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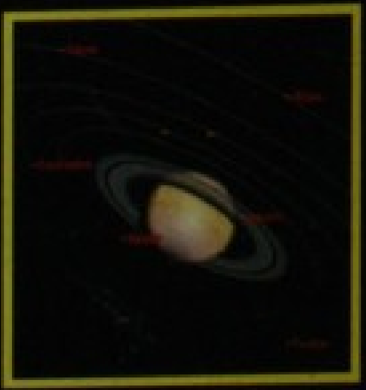

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The Reviews are In:
"A telescope mount for the 21st century" *Astronomy* magazine, November 2005

–"The Star Book is so easy to operate it flirts with user-interface perfection..."
–"As it stands now, the Sphinx is by far the easiest-to-use go-to mount."
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–"The Sphinx is an extraordinary value because this amount of periodic error is normally encountered only in mounts 4 or 5 times its cost."
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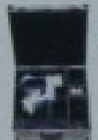

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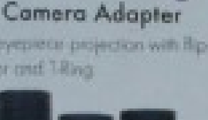

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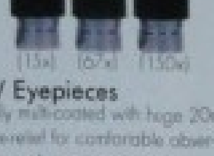

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ON THE COVER: *This extreme-ultraviolet image shows million-degree coronal plasma confined by ever-changing magnetic fields — the forces behind space weather. TRACE satellite image courtesy Stanford-Lockheed Institute for Space Research and NASA.*

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spectrum | by richard tresch fienberg

Clouded Vision

> It remains to be seen if the Vision for Space Exploration will be good for astronomy.

IF YOU WANT to spark some animated conversation among astronomy and space enthusiasts, ask for their opinions of President Bush's Vision for Space Exploration. Unveiled in January 2004, it calls on NASA to return the Space Shuttle to flight, to finish building the International Space Station (ISS), and then to phase out the shuttle by the end of this decade. More important, the Vision ("VSE" in NASA-speak) directs the agency to develop a new spacecraft that can ferry astronauts to and from the ISS, return people to the Moon by the end of the next decade, and eventually land them on Mars.

Because the lion's share of US astronomical research is funded by NASA, astronomers can't help but pay attention to how the agency spends its money. In reaction to the Vision, they've split mainly into two camps. Some reflexively oppose the plan because of its emphasis on human space flight. They worry that NASA will divert funding from planetary probes and space telescopes, which invariably pay huge scientific dividends, to piloted missions, which may not.

Others support the Vision because it might (just might) fulfill a dream left over from the Apollo era: to build powerful telescopes on the Moon. But as Dan Lester argues in this month's Focal Point essay (page 110), the Moon — despite its airlessness and two-week-long nights — isn't such a great place to put telescopes after all.

Does this mean there's not a single reason for astronomers to endorse the Vision? Not at all. Lester suggests, and I agree, that if NASA develops the capability to send astronauts on roundtrips to the Moon and Mars, the agency will also gain the ability to build and maintain large observatories in deep space — though there's no guarantee Congress will actually fund such facilities. Think of how wonderful it would be if high-flying successors to the Chandra X-ray Observatory and the infrared Spitzer Space Telescope could be refurbished with state-of-the-art detectors and computers the way Hubble has been upgraded for the past 15 years — and the way many older ground-based telescopes have been maintained at the scientific leading edge for decades.

Unfortunately, only two years into the plan and less than a year into the tenure of NASA administrator Michael Griffin, the Vision is in trouble. Getting the shuttle flying again is taking a lot longer, and costing a lot more, than anyone anticipated. The only ISS worth having in the context of the Vision, according to the prestigious National Research Council, is one on which life-science research prepares NASA to send astronauts on long-duration missions to Mars. Yet such studies are being cut back dramatically to save money. And following Griffin's not-very-encouraging speech at January's meeting of the American Astronomical Society, astronomers fear that some of their high-priority projects will be sent to the chopping block too. (In truth, quite a few incipient astronomy missions are embarrassingly over budget and behind schedule, making them tempting targets at a time when the US economy is straining against the mounting costs of the war in Iraq, disaster relief, and other challenges.)

I still think it would have been better to kill the ISS and let the shuttle fade away — perhaps after one last mission to service Hubble. That would have freed up billions of dollars to speed the development of new space vehicles and to advance space exploration in the broadest sense, including studies of Earth and the Sun; human and robotic expeditions to the Moon, Mars, potentially threatening asteroids, and the outer solar system; and the construction and servicing of telescopes in high orbits that give them nearly continuous access to the entire sky.

Ironically, President Reagan's long-forgotten National Commission on Space suggested just such a wide-ranging, balanced approach in 1986. But its report was overshadowed by the *Challenger* disaster and was ignored while the country turned its attention to getting the shuttle flying again so that we could build a space station.

NASA / JOHN FRASSANITO & ASSOCIATES

Rick Fienberg

EDITOR IN CHIEF

▸ The Great Andromeda Galaxy

BY TONY AND DAPHNE HALLAS

An incredible wealth of detail is evident in this 3°-by-4° portrait of M31. Note the galaxy's exquisite spiral structure as well as its faint, rarely recorded outermost regions. Also visible are its two fuzzy companion galaxies: M32 to the south (lower left) of M31's starlike core and M110 to the northwest (right). **DETAILS:** *6-inch f/8 Stellarvue triplet refractor with field flattener and SBIG STL-11000M CCD camera. Mosaic of nine 2½-hour exposures taken in October 2005.*

Astrophotographers whose images are selected to appear in Gallery receive a $50 Sky Publishing gift certificate.

◂ Full Beaver Moon

BY RONALD E. ROYER

From his home observatory in Springville, California, Ronald Royer snapped this view of the Moon last November as it rose over the Sierra Nevada Range near Sequoia National Park. "The night was hazy, which accounted for the Moon's golden color," he wrote.

DETAILS: *12½-inch f/6 Newtonian reflector and Fujichrome Provia 400F slide film.*

▾ Iridium Flash

BY OLIVIER R. STAIGER

Sunlight glinting off one of the orbiting Iridium satellites produced this brilliant flare last October 9th as the satellite crossed Orion's Belt as seen from Satigny, near Geneva, Switzerland.

DETAILS: *Tripod-mounted Canon EOS 350D digital SLR camera and a zoom lens set at 10 mm. 30-second unguided exposure at ISO 800.* ✶

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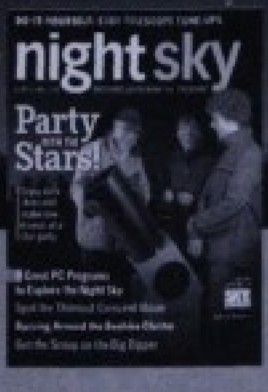

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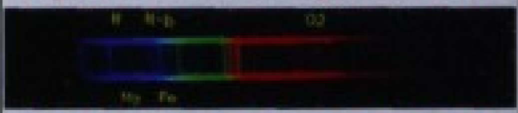

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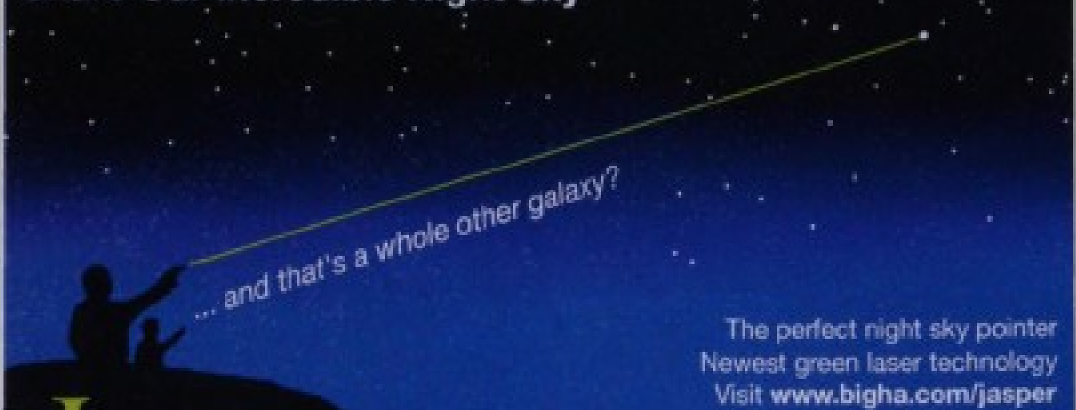

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focal point | by dan lester

Here's Dirt in Your Eye

WE'VE COME a long way. Astronomy used to be about photographic plates and about mountaintops, riveted steel, bedrock, and concrete. But as we move out into space and realize opportunities for seeing the cosmos without Earth's atmosphere distorting the view, old rules don't apply.

Some 30 years ago astronomers got excited about doing astronomy from the Moon, which has no atmosphere and no clouds. We saw the Moon as a stable platform where we could plant our telescopes on rock. The sky moved slowly overhead, and the long exposures required by insensitive emulsions could be made. We could pour concrete and stack bricks. Besides, we were already there.

Telescopes on the lunar surface may no longer offer value.

But in those 30 years technology moved ahead dramatically, exemplified by the huge success of the Hubble Space Telescope. As we now look ahead to a return to the Moon guided by President Bush's Vision for Space Exploration, we need to ask ourselves whether telescopes on the lunar surface still offer value. There are good reasons why they might not. Compared with venues in free space, the Moon offers dirt and gravity, and neither is particularly enabling for major astronomy goals.

Some clever ideas for Moon-based telescopes are around. A radio telescope on the far side could avoid terrestrial noise. That's a good use for dirt — put it between you and Earth. But the far side may not be radio quiet forever. A large zenith-pointing telescope with a rotating liquid mirror has been proposed. That telescope needs gravity. But the engineering challenges for it have hardly been considered, and the small field of view is a serious handicap.

The lunar surface may offer more trouble than benefit for high-precision optical and mechanical systems. Surface operations? Dust was a major problem for the Apollo astronauts, and we can assume it'll likewise be a serious issue for telescopes. Astronauts living nearby? Performance trumps accessibility, which is one reason you don't find observatories in New York's Central Park.

We now have telescopes in free space that point and track with exquisite precision. We don't need a pier anchored on bedrock. Free-space venues like the Earth-Moon or Earth-Sun Lagrangian points and the use of simple solar shields offer thermal stability and freedom from dust and debris, unlike low Earth orbits or the lunar surface. The lack of gravity in free space is a blessing. We just build our space telescopes to survive launch while they're stowed, not to precisely support their large mirrors while they're tracking across the sky. More of their mass provides scientific value, and less is squandered on landing legs and descent systems. Getting people and equipment into free space is far easier than getting them safely onto the lunar surface. And while our current crop of deep-space observatories don't require astronaut house calls, new exploration architectures will give us the ability to perform them, providing marvelous new opportunities. Besides, we're basically there right now. We know how to rendezvous with, service, and build large structures in orbit, and we're going to get a lot better at those things as we prepare to go to Mars.

It's time to renew our excitement about doing astronomy in space — not instead of going to the Moon or Mars, but to build on capabilities we'll gain by doing so. Whether done in Earth orbit or in more scientifically compelling places like the Lagrangian points, our investments in the Crew Exploration Vehicle, life-support systems, and sophisticated robots, for example, will bring a renaissance in large-observatory operations. With humans and robots we can build telescopes in space that could never fit into existing launchers.

CHRISTOPHER SERRA

Advocates for astronomy should regard the Vision for Space Exploration cautiously and enthusiastically: cautiously, in that our dollars should buy the best science, but enthusiastically, in that the capabilities it brings could dramatically enhance our perspective on the universe. We need to let science be an honest driver of our requirements. Renewed lunar exploration may well benefit astronomy, but we should not succumb to an increasingly obsolete paradigm that forces us to build telescopes down in the dirt. ◆

DAN LESTER *is an astronomer at the University of Texas with interests in infrared studies of star formation and federal science policy.*


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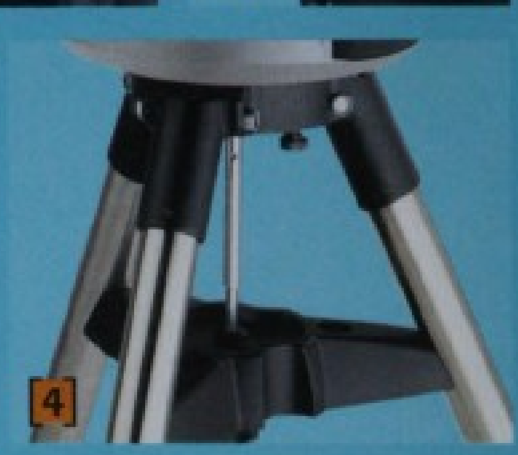
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GALEX Lives

We enjoyed your special report on NASA's "other" space telescopes and would like to share with your readers an update on the Galaxy Evolution Explorer (GALEX) mission (January issue, page 40). Shortly after your magazine went to press last October, the far-ultraviolet detector resumed normal, full-time operation. The detectors continue to perform unimpaired, returning about 24 gigabits per day of data that provide superb images of nearby galaxies and global sky surveys. According to plan, the mission will begin its extended phase next fall (pending NASA approval) and will continue to map the heavens through September 2008 or longer. GALEX is in excellent health and will likely exceed its original goals.

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Pasadena, CA 91125

Moon Illusion

In his letter, Anthony Ayiomamitis claims that the Moon seems bigger near the horizon because of familiar landmarks (November 2005, page 12). But the Moon illusion occurs on the open sea and on the flatlands, too. There is a better explanation.

First, when we see a bird or a cloud flying near the horizon, we notice that it looks much farther away than if it were flying directly overhead — even though both instances might be at the same altitude. Our brain has an inner map of the sky that is shaped like a flattened hemisphere. Our knowledge of the Moon's real near-constant distance should be able to replace the inner map, but since we trust our eyes for survival, this is not the case.

Second, our brain is very good at measuring sizes and angles. On any given day the distance to the Moon doesn't vary much. Hence with the Moon appearing much farther away at the horizon (as our inner map tells us) yet still covering the same angular diameter of sky, our brain can't help but interpret this scenario as if the Moon really is larger at the horizon. No landmarks are needed.

Lars Engström
Stockholm, Sweden
suslars@telia.com

Editor's note: *For more on this topic, see this month's Rambling Through the Skies column on page 43.*

Lowell's Legacy

I read with interest William Sheehan's article on my great-uncle's activities in Japan, "To Mars by Way of Noto" (December 2005, page 108). "Uncle Percy," as the corporate soul of the Percival Lowell Observatory is now referred to by its staff, was a man of great importance to the future of astronomy, though many of his confreres did not think so at the time.

In 1987 I too visited Anamidzu on the Noto Peninsula of Japan, ate "Lowell cakes," sailed down the bay to Nanao, and attended civic gatherings. A couple of years ago we entertained a delegation from the Noto area here on Mars Hill in Flagstaff. In short, we do everything we can to maintain the cordiality that the town of Anamidzu has shown toward the memory of our founder.

We appreciate Sheehan's bringing to light Lowell's travels to Japan before he founded Lowell Observatory. Today we are still furthering Uncle Percy's vision — he was a man who put all his money where his mouth was. We feel that Uncle Percy would be proud of our new relationship with Discovery Communications, which is constructing a 4.2-meter telescope at the nearby Happy Jack Hill.

William L. Putnam
Lowell Observatory
Flagstaff, AZ
w.putnam@lowell.edu

Write to Letters to the Editor, *Sky & Telescope*, 49 Bay State Rd., Cambridge, MA 02138, or send e-mail to letters@SkyandTelescope.com. Please limit your comments to 250 words.

For the Record

■ *In the January issue, page 54, the Hyades star labeled Beta (β) is actually Epsilon (ε).*

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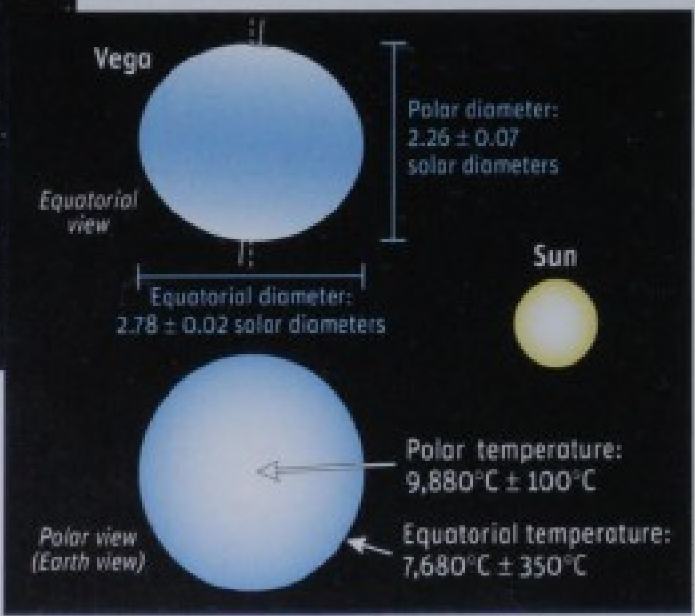
Vega Mystery Solved

Astronomers are gaining new insights on stars by measuring their diameters with telescope arrays.

USING A HIGH-TECH telescope array with resolution better than Hubble's, astronomers have finally solved the long-standing mystery of why Vega, the fifth-brightest star in the night sky, is 50 percent more luminous than other stars of its *A0* spectral type. But another group using the same facility has uncovered a new mystery: red dwarfs, the most common stars in the universe, are usually larger than scientists thought they were.

Both groups used Georgia State University's Center for High Angular Resolution Astronomy (CHARA) Array, a Y-shaped layout of six 1-meter telescopes on Mount Wilson in California. The CHARA Array is an *interferometer* — a grid of telescopes linked so that individual light waves from each instrument can be combined to achieve extremely high resolution. The two CHARA telescopes farthest from each other are separated by 331 meters (1,086 feet), which gives the array nearly the resolution of a hypothetical 331-meter optical telescope. CHARA can resolve details as small as 200 microarcseconds — the angular size of a nickel seen from 20,000 kilometers (12,000 miles) away.



First-magnitude Vega is by far the brightest star in Lyra. The star is actually oblong because of its fast rotation. Its polar axis points almost directly toward Earth.

A team led by Jason Aufdenberg (National Optical Astronomy Observatory, Tucson) used the CHARA Array to measure the angular size of Vega, located 25 light-years away in Lyra. With CHARA's sharp resolution, Aufdenberg and his colleagues confirmed long-standing suspicions that Vega is oblong because it rotates rapidly, and that we happen to view the star nearly pole-on. This geometry is the key that unlocks the luminosity mystery.

Vega rotates every 12.4 hours, or 92 percent of its calculated breakup rate. "Rapid rotation means a star's poles will be hotter," explains Aufdenberg. In fact, the observations show that Vega's poles are about 9,900°C (18,000°F), a whopping 2,200°C (4,000°F) hotter than the equator. A civilization whose planet is aligned with Vega's equator would see a much cooler and less luminous star.

"Vega looks like a star with 60 solar luminosities, but it should be about 40," says Aufdenberg. When the team corrected for the reduced equatorial light output, the astronomers calculated that Vega

The Helix Exposed

SOME 650 LIGHT-YEARS away in Aquarius lies the Helix Nebula (NGC 7293). In this combined visible and infrared image from the Hubble and Spitzer space telescopes, the planetary nebula reveals a seemingly countless number of "cometary knots." Although superficially resembling comets, these compact blobs of gas are each about twice as large as our solar system.

The image shows how the cometlike streamers are energized by ultraviolet radiation from the hot core of the dying star that spawned the Helix. There is a very strong transition from ionized, very hot gas (oxygen III, colored blue as seen by Hubble), to mostly atomic gas (hydrogen alpha, colored green as seen by Hubble), to warm, mostly molecular gas (4.5- and 8.0-micron molecular hydrogen, colored red as seen by Spitzer). Indeed, the reddish tails are relatively well shielded from the central star's radiation. In time the nebula will become redder and fainter as it expands and dissipates into the blackness of space. — DAVID TYTELL

---

emits 37 times more light than the Sun — a close match to other A0 stars.

CHARA may have closed the books on the Vega mystery, but it has thrown stellar models for a loop regarding red dwarfs — small, cool, dim stars that comprise about three-fourths of the stars in our galaxy.

A team led by David Berger (University of Michigan) precisely measured the diameters of six *M*-type red dwarfs. Five turned out to be 15 to 20 percent larger than theoretical models predict. The CHARA observations confirm red-dwarf measurements made by other interferometers, as well as determinations made with conventional telescopes of red dwarfs in eclipsing binary systems. "If we don't understand this result, we don't understand low-mass stars," says Berger.

For late-breaking astronomy news between monthly issues, visit SkyandTelescope.com/news

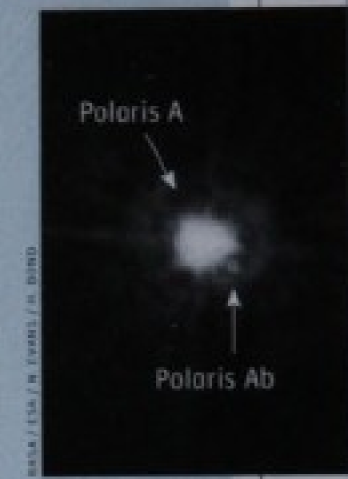
Berger and his colleagues suspect that the models fail to fully account for the presence of molecules such as water vapor in a red dwarf's upper atmosphere. These molecules would tend to darken a star slightly, therefore requiring the star to be larger in order to emit the amount of observed light.

Berger and Aufdenberg presented their respective results at January's American Astronomical Society conference in Washington, DC. — ROBERT NAEYE

Probing Polaris

Of the countless stars that grace the night sky, among the most famous is Polaris, the North Star. But this 2nd-magnitude star holds secrets not visible to the naked eye: it's actually a triple-star system, and, at a distance of just 430 light-years, it's the brightest Cepheid variable in the sky.

Polaris's larger but fainter sibling, Polaris B, has been known for centuries. Some 18 arcseconds from the North Star, it was first spotted by William Herschel in 1780 and can be seen through modest amateur instruments. But the much closer partner, Polaris Ab, had been recorded only by spectrometers and had managed to avoid being photographed — until now.



Nancy Evans (Harvard-Smithsonian Center for Astrophysics) and her team used the Hubble Space Telescope to capture the first-ever picture of this otherwise nondescript Sun-like companion. With that information and the orbit, they determined one of the most accurate mass measurements ever for a Cepheid variable: Polaris weighs in at 4.3 ± 1.1 solar masses.

Polaris Ab was tricky to spot. While spectroscopic studies had told astronomers much about the object, including its orbit, those same observations failed to reveal the separation between it and the primary. The new Hubble images show the companion to be a scant 0.2 arcsecond away, translating to just 3.2 billion kilometers (2 billion miles), comparable to the distance from the Sun to Uranus. Further hampering the detection was the brightness difference between the two, as the faint light from much smaller Polaris Ab is overwhelmed by its supergiant big brother.

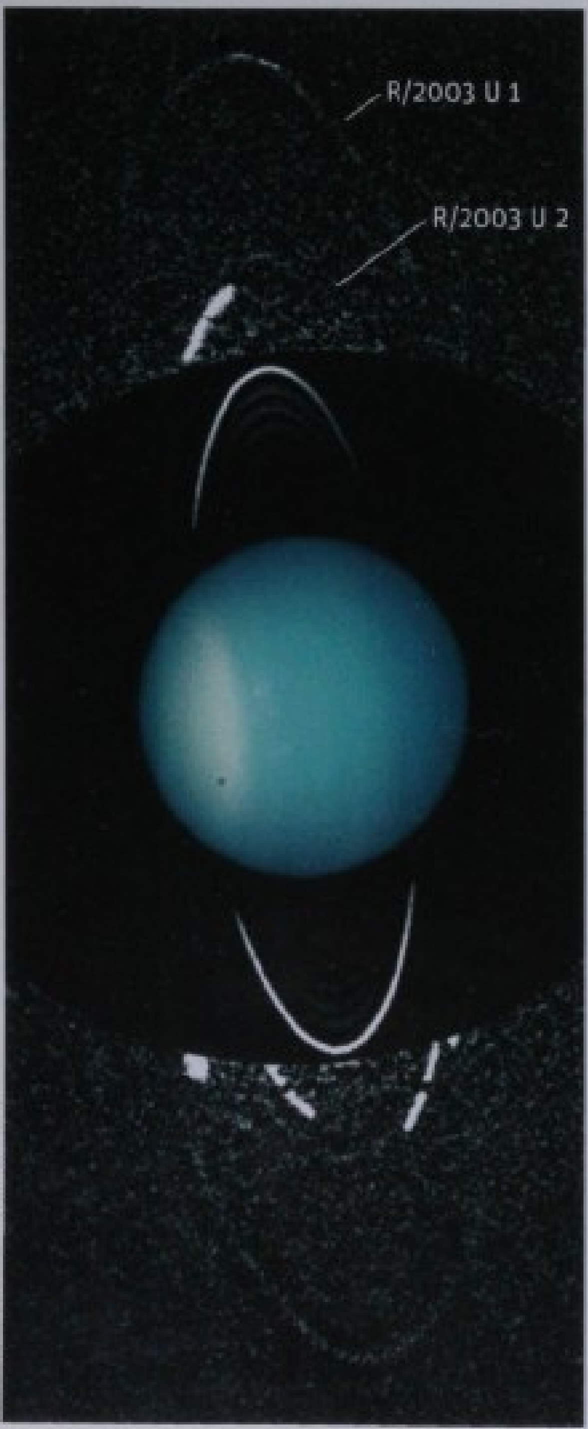
While not completely understood, Cepheid variables are well known in astronomical circles for acting as standard candles. Because the period of a Cepheid's variability is tightly related to its luminosity, astronomers can study how its brightness rises and falls to measure its distance. Learning more about these unique stars is critical since they play a key role in determining the universe's expansion rate and age. — D. T.

Uranus's New Rings

WHEN PEOPLE THINK of the best Hubble Space Telescope targets, planets might not come to mind. Yet the telescope's Advanced Camera for Surveys continues to make unexpected discoveries within our solar system. Mark Showalter (SETI Institute) and Jack Lissauer (NASA/Ames Research Center) looked at Uranus four times between July 2003 and August 2005 and recovered a satellite (now named Perdita) first observed in Voyager 2 images shot in 1986. They also found two new moons (*S&T:* January 2004, page 30), which go by the names Mab and Cupid.

More interesting were two new tenuous rings girdling the planet. The new rings, found in the initial 2003 campaign and confirmed in subsequent observations, reside far beyond Uranus's other rings. The planet apparently sports two separate ring systems — an "inner" group of 11 and the newly discovered outer pair. Mab "almost certainly is the [outermost] ring's primary source body," report Showalter and Lissauer in a December 22, 2005, International Astronomical Union (IAU) *Circular*. The second ring is trickier to explain because it peaks in brightness where no known moons are present. Without a source of dust to replenish the supply, rings like these survive only centuries or less.

The IAU assigned names to three other Uranus moons in December 2005. As is customary for Uranian satellites, the new names (Francisco, Margaret, and Ferdinand) refer to figures mentioned in Shakespearean plays. Uranus now has 27 confirmed, named moons. The new rings have been designated R/2003 U 1 and R/2003 U 2. — D. T.



NASA / ESA / M. SHOWALTER (SETI INSTITUTE)

A Colder Pluto

Astronomers using the Smithsonian Submillimeter Array on Mauna Kea in Hawaii have measured the temperature of Pluto and have confirmed that the planet's surface is colder than scientists would expect given its distance from the Sun. The icy surface is only −230°C (−382°F). Pluto's temperature should match that of its largest moon, Charon, which is about 10°C warmer.

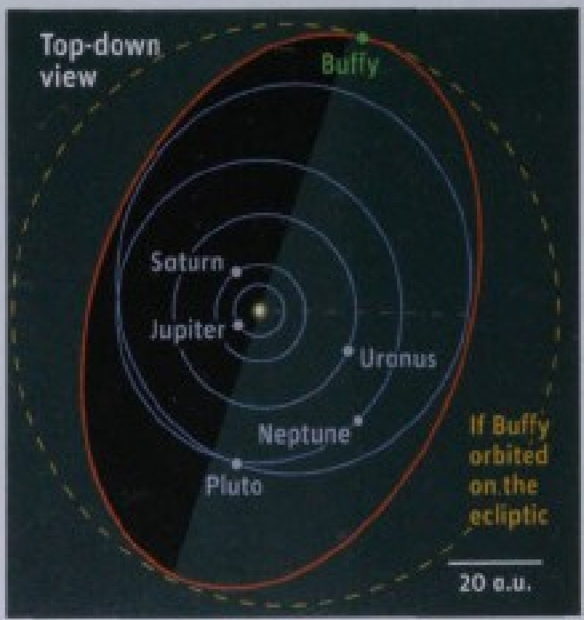
Mark Gurwell (Harvard-Smithsonian Center for Astrophysics) attributes this long-suspected discrepancy to a kind of reverse greenhouse effect. Rather than heating the surface, the scant bits of sunlight that reach the planet convert Pluto's nitrogen ice to gas. Because evaporation is a cooling process, the ground chills a bit as a result, just as evaporating perspiration cools your skin. — D. T.

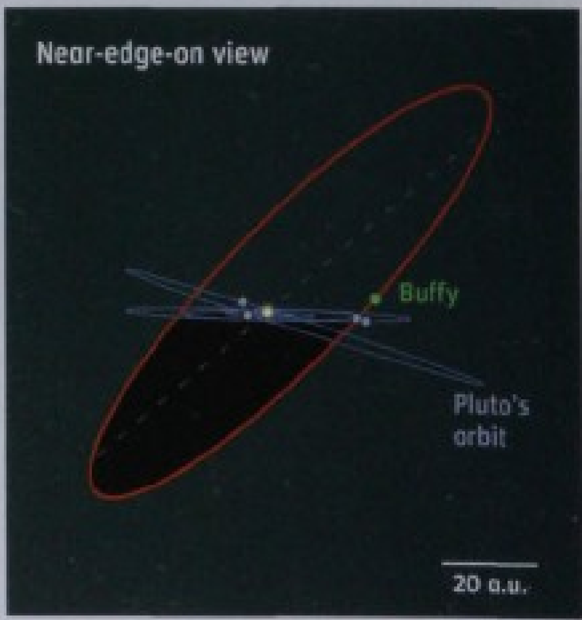
One Weird Kuiper Belt Object

Kuiper Belt discoveries are becoming rather mundane. Unless they rival Pluto in size, the public pays them little mind. Except for the weird ones.

Last December Lynne Allen and Brett Gladman (University of British Columbia, Canada) announced 2004 XR_{190}, an object they affectionately dubbed "Buffy." But cute names aside, this one has caught even jaded astronomers' attention. Its 440-year orbit stretches out to 57.2 Sun–Earth distances, and its inclination is a whopping 46.6°. But most curious is its eccentricity — Buffy's orbit is practically circular!

Dynamicist Scott Kenyon (Harvard-Smithsonian Center for Astrophysics) suggests that a flyby from a passing star early in the solar system's life could have disrupted objects in the Kuiper Belt enough to fling them into bizarre orbits. The gravitational effect this would have on Kuiper Belt bodies would vary. Many would be ejected from the system, some would be captured by the passing star, and others would have huge energies transferred into their orbits. The numbers allow for a wide range of resulting orbits — objects with 90° inclinations and even ones that circle the Sun backward. But astronomers need to discover more objects like Buffy to test the models. "Once we have 12 or more, we'll have a better idea," says Kenyon. — D. T.





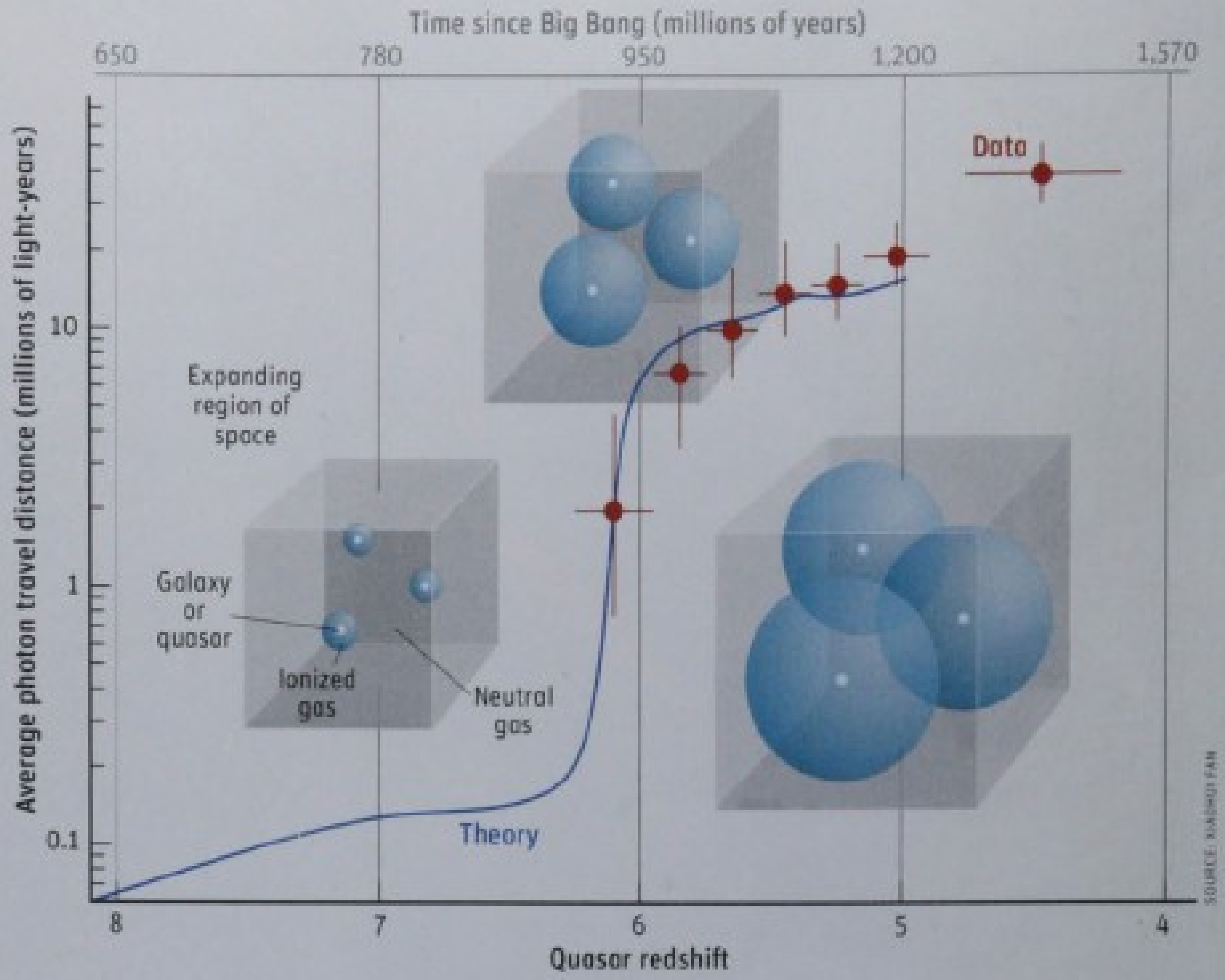
SOURCE: L. ALLEN / B. GLADMAN (2)

Cosmic "Twister"

Tornados might be familiar sights on the Kansas plains but not in the frigid depths of interstellar space. That's why astronomers were stunned when they saw this new color-coded image from the Spitzer Space Telescope's Infrared Array Camera (IRAC). "In the thousands of Spitzer images we've looked at, we've never seen anything like this before," says IRAC lead scientist Giovanni Fazio (Harvard-Smithsonian Center for Astrophysics).

The 0.3-light-year-long "tornado," an object in Chamaeleon known as Herbig-Haro 49/50, is not actually spinning. It probably formed when a protostar just above the field of view launched a jet "downward" through an interstellar dust cloud. The jet is ramming into the cloud at 160 kilometers (100 miles) per second, heating the material and causing it to glow in infrared light. The cause of the helical shape remains unknown, but it might have to do with magnetic fields or instabilities generated by the shock front.

In this Spitzer image, which was presented by John Bally (University of Colorado) and his colleagues at January's American Astronomical Society meeting, blue represents short infrared wavelengths and red longer ones. The star in the center of the blue emission at the bottom of the "tornado" is probably a chance superposition. — R. N.



Using a new sample of extremely distant quasars as probes of the intergalactic medium, astronomers have pinpointed the so-called reionization era, a period, just a billion years after the Big Bang, during which the universe became largely transparent to photons of ultraviolet light.

Reionization Revealed

A NEWLY ANALYZED sample of 19 extremely distant quasars has documented a key cosmic transformation — one that cleared away a fog of intergalactic hydrogen atoms left over from the Big Bang. The lifting of the fog enabled light from some of the first galaxy-like objects to traverse the visible universe and reach telescopes on Earth.

Finding out *what* caused this transformation — known as *reionization* — remains one of cosmology's Holy Grails. Whatever the cause (star-forming galaxies are leading contenders), astronomers are increasingly confident that it finished its work by a redshift of 6, just 950 million years after the Big Bang, when the universe was only 7 percent of its present age.

Observations from the past few years had suggested that the farthest known quasars shone through partially opaque material. But it wasn't until late last year that Xiaohui Fan (University of Arizona) and nine colleagues analyzed an unprecedentedly large sample of high-redshift quasars. They discovered the 19 hyperluminous galactic nuclei in data taken as part of the Sloan Digital Sky Survey (*S&T*: February 2005, page 34).

As Fan's team explains in its submission to the *Astronomical Journal*, follow-up spectra taken of the quasars revealed that at a redshift of 5 (1.2 billion years after the Big Bang), the universe had become 200 times more transparent to ionizing photons than it had been just a quarter billion years earlier.

This result, says Princeton University theorist Jeremiah Ostriker, is precisely what one would expect of a universe sprinkled with luminous objects, each carving an ever-growing bubble in the intergalactic medium with hydrogen-busting ultraviolet light. "At some point, they grow and overlap and merge," says Ostriker of these bubbles. The spreading reionization fronts changed the equivalent of thick pea soup with a few transparent bubbles into a perforated chunk of Swiss cheese.

The new Sloan study, says Ostriker, "makes it absolutely conclusive" that reionization took place. Even so, finding out when it *began* will have to wait until observers capture infrared spectra of quasars or gamma-ray bursts with redshifts around 7 or higher, says Fan, and no such objects have been conclusively identified. — JOSHUA ROTH

Sky-Watcher
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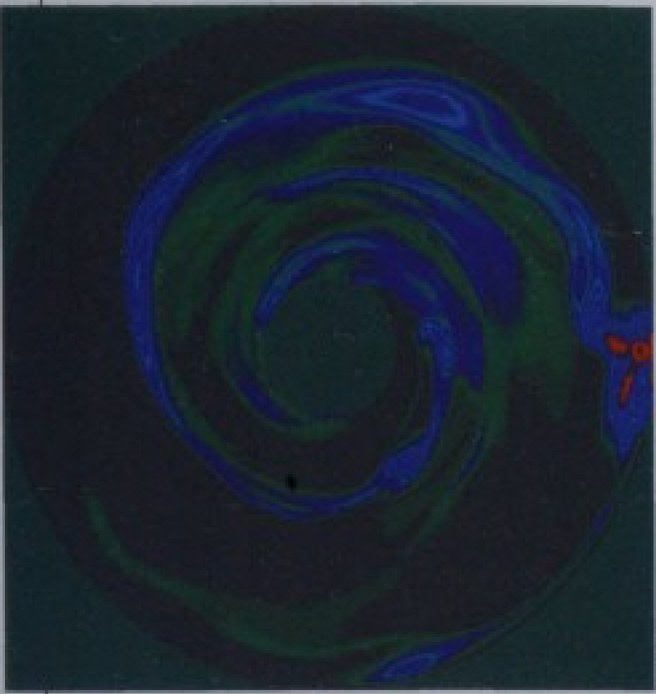
Binary-Star Planets Common

ANYONE ESTIMATING the number of life-bearing planets in our galaxy must confront the question of whether planets can exist in binary or higher-order multiple-star systems. After all, about two-thirds of all Sun-like stars reside in multiple systems.

New observational and theoretical studies announced at January's American Astronomical Society meeting in Washington, DC, offer good news for astrobiologists. These results build on and help explain earlier discoveries of 21 exoplanet host stars in binaries and 2 in triple systems (S&T: November 2005, page 20).



ALAN BOSS

This computer simulation shows a protoplanetary disk around one member of a binary system. Jupiter-mass clumps of gas (red and blue regions) form easily and later collapse to form gas-giant planets.

A group of Georgia State University astronomers led by Deepak Raghavan and Todd Henry scrutinized modern and archival images of 131 stars known to harbor at least one planet. The team was looking for stars in a field that share the planet-host star's motion across the sky (proper motion), a strong indicator that the stars are gravitationally bound. Follow-up photometry and spectroscopy were used to confirm whether potential stellar companions lie at the same distance from Earth.

Henry and his colleagues found that 29 of the 131 planet-host stars have stellar companions. The results include the discovery of five new binaries (for a total of 26) and one new triple (for a total of 3). These 29 stars have a combined 36 known planets. Three of the hosts have stellar companions at projected separations as close as 20 astronomical units (Uranus's distance from the Sun), and two of the stars are accompanied by white dwarfs, meaning that the planet endured the companion's evolution into a red giant. "Our results show that planetary systems can form and survive in a variety of environments," says Raghavan.

Theoretical studies also show that planets can readily form in binary systems, despite the gravitational tug-of-war between competing stars. Alan Boss (Carnegie Institution of Washington) presented computer simulations demonstrating that a distant stellar companion's gravity can actually induce planet formation by triggering the formation of dense gas clumps within a protoplanetary disk. The clumps quickly collapse to form gas-giant planets. Jack Lissauer (NASA/Ames Research Center) presented his group's findings that Earth-size planets can form in wide orbits around two stars in a tight binary and in close orbits around one of the two stars in a widely separated binary.

"The take-home message is that half of all wide binary-star systems can harbor planets because the separation is great enough to permit both the formation and the subsequent stability of the resulting planetary orbits," says Geoff Marcy (University of California, Berkeley), coleader of the team that has discovered more than half of the 170-plus known exoplanets. "There are surely tens of billions of Sun-like stars in the galaxy that can easily harbor planets." — R. N.

Extreme Parallax

The surest way to measure the distance to a star is by the star's *trigonometric parallax:* how much it appears to shift from side to side against distant background stars as Earth moves from one side of its orbit to the other every six months. The parallax shift gives the star's distance by simple geometry, with no troublesome unknowns or hidden assumptions.

However, most stars are so far away that their parallax shifts are extremely small and hard to measure. A major breakthrough came in 1997 with the European Space Agency's Hipparcos satellite. It measured the parallaxes of 118,218 bright stars to the extraordinary precision of about 1 milliarcsecond. As a result, the distances of these stars are known to 1 percent accuracy out to a few dozen light-years, and 10 percent accuracy out to a few hundred.

But astronomers are coming up with techniques for doing much better. Radio observers are using the worldwide Very Long Baseline Array (VLBA) to measure parallaxes of a few objects to 10 microarcseconds, beating Hipparcos by a factor of 100. Two groups recently used this technique to measure the parallaxes of water and methanol clouds in the nebula W3(OH), part of IC 1795 in Cassiopeia. The nebula is located in the Perseus spiral arm of the Milky Way, the next arm out from ours. The researchers find that the nebula is 6,470 light-years away with an uncertainty of only 2 percent.

This resolves a factor-of-2 discrepancy in two other measurements of the nebula's distance, based on the assumed luminosities of its stars and on the assumption that it is moving along a circular orbit around the galaxy. W3(OH) turns out not to be on a circular orbit; it is moving toward the galactic center by 22 kilometers per second. This refinement gives an indication of the density of the Perseus Arm compared to the inter-arm regions, and gives hints about the distribution of dark matter in the Milky Way. A paper on this work appears in the January 6th *Science*.

Additional extreme parallaxes are on the way. "We've just recently figured out how to do this well with the VLBA," says Mark Reid (Harvard-Smithsonian Center for Astrophysics), a member of both teams. "We're looking at about 14 objects now, including the Orion Nebula. We hope to get a distance to the Orion Nebula that's better than 1 percent accurate."

Much more is on the horizon. Hipparcos's successor, the European Space Agency's Gaia satellite, is due to launch in 2011. By 2015 it should be producing tens of millions of star parallaxes as accurate as the handful of VLBA radio parallaxes being acquired now — bringing a precision revolution that will advance practically every branch of astronomy.

— ALAN MACROBERT

Elliptical Mergers: Caught in the Act

WITH THEIR NEARLY FEATURELESS profiles and uniformly ancient stellar populations, elliptical and lenticular (S0) galaxies are the epitome of cosmic stasis in many astronomers' minds. But when Yale astronomer Pieter van Dokkum studied extremely deep images of 126 luminous red galaxies — many of which were ellipticals and lenticulars — he was in for a surprise. As he reported in the *Astronomical Journal* last December, more than half of those galaxies are distended, surrounded by faint asymmetric envelopes, or paired with lesser systems — compelling evidence that they have interacted or merged with other galaxies.

And this, says van Dokkum, resolves a major conundrum. Reigning cosmological models dictate that massive objects continuously accrete new matter. Yet earlier generations of astronomers had concluded that elliptical and lenticular galaxies stopped bulking up billions of years ago. For one thing, shallower photographs showed little evidence for interactions with other galaxies. Furthermore, these massive galaxies contained uniformly ancient stars, which are relatively red, while well-documented galaxy collisions inevitably seem to spawn young, blue stars.

But van Dokkum says he has resolved the discrepancy. In his view, the ellipticals and lenticulars that he caught *in flagrante delicto* are obviously absorbing or tussling with other galaxies, but they contain little interstellar gas — the raw material for making new stars. "The galaxies that result from these mergers are relatively young," he explains, but their *stars* are old. This resolves the age discrepancy and allows structure formation to proceed apace in the modern universe, as expected.

François Schweizer (Carnegie Observatories) isn't convinced that van Dokkum's study has really settled the issue. Not that Schweizer disputes the idea of today's ellipticals interacting with other galaxies: in fact, he photographed dozens of cases in the 1980s and early 1990s. But Schweizer thinks that by focusing on very red objects, van Dokkum has fooled himself into giving primacy to so-called "dry mergers" — smashups of gas-poor galaxies that can't fuel starbirth.

For his part, van Dokkum retorts that in many cases, it's apparent that two obviously bulge-dominated galaxies are interacting, while in others, the glowing leftovers of a gobbled-up galaxy are rather diffuse — in stark contrast to the narrow tails created when spinning, gas-rich spirals collide. Furthermore, says van Dokkum, preliminary spectra of many of his systems show little evidence for star formation.

On one point Schweizer and van Dokkum agree: Hubble Space Telescope images would shed the most light on the nature of the enigmatic ellipticals. In January van Dokkum asked for permission to use the orbiting observatory toward this end. — J. R.

PIETER VAN DOKKUM (4)

Taken by the 4-meter reflectors on Kitt Peak in Arizona and Cerro Tololo in Chile, these color-composite images show 15th- and 16th-magnitude galaxies roughly 1 billion light-years distant in Boötes and Virgo. Each frame depicts what astronomers think is a different stage in the merger of two galaxies. (Panel *A* spans 5′; panels *B* through *D* are 2.5′ wide.) If two merging galaxies are gas-poor ellipticals or lenticulars, they can coalesce in as little as 200 million years without forming new stars.

Einsteinian Energy Bolstered

By repeatedly imaging 1-square-degree fields with the 3.6-meter Canada-France-Hawaii Telescope, participants in the Supernova Legacy Survey (SNLS) are on track to detect hundreds of Type Ia supernovae billions of light-years distant. These "standard candles" will enable the astronomers to chronicle the history of the cosmic battle between gravity (which slows the universe's expansion) and "dark energy" (which speeds it up). The first year of SNLS data turned up 71 Type Ia supernovae, some of which exploded when the universe was only 6 billion years old (at redshift 1.0). By combining information on these supernovae with data from the Sloan Digital Sky Survey, Pierre Astier (National Energy Research Scientific Computing Center, France) and his numerous SNLS colleagues have strengthened the case that dark energy takes its simplest possible form: Albert Einstein's cosmological constant, a mysterious kind of vacuum energy whose density remains unchanged throughout space and time (*S&T:* March 2005, page 32). — J. R.

mission update *by jonathan mcdowell*

New Horizons

On January 19th the $650 million New Horizons probe launched to the ninth planet, Pluto. The 465-kilogram (1,025-pound) spacecraft carries three cameras: an 8-centimeter-aperture (3-inch) instrument for visible and infrared imaging, an ultraviolet spectrometer, and a 20.8-cm telescope for long-range pictures. A dust sensor, an energetic-particle spectrometer, and a solar-wind instrument complete the small payload complement, together with the high-gain radio antenna (also used for science measurements). Unlike larger probes such as Voyager, the New Horizons instruments are fixed on the spacecraft instead of being mounted on a moving scan arm, so the whole vehicle must be pointed to aim the cameras.

As a tribute to Clyde Tombaugh, the man who discovered Pluto, a small amount of his cremated remains was placed onboard. The spacecraft will fly by Jupiter for a gravity assist in February 2007. In July 2015 the New Horizons flyby of Pluto and its three known moons will complete humanity's initial reconnaissance of all the traditional major planets in the solar system. But now there's 2003 UB_{313}, and maybe more to come. . . .

Stardust

The Stardust capsule landed successfully on January 15th in the highest-velocity spacecraft reentry ever. Its safe landing onto the Utah Test and Training Range marked the end of the probe's seven-year trek around the inner solar system.

Stardust launched in February 1999 and a year later deployed its aerogel collectors to soak up interplanetary and interstellar particles. Dust collection continued through the November 2002 flyby of asteroid 5535 Annefrank. In January 2004 Stardust reached its prime target, Comet 81P/Wild 2, and collected cometary particles on the back side of its aerogel samplers.

Soon after it landed, scientists examined the aerogel collectors and deemed the mission a triumphant success. According to lead scientist Donald Brownlee (University of Washington), Stardust may have collected more than a million microscopic specks of dust. The samples are undergoing analysis in Houston, Texas.

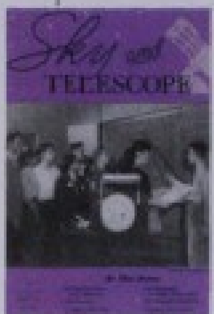
Stardust isn't the first vehicle to return to Earth from beyond lunar orbit. Most recently, in 2004, Genesis crash-landed at the Utah range at the end of its mission (*S&T:* December 2004, page 26). Fortunately, Stardust's parachutes deployed perfectly and didn't repeat Genesis's hard landing.

JONATHAN MCDOWELL, *a staff scientist for the Chandra X-ray Observatory, provides updates of space missions on his Web site at www.planet4589.org/space/jsr/jsr.html.*

50 & 25 years ago *by leif j. robinson*

APRIL 1956

Good Counsel "Changes in the angles of illumination and observation alter the appearance of lunar scenery somewhat as a kaleidoscope redesigns its patterns. Mountain walls that tower tonight may appear insignificant tomorrow. Small craters that dot floors of larger rings under one illumination may be absent under others. Long clefts, clearly marked at times, vanish with the shifting of light and shadow. . . .



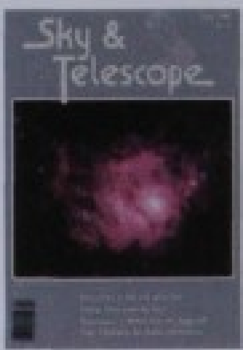
"Is it surprising, then, that so many dubious things have been seen on the moon? Among the oddities reported are snow, hoarfrost, vanishing craterlets and light streaks, gray or black areas of vegetation, and shadowy masses of moving animals. . . .

"Observers should distinguish between fact and fancy, moonlight and moonshine."

A frequent contributor to this magazine, Leland Copeland could not have presented a better case — especially in that innocent era — for caution in interpreting what one sees on the Moon.

APRIL 1981

Star Building "During the past decade the quest to understand star formation has become one of the most active endeavors in Milky Way research. . . .



"There is now a firm bridge connecting studies in the farthest infrared with ones at the shortest radio wavelengths. These studies, combined with spectrographic observations of objects that were out of reach 10 years ago, are giving us a fascinatingly complete picture of the physical conditions and processes at work inside the clouds of gas and dust. We suspect these clouds of harboring protostars and, in several cases, we have found some very young stars."

So wrote Bart Bok, one of the great pioneers in the study of star formation's early stages. Thanks to technology, our understanding of the process has continued to explode.

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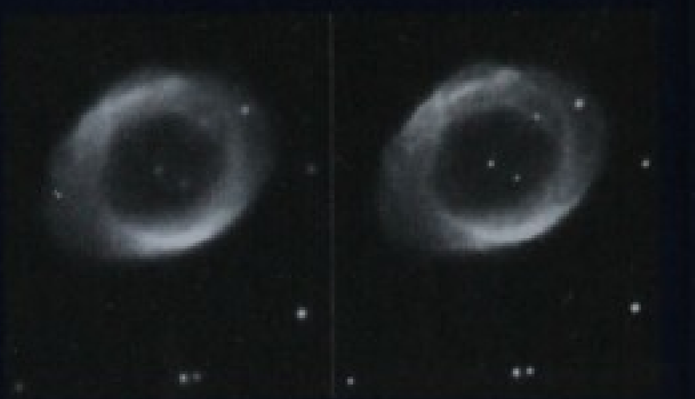


ADAPTIVE OPTICS: The dual sensor design of SBIG's self-guiding cameras, as well as the new remote guider, also makes it possible to use the first affordable Adaptive Optics device currently available to amateur astronomers. By sampling a guide star on the guiding CCD at a high rate, corrections can be made to a movable mirror or window up to 40 times per second. The result is a highly stabilized image, free of mount errors, vibration, wind-induced motion, and image wander due to low order atmospheric effects. Many of the highest resolution, long exposure, deep space images taken by amateurs have utilized the AO-7 to enhance the ultimate sharpness of the image. The AO-7 is compatible with all dual sensor ST-7, ST-8, ST-9, ST-10 and ST-2000 cameras. NEW The new AO-L Adaptive Optics device is now available for the larger format, Research Series cameras.

INTEGRATED FILTER WHEELS: Although SBIG also offers cameras with color CCDs for simple color imaging, the best color images are obtained using a monochrome CCD and high quality color filters. A separate filter wheel also allows for narrow band imaging through H-alpha filters, or through UBVRI filters for photometric studies. Our color filters are research grade, high transmission, interference filters designed specifically for the spectral response of the CCDs used in our cameras. No better quality color filters for our cameras can be found anywhere. The CFW8A, five-position filter wheel, and CFW10, ten-position filter wheel, both with 1.25" filters are designed to mate directly to the ST-7, ST-8, ST-9, ST-10 and ST-2000 cameras, making an integrated unit when attached. The new low cost ST-402ME and the Research Series cameras have a filter carousel built into the camera. NEW A low profile, eight-position 2" filter wheel is also now available for the STL series cameras, compatible with the AO-L Adaptive Optics accessory.

HIGH SENSITIVITY AT A LOW PRICE: The latest scientific grade sensors from Kodak push the quantum efficiency of the front illuminated CCD into what was previously the realm of exotic, expensive, thinned back illuminated CCDs costing many thousands of dollars. The good news is that this is done with low noise and improved cosmetic specifications. The really good news is that the new technology is available in our lowest priced ST-402ME camera! With peak QE approaching 90%, the ST-402ME at under $1500 simply cannot be beat when it comes to sensitivity vs. price. The same high QE technology is also available in the ST-7XME, ST-8XME and ST-10XME cameras. Include NEW improved TE cooling, high speed USB2.0, 16 bit A/D, the ability to take long exposures, and the ability to act as an autonomous autoguider, and you begin to see why the ST-402 has become the camera of choice for those just getting into CCD imaging.

the Science Behind the Solar Corona

By Carolus J. Schrijver

If you are one of the fortunate people with the means to see the next total solar eclipse, you'll catch a glimpse of the Sun's corona (weather permitting); if not, you'll see pictures of the event on this magazine's pages shortly afterward. What makes up the corona that you see during the all-too-brief totality? What shapes it? What makes it glow?

Only by observing the Sun in many ways have astronomers been able to fully appreciate how electrical currents and magnetic fields shape the corona while powering far-reaching space storms.

The amazing spectacle that we see when the Moon covers the bright solar disk is the Sun's outer atmosphere. That atmosphere has two clearly distinct components. Eclipse watchers may see the lower component, the *chromosphere*, just beyond the Moon's limb. Some 4,000 kilometers thick, the chromosphere is a wispy coating that glows at temperatures of about 10,000°C (18,000°F) with the reddish light of hydrogen atoms. Above that reddish band lies the *corona*, spreading its tentacles into interplanetary space.

A blistering multimillion-degree plasma of shattered atoms, the corona is a dynamic environment, often disturbed by explosions that rock its very structure and throw material into interplanetary space. These explosions cause storms within the *solar wind*, a stream of electrons, protons, and partially ionized atoms that ceaselessly emanates from deep within the corona and courses beyond the farthest planets in our solar system.

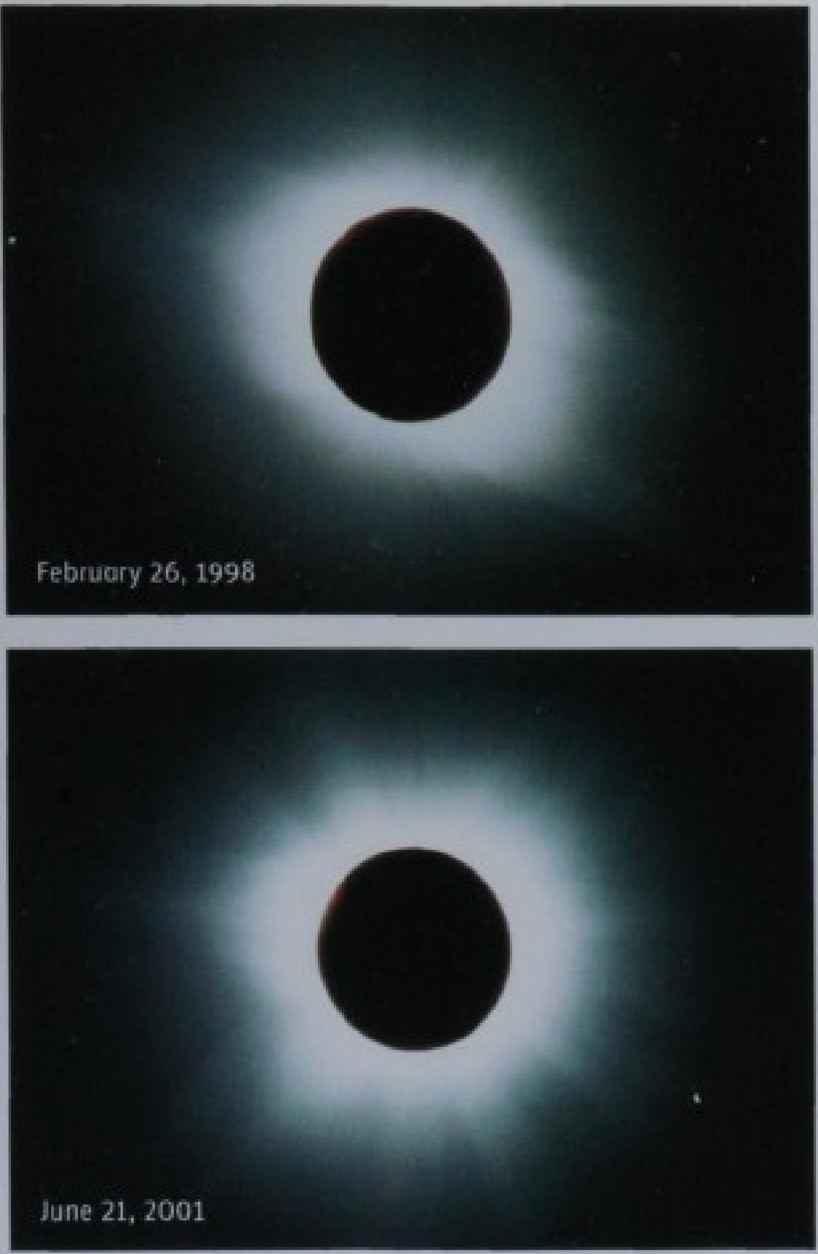
The interaction of the solar wind with Earth's outer atmosphere and magnetic field affects our society in many ways. One crucial issue that arises when we study this "space weather" is how the Sun couples to its surroundings. That coupling is dramatically revealed in the shape of the corona during a total solar eclipse.

We have learned much about the solar corona in the past few decades. But much remains mysterious, for while the

What forces shape the ephemeral structures seen during total solar eclipses?

While amateur astronomers can view our star's outer atmosphere only during total solar eclipses, Space Age technology has enabled professionals (and anyone with an Internet connection) to enjoy around-the-clock views — views that are advancing the science of space weather. Steve Albers combined five different exposures, each optimized for a different radius, in order to make this mosaic of the July 11, 1991, total solar eclipse. Photographs by Dennis di Cicco and Gary Emerson.

laws of physics apply everywhere, coronal conditions are so different from those on Earth that many phenomena are thoroughly unfamiliar. Fortunately, increasingly sophisticated telescopes, each a technological marvel, are rapidly advancing our knowledge of the Sun's capricious crown.



Above: Each of these photographs by eclipse aficionado Fred Espenak is a 2-second exposure on Kodak Royal Gold 100 film with a 90-mm refractor at f/8. The February 26, 1998, view reflects the corona's typical appearance during solar minimum, when sunspots are few or absent: the longest streamers extend along an axis defined by the Sun's equator. By contrast, the June 21, 2001, view typifies the solar-maximum corona, with streamers radiating in all directions.

Introducing the Solar Corona

To appreciate what we see during a total solar eclipse, we must first realize that even though the corona spans a huge volume of space, it is a lot of almost nothing. At visual wavelengths, the corona is only one-millionth as bright as the Sun, a quivering candle next to a blinding searchlight. That explains why we don't see it unless the Sun's *photosphere*, or "surface," is blocked. The Moon performs this service most effectively because it appears to have very nearly the same size as the photosphere when seen from Earth — a remarkable coincidence.

Not quite as bright as a full Moon, the eclipse corona glows as faintly as it does in large part because there is very little of it to light up. In fact, what we see of the eclipse corona with the unaided eye is not even its own glow. Rather, we see light from the photosphere that is scattered toward us by free electrons in the corona. This phenomenon forms a halo much like that around a streetlight in a fog.

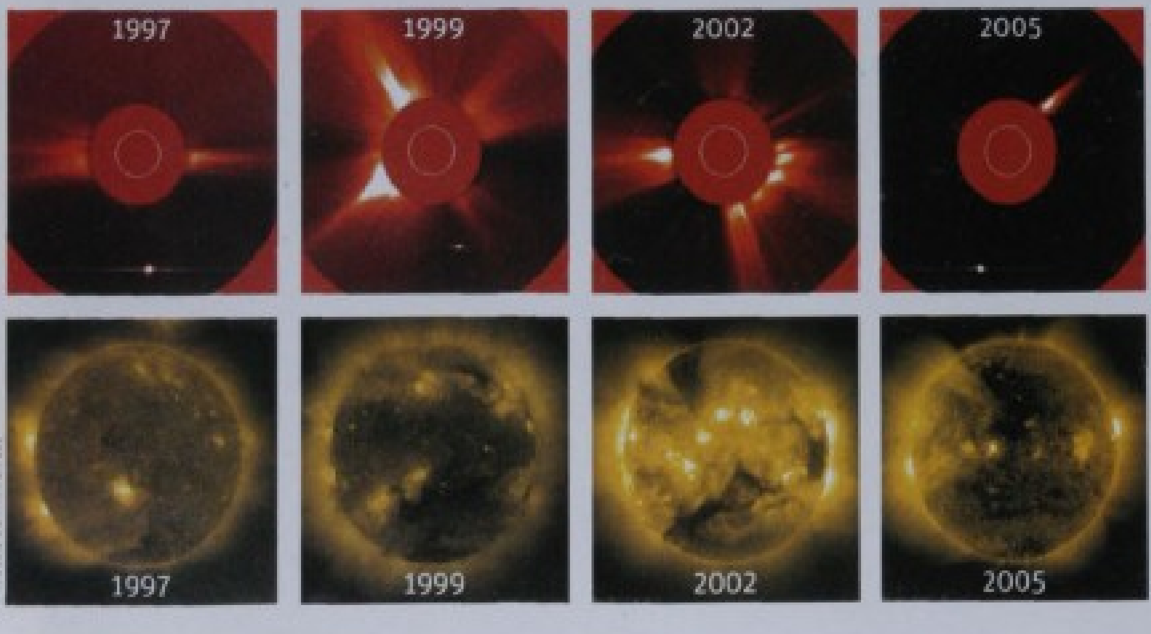
We see that halo only because the corona is so vast that its eerie emptiness can add up to something when viewed as a whole. Even at its base, where it is thickest, the corona is 100 billion times less dense than Earth's atmosphere at sea level. Earth's atmosphere isn't this thin until you go somewhat above the highest Space Shuttle orbit, which many call outer space.

Perhaps the most striking features that we see during a total eclipse are the so-called *streamers* that extend more or less radially outward from the Sun. Their overall pattern depends on how magnetic the Sun is at the time. When magnetic activity is low and its telltale sunspots are few (as is the case this year), the corona looks relatively featureless, with just a few streamers on opposing sides of the Sun's equatorial belt. During sunspot maximum, by contrast, more than a dozen streamers usually exist, each going in a different direction.

The Magnetic Corona

This change in guise with the coming and going of sunspots hints at what is the corona's most important defining characteristic: its ubiquitous magnetic field.

On Earth, we tend to ignore magnetic fields in our everyday lives. But they are critically important in the Sun's atmosphere. This is especially true in the corona, where atomic nuclei have been almost entirely stripped of their electrons, making for an electrically conducting gas, or



CAROLUS SCHRIJVER (8)

Left: Taken on April 1st in the indicated years, these false-color images from the Solar and Heliospheric Observatory (SOHO) spacecraft show how the Sun's degree of sunspot activity affects coronal streamers (seen at visual wavelengths in the top row) and the 2.5-million-degree Celsius gases associated with active regions in the lower corona (seen in extreme ultraviolet, or EUV, light in the bottom row). Sunspot activity reached a minimum in 1996 and peaked a half decade later before declining toward its next minimum, which is expected in 2007 or 2008. The blank central zone within the visible-light images represents the 1°-wide field (twice the Sun's apparent diameter) blocked by the occulting disk in SOHO's LASCO coronagraph.

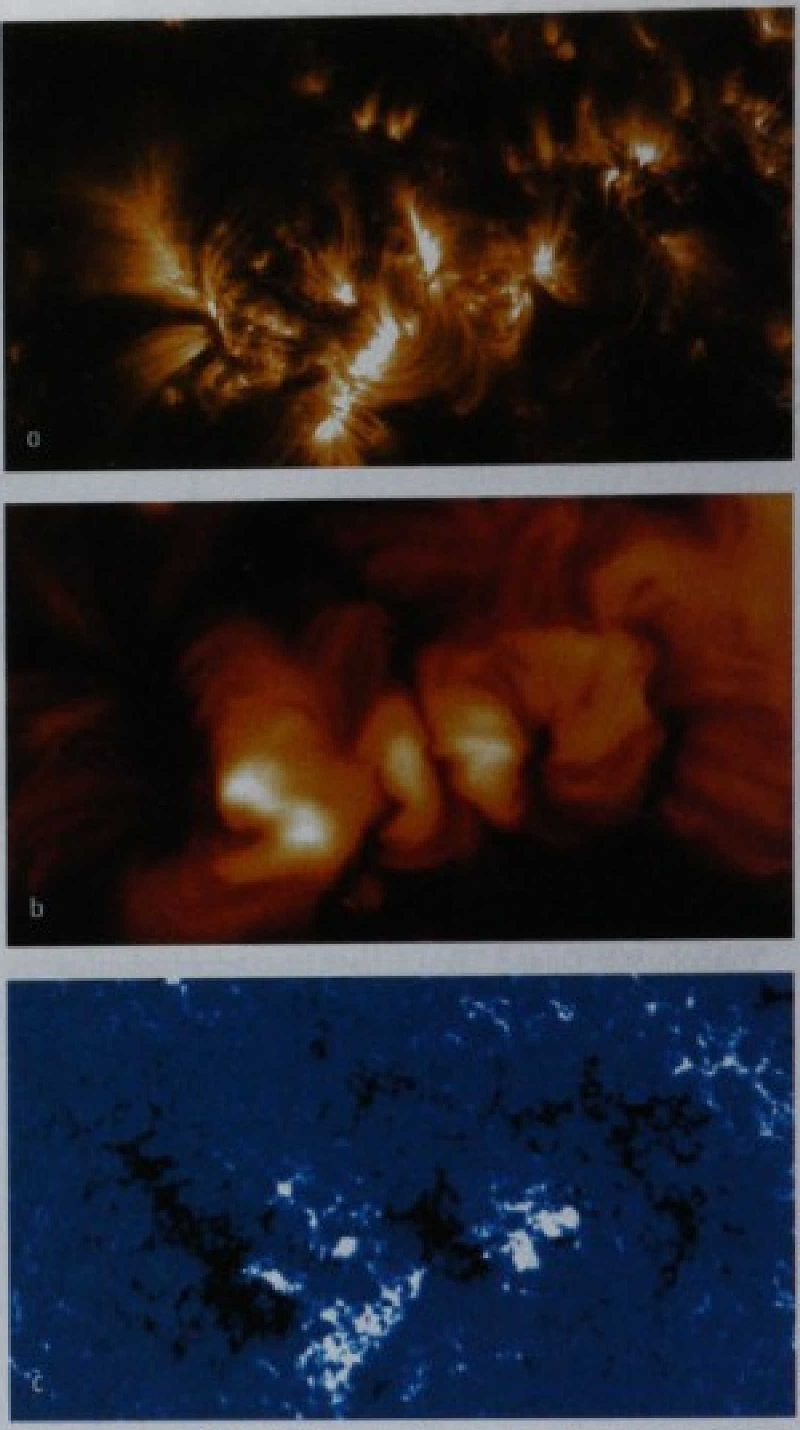
plasma. Like all charged particles, the electrons and ions that make up this plasma are readily deflected by magnetic fields. And while in most of the corona the Sun's magnetic field is not much stronger than Earth's, coronal gases are exceedingly rarefied. Consequently, the solar corona is shaped according to the rules of magnetism rather than of gravity.

The Sun's magnetic field fundamentally differs from Earth's. On human time scales, the Earth's field is essentially a stationary single magnetic dipole, like that of a bar magnet. But the Sun's magnetic field is made up of many such dipoles, with multiple strong "bar magnets," known as *active regions*, strung around its circumference in numbers that wax and wane with the 11-year sunspot cycle. The active regions emerge from the deep solar interior and break through the photosphere at unpredictable locations, where they often form sunspots.

Although George Ellery Hale discovered the Sun's magnetic field at Mount Wilson in 1908, it took more than six decades for solar astronomers to understand how it shapes the corona. Why so long? One reason is that until 76 years ago we could observe the corona only during infrequent, brief total solar eclipses.

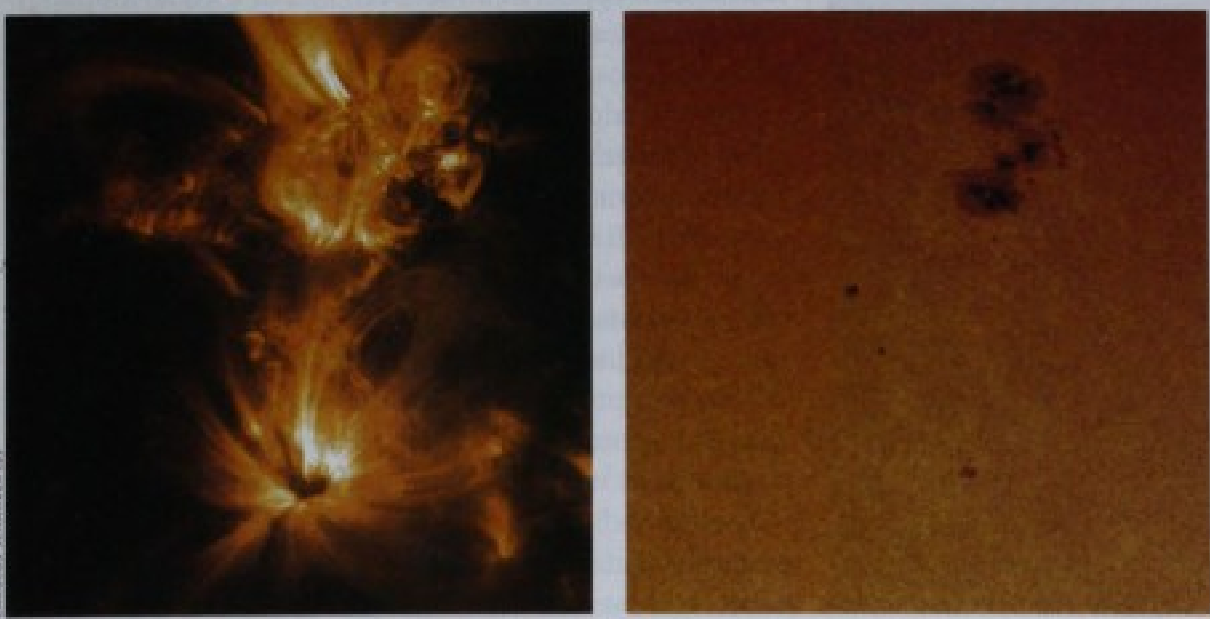
Then, in 1930, French astronomer Bernard Lyot built a *coronagraph*: a special-purpose instrument that used a disk to block the Sun's direct light. This opened a new chapter in solar astronomy, as one no longer needed to await a total eclipse to view the Sun's tenuous outer atmosphere. Even so, visible-light observations couldn't show the corona's transparent structures one by one. Rather, these structures were seen projected on top of each other, and this tremendously complicated their interpretation. Compounding the puzzle further, magnetic fields could not be properly mapped near the Sun's limb. Hence, learning how field and corona were connected was initially very difficult.

That remained so until the early 1970s, when X-ray telescopes onboard the Skylab space station allowed astronomers at last to routinely see those parts of the corona that lie between Earth and the photosphere, where magnetic fields could be mapped. To do this, we exploited the corona's high temperature, which is typically 10,000 times hotter than a comfortable room. A gas this hot emits light primarily at X-ray and extreme-ultraviolet (EUV) wavelengths, while the much cooler solar "surface" emits essentially no such light. An X-ray or EUV telescope therefore shows bright



BART DE PONTIEU / LMSAL (3)

Taken on February 8, 2001, these panels show how the corona appeared to the Transition Region and Coronal Explorer (TRACE) satellite, which observed EUV emission from 1,000,000°C gas *(a)*, and how it appeared when seen by the now-defunct Yohkoh satellite, whose soft X-ray telescope detected plasma at temperatures between 2 and 5 million degrees C *(b)*. SOHO's magnetograph *(c)* color-codes the strengths and polarities of magnetic fields within the underlying photosphere, which it measures indirectly using visible light. Each image spans 700,000 kilometers (one solar radius) from side to side.



CAROLUS SCHRIJVER (2)

Taken on May 11, 2005, these simultaneous EUV *(far left)* and visible-light views show two active regions anchoring a plethora of coronal loops. Intriguingly, the lower (eastern) region, with its "sunflower" pattern of relatively cool coronal loops, lacks major sunspots — despite its obviously magnetic nature. Both of the images were made with the TRACE spacecraft and show the same small part of the Sun.

coronal material enveloping a dark sphere.

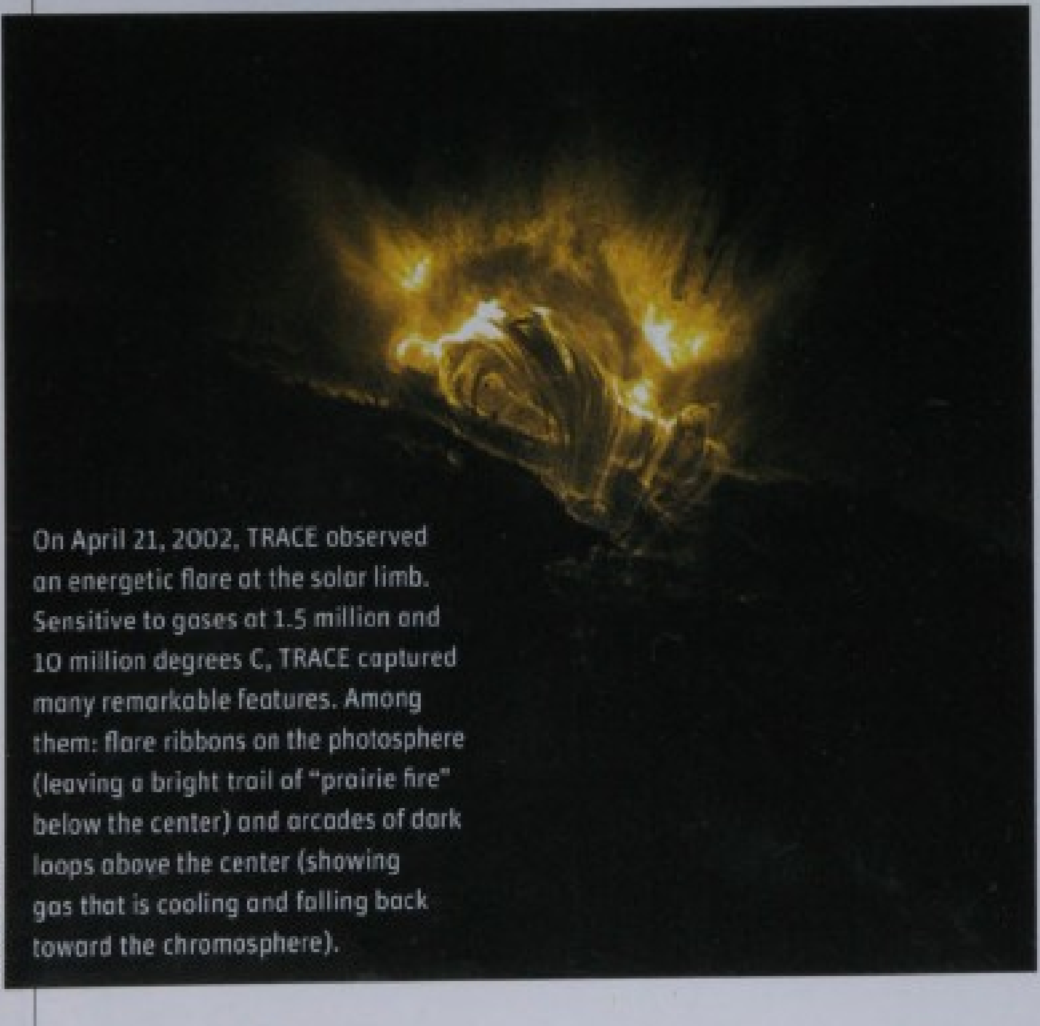
In order to take advantage of this fortuitous state of affairs, we had to launch telescopes above Earth's protective atmosphere, which blocks X-ray and EUV light. Rocket-borne instruments and the Earth-orbiting Skylab paved the way during the early years of the Space Age. But coronal X-ray and EUV imaging became an everyday experience only with the 1991 launch of Japan's Yohkoh satellite, the 1995 launch of the SOHO satellite (a joint European Space Agency and NASA project), and the 1998 launch of NASA's TRACE satellite. (Yohkoh fell to Earth last year, but SOHO and TRACE remain in service.)

SOHO / EIT CONSORTIUM

This false-color composite image comprises three SOHO exposures at different wavelengths, each representative of plasma at a different temperature. Blue represents 17.1-nm light (from material at 1 to 1.5 million degrees C); green, 19.5-nm light (from material between 1.5 and 2 million degrees C); and red, 28.4-nm light (from material at temperatures hotter than 2.5 million degrees C). The different filters transmit emissions from iron atoms that have been ionized by varying amounts. Taken together, they allow astronomers to characterize the physical state of the lower corona.

Thanks to these successful missions, we have been able to compare X-ray and EUV images of the corona to maps of photospheric magnetic fields. And that has revealed the corona's magnetic nature, for where magnetic fields are strongest, the corona is hottest and brightest — just as one would expect if magnetic fields were confining the plasma and increasing its temperature and density.

Yohkoh, SOHO, and TRACE have discovered many of the corona's curious properties. With their 1- to 5-arcsecond resolution, the sharp images from these spacecraft have revealed a variety of intriguing structures. Those that stand out most prominently are thin, bright strands that arch through the corona, each connecting two photospheric regions with opposite magnetic polarities. We now understand these so-called *coronal loops* as a natural consequence of the magnetic forces dominating the corona. The magnetic-field lines tracing these loops trap hot coronal gases, which can flow only from one end to the other, losing energy in the form of X-ray or EUV light.



On April 21, 2002, TRACE observed an energetic flare at the solar limb. Sensitive to gases at 1.5 million and 10 million degrees C, TRACE captured many remarkable features. Among them: flare ribbons on the photosphere (leaving a bright trail of "prairie fire" below the center) and arcades of dark loops above the center (showing gas that is cooling and falling back toward the chromosphere).

CAROLUS SCHRIJVER

The Explosive Corona

In addition to their sharp optics, Yohkoh, SOHO, and TRACE also have given us the ability to take long series of rapid exposures. With this "movie-making" capability we have learned to appreciate the corona as a place of utter impermanence, in which every structure changes its appearance within a matter of hours.

One long-standing mystery has been the source of the energy that heats the corona to million-degree temperatures. Large numbers of small-scale explosions certainly contribute to this heating, with strong winds often blowing up or down the magnetic-field lines as coronal gases adjust to them. However, SOHO and TRACE observations suggest that the corona is heated primarily by electrical currents. These currents are generated by convective bubbles that seethe tirelessly just beneath the photosphere.

Heating the corona is but one of the roles played by the electrical currents coursing through coronal loops. When the largest of these immense currents become unstable, they cause *solar flares:* giant explosions that can outshine the entire X-ray corona 1,000 times over. We are far from understanding how solar flares release their energy so explosively. We do know that much, if not most, of a flare's energy first goes into generating large numbers of ions and electrons, which are accelerated to speeds that are a good fraction of the speed of light. These charged particles race along the magnetic field away from the flare-initiation sites, which often appear to lie between sets of coronal loops.

Many of these particles quickly crash into the upper layers of the chromosphere, where they form bright ribbons visible in hydrogen-alpha and ultraviolet images. The kinetic energy of these particles is then transformed into heat. The heated chromospheric matter responds by evaporating into the corona, where it can increase the gas density within a flaring loop a thousandfold. And since dense gas radiates far more efficiently than rarefied gas, the heat is quickly lost into space in the form of bright X-ray radiation.

That energetic radiation has real-world consequences when it reaches Earth. It can puff up the outermost (ionospheric) layers of the atmosphere, thereby affecting long-range radio communications. It also increases the atmospheric drag that steadily works to bring down low-Earth-orbit satellites and rocket debris.

The Interplanetary Corona

Energetic X-rays aren't the only emanations to reach Earth from the solar corona. We are gradually learning to appreciate all the ways in which magnetic activity within the Sun's atmosphere spreads into interplanetary space, causing phenomena that we now know as space weather.

Space weather, like Earth's, has two components. One is a background "seasonal" state that changes on time scales of days, months, or years. The other is made up of highly perturbed states that behave like dangerous storms. Space weather changes day by day as active regions emerge, age, and disintegrate.

The hot coronal gases trapped above an active region are permeated by a variety of waves. The coronal gases and those waves exert pressure on the magnetic field. In most of the corona, the magnetic field is strong enough to resist these forces, and the gas remains trapped in closed loops.

However, where the field is weak, it yields to these forces, which then drag it into interplanetary space. Those parts of the magnetic field that just manage to remain unbroken are stretched, like taffy, into the tendril-like shapes that we see as streamers during a total eclipse. Next to them, rivers of gas are pushed into the solar wind, where they are too insubstantial to be observed among the streamers.

We can reproduce the general appearance of the eclipse corona with state-of-the-art computer calculations. We therefore believe that we are on the right path to understanding how the streamers and the solar wind form. However, the coronal eruptions that cause dangerous space storms are much harder to comprehend.

A few times each day, such events force the magnetic field to snap open above as much as 10 percent of the upper corona. Particles accelerated by these events can find themselves on the road to interplanetary space. Some may be guided toward Earth by open-ended magnetic-field lines.

Known as *coronal mass ejections*, or CMEs, such eruptions can propel a billion tons of hydrogen and helium outward. The particles accelerated during a CME's *initial* eruption reach near-light speeds. However, most of the gas that a CME ejects travels at speeds of "only" about 500 kilometers per second. But its bulk more than compensates for its relative sluggishness: when a CME carries plasma and magnetic-field lines past Earth, it can cause power outages and damage satellites. With human affairs increasingly dependent upon power grids and global communication networks, the corona in a real sense touches nearly everyone's life.

Forecasting Space Weather

The origin, evolution, and consequences of explosive phenomena in the solar corona are at the forefront of science today: we need to learn what powers these explosions, why they happen when they do, and how we can forecast them.

We have made good progress in knowing which active regions are likely to produce the largest flares: these generally occur in regions into which new twisted magnetic-field lines emerge from below the photosphere. But we still cannot forecast exactly when an eruption will occur or how much energy it will release.

New observatories will help us answer the many questions that past generations have raised. Later this year, the international Solar-B mission will begin to provide high-resolution optical, ultraviolet, and X-ray views of the Sun's photosphere, and the twin spacecraft of NASA's STEREO mission will use binocular vision to watch coronal mass ejections travel through the heliosphere. In 2008, the Solar Dynamics Observatory will enable us to continuously observe all of the visible photospheric magnetic fields and coronal gases with unprecedented temporal resolution.

Complemented by existing facilities in space and on the ground, this fleet of solar observatories will move us into a new era of research: we will be able to observe the entire progression of solar activity, from the Sun's interior through the solar atmosphere and into the heliosphere, where the Sun connects with the planets in more ways than one. With luck, we soon will fully understand the Sun's dangerous crown, which we so rarely get to see with the unaided eye. •

On October 28, 2003, the Sun spawned the brightest X-ray flare ever seen — a dramatic reminder of the violent power contained with the solar atmosphere's electrical currents. This false-color composite comprises TRACE's visible-light (yellow) and EUV (red) exposures of the event. The EUV-emitting material above the solar limb reached temperatures ranging from 15 to 20 million degrees Celsius during the record-setting flare.

CAROLUS SCHRIJVER

A solar physicist with the Stanford-Lockheed Institute for Space Research, Karel Schrijver *plays a key role in the TRACE mission and in the upcoming Solar Dynamics Observatory.*

HAO / NCAR / NSF

SAIC

Although the real solar corona *(left)*, as observed during the February 26, 1998, eclipse, shows many details that are not yet captured in simulations, its large-scale structure was reproduced quite nicely by a recent computer model *(right)*.

ASTRONOMERS HAVE FOUND BIG BLACK HOLES AND

A New Breed of BLACK HOLE

By DAVIDE CASTELVECCHI

CRAM THE RIGHT AMOUNT of mass into a small enough volume of space, and gravity will make a black hole of any size you want. For years astronomers had seen only two classes of black holes: 3- to 20-solar-mass corpses of massive stars, and million- to billion-solar-mass monsters in galaxy cores. Strangely, black holes seemed to avoid a huge range of possible masses in between. Mother Nature rarely leaves such gaping chasms in her creations. After all, the distributions of galaxy, star, and planet masses form smooth continuums. Why should black holes violate this universal principle?

Then, starting in 1979 with NASA's Einstein X-ray Observatory, Giuseppina Fabbiano (Harvard-Smithsonian Center for Astrophysics) began spotting pointlike X-ray sources in other galaxies that were orders of magnitude more luminous than stellar-mass black holes in our galaxy. Astronomers wondered if they could be the missing intermediate-mass black holes (IMBHs) that weigh hundreds to thousands of solar masses.

Some 200 of these "ultraluminous X-ray sources" (ULXs) have been discovered since then with Japan's ASCA, NASA's Chandra, and the European Space Agency's XMM-Newton X-ray observatories. In 1999 Chandra spotted an unusually energetic ULX in a dense stellar cluster within the Ursa Major galaxy M82. At 10^{41} ergs per second, this source (M82 X-1) radiates more than 10 million times as much energy per second as the Sun. Many astronomers surmise that it can't be anything but an accreting black hole with a few hundred to a few thousand solar masses.

But a debate rages about the nature of the other ULXs. What fraction are intermediate-mass black holes? Are IMBHs numerous enough to constitute a new class of cosmic object? The question of whether the universe is still

SMALL BLACK HOLES. WHERE ARE THE ONES IN BETWEEN?

ILLUSTRATION BY CASEY REED

making midsize black holes has set theorists into feverish activity as they try to imagine exotic new ways that nature could create these objects. Perhaps they form through runaway stellar mergers in crowded clusters. Understanding these processes could help answer the critical question of how supermassive black holes formed in the early universe. Meanwhile, observers are trying to refine their ULX mass estimates in order to satisfy the skeptics.

Weighing Black Holes

Even though astronomers can't see black holes directly, they can detect X-rays radiating from matter that heats up before it falls into the abyss. Actively accreting black holes can be relatively easy to detect with X-ray observatories such as Chandra. But measuring black-hole masses is a much trickier proposition.

In the case of some stellar-mass black holes in binary systems, such as the famous source Cygnus X-1, observers can study a companion's orbit. This provides a reliable estimate of the hole's mass. But most black holes lack binary companions. And even for those black holes that are members of a binary, astronomers rarely can detect orbital motion.

Unless orbital motion can be measured, the most obvious clue to the black hole's mass is its X-ray luminosity. Unfortunately, luminosity has less to do with a black hole's mass than with how fast it swallows nearby material. For example, the monster in the Milky Way's nucleus is surprisingly dim (emitting less than 10^{37} ergs per second) given its 3.7 million solar masses. Many smaller black holes may be all but invisible as they wander alone with no nearby material to accrete. But if two black holes have the same food supply, the heavier beast will devour matter faster, and thus emit more X-rays, than its lighter counterpart.

Astronomers commonly deem an X-ray source "ultraluminous" if it shines with a luminosity above about 5×10^{39} ergs per second — the maximum energy output of a 20-solar-mass black hole that radiates uniformly in all directions. Astrophysicists have long thought that the largest stars forming in the modern-day universe, after exploding as supernovae or gamma-ray bursts, cannot leave behind black holes greater than 20 solar masses. A heavier black hole in a ULX must have formed by a different process or found some way to gobble additional mass.

Beam Me Out

The discovery of so many ULXs indicated a new, exotic class of black holes — leading to the ongoing flurry of research. But not all astronomers agree that these ULXs are powered by midsize black holes. Several different teams, including one led by Andrew King (University of Leicester, England), have noted that a black hole's X-ray luminosity could appear anomalously high if it beams its radiation preferentially in our direction. Such beaming is typical of stellar-mass and supermassive black holes, as observed in gamma-ray-burst and quasar jets. A stellar-mass black hole could easily masquerade as an IMBH by beaming most of its radiation toward Earth, which could fool astronomers into overestimating its luminosity.

Given the possibility of beaming, only one known X-ray source falls safely into the IMBH category. "M82 X-1 seems difficult to kill," says Fabbiano. Several conservative estimates put that black hole between 100 and 3,000 solar masses. No one has demonstrated how beaming could make a stellar-mass black hole appear to emit 10^{41} ergs per second.

Astronomers have tried to rule out beaming for several other ULXs, which would push their black holes into the intermediate-mass regime. Richard Mushotzky (NASA/Goddard Space Flight Center) and his collaborators used archival data from the Very Large Array and found radio halos around several ULXs. All these sources exhibit uniform, round glows, bearing no obvious signs of beaming. In March 2005 Mushotzky and two colleagues published

This amateur image of M82, including hydrogen-alpha light, shows a wind of hot gas escaping the galaxy. *Insets:* The ultraluminous X-ray source (ULX) M82 X-1 (arrowed in the top panel) is the best IMBH candidate. The object is offset 600 light-years from the center of the host galaxy. These two images from NASA's Chandra X-ray Observatory, taken three months apart, demonstrate how the object varies in intensity — a strong indicator of black-hole activity.

Far left: The brightest spots in this Chandra image are ULXs in the Antennae (NGC 4038 and 4039), the product of a merger between two large spiral galaxies in Corvus. ULXs are several hundred times more luminous in X-rays than typical binary systems that contain a stellar-mass black hole. The high luminosity of ULXs suggests they are powered by black holes with a few hundred to a few thousand solar masses, but they could also be stellar-mass black holes that beam most of their energy toward Earth. *Left:* An amateur image of the Antennae shows bright clumps of stars — young clusters resulting from the galaxy merger.

the first of these results, on a source in the galaxy Holmberg II. "If there's a jet there, it's totally different from anything we have ever seen," says Mushotzky.

But King insists that such results don't completely rule out beaming. The uniform glow could be the result of a spherical wind emanating from the black hole that blows a large bubble in the surrounding gas. Such bubbles have been seen around several ULXs, including M82 X-1, and the sizes of these structures can exceed those of supernova remnants. As King explains, "A black hole that's trying to accrete at its upper limit will blow out a lot of material."

Other Lines of Attack

Observers would prefer to obtain direct mass measurements by tracking the orbits of binary companions. Most ULXs probably have stellar companions that were captured by the black hole's gravity, with the star being the source of accreted matter that makes the black hole visible in the first place. For example, recent observations by Philip Kaaret (University of Iowa) and two colleagues with NASA's Rossi X-ray Timing Explorer satellite indicate that M82 X-1 has an evolved companion star on a 62-day orbit.

Observers have tried to measure Doppler shifts derived from spectra of these binaries — the same method astronomers have used to detect extrasolar planets. But finding optical counterparts to such distant X-ray sources is problematic at best. If an observer tries to overlap Chandra and Hubble shots of the same swath of sky and match up point-like sources, the pairing is subject to a 1-arcsecond angular error, and in that diameter one usually finds several stars for each X-ray source. Astronomers have tried to single out a star with an unusual spectrum or one whose variability correlates to that of the X-ray source, but few convincing optical counterparts have yet been found. "We have a grand total of two," says Mushotzky, and no one has managed to detect orbital motion in either object. Despite the lack of conclusive results so far, this method could someday prove that at least some ULXs harbor IMBHs.

Astronomers have also pursued various indirect lines of attack to estimate ULX masses. One idea is to compare ULX spectral features or time-variation patterns to similar properties of better-known X-ray sources. The luminosity of an accretion disk surrounding a stellar-mass black hole is "quasi-periodic," meaning it flickers at not-quite-periodic intervals as orbiting blobs of hot gas disappear behind the black hole and then reappear. The timing of these oscillations is indicative of orbital periods, so they should correlate roughly with the black hole's mass. Mushotzky and Tod Strohmayer (also at NASA/Goddard) found that M82 X-1's quasi-periodic behavior stretches over long intervals, indicating an intermediate mass for the black hole. But mass estimates of other ULXs remain more controversial.

An entirely different confirmation of intermediate-mass black holes could come from gravitational waves. Cole Miller (University of Maryland) calculates that a star merging with an IMBH, two colliding IMBHs, or an IMBH falling into a supermassive black hole would produce intense waves with a recognizable signature. If one of these rare events takes place close enough to our galaxy (within a few million light-years for the first type of event, a few billion light-years for the latter two), future ground-based observatories and the planned NASA/ESA Laser Interferometer Space Antenna will pick them up.

Birth of a Middleweight

While observers busily dissect ultraluminous X-ray sources, theorists have tried to concoct plausible mechanisms for IMBH formation. In principle, a stellar-mass black hole could swallow gas from its vicinity until it accretes hundreds or thousands of solar masses. But Miller calculates that a stellar-mass black hole would take longer than the age of the observable universe to grow to midsize. "The ones that might be 1,000 solar masses should have a qualitatively different history," he says.

One possibility is that the early universe was populated by megastars containing hundreds of solar masses. The most massive of these so-called Population III stars would have lived extremely short lives. With no elements heavier than hydrogen and helium, such massive stars behaved differently from stars in the modern-day universe. At the ends of their lives, their cores collapsed into black holes with several hundred solar masses. As the universe's chemical composition changed, such massive stars might no longer form. But the black-hole remnants of the original population might still be around today.

IMBHs could also be forming today in dense, young star clusters. Observational support for this idea comes from the fact that most of the 200 known ULXs inhabit star-forming

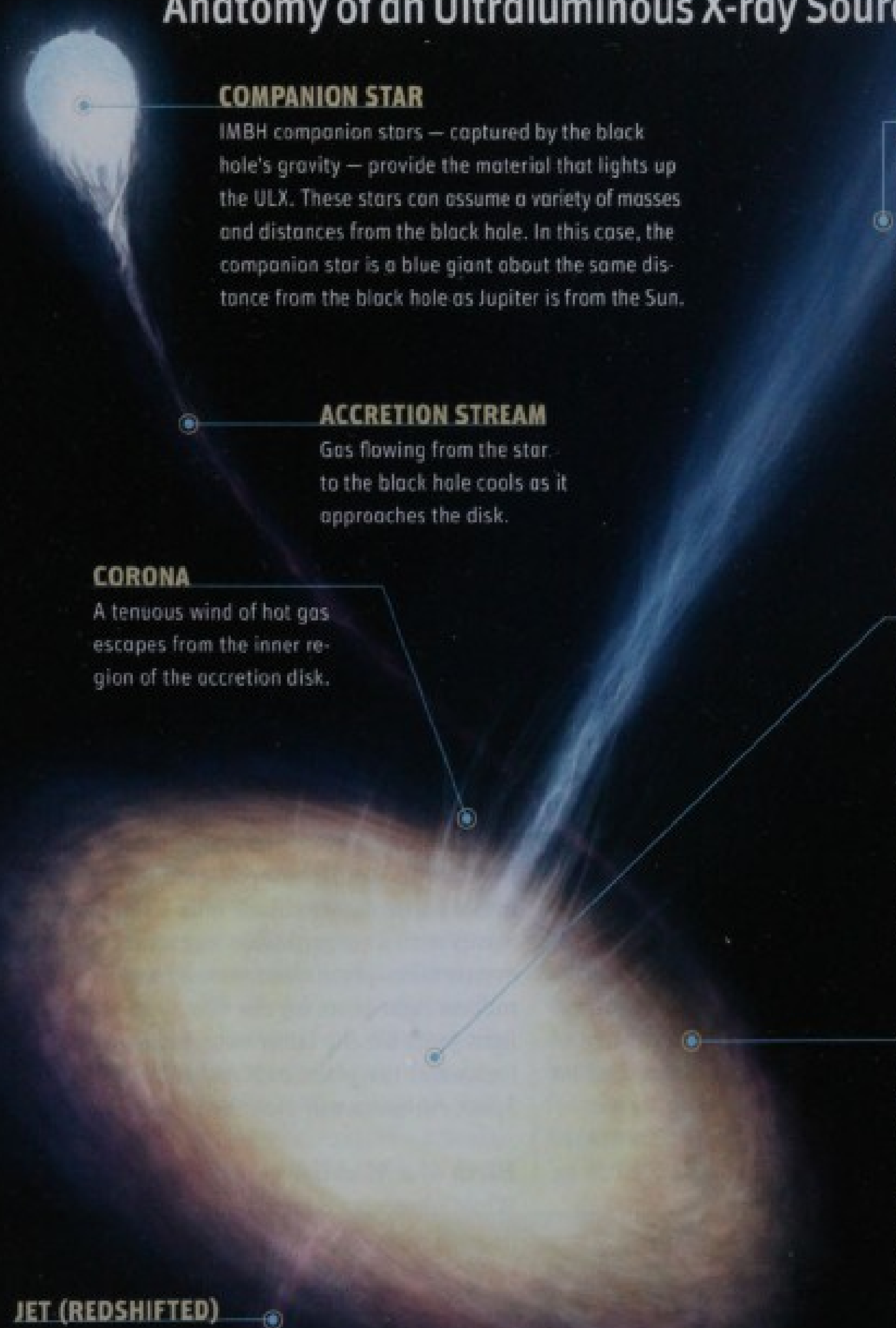
Anatomy of an Ultraluminous X-ray Source (ULX)

BIRTH OF AN IMBH

1. IMBHs possibly form in dense clusters of young, massive stars.

2. Multiple stars merge in the cluster center to form a short-lived megastar.

3. The megastar collapses to form a black hole of several hundred solar masses.



COMPANION STAR
IMBH companion stars — captured by the black hole's gravity — provide the material that lights up the ULX. These stars can assume a variety of masses and distances from the black hole. In this case, the companion star is a blue giant about the same distance from the black hole as Jupiter is from the Sun.

ACCRETION STREAM
Gas flowing from the star to the black hole cools as it approaches the disk.

CORONA
A tenuous wind of hot gas escapes from the inner region of the accretion disk.

JET (BLUESHIFTED)
Twisting magnetic-field lines in the accretion disk channel material into two counterflowing jets that approach the speed of light. The jet pointing toward the observer would appear brighter and bluer than its counterpart because of relativistic effects and the blueshifting of its light.

INTERMEDIATE-MASS BLACK HOLE (IMBH)
The central black hole, containing several hundred to several thousand solar masses, is the engine that drives the ULX. From a distance the black hole itself would be impossible to see in visible light because of the intense glare of the disk and jets.

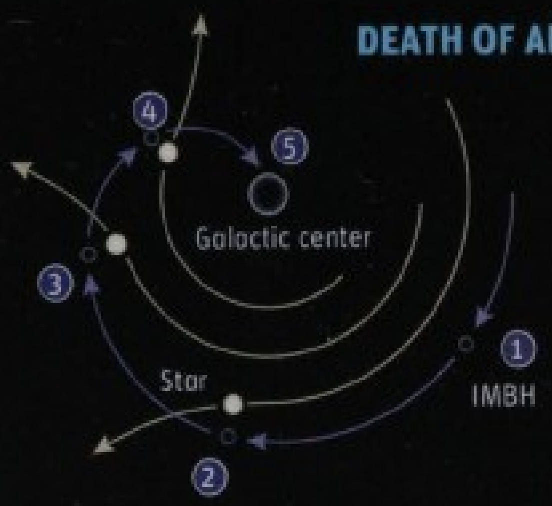
ACCRETION DISK
The captured gas whirls around the black hole at very high speed in a disk. Were it not for the disk, this material would orbit the black hole without falling in. But friction within the disk causes the gas to spiral inward, where it meets its doom in the central black hole.

JET (REDSHIFTED)

POSSIBLE SOURCES OF ULXs

If a ULX jet is pointed directly toward Earth, astronomers might overestimate the source's luminosity, which could also cause them to overestimate the central black hole's mass. If we view a ULX off-axis, however, its central black hole almost certainly has a mass of hundreds to thousands of Suns.

DEATH OF AN IMBH



Each time an IMBH (1) encounters a star (2-4), it boosts the star's velocity. Each of these gravitational interactions causes the IMBH to sink inward. Eventually it sinks to the galactic center, where it merges with the galaxy's supermassive black hole (5).

S&T: CASEY REED

regions. For example, 18 have been identified in the Antennae (NGC 4038 and 4039), a pair of colliding galaxies that is spawning enormous numbers of new stars in dense clusters.

In these crowded systems, stellar collisions could be frequent enough to form extremely massive stars through runaway mergers. In simulations using the University of Tokyo's astrophysics supercomputer GRAPE-6, a group led by Simon Portegies Zwart (University of Amsterdam, Netherlands) showed that under certain conditions, enough stars could merge in a cluster's center to form a megastar of 800 to 3,000 solar masses, which would collapse quickly to form a black hole of similar mass (*S&T:* August 2004, page 20). "The entire process takes about 3 million years, which is very short," says Portegies Zwart.

His team followed the evolution of "virtual" clusters containing as many as 600,000 stars and showed that only very special clusters — similar in size and density to the one containing M82 X-1 — would produce a runaway merger. The simulations of larger or smaller clusters having similar density — like a ULX-free group in M82 — failed to produce megastars. If no megastars form, no IMBHs form. In a recent paper, M. Atakan Gürkan (now at Sabanci University, Turkey) and two colleagues report that their computer simulations usually result in binary IMBHs, whose two components merge within a billion years.

Once an IMBH forms, it interacts gravitationally with other stars in its home galaxy, boosting their velocities. This interaction, in turn, slows an IMBH's orbital velocity, causing it to sink toward the galaxy's core, where it will eventually merge with the central monster. "Supermassive black holes in normal spiral galaxies would grow by accreting intermediate-mass black holes," says Junichiro Makino (University of Tokyo), one of Portegies Zwart's collaborators.

Dense star clusters probably formed in enormous numbers in the early universe. These clusters must have collided constantly with one another, leading to IMBH mergers that eventually produced supermassive black holes. "There is the enticing prospect that by looking at ULXs and dense star clusters now, we are getting an idea of what conditions were like in the good old days," says Miller. "Then, by extrapolation, we might learn more about where we come from, and the role of black holes in cosmic evolution."

Desperately Needing Data

Despite the 200 known ULXs, skeptics are still unconvinced there's enough evidence to justify a new breed of black hole. After all, most ULXs could turn out to be unusually luminous X-ray binaries with stellar-mass black holes. Smaller IMBH candidates could have formed through ordinary stellar evolution and accretion. Plotting the number of X-ray sources of any given brightness results in a smooth curve, from ordinary X-ray binaries to the ULXs. "This suggests [the ULXs] are part of the same population of stellar-mass objects, but in an unusual phase," says King.

On the other end of the scale, the heaviest IMBHs could represent the low end of the supermassive category. King suggests that M82 X-1, which is 600 light-years from its galaxy's center, might be the former nucleus of a smaller galaxy that merged with M82 in relatively recent times. Observations of galaxy cores show a correlation between black-hole masses and the spheroidal components of their host galaxies, so low-mass galaxies are expected to have relatively low-mass central black holes.

Only more data can settle the debate. So far, evidence for IMBHs is strong in a dozen cases if you ask Mushotzky, a half-dozen if you ask Miller, and just one if you ask King. Miller thinks it's very likely that these midsize black holes are still forming today. "I would bet a very good dinner on this fact," he says. But he concedes that he might end up picking up the check. "These things are far away, which means it's difficult to get really good evidence one way or the other." ✦

Freelance science writer Davide Castelvecchi *is a Web editor at the American Institute of Physics.*

A Black Hole Hive?

BY ROBERT NAEYE

In a paper accepted for publication in the *Astrophysical Journal*, Simon Portegies Zwart, Junichiro Makino, and four collaborators argue that the dense star clusters found near galaxy centers are highly susceptible to runaway stellar mergers and are thus efficient IMBH producers. The team's computer simulations suggest that the Milky Way's innermost 30 light-years harbor about 50 black holes of roughly 1,000 solar masses each. These IMBHs sink toward the core as they gravitationally interact with stars. But their migration stalls less than 1/100 light-year from the central black hole because there are no longer enough stars in the vicinity to drive them inward. "We argue that there is a steady population of several IMBHs within a hundredth of a light-year of the galactic center," says Portegies Zwart.

These IMBHs gravitationally interact with one another, causing an IMBH to fall into the supermassive black hole about once every 10 million years. By steadily ingesting IMBHs, the central monster slowly bulks up over billions of years. The group cites rapid stellar motions within two clusters near the galactic center as evidence of an IMBH population, though other astronomers say observational support for this scenario remains scant at best.

Andrea Ghez (University of California, Los Angeles), who has measured the mass of the Milky Way's central black hole by tracking the motions of stars around it, says a population of IMBHs could help explain why there are so many young stars in the galactic core, where extreme tidal forces should rip apart the gas clouds from which stars form (January issue, page 24). If the stars formed farther out, where tidal forces are less extreme, IMBHs could shepherd them inward. "The observations of possible young clusters of stars in the galactic center, which appear to need IMBHs to be there, are very exciting indeed," says Ghez.

Fooled by the Moon

APRIL FOOLS' DAY arrived in February for Apollo 14 astronauts Alan Shepard and Edgar Mitchell. Disoriented by the absence of distinct landmarks and unable to assess distances accurately in the alien environment of the Moon, they couldn't find the rim of Cone Crater in the Fra Mauro highlands as they explored the lunar surface in 1971. Although they negotiated the crater's slope for more than an hour and actually approached within 20 meters (65 feet) of its lip, the astronauts didn't know exactly where they were and had to return to the lunar module before achieving their goal.

The Moon sometimes makes us think it's closer than it is in reality.

Earth's atmosphere cues us to distance through softening the appearance and altering the color of the distant horizon, but the airless Moon doesn't offer the same hints. In Cone Crater's vicinity, Shepard explained, "It's so crystal clear up here it just looks a lot closer than it is."

Here on Earth, too, the Moon sometimes fools us into thinking it's closer than it is. Nearly everyone has noticed that the Moon looks bigger along the horizon than when it's high in the sky. Rising or setting with the illusion of a larger size, it cons us into believing that it's nearer to us.

Actually, the Moon is a little farther away when it appears on the horizon. As Earth's rotation lifts the Moon's position higher in the sky, our separation diminishes slightly, but the change is too small to notice. For all practical purposes, the angular size of the Moon remains the same each night whether it's measured near the horizon or well above it.

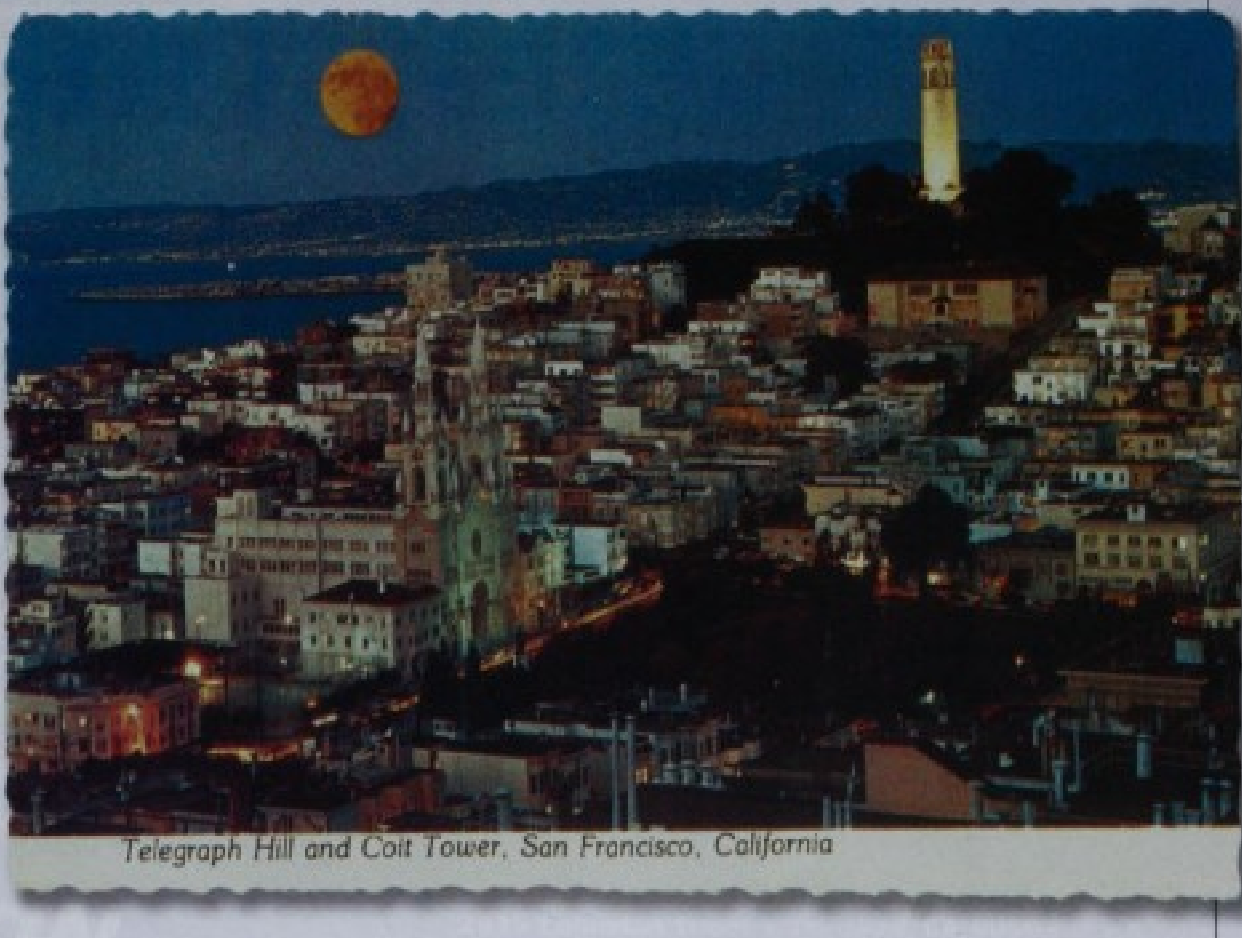
The Greek philosopher Aristotle wrote the oldest known account of the Moon's horizon intrigue in the 4th century BC. The air, he asserted in *Meteorology*, magnifies the Moon. He must have let the air out of that explanation, however, for later in *On Sense and the Sensible* he disputed the idea. Other ancient authorities, like Posidonius in the 2nd century BC, also attributed lunar enlargement to atmospheric optics. Earth's atmosphere does alter the appearance of the Moon, but it flattens the disk through refraction. It doesn't magnify the Moon.

LUNAR EXPRESS Because the Moon looks bigger near the horizon, it seems closer and even within reach. In *The Way of the Soul*, artist William Thomas Horton allows the Moon to pick up a passenger. Illustration from *Art Nouveau Graphics*, T. Walters, ed. (1971).

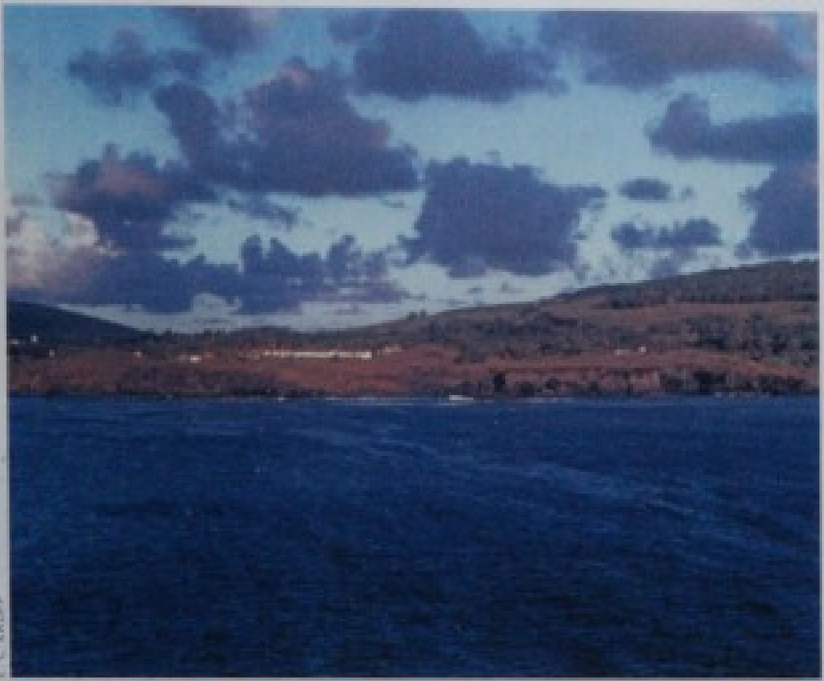
Today the Moon illusion is usually explained as a consequence of the eye and brain comparing the lunar disk with adjacent terrestrial references — like trees, buildings, or mountain peaks. When the Moon is elevated, those familiar horizon features fall away, and the illusion fails.

Although we are afflicted by misperception when the Moon is low, we have a cure. Turn your back to that horizon-huge Moon, bend over, and look at it between your legs. In this posture the Moon doesn't loom as large as you left it when you were still respectably right-side up. It shrinks for your inverted eye, allegedly because the upturned landscape no longer looks so familiar.

This explanation is neither sufficient nor necessary. When the Moon floats upon the open sea without nearby landmarks, it still looks big. Those who have thought more



MOCK MOON This Moon illusion was produced not in nature but in the darkroom. A real Moon this large over San Francisco's Telegraph Hill and Coit Tower would be more than an illusion — it would be a disaster. Mailed in 1978, this postcard also flips the lunar disk, showing an impossibly reversed face.

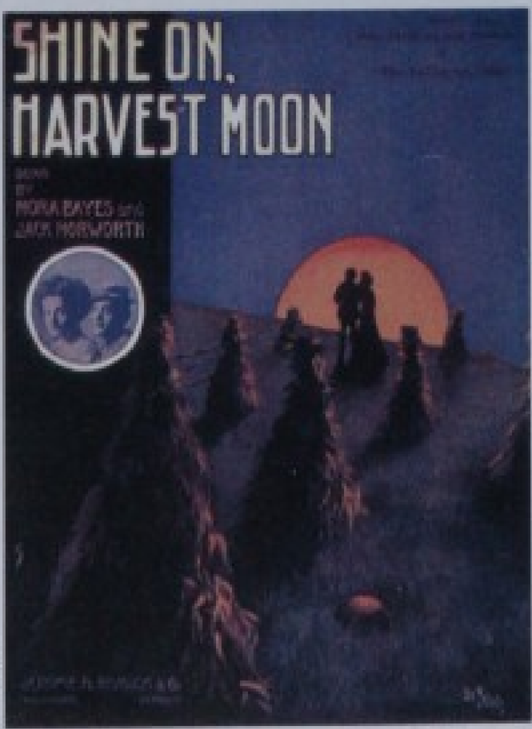


THE NEAR SKY As clouds recede on this South Pacific horizon, perspective and foreshortening create the illusion of a flattened sky.

carefully, and in many positions, about how we perceive the Moon's disk insist that there's more to the story.

In *The Mystery of the Moon Illusion* (Oxford University Press, 2002), two academic psychologists, Helen Ross and Cornelis Plug, remind us that the size illusion distorts other things in the sky. The Sun looks enlarged near the horizon, and familiar star patterns, like Orion and the Big Dipper, also project a greater profile. So whatever is fooling people, it affects more than just the Moon.

In their comprehensive catalog and critical review of Moon-illusion research, Ross and Plug assess exactly how much larger the Moon appears on the horizon and indicate that most people feel that the Moon looks about 50 percent larger when it hugs the landscape. Keeping the company of familiar references and being visible over recognizable terrain are, they say, part of the Moon's trick. But the Moon's misdirection also relies on three additional tactics: the atmosphere's ability to alter the color and clarity of more distant scenery, the eye's and brain's response to lifted sightline and adjusted posture, and our perception of the sky as a flattened vault.

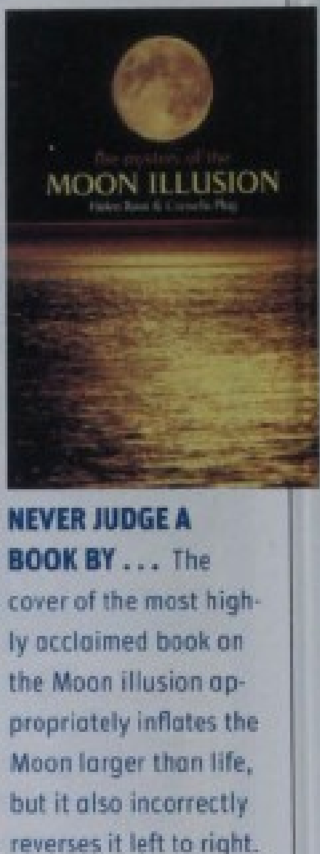


BEFORE PERRY COMO Sheet music fools us in April with a seasonally incorrect Harvest Moon and reinforces the romance of the Moon illusion with a silhouetted couple dwarfed by the lunar light. Nora Bayes and Jack Norworth composed the song in 1908.

When we locate and map celestial objects, we imagine the sky to be a hemispherical dome, but we actually perceive it differently. The horizon usually seems to be farther away than the point directly overhead. Some people claim that we unconsciously conclude that the Moon is closer to us when it is high and farther when it is low. Because it actually has the same angular size in both locations, we make the lower, farther Moon bigger in our mind's eye. This is said to compensate for our sense that the same Moon is farther away. Our eyes "see" that it's the same size, but our brain "knows" that it's more distant. It should appear smaller, but it doesn't. So our brain tells us that it has to be bigger to be the same size, and this is what we see.

Ross and Plug regard the effort to understand the Moon illusion via a flattened-dome sky as a fool's errand, but since we do see the sky that way they acknowledge that the flat-sky illusion deserves an explanation.

In an article published in the September 2001 *Griffith Observer*, astronomer Arthur Young allied the Moon illusion with our unconscious inference of a flattened sky, and his explanation for the flattened shape seems promising. According to Young, clouds form our sense of the horizon's distance. Although the clouds on the horizon are roughly 50 times farther away than those overhead, their geometric regularity, physical uniformity, and altitude allow foreshortening to fool us into thinking that the cloud horizon is closer than it is — only six times farther than the zenith, according to Young's calculations.



NEVER JUDGE A BOOK BY . . . The cover of the most highly acclaimed book on the Moon illusion appropriately inflates the Moon larger than life, but it also incorrectly reverses it left to right.

Others have also looked at clouds from both sides. As early as the 17th century, Dutch astronomer Christiaan Huygens recalled the sky's illusions when describing that things overhead seem "to be no farther away than the clouds that float above our heads." He added, "So now when two bodies of equal magnitude cover the same visual angle, we always judge as larger the one taken to be farther away."

Still, our effort to understand the Moon illusion has not diminished our expectations. We are so primed to see a big Moon rising that we're easy marks for the fabricators who use *Adobe Photoshop* to paste oversize Moons onto tourist postcards. Years ago, Fritz Leiber, one of America's most literate science-fiction and fantasy writers, and I regularly exchanged postcards featuring errant Moons — sometimes too large, often backward, and usually both.

Even those most attuned to the illusions of the Moon can't always avoid moonshine. The huge Moon that moonlights the dust jacket of *The Mystery of the Moon Illusion* is a wrong-way Moon that turns the sky inside out. No Moon is foolproof. ✶

E. C. Krupp rushes in and fools around with the Moon at Griffith Observatory in Los Angeles.

Celestron Accessories

Enhance the night sky with these quality accessories!

Binocular Viewer

- Adapt two eyepieces to the telescope
- 3-D effect when observing many celestial objects
- Fully multi-coated BAK-4 prisms
- Foam lined aluminum storage case
- Eyepiece diopter scales for sharp focus

Item #93691 $199.00

2" Eyepiece and Filter Kit

- Three E-Lux 2" eyepieces – 3-element fully multi-coated in 26, 32 and 40mm focal lengths
- 2" Barlow lens – 2x; fully multi-coated
- Five colored eyepiece (Lunar & Planetary) filters
- 2" mirror diagonal – fits Schmidt-Cassegrain telescopes and includes an adapter to use with refractor telescopes.
- Aluminum carrying case – die-cut foam interior

Item #94305 $299.00

Power Tank™ 17

- 17 amp hour, 12V D.C.
- 2 x 12V DC output car jack socket
- DC 3, 6, 9V output jacks
- Built-in AM/FM radio and siren
- Removable red filtered flashlight
- Multi-angle 800,000cp halogen spotlight
- Jump-start system – 250 cranking AMPS (5 sec.)
- Switchable 110v-220v recharger

Item #18777 $129.00

Power Tank™

- 7 amp hour, 12V D.C. rechargeable power supply
- 2 x 12V DC output car jack socket
- DC 3, 6, 9V output jacks
- 800,000cp halogen spotlight; booster terminal
- AC adapter included (110v-220v)

Item #18774 $69.00

Digital Camera Adapter

- Allows you to attach a digital camera to most telescopes and spotting scopes
- Compatible with 1¹/₄" or even 2" eyepieces
- Dual axis fine adjustments

Item #93626 $49.00

Ultima® 2x Barlow Lens

- 2x – 1¹/₄" air-spaced, 3-element apochromatic design with a 27mm clear aperture
- Fully multi-coated

Item #93506 $79.00

93526 93527

2" XLT Diagonal

- Celestron's high performance **XLT coating** for maximum reflectivity >96%
- Interferometer tested **10th wave** flat mirror
- All machined housings for accurate alignment of optics
- **Aluminum case** for storage and protection

Item #	Description	Price
93526	For Refractor Telescopes	$149.00
93527	For Schmidt-Cassegrain Telescopes	$149.00

93712 94178

NexImage™ Solar System Imager

- Complete CCD solar system imager
- View and capture live video with your computer
- Software automatically filters out poor video frames, leaving the sharpest, frames to be stacked and aligned into one quality image
- Easy to follow quick start guide and tutorial
- Camera control software allows you to adjust the gain, contrast, exposure time, frame rate and color saturation manually on your PC
- Compatibility – 1.25" adapter barrel makes NexImage compatible with most any telescope
- Versatility – 1.25" adapter is threaded for standard eyepiece filters and can be removed and replaced with optional focal reducer lens

Item #93712 $99.00

NexImage™ Reducer Lens

- Increase your field of view by over two times for wide field lunar and filtered solar imaging
- Replaces the 1.25" barrel and threads directly into the NexImage housing

Item #94178 $24.00

Radial Guider

- Specifically for use in prime focus, deep-sky imaging or astrophotography with Schmidt-Cassegrain telescopes
- Makes it possible to simultaneously photograph and guide through the optical tube assembly of your telescope
- Compatible with Celestron's Schmidt-Cassegrain telescopes
- Must be used with a guiding eyepiece, camera T-Ring and drive corrector (dual axis preferred)

Item #94176 $124.00

Focal Reducer/Field Corrector Lens f/6.3

- Works with all Celestron 5", 8", 9¹/₄", 11" and 14" Schmidt-Cassegrain telescopes
- Makes it possible to have a dual focal ratio instrument, without sacrificing image quality
- Offers wide fields of view
- Used for astrophotography, it reduces exposure time by a factor of 3

Item #94175 $139.00

E-Lux™ Series Eyepieces

- Available in 1¹/₄" and 2" models
- 1¹/₄" E-Lux is a 4-element Plössl with fully coated lenses, eyepiece cups and is threaded for use with eyepiece filters.
- 2" E-Lux class is a 3-element fully multi-coated optical design. The 2" E-Lux provides a wider field of view and longer eye relief than standard Plössls.

Item #	Description	Price
93300	1¹/₄" – 10mm	$34.00
93301	1¹/₄" – 25mm	$34.00
93302	1¹/₄" – 40mm	$34.00
93303	1¹/₄" – 6mm	$34.00
93334	2" – 26mm	$69.00
93335	2" – 32mm	$69.00
93336	2" – 40mm	$79.00

Omni™ Series Eyepieces

- 4-element premium symmetrical Plössl optical design
- Multi-layer coating group on each lens
- Two-step anodizing process to prevent reflection from the top eyepiece barrel
- Threaded barrels accept 1¹/₄" filters

Item #	Description	Price
93316	1¹/₄" – 4mm	$44.00
93317	1¹/₄" – 6mm	$44.00
93318	1¹/₄" – 9mm	$44.00
93319	1¹/₄" – 12mm	$44.00
93320	1¹/₄" – 15mm	$44.00
93321	1¹/₄" – 20mm	$44.00
93322	1¹/₄" – 25mm	$44.00
93323	1¹/₄" – 32mm	$54.00
93326	2x Barlow Lens	$49.00

X-Cel™ ED Series Eyepieces

- Great for planetary viewing
- 6-element fully multi-coated optical design with extra low dispersion (ED) glass on its most highly curved surfaces
- Wide 55° apparent field of view, and a large 25mm clear aperture
- Comes with soft rubber eyecups
- 20mm eye relief
- Threaded barrels accept 1¹/₄" thread-in filters

Item #	Description	Price
93386	1¹/₄" – 2.3mm	$69.00
93387	1¹/₄" – 5mm	$69.00
93388	1¹/₄" – 8mm	$69.00
93389	1¹/₄" – 10mm	$69.00
93390	1¹/₄" – 12.5mm	$69.00
93391	1¹/₄" – 18mm	$69.00
93392	1¹/₄" – 21mm	$69.00
93393	1¹/₄" – 25mm	$69.00

Eyepiece Filters

93608

- An invaluable aid in lunar and planetary observing
- Reduce glare and light scattering, increase contrast through selective filtration, increase definition and resolution, reduce irradiation and lessen eye fatigue
- Filters are double-threaded, so they can be stacked

Item #	Description	Price
93608	Polarizing Filter Set	$29.00
93623	OIII Filter 1¹/₄"	$69.00
93624	OIII Filter 2"	$99.00
94121	Minus V Refractor Filter 1¹/₄"	$49.00
94123	UHC/LPR Filter 1¹/₄"	$69.00
94124	UHC/LPR Filter 2"	$99.00
94125	UV/IR Cutoff Filter 1¹/₄"	$59.00
94119-A	Moon Filter 1¹/₄"	$14.00

Prices shown are suggested U.S. mail order prices.

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by fred schaaf

Secrets of the Lion's Heart

Sing a song of bright stars, a pocketful of light,
Twenty in the 1st magnitude, and all of them are bright.

I WROTE THOSE LINES, in imitation of a well-known nursery rhyme, when I was around seven years old and first learning about the very brightest stars. My passion for the brightest stars hasn't dimmed; in fact, I'm writing a book about them. But some of you may have noticed a factual mistake in my little verse. If by "1st magnitude" we mean all stars brighter than magnitude 1.50, then I should have written "twenty-one."

> It's not only the closest star of its type; it's spinning so fast that it's almost flying apart.

As it turns out, the 21st brightest star in the night sky, though the least of the 1st-magnitude family, is far from being the least interesting. The star is Regulus, in kingly Leo.

The hemisphere of evening sky on the facing page, drawn for 40° north latitude, contains 11 of the 15 stars shining at 1st magnitude and brighter that can ever be seen from this latitude. But only Regulus lies near the sky's north-south meridian on April evenings. This star has been associated with royalty throughout history. It's also famous as the bright star closest to the ecliptic and thus the one that most often has close conjunctions with planets.

What isn't so famous is its fascinating physical nature.

THE CLOSEST MAIN-SEQUENCE *B* STAR. Regulus is 350 times as luminous as the Sun and 3.4 times as massive. It is not, however, a giant or supergiant. It's an unevolved, main-sequence star like the Sun, still shining by converting hydrogen to helium in its core. And at a distance of 77 light-years, Regulus is the closest main-sequence star of the hot spectral type B.

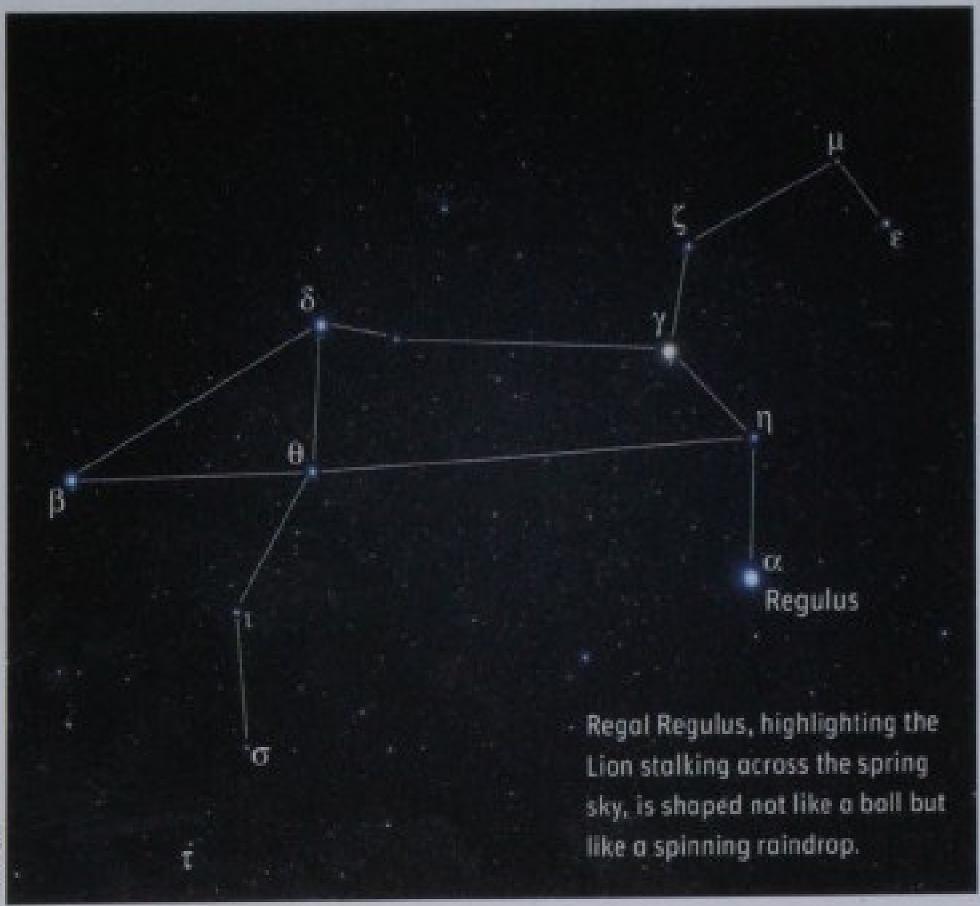
Astronomers using long-baseline optical interferometry (*S&T*: May 2003, page 30) recently measured the size and shape of Regulus directly.

Previous investigations of Regulus put its surface temperature at 12,000 kelvins (compared to the Sun's 5,770 K) and its diameter at 3.5 times the Sun's. But in a 2005 study, Harold McAlister of Georgia State University and his colleagues found (by actual measurements using interferometry) that Regulus is not round but oblate. Its equatorial diameter is 4.15 times the Sun's, and its polar diameter is 3.15 times. What's more, the polar temperature is 15,400 K, while the equatorial temperature is only 10,300 K. Since brightness scales as the *fourth power* of temperature, the surface of Regulus at its equator produces only 20 percent as much light per square meter as the surface at the poles.

Why is Regulus so flattened? Like many B stars, Regulus is a fast rotator. It spins once every 15.9 hours, compared to the Sun's 26 days or so. Its equatorial rotation velocity is about 315 kilometers per second, 160 times faster than the Sun's, and about 86 percent of the speed at which Regulus would start to fly apart.

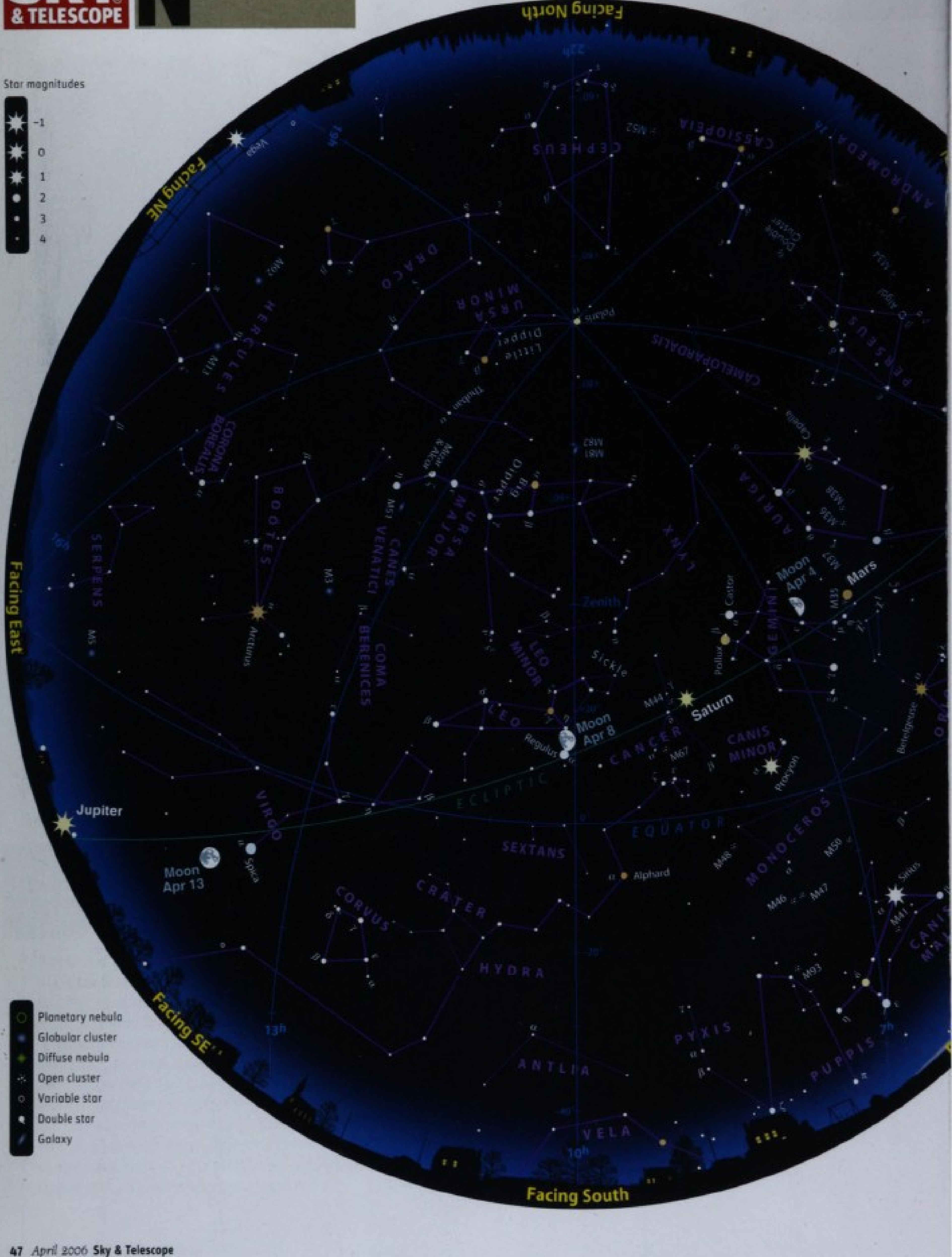
Regulus isn't the only hot 1st-magnitude star known to be flattened by fast rotation. The equatorial diameter of Regulus is 32 percent greater than its polar diameter. That's more than the flattening of the *A*7 star Altair (14 percent) but less than that of the *B*3 star Achernar (56 percent).

Fast rotation also explains why past estimates of Regulus's age, based on the appearance of its spectral lines, made it a puzzling three times older than its companion stars. After we compensate for the effect of the fast rotation and differing surface temperature, Regulus should be the same age as the companions: about 50 million years old, hardly more than 1 percent as old as our Sun. ✦



Regal Regulus, highlighting the Lion stalking across the spring sky, is shaped not like a ball but like a spinning raindrop.

FRED SCHAAF *welcomes mail at fschaaf@aol.com.*


Star magnitudes
−1
0
1
2
3
4
Facing North
Facing NE
Facing East
Facing SE
Facing South
Vega
CEPHEUS
CASSIOPEIA
ANDROMEDA
DRACO
URSA MINOR
Polaris
Little Dipper
Thuban
HERCULES
M13
M92
CORONA BOREALIS
CAMELOPARDALIS
PERSEUS
Algol
Double Cluster
Capella
AURIGA
M36
M38
M37
M35
M81
M82
Big Dipper
URSA MAJOR
Mizar & Alcor
CANES VENATICI
M3
M53
BOÖTES
Arcturus
SERPENS
M5
COMA BERENICES
LEO MINOR
Zenith
LYNX
Sickle
GEMINI
Castor
Pollux
Moon Apr 4
Mars
Betelgeuse
LEO
Regulus
Moon Apr 8
M44
Saturn
CANCER
M67
CANIS MINOR
Procyon
ECLIPTIC
EQUATOR
VIRGO
Jupiter
Spica
Moon Apr 13
SEXTANS
Alphard
MONOCEROS
M48
M50
M46
M47
Sirius
M41
CANIS MAJOR
CORVUS
CRATER
HYDRA
M93
PYXIS
PUPPIS
ANTLIA
VELA
13h
10h
7h
16h
19h
22h
Planetary nebula
Globular cluster
Diffuse nebula
Open cluster
Variable star
Double star
Galaxy

Using the Star Chart

WHEN

Late April	Dusk
Early April	10 p.m.*
Late March	10 p.m.
Early March	11 p.m.
Late February	Midnight

*Daylight-saving time.

HOW

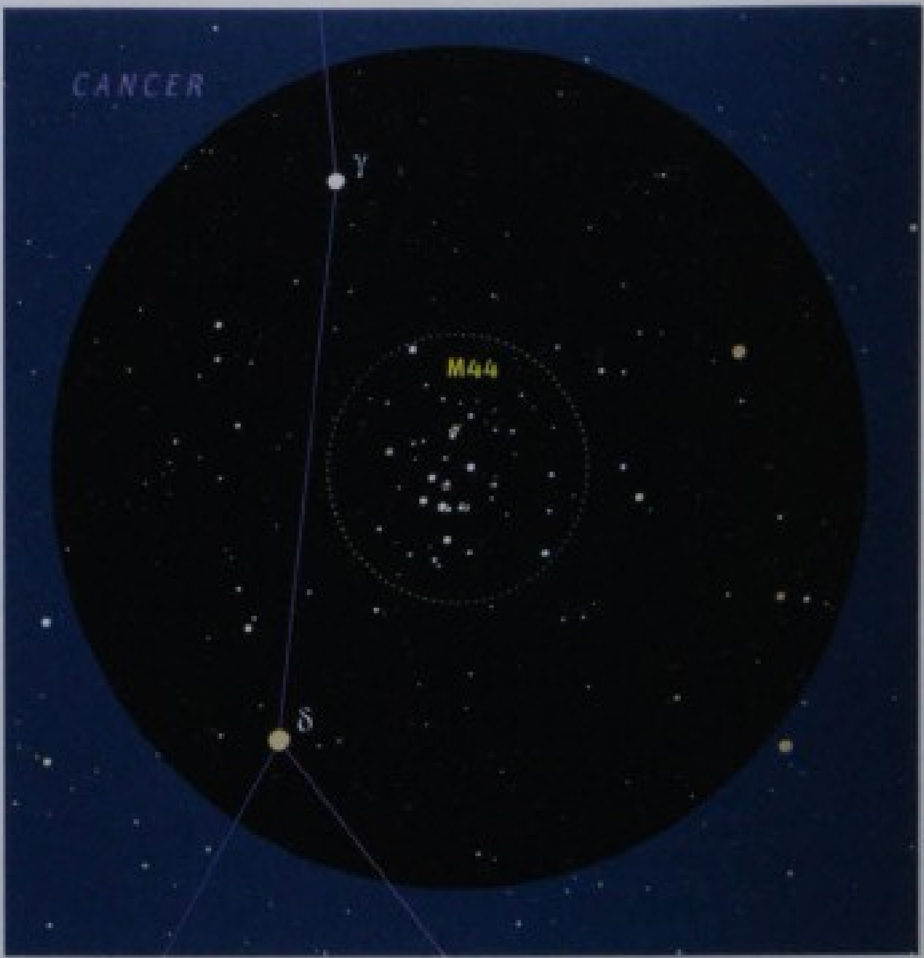
Go outside within an hour or so of a time listed above. Hold the map out in front of you and turn it around so the label for the direction you're facing (such as west or northeast) is right-side up. The curved edge represents the horizon, and the stars above it on the map now match the stars in front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

Example: Turn the map around so "Facing East" is right-side up. Almost halfway from there to the map's center (the zenith) is bright, yellow-orange Arcturus. Go out, face east, and look nearly halfway from horizontal to straight up. There's Arcturus!

Note: Mars, Saturn, and Jupiter are positioned for mid-April. Also, the map is plotted for 40° north latitude (for example, Denver, New York, 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.

ONLINE

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



The Beehive Cluster

ALTHOUGH CANCER is a dim constellation, it contains one of the northern sky's best binocular sights: M44, otherwise known as the Beehive Cluster. It's a particularly fine target for city-bound binocular observers. The cluster's 10 brightest stars shine at 7th magnitude or brighter and are sprinkled evenly across more than 1° of sky. With a little care, another dozen cluster stars can be made out with steadily held 10 × 50 binoculars. M44 is an impressive sight made all the more striking by its relatively barren surroundings. Unlike so many of the winter clusters now slipping into the west, the Beehive isn't set against a rich background of Milky Way stars.

Whenever I view the cluster I see a lopsided box, looking like a miniature of the constellation Corvus, surrounded by a ring of stars. The overall appearance strikes me as less like a beehive than a celestial crab — the box is the body, and the ring stars mark the tips of the crustacean's legs and pincers. But it's all too easy to draw patterns in the sky. Perhaps my imagination is simply making a subconscious connection between the cluster and its constellation.

M44 is situated on the ecliptic, so it's frequently visited by the Moon and planets. Last February Saturn became the brightest bee in the hive when it skirted the grouping's southern edge — a feat it will repeat in June. And in the middle of that month, Mars will pass through the heart of the cluster just as Saturn makes its exit. The nightly motions of these planets will make for an exciting binocular show!

Tear out this monthly map for use outdoors.

southern binocular highlight | by les dalrymple

NGC 3532: Best of the Best?

NO LESS AN OBSERVER than John Herschel declared NGC 3532 "a glorious cluster" and "the most brilliant object of the kind I have ever seen." Nicolas-Louis de Lacaille uncovered this gem in 1752 in his feeble ½-inch, 8× refractor while in South Africa. Even in this diminutive instrument he noted "a prodigious number of faint stars." For my part, I can only add that it is quite simply one of the best open clusters in the southern sky.

Located in Carina in the same rich Milky Way binocular field as the mighty Eta (η) Carinae nebula, NGC 3532 (also listed as Caldwell 91) is an obvious hazy spot to the naked eye even when viewed under suburban skies. The cluster is a very rich gathering that contains more than 600 true cluster members and lies relatively nearby — only about 1,300 light-years distant.

The object described here is also visible from latitudes up to 25° north.

Many open clusters exhibit a kind of sameness in binoculars and appear as simply a milky spot with a handful of embers sewn in. Not NGC 3532. Even my 10 × 50 binoculars show at least 35 individual stars between 6th and 8th magnitude set against a hazy background. The cluster is clearly elongated in an east-west orientation and spans just a little more than 1°.

When I use my 15 × 70 binoculars, about 60 stars can be seen along with an oval-shaped, denser region near the cluster's center. Two yellow suns stand out clearly from the crowd. The brighter one on the cluster's southeastern edge is 6th magnitude, while the other is a little fainter and marks the east end of the central swarm. The outer areas of the cluster contain many curved chains of stars that seem to anchor this gem to a profuse Milky Way field that in itself is almost beyond compare.

Tear out this monthly map for use outdoors.

Using the Star Chart

WHEN

Late April	7 p.m.
Early April	8 p.m.
Late March	9 p.m.
Early March	10 p.m.
Late February	11 p.m.

These are standard times.

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 label for the direction you're facing (such as west or northeast) is right-side up. The curved edge represents the horizon, and the stars above it on the map now match the stars in front of you in the sky. The center of the map is the zenith, the point in the sky directly overhead.

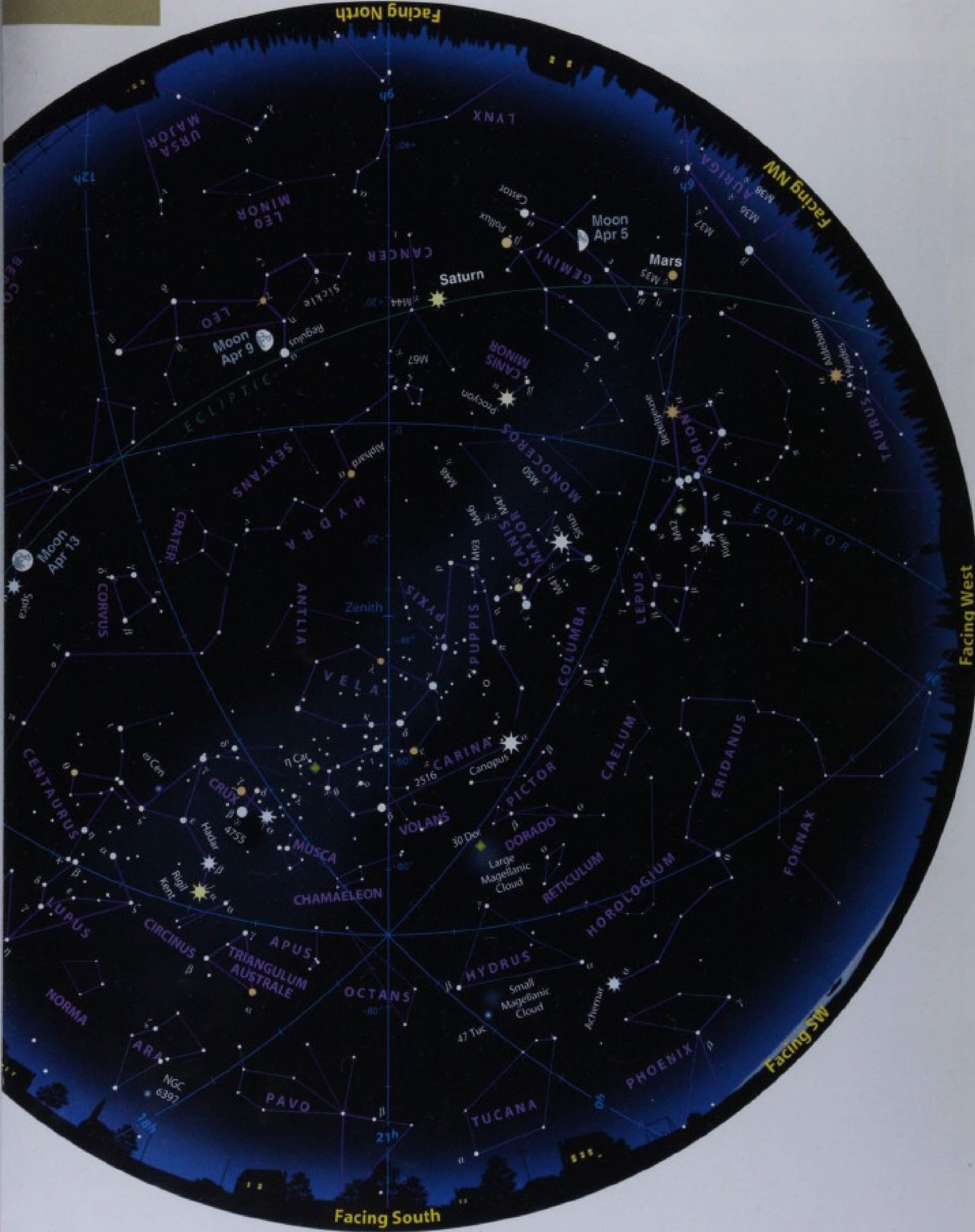
Example: Turn the map around slightly so the label "Facing SW" is right-side up. About one-third of the way from there to the map's center (the zenith) is the bright star Achernar. Go out, face southwest, and look about one-third of the way from horizontal to straight up. There's Achernar!

Note: Mars, Saturn, and Jupiter are positioned for mid-April. The map is plotted for 35° south latitude (for example, Sydney, Buenos Aires, Cape Town). If you're far north of there, stars in the northern part of the sky will be higher and stars in the south lower. For south of 35° the reverse is true.

ONLINE

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

SKY & TELESCOPE southern


Facing North
Facing NW
Facing West
Facing SW
Facing South
LYNX
URSA MAJOR
LEO MINOR
LEO
Sickle
Regulus
Moon Apr 9
Moon Apr 5
Moon Apr 13
CANCER
M44
Saturn
GEMINI
Castor
Pollux
Mars
M35
AURIGA
M37
M36
M38
TAURUS
Aldebaran
Hyades
CANIS MINOR
Procyon
M67
ECLIPTIC
ORION
Betelgeuse
Rigel
M42
EQUATOR
MONOCEROS
M50
SEXTANS
Alphard
HYDRA
CRATER
CORVUS
Spica
M48
M46
M47
CANIS MAJOR
Sirius
M41
M93
LEPUS
ANTLIA
PYXIS
Zenith
PUPPIS
COLUMBA
VELA
CARINA
Canopus
2516
η Car
ω Cen
CENTAURUS
CRUX
4755
Hadar
Rigil Kent
MUSCA
VOLANS
30 Dor
DORADO
Large Magellanic Cloud
PICTOR
CAELUM
ERIDANUS
FORNAX
RETICULUM
HOROLOGIUM
CHAMAELEON
LUPUS
CIRCINUS
APUS
TRIANGULUM AUSTRALE
NORMA
OCTANS
HYDRUS
Small Magellanic Cloud
47 Tuc
Achernar
PHOENIX
ARA
NGC 6397
PAVO
TUCANA
9h
12h
18h
21h
0h
3h
6h

Sailing Along the Galactic Plane

April evenings in the Southern Hemisphere are a fine time to peruse our home galaxy.

DURING APRIL EVENINGS our autumn sky is split from northwest to southeast by the Milky Way's luminous band arching across the heavens' vault. We see it this way because we are located within the galactic plane (a mere 20 light-years above it in the direction of the galactic north pole), so it appears to encircle us in the sky. Some 28,000 light-years from the galactic center, or roughly a third of the way from the center to the outer edge, we are within what is known as the Orion Arm.

The galactic equator, tilted about 63° to our celestial equator, passes through 27 of the sky's 88 constellations. The galaxy's center (galactic longitude 0°) is in Sagittarius, which will be rising in a few hours. The "anticenter," 180° away, lies in Auriga near the Taurus border east of Beta (β) Tauri, low in the northwest sky.

During April evenings we can easily trace the path of the galactic plane across the sky. From Auriga and Taurus, it climbs through Gemini, Orion, and Monoceros. Continuing on across Canis Major and Puppis, it passes into Vela, which is culminating just south of the zenith. Exiting Vela, the galactic plane sweeps through Carina, Centaurus, Crux, and Circinus before reaching the southeastern horizon and the constellations Norma and Ara.

Were we to divide the galactic plane into quadrants, the galactic center and anticenter would be key points. Accordingly, so would longitude 90° (which lies in Cygnus near Deneb, rising before dawn at this time of year) and 270° in Vela near 4th-magnitude c Velorum. There are two other notable 4th-magnitude stars on the galactic equator in Vela: d Velorum and Phi (φ) Velorum. This trio of naked-eye stars shows us the route of the galactic equator across Vela. Of the 27 constellations through which the Milky Way's equatorial plane passes, only one — the far northern constellation Cassiopeia — hosts a greater stretch than Vela.

Despite being just one part of the now-defunct constellation Argo Navis (and thus having no Alpha or Beta star, because these stars ended up being part of neighboring Carina), Vela still enjoys its fair share of bright stars. South of the galactic plane there are 1.8-magnitude Gamma (γ), 1.9-magnitude Delta (δ), and 2.2-magnitude Kappa (κ), while 2.5-magnitude Lambda (λ) is north of the plane. Vela formed the sails of the ancient Argo Navis, and we can make nice triangular sail-like shapes with the stars Lambda, Kappa, and Delta, as well as Lambda, Delta, and Gamma. The eastern half of Vela appears less luminous, with 2.7-magnitude Mu (μ) Velorum being the brightest star.

Delta Velorum leads us to the open cluster IC 2391, visible to the naked eye as a dim patch. Within it we see 4th-magnitude Omicron (o) Velorum, and that's why this grouping is also known as the Omicron Velorum Cluster. IC 2391 is a member of a recently discovered moving group of young stars. Known as "Carina-Vela," this association is not gravitationally bound but rather has a common origin in one or more large molecular clouds. These groups have similar motion as they orbit our galaxy, though over time the individual stars will disperse.

Vela is home to a reasonably bright binocular globular cluster, 7th-magnitude NGC 3201. To find it, draw a line from Mu Velorum to q Velorum. You'll see NGC 3201 to the west of the line's halfway point. Discovered by James Dunlop in 1826 during the course of his survey of the southern sky from Parramatta, New South Wales, NGC 3201 is somewhat less condensed as globulars go. Astronomers have found that this cluster orbits the Milky Way in the direction opposite to virtually everything else in our galaxy. Going against the current of stars and fellow clusters revolving around the galactic center, NGC 3201 is just one of the surprising delights that can be found on a voyage among the star fields of our autumn Milky Way. ✶

Contributing editor GREG BRYANT *can be reached at greg@austskyandtel.com.au.*

Arching across the Southern Hemisphere's April evening sky, the Milky Way's luminous band defines the plane of our home galaxy. It appears prominently in this south circumpolar star-trail photograph.

AKIRA FUJII

Planets Flirt with Star Clusters

APRIL OFFERS US three evening planets. As twilight fades, Saturn comes into view high in the south and dimmer Mars appears high in the west. Later in the evening, Jupiter climbs into view in the southeast. And Venus flames low in the eastern sky at dawn.

> After viewing Saturn near the Beehive, check out Mars near the famous cluster M35.

Mars is still prominent high in the west after dusk. It progresses from Taurus into the feet of Gemini during April, fading from about the intensity of Pollux to that of Castor. Even by month's end, Mars doesn't set until after midnight (daylight-saving time).

Watch Mars start the month between Beta (β) and Zeta (ζ) Tauri, the moderately bright stars that mark the long horn tips of Taurus, the Bull. The golden orange planet moves on, reaching its most northerly point in the heavens on April 12th. A special treat awaits skywatchers on the evening of the 17th, when binoculars and small telescopes show the planet only $^1/_4$° from the center of the sprawling star cluster M35, itself $^1/_2$° across.

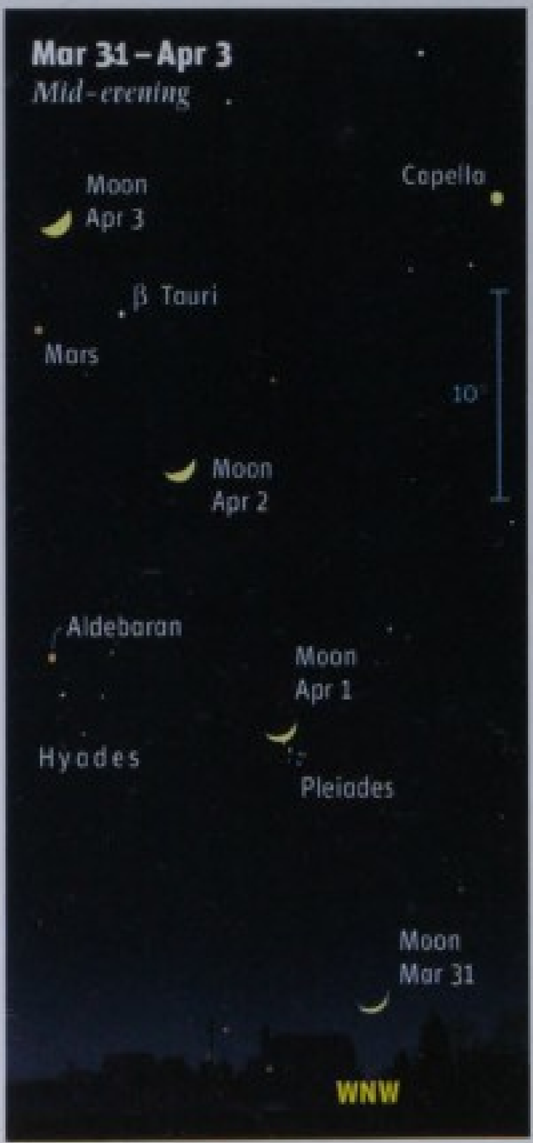
Sky positions. In Sun, Moon, and Planets, most descriptions that relate to your horizon or zenith — including directions like up, down, right, and left — are written for skywatchers in the world's mid-northern latitudes. Configurations of the Moon with specific planets are a special case because they also depend on longitude, and these are given for North America (except as noted otherwise).

Times. In North America, Eastern Daylight Time (EDT) equals Universal Time (UT or GMT) minus 4 hours. Pacific Daylight Time (PDT) equals UT minus 7 hours.

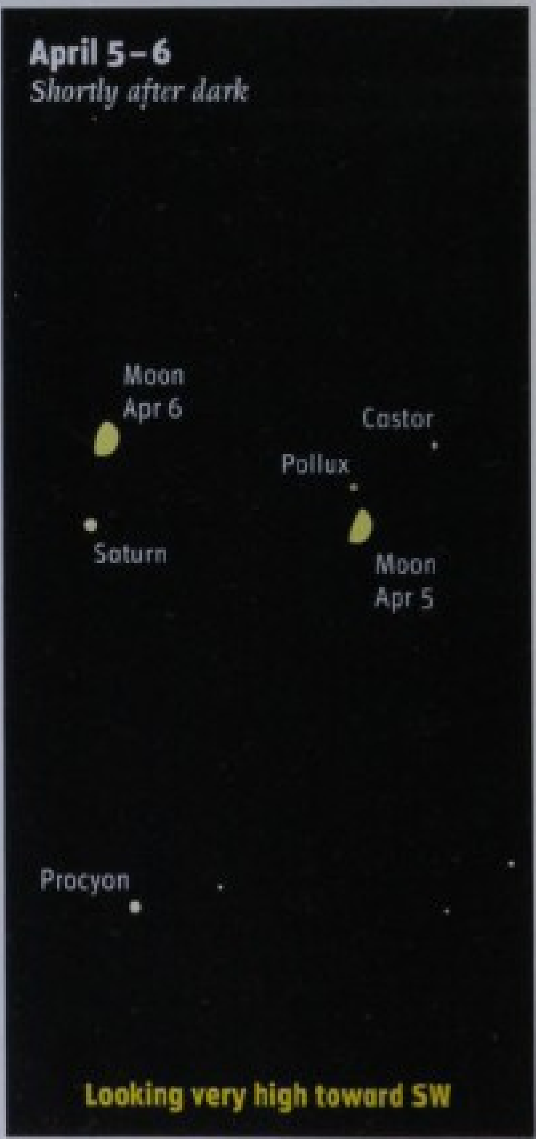
Angles on the sky. Conjunctions are often described by the angular separation of the planets involved. To make sense of these values, remember that the Moon always appears about $^1/_2$° across (but it is exaggerated in size three times on our charts, for clarity). Your fist held at arm's length spans about 10°, while the Big Dipper stretches about 25°.

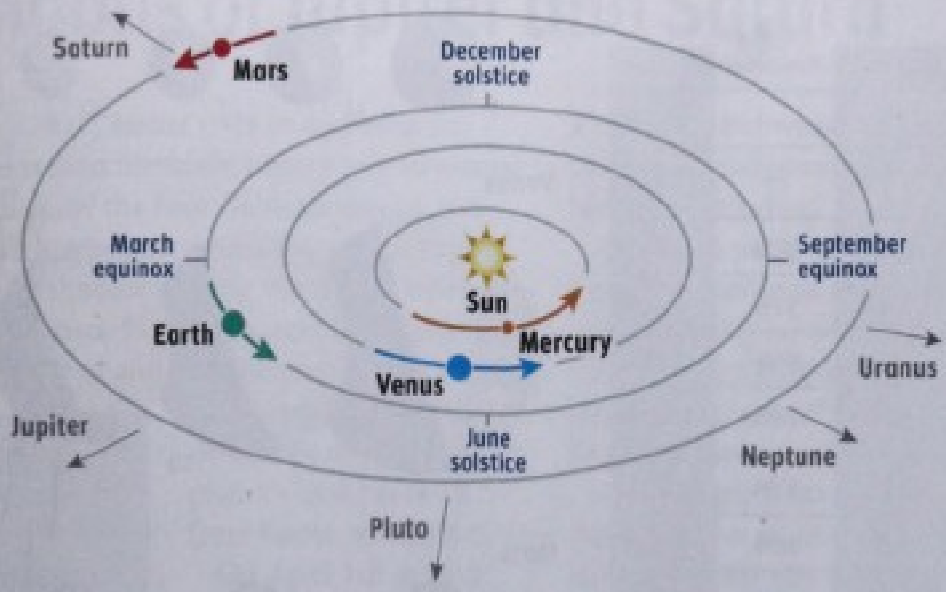
Mars, already tiny, shrinks even smaller in telescopes week by week, and on April 30th it's only 5″ across. That evening the slightly gibbous planet is $^1/_2$° from the 3.1-magnitude star Epsilon (ε) Geminorum, also known as Mebsuta. Thirty years ago this month, Mars occulted Mebsuta in a spectacular event that was widely observed in amateur telescopes across the eastern US.

Saturn shines sedate and golden, high in the south in Cancer. It fades only slightly in April, from magnitude +0.1 to +0.3. The ringed world halts its retrograde motion (movement westward relative to the stars) on April 5th and spends the rest of the month beginning an eastward creep back toward M44, the Beehive Star Cluster, easily seen in binoculars. The gap between Saturn and M44 closes from 3° to $2^1/_2$° during April.



This spring offers the last opportunity until 2013 to see Saturn's rings tilted anywhere near as much as 20° from edgewise. Although Saturn does not set until about 3 a.m., the steadiest, crispest view of it in telescopes will come in the early evening, when the planet is still high. Saturn reaches eastern quadrature (90° east of the Sun) on April 25th, so this month the





The curved arrows indicate each planet's movement during the month, as if you were looking down on the inner solar system from the constellation Ophiuchus.

globe casts its shadow farthest to the side onto the rings (see page 54), creating the greatest appearance of depth and dimensionality.

Jupiter starts April rising an hour after the end of evening twilight, but it comes up earlier and earlier each week. As soon as the king of planets clears horizon obstructions in the east-southeast, it grabs the attention of any skywatcher. Late in the month, notice that Jupiter passes about 1° north of the wide double star Alpha (α) Librae, or Zubenelgenubi. Telescopic views of Jupiter during April are best in the middle of the night,

when the planet has gotten at least moderately high.

Pluto is in Serpens high in the south before dawn, but most seekers of this dim world will wait a few months for it to get high at a more convenient hour.

Neptune is still deep in the glow of dawn.

Venus is a shout of light when it rises in the east around the time of dawn's first gleaming in April. The planet is just past its March 25th greatest elongation from the Sun. Nevertheless, it's less than 20° high at sunrise for observers around latitude 40° north in April, and its blaze dims a little during April as its globe shrinks to less than 20″ wide.

A fairly difficult but fascinating opportunity for telescope users occurs before dawn in the Americas on April 18th: to see the tiny 6th-magnitude planet **Uranus,** glowing as a pale blue-green dot, only 0.3° south of Venus! The latter is slightly more than half lit.

Mercury reaches greatest elongation of 28° from the Sun on April 8th, but for observers at mid-northern latitudes it's buried deep in the glow of dawn. Look for it about 30 minutes before sunrise just above the eastern horizon all month, well to the lower left of Venus. This is a very poor apparition for those of us living well north of the equator, but a superb one for southern lands. For example, Mercury is some 26° high by sunrise for observers around latitude 35° south.

The **Moon** is a lovely crescent on the evening of April 1st. It passes through the Pleiades for viewers in eastern and central North America, causing many occultations as described on page 61. After swelling past first quarter, the Moon appears a few degrees from Mars on April 3rd and from Saturn on April 6th. The Moon is just past full when it rises about 7° to the right of Jupiter at the end of evening twilight on April 14th.

On April 24th, the waning lunar crescent is only a few degrees right of Venus at dawn, then occults Venus in the daytime for observers in southern and eastern South America. Venus disappears and reappears at these Universal Times: Santiago (Chile), 12:41, 14:04; Rio de Janeiro, 13:53, 15:01; Buenos Aires, 13:03, 14:20; Tierra del Fuego, 12:41, 13:28.

Observers in Japan can try to spot an extremely thin crescent Moon, 14 hours old, on the evening of the 28th.

April Events of Note

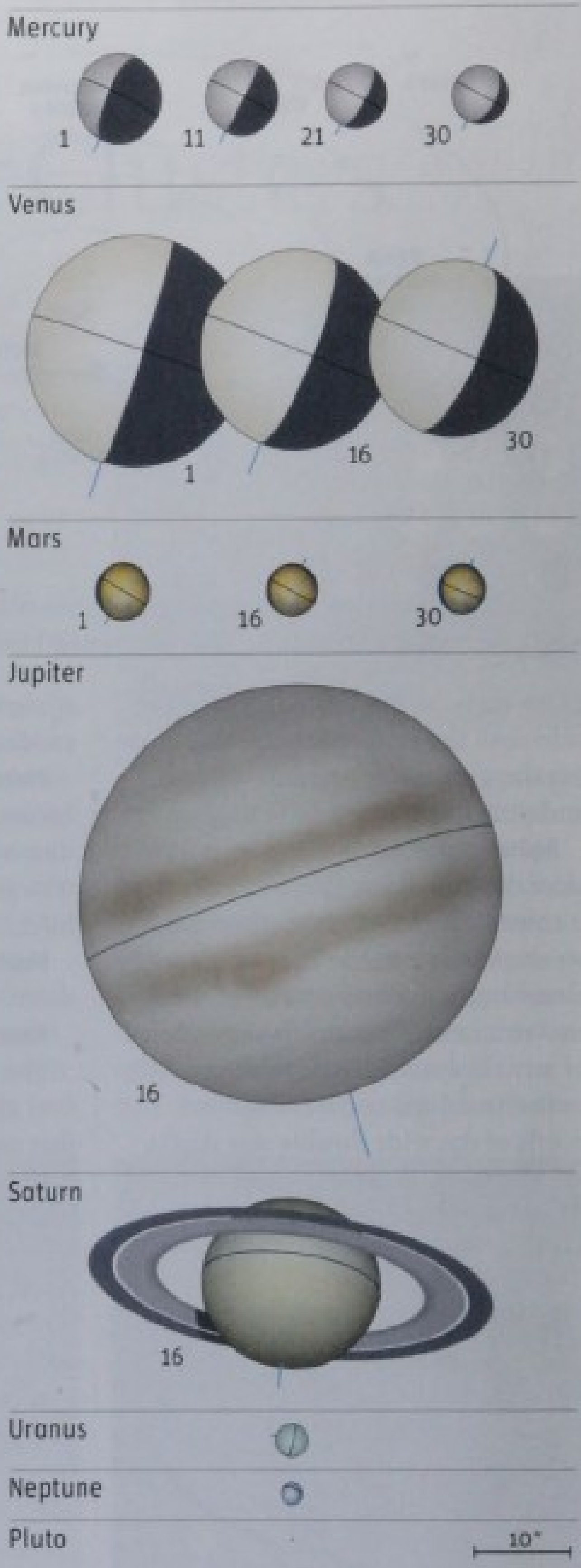
- 1 The crescent Moon occults the Pleiades for eastern and central North America (see page 61).
- 3 Look for asteroid 4 Vesta (mag. 7.9) about 25′ north of 37 Geminorum tonight.
- 5 First-quarter Moon (8:01 a.m. EDT). • Slow-moving Neptune is just 25″ south of a star nearly as bright, SAO 164387, at 3^h UT; find the pair 1.9° north-northeast of ι Capricorni.
- 7 Mercury reaches greatest illuminated extent, 23 square arcseconds.
- 8 Mercury stands at greatest elongation, 28° west of the Sun in the morning sky.
- 13 Full Moon (12:40 p.m. EDT).
- 17 Mars is ¾° north of the center of the open star cluster M35 in Gemini.
- 18 Near 10^h UT, Venus and Uranus are just 18′ apart.
- 20 Last-quarter Moon (11:28 p.m. EDT).
- 22 Lyrid meteors peak before dawn.
- 25 Saturn is 90° east of the Sun.
- 27 New Moon (3:44 p.m. EDT).

SOME ITEMS: JEAN MEEUS

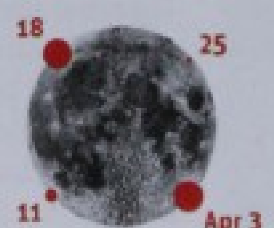
Sun and Planets, April 2006

	April	Right Ascension	Declination	Elongation	Magnitude	Diameter	Illumination	Distance
Sun	1st	0h 40.9m	+4° 24′	—	−26.8	32′ 00.8″	—	0.999
	30th	2h 28.5m	+14° 40′	—	−26.8	31′ 45.5″	—	1.007
Mercury	1st	23h 05.9m	−6° 34′	26° Mo	+0.5	8.8″	35%	0.763
	11th	23h 39.2m	−4° 37′	28° Mo	+0.2	7.4″	52%	0.907
	21st	0h 26.9m	−0° 02′	25° Mo	−0.1	6.4″	66%	1.054
	30th	1h 18.9m	+5° 46′	19° Mo	−0.6	5.7″	78%	1.178
Venus	1st	21h 46.7m	−12° 16′	46° Mo	−4.3	22.8″	53%	0.732
	11th	22h 28.0m	−9° 27′	46° Mo	−4.1	20.6″	58%	0.810
	21st	23h 09.9m	−6° 04′	45° Mo	−4.0	18.8″	62%	0.888
	30th	23h 47.7m	−2° 38′	43° Mo	−4.0	17.4″	65%	0.957
Mars	1st	5h 27.1m	+24° 56′	71° Ev	+1.2	5.7″	91%	1.645
	16th	6h 05.0m	+25° 05′	65° Ev	+1.4	5.2″	92%	1.785
	30th	6h 40.9m	+24° 42′	60° Ev	+1.5	4.9″	92%	1.909
Jupiter	1st	15h 02.6m	−15° 51′	143° Mo	−2.4	42.9″	100%	4.592
	30th	14h 50.1m	−14° 56′	175° Mo	−2.5	44.6″	100%	4.418
Saturn	1st	8h 27.7m	+19° 53′	113° Ev	+0.1	19.1″	100%	8.682
	30th	8h 29.8m	+19° 46′	85° Ev	+0.3	18.1″	100%	9.154
Uranus	16th	22h 59.0m	−7° 18′	43° Mo	+5.9	3.4″	100%	20.804
Neptune	16th	21h 27.7m	−15° 09′	66° Mo	+7.9	2.2″	100%	30.443
Pluto	16th	17h 46.3m	−15° 46′	119° Mo	+13.9	0.1″	100%	30.603

The table above gives each object's right ascension and declination (equinox of date) at 0h Universal Time on selected dates and its elongation from the Sun in the morning (Mo) or evening (Ev) sky. Next are listed 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. equals 149,597,870 kilometers, or 92,955,807 international miles. **Planet disks at right** have north up; ticks indicate the pole currently turned toward Earth.



Moon, April 2006



The Moon is shown with north up. For key dates, the red dots indicate what part of the limb is tipped the most toward Earth by libration. Amounts are listed below.

First Quarter	Apr. 5, 12:01 UT
Full Moon	Apr. 13, 16:40 UT
Last Quarter	Apr. 21, 3:28 UT
New Moon	Apr. 27, 19:44 UT
Apogee	Apr. 9, 13h UT (dist. 405,551 km; diam. 29′ 28″)
Perigee	Apr. 25, 11h UT (dist. 363,731 km; diam. 32′ 51″)
Max. libration	9.6°, Apr. 3, 21h UT (Mare Australe, on bright limb)
Min. libration	1.6°, Apr. 11, 7h UT (Mare Orientale, on dark limb)
Max. libration	9.0°, Apr. 18, 17h UT (craters McLaughlin and Chapman, on bright limb)
Min. libration	0.4°, Apr. 25, 9h UT (Mare Humboldtianum, on dark limb)

Moons of Jupiter and Saturn

IN APRIL, **Jupiter** rises in mid-evening. From then till dawn, almost any telescope will show the four Galilean moons and their interesting interactions with Jupiter or its shadow. During the course of every revolution, Io, Europa, and Ganymede pass in front of and then behind Jupiter's disk. Wide-ranging Callisto continues to miss the planet's disk, as seen from Earth, until 2008.

To display Jupiter's moons on any date and time that you wish to see them, visit SkyandTelescope.com/jupmoons

On April 5th at 10:27 UT, which corresponds to 3:27 a.m. Pacific Daylight Time, Ganymede's shadow can be found just inside the planet's northern limb. But as illustrated in the first panel below, Ganymede itself is still somewhat east of Jupiter; it won't start a transit of the disk until about 2 hours later.

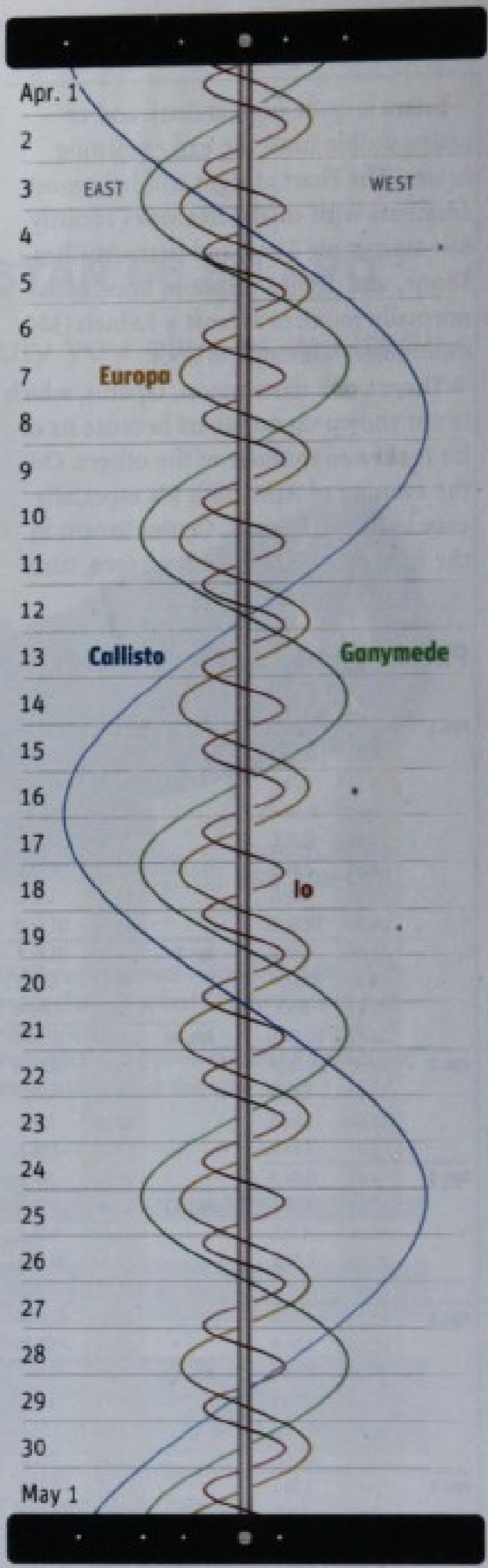
As you look at the second panel, try to visualize Ganymede beyond (rather than in front of) the planet. On April 16th, after being eclipsed by Jupiter's shadow for nearly 2 hours, Ganymede is in the process of reappearing at 5:26 UT (1:26 a.m. EDT). But within 10 minutes this moon will disappear again as it goes behind Jupiter's disk.

The third panel shows how Callisto looks for European observers just after midnight (UT) on the night of April 20-21. Instead of going directly in front of Jupiter, it skims just 12″ north of the planet's northern limb.

The complete list of phenomena for April appears on the next page, but any given observer can view only about one-third of them (namely, those that occur when Jupiter is visible at night).

continued on the next page

At right, the curving lines represent Jupiter's four bright satellites. Jupiter itself is the center vertical bar. Each horizontal band represents a full day, from 0ʰ (upper edge of band) to 24ʰ Universal Time. The date is given at left. East is left and west is right to match the view from the Northern Hemisphere in binoculars. **Shown below** for several dates and times are particularly interesting configurations of the moons; north is up.



The Sun and planets are located for mid-April; arrows show motion throughout the month. The Moon is plotted for evening dates in the Americas when it is waxing (right side illuminated) or full, and morning dates when waning (left side). It is shown on the nights nearest first quarter, full, and last quarter, as well as on dates of selected crescent and gibbous phases. "Local time of transit" tells when objects cross the meridian at midmonth; transits occur an hour later on the 1st and an hour earlier at month's end. For specific configurations of the Moon and planets, as seen in your own sky, try our Interactive Sky Chart (SkyandTelescope.com/observing/skychart).

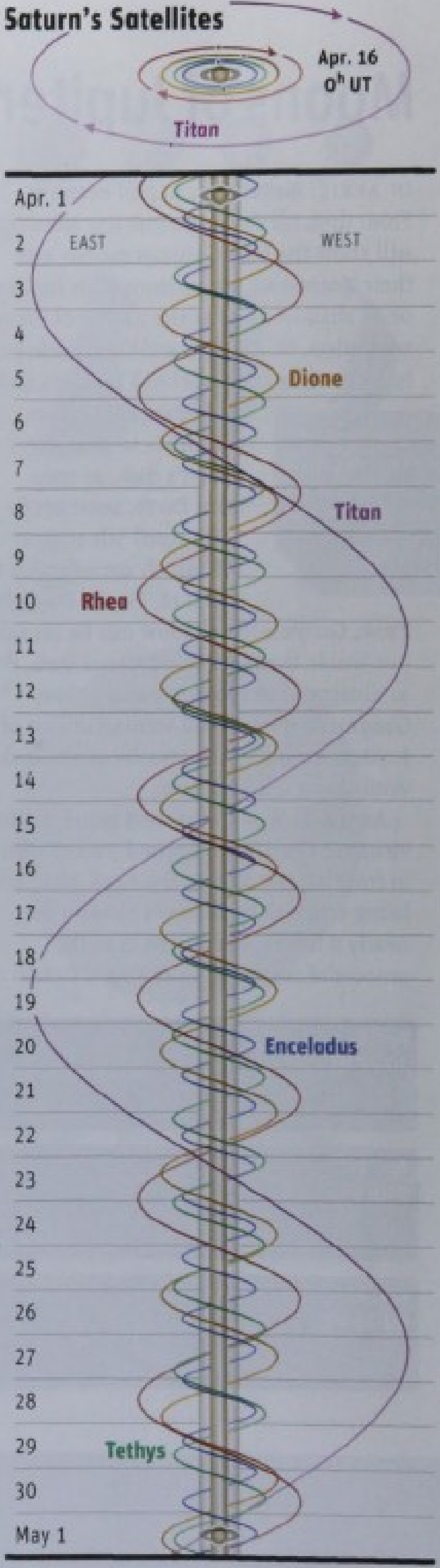
Saturn is quite high at dusk and remains visible until the early morning hours. The chart at right will help most amateurs with small telescopes identify 8th-magnitude Titan and perhaps Rhea, Dione, and Tethys. Close-in Enceladus normally requires at least a 12-inch (300-millimeter) telescope to spot.

There's one more moon, Iapetus, which is not shown on our chart because its orbit is skewed to those of the others. On the evening of April 12th it's especially easy to locate Iapetus. Center Saturn in the field of a high-power eyepiece, turn off the telescope's drive (if it has one), and count off 35 seconds. Earth's rotation should put Iapetus squarely in the center of the field, shining feebly at 12th magnitude. This moon is moving slowly away from Saturn, and on April 19th (greatest elongation) it lies slightly north of Saturn's location after a drift time of 40 seconds.

Visit SkyandTelescope.com and click on Observing > Celestial Objects > Planets to find handy applets that display the satellite configurations of Jupiter and Saturn at any given time.

— Roger W. Sinnott

Saturn's Satellites



The curving lines represent Saturn's brightest moons. The planet's disk and rings are indicated by vertical bands. Each horizontal band represents a full day, from 0^h to 24^h Universal Time. Titan is the easiest moon to see, and a 100-mm telescope can show Rhea, Dione, and Tethys. Enceladus may need a 300-mm. The wavy-line chart gives only east-west shifts. Refer to the ellipses at top to estimate each moon's location north of (above) or south of the ring extension.

Phenomena of Jupiter's Moons, April 2006

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

For telescopic observers in April, here is the complete list of phenomena involving Jupiter's four bright moons and the planet's disk or shadow. The first columns give the date and midpoint time of the event in Universal Time. Next is the satellite involved: **I** for Io, **II** Europa, **III** Ganymede, or **IV** Callisto. This is followed by the type of event: **Oc** for an occultation of the satellite behind Jupiter's limb, **Ec** for an eclipse by Jupiter's shadow, **Tr** for a transit of the satellite across the planet's face, or **Sh** for the satellite casting its tiny black shadow onto Jupiter. An occultation or eclipse begins when the satellite disappears **(D)** and ends when it reappears **(R)**. A transit or shadow passage begins at ingress **(I)** and ends at egress **(E)**. Each event is gradual, lasting several minutes. These predictions are courtesy IMCCE/Paris Observatory.

Jupiter's Red Spot

HERE ARE THE Universal dates and times when the center of the Great Red Spot should cross Jupiter's central meridian, the imaginary line down the center of the planet's disk from pole to pole. The spot has been pale orange-tan in recent years.

For example, a transit is listed for 6:06 Universal Time on April 2nd, which is 1:06 a.m. Eastern Standard Time in North America. (That's 2:06 a.m. Eastern Daylight Time if you've set your clock ahead already.) Features on Jupiter appear closer to the meridian than to the limb — and thus are well placed for viewing — for 50 minutes before and after their transit times.

Geoff Chester of Alexandria, Virginia, used a Celestar 8-inch telescope for the image above, showing Jupiter's moons Io and Europa (near the right limb) and their shadows on March 30, 2004, at 3:38 UT. Note that the Red Spot appears centered, yet the March 2004 issue had forecast a transit 8 minutes earlier. This indicates the spot had already begun to drift from 89° longitude, then used for predictions. ✶ — R. W. S.

Red Spot Transit Times, 2006

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

These predictions assume the Red Spot is at Jovian System II longitude 104°, the most recent value provided by John W. McAnally of the Association of Lunar and Planetary Observers (www.lpl.arizona.edu/alpo). If it has drifted, it will transit 1⅔ minutes late for every 1° of longitude greater than 104°, or 1⅔ minutes early for every 1° less than 104°. Check SkyandTelescope.com/redspot for updates.

by charles a. wood

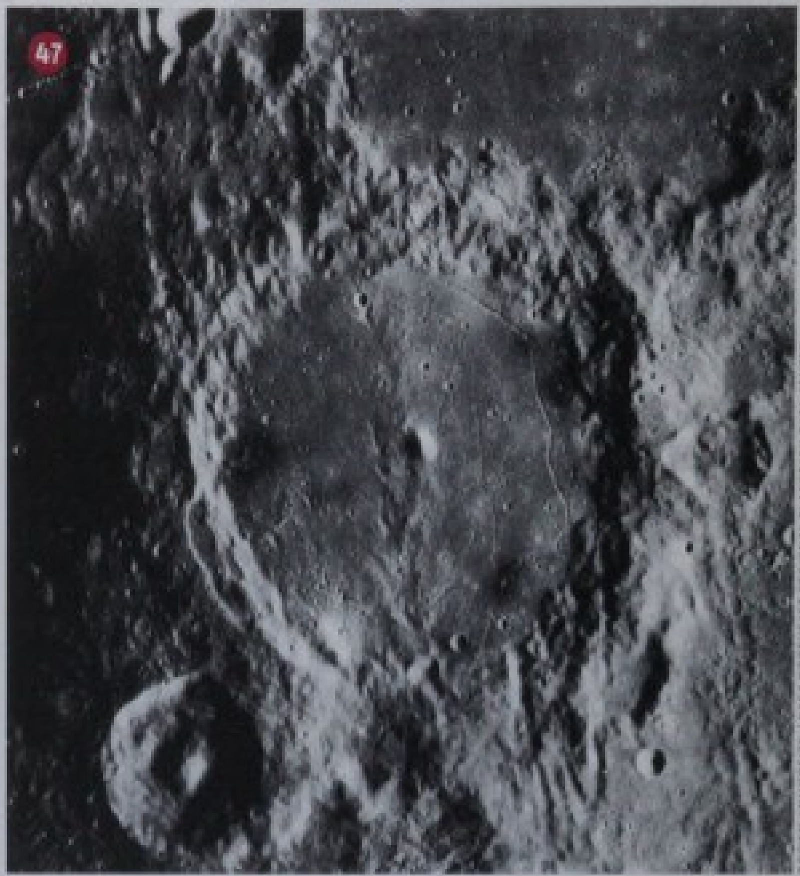
Little Lunar Volcanoes

THE MOON'S SURFACE is dominated by cratering and volcanism. Nearly all its craters were formed by impacts, and nearly all its volcanism is *extrusive* — characterized by flowing lava. But there are also some non-impact craters and some non-extrusive volcanic features.

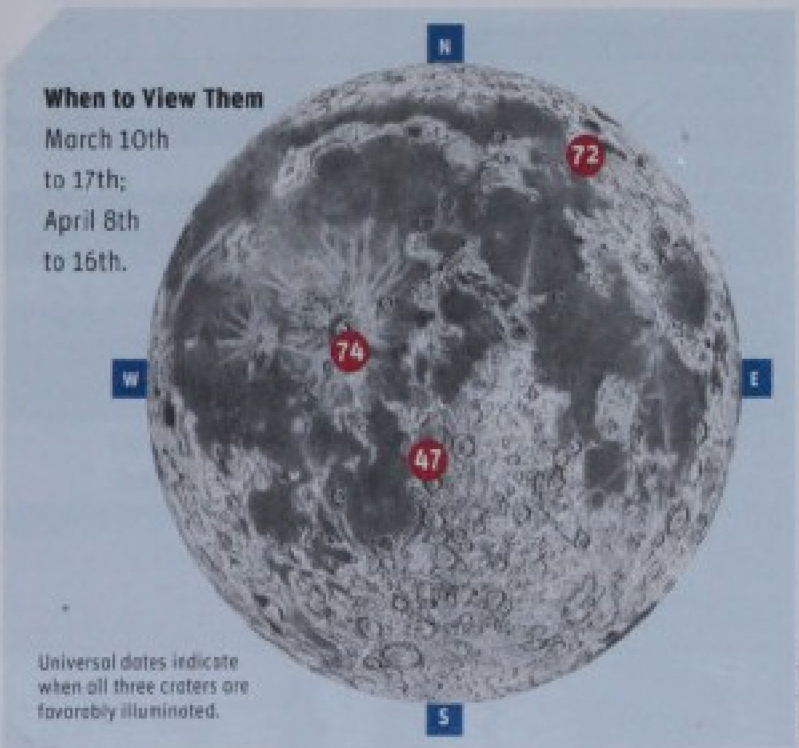
Almost all Moon craters are impact features, but there are a few fascinating exceptions.

On Earth one form of volcanic activity is literally explosive and is caused by gases within molten rock, or *magma*. Gas bubbles form within the magma and grow in size as the magma approaches the surface and the pressure decreases. When the magma reaches the surface and erupts, the gas inside expands explosively and shreds the molten rock into pieces called *pyroclastic deposits*.

Pyroclastic eruptions often build steep-sided volcanoes such as Mount Fuji in Japan. Larger and more explosive eruptions fling the pyroclastics farther away, constructing huge, low-rimmed craters such as the Yellowstone caldera in Wyoming. But there are no Fujis or Yellowstones on the Moon. This is probably because the lunar crust and magmas did not contain water — the most common volcanic gas on Earth.



The magnificent crater Alphonsus dominates this Lunar Orbiter view. Several tiny volcanic craters surrounded by dark halos of pyroclastic material are visible near the main crater's east and west walls.



When to View Them
March 10th to 17th; April 8th to 16th.

Universal dates indicate when all three craters are favorably illuminated.

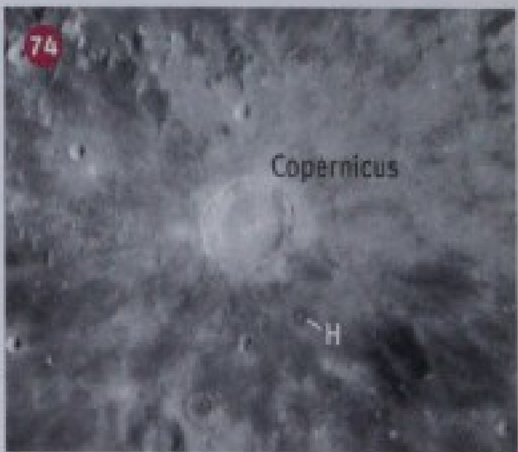
But (as I noted in my August 2005 column) there *are* pyroclastic deposits on the Moon, so it must possess some suitable volcanic gases. Further evidence of the existence of lunar gases is found in mare basalt samples that are full of holes (vesicles) formed by bubbles. But what was the gas? Chemical studies show that it probably was carbon dioxide, carbon monoxide, and sulfur. These gases are also found in terrestrial volcanic rocks but are secondary in importance to water. On the Moon they are the whole story.

The best-known pyroclastic volcanoes on the Moon are the dark-halo craters (DHCs) found on the floor of Alphon-

The Lunar 100

L	Feature name	Significance
47	Alphonsus dark spots	Dark-halo eruptions on crater floor
72	Atlas dark-halo craters	Explosive volcanic pits on the floor of Atlas
74	Copernicus H	Dark-halo impact crater

See *Sky & Telescope*: April 2004, page 113, or point your Web browser to SkyandTelescope.com/lunar100.



sus (L47 in the Lunar 100). The halos are easiest to view in a telescope when the Sun is high and shadows are short. If you look closely with your telescope you'll see four relatively small dark patches on the crater's floor. In fact, Alphonsus has 11 DHCs in all with diameters less than 4 kilometers (2½ miles). These craters have very low rims, and some feature non-circular outlines. What really gives away their volcanic origins is that they occur on narrow rilles. The rilles are probably the surface expressions of vertical conduits of magma (dikes) under Alphonsus. In 11 places, the rising magma broke through to the surface and scattered dark ash as far as 6 km beyond the craters. The tiny central pits probably formed by erosion from the jet of erupted pyroclastics and later collapse, which enlarged the size of the eruption vent.

The Alphonsus examples are very similar to other volcanic dark-halo craters on the Moon. Look inside the crater Atlas, near the eastern end of Mare Frigoris. Atlas (L72) is an 87-km-wide floor-fractured crater that has a network of vaguely concentric rilles with two dark-halo patches on opposite sides of the floor near the rim. The smaller nearby crater Franklin looks similar and also features rilles and DHCs. Other dark halos are found in Petavius and Cleomedes, though those in the latter crater are tiny and very difficult to detect.

One of the easiest DHCs to find is Copernicus H (L74), located just southeast of the conspicuous ray crater Copernicus. But this 5-km-wide DHC is not volcanic. It's a normal impact crater that excavated through the bright surface material (probably ejecta from Copernicus) and dug up underlying dark mare. In fact, most of the 80 known DHCs are impact features like Copernicus H.

Of course, this invites the question: How can you tell if a DHC is of volcanic or impact origin? The best way is to look at the surroundings. Is the DHC on or near a rille? Are there two or more close together? Does it occur inside an impact crater that has rilles or other volcanic features? If the answer to one or more of these questions is yes, you're probably looking at a little lunar volcano. ✱

CHARLES A. WOOD *is a longtime Moon explorer, volcano expert, and the author of* The Modern Moon: A Personal View *and the* Lunar 100 Card *(both available from Sky Publishing).*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A Spectacular Pleiades Occultation

Watch the crescent Moon cross many stars on April 1st. By David Dunham

IF YOU DON'T PAY much attention to occultations, now's the time to pay attention. Early on Saturday evening, April 1st, the thin (16 percent sunlit) crescent Moon will pass over parts of the Pleiades for observers in eastern North America and the Caribbean.

The details vary depending on your location, but in general, the show begins as soon as evening twilight starts fading and ends 2 or 3 hours later when the Moon gets very low in the west. The Moon's dark limb, glowing gray by earthshine, will gradually approach one star after another and wink it out. The stars will reappear from behind the Moon's bright, sunlit limb up to an hour or more later, but these events will be harder to observe.

Binoculars will give a fine view, especially if you can mount them on a tripod or image-stabilize them with a shoulder support (*S&T*: October 2005, page 107). In a telescope the view will be gorgeous. Use the diagram below and instructions at right to see what will happen, and when, for your location.

Join a Graze Expedition

Eighteen *grazing occultations* of stars of magnitude 7.5 or brighter will crisscross eastern North America. People who can travel with a telescope to within a mile of one of these lines will be able to see the star disappear and reappear several times among the mountains and valleys along the Moon's northern or southern edge. Of special note will be the northern-limb grazes of 4th-magnitude 19 Tauri (Taygeta) and 20 Tauri (Maia), and the southern-limb graze of 3rd-magnitude Eta Tauri (Alcyone, the brightest Pleiad). These three paths

Predicting Your Events

You can use the diagram below to see which stars will be occulted at your site, and when.

Each line shows the path of the Moon's center across the Pleiades as seen from a particular city. Make a photocopy of the Moon disk at lower right, cut it out, and punch a hole in its center. Keeping it oriented the way the Moon is here, slide your cutout from right to left while keeping its center on the appropriate city's line. This way you can see how the edges of the Moon will cover and uncover stars as seen from that city.

Each line has Universal Time ticks every 15 minutes. When a star crosses your cutout-Moon's edge, read the approximate time on the line in the center hole. (To get North American times, remember that 0:00 UT is 7:00 p.m. EST, 6:00 p.m. CST, and 5:00 MST.)

Each line begins when evening twilight fades and the stars come out, and ends when the Moon gets very low in the west.

If you're not in one of the cities indicated, interpolate between the same time ticks for the two or three cities nearest you. Mark your spot with a pencil dot, repeat for each time tick, and connect your dots to make a line of your own.

Stars are plotted to 10th magnitude. All should be visible in a 3-inch telescope under good sky conditions.

— Alan MacRobert

are shown on page 71 of the January issue.

The graze of Taygeta has special interest following claims in 1969 by Robert Sandy and Harold Povenmire that the star is a close double; they visually observed gradual dimming phenomena and step events during the multiple contacts of a grazing occultation that year. The star is now known to be a spectroscopic binary; the 1969 observations resolved it directly for the first time. Photoelectric occultation records showed the components to be magnitudes 4.6 and 6.1 with a separation of up to 0.04″, depending on where in the 3.6-year orbit the companion happened to be.

Dave Gault in Australia videorecorded the reappearance of Taygeta during an occultation just last September, but analysis of his recording (with the *Limovie* software) failed to show effects of duplicity — either because the secondary star was too close to the primary (near periastron) or was in a direction from the primary star roughly parallel to the lunar limb. Video recordings of the upcoming occultation could determine the pair's current separation and position angle — which, when combined with the spectroscopic and other data, should allow a better determination of the pair's 3-D orbit in space and thus each star's mass.

Especially useful will be observations of the graze of Taygeta across Alabama, Georgia, and southernmost South Carolina, since the shallow-slope contacts will give the best resolution. Also, multiple contacts will occur at a variety of position angles, giving several different fixes on the binary's separation and position angle. Povenmire (katiegraze1@aol.com; 321-544-5658) and Roger Venable (rjvmd@knology.net) plan to lead an expedition to observe this graze near Statesboro, Georgia. They would like help, since the detail of the lunar profile and the quality of the stellar parameters will be proportional to the number of observers.

Another spectacular graze, also visible with good binoculars, involves 20 Tauri across Ohio (just north of Columbus) and Mid-Atlantic states, including the northern suburbs of Washington, DC. To join an expedition there, contact me at dunham@starpower.net or 301-526-5590.

Alcyone, though brighter, will present a more difficult graze among sunlit lunar features, so at least a small telescope is needed. The Alcyone path passes over the Houston and Miami areas.

These and 15 other graze paths are plotted in the 2006 RASC *Observer's Handbook*. Among the many cities they go near are New York, Philadelphia, Halifax, and Jacksonville.

Charlie Ridgway in New York City has produced an interactive Google Maps overlay of all of these paths at http://digitalmagic.i8.com/Astronomy/Occultations/06/Grazes/M45.html. You can use it to zoom in to see the graze lines plotted in great detail on maps and aerial imagery of your area.

David Dunham *is the longtime president of the International Occultation Timing Association.*

Variable Stars for April

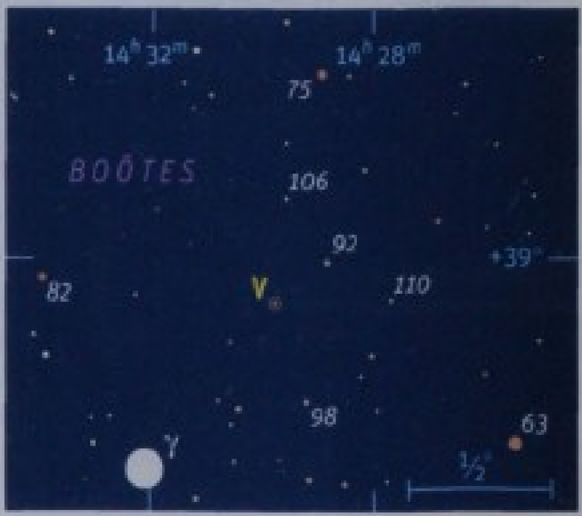
AMONG THE EASIEST of long-period variable stars to locate is V Boötis, lying just 0.7° northwest of 3rd-magnitude Gamma Boötis (see the all-sky chart on page 47 to identify Gamma). This month V should be near peak brightness, according to the American Association of Variable Star Observers. It typically ranges from magnitude 10 to 7 and back in an 8- or 9-month cycle.

This star's variability was discovered in 1884 by Swedish astronomer N. C. Dunér while he was measuring star positions with a meridian circle at Lund Observatory. On May 21st that year he found the star fainter than magnitude 9.5, but he remembered recording it as 7.0 on April 29th and May 7th.

The AAVSO seeks measurements of this and other long-period variables. Those predicted to be 8th magnitude or brighter in April are listed at right.

Also accessible on April evenings is the bright eclipsing variable Algol (β Persei), in the northwestern sky. Every 2 days 20 hours 49 minutes, Algol is at its dimmest, magnitude 3.4 instead of its usual 2.1. The star is nearly this faint for two hours, and it takes several hours to fade and brighten. To find out when Algol's minima are due, visit SkyandTelescope.com/algol and use our handy online calculator. See the table at lower right for dates and Universal Times of minima in April. ✦

— Roger W. Sinnott



Point any low-power telescope at Gamma (γ) Boötis and you've probably got V Boötis in the field. Included here are magnitudes of comparison stars to tenths (with decimal points omitted).

Variable-Star Maxima

2006	Star	Mag.	RA	Dec.
Apr. 2 (I)	V Boo	7.0	14h 29.8m	+38° 52′
Apr. 3	R And	7.0	0h 24.0m	+38° 35′
Apr. 5	V Cnc	7.9	8h 21.7m	+17° 17′
Apr. 9	R Sgr	7.3	19h 16.7m	−19° 18′
Apr. 13	T Nor	7.4	15h 44.1m	−54° 59′
Apr. 15	T Aqr	7.7	20h 49.9m	−5° 09′
Apr. 17	T Sgr	8.0	19h 16.3m	−16° 59′
Apr. 18	o Cet	3.4	2h 19.3m	−2° 59′
Apr. 21	U Cyg	7.2	20h 19.6m	+47° 54′
Apr. 21	V CVn	6.8	13h 19.5m	+45° 32′
Apr. 29	R Leo	5.8	9h 47.6m	+11° 26′
Apr. 30 (II)	R Cen	5.8	14h 16.6m	−59° 55′

For each of these long-period variable stars, the table gives the date peak brightness is expected, the star's typical visual magnitude at maximum, and its right ascension and declination (equinox 2000.0). The actual maximum may be brighter or fainter and many days early or late. Some stars have a primary (I) and a secondary (II) maximum. Courtesy Elizabeth Waagen, American Association of Variable Star Observers (aavso.org).

Minima of Algol

April	UT	April	UT
2	5:31	5	2:21
7	23:10	10	19:59
13	16:48	16	13:37
19	10:26	22	7:15
25	4:05	28	0:54
30	21:43	—	—

These geocentric predictions are from the heliocentric elements Min. = JD 2,452,253.567 + 2.867321*E*, where *E* is any integer. Derived by Marvin Baldwin (AAVSO), they are based on 17 timings collected from 1999 to 2003 and on the star's average period during the previous 35 years.

An Eclipse Timetable

A simple checklist will enhance your eclipse-watching experience.

IT'S TRUE. Ask any solar-eclipse veteran. Totality, no matter how long its duration, seems to last only 8 seconds – a maxim attributed to former *S&T* editor Norm Sperling. Totality begins, you gasp, you blink, and it's over. Paralysis of the eye-brain system is quite common among those within the Moon's shadow. That's why I've created an eclipse timetable – a checklist that I use to get the most out of experiencing not only totality but also the entire eclipse. But be forewarned: You need a strong will to succeed, as the mind-numbing power of totality is awesome!

1. First contact – the moment the Moon's limb is first seen against the Sun's disk – happens three times: first in a telescope, second in binoculars, and third with the unaided eye. Decide which event you want to see, and stay the course.

2. After first contact, record the color and quality of the sky and clouds. Note the color and quality of light on and around a few select nearby objects. Do the same for the distant landscape. Study the sharpness of shadows; how well can your eye penetrate them? Is the air hot or cold? Is there a wind? If so, is it warm or cold? What sounds of nature do you hear? How are birds and animals behaving?

3. If you have a telescope with a safe solar filter, inspect the Moon's advancing limb for fringes of color. Do the same for the Sun's upper and lower limbs and the borders of sunspots. If no colors are visible, look for a bright contrast band just beyond the Moon's leading limb.

4. When the Sun is half eclipsed, repeat Steps 2 and 3.

5. When the Sun is 75 percent eclipsed, repeat Steps 2 and 3. Look at your own shadow cast on the ground; one side should appear fuzzier than the other. Look under trees for tiny images of the waning crescent Sun.

6. Fifteen minutes before totality, repeat Step 2. The Moon's shadow should now be visible on the western horizon looking like a gathering storm. Skilled telescopic observers should place the bright solar crescent outside the field of view, remove the solar filter, and look on the side opposite the disappearing crescent for the Moon's silhouette against the solar corona.

7. Ten minutes before totality, repeat Step 2. Bright planets should now be visible. Skilled binocular observers should block the solar crescent with a distant object, remove any solar filters, and look for the Moon's following (trailing) limb projected against the Sun's inner corona.

8. Two minutes before totality, take 30 seconds to look for shadow bands as they ripple across the ground.

9. One minute before totality, look for an aquamarine color to the Sun's corona surrounding the Moon's following limb.

10. About 10 seconds before totality, through a proper solar filter, look for Baily's Beads and red chromosphere.

11. About five seconds before totality, quickly face west, sweep your head from north to south, and look for the Moon's approaching shadow. It will crash into the Sun in concert with the final appearance of the "diamond ring."

12. At second contact – the moment the Moon fully blocks the Sun – the corona will try to steal your attention. But look at the Moon's leading edge for red chromosphere and prominences, which sometime linger for only seconds before being covered by the advancing lunar limb. Once the red is gone, note the general structure and color of the inner corona. Next, sweep your head back and forth across the sky using averted vision to determine the extent of the Sun's outer corona in solar diameters.

13. At mid-totality, repeat Step 2. Once again estimate the extent of the Sun's outer corona in solar diameters. Do you see a diffuse brightening along the ecliptic plane?

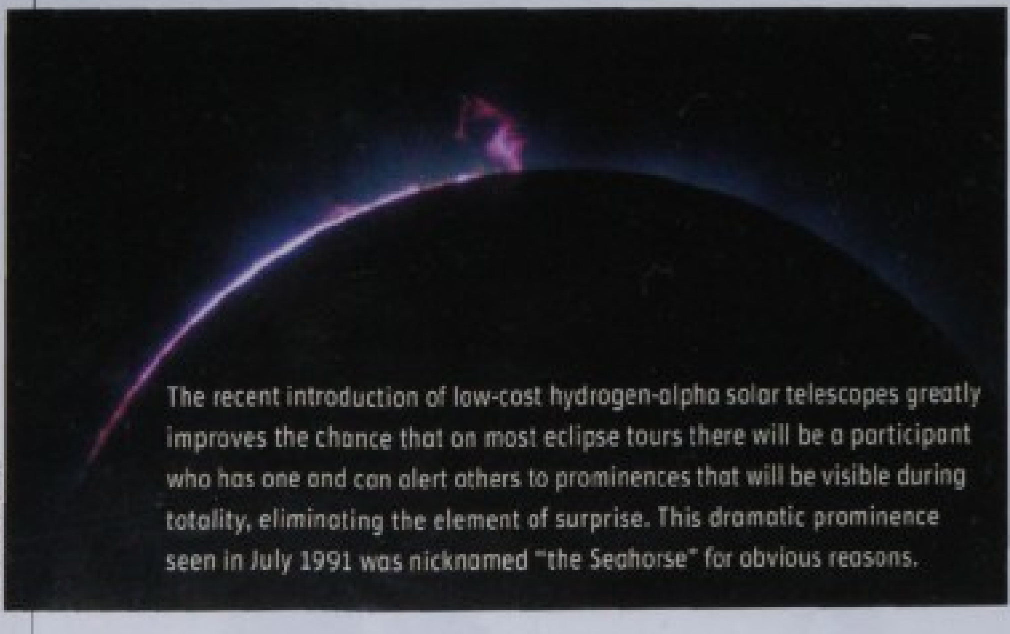
14. Just before third contact – when the first bit of sunlight returns – scan the Moon's following limb for prominences and chromosphere.

15. At third contact, immediately look for shadow bands.

16. The eclipse isn't over! For the next 10 minutes or more, block the Sun's waxing crescent with a distant object and look for the Moon's silhouette against the Sun's corona. Your eyes will now be better adapted to seeing it.

17. Fifteen minutes after totality, go to Step 5 and then work backward.

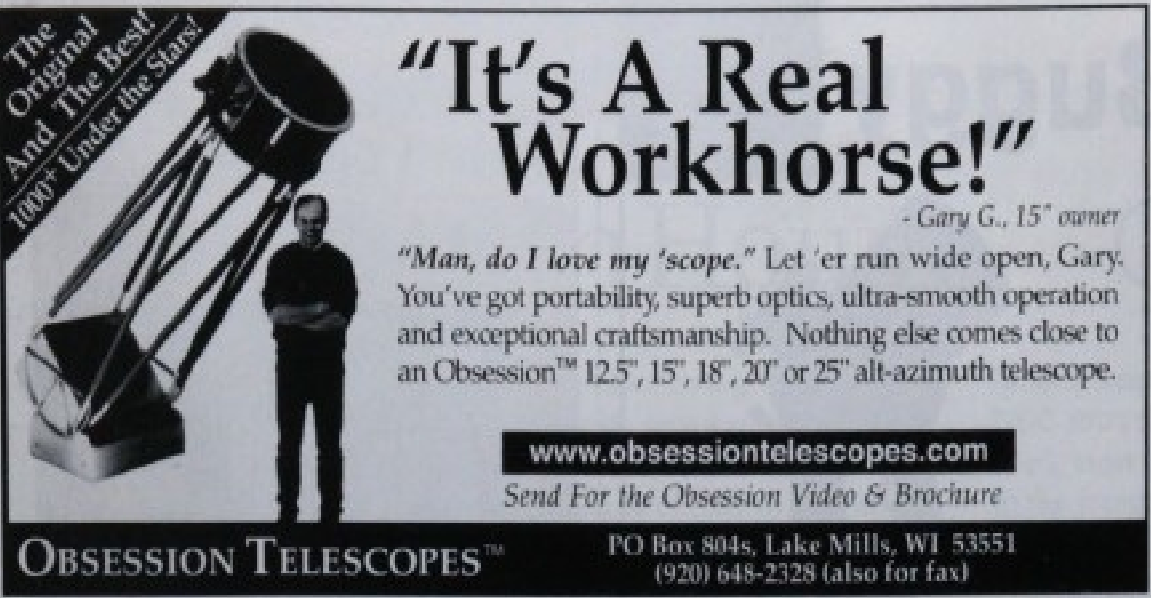
The key to seeing the most phenomena is to have a plan and stick to it. There is one caveat: If you see an unusual phenomenon (like an unexpected comet – yes, it happens!), be prepared to abort your plan; then, after making careful notes, return to the timetable. If you don't expect the unexpected, your head will spin and time will pass; you'll be stuck with your mouth agape and no specific memories. ✶



The recent introduction of low-cost hydrogen-alpha solar telescopes greatly improves the chance that on most eclipse tours there will be a participant who has one and can alert others to prominences that will be visible during totality, eliminating the element of surprise. This dramatic prominence seen in July 1991 was nicknamed "the Seahorse" for obvious reasons.

S&T: DENNIS DI CICCO

STEVE O'MEARA *has stood in the Moon's shadow nine times. He says sometimes it's fun to forget timetables and just be overwhelmed.*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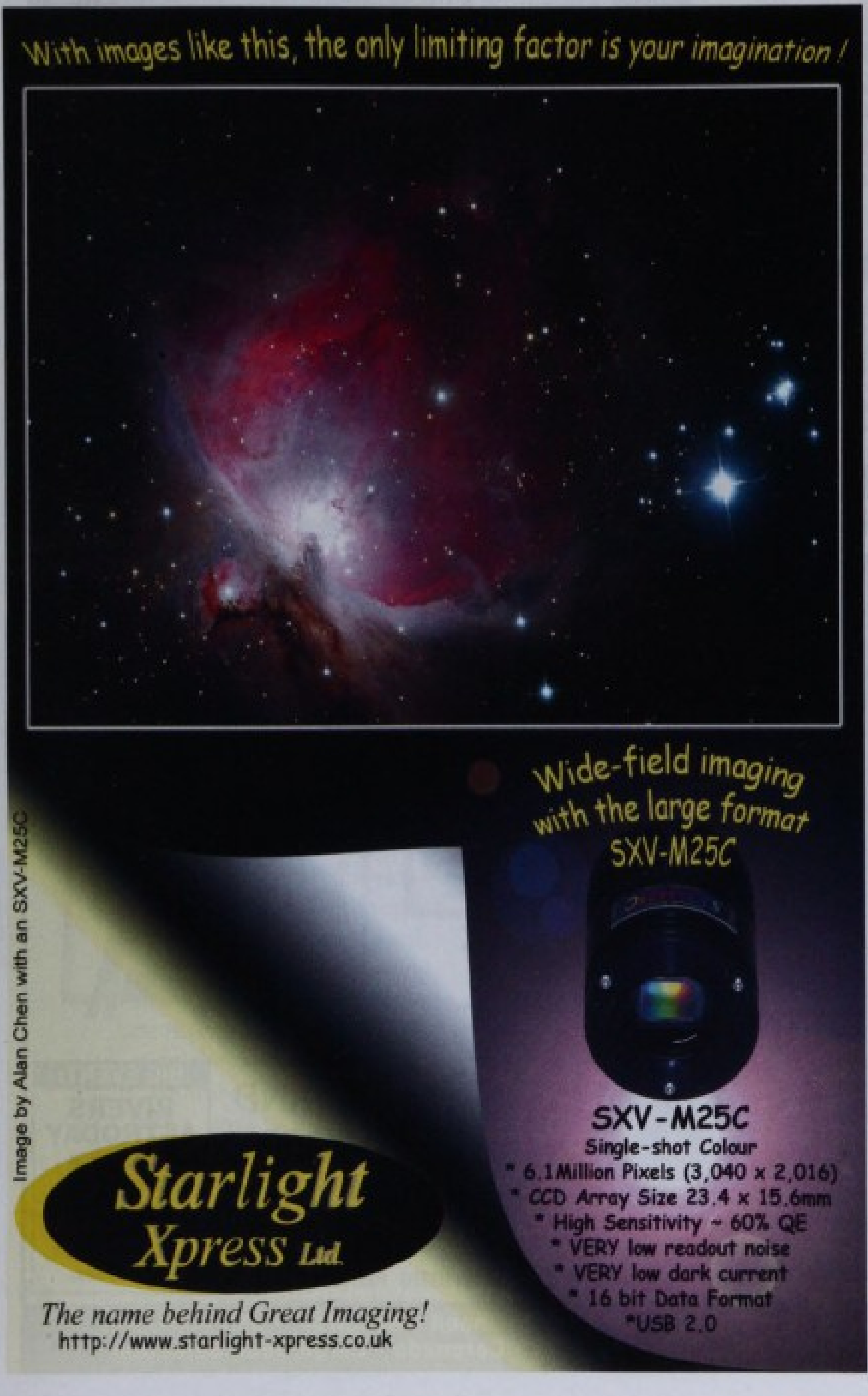
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Leo's 11th Hour

THE CONSTELLATION LEO, the Lion, now graces our evening sky. As the Lion slowly prowls westward during the night, the last part to linger in the sky is Leo's 11th hour of right ascension. This gives us plenty of time to dive into the sea of galaxies that enriches this area of the heavens.

Sky Atlas 2000.0 (2nd edition) plots 40 galaxies in Leo's 11th hour, while the *Millennium Star Atlas* maps a whopping 249. Let's pare down this rather overwhelming number of galaxies by concentrating on the Lion's hindquarters, where we find the NGC 3607 Group. This physically related collection of galaxies is about 65 million light-years away, but various sources assign different members to the group. My selection is simple. From the lists, I've chosen any galaxy that I've viewed with my 4.1-inch (10.5-centimeter) refractor plus two that share the field in my 10-inch reflector.

April evenings are a fine time to dip into the sea of galaxies in eastern Leo.

Let's begin with **NGC 3607** itself, visually the brightest and largest member of the group. It lies about halfway along and 1/2° east of a line between Delta (δ) and Theta (θ) Leonis. With my little refractor at 28×, I see two small fuzzy spots. The southern one is NGC 3607. Zooming in on the scene at higher magnifications, I find my best view at 127×. NGC 3607 shows a stellar nucleus, a bright round core, and a faint oval halo that's 2′ long northwest to southeast. A triangle of faint stars rests 4′ southeast, and the star at the southern point hugs a close companion.

NGC 3608, the northern galaxy, occupies the same high-power field as NGC 3607. A smaller and fainter version of its companion, NGC 3608 runs east-northeast to west-southwest for 1 1/2′. It grows brighter toward the center with a nearly round core and an elusive stellar nucleus. Two 12th-magnitude stars guard the galaxy's northern rim.

A third galaxy inhabits the field 3′ southwest of NGC 3607's nucleus. While averted vision helps me spot **NGC 3605,** I can hold it with direct vision once I know exactly where it is. The galaxy is just a little smudge in the refractor, but my 10-inch reflector at 166× reveals an elongated 1′ glow with a broadly brighter oval core. Despite its apparent proximity to NGC 3607, these galaxies don't form an interacting pair. Indeed, most distance estimates place NGC 3605 considerably in the foreground of its brighter neighbor. According to one source, NGC 3607, NGC 3608, and NGC 3605 lie at 58, 67, and 47 million light-years, respectively. The galaxies of the NGC 3706 Group are a bit too near for their radial velocities to yield reliable distances and a bit too far away for easy study of their stars. This makes it particularly difficult to pin down how far away they are. The actual distances may be off as much as 30 percent from the figures I'm quoting.

If I drop the magnification in my 10-inch scope to 115×, I can fit the galaxy trio in the same field with **NGC 3599,** located 1/3° to the west in a barren field. I see a 1′-long oval sloped west-northwest to east-southeast and gently brightening toward the center, harboring a stellar nucleus. In my 4.1-inch refractor, the galaxy is faintly visible with averted vision at 87× and with direct vision at 127×. It's estimated to be 53 million light-years distant.

Sweeping 3° westward takes us to **NGC 3507,** which exhibits low-level emissions from its nuclear region that are thought to arise from a combination of starburst and black-hole activity. In my little refractor at 47×, NGC 3507 is a faint glow enveloping an 11th-magnitude star. It's sandwiched between

The lenticular galaxy NGC 3607 anchors a small collection of galaxies in Leo's hindquarters that are well within range of a 6-inch telescope under dark skies. The author has seen most of the galaxies mentioned in this month's column with her 4.1-inch refractor. The view here is 0.6° wide with north up.

a slightly dimmer star 5′ north-northeast and a 10th-magnitude star 3′ south-southwest. At 127×, the galaxy is 2′ long and slightly oval east-west. It has a brighter core that's difficult to make out because of interference from the superposed star just off its northeast side. With my 10-inch scope at 166×, I also see the flat (edge-on) galaxy **NGC 3501** lying 13′ southwest. It appears very thin and 2′ long. NGC 3501 has a low surface brightness, and placing the nearby 9th-magnitude star out of the field gives me a better view. NGC 3507 and NGC 3501 are 61 and 68 million light-years distant, respectively.

Let's return to NGC 3607 and then work our way eastward. In my small refractor at 47×, **NGC 3626** sits 48′ east-northeast in the same field. It's easily visible as a little oval with a brighter center. Boosting the magnification to 87×, I can tease out a stellar nucleus. In the 10-inch reflector at 115×, the galaxy's 2′ halo is tipped a little west of north, and its tiny nucleus is quite intense. NGC 3626 is a strange galaxy whose gas and stars circle around its center in

Galaxies Galore

Object	Type	Mag.	Size	RA	Dec.	MSA	U2
NGC 3607	Lenticular galaxy	9.9	5.5′ × 5.0′	11h 16.9m	+18° 03′	705	73L
NGC 3608	Elliptical galaxy	10.8	4.2′ × 3.0′	11h 17.0m	+18° 09′	705	73L
NGC 3605	Elliptical galaxy	12.3	1.6′ × 1.2′	11h 16.8m	+18° 01′	705	73L
NGC 3599	Lenticular galaxy	12.0	2.7′ × 2.2′	11h 15.5m	+18° 07′	705	73L
NGC 3507	Barred spiral galaxy	10.9	4.6′ × 3.7′	11h 03.4m	+18° 08′	705	73L
NGC 3501	Spiral galaxy	12.9	4.6′ × 0.6′	11h 02.8m	+17° 59′	705	73L
NGC 3626	Spiral galaxy	11.0	3.2′ × 2.3′	11h 20.1m	+18° 21′	705	73L
NGC 3655	Spiral galaxy	11.7	1.5′ × 0.9′	11h 22.9m	+16° 35′	704	91R
NGC 3686	Barred spiral galaxy	11.3	3.2′ × 2.4′	11h 27.7m	+17° 13′	704	91R
NGC 3684	Spiral galaxy	11.4	3.0′ × 2.0′	11h 27.2m	+17° 02′	704	91R
NGC 3681	Barred spiral ring galaxy	11.2	2.0′ × 2.0′	11h 26.5m	+16° 52′	704	91R
NGC 3691	Barred spiral galaxy	11.8	1.3′ × 0.9′	11h 28.2m	+16° 55′	704	91R

Angular sizes or separations are from recent catalogs. The visual impression of 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 columns headed *MSA* and *U2* give the chart numbers of objects in the *Millennium Star Atlas* and *Uranometria 2000.0 Deep Sky Atlas*, respectively.

This ½°-long line of 11th-magnitude galaxies begins (at lower right) about ½° north-northeast of the 5.6-magnitude star 81 Leonis. The field is 0.6° wide with north up.

opposite directions. This may be evidence of a long-ago merger with a gas-rich dwarf galaxy. NGC 3626 is the most distant galaxy of our group at 85 million light-years.

NGC 3655 is nearly as remote but is just a short star-hop away. To locate it, look for a right triangle of three 7th-magnitude stars about 1¼° southeast of NGC 3626. Then center the longer leg of the triangle in your field of view and drop ⅔° southward. This little galaxy is very faint in my 4.1-inch scope. It displays a somewhat brighter center and a 13th-magnitude star 2.5′ to the east-northeast. With my 10-inch at 166×, I see a ¼′ oval leaning northeast, a brighter oval core, and a stellar nucleus.

Now center the shorter leg of the triangle in your field of view and sweep 52′ eastward. Here we come to **NGC 3686,** the largest of a group of four galaxies clumped within a ½° patch of sky. In my little refractor at 68×, NGC 3686 is a small oval, tipped north-northeast, with a large, weakly brighter core. The other three galaxies are less obvious. **NGC 3684** sits 14′ southwest and shows a faint northwest-southeast oval with a uniform surface brightness. Another 14′ southwest, **NGC 3681** is a bit more apparent and makes a nice straight line with the galaxies above. It's small and round with a brighter center, and it makes a shallow curve with two nearby 12th-magnitude stars. With my 10-inch scope, the tiny galaxy **NGC 3691** joins the scene. Look for it 15′ east-southeast of the center galaxy in the line. In the order presented above, these galaxies are 69, 70, 73, and 66 million light-years away. ✦

Sixty of Sue French's *past columns on deep-sky observing are compiled in the new book* Celestial Sampler *from* Sky Publishing.

A Look Back at Mars in 2005

The Red Planet yielded observing details rivaling those of the Great Apparition of 2003. By Edwin L. Aguirre

JUST TWO YEARS after its record-breaking close pass by Earth in 2003, Mars again delighted observers and astrophotographers with a fine display last October and November. The Red Planet spanned only 20.2 arcseconds during its closest approach on the night of October 29–30 (compared to 25.1″ in 2003), but it climbed nearly twice as high in the sky (more than 60°) as seen from mid-northern latitudes — well above most atmospheric haze and turbulence.

"I've never seen so many very high-quality images and drawings of Mars," says Donald C. Parker, assistant coordinator in the Association of Lunar and Planetary Observers' Mars Section (www.lpl.arizona.edu/~rhill/alpo/mars). "The webcam revolution has really taken hold. With observers in 20-plus countries, we truly had 24-hour-a-day coverage of much of the 2005 apparition."

A Great Disappearing Act

ALPO Mars Section coordinator Daniel M. Troiani notes that several surface albedo features that were inconspicuous during some recent apparitions returned, and some cloud/dust events that were quite typical for the Martian season partly covered the planet's southern hemisphere during that hemisphere's spring and summer.

One feature that practically disappeared was the white south polar cap. As Mars's opposition on November 7th approached, the rapid seasonal retreat of the polar cap proved dramatic. After being bright and prominent in 2003, last year the cap shrank to a remnant hardly an arcsecond in diameter. "Observers faithfully imaged and sketched this feature," wrote Troiani, "to the point where both methods revealed a good hint of a hitherto unknown rift even as the cap became as diminutive as it ever gets. During public star parties this time, people actually expressed their disappointment at the cap's inconspicuous appearance. One even complained that the optical quality of our telescopes had diminished so that they were not able to detect it well any longer!"

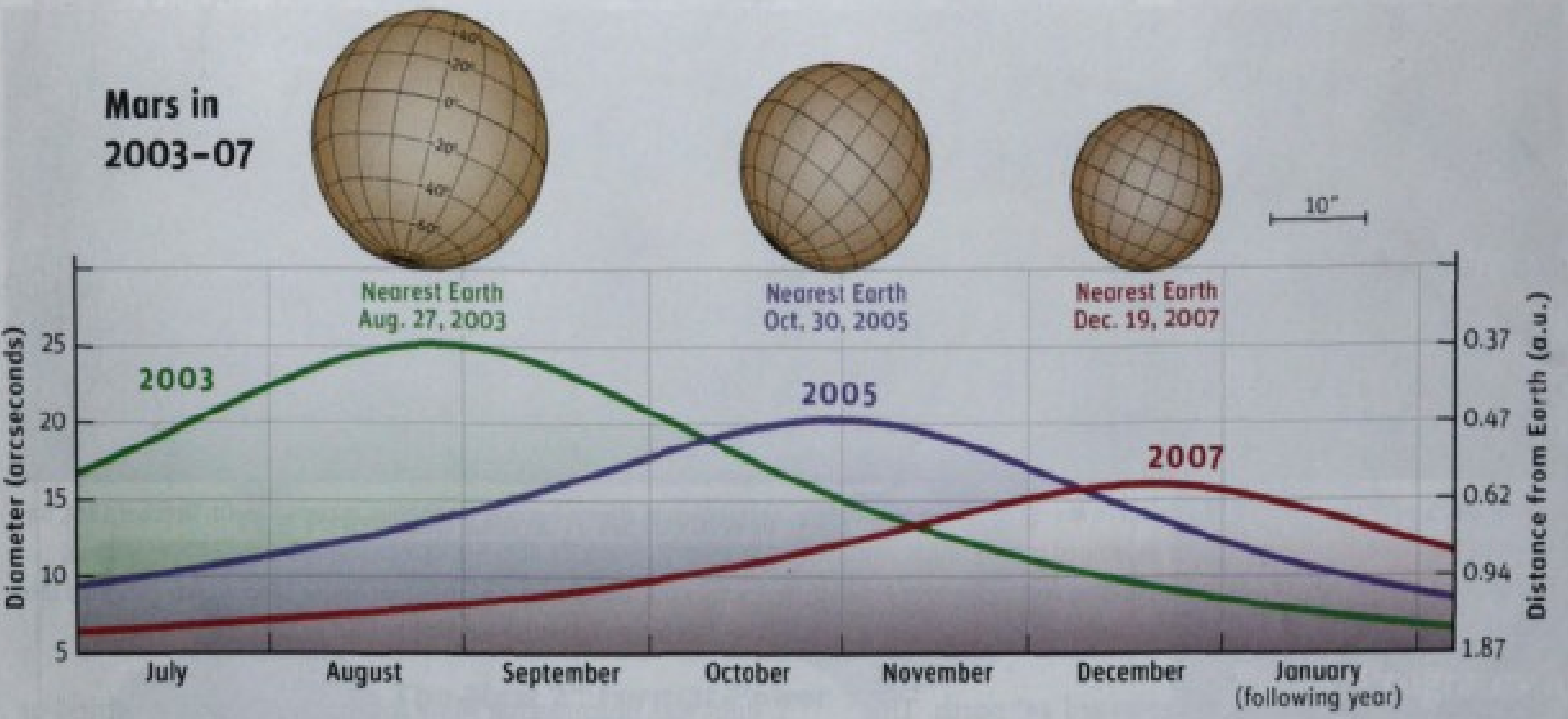
According to Richard W. Schmude Jr., ALPO Mars Section acting assistant coordinator for photometry and polarimetry, Lowell Observatory astronomer E. C. Slipher published in 1962 a table he compiled of the angular sizes of Mars's south polar cap on the first day of southern-hemisphere summer for various years between 1798 and 1956. "I've measured the cap's size on the first day of Martian summer in 1986, 1988, 2003, and 2005," says Schmude. "I then plotted my data and that of Slipher's on a graph and found a trend — essentially, the south polar cap has gotten larger over the last 125 years." He plans to publish this graph in ALPO's *Strolling Astronomer* journal in late 2006 or early 2007.

Dust to Dust

As the Sun warmed the Martian atmosphere, dust activity kept observers glued to the eyepiece. Day-to-day changes were readily apparent even through modest backyard telescopes. Luckily for planet watchers, the dust events didn't interfere much during Mars's closest approach, but they did leave a noticeable hazing-up of surface markings in parts of the southern hemisphere.

For example, on October 13th a small yellowish cloud was spotted just west of Margaritifer Sinus, on the southern border of the bright region Chryse. Five days later it developed into a full-scale dust storm, surging north across Chryse and rapidly spreading over much of the length of

The orbiting Hubble Space Telescope, with its 2.4-meter-diameter (94.5-inch) primary mirror and Advanced Camera for Surveys, captured this remarkable portrait of Mars last October 28th, just before the planet's closest approach to Earth (at a distance of 69.4 million kilometers). The bright, elongated patch above the disk's center was a 1,500-km-long dust storm that had been churning in the planet's Sinus Meridiani region for several days and was responsible for the yellowish haze across its southern hemisphere. North is up.



This diagram shows Mars receding from us with each apparition. The globes at top depict the changing size and orientation of Mars's disk, with the dates of its closest approach to Earth. Celestial north is up. At the closest approach in 2007 we will be looking almost straight down on the Martian equator.

the great Valles Marineris canyon system.

"This dust storm covered an area up to 2.8 million square kilometers, or roughly four times the size of Texas," notes Schmude. Fortunately, unlike the 2001 apparition (*S&T:* December 2001, page 117), the event didn't develop into a massive, planet-enshrouding dust storm.

On October 17th another dust disturbance sprang up, this time at the western border of Tempe. "By the 21st, fingers of dust had spread into, or more likely, secondary dust cores had freshly arisen over, northern Argyre and southern Solis Lacus," notes Richard J. McKim, director of the British Astronomical Association's Mars Section (www.britastro.org/mars), in a BAA *Circular*. "The Argyre activity rapidly spread southeast into southern Noachis and began to impinge upon the south polar cap. On October 28th, a spectacular resurgence of activity occurred over Margaritifer Sinus-Aram (Thymiamata), as the original core of the storm was decaying. This latter activity, captured in detail by the Hubble Space Telescope [facing page], expanded to the southeast, and Sinus Meridiani was greatly obscured by the 30th. The small, summer south polar cap was affected by the dust, becoming faint and hard to see."

McKim adds: "The dust reached and dimmed Hellespontus to the east, but no dust core arose in neighboring Hellas, nor did the event penetrate beyond Solis Lacus to the west. The event did not last more than a few weeks, but a persistent dusty haze veiled some of the markings – especially around Noachis-Argyre-Margaritifer Sinus – for some time afterward."

"This late-October dust event was the first such case that was monitored fully by Earth-based observing stations, as the storm progressed from Mars's early-morning to late-evening side," explains Masatsugu Minami, director of the Oriental Astronomical Association's Mars Section (www.mars.dti.ne.jp/~cmo/oaa_mars.html). "This was a result of the combined efforts of European and US observers. I was happy I was able to join this monitoring network, since I stayed at Mount Hamilton in California during that period and could observe the dust event visually with Lick Observatory's 36-inch refractor."

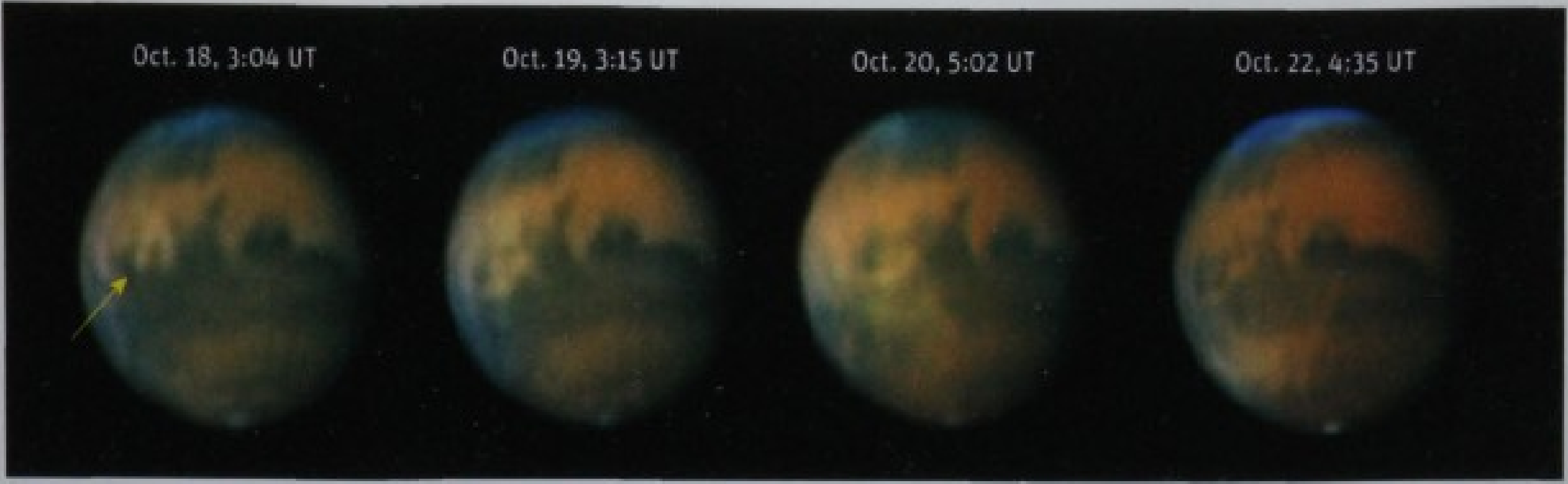
The North Polar Hood

Throughout the entire apparition, an unusual aspect was the persistence, extent, and brightness of the North Polar Hood – an immense, bright cloudbank hovering over the north polar region. The hood extended farther south at some longitudes than others; this was pointed out in September by Christophe Pellier, Mars Section coordinator for the Société Astronomique de France (www.saf-lastronomie.com), and was confirmed by Schmude a few weeks later.

"The edge of the North Polar Hood extended to an average latitude of 37° north in early September," notes

NASA / ESA / HUBBLE HERITAGE TEAM (STSCI / AURA) / J. BELL (CORNELL UNIV.) / & M. WOLFF (SPACE SCIENCE INST.)

Compare Hubble's view of the "full" Mars at opposition on November 7th *(far left)* with that obtained by Rolando Chavez the following night from his driveway in Powder Springs, Georgia. Chavez used a Philips ToUcam Pro II 840 webcam on his 12½-inch Cave Astrola Newtonian reflector operating at f/36. His image at left consists of 1,000 video frames stacked and processed with *RegiStax 3.* The November Hubble image, taken with the Wide Field and Planetary Camera 2, was obtained as part of a simultaneous observing campaign between Hubble and the Spirit Mars rover. North is up.

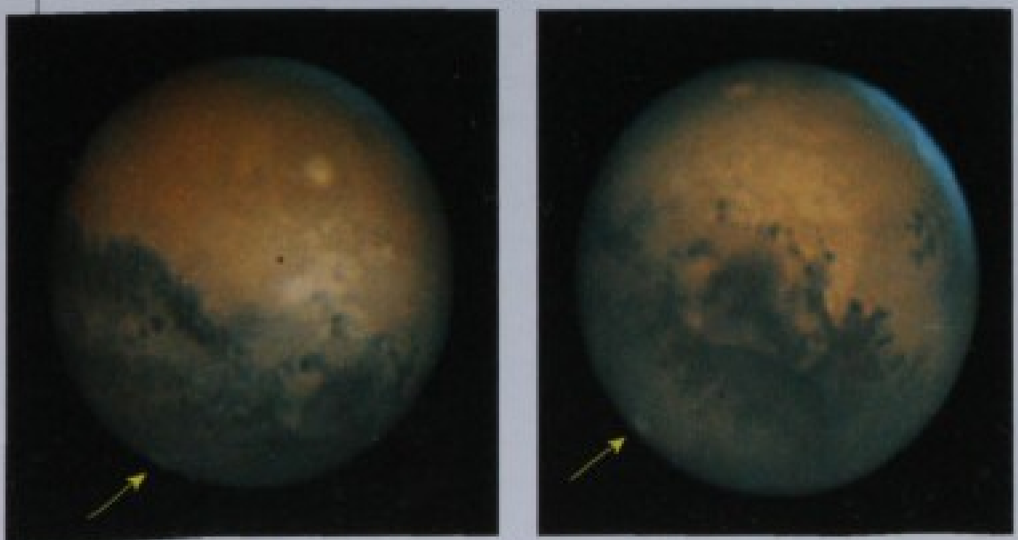


In late 2005, with the advance of summer in Mars's southern hemisphere, regional dust storms become a common occurrence. On October 18th, an inverted V-shaped storm (arrow) that developed in the Chryse region began to spread southward. It eventually obscured much of Aurorae Sinus and filled the Valles Marineris canyon, spilling southward over Mare Erythraeum before dissipating. *S&T* assistant editor Sean Walker compiled this sequence with a Philips ToUcam Pro 740 webcam and his 7-inch Intes Maksutov-Newtonian telescope working at f/60 or f/80. North is up.

Schmude. "By late October it averaged 44° north. This shows that the hood shrank as the season changed from early to mid-winter in the north polar region. I also measured the hood's size in 2001 and 2003 from hundreds of color images of Mars, and found that it grew in size during the northern-hemisphere autumn. Therefore, using data from 2001, 2003, and 2005, I feel that the hood reached its maximum size near the first day of winter for Mars's northern hemisphere."

Olympus Mons's Changing Appearance

The telescopic appearance of the immense shield volcano Olympus Mons in Tharsis can vary as a result of both orographic clouds and phase effects. Phase effects include the angle at which we see sunlight hitting an object. In August, Olympus Mons appeared as a dark spot because the phase (Sun-Mars-Earth) angle was around 45°, and so sunlight was hitting Mars somewhat from the side as seen from Earth. By early November, the situation reversed: Mars's phase angle had dropped below 3° and, as a result, sunlight was illuminating Mars from almost directly behind us Earthly viewers. "During early November, Olympus Mons and at least four other volcanoes — Ascraeus Mons, Elysium Mons, Hecates Tholus, and Albur Tholus — appeared as bright spots in CCD images," says Schmude.



Left: The shield volcano Olympus Mons appears as a bright spot above right of center in this image taken on November 6th at 23:05 Universal Time. *Right:* Note the bright North Polar Hood on the upper-right limb of this image taken on the 12th at 22:59 UT. Unlike in 2003, when Mars's south polar cap appeared bright and prominent, in late 2005 the ices in the polar cap had largely sublimated with the approach of southern-hemisphere summer and the cap became inconspicuous (arrows). Damian Peach captured these views with a Lumenera Lu075M CCD camera and a 14-inch Celestron Schmidt-Cassegrain telescope at f/40.

Brightness and Color

Schmude's preliminary analysis of ALPO's photometric data indicates that in May 2005 the Red Planet was slightly brighter than predicted. This was due to the still relatively large south polar cap, which reflects about three times as much light as the bare surface. Then, on November 8th, Mars was about 15 percent brighter than predicted because of the "opposition effect" when the phase angle nears 0° — sunlight hitting Mars from directly behind us and being reflected straight back to Earth.

"Based on the ratio of green and blue light reflected by Mars, the planet also appeared a bit less red in 2005 than in 2001 and 2003," adds Schmude. "I'm not sure exactly why, but I feel that it has to do with there being more clouds in 2005, especially in the north polar region. The North Polar Hood last year was larger than in 2001 and 2003."

Mars Now

As this issue went to press, observers continued to monitor Mars's tiny south polar cap well into the southern hemisphere's autumn. Equinox occurred on January 21st, with the Red Planet appearing just 9.8" wide. With the onset of southern-hemisphere autumn, observers reported seeing the formation of the South Polar Hood around January 7th and the continued weakening of its northern counterpart. Keen-eyed observers should be able to start detecting the north polar cap as the northern hemisphere's spring progresses.

More observations and images are available at the International Mars Watch 2005 site, http://elvis.rowan.edu/marswatch. If you missed seeing the Red Planet up close through a telescope, the next opposition comes in December 2007, when the planet will attain a fairly decent apparent width of 15.9". ✶

Associate editor EDWIN L. AGUIRRE *looks forward to seeing Mars in 2018, when it will reach 24.3" in diameter.*

Two New Binos

Recent offerings from Canon and Apogee expand the marketplace for astronomical binoculars.

By Gary Seronik

Sky & Telescope photographs by Craig Michael Utter

WHAT WE LIKE:

- Comfortable right-angle views
- Magnification can be changed

WHAT WE DON'T LIKE:

- Heavy, requiring substantial mount
- Difficult to aim accurately

APOGEE RA-88-SA

CANON 10×42 L IS WP

WHAT WE LIKE:

- Excellent optics
- Effective image stabilization

WHAT WE DON'T LIKE:

- Power hungry
- Relatively expensive

THERE ARE TWO main groups of binocular observers. In one camp are the minimalists, for whom the main attraction of binoculars is being able to enjoy astronomy with as little equipment as possible. In the other camp are those who look upon binocular astronomy as a road paralleling the one traveled by telescope users. These stargazers like binoculars that have capabilities overlapping those of small (and sometimes, not-so-small) telescopes.

Each of the binoculars reviewed here will appeal mostly to one group or the other; the Canon 10 × 42 L IS WP image-stabilized binoculars will catch the interest of the minimalists, while the Apogee RA-88-SA right-angle binoculars will grab the attention of the binoculars-as-telescopes group. But do these instruments deliver enough performance to please their respective audiences? To find out, we borrowed production samples of each and put them to the test.

Better Binos

Right-Angle Binos: Apogee RA-88-SA: 88-millimeter, right-angle, 20×/32× binoculars. Includes case, eyepieces, dust covers, and removable handle.

US price: $699.95

Apogee Inc., www.apogeeinc.com

Stabilized Binos: Canon 10 × 42 L IS WP: Image-stabilized, waterproof binoculars. Includes soft case, dustcap for eyepieces, strap, and batteries.

US price: $1,500

Canon, www.canonusa.com

Apogee's "Semi-Apo" Right-Angle Binoculars

One of the most troublesome aspects of binocular astronomy is the physical discomfort that often goes hand in hand with a good view. One solution to the neck-craning hardship of viewing celestial objects is to have the eyepieces positioned at right angles to the optical axis. And that's what the "RA" in Apogee's binoculars stands for. But this piece of gear has other attractions too. The twin 88-mm objectives are triplet "semi-apo" lenses that, in theory, offer better correction for chromatic aberration (color error) than ordinary objectives. In addition, the RA-88-SAs allow the user to change magnification with optional eyepieces. And, as icing on the cake, these binos come with a removable handle and a sturdy aluminum carrying case.

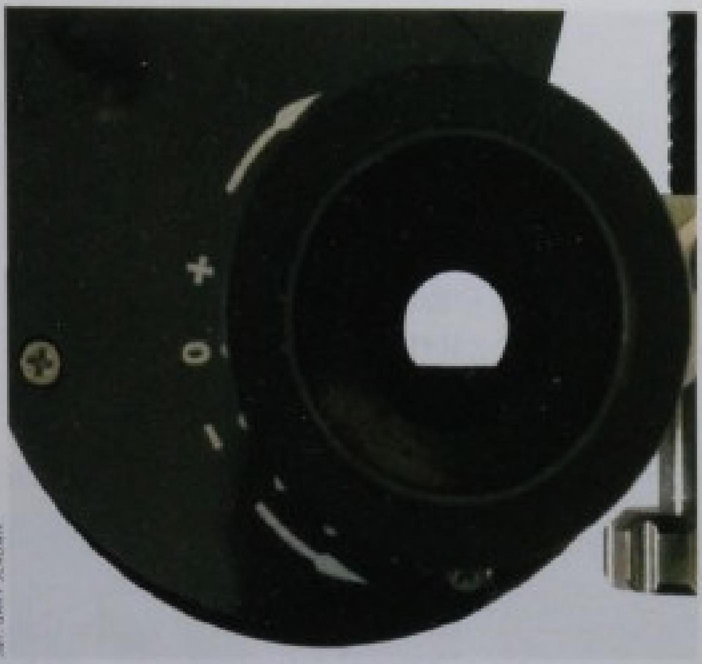
Although not strictly a "feature," it is notable that when it comes to affordable right-angle binoculars, there really is very little to choose from. Indeed, the nearest approximate equivalent to the Apogee binos costs several hundred dollars more. So price alone will cause big-binocular fans to sit up and take notice of the Apogee RA-88-SAs.

The first thing that impressed me as I pulled the Apogee binos out of their foam-lined carrying case is that they look great — all high-gloss black and shining chrome. I also noticed that they're heavy. The fact that they tip the scales at 13.9 pounds (6.3 kilograms) means that a normal camera tripod is not going to be up to the task of carrying them — something to factor into the price of admission if you don't already own a suitable mount. I tested the binoculars on Universal Astronomics' MicroStar (priced from $149) and UniStar (priced from $299) mounts. The MicroStar represents the absolute bare-minimum level of support, while the UniStar provides very good stability and, as a result, was used for most of our evaluation. The heavy-duty Bogen 3068 tripod that is used with the mount had a nice, adjustable center column, which proved very handy since the eyepiece position varies greatly with binoculars of this type.

So how were the views? At first blush, impressive. There's no denying that using both eyes makes for a more relaxing and pleasurable experience than is possible with single-eyed observing. Add to this the comfort of right-angle viewing and of a seated observing position, and you have a means of cruising the sky that is hard to beat. Whether sweeping star fields along the Milky Way or scanning the surface of the Moon, some of my sessions with the RA-88-SA binoculars were among the most enjoyable I've had.

EYEPIECES. One feature that distinguishes these binoculars from most others is that you can change the magnification by switching eyepiece pairs. Our loaner binocular came with two sets of oculars: the standard 20× pair and a 32× set that is included as part of an introductory offer and normally sells for $169.95. (Apogee also offers 26× and 40× eyepiece sets for $149.95 and $129.95, respectively.) The 20× eyepieces have apparent fields of 52° and provide a true field of about 2.6° across. The 32× pair (measured as producing 35×) have apparent fields of 66° and deliver a true field of 1.9°. Eye relief is tight for the high-power pair, so users with glasses will have to remove them to

Apogee's right-angle binoculars are seen here on a Universal Astronomics UniStar Heavy altazimuth mount and Bogen model 3068 tripod. We found that a beefy setup such as this is necessary to fully exploit the capabilities of these binoculars.



As this photograph shows, the exit pupil of the Apogee binoculars is clipped at the bottom, resulting in some minor loss of image brightness in that part of the field.

S&T: GARY SERONIK

see the whole field of view.

Each eyepiece fits into its own helical-style focuser that has a range of about ½ inch, which may not be enough to accommodate some users who wish to observe without their glasses. Of special note is that while standard 1¼-inch eyepieces will fit loosely into the focusers, only the eyepieces designed to work specifically with Apogee RA-series binoculars will reach focus. Friction alone holds the eyepieces in place, and I found this worked well for the most part, but the force required to insert the 32× eyepieces was often enough to move the binoculars off their target. Interocular spacing is precisely controlled by a clever articulated mechanism and varies from 58.5 to 72.5 millimeters.

FIELD NOTES. The greatest difficulty I had using the binoculars was actually getting them aimed. Because the Apogee binos behave more like a small telescope than binoculars, the lack of a finder proved to be a significant inconvenience. I aimed them by sighting along the handle, but this was, at best, a workaround. I expect most users will want to add a red-dot sight of some kind.

As mentioned earlier, the views were very good so long as the user keeps in mind the limitations intrinsic to the aperture and magnifications. Star images in the 20× eyepieces remained round across most of the field and began to flare noticeably only in the outer 25 percent. The 32× oculars showed blurring halfway to the edge of the field.

The color correction of the objectives was perfectly acceptable for most observing, but the lunar limb did exhibit a vivid green edge when the Moon wasn't exactly centered. Experienced observers may also note a certain lack of crispness in the overall image. Star testing showed that the optics, while acceptable for the intended magnifications, exhibited significant spherical aberration.

Our binoculars arrived about 10 percent out of horizontal collimation. Although some observers are more tolerant of alignment errors than others, I experienced some strain-related eye fatigue after a viewing session.

However, these shortcomings don't seriously hinder what is essentially a very useful piece of observing gear. In spite of their shortcomings, the Apogee RA-88-SA binoculars provide very enjoyable and comfortable views. For the price, there really is nothing else like them.

Canon's 10 × 42 L IS WP Binoculars

Image-stabilized binoculars (ISBs) have been a real boon to binocular astronomy. Such instruments mate the convenience of hand-held optics with the steady views usually associated with tripod-mounted gear. We reviewed the 15 × 45 Canon ISBs when they first appeared on the scene (*S&T:* May 1998, page 48) and concluded that they represented "truly a quantum leap in binocular observing." Some eight years on, Canon's stabilized binoculars have become a popular choice for observers. When the 10 × 42s were announced, we borrowed a production model to see if the newest member of the Canon ISB family lives up to the reputation of its predecessors.

So does it? I won't keep you in suspense. These are simply the finest binoculars I have ever used for astronomy — and that includes the other Canon offerings.

OPTICAL MATTERS. The optics are superb. Star images are point sharp and show only a minor amount of bloating at the very edge of the field. Views of the Moon are stunning and show a lunar surface crowded with sharp detail. Indeed, seeing the Moon's brilliant disk floating in a dark, nearly ghost-free 6½° field was something I couldn't resist returning to night after night. Views of star clusters and rich Milky Way fields were simply breathtakingly wondrous. Under a dark sky, these binoculars could keep a determined observer busy for years.

Much of the impact of these binoculars is attributed to hitting a specification "sweet spot." In gen-

S&T RATINGS

Apogee RA-88-SA binoculars		
Optics	★ ★ ½	**Bottom-line summary:** *Very nice, user-friendly, big binos at an unmatched price.*
Mechanics	★ ★ ★	
Overall	★ ★ ★ ½	
Canon 10 x 42 L IS WP image-stabilized binoculars		
Optics	★ ★ ★ ★	**Bottom-line summary:** *Excellent optics plus image stabilization make a strong case for these being the perfect binoculars for astronomy.*
Mechanics	★ ★ ★ ★	
Overall	★ ★ ★ ★	

★★★★★ Sensibly perfect. No meaningful improvements possible.
★★★★ Any shortcomings will go unnoticed in normal use.
★★★ Problems noticeable but do not seriously affect performance.
★★ Problems noticeable during normal use — performance compromised.
★ Problems so severe that the equipment is virtually unusable.

Ratings are intended to convey performance compared with equivalent equipment and should not be used to predict the relative performance of instruments having markedly different apertures or optical designs.

The stabilization feature of the Canons is activated with the push of a button (located next to the focuser knob) and draws approximately 350 milliamps of current from a pair of ordinary AA-size batteries. *Far left:* The binoculars also come equipped with a standard ¼-20 socket so that they can be tripod mounted to minimize arm fatigue, especially when used for scanning the horizon.

eral, 10× binoculars provide a near-ideal balance between magnification and field size — one usually wants the widest true field at the highest power for views with the best contrast and the most detail. The Canon's eyepieces feature a 65° apparent field, which translates into a 40 percent increase in true field compared with standard 10× binoculars.

To achieve these results Canon puts a lot of glass between you and your target. The objectives are a 3-element design protected by optical windows. The eyepieces have 7 elements, including a 2-element field flattener. In addition, starlight has to pass through a roof-prism assembly and the "vari-angle prism" that performs the stabilization. That's so much glass that you might wonder how much light actually makes it to your eyes. To answer this, I did side-by-side comparisons between the Canons and a pair of my own recently purchased 10 × 50 standard binoculars. I found the Canons actually produced a brighter image in spite of their smaller objectives. This is only a single data point, but clearly the optical coatings used on these Canon binoculars are very efficient.

Optics aside, the Canons feel great in my hands. They are solidly built and feel as if they could take a lot of rough use — nothing was loose or rattled, and the rubberized exterior was comfortable to hold. And though most stargazers won't fully exploit this feature, the binoculars are waterproof.

The objective lenses of the Canon binoculars are protected by coated optical windows. Like other image-stabilized binoculars in the Canon line, these focus by moving the objectives instead of the eyepieces.

STABILIZATION MAGIC. The stabilization mechanism is powered by a pair of AA batteries and works through a combination of motion sensors and the vari-angle prism. The effect never fails to startle and impress first-time users. That said, the very best views I had came when I held the binoculars reasonably steady. Using a chair is not only a more comfortable way to observe but also helped me get the most out of these binoculars.

Stabilization is activated by a single button push. Pushing the button again turns it off. One nice feature of these binoculars is what appears to be an orientation sensor that prevents the user from accidentally activating the stabilization when the binoculars are hanging from your neck and aimed straight down. Once turned on, though, the binoculars can be aimed straight down. Also, to conserve battery life, the power shuts off automatically after five minutes of inactivity.

Given that Canon also makes similarly priced 15 × 50 and 18 × 50 stabilized binoculars, why go for the smaller 10 × 42s? I found several compelling reasons. First, both the 50-mm Canons have more restrictive fields of view: 4.5° for the 15× model and 3.7° for the 18×. That's roughly ½ and ⅓ as much sky coverage, respectively, as the 10 × 42s offer. And not only are the 10 × 42s smaller; at 2.3 pounds, they weigh about ⅓ pound less than their bigger brothers. That might not sound like much, but it is a difference you can feel when holding them for extended periods. Also, birders will appreciate the close-focus distance of the 10 × 42s — a mere 8.2 feet, versus 19.7 feet for Canon's 50-mm models. All this adds up to binoculars that should see a lot of use, night *and* day. ✱

Associate editor Gary Seronik *authors this magazine's monthly Northern Binocular Highlight column.*

S&T | test report

Starry Starry Night

A popular planetarium package gets a big upgrade to dramatically improve your view of the virtual sky. By David Ratledge

WHAT WOULD IT TAKE to get you to change from your favorite planetarium software? Would more sky realism and gorgeous horizon panoramas do the trick? Or what about a built-in database with around 1 million galaxies? How about if a slick telescope control using the ASCOM standard were included? Are you weakening? If you're like me, then these may be very appealing features, but on their own they're probably not quite enough to offset the hassle of having to learn a new program. So what is the killer, must-have feature we wouldn't be able to resist? How about an integrated all-sky mosaic image down to magnitude 15? That's probably enough to tip the balance, and it's precisely what Imaginova was thinking when it added all these features to its popular planetarium software and called the result *Starry Night Pro Plus 5*. While the title is a bit of a mouthful, it does promise some tasty morsels, and it certainly got me to take notice.

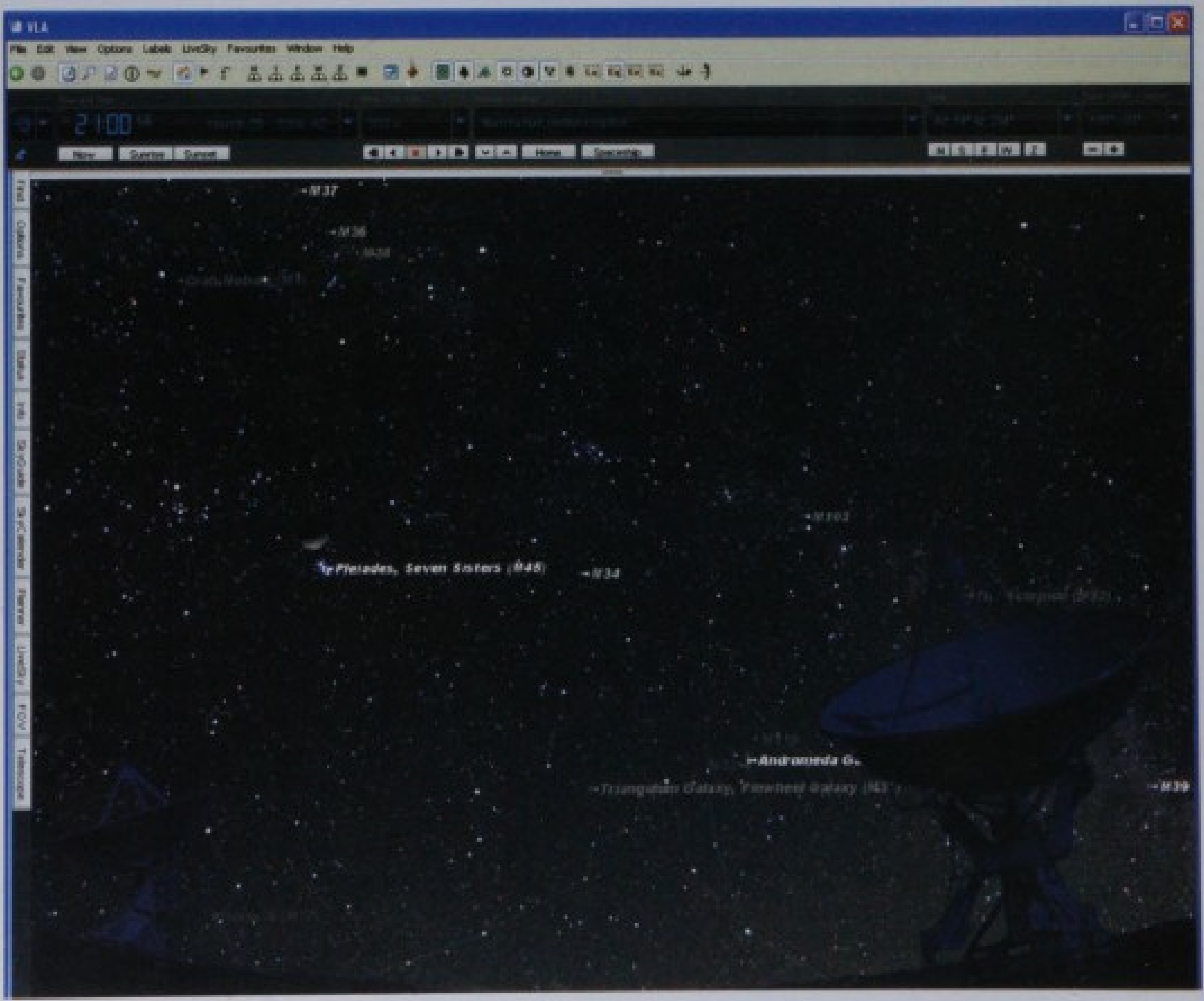
WHAT WE LIKE:

- Stunning sky realism
- All-sky mosaic well integrated
- Ease of customization

WHAT WE DON'T LIKE:

- Printouts uninspiring
- Nebula outlines not adjustable

I tested *Starry Night Pro Plus* supplied on DVD as version 5 with a free upgrade to V5.7 available online. Installation took less than an hour despite the large volume of data provided on the DVD, but the upgrade took a few days! Imaginova has incorporated what it calls PowerUpdates, which I find to be a sensible idea. The software checks for upgrades online and then installs them. Unfortunately, when I tried this Imaginova's server was down for a day or so, which cast doubts as to whether the problem was on my end or the server's. But it also gave me a chance to anonymously test Imaginova's response to online queries, which it passed with flying colors. I asked two questions and received replies to both within 24 hours. My only criticism of the online update is that there was no clue as to the size of the file being downloaded. It took me about five minutes with a broadband connection, which makes



Starry Night Pro Plus is big on realism since it incorporates the all-sky mosaic image from the now-discontinued *Desktop Universe* program by Main-Sequence Software. In this view for March 5, 2006, a foreground panorama of the Very Large Array frames the setting Milky Way with the Moon and the Pleiades as the sky actually appears for the author's location in England. The all-sky mosaic, in medium resolution, has been selected, along with other options for horizon light pollution, Messier-object labeling, and constellation figures. The side-pane menus have been collapsed to give a large viewing area.

me think that upgrading to version 5.7 with a dial-up connection might not be practical.

Once past the usual preliminaries of setting your location, the all-sky mosaic is the first thing you'll see. Originally I thought the advertising claim "the world's most realistic planetarium software" was probably just hype. However, selecting one of the many photographic horizon panoramas and then watching the Milky Way rise above it was enough to make me a believer! I watched the rising Sun on June 21st from inside Stonehenge and then whisked my view to the other side of the world to witness the Magellanic Clouds riding high above a beautiful Australian lake. These and many other classic sights are relatively easy to master and enjoy without ever having to leave your armchair.

Starry Night's menu arrangement is somewhat unusual, but I found the user interface one of the easiest to customize, with just about everything adjustable to the user's own taste. There are the usual pull-down menus across the top of the screen, but the heart of *Starry Night* is its side menus. These, when opened, reduce the sky area but provide access to nearly all the display options. Most modern software allows users to customize the appearance, but often the commands for doing this are relatively hidden. With *Starry Night*, changing how the sky appears is never a puzzle. The only exception is setting north vertical (called Orientation), as this is available only on a conventional pull-down menu.

There are 11 side-pane topics, and the ones I use most are Find, Options, FOV (field of view), and Telescope. Find does what it suggests and lets the user locate anything from the Moon to deep-sky objects. For the solar system, there are cascaded lists. Select Saturn and a comprehensive list of its attendant moons appears. Double-click any object and you are smoothly transported across the sky to your choice. A common feature of the side-pane system is tick boxes for both the object and its label, and often there's a slider to tweak some variable such as brightness or quantity. For planetary moons, the tick box switches on their orbit. For deep-sky objects you have to know a catalog number, but otherwise the procedure is the same and very intuitive.

I spent hours discovering (or was it playing with?) the items in the Options side pane. Here is where I set the foreground panorama, and there's a good selection available. After trying them all, I settled on the Very Large Array, as it seemed a great environment for skywatching. Settings for the all-sky mosaic are located in the Options side pane, and with version 5.7 its brightness can be varied with a simple slider. I particularly liked the light-pollution controls. It may seem strange to configure a virtual sky with light pollution, but the scene did look much more convincing when there was a friendly horizon glow.

For deep-sky objects there are the usual catalogs, and with the side-pane system it's easy to get the number of objects, their labels, sizes, and colors just as you want them. A new feature of version 5.7 is nebula outlines, but the line style and color of the outline can't be adjusted.

Chart printouts are a tad ordinary. The default printing of a Messier object can result in nothing visible. These minor gripes apart, I found that the setting in the Options side pane could do just about anything I wanted and without my having to resort to reading through manuals.

The FOV side pane offers support for several common digital SLR cameras, though the Canon Digital Rebel/300D, which probably started the astronomical DSLR revolution, is not there. You will, however, find its replacement, the XT/350D. For FOV to function you have to enter telescopes, cameras, and finders with, as you would expect, common ones available from drop-down lists. When selected, the FOV of choice appears centered on the screen, so you have to move the sky to the field of view rather than what I would regard as more logical, moving the camera outline to the object. Planning a mosaic

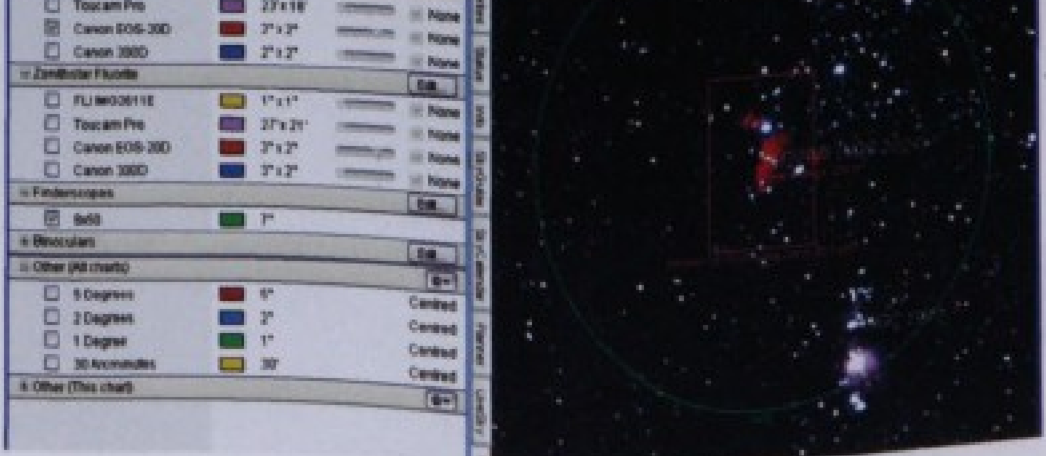
Starry Night Pro Plus 5

Imaginova Canada
284 Richmond St. E., Suite 300
Toronto, ON
Canada M5A 1P4
416-603-8381
www.starrynight.com

Requirements: Windows XP with 800-MHz processor, or Macintosh OS 10.3 or higher, G4 800-MHz processor, 256 megabytes RAM (512 recommended), 3 gigabytes disk space, 64 megabytes graphics memory with *OpenGL* support (see text for details), and 1,024-by-768-pixel display. Internet connection recommended.

US price: $249.95

The side-pane menus are a big feature of *Starry Night*, and here the FOV (Field of View) pane is open. A Takahashi telescope in conjunction with a Canon 20Da digital SLR camera has been selected. The slider adjacent to the Canon is used to rotate the FOV outline so that objects can be framed to advantage. The finder FOV is also displayed.



of CCD or DSLR images to cover a large object was tricky. For this I had to make my own frames rather than use the ones created automatically.

The Telescope side pane covers telescope control. Here, at least for Windows, the ASCOM standard is adopted, and version 4.1 of this platform is supplied in the box. Once the platform is installed you are ready to connect to most common Go To telescopes and control them from the computer. I wanted a sterner test, however, and decided to try connecting to my Vixen Sphinx mount. To do this I first had to download and install Peter Enzerink's driver for the mount at www.enzerink.net/peter/astronomy. The Sphinx then appeared on *Starry Night*'s list of telescopes, and I was up and running. The Sphinx has only a limited catalog of deep-sky objects in its memory, so controlling it via *Starry Night* opens up a lot more objects. Version 5.7 has a nice telescope-control interface with a neat "nudge" command for centering objects in the telescope's field. I had just a few glitches, but I put them down to Vixen's software, which still has some bugs.

Starry Night does much, much more. It has calendars, observation planners, viewing logs, and the list goes on. You are not limited to viewing the night sky from Earth, and to get you out among the stars there are several built-in favorite scenes.

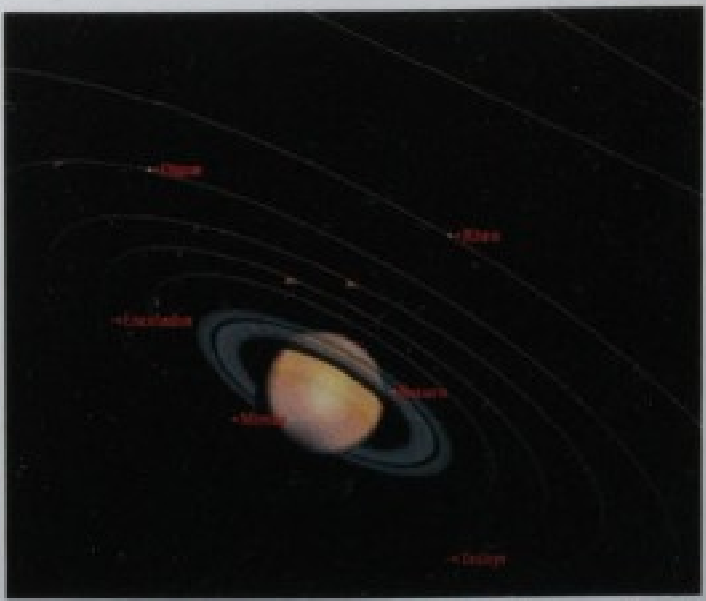
The companion book supplied with the software is largely targeted at beginners, and there's also a DVD that contains a mixture of documentaries and trailers. The user manual is provided electronically and runs to 188 pages, so it's quite a hefty stack of paper if you decide to print it out. Some features of the software require an Internet connection, and to get the most out of *Starry Night* I regard the connection as just about essential.

With its all-sky mosaic and expanded databases, it's not surprising that *Starry Night* requires some serious hardware to perform at its best. I would recommend at least a 2-GHz processor with a top-notch graphics card to avoid jerky motion and slow reactions. Even so, moving around the all-sky mosaic is never going to be lightning fast. I tested the software on three PCs with varying graphics memory (VRAM) of 32, 64, and 128 megabytes. One of the graphics cards needed new drivers to support the *OpenGL* standard. Without *OpenGL* support, many of *Starry Night*'s desirable features (the all-sky mosaic, realistic panoramas, and 3-D rendering of the planets) disappear.

The PC with 32 megabytes of VRAM could display the all-sky mosaic only at its lowest resolution. With Imaginova's recommended 64 megabytes of VRAM, the medium-resolution mosaic is available. Only my PC with 128 megabytes of VRAM could display the highest resolution, but the manual says this is possible with 96 megabytes of VRAM. Having said that, comparing the all-sky mosaics on the three PCs, I saw little difference between the high- and medium-resolution versions, but the lowest resolution was disappointing. So I regard 64 megabytes of VRAM and *OpenGL* support as essential.

Starry Night Pro Plus does what it says on the box. It's first and foremost planetarium software, and if you wish to recreate the majesty of the night sky indoors then it's hard to imagine how it could be improved. I had many happy hours just admiring the view. When that view is projected onto a large screen, it's awesome. It does work best with powerful hardware, but realism like this doesn't come easy.

So, will I be changing from my favorite software? Well, yes and no. For mundane tasks, such as printing charts, probably not, but for planetarium shows the answer is a resounding yes. ✶



Starry Night Pro Plus features 3-D rendering of the planets, and here Saturn and its brightest moons are shown with the option set for displaying their orbital paths. Small arrows on the orbits show the directions of motion.

Telescope control uses the ASCOM standard, and the author used it to connect to his Vixen Sphinx mount (see the text for details). This display shows that the mount has been directed to the Andromeda Galaxy, M31. An innovative "nudge" keypad has been added to version 5.7 of the software, which is used for precise centering of objects.

Contributing editor David Ratledge *had to be dragged away from* Starry Night Pro Plus*'s virtual Stonehenge to finish editing his latest book,* Digital Astrophotography: The State of the Art, *published by Springer.*

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BANDWIDTH	<1.0A-<0.6A	MAX 2.28
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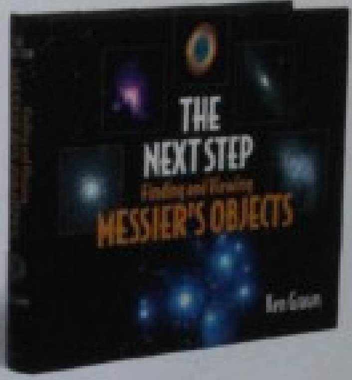
A Fresh Look at the Classics

Review by Tony Flanders

Is there really room for a *fourth* Messier guide? Amazingly, yes.



The Next Step: Finding and Viewing Messier's Objects
Ken Graun (Ken Press, 2005). 352 pages.
ISBN 1-928771-12-2.
$29.95.

YOU HAVE TO BE VERY BRAVE — or very foolish — to publish a new book on the Messier objects. The subject has already been covered by three acknowledged masterworks: Kenneth Glyn Jones's book *Messier's Nebulae and Star Clusters* summarizes all the major observations by early astronomers; *The Messier Objects*, by Stephen James O'Meara, has superb sketches and descriptions by one of today's greatest observers; and Harvard Pennington's *Year-Round Messier Marathon Field Guide* sets a new standard for clarity in helping beginners find these objects. Is there really room for a *fourth* Messier guide?

Amazingly, yes. Ken Graun, a stargazer, author, and publisher based in Tucson, Arizona, has just made a small but original contribution to the field. *The Next Step: Finding and Viewing Messier's Objects* includes a wealth of background and biographical information about Charles Messier that appears (to my knowledge) nowhere else in English. This is supplemented by wonderful photographs of Badonviller, France, where Messier was born, and Paris, where he worked. There are also short but excellent biographies of Messier's collaborator Pierre François André Méchain and their great contemporary Joseph-Jérôme Lefrançais de Lalande. Graun clearly identifies with Messier — perhaps to the extent of compromising his objectivity. As a dabbler in astronomical history, I wish that Graun had left a better scholarly trail so that I could distinguish more easily between his extrapolations from solid evidence and others that were pure flights of fancy. But that's a petty gripe; there's no doubt that this book does a superb job of bringing Messier to life.

Ken Graun presents Charles Messier's life and observations in a modern context with superb text and illustrations — like this photo of the house in Badonviller, France, where Messier was born.

KEN GRAUN

The other distinguishing feature of *The Next Step* is that all the observations were made in a uniform way — at 48× with a 4-inch refractor. Likewise, all the objects are illustrated with photographs that have identical scales (2.3° by 1.3°) and exposures (20 seconds at f/5.4 on ISO 400 film). This is both good and bad. The uniform presentation allows the objects to be compared objectively, but it can't possibly do justice to all of them. The visual magnification is ideal for the Pleiades but ludicrously low for globular clusters — arguably the greatest showpieces of the lot. And while the short exposures on contrasty black-and-white film do a fine job of mimicking the eye's response to faint nebulosity, they burn out the bright central regions of all the globular clusters and most of the galaxies (see below).

For these reasons, I wouldn't recommend *The*

Right: Shooting every Messier object the same way has its advantages and disadvantages: as shown in Graun's book, nebulosity in objects such as Messier 20, the Trifid Nebula in Ophiuchus, looks realistic, but some globular-cluster gems like Messier 13 in Hercules appear overexposed.

KEN GRAUN (2)

Next Step as one's *sole* Messier guide. Beginners who are concerned primarily with finding the Messier objects would do better with Pennington, and O'Meara would be more helpful for people who are eager to tease out the maximum detail from their eyepiece views. But this is a wonderful *second* book for anybody who wants a fresh perspective on these celestial showpieces. The historical material on Messier's life and times is unique. And the book is infused throughout with Graun's infectious enthusiasm.

Associate editor TONY FLANDERS *has observed the complete Messier list under urban, suburban, and rural skies with instruments ranging from handheld binoculars to a 12.5-inch telescope.*

briefly noted *by david tytell*

Comets II

Michel C. Festou, H. Uwe Keller, and Harold A. Weaver, editors (University of Arizona Press, 2004). 764 pages. ISBN 0-8165-2450-5. $85.

The iconic University of Arizona Press Space Science Series recently released its latest edition to the family: *Comets II*. It's amazing to think how much the field has changed since the first *Comets* was published in 1982. There have been close-up spacecraft analyses of comets 1P/Halley, 19P/Borrelly, and 81P/Wild 2. We've had several amazing close encounters including Hale-Bopp (C/1995 O1) and Hyakutake (C/1996 B2). And who can forget the death of Shoemaker-Levy 9 (D/1993 F2) as its shredded corpse slammed into Jupiter?

The book is organized logically, with sections on origins, orbits, the nucleus, coma, and dust. Unfortunately, it's already out of date. Deep Impact's collision with Comet 9P/Tempel 1 occurred after the book went to press. But that's OK; it just means there's even more reason to publish *Comets III*.

Like the other books in the series, this is a reference book for planetary scientists and is not intended for the general public. That said, the best and brightest comet scientists have all contributed to the mix here. It's one-stop shopping for comet information. Any astronomy library without this title on its shelf is incomplete.

Pluto and Charon: Ice Worlds on the Ragged Edge of the Solar System, Second Edition

S. Alan Stern and Jacqueline Mitton (Wiley-VCH, 2005). 262 pages. ISBN 3-527-40556-9. $79.95.

Much like *Comets II*, here's another case of a book that's already out of date, as two watershed discoveries in Kuiper Belt science have been made since this hit bookstores: 2003 UB_{313}, the solar system's "10th planet" (S&T: October 2005, page 28), and the identification of two more moons in the Pluto system. The former is mentioned in passing in the authors' preface. The latter, a discovery made by Stern himself (February issue, page 18), receives no mention. Since the Hubble observations of the Pluto satellites were made in May 2005 and the preface was written in August, Stern was aware of *both* observations before the book went to print. So why not hold the book six months to include the moon announcement? My guess is a rush to have it out before the New Horizons Pluto–Kuiper Belt mission (see page 24).

There is a lot of great historical information here. It is written for a general audience, and it contains a wealth of scientific findings about Pluto, Charon, and many other Kuiper Belt objects. And it does cover most of the explosion in Kuiper Belt science that occurred between the first edition's 1997 publication date and 2005. Still, too many critical discoveries are already missing for this to be the comprehensive book it should be.

Transits of Venus: New Views of the Solar System and Galaxy

Don Kurtz, editor (Cambridge University Press, 2005). 554 pages. ISBN 0-521-84907-1. $90.

This collection of scientific papers, the proceedings of the 196th colloquium of the International Astronomical Union held June 7–11, 2004, does an admirable job detailing the rich history and science behind Venus's past trips in front of the Sun. Because of this, the text is accessible to the interested amateur (something rare for IAU proceedings), and it serves as a great reference. Since the conference took place during the 2004 transit event, the reader gets to see fun photos of professional astronomers at play as they observe and celebrate history in the making. ✱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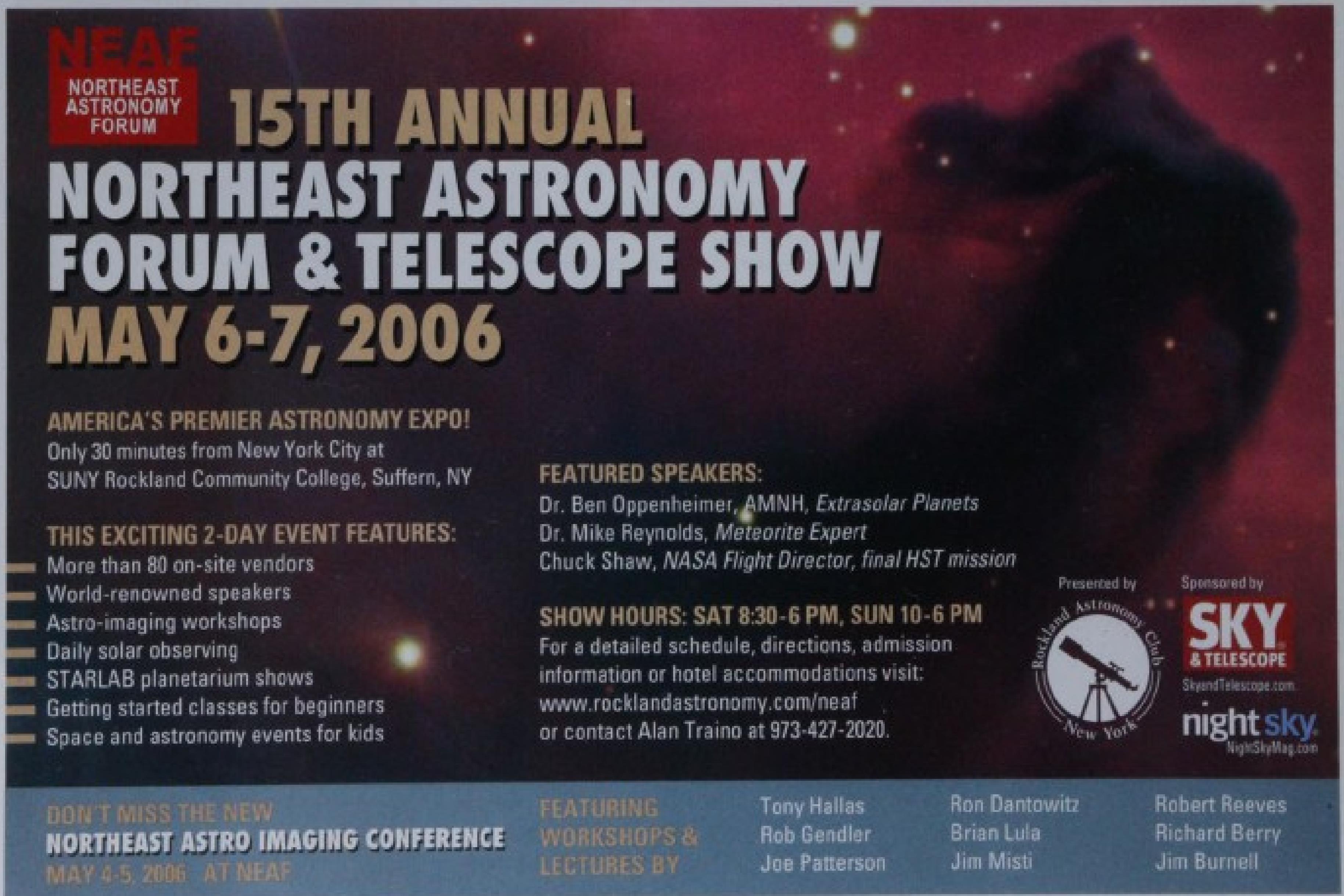
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▲ April 8, 2005
Pitcairn Islands

Solar Eclipses on Stamps

Eclipses of the Sun get stamps of approval. By Edwin L. Aguirre

A TOTAL ECLIPSE of the Sun is one of nature's most spectacular celestial phenomena, and over the years it has been depicted on commemorative postage stamps issued by countries that lie within the path of totality. Special first-day covers for these stamps are postmarked on the day of the eclipse itself.

Eclipse chasing is now a huge business for tour operators, hotels, airlines, and cruise lines. The infusion of tourism revenue also helps boost local economies, especially in developing countries. For example, for the April 8, 2005, annular-total eclipse in the South Pacific (*S&T:* September 2005, page 87), the Pitcairn Islands came out with the nice set of stamps above, which was sold to collectors and travelers aboard passing cruise ships. These tiny, isolated volcanic islands subsist on fishing, farming, and selling handicrafts and postage stamps.

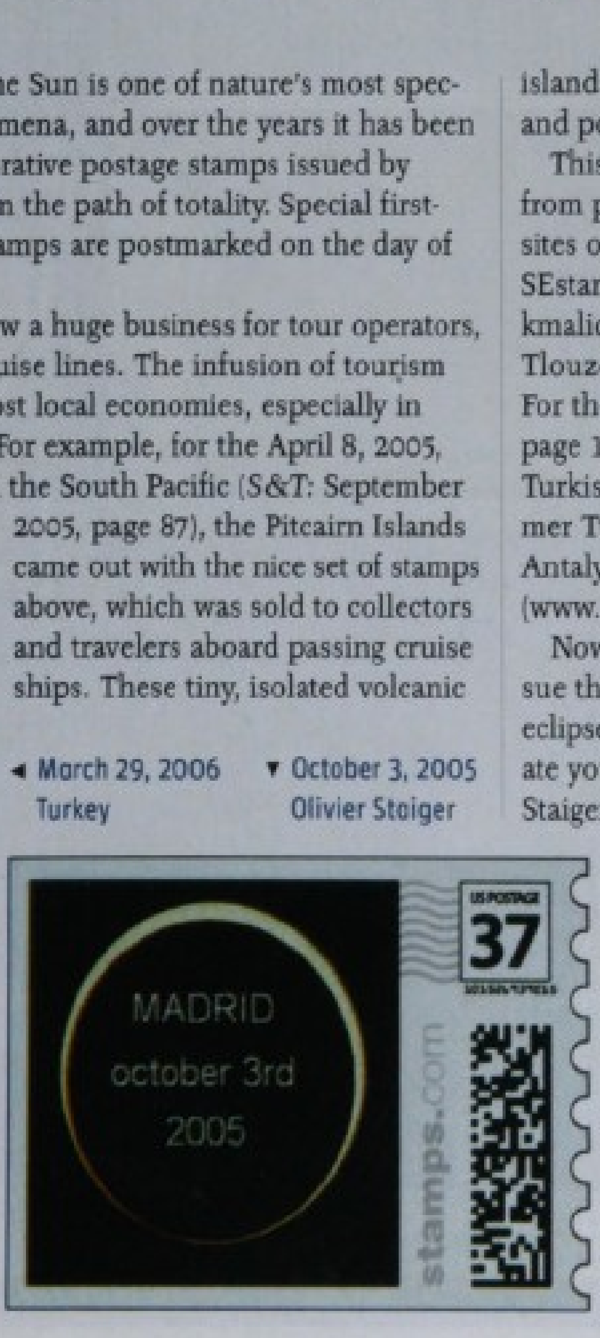
This article gives a sampling of the various stamps issued from previous eclipses. For more examples, see the Web sites of Fred Espenak (www.mreclipse.com/SEstamps/SEstamps1.html), Chris Malicki (http://ca.geocities.com/kmalicki@rogers.com/index.html#stamps), and Martine Tlouzeau (http://mseclipse.free.fr/timbres/timbres.htm). For the total solar eclipse on March 29th (January issue, page 115), Turkey will mark the occasion with a 0.70 New Turkish Lira stamp (far left) designed by research astronomer Tuncay Özişik of TÜBITAK National Observatory near Antalya. Contact the Philately Section of the Turkish PTT (www.ptt.gov.tr/eng) for more information.

Nowadays you don't even have to wait for countries to issue their official eclipse stamps. You can use your favorite eclipse photos (or almost any photos, for that matter) to create your own postage stamps. Veteran eclipse chaser Olivier Staiger used PhotoStamps (http://photo.stamps.com) for his suite of eclipse stamps, including one that shows last October 3rd's annular eclipse from Madrid (left). These customized stamps are valid US postage and are approved for use by the US Postal Service.

Happy collecting!

continued on the following page ▸

◂ March 29, 2006
Turkey



▾ October 3, 2005
Olivier Staiger

Associate editor EDWIN L. AGUIRRE, *together with S&T photo editor Imelda B. Joson, proposed the March 1988 eclipse stamps issued by the Philippine Postal Service. Unless otherwise noted, all stamps in this article are from their personal collection.*

▲ June 11, 1983
Indonesia

GEORGE YOUNG

▲ July 11, 1991
Mexico

► October 24, 1995
Thailand

▼ March 18, 1988
Philippines

GEORGE YOUNG

▲ March 9, 1997
Mongolia

► February 26, 1998
Aruba

▼ August 11, 1999
Iran

▲ August 11, 1999
Romania

◄ June 21, 2001
Zimbabwe

▼ December 4, 2002
South Africa

event calendar

MARCH 31–APRIL 2
Tennessee Spring Star Party
Fall Creek Falls State Park, Tennessee
Scott Smith, spsmith@bellsouth.net

APRIL 6–9
NSTA National Conference on Science Education
Anaheim, California
703-312-9221; conferences@nsta.org

APRIL 20–23
Georgia Sky View 2006
Indian Springs State Park, Georgia
Dawn Knight, sdknight@flintriverastronomy.org

APRIL 20–23
Southern New Mexico Star Party
City of Rocks State Park, New Mexico
John Gilkison, 505-527-8386; jgilkiso@zianet.com

APRIL 21–22
North Central Region Astronomical League Convention
Appleton, Wisconsin
webmaster@new-star.org

APRIL 21–23
Aschberg Spring Telescope Meeting
Schleswig-Holstein, Germany
Armin Quante, +49 4351-475830; aft2006@aft-info.de

APRIL 23–30
Texas Star Party
Fort Davis, Texas
Anne Adkins, tspreg@texasstarparty.org

APRIL 26–30
Desert Sunset Star Party
Three Points, Arizona
chartmarker@cox.net

APRIL 26–29
Mid-South Star Gaze 2006
French Camp, Mississippi
Rainwater Observatory, 662-547-6377; info@rainwaterobservatory.org

APRIL 28–30
South Jersey Spring Star Party
Belleplain State Forest, New Jersey
Paul Ostwald, 267-304-4156; paostwald@aol.com ✶

star trails | by david h. levy

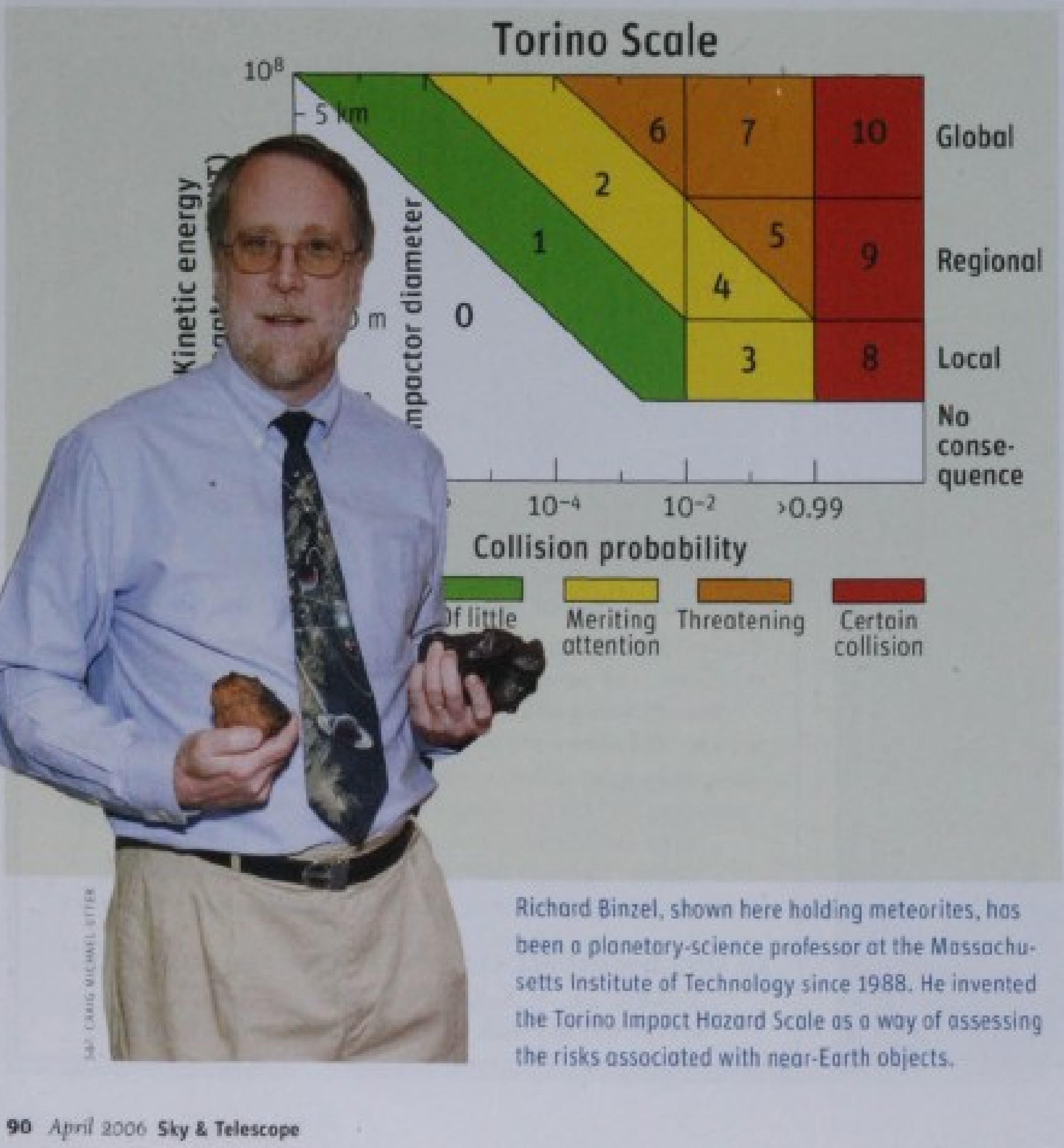
Asteroid Alerts: A Risky Business

Here's one scientist's way of categorizing cosmic threats.

SOMETIMES MAJOR scientific ideas can begin very simply — for example, at an informal dinner hosted by The Planetary Society. In the early 1990s, the possibility that a wayward comet or asteroid might collide with Earth was seemingly so remote that it was treated by the public and the press as a joke — in fact, the asteroid-research community had to consider how to deal with the "giggle factor." The group at the dinner included Planetary Society cofounders Carl Sagan and Louis Friedman and a young planetary scientist named Richard Binzel. "Carl was seated to my left," says Binzel, now with the Massachusetts Institute of Technology. He remembers that there were several conversations going on simultaneously around the table that evening: "I said merely that we needed something like the Richter scale to communicate quickly to the public whether or not there is an impact hazard." Sagan looked up and called across the table to Friedman. "Tell Lou," said Sagan, gazing intently at Binzel, "what you just told me." And thus came the birth of a scientific idea.

The issue of near-Earth objects, or NEOs, actually goes back to the early 1970s, when the late Gene Shoemaker began a program to determine the number of asteroids and comets that could pose a threat to our home planet. Only a handful were known at the time. Two decades later, with some 200 NEOs cataloged, Comet Swift-Tuttle made an appearance, and for a few weeks there was the scary possibility that at its next return on August 14, 2126, the comet could strike Earth (S&T: January 1993, page 16). Swift-Tuttle turned out to be a false alarm, but it was a wake-up call — someday there might be a real threat, and when there is, what is the astronomical community going to do about it? How will the public be informed?

For Binzel the answer is a hazard scale, much like the Richter scale for earthquakes or the Saffir-Simpson scale for hurricanes. In his system, an object is assigned a value from zero to 10, based on its collision probability and the kinetic energy (in megatons of TNT) released at impact. Additionally, the values are grouped in colors that resemble the five-step terror-alert scale adopted by the US Department of Homeland Security. If an object won't hit Earth or the probably of it impacting is so low as to be practically nil, then it's a zero (white zone). If a collision is extremely unlikely, with no cause for public attention or concern, then it's a 1 (green). A value of 2 to 4 (yellow) means a possible close encounter of a sizable object with Earth that merits attention by astronomers. A 5 to 7 (orange) is given to close encounters that pose a serious but still uncertain threat. Finally, an 8 to 10 (red) indicates that collision is certain, with effects ranging from localized destruction to global catastrophe (see http://neo.jpl.nasa.gov/torino_scale.html).



S&T: CRAIG MICHAEL UTTER

Richard Binzel, shown here holding meteorites, has been a planetary-science professor at the Massachusetts Institute of Technology since 1988. He invented the Torino Impact Hazard Scale as a way of assessing the risks associated with near-Earth objects.

By 1995 Binzel's idea had evolved enough to be presented at a United Nations conference, which I attended. I sat there listening to how all these countries might protect their citizens against a cosmic threat. Thanks to Binzel's scale, objects from space could now be more easily understood and respected by the public. Four years later, he offered a revised version at an NEO workshop held in Torino (Turin), Italy. And more recently, the scale's explanation has been updated again to better communicate the risks to the public and minimize media hype (S&T: September 2005, page 22).

"We're now very clear," says Binzel, "that the lowest numbers mean that there is no hazard, and that as the numbers increase the risks merit at first, attention by astronomers, and later by the public. More and more journalists are learning how to use this scale."

Scientists are becoming comfortable with it as well. Ideally, when a potentially threatening object gets discovered, observers and orbital dynamicists spend a few days refining the orbit. Not too many days, however: "The least risky way to go is to communicate the data openly," he says, "as this opens the public's mind to the whole idea of the scientific method."

Although Binzel is best known for his idea of what would become the Torino Impact Hazard Scale*, his career literally spans the solar system. His interest in planetary science started very early in his life. Born in 1958 in Ohio, he enjoyed working with Michelle Kleinrichert, his high-school biology lab partner. After graduation, he attended Macalester College in St. Paul, Minnesota. It was quite a coincidence when Michelle arrived at Macalester as a member of the school's debating team. This time, the couple started dating; they got married in 1982. They have two children, Steven and Christine. Binzel went on to the University of Texas for his master's degree and doctorate in astronomy. His main areas of research are asteroids and their connection to meteorites.

He is now general editor of the University of Arizona Press Space Science Series, whose volumes have enriched our understanding of the Sun's family. And as a member of the science team for the New Horizons mission to Pluto, his particular focus is on the nature and size of the planet's polar caps. "I've been studying Pluto for 25 years," he says, "and I've mapped Pluto's surface using the mutual eclipses between Pluto and its moon, Charon, in the 1980s. I look forward to seeing whether there is evidence of these polar caps undergoing seasonal variations over the course of the planet's 248-year orbit."

DAVID LEVY *and his wife, Wendee, interviewed Richard Binzel last January 3rd on* Let's Talk Stars *(www.letstalkstars.com).*

**A similar, but more complex risk estimator, called the Palermo Technical Impact Hazard Scale, was published by Steven R. Chesley (NASA/Jet Propulsion Laboratory) and his colleagues in 2002. This continuous, logarithmic scale is not intended for the general public; it's designed for use by NEO specialists to quantify and prioritize the potential risks posed by such bodies (see http://neo.jpl.nasa.gov/risk/doc/palermo.html).*

The editors of *Sky & Telescope* answer your questions about amateur astronomy.

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

SHOOTING STARS

How well defined is a meteor-shower radiant? Is it a point on the sky or a several-degree-wide spot?

— Tye Szwarc, Hillsborough, NJ

Radiants are spots, not points. A meteor shower's radiant is the location on the sky where all the meteors would appear to come from if we could see them approaching in the very far distance. However, the members of a meteoroid stream do not travel perfectly in parallel; over the centuries their orbits become increasingly scattered. Their nonparallel paths mean that the shower's perspective point is not really a point.

For example, the International Meteor Organization's *Handbook for Visual Meteor Observations* lists radiant diameters of 3° for the Perseids, 2° for the Leonids, 4° for the Geminids and Eta Aquarids, "complex" for the Orionids and Taurids, and "diffuse" or unknown for many others.

— Alan MacRobert

GALACTIC COINCIDENCE

As a teenager, when examining an equinox-1950 star atlas, I noticed that the galactic equator crossed the ecliptic very close to the latter's northern and southern extremes (that is, the solstices at right ascension 6^h and 18^h). On equinox-2000 charts they are even closer. I'd love to know when the exact coincidence will (or did) occur.

— Peter Sferra, Mountain View, CA

You are not alone. Jean Meeus addresses this very question in chapter 48 of his 1997 book *Mathematical Astronomy Morsels* (available from Sky Publishing). Because of precession, the ecliptic longitude of each intersection point increases 50.3 arcseconds per year. He finds that the galactic equator (as defined by the International Astronomical Union in 1959) passed over the solstice points during May 1998.

— Roger W. Sinnott

GIVE OR TAKE A LIGNE OR TWO

Paging through a reproduction of the 1909 Sears, Roebuck and Co. catalog, I found a telescope with an aperture of 25 lignes. Are you familiar with that term?

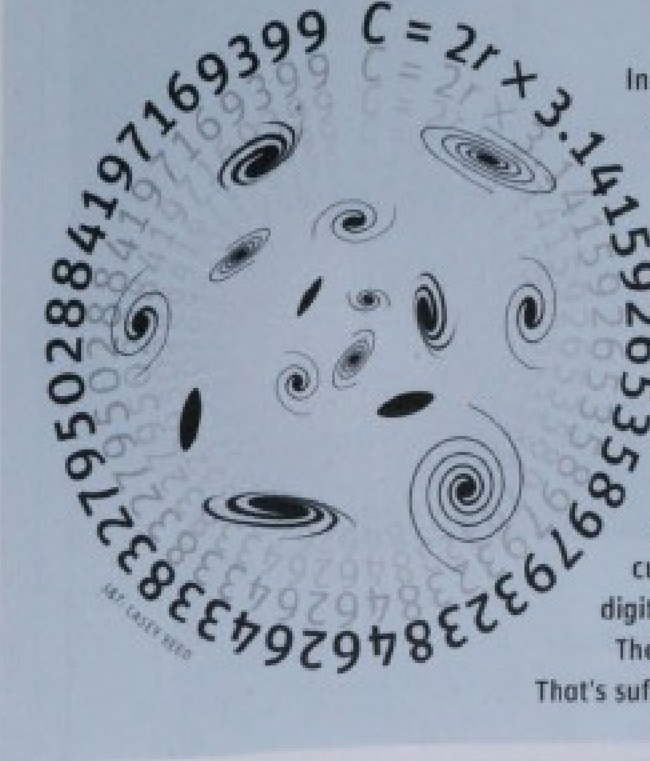
— Leif J. Robinson, Tárcoles, Costa Rica

In short, no. We're also surprised to learn that such an archaic measurement was attached to a "modern" telescope. A ligne is one-twelfth of the old French inch (about 2.256 millimeters or 0.0888 English inch), and it was often ascribed to telescopes before France adopted the metric system in the late 1700s. For example, Charles Messier wrote that his detailed observations of the Orion Nebula in February and March 1773 were made with an achromatic Dollond refractor of 40-ligne aperture. The ligne did linger longer in the lexicon of horologists, however, where until rather recently it was used to describe the diameter of watch movements.

By the way, that 1909 Sears telescope with optional 80× "astronomical" eyepiece cost $20.55, or about the equivalent of $420 today. Flipping through recent issues of this magazine, we found several very handsome refractors for about that price with apertures of 80 mm . . . er, $35\frac{1}{2}$ lignes.

— Dennis di Cicco

FAST FACT: The Universal Constant Pi



In the 3rd century BC, Archimedes proved that the ratio of a circle's circumference to its diameter is less than $3\frac{1}{7}$ but larger than $3\frac{10}{71}$. That's about 3.141. Later mathematicians have computed what we now call π (pi) to greater and greater accuracy — but how many digits are "enough"?

The answer is 45 digits. That's sufficient for one of the most grandiose calculations using π that I can imagine — namely, finding the circumference, *C*, of the known universe down to the width of a single quark. Not even one-thousandth the size of a proton, this subatomic particle is no more than 1×10^{-18} meters across. The universe has a radius, *r*, of some 14 billion light-years, or 1.3×10^{26} meters, and thus a diameter twice as large that needs 45 digits to express in quark units. If we knew the diameter to this level of precision (which we don't) and wanted to compute the circumference just as accurately, we would need π to the same number of digits.

According to Petr Beckmann's 1971 classic, *A History of Pi*, English astronomer Abraham Sharp was the first to evaluate π past 35 digits; he attained 72 in the year 1705. The quest for more digits is still going on, and in 2002 Yasumasa Kanada and colleagues (University of Tokyo; see super-computing.org) surpassed 1 trillion digits. Their motivation is mathematical curiosity, not practicality!

— R. W. S.

Of Color and Composition

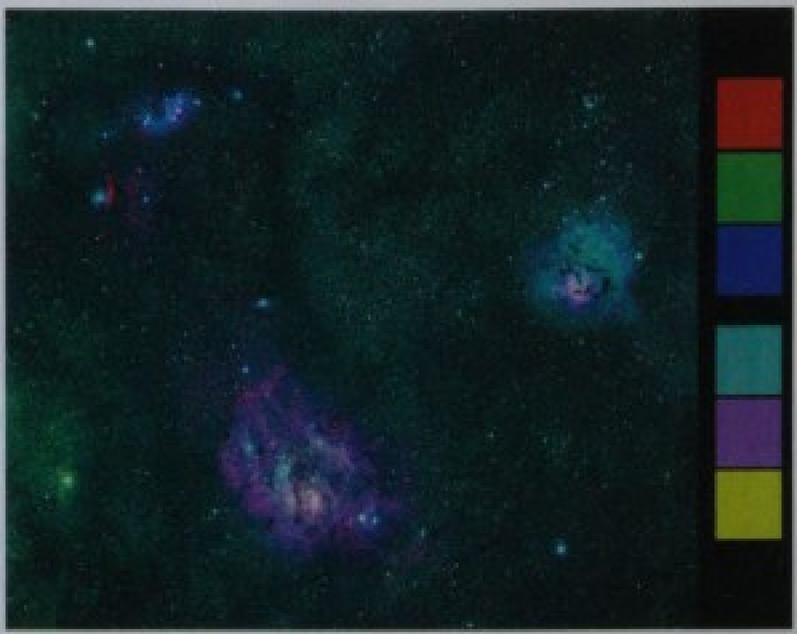
Some simple lessons from the art community will help astrophotographers achieve the greatest visual impact with their images. By Tony Hallas

IT'S ONE THING to capture the deepest exposure of a galaxy, star cluster, or nebula, but quite another to consider the essential question of image composition before your camera starts collecting photons. Likewise, it's equally critical to control color balance during post-processing. As readers of this magazine know well, amateur astrophotography has made great strides in the past decade, encouraging many to try their hand at photographing the night sky. Some fundamental compositional rules carried over from the world of fine art and professional photography can help astro imagers frame their subjects to produce pictures that have maximum impact.

The Color of Perfection

Professional lab technicians typically spend three to five years as apprentices before they are qualified to judge color "on the fly." Astrophotographers rarely enter the hobby with the benefit of such training, so most are forced to flounder about until they stumble upon a color balance that looks adequate. Fortunately, simple tools are available to help us quickly establish proper color balance in our images.

A quick look at the image at right tells us it's the wrong color, but what color is it? We need to know the color cast to make a good correction. Since our visual system's comparative faculty is well developed, it's a simple matter to put a color chart next to an image and compare the colors to pick the right one. In this case the offending color is cyan, and we need to add the opposite color (red) to the image to bring the color to a neutral balance. The result is presented at left.



The image above has a strong cyan bias — note how the color overwhelms the red nebulae. Using a simple color chart placed next to the picture, the astrophotographer can easily identify the offending color bias. By adjusting the cyan levels in *Adobe Photoshop*, the author achieved a neutral balance in the image below, allowing us to see the "push-pull" of the various colors making up the image.

One goal of color balance in astrophotography is to establish a neutral background. If we have a color bias (if our image is predominantly one color) the other colors are all suppressed by the dominating one. In the professional-photography community, we would say that there is no "push-pull" in the colors. When a neutral balance is established, we see the push-pull of the various colors making up the image. The photo can now breathe.

In photography of any kind, one element that can cripple an image instantly is called clipping. The great photographer Ansel Adams was famous for the detail he kept in the shadows and highlights of his images, and we want to do

Careful attention to color balance and composition is the best tool for turning a good image into an excellent one. By studying basic principles of color theory and image composition, astrophotographers can learn to control how people interpret their images. In this photograph of M8, the Lagoon Nebula, and M20, the Trifid Nebula, the author composed the subjects to obey the compositional "rule of thirds," creating a sense of balance and unity. All images are courtesy Tony and Daphne Hallas.

the same thing with our astrophotography. In *Adobe Photoshop*, the best way to monitor our images to avoid clipping is the histogram tool. Our goal while adjusting the histogram is to keep both the highlights (represented by the right of the histogram) and the shadows (the left side) from getting chopped off at the ends. A good histogram allows the shadows to rise from zero levels, rather than starting at a high level. The histogram should peak, then taper back down to zero at the highlights before ending.

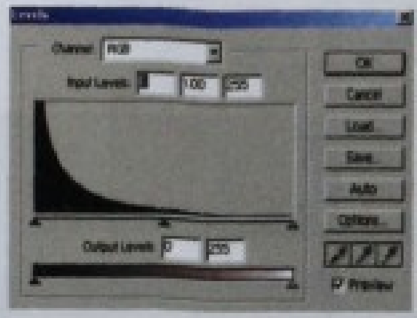
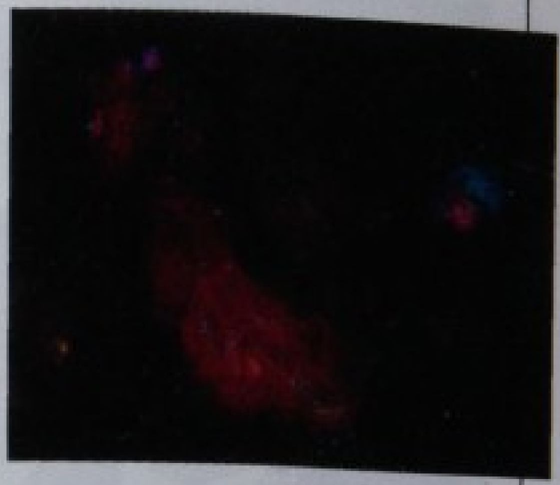
Another error in astrophotography is called color crossover. This is especially common in photographs made with a digital printer. Color crossover causes differences in the color biases of the highlights and the shadows in images.

Let's use the image of the Moon below as an example. In this photograph, the shadows appear magenta and the highlights green. We cannot simply add green to make the shadows better because that will make the highlights worse. The solution is to open the Curves function in *Adobe Photoshop* (or any other software that has curves control) and identify where on the green curve the shadows and highlights are positioned. In the shadow area we will pull the green curve up to counter the magenta, and in the highlights area we'll bring it down to reduce the green. The result should now have even color from the shadows to the highlights. Crossovers are not always obvious, and they can be tricky to analyze visually if not for a very useful tool: the grayscale. With it, very small color errors become visible because gray is very sensitive to the slightest color change. In the chart on the next page, the grayscale on top has the magenta-green crossover, and the one underneath has been corrected using Curves. Knowing what the correction is, we can apply it to whatever piece of artwork we are working on by using *Photoshop*'s feature of saving the curves and applying them to other images.

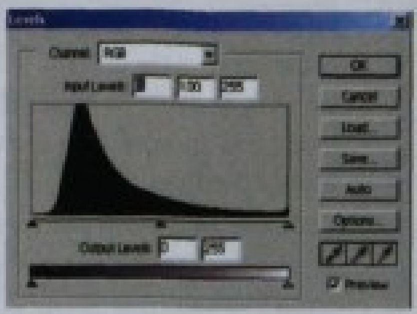
Compositional Considerations

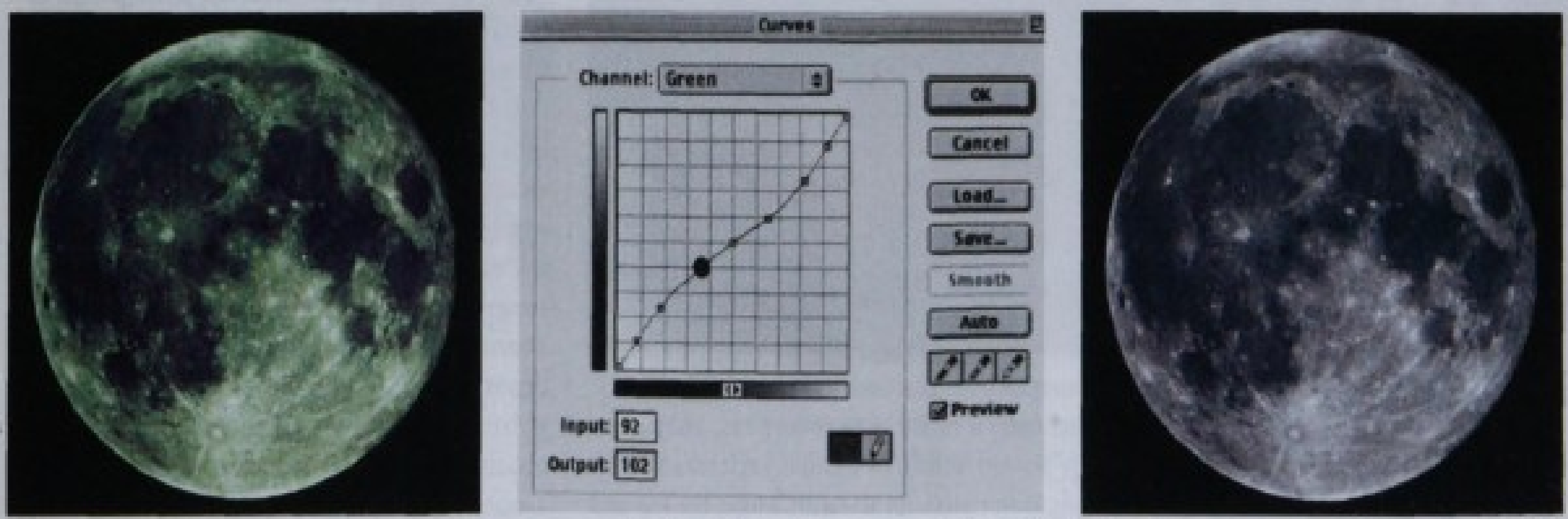
Besides color balance, visual psychology is important in the creation of a pleasing image. In our culture we're used to reading from left to right, so our eyes pick up an image on the left and follow it across to the right. If we don't have something to bring our eye back to the beginning, we won't feel the unity of the image. If we look at the image of the irregular galaxy M82 on page 96, the star at upper left serves to bring our eyes back to the beginning since we're always attracted to a bright point source. Furthermore, the red streamers from the galaxy also direct our gaze back to the beginning of the image.

Distracting elements can take away from an otherwise excellent image. Sometimes a bright star will be on the edge of our image, but anything with high contrast close to the picture border draws our attention away from the main subject, creating a feeling of tension. An image of Stephan's Quintet (page 96, right) is an excellent example of this situation. In this mirror-reversed image, the picture doesn't function in harmony because the bright star is pulling us away from the beginning of the image and the galaxies are pointing out of the frame. In the correct orientation, the

These images show shadow *(top)* and highlight *(bottom)* clipping — eliminating image detail at the extremes of the dynamic range. The best way to monitor images to avoid these conditions is to view the image histogram in *Photoshop*.



Left: This image of the Moon suffers from color crossover — the highlights display a green bias, while the shadow regions are notably magenta. This problem is common in prints made with ink-jet printers, but it can be corrected using the Curves function in *Adobe Photoshop*. We can identify the shadow and highlight regions in the curve *(middle)* by clicking on an area in the image; a point will appear on the curve that represents the same level. We can then raise the green in the shadows to counter the magenta and lower the highlight area, resulting in a neutral color balance *(right)*. This corrected color curve can be saved and applied to other images.

Left: A grayscale chart is a powerful tool that helps identify color crossovers. The top grayscale suffers from the same color crossover as the Moon's image on the previous page. By loading the same curve used to fix the Moon picture, the author was able to render the neutral grayscale shown below.

In this photo of the irregular galaxy M82 *(left)*, the star at top left carries our gaze back to this point. In western culture, we're trained to read from left to right, so our eyes pick up the image on the left and follow it across to the right. If we don't have something to bring our eye back to the beginning, we won't feel the unity of the image. Furthermore, the red streamers from the galaxy also direct our gaze back to the beginning of the image. The view of Stephan's Quintet *(right)* is intentionally displayed mirror-reversed to illustrate the same point — notice how the bright star at top right draws our attention away from the galaxies and creates an unnatural tension within the image.

image has the star pulling us back to the beginning of the picture and the galaxies are pointing there, too.

The "rule of thirds" is another well-known compositional tool. When a composition bisects the horizon line, we are drawn mostly to the center of the image since it lies on this powerful compositional element. But dividing the image into thirds and arranging it so the subjects lie in the first and third sections spreads our gaze over the entire image. Composing a photograph in thirds creates a feeling of

An important compositional rule in most forms of photography is called the rule of thirds. Imagine an image divided into three sections horizontally. By placing major pictorial elements within the top and bottom sections, we create a balance that draws our attention around the entire image. This composite was prepared with this in mind. Notice how the Moon draws our attention back to the top, yet the trees in the foreground create pictorial harmony.

harmony and unity. The image of the Lagoon and Trifid nebulae on page 94 is compositionally balanced this way. None of the three objects of interest lies directly in the middle of the image, and the subjects draw the viewer's eye around the entire composition.

Another powerful compositional tool is a weighted center. Our mind likes to see a slight amount of extra room under the main part of an image before deciding that it is in the middle, and this adds to the feeling of harmony. Too much room changes the balance of the image, resulting in either a top-weighted or bottom-weighted image. While these conditions can work well in normal daytime photography, rarely do they function positively in celestial images.

Interesting effects can be accomplished by intentionally breaking these rules. For example, we can build tension into an image by design. Although I like harmony in my celestial images, being aware of these simple rules gives photographers a greater chance of success when we intentionally ignore them. So consider these tips before your first exposure of the evening, and chances are you can kick your images up a notch or two. ✦

Tony Hallas *captures the beauty of the universe from his backyard observatory in Foresthill, California. You can see more of his work at www.astrophoto.com.*

gallery Astrophotos from Our Readers

Each month Gallery showcases the finest astronomical images submitted to us by our readers. We encourage you to send your very best shots to gallery@SkyandTelescope.com; for more information, see our Astro Imager's Guide on the Web at SkyandTelescope.com/aboutsky/guidelines. Not all submissions can be published.

▲ Texas Star Trails

BY BILL WILLIAMS

Bill Williams captured these 5½-hour-long trails of stars over the Harvard radio telescope in the Davis Mountains in May 1990. "Cows were curious about my camera as I left it there to observe at the nearby Texas Star Party," he recalls. "Luckily, no planes crossed the field of view during the exposure, and the cows didn't chew on the camera!"

DETAILS: *Tripod-mounted Pentax 6×7 medium-format camera, 55-millimeter f/4 lens, and Fujicolor 400 color-negative film.*

◄ Celestial Lagoon

BY ALAN CHEN

Visible to the naked eye on dark, transparent nights, M8, the Lagoon Nebula in Sagittarius, got its popular nickname from the dark band that bisects the nebula's brightest regions, which Agnes M. Clerke, in *The System of the Stars* (1890), likened to a lagoon.

DETAILS: *10-inch f/4 homebuilt Newtonian reflector and Starlight Xpress SXV-H9C CCD camera. Total exposure time was 2.9 hours last May 8th. North is to the upper left in this 20′-wide view.*

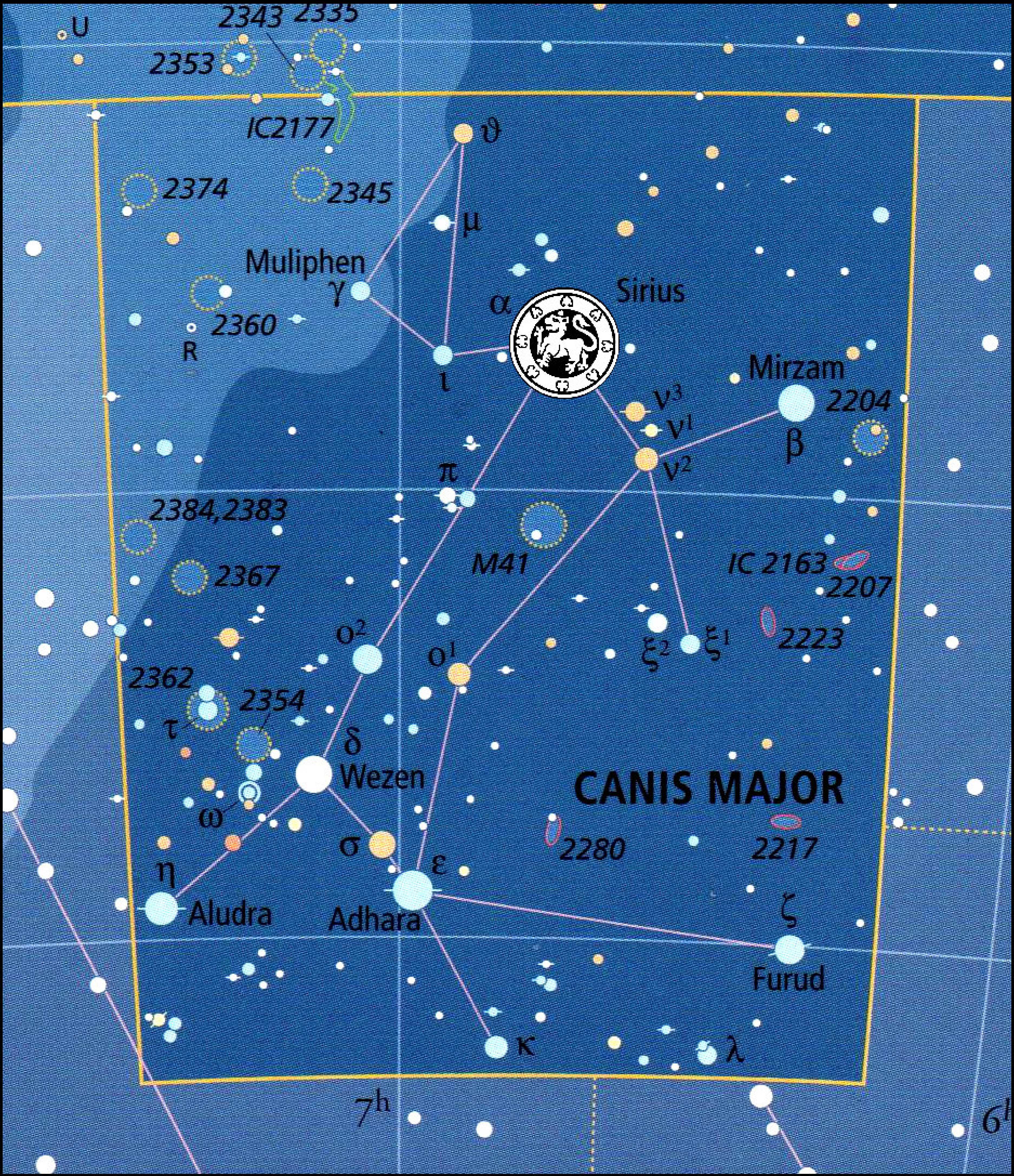
◂ Showpieces in Orion

BY DANIEL VERSCHATSE

The famous Horsehead Nebula is seen here silhouetted in majestic glory against the red glow of the emission nebula IC 434. To its lower left shines the blue reflection nebula NGC 2023. The bluish rays are optical reflections from 4th-magnitude Sigma Orionis, situated off the west (top) of the 24′-wide field. **DETAILS:** *14½-inch f/9 RC Optical Systems Ritchey-Chrétien telescope and SBIG STL-11000M CCD camera. Total exposure time was 7.4 hours on October 30–31, 2005, from San Esteban, Chile.*

For astrophotography tips visit SkyandTelescope.com/howto/imaging

Sírius



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