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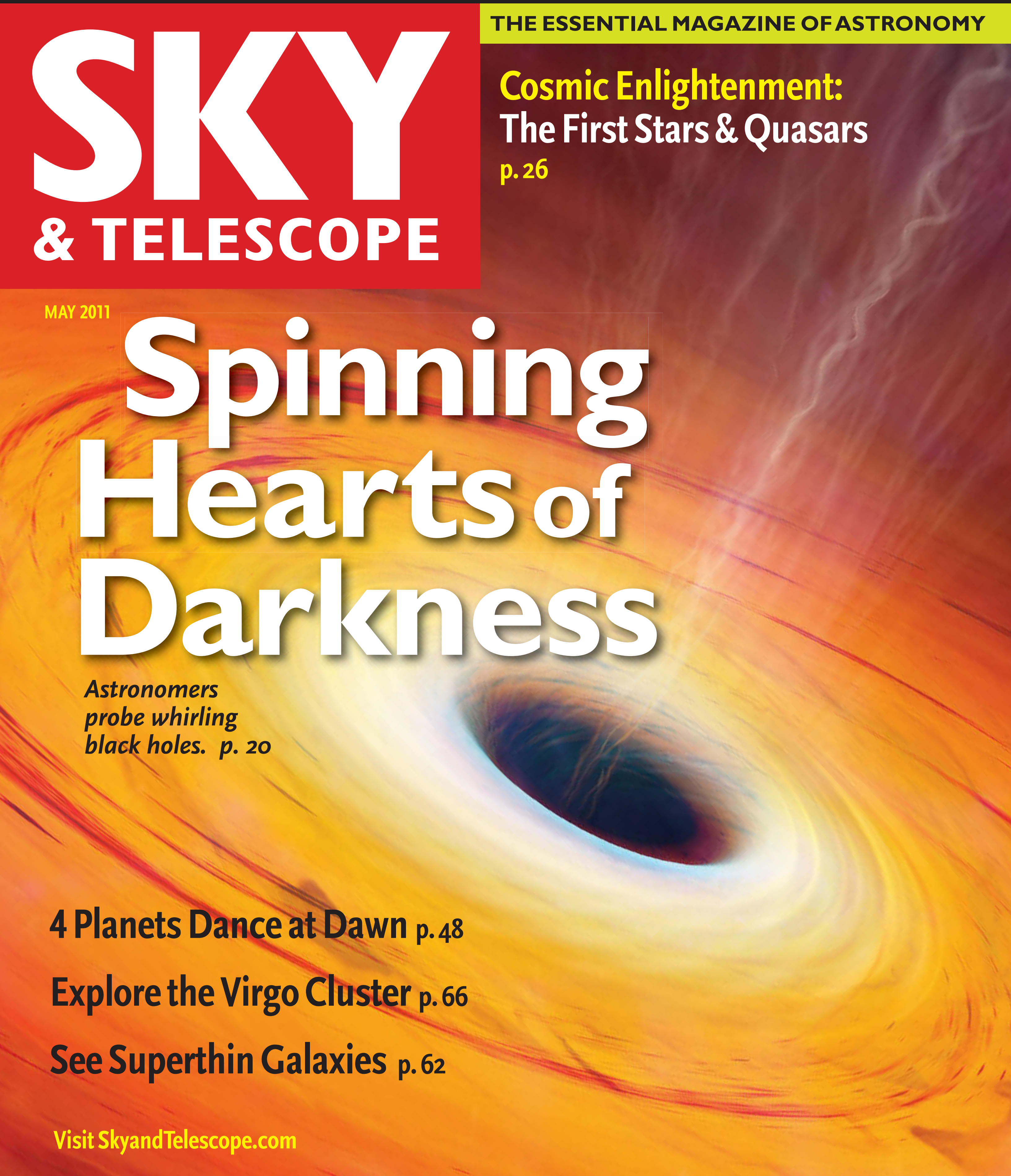
THE ESSENTIAL MAGAZINE OF ASTRONOMY

SKY & TELESCOPE

Cosmic Enlightenment:
The First Stars & Quasars
p. 26

MAY 2011



Spinning Hearts of Darkness

Astronomers probe whirling black holes. *p. 20*

4 Planets Dance at Dawn p. 48

Explore the Virgo Cluster p. 66

See Superthin Galaxies p. 62

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May 2011

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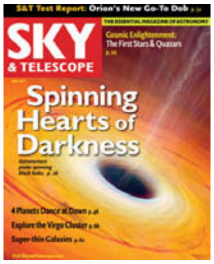

MARK GARLICK

On the cover: This artwork portrays a black hole that must be spinning fast, because material in the disk is orbiting very close.

FEATURES

THIS MONTH'S SKY

S&T TEST REPORT

ALSO IN THIS ISSUE

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Users choose the number of stars they would like to use to paint the subtleties of the night sky, and then GOTO uses that number in the manufacture of their projector. In this case, the 140 million stars create a sky that just looks better and better the closer you get to the dome, or when using binoculars to observe the planetarium sky. The use of micro-star technology allows us to show 337 emission nebulae and even 2,140 dark nebulae.

Of course the CHIRON is paired with two ultra-high resolution video projectors which add a fulldome video scene with more than 13 million pixels of colorful, animated imagery. These fulldome video images are synchronized to move precisely with the motions of the CHIRON starball, sun, moon, and planets, for the ultimate planetarium experience.

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The Exoplanet Explosion

I HAVE COVERED developments in the field of extrasolar planets since 1995, when the first exoplanet orbiting a Sun-like star was announced around 51 Pegasi. With the pace of discovery advancing at what seems like an exponential rate, I feel a bit jaded whenever a new exoplanet result is announced. It takes a lot to impress me.

But suffice it to say, my jaw practically dropped to the floor when I heard the latest Kepler results, which we cover in our News Note that begins on page 12. Not only have Kepler scientists identified a bizarre new system with *six* transiting planets, they have announced more than 1,200 planet candidates, 54 of which orbit within the habitable zones of their host stars, with 5 of those being roughly the diameter of Earth. Most of these candidates are real planets.

NASA / JPL-CALTECH / ROBERT HURT (SSC-CALTECH)

The pace of exoplanet research is dizzying. I remember the time in the 1990s when the discovery of every new hot Jupiter would generate headline news around the world. Then came planets on more distant orbits, planets on eccentric orbits, transiting planets, puffed-up planets, multi-planet systems, resonant planets, detections of exoplanet atmospheric gases, direct images of exoplanets, mini-Neptunes, super-Earths, rocky exoplanets, etc. etc.

I marvel at how astronomers have employed clever observational techniques and modeling to not only detect these distant worlds, but to actually learn something about their atmospheres, internal structures, and physical characteristics. When I attend science conferences, it's immediately obvious that exoplanet research is attracting many of the brightest young minds, not only because of the field's obvious "sex" appeal, but also because budding researchers see it as a dynamic field that is making incredibly rapid progress. If I were an astronomy graduate student right now, I'd go into this field. And as I have reported in previous issues, many amateurs have volunteered to help as well, and have made important contributions (for example, see the December 2009 issue, page 22).

What excites me the most is not the latest discoveries, but what Sara Seager wrote at the end of her October 2010 issue cover story: "the best in exoplanet research is yet to come." There's no doubt that Kepler's most exciting results lie in the future. And who knows, after the exoplanet count has risen into the thousands, and astronomers have characterized planets and systems to the point where they have a decent understanding of the full diversity of what's out there, we'll be able to put our solar system in its proper context, and know whether or not it's a freak. Unlike the quest to understand dark energy, I expect this to happen in my lifetime.

Robert Naeye
Editor in Chief

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The Essential Magazine of Astronomy

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Astro Outreach in the Canaries

We would like to invite *Sky & Telescope* readers to join us for the Starmus Festival, a major science outreach event celebrating astronomy and the space sciences to take place on the Canary island of Tenerife June 20–25, 2011.

Starmus will bring astronauts, cosmonauts, astronomers, biologists, astrophotographers, musicians, and artists together in presenting to the public, in a vibrant and informative way, the latest advances in our study of the cosmos. Participating will be Nobel laureates George E. Smith, Jack Szostak, and George Smoot, along with Jill Tarter of the SETI Institute, evolutionary biologist Richard Dawkins, and many other leading scientists. Pioneering cosmonauts and astronauts Valentina Tereshkova, Alexei Leonov, Buzz Aldrin, Jim Lovell, and Charlie Duke will celebrate humanity's first half-century in space. From the musical world will be Queen guitarist and astrophysicist Brian May, Tangerine Dream, and Graeme Revell.

There will also be a space art and 3-D astronomy exhibition, and an astrophotography exhibition and competition. The winner receives 60 minutes of observing time on the 10.4-meter Gran Telescopio Canarias (GTC) in La Palma, the world's largest optical telescope.

The Festival will be topped by a star party on the peaks of Tenerife, a round-table discussion on our future in space, and a webcast live from the dome of the GTC. Full information is available at www.starmus.com.

Garik Israelian
Astrophysical Institute
of the Canary Islands
La Laguna, Spain

On the Web

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Astronomer Heroes Remembered

I greatly enjoyed Albert Boudreau's Focal Point column "How Good We Have It" in the March issue (page 86). The column was particularly poignant for me, as I remember the May 1958 issue of *Sky & Telescope* very well.

Today, readers can enjoy all the back issues by obtaining the *Complete Sky & Telescope: Seven Decade Collection* on DVDs. When I read the May 1958 issue as a mere youth of 12, I was simply awed by the incredible astrophotography performed by Dr. Custer with his 12½-inch telescope. That issue's center spread was a photomontage of M31, "The Great Nebula in Andromeda" as it was then called. The montage reached the incredible magnitude of 17.5, far beyond what was expected for amateur astrophotography in those days.

In 1986 I was fortunate to meet Dr. Custer on *Sky & Telescope*'s tour to Australia to view Comet Halley. He was a spry octogenarian still working on his astrophotography skills, experimenting with hyper-sensitization of Kodak 2415 film. He still had original prints of his splendid mosaic, one of which he sent me. I proudly display it framed in a position of honor in my astronomy den.

Times have changed. While our skies are not as dark, our equipment is far better. What remains unchanged is that amateur astronomy is fun and exciting, and Dr. Custer is still one of my heroes.

Tim Hunter
Tucson, Arizona

Thank you for your comments in the March 2011 issue on the passing of several illustrious astronomers, particularly Allan Sandage ("A Quadruple Whammy for Astronomy," page 6).

In the early fifties, when I was roughly 14, I used to bum a ride from La Cañada, California, to Mount Wilson with the KTTV crews who manned the pre-satellite-era TV towers on the mountain. I would spend the weekend enjoying the run of the Mount Wilson Observatory under the watchful eye of my friend Joe Hickock, who did the routine work on the solar towers and who maintained the "monastery," where the astronomers slept.

When not having exclusive use of the observatory's 6-inch Alvin Clark refractor, I was often invited to share the night on the 60-inch or the 100-inch Hooker with the astronomers. I remember at least one night sharing the 100-inch Newtonian platform — 80 feet off the observatory floor with no rails, thank you very much — with Dr. Sandage, who at that time may have been a graduate student.

Sandage and his assistant were dressed in WW2 Air Force heated flight suits. I was not, and I was freezing. A busy, humorous repartée went on through the night, mostly regarding the ghosts sometimes seen passing ominously through the building in the wee hours. After midnight lunch, replete with raccoons, foxes, and other critters begging at the door for treats, we returned to the dome and the remaining night's work.

Towards dawn, Sandage turned the telescope to Jupiter, and what a sight! It seemed to fill the dome with its magnificence. It truly was the most memorable astronomical event of my life and, whenever I turn my own puny instrument on that giant, I fondly remember that night and the kindness and humor of Allan Sandage.

Bill Deák
Prescott Valley, Arizona

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Alien Misinformation

After reading the letters in the January issue responding to your recent SETI article, I was stunned by the lack of understanding of this endeavor by the writers ("Finding E.T.," page 8).

Two letters argued that "contact" with aliens is dangerous, because they may come and destroy us or make us "a footnote in [their] history book." SETI is one-way contact, not communication. It only listens, it does not transmit. That's done by our TV and radio transmissions and, more powerfully, by NORAD and our air-traffic-control system. It's too late to worry about E.T. detecting our presence. We have been transmitting 24/7 for at least 60 years!

Peter Burkey
Holland, Michigan

Historical Correction

Chester Hollaway's letter (January issue, page 8) misstates Stephen Jay Gould's opinion about evolution's capacity to form intelligent life, here or anywhere. Mr. Hollaway writes, "As Stephen J. Gould said, if you rewind the tape of the history of life on Earth and play it again, nothing approaching our level of consciousness and intelligence would occur again."

No. For Gould's actual opinion, turn to page 290 of Gould's book *Wonderful Life*: "And so, ultimately, the question of questions boils down to the placement of the boundary between predictability under invariant law and the multifarious possibilities of historical contingency. . . . Whether the evolutionary origin of self-conscious intelligence in any form lies above or below the boundary, I simply do not know."

Dr. Gould recognized the folly of generalizing from a statistical sample of one.

Steven Morris
Professor of Physics
Los Angeles Harbor College
Los Angeles, California

For the Record

✷ *The double star Struve 742 lies ½° east of M1, not west as stated on page 62 of Deep-Sky Wonders in the February 2011 issue.*

✷ *Halley's Comet will next reach perihelion in 2061, not 2062 as stated in the caption to the photo on page 42 of the March issue.*

50 & 25 Years Ago

Leif J. Robinson

May 1961

The Helium Flash "After a star of Population II has evolved away from the main sequence of the Hertzsprung-Russell diagram and become a red giant star, a remarkable 'thermal runaway' occurs deep in its interior. This had been predicted by E. Mestel, and is now confirmed in step-by-step calculations . . . by R. Härm and M. Schwarzschild. . . .

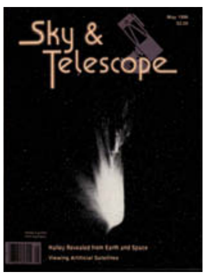
"The helium burning sets in when the temperature in the contracting core reaches about 80 million degrees Kelvin. The energy released can only raise the temperature further, as the high pressure on the degenerate matter prevents its expansion. The helium burning thus becomes more and more rapid, with the temperature continuing to rise to a maximum of about 350 million degrees! At that time, the core is liberating as much energy as 10^{12} suns, but practically none of this escapes, because of the high opacity of [an overlying] hydrogen shell.

"At such a high temperature, the core is finally forced to expand, and . . . the thermal runaway terminates."

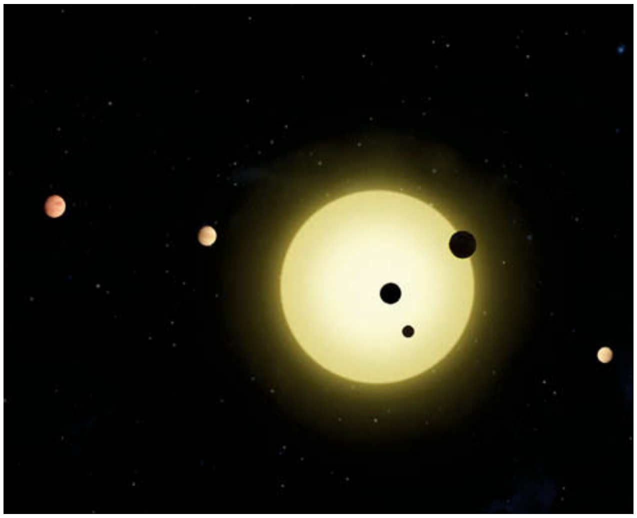
This depiction is still basically sound. The calculations involved were only practical because of an electronic computer. By today's standards, the computer they used would be regarded as primitive indeed.

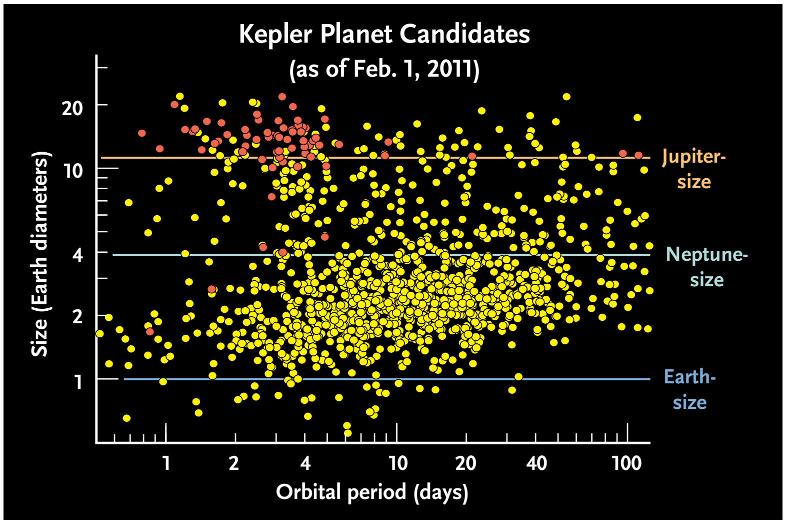
May 1986

Well-Deserved Victory "Harvard astronomer Fred Whipple signals success after the Giotto spacecraft glimpsed the nucleus of Halley's comet. Whipple's theory that cometary nuclei are 'dirty snowballs,' advanced in 1950, was confirmed in March by a spectacular series of visits to Halley by spacecraft."



Kepler's Latest Planet Bonanza





***Left*: On August 26, 2010, the Kepler spacecraft observed the Sun-like star Kepler-11 being transited by three of its six planets simultaneously, as depicted in this artist's concept. *Right*: As of its latest data release, NASA's Kepler science team had identified 1,235 planet candidates (yellow dots), far more than the number of transiting exoplanets known prior to the mission (red dots).**

Torrents of likely new exoplanets are pouring in from NASA's Kepler space telescope — more than 1,200 of them so far, large and small, including weird worlds and systems that no one expected. The Kepler science team unveiled its latest batch of findings on February 2nd, based largely on data from just the first four months (May 12 to Sept. 17, 2009) of Kepler's planned 3½-year mission.

The Kepler scientists highlighted two themes. One was the sheer number and variety of likely planets being found, especially small ones, including several small ones in their stars' habitable zones. The team also highlighted one system in particular. A 14th-magnitude star dubbed Kepler-11 seems to have *six* super-Earths and Neptunes transiting it. All are orbiting in nearly the same plane, five of them in compactly nested orbits closer to the star than Mercury is to the Sun. Two or three of these planets have such unexpectedly low average densities that they would float in water.

1,235 Likely Worlds

The new data release brings Kepler's total to 1,235 planet candidates apparently transiting stars. Team member Geoff Marcy (University of California, Berkeley) estimates that "90% to 95% of these candidates are bona fide planets." This compares to 513 exoplanets discovered by all other projects since 1993.

Of the new candidates, dozens are roughly Earth-diameter or smaller. Adds team member Daniel Fabrycky (University of California, Santa Cruz), "There are a ton of multiple-planet candidates: 115 doubles, 45 triples, 8 quadruples, 1 quintuple, and 1 sextet."

Sixty-eight are roughly the diameter of Earth. The total includes 288 more with super-Earth diameters, 662 in the Neptune class, 165 about the size of Jupiter, and 19 significantly larger than Jupiter.

Of the 68 roughly Earth-size bodies, five are within the habitable zones of their host stars: the not-too-hot, not-too-cold region where liquid water could lie exposed on the surface under modest atmospheric pressure, as on Earth. Forty-nine other worlds within habitable zones range from about twice Earth's diameter to larger than Jupiter.

Overall, when you consider the unlikelihood that an object will transit its star at all as seen from our line of sight, the statistics indicate that some 20% of stars are closely orbited by planets Earth-size and up.

The Six-Transit System

Of the 156,000 stars that Kepler is watching, the team drew particular attention to Kepler-11, a near-copy of the Sun about 2,000 light-years away under the eastern wing of Cygnus. Six small bodies orbit it with periods from 10 to 118 days. The amount of the star's light that each blocks during its transits tells its size. Counting out from the star, they have 2.0, 3.2, 3.4, 4.5, 2.6, and 3.7 Earth diameters.

The six worlds are too lightweight, and the star is too far and faint, for astronomers to measure their masses by the

gravitational wobbles that they induce in the star. But in a tour de force of celestial mechanics, the Kepler team measured the slight delays and speedups in their observed transit times due to their gravitational influences *on one another*. The team was able to untangle all the interactions. The transit-timing variations yielded masses for the five inner bodies: 4, 13, 6, 8, and 2 Earth masses.

Combining the masses with the diameters gives each object's average density: about 3, 2, 0.9, 0.5, and 0.7 grams per cubic centimeter. The last three are less dense than water (1.0). Earth's average density, by comparison, is 5.5. They probably have rock-iron cores surrounded by thick envelopes of "ices" (mainly water, methane, and ammonia, either solid or liquid) and gas (mainly hydrogen and helium). In other words, they're miniature giants. Says team member Jonathan Fortney (UC, Santa Cruz), "I think of them as being like a marshmallow with a ball bearing in the center. Most of the mass is in the core, but most of the volume is in the atmosphere."

Says exoplanet researcher David Charbonneau (Harvard-Smithsonian Center for Astrophysics), "It's quite simply one of the most beautiful data sets I have ever seen."

Computer simulations show that the configuration can be gravitationally stable over the star's estimated age of 8 billion years. Surprisingly, none of the planets are locked in orbital resonances with their neighbors. They almost certainly formed farther out and migrated inward, due to gravitational interactions with a massive gas-and-rubble disk when the system was young. The disk would also tend to circularize their orbits, keep the orbital planes well aligned, and help prevent the planets from locking one another into resonances.

The planets generally become less dense the farther they orbit the star, a relationship that hardly comes as a surprise. The star's heat and wind are likely to be slowly stripping the atmospheres away, with the innermost planets suffering the most. "This is exactly the kind of system you want in order to study this mass-loss process," says Fortney. "Six planets around the same star — it's ideal for comparative planetary science."

CXC / HST / NASA / J. HESTER ET AL.

The inner part of the Crab Nebula is imaged here in X rays (blue) and visible light (red). The pulsar at the center powers the nebula to glow at all wavelengths. The rings mark where a "pulsar wind" of charged particles, flying away in the plane of the pulsar's equator, plows into nebular material and heats it to high temperatures. The innermost ring is about one light-year across.

The Inconstant Crab Nebula

Astrophysicists have long assumed that the Crab Nebula, the strongest permanent X-ray source in the sky, is a steady "standard candle" at these wavelengths, and they have used it to calibrate X-ray telescopes accordingly. The brightnesses of other X-ray sources are often stated in "millicrabs." But a NASA team now confirms what others have been unwilling to admit: this "standard candle" varies by at least several percent. The group compared observations from four separate X-ray satellites and found the same variations over the years. These include a steady decline totaling 7% in the past two years in four high-energy X-ray bands ranging from 12,000 to 500,000 electron volts. Checking further back, the group found that the Crab brightened and dimmed in X rays as much as 3.5% from year to year since 1999.

Previous observers had assumed that these variations were in their equipment.

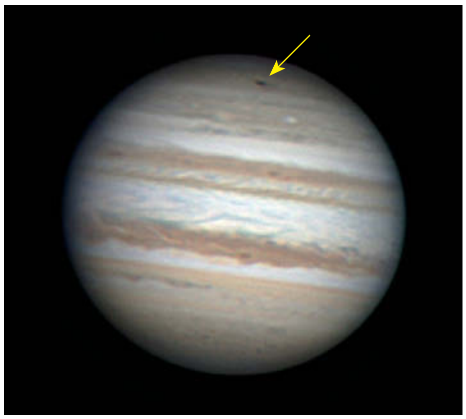
"Since we haven't gone back yet and reanalyzed previous results, we can't say for sure what the impact will be," said team member Colleen Wilson-Hodge (NASA/Marshall Space Flight Center). "For some instruments and observations the effect would be slight, but there may be instruments for which re-analysis could change conclusions of some studies."

The Crab Nebula is the remnant of a supernova seen in 1054 A.D. The exploding star's core became a pulsar, a hyperdense neutron star now spinning 30 times per second. The pulsar is slowing down by magnetic braking, and the lost spin energy ends up exciting the nebula to glow. The nebula's inner portion "is dominated by the pulsar's magnetic field, which we suspect is organized precariously," says Roger Blandford, director of the Kavli Institute for Particle Astrophysics and Cosmology. "The X-ray changes may involve some rearrangement of the magnetic field, but just where this happens is a mystery."

Jupiter Swallowed an Asteroid

On July 19, 2009, Australian planetary imager Anthony Wesley spotted a new dark smudge near Jupiter's south pole. It looked like something had hit the giant planet for the first known time since Comet Shoemaker-Levy 9's celebrated death plunge in 1994. In the next few days astronomers at several observatories recorded as much information as they could before the ashes faded from view.

It's taken a while, but two articles in January's planetary-science journal *Icarus* detail what infrared observers learned in the days and weeks following the impact. Five days after the black spot appeared it was still glowing in the infrared, indicating that stratospheric gases were still slightly



Anthony Wesley's image of Jupiter on July 19, 2009, showed a new black marking like those left when pieces of Comet Shoemaker-Levy 9 hit Jupiter in July 1994. South is up.

warm (by a few degrees). Leigh Fletcher (Oxford University) and colleagues conclude that the incoming object delivered a punch that would have come from a body 70 to 500 meters (230 to 1,600 feet) across. The spectra also showed soot rich in iron, silicate minerals (rock dust), and silica (SiO_2) lying atop the stratosphere — evidence that the impactor was an asteroid, not a comet nucleus.

Similar conclusions appear in a second report. Glenn Orton (Jet Propulsion Laboratory) and others conclude that the interloper was 200 to 500 meters across, and their spectra also show silicates and silica. Silica wasn't detected during the much more energetic Shoemaker-Levy 9 comet strikes.

"We weren't expecting to find that an asteroid was the likely culprit in this impact," said small-body specialist Paul Chodas. But a little dynamical digging turned up asteroids with unstable orbits that could make close brushes with Jupiter.

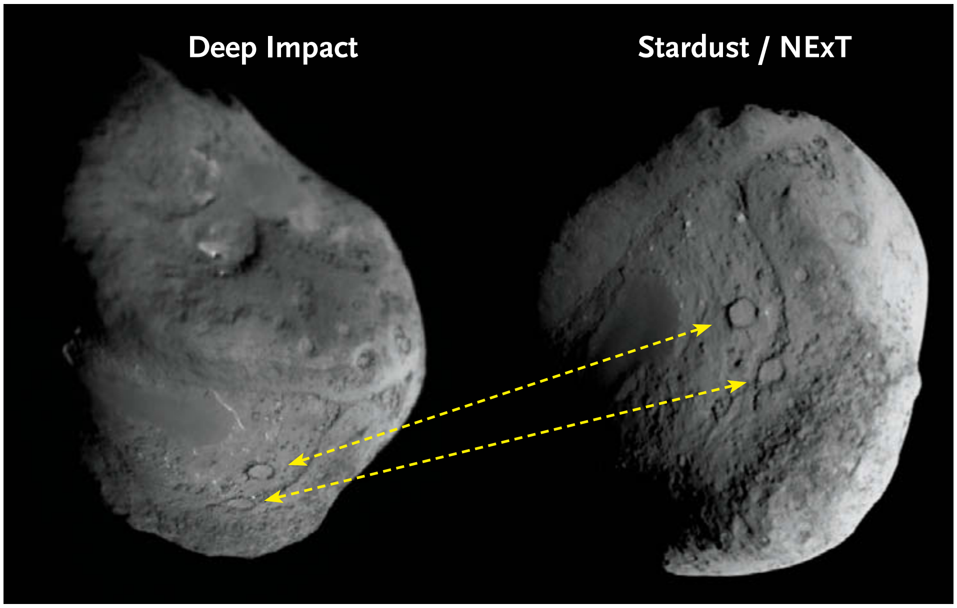
Comet Tempel 1 Gets a Second Look

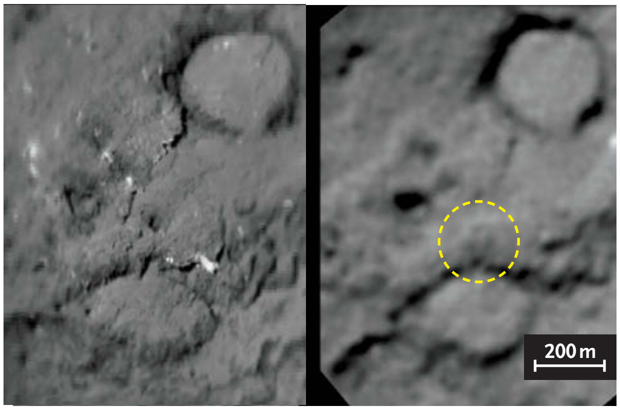
When NASA's Stardust spacecraft returned samples of Comet 81P/Wild 2 to Earth in early 2006, its mission seemed complete. However, planetary scientists soon hatched a plan to redirect the still-healthy craft to a second target. At 3:40 Universal Time on February 15th, Stardust became a successful two-timer when it skirted 110 miles (178 km) past the nucleus of periodic Comet 9P/Tempel 1.

It was a second time for the comet also. Tempel 1 is the comet that the Deep Impact spacecraft flew by and whacked with an 815-pound (370-kg) copper projectile in mid-2005.

Stardust's sole camera, pieced together from an old lens from the Voyager program and a detector from Galileo, recorded a diverse and structured dirty icescape that looked very familiar. Researchers were especially keen to see Deep Impact's strike point; the hit released an unexpectedly huge cloud of gas and dust (*S&T:* October 2005, page 34).

The Deep Impact crater is not obvious, but it's there. "We did get it, there's no doubt," says Peter Schultz (Brown University). He describes the crater as subdued and about 150 meters across with a small central mound. "It looks as if stuff from the impact went up and came back down."





***Above*: The nucleus of Comet Tempel 1 got a second close-up scrutiny *(right)* when NASA's Stardust spacecraft paid it a visit on February 15th. The same craters are indicated for comparison. *Right:* Before-and-after images of the spot hit by the impactor from Deep Impact. The left frame shows the target zone just before it was struck in July 2005. At right, a circle draws attention to the resulting crater, about 500 feet (150 m) across.**

NASA / JPL / CORNELL UNIVERSITY

That the impact zone was seen at all, with excellent lighting just as Stardust came closest, is a testament to a years-long effort by ground-based observatories to nail down the comet's rotational state and spin period. This allowed Jet Propulsion Laboratory dynamicists to time the encounter for optimum viewing. Indeed, the nucleus had rotated to within just a few degrees of where the team hoped it would be.

This is the first time a comet has been seen up close before and after its perihelion with the Sun. Besides spotting the muted crater, the science team found changes elsewhere on the 5-by-3-mile (8-by-5-km) nucleus, particularly around a flat tongue of debris, about 2 miles long, that appears to have shrunk since Deep Impact's visit.

Stardust's dust detector also recorded several thousand hits as it cruised through the comet's coma of gas and dust. But rather than slowly rising to a crescendo and then falling smoothly, the recorded hits reveal that dust peppered the craft in rapid-fire bursts with silence in between, a consequence of small "clods" disintegrating into countless smaller flecks after leaving the nucleus.

NASA now can claim two spacecraft that have each visited a pair of comets. Just two months ago, on November 4th, Deep Impact performed its own second rendezvous: a successful flyby of Comet 103P/Hartley 2 (February issue, page 14).

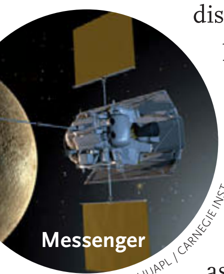
Sending Stardust to a second comet was a bargain, adding only $29 million to the mission's $300 million total cost.

2011's Solar System Bonanza

Stardust's encounter with Comet Tempel 1 was just the start of a big year expected for planetary science. In the next several months NASA's interplanetary exploration is set to proceed at a rapid pace:

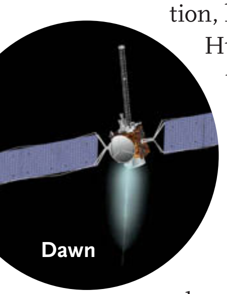
• The twin STEREO solar observatories have already taken up their positions on opposite sides of the Sun. For the first time, solar scientists can monitor all of the Sun's surface at once. That should pay big dividends as solar activity ramps up.

March 18: After three brief flybys in 2008 and 2009, NASA's Messenger spacecraft will brake into a permanent, looping polar orbit around Mercury. Once per orbit the craft will skim 125 miles (200 km) from the surface. With its seven cameras, spectrometers, and other instruments, Messenger has already made many new discoveries about the innermost planet. But the real science breakthroughs, such as its interior structure, will come after the orbiter has made long-term observations.



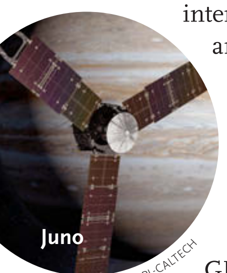
NASA/ JHUAPL / CARNEGIE INST.

July 16: The Dawn spacecraft will reach 4 Vesta, the asteroid belt's most interesting chunk of rock. It's thought to have an iron-nickel core, an olivine mantle, a rock crust of nearly unique composition, lava flows, and a giant crater. Hubble images have given only the vaguest of looks, but Dawn will open up this new world in high resolution. Dawn will orbit Vesta for a year before easing away and setting course for 1 Ceres.



NASA

August 5 is the scheduled launch date for NASA's ambitious Juno mission. When it reaches Jupiter in 2016, Juno is to slip into a looping polar orbit that will subject it to dangerously intense radiation but allow it to answer, its science team hopes, key questions about Jupiter's composition and interior structure — and from those results, how Jupiter and other giant planets formed.



NASA / JPL-CALTECH

September 8: The twin GRAIL spacecraft (Gravity Recovery and Interior Laboratory) will rocket Moonward to fly in tandem just 30 miles (50 km) above the lunar surface. By tracking their positions with respect to each other extremely precisely as they orbit, scientists hope to derive, once and for all, the detailed gravitational structure of the lunar interior from crust to core.

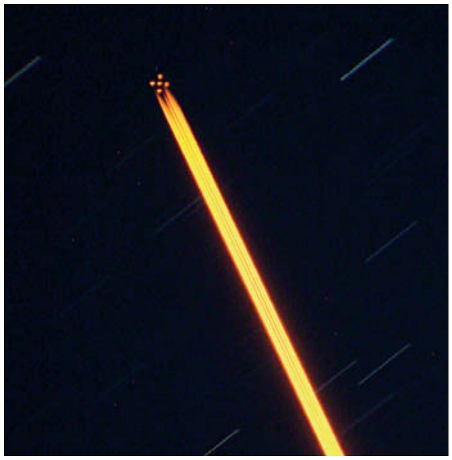
November 8: The Russian Space Agency hopes to launch its own much-delayed Phobos-Grunt mission. (Grunt is Russian for "ground.") Conceived in 1996 to land on the larger of Mars's two satellites and return a sample to Earth, Phobos-Grunt has been redesigned several times. In its latest configuration it will carry the small, Chinese-built spacecraft Yinghou 1, which will detach and orbit Mars for up to a year. Plans still call for the main craft to land on Phobos, collect 85 to 160 grams (3 to 5½ ounces) of samples, and return them to Earth by early 2013.

November 25: Another delayed mission, NASA's Mars Science Laboratory, will launch toward Mars. The primary scientific objective for this large rover is to advance the assessment of whether the Red Planet ever had an environment conducive to life — or still does. The rover was named Curiosity following a Disney-inspired contest in 2009.

Some dates are subject to change.

The Next Step for Adaptive Optics

The giant telescopes of the future — the planned Thirty-Meter Telescope (TMT), the 24-meter Giant Magellan Telescope (GMT), and the 42-meter European Extremely Large Telescope (E-ELT) — will need the most advanced adaptive-optics systems possible if they are to reach their full potential. Adaptive optics work to cancel out the blurring effects of Earth atmosphere. The current cutting edge of the art is "multi-conjugate adaptive optics," or MCAO. This version models not just the two-dimensional wavefront of light reaching the telescope, but the entire, three-dimensional column of air in front of the telescope's aperture. This allows the image-sharpening process to work over a much wider field of view; narrow fields are a severe limitation of current systems.


MAXIME BOCCAS / BENOIT NEICHEL / GEMINI OBSERVATORY

The Gemini South MCAO system creates a tiny "constellation" of five artificial guide stars by exciting sodium atoms about 60 miles up. The guide stars look bright in this 30-second zoomed-in exposure but are invisible to the naked eye. The upward beam, however, is easy to see from up to a few hundred yards away.

Standard adaptive optics work by watching a single guide star for atmospheric distortions, taking readings as rapidly as 1,000 times a second and adjusting a flexible mirror just as rapidly to compensate. The star can be either real or artificial: created by a laser that's tuned to excite the sodium atoms in a layer of atmosphere about 60 miles (90 km) up. MCAO, on the other hand, requires monitoring *several* guide stars at once.

On January 22nd engineers at the Gemini South observatory in Chile test-fired a 50-watt laser to create a tight, 1-arcminute-wide "constellation" of five sodium stars. Project leader Celine d'Orgeville says that Gemini's MCAO system should allow the 8.1-meter telescope to see ultrasharp views up to 2 arcminutes wide starting in 2012.

Other observatories are pursuing adaptive optics with multiple guide stars. In 2007 the European Southern Observatory's Very Large Telescope tested a system that uses natural stars, and a system using four laser guide stars should be ready in 2015. The MMT Observatory in Arizona has tested a system that uses a green laser to create multiple artificial stars in the lower atmosphere by scattered light. ✦

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Spinning Hearts of Darkness

Astronomers are measuring the rotation rates of black holes to determine their formation and history.

Disney must have had close ties with some of our local TV stations in the 1980s, because it seemed like *The Black Hole* was playing whenever I was home sick from elementary school. My love for this movie blossomed in spite of its cartoonishly stereotypical characters, cheesy costumes, and laughable special effects. I didn't care about the movie except for the black hole itself. The cosmic beast was hypnotic and omnipresent — a dark, gaping maw surrounded by an infalling funnel of fluorescent gas. I was mesmerized. The thought of such an extreme object existing out there was amazing, but even more so was the notion that humans could travel into one and emerge in some other dimension.

I was later disappointed to learn that physicists deem it virtually impossible to journey into a black hole and exit elsewhere intact. In fact, black holes are nature's simplest objects, described only by their mass and spin. So why do so many scientists study these objects, and why does the public gobble up fictional accounts of them? Perhaps it's because black holes represent the ultimate unknown.

Spinning Black Holes

Black holes were given their name because their gravity is so strong that not even light can escape once it passes a critical outer boundary known as the *event horizon*. If we sent a probe past the event horizon with instructions to beam back pictures, the beam would lack the necessary velocity to escape the hole's gravitational pull, even though it would travel at the speed of light. So black holes neither emit light nor let incoming light out once it crosses the event horizon. But we can observe the radiation from infalling gas that doesn't quite make it past the event horizon. This released energy can influence the black hole's surroundings to great distances.

LAURA BRENNEMAN

A black hole actively gorging itself on nearby gas will belch out prodigious energy. These objects also tend to be the ones that offer us the best glimpse into the nature of the innermost accretion disk, closest to the hole and where most of the action is taking place.

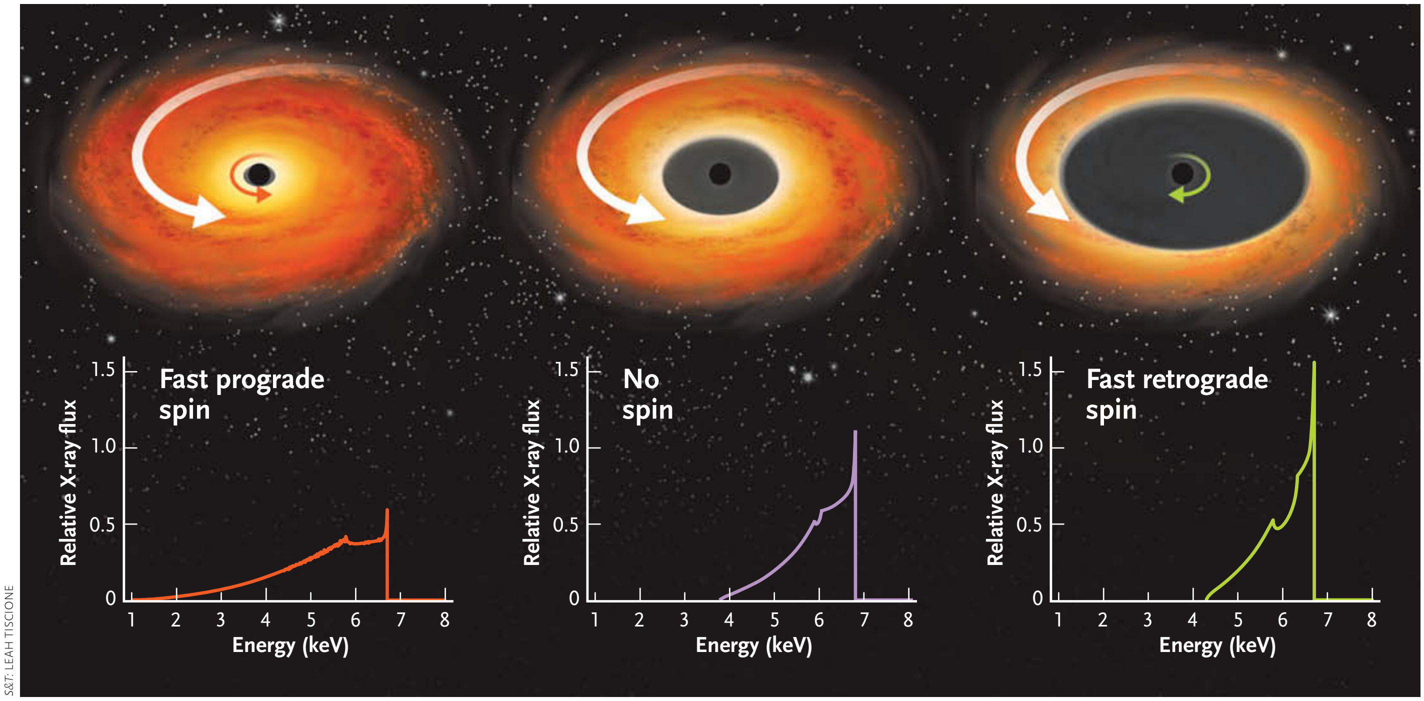
The action that I'm most interested in is how fast the black hole is spinning. We can access this information only by observing radiation coming from very close to the event horizon, where material is so hot that energy is emitted as X rays. Because Earth's atmosphere blocks this

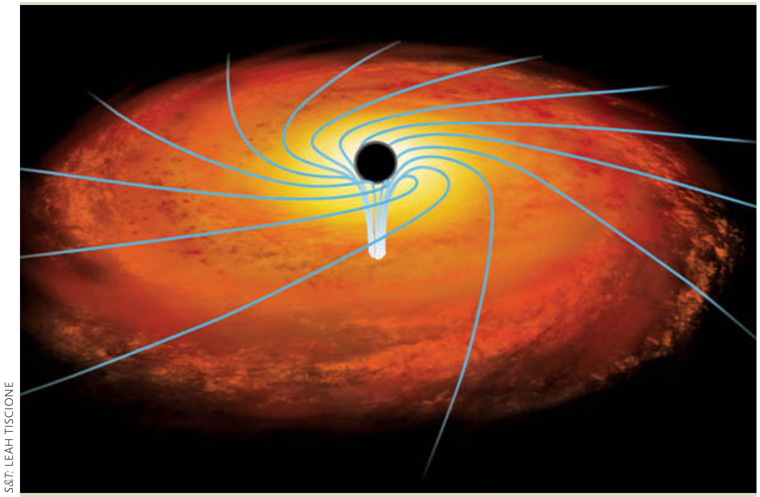
high-energy radiation, orbiting telescopes perform the lion's share of the work.

Why bother figuring out how fast a black hole is spinning? What do we hope to learn that will justify the effort?

First, most galaxies contain supermassive black holes (SMBHs) at their cores, which can range from millions to billions of solar masses. A SMBH plays a pivotal role in shaping its host galaxy. It determines how large its galaxy gets and how many stars it contains, and will do so in spite of having a relative size ratio to its galaxy equivalent to that of a grain of sand in the center of the United States. The black hole accomplishes this feat largely through its unparalleled efficiency in releasing energy from the gas it accretes, and the black hole's spin is a key cog in that engine. Jets released from SMBHs shoot out like geysers from a galaxy's core, keeping intragalactic gas warm enough to stop star formation in the host galaxy,

GAPING MAW Like almost all objects in space, black holes rotate. Along with mass, the spin rate is one of only two fundamental characteristics of a black hole, and it has a profound influence on the surrounding spacetime and how the black hole accretes matter. This artistic rendering shows a black hole accreting material from its surrounding disk.





THE POINT OF NO RETURN

All black holes have an innermost stable circular orbit (ISCO), the distance from the event horizon at which the energy and angular momentum of orbiting material is no longer sufficient to counteract the inward pull of gravity. Once material crosses the ISCO, it plunges into the black hole on a ballistic trajectory.

The ISCO's distance from the event horizon depends on the black hole's mass and spin. According to general relativity, a spinning massive object drags the surrounding spacetime, an effect known as frame dragging. A fast-spinning black hole will spin up nearby spacetime, imparting more angular momentum to material orbiting in the inner accretion disk. This energy enables the material to resist the black hole's gravity, keeping it from plunging into the hole at the distance it otherwise would have without the help of frame dragging.

SPIN *Above:* A black hole's spin plays a pivotal role in determining how close material can orbit before falling into the abyss. Material orbits farther from a nonspinning black hole, and farther still from a retrograde hole. Simulated spectra of the Fe Kα line are below. *Left:* The faster a black hole spins, the larger the frame dragging (represented by blue lines). This effect of general relativity allows material to orbit very close to a fast-spinning, prograde black hole.

thus regulating its size. Physicists think jet power is directly related to black hole spin.

Second, measuring black hole spin can tell us about the recent growth history of a SMBH and its host galaxy. According to computer simulations by Marta Volonteri (University of Michigan) and her collaborators, black holes that grow primarily by accretion will spin faster than those that grow mostly by mergers with other black holes. Prolonged accretion usually funnels gas onto the accretion disk in the same direction that it (and the black hole) is already spinning, increasing the hole's spin. In contrast, black hole mergers occur at random angles, which can alter the spin direction and speed of the resulting black hole. SMBH mergers occur millions of years after their host galaxies merge (*S&T:* April 2009, page 26).

Spin, therefore, is an excellent diagnostic for assessing a black hole's recent history of mergers versus accretion. As the number of SMBHs with reliable black hole spin measurements grows, so too will our knowledge of spin demographics and its relation to other physical properties of SMBH systems such as mass, accretion rate, jet power, and host-galaxy mass and type.

In the case of black holes that originate from dying massive stars (the so-called galactic black holes, or GBHs), constraining their spin rates will provide insight into the nature of supernovae, which are the most common precursors of GBH formation. GBH spins are not likely to undergo significant evolution, since a black hole must accrete roughly its own mass in order to have its spin change appreciably, and the typical supply of gas for GBHs is too scarce to provide enough fuel. Therefore, GBH spins are thought to be natal — the result of the collapse of spinning stellar cores.

Measuring Spin

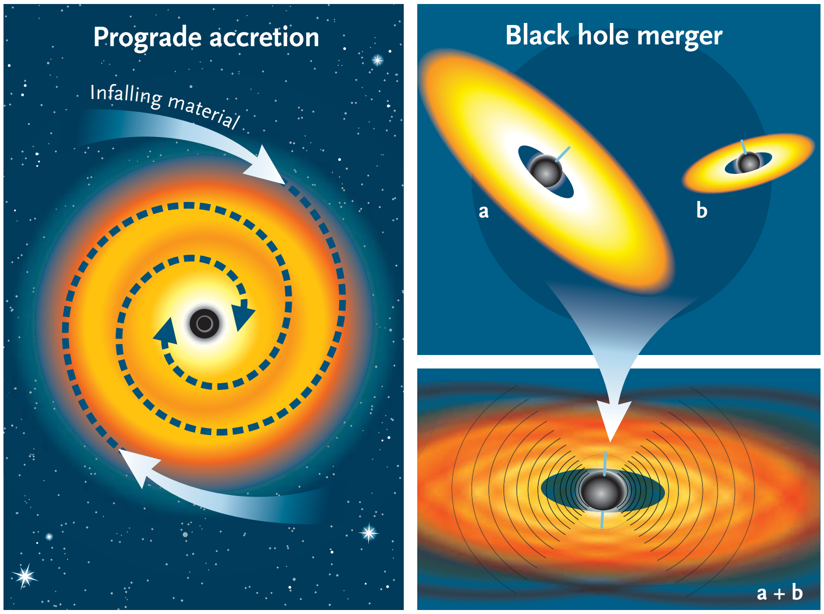
The black hole's spin determines the distance of the accretion disk's inner edge from the event horizon. According to Einstein's general theory of relativity, if the black hole and its accretion disk spin in the same direction (prograde), the faster the black hole spins, the closer the disk's inner edge will be to the event horizon. If the hole and disk spin in opposite directions (retrograde), then the opposite is true; in fact, a maximally spinning retrograde black hole will have a disk inner edge 9 times farther away than the event horizon. If the black hole is not spinning at all, the disk's inner edge is located 3 times farther away from the event horizon. So if we can determine the edge of the innermost disk, we can infer the black hole's spin.

Unfortunately, most SMBHs are so far away that their inner disks are too small to be seen in an image. Currently, the most reliable way to constrain an accretion disk's innermost edge involves examining the spectrum of X rays we observe from the inner disk. There are two techniques employed to constrain the inner edge from X-ray spectra: spectral-line modeling and thermal modeling.

Spectral-line modeling typically requires the detection of an iron emission line known as Fe Kα. This strong spectral feature is often emitted from gas throughout the accretion disk, but when it's observed from the inner disk, the gas's rapid motion drastically alters the line's shape. Gas in the inner disk is closer to the event horizon, and if we imagine a black hole's strong gravity acting on the fabric of the surrounding spacetime like a bowling ball in the middle of a trampoline, this gas is deeper in the valley, so to speak. As such, it orbits the black hole extremely rapidly and is also subject to the peculiarities of warped spacetime near a black hole as dictated by relativity.

The Fe Kα line's shape is thus quite broadened and skewed. The degree of broadening and distortion is directly related to the location of the disk's inner edge, making these broad Fe Kα lines ideal probes of black hole spin. By applying spectral models that take relativity into account, we can use these broad emission spectral lines to constrain a black hole's spin.

Thermal modeling cannot be used for SMBHs; it's useful only in GBH systems where the accretion disk is so hot that it radiates thermally in X rays, and in which the



S&T: LEAH TISCIONE

TORQUING A BLACK HOLE
Above left: **A black hole will "spin up" if it accretes matter from a disk revolving in the same direction. If it can accrete enough material, it can spin up almost to the maximum possible velocity allowed by relativity — the speed of light.** ***Above right:*** **When two black holes collide, they can do so at random angles. Depending on the collision angle, the merger can either spin up or spin down the resulting black hole, and it can torque its rotational axis.**

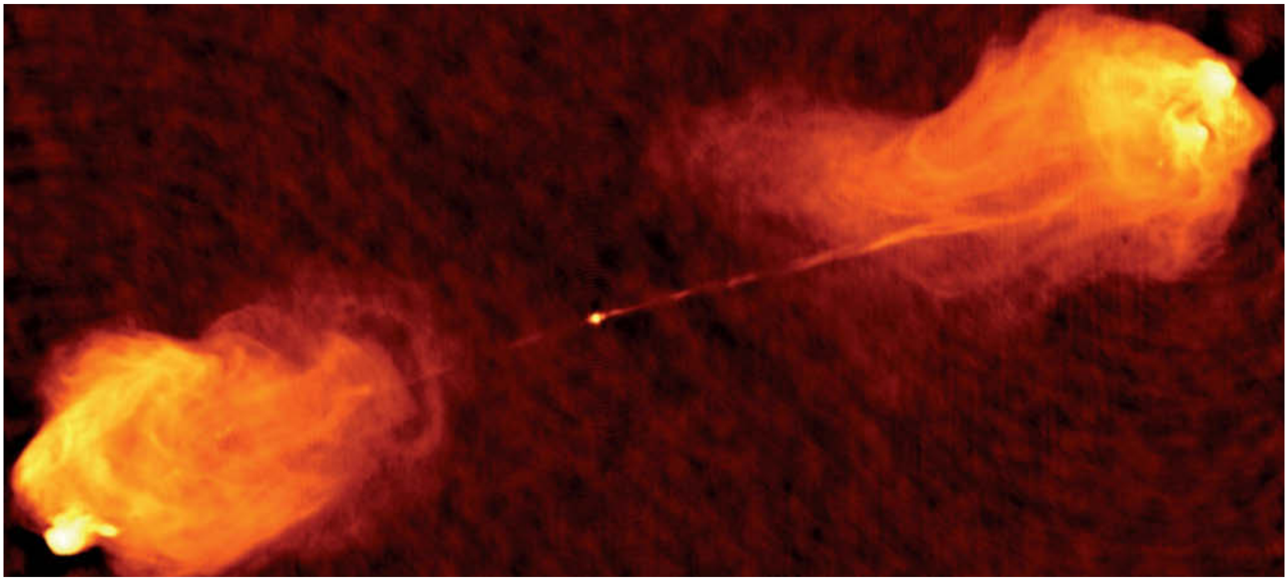
Galactic Black Holes

Black Hole	Spin (a)	Method
GRS 1915+105	0.98±0.01	SM
	0.99±0.01	TM
LMC X-1	0.92±0.06	TM
M33 X-7	0.84±0.05	TM
4U 1543–47	0.30±0.10	SM
	0.80±0.05	TM
J1655–40	0.98±0.01	SM
	0.70±0.05	TM
A0620–00	0.12±0.19	TM
J1550–564	0.76±0.01	SM
	0.78±0.02	TM
J1650–500	0.79±0.01	SM
	0.87±0.01	TM
GX 339–4	0.94±0.02	SM
J1711.6–3808	0.60±0.30	SM
	0.60±0.40	TM
J1908+094	0.75±0.09	SM
	0.75±0.09	TM
Cygnus X-1	0.05±0.01	SM
	<0.05	TM
J1753.5–0127	0.76±0.15	SM
	0.40±0.45	TM
J1652–453	0.50±0.10	SM

SM = Spectral-line Modeling TM = Thermal Modeling

Supermassive Black Holes

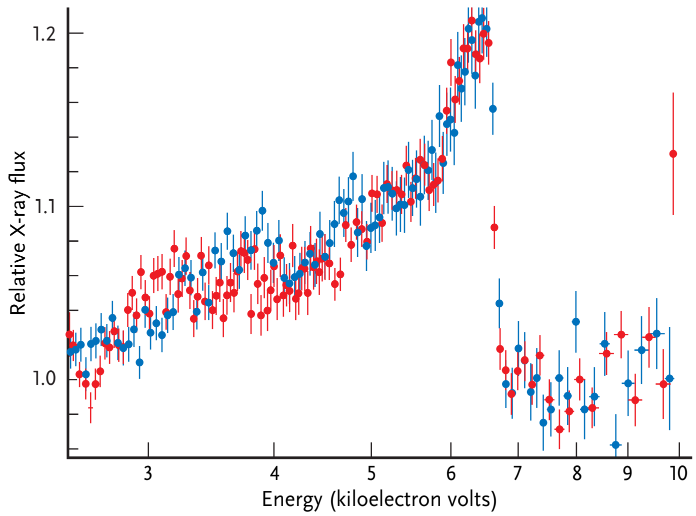
Black Hole	Spin (a)
MCG-6-30-15	>0.98
Fairall 9	0.65±0.05
J2127.4+5654	0.60±0.20
1H0707–495	>0.98
Markarian 79	0.70±0.10
NGC 7469	0.69±0.09
Markarian 335	0.70±0.12
NGC 3783	>0.98



NRAO / AUI / RICHARD PERLEY, ET AL.

POWERFUL JET Like other supermassive black holes at the centers of large galaxies, the beast at the center of galaxy Cygnus A (seen as the bright central dot in this radio image) shoots out jets that stretch for hundreds of thousands of light-years. According to a recent theory, the most powerful jets like this one result from retrograde-spinning black holes.

black hole's distance and mass are very accurately known. The disk's X-ray luminosity is a simple function of its temperature and size (in this case, the size is the radius of the inner disk edge). By measuring the disk's flux and temperature, and if we know the system's distance and mass, we can compute the inner disk's radius and thus infer the black hole's spin. These two methods can be used to check each other on GBH spin measurements.



S&T: G. DINDERMAN, SOURCE: L. BRENNEMAN / A. FABIAN / G. MINIUTTI, ET AL.

BLACK HOLE SPIN SIGNATURE Using XMM-Newton date (blue) and Suzaku data (red), the author's research group analyzed the special iron spectral line (Fe Kα) from the inner part of the accretion disk around the supermassive black hole in the galaxy MCG-6-30-15. The specific distorted shape of the line indicates a black hole spinning very close to the speed of light, the maximum possible rotation velocity.

Demographics of Black Hole Spin

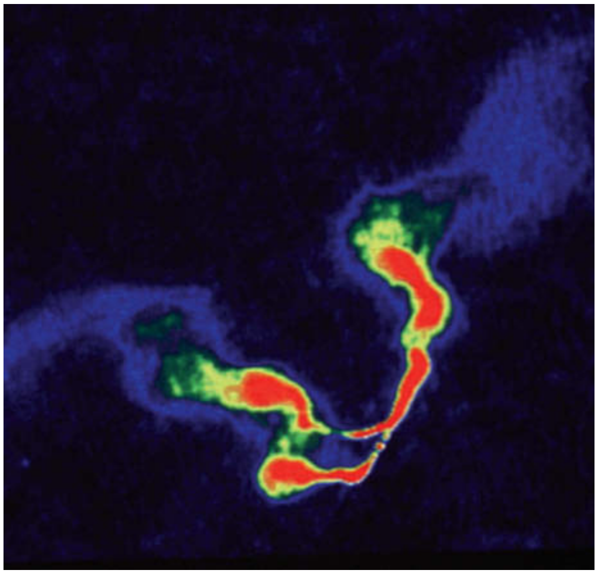
Several teams have obtained black hole spin measurements resulting from X-ray emission spectral-line modeling of broad iron lines (in SMBHs and GBHs), as well as thermal modeling (GBHs only). The data must have excellent signal-to-noise and spectral resolution (requiring advanced CCD detectors or calorimeters). Current X-ray space observatories have provided unprecedented advances in this field, allowing robust constraints on black hole spin in several SMBHs and GBHs.

Black hole spin can range from –1 to 1, where negative values represent retrograde black hole spin, zero means no spin, and positive values imply prograde spin relative to the accretion disk. An absolute value of 1 is the maximum possible prograde or retrograde spin as dictated by general relativity (the velocity at which the event horizon is spinning at the speed of light). While we don't yet have a large enough sample of black hole spins measured for either SMBHs or GBHs to infer any meaningful correlations between spin and other system properties, we can say that the measured spins span a large range of values rather than being clustered around high or low values.

GBHs exhibit a broader range of spins than do SMBHs, though we have fewer SMBHs with statistically robust spin constraints. Three GBH measurements are consistent with near-zero or negative spins, though models allowing retrograde black hole spin have only been developed within the past year by Thomas Dauser (University of Erlangen-Nuremberg, Germany) and his colleagues. By contrast, none of the SMBHs have a spin less than 0.4, taking model-fitting errors into account. In fact, three of the eight measured sources have spins above

0.9, implying that these black holes have experienced a recent period of prolonged prograde accretion, possibly in addition to major mergers over billions of years.

Although the exact role of spin in jet production remains unclear, a recent theoretical study by David Garofalo (JPL/Caltech) and his colleagues concludes that retrograde-spinning black holes can power jets up to 100 times stronger than their prograde counterparts, but that retrograde spin will only persist for a short fraction of a SMBH's lifetime, usually immediately after a major galaxy merger that leads to an SMBH merger. If correct, the most powerful jets originate from retrograde-spinning SMBHs, a conclusion reinforced by the small number of such observed sources, and the fact that most galaxies with luminous jets are ellipticals, as expected after major galaxy mergers. Constraining black hole spin in galaxies with luminous jets will provide evidence to support or refute this theory.



NRAO / AUI / FRAZER OWEN, ET AL.

SPIN FLIP This image of radio galaxy 3C 75 shows four jets aimed in different directions. This could be the signature of a black hole binary. When the black holes coalesce, the resulting hole may briefly have a spin direction opposite of its accretion disk.

Future Directions

What is the distribution of black hole spins among SMBHs and GBHs? How does spin correlate with other environmental variables such as accretion rate, host galaxy shape, and black hole mass? What role does spin play in the triggering of powerful jets from black hole systems, and how does this feedback dictate the host galaxy's evolution? These are just a few important questions remaining to be answered in black hole astrophysics.

A larger sample size of SMBH and GBH spins is needed to begin finding answers. Such a census of black hole spin is currently underway using spectra from the Suzaku, Chandra, and XMM-Newton X-ray observatories.

I'm one of the lead investigators behind the effort to measure SMBH spin using broad iron spectral lines. Our collaboration hopes to utilize long Suzaku observations of the SMBHs in six active galaxies in order to increase our total number of robust SMBH spin measurements. Because of the sensitivity of our spin measurements, we must combine several days worth of observations in order to achieve the necessary data quality.

Ideally, we'd like to precisely measure the broad iron line profile during a single orbit of inner-accretion-disk material, rather than having to rely on long exposures spanning many orbits to achieve the required signal-to-noise, as we do currently. While the hole's spin is expected to remain constant over long timescales, the broad iron line's shape can change dramatically if the nature of the accretion flow is changing. Measuring these changes will allow us to compare how black hole spin and dynamical processes in the accretion disk shape the inner accretion flow.

The next generation of X-ray observatories will make such observations of SMBHs and GBHs a reality. Japan's Astro-H mission (scheduled for launch in 2014) will improve on Suzaku's capabilities by roughly a factor of 20. NASA's Gravity and Extreme Magnetism Small explorer (GEMS, also scheduled for launch in 2014) will bring the science of polarimetry to bear on measuring black hole spin, allowing constraints to be placed on spin independent of spectral modeling. The International X-ray Observatory (IXO), if built, would improve on the collecting area of current X-ray missions by a factor of 100 while simultaneously improving on the spectral resolution of Astro-H by a factor of 3. Combined, these sensitivity increases would make IXO an unparalleled tool with which to measure black hole spin, enabling hundreds of fainter SMBHs and GBHs to be observed. We could finally probe the demographics of black hole spin in a larger statistical sense.

We currently live in the golden age of X-ray astronomy, with several powerful observatories in orbit. Because X rays from galaxy cores often originate from material very close to a SMBH's event horizon and encode information about the black hole's spin, we are now finally poised to probe this fascinating, fundamental property of black holes. In so doing, we can unlock the mysteries of how these cosmic vortexes consume and emit energy, shape the lives of galaxies, and influence their surroundings on scales that dwarf them by many orders of magnitude.

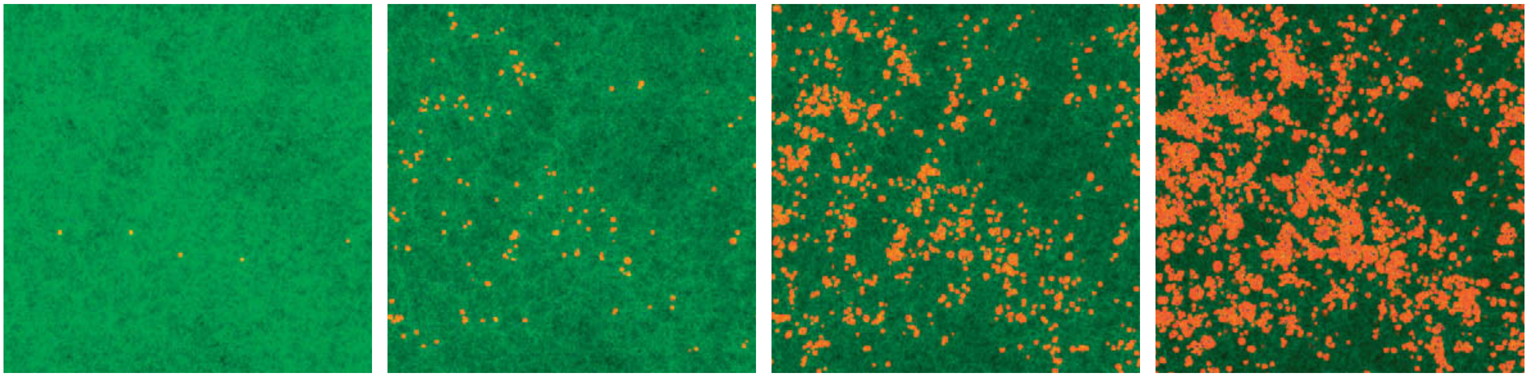
Surely, Disney would find this a worthy adventure. ✦

__Laura Brenneman__, a postdoctoral fellow at the Harvard-Smithsonian Center for Astrophysics, has authored numerous papers on the topic of black hole spin. She also played baseball for the U.S. Women's National Team from 2002–07.

Watch a **FREE BONUS VIDEO**

To watch a video conversation with author Laura Brenneman, visit SkyandTelescope.com/bhspin.

End of the Cos




CREDIT: HANS HORDIJK

A novel radio array may be first instrument to detect the elusive signal from the Epoch of Reionization.

GOVERT SCHILLING

LET'S FACE IT: it doesn't look too impressive at first sight. A casual tourist, strolling or cycling through the scenic landscape of the Dutch province of Drenthe, would hardly notice the central antenna fields of the Low Frequency Array (LOFAR). Unlike the 305-meter Arecibo dish, this novel radio observatory, inaugurated by Her Majesty Queen Beatrix on June 12, 2010, will never be featured in a James Bond movie. The array's inconspicuous omnidirectional antennas are arranged in clusters that are concentrated near the rural village of Exloo. But they are spread out all over northwestern Europe, and they lack high-tech sex appeal.

Still, LOFAR might soon give us our first glimpse of an important phase in the universe's very early history: the Epoch of Reionization.

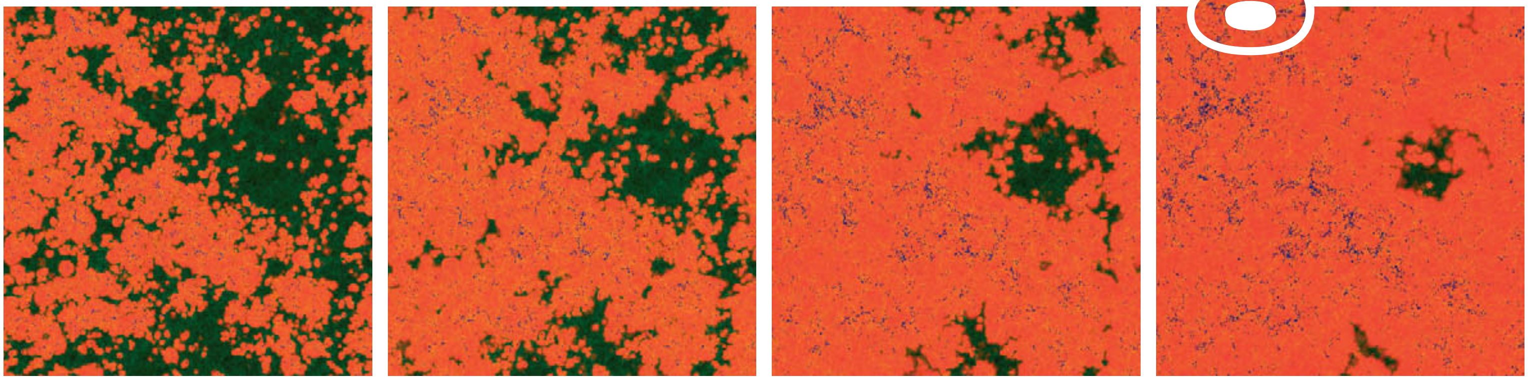
The early universe went through a period of frigid gloom — the Dark Ages. During the subsequent Epoch of Reionization (EoR), high-energy radiation from the first cosmic beacons turned the murky clouds of neutral hydrogen and helium into the hot, ionized plasma that fills intergalactic space today. But no one knows exactly how and when this happened. LOFAR might soon provide the first hint of an answer. "It would be a major scientific result," says Steve Rawlings (Oxford University, England), "but it's also a big technological challenge." Adds LOFAR Director Mike Garrett of the Netherlands Institute for Radio Astronomy (ASTRON): "This is Nobel Prize stuff."

Cosmic Rennaissance

Our universe was born in a hot Big Bang some 13.7 billion years ago. For hundreds of thousands of years it was filled with seething and glowing plasma — a gas consisting of positively charged hydrogen and helium nuclei and free negatively charged electrons. In other words, the normal baryonic matter in the expanding universe was fully ionized, because the electrons were not attached to the atomic nuclei. (The universe also contained huge amounts of mysterious, nonbaryonic dark matter.)

But 380,000 years after the Big Bang, temperatures had dropped to below 3,000 Kelvins, low enough for nuclei and electrons to combine into neutral atoms, which do not affect photons of light. Without free electrons to impede their progress, photons from the cosmic background radiation — the "afterglow" of the Big Bang — could propagate freely through space. The universe became transparent. From then on, the expanding uni-

mic Dark Ages



ILIAN ILIEV (UNIV. OF SUSSEX) / GARRELT MELLEMA (STOCKHOLM UNIV.) / PAUL SHAPIRO (UNIV. OF TEXAS AT AUSTIN)

REIONIZATION, THE MOTION PICTURE These computer simulation frames trace the reionization process over several hundred million years. In the first frame, the universe consists of almost entirely neutral gas (green), with a few tiny bubbles where radiation from massive stars and black holes has started to ionize the surrounding gas (orange). As more stars and black holes form, more ionized bubbles form. Eventually, they expand and overlap, ionizing all of the gas between galaxies — ushering in the modern universe.

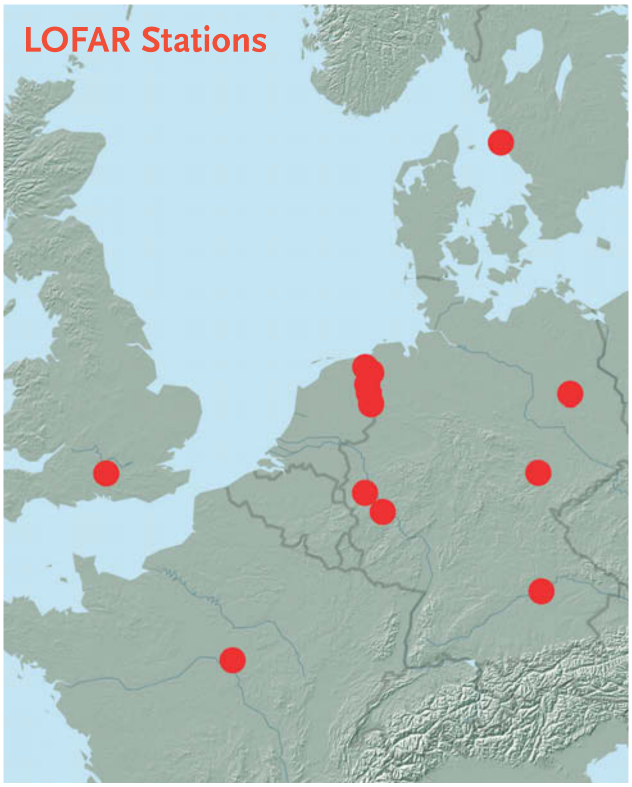
verse only became emptier and darker. Moreover, it cooled down, eventually to just a few tens of degrees above absolute zero — cold enough for molecular hydrogen (H_2) "snowflakes" to occasionally form. The universe plunged into the Dark Ages.

But just as Europe's uninspiring Middle Ages were overcome by the Renaissance (literally "rebirth"), the cosmic Dark Ages were supplanted by the Epoch of Reionization, where the prefix 're' acknowledges the fact that the universe had gone through an earlier ionized phase. Ever since, interstellar and intergalactic space has contained a hot plasma of nuclei and free electrons — just like in the early days, albeit much more tenuous. Neutral atoms can now be found only in dense, molecular clouds, where they can't be ripped apart by high-energy photons.

Analyses of the cosmic microwave background, which is slightly affected by free electrons, show that the Dark Ages lasted at least 400 million years. And observations of absorption lines in the spectra of very remote quasars indicate that reionization was almost complete when the universe was 1 billion years old. In other words, the EoR occurred somewhere between 13.3 and 12.7 billion years ago, corresponding to redshifts between 12 and 6.

According to Rawlings, theorists have known for a long time that the universe emerged from a dark, neutral

To view an animated computer simulation of the ionization process, visit SkyandTelescope.com/reionization.



S&T: GREGG DINDERMAN

LOFAR LOCATIONS This map shows the location of the various stations that make up the Low Frequency Array (LOFAR). Additional antennas will be built in the future.

STFC / LOFAR

ASTRON / LOFAR

TOP_FOTO, ASSEN

LOFAR ANTENNAS The LOFAR stations consist of two types of antennas. The flat black panels, such as the ones seen in the central core of the array (Superterp) in the Netherlands ***(above)*** and Effelsberg, Germany ***(above left)***, are high-band antennas that pick up radio signals in the 120 to 240 megahertz range. This group of poles in the Netherlands ***(left)*** forms a low-band antenna, which picks up signals from 30 to 80 megahertz.

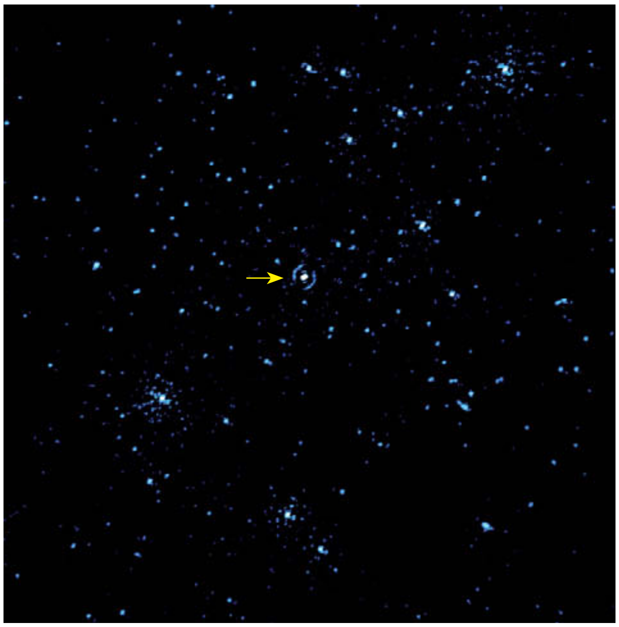
phase. But only since the mid-1990s did the EoR start to catch the attention of observational astronomers, as the universe's early youth slowly came within reach of new instruments and technologies. Finally, it looked like astronomical observations might solve the riddle of what exactly reionized the universe. High-energy photons certainly did the job, but what was their source? When did the EoR start, how long did it last, and how did it proceed?

ASTRON astronomer Ger de Bruyn, who heads LOFAR's EoR key science project, began preliminary observations this past winter. "In the late 1990s, we first discussed the possibility of detecting the signal," he says. If the EoR occurred when the universe was just 100 million years old, as some theorists suggested a decade ago, LOFAR would never be able to succeed. But, says de Bruyn, there's now enough circumstantial evidence that the Dark Ages lasted some 800 million years. "Later this year we should have a good idea of our chances of success."

Blowing Bubbles

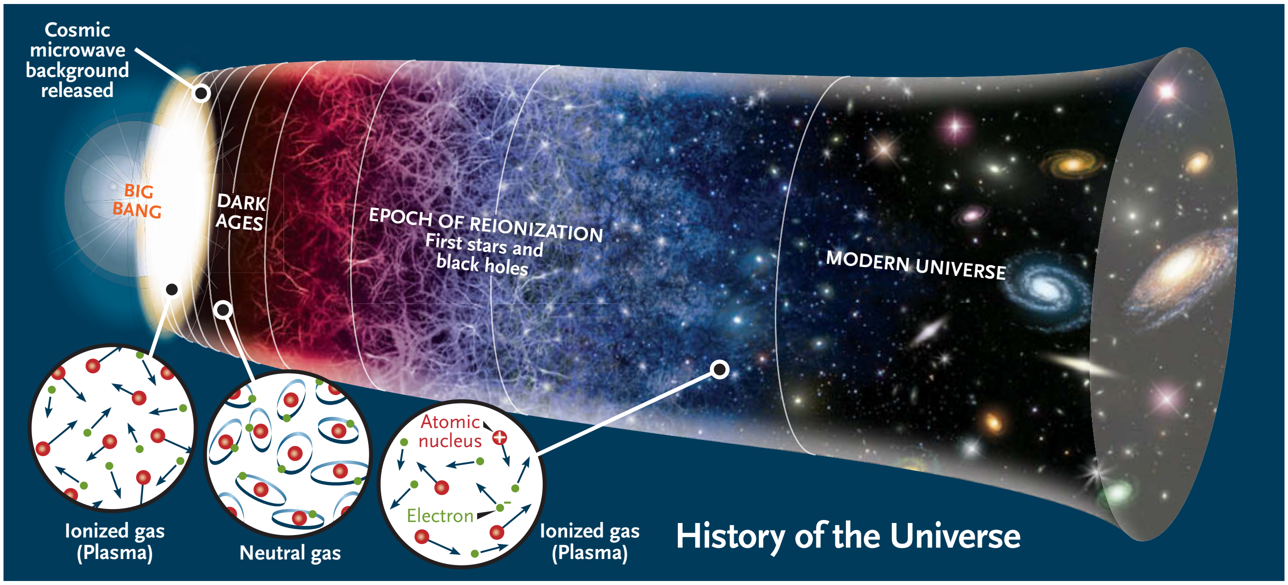
During the Dark Ages, gravity started to draw clumps of dark matter together, establishing the skeleton of the universe's large-scale structure. Neutral hydrogen and helium atoms were pulled along with the dark matter, and accumulated in the highest-density regions. But the details of this primordial gravitational clumping are poorly known, and we don't know which came first, individual stars (probably extremely hot, massive, and luminous) or giant black holes that would later act as the seeds for the formation of full-blown galaxies.

Both stars and black holes produce high-energy photons. Hot, luminous stars emit prodigious amounts of ultraviolet radiation. Matter falls toward black holes, which accumulates in whirling accretion disks that become hot enough to produce X rays (see page 20). No



ASTRON / LOFAR

LOFAR FIRST LIGHT In January 2011, the entire LOFAR network, with the newly completed station in Hampshire, England, took this "first light" image of the quasar 3C 196 (arrowed). With the new station, the array is nearly 1,000 kilometers wide, making it one of the largest telescope networks in the world.

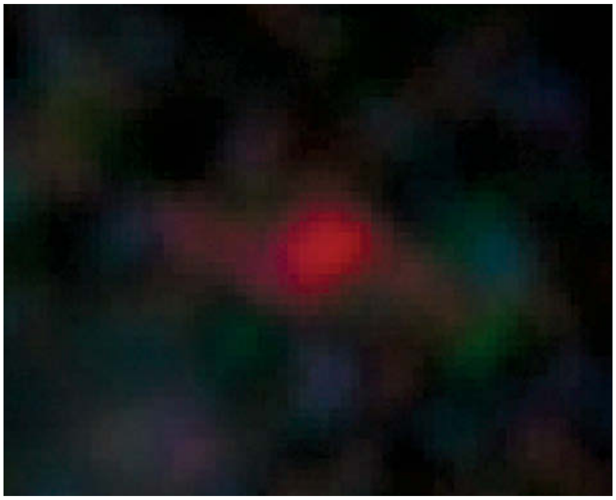


S&T: LEAH TISCIONE

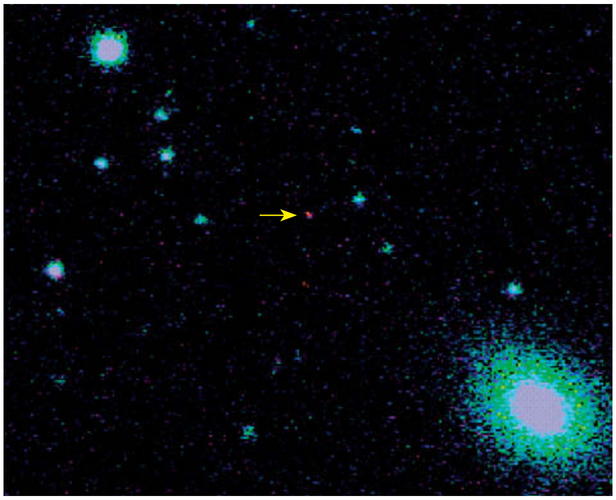
one knows what kind of objects first started to shine brilliantly, but one thing's for sure: after hundreds of millions of years, the universe's lights were switched on. And slowly but surely the neutral hydrogen and helium gas surrounding these first beacons became ionized again.

According to computer models, the universe's reionization did not occur in one fell swoop at one particular moment, but in fits and starts, slowly at first and then accelerating, more or less like water in a heated pan as it starts to boil. The EoR probably lasted hundreds of millions of years. Most likely, both giant black holes and individual stars contributed to the process, at different places and different times, and by uncovering the details of the reionization, cosmologists hope to shed more light on the universe's early clumping history.

Whatever the true nature of the first sources of radiation, theorists think they were surrounded by expanding bubbles of ionized matter. And because of the difference in energy output, the bubbles surrounding black holes grew faster and become larger than the bubbles surrounding individual stars. Eventually, ionized bubbles started to overlap, and in the end, the entire universe was reionized. Computer simulations support this simple view, although the details are a bit messier because of environmental effects. For example, stars and black holes are born in high-density regions, and the interiors of dense clouds of



NASA / ESA / GARTH ILLINGWORTH (UCSC), ET AL.

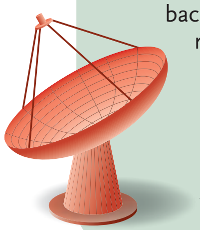


SLOAN DIGITAL SKY SURVEY

THE CULPRITS Two known types of sources radiated sufficient quantities of high-energy radiation to ionize the early universe: stars and giant black holes. *Left:* This Hubble Space Telescope image shows what is probably the most distant known galaxy, at a redshift of 10.3 (500 million years after the Big Bang). Even at this early cosmic age, it was bursting with young, massive stars that had plenty of oomph to ionize the surrounding gas. *Right:* The Sloan Digital Sky Survey picked up this quasar at a redshift of 6.4 (900 million years after the Big Bang). The quasar is powered by material falling toward a supermassive black hole.

TUNING INTO THE PAST

Neutral hydrogen emits characteristic radio waves at a frequency of 1420.4 megahertz, which corresponds to a wavelength of 21.1 centimeters. But hydrogen in the early universe had its radio waves stretched out by cosmic expansion during the long journey to Earth. As a result, we observe the hydrogen signal at a longer wavelength and a correspondingly lower frequency. Because of the light travel time, astronomers look back into the universe's past by observing these redshifted signals. For example, the emission of primordial neutral hydrogen at a redshift of 7 is observed at a wavelength of about 1.7 meters (corresponding to a frequency of 178 MHz), and at this redshift, astronomers are observing the universe as it was 780 million years after the Big Bang.



S&T: GREGG DINDERMAN

cool, neutral gas are difficult to ionize.

But in general, the pattern in which the ionized bubbles grew with time will tell astronomers what caused them in the first place. In other words, charting the universe's reionization history answers the question of which came first — stars or black holes. And that's where low-frequency radio telescopes such as LOFAR come in. Before neutral hydrogen gets ionized, it emits characteristic radio waves at a wavelength of 21.1 centimeters (a frequency of 1420.4 megahertz). By the time these waves reach Earth — some 13 billion years later — cosmic expansion has redshifted these waves to longer wavelengths and lower frequencies (see "Tuning into the Past" on the left).

Cosmic Tomography

By observing at different wavelengths, LOFAR will pick up the hydrogen emission from different epochs in the universe's early history. At the very longest wavelengths (the very lowest frequencies), astronomers look back to an era before reionization set in, and the hydrogen signal from this epoch can't be observed, mainly because such a weak, "smooth" signal can't be extracted from the contribution of foreground sources. But at slightly shorter wavelengths (higher frequencies), LOFAR looks back to a time where the first bubbles began to appear, and the radio sky should attain a "Swiss cheese" appearance, which makes it detectable for an interferometer such as LOFAR. At even shorter wavelengths and higher frequencies (but still very much in the low-frequency range), the ionized bubbles should be larger, and the radio signal should start to diminish.

So by tuning the frequency dial, LOFAR effectively carries out tomography on the early universe. Given the

LOFAR and Its Competitors

LOFAR is a novel radio telescope under construction in northwestern Europe. Eventually, it will consist of many thousands of small, simple antennas of two types, for two frequency ranges. The unmovable, omindirectional antennas are clustered in 44 stations, half of which lie in the core region, close to the village of Exloo in the northern part of the Netherlands. Others are spread out over the Netherlands, with outlying stations in Germany, France, the United Kingdom, and Sweden (see the map on page 27). A fast fiberoptic network connects all antenna stations to a powerful central supercomputer in Groningen, the Netherlands.

Unlike traditional radio telescopes, the LOFAR antennas cannot be aimed at a particular point in the sky. They pick up low-frequency radiation from all directions simultaneously. "Pointing" the telescope is done by sophisticated software that takes into account tiny differences in photon arrival time for the individual antennas. As a result, LOFAR can "look" in as many as eight different directions simultaneously. Even though the observatory is not yet completed, it has already obtained promising observations of radio galaxies, pulsars, cosmic-ray showers, and solar flares.

B. PREMKUMAR / NCRA

LOFAR is not the only radio observatory trying to detect signals from the Epoch of Reionization. In western India, the Giant Metrewave Radio Telescope (GMRT) is also in the race to observe the faint signal. In western Australia, the Murchison Widefield Array (MWA) is trying to do the same. Like LOFAR, MWA is a precursor instrument for the future Square Kilometre Array (SKA), a giant network of radio antennas that will be built by an international consortium either in western Australia or in southern Africa.

array's very large field of view, such observations should, in principle, reveal the chronology of the EoR, thus answering fundamental questions about the very earliest stages of the universe's history. But de Bruyn cautions, "The signal is incredibly weak. Only a giant future radio observatory such as the SKA (Square Kilometre Array) will be able to produce nice maps and images of this epoch." Still, the statistical evidence that LOFAR may provide for structure in the universe from hydrogen emission at various redshifts and lookback times will be very important for theorists.

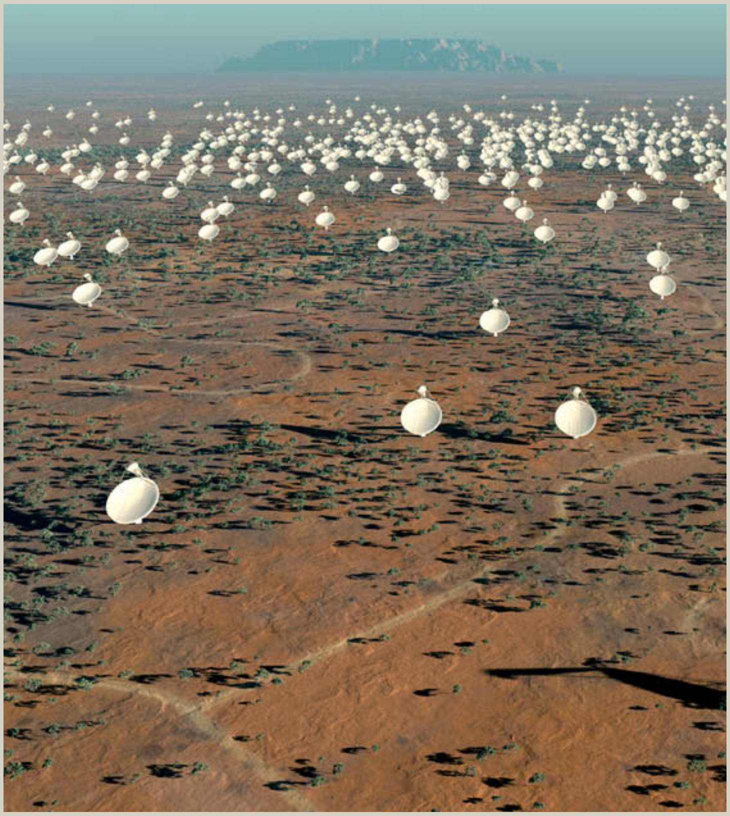
Both de Bruyn and Rawlings, who heads the United Kingdom involvement in LOFAR and who chairs the SKA's Science Advisory Committee, point to similarities between the current hunt for the EoR signal and the hunt for structure in the cosmic microwave background (CMB). "The LOFAR observations might be comparable to the initial discovery of the CMB in the 1960s and the detection of the ripples by NASA's Cosmic Background Explorer (COBE) satellite," says de Bruyn. According to Rawlings, "A first detection by LOFAR would tell us what kind of instruments we need to build for better imaging." Thus, SKA would be to the EoR what the WMAP and Planck satellites — the successors of COBE — are to the CMB.

And just like measuring minuscule temperature fluctuations in the CMB, it won't be easy to detect the EoR signal. In fact, the faint, redshifted radiation of primordial neutral hydrogen will be swamped by much stronger foreground emissions, both inside and outside our Milky Way Galaxy. These foreground signals — mainly synchrotron radiation from electrons spiraling along magnetic field lines — can be filtered away because they show a different dependence on frequency. "Still," says de Bruyn, "this is probably the most difficult project ever undertaken in radio astronomy."

Five years from now, new observatories such as the Atacama Large Millimeter Array (ALMA) in northern Chile and NASA's James Webb Space Telescope may actually reveal the very first generation of stars, black holes, and galaxies in the universe. Although these observatories have a very small field of view compared to radio observatories such as the future Square Kilometre Array, they could provide important supporting evidence for the preliminary findings on the Epoch of Reionization that LOFAR may provide. Says de Bruyn: "I remain confident that we will succeed." ✦

Like tens of millions of other Europeans, S&T *contributing editor* ***Govert Schilling*** *lives inside the LOFAR telescope, some 140 kilometers southwest of the array's core region.*

MIGUEL MORALES (UNIV. OF WASHINGTON)



SKA / SWINBURNE ASTRONOMY PRODUCTIONS

JOINING THE HUNT **Several other radio arrays will join the hunt to detect radio signals from the Epoch of Reionization. *Left:* This 45-meter antenna is part of the Giant Metrewave Radio Telescope, near Pune, India. The 30-telescope array can detect frequencies from about 50 to 1420 megahertz. *Above:* The small white structures are dipole antennas belonging to the Murchison Widefield Array in Western Australia, which is still under construction. The MWA picks up signals from 80 to 300 MHz. *Right:* An artist depicts the future Square Kilometre Array. Construction of this network of radio antennas is scheduled to begin in 2016 in Western Australia or southern Africa. SKA should be able to study the EoR signal in considerable detail.**

Building My Dream Observatory

A veteran telescope maker spent four years building this novel 32-inch reflector and home observatory.

MARIO MOTTA

Perched at the highest point in the area, Mario Motta's observatory has a commanding 360° view of the sky.

AS A TEENAGER, I started grinding mirrors and building telescopes because my dreams always exceeded my budget. My projects include a 16-inch Newtonian reflector and backyard observatory finished in the 1980s, and a 32-inch Newtonian and another observatory built in the '90s. When my wife, Joyce, and I planned a move to Gloucester, Massachusetts (her for the natural beauty of the beach, and I for the darker sky), we agreed that an observatory would be an integral part of our new house.

Given today's plethora of commercial telescopes, some people wonder why I still build my own. The answers are simple: for large telescopes, it can be very cost effective, you control the quality, and there's real pride in making and using your own instrument.

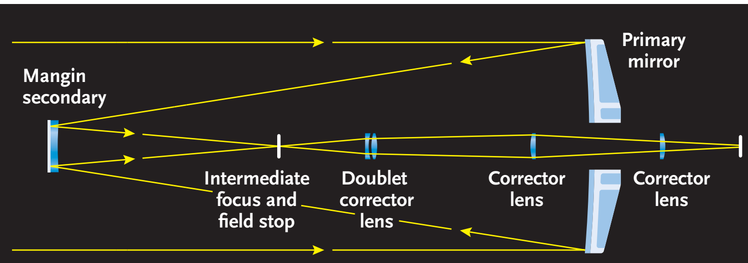
As a galaxy hunter, I find that the views through an optically excellent, large telescope are beyond my wildest dreams. So my initial plan was to build another, better 32-inch Newtonian, since I'd become relatively adept at making parabolic mirrors. But a close friend and optical designer, Scott Milligan, changed my mind. He had been perfecting a radical new design for a "relay telescope," building on the work of others, particularly Donald Dilworth, who described his 16-inch relay telescope in this magazine's November and December 1977 issues.

It's a story played out countless times in the last century: an amateur astronomer's quest for a dream telescope becomes a journey through the world of telescope making and surplus materials. Only a few of these stories, however, end as dramatically as the one told here. The author is pictured with his unusual 32-inch f/6 relay telescope in an observatory that is part of his hilltop house.

UNLESS OTHERWISE CREDITED, ALL PHOTOGRAPHS ARE BY THE AUTHOR.

Using advanced ray tracing, Scott settled on a system with four correcting elements. It promised many advantages over a simple Newtonian, not the least of which was a very sharp and flat focal plane. I was intrigued, and to further sweeten the deal, Scott offered to help build the telescope. It was an offer I simply couldn't refuse.

Built at the same time as the house's foundation, a massive 23-foot-tall pier of reinforced concrete provides a stable base for the telescope even when there is considerable activity in the adjacent rooms.



Described in detail in the accompanying text, the scope has 11 optical surfaces, all of which are either spherical or flat. This greatly simplifies their fabrication. The primary mirror's intermediate focal point falls inside the tube, where it is "relayed" to a Cassegrain focus by a set of corrector lenses mounted within a baffle tube.

S&T: GREGG DINDERMAN, SOURCE: SCOTT MILLIGAN

First, the Optics

Outwardly the scope has the appearance of a large Cassegrain. The primary mirror is f/3, and the final image is f/6 with an effective focal length of 4,800 millimeters. Scott's design, however, can be easily modified to produce scopes from f/4 to f/12.

The system has six elements, 11 optical surfaces, and a field stop. It sounds complicated, and in some ways it is. But I had already suffered through the extreme difficulty of grinding and polishing a 32-inch mirror to a paraboloid. The best I could manage was a surface accuracy of about ⅕ wave after 2½ years of effort. I wanted my new scope to be even better, and a big advantage of Scott's design is that all the curved optical surfaces are spherical, including the 32-inch primary mirror. As any glass pusher knows, it's much easier to grind and polish a perfect sphere than a paraboloid. Indeed, from start to finish, work on the new primary was completed in about six months.

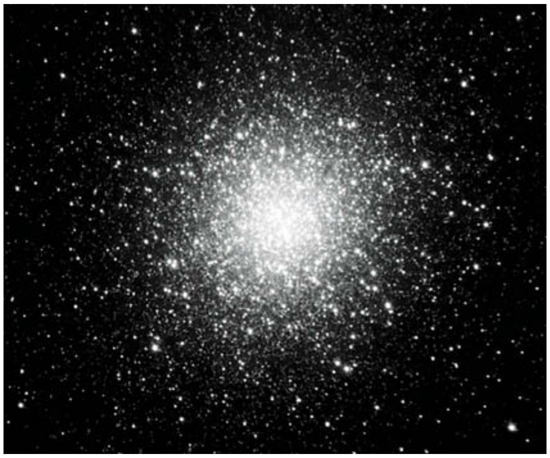
The next challenge was the scope's 7.8-inch-diameter Mangin secondary, which is a combination lens and mirror. It has a concave surface facing the primary mirror and a flat back surface that is silvered. The light path from the primary passes through the Mangin's glass and curved surface twice, correcting the primary's inherent spherical aberration. But because it is a lens as well as a mirror, it introduces some color aberration to the system.

The Mangin secondary folds the light path back to an intermediate focus falling near the middle of the telescope tube. At this point there is a field stop 1.8 inches in diameter, which preserves the scope's high contrast by preventing stray light from reaching the focal plane. The field stop is very effective, and as proof, someone can shine a flashlight down the tube toward the primary when I'm observing and it will lighten the field of view only a little bit.

From the intermediate focus at the field stop, the light path is "relayed" through four corrector lenses to the final focus behind the primary mirror. The lenses are held rigidly in a long baffle tube and are set up as a doublet and two singles. They correct the system's color aberration as well as flatten the focal plane.

In the past, optical designers might have shied away from a system with this many optical surfaces because it could be compromised by internal reflections and a significant loss of light and image contrast. But modern antireflective coatings on all the lenses keep light loss to less than 0.25% on each air-to-glass lens surface.

There are some significant mechanical constraints to this optical design that require careful consideration. The most significant one involves the spacing between the primary and the secondary mirrors, which cannot vary by more than 0.025 inch. As such, the structural elements holding the mirrors apart cannot be made from



***Left*: After six months of making parts for the dome, the author enlisted the help of a dozen members from the Amateur Telescope Makers of Boston for a "very long weekend" spent assembling the dome atop the observatory walls. *Right*: The telescope's pinpoint star images are apparent in this image of the globular star cluster Messier 13 in Hercules.**

aluminum or other common materials, since thermal expansion and contraction would badly defocus the image in a way that isn't correctable by merely refocusing the eyepiece. The telescope's optical collimation is also quite sensitive and requires that the Mangin secondary not tilt or sag laterally.

These are serious constraints, and we overcame them by using structural carbon-fiber materials for the scope's truss construction and cross bracing. Thanks to a friend in the optics industry, I was fortunate in obtaining a large cache of scrap carbon-fiber tubing left over from a satellite project. The baffle tube holding the corrector lenses is also carbon fiber, with only the lens cells being made from aluminum.

The primary mirror's support proved to be an issue. The lightweight mirror blank was cast by Wangsness Optics in Tucson, Arizona. Its back is a conical shape, tapering from 4½ inches thick at the center to 1½ inches at the periphery. Weighing only 97 pounds, it was originally mounted on a support passing through a 5-inch hole cast in the center of the blank. In the end, however, this method of supporting the mirror caused some flexure that resulted in an optical error amounting to nearly ⅓ wave. It took finite-element analysis to realize that I needed to make a more traditional 18-point support for the back of the mirror. Fortunately, that solved the flexure problem, and the scope has a final wave-front accuracy of about 1⁄12 wave — quite a feat for a telescope of this size.

Its images are nothing short of spectacular. Viewing with a Tele Vue 41-mm Panoptic eyepiece at 117×, I see an evenly illuminated true field that is 31 arcminutes across. The image is sharp, has rich contrast, and tolerates high magnifications very well. The scope is far more than just a big light bucket, and it's a real joy to use it for observing planetary detail.

Next, the Mechanics

All 584 mechanical parts for this telescope were hand made, many with a lathe and milling machine that I acquired secondhand years ago for telescope projects. The pieces were also made from mostly scrap materials, thus keeping costs very low for a project of this size. Some items were donated by friends, such as a 40-inch-diameter aluminum disk that was originally part of an industrial centrifuge. This now serves me quite well as the mount's

The relay telescope's novel optical design is the handiwork of Scott Milligan, who also did much of the optical fabrication as "incentive" for the author to select the design for his project. Note the primary mirror's lightweight structure described in the text.

This view of the well-known spiral galaxy Messier 81 in Ursa Major was assembled from separate CCD exposures through red, green, and blue filters.

polar disk supporting the steel fork arms. The disk rides on pillow block ball bearings, while the south end of the polar axis rests on a surplus 6-inch Timken thrust bearing.

The telescope's drive motors are computer controlled thanks to another friend, Chris Houghton of Astrometrics. His electronic design allows me to accurately slew to and track objects with the precision needed for deep-sky astrophotography. I use an SBIG STL-1001E as my primary camera, since its 24-micron pixels have an image scale of 1 arcsecond per pixel with this scope.

A self-proclaimed galaxy hunter, the author recorded dozens of island universes in this ¼°-wide photograph of the Hercules Supercluster, Abell 2151.

Finally, the Observatory

We designed the observatory as an integral part of our new house. As such, a massive 23-foot-tall pier made of reinforced concrete with a 2-by-6-foot cross section was constructed along with the foundation. The house was built around the pier, making sure that there was no contact between floors and the pier. This is critical in preventing any vibration from shaking the telescope when people are walking around inside the house.

Because the top of the dome exceeded normal height restrictions for our local zoning, we had to get a building variance from the neighbors. But the result is a dome that is the highest point around, and I don't have to worry about trees. I was also fortunate in convincing my hometown to adopt a light-pollution ordinance!

I made the frame for the 20-foot dome from plywood struts that were cut with a router. The outer covering is 0.052-inch-thick fiberglass sheets that I obtained for free from a local manufacturer's pile of discarded material. Several friends and I cut the sheets to shape and attached them to the plywood skeleton with screws, each of which we fitted with a small rubber sink washer to make a watertight seal. We bonded the fiberglass seams with Phenoseal Vinyl Adhesive Caulk to make the dome waterproof.

The dome has 24 sets of wheels riding on a base ring made of wood and covered with ¼-inch-thick aluminum plate. Four ⅛-horsepower motors move the dome very nicely. Although it took me six months to make the dome's wood and fiberglass pieces, it required only one very long weekend to assemble it thanks to help from a dozen members of the Amateur Telescope Makers of Boston. Since the fiberglass was free, the dome cost only about $2,000 for the plywood, motors, and minor parts. One large order of pizzas covered the labor costs.

All told, it took me about four years to build the telescope and observatory. Was it worth the effort? Absolutely. Views through this scope are simply amazing, with high-contrast, razor-sharp stars across the field. On nights of good seeing, I can use very high magnifications with no breakdown of the image. Detail on planets is excellent. And galaxies, which are my favorite objects, really look like galaxies rather than "faint fuzzies." The project did indeed create the dream telescope I've been wanting since I was a teenager. ✦

***Mario Motta** is a Massachusetts-based cardiologist. The past president of the Massachusetts Medical Society, he currently serves on the American Medical Association's Council of Science and Public Health. Adding to his many astronomical credentials, he is a recipient of the Astronomical Society of the Pacific's Las Cumbres Amateur Outreach Award.*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Halley and His Comet

What is it like to be passed, in the cold and the still of the night, by a ghost 10,000 times the size of the Earth?

I HOPE SOME of you readers and your astronomy clubs will hold parties this spring to celebrate what I call the 25/50 anniversary of Comet Halley (25 years since the last return, 50 years until the next). It would be a good activity for this initial year of the International Decade of the Sky, 2011–2020.

The sentence in italics that heads this article is the first in Chapter 1 of my book *Comet of the Century* (Springer-Verlag, 1996). I wasn't thinking of my observations of the great comets Bennett (1970), West (1976), or Hyakutake (1996) when I wrote those words. I was thinking of something that I and relatively few other observers detected in very dark, clear skies in late April and early May 1986: the mostly very faint but amazingly long dust tail of Halley's Comet.

I'll return to this eerie tail at the end of this column. But first let's consider some of the current sights in the May sky that you can use to celebrate the most famous of all comets.

May's Halley meteors. You may be out before sunrise some days this month to observe the amazing tight gathering of four planets (see page 48). In the first 10 days of the month, getting up a bit earlier (just before dawn brightens) will provide you with a chance to see flaming debris from Halley's comet itself — the Eta Aquarid meteors (see page 57).

Those meteors appear to diverge from Aquarius, rising in the southeast, and you can note the constellation Pegasus above Aquarius. If you do, you'll be seeing the region of the sky where, 101 years ago this May 18th and 19th, Edward E. Barnard sketched part of the 120°-long tail of Halley's Comet just before Earth passed through its edge.

Contrary to widespread public fears, the gas tail did not poison the inhabitants of Earth.

May's Halley star. The evening sky of May also holds some Halley connections. Near the zenith on our all-sky map is an important 2nd-magnitude star which for 175 years was widely believed to have been named by Edmond Halley. The true story about this star name, Cor Caroli (Charles's Heart), was finally made public in a letter in the September 1976 issue of *Sky & Telescope* by Deborah Jean Warner, curator at the National Museum of American History. It turns out that court physician Sir Charles Scarborough, not Halley, named the star, and it was named not for King Charles II of England, as widely assumed, but for the "martyred" Charles I. Regardless, Cor Caroli remains a lovely sight for small telescopes. Its constellation Canes Venatici is today best known among amateur astronomers for great deep-sky objects such as the spiral galaxy M51 and the bright globular cluster M3. But Cor Caroli is a beautiful 19″-wide double star with components of magnitude 2.9 and 5.6.

Next month I'll discuss two other celestial objects with Halley connections — the far-south star Beta Carinae and not-so-far-south globular cluster Omega Centauri.

How long was the tail? Five years ago in this column I asked readers who observed the long Halley tail in April and May 1986 to e-mail me. But the fascinating replies were lost in the most unfortunate computer mishap I've ever had. So I'm making this request again. Please send your words and images to the e-mail address below. ✦

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Edward Emerson Barnard took this photograph of Halley's Comet on May 29, 1910.

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

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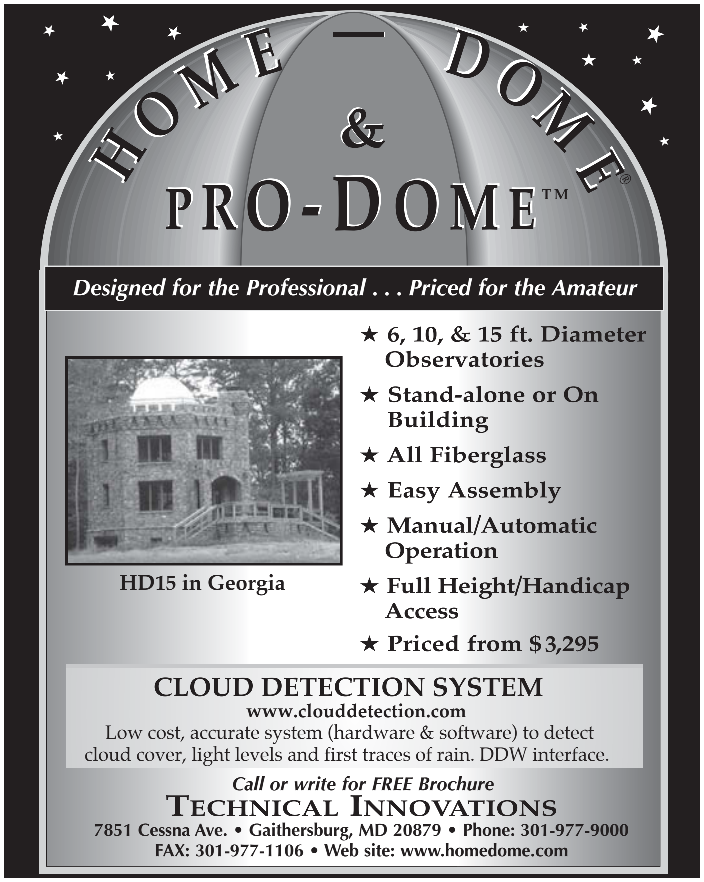

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May 2011

MOON PHASES

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

PLANET VISIBILITY

	◀ SUNSET — MIDNIGHT — SUNRISE ▶	
Mercury	Probably visible in binoculars all month	E
Venus	Bright and easy to the naked eye all month	E
Mars	Easily visible in binoculars by mid-May	E
Jupiter	Visible naked-eye all month, easy by mid-May	E
Saturn	SE S W	

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

IMAGE BY DENNIS DI CICCO

THE MOON, Venus, and Jupiter formed a spectacular trio shortly after sunset on December 1, 2008.

1 **DAWN:** If the air is very clear, binocular observers in North America can see the thin crescent Moon clustered with Venus, Jupiter, Mercury, and faint Mars just above the eastern horizon shortly before sunrise, as shown on page 48.

2 **DAWN:** Binoculars may show a very thin crescent Moon about 11° left of Jupiter, very low in the east just before sunrise.

3 **NEW MOON** (2:51 a.m. EDT).

4 **DUSK:** The Pleiades are lower right of the thin crescent Moon low in the west-northwest as twilight fades.

6 **PREDAWN:** The Eta Aquarid meteor shower peaks; see page 57.

7–15 **DAWN:** Binoculars show Mercury less than 1½° lower right of Venus with Jupiter fitting into the same 5° field of view. Track the changing configuration of this spectacular trio each clear morning!

10 **FIRST-QUARTER MOON** (4:33 p.m. EDT).

11 **DAWN:** Jupiter and Mercury are just ½° above and 1½° below Venus, respectively.

13, 14 **EVENING:** The Moon is far to Saturn's lower right on the 13th and closer to Spica's lower right on the 14th.

15–20 **DAWN:** Mercury remains within 1½° of Venus. Faint Mars is less than 5° to their left.

17 **FULL MOON** (7:09 a.m. EDT).

20, 21 **DAWN:** Venus forms a right triangle a little more than 2° wide with Mercury below it and faint Mars to its left.

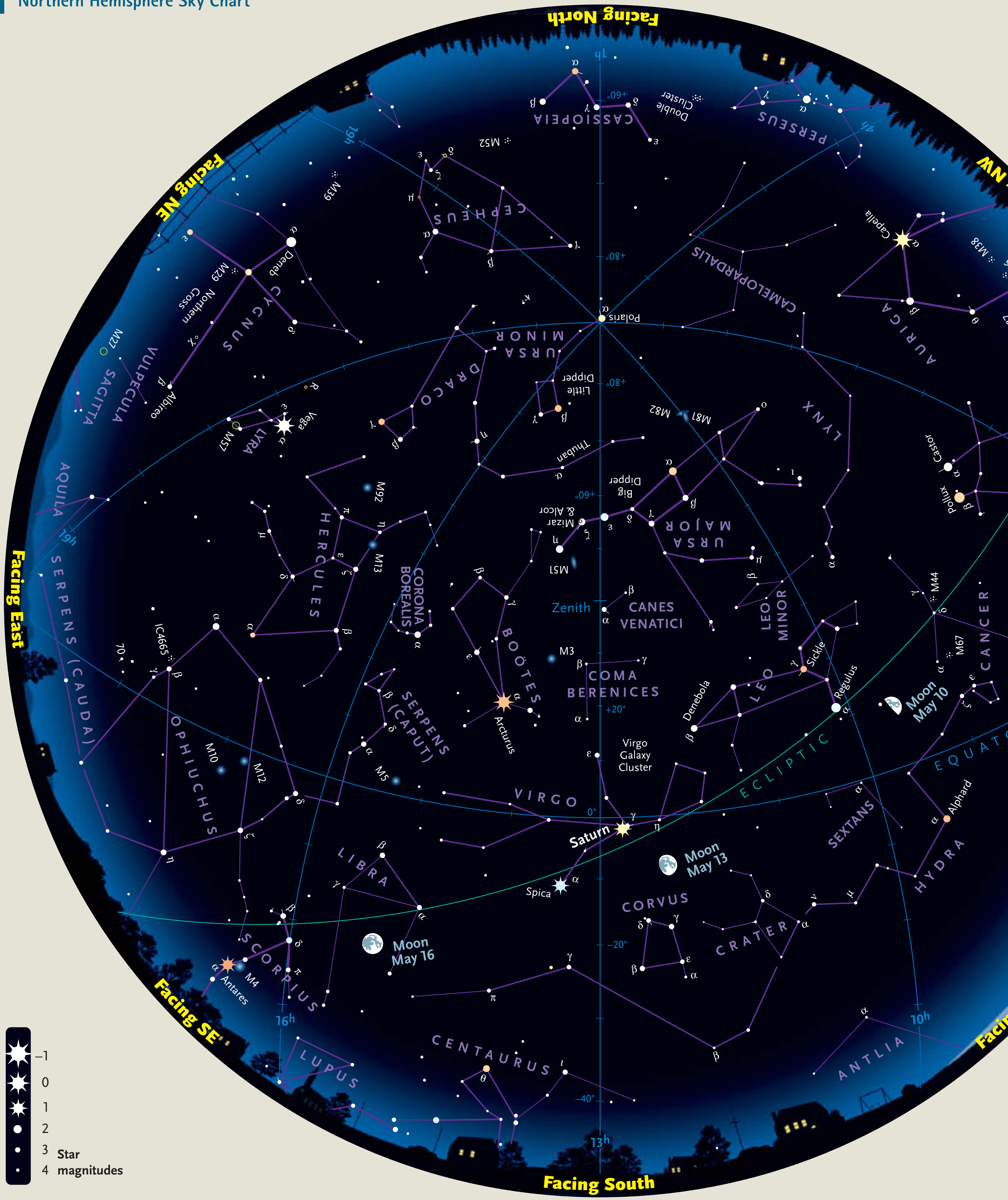
22–24 **DAWN:** Mars passes about 1° above Venus these three mornings, with Mercury less than 4° to their lower left.

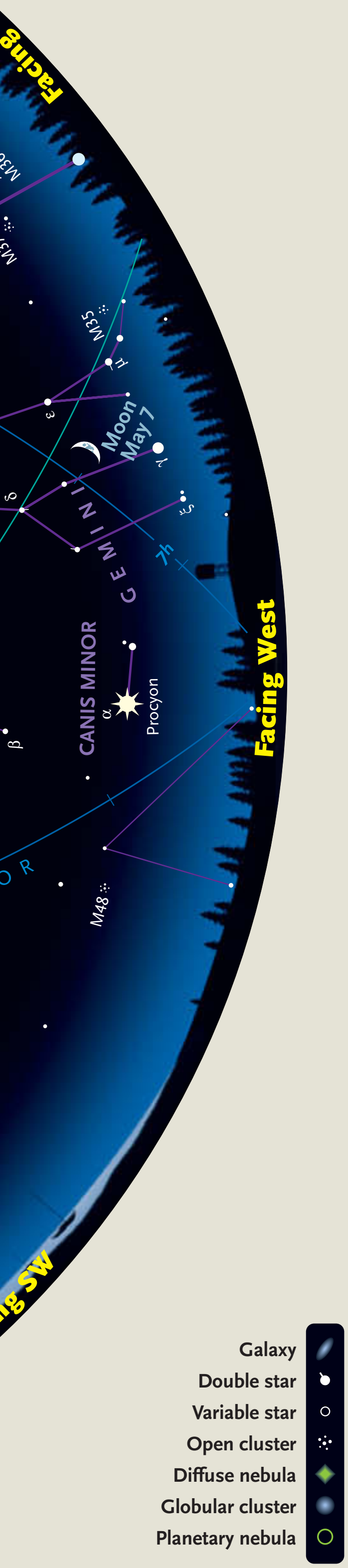
24 **LAST-QUARTER MOON** (2:52 p.m. EDT).

29–31 **DAWN:** The waning crescent Moon is upper left of Jupiter on the 29th, upper right of Venus on the 30th, and clustered with Venus and Mercury barely above the bright pre-sunrise horizon on the 31st; see page 48.

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

Northern Hemisphere Sky Chart





Using the Map

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.

HOW

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

Example: Hold up the map so that "Facing South" is at the bottom. About halfway from there to the map's center are Spica and Saturn. Go out, face south, and look halfway up the sky. There they are!

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

You can make a sky chart customized for your location at any time at SkyandTelescope.com/skychart.

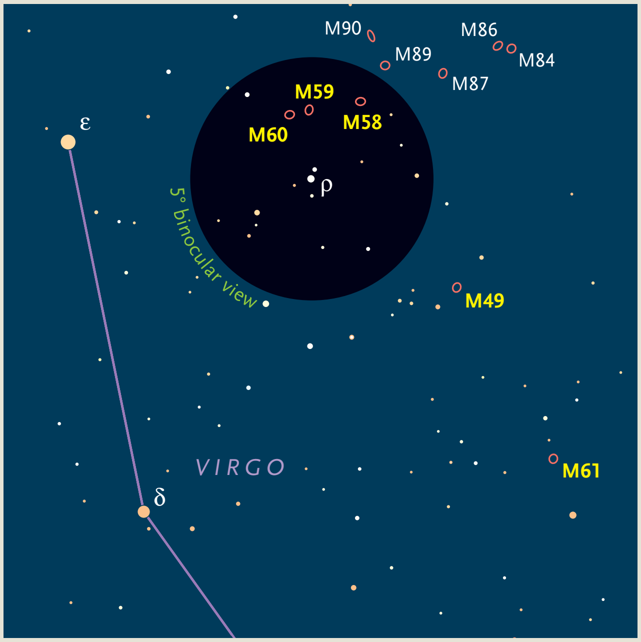
Binocular Highlight: More Virgo Clutter

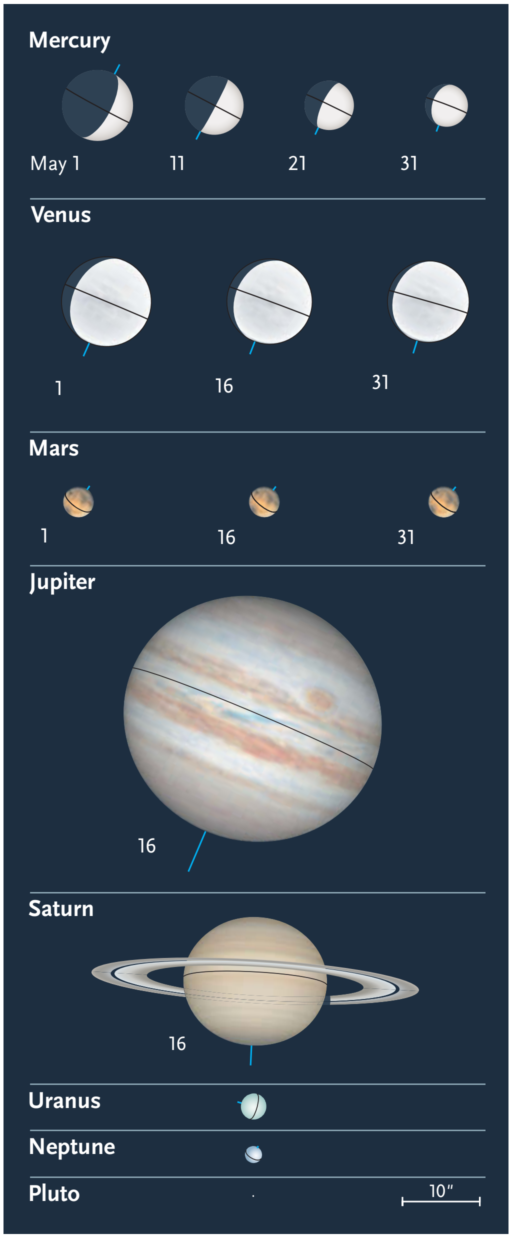
MESSIERS ABOUND in the Virgo Galaxy Cluster (see page 66). In the May 2010 issue, we ploughed through the main, east-west galaxy corridor. Now it's time to clean up the remaining Virgo clutter in the region west of Vindemiatrix, Epsilon (ε) Virginis.

Let's begin with a trio of galaxies lying just north of 4.9-magnitude Rho (ρ) Virginis: M58, M59, and M60. The brightest and easiest galaxy of this group is **M60**. Of course in this neck of the celestial woods, "bright" and "easy" are relative terms — even M60 isn't a piece of cake. I was able to locate this 8.8-magnitude puffball of a galaxy in my 10×50s, though I needed to use averted vision. If you succeed with M60, try to glimpse its close neighbor, **M59**. I found M59 a challenge in 10×50s and was able to detect it only half the time. The NGC/IC Project database lists M59 as a full magnitude fainter than M60, so this isn't surprising. Fainter still is nearby **M58**, listed at magnitude 10.1. But because this galaxy is parked next to an 8th-magnitude star, it's easier to pin down than M59. I never did see M58 in my 10×50s, but I managed to view it intermittently in my 15×45 image-stabilized binos.

Moving southwest from Rho, we come to 8.4-magnitude **M49**. I located this galaxy in my 10×30 image-stabilized binoculars, though my 10×50s gave a much better view. M49 has the appearance of a tiny globular cluster — a starlike core surrounded by a faint haze. The last stop on our Virgo tour is **M61**. Another faint object (magnitude 9.6), I could see it in my 15×45s, but in 10×50s it was very difficult. Frankly, by this point, you might just be glad to check these off your list and move on. ✦

— *Gary Seronik*



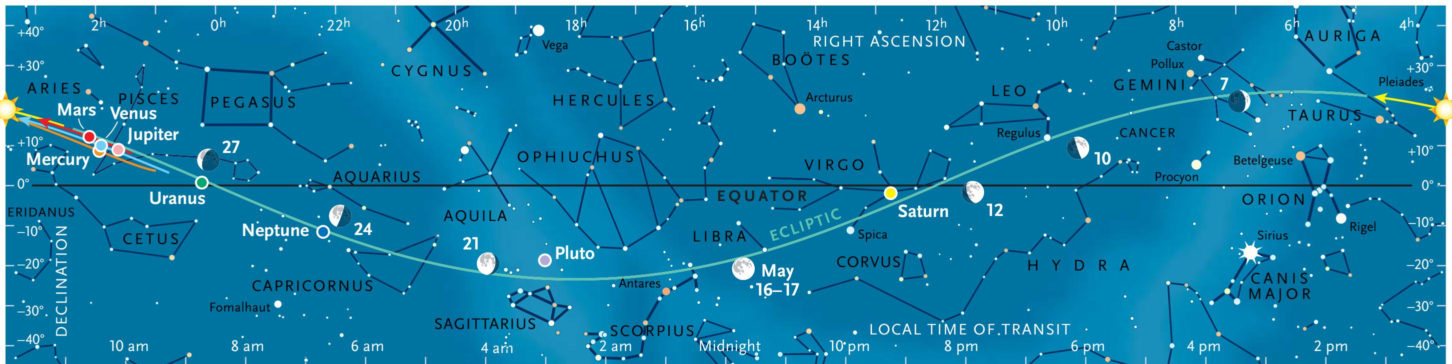


Sun and Planets, May 2011

	May	Right Ascension	Declination	Elongation	Magnitude	Diameter	Illumination	Distance
Sun	1	2^h 30.9^m	+14° 51′	—	–26.8	31′ 45″	—	1.007
	31	4^h 29.5^m	+21° 49′	—	–26.8	31′ 33″	—	1.014
Mercury	1	0^h 59.1^m	+3° 37′	25° Mo	+0.8	9.2″	31%	0.730
	11	1^h 32.4^m	+6° 17′	26° Mo	+0.2	7.6″	47%	0.882
	21	2^h 22.5^m	+11° 20′	23° Mo	–0.2	6.4″	64%	1.050
	31	3^h 29.1^m	+17° 32′	15° Mo	–0.9	5.5″	83%	1.212
Venus	1	0^h 45.8^m	+3° 07′	28° Mo	–3.8	11.6″	88%	1.433
	11	1^h 30.8^m	+7° 43′	26° Mo	–3.8	11.2″	90%	1.485
	21	2^h 16.9^m	+12° 03′	24° Mo	–3.8	10.9″	92%	1.532
	31	3^h 04.3^m	+15° 57′	21° Mo	–3.8	10.6″	93%	1.575
Mars	1	1^h 22.6^m	+7° 55′	18° Mo	+1.2	4.0″	99%	2.323
	16	2^h 05.4^m	+12° 05′	21° Mo	+1.3	4.1″	98%	2.306
	31	2^h 48.7^m	+15° 47′	25° Mo	+1.3	4.1″	98%	2.285
Jupiter	1	1^h 23.5^m	+7° 37′	18° Mo	–2.1	33.4″	100%	5.897
	31	1^h 49.0^m	+10° 02′	40° Mo	–2.1	34.7″	100%	5.681
Saturn	1	12^h 47.4^m	–2° 09′	151° Ev	+0.5	19.1″	100%	8.724
	31	12^h 42.4^m	–1° 43′	121° Ev	+0.7	18.3″	100%	9.064
Uranus	16	0^h 13.0^m	+0° 38′	51° Mo	+5.9	3.4″	100%	20.700
Neptune	16	22^h 11.7^m	–11° 43′	84° Mo	+7.9	2.3″	100%	30.099
Pluto	16	18^h 29.5^m	–18° 44′	137° Mo	+14.0	0.1″	100%	31.276

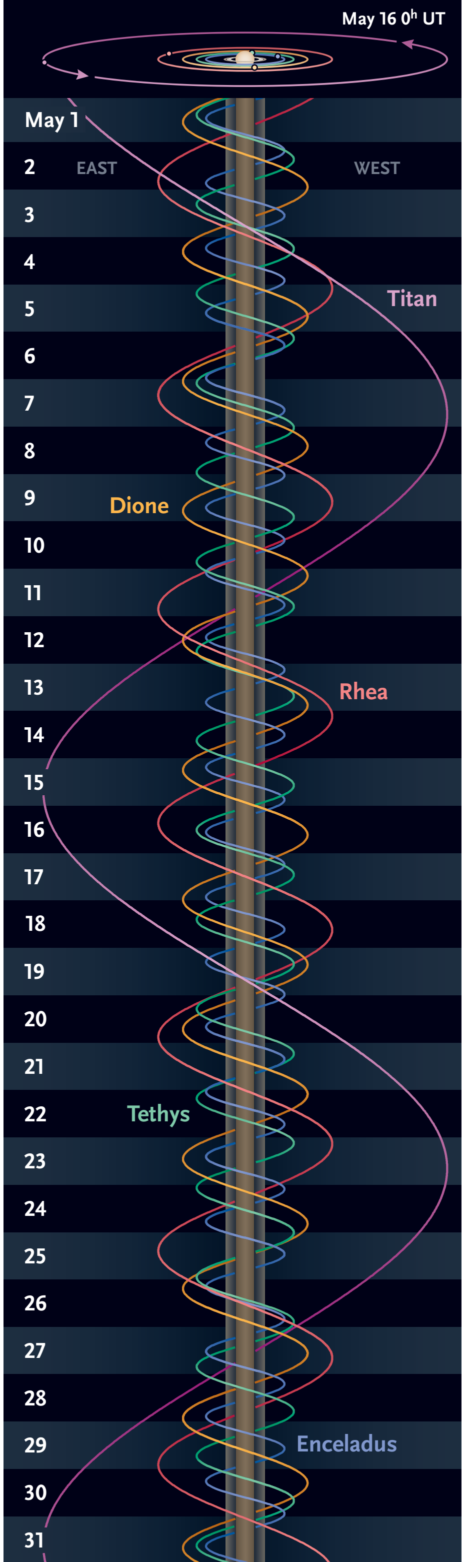
The table above gives each object's right ascension and declination (equinox 2000.0) at 0^h Universal Time on selected dates, and its elongation from the Sun in the morning (Mo) or evening (Ev) sky. Next are the visual magnitude and equatorial diameter. (Saturn's ring extent is 2.27 times its equatorial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

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



The Sun and planets are positioned for mid-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.

Saturn's Moons



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

Fred Schaaf

Sun, Moon, and Planets

Drama at Dawn

Four planets dance in bright morning twilight.

THIS MAY the most compact visible gathering of four bright planets in decades can be glimpsed low in bright dawn. Adding to the excitement, a thin crescent Moon joins the group at the beginning and end of the month. Unfortunately, although this event takes place fairly high in the sky in the Southern Hemisphere, the angle of the ecliptic becomes more unfavorable the farther north you live. At 40° north latitude, these planets are only 2° to 6° high 30 minutes before sunrise for most of the month, so some will be visible only with optical aid.

Saturn, the only bright planet missing from the dawn drama, is well-placed for observation from evening twilight until midnight or later.

DUSK TO DAWN

Saturn, fading from magnitude +0.5 to +0.7 in May, shines in the southeast to south each evening about 15° upper right of slightly fainter Spica. Just to the upper right of Saturn is the 3rd-magnitude star Gamma Virginis (Porrima), whose separation from the planet shrinks from about 1½° to ½° in May.

In a telescope, Saturn's rings are a narrow slash 7° or 8° from edge-on. Examine the globe's exposed northern hemisphere for any streaky remains of the great white outbreak that began last December. And Gamma Virginis is a famous double star, a high-power telescopic showpiece in its own right (see the April issue, page 56).

Saturn and Gamma Virginis are highest in the south about 11 p.m. (daylight-saving time) on May 1st and 9 p.m. on May 31st.

Uranus, **Neptune**, and **Pluto** are best observed just before the sky starts to grow light. Finder charts will appear in later issues, when these bodies are visible in the evening sky.

DAWN

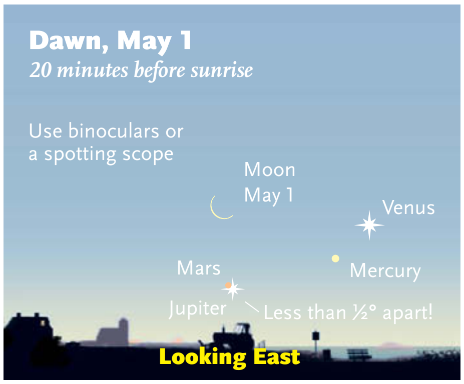
Venus, Jupiter, Mercury, and Mars fit within a 6° binocular field on May 12th, and within a 10° circle from May 2–19. After that, Jupiter exits the grouping to the upper right, but the other three planets remain tightly clustered almost until month's end.

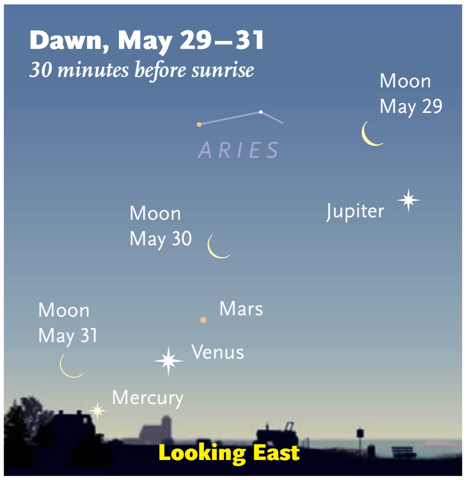
Venus, shining at magnitude –3.8, is obvious to the unaided eye all month despite its modest altitude.

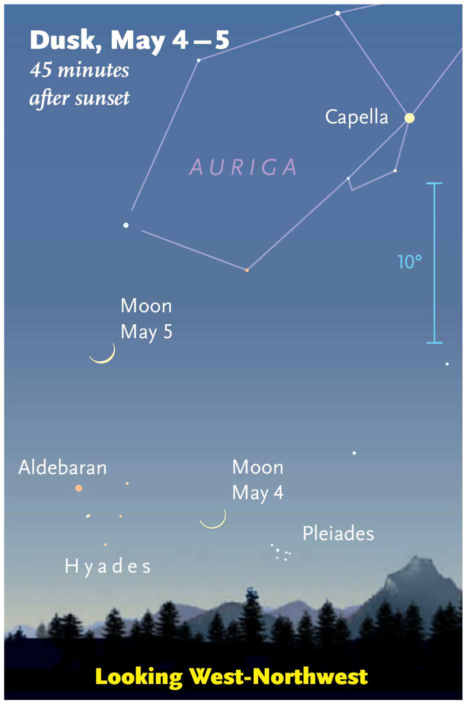
SkyandTelescope.com/May2011Planets has more graphics of this month's four-planet dance.

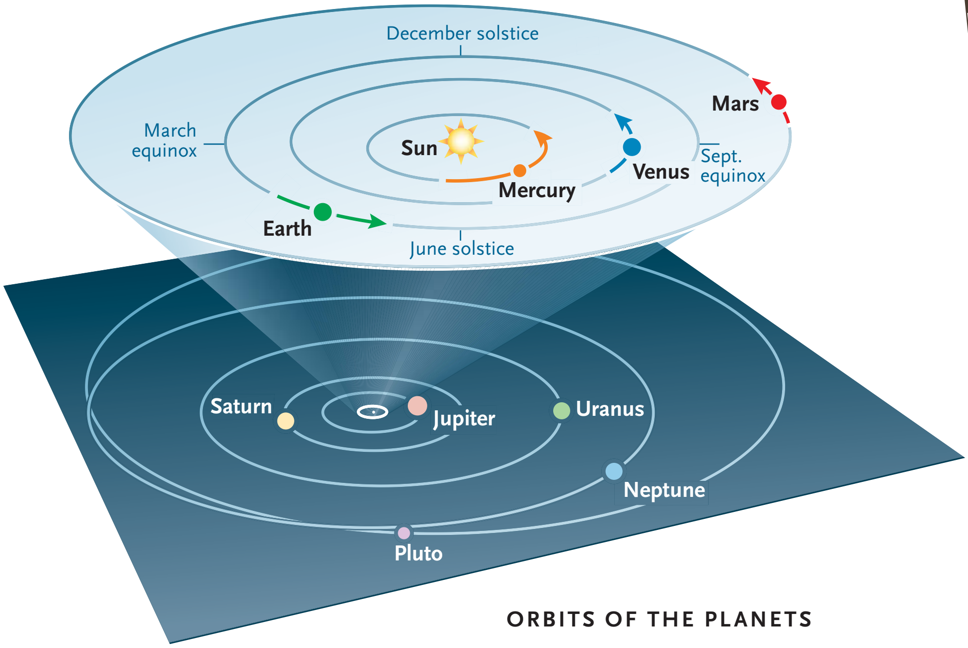
Jupiter (magnitude –2.1) is very low at the beginning of May for observers at mid-northern latitudes, and hard to spot without binoculars. But it soon becomes an easy naked-eye target, ending the month much higher than Venus.

Mercury brightens from magnitude +0.8 to –0.9 during May, but it's so low that it will be difficult or invisible without optical aid all month. Telescopes show its disk shrinking widthwise from 9.2″ on May 1st (almost as wide as Venus, at 11.6″) to 5.5″ on May 31st. Meanwhile, Mercury's phase enlarges from 31% to 83% lit.



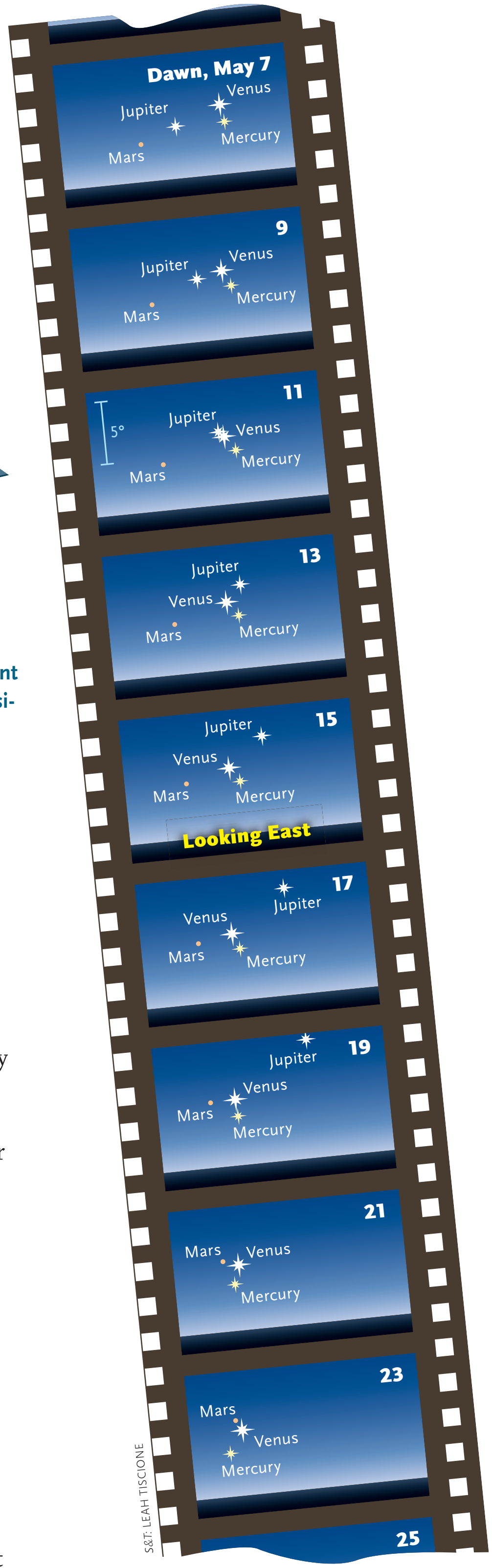






ORBITS OF THE PLANETS

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.



Venus, Jupiter, Mercury, and Mars dance very low in the east in May. This is how they appear 30 minutes before sunrise at 2-day intervals.

Mars is faint and small, magnitude +1.3 and 4.1″ wide. It appears higher each morning, but it's too low to see without optical aid until the last week in May at the very earliest.

May 1: Venus rises about an hour before the Sun for viewers at mid-northern latitudes, with a thin crescent Moon 10° to its left. Much dimmer Mercury rises 10 minutes after Venus and 3° to its lower left. Ten minutes after that, Jupiter and faint Mars rise just 0.4° from each other and far below the Moon, as shown on the facing page.

May 2: the Moon is very thin and difficult, less than 2° high 30 minutes before sunrise, and 11° to Jupiter's lower left.

May 7–15: During these nine mornings, Venus, Jupiter, and Mercury form the first of the month's two remarkably long-lived, overlapping "trios" — three planets within 5° of one another.

May 7th is also when Venus and Mercury, matching motions, begin an amazing run of 14 days within 1½° of each other without ever having a conjunction in right ascension. Venus and Mercury remain within 5° of each other from April 29th through May 28th — a month-long "quasi-conjunction!"

But by far the most thrilling events between May 7th and 15th are the *close conjunction of brilliant Venus and Jupiter* and the *greatest concentration of the four planets*. On May 11th Jupiter is about 0.6° upper left of Venus. On May 12th, with Jupiter still just 1° above Venus, the four planets form their most compact grouping — 6° wide. The Jupiter-Venus-Mercury trio is near its tightest (2.1° wide) on both mornings.

May 15–25: Jupiter moves to the upper right relative to Venus and Mercury, which close in on Mars and then pass to the left of it. The *Venus-Mercury-Mars trio* begins on May 15th, the last morning of the Venus-Jupiter-Mercury trio, and lasts through May 25th. It is tightest — just over 2° wide — on the 21st. After that Mercury drifts slowly off to the lower left while still brightening, and Venus pulls within 1° of Mars on May 23rd.

May 26–30: The planets pull rapidly apart. The separation between Mercury on the lower left and Jupiter at upper right increases from 18° on May 26th to 26° on May 31st. The Moon passes about 5° upper left of Jupiter on the 29th, 7° upper right of Venus on May 30th, and 3° above Mercury on May 31st. ✦

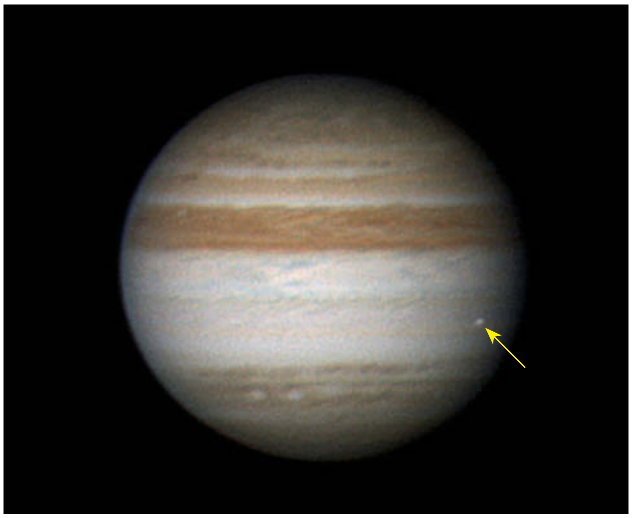
Sean Walker

Planetary Imaging Primer

Planetary observing today involves cameras as much as eyeballs.

It's an exciting time for planetary observers. Since 2009, Jupiter has been whacked by no less than three objects and its South Equatorial Belt disappeared and then re-emerged in equally spectacular fashion. In each case, dedicated amateurs who regularly photograph the planets recorded these events and recognized the importance of their observations. They quickly alerted the world-wide network of planetary observers, which include a number of professional planetary scientists.

Solar system observing today isn't limited to just looking through an eyepiece. Of the four recent Jupiter impacts (including Comet Shoemaker-Levy 9), all were discovered by photographic means. However, the two most recent events were fleeting occurrences lasting just seconds, and they left no visible mark on the gas giant's cloud tops. If these flashes had only been observed visually, scientists likely would have discounted both as spurious observations. But because the observers had recorded the planet through their telescopes with high-speed video cameras, they could present concrete proof the events actually took place.



CHRISTOPHER GO

This frame of a video from Philippine amateur astronomer Christopher Go offers proof of an impact on Jupiter in June 2009. The arrow points to a flash from the impact. Without an actual image, it's doubtful that professional astronomers would have taken visual observations seriously.

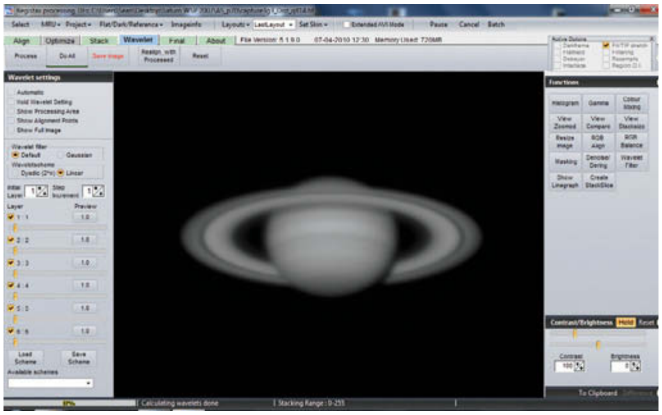
To get involved in planetary photography, you only need to add a digital camera and laptop computer to your observing toolkit. While any astronomical CCD or DSLR camera will capture respectable planetary images, high-speed "webcam" style cameras are best suited for planetary work. These lightweight cameras can capture dozens of frames per second in an uninterrupted data stream, allowing you to catch sharp frames during fleeting moments of atmospheric steadiness. Introductory models are available for as low as $50, though high-end cameras can cost $1,000 or more.

Recording high-quality planetary videos through your telescope is a relatively straightforward process. First, make sure your telescope is well collimated and your mount is tracking properly. Use a high-power eyepiece to ensure your target is centered in the field of view, then attach the camera to an eyepiece or Barlow lens to increase the magnification, and simply put this into the eyepiece holder. Next, adjust the focus and exposure until you clearly make out distinctive markings on your target. Once you're satisfied, start recording your images.

Each planet requires different considerations while imaging. Jupiter and Saturn rotate very fast, so in order to avoid blurring detail, color video clips shouldn't exceed 2 minutes. Mars rotates much slower, and videos as long as 6 minutes will still avoid rotational blurring. Both Venus's cloud tops and Mercury turn so slowly that recording several long videos and combining the results into one image will not show any appreciable rotation. Uranus and Neptune are so distant that recording vague bright and dark bands on their cloud tops is just within the possibility of amateur equipment.

When using a monochrome camera with red, green, and blue color filters, you should capture your movies within the aforementioned time spans to minimize rotation of cloud or surface features between your color videos.

Each planet reveals additional information when recorded through specialized scientific filters. Jupiter presents a radically different appearance compared to visible light when imaged through a narrowband filter centered on the wavelength of 889 nanometers, where methane gas absorbs light. The methane filter is less effective when imaging Saturn, due to the long exposures required for achieving sufficient exposure through amateur equipment.



S&T: SEAN WALKER

Left: **Software such as *RegiStax* assesses image quality, align frames, and stacks the best results.** ***Right:*** **The author's planetary imaging setup on his 12½-inch Newtonian reflector includes a lightweight monochrome Imaging Source camera, a color filter wheel, and a short Barlow lens used to increase the image scale on the camera's detector.**

Near-infrared filters will present high-contrast albedo features on the surfaces of Mars, Mercury, and the Moon. Near-IR light is also less affected by atmospheric turbulence.

At the long wavelength of 1,000 nanometers (1 micron), Venus can reveal thermal emissions emanating from its blazing-hot surface (*S&T*: October 2010, page 72). Venus also presents enigmatic cloud detail when imaged through ultraviolet filters (*S&T*: October 2007, page 96).

Once you've recorded your data, the next step is to process your videos into sharp images. The table below lists software that easily sorts your sharpest frames into a final color picture. Though some of these programs include more extended image-processing tools, each one works well for planet photos. Just remember to carefully watch each of your videos; stacking them will obliterate any transient events.

Consider adding video to your observing arsenal. Who knows, you may be the first to discover another fantastic event that could advance our understanding of the solar system. ✦

S&T *imaging editor* ***Sean Walker*** *records the Sun, Moon, and planets from his driveway in Manchester, New Hampshire.*

Planetary Stacking Software

Program	Website	Operating System	Price
AstroStack	www.astrostack.com	Windows	$39
Astro IIDC	www.outcastsoft.com/ASCASTROIIDC.html	Apple	$110
AutoStakkert!	www.astrokraai.nl/autostakkert.php	Windows	Free
AviStack	www.avistack.de	Windows	Free
Craterlet	www.stark-labs.com/page26/craterlet.html	Windows	Free
IRIS	www.astrosurf.com/buil/us/iris/iris.htm	Windows	Free
Keith's Image Stacker	http://keithwiley.com/software/keithsImageStacker.shtml	Apple	$15
K3CCDTools	www.pk3.org/Astro/index.htm?k3ccdtools.htm	Windows	$49.99
Lynkeos	http://lynkeos.sourceforge.net	Apple	Free
MaxIm DL	www.cyanogen.com	Windows	$199
Ninox	http://acquerra.com.au/astro/software/ninox	Linux / Windows	Free
RegiStax	www.astronomie.be/registax	Windows	Free

Gary Seronik

Orion's Robo Dobsonian

Good things happen when Go To pointing meets a mass-market Dobsonian.

Orion SkyQuest XT10g GoTo Dobsonian Telescope

U.S. price: $1,099.95
Orion Telescopes & Binoculars
89 Hangar Way, Watsonville, CA 95076
800-676-1343, www.oriontelescopes.com

ALL PHOTOGRAPHS BY THE AUTHOR

The addition of computerized pointing on a mass-produced telescope makes the Orion XT10g one of the first in a new breed of Dobsonian.

Since debuting in 1980, commercial Dobsonians have gone though numerous evolutionary updates. The design has morphed from a boxy, no-frills, cardboard-and-plywood light bucket to sleek instruments boasting impressive arrays of bells and whistles. And the latest, and perhaps most game-changing bell (or is it a whistle?), is the addition of motorized Go To pointing on a mass-market Dob. As soon as Orion Telescopes & Binoculars introduced its line of 8-, 10-, and 12-inch robo Dobs, we arranged to borrow a 10-inch for review.

Less Assembly Required

The XT10g arrived in two large boxes — one containing parts for the mount, the other the fully assembled optical tube assembly. (The 12-inch model ships with its primary mirror in a separate box.) I was expecting a scope of this sophistication to require a few extra assembly steps, but the XT10g took less time to assemble than Orion's more-basic SkyQuest XX12 that I reviewed in the July 2009 issue, page 34. This is because most of the additional components (the motors and drive train) are already integrated into the mount. Apart from plugging in a couple of cables, there's nothing extra to attach. Indeed, so long as you carefully follow the instructions, the Go To feature doesn't present any new opportunities to go wrong. It took me about an hour to assemble the XT10g using the tools included with the scope.

One word of caution: be careful unpacking the mount. Sandwiched between the ground board and the rocker's base is a foam doughnut surrounding the azimuth gear. If you normally dispose of packing materials first and ask questions later, don't! As the instructions note, this piece of foam is part of the mount.

WHAT WE LIKE:

Very good optics

Easy to assemble and use

Extensive feature set

WHAT WE DON'T LIKE:

Image vibration

Unexceptional pointing accuracy

One of the scope's altitude trunnions rests on a pair of roller bearings while the other engages a large dovetail fitting attached to the altitude motor, as shown in the photo on page 54. A nicely designed captive hand knob clamps the tube to the mount, and making the connection takes only a moment. As such, it's very easy to separate the scope and mount for transporting and storing.

Pick a Mode, Any Mode

The once-heated debates about the virtues of Go To are a thing of the past. When a new computerized instrument appears on the market today, the discussion revolves around its pointing accuracy, feature set, and user-friendliness. Not to give away the punch line, but the XT10g scores "good," "excellent," and "good" in these categories. The devil, however, is in the details, and there are plenty of factors to consider before deciding if this is the scope for you.

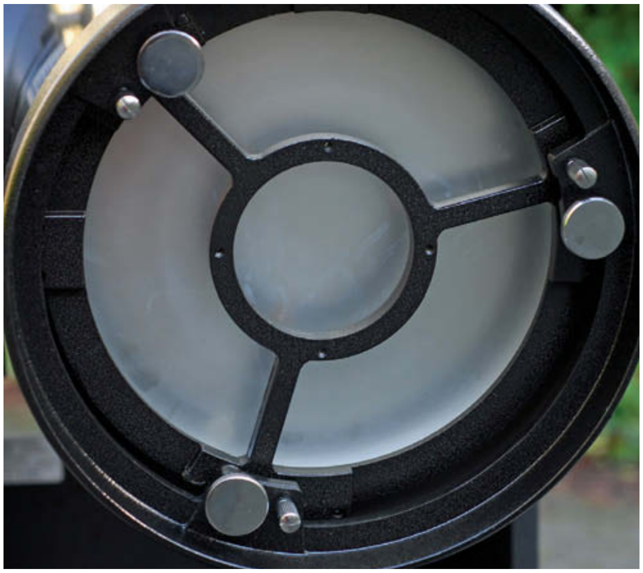
The XT10g is a motorized Go To telescope with a computerized hand control. It's also a Dobsonian, and can be manually moved like one (albeit, one with sticky motions), but I suspect most users would do so only if 12-volt DC power to run the scope's electronics isn't available. Still, it's nice to know that if your battery runs dry, you're not left standing next to an inert heap of hardware.

The scope has two modes of motorized operation: Go To, and what Orion calls "Auto Tracking." The latter simply allows the instrument to operate like a motor-driven altazimuth telescope without the computerized pointing. This is very handy for when you just want to look at the Moon or planets and don't want to bother with the celestial alignment necessary for Go To pointing. With Auto Tracking, all you do is set the scope level and pointed north, turn on the power, and enter the time and date when prompted by the hand controller. After that you can aim the scope at your target (either by slewing with the motors or pushing it by hand), and enjoy the view while the motors automatically keep the target in the field of view. Because auto tracking doesn't require alignment stars, you can even use it during the day or when the sky is too bright to easily see stars, as was the case one memorable morning when I set up to view Jupiter in the dawn.

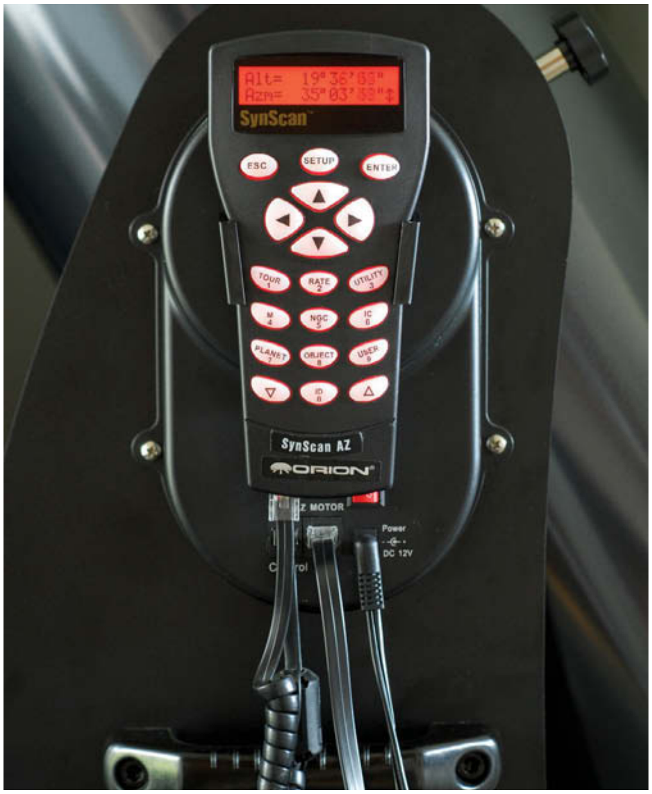
As handy as Auto Tracking is, I found a couple of minor niggles worth mentioning. Although the tracking was quite good, I needed to regularly nudge the scope with the hand control's buttons to keep objects centered while observing at high magnifications. Also, Auto Tracking setup requires a lot of button pushing. Partly this is because you have to set the hand unit's clock whenever you power up the scope (the computer reverts to 20:00 hours and the date of your previous observing session), but also because the feature is buried deeper in the hand control's menu system than is ideal for a quick-use item.

Going To It

For Go To functionality, you have to perform an alignment procedure after you've entered the specifics of your location (a setting retained in memory) and the current



The open design of the scope's mirror cell helps the primary cool to the night temperature for optimal performance. The cell's three mirror-support points (hidden behind the radial struts) are positioned roughly 40% of the way from the mirror's center to its edge, acknowledging recent thinking on mirror-cell design. The assembly's three large hand knobs help make collimation relatively easy.



The brains of the operation reside in Orion's SynScan computerized hand unit. Among the deep-sky objects included in its memory are 7,840 NGC objects as well as the Messier and Caldwell catalogs. Tens of thousands of stars help bring the total database to 42,900 objects.

Left: The scope's focuser-side altitude trunnion engages a dove-tail fitting on the motor and bearing assembly attached to the base, and locks into position with a large, captive hand knob (***inset***). Loosening the hand knob allows you to quickly and easily separate the optical tube assembly from the mount for transport and storage. ***Right***: A silky smooth 2-inch focuser is standard equipment with the XT10g. The focuser features a 10:1 reduction mechanism for ultra-precise fine focus. The red-dot finder is familiar equipment to most readers.

time and date. The Orion scope has two alignment modes to choose from. One is for people who can't identify anything in the sky (called Brightest Star Alignment), and the other is for those who can pick out such stars as Arcturus and Vega (Two-Star Alignment). In the bright-star procedure, you point the scope at the brightest star visible and, using compass directions, tell the computer where it is in the sky. The computer makes a guess as to which star you've selected, and then slews the scope to another bright star, which you center in the eyepiece. Essentially this is two-star alignment with some assumptions.

The actual two-star alignment requires you to aim the scope at two known stars chosen from a menu displayed on the hand unit. Neither method is particularly difficult or time consuming. The manual states that the two-star alignment is more precise, though it's unclear why this should be so since both methods basically amount to the same thing.

After many nights of testing, I found the Go To pointing accuracy adequate, but not exceptional. The computer always put the desired object within the 2° field of view of the supplied low-power eyepiece, but almost always closer to field's edge than its center. This is fine for most purposes, but if you're trying to use Go To pointing to sort out which galaxy is which in the Virgo Cluster, for example, you're going to be left scratching your head.

Can the pointing accuracy be improved? Perhaps. The hand unit's menus suggest that possibility, but the owner's manual (revision B dated November 2010) doesn't provide the necessary detail. For example, the menu has a function called Set Backlash about which the manual states "for improved pointing accuracy, it is important that the backlash value is set to be equal or greater than the actual amount of backlash between the gears." That's fine, but the manual is far too vague about how you make the backlash situation better.

SPECIFICATIONS & MEASUREMENTS*	
SkyQuest XT10g	
Aperture	10 inches (254 mm)
Central obstruction	2.56 inches (26%)
Focal length	47.1 inches (f/4.7)
*All values measured by *Sky & Telescope*.	

The manual also lacks basic pointers for choosing optimal alignment stars. Although you can select any two stars in the alignment list for this procedure, some pairings will give better results than others. These sections need to be brought up to the same high standards as the rest of the manual.

With the scope aligned, a feature called Pointing Accuracy Enhancement (PAE) allows you to sync the computer to the object of interest, which helps locate other objects in the immediate area. But it doesn't improve overall pointing accuracy. For example, if you sync on the magnificent globular cluster M13 in Hercules, and then make a Go To slew to the globular M92 about 10° away, PAE doesn't help. If, however, you then return to M13, it will be perfectly centered in the field of view.

Long slews can try one's patience, especially if a large amount of azimuth movement is needed. At maximum speed, the azimuth motor drives the scope at a leisurely 1.7° per second, requiring nearly a full minute to go from due east to due west. The altitude speed is twice as fast. You can, however, move the scope rapidly by hand without

The scope includes two eyepieces: a 28-mm for wide-field viewing and locating objects, and a 12.5-mm illuminated reticule Plössl to aid in centering alignment stars. A handy eyepiece rack attaches to the front of the rocker box.

losing the computer's celestial alignment.

My biggest complaint about the scope's motorized operation is that high-magnification views are compromised by vibration. Every time the motors make a tracking "step," the image jiggles. There was often only a brief moment of steadiness between jiggles. This was troublesome at the moderate- and high-magnifications I used for viewing planets and double stars. A set of vibration-reduction pads placed under the feet on the scope's base helped a great deal, but didn't completely eliminate the problem.

And the Scope...

Concentrating on the computerized capabilities makes it easy to forget that none of those features really matter if the views through the scope aren't up to snuff. Fortunately, this is where the XT10g scores high marks. Most impressive is the 10-inch primary mirror. From the outset I knew it was a winner — the fabulously detailed views of Jupiter demonstrated its quality. Bench and star testing revealed it to be a very good paraboloid with no detectable astigmatism or turned edge.

Enhancing the mirror's performance is the open-frame support cell, which exposes much of the back surface of the mirror to the ambient air, helping the glass reach thermal equilibrium. The cell has large hand knobs, which make precise collimation easy; the primary is center-marked, and a collimation cap for the focuser is included with the scope. This is how every reflector should be sold.

I also really liked the focuser. It's a nicely made 2-inch model with a fine-focus control that allows very precise focusing at high magnifications. Orion includes a pair of interesting eyepieces with the XT10g. There's a very useful 2-inch, 28-mm DeepView eyepiece, which provides a 2° true field with the 10-inch. The other is a 12.5-mm Plössl eyepiece with an illuminated reticule. While the reticule is helpful for centering alignment stars, it's also somewhat of a distraction in what would otherwise be a nice medium-power 96× eyepiece for general observing.

Overall, the Orion XT10g is a well conceived scope with some first-rate features and very good optics. Ideally, the pointing accuracy would be a touch better, but the only real barrier to fully exploiting the scope's capabilities is the motor-induced vibration. There's no question in my mind that the pluses outweigh the minus here by a substantial margin — especially when you consider how much telescope and technology you're getting for the money. For deep-sky enthusiasts, the XT10g should prove a very enjoyable performer. ✦

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*Contributing editor **Gary Seronik** is an experienced telescope maker, user, and reviewer. He scans the skies from his home near Victoria, B.C., Canada, and can be contacted through his website: www.garyseronik.com.*

The XT10g separates into two manageable pieces that are easy to carry. Assembling (and disassembling) the system takes only moments and requires no tools.

Big Black Asteroid in Libra

The largest asteroid you've probably never heard of is now unusually close.

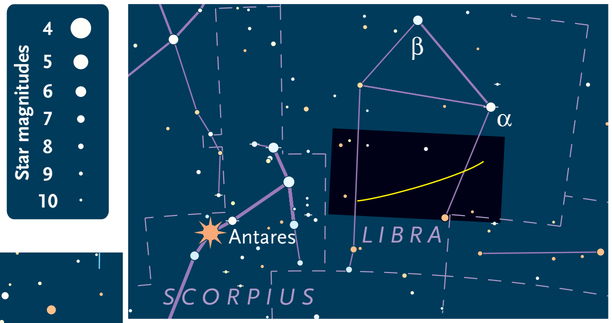
THE ASTEROID 10 HYGIEA is the fourth-largest object in the asteroid belt, after Ceres, Pallas, and Vesta. So why haven't many of you heard of it?

The reason, no doubt, is that Hygiea is the largest of the dark carbonaceous asteroids, type C, that dominate the asteroid belt's outer reaches. Hygiea's blackish surface (albedo 7%) and its distance from Earth make it appear dim despite its size: an oblong 320 by 220 miles (520 by 360 km).

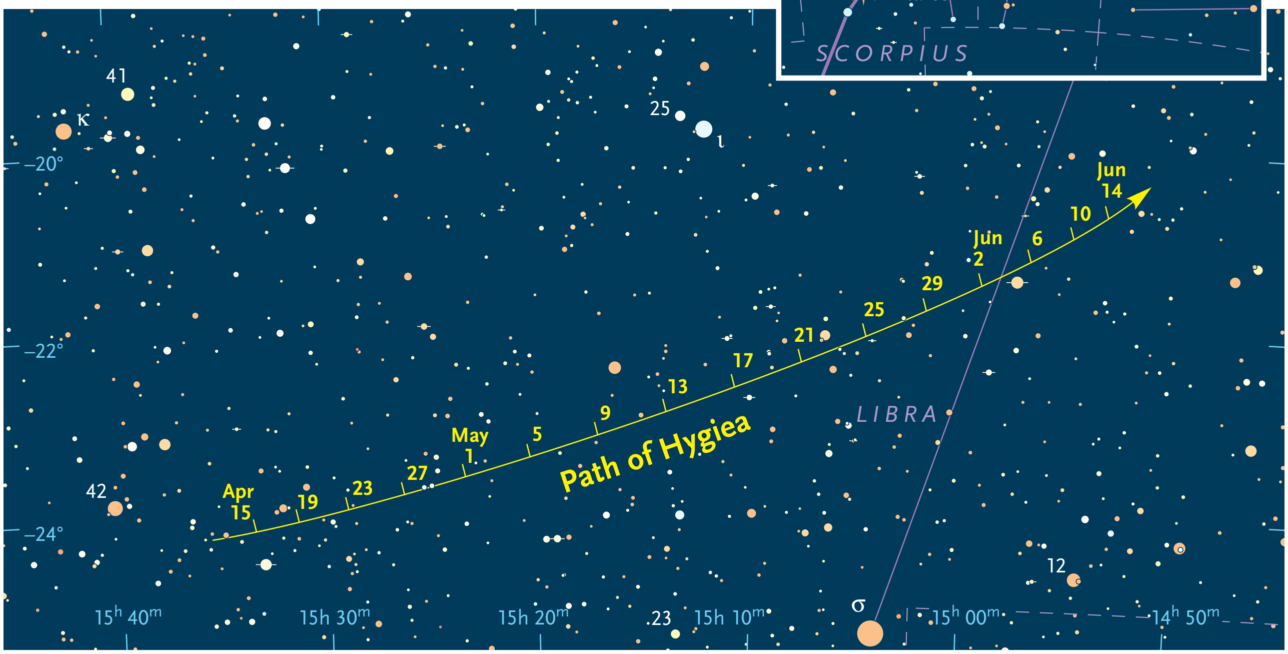
This May, however, Hygiea swings through one of the closest oppositions it can ever have. It should be as bright as magnitude 9.2 from about May 6th through 22nd. It will be brighter than 9.7 and visible in a 3-inch telescope from mid-April through mid-June, the period covered by the finder chart below.

During this time, Hygiea passes through the southern part of Libra the Scales, above Upsilon (υ) and Sigma (σ) Librae, the stars representing the scales' two swinging pans. The naked-eye landmark for locating this region is the head of Scorpius, as shown in the inset below. In May you'll have to wait up until midnight or later for this area to rise to a good altitude in the south-southeast to south.

Like the other C-type asteroids, Hygiea's surface material is similar to ancient, relatively unaltered carbonaceous chondrite meteorites. It also shows spectral evidence that minerals now at its surface were modified by water at some point. Moreover, Hygiea seems to have an unusually low density of about 2.1 grams/cm³ — more like that of the ice-and-rock Kuiper Belt objects and satellites of the outer solar system than the rock-and-metal asteroids of the inner asteroid belt.



Discovered in 1849 and named for the Greek goddess of health, the big asteroid 10 Hygiea has a black surface, rendering it only magnitude 9.2 even at this year's favorable opposition. The black rectangle at right shows the area of the finder chart below.



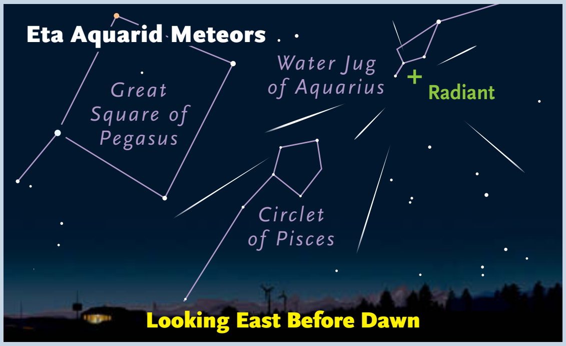
Two Asteroid Occultations

A 7th-magnitude star in Ophiuchus will disappear behind the faint asteroid 217 Eudora for up to 11 seconds late Saturday night, **May 28–29,** along a track from Florida across Oklahoma and Colorado to Oregon. The star will be high in the southeast as seen from Florida, where the occultation should happen around 2:36 a.m. on the morning of the 29th Eastern Daylight Time. It will be lower in the southeast for Oregonians, who may see the event around 11:44 p.m. on the 28th Pacific Daylight Time. The asteroid is 40 miles (66 km) wide.

Then on the **morning of May 30th,** the 4.9-magnitude orange star Nu (ν) Pegasi will be occulted for up to 1.2 seconds by the little asteroid 4569 Baerbel, only 9 miles (14 km) wide, along a thin track from southernmost California through Arizona, Colorado, and the Dakotas. You'll have to be luckily stationed to catch this one! The star will be low in the southeast around occultation time: 1:45 a.m. PDT, 2:47 a.m. MDT.

Full information for both events can be found at www.asteroidoccultation.com/IndexAll.htm, along with many more asteroid-occultation predictions worldwide.

For more about observing and timing these events, especially by video, see www.asteroidoccultation.com/asteroid_help.htm.



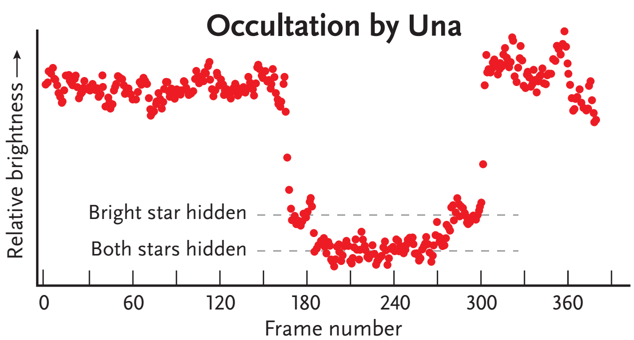
May Meteors

The Eta Aquarid meteor should peak in the dark of the Moon this year during the pre-dawn hours of May 6th. The shower is also quite active for several mornings before and after. The Eta Aquarids are usually the best meteor shower of the year for skywatchers in the Southern Hemisphere, but the numbers are lower if you're as far north as the southern U.S. and are nearly zero if you're above 40° north latitude.

The Eta Aquarids and the Orionids of October are the same meteoroid stream, shed by Comet Halley. Earth's orbit intersects the stream in two places.

DENNIS DI CICCO

On the unusually frigid night of last January 23–24, *S&T* senior editor Dennis di Cicco videorecorded a 9.1-magnitude star in Leo as it was occulted by the 13th-magnitude asteroid 160 Una. He used a 16-inch telescope fitted with an image intensifier, an aging camcorder, and an external time base. Many asteroid occultations can be recorded and timed with a much less ambitious setup!



DENNIS DI CICCO / BRAD TIMERSON

Brad Timerson of the International Occultation Timing Association (IOTA) analyzed di Cicco's video recording and produced this light curve. By surprise, the star faded and reappeared in two steps, revealing it to be a hitherto unknown binary. Using this analysis along with results from eight other observers, IOTA's Tony George determined the binary to have a separation of 0.0065 ± 0.0011 arcsecond. The step occultation is very obvious in the video, which you can watch at SkyandTelescope.com/una.

When all the Stars are Sown

Coma Berenices hosts both clusters and galaxies.

S&T: LEAH TISCIONE

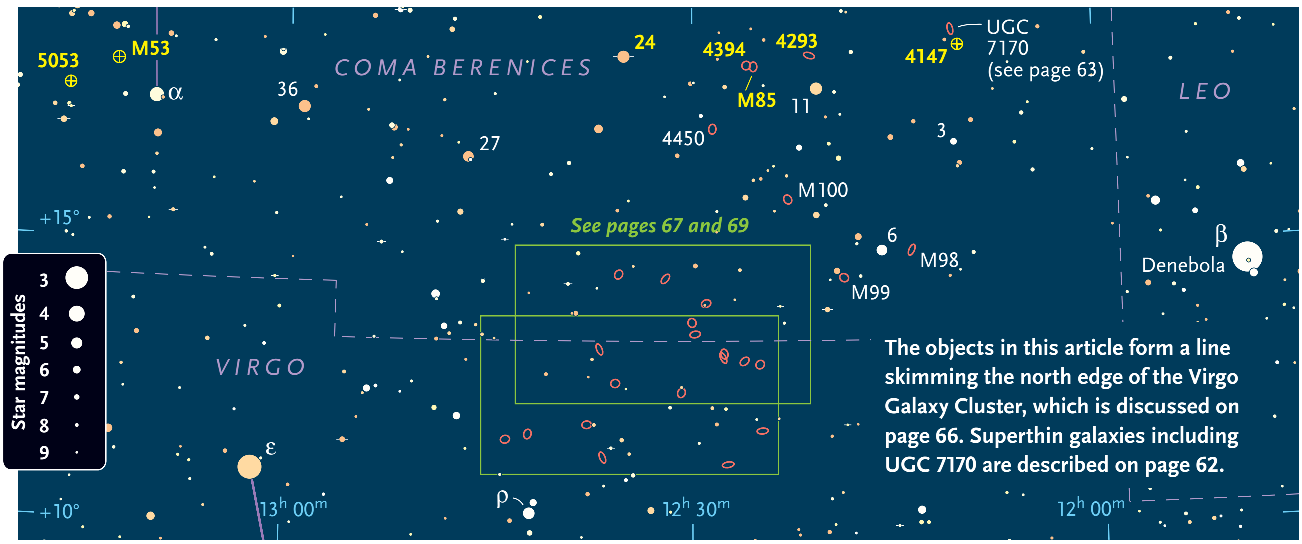
When all the stars are sown
Across the night-blue space,
With the immense unknown,
In silence face to face.
We stand in speechless awe
While Beauty marches by,
And wonder at the Law
Which wears such majesty.
— Bliss Carman,
The Heart of Night

THOUGH THEY BLEND together in hazy confusion, never do we see stars more richly sown than when gazing at sun-stuffed globular clusters or far-flung galaxies. On the walls of night, globular clusters seem to crowd around the core of our galaxy. But constellations in that direction display a paucity of bright galaxies, because such remote star cities are heavily veiled by the dust clouds that line our Milky Way. Instead, we see them best in constellations far above or below the plane of our galaxy. Away from the hubbub of the Milky Way and its bright young stars, some of the dimmest constellations offer us the greatest starry majesty in the form of distant galaxies.

Coma Berenices is one of the richest constellations for galaxy lovers, yet far as it is from the galactic plane, it still harbors a few nice globular clusters. The brightest is **Messier 53**, the globular listed as having the highest galactic latitude in William Harris's *Catalog of Milky Way Globular Clusters*. (http://physwww.mcmaster.ca/~harris/Databases.html). In his 1844 *Bedford Catalogue*, William H. Smyth calls this "brilliant mass of minute stars" a "ball of innumerable worlds."

Despite its great distance of 58,000 light-years, M53 is an obvious fuzzball with a brighter core when seen through 18×50 binoculars from my semirural home. It shares the field of view with Alpha (α) Comae and sits south of the western end of a meandering asterism of several field stars. Through my 105-mm (4.1-inch) refractor at 87×, M53 is roughly 8′ across, with two field stars watching its south-southeastern side. The granular core is half as large and grows much brighter toward the center. A lone star glimmers in its northeastern edge. M53 is a beautiful cluster in my 10-inch reflector at 213×. Its mist precipitates into myriad stars, some right down to its brilliant center. The draggled fringes of the 10′ halo appear sparsely populated, while its inner reaches sport many relatively bright stars.

When observing star-spattered M53, you're seeing a globe of roughly 260,000 stars. **NGC 5053** is close to M53 both in space and as seen on the sky, but it's a much less concentrated cluster, commanding only 43,000 stars.



The objects in this article form a line skimming the north edge of the Virgo Galaxy Cluster, which is discussed on page 66. Superthin galaxies including UGC 7170 are described on page 62.

NASA / ESA / STSCI / WIKIMEDIA COMMONS

This Hubble Space Telescope high-resolution view of Messier 53 reveals individual stars nearly to the core.

In 18×50 binoculars NGC 5053 is a small faint glow making a squat isosceles triangle with M53 and Alpha Comae. A faint star guards its east-southeastern edge. My 105-mm scope at 87× shows a ghostly glow spanning 6′ with a slightly brighter center. NGC 5053 swells to 8′ through the 10-inch scope at 213×, and it shows about two dozen stars sprinkled across its face. Former *Deep-Sky Wonders* columnist Walter Scott Houston described this cluster as a "gem of weaving fairy fire" when seen through larger scopes (*S&T*: May 1953, page 196).

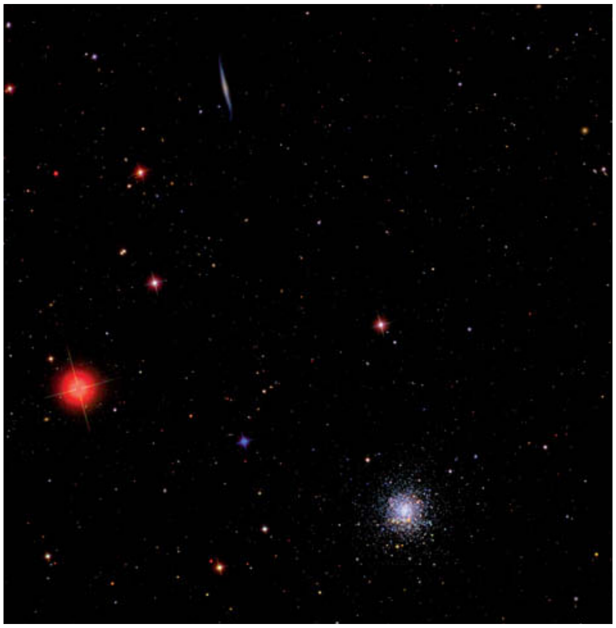
Exactly 9° west of M53, **24 Comae** gleams at magnitude 5.0 and is visible to the unaided eye from my home. A glance through my 105-mm refractor at 17× discloses a lovely double star whose golden 5.1-magnitude primary is married to a white 6.3-magnitude companion. Through my 10-inch reflector, the dimmer star shows a touch of yellow.

Many observers see the companion star as bluish, a common color-contrast illusion experienced when a yellow, orange, or red star is seen in close proximity to a fainter star that isn't strongly colored. The illusion can sometimes be dispelled by using high magnifications to widely separate the stars. Spectral studies show that the companion star of 24 Comae is actually a close binary whose blended components shine pale yellow-white.

Sweeping 2.3° west from 24 Comae brings us to **Messier 85**, the northernmost Virgo Cluster galaxy listed in Charles Messier's 18th-century catalog. M85 is a lenticular (lens-shaped) galaxy seen nearly face on. Faint outer shells that appear on deep images, and astronomically recent star formation, may be the result of a merger with another galaxy.

SLOAN DIGITAL SKY SURVEY

Messier 85 (on the right) is big and bright, but relatively featureless. Its companion NGC 4293, by contrast, is a beautiful example of a barred spiral galaxy.



SLOAN DIGITAL SKY SURVEY

The small, fairly distant globular cluster NGC 4147 shares the same field of view with the superthin galaxy UGC 7170, 18′ to its north-northeast. UGC 7170 is discussed on page 63.

Through 18×50 binoculars M85 is a fairly bright oval with a small core. The galaxy spans about 4′ × 3¼′ and leans north-northeast in my 105-mm refractor at 87×. It grows much brighter toward a 1′ core with a stellar nucleus. A 10th-magnitude star is perched near the galaxy's edge, southeast of the nucleus. In my 10-inch reflector at 187×, M85 is just a tad longer and wears a superposed star ¾′ north-northeast of center.

The views through the 105-mm and 10-inch scopes also encompass M85's companion galaxy, **NGC 4394**. My little refractor displays a very faint 1¾′ × ½′ spindle, elongated southeast-northwest and dominated by a comparatively large, bright core. A faint star sits 3′ south. In the larger scope, the spindle is enfolded in a faint 2½′ × 1½′ halo, and its core is oval with a stellar nucleus.

NGC 4394 is a barred spiral galaxy. The spindle extensions we see are the galaxy's bar, and the faint halo is the realm of its spiral arms.

The odd-looking galaxy **NGC 4293** lies just 1° west and a shade north of M85. It's the northernmost *New General Catalogue* member of the Virgo Cluster (see page 66). The *NASA/IPAC Extragalactic Database* (NED) lists NGC 4293 as type (R)SB(s)0/a. This complex classification means that the galaxy is a transition type between a barred lenticular and a barred spiral, with weak arms that start from the end of the bar and an outer ring.

In my 105-mm refractor at 76×, NGC 4293 shows an extremely shallow S curve that's wider in the center. A fainter glow fills the curves and feathers the edges of the S, giving the galaxy a slender lens shape roughly 3′ × 1′ tilted east-northeast. The wider core area spans about ¾′. A wavy chain of field stars wanders eastward from the galaxy, and a lone star lies off the galaxy's western end. The faint halo of NGC 4293 grows to 4½′ × 1½′ through my 10-inch reflector at 187×. The galaxy's unusual structure stands out well, and even the core seems to have a slight S shape. Three faint stars hug the galaxy's perimeter north, east, and south-southwest.

NED gives the mean distances to M85, NGC 4394, and NGC 4293 (determined from astrophysical literature) as 57, 55, and 51 million light-years, respectively.

We come to our final globular cluster, **NGC 4147**, 2.6° west of NGC 4293 and 1.7° north of 3 Comae. It's the least populous of our three globulars, with approximately 25,000 stars, and the most distant at 63,000 light-years. The brightest stars of M53 and NGC 5053 are about magnitude 13.8, while those of NGC 4147 are only magnitude 14.5.

Through 18×50 binoculars NGC 4147 is a moderately faint and small puff with a brighter heart. My little refractor at 87× shows this globular at the southwestern end of a 19′ wedge that it forms with five field stars, magnitude 8 and fainter. The faint 2½′ halo enfolds a mottled 1½′ core that grows brighter toward the center. In my 10-inch scope, the asterism gains a couple of stars and becomes a fir tree that points east-northeast, with NGC 4147 at its base. At 220× several extremely faint stars sparkle in and out of view across the cluster, and the bright core houses an intense quasi-stellar center. Even my 14.5-inch scope at high power shows me only 20 stars.

Whether you favor globular clusters with their tens to hundreds of thousands of stars or galaxies with their billions of stars, you can behold the majesty of such richly sown wonders on any clear, dark night. ✦

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

Queen Berenice's Crown Jewels

Object	Type	Mag(v)	Size/Sep	RA	Dec.
Messier 53	Globular cluster	7.6	13′	13^h 12.9^m	+18° 10′
NGC 5053	Globular cluster	9.5	10′	13^h 16.5^m	+17° 42′
24 Comae	Double star	5.1, 6.3	20″	12^h 35.1^m	+18° 23′
Messier 85	Galaxy	9.1	7.1′ × 5.5′	12^h 25.4^m	+18° 11′
NGC 4394	Galaxy	10.9	3.6′ × 3.2′	12^h 25.9^m	+18° 13′
NGC 4293	Galaxy	10.4	5.6′ × 2.6′	12^h 21.2^m	+18° 23′
NGC 4147	Globular cluster	10.3	4.4′	12^h 10.1^m	+18° 33′

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.

The View from Edge-on

Hone your observing skills on superthin galaxies.

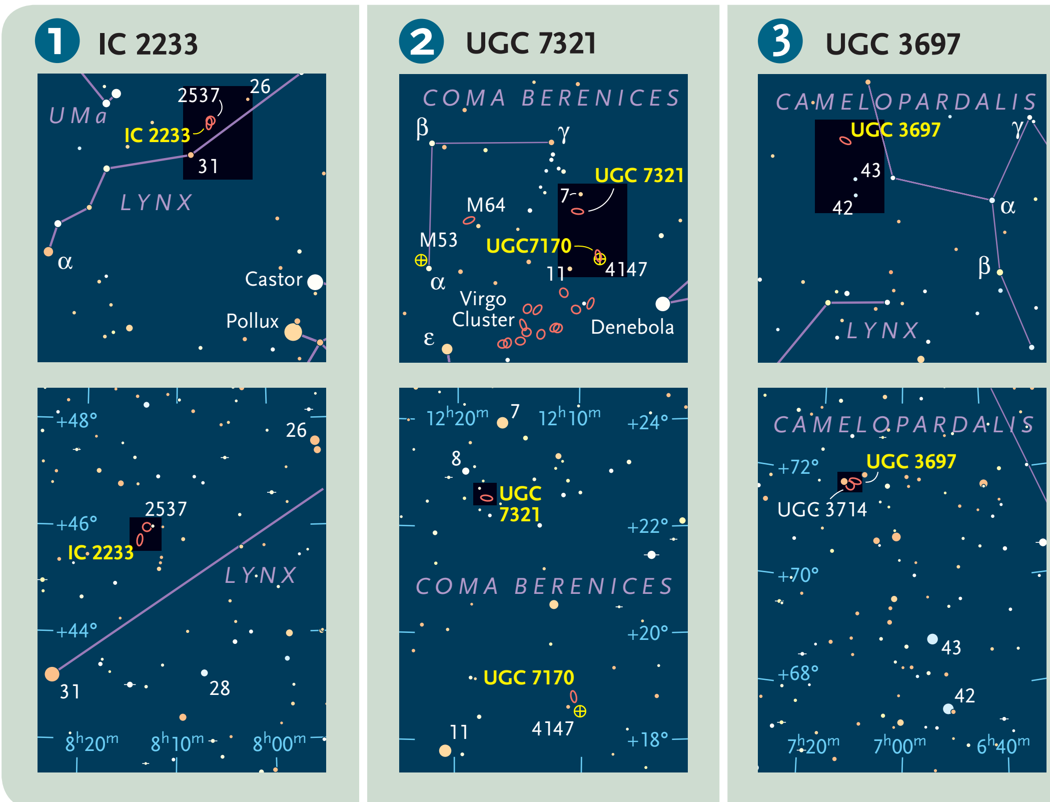
When the plane of a spiral galaxy tilts directly toward our line of sight, the edge-on perspective can provide a breathtaking view of the bright central bulge and equatorial dust lane. NGC 4565 epitomizes the beauty and symmetry of these features. But not all disk galaxies contain large bulges and obscuring dust bands.

Highly flattened edge-on galaxies with little or no bulge are called flat galaxies. The *Revised Flat Galaxy Catalogue* (RFGC) includes 4,236 galaxies with an axial ratio of 7:1 or higher and a major axis extending at least 0.6′.

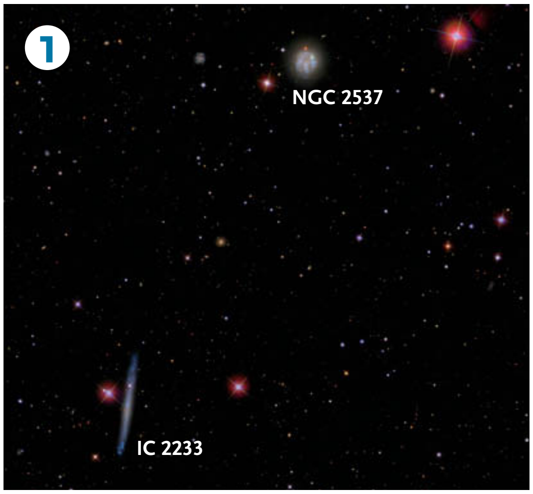
The most extreme edge-ons are known as superthin galaxies, a term coined in 1981 by researchers Jean Goad of Kitt Peak and Morton Roberts of the National Radio Astronomy Observatory. These wafer-thin galaxies have axial ratios ranging from 9:1 to 20:1 and consist of gas-rich late-type spirals (Sc, Sd, or Sm) that lack a discernible bulge or organized dust lane. Generally, superthins have a very low, even surface brightness, so they're much tougher visual targets than their magnitudes suggest. Follow along and we'll explore four of these ethereal wisps.

One of my favorites is **IC 2233**, also known as RFGC 1340 (*S&T*: March 2010, page 64). This 12.6-magnitude superthin is located 17′ southeast of the peculiar Bear-Paw Galaxy (NGC 2537) in Lynx. In my 18-inch Dobsonian at 100×, a needle-thin slash is just visible, tilting north-northwest to south-southeast. Use higher magnification to darken the background and boost the contrast. This sliver is easier to view at 220× and extends 1.8′ × 0.2′. A 14th-magnitude star is perched at the north tip, and a pair of 10th- and 13th-magnitude stars lies just off the east side.

Last April I had a stunning view of this superthin at 510× in the 48-inch f/4.0 Dobsonian of Texan amateur



The thumbnail charts show stars to magnitude 5.5 and the close-up charts to magnitude 9.0. Each photograph includes at least one star plotted in the corresponding close-up chart. See pages 58 and 60 for a detailed chart and photograph of UGC 7170.



SLOAN DIGITAL SKY SURVEY

Superthin Galaxies

Galaxy	Const.	Mag(v)	Size	RA	Dec.
IC 2233	Lyn	12.6	5.2′ × 0.6′	$8^h\ 14.0^m$	+45° 45′
UGC 7321	Com	13.4	5.5′ × 0.3′	$12^h\ 17.6^m$	+22° 32′
UGC 7170	Com	14.3	3.3′ × 0.3′	$12^h\ 10.6^m$	+18° 50′
UGC 3697	Cam	12.9	2.2′ × 0.2′	$7^h\ 11.3^m$	+71° 50′

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

Jimi Lowrey. With this remarkable instrument, IC 2233 stretched a full 4′ × 0.25′ and displayed a mottled texture on the north side of the 14th-magnitude star.

Next let's head 4° southwest of the Coma Berenices Star Cluster to 13.4-magnitude **UGC 7321**. With a highly flattened disk yielding an axial ratio of more than 18:1, UGC 7321 is the prototype superthin galaxy. Careful viewing at 220× teases out a ghostly filament spanning 4.0′ × 0.25′ west-southwest to east-northeast. A 14th-magnitude star lies just beyond the eastern tip.

While in Coma Berenices, drop 4° south-southwest to the globular cluster NGC 4147. Little-known **UGC 7170** is a challenging 14.3-magnitude superthin situated 18′ north-northeast in the same low-power field, as shown on page 60. I usually first notice the slightly brighter central region at 100×. Using averted vision at 220×, I can glimpse razor-thin extensions reaching 1.5′ × 0.5′ and sloping south-southwest to north-northeast. Images reveal a very subtle bend to the disk. I wonder if this feature can be detected visually?

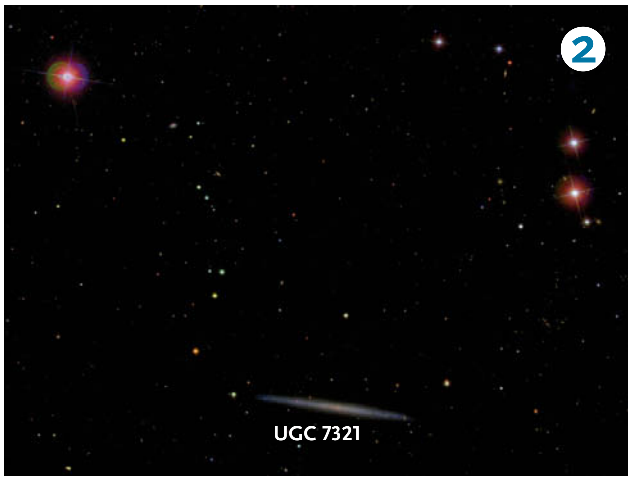
As a math teacher, I was fascinated when I first saw an image of **UGC 3697**, also known as the Integral Sign Galaxy. This distorted superthin has a striking S-shaped warp with curved extensions at the tips simulating a skinny version of the familiar calculus symbol. The twist in UGC 3697's disk is probably the result of a tidal interaction with a nearby neighbor.

UGC 3697 is located off the beaten path in Camelopardalis, just 7.6′ northwest of 11.9-magnitude UGC 3714, one of the brightest galaxies missing from the NGC and IC. The Integral Sign appears as a very faint, exceedingly thin streak, roughly 2.2′ × 0.2′, piercing the sky in an east-west direction. I was disappointed, though, when I failed to detect the intriguing curved tips with my 18-inch.

But it's a different story in Lowrey's 48-inch behemoth. At 510× UGC 3697 spans 3.3′ from tip to tip with a maximum thickness of 10″ (roughly a 20:1 axial ratio!). Near the west end the galaxy clearly hooks to the northwest and fades, terminating at an elongated knot. The east end exhibits a more gradual, subtle bending. Two faint stars straddle the galaxy, just off the north and southwest side.

If I've whetted your appetite for observing flat or superthin galaxies, check out the Astronomical League's "Flat Galaxies Club" at www.astroleague.org/observing. Its list features 222 galaxies from the RFGC, with pins and certificates awarded for reaching observing milestones. ✦

***Steve Gottlieb** loves galaxies bright and faint, fat and thin, and everything in between. To discuss them, send e-mail to steve_gottlieb@comcast.net.*



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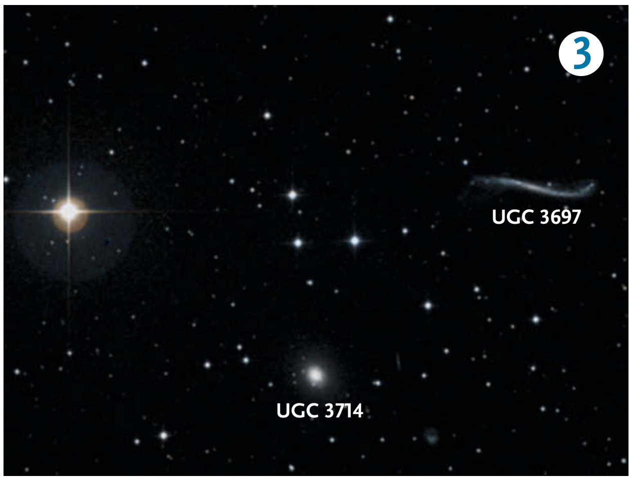


POSS-II / CALTECH / PALOMAR OBSERVATORY

The Art of Telescope Making

This striking refractor combines Victorian beauty with modern functionality.

TIM AND SHAYN-AMBER WETHERELL (3)

Australian telescope-maker and artist Tim Wetherell and his wife, Shayn-Amber, with the 8-inch refractor they use at their Canberra home.

As i've written here many times before, making your own telescope is the surest way to get exactly the instrument you want. Normally, this means building something that's optimized for a particular observing or imaging task, but some ATMs have other goals in mind. Take, for example, Australian Tim Wetherell. His beautiful 8-inch (200-mm) refractor is built to evoke the style of the Victorian era while taking advantage of modern optics.

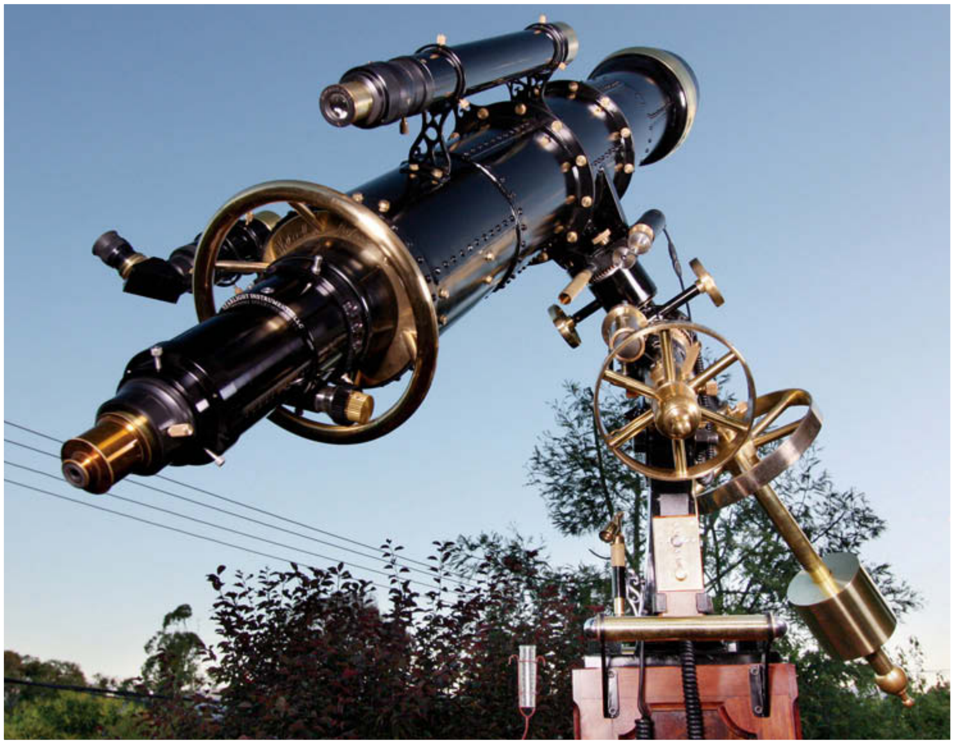
Tim is an accomplished artist and a former research physicist, so his scope's elegant combination of form and function is hardly surprising. He also has a deep appreciation for machinery from the Victorian era. "Back then," he notes, "so much effort went into making objects attractive as well as functional. It was an age when everything from steam pumping engines to gas lamps was made well, and made beautiful."

That concept guided his project. "I didn't want to build an exact replica of a Victorian instrument," he writes, "I wanted to incorporate the best of that era's perfection with modern innovations, such as ED glass and electronic tracking." Indeed, the objective is something that a 19th-century astronomer would have paid a queen's ransom for: an f/9 apochromat designed and made by Yuri Petrunin of the Telescope Engineering Company.

At the heart of the scope's antique appearance is the tube, which is fabricated from thin steel plates that are welded, riveted, and bolted together. Its design plays to Tim's strengths as a sculptor, and he notes that it was relatively easy to make. "The most difficult parts by far," he says, "were the setting circles. One hundred years ago you could have had them made by any number of skilled craftsmen, but not today." He eventually had them fabricated with the help of a talented machinist who used a 1940s engraving machine resurrected from the basement of a local university.

The setting circles are large enough to aim the scope with considerable accuracy. "I take great pleasure in identifying objects in star catalogs," he writes, "and then dialing up the coordinates on the circles. I guess it's all part of the Victorian astronomy experience."

The scope has a long list of nifty features, but one of Tim's favorites is the beautifully finished wood-covered



pier built around a steel frame. It serves as a storage cabinet for Tim's eyepiece collection. "I have quite a few (okay, way too many) eyepieces," he says, "arranged by type on rotating lazy-Susan shelves. Thanks to a pair of doors, I can access them from either side of the pier, depending which side of the meridian the scope is working."

In keeping with the style of great 19th-century refractors, Tim's scope also is equipped with a large brass "steering wheel" at the eyepiece end. Again, form and function merge. It's solid and heavy, and it counterbalances the objective to bring the balance point to the center of the tube. It also enables him to pull the scope around with ease.

Although all ATMs strive to build instruments that work well, not everyone takes the extra steps to make their scopes beautiful. Tim's refractor is an excellent example what those extra steps can yield when sufficient skill and artistry are applied. You can see more of this scope (and other examples of Tim's art) at www.timwetherell.com. ✦

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

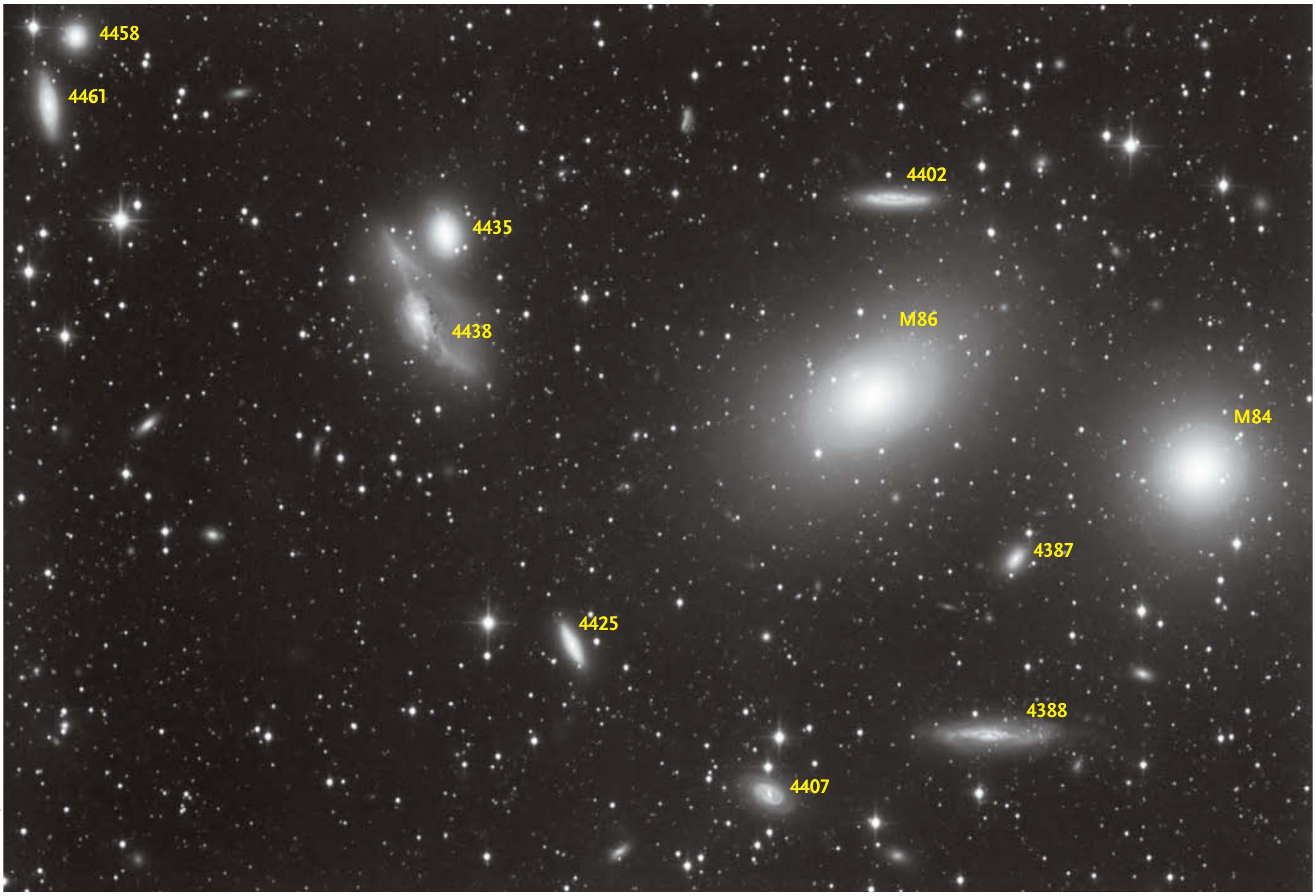
Disguised beneath its beautiful Victorian appearance, the 8-inch refractor features a state-of-the-art ED-glass f/9 apochromatic objective and modern electronic drive controls.

The scope's pier opens to reveal an impressive collection of eyepieces stored on rotating platters. The steel-framed cabinet keeps the eyepieces dew free and readily accessible.

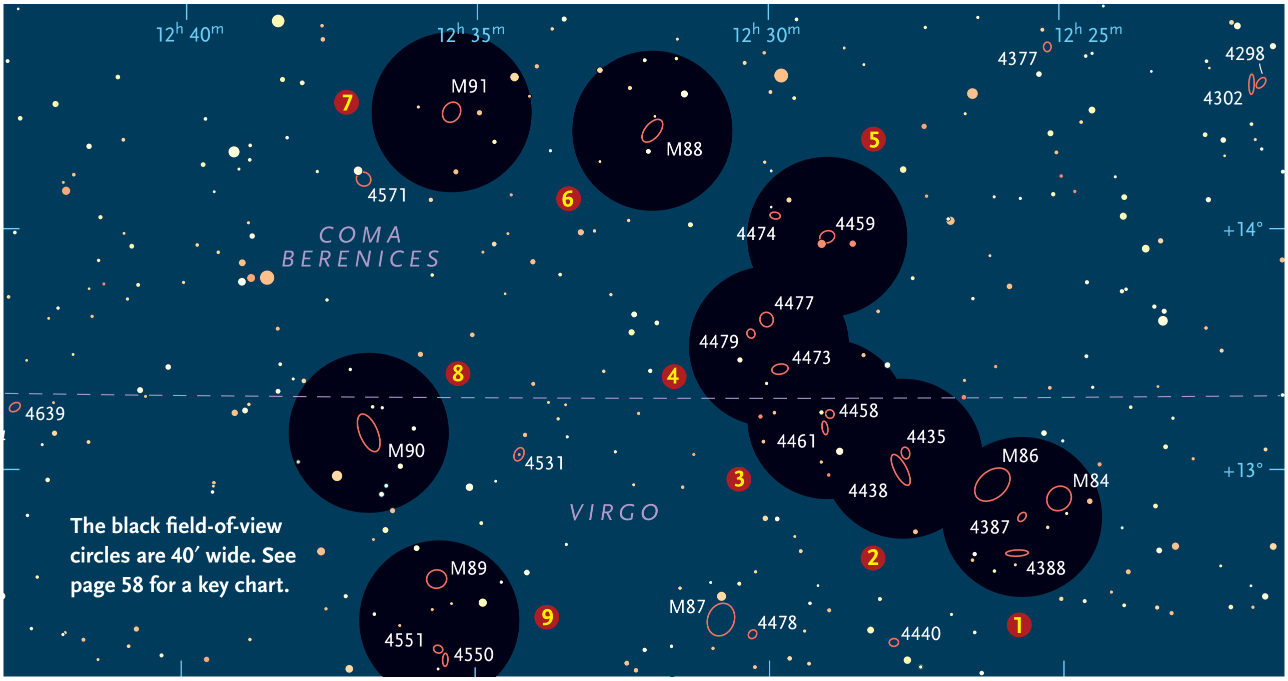
Galaxy-Hopping the Virgo Cluster

TED FORTE

Explore the wonderland of galaxies on the border between Virgo and Coma Berenices.

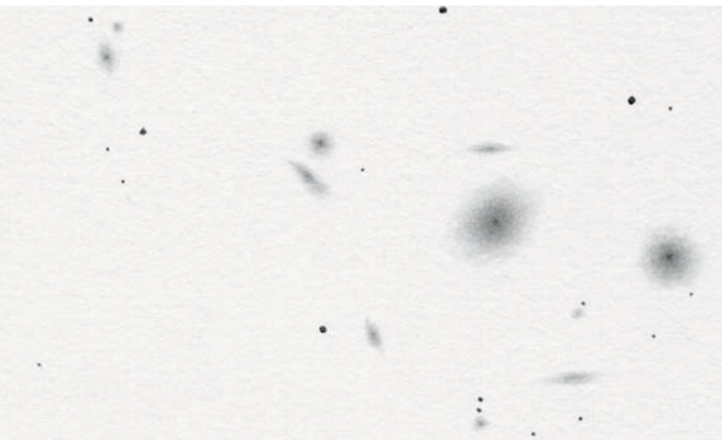


CORD SCHOLZ / MISCHA SCHIRMER



AIM A TELESCOPE MIDWAY between the bright stars Beta Leonis (Denebola) and Epsilon Virginis (Vindemiatrix) and you will find yourself in the heart of the richest galaxy-hunting ground in the sky. Under dark skies, an 8-inch telescope can show you at least 100 galaxies in an area that you can cover with your outstretched fist. You'll encounter several giant elliptical galaxies and dozens of beautiful spirals tipped at every conceivable angle to our line of sight. It is a menagerie of endless wonders that gets more interesting each time you return, and with each increase of aperture.

***Left*: This exceptionally deep image of Markarian's Chain shows eight of the galaxies discussed in this article, three more that are readily visible in a 12-inch scope (NGC 4402, 4407, and 4425), and dozens of fainter galaxies. *Below*: This sketch does a better job than any photo of capturing the visual appearance of Markarian's Chain, as seen at 37.5× through an 8-inch scope under dark skies.**



JEREMY PEREZ

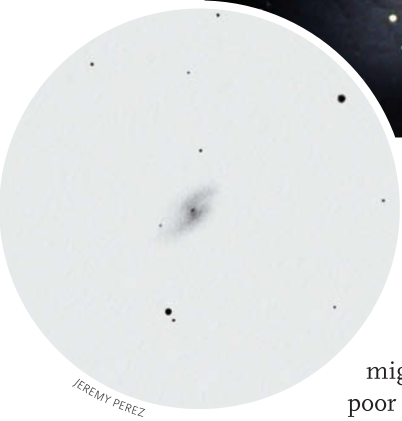
The Virgo Galaxy Cluster consists of about 2,000 individual galaxies lying 50 to 60 million light-years from Earth. It's often called the Virgo-Coma Galaxy Cluster, as it straddles the border between Virgo and Coma Berenices. The Virgo Cluster is the core of the far larger Virgo Supercluster, which includes our own Milky Way and Local Group as outlying members.

The patriarch of this giant celestial family is Messier 87, sometimes referred to as Virgo A. This supersized elliptical star city is close to the center of the Virgo Cluster. Roughly 150 galaxies brighter than visual magnitude 12.5 lie within 5° of M87. You can log 14 other Messier objects with little more than a nudge of the scope. There are so many galaxies here that we can forget the stars and just galaxy-hop our way from target to target.

And that's the problem! This small area contains so many galaxies that it's easy to get lost and confused. An accurately aligned Go To scope can solve this problem, but I would argue that something intangible is lost to the explorer when relying on it. That's why we've provided detailed charts to help you in your galaxy-hop. But even so, a big scope under dark skies can show far more galaxies than we've plotted here.

1 When I enter a swimming pool, I like to dive right into the deep end rather than wade in from the edges, and that's the way I like to approach the Virgo Cluster too. Not far from M87 is an easily found and unmistakable field dominated by the giant elliptical galaxies **M84** and **M86**, which are nearly as bright as M87. They form a triangle with the edge-on spiral galaxy **NGC 4388** to their south. The modest little elliptical galaxy **NGC 4387**, which

JIM QUINN / ADAM BLOCK / NOAO / AURA / NSF


JEREMY PEREZ

Messier 88 is a barred spiral, probably similar in shape to our own Milky Way Galaxy. An 8-inch scope at 120× under dark skies provides enough aperture to glimpse Messier 88's major features.

might not even show up in small scopes or poor sky conditions, lies near the center of the triangle. The field is almost exactly midway between Denebola and Vindemiatrix, making it a quick and easy starting point. Once you can reliably recognize this field, it's easily retrieved whenever you become lost. From this home base, it's fairly easy to galaxy-hop to most of the area's treasures.

M84 and M86 anchor the remarkable string of eight galaxies known as Markarian's Chain. The chain forms a gentle arc of nearly equally spaced bright galaxies, arrayed like steppingstones through the heart of the cluster. A 1961 scientific paper by the Armenian astrophysicist Benjamin Markarian argued that the chain represents a real physical structure rather than a coincidental grouping, as seven of the galaxies move coherently. But regardless of their true nature, they form a magnificent trail of targets. Many observers consider the chain to run all the way from M84 in the southwest to M88 in the northeast. Others extend it even farther, turning it east through M91 and NGC 4571. But the official chain discussed by Markarian includes M84 and M86 together with NGC 4435, 4438, 4458, 4461, 4473, and 4477.

2 M86 is more oval than M84, which is round. The *longer* axis of M86 can remind you that a *long* chain of galaxies extends off in that direction — a good way to remember which is which. Using an eyepiece that yields a field of view between 45′ and 50′ makes galaxy-hopping along the chain foolproof. Push your scope from M84 through M86, and before the latter is out of the field, your next pair of targets is in view. **NGC 4438** and **4435** are known as The Eyes, a name given to them by Leland S. Copeland, who penned *Sky & Telescope*'s Deep-Sky Wonders column in the 1940s. Study NGC 4438 and you might start to detect evidence of disturbance. It has long been assumed that there might be interaction with its smaller neighbor, or perhaps a merger in the distant past. A 2008 hydrogen-alpha image by the Mayall Telescope at Kitt Peak hints at a past collision with M86.

3 A farther eyepiece field along the path brings **NGC 4461** and **4458** to center stage. They're less than 4′ apart and bright enough to show in an 8-inch scope under decent skies, but this galaxy pair is clearly the weakest link in the chain.

4 Crossing into Coma Berenices, the final two members of the chain, **NGC 4473** and **4477**, are easy and bright targets about equal steps away. NGC 4473 is obvious with 8 inches of aperture even under typical suburban skies; it's large, bright, a little elongated, and of uniform brightness. NGC 4477 is an open-faced barred spiral, but I've never noted any structure through the eyepiece. Larger scopes (or darker skies) will reveal the stellar nucleus of **NGC 4479** in the same field of view.

5 Continuing along what we might term the Grand Tour, we turn a bit northwest to **NGC 4459**, one of the brightest in this string of galaxies, which should be visible in a 6-inch scope. It's round with a bright core and has an 8th-magnitude star to the southeast.

6 Our next hop is a bit more of a stretch. Move northeast from NGC 4459 through faint little **NGC 4474** (if you can see it). Just as you lose sight of NGC 4459 — and a nudge more — the large oval glow of **M88** will come into view. It's a startling effect. Spend some time here. This Milky Way analog might just be the finest galaxy in this part of the cluster.

7 One full field almost due east of M88 is fainter **M91**. This galaxy has low surface brightness, so it appears considerably dimmer than its listed magnitude would lead you to expect. As you gain experience in observing faint extended objects, you will employ a number of techniques to enhance your views. Of these, averted vision is the most powerful. M91 is an excellent practice target. Look away from the object in a direction opposite your nose to place the galaxy between the center of your eye and your nose. This position employs your eye's rod cells, the area of your retina most sensitive to dim light. Give your visual apparatus ample time; it takes several seconds for your eye to detect truly faint objects.

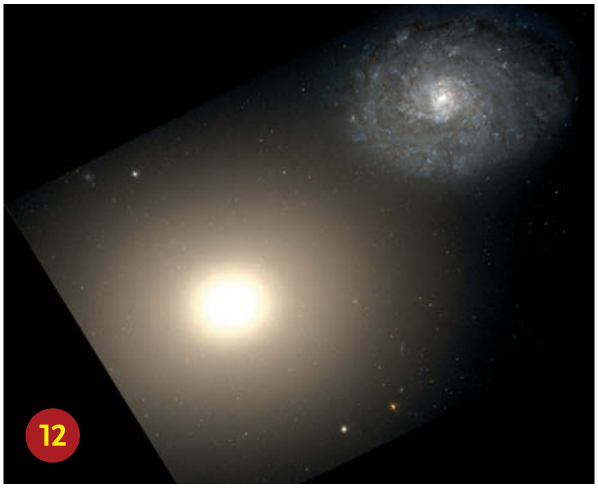
8 Our next stop on the tour will be **M90**, and we will have to jump across a large expanse without a bright steppingstone. Put M91 on the north-northwestern edge of the field and select a star as close as possible to the opposite edge. Keeping your eye on the selected star, shift the scope so that the star moves to the spot previously occupied by M91, and maybe go a bit farther. That should bring M90 into view. It's a fine elongated object, rather similar to M88.

9 One field away to the southwest is **M89**, which is small, bright, and very round. It shares a wide telescope field with a fainter pair of galaxies to the south, elongated **NGC 4550** and round **4551**. Directly to the west from here lies giant M87 with its retinue of fainter companions, but let's go a different way.

10 Angling southeast, you may be able to include **M58** in the same field with NGC 4550/51. This bright spiral may show some structure and a bar to the careful observer.

11 Two fields to the east of M58 is a Messier twofer. To get to them, we'll use **NGC 4606** as a steppingstone. Look for an elongated 12th-magnitude smudge punctuated with a 13th-magnitude star one full field east of M58. You might also be able to spy its fainter companion, **NGC 4607**.

12 Bright, modestly elongated **M59** fits in the same field with NGC 4606 and 4607. Nudge the scope eastward, and the even brighter and larger **M60** will be obvious. Its

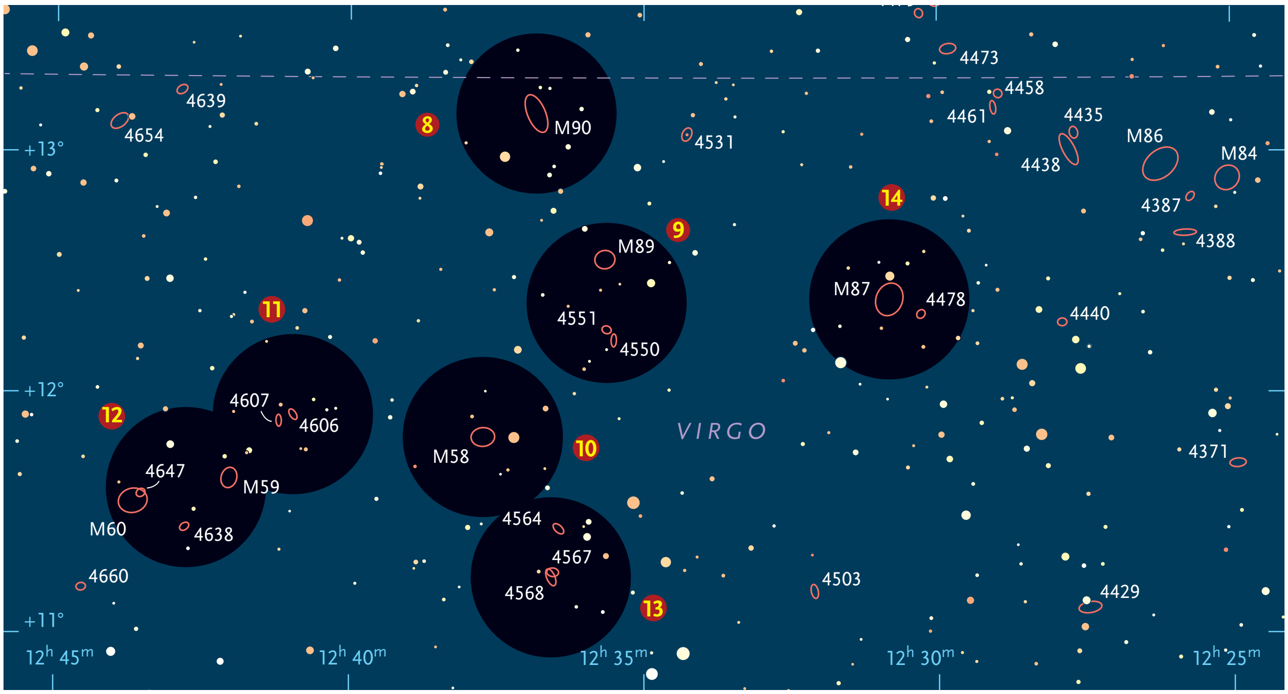


NASA / ESA / STScI / HUBBLE LEGACY ARCHIVE

This image, processed from raw Hubble Space Telescope data by Wikimedia contributor "Fabian RRRR," shows the contrast between the hot, young, blue stars of the spiral galaxy NGC 4647 and the old, reddish stars of the elliptical galaxy Messier 60. Areas not included in the Hubble data were left black.

smaller, fainter, very close companion **NGC 4647** should be easy in 8-inch or larger scopes. And to the south, tiny **NGC 4638** forms a flattened triangle with M59 and M60 similar to the triangle that NGC 4387 forms with M84 and M86.

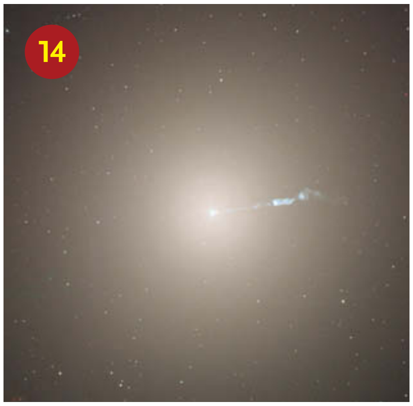
13 To reach our next major destination, we'll first backtrack a bit to M58, again using NGC 4606 and 4607 as a steppingstone. We're heading for one of my favorite sights



in the cluster. The Siamese Twins, **NGC 4567** and **4568**, present an interesting view to larger scopes: two similar sized spirals, possibly an interacting system, that overlap each other. They will just fit in a wide-field view with M58. The elongated 11th-magnitude **NGC 4564** to the north of the twins further enriches this stop.

14 We have just one more must-see target, and to go there directly will require a long jump through an area sparsely populated by faint stars and fainter galaxies. There are three stars in the field with the Siamese Twins that point our way. A 7.6-magnitude star lies 26′ northwest of the Twins, with a pair of 9th- and 10th-magnitude stars halfway between the galaxies and the bright star. Continuing northwest along this imaginary line, jump 1½° from the 7.6-magnitude star, and the Virgo Cluster's anchor, the giant elliptical **M87** will come into view. This galaxy is also known as Virgo A, because the massive black hole at its center is the brightest radio source in Virgo. If you get lost, it will comfort you to know that M87 is a little more than 1° east-southeast of our home base, the triangle formed by M84, M86, and NGC 4388.

M87 is an easy catch, a large oval glow. It has a few companions; the larger your scope the more companions you'll notice, but even small scopes should be able to detect **NGC 4478**. Those lucky observers with behemoth apertures and dark skies will not only record several companions, but might just spy the elusive jet of energetic gas ejected by M87's black hole; it has been reported using apertures as small as 16 inches! We'll end the tour here having just scratched the surface of this galaxy wonderland, enough to whet your appetite and allow you to appreciate the richness of the cluster.



NASA / ESA / HUBBLE HERITAGE TEAM

The famous jet emanating from the black hole at the center of Messier 87 can be glimpsed through a large amateur telescope under perfect conditions.

It's easy to think of galaxies as merely faint patches of light, fuzzy blotches to challenge your eye and your telescope. We sometimes have to remind ourselves that these objects are actually unimaginably vast realms of stars, planets, and nebulae. Undoubtedly, they are places of beauty, grandeur, and incredible violence. Quite possibly, they contain abodes for life, maybe intelligence, even technological civilizations. So the next time you peer through the eyepiece at a grand spiral or an ancient elliptical, stop to consider for a moment what marvels must lie in that small, faint smudge. ✦

Ted Forte observes faint fuzzies from dark-sky sites near his home in Virginia Beach, Virginia.

Galaxies in the Virgo-Coma Cluster

	Galaxy	Mag(v)	Size	RA	Dec.
1	Messier 84	9.1	6.7′ × 6.0′	$12^h\ 25.1^m$	+12° 53′
	NGC 4387	12.1	1.7′ × 1.1′	$12^h\ 25.7^m$	+12° 49′
	NGC 4388	11.0	5.6′ × 1.5′	$12^h\ 25.8^m$	+12° 40′
	Messier 86	8.9	9.8′ × 6.3′	$12^h\ 26.2^m$	+12° 57′
2	NGC 4435	10.8	3.0′ × 2.2′	$12^h\ 27.7^m$	+13° 05′
	NGC 4438	10.2	8.5′ × 3.0′	$12^h\ 27.8^m$	+13° 00′
3	NGC 4458	12.1	1.6′ × 1.5′	$12^h\ 29.0^m$	+13° 15′
	NGC 4461	11.2	3.4′ × 1.4′	$12^h\ 29.0^m$	+13° 11′
4	NGC 4473	10.2	4.2′ × 2.6′	$12^h\ 29.8^m$	+13° 26′
	NGC 4477	10.4	3.7′ × 3.3′	$12^h\ 30.0^m$	+13° 38′
	NGC 4479	12.4	1.6′ × 1.3′	$12^h\ 30.3^m$	+13° 35′
5	NGC 4459	10.4	4.0′ × 3.1′	$12^h\ 29.0^m$	+13° 59′
	NGC 4474	11.5	2.4′ × 1.6′	$12^h\ 29.9^m$	+14° 04′
6	Messier 88	9.6	6.8′ × 3.7′	$12^h\ 32.0^m$	+14° 25′
7	Messier 91	10.1	5.2′ × 4.2′	$12^h\ 35.4^m$	+14° 30′
8	Messier 90	9.5	9.9′ × 4.4′	$12^h\ 36.8^m$	+13° 10′
9	NGC 4550	11.7	3.3′ × 0.9′	$12^h\ 35.5^m$	+12° 13′
	NGC 4551	12.0	1.8′ × 1.4′	$12^h\ 35.6^m$	+12° 16′
	Messier 89	9.8	5.3′ × 4.8′	$12^h\ 35.7^m$	+12° 33′
10	Messier 58	9.7	6.0′ × 4.8′	$12^h\ 37.7^m$	+11° 49′
11	NGC 4606	11.8	3.3′ × 1.7′	$12^h\ 41.0^m$	+11° 55′
	NGC 4607	12.8	2.9′ × 0.7′	$12^h\ 41.2^m$	+11° 53′
12	Messier 59	9.6	5.3′ × 4.0′	$12^h\ 42.0^m$	+11° 39′
	NGC 4638	11.2	2.4′ × 1.7′	$12^h\ 42.8^m$	+11° 27′
	NGC 4647	11.3	2.9′ × 2.3′	$12^h\ 43.5^m$	+11° 35′
	Messier 60	8.8	7.6′ × 6.2′	$12^h\ 43.7^m$	+11° 33′
13	NGC 4564	11.1	3.2′ × 1.8′	$12^h\ 36.4^m$	+11° 26′
	NGC 4567	11.3	3.1′ × 2.2′	$12^h\ 36.5^m$	+11° 15′
	NGC 4568	10.8	4.6′ × 2.2′	$12^h\ 36.6^m$	+11° 14′
14	NGC 4478	11.4	1.8′ × 1.5′	$12^h\ 30.3^m$	+12° 20′
	Messier 87	8.6	8.7′ × 6.6′	$12^h\ 30.8^m$	+12° 23′

Data are from the Saguaro Astronomy Club Database. 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.

Residual Bulk Image: Cause and Cure

Understanding the subtleties of your CCD camera will help you create better images and scientific data.

RICHARD CRISP

AFFORDABLE CCD CAMERAS with large scientific-grade sensors offer astrophotographers unprecedented imaging opportunities. But these sensors also present challenges that must be carefully considered if we are to exploit their full potential.

One of these challenges involves a phenomenon known as *residual bulk image*, or RBI, which is CCD jargon for something photographers might simply call "ghost" images. While RBI can degrade an otherwise beautiful photograph of a nebula or galaxy, it has an even more insidious side. It's not uncommon for advanced astrophotographers to be fooled by RBI and think that they've captured a nova or uncataloged nebula. And even when RBI doesn't leave a visible image artifact, it can compromise scientific data recorded with a CCD camera.

What Causes RBI?

Light striking a CCD creates electronic charge that accumulates in the sensor's pixels. When the exposure is complete, this charge is read out and converted into an image. RBI arises when some of the charge becomes trapped in the region below the pixels and is left behind during readout. But the trapped charge doesn't remain trapped; it eventually leaks back into the pixels and is read out as part of subsequent exposures, including calibration frames. Because the trapped charge can leak into a number of subsequent frames, pixel-rejection algorithms used for image processing will not remove it from the final composition.

Some image sensors are more susceptible to RBI than others. Many front-side illuminated full-frame CCDs, including some of the very popular full-frame chips in Kodak's KAF series, suffer from RBI. The problem is not camera-specific; it is a CCD property arising from the silicon wafer manufacturing process.

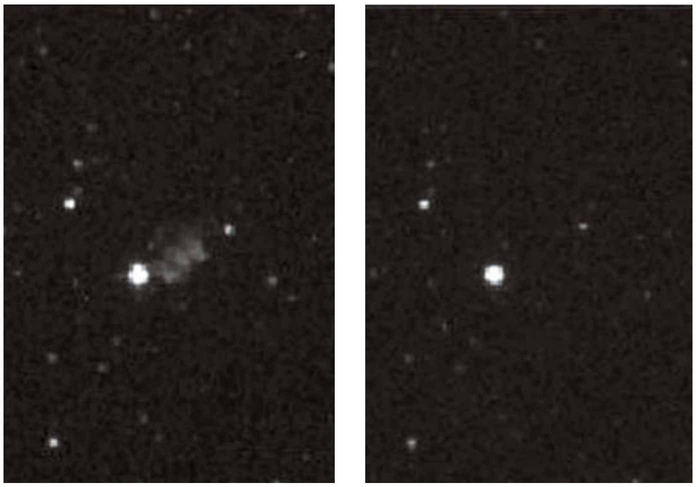


Image artifacts caused by RBI can appear similar to nebulosity or other faint deep-sky objects. Consider, for example, the fuzzy object in the left image. The author wasted several hours searching catalogs in an attempt to identify this nonexistent nebula. The object was simply an RBI artifact of a bright star that was earlier used to focus the telescope. The image using the light-flood method at right eliminated the artifact.

To take deep, detailed images like this narrowband composite of NGC 7000, astro-imagers will benefit from an understanding of the inner workings of their cameras. Many of today's popular front-illuminated CCD chips suffer from a phenomenon known as a residual bulk image (RBI), which can leave "ghost" images of bright objects from one exposure to the next. Understanding its cause and ways to eliminate the problem will lead to better images and scientific data recorded with a CCD camera. All images are courtesy of the author.

A CCD is made on a highly pure and uniform crystal of silicon. The uniformity of the crystal lattice affects how electronic charge moves through it, and any lattice disruption can create regions that will trap electrons.

Light penetration depth into silicon is wavelength-dependent: longer wavelengths penetrate deeper. That means RBI is more problematic for red and near-infrared light than it is for blue light. The CCD's temperature is also a factor, since it influences the rate that trapped electrons leak back into pixels. The more aggressively you cool a CCD, the slower the RBI charge leaks into subsequent images.

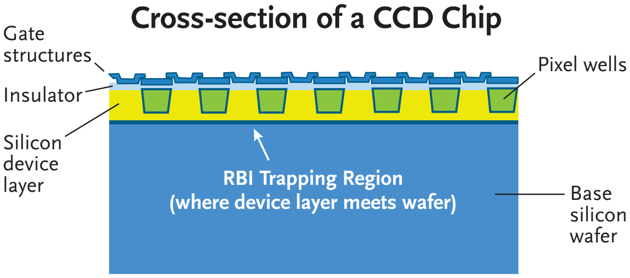
Pretty pictures are frequently ruined by RBI. For example, an astrophotographer might snap a few twilight pictures of the crescent Moon, and then find a ghost image of the crescent contaminating deep-sky exposures for the next several hours. Trapped charge leaking into images also introduces an unacceptable uncertainty into photometry data. In astrometry, a residual artifact from a bright star in an earlier exposure can confuse the results.

How to Deal with RBI

Because the rate at which trapped charge leaks back into pixels is strongly regulated by temperature, one solution for reducing the effects of RBI is to operate the CCD at warm temperatures. This may be an acceptable approach for short exposures, which don't require deep cooling since there is little time for dark current to accumulate in the pixels. But long exposures made at warm temperatures can suffer from excessive dark current and the associated noise that goes with it.

Another method of reducing RBI is to simply wait for any trapped charge to dissipate before taking the next exposure. But this has the obvious disadvantage of wasting precious imaging time, especially when a CCD is running at very cold temperatures, slowing the rate that trapped charge dissipates.

Cross-section of a CCD Chip

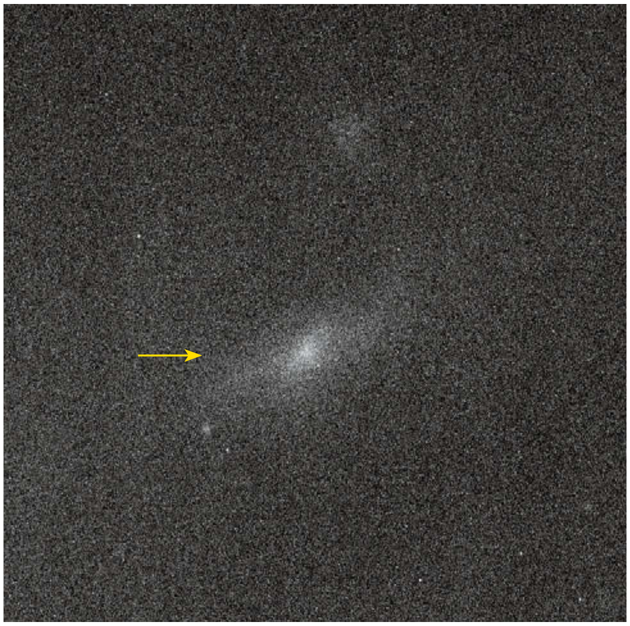


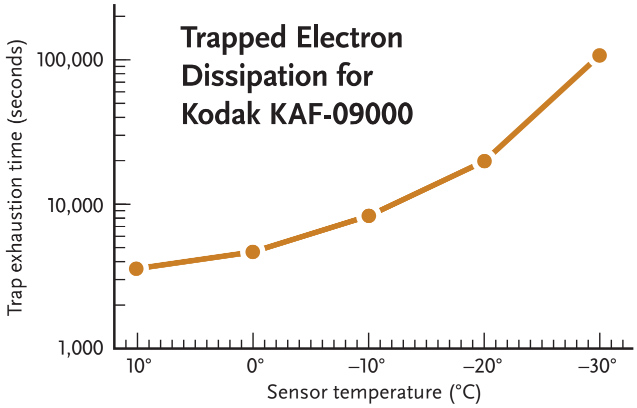
Most RBI traps are formed in CCD detectors at the interface between the silicon device layer and the silicon base wafer. Additional traps are formed by slight imperfections in the device layer.

One of the best solutions for deep-sky astrophotographers is the same one used for the custom-made CCD sensors on NASA's Galileo and Cassini space probes: flood the sensor with near-infrared light and then "flush" it (read out the chip) just before every exposure. This flood/flush/integrate protocol (or "light-flood") eliminates RBI artifacts by completely filling *all* the CCD's traps before any exposure. This obliterates any remnant image prior to taking a new one.

To learn more about RBI, visit www.narrowbandimaging.com/rbi_paper_crisp_page.htm.

The trapped charge that arises from the light-flood leaks into the next exposure just like any other RBI, but has a consistent pattern in every frame. Nevertheless,





Left: **An RBI "ghost galaxy" (arrowed) is clearly visible in this 5-minute dark frame taken two hours after the conventional light exposures were made of the galaxy.** ***Above:*** **This graph for a Kodak KAF-09000 CCD plots the measured time necessary for trapped electrons to dissipate at temperatures decreasing in 10° increments. Even when operated at a relatively warm 10°C, the RBI charge did not completely drain for nearly an hour.**

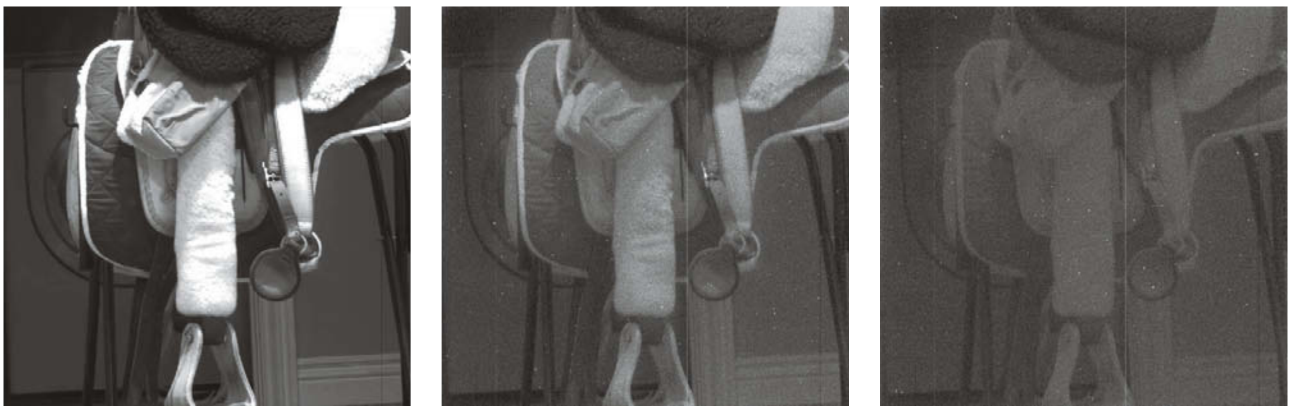
the leaked charge still contributes noise to subsequent exposures, so it is best to use aggressive cooling to slow the rate of leakage.

When a light-flood is used, light and dark images will often reveal arc-like swirling patterns or other visible features that appear permanently fixed in the CCD. These are normal and are caused by a nonuniform distribution of trapping sites that arise during the chip's manufacturing process. Proper dark subtraction can remove these fixed patterns. If you don't see a fixed pattern in dark frames made with a light-flood protocol, it may be an indicator that the traps were not sufficiently filled during the light-flood and that the flooding time needs to be increased.

Occasionally, the fixed pattern will remain in the image after calibration. This is often caused by calibrating with dark frames that have been scaled. Because the rate at which trapped electrons leak back into pixels decays with time, dark frames made with a light-flood protocol should not be scaled. The simple solution is to avoid scaling calibration frames and use dark frames that are made with the same exposure time and temperature as the light-flooded exposures they are being used to calibrate. I often use cloudy nights to build a library of dark frames at the same temperature and duration as I typically use for my light exposures. This avoids the issue of scaled dark artifacts, as well as reducing the time needed on clear nights to generate dark frames.

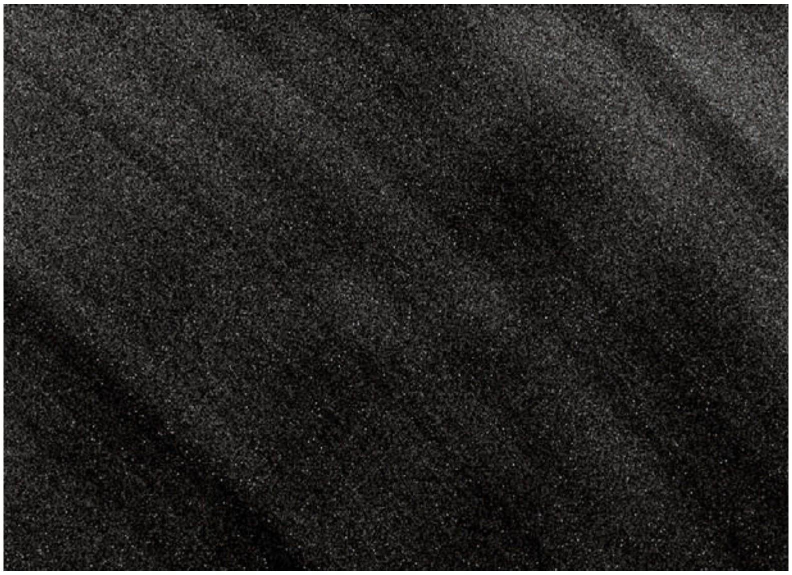
Noise Considerations

The preferred way to light-flood a CCD is to install a group of near-infrared LEDs inside the camera to provide a uniformly distributed flood signal. Several manufacturers of high-end CCD cameras build flooding LEDs into their CCD chambers. Cameras that don't have this feature



This textbook example demonstrates the tenacity of RBI artifacts when operating a Kodak KAF-09000 CCD cooled to -25°C. The initial exposure (*left*) is clearly visible as a ghost image in a dark frame made immediately after it (*center*), and still remains apparent in a dark frame captured one hour later (*right*).

Top: **When a light-flood protocol is used to obliterate the effects of RBI, dark frames will often display arc-like swirling patterns caused by a non-uniform distribution of the trapping sites in the CCD created during the chip's manufacture.** ***Center:*** **These fixed-pattern artifacts can appear in a processed image if the dark frames used for calibration are scaled.** ***Bottom:*** **This image used the same calibration frames with dark scaling disabled.**



can have their chips flooded manually using an external light source (for example, a flashlight shined into the telescope's aperture during a brief exposure through a clear or luminance filter) combined with several manual read outs (bias frames) to flush the chip.

A typical light-flood would create electrons that exceed 100 times the full-well capacity of the CCD's pixels. This is followed by several flushes to guarantee the pixels are empty prior to making a data exposure. Since it can take as much as 5 seconds of exposure to properly flood a chip, and several read outs to completely flush a saturated array, a significant amount of time can be consumed by the light-flood protocol. Fortunately, it's really only necessary to use this method for science images and their calibration darks.

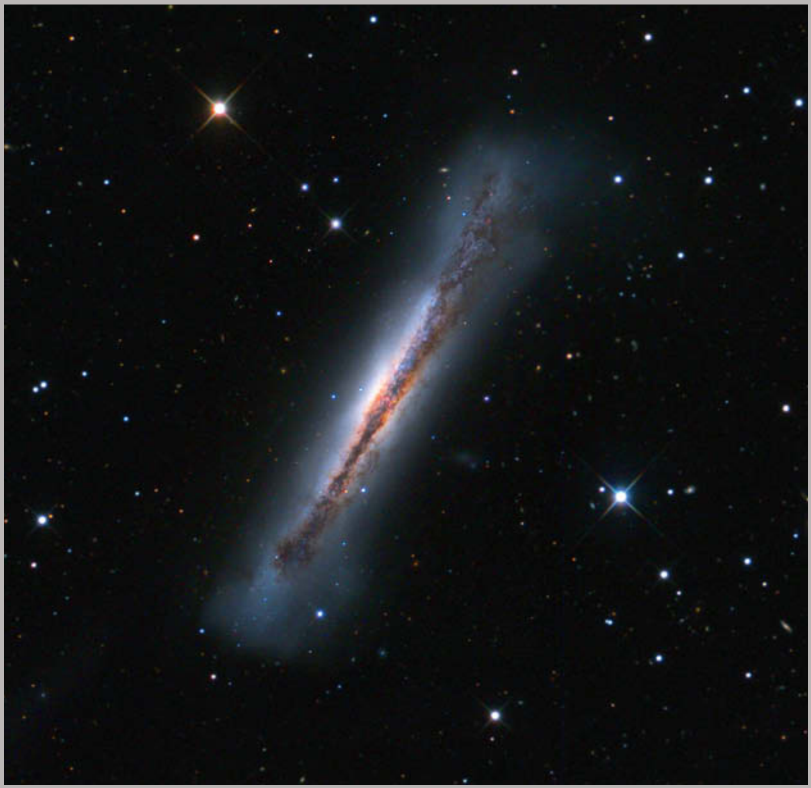
When filled traps leak charge, they add to the CCD's dark current. But unlike thermally generated dark current that is constant with time, the traps have a finite capacity. When the trap's charge is completely dissipated, it can't contribute further to the dark signal. At typical CCD operating temperatures, the rate that electrons leak from a trap decreases with time and is about 5 to 10 times greater than the thermally generated dark signal at the beginning of an exposure.

The total dark signal can therefore be significantly higher when using a light-flood protocol unless preventive steps are taken. For this reason it's desirable to operate a CCD camera used for long exposures with aggressive cooling to keep the noise due to the total dark signal (thermally generated electrons plus RBI leakage) below your target limits for the planned maximum exposure time. For example, the Cassini cameras operate at –100°C.

A commonly used criterion is to limit noise from the total dark signal to be less than the read noise of the camera. Since thermally generated dark noise grows with time, for any given operating temperature there will be a maximum exposure time for which this constraint is satisfied. Longer exposures will therefore require greater cooling.

While a light-flood protocol may be time consuming, it can prevent having all the images from a perfect night being ruined, and save you many hours of searching catalogs for nonexistent objects that appear in your images as RBI artifacts. Knowing the inner workings of your CCD camera can lead to better images, and accurate scientific data. ✦

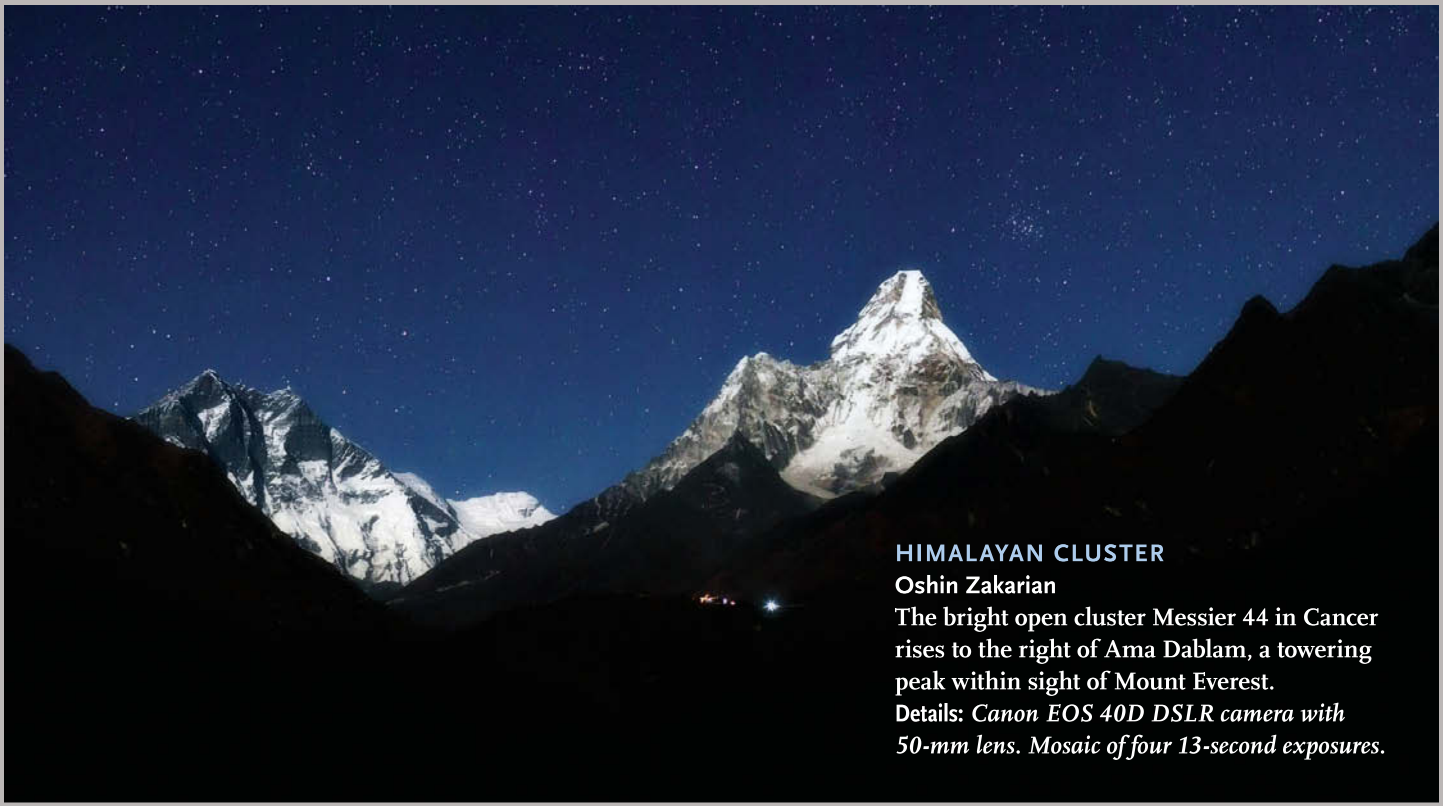
Avid astrophotographer ***Richard Crisp*** *is a research and development professional in the semiconductor industry.*



◄ ARP 317, THE HAMBURGER GALAXY
Jan Rek
NGC 3628, a member of the famed "Leo Trio" of galaxies, displays a bloated outer halo of stars attributed to recent interactions with the neighboring spiral galaxies M65 and M66.
Details: *Officina Stellare RC 400 Ritchey-Chrétien reflector with SBIG ST-11000M CCD camera. Total exposure is 12⅓ hours through color and luminance filters.*

► REFLECTIONS OF YOUTH
Brian Peterson
Deep images of M78 in Orion reveal a colorful interplay of bluish reflection nebulosity and dark dust lanes. Reddish Herbig-Haro objects at the bottom right hint at many unseen young stars still embedded deep within this molecular cloud.
Details: *Hyperion 12½-inch astrograph with SBIG STL-11000M CCD camera. Total exposure is 4½ hours through Custom Scientific color filters.*

Visit SkyandTelescope.com/gallery for more gallery online.



HIMALAYAN CLUSTER
Oshin Zakarian
The bright open cluster Messier 44 in Cancer rises to the right of Ama Dablam, a towering peak within sight of Mount Everest.
Details: *Canon EOS 40D DSLR camera with 50-mm lens. Mosaic of four 13-second exposures.*

▶ ECLIPSED SOLSTICE

John G. Love

This portrait of the total lunar eclipse on December 21, 2010, displays a rich palette of hues, signifying Earth's stratosphere was relatively free of volcanic aerosols.

Details: *Orion Premium 110-mm f/7 ED refractor with Olympus E-500 EVOLT DSLR camera. Exposure time was 4 seconds from Denton, Texas.*

▶ A STELLAR GHOST

David Ratledge

The planetary nebula Jones 1 in Pegasus is a notably faint object for modest amateur telescopes, shining mainly with the bluish light of doubly ionized oxygen.

Details: *RCOS 12½-inch Ritchey-Chrétien reflector with Apogee Alta U9 CCD camera. Total exposure was 6.7 hours through Hα and O III narrowband filters.*

▼ DUST WITHIN PERSEUS

Lynn Hilborn

This deep image reveals the space between open cluster IC 348 at far left and the starbirth complex NGC 1333. The latter is rife with faint dust and gas.

Details: *Tele Vue NP-101 refractor with Finger Lakes Instrumentation ML8300 CCD camera. Mosaic of two frames, each totaling 9 hours of exposure through color and Hα filters.* ✦

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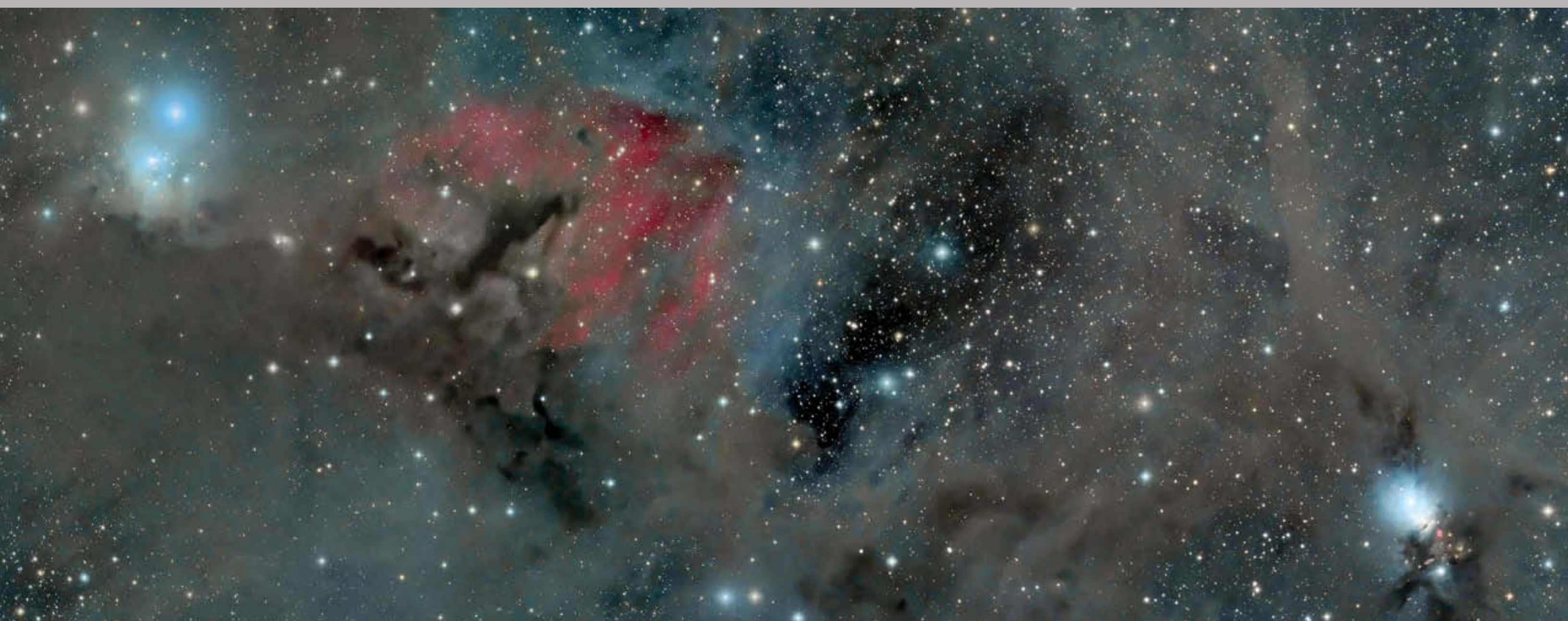

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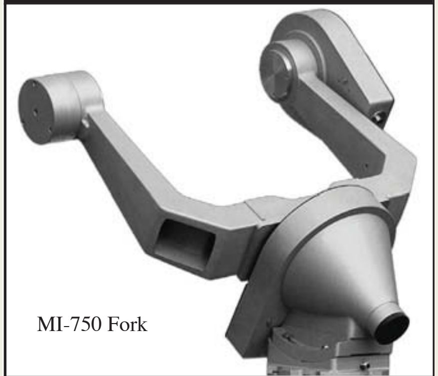

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A balloon-borne telescope over Antarctica investigates what happened to half of the universe's starlight.

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On the eve of its 100th anniversary, the AAVSO is undertaking a massive 5-color photometric survey of all stars between 10th and 17th magnitude.

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Many fine deep-sky objects lurk in the glare of bright stars.

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BOTTOM: R. JAY CABANY; TOP: MARK HALPERN

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 Al Schlafli

Finding a Star Party Location

A Colorado astronomy club overcame obstacles to keep its star party alive.

Actions by the U.S. Forest Service forced cancellation of a 2009 star party in Wyoming (Weekend Under the Stars), once again suggesting that astronomy clubs can no longer rely on the use of public lands to hold large star parties. The Colorado Springs Astronomical Society faced similar problems trying to secure sites on National Forest land for Rocky Mountain Star Stare.

RMSS started in 1986 with 50 attendees, mostly CSAS members and friends. The event has always aimed to provide astronomers a few dark nights each summer in the Rocky Mountains, and a camping trip that amateurs could share with their entire family. This area is known for its pitch-black skies and outstanding transparency. What could be a better place for a star party?

RMSS originally used U.S. Forest Service land, but it became increasingly difficult to reserve a location. The agreement with the Forest Service changed from a handshake and a modest fee to a very stringent contract and an annual fee of more than $500. The camping restrictions went from anywhere within 100 yards of an established road to no farther than one car length off the road. What had been a casual camping experience now looked like a private RV park. In 2007 the Forest Service awarded RMSS a site only two weeks before the event, making it clear that Forest Service land was no longer going to be an option.

Club members then began actively looking for property to buy. Our wish list included land within a two-hour drive, no utilities, trees for morning shade, reasonable cost, and because the event is the *Rocky Mountain* Star Stare, it had to be in the mountains. How would CSAS pay for this land? It would have cost $3,000 for a CPA to verify our books, a requirement for a loan application. We decided CSAS would purchase a dark site using savings and funds borrowed from members. RMSS would be the income tool to repay the member loans, offered without interest.

The land search took more than two years, delayed during winter and early spring months by snow. During our search, we found that trees were expensive — bare land was $1,000 per acre, but similar land with trees would add a $1,000 premium per tree. Property west or northwest of Colorado Springs was expensive, and we had to consider the worsening light domes from Denver and Colorado Springs. We turned south and in 2008 found a 35-acre parcel near Gardner, Colorado. It had trees, extremely dark skies, excellent transparency, and no utilities. And it was affordable.

In 2011 RMSS will mark its 25th anniversary (June 29th to July 3rd, see www.rmss.org). The club will pay off the members who enabled the purchase. Astronomers will attend from across the nation, camp where they please on our land, set up telescopes, and enjoy some of the darkest skies in the nation. Our example shows how clubs can overcome setbacks and find ideal and affordable sites for their star parties. ✦

GAIL TERRY

RMSS FROM THE AIR This aerial photo shows the 2009 Rocky Mountain Star Stare, at its new site near Gardner, Colorado.

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