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- Sweet Stars
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Observing Highlights

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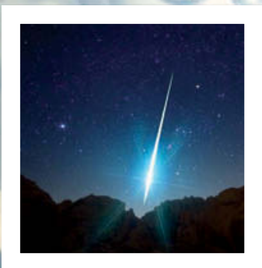

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SKY & TELESCOPE

December 2012 VOL. 124, NO. 6

On the cover: Cosmologists think our universe might be just one bubble in a vast bubble bath of universes. If so, crashes between bubbles could leave detectable scars.

COVER: CASEY REED

INSET IMAGES
NEIL ARMSTRONG: NASA
GEMINID METEOR: WALLY PACHOLKA
SATURN MOONS: NASA / JPL / SPACE SCI. INST.
STAR CLUSTER NGC 290: ESA / NASA

FEATURES

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OBSERVING DECEMBER

S&T TEST REPORT

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S&T's Topographic Moon Globe

THIS IS A MONTH with good news and bad news. I'll start with the good: a beautiful *S&T* topographic Moon globe has just gone on sale.

You might remember that earlier this year we produced a new Moon globe based on 15,000 images from NASA's Lunar Reconnaissance Orbiter (June issue, page 6). That globe has been such a big success in terms of customer interest and satisfaction that it compelled us to produce another LRO Moon globe in partnership with Replogle. This time, the globe is based on LRO altimetry data rather than camera images.

We're very proud of the result: *Sky & Telescope's* Topographic Moon Globe. As you can see on page 75, this 12-inch-wide globe is color-coded to highlight the dramatic variations in lunar elevations. Impact basins and deep craters show up clearly in blue, whereas high peaks and rugged terrain are colored white, red, and orange. Basins that are virtually invisible in the earlier Moon globe jump right out in the topographic version. The huge South Pole–Aitken Basin is particularly dramatic (see the image in the June issue, page 21). The new globe has about 850 labeled features.

Developing these globes and ensuring their accuracy has been a team effort. But special commendations go to illustration director Gregg Dinderman, senior contributing editor Kelly Beatty, imaging editor Sean Walker, and production manager Mike Rueckwald. We also thank our friends on the LRO mission, at the U.S. Geological Survey, and at Replogle.

Now the bad news. My colleagues and I are mourning the September 3rd passing of William Shawcross (1934–2012). As my colleague Dennis di Cicco points out, Bill's byline appeared infrequently in *S&T*, but he was a seminal figure in this magazine's history from the time he joined the editorial staff in 1956 to his retirement in 1991. During that period, he served the magazine in many capacities, including managing editor of *S&T* and president of Sky Publishing Corporation. Bill was a man of many talents; he helped in advertising sales, copy-editing, fact checking, computer technology, design, and even snow shoveling. As Dennis wrote in a web obituary (**skypub.com/Shawcross**), "Bill's death is a significant loss for those of us who knew and worked with him for many years, and it closes a chapter on one of the magazine's most important eras."

S&T: DENNIS DI CICCO

Robert Naeye
Editor in Chief

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The Essential Guide to Astronomy

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S&T: LEAH TISCIONE

Misquote in Misquotes Article?

The entertaining article by Dave English, "Misquotes in Astronomy" (August issue, page 26), begins with the remark Galileo Galilei allegedly made after recanting his support of the Copernican theory. English wrote that the quote was "*eppur si move*," but in Italian the quote would be "*eppur si* muove," from "*muovere*."

In my opinion, it doesn't really matter whether Galileo actually said the phrase or not. It's a splendid story of a persecuted man's integrity, maintained despite formidable opposition. It's a myth not in the trivial sense of a "lie," but a myth that captures an exemplary human experience.

D. C. Riechel
Columbus, Ohio

Editor's Note: *There are a few versions of Galileo's famous quote. In modern Italian, the quote would be* "eppure si muove." *However, the original quote that appeared in Giuseppe Baretti's 1757* The Italian Library *was* "eppur si move." *Baretti might have been quoting Galileo in the Tuscan dialect, in which* "muove" *becomes* "move" *(*"move" *appears in some Italian dialects but is considered a more vulgar form of the proper Italian* "muove"*). It's also possible that Baretti simply made a mistake.*

Thanks to Dave English for his informative piece on famous misquotes in astronomy. The translation of Konstantin Tsiolkovsky's quote, though, could use a further tweak. The Russian word "*razum*" in this context is best rendered as "reason" or "intellect," not "mind." And because Russian lacks definite and indefinite articles, we have to deduce from context whether he meant "a" planet, as in any planet, or "the" planet, as in Earth. Clearly the latter was his intended meaning, so the quote is perhaps best translated as "Earth is the cradle of reason, but one cannot live forever in a cradle."

Robert Gillette
Ossipee, New Hampshire

Editor's Note: *Another Russian speaker noted that the second "cradle" in Tsiolkovsky's quote is actually plural; he offered the rendering, "The planet is the cradle of reason, but it is impossible to live eternally in cradles." Our discussions with readers on these translations have delighted us.*

Double Stars and Observing

I especially enjoyed your September issue with Sissy Haas's article "Finding the Limit for Uneven Double Stars" (page 68) and Gary Seronik's article "Easy Reflector Collimation" (page 72). Sissy's article helped me feel more comfortable with what I am able to see and record when looking at double stars. Gary's article put me more at ease with my collimations and with how much detail I am seeing and not seeing with my 10-inch reflector. I am a visual observer who is happy to open my observatory only a couple times a month and enjoy and record what there is to see. This is all I have time for, but it's enough.

Dick Mastin
Alto, New Mexico

In her article on double stars, Sissy Haas mentioned that she knew of no observational study that had tested my predictions for resolving double stars. I'd like to point out that my empirical resolution formula was actually based on Thomas Lewis's 1914 analysis of the means of 159 pairs of double stars and supplemented by my own observations of 94 pairs, which I made with four telescopes ranging in aperture from 3 to 10 inches over a 20-year period (1973 to 1993). Lewis's data included observations made with 43 different telescopes ranging from 4 to 36 inches in aperture. Pairs from both Lewis's and my analysis included equal-bright and equal-faint pairs, as well as unequal pairs (with a magnitude difference of 3) and very unequal pairs (magnitude difference 5).

A PDF download of my paper is available at **http://bit.ly/RGUr5W**. All the pairs I measured are listed in the appendix.

The international double-star observing group Spirit of 33 includes a project whose purpose is to test my formula. The software *AstroPlanner*, written by Paul Rodman, also uses my unequal double-star limit. It may be used to determine the difficulty of any pair in any telescope, in any seeing state. What still is needed is a careful analysis of the eye's physiology and how it leads to my equation and to the Dawes limit. I and others have been working on this question, but there is a ways to go yet.

Chris Lord
Little Eversden, Cambridge, England

Another Look at the Canon 60Da

I was intrigued enough by Alan Dyer's review of the Canon 60Da DSLR (September issue, page 38) that I purchased one. I decided to wait on buying remote cable

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releases and long exposure timers until I received the camera and had some experience with it.

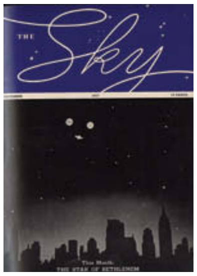
I was pleasantly surprised to find that Canon ships the camera with its *EOS Utility* software that allows virtually every function of the camera to be controlled by a PC (or Mac) via a single USB 2.0 connection. I can sit at my computer and remotely set up the camera, compose the picture with a live-view picture on my monitor, take the exposure (for up to 99 minutes), download the file to my PC automatically, and even use Canon's image software for analysis and manipulation. My mount and telescope focus were already controlled by PC; now I can do everything needed to take an image remotely from a PC while the camera remains mounted to my telescope.

The *EOS Utility* software is easy to install and operate, and its inclusion makes the Canon 60Da a very user-friendly DSLR astronomy camera.

Richard Finlon
Denver, Colorado

75, 50 & 25 Years Ago

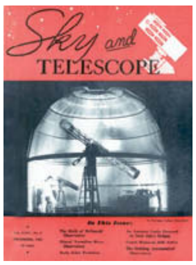
Roger W. Sinnott



December 1937

Mars Is Dry "The present year was favorable for an investigation of the water vapor content of the atmosphere of Mars. A month or two preceding opposition the earth was approaching the planet rather rapidly, at least rapidly enough for the water vapor absorption lines of the Martian atmosphere to be displaced (according to the Doppler-Fizeau principle) to the violet of the telluric lines. No Martian lines appeared, indicating to [Walter S.] Adams and [Theodore] Dunham [Jr. that] less than 5 per cent as much water vapor [exists] as obtained in our own air. At a more favorable opposition, with Mars higher in the sky, perhaps more will be learned about the region over the polar caps, the present study being of the center of the planet. But the possibility of Martians closely akin to earthly creatures seems to be out."

Adams and Dunham's work at Mount Wilson began to put a damper on several centuries of wild speculation. The idea that Mars might harbor intelligent life wasn't all that far-fetched at the time, as Orson Welles's famous broadcast the following Halloween would demonstrate.

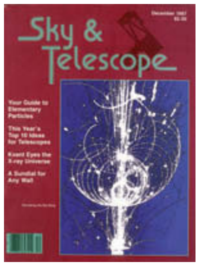


December 1962

Meteor Cloud? "At approximately 8:53 on the evening of August 3, 1962, while watching for the Echo satellite, I saw a most unusual meteor. . . . Traveling northwest through an arc of 80 degrees, it faded out just below the bowl of the Big Dipper.

"This meteor was unusual in several respects. Although only of 1st magnitude, it appeared to have several times the apparent diameter of Polaris. Its quality of light was like that of a midday moon and not at all like ordinary shooting stars. . . . Throughout, it displayed a tail eight or 10 degrees long. . . .

This letter to the editor came from meteorite authority Harvey H. Nininger (1887–1986).



December 1987

Demise of Earth "Most astronomy texts explain that some 5 billion years from now the Sun will turn into a red giant. When it does, its size will expand a hundredfold or more, engulfing in turn Mercury, Venus, and eventually Earth. However, little attention has been paid to our planet's fate thereafter.

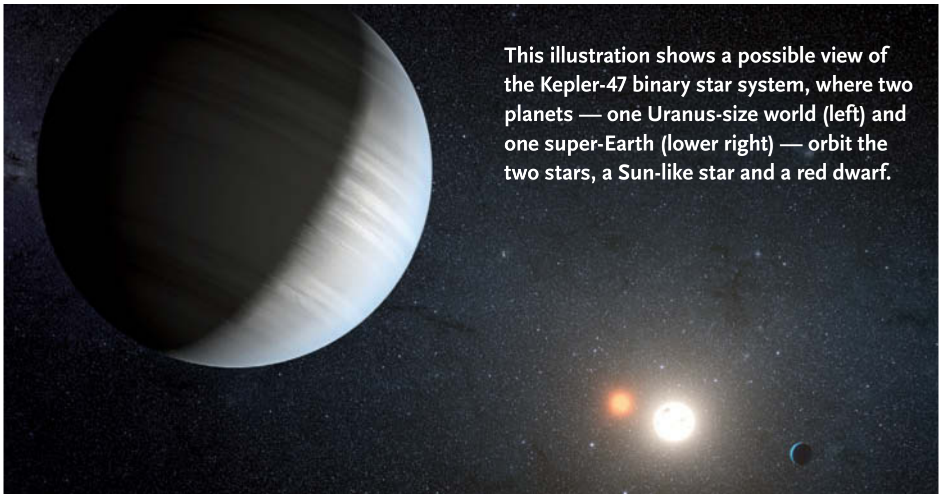
"This question is posed and answered by Jeff Goldstein (University of Pennsylvania). . . . At maximum size, the Sun's radius will only be about 1.1 astronomical units, so our planet will not be swallowed too deeply into the Sun's bulk. . . .

"Once the Earth enters the solar atmosphere it is subject to ablation, vaporization, and orbital decay. Neglecting the first two factors, Goldstein found that Earth's orbital radius would decay by 99 percent in less than 300 years. When the other factors are included the picture looks even bleaker."

Recent research (S&T: *June 2007, page 32) has made Earth's fate less certain, albeit just as bleak.*

To get astronomy news as it breaks, visit skypub.com/newsblog.

EXOPLANETS | Kepler Spots a Tatooine Family



This illustration shows a possible view of the Kepler-47 binary star system, where two planets — one Uranus-size world (left) and one super-Earth (lower right) — orbit the two stars, a Sun-like star and a red dwarf.

NASA / JPL-CALTECH / TIM PYLE

Astronomers have discovered two exoplanets orbiting the binary star system Kepler-47, Jerome Orosz (San Diego State University) and his colleagues reported online August 28th in *Science* and announced at the International Astronomical Union meeting in Beijing. This system is the first binary found to host multiple planets.

The inner planet, possibly a rocky one about three times the size of Earth, whizzes around the host stars roughly every 50 days. The outer planet is probably a gas giant slightly larger than Uranus and takes just over 300 days to complete an orbit. Ironically, it's the gas giant, not the super-Earth, that lies in the stars' "habitable zone," the region where a rocky planet with a thick atmosphere could have liquid water on its surface.

The larger, brighter star in the system is similar to the Sun in mass, girth, and temperature; it's 176 times brighter than its companion, which is one-third its size. Kepler detected the planets while monitoring light from this Sun-like star, catching 18 transits of the inner planet and 3 transits of the outer world. Although Orosz and his colleagues only saw the planets transit the primary star, analysis suggests the planets likely orbit both stars.

The two worlds are the fifth and sixth planets discovered via the transit method to orbit both components in a binary system, but Kepler-47 is the first observed system to host more than one planet in this configuration.

The discovery could pose problems for theories of planetary formation. In the standard picture, dust grains only a few microns across fly thick and furious around a newly formed star, smacking into one another again and again until they start to stick together, eventually creating planets.

But in binary systems, gravitational tugs from the two stars should speed up collisions so much that planet-forming bodies should smash one another apart instead of glomming together. "The disk would basically grind itself down without managing to form planets," says Greg Laughlin (University of California, Santa Cruz), who was not involved in the study. "Clearly that didn't happen in Kepler-47."

One possible solution is that the planets formed farther out, where the host stars exert a weaker effect, and then migrated in via interactions with the leftover material from the disk that formed them. It's also possible that gravitational instabilities in the disk collapsed to create the planets right where they are, circumventing the standard model.

■ **MONICA YOUNG**

MISSIONS | Space Probes Launched

On August 30th, an Atlas V rocket shot two identical probes toward a region of space most satellites dread to enter: the Van Allen radiation belts. These two belts are filled with trillions of charged particles, some of them whipping around Earth at nearly the speed of light. At those speeds, even an electron can damage satellites. But NASA has designed its Radiation Belt Space Probes (RBSP) to thrive in this zone of killer electrons.

The particles in the Van Allen belts come from the solar wind's interaction with Earth's magnetic field; they're also produced when superspeedy charged particles called cosmic rays (August issue, page 16) crash into our planet's upper atmosphere. The belts' shapes change with solar activity as the interplay between the

Continued on page 14

The Radiation Belt Space Probes, one pictured here in an artist's illustration, will probe the Van Allen radiation belts that circle Earth.

JHU / APL, NASA

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Continued from page 12

solar and terrestrial magnetic fields varies. Astronomers have vague ideas of how these changes work, but they need solid data on what goes on when, and where.

"It's like baking a cake," says deputy project scientist Nicky Fox (Johns Hopkins Applied Physics Laboratory) of efforts to predict the belts' behavior. "You know the ingredients, but you don't know their proportion in each given solar storm."

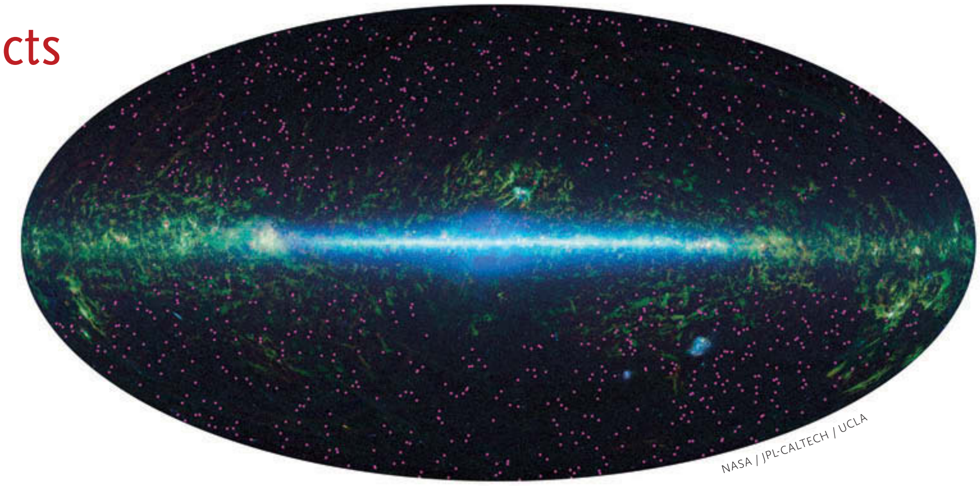
Each octagonal probe weighs almost 1,500 pounds (680 kg) and carries five instrument suites to study the belts' structure and dynamics. The instruments will tease apart the various mechanisms that engage in a perpetual tug-of-war with energetic particles in the charged, doughnut-shaped region.

As the two spacecraft whizz around Earth in highly elliptical orbits, they sample the full extent of the radiation belts, tracking changes in different places at the same time. That will help scientists understand the effect of solar activity on the Van Allen belts, which can grow to cross the orbits of geosynchronous satellites during strong geomagnetic storms.

RBSP instruments have already started recording data and have caught the sound of radio waves whistling through the radiation belts. (Take a listen at **www.skypub.com/chorus**.) The satellites have a two-year primary science mission planned.

■ **MONICA YOUNG**

GALAXIES | WISE Detects Blazing Black Holes



This map from NASA's Wide-field Infrared Survey Explorer shows the locations (magenta dots) of the roughly 1,000 hot dust-obscured galaxies, or "hot DOGs," detected by the spacecraft. In some cases, the hot DOGs emit more than 1,000 times as much energy as our Milky Way Galaxy does.

There are hot dogs in the sky.

Astronomers using data from the NASA Wide-field Infrared Survey Explorer all-sky survey (July issue, page 16) have discovered a new class of galaxies in the distant universe. These galaxies are at least 10 times brighter than extreme star-forming galaxies and rival the brightest active galactic nuclei (AGNs), galaxy cores in which frantically gobbling supermassive black holes spit out jets of plasma.

One of WISE's main science goals was to find the most luminous, dusty galaxies out there, but WISE project scientist Peter Eisenhardt (Jet Propulsion Laboratory) says the new group of galaxies took them by surprise. Instead of showing up in all four WISE bands, the hyperluminous galaxies are invisible in the two shorter wavelengths — 3.4 and 4.6 microns — but bright at 12 and 22 microns. The strong 22-micron emission likely comes from warm dust that is either widespread enough or thick enough (or both) to block emission at shorter wavelengths from the jet-shooting central black holes.

This dust radiates heat between 60 and 120 kelvin, three to four times the temperature of the next brightest class of infrared galaxies. The warm, black-hole-enshrouding dust inspired team member Jingwen Wu (JPL) to label the objects "hot dust-obscured galaxies," or hot DOGs.

The team found only about 1,000 hot DOGs among the 2.5 million AGNs detected by WISE, which were announced with the hot DOGs in a NASA press conference on August 29th and reported in three papers in the *Astrophysical Journal*.

So far the team has measured distances to 147 of the hot DOGs using follow-up observations with other facilities, including the Caltech Submillimeter Observatory. Most of the sources cluster around redshift 2 to 3, or within the universe's first few billion years of existence, when cosmos-wide star formation reached its peak. Yet although the hot DOGs are experiencing bursts of star formation, starlight makes up less than 10% of the galaxies' total light. Starlight also can't heat dust to high enough temperatures to explain the infrared glow. But gas-guzzling black holes can produce an intense radiation field that heats dust, so the hot DOGs' central black holes are likely to blame.

To explain the infrared light pouring out of these galaxies, the central black holes must either be among the most massive black holes known or are gobbling down gas at a higher rate than ought to be physically possible. Eisenhardt and his colleagues consider the latter scenario to be more likely and say these galaxies might be in a short-lived stage in their evolution.

AGN researcher Rachel Somerville (Rutgers University) agrees that the hot DOG phase is probably short-lived, maybe less than a million years. It might turn on when galaxies collide, which spurs star formation and funnels gas and dust into the black hole's maw. But if true, black hole activity should lag behind starbursts, while in hot DOGs the activity seems to come as star formation is just getting started. Why that is remains unclear.

■ **CAMILLE M. CARLISLE**

COSMOCHEMISTRY | Space a Little Sweeter

A team of astronomers has found molecules of the simple sugar glycolaldehyde in the gas surrounding a binary system in the Rho Ophiuchi star-forming region.

The IRAS 16293–2422 system comprises a pair of protostars that have coalesced from two collapsing clumps of gas but that have not yet begun fusion in their cores. The protostars are young enough that they still hide inside their natal cocoons, which glow from the protostars' warmth as the stars contract.

An international team studied the dusty cocoons with the Atacama Large Millimeter/submillimeter Array (ALMA), a world-class network of radio dishes being assembled in Chile. Observing with a subset of ALMA's antennas, the group detected about a dozen spectral lines that clearly come from glycolaldehyde, Jes Jørgensen (Niels Bohr Institute, Denmark) and his colleagues report in the September 20th *Astrophysical Journal Letters*.

The team's ALMA data are truly impressive, says Paul Woods (University College London), who studies the formation of molecules in space. "They're achieving a factor of 10 better in sensitivity than observations made only a few years ago," he says. "This is astounding."

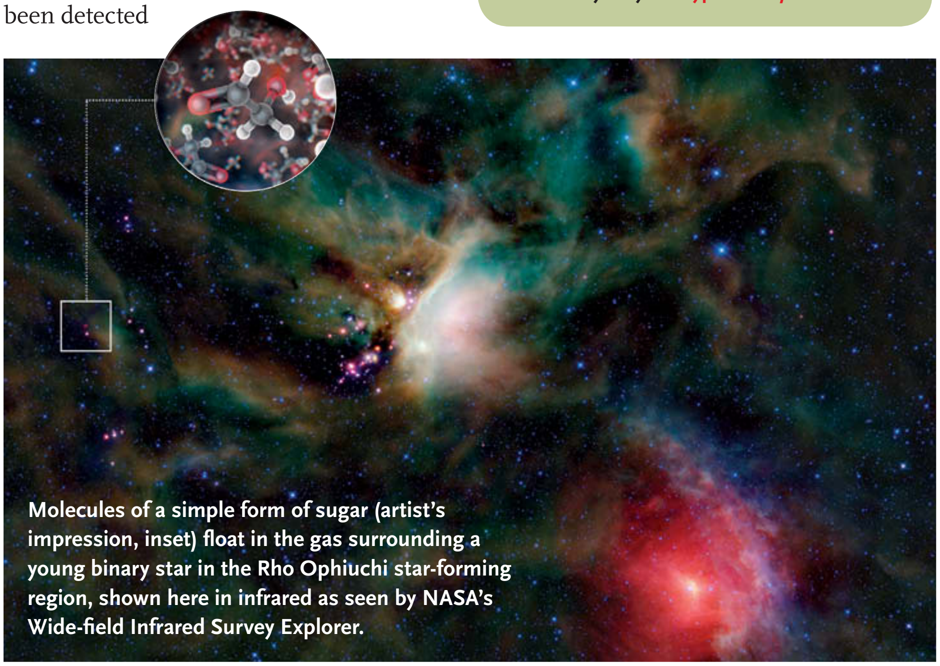
Glycolaldehyde ($HCOCH_2OH$) has been detected twice before in space, in a giant cloud near the Milky Way's center and a massive star-forming region called G31.41+0.31. IRAS 16293 and G31.41 contain many of the same complex compounds, so finding the sugar in IRAS 16293 was not surprising.

The amount of glycolaldehyde and other molecules in IRAS 16293 matches what's expected if the sugar formed on icy dust grains in the cloud. In cold conditions molecules can "freeze out" onto grains' surfaces, just as frost forms on leaves on a winter's morning, Woods explains. Once that happens, chemical reactions can occur on the dust, forming molecules such as glycolaldehyde. When the protostars start glowing and warm the grains, these ices evaporate into the surrounding gas, where Jørgensen and his colleagues detected the sugar.

Glycolaldehyde is a first step in a long series of reactions to make ribose, the backbone molecule of RNA. But even if the sugar survives fusion kickoff and planet formation, and even if conditions one day favor ribose's creation, there's still a long way to go from ribose to life.

■ **CAMILLE M. CARLISLE**

Watch a zoom-in video pinpointing IRAS 16293 in the Milky Way at skypub.com/IRAS16293.



Molecules of a simple form of sugar (artist's impression, inset) float in the gas surrounding a young binary star in the Rho Ophiuchi star-forming region, shown here in infrared as seen by NASA's Wide-field Infrared Survey Explorer.

MOLECULES: ALMA (ESO / NAOJ / NRAO) / LUÍS CALÇADA (ESO); CLOUD: NASA / JPL-CALTECH / WISE TEAM

IN BRIEF

The United States Naval Observatory (USNO) has released the fourth and final edition of its USNO CCD Astrograph Catalog (UCAC4). UCAC4 is a comprehensive star catalog of about 113 million stars and includes all stars down to about 16th magnitude, with proper motions for most of those stars. The catalog also includes data from the AAVSO's Photometric All-Sky Survey (September issue, page 18), matching up about half the UCAC stars with AAVSO measurements. For stars between 10th and 14th magnitude, positions are known to within 20 milliarcseconds. The current optical reference, the Hipparcos Catalog, reaches only 8th magnitude or so. The next advance in this area will probably be from the ESA's upcoming Gaia mission. UCAC4 is available through bit.ly/OFbDUJ.
■ **ROGER W. SINNOTT**

The still-developing Event Horizon Telescope (February issue, page 20) has resolved the innermost structure of a plasma jet shooting from the quasar 1924–292. The EHT team used four telescopes at three sites to observe the jet at 1.3 mm (230 GHz), and at this frequency the jet appears to bend more sharply than it does at higher frequencies, Ru-Sen Lu (MIT Haystack Observatory) and colleagues report in the September 20th *Astrophysical Journal Letters*. The curvature probably looks far more dramatic than it actually is due to the jet's projection on the sky, says quasar expert Alan Marscher (Boston University). The result shows that the EHT can now make crude images with a resolving power of tens of microarcseconds, more than 1,000 times finer than visible-light images from the Hubble Space Telescope.
■ **CAMILLE M. CARLISLE**

After a brilliant landing by Curiosity (November issue, page 20), NASA has announced that Mars will also be the target for its next Discovery-class mission, named "Interior Exploration using Seismic Investigations, Geodesy and Heat Transport," or Insight. Insight will probe the Red Planet's formation history from both ground and space using the Phoenix spacecraft and lander design. The data it gathers should reveal the size of Mars's core and the planet's composition, possibly helping astronomers understand how terrestrial planets form. ✦
■ **CAMILLE M. CARLISLE**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Life on Saturn's Moons?

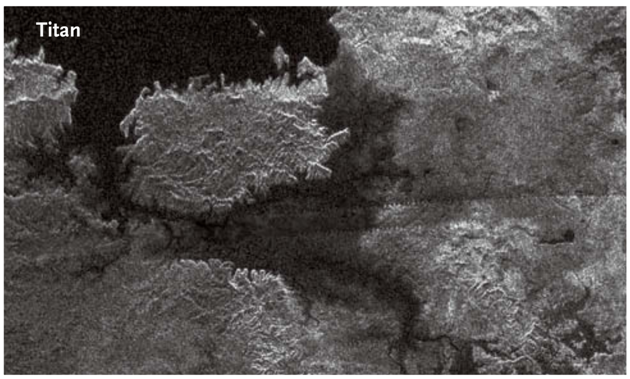
Two worlds will allow us to test contrasting views of planetary habitability.

HOW DO WE SEARCH for life elsewhere? A common view is that we should seek planets with Earth-like conditions and materials: liquid water, an energy source, and organic molecules. I have explored an alternative I call the Living Worlds Hypothesis. The idea is that life is not simply an isolated phenomenon that can exist in watery pockets on otherwise dead worlds, but is a property of a world as a whole that both utilizes and transforms planet-wide activity.

Either way, Mars remains the best place to search for ancient life. After a primordial Earthlike phase, the Red Planet has been inactive, preserving rusted rocks from an era that has been almost completely erased from the terrestrial record by the same restless interior and hydrosphere that make Earth a living world. A geologically deceased world such as Mars provides an advantage for seeking early life, but may spell doom for the continuing presence of life.

What about finding life today? Two moons of Saturn have emerged as places to search. Titan and Enceladus are promising in different ways, which contrast two differing views of the requirements for habitability.

Titan is shrouded in organic molecules that constantly snow down on its surface and may be re-enacting the chemistry that led to life on Earth. A liquid-methane cycle forms clouds, lakes, and rivers that course over a relatively young surface largely devoid of impact craters and girded by vast organic dune fields. Methane gas feeds the organic factory. In these global meteorological and geological cycles are the components of a possible biosphere, including potential niches for exotic biochemistry.



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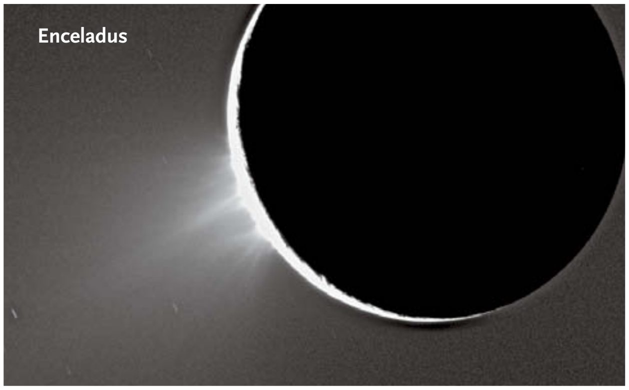


NASA / JPL-CALTECH / SPACE SCIENCE INSTITUTE

An environment supporting "life as we know it" may also exist on Titan. An ocean of water lies underground. Geological activity probably stirs in the rich chemical harvest of surface organics. But these depths would be inaccessible to our probes; like the tantalizing oceans of Jupiter's moon Europa, they hide beneath a thick ice shell.

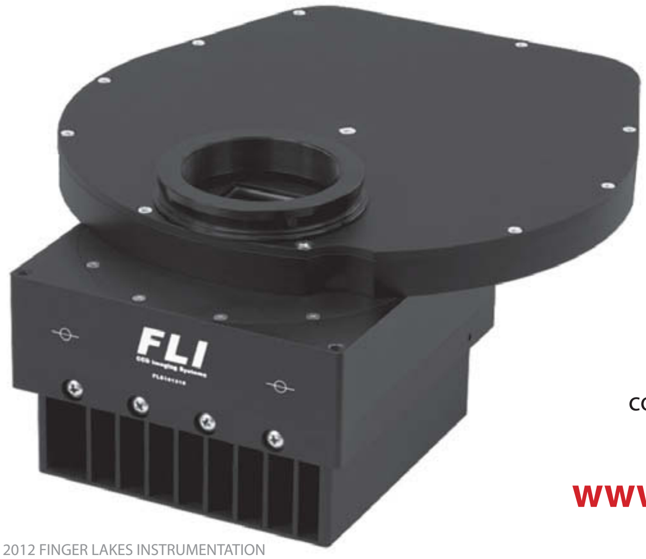
Do all these frigid moons keep their water concealed beneath kilometers of ice? No. Cassini discovered that the small moon Enceladus spews plumes of water into space from its strangely warm south pole. Any organisms in Enceladus's buried water are squirting into orbit and snowing down on its surface. To search for life on Enceladus, you don't need a drill, just a shovel.

So which is the better place to look for life? If life simply requires water, organics, and energy, then it might exist on Enceladus right now. But Enceladus doesn't seem like a world with a biosphere and probably has not been continuously active over billions of years. I favor a view where a biosphere is inseparable from constant, cyclic global activity, so I think Titan is a more promising place to look for life. But this is only a hypothesis.

When it comes to biospheres, we're still stuck with a sample size of one, and thus we remain profoundly ignorant about life's universals. In searching for biology among the wondrous moons of Saturn, we have to keep our eyes and minds wide open. We have to explore both worlds. ✦

David Grinspoon *was recently appointed to be the first Chair of Astrobiology at the Library of Congress. Follow him on* ***Twitter@DrFunkySpoon***.


Lagoon Nebula Region in Hα
ProLine PL16803 | John Gleason


FLI

Cosmic Collisions

Camille M. Carlisle

Astronomers seek direct observational evidence for multiple universes.

MOST PEOPLE don't wake up in the morning hoping to find a black eye. But some cosmologists would like nothing better than to spot a big, round shiner on the universe's face.

That face is the cosmic microwave background (CMB), the thermal radiation filling the entire universe. This radiation was released about 380,000 years after the Big Bang, when the fireball universe cooled down enough that electrons could combine with protons to form atoms, allowing photons to travel freely without scattering. But astronomers also think of the CMB's photons as being emitted from a surface, the outermost "edge" of the observable universe. When thought of as a surface, the CMB is our view of the set of points in space and time when the universe stopped being a superhot, ionized soup and its primordial photons scattered for the last time.

Discovered by Arno Penzias and Robert Wilson in 1964, the CMB quickly became the foremost evidence for the Big Bang. But for some time now, cosmologists have wondered whether that big bang was the only bang. Theories of modern cosmology and physics imply that our universe could be just one bubble in an endless bubble bath of universes, a landscape with the exotic name of *multiverse*.

The multiverse is, for now, mere speculation. But cosmologists are hoping that it won't always be. Detailed studies of the CMB's dappled surface might support this wild vision — not by letting us see other universes directly, but by recording the scars they left behind when they crashed into our cosmos.

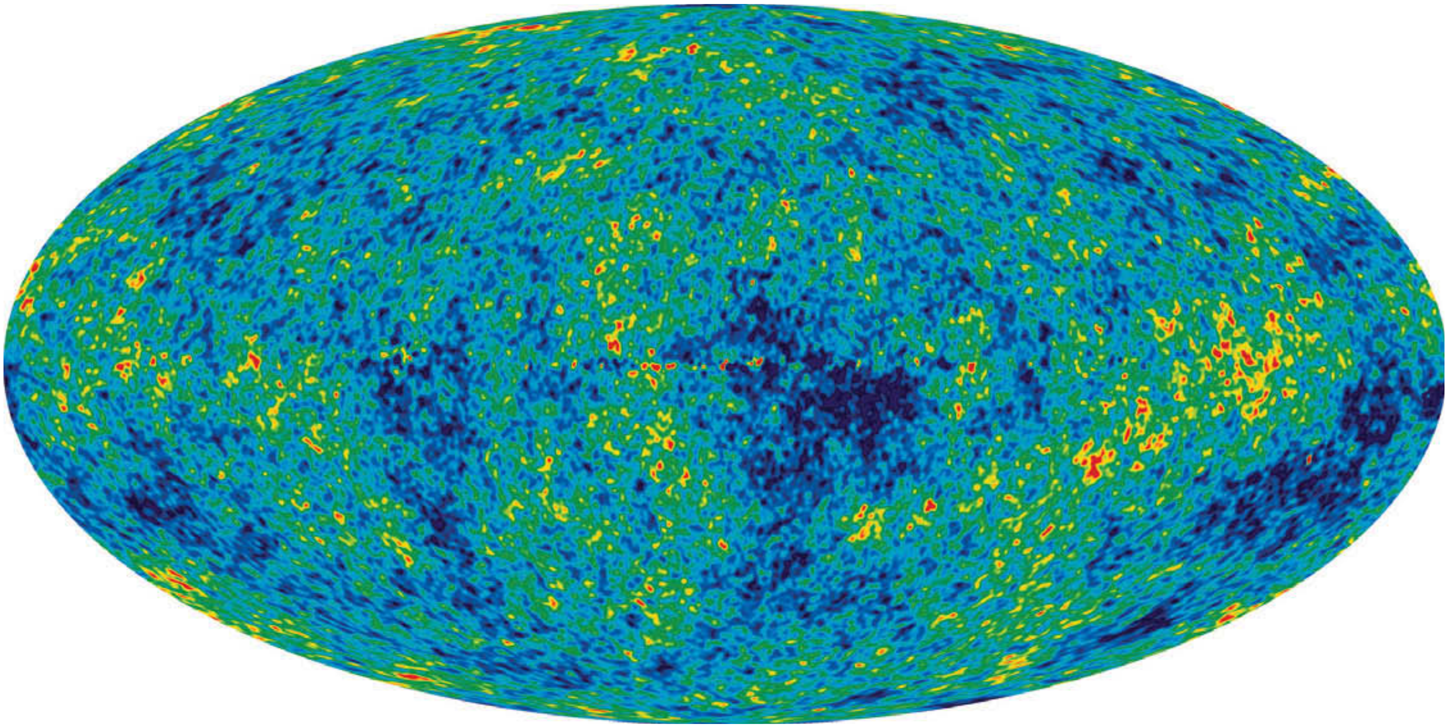
Illustration by Casey Reed

Pocket Universes

At first glance, multiple universes seem the plaything of cosmologists who grew bored with having only one universe to toy with. But it turns out that one of the most popular frameworks of modern cosmology — inflation — usually predicts the creation of an infinity of "pocket universes" (*S&T*: December 2006, page 36).

Proposed by Alan Guth (now at MIT) and others at the start of the 1980s, inflation fixes several major problems with Big Bang cosmology. It explains why the universe looks uniform in all directions, why spacetime appears to be flat on large scales, and why experimentalists haven't detected huge numbers of particles with only one magnetic pole (so-called magnetic monopoles).

Inflation accomplishes this feat by introducing a cosmic hiccup (*S&T*: November 2005, page 32). Instead of expanding as fast as Big Bang physics predicts, the universe expanded more slowly at first, then suddenly went *poof* and ballooned to be at least a million billion billion times larger. The energy inherent in space itself, called vacuum energy, fueled this exponential burst, because vacuum energy exerts enormous repulsive force when concentrated. The universe expanded faster than the speed of light (Einstein's speed limit doesn't apply to



NASA / WMAP SCIENCE TEAM

Mapped in detail by NASA's Wilkinson Microwave Anisotropy Probe, the cosmic microwave background is the radiation released when the universe cooled down enough for photons to travel freely. This all-sky picture of the infant universe was created from seven years of WMAP data and is color-coded to reveal minuscule temperature fluctuations that correspond to subtle differences in the density of matter in the early universe.

spacetime itself) for at least 10^{-35} second, growing to be at least 1,000 times bigger than the universe we can actually observe, Guth says. After inflation ended, cosmic expansion proceeded at a normal pace.

So far, inflation has passed every observational test thrown at it with brilliant success, most notably predicting the size of warm and cool spots in the CMB. But inflation doesn't exactly tie off the universe's history with a nice tidy bow. It introduces a major conundrum: most forms of inflation are eternal. The energy that powered inflation should replenish itself as space expands, fueling an endless succession of big bangs. As Columbia University physicist Brian Greene explains in his recent book *The Hidden Reality,* the single point in the multiverse landscape that became our little cosmic bubble has recovered from its inflationary fever, but the multiverse as a whole might still be sick, expanding faster than any of its pockets like an ever-growing mound of Swiss cheese. As it grows, the cheese develops new holes. Inside one of these holes lies our observable universe.

"Most of the physicists who think a lot about inflation will tell you either that, 'Yeah, inflation is usually eternal and I love it,' or 'Inflation is usually eternal and I try not to think about it,'" says Anthony Aguirre (University of California, Santa Cruz). "And if we have eternal inflation, then these bubble universes are no weirder than anything else."

Our little cosmic bubble has recovered from its inflationary fever, but the multiverse as a whole might still be sick.

There's another reason the multiverse idea is popular: string theory. String theory postulates that every particle in the universe is a tiny strand of energy that vibrates in 10-dimensional spacetime. This theory remains the most detailed attempt so far to unify three sectors of physics: particle physics, Einstein's general theory of relativity (which describes gravity), and quantum mechanics (which describes particle interactions and forces at tiny scales). Despite string theory's reputation for being unverifiable with modern technologies, approaches based on its mathematical framework currently offer the best explanation to certain physical problems, including the behavior of some weird extremes of matter called perfect liquids.

Cosmologists favor string theory because it makes dark energy's value less shocking. "Dark energy" is the generic term for whatever is making cosmic expansion accelerate, but theorists' calculations show that dark energy's influence should be more than 100 magnitudes greater than observations suggest — the largest discrepancy between theory and observation in all of science.

String theory could solve this problem if multiple universes exist. The theory implies the existence of 10^{500} different types of empty space, with different particles, forces, and amounts of dark energy allowed in each, Guth explains. If instead of just one, *every* one of these 10^{500} possible solutions is correct — meaning each solution matches a different universe that exists in a larger multiverse — then dark energy's value isn't weird at all. We just live in one of the universes where the amount of dark energy is what we measure it to be, a value particularly friendly to our existence.

These theoretical arguments do not constitute direct evidence for multiple universes. But such evidence might be found. The infinite, higher-dimensional multiverse (the cheese in the Swiss cheese) into which these bubble universes are born would expand faster than any of its individual bubbles, but if enough universes popped into being in this landscape, some of them might form close enough to collide with our own.

When Universes Collide

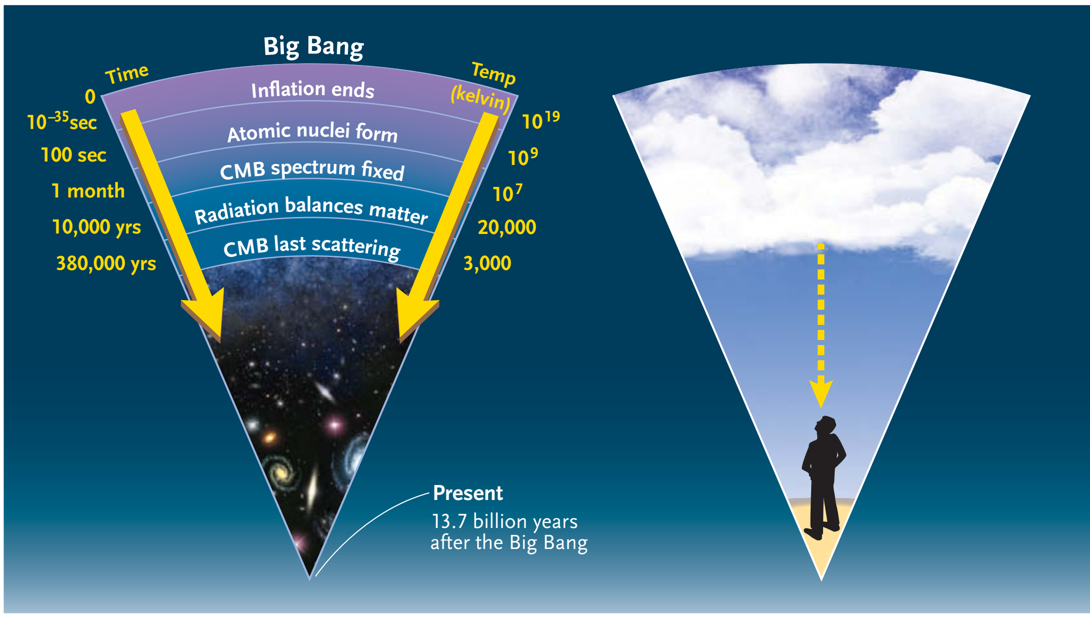
This collision could leave a temperature bruise in the CMB's mottled surface shaped like a faint, round disk. Such a disk would consist of photons that are slightly warmer (or cooler) than the surrounding CMB, anomalies that are even weaker than those that show up in the iconic map from NASA's Wilkinson Microwave Anisotropy Probe (WMAP). That's saying something, because the CMB's 2.7-kelvin temperature deviates by at most 0.0002 kelvin from one point to another across the entire sky.

To understand why a cosmic collision would create a disk in the microwave background, imagine a pocket universe forming so close to ours in the multiverse that it slammed into ours like one sumo wrestler ramming into another. This violent crash would glom the universes onto each other, just like two soap bubbles stuck together. (The bubbles never bounce.) In most cases a round, soap-membrane-like wall forms between the universes. This membrane rings from the smack, and the vibration creates a wake that propagates into both universes, says Matthew Kleban (New York University), who in 2009 collaborated on the first detailed predictions of a collision's effect on the microwave background.

Our universe expands rapidly while this wave propagates through it, which dilutes the wake's energy. But the wake is still distinct enough to alter the density of the part of our universe it passes through, much as sound waves change air's density as they move from a clashing cymbal to our ears. When the universe cools enough to release photons, the wake's effect on the early universe's density shows up as a subtle, round temperature anomaly in the CMB.

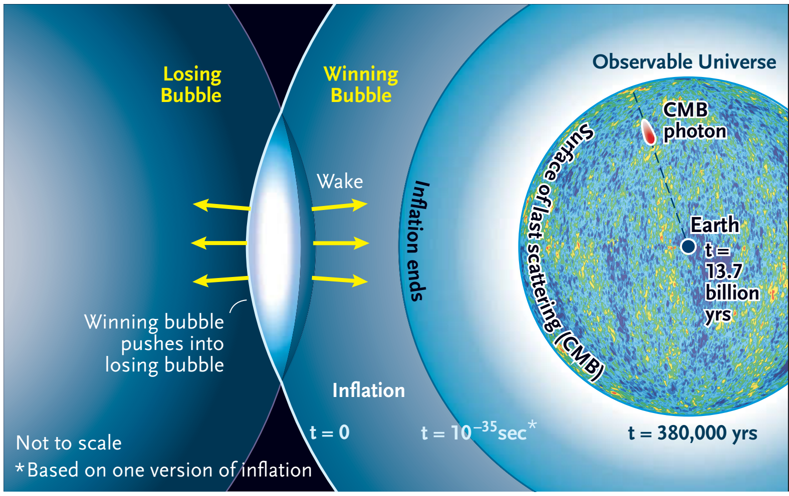
"MULTIVERSE?"

An infinite landscape of universes is a hard thing to imagine. Although the commonly cited name for this bubble-bath landscape is "multiverse," it's just as correct to think of it as a single universe that's not the same everywhere — a universe that has regions, or "pockets," vastly different from one another. Cosmologists adopted "multiverse" to make clear that this landscape is something far bigger and more exotic than the universe we normally talk about. (And besides, "universe" was already taken.)



The CMB's "surface" is somewhat like the light we see coming from a cloudy sky. When we look up at the clouds, we can only see the surface of the cloud off which light last scattered. Similarly, when WMAP observes the CMB sky, it looks back to a time in the universe when photons could scatter off free electrons.

SOURCE: NASA / WMAP SCIENCE TEAM. ILLUSTRATION: S&T: LEAH TISCIONE



S&T: LEAH TISCIONE

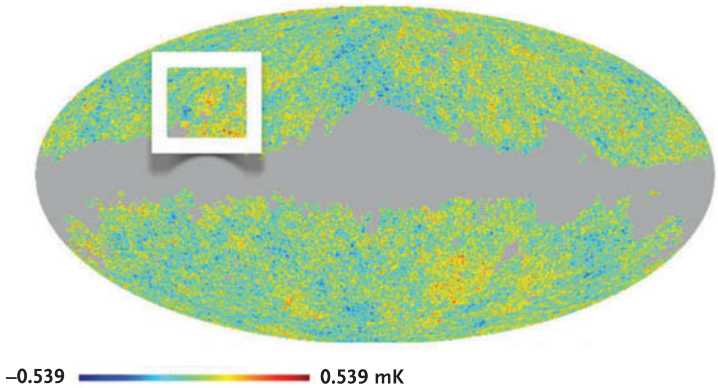
Colliding Universes

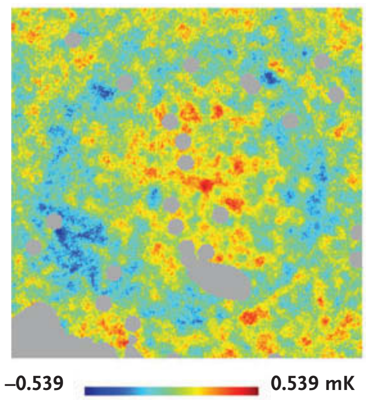
From our perspective, any collision between our universe and another universe has already happened. For us, our universe's wall is not a point in space, but in time — the Big Bang, when time began. Moving from Earth into the distant universe corresponds to moving backward in time, as though through a concentric series of shells. If another universe hit ours, the wake from that collision would have to pass through these shells as it entered the universe, moving through our universe's entire history before reaching us.

If our universe actually experienced fender-benders with other bubble universes, the number of bruises our microwave background sports from these crashes will never change; it'll be the same now as in the past and the future. That's basically because from our perspective any and every collision has already happened, explains Aguirre. They happened long before the CMB formed. From the inside, the bubble's wall doesn't correspond to a point in space. Rather, it's a point in time — the Big Bang, the moment when time began. Moving farther into the bubble (as seen from the outside) corresponds to moving forward in time (as seen from the inside).

In this scenario, different eras in the universe are like a series of concentric shells. The outermost is the Big Bang. Within that shell lie the shells that mark when inflation ended, when the universe became transparent to light, and so on. A collision's effects have to pass through these time shells to reach us. Therefore from the inside, no "new" collisions ever happen. Astronomers will never look at the CMB and say, "Gee, that spot wasn't there yesterday."

By the same reasoning, none of these collisions can ever harm us. As Aguirre notes, if we're here, we've already escaped the possible consequences.





This figure shows one version of what a cosmic collision's mark might look like: a round hot or cold spot hiding in the CMB. Matthew Johnson and his colleagues created this simulated cosmic bruise to confirm that their detective methods could find marks they had hidden in fake data before they tried studying the real microwave background.

STEPHEN M. FEENEY ET AL. / *PHYSICAL REVIEW D* 84, 043507 (2011), COPYRIGHT APS

Hunting for Marks on the Sky

Cosmologists hope to detect these weak bruises on the CMB. Yet no obvious round spots appear in WMAP data of the microwave background; even the infamous Cold Spot has been dismissed as a statistical blip.

"The patterns we're talking about are covered by all sorts of random fluctuations," Kleban says. "It's like trying to watch TV with tons of static."

"There's just too much data to directly test the hypothesis," adds Matthew Johnson (Perimeter Institute for Theoretical Physics, Canada). "The WMAP experiment has something like 3 million pixels, and to test this hypothesis you need to test the correlation between each pair of 3 million pixels — which is an astronomically huge number of computations. Even modern supercomputers can't do it."

So Johnson and his colleagues have started looking for filters to weed out the gold from the sand. These filters are unique tactics of information processing that look for a predicted signal in the noise. The danger with such filters is that you can't use the method unless you know what you're looking for (in other words, the filter is designed to look for a signal that matches your theory). Johnson's team double checks itself by calculating how likely it is that the collection of candidate spots are cosmic

bruises, given how the theory and data line up. If the probability is low, the candidates probably don't come from bubble collisions.

In companion papers published last year in two leading physics journals, Johnson and his colleagues described this self-check on their first generic filter attempt, called the *needlet filter* after the type of analysis performed. The initial run had found several anomalies in the WMAP 7-year results, but the self-check ruled out bubble collisions as the most likely explanation.

Other signals could corroborate collision candidates in the CMB. If a bulk flow of galaxies or a cosmic void lined up with these round spots, for example, that would be strong evidence in their favor. While suggestions of such phenomena have arisen, none has yet fully proven itself.

Toil and Trouble

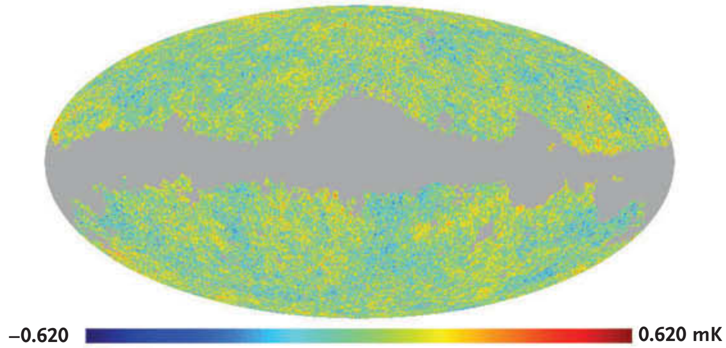
Even assuming that eternal inflation, bubble universes, and the multiverse exist, it's possible that bubbles don't form fast enough to smack into one another before the

> Imagine a pocket universe forming so close to ours in the multiverse that it slammed into ours like one sumo wrestler ramming into another. This violent crash would glom the universes onto each other.

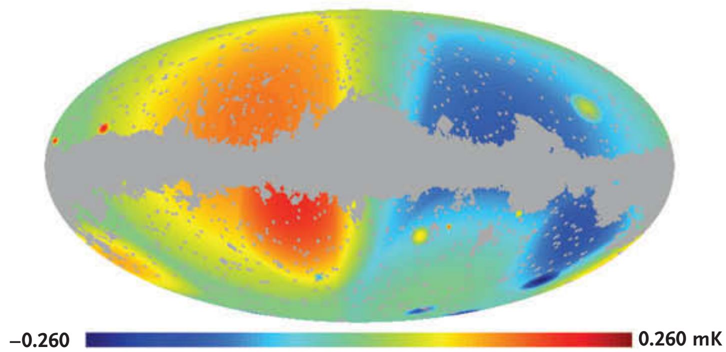
Undeterred, the group came up with a better algorithm specifically designed to look for bubble collisions. The algorithm uses so-called *optimal filters*, employed by various branches of physics and signal processing to detect compact objects hidden in a random background. Using this method, the team's initial results (before self-check) identified 16 candidate collisions, including all those originally found with the needlet method. The candidates range from 1.5° to 90° in angular radius. But the team hasn't run the self-check yet, so Johnson and his colleagues don't know how likely it is that the signatures are actually from cosmic smashups instead of mere statistical fluctuations.

The team is waiting on results from the European Space Agency's Planck spacecraft before it performs the double-check. Launched in 2009, Planck surveys both the temperature and polarization of the microwave background, working at an angular resolution roughly twice as fine as that of WMAP. Planck finished five full-sky surveys before its High Frequency Instrument ran out of coolant on January 14th this year. Its Low Frequency Instrument has continued working, adding data astronomers will use to improve calibration. ESA will release the first 15 months' worth of CMB data in early 2013, and the full data release will come in 2014.

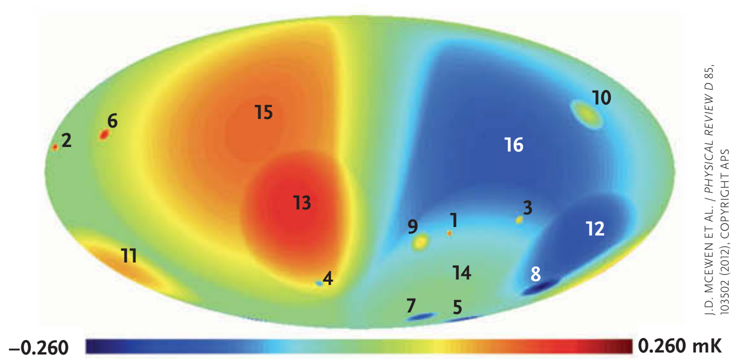
It's unclear whether Planck's instruments have high enough sensitivity to detect the signatures cosmologists hope to see. Nor is it clear whether anomalies could be confidently linked to collisions or still remain vague enough to leave a lot of doubt. "I think Planck could detect something that could be strong evidence of a bubble collision," Kleban says. "Whether everyone would then believe it, I don't know. You'd have to ask everybody."



WMAP 7-year observations (94 GHz)



Candidate bubble collisions (gray is the Milky Way)



Labeled candidate bubble collision signatures

J.D. MCEWEN ET AL. / *PHYSICAL REVIEW D* 85, 103502 (2012), COPYRIGHT APS

A preliminary analysis of the CMB using a special algorithm turned up 16 anomalies that might be from other universes colliding with our own. Cosmologists don't know yet whether bubble collisions are the best explanation for these anomalies.

larger multiverse's inflation carries each bubble away from every other one. So the violent-bubble-bath picture could be true, but we might never see a mark.

"It's very much verifiable, but it's not necessarily falsifiable," Johnson cautions. And if they never detect anything? "Then we're in murky waters," he says.

"I think the primary skepticism surrounds how likely we are to see" one of these collision marks, Kleban says. "And I share that concern. I would never bet any significant amount of money that we're going to detect it, because we have to be a bit lucky."

Nevertheless, bubble collisions offer the first real possibility of finding observational evidence for something that Aguirre says his colleagues generally labeled as "a relatively innocuous pastime that will probably turn up nothing interesting."

"Years ago," he says, "when people were talking about eternal inflation and the multiverse, it was easy to dismiss that as, 'Well, that's all fun but if we can't observe it why are we bothering to think about it? This is speculation, fantasy — maybe your models predict it, but who cares?'" With the chance to observe the aftermath of a cosmic crash, bubble cosmology rises above the accusation of not being real science. Uncovering that aftermath would be a game-changing discovery.

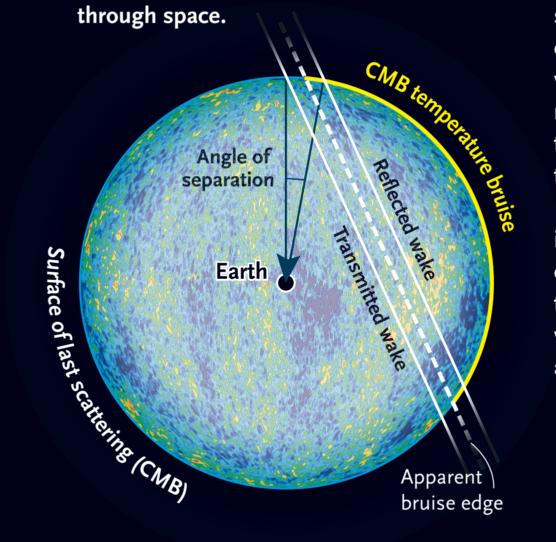
There's also the chance that, even if cosmologists never find a CMB bruise, they'll find something else they weren't looking for. They'd be in good company: science often advances through serendipity as much as through slogging along.

"The odds are high that I'll be disappointed and we won't find these things," Kleban says. "But it's always worth pursuing these avenues, because you never really know what's there until you do." ✦

Assistant editor ***Camille M. Carlisle*** *is a fond denizen of our cozy little cosmos and, frankly, plans to keep her sights within its confines until evidence demands otherwise.*

Rings Around the Rosies

COSMIC PUNCHES from other universes could leave a second kind of bruise in the cosmic microwave background. But this second bruise wouldn't be in the microwave background's temperature. It would show up as a unique pattern in the way the CMB's light vibrates as it propagates through space.



S&T: LEAH TISCIONE

If a wake from a universe collision traveled through the universe, it would tweak the universe's matter density where it passed. The odd thing about these density blips is that they come in pairs. A sound wave hitting a lake's surface changes speed as it passes from air to water, because sound travels at different speeds in different media. But not all the sound hitting the water's surface passes through. Some of it reflects. The result is two acoustic waves for the price of one, with one going forward and the other backward.

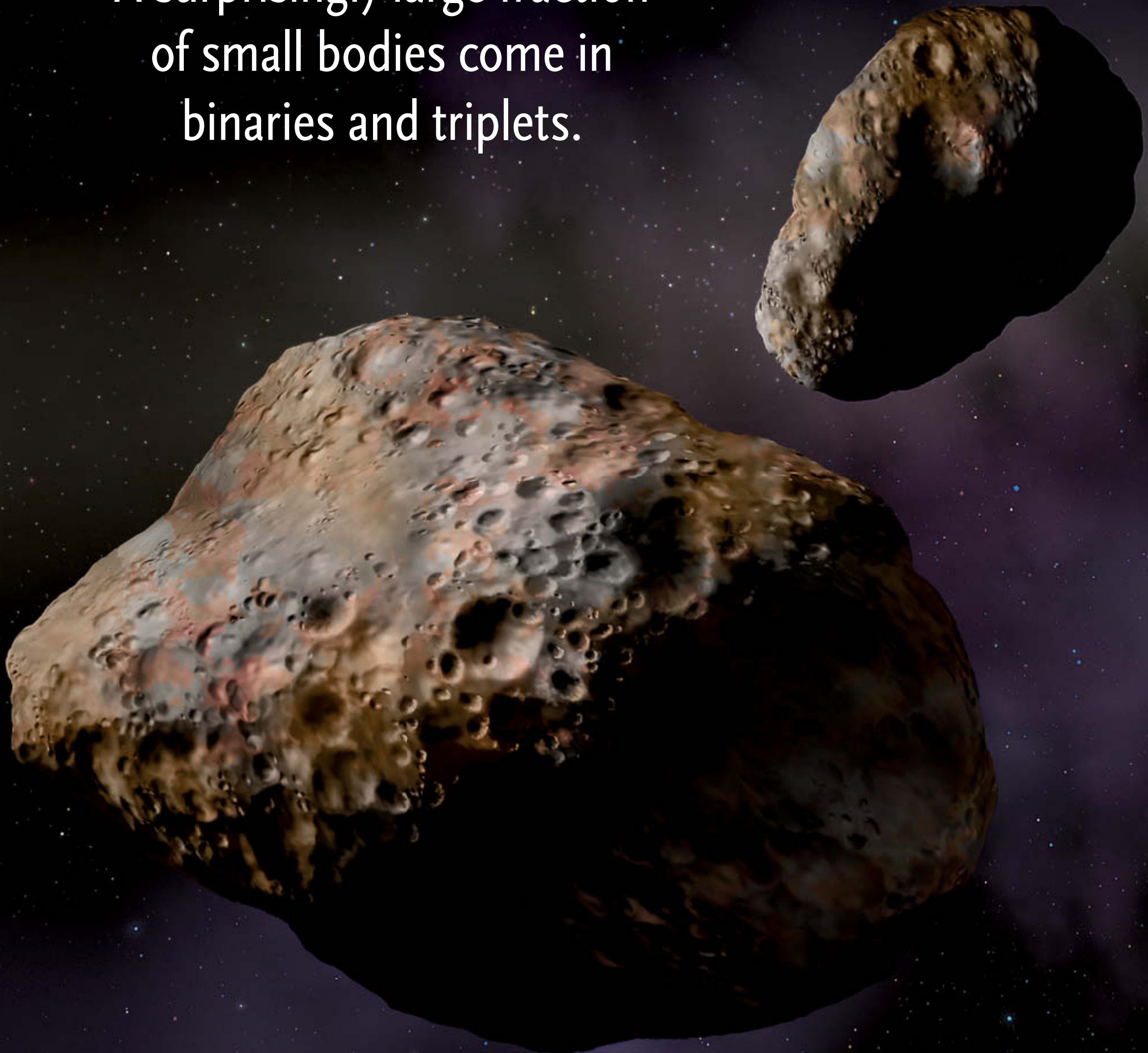
Two waves will also arise in an expanding universe if the speed of sound changes everywhere in space at roughly the same time, says Matthew Kleban. That's just what happened when the universe thinned and cooled from a fireball soup to a near-vacuum. The cosmic wake is a pressure wave, like a sound wave. So when matter took over in the universe, this wave split into a reflected part and a transmitted part, leaving behind two density blips instead of one. When the photons fly soon after, they scatter off both blips.

This scattering *polarizes* the CMB photons, making their wavelengths wiggle in certain directions in a specific way. If the temperature bruise is about 12° across or larger, the polarization signal will appear as two rings, one inside the temperature bruise, the other outside. If observers can detect polarization signatures that match up with a temperature disk in the CMB, that would give cosmologists far more confidence that they've actually found a bruise from a colliding universe.

This cutaway shows the transmitted and reflected wakes from a bubble collision. Sliding the set of wake-bruise-wake slices nearer and farther from Earth corresponds to larger and smaller temperature marks on the CMB, respectively. When the slices lie closer to the sphere's edge, the apparent angle of separation between the wakes grows larger, but it's never more than a couple of degrees.

Why Do Asteroids

A surprisingly large fraction of small bodies come in binaries and triplets.



LYNETTE COOK / W. M. KECK OBSERVATORY

Come in Pairs?

Michael Shepard

In 1977, Johns Hopkins University astronomer David Dunham organized a group of amateurs and professionals to observe a star occulting the asteroid 6 Hebe. The asteroid's shadow passed through central Mexico, where three observers witnessed the star briefly flicker out. But experienced Texas amateur Paul Maley visually observed a 0.5-second occultation at the same time — some 500 miles north of the other observers. Was this evidence for an asteroid satellite? Unfortunately, researchers had no way to confirm Maley's sighting.

Over the next 15 years observers found hints of binary asteroids in other occultations, odd light curves, and radar echoes, but nothing could be confirmed. All of the speculation became moot on August 28, 1993. On that day, NASA's Galileo spacecraft flew by asteroid 243 Ida en route to Jupiter and made a profound discovery — a tiny moon later named Dactyl (last month's issue, page 28).

Up to then, astronomers had discovered more than 10,000 asteroids using ground-based telescopes. None were known to have companions and only a few were suspected to have one. Now, after two asteroid flybys (Galileo flew past 951 Gaspra in 1991), one was discovered to have a moon. Which of these statistics reflected the true nature of asteroids? Were binaries a few in 10,000, or one in two?

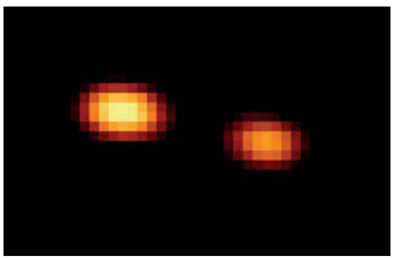
Opening the Floodgates

Within months of Dactyl's discovery, planetary astronomers began to report more evidence of asteroid satellites. Most were orbiting near-Earth asteroids (NEAs), tiny objects only a few kilometers wide that cross the orbits of the inner planets. The companions were suggested in high-quality light curves that could only be explained if there were two objects orbiting each other. At least one was spotted when one member eclipsed its partner, just like an eclipsing binary star.

By 2000 two new techniques for binary discoveries became mainstream and important: adaptive optics (AO) and radar. Large telescopes fitted with AO to beat atmospheric distortion could now resolve asteroid companions (the Hubble Space Telescope could also accomplish this feat). Using the 3.6-meter Canada-France-Hawaii Telescope, William Merline (Southwest Research Institute) and his colleagues discovered the first asteroid satellite with AO in 1999 when they found that 45 Eugenia was orbited by a small moon now known as Petit-Prince. Likewise, the newly upgraded Arecibo radio telescope in Puerto Rico could use radar echoes to produce high-resolution asteroid images. The first radar binary discovered was the near-Earth asteroid (185851) 2000 DP_{107}.

In 2005 planetary scientists received another pleasant surprise when Franck Marchis (University of California, Berkeley) and his colleagues found a triple asteroid, the large main-belt asteroid 87 Sylvia. The primary body had two small companions — later named Romulus and Remus for the mythical founders of Rome (Sylvia was their mother). And in 2008, astronomers using Arecibo discovered the first triple near-Earth asteroid, 2001 SN_{263}. The discovery floodgates had opened.

This brief history lesson would be incomplete without mentioning the other main reservoir of binary "asteroids" — the Kuiper Belt. Technically, the first discovery in this region was that of Pluto's moon Charon in 1978. Because



FRANCK MARCHIS ET AL. / *NATURE*

BINARY ASTEROID ***Opposite page*: This artist rendition depicts the binary Trojan asteroid 617 Patroclus, which trails Jupiter by 60° in the planet's orbit around the Sun. *Near left:* Using the laser-guide-star adaptive optics system on the 10-meter Keck II telescope, astronomers have taken images showing that Patroclus actually consists of two bodies nearly equal in size, making it a true binary-asteroid system. The larger object (Patroclus) is about 122 kilometers (76 miles) across and the smaller body (now named Menoetius) is 112 km across. They orbit a common center of mass every 4.3 days at an average distance of 680 km. The two binary members might have originated from a single body that was tidally ripped apart during a close pass of Jupiter billions of years ago.**

SMOKING GUN After NASA's Galileo spacecraft took this image of 243 Ida and its small moon (later named Dactyl) in August 1993, nobody could deny that at least some asteroids have satellites.

NASA / JPL

S&T: LEAH TISCIONE; SOURCE: IOTA

ASTEROID OCCULTATION On March 5, 1977, three amateur astronomers along a path that crossed through Mexico witnessed asteroid 6 Hebe briefly occult a star. Amateur Paul Maley in Texas witnessed the star blink out for half a second. This was tantalizing evidence for a moon, but its existence remains unconfirmed.

Pluto was considered a major planet until 2006, the distinction of the first official Kuiper Belt binary belongs to 1998 WW_{31}, announced in 2001, also found with AO. Since then, more than 70 Kuiper Belt binaries have been reported.

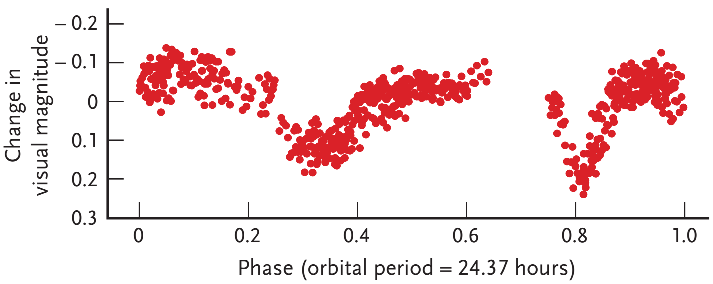
Classifying the Zoo Animals

After the discovery of 1 Ceres in 1801, it took nearly 200 years to find the first binary asteroid. In the past 19 years, scientists have discovered some 200 more. The main belt and Kuiper Belt account for nearly 80% of these, and the bulk of those remaining are found among the NEAs. We're now at the stage where we can classify binary systems.

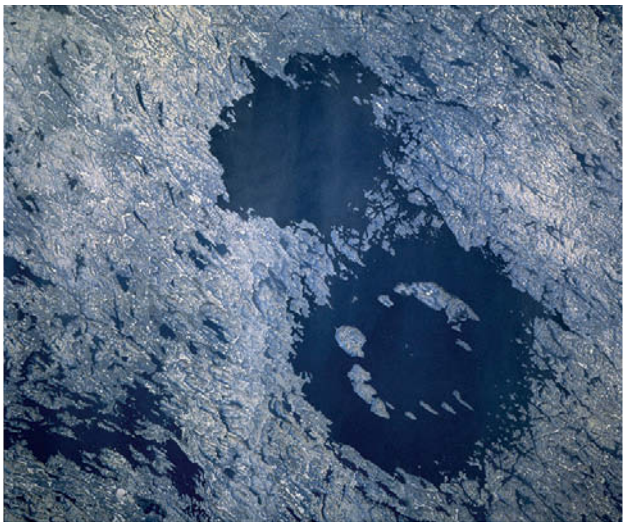
Planetary scientists estimate that 15% of near-Earth asteroids are binaries or higher-order multiples. Most primaries are small, with diameters less than 10 km, and they rotate rapidly, usually once every two to four hours. The primaries are nearly spherical, sometimes with an equatorial ridge, and their secondaries are considerably smaller. Planetary scientists report the relative sizes of the two components as a ratio of diameters, D_s/D_p, where "s" refers to the secondary and "p" refers to the primary. In the NEA population, the diameter ratio is usually less than 0.5, meaning the secondary is 50% the primary's diameter or smaller. The classic example of this group is 1999 KW_4, with $D_s/D_p = 0.34$.

Main-belt binaries fall into two camps. Those with primaries smaller than 10 km in diameter have properties similar to the NEA binaries and are found in similar abundances, about 15%. Those with primaries much larger than 10 km are less common — only a few percent — and most have D_s/D_p ratios of less than 0.1. Ida-Dactyl is a quintessential member of this group ($D_s/D_p = 0.04$). These systems have no particular pattern of shape or rotation rate.

Because Kuiper Belt objects are so far away, we can only see bodies 100 km or larger. Of those binaries discovered, the companions are almost always comparable in



TELLTALE LIGHT CURVE Colorado astronomer Brian Warner monitors the brightness of main-belt asteroid 5477 Holmes. He compiled his data into this light curve, which clearly shows brightness dips as the two asteroids periodically eclipse each other as they orbit a common center of gravity every 24.37 hours.



NASA

DOUBLE WHAMMY For decades, many scientists thought the Clearwater Lakes in northern Québec resulted from the impact of a binary asteroid about 290 million years ago. The recent discovery that binary asteroids are common strongly supports this view. The larger of the lakes is 36 km (22 miles) across.

For links to sites with further information and images about asteroid and their companions, visit skypub.com/asteroidmoons.

size to the primary. A good example is 1998 WW_{31}, with a 130-km primary and a 110-km secondary ($D_s/D_p = 0.85$). The asteroid 617 Patroclus/Menoetius ($D_s/D_p = 0.92$), one of only four known binaries in the Trojan population (orbiting the Sun 60° ahead of or behind Jupiter), is also this type. When there are exceptions in the outer solar system — such as Pluto's four smallest moons — they tend to be much smaller than their primary, similar to the main-belt binaries with large primaries.

About 10 to 15% of Kuiper Belt objects are binaries, but they are oddly distributed. The Kuiper Belt has three distinct populations: the "cold classical" belt, a group of objects that have nearly circular and low-inclination orbits (within a few degrees of the ecliptic plane); the "hot classical" belt, objects with near-circular orbits, but inclined more than 6° or so to the ecliptic plane (the boundary is debated); and the "scattered disk," a population with far more eccentric and inclined orbits. Oddly, nearly half the objects in the cold classical Kuiper Belt are binary, whereas the ratio in the other two groups is less than 10%.

What Does This All Mean?

1. Asteroids Are Sandbags, Not Solid Rocks.

One of the beauties of a binary is that it allows astronomers to use Newton's Law to measure a system's mass and, with a few assumptions, estimate its bulk density. Most asteroids measured have bulk densities lower than solid rock — some as low as 1 gram/cm^3, the same as water. This means that the majority of asteroids are highly porous. The current consensus is that most asteroids were completely shattered by large impacts and later reassembled into rubble piles. This finding has two consequences — one for the way in which small binary asteroids form, and another for mitigating the threat of an asteroid impact. Rubble piles, like sandbags, absorb energy differently than solid objects, so the Hollywood version of deflecting a killer asteroid by detonating a nuclear bomb on or near it might not work. We have to rethink deflection strategies (*S&T:* December 2010, page 22).

2. Several Different Mechanisms Make Binaries.

The earliest hypothesis for binary formation assumed most were created by impact — just like our Moon. We know impacts were common in the early solar system, and presumably they're still occurring in the main belt. When scientists attempt to model binary formation with impacts, they can readily create binaries such as the Ida-Dactyl pair, but they have difficulty reproducing the other common types, especially the NEA systems. In the rarified Kuiper Belt, the opportunities for collisions are far less frequent and impacts appear unlikely to produce the many large, equal-sized pairs. Pluto's five known moons,

WHAT'S A BINARY?

A binary is any separated pair of mutually orbiting objects. If two bodies are physically joined at a small point or neck, we call it a *contact binary*. If the center of mass of the two asteroids (the barycenter) is inside the larger asteroid, it's called the primary and the other can rightly be called a moon, moonlet, or, less romantically, a secondary. If the barycenter is outside both objects, it's more appropriate to stick with the generic terms "primary" for the larger of the pair and "secondary" for the smaller body.

CONTACT BINARY? Japan's Hayabusa spacecraft returned this picture in 2005 of the near-Earth asteroid 25143 Itokawa. It looks like a single body, but it could be a contact binary — an asteroid consisting of two unequal-size objects that joined together in a relatively gentle collision.

JAXA

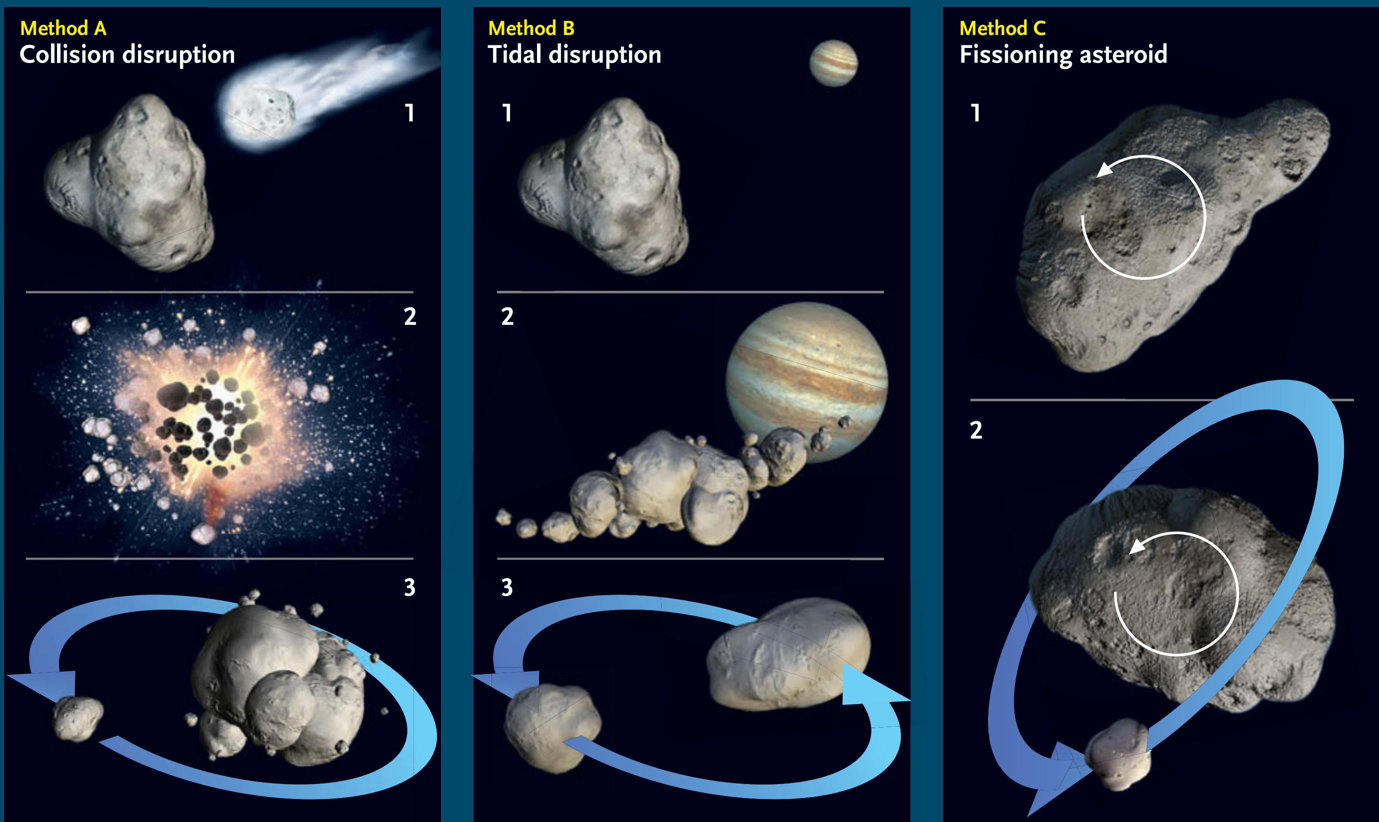
however, appear to be the result of an impact, perhaps a smaller-scale version of the one that formed our Moon.

Another hypothesis for binary formation invokes tidal disruption of an asteroid during a planetary close approach, somewhat analogous to Jupiter pulling apart Comet Shoemaker-Levy 9. But models suggest that this process could only form a tenth of the near-Earth binaries we see. It's also unlikely to be important in the main belt or Kuiper Belt, where encounters with large planets are rare or nonexistent.

In 2000 David Rubincam (NASA/Goddard Space Flight Center) suggested that sunlight could create small binaries. Asteroids absorb sunlight, heat up, and then radiate that heat into space as infrared light. Because asteroids are never perfect spheres, they always radiate slightly more in one direction than another, imparting a mild torque. Depending upon the initial spin direction, this torque will either slow the rotation and eventually reverse its direction, or it will speed it up so high that a rubble-pile asteroid will fission, forming a binary.

This spin-up process is called the *YORP effect* (for Ivan Yarkovsky, John O'Keefe, Vladimir Radzievsky, and Stephen Paddack). It works best on small asteroids; the spin-up rate is inversely proportional to the square of the asteroid size, so a 2-km-wide asteroid will spin up four times faster than a 4-km asteroid. It also takes awhile to act. Given an NEA's typical 10-million-year lifetime, it's only expected to work on asteroids smaller than 10 km. But everything we now know about the near-Earth and small main-belt binaries — their size and shape, rubble-pile nature, and rapid rotation — suggests that YORP is the main formation mechanism.

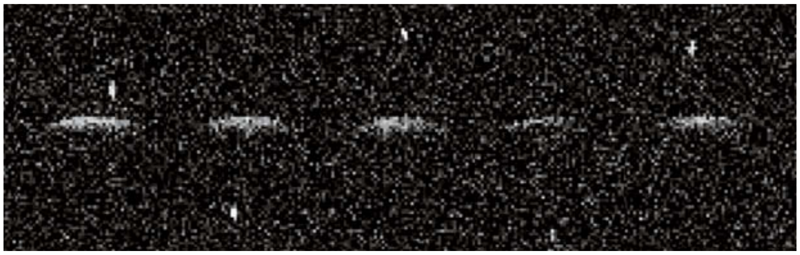
Three Methods of Binary Asteroid Formation



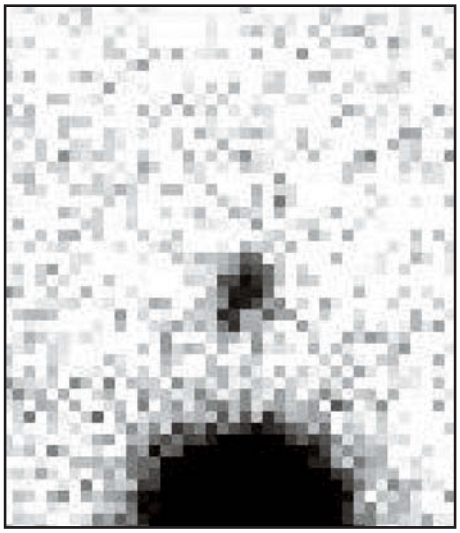
Diagrams not to scale

S&T: LEAH TISCIONE

FORMATION MECHANISMS Asteroid satellites probably form by a variety of mechanisms, three of which are illustrated above. *Left:* A satellite can form when an impact smashes fragments off of a large asteroid. Some of these shards eventually coalesce into a small satellite. *Center:* A moon can form when a low-density asteroid (a rubble pile) ventures too close to a planet and is tidally shredded into many smaller fragments, which can later reassemble gravitationally into more than one body. *Right:* An asteroid moon can form when the YORP effect spins up a rubble pile past its breaking point, allowing a small piece to break off. Collisions and fissioning events are more common in the inner solar system. Comet Shoemaker-Levy 9 was tidally disrupted, but this process occurs infrequently. Most Kuiper Belt binaries are probably primordial.



J.-L. MARGOT / CORNELL UNIV. / *SCIENCE*



CHRISTIAN VEILLET / CFHT

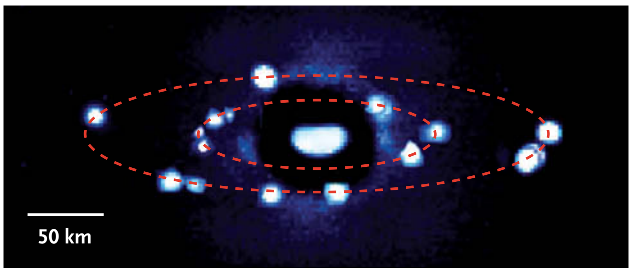
BINARIES EVERYWHERE ***Above:*** **This sequence of Arecibo radar images provided conclusive evidence that near-Earth asteroids have satellites. The images show a small object orbiting 2000 DP$_{107}$ once every 1.76 days. The two objects are about 800 and 300 meters across, respectively. The primary's size and elongation appear exaggerated due to its rapid rotation. The satellite probably broke off due to the YORP effect.** ***Right:*** **This 2000 image from the Canada-France-Hawaii Telescope shows that the Kuiper Belt object 1998 WW$_{31}$ is a binary. The primary is about 20% larger than the secondary, and the two orbit a center of gravity every 570 days. The Pluto-Charon system was actually the first known Kuiper Belt binary.**

3. Some Binaries May Be Primordial.

The Kuiper Belt binaries are dominated by large, roughly equal-sized pairs. At 40 or more astronomical units from the Sun and with diameters of hundreds of kilometers, these objects are unaffected by YORP. And as noted earlier, impacts are extremely rare in this vast region of space, at least today.

So what's left? Recent solar system formation models, and the unusually high percentage of binaries found in the cold classical Kuiper Belt, suggest they are primordial. The early Kuiper Belt probably contained a few hundred times more mass than it does today and mechanisms such as gravitational capture, impact, or some hybrid process may have been far more common. The original Kuiper Belt may have assembled much closer to the Sun and been full of binaries. But the proposed early outward migration of Saturn, Uranus, and Neptune (*S&T:* September 2007, page 22) disrupted most of these pairings. Only the cold classical belt was left relatively unscathed and still preserves that early primordial binary proportion.

No matter how a binary forms, the story doesn't end there, particularly for those that may have been created by YORP. The angular momentum of a fissioning system undergoes wild changes and is initially unstable. Tidal stresses between a primary and its secondary become important. And it appears that another sunlight-related effect, called *Binary YORP* (BYORP), also comes into play. Here, the asymmetric torques affect the system as a whole, leading to three possible end states: a long-lived, stable binary system; an escape leading to two asteroids sharing the same heliocentric orbit, but not mutually orbiting each other; or a gentle collision resulting in a contact binary, probably resembling 25143 Itokawa (recently visited by Japan's Hayabusa spacecraft).



ESO

THE FIRST KNOWN TRIPLE **Using the European Southern Observatory's Very Large Telescope in Chile, astronomers discovered in 2005 that the 286-km-wide main-belt asteroid 87 Sylvia has two orbiting companions. This composite image, taken over 9 nights, shows the outer moon Romulus (18 km across) and the inner moon Remus (7 km).**

We're Just at the Beginning

The current picture is certain to be refined or even overturned as astronomers discover more binaries and planetary scientists piece it all together. But we're only 20 years into this new field, and this is one area where amateurs with modest telescopes, CCD cameras, and careful observing habits can play an enormously important role (*S&T:* October 2010, page 60).

Although the Kuiper Belt remains out of reach for anyone without access to meter-scale telescopes, the near-Earth, main-belt, and Jupiter Trojan populations are readily accessible to today's amateurs. A number of dedicated observers around the world collect asteroid light curves and search for new binaries (see **http://MinorPlanet.info** for more information). A slew of professional papers on binary discoveries in the near-Earth and main-belt populations include amateur coauthors. Indeed, this work wouldn't be possible without them. ✦

Michael Shepard *is a Professor of Geosciences at Bloomsburg University of Pennsylvania. He regularly uses the Arecibo radar system to study asteroids in the main-belt and near-Earth populations.*

Changing Times for U.S. Astronomy

J. Kelly Beatty

The budgetary writing is on the wall: the National Science Foundation doesn't have enough money both to operate all of its existing facilities and to build big, expensive new ones.

A telling moment for the future of U.S. astronomy came last October. That's when James Ulvestad, who heads the astronomy division of the National Science Foundation (NSF), delivered a bleak budgetary forecast. Federal funding for the country's national observatories, and for the community that depends on them, was declining — with no real prospect for a short-term rebound.

Everyone in the NSF's advisory committee knew what that meant. Just a year before, a 324-page road map (titled *New Worlds, New Horizons in Astronomy and Astrophysics*) had put forward a vision for astrophysics in the coming decade that would maintain and extend U.S. leadership in space- and ground-based astronomy. But to attain even some of those goals with a reduced budget, astronomers would need to tighten their collective belts elsewhere.

Now we know how those cuts will likely occur: by cutting off funding for six existing facilities, some of which are still producing cutting-edge science.

In August a 17-member task force, led by Harvard cosmologist Daniel Eisenstein, released its analysis of what the NSF can likely afford in the years ahead — not only the construction and operation of facilities at the four U.S. national observatories (listed on page 35) but also the money needed for investigator grants, new instrumentation, and other capabilities. Eisenstein's group wasn't allowed to second-guess the scientific objectives spelled out in *NWNH*. Instead, it had to figure out how to achieve those objectives, and then optimize the NSF's investments accordingly beginning with the fiscal 2017 budget.

The reality is that the landscape for observational astronomy is changing rapidly. During the 1950s and early 1960s, establishment of the National Optical Astronomy Observatory (NOAO) in Tucson, Arizona, and construction of several observatories on nearby Kitt Peak, finally gave all U.S. astronomers dependable access to first-rate telescopes. This model was eventually expanded to the solar and radio

FUTURE SKY SENTINEL The Large Synoptic Survey Telescope is a planned 8.4-meter telescope capable of photographing the entire sky twice each week. If funding is approved, project managers hope to begin full operations within a decade.
LSST CORPORATION

domains, and it worked well through the 1990s. But the soaring cost of today's superscopes has required partnerships not just between major universities but also among multiple countries.

Staying Competitive, Staying Alive

Even as construction bills continue to pile up for the billion-dollar Atacama Large Millimeter/submillimeter Array (ALMA) in Chile and the Advanced Technology Solar Telescope (ATST) in Hawaii, U.S. astronomers are dreaming about the Large Synoptic Survey Telescope (LSST) and the proposed Cerro Chajnantor Atacama Telescope (CCAT), which aren't even in the NSF budget yet. But they likely will be soon, so to create some budgetary breathing room, Eisenstein and his committee prioritized NSF's astronomy assets with an eye toward identifying existing facilities that could — and should — be "divested" by 2017.

"It's a very sobering thing to look at the budget," observes Eisenstein. "When it drops by 20%, that's going to cause reductions — and ultimately many peoples' jobs." With that in mind (and following *NWNH*'s lead), the committee recommends a strong commitment to continued NSF funding of grants to individual investigators and to instruments, surveys, and experiments.

The committee's portfolio includes continued funding of ALMA, ATST, the Very Large Array, Arecibo, the twin 8.1-meter Gemini telescopes, and NOAO's two 4-meter telescopes in Chile. The committee also urged that the construction of the LSST start as soon as possible.

With all that on the table, something had to give. Eisenstein's committee felt NSF should end support for three optical telescopes on Kitt Peak, as well as the nearby McMath-Pierce Solar Telescope, the Green Bank Telescope in West Virginia, and the globe-spanning Very Long Baseline Array.

Understandably, many astronomers are shocked and saddened by the committee's choices. While the McMath solar telescope was to be phased out anyway (though not so soon) to make way for ATST, seeing the Green Bank Telescope on the list was unexpected. After all, it's the largest fully steerable radio antenna in the world — and it's only 12 years old. Managers of the GBT and the VLBA countered that both have "crucial capabilities that cannot be provided by other facilities."

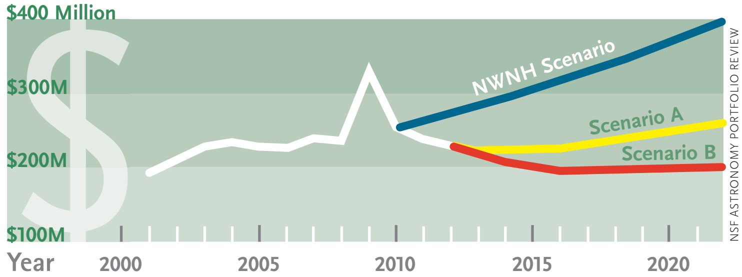
The potential loss of the three reflectors on Kitt Peak, with apertures of 2, 3½, and 4 meters, poses a different kind of problem, making it harder for young postdocs and graduate students to get real-world observing experience.

Timothy Beers, who took over as Kitt Peak's director only last year, is disappointed — and puzzled — by the NSF report. "They're going to trade away 700 to 1,000 observing nights per year to liberate funds for future projects, and that is a real change of pace." But he remains optimistic that the summit's big eyes will carry on in some capacity. "We're not planning on closing Kitt Peak National Observatory but rather to reconfigure it," he explains.

We have not heard the last of this emotional debate. Larger forces — within the NSF, the president's administration, and the Congress — will dictate the final outcome. "This is the start of a very long process," Ulvestad says, "and I can't predict where it's going." ✦

Senior contributing editor ***Kelly Beatty*** *notes that the panel's full report, titled* Advancing Astronomy in the Coming Decade: Opportunities and Challenges, *can be downloaded for free at* **www.skypub.com/nsf_review**.

NSF's Astronomy Purchasing Power



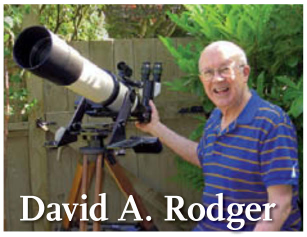
FACING CLOSURE? ***Top:*** **After many years of steady growth, boosted by stimulus funding in 2009, NSF's astronomy budget has declined recently — and might shrink further. The authors of the** ***New Worlds, New Horizons*** **decadal survey envisioned an almost doubled budget by 2022 (blue line). More realistic are the optimistic (yellow) and pessimistic (red) scenarios. (Dollars adjusted to fiscal year 2011.)** ***Bottom, left to right*****: The Robert C. Byrd Green Bank Telescope, the 4-meter Mayall Telescope, and the 3.5-meter WIYN Telescope might lose NSF funding by 2017.**

U.S. National Observatories

The NSF underwrites four federally funded facilities that provide unrestricted access to all U.S. astronomers:

- **National Optical Astronomy Observatory** oversees several optical telescopes atop Kitt Peak in Arizona as well as Cerro Tololo Inter-American Observatory and the SOAR Telescope in Chile *(NSF budget in fiscal 2012: $26.1 million)*.
- **National Solar Observatory** manages big Sun-watching telescopes on Kitt Peak and on Sacramento Peak in New Mexico, as well as the forthcoming Advanced Technology Solar Telescope in Hawaii *($11.1 million)*.
- **National Radio Astronomy Observatory** is responsible for the massive Green Bank Telescope, as well as the Very Large Array and Very Long Baseline Array; it also operates ALMA in partnership with other nations *($71.7 million)*.
- **Arecibo Observatory** in Puerto Rico is the world's largest and most sensitive radio telescope *($5.5 million)*.

Exploring Those Odd-Named Star Clusters



Collinder, Stock, Trumpler — open clusters with no Messier or NGC number can be surprisingly bright and easy.

PEOPLE LOVE LISTS! Whether it's top-scoring ballplayers, best-selling books, or Colorado's best ski resorts, everybody loves lists. Astronomers aren't immune to listmania either.

Credit Charles Messier with starting the fad in the late 18th century. Working through his list of "not comets" — 109 or 110 star clusters, galaxies, and nebulae — is a rite of passage for today's amateur astronomers.

After completing the Messiers, many amateur astronomers move on to other lists, such as the Herschel 400 — a selection of the best objects observed by William Herschel (1738–1822) — or even Herschel's full, 2,500-object catalog (August issue, page 60).

Herschel's designations rarely appear on modern star charts, because his discoveries were subsumed into the monumental *New General Catalogue* (NGC) in 1888. Together with the supplemental *Index Catalogues* (IC), these include most of the objects observed by amateur astronomers today.

Many of the biggest star atlases also show objects from other catalogs such as the *Uppsala General Catalogue of Galaxies* (UGC), or the *Catalogue of Galactic Planetary Nebulae* (P-K or PN) compiled by Czech astronomers Luboš Perek and Luboš Kohoutek. Most of these are challenge objects, visible only through big telescopes under pristine dark skies.

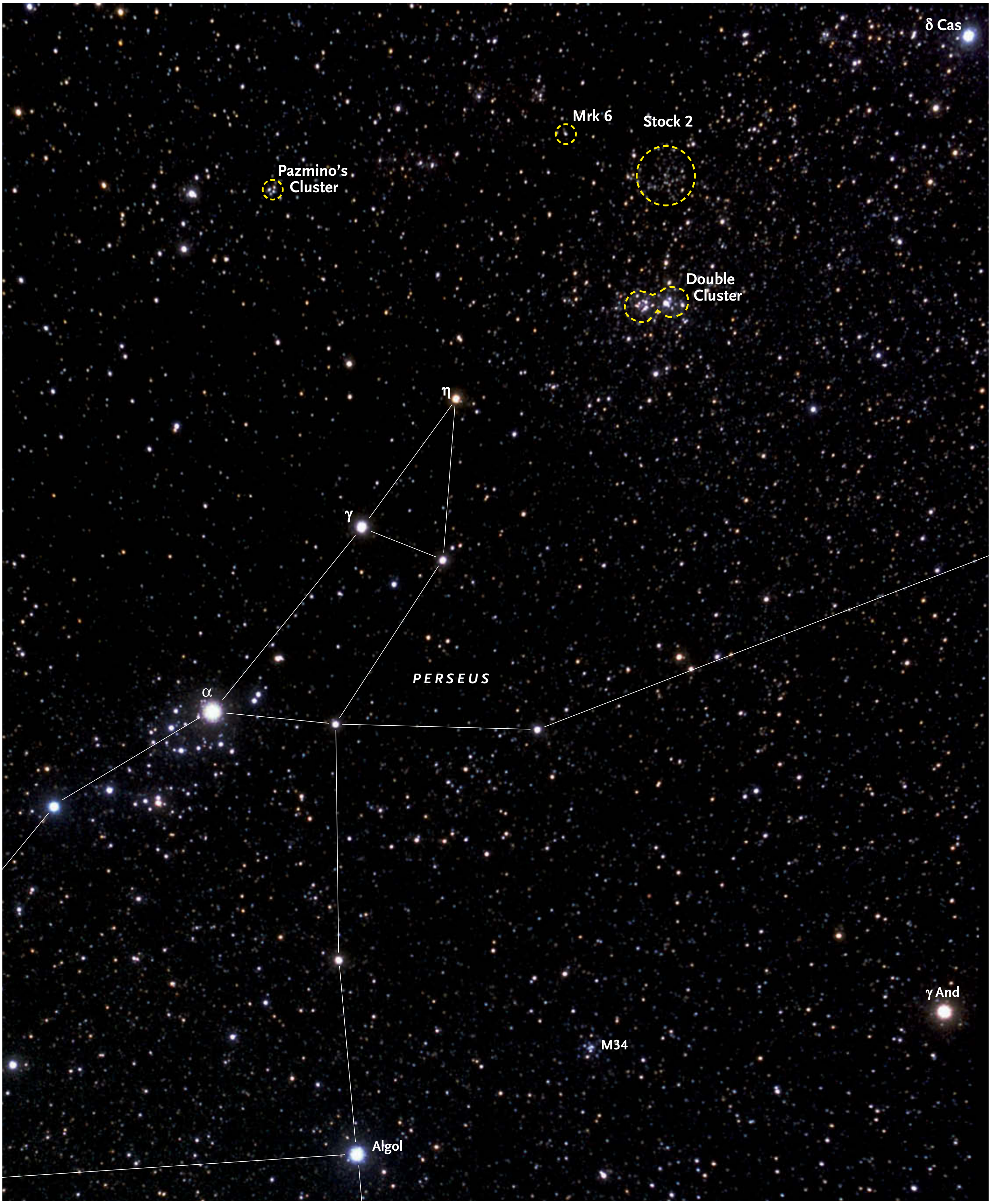
Above: The author at home with his 5-inch altazimuth refractor, "Capella."

But even simple charts such as the ones in *Sky & Telescope*'s *Pocket Sky Atlas* show many open star clusters labeled with designations such as Stock, Tr, Cr, and Mrk. Ever wonder about those?

These clusters were generally omitted from the NGC and IC not because they're too faint, but because they're too big, sparse, or scattered to stand out in the long-focus scopes and narrow-field eyepieces generally used by the NGC contributors. Many of these clusters are best observed through small, wide-field telescopes or even binoculars. And unlike galaxies and nebulae, they tend to stand up well to light pollution.

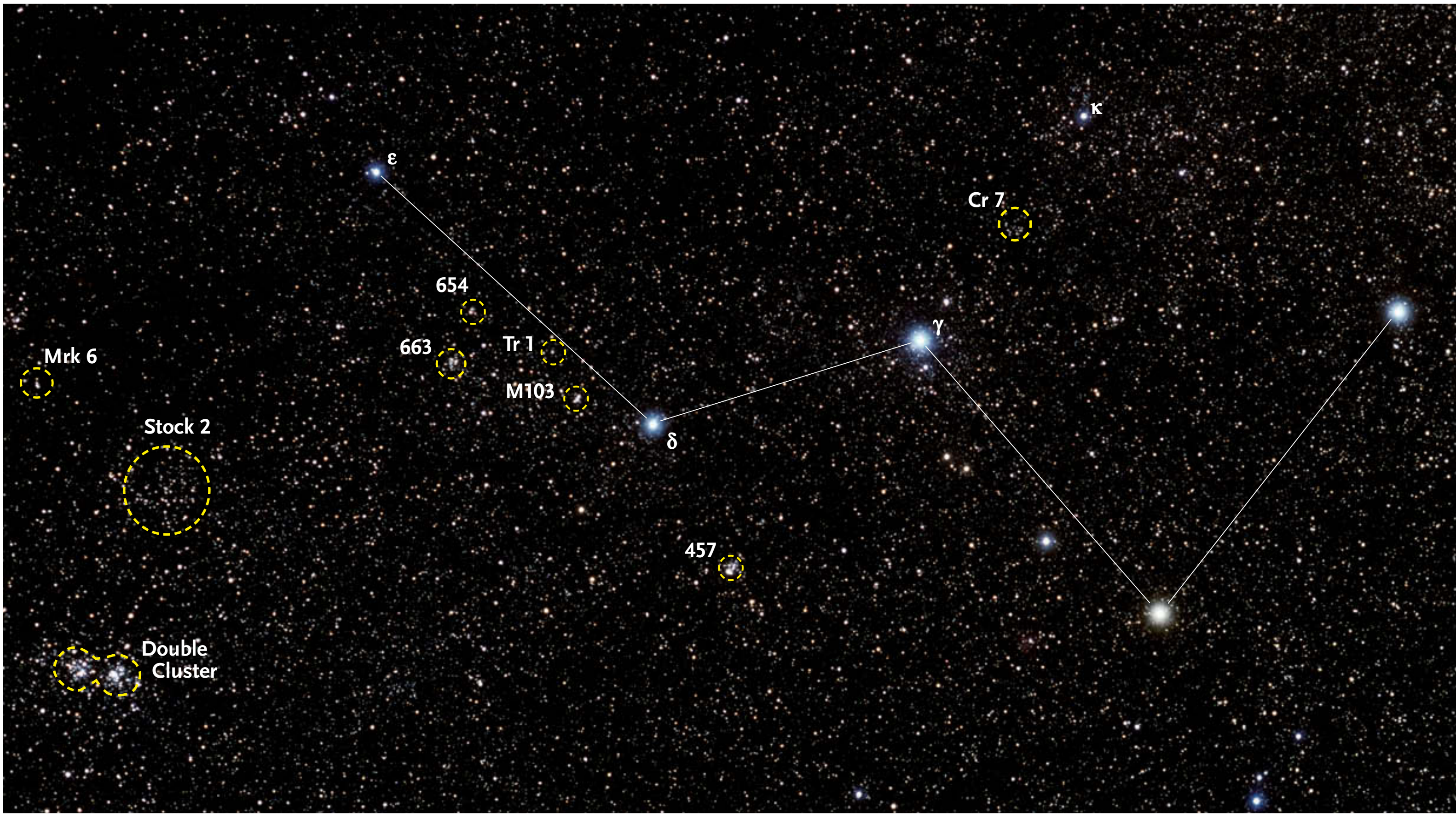
Let's take a look at the people behind these star cluster designations and why they compiled their catalogs.

Jürgen Stock (1923–2004) was born in Germany but compiled his list of 25 clusters while based at Case Western Reserve University in Cleveland, Ohio, in the early 1950s. He discovered (or at least first described) all 25. Most are faint and generally lacking visual appeal, so that only a few of them are plotted on familiar star atlases. But all can be observed in amateur telescopes. Look along the Milky Way for Stock clusters, particularly in Cassiopeia, Perseus, Camelopardalis, and Cygnus. Stock clusters tend to be large in area but sparse in members.



AKIRA FUJII

The Double Cluster in Perseus is just the starting point of a hunt for non-Messier, non-NGC star clusters in the area.



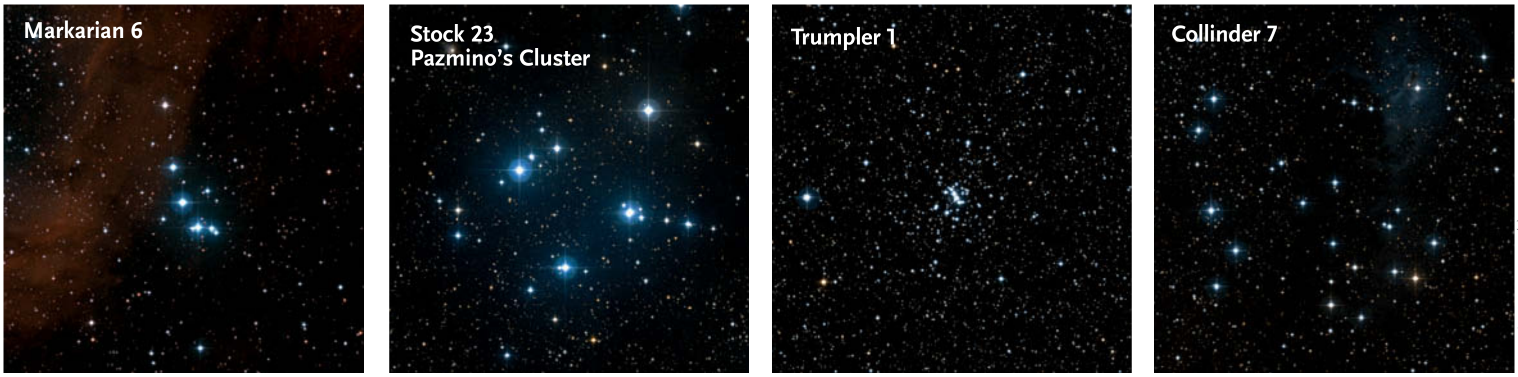
AKIRA FUJII

Cassiopeia plays host not just to its familiar Messier and NGC clusters, but to little-known groups from challenging to surprisingly easy. North is up in all photos, but north is *down* from Cassiopeia when it's high in the northern sky at this time of year.

"Tr" refers to Swiss astronomer **Robert Trumpler** (1886–1956). He investigated the distances, sizes, and spatial distribution of open clusters, then published a catalog of 37 he had discovered and investigated. Even the most prominent are easily missed by users of small telescopes.

"Mrk" clusters were identified by the Armenian astronomer **Beniamin Markarian** (1913–85). At Byurakan Observatory in Georgia (then part of the Soviet Union), he photographed open clusters and published a catalog of 50. He studied the instability of open clusters, and so his catalog lists faint, mostly difficult-to-distinguish groups that are in the process of dissipating. Thus it contains no real visual showpieces.

"Cr" refers to the catalog of every known open star cluster, bright and faint, large and small, that was compiled in 1931 by Swedish astronomer **Per Collinder**



DSS / S&T: SEAN WALKER (4)

Zooming in deeper to telescope-like views, these odd little groups tend to show more variety than richer, better-known clusters. Each frame is 0.3° wide.

(1890–1975). It's by far the largest of the lot, with 471 entries heavily overlapping the Messier and NGC lists. It also includes a few asterisms (groups of unrelated stars). Entries are listed by right ascension.

Other open-cluster names you may encounter on charts include Bark (Barkhatova), Berk (Berkeley), Biur (Byurakan), Do (Dolidze), Do-Dz (Dolidze-Dzimselejsvili), Haf (Haffner), K (King), Ly (Lynga), Mel (Mellotte), Ru (Ruprecht), Ste (Stephenson), van den Bergh (vdB), and Westr (Westerlund). Sue French often discusses these in her *Deep-Sky Wonders* column; for example her September 2011 column is entirely devoted to Berkeley clusters.

A Catalog Revived

Of all the above, the Collinder list is my favorite. Like many amateurs, I first encountered Cr clusters (such as Cr 399, the Coathanger in Vulpecula) while exploring the Milky Way. I knew nothing of Per Collinder or his cataloging objectives until I read an article that Arizona astronomy writer Thomas Watson posted two years ago along with the entire Collinder Catalog. You can find both at **skypub.com/collinder**.

Watson, like me, was curious about the "Cr" objects he had encountered during his observing sessions. Internet and library searches turned up basic information. Per Collinder was an astronomy graduate student in Sweden who published "On structural properties of open clusters and their spatial distribution" for his doctoral thesis. But Watson was unable to obtain the catalog included in Collinder's thesis and soon dropped his quest.

Then he read Nancy Thomas's article "Per Collinder and his Catalog" in *Amateur Astronomy* for winter 2005. "At the end of her essay," says Watson, "Ms. Thomas expressed the hope that amateur astronomers would take up the challenge of using Collinder's catalog as an observing list." She had a photocopy of it and sent it to Watson. With that in hand, he decided to answer her challenge. He set about correcting its positional errors, updating coordinates, eliminating duplicate entries, and reshaping the catalog into a format that both amateurs and professionals would find useful.

"Collinder was trying to gain an insight into the structure of the Milky Way Galaxy," says Watson, "by determining how open clusters were distributed and seeing whether the majority of them populated the galactic plane. This proved true and, as a result, Collinder's catalog reflects that distribution."

Of the first 20 entries in the Collinder catalog (ordered by right ascension), 19 are in Cassiopeia and one is in Cepheus, definitely in the plane of the Milky Way. But with the exception of Collinder 15, they're also in the NGC, IC, and/or Messier catalogs. Indeed, that's true of most Collinder objects, which is why only a few of the 471 "Cr" designations appear on star charts. Collinder 42, for instance, is the Pleiades (M45). Collinder 285 is the huge

PETER RAQUETTE / UNIV. OF LUND / POPULAR ASTRONOMI

Per Collinder, second from lower left, attending a lobster dinner at the University of Lund in Sweden, probably around 1931.

Ursa Major Moving Group, which includes five of the seven Big Dipper stars.

Watson writes, "As you observe these objects through the eyepiece, keep in mind that Collinder apparently never saw with his own eyes the majority of the clusters he listed. Much, if not most, of his work was done using photographic plates from a number of observatories."

Also unusual are Collinder's classifications. Although Herschel grouped his objects into "Bright Nebulae," "Faint Nebulae," "Very Compressed and Rich Clusters of Stars," and so on, Collinder used actual clusters for three of his classifications: "Pleiades," "Praesepe" (M44 in Cancer), and "Mu Normae" (NGC 6169). I'm too far north to see the Mu Normae group, so I asked Arizona-based Watson what it looks like. "It's fairly sparse," he said, "with a few rather faint stars dominated by the namesake star."

Check out Collinder 45 (NGC 1502) in Camelopardalis or Collinder 112 (NGC 2264) in Monoceros. Both are classified as Mu Normae clusters. What do you think distinguishes them from Collinder's Pleiades or Praesepe classes?

I love star clusters! Thanks to Watson's work, the Collinder Catalog is now fully accessible, with 2000.0 coordinates and informatively annotated (**skypub.com/collinder**). Although many Collinder clusters lie far south and below my Vancouver horizon, there are more than enough to keep us busy in Taurus, Perseus, Auriga, Cygnus, Lacerta, and Sagittarius, as well as Cassiopeia and Cepheus.

Along with the other such catalogs, it contains some gems that are easy to miss if you depend only on the Messier list and the NGC.

The Coathanger asterism, Collinder 399 in Vulpecula, is upside-down for mid-northern skygazers. It's not a real cluster, just an interesting set of line-of-sight coincidences.

S&T: DENNIS DI CICCO

Six Favorite Targets

Take a look at what I mean! Here are six of my favorite Collinder, Stock, Markarian, and Trumpler clusters. Most are in or around Cassiopeia — high overhead these evenings. For finder charts, use the wide-field images on pages 37 and 38.

Stock 2 (Perseus, RA 2^h 15.0^m, Dec. +59° 16′)
Sprawling across the Cassiopeia-Perseus border, this big, loose, well-populated cluster — a full 1° in diameter! — rewards wide-field viewing in small telescopes and binoculars (see page 45). It's just 2° north of the much more obvious and famous Double Cluster in Perseus, which likely accounts for why it's poorly known; the Double Cluster hogs the stage! But once you recognize Stock 2, you'll never miss it again.

At its core is a quadrilateral that reminds me of a broader Hercules Keystone. From this, several lines of stars trickle off; some of these form a big, ragged plus sign oriented north-south-east-west. Off the group's northeast edge sits a lovely, nearly equal 7th-magnitude double star (magnitudes 7.0 and 7.3, separation 63″).

Markarian 6 (Cassiopeia, RA 2^h 29.6^m, Dec. +60° 39′)
About 2° northeast of huge Stock 2 is tiny Markarian 6, a curved line of a mere half dozen 10th-magnitude stars. It's 0.1° long and runs north-south. I think it looks like a lacrosse stick. Others have described it as a fish hook.

Stock 23 (Camelopardalis, RA 3^h 16.3^m, Dec. +60° 02′)
This small cluster at the Camelopardalis-Cassiopeia border is identified on some star atlases as Pazmino's Cluster, for John Pazmino of New York, who independently discovered it and described it in the March 1978 *Sky & Telescope*. It's easy in binoculars, if a little sparse. You wonder how it was overlooked! In my 127-mm refractor I see a small, compact group of eight to ten stars. It also includes a prominent double, in the southwestern edge of the bright central bunch.

Trumpler 1 (Cassiopeia, RA 1^h 35.7^m, Dec. +61° 17′)
Tr 1 lies just 0.7° north-northeast of much bigger, brighter M103, which is just 1° east-northeast of Delta (δ) Cassiopeiae. Tr 1 is a tiny, faint cluster dominated by a straight line of four stars of about 12th magnitude. They're so close together that they're unresolved in many amateur scopes and look positively weird accordingly. Tr 1 rewards high power and large aperture; I like what I see in my 11-inch Schmidt-Cass at 175×. It's a tricky little find, outshone not just by M103 but by NGC 663 and 654 a degree east.

Collinder 7 (Cassiopeia, RA 0^h 43.4^m, Dec. +61° 47′)
This is a remarkable group midway between Gamma (γ) and Kappa (κ) Cas. Is it a crown? Aladdin's lamp? The Holy Grail? A parachute? It depends on how it's oriented in your field of view. Some 20 stars here include a ragged semicircle outlining its southeastern side. My 11-inch at 90× provides the view I like best.

This group includes NGC 225 or maybe is identical to it, though the NGC object is listed as smaller and not positioned to include the western part of the semicircle.

Collinder 399 (Vulpecula, RA 19^h 25.4^m, Dec. +20° 11′)
How can one not chuckle at the eyepiece on first sighting Collinder 399? It definitely looks like an upside-down coathanger! Or maybe it's an old-fashioned telescope with a pea-shooter tube on a tabletop tripod. Many people have independently discovered it in the Milky Way 8° south of Cygnus's Albireo. It looks like a faint haze patch to the unaided eye at a dark site. Its long part spans 1.3°.

Now, excuse me. I have to get back to compiling the "R (Rodger) catalog of northern star clusters visible with a 5-inch refractor in an urban sky at latitude 49.5°." ✦

***David A. Rodger**, founding director of Vancouver's H. R. MacMillan Planetarium, observes deep-sky objects from his north-facing patio in North Vancouver, BC. His article* "In Praise of the Great Dark North" *appeared in the September 2011 issue.*

Dazzling Jupiter was near the Hyades and Pleiades in December 2000, as it is now 12 years later. But Saturn, the bright "star" lower right of Jupiter in this photo, is now in Libra.

PHOTOGRAPH: AKIRA FUJII

In This Section

Sky at a Glance

DECEMBER 2012

Nov. 27 – Dec. 12 **DAWN:** This is Mercury's best apparition of the year for viewers at mid-northern latitudes. Mercury rises more than an hour before the Sun and is easily located in the east-southeast 6°–10° lower left of dazzling Venus; see page 48.

Dec. 2–3 **ALL NIGHT:** Jupiter is at opposition — rising around sunset, setting around sunrise, and essentially at its brightest and biggest in a telescope; see page 52.

8–9 **ALL NIGHT:** Vesta, the brightest asteroid, is at opposition; see page 50.

9–11 **DAWN:** The waning crescent Moon is very close to Spica on the 9th and lower right of Saturn on the 10th. A very thin Moon forms a spectacular close pair with Venus on the 11th, with Mercury to their lower left.

11–12 **NIGHT:** Asteroid Toutatis is 4,307,000 miles (6,932,000 km) from Earth, its closest approach since 2004. See page 53.

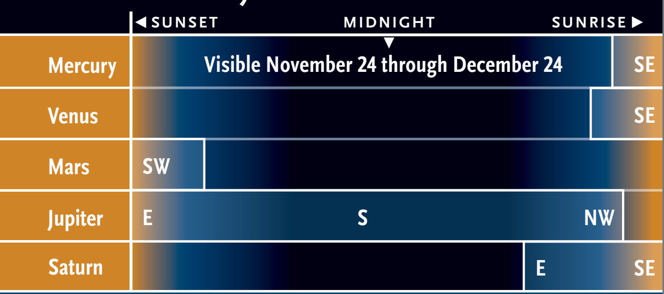
13–14 **NIGHT:** The Geminid meteor shower peaks on this moonless night. You're likely to see the highest rates from 10 p.m. until dawn; see page 52.

17–18 **ALL NIGHT:** Ceres, the largest main-belt asteroid, is at opposition; see page 50.

21 **WINTER BEGINS** in the Northern Hemisphere at the solstice, 6:12 a.m. EST (3:12 a.m. PST). Coincidentally, the Mayan calendar flips over to a new *baktun*, as it does every 144,000 days (*S&T*: November 2009, page 22). Contrary to the doomsayers, no astronomical catastrophe will ensue.

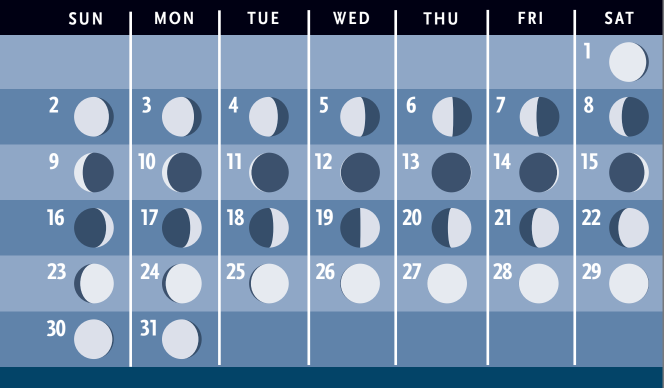
25 **EVENING:** Jupiter forms a spectacular close pair with the just-past-full Moon. The Moon occults (hides) Jupiter for parts of southern Africa and South America.

Planet Visibility



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

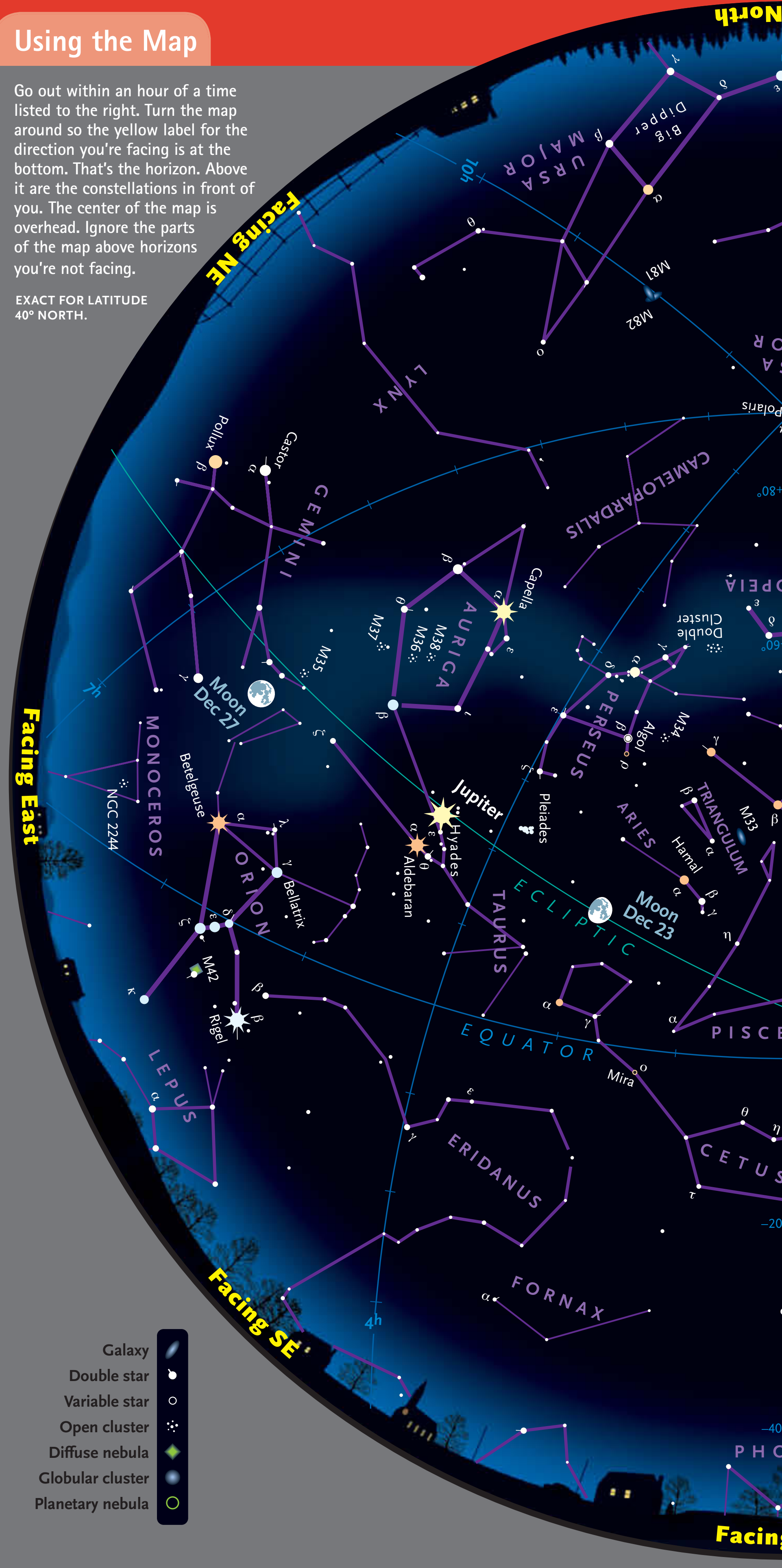
Moon Phases

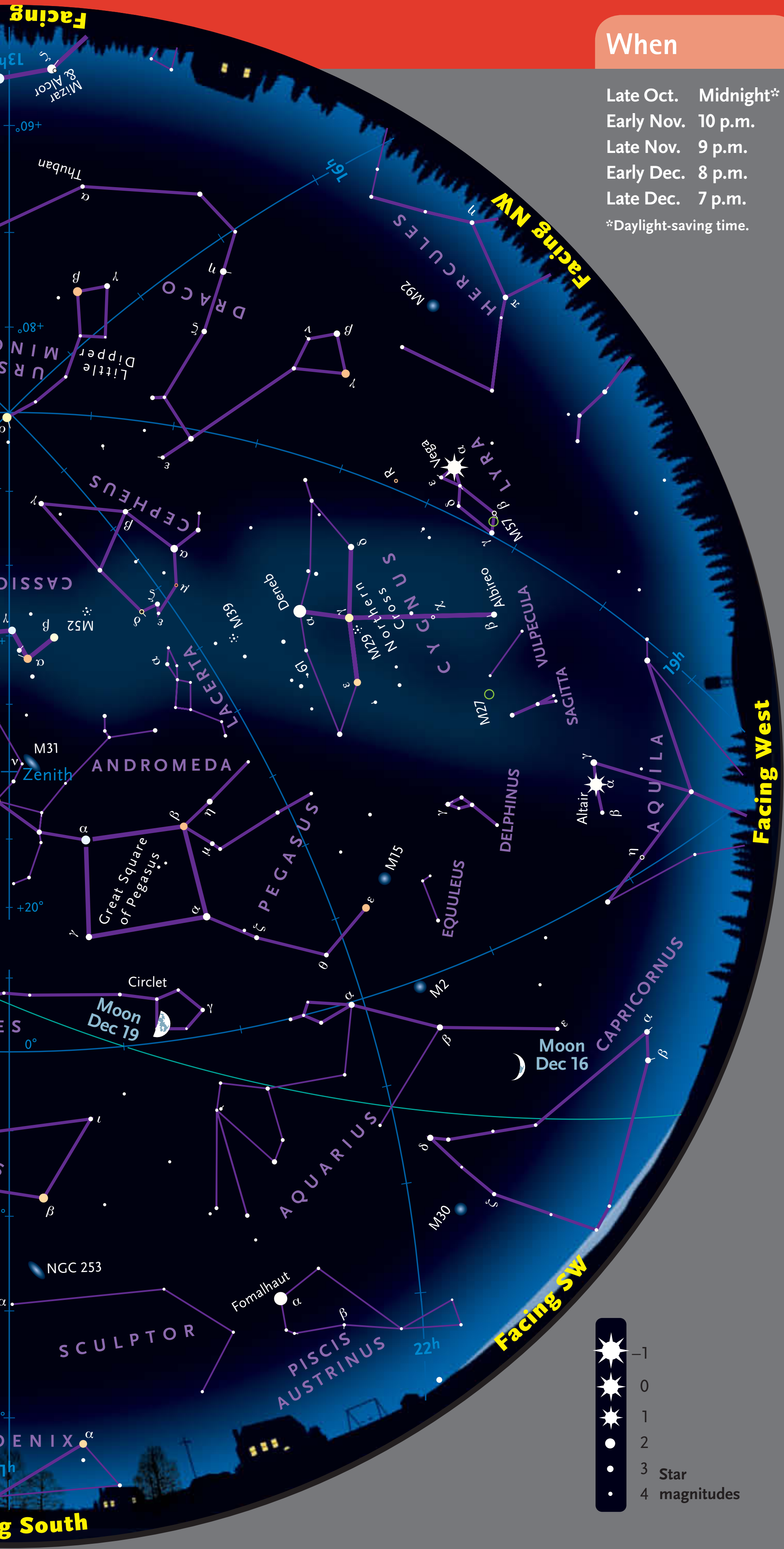


Using the Map

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

EXACT FOR LATITUDE 40° NORTH.





When

Late Oct.	Midnight*
Early Nov.	10 p.m.
Late Nov.	9 p.m.
Early Dec.	8 p.m.
Late Dec.	7 p.m.

*Daylight-saving time.

Gary Seronik

Binocular Highlight

Asteroids on Steroids

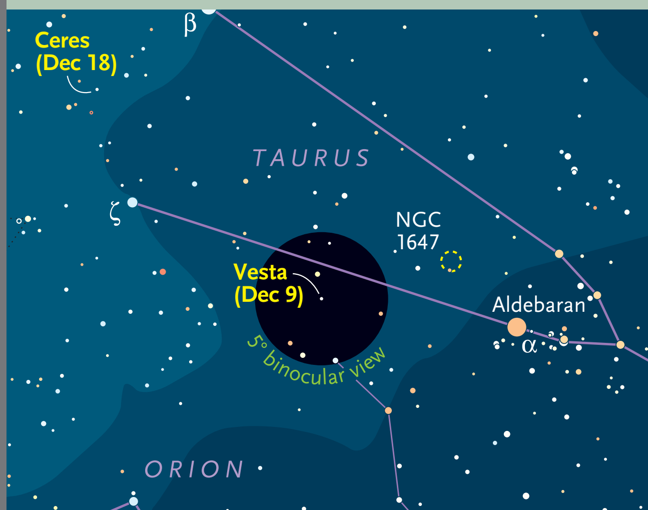
Most of my Binocular Highlight columns over the years have featured deep-sky objects, but this month there's a solar system happening that makes for a terrific bino sight. As noted on page 50, the two brightest asteroids, **Ceres** and **Vesta**, both come to opposition in December. That means they'll be at their best for viewing and, what's more, both are situated near bright stars in Taurus!

Ceres is the largest asteroid and the first one discovered, having been found on the first day of the 19th century (January 1, 1801) by the Italian astronomer Giuseppe Piazzi. This little world measures 942 km (585 miles) in average diameter, roughly ¼ the diameter of the Moon. Ceres reaches opposition on December 18th, when it will lie within the same binocular field as 3rd-magnitude Zeta (ζ) Tauri. On that night the asteroid will be 4.5° north-northeast of the star and shining at magnitude 6.7 — bright enough to be in easy reach of even the smallest binoculars.

Nearby Vesta was the fourth asteroid found, but it's actually the brightest of them all. With an average diameter of 525 km, Vesta is half the size of Ceres, yet it shines at magnitude 6.4 when it reaches opposition on December 9th. That night Vesta will be almost exactly equidistant from Zeta and Taurus's leading light, 1st-magnitude Aldebaran (not counting Jupiter!). The asteroid should be pretty easy to identify — just don't confuse it with nearby 4.9-magnitude 104 Tauri, which lies about 1° to its north.

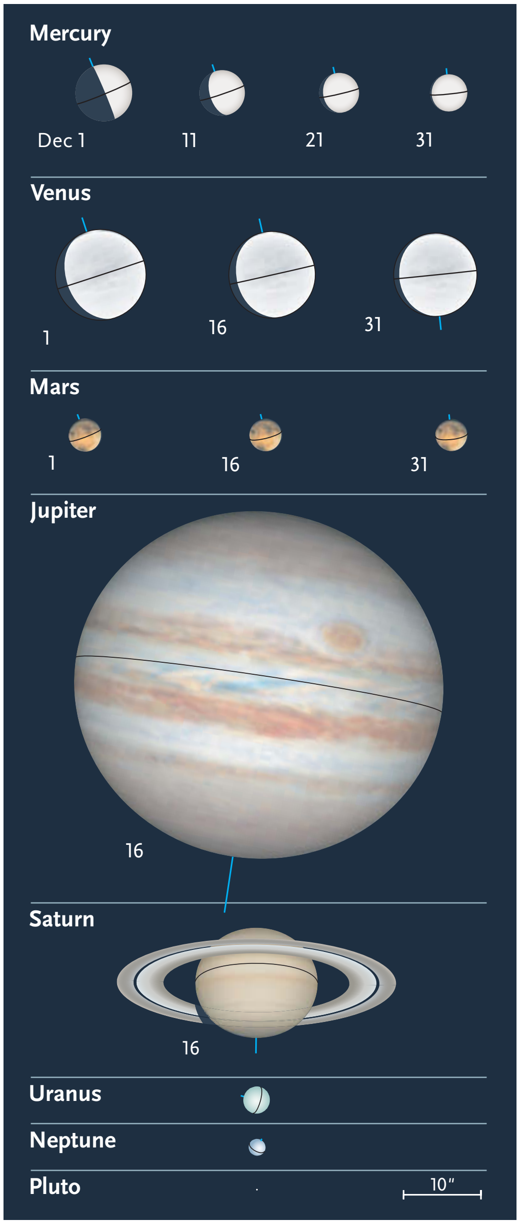
The chart below plots both asteroids on their opposition dates. The best way to confirm your sighting is to check back a night or two later to see if your suspect point of light has moved. ✦

— *Gary Seronik*



Watch a SPECIAL VIDEO

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

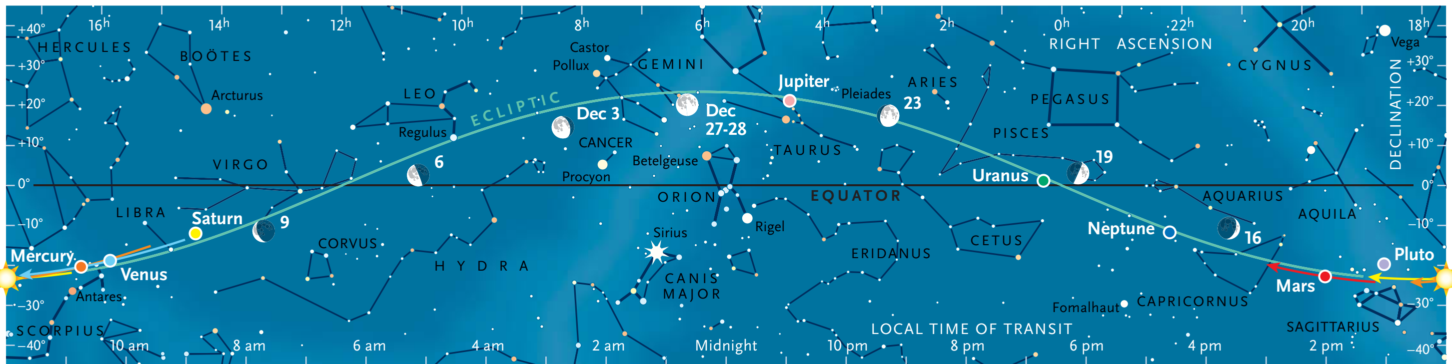


Sun and Planets, December 2012

	Dec.	Right Ascension	Declination	Elongation	Magnitude	Diameter	Illumination	Distance
Sun	1	$16^h\ 29.3^m$	–21° 48′	—	–26.8	32′ 26″	—	0.986
	31	$18^h\ 41.5^m$	–23° 06′	—	–26.8	32′ 32″	—	0.983
Mercury	1	$15^h\ 10.4^m$	–15° 05′	20° Mo	–0.3	7.4″	48%	0.913
	11	$15^h\ 51.7^m$	–18° 24′	20° Mo	–0.5	5.9″	77%	1.140
	21	$16^h\ 50.1^m$	–22° 00′	16° Mo	–0.5	5.2″	90%	1.300
	31	$17^h\ 55.3^m$	–24° 09′	11° Mo	–0.6	4.8″	96%	1.394
Venus	1	$14^h\ 36.0^m$	–13° 30′	28° Mo	–3.9	11.8″	88%	1.419
	11	$15^h\ 25.3^m$	–17° 12′	26° Mo	–3.9	11.4″	90%	1.465
	21	$16^h\ 16.5^m$	–20° 10′	24° Mo	–3.9	11.1″	92%	1.508
	31	$17^h\ 09.5^m$	–22° 11′	21° Mo	–3.9	10.8″	94%	1.547
Mars	1	$18^h\ 45.6^m$	–24° 11′	31° Ev	+1.2	4.4″	97%	2.146
	16	$19^h\ 35.8^m$	–22° 48′	28° Ev	+1.2	4.3″	97%	2.186
	31	$20^h\ 25.3^m$	–20° 26′	24° Ev	+1.2	4.2″	98%	2.223
Jupiter	1	$4^h\ 39.9^m$	+21° 21′	177° Mo	–2.8	48.5″	100%	4.069
	31	$4^h\ 24.1^m$	+20° 53′	148° Ev	–2.7	46.9″	100%	4.201
Saturn	1	$14^h\ 19.5^m$	–11° 32′	33° Mo	+0.7	15.7″	100%	10.600
	31	$14^h\ 30.6^m$	–12° 22′	60° Mo	+0.6	16.2″	100%	10.242
Uranus	16	$0^h\ 17.4^m$	+1° 06′	100° Ev	+5.8	3.5″	100%	19.861
Neptune	16	$22^h\ 11.2^m$	–11° 52′	66° Ev	+7.9	2.2″	100%	30.374
Pluto	16	$18^h\ 36.4^m$	–19° 49′	15° Ev	+14.2	0.1″	100%	33.302

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

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



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

Fred Schaaf

Peerless Perseus

The constellation is as prominent in the sky as the hero is in myth.

Morning brings back the heroic ages.
— Henry David Thoreau, *Walden*

Certain mornings of November and December this year offer sights we might truly call heroic. At dawn on November 26th and 27th, Venus and Saturn are less than 1° apart. On the mornings of December 9th through 11th, the crescent Moon steps down a staircase of a 1st-magnitude star and two bright planets (see page 48).

And as the year nears its end, evening also brings back the heroic ages — to the eye and mind.

Hero Perseus flies high. At the time of our all-sky map — mid-evening in November and earlier evening in December — the noble constellation of Perseus soars high in the northeast. According to Greek mythology, Perseus was the first great hero. He saved the chained princess Andromeda (also a constellation) from the sea monster Cetus (another constellation), which Poseidon had sent to punish Andromeda's parents Cassiopeia and Cepheus (two more constellations). In some versions of the myth, Perseus had the assistance of Pegasus — yet another constellation.

Perseus presents us with a severed part of another figure from Greek mythology: the serpent-tressed head of the monstrous Gorgon sister Medusa, represented by the classic eclipsing binary star Algol. Novice amateur astronomers learn that every 2.87 days a dim companion star partly hides the brighter primary star of the Algol system for several spooky hours, reducing Algol's brightness from magnitude 2.1 to 3.4 (see page 51). But we don't often see the distance to Algol mentioned. The "Demon Star" is located only 93 light-years from Earth, a little farther than the central stars of the Big Dipper.

The only star in Perseus brighter than Algol at its maximum is 1.8-magnitude Alpha Persei, also known as Mirfak. Swarming around it in the heart of the imagined hero is a grouping of stars more than 3° across known as the Alpha Persei Association. It's centered about 500 light-years from us. But northwest of Perseus's helmet is an elongated glow, which a telescope shows to be adjacent piles of stellar jewels. This is the Double Cluster of Perseus, a pair of star clusters more than 7,000 light-years from Earth. Imagine how bright — brimming with 1st-magnitude stars — the Double Cluster would appear if brought as near to us as the Alpha Persei Association.

The brightest hero. Perseus is the quintessential star-hero of Greek myth. But can we find an even brighter hero constellation?

Strongman Hercules has a constellation, though its last parts are sinking below the northwest horizon at this hour. But as a constellation, Hercules is surprisingly dim. I say surprisingly because you would think that the mightiest and most popular hero of Greek mythology would have been given a more conspicuous star pattern.

If we look low in the east at this time, we'll see rising the most brilliant constellation of all: Orion.

In Greek mythology Orion was vain, rude, and intemperate — not really heroic in character. But if we concentrate on the constellation's visual aspects — its two 1st-magnitude stars, its now-vertical three-star Belt, its Sword with a gleam of nebula, and especially its resemblance to a huge human figure — most of us would agree that Orion is the most heroic constellation in all the heavens. ✦

S&T ARCHIVES

Benvenuto Cellini's statue of Perseus holding Medusa's head is on public display in Florence, Italy.

Jupiter Rules the Night

This is the peak month to view the king of planets.

For yet another month, Mars languishes low in the southwest at dusk. Jupiter comes to opposition and blazes all night. Saturn rises in the lonely time after midnight. And for most of December, Mercury pairs with dazzling Venus at dawn.

DUSK AND EVENING

Mars remains low in evening twilight in December for its fifth month in a row, modestly dim at magnitude +1.2. Look for it about 10° above the southwest horizon ¾ hour after sunset. It's a tiny dot through a telescope — barely more than 4″ wide.

Uranus, in Pisces, and **Neptune**, in Aquarius, are best observed around nightfall. Uranus is fairly high in the south then, but Neptune is low in the southwest. For finder charts see the September issue, page 50, or **skypub.com/urnep**.

ALL NIGHT

Jupiter comes to opposition on the American evening of December 2nd. That night Jupiter rises around sunset, is highest around midnight, and sets around sunrise. This is one of the closest oppositions in Jupiter's 12-year orbit, so the planet blazes at magnitude –2.8, and its disk is 48.5″ across the equator.

At the end of December Jupiter is still nearly as big and bright as it was at opposition, and it rises high much earlier. On New Year's Eve it's already ⅓ of the way up the sky by mid-twilight. Jupiter is nearly as far north as it can ever travel among the constellations, so viewers at mid-northern latitudes see it remarkably high for remarkably long.

Jupiter's slow movement against the background stars of Taurus adds even more interest. Jupiter retrogrades (moves westward through the stars) in December about 5° north of Aldebaran, the 1st-magnitude eye of the Bull. It comes much closer to 3.5-magnitude Epsilon (ε) Tauri, which marks the northwest end of the Hyades' V pattern, and is often considered to be Taurus's other, much dimmer eye. Jupiter passes closest to Epsilon (1.7°) on December 22nd but remains within 2° of it for the entire second half of the month.

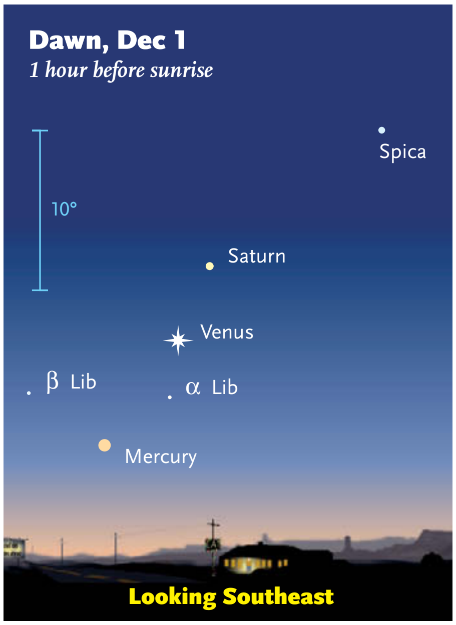
Jupiter is heading almost directly toward 4.9-magnitude Omega (ω) Tauri, which will be just 10′ from the planet when it resumes normal prograde (eastward) motion at the end of January.

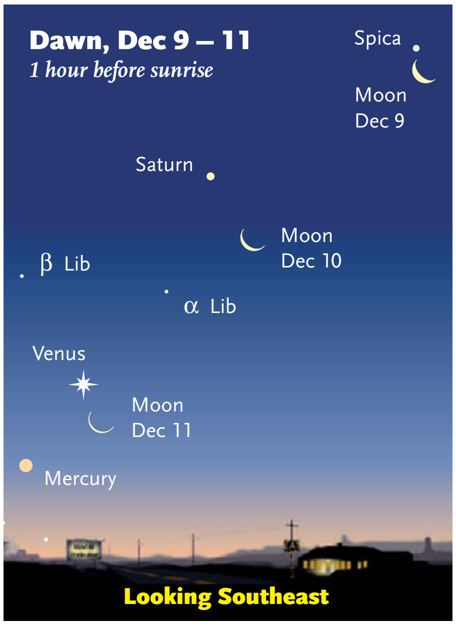
And Jupiter pairs spectacularly with the Moon on December 25th, as described in the Sun and Moon section below.

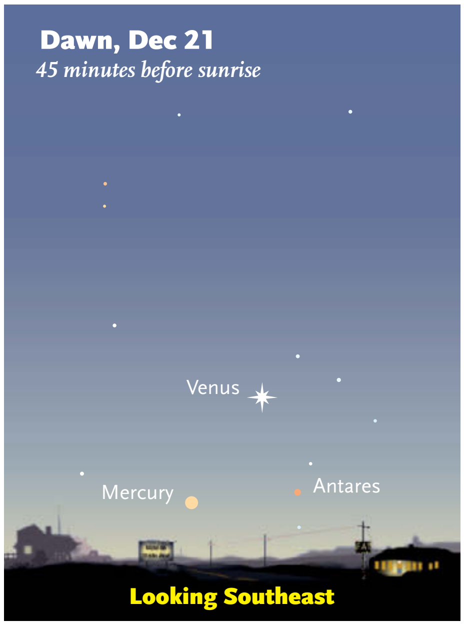
PREDAWN AND DAWN

Saturn rises around 4 a.m. as December starts and about 2:30 a.m. by month's end. The gold planet brightens a little, from magnitude +0.7 to +0.6, during December.

Saturn has been in Virgo, the longest constellation of the zodiac, for more than three years, but in early December it finally crosses the border into Libra. (It will dip back into Virgo for a few months in mid-2013). Saturn ends the year 16° east







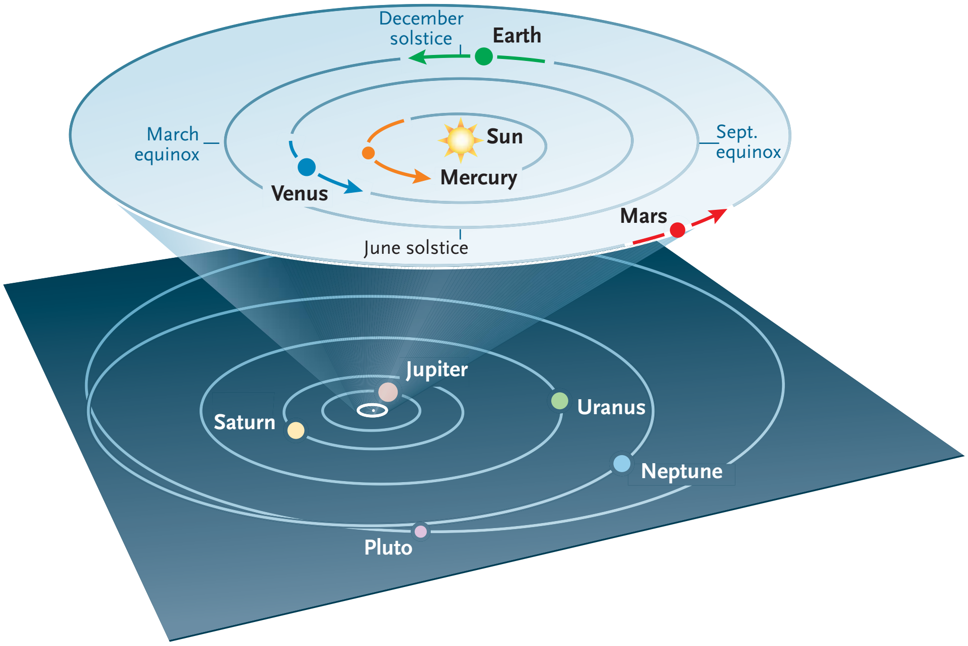
***Fred Schaaf** welcomes your comments at fschaaf@aol.com.*

Fred Schaaf

of Spica and 6° northwest of the ultrawide double star Alpha Librae, which is also (unforgettably) named Zubenelgenubi.

In a telescope, Saturn's fabulous rings are opening to our view. Their northern face is tilted 18° or 19° toward Earth throughout December.

Venus and **Mercury** adorn the ecliptic lower left of Spica and Saturn before and during dawn, as shown at the bottom of the facing page. Venus starts December only 5° from Saturn, and it's a good 16° above the eastern horizon (at latitude 40° north) in mid-dawn 45 minutes before sunrise. But each morning Venus appears lower and Saturn higher, so by month's end the planets are 40° apart and Venus is beginning to sink into the twilight glow.



ORBITS OF THE PLANETS

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

Mercury has its best apparition of the year for mid-northern latitudes. It rises unusually high, and it's very easy to locate to Venus's lower left throughout December. The planets are 8° apart on December 1st, $6\frac{1}{3}$° at their closest on December 9th, and 10° on December 31st. Venus and Mercury shine all month around magnitude –3.9 and –0.5, respectively. Mercury will probably be too low to see without binoculars in the last week of December.

On December 3rd Venus stands equidistant from Saturn and Mercury, forming a slightly curved diagonal line with them. On the next morning, December 4th, it's just $1\frac{1}{4}$° left of Zubenelgenubi, its closest approach to that star. This is also when Mercury reaches greatest elongation from the Sun, rising more than $1\frac{1}{2}$ hours before sunup at mid-northern latitudes.

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

On December 22nd Venus stands 6° upper left of Antares and $8\frac{1}{3}$° upper right of Mercury, forming a not-quite equilateral triangle with them. By then Mercury is much lower than it was at its peak, rising only an hour before the Sun.

SUN AND MOON

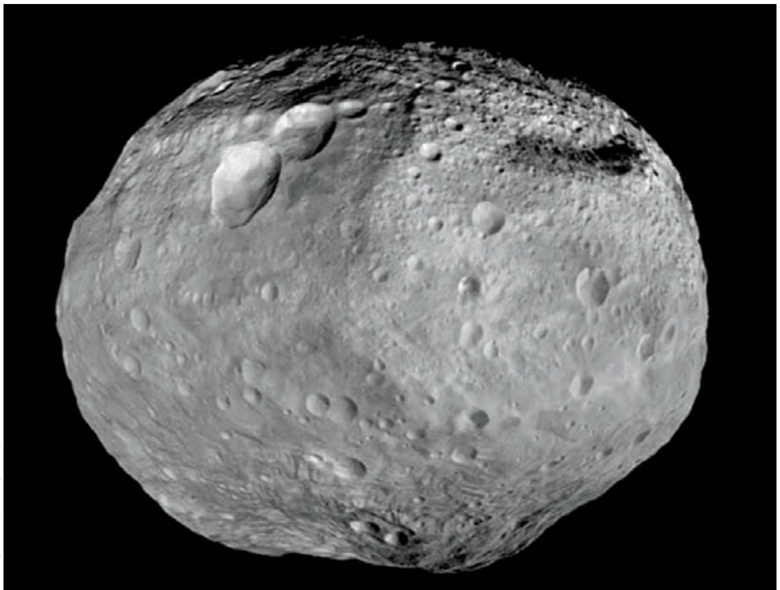
The waning crescent **Moon** walks down the stairs of Spica, Saturn, and Venus on the American mornings of December 9th, 10th, and 11th, respectively, posing with each one after another.

At dusk on December 25th, Christmas Day, the just-past-full Moon is only about 1° from Jupiter for viewers in the U.S. The Moon occults (hides) Jupiter around sunset in central South America and early on the morning of the 26th in parts of southern Africa.

The **Sun** reaches the solstice at 6:12 a.m. EST on December 21st, starting winter in the Northern Hemisphere and summer in the Southern Hemisphere. ✦

Ceres & Vesta Shine Brightest

The two leading asteroids come to opposition in a jazzy part of the sky.



NASA / JPL-CALTECH / UCAL / MPS / DLR / IDA

Full Vesta. NASA released this composite goodbye image in September as the Dawn spacecraft departed into the distance.

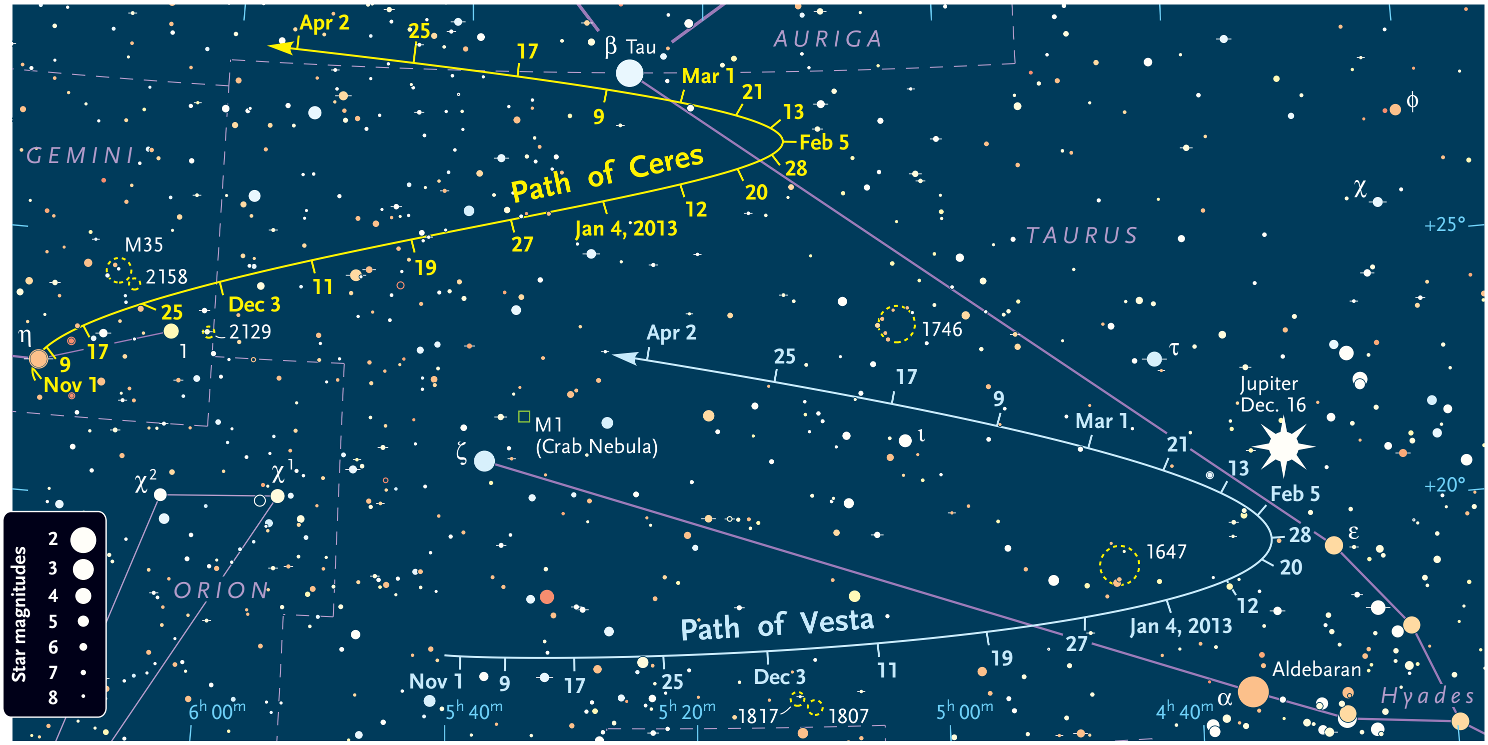
Jupiter, Aldebaran, the Hyades, and the Pleiades draw the eye on November and December evenings all grouped together in the east. Also in that area, just below naked-eye visibility, are two more attractions: 1 Ceres, the largest asteroid in the main belt, and 4 Vesta, the brightest. Both reach opposition in mid-December (see page 45). They remain 10° to 13° apart from November into spring 2013.

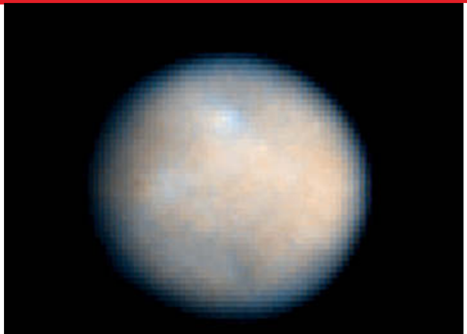
Binoculars and the chart below are all you'll need for most of this period. Ceres shines at the following magnitudes: **November 1**, 8.0; **Dec. 1**, 7.2; **Dec. 18** (opposition), 6.7; **Jan. 1**, 7.1; **Feb. 1**, 7.8; **Mar. 1**, 8.3; **Apr. 1**, 8.6.

Vesta is a little brighter: **Nov. 1**, 7.2; **Dec. 1**, 6.6; **Dec. 9** (opposition), 6.4; **Jan. 1**, 6.9; **Feb. 1**, 7.5; **Mar. 1**, 7.9; **Apr. 1**, 8.2.

Ceres is by far the largest asteroid, a near-sphere 585 miles (942 km) wide. Its size and roundness have earned it a place in the recently defined category of "dwarf planet,"

Below: **Use this chart to find Ceres and Vesta from November through next March. The date ticks are plotted every 8 days at 0^h UT (which falls on the evening of the previous date in the time zones of the Americas). Stars are plotted to magnitude 8.5.**





One of the best-yet images of Ceres, taken by the Hubble Space Telescope on January 23, 2004, in visible and ultraviolet light.

NASA / ESA / J. PARKER (SWRI)

none of which have yet been visited by spacecraft. But that will change in 2015.

Vesta is only about half the size of Ceres. Its greater brightness is due to the unusually light-gray minerals making up its dusty, battered surface.

Right now, Ceres and Vesta are as famous and exciting as they've ever been since their discoveries in 1801 and 1807. NASA's Dawn spacecraft recently ended a year of orbiting Vesta, returning spectacular images and groundbreaking science (September issue, page 32). Dawn is now traveling onward to take up permanent orbit around Ceres in February 2015.

Minima of Algol

Nov.	UT	Dec.	UT
1	22:51	3	11:50
4	19:40	6	8:40
7	16:29	9	5:29
10	13:18	12	2:18
13	10:07	14	23:07
16	6:56	17	19:56
19	3:45	20	16:45
22	0:34	23	13:35
24	21:23	26	10:24
27	18:12	29	7:13
30	15:01		

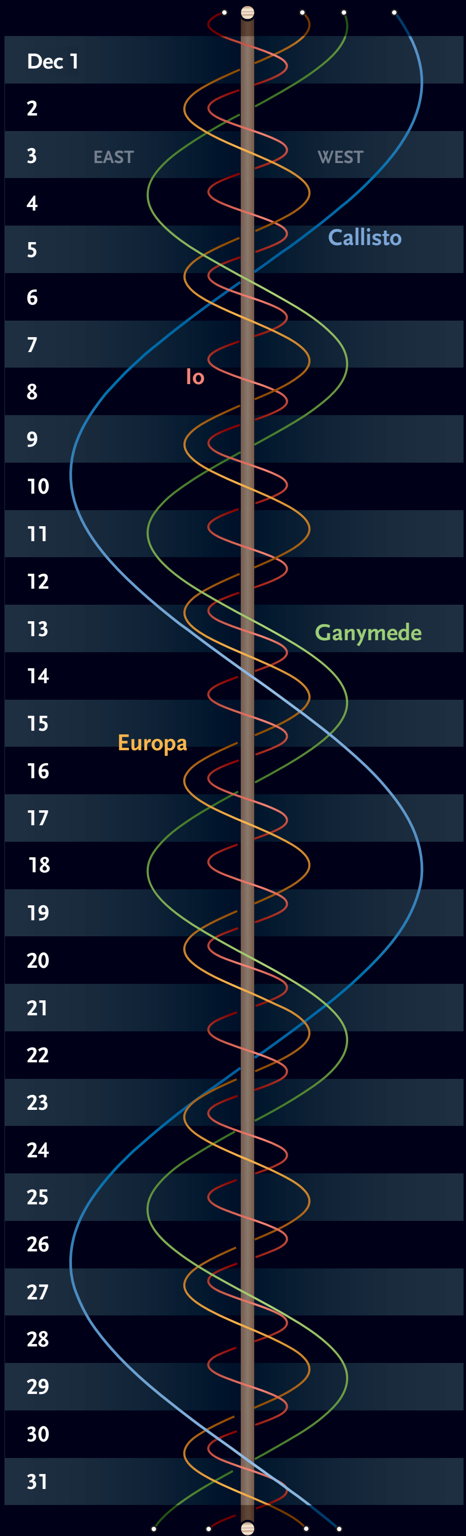
These geocentric predictions are from the heliocentric elements Min. = JD 2452253.559 + 2.867362E, where E is any integer. Courtesy Gerry Samolyk (AAVSO). For a comparison-star chart and further information, see skypub.com/algol.

Phenomena of Jupiter's Moons, December 2012

Dec. 1	3:22	I.Sh.I
	3:26	I.Tr.I
	5:33	I.Sh.E
	5:36	I.Tr.E
	13:59	II.Ec.D
	16:26	II.Oc.R
Dec. 2	0:43	I.Ec.D
	2:55	I.Oc.R
	12:31	III.Ec.D
	14:38	III.Ec.R
	21:51	I.Sh.I
	21:52	I.Tr.I
Dec. 3	0:01	I.Tr.E
	0:02	I.Sh.E
	9:09	II.Sh.I
	9:10	II.Tr.I
	11:31	II.Tr.E
	11:34	II.Sh.E
	19:11	I.Oc.D
	21:23	I.Ec.R
Dec. 4	16:17	I.Tr.I
	16:20	I.Sh.I
	18:27	I.Tr.E
	18:31	I.Sh.E
Dec. 5	3:12	II.Oc.D
	5:42	II.Ec.R
	13:37	I.Oc.D
	15:51	I.Ec.R
Dec. 6	2:25	III.Tr.I
	2:37	III.Sh.I
	4:17	III.Tr.E
	4:44	III.Sh.E
	10:43	I.Tr.I
	10:48	I.Sh.I
	12:53	I.Tr.E
	12:59	I.Sh.E
	22:16	II.Tr.I
	22:27	II.Sh.I
Dec. 7	0:37	II.Tr.E
	0:52	II.Sh.E
	8:03	I.Oc.D
	10:20	I.Ec.R
Dec. 8	5:09	I.Tr.I
	5:17	I.Sh.I
	7:19	I.Tr.E
	7:28	I.Sh.E
	16:19	II.Oc.D
	19:00	II.Ec.R
Dec. 9	2:29	I.Oc.D
	4:49	I.Ec.R
	15:55	III.Oc.D
	18:39	III.Ec.R
	23:35	I.Tr.I
	23:46	I.Sh.I
Dec. 10	1:45	I.Tr.E
	1:57	I.Sh.E
	11:23	II.Tr.I
	11:46	II.Sh.I
	13:45	II.Tr.E
	14:10	II.Sh.E
	20:55	I.Oc.D
	23:17	I.Ec.R
Dec. 11	18:01	I.Tr.I
	18:14	I.Sh.I
	20:11	I.Tr.E
	20:25	I.Sh.E
Dec. 12	5:25	II.Oc.D
	8:18	II.Ec.R
	15:20	I.Oc.D
	17:46	I.Ec.R
Dec. 13	5:39	III.Tr.I
	6:37	III.Sh.I
	7:33	III.Tr.E
	8:45	III.Sh.E
	12:27	I.Tr.I
	12:43	I.Sh.I
	14:37	I.Tr.E
	14:54	I.Sh.E
Dec. 14	0:30	II.Tr.I
	1:03	II.Sh.I
	2:52	II.Tr.E
	3:28	II.Sh.E
	9:46	I.Oc.D
	12:15	I.Ec.R
Dec. 15	6:53	I.Tr.I
	7:12	I.Sh.I
	9:03	I.Tr.E
	9:23	I.Sh.E
	18:33	II.Oc.D
	21:37	II.Ec.R
Dec. 16	4:12	I.Oc.D
	6:43	I.Ec.R
	19:11	III.Oc.D
	22:41	III.Ec.R
Dec. 17	1:19	I.Tr.I
	1:41	I.Sh.I
	3:29	I.Tr.E
	3:52	I.Sh.E
	13:38	II.Tr.I
	14:22	II.Sh.I
	15:59	II.Tr.E
	16:46	II.Sh.E
	22:38	I.Oc.D
Dec. 18	1:12	I.Ec.R
	19:45	I.Tr.I
	20:09	I.Sh.I
	21:55	I.Tr.E
	22:20	I.Sh.E
Dec. 19	7:40	II.Oc.D
	10:55	II.Ec.R
	17:05	I.Oc.D
	19:41	I.Ec.R
Dec. 20	8:55	III.Tr.I
	10:37	III.Sh.I
	10:51	III.Tr.E
	12:46	III.Sh.E
	14:11	I.Tr.I
	14:38	I.Sh.I
	16:21	I.Tr.E
	16:49	I.Sh.E
Dec. 21	2:45	II.Tr.I
	3:40	II.Sh.I
	5:07	II.Tr.E
	6:04	II.Sh.E
	11:31	I.Oc.D
	14:10	I.Ec.R
Dec. 22	8:37	I.Tr.I
	9:07	I.Sh.I
	10:48	I.Tr.E
	11:18	I.Sh.E
	20:48	II.Oc.D
Dec. 23	0:14	II.Ec.R
	5:57	I.Oc.D
	8:38	I.Ec.R
	22:28	III.Oc.D
Dec. 24	0:26	III.Oc.R
	0:32	III.Ec.D
	2:42	III.Ec.R
	3:04	I.Tr.I
	3:36	I.Sh.I
	5:14	I.Tr.E
	5:47	I.Sh.E
	15:53	II.Tr.I
	16:58	II.Sh.I
	18:15	II.Tr.E
	19:22	II.Sh.E
Dec. 25	0:23	I.Oc.D
	3:07	I.Ec.R
	21:30	I.Tr.I
	22:04	I.Sh.I
	23:40	I.Tr.E
Dec. 26	0:15	I.Sh.E
	9:56	II.Oc.D
	13:33	II.Ec.R
	18:49	I.Oc.D
	21:36	I.Ec.R
Dec. 27	12:14	III.Tr.I
	14:13	III.Tr.E
	14:38	III.Sh.I
	15:56	I.Tr.I
	16:33	I.Sh.I
	16:48	III.Sh.E
	18:07	I.Tr.E
	18:44	I.Sh.E
Dec. 28	5:01	II.Tr.I
	6:16	II.Sh.I
	7:23	II.Tr.E
	8:40	II.Sh.E
	13:16	I.Oc.D
	16:05	I.Ec.R
Dec. 29	10:23	I.Tr.I
	11:02	I.Sh.I
	12:33	I.Tr.E
	13:13	I.Sh.E
	23:05	II.Oc.D
Dec. 30	2:52	II.Ec.R
	7:42	I.Oc.D
	10:33	I.Ec.R
Dec. 31	1:47	III.Oc.D
	3:49	III.Oc.R
	4:32	III.Ec.D
	4:49	I.Tr.I
	5:31	I.Sh.I
	6:43	III.Ec.R
	6:59	I.Tr.E
	7:42	I.Sh.E
	18:10	II.Tr.I
	19:34	II.Sh.I
	20:32	II.Tr.E
	21:58	II.Sh.E

Every day, interesting interactions happen between Jupiter's satellites and the planet's disk or shadow. The first columns give the date and mid-time of the event, in Universal Time (which is 5 hours ahead of Eastern Standard Time). Next is the satellite involved: **I** for Io, **II** Europa, **III** Ganymede, or **IV** Callisto. Next is the type of event: **Oc** for an occultation of the satellite behind Jupiter's limb, **Ec** for an eclipse by Jupiter's shadow, **Tr** for a transit across the planet's face, or **Sh** for the satellite casting its own shadow onto Jupiter. An occultation or eclipse begins when the satellite disappears **(D)** and ends when it reappears **(R)**. A transit or shadow passage begins at ingress **(I)** and ends at egress **(E)**. Each event is gradual, taking up to several minutes. Predictions courtesy IMCCE / Paris Observatory.

Jupiter's Moons



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

Action at Jupiter

Jupiter blazes high in the evening in Taurus, coming grandly to opposition on December 2nd. It's at least 47 arcseconds wide all November and December.

Any telescope shows Jupiter's four big moons. Binoculars usually show at least two or three. Identify them with the diagram at left. Listed on the previous page are all of their many interactions with Jupiter's disk and shadow in December, which are fascinating to watch.

Following are the times, in Universal Time, when Jupiter's Great Red Spot should cross the planet's central meridian. The dates (also in UT) are in bold. The Red Spot appears closer to Jupiter's central meridian than to the limb for 50 minutes before and after these times:

December 1, 9:47, 19:43; **2**, 5:38, 15:34; **3**, 1:30, 11:25, 21:21; **4**, 7:16, 17:12; **5**, 3:07, 13:03, 22:59; **6**, 8:54, 18:50; **7**, 4:45, 14:41; **8**, 0:37, 10:32, 20:28; **9**, 6:23, 16:19; **10**, 2:15, 12:10, 22:06; **11**, 8:01, 17:57; **12**, 3:53, 13:48, 23:44; **13**, 9:39, 19:35; **14**, 5:31, 15:26; **15**, 1:22, 11:17, 21:13; **16**, 7:09, 17:04; **17**, 3:00, 12:55, 22:51; **18**, 8:47, 18:42; **19**, 4:38, 14:33; **20**, 0:29, 10:25, 20:20; **21**, 6:16, 16:12; **22**, 2:07, 12:03, 21:58; **23**, 7:54, 17:50; **24**, 3:45, 13:41, 23:36; **25**, 9:32, 19:28; **26**, 5:23, 15:19; **27**, 1:15, 11:10, 21:06; **28**, 7:02, 16:57; **29**, 2:53, 12:48, 22:44; **30**, 8:40, 18:35; **31**, 4:31, 14:27.

To obtain Eastern Standard Time, subtract 5 hours from UT; for Pacific Standard Time, subtract 8. (The times listed assume that the spot is centered at System II longitude 184°.)

On September 15th, when Christopher Go took this superb image, Jupiter's orange Oval BA ("Red Spot Junior") was passing just south of the Great Red Spot with no apparent effect on either. South is up.

Geminid Meteor Alert!

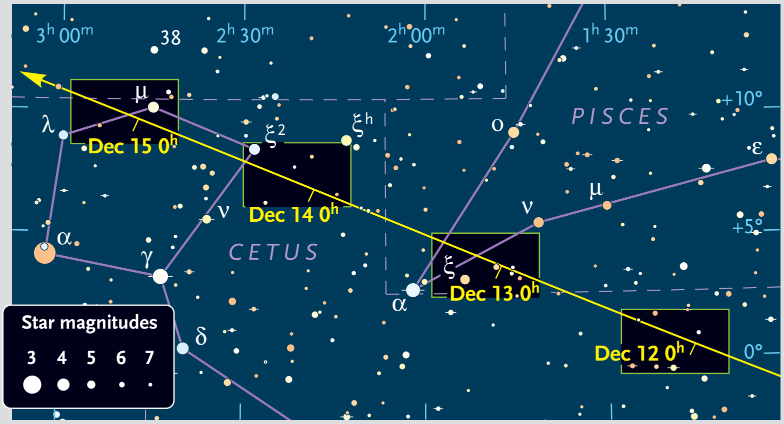
The Geminid meteor shower this year should be excellent. It reliably produces about 120 meteors visible per hour for an observer at a dark-sky site late on the peak night, and this year there's no moonlight.

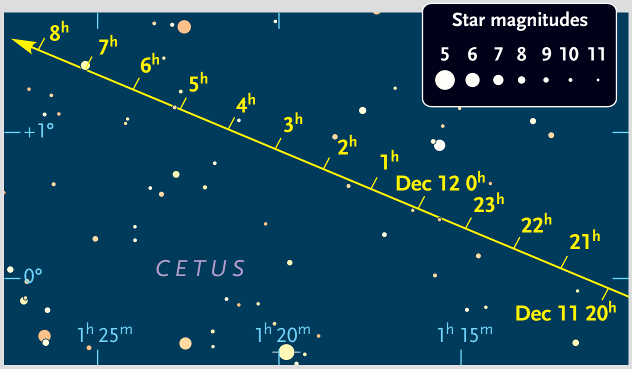
Peak activity should come on the night of December 13–14, though the shower is also active for a couple days before and about a day after. Bundle up, lie back in a sleeping bag in a reclining lawn chair, watch the sky, and be patient. A meteor is a Geminid if its path, followed backward far across the sky, would lead back to a point close to Castor in Gemini.

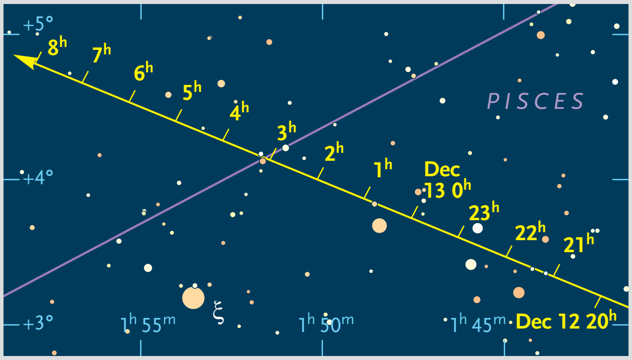
Try doing a real meteor count to report! See **skypub.com/meteors**, "Advanced Meteor Observing."

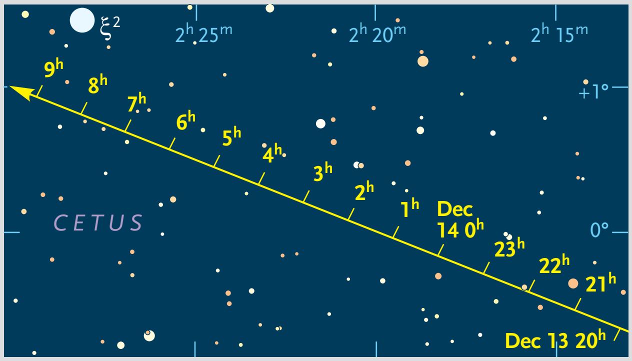
An exceptionally dazzling Geminid fireball plunged across Orion during one of the 1,521 exposures that Wally Pacholka had his camera take on the morning of December 14, 2009. Try it yourself. Good luck; this was a one-in-a-million shot!

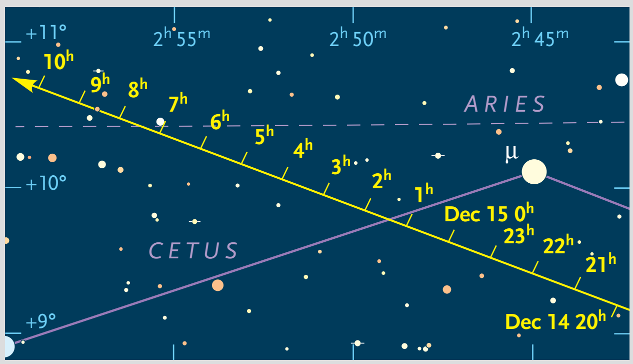
"Sky-Is-Falling" Asteroid Flies By











The path of Toutatis on the four nights when it's closest and brightest: magnitude 10.9 to 10.5. Times and dates are in Universal Time. Blowups are at right.


JPL / STEVE OSTRO

Toutatis imaged by radar during its November 1996 flyby.

Meanwhile, a very different asteroid makes one of its periodic close passes by Earth in mid-December. Little 4179 Toutatis is an irregular double lump measuring just 2.8 × 1.5 × 1.2 miles (4.5 × 2.4 × 1.9 km). Its flybys every four years are what make this asteroid remarkable.

Astronomers first spotted it during a flyby in 1934 but soon lost it. It was rediscovered in 1989 and was named with its possible threat of crashing to Earth in mind. "Toutatis" was a god of ancient Gaul who's now best known from the French *Astérix le Gaulois* cartoons and comic books. In them, the village chief often prays to Toutatis to keep the sky from falling. It always works.

Toutatis is in a chaotic 4-year orbit that's currently governed by a 1:4 resonance with Earth and a 3:1 resonance with Jupiter. But the asteroid is tweaked this way and that by its close Earth passes. We're safe from it for at least the next six centuries, and in the long run, it's much more likely to be ejected from the solar system than to hit our planet.

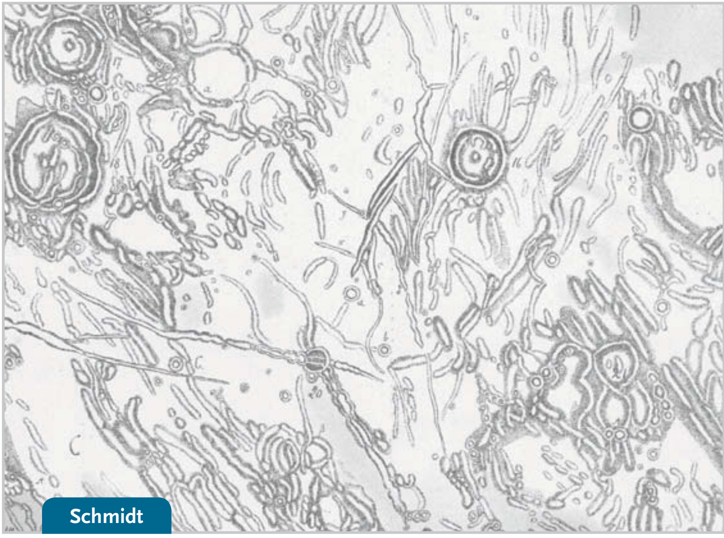
Toutatis passes closest on the night of December 11–12 at a distance of 0.046 astronomical unit (4.3 million miles, 6.9 million km). It should then be shining at magnitude 10.9, brightening to a peak of 10.5 four nights later. During that time it's crossing Cetus and Pisces high in the evening sky. Our charts here plot it for American and European observing hours on those four key nights. Toutatis will be creeping across the stars at about 20 arcseconds per minute, fast enough for you to see its motion in real time.

Four years ago it didn't come quite so close. But four years before that (in September 2004) it missed Earth by just 0.01 a.u., less than a quarter of its distance this time. Its best showing then was for the Southern Hemisphere, but many mid-northern observers will remember tracking it low in the south a few days later at magnitude 10. ✦

Observing History

Challenge yourself to see as well as the best 19th-century lunar cartographers.

NASA / GSFC / ARIZONA STATE UNIVERSITY



Recently while observing the Moon with my 4-inch f/11 refractor, I spent some time thinking about why I like this particular instrument. Besides the high contrast and sharp definition it provides, the telescope presents me with a tangible connection with famous lunar observers of the 19th century. The premier lunar mappers of that era — Johann Mädler, Edmund Neison, and Julius Schmidt — used refractors with apertures of 3.7 to 6 inches.

These observers needed infinitely more patience than amateurs today, because they worked before photography became an effective astronomical tool. All of their maps were based on drawings made at the eyepiece. I'm still awed by what these classic observers saw, and contemplating their long hours bent over sketchbooks makes me more forgiving of the errors they made in depicting lunar features at the edge of their resolution limits.

While observing the seven-day-old Moon recently, I found it especially difficult to detect the K-shaped pattern of rilles east of **Triesnecker Crater**. I found that if I focused intently on the nearby **Rima Hyginus** and then shifted my gaze to Triesnecker, I could glimpse the main north-south rille, but otherwise the "K" was invisible to me. If I had not known it existed, I wouldn't have suspected anything was there.

But Mädler, when observing with a 3.7-inch telescope during the early 1830s, saw the Triesnecker rilles; his map has some errors, but the general pattern of the rilles is correct. The same is true for Neison and probably Schmidt, although his mapping style is less clear than that of the others. Perhaps the eyes or telescopes of these observers were superior to mine. On the other hand, I only spent one evening looking, while these men spent years compiling their maps, using multiple observations to confirm what they saw. I wonder, what size scope is needed by modern observers to definitely see the Triesnecker rilles?

Comparing these three cartographers' depictions of the Rima Hyginus quickly reveals differences. Neison's map of the eastern rille shows five pits along its length, but none are in Mädler's. In the 19th century, astronomers sometimes thought these differences signaled the sudden appearance of new features, proof that the Moon was still geologically active. Without any credible authority to take a side on which features existed, it was easy to think differences might reflect real changes. Thus, the mistaken belief in lunar activity continued for more than 100 years.

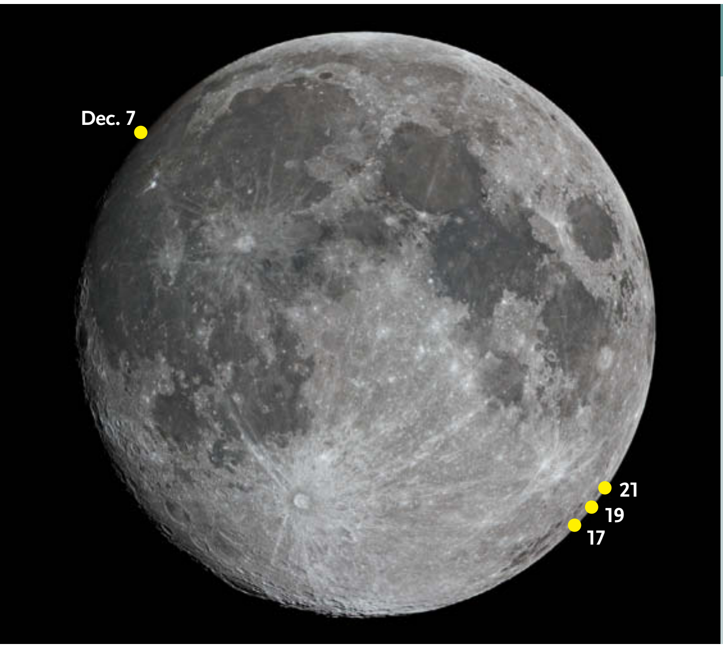
Unfortunately, this search for changes diverted attention from understanding the Moon's geologic history. While looking for small changes, observers overlooked features such as the multi-ring impact basins, the largest lunar landforms. Over time, excited claims of alterations in features such as Linné, Hyginus N, and the small craterlets in Plato became doubtful, perhaps because no

unambiguous change was ever documented.

Now that imagers often capture smaller detail than can be seen through an eyepiece, I sometimes ask, why bother to visually observe the Moon? But as soon as I look through my little refractor, I know the answer. The Moon is always changing, although not physically as 19th-century observers hoped. The view it presents is always new as sunlight relentlessly moves across its face and the Moon tips back and forth in its librations. There are only so many good images of any one place on the Moon, but over a lifetime I can see an unending series of new perspectives.

These details affect me more viscerally when I notice them at the telescope than they do when I'm having similar revelations sitting in front of a computer screen. So I await the next opportunity of personal discovery, when I can point my telescope at the Moon and find features I have overlooked and under-appreciated. ✦

Comparing features around Triesnecker Crater to their depictions in 19th-century maps by Julius Schmidt, Edmund Neison, and Johann Mädler helps the author gain new appreciation for these classic cartographers' observational talents. South is up to match the depiction in the three accompanying maps. (Turn the page upside down to see the "K" pattern of rilles.)



The Moon • December 2012

Phases

LAST QUARTER
December 6, 15:31 UT

NEW MOON
December 13, 8:42 UT

FIRST QUARTER
December 20, 5:19 UT

FULL MOON
December 28, 10:21 UT

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

S&T: DENNIS DI CICCO

Distances

Perigee	December 12, 23ʰ UT
223,405 miles	diam. 33′ 14″
Apogee	December 25, 21ʰ UT
251,253 miles	diam. 29′ 33″

Librations

McLaughlin (crater)	December 7
Lyot (crater)	December 17
Jenner (crater)	December 19
Abel (crater)	December 21

The Laconian Key

A great variety of clusters occupy one tiny piece of Cassiopeia.

But lustrous in the full-mooned night, sits Cassiopeia.
Not numerous nor double-rowed
The gems that deck her form.
But like a key which through an inward-fastened
Folding-door men thrust to knock aside the bolts,
They shine in single zigzag row.

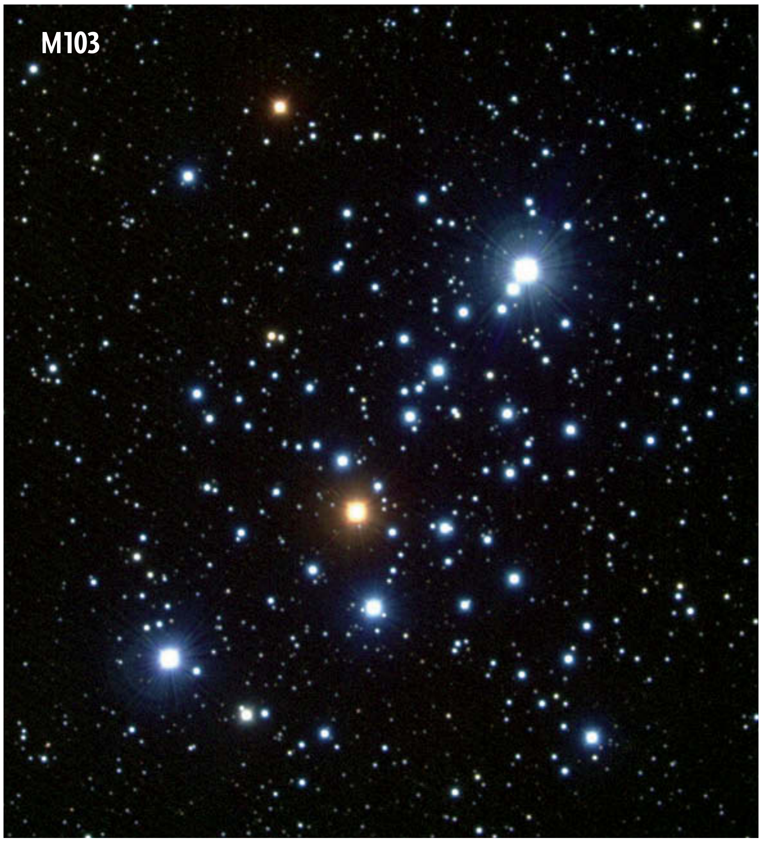
— Aratus, *Phaenomena*

Gazing northward on a wintry night, we see the familiar pattern of Cassiopeia as an M inscribed on the sky. The Greeks also knew this pattern as the Laconian key, whose creation they attributed to the Spartans in the region of Greece known as Laconia. A Laconian key supposedly had three teeth that gave it the shape of an M, but a blockier M than we behold in our heavenly queen.

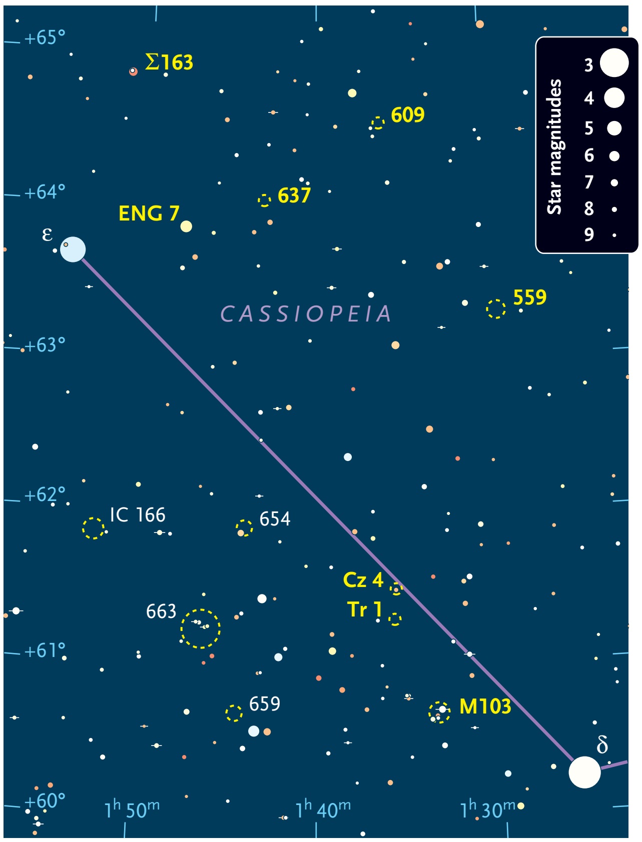
Let's begin our sky tour with **Messier 103**, handily located near Delta (δ) Cassiopeiae in the Laconian key. Charles Messier's friend and colleague Pierre Méchain discovered this open cluster, and Messier didn't have time to observe the cluster himself before incorporating it into his 1781 catalog. M103 is the last object that Messier ever added to the catalog. More than a century later, other astronomers appended M104 through M110, citing evidence that they were seen by either Messier or Méchain.

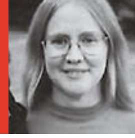
M103 is visible in my 9×50 finderscope as a compact line of three stars, the middle one having a faint companion to the south. Delta and M103 share the field of view through my 105-mm (4.1-inch) refractor at 28×. The line's middle star is an orange ember, and 11 faint stars transform the group into a 5′ triangle with its brightest star adorning the north-northwestern corner. At 87× the cluster swells to about 6′ and 30 stars, some beyond the triangle's border. My 10-inch reflector at 187× polishes these gems and adds about 10 more sparkles to this very pretty cluster.

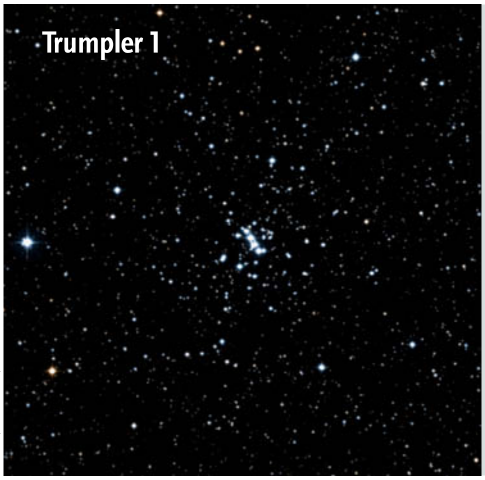
Climbing 41′ north-northeast we come to the open cluster **Trumpler 1.** My 105-mm scope at 122× shows a tight

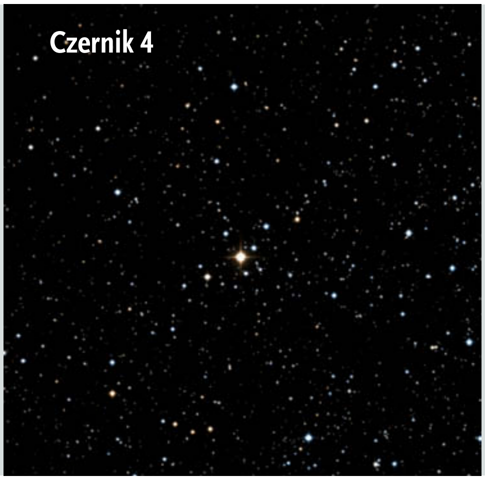


HILLARY MATHIS / NIGEL A. SHARP / NOAO / AURA / NSF









POSS-II / CALTECH / PALOMAR OBSERVATORY (2)

Messier 103, the brightest star cluster described in this article, is shown on the facing page in a field of view 8′ wide. All the other clusters are shown at a smaller scale, in fields of view 15′ wide.

little line of four stars in a northeast-southwest line. Massachusetts amateur John Davis calls this "marvelous little asterism" the Zipper. My scope also shows several fainter stars: two flanking the Zipper's northeastern end, one just west of its southwestern end, a longer line of three stars to its south, and a couple of very faint stars intermittently visible to its west. The entire group spans only 2½′.

Trumpler 1 is named for Robert Julius Trumpler, who included it in his 1930 *Lick Observatory Bulletin* on open clusters. It was the first anonymous object in Trumpler's list of 334 clusters, but Trumpler acknowledges its previous photographic discovery by Isaac Roberts (*Monthly Notices of the Royal Astronomical Society*, 1893), who called it "a very remarkable group of stars arranged in two parallel straight lines of four each. The stars are all of about 10th mag., and the photo-disks partly overlap each other, so that the combination appears like a star trail; and, in order to make sure that it was not a trail, a second photograph was taken with a short exposure."

Through my 10-inch scope at 187×, **Czernik 4** pops out 11′ north of Trumpler 1 in the same field of view. This nifty little cluster is dominated by a bright golden star that forms a ½′ box with three fainter suns. The box is neatly nestled inside a 1½′-tall trapezoid of four more stars.

The Polish astronomer Mieczyslaw Wojciech Czernik discovered his clusters by examining *National Geographic Society – Palomar Sky Atlas* charts. Of the 45 objects that he reported in *Acta Astronomica* (1966), three weren't original discoveries and four weren't clusters.

Exactly 2° north-northwest of Czernik 4, we come to the open cluster **NGC 559** (shown on the following page). It's easy to spot as a granular hazy patch with a few faint specks through my 105-mm refractor at 17×. A few additional stars turn up at 87×. The group appears about 6′ across, and a ragged tail of 10th- to 12th-magnitude stars reaches northwest from the group. In my 10-inch scope at 118×, NGC 559 is a pretty cluster, rich in faint stars, and elongated northeast-southwest. At 171× I count 45 stars in about 5½′ × 4′. The three brightest stars make a skinny isosceles triangle near the center of the group.

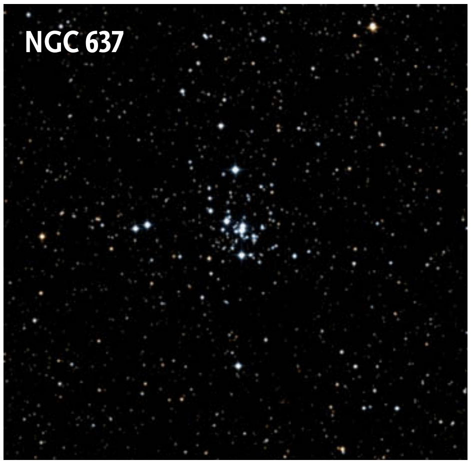
In a 2007 paper in *Astronomy & Astrophysics*, Gracjan Maciejewski and Andrzej Niedzielski estimate that NGC 559 has 7,286 stars and a total mass 3,170 times greater than our Sun. The authors give the cluster's core radius as 2.3′ and its limiting radius as 14.5′.

Now we'll move to Epsilon (ε) Cassiopeiae in the Laconian key and then sweep 46′ west-northwest to the double star **Engelmann 7** (ENG 7). This is a widely split and colorful pair through my 105-mm refractor at 17×. The bright golden primary watches over a considerably dimmer reddish companion to the south.

Clusters and Double Stars in Eastern Cassiopeia

Object	Type	Mag(v)	Size/Sep	RA	Dec.	Distance
M103	Open cluster	7.4	6.0′	$1^h 33.4^m$	+60° 40′	7,000 l-y
Tr 1	Open cluster	8.1	3.0′	$1^h 35.7^m$	+61° 17′	8,000 l-y
Cz 4	Open cluster	—	4.0′	$1^h 35.6^m$	+61° 29′	5,000 l-y
NGC 559	Open cluster	9.5	7.0′	$1^h 29.5^m$	+63° 18′	4,000 l-y
ENG 7	Double star	5.7, 9.9	46″	$1^h 47.7^m$	+63° 51′	—
NGC 637	Open cluster	8.2	3.5′	$1^h 43.1^m$	+64° 02′	7,000 l-y
NGC 609	Open cluster	11.0	3.0′	$1^h 36.4^m$	+64° 32′	13,000 l-y
Σ163	Double star	6.8, 9.1	35″	$1^h 51.3^m$	+64° 51′	—

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



POSS-II / CALTECH / PALOMAR OBSERVATORY (3)

A study in the *Journal of Double Star Observations* (2005) indicates that the components of Engelmann 7 aren't physically related. The investigators conclude that the companion star's motion is consistent with travel in a straight line and too fast for a gravitationally bound system.

The cluster **NGC 637** sits 33′ west-northwest of Engelmann 7. My 105-mm scope at 127× shows a right triangle made by four 10th- and 11th-magnitude field stars. Two of the stars mark the triangle's eastern point, and the other two form its 6.3′-long, north-south hypotenuse. NGC 637 dangles just below the triangle's northern corner. The group harbors a small knot of four stars similar in magnitude to the triangle stars, plus quite a few very faint to extremely faint stars. Just 9″ apart, two of the knot's stars form the double Stein 264 (STI 264). My 10-inch reflector at 171× crowds 25 suns into a 3½′ cluster.

The pulsations of certain variable stars can be used as seismic waves to probe their internal structure. NGC 637 promises to be a good target for this type of study, known as asteroseismology. In *Astronomy & Astrophysics* last year, Gerald Handler and Stefan Meingast confirmed the presence of one Beta Cephei variable in NGC 637 and discovered at least three more. Having several pulsators in a cluster simplifies asteroseismic studies. Their better-known distances help astronomers determine key properties such as luminosity and temperature, and their similar ages and chemical compositions constrain the derived stellar models.

The rich cluster **NGC 609** is perched 53′ northwest of NGC 637. It's merely a small spot of fuzz through my 105-mm refractor at 47×. The northernmost member of a very widely spaced pair of 9th-magnitude stars guards its southeastern flank. My 10-inch scope at 118× unveils only a few very faint stars, but at 220× many very faint to extremely faint stars spangle a glowing mist 3′ across.

NGC 609 is an ancient open cluster about 1.7 billion years old, while the rest of the groups in this tour have relatively youthful ages of 10 million to 100 million years. NGC 609 is also the most distant at 13,000 light-years. The distances to the other clusters are listed in the table on the previous page.

Returning to the Draconian-key star Epsilon and then hiking 1.2° north-northwest takes us to another colorful double star, **Struve 163** (Σ163 or STF 163). I can recognize the 6.8-magnitude primary immediately by its lovely red-orange color when viewed with my 105-mm scope at 17×. A wide and considerably fainter companion attends it from the northeast. The companion shows no color through my little refractor, but it appears icy blue-white in the 10-inch reflector. ✦

DID YOU KNOW?

Senior contributing editor J. Kelly Beatty records a podcast describing the most exciting celestial sights and events for each month. It's a great way to tour the night sky without losing your dark adaptation by reading text off a bright screen. You can find it at skypub.com/podcasts.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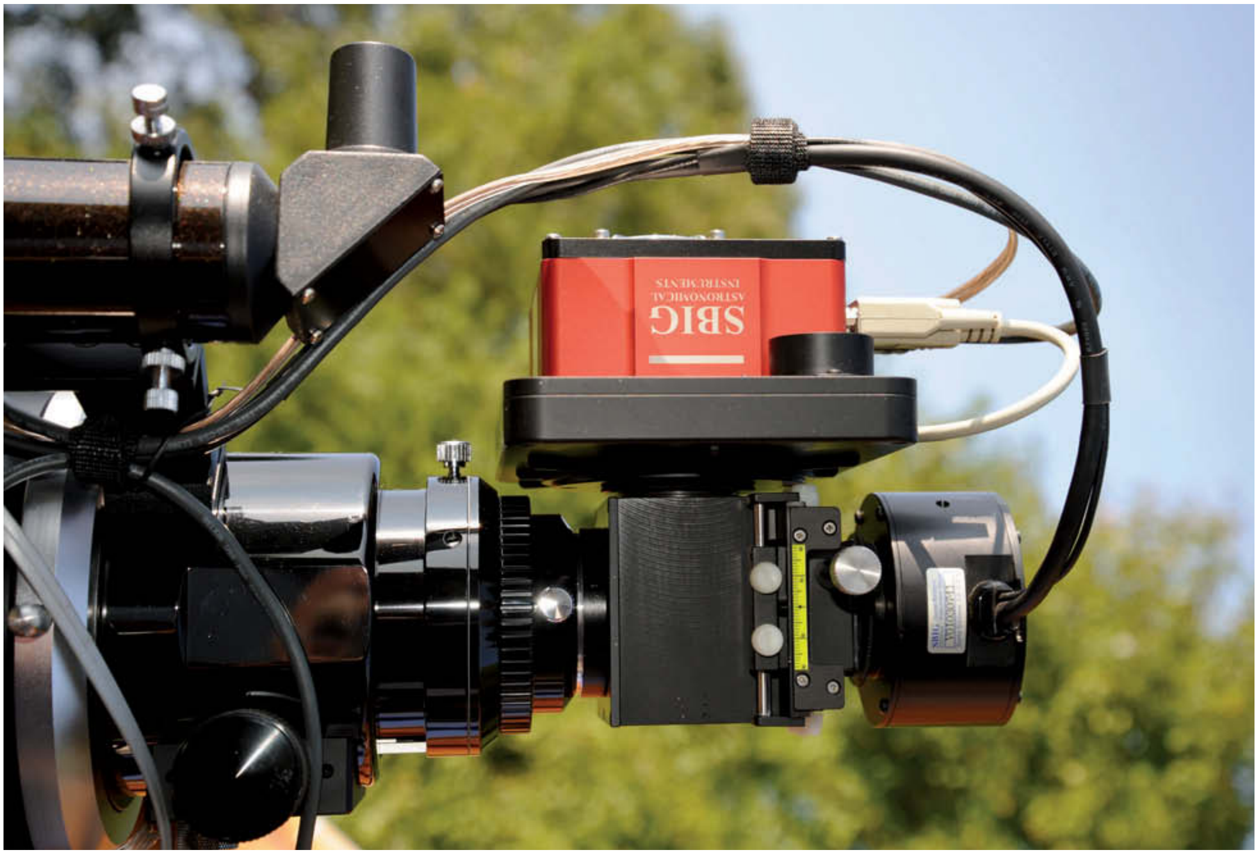
Background image taken by Michel Lefevre, winner of the 2011 ATIK Imaging Competition.

 Dennis di Cicco

The ONAG from Innovations Foresight



ALL IMAGES BY THE AUTHOR

The ONAG looks like an exotic star diagonal and works by reflecting visual light to an imaging camera and transmitting infrared light to an autoguider. The author tested it with the Sky-Watcher 120-mm f/7 refractor reviewed in last June's issue, page 34.

The digital revolution (and the ONAG) gives us a new way to guide our astrophotos

Innovations Foresight's ONAG

U.S. price: $989
Innovations Foresight, LLC
225 Cadwalader Ave.; Elkins Park, PA 19027
innovationsforesight.com; 215-885-3330

Observers have been guiding their telescopes since the dawn of long-exposure astrophotography. It's a need that arises from a very long list of mechanical, optical, and atmospheric factors that makes it all but impossible for a simple telescope drive to precisely follow a celestial object for more than a minute or two as it moves across the sky.

The history of astrophotography is filled with ingenious ways people have devised to guide telescopes, and I thought about recapping some of them. But then I realized it would take way too much space to cover just the methods developed before the digital revolution began rewriting astrophotography's rules. Indeed, I've reviewed two products recently — the Telescope Drive Master (October 2011 issue, page 60) and the Paramount

MX (July 2012, page 64) — that use digital technology to transform the way we guide our telescopes. Now the ONAG (short for on-axis guider) from Innovations Foresight offers yet another fascinating method that is a byproduct of the digital age.

The Concept

One of the best ways to guide a telescope has always been to track a star at the edge of its field of view. Known as off-axis guiding (because the guide star is outside the field being photographed), the method eliminates many (but not all) of the mechanical, optical, and atmospheric problems mentioned above because the images of the celestial object being recorded and the guide star are formed by the same optical system. Off-axis guiding became mainstream with amateurs after the introduction of popular Schmidt-Cassegrain telescopes in the early 1970s, but it dates back to the earliest days of long-exposure photography at the turn of the 20th century. And it's the way the largest professional telescopes were guided when emulsion-based photography ruled the world of astronomy.

One downside to off-axis guiding, especially in the case of moving objects such as asteroids and comets, is that you can't guide on the same object you are imaging. Some people have tackled this problem by using a beam splitter to share a telescope's field of view with the imaging camera and guiding system, but this robs the camera of valuable light.

Enter the ONAG. Because digital detectors in today's autoguiders are sensitive to near-infrared (NIR) light beyond the visual spectrum, the ONAG works by sending a telescope's visible light to the imaging camera and the NIR to the guiding system. It does this with a beam splitter made from a so-called "cold mirror" that reflects visual wavelengths between 350 and 750 nanometers to one focal plane and transmits NIR beyond 750 nm to another. Ingenious! And it works because digital technology has given us the opportunity to easily use NIR light for guiding.

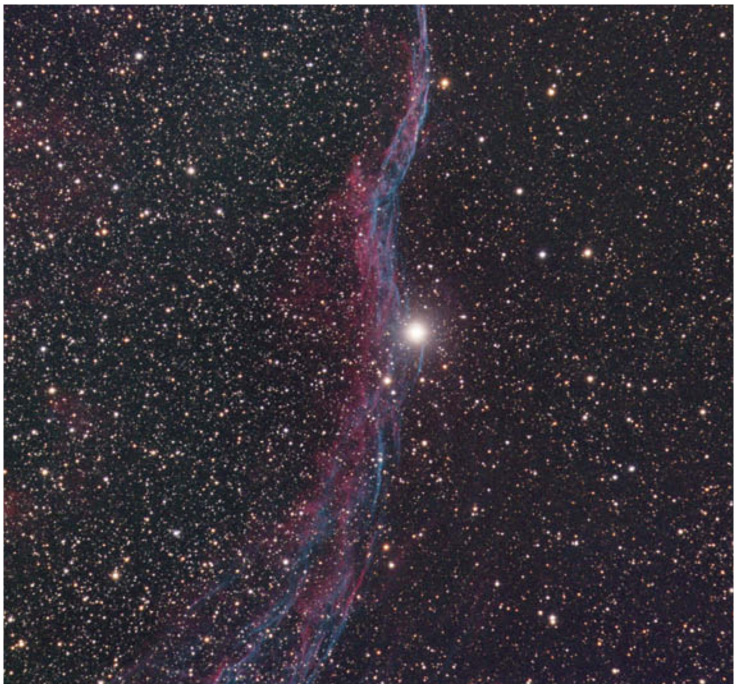
The ONAG

As clever as the concept behind the ONAG is, the devil is in the details, and that's where the ONAG really shines. The device, which from a distance looks a bit like an oversized star diagonal, is extremely well engineered and, more importantly, well made.

Even people new to long-exposure astrophotography have heard about the gremlin "differential flexure" that ruins photographs when there's shift between the imaging and guiding systems. This is a particularly common problem for people using separate telescopes for guiding and imaging. Despite conventional wisdom, differential flexure can also be a problem with off-axis (and on-axis) guiding if there isn't an absolutely rigid connection between the imaging and guiding detectors. The ONAG has a very rigid connection, and it's especially noteworthy

Left and below: **The ONAG's autoguider port accepts standard 1¼-inch equipment and comes with a fitting that has male T threads. The port is on an X-Y platform that travels on pairs of precision rails and locks in place with a total of eight nylon thumbscrews. The yellow scales on the X-Y axes can assist in positioning the port for guide stars selected in advance from star charts.**

Below: **Faint ghost images sometimes appeared near bright stars centered in the field of view, but it's unknown if they were due to the ONAG. Because the bright star 52 Cygni was slightly displaced from the center, it did not show a ghost in this view of the western Veil Nebula, NGC 6960.**



Guiding with the ONAG was so accurate that the author did not need to use stars to register the 90 minutes of exposures that were stacked for this view of the "Central America" region of the North America Nebula. Sean Walker did the final processing for all the astronomical images in this review.

because the device has an adjustable X-Y mounting for the guide camera, which helps in the search for suitable guide stars.

Using the ONAG involves getting your imaging camera and autoguider to reach focus simultaneously, and that means there are a lot of physical parameters to consider for your particular equipment. Fortunately, the Innovations Foresight website (**http://innovationsforesight.com**) gives very detailed mechanical specifications for the ONAG. So I'll just relate a few of the fundamental ones here. Because the ONAG's imaging port has a camera mount with male T threads, the system is best for detectors that span no more than 28 mm across their diagonal dimension. Although this includes the APS-size chips in popular DSLR cameras and Kodak's KAF-8300 CCD found in many high-end astronomical cameras, it is not large enough to completely illuminate the detectors in full-frame DSLRs or Kodak's KAF-11000 CCD.

The minimum back-focus distance between the female T threads on the ONAG's front mounting plate and the imaging port is 66 mm (2.6 inches), while the nominal back focus to the guiding port is 90 mm, with plus or minus 4½ mm available for focusing. Since most imaging cameras have more internal back focus (for filter wheels and the like) than autoguiders, the difference between the back focus on the ONAG's imaging and guiding ports is an advantage. As the accompanying pictures show, my setup with an early model SBIG ST-8300 camera and filter wheel and a now-vintage SBIG STV autoguider came to perfect focus without additional adapters. But for other setups that might need them, the ONAG comes with a set of 8-, 16-, and 24-mm extension tubes that work on both ports. The ONAG comes with a standard 2-inch nosepiece as well as a dedicated adapter that attaches directly onto the back of 8-inch Schmidt-Cassegrain telescopes.

The Guide Stars

The guider port accepts standard 1¼-inch equipment, and it comes with a drawtube with male T threads. As mentioned above, there's an X-Y stage on the guider port that allows the user to move the center of the autoguider's view 28 mm horizontally and 23 mm vertically, so you can essentially "explore" a 46-mm-diameter area of your telescope's focal plane to search for appropriate guide stars. This area is huge compared to what's available with most off-axis guiding systems. But there's another aspect of the ONAG that further improves the efficiency of finding a guide star.

As anyone who has done off-axis guiding knows, many telescopes produce crummy off-axis star images that are smeared by optical aberrations and dimmed by vignetting. Fainter off-axis stars can be so compromised that it becomes difficult for an autoguider to lock onto them for tracking. The guide stars available to the ONAG are closer to the telescope's optical axis and are thus of much better quality for guiding. That said, the ONAG's guide stars are not perfect, since they suffer from astigmatism introduced by the telescope's converging beam passing through the cold mirror's glass substrate tilted at a 45° angle to the optical axis. With careful focusing of the guide camera, the ONAG's guide stars were "tight" enough for my setup to easily guide on them. But Innovations Foresight offers an optional astigmatism corrector for those who want "imaging quality" stars available at the guiding port.

Although you can use virtually any camera that works as an autoguider with the ONAG, it has to be one without a built-in infrared-blocking filter. The only cameras that might have such a filter would be one-shot color cameras. Another aspect of the ONAG's guiding system worth noting is the apparent brightness of stars viewed at NIR wavelengths. What you "see" is not always what you get. Many stars that appear bright to our eyes can be relatively faint at NIR wavelength, and vice versa. This is of little consequence if you're hunting for guide stars by taking snapshots with your autoguider, since you'll just pick an appropriate star from the images. But it can complicate matters if you plan your imaging sessions beforehand with star charts.

As a case in point, consider the image of the open star cluster Collinder 399 (The Coathanger) on page 40. Although the westernmost star in the Coathanger's bar is visually the faintest, my autoguider on the ONAG saw it as nearly twice the brightness of any of the other stars in the bar. Typically, stars with later spectral types (those redder than the Sun) are relatively brighter at NIR wavelengths than earlier (bluish and white) stars. As such, planetarium programs that show stellar spectral types (such as Software Bisque's *TheSkyX*) can be helpful if you want to pinpoint potential guide stars in advance.

The only other aspect of the ONAG that I had to adapt to was the mirror-reversed "raw" views from my imaging camera. Although image-processing software can flip these images to make them right reading, I didn't always do this at the telescope. I was also handicapped by years of experience framing photos based on the merest hints of an object visible in a camera's viewfinder or in short test exposures, so more than once I mistakenly used a raw test exposure from the ONAG to nudge the telescope in the wrong direction before shooting a long exposure. All astrophotographers develop their own system of workflow at the telescope, so I can't recommend the best way to deal with the ONAG's mirror-reversed images other than to just call attention to them.

The Results

From the get-go I had excellent results with the ONAG. With autoguider exposures of 5 seconds or less, I could often find a suitable guide star without having to move the autoguider on the X-Y platform after I had my target framed in the field of the ST-8300 imaging camera. Those using imaging cameras with smaller detectors (which offer less flexibility framing targets), or with telescopes having a slower focal ratio than the f/7 system I was using (finding guide stars is a function of f/ratio, not aperture or focal length alone), may have to rely more on the X-Y adjustments to locate guide stars.

The guiding was remarkably accurate during all of my testing. The image of the asteroid 2 Pallas below is a good example. Although the picture shows that I could guide on the moving target *and* image it simultaneously, it's the result of stacking 18 five-minute exposures by registering the frames only to themselves (not to the asteroid or any stars). Had there been wobbly guiding or any differential flexure between the imaging camera and autoguider, Pallas would have showed a trailed image along with the stars. Although I generally use multiple stars as registration points when I stack my deep-sky frames, I could often dispense with this step when stacking images made with the ONAG. The cold mirror did not introduce any obvious color shift to my images.

After working with the ONAG for many nights last fall, I can certainly say that it's easier to use than any off-axis system I've tried (and that includes a few that I built myself). It also produced some of the most accurately guided image sequences I've ever obtained. It's yet one more way that digital technology has made the challenge of acquiring accurately guided images easier than ever before. ✦

What we liked:

- Uses guide stars in the same field being imaged
- Excellent engineering and mechanical construction
- Capable of extraordinary guiding accuracy

What we didn't like:

- Size of imaging field limited by T-thread fittings
- Selecting guide stars in advance based on visual magnitudes can be misleading

As explained in the accompanying text, the author could simultaneously image *and* guide on the asteroid Pallas in this 1½-hour exposure obtained during the early morning of last September 24th.

*Senior editor **Dennis di Cicco** doubts he can recall all the ways he's tried guiding telescopes during his nearly 50 years as an active astrophotographer.*

New Product Showcase

▼ **NEW TAK** Takahashi unveils its new FC-76DC apochromatic refractor ($1,949). This 76-mm f/7.5 telescope utilizes a two-element, air-spaced objective with a multi-coated fluorite rear lens and an "eco-glass" front element to provide color-free views and tack-sharp images. Weighing 4 pounds (1.8 kg) and being only 25 inches (64 cm) long, the scope also features a 2.6-inch focuser to accommodate large CCD and DSLR detectors and other heavy accessories. A dedicated focal reducer is available that shortens the focal ratio to f/5.5 and fully illuminates a 36-mm image circle. A non-reducing, dedicated field flattener is also available as an option.

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1925A Richmond Ave., Houston, TX 77098
713-529-3551; www.takahashiamerica.com

TEXAS NAUTICAL REPAIR

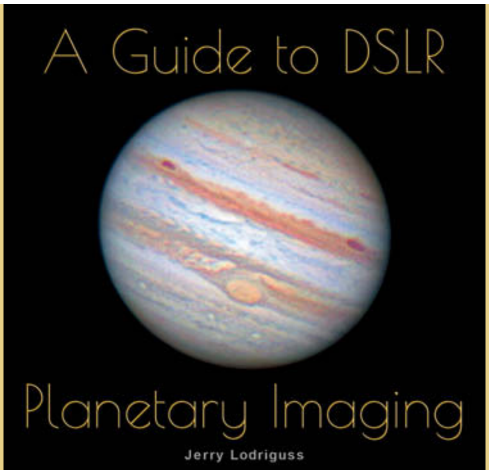
SOFTWARE BISQUE

▲ **PORTABLE PIER** Software Bisque unveils its new Pyramid Portable Pier ($1,700). Weighing only 20 pounds (9 kg), the pier is designed to mate with the company's new Paramount MX Robotic Telescope Mount (reviewed in last July's issue, page 64). The pier's tubular leg design is capable of supporting up to 250 pounds, and its mounting base can rotate a full 360°. Raised leveling-adjustment knobs allow you to find horizontal position without crouching, and the pier feet swivel to conform to uneven terrain. The Pyramid Portable Pier also includes a center tray to hold accessories.

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

PLANETARY HOW-TO The new CD-ROM book *A Guide to DSLR Planetary Imaging* by Jerry Lodriguss ($39.95) explains how to capture and process high-resolution images of the Sun, Moon, and planets by recording high-definition video with a Canon DSLR camera. Learn how to use "lucky imaging" techniques to record sunspots, tiny lunar craters, and subtle detail on the planets. The book is written in HTML and can be viewed with any web browser on both Mac and PC computers. It also includes a glossary of planetary-imaging terms, a built-in search engine, imaging formulas and calculators, and video tutorials on processing planetary images. See the author's website for additional details.

Jerry Lodriguss: *A Guide to DSLR Planetary Imaging*, Available at www.astropix.com



JERRY LODRIGUSS

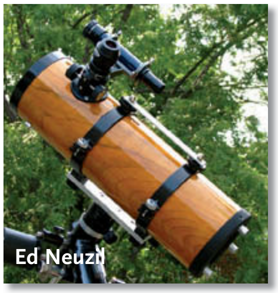
New Product Showcase is a reader service featuring innovative equipment and software of interest to amateur astronomers. The descriptions are based largely on information supplied by the manufacturers or distributors. *Sky & Telescope* assumes no responsibility for the accuracy of vendors' statements.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

Pimp Your StarBlast

Here's how several readers have customized Orion's popular reflector.

ONE OF THE BEST WAYS to dip a toe into the telescope-making waters is to modify an existing instrument. In addition to getting some valuable hands-on experience, you'll also end up with a piece of gear that's uniquely your own. The popular 4½-inch StarBlast reflector from Orion Telescopes & Binoculars is a good customization candidate. It's basic, relatively inexpensive, and, as several have reported, fun to modify.

One striking example of a cosmetic upgrade is Ed Neuzil's faux wood-tubed StarBlast. "I used contact cement to glue a thin veneer of cherry wood onto a 5½-inch phenolic model-rocket tube," Ed explains. He finished it off with a couple of coats of orange-tinted polyurethane that he buffed to a high-gloss finish with automotive polishing compound.



Ed Neuzil

Ed says that if were to do it again, he'd use a stronger material called "blue tube" from Apogee Components (**www.apogeerockets.com**). Because his new tube was thicker than the scope's original metal tube, the front and rear fittings had to be changed. "The rear cell is from another scope that had the right inside diameter," he explains. "The front ring is actually several strips of 1-inch-wide veneer laminated onto the tube and painted black." The finished scope is wonderfully elegant and evokes a 19th-century aesthetic. (Readers can contact Ed at **ngc7332@gmail.com**.)

On the wish list for many StarBlast owners is a focuser for 2-inch eyepieces. But as Paul Starr discovered, making this mod isn't quite as simple as swapping the stock focuser for a new one, since the replacement unit needs to be the same height. "I looked into changing the focuser several times in the past and couldn't find anything appropriate that didn't approach the price of the scope itself," Paul recalls. Eventually he came upon an inexpensive helical focuser by Meridian Telescopes (**www.meridiantelescopes.com**).

Paul Starr

Paul had to first enlarge the exiting focuser hole by trimming the tube with tin snips. To provide a sufficiently robust connection for the new focuser, he fabricated a mounting plate from 20-gauge sheet metal, attached the focuser to the plate, and then bolted the whole assembly to the scope.

The result is a StarBlast that better suites Paul's observing needs. "I can now use heavy, well-corrected 2-inch eyepieces for really wide fields of view," he reports. "The new focuser improves the utility of the scope and was well worth the money, time, and effort to install." (Paul can be reached at **pstarr7@yahoo.com**.)

One of the StarBlast's greatest virtues is that it works for many different observing tasks. "I've been interested in observing satellites since the days of Sputnik," John Graham recounts. "I tend to use scopes with wide fields of view, so the StarBlast seemed like it would be a fine satellite tracker."

John Graham

The stock StarBlast mount is simple and sturdy, but it lacks setting circles. For John, this was a mod waiting to happen. "I designed a set of setting circles using a CAD program, printed them out on heavy card stock, and laminated them onto foam-core sheets with clear packing tape."

The setting circles help him aim the scope at a point along the target satellite's flight path. "I use a program called SatSpy, which prepares tables listing a satellite's altitude and azimuth at 1-minute intervals," John explains. "I set the telescope to a position listed in the table, wait for the satellite to appear, and then follow it across the sky."

The setting circles assist with more than just satellite tracking. Using a software package that provides real-time altitude and azimuth coordinates, John also locates difficult deep-sky objects by dialing in their positions. From Earth-orbiting satellites to the depths of the universe — now that's a versatile scope. (John can be e-mailed at **john.graham@udri.udayton.edu**.) ✦

*Contributing editor **Gary Seronik** has his own modified Star-Blast featured on his website, **www.garyseronik.com**.*

ABCs of CCD Imaging

Follow these simple suggestions to get the most out of your CCD images.

Warren Keller

Have you ever been told to mind your P's and Q's? How about cross your T's or dot your I's? Attention to detail is essential to the art and science of deep-sky CCD imaging. But if you're thinking about getting started collecting your own photons, I have good news. You can forget about 25 letters of the alphabet and concentrate on one — S — and its multiple meanings.

Signal

Great astrophotography is all about signal, and having lots of it. Producing beautiful astrophotos today is done by making many short individual exposures (known as subframes) and combining them into master files. In this way, a faint signal from an astronomical target accumulates on a CCD, while the random electronic noise associated with digital exposures is reduced.

Obtaining quality signal isn't easy, but once you've mastered the technique of shooting sharply focused images with nice, round stars, you're ready to move ahead with gathering good signal. Whether you acquire the exposures with a one-shot color (OSC) CCD camera, a DSLR, or through separate color filters and a monochromatic CCD camera, you need to calibrate and then *stack* them. Stacking is a metaphor for digitally combining multiple exposures.

Subtract

Besides the "light" exposures of your target, you need additional exposures so that you can properly calibrate the light frames before stacking them. These exposures include dark frames, bias frames, and flat-field images. Let's have a look at what each of these shots accomplish and how they make your final results better.

Because most astronomical subjects beyond our solar system are exceedingly faint, it takes many minutes of exposure to accumulate enough signal to detect their dimmest regions. During these long exposures, your digital camera generates thermal noise that appears as snowy dots all across your image. Fortunately, this unwanted noise is predictable and can be minimized by subtracting what is known as a *dark frame*.

Dark frames are exposures made with the camera or telescope objective covered, so that no light reaches the

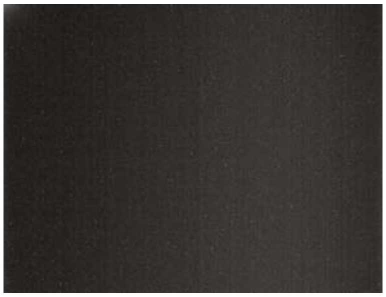
ALL IMAGES COURTESY OF WARREN KELLER

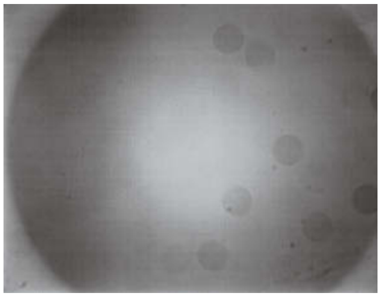
This dazzling color image of IC 434 in Orion is just one example of what's possible with digital cameras today. Author Warren Keller explains the basic processing steps necessary to get you started on producing your own celestial masterpieces.

detector and only the camera's thermal signal is recorded. To be effective, dark frames must be taken with the same conditions — exposure duration, detector temperature, and pixel binning mode — as the light frames they are meant to calibrate. When many dark frames are recorded and combined to make a master dark frame, and that master is subtracted from each individual light exposure, it removes the majority of the snowy dots of thermal signal.

In the case of low-noise chips such as Sony's Super HAD CCD detectors, darks have been shown to be redundant and may actually contribute noise. Rather than use dark frames for calibration, you can often process an image from these detectors using a defect map of the sensor's *hot pixels*. Hot pixels appear as bright specks in an image. Every sensor has them, and they become especially problematic during image stacking. Some image-processing software can use a sensor's defect map to eliminate bad pixels by filling them with an average value from the surrounding pixels. In this case, the result is better than a dark-frame calibration, as darks merely subtract the hot pixels, leaving a black pixel.

Because flat-field frames for image calibration can be tricky, they are often the last ones to be conquered by new imagers. Just as darks and biases are portraits of the flaws in the camera's electronics, flats are a portrait of the anomalies in the optical system. In some cases, you can dispense with flats, but when uneven illumination and dust particles are visible in your light images, the best





***Far left*: It's necessary to subtract dark frames from most CCD images. Dark frames record the thermal charge that builds up during an exposure. They should be recorded at the same temperature and duration as the light frames they are to be applied to. *Near left:* Flat-field images should also be applied to your raw files to remove dust shadows and vignetting (uneven field illumination). Flat-field images are pictures of a blank, evenly illuminated target.**

way to correct them is by using flats.

Flat-field frames are exposures made with your telescope pointed at a blank, evenly illuminated target. They should have an exposure duration that produces pixels with an average brightness value of one-third to one-half of the camera's specified saturation level (this value is easily read by software). Light boxes and electroluminescent panels with adjustable brightness settings are increasingly popular devices for making flat-field exposures, as Peter Kalajian explained in his article in the March 2011 issue, page 72. Just like light exposures, you should record and calibrate your flat-field images with multiple dark frames recorded at the same temperature and duration.

Stacking

Once you've completed calibration of your light frames, you can move on to combining them. If you're imaging with an OSC camera, you should debayer (color convert) the individual subexposures, transforming the grayscale images into color pictures, before stacking. The individual subexposures should now be aligned, since it's inevitable that a slight image drift will occur between subexposures, making the same bit of image detail fall on different pixels in each frame. Drift sometimes includes field rotation as well as simple translation. Most astronomical image-processing programs include some method to align images by matching star patterns in each image with subpixel accuracy. Once the images are aligned, the files are ready to be stacked into a master.

Software typically offers several methods to combine subexposures, with *sum*, *average*, *median*, and *sigma reject* being the most common. Because of some inevitable random signal present in many images (such as cosmic ray artifacts or satellite and airplane trails), the sum and average methods are not my first choice because they include these artifacts in the stacked result, though they produce the highest signal. To deal with these anomalies, you should use a statistical-rejection method. Median combine removes many of these image artifacts,

Combining multiple exposures together reduces the grainy appearance while increasing the signal of faint targets. The examples at left show the result of a single exposure *(top)* compared to a stack of three subexposures *(middle)*, while the result of combining nine images *(bottom)* is even smoother.

but it produces a grainy result. Most imagers choose a sigma-rejection stacking method, essentially an excellent compromise between average and median combine. Sigma-reject stacking checks to see if a given pixel's brightness value is relatively similar in a majority of the subexposures, and rejects any pixel value that is beyond the standard deviation of the majority.

In the case of one-shot color cameras, the stacked image is now ready for post-processing. Images recorded through separate color filters with a monochromatic camera require a few more steps. Separate red, green, and blue master files (and unfiltered luminance images) have to be aligned and stacked independently. You create the color image by aligning and combining these color-filtered stacks into a master RGB image called a *chrominance*. Although the chrominance image provides the beautiful color, it's the *luminance* image (shot without color filters) that can contribute some of the sharpest detail. Your CCD image-processing software can combine luminance and chrominance, but it's often best to reserve this step for other post-processing software such as *Adobe Photoshop,* which provides better control over both components.

Stretching

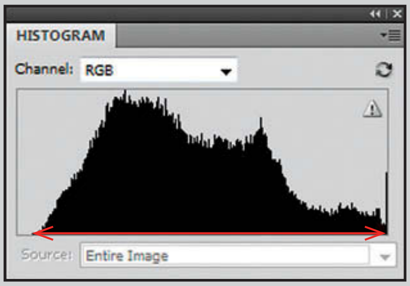
Stacked subframes produce an image that needs to be stretched. Unlike daylight images, the vast majority of celestial objects are so faint that even with hours of exposure, the combined result appears mostly black with a smattering of stars across the field. We need to *stretch* the image to reveal our target.

So what is stretching? To find out, we first need to examine a graph called a *histogram*. The histogram displays the range of dark and light levels in an image. Every good image-processing program has some form of histogram display. If we look at the histogram of a typical daylight photograph, the intensity range is spread out, occupying the majority of the graph. But when we examine the histogram of a typical unprocessed deep-sky photo, it generally consists of a flat graph with a single thin spike. That spike holds the bulk of the information in our precious data; everything to the right of that spike is a star. Our task is to redistribute, or stretch, the pixels over the greater part of the graph to better resemble the dynamic range of terrestrial photographs. This is where the art in astrophotography comes into play.

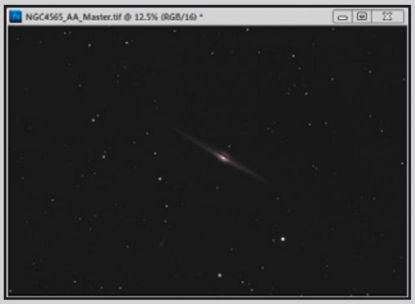
Using stretching tools in our CCD image-processing software such as Digital Development or Curves, we can keep the background sky dark and the stars from becoming too bright while giving a significant boost to the critical midrange where our subjects generally hide. The image on page 72 shows a typical application of the Curves tool in *Adobe Photoshop*. The left side of the graph represents shadows, the right is highlights, and the midrange lies in between. Judicious applications of Curves preserve all of the detail and color that you originally captured. With the histogram stretched to an appropriate brightness level, you can then sharpen and further enhance an image to increase local contrast.

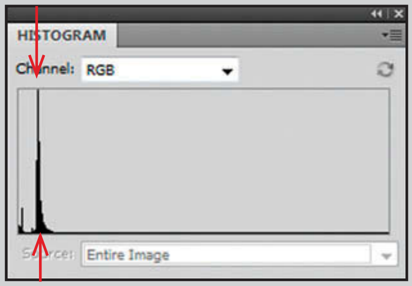
Stretching usually reveals one final artifact that needs to be dealt with in astrophotos: *gradients*. Gradients are

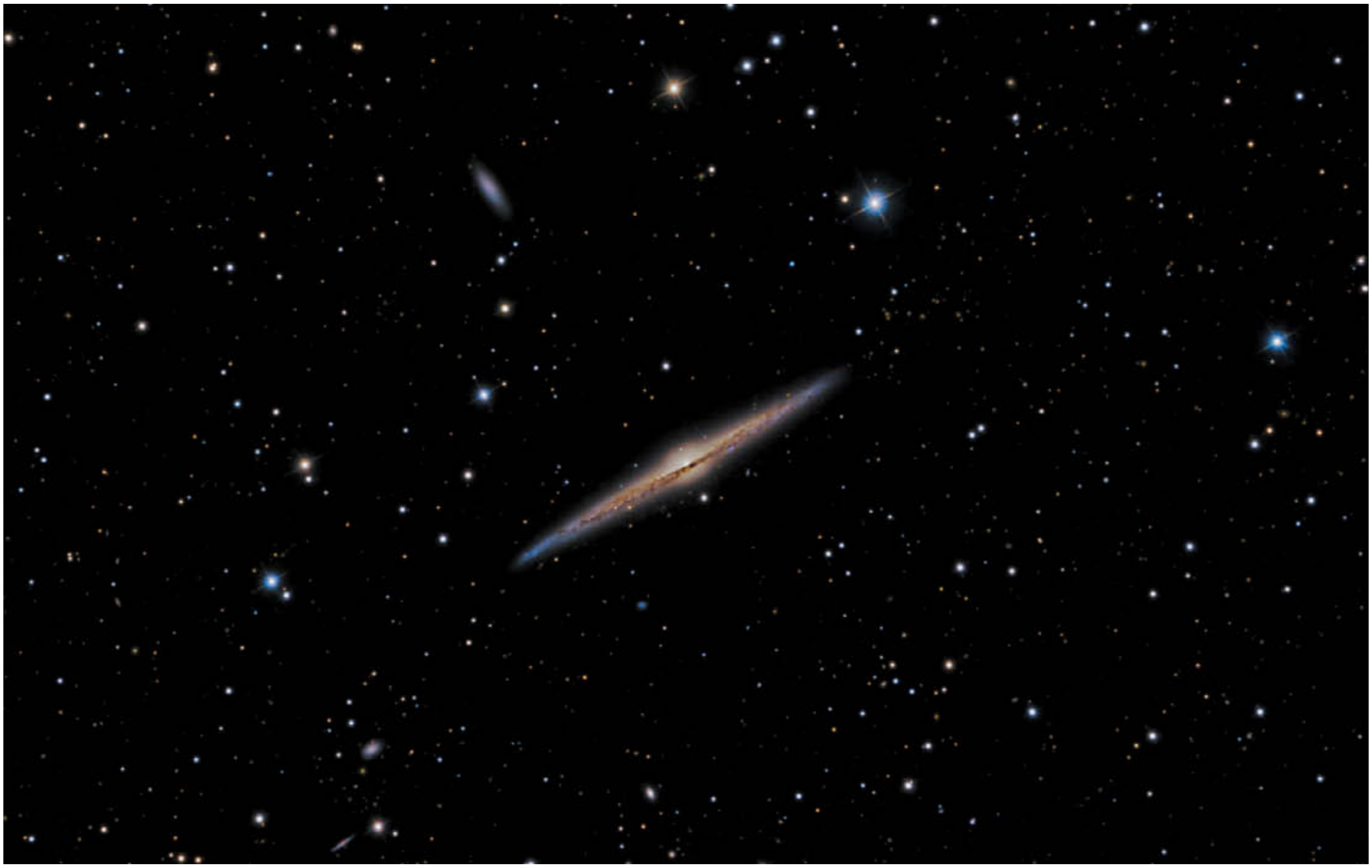
When we examine the histogram *(below)* of a typical daylight photo such as the canyon at right, it displays a wide range of brightness levels from the darkest regions at the left of the graph to the bright highlights at the right. The histogram of the calibrated deep-sky image at the far lower right reveals a single spike that represents the signal of galaxy NGC 4565 in the image. This spike needs to be stretched sideways to better distribute the light and dark levels in the galaxy.

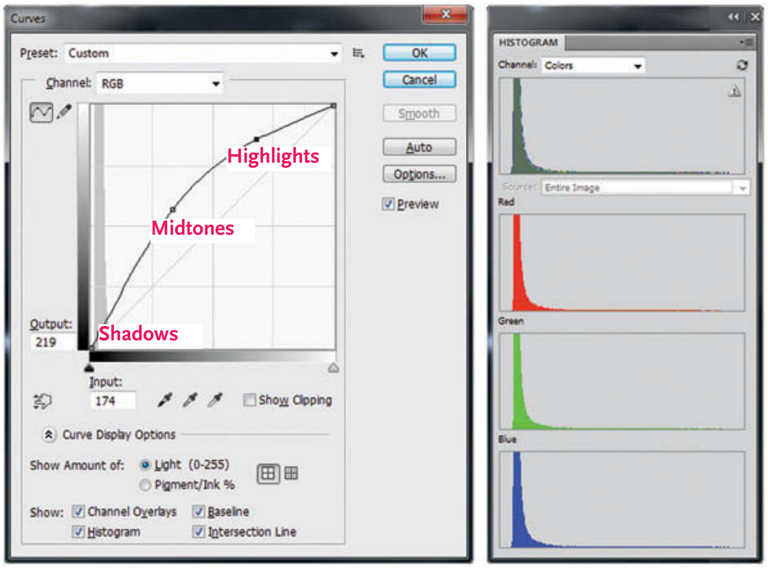


Stretching









***Left: Photoshop*'s Curves tool allows you to boost the midrange in your image while keeping the highlights (usually stars) from becoming white splotches. *Right:* When stretching a color image, you should monitor the histogram of all three color channels to retain the color balance of the image. A good rule of thumb is to stretch the histogram of the red, green, and blue channels similarly to avoid introducing a color bias. The curve above helped to reveal the bluish outer arms in the image of edge-on galaxy NGC 4565 at top.**

often the result of light pollution, and appear as a linear brightening across an image. Most image-processing programs include tools for reducing gradients.

Saturate

Finally, it is rich color that makes the human brain think "Wow!" In astrophotography, we can use artistic license by boosting color saturation to an aesthetically stimulating level. Unfortunately, it's not as easy as dragging a slider to "More." Advanced imagers devote a great deal of time to achieving good color balance. When you assemble red, green, and blue images into a chrominance photo, be careful to stretch them equally and to monitor the way these three channels relate to one another. Linear adjustments such as *Photoshop*'s Levels and Color Balance tools work well for subtle adjustments, and astronomy-specific programs such as *PixInsight*'s "ColorCalibration" tool is nothing short of brilliant.

In truth, we have only begun to learn our ABCs. There is so much more to producing jaw-dropping images of the heavens, but beginning with these basic "S's" will give you a head start to mastering the CCD alphabet. ✦

***Warren Keller** is author of the video tutorial series* Image Processing for Astrophotography, *available at **www.ip4ap.com**.*

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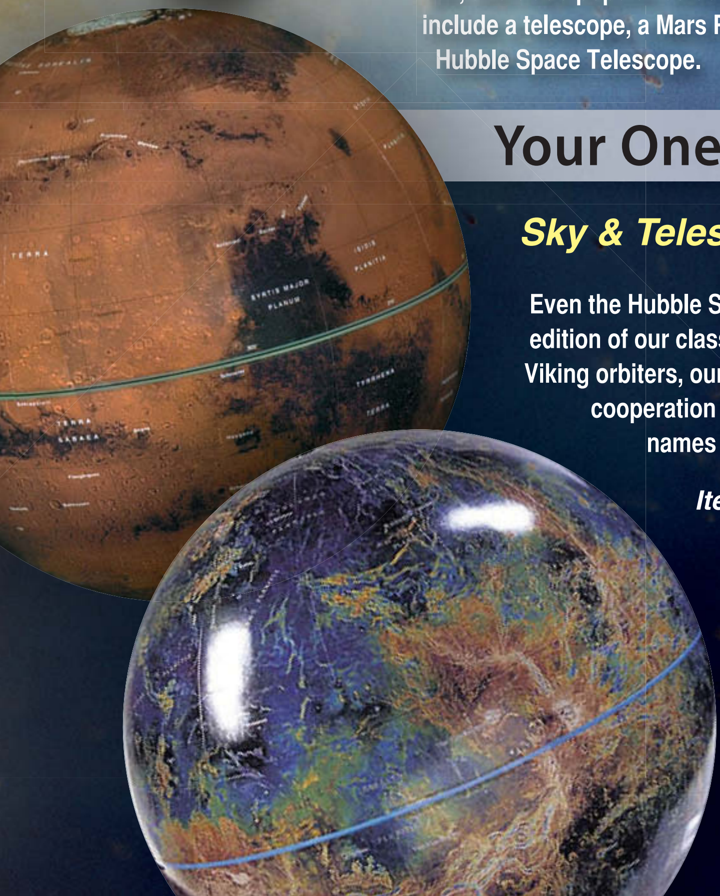

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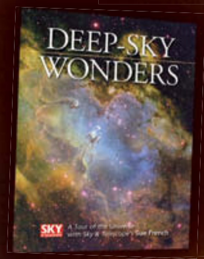

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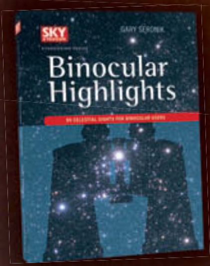

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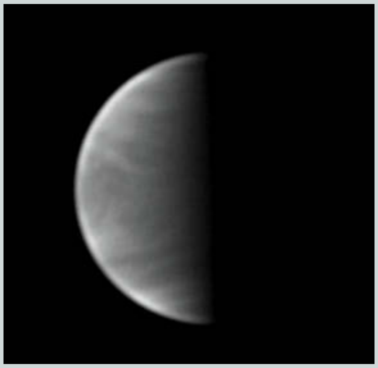

▲ **RED SPOT GATHERING**

Paulo Casquinha

Jupiter's famous Great Red Spot is joined by Oval BA and a dark brown storm in this image captured on the morning of August 21, 2012.

Details: *Celestron C14 Schmidt-Cassegrain telescope with Lumenera SKYnyx2-0M video camera. Stack of multiple frames recorded through Astronomik Type II color filters.*

◄ **VENUS REVEALED**

Rick Schrantz

Venus displays subtle banding in its upper atmosphere in this ultraviolet image taken on the morning of August 23rd.

Details: *10-inch Newtonian reflector with Imaging Source DMK 21AU04.AS video camera. Stack of multiple frames recorded through a Schuler ultraviolet filter.*

▼ **SCENIC SAGITTARIUS**

Kfir Simon

Nebulae IC 1274 (top) and NGC 6559 (center) are a colorful mix of reddish hydrogen and bluish reflection nebulosity, each bisected by opaque dust.

Details: *16-inch f/3.75 Dream Astrograph with Apogee Alta U16M CCD camera. Total exposure was 48 minutes through color filters.*

◀ **HOLLOW AND CLUSTER**

Roth Ritter

The glittering jewel-like stars of open cluster M52 (top left) present imagers with an interesting visual contrast with neighboring NGC 7635, the Bubble Nebula, in Cassiopeia.

Details: *RCOS 10-inch Ritchey-Chrétien telescope with SBIG STL-11000M CCD camera. Total exposure was 10⅔ hours through Baader color filters.*

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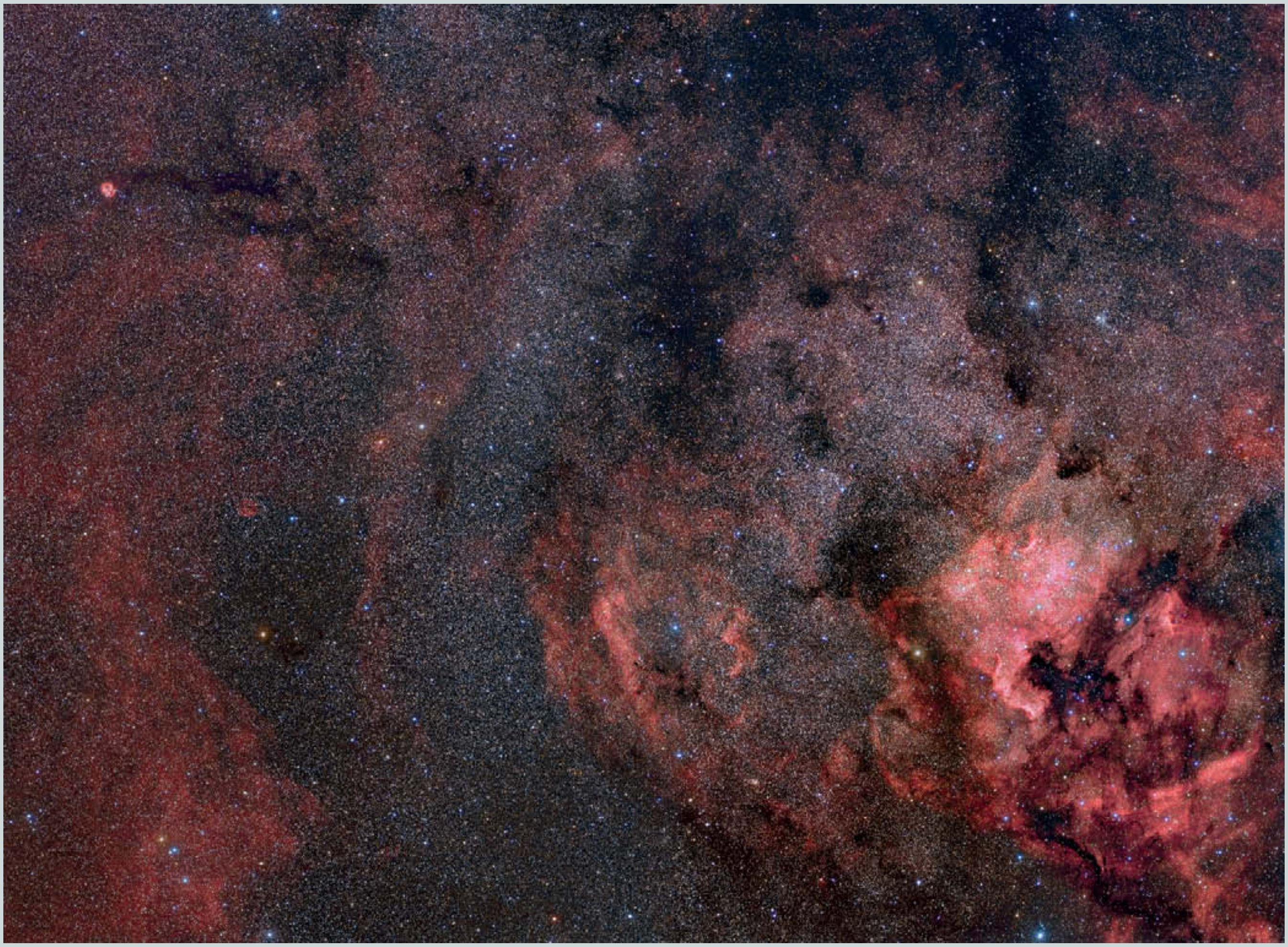

▲ **COCOON TO THE PELICAN**

John Davis

Giant clouds of gas and dust permeate the constellation Cygnus, including IC 5146 at top left, and the North America Nebula, NGC 7000, at bottom right.

Details: *Takahashi FSQ-106N astrograph with SBIG STL-11000M and QSI 583 CCD cameras. 8-frame mosaic. Total exposure was 12 hours through color filters.*

► **FARAWAY CLUSTER**

Bob Fera

Despite being about 2.5 million light-years away, the star cluster NGC 206 in the spiral galaxy M31 in Andromeda resolves into individual stars in large telescopes.

Details: *Officina Stellare RC-360AST 14-inch Ritchey-Chrétien telescope with Apogee Alta U16M CCD camera. Total exposure was 12 hours through Astrodon color filters.* ✦

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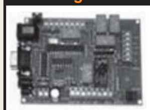

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PS Form 3526 (Facsimile), October 1999 (Reverse)

Neil Armstrong, Lunar Explorer

The first moonwalker's brief lunar sojourn yielded a scientific treasure trove.

LAST AUGUST 25TH, on the day Neil Armstrong died, I found myself looking at the Moon and thinking about his impact. He was an icon to the world, but I was lucky enough to know him as a friend. I feel his loss profoundly, for the many personal qualities that made him such an admirable and likeable human being, and the extraordinary contributions he made to space exploration. No one could have been better suited to carry out history's first lunar landing, which for a superb engineering test pilot like him represented the ultimate flying challenge. But there was another, surprising side to Armstrong that he revealed on July 20, 1969: He was a wonderfully skilled scientific explorer.

Time was tight during Apollo 11's 2½-hour moonwalk, as Armstrong and Buzz Aldrin carried out a packed agenda that included planting the American flag, deploying experiments, collecting samples, documenting everything on film, and even taking a phone call from President Nixon. No one would have faulted Armstrong for paying little attention to science. And yet, with the world looking over his shoulder, and despite limited scientific preparation (including just one geology field trip during training), his performance as history's first lunar field geologist was nothing short of remarkable.

Soon after stepping onto the Moon, Armstrong had only a few brief minutes to fill a small bag with lunar soil, the so-called contingency sample. Even so, with the clock ticking, he managed to include some small rocks, and radioed detailed descriptions of the samples and of the powdery lunar surface. Later, he noticed shiny blebs in the bottoms of some craters that would turn out to be glass produced by the heat of meteorite impacts. And late in the moonwalk, Armstrong seized the opportunity to venture about 200 feet (60 meters) from the lunar module *Eagle* to an 80-foot-diameter crater, where he photographed its rock-strewn floor. That brief reconnaissance wasn't in the plan, and it epitomized Armstrong's commitment to the mission's scientific return.


NASA / ANDREW CHAIKIN

When it came time to collect a suite of rocks using a long-handled scoop, Armstrong selected a beautifully diverse assortment. Then, seeing there was still room in the "rock box" but having run out of time for prospecting, he dumped in scoopfuls of lunar dust, which have remained among the most valuable samples in the Apollo collection. Fellow moonwalker Jack Schmitt, who became the only professional geologist to visit the Moon in 1972, wrote that "Neil's 30 minutes of sampling decisions ... remain the most productive half hour in lunar exploration."

For me, the most surprising moment happened not when Armstrong and Aldrin were on the Moon, but when they were just 1,000 feet above it. Standing at *Eagle*'s controls, Armstrong saw that the onboard computer was targeting them for a stadium-size crater, ringed with automobile-size boulders. With fuel running low, Armstrong actually considered trying to set *Eagle* down near the boulders, which he knew would be a geologic bonanza. But as he wryly quipped in my 1988 interview with him, "I didn't have that much courage." Yet he had more than enough courage — not to mention supreme self-confidence and skill — to make space-exploration history. ✦

***Andrew Chaikin** is the author of* A Man on the Moon: The Voyages of the Apollo Astronauts.

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