter Cargill (Imperial College London, England) cautions that it isn't clear that the unwinding Hi-C sees is definitely heating the corona. "After all, it is 'just' five minutes of data," he says. "The achievement documented here is to show that Hi-C works, and that, with a little more time, good science can be done."

The team thinks the structures are "magnetic braids," ropes of field lines in which different strands are interwoven, like hair in a pigtail. Other researchers are split over that interpretation, but detecting braids would be exciting because, while a mainstay in solar physics theories, magnetic braids have never been directly observed.

■ **CAMILLE M. CARLISLE**



AMY WINEBARGER / NASA MSFC

The High-resolution Coronal Imager (Hi-C) captured more than fifty 16-megapixel images of the solar corona in the extreme ultraviolet at a wavelength of 19.3 nanometers, which highlights plasma at a temperature of 1.5 million kelvin. The large image is the full frame; the three small ones on the left are details of the Hi-C image. A twisted plasma rope appears in the central left image.

IN BRIEF

X-ray and radio observations have detected a strange switcheroo in the radiation from a pulsar, an international team reports in the January 25th *Science*. Astronomers knew that the radio emission from PSR B0943+10 turns on and off periodically, but now they've discovered that the pulsar's X-ray emission does too — in reverse order to the radio emission. When the radio emission is bright the X-rays are not, and vice versa. The changes indicate big, fast upheavals in the pulsar's magnetosphere, an unexpected phenomenon that perplexes researchers.

■ **CAMILLE M. CARLISLE**

An analysis of 3,897 cool red dwarfs that NASA's Kepler spacecraft is watching might raise hopes for detecting Earth-size planets. Courtney Dressing and David Charbonneau (Harvard-Smithsonian Center for Astrophysics) carefully recalibrated the stars' temperatures to match stellar models, and this work downsized the diameters of the stars — and hence their candidate planets — by about 30%. The sample includes 64 stars that have a total of 95 planet candidates, including three (now) Earth-size objects in habitable zones. Extrapolating from these observations, the astronomers estimate that roughly 6% of all red-dwarf stars have an Earth-size planet orbiting in the habitable zone.

■ **CAMILLE M. CARLISLE**

Asteroid mining might seem like a pipe dream, but it's already getting competitive. Deep Space Industries announced plans on January 22nd that optimistically call for a first-phase launch of asteroid probes in 2015. This follows last year's similar announcement by Planetary Resources (*S&T*: August 2012, page 18). So far, Planetary Resources has notable advantages, including several billionaire investors and a working prototype spacecraft. The growing interest also raises questions of regulation: there's no system controlling private companies' licensing and liability in space.

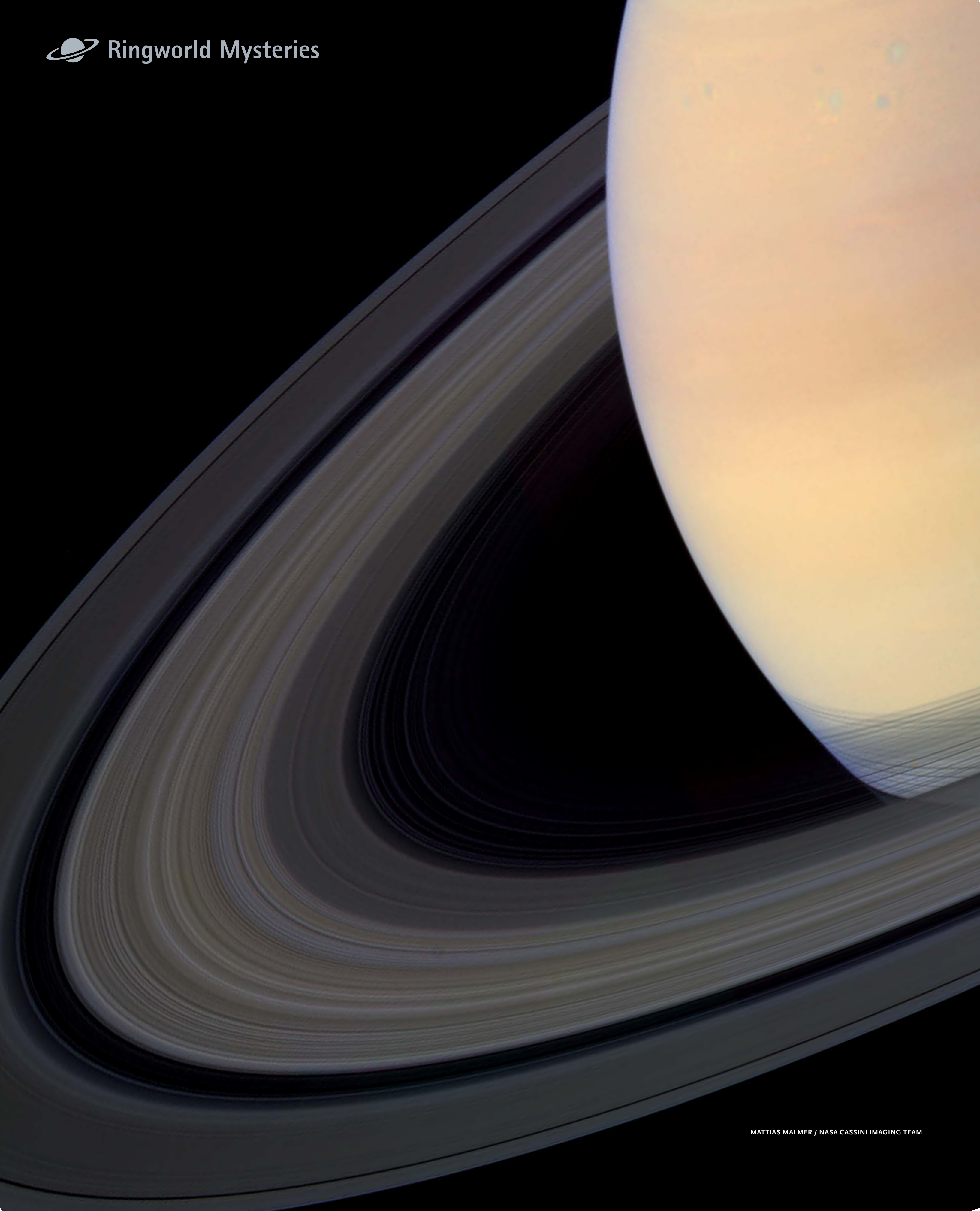
■ **MONICA YOUNG**

Astronomers working with NASA's Fermi Gamma-ray Space Telescope say they might finally have the smoking gun they've needed to convict supernova remnants as a major source of the energetic particles called cosmic rays. An international team reported in the February 15th *Science* that the gamma rays from the remnants W44 and IC 443 roughly match those expected from the decay of subatomic particles called pions produced by cosmic-ray protons colliding with gas in the surrounding molecular clouds. The observations are the best evidence yet to affirm the long-standing theory that supernova remnants accelerate the high-energy particles.

■ **CAMILLE M. CARLISLE**

Ground- and space-based observations suggest that Io's volcanism might affect Jupiter's auroral activity, Japanese and Belgian researchers report in an upcoming *Icarus*. Jupiter's sodium nebula — produced from Io's volcanic spew — beefed up in May and June 2007, indicating that the moon's volcanism increased. But shortly after this enhancement began, radio emission associated with Jupiter's aurora quieted, suggesting the uptick also suppressed auroral activity. The results add to other evidence that Io's volcanism controls Jupiter's magnetospheric activity. ✦

■ **CAMILLE M. CARLISLE**



MATTIAS MALMER / NASA CASSINI IMAGING TEAM

Saturn's *amazing* Rings

J. Kelly Beatty

Astronomers' understanding of these beautiful bands has come a long way since Galileo first spied "a case so surprising" in 1610.

MANY OF US got our first big celestial thrill by peering into an eyepiece at the planet Saturn. This month the ringed wonder has again positioned itself for easy telescopic viewing, as Alan MacRobert explains on page 50. But no matter how good the telescope, views of Saturn's rings from Earth are no match for what spacecraft have revealed with close-range inspection.

Future space historians will recall two great epochs of discovery concerning Saturn. During the first, in 1980–81, Voyagers 1 and 2 revealed that the planet's stunning ring system is not a single smooth sheet but rather consists of thousands of individual ribbons, at once beautiful and strange in their collective organization. In the second, beginning in mid-2004, NASA's Cassini orbiter found the rings to be even more beautiful — and stranger — than we'd previously imagined.

It's no accident that the images returned by Cassini are dramatically otherworldly. Carolyn Porco (Space Science Institute) says that when she was chosen to head the mission's imaging team, "I knew I was going to make singular use of the camera and pay a lot of attention to how its images would be presented to the public." Porco has always had a soft spot for Saturn's elegant bands — she picked up the nickname "Ring Lady" while researching ring dynamics for her doctoral thesis.

Cassini has certainly been busy. Since the spacecraft's arrival at Saturn its wide-angle and telephoto cameras (just one of 12 experiment packages) have snapped an astounding 285,000 frames. But there's a lot of territory to cover: the planet's three "classic" A, B, and C rings have a combined area of roughly 40 billion square kilometers (15 billion square miles), nearly 100 times Earth's surface area.

So what's been learned since Cassini became Saturn's first artificial satellite? As Porco sums it up, "We've come to understand how the rings behave if left to themselves." Their behavior is often chaotic and unpredictable, with a structure much more complicated than astronomers expected. "There's a lot going on," says Jeffrey Cuzzi (NASA/Ames Research Center). "The rings are changing before our eyes."

The last few years have witnessed an explosion of new revelations about Saturn's beautiful bands, and this article will recap some of those findings, from the outside inward.

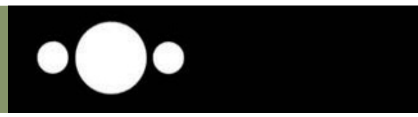
Dynamic Dust

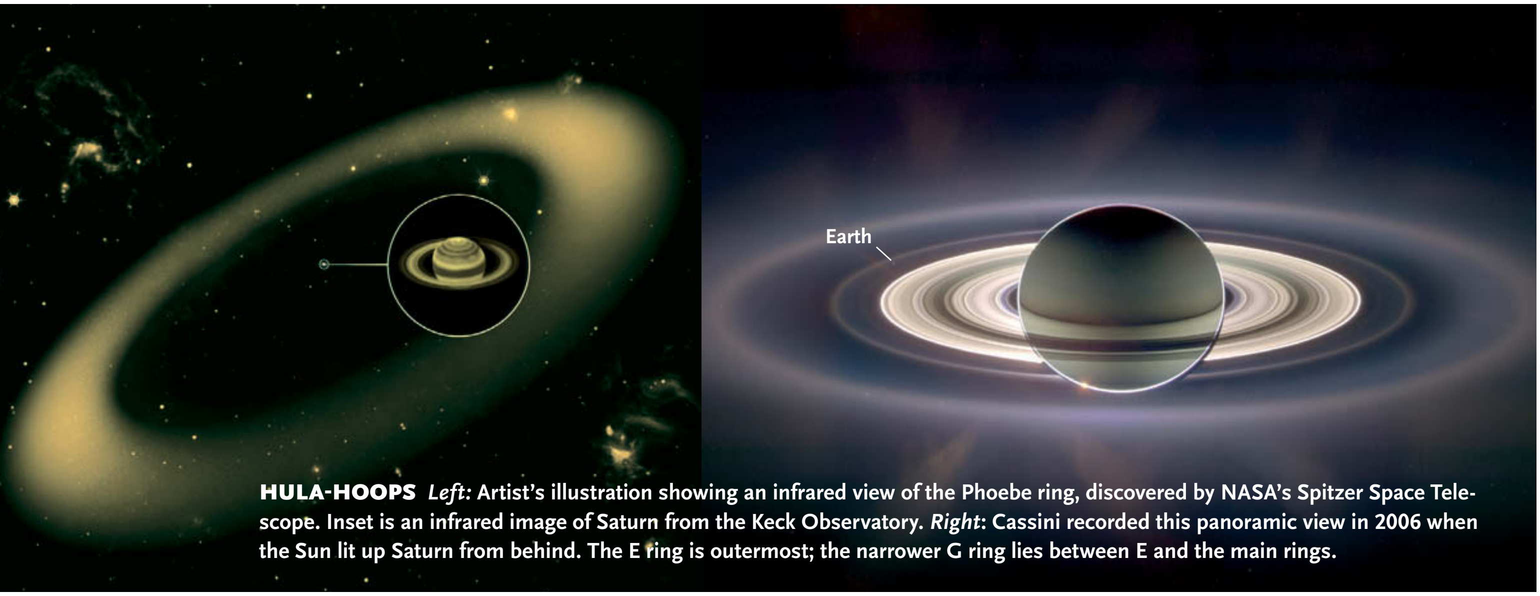
In 2009 astronomers used deep-infrared scans by NASA's Spitzer Space Telescope to detect a tenuous yet enormous doughnut of ring material 6,000,000 to 12,000,000 kilometers from Saturn — 50 to 100 times the planet's diameter. It extends all the way out to dark little Phoebe, an oddball moon just 215 km (135 miles) across that moves in a retrograde orbit tipped roughly 28° to Saturn's equator.

Apparently, impact debris that has escaped from Phoebe is being dragged toward Saturn by subtle gravitational and radiational forces. Some of this dust gets swept up by the next moons inward, particularly the leading hemisphere of Iapetus and (probably) all of Hyperion. It strikes Iapetus at very high velocities, "like bugs on a car's

RINGWORLD Mattias Malmer pieced together this mosaic of Saturn and its rings from 102 frames recorded by NASA's Cassini spacecraft in October 2004. Cassini's observations reveal wondrous and delicate details, from ringlets hiding in "empty" gaps to kilometer-long spikes gravitationally splashed out by passing moonlets.

A drawing of Saturn by Galileo Galilei made in 1610





HULA-HOOPS *Left:* Artist's illustration showing an infrared view of the Phoebe ring, discovered by NASA's Spitzer Space Telescope. Inset is an infrared image of Saturn from the Keck Observatory. ***Right***: Cassini recorded this panoramic view in 2006 when the Sun lit up Saturn from behind. The E ring is outermost; the narrower G ring lies between E and the main rings.

LEFT: NASA / JPL / KECK; RIGHT: NASA / JPL / SPACE SCIENCE INSTITUTE

windshield," observes Douglas Hamilton (University of Maryland), and helps explain why the moon is strikingly two-faced, with its leading hemisphere black as coal and a backside that's icy white (*S&T:* June 2009, page 26).

The Phoebe ring joins a growing list of Saturnian bands created by moons embedded within them. For example, Cassini captured a cluster of geysers near the south pole of Enceladus dramatically spewing particles into space, and these spread out to form the E ring (*S&T*: March 2006, page 38). The spacecraft has also spotted faint rings centered on the orbits of Pallene and the co-orbiting moonlets Janus and Epimetheus, as well as partial rings, or "arcs," extending to either side of the tiny moons Methone and Anthe.

But these interactions are all tame compared with the shenanigans of the F ring, a dusty sibling located just outside the A ring (see image at top of facing page). Voyager photographs of this ring showed tortured twists and kinks that left mission scientists slack-jawed in disbelief.

It's clear now that the F ring has a relatively dense core that's accompanied by thinner bands full of waves and ripples. Much of this structure is driven by repetitive gravitational yanks, primarily from the tiny moons Prometheus and (to a lesser extent) Pandora, which circle just inside and outside of it, respectively. But there's much more going on. Cassini images taken last year reveal clusters of elongated streaks — some up to 250 km long — jutting from the F ring. Apparently these "minijets" are being dragged along by giant snowballs, roughly 1.5 km across, that are moving unseen within the dense core.

A sketch of Saturn by Francesco Fontana made in 1646

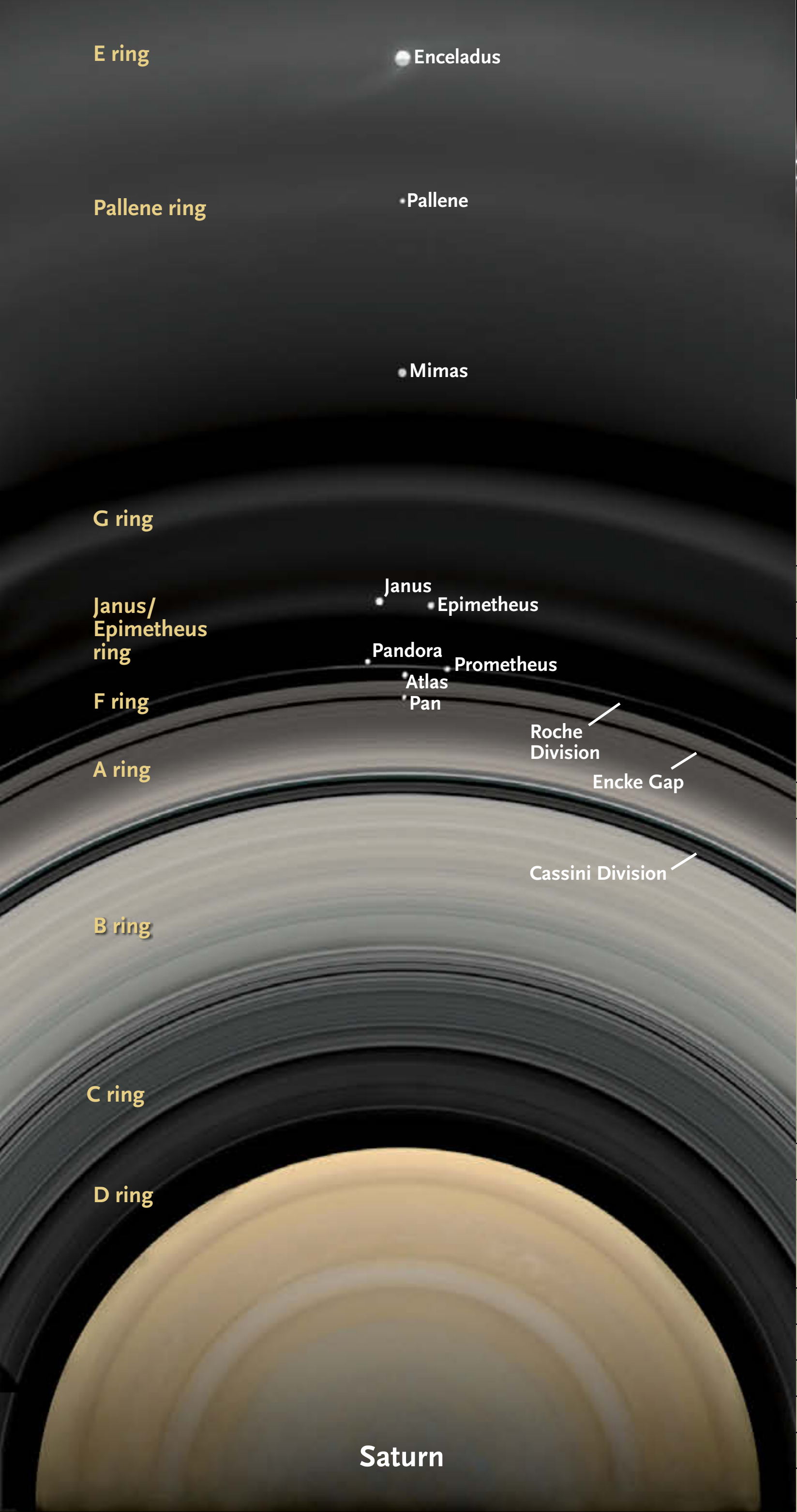
All this jostling can't have been going on for more than a few million years. "My own suspicion is that the F ring is a relatively recent addition to the ring system and may be the result of the collisional breakup of a small moon — perhaps one that formed in the disk and migrated outward," suggests Carl Murray (Queen Mary University, England).

Prior to the arrival of the Voyagers and Cassini, dynamicists imagined that gentle jostling among all the icy bits in the main A and B rings would tend to smooth out localized clumps and fill any voids. But when spacecraft images revealed thousands of discrete ringlets, such thinking had to change. Instead, there's a newfound appreciation that ring particles prefer to act collectively rather than individually.

Those in the A and B rings range from centimeters to meters in size, and computer modeling suggests that they often come together in loosely bound clumps that quickly break apart. Then, rather than scattering randomly, the bits peel off in upstream and downstream wakes created by Keplerian shear: those closest to the planet orbit a little faster and creep ahead of the main clump, while those on the outer edge trail behind it.

These *self-gravity wakes* appear to be ubiquitous throughout the A and B rings, and dynamicists think these same structures should be present in the protoplanetary disks surrounding newly formed stars and perhaps even in galactic arms. "We knew self-gravity was important all along, but it was beyond our observational capability," says Cuzzi. However, mission scientists could still "see" the wakes by having Cassini direct its radio beacon through the rings en route to Earth, which it has done hundreds of times in the past 9 years. "It's like taking a 3-D CAT scan of these structures," he explains.

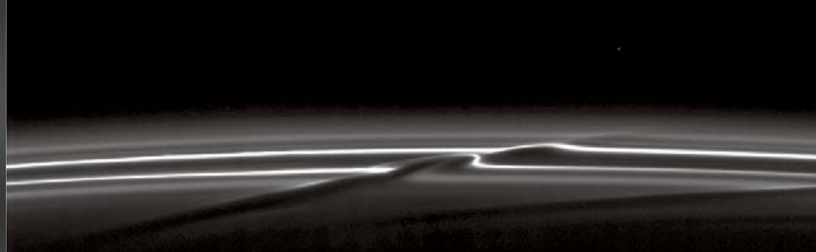
Another kind of organized bulk motion is related



RUBBLE PILE
According to one estimate, there are 10 million trillion (10^{19}) ring particles at least 1 cm across in Saturn's three main rings.

PRECISION AND ORDER Spanning hundred of thousands of kilometers, Saturn's rings are highly structured, as shown in this (roughly to scale) illustration. The D ring orbits only a few thousand kilometers above the planet's atmosphere.

DON DAVIS

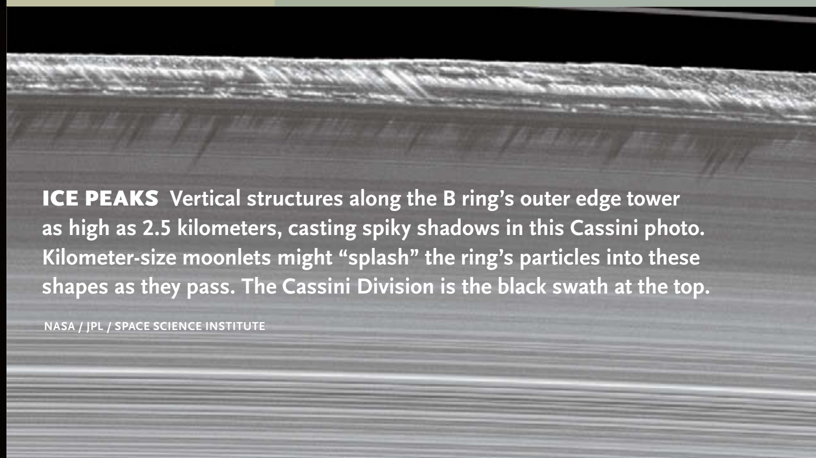


WARPED PERSPECTIVE An image taken by Cassini in September 2008 shows striking distortions in Saturn's F ring (seen from its unilluminated side). These irregularities are created by close approaches of the moon Prometheus, which has a slightly eccentric orbit.

NASA / JPL / SPACE SCIENCE INSTITUTE

A System Like No Other

Feature	Distance from Saturn's center (km)	Radial width (km)
D ring	67,000 – 74,490	7,500
C ring	74,490 – 91,980	17,500
Colombo Gap	77,800	100
Maxwell Gap	87,500	270
Bond Gap	88,690 – 88,720	30
Dawes Gap	90,200 – 90,220	20
B ring	91,980 – 117,500	25,500
Cassini Division	117,500 – 122,050	4,600
Huygens Gap	117,680	285 – 440
Herschel Gap	118,183 – 118,285	102
Russell Gap	118,597 – 118,630	33
Jeffreys Gap	118,931 – 118,969	38
Kuiper Gap	119,403 – 119,406	3
Laplace Gap	119,848 – 120,086	238
Bessel Gap	120,236 – 120,246	10
Barnard Gap	120,305 – 120,318	13
A ring	122,050 – 136,770	14,700
Encke Gap	133,570	325
Keeler Gap	136,505	35
Roche Division	136,770 – 139,380	2,600
F ring	140,224	30 – 500
Janus/Epimetheus ring	149,000 – 154,000	5,000
G ring	166,000 – 174,000	8,000
Pallene ring	211,000 – 213,500	2,500
E ring	180,000 – 480,000	300,000
Phoebe ring	~6,000,000 – ~12,000,000	~6,000,000



ICE PEAKS Vertical structures along the B ring's outer edge tower as high as 2.5 kilometers, casting spiky shadows in this Cassini photo. Kilometer-size moonlets might "splash" the ring's particles into these shapes as they pass. The Cassini Division is the black swath at the top.

NASA / JPL / SPACE SCIENCE INSTITUTE

to how collisions transport angular momentum in the rings. Normally, explains Heikki Salo (University of Oulu, Finland), ring material quickly flows away from dense regions and toward sparse ones. However, in close quarters the velocities of individual particles can become damped, or slowed, causing pileups. The result is a kind of resonant "splashing" between closely separated ringlets — not unlike the back-and-forth wave action seen in a bathtub or swimming pool.

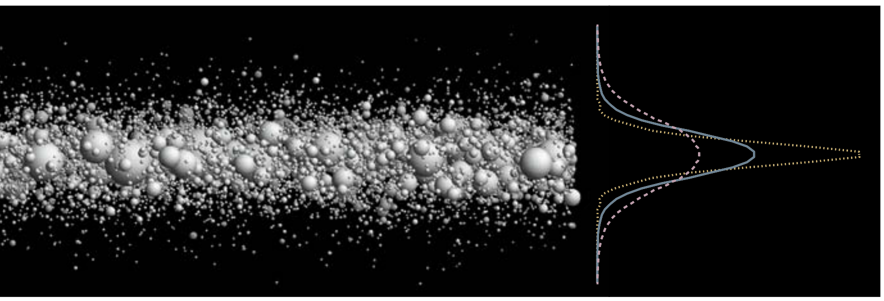
Strokes, Spokes, and Pokes

One of the most curious ring discoveries involves localized twists of icy rubble dubbed "propellers" because of their distinctive twin-lobed shape (see image at right). Cornell University researcher Matthew Tiscareno has intently followed these curious features since their discovery by Cassini in 2006. He's concluded that their twin "blades" appear to be voids or concentrations of ring particles, either of which can look bright against the background around them. Predicted to exist even before Cassini's arrival, propellers are apparently caused by tiny embedded moonlets roughly 300 meters across. These are too small to be resolved in images, but they're massive enough to disturb the flow of particles in their vicinity.

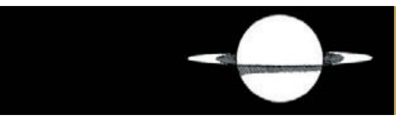
Cassini's cameras have spotted thousands of propellers in three narrow zones within the A ring, yet so far only one has been spotted in the B ring, where the particles are packed much closer together. The biggest propellers, which are thousands of kilometers long and have nicknames that honor early aviators, occupy a strip between the Encke Gap and the A ring's outer edge.

The one dubbed Blériot (for French aviation pioneer Louis Blériot) isn't particularly well-behaved. It sometimes precedes or lags its expected position by hundreds of miles. Maybe the responsible moonlet is being swayed by the gravitational influence of another, larger moon, or perhaps it's being bumped and jostled by rogue waves in its vicinity. Either way, Tiscareno says, "It's actually quite astounding." Ring specialist Joseph Burns (Cornell University) adds that it's the kind of jerky migration dynamicists would expect to see on a much larger scale when just-forming planets start growing in stars' protoplanetary disks (see page 26).

STACKED DECK Despite their enormous size, Saturn's rings are incredibly thin — no thicker than about 10 to 20 meters in most places. In this edge-on simulation, the largest particles (at least 1.7 meters across) cluster near the ring's midplane; the yellow curve at right shows their distribution. But mid-size (blue curve) and small (pink curve) particles "float" somewhat, creating slightly thicker layers.



HEIKKI SALO



A sketch of Saturn by Christiaan Huygens made in 1655

NASA / JPL / SPACE SCIENCE INSTITUTE (2)

FOUNTAINHEAD ***Top:*** **Saturn's moon Enceladus, seen at center, is the source of the E ring. Gas-fueled geysers constantly jettison ice crystals into space.** ***Bottom*****: This propeller-shaped disturbance in Saturn's A ring, nicknamed Blériot, is created by a moon too small to be resolved. Disturbed ring material close to the moon reflects sunlight brightly and thus appears white.**

Meanwhile, in the B ring, researchers are still trying to understand the furtive features called spokes. First photographed by Voyager 1 in 1980 (though reported by a few visual observers before that), these dusky streaks appeared dark against the bright ring as the spacecraft approached. But they looked bright in images taken when looking at the planet with the Sun behind it, implying that they consist of microscopically fine dust particles that scatter light strongly at large angles, much like dust on a car windshield (*S&T*: February 2007, page 32).

Typically, spokes materialize in a few minutes as radial streaks in the B ring, then smear out as they shear apart due to the differential orbital speeds along their lengths. Spoke activity can be absent for years at a time, yet it seems to peak when the ring plane is nearly edge-on as seen from the Sun during Saturn's 29½-year orbit (most recently in 2009).

Theorists quickly seized on the idea that these quickly forming spokes are triggered by some kind of episodic disturbance in the planet's strong magnetosphere. No physical motion can cover such large radial distances

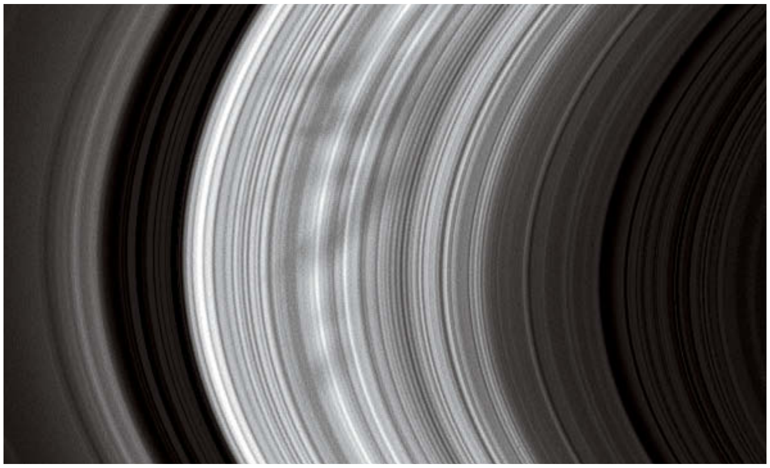
HOW BIG?
Saturn's "classic" A, B, and C rings span 70% of the Earth-Moon distance and have nearly 100 times the surface area of Earth.

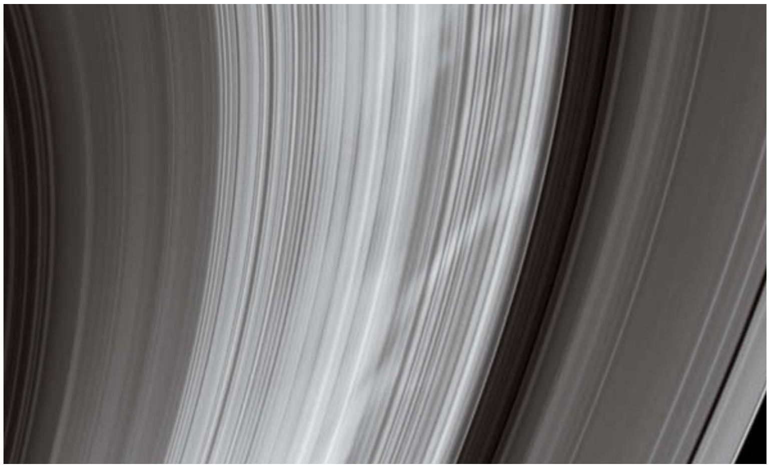
so quickly, but Saturn's strong magnetic field flows through the rings all the time. Most proposed explanations either assume that elongated dust grains somehow become charged and aligned with the planet's magnetic or electric fields or that microscopic grains pick up an electrostatic charge strong enough to levitate them rapidly out of the ring plane.

One widely accepted model, put forward by Christoph Goertz and Gregor Morfill in 1983, argued that meteoritic impacts generated rapidly expanding plasma clouds that charged and levitated the dust. But several years ago follow-up analysis showed that the plasma couldn't spread fast enough to match some spokes' rapid onset.

"Despite 30 years of work, there are no models for spoke formation that fully satisfy all of the observations," says Daniel Jontof-Hutter, an interplanetary-dust specialist at NASA's Ames Research Center.

Still, the notion of an impact-induced trigger has merit, and Jontof-Hutter is pursuing an idea put forward a few years ago by Hamilton. It's still a work in progress, but Hamilton's basic concept is that a meteoroid strikes the B ring, releasing a cloud of charged particles. These are quickly accelerated out of the ring plane by gravity and electromagnetic forces, which slam them back into the ring at high speeds in some other location, generating more debris. This collisional cascade would stretch to cover a wide radial range in the ring but be rather confined in longitude, Jontof-Hutter explains, matching the





NASA / JPL / SPACE SCIENCE INSTITUTE (2)

DUSTY MIRAGES? The dark, shadowy fingers known as "spokes" in Saturn's B ring remain a puzzle to ring specialists. They appear bright (*bottom*) when seen in forward-scattered light; this implies that the dust particles in them are quite small.

HEIKKI SALO

RIPPLE EFFECT Scientists suspect that in 1983 a large meteoroid broke up just before striking the C ring. The impact caused a localized tilt in the ring that propagated outward as its nodes precessed around Saturn, as shown in this simulation. This action created a series of subtle corrugations detected in Cassini images.

The Cassini Division

Although the big gap between Saturn's A and B rings appears black and empty from Earth, it's not. In fact, the Cassini Division (named for Jean-Dominique Cassini, who discovered it in 1675) is full of interesting features — including eight narrow gaps that really *are* empty.

Dynamicists don't really know why the Cassini Division exists. They've known for decades that the B ring's outer edge is defined by a strong orbital connection with the moon Mimas. Particles there travel around Saturn exactly twice in the time that Mimas orbits once, and because of this resonance the boundary has a decidedly oval shape.

Calculations by Valéry Lainey (IMCCE, Paris) and others suggest that the orbit of Mimas is slowly collapsing inward, thanks to a slight forced eccentricity due to neighboring Tethys and gravitational perturbations by Saturn. If the researchers' preliminary conclusions hold up, then Mimas has been moving closer to Saturn by about 2 mm per day over the past 20 million years — and so has the outer edge of the B ring. Assuming the inward migration has been ongoing continuously, a gap as wide as the Cassini Division could have formed in less than 10 million years.

sharp radial edges along which spokes seem to form.

The rings are occasionally hit by interplanetary projectiles, with interesting consequences. In August 2009, when the ring plane was almost exactly edge-on to the Sun, a team led by Cornell's Matthew Hedman spotted a subtle corrugation in Cassini images that extended across the entire C ring. The ripples were separated by 30 to 80 km and ranged from 2 to 20 meters tall. But the edge-on illumination accentuated their presence by creating long, distinct shadows.

Hedman's team concluded that the corrugation was a "splash pattern" of sorts caused by the impact of a billion-ton debris cloud — not a single object, but instead something that had broken apart on its way in. The impulse of kinetic energy had caused a localized tilt in the ring, which then got torqued around in longitude by Saturn's uneven gravity field. Over time the vertical warping became wound up like a watch spring as it extended throughout the C ring. By "unwinding" the corrugation backward in time, the researchers concluded that the ring likely took the hit around September 1983. Smaller impacts likely happen all the time.

Jean-Dominique Cassini's sketch showing his division, made in 1676

The End Game

Ultimately, planetary scientists would like to solve the centuries-old puzzle of how Saturn's ring system came to exist (see below). But a critical missing piece is knowing how much mass is hiding in those beautiful bands and, specifically, in the dense, optically opaque B ring. Right now there's no way to know for sure — it might be 10^{17} tons (a couple of Mimas's worth), but all that clumping due to

MOON DEBRIS Saturn's rings perhaps formed when a large moon ventured too close to the young planet and was stripped of its icy outer layers. The rocky core ended up falling into Saturn.

S&T: GREGG DINDERMAN

Where Did the Rings Come From?

The nature and origin of Saturn's ring system has perplexed astronomers for four centuries. Galileo sketched them as "ears" on the planet in 1610, but two years later they vanished from view when Saturn passed through an equinox. "I do not know what to say in a case so surprising, so unlooked for, and so novel," wrote the exasperated observer.

In 1859 James Clerk Maxwell proposed that the rings could not be solid but must instead be composed of numerous small particles, all independently orbiting Saturn. Dynamicists now realize that the rings lie within what's termed the *Roche limit*, inside of which tidal stresses from Saturn would tear apart any large solid object. Past attempts to explain Saturn's rings either assumed that the planet formed encircled by a close-in disk that could not assemble into a single object, or that a large body wandered too close to Saturn early in the solar system's history and was ripped apart by tidal forces.

But two aspects of the Saturnian system put serious constraints on any would-be explanation for those magnificent bands. First, the ring particles (in the main rings, at least) consist almost entirely of water ice. It's hard to imagine primordial leftovers or a hapless moon with a pure-ice composition — most likely it would contain roughly equal amounts of ice and rock. In addition, over time the rings should have become increasingly contaminated with rock, metal, and carbon from meteoroid strikes. Calculations suggest the accumulated debris should account for roughly 10% of the rings' mass, but observations suggest that it's no more than about 1%.

Second, the rings' origin must somehow be tied to that of Saturn's moons. It's self-gravity wakes might be masking several times more.

Once again Cassini might provide an answer. Its prime four-year mission ended in 2008, and a two-year extension carried it through a Saturnian equinox in 2010. Figuring that another spacecraft might not be sent Saturn's way for decades to come, NASA managers gave a green light to keep Cassini going until the planet reaches its northern summer solstice in May 2017.

In the final 10 months of operation, mission controllers hope to reposition the spacecraft to perform a series of close-in maneuvers. First come 20 high-inclination orbits that pass just outside of the F ring. Then a close flyby of Titan will squeeze the periapse distance further, allowing Cassini to repeatedly dive through the clearing between the innermost D ring and Saturn's upper atmosphere that's only 3,000 km wide.

Careful tracking of the barnstorming spacecraft will not only reveal unprecedented details about Saturn's gravity field (and, from that, its internal structure), but also determine the rings' mass. Moreover, Cassini will map the inner magnetosphere and probe Saturn's ionosphere directly — and close-up images of the rings and planet should be breathtaking. "It's really exciting, and it's also fun," Burns muses. "The science is so different than what we've been able to do that it really changes the mission."

On September 15, 2017, one month shy of the 20th anniversary of its launch, the spacecraft will plunge into Saturn's atmosphere. But by then it will have amassed enough revelations to keep researchers busy for decades.

To see video animations of Saturn's rings in action, go to skypub.com/satrings.

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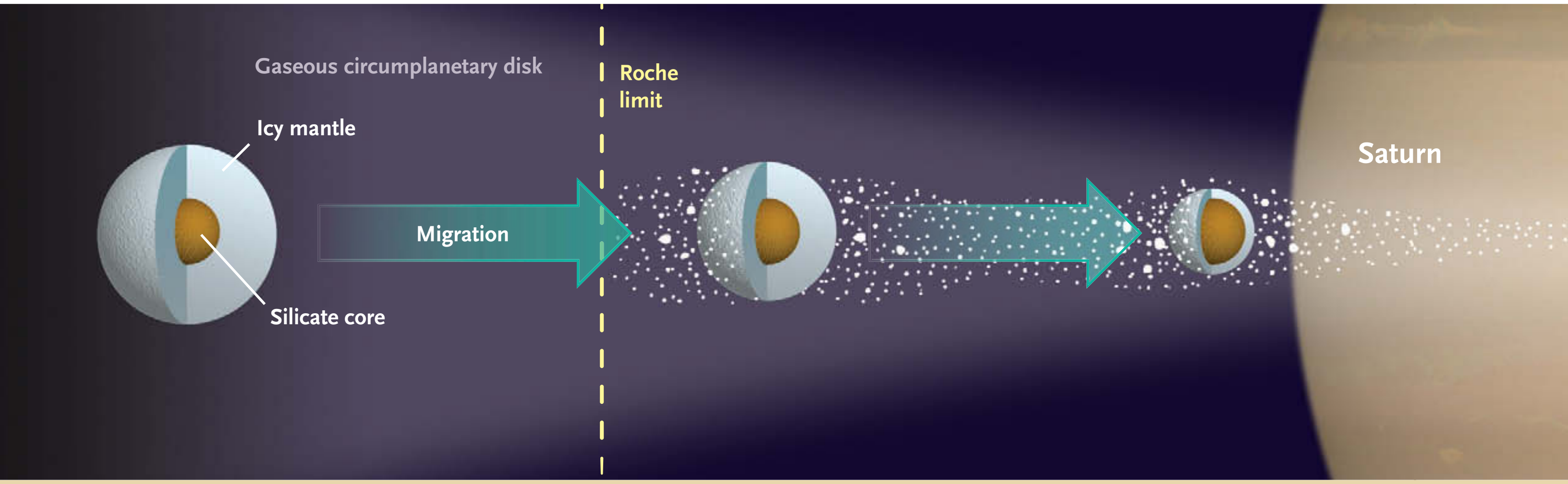
*Senior contributing editor **J. Kelly Beatty** still gets a thrill whenever he looks at Saturn through a telescope.*



S&T: GREGG DINDERMAN

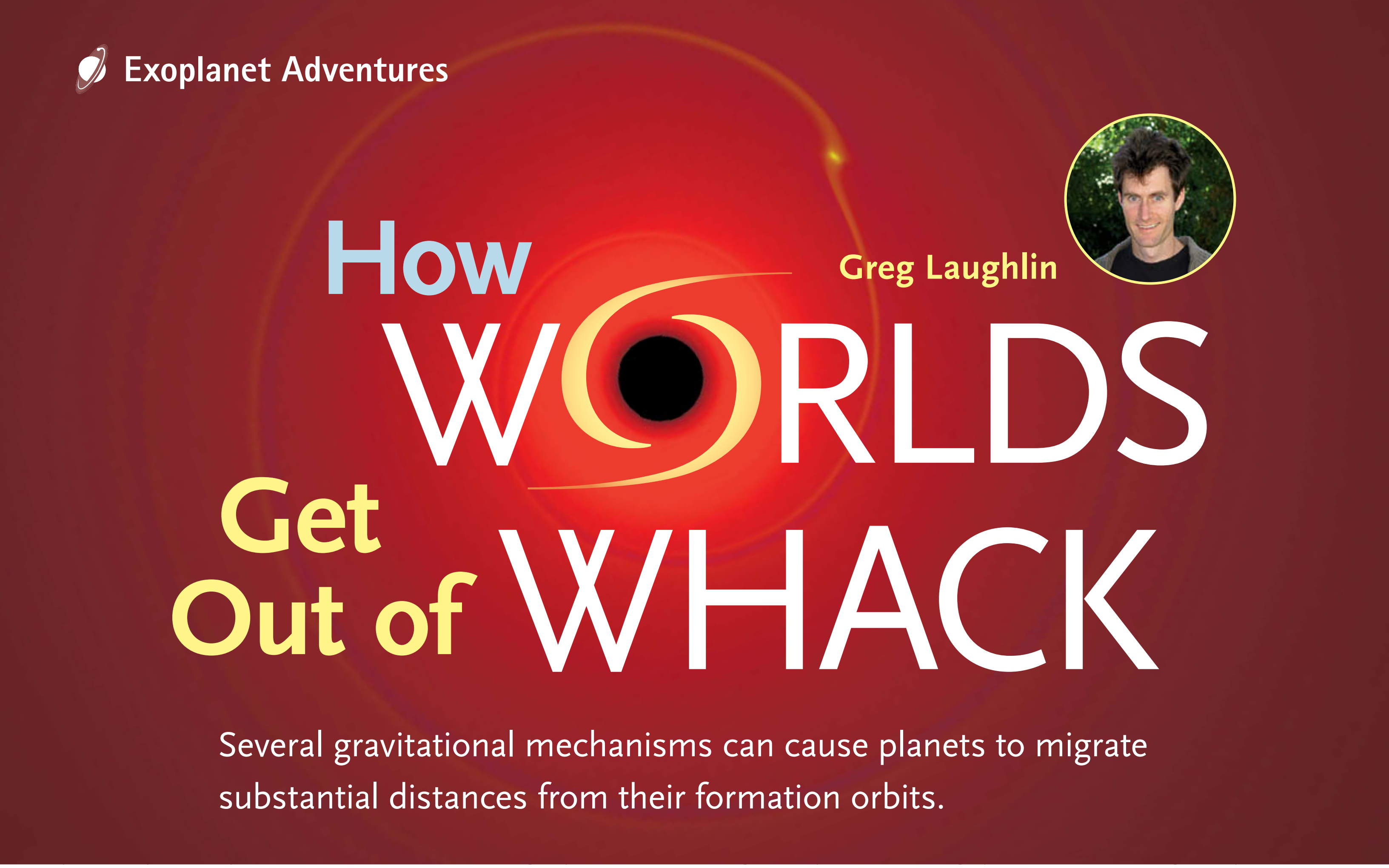
unlikely that the proto-Saturn nebula was big enough to form the massive moons Titan and Iapetus as far away as they are now from the planet, or that the mid-size moons near the rings could have ended up with such a wide range of densities (Tethys must be nearly pure ice, whereas neighboring Enceladus and Dione contain lots of rock).

So how can you pulverize a moon without adding lots of rocky rubble to the rings? The answer, says Robin Canup (Southwest Research Institute), is to take it apart very, very carefully. In late 2010, she proposed that a moon of roughly Titan's size — and which had segregated into a rocky core and icy exterior, as Titan has — started breaking up as it neared Saturn. But the Roche limit for disrupting a rocky body is much closer to the planet that the one for ice (because rock is denser). So while the moon's icy exterior was literally falling apart, the rocky core remained intact and eventually fell into Saturn.

All the chips-off-the-block left behind, orbiting close to the planet, would have been nearly pure ice. Moreover, there would have been a lot of them — totaling perhaps 20 billion billion tons, hundreds of times more mass than estimates for what the ring system holds now. "It would have been a vastly more massive initial ring," she admits. Later, lots of that matter would have migrated outward — beyond the Roche limit — where it became the building blocks for moons like Tethys.

Others have likewise posited that Saturn's mid-size moons are "children of the rings," but Erik Asphaug (Arizona State University) sees a glass half empty. "Canup's paper is very interesting, and I think those things happened," he says, "but I don't think you can make Dione and Rhea in that manner, let alone Iapetus."

Instead, Asphaug and Andreas Reufer (University of Bern, Switzerland) propose that Saturn was initially endowed with a set of big moons, like Jupiter's Galilean satellites, that collided and merged, ultimately forming Titan. In their computer simulations, these skirmishes liberate ice-rich spiral arms that later coalesce into Saturn's mid-size inner moons. A somewhat similar collisional scheme has been proposed by Yasuhito Sekine and Hidenori Genda (University of Tokyo, Japan), though in their view Titan was on the scene from the outset. ✦



Greg Laughlin

How WORLDS Get Out of WHACK

Several gravitational mechanisms can cause planets to migrate substantial distances from their formation orbits.

PHIL ARMITAGE (UNIV. OF COLORADO, JILA)

In 1980-81, NASA's Voyager probes flew past Saturn and revealed its ring system in detail for the first time. Instead of the bright, featureless platters seen in Earth-bound telescopes, the rings — composed of an avalanche of small icy particles — were seen to be positively alive, shimmering with spiral waves, rapidly evolving ringlets, and embedded moons. The clarity of Voyager's images ensured that astronomers could study the ring environment as a useful proxy for the disks of gas and dust that surround newborn stars and give rise to planets.

Of particular interest were Voyager's images of small moons embedded in the rings. The ring environment is calm enough so that the weak gravitational forces between the rings and the moons can strongly influence how the whole system evolves. Specifically, a moon orbiting in a ring generates a wake that runs through the ring particles, much like the way that a speedboat in water develops a V-shaped wake. Ring particles closer to the planet orbit faster than those farther away. As a result, the moon-driven wake spirals ahead of the satellite in the region near the planet, and spirals back in the ring's outer region.

The forward-running wake is a concentration of mass that continuously pulls the moon forward, imbuing it with energy that causes the body to drift outward. Simultaneously, the outward-running wake continually pulls back on the moon, imparting a tendency to spiral inward. Whether the moon's net movement is inward or outward depends largely on whether the ring has more mass outside or inside the moon's orbit.

In a landmark paper published just before the Voyager data were returned, Peter Goldreich and Scott Tremaine illuminated how the dynamics in Saturn's rings have much in common with the processes that should operate in planet-forming disks. They noted that migrating planets might be common, and they startlingly pronounced that, "Substantial changes in both the structure of the disk and the orbit of Jupiter must have taken place on a time scale of a few thousand years."

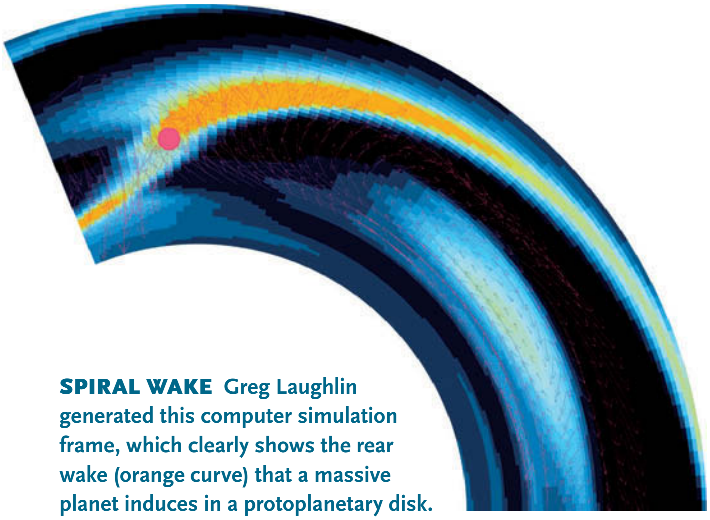
Planets Where They Shouldn't Be

In 1995 astronomers were shocked by the discovery of a Jupiter-class planet in a 4.23-day orbit around 51 Pegasi, a nearby Sun-like star. This world was utterly alien. Its very existence flew directly in the face of astronomers' understanding (from studying the solar system) of how massive planets arise inside disks that surround newly forming stars. Conventional wisdom dictated that icy material far from the star accretes into a Neptune-like embryo whose substantial gravity draws in hundreds of additional Earth masses of gas, rapidly growing to Jupiter-like proportions.

By contrast, the conditions in the inner disk, where the orbital period is just a few days, and where the temperature is well over 1000 Kelvins (1340°F), seemed entirely hostile to the in-situ assembly of a gas-giant planet.

But astronomers quickly realized that the processes described by Goldreich and Tremaine might provide an explanation for 51 Peg b. It could have formed in the outer disk where conditions were favorable, and then migrated to its sweltering final location.

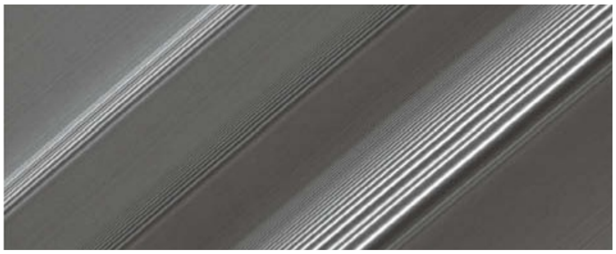
Astronomers have since discovered an armada of exoplanets, and hot Jupiters such as 51 Peg b turned out to be numerous. Planet migration became a hot research topic. Astronomers worked hard to master the theoretical details of the disk-planet interaction, and they carried out supercomputer simulations of the migration process. It became clear that there are likely two flavors of planetary migration from disk interactions. The so-called Type I variety operates when the planet's mass is small in comparison to the surrounding disk. In this case, the planet is directly embedded in the disk itself, and gravitational interaction with the outer spiral wake induces rapid inward migration. Type II migration occurs when the planet exceeds roughly 100 Earth masses. The planet's gravity clears a ring-shape gap in the disk that is free of both gas and larger particles. The gap's presence weakens the planetary wake, slowing migration by a factor of 10 or more.



SPIRAL WAKE **Greg Laughlin generated this computer simulation frame, which clearly shows the rear wake (orange curve) that a massive planet induces in a protoplanetary disk.**

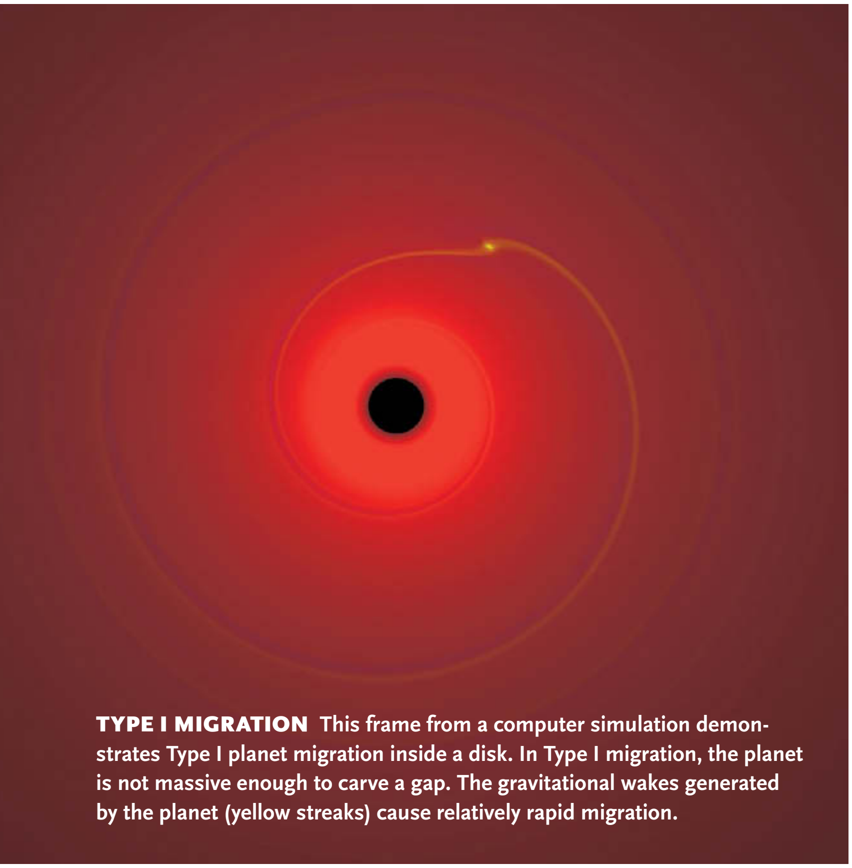
Until recently, long-distance planetary migration arising from some combination of Type I and Type II processes was essentially unchallenged as the primary mechanism that sculpts the overall orbital distribution of planets. The theory grew sophisticated, with testable predictions. For example, disk migration should generate hot Jupiters whose orbital planes are generally aligned with the host star's equator, like the planets in our solar system.

Furthermore, by 2004 several groups designed sophisticated migration simulations to model the formation

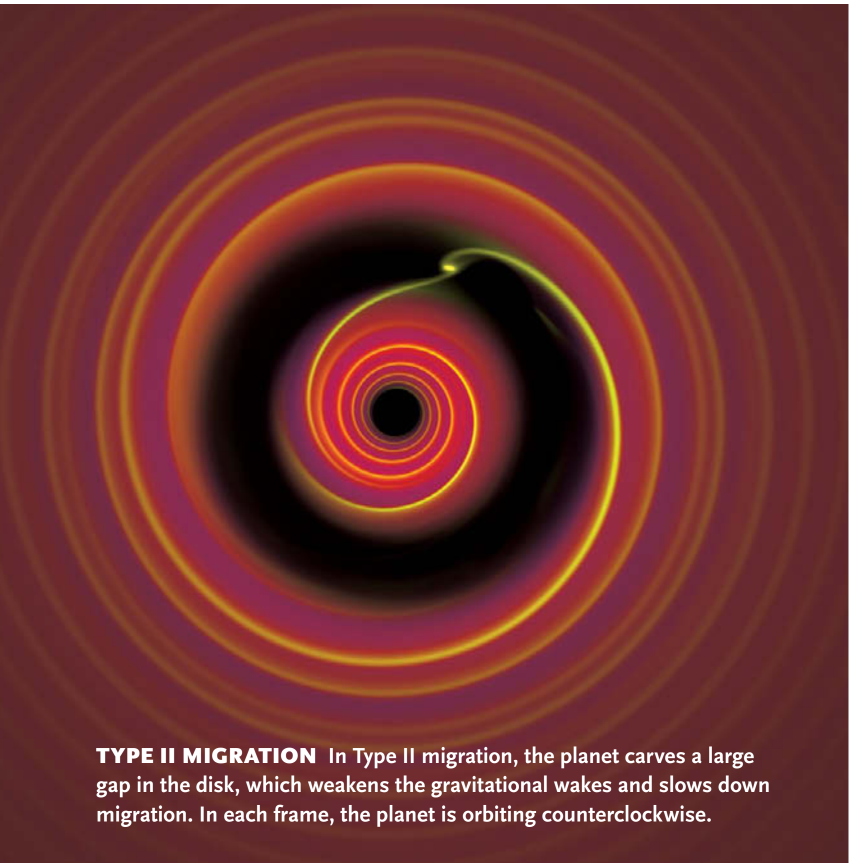


NASA / JPL / SPACE SCIENCE INSTITUTE (3)

PROXY FOR PLANETS **Scientists study Cassini images of Saturn's rings to understand how objects within a disk can perturb the structure's dynamics. *Top:* The gravity of distant moons generated these spiral density waves in the A ring. Such waves drive planetary migration in circumstellar disks. *Above:* The diminutive moon Daphnis sculpts not only the Keeler Gap, it creates wake-like disturbances both ahead and behind it (this image was taken from under the ring plane). *Right:* The small moon Pan carves the Encke Gap, just as a massive planet can carve a gap inside a gaseous disk. The narrower Keeler Gap is also visible at the left.**



TYPE I MIGRATION This frame from a computer simulation demonstrates Type I planet migration inside a disk. In Type I migration, the planet is not massive enough to carve a gap. The gravitational wakes generated by the planet (yellow streaks) cause relatively rapid migration.



TYPE II MIGRATION In Type II migration, the planet carves a large gap in the disk, which weakens the gravitational wakes and slows down migration. In each frame, the planet is orbiting counterclockwise.

PHIL ARMITAGE (UNIV. OF COLORADO, JILA) (2)

of various combinations of planets. These simulations explained features of the exoplanetary distribution that were then evident. They reproduced the relative numbers of both hot Jupiters and "eccentric giants" (Jovian planets with eccentric orbits and periods of roughly a year). Slightly less than 1% of local Sun-like stars harbor a hot Jupiter, whereas eccentric giants can be found around about 5% of such stars. The simulations predicted that Type I migration should generate a severe shortfall (or desert) of planets with periods less than 100 days and masses less than about 30 Earth masses.

Orbits Out of Whack

After the recent rapid progress in the discovery and characterization of exoplanets, the migration theory's two predictions of coplanarity and a planet desert have not held up particularly well. In the past several years, astronomers have exploited a phenomenon known as the Rossiter-McLaughlin effect to measure the angle between exoplanet orbital planes and the equators of their host stars for many known transiting planets. These measurements have revealed that many short-period planets are badly misaligned with the equators of their host stars. This is entirely unexpected if long-distance disk migration drives planets into short-period orbits.

A possible solution to the dilemma arises from a process known as Kozai Cycles with Tidal Friction. Yoshihide Kozai described the key physical ingredient in 1962 in an investigation of artificial satellite orbits in the Earth–Moon system. Kozai showed that a curious phenomenon occurs when two orbits are tilted by more than 39.2° to each other. Such a situation can arise, for example, if a Jupiter-mass planet orbits a parent star with a wide binary stellar companion. In Kozai's mechanism, gravitational interactions drive the planet's orbit toward the companion star's orbital plane, while at the same time, to compensate, the planet's orbital eccentricity is forced to increase. Over many orbits, the planet executes regular cycles between extremes of eccentricity and inclination.

During the high-eccentricity phases, when the orbital elongation is at its most extreme, a planet suffering from Kozai migration dips perilously close to its parent star — close enough so that the strength of the star's gravity varies significantly from the planet's day to its night side. During the hours surrounding the closest approach, the extreme tides gravitationally deform the planet and ring it like a bell. These oscillations drain energy from the planet's orbital motion and radiate it away as heat. The orbit gradually shrinks and is rendered slightly less eccentric — an alternative mechanism for inward migration.

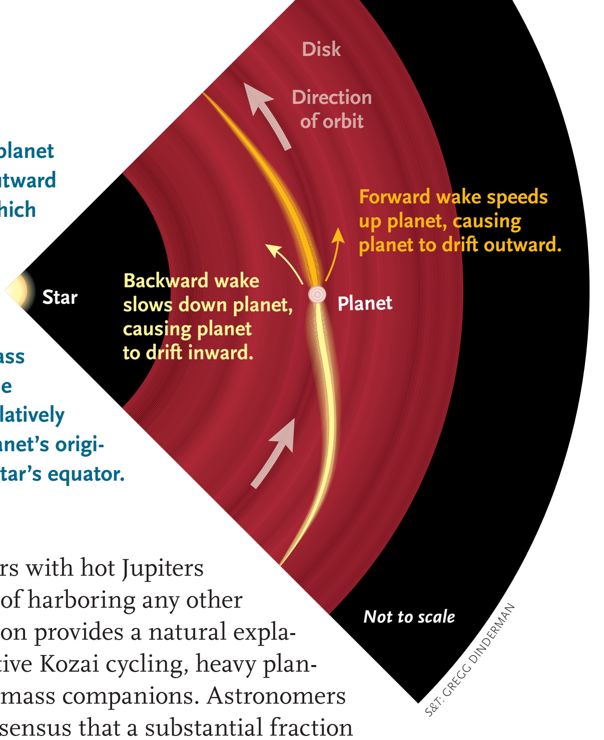
To listen to an audio interview with author Greg Laughlin, visit skypub.com/migration.

The bizarre 4-Jupiter-mass planet HD 80606b presents what appears to be a textbook outcome of the Kozai process. The parent star is a near twin of the Sun, and is paired with HD 80607, a similarly Sun-like companion lying a large distance away (at an average of 1,200 astronomical units). HD 80606b has one of the largest orbital eccentricities ($e = 0.93$) yet measured for an exoplanet. During its close approach, it charges through several torrid hours at a distance of only about 6 stellar radii above the star (March issue, page 21). Eight weeks later, it reaches its far point — nearly an Earth–Sun distance.

In 2003, soon after the planet was discovered, Norman Murray and Yanqin Wu elucidated a tortuous history for HD 80606b. In their model, the planet formed from ices and cold gas at a Jupiter-like distance, in an orbit that was almost perpendicular to the stellar binary orbital plane. Strong Kozai cycles ensued, and tidal friction acted during the high-eccentricity phases. Eventually, the orbital decay produced a period that was only somewhat longer than the present-day value. At that point, the subtle but persistent effects of general relativity destroyed the Kozai cycles. Over the past few billion years the planet has been marooned on its eccentric, slowly circularizing orbit. Measurements of the spin-orbit angle during transits show that, as expected, the orbit is strongly tilted with respect to the stellar equator (*S&T:* December 2009, page 23). If given sufficient time, it will eventually wind up as an ordinary hot Jupiter on a circular orbit.

Many hot Jupiters have probably completed the full Kozai process, as evidenced by the full range of observed misalignment angles, even for planets with circular

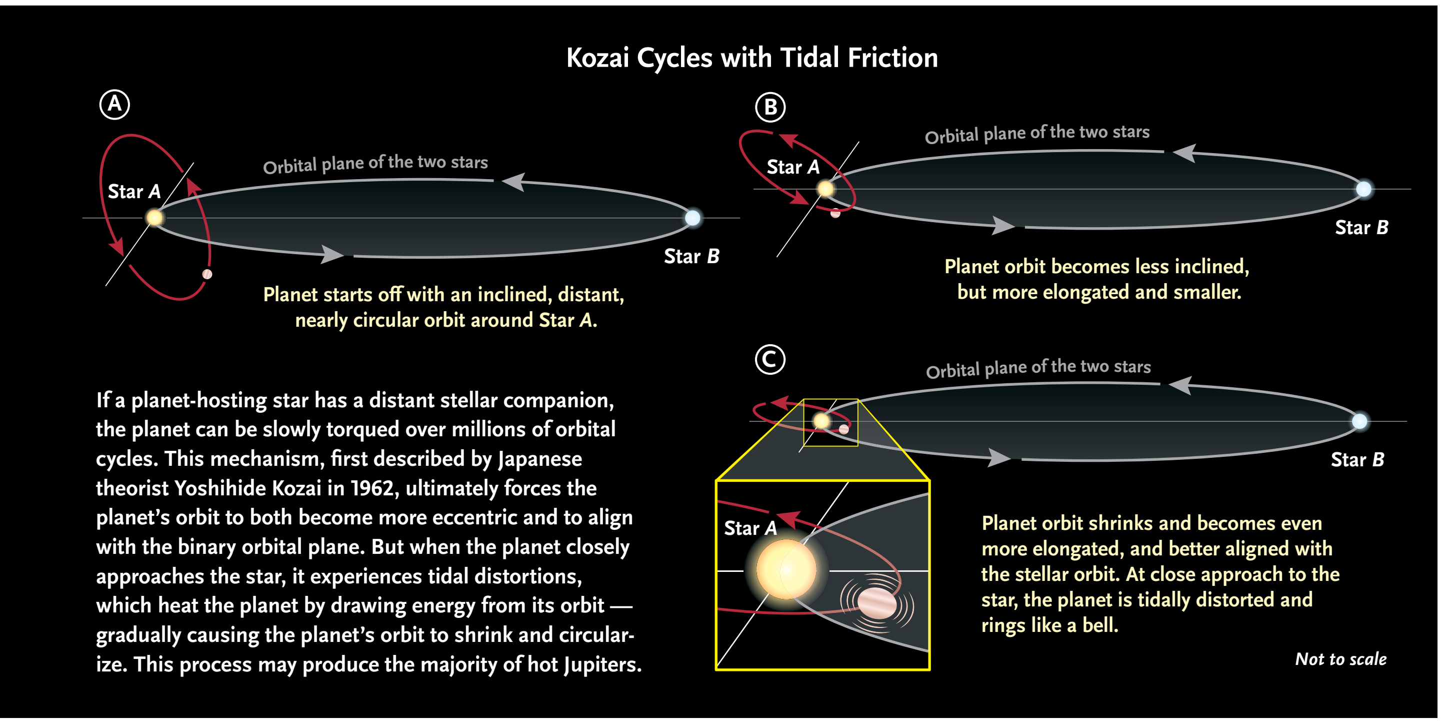
DISK MIGRATION A planet induces a forward and outward wake in a disk, each of which can drive migration. Whether the planet migrates inward or outward depends mostly on the amount of disk mass interior and exterior to the planet. This process is relatively gentle, preserving the planet's original coplanarity with the star's equator.



orbits. In addition, stars with hot Jupiters usually show no trace of harboring any other planets. Kozai migration provides a natural explanation. During the active Kozai cycling, heavy planets rapidly eject lower-mass companions. Astronomers are approaching a consensus that a substantial fraction of hot Jupiters, even a majority of them, are produced by Kozai migration rather than disk migration.

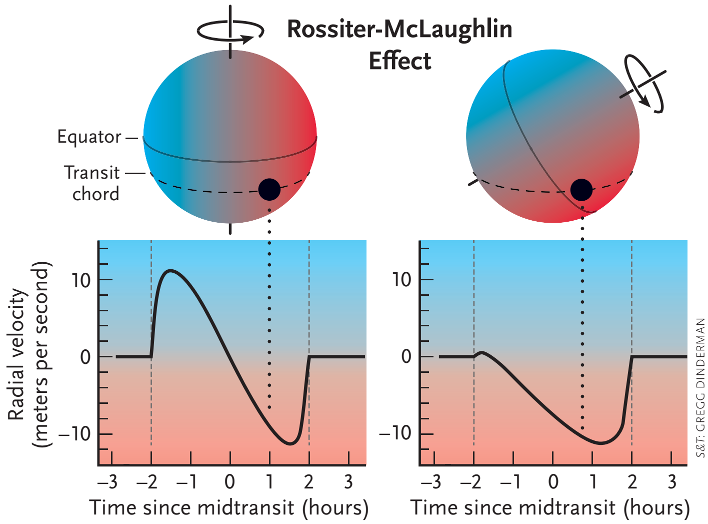
Clues from Resonances

Rossiter-McLaughlin studies have demonstrated that some hot Jupiters have orbits that are badly off-kilter with respect to their parent stars' equators. But things aren't necessarily askew. Indeed, an isolated hot Jupiter on a circular orbit provides few clues to its origin; disk migration, Kozai evolution, or in-situ formation all lead to planets stuck in scorching-hot orbits. An unambiguous signature of disk migration requires several interacting planets.



If a planet-hosting star has a distant stellar companion, the planet can be slowly torqued over millions of orbital cycles. This mechanism, first described by Japanese theorist Yoshihide Kozai in 1962, ultimately forces the planet's orbit to both become more eccentric and to align with the binary orbital plane. But when the planet closely approaches the star, it experiences tidal distortions, which heat the planet by drawing energy from its orbit — gradually causing the planet's orbit to shrink and circularize. This process may produce the majority of hot Jupiters.

S&T: GREGG DINDERMAN



MEASURING OFF-KILTER ORBITS Astronomers use the Rossiter-McLaughlin effect, first observed in eclipsing binary stars, to measure the inclination of a transiting exoplanet's orbit with respect to its host star's equator. *Left:* If a transiting planet orbits its star in the same plane as the equator, it covers blueshifted and then redshifted light during a transit, producing a symmetrical shift in the star's radial velocity. *Right:* In this example of a highly inclined orbit, the planet blocks only redshifted light, leading to a skewed radial-velocity plot.

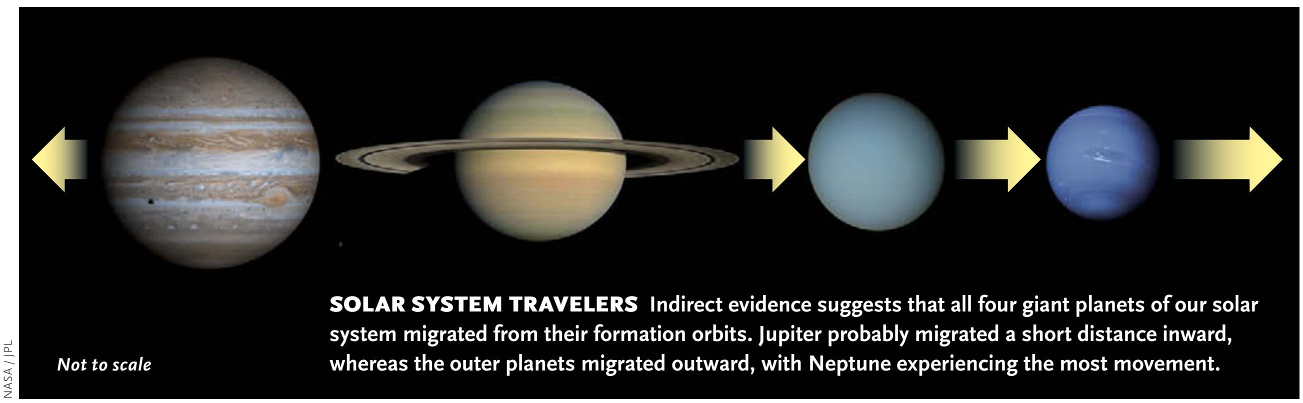
Planets rarely form as singletons. When multiple planets arise, migration is substantially altered. Consider two planets that form on widely separated orbits. Beyond the planets lies a disk composed of gas or of trillions of mountain-sized planetesimals. The spiral wake that runs through this disk will continuously pull back on the outer planet, causing it to gradually spiral inward, whereas the inner planet, more isolated from the action, experiences a much smaller net effect.

As the outer planet migrates inward, the orbital periods of the two planets pass through phases where they are exact multiples of each other, for example, a 2:1 ratio or a 3:2 ratio. During these resonant phases, the ebb and flow of the planets' mutual gravitational tugs are exerted in a precisely regulated manner, and quite remarkably, the gravitational interaction can compel both planets to migrate inward in a manner that continuously maintains the simple ratio. This phenomenon of "capture" into resonance illustrates that Newton's seemingly simple law of gravity is capable of generating remarkable behavior (*S&T:* January 2005, page 44).

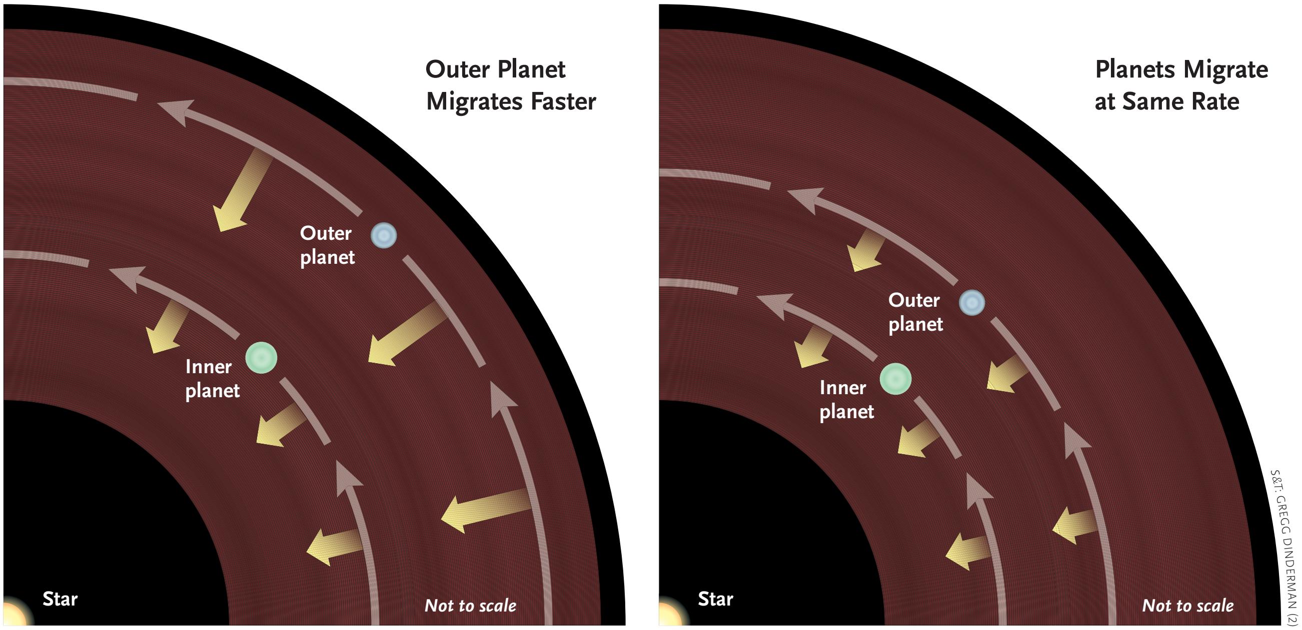
The Kuiper Belt contains a plethora of small worlds that are locked in such resonances with Neptune. Pluto, for example, orbits the Sun twice for every three Neptunian orbits. Many additional Kuiper Belt objects — dubbed plutinos — share 3:2 orbital ratios with Neptune. Their collective presence indicates that Neptune must have migrated outward from the Sun, sweeping up the plutinos into resonances as it went, effectively gathering and pushing the swarm outward while maintaining the 3:2 ratio. This fossil trace is the smoking gun that planetary migration actually occurs, and it's a linchpin of the so-called "Nice Model" (named after the town in France where it was conceived) that invokes early planetesimal-driven migrations of all four giant planets in order to explain curious features of the present-day solar system, such as Jupiter's Trojan asteroids (*S&T:* September 2007, page 22).

When a disk locks two planets into resonant migration and compels them to shrink or expand their orbits while maintaining a fixed period ratio, orderly migration can't proceed indefinitely. The planets are simultaneously drained of energy and angular momentum in a manner that prevents both orbits from remaining circular. As the planets move inward, their orbital shapes increase in eccentricity at a rate that we can precisely calculate. Joint migration often forces the orbits to become so elongated that their paths cross and destabilize before the orbital periods have managed to change by a factor of two.

The nearby red dwarf Gliese 876 has at least four planets. The first two to be discovered — planets "b" and "c" — have masses at least 2.3 and 0.7 times that of Jupiter and orbital periods near 60 and 30 days that maintain a 2:1 resonance. The eccentricities ($e = 0.03$ and $e = 0.26$) are precisely what we expect if the planets were trapped in a resonance and then migrated inward by an amount equal to 8% of their current orbital distances — not a



SOLAR SYSTEM TRAVELERS Indirect evidence suggests that all four giant planets of our solar system migrated from their formation orbits. Jupiter probably migrated a short distance inward, whereas the outer planets migrated outward, with Neptune experiencing the most movement.



RESONANCE CAPTURE If an outer planet migrates inward faster than an interior planet *(left)*, the two worlds can get caught in a resonance whereby the two planets orbital periods are a simple integer ratio such as 2:1. When this happens, the two planets can essentially lock each other so they migrate inward at the same rate *(right)*, maintaining the simple ratio. But this relationship can force the eccentricity of both planets' orbits to fluctuate, ultimately causing one of the planets to be ejected from the system.

particularly long journey. If the overall migration actually occurred over a larger distance, then a poorly understood process must have somehow acted to continuously damp down the eccentricities as the planets migrated inward.

A Consensus?

It's natural to wonder exactly how critical a role migration actually plays in sculpting the galactic planetary census. The solar system's giant planets have clearly experienced a modest degree of migration, but there's no evidence of the long-distance inward travels required of a hot Jupiter. The discovery of short-period Jovian planets generated interest in disk migration, but it now appears that the Kozai process can generate many, perhaps even a majority, of the hot Jupiters. In the few cases, such as Gliese 876b and c where disk migration clearly took place, the total radial movement is relatively small.

NASA's Kepler mission provides hope for a resolution to the puzzle. Kepler has revealed thousands of high-quality candidate planets, and its results, combined with ground-based radial-velocity exoplanet surveys, indicate that roughly half of the stars in the solar neighborhood contain systems of multiple planets with masses in the super-Earth to Neptune mass range, orbital periods ranging from days to weeks, and nearly circular orbits. The architectures, orbital periods, and planet-to-primary mass ratios of these systems are startlingly reminiscent of the satellite systems of Jupiter, Saturn, and Uranus, and it's no exaggeration to state that they represent the dominant outcome of the planet-formation process.

If long-distance migration is important, then the planets will have formed in regions where ices were abundant, and they will have water-dominated compositions like Uranus and Neptune. Alternately, if migration played little role, then this population will consist of rock–metal cores with deep hydrogen atmospheres. Forthcoming observations of nearby transiting planets will distinguish between these two alternatives, greatly helping to elucidate migration's true role in the evolution of planetary systems. ✦

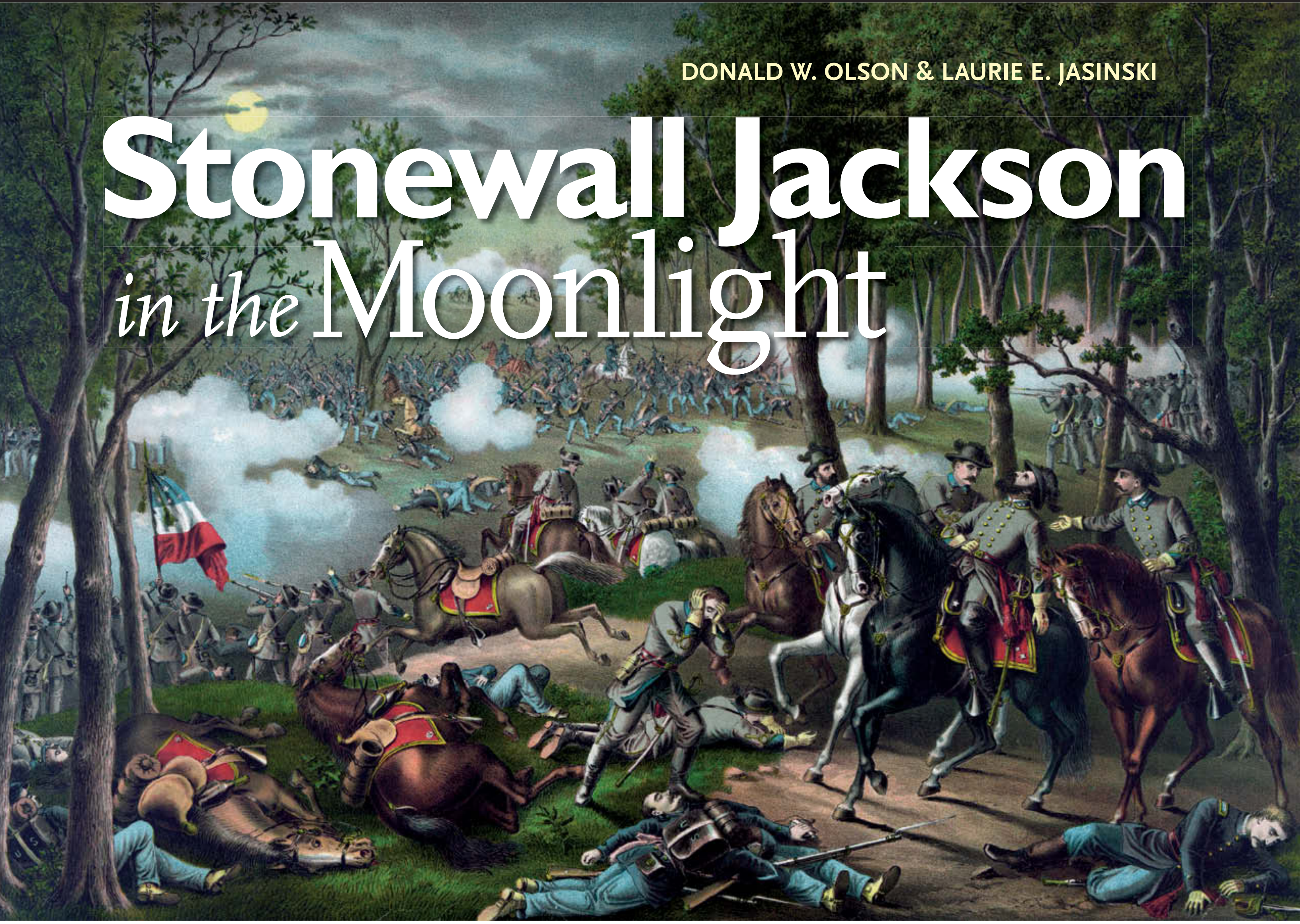
MIGRATION BY SCATTERING

Planets can also migrate inward or outward by gravitationally scattering asteroids, comets, and planetesimals. For example, if a comet flies behind Jupiter at close distance, it picks up a small amount of the giant planet's orbital energy, accelerating its velocity. In response, Jupiter loses a minuscule amount of orbital energy, causing it to drift slightly inward. Calculations strongly suggest that by scattering huge numbers of planetesimals and comets billions of years ago, Jupiter drifted slightly inward during its history, and the other three giant planets drifted outward. NASA has taken advantage of this free energy source to provide gravitational assists for many interplanetary spacecraft.

University of California, Santa Cruz astrophysicist ***Greg Laughlin*** *is involved in the detection and characterization of exoplanets. He is coauthor of the book* The Five Ages of the Universe: Inside the Physics of Eternity *with Fred Adams. He writes regularly about exoplanets at his blog,* ***www.oklo.org****.*

DONALD W. OLSON & LAURIE E. JASINSKI

Stonewall Jackson in the Moonlight



DONALD W. OLSON COLLECTION

In the battle at Chancellorsville, Virginia, a full Moon may have changed the course of the American Civil War.

MORTAL WOUND This Kurz and Allison chromolithograph from 1889 depicts the moment when Stonewall Jackson (on horseback at lower right) was hit by shots fired from the 18th North Carolina regiment. The phase and position of the Moon are rendered relatively accurately at the upper left, although the actual scene would have been much darker than this artwork suggests.

Among the storied tactics employed by both sides during the American Civil War, one of the most brilliant was a flank attack by Confederate Lieutenant General Thomas J. "Stonewall" Jackson that routed the Union army's right wing on May 2, 1863, at the Battle of Chancellorsville in northeastern Virginia.

Less than two hours of daylight remained when Jackson launched his assault. Then he did something unusual for the 19th century: He decided to continue fighting into the night. A full Moon was rising, and as historian Douglas Southall Freeman described it (in *Lee's Lieutenants*, 1943), "A kindly Providence seemed to be lifting that lantern in the sky to light the Confederacy on its way to independence."

Captain William Fitzhugh Randolph was riding at Jackson's side on that ill-fated night:

> When night closed upon the scene the victory seemed complete. The infantry of the enemy had disappeared from our immediate front. . . . The moon was shining very brightly, rendering all objects in our immediate vicinity distinct. . . . The moon poured a flood of light upon the wide, open turnpike. (*Confederate Veteran,* December 1903.)

Then, without warning, the Southern cause was struck by a tragic accident. Jackson, who stood next in command to General Robert E. Lee himself, and whose bold, rapid movements proved decisive in several previous Confederate victories, was fatally wounded by "friendly fire." Most writers have framed the accident as a bitter stroke of bad luck. But as we'll show here, the event might have an explanation after all — for sound astronomical reasons.

Fatal Volley in the Moonlight

At about 9 p.m. Jackson's group rode forward to carry out a reconnaissance. If he could cut off Union troops from the fords and pontoon bridges along the Rappahannock River, this night's attack might deliver a crushing blow to the Army of the Potomac, the largest and most powerful of the Union's armies. Colonel Edward Porter Alexander of the Confederate artillery detailed the disastrous event when soldiers of the 18th North Carolina regiment fired on the riders, mistaking them for Union cavalry:

> The moon was full that night. . . . the experiences of this occasion will illustrate the difficulty of fighting, even when the moon is at its best. . . . Jackson, followed by several staff-officers and couriers, rode slowly forward upon an old road, called the Mountain road. . . . Jackson, at the head of his party, was slowly retracing his way back to his line of battle, when this volley firing began. Maj. Barry, on the left of the 18th N.C., seeing through the trees by the moonlight a group of horsemen moving toward his line, ordered his left wing to fire. (*Military Memoirs of a Confederate,* 1907.)

South Carolinian Berry Benson was close enough to hear the volley:

> The full moon was shining brightly and objects were visible at a good distance. . . . About 9 or 10 o'clock we halted . . . a sudden volley in our front startled us. . . we had lost Jackson, struck down by our own men. (*Berry Benson's Civil War Book,* 1962.)

A total of three bullets hit Jackson, one in the right hand and two in the left arm, though the wounds did not prove immediately fatal. Aides placed Jackson on a stretcher and carried him to a field hospital.

Around the same time, the Confederate lines came under fire from dozens of Federal guns massed on nearby Fairview Heights. According to Union artillery officer Thomas W. Osborn, they opened up on the Confederates

DONALD W. OLSON COLLECTION

THE GENERAL This photo of Lt. General Thomas J. "Stonewall" Jackson was taken in late April 1863, less than two weeks before he was mortally wounded at the Battle of Chancellorsville.

Thomas J. "Stonewall" Jackson (1824–1863)

Thomas Jonathan Jackson is widely regarded by historians as one of the great subordinate commanders of the American Civil War. Raised in comparative poverty in western Virginia, he later earned an appointment at the U.S. Military Academy at West Point, New York, and graduated an impressive 17th in a class of 59 cadets in 1846.

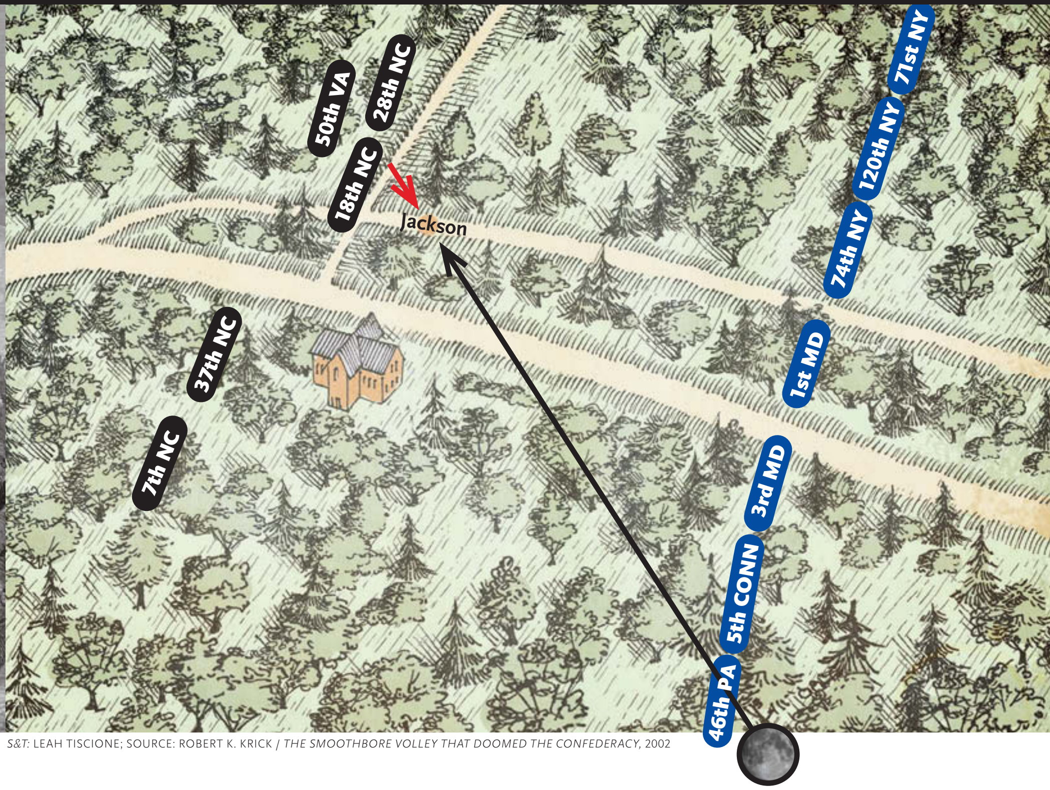
After serving with distinction and being given brevet promotions to the rank of captain then major in the U.S. war with Mexico, Jackson left the army in 1851 and served as a professor at the Virginia Military Institute. When Virginia seceded from the Union in 1861, Jackson took command of a Virginia infantry brigade and after leading successful raids on Union railroads, he was promoted to brigadier general on June 17th.

Jackson attained great fame and the nickname "Stonewall" during the Battle of First Manassas (also known as the First Battle of Bull Run) on July 21, 1861, the first large-scale confrontation of the war. Jackson and his brigade held the Confederate line against a powerful Union attack, leading Confederate Brigadier General Barnard E. Bee, Jr., to exclaim, "There is Jackson standing like a stone wall!"

During a series of relatively small battles from March to June 1862, Jackson's exploits rose to legendary status. With bold, rapid movements, Jackson's "foot cavalry" drove larger but poorly led Union forces out of the Shenandoah Valley — one of the Confederacy's major breadbaskets. However, Jackson disappointed his superior, General Robert E. Lee, with lackluster performances during the Seven Days campaign near the Confederate capital of Richmond, Virginia. But later decisive attacks at the battles of Second Manassas and Chancellorsville secured Jackson's lofty reputation.

According to Civil War historian Gary W. Gallagher (University of Virginia), "Although Jackson never displayed tactical brilliance, his swift marches and ability to place his soldiers where Lee wanted them helped set the stage for a series of striking victories." We can only speculate how the conflict may have played out had Jackson, silhouetted by a full Moon, not been mortally wounded by his own men at the Battle of Chancellorsville. — *Robert Naeye*

DONALD W. OLSON COLLECTION



S&T: LEAH TISCIONE; SOURCE: ROBERT K. KRICK / *THE SMOOTHBORE VOLLEY THAT DOOMED THE CONFEDERACY*, 2002

UNION MIDNIGHT ATTACK ***Above left:*** **A woodcut from the 1898 publication *Official and Illustrated War Record* depicts the Union midnight attack at Chancellorsville led by Major General Daniel E. Sickles. The illustration properly shows the full Moon. A *New York Times* correspondent reported, "This night attack was the most grand and terrific thing of the war. The moon shone bright, and an enemy could be seen at good musket range."** ***Above right:*** **As shown in this map, Stonewall Jackson and his scouting party were positioned between the Confederate and Union lines at 9:00 p.m. on May 2, 1863, the time of the friendly fire shooting. The full Moon was behind Jackson, leaving him and his escort in silhouette as seen from the position of the 18th North Carolina regiment. All the units in this map were infantry regiments consisting of about 400 to 450 men. The opposing forces were about ¼ mile (400 meters) apart.**

around 9:30 p.m., and the "havoc in their ranks was fearful." Osborn explained that, although the opposing lines of battle were "closely engaged," the "beautiful moonlight night" enabled his artillerymen to arc shells just over the Union positions. The bombardment "tore the rebel lines to fragments" without wounding a single Federal soldier. Union artillerist Lieutenant George B. Winslow agreed that such precise aiming was possible at night since "a cloudless sky and a bright moon enabled us to sight our guns with a considerable degree of accuracy."

Many bloody Civil War battles were fought around the capitals of Washington and Richmond. A major battle know as the Wilderness was fought near Chancellorsville.

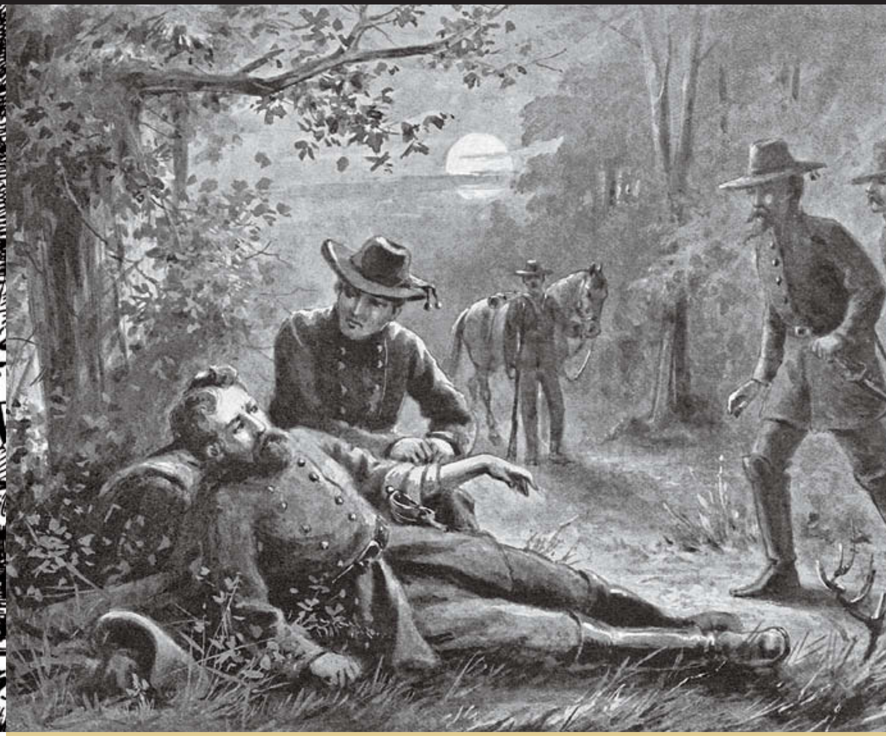
S&T: LEAH TISCIONE

Night Fighting

The Confederates halted their advance after Jackson's wounding. Fighting continued, however, when Union Major General Daniel E. Sickles launched a midnight assault. Sickles recalled that the "night was very clear and still; the moon, nearly full, threw enough light in the woods to facilitate the advance."

Fighting eventually ceased for the night as both sides paused to regroup. Major General J. E. B. Stuart assumed command of Jackson's forces and ordered Colonel Alexander to determine the best gun positions for the next day's engagement. Alexander always remembered that night, when he carried out his mission under a "glorious, clear, calm, full-moon" (*Fighting for the Confederacy*, Gary W. Gallagher, editor, 1989). The next day, the Confederates drove the Union forces from Chancellorsville, ending the threat to the capital of Richmond, Virginia, and securing what scholars often refer to as Lee's greatest victory.

DONALD W. OLSON COLLECTION



ROBERT K. KRICK COLLECTION

Moonlit Reflections

Historians looking back at the Chancellorsville campaign generally mention the Moon, of course. But details become much clearer when we look carefully at the times of moonrise and sunset, the duration of twilight, the exact lunar phase, and the Moon's location in the sky.

The table on the right shows that the nearly full Moon rose 42 minutes before sunset on May 2nd and was already rising higher into the sky as the twilight deepened. Therefore, the Chancellorsville battlefield was never totally dark. The light from the rising Moon emboldened Jackson to capitalize on the afternoon's success with a night attack.

We then realized that the calculated position of the Moon could help explain an especially significant point — why the soldiers of the 18th North Carolina regiment failed to recognize General Jackson and fired the fatal volley.

According to James Gillispie's *Cape Fear Confederates* (2012), the 18th North Carolina "unfortunately became famous and best known for accidentally wounding Stonewall Jackson." Gillispie commented that Major John Barry "felt extreme guilt over giving the command to fire" and that after the war Brigadier General James Lane was "understandably touchy about any criticism of his brigade generally or the 18th North Carolina specifically." Lane characterized the tragedy as a "misapprehension caused by the darkness."

In the 150 years since Chancellorsville, writers have offered conflicting opinions as to whether May 2, 1863, was a bright moonlit night or a murky dark night. Espe-

MAY 2, 1863 CHANCELLORSVILLE, VIRGINIA

77°39′ west longitude, 38°19′ north latitude

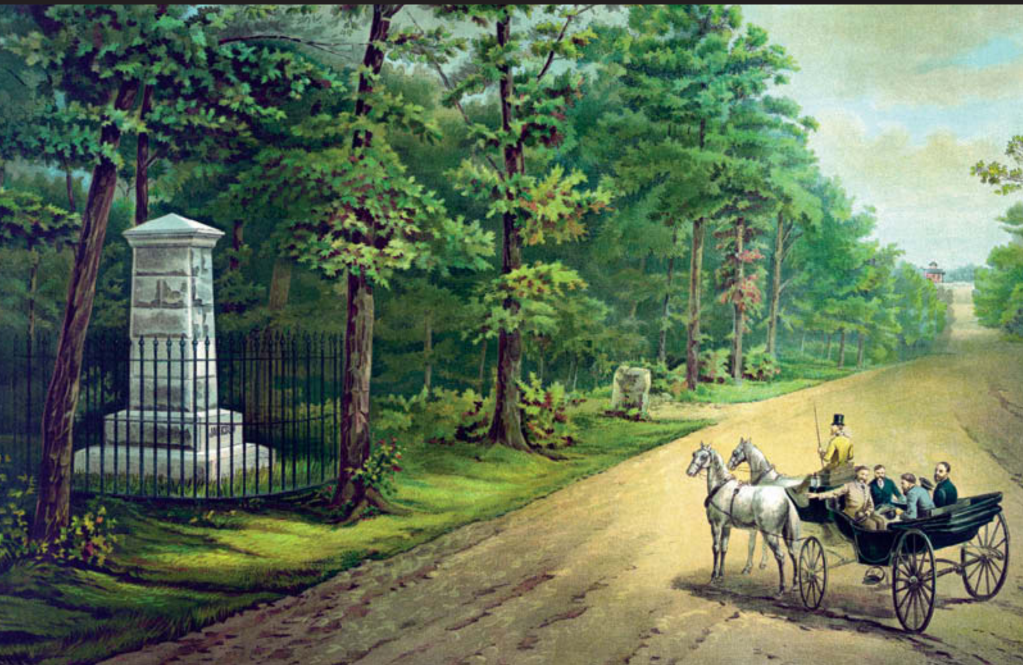
LOCAL MEAN TIME	MOON'S ALTITUDE	MOON'S AZIMUTH	EVENT
6:10 p.m.	0°	110°	Moonrise
6:52 p.m.	6°	116°	Sunset
7:20 p.m.	11°	121°	End of civil twilight
7:55 p.m.	16°	127°	End of nautical twilight
8:32 p.m.	22°	135°	End of astronomical twilight
9:00 p.m.	25°	141°	Approximate time of Jackson's wounding

The times are expressed in local mean time, $5^h\ 11^m$ behind UT. Virginia did not adopt standard time zones until 1883.

The Moon was 99.6% illuminated on the evening of May 2. The exact instant of full Moon fell on May 3, 1863, at $14^h\ 52^m$ UT.

MOONLIGHT VOLLEY ***Above left:*** **This woodcut from John Casler's 1906 memoir *Four Years in the Stonewall Brigade* correctly shows the position of the rising full Moon, shining behind Jackson and his scouting party. The riders would have appeared as even darker silhouettes, explaining why the North Carolina men failed to recognize Jackson as one of their own.**

BINDING JACKSON'S WOUNDS ***Above right:*** **This artwork from *The Story of American Heroism* (1897) shows Major General Ambrose Powell Hill, Jr. binding Stonewall Jackson's wounded left arm minutes after he was shot. Eight days later Jackson died from complications resulting from his injuries, depriving the Confederates of one of their ablest commanders.**



DONALD W. OLSON COLLECTION

U.S. NATIONAL PARK SERVICE

JACKSON MONUMENT ***Above left and right:*** **This monument to Jackson was erected in 1888 near the spot at Chancellorsville where his wounds were initially tended. Visitors can follow a short trail east of the adjacent visitor center to the actual site of the fatal volley. The chromolithograph at left was published in 1890.**

cially to those on the Confederate side, the idea that their soldiers could not recognize such an illustrious figure as Stonewall Jackson seemed inexplicable, and many insisted on the darkness of the night as the primary reason for the friendly fire.

The publication *Confederate Veteran* printed a letter in June 1902 from Virginian E. S. Anderson, who recalled, "I was in the battle of Chancellorsville, and saw Jackson when he fell. It was a beautiful moonlight night." But in the October 1902 issue, Georgian I. Roseneau retorted that Anderson's "statement is incorrect. . . . General Jackson was shot to my left, and I remember distinctly that 'it was the darkest night I ever saw.' . . . Had it been a beautiful moonlight night, his comrades who shot him would have recognized General Jackson and avoided the terrible catastrophe."

This last account, however, is amply refuted by those quoted earlier, which clearly demonstrate that the opposing armies fought under a bright Moon.

We can offer a different explanation for Jackson's wounding, one based on the *direction* of the moonlight. Detailed battle maps show that the soldiers of the 18th North Carolina were looking to the southeast, exactly toward the rising Moon, which had reached an altitude of 25° above the horizon at 9 p.m., the approximate time of Jackson's wounding. The moonlight therefore silhouetted Jackson and his party as they rode back toward the Confederate lines — a fact that has not been noted by historians, so far as we know. The riders would have appeared as dark figures, not recognizable, so our astronomical analysis partially absolves the 18th North Carolina from blame for the wounding of Jackson.

To see a list of references and to see more images, visit skypub.com/Chancellorsville.

In the hours after the fatal volley, surgeons were forced to amputate Jackson's left arm. A few days later General Lee, who considered Jackson irreplaceable, was famously moved to say: "He has lost his left arm; but I have lost my right arm." Jackson's condition continued to worsen, and he died of complications from pneumonia on May 10, 1863, at age 39.

Postscript

The United States is currently in the midst of a four-year commemoration of the Civil War, and the month of this issue marks the 150th anniversary of Chancellorsville. But an even more famous battle took place just two months later, on July 1–3, 1863, near the time of another full Moon. Widely seen as the turning point of the war, the Battle of Gettysburg lacked an important player for the Confederate cause: Stonewall Jackson.

The Confederate army initially had success at Gettysburg on July 1st but failed to seize the high ground of Culp's Hill and Cemetery Hill, key tactical landmarks that Federal troops eventually occupied in force. On July 3rd, the Southern cause suffered a crushing blow with the disaster of the infamous Pickett's Charge against the

BUDDY SECOR

CHANCELLORSVILLE AT DAWN This award-winning photo shows the rising Sun illuminating the position called Fairview Heights. From this location, Union artillery ravaged the Confederate line during the moonlit night of May 2–3, 1863. Despite this Union success, the much smaller Confederate Army of Northern Virginia drove the Union Army of the Potomac from the field.

THE BATTLE OF CHANCELLORSVILLE

The Union Army of the Potomac, commanded by Major General Joseph Hooker, entered the Battle of Chancellorsville with an estimated 130,000 men. After Confederate attacks drove the Federals from the field, President Abraham Lincoln reportedly exclaimed, “My God! My God! What will the country say?” The Union suffered about 18,000 casualties. The Confederate Army of Northern Virginia, led by General Robert E. Lee, started the battle with about 60,000 troops. Lee’s strategic victory was tempered by the loss of about 13,000 men, including Stonewall Jackson.

Union line on Cemetery Ridge.

In his reminiscences written after the war’s end, General Lee again lamented Jackson’s absence, commenting, “If I had had Stonewall Jackson at Gettysburg, we should have won a great victory.” Confederate Major General Lafayette McLaws expressed a similar view about the need for Jackson’s initiative at this crucial battle:

> If he had been at Gettysburg on the evening of July 1st, when the enemy were in full retreat and in confusion upon the hill and ridge . . . there would have been no delay in the onward march of his then victorious troops; he would . . . have gone forward, with his characteristic dash and daring, and those important positions would doubtless have been ours, and the battle of Gettysburg of the 3d would not have occurred. This was the reputation he had made for himself, to last forever. (Quoted in *Memoirs of Stonewall Jackson*, 1895.)

We will never know how the American Civil War would have unfolded, or if the Battle of Gettysburg would have even taken place, had Stonewall Jackson not been mortally wounded on the fateful night of May 2, 1863. One thing we do know is that the Union advantages in manpower and industrial capacity were brought increasingly to bear as the conflict dragged on year after year. But without question, the full Moon at Chancellorsville played a role in changing the course of the war. ✦

Donald W. Olson *teaches physics and astronomy at Texas State University and is the author of the forthcoming book,* Celestial Sleuth *(Springer, 2013).* ***Laurie E. Jasinski*** *is a Texas State graduate and the editor of* The Handbook of Texas Music, Second Edition *(Texas State Historical Association, 2012).* *The authors are grateful for research assistance from Margaret Vaverek of the Alkek Library at Texas State.*

EXPLORING THE M83 GALAXY GROUP

Under the tail of Hydra lies a collection for deep-sky connoisseurs.

Les Dalrymple

One of the nearest galaxy clusters to us, after the Milky Way's own Local Group, is the little-known M83 family. Scattered about 10 to 20 million light-years away and spanning some 30° of sky, the M83 Group lies in the southern end of the gigantic Virgo Supercluster band of galaxies running from Ursa Major to Centaurus. This nearby southern subgroup offers visual feasts and challenges for both small and large scopes. Its members include the iconic M83 and Centaurus A (NGC 5128), leading it sometimes to be called the M83/Cen A Group. It also has NGC 4945, 5102, 5253, 5264, 5408, and more than a dozen small, dim IC and ESO galaxies.

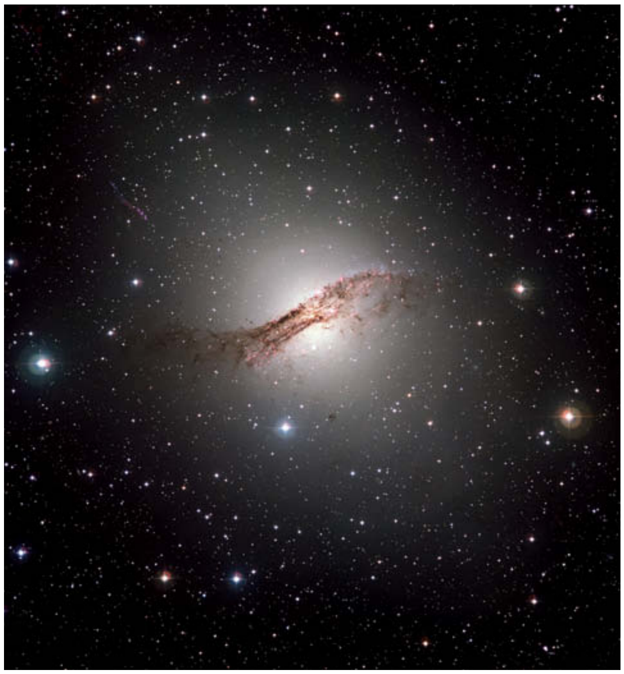
So, why isn't this scattered collection better known? The reason is simple. It's pretty far south. But its galaxies cross the meridian late on April nights and earlier after dark in May, affording northerners a narrow seasonal viewing window. Let's take a tour.

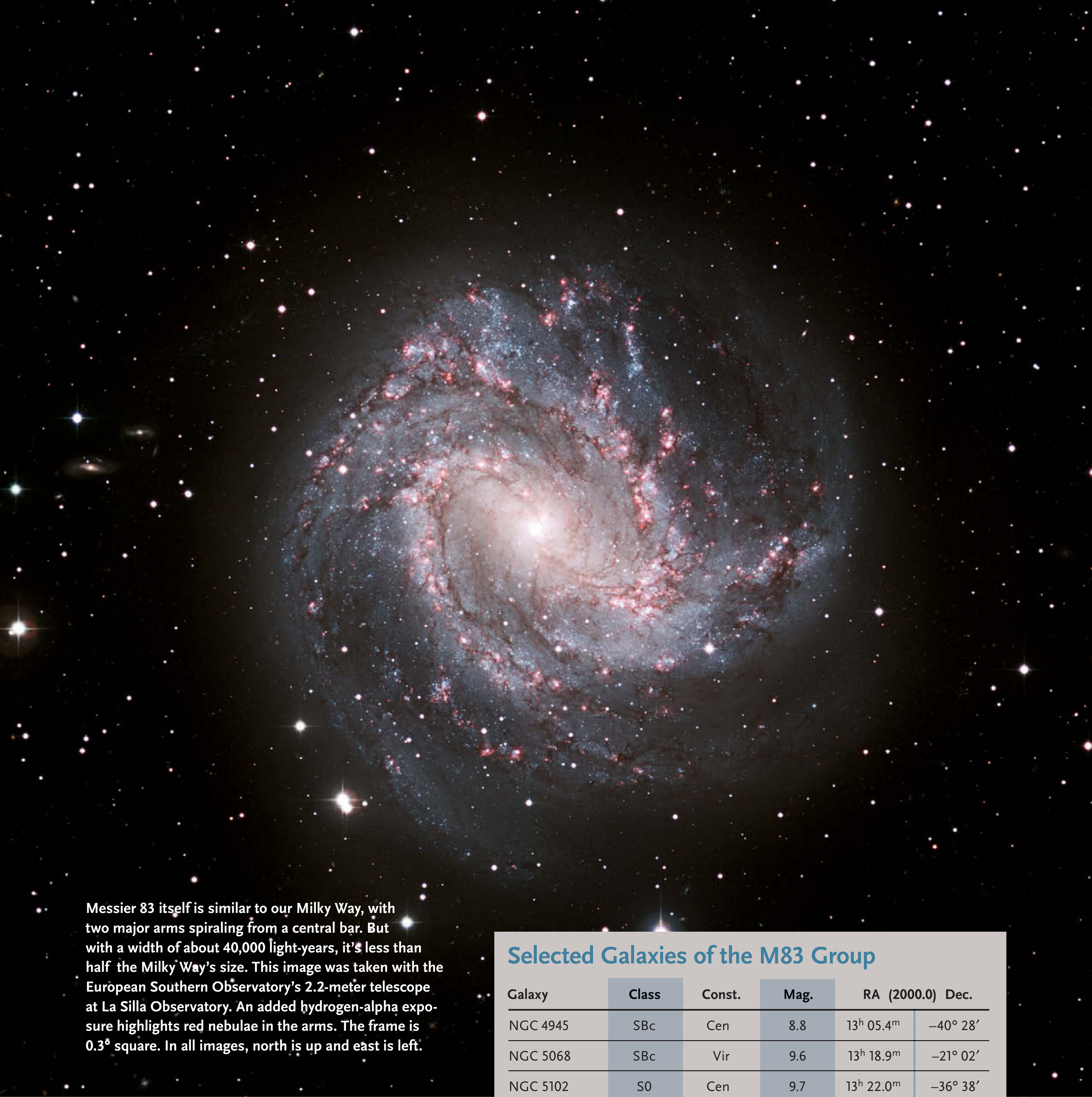
Meet the Family

Let's start with **M83** itself. It's one of the northernmost of the group, at declination –30° near the border of Hydra and Centaurus (yes, Centaurus butts up that far north). So even if you live as far north as latitude 40°, M83 is positioned a good 20° above your south horizon when on the meridian.

M83 is one of the most inviting spirals in the sky, with a structure similar to our Milky Way's. Find it 19° south of Spica and 4° northwest of the distinctive triangle formed by the 4th-magnitude stars 1, 2, 3, and 4 Centauri, as seen on the middle *Sky Atlas 2000.0* snippet on page 41. The galaxy spans nearly 0.2° as seen in my 12.5-inch reflector, looking generally circular but with a flattened northwest side. Its core is small and bright, with a bar running northeast to southwest.

Under excellent sky conditions at my home in Australia, where M83 passes overhead, an 8-inch scope will





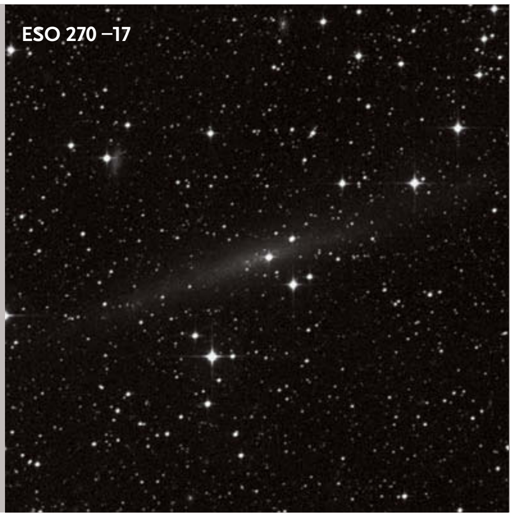
Messier 83 itself is similar to our Milky Way, with two major arms spiraling from a central bar. But with a width of about 40,000 light-years, it's less than half the Milky Way's size. This image was taken with the European Southern Observatory's 2.2-meter telescope at La Silla Observatory. An added hydrogen-alpha exposure highlights red nebulae in the arms. The frame is 0.3° square. In all images, north is up and east is left.

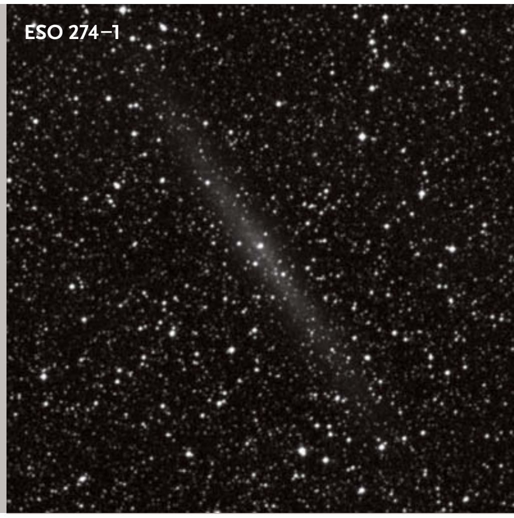
ESO (2)

Left: Centaurus A (NGC 5128) seems to be an elliptical galaxy that merged with a spiral. It and M83 are both at the about same distance, 10 to 16 million light-years, within the fairly large uncertainties that remain. The two dominate the sprawling M83/Cen A Galaxy Group. This image, ⅓° wide, was taken with the European Southern Observatory's 2.2-meter telescope at La Silla, Chile.

Selected Galaxies of the M83 Group

Galaxy	Class	Const.	Mag.	RA (2000.0)	Dec.
NGC 4945	SBc	Cen	8.8	13^h 05.4^m	–40° 28′
NGC 5068	SBc	Vir	9.6	13^h 18.9^m	–21° 02′
NGC 5102	S0	Cen	9.7	13^h 22.0^m	–36° 38′
Centaurus A	S0	Cen	7.0	13^h 25.5^m	–43° 01′
ESO 270–17	SBc	Cen	~11	13^h 34.8^m	–45° 33′
M83	SBc	Hya	7.6	13^h 37.0^m	–29° 52′
NGC 5253	I(p)	Cen	10.2	13^h 39.9^m	–31° 39′
ESO 274–1	Sc	Lup	~11	15^h 14.2^m	–46° 49′





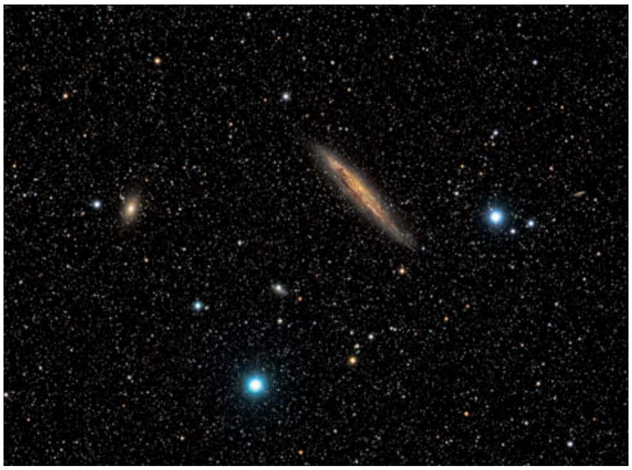
DIGITIZED SKY SURVEY (2)

The enigmatic Fourcade-Figueroa Object (*left*) and similarly dim, elongated ESO 274–1 (*right*) are challenge objects even in the best of circumstances. Each frame is ¼° on a side.

show its most prominent spiral arms at high power. In my 12.5-inch, one arm runs from the northeastern end of the galaxy's bar around to the south, where it merges with the galaxy's disk. The opposite arm appears broader but dimmer; I can trace it from the bar's southwest end around over the northern side. In my 20-inch reflector, M83 begins to resemble its photographic appearance.

This galaxy has popped off with six supernovae in the last 90 years, so keep an eye out for any extra star of 12th to 14th magnitude not on photos.

Countless Messier-object loggers have observed M83. But how many know to work just 2° south from it to catch tiny but relatively bright **NGC 5253**? It's 10th magnitude compared to M83's 7.6, but being only 5′ × 2′ in size, it has a higher average surface brightness. It's classified as a peculiar irregular galaxy and owes its brightness to



DIETMAR HAGER / THORSTEN BRANDES / JOHANNES SCHEDLER

The very dusty edge-on spiral NGC 4945, about as big as the Milky Way, is some 13 million light-years distant. This wide view spans nearly 2° and includes the 4th- and 5th-magnitude bluish stars Xi^2 and Xi^1 Centauri. The next most prominent galaxy in the field, NGC 4976, is about 35 million light-years distant, well in the background of the M83/Cen A Group.

areas of furious star formation. Astronomers think it had a close encounter with M83 one to two billion years ago that "pulled the trigger" on a frenzied starburst. Its inner spindle is oriented northeast-southwest with a brighter core. Observatory images show a dozen mammoth star clusters and a compact super-nebula.

If any galaxy has a more spectacular dark dust lane than **Centaurus A (NGC 5128),** I'd like to hear about it. Other showy galaxies such as M104 (the Sombrero) in Virgo and M64 and NGC 4565 in Coma Berenices exhibit major dust lanes too, but they do little to prepare you for your first sight of this enigmatic giant. Centaurus A reveals its central lane in telescopes as small as 4 inches when it's high in a dark sky. But it's 13° farther south than M83, so northerners will find it more of a challenge. If you're in the latitudes of the southern U.S., the standard way to find it is to slide 4.5° due north from the spectacular, 4th-magnitude globular cluster Omega Centauri.

Many astronomy books proclaim M31, the Andromeda Galaxy, or M33 in Triangulum (both less than 3 million light-years away), as the most distant object visible to the naked eye. More recently, NGC 253 in Sculptor (11 or 12 million light-years) and M81 in Ursa Major (12 million) have claimed this title. Many experienced Southern Hemisphere observers have spotted 7th-magnitude Cen A without optical aid under perfect conditions. I first managed this in March 2002 at the South Pacific Star Party. At 10 to 16 million light-years (measurements vary), Centaurus A may be the absolute naked-eye record holder.

In my 12.5-inch at 150×, Centaurus A appears about 15′ × 12′ in size, with its very diffuse edges growing steadily in brightness toward the galaxy's center. The dust lane bisects it east-southeast to west-northwest. Visually, the western end appears noticeably narrower than the eastern end, which contains a wedge of faint, ill-defined mist dividing the lane into two equal streams.

M83 and Cen A are the two biggies of the M83 Group. On now to fainter challenges!

Looking Deeper

About 3° southeast of Centaurus A, not quite between it and Omega Cen, lies **ESO 270–17**, a strange, edge-on segment called the Fourcade-Figueroa Object after its discoverers. I wonder how many observers have unwittingly passed over it while star-hopping from Omega Cen to Cen A. Through my 12.5-inch, the phantom form of this strange, core-less shred seems to extend 7′ × 1′ east-southeast to west-northwest. It has an extremely low surface brightness, making it a challenge indeed for North Americans.

Can you work even farther south? Exactly 4° southwest of Omega Centauri is long, narrow **NGC 4945**. Find it nearly between Xi^1 and Xi^2 (ξ^1 and ξ^2) Centauri as shown on the chart at right. It's fairly easy to spot for us Australians — even 10×50 binoculars easily show it in a dark sky. Under good skies my 12.5-inch reveals NGC 4945 as a patch 16′ long and 3′ wide, shaped like a candle flame and oriented northeast-southwest. My averted vision gives only a hint of the dark lane at its southeastern edge, evident in the photograph at the bottom of the facing page.

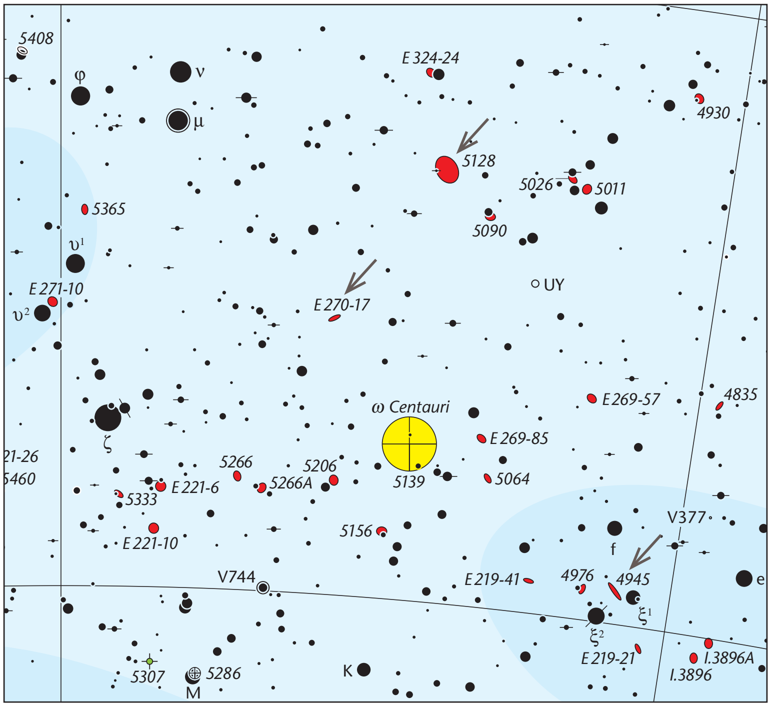
Jumping back north to declination –37°, bright little **NGC 5102** is seemingly hitched up to 3rd-magnitude Iota (ι) Centauri, located 8° south-southwest of M83. Look 15′ to Iota's east-northeast. I find NGC 5102 easy in an 8-inch from Australian suburbs, but for northerners it will be a more noteworthy pickup. Its long oval shape extends about 9′ × 2½′ northeast-southwest.

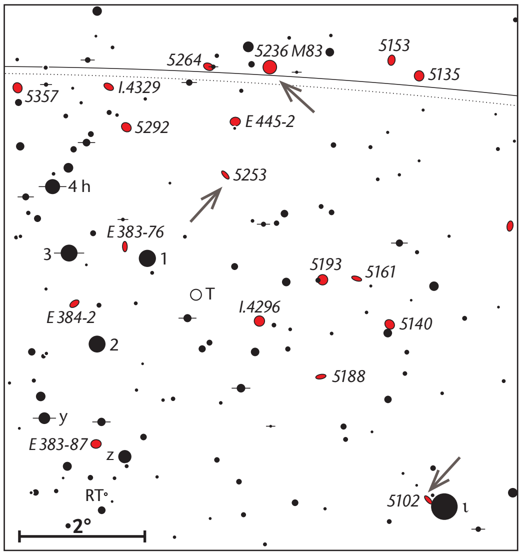
Back farther north! Just across the border from Hydra into Virgo — constellations less daunting to Americans — **NGC 5068** lies about 2° north of Gamma Hydrae; see the bottom chart at right. It's a possible outlying member of the M83 Group: fairly large and dim, about 4½′ in diameter, with indistinct edges and only a slight overall central brightening. The galaxy appears slightly elongated east-southeast to west-northwest. An unrelated neighboring galaxy, NGC 5084, can be seen to its southeast.

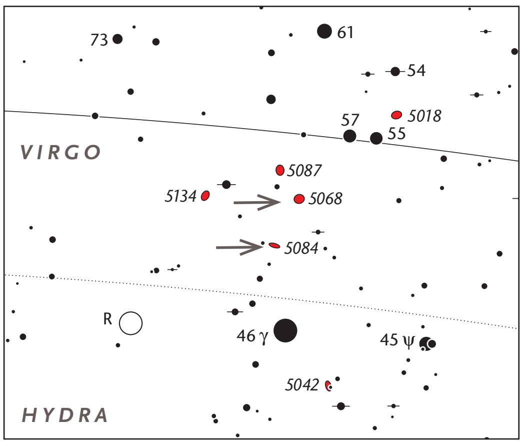
Finally, we drop far south again and over to the east for our other family ghost, **ESO 274–1** in Lupus. It's only a tad brighter than its phantom cousin streak near Centaurus A and also requires a fairly large aperture and a very dark, transparent sky. You might try for it from the deserts of the Southwest. It lies not quite halfway from Mu to Lambda Lupi, in a field richly carpeted with stars small and dim. This edge-on spiral is a very thin, 9′ × 0.7′ sliver of gossamer haze oriented northeast-southwest. It has a small, slightly brighter, elongated core. This object is certainly a challenge to see even at a good altitude under pitch-black skies — you'll need at least a 12-inch to tackle it.

The M83 group contains many other family members, but all are smaller and fainter than this article's selection. If you have a southward view without too much light pollution, take the challenge to give these a try! ✦

Les Dalrymple (lesdal22@tpg.com.au) works as a guide and lecturer at Australia's Sydney Observatory.







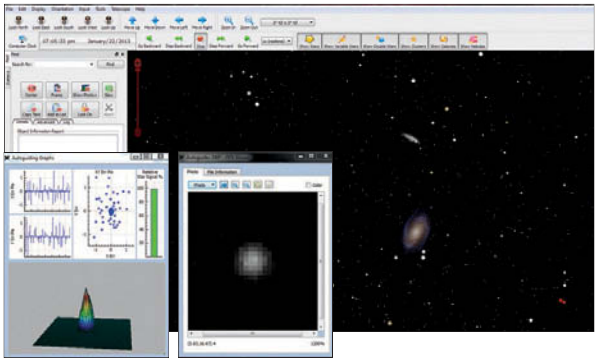
These charts are reproduced from the deluxe edition of *Sky Atlas 2000.0* at the original scale. Arrows point to M83 Group members described in the text.

Above: The southern showpieces Centaurus A (labeled 5128) and Omega (ω) Centauri can be seen from farther north than many northerners assume. The group members ESO 270–17 and NGC 4945 are tougher challenges. The field is 11° tall.

Middle: The sky from M83 to Iota (ι) Centauri. The field is 8° tall.

Left: Farther north, NGC 5068 and 5084 can be found a couple degrees north of 3rd-magnitude Gamma (γ) Hydrae east of Corvus. This frame is 6° tall.

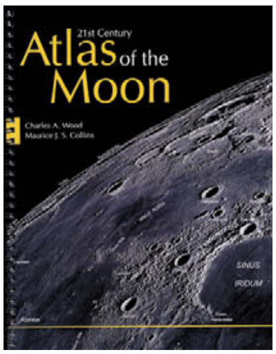
New Product Showcase



▲ **SKYX CAMERA CONTROL** Software Bisque announces its long-anticipated Camera Add On to *TheSkyX Professional Edition* ($199). The component allows users to control two cameras simultaneously, one for imaging and the other for autoguiding on PC or Mac platforms. This includes all Canon, SBIG, QSI, and Orion cameras, as well as certain video cameras. Sequence your entire night of imaging and reduce your data with flat frames, darks, and biases all within the program. *TheSkyX Pro* Camera Add On also enables you to perform automated focus with supported electric focusers, and can also control a host of additional *ASCOM*-compatible products. See the manufacturer's website for additional details.

Software Bisque
862 Brickyard Circle, Golden, CO, 80403
303-278-4478; www.bisque.com

▼ **MOON ATLAS** Lunar scientist and *Sky & Telescope* columnist Charles A. Wood teamed up with amateur astronomer Maurice J. S. Collins to produce *The 21st Century Atlas of the Moon* ($29.95). This spiral-bound atlas is based on global maps derived from Lunar Reconnaissance Orbiter images. It divides the lunar nearside into 28 sections, plus it has an additional 8 charts that depict the limb regions visible from Earth during favorable librations. Each full-page chart is accompanied by notes explaining which Lunar 100 targets are visible. The book also provides close-up highlights of major features with pertinent geological and historical information. Four full Moon maps are also included, as are sections on lunar basins, mare ridges, and the landing sites of the Apollo missions and robotic probes. Spiral bound, 112 pages. ISBN 978-0-9886430-0-0.



Lunar Photo of the Day
http://lpod.wikispaces.com/21st+Century+Atlas+of+the+Moon

▼ **UNIQUE MOUNT** The history of telescope making is filled with ingenious variations on the traditional German equatorial mount that debuted in the early 19th century. Very few of them, however, have become commercial products. But the list has just grown by one thanks to the folks at iOptron, one of the world's leading manufacturers of telescope mounts. The ZEQ25GT (price not yet available at press time) has the declination shaft and telescope mount at one end of the polar axis and the counterweight at the other. This arrangement keeps the mount's center of gravity better distributed over the tripod, and the pivoting counterweight shaft won't interfere with the tripod legs when the mount is used at low latitudes. The ZEQ25GT retains the features of iOptron's highly regarded equatorial mounts, including Go To pointing, a precise polar-alignment scope, and an excellent payload-to-weight ratio. It's rated for loads up to 25 pounds (11 kg). Contact the manufacturer for more details.

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

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

In This Section

IMAGE: EUROPEAN SOUTHERN OBSERVATORY
The exotic galaxy Centaurus A is the brightest member of the M83 group, which is discussed on page 38.

OBSERVING

Sky at a Glance

MAY 2013

5 **EARLY MORNING:** The Eta Aquarid meteor shower, best for southern latitudes, should be strongest just before the sky starts to grow light; see page 52.

10 **AN ANNULAR SOLAR ECLIPSE** is visible from parts of Australia and the Pacific; see page 52 and skypub.com/may2013eclipses.

DUSK: Binoculars may show an extremely thin crescent Moon very close to Venus low in the west-northwest shortly after sunset, as shown on page 48.

11, 12 **DUSK:** A beautifully thin crescent Moon floats below Jupiter on the 11th and upper left of Jupiter on the 12th.

17 **EVENING:** Regulus shines above the first-quarter Moon.

21, 22 **EVENING AND NIGHT:** The waxing gibbous Moon is close to Spica's right on the 21st and to Saturn's lower right on the 22nd.

24 **DUSK:** Mercury is just 1½° upper right of Venus low in the west-northwest shortly after sunset, as shown on page 48. This is the first of six evenings when Venus, Jupiter, and Mercury all fit in a 5° circle; see skypub.com/may2013planets.

EVENING: The full Moon occults (hides) the 2nd-magnitude star Beta Scorpii for much of the eastern U.S.; see page 52.

26 **DUSK:** Venus, Jupiter, and Mercury are closest in the sky, forming a nearly equilateral triangle.

28 **DUSK:** Jupiter is just 1° lower left of Venus.

Planet Visibility

SHOWN FOR LATITUDE 40° NORTH AT MID-MONTH

Planet	◀ SUNSET	MIDNIGHT	SUNRISE ▶
Mercury	NW	Visible May 19 through June 21	
Venus	NW		
Mars		Hidden in the Sun's glow all month	
Jupiter	NW		
Saturn	SE	S	W

Moon Phases

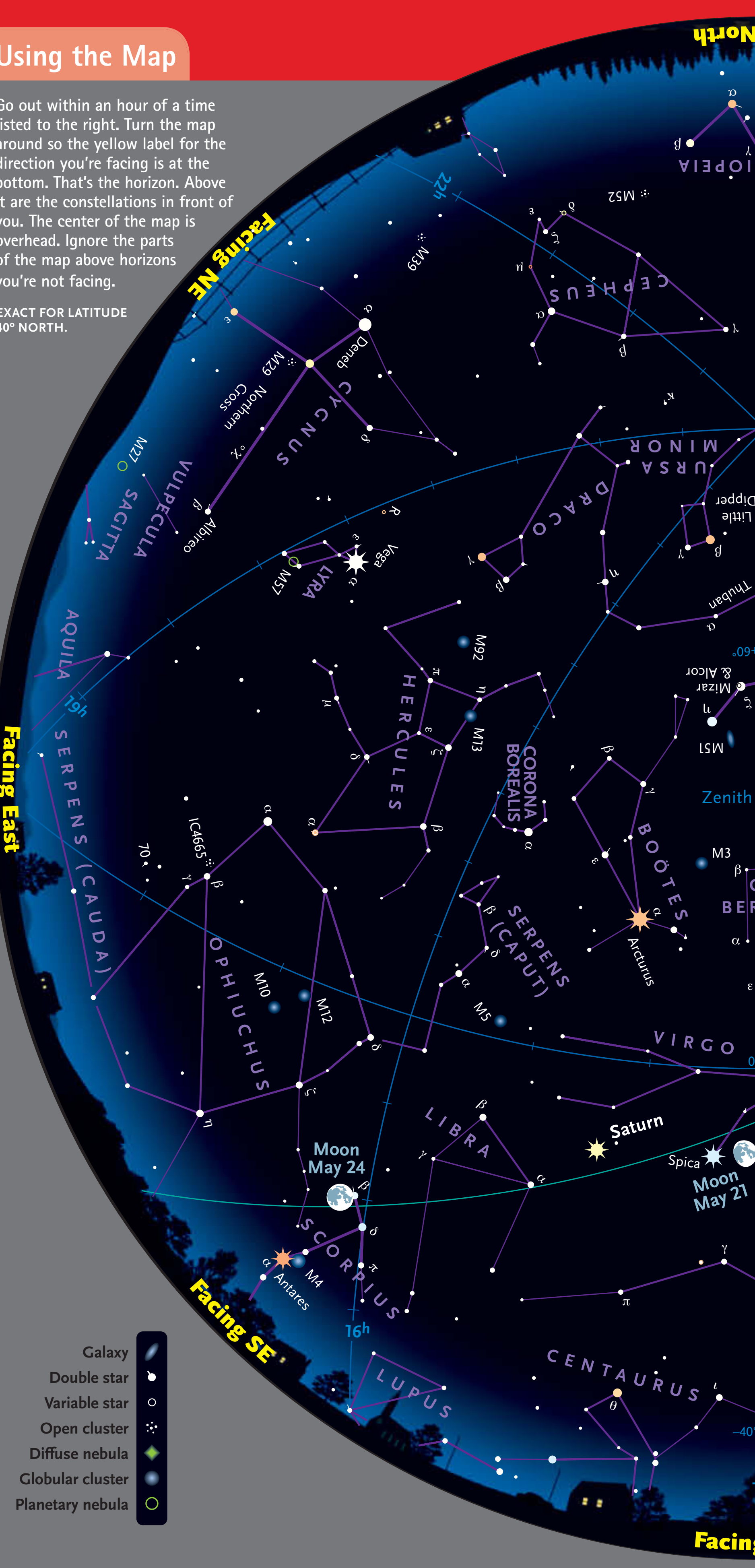
New	May 9	8:28 p.m. EDT	
Full	May 25	12:25 a.m. EDT	
Last Qtr	May 2	7:14 a.m. EDT	
First Qtr	May 18	12:35 a.m. EDT	
Last Qtr	May 31	2:58 p.m. EDT	

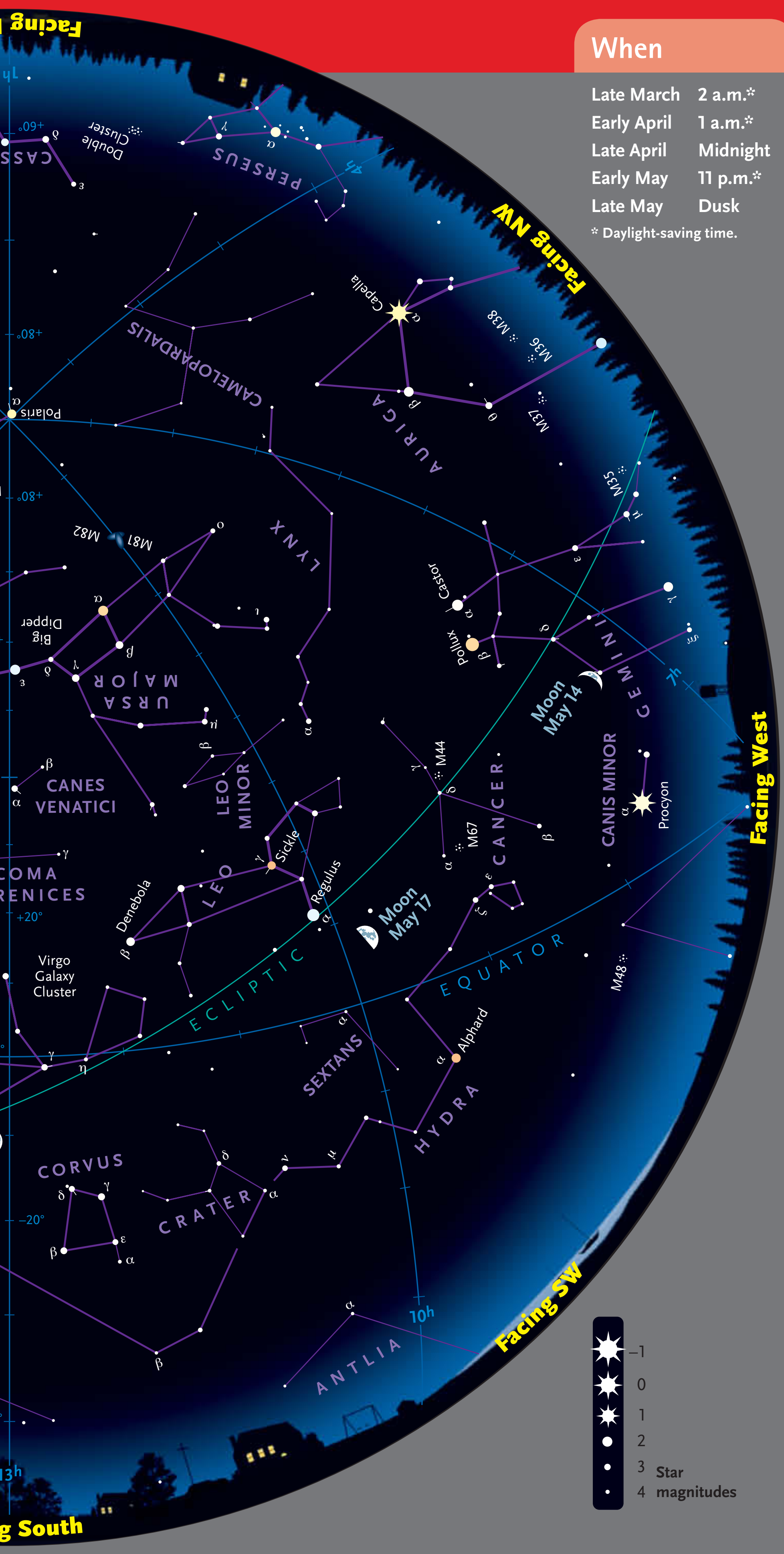
SUN	MON	TUE	WED	THU	FRI	SAT
			1	2	3	4
5	6	7	8	9	10	11
12	13	14	15	16	17	18
19	20	21	22	23	24	25
26	27	28	29	30	31	

Using the Map

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

EXACT FOR LATITUDE 40° NORTH.





When

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

* Daylight-saving time.

Gary Seronik

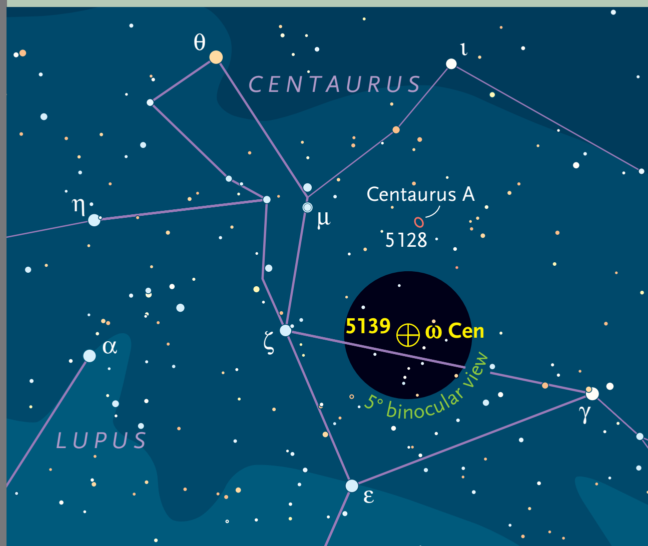
Binocular Highlight

Magnificent Omega Cen

Our Milky Way is home to more than 150 globular star clusters. Of these, a handful are reasonably easy binocular targets. But the best globular in the entire sky for ordinary binos is **Omega Centauri**. Also known as NGC 5139, this mass of some 10 million ancient suns is big (36′ across) and bright (magnitude 3.9). But for most readers of this magazine, it has one significant flaw — it's too far south for a really good look.

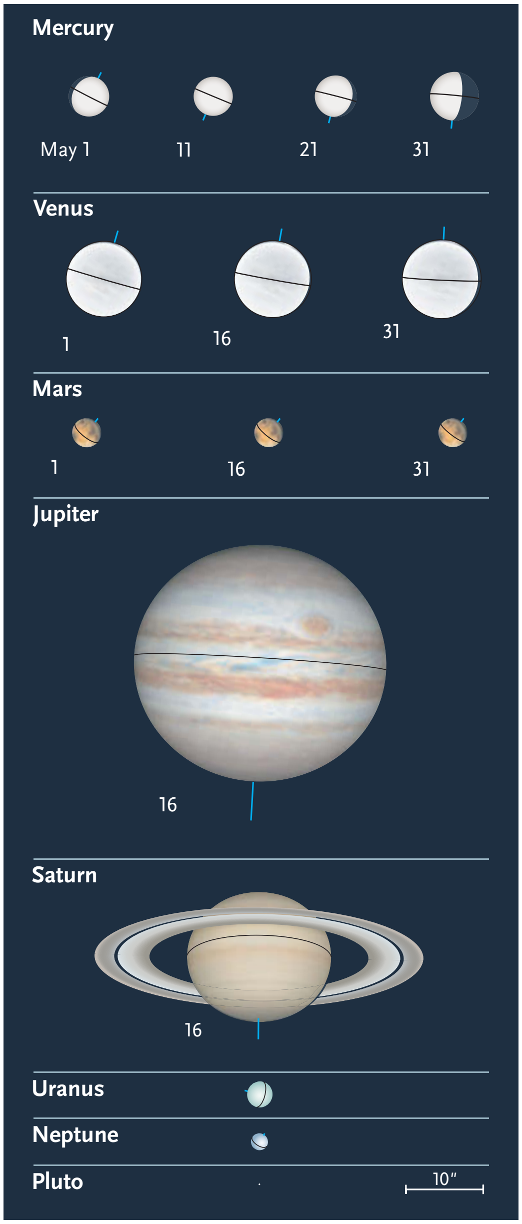
With a declination of –47½°, Omega can, at least in theory, be seen skimming the horizon as far north as 42½° latitude. But is that realistic? Perhaps. The globular has been sighted (though not with binoculars) and imaged from the southernmost point in Canada, which is at latitude 42°. That means Omega is also observable from much of the continental United States. Can you see it from your location? Obviously you'll need a good southern horizon to have a shot, but I'd be interested in reading your reports, both positive and negative.

From more southerly locations, Omega is a stunner — an impressive sight even in my 10×30s. I've seen it many times from Costa Rica, at 10° north latitude. It's the one globular that appears clearly non-stellar even to novice binocular observers. Ironically, Omega may not be a true globular cluster. If recent studies are correct, this grand swarm of stars is the remnant core of a dwarf galaxy that was stripped of its outer stars when it was absorbed by our Milky Way. ✦



Watch a SPECIAL VIDEO

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

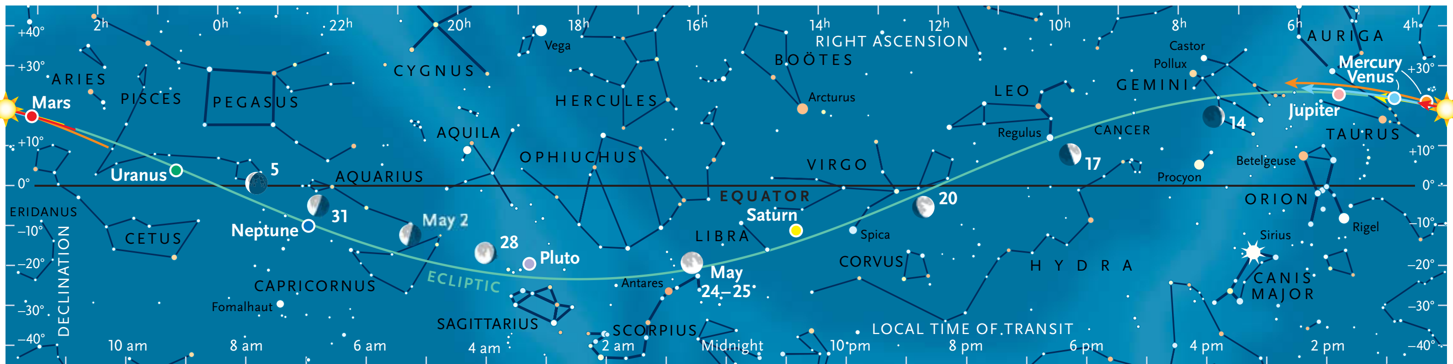


Sun and Planets, May 2013

	May	Right Ascension	Declination	Elongation	Magnitude	Diameter	Illumination	Distance
Sun	1	2^h 32.7^m	+15° 00′	—	–26.8	31′ 45″	—	1.008
	31	4^h 31.4^m	+21° 53′	—	–26.8	31′ 33″	—	1.014
Mercury	1	1^h 48.5^m	+9° 26′	12° Mo	–1.0	5.2″	91%	1.280
	11	3^h 07.2^m	+17° 28′	1° Mo	–2.3	5.1″	100%	1.325
	21	4^h 35.6^m	+23° 34′	11° Ev	–1.3	5.4″	90%	1.244
	31	5^h 57.0^m	+25° 38′	20° Ev	–0.5	6.3″	65%	1.064
Venus	1	3^h 07.4^m	+17° 09′	9° Ev	–3.9	9.8″	99%	1.702
	11	3^h 57.5^m	+20° 29′	11° Ev	–3.9	9.9″	98%	1.684
	21	4^h 49.4^m	+22° 53′	14° Ev	–3.9	10.0″	97%	1.660
	31	5^h 42.6^m	+24° 12′	17° Ev	–3.8	10.2″	96%	1.630
Mars	1	2^h 21.5^m	+13° 49′	3° Mo	+1.3	3.8″	100%	2.447
	16	3^h 05.0^m	+17° 17′	6° Mo	+1.3	3.8″	100%	2.460
	31	3^h 49.1^m	+20° 06′	10° Mo	+1.4	3.8″	100%	2.466
Jupiter	1	5^h 04.9^m	+22° 31′	37° Ev	–2.0	33.6″	100%	5.876
	31	5^h 33.3^m	+23° 02′	14° Ev	–1.9	32.4″	100%	6.090
Saturn	1	14^h 25.4^m	–11° 35′	176° Ev	+0.1	18.8″	100%	8.817
	31	14^h 17.4^m	–10° 58′	146° Ev	+0.3	18.5″	100%	8.972
Uranus	16	0^h 40.9^m	+3° 40′	44° Mo	+5.9	3.4″	100%	20.761
Neptune	16	22^h 28.5^m	–10° 15′	80° Mo	+7.9	2.3″	100%	30.144
Pluto	16	18^h 47.2^m	–19° 42′	134° Mo	+14.1	0.1″	100%	31.728

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

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



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

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

Fred Schaaf

Pursuing Mythic Sky Bears

The Great and Little Bears are the stuff of history and legend.

For the past two months, we have been touring spring skies by visiting what I've called myth-groups: constellations related to one another by a single major myth or mythological figure. This month, we'll finish with a tour of the Ursa Major myth-group.

Mythical sky bears. The Big Dipper — the Plough in Great Britain — is probably the best-known asterism in the sky. But it's only part of the much larger, official constellation Ursa Major, the Great Bear. And the Little Dipper is an asterism made from stars of the official constellation Ursa Minor, the Little Bear — including Polaris, the North Star.

But only the Great Bear existed in earliest Greek times — and probably long before that as well. The Little Bear was reputedly introduced around 600 BC by Thales of Miletus, who is sometimes called the Father of Science. He was apparently inspired by precession: the slow wobble of Earth's axis.

The north celestial pole lay near the star Thuban (Alpha Draconis) when the Egyptians were building pyramids. By Thales's time it had shifted near the stars Kochab and Pherkad (Beta and Gamma Ursae Minoris, respectively), which became known as the Guardians of the Pole. Their newly important positioning prompted Thales to create Ursa Minor from the wings of Draco.

Precession has moved the celestial pole onward to Polaris in our time, but Kochab and Pherkad are still fascinating to observe. They're relatively bright — Kochab nearly equals Polaris in brightness — while the rest of Ursa Minor is quite dim.

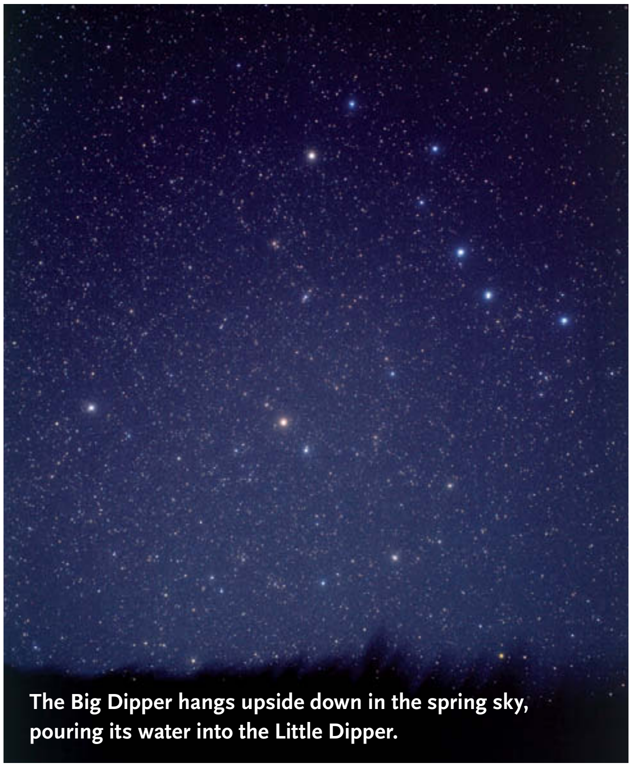
Ursa Major is famous for deep-sky objects such as those discussed in the February column (M81 and M82, M97 and M108), but there also are wonderful sights in and near the Great Bear's tail (the Big Dipper's handle). The bend in the tail is marked by Mizar and Alcor, the naked-eye star pair whose brighter member, Mizar, can itself be split into a double star with modest telescopic magnification. Just north of the tail lies the beautiful though elusive spiral galaxy M101.

Many stories agree that Ursa Major and Minor were humans turned into bears, though details differ. The most common account says that Ursa Major was originally Callisto, a mistress of Zeus (Roman Jupiter), who now has a moon of Jupiter named for her. And Ursa Minor was originally her son Arcas.

Herdsman and dogs. The constellation Boötes is called the Herdsman — the name literally means an ox-herd. But there are no celestial bovines for Boötes to herd. Boötes' brilliant, dominant star is named Arcturus, meaning "Bear Guardian." The bear referred to is the huge, fierce Ursa Major — from which the herdsman is trying to protect his imagined flock . . . or the entire flock of the other constellations.

But there's another constellation connected with the Bears: Canes Venatici, the Hunting Dogs. They're often regarded as Boötes' dogs, but if they're supposed to be helping him with his herd, what do they have to do with hunting? Are they hunting down Ursa Major?

These dogs were known to the ancient Greeks, but they didn't get a distinct constellation of their own until the 17th century. The Alpha star, popularly known as Cor Caroli, is a beautiful double. And the modern boundaries of Canes Venatici include two of the greatest deep-sky objects. M51 is the Whirlpool Galaxy, and M3 is a magnificent globular cluster. ✦



The Big Dipper hangs upside down in the spring sky, pouring its water into the Little Dipper.

AKIRA FUJII

May's Amazing Planet Trio

The three brightest planets form an extremely tight group at dusk.

Saturn is well placed for viewing almost all night throughout May. And a remarkable planetary drama unfolds in the last third of the month: Venus, Jupiter, and Mercury converge into a very tight knot low in the evening twilight.

DUSK

May begins with **Jupiter** high and **Venus** low in the west-northwest shortly after sunset. Venus sets in bright twilight, just ¾ hour after the Sun. Jupiter, a huge 27° to Venus's upper left, remains visible long after the sky is dark. But Jupiter appears about ¾° lower each evening, while Venus creeps a little higher, as they head toward conjunction on May 28th.

Venus and Jupiter form lovely configurations with the crescent Moon on May 10–12, as shown below.

Mercury is invisible for the first half of May, passing through superior conjunction behind the Sun on May 11th. But it joins the evening planet scene just eight days later.

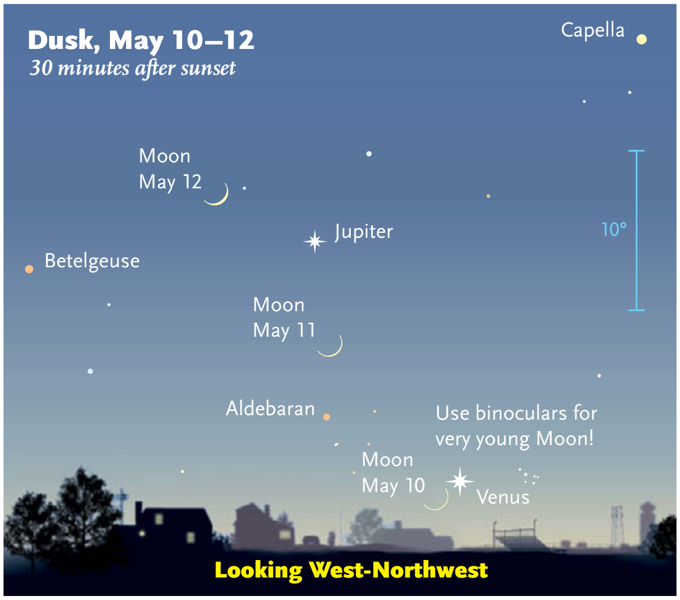
On May 19th, Jupiter, Venus, and Mercury form a line less than 13° long. Mercury is only about 3° high a half hour after sunset, so you may need binoculars to spot it even though it shines at magnitude –1.4. Venus is about 4° upper left of Mercury, and Jupiter 9° upper left of Venus.

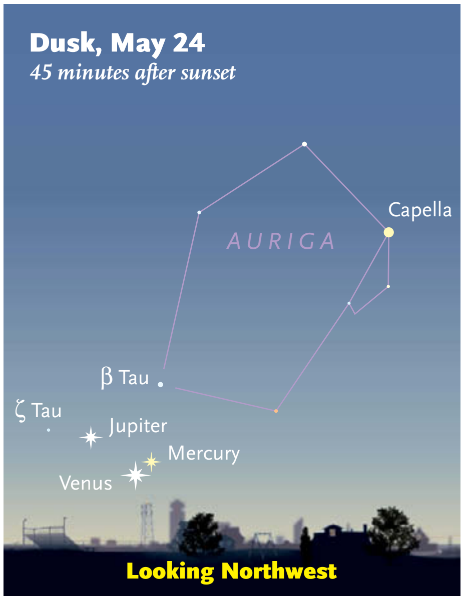
The line shortens each evening as Mercury appears higher and Jupiter lower. From May 24–29, Venus, Jupiter, and Mercury form a "trio" — a temporary gathering of three celestial objects that fits within a circle 5° or less wide. The event takes place fairly low in bright twilight, but it's readily visible because all three planets are very bright. Mercury fades just a trace, from magnitude –0.9 to –0.7, while Venus and Jupiter hold steady at magnitude –3.9 and –1.9, respectively. For skywatchers around latitude 40° north, all three planets are more than 6° above the west-northwest horizon a half hour after sunset throughout the trio.

Venus and Mercury appear closest together on May 24th, with Mercury 1⅓° upper right of Venus. The trio is most compact on the evening of May 26th in the Americas, when the three planets fit within a circle less than 2½° wide. This is also when Jupiter and Mercury are closest. On May 27th, Venus and Jupiter are side by side 1¼° apart with Mercury less than 2⅔° above them. Then on May 28th, Venus and Jupiter, the two brightest planets, are only 1° apart.

Compare the disks of the three planets in a telescope while they're a trio: Jupiter is 32″ wide and fully lit, Venus 10″ wide and about 96% lit, while Mercury's gibbous disk alters subtly from 5.7″ and 80% lit to 6.2″ and 68% lit. Try to catch the planets immediately after sunset, while they're as high as possible above the horizon.

All good things must come to an end. On May 31st the three planets are again in a diagonal line, but now it's expanding — Venus is 4° lower right of Mercury and Jupiter 3½° lower right of Venus. And Jupiter, falling out of the gathering, starts setting less than an hour after the Sun.



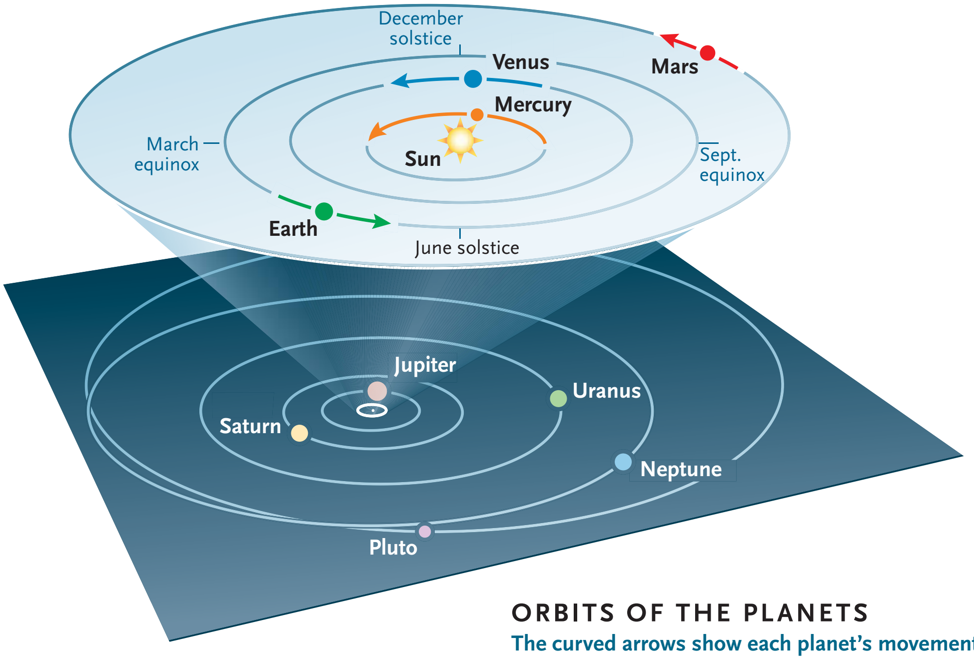


These scenes are always drawn for near the middle of North America (latitude 40° north, longitude 90° west); European observers should move each Moon symbol a quarter of the way toward the one for the previous date. In the Far East, move the Moon halfway. The blue 10° scale bar is about the width of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

See **skypub.com/may2013planets** for an animation of the planets' changing configurations.

DUSK THROUGH MOST OF NIGHT

Saturn was at opposition on April 28th, so in May it remains bright, bigger than usual in telescopes, and visible almost all night long. The planet shrinks and dims just a little, ending May at magnitude +0.3. But it climbs high earlier in the night. At dusk on May 31st Saturn is already well up in the south-southeast, shining about one-third the way up the sky. Saturn retrogrades out of Libra into easternmost Virgo this month. Its separation from Spica decreases from 15° to 13°.



ORBITS OF THE PLANETS

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

DAWN

Uranus, in Pisces, and **Neptune**, in Aquarius, are highest at dawn; see **skypub.com/urnep** for finder charts.

Pluto, in Sagittarius, is highest around the beginning of morning twilight; next month's issue will contain finder charts.

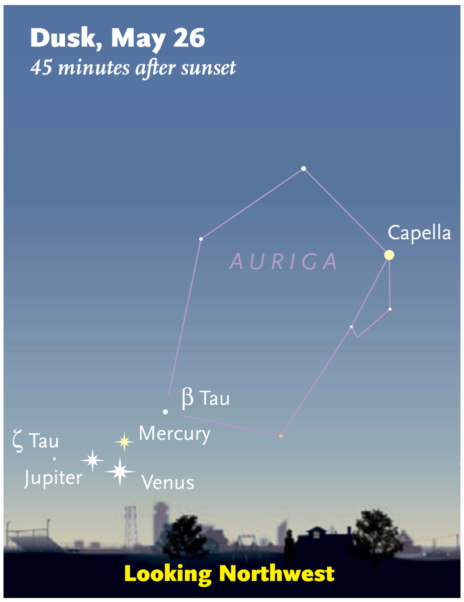
Mars rises too soon before the Sun to be observed.

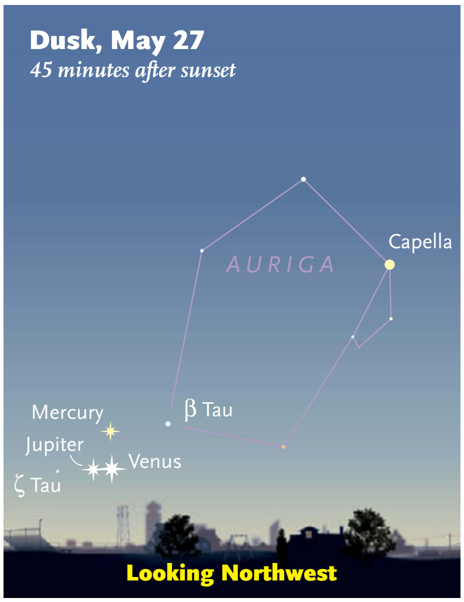
SUN AND MOON

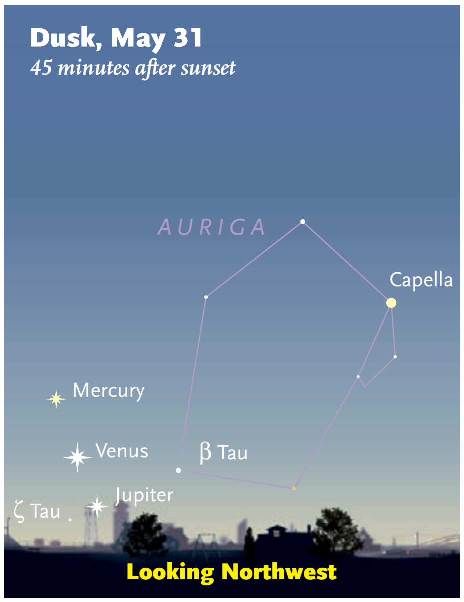
The **Sun** undergoes an annular eclipse on May 9–10. The eclipse is visible mostly over the Pacific, but the path of annularity crosses northwestern Australia, and the partial phase is visible in most of Melanesia, Australia, and New Zealand. See **skypub.com/may2013eclipses** for details on this and the lunar eclipse described below.

The **Moon** undergoes an extremely slight penumbral eclipse on the American night of May 24–25, probably undetectable even by the most sensitive scientific instruments. But there's a consolation that night: the full Moon occults the double star Beta Scorpii in the southeastern U.S. and elsewhere; see page 52.

The Moon is a very thin crescent just lower left of Venus on May 10th very low in the west-northwest a half hour after sunset. It passes Jupiter on the 11th and 12th. The waxing gibbous Moon is just to the right of Spica on the American evening of May 21st and near Saturn on the 22nd. ✦

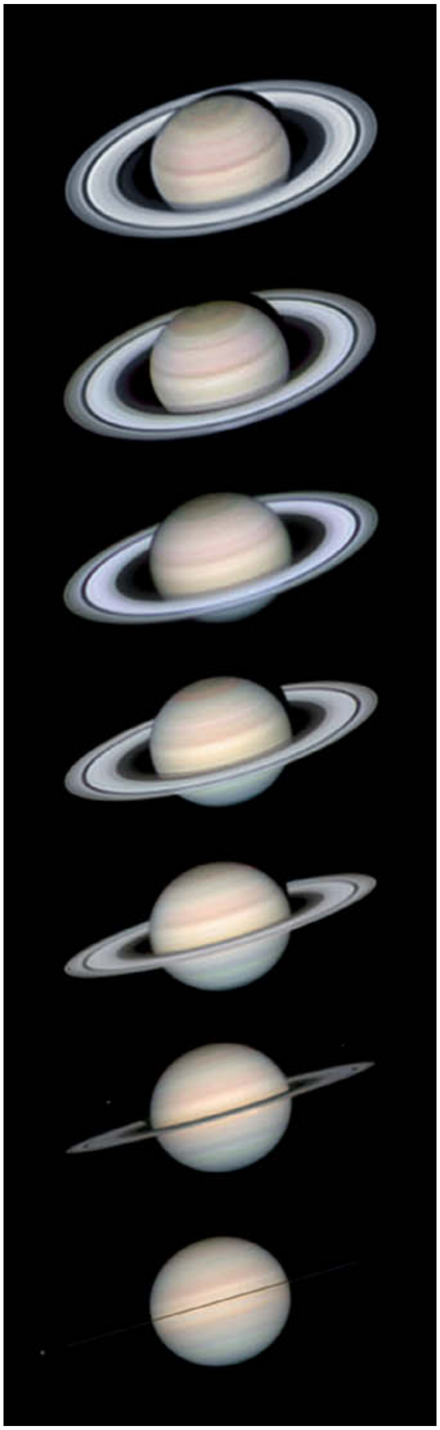






Scrutinizing Saturn

With its rings tipped into nice wide view, Saturn invites your closest examination.



Saturn takes over from Jupiter as the starring planet of the evening sky this spring, and in April and May it's at its closest, biggest, and brightest for the year. The ringed planet comes to opposition on the night of April 27–28, and for all April and May it remains essentially the same apparent size: 19″ across the globe's equator and 42″ from ring-tip to ring-tip (about a Jupiter-width). Saturn shines fairly high in the southeast by late evening in April and early evening in May, below Arcturus and Spica.

If you still haven't looked at Saturn in a telescope since last year, the change will be dramatic. The rings now present themselves very invitingly, tilted a wide 18° or 19° from our line of sight, the widest they've appeared since 2006. They will continue to open (with minor seasonal fluctuations) until reaching a maximum of 27° in 2017.

Markings on the Globe

Like Jupiter, Saturn is a gas planet showing us banded cloudtops. But Saturn is both smaller and farther than Jupiter, and because it is colder, its markings are more deeply veiled under high-altitude haze. Even so, my 6-inch reflector almost always shows some of Saturn's banding: the bright Equatorial Zone, the slightly darker North Equatorial Belt (the South Equatorial Belt is behind the rings now), and the dusky North Polar Region. Occasional subtler banding is sometimes detectable in the mid-latitudes.

Top to bottom: From 2004 to 2009 Alan Friedman of Buffalo, New York, took this series of Saturn's rings closing year by year. South is up. The ring tilt now resembles the third or fourth image from top. In those years we saw Saturn's southern hemisphere and south ring face. You can tell which image was taken closest to opposition by two things: the absence of almost any shadow of the globe on the rings behind it, and the relative brightness of the rings due to the Seeliger effect. The rings also become brighter as they open. Friedman used an Astro-Physics 10-inch Maksutov-Cassegrain telescope and DMK 21BF04 planetary video camera.

Two and a half years ago, Saturn broke out with a record-smashing white storm at about 40° north latitude that became easy to spot in amateur scopes (*S&T*: May 2012, page 20). The planet's fast upper winds tore a turbulent trail of white clouds from the storm's active head, and these clouds eventually ran completely around the planet. Only subtle traces of this band now remain.

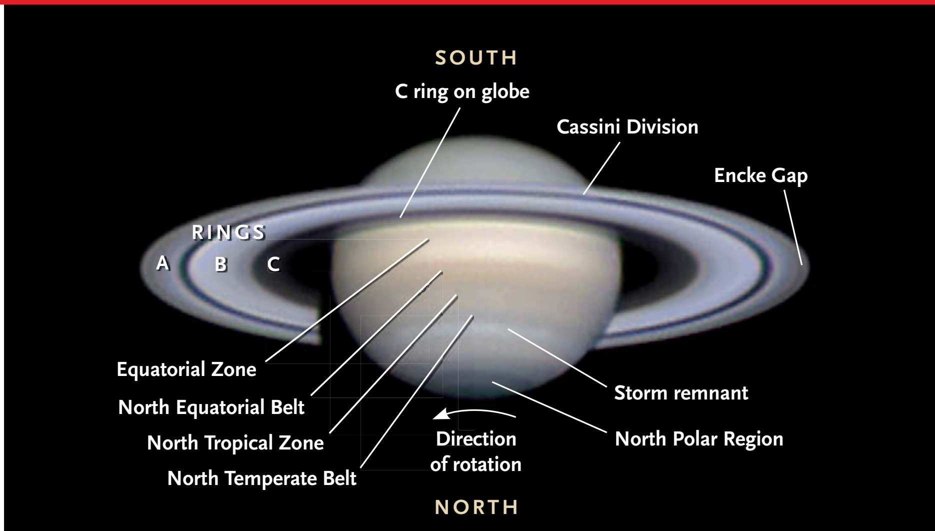
Large scopes more often show tinier white spots: smaller round or oval storms, visible only during very steady seeing.

Rings on Display

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

The dusky C ring is more of a challenge to spot where it appears against the dark-sky background. But the C ring's shading is easier to see where it crosses Saturn's bright face just inside the B ring. The C ring in front of Saturn is often indistinguishable from the rings' dark shadow on the globe at the same latitude — but not this year. The rings cast no visible shadow on the globe for most of April and part of May from Earth's viewpoint, then they cast their shadow increasingly *poleward* above the rings for the next few months (rather that equatorward behind the C ring). This hairline rim of black shadow will help define the rings' outer edge against the planet's disk from late spring into the summer. (See the ring map on page 21.)

In the weeks and months away from



The rings were tilted 15° on February 7, 2012, when Robert English in Kentucky took this fine image using a 20-inch Newtonian reflector and a Point Grey Research Flea3 planetary video camera. Even the hairline Encke Gap is detectable.

opposition, note the shadow of the planet's *globe* on the *rings*. It's the narrow black gap right where the rings pass behind the globe's celestial west (preceding) side before opposition, and the east (following) side after opposition. The globe's shadow will appear its broadest and most obvious on the rings this summer.

Seeing any further detail in the rings really takes magnification upwards of 200× on a high-quality 8-inch or larger scope. It also takes times and patience. Rare is the night when the atmospheric seeing is steady and sharp enough to let your scope do its best. Moreover, it takes a lot of time gazing into the eyepiece to register everything at the limit of your vision.

Very subtle banding in the rings is occasionally detectable under near-perfect conditions. The fabled *ring spokes* have even lower contrast, eluding all but the most experienced visual observers using large scopes (*S&T*: July 2011, page 50). Usually they aren't there at all. Fortunately, stacked-video imaging has brought such elusive details within reach of backyard observers. To capture spokes if they are present, shoot short video clips no more than 90 seconds long to stack frames. Any longer and the rapid orbital motion of the ring material will blur any spokes. And always, be very careful not to overprocess your Saturn images or false features will creep in, especially near the many sharp edges.

For several nights around Saturn's April 27–28 opposition, watch for the *Seeliger effect:* a noticeable brightening of the rings with respect to the globe. This is caused by the fact that the solid ring particles "backscatter" sunlight in the direction it came from more effectively than the planet's cloudtops do.

Moon Dance

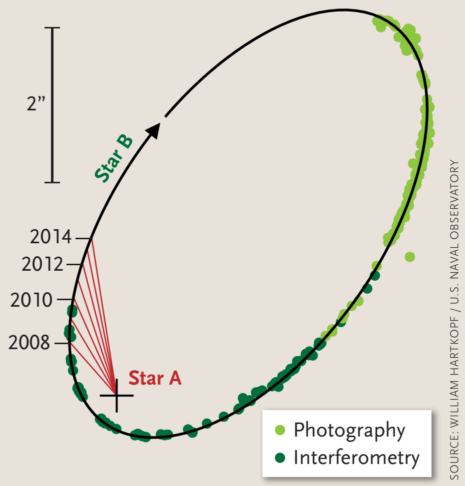
Of course, Saturn and its rings are surrounded by a bunch of extra baubles: more moons for amateur scopes than around any other planet.

Even a 60-millimeter scope will usually reveal appropriately named Titan, half again as big as our Moon. A 4-inch will show the orange tint of the photochemical smog that makes Titan's atmosphere opaque, hiding the moon's rainclouds, rivers, and lakes of liquefied natural gas.

A 4- or 6-inch scope will also show Iapetus, Rhea, Dione, and (with a little difficulty) Tethys. An 8-inch may also get you Enceladus, which hides deeper in the planet's glare. Some planetary imagers have even captured Mimas. Identify the moons you see, or locate exactly where to look for them, using **skypub.com/satmoons**. Or for handy use at the scope, get our new SaturnMoons app described below.

And of course, take every opportunity to show Saturn to other people! So many amateurs remember a first view of Saturn in some telescope, somewhere, as the thing that first turned them on to the riches of astronomy.

Porrima Widens



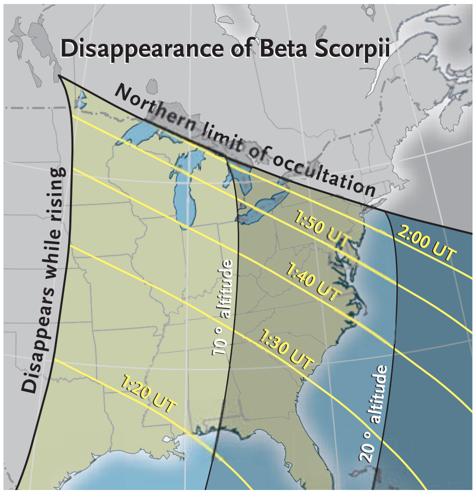
The famous springtime double star Gamma (γ) Virginis, or Porrima, is becoming a little easier to split every year. Its two equal stars, A and B, are 2.0 arcseconds apart as of May 2013 after appearing single around periastron in 2005. Drawn here is the pair's well-determined orbit (green dots are measurements) as seen projected on the sky.

A Full Moon Occultation

Amateur astronomers don't usually think of full-Moon night as good for anything, the Moon included. But the evening of May 24th may be an interesting exception. With the Moon more than 99% sunlit and technically still waxing, the extremely thin dark zone that remains along its celestial-southeastern limb will cover the bright multiple star Beta Scorpii, snapping it out of view for some of the eastern U.S. and points south.

In the U.S., telescope users near the Eastern Seaboard will have the best view, with the Moon fairly high and night fully fallen. Farther inland it will still be twilight and the Moon will be lower.

Under normal circumstances Beta Sco is a fine visual double star: magnitudes 2.6 and 4.9, separation 13.5″, with the faint star to the primary's north-northeast. Only the bright one, however, may be visible through the dazzling lunar glare even where twilight has ended. Six stars make up this complex system all told, so keep an eye out for a possible *stepwise* occultation: two sudden fades instead of one. Use your highest power. The star will vanish just before the sunlit mountains reach it.



S&T: TONY FLANDERS / LEAH TISCIONE

Telescope users along the East Coast will have the best look at the almost-full Moon occulting Beta Scorpii on the evening of May 24th, as explained in the text.

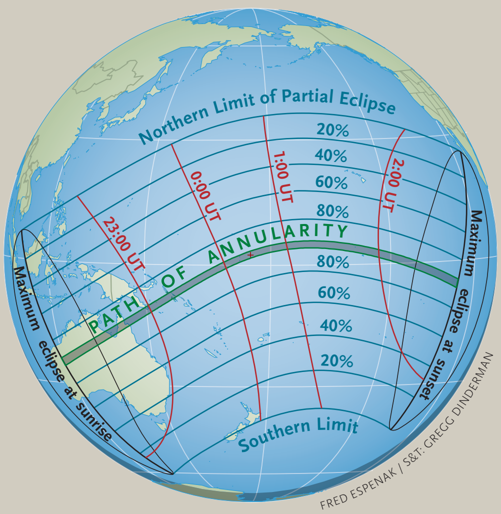
The map above shows the situation in North America. Mark your location and interpolate between the yellow time lines to find when the star disappears. The times are in Universal Time May 25th; subtract 4 hours to get Eastern Daylight Time, 5 hours to get Central Daylight Time. Interpolate between the black altitude lines to find how high the Moon and star will be.

The Moon's altitude will be about equal to the Sun's depression below the western horizon. Nautical twilight ends when the Sun is 12° down; astronomical twilight ends when the Sun is 18° down.

The Caribbean and much of northern South America have a better view, where the event happens later at night. For a world map and timetables, see **skypub .com/may2013occultation**.

A Penumbral Micro-Eclipse

Oh yes, there's one more thing this odd full-Moon night. Two or three hours later, the *exactly* full Moon undergoes the slightest lunar eclipse you can imagine. A scant 4% of the Moon's diameter skims through the utterly unobservable northernmost fringe of Earth's shadow penumbra. But it's an official lunar eclipse for the books, and perhaps for your own lifetime eclipse tally if you're keeping count. Mid-eclipse happens at 12:10 a.m. EDT (4:10 UT) on the 25th. Take a look at the Moon's south limb just so you can say you did.



May 10th Annular Eclipse

Parts of Australia and a few Pacific islands have an annular eclipse of the Sun on the morning of May 10th local date. A much wider area sees a partial eclipse, as mapped here. The eclipse moves eastward through the day across the Pacific (and the International Date Line), until ending at sunset on the 9th local date over open ocean.

At any location, interpolate between the red lines to find the Universal Time of maximum eclipse. Times near 23:00 are on May 9th UT, and times after 0:00 are on the 10th UT. Interpolate between the blue lines to find the percent of the Sun's diameter that the Moon will cover at maximum eclipse.

May Meteors

The Eta Aquariid meteor shower should peak on the morning of May 5th this year. This is often the year's best shower for skywatchers in the tropics and the Southern Hemisphere, with about a meteor every minute or two visible in a dark sky before the first light of dawn. But the farther north you are, the lower the count. From North America and Europe the shower's radiant in Aquarius is still very low in the southeast when the early May dawn begins to brighten, so practically no Eta Aquariids are reported from north of 40° latitude.

The waning crescent Moon will be thin enough that its light will pose little or no interference. ✦

Discovery at Titan

Was Titan's atmosphere first detected visually?

Titan is the largest member of Saturn's family of moons, slightly larger in diameter than the planet Mercury but only half as massive. A frigid but weirdly Earth-like world, Titan is surrounded by a dense, hazy atmosphere laden with orange photochemical smog.

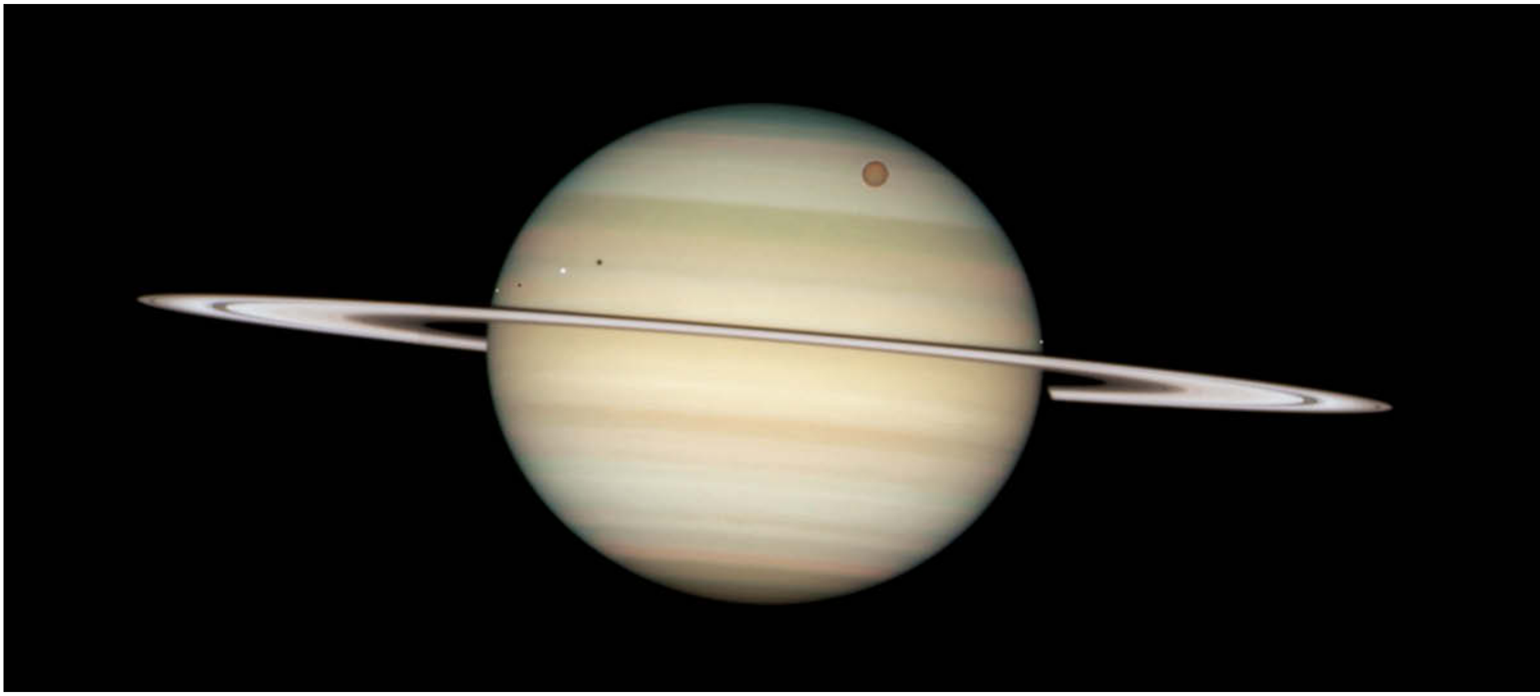
The discovery of Titan's atmosphere has been widely credited to Gerard Kuiper, who used the 82-inch reflector at McDonald Observatory in 1944 to photographically record the prominent absorption bands of methane gas in Titan's spectrum. Although Kuiper was vaguely aware of a decades-old report that Titan possesses an atmosphere, he dismissed as utterly impossible the notion that any visual observer could have ascertained the presence of an atmosphere on the minuscule disk of such a remote object.

The observation that Kuiper scorned was published in 1908 in the leading professional astronomical journal of its day, *Astronomische Nachrichten* ("Astronomical News"). Titled "Observations of the Principal Satellites of Jupiter and of Titan," it was written by the director of the Fabra Observatory in Barcelona, Spain, José Comas Solá. He recounted an observation made with a 15-inch refractor:

> On August 13, 1907, with a very beautiful image and a magnification of 750 times being useful, I saw Titan with a very dusky edge that trailed off into the darkness of the sky (something similar to what one observes with the disk of Neptune), while towards the central part, much more clearly, one saw two whitish patches that gave me the impression of a diffuse double star. We can justifiably suppose that the pronounced obscurity of the limb demonstrates the existence of a very absorbent atmosphere surrounding Titan.

Comas Solá was certainly a credible witness. Born in 1868, he made his mark at an early age as a keen-eyed observer of the planets and emerged as a leading critic of the contemporary reports of a network of canals on Mars. He had been studying the surface markings of Jupiter's Galilean satellites for two years prior to his observa-

The limb darkening of Titan's dusky, brownish disk is readily apparent in this Hubble Space Telescope image of four Saturn moons passing in front of their parent planet, captured on February 24, 2009. Below and to the left of Titan, icy Enceladus and Dione and the shadows they cast can be seen against the backdrop of Saturn's clouds. Tiny Mimas is visible at right.



NASA / ESA / HUBBLE HERITAGE TEAM

tion of Titan, so he was already intimately familiar with the appearance of very small disks. Comas Solá never reported limb darkening on these four virtually airless bodies.

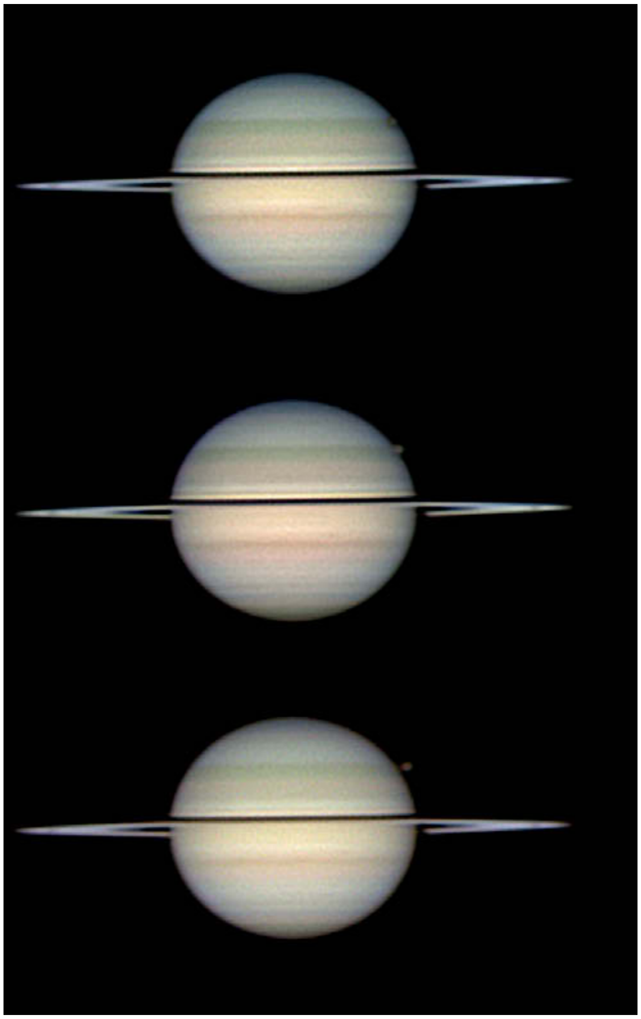
Titan expert Ralph Lorenz (University of Arizona) and Josep Oliver of the Astronomical Association of Sabadell in Spain have staunchly defended the legitimacy of Comas Sola's priority for the discovery of Titan's atmosphere. Recent observations lend even more credence to their persuasive arguments.

Although the solid body of Titan has a diameter of 5,150 kilometers, its distended visible atmosphere extends to a diameter of 5,550 kilometers. When Saturn comes to opposition on April 28th, Titan's apparent diameter will subtend slightly more than 0.8 arcsecond, a value that is almost identical to the maximum apparent diameter of the largest asteroid, Ceres, and only a bit larger than the 0.7-arcsecond-wide Cassini Division separating Saturn's A and B rings (see pages 18 and 50). Jupiter's largest satellite, Ganymede, appears 1.7 arcseconds across at opposition.

Suffice it to say that observing Titan is like studying a penny from a distance of three miles. Nevertheless, under good seeing conditions it is possible to resolve Titan as a nonstellar disk using a 9- or 10-inch telescope, although comparing Titan's appearance to the point-source diffraction pattern of a star of comparable brightness may be required to be sure of the fact.

At the magnification of 750 that Comas Solá employed, Titan is enlarged to almost one-third of the diameter of the Moon seen with the naked eye but appears much dimmer than the Moon. The Saturn system orbits the Sun at more than nine times the distance that Earth does and receives less than 1.2% of the Sun's radiated energy. Combine this feeble level of illumination with the fact that Titan reflects only 20% of incident sunlight in visible wavelengths (compared to 47% for Saturn's cloud canopy and 60% for the brightest portions of the planet's icy rings) and it is little wonder that Titan has a very low apparent surface brightness when observed through a telescope. Per unit area, Titan appears almost seven times duller than Ganymede and only 1.6 times brighter than the far more distant but highly reflective planet Uranus.

Ironically, Titan's low apparent surface brightness makes it easier to distinguish the limb darkening of its tiny disk. Russian astronomer Vsevolod Sharonov, a pioneer in the field of planetary photometry, pointed out that reducing the difference in brightness between the disk of a planet and the background against which it is seen significantly improves the threshold contrast sensitivity of the eye. He noted that "the limb darkening of Venus and Jupiter is hardly noticeable at night, while during daytime or in twilight it is very much in evidence." For the same reason, the surface markings of Jupiter's Galilean satel-



CHRISTOPHER GO

Christopher Go recorded Titan's limb darkening during the February 9, 2009 transit. This remarkable feat was accomplished using a telescope with an aperture of only 11 inches.

FABRA OBSERVATORY

A talented planetary observer, José Comas Solá (1868–1937) discovered a pair of comets and 11 asteroids late in his career. He was a prolific author of popular scientific articles and books.

lites are much easier to see during transits, when these bodies are seen against the backdrop of Jupiter's cloud tops (which are of comparable brightness) rather than a dark sky. Comas Solá himself called attention to this fact.

Titan's limb darkening is especially prominent during transits, when the satellite crosses the face of Saturn. These comparatively rare events occur at intervals of 14 to 15 years when the Earth passes through the plane of Titan's orbit. On February 8, 2009, renowned planetary imager Christopher Go of Cebu City in the Philippines recorded a transit of Titan using an 11-inch Schmidt-Cassegrain. The moon's limb darkening is quite easy to make out in his superb images. Go also observed the event visually at a magnification of 350× and commented that when the satellite's tiny, ruddy disk was silhouetted against the backdrop of Saturn's globe, it exhibited a stunning three-dimensional appearance that he attributed to its darkened edges.

Fifteen days later, Go collaborated with the Hubble Heritage Team to record an exceedingly rare quadruple transit using the Hubble Space Telescope (shown on page 54). Titan's limb darkening is strikingly obvious in the beautiful series of images they obtained.

The eminent British planetary observer David Gray has been able to convincingly replicate Comas Solá's more difficult observation of Titan's limb darkening against a dark sky background. In March 2009 Gray took advantage of a night of superb seeing to carefully compare the tiny disks of Titan and the asteroid Ceres, which were almost identical in apparent size at the time. Gray's 16-inch Dall-Kirkham Cassegrain reflector has a secondary mirror that is supported by an optical window, giving refractor-like images free of the diffraction spikes produced by the spider supports common to most reflectors. He recounted:

Gerard Kuiper (1905–1973) is generally credited with the discovery of Titan's atmosphere using a spectrograph on the 82-inch telescope at McDonald Observatory in 1944.

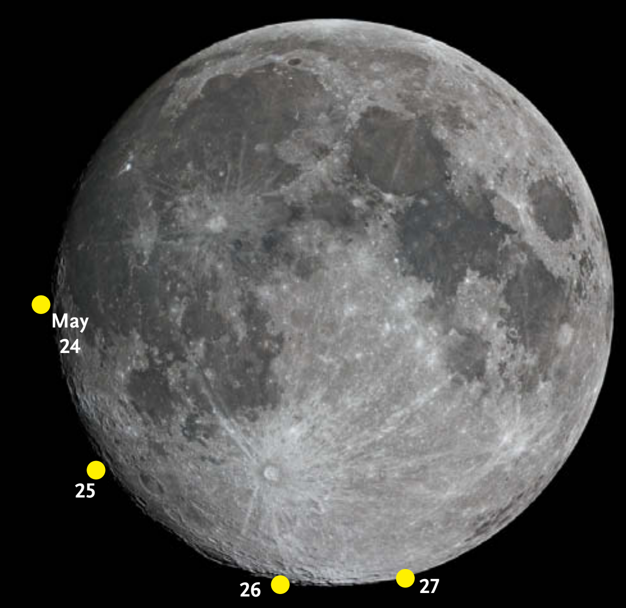
MCDONALD OBSERVATORY

> To condition my eye I spent some time looking at the fine bluish double star 54 Leonis, which was close to the south. This 'trick' works very well, as when going to Ceres it could be seen at once that there was a true disc, looking decidedly non-stellar at 365× and unmistakable at 535×.

Gray then trained his telescope on Titan, which displayed a pale disk with an orange hue that contrasted with the amber color of Ceres. By comparison Titan was "soft-edged, presumably due to its atmosphere."

Like the transient spokes in Saturn's rings reported by Stephen O'Meara in 1977, Titan's atmosphere seems to be yet another example of a bona fide discovery by a visual observer that was greeted with skepticism and even ridicule. The combination of the eye, the brain, and a surprisingly modest telescope can be remarkably powerful. I encourage *S&T* readers to look for Titan's limb darkening now that Saturn and its largest moon are at opposition. ✦

The Moon • May 2013



Phases

LAST QUARTER
May 2, 11:14 UT

NEW MOON
May 10, 0:28 UT

FIRST QUARTER
May 18, 4:35 UT

FULL MOON
May 25, 4:25 UT

LAST QUARTER
May 31, 18:58 UT

Distances

Apogee 252,168 miles	May 13, 14^h UT diam. 29′ 26″
Perigee 222,686 miles	May 26, 2^h UT diam. 33′ 20″

Librations

Hartwig (crater)	May 24
Vallis Bouvard	May 25
Casatus (crater)	May 26
Boussingault (crater)	May 27

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

S&T: DENNIS DI CICCO

Sue French

The Realm of the Nebulae

Some unusual galaxies lie near the Virgo Cluster's eastern edge.

"The universe is empty, for the most part, but here and there, separated by immense intervals, we find other stellar systems, comparable with our own. . . . These huge stellar systems appear as dim patches of light. Long ago they were named 'nebulae' or 'clouds' — mysterious bodies whose nature was a favorite subject for speculation."

American astronomer Edwin Hubble penned these words in the first chapter of his 1936 book *The Realm of the Nebulae*. Hubble sided with tradition, calling these distant stellar systems *extragalactic nebulae*, but today they're more commonly known as *external galaxies*.

When amateur astronomers think of the Realm of the Galaxies, the area of the sky dominated by Virgo and Coma Berenices quickly comes to mind. This region holds the north galactic pole, one of the two spots in the sky farthest from the dust-laden plane of our galaxy's disk. Here we have a clear window into the depths of the universe, where we can view distant galaxies unobscured by the Milky Way.

Let's explore some lesser-known galaxies on both sides of the boundary between Virgo and Coma Berenices within a few degrees of the deep yellow star Epsilon (ε) Virginis, also known as Vindemiatrix.

We'll start our galaxy tour with a hop 2.5° northwest from Vindemiatrix to 41 Virginis, and then jump 1.8° in the same direction to 28 Comae. The star 28 Comae sits 14′ south-southeast of **NGC 4689**, and they make a lopsided box with two relatively bright stars to the galaxy's south and southwest. The box nicely fits within a low-power field of view. Through my 130-mm refractor at 37×, NGC 4689 is a fairly dim eddy of mist filling a plump oval, tipped north-northwest, and harboring a somewhat brighter core. A faint star watches the galaxy's north-northeastern side, and at 117× it's accompanied by a dimmer sentry. The higher magnification also makes NGC 4689 look vaguely woolly, with a ¾′-long, oval core and a 2½′ halo.

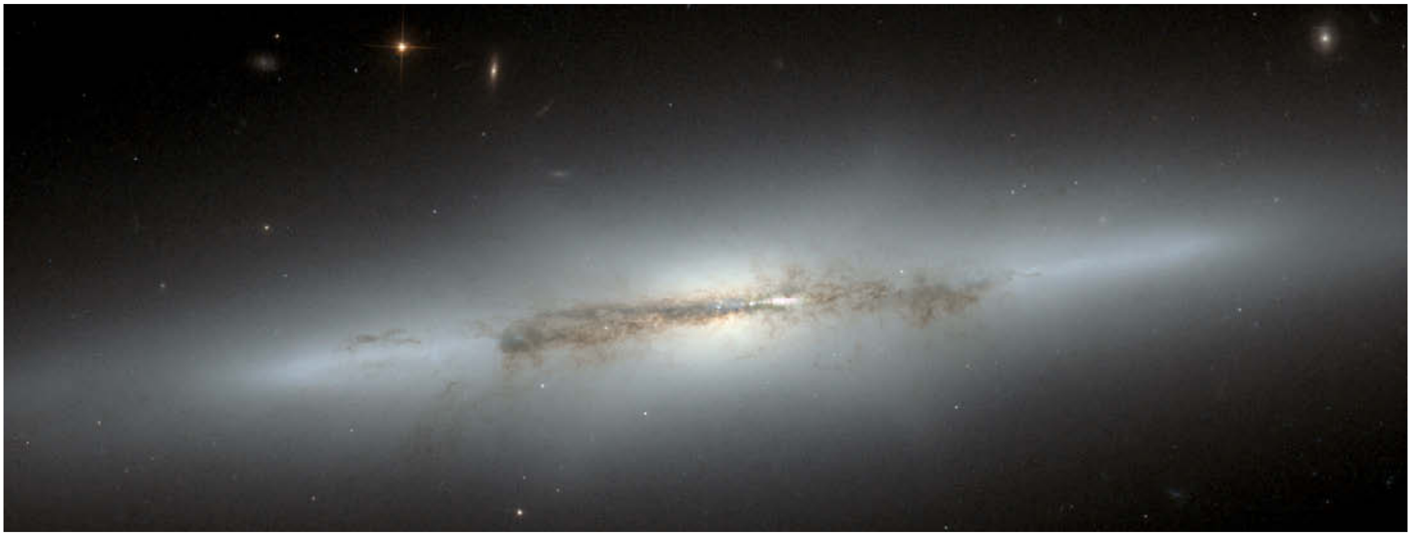
SLOAN DIGITAL SKY SURVEY

The blue areas in this image of the spiral galaxy NGC 4689 are regions of recent star formation.

NGC 4689 is roughly 58 million light-years away, in the outskirts of the Virgo Cluster. In deep images, this galaxy shows a fleecy inner disk with ongoing star formation that abruptly gives way to a diffuse outer disk. Studies indicate that the outer disk's lack of star birth is due to gas being stripped away by the hot intracluster medium.

The star 29 Comae lies 27′ northeast of NGC 4689, and climbing 1.1° north from there takes us to **NGC 4710**. The galaxies share the field in my 130-mm scope when I use a wide-angle eyepiece that gives me 37× and a true field 2.2° across. NGC 4710 is moderately faint and very elongated, leaning north-northeast. A 12.6-magnitude star rests 1.5′ east of the galaxy's center. The double star **Struve 1678** (Σ1678 or STF 1678) also inhabits the field of view, making a right triangle with the two galaxies. The 7.2-magnitude white primary is widely separated from the 7.7-magnitude yellow companion that dangles to its south. At 117×, NGC 4710 covers about 4½′ × 1′ and hosts a large, elongated core that brightens toward the middle.

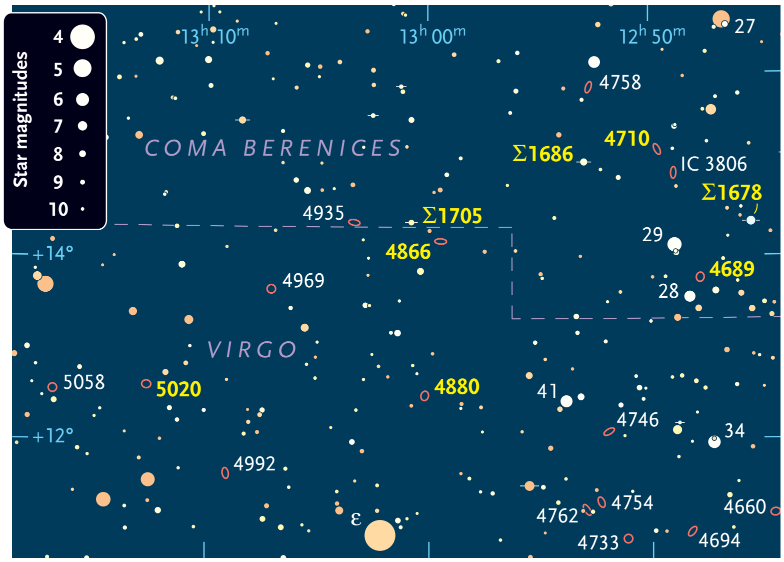
A second double star can just be crammed into the 2.2° field, but it puts on a better show when centered. **Struve 1686** gifts us with a fine, nearly matched, yellow-white pair of 9th-magnitude suns, the primary closely guarding its companion to the south. The stars show a fairly wide



NASA / ESA

Above: NGC 4710 is unusually dusty for a lenticular galaxy. North is to the upper left in this image from the Hubble Space Telescope. *Below:* This beautiful image of NGC 4866, a more typical lenticular galaxy, was retrieved from the Hubble Legacy Archive and placed in Wikimedia Commons.

NASA / ESA / STSCI



separation at 63× and look like the gleam of two little eyes watching us from the depths of space.

NGC 4710 is an S0 (lenticular) galaxy with half the stellar mass of our Milky Way Galaxy. It's about 55 million light-years distant, in the outlying regions of the Virgo Cluster. NGC 4710 has a dusty disk, which is puzzling. An S0 galaxy's dust ought to be quickly eroded away by impacting ions in the galaxy's "atmosphere." Although dust might be replenished by unexpectedly high rates of star formation, a 2010 study by Yuanyuan Su and colleagues suggests that dusty S0 galaxies simply lack the atmospheres of hot, X-ray-emitting gas found in most S0s. The authors studied three edge-on S0 galaxies with dusty disks, including NGC 4710, and found that their ratios of X-ray to optical luminosity are among the lowest known for S0 galaxies.

NGC 4866 is another outer Virgo Cluster member, but this one is 78 million light-years away from us. Look for it 2.6° east of 29 Comae. Through my 130-mm refractor at 37×, the galaxy is a nice, highly elongated, east-west streak that grows brighter toward the center. Just 23′ to the east-northeast, the wide double **Struve 1705** shares the field of view. Its 9th- and 10th-magnitude components are widely split, shining pale yellow and yellow, respectively. At 117× the galaxy appears about 5′ long with an elongated 3′ core and a small, bright center. The core wears a faint star on its northern flank roughly halfway from the galaxy's center to its western tip.

We can reach **NGC 4880** by dropping 1.7° south from NGC 4866 or by working our way 1.6° north-northwest from Vindemiatrix. In my 130-mm scope at 63×, it's just a small, very faint fuzzspot that's considerably easier to see with averted vision. At 117× the galaxy displays an oval glow leaning west of north. Through my 10-inch reflector at 213×, NGC 4880 grows gently brighter toward the

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


SLOAN DIGITAL SKY SURVEY

NGC 5020, a spiral galaxy with a weak bar and broken ring, looks strikingly like a miniature version of Messier 61, which is discussed on page 64.

center, and its diaphanous halo covers about 2′ × 1¼′. A very faint star neighbors the galaxy's south-southeastern edge, and an orange 9.8-magnitude star rests 11′ southeast of its center.

NGC 4880 is about 51 million light-years distant and may be related to other galaxies in the Virgo Cluster's outskirts. But our final galaxy, **NGC 5020**, lies well beyond the Virgo Cluster at a distance of 160 million light-years.

The face-on spiral galaxy NGC 5020 sits 3° east of NGC 4880 and the same distance away from Vindemiatrix. It makes a straight line with two yellow-orange stars (magnitude 8 and 9) to the west-northwest. The line is 29′ long, and the three objects are evenly spaced. NGC 5020 is a very faint touch of haze with a moderately brighter center as seen with my 130-mm refractor at 37×. Boosting the magnification to 117× reveals a dim, roundish halo spanned by a brighter, nearly north-south glow that has a small, relatively bright core. Although my 10-inch scope at 166× brightens and clarifies the image, it reveals no further details except for a starlike nucleus.

NGC 5020 is a photogenic galaxy with striking spiral arms. It's morphological type is SAB(rs)bc. The *S* tells us that this is a spiral galaxy, *AB* signifies its weak bar, *rs* denotes the broken pseudo-ring that the bar spans, and *bc* indicates that the galaxy has fairly open spiral arms and a small but obvious central bulge. According to a 2010 study by Sébastien Comerón and colleagues, NGC 5020 also has a tiny, star-forming nuclear ring only 8.6″ in diameter. On most images, this ring is lost in the galaxy's overexposed core.

NGC 5020 also played host to a Type II supernova in 1991. Only three images of it were taken. At discovery, it had a red magnitude of 17. It had faded in the two subsequent images, taken 48 and 105 days later. A Type II supernova is caused by the core collapse of an aging, supergiant star. The outer layers of the star explode outward, while the crushed core usually becomes a neutron star. A typical neutron star is only 10 miles across, but if you packed a box that's one foot long on each side with neutron star stuff, it would weigh 3 trillion tons. For the metric-minded, that's 100 thousand trillion kilograms in a box one meter on each side. ✦

Galaxies & Double Stars near the Virgo-Coma Border

Oject	Type	Magnitude	Size/Sep.	RA	Dec.
NGC 4689	Galaxy	11.0	4.3′ × 3.5′	$12^h 47.8^m$	+13° 46′
NGC 4710	Galaxy	11.0	4.9′ × 1.2′	$12^h 49.6^m$	+15° 10′
Σ1678	Double star	7.2, 7.7	37″	$12^h 45.4^m$	+14° 22′
Σ1686	Double star	8.6, 8.7	5.7″	$12^h 53.0^m$	+15° 02′
NGC 4866	Galaxy	11.2	6.3′ × 1.3′	$12^h 59.5^m$	+14° 10′
Σ1705	Double star	9.0, 10.3	27″	$13^h 00.8^m$	+14° 23′
NGC 4880	Galaxy	11.4	3.2′ × 2.3′	$13^h 00.2^m$	+12° 29′
NGC 5020	Galaxy	11.7	3.2′ × 2.7′	$13^h 12.7^m$	+12° 36′

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

DID YOU KNOW?

Sky & Telescope's YouTube channel features dozens of videos. They include the weekly SkyWeek TV show, time-lapse videos and computer animations of astronomical phenomena, profiles of authors and S&T editors, how-to demonstrations, and remembrances of S&T's 70-year history. You can access the YouTube channel at www.youtube.com/user/SkyandTelescope.

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Alan Whitman
Going Deep

Virgo's Richest NGC Field

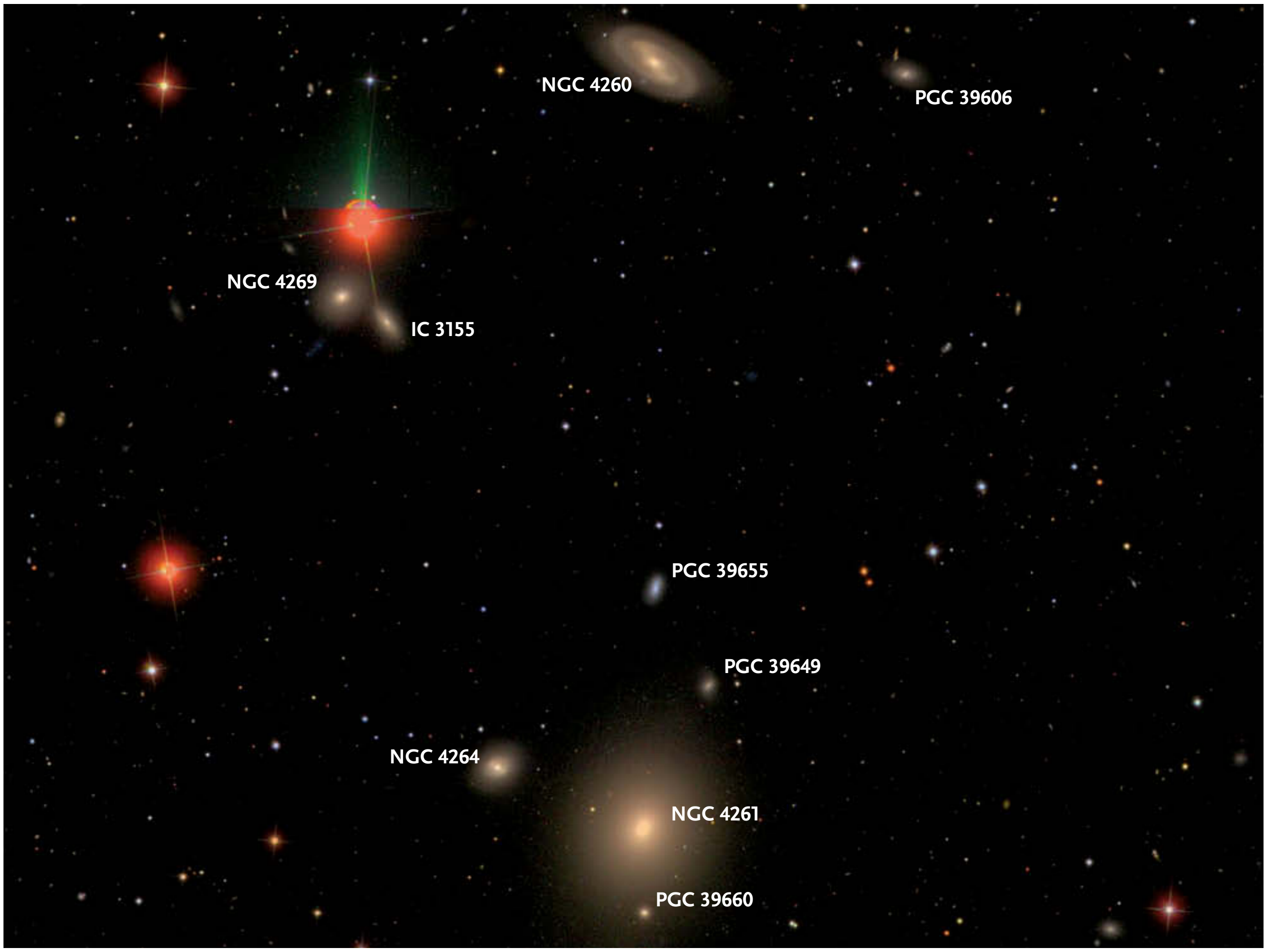
This grouping is remarkably rewarding through 8-inch and larger telescopes.

A DEGREE NORTHWEST of Messier 61 lies the densest clump of *New General Catalogue* galaxies in the Virgo Cluster: 17 NGCs in a field less than 1° in diameter.

On two consecutive nights of steady seeing and legendary transparency, my 8-inch f/6 Newtonian equatorial, sporting a freshly re-aluminized mirror, revealed 15 galaxies here. In addition to 10 NGC galaxies, the scope pulled in three galaxies from the *Index Catalogue* (IC) and two from the *Principal Galaxies Catalog* (PGC). These PGCs are the only galaxies that I have ever spied with an 8-inch that aren't in the NGC, IC, or UGC (*Upsalla General Catalogue of Galaxies*).

Let's begin our tour at **Messier 61**. Its large amorphous halo and bright stellar nucleus mark it as a face-on spiral in an 8-inch scope at 122× — the power that I used on the first night for all the 8-inch observations below.

The double star **17 Virginis** lies 51′ north-northeast of M61. It has a 6th-magnitude yellowish primary with a 9th-



ADAM BLOCK / NOAO / AURA / NSF

The area between the giant elliptical galaxy NGC 4261 and the handsome barred spiral NGC 4260 is particularly fascinating. The author missed two of the galaxies labeled on this photograph: PGC 39649 and 39660, which closely flank NGC 4261. The odd flared star north of NGC 4269 lies at the boundary of two Sloan Digital Sky Survey fields.

magnitude orange secondary 20″ to its north. On another night I called the secondary purple. What color do you see?

Just 13′ west-northwest of 17 Vir you'll find the fairly obvious galaxy **NGC 4300**. This elongated spiral displays some central brightening. Photographs show a prominent ring structure within the disk.

West of NGC 4300 by 20′ is **NGC 4281**, the brightest galaxy in the southern section of this galaxy field. A lenticular, it's elongated east-west and has a brighter core. Just 7′ to the west-southwest sits a barred spiral, larger and fainter **NGC 4273**. It's also elongated, but north-south. The galaxies' axes lie at right angles to each other, making an interesting contrast.

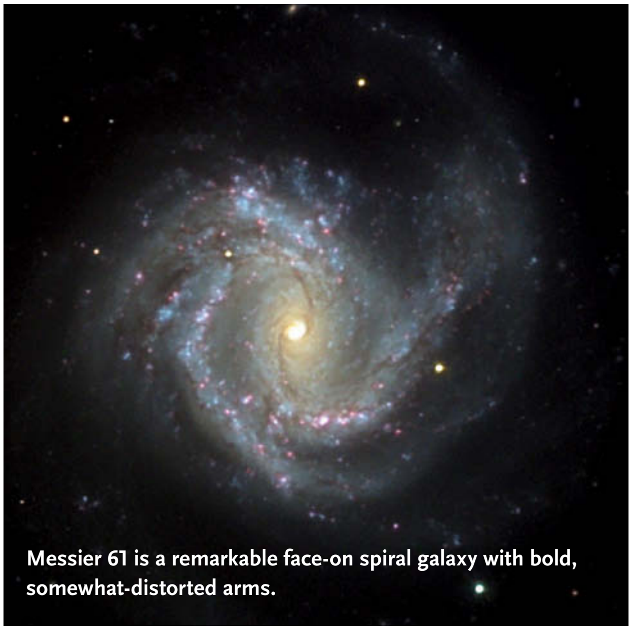
NGC 4270, another lenticular, forms almost an equilateral triangle with NGC 4281 and 4273. NGC 4270 is small with a brighter core and seemed round with this aperture telescope — but see the table on page 66 for its very different appearance through a 16-inch. Five other NGCs lie adjacent to this trio, but I could detect only two of them with my 8-inch: spiral **NGC 4268** and the 14.6-magnitude lenticular **NGC 4282**, which was a barely perceivable smudge with averted vision. (This article uses blue magnitudes because they're available even for the faintest galaxies. These run up to a full magnitude fainter than the visual magnitudes usually cited in observing articles.)

On the second night I increased the power to 153×. While I hunted unsuccessfully for 14.7-magnitude NGC 4249, 15.2-magnitude **PGC 39488** kept popping into my averted vision 6′ to the north-northeast of my unseen target. This, the first PGC galaxy that I have ever bagged with only an 8-inch, was a huge surprise. Images show a very tight pair, an edge-on spiral immediately north of a face-on spiral with an unusually bright nucleus.

The giant elliptical galaxy **NGC 4261** is the brightest member of the group, at magnitude 11.4. It harbors a half-billion-solar-mass black hole at its center. NGC 4261 is round with a bright center that's slightly larger than stellar. Its adjacent small companion, **NGC 4264**, is visible with direct vision, and exhibits a slight central condensation. Photographs of NGC 4264 show a prominent inner ring with a bar across it. I could see **PGC 39655**, a 14.6-magnitude speck 5′ north of NGC 4261, only in the sweet spot of my averted vision, but it was a definite detection — it looked the same size as NGC 4264.

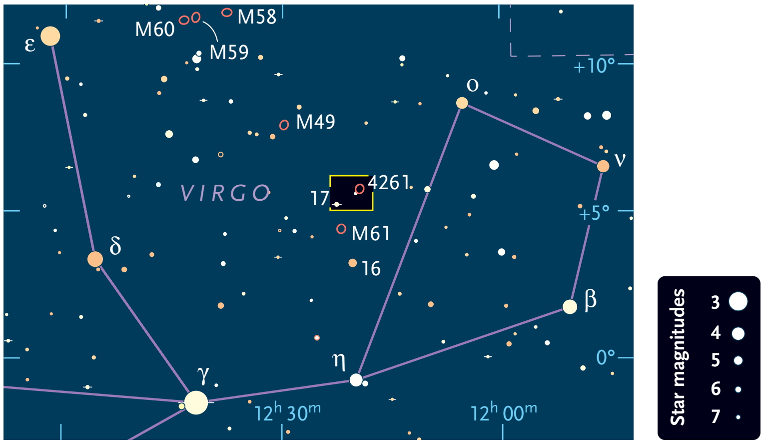
NGC 4269 is tiny and round. This lenticular's high surface brightness makes it visible even though it's only 1.5′ south of a glaring 7.7-magnitude star. Move 7′ west-northwest of this star to see **NGC 4260**, a bright spiral. It's oval in the ratio of 3:2 at position angle 58°, and offers a faint, near-stellar nucleus.

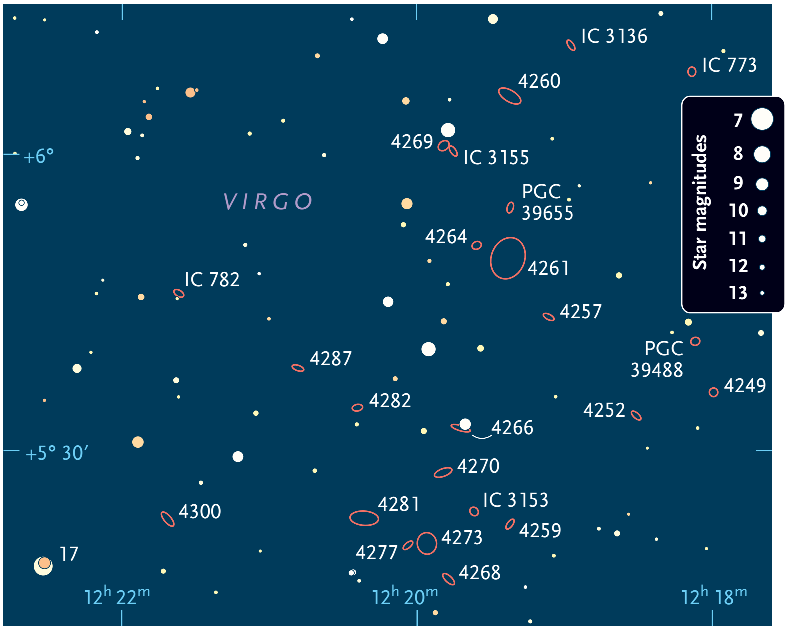
After five hours of dark adaptation I succeeded with the blur of the 14.9-magnitude spiral **IC 3136**, which I found by extending the line from NGC 4269 through 4260 about the same length. Next I detected the outlying lenticular galaxy **IC 773**, 13′ west of IC 3136. Both IC galaxies



Messier 61 is a remarkable face-on spiral galaxy with bold, somewhat-distorted arms.

SLOAN DIGITAL SKY SURVEY





required moving my head around gently until they passed through my averted vision's sweet spot; IC 773 was slightly easier. Encouraged by these successes, I attempted **IC 782**, a barred spiral with an inner ring near the group's eastern edge, and found what appeared to be a "double star" at the correct location. Raising the power to 203× made the northern component appear non-stellar, and when I checked my planetarium program it showed a 13.2-magnitude star 33″ south of the tiny 14.4-magnitude galaxy.

As I commented last May in my article on the Coma Cluster, it interests me that 19th-century observers discovered some very faint galaxies that thus received NGC numbers while missing some brighter and easier IC and PGC galaxies only a few arcminutes away.

I reobserved this Virgo Cluster galaxy clump with my observatory's 16-inch f/4.5 Newtonian. A 24-mm Panoptic giving 76× showed eight NGC galaxies simultaneously, with NGCs 4268 and 4260 at the opposite edges of the 51′ field of view. At 152× the 16-inch showed more details in these galaxies than the 8-inch could, and also revealed the seven very faint NGCs that the 8-inch couldn't find. My observations are listed in the table below.

At Chaco Observatory (*S&T*: May 2012, page 32), I enjoyed a view of M61's spiral arms through a 25-inch telescope at 275×. M61 has a long north-south bar with a bright nucleus. A faint, starlike H II region lies near the bar's southern end, where a short arm leaves the bar and curls to the northwest, fading away just inside a 14th-magnitude star. A longer arm leaves the bar's northern end and curls along the entire eastern side of the galaxy until petering out near the opposite end of the bar. A knot on this arm lies due east of the nucleus. An outer arm also leaves the northern end of the bar. This arm is short, bright, and pointed northeastward. M61's arms look tidally distorted on images. ✦

Alan Whitman*'s description of the nearby NGC 4365 and M49 galaxy groups appeared in the April 2003 issue.*

Observing Notes from a 16-inch Newtonian Telescope

Galaxy	RA	Dec.	Mag (b)	Size	Comments
NGC 4249	12^h 18.0^m	+5° 36′	14.7	0.9′ × 0.8′	Small, faint, but not difficult
PGC 39488	12^h 18.1^m	+5° 41′	15.2	0.7′ × 0.6′	Faint but definite at 114×
IC 773	12^h 18.1^m	+6° 08′	14.5	0.8′ × 0.6′	Very small, weak central condensation
NGC 4252	12^h 18.5^m	+5° 34′	14.9	1.2′ × 0.4′	Fairly small blur
IC 3136	12^h 19.0^m	+6° 11′	14.9	1.2′ × 0.5′	Elongated 4:1
NGC 4257	12^h 19.1^m	+5° 44′	15.0	0.5′ × 0.2′	Faint, hint of elongation
PGC 39655	12^h 19.4^m	+5° 55′	14.6	0.8′ × 0.4′	Very small, obviously nonstellar compared to star 1.1′ north
NGC 4259	12^h 19.4^m	+5° 23′	14.6	1.0′ × 0.4′	Very small, paired with 14.8-magnitude star 23″ northeast
NGC 4260	12^h 19.4^m	+6° 06′	12.7	2.5′ × 1.1′	Fairly large, elongated 3:1, gradually brighter core, faint nucleus
NGC 4261	12^h 19.4^m	+5° 50′	11.4	4.3′ × 3.4′	Bright, large, round, gradually much brighter core, bright nucleus
NGC 4264	12^h 19.6^m	+5° 51′	13.8	0.9′ × 0.7′	Small, gradually brighter core, faint nucleus
IC 3153	12^h 19.6^m	+5° 24′	15.0	0.5′ × 0.5′	Very small, very faint, seen intermittently
NGC 4266	12^h 19.7^m	+5° 32′	14.6	2.0′ × 0.5′	Faint streak within glow of 9th-magnitude star
IC 3155	12^h 19.8^m	+6° 00′	14.9	1.0′ × 0.5′	Blur, not too tough
NGC 4268	12^h 19.8^m	+5° 17′	13.8	1.5′ × 0.6′	Obvious, gradually brighter central condensation, nucleus
NGC 4269	12^h 19.8^m	+6° 01′	13.7	1.2′ × 0.9′	Small, gradually brighter core, faint nucleus
NGC 4270	12^h 19.8^m	+5° 28′	13.1	1.9′ × 0.8′	Elongated 3:1, gradually much brighter core, nucleus
NGC 4273	12^h 19.9^m	+5° 21′	12.3	2.2′ × 1.9′	Fairly large and bright, elongated, brighter core, very faint nucleus
NGC 4277	12^h 20.1^m	+5° 20′	14.6	0.8′ × 0.3′	Fairly small, amorphous
NGC 4281	12^h 20.4^m	+5° 23′	12.3	2.9′ × 1.4′	Bright, fairly large, elongated 3:1, tiny bright core, very bright nucleus
NGC 4282	12^h 20.4^m	+5° 34′	14.6	0.9′ × 0.6′	Small, elongated, little brighter central condensation
NGC 4287	12^h 20.8^m	+5° 38′	14.9	1.2′ × 0.4′	At 229×: extremely faint, 23″ east of 14th-magnitude star
IC 782	12^h 21.6^m	+5° 46′	14.5	1.1′ × 0.6′	Very small, brighter core
NGC 4300	12^h 21.7^m	+5° 23′	13.7	1.8′ × 0.7′	At 76×: bright, elongated

 Dennis di Cicco

iOptron's SkyTracker

The newest tracking platform for camera-only astrophotography is among the best ever.

iOptron SkyTracker

U.S. price: $399.00
ioptron.com

iOptron's SkyTracker is available in white or black and comes with a polar-alignment scope and carrying case. The author highly recommends the $49 optional ball head since it outperformed ones he's spent twice as much for.

ALL PHOTOGRAPHS BY THE AUTHOR

IF YOU BELIEVE the American humorist Arnold H. Glasow's contention that "Success is simple. Do what's right, the right way, at the right time," then iOptron's new SkyTracker is a sure-fire success. Well-engineered and equally well-manufactured, this highly portable camera tracker has hit the astrophotography market at an ideal time.

Another thing that's right is its price. At $399, the SkyTracker offers the hands-down best value I know of for a camera-tracking platform.

Small mounts intended for camera-only astrophotography have been commercially available on and off for decades. Over the years I've purchased several of them, used a few others, built a couple from scratch, and designed a bunch more in my head. These trackers have served mostly a niche market, since only a relative handful of astrophotographers, at least in North America, were willing to spend money on tracking mounts that were generally too small for telescopes. Most sky-shooters were content to do skyscapes with their cameras on fixed tripods or take occasional wide-field tracked photos with cameras riding piggyback on equatorially mounted telescopes.

Times have changed, however, and we all know that digital photography is profoundly altering astrophotography. One of the biggest changes is that regular daytime photographers are learning that they don't need to put their cameras away when the Sun sets. Beautiful pictures with a starry sky backdrop have entered mainstream photography. And you need look no further than several recent astrophotography-themed TV commercials for computers and cars for proof of that. It seems that those of us who love shooting pictures of the night sky no longer have to feel that we have a really unusual hobby!

With so many new people photographing starscapes, the time has never been better for small tracking camera mounts, and several have recently entered the market. The newest is iOptron's SkyTracker. I borrowed one from the manufacturer to test last February, and from my first night out I was highly impressed with its performance.

The SkyTracker is about the size of a paperback book and has two features that immediately set it apart from the competition. Foremost is the included polar-alignment scope. The other is a precision, worm-driven latitude adjuster. As with other tracking mounts, iOptron's is designed for use on a camera tripod, but there's no need to use a camera head (often the least rigid part of a photographic tripod) to achieve polar alignment. I attached the SkyTracker directly to the center column of a heavy-duty Manfrotto tripod. Since both azimuth and altitude adjustments are needed to achieve polar alignment, it would be nice to have a tripod with a center column that rotates (mine didn't), but it was surprisingly easy for me to nudge the tripod into the correct azimuth position. It was even easier to set the proper altitude thanks to the fine motion of the built-in latitude adjuster, and this was particularly true when I had a heavy camera on the mount.

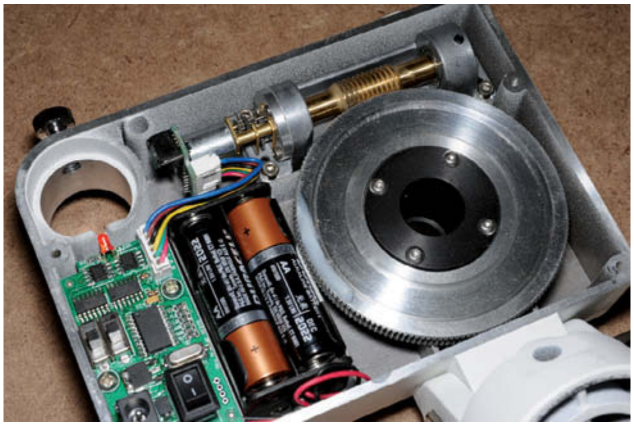
The Polar Scope

The included polar-alignment scope is the same one built into iOptron's high-end equatorial mounts that I have reviewed in the past. It's exceptionally accurate and extremely easy to use. It has an illuminate reticle with calibrated circles for Polaris (Northern Hemisphere) and Sigma Octantis (Southern). The circles are divided into 12 hours like the face of a clock. With iOptron's telescope mounts, the Go To hand controller graphically displays where to position Polaris or Sigma Octantis on the reticle to achieve accurate alignment. Since the SkyTracker has no hand controller, iOptron created a $2 app for Apple mobile devices. What I particularly like about this system is that you don't need to do any calculations — you just move the SkyTracker until the alignment star appears on the reticle in the location shown on the app's display and you're aligned. It takes only moments to do.

In principle, the polar scope needs the SkyTracker to be level in its east-west direction so that the reticle's clock face is oriented correctly. But in practice, eyeball-leveling is sufficient. If you don't have an Apple device for the app, there are other ways to determine Polaris's position relative to the celestial pole, but you'll need to "flip" the star's real position in the sky to match the inverted view in the polar scope.

And here's a word of caution: don't assume other polar-align apps will work. Astro-Physics has developed a similar app for its polar-alignment scope (January 2013 issue, page 37). But its app is incompatible with the SkyTracker because the Astro-Physics polar scope has a right-angle viewer that produces a different field orientation.

The author tested the SkyTracker with it attached directly to the center column of a heady-duty Manfrotto tripod. If the polar-alignment scope interferes with equipment mounted on the tracker, it can be removed after the tracker is aligned.



The iOptron unit is exceptionally well made and includes a miniature servomotor with an optical encoder for speed regulation and a gear train that would impress a watchmaker. The worm gear and worm wheel are each mounted in a pair of ball bearings.

WHAT WE LIKE:

Solid, die-cast aluminum construction

Superb, easy-to-use polar-alignment system

Accurate drive rate with half-speed setting (see text)

WHAT WE DON'T LIKE:

Why something this good wasn't available years ago

The SkyTracker is ideal for wide-field starscapes such as this moonlit view made with a 14-to-24-mm zoom lens set to 16 mm. The unconventional half-speed tracking rate, which was used for this 1-minute exposure, evenly divides image blur between the stars and landscape, making both appear sharp to the eye.

iOptron's Ball Head

To have flexibility framing your pictures, you need to use some kind of photographic ball head between the SkyTracker's driven mounting block and your camera. iOptron offers one for $49. I've spent twice as much for ball heads that weren't nearly as good as the iOptron model, so I highly recommend you buy it if you don't already own one. It's solidly built, robust enough for heavy DSLR cameras, and it clamps securely with only light finger pressure on the locking knobs. I especially like the ball head's quick-release plate for attaching a camera, since this feature allows you to get everything set up and roughly adjusted before adding the weight of the camera. That said, I strongly suggest that you do your final adjustment of the tracker's polar alignment *after* the camera is in place.

The SkyTracker is extremely simple to use, and the illustrated manual is well done, even to the point of detailing how to install the four AA batteries, since the battery holder fits very tightly into its compartment. iOptron states that fresh batteries can run the tracker for up to 24 hours in mild weather. That may be, but my frigid February nights, with temperatures well below freezing, took their toll on battery life, and I barely got 12 hours from my first set of batteries. There is the option of powering the tracker with an external source of DC current between 9 and 12 volts.

The most challenging aspect of using the tracker is identifying Polaris for the polar alignment. This isn't a problem for anyone who has a basic knowledge of the night sky. There's a small hole drilled trough the tracker's body that serves as a peep sight, and you'll be roughly aligned when you can see Polaris centered in the

iOptron's app for Apple mobile devices makes SkyTracker's polar-alignment system all but foolproof. Using the date, time, and location from the "smart" device, the app shows you where to position Polaris (for Northern Hemisphere observers) on the polar scope's reticle to achieve accurate alignment. The position is given relative to an imaginary clock face divided into 12 hours and corrected for the polar scope's inverted view.

hole. This alignment is sufficient for short exposures made with wide-angle lenses, but I always took the extra minute or two to refine the alignment with the polar scope. That way I could shoot longer exposures and use modest telephoto lenses and still have pinpoint stars. Indeed, with the SkyTracker carefully aligned, the tracking was the match of many small equatorial mounts I have used for telescopes.

For one test on my first night out with the SkyTracker, I made a long series of back-to-back 3-minute exposures with a 24-mm lens. The left picture in the illustration below was made by stacking the first and last frames (aligning the image on the frame and not the stars), and it shows how little the stars drifted during the nearly 5-hour sequence. And some of this apparent drift was due to the camera flexing on its mount as Orion neared the western horizon, since I had even better tracking on another night shooting a sky sequence that crossed the meridian.

I used the SkyTracker with lenses up to 180 mm in focal length. Shooting 3-minute exposures with that lens produced about 9 out of 10 images with pinpoint stars when the camera was randomly oriented on the tracker. The success rate was higher when the camera's weight was on the east side of the mount, causing the drive to "lift" the weight. Lenses with focal lengths of 50 mm or less had success rates close to 100% regardless of camera orientation.

The SkyTracker's camera-mounting block (left) has a brass inset that can be reversed for use with ball heads that have either ¼-20 or ⅜-16 threaded sockets. The optional ball head is noteworthy for its features, including a quick-release plate and solid locking mechanism.

In addition to the on/off switch, the Sky Tracker has only two controls — a switch for Northern or Southern Hemisphere operation and one that sets the tracking rate to either sidereal or half-sidereal rate. At first blush, the half rate might seem strange, but it evenly divides image blur between the sky and foreground. With wide-angle lenses, it can produce dramatic images of a starry sky suspended above a landscape with everything appearing sharp to the eye. Until relatively recently, a half-speed drive rate was rarely used except by a handful of the world's elite starscape photographers. Now their secret is out and manufacturers are taking note!

My final surprise with the SkyTracker came when I took the back off the unit for a peek at its inner workings. What I found was construction quality that I would have expected for a unit costing much more than $399. Particularly noteworthy are a servomotor with an optical encoder for speed regulation and a worm gear mounted with a pair of ball bearings. The worm wheel is also mounted with a pair of ball bearings, which is part of the reason why the 3-pound SkyTracker, which is made of die-cast aluminum, has a rated load capacity of 6.6 pounds (3 kg).

As I have mentioned in past reviews in this magazine, iOptron has become a major player in the world of telescope mounts. The company offers some of the best values for alt-azimuth and equatorial Go To mounts for light- and medium-weight scopes. And now with SkyTracker, it is offering the best value I know of for a camera tracker. If you're on the fence about purchasing a tracker, I suggest moving sooner rather than later, since Comet ISON's potential to put on a significant display later this year is sure to create a demand for them. ✦

***Left*: Described in the accompanying text, this view shows how well SkyTracker kept a camera fixed on a star field during a nearly 5-hour span. The cropped image is from a stacked pair of 3-minute exposures made at the beginning and end of the interval and aligned to the frame edges, not the stars. *Right*: Because of its precise polar-alignment system, accurate drive rate, and solid construction, the SkyTracker is suitable for use with modest telephoto lenses. This 3-minute exposure of the region around the Orion Nebula was made with a 180-mm lens and full-frame DSLR camera.**

*Despite his enthusiasm for telescope-making projects, senior editor **Dennis di Cicco** doubts he'll ever make another driven platform for cameras now that SkyTracker exists.*

The Spring's the Thing

This relatively simple modification will give your Dobsonian reflector better motions and make it easier to control.

DOBSONIAN TELESCOPES are remarkably effective instruments in spite of their inherent simplicity. And yet, there are good ones and there are bad ones — it all comes down to how smooth and controllable the scope's motions are. It's been my experience that it's the smallest, most-lightweight Dobs that tend to perform the least satisfactorily. Such instruments can be finicky to balance, and they often move too easily for precise aiming. Luckily, there's a simple hardware-store fix: springs.

GARY SERONIK (2)

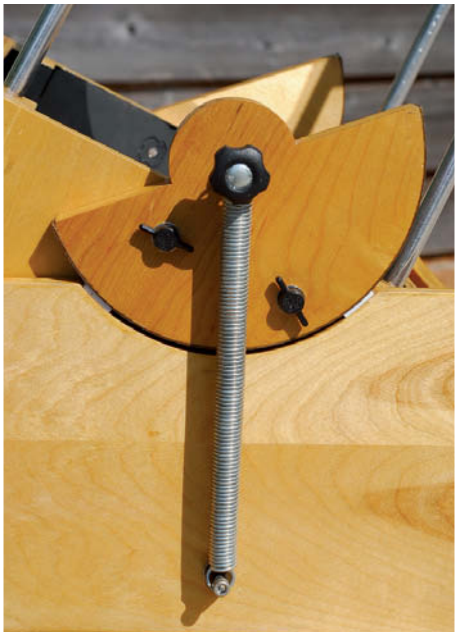
A spring added to a lightweight Dob such as the author's 8-inch travelscope can help fine-tune the scope's altitude motion.

The crux of the problem is that you can precisely balance a scope for only one eyepiece weight. Trouble arises in lightweight scopes because the mass of the eyepiece is proportionally greater than it is in heavier Dobs. Whenever you use an eyepiece that's too light or too heavy, the telescope tube will become unbalanced. A secondary problem arises if a Dobsonian isn't well balanced along its vertical axis. As such, the scope might work acceptably when the tube is roughly horizontal, but still be prone to drift when it's aimed near the zenith.

Properly chosen springs can solve both of these problems. Indeed, for lightweight instruments, especially those of 8-inch aperture or less, I feel that springs are a necessity. They can also help with big scopes. And springs are useful for keeping the height of a Dob's rocker box low, even when the tube's center of balance is far from its back end.

Generally, I use two springs on my Dobs — each solving a different problem. The first is a high-tension spring that simply adds friction to the altitude bearings. One end of this spring is attached to the center of a side bearing (photo on facing page), and the other end is affixed to the rocker box. I mount this spring on the opposite side of the tube from the focuser, though the choice isn't critical. I get the desired friction increase by selecting a strong spring, and by tensioning it the correct amount with careful placement of the anchor point on the rocker box. The goal is introduce enough tension to ensure that the force required to move the scope in altitude matches the amount needed to move it in azimuth. Socket-head cap screws are ideal for the anchor points because they make it easy to slip the spring's end loop over the screw head.

Some readers might wonder why I don't increase altitude friction with some kind of brake mechanism, or by choosing different bearing materials. The answer is because I don't want the added friction to come with extra *stiction* — the term used to describe the amount of force necessary to start the scope moving and keep it in motion. Too much stiction will give your Dob a jerky feel that makes it difficult to aim accurately. The beauty of using a spring is that you are able to increase friction, yet retain the excellent stiction properties inherent in classic



A spring adds friction to a scope's altitude bearing without changing the bearing's stiction characteristics. Tension is set by choosing an appropriate anchor point on the rocker box.

Telflon-and-Formica bearings.

With some of my scopes I add a second spring, offset from the side bearing's axis of rotation, as shown in the photo on the facing page. Mounted this way, the spring supplies tension that changes with the scope's altitude. Depending on where you position the anchor points, you can have the tension increase or decrease as the scope is aimed higher. This also works well when the goal is to keep the side bearings near the ground so that the tube can be used with a low-profile rocker box.

For either situation you can build a little adjustment into the setup — all you need to do is add a turnbuckle at one end of the spring. This way, you can fine-tune the spring's tension to taste.

If you want to delve a little deeper into the topic, check out Tom Krajci's excellent article, which appeared in this magazine's November 1999 issue, page 130. Tom describes a detailed, mathematical approach that yields an optimized "virtual counterweight." But I've found that basic experimentation also works well. ✦

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

Sean Walker

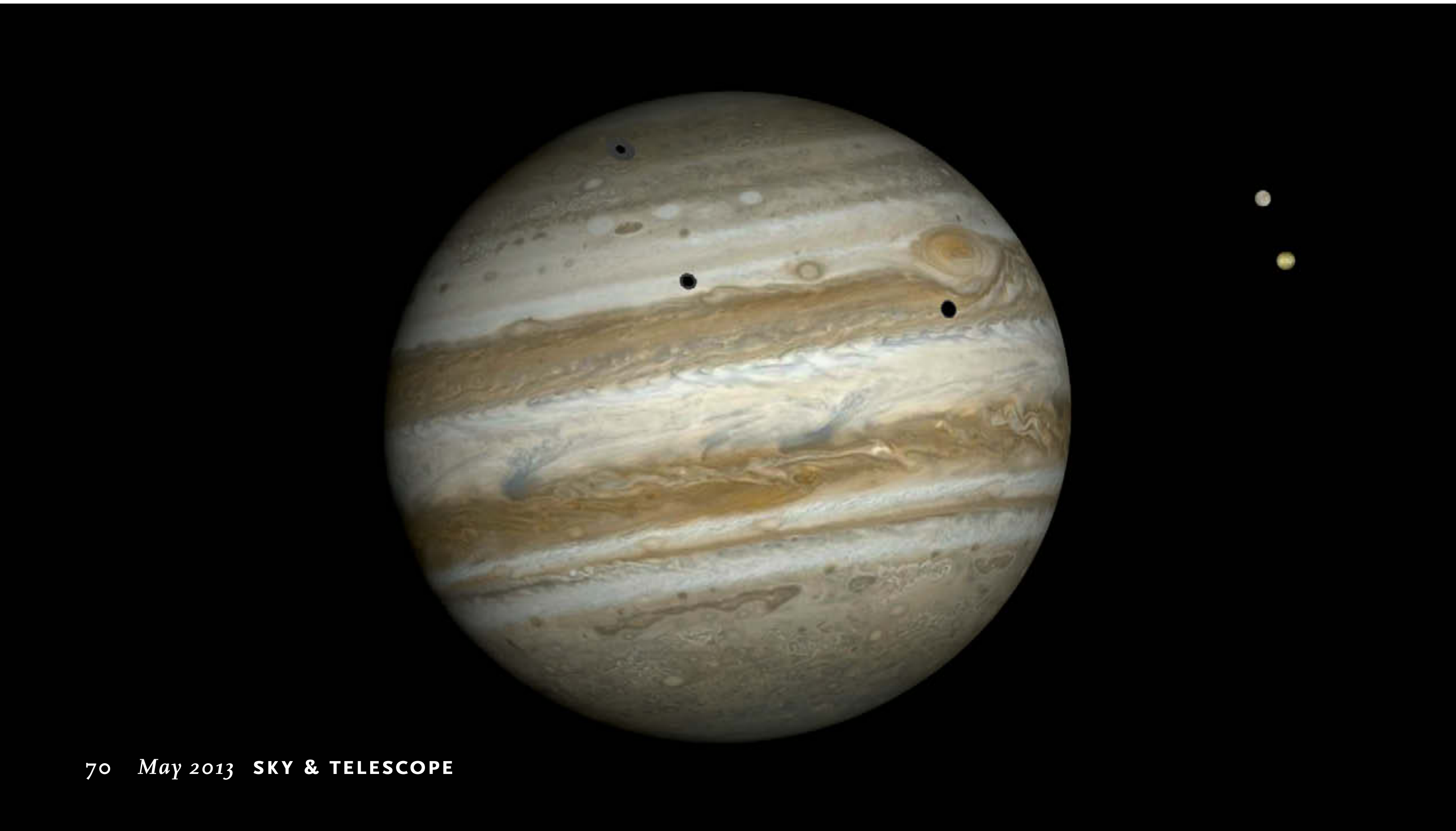
A Planetary Breakthrough

WinJUPOS eliminates the race against time in planetary imaging.

Since the start of the millennium, amateur planetary imaging has rapidly come of age. Beginning with the introduction of the modified webcam and the development of stacking software, amateurs have routinely produced images that approach the theoretical limits of what is possible with ground-based telescopes. Besides the limitations of shooting through our planet's churning atmosphere, the only barrier remaining was the blurring effect of a target planets' rapid rotation. At least it was until now.

The software *WinJUPOS* (**http://jupos.privat.t-online.de/index.htm**) by German amateur Grischa Hahn has become an important tool for serious planetary imagers. Its origin can be traced back to 1989 as the DOS program *ZMPP* by Hans-Jörg Mettig, used to time central-meridian transits

The *WinJUPOS* software package generates ephemerides of the Sun, Moon, and planets with unparalleled accuracy. This image shows a simulation of a triple shadow transit on Jupiter as it will appear at 5:00 UT October 12, 2013. The shadows are from Callisto (top), Europa (near center), and Io (right). To the right of Jupiter are Europa (top) and Io.



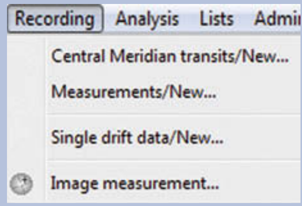
of Jupiter's Great Red Spot. In 1992 Hahn took over and developed additional versions focused on each of the brightest planets. Finally, in 2002 he released the first version of *WinJUPOS*, which combined all the previous iterations into a single platform that operates in Microsoft Windows.

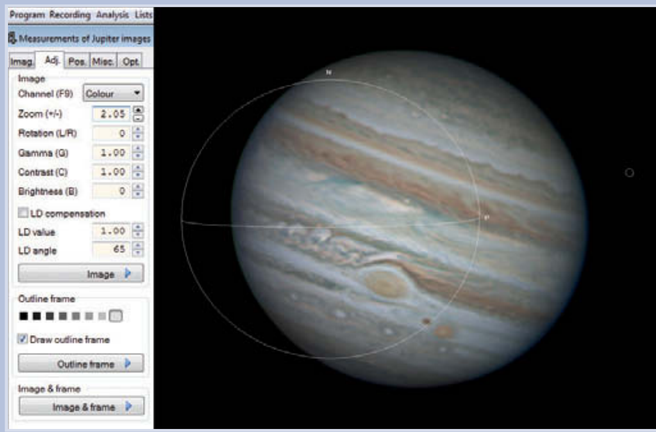
Over the years *WinJUPOS* has grown to become one of the most accurate programs for timing precise events, such as shadow transits on Jupiter and Saturn. It enables users to generate maps of a planets' entire visible surface in order to create custom textures and animated globes. It also allows users to precisely measure the positions of features on any of the visible planets. A great introductory video to the program by planetary imager Michael Phillips is available at **http://www.youtube.com/watch?v=KJf-XvVVC0c**.

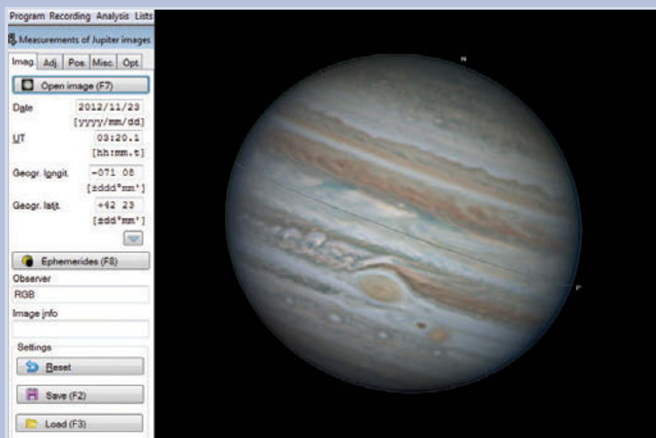
Recently, Hahn has incorporated a complex suite of features that allow imagers to remove a planet's rotation from a long video stream or series of images. This is a huge breakthrough for planetary imagers, particularly those who photograph Jupiter and Saturn. These two gas giants each rotate in about 10 hours, so in order to take sharp images using the popular stacked-video-frame method, an imager needs to limit the capture length of a video to about 2 minutes to avoid smearing the details within these gaseous atmospheres. Now amateurs can shoot Jupiter for longer than 2 minutes. Here's how to do it.

PLOTTING SIZE AND ANGLE

Top: **The first step to de-rotating images in *WinJUPOS* requires accurately plotting the size and angle of your imported image. The software does this by overlaying an outline of the target planet (and attendant moons) based on the exact date and time that you enter. *Bottom:* In the Adj. tab, select the color filter used for your video, and then you rotate, expand, or contract the planet outline until it matches your image. When you're done, return to the Imag. tab and hit the Save (F2) button to create an IMS file used in the next steps.**







Measuring Your Photos

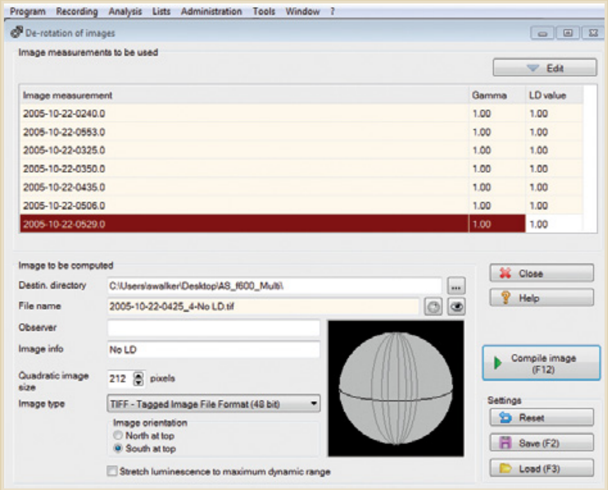
Let's start off by de-rotating two stacked and sharpened images of Jupiter taken 10 minutes apart. To use *WinJUPOS* to de-rotate planetary images, you need the precise start and stop times of your video recordings. Make sure to note these exactly. I set my Imaging Source camera's *IC.Capture* software to title my videos by the date and time down to the second. It's helpful to set your computer's internal clock to a recognized accurate standard, such as the U.S. Naval Observatory Master Clock (**http://tycho.usno.navy.mil/simpletime.html**). Using a known standard is particularly important if you're lucky enough to record a transient impact flash on your target.

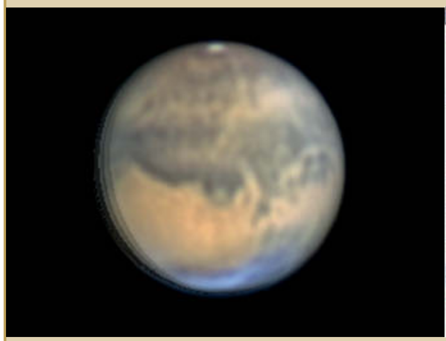
Begin by opening *WinJUPOS* and selecting which planet you're measuring from the pull-down menu along the top left of the screen. For this demonstration we'll use Jupiter, so choose Program/Celestial Body/Jupiter. Next, select Recording/Image measurement. This opens a new window where you will input and save all the measurements of your images.

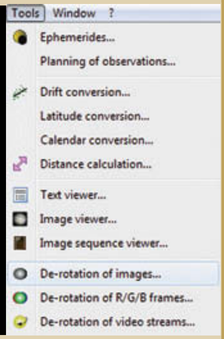
In the measurement window, click the Open image button and find your first image to measure. *WinJUPOS* accepts many image formats, including JPEG, TIF, FITS, and BMP. After this, the planet's white outline will appear over your image with an equator line and the letters N and P, denoting north and planetary east. It most likely won't match the size or proper orientation, but we'll fix that shortly. Input the date that the image was taken in the Date line. Then, enter the midpoint of your recorded image in the UT line. For example, if your image was begun at 21:23:00 and the video was 1 minute long, the midpoint should be entered as 21:23:5 (*WinJUPOS* divides a minute into tenths). You can skip latitude and longitude, unless you're measuring images that include Earth's Moon or the Sun, such as occultations and eclipses.

Next, you need to match the white outline with your image. Click on the Adj. tab. You should first select what kind of image you are measuring — are you aligning a stacked color image, or individual red, green, and blue images? In this example, the image is a color photo, so you

DE-ROTATING A SERIES OF IMAGES

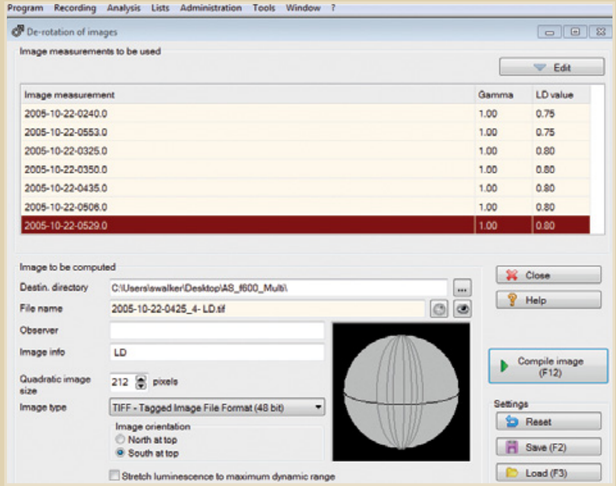




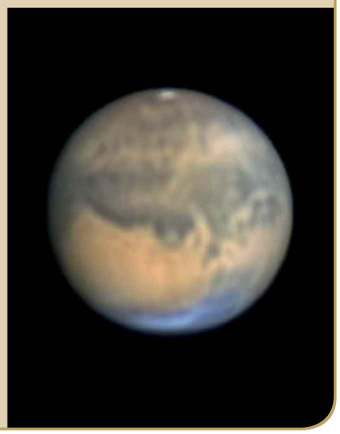


To de-rotate a series of images, select Tools/De-rotation of images. In this window you'll import your IMS files by clicking the Edit button and selecting the Add option. Simply choose all your IMS files to combine, select the file format you prefer your result to be saved as, and then click Compile image (F12).

CORRECTING EDGE ARTIFACTS



Combining images taken at widely spaced intervals can often produce an unsightly edge artifact in the combined result due to the rotation of the planet (seen at left). You can mitigate this by lowering the LD value (right column) in the images nearest the start and end of the combined series. The result at right shows 3 hours of Mars images combined into a single, smooth result.



should change the Channel option to Color. If your image looks small in the window, use the zoom feature to make it fill the frame comfortably. Now you can simply use the arrow keys on your keyboard to move the outline to match your image. The N and P keys rotate the outline, and the PageUp and PageDown keys will expand and contract it. You can also change the color of the outline to a shade of gray to make the limb of your photographed planet easier to see. Having one of the Galilean moons is particularly helpful with alignment because *WinJUPOS* also includes their exact positions. The other options in this tab aren't important for de-rotation.

Once you've accurately aligned this outline, return to the Imag. tab and click the Save button at the bottom left in the window. This creates an "Image measurement settings" (IMS) file that you'll need for the next step. Repeat this routine for any additional images you want to include in your de-rotated group, and remember to change the Channel setting to match which filter you used to record the video if you're de-rotating color-filtered images.

Combining Measured Images

When you've completed measuring and saving all of your image measurement settings, click the Tools pull-down menu and select De-rotation of images. A new window opens where you'll combine all of your images into a single perfectly aligned and de-rotated result. In this window, click Edit/Add to select the IMS files you want to combine. Two or more vertical gray lines will appear on the disk to graphically depict the central meridians of each of your images.

Before you compile your image, click the button marked "..." to select the destination folder for saving your de-rotated result. Also, you can modify the file name for your result by typing into the lines called Observer and Image info. *WinJUPOS* will automatically crop your de-rotated result to include the entire planet, but you can increase or decrease this value by typing in your own preferred size in the Quadratic image size line. The program also outputs your result in a variety of

Visit SkyandTelescope.tv to see previews of Sean Walker's image processing tutorial videos.

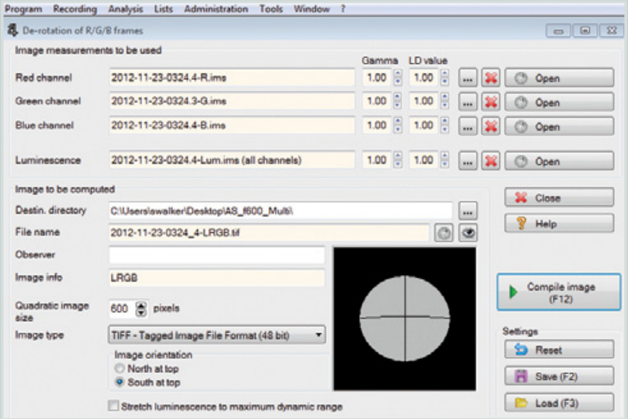
formats, including BMP, PNG, 48-bit FITS, JPEG, JPG2, GIF, PCX, and 48-bit TIF. I prefer TIF because I can then open the result in any image-processing software, such as *Adobe Photoshop,* for additional adjustments if necessary. Next, choose whether you want your result to be output as North or South at top. Once you've gone through all these options, click the Compile image button, and after a few moments your de-rotated result will appear.

If you're combining images taken over the course of 10 minutes or more, you may notice a distracting hard-edge artifact along the trailing limb of the planet. This can be smoothed out by lowering the LD value from 1.00 at the far right of each of your included IMS files. Experiment by lowering this value slightly and compiling your result until the limb artifact disappears. You can then save all your work as a "Settings of De-rotation of images" file (.icm) that you can load and modify in the future if desired.

De-Rotating Color Channels

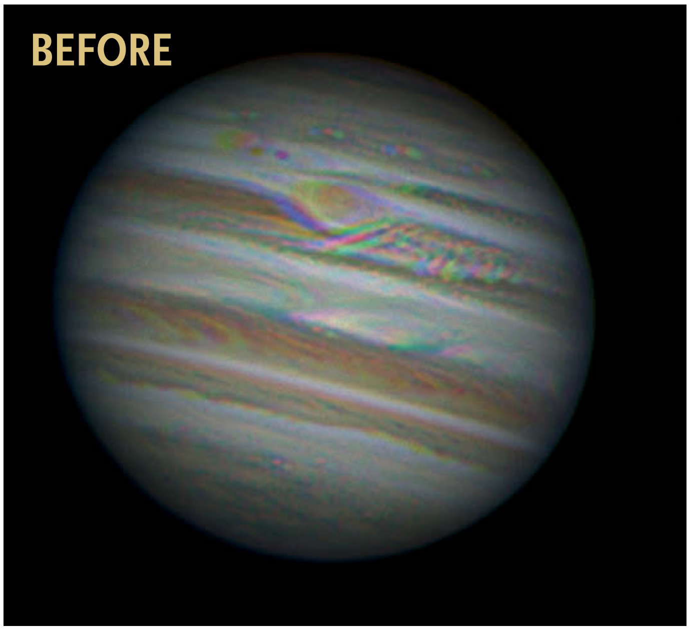
WinJUPOS also allows you to perfectly de-rotate individual color-filtered images taken at widely spaced intervals that were previously impossible to combine without complex 3-D manipulation software. This is done by measuring the displacement of each of your red, green, and blue images and saving each IMS file. To combine them into a de-rotated color result, select the pull-down menu option Tools/De-rotation of R/G/B frames. The resulting window is similar to the De-rotation of images window, except that the top four lines are reserved for your red, green, blue, and optional luminescence images. Simply select each of your respective color channels by clicking the "..." button to the right of each line. Once again, you may need to lower the LD value of the images at the beginning and end of the image

DE-ROTATING COLOR-FILTERED IMAGES



The De-rotation of images feature also allows you to combine many separate color-filtered images into a single, smooth luminescence file that you can then combine with a set of individual color-filtered images. This produces a sharper result like the photo shown at right.

Below: **De-rotation of R/G/B frames allows you to combine color channels taken at widely spaced intervals — something that was beyond the capabilities of amateurs until now. The image on the left shows Jupiter recorded through red, green, and blue filters in 5-minute increments combined in *Photoshop*. The image on the right shows the same view with the color channels accurately de-rotated.**



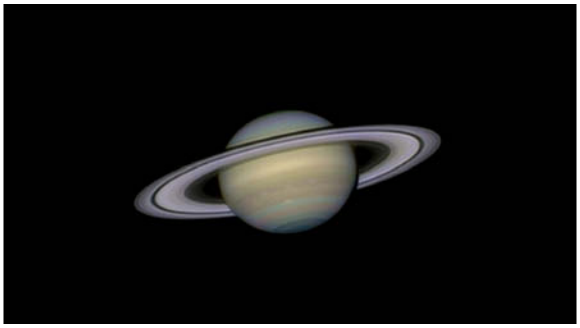
series to eliminate any residual limb artifacts. All the other settings are exactly as described for the De-rotation of images window.

I generally use a combination of these two routines when shooting planetary images under fair seeing conditions. I'll shoot an alternating pair of 1-minute color-filtered videos through each color filter and stack the results, and then combine both the red images, each of the green photos, and the blues together in the De-rotation of images window. These combined color frames have much less noise than a single stacked result per color filter, and can thus be sharpened a bit more than the single ones. You can then combine them into a single RGB image using the De-rotation of R/G/B frames tool.

De-rotating Videos

The last and perhaps most powerful new tool in *WinJUPOS* is the De-rotation of video streams feature. The program can de-rotate every frame in a long video stream of 10 minutes and longer. This is immensely beneficial to imagers because it allows you to potentially stack thousands of frames into a super-smooth result, while eliminating the blur of rotational effects. One warning: de-rotation of large video files takes a lot of processing power and tends to fail on older machines. Also, it functions best on videos taken in very good to excellent seeing.

To de-rotate a video stream, let's assume you have recorded a 10-minute video of Jupiter. *WinJUPOS* needs to measure a stacked image created from the first two minutes of the video. I created this by using *AVIedit* (**www.am-soft.ru/aviedit.html**) to clip the first two min-



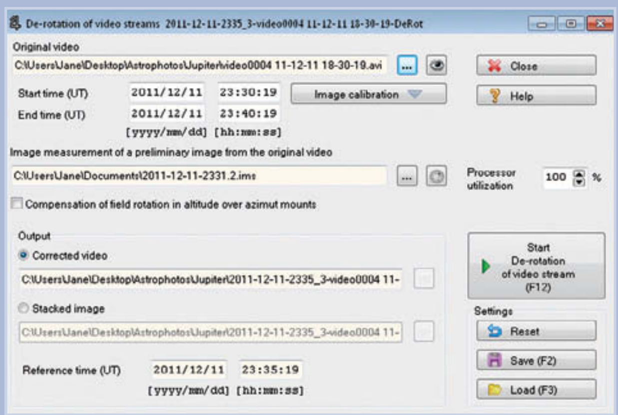
Video de-rotation is extremely useful on Saturn because the planet is much fainter than Jupiter and requires longer exposures to produce a smooth result. Renowned planetary imager Damian Peach routinely combines 20-minute video streams to produce excellent pictures, such as this photo captured on the morning of December 27, 2012.

utes of the video and stacking the result in *Autostakkert! 2* (**www.autostakkert.com**), then generated an IMS measurement file from this image as described earlier. I then selected Tools/De-rotation of video streams. In this window, begin by clicking the "..." button to select your original video. Next, input the start time of your video in the next lines — remember to be exact. The program then automatically inputs the length and end time of your video. If you calibrate your videos with dark frames, flat-field images, and bias frames, you can click the Image calibration button and input those in their respective lines. Now, input the 2-minute image stack IMS file in the next line.

Finally, choose which output you desire, either a corrected video or a stacked image, by checking the respective button. I suggest avoiding the stacked image option, because *WinJUPOS* will not eliminate any poor frames. When these are done, simply hit the Start De-rotation of video stream button and let it run. This can take a long time to complete, so be patient. When completed, the corrected video will have "De-Rot" added to the end of its file name. This video can then be stacked in your preferred video-stacking program.

De-rotating images and videos opens up a realm of imaging previously beyond the reach of amateur astronomers. Not only can long data streams be combined and analyzed, but old images from months, years, and even decades ago can be measured accurately and compared to modern images to spot previously unnoticed changes on the cloud tops of the gas planets or albedo changes on the surfaces of Mars and Mercury. And more frames included in your stacked results will enable you to use more aggressive sharpening settings without bringing out objectionable noise. ✦

DE-ROTATING VIDEO FILES



To de-rotate an entire video stream, you'll need to produce a stack of the first 2 minutes of video to use for measurements. Once completed, input the start time of your video. *WinJUPOS* will automatically calculate the mid-point and length of the video and de-rotate every frame to match this point. Currently, the program can de-rotate AVI and SER video formats.

S&T imaging editor ***Sean Walker*** *often shoots the planets from his home in Manchester, New Hampshire.*

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◀ **GALACTIC SEAGULL**

Gerald Rhemann

Straddling the border between Monoceros and Canis Major, the large emission nebula IC 2177 surrounds the open cluster NGC 2335 left of center. Open cluster NGC 2343 is visible in the lower-middle of this image. North is at left.

Details: *ASA astrograph H f/2.8 with FLI ProLine PL16803 CCD camera. Total exposure was 21⅘ hours through color filters.*

◀▼ **SATURN AND ATTENDANTS**

Darryl Pfitzner Milika

Saturn is accompanied by its moons (left to right) Dione, Enceladus, Mimas, and Tethys on the morning of January 26th. Just visible is the planet's olive-colored hexagonal polar region at the bottom (north).

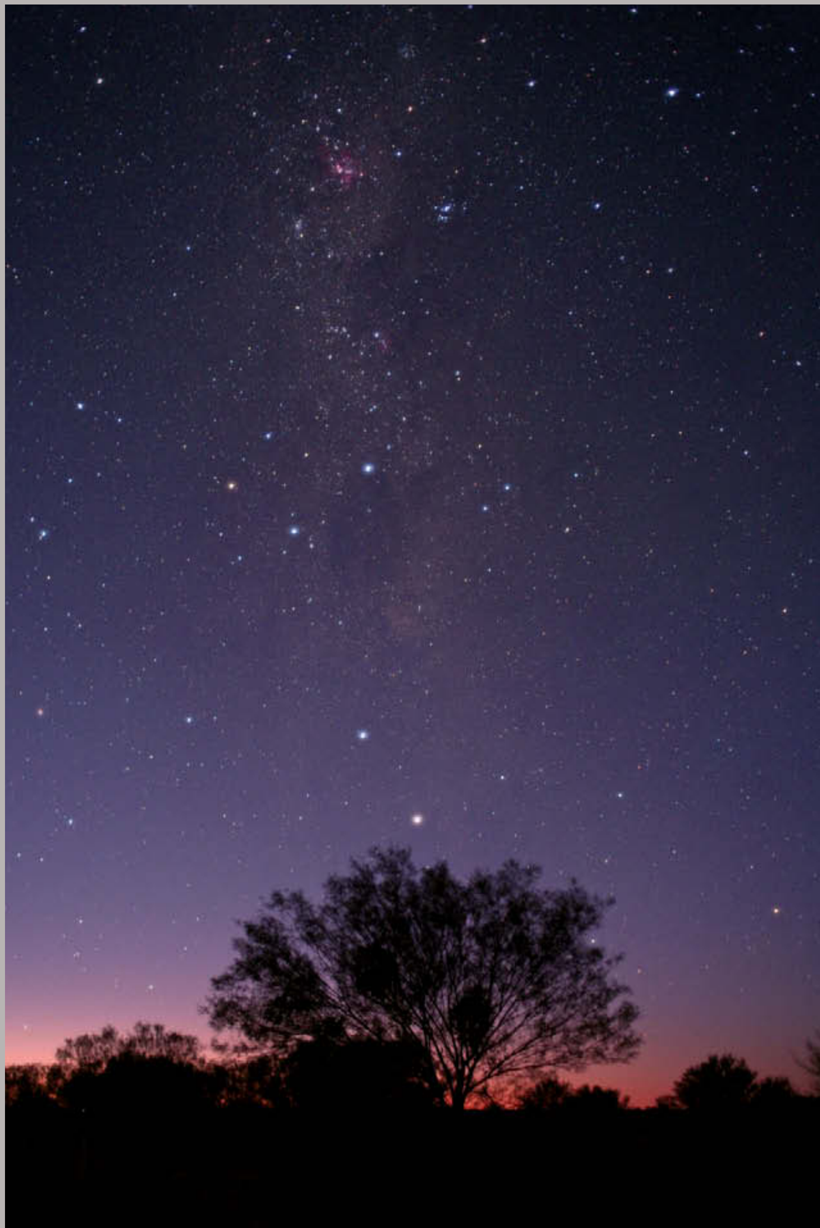
Details: *Celestron C14 Schmidt-Cassegrain telescope with ZWO Design ASI120MM video camera. Stack of multiple exposures recorded January 26, 2013, at 18:38 UT.*

▼ **MIDMORNING ARCHIMEDES**

Alessandro Bianconi

This high-resolution photo of the lunar crater Archimedes reveals dozens of craterlets scattered across its lava-flooded floor.

Details: *Celestron C14 Schmidt-Cassegrain telescope with Basler Ace acA640 mono video camera. Stack of multiple exposures recorded on the evening of October 6, 2012.*



AYERS

Tunç Tezel

Three popular southern objects line up in this view from Uluru in Australia. The bright star just above the tree is Alpha Centauri, the closest star system to Earth. At the center is the Southern Cross, with the Coalsack dark nebula, while at the top is the massive Carina Nebula, NGC 3372.

Details: *Canon EOS 5D DSLR camera with 35mm f/2 lens. Total exposure was 25 seconds at ISO 1600.*

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◀ **THE RUNNING MAN NEBULA**

Bob and Janice Fera

Roughly ½° northeast of M42 in Orion lie the nebulae NGC 1973, 1975, and 1977, consisting of a subtle mix of bluish reflected starlight and pinkish hydrogen emission.

Details: *Officina Stellare RC-360AST 14-inch Ritchey-Chrétien telescope with Apogee Alta U16M CCD camera. Total exposure was 7⅔ hours through Astrodon color filters.*

▼ **STARBIRTH IN CEPHEUS**

Brian Peterson

The presence of young embryonic stars within the bluish reflection nebula NGC 7129 is betrayed by the tiny reddish Herbig-Haro objects that dot the field. North is at left.

Details: *Hyperion 12½-inch f/8 Astrograph with SBIG STL-11000M CCD camera. Total exposure was 4⅔ hours through Astrodon color filters.* ✦

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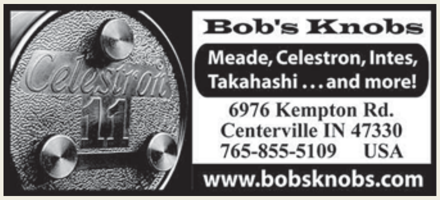

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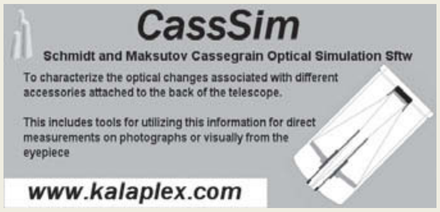

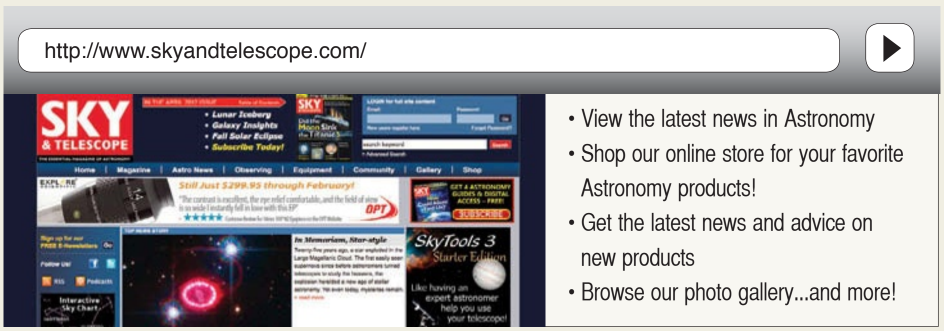

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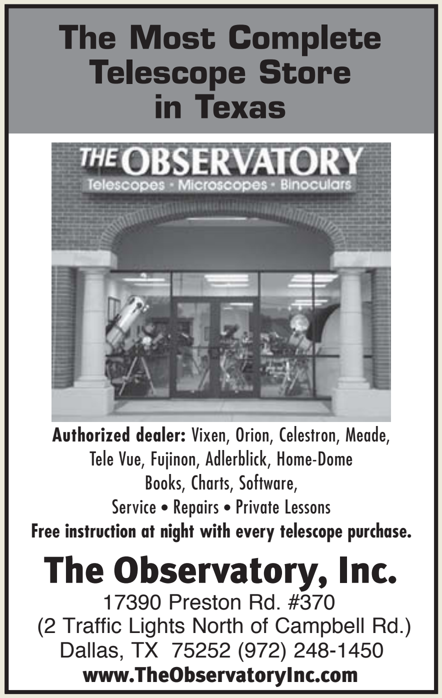

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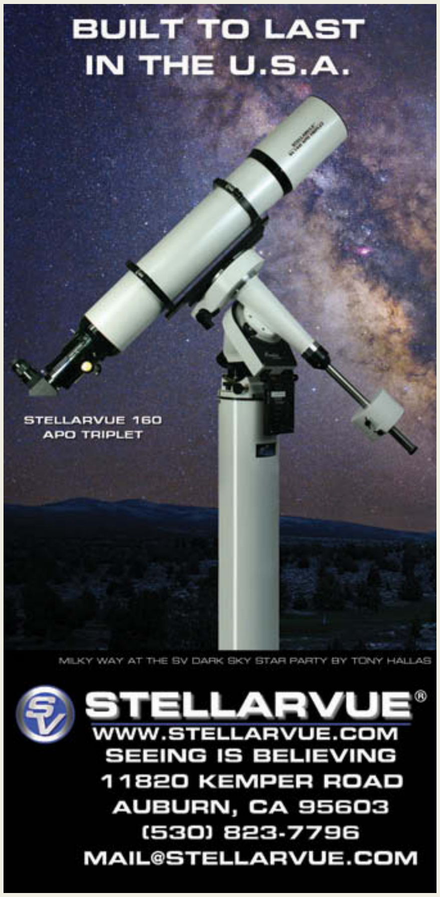

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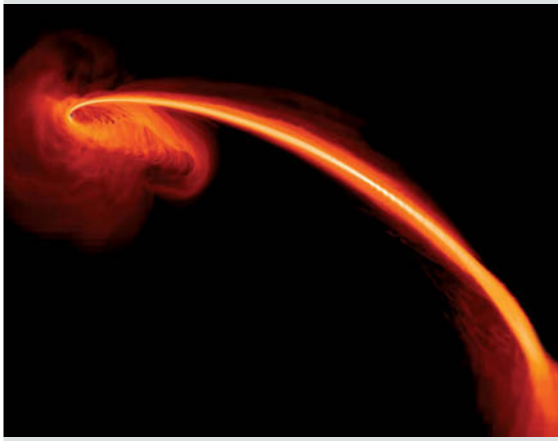

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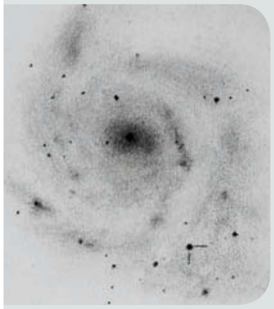

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Which Way to Mars?

We'll need a step-by-step approach to colonize space.

In considering how to fund a human mission to Mars, and eventual settlement, two methods stand out. One is a mega-budget approach costing hundreds of billions of dollars and the other is based on an incremental strategy.

The mega-budget method involves extraordinary Apollo-level government funding commitments spread over many years (which are subject to the vagaries of changing political budgets and national priorities), or private investment vastly beyond amounts typically available to private individuals or corporations. This approach has a fundamental weakness: it fails to address the elephant in the room — the potentially massive failures and unknown costs of any human Mars mission and colony design. This explains why no government or private-sector group has seriously committed to such a mega-project to date — it's simply a bridge too far.

Private-sector funding models have more flexibility options than government programs, but they will hit the wall when they run into the huge cost overruns that will inevitably occur in such a complex undertaking. Funding humans-to-Mars projects from a single revenue source won't work if done as a one-shot deal. To account for the great unknowns, this approach will require a never-ending money stream to pay for multibillion-dollar resupply missions. One-time fund-raising programs, even if initially successful, will run out of steam, leaving the dreams of Martian colonization cut short.

Enter the incremental approach, a step-by-step process that builds ever-bigger phases of the program as each milestone is passed. It's a strategy that addresses the low-cost space-access challenge and tackles the technological challenges within an incremental testing approach that can succeed where other methods fail.

For private Martian settlement programs, this may require development of low-cost space vehicles and the establishment of commercial space industries where nearer destinations (the Moon, Lagrangian points, and near-Earth asteroids) are visited first in a step-by-step fashion. With this approach, Mars transit costs come down, safety levels increase, and a sustainable budget is constructed. It accounts for financial realities, creating a new, stronger model that can withstand unknown development challenges.

Wealthy entrepreneurs such as Elon Musk, Jeff Bezos, and Richard Branson exemplify how this phased approach can work. Having strong sources of non-space revenues that help them fund their own programs, they focus on low-cost space-access technologies. They dream of Mars, but are prudent enough to keep their priorities in order. They don't outsource the work, rather, they own the process. When spaceflight costs come down to $1,000 or $100 per kilogram or less, they know that risks can be accounted for and trips to Mars won't break them. Such visionary business executives are following this model right now while others flounder around trying to figure out how to fund mega-billion-dollar Mars plans.

Old ways of trying to justify multi-billion-dollar space missions are dying. But with the new "Musk/Bezos/Branson" model, we can reach Mars much sooner than many people think. Critics only see space missions in black-or-white and success-or-failure terms, but our goal should be far bigger than a Mars colony. It's about opening up space to all, at an affordable and sustainable price with technologies and financing plans that work. With that goal reached, the doorway to space can be kicked wide open. ✦

***Frank Stratford** of Melbourne, Australia, is chief executive officer and founder of Mars-Drive. His writing is focused on solutions to commercial space development with a focus on Mars settlement.*

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