SKY & TELESCOPE® The Essential Magazine of Astronomy

50,000 Pages and Counting

November 1941
1st issue

April 1963
10,000th page

July 1975
20,000th page

June 1984
30,000th page

December 1991
40,000th page

Thanks to the staggering arithmetic skills of last summer's editorial intern, Will Dane, we know that *this* is *S&T*'s 50,000th published page. It's a trivial milestone, really, but it gives me another excuse to pontificate.

As you learned in the February issue, I suffer from a bad case of time compression. Events are blending together as never before. Will's page count explains why. It took *S&T* 21 years to publish its 10,000th page; the next milestones came at 12-, 9-, 8-, and 6-year intervals. (I wilted badly upon realizing that I've helped produce 80 percent of those 50,000 pages.) What this compression confirms is that astronomy is dramatically maturing as a science, so there is ever more neat stuff to report. It also says that the amateur community is buying ever more goods, so venders and ad pages are growing too.

The surest way to damnation is to make a prediction. So . . . what the hell . . . I'll say that amateur astronomy has its best nights still ahead. The quality of education in the U.S. seems to have passed its nadir, and an uptick is bound to be good for cerebral hobbies like astronomy. I'm also counting on gaining defectors from consumers who've tired of increasingly patronizing TV news and "entertainment." Here's one arcane datum that suggests I'm right: over the last decade attendance by the "twenty-something" crowd at grand-opera performances has grown about 20 percent — and opera is exploding nationwide!

May 1998
50,000th page

When I look back at *S&T*'s 50,000 pages, I see a societal enigma. Among professionals, the number of female astronomers has swelled dramatically. Yet there's been no comparable infusion of women into the amateur ranks — that community remains pretty much a fraternity of white, middle-aged males making big bucks. I'm confident astronomy will continue to flourish as a science. But, if I'm not to lose myself to the devil, we've got to get women, minorities, and underprivileged persons more involved in the hobby.

It's not that folks haven't tried hard for change — the sidewalk-astronomy movement, Astronomy Day, and a host of other efforts have been exemplary. Yet, despite these evangelistic programs, astronomy hasn't percolated into new markets. Maybe we are a very odd lot — people who think it's fun to be intellectually challenged. Maybe the broader public, in this age of banal commonality, sees that attitude as something to avoid.

My sincere hope is that by the time we publish our 60,000th page in 2003 somebody will have come up with an outreach program that begins to diversify participants as it grows the hobby. And, by the time we publish our 100,000th in 2021, I hope the mix of amateur astronomers mimics folks everywhere.

Leif J. Robinson

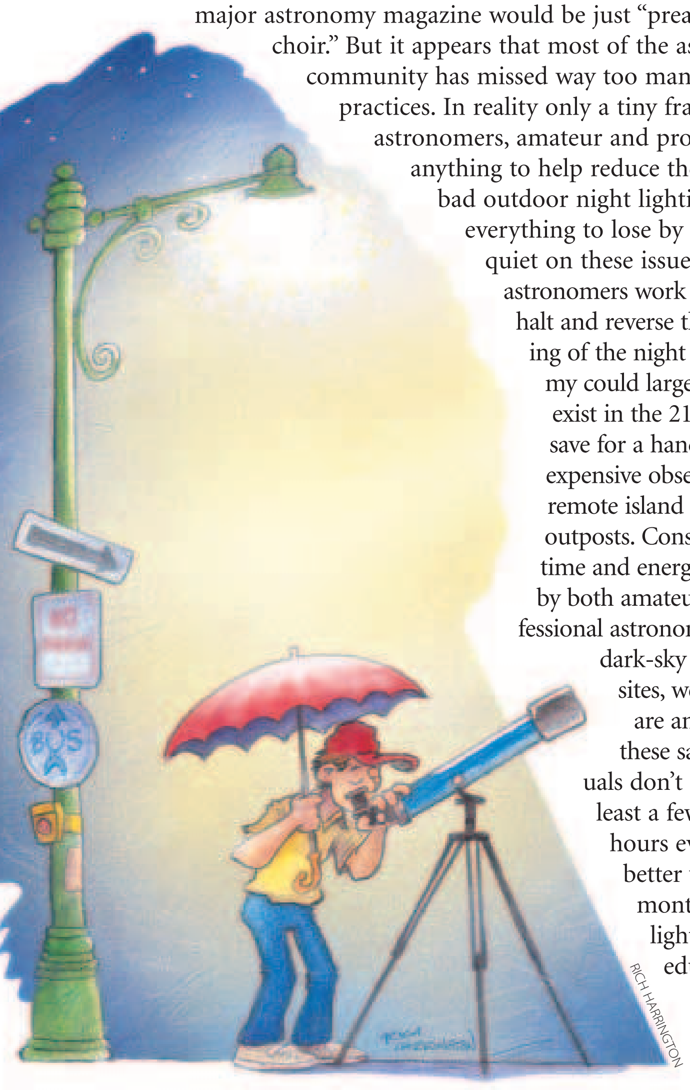
Astronomers and Light Pollution

How many of us care about dark skies? Not enough, suggests **Daniel W. E. Green**.

THOSE FEW OF US ACTIVELY INVOLVED IN FIGHTING LIGHT pollution often ask ourselves: "Where are all the astronomers?" At least 200,000 readers comb through popular astronomy magazines such as *Sky & Telescope* every month, so a great many people have at least heard of light-pollution problems and of the International Dark-Sky Association (IDA). Yet, 10 years after its founding, the association can claim only 2,000 members — barely 1 percent of its potential.

It is a sad fact that so few have responded to the IDA's recruiting efforts. One chapter chairman told me that recently, after speaking to a regional gathering of 75 amateur astronomers on light pollution, he asked how many in the audience were IDA members. Only four raised their hands. After pleading, "If not you, then who?" he managed to leave the meeting with five new members. In other words, more than 85 percent of the audience walked away without showing support for IDA. "Who?" indeed!

One would think that writing about light pollution in a major astronomy magazine would be just "preaching to the choir." But it appears that most of the astronomical community has missed way too many choir practices. In reality only a tiny fraction of all astronomers, amateur and professional, do anything to help reduce the bane of bad outdoor night lighting. We have everything to lose by being too quiet on these issues. Unless astronomers work en masse to halt and reverse the brightening of the night sky, astronomy could largely cease to exist in the 21st century, save for a handful of very expensive observatories at remote island or mountain outposts. Considering the time and energy expended by both amateur and professional astronomers to reach dark-sky observing sites, we in the IDA are amazed that these same individuals don't put in at least a few dedicated hours every year (or better yet, every month) to further light-pollution education. This is an area in which *all* astronomy clubs, and organizations can make a huge difference. Groups like the American Astronomical Society and the Astronomical League are IDA members yet have supported the association in a pathetically limited way. Most of their individual members have been totally silent. The IDA still does not have enough money to employ even one full-time staffer to answer the queries that constantly bombard its Tucson office. (About 100,000 information sheets were mailed last year alone!) Instead, almost all light-pollution education, including all that IDA accomplishes, must be done on an entirely volunteer basis.



RICH HARRINGTON

Unfortunately, the war is being lost because we are unable to intercede in the many battles over poor-quality lighting worldwide. In Massachusetts, for example, pending legislation would require virtually all new and replacement state-funded outdoor lighting to utilize "full-cutoff" fixtures (which force all their direct light downward and none of it upward). Patterned after a Maine law passed in 1992, the Massachusetts bill sailed through two committees in 1997 with little opposition. But now the legislators who sponsored the bill are wondering why they have received so few supporting phone calls and letters from the state's many amateur and professional astronomers. Apparently only a handful have bothered to ask their state representatives to vote for the bill.

Despite this general indifference and apathy, a lot of effort has been devoted to the cause by a few individual IDA activists. Thanks to them, great strides have been made in the last decade on improving outdoor-lighting practices. For example, both the Illuminating Engineering Society of North America (IESNA) and the International Lighting Commission (CIE) now formally acknowledge the potentially adverse environmental problems caused by glare, obtrusive lighting, and urban sky glow. Their technical committees are drafting recommended practices that both discuss the issues and urge the use of full-cutoff lighting for most applications. David Crawford, the IDA's (volunteer) executive director, sits on most of these committees. As evidence that the lighting industry is taking these issues seriously, he was elected a Fellow of the IESNA at its annual meeting last August. Crawford deserves our heartfelt thanks and praise for his role on behalf of astronomers worldwide.

With professional societies like these now pushing for glare-free outdoor lighting, we have gained some powerful allies. Many lighting manufacturers have begun to produce a greater choice in cutoff lights. However, the manufacturers — together with architects, homebuilders, and retail stores — need to be urged to produce and market such fixtures for all commercial and residential applications. This will not happen unless many additional voices are heard in support of the cause. We need to let them and our public officials know that we really do care. Please get involved! It has been shown repeatedly that friendly, tactful efforts by even one or two thoughtful individuals can create huge changes in the outdoor-lighting practices of an area as small as a neighborhood or as large as a state. Lack of awareness and inertia and widespread apathy are the real problems — not strong resistance by

communities or by the lighting industry.

One of the hard-won lessons of the past decade is that using astronomy as an issue to fight light pollution can often serve as a very positive factor — but it is not enough. We cannot be perceived as just a narrow special-interest group. We must continually stress safety and security issues, and the fact that bad lighting depresses property values by reducing the aesthetic quality of a neighborhood. Light trespass is an obnoxious nuisance, and the wasted energy from poorly designed lighting costs us all. Hasn't every one of us been adversely affected by bad nighttime lighting of some kind — whether the disabling glare of roadway lights, a neighbor's floodlights, or the glow over an industrial park?

"OK," you might say. "I know there's a problem. But what can *I* do about it?" Plenty! First, study the issues and learn about the solutions. Then educate others. Encourage businesses in your community to reduce or eliminate outdoor lighting after closing at night. Ask that their signs be lit by low-lumen lighting from above, not below. Approach your city, county, or state representatives about enacting ordinances or laws to reduce glary, wasteful outdoor lighting. If every *Sky & Telescope* reader devoted as little as one or two constructive hours a year to addressing light-pollution problems, we could ensure much darker skies for all. That hour could include writing letters to your local planning boards and state representatives, or showing a civic group how much of the night sky we lose to bad lighting practices.

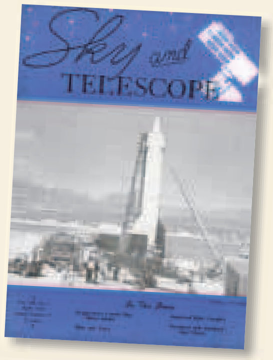
Plenty of help and support are available. The IDA stands ready to assist anybody working on outdoor-lighting issues, whether at the neighborhood, city, state, or national level. Its 130 information sheets cover a broad spectrum of topics, such as lighting and crime, energy and cost issues, and even templates for successful state laws and municipal ordinances. There are also newsletters, slide sets, videos, posters, and the IDA Web page (http://www.darksky.org) — great resources for anyone wanting to learn and to get involved.

So, please, become active today in light-pollution issues. Educate yourself about the problems and the solutions. Push to make your astronomy club a useful, informed source on outdoor-lighting issues that affect your community. Ask your local and national astronomy organizations to support the IDA financially, perhaps by allocating a portion of each member's annual dues. Join the IDA yourself, now, as an individual member (for most, the minimum annual fee is $30). With your help, we can and will make a real difference. We must work together — *all* of us.

Daniel W. E. Green *chairs the New England Light Pollution Advisory Group, which maintains an extensive Web site at http://cfa-www.harvard.edu/cfa/ps/nelpag.html. Contact the IDA at 3545 N. Stewart Ave., Tucson, AZ 85716 (phone: 520-293-3198). Green thanks David Crawford and Kelly Beatty for useful discussions in preparing this essay.*

50&25 YEARS AGO

MAY 1948 "Most cosmic ray investigations have been conducted in laboratories at various altitudes on the surface of the earth. Yet the broadest perspective on the subject has been acquired from observations high in the atmosphere with equipment carried by balloons, in particular, and by aircraft. During the recent war, rockets were brought at last to such a state of development as to become suitable vehicles for the transport of experimental equipment to levels of the atmosphere previously inaccessible. . . .



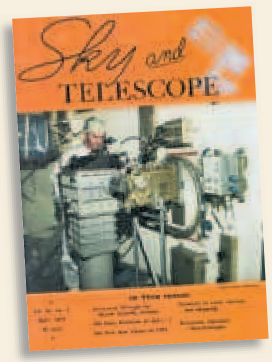
"There can be little doubt that the very high-energy nuclear and electromagnetic processes, induced in the upper atmosphere by cosmic rays, comprise a rich range of new physical phenomena. . . .

"Even quite rudimetary questions about the primary cosmic rays are still unanswered. It is reasonably certain that the primary rays carry an electric charge, but it has not been established with certainty whether this charge is positive or negative; and it may be that there is a mixture of positive and negative rays."

We now know that cosmic-ray particles come with both charges and represent some of the highest-energy processes known in the universe. Author James A. Van Allen then went on to describe questions needing answers and some experimental results obtained during V-2 rocket flights. Van Allen became a celebrity in 1958 for his discovery of Earth's magnetospheric radiation belts, which now bear his name. This was one of the first major discoveries of the Space Age.

MAY 1973 "The newly discovered Comet Kohoutek (1973f) should become a conspicuous naked-eye object, 1st magnitude or brighter, around the end of this year. . . .

"At [the time of its discovery] Comet 1973f was still five astronomical units distant from the sun. . . . It will pass through perihelion on December 29, 1973, at about 0.14 astronomical unit. . . .



"In January, Comet 1973f should be brilliant in the evening sky. . . ."

Comet Kohoutek sparked an enormous amount of hype, and its "underperformance" turned out to be a public-relations disaster for astronomers. Nevertheless, for amateur and professional astronomers in dark skies, the comet put on a respectable show.

"One of the useful astronomical byproducts of the Mariner 9 deep-space mission is a straightforward and very precise determination of the mass of the moon. On that spacecraft's flight from Earth to the vicinity of Mars, it was tracked by Jet Propulsion Laboratory's Deep Space Network.

"Using 15 weeks of tracking data from June 5 to September 15, 1971 [scientists] find that the earth's mass is 81.3007 ± 0.0001 times that of the moon."

This was indeed an accurate determination of the Earth/Moon mass ratio, one that can be used in dynamical calculations today.

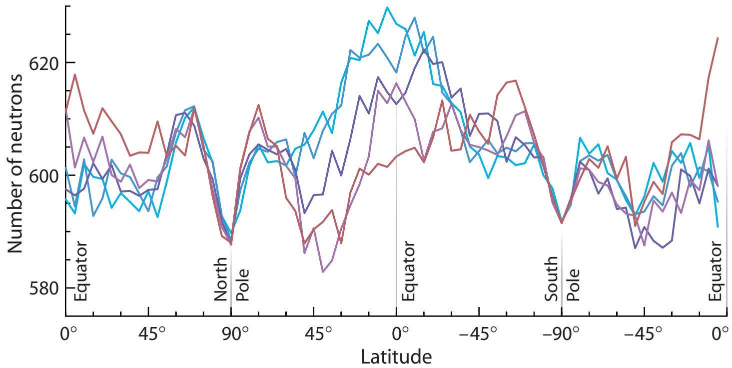
Spacecraft Finds Signs of Lunar Ice

(MOFFETT FIELD, CA) Conjuring up images of lunar bases and copious rocket fuel, scientists have announced that the Lunar Prospector spacecraft has found evidence for billions of gallons of frozen water on the Moon. While stressing that the numbers remain preliminary, “there are significant quantities of water at both poles,” said Principal Investigator Alan Binder (Lunar Research Institute) at a March 5th press briefing. Binder and his colleagues tentatively estimate that tens or hundreds of millions of tons of water are locked up as ice in the lunar soil.

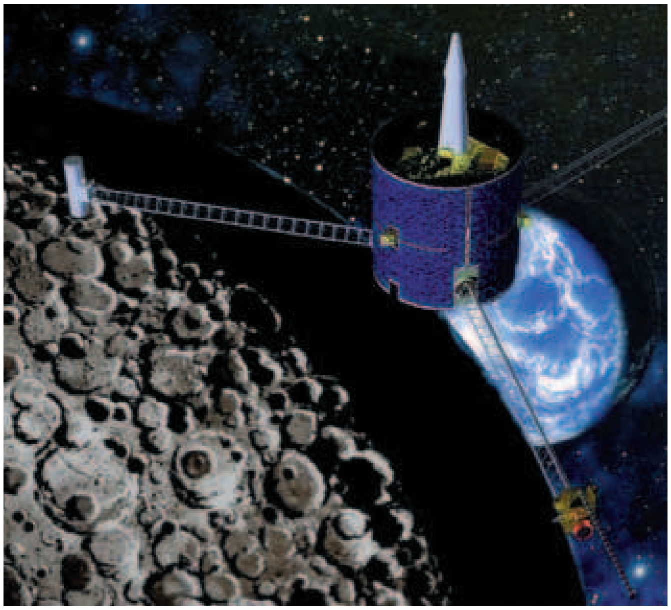
The evidence comes courtesy Lunar Prospector’s neutron spectrometer, which tallies neutrons with differing amounts of energy. Energetic neutrons are spawned when cosmic-ray particles smash into atoms on the Moon’s surface. The neutrons then slow down gradually as they ricochet off the nuclei of other atoms. Hydrogen nuclei (protons) most effectively slow the neutrons because they are lighter, and hence easier to accelerate, than are other atomic nuclei.

On each of its numerous polar passes, Lunar Prospector saw intermediate-energy neutrons drop in number by a few percent (3.4 percent at the north pole; 2.2 percent at the south). William Feldman (Los Alamos National Laboratory), who designed the neutron spectrometer, cautions that this only proves that an excess of hydrogen is present at the lunar poles. However, he says, water is the likeliest compound to contain that hydrogen. Furthermore, water has long been expected to arrive as comets strike the lunar surface, then to accumulate in the permanently shadowed bottoms of polar craters.

The finding bolsters tantalizing but contested radar evidence from the Clementine satellite, which orbited the Moon in 1994 (*S&T:* February 1997, page 24). Clementine found evidence for ice only in the Moon’s south-polar regions. Such asymmetry seemed plausible since far less of the lunar north pole’s acreage



Charted here are the numbers of intermediate-energy neutrons detected by Lunar Prospector at five widely separated longitudes during its first month in orbit. Dips repeatedly seen at each lunar pole suggest excess numbers of hydrogen atoms, implying the presence of water ice. Courtesy William Feldman.



JOE BERGERON

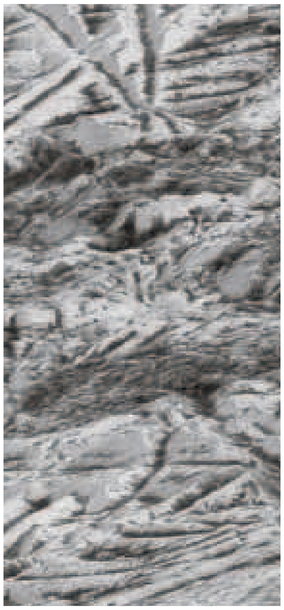
was thought to lie in permanent shadow. However, according to Feldman, Lunar Prospector actually seems to have found 50 to 100 percent more water at the north pole than at its southern counterpart.

Lunar Prospector was launched on January 6th from Kennedy Space Center; shortly thereafter, it entered a two-hour polar orbit 100 kilometers above the Moon’s surface (April issue, page 26). During the remaining months of its nominal year-long mission, it will map the Moon’s elemental composition, surface gravity, and magnetic fields. It will also “sniff” for radioactive radon that may issue from the lunar surface as a result of tectonic activity.

Handing Over Hubble’s Helm

(BALTIMORE, MD) The Space Telescope Science Institute will get its third director in September when Robert E. Williams passes the torch to Steven V. W. Beckwith, a pioneering infrared astronomer who now directs Germany’s Max Planck Institute for Astronomy. Williams has presided over two successful upgrades for the Hubble Space Telescope during his tenure. The first, in December 1993, installed corrective optics to compensate for the telescope’s misshapen primary mirror. The second, in February 1997, brought a new imaging spectrograph and Hubble’s first infrared camera into play. But he may be best remembered for bringing about the Hubble Deep Field, a 10-day-long exposure that revealed the faintest galaxies yet known (*S&T*: May 1996, page 48). Scores of scientific papers have already been published on this singular Hubble image, which Williams made available to astronomers worldwide within days of its acquisition. “I really like being at Space Telescope,” says Williams, but he is eager to return to research. For the time being, he will remain at the institute and concentrate on the astrophysics of emission-line objects, novae, and supernovae. Williams also looks forward to helping his Yerkes Observatory thesis adviser, Donald Osterbrock (now at the University of California, Santa Cruz), with the next edition of Osterbrock’s seminal textbook on gaseous nebulae and active galactic nuclei.

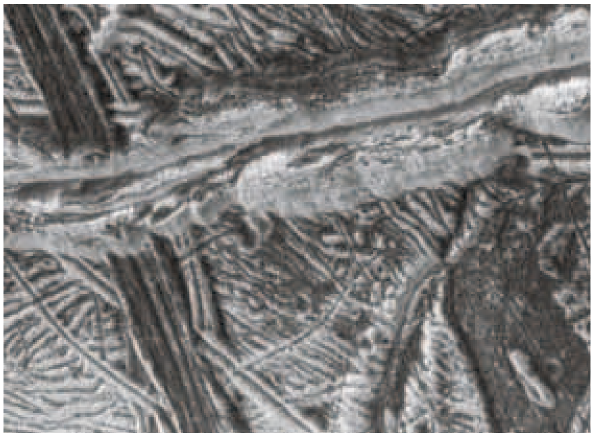
Support Deepens for Europan Ocean



(PROVIDENCE, RI) New pictures from the Jupiter-orbiting Galileo spacecraft have strengthened the belief that Europa may have a global subsurface ocean (S&T: December 1997, page 50). The spacecraft made its closest flyby of Europa on December 16, 1997, passing only 200 kilometers above the icy surface and providing the nearest views of Europa that Galileo will ever capture. The images were publicly released on March 2nd at Brown University.

The planetary scientists gathered there pointed to various surface features supporting the notion that the ice has been warmed to at least a slushy consistency, presumably by tidal flexing of the moon by Jupiter and the other Galilean satellites. Telltale signs include a crater whose basin appears to have been filled in by warm ice, fields of jumbled iceberglike debris, and fractures filled by smooth ribbons of fresh ice.

According to James Head (Brown University), "Together, the evidence supports the hypothesis that in Europa's most recent history, liquid or at least partially liquid water existed at shallow depths below the surface of Europa in several different places." The spacecraft will revisit Europa periodically over the next two years.

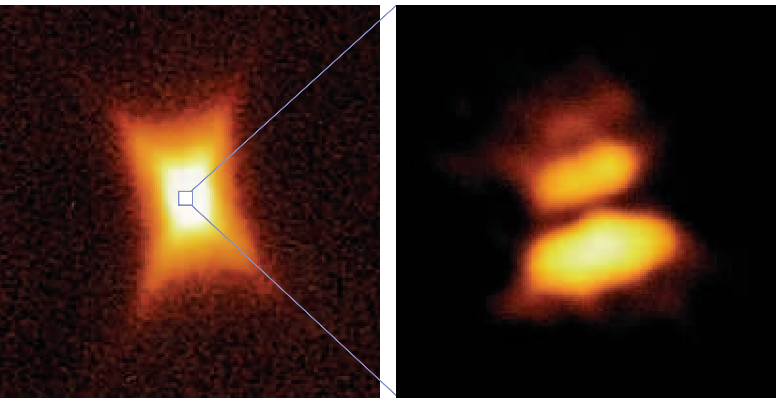


Above: **Cruising only 200 kilometers above Europa, the Galileo spacecraft took this oblique view of the satellite's icy surface. The smallest visible features in this 1.8-km-wide field are 6 meters across.** ***Right:*** **Darker areas in this 20-km-wide region of Europa indicate relatively fresh ice that has welled up from a warmer and deeper surface layer — possibly an ocean of liquid water. Courtesy JPL/NASA.**

Dusty Disk Found Around Aged Stellar Pair

(AMSTERDAM, THE NETHERLANDS) Dusty, icy disks with the potential for forming planets have been found encircling a number of newborn stars. Now one has been identified around an aged star that has long since left the hydrogen-burning main sequence.

So say Rens B. F. M. Waters (University of Amsterdam) and his colleagues in *Nature* for February 26th. They scrutinized HD 44179, an evolved binary star in Monoceros whose primary member has passed through its red-giant phase and is on its way to becoming a white dwarf. Shining at 9th magnitude, HD 44179 lies within a cloud of carbon-rich dust known as the Red Rectangle. Martin Cohen (University of California, Berkeley), who discovered the Red Rectangle in 1975, first suggested that a disk of some kind might have shaped the elongated nebula. Infrared images taken in the 1990s bolstered that notion, but the disk's origin and composition have remained a mystery.

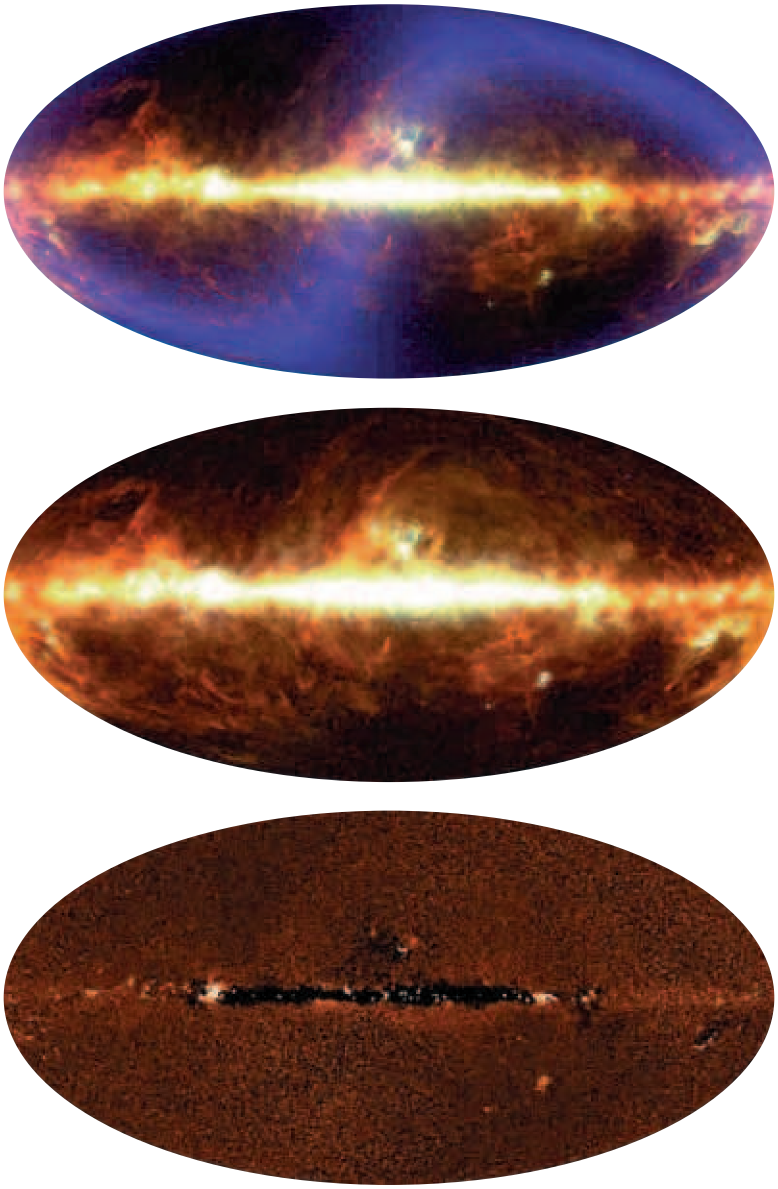


Waters and his colleagues directed the Infrared Space Observatory toward HD 44179 last October. The spectrum they obtained shows the star to be surrounded by silicate-rich minerals and maybe water ice as well. This, says Waters, makes the circumbinary disk similar to those attending several younger stars and to the leftover dust and ice grains in our own solar system.

However, Waters stresses, the silicate-rich disk at the Red Rectangle's heart is not a remnant of the binary's birth, nor of planets roasted by the swelling red giant. Rather, it probably coalesced from oxygen-rich material that was dredged up and blown away by the red giant's convective atmosphere. (The carbon-rich Red Rectangle was presumably disgorged later on.)

Waters admits that the disk is extremely unlikely to form full-fledged planets like those in our solar system; its inferred radius is several thousand astronomical units and its mass less than Jupiter's. But, he says, the system remains important to people seeking evidence for extrasolar planets. That's because it shows that minerals can coalesce into grains even in a relatively diffuse disk around an evolved star. Grains of dust and ice are widely believed to be necessary precursors to the formation of planets.

Rectangle or hourglass? The Red Rectangle's overall infrared glow is captured in the 10-arcsecond-wide view at left. The high-resolution view at right highlights emission from carbon-rich compounds. Such compounds are apparently missing from a mineral-rich disk surrounding the nebula's central binary star. Both images were made with European telescopes on La Silla, Chile. Courtesy H. van Winckel, G. Weigelt, and R. Osterbart.



Several years ago the COBE satellite's Diffuse Infrared Background Experiment produced a map of the sky's far-infrared appearance (top). But only recently have scientists been able to precisely subtract the glow from our solar system's zodiacal dust (to get the middle image) and the Milky Way's interstellar medium to show how the sky would appear from a hypothetical vantage point in intergalactic space (bottom). Imperfections aside, the resulting map appears featureless, as expected of the accumulated glow from dust-enshrouded stars billions of light-years away. In these false-color views, blue, green, and red denote wavelengths of 60, 100, and 240 microns, respectively. Courtesy Michael Hauser and NASA.

COBE's Mission Completed

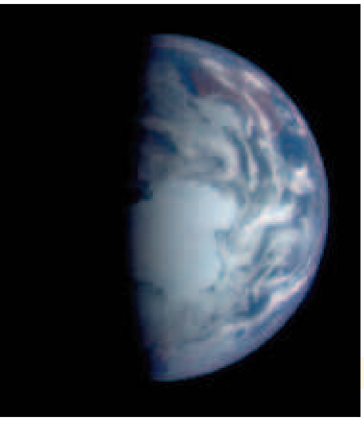
The third broad scientific goal of the long-defunct Cosmic Background Explorer (COBE) satellite has now been achieved: a firm measurement of the night sky's far-infrared brightness. The result strengthens the conservative view that most of the universe's stars were born billions of years ago, many behind veils of dust.

Launched in 1989, COBE is best known for confirming two tenets of the Big Bang theory. By demonstrating the thermal "blackbody" nature of the cosmic microwave background with extraordinarily high precision, COBE showed that the universe was once at least 1,000 times hotter and a billion times denser than it is today. Shortly thereafter, COBE went on to find very slight temperature differences between different spots on the microwave sky. Such "lumpiness" had long been anticipated as a necessary precursor to today's galaxy superclusters and voids.

But COBE's final goal — a firm measurement of the cosmic *infrared* background — has been far more elusive. In its first year of operation, COBE's Diffuse Infrared Background Experiment, or DIRBE, measured the sky's brightness at 10 widely spaced infrared wavelengths. Particularly at the shorter wavelengths, the signals were dominated by our solar system's zodiacal dust and by far vaster dust clouds scattered throughout the Milky Way. While interesting in their own right, these two foreground sources swamped any radiation that might have accumulated from early generations of dust-enshrouded stars.

Now, however, two research groups have painstakingly subtracted these "local" infrared sources, enabling them to quantify the far-infrared background at DIRBE's two longest wavelengths. In the first of these studies to be accepted for publication, David Schlegel (University of Durham) and his colleagues simply used DIRBE's 25-micron map as an indicator of the solar system's zodiacal glow. By contrast, the team led by DIRBE Principal Investigator Michael Hauser (now at the Space Telescope Science Institute) developed a complex three-dimensional model for the solar system's dust. "Ours is a poor-man's model of the zodiacal light," admits Schlegel. But "we just did what we needed, and we got the same answer."

That answer, as more precisely determined by the DIRBE team, is a feeble 140-micron sky brightness of $25\pm7\ \ 10^{-9}$ watt per square meter per steradian for each factor of 10 in wavelength. Hauser and his collegues



A Look Back Home

The Near Earth Asteroid Rendezvous (NEAR) spacecraft was launched on February 17, 1996, to give astronomers their closest-yet look at our solar system's asteroids. The craft skirted its first target, 253 Mathilde, last June, passing within 1,200 kilometers of the pockmarked body (*S&T:* October 1997, page 30). But in order to nuzzle up to minor planet 433 Eros for extended close-range study in 1999, NEAR had to take advantage of a gravitational boost from its home planet. This color-composite image of Earth's Southern Hemisphere, centered on Antarctica, was obtained from a distance of 400,000 km on January 23rd. NEAR's multispectral imager used blue, green, and infrared filters to highlight differences between rock types, water, and vegetation. Courtesy Johns Hopkins University and NASA.

also obtained a value of 14±3 10^{-9} at 240 microns. According to COBE scientist Edward L. Wright (University of California, Los Angeles), this means that the sky's far-infrared brightness is some 200,000 times weaker than that of a floor heater held at arm's length. But, as Schlegel and his coauthors explain in their upcoming *Astrophysical Journal* paper, it is roughly twice the energy density emitted at visible wavelengths by galaxies in the deepest-yet image of intergalactic space: the Hubble Deep Field. Those galaxies seem to have formed most of their *visible* stars between five and 10 billion years ago. Together, says Schlegel, these results suggest that much of the universe's early star formation took place in dust-enshrouded regions.

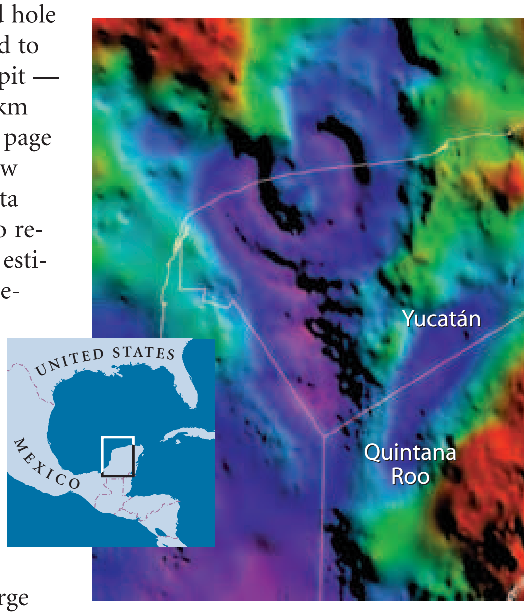
Because DIRBE sampled the sky in relatively coarse 0.7°-wide patches, it remains an open question whether galaxies like those in the Hubble Deep Field are the ones that actually produced the far-infrared background. If so, they must on average be both dustier and more luminous than previously thought. Alternatively, says DIRBE coinvestigator Eli Dwek (NASA/Goddard Space Flight Center), "it may well be that some galaxies were completely hidden behind veils of dust and not seen" by Hubble. Next-generation telescopes like NASA's Space Infrared Telescope Facility (SIRTF) and the European Space Agency's Far Infrared and Submillimetre Telescope (FIRST) should be able to settle the question.

Recalibrating Chicxulub

THE SCIENTIFIC COMMUNITY HAS GENERALLY AGREED for some time that a comet or asteroid slammed into Earth 65 million years ago, sealing the dinosaurs' fate and marking the end of the Cretaceous period. Geologists have been certain of the impact's location since a submerged crater was discovered in Mexico in 1978. But only recently have they been able to accurately define the size and structure of Chicxulub, as the crater is known.

Named for the Mexican town situated above its sediment- and water-filled basin, the crater straddles the Yucatán Peninsula's northern shoreline. Of the three largest known terrestrial craters, Chicxulub's well-preserved state has provided scientists with their best chance to study what happens when large bolides strike our home planet.

In 1996 the British Institutions Reflection Profiling Syndicate — an international team based at London's Imperial College — used air guns to send seismic waves through Chicxulub. The resulting high-resolution images trace the crater's structure as far as 40 kilometers below sea level. Gravity data obtained several years earlier had led many scientists to believe that Chicxulub's transient cavity — the short-lived hole that quickly collapsed to form an even larger pit — spanned nearly 180 km (*S&T:* January 1994, page 12). However, the new seismic-reflection data have led the group to revise its previous size estimate. Its findings, presented in *Nature* for December 4, 1997, suggest a 100-km diameter for the short-lived cavity.



Ground zero on the Yucatán. This false-color image depicts gravity anomalies that trace the Chicxulub impact crater, formed by a miles-wide bolide 65 million years ago. Courtesy V. Sharpton, Lunar and Planetary Institute.

The modification has significant implications for theories about large impact effects. Team member Virgil Sharpton (Lunar and Planetary Institute) says the group believes a 10- to 14-km-wide impactor was responsible for the crater-causing blast, and that it released the energy equivalent of roughly 120 trillion tons of TNT; previous impact-energy assessments were anywhere from 3 to 33 times higher. The revised crater dimensions also lower estimates for the amount of sulfur the blast launched from crustal rocks into the atmosphere; sulfur compounds created acid rain and temporarily cooled the planet after the impact. The revisions suggest that impacts can cause devastating environmental effects with less energy than once deemed necessary.

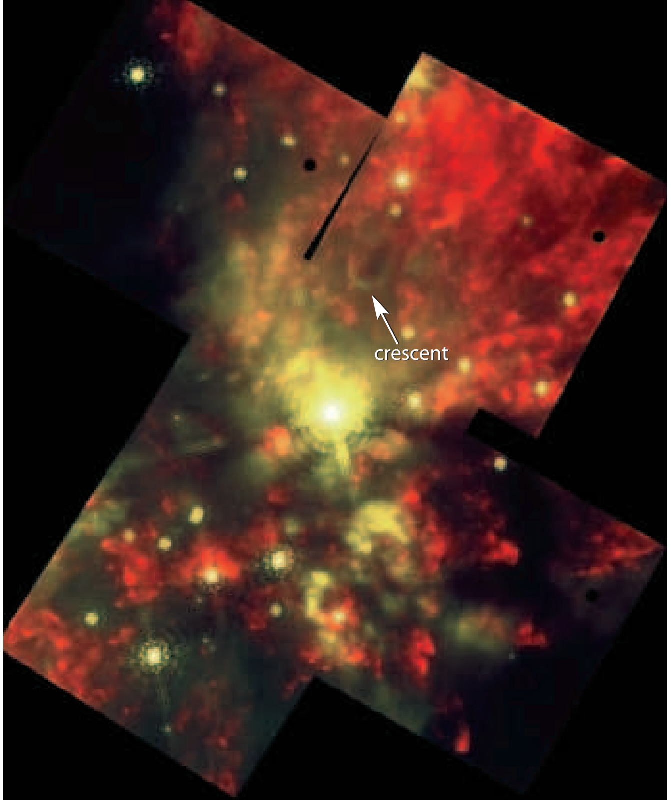
Hubble's Infrared Eye Examines Orion

Some spectacular new infrared images of the giant Orion Molecular Cloud, taken with the Hubble Space Telescope's NICMOS camera, are offering astronomers a detailed look at the goings-on in this neighboring star-forming region.

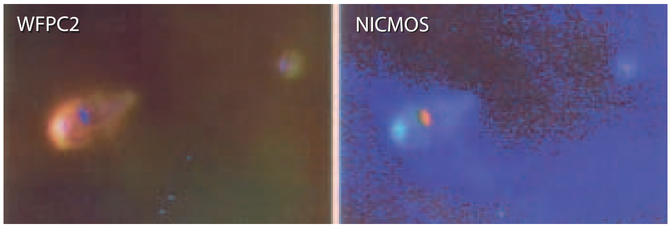
In one study, a team led by Susan Stolovy (Steward Observatory) has both uncovered new structures and resolved some previously but poorly known features for the first time. The team's mosaic, shown at right, exhibits many telltale signs that protostars are developing deep within the cloud's condensations of molecular hydrogen. For instance, a newly discovered crescent (arrowed) may represent where a dense knot of gas faces into a fast wind from a massive star embedded to its southeast (below and to the left). The knot itself may hide a protostar on the verge of being disrupted by the outflow.

Intriguingly, the brightest star in this image, known as the Becklin-Neugebauer (BN) object, is likely an interloper to the region — a *B*-type main-sequence star that only mildly affects its surroundings. The cloud's most luminous object, IRc2, is completely obscured here by cool gas, though observations at longer wavelengths show it southeast of BN. With more than 10,000 times the luminosity of the Sun, says Stolovy, IRc2 is probably shaping the evolution of much of this region. These results were reported at January's American Astronomical Society meeting and in *Astrophysical Journal Letters* for January 10th.

Another paper in the same journal discusses NICMOS images of targets in another part of Orion — the heart of its Great Nebula, M42. Those images are providing Hua Chen (also at Steward Observatory) and his colleagues with a different view of ongoing star formation. Several years ago Hubble's Wide Field and Planetary Camera 2 (WFPC2) revealed numerous isolated, compact pockets of gas and dust in the nebula's Trapezium region. Many of these knots exhibit dark centers thought to be the circumstellar disks of protostars (*S&T:* December 1996, page 15). The new NICMOS views of two of these so-called *proto*pl*anetary* d*isks*, or *proplyds,* record emission from molecular hydrogen and show the embedded disks glowing brightly. This provides the first confirmation that the disks are predominantly made of molecular gas, which suggests that they may be dense enough to lead to planet formation — that is, if they are not first disrupted by the powerful winds and ultraviolet photons from nearby *O*-type stars.



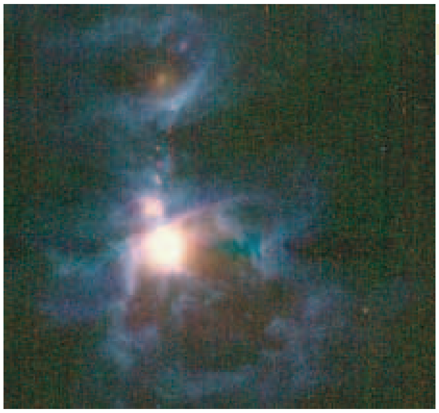
SUSAN STOLOVY



HUA CHEN

Top: **This mosaic of infrared images, taken by the Hubble Space Telescope's NICMOS camera, showcases the crowded, dynamic conditions in Orion's star-forming regions. The roughly 40-arcsecond-wide (0.3 light-year) picture is centered on an unrelated *B*-type star that happens to be moving through the cloud. The crescent-shaped feature may be the illuminated edge of a dense knot of gas within which a protostar is developing. In both this and the images below, details the size of our own solar system have been resolved.**

Bottom: **Meanwhile, in the Trapezium region of the Great Nebula in Orion, dense knots of gas known as proplyds exhibit dark centers in images taken at visible wavelengths *(left).* Thought to be the circumstellar disks around embedded stars, the dark regions glow brightly at infrared wavelengths that record emission from molecular hydrogen *(right)*.**



Another Infrared View of Orion

The orbiting Midcourse Space Experiment, or MSX (*S&T:* June 1997, page 22), has surveyed the Orion Nebula and its environs at long midinfrared wavelengths. The satellite's 33-centimeter telescope resolved dust structures and detected complex organic molecules known as polycyclic aromatic hydrocarbons (PAHs). Four MSX images were combined into this three-color picture. According to Thomas Kuchar (Air Force Research Laboratory), the wispy blue emission in this 1.5°-wide image is dominated by PAH-bearing material heated by radiation from surrounding stars. Red and yellow emission depicts the infrared glow of hotter dust heated by the young *O*- and *B*-type stars embedded in the nebula. MSX images of the Orion region will appear in a future issue of the *Astrophysical Journal.* Courtesy Air Force Research Laboratory.

A Proxima Dwarf?

Astronomers using the Hubble Space Telescope may have detected a faint companion orbiting Proxima Centauri. A team led by Alfred B. Schultz (Space Telescope Science Institute) obtained two images of the nearest star to the Sun using the Faint Object Spectrograph (FOS). Taken 103 days apart, they reveal a tiny speck, with an estimated red magnitude of 16, that appears to move with Proxima across the sky. The two bodies' apparent separation increased from 0.23" in the first image to 0.34" in the second — suggesting an eccentric orbit. Schultz's group claims it may have spotted a brown dwarf or giant planet.

One possible alternative — that the FOS captured a chance alignment with a more distant star — seems to be ruled out by the companion's motion. In addition, a search of HST data archives down to 23rd red magnitude didn't turn up any background object in the same position. In the January 1998 *Astronomical Journal*, Schultz's team estimates that the feature's inherent brightness is about six times that of Gliese 229B, a known brown dwarf. That means it would be glowing with its own light, not just reflecting Proxima's.

But even Schultz remains cautious about the object's existence, since there is no other evidence, either from HST or ground-based observations, to support it. At January's meeting of the American Astronomical Society, David A. Golimowski (Johns Hopkins University) and Daniel Schroeder (Beloit College) underscored these doubts with pictures taken by HST's Wide Field and Planetary Camera 2. Despite being able to see to within 0.09 arcsecond of Proxima, the two astronomers found no evidence for a companion.

So what did the FOS see? Perhaps Proxima itself! Golimowski and Schroeder suggest that diffraction rings in the star's image could have been modified by the secondary mirror support in the HST's optical path into a ring of "beads," much like in an amateur's reflector. They calculated that just such a bead-ring would be in approximately the same position, and have the same brightness (about 7.5 magnitudes fainter than Proxima itself), as Schultz's feature. So which interpretation is right? Until further studies are made, including a planned session with another HST instrument, the Near Infrared Camera and Multi-Object Spectrometer, the jury remains out.

Separating the Planets from the Brown Dwarfs

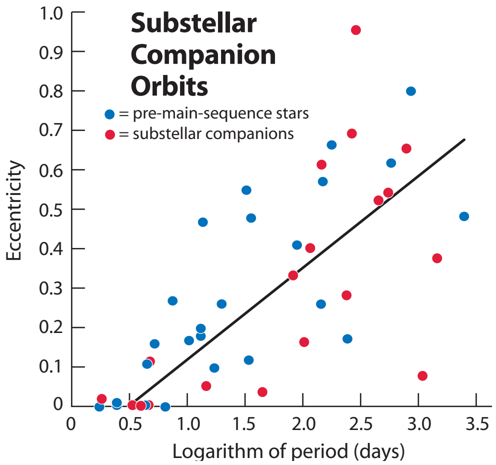
Although astronomers still have not directly imaged an extrasolar planet, they are confident such planets exist. That's because of the gravitational effects the planets impart on their parent stars (March issue, page 30). By tracking these motions, astronomers can determine a suitable orbit for any putative planet. But how can you tell the difference between a not-quite-stellar brown dwarf and a massive planet? According to David C. Black (Lunar and Planetary Institute), the answer may be in its orbit.

Writing in the December 1, 1997, *Astrophysical Journal Letters,* Black explains that the physical distinction between stars and planets arises because of their different formation paths, and their orbital characteristics may be the key in classifying them. Stellar companions, whether they are full-fledged stars or eternally cooling brown dwarfs, coalesce from gas at the same time. Planets, by contrast, form slightly later than their parent stars, as remnant circumstellar matter clumps together. Theory and observations both suggest that circumstellar matter will settle into a rotating disk, maintained by centripetal forces. Consequently, while binary stars can orbit each other at any eccentricity (as borne out from binary-star observations), the only directly observed planets — those of our solar system — have circular orbits. Furthermore, the planets attending pulsar PSR 1257+12 also have circular orbits and are believed to have formed by accretion.

Black examined the orbital properties of the substellar companions to 19 stars. He found that all but two have orbital characteristics indistinguishable from those of pre-main-sequence binary stars. Thus, he surmises, both classes of object likely formed in the same way, and the presumed planets may really be brown dwarfs. "The high eccentricities that are seen for the putative planets with orbital periods longer than a few weeks is perfectly natural if they are brown dwarfs," he writes.

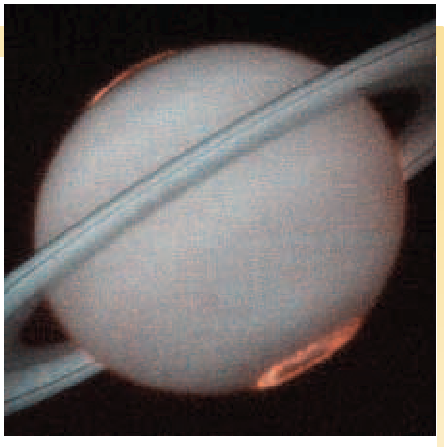
Black also notes that while companions with periods of only a few days are in circular orbits, that doesn't necessarily mean that they are planets. He explains that tidal forces would circularize a tight orbit, regardless of whether the body was a planet or brown dwarf.

The best test will come when astronomers are able to take individual spectra of stars and their hitherto unseen companions. Brown dwarfs should appear similar to Gliese 229B, the best-studied example to date. A planet, however, even a gas giant, would have a higher heavy-element fraction than its parent star. Unfortunately, such observations are vastly beyond the capabilities of today's instrumentation.

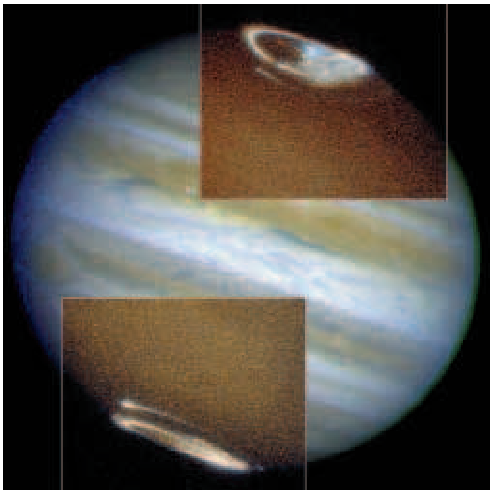


The shape of a substellar companion's orbit may reveal whether the body is a planet or brown dwarf. Comparing the eccentricities and periods of pre-main-sequence binary stars (blue) and recently discovered substellar companions (red) reveals a similarity. Adapted from the *Astrophysical Journal Letters;* courtesy David C. Black.

Extraterrestrial Auroras



One of the Hubble Space Telescope's two new instruments has returned the most detailed images yet of the auroras on Jupiter and Saturn. The Space Telescope Imaging Spectrograph (STIS) took these ultraviolet images last fall. (In the mosaic shown here, Jupiter's surface was imaged separately by Hubble's Wide Field and Planetary Camera.) The pictures highlight the similarities and differences between the two planets' "northern lights." The auroras light up when energetic particles, mostly electrons, collide with hydrogen atoms and molecules in each planet's atmosphere. But the similarity ends there. Saturn's aurora, like Earth's, is caused when solar-wind electrons are captured by the planet's magnetic field. By contrast, Jupiter's is generated by particles spewed out by Io, the giant planet's volcanically active moon. Some of these particles reside in the Jupiter-encircling Io torus; they generate the main auroral ovals that circle the planet's poles. Others directly connect Jupiter and Io, coursing in a million-ampere "flux tube" that creates the commalike trails seen outside each circumpolar oval. Jupiter and Saturn images courtesy John Clarke (University of Michigan) and John Trauger (Jet Propulsion Laboratory), respectively.



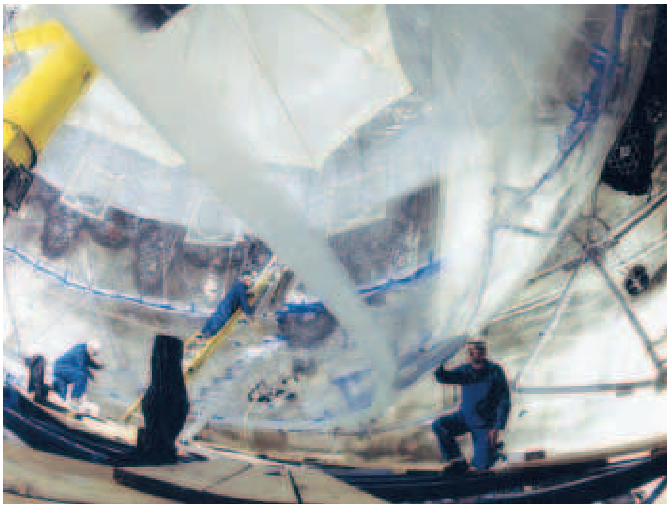
Neutrino Observatory Nears Completion

Neutrinos are the most evanescent of subatomic particles, but they pose some of the biggest questions. Do they have mass, perhaps enough to affect the expansion of the universe? Do they change from one "flavor" to another as they fly through space, contrary to the standard model of particle physics? Why do we see an unexplained shortage of neutrinos coming from the Sun?

Answers to these and other questions may soon be on the way. Two kilometers underground in a nickel mine in Sudbury, Ontario, the Sudbury Neutrino Observatory (SNO) is nearing completion.

The heart of the observatory is a clear acrylic flask, 12 meters in diameter, filled with 1,000 tons of heavy water. In each heavy-water molecule, the ordinary hydrogen atoms have been replaced by deuterium (hydrogen-2). SNO will join a variety of other neutrino detectors around the world — most notably Super-Kamiokande in Japan, which began operations just a year ago. What sets SNO apart is its heavy water, allowing it to detect not just the common electron neutrinos, which stream through us from nuclear reactions in the core of the Sun, but also the other two types, tau and muon neutrinos.

Standard theory holds that neutrinos cannot change among these three "flavors." But some experiments suggest they might. This could explain why we receive only about half as many electron neutrinos from the Sun as predicted by nuclear physics. Perhaps neutrinos "oscillate" between types while in flight, with half of them turning into the flavors that most neutrino detectors cannot directly observe. Physics dictates that if neutrinos *do* change flavor they must have mass. And, if so, the diminutive particles may actually account for an important fraction of the dark matter in the universe.



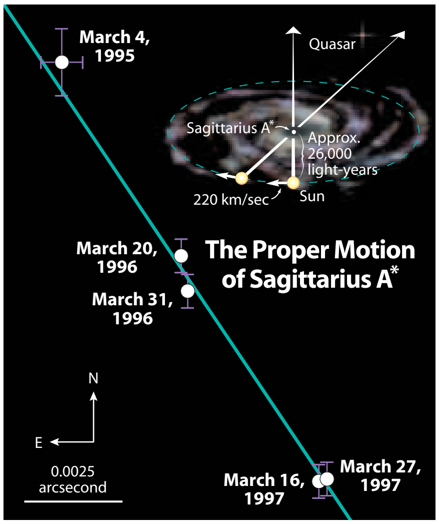
DOUGLAS HALLMAN/SNO

Building a neutrino target. In a cavern two kilometers underground, the Sudbury Neutrino Observatory should start yielding data this spring. The inner flask shown here will contain 1,000 tons of heavy water; the rest of the cavern will be filled with 7,000 tons of ordinary water as radiation shielding. Neutrinos striking deuterium atoms in the flask should generate two observable products: stray neutrons and telltale flashes of light.

SNO should begin recording electron neutrinos in May, by detecting the tiny flashes of light that their rare interactions induce in the water. About nine months later, neutron detectors will be installed in the heavy-water flask to start keeping a separate tally of muon- and tau-neutrino events. All three neutrino types will occasionally split a deuterium nucleus into its constituent proton and neutron.

Triangulating the Galactic Center

In the 1910s Harvard astronomer Harlow Shapley concluded that we lie far from the center of our "island universe," the Milky Way. Shapley used globular star clusters to deduce the center's location and distance: some 43,000 light-years in the direction of the constellation Sagittarius. Since then, generations of astronomers have approached the problem in a variety of ways. Some relied on "standard-candle" variable stars, chiefly RR Lyraes; others exploited the motions of distant gas clouds or of nearby stars. All such inferences relied on complicating assumptions, and perplexing differences remain between even the latest estimates (though on average they favor a distance about 40 percent shorter than Shapley's original estimate).



SOURCE: MARK REID; INSET SOURCE: *THE GUIDE TO THE GALAXY*

As Mark Reid and his colleagues explained at January's meeting of the American Astronomical Society, positional data from the continent-wide Very Long Baseline Array have directly revealed the solar system's orbit around Sagittarius A*, the powerful radio source at the center of our galaxy. But the enigmatic object's parallax remains just out of reach.

Now, however, Mark J. Reid (Harvard-Smithsonian Center for Astrophysics) hopes to do what astronomers consider the next-best thing to going there: measuring the galactic center's parallax. This back-and-forth motion, induced by Earth's orbit around the Sun, is the method of choice for measuring distances beyond the solar system.

Fortunately, at the Milky Way's heart lies a compact source of radio waves known as Sagittarius A* (Sgr A*). For the last three years Reid and his colleagues have been using the Very Long Baseline Array (VLBA) radio telescope to track how Sgr A* shifts with respect to two quasars that lie at vastly greater distances (*billions* of light-years). The team's positional measurements are good on average to 0.2 milliarcsecond — the apparent size of an astronaut's footprint on the Moon. This has enabled the astronomers to see Sgr A* move in a

Charles E. Worley, 1935–1997

A pioneer of double-star astronomy was lost when the U.S. Naval Observatory's Charles Worley died last December 31st at the age of 62. In 1961 Worley joined the USNO staff, where he observed prodigious numbers of double stars and maintained the Index Catalogue of Visual Double Stars (now known as the Washington Double Star Catalog). Worley wrote several articles on double-star astronomy for *Sky & Telescope* in the early 1960s.

Voyager 1 Outraces Pioneer 10

On February 17th the Voyager 1 spacecraft became the human-made object most distant from Earth. The honor previously belonged to Pioneer 10. Voyager 1 was launched in 1977 and visited Jupiter in 1979 and Saturn in 1980. Voyager 1 is now 10.4 billion kilometers (69 astronomical units) from Earth and is receding at a speed of 17.4 km per second (39,600 miles per hour) toward a point on the border between Ophiuchus and Hercules. Data continue to be received from Voyager 1, and scientists hope to discern its passage through the heliopause — the interface between the solar wind and the interstellar medium — in the next few years.

south-southwesterly direction — just as one would expect from the solar system's 220-kilometer-per-second orbit around the Milky Way's core (see the graph on the facing page).

In the coming year Reid hopes to sharpen his VLBA views by a factor of 3 to 5, chiefly by better compensating for atmospheric distortions. If he succeeds, then further work may reveal the expected ⅛-milliarcsecond parallax. If measured precisely this would exceed the range of the farthest existing triangulations — of stars, by the Hipparcos satellite — nearly 10 times over.

Information about many of the latest astronomy news stories can be found on the Internet. We provide links on our World Wide Web site's Weekly News Bulletin.

http://www.skypub.com/

tropical totality

tropical totality

Eclipse '98 in a Caribbean paradise.

"It was spectacular!"

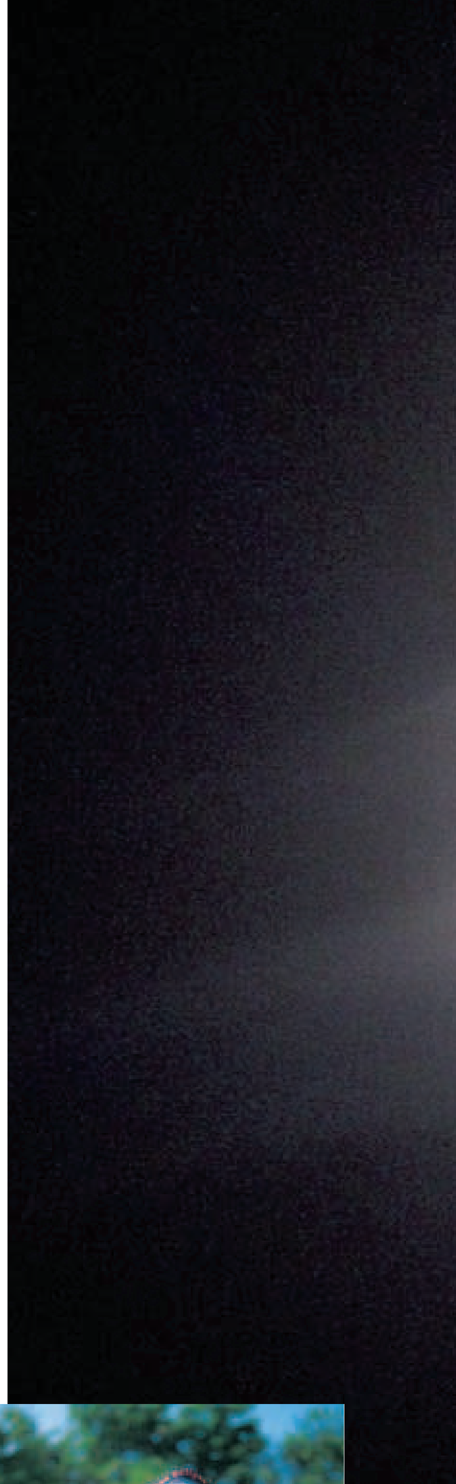
"It was spectacular!"

said Carlos Sonensein, who books sailboats for tourists on Aruba, describing the total solar eclipse of last February 26th. His joyful sentiment was shared by the tens of thousands of lucky viewers along the eclipse path in that vacationer's paradise known as the Caribbean. And why not? When circumstances combine to produce a lengthy totality during a typically sunny season in that part of the world, eclipse chasers know they've got it good.

JAY PASACHOFF

That's why a number of *Sky & Telescope* editors escaped the wintry confines of our offices in Cambridge, Massachusetts, and journeyed south in February to various tropical locales. Most were on cruise ships, affording the most flexibility if weather threatened to close in on the eclipse, while one landlubber was stationed on the beautiful island of Aruba. Cloudiness hounded many of our editors in the days prior to the 26th, but Mother Nature smiled on them when it counted most.

Each editor brought with him different backgrounds and expectations to the Caribbean, and each came away with a unique perspective on the experience. Here are their thoughts upon their return to our offices, as well as reports from meteorologist Joe Rao and *Sky & Telescope* contributing editor Stephen James O'Meara.



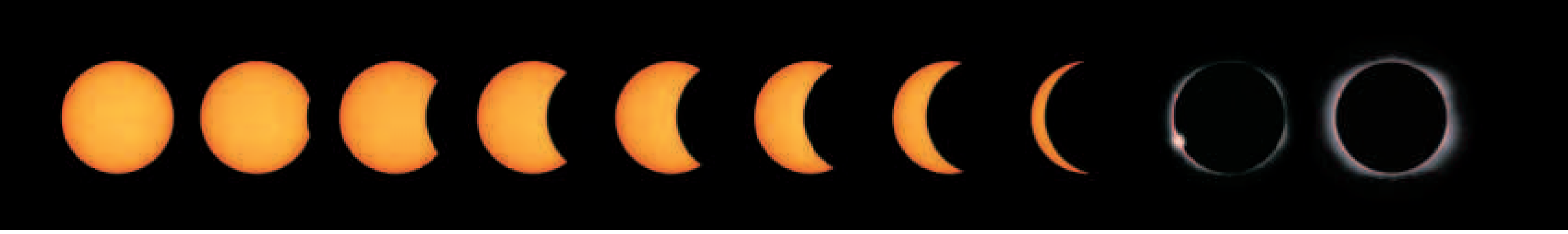
BEN GOMES-CASSERES

JAY PASACHOFF

One eclipse goer described totality on February 26th as a "black, angel-like Sun" with complex wings of corona. This spectacular image taken by contributing photographer Johnny Horne gives us an idea of what inspired that observer.

JOHNNY HORNE

JOHNNY HORNE



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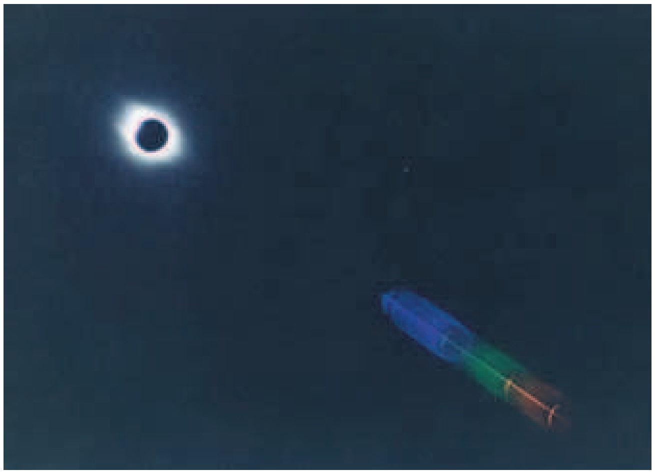
Above: **Robert and Elisabeth Slobins of Laredo, Texas, captured one of the most talked about highlights of totality: Mercury (top) and Jupiter accompanying the Sun.** ***Below:*** **At third contact they recorded the flash spectrum, which shows the chromosphere's prominent emission lines.**



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First Darkness

panama

By J. Kelly Beatty • off the Pacific coast of Panama

Like any first-time eclipse chaser, I agonized over how to make the most of my precious few minutes in lunar shadow. To photograph, or not to, consumed me for days. I'd heard countless stories of carefully prepared plans turned to mush by balky shutters, inadvertent goofs, and the mesmerizing power of the solar corona. In the end I decided simply to observe, both with my unaided eyes and through an 80-mm refractor.

Cloudiness and high seas dogged us on Cunard's *Vistafjord* southward through the Caribbean, but February 26th dawned with nearly cloud-free skies. Satellite images showed us sitting squarely in a fat clearing amid the equatorial cloud masses.

As the Sun's light waned, I mentally reviewed what I call The Script: the obligatory viewing checklist found in every eclipse guide. A well-prepared observer, we're told, should be alert to the onset of eerie twilight, tiny crescents dappling the ground, shadow bands, sky color, Baily's Beads, diamond rings, coronal streamers, brushes, prominences, and so on — a daunting set of observational must-sees. As a tour leader on the *Vistafjord,* I admit to having endorsed The Script to those in my group. "Watch for the Moon's approaching shadow," I had urged. "Take time to look for planets and stars."

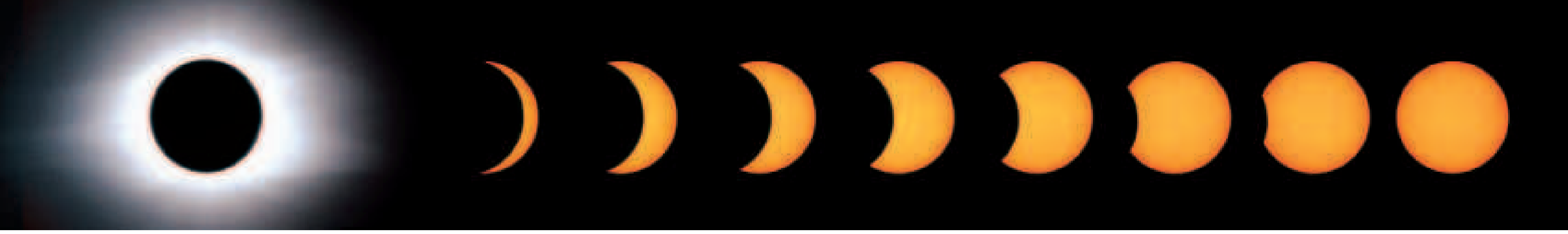
Suddenly, and more abruptly than I'd anticipated, totality enveloped us. I tried gamely to take in the rush of sensations with measured pacing, but it was no use. No matter what else I tried to observe, my eyes were drawn again and again to two phenomena for which I was totally unprepared.

One was the naked-eye spectacle of two planets closely accompanying that glorious hole in the sky. Tiny Mercury blazed at magnitude –1.5, the visual equal of distant Jupiter at –1.9. As shipmate Suzanne Barnett of Nazareth, Kentucky, described it, the paired planets were "riding escort on either side of the eclipsed Sun, with much brighter Venus farther west like an announcing herald." The other stunner was how dazzlingly bright the corona appears to the unaided eye. The Sun's million-degree atmosphere is incandescent in its own right, but I had expected something more muted. The telescope revealed delicate yet distinct detail in the polar brushes and equatorial streamers. No mere image can do it justice.

A long, unbroken arc of deep-salmon chromosphere lingered on the west limb for several seconds. Then it was over.

I was immediately depressed. My heightened senses were anything but satisfied, left exposed to the Sun's waxing crescent like raw nerve endings. Despite the generous span of totality, I had seen no shadow bands, no Baily's Beads. A pair of modest prominences were colorful but hardly spectacular. The sky did not get nearly as dark as I'd hoped it would.

Maybe I had expected too much. Veteran eclipse chasers tell me that each event has a unique character. So I suspect that The Script applies to all totalities in sum, not just one in isolation. That being the case, bring on August 1999!



These 19 exposures span 3 hours 15 minutes, encompassing the entire eclipse as seen from Westpunt, Curaçao. A native of Curaçao now living in Lexington, Massachusetts, Benjamin Gomes-Casseres photographed this series through a Takahashi FS102 4-inch f/8 refractor using an Olympus OM-1 camera and Fuji Velvia film.

Reactions from the Locals

By Alan M. MacRobert Aruba

On the Caribbean island of Aruba, a prime destination for eclipse tourists, the residents were just as enthusiastic. In the capital city, Oranjestad, the onset of totality was greeted by crowds gasping, whooping, and cheering in the streets. Car horns blared in a steady chorus of celebration, and a fireworks display arched Sunward. The emotional power of the eclipse affected everyone. "I was imagining I was in a different world," said local hotel worker Willie Balisalisa, groping for words. "We observed everything going dark, the streetlights going on, the colder temperature, the dark eclipse in the sky — it was not like the world we live in."

The city came to a standstill around eclipse time, with most businesses and stores closing so everyone could go out and watch. Cardboard "eclipse shades" with aluminized Mylar filters had been widely distributed among the island's 89,000 residents and 14,000 tourists who had booked every available room. Some failed to realize that it was safe to remove the eye protectors when totality began. Others expressed fear that their pets might go blind because they couldn't wear the shades. But most Arubians approached the eclipse with enthusiasm over the "great scientific event," the flood of tourists, the presence of NASA scientists and CNN cameras, and the chance to extend the local Carnival season an extra day.

In some places, enlightenment about eclipses was more the exception than the rule. In Haiti, according to an Associated Press report, fear of the partial eclipse "produced a panic that caused schools to cancel classes and businesses to shut. Parents thrust children under beds. A Haitian mayor had warned that people's eyes would burst if they looked at the sun." Four members of a family died either from suffocation — they had plugged every opening in their home to keep out sunlight — or from overdoses of sleeping pills taken to calm their fears. On the mountainous coast of Colombia, the indigenous Arhuaco people reportedly hid and prayed to the Father Sun god.

This passenger aboard the *Statendam* showed some innovation in his setup, securing his Questar to a patio table with duct tape!

Just after third contact, Gomes-Casseres caught this "long crescent" diamond with a 1/30-second exposure. His setup, together with 5½-year-old daughter Rachel, is shown on page 28.

They told reporters that the eclipse was a sign of the Sun god's anger at the ongoing environmental damage to their region. In Nicaragua, pregnant women reportedly took cover due to a local superstition that they would be harmed by exposure to an eclipse.

But with the spread of modern communications such reactions are probably growing rarer. Elliot Tramer, a professor of biology at the University of Toledo, Ohio, found himself in a remote fishing village of about 30 people on the Venezuelan coast as eclipse time approached. The locals had never seen optical gear before and marveled at views of boats through his 20 spotting scope. But as for the eclipse, Tramer said, "they were pretty sophisticated about it. Most of them knew it was the Moon covering the Sun. Someone even had welder's glasses that they passed around to watch. I made a pinhole in a business card and showed some children how to project the crescent Sun on the ground. The parents were feigning disinterest, but every so often when they thought no one was looking they would take the card and project an image to see the progress of the eclipse.

"Everyone just took it as a lot of fun. They broke out beers for us. They were about as excited by it as we were."

Left: **Conrad Pope of Wilmington, North Carolina, captured earthshine on the eclipsing Moon using a 94-mm Brandon refractor and field flattener from Aruba.** ***Right:*** **Baily's Beads are a classic eclipse must-see, but many observers claimed difficulty seeing them with the unaided eye. With a 1/500-second exposure Johnny Horne imaged them using a Nikkor 600-mm f/4 lens set at f/5.6 and Fujicolor HGV 400 film.**

A New Era for Eclipse Imaging

By Dennis di Cicco ● in the eastern Caribbean

Eclipse photography has been around as long as, well, photography itself. In July 1842, less than three years after Louis Jacques Mandé Daguerre revealed his daguerreotype process, G. A. Majocchi successfully recorded the partial phase of a total eclipse at Milan, Italy. Although he failed to capture the corona, in less than a decade it too was being routinely photographed and there was no looking back.

S&T / DENNIS DI CICCO

During the last 25 years, eclipse travel blossomed into a cottage industry as many thousands of people, creative photographers included, ventured into the path of totality. The result is a stunning array of photographs as evidenced by hundreds of fine pictures that have appeared in this magazine.

As this century draws to a close, a new era in eclipse imaging is emerging — the digital era. As always, the challenge is to capture the full range of coronal detail and brightness in a single view. To that end, previous photographers resorted to radially graded filters and sophisticated darkroom techniques such as combining a sequence of exposures. While pioneering work was done in the darkroom, today's digital processing offers numerous advantages.

Nevertheless, it was the exception rather than the rule for passengers aboard Holland America's *Ryndam* to have advanced photographic plans. Missing from its decks was the heavy telescope equipment that often springs up at land-based sites. The fare was definitely lightweight camera gear.

Charnanis Chiu of North Point, Hong Kong, came prepared to image! His equipment included a Canon L1 video camera with an image-stabilized lens and two programmable Canon cameras attached to 400-mm f/2.8 and 200-mm f/1.8 lenses both with 2 converters.

Indeed, a remarkable number of people simply chose to record the event with hand-held cameras and short exposures — even those using telephoto lenses of 200-mm focal length and greater. Although most of these images recorded only the bright, innermost corona, the results exceeded most people's expectations and stand as testament to what can be accomplished with today's fine-grain, high-speed color emulsions.

A few 3- to 5-inch Maksutov and Schmidt-Cassegrain telescopes were scattered about the ship, but the preferred optics were telephoto lenses in the 300- to 500-mm range. While some of the photographers were intrigued by the idea of computer processing their eclipse shots, no one I spoke with had specific plans.

There were scores of video cameras pointed Sunward during the eclipse. But here too the photographers rarely had elaborate goals and many were only making casual recordings. At a standing-room-only, show-and-tell session after the eclipse only a few of the more than 1,200 passengers offered to show their video recordings.

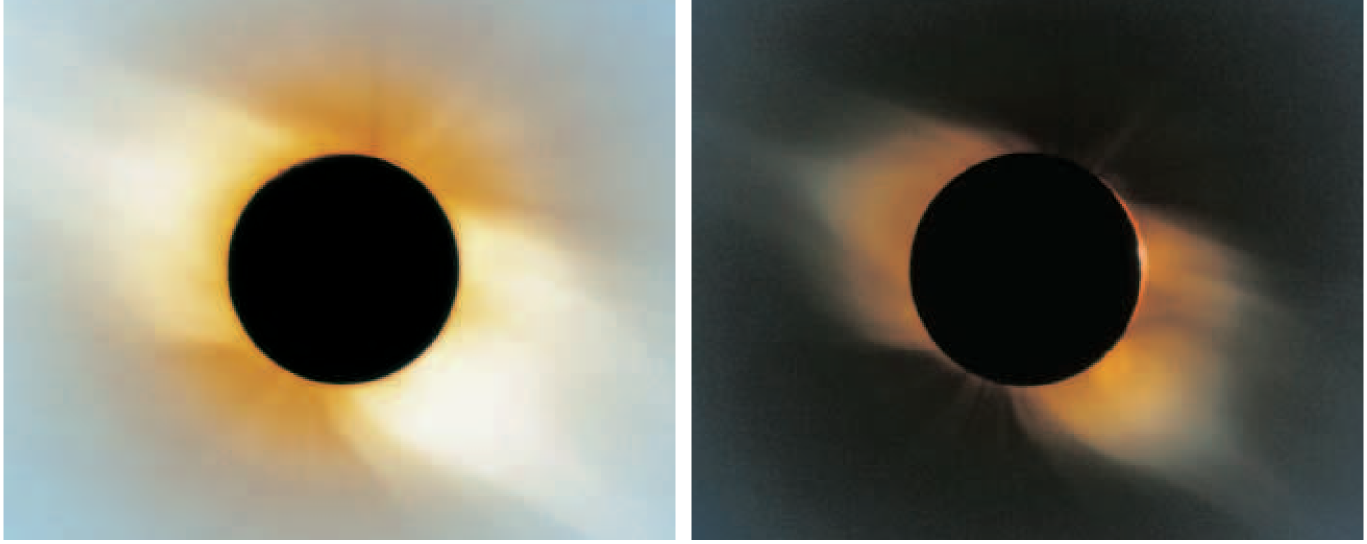
For the most part, people aboard the *Ryndam* were there to enjoy the eclipse visually and perhaps bring home a snapshot or two for their scrapbooks. As one passenger summed it up moments after totality ended, "How could any photograph do justice to such an overwhelmingly spectacular sight? To experience it you have to have seen it firsthand." Few would argue the point.

Confessions of Eclipse Chasers

By Edwin L. Aguirre ● mid-Caribbean

The Moon's shadow had barely left the Earth's surface on February 26th when thousands of amateur astronomers along the path of totality in the Caribbean asked, "When is the next one?"

The business of chasing solar eclipses to far reaches of the world has become a multimillion-dollar commercial tourism industry. During the last 40 years, the availability of economical land, sea, and air transportation has made eclipse sites accessible to practically anyone — from serious observers to plain sightseers. It's no wonder that people are spending more and more time under the Moon's shadow than during



Jonathan Kern, part of an eclipse expedition to Aruba sponsored by Williams College, recorded these coronal images using entirely homemade equipment, including a 4-inch quartz/fluorite doublet fed by a coelostat and a radially graded neutral density filter. At left is a 5-second exposure taken on Kodak Pro 400 PPF-2 film. The 1-second exposure at right is of the emerging third-contact diamond ring taken on Fujicolor NPS film.

any period in history. “We let Mother Nature plan our vacations!” declared Derald and Denise Nye of Tucson, Arizona, who witnessed the February eclipse aboard the Holland America cruise ship *Veendam*. “We go wherever the eclipse takes us.”

The Nyes started eclipse chasing in the early 1970s. They now have a combined total of 28 solar eclipses (21 totals and 7 annulars), spending more than an hour under the Moon’s shadow. They consider this recent eclipse to be the best one so far, in terms of the planets visible during totality. “To see Mercury, Jupiter, and Venus all lined up together with the eclipsed Sun is simply stunning!”

Glenn Schneider, a professional astronomer at Steward Observatory in Arizona, has been chasing eclipses purely for aesthetic reasons and personal enjoyment. His first one was as a 15-year-old in North Carolina in March 1970, and he has been hooked ever since. Schneider has seen 18 out of the 21 total eclipses he’s traveled to, accumulating about an hour’s worth of totality. He found the February event “really spectacular, with a well-structured corona seen high in the sky.” He shared the experience with his 3-year-old daughter, Maia.

The youngest eclipse viewer aboard was 7-week-old Elizabeth Anne Weeks. According to her parents, Douglas and Richelle Weeks of Roseburg, Oregon, Elizabeth was “a bit frightened, restless, and anxious” with the approach of the Moon’s shadow, but she calmed down as soon as totality began. The oldest eclipse veteran, 101-year-old Philip Carret of Scarsdale, New York, bagged his 20th successful total eclipse to date. Carret finds eclipses a very “religious and awe-inspiring experience.” He saw his first one in 1925 in Westerly, Rhode Island, and he intends to see the last total eclipse of the millennium next year in Europe.

S&T / EDWIN AGUIRRE

The youngest and oldest eclipse goers aboard Holland America’s *Veendam.* Tiny 7-week-old Elizabeth Weeks poses with her parents and 101-year-old Philip Carret, a veteran of 20 totalities.

Eclipses at Sea: Commercial, Yes! Successful, Yes!!

By Leif J. Robinson off Curaçao

Like diamonds strung on a necklace, each total solar eclipse is as beautiful as it is unique. Yet I’ll remember 1998’s mainly because it featured the largest flotilla ever to sail in search of darkness — at least 16 major cruise ships accompanied by windjammers and other “escorts.” The Caribbean was littered with enthusiasts afloat. The reason is simple: this eclipse was long, the U.S. economy was robust, clear-weather prospects were fabulous, and nature’s timing provided a nifty excuse for North Americans to trade ice for sunshine.

The ships had grand success. No surprise here — that’s been the rule for major eclipse cruises. The capability of carrying huge numbers of people many miles to avoid weather problems at the 11th hour probably doubles the chances of seeing an eclipse. (But this spectacular track record could be tarnished in 1999 by very-high-risk trips into the North Atlantic; see the April issue, page 36.)

Just after the eclipse ended, I thought about how the sport of eclipse chasing en masse began. It wasn’t that long ago — 1972 to be exact — and, curiously, it started with the *Olympia*’s sea voyage. Major land tours began to crop up only later, when cruises weren’t an option.

By my estimate, 20,000 people wined, dined, and absorbed this event at sea. By another estimate, I think this number doubles that for all previous eclipse sailors!

But numbers can be deceiving. The 14 or so ships that sailed to the six eclipses between 1972 and 1995 almost exclusively carried amateur astronomers and their families. They were advertised and executed as true eclipse expeditions.

That wasn’t the case in 1998. Some lines merely added an eclipse cachet to their promo pieces but did not have a plan to maximize the chance of actually viewing the event. Others skipped the science-enrichment program that highlighted previous eclipse cruises. One "clothing optional" cruise was even billed as "not designed as a scientific expedition with stuffy professor lecturers peering through binoculars"!

Nevertheless, it's probably fair to say that about as many amateur astronomers and eclipse buffs watched the 1998 spectacle from shipboard as had done so during the previous quarter century! Aboard Holland America's *Statendam,* I polled the 1,300 passengers and found that 80-90 percent were taking their first eclipse cruise. It seems that eclipse cruising has taken a quantum leap in popularity.

Ever better satellite imagery, communications, and weather predictions will only enhance the ability of shipboard expeditions to satisfy enthusiasts with great views of eclipses. I hope everyone gets a chance to experience at least one of them at sea!

Benjamin Gomes-Casseres took no chances when preparing to snap this 1-second exposure of the Sun's corona. The night before the eclipse he aligned the equatorial mount on solid ground and sheltered it from the wind. (His equipment is described on page 31.)

A Narrow Escape

By Joe Rao ◐ off Guadaloupe

Exactly 19 years after observing my third solar eclipse in the near-freezing conditions of Roy, Montana, I observed my seventh in summerlike weather from the deck of Celebrity Cruises' *Galaxy.*

JAY PASACHOFF

On eclipse morning under 80 percent cloud cover, we stopped at St. Johns, Antigua, to allow passengers to disembark if they wished. After leaving port we were soon drenched with a brief rain squall, and the forecast didn't look good. But as we approached Guadaloupe and first contact, we had blue sky. When the last of the clouds dissipated a half hour before second contact, electricity filled the air: the nearly 2,000 passengers knew that our weather problems were now behind us.

The water took on an eerie deep purplish hue as totality approached. When it arrived, the pearly corona was a classic "minimum" type, with long coronal streamers, streaks, and tendrils seen through 7 35 binoculars. Mercury and Jupiter seemed to explode into view at the moment of second contact. After a breathtaking 3 minutes and 12 seconds, our second diamond ring of the day emerged. For those fortunate to be near the front of the ship, two whales were seen to breach the sea surface right after totality ended.

When we docked at Antigua that evening, some returning passengers reported being hampered by clouds during the eclipse while others experienced ideal conditions.

JOHNNY HORNE

Magic in the Galápagos

By Stephen James O'Meara ◐ off Pinta Island

Aboard a 100-foot yacht among the Galápagos Islands, 24 eclipse adventurers and I observed 3 minutes and 59 seconds of totality under crystal clear skies at the eclipse centerline. Actually, totality was prolonged because the diamond ring at third contact lasted a full 10 seconds, so the total experience was longer than 4 minutes.

The morning of the 26th dawned calm and clear over the yacht, though shortly after first contact at 9:30 local time, conditions began to change. Seas swelled and a stiff breeze picked up. The temperature dropped from a stifling 115° Fahrenheit in the Sun to 88° F just before second contact.

Suddenly someone shouted that it was beginning to rain! This caught everyone off guard, because the sky was perfectly clear. Yet a look off the eastern bow revealed the water dancing madly, seemingly from an invisible rainstorm. Precious seconds were ticking away in utter confusion, until Donna O'Meara yelled out that the night fish had surfaced and were in the midst of a feeding frenzy!

Totality fell without grace from the apex of the sky — like a man falling from a plane without a parachute — hitting the surface of the Earth with a visual SLAM! As the end of totality neared, something magical happened. Two distinct rubies appeared from the lunar valleys and flared to prominence. Then, the entire western limb of the Moon turned red — it was pure magenta fire! After several seconds the apparition began to separate into a broken hedgerow before a prolonged diamond ring emerged, lasting 10 seconds, during which time the corona could still be seen with the naked eye. Moments later, dozens of dolphins leapt from the water near us, frolicking and careening in the waves.

have you been flashed by iridium?

by philip chien

You're out in your yard at night, observing the stars. Suddenly you notice an incredibly bright flare growing in the sky, one that outshines Venus 100 times over. It moves slowly and steadily, swelling in brilliance before fading away seconds later.

Have you just seen a burning airplane? Some kind of slow-motion meteor? Or perhaps a supernova or a meteor? If your sighting has taken place since May 5, 1997, you've more than likely seen sunlight reflecting off an Iridium* communications satellite. The satellites' antenna arrays are almost perfect mirrors. And when they catch the Sun just right — *wow!*

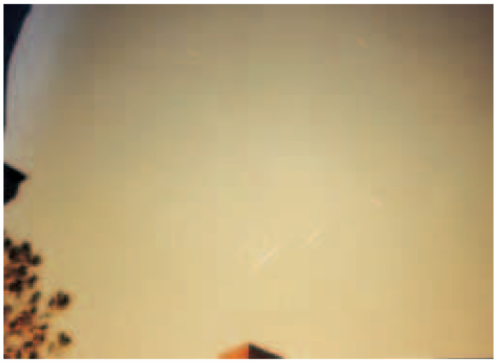
*IRIDIUM® IS A REGISTERED TRADEMARK OF IRIDIUM LLC.

an iridium primer

Iridium is the first of several anticipated "Big LEO" satellite constellations. Each will contain a large number of *l*ow-*E*arth-*o*rbit spacecraft. Several, like Iridium, will transmit digitized phone calls. Others are being designed with wireless electronic mail in mind. Iridium's shiny Main Mission Antennas (MMAs) are built to relay digital traffic at frequencies from 1616 to 1626.5 megahertz. The MMAs are made by Raytheon; the spacecraft are being assembled by Motorola Satellite Communications, Inc., in Chandler, Arizona.

If all goes according to plan, the $5-billion project's 66 satellites will orbit the Earth in six evenly spaced orbital planes, with 11 spacecraft in each. Originally there were supposed to be seven planes and 77 satellites. Hence the name Iridium, whose atomic number is 77. Appropriately, perhaps, drawings of the finished satellite array bear a superficial resemblance to the high-school model of electrons orbiting an atomic nucleus. (Understandably, when the constellation was reduced to 66 satellites Motorola chose not to rename it Dysprosium.)

The first five Iridium satellites were launched on May 5, 1997, aboard a Delta II rocket. Amateur satellite observers were anxious to see the quintet in its parking orbit because of the unusual sight they anticipated: several satellites in a row, looking like a line of dots traveling across the sky. They were not disappointed. Within a day of the May 5th launch, spacecraft sleuth



Above: **A textbook flare. Iridium satellite number 35 lit up the predawn sky in Boston's western suburbs on February 1, 1998. *Sky & Telescope* photograph by Dennis di Cicco.**

Early birds. Looking southwest last August 26th from Houston, Texas, Paul Maley caught five Iridium spacecraft (from left to right, numbers 22 through 26) as they flared while crossing the southernmost reaches of Cetus. Maley took this 90-second photograph at 11:02 UT. The spacecraft have since separated to occupy separate positions in a common orbital plane.

Bane or boon? A new fleet of communications satellites sparkles in the evening and predawn skies.

A mystery no more. Meteor-like flares from the Iridium communications satellites can now be predicted with freely available software and orbital elements. This photograph of the north celestial pole, taken by Ronald Lee last October 5th, caught sunlight glinting off Iridium satellite number 6.

Ronald Lee reported seeing all five satellites.

Since Iridium's inaugural launch, American Delta, Russian Proton, and Chinese Long March vehicles have been used to put more of its satellites in orbit. Each launch vehicle's dispenser system ejects the satellites into a 500-km-high parking orbit, where they typically spend a couple of weeks being checked out by ground stations. The "birds" are then raised by their own onboard propulsion systems to their intended operating altitude of 792 kilometers. In its 100-minute operational orbit, each satellite circles the Earth 14.34 times a day.

Iridium LLC hopes to deploy all 66 spacecraft, in addition to 6 spares, sometime in mid-1998. At press time 51 Iridium spacecraft had been launched, though two had technical problems that have prevented them from reaching their intended orbits.

a spark in the dark

As skywatchers well know, many artificial satellites occasionally brighten as seen from the ground. Indeed, the Hubble Space Telescope is one of the most popular "variable-magnitude" satellites. As Hubble turns to aim at a new target, its solar arrays and highly reflective surfaces can appear to brighten by a couple of magnitudes. So it wasn't a complete surprise when bright Iridium flares were first reported last summer by Brian K. Hunter, a chemistry professor at Queen's University in Ontario, Canada.

On August 16, 1997, Hunter reported the following to the members of SeeSat, an electronic-mail group of satellite watchers: "I was observing on Thursday evening [August 14th] when my attention was drawn to a very bright object in the northeast. . . . It stayed very bright for several seconds and then faded slowly."

"As it faded," Hunter continued, "I picked it up in my 80-mm f/5 telescope at 32 . It faded to a bit less than 6th magnitude by the time it passed 2 degrees above Kappa Pegasi at 01:54:31 [Universal Time]. The timing is dead on for Iridium 4, and the [nonflare] brightness is typical of the Iridium satellites."

As numerous subsequent observers can attest, it's incredibly exciting to get "irradiated." A typical Iridium flare lasts 10 to 20 seconds and can range from "just visible" to "incredibly bright," depending on the Sun-satellite-observer angle. At its peak it's difficult to estimate a flare's magnitude because there's often nothing comparably bright in the night sky. During their brightest periods the spacecraft will typically cross 5° to 10° of sky.

Lee described one of his flare observations on an October 5, 1997, posting: "I set up my camera [in Falcon, Colorado]" and saw Iridium

On their way. Following a November 9, 1997, evening launch from Vandenberg Air Force Base *(right)*, a Delta II rocket heads south with another five Iridium spacecraft *(above)*. Brian Webb took this photo from Santa Ynez Peak near Santa Barbara, California. Sunlight illuminated the vehicle's exhaust plume while Venus sparkled to the right. Launch photograph courtesy Boeing Co.; trail photograph copyright 1997 Brian Webb.

freeware for predicting iridium flares

If you're like most of our readers, you'll probably be content with a Web page that tells when the next Iridium flares can be seen from your home. Thanks to the German Aerospace Center (Deutsches Zentrum für Luft- und Raumfahrt, or DLR), such a site exists, and it's even in English. It simply asks for your latitude, longitude, and time zone. It then lists your Iridium flares for the next seven days. (The program provides only those flares that occur when the Sun is below the horizon.) Each comes with its date, time, predicted visual magnitude, elevation, and azimuth; the identity of the flaring satellite is listed too. Point your browser to http://www.gsoc.dlr.de/satvis/. You can also get Mir-pass predictions and other satellite-viewing tips.

For those who want to investigate the Iridium-flare phenomenon a bit more deeply, two MS-DOS programs for predicting flares are freely available over the Internet. The programs, written by Randy John and Rob Matson, can be downloaded from the Visual Satellite Observer's Home Page (VSOHP) for Iridium observations (http://www.satellite.eu.org/sat/vsohp/iridium.html). Documentation provided with each program tells how to operate it.

			Iridium Coordinates				Range	Sat.		Solar					Peak	Std.	Maximum Flare	
Ir	Date	Time	Azm.	Elev.	R.A.	Dec.	(km)	N	Ill	Azm.	Elev.	M	Flr. Ang.	Mag.	Mag.	Mag.	Latitude	Longitude
30	97-12-17	6:20:47.3	064	27	18^h00	35.9	1476.8	D	Lit	114	−8.0	F	0.81	0.0	−6.7	−1.6	42.5058	−71.3510
30	97-12-17	6:20:51.0	066	27	17^h57	35.1	1471.9	D	Lit	114	−8.0	F	0.24	−6.0	−6.6	−7.6	42.3316	−71.2839
30	97-12-17	6:20:54.6	067	27	17^h54	34.4	1467.6	D	Lit	114	−8.0	F	0.80	0.0	−6.6	−1.6	42.1618	−71.2195

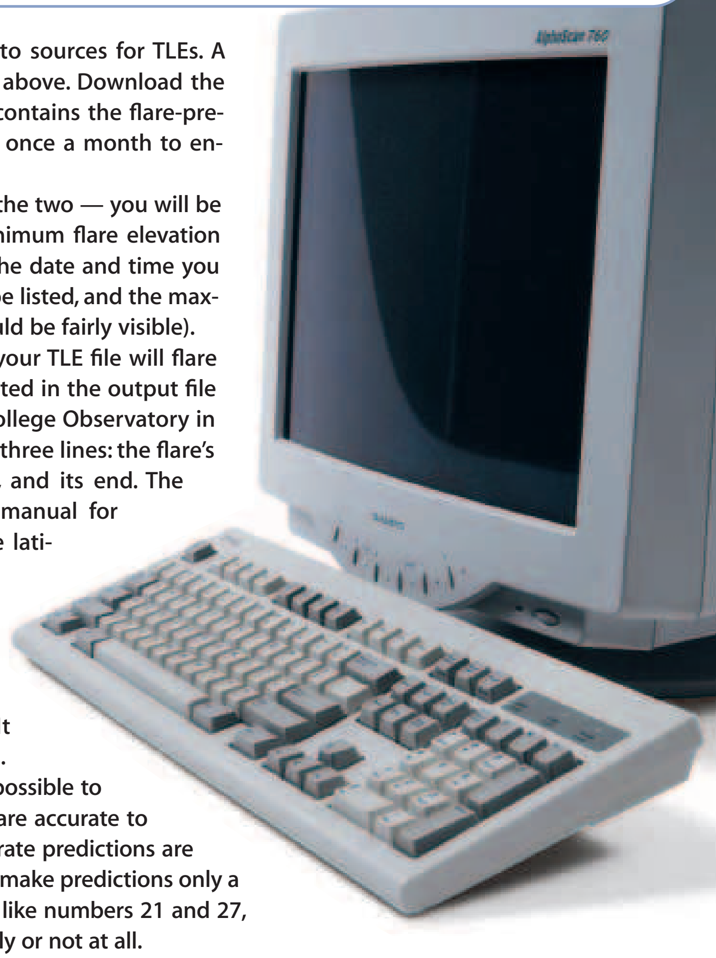
Latitude: 42.38000 Longitude:−71.13000 Altitude: 24.0 m; Time Zone: UTC −5.0^h

```
                  TWO-LINE ELEMENTS FOR IRIDIUM 8
1 24792U 97020A   97349.24306626  .00000010  00000-0 -36164-5 0  1419
2 24792  96.4004  55.3584 0003260 109.8578 250.2967 14.34215336 32117
```

Each program requires an ASCII file containing recent "two-line elements" (TLEs), the standardized mathematical quantities that define a satellite's orbit. The VSOHP home page includes several links to sources for TLEs. A representative TLE for Iridium satellite number 8 appears just above. Download the latest Iridium TLEs and save them to the same directory that contains the flare-prediction program. You should download new elements at least once a month to ensure accurate predictions.

When you run Matson's IRIDFLAR program — the simpler of the two — you will be prompted for the name of your TLE file (IRIDIUM.TLE), the minimum flare elevation angle, your latitude, longitude, and elevation, your time zone, the date and time you want the calculations to start, the dimmest flare magnitude to be listed, and the maximum reflection angle (anything less than about 5 degrees should be fairly visible).

The program will then determine whether each satellite in your TLE file will flare within the constraints you've imposed. The flares (if any) are listed in the output file in chronological order. A sample flare prediction for Harvard College Observatory in Cambridge, Massachusetts, appears above. Each prediction has three lines: the flare's approximate beginning, its moment of maximum brightness, and its end. The columns are thoroughly explained in FLARE.TXT, the user's manual for Matson's program. One useful feature: the output file lists the latitude and longitude where each flare is expected to be brightest. This could tell you if a drive across town will greatly enhance your view of a flare — information not currently available on the DLR Web site.



Randy John's program produces a sky map that shows a satellite's position against the stars at the time of each flare. It also can be used to produce a simple listing similar to Matson's.

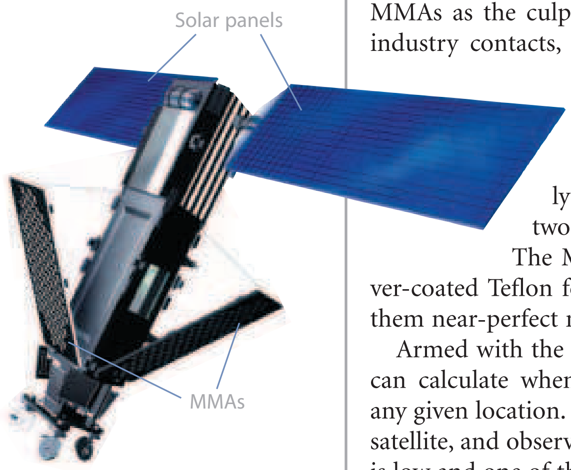
Obviously these utilities can't predict your weather! But it is possible to see bright flares through thin cloud cover. The predicted times are accurate to within seconds, so set your watch ahead of time. The most accurate predictions are generated when you use the most recent two-line elements and make predictions only a day or two into the future. A recently launched satellite (or one, like numbers 21 and 27, that has failed to reach its intended orbit) may flare unpredictably or not at all.

#6 appear, "dim at first . . . then it flared up quickly to [become] the brightest satellite I have ever seen. Sirius looked DIM in comparison."

a specular solution

As the summer of 1997 progressed, many satellite observers reported their observations to one another, carefully noting the position of a particular Iridium when it flared. It was quickly evident that the flares are very sensitive to the geometry of the satellite, the Sun, and the observer.

At first, satellite aficionados assumed that the flares were caused by solar panels reflecting sunlight. But detective work by Paul Maley of the NASA/Johnson Space Center Astronomical Society identified the flat, shiny MMAs as the culprit. As Maley learned from industry contacts, an Iridium satellite's main axis always points toward the center of the Earth. One antenna faces roughly forward and slightly downward, while the other two antennas point to the sides. The MMAs are covered with silver-coated Teflon for thermal control, making them near-perfect mirrors.



Iridium anatomy. When deployed as intended, an Iridium communications satellite's axis points to the center of Earth, while three silvered Main Mission Antennas (MMAs) lean outward, peppering the Earth with data-bearing radio transmissions — and the occasional glint of sunlight. (The third MMA lies behind the triangular spacecraft in this depiction.) Courtesy Donald Baker, Iridium LLC.

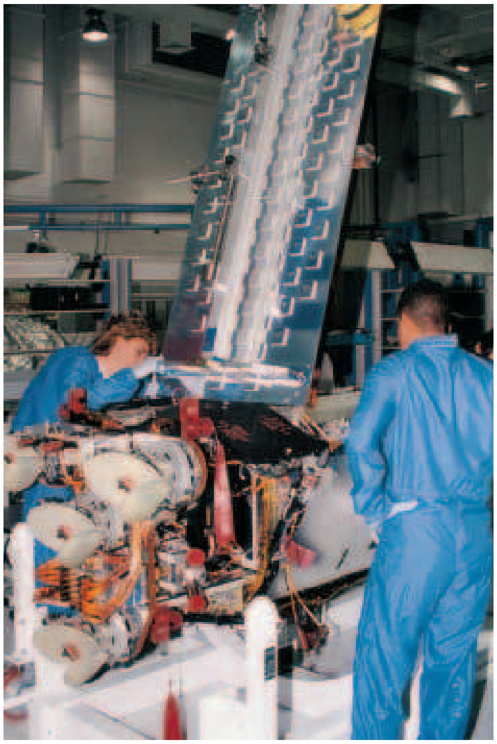
Armed with the proper data, a programmer can calculate when a satellite is visible from any given location. The angle between the Sun, satellite, and observer follows. When that angle is low and one of the MMAs rotates into place, an incredible flare will dazzle the observer.

By September 29th, artificial-satellite followers Rob Matson and Randy John almost simultaneously announced that they had independently figured out how to predict when an Iridium "bird" would flare. Each has generously made his program available for free on the Internet (see page 37). Using public orbital data from the United States Space Command (USSPACECOM, formerly NORAD), the programs determine where Iridium satellites are in their orbits. They then calculate the angle between the Sun, the MMAs, and you to determine when you'll see a flare.

mirror, mirror, on the sky

You may find the brightness of an Iridium flare hard to comprehend until you actually see one. Observers have reported seeing flares as bright patches in the clouds when the sky has been thinly overcast. Many have seen flares in blue daytime skies. Finding daytime flares is similar to viewing Venus during the day: if you know exactly where to look (and in the case of satellites, when) then it can be done.

At first glance, it's rather amazing that each MMA is just a door-size 188 by 86 centimeters. It's hard to believe that what amounts to a full-length dressing mirror can cause such a bright glint from its 800-km orbit around the Earth. But it turns out that each MMA spans about 0.11 square arcsecond on the sky when nearly overhead. A patch of the Sun's surface this size shines at a magnitude of roughly –8, comparable to the brightness of a thick crescent Moon.



The Model T of communications satellites. Motorola employees carry a Main Mission Antenna *(top)* to an awaiting Iridium spacecraft *(middle)*, then mate them *(bottom)*, ultimately placing three antennas on each satellite. At times in 1997, a satellite rolled off the Chandler, Arizona, assembly line every five days. Courtesy Kathi Haas, Motorola Satellite Communications Group.

Brighter-than-Venus flares are visible only from a small area at any given time. A drive across town can convert a merely impressive flare into an incredibly bright one. Prediction programs assume that the MMAs are at their specified angles from the spacecraft's body, that the satellite's main axis is perfectly vertical, and that the Earth is smooth. None of these assumptions holds exactly, so a flare's predicted magnitude should be taken with a grain of salt. That being said, the predictions have often proved to be spot-on.

Statistically, the greater your latitude (north or south), the higher the chances that an Iridium satellite will be visible. The six highly inclined orbital planes converge nearly over the poles. At intermediate latitudes in the winter — poor viewing circumstances — you can expect an average of one or two modest flares per night. The odds of seeing a "monster" flare are much lower.

a blessing or a curse?

The good news is that the flares, while a potential nuisance for observational astronomers, are too brief to be a major source of light pollution. There are more than 8,000 artificial objects in space, and every one of them has the potential for leaving a streak on a long-duration photographic exposure. So in percentage terms, 72 additional objects and a handful of upper rocket stages do not add up to a very large addition.

In a narrow field of view, the odds that an Iridium flare will occur as you're observing are quite low. But with a wide field, especially a long-duration time exposure, it's certainly a concern. One obvious precaution is to obtain computer predictions before planning astrophotography. If a flare is anticipated within your target's field of view, you can either take the image another time or cover the lens with your hand when the flare is anticipated.

It's possible that a flare could affect dark-adapted eyes. But the flares certainly are not as harmful to night vision as a searchlight or car headlight seen head-on.

Admittedly, it's always regrettable when a new source of light pollution is created. But now that the flares are predictable with a fair amount of accuracy, they can be — depending on your attitude — exciting events in their own right.

PHILIP CHIEN *is a Florida-based space writer. He extends special thanks to the members of the SeeSat electronic discussion group for their assistance and observations. SeeSat can be joined by sending an electronic-mail message with the word "subscribe" in the subject field to the administrative address (SeeSat-L-request@lists.satellite.eu.org).*

iridium's astronomical impact

by joshua roth

If you are an eyeball astronomer or astrophotographer, you may or may not agree with Philip Chien when he asserts that brief flares of reflected sunlight from the Iridium satellites don't pose a major threat. True, most telescopes have narrow fields of view and are hence unlikely to endure many wiped-out exposures. But the Iridium spacecraft will follow one another only 9 minutes apart on near-polar orbits, one or more of which lie above the horizon at any given time. Furthermore, they will be visible to many of the world's astronomers for much of the night during summer months.

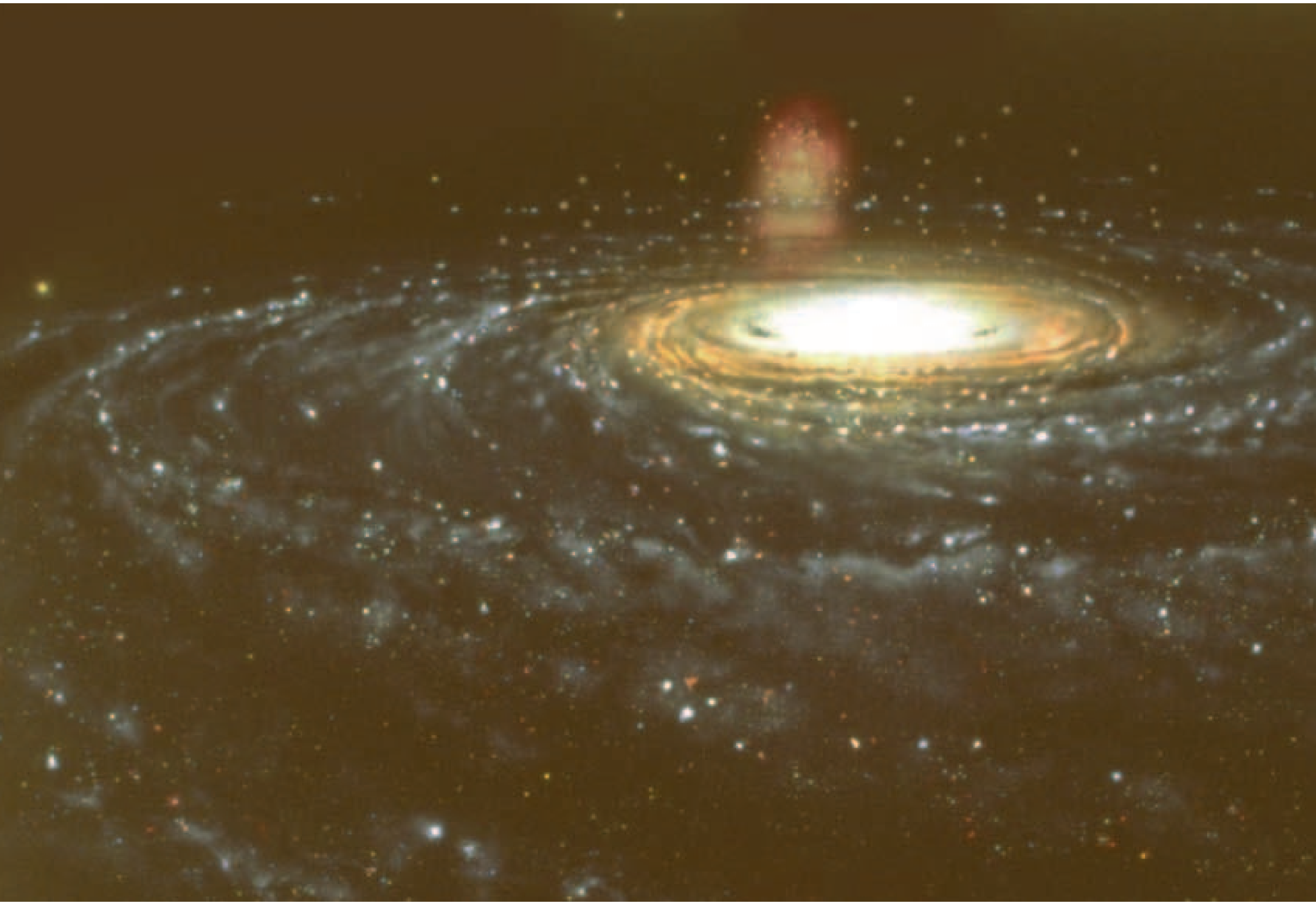
Radio astronomers have a lot more to worry about. Iridium satellites are virtually guaranteed to fall within their telescopes' sidelobes (areas of unintended but unavoidable sensitivity). A narrow spectral band from 1610.6 to 1613.8 megahertz (MHz) has been set aside for astronomical use by international law; it brackets the 1612-MHz line emitted by hydroxyl (OH) radicals in star-forming clouds and cool stellar envelopes. In the United States, the Federal Communications Commission (FCC) has authorized Motorola Satellite Communications to beam slightly higher frequencies (1621.35 to 1626.5 MHz) from Iridium satellites to handsets on U.S. soil. If done perfectly, this should pose no problems for hydroxyl-line studies.

NRAO'S 42-METER RADIO TELESCOPE AT GREEN BANK, WEST VIRGINIA; COURTESY NRAO

But astronomers have concluded — and Motorola has conceded — that Iridium's Main Mission Antennas are destined to generate some signals in the protected hydroxyl band (*S&T:* April 1997, page 41). The spillover is expected to increase with the volume of phone and/or data traffic on the Iridium network. However, the precise relationship between such traffic and proscribed emissions must be calibrated empirically before Motorola can decide how best to protect astronomical observations — a requirement of its provisional U.S. license. Motorola was supposed to conduct spectral-spillover tests with the U.S. National Radio Astronomy Observatory (NRAO) last year. But as this issue of *Sky & Telescope* went to press, NRAO had not yet been given the opportunity to calibrate the emissions from any of the Iridium satellites.

Once the tests do take place, Motorola will know if it needs to curb or reroute some of Iridium's usage in order to satisfy the conditions of its FCC license. (The satellites themselves cannot be modified once in orbit, and two-thirds of the system has already been launched.) NRAO, for its part, isn't banking entirely on protection from the FCC. In a 1994 memorandum of understanding with Motorola, the institution agreed to restrict hydroxyl-line work to early-morning hours, when Iridium usage should bottom out. But at the time of this writing, no other major radio observatory had signed a similar agreement, despite intense lobbying from Motorola. (So say numerous astronomers; Motorola declined to comment on the subject or to grant *Sky & Telescope* an interview.)

Follow the **needle-in-a-haystack** search for galaxies



Our Galaxy's Nearest Neighbor

By Ray Jayawardhana

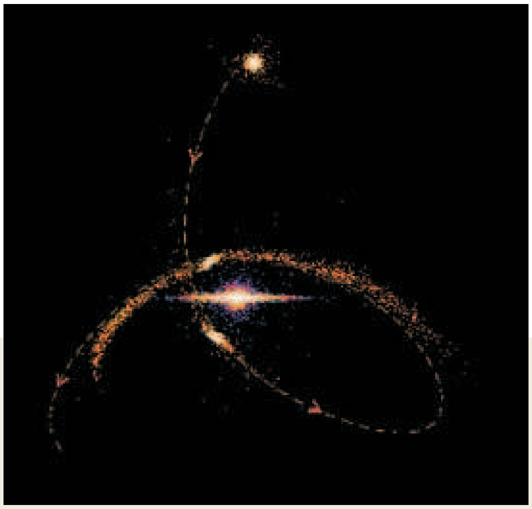
As part of his doctoral thesis at Cambridge University, Rodrigo Ibata set out to scrutinize certain stars near the center of the Milky Way. Under the guidance of his adviser, Gerard Gilmore, he wanted to find out how our galaxy's bulge rotates and to study the chemical composition of bulge stars. In early 1994 Ibata was at the 3.9-meter Anglo-Australian Telescope (AAT) in Coonabarabran, Australia, to obtain spectra of some of the stars in his sample. The AAT — equipped with a multiobject spectrograph that could measure the light of more than 50 stars at a time — was ideal for his purpose.

being cannibalized by the Milky Way.

"We were in the middle of the survey when I noticed a few of the stars, which happened to be very red, had rather peculiar velocities, different from the rest of the stars," says Ibata. "They appeared to be moving together." Most of the bulge stars he looked at have radial velocities close to zero. That is, they move neither away from nor toward us, but instead primarily across our sight line. But in three patches of sky Ibata was observing, a few stars were moving rather swiftly away from Earth — at about 140 kilometers per second. "It was a very, very weak signal initially, and I wondered if it was a statistical fluke," he remembers. After all, there were only about 10 stars in his sample with velocities this high. But, when Ibata plotted the velocities of all the stars against their colors, he noticed something intriguing. "Those 10 or so stars happened to have almost exactly the same color. . . . That's what tipped us off."

First Hints

The next night Ibata decided to get spectra for more of the red stars in his sample. When he added their velocities to the plot, his previous hunch seemed justified. "The signal got stronger, and we were very excited." The following night he and his colleagues measured red stars almost exclusively.

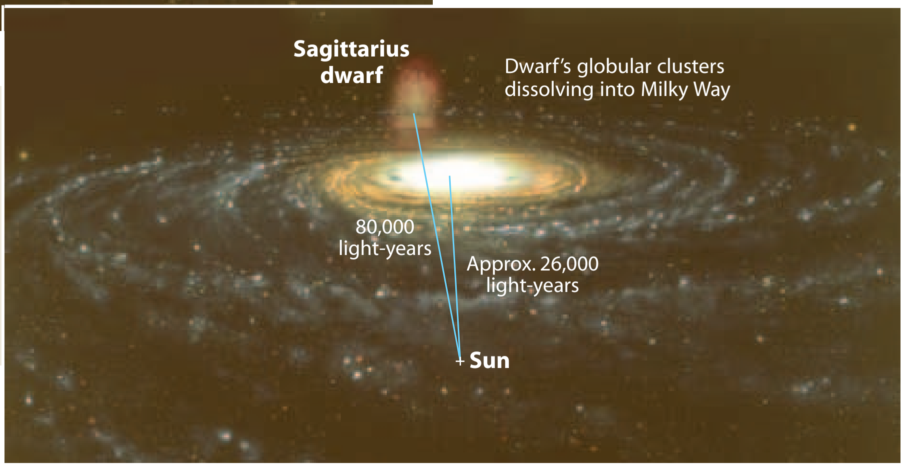


KATHRYN JOHNSTON AND CHRIS MIHOS

When he went back to Cambridge, Ibata wondered how these fast stars were distributed in the sky. To find the answer he walked down the road to the Royal Greenwich Observatory, where Michael Irwin had a stack of photographic plates taken with a wide-field Schmidt telescope. Together Ibata and Irwin scanned the plates for the same region of sky and plotted the positions of red stars that have brightnesses similar to those with the unusual velocities.

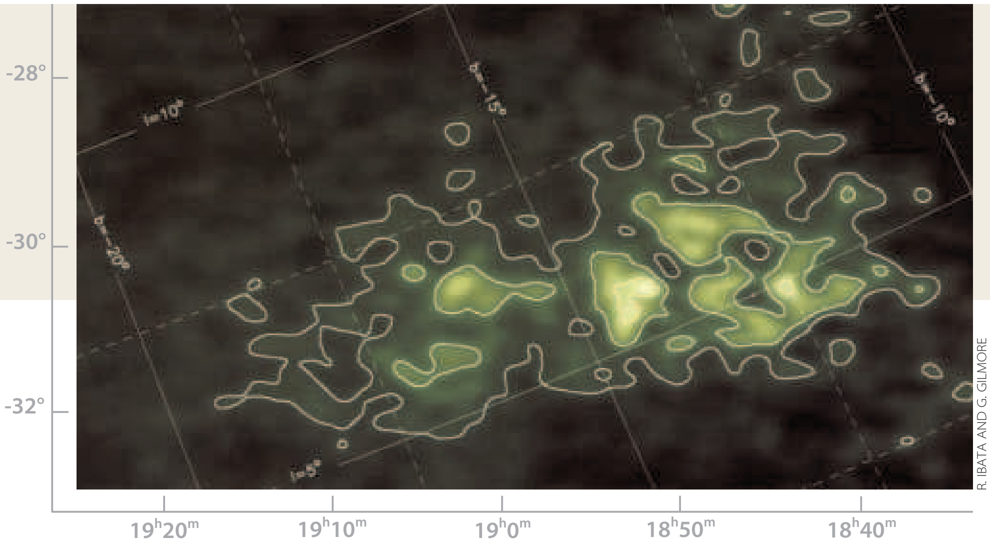
Confirmation

"All of a sudden, you could see the contours of what looked like a new galaxy," says Ibata. And that's exactly what it turned out to be — a nearby dwarf spheroidal galaxy that had eluded astronomers because it lies roughly 100,000 light-years away on the other side of our galaxy's center, where it is nearly hidden by the Milky Way's thick veil of stars and dust. The new galaxy, named Sagittarius after the constellation it lies in, appears to be tidally disrupted by our galaxy's gravity, so that its gas and the orbits of its stars are stretched out. To Ibata it seemed to be spread over some 10° —



"All of a sudden, you could see the contours of what looked like a new galaxy."

Facing page: **The Sagittarius dwarf galaxy is plotted against Jon Lomberg's *Portrait of the Milky Way,* copyright the artist and the National Air and Space Museum. *Above:* Because the dwarf lies on the far side of our galaxy from the Sun, it is impossible to discern visually. *Upper right:* The distribution of the Sagittarius dwarf's stars suggests that the galaxy is being tidally disrupted by the Milky Way. A simulation of the dwarf's orbit starts with the intact galaxy a half billion years ago, followed by its present state of distortion. The simulation ends a billion years from now with Sagittarius's stars spread out over a vast region of space. The dwarf's size with respect to the Milky Way is greatly exaggerated here.**



This false-color image shows density contours for the Sagittarius dwarf spheroidal galaxy, the nearest companion to the Milky Way. The light of foreground stars has been subtracted. The brightest, densest clump in this image is globular cluster M54.

about 20 times the Moon's apparent size — in the sky, lying roughly perpendicular to the plane of the Milky Way. That means it is about 10,000 light-years across, or 10 times the size of a normal dwarf spheroidal galaxy.

Ibata and his colleagues reported their discovery at a symposium in Scotland in April 1994, and in a paper published in *Nature* that July. When the news reached Mario Mateo of the University of Michigan, he was on a long observing run at Las Campanas Observatory in Chile. He decided to monitor the newly discovered galaxy to see if any of its stars showed signs of varying in brightness. He hoped to discover RR Lyrae stars — bloated, aging stars with regular variations that could be used to infer their intrinsic brightnesses, and thus their distances. Sure enough, he found a number of them. The result was a more accurate distance to the Sagittarius dwarf: it lies only 80,000 light-years away from Earth, 50,000 light-years on the other side of the galaxy's center. This is closer than any other companion galaxy to the Milky Way yet known, about half the distance of the Large Magellanic Cloud.

What's more, Mateo obtained deeper images that revealed for the first time some of the dwarf's main-sequence stars — those that, like the Sun, burn hydrogen in their cores. Ibata's team had measured only bright red giants that had already left the main sequence and were approaching the ends of their lives. "We agreed in almost every detail with Ibata's group," says Mateo. "They had done a very nice job of identifying and getting the preliminary characteristics of Sagittarius."

Follow-Up

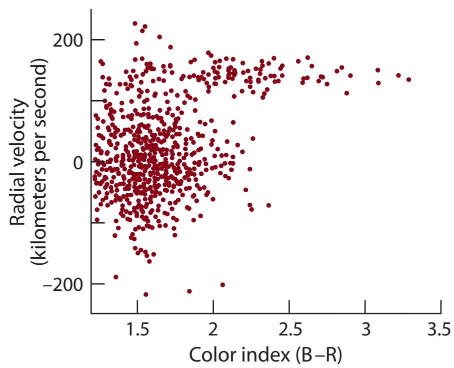
The next challenge was to "map out the full extent of Sagittarius — see how far out we can trace it," Mateo explains. Against the Milky Way's star-packed central regions, it is no easy task to identify which of those tens of thousands of stars belong to the evanescent Sagittarius dwarf. Several groups of astronomers, including Mateo's, did the best they could, first by picking out the stars with appropriate colors and brightnesses, then subtracting those known to be foreground objects. What they were left with, they hoped, would be true Sagittarius-dwarf stars. Of course, the only way to be sure would have been to obtain a spectrum of *each star* and measure its velocity.

From their studies of star fields in the direction of the globular cluster M55 (unrelated to the newfound galaxy), Mateo's group found a string of Sagittarius-dwarf stars — a "tidal tail" that lies 10° away from the tiny galaxy's center. Meanwhile, in a 1995 paper Gary Da Costa (Mount Stromlo Observatory, Australia) and Taft Armandroff (Kitt Peak National Observatory) argued that four globular clusters previously believed to be part of the Milky Way actually belong to the Sagittarius dwarf. They based this conclusion on the globulars' velocities, distances, and positions in the sky. These are M54, Terzan 7, Terzan 8, and Arp 2. "Taken together, these results suggest that Sagittarius is at least 20° [20,000 light-years] long along its major axis!" says Mateo.

The observations showed that the dwarf galaxy is so spread out its gravity can't possibly hold the stars together. In fact, some of its stars, and even globular clusters, may have already crossed over to the Milky Way. As Ibata's team pointed out in its *Nature* paper, Sagittarius "provides us with a snapshot of an early phase of the tidal destruction of a satellite galaxy." Mateo agrees: "Sagittarius is the most extreme example of a dwarf galaxy torn apart by tides. It is depositing globular clusters into our galaxy's halo right now."

Observers as well as theorists are excited because Sagittarius provides a

Analysis



This plot represents the first star fields measured by Rodrigo Ibata in the direction of the Sagittarius dwarf. He discovered that galaxy thanks to the high radial velocities of its stars, between about 120 and 180 kilometers per second, making them stand out sharply from the more sluggish field stars in the Milky Way.

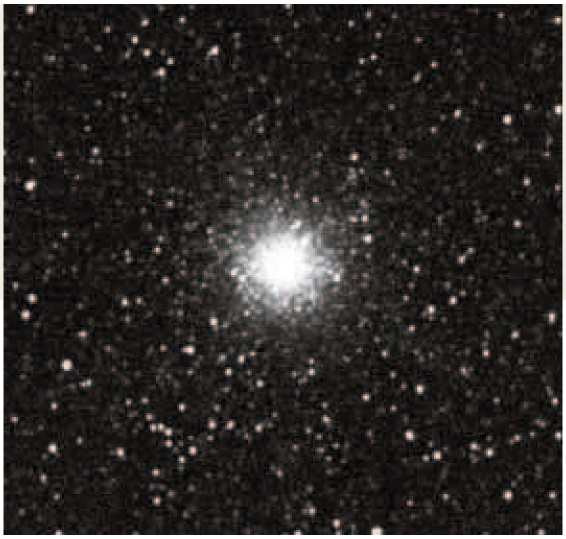
> **"Sagittarius is the most extreme example of a dwarf galaxy torn apart by tides. It is depositing globular clusters into our galaxy's halo right now."**

Implications

unique example of how the Milky Way eats up dwarf galaxies that come near it. "We're quite interested in how a dwarf galaxy like this might dissolve and turn into the galactic halo," says Mateo. In fact, he likens the halo of our galaxy to "a bowl of spaghetti where the strands correspond to the orbits of things that were disrupted long ago." While the exact orbit of Sagittarius is not known, most astronomers who study it believe its stars will be fully incorporated into the Milky Way within the next 100 million years or so. However, its remains — in the form of star groups moving together in the galactic halo — should be detectable for more than a billion years, according to computer simulations by Kathryn Johnston (then at the University of California, Santa Cruz) and her colleagues.

Given that Sagittarius is dissolving into our galaxy's halo, "there is reason to start wondering if other parts of the halo formed via similar accretions," says Mateo. But astronomers aren't yet sure how much of the halo might have formed this way. Globular clusters in the halo seem rather similar to their counterparts in dwarf spheroidal galaxies; after all, the four clusters now known to belong to Sagittarius were long believed to be normal halo clusters. However, so-called "dark matter" — matter whose presence is inferred from its gravity but isn't directly visible — may pose a problem to this model of halo formation. Our galaxy's halo appears to contain 10 to 100 times more dark matter than observed dwarf spheroidals do.

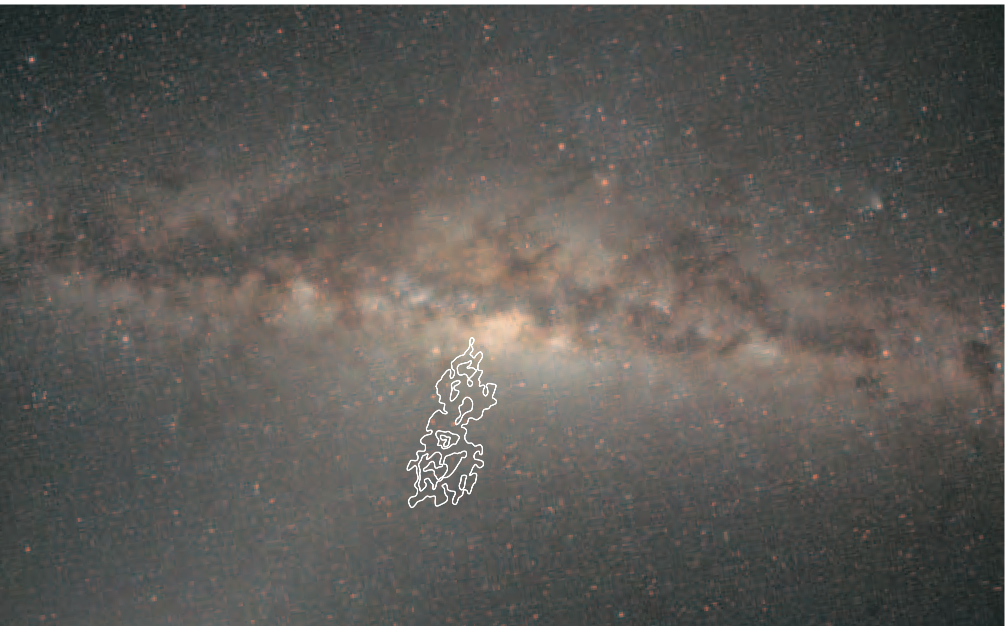
One way out of the dark-matter discrepancy would be to argue that there are lots of extremely dark dwarf galaxies with very few, if any, stars. "The general claim that the halo is made up of dissolved dwarfs is not ruled out by observations, but does demand a few odd things — like dark dwarfs and a much higher accretion rate in the past — that need to be proven or refuted," says Mateo in summary.



Once thought to be a Milky Way denizen, globular cluster M54 is now known to belong to the Sagittarius dwarf galaxy because of its velocity and distance.

FRED KREIMER

As its name implies, the Sagittarius dwarf lies on the far side of the Milky Way's center from us in the direction of the constellation Sagittarius. This composite image, roughly to scale, shows the dwarf's location. A backyard photograph of this region would show no sign of our nearest galactic neighbor, as its diffuse stars are hidden by intervening dust and gas.



SAGITTARIUS DWARF: R. IBATA AND G. GILMORE. MILKY WAY IMAGE: S&T / DENNIS DICICCO

Could there be other dwarf satellites of the Milky Way yet to be found? "Boy, I sure hope so!" is Mateo's answer. "I wouldn't be surprised if there are a couple more hiding near or behind the galactic disk." In addition, there may be signatures of disrupted dwarfs in the galaxy's halo. Steven Majewski (University of Virginia) and his colleagues are looking at various sight lines in the halo for groups of stars that appear to be moving together — possible remnants of dissolved dwarf galaxies. Mateo himself is conducting a large-scale survey of our galaxy's halo for such remnants. But don't expect a rush of discoveries anytime soon. As Mateo explains, "It is a *very* slow business even when you are observing every month!"

Ray Jayawardhana, *a graduate student at Harvard University, studies star formation. His article "Destination: Galactic Center" appeared in the June 1995 issue.*

Revolutionary New Binoculars

Canon's new image-stabilized binoculars offer remarkably steady hand-held views of the night sky at an attractive price. | **By Dennis di Cicco**

Test Report: Binoculars

Canon's 15 45 IS Binoculars
Image-stabilized roof-prism binoculars

Canon U.S.A.
One Canon Plaza
Lake Success, NY 11042
www.usa.canon.com
Street Price: $1,100+

It's no gimmick. Hand-held, the image-stabilized Canon 15 45 binoculars yield astronomical views matching those in much larger glasses. All photographs by Chuck Baker.

"THE NICEST BINOCULAR OBSERVing I've ever done." That's how *Sky & Telescope* Associate Editor Alan MacRobert summarized his first outing with Canon's new 15 45 image-stabilized binoculars. My experience was just as profound. Indeed, I was astonished when my first view through these technological marvels resolved the three brightest Trapezium stars in the Orion Nebula — I'd never done that before with hand-held binoculars. If our initial reactions sound like an endorsement, they should; together we've accumulated decades of experience observing the night sky with many different binoculars.

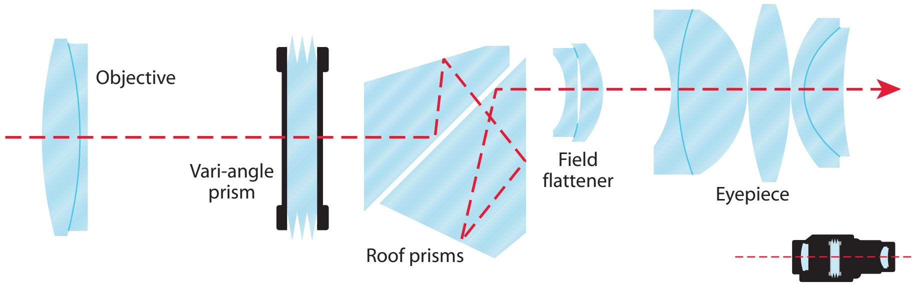
I've never heard anyone speak disparagingly of a binocular view of the heavens. Binoculars offer the novice an excellent and intuitive way to explore what the sky has to offer, while veterans typically savor the low-power, wide-field views coupled with the comfort of using both eyes.

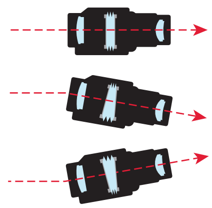
But pick up any pair of binoculars and you'll quickly discover a major shortcoming — the image jiggles. No matter how steady your hands are, or how carefully you brace yourself, the view in binoculars always bobs around. The shaking becomes particularly pronounced with magnifications of 10 or greater. This motion robs the image of fine detail and compromises any view of the night sky.

To counter this shake, amateur astronomers and entrepreneurs have devised a remarkable assortment of binocular mounts ranging from simple tripod brackets to contraptions so elaborate that a reviewer likened one to a "mechanical donkey." As useful as these devices can be, they all restrict the simplicity and freedom that I consider a fundamental aspect of binocular viewing. Whether I'm standing, sitting, or lying on the ground, what I like best about this type of observing is the ability to instantly point a pair of binoculars at any part of the sky. Too bad these views are shaky.

Well, not any more. The revolutionary image-stabilizing technology that Canon developed for its video camcorders is now available in three pairs of Canon binoculars — 10 30, 12 36, and 15 45. We borrowed the most powerful pair for testing because high magnification places the greatest demands on image stabilization and because the large aperture is best suited to astronomical work. Nevertheless, if our experience serves as a guide, the smaller apertures should work well too, especially since the image stabilization allows you to view fainter objects than you might think possible with these apertures.

At the heart of the image stabilization is what Canon calls a vari-angle prism — a pair of glass plates joined by flexible bellows. The space between is filled with a silicon-based oil. Solid-state sensors, using Canon's proprietary technology, and a





In addition to the vari-angle prism *(right)* that flexes to stabilize the image, the Canon binoculars include a field-flattening doublet ahead of the eyepiece. It helps deliver a razor-sharp image to the edge of the field.

microprocessor detect pitch and yaw movements and silently control the vari-angle prisms to stabilize the image. The sensors work at any orientation, so there are no restrictions on where the binoculars can be pointed. They also work in total darkness and are thus fine for astronomical observing.

Outwardly the binocular appears rather conventional, if slightly bulky, except that the objectives remain fixed and the 60-to-70-millimeter interocular distance is adjusted by swiveling the eyepieces. There is a standard ±3 diopter adjustment on the right eyepiece that had more than enough range for my widely disparate eyes. Focusing is accomplished with a center knob, and the close-focus distance was about 17 feet (5 meters) for the test unit.

A pair of AA batteries powers the image-stabilization system. Canon recommends alkaline, lithium, or rechargeable nickel-cadmium batteries. The system becomes operational at the press of a button on the top right of the housing. This location is conveniently reached with either the right index or middle finger. When the batteries are good a small, red, light-emitting diode goes on for a second or two each time the button is pressed. It takes a fraction of a second for the stabilization to kick in, and it stops the instant the button is released.

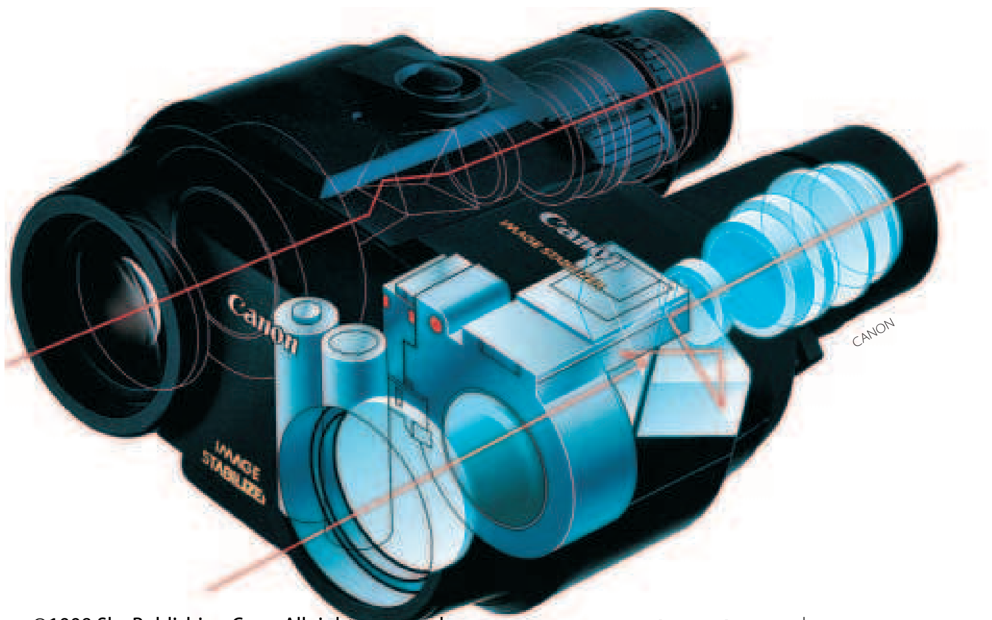
Canon lists the range of operating temperature for the stabilization system as 14° to 112° Fahrenheit (–10° to 45° Celsius). On one 9° F night I left the binoculars outside for several hours and they worked fine. Battery life, however, is very dependent on the type and temperature of the batteries. Canon rates alkaline batteries for only 5 minutes of continuous operation at the minimum specified temperature, but lithiums should last 3 hours. Since our test alkalines lasted 18 minutes at 13° F, the Canon rating seems quite conservative. At room temperature Canon says alkaline batteries will last for 1½ hours of continuous use and lithiums for 7 hours. Since real-life applications would rarely call for continuous operation for more than a minute or two at a time, the batteries last much longer than these numbers imply. Nevertheless, it's a good idea to keep an extra pair of fresh batteries in a warm pocket when you are planning a long night under the stars.

Even without the stabilization, this is a fine pair of roof-prism binoculars. The fully multicoated optics deliver bright, contrasty images that are completely free of color fringing. The view is also razor sharp to the edge of the field. The apparent field is 67°, while the true field is a very generous 4.5°. Deep rubber eyecups effectively block stray light from entering the eyes of people who observe without eyeglasses. The cups fold down for eyeglass wearers. The eye relief is 15 millimeters, so most people who wear eyeglasses can still see the full field. The binoculars weigh 2¼ pounds (1 kilogram), which is a few ounces on the heavy side of average for this aperture glass. Rubber "armor" provides a nonslip grip and helps protect from small bumps if the glasses are knocked about.

What really sets these binoculars apart, however, is the stabilization system. Press the button and the image settles down. It doesn't freeze solid as it would if the binoculars were on a fixed mount, but the image "wanders" so slowly that your eyes effortlessly lock on to it, making fine detail easy to see. MacRobert's observations paint an accurate picture.

> I barely resolved the brightest three stars in the Trapezium. The companion of Delta Orionis was easy, and I suspected the companion of Rigel. Lots of new double stars will qualify as "binocular doubles" with these glasses. I picked up the diffuse nebula M78 in Orion, and I could see the orientations of the galaxies M81 and M82 in Ursa Major. Lots of open star clusters were partially or totally resolved as never before in hand-held binoculars. Fine detail on the Moon was like using a small telescope!

What I found particularly impressive was how well these binoculars compared to much larger apertures. At first I pitted them against a good pair of 7 50 binoculars that I've used for astronomy during the past 20 years. But the difference in magnification and field of view made a subjective comparison difficult. Stars seemed as bright in both glasses, but the added magnification of the Canon binoculars made easier work of targets like



The image-stabilization system is located just behind the objectives and includes a flexible prism, solid-state pitch and yaw sensors, and a microprocessor. With dead batteries or even a system failure the binoculars still function as "regular" 15 45 glasses.

Jupiter's moons, even without the stabilization working. I switched it on and the view totally blew away what I had seen in the 7 50s!

In another test I paired the Canon glasses against my 16 70 FMT-SX Fujinon. Initially it didn't seem like a fair match. While the magnifications and fields of view were similar, could I really expect a 45-mm aperture to compete with one having nearly 2½ times the light-gathering power? I settled into a comfortable chair and turned toward Orion's Sword. Although the stars were noticeably brighter in the Fujinon, when it came to the faintest ones visible, the glasses were essentially matched! The Canon stabilization makes easy work of faint stars that would otherwise be lost in the bobbing view of conventional binoculars. Indeed, releasing the stabilization switch confirmed this instantly. But with the switch pressed I could see everything in the Canon glasses that I could with the Fujinon. Astounding!

Of course, with the larger binoculars firmly mounted, I had about a magnitude deeper penetration. But for handheld use the Canon was just as effective as the larger glass, and less than half the weight. Anyone who tries the Canon binoculars is bound to fall in love with them very quickly.

Canon states that the vari-angle prisms compensate for angular tilts up to 0.72°, and that they will work while you are riding in a moving vehicle. Nevertheless, it does help if you hold them moderately steady while observing. "Bouncing" the glasses imparts a very small amplitude, high-frequency "buzz" to the image, which can mask fine detail. Even so, the image shows far more than would be visible without the stabilization working. Hold steady and the image becomes supercrisp almost instantly. There is a slight "hesitation" to the image when you are sweeping, but after using the binoculars for a few minutes this simply becomes part of the view and is not objectionable in any way.

When I first heard about Canon's image-stabilized binoculars I thought this was some type of gimmick. But how my thoughts changed after using them for a few nights. This is truly a quantum leap in binocular observing.

Several manufacturers, including Zeiss and Fujinon, offer image-stabilized glasses based on mechanical gyroscopes. These correct over a greater range of motion than the Canon binoculars and are designed primarily for surveillance and search-and-rescue work from moving vehicles. But they come with considerably higher price tags. For example, Fujinon's 16 40 stabilized binoculars have a smaller aperture, a field of view less than 3½° across, nearly twice the weight, and more than four times the cost of the Canon we tested. The price and proven astronomical performance of the Canon binoculars will certainly make them a hot item for amateur astronomers.

Pressing a button on the top of the binocular housing operates the image-stabilization system. The button is conveniently reached with the index finger of even small hands.

Take Two . . . and Three

By Leif J. Robinson

Take Two. The Canon stabilized binoculars work at least as well for daylight nature study as they do for stargazing. In January, on a cold, very windy day, I took them afield (instead of my trusty 8 Bausch & Lomb Elites) and thoroughly enjoyed the experience.

Bird watchers, especially, might blow off these binoculars just from their specs. Mistake! Their 4.5° field, though very narrow by ordinary standards, is actually very generous for a 15 glass. The 17-foot close focus, though, is about twice that I ordinarily demand. But these binoculars are not for looking at critters eyeball-to-eyeball; their mission is to give you highly magnified, impeccable views of distant targets. For example, I can imagine stabilized binoculars revolutionizing marine-life studies from small, bobbing boats.

The placement of the focusing wheel could be improved. If you like to wear a duck-bill cap, you have to sandwich your hands between the bill and the binoculars to focus. The consequence is that your cap gets tilted upward, so even a slight breeze can blow it away. Eyeglass wearers will then have the view spoiled by glare that probably prompted them to put a cap on in the first place!

It took only a little while to figure out how to focus with my left hand while pressing the stabilizer button with my right. Although the Canon binoculars are bulky, people with ordinary-size hands should be able to manage both operations simultaneously.

Take Three. The application of new technology to simple situations always delights me.

So I couldn't wait to try the Canon out on the February 26th eclipse — portability and power, just the ticket! As totality began, a scan of the Sun's east limb revealed a really fine prominences — rock steady, of course. Then, at midtotality, I looked for tiny details in the corona, particularly at the poles. I was amazed by the intricate structure in the "brushes" there; I had never before seen such crispness. Of course, I couldn't resist taking a peek through my 8 B&L's with their 7.0º wide field. Both views were magnificent yet so *very* different. Canon's was flushed with intricate detail while B&L's featured Mercury smirking alongside the corona. In the final minute, as the west limb of the Sun began to be uncovered, I gravitated back to Canon's big, steady image and enjoyed an even bigger, brighter prominence.

Crazy as it might seem, as I watched the eclipse my mind kicked back to the first nighttime view I'd had through these binoculars. There in my mind's eye was the Orion Nebula — rock steady and *big,* surrounded by enormous gobs of sky. I'd never seen the nebula at 15 before — 7-10 , of course, and 50–500 , but not in between. As with the corona, the Canon gave an old friend a neat face-lift.

At night, or in daylight, these binoculars are sure to provide new perspectives to viewers of all stripes.

To the Visual Limits

Visual limiting magnitude depends on many factors, and now they're all assembled into one program. | **By Bradley E. Schaefer**

STAR LIGHT, STAR BRIGHT, FIRST *star I see tonight.* Many of us have wished upon the first star spotted in the evening twilight. I have often tried to use my knowledge as an astronomer to gain an advantage at knowing where and when to see the first star.

Long-time readers of this department will know my programs for predicting the visibility of stars under many conditions. Central to all these applications is determining the extinction of light (intensity reduction) by the atmosphere and the sky brightness under a wide range of conditions. In particular, the greatest uncertainty in most of my results arises from the accuracy to which the haziness of the air can be estimated. Consequently, I have spent much research time deriving equations that can predict extinction for anywhere in the world and sky brightnesses for any illumination conditions. The result is a usable set of equations that covers moonlight, twilight, and daylight for the first time. Recently, I have extended these from the visual band to the entire optical range.

Extinction and sky brightness are both strongly related to many environmental conditions, making reasonable estimates feasible. Most of these relations are from known physical laws, while some are merely empirical. Taking them together, I can translate information about a site's latitude, altitude, temperature, relative humidity, and the time of year into acceptable predictions of the atmospheric haziness for any filter. With these extinction values, the stage of solar activity, the phase of the Moon, the Moon's altitude and distance from the direction of interest, the altitude and angular distance to the Sun, and the altitude that the telescope is pointing, I can calculate the sky brightness under any clear conditions for any optical filter.

The Program

As published here, the program incorporates typical values for the case of a dark night sky in southern Arizona. For parameters that you will frequently vary, lines can easily be changed from direct values to INPUT statements (such as line 220).

My model for extinction and sky brightness is implemented as two subroutines. These chunks of computer instructions can be included in earlier programs — for telescopic limiting magnitudes (*S&T:* November 1989, page 522), heliacal rising (*S&T:* September 1985, page 261), lunar occultations (*S&T:* January 1993, page 89), and extinction angles (*S&T:* April 1987, page 426) — to yield more accurate results.

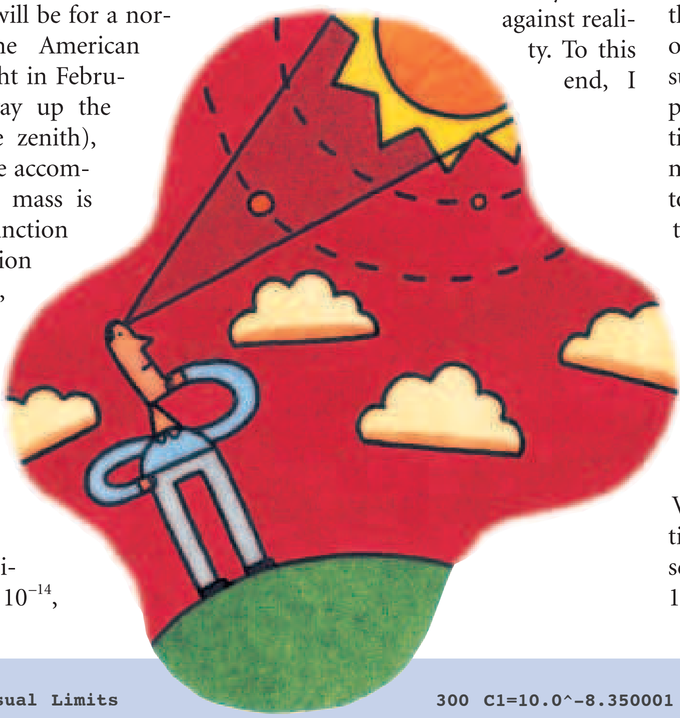
The main program consists of parameter input, calls to the two subroutines, and one calculation for the visual limiting magnitude. The basic equation for this calculation (lines 310 and 320) is the

ILLUSTRATIONS BY JAMES KACZMAN

foundation of all my visibility programs. (Readers are cautioned that the program may not work with all BASIC interpreters, because some variables may exceed the range of valid values.)

Let me present one completely worked example to demonstrate the typical values as well as to help you debug typing errors. The sample case will be for a normal observer from the American Southwest on a dark night in February 1998 looking halfway up the sky (45° away from the zenith), with input as given in the accompanying listing. The air mass is 1.41 for the various extinction components. The extinction coefficients in the U, B, V, R, and I wavebands are, respectively, 0.62, 0.32, 0.19, 0.09, and 0.05 magnitude per air mass with total extinctions of 0.87, 0.46, 0.27, 0.13, and 0.07 magnitude. At these wavebands, the sky luminosity is 3.1 10^{-14}, 4.0 10^{-14}, 6.8 10^{-14}, 7.8 10^{-14}, and 2.5 10^{-13} in units of ergs per square centimeter per second per micron per square arcsecond. The visual sky brightness is 61 nanolamberts, which corresponds to an unaided-eye limiting magnitude of 6.29.

It is vital that any such model be exhaustively tested against reality. To this end, I collected numerous and varied databases from scientific papers and then compared them with my model predictions. I am glad to find that the model faithfully reproduces the extinction coefficients and sky brightnesses over an extremely wide range of conditions with a typical accuracy of 20 percent. The differential accuracy of this program is substantially better, likely only a few percent. This is remarkable for such "simple" equations with no adjustable parameters. Nevertheless, special conditions (such as local air and light pollution) may significantly alter the sky as compared to the program. An article detailing these tests (and the model itself) has been submitted to the *Publications* of the Astronomical Society of the Pacific.



As Far as an Eye Can See

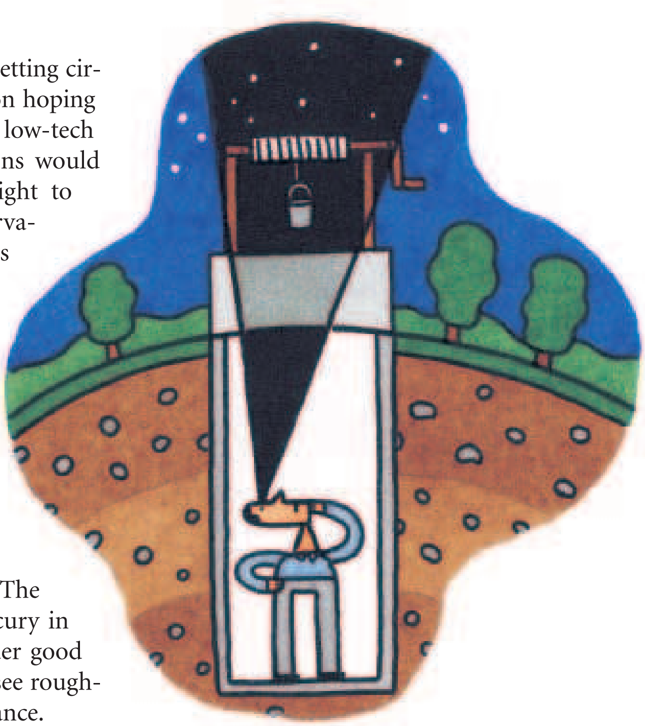
How far can you see on a clear day? The usual answer is the 150 million kilometers to the Sun. But specific application of this program shows that Venus can be seen at distances substantially farther than our star. Normal observers can discern Venus at only about 10° from the Sun, while keen-eyed per-

```
10 REM VISLIMIT.BAS Visual Limits
20 REM by Bradley E. Schaefer
30 FOR I=1 TO 5 : READ WA(I) : NEXT I
40 DATA 0.365, 0.44, 0.55, 0.7, 0.9
50 FOR I=1 TO 5 : READ MO(I) : NEXT I
60 DATA -10.93, -10.45, -11.05, -11.90, -12.70
70 RD=3.14159/180.0
80 REM Input for Moon and Sun
90 AM=180.0 : REM Moon phase (deg.; 0=FM, 90=FQ/LQ,
   180=NM)
100 ZM=180.0 : REM Zenith distance of Moon (deg.)
110 RM=180.0 : REM Angular distance to Moon (deg.)
120 ZS=180.0 : REM Zenith distance of Sun (deg.)
130 RS=180.0 : REM Angular distance to Sun (deg.)
140 REM Input for the Site, Date, Observer
150 RH=40.0 : REM relative humidity (%)
160 TE=15.0 : REM Air temperature (deg. C)
170 LA=30.0 : REM Latitude (deg.)
180 AL=1000.0 : REM Altitude above sea level (m)
190 M=2.0 : REM Month (1=Jan, 12=Dec)
200 Y=1998.0 : REM Year
210 SN=1.0 : REM Snellen Ratio (20/20=1.0, good 20/10=2.0)
220 INPUT "Zenith distance (deg.): ";Z
230 GOSUB 1000 : REM Extinction
240 GOSUB 2000 : REM Sky
250 REM Visual limiting magnitude
260 BL=B(3)/1.11E-15 : REM in nanolamberts
270 IF BL>1500.0 THEN GOTO 300
280 C1=10.0^-9.8: C2=10.0^-1.9
290 GOTO 310
300 C1=10.0^-8.350001 : C2=10.0^-5.9
310 TH=C1*((1.0+SQR(C2*BL))^2.0) : REM in foot-candles
320 MN=-16.57-2.5*(LOG(TH)/LOG(10))-
    DM(3)+5.0*(LOG(SN)/LOG(10))
330 PRINT : REM Write results and stop program
340 PRINT USING "Visual sky brightness (nL): ######"; BL
350 PRINT USING "Visual limiting magnitude: ###.##"; MN
360 END
1000 REM Extinction subroutine
1010 FOR I=1 TO 5: READ OZ(I): NEXT I
1020 DATA 0.000, 0.000, 0.031, 0.008, 0.000
1030 FOR I=1 TO 5: READ WT(I): NEXT I
1040 DATA 0.074, 0.045, 0.031, 0.020, 0.015
1050 LT=LA*RD
1060 RA=(M-3)*30.0*RD
1070 SL=LA/ABS(LA)
1080 REM Airmass for each component
1090 ZZ=Z*RD
1100 XG=1/(COS(ZZ)+.0286*EXP(-10.5*COS(ZZ)))
1110 XA=1/(COS(ZZ)+.0123*EXP(-24.5*COS(ZZ)))
1120 XO=1/SQR(1.0-(SIN(ZZ)/(1.0+(20.0/6378.0)))^2)
1130 REM UBVRI extinction for each component
1140 FOR I=1 TO 5
1150 KR=.1066*EXP(-1*AL/8200)*((WA(I)/.55)^-4)
1160 KA=.1*((WA(I)/.55)^-1.3)*EXP(-1*AL/1500)
1170 KA=KA*((1-.32/LOG(RH/100.0))^1.33)*(1+SL*SIN(RA))
1180 KO=OZ(I)*(3.0+.4*(LT*COS(RA)-COS(3*LT)))/3.0
1190 KW=WT(I)*.94*(RH/100.0)*EXP(TE/15)*EXP(-1*AL/8200)
1200 K(I)=KR+KA+KO+KW
1210 DM(I)=KR*XG+KA*XA+KO*XO+KW*XG
```

sons can see it to about 5°. You might want to calculate whether Venus can be seen at conjunction, perhaps just after sunset from high latitudes.

Venus is easy in the daytime — if you know where to look. Nevertheless, most people tend not to look up, much less scan the sky closely. Thus, it always comes as a surprise to see Venus during daylight. The Chinese considered the visibility of Venus in the daytime to herald a change in the dynasty. A sighting in Paris marred a reception for Napoleon in 1797 when the 20,000 onlookers paid no attention to the conqueror of Egypt but stared at the sky instead. By early 1798, this particular incident was then somehow convoluted into the notion that a comet would impact the Earth and cause great destruction. Panic ensued over a comet that never appeared.

The trick to catching Venus in daylight is knowing *exactly* where to look. The eye's day vision is 10 to 20 times more sensitive in the 1° area centered on the fovea. Thus, looking away from Venus by even ½° could make the difference between detection and invisibility. To find it, you could use a telescope with setting circles, or you could scan the region hoping to pass exactly over Venus. A low-tech method for morning apparitions would be to follow Venus from twilight to daylight with frequent observations. For evening apparitions note Venus's position with respect to foreground landmarks at successively earlier times over a series of afternoons.



Venus is not the only planet that sharp-eyed observers can see during the day. Under good conditions, many people have seen Jupiter, while Mars is possible too. The Babylonians also reported Mercury in daylight. So on a clear day under good conditions, we can fairly easily see roughly five times the Earth-Sun distance.

But we can do much better than this. Sirius (8.6 light-years distant) is also detectable. However, conditions have to be just right to spot it — the atmosphere must be very clear (which implies a high altitude), the Sun must be almost touching the horizon, and the star must be near the zenith.

There have long been claims (from Aristotle to O. Henry) that day stars can be seen with the unaided eye from the

```
1220 NEXT I
1230 REM Write results and return
1240 PRINT : PRINT "Airmass (gas, aerosol, ozone): ";
1250 PRINT USING "####.## "; XG, XA, XO
1260 PRINT "Extinction coefficients (UBVRI): ";
1270 PRINT USING "####.## "; K(1), K(2), K(3), K(4), K(5)
1280 PRINT "Total extinction (UBVRI): ";
1290 PRINT USING "####.## "; DM(1), DM(2), DM(3),
     DM(4), DM(5)
1300 RETURN
2000 REM Sky subroutine
2010 FOR I=1 TO 5: READ BO(I): NEXT I
2020 DATA 8.0E-14, 7.0E-14, 1.0E-13, 1.0E-13, 3.0E-13
2030 FOR I=1 TO 5: READ CM(I): NEXT I
2040 DATA 1.36, 0.91, 0.00, -0.76, -1.17
2050 FOR I=1 TO 5: READ MS(I): NEXT I
2060 DATA -25.96, -26.09, -26.74, -27.26, -27.55
2070 X=1/(COS(ZZ)+.025*EXP(-11*COS(ZZ))) : REM air mass
2080 XM=1/(COS(ZM*RD)+.025*EXP(-11*COS(ZM*RD))) : REM air
     mass Moon
2090 IF ZM>90.0 THEN XM=40.0
2100 XS=1/(COS(ZS*RD)+.025*EXP(-11*COS(ZS*RD))) : REM air
     mass Sun
2110 IF ZS>90.0 THEN XS=40.0
2120 FOR I=1 TO 5
2130 REM Dark night sky brightness
2140 BN=BO(I)*(1+.3*COS(6.283*(Y-1992)/11))
2150 BN=BN*(.4+.6/SQR(1.0-.96*((SIN(ZZ))^2)))
2160 BN=BN*(10^(-.4*K(I)*X))
2170 REM Moonlight brightness
2180 MM=-12.73+.026*ABS(AM)+4E-09*(AM^4) : REM Moon
     mag in V
2190 MM=MM+CM(I) : REM Moon mag
2200 C3=10.0^(-.4*K(I)*XM)
2210 FM=6.2E+07*(RM^-2)+(10^(6.15-RM/40))
2220 FM=FM+(10^5.36)*(1.06+((COS(RM*RD))^2))
2230 BM=10^(-.4*(MM-MO(I)+43.27))
2240 BM=BM*(1-10^(-.4*K(I)*X))
2250 BM=BM*(FM*C3+440000.0*(1-C3))
2260 REM Twilight brightness
2270 HS=90.0-ZS : REM Height of Sun
2280 BT=10^(-.4*(MS(I)-MO(I)+32.5-HS-(Z/(360*K(I)))))
2290 BT=BT*(100/RS)*(1.0-10.0^(-.4*K(I)))
2300 REM Daylight brightness
2310 C4=10.0^(-.4*K(I)*XS)
2320 FS=6.2E+07*(RS^-2)+(10^(6.15-RS/40))
2330 FS=FS+(10^5.36)*(1.06+((COS(RS*RD))^2))
2340 BD=10^(-.4*(MS(I)-MO(I)+43.27))
2350 BD=BD*(1-10^(-.4*K(I)*X))
2360 BD=BD*(FS*C4+440000.0*(1-C4))
2370 REM Total sky brightness
2380 IF BD>BT THEN GOTO 2410
2390 B(I)=BN+BD
2400 GOTO 2420
2410 B(I)=BN+BT
2420 IF ZM<90.0 THEN B(I)=B(I)+BM
2430 NEXT I
2440 PRINT "Sky brightness (UBVRI):";
2450 PRINT USING " ##.#^^^^"; B(1), B(2), B(3), B(4), B(5)
2460 RETURN
```

bottom of wells or mine shafts. Alas, no reliable first-hand reports exist of anyone ever having seen stars in this manner. Indeed, there's strong theoretical knowledge indicating that visibility actually worsens under such conditions. Many modern attempts to reproduce these claims have only shown Aristotle to be wrong in yet another way. So this old canard must be relegated to the status of "ancient urban myths."

With some sophisticated modifications the program can answer the question of whether using a color filter or polarizers would increase success. My calculations suggest yes; however, it's been my experience that color filters don't help while polarizers only push the visual limits by a small amount.

I expect the modern distance record is likely for the star Canopus at about 310 light-years. I have seen Canopus while the Sun was above the horizon from Chile's Cerro Tololo under optimum conditions with much preparation. Here, I had the advantage of a world-class observing site, the horizon dip allowing the Sun to get lower and dimmer, Canopus near zenith, a long, hollow sighting tube coaligned with a scope tracking the star, and a polarization filter.

Nevertheless, on occasion, for unaided visual observations, the correct answer is greatly farther than Canopus. During a solar eclipse, fainter stars can be seen, with Deneb, at around 1,600 light-years away, a likely most-distant quarry. Yet even this

```
Zenith distance (degrees): ? 45

Airmass (gas, aerosol, ozone):    1.41     1.41     1.41
Extinction coefficients (UBVRI):  0.62     0.32     0.19     0.09     0.05
Total extinction (UBVRI):         0.87     0.46     0.27     0.13     0.07
Sky brightness (UBVRI):           3.1E-14  4.0E-14  6.8E-14  7.8E-14  2.5E-13

Visual sky brightness (nL):       61
Visual limiting magnitude:        6.29
```

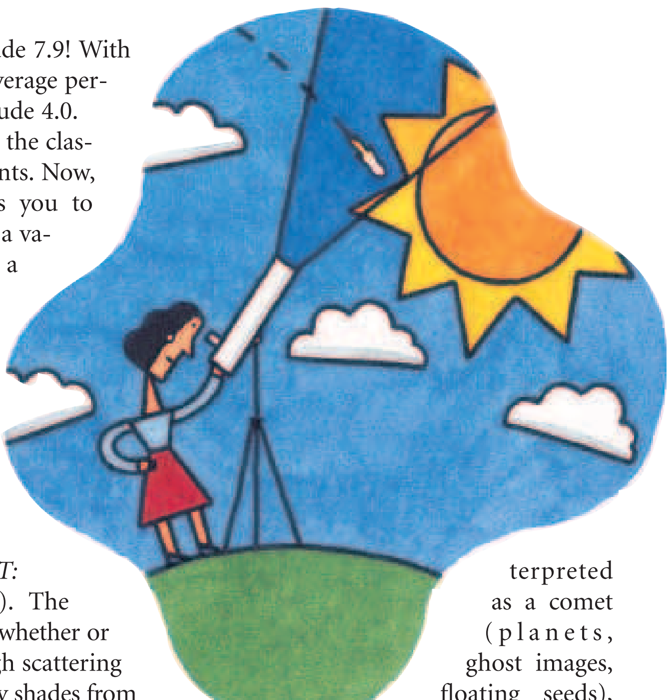
After working over the various parameters of an observing site, the program returns with the all-important limiting magnitude.

is not the all-time record, since various historical supernovae have been day stars with distances on the order of 10,000 light-years.

Further Explorations

The program confirms the wisdom that under dark-sky conditions typical limits are around 6th magnitude. This depends on the acuity (and experience) of the observer, such that someone with very good vision can look to magnitude 7.9! With a full Moon 45° away, an average person can see to only magnitude 4.0.

"Why is the sky blue?" is the classic question to stump parents. Now, the Sky subroutine allows you to calculate sky brightness for a variety of conditions based on a simple model of light scattering. The sky brightnesses will be expressed in ergs per square centimeter per second per micron per square arcsecond, which can then be interpolated into the color calculator of my green-flash program (*S&T:* February 1992, page 200). The daytime sky is indeed blue, whether or not you include the Rayleigh scattering component. The twilight sky shades from blue near the zenith to pale yellows near the horizon, just as observed. Note that the model does not include the beautiful reds arising from illuminated clouds or volcanic sunsets.



Are Sun-grazing comets visually discernible? The program shows that the limit will be around magnitude –8 for a solar distance of 1°, and so bright comets like Ikeya-Seki can be easily spotted with no optical aid. With a highly magnified view, an 8-inch telescope should reach zero magnitude, which is good enough for the amateur to confirm the Sun-grazers currently only spotted with space-based coronagraphs.

This suggests that the tables can be turned and amateur astronomers could discover these comets, perhaps several per year. Starting a survey of Sun-grazing comets would require good skill — to cover the orbit track with the small field-of-view, to allow the eye to get in focus, and to avoid any direct view of the Sun. Also, since many things might be interpreted as a comet (planets, ghost images, floating seeds), the observers must avoid false alarms by watching long enough to measure a nearly sidereal rate, by checking for ghosts and planets, and by getting independent confirmation. I'd like to hear from anyone interested in pursuing this.

Adventurous amateurs or needy professionals can use or modify the program for many purposes. For CCD flat fields in the ultraviolet, the twilight sky is best, and the program can provide sky brightnesses for estimating exposure times to within about 20 percent. Indeed, the extinction and sky brightnesses can be fed into a general program to calculate the limiting magnitude for CCD cameras, and this is exactly what I provide in a companion article on page 117.

And what about wishing upon the first star? Here, the answer will depend in detail on specific circumstances that you can now calculate. And I personally think that it is perfectly fair to use astronomical preparation to get your wish.

Bradley Schaefer *journeyed to Aruba to witness the February total solar eclipse, and he indeed saw Deneb during the day. He can be contacted at Physics Department, JWG 463, Yale University, New Haven, CT 06520; schaefer@grb2.physics.yale.edu.*

The Eclipse and "Weblock"

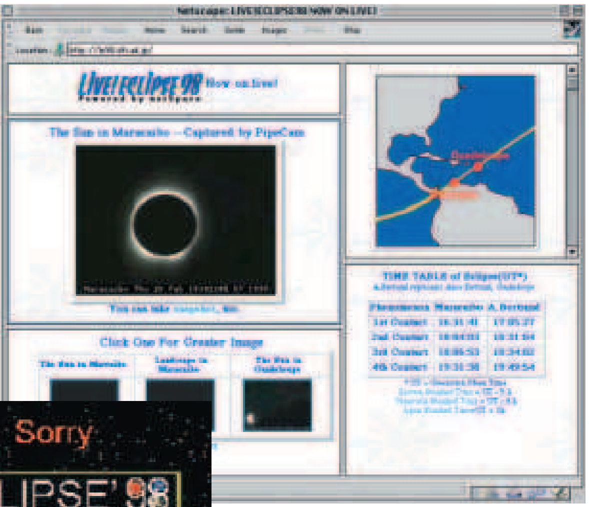
On ABC News' *World News Tonight* for February 26th, anchor Peter Jennings claimed that millions of people had watched that day's total solar eclipse on the Internet. I suppose that could be true, but I wonder how successful people actually were in viewing the eclipse online. It was slow going for much of the event. Even *Sky & Telescope*'s Web server showed signs of the strain and only fully recovered after a late-afternoon restart.

My experience was reasonably triumphant. But perhaps I had preferable circumstances because I avoided the office network problems by watching from home with my high-speed cable modem. I did, in fact, see the nearly 3 minutes of totality "live" as shown from Maracaibo, Venezuela. Despite a slow start, LIVE!ECLIPSE 98, organized by Japanese eclipse chasers, successfully captured the event on its site (http://www.solar-eclipse.org/). But was I just lucky? Soon after the event, the site introduced itself with an apology and short explanation of some of the group's computer troubles.

It wasn't alone. Philip Staiger, organizer of the multistation Eclipse '98 Webcast for Staigerland Entertainment (http://www.excelsoft.com/eclipse/), reported that heavy network traffic prevented observers from uploading images. Staiger explained, "One thing I learned from this project is that we need to have machines that are much more powerful than what we had, and they need to be dedicated." Although I checked several mirror sites during the event, I never saw a real-time eclipse image from Staiger's sites. Michael Rushford, a member of the Eclipse '98 team, who was aboard the cruise liner *Vistafjord* in the Pacific Ocean, managed to transfer only a few images directly to *S&T*'s server. Many pictures from several participants were posted later, after Internet traffic waned.

Perhaps the most impressive endeavor was that mounted by San Francisco's Exploratorium (http://www.exploratorium.edu/eclipse/). With several cosponsors, including NASA and Discovery Online (http://www.discovery.com/), it presented two hours of live audio and video using streaming technology from RealNetworks (http://www.real.com/). While I *listened* to nearly all of the Exploratorium Webcast, I joined the video presentation late. The slow data rates and juggling of browser windows (and continued attempts to reload them) made me overlook the link I needed to click.

I expect things will go better for the August 11, 1999, eclipse (April issue, page 36) — partly because of what was learned this time, and partly because of Europe's better telecommunications infrastructure. I just hope I won't have to settle for watching it online.



ECLIPSE!LIVE 98 *(above)* successfully brought the February eclipse to the Internet, while others got stuck in intense electronic traffic *(inset)*.

Atlas for the Ages

Millennium Star Atlas

Roger W. Sinnott and Michael A. C. Perryman
(Sky Publishing Corp. and the European Space Agency, 1997). 3 volumes, 1,548 charts. ISBN 0-933346-84-0. $249.95.

Review by William Liller

CHUCK BAKER

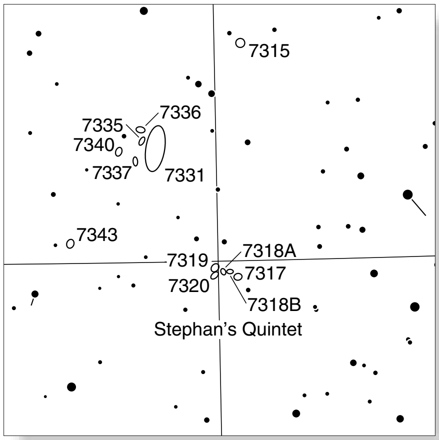
AS A FREQUENT USER OF STAR CHARTS, I had been looking forward to receiving this latest entry into the somewhat crowded field of sky atlases. To say I was not disappointed would be a huge understatement: the *Millennium Star Atlas is,* simply put, magnificent. From the stunning first appearance of the three dark blue volumes lettered in gold to the many checks and tests that I subsequently made, this atlas has impressed me immensely.

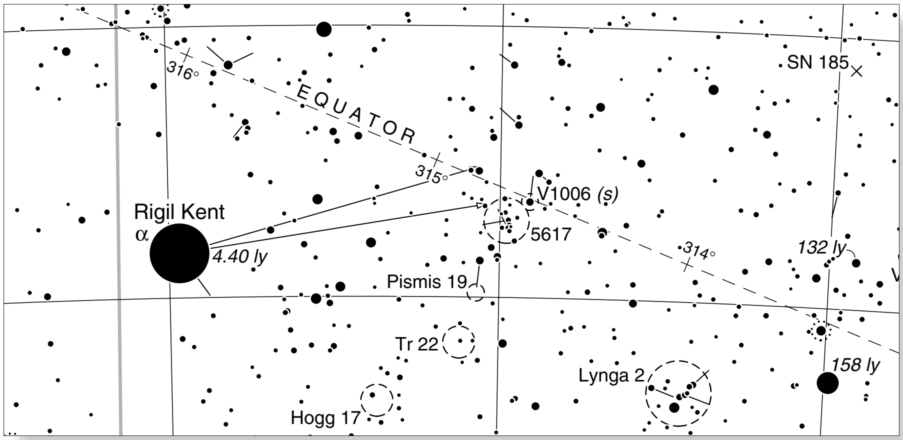
The subtitle within each volume, "An All-Sky Atlas Comprising One Million Stars to Visual Magnitude Eleven from the Hipparcos and Tycho Catalogues and Ten Thousand Nonstellar Objects," makes it clear that the *Millennium Star Atlas* (hereafter *MSA*) is an atlas of a new dimension. Its closest rival and probably best-known predecessor, *Uranometria 2000.0,* never really presents a challenge. The latter, with 332,556 stars, is based on the old *BD, SBD,* and *CoD* star catalogs and suffers from the omissions, lapses, and sudden changes in limiting magnitude common to the older surveys. At most places in the sky, it reaches to 9th magnitude or a little fainter. *MSA* is 90 percent complete to magnitude 10.5.

Readers acquainted with the impressive accomplishments of the Hipparcos satellite mission (*S&T:* July 1997, page 28) will know that the enormous number of highly accurate stellar positions, unbiased magnitude measurements, and greatly improved parallaxes and proper motion determinations would make it possible to produce an atlas like never produced before. *MSA* is it.

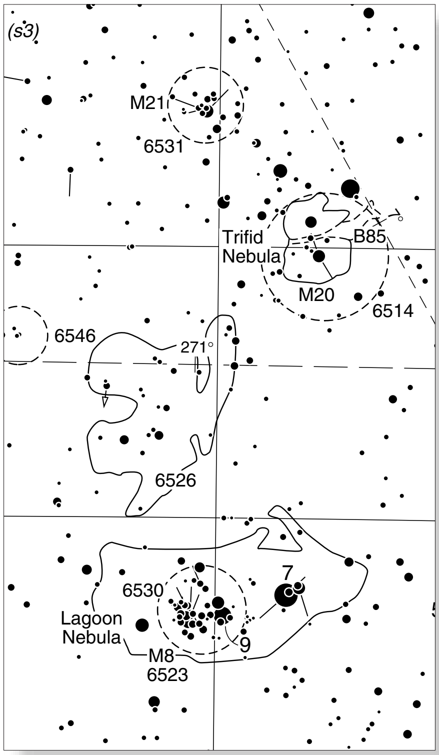
Cursory examination of a random page full of crisp, black star images printed on high-quality white paper with a clearly labeled coordinate grid reveals few of the innovative changes that are incorporated in these three volumes. With a million stars, the scale had to be chosen so that crowding in the richer regions of the Milky Way would not be a problem. Sinnott and Perryman settled on a logical and convenient 100 arcseconds per millimeter. Previous atlas makers seemed to be more concerned with fitting charts to page size rather than adopting a logical scale. *MSA*'s 9-by-13-inch pages, only slightly larger than those of *Uranometria,* provide a generous 7.3° spread in declination and a minimum of 21.5 minutes of right ascension (5.4°) at the equator.

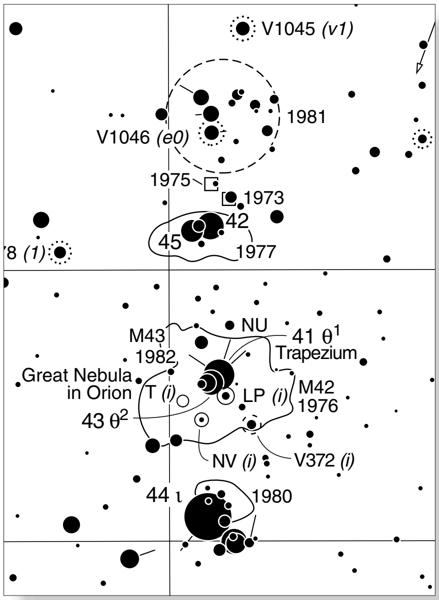
One of the most welcome decisions the authors made was to have facing pages run continuously in right ascension. Thus, at the equator, with the atlas spread open, you'll have, for example, just under $6^h\ 00^m$ at the right edge passing through $6^h\ 20^m$





Significant features of the *Millennium Star Atlas* include stellar proper motions *(above),* size and orientation of galaxies *(top left),* and nebula outlines *(middle and bottom left).* All chart details are shown at actual size.





in the center, to just over $6^h\ 40^m$ at the left edge, a full reach of nearly 11°. And to move to charts farther to the east, you flip pages, logically, toward the front of the volume rather than the back. I never did quite get the hang of using *Uranometria*'s somewhat convoluted system.

Although all the symbols used in the atlas appear in abbreviated fashion at the bottom of each page, and each volume begins with a condensed "How to Use This Atlas," make sure to read carefully the detailed and fascinating introduction of Volume 1.

What really sets *MSA* aside from all the others is the treatment of stars. To begin with, magnitudes are indicated by a continuous gradation of dot size. Thus, careful inspection reveals that a 4.0-magnitude star is indeed a bit brighter than a star of magnitude 4.1. The dots are based on the visual (V) magnitudes as measured by the Hipparcos mission. Upon reading this, I wondered, exactly how accurately could I derive a magnitude from *MSA* simply by measuring the dot diameter? And so with nothing more than an inexpensive six-power comparator, I measured diameters of some 40 randomly selected stars with visual magnitudes between 2.0 and 11.5. The correlation between dot size and magnitude was incredibly close: the average difference between the Hipparcos magnitude and my measurement was a mere 0.023 magnitude. Such an improvement over old atlases that used a single dot size for a range of a full magnitude!

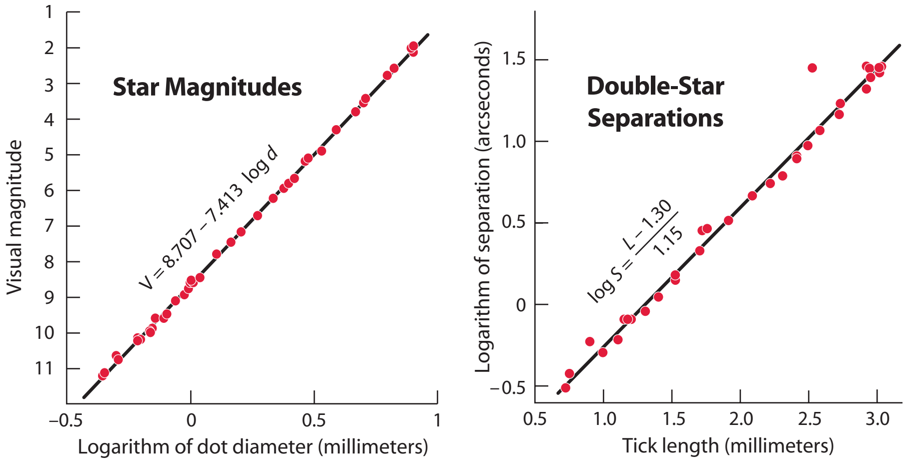
Now, without having to chase down tabulated magnitudes, it's possible to make diameter measurements and quickly assemble a series of standard stars near a new comet or variable with magnitudes nearly as accurate as the measurements of modern-day Earthbound photometrists. To see how accurately one could measure the position of a celestial discovery carefully plotted in *MSA,* I used the astrometry program described in the July 1990 *Sky & Telescope* (page 71) and with only four comparison stars, my comparator, and positions from the *Hipparcos Catalogue,* the computed standard error was an impressively small ±6.3 arcseconds. Had I used more stars and a better comparator, the precision would have been substantially better.

Variable stars receive an interesting and useful treatment. Each dot has a size corresponding to the median magnitude as measured by Hipparcos, and it is surrounded (usually) by a dotted, dashed or solid circle depending on the range of magnitude — less than 0.1, 0.1 to 1.0, or greater than 1.0, respectively. Additionally, the star's standard designation appears next to the symbol, and next to that, in parentheses, a lowercase italic letter identifies the class of variable — for example, *e* for eclipsing, *c* for Cepheid, or *m* for Mira — followed by a single italicized digit indicating the period — *1* for less than a day, *2* for 1 to 9 days, or *3* for 10 to 999 days. Hipparcos discovered 5,100 new variables and more than 3,000 appear in *MSA.* Finally, a few hundred additional variables are plotted as open circles. These are known to have a maximum brightness of at least 9th magnitude but were not detected because they happened to be too faint during the Hipparcos mission.

Double and multiple stars likewise receive an innovative treatment. At least one tick mark protrudes from the star dot, the length and orientation of which indicate the state of the system as of 1991.25, the epoch of the Hipparcos mission. To convert tick lengths to separations in arcseconds, the authors again provide a simple formula. I checked about 20 stars with my comparator; the formula was right on again.

A novel feature of *MSA* is the indication of proper motions greater than 0.2 arcseconds per year. A thin arrow extends from the star in the direction of the star's motion, its length equaling the angular distance the star moves in 1,000 years. Again, I inspected a dozen stars at random and found arrow lengths and directions to be correct to within a few percent. Many of these high-proper-motion stars are, of course, nearby. *MSA* makes this fact obvious because every star closer than 200 light-years is labeled with its measured distance.

Nonstellar objects are given careful attention with the symbols much the same as for *Uranometria*. The outlines of large nebulae — bright and dark — are plotted, while galaxies down to about visual magnitude 13.5 are represented by ellipses whose aspect ratios and orientations correspond to images taken with deep exposures. Finally, the charts offer quasars to 16th magnitude and galaxy clusters with at least 10 members of 16th magnitude or brighter.



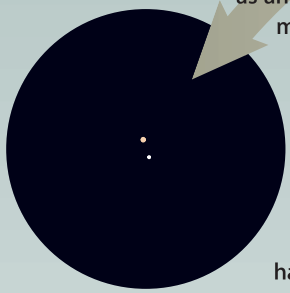
Left: **The reviewer demonstrated the progression of smooth dot size by measuring 40 dots in the atlas and comparing them to the stars' actual visual magnitude.** ***Right:*** **Similar measurement of the separation ticks for 33 double stars also had good agreement. The errant point, whose tick is partly blocked by a faint star, is the distant giant Eta Persei.**

The Small-Telescope Perspective

By Sissy Haas

"Good Lord!" I first thought. "This map weighs more than my telescope!" I like my little refractor, and I doubted that I'd want to carry this monster out to guide it. But now that I have, I'd say the *Millennium Star Atlas* is just the thing for a small scope. However, this doesn't mean that I'm gripe-free about it. I wish the key charts in the back of each volume showed more detail (so I don't need my 5th-magnitude map) and I wish it came with a grid overlay (so I don't need a fine ruler to find an object's coordinates).

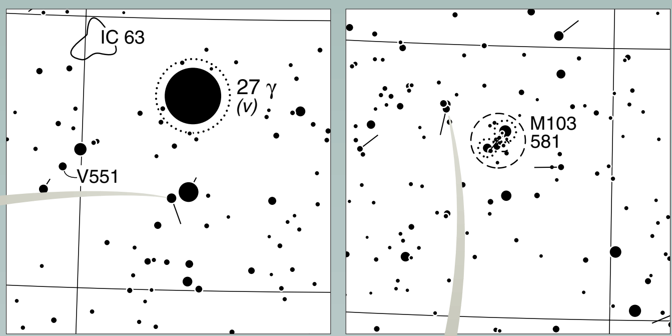
With my 5th-magnitude atlas next to it, I found *Millennium* remarkably easy to read. This makes it good for the beginner, but this isn't why I say that it is great for a small scope. I see the atlas as an alternative to a large scope, for a lot less money. I could confidently enter a Messier marathon with my 2.4-inch refractor if the sky was good and I had this atlas. That's what I discovered the first night I used it with my telescope. The sky was only mediocre then, but the maps enabled me to quickly find and enjoy M1, M76, M77, and M79. These objects have proved frustrating with my 2.4-inch using other charts — I usually start out sweeping right past them. But that didn't happen this time because *Millennium*'s charts are too precise.



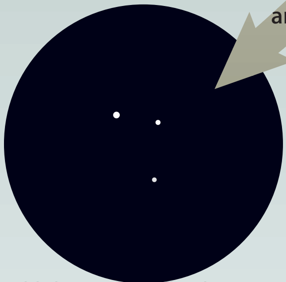
Furthermore, they let me exploit averted vision to the maximum, which is kind of like adding aperture to my little scope. I'm referring to the technique of gazing at the spot where something is out of the corner of your eye. This makes dim objects appear much brighter, but the trick works only when you know exactly where to look.

In terms of quantity, *Millennium* may offer as much for a small telescopist to find as many maps do for an 8-inch instrument. That's what I discovered about it the second night I used it. The sky wasn't great then either, but the maps enabled me to easily find four new double stars. All I did was check the wider pairs near Cassiopeia's five brightest naked-eye stars (the ones that make its *W* pattern). This is what's possible with an atlas that marks all double stars by their separations. Just imagine how many other obscure pairs await me and my 2.4-inch! And after all those, there's the huge quantity of large clusters and asterisms.

I definitely see *Millennium* as an alternative to a big scope for the small telescopist.



So many double stars, so little time. With the help of the *Millennium Star Atlas*, small-telescope owner Sissy Haas observed and sketched several double stars in Cassiopeia that she had never seen before.



Sɪssʏ Hᴀᴀs *has written several articles for double-star observers (see the April issue, page 90). She and her 2.4-inch refractor can be reached at 823 Reamer Ave., Greensburg, PA 15601.*

The back of each volume features tabulated chart numbers for interesting objects, bright stars (Volume 1 only), Messier objects, and, last, a key chart for finding chart numbers quickly.

With nothing substantive to criticize, let me end by pointing out that several CD-ROM atlases now incorporate Hipparcos data. I use *Guide 6.0,* by Project Pluto, and it does pretty much everything that *MSA* does but also goes fainter and provides actual star designations from Hipparcos and several other catalogs. Which is preferable, the printed atlas or the CD-ROM? It depends entirely on the user. I have *Guide* installed on my home computer, but it is the *Millennium Star Atlas* that I now take to the telescope. How lucky we are to live in the age of Hipparcos! What a superb atlas Sinnott and Perryman have produced.

A former chair of the astronomy department at Harvard University, William Liller *moved to Chile in 1981 to become Associate Director of the Isaac Newton Institute.*

briefly noted

1001 Things Everyone Should Know About the Universe, William A. Gutsch Jr. *(Doubleday, 1998). 353 pages. ISBN 0-385-48223-X. $25.95.*

Sentence-long factoids are briefly elaborated upon with single paragraphs. This summary of astronomical knowledge includes the Sun, Moon, planets, stars, galaxies, cosmology, and life in the universe.

A Practical Guide to CCD Astronomy, Patrick Martinez and Alain Klotz *(Cambridge University Press, 1998). 243 pages. ISBN 0-521-59063-9; $74.95, cloth. ISBN 0-521-59950-4; $29.95, paper.*

This English translation of a French work first published in 1994 contains much useful information for today's amateurs involved with digital imaging. Fundamentals of CCD operation and image calibration are covered with emphasis on ways to optimize imaging performance. There is plenty of practical information about using CCD cameras on amateur telescopes, including discussions on aiming, focusing, and guiding exposures. Although the extensive sections on image processing were written before software was widely marketed for home computers, the material is still valuable to those working with commercial programs that often lack fundamental details in their documentation.

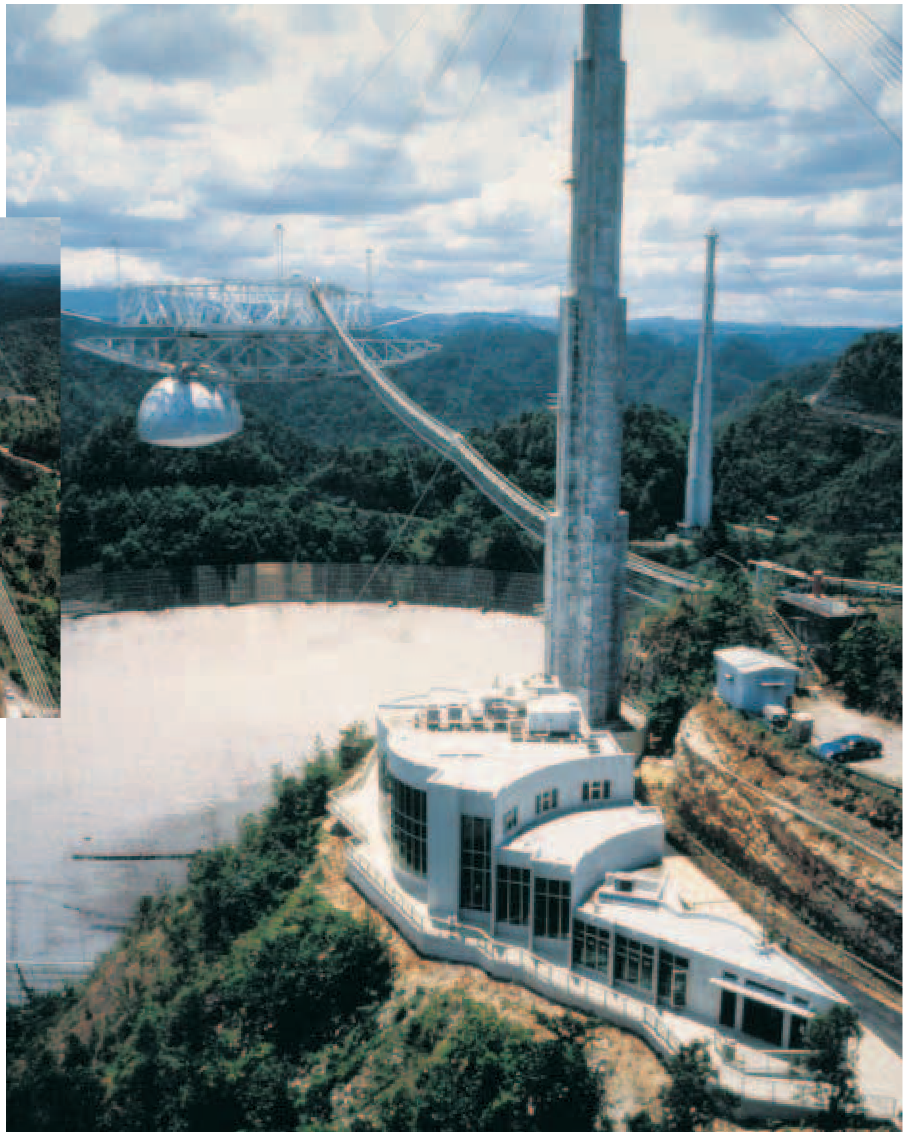
Bringing the Stars to the People

Arecibo Observatory's recently opened visitor center and educational facility offer visitors a new learning experience about the universe and our place in it. | **By Daniel R. Altschuler and Jo Ann Eder**

Running along the north coast of Puerto Rico is a modern expressway linking the bustling capital city of San Juan to Arecibo. On turning south from Arecibo and heading into the interior, the road becomes progressively narrower and the curves sharper. As the route ascends the rugged hills of the karst (limestone) terrain, images of the modern metropolis rapidly fade into rustic countryside scenes, where cows and chickens roam freely and the slopes are covered with lush ferns, grasses, wild orchids, and begonias.

This is the Puerto Rico of the past. But a few kilometers beyond the small town of Esperanza, past a few scattered houses, you arrive at the gates of an island within this island — the Arecibo Observatory. Suddenly the rural scenery gives way to an ultramodern technological landscape, one that is at the forefront of cutting-edge research.

The Arecibo Observatory (which has gained new fame from the movie *Contact*) recently became more of an astronomical tourist attraction with the opening in March 1997 of its new visitor center, the Angel Ramos Foundation Visitor and Educational Facility. Here you can see and learn about the largest single-dish



SCIENCE PHOTO LIBRARY / DAVID PARKER

Above: **Located 1,000 miles southeast of Miami, Florida, is the island of Puerto Rico, home to the Arecibo Observatory. Its newly upgraded 305-meter radar/radio telescope, which rests in a mountaintop sinkhole, is the largest single-dish reflector in the world. Each year tens of thousands of visitors tour the facility.**

Right: **The newly opened Angel Ramos Foundation Visitor and Educational Facility is situated on a hilltop overlooking Arecibo's dish. The center features exhibits, an auditorium, meeting rooms, offices, and a viewing platform.**

ALFREDO PÉREZ

Performing the center's ribbon cutting on March 1, 1997, were (from left) Santiago Rosado (Arecibo Observatory); author Daniel Altschuler and his wife, Celia; Arecibo Mayor Angel Roman; Frank Rhodes (President Emeritus, Cornell University); and Argentina Hills (President, Angel Ramos Foundation).

radar/radio telescope in the world, used by researchers to study phenomena as close as 3 kilometers (2 miles) in the Earth's atmosphere and as far as the most distant parts of the observable universe more than 10 billion light-years away.

The Observatory

Inaugurated in 1963, the Arecibo telescope consists of a 305-meter (1,000-foot) spherical reflector nestled in a natural bowl-shaped depression some 65 km (40 miles) southwest of San Juan. Radio waves collected by the reflector are focused toward a 900-ton triangular platform suspended 135 meters (450 feet) above the dish by cables on three giant towers. Attached to the underside of the platform is a new six-story-high, 90-ton dome containing a 25-meter (80-foot) Gregorian secondary reflector and a smaller tertiary reflector. These correct the spherical aberration of the primary to provide a wider, sharper radio view. The dish can also send radar pulses from the Gregorian's 1-megawatt transmitter to targets within the solar system, then listen for the echoes minutes or hours later.

The observatory's main research thrusts have been radio astronomy and planetary radar and atmospheric studies. It operates continuously, 24 hours a day. Visiting scientists from all over the world use it, and numerous students have completed observations that led to their master's and doctorate degrees.

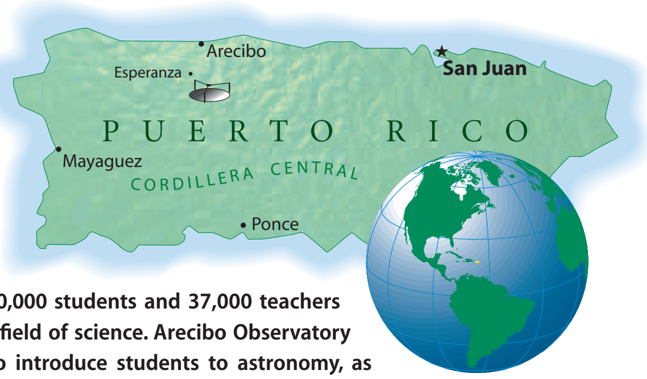
The telescope is the centerpiece of the U.S. National Astronomy and Ionosphere Center operated by Cornell University in cooperation with the National Science Foundation (NSF). A $27 million upgrade funded by NASA and the NSF is now nearing completion. This should dramatically enhance Arecibo's sensitivity and spectral coverage.

Public Outreach

The Commonwealth of Puerto Rico is home to about 3.5 million American citizens who are grossly underrepresented in professional science, mathematics, and engineering. There are very few extracurricular opportunities that can provide positive and meaningful exposure to these disciplines.

Arecibo Observatory provides a chance to make a difference in this regard. Even before there were any formal visitor programs, approximately 40,000 people toured the observatory each year, half of them schoolchildren. We anticipate that with our new visitor center and educational facility, attendance will easily reach 100,000, an expectation confirmed by its first few months of operation. Within 10 years the center will have been visited by roughly a fourth of the island's population.

The idea for a visitor center came from Riccardo Giovanelli in 1988. Giovanelli was formerly a staff scientist and director of Arecibo and is now a Cornell University professor. After he left the observatory in 1989, author Daniel Altschuler took over the project. An eight-year-long fundraising effort yielded contributions from both government and private organizations. In 1991 Puerto Rico's Angel Ramos Foundation provided a generous grant that covered half of the construction cost. This helped greatly in securing matching funds from the municipality of Arecibo and the Puerto Rican government, as well as from several corporations and individuals. Separate funding for the exhibitions came from a grant awarded by the NSF's Informal Science Education program.



Puerto Rico has approximately 650,000 students and 37,000 teachers of whom about 11,000 are in the field of science. Arecibo Observatory is using its educational facility to introduce students to astronomy, as well as holding science workshops and training courses for educators.

FRANK DiMEO

FRANK DIMEO

Youngsters enjoy playing with the cloud-making machine in the center's atmospheric-science exhibit. Schoolchildren comprise about half of the more than 40,000 visitors to the observatory each year. With Arecibo's new visitor center, the authors expect this attendance to soon reach 100,000.

The Visitor Center

The Angel Ramos Foundation Visitor and Educational Facility is unique in the way it serves the island's schools and public. Designed by architect Luis Badillo of San Juan, the new building, located at the foot of one of the giant towers supporting the telescope's platform, offers a great view of the main radio dish. It houses more than 3,500 square feet of audio-visual and interactive exhibits in two levels connected by a panoramic elevator. A 100-seat multipurpose auditorium, gift shop, conference rooms, and offices complete the facility.

For more than two years we worked with the Arecibo staff and Eileen Zalisk and Peter Martin of Zalisk-Martin Associates of Cambridge, Massachusetts, in designing, fabricating, and installing the exhibits. The interactive displays were made by Museum Productions of Toronto, Canada.

The exhibit's theme, "More Than Meets the Eye — Exploring the Invisible Universe," reflects the notion that we can study our physical world using tools that extend our direct sensory experience. Radio wavelengths were the next area of the electromagnetic spectrum to be exploited for astronomical research after centuries of such studies being limited to visible light. In the last 50 years radio astronomy has added immeasurably to our understanding of the universe. More recently, instruments aboard orbiting satellites have opened up the entire electromagnetic spectrum, from radio waves to gamma rays. We'd like our audience to feel and appreciate how fortunate they are living in this exciting golden age of exploration.

Our bilingual (English and Spanish) programs introduce young minds to the invisible radio sky. Specifically, they give visitors a graphic explanation of the electromagnetic spectrum, which, in turn, provides the framework for understanding the function and operation of the Arecibo telescope. Talking figures of radio-astronomy pioneers Karl Jansky and Sydney Chapman greet visitors at the entrance. A talking Sun, an orrery, and information on the solar system, Earth, our atmosphere, and the Moon comprise the initial exhibits. Complementing these are a meteorite collection and a *Powers of Ten* movie.

The large central area of the exhibit hall features displays about stars, galaxies, and the various tools of scientific exploration. There's even a movable scale model of the Arecibo telescope showing how it can be steered to receive signals from a desired position in the sky. Surrounding it are three monitors that give real-time feeds from the telescope control room and tell visitors about the instrument's current position and status.

Some of Arecibo's most exciting discoveries — from water ice in Mercury's polar craters to at least three planets orbiting a pulsar some 1,600 light-years away in Virgo — are presented in the upper level. A pulsar model, a light table explaining telescope optics, and a small atmospheric-phenomena theater are some of the exhibits here. In the auditorium a 15-minute video presentation, "A Day in the Life of the Arecibo Observatory," tells the story of the people who make science at Are-

TONY ACEVEDO

The exhibits, given in both English and Spanish, provide guests with background information on the various scientific investigations being carried out at Arecibo Observatory, as well as insight into the daily activities at a major research facility.

FRANK DiMEO

Local schoolchildren take turns using magnifiers to find their homes on a mural-size aerial mosaic of Puerto Rico island. This is part of the ground level's hands-on displays that include a meteorite collection, an orrery, and a solar-system exhibit.

cibo possible, from the kitchen staff and security guards to the telescope operators and visiting scientists. The auditorium also serves as a venue for international scientific workshops, colloquiums, and meetings.

An integral part of our educational outreach program is to offer workshops for science teachers. These will provide basic training in astronomy and atmospheric sciences as well as suggestions for classroom activities. In fact, the first high-school teacher has already completed her summer internship.

The day-to-day operation of the new center is fiscally independent from that of the observatory. Income from admissions, store sales, and vending machines covers the cost of running the center. Its staff of five full-time members and one part-timer is augmented by student guides from the University of Puerto Rico's Arecibo campus, especially during times of high visitor attendance on weekends and in the summer.

In this complex world of changing priorities, we must do all we can to help people better understand and appreciate the value of science and technology, to convey the importance and excitement of exploration, and to encourage youth in pursuing science education. We owe it to ourselves and to society.

Daniel R. Altschuler *is director of the Arecibo Observatory, and* Jo Ann Eder *is one of the facility's research associates.* *The authors are grateful to José N. Maldonado, Rey F. Medina, and their colleagues at the observatory for helping to make the visitor center a reality.*

If You Plan to Visit

The Arecibo visitor center hours are:

Wednesday–Friday	noon – 4:00 p.m.
Saturdays, Sundays, and holidays	9:00 a.m.– 4:00 p.m.
Monday–Tuesday	closed

Admission: Adults $3.50; children and seniors $1.50

For more information write to Arecibo Observatory, P.O. Box 995, Arecibo, PR 00613; 787-878-2612; 787-878-1861 (fax); http://www.naic.edu/.

S&T / EDWIN AGUIRRE

Astronomy Day 1998

By Gary Tomlinson

On May 2nd thousands of amateur astronomers worldwide will celebrate a momentous occasion: the 25th anniversary of Astronomy Day. Doug Berger of the Astronomical Association of Northern California first planted the seed for the event in 1973. His idea was to promote public awareness in the science by hosting astronomy-related events in urban areas; normally people must travel to dark, country skies or out-of-the-way observatories to meet with fellow astronomy enthusiasts. By giving lectures and setting up displays in accessible public areas, Berger essentially kick-started the concept of "bringing astronomy to the people." Over the last quarter century, Astronomy Day has blossomed from a home-grown activity to a truly international event, which sometimes lasts a week or more.

Astronomy Day continues to evolve, as reports from last year's activities suggest. More and more, the event is turning into something beneficial not only to the amateur clubs involved (by increasing membership) but also to the local community and the environment. For example, the Eastern Missouri Dark Sky Observers Astronomy Club did more than dedicate its Schmidt-Scott Memorial Observatory (the culmination of five years of labor) on Astronomy Day — it donated the facility to the region's East Central College for use as a teaching laboratory. The observatory will help pave the way for student and public education in astronomy.

Is amateur astronomy advantageous to the local economy? Just ask New Mexico's Albuquerque Astronomical Society. For its 1997 Astronomy Day celebration the society set up "science-fair" quality astronomy displays in a local shopping mall. One of them — a student experiment on how to grow and photograph crystals in space — will fly on a future Space Shuttle mission. By advertising these displays well in advance, the club increased mall traffic by up to 3,000 people. Likewise, the Ventura County Astronomical Society in California solicited and raffled off more than 50 prizes from the local mall merchants, including two telescopes donated by Orion and Meade. The fund-raising effort netted more than $1,200. The society plans to use this money to host other public events and to fight light pollution.

For its 1997 Astronomy Day, the Boston Museum of Science and Charles Hayden Planetarium offered 10 public talks (three in Spanish) and nine planetarium shows throughout the day. Coordinator Noreen Grice says that the planetarium made a special effort to reach underserved Hispanic members of the community, as well as visitors with disabilities.

On the international front a consortium of clubs and organizations — consisting of the Toronto Centre of the Royal Astronomical Society of Canada, the Ontario Science Center, the University of Toronto, York University, and the Royal Ontario Museum — joined hands to host a variety of Astronomy Day events throughout Toronto over several days. Most popular was a teacher's workshop featuring the outstanding French astronomy educator Michele Gerbaldi.

Pam Spencer of *Astronomy Now* reports that clubs in the United Kingdom hosted a variety of Astronomy Day activities throughout the year. One major show in London brought the public together with astronomers and astronauts from around the world.

In Southeast Asia, the Philippine Astronomical Society and the Philippine Atmospheric, Geophysical, and Astronomical Services Administration hosted the 1997 National Astronomy Week festivities beginning on February 17th at the National Museum Planetarium in Manila. Founded in 1990 by *Sky & Telescope*'s Edwin L. Aguirre and Imelda B. Joson, this an-

Above: **On May 2nd, Astronomy Day celebrates its 25th anniversary of bringing astronomy to the people. *Right:* Last year's *Sky & Telescope* Astronomy Day award went to Georgia's Oglethorpe Astronomical Association for promoting the science to its community through special public events.**

nual event features public lectures, exhibits, movies and planetarium shows, and star parties nationwide.

Most noteworthy, however, is the effort of the Sirius Astronomy Association in Algeria. The group hosted a series of events over four days at various regional educational facilities. It produced a television program, "Cosmic Journey," the country's first locally produced scientific show. The program involved seven astronomers — three from Algeria, two from the United States, and one each from France and Kuwait. An estimated 12 million people watched the show.

The 1997 Astronomy Day Award

Every year since 1989 *Sky & Telescope* has given an award for the group or organization that best exemplifies the concept of Astronomy Day by hosting special public events. The 1997 award went to the Oglethorpe Astronomical Association (OAA) in Savannah, Georgia. The association hosted a series of pre-Astronomy Day public activities, including comet watches (at two separate locations) and a star party for a local elementary school. These events were used to promote a major exhibit inside a shopping mall. In the mall, club members set up a Starlab portable planetarium and a telescope display, showed educational astronomical videos, and created a special area "just for kids," complete with coloring pads and astronomy puzzles. Every child who participated in the Astronomy Day activities was given a free photograph of Comet Hale-Bopp and a commemorative comet-viewing sticker. OAA representative Harleston E. Cabaniss Jr. adds that the store that loaned telescopes for the mall display experienced an increase in telescope sales following the event.

Organizations wanting to host their own Astronomy Day event in May and apply for the *Sky & Telescope* Astronomy Day Award should go to this magazine's Web site, SKY Online, at http://www.skypub.com/astroday/astroday.html. Additional information can also be found on the Astronomical League's Web site, http://www.mcs.net/~bstevens/al/astroday.html. Otherwise, please contact me at the address below, or call 616-456-3532.

Astronomy Day Coordinator Gary Tomlinson *can be reached at the Public Museum of Grand Rapids, 272 Pearl NW, Grand Rapids, MI 49504; gtomlins@triton.net.*


LEE CATALINE

star trails | *By David H. Levy*

People of the Texas Star Party

THERE IS SOMETHING SPECIAL ABOUT dusk at the Texas Star Party. For many of the hundreds of people who attend this event, it is a time they've been eagerly anticipating for months. The TSP is an amateur gathering unlike any other. Walking along the telescope field in the growing darkness is like experiencing a scene straight from *Close Encounters of the Third Kind*.

Last year's TSP, held May 4–11 at the Alto Frio Baptist Encampment near Leakey in central Texas, was hampered by cloudy skies. However, this failed to dampen the spirit of the nearly 700 deep-sky enthusiasts assembled there. The final night did offer several hours of pristine, pitch-black skies, with stars as faint as 7th magnitude being visible without optical aid to some eagle-eyed observers. But time during overcast sessions was far from wasted. It was a chance to get acquainted with some remarkable people. This month let's meet three of them: a lawyer, a computer-systems director, and an executive secretary.

Edward W. Szczepanski is the lawyer. Specializing in maritime law, Szczepanski (pronounced shu-pan-ski) is also an accomplished astrophotographer and telescope maker. One day in January 1996 he was perusing old astronomy magazines during his lunch break when an article I wrote on comet hunting caught his attention. As he read he wondered what it would be like to discover a comet. That evening Szczepanski drove out to the Houston Astronomical Society's observatory site near Columbus for a solitary astrophotography session. He set up his 4-inch Takahashi refractor and, with Kodak Technical Pan 2415 film, began imaging deep-sky objects.

M101, the huge spiral galaxy north of the Big Dipper's handle, was the last one on his list. When he developed his film the following day, he was surprised to see the trailed image of a 10th-magnitude fuzzy object ½° south of M101. He immediately reported it to the IAU's Central Bureau for Astronomical Telegrams. On January 28th IAU *Circular* 6296 announced to the world the discovery of Comet Szczepanski, C/1996 B1. Although overshadowed by Comet Hyakutake, C/1996 B2, Szczepanski's first comet find produced a decent showing as it cruised the northern sky in early spring (*S&T:* May 1996, page 99).

Above: **A long-time Houston, Texas, amateur, Edward Szczepanski stands by the 4-inch Takahashi refractor (white tube) he used to discover his first comet in January 1996.**


DANA LAMBERT

Two of the moving forces behind the annual Texas Star Party, Steve and Amelia Goldberg pose with their 13-inch Dobsonian at their home in suburban Houston.

Amelia and Steve Goldberg met through the Houston Astronomical Society in 1981. When Steve, then the club's president, asked for Astronomy Day volunteers, Amelia was among the first in line. Married three years later, the couple spent their honeymoon at — of all places — the Astronomical League convention in Milwaukee, Wisconsin. A computer-systems director for Stewart Title Company, Steve is mainly interested in educating the public about astronomy; he also engages occasionally in astrophotography. The Goldbergs enjoy helping novices find their way around the skies at star parties.

Amelia, an executive secretary for an oil and gas company, is the observer of the two. Her first look through a department-store telescope was at Saturn. "Those magnificent rings," Amelia says, "just burned in my mind! I'll never forget them." She has been attending Texas Star Parties regularly since 1983. Just recently she completed observations of all the objects in the Astronomical League's Herschel 400, which lists the best targets from William Herschel's deep-sky catalogs.

A private, soft-spoken person, Amelia is nevertheless as devoted to getting new observers going as she is passionate in adding more faint objects to her list. For the past two years she has been working on an observing program for beginners called Universe Sampler. Designed to familiarize them with all aspects of the night sky, the program is based on a few basic concepts and sample targets spread around the year. The project opens with the fundamentals of sky movement, how objects are found in the sky using celestial coordinates, and the technique of star-hopping. Unlike stargazing primers written by people who have never really looked at the sky, the Universe Sampler has a whole chapter on the art of seeing.

"You have to train yourself to observe the sky," Amelia insists, "or you won't see anything." Amelia should know — she lives for those precious dark nights of the Texas Star Party, when she and her trusty 13-inch Dobsonian peer deep into space. She observes with quiet intensity, carefully logging each observation, each target much dimmer than the last. Through her experienced eye and under a clear, coal-black sky, the universe is more exciting than we can ever imagine.

Last year's Texas Star Party was author David Levy*'s tenth.*

The English poet Alexander Pope adopted the strategy of Conon of Samos and sent Belinda's violated lock of hair into the heavens as a new star. Here, Aubrey Beardsley reveals the transformation in an illustration he produced for *The Rape of the Lock.* From *The Later Work of Aubrey Beardsley,* 1967.

Hair-Raising Tale

An Egyptian queen offered her hair to the gods who, a courtier claimed, saw fit to place it among the stars. | **By E. C. Krupp**

For most people concerned with image and appearance, hair is a crowning glory. In the ancient world, hair was valued by the gods and was believed to contain vital, personal energy. Tendering hair was like offering the soul — it put the petitioner in divine hands.

Hair loss, however, can undermine confidence and sabotage charisma. Samson's strength declined when Delilah cut his hair. Schemes for rejuvenation of bald scalps dilute the financial resources of the desperate, and toupees provoke derision. But what may be troubling for men is even more devastating for women.

Nonetheless, Egypt's Queen Berenice willingly clipped her curls as a potent sacrifice to the gods for the safe return of her husband, the Pharaoh Ptolemy Euergetes III, from war in Syria. But the burden of her divestiture was aggravated when the hair she had trimmed vanished overnight from the altar of Aphrodite. Thanks to Conon of Samos, however, you can see Berenice's hair (the constellation Coma Berenices) near the middle of our gatefold map of May's night sky.

Based in Alexandria in the third century B.C., Conon was an astronomer and mathematician who attracted the praise of Archimedes and the attention, four centuries later, of the astronomer Ptolemy. Some scholars guess that Conon's seven books — long since lost — may have furnished the Chaldean foundation on which Hipparchus relied to quantify precession. If so, Conon helped transform the conceptual framework of the cosmos in antiquity.

Berenice's high-flying hair memorializes the sacrifice of her fabled amber tresses for the safe return of her husband from war. When it was discovered the locks had disappeared, Conon the astronomer explained that the hair had been honored with a place in the heavens, a sprinkling of stars formerly assigned to Leo, the Lion. From Samuel Leigh's 1825 *Urania's Mirror,* and reprinted in 1993 in *The Box of Stars* by Catherine Tennant.

Conon's invention of Coma Berenices illustrates his access to royalty and his ability to navigate the corridors of Pharaonic power. When the queen's ringlets were discovered missing, Conon interpreted their absence to the king. Glibly pointing to the loose fog of stars just above the tail of Leo, the Lion, he explained that the queen's hair had been lifted into the sky. Honoring Berenice with hair in heaven, Conon kept the hairy crisis from coming to a head.

The stars of Coma Berenices were known before Conon attached Berenice's name to them, but they were not really regarded as an independent constellation. Although the *Catasterismi,* the oldest surviving collection of Greek constellation myths, identifies seven faint stars in the shape of a triangle as the "Lock of Berenice Euergetis," the author treats them as part of Leo. In the chapter on Corona Borealis, the same stars are named the "Lock of Ariadne" after the legendary daughter of King Minos of Crete. She led Theseus out of the Labyrinth and is part of an older mythic tradition than Queen Berenice.

Berenice belongs to the third century B.C., the era of the Alexandrian Eratosthenes, on whose work the *Catasterismi* is based. Berenice's husband ruled Hellenistic Egypt from 246 B.C. to 222 B.C. and conducted several successful wars against eastern kingdoms. Berenice was her husband's half-cousin, but the Latin poet Hyginus calls her Ptolemy Euergetes's sister in his book of star myths, the *Poeticon Astronomicon.* Hyginus was probably confused by more than one Berenice in the dynasty. The Pharaoh's sister was also named Berenice, and she was the wife of Antiochus II, the king of Syria. When Antiochus was poisoned by court conspirators, Ptolemy Euergetes launched the military campaign that led his spouse to snip her hair on his behalf.

The aggressive style of Ptolemy Euergetes III was well matched by a wife who could, when necessary, let her hair down. Her entry in Jessica Amanda Salmonson's work *The Encyclopedia of Amazons* confirms she was "beautiful, greatly beloved, and brave in battle." Her success in chariot races qualifies her as a Ptolemaic low rider, admired for her initiative and for her amber tresses.

From Conon's timely astronomical intervention, and probably before, Coma Berenices has been recognized as something interesting, but no one advocated its official status until the 16th century. In the third century B.C. Aratus didn't even mention it in his *Phaenomena.* Perhaps taking a page from Eratosthenes, in his *Poeticon Astronomicon* Hyginus treats it as part of Leo, the Lion. (English translations of both the *Catasterismi* and the *Poeticon Astronomicon* by Theony Condos, with commentary, have recently been published by Phanes Press as *Star Myths of the Greeks and Romans: A Sourcebook.*) Ptolemy described Coma Berenices in the middle of the second century A.D. in the *Almagest,* but as a feature of the sky, not as a constellation. In 1536 the German astronomer Peter Apian named it, but did not illustrate it, on his figurative map of the constellations. The true constellational debut of Coma Berenices occurred in 1551 on cartographer Gerard Mercator's celestial globe, but it took inclusion by Tycho Brahe in the star catalog of 1602 to persuade the astronomical community to make Berenice's Hair permanent.

Coma Berenices is a subtle, powdery wig of stars. The filaments may be faint, but they are unintimidated by the flamboyant mane of the Lion nearby. For almost a century, writers have deferred to Garrett P. Serviss, an American journalist and astronomy popularizer, for the most evocative handling of Berenice's Hair. It twinkles "as if gossamers spangled with dewdrops were entangled there. One might think the old woman of the nursery rhyme who went to sweep the cobwebs out of the sky had skipped this corner."

Its dedication by Conon of Samos put this group of stars on its current career trajectory. But Berenice's celestial tresses also received an important boost from the Alexandrian poet Callimachus, who documented Conon's constellation creativity in the *Lock of Berenice.* Only a fragment of this poem survives, but a later verse (#66) by the Latin poet Catullus is believed to be modeled on the Callimachus original.

Catullus tells the hair-raising tale from the point of view of Berenice's curls. After saluting Conon's astronomical knowledge, the locks lament the partition that dispatched them to the sky. Catullus details the hair's separation anxiety: it would rather adorn Berenice than reside with the stars but resigns itself to adding luster and sheen to the sky.

Roughly 2,000 years after Conon lodged Berenice's locks among the stars, the English poet Alexander Pope put Conon's strategy back to work in *The Rape of the Lock.* The story is based upon the liberty an English lord took with a maiden's hair. He craved one of the two curls that graced the back of Belinda's "smooth ivory neck" for his collection of offerings on the altar of romance: "three garters, half a pair of gloves; and all the trophies of his former loves."

Clipped as a token of masculine conquest, the unauthorized harvest of hair cultivated a quarrel between patrician families of London. In mock-heroic style, Pope resolved the dispute with Conon's resourcefulness. In the confusion of the theft and subsequent confrontation, the purloined lock rose up. It was "a sudden star" that "shot through liquid air and drew behind a radiant trail of hair." According to Pope, not even "Berenice's Locks first rose so bright, the heavens bespangling with dishevelled light." Like Berenice's Hair, the ravished lock now "adds new glory to the shining sphere" and "midst the stars inscribes" Belinda's name.

In fact, Belinda was not commemorated in stars. Two other characters in the drama made their way to the sky, however. Ariel, the girl's guardian Sylph, and Umbriel, the melancholy Gnome of her sorrow, were named in heaven as two newly discovered moons of Uranus by William Lassell in 1851. Belinda's chance to have her name in lights looked slim, but when Voyager 2 discovered 10 more moons accompanying Uranus, 1986 U5 was assigned to her. Without Voyager, the lass who lost her lock might never have received her celestial reward. Astronomy sometimes allocates fame by a hairsbreadth.

AKIRA FUJII

The constellation Coma Berenices consists of a faint clustering of stars (center) surrounded by Virgo, Leo, Canes Venatici, and Boötes. The bright star at lower right is Denebola in Leo. When we stare at Berenice's Hair we are looking perpendicular to the disk of our galaxy, a view less contaminated by interstellar dust. Through this clearer window high-powered telescopes show us the celebrated Coma Cluster of distant galaxies.

E. C. Krupp *is usually in somebody's hair at Griffith Observatory in Los Angeles.*

May's Meadow in the Sky

As the season grows warm, a forest of bright springtime stars encircles a big, dim clearing nearly overhead. | **By Fred Schaaf**

"A meadow in the middle of the sky" — that's what Carl Sagan called the Earth in space. As we look outward from Earth with springtime now greening the fields around us, I find a figurative meadow of sorts amid the May constellations themselves.

Take a look at our foldout sky map at right. The zenith — the overhead point — is at the map's center. Occupying the zenith at map time are several dim but interesting constellations.

You'll need quite a dark sky (or binoculars) to see these constellations well. So before we examine them and why I call their region a "meadow," let's look at the brighter sights lower near the horizon.

Low in the west (turn the map around so its "West" horizon is down), bright Procyon is about to set. To Procyon's right are the Gemini twins, now standing upright. Low in the northwest sparkles Capella. And low in the north is the flat W of Cassiopeia.

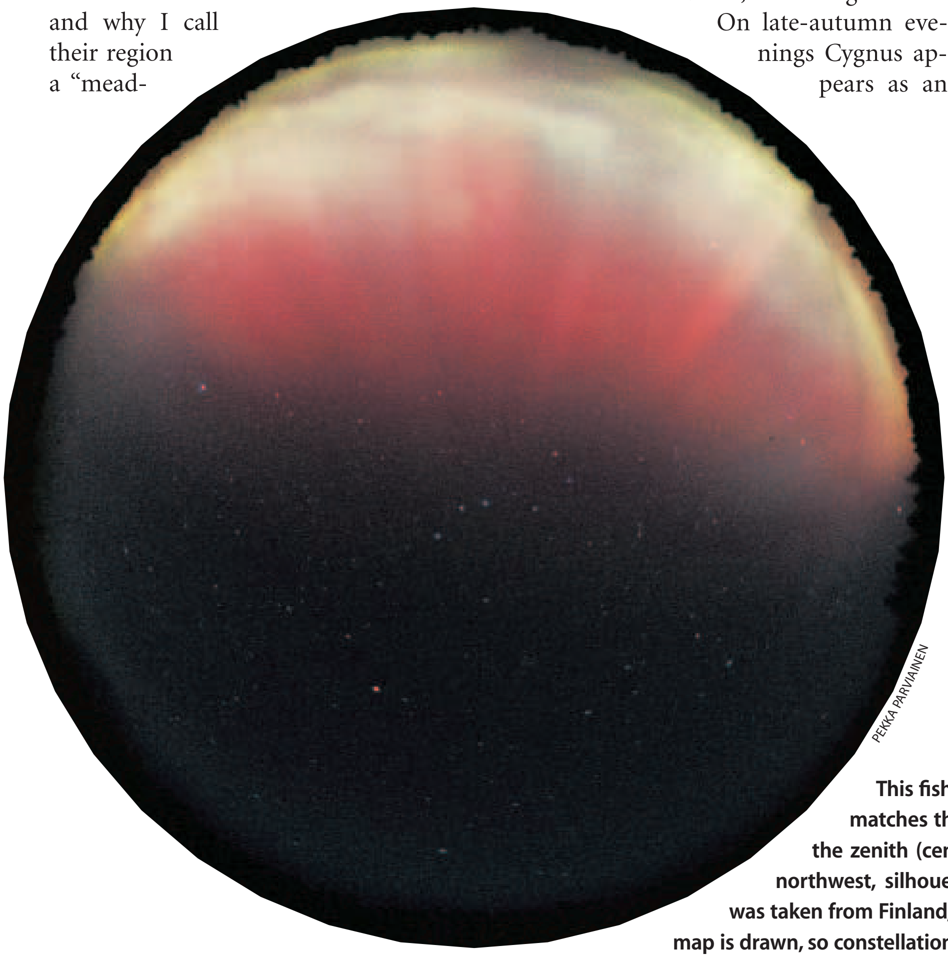
Looking low in the southeast, we behold the fiery flicker of Antares rising beneath the head of Scorpius.

Splendid Vega is already well up in the north-northeast, and below it is Cygnus, the Swan, featuring Deneb. On late-autumn evenings Cygnus appears as an upright "Northern Cross" when it's setting. But now that it's rising, it flies parallel to the horizon.

Shining brilliantly almost overhead when you face southeast is Arcturus.

It's time to turn to the pastoral constellations of spring. Partway up the southern sky is the curious pattern of Corvus, the grain-seeking Crow. To its upper left is 1st-magnitude Spica, the brightest star of Virgo, who traditionally represents a maiden sowing grain in a springtime field. Now trace from Spica a rough loop of bright constellations surrounding the zenith. To her right is proud Leo, the Lion, a creature of wild, open spaces. Past the zenith in the north is the Great Bear, incorporating the Big Dipper. Beyond the curve of the Big Dipper's handle is the moderately bright length of Boötes, the Herdsman. His star pattern curves around to Arcturus — from which it's only a short run back to Spica.

I picture this circle of bright star figures, with its natural and bucolic themes, as the surrounding "forest." Inside this ring, in the midst of the May evening sky overhead, is the unassuming "meadow." Here dark skies reveal the dim little patterns of Coma Berenices and Canes Venatici. The slightest optical aid will show (or clarify) the Coma star cluster. More power and aperture will show the globular cluster M3. Then there are galaxies such as M51 (which seems to be leading a smaller galaxy by the hand) and the three featured in the Binocular Highlights section at far right. Most provocative of all is the teeming Virgo cluster of galaxies. Faint as the cluster members may be, they are strewn over this dim region like a spring's growth of flowers across the meadow in the sky.



PEKKA PARVIAINEN

This fisheye photograph of the spring evening sky nearly matches the foldout map at right. Note the Big Dipper near the zenith (center). Bright aurora fills the sky to the north and northwest, silhouetting trees along the horizon. The photograph was taken from Finland, about 20° north of the 40° latitude for which the map is drawn, so constellations appear shifted about 20° southward.

Northern Hemisphere Sky

When to use the map

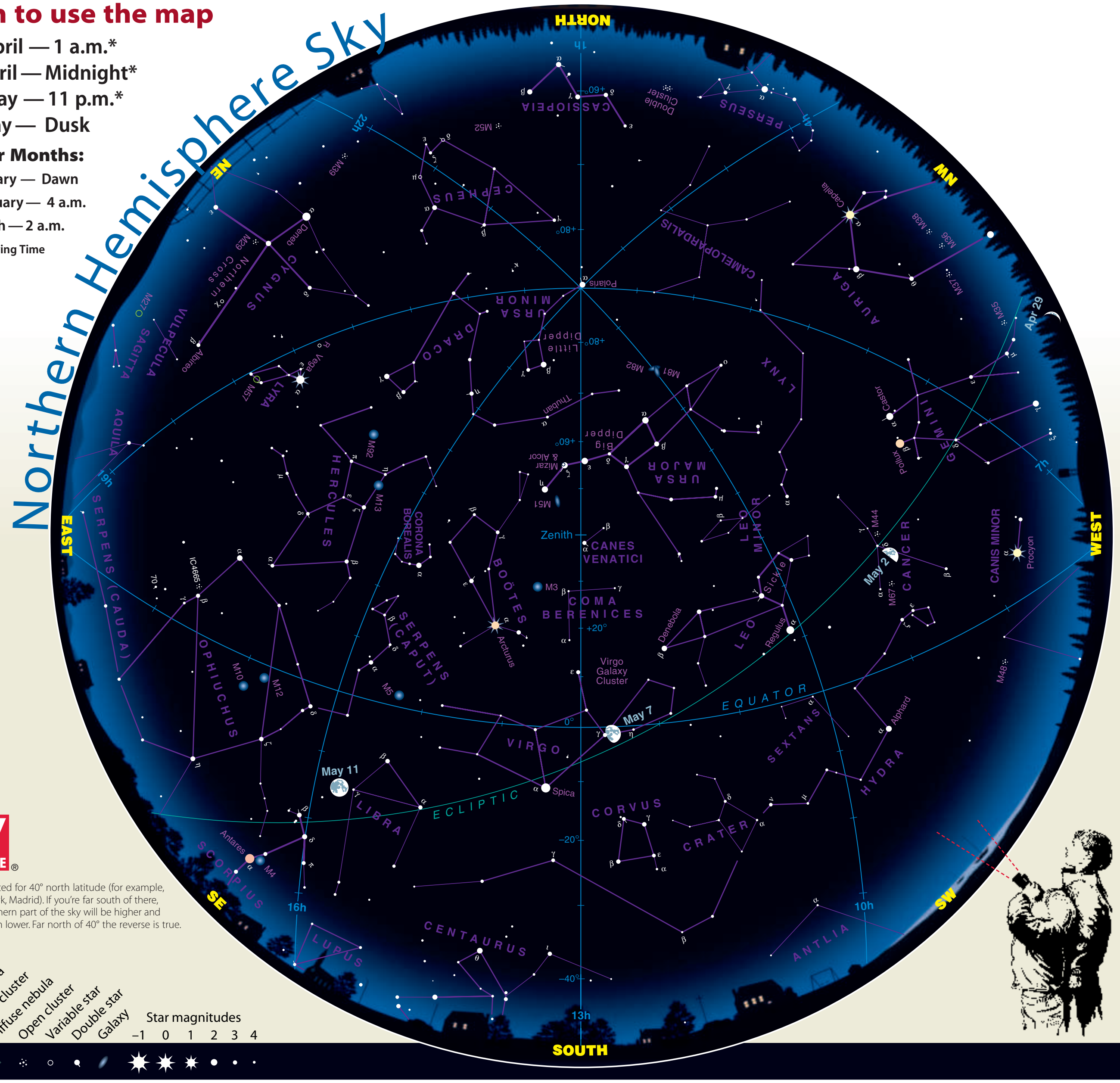
Early April — 1 a.m.*
Late April — Midnight*
Early May — 11 p.m.*
Late May — Dusk

In Other Months:

Early January — Dawn
Early February — 4 a.m.
Early March — 2 a.m.

*Daylight Saving Time

Tear out this monthly map for use outdoors.



SKY & TELESCOPE®

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.

Planetary nebula · Globular cluster · Diffuse nebula · Open cluster · Variable star · Double star · Galaxy

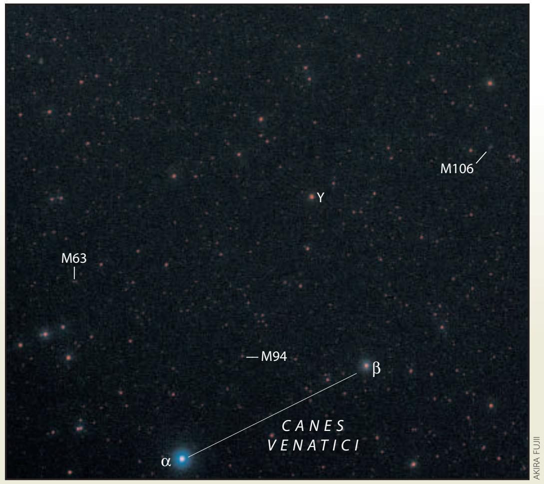
Star magnitudes −1 0 1 2 3 4

How to use the map

Go out within an hour or so of the time listed at far left. *Turn the map around* so the edge marked with the direction you're facing (north, southeast, or whatever) is *down*. The stars above this horizon on the map now match the stars you're facing.

The map's center is overhead. So a star plotted halfway from the edge to the center can be found in the sky about halfway from horizontal to straight up.

For example: As you're holding it now, the map has south down. About halfway from there to the map's center is the bright star Spica, with the little constellation Corvus at its lower right. Go out and look south about halfway up the sky. There they are!



binocular highlights | *By Alan M. MacRobert*

M94, M63, and M106

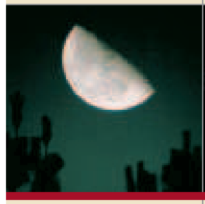
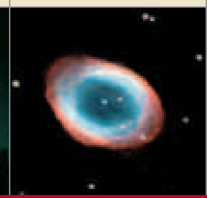
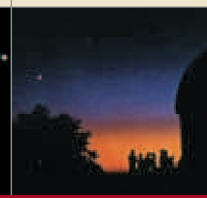
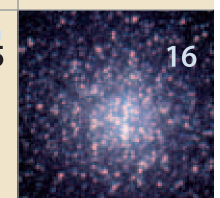
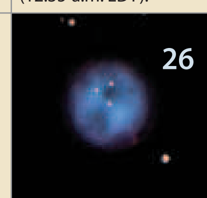
NESTLED UNDER THE CURVE OF THE BIG DIPPER'S HANDLE IS THE constellation Canes Venatici, the Hunting Dogs. It's plotted dead center (at the zenith) on our map at left. Only two of its stars are bright enough to get onto the map. But the constellation is full of galaxies.

The most famous is M51, which was featured here in the May 1996 issue. At least three other galaxies in Canes Venatici are within reach of 50-mm binoculars on a dark night.

M94, M63, and M106 are similar in total brightness, with magnitudes of 8.2, 8.6, and 8.4, respectively. But their appearances differ. M94 looks starlike in 10×50 binoculars if you have a less than perfect sky. M106 is fuzzy and elongated northwest-southeast. M63 is smaller and dimmer, a narrow spindle oriented nearly east-west with an 8th-magnitude star just off its west end.

Also labeled on the photograph is the carbon star Y Canum Venaticorum. Its deep orange-red color earned it the nickname "La Superba."

May 1998

S	M	T	W	Th	F	S
			29	30	1	2 Binoculars show the Beehive Cluster about 5° to the right of the Moon.
3 First-quarter Moon (6:04 a.m. EDT).	4 • Mercury is at greatest elongation in the dawn. • Regulus is to the Moon's right this evening.	5	6	7	8 • Spica is below the Moon. • Moon at apogee, 9^h UT (distance 405,861 km, diameter 29' 27").	9
10	11 Full Moon (10:29 a.m. EDT).	12 • Mars is in conjunction behind the Sun. • Saturn is 1° left or upper left of Mercury very low in the dawn.	13 Saturn is 1° above Mercury.	14	15	16 
17 The Big Dipper is nearly overhead in the north during evening around this time of year.	18	19 Last-quarter Moon (12:35 a.m. EDT).	20	21 Jupiter is to the Moon's upper right at dawn; Venus is far to the Moon's lower left.	22 Venus is lower left of the Moon at dawn. Saturn is to Venus's lower left.	23
24 Moon at perigee, 0^h UT (distance 361,659 km, diameter 33' 02").	25 New Moon (3:32 p.m. EDT).	26 	27 Pluto is at opposition tonight.	28 Saturn is less than 0.7° from Venus this morning and tomorrow morning.	29	30
31 Regulus appears about 1° or 2° from the Moon.						

The Moon diagrams in the calendar show the Moon's phase in the evening when waxing or full, and in the early morning hours of the date when waning. Celestial north is up, and a tick indicates the Moon's north pole. The red dot shows the Moon's limb that's tipped into best view by libration; the dot's size indicates by how much. The maximum libration plotted is 8.7° on May 1st; the minimum is 3.6° on the 7th. Moon diagrams adapted by Guy Ottewell from his *Astronomical Calendar 1998*.

FROM TOP LEFT: TRUDY KOLLER-ANES, JACK NEWTON, BOB SANDY, JACK NEWTON, JACK NEWTON

The Sun, Moon, and Planets in May

By Fred Schaaf

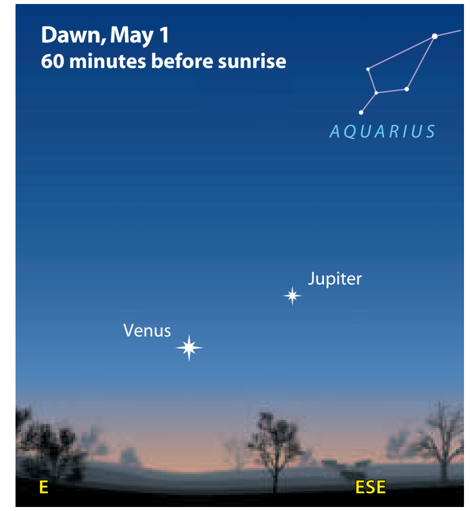
Only one planet is in the evening sky during May — faint little Pluto! Of the five classical planets (those visible to the naked eye), four can be seen before dawn for much of the month. Jupiter and Venus are bright and obvious in the east before sunrise, while Mercury and Saturn are lower and harder to spot.

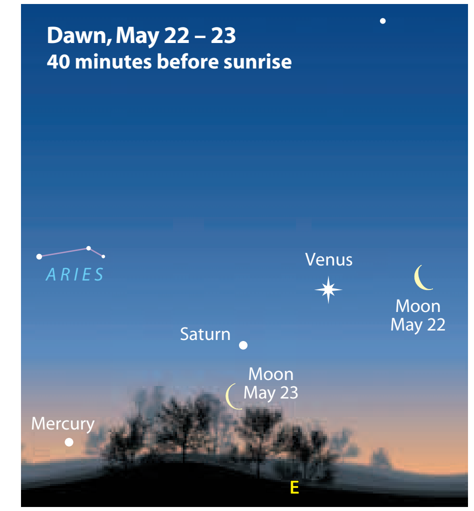
If you're an early riser, mark your calendar for two planetary pairings. Mercury and Saturn appear close together near the sunrise horizon on May 12th and 13th. Then Saturn has a marvelously close conjunction with Venus on the mornings of May 28th and 29th.

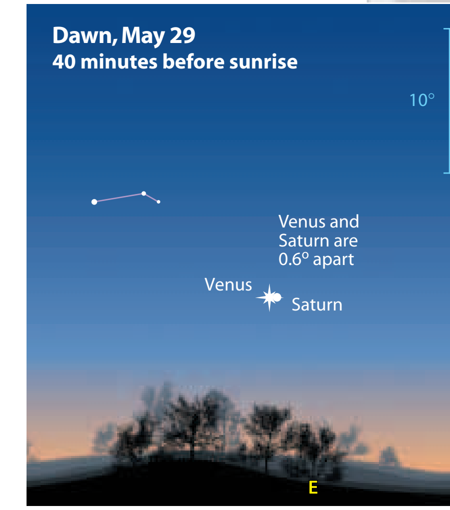
Venus and **Jupiter** are the two brightest planets. They shine low in the east as morning twilight strengthens; Jupiter is to Venus's upper right. They're separating from each other after their close conjunction (only ½° apart) on the mornings of April 22nd and 23rd. During May the gap between them continues to widen by about a degree a day, from 8° to 37° at month's end.

Jupiter is nearly two magnitudes (six times) fainter than magnificent Venus. However, it is getting higher week by week while Venus is slowly heading down toward the horizon. By the last week of May Jupiter should provide a fairly good telescopic view, being at least 20° up in the southeast during morning twilight (for observers at midnorthern latitudes).

On the morning of May 10th optical aid shows a 6th-magnitude orange star, SAO 146736, just 8' south of Jupiter and its four Galilean satellites. On May 20th Australian telescope users can watch the waning crescent Moon occult Jupiter in daylight around 23^h Universal Time.







Venus and Jupiter shine low in the east at dawn in May. Each morning they move 1° farther apart. Meanwhile, Saturn appears to climb upward from Mercury to Venus during the month. These diagrams are drawn for a skywatcher at 40° north latitude.

A telescope will show gibbous Venus shrinking in angular size while waxing in phase during May. Venus is receding from Earth as it races ahead of us in its faster orbit around the Sun. The brilliance of Venus never fails to delight, though, and its conjunction with Saturn is the best attraction of the month for planet watchers.

Four planets shine at dawn in May. Venus and Jupiter blaze brightly; Saturn and Mercury are lower and dimmer.

Saturn is still immersed deep in the glow of sunrise as May begins, but by midmonth it's peeking into view. Look well to Venus's lower left about 30 minutes before sunrise.

Saturn is located just 3° from brighter **Mercury** on May 10th, 2° from it on May 11th, and about 1° on the 12th and 13th. Bring binoculars; this is a low conjunction that will be difficult to observe. From the 14th on, the two planets separate by more than a degree a day.

Two weeks later Saturn is quite a bit higher, approaching a much finer conjunction with radiant Venus. Less than 3° divides Saturn from Venus on May 26th. They're closest on the mornings of May 28th and 29th, separated by about 0.5° to 0.7° depending on where you are in North America. In a telescope the gibbous globe of Venus will be slightly smaller in angular size than Saturn — but this may be hard to believe in the face of Venus's overpowering brightness. By May 31st Venus and Saturn separate to about 2½° apart.

And what about Mercury, left behind way down on the east-northeastern horizon? This is Mercury's worst morning apparition of the year for midnorthern latitudes. The elusive planet stays low in the glow of sunrise for the first 20 days of May, then sinks even lower.

Uranus and **Neptune** glow in Capricornus at 6th and 8th magnitude, respectively. They're in the southeastern sky before the first light of dawn, awaiting the ambitious early riser using binoculars or a telescope and the finder chart on page 96.

Pluto, magnitude 14, is north of the head of Scorpius. It's well up in the southeast by midnight daylight saving time. You'll need a fairly large amateur telescope and the map on page 97. Pluto reaches opposition on May 28th.

Mars is out of sight all month; it passes through conjunction with the Sun on May 12th. For only the second time since 1976, Mars actually goes behind the disk of the Sun as seen (or, rather, not seen) from Earth. Not until spring 1999 will Mars reach its next opposition.

The **Moon** is at first quarter on the evening of May 2nd, shining about 5° to the left of the Beehive star cluster in Cancer (at North American viewing hours). The Moon is full on the 11th and at last quarter on the morning of the 19th. Then from May 20th to 24th the waning Moon cascades down a sloping line of planets — Jupiter, Venus, Saturn, and Mercury, in that order — in the dawn sky. New Moon comes on May 25th.

Fred Schaaf *welcomes mail at 681 Port Elizabeth-Cumberland Rd., Millville, NJ 08332, and e-mail at fschaaf@aol.com.*

LIGHT-POLLUTION NOTES: AN ASTRO-BUSINESS CHALLENGE

I have a challenge. I've often urged individuals to join the International Dark-Sky Association (IDA). It's having heartening, if still limited, successes in its quest to change the world's lighting practices away from uselessly spilling glare into the night sky. My challenge is for companies selling astronomy equipment to support the IDA too.

Companies catering to amateurs (and professionals) can become corporate members. They can advertise their involvement and help promote the IDA's goals. I'm aware of only two equipment sellers that have gotten onboard. Orion Telescope and Binocular Center has long featured a prominent box in its catalog discussing light pollution and the IDA. Kevin Conod of the Newark Museum in New Jersey persuaded the Edmund Scientific Company to include a mention light pollution and the IDA on its planispheres. As far as I know, that's it. (Also see Daniel W. E. Green's Focal Point on page 10.)

The world is starting to notice this issue. In the last year "we have been flooded by requests for assistance," the IDA reports. "Many dozens of cities are currently passing or revising light-control ordinances. Over the past seven months we have mailed over 55,000 IDA information sheets from the office." Funds are badly needed to keep up with such demands. Write to the IDA at 3545 N. Stewart Ave., Tucson, AZ 85716 or leave mail through its Web site, http://www.darksky.org/.

Tear out this monthly calendar for use outdoors.

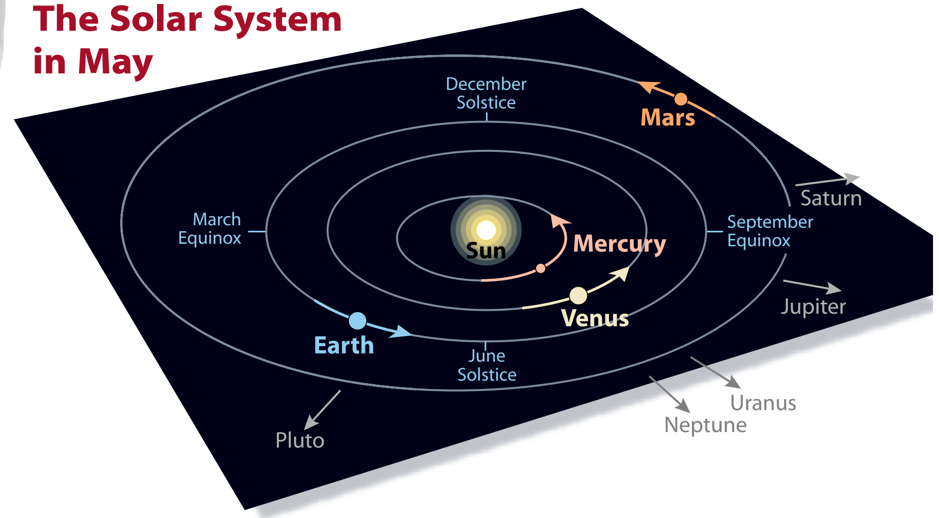
The Sun

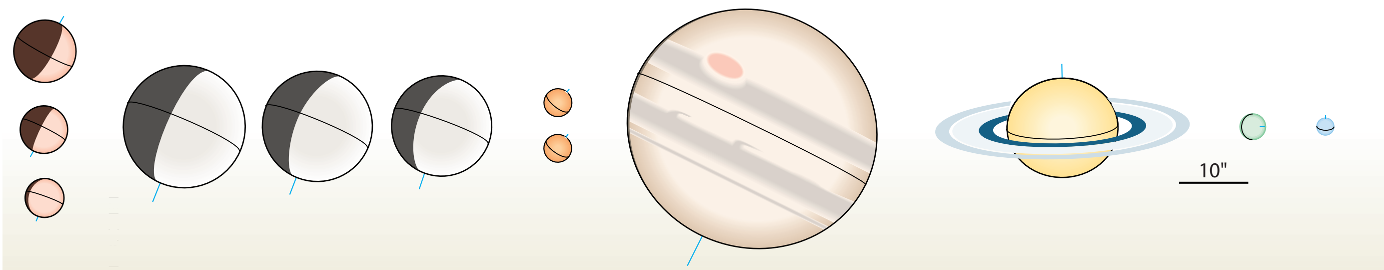
Date	May 1st	15th	31st
Right Ascension	$2^h32.1^m$	$3^h26.4^m$	$4^h30.7^m$
Declination	+14°57'	+18°46'	+21°51'
Diameter	31'45"	31'39"	31'33"
Distance (a.u.)	1.007	1.011	1.014

The Moon

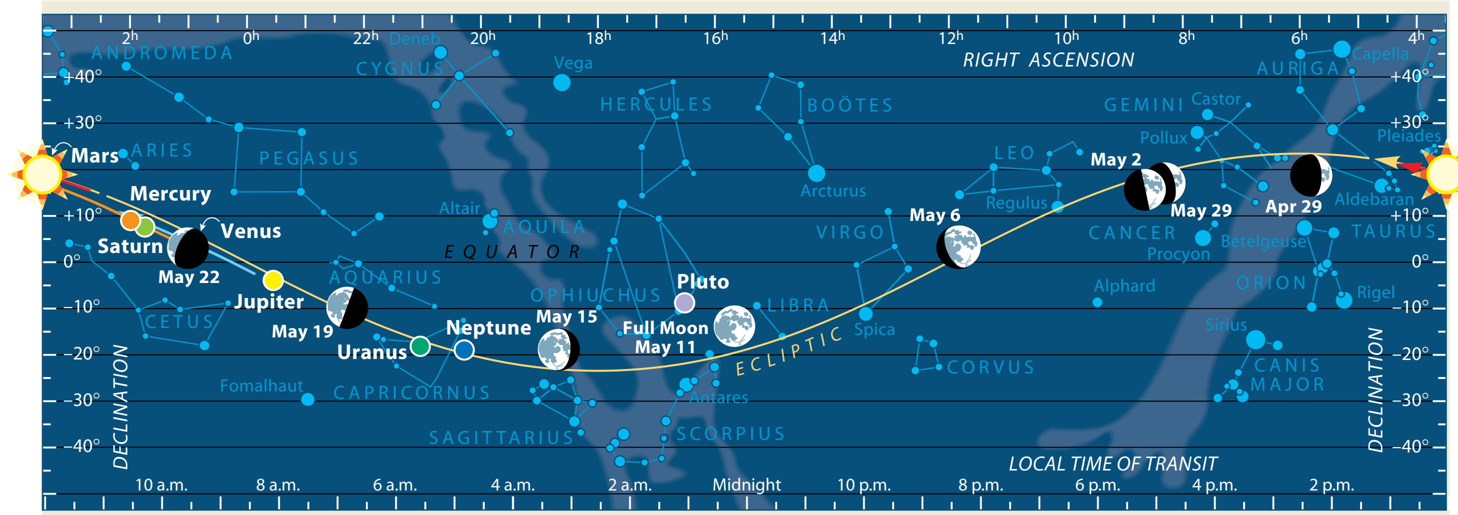
First Quarter	May 3	10:04 UT
Full Moon	May 11	14:29 UT
Last Quarter	May 19	4:35 UT
New Moon	May 25	19:32 UT

The Solar System in May





May	Mercury 1st	Mercury 15th	Mercury 31st	Venus 1st	Venus 15th	Venus 31st	Mars 1st	Mars 31st	Jupiter 15th	Saturn 15th	Uranus 15th	Neptune 15th	Pluto 15th
Right Ascension	$0^h56.5^m$	$1^h55.3^m$	$3^h41.0^m$	$23^h50.4^m$	$0^h49.5^m$	$1^h59.1^m$	$2^h43.4^m$	$4^h11.4^m$	$23^h32.6^m$	$1^h44.5^m$	$21^h01.6^m$	$20^h17.2^m$	$16^h29.2^m$
Declination	+3°07'	+8°41'	+18°38'	–2°21'	+3°22'	+9°58'	+15°45'	+21°20'	–4°07'	+8°22'	–17°36'	–19°20'	–9°13'
Elongation	26° Mo	24° Mo	12° Mo	44° Mo	41° Mo	38° Mo	3° Ev	5° Mo	62° Mo	27° Mo	101° Mo	112° Mo	162° Mo
Magnitude	+0.7	0.0	–1.1	–4.1	–4.1	–4.0	+1.3	+1.4	–2.2	+0.6	+5.8	+7.9	+13.7
Diameter	8.6"	6.7"	5.4"	17.6"	15.9"	14.3"	3.8"	3.7"	36.6"	16.2"	3.6"	2.3"	0.1"
Illumination	37%	59%	89%	65%	70%	75%	100%	100%	99%	100%	100%	100%	100%
Distance (a.u.)	0.778	1.001	1.251	0.946	1.051	1.166	2.467	2.509	5.385	10.221	19.638	29.750	29.099



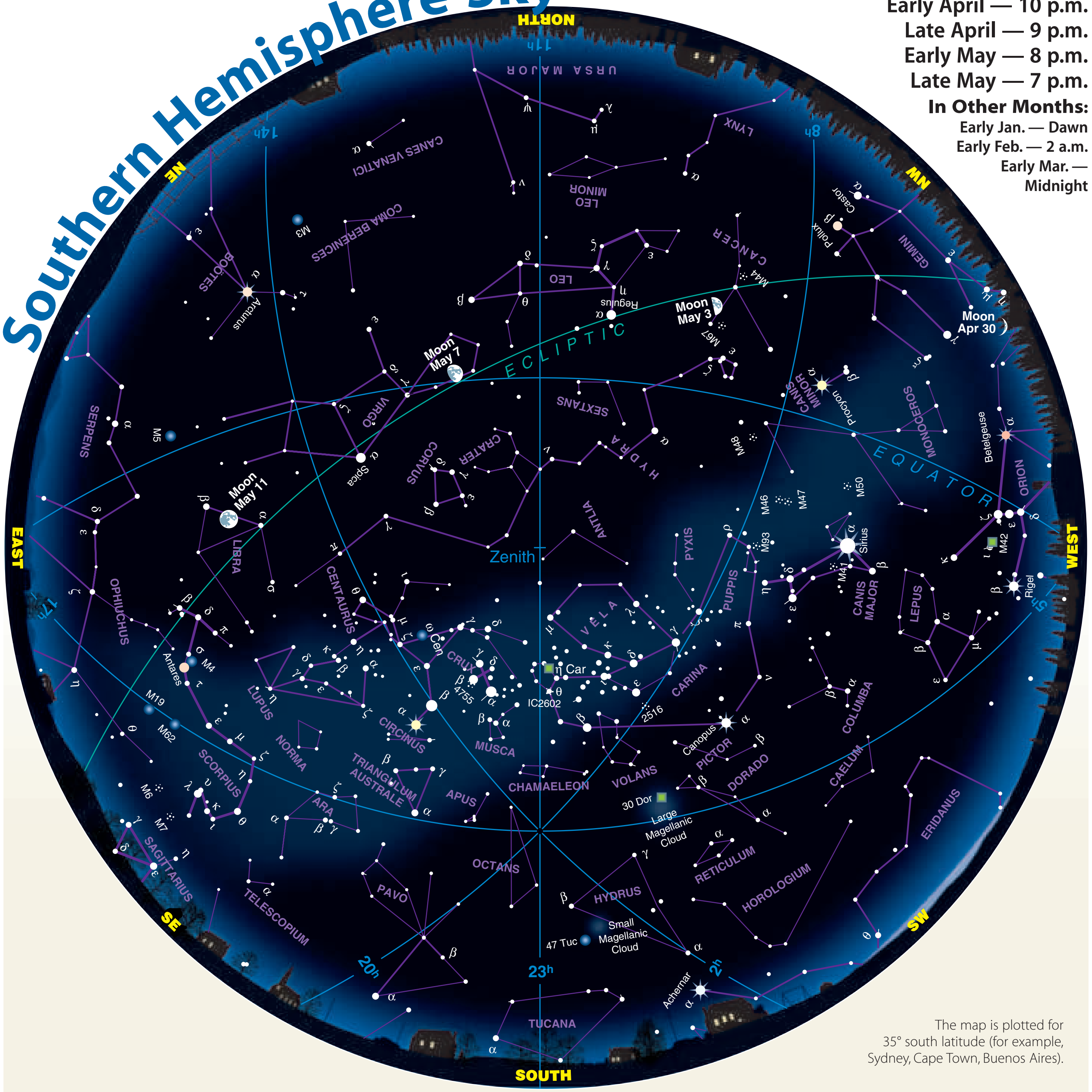
Top right: In this view of the inner solar system, curved arrows indicate each planet's movement during the month. *Planet disks* have south up; ticks indicate the pole turned Earthward. *Map above:* The Sun and planet symbols are for mid-May; arrows show motion throughout the month. The Moon is plotted for evening dates when it is waxing (right side illuminated) or full, and morning dates when waning (left side illuminated). *Local time of transit* tells when objects cross the meridian at midmonth; transits occur an hour later on the 1st, an hour earlier at month's end.

Southern Hemisphere Sky

When to use the map

Early April — 10 p.m.
Late April — 9 p.m.
Early May — 8 p.m.
Late May — 7 p.m.

In Other Months:
Early Jan. — Dawn
Early Feb. — 2 a.m.
Early Mar. — Midnight

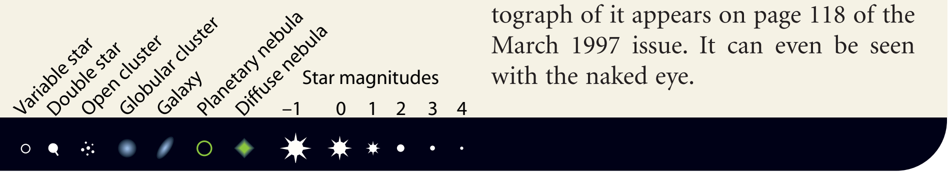


The map is plotted for 35° south latitude (for example, Sydney, Cape Town, Buenos Aires).

By Fred Schaaf

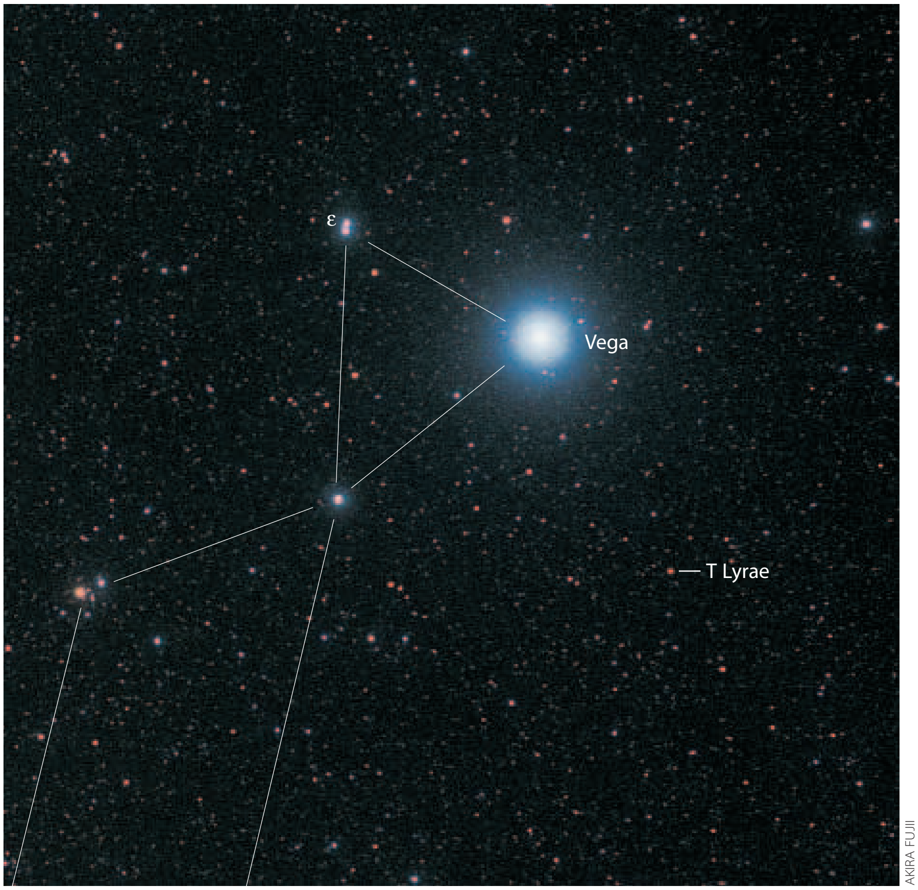
Just south of the Southern Cross is a most overlooked little constellation: Musca, the Fly. Yet it contains five stars brighter than magnitude 4.0 (the brightest is 2.9) as well as rich Milky Way and part of the Coalsack. It has several 7th- and 8th-magnitude globular and open clusters. It offers three 6th-magnitude variables (two Cepheids and one irregular). It has true binaries such as Beta Muscae, a white pair 1.3" apart, and beautiful naked-eye pairs such as Lambda and Mu Muscae, white and orange, ¼° apart.

Then there's NGC 5189. Astronomers have debated what type of nebula it is; the latest consensus calls it a planetary. It's visible in binoculars as a dim oval about 2' across. Another strange Musca object is the nearly 3°-long dark nebula that Dennis di Cicco and Roger Sinnott of *Sky & Telescope* nicknamed "the Dark Doodad." It curves partway between Alpha Muscae and the globular NGC 4372. A fine photograph of it appears on page 118 of the March 1997 issue. It can even be seen with the naked eye.



Carbon Stars: Reddest of the Red

Stars with carbon-rich atmospheres are the most deeply colored ones you can see. | **By Brian A. Skiff**



About 10 years ago the Canadian comet discoverer Rolf Meier and his wife, Linda, stopped by Lowell Observatory in Flagstaff, Arizona, where I work. I showed them the cool supergiant variable star S Persei, whose light I was measuring with a photometer on the observatory's 21-inch telescope. Linda looked at the star in the photometer's viewing eyepiece and exclaimed, "Oh! It's *very* red!"

Thanks to my red-deficient color vision (common among men but rare among women), the 9th-magnitude star looked completely colorless to me. But I knew from my measurements through blue and yellow filters that it must indeed be deeply colored.

I had always been amazed that even novice observers looking at Orion see a distinct color contrast between Betelgeuse and Rigel — orange-red and pale blue-white, respectively. To me they look practically alike. Since stop signs and apples do look "red" to me, I began to wonder if any stars are red enough for me to see strong color in them. After poking around in the observatory library, and with a few hints from fellow amateurs, I found the answer: carbon stars.

Astronomers often describe a star's color by its *color index*. This is simply the difference in the star's magnitude as measured through two different standard color filters.

The most commonly used color index is the difference between a star's brightness measured through a broadband blue (B) and a "visual" (V) filter. The V filter passes the yellow and green wavelengths to which our eyes are the most sensitive; the filter itself looks pale straw color. This is why color index is often written as B–V ("B minus V"). Its value turns out to be closely related to a star's surface temperature.

On this scale, a star that most people

Above: **Easily spied 2° south-southwest of Vega, the carbon star T Lyrae has an extreme B–V color index of about 5.5, making it one of the reddest stars in the sky. It has varied irregularly between magnitudes 7.8 and 9.6; it's sometimes visible in binoculars and always colorful in a telescope.** ***Left:*** **Author Brian Skiff has red-deficient color vision; even red supergiant stars such as Betelgeuse and Antares look nearly white to him. But even he perceives carbon stars as red. Here Skiff stands with the 21-inch telescope at Lowell Observatory in Flagstaff, Arizona, which he uses to measure star brightnesses and colors photoelectrically.**

would call “pure white” has a color index of +0.2 or +0.3. Vega and Sirius, white with just a hint of blue, are 0.0. The hottest, bluest stars, such as Spica, Bellatrix, and the stars of Orion’s Belt, have a negative B–V of about –0.25.

The pale yellow Sun has a B–V color of about +0.65. (In a large telescope I see such stars as exactly white.) Cooler Arcturus and Aldebaran have B–Vs of about +1.0 and +1.5, respectively; most people see them as pale yellowish orange to pale orange-red. (See “The Truth About Star Colors,” *S&T:* September 1992, page 266.)

The reddest ordinary stars are *M*-type supergiants such as Betelgeuse and Antares, both of whose B–Vs are about +1.85. But to me, even through a telescope, these stars appear more yellow than red.

Carbon Stars

Strongly colored stars have always fascinated astronomers. The long history of red-star observations begins in the early 19th century. Such famous observers as Angelo Secchi, Nils C. Dunér, and Thomas E. Espin found red stars of interest not only for their strong color but also because they provided a rich lode for hunting new variables. The pioneering visual spectroscopists (starting with Secchi around 1860) also found their complex spectra to be of extreme curiosity. In 1890 Espin produced a catalog of 766 red stars, including detailed observations of their colors and variability as well as descriptions of their spectra.

In his visual surveys with an eyepiece spectroscope, Secchi found that most stars fit into three broad categories. Bluish white stars such as Sirius showed a spectrum marked only by a few strong dark lines, now known to be due to hydrogen absorption. Another group, including the Sun, showed additional, weaker lines. In a third class were redder stars such as Antares and Betelgeuse, which had innumerable fine lines as well as several broad, dark bands. It was not until early this century that these dark bands were found to result from titanium oxide (TiO) molecules.

Before long Secchi also isolated a fourth class, which were generally among the reddest of stars. These also showed dark spectral bands, but the pattern was different from those in the Antares-like stars. Secchi himself identified these bands as being due to carbon, which he deduced by comparing the stellar spectra to the flame spectrum of paraffin in a laboratory. These very red stars are now called “carbon stars.” The image of a star surrounded by soot and smoke also turns out to be appropriate.

How does so much carbon end up in a star’s atmosphere? After a star of about the Sun’s mass enters the red-giant phase of its evolution, convective currents circulate deep into the stellar interior. Heavy elements such as carbon, which were created by nuclear fusion earlier in the star’s life, are brought up to the surface. The bands in the visible part of the spectrum are the fingerprints of molecules (such as C_3, CN, and CH) formed by the dredged-up carbon. The TiO bands are absent.

Ordinary orange-red stars like Betelgeuse get their color from their low surface temperatures. Carbon stars are also cool giants, but they are deeper red because the blue and violet portions of their spectra are almost completely absorbed by the various molecules in their atmospheres. In other words, they are wrapped in gaseous red filters.

Stellar astronomers think of carbon stars as forming a sequence parallel to the ordinary cool giants. Although they are classified in a distinct bin (spectral type *C*), carbon stars actually form a continuum — from those showing mere traces of carbon (and much oxygen) to those where carbon dominates the spectrum. Carbon-star spectra includes two numbers, such as *C*5,4. The first indicates decreasing temperature from 0 to 9, while the second indicates the strength of the carbon-related molecules on a scale of 1 to 5. A type *C*5,4 star has a temperature similar to a normal red giant near type *M*0, and it has strong C_2 bands. (As in other spectral types, *e* indicates the presence of emission lines.)

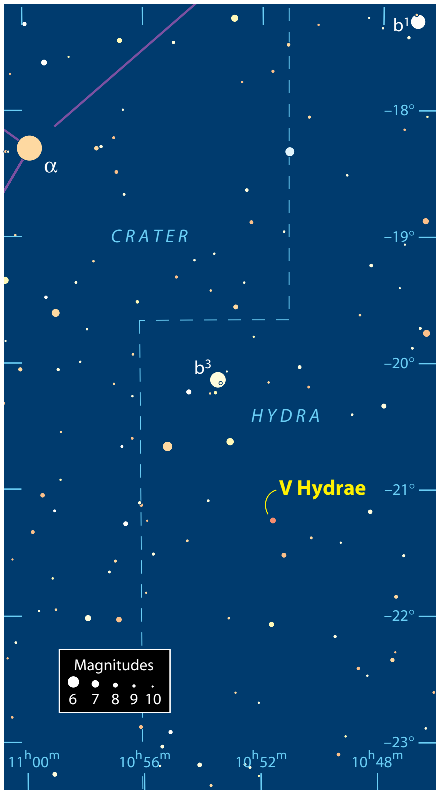
Carbon stars are rare. A mere handful are easily visible to the naked eye, and only about 200 appear among the half million stars brighter than magnitude 9. But they have been searched out more assiduously than any other spectral class of star. The most recent catalog of them, published in 1989 by C. Bruce Stephenson, includes 6,000 entries, nearly all fainter than visual magnitude 12.

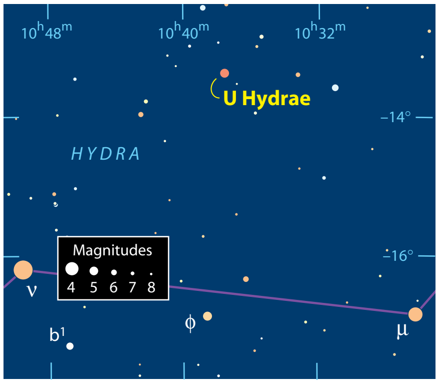
The table below shows some representative carbon stars and a few well-known “ordinary” red stars for comparison. The table includes *approximate* V (visual) magnitudes and B–V colors. All but one of these stars are variable (and that one star is merely unstudied for variability). Some display large changes in brightness (the carbon Miras), so the magnitudes refer to either a typical brightness or a magnitude near maximum.

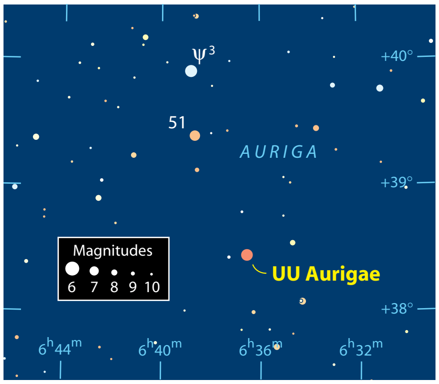
The B–V colors in the table cannot be considered precise. In addition to some innate variability in the color index, the standard photometric systems are not defined for stars redder than ordinary *M*

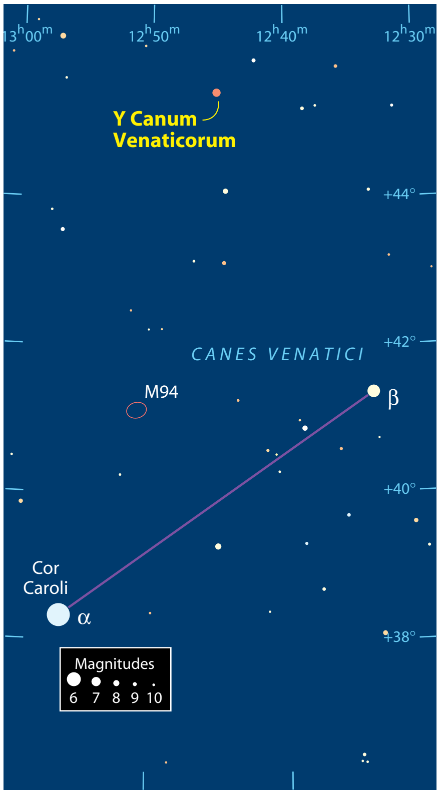
Some Very Red Stars

Name	R. A. (2000)	Dec.	Typical V Mag.	B–V	Range of V Mag.	Spectral Type	Period (Days)	Type of Variable
VX And	$0^h\ 19^m\ 54^s$	+44° 42.6'	8.5	4.4	7.8–9.3	*C*5,4	369	Carbon Mira
V466 Cas	$1^h\ 19^m\ 54^s$	+58° 18.5'	8.5	2.1	8.0–9.0	*M*0.5Ib	—	Irregular
R Scl	$1^h\ 26^m\ 58^s$	–32° 32.6'	6	4.0	5.0–9.0	*C*6,5	370	Carbon Mira
RS Per	$2^h\ 22^m\ 24^s$	+57° 06.6'	8.5	2.3	7.8–10.0	*M*3+Iab	152?	Irregular?
R Dor	$4^h\ 36^m\ 46^s$	–62° 04.6'	5.5	1.6	4.8–6.6	*M*8IIIe	338?	Carbon Mira
R Lep	$4^h\ 59^m\ 36^s$	–14° 48.4'	7	5.5	5.5–11.7	*C*7,4e	427	Carbon Mira
UU Aur	$6^h\ 36^m\ 33^s$	+38° 26.7'	6	2.6	5.3–6.5	*C*5,3	235?	Semiregular
U Hya	$10^h\ 37^m\ 33^s$	–13° 23.1'	5	2.6	4.8–6.5	*C*7,3	450	Semiregular
V Hya	$10^h\ 51^m\ 37^s$	–21° 15.0'	7	5.5	6.0–12.0	*C*7,5e	550	Semiregular
SS Vir	$12^h\ 25^m\ 20^s$	+0° 47.8'	8	4.2	6.0–9.6	*C*6,3e	355	Carbon Mira
Y CVn	$12^h\ 45^m\ 08^s$	+45° 26.4'	5	2.5	4.8–6.5	*C*5,4	158	Semiregular
E-B 365	$12^h\ 47^m\ 25^s$	–59° 41.7'	9	5.8		*C*		
V CrB	$15^h\ 49^m\ 31^s$	+39° 34.3'	8	4.4	6.9–12.2	*C*6,3	358	Carbon Mira
V Pav	$17^h\ 43^m\ 19^s$	–57° 43.4'	7	4.0	7.5–13.8	*C*5,4	229	Semiregular
T Lyr	$18^h\ 32^m\ 20^s$	+36° 59.9'	8.5	5.5	7.8–9.6	*C*6,5	—	Irregular
V Aql	$19^h\ 04^m\ 24^s$	–5° 41.1'	7	4.2	6.6–8.4	*C*5,4	353	Carbon Mira
UX Dra	$19^h\ 21^m\ 36^s$	+76° 33.6'	6	2.9	5.9–7.1	*C*6,4	168	Semiregular
RS Cyg	$20^h\ 13^m\ 24^s$	+38° 43.7'	7.5	3.0	6.5–9.7	*C*8,2e	417	Carbon Mira
Mu Cep	$21^h\ 43^m\ 30^s$	+58° 46.8'	4	2.5	3.4–5.1	*M*2Ia	730?	Irregular
LW Cyg	$21^h\ 55^m\ 14^s$	+50° 29.8'	9	4.2	8.5–10?	*C*4,2	—	Irregular
19 Psc	$23^h\ 46^m\ 24^s$	+3° 29.2'	5	2.5	4.5–5.3	*C*7,2	220	Semiregular









giants, so large systematic deviations occur when different filters and photomultiplier tubes (or CCDs) are used for the measurements.

Nevertheless, the large B–V values give some indication of what to expect at the eyepiece. While "red" stars are usually thought of as having colors of 1.5 to 2.0, several stars here have had their B–V measured as high as 5.5!

Some are bright enough for their strong color to be evident in binoculars. Others require a telescope. Remember that the part of your eye most sensitive to color is the fovea, the center of your vision. So you want to look right at these stars, unlike in much deep-sky observing, where the emphasis is on averted vision.

A Spring Collection

Compare **V Hydrae** to HD 94073, the 8th-magnitude star ¼° to its south-southwest. According to the new Hipparcos catalog, HD 94073 has a B–V of 1.66, slightly redder than Aldebaran. Yet its paleness next to deep-red V Hydrae is striking.

V Hydrae normally ranges between magnitude 7 and 9 in about 17 months. But about every 18 years dust condenses around the star, causing it to dim to as faint as magnitude 12. The most recent dimming occurred in the mid-1990s; since then V Hydrae has slowly recovered to nearly its usual brightness.

A bipolar (two-sided) outflow of material from the star has been observed at infrared and radio wavelengths, suggestive of the structures seen in planetary nebulae. Perhaps this is a sign that V Hydrae is already making its expected transition from the red-giant stage to a planetary nebula.

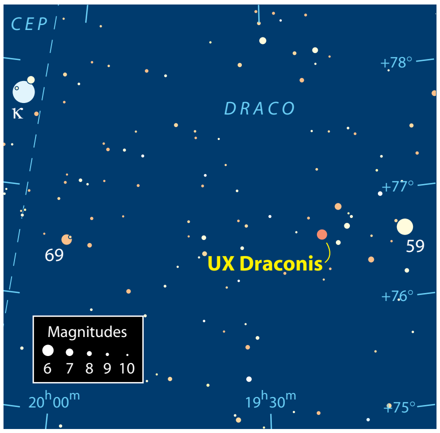
About 9° north-northwest of V Hydrae is the brighter but less-red carbon star **U Hydrae .** It's bright enough that its red color should be distinctive in binoculars. U Hydrae normally remains about 5th magnitude. Its brightness suggests that it is among the nearest carbon stars. Indeed, the Hipparcos spacecraft supplies us with a parallax measurement that puts it 520 light-years away with an uncertainty of only 10 percent.

Three other bright but not extremely red carbon stars lie in the northern spring sky. In the eastern reaches of Auriga, about 7° east-northeast of Theta (θ) Aurigae, is 6th-magnitude **UU Aurigae.** One of the first carbon stars found, it was noted as very red by the French astronomer J.-J. Lalande in the late 18th century. It hovers between magnitude 5.5 and 6.0.

Nearly overhead these evenings, only 4° northeast of Beta (β) Canum Venaticorum, is **Y Canum Venaticorum.** Secchi named it "La Superba." It generally remains between magnitude 5 and 6. The Hipparcos parallax puts the star some 720 light-years away, almost directly above the plane of the galaxy.

Finally, in the northeast is **UX Draconis,** a circumpolar object for most Northern Hemisphere observers. It lies only 2¾° southwest of Kappa (κ) Cephei. It's a little fainter than Y Canum (between 6th and 7th magnitude) but is still a striking sight in a telescope.

The easiest carbon star to find in the whole sky — if you live in the Southern Hemisphere — is also one of the reddest. Just 2' west of 1st-magnitude Beta (β) Crucis, the eastern star of the Southern Cross, is **Espin-Birmingham 365.** Although it was observed as early as the 1830s by John Herschel, it has no modern designa-



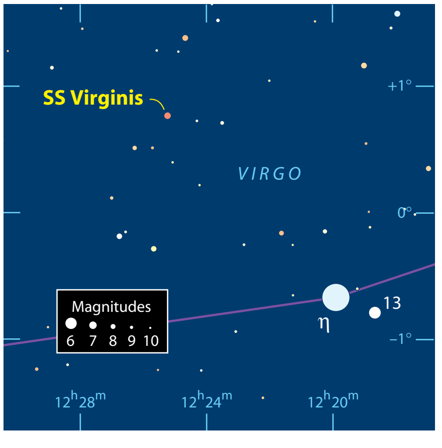
tion other than its entry in Stephenson's carbon-star catalog. It was rediscovered as a carbon star after World War II by A. D. Thackeray in South Africa, but no published observations show it to be variable.

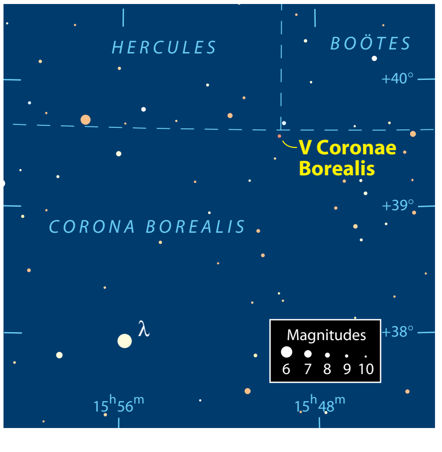
Several times astrophotographers have asked me about this conspicuous, 9th-magnitude red dot on their color photos of the Southern Cross. As the table shows, it is one of the reddest stars known, at B–V = 5.8, so that in color filmi the red emulsion layer is the only one exposed. It looks like a photo defect!

Two quite red variable stars — **SS Virginis** and **V Coronae Borealis** — are known as "carbon Miras" because of their long periods. Ordinary Miras are *M* giants with B–V colors between about 1.5 and 2.0, in contrast to about 4.3 for these two carbon stars.

SS Virginis lies about 2° northeast of Eta (η) Virginis near the ecliptic, where it can be occulted by the Moon. Last summer Mars passed near the star, causing some observers to comment on its extraordinary color compared to the much paler "red planet."

V Coronae Borealis is 2° northwest of Lambda (λ) Coronae Borealis. Like other Miras both stars have a large brightness

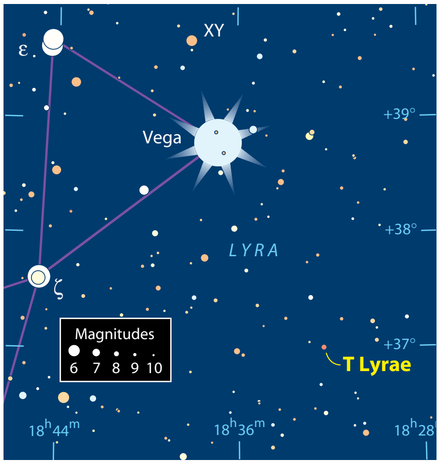


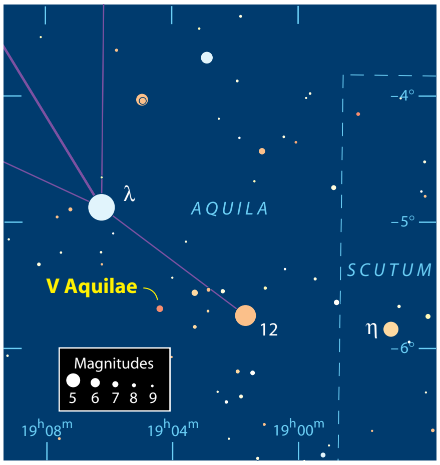


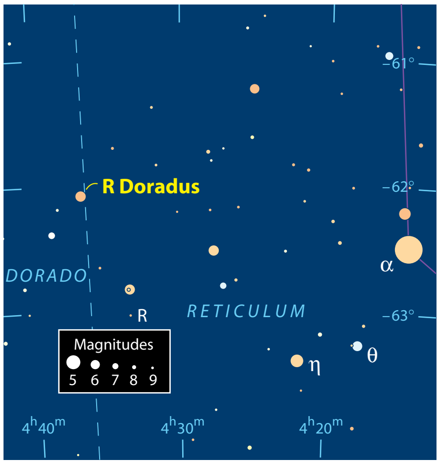
range (getting as faint as magnitude 12), so sometimes they are not readily visible.

Summer and Autumn Stars

As summer approaches be sure to scout out **T Lyrae** about 2° southwest of Vega. Its extreme B–V color (5.5) makes it a sure winner even for those of us who are colorblind. Compare T Lyrae to orange HD 170970, the star of similar brightness (about magnitude 7.5) less than 1° to its southwest. This is a garden-variety red giant with a spectral type of *M3* and a







B–V of 1.57 from the Hipparcos catalog. (It was found to be slightly variable by Hipparcos, and its newly assigned variable-star name, V530 Lyrae, appears in the *Millennium Star Atlas.*)

The "carbon Mira" **V Aquilae** is in the circlet of stars marking Aquila's tail, near Messier 11. Compare this to any ordinary Mira of similar brightness, and you'll see how distinctive the carbon stars are. T Lyrae and V Aquilae are nice show objects for public star parties.

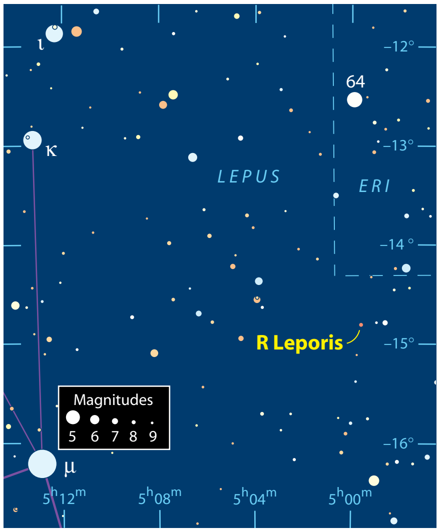
It's common to see a single distinctively red star in an open cluster. None of these, however, is a carbon star. Instead they are *K* or *M* giants or supergiants, two examples of which are given in the table. **V466 Cassiopeiae** resides in the bright cluster NGC 457, on the north side of the main clump. Since it is relatively faint an 8-inch or larger telescope will be necessary to distinguish it from the bluer cluster members.

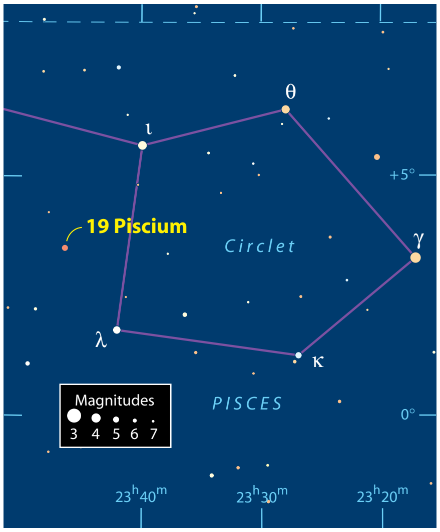
RS Persei is easier to pick out. It is one of about 20 *M*-supergiant variables centered on the eastern cluster (NGC 884) of the Perseus Double Cluster. RS Persei is on the southeastern side of the cluster core; it's the reddest star near the center. RS Persei has been reported as faint as magnitude 10 only once; it usually spends its time around magnitude 8.5. (For more on red stars in the Double Cluster, including a map, see the December 1994 issue, page 46.)

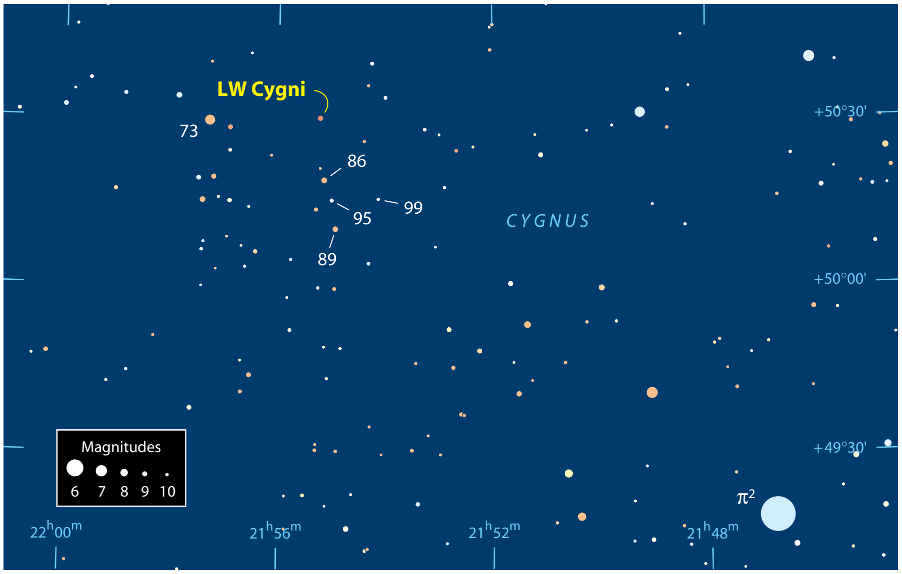
Two other *M*-type variables in the table have comparatively "blue" colors. **R Doradus,** 2½° east-northeast of Alpha (α) Reticuli in the far southern sky, is the brightest star to have a spectral type as late as *M*8. It is among the nearest *M* giants, 200 light-years away according to the very reliable Hipparcos parallax measurement. If we could stick a thermometer into its surface we'd probably find this star to have the lowest temperature of any on the list. But the B–V color is the least red!

Just as far into the northern sky is somewhat brighter **Mu (μ) Cephei,** long known as "Herschel's Garnet Star." It ranks as the reddest star easily visible to the unaided eye, though I need at least binoculars to see its tint.

Another bright variable, **R Leporis,** is known as "Hind's Crimson Star" after another active 19th-century observer. In this case the B–V color (5.5) indicates the name is justified. This roughly 7th-magnitude ember can be found about 3½° northwest of Mu Leporis. More about it







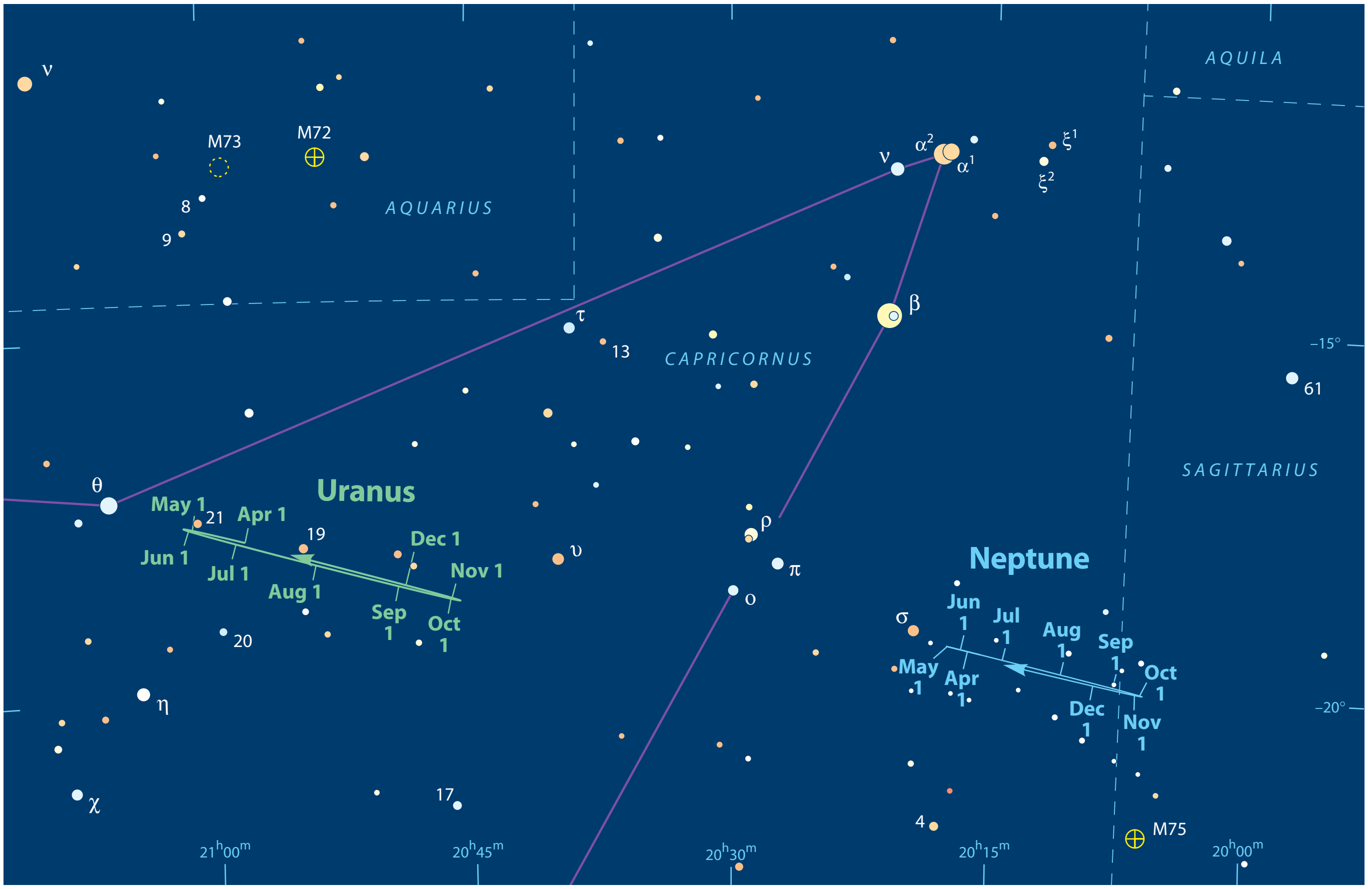
is in the March 1994 issue, page 73.

The brightest carbon star in the sky is **19 Piscium (TX Piscium)** in the eastern edge of the Circlet asterism under the Square of Pegasus. Its color is not extreme but conspicuous even so. The fourth *General Catalogue of Variable Stars* classes it among the irregular variables. But Maryland amateur Rick Wasatonic recently monitored it for several years from his backyard using an 8-inch Schmidt-Cassegrain telescope and a solid-state photometer. He found the variations to be well defined, showing an average cycle length near 220 days with a brightness range of magnitude 4.5 to 5.3.

The chart for the red variable **LW Cygni** above gives some V magnitudes that I measured for comparison stars in the field. (The decimal points are omitted.) This star was first noticed by the amateur observers John Birmingham and Thomas W. Webb in the 1870s. Later Dunér and Espin, using visual spectroscopes, were the first to see its carbon signature.

LW Cygni may undergo episodes of strong dimming, perhaps caused by carbon soot condensing in its outer atmosphere. But I could not find any actual observations of this in the literature. Despite catalog claims of it getting as faint as magnitude 14, all published data show it between magnitude 8 and 10. This is not a commonly observed star in any case, so it makes a good target for amateurs. It's accessible to Northern Hemisphere observers practically all year, lying in a gorgeous field near the Cygnus-Cepheus border.

One of the world's most respected deep-sky observers, Brian A. Skiff *is a research assistant at Lowell Observatory and coauthor of the* Observing Handbook and Catalogue of Deep-Sky Objects *with Christian Luginbuhl.*



Uranus, Neptune, and Pluto This Year

By Alan M. MacRobert

THE EIGHT MAJOR PLANETS OF THE solar system (aside from Earth) span a range in brightness of about 30 million; Venus this year gets 18.6 magnitudes brighter than Pluto. Their size differences, by comparison, are much smaller. Venus is only 5 times as large as little Pluto, and even giant Jupiter has just 60 times Pluto's diameter. The planets' enormous range in brightness is mostly due to their different distances from the Sun (which determine how brightly they are lit) and from Earth (affecting how big they appear to us).

Nevertheless, all the planets but one can be spotted without a telescope.

Mercury, Venus, Mars, Jupiter, and Saturn are the five classical naked-eye worlds. You can add Uranus to your list pretty easily using binoculars. It's about magnitude 5.7, technically making it a naked-eye object under good sky conditions. Neptune is a somewhat tougher binocular trophy at magnitude 7.9. Pluto, magnitude 13.7, generally requires at least an 8- or 10-inch telescope used at high power with an extremely deep chart.

The charts here show where to locate the three outermost planets on any date for the rest of this year's observing season.

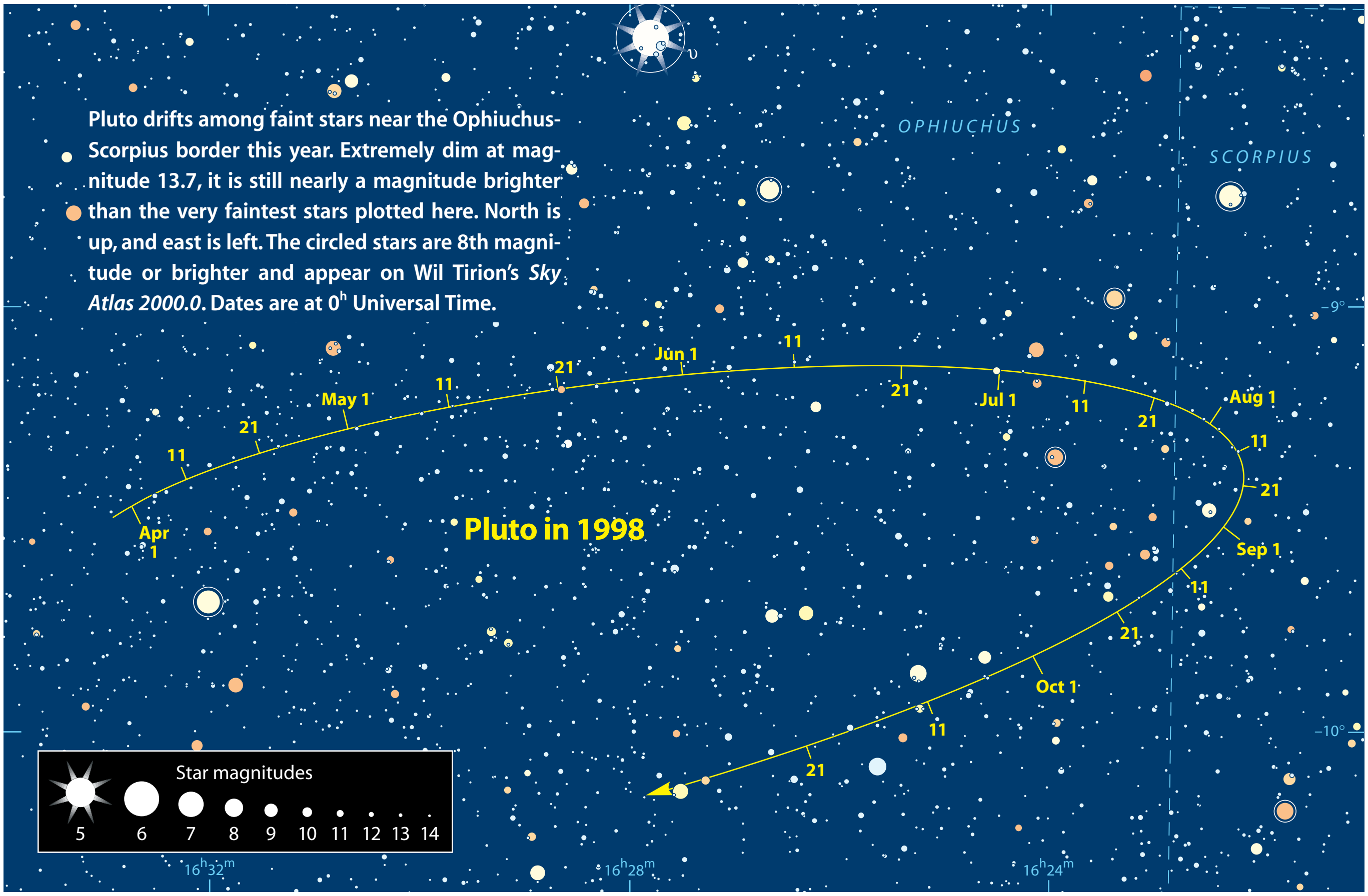
Uranus and Neptune are in Capricornus about 10° apart. In April and May they can be found fairly low in the southeast just before the first light of dawn. By the beginning of summer they're in this part of the sky around midnight. They come to opposition in early August and late July, respectively. Their most convenient observing season is late summer through early fall, when they'll be high in the south in early evening.

Join the nine-planet club by tracking down the three farthest worlds of our solar system.

Pluto spends most of 1998 in southern Ophiuchus; it's a degree or two south of the 4.6-magnitude star Upsilon (υ) Ophiuchi. (During late summer it edges over the border into Scorpius.) Pluto is currently high in the south in the early morning hours, approaching its May 27th opposition. It will be an evening object in late spring, summer, and early autumn.

Because Pluto looks just like millions of similarly faint stars, identifying it is an exercise in precision map work at the telescope. The map on the facing page, drawn largely from the Hubble *Guide Star Catalog,* shows stars as faint as blue magnitude 14 or 15, somewhat dimmer than Pluto. However, many faint stars near this limit are missing from the *Guide Star Catalog,* and its magnitudes are not very reliable. To be sure you've got Pluto, check back on another night to see that your suspect has moved.

Uranus and Neptune spend 1998 shifting back and forth in Capricornus. Stars are plotted to magnitude 7.2 except near Neptune, where the limit is 9.0. Ticks show the position of each planet at the beginning of every month.



Pluto drifts among faint stars near the Ophiuchus-Scorpius border this year. Extremely dim at magnitude 13.7, it is still nearly a magnitude brighter than the very faintest stars plotted here. North is up, and east is left. The circled stars are 8th magnitude or brighter and appear on Wil Tirion's *Sky Atlas 2000.0*. Dates are at 0h Universal Time.
OPHIUCHUS
SCORPIUS
Pluto in 1998
Apr 1
11
21
May 1
11
21
Jun 1
11
21
Jul 1
11
21
Aug 1
11
21
Sep 1
11
21
Oct 1
11
21
−9°
−10°
Star magnitudes
5 6 7 8 9 10 11 12 13 14
16h32m
16h28m
16h24m

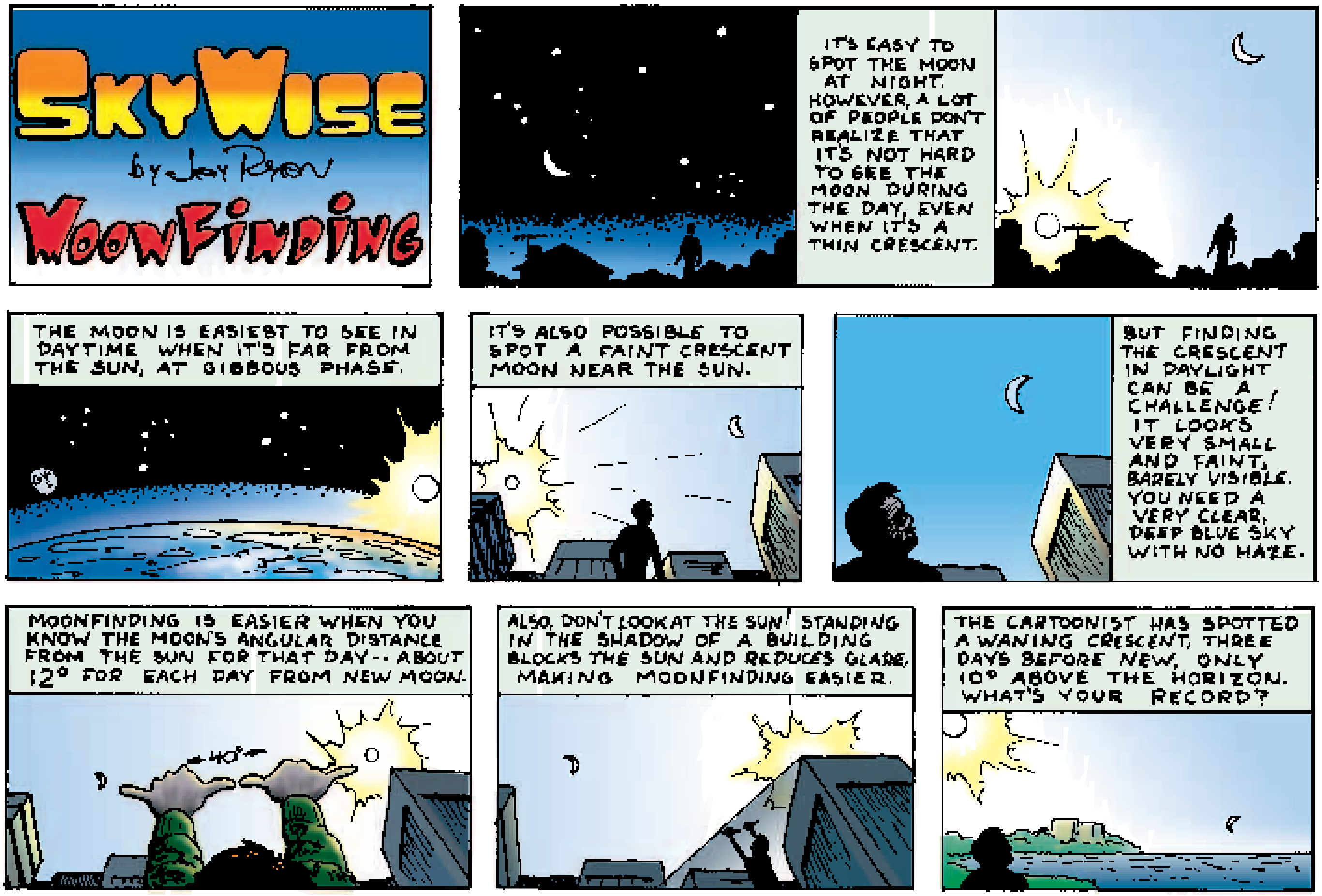


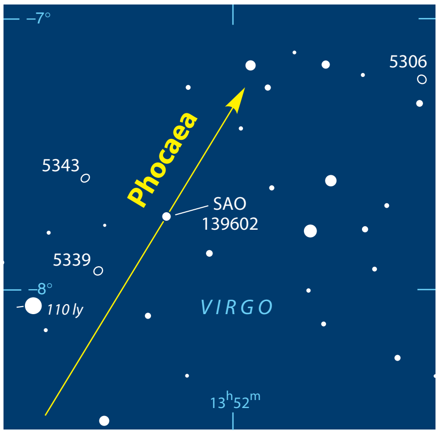
ILLUSTRATION BY JAY RYAN, HTTP://WWW.SKYWISE.COM

calendar notes

Asteroid occultation. On the evening of May 12th, during or just after twilight, telescope users in parts of the Southwest and Mexico can try timing the 11th-magnitude minor planet 25 Phocaea occulting an 8.3-magnitude star near Spica. The occultation should come around 2:53 Universal Time May 13th and last for up to 7 seconds. The tricky part will be finding the star quickly in the fading dusk — assuming the sky will be dark enough at your location at all.

North is up on the finder chart here, adapted from the *Millennium Star Atlas.* For more information see the February issue, page 86, or the asteroid occultation Web page of the International Occultation Timing Association (IOTA), accessible through SKY Online at http://www.skypub.com/occults/occults.html. Late updates may also be on IOTA's voice recording at 301-474-4945 a few days or hours beforehand.

IOTA hopes to notify as many observers as possible when a last-minute update brings an asteroid occultation path into their area. To get on the list for e-mail notification, send your location and e-mail address to dunham@erols.com.



ADAPTED FROM *MILLENNIUM STAR ATLAS*

Lunar occultation correction. On the morning of May 9th the dark limb of the waxing gibbous Moon will occult a 4.8-magnitude star in Virgo. In the timetable in the January issue, page 97, the star is misidentified as ι (Iota) Virginis; it is actually l^2 Virginis, better known as 74 Virginis.

Variable-star maxima. April 7, T Normae, 1536**54,** 7.4; 14, T Camelopardalis, 043065, 8.0; 15, R Carinae, 0929**62,** 4.6; 18, R Aquarii, 2338**15,** 6.5; 20, R Octantis, 0556**86,** 7.9; 22, R Caeli, 0437**38,** 7.9. May 4, V Coronae Borealis, 154639, 7.5; 6, S Ursae Majoris, 123961, 7.8; 6, R Draconis, 163266, 7.6 (see chart, July 1993, page 70); 8, T Cephei, 210868, 6.0 (see chart, September 1994, page 41); 10, R Cassiopeiae, 235350, 7.0; 17, R Hydrae, 1324**22,** 4.5 (see chart, May 1996, page 69); 20, R Andromedae, 001838, 7.0; 25, T Eridani, 0351**24,** 8.0; 31, V Boötis, 142539, 7.0.

The data above are, in order: the day of the month near which the star should be at maximum brightness; the star's name; its designation number, which gives rough right ascension (first four digits) and declination (boldface if southern); and the star's typical visual magnitude at peak brightness. The actual maximum may be brighter or fainter and many days early or late. All predictions are by Janet Mattei using recent data of the American Association of Variable Star Observers, 25 Birch St., Cambridge, MA 02138 (http://www.aavso.org/).

Universal Time (UT or UTC) is used worldwide by all who need to avoid confusion between time zones.

To convert a UT time and date to a standard time and date in North America, subtract the following hours: to get Eastern Standard Time, 5; CST, 6; MST, 7; PST, 8; Alaska, 9; or Hawaii, 10. To obtain daylight saving time ("summer time"), subtract one hour less than these values. If you get a negative number of hours, add 24; in this case the result is on the date before the UT date given.

For example, 6:45 UT May 9th is 2:45 a.m. on the 9th EDT and 11:45 p.m. on the 8th PDT.

You may find it easier just to remember when 0:00 UT happens in your time zone. This is on the previous date at 7 p.m. EST, 6 p.m. CST, 5 p.m. MST, or 4 p.m. PST. When daylight saving time is in effect: 8 p.m. EDT, 7 p.m. CDT, 6 p.m. MDT, or 5 p.m. PDT.

A note on sky positions. In *Sky & Telescope* descriptions of where things appear with respect to the horizon or zenith are written for the world's midnorthern latitudes. Descriptions that also depend on longitude are for North America, except as otherwise noted.

Skyline: our telephone news service. To provide all readers with access to fast-breaking news such as comet and nova discoveries, *Sky & Telescope* maintains Skyline, a dial-up news service. The three-minute voice recording is updated every Friday afternoon. Call 617-497-4168.

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My Favorite Asterisms

Horseshoes, sharks, birds — the sky is full of evocative telescopic star patterns. Here are some for spring and summer nights. | By Philip Harrington

The Big Dipper currently looms high in the north-northeast after dusk. This most famous asterism has been many things to many people. In England it is the Plough, formerly the Wain (wagon). In Siberia it was a stag, in ancient Egypt a leg of beef, among the Aztecs a parrot. What would you make it into if you saw it for the first time? Akira Fujii photograph.

EVERYONE WHO LOOKS AT THE stars sees shapes in their arrangements. In addition to the 88 formal constellations, the sky is full of unofficial star patterns, or asterisms. Some well-known ones are the Big Dipper, the Summer Triangle, and the Winter Hexagon or G. How many others can you name?

Countless miniature asterisms have also caught observers' eyes in binoculars and telescopes. Although not deep-sky objects in the truest sense, they form some of the most distinctive celestial sights. Unlike open clusters, whose stars are likely to remain together for a few hundred million years, most asterisms are chance alignments of widely separated stars on nearly the same line of sight from Earth. We just happen to be in the right place at the right time to catch the view.

While writing *The Deep Sky: An Introduction,** I thought it would be fun to collect a list of asterisms that today's amateurs have found and named. In response to a request in *Sky & Telescope,* many readers submitted their favorites. My list now contains nearly 40. Here are some telescopic asterisms for spring and summer evenings.

The Spring Sky

Stargate. Apart from being a nice telescopic double star (magnitudes 3 and 9, separation 24"), Delta (δ) Corvi teams with 4th-magnitude Eta (η) Corvi to create a wide optical double for the naked eye or binoculars. Center your finderscope on Eta, then scan 3° due north for a rather narrow isosceles triangle of 6th-magnitude stars 1° on a side. The triangle points northeast toward a faint pair of stars 1° away that may be just visible in your finder. These are the bright-

**Available from Sky Publishing Corp.*

est two stars in the Stargate asterism.

Several observers independently told me of this grouping, including John Wagoner, Lucian Kemble, Tom Mote, and Don Farley. All describe a symmetrical, triangles-within-a-triangle pattern of four stars ranging from 7th to 10th magnitude. Kemble called it the "Delta-Wing Starship." To Mote it's the "TSP Triangle" (he first encountered it at the Texas Star Party). I prefer Wagoner's "Stargate." Call it what you will, this is a one-of-a-kind celestial sight.

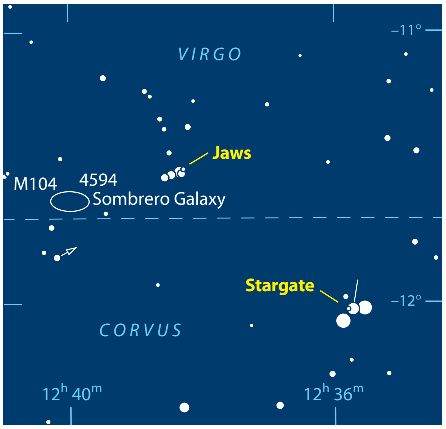
Jaws. From the Stargate, shift your view 1° farther northeast to a 7th-magnitude sun. This is the brightest in another asterism, nicknamed Jaws.

John Barra of Peoria, Illinois, and Mote of San Antonio, Texas, introduced this pattern to me. Mote calls it "Little Sagitta" after its slight resemblance to that summertime constellation. Barra teams it with the Stargate to form the "Double T Clusters." In a telescope at low power I see it more as a west-northwestward-swimming shark, with the brightest star marking a portion of the head or mouth and fainter stars forming an emaciated body. With a little imagination, you'll even see a dorsal fin to the south.

Both of these asterisms are on the route from the naked-eye stars of Corvus

Some Telescopic Asterisms

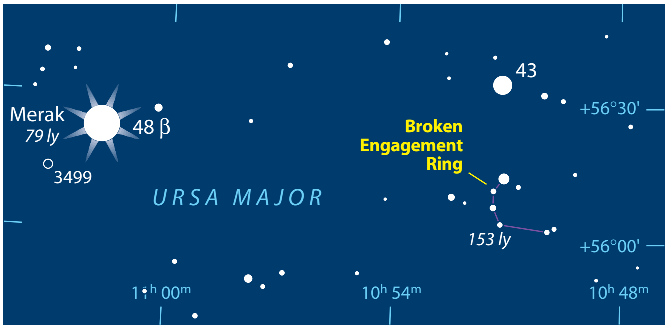
Name	Const.	R.A. (2000)	Dec.	Diameter
Stargate	Crv	12^h 35.7^m	−12° 00'	8'
Jaws	Vir	12^h 38.5^m	−11° 30'	7'
Broken Engagement Ring	UMa	10^h 51.0^m	+56° 10'	20'
Red-Necked Emu	Cyg	20^h 14.0^m	+36° 30'	40'
Horseshoe	Cyg	21^h 07.0^m	+47° 15'	12'
Dolphin's Diamonds	Del	21^h 07.0^m	+16° 20'	30'
Little Queen	Dra	18^h 36.0^m	+72° 15'	20'
Mini-Coathanger	UMi	16^h 29.0^m	+80° 15'	15'



Eight telescopic asterisms for spring and summer are described in the text. Each chart, adapted from the *Millennium Star Atlas,* shows stars to 11th magnitude and has north up. You can locate these small fields on wider-field star charts from the coordinates marked on the edges. *Sky & Telescope* photographs by Dennis di Cicco.

to the famous Sombrero galaxy, M104. The galaxy glows at 8th magnitude just 0.4° east-southeast of Jaws, which is swimming directly away from it.

The Broken Engagement Ring. Here is a neat little asterism that I bumped into while stalking galaxies just off the Big Dipper. To find the Broken Engagement Ring, scan 1.5° west from Merak, Beta (β) Ursae Majoris, in the bottom front of the Dipper's Bowl. You'll hit a north-south pair of 6th- and 7th-magnitude stars ⅓° apart. Center your telescope on the fainter, southern star in the pair and take a look. A low-power eyepiece will show this to be the brightest of seven suns that form a broken oval about ¼° in diameter, extending southwest. It reminds me of a ring with the bright star representing a diamond. From the shape it's in, however, the ring must have been through quite a battle, so it seems only appropriate to call it the "Broken Engagement Ring."

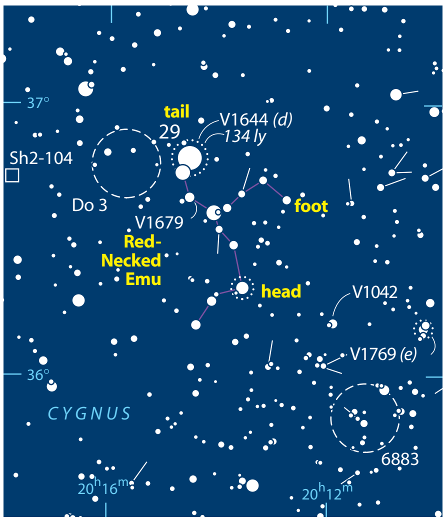


The Summer Sky

The Red-Necked Emu. This unearthly little bird accompanies Cygnus, the Swan, across the summer sky. John Barra noticed the Emu with an 8-inch reflector at low power. Start from Gamma (γ) Cygni in the center of the Northern Cross, move 2.5° south-southwest along the neck of Cygnus to 34 or P Cygni, then another 1.3° on to 29 Cygni. This latter star, a wonderful multiple sun, marks the Emu's tail.

The Red-Necked Emu is drawn in profile on the sky, with its foot to the northwest and its head cocked southeast. All of the stars in the Emu's tail, feet, triangular body, and head shine blue-white. Only a lone reddish star marking part of its neck appears noticeably different. Try your luck capturing this rare bird when Cygnus makes its appearance in the east.

The Horseshoe. As a different kind of observing project, Daniel Hudak of Canfield, Ohio, has systematically surveyed the many fine star fields mentioned by Thomas W. Webb in his classic guidebook, *Celestial Objects for Common Tele-*



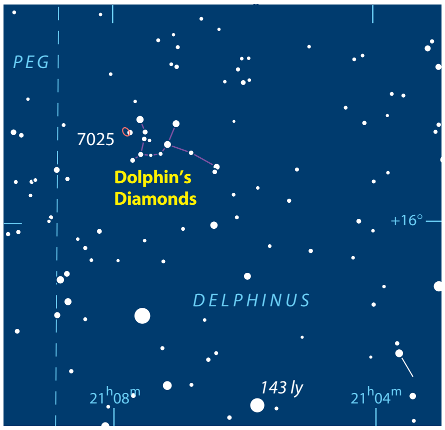
scopes, which appeared in six editions from 1859 to 1917. This asterism, a horseshoe of stars, is especially attractive.

Starting from Deneb at the head of the Northern Cross, slide 3½° east-northeast to 5th-magnitude 60 Cygni, then nearly 2° farther northeast to 5th-magnitude 63 Cygni. The Horseshoe is less than a half degree south of 63. Look for an arc of about 14 suns ranging from about 7th to 11th magnitude and spanning ¼°. Webb described this as "a curious horseshoe and magnificent Galaxy field." Hudak adds that this is an "excellent object; despite being set against a star-packed Milky Way background, the Horseshoe stands out."

The Dolphin's Diamonds. I first came upon this little asterism, nestled just inside the eastern border of Delphinus, at the 1993 Stellafane convention in Springfield, Vermont. From the Dolphin's diamond-shaped body, sweep 5° due east to an isosceles right triangle of four 6th- and 7th-magnitude stars. The triangle is a little more than 1° wide, with the right angle in the southeast corner at right ascension 21^h 08^m, declination +14.7°. Peering through your telescope with a low-power eyepiece, extend the triangle's eastern side northward for about ¾° to locate a much smaller triangle of 9th-magnitude stars.

Those three stars, along with a cloud of a dozen fainter stellar diamonds, make up the treasure chest. The view in 6-inch and smaller backyard telescopes is especially impressive, as larger instruments tend to dissolve the treasure's misty effect. Detailed star charts, as in the *Millennium Star Atlas,* show the galaxy NGC 7025 also buried here, but it's 13th magnitude and has a low surface brightness, putting it out of most amateur instruments' reach.

The Little Queen is a charming asterism independently discovered by Raymond



Maher Jr. of Port Elizabeth, New Jersey, and Attila Kovacs of Vac, Hungary. It bears a resemblance to the W shape of Cassiopeia, though this W is less flattened.

In the Little Dipper's bowl, extend a line from Kochab, Beta Ursae Minoris, diagonally across through Eta and onward an equal distance. From that point go 3° south to the triangle formed by 3rd- and 4th-magnitude Phi (ϕ), Chi (χ), and Upsilon (υ) Draconis. From Chi, the brightest, shift east-southeast 1° to the Little Queen, a small clump of 6th- to 9th-magnitude stars. Their distinctive W is ⅓° wide and is even visible in 8×50 binoculars on dark nights. Telescopes reveal 18 stars ranging down to 11th magnitude that contribute to this pretty asterism.

The Mini-Coathanger is one of those unexpected surprises you're bound to come across every now and then. It is named for its resemblance to the famous binocular Coathanger asterism in Vulpecula. I learned of it at the Starfest '93 convention in Kingsport, Tennessee, where Tom Whiting of North East, Pennsylvania, told how he bumped into it in the Little Dipper's handle. Starting from Epsilon (ε) Ursae Minoris, move your finderscope about 2½° south to a lopsided four-star pattern of 6th- and 7th-magnitude suns about 1° across. Now look ½° north of the northwesternmost of the four.

The Mini-Coathanger comprises 11 stars ranging from 9th to 11th magnitude spanning about ⅓°. Their combined likeness to a coathanger is unmistakable, with several of the stars forming the hook and others the nearly north-south crosspiece. Thanks to its circumpolar location, the Mini-Coathanger can be enjoyed all year.

These are just a few of my favorites. Surely you can add your own! I'd like to hear of them. Write me at 54A Dilmont Dr., Smithtown, NY 11787, or send e-mail to pharrington@compuserve.com.

Longtime deep-sky observer Philip Harrington *is author of* Touring the Universe through Binoculars, Star Ware, Eclipse!, *and* The Deep Sky: An Introduction.

After gathering reports of the exploding fireball seen above Greenland in the early morning hours of last December 9th, astronomical artist Don Davis prepared this rendering.

observer's notebook | *By Dennis di Cicco*

Greenland Bolide

An unusually large number of fireball reports reached *Sky & Telescope* as 1997 drew to a close. It isn't clear whether this was the result of increased meteor activity or just because more observers were watching the sky, perhaps inspired by heightened interest in the annual November Leonid meteor shower (February issue, page 99). Of the fireballs reported, certainly the most spectacular occurred in the December 9th predawn skies above southwest Greenland.

At about 5:11 a.m. local time (8:11 Universal Time), the long Arctic night was interrupted by an enormous fireball that may have become as bright as magnitude –20, some 1,500 times brighter than the full Moon. Astronomical artist Don Davis, who made the above painting, gathered reports of the event, which are summarized here.

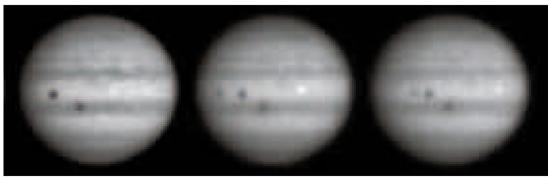
Jens Nielson was aboard the fishing trawler *Nicoline* in the waters of Davis Strait west of Greenland. Although he did not have a direct view of the meteor, he saw the distant mountains along the coast brilliantly illuminated for a few moments with an orange-red glow. The fireball was also seen from the trawler *Regina C* off the southeast tip of Greenland an estimated 500 kilometers (300 miles) away. One sailor likened the meteor's appearance to "the center of an electrode welding on iron." A brilliant flash occurred after the object dipped below the local horizon.

On Greenland's southwest coast the town of Nuuk lay close to the meteor's estimated ground track. A video recording made by a parking lot surveillance camera captured the foreground suddenly illuminated by the fireball and shows moving shadows cast by stationary objects as the meteor streaked across the sky. At one point the fireball itself appears at the edge of the field, completely flooding the scene with light. The terminal burst showed distant mountains in silhouette against the momentarily brightened sky.

Eyewitnesses reported a constant "sputtering" as small pieces broke off the meteor's main body. Rumblings and even subtle tremors were reported from widely scattered areas of southern coastal Greenland. Bad weather interfered with initial aircraft searches for possible impact sites, which, if they exist, are estimated to be near longitude 49° 30' west, latitude 62° 50' north. Thus far nothing has been found on the ground.

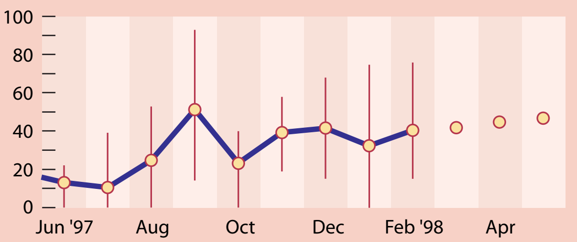
Triple Shadows Imaged

When the shadows of Io, Ganymede, and Callisto simultaneously crossed Jupiter's face last November, many eager amateurs in the western United States observed the event (March issue, page 110). But some professional astronomers, too, were in on the fun. Erich Karkoschka of the University of Arizona and Scott Murrell of New Mexico State University captured the crossing using the latter institution's 24-inch telescope. The series of images above were taken variously through visible-light and near-infrared filters to compensate for changing observing conditions (the region was partially overcast). The first image shows the shadows of Ganymede (left) and Callisto, with Io itself as a yellow-orange spot visible near the center of Jupiter. Next Io's shadow appears at far left (the Sun is shining from the right). Finally, the shadows of fast-moving Ganymede and even-faster Io approach the sluggish Callisto shadow.



Only once or twice in a century do triple shadows cross Jupiter's face.

Monthly Sunspot Numbers



Pierre Cugnon of the Sunspot Index Data Center supplied these provisional sunspot numbers. The range of minimum and maximum daily numbers (vertical lines) and monthly means (connected points) are shown for the nine most recent months. There are also three months of predictions. Daily numbers are available at http://www.oma.be/KSB-ORB/SIDC/index.html.

A Do-It-Yourself Dome Observatory

Here's how to construct a professional-looking telescope housing at modest cost. | **By Curtis D. MacDonald**

A few years ago my wife, Barbara, and I purchased 37 acres of land 7 miles north of Laramie, Wyoming. Located in a wide valley 7,200 feet high near the Laramie Mountains, our site is blessed with dark, pristine skies and steady seeing. Since my main interests are deep-sky observing and astrophotography, it didn't take me long to decide to build a permanent home for my 12½-inch telescope.

In choosing the plan for the observatory I considered two factors: access to a full 360° horizon and protection from Wyoming's notorious winds and long winters. For access to the horizon, my telescope's design limits the wall height to about 40 inches. (Although popular among amateurs, a roll-off-roof observatory with low walls would offer little protection from wind for my scope's more than 8-foot-long tube.) The housing also had to be roomy enough to accommodate guests and future equipment upgrades. As a result, I decided on a conventional dome observatory 19 feet in diameter.

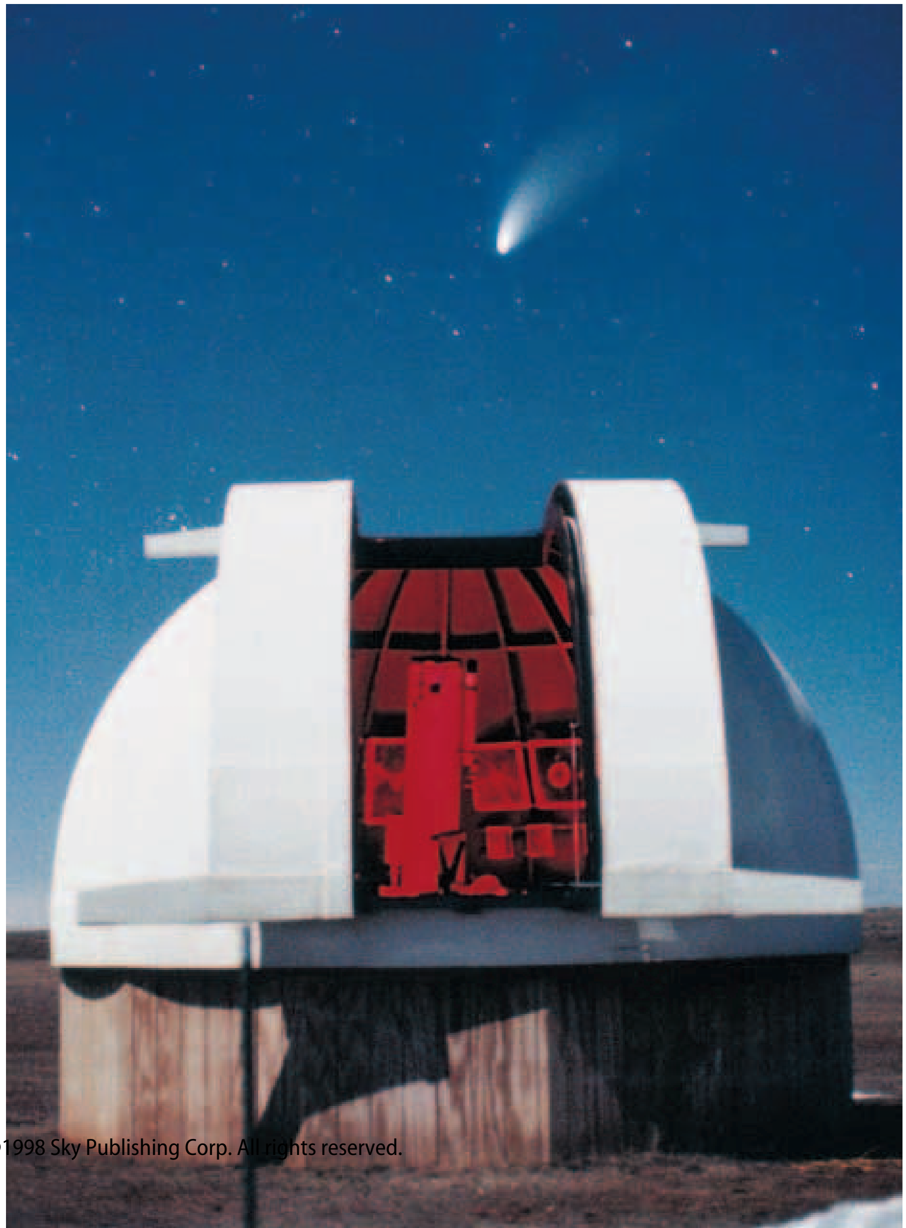
Laying the Foundation

Although I don't have a background in architecture or engineering, the design and construction of the observatory proved relatively easy and straightforward. My equipment consisted of a few hand tools (hammer, bubble level, T-square, screwdrivers, and tape measure, to name a few), as well as common power tools (jigsaw, reversible drill, and circular saw).

Construction began in early autumn with the excavation of a hole 4 feet deep for the telescope pier. I also dug a 50-foot-long trench for the observatory's power lines. A piece of Sonotube 24 inches in diameter was used as a concrete form for the lower pier. This was reinforced with 40 feet of steel bars. Four additional holes 10 inches wide and 4 feet deep were dug and fitted with rebar loops to serve as the building's tie downs.

Two cubic yards of concrete were poured into the pier form and tie-down holes, as well as the 5-foot-wide pit around the form. Four ¾-inch anchor bolts for the upper pier's steel base plate were set in place and the concrete was allowed to cure.

Using concrete blocks and slabs as support, I constructed the observatory's girder frame using paired 2-by-6s. Upon it I built an 18-foot-wide, 12-sided floor with 2-by-6 joists. This was leveled and decked with ¾-inch plywood. (I left a ½-



Comet Hale-Bopp rising above Curtis MacDonald's Mountain Skies Observatory in Laramie, Wyoming, last year. Completed in March 1992, the observatory features a homemade dome 9½ feet tall and 19 feet in diameter. All photographs in this article are courtesy the author.

Left: **MacDonald working on the observatory's 18-foot-wide, 12-sided foundation. The floor is made of 2-by-6 girders and joists and 3/4-inch plywood, while the walls consist of 2-by-4s covered with wooden siding. The telescope's concrete pier extends to floor level.** ***Right:*** **The 19-foot-diameter dome and base rings made from several layers of 3/4-inch plywood. Notice the 5-inch, heavy-duty support and guide-wheel assemblies.**

inch gap between the pier and floor to prevent the building's vibrations from traveling to the telescope.) Finally, I erected a 28-inch-high wall made of 2-by-4s and covered the entire structure with wooden siding. Since the floor is 28 inches above the ground, I added a 3-step staircase that leads to a low but comfortable doorway.

Constructing the Dome

After the foundation was completed the slowest and most tedious stage of construction started — the cutting of the dome rings and ribs. Additional lighting and portable heaters were installed in the barn where the cutting was to take place over the next two winter months. To mark the various curves on the ¾-inch plywood I designed an arc-making table. It consisted of an 8-foot-wide flat surface and an 11-foot-long arm with holes drilled in one end for the different curve radii.

For each set of identical arcs, one piece was marked and carefully cut out. This was then used as a master pattern for the remaining arcs. This method proved to be a lot faster than marking each piece individually with the arc arm.

The base ring consists of two layers of plywood 10 inches wide and 19 feet in diameter. I placed sections of the ring on the building walls and carefully fitted them to within ⅛-inch of a perfect, level circle. These were then fastened together and secured to the building with dry-wall screws.

Next the dome ring was cut. It is made up of four layers of plywood 9 inches wide and 19 feet 2 inches in diameter. To support the dome itself, I attached eight heavy-duty caster wheels to the base ring. These wheels, made of hard rubber 5 inches in diameter and 2 inches wide, have a load capacity of 650 pounds each. A ring of ¼-inch tempered Masonite was fastened to the dome ring's underside to serve as the bearing surface for the wheels. (Although flexible, Masonite is very hard and resists compression. After years of use it has shown very little wear.) I also added six lateral guide wheels that run on the inside surface of the dome ring and prevent the dome from falling off the base ring.

The dome's slit frame, made from three layers of ¾-inch plywood, was raised into position using a 12-foot-high scaffolding. The slit opening is almost 5 feet wide and passes 2½ feet past the vertical to allow access to the zenith. Starting from the back and working forward, I attached the ribs one by one at 2½-foot intervals. A total of 21 ribs were used, each one 4 inches wide and two layers thick. These were secured to the dome ring and slit frame with screws and metal connectors. I also added interrib braces 8 feet up to serve as extra support for securing the dome skin.

I made four more arches, each about 18 feet long and three layers thick, for the dome shutters. I also cut out a 16-inch-wide skirt of Masonite, which I fastened to the lower half of the dome ring. This skirt extends 4 inches below the base ring to provide good weather protection. In the end, I had cut a total of 195 arcs of various sizes, resulting in three burned-out jigsaws and about four dozen dull or broken saw blades.

Attaching the Dome Skin

Up until now I had done all of the work myself, with help from my very understanding wife, Barbara, and my ever-helpful 2-year-old daughter, Tegan. The time had come, however, to attach the dome's skin and I needed extra help. A request for assistance to my fellow members in the Cheyenne Astronomical Society (CAS) quickly produced some eager volunteers.

On a very chilly weekend in midwinter, my hardy crew gathered. We hauled the no-longer-needed arc-making table

MacDonald with his custom-built 12½-inch f/7.5 Newtonian reflector and 5-inch f/8 refractor. He has plans to replace the instrument with a telescope in the 20- to 25-inch range.

out to the observatory site for use as a work platform. Although looking like triangles, the spaces between the ribs are actually sections of a hemisphere and, as a result, have two curved sides. To mark each section the ¼-inch Masonite, which I had chosen for the skin, was laid in place and the desired shape was traced along the ribs from the inside.

Cutting the Masonite with a jigsaw proved rather slow and sloppy. Fortunately, one of my crew suggested using a circular saw — it was able to make quick, smooth cuts. With one person on the saw and three of us marking and securing the gores to the ribs, we finished the job in two days. The skin was attached to the dome framework with decking screws and ribbed nails.

The completed dome framework with all 21 ribs fastened to the nearly 5-foot-wide slit frame. The slit extends 2½ feet past overhead to allow telescope access to the zenith. The 2-by-4 crossbraces in the dome opening were removed after the dome skin was attached.

The observatory's twin curved shutters roll on a pair of 10-foot-long steel tracks bolted to the dome opening. Each shutter was reinforced with 2-by-4 crossbraces and then covered with Masonite. With Laramie experiencing eight months of snow and freezing temperatures annually, it is important to keep the shutters operational all year round. That's why I added covers to the tracks to prevent snow and ice from accumulating on them. Opening and closing the 130-pound shutters are done with a system of cables and pulleys described in *Amateur Telescope Making* — Book II.

The dome can be turned using a ¾-horsepower reversible motor. The motor is coupled to a reduction gearbox, which turns a 10-inch go-cart wheel pressed against the inside rim of the dome ring. Weighing about 1,700 pounds, the finished dome can make a complete rotation in about one minute. To prevent any voltage drop that might affect the telescope's drive when the dome motor is engaged, the observatory's 220-volt, 30-ampere power line is fed into a circuit-breaker box that splits it into two circuits. One serves the dome's drive motor and interior lights, while the other handles the telescope drive and electrical outlets.

As temperatures warmed up in early spring, I sealed the seams of the dome skin with acrylic latex caulk. The dome was primed and painted white with exterior latex; gray paint was applied to the floor, and the rest of the interior was painted black.

Mountain Skies Observatory

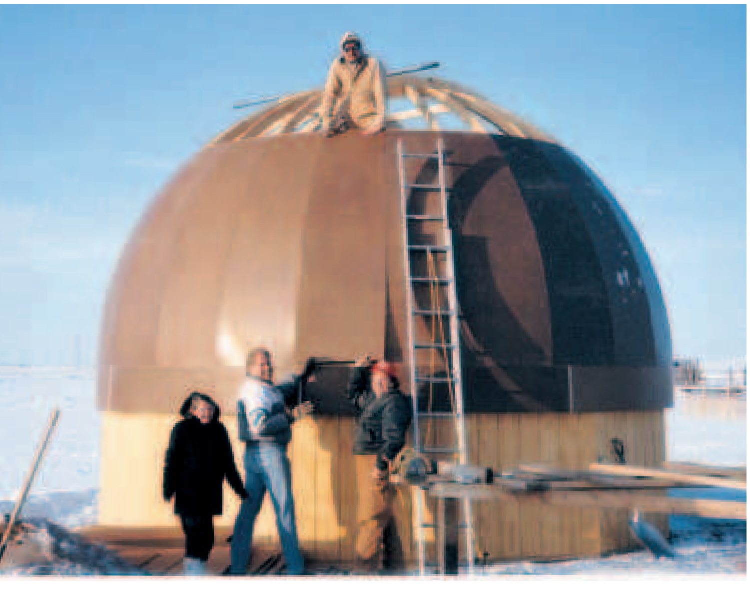
My telescope setup is entirely homemade. The main instrument is a 12½-inch f/7.5 Newtonian reflector on a massive German equatorial mount. Riding piggyback on it is a 5-inch f/8 refractor built from a Bausch & Lomb aerial photo lens. The drive is based on the double curved-bolt design featured in the July 1989 issue of *Sky & Telescope*, page 100. Everything had to be disassembled and stored for the duration of the observatory construction.

Finally, after six months of part-time work and a cost of nearly $2,500, the telescope's steel pier was welded to the base plate. It was eased into position on the lower concrete pier and bolted down — a perfect fit! My telescope was quickly reassembled, and on March 25, 1992, we had first light.

Our new facility, christened the Mountain Skies Observatory (MSO), was now operational. Since then it has been used nearly every clear night. Members of the CAS and Laramie Astronomical Society & Space Observers have hosted public star parties at the site. The observatory has also been used to teach astronomy to students enrolled in the University of Wyoming's noncredit programs. For further information about the MSO and its construction, visit my Web site at http://www.lariat.org/LASSO/mso.html.

"Rubber Paint"

The dome has been made weatherproof with Masonite flashing and foam seals along the shutters, as well as rubber strips between the base ring and dome skirt. These barriers proved to be effective against blowing snow, yet rain leaks gradually began to appear. Close examination revealed tiny cracks between the caulk and the Masonite, especially after the observatory had been used on nights experiencing subzero temperatures. Apparently there is enough flexure in the dome to



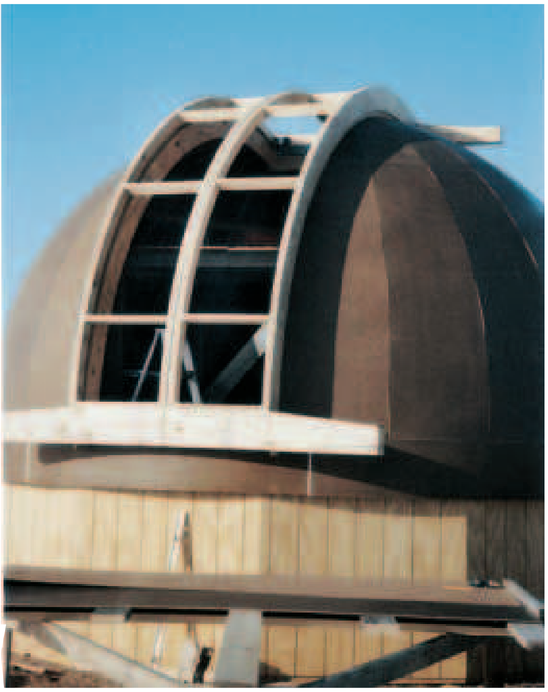
Cheyenne Astronomical Society members Rebekah Zumbrunnen and Marty Curran (first and second from left) and Robert Asher (top), help the author fasten a gore of ¼-inch-thick tempered Masonite skin.

cause the caulk to come loose when it stiffened in the cold weather. Recaulking and repainting the seams slowed but did not halt the problem.

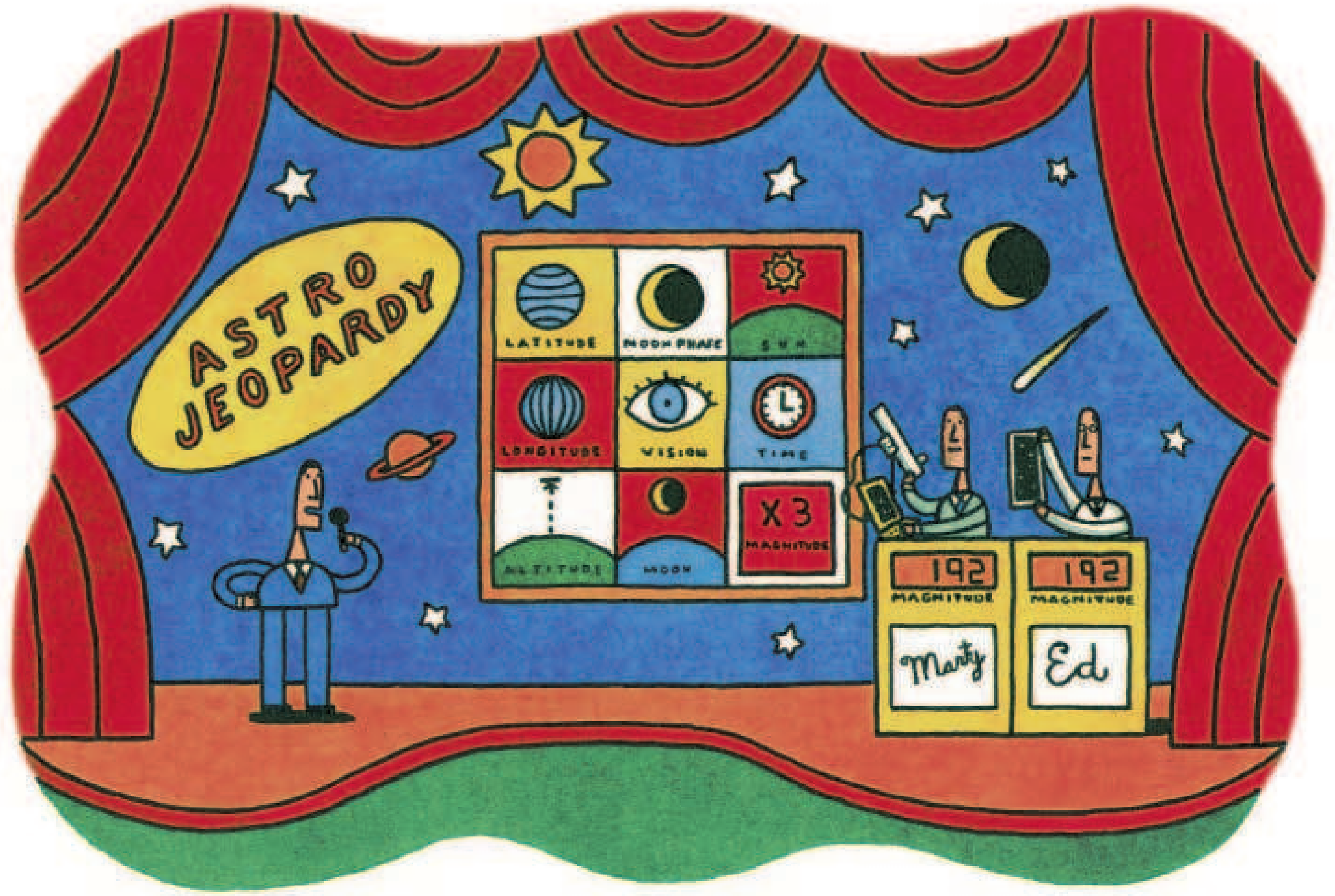
Fortunately, an elastomer-like roof-coating product known as "rubber paint" can be found in hardware stores. Since the paint and the seam tape for it are available in white, I decided to give them a try. First I applied a coat onto the seams; next the tape was laid along the seams and smoothed out. I then applied another coat to seal the tape down. After drying, two more coats were applied and the entire dome was covered with rubber paint. This has proved to be very effective — the interior has remained dry ever since.

Although building the Mountain Skies Observatory required considerable investment in time, money, and effort, the results have exceeded my expectations. With a permanent site sheltered from the elements and a telescope that can be readied for use in just a few minutes, my observing time has more than tripled.

Last October Curtis MacDonald *found a new job in Mountain View, 250 miles west of Laramie, and had to relocate his observatory. You can contact him at P.O. Box 1024, Mountain View, WY 82939; deepsky@union-tel.com.*



The finished framework of the dome shutters ready for covering with Masonite. Extending on both sides of the shutters are covers to prevent snow and ice from accumulating on the shutter tracks. A large C-clamp holds the shutters tightly closed in bad weather.



Limiting Magnitudes for CCDs

CCDs allow amateurs to look farther into the cosmos than ever before. Here's a way to predict how far. | **By Bradley E. Schaefer**

One aspect of digital imaging that continually impresses me is the remarkable reach a backyard observer has with a CCD. Perhaps this is because I grew up in the days of small telescopes and inefficient films. That an amateur telescope in a suburban sky can now better the photographic limits of the 200-inch telescope on California's Palomar Mountain is awesome. Moreover, digital technology allows today's amateurs to participate in many programs that were formerly restricted to professionals at mountaintop observatories. Of course, some imagination, plenty of critical thinking, and a lot of hard work may be required to compete with professional projects.

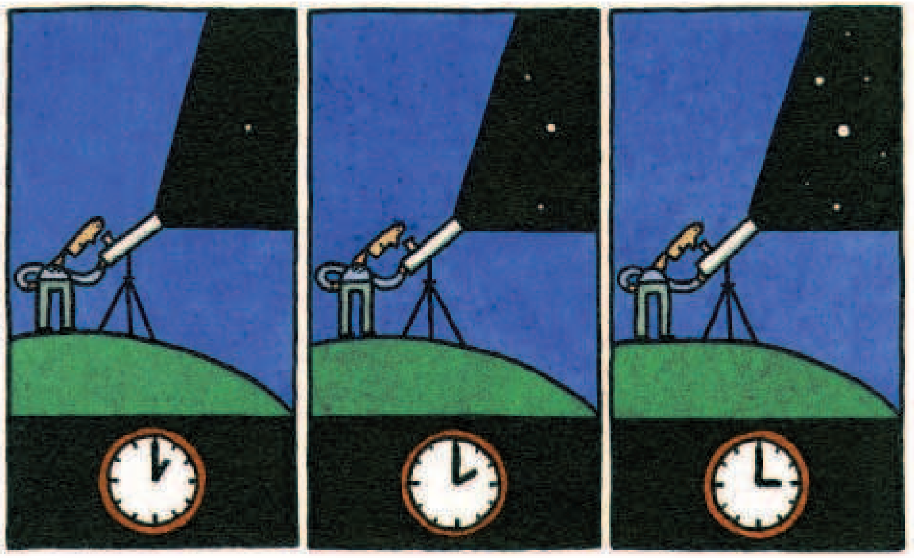
There are many occasions when the CCD user would like to predict the limiting magnitude for a given imaging system and a particular set of observing conditions. Recently, I had to ponder many questions relating to a CCD's limiting magnitude for the QUEST quasar survey at Yale University. My previous study of celestial visibility with human vision gave me a firm understanding of the sky in the visual band, but for CCDs this had to be extended to include a greater wavelength range. I had to make many refinements to my earlier equations. Some were needed to separate the atmospheric light loss caused by aerosol scattering from that due to water-vapor absorption, while others derived the correct formulas for CCD noise.

The end result is a program that answers vital questions for every CCD user. It can calculate limiting magnitudes using known or tabulated quantities. With this program, observers can select appropriate exposure times, optimize filters, and calculate the signal-to-noise ratio (SNR) for given images.

The sensitivity of an imaging system depends on telescope and detector properties. These include the number and reflectivities of mirrors, transmission characteristics of filters, a CCD's read noise, and a chip's quantum efficiency. The program, which is described at the end of this article, needs to know some picky details about your instrumentation. If you are not sure of these values, the pro-

It is remarkable that today a CCD-equipped amateur telescope in a suburban backyard can better the photographic limits of the 200-inch telescope at Palomar Observatory.

Illustrations by James Kaczman



gram has typical ones already inserted that are adequate for many situations encountered with amateur equipment.

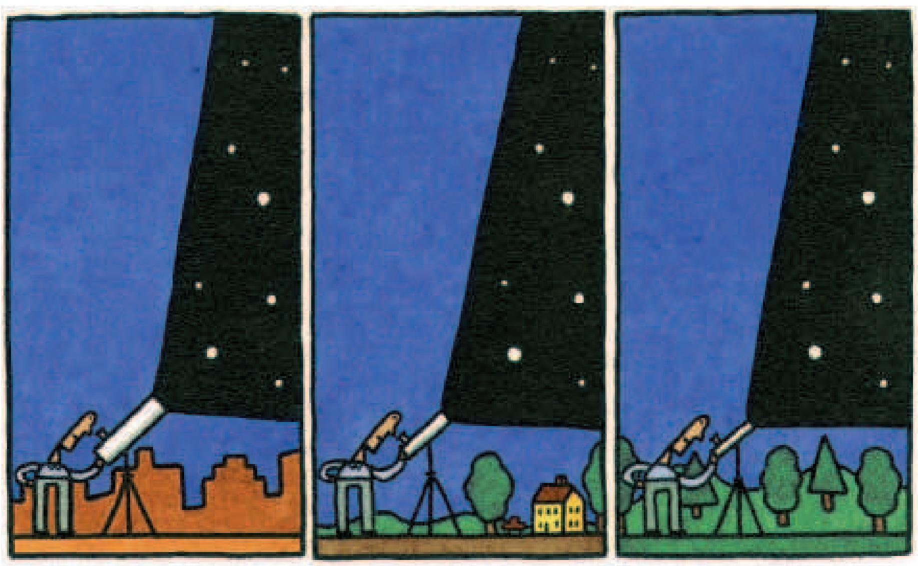
The program's validity was tested on a range of data obtained at several professional observatories where all important quantities such as atmospheric extinction, sky brightness, and the CCD and filter characteristics were independently measured. The typical accuracy of the limiting-magnitude prediction is 0.2 magnitude and is likely caused by an accumulation of the usual uncertainties in the many inputs. When used for differential comparisons, the model is likely accurate to hundredths of a magnitude. The details of the model and my tests are in a paper scheduled to appear in the *Publications* of the Astronomical Society of the Pacific.

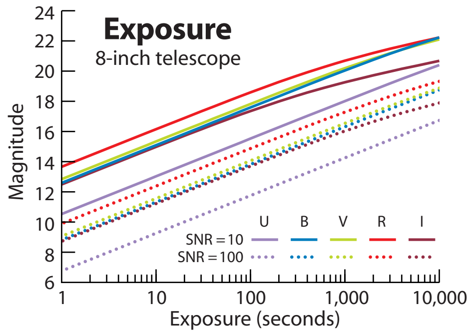
Key Questions (With Answers)

Even if you have no need to calculate an exact limiting magnitude or SNR, the program can be used to answer important questions. Here's a sample that will surely interest amateurs.

How much deeper can you go with a larger telescope? Will the improved limiting magnitude be worth the cost of a larger instrument? It is very interesting to calculate how limiting magnitude obtainable at a dark site varies with aperture. For example, an upgrade from an 8- to 12-inch telescope might cost several thousand dollars, yet this typically gains only 0.8 magnitude. How much deeper you go with a larger telescope depends on whether the CCD's readout noise or noise from the sky background dominates the image.

With short exposures that have a negligible contribution from the sky background, the SNR scales as the surface area of the telescope's primary mirror. Thus, a doubling of the aperture will improve your limit by 1.5 magnitudes. Alternatively, for long exposures or bright skies, the SNR scales as the mirror's diameter so that a doubling of the aperture buys you only 0.75 magnitude.

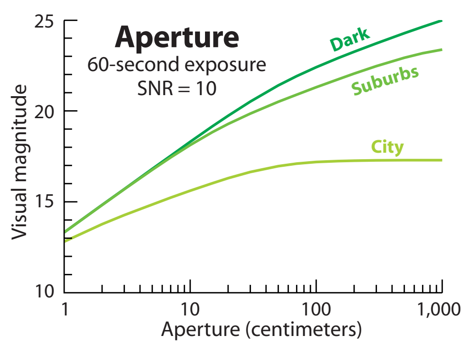




Is it worthwhile carting your telescope to a dark site? The graph below shows the limiting magnitude for three lighting conditions: dark skies, suburban skies with a naked-eye limiting magnitude of 5, and big-city skies where the naked eye sees only stars of 3rd magnitude and brighter. The difference between the suburbs and the countryside is around a half magnitude, and a lot of observers may not consider this gain worth the hassle of transporting equipment. Another way of looking at it might be to realize that carting your 8-inch scope to a dark site will give you the same results as having a 12-inch in your backyard.

The worst case is the light pollution of a big city, where you lose more than three magnitudes and no upgrade in aperture will buy it back. But the good news is that the power of CCDs lets city dwellers reach depths that were unimaginable in the days of film. Digital technology, as many amateurs are finding out, is attractive for even the most light-polluted conditions.

Can you compensate for small aperture or light pollution with extra exposure time? The answer is yes. A 10-minute exposure with a 12-inch telescope reaches the same depth as a 25-minute exposure with an 8-inch. If the 10-minute exposure is made with a 20-inch instrument, it can be duplicated by exposing for an hour with the 8-inch. As with the case of aperture, the scaling depends on the dominant source of noise



in the image. If the noise is due to sky background, the threshold of detection varies as the square root of the exposure — doubling the exposure gains you 0.37 magnitude.

It is also possible to compensate for moderate light pollution by increasing the exposure time. With an 8-inch telescope, a 6-minute exposure in the countryside is like a 10-minute exposure in the suburbs. Bad light pollution, however, requires a large exposure increase. A 25-second exposure from a dark site yields the same limits as a 10-minute exposure in a big city.

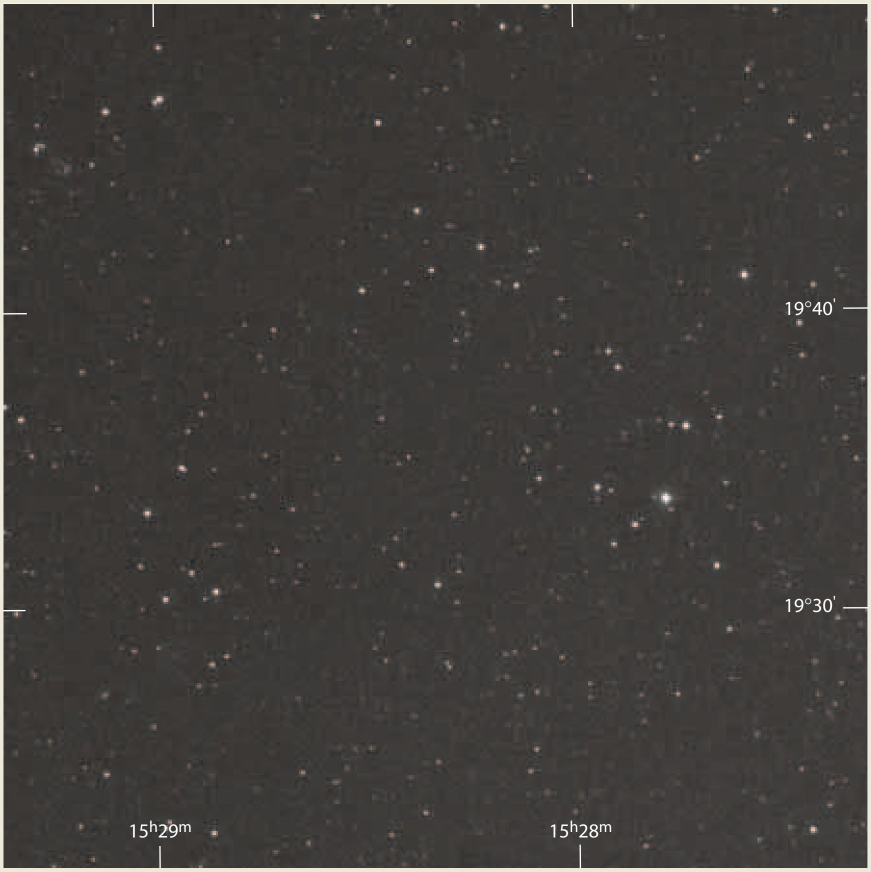
The Moon is up; should you go to bed? What is the loss of limiting magnitude as a function of lunar phase and the distance your target is from the Moon? Which filter is least affected by bright moonlight? How much twilight can you tolerate when making CCD exposures? This program allows a quantitative evaluation of the effects of moonlight and twilight.

Three graphs for moonlight and twilight on pages 120 and 122 show the loss in limiting magnitude for the standard U, B, V, R, and I photometric bandpasses. In general, the physics of light scattering in the atmosphere makes moonlight and twilight brighter in the blue portion of the spectrum than in the red. The U band would be the most sensitive to natural sky light, except that at this wavelength the CCD readout noise always dominates over sky-background noise. The bright sky becomes less of a problem as we progress to redder wavelengths, but only the I band is substantially unaffected by a bright skylight.

Other interesting aspects of natural skylight emerge from the program. Moonlight does not change much for sky locations 60° or more from the Moon. On the other hand, lunar interference increases greatly as we look close to the Moon's position. The loss of limiting magnitude is negligible for a crescent Moon, while even a gibbous Moon is not a horrendous problem for CCDs. Similarly, near the zenith, dawn causes substantial harm only after the start of nautical twilight (Sun is 12° below horizon).

How Deep Can You Go?

How deep can you go from your backyard? Let's suppose that we take a 30-minute, unfiltered exposure with a 16-inch f/4.5 reflector and a typical CCD camera having a Kodak KAF-0400 chip. The image should record stars (at the



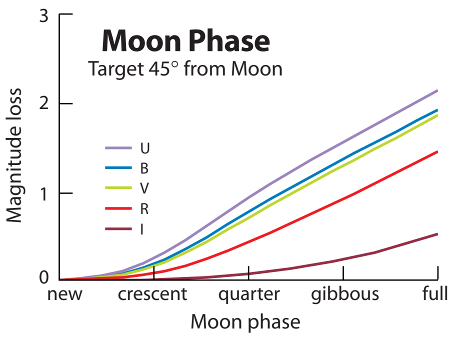
The author's deep-field challenge is centered in this ½°-wide finder chart based on a red-light photograph made with the 48-inch Oschin Schmidt telescope on California's Palomar Mountain. Although stars are recorded to about 20th magnitude, there is no sign of what some astronomers believe is the possible host galaxy responsible for the gamma-ray burst that occurred in January 1996.

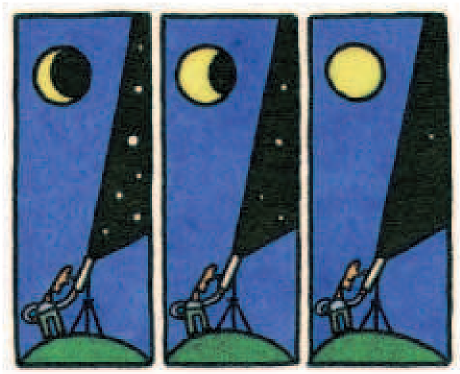
The Deep-Field Challenge

How deep can amateurs go with CCDs? I'd like to present a challenge that will help answer this question, contribute to the field of gamma-ray astronomy, and crown an amateur King or Queen of the Deep Sky. The field I propose people image is in the constellation Serpens centered at $15^h\ 28^m\ 20^s$, +19° 36' (epoch 2000.0 coordinates). It is here that an intense gamma-ray burst was recorded on January 11, 1996. Deep images of this region may show the host galaxy that some astronomers believe is the source of the burst.

This challenge is open to everyone, but some restrictions apply if you're vying for the amateur title. In this case your telescope must not be owned or operated by a professional astronomical group, and the observer must not be employed more than half time in an astronomical job. A hard copy of the image entered in the challenge should be sent to me at the Department of Physics, JWG 463, Yale University, New Haven, CT 06520-8121, by the end of June. Please give as much information as possible about how the image was made, including details on the telescope and CCD equipment, filters, exposures, and image-processing techniques. After a preliminary evaluation, I'll request the deepest images be forwarded in an electronic version for further analysis.

The deepest image, whether or not it shows a possible host galaxy for the gamma-ray burst, will appear in a future issue of this magazine as well as on the Web as the Astronomy Picture of the Day (http://antwrp.gsfc.nasa.gov/apod/astropix.html). The real reward for participating in this challenge, however, will be the personal satisfaction that comes from a job well done, and a possible view of galaxies far away and long, long ago.





SNR=10 level) as faint as visual magnitude 21.81 — about the photographic limit of the 200-inch telescope! However, by carefully adding together aligned frames, we can push this limit substantially deeper. With 20 frames, the limit is 23.52. Furthermore, if our target is a star with a color index (B–V value) of 1.2, an astounding limit of magnitude 24.67 can be reached with these 20 frames. To achieve this threshold the observer's technique would have to be superb to overcome systematic problems arising from working this far below sky's brightness level of even the darkest mountaintop sites.

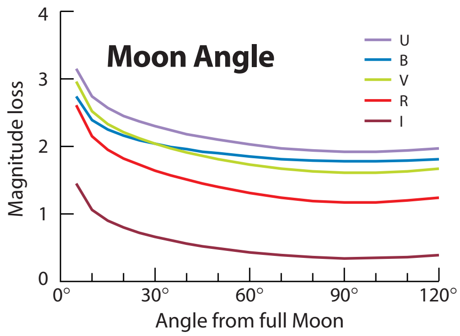
The Program

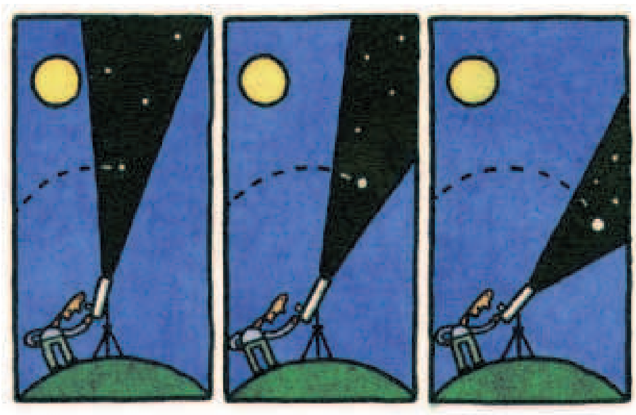
Here is some information for those individuals interested in running the accompanying program. The main program consists primarily of input and output calls to three subroutines, and a calculation of the signal-to-noise ratio. Two subroutines (Sky and Extinction) are presented in a companion article (page 57). The subroutine CT calculates the number of detected photons in both the star and background. The primary output is the SNR and the uncertainty in the magnitude. An SNR of 10 is needed for a confident detection of a star, while an SNR of 3 is adequate for a marginal detection. For the best photometry, with an uncertainty from photon statistics of less than 0.01 magnitude, an SNR greater than 100 is needed.

Here is an example involving typical values that you can use to check that the program is working correctly. It is for an 8-inch f/10 Schmidt-Cassegrain telescope with an SBIG ST-7 camera (Kodak KAF-0400 chip) and a single 10-minute exposure in good seeing from the American Southwest in February 1998. All the other parameter values are explicitly presented in the program.

Consider a zenith distance of 45° and make an SNR calculation for a star of visual magnitude 18.0. The counts from the photometry aperture (the specified pixels containing the star's light as well as that of the background sky) for the U, B, V, R, and I bands are 45, 447, 1,017, 3,084, and 1,443 for the star and 4, 16, 54, 260, and 568 for the sky, respectively. For the star with U=19.05, B=18.70, V=18.00, R=17.48, and I=16.88, the SNR values are 1.5, 12.1, 22.3, 44.0, and 21.6, which corresponds to 1-sigma uncertainties of 0.71, 0.09, 0.05, 0.02, and 0.05 magnitude, respectively. Successive applications of the program reveal limiting magnitudes for an SNR of 10 to be U=16.83, B=18.95, V=19.07, R=19.49, and I=17.83.

The program can be modified in many

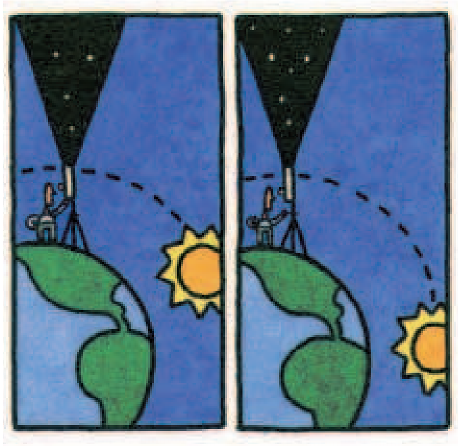


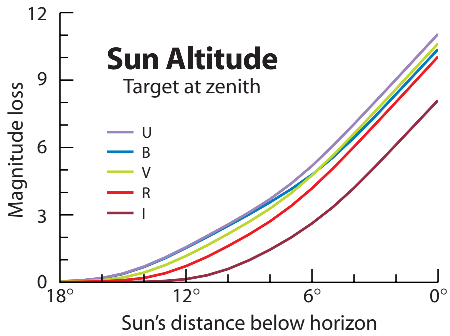


ways to accommodate specific needs. For example, a programmer can easily place the calculation of counts and SNR into a loop that automatically seeks a limiting magnitude for a given SNR, or determines an exposure time required to produce a given SNR. For parameters that you will frequently vary, you might want to change lines from an equality — like line 260, where D=20.32 — to a user input — like INPUT "Telescope aperture (cm): ";D — or vice versa. Also, if the star color is known, you might insert it into the program for greater accuracy (line 330).

I prepared a research version of the program for which the input comes from a parameter file. This allows the software to loop sequentially through many cases and saves much tedium of input. I also created a spreadsheet version of the program that readily shows me intermediate quantities of interest for all five filters simultaneously.

```
10 REM CCDLIMIT.BAS CCD Limits
20 REM by Bradley E. Schaefer
30 FOR I=1 TO 5 : READ WA(I) : NEXT I
40 DATA 0.365, 0.44, 0.55, 0.7, 0.9
50 FOR I=1 TO 5 : READ Q(I) : NEXT I
60 DATA 15.0, 25.0, 40.0, 56.0, 26.0
70 FOR I=1 TO 5 : READ MO(I) : NEXT I
80 DATA -10.93, -10.45, -11.05, -11.90, -12.70
90 REM Input for position
100 RD=3.14159/180.0
110 INPUT "Zenith distance (deg.) : ";Z
120 AM=180.0 : REM Moon phase (deg.; 0=FM, 90=FQ/LQ, 180=NM)
130 ZM=180.0 : REM Zenith distance of Moon (deg.)
140 RM=180.0 : REM Angular distance to Moon (deg.)
150 ZS=180.0 : REM Zenith distance of Sun (deg.)
160 RS=180.0 : REM Angular distance to Sun (deg.)
170 REM Input for the Site and Date
180 TS=1.0 : REM FWHM of seeing in V at zenith
190 RH=40.0 : REM Relative humidity (%)
200 TE=15.0 : REM Air temperature (deg. C)
210 LA=30.0 : REM Latitude (deg.)
220 AL=1000.0 : REM Altitude above sea level (m)
230 M=2.0 : REM Month (1=Jan, 12=Dec)
240 Y=1998.0 : REM Year
250 REM Input for the telescope and detector
260 D=20.32 : REM Telescope aperture (cm)
270 TP=.91 : REM Pixel size (")
280 DS=4.0 : REM Diameter of secondary (cm)
290 NM=2 : REM Number of mirrors (-)
300 NL=2 : REM Number of lens/glass in path (-)
310 RN=15.0 : REM Read noise of CCD (electrons)
320 INPUT "Enter V-band magnitude of star: ";MV
330 CI=.7 : REM Color index [B-V] for star (mag)
340 INPUT "Exposure time (seconds): ";E
350 NR=1 : REM Number of CCD readouts (-)
360 TA=1.0 : REM Radius of photometry aperture (") [best :
      TA=TS]
370 GOSUB 1000 : REM Extinction subroutine
380 GOSUB 2000 : REM Sky subroutine
390 REM Calculate counts from star and sky
400 MA(1)=MV+2.35*CI-.6 : REM U
410 MA(2)=MV+CI : REM B
420 MA(3)=MV : REM V
430 MA(4)=MV-.75*CI : REM R
440 MA(5)=MV-1.6*CI : REM I
450 GOSUB 3000 : REM CT subroutine
460 REM Calculate SNR (see PASP article for exact formula)
470 P=3.14159*(TA/TP)^2
480 IF P<1.0 THEN P=1.0
490 FOR I=1 TO 5
500 VA=NS(I)+P*NB(I)+P*NR*RN*RN
510 SN(I)=NS(I)/SQR(VA)
520 SI(I)=1.068/SN(I)
530 NEXT I
540 PRINT : PRINT "For star with U, B, V, R, I ";
550 PRINT USING " #####.##"; MA(1), MA(2), MA(3), MA(4), MA(5)
560 PRINT " their respective SNR are ";
570 PRINT USING " #####.##"; SN(1), SN(2), SN(3), SN(4), SN(5)
580 PRINT " with 1-sigma errors (mag.) of ";
590 PRINT USING " #####.##"; SI(1), SI(2), SI(3), SI(4), SI(5)
600 END
1000 REM Insert Extinction subroutine
2000 REM Insert Sky subroutine
3000 REM Subroutine CT
3010 FOR I=1 TO 5 : READ DL(I) : NEXT I
3020 DATA 0.068, 0.098, 0.089, 0.22, 0.24
3030 FOR I=1 TO 5 : READ RE(I) : NEXT I
3040 DATA 0.83, 0.86, 0.88, 0.87, 0.90
3050 FOR I=1 TO 5 : READ TR(I) : NEXT I
3060 DATA 0.970, 0.983, 0.987, 0.983, 0.980
3070 FOR I=1 TO 5 : READ TF(I) : NEXT I
3080 DATA 0.70, 0.70, 0.70, 0.70, 0.70
3090 REM Seeing
3100 FOR I=1 TO 5
3110 X=1.0/(COS(Z/57.28))
3120 T1=(TS^2)*(X^1.2)*((WA(I)/.55)^-.4)
3130 T2=5.54*((3600.0*57.28*(WA(I)/10000.0)/D)^2)
3140 TT(I)=SQR(T1+T2) : REM Total seeing FWHM (")
3150 NEXT I
3160 REM Efficiencies
3170 FOR I=1 TO 5
3180 EF(I)=(Q(I)/100.0)*TF(I)*(RE(I)^NM)*(TR(I)^(2.0*NL))
3190 F(I)=1-EXP(-2.77*((TA/TT(I))^2)) : REM Fraction in
      photometry aperture
3200 NEXT I
3210 A=(3.14159/4.0)*(D^2-DS^2) : REM Light-collecting area
3220 REM Source and sky counts
3230 FOR I=1 TO 5
3240 IN=10^(-.4*(MA(I)-MO(I)+DM(I)))
3250 PE=(WA(I)/10000.0)/(6.62E-27*2.997E+10)
3260 NS(I)=IN*F(I)*A*EF(I)*E*DL(I)*PE
3270 NB(I)=B(I)*A*EF(I)*E*DL(I)*PE*(TP^2)
3280 NEXT I
3290 PRINT : PRINT "Star counts in photometry aperture
      (UBVRI):";
3300 PRINT USING " #####."; NS(1), NS(2), NS(3), NS(4), NS(5)
3310 PRINT "Star counts in sky aperture (UBVRI): ";
3320 PRINT USING " #####."; NB(1), NB(2), NB(3), NB(4), NB(5)
3330 RETURN
```





Perhaps the most common modification will be the introduction of nonstandard filters. For this, you should change the values for central wavelength (WA in microns on line 40), the peak transmission (TF expressed as a fraction on line 3080), the full-width-half-maximum transmission of the filter (DL in microns on line 3020), the quantum efficiency at the central wavelength (Q given as a fraction on line 60), and the zero of the magnitude system (MO on line 80). For the last two quantities you can interpolate from the values given for the standard filters.

An important special case, which will be applicable to many amateurs, is for exposures involving no filter. Here, the wide range of wavelengths can be handled by breaking up the optical region into five bands with TF=1.0. The five bands will retain the standard WA, Q, and MO values, but take DL equal to 0.07, 0.10, 0.10, 0.20, and 0.20 to cover the entire visible range. The source and background counts from all five bands should then be added together for feeding to the SNR subroutine.

Bradley Schaefer *is a frequent contributor to this magazine on diverse topics ranging from astronomical history to sundials. At Yale University he is involved with building an array of CCD cameras, now installed in Venezuela, to survey the equatorial sky for quasars.*

French Moonbow *(right)*

by PETER VAN HOECKE

Members of the Belgian astronomy association VVS-Io Evergem were delighted to see a moonbow in the aftermath of a storm at a dark-sky site near Puimichel, France, last July 16th. Colorless to the eye, the moonbow displayed the rich hues of its daylight counterpart to the camera's patient gaze.

Saturn *(below)*

by DAVID HANON

This detailed tricolor CCD image was made last October 7th when the planet was a few days before opposition and 8.395 astronomical units (780 million miles) from Earth. Our view of the dramatic ring system will continue to improve for the next five or so years as the southern face of the rings tilts further into our line of sight.

Sunset on Posidonius *(below right)*

by REMY COURSEAUX

French amateur Remy Courseaux photographed the crater Posidonius near the terminator of the waning gibbous Moon in August 1996. For small telescopes, the 60-mile-diameter crater is a prominent feature on the edge of Mare Serenitatis.

The Galaxy NGC 3628 *(facing page, bottom left)*

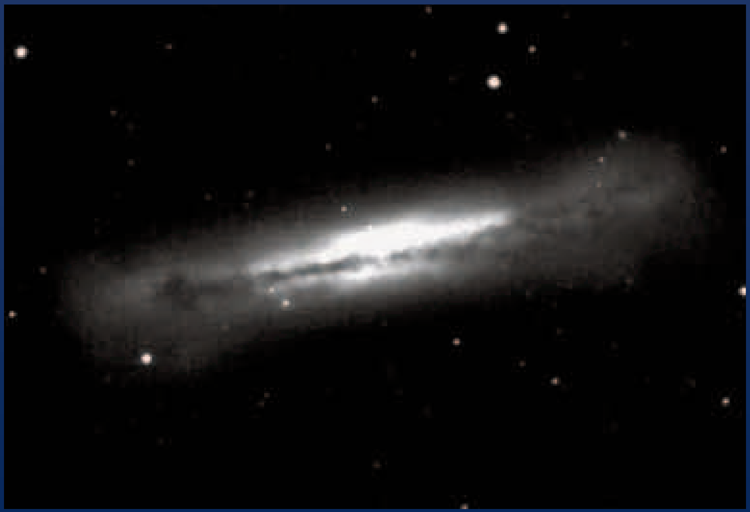
by JOSE G. TORRES

Visible in the same low-power telescopic field as the well-known galaxies M65 and M66 in Leo, this edge-on spiral with a prominent dust lane is a popular target for backyard observers with dark skies.

The Whirlpool Galaxy, M51 *(facing page, bottom right)*

by C. CAVADORE, J. LOPEZ, and A. JACQUEY

Obtained in March 1997, this stunning view of perhaps the most recognized galaxy in the heavens demonstrates the remarkable strides that amateurs have made with CCD imaging in recent years. Not long ago even professional observatories were unable to produce color views showing this level of detail.



Cygnus Milky Way *(above)*

by JASON WARE

Milky Way star fields in northeastern Cygnus serve as a backdrop for the Cocoon Nebula (lower left) and the graceful river of obscuring dust that flows to its west. The Cocoon itself is a star cluster involved with emission and reflection nebulosity, which gives rise to its purplish cast.

The Dumbbell Nebula, M27 *(left)*

by AL KELLY

This tricolor CCD image made last August 30th transforms the well-known planetary nebula's "boxy" visual appearance in a typical amateur telescope into a colorful oval glowing with the predominantly green light emitted by ionized oxygen atoms.

Evening Planetary Lineup *(upper image)*

by TIM BARNWELL

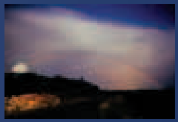
Shortly after sunset on New Year's Day, Tim Barnwell photographed the crescent Moon near Jupiter, with fainter Delta Capricorni some 2° to the planet's left. Venus is the bright "star" near the horizon, while Mars appears near the center of the field.

Geostationary Satellites *(lower image)*

by STEFANO SPOSETTI

This extraordinary CCD image by Swiss observer Stefano Sposetti shows the trails of seven faint geostationary satellites (curved streaks) recorded during a 12.6-hour period last January. The horizontal streaks are stars that crossed the 13'-wide field during the exposure made with a stationary telescope. Most of the satellites appear to brighten around midnight, when they are near opposition.

HOW THEY DID IT

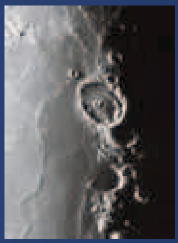


French Moonbow

28-millimeter f/2.8 Nikkor lens, Fujicolor Super G 800 film, 30-second exposure.

Saturn

7-inch f/9 Astro-Physics refractor working at f/90 with eyepiece projection. SBIG ST-8 CCD camera and exposures of 2, 3, and 8 seconds through red, green, and blue filters, respectively.

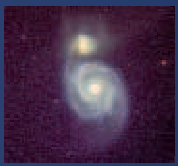


Sunset on Posidonius

Takahashi 9-inch Schmidt-Cassegrain telescope with Barlow projection yielding f/58. 1-second exposure on Kodak Technical Pan 2415 film. Negative digitally scanned and processed with *Adobe Photoshop.*

The Galaxy NGC 3628

Meade 10-inch f/10 LX200 Schmidt-Cassegrain telescope fitted with an Optec f/3.3 MAXfield focal reducer. SBIG ST-7 CCD camera, composite of two 3-minute exposures. Field 16' wide centered at $11^h\ 20.3^m$, +13° 36'; north is up.

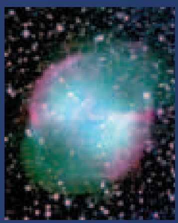


The Whirlpool Galaxy, M51

16-inch f/4.5 Newtonian reflector, CCD camera with Thomson 512-pixel-square, thinned, back-illuminated chip. Exposures of 480, 660, and 780 seconds through red, green, and blue filters, respectively. Field 18' wide centered at $13^h\ 29.8^m$, +47° 12'; north is up.

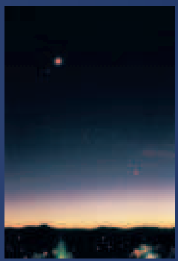
Cygnus Milky Way

Meade 12-inch f/2.2 Schmidt camera. Two 17-minute exposures on Kodak 120-format Ektar 25 film were stacked and copied to make a pair of transparencies. The transparencies were stacked and printed to make a pair of internegatives, which were stacked to make the print used for this reproduction. Field 4⅓° wide centered at $21^h\ 44^m$, +48.2°; north is up.



The Dumbbell Nebula, M27

17½-inch f/4.5 Newtonian reflector and homemade Cookbook CB245 CCD camera. Exposures of 5.5, 8.5, and 12.5 minutes were taken through red, green, and blue filters, respectively. Field 8' wide centered at $19^h\ 59.6^m$, +22° 44'; north is at upper left.



Evening Planetary Lineup

35-mm camera with 50-mm lens set at f/4, Kodak Ektachrome 400 film, 4-second exposure.

Geostationary Satellites

Celestron 8-inch Schmidt-Cassegrain telescope with an f/6.3 focal reducer. Hi-SYS 22 CCD camera. Combination of 368 2-minute exposures that began at 17:11 Universal Time on January 10th and ended at 5:51 UT on the 11th. Field is 13' wide.