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THE ESSENTIAL GUIDE TO ASTRONOMY

SKY & TELESCOPE

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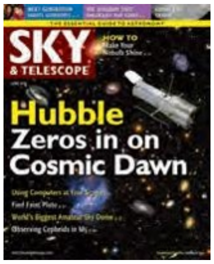

On the cover: The Hubble Space Telescope goes ultra-deep to reveal galaxies in the early universe.

PHOTO: NASA / ESA / S. BECKWITH (STSCI) / HUDF TEAM

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OBSERVING JUNE

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Visit Our New Website, and an Eclipse Cruise

A LOT HAS BEEN HAPPENING since F+W Media acquired *S&T* in January. One highlight is that we're moving fast forward on a major redesign to our website. Given the wealth of information on our site going back to the 1990s, it's a massive undertaking to migrate all of the content from the old platform to the new. This migration process is underway as I write this column in mid-March, and we expect to unveil our new website in April, after this issue has shipped to the printer.

Our new home page will have a cleaner, more elegant appearance. Its modern design enables us to more efficiently display the many features we have to offer. The site will also be easier to navigate, with better search functionality, and you'll find an improved display for our online photo gallery and for clubs and events listings. A lot of people helped make this happen. I want to express my gratitude to Chad Phelps, Amanda Malek, everyone on the F+W web development team, and *S&T* web editor Monica Young, for their enthusiasm in embracing this challenge. Check out the new **SkyandTelescope.com**!!!

We have more details about our cruise to view the March 9, 2016 total solar eclipse. We're conducting this tour in partnership with InSight Cruises, an experienced company with whom we have previously collaborated on several successful astronomy trips. The cruise starts and ends in the great port city of Singapore, one of Asia's crown jewels. We'll sail through the Indonesian archipelago on the Holland America liner *ms Volendam*, making ports of call in choice destinations such as Jakarta, Komodo, Lombok, and Bali. We will view the eclipse in the Makassar Strait, between the islands of Borneo and Sulawesi. Weather permitting, our ship will be positioned right on the eclipse centerline, where we'll enjoy 2 minutes and 45 seconds of totality.

ISTOCKPHOTOS.COM

We'll explore Indonesia's legendary cultures, see stunning natural beauty, and sample traditional cuisines. The cruise runs from March 1 to 17, 2016, although you can join the group after we depart from Singapore, or leave early, when the ship stops in Bali on March 13th. We'll also have a great lineup of speakers to stimulate your brain. For more information and a detailed itinerary, see page 83 and visit **skypub.com/2016eclipse**. ✦

Robert Naeye
Editor in Chief

SKY & TELESCOPE

Founded in 1941 by Charles A. Federer, Jr. and Helen Spence Federer

The Essential Guide to Astronomy

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Kuiper Belt Shines — in Print

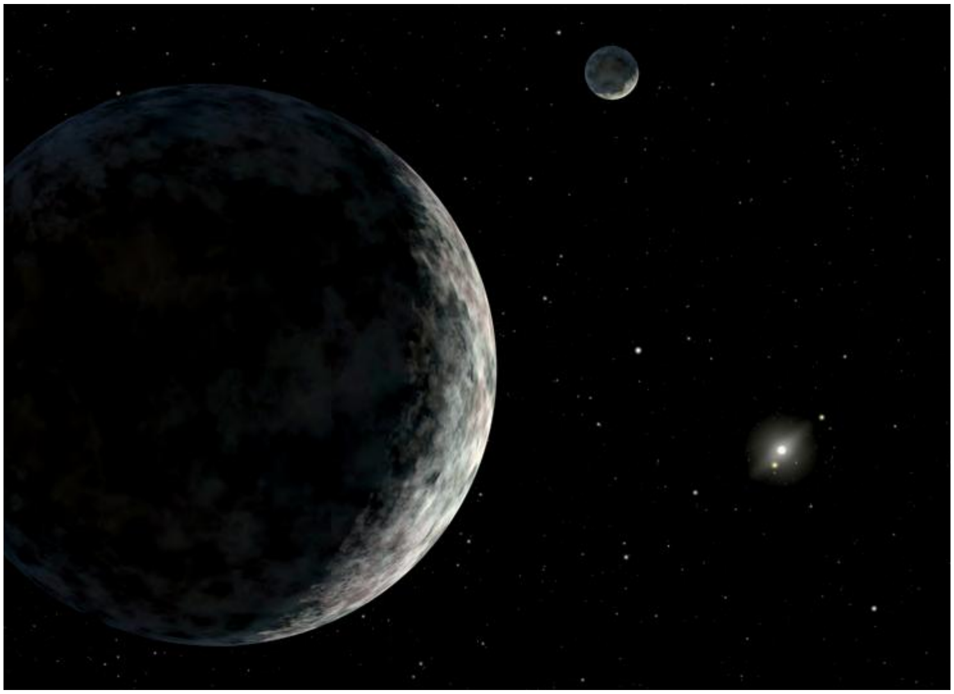
Many thanks to Emily Lakdawalla for her superb article on Pluto and the Kuiper Belt (*S&T*: Feb. 2014, p. 18). Among much else to praise, the figure at the top of pages 22–23 — which shows to scale the sizes, colors, and brightnesses of the belt's largest objects — told me more than I had known about the nature of Kuiper Belt objects and why it was important to stop calling Pluto a planet. A wonderful overview of the whole subject.

Bruce Sherwood
Santa Fe, New Mexico

I have just finished reading Lakdawalla's article. It is outstanding in explaining the new facts of the Kuiper Belt. When I began studying the solar system in 1954, the system stopped with Pluto. I would hope that she would consider an article that would bring us up to date on the Oort Cloud.

Gary Brodersen
Via e-mail

Editor's Note: *Unfortunately there's not much to say! David Jewitt's discussion of the Oort Cloud in his March 2010 article "What Else is Out There?" (page 20) sums up where things stand.*


CALTECH

This illustration shows Eris and its moon, Dysnomia, in their cold home in the Kuiper Belt.

The fact that teachers told Lakdawalla's daughter that Pluto is a star is troubling, but it's not unique in the spectrum of astronomy education students receive. Our own children learned in school that the phases of the Moon were caused by Earth's shadow. And in a shocking display of misplaced priorities, our school district demolished a fine planetarium to make room for a regular classroom.

Science has become a hard sell, but maybe we can all help a little. The upcoming total solar eclipses across parts of the U.S. in 2017 and 2024 provide a great opportunity. I've made presentations to my Central Bucks school board, as well as boards in nearby school districts, on the educational opportunities an eclipse-viewing field trip would offer students. The educational attributes include not only science and math but also historical and literary aspects, such as the saros cycle from the ancient Babylonians and the many astronomy references in Shakespeare. I have met with my state senator and Congressional representative to encourage them to consider an initiative for a state-sponsored field trip program, which would allow students to behold the wonders of the total eclipses firsthand. I propose that readers do likewise. Anyone interested in helping to promote the idea is more than welcome to e-mail me for a copy of my presentation.

Andrew Ochadlick, Jr.
andrewochadlick@comcast.net
New Hope, Pennsylvania

Lakdawalla's article is a fine survey of the varied bodies in the outer solar system. I admit I feel more comfortable calling these objects "trans-Neptunians." Their existence was suggested in 1930 by Frederick Leonard, in 1943 and 1949 by Kenneth Edgeworth, and in 1950 by Gerard Kuiper — but he actually did not believe that the belt still existed. His suggestion was that the bodies had been there early on but been scattered outward to the Oort Cloud by Pluto.

In 2005, trying to adjust some wording about Pluto for my *Astronomical Calendar 2006*, I got help from the great Brian Marsden (1937–2010), then director of the Minor Planet Center. In one of his e-mails to me, he wrote:

> Much as I admired Kuiper, I think the 1980s revisionists gave him too much credit for what he didn't do. The best early description of the transneptunian belt was made by Fred Whipple in 1964. There is a diagram (reproduced in IAU Symp. No. 45 in 1972) showing the "comet ring" at just the right distance, with Pluto itself simply a member of it. The point is that Whipple was talking about something still there: Kuiper had it there only in the early solar system. . . . (I was actually a nonbeliever in the belt, but Fred always believed something was there.)

Sometimes "Edgeworth-Kuiper Belt" is used, and indeed Leonard's or Whipple's name might be applied to it. But "trans-Neptunians" seems the least invidious. The only trouble with it is whether to use capital letters and a hyphen!

Guy Ottewell
Lyme Regis, Dorset, United Kingdom

***Editor's Note:** The* S&T *style gurus have declared that the correct style is "trans-Neptunian." QED.*

Glories of the Milky Way

Kudos to Craig Crossen for his excellent three-part guide to observing the Milky Way (*S&T*: July 2013, Oct. 2013, and Feb. 2014). In this age of light pollution and electronic optics, we often overlook the timeless, silent elegance and majesty of our galaxy. Crossen's articles reminded me not to neglect the forest for the trees.

Marcus Honnecke
North Park, Colorado

Crossen's series on the Milky Way is the best description of our galaxy I have read, because he uses what we can see with our unaided eyes and very modest optics as the framework for understanding the galaxy's shape and dynamic processes. I literally see more when I look at the Milky Way now. This is what *S&T* does best: integrating careful but accessible observations with scientific theory. I hope you will consider reprinting these three articles and the foldout map as a monograph. I would love to have it handy when I'm out with binoculars.

Anthony Barreiro
San Francisco, California

***Editor's Note:** We received a couple of requests to this effect and will explore possibilities for the future.*

In Crossen's fine article on the winter Milky Way (*S&T*: Feb. 2014, p. 26), he notes that the winter Milky Way isn't as bright as the summer's Milky Way and requires a dark sky to see well. That fact was brought home to me during a February public star party at McDonald Observatory, which has some of the darkest night skies of any observatory in the continental U.S. Running north-south just east of Orion, the Milky Way that night was such a bright river of light that I considered it a source of light pollution! It adversely affected my ability to see both the constellations spanning it and those adjacent to it.

Bill Dellinges
Apache Junction, Arizona

The Iron Planet Revealed

I would like to congratulate *S&T* on producing a superb globe of the planet Mercury. Mercury is an amazing planet, but the difficulties inherent in observing it long limited surface mapping to enterprising astronomers, such as Giovanni Schiaparelli (1885) and Eugène Antoniadi (1934). Of course, very few surface details were known until Mariner 10 made the first surface photos during its three flybys from March 1974 to March 1975. Not until October 2011 did mankind survey the complete surface, with NASA's Messenger orbiter. Now thanks to your detailed Mercury globe, all amateur astronomers can finally admire the planet in its full glory!

Philip Corneille
Royal Astronomical Society
De Haan Aan Zee, Belgium

75, 50 & 25 Years Ago

Roger W. Sinnott

May–June 1939

Old Photos "The history of the heavens during the past fifty years lies perpetuated at Harvard in the famous collection of astronomical photographs. During the past six months, an astronomical expedition, financed by the Milton Fund of Harvard University, has made an excursion into the past, and is measuring changes of the brightness of several thousand variable stars, never again accessible to direct observation, on these photographs. . . . The regularities of the variable stars are not so great as might be supposed. . . ."

*Harvard College Observatory continued taking photographic plates with various telescopes and patrol cameras through 1992. The ongoing digitizing project (see **skypub.com/dasch**) will make research with them easier and more fruitful than it was in 1939.*

June 1964

Water on Venus "For the first time, definite evidence has been obtained for the existence of

water vapor in the atmosphere of Venus, report John S. Strong and his co-workers at Johns Hopkins University.

"Water vapor produces characteristic absorption bands in the infrared part of a planet's spectrum, but these are completely obliterated by the intense H_2O absorptions originating in the earth's atmosphere — for telescopes on the ground. Thus, on February 21, 1964, the crucial observations were made during a daylight balloon ascent to 87,500 feet. . . .

"What is the total amount of water vapor in the planet's atmosphere[?] . . . perhaps comparable to that in the earth's atmosphere. But an accurate estimate cannot be made, because of the large uncertainties in estimates of atmospheric pressure at the planet's surface."

Strong's detection, while valid, hardly gave the real picture. Astronomers now know that Venus's upper atmosphere is overwhelmingly carbon dioxide with a little nitrogen; water is only 1/100th as abundant as it is on Earth, compared with other constituents. The clouds of Venus are mostly droplets of sulfuric acid, created from sulfur dioxide and water vapor.

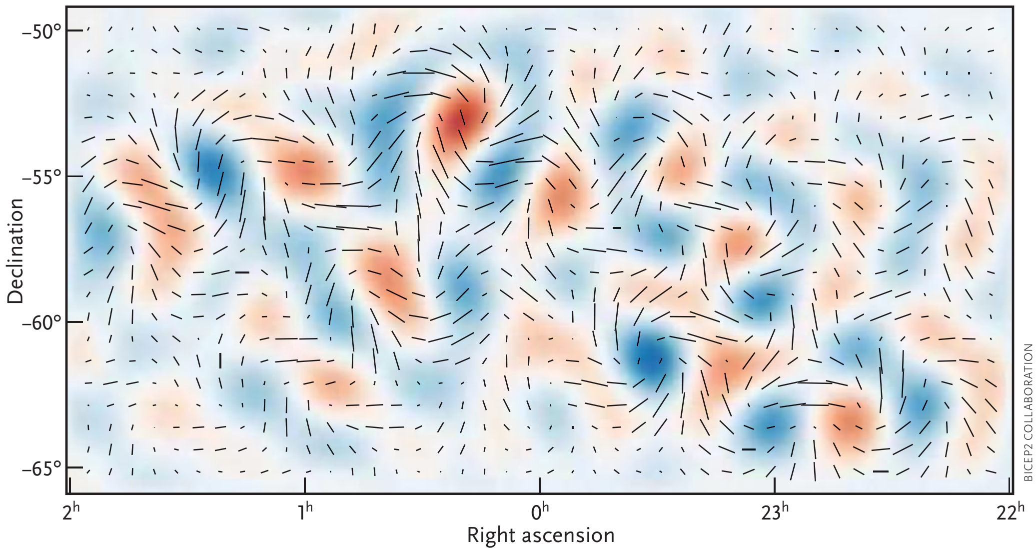
June 1989

Ring Arcs "As Neptune approached the star [on July 22, 1984], both ESO telescopes recorded a second-long dimming in the near infrared amounting to about 35 percent — but it was not seen on the other side of Neptune, as would be expected from a complete ring. . . .

"Despite this [and other stellar occultations], we have yet to understand the nature of the material around Neptune. Is it a small object moving in a strange orbit? A family of small arcs? One continuous but highly variable ring? The occultation observations seem irrefutable, so we are not dealing with some Neptunian version of the Loch Ness monster."

When planetary scientists André Brahic and William Hubbard wrote these words, NASA's Voyager 2 spacecraft was rapidly closing in on Neptune. In a few months it would image a stunning mix of ring arcs, continuous rings, and small satellites never before seen.

COSMOLOGY | 1st Direct Evidence of Big Bang Inflation



The "curly" B-modes of polarization in the cosmic microwave background appear in this map of the sky near the south galactic pole, about 15° tall, crossing the constellations Phoenix and Tucana. Each line is a measure of polarization at one point on the sky. The strongest curl patterns (emphasized with colors — orange is counterclockwise, blue is clockwise) are a couple of degrees wide.

Researchers with the BICEP2 experiment set the world's cosmologists buzzing on March 17th with the announcement that they've detected the fingerprints of inflation — the exponential expansion that put the "bang" in the Big Bang.

About 10 teams of researchers have been actively looking for this signal, called *primordial B-modes* (*S&T*: Oct. 2013, p. 22). B-modes are a particular spiral pattern of polarization. If inflation greatly increased the universe's size, then the rapid expansion should have sent gravitational waves rippling through spacetime. These waves would have imprinted the B-mode polarization pattern on the cosmic microwave background (CMB), the afterglow of radiation left over from the Big Bang.

The discovery comes from the second round of the Background Imaging of Cosmic Extragalactic Polarization (BICEP) experiment, based at the South Pole. It's one of several projects observing the CMB in the Southern Hole, a patch of sky visible from Antarctica that's a direct sightline out of our galaxy and into the cosmic depths.

Using 3 years of data, the BICEP2 team meticulously analyzed its polarization measurements. The group also compared its data with observations from BICEP1 and from the team's new Keck Array, which is basically like five BICEP2s in one. It was this ability to combine three data sets that ultimately allowed the team to make its discovery.

After a year of intense work — including ruling out more than a dozen alternate explanations — team members are confident that they're seeing the signal of inflation, on a scale of about 2° on the sky. In statistical terms, their signal is better than 5 sigma, the gold standard a detection has to meet before physicists accept it as a discovery.

Other researchers are also swayed. "This looks as solid as any result that I've seen," says Alan Guth (MIT), codeveloper of the inflation paradigm. He and the physics community (including the team) want confirmation from other groups, but the signal looks like it's from inflation.

"This is not something that's just a home run, but a grand slam," says Marc Kamionkowski (Johns Hopkins University), one of the theorists who first suggested that inflation-triggered B-modes might be detectable in the CMB. "It's the smoking gun for inflation."

From the BICEP2 results, it looks like inflation happened roughly 10^{-38} second after the Big Bang, says Kamionkowski.

The measurement also suggests that inflation might have had something to do with the unification of three of the four fundamental forces of nature — the strong, weak, and electromagnetic. The energy level implied by the BICEP2 data — we're talking 2×10^{16} GeV, according to Guth, or roughly a trillion times the energy of the Large Hadron Collider — matches the energy of grand unified theories, or GUTs. That's an idea theorists have toyed with since the late 1970s, but the BICEP2 result is the missing link they've sought for decades.

The data also tell researchers something about the ratio of gravitational waves (which are a type of density perturbation) to the run-of-the-mill density fluctuations in the CMB. The BICEP2 team calculates a ratio of about 0.2, which means the gravitational waves were "pretty big," Kamionkowski says. The Planck team had come up with an upper limit of 0.11, but BICEP2 analysis head Clem Pryke (University of Minnesota) says the apparent conflict might be easy to resolve.

The results do not tell us what set inflation in motion, only that it happened. Nor do they say whether inflation is eternal, setting off an endless series of big bangs and creating multiple universes (*S&T*: Dec. 2012, p. 20). However, it's hard to tune inflation such that pocket universes don't sprout from inflating spacetime. The results also mean that the universe is vastly larger than the part we can observe. ■ **CAMILLE M. CARLISLE**

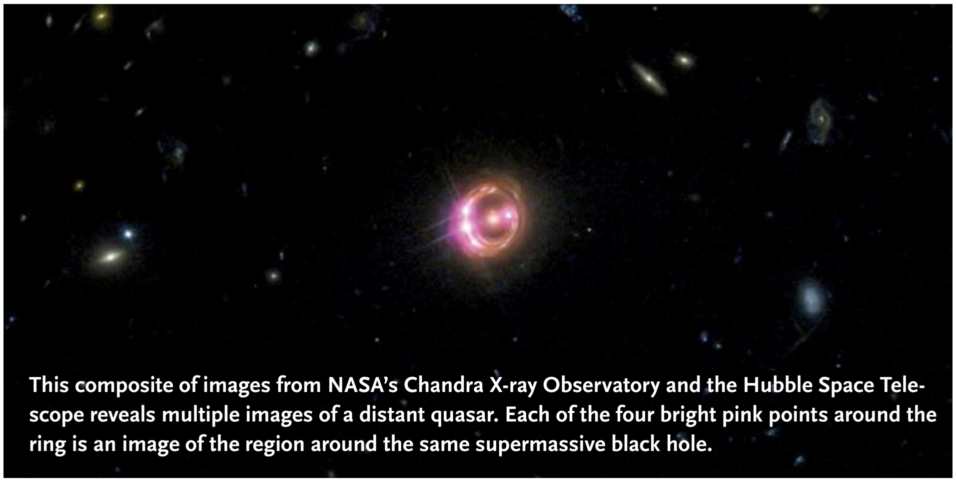
Read the full digest on what the BICEP2 result means for our understanding of cosmology and gravity at skypub.com/bmodesfound.

BLACK HOLES | Farthest Spinner Found . . .

Astronomers have peered into a distant galaxy and caught its supermassive black hole spinning at nearly 90% of its maximum allowed value. The black hole is the most distant yet for which observers have achieved this measurement, and the success may open a new window into how black holes grew in the universe's last several billion years (*S&T:* May 2011, p. 20).

Astronomers have robust spin measurements for about two dozen "local" active galactic nuclei (AGN). The signals from the black holes inside these AGN mostly reach us from the universe's last 300 million years.

Observers estimate spin using X-rays, which many think are produced by a hot corona above and below the accretion disk. These X-rays reflect off the innermost disk, where spacetime is warped and dragged around by the spinning black hole. The X-rays then fly off into space, carrying with them the spectral fingerprints of how the black hole has twisted spacetime, revealing the black hole's spin.



X-RAY: NASA / CXC / UNIV. OF MICHIGAN / R. C. REIS ET AL; OPTICAL: NASA / STSCI

This composite of images from NASA's Chandra X-ray Observatory and the Hubble Space Telescope reveals multiple images of a distant quasar. Each of the four bright pink points around the ring is an image of the region around the same supermassive black hole.

Rubens Reis (University of Michigan) and colleagues have now taken this method farther than ever before. They observed 1RXSJ113151.6–123158, an AGN whose emission has traveled 6 billion years. Inside RXJ1131's core lies a black hole of about 200 million solar masses.

This AGN lies behind a much closer elliptical galaxy. The nearby galaxy's gravity lenses the AGN's emission, creating four duplicate images, each magnified roughly tenfold — making the X-rays easier to decipher. Reis's team analyzed the X-rays and estimated that the black hole's spin is about 87% of its maximum allowed value, the researchers report in *Nature*.

The high spin implies that the black hole ate from a coherent stream of gas coming in from a beefy accretion disk, revving up the object's rotation like water from a garden hose spins up a beach ball. The team hopes to study a number of other lensed systems as well.

■ **CAMILLE M. CARLISLE**

. . . and the Black Hole that Ate Too Much

A black hole in the galaxy M83 might have bitten more off than it should be able to chew. Black holes theoretically adhere to the *Eddington limit*, which predicts that an accreting black hole can only spew so much energy in jets, winds, and radiation from its fluffy disk. Above the limit, all that outward-pushing radiation cuts off the flow of infalling gas and starves the beast.

Black holes occasionally violate this limit, but only for short periods of time. But as Roberto Soria (Curtin University, Australia) and colleagues report February 27th in *Science*, one black hole looks like it broke its limit for roughly 20,000 years.

The team studied the binary system MQ1 in X-rays, optical, infrared, and radio. The X-rays come from the black hole's accretion disk, and based on how the disk's emission should look for a given mass, the team used the system's X-ray brightness to estimate the black hole's mass.

The astronomers also studied a bubble around MQ1, ostensibly inflated by the black hole's jets and other outflows. Based on the emission from hot gas inside the bubble, they calculated how much energy was dumped into the gas and, therefore, the average jet power needed to do it.

Finally, they used the estimated jet power, the bubble's estimated size, and the gas's presumed density to calculate how long the structure had been expanding.

Put together, the evidence suggests that the black hole is between 10 and 115 solar masses, with a best guess of a little more than 40. Over 20,000 years, it ejected 10^{52} ergs in energy into its surroundings, 10 times more than a typical supernova would. If the black hole is about 40 solar masses, the energy output is a few times above its Eddington limit.

Joey Neilsen (Boston University) says the biggest puzzle is why the black hole appears to have broken the Eddington limit for so long. Stellar-mass black holes in binary systems often "turn on" for several months or a year, spitting out jets, and then they fade away for a decade or more.

Soria says it should be possible for a black hole to go three to four times above its Eddington rate for up to 100,000 years if a massive companion star dumps a huge amount of dense, opaque gas onto the black hole. Normally, the pressure of photons produced inside the infalling gas can build up so much that it can shut off the infall. But if the gas is very dense and opaque to radiation, the photons' escape is delayed — sometimes they can't even emerge before the gas surrounding them crosses the black hole's event horizon. In this case, the photons can't "do their duty of pushing gas away," he says. He suspects that's what happened with MQ1.

■ **CAMILLE M. CARLISLE**

ASTEROIDS | Hubble Catches Rock Crumbling

NASA / ESA / D. JEWITT (UCLA)

Astronomers watched the asteroid P/2013 R3 disintegrate over three months.

The main-belt asteroid P/2013 R3 has broken into at least 10 pieces, likely due to the subtle power of direct sunlight.

Asteroids and comets can shatter from head-on collisions, break apart near massive planets from tidal forces, and rupture due to internal gas pressure. But none of these scenarios applies to P/2013 R3.

The object first caught astronomers' attention last September 15th, when the Catalina and Pan-STARRS sky surveys detected it as a fuzzy, comet-like object near the inner edge of the main asteroid belt. Follow-up observations showed it to be three co-moving bodies enshrouded in a large, dusty envelope. Spectra revealed no signs of gas but rather had features consistent with a primitive asteroid.

On October 29th, David Jewitt (UCLA) and colleagues utilized the Hubble Space Telescope to discover that P/2013 R3 comprised at least 10 objects, each with its own dust tail. The largest fragments are up to 200 meters (700 feet) across.

Later Hubble images revealed the fragments drifting away from one another at just 1.6 km per hour (1 mph). When the researchers extrapolated this sluggish motion backward, they found that the components came apart over several months.

The only explanation is the Yarkovsky-O'Keefe-Radzievskii-Paddack (YORP) effect, which occurs when a small asteroid has an irregular shape. The object's surface absorbs sunlight and then doesn't radiate heat evenly. This creates a small torque that can rev up an asteroid's spin. Centrifugal forces can then literally rip apart a fragmented, weakly bound body.

■ **SHANNON HALL**

EXOPLANETS | Kepler Planets by the Hundreds

Data from NASA's crippled Kepler space telescope has yielded 715 newly confirmed exoplanets, raising the number from roughly 1,000 to about 1,700.

All the planets were already on Kepler's list of about 3,500 "planet candidates," periodic transit-like signatures that likely indicate real worlds but may still be false alarms (*S&T*: Feb. 2014, p. 14). The problem is that there are other things that can produce the same slight clockwork dimmings in starlight. Stars in binary systems often eclipse each other. And sometimes, a normal eclipsing binary appears blended with the light of a brighter third star in the same field of view. The result can look remarkably similar to the dimming created by a planet.

Confirmed planets used to trickle in slowly, because verification usually required large ground-based telescopes to make slow, painstaking radial-velocity measurements of the star in search of its signature gravitational wobble.

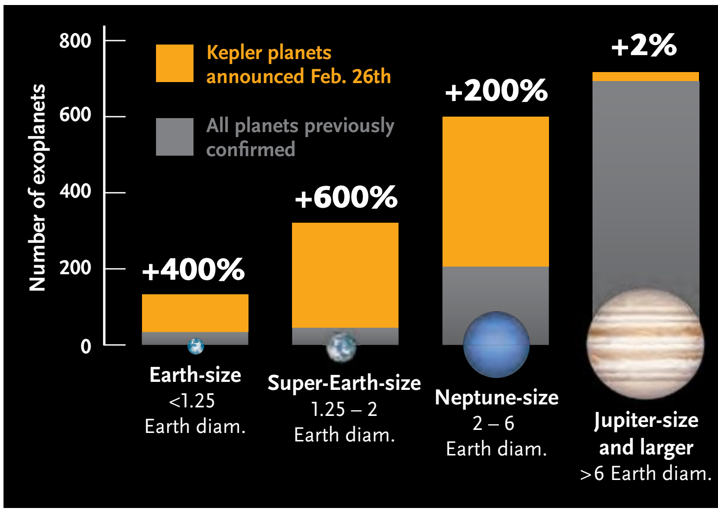
The key to the new technique, known as *verification by multiplicity*, is that systems in which two or more planet candidates transit a star are very unlikely to contain false positives. For a system with three bodies or more to remain stable, there needs to be a large central mass (i.e. either one star or two closely bound stars), with all other masses relatively small. So the team is now confident (at the 99% level) that any Kepler-monitored star with multiple signatures must have them thanks to low-mass objects — in other words, planets.

Besides bringing the flood of "new" exoplanets, this method makes it much easier to confirm small planets. In fact, 95% of the new worlds rank as Neptunes or smaller. Four are less than 2.5 Earth diameters and orbit in the habitable zone.

Astronomers pulled the 715 confirmations from Kepler's first two years of data. They will next sift through the entire database. It takes much longer to catch at least three transits of Earth-size planets with orbital periods of a year. With the longer time frame of the full data set, the team expects to find hundreds of small worlds, including a greater proportion in their stars' habitable zones.

■ **SHANNON HALL**

Watch an animation of stable planetary orbits versus wacky stellar orbits at skypub.com/transitorbits.



This histogram shows the number of all known exoplanets by size, not just those detected by Kepler. The orange bars represent Kepler's newly verified planets. Size bins are defined by NASA, and percent changes are from before and after the recent release.

S&T: GREGG DINDERMAN, SOURCE: WENDY STENZEL / NASA AMES

IN BRIEF

Second-Generation Star Observed. Astronomers have discovered the "purest" star yet seen, located 6,000 light-years away in Hydrus. The star, SMSS J031300.36–670839.3, has 15 million times less iron than our Sun, and nearly 1⁄40 the iron level of the previous record-holder. This low level suggests the star formed in the early universe, because the Big Bang produced only hydrogen, helium, and a trace of lithium. Given its high carbon, this star was likely enriched by an abnormally weak supernova, Stefan Keller (Australian National University) and colleagues conclude in the February 27th *Nature*. It is thus a second-generation star, nearly as old as the universe.

■ **SHANNON HALL**

New Record for Oldest Earth Rock. Geochemists have determined that a grain of zircon from Western Australia is 4.374 billion years old, pushing back the date when Earth's crust solidified by millions of years. John Valley (University of Wisconsin) and colleagues report the find in the February 23rd *Nature Geoscience*. It supports the idea that Earth's crust started to solidify within 100 million years after the planetary pummeling that gave birth to our Moon. Knowing that the crust reformed so soon after the blast should provide new insight into how soon our planet became habitable.

■ **J. KELLY BEATTY**

Pesky Problems for Lunar Reflectors. To determine the Moon's location and distance from Earth, astronomers fire lasers at reflectors left on the lunar surface by Apollo astronauts and Russian rovers. But these suitcase-size mirrors bounce back only about 10% of the photons that they should, likely due to a thin coating of lunar dust. The drop-off worsens to just 1% around full Moon, when sunlight fully illuminates the reflectors' prisms. Apparently, heat from the Sun-warmed dust causes optical distortions, Tom Murphy (UC San Diego) and colleagues report in the March 1st *Icarus*. The results imply about 50% of the reflectors' surfaces are covered in dust.

■ **J. KELLY BEATTY**

SUPERNOVAE | No-go for Jets?

A new view of a well-studied supernova remnant is complicating astronomers' understanding of stellar death.

Cassiopeia A is a beautiful cascade of gases surrounding a neutron star born in a supernova some 300 years ago. Despite years of observations, astronomers so far haven't been able to reconstruct the details of the progenitor star's explosion, which was triggered when its iron core collapsed into the neutron star. But scientists may gain a better understanding thanks to new observations of the radioactive isotope titanium-44, which forms right at the boundary that divides the imploding stellar core from its exploding outer layers.

Brian Grefenstette (Caltech) and colleagues have mapped the isotope's distribution using NASA's NuSTAR space telescope (*S&T*: Oct. 2012, p. 34). As they report in the February 20th *Nature*, X-rays from titanium-44 radiate from clumps scattered unevenly around the remnant's center. And surprisingly, the clumps don't align with a jetlike feature seen in previous optical and X-ray observations.

Some models had suggested that a jet might have ripped Cas A's progenitor star apart — a reasonable theory given that evidence suggests jets are involved in the most bombastic supernovae, which produce long gamma-ray bursts. But if a jet emanated from Cas A's neutron star itself, titanium-44 should have clumped along the same axis.

Instead, the team argues that patchy material had surrounded the progenitor star before its death. When it exploded, the star's outer layers shoved their way through the thinner patches first, producing a deceptively jetlike feature.

The titanium's uneven distribution might point to sloshing within the progenitor star before it went supernova. The explosion's shock wave (and whatever traveled with it) would have preserved the sloshing star's clumpiness.

Simulations bolster the suggestion that a jet was not responsible for blowing apart Cas A's progenitor star, but the team hasn't yet worked out simulations for the sloshing-star theory.

■ **MONICA YOUNG**

Watch a video of a star slosh before exploding at skypub.com/CasAslosh.

PULSAR | Stellar Lighthouse Devours Asteroid?

The pulsar PSR J0738–4042 might have encountered an asteroid that's thrown off its ultra-precise ticking.

A pulsar's beat relies on powerful magnetic fields that send jets of particles streaming out from its magnetic poles at relativistic speeds. As the pulsar spins, this beam appears to flash at us, usually with astounding regularity.

Paul Brook (Oxford University, UK) and colleagues analyzed fluctuations in PSR J0738–4042's pulse pattern using observations taken with the Hartebeesthoek Radio Astronomy Observatory in South Africa and the Parkes radio telescope in Australia from 1988 to 2012. In September 2005, the pulsar abruptly hiccupped, leading to a reduced spindown rate.

The glitch corresponds to what's expected from a mass influx of about 1 trillion kg (1 billion tons), consistent with asteroid masses. We could be witnessing a close encounter with an asteroid or infalling debris, the team argues in the January 10th *Astrophysical Journal Letters*.

Debris disks should form around some pulsars from material that falls back toward the stellar corpse after the supernova. Should an asteroid-size piece from the disk embark on a collision course, the pulsar's intense radiation would vaporize the rock before it came too close. But the dismembered asteroid's charged particles would then flow into the pulsar's magnetic field and alter its currents. Since the magnetic field powers the beam of particles, incoming asteroid guts would throw off the pulsar's clock. Still, an asteroid is only one of many possible solutions. ✦

■ **EMILY POORE**

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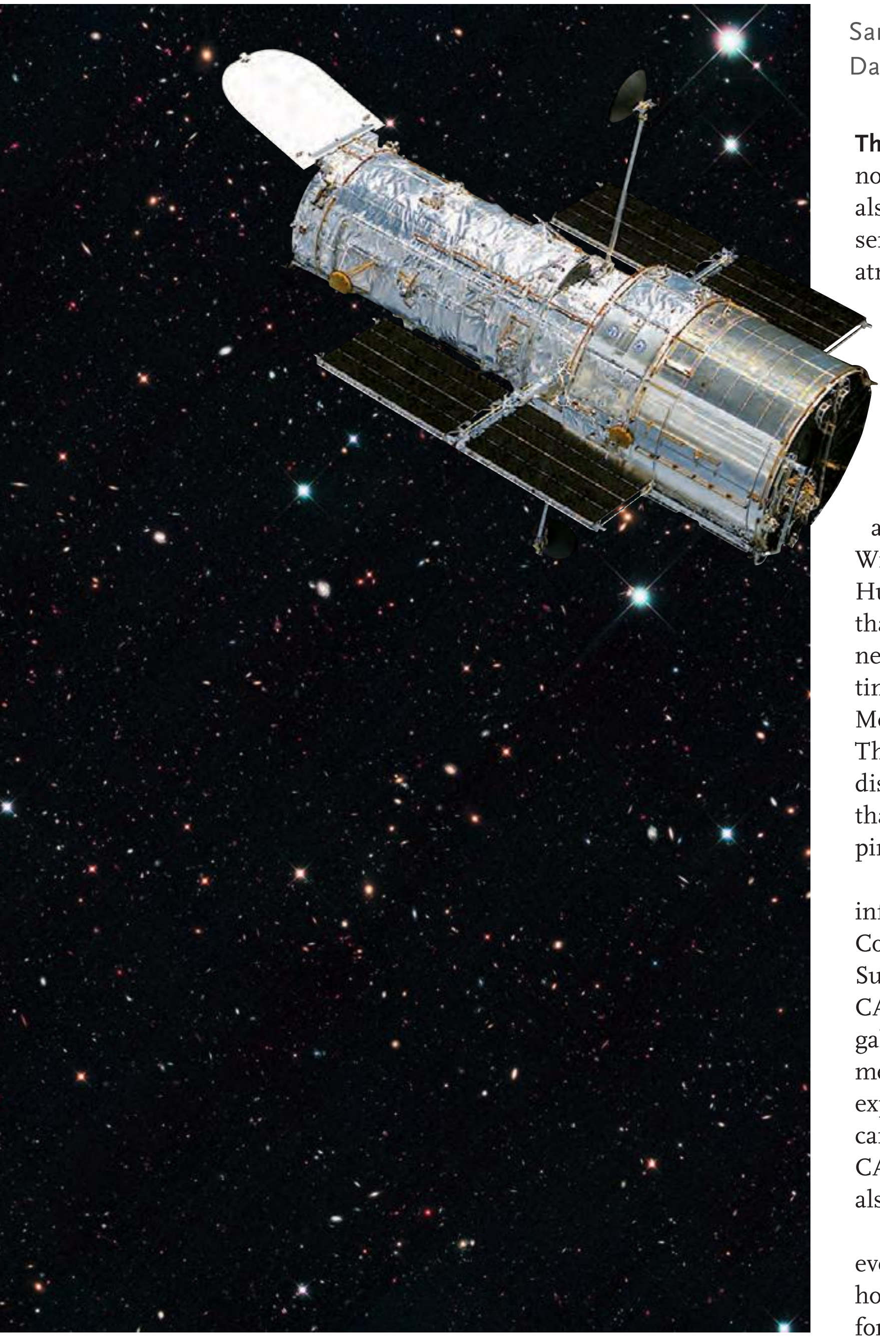
Staring Back to

Hubble's single largest observing program is detecting the earliest galaxies, finding the most distant

COSMIC SURVEY As part of the CANDELS survey, the Hubble Space Telescope scanned a small patch of Cetus for a total of 61 hours. The 61 hours were divided among 352 separate exposures spread across a mosaic of 44 different telescope pointings. The picture reveals a few foreground stars in our galaxy, and thousands of galaxies ranging from the local universe to a time when the universe was less than 1 billion years old.

Cosmic Dawn

supernovae, and revealing the fireworks-like peak of star formation at cosmic high noon.



NASA / ESA / A. VAN DER WEL / H. FERGUSON / A. KOEKEMOER / CANDELS TEAM

Sandra M. Faber, Henry C. Ferguson,
David C. Koo, Joel R. Primack & Trudy E. Bell

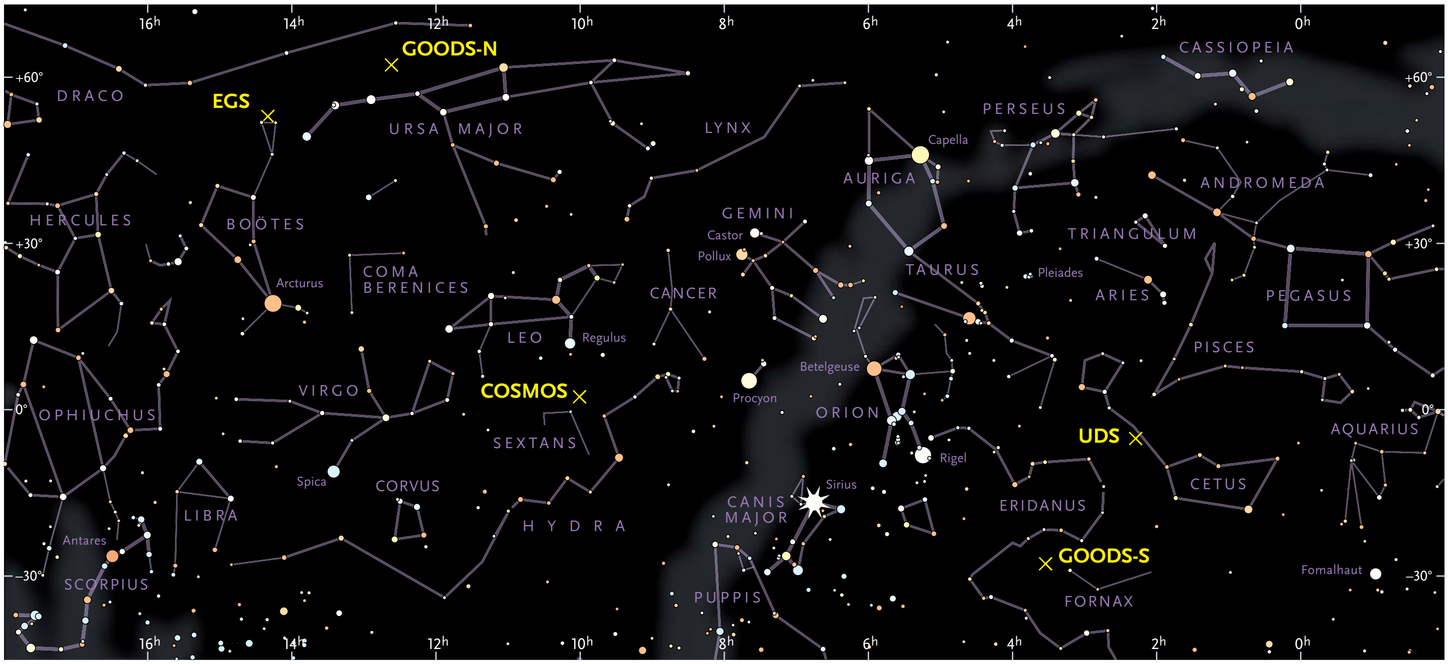
The Hubble Space Telescope is a time machine, staring not only billions of light-years into the depths of space but also billions of years back in time. With its extraordinarily sensitive detectors above Earth's shrouding and blurring atmosphere, HST can witness the peak of star formation at cosmic high noon, which ended about 5 billion years after the Big Bang. And at the outer limits of its capabilities, we wondered if it could detect the faintest candles of creation: the earliest galaxies made of the earliest stars at cosmic dawn, when the universe was less than a billion years old.

Those were the hopes of two of us authors (Faber and Ferguson) after NASA astronauts installed HST's Wide-Field Camera 3 (WFC3) in 2009, which enabled Hubble to survey the infrared sky about 30 times faster than before. Within a few months, Hubble pointed the new camera at the Hubble Ultra-Deep Field (HUDF) — a tiny region in Fornax only a tenth the diameter of the full Moon — and took exposures totaling about three days. Those deep HUDF images revealed some of the most distant galaxies ever found, which look very different than nearby galaxies. But the HUDF represented just a pinprick poke at the universe.

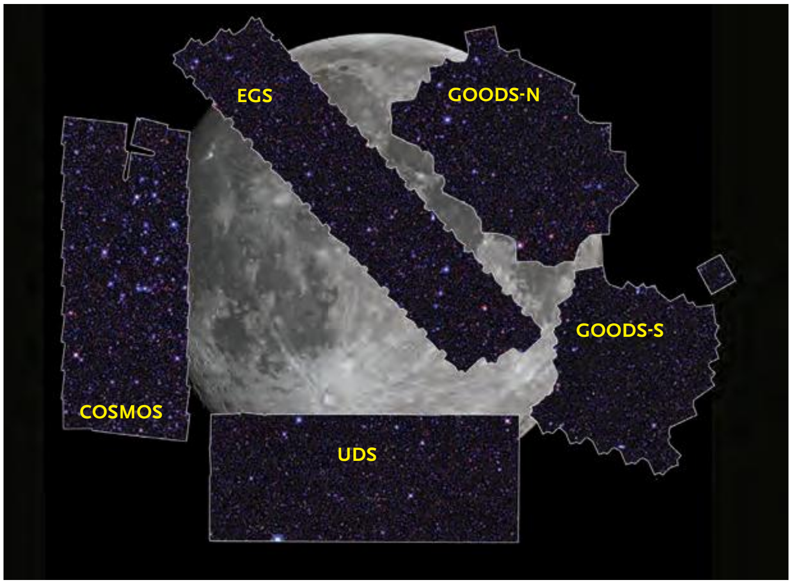
So we began an ambitious program at visible and near-infrared wavelengths as a natural successor to HUDF: the Cosmic Assembly Near-infrared Deep Extragalactic Legacy Survey (CANDELS), pronounced "candles." We designed CANDELS primarily to document the first one-third of galaxy evolution. The program also would enable astronomers to search for the most distant Type Ia supernovae — exploding white dwarfs that are the best-known standard candles for measuring the universe's recent expansion rate. CANDELS could thus test whether Type Ia supernovae are also a valid yardstick for the early universe.

CANDELS became the largest observing program ever undertaken by Hubble. The telescope devoted 600 hours — fully 10% of its observing time — to CANDELS for three years, surveying an area of sky 60 times larger

To view more images related to this article, visit skypub.com/CANDELS.



S&T: GREGG DINDERMAN; SOURCE: CANDELS TEAM



CANDELS TEAM; MOON PHOTO: S&T: DENNIS DI CICCO

CANDELS FIELDS The CANDELS survey targeted five different fields at various depths and wavelength coverage. Even though the combined fields cover only about the area of the full Moon, they provide representative samples of the deep universe.

than the HUDF, albeit to brighter limiting magnitudes (about 27 for CANDELS compared to 30 for the HUDF). CANDELS targeted five patches of the northern and southern skies, each about one-fourth the angular size of the Orion Nebula (M42). Each patch has been well studied from radio to X rays, giving plenty of complementary data across the electromagnetic spectrum.

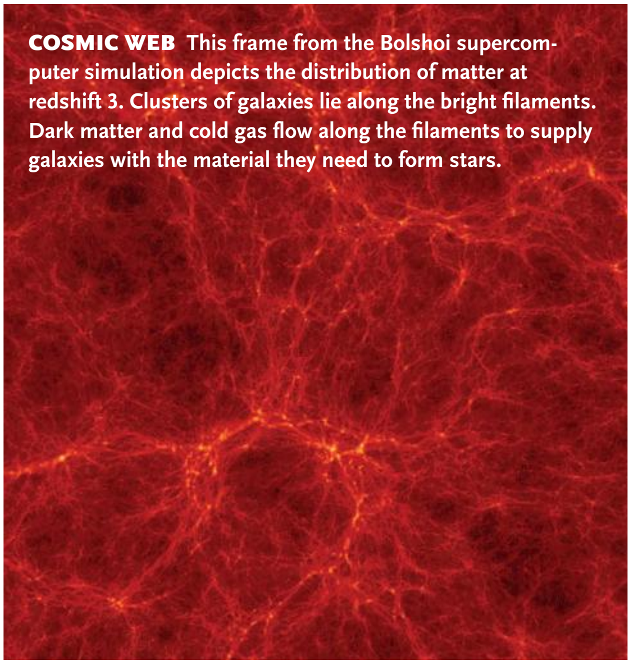
Because remote galaxies are so faint, the five target areas were away from our Milky Way's star-studded plane. Much as pollsters and medical researchers learn about the human population as a whole by studying carefully selected samples of a small number of individuals, we chose the five target areas because they're physically representative of the universe at large.

Depending on the field, CANDELS took multiple images with exposure times ranging from 40 minutes to roughly 3 hours through each of two or three infrared filters. Although CANDELS surveyed a total area only about that of the full Moon, the long exposures looked so deep into the cosmos that they recorded roughly a quarter-million ancient galaxies in enough detail to reveal their sizes, shapes, and even gross internal structures. Such a rich treasure trove provides powerful new data for statistical studies of galaxy growth and evolution.

Astrophysicists will continue to analyze the wealth of observations for years to come. The data have already led to new findings and mysteries about the early universe.

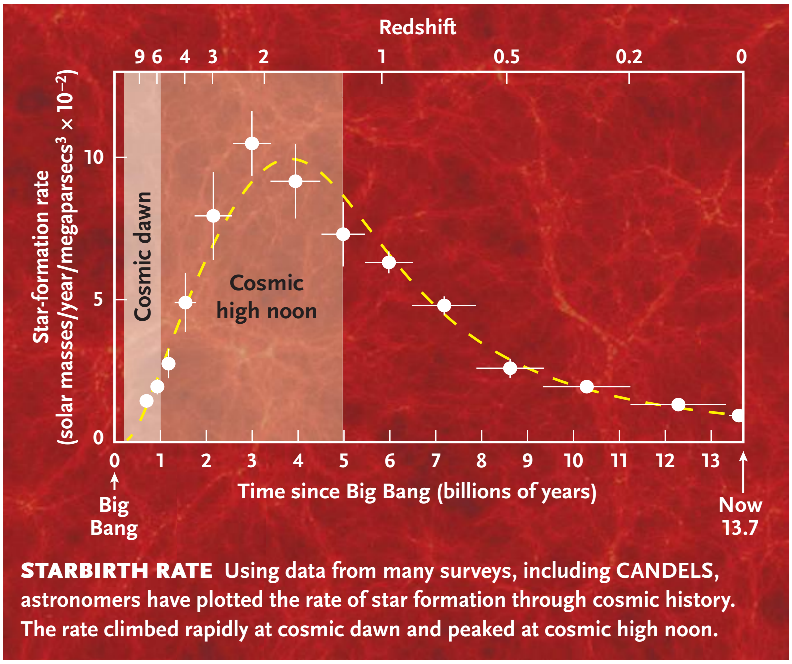
Red, Blue, and "Green" Galaxies

In the nearby and moderately distant universe, most galaxies tend to be red or blue. Red galaxies are commonly elliptical and relatively featureless, and they stopped forming stars more than a billion years ago. Most of their light is emitted by red giants near the end of their lives, and they have little or no cold gas from which new stars can form. An example is M87, the biggest galaxy in the Virgo Cluster. In contrast, blue galaxies commonly have flat disks and spiral arms possessing lots of cold gas and stars of different ages. A small fraction of newborn stars are short-lived blue supergiants, which are so luminous that star-forming regions appear blue. A nearby example is the beautiful Whirlpool Galaxy (M51) in Canes Venatici.



COSMIC WEB This frame from the Bolshoi supercomputer simulation depicts the distribution of matter at redshift 3. Clusters of galaxies lie along the bright filaments. Dark matter and cold gas flow along the filaments to supply galaxies with the material they need to form stars.

ANATOLY KLYPIN / STEFAN GOTTLÖBER



STARBIRTH RATE Using data from many surveys, including CANDELS, astronomers have plotted the rate of star formation through cosmic history. The rate climbed rapidly at cosmic dawn and peaked at cosmic high noon.

S&T: GREGG DINDERMAN; SOURCE: KENNETH DUNCAN (UNIVERSITY OF NOTTINGHAM) / CANDELS, ET AL.

At the present day, only a few galaxies lie between the peaks of the blue and red galaxies, in the so-called "green valley" (so named because green wavelengths are midway between red and blue in the spectrum). A blue galaxy that is vigorously forming stars will become green within a few hundred million years if star formation is suddenly quenched. On the other hand, a galaxy that has lots of old stars and a few young ones can also be green just through the combination of the blue colors of its young stars and the red colors of the old ones. The Milky Way probably falls in this latter category, but the many elliptical galaxies around us today probably made the transition from blue to red via a rapid quenching of star formation. CANDELS lets us look back at this history.

Most galaxies of interest to astronomers working on CANDELS have a look-back time of at least 10 billion years, when the universe was only a few billion years old. Because the most distant galaxies were relatively young at the time we observe them, we thought few of them would have shut off star formation. So we expected that red galaxies would be rare in the early universe. But an important surprise from CANDELS is that red galaxies with the same elliptical shapes as nearby red galaxies were already common only 3 billion years after the Big Bang — right in the middle of cosmic high noon.

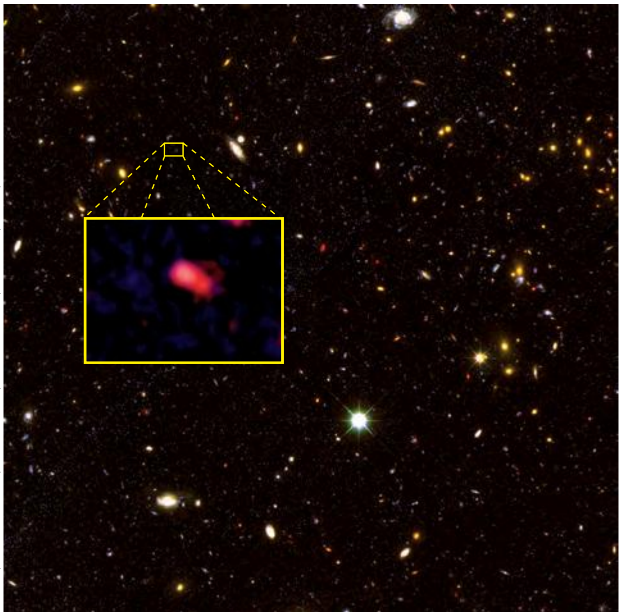
Puzzlingly, however, elliptical galaxies from only about 3 billion years after the Big Bang are only one-third the size of typical elliptical galaxies with the same stellar mass today. Clearly, elliptical galaxies in the early universe must have subsequently grown in a way that increased their sizes without greatly increasing the number of stars or redistributing the stars in a way that would change their shapes. Many astronomers suspect that the present-day red ellipticals with old stars grew in size by "dry" mergers — mergers between galaxies having older red stars but precious little star-forming cold gas. But the jury is still out on whether this mechanism works in detail to explain the observations.

The Case of the Chaotic Blue Galaxies

Ever since Hubble's first spectacular images of distant galaxies, an enduring puzzle has been why early star-forming galaxies look much more irregular and jumbled than nearby blue galaxies. Nearby blue galaxies are relatively smooth. The most beautiful ones are elegant "grand-design" spirals with lanes of stars and gas, such as M51. Smaller, irregular dwarf galaxies are also often blue.

But at cosmic high noon, when stars were blazing into existence at peak rates, many galaxies look distorted or misshapen, as if galaxies of similar size are colliding. Even the calmer-looking galaxies are often clumpy and irregular. Instead of having smooth disks or spiral arms, early galaxies are dotted with bright blue clumps of very active star formation. Some of these clumps are over 100 times more luminous than the Tarantula Nebula in the Large Magellanic Cloud, one of the biggest star-forming regions in the nearby universe. How did the chaotic, disordered galaxies from earlier epochs evolve to become the familiar present-day spiral and elliptical galaxies?

Because early galaxies appear highly distorted, astrophysicists had hypothesized that major mergers — that is, collisions of galaxies of roughly equal mass — played an important role in the evolution of many galaxies. Mergers can redistribute the stars, turning two disk galaxies into a single elliptical galaxy. A merger can also drive gas toward a galaxy's center, where it can funnel into a black



V. TILVI / S. FINKELSTEIN / C. PAPOVICH / A. KOEKEMOER / CANDELS / STSCI / NASA

RECORD HOLDER Astronomers discovered the earliest known galaxy (*inset*), as of March 2014, in this CANDELS frame. Using the 10-meter Keck 1 telescope, the team spectroscopically measured a redshift of 7.51, meaning we see the galaxy as it existed just 700 million years after the Big Bang. The galaxy, designated z8_GND_5296, appears red due to its extreme redshift. It's forming stars at a rate about 100 times greater than our Milky Way.

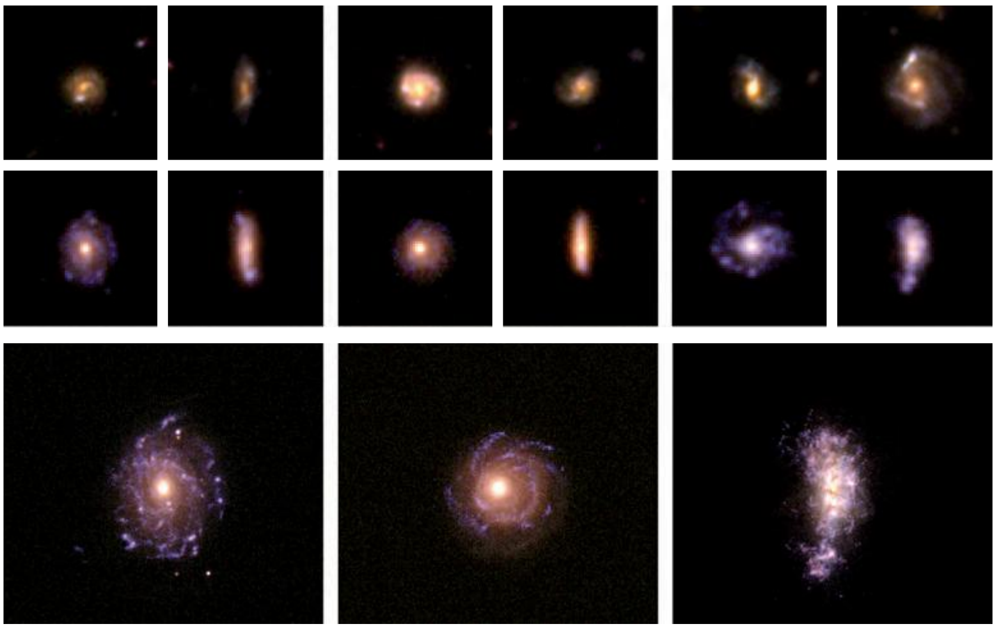
hole, building up its mass and triggering a huge outflow of energy that can heat or eject any remaining gas, thus quenching further star formation. Mergers, then, seemed to explain why elliptical galaxies look like they do and why they stopped forming stars.

But CANDELS revealed that major mergers appear to be less important in galaxy evolution than we had thought. Instead, when combined with supercomputer simulations, the CANDELS observations are beginning to tell a very different story. After the Big Bang, the universe was a nearly uniform sea of dark matter and of gaseous hydrogen and helium. But it wasn't perfectly uniform. As the universe expanded, the denser regions of dark matter and gas expanded more slowly, held back by their own gravity. Eventually, the gas and dark matter in denser regions collapsed into smaller structures: first sheets and filaments known as the "cosmic web," and then into denser blobs of gas and dark matter at the intersections of dark matter filaments. These structures later collapsed to form the seeds of galaxies.

More cold gas flowed along the dark matter filaments into galactic disks, where it became gravitationally unstable and formed clumps. Nearby galaxies have comparatively little gas, so star-forming clumps of gas generally won't grow beyond about a million solar masses. But in early galaxies, the gravity of the much more abundant gas formed gigantic clumps — up to about a billion solar masses — and rapidly formed stars. Then fairly quickly — in only a few hundred million years according to computer simulations — the clumps migrated inward and merged into the central bulge. The CANDELS observations support this theoretical picture: most of the giant clumps in ancient galaxies are young, with older clumps tending to lie closer to galaxy centers. This process presumably fueled quasar activity and led to the rapid growth of supermassive black holes.

Cosmic Dawn

We sought to identify hundreds of primordial galaxies at cosmic dawn, when the universe was only 500 million to 2 billion years old and the first stars were igniting



CANDELS TEAM (15)

CLUMPY GALAXIES *Top row:* Six galaxies from CANDELS are seen when the universe was 4 to 6 billion years old. *Middle row:* These computer simulation frames show three disk galaxies as if imaged by CANDELS when viewed roughly face-on (*left of pair*) and edge-on (*right*). *Bottom row:* This is how these galaxies would appear if we could see them closer up from one angle. All three are about 4 billion years old and have large clumps of rapidly forming stars ignited by instabilities in their disks.

in the first galaxies. We wanted to see enough detail to reveal the galaxies' sizes, shapes, and star-formation rates. Giant 8- to 10-meter ground-based telescopes are already spectroscopically measuring precise redshifts (distances) and helping to nail down the masses of the brightest of these galaxies. Prospects will be even more exciting once 20- to 30-meter behemoths become available next decade, complementing the data we'll be getting from NASA's James Webb Space Telescope.

CANDELS has produced the largest sample of candidate galaxies that formed within the first 1 billion years of the universe's existence. As of March 2014, the spectroscopic record-holder is a galaxy at a redshift of 7.51, corresponding to a time just 700 million years after the Big Bang. Despite being less than a tenth the mass of our Milky Way, this diminutive galaxy is churning out stars at a rate about 100 times higher.

Combined with data from the HUDF and a few other surveys, the CANDELS observations have given us a much more detailed view of the first billion years of galaxy formation. The overall star-formation rate in the universe 500 million years after the Big Bang was about the same as it is today. The fireworks came later, reaching a peak when the universe was 3 to 4 billion years old, with a rate about 10 times higher. But the galaxies we see at cosmic dawn were tiny — about 10% the diameter of our Milky Way — so they packed a lot of star formation into a much smaller volume.

CANDELS is also helping to solve a big mystery about the rarefied gas between galaxies. Most of this gas in the nearby universe is ionized — that is, the electrons of most of the hydrogen atoms are stripped from their protons. As a result, the intergalactic medium is utterly transparent to ultraviolet light for billions of light-years. But observations of the cosmic microwave background and of light from the most distant quasars show that in the early universe — roughly from about 400,000 years to 1 billion years after the Big Bang — the intergalactic medium was mostly neutral (that is, in atomic form). If you existed then and had eyes sensitive to ultraviolet light, the universe would have been filled with a gray fog!

Clearly something big must have happened. Neutral hydrogen can be ionized by absorbing ultraviolet light — but reionizing most of the atoms throughout the entire intergalactic medium a billion years after the Big Bang would have required a phenomenal influx of ultraviolet radiation. What could have produced so much UV energy? Evidence from CANDELS and other recent observations suggest that the earliest galaxies alone — not some other exotic explanation, such as the decay of dark matter — were responsible for such widespread reionization of the universe because their early stars were particularly massive, energetic, and blue. Such stars produce UV light in prodigious quantities.

CANDELS' Standard Candles

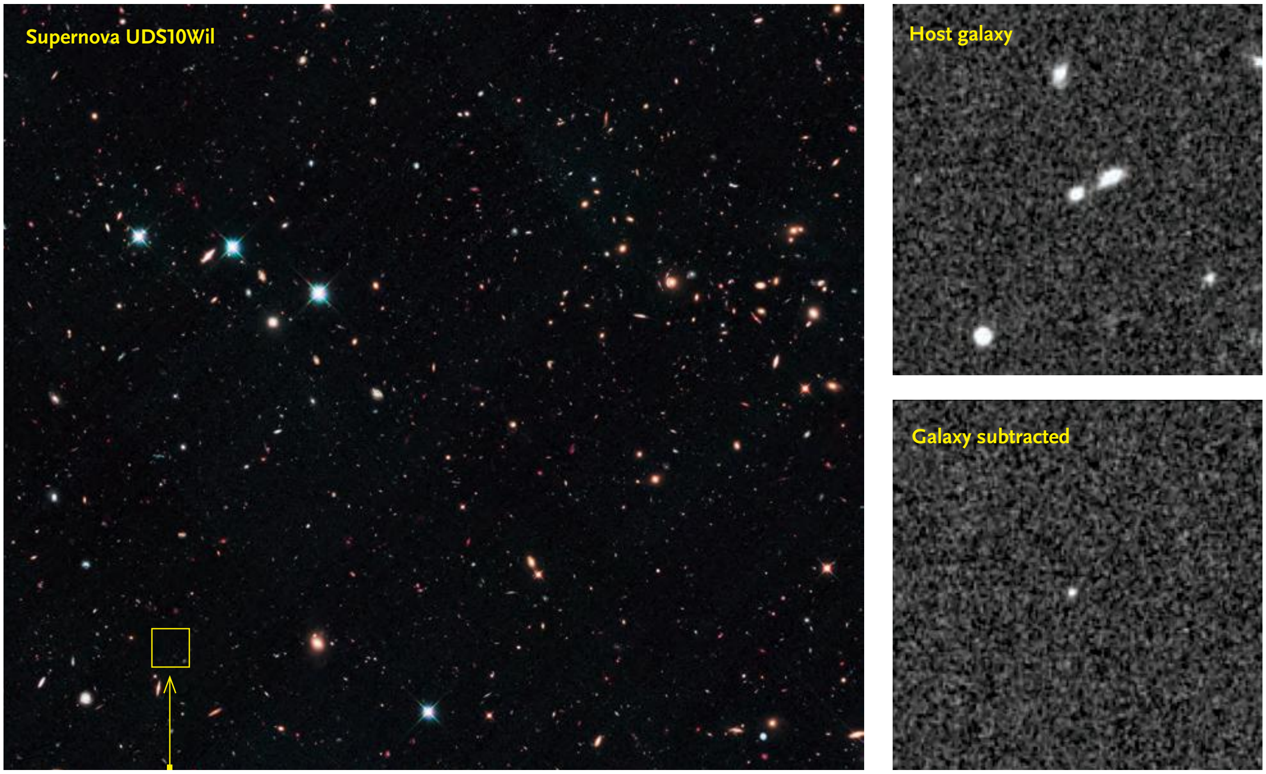
Instead of acquiring a single long time exposure of each tiny target patch of sky, the CANDELS survey typically took two or more exposures about 60 days apart. For studying galaxies, the two exposures were stacked (combined) on a computer to create a longer exposure that revealed more detail. But subtracting one image from the other enables astronomers to see anything that changed. Specifically, we were looking for distant Type Ia supernovae, from exploding white dwarfs.

Type Ia supernovae are remarkably useful because their brightness is correlated with the supernova's color and fade time. Because we can measure a Type Ia supernova's absolute brightness, its apparent brightness depends on its distance. Thus, Type Ia supernovae have become a powerful tool allowing astronomers to determine the universe's expansion history.

NASA / ESA / HUBBLE HERITAGE TEAM (STSCI/AURA)

NASA / ESA / S. BECKWITH / HUBBLE HERITAGE TEAM (STSCI/AURA) (2)

RED AND BLUE GALAXY The elliptical galaxy M87 (*left*) and the spiral galaxy M51 (*right*) are classic nearby examples of red and blue galaxies, respectively. Despite M87's enormous size, it's devoid of gas and has thus stopped forming new stars. Its light is dominated by old, reddish stars. In contrast, the spiral arms of M51 are ablaze with the brilliant blue light of newborn hot stars.



NASA / ESA / A. RIESS / D. JONES / S. RODNEY (3)

DISTANT SUPERNOVA *Left:* Astronomers spotted the most distant supernova ever detected in this CANDELS field. *Top right:* Zooming into the boxed region reveals the host galaxy. *Above right:* A Type Ia supernova is seen once the host galaxy is subtracted. The supernova occurred at a redshift of 1.9, meaning the explosion took place 3.5 billion years after the Big Bang. Studying such distant supernovae will help astronomers determine the universe's expansion history, providing clues to the nature of dark energy.

Major surveys before CANDELS revealed that cosmic expansion was decelerating until about 5 billion years ago. But measurements of Type Ia supernovae convinced astronomers in 1998 that cosmic expansion has been accelerating ever since, research that led to the 2011 Nobel Prize in physics. Astronomers hope that studying Type Ia supernovae identified by CANDELS at various distances will reveal more about the details of this transition from decelerating to accelerating expansion, and thus yield precious information about the nature of the enigmatic dark energy responsible for the acceleration.

But to improve the precision of such cosmological measurements, astronomers need to understand Type Ia supernovae better. For example, do they come from a single exploding white dwarf, or from merging white dwarfs? Scientists also need to see if there is a systematic trend in supernova luminosity that correlates with cosmic age. After all, early stars were poorer in elements heavier than helium. Moreover, the typical white dwarf in the early universe was more massive than a typical white dwarf today because in the early universe only the most massive, fast-burning stars had enough time to evolve into white dwarfs. CANDELS can detect supernovae when the universe was only 3 billion years old, so astronomers can test for such trends.

Stay Tuned!

The proposers of a Hubble observation normally have sole access to the data for a year. But the CANDELS raw images were made public within hours of being downlinked, and the CANDELS team has been providing carefully calibrated images to the astronomical community within a few months of the observations. The team includes more than 150 collaborators from 45 different institutions in 12 countries. Nevertheless, roughly a third of the papers published so far using the CANDELS data have come from outside the team. The pace of discovery shows the power of combining data from across the spectrum, and having observers work with theorists and computer models. Watch for new findings during the years to come! ✦

Sandra M. Faber *and* ***Henry C. Ferguson*** *are co-principal investigators of CANDELS. Faber, based at the University of California, Santa Cruz (UCSC), is interim director of the University of California Observatories (UCO). Ferguson is an astronomer at the Space Telescope Science Institute.* ***David C. Koo*** *is an astronomer with UCO and professor at UCSC.* ***Joel R. Primack*** *is a UCSC physicist and also Director of the University of California High-Performance Astro-Computing Center (UC-HiPACC).* S&T *contributing editor* ***Trudy E. Bell*** *is the senior writer for UC-HiPACC.*

From Space

to School

AN INTERNATIONAL COLLABORATION PUTS ASTEROID HUNTING IN THE HANDS OF STUDENTS.

On New Year's Day 1801, the Catholic monk Giuseppe Piazzi discovered an unknown object in the evening sky. At first, astronomers thought it was the long-sought "missing" planet between Mars and Jupiter. But observations by William Herschel showed that it was smaller than the Moon.

By the end of 1850 observers had found 12 more of these *asteroids*, a name derived from the Greek for "star-like." Piazzi's object, Ceres, is the largest of the group. By the end of 1890, more than 300 were known. By the turn of the 21st century, there were over 200,000 of these boulders, which vary in size from a few meters to hundreds of kilometers. Just how many of these objects are there? Nobody knows. They probably number in the millions.

The ability to discover asteroids is an exciting prospect. In the late 1990s, Hands-On Universe (HOU) at the Lawrence Hall of Science (University of California, Berkeley) initiated the first nationwide asteroid search effort. Working with scientists, HOU high-school students began discovering main-belt asteroids. Remarkably, students also discovered a Kuiper Belt object (KBO).

Under the direction of Patrick Miller (Hardin-Simmons University), a group of professional astronomers, amateurs, and teachers united in October 2006 to form the International Astronomical Search Collaboration (IASC, pronounced "Isaac"). IASC was established as a free, internet-based asteroid discovery program headquartered at Miller's home institution in Abilene, Texas.

HOU science teacher Harlan Devore and his students at Cape Fear High School in North Carolina pioneered the analysis techniques. They helped develop the methodology used in IASC to search for asteroids.

Since the program's foundation, IASC students have discovered several hundred objects. "It's kinda neat we are the first ones to see these new asteroids," says student Austin Sobon (Folsom Lake College, California).

"As a teacher," says Glenn Reagan (Cordova High School, California), "I feel excited about my students getting so engaged in the process of science. Their skills are learned quickly and immediately applied in the image analysis. Plus, their awareness of their place in the solar system and its composition is personally enhanced without reading a book, listening to a lecture, or watching a video."

Lynne F. Zielinski & J. Patrick Miller

***Inset*: Students at the Pierre and Marie Curie School in Nicaragua watch a visualization of the orbit of asteroid 2012 FE_{52}, which they discovered during IASC's program for Global Astronomy Month 2012 (organized by Astronomers Without Borders).**

***Backdrop*: The Astronomical Research Institute's four scopes — ranging from 24 to 50 inches — acquire many of the images that students in the IASC program use to discover asteroids.**

SCOPES: BOB HOLMES / ASTRONOMICAL RESEARCH INSTITUTE; INSET: MARIA ESPERANZA ZELAYA

MARIA ESPERANZA ZELAYA

WILLIAM JESSUP UNIVERSITY

***Top*: Students in Nicaragua show teacher Isaac Ponimansky how the program *Astrometrica* works. *Bottom*: William Jessup University students Megan Horrocks and Eric Coutryer point to an image of the asteroid they've (preliminarily) discovered.**

How It Works

Father Piazzi could only dream about today's observing tools. Even amateur astronomers can afford large optical telescopes and sensitive CCD cameras. Inexpensive, high-speed computers equipped with sophisticated software sit on desktops in almost every home and school, with the internet providing instant worldwide communication.

IASC has bundled these tools together to create its asteroid search program. Sitting at a computer in their classrooms, students analyze telescopic images taken only hours earlier. They discover asteroids and make important position measurements, information used to refine the objects' orbits.

Currently, IASC's image pipeline comes from three sources. The Astronomical Research Institute (ARI) provides images year-round from its prime-focus telescopes located under the dark skies of Westfield, Illinois (*S&T*: Dec. 2011, p. 32). The University of Hawaii's Pan-STARRS PS1 telescope provides images for spring and fall campaigns. PS1 sits at 10,000 feet atop Haleakalā on Maui. The 0.8-meter Schulman Telescope at the Mt. Lemmon SkyCenter, which is part of the Sierra Stars Observatory Network, provides images for special campaigns, including those for schools in China.

Each month when the skies are dark and clear, images are taken along the ecliptic during a 30- to 60-minute period. Just hours later, the images are stacked, uploaded to the IASC website (**iasc.hsutx.edu**), and made available to schools. When students arrive in the morning, they download their image sets. Using the software *Astrometrica* to align and blink the images back and forth, they look for anything that moves. *Astrometrica* was written by Austrian amateur Herbert Raab and is designed to do accurate asteroid astrometry (**www.astrometrica.at**).

When a student finds a moving object and it's not in the official database maintained by the Minor Planet Center (MPC), the race is on! Students have *Astrometrica* prepare a written report of the discovery and related observations. They next e-mail that report to IASC. It's evaluated by the IASC Data Reduction Team (IDaRT) and forwarded to the MPC, which is chartered by the International Astronomical Union (IAU) to maintain the world's official asteroid database. Confirmation images are taken and more measurements are made.

Before recognizing a discovery, the MPC requires that follow-up observations be made within 7 to 10 days of the initial sighting. IASC obtains second images from collaborators located around the globe (see sidebar on page 31).

In addition to asteroid discoveries, students make key measurements of near-Earth objects (NEOs). These objects include errant asteroids that have wandered out of the main belt and pass near, or even cross, Earth's orbit. On rare occasions these objects include comets.

New NEOs can be more important than main-belt asteroid discoveries because these objects can pose an impact hazard. NASA's Near-Earth Object Program seeks to find all Earth-crossing NEOs with a diameter greater than 1 kilometer and perihelion less than 1.3 astronomical units. An impact by one of these beasts in a populated area would be catastrophic — the Chelyabinsk impactor was less than 20 meters (60 feet) wide and entered the atmosphere at a grazing angle, yet its airburst in February 2013 injured roughly 1,500 people (*S&T*: June 2013, p. 24).

IASC students have made significant NEO contributions. In January 2009, two IASC participants codiscovered the NEO 2009 BD_{81}. This object is a potentially hazardous asteroid (PHA), a body that comes 0.05 a.u. or closer to Earth. Robert Holmes (ARI) made the original observation, and IASC's Steven Kirby (Ranger High School, Texas) and graduate student Kolyo Dankov (Bulgarian Academy of Sciences) verified it hours later.

"When I discovered 2009 BD_{81}, Dr. Miller informed me that the asteroid was probably an NEO due to its speed, which made the discovery even more exciting," Kirby says. "I was definitely surprised when it was later determined that it was also a PHA."

The object is 300 meters in diameter, 10 times the size of the Chelyabinsk meteoroid. In 2042 it will pass within 5.5 Earth radii (35,000 km) of Earth. That's about the altitude at which geosynchronous satellites orbit above our planet's surface. But even so, the chances for impact are extremely low: about 1 in 2,500,000.

The Image Pipeline

IASC's success today comes from a consistent, reliable flow of images coupled with a team of volunteers from all around the world. IASC piloted its first campaign in the fall of 2006 with five schools, using images from the Cerro Tololo Inter-American Observatory in Chile. Students detected some asteroids, but the measurements weren't accurate enough to report them to the MPC.

The next campaign used images from ARI and included 15 schools from the U.S. and Poland. Participants found 30 asteroids during that 6-week campaign. From that point forward, IASC has grown every year through recruitment from Global HOU and word of mouth.

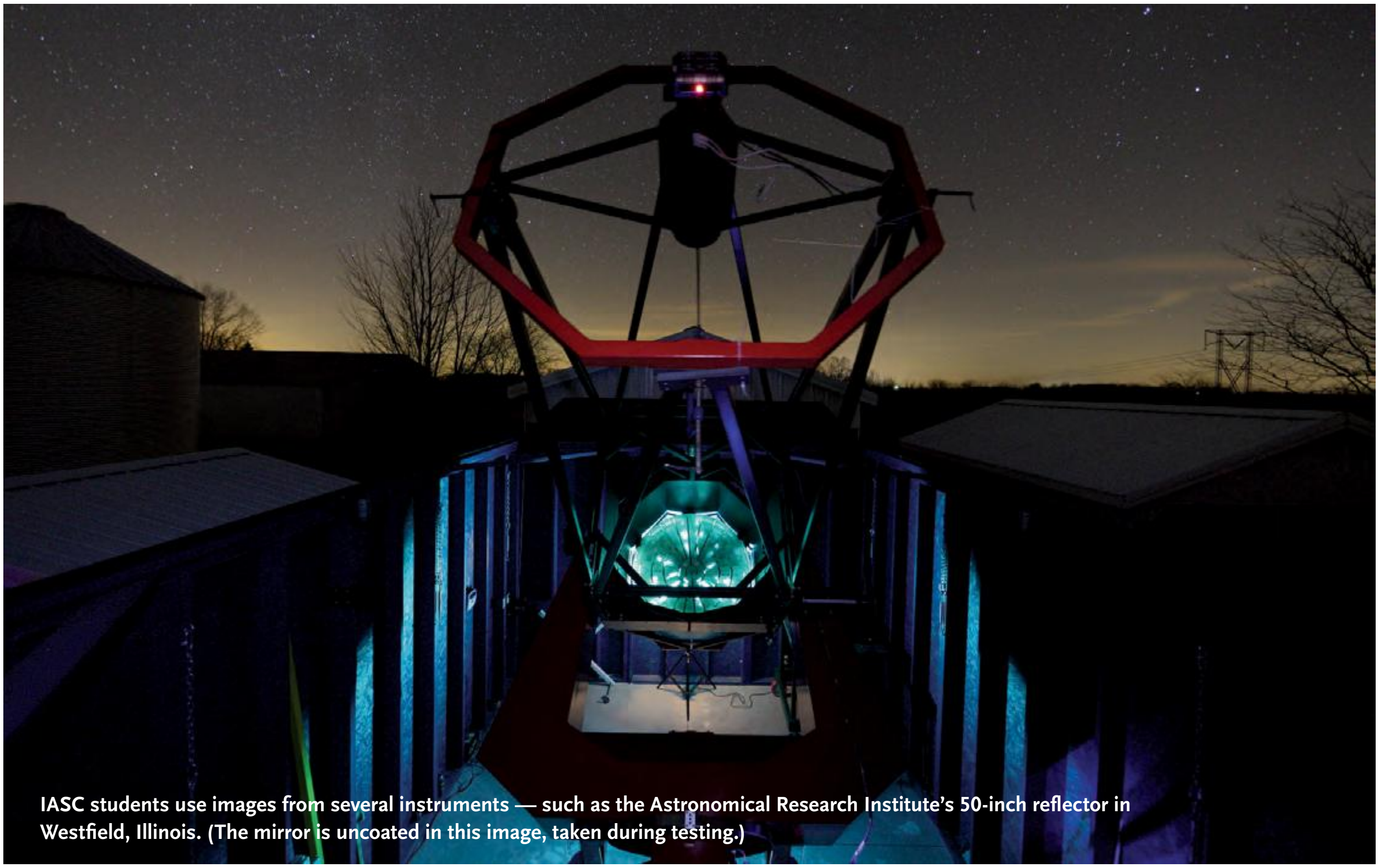
ARI's telescopes provide IASC students with direct access to images year-round. In 2010, PS1 also joined the IASC image pipeline, becoming IASC's second major source of image sets. PS1 is a 1.8-meter telescope and sports the world's largest digital camera, with 1.4 gigapixels. A single Pan-STARRS image covers a 3.2°-diameter field of view. This is gigantic compared to the 0.3° or less of most large research-class telescopes.

Every spring and fall, PS1 provides IASC two image sets per week for its 5-week campaigns. A set consists of four images, each of 1.4 gigapixels, that together span a 1-hour time frame. These massive images are partitioned into 416 sub-images for 60 schools. Both ARI's telescopes and PS1 can capture faint, 22nd-magnitude objects — PS1 can do so with only a 30-second exposure. Asteroids this faint can sometimes be missed by automated processing software, and eager students benefit as a result. Students carefully inspect each sub-image with their own eagle eyes to reduce the potential for missing a main-belt asteroid or, on occasion, an NEO.

The Participants

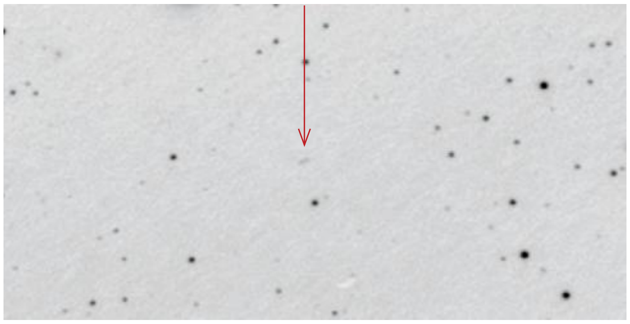
Presently, 500 schools from 70 countries participate in the IASC asteroid search program. Ten 5-week campaigns are fed by ARI's year-round data sets. Two additional campaigns are fed by Pan-STARRS. During one campaign, 30 to 95 schools can be accommodated depending upon the availability of data sources.

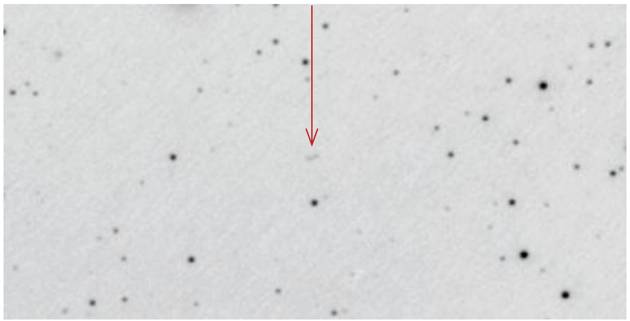
From year to year these 500 schools aren't always the same, though many do return (85%) with a new group



IASC students use images from several instruments — such as the Astronomical Research Institute's 50-inch reflector in Westfield, Illinois. (The mirror is uncoated in this image, taken during testing.)

BOB HOLMES / ASTRONOMICAL RESEARCH INSTITUTE

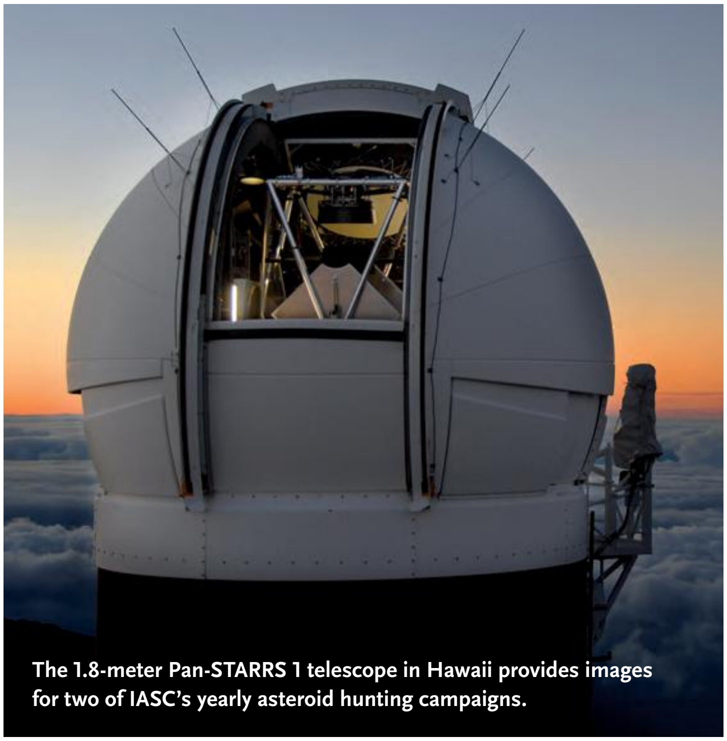




These three frames from ARI show the near-Earth asteroid 2009 XJ_8 and are from one of the practice sets used to train teachers on *Astrometrica*. The object is an Amor asteroid, meaning its orbit lies outside Earth's and approaches or crosses that of Mars.

of students. Others participate just once and are replaced with new schools eagerly waiting in line to join IASC. Generally, the PS1 campaigns fill up about 6 months in advance, but IASC manages to accommodate the other schools with ARI data. Each year, schools from three to five new countries are added.

On occasion, a 35-day search campaign is set up for only one country. These campaigns are organized in collaboration with an in-country education organization and students from high schools, colleges, or organized teams within that country participate. Previous campaigns have involved schools in Portugal, Uruguay, China, Brazil, Bulgaria, India, Poland, Venezuela, and other countries. Among the many participating in-country organizations are Global HOU, Núcleo Interactivo de Astronomia



ROB RATKOWSKI / PSI SCIENCE CONSORTIUM

The 1.8-meter Pan-STARRS 1 telescope in Hawaii provides images for two of IASC's yearly asteroid hunting campaigns.

(NUCLIO, in Portugal), Science Popularisation Association of Communicators and Educators (SPACE, in India), the Center for Theoretical Physics (Poland), Astronomical Observatory (Bulgaria), and the National Astronomical Observatories of China (NAOC).

IASC organizes search campaigns for Astronomers Without Borders as part of Global Astronomy Month and the Space Generation Advisory Council. It does the same with the University of Arizona's outreach program Target Asteroids! (*S&T*: Apr. 2013, p. 38). Using IASC follow-up resources, students can do astrometry, taxonomy, and create light curves for about 80 NEOs identified by the Target Asteroids! program. IASC also runs a special asteroid search campaign for the program's participants.

Discoveries and Observations

Since October 2006, IASC students have discovered 850 new asteroids. Compare that with the 13 discovered from 1801 to the end of 1850!

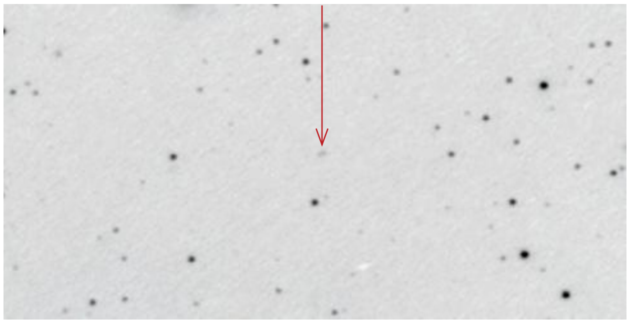
The Minor Planet Center monitors the confirmed discoveries until they have been observed sufficiently to fully determine their orbits. This is a process that takes 3 to 6 years or longer. At that point, the asteroids are numbered and the student discoverers can propose a name. To date, IASC has 30 numbered asteroids.

Denise Rothrock started participating in IASC in 2008, while teaching eighth-grade science at Madisonville Junior High in Texas. Her students were thrilled when they discovered not one, but two asteroids the first year.

It happened that Denise transferred to teaching at the local high school, and when the students who had discovered the object were seniors, they were given the chance to name 2008 SE_{209} "Madisonvillehigh."

"I was shocked this only took four years from discovery to naming," she says. "I felt it was appropriate to name the asteroid after our school. We are a small rural school that deserved to be recognized in such a unique way."

"The program is a great way to take what you're learning in the classroom and apply it to the real world," says another asteroid discoverer, former Cordova High School student Melody Ladd. "Because of the program, I feel like I've made some kind of contribution to the scientific community. I participated in the program three years ago and I still tell people I meet about it and how I discovered an



ASTRONOMICAL RESEARCH INSTITUTE (3)

asteroid. It was one of the most fun experiences I've had in high school. It's always fun telling someone, 'Guess what? I discovered an asteroid!'"

Beyond the Asteroids

Future plans abound for IASC. Pilot programs are under way for three new searches. One is a Kuiper Belt object (KBO) search program. KBOs can be much larger than Ceres — the largest two known, Pluto and Eris, are each about 2,300 km across, about 1,300 km larger than their main-belt counterpart. But they're also much farther away. At 19th or 20th magnitude, many KBOs are challenging targets.

Astronomers have discovered more than 1,000 KBOs (*S&T*: Feb. 2014, p. 18). In October 2012, IDaRT director Tomáš Vorobjov discovered the KBO 2012 HH_2, IASC's first. There are tens of thousands of these icy boulders lurking out past Neptune.

Another future IASC search target will be comets. A comet search program will look along the horizon just after sunset and before sunrise, in the hopes of catching these icy bodies as they approach the Sun. While testing this technique in 2008, Robert Holmes discovered C/2008 N1 (Holmes). More recently, in October 2012, Vorobjov discovered the Jupiter-family comet P/2012 T7 (Vorobjov).

A new citizen-science program is under development by IASC, too. With a target launch date of fall 2014, the online program will enable anyone to search for NEOs using archival images from IASC participating scopes. Eventually, there will be a smartphone app for this new program as well.

Want to Participate?

Want that thrill of making an original astronomical discovery? You can participate in IASC free of charge! IASC is open to any interested high school or college, as well as amateur astronomy clubs, science museum classes, and, on occasion, individuals.

Check out the IASC homepage at **http://iasc.hsutx.edu**. To participate, contact IASC director Patrick Miller at **iascsearch@hsutx.edu** for additional information. ✦

Lynne F. Zielinski is a long-time HOU resource teacher and retired national award-winning physics and astronomy teacher from Illinois. She is currently a NASA JPL Solar System Ambassador, a Yerkes Observatory educator, and National Space Society director, public affairs vice president, and education and outreach chair.

J. Patrick Miller is the founder of the International Astronomical Search Collaboration. He is a professor of mathematics at Hardin-Simmons University and a guest researcher at the Lawrence Berkeley National Laboratory.

Follow-up Collaborators

IASC receives observational support from several institutions, in addition to the Astronomical Research Institute and Pan-STARRS's PS1. Western Kentucky University provides IASC about 40% of its Robotically Controlled Telescope's available time. This 1.3-meter telescope is located at the Kitt Peak National Observatory in Arizona.

Second images also come from the Sierra Stars Observatory Network, Tarleton State University (Stephenville, Texas), the Faulkes Telescope Project (North on Haleakalā and South in Siding Spring, Australia), and the G. V. Schiaparelli Observatory (Varese, Italy). When fast movers (near-Earth objects) or slow movers (Jupiter Trojan asteroids or KBOs) are found, additional follow-up support comes from the Magdalena Ridge Observatory located in Socorro, New Mexico.

DENISE ROTHROCK

Teacher Denise Rothrock and five students present a plaque to their school board after they named the asteroid they discovered "Madisonvillehigh."

The H-R Diagram's 100th Anniversary

Jay M. Pasachoff

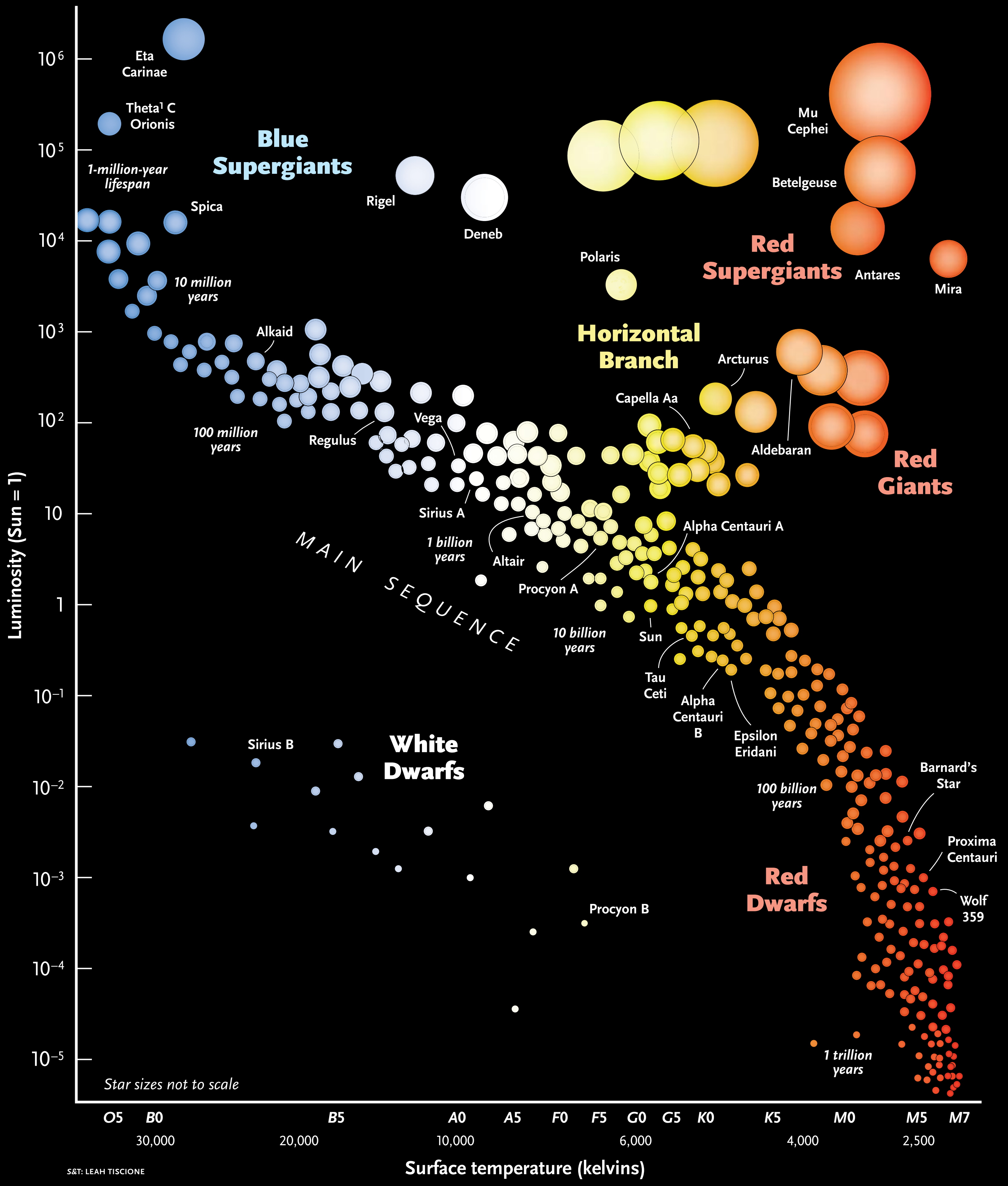
This year we celebrate the centennial of one of astronomy's cornerstone achievements.

The precocious 7-year-old grandson of an old friend recently asked me some questions about the Milky Way, including how we determine the ages of globular clusters. I found myself explaining the essence of the Hertzsprung-Russell diagram to a child, reminding me how fundamental it is to understanding the universe. Over the last century, this deceptively simple diagram has become the cornerstone to our comprehension of stars and stellar evolution. With it, we can follow the life stories of stars as simply as we follow turn-by-turn instructions on Google Maps.

The H-R diagram was for decades known in the U.S. as the Russell diagram. Henry Norris Russell (1877–1957) was an astronomer at Princeton University, where he had served on the faculty since 1905 following his brilliant undergraduate and graduate career there. In 1914 he summarized the current knowledge of stars before a joint

HERTZSPRUNG: D. HOFFLEIT / YALE UNIV. OBS. / AIP E. SEGRÈ VISUAL ARCHIVES
RUSSELL: AIP E. SEGRÈ VISUAL ARCHIVES

FOREVER LINKED Henry Norris Russell (seen with his family) and Ejnar Hertzsprung (*above*) will always be linked in the history books for independently coming up with similar concepts that led to the diagram that bears their names.



Eta Carinae
Theta¹ C Orionis
1-million-year lifespan
Spica
Blue Supergiants
Rigel
Deneb
Polaris
Red Supergiants
Mu Cephei
Betelgeuse
Antares
Mira
10 million years
Alkaid
Horizontal Branch
Arcturus
Capella Aa
Aldebaran
Red Giants
100 million years
Regulus
Vega
Sirius A
1 billion years
Altair
Procyon A
Alpha Centauri A
MAIN SEQUENCE
10 billion years
Sun
Tau Ceti
Alpha Centauri B
Epsilon Eridani
Sirius B
White Dwarfs
100 billion years
Barnard's Star
Proxima Centauri
Wolf 359
Red Dwarfs
Procyon B
1 trillion years
Star sizes not to scale
Luminosity (Sun = 1)
10⁶
10⁵
10⁴
10³
10²
10
1
10⁻¹
10⁻²
10⁻³
10⁻⁴
10⁻⁵
O5 B0 B5 A0 A5 F0 F5 G0 G5 K0 K5 M0 M5 M7
30,000 20,000 10,000 6,000 4,000 2,500
Surface temperature (kelvins)
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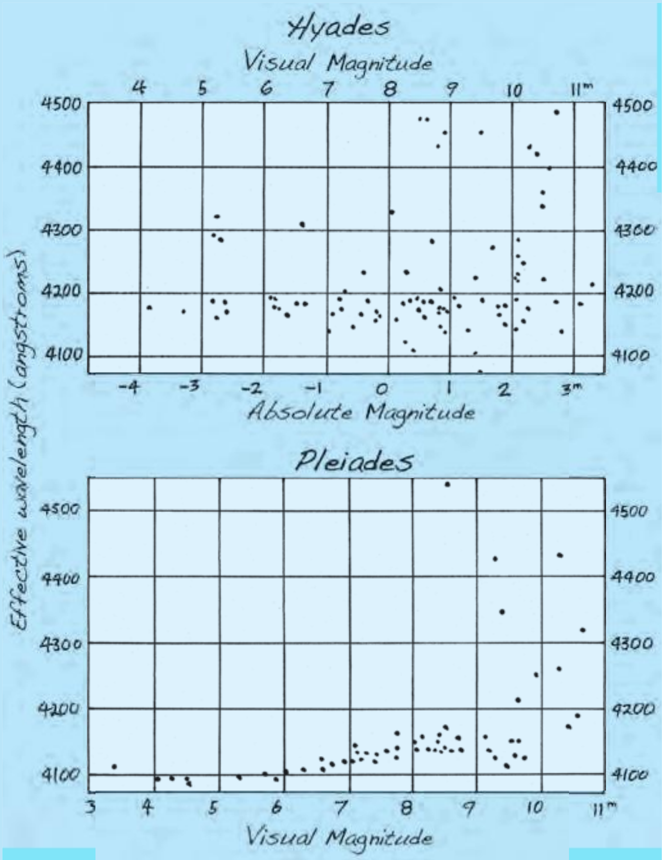
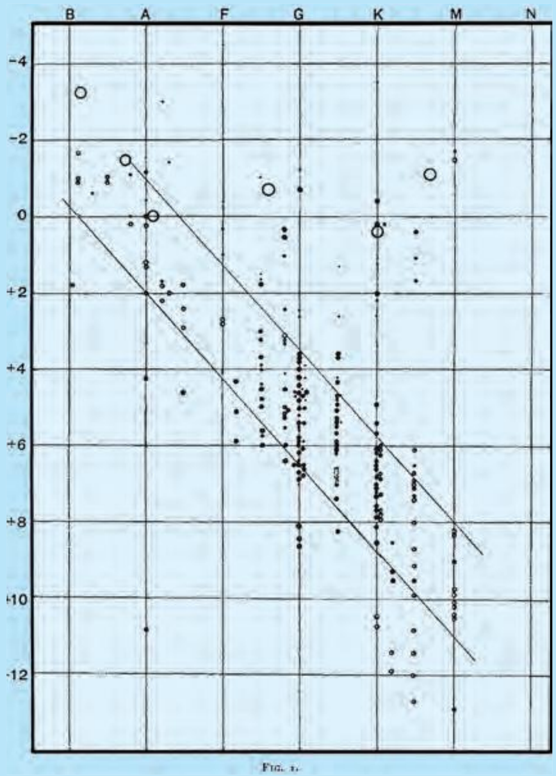


PUBLIKATIONEN DES ASTROPHYSIKALISCHEN OBSERVATORIUM ZU POTSDAM (2)



NATURE / S&T ARCHIVE

meeting of the Astronomical and Astrophysical Society of America and the astronomy section of the American Association for the Advancement of Science. We now celebrate the centenary of the first appearance in print of his diagram, in the publication of his talk in *Nature* as a three-part article in April and May 1914 and, in the same year, in *Popular Astronomy* (the *Sky & Telescope* of its day).

Brightness vs. Temperature

In its usual form established by Russell, the H-R diagram is a graph showing the relation of stellar luminosities on the vertical axis and temperatures on the horizontal axis, with the brighter stars near the top and the hotter stars on the left. Spectral type corresponds to temperature, and Russell drew his 1914 diagram with an ordinary series of spectral types that we now know has temperature decreasing toward the right.

Most stars fall on a diagonal line — the main sequence — from upper left to lower right. But the right half also has some higher points, which branch off from near the top left to form a shorter branch of a wishbone. These stars are giants and supergiants, since they must be very large to be so much brighter than the main-sequence stars below them. And at the diagram's extreme lower left, Russell plotted a single faint, hot star. More were added later, and such stars are today called white dwarfs. Though our understanding of what it all means has greatly improved over the last century, the diagram's form looks the same since Russell first drew it in 1914.

The concept of measuring stellar brightnesses in terms of magnitudes dates back to the Greek astronomer Hipparchus around 130 B.C.E. In the 19th century, astronomers learned how to convert a star's apparent brightness into its intrinsic brightness (luminosity) by measuring its distance using the parallax method. But it wasn't until the early 20th century that astronomers started to measure the temperatures of the outer atmospheres of stars.

Annie Jump Cannon of Harvard College Observatory played a key role by classifying hundreds of thousands of stellar spectra based on their black-and-white photographs. After first assigning the letters *A*, *B*, and so on alphabetically based on the strength of dark lines from hydrogen gas that were always at the same positions across the stars' spectra, she later rearranged the letters, giving the *O B A F G K M* sequence that is familiar to generations of astronomers and students as a temperature sequence (*S&T:* August 2013, p. 28). Around this

THE ORIGINALS Although unrefined by modern standards, these early diagrams from Hertzsprung (*above*) and Russell (*left*) clearly show the main sequence — a remarkable feat given that measurements of stellar distances and temperatures were less precise back then than they are today. Note that Russell's diagram (from his 1914 *Nature* paper) is much closer to the one in use today, particularly in how the axes are arranged.

time, Russell himself was pondering the idea that the differences among the stars' spectra depended more on temperature than their chemical composition.

Scientists knew there were ways to plot the stars on the horizontal axis other than looking at the dark spectral lines. In 1900 German physicist Max Planck had published his formula showing how gases of different temperatures have peak wavelengths that correspond to hotter stars appearing bluer and cooler stars appearing redder. So the temperature axis amounted to a color axis ranging from blue (left) to red (right). Thus the H-R diagram is also called the color-magnitude diagram.

PARALLAX

Astronomers have traditionally measured distances to relatively nearby stars by using astrometry. This involves the measurement of tiny shifts in a star's position against the backdrop of more distant stars as Earth changes positions in its yearly orbit.

Almost, But Not Quite There

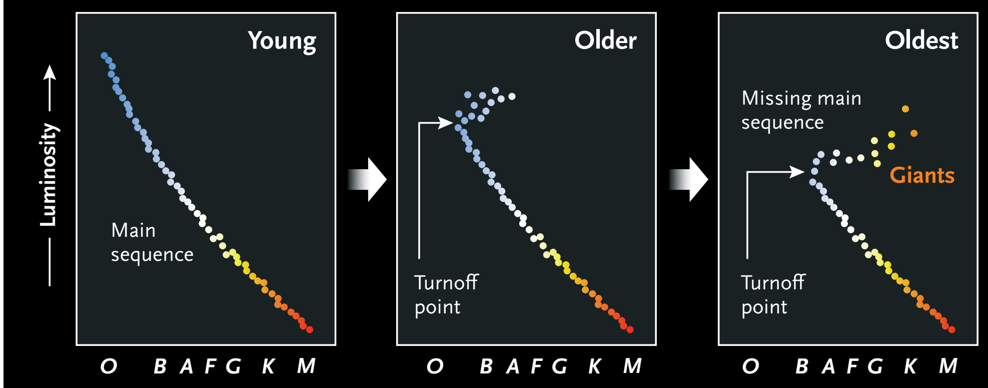
In the decade before Russell's work, Ejnar Hertzsprung (1893–1967) had studied stars and independently came to some ideas that were precursors to Russell's diagram. Born in Denmark, Hertzsprung earned a degree in chemical engineering at Copenhagen Polytechnic and later worked at Dutch and German observatories. After using various methods to derive distances to individual stars, Hertzsprung noted that some *K* and *M* stars were more luminous than other stars of the same color. Stars of the same surface temperature would give off the same amount of energy per square meter. Therefore, the brighter ones must have more surface area; that is, they're bigger.

In 1911–12 Hertzsprung worked out a link between stellar temperatures and luminosities in the Pleiades and Hyades open star clusters. But his resulting diagram, made easier because all the stars in each cluster lie at about the same distance, looked very different from today's H-R diagram, because it had only one diagonal line. Moreover, he plotted his diagram with stellar magnitudes on the horizontal axis and a measurement of color on the vertical axis, reversed from Russell's form and the form in use today. Hertzsprung published his result in a journal devoted to photography rather than astronomy, so even this not-quite-there result was unknown or unappreciated by astronomers. Unfortunately for Hertzsprung, his two clusters are so young that almost all of their stars lie on the main sequence (a term he coined), and very few have reached the giant phase. A diagram he published in 1929 still had magnitudes on the horizontal axis and temperature on the vertical axis, reversed from what we use today.

By 1913–14, astronomers had greatly improved methods of taking simultaneous spectra of many stars by using big prisms and of finding distances to stars by

HISTORIC MEETING Russell presented his diagram on December 29, 1913 at the American Astronomical Society meeting in Atlanta. In this conference photo, Russell is second from right in the center row. AAS president Edward C. Pickering is at the front center.

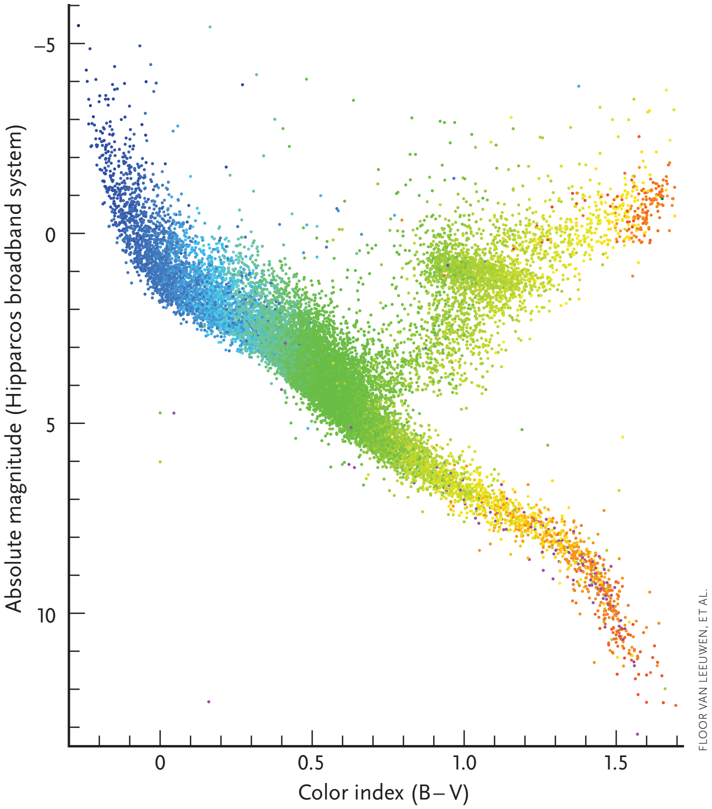
AAS



DATING CLUSTERS Using H-R diagrams, astronomers can measure the ages of star clusters (open and globular) by seeing where their main sequences turn off. The more massive and luminous stars live the shortest lives, so they're only found in young clusters

S&T: GREGG DINDERMAN

observing their parallaxes. All this information enabled astronomers to link the stars' distances with their apparent brightnesses to calculate their intrinsic brightnesses, and also measure their surface temperatures (or, at least, their spectral types). Russell also described how the differences in spectral lines among stars of different spectral types were caused by differences in the temperature of their outer layers rather than by differences in chemical composition, as many astronomers still expected.



MODERN DIAGRAM Using data from the European Space Agency's Hipparcos satellite, astronomers have assembled the most complete and accurate H-R diagram yet. This diagram includes points for 17,502 stars whose parallaxes are known to better than 7%.

Knowing the intrinsic brightnesses of stars instead of merely how bright they appear to us required measuring their distances. Distances derived from parallax measurements back then were much more uncertain than they are now, and Russell combined some points to gain accuracy for the stars on his graph. Russell's 1914 graph, even with its large measurement uncertainties of about ±1.5 magnitudes, clearly showed that the bulk of stars lie on the main sequence, with additional cool stars to the upper right.

Russell correctly realized that extremely hot stars, such as class *B*, are decidedly more massive on average than those of other spectral types. As he wrote, "On the present theory, this is no mere chance, but the large masses are the necessary condition — one might almost say the cause — of the attainment of unusually high temperature." So far, so good. But, he went on, "Only these stars would pass through the whole series of the spectral classes, from *M* to *B* and back again, in the course of their evolution."

We modern-day astronomers know that Russell's ideas of stellar evolution were completely wrong. Among other problems, scientists of his day had yet to discover that stars shine by fusing lighter atomic nuclei into heavier nuclei. We now know that each star reaches a place on the main sequence depending on its mass, and that it remains essentially there for its normal lifetime — shorter for hotter stars and longer for cooler stars — before it evolves up and to the right on the H-R diagram as the star expands into a giant.

Astronomers didn't know it 100 years ago, but we now realize that the surface temperatures and intrinsic brightnesses of stars vary back and forth a bit after they leave the main sequence, as different types of fusion processes switch on and off. But it wasn't until the late 1930s that Hans Bethe worked out the fusion processes in stars.

With his incorrect ideas of stellar evolution, Russell erroneously thought that "The great majority of the stars visible to the naked eye, except perhaps in Class *F*, are giants." He went on to reason about the temperatures reached by stars, but his physical process was hopeless because he had no concept of nuclear fusion. But to his credit, Russell knew his ideas were incomplete. He wrote, "I need scarcely add that, if what I have said proves of interest to any of you, your frank and unsparing criticism will be the greatest service which you can render me."

Intrigue over Credit

For decades after its 1914 publication, the diagram was known as the Russell diagram, especially in the U.S. and England. In his biography of Russell, David DeVorkin describes how Hertzsprung's name not only became attached to the diagram but also ended up first. The change had to do with international intrigue and national pride involving Danish-born astronomer Bengt Strömgren and Dutch-born astronomer Gerard Kuiper in the 1930s. Apparently, Strömgren and Kuiper badgered their University of Chicago colleague Subrahmanyan Chandrasekhar to add credit to Hertzsprung when Russell's diagram was discussed in the *Astrophysical Journal*, of which Chandrasekhar was an editor. In the late 1940s, DeVorkin writes, "Chandrasekhar, tiring of Kuiper's continued rants, settled the matter by declaring 'H-R diagram' to be the standard nomenclature for the journal," which had become the journal of record for astronomy.

Later in the 20th century, measurements of stellar luminosities improved, which diminished the main sequence's apparent thickness. The shape of the main sequence thus became important to determining the ages of star clusters. The main sequences of open clusters vary widely in length. The main-sequence stars of younger clusters include hot *O* and *B* stars, but being massive, they consume their nuclear fuel at a prodigious rate and thus have relatively short lives. Older open clusters lack hot, luminous main-sequence stars because they long ago evolved into giants and stellar remnants.

On the other hand, all globular clusters in our galaxy have similar H-R diagrams, with short, stubby main sequences that lack hot, luminous stars. Globulars must be at least 10 billion years old, dating most of the way back to our galaxy's formation.

Looking Ahead

Astrometry took a giant step in 1989, when the European Space Agency launched its High-Precision Parallax Collecting Satellite (Hipparcos), named for the aforementioned Greek astronomer Hipparchus. After years of observations, team members measured distances to more than 100,000 stars, even though their calculations were made more difficult by the satellite's failure to reach its planned orbit. Hipparcos also measured stellar motions across the sky (proper motions) to a high accuracy. Some measurements — brightnesses and positions though not parallaxes — were even made of a million stars, later enlarged to 2.5 million stars, at a much lower positional accuracy.

A new study published in 2007, which took into account an improved understanding of the spacecraft's motions, led key Hipparcos team member Floor van Leeuwen (Cambridge University, UK) to an improved catalog and a more accurate H-R diagram for the 17,502 stars whose parallaxes are known to better than 7%.

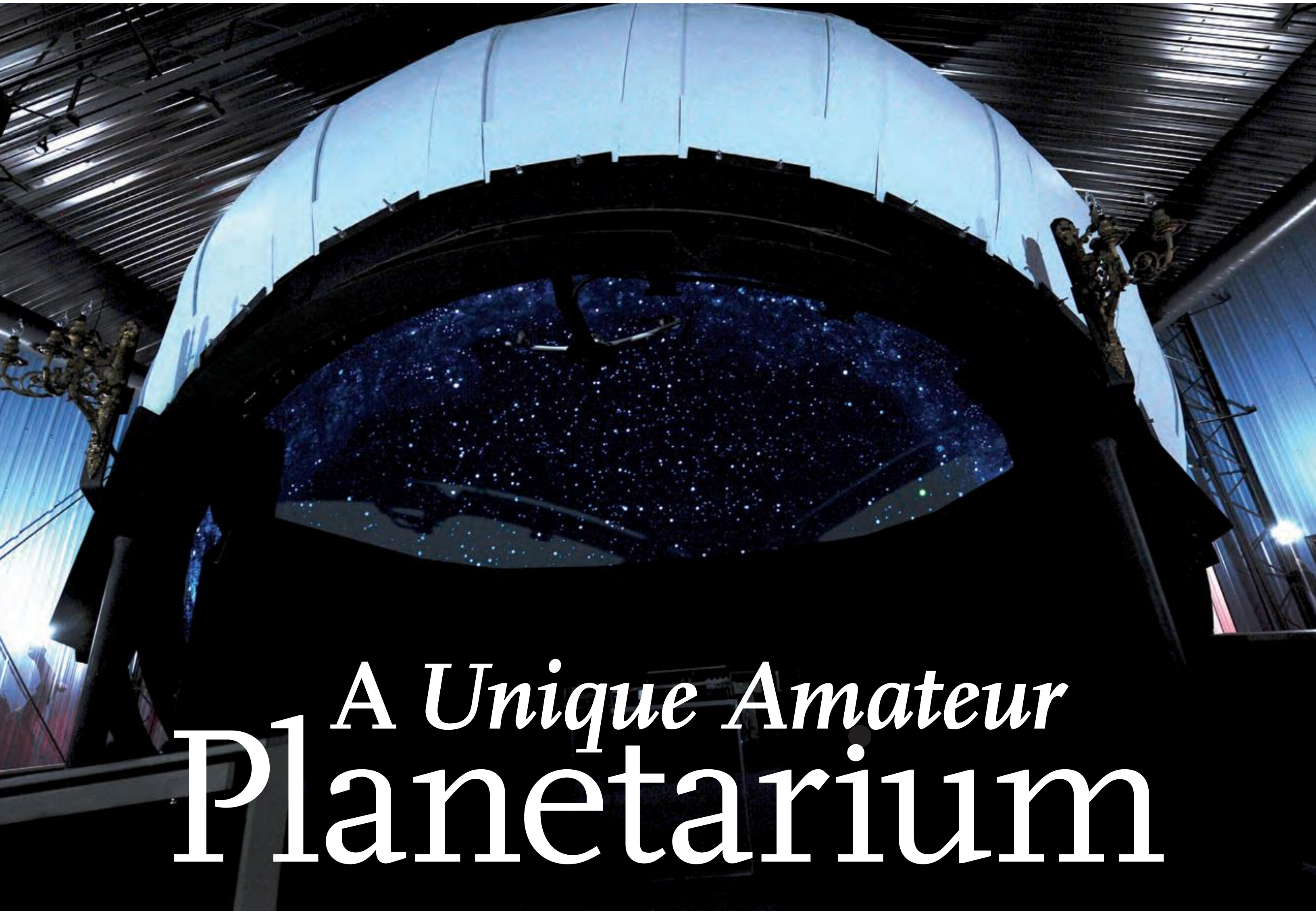
On December 19, 2013, ESA launched its Gaia satellite. Gaia will measure parallaxes even more accurately than Hipparcos did, and will do so for all stars brighter than magnitude 20 that are resolved on its detectors. Gaia will measure parallaxes to about 1 billion stars compared to Hipparcos's 100,000 stars, and these measurements are expected to reach accuracies that are 10 to 100 times higher than those obtained by Hipparcos. Gaia will derive accurate distances for rare and intrinsically bright stars in relatively large numbers. These same stars are used to determine intergalactic distances, so establishing their luminosities through direct parallax determinations is a big step forward from the current combination of indirect methods. Gaia will extend the H-R diagram to the lower right by measuring both cooler and fainter stars, and its more accurate measurements will provide much more detailed information on the main sequence.

So by the 100th anniversary of Russell's 1914 publications, we have plotted millions of stars on H-R diagrams and have an orbiting spacecraft that will provide measurements of millions more. H-R diagrams enable students and researchers alike to understand the evolution of stars in our Milky Way Galaxy and therefore elsewhere, and we have extended the diagram's range to stars and brown dwarfs so cool that they could not even have been seen a generation ago. Let's hope that some of today's astronomical discoveries prove to be as important when examined from the vantage point of a century from now. ✦

Jay M. Pasachoff has been lecturing about the H-R diagram since he started teaching at Williams College in 1972 and writing about it in his textbooks, most recently the 2014 edition of The Cosmos: Astronomy in the New Millennium. *In September 2013 he received the Janssen Prize of the Société Astronomique de France.*

Crediting His Colleagues

Russell concluded his third *Nature* paper of 1914: "If the ideas to which you have so kindly listened to-day shall prove of any help toward removing the need for belief in unknown forces, and extending the domain of those already known, my labour will be far more than repaid; but it should not be forgotten that the real labourers have been those who, through long and weary nights, accumulated bit by bit, and, through monotonous days, prepared for the use of others the treasures of observational knowledge with which it has been my pleasurable lot to play in the comfort of my study."



A *Unique Amateur* Planetarium

DEAN ACHESON

Ron Legro & Avi Lank

Ten years of dogged work brought forth this amateur astronomer's dream.

The world's largest revolving-globe planetarium has an unlikely history and location. The Kovac Planetarium greets the rural traveler on a narrow, twisting gravel road in the sparsely populated north woods of Wisconsin, near the small town of Monico, population 364. It's the epitome of a do-it-yourself project, formed in the mind of Frank A. Kovac, Jr., who spent a decade building it.

The hollow, two-ton, 22-foot globe displays more than 5,000 stars in ultraluminescent paint that Kovac dotted into place by hand. Since 2007 visitors have been trekking to Monico (a five-hour drive north of Chicago) to sit inside the rotating globe and hear Kovac's live 90-minute show. The planetarium's impresario and sole employee, Kovac has built his audience to about 4,500 annually, drawing customers from as far as Australia, mostly through word of mouth and web reference.

STAR GATE In the wilds of northern Wisconsin, Frank Kovac spent five months hand-painting the 5,000 naked-eye stars visible from his latitude on the inside of his rotating-dome planetarium using ultraluminescent paint.

Kovac created the planetarium from scratch, overcoming false starts and disasters. He designed it mostly in his head and built it using little more than home power tools and shop math. He solved myriad technical problems, including how to rotate and suspend the globe from the ceiling of his planetarium building. He financed the $180,000 project with wages from his former job in a nearby paper mill, loans, and small inheritances.

A self-taught astronomy buff, Frank Kovac, 48, grew up in Chicago. He developed a fascination with the stars as a boy thanks to his father, now deceased, for whom the planetarium is named. A blue-collar immigrant from Hungary, Frank Sr. took his son on visits to Chicago's Adler Planetarium and bought him a small telescope. Later the youth built a 10-inch Dobsonian reflector. Then, in his teens, he used luminescent paint to decorate a wall of his basement bedroom so it would look like the viewport of a spaceship approaching Saturn.

His parents took the family on vacations in rural Wisconsin, where the night sky was spectacularly free from light pollution. Frank was hooked. He decided he wanted to be an astrophysicist, but lacking grades good enough for college, he took a blue-collar job as a production machinist in Chicago.

His planetarium idea took shape after he enlisted in the Air Force. Stationed at K. I. Sawyer Air Force Base in Michigan's Upper Peninsula, Kovac had plenty of time to observe the unspoiled night sky. Before enlisting he had bought some wooded acreage 150 miles southwest of the base, where he could stargaze when he liked. The land was rugged, but the price was right, and Kovac only cared about the sky overhead. He remembers telling a real estate agent: "Out in the middle of nowhere — that's perfect!" He built a home and a small observatory shelter on his property and invited guests to stargaze with him.

But one summer evening in 1996, clouds rolled in and no stars were visible, disappointing a group of Boy Scouts. "That was when I decided to build the planetarium," recalls Kovac in a soft voice. He knew the task would be daunting, expensive, and unusual for such a remote area. But he thought, "If I do it over many years . . . I can afford it."

Kovac hand-sketched his dream, and the drawings look remarkably like what he ended up building. He would craft a giant hollow globe, tilted to match Monico's latitude near 45° north, with seating inside for about 25 guests who would enter through a large opening in the globe's tilted southern base.

Kovac began construction in 1997 and devoted tens of thousands of hours of labor over the next decade. "Can you imagine," he says now, "spending years of your time putting this together and still not knowing if it's going to look like what you're thinking?" Indeed, several major incidents during construction gave him reason to doubt he'd ever finish.

Kovac first tried using a lattice of PVC plastic pipe for the framework of the globe. But the pipe became too brittle in Wisconsin's frigid winter, and the globe collapsed. Kovac turned to his carpentry skills. He laminated plywood boards together, and from this he cut strong curved ribs to frame the globe. He then cross-braced them with bolted metal ribbons. Some of the wood and metal was scavenged from scrap bins at the paper mill where he worked.

One day in 2001, Kovac was alone testing the globe's new weight-bearing system. "I was underneath this thing, which was suspended on winched slings," he recalls. Standing inside his massive creation, Kovac narrowly escaped injury when the globe broke free and fell, crashing so loudly it brought out a neighbor. "It fell down all around me," he says. Kovac was able to crawl out through the frame of

REALIZED DREAM Frank Kovac stands in front of his finished building in 2008.

RON LEGRO

FRANK KOVAC (2)

"THE INVENTION" The dome *(left)* went up before the final building around it. Neighbors suggested that aliens had landed. Two earlier shelters around it, including the one at right photographed in 1997, were inadequate and had to come down, adding to the project's daunting challenges.

the globe past the wreckage of its shattered base.

Briefly shaken, and doubting anew that he would ever succeed, he shifted gears. After repairing the damage in about a month, he realized that he needed a better way to support some of the globe's weight. He recalled his Air Force days when he used winches to hoist nuclear weapons into B-52s. Drawing on that experience, he devised a spring-and-bearing system that would support part of the globe's weight from the roof of the outer building.

Meanwhile, after five years of globe construction, Kovac's temporary shelter made with spruce poles began to sag, so he pulled it down and covered the globe with giant tarps. He eventually bought and erected the prefabricated steel-frame building that visitors see today. Built on a concrete pad, it would permanently house the globe and planetarium facilities.

FRANK KOVAC

BUILT TO LAST The final prefab steel-framed building was expensive but poses no risk of collapse even under heavy Wisconsin winter snow.

But it took several more years to get the globe to turn properly. "There were times when I had tears in my eyes," Kovac recalls. "It was so difficult."

After finding a suitable ½-horsepower Dayton gear motor, Kovac worked with a neighbor who was a welder to assemble a new wheeled-ring track system of wood, polyurethane, and metal. Early track designs could not manage the globe's entire two-ton mass, which was centered away from the base ring, or reduce a persistent wobble when it turned, so Kovac experimented until he found materials and techniques that solved the problems.

Finally, he needed to depict the stars and Milky Way on the globe's interior. Kovac couldn't afford a projector, so he returned to the example of the mural he'd made on his childhood bedroom wall. He decided to try $200-per-gallon ultraluminescent paint, which glows brightly for hours after exposure to ordinary lamps.

To paint an accurate sky map, Kovac treated the dome's faintly gridded interior styrene panels as a coordinate system, with 24 sections representing the hours of right ascension. Referencing star maps, he hand-painted within each section every star visible to the naked eye over Monico. He used a sponge to apply paint for the Milky Way. For the visible planets, Kovac positions removable appliques on the dome so he can update their changing locations as needed.

Painting took five months. Kovac stood on a scaffold and ladder for much of the time. Like a techno-modern Michelangelo, he worked painstakingly, illustrating the heavens on his more prosaic equivalent of the Sistine Chapel ceiling.

The results were beyond his wildest hopes. The resulting sky display is, in its subtle but star-like luminescence, surprisingly three-dimensional and faithful to the real cosmos. Due to limitations of other ultraluminescent pigments, however, all the stars shine in monochromatic light blue, and some are substantially larger than they appear in the actual sky to show the proper relative brightnesses.

Only after he was nearly done did it occur to him that he might need to file state and county paperwork, getting permits to run the planetarium as a business open to the public. He hired a consulting engineer and several contractors. Issues included proper site drainage, electrical and plumbing standards, and whether there was wheelchair access to the seating inside the globe.

The entire project might have come to a premature end over the wheelchair issue. Luckily, Kovac had unwittingly provided a solution when he fixed an earlier problem. The globe had proved slightly too large to fit inside the steel-frame building with proper clearance. Kovac rectified that situation by digging a three-foot pit beneath the globe. That extra space allowed a wheelchair ramp to be properly angled into the globe.

In all, the permitting process consumed the final three years of Kovac's space odyssey. He estimates that he did 90% of the work himself with occasional help from friends, family, and contractors.

It was only around the time he opened the planetarium that Kovac discovered that his rotating hollow globe design was not unique. Smaller ones are in German and Russian museums, and as Kovac was building his, another, the Atwood Sphere, was being restored in Chicago. The Atwood (also smaller) was built in 1913 and is now on display at the Adler Planetarium. Kovac's globe is the only one operating as a profit-making business; ticket sales now provide most of Kovac's annual income.

While he was building what he calls his "invention," his rural neighbors along Mud Creek Road thought Kovac might be unhinged. They wondered what exactly he was up to. One joking theory was that "the mothership" had dropped it off. As for other curious onlookers, Kovac smiles. "I said it is going to look like the universe inside this rolling ball. I said there were people who were trying to make flying machines who were considered nuts long ago, and now we've got rockets."

Kovac's next projects: Upgrading his show's electronics, which mostly consist of a laptop with a small-screen projector, and building a small public observatory nearby to house his 10-inch reflector.

"I had a friend who would tell me sometimes, 'Frank, you're going to kill yourself out here,' " Kovac recalls. "I looked at it this way: We would not have gone to the Moon if we were worried about risk." He likes to compare himself to a mountain climber. He didn't give up until, in virtual fashion, he reached the stars. ✦

__Ron Legro__ and __Avrum D. Lank__ are Milwaukee journalists working on a book about Frank Kovac and his planetarium, scheduled for publication in 2015. The planetarium's website is __www.kovacplanetarium.com__.

DEAN ACHESON (2)

THE FINISHED PRODUCT **The rotating-globe planetarium, the largest of its kind in the world, now receives about 4,500 visitors per year.**

New Product Showcase

◄ **EYE RELIEF OCULAR** Vixen's new SLV Lanthanum Eyepiece series ($169 each) is designed with the eyeglass wearer in mind. Each of these 1¼-inch oculars is designed with 20 millimeters of eye relief and a twist-up eyecup, allowing eyeglass wearers to comfortably enjoy the entire 50° field. The SLV Eyepieces also incorporate a 7-element design in 4 groups with fully multicoated glass-to-air surfaces, a scratch-resistant coating on the field lens, and a rare-Earth lanthanum element. The unique polygonal barrel is easy to grip and will not roll away when placed on its side. The series is available in 2.5, 4, 5, 6, 9, 10, 12, 15, 20, and 25-mm focal lengths to suit most observing needs.

Vixen Optics
1023 Calle Sombra, Unit C, San Clemente, CA 92673;
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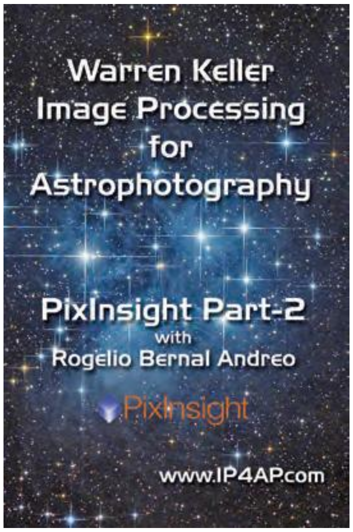
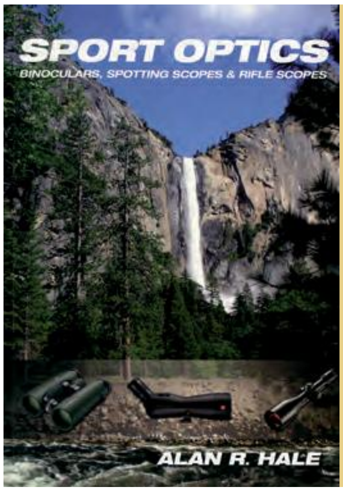


► **PROCESSING LESSONS** Premier astrophotographers Warren Keller and Rogelio Bernal Andreo team up to bring you their latest video tutorial in the IP4AP series. *Image Processing for Astrophotography: PixInsight Part-2* ($74.95) is available for online streaming or as a DVD. It contains 2½ hours of information in 27 scripted *Adobe Flash* tutorials that continue to familiarize you with the software *PixInsight*, a powerful and affordable alternative to *Adobe Photoshop* designed specifically for astrophotography. Part 2 of the series details advanced image-processing techniques, including nonlinear stretching, noise reduction, detail enhancement, controlling star bloat, and much more. Each tutorial runs about 5 to 7 minutes and contains concise demonstrations of the concept to help you get the most out of your astroimages.

IP4AP.com
2730 Upper Mountain Rd.,
Sanborn, NY 14132
716-864-7400; www.ip4ap.com



SPORTS OPTICS Binoculars, spotting scopes, and rifle scopes, collectively known as sports optics, have improved due to a wide range of technological advances in recent years. From new optical designs, to improved optical coatings, to sophisticated electronics for stabilizing the view through hand-held equipment, modern sports optics are a far cry from their predecessors. The new book *Sport Optics* ($24.95) by Alan R. Hale offers a comprehensive and up-to-date look at the sports optics currently on the market. It covers the technological advances in a way that cuts through advertising hyperbole and presents the pros and cons of modern equipment in an easy-to-understand manner. The sections on binoculars and spotting scopes will be of particular interest to amateur astronomers. Author Alan R. Hale is a former president and C.E.O. of Celestron International who has more than 50 years of experience in the optics industry. Paperback, 186 pages, ISBN 978-0989791601.

Hale Optics
www.haleoptics.com

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

In This Section

This Hubble Space Telescope image of Messier 5's core shows the Cepheid variable V84. Can you identify it using the information in the article on page 60?
ESA / NASA

JUNE 2014

7 EVENING: The waxing gibbous Moon shines below Mars, with Spica to their left; see page 48.

8 EVENING: Now the Moon shines near Spica, with Mars to their right.

9, 10 EVENING: The Moon shines to the right of Saturn for the Americas on the 9th and left of Saturn on the 10th. In between, around 19h UT on the 10th, the Moon occults (hides) Saturn for viewers in southernmost Africa.

21 THE LONGEST DAY of the year in the Northern Hemisphere. Summer begins at the solstice, 6:51 a.m. EDT.

24 DAWN: The waning crescent Moon forms a spectacularly close pair with Venus for the Americas, with the Pleiades to their upper left. The Moon and Venus appear somewhat farther apart at dawn elsewhere around the world.

25 DAWN: A very thin crescent Moon shines left of Aldebaran very low in the east-northeast shortly before sunrise for North America, with Venus and the Pleiades above them.

29 DUSK: Jupiter shines well to the right of the waxing crescent Moon very low in the west-northwest shortly after sunset; see page 49.

June 29 – July 12 EVENING: Ceres and Vesta appear less than ½° apart, fitting in the same low-power field of view in most telescopes. See skypub.com/asteroids for a finder chart.

Planet Visibility SHOWN FOR LATITUDE 40° NORTH AT MID-MONTH

	◀SUNSET	MIDNIGHT	SUNRISE▶
Mercury	NW	Visible May 3 through June 4	
Venus			E
Mars	S	W	
Jupiter	W		
Saturn	SE	S	W

Moon Phases

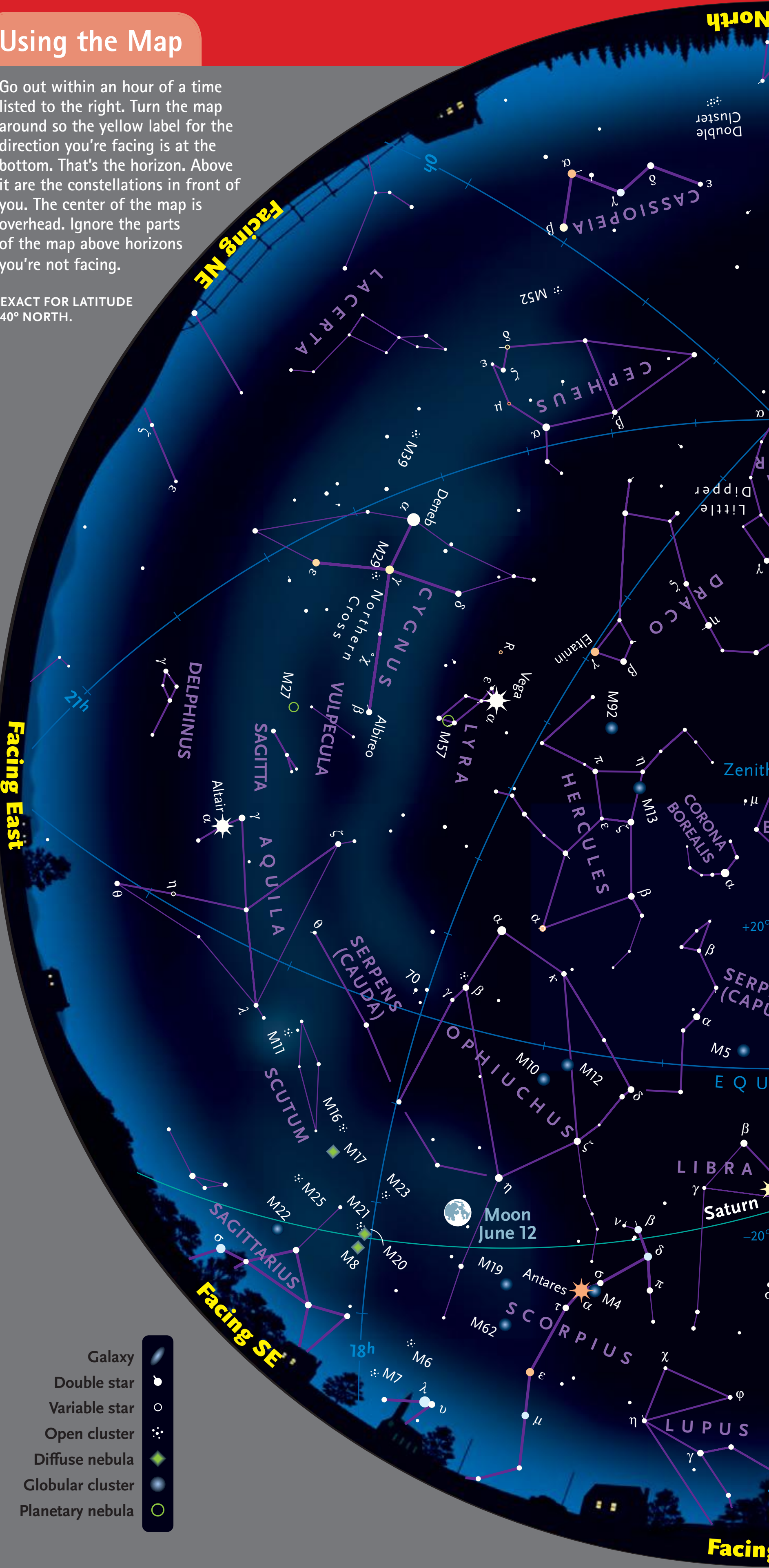
First Qtr June 5 4:39 p.m. EDT
Full June 13 12:11 p.m. EDT
Last Qtr June 19 2:39 p.m. EDT
New June 27 4:08 p.m. EDT

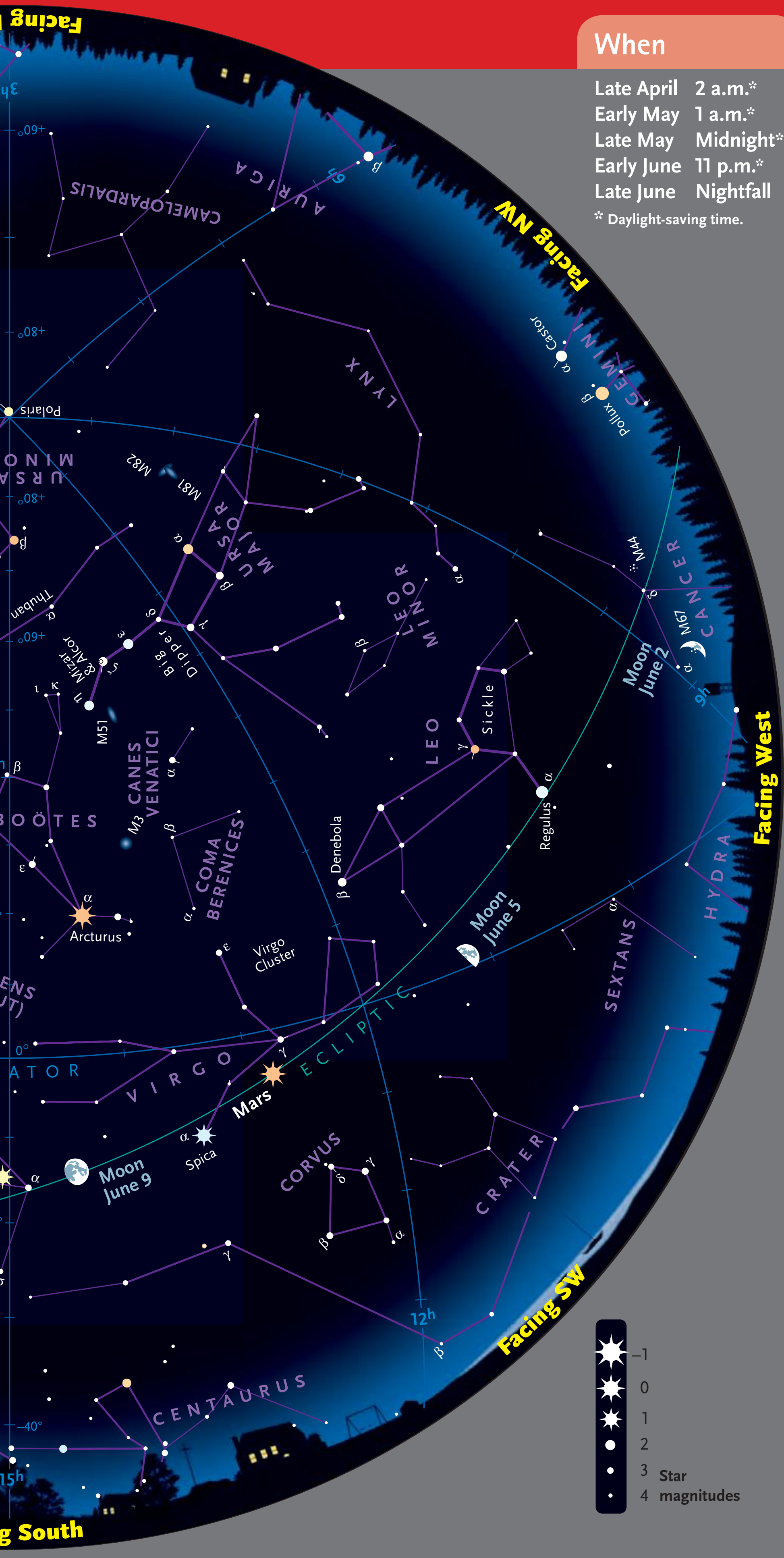
SUN	MON	TUE	WED	THU	FRI	SAT
1	2	3	4	5	6	7
8	9	10	11	12	13	14
15	16	17	18	19	20	21
22	23	24	25	26	27	28
29	30					

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 April	2 a.m.*
Early May	1 a.m.*
Late May	Midnight*
Early June	11 p.m.*
Late June	Nightfall

* Daylight-saving time.

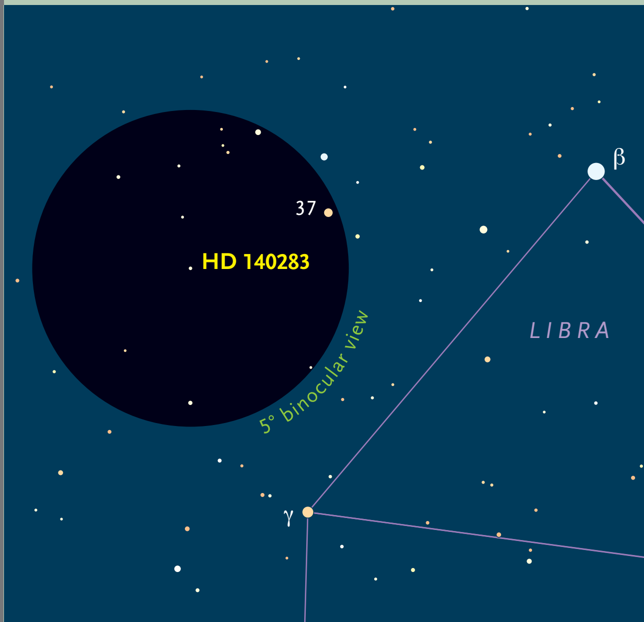
Libra's Methuselah Star

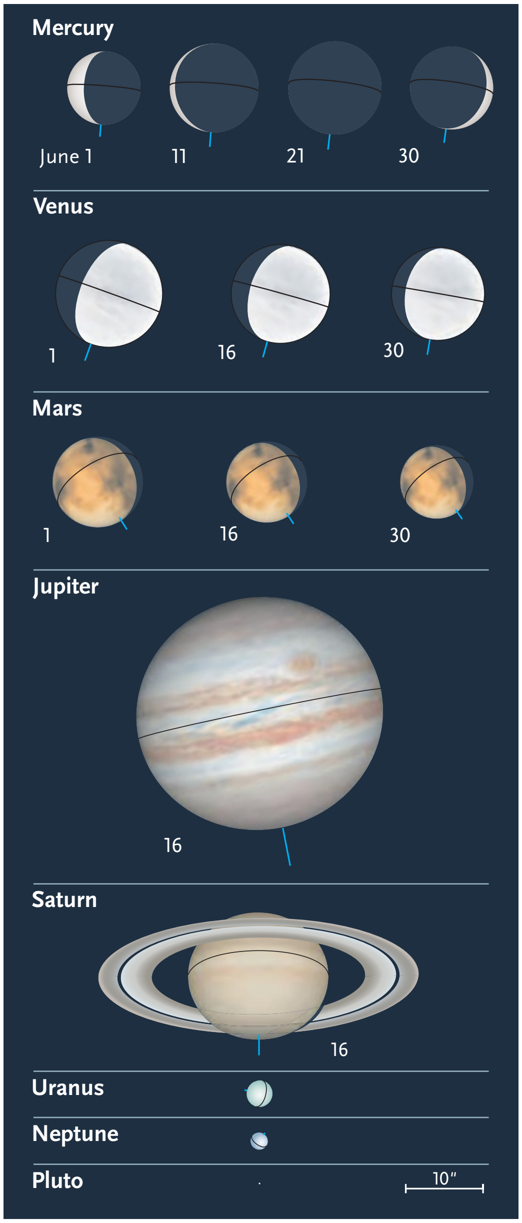
Visual astronomy is remarkably compelling because it engages both the mind and the eye. But there's no doubt that some binocular sights rely more on the former than the latter. Many objects are interesting for what they are, rather than how they look. Consider the 7.2-magnitude star **HD 140283**, for example.

HD 140283 lies only 190 light-years away in the constellation Libra. You can locate it by centering 2.6-magnitude Beta (β) Librae in your binoculars, then shifting east-southeast until you pick up 4.6-magnitude 37 Librae. HD 140283 is nearly an equal distance farther in roughly the same direction. Use the chart below (which plots stars down to magnitude 8.0) to pinpoint our target.

So what makes HD 140283 worth finding? It's a leading candidate for the title of "oldest known star." According to a 2013 study, its low heavy-element content suggests that it formed only a few hundred million years after the Big Bang. Pause a moment to consider what that means. This obscure subgiant has been shining away three times longer than our Sun. And it may provide an important clue about how and when our Milky Way Galaxy first began to form.

From childhood on, most of us have a fascination with knowing about the biggest, the fastest, the farthest, and the oldest. Such superlatives help delineate the contours of the imagination, and they shape our sense of wonder. Perhaps that's why this dim point of light — this so-called Methuselah Star — is really worth seeking out. Something in its feeble, ancient glow suggests answers to the question of why we look up to the night sky in the first place. It's not just the way that starlight tickles our optic nerves, it's the way it excites our minds. ✦





Sun and Planets, June 2014

	June	Right Ascension	Declination	Elongation	Magnitude	Diameter	Illumination	Distance
Sun	1	4^h 34.5^m	+21° 59′	—	–26.8	31′ 33″	—	1.014
	30	6^h 34.6^m	+23° 12′	—	–26.8	31′ 28″	—	1.017
Mercury	1	6^h 05.9^m	+24° 28′	21° Ev	+1.2	9.5″	23%	0.708
	11	6^h 10.9^m	+21° 56′	13° Ev	+3.4	11.5″	6%	0.585
	21	5^h 50.6^m	+19° 26′	4° Mo	—	12.1″	1%	0.557
	30	5^h 35.9^m	+18° 43′	14° Mo	+2.7	10.7″	9%	0.625
Venus	1	2^h 06.8^m	+10° 41′	37° Mo	–4.0	13.9″	77%	1.204
	11	2^h 52.4^m	+14° 29′	35° Mo	–3.9	13.1″	80%	1.270
	21	3^h 39.7^m	+17° 46′	33° Mo	–3.9	12.5″	83%	1.333
	30	4^h 23.9^m	+20° 08′	30° Mo	–3.9	12.0″	85%	1.386
Mars	1	12^h 36.2^m	–3° 31′	119° Ev	–0.5	11.8″	91%	0.794
	16	12^h 47.6^m	–5° 14′	108° Ev	–0.2	10.5″	89%	0.889
	30	13^h 04.8^m	–7° 24′	100° Ev	0.0	9.5″	88%	0.982
Jupiter	1	7^h 27.5^m	+22° 15′	40° Ev	–1.9	32.9″	100%	5.985
	30	7^h 53.1^m	+21° 16′	18° Ev	–1.8	31.7″	100%	6.214
Saturn	1	15^h 06.1^m	–14° 55′	158° Ev	+0.2	18.5″	100%	8.966
	30	15^h 00.0^m	–14° 35′	129° Ev	+0.4	18.0″	100%	9.250
Uranus	16	0^h 59.2^m	+5° 36′	69° Mo	+5.9	3.5″	100%	20.367
Neptune	16	22^h 37.4^m	–9° 28′	107° Mo	+7.9	2.3″	100%	29.658
Pluto	16	18^h 53.4^m	–20° 14′	162° Mo	+14.1	0.1″	100%	31.703

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

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

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

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

Fred Schaaf

Between Spring & Summer

The stars in and north of Libra are faint but fascinating.

I once owned a T-shirt that featured a beautiful design and the words "Spring into Summer." That's what astronomical observers should do in June. Taking spring not just as a season's name but also as a verb, we should leap into the thrilling realms of the summer constellations.

But before we turn to sights such as the summer Milky Way and Summer Triangle, which are still low in the east or southeast, we should look at a higher zone that represents the true transition from spring to summer constellations. For want of a better term, let's call it the Spring into Summer Zone.

The Spring into Summer Zone. The north-south strip of sky I'm talking about is virtually on the meridian of our all-sky map for June evenings. It almost corresponds with the slice of heavens between 15 and 16 hours of right ascension, but I'll shift it a little to the west so that it just misses all the bright stars of the Scorpion while including Alpha Librae (Zubenelgenubi). The Spring into Summer Zone has a bright visitor in 2014 — Saturn — but is otherwise surprisingly dim. However, as we'll see, that doesn't mean that it's uninteresting.

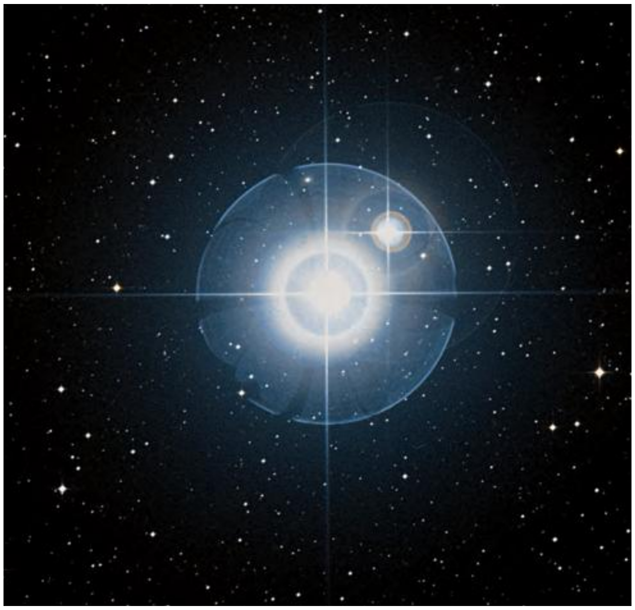
Saturn itself is in Libra, and north of Libra is Serpens Caput, the Serpent's Head. Both constellations' patterns are marked entirely by 3rd- and 4th-magnitude stars.

Moving northward we encounter the most prominent constellation of the Spring into Summer Zone: Corona Borealis, the Northern Crown. But even Corona Borealis has just one reasonably bright star: its alpha star, 2.2-magnitude Alphecca, also known as Gemma. It's not the pattern's brightness but its compactness and elegant semicircular shape that make it so striking.

After we cross the zenith we pass through a dim part of Draco the Dragon, and then encounter a pleasant surprise: Beta and Gamma Ursae Minoris, also known as Kochab and Pherkad, the Guardians of the Pole. We'll stretch the zone slightly to include the entire Little Dipper, which is now standing on its handle. Most of the Little Dipper's stars are faint, but they do include 2.0-magnitude Polaris and 2.1-magnitude Kochab.

Doubles, variables, and colored stars. In June and July last year, this column featured Corona Borealis and its wondrous double stars Eta, Zeta, and Sigma, as well as the great variable stars R and T CorBor.

Alpha Librae, which lies very close to the ecliptic and only a few degrees from Saturn this month, is one of the widest binary stars in the sky. Its components shine at magnitudes 2.7 and 5.2, and are just short of 4′ apart. Can you see the fainter star as a separate speck with your unaided eyes?



POSS-II / CALTECH / PALOMAR OBSERVATORY

The ultrawide double star Alpha Librae combines a hot, blue, *A*3 primary with a somewhat cooler *F*4 primary.

Stars in double-star systems often appear more colorful due to the contrast of their hues in close proximity. But some single stars are also colorful. Beta Librae (Zubeneschamali) has a reputation for appearing slightly greenish. What do you think? A beautiful orange star in the Spring into Summer Zone is Alpha Serpentis (Unukalhai). By an odd coincidence Alpha Serpentis, Beta Librae, and the combined components of Alpha Librae all shine at magnitude 2.6, just 0.1 magnitude too dim to qualify as 2nd-magnitude stars.

Look 4.8° north-northwest of Alpha Serpentis for the fine double star Delta Serpentis, a pair of spectral-type *F*0 bright giants with apparent magnitudes 4.2 and 5.2. They're 210 light-years from Earth and appear 4″ apart in this era of their 3,000-year-long orbit.

The grandest deep-sky object of the season lies less than 8° southwest of Alpha Serpentis. This is the great globular cluster Messier 5, which is discussed in detail on page 60. ✦

Saturn & Mars Rule the Night

Only two planets are visible during most of the night in June.

As twilight fades after June's late sunsets, Jupiter shines low in the west-northwest near Pollux and Castor. At nightfall Saturn stands near the meridian. Fading Mars is well past the meridian, with Spica to its lower left.

The sole bright planet at dawn this month is Venus, shining low in the east.

DUSK

Jupiter sets almost 3 hours after the Sun on June 1st but only about an hour after the Sun on June 30th. Its brightness (magnitude –1.8) and equatorial diameter (32″) are near their minimum for the year as Jupiter heads toward its July 24th conjunction with the Sun.

As it descends, Jupiter forms an attractive dogleg with Pollux and Castor during much of June. The big planet passes 6½° south (lower left) of Pollux on the 21st. By month's end, low in twilight, Jupiter moves into an almost straight line with Castor and Pollux to its right.

Mercury is visible low in the west-northwest about 45 minutes after sunset at the start of June; look far to Jupiter's lower right. But it's lost to view in just a few days due to its rapidly decreasing brightness. Mercury passes through inferior conjunction with the Sun on June 19th.

DUSK TO PREDAWN

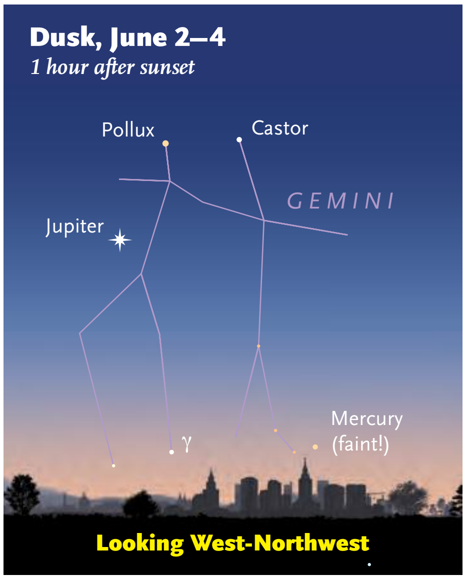
Mars glows into view due south as twilight deepens at the beginning of June, but it's well past the meridian at sunset by the end of the month. On June 1st Mars burns at magnitude –0.5. By June 30th the planet has faded to 0.0, matching Arcturus and Vega. This is a good month to compare Mars's fire-colored glow with the champagne-colored radiance of Arcturus.

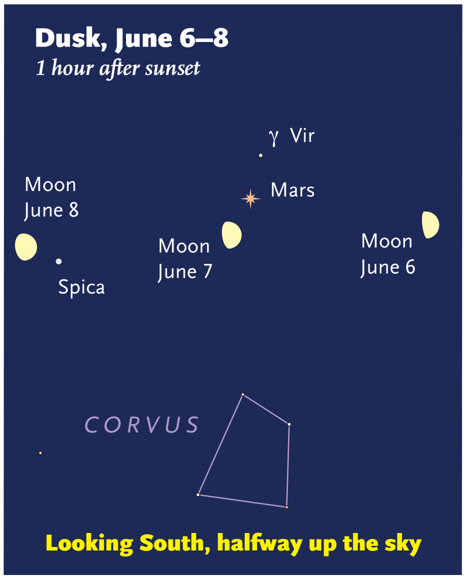
Mars was stationary with respect to the stars on May 21st, and during June it moves increasingly rapidly eastward through Virgo. It heads almost directly toward Spica, which it will pass on July 14th. The Red Planet crosses southward across the ecliptic on June 11th.

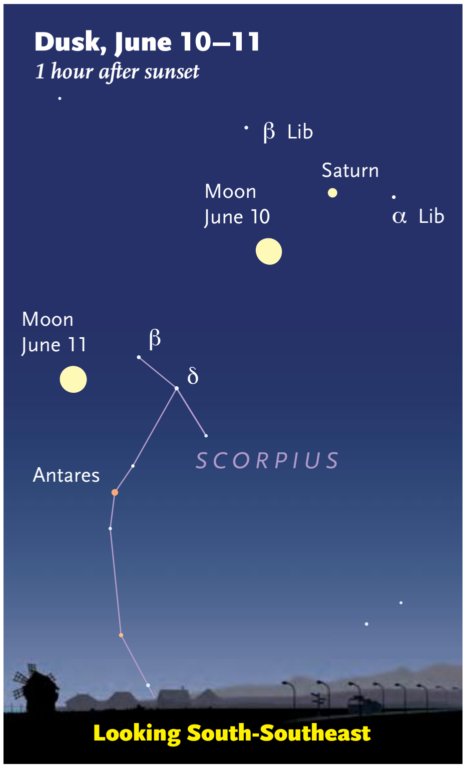
Earth is leaving its outer, slower neighbor behind in their orbital race, so Mars's globe dwindles from 11.8″ to 9.5″ during June. This is the last month when you're likely to have good views of multiple surface features on Mars through a medium-sized telescope.

Ceres and **Vesta** were at opposition less than 2 days apart back in April, when the two asteroids shone at magnitudes 7.0 and 5.8, respectively. Since then, they've remained very close in the sky, pursuing their retrograde loops near Zeta (ζ) Virginis, well north of Spica. In June and July they appear even closer together — an amazing encounter. Ceres and Vesta are separated by less than ½° from June 29th to July 12th. They're most tightly paired on July 5th, when 8.4-magnitude Ceres is less than 10′ from 7.1-magnitude Vesta. For full details, see **skypub.com/asteroids**.

Saturn begins the night at or near its highest in the south. It glows about

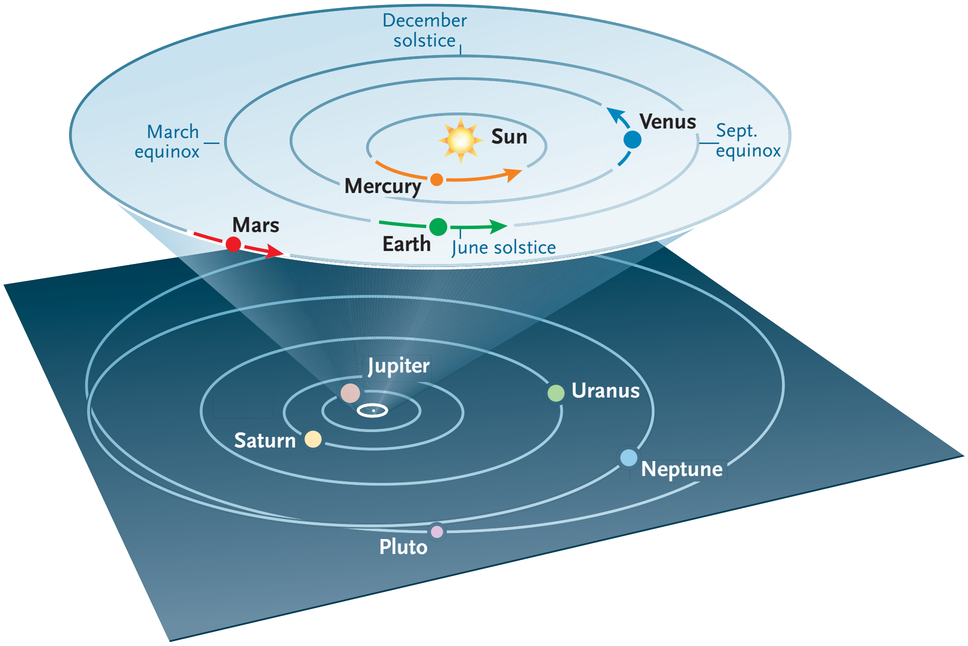






ORBITS OF THE PLANETS

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



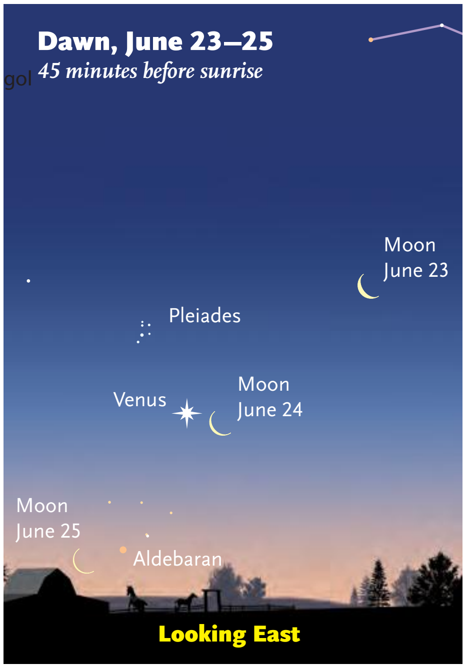
midway in the huge gap between Spica and Antares, and continues to retrograde a little closer to the wide double star Alpha Librae (Zubenelgenubi). Saturn dims slightly during June, from magnitude +0.2 to +0.4, and its globe shrinks from 18.5″ to 18.0″ in equatorial diameter. The rings remain beautifully displayed 21° from edge on, beckoning to telescope users on calm June evenings.

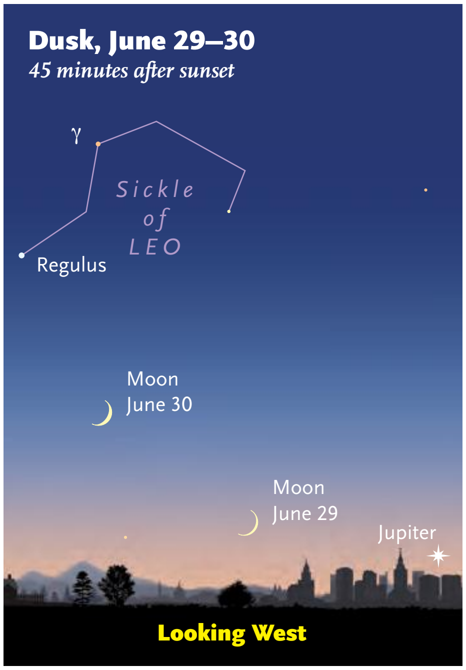
Pluto glows feebly around magnitude 14.1 in Sagittarius. It will be at opposition to the Sun on July 4th, so it's highest in the small hours of the morning during June. See page 50 for a finder chart.

PREDAWN AND DAWN

Neptune rises in the middle of the night and **Uranus** 1½ hours later. By the start of morning twilight, they're high enough for a good look in telescopes. Finder charts are available at **skypub.com/urnep**.

Venus starts coming up a little sooner before sunrise and appearing a little higher in morning twilight for observers at mid-northern latitudes — but it's still fairly low at dawn. Look east as dawn brightens. It's relatively faint (for Venus) at magnitude –3.9. In a telescope it's a small gibbous object less than 14″ wide.





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 symbol halfway toward the Moon for the previous date.

SUN AND MOON

The **Sun** reaches the June solstice at 6:51 a.m. EDT on June 21st, beginning summer in the Northern Hemisphere and winter in the Southern Hemisphere.

The **Moon** is a waxing crescent far left of Jupiter at dusk on June 1st. The gibbous Moon is just lower left of Mars on the evening of June 7th and just left of Spica the next evening. An even thicker Moon is well to the lower left of Saturn on the American evening of June 10th. Some hours earlier, viewers at the southern tip of Africa can see the Moon occult Saturn.

The waning lunar crescent is spectacularly close to Venus low in the east at dawn on June 24th in the Americas. It's very thin and low the next dawn, now lower left of Aldebaran.

Back in the evening sky, the waxing lunar crescent is far left of Jupiter at dusk on June 29th. ✦

Pluto Is for the Persistent

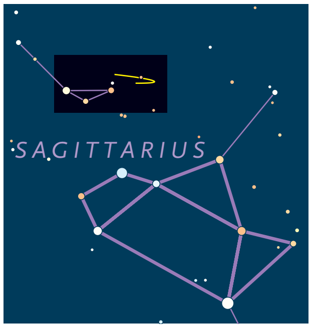
The brightest Kuiper Belt object? It's 14th magnitude in Sagittarius.

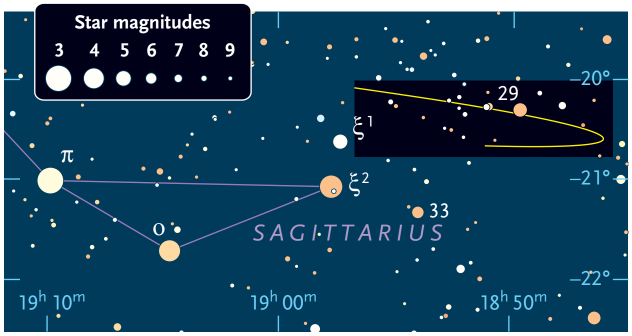
Oh, for those days a generation ago when Pluto was as bright as magnitude 13.6, as high as the feet of Virgo, and the ninth planet. Now it's magnitude 14.1, lurking low at declination –20°, and called a "dwarf planet" by the IAU. At least it's the leading "plutino": a Kuiper Belt object stuck in a 2:3 orbital resonance with Neptune.

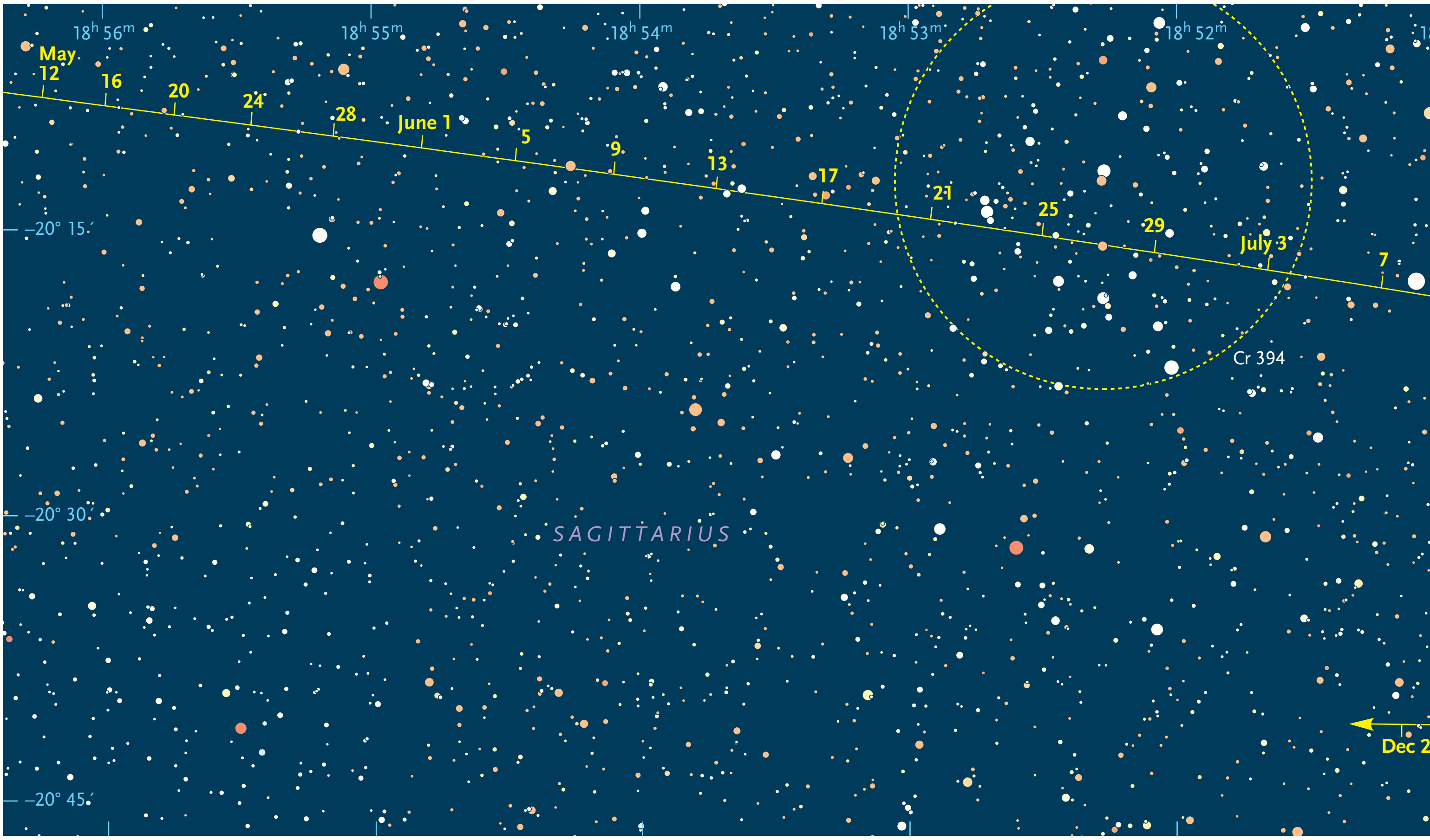
More to the point for amateurs, Pluto is by far the *brightest* Kuiper Belt object, which at least puts this fascinating class of remote ice worlds in detection range for some backyard observers. You'll probably need a 12-inch scope and a very dark sky low in the south (unless you're in the Southern Hemisphere, where Pluto passes high overhead). If you'd like to try for entry into the increasingly exclusive Pluto club, here's your finder chart for the rest of this year.

One good thing that Pluto hunters have going for them this year is that it's near the bowl of the naked-eye Sagittarius Teaspoon, so at least you have an easy starting point. (And if the Teaspoon isn't naked eye for you, forget Pluto.)

The big close-up chart shows stars to magnitude 14.5. The brightest star on it, 29 Sagittarii, is magnitude 5.2. The





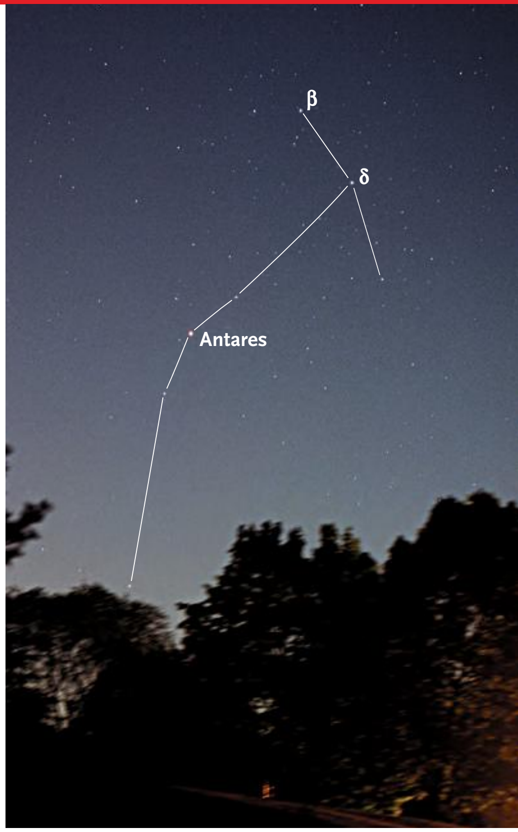


sparse open cluster Collinder 394 is about 1/3° wide and barely distinguishable from the background.

Ticks on Pluto's path mark its position at 0^h Universal Time every four days. Interpolate between the ticks to put a pencil dot on Pluto's exact location for the time and date you plan to hunt it. Once you've star-hopped to Pluto's field at low power, switch to your highest power for working the final steps among the faintest specks to the position of your pencil dot.

To be sure you've found the correct tiny glimmer, check back the next clear night to see that it has moved.

Things won't be getting any better for poor little Pluto (or rather its poor frustrated seekers) anytime soon. It won't stop creeping south until reaching nearly –24° in 2030. And it won't stop fading until it reaches magnitude 16.0 at aphelion in 2112. Mid-northern observers will never see it any better than now.

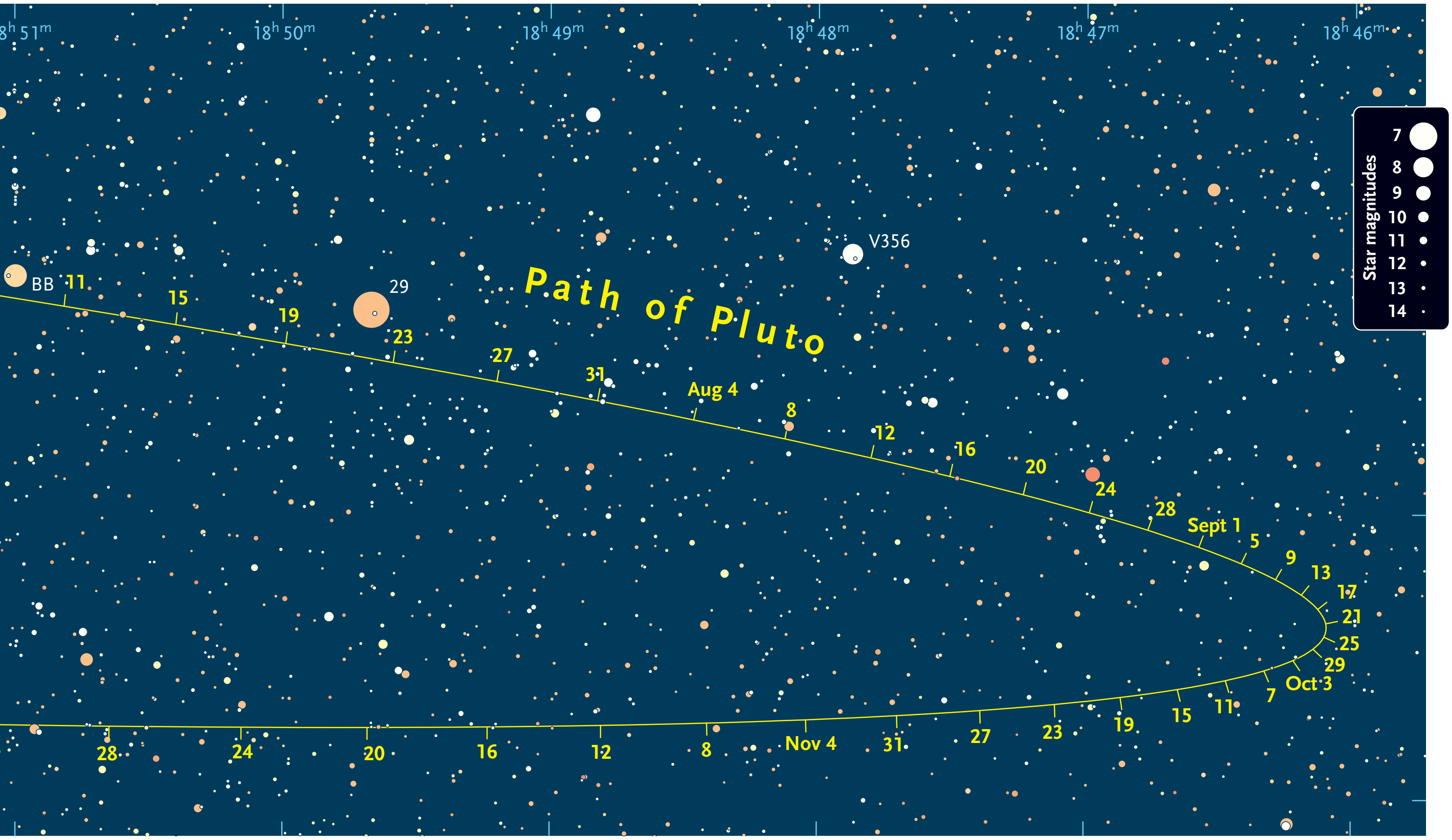


S&T: DENNIS DI CICCO

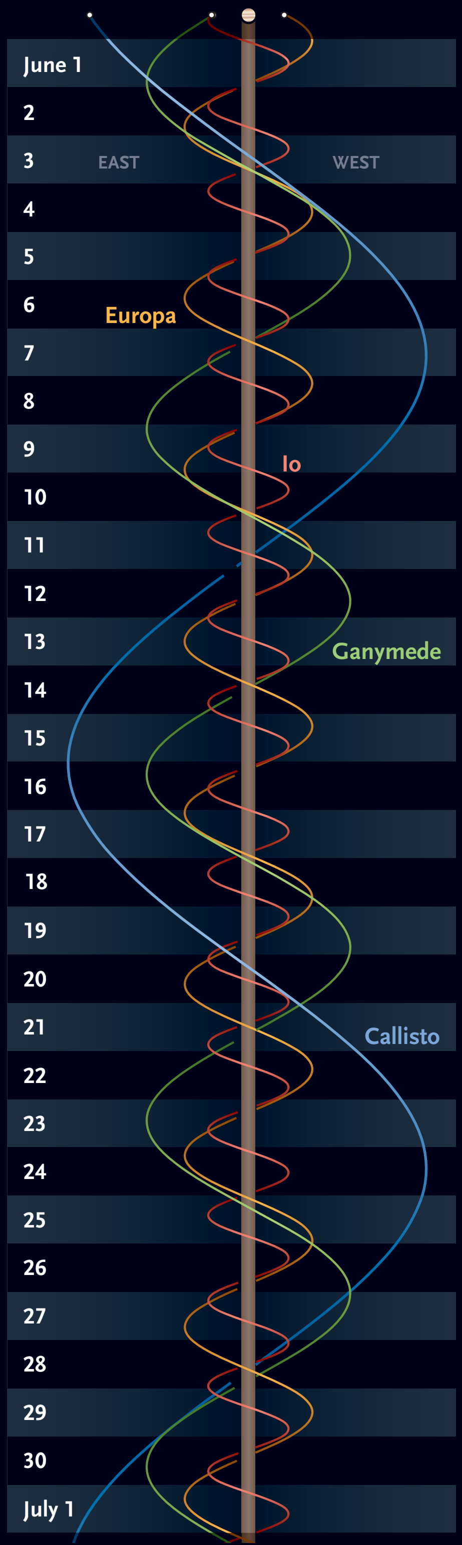
Delta Scorpii *Still* Bright

What's going on here? Fourteen years after Delta (δ) Scorpii flared up in July 2000, it remains brilliant at magnitude 1.9, outshining its former superior Beta (β). It peaked at 1.6 in 2003, faded to 2.3 in 2005–06, then returned to 1.6 for a while in 2011. Small variations have continued throughout, including a 60-day cycle of about 0.2 magnitude. Estimate its brightness these nights using Beta, 2.6, and Antares, 1.1.

Delta Sco is a fast-spinning *Be* star 500 light-years away that apparently spun off a bright disk from its equator. A companion star in a very eccentric orbit dips close to the primary every 10.8 years, and this may have played some role in setting off the ongoing event.



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 performs its swan song as summer comes in, lying down in the sunset to expire by the end of June.

Here are the dates (bold) and Universal Times when the Great Red Spot should cross Jupiter's central meridian:

June 1, 8:42, 18:38; **2**, 4:34, 14:30; **3**, 0:26, 10:22, 20:18; **4**, 6:13, 16:09; **5**, 2:05, 12:01, 21:57; **6**, 7:53, 17:48; **7**, 3:44, 13:40, 23:36; **8**, 9:32, 19:28; **9**, 5:24, 15:19; **10**, 1:15, 11:11, 21:07; **11**, 7:03, 16:59; **12**, 2:54, 12:50, 22:46; **13**, 8:42, 18:38; **14**, 4:34, 14:30; **15**, 0:25, 10:21, 20:17; **16**, 6:13, 16:09; **17**, 2:05, 12:01, 21:56; **18**, 7:52, 17:48; **19**, 3:44, 13:40, 23:36; **20**, 9:31, 19:27; **21**, 5:23, 15:19; **22**, 1:15, 11:11, 21:07; **23**, 7:02, 16:58; **24**, 2:54, 12:50, 22:46; **25**, 8:42, 18:37; **26**, 4:33, 14:29; **27**, 0:25, 10:21, 20:17; **28**, 6:13, 16:08; **29**, 2:04, 12:00, 21:56; **30**, 7:52, 17:48. ✦

Phenomena of Jupiter's Moons, June 2014

June 1	0:12	I.Tr.I
	1:02	I.Sh.I
	2:28	I.Tr.E
	3:19	I.Sh.E
	20:49	II.Oc.D
	21:27	I.Oc.D
June 2	0:33	I.Ec.R
	1:18	II.Ec.R
	18:42	I.Tr.I
	19:31	I.Sh.I
	20:59	I.Tr.E
	21:48	I.Sh.E
June 3	7:57	IV.Tr.I
	12:01	IV.Tr.E
	14:56	III.Tr.I
	15:24	IV.Sh.I
	15:35	II.Tr.I
	15:57	I.Oc.D
	17:08	II.Sh.I
	18:08	III.Sh.I
	18:16	III.Tr.E
	18:18	II.Tr.E
	19:01	I.Ec.R
	19:44	IV.Sh.E
	19:53	II.Sh.E
	21:33	III.Sh.E
June 4	13:12	I.Tr.I
	13:59	I.Sh.I
	15:29	I.Tr.E
	16:17	I.Sh.E
June 5	10:14	II.Oc.D
	10:27	I.Oc.D
	13:30	I.Ec.R
	14:38	II.Ec.R
June 6	7:43	I.Tr.I
	8:28	I.Sh.I
	9:59	I.Tr.E
	10:45	I.Sh.E
June 7	4:58	I.Oc.D
	4:58	II.Tr.I
	5:02	III.Oc.D
	6:25	II.Sh.I
	7:41	II.Tr.E
	7:59	I.Ec.R
	9:11	II.Sh.E
	11:31	III.Ec.R
June 8	2:13	I.Tr.I
	2:57	I.Sh.I
	4:30	I.Tr.E
	5:14	I.Sh.E
	23:28	I.Oc.D
	23:38	II.Oc.D
June 9	2:27	I.Ec.R
	3:56	II.Ec.R
	20:43	I.Tr.I
	21:26	I.Sh.I
	23:00	I.Tr.E
	23:43	I.Sh.E
June 10	17:58	I.Oc.D
	18:21	II.Tr.I
	19:19	III.Tr.I
	19:43	II.Sh.I
	20:56	I.Ec.R
	21:05	II.Tr.E
	22:07	III.Sh.I
	22:28	II.Sh.E
	22:41	III.Tr.E
June 11	1:33	III.Sh.E
	15:13	I.Tr.I
	15:55	I.Sh.I
	16:17	IV.Oc.D
	17:30	I.Tr.E
	18:12	I.Sh.E
	20:29	IV.Oc.R
	22:43	IV.Ec.D
June 12	3:09	IV.Ec.R
	12:28	I.Oc.D
	13:04	II.Oc.D
	15:25	I.Ec.R
	17:15	II.Ec.R
June 13	9:44	I.Tr.I
	10:23	I.Sh.I
	12:01	I.Tr.E
	12:41	I.Sh.E
June 14	6:58	I.Oc.D
	7:44	II.Tr.I
	9:00	II.Sh.I
	9:27	III.Oc.D
	9:53	I.Ec.R
	10:28	II.Tr.E
	11:46	II.Sh.E
	15:31	III.Ec.R
June 15	4:14	I.Tr.I
	4:52	I.Sh.I
	6:31	I.Tr.E
	7:10	I.Sh.E
June 16	1:28	I.Oc.D
	2:29	II.Oc.D
	4:22	I.Ec.R
	6:34	II.Ec.R
	22:44	I.Tr.I
	23:21	I.Sh.I
June 17	1:02	I.Tr.E
	1:38	I.Sh.E
	19:58	I.Oc.D
	21:08	II.Tr.I
	22:17	II.Sh.I
	22:50	I.Ec.R
	23:44	III.Tr.I
	23:52	II.Tr.E
June 18	1:03	II.Sh.E
	2:06	III.Sh.I
	3:07	III.Tr.E
	5:33	III.Sh.E
	17:15	I.Tr.I
	17:50	I.Sh.I
	19:32	I.Tr.E
	20:07	I.Sh.E
June 19	14:29	I.Oc.D
	15:55	II.Oc.D
	17:19	I.Ec.R
	19:53	II.Ec.R
June 20	4:15	IV.Tr.I
	8:28	IV.Tr.E
	9:26	IV.Sh.I
	11:45	I.Tr.I
	12:19	I.Sh.I
	13:51	IV.Sh.E
	14:02	I.Tr.E
	14:36	I.Sh.E
June 21	8:59	I.Oc.D
	10:31	II.Tr.I
	11:35	II.Sh.I
	11:48	I.Ec.R
	13:16	II.Tr.E
	13:52	III.Oc.D
	14:21	II.Sh.E
	19:31	III.Ec.R
June 22	6:15	I.Tr.I
	6:47	I.Sh.I
	8:33	I.Tr.E
	9:05	I.Sh.E
June 23	3:29	I.Oc.D
	5:20	II.Oc.D
	6:16	I.Ec.R
	9:12	II.Ec.R
June 24	0:46	I.Tr.I
	1:16	I.Sh.I
	3:03	I.Tr.E
	3:34	I.Sh.E
	21:59	I.Oc.D
	23:55	II.Tr.I
June 25	0:45	I.Ec.R
	0:52	II.Sh.I
	2:40	II.Tr.E
	3:38	II.Sh.E
	4:10	III.Tr.I
	6:06	III.Sh.I
	7:35	III.Tr.E
	9:34	III.Sh.E
	19:16	I.Tr.I
	19:45	I.Sh.I
	21:34	I.Tr.E
	22:02	I.Sh.E
June 26	16:30	I.Oc.D
	18:46	II.Oc.D
	19:13	I.Ec.R
	22:31	II.Ec.R
June 27	13:47	I.Tr.I
	14:13	I.Sh.I
	16:04	I.Tr.E
	16:31	I.Sh.E
June 28	11:00	I.Oc.D
	12:44	IV.Oc.D
	13:19	II.Tr.I
	13:42	I.Ec.R
	14:09	II.Sh.I
	16:04	II.Tr.E
	16:56	II.Sh.E
	18:18	III.Oc.D
	21:16	IV.Ec.R
	23:30	III.Ec.R
June 29	8:17	I.Tr.I
	8:42	I.Sh.I
	10:34	I.Tr.E
	11:00	I.Sh.E
June 30	5:30	I.Oc.D
	8:11	II.Oc.D
	8:11	I.Ec.R
	11:49	II.Ec.R

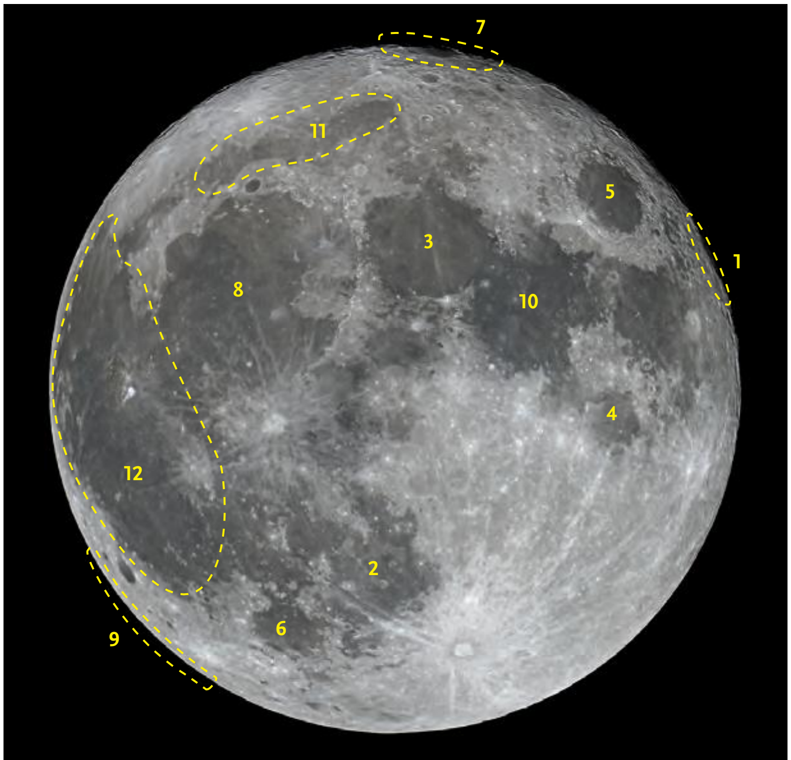
Every day, interesting events happen between Jupiter's satellites and the planet's disk or shadow. The first columns give the date and mid-time of the event, in Universal Time (which is 4 hours ahead of Eastern Daylight Time). Next is the satellite involved: **I** for Io, **II** Europa, **III** Ganymede, 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 takes up to several minutes. Predictions courtesy IMCCE / Paris Observatory.

Lunar Time Travel

Observe 4.5 billion years of lunar history.

Skilled observers of the Moon learn to interpret the geologic history of its features. This exploration can go further back in time on the Moon than on any other observable body in the solar system because the lunar surface preserves markings from yesterday all the way back to its earliest days. It retains large expanses of ancient surfaces, which we can see with the unaided eye. Look at the Moon when it's nearly full and you'll see large areas of light-colored material interspersed with broad oval patches of dark stuff. The dark material is volcanic lava that erupted mostly from 3.8 to 2.5 billion years (gigayears, or Gyr) ago, and the bright material is even older.

As I explained in my April column (page 54), the early Moon melted, with low-density, aluminum-rich material rising to the surface to form the light-colored crust. Impacts have scarred much of this bright crust, but the basic material that you observe arose due to global melting roughly 4.5 Gyr ago.



Touring the Moon with only the naked eye reveals the largest impact basins. Each number corresponds to one of the named maria in the article.

S&T: SEAN WALKER

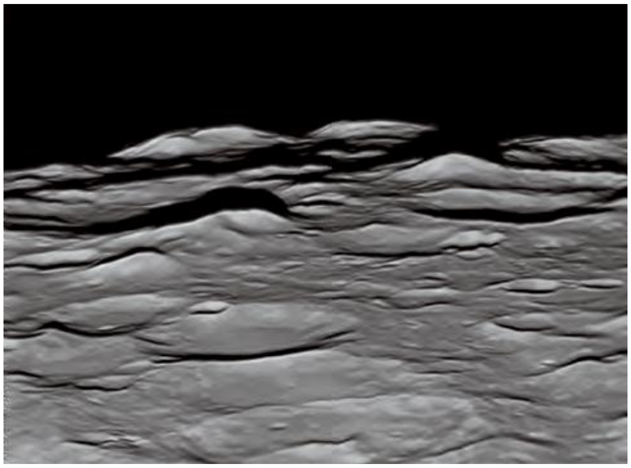
The next-oldest identifiable feature on the Moon is the South Pole-Aitken (SPA) impact basin, a roughly 1,500-mile-wide (2,400-km-wide) megacrater whose formation age remains unknown. It was most likely excavated just a few hundred million years after the bright crust solidified. And though the SPA Basin is located on the lunar farside, part of its rim is visible near the lunar south pole as a series of tall mountains that often appear in profile against the darkness of space during favorable librations. Formerly known as the Leibnitz Mountains, these rounded massifs are among the tallest peaks on the Moon.

Asteroid and comet impacts formed hundreds of thousands of craters and many basins during the Moon's first half-billion years, but we don't know their precise ages. We can estimate their sequence of relative ages by comparing the morphological degradation of basins, their overlap with other basins, and by counting the number of subsequent impact craters within their boundaries. Basins are named for the maria within them. On the eastern limb, **Smythii** (1) is thought to be the oldest nearside basin, with **Nubium** (2) and **Serenitatis** (3) being slightly younger, and **Nectaris** (4), **Crisium** (5), **Humorum** (6), and **Humboldtianum** (7) even younger still. We know all of these basins formed before **Imbrium** (8), which was dated at 3.8 Gyr using Apollo samples. The **Orientale Basin** (9) formed soon after.

As you observe these lava-flooded basins, notice that the older ones, such as Nubium and Serenitatis, lack prominent rims. Younger basins still have dramatic rims, such as the **Rupes Altai** and **Montes Apenninus**. Nubium and Serenitatis probably were originally surrounded by such towering rings, too.

Many large craters survive from this period of basin formation, although they were often strongly modified by basin ejecta. Prominent craters that existed before the Imbrium Basin formed include **Ptolemaeus** and **Alphonsus**, whose rims are scoured by Imbrium's ejecta. Similarly, **Janssen** includes debris from the formation of the Nectaris Basin and thus must precede it.

Following the period of giant impacts, lavas erupted into the deep depressions of the basin floors, filling them with the dark maria we see today. Crater counts by German scientist Harry Hiesinger and his colleagues have yielded model ages of when the different mare lavas likely erupted. Ancient lavas, dating back to about 3.8 to 3 Gyr



LEO AERTS

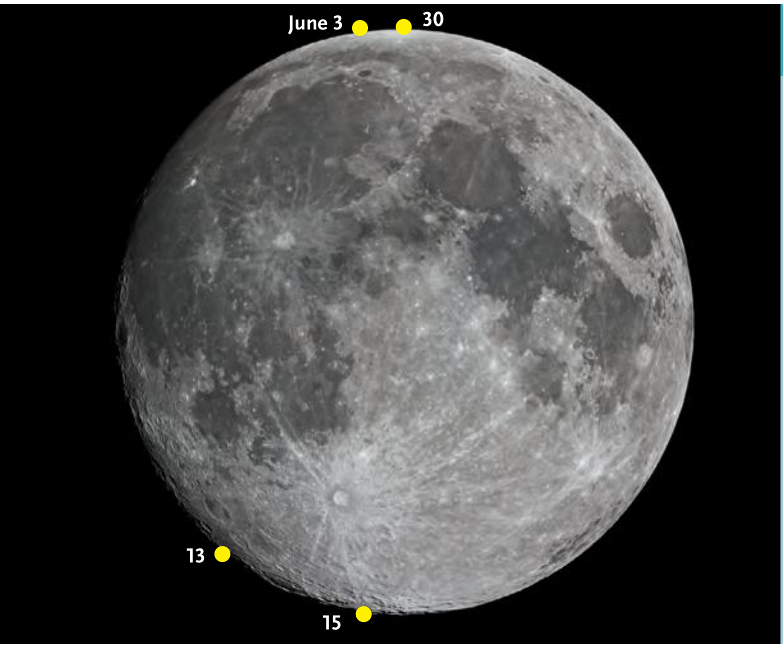
Sometimes visible not far from the lunar south pole are the tall mountains that mark the nearest rim of the South Pole-Aitken Basin, one of the largest impact basins in the solar system.

ago, are found in most basins, with the oldest lavas filling the basins in the eastern hemisphere. **Mare Tranquillitatis** (10) is the largest expanse of such old lavas visible on the Moon, particularly in the western half spanning from the Apollo 11 landing area past **Lamont** and up to **Dawes**. Similar-aged lavas are exposed around the edges of Mare Serenitatis and **Mare Frigoris** (11), suggesting that older lavas were covered by the younger ones that fill the interiors of the basins.

All of the youngest mare lavas are in **Oceanus Procellarum** (12), with the very youngest — about 1.2 Gyr old — draped around the southern and western edges of the Aristarchus Plateau. Those lavas probably erupted at the Cobra Head vent and carved **Vallis Schröteri** as they flowed toward the mare. Dark lavas about 1.5 Gyr old fill the area from **Mons Rümker** eastward to the ejecta from **Sinus Iridum**.

Many impactors hit during the 3-Gyr period of lunar volcanism that created the maria. Crater counts suggest that **Vlacq** and **Piccolomini** are 3.9 Gyr old, and the Copernicus-like crater **Hausen** is surprisingly old at 3.5 Gyr. **Geminus** (3.2 Gyr), **Theophilus** (3 Gyr), and **Aristoteles** (2.7 Gyr) are all older than I expected, but cratering model ages are estimates, not precise determinations.

The youngest big craters on the Moon are all observers' delights: **Copernicus** is about 800 million years (Myr) old, **Aristarchus** is roughly 175 Myr, and **Tycho**, whose rays spread over much of the Moon, dates back to about 109 Myr. We have to look more closely to spot younger craters. We find very young but small craters near the Apollo 16 landing site north of **Descartes**. The lunar module *Orion* landed between North Ray and South Ray craters. Astronauts collected samples from each, so we know that the 0.4-mile-wide North Ray is 50 Myr old; 0.6-mile-wide South Ray formed only 2 Myr ago, when early humans lived on the African plains. These recently formed craters are too small to detect telescopically, but their bigger bright rays, especially those of South Ray, are just visible in amateur telescopes. So from the bright highlands to South Ray crater, you can observe 4.5 billion years of lunar history in one informed night at your telescope. ✦



S&T: DENNIS DI CICCO

The Moon • June 2014

Phases

FIRST QUARTER
June 5, 20:39 UT

FULL MOON
June 13, 4:11 UT

LAST QUARTER
June 19, 18:39 UT

NEW MOON
June 27, 8:08 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.

Distances

Apogee 251,627 miles	June 3, 4^h UT diam. 29′ 30″
Perigee 224,977 miles	June 15, 3^h UT diam. 33′ 00″
Apogee 252,233 miles	June 30, 19^h UT diam. 29′ 26″

Librations

Peary (crater)	June 3
Vallis Baade	June 13
Bailly (crater)	June 15
Nansen (crater)	June 30

Serpentarius & the Serpent

Fascinating stars and galaxies lie northwest of splendid M10 and M12.

A head of splendour Serpentarius rears:
As crystal clear his shoulder broad appears . . .
With outstretch'd arms he holds the serpent's coils:
His limbs it folds within its scaly toils.
With his right hand its writhing tail he grasps,
Its swelling neck his left securely clasps.
— Aratus, *Phaenomena*

Serpentarius and the Serpent are our late spring constellations Ophiuchus and Serpens. The name Ophiuchus is derived from Greek words meaning "serpent holder," whereas Serpentarius is a Latin name with the same connotation. We'll begin this month's tour of deep-sky wonders in the torso of Ophiuchus and then work our way into the Serpent's neck and head — the half of Serpens on the west side of its handler.

Let's start with **Messier 10**, a very pretty globular cluster adorning the navel of Ophiuchus. You'll find it 1° west of 30 Ophiuchi, which is visible to the unaided eye in a fairly dark sky. Through my 9×50 finder, the star shines with a golden hue, and M10 is easily visible as a misty ball that grows brighter toward its center. My 105-mm (4.1-inch) refractor at 28× reveals a bright core 5′ across encased in a large, dim halo sprinkled with several faint stars. Many stars, covering a large brightness range, beautify the cluster at 87×. The core intensifies partway in, yet even the center displays a few brighter chips against a blaze of blended suns.

BOB FRANKE

At a distance of 16,000 light-years, Messier 12 is one of the closest globular clusters. The two faint galaxies visible 6.5′ south-southwest of M12's center are 800 million light-years distant. The field of view is 25′ wide.

M10 is gorgeous through my 10-inch reflector. At 68× its thinly populated halo spans 16′, and the density of stars increases dramatically inward. Some of the brightest stars bisect the core in a north-northeast to south-southwest string, which stands out better at 115×. For the higher magnification, I prefer a wide-angle eyepiece to maximize the number of visible stars while generously framing this starry blizzard with surrounding sky.

If I nudge my scope northwest, globular clusters M10 and **Messier 12** share my finder's field of view, with two bright field stars between them. M12 looks a bit smaller and more uniform in brightness than its neighbor. My 105-mm scope at 28× differentiates the cluster into a bright core enshrouded in a dim 8′ halo that appears mottled and is flecked with a few stars. At 87× many stars of mixed brightness are visible in the outer parts of the core and throughout the halo, which now spans 10′. The core's inner reaches are a softly dappled haze.

In my 10-inch reflector at 68×, M12 flaunts many stars, but not as richly as M10 and without as many prominent ones. Three brighter foreground stars decorate the cluster — one on its east-northeast edge, another within the halo a bit east of north, and the last deep inside the halo south-southeast. M12's sparse halo gives way to greater crowding just inside the southern star. The 3′ × 2½′ core is elongated roughly northwest to southeast, with faint stars stippling a blurry backdrop. A magnification of 115× greatly improves the view. Individual stars stand out much better, including several pairs and star chains. Lonely outliers swell the cluster to a diameter of 11′.

Images show M12's south-southwestern fringe superimposed on a pair of galaxies that appear to be in contact with each other. They feebly shine at magnitudes of 16 and 16½, or thereabouts, and are probably well beyond my grasp. Are any large-scope aficionados willing to give them a try?

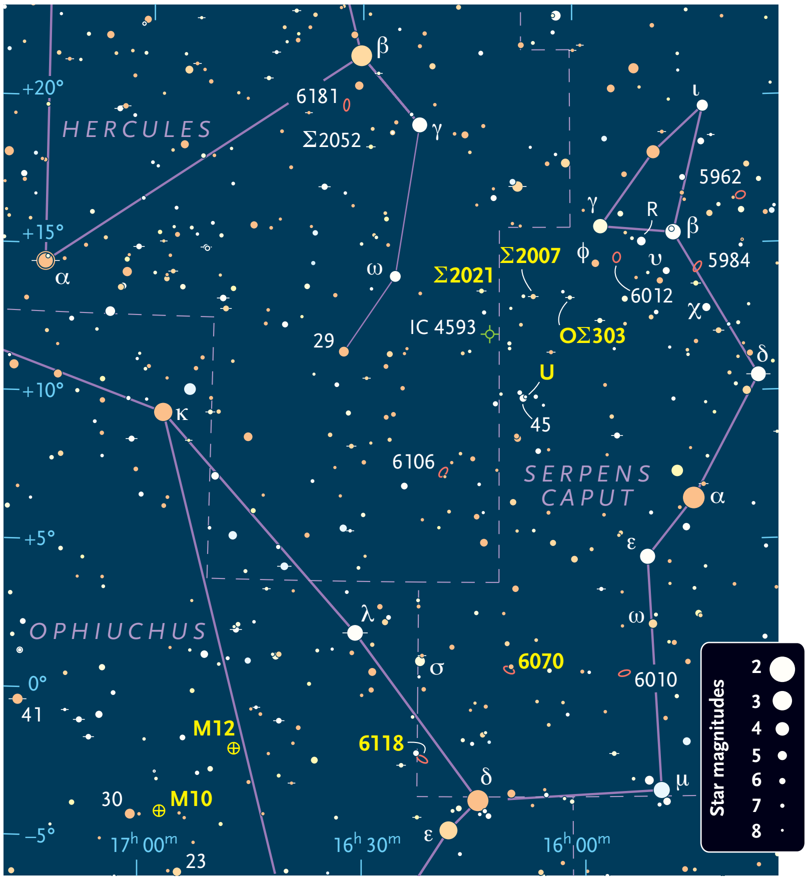
Charles Messier discovered M10 and M12 in 1764, the first on the night of May 29–30 and the second on the following night. Even with his 6.4-inch Gregorian reflector at 104×, Messier could see no stars within either of these "nebulae," but we must remember that his scope had a metal mirror that was far less reflective than today's aluminum-coated glass mirrors.

M10 has approximately 80,000 stars and lies 14,000 light-years away from us, whereas M12, at 16,000 light-years, has 70,000 stars. Both sit well above the plane of our galaxy on the near side of the galaxy's bar.

Barely over the border into Serpens, we find the galaxy **NGC 6118** sitting 18′ southwest of the 6.3-magnitude star HD 147550 (SAO 141129). On a good night, this galaxy is visible at 63× in my 130-mm refractor as a ghostly, oval glow with uniform surface brightness. A 2′ triangle of very faint stars hangs 4′ south of the galaxy. NGC 6118 is still

ESO

NGC 6118 appears faint and subtle through a telescope, but this image from the European Southern Observatory's Very Large Telescope shows it to be a fine example of a grand-design spiral galaxy.



faint through my 10-inch scope at 213×, but its 3′ × 1′ halo now enfolds a very small, slightly brighter core. One dim star is pinned to the southern edge of the galaxy's northeastern end, and another dangles 1.6′ south of its core.

NGC 6118 is 77 million light-years distant. The NASA/IPAC Extragalactic Database (NED) gives a morphological classification of SA(s)cd, which means that NGC 6118 is a nonbarred (A) spiral galaxy (S) whose arms proceed directly from a central bulge (s). The "cd" indicates an insignificant central bulge and loosely wound spiral arms that show widespread resolution into star clouds.

The galaxy **NGC 6070** is handily pointed out by a 9′-tall, 4-starred kite to its northwest. The brightest star, at the kite's foot, is 6.7-magnitude, yellow-orange HD 145204 (SAO 121396). My 130-mm refractor at 63× shows a moderately small, fairly faint oval. At 117× the oval grows gently brighter toward the center and has a faint star off its northeastern tip. I estimate its dimensions as 2½′ long and half as wide. Through my 10-inch reflector at 213×, the galaxy is 3′ × 1¼′, and the area surrounding its small core appears mottled.

NGC 6070 is 100 million light-years distant and has the same morphological type as NGC 6118. Several very dim galaxies sit a few arcminutes to its northeast. The brightest are the galaxy pair NGC 6070B and the single galaxy NGC 6070C, which is perched 1.2′ northeast of the duo. They're about magnitude 15½.

The long-period variable star **U Serpentis** reached its maximum brightness of roughly 8th magnitude in mid-May, and you'll be able to watch it slowly fade to a minimum of about 14th magnitude in September. If your

NGC 6070 is the largest galaxy in this Sloan Digital Sky Survey image. It forms an almost straight line with the galaxy pair NGC 6070B to its northeast and NGC 6070C northeast of that.

telescope won't show you stars that faint, U Ser will seem to disappear altogether sometime before then. Poof! Look 5.4′ west-northwest of 5.6-magnitude 45 Serpentis to spot this variable star, which is currently brighter than any other star that close to 45 Ser. U Serpentis is also recognizable by its orange hue. It's a Mira-type variable, an unstable giant star whose outer layers periodically expand and contract.

A collection of nice double stars floats north of U Ser. Let's take a look at a few of the most colorful ones, starting with **OΣ 303** (STT 303), which lies 1.4° southeast of Phi (φ) Serpentis. The yellow primary holds a yellow-white companion a snug 1.6″ to its south. Through my 130-mm scope, they're just split at 102×, close but nicely split at 117×, and well split at 164×.

Sweeping 1.3° east brings us to **Σ2007**, which consists of a deep-yellow primary with a yellow-orange companion 38″ northwest. The components are easily split at the lowest magnification I have available for the 130-mm scope, 23×.

Farther east by 1.8°, **Σ2021** is a nearly matched pair of lovely golden suns arrayed north-south and separated by 4.1″. They're well split at 102× in my 130-mm scope. This star was once known as 49 Serpentis, but modern constellation borders now place it in Hercules. Σ2021 is a visual binary with an orbital period around 1,350 years, so don't expect to see any drastic changes soon. From my birth until now, the separation of the pair has changed less than a tenth of an arcsecond, and the position angle of the pair has only increased by 12 degrees.

The colors for these double stars describe how they look to me. Your mileage may vary. ✦

Stars, Galaxies, and Globular Clusters in Ophiuchus and Serpens

Object	Type	Mag.	Size/Sep.	RA	Dec.
Messier 10	Globular cluster	6.6	20′	$16^h\ 57.2^m$	–4° 06′
Messier 12	Globular cluster	6.7	16′	$16^h\ 47.2^m$	–1° 57′
NGC 6118	Galaxy	11.7	4.7′ × 2.0′	$16^h\ 21.8^m$	–2° 17′
NGC 6070	Galaxy	11.8	3.5′ × 1.9′	$16^h\ 10.0^m$	+0° 43′
U Serpentis	Variable star	7.7 – 14.7	—	$16^h\ 07.3^m$	+9° 56′
OΣ 303	Double star	7.7, 8.1	1.6″	$16^h\ 00.9^m$	+13° 16′
Σ2007	Double star	6.9, 8.0	38″	$16^h\ 06.0^m$	+13° 19′
Σ2021	Double star	7.4, 7.5	4.1″	$16^h\ 13.3^m$	+13° 32′

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.

M5 Surprise

The great globular cluster sports two stunningly bright variable stars.

Howard Banich

Have you seen the two Cepheids in M5 lately?" asked Tom. "They're both near maximum brightness."

Caught completely by surprise, I could only stammer, "What? Cepheids in M5? I've never heard of such a thing!"

"Sure!" said Tom, "Come have a look in my scope. They stand out best during twilight like this."

This was, more or less, how Tom Osypowski introduced me to V42 and V84, M5's two Type II Cepheid variable stars, at the 2013 Golden State Star Party. It seemed that none of the other observers nearby had heard about M5's Cepheids either, making Tom the only person there who knew about this surprising sight.

So I looked in Tom's 20-inch scope and immediately noticed two rather bright stars near M5's core. Tom confirmed that they were the Cepheids, and I was instantly hooked. The idea of observing the northern sky's brightest globular cluster (M5 is a hair brighter than M13) and watching its brightest stars change night after night was irresistible. I soon decided to follow them in my 28-inch scope during the Oregon Star Party the next month. I'd be there for several nights around both Cepheids' maxima, but I'd need almost the entire month of August to follow their full light curves. V42 takes 25.72 days to go from maximum to minimum to back again, while V84's period is somewhere between 26.4 to 26.9 days.

To follow the full cycles of both stars, I'd need to continue my observations from home, which is walking distance from the center of downtown Portland, Oregon. Could I even see M5 from my urban backyard, let alone follow these two Cepheids as they fade? V42 varies from magnitude 10.5 to 12.1 whereas V84 varies from 10.8 to 12.3. That's plenty bright enough to see with my 8-inch Dob in a dark sky, but I worried that my backyard might have too much light pollution.

I set up the 8-inch in my backyard to find out. The night was hazy, and the Moon was almost full, but after a brief search I located M5 and had no trouble seeing both V42 and V84. Yes! It would be easy to follow these stars from my backyard, which means just about anyone can do the same with an 8-inch scope.

To help make this point, the variability of V42 and V84 was discovered with only a 4.5-inch refractor by British astronomer David E. Packer. That was in 1890 — 188 years after M5's discovery by Gottfried Kirch and 99 years after William Herschel first resolved the cluster into individual stars.

E. E. Barnard's comments after observing M5's variables with the 40-inch Yerkes refractor in 1898 are also interesting to note:

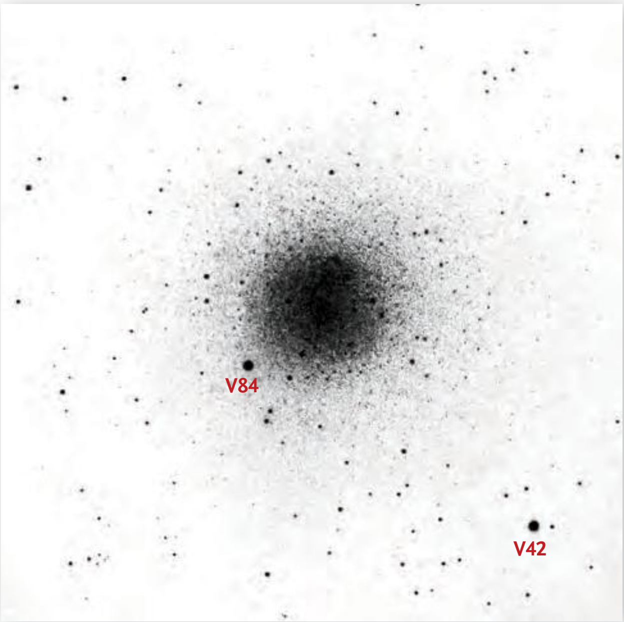
"No.42 is the most conspicuous star connected with the cluster and precedes it by some 3′. It is one of the outliers and can be observed with a very small telescope — five or six inches aperture will show its variation well. No.84 can also be studied with an aperture somewhat larger than this."

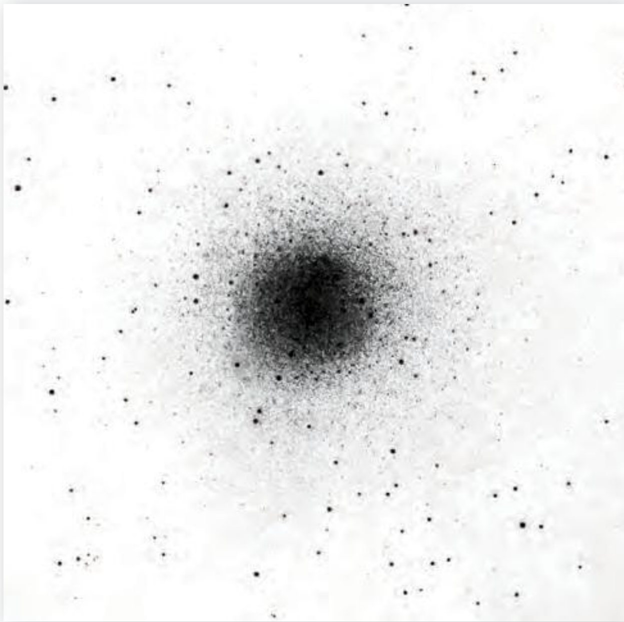
The Plan

My initial plan was to make a visual record of how bright the Cepheid variables looked every night that I could observe them in August. I also wanted to note how they

This photograph caught the Cepheid variable V84 near its minimum brightness and V42 fairly close to its maximum. But even at its faintest, V42 is one of the most prominent stars in Messier 5. The field of view shown here is 15.5 arcminutes wide.

ADAM BLOCK / MOUNT LEMMON SKYCENTER / UNIVERSITY OF ARIZONA





HOWARD BANICH (2)

The author first noticed M5's Cepheids when both were close to maximum brightness, as shown at left. The right sketch shows how much the cluster's overall appearance changes when both stars are near the bottom of their cycles.

influenced the globular cluster's overall appearance as they dimmed and brightened again. I wasn't trying to make rigorous estimates of their magnitudes, I just wanted to see how bright they appeared compared to the stars near them and to M5 in general.

As it turned out, I was able to make a total of 13 observations of V42 and V84. Even with only half the nights clear enough to observe, and M5 gradually getting closer to the western horizon each night, I was able to follow both stars and found myself looking forward to seeing three things:

1. Which star would be brighter?
2. How well did each star stand out compared to the overall cluster?
3. How did the look of the cluster change?

Complicating this somewhat is the fact that M5 contains many variable stars besides the two bright Cepheids. My 28-inch scope is big enough to show M5's RR Lyrae variables, which shine around 15th magnitude. RR Lyraes are abundant in globular clusters — so much so that they used to be called "cluster variables."

AMERICAN ASSOCIATION OF VARIABLE STAR OBSERVERS

What's a Cepheid Variable?

Cepheid variables are the brightest category of pulsating variables — stars that change brightness periodically as they grow and shrink. By strange coincidence, their story is intertwined with the lives of two deaf astronomers.

John Goodricke discovered the variability of Delta Cephei, the prototype of the class, in 1784. Goodricke correctly hypothesized that Delta's smooth variations are due to cyclical changes in the star, whereas the sharper and briefer drops in the brightness of Algol (Beta Persei) are caused by an eclipsing companion.

In 1908, Henrietta Swan Leavitt studied Cepheid variables in the Large Magellanic Cloud and discovered that there is a relationship between Cepheids' periods and their inherent brightnesses. This proved to be the key to determining the structure of the universe.

Because Cepheids are so bright, many of them are identifiable even in other galaxies. Knowing a Cepheid's period, we know its inherent brightness. And that, together with its apparent brightness, tells us how distant the host galaxy is. Many astronomers think that Leavitt deserved a Nobel Prize for her brilliant insight and the painstaking work underlying it.

Cepheids are broadly divided into two classes. Type I Cepheids, including Delta Cephei, are relatively young, hyperluminous, and typically 5 to 10 times more massive than our Sun. Type II Cepheids, such as those in M5 and other globular clusters, are much older, less luminous, and about half as massive as our Sun. — ***Tony Flanders***

Oddly, some of the 12th- and 13th-magnitude stars near the Cepheids also seemed to change in brightness. A recent paper suggests that many of M5's red giants are long-period variables, but that wouldn't explain why these stars seemed to vary from one night to the next.

V42 is far from the cluster's main concentration, making it easy to identify. V84 is much harder to pick out both because it's fainter and because it's less than one arcminute from M5's center, on the southeast edge of the densely packed core. I came to identify V84 as part of a V-shaped asterism with two pairs of stars in a line, as shown below. V42 forms another handsome asterism — a parallelogram — together with three fairly bright stars.

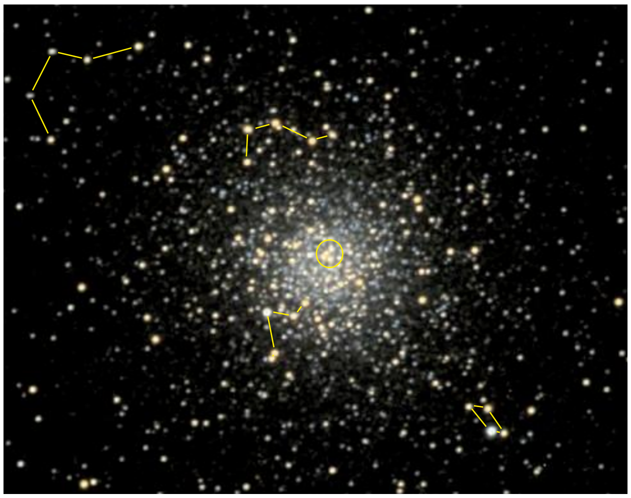
Although not needed to locate either variable, there are a few other asterisms that are fun to look for. First is a tiny V-shape group of stars on the north edge of the bright core, circled on the photograph below. They tended to draw my eye as the brightest part of M5's core.

Next are two dipper-shaped asterisms away from the main body of M5 that are notable for both their similarly oriented shapes and also their proximity to each other.

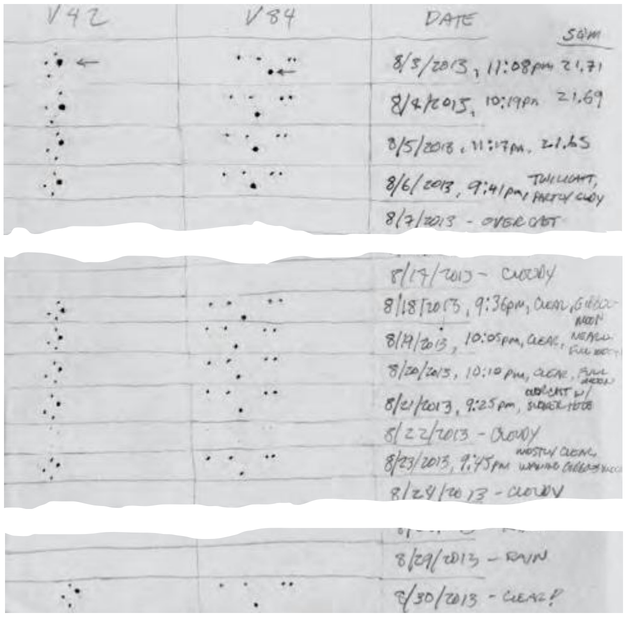
It was surprisingly difficult to compare the relative brightness of V84 to V42 because V84 is so close to M5's bright core. Here are a few techniques I tried to make it easier to judge them more accurately.

Viewing in Twilight

Tom introduced me to V42 and V84 in twilight, because he found they stand out best when M5 is barely visible. That makes M5 tough to find if you don't have a Go To scope, but it can be done with a little practice. The view is quite remarkable: V42 and V84 stand out wonderfully, whereas M5 is a faint glow. M5 becomes more prominent when the sky grows darker, and V84 seems a little dimmer as it's overwhelmed by the bright core. It was much easier to compare the two Cepheids in twilight.



New Jersey amateur Robert Vanderbei took this image on June 7, 2005 to collect data for the H-R diagram shown on the following page, as discussed in the December 2010 issue, p. 30. The yellow lines depict (or encircle) the asterisms discussed by the author.



The author tracked the Cepheids' brightness with respect to nearby stars on most clear nights in August 2013.

Clouds and Other Filters

Thin clouds passed in front of M5 a few times during my August observing campaign, and for brief moments they would simulate the twilight view described above. But the view changed too quickly to make a solid judgment of the stars' relative brightness. However, the clouds inspired me to try using a variable polarizing filter, the kind often used for observing the Moon.

The filter can evenly tune the brightness of the entire field of view to simulate the twilight view, dimming M5 so that V42 and V84 can be compared without distraction. It was interesting to turn the polarizing filter to see at what point the brightness of M5 started to affect how bright V84 looked. This instantly became my preferred method with the 28-inch scope, and I plan to make future magnitude estimates this way.

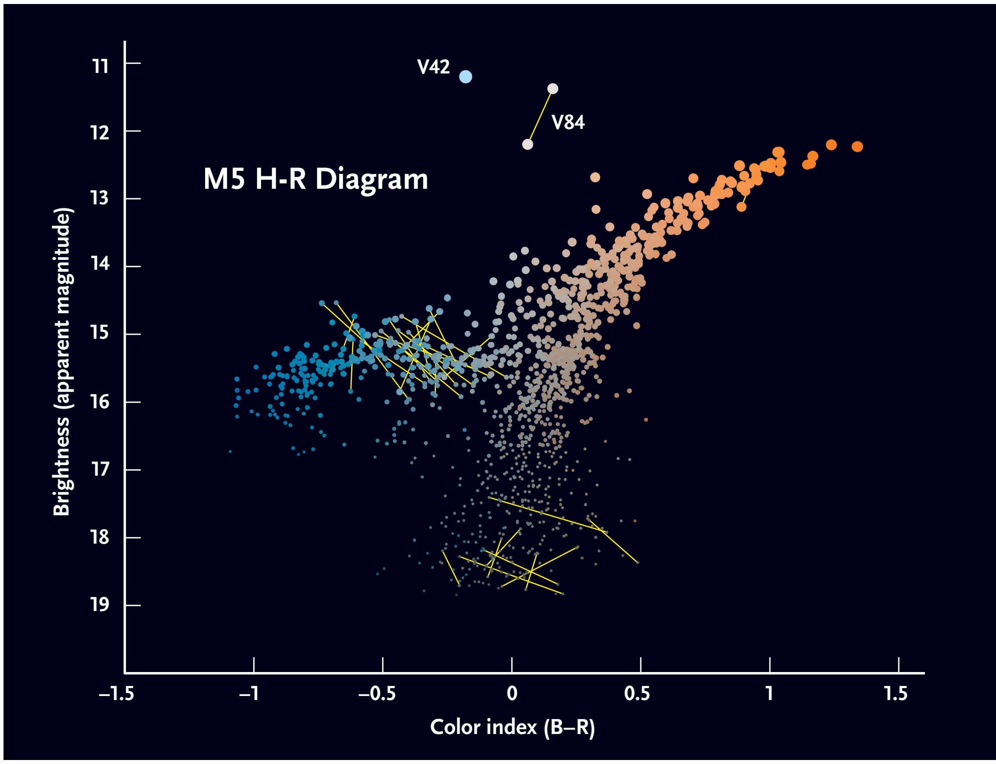
Final Thoughts

Some of my nightly sketches of the two variables with their reference asterisms are shown above. They indicate that V42 usually seemed to be the brighter of the two throughout August 2013, but most of those estimates were made before I started using the variable polarizing filter. That means that V84 looked dimmer than it really was because of its location near the core of M5. Also, I came close to seeing V84's minimum, when it completely blended into the general mass of M5's stars on August 23rd. But I missed V42's minimum a few days later due to bad weather. By my next observation on the 30th, both had begun brightening again. That's the way it goes, but thanks to Tom this has become the most enjoyable observing project I've ever taken on.

Sketching M5 was sometimes a tedious exercise in trying to draw dots in correct relation to each other. But as the sketch became a drawing, those dots — stars — had become familiar landmarks. I see these landmarks every time I look at M5 now.

The process of sketching worked its magic again; seemingly random stars became familiar, because sketching is really just a disciplined way of focusing attention. Without that night-by-night attention, I would never have come to appreciate M5's dynamic nature. Following the slow variations of V42 and V84 breathed a new kind of life into what I'd previously considered a beautiful but staid ball of stars, and provided a glimpse of the great globular's ever-changing, 13-billion-year-old pulse.

***Howard Banich** observes the sky with a 28-inch f/4 motorized alt-azimuth Newtonian and an 8-inch Dob. He welcomes questions and comments at howard.banich@nike.com.*



ROBERT J. VANDERBEI

This Hertzsprung-Russell diagram combines data from the photograph on the previous page and another taken 11 months later. Yellow lines connect data for stars that varied between the two exposures. The dense clump of yellow lines lower left of the Cepheids are the RR Lyrae variables. By pure chance, V42 happened to be about equally bright in both exposures. See skypub.com/m5vars for a link to Robert Vanderbei's website, where the same information is displayed as a blink comparison between the two images. H-R diagrams are discussed in detail starting on page 32.

Taking the Cepheids' Pulses

Sebastián Otero, a consultant for the American Association of Variable Star Observers, prepared the ephemeris below, which shows V42's predicted maxima through September. For additional dates, you can reference Otero's ephemeris generator and other useful material at **skypub.com/m5vars**.

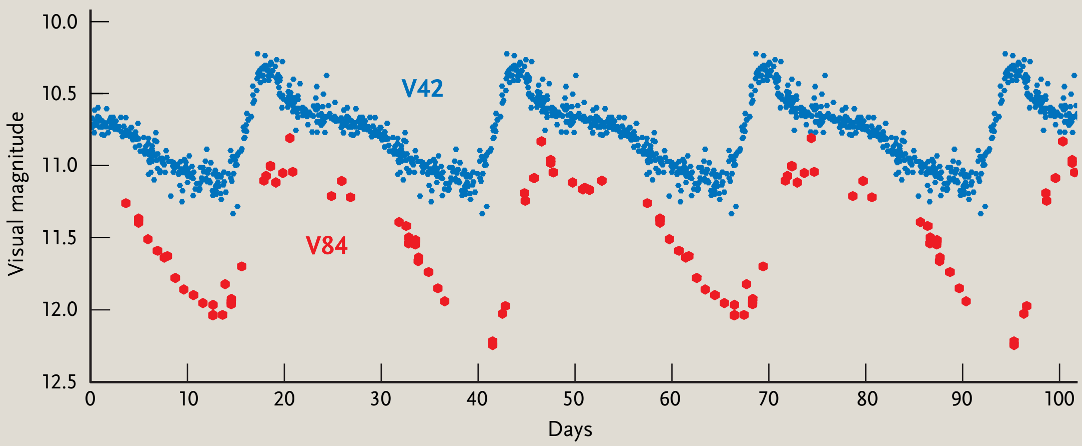
Otero's ephemeris is based on a comprehensive 2010 study by Katie Rabidoux (then a student at Michigan State University) and colleagues. V42's period holds steady around 25.72 days, though it may have changed slightly since the 19th century. Its light curve has ample data points because it's far enough from M5's core to be measured by the All Sky Automated Survey telescopes.

By contrast, Rabidoux and colleagues show that V84's period has varied irregularly by over a half day since its discovery, making a reliable ephemeris impossible. V84 also seems to alternate between deeper and shallower minima. That may be a sign that it's changing into an RV Tauri star, a special subclass of Cepheids — or perhaps a separate category.

Otero comments, "Making predictions for this star is risky. Instead of giving an ephemeris, I would just mention that the fun part of observing V84 is not knowing how bright it will be, since its period changes." ✦ — ***H. B.***

Ephemeris for V42

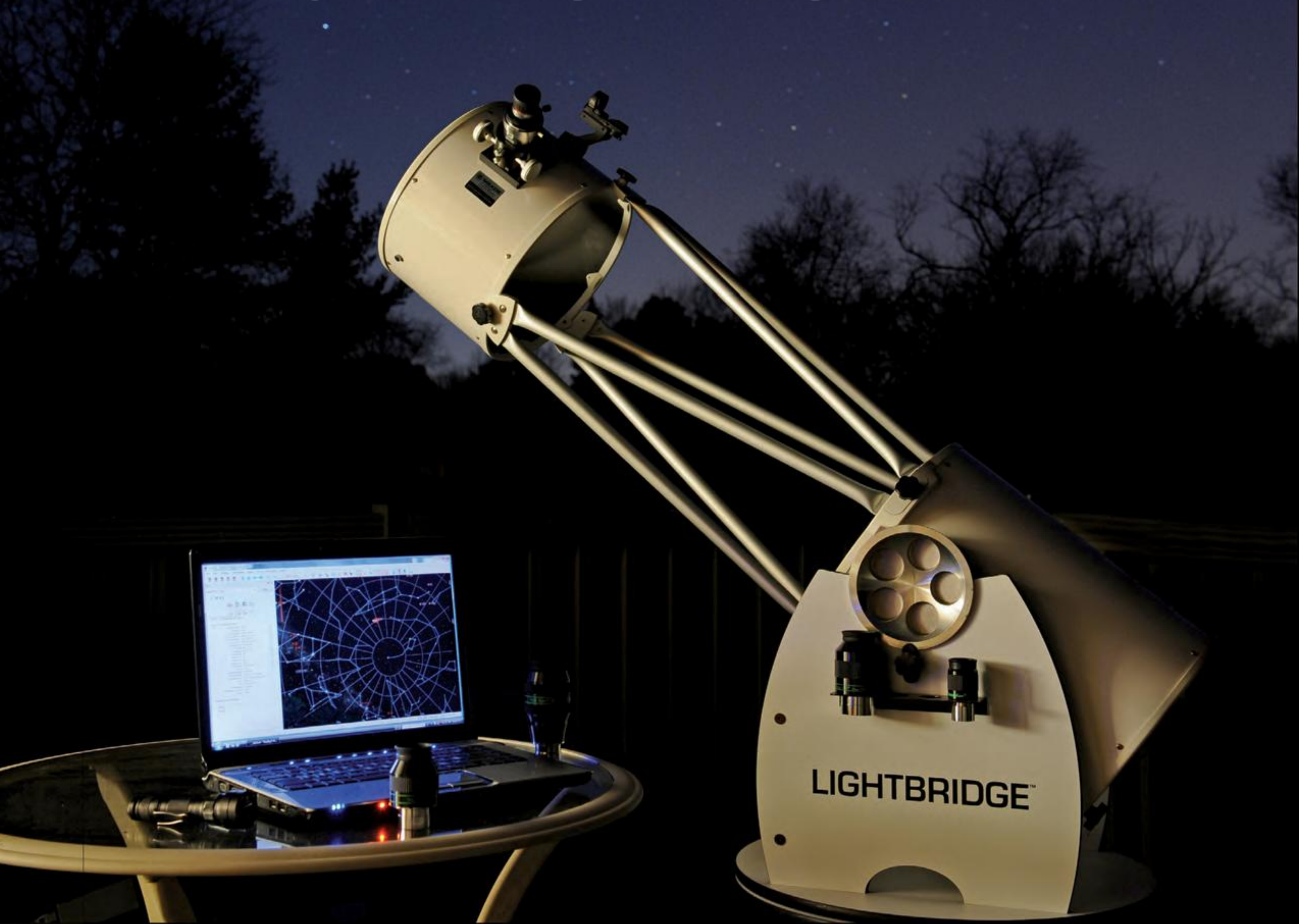
Predicted Maximum
April 19, 2014 9^h UT
May 15, 2014 2^h UT
June 9, 2014 19^h UT
July 5, 2014 13^h UT
July 31, 2014 6^h UT
Aug. 25, 2014 23^h UT
Sept. 20, 2014 16^h UT



S&T: GREGG DINDERMAN / SOURCE: KATIE RABIDOUX ET AL.

Wired ASTRONOMY

Rod Mollise



Initially a novelty item for amateur astronomers, computers are now almost as important as telescopes.

Personal computers and amateur astronomy are made for each other. The tasks computers do well — storing and retrieving large amounts of data and making it understandable, often in graphic form — are just what amateur astronomers need to make stargazing easier.

Not that this was obvious to me when I got my Commodore 64 computer in 1983. That computer was fun, but it was just a toy. I didn't see a practical use for it in amateur astronomy, though I knew professional astronomers had been using computers for years. Then, one afternoon I was wandering through a mall computer store and came upon a Commodore program called *Sky Travel.* It could show the sky as it was right now, in the future, or in the past. By today's standards, it was slow and crude, but I loved it. It was a hint of what the future might be.

It was one thing to realize computers had the potential to be useful in amateur astronomy, but it was another to put them to work. It took a few years and a few generations of PCs and Macintoshes before the machines became not just useful but indispensable for my observing. I now use them indoors before I head to the observing field as well outside under the stars. Since most observing sites don't have internet access, what follows are the things you can do with an unconnected computer.

What's Up?

Most of the time I use my PC the same way I used the Commodore 64 — to show what the sky looks like at a given time and date. Is Saturn high enough? How late do I have to stay up to catch Messier 15? If you've been in this hobby for a number of years, it's easy to think of computer planetarium programs as the digital version of planispheres, those cardboard "star wheels" we used before the computer revolution.

Printed star charts still have their place since there's no reason to use a computer unless it is better for a task. A paper chart only costs a few dollars and doesn't need batteries, but a computer is better for showing what's up in the sky. A planisphere can approximate the locations of stars and constellations, but it can't show the positions of the planets or the phase of the Moon.

There are many good planetarium programs, including excellent free ones. Most astronomy programs need far less computer horsepower than games, so even on an inexpensive PC the freeware program *Stellarium* (www.stellarium.org) can create a realistic view of the sky complete with satellites, clouds, Moon phases, and detailed horizons. Planetarium programs are almost good enough to make me stop cussing the weather on cloudy nights.

Planning

I've been known to give advice to new amateur astronomers (whether they ask for it or not) and one of the things I emphasize is planning. If you take a telescope outside without a list of objects to view, you won't see much and probably won't be outside long: "Seen M15, seen M42, seen M31. Guess that's all for tonight."

Back in the old days, I'd grab a copy of *Burnham's Celestial Handbook,* a steno pad, and a pencil and compile an observing list. That worked, but it's easier to do that now with a PC. Computers excel at assembling lists of objects from databases and sorting those objects. Today, I rarely observe without the aid of a planning program.

Most observing planners can draw star charts, but, unlike the planetarium programs, that's not their main function. Planning programs are giant databases of astronomical objects. Leading programs such as *SkyTools 3* (www.skyhound.com) and *Deep-Sky Planner 6* (http://knightware.biz) contain more than a million objects. With the aid of these programs, which enable you to easily choose objects based on their visibility, brightness, location in the sky, and other parameters, you'll never be without an observing list.

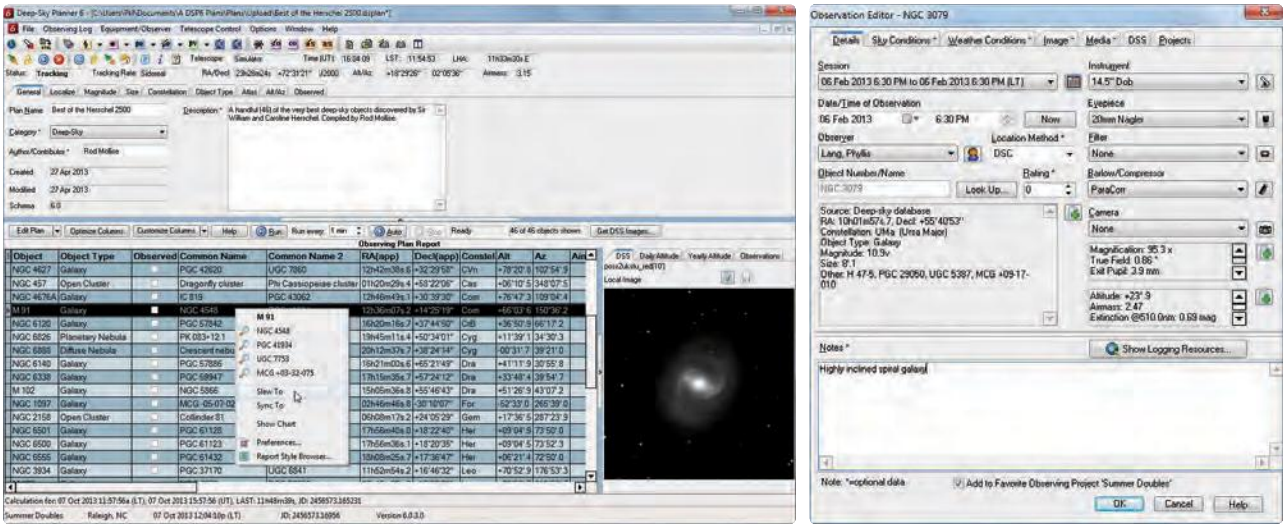
Computerized Telescope Pointing

When amateurs new to wired astronomy think "computer" they often think "Go To telescope" — telescopes that automatically point to celestial objects. Go To telescopes have small computers built into their electronic hand controls, but a laptop PC or Mac can enhance the power of the hand control and make the telescope easier to use.

Connecting a laptop to a telescope will greatly increase the number of objects in the scope's library. The typical hand control boasts 30,000 to 40,000 deep-sky objects and

It's no exaggeration to say that today's amateur astronomers probably spend more time pursuing their hobby with a computer than they do with any other single piece of equipment. In the accompanying article, veteran amateur Rod Mollise explains why computers have become so important for observers.

S&T: DENNIS DI CICCO



Astronomical planning software can sort through huge databases of celestial objects to generate customized observing lists based on an individual's interests, equipment, and sky conditions. Some programs, such as *Deep-Sky Planner 6* shown here, can also control Go To telescopes and create a digital logbook for recording your observing notes.

stars, but advanced amateurs using sensitive cameras and large telescopes may need more. A top-of-the-line computer program such as *Deep-Sky Planner 6* will increase the number of star clusters, nebulae, and galaxies available for Go To scopes from tens of thousands to hundreds of thousands.

With a computer, it's also easier to point a Go To scope at objects of temporary interest such as comets and asteroids. A hand control typically requires you to enter these objects' current celestial coordinates before it can point the scope. But planetarium and planning programs can download orbital elements for these objects from the internet and show their locations among the stars displayed on the monitor. You then click on the one of interest and the telescope will go to it, the same as any other object.

S&T: DENNIS DI CICCO

Astronomical CCD cameras require computers, but many astrophotographers working with DSLRs are opting to control their cameras with them too. Computers make it easy to focus lenses and telescopes and to program sequences of exposures.

Keeping Track

I've been observing for going on 50 years, and for much of that time have kept notes on what I've seen. Unfortunately, my early observing logs have been lost or destroyed. Now, however, I keep my logbook on a computer and have a backup copy in my pocket on a small flash drive. Although some planetarium programs include logbooks, this is usually a feature of planning software. And you can record more than just notes about an object's appearance because most programs will enter the time, date, object designation, and other vitals automatically. Some computer logbooks even enable you to attach photos and sketches to entries.

Astrophotography

It's possible to take astrophotos with a digital camera without a computer, but most amateurs operate their cameras with laptop computers. A computer is required for astronomical CCD cameras, but it's also a boon for digital single-lens reflex (DSLR) cameras. It's much easier to focus an image on a laptop's monitor than on a camera's tiny screen. Computers also make imaging less arduous. Using a program such as *Nebulosity 3* (**www.stark-labs.com**), I can instruct my camera to take 20 sequential 3-minute exposures and alert me when it is done. I'm then free to look through friends' telescopes or scan the sky with binoculars.

The pictures that come out of a digital camera usually don't look very good. Just as in the days of film, astro-photos require processing. The difference today is that computers take the place of darkroom chemicals and enlargers. Computers aren't just less messy; a program such as *MaxIm DL* (**www.cyanogen.com**), which is designed to process astronomical images, or a general-purpose photo-editing application such as *Adobe Photoshop* (**www.adobe.com**) can work magic on astronomical images. It's not unusual to see a newcomer with a DSLR and a few months experience turning out pictures that are better than the "masterpieces" of the 1990s.

Going Deep

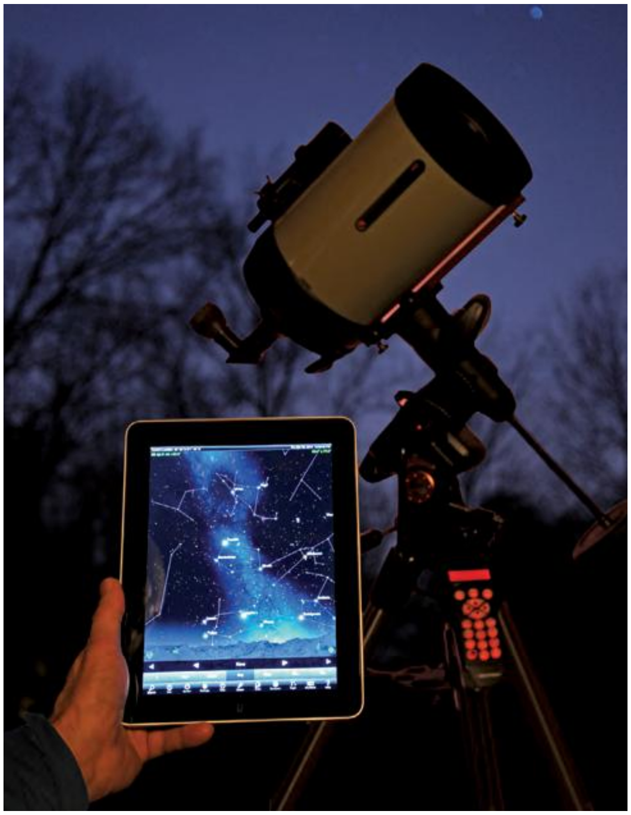
I love my printed star atlases; I just don't use them much anymore. As I've gone beyond the showpiece objects to the dim and distant, I need more depth than any printed star atlas can provide, so I've turned to computer-generated charts. The *Millennium Star Atlas,* which is probably the most advanced star atlas ever published, contains 1 million stars and 10,000 deep-sky objects in its three volumes. In contrast, the built-in atlas of *SkyTools 3* can plot charts based on 522 million stars and more than 1 million nonstellar objects.

Not only can computer atlases show far more objects than would be practical for a book, their charts can be flipped and inverted to match the views in a telescope eyepiece. You can zoom-in on areas of interest and even call up photos of many of the objects plotted on the charts.

Computers in the Field

When I started using personal computers, there was no such thing as a laptop. The closest thing to one was a sewing-machine-sized "portable" PC. Even after the coming of smaller computers, I didn't take one onto the observing field. They were expensive and I was afraid to expose them to dewy nighttime conditions. That's changed. Laptops are cheap now, and I've found ways to protect them from the elements and use them productively even at primitive observing sites.

Protecting a computer from dew is not as hard as I'd originally feared. Most laptops generate enough internal heat to keep themselves dry. Still, there are nights that are damp enough to be a problem. There are commercial solutions in the form of small tent-like enclosures for computers, but being cheap and a fan of simple, I decided to make a computer shelter (it's pictured at lower right).



S&T: DENNIS DI CICCO

All Go To telescopes have internal computers, but adding an external laptop or, as seen here, a tablet computer, will greatly enhance the capabilities of Go To scopes, providing advanced graphics and access to far more objects and astronomical information.

I imagined a three-sided box with no bottom that goes on my observing table and covers the laptop. The problem was the material, since I wanted something light, inexpensive, waterproof, and durable. The answer came one afternoon when a politician asked to place a corrugated plastic campaign sign in our yard. The material would be perfect for my computer's little house. A search on the internet turned up several dealers for plastic sign material. It's inexpensive and available in a variety of colors.

I cut the sheets to size and used industrial-strength

ROD MOLLISE (2)

Although many programs made for use at the telescope have a night-vision setting, computer monitors are often still too bright. The author's solution is a red plexiglass sheet to cover the screen. His computer shelter is described in the text.

Velcro and duct tape to connect the sides, top, and back, leaving enough space between pieces so the enclosure could be folded flat for transport. I also taped a black plastic trash bag to the top front to cover the open side when I wasn't using the computer. This simple and effective enclosure has lasted for years.

Power

Laptops have internal batteries, but they usually don't last as long as my observing sessions. Initially, I bought an expensive DC power supply that took the place of my computer's AC power "brick." It worked, but it still didn't supply enough power for my needs. When I'd plug something into the laptop's USB port that drew power from the computer — a CCD camera, for example — the power supply would shut down.

The only other solution I could think of was to use an inverter that converts DC power from a battery to AC for the laptop. At first, I was concerned that an inverter might not produce AC current good enough for a laptop, but I discovered that modern inverters produce surprisingly "clean" power.

How large an inverter do you need? The label on a computer's AC power supply will give an approximation of how much power the laptop consumes, but an inverter that delivers 100 watts of power is usually sufficient. Small inverters that plug directly into a car's power receptacle are commonly available in computer and automotive-parts stores.

Most astronomy programs have a night-vision mode that turns the screen red, but laptop displays usually can't

S&T: DENNIS DI CICCO (2)

There are hundreds of astronomy apps for mobile devices. *SkyGuide* (www.fifthstarlabs.com) shows at a glance what's in the sky where an Apple device is pointed.

Evolving technology makes connecting computers and telescopes a constantly moving target, but wireless communication via a Wi-Fi link is becoming popular. There are several companies that make Wi-Fi adapters for Celestron and Meade telescopes, including the one here from Orion Telescopes (www.telescope.com).

be dimmed enough to protect your dark adaptation and still remain legible. I've found that in addition to using a program's night-vision colors, I need to place a red filter over the computer's screen. Where do you get a red filter? Astronomy dealers sell sheets of red plexiglass cut to size for various computer displays. Plexiglass is durable and can be easily cleaned.

Telescope Interface

Connecting a computer to a telescope is the ultimate in computer-aided astronomy, but it can be confusing. The biggest problem typically involves the data format, because all but the newest telescopes usually use an old-fashioned RS-232 serial connection, whereas most modern laptops no longer have a serial port. If you're confronted with this dilemma, you'll need a USB-to-serial adapter. One end of the adapter plugs into a computer's USB port and the other end has a standard DB-9 connector for the telescope's serial cable. You should always consult your scope's manual before making a computer connection, since plugging in wires the wrong way can potentially damage the telescope.

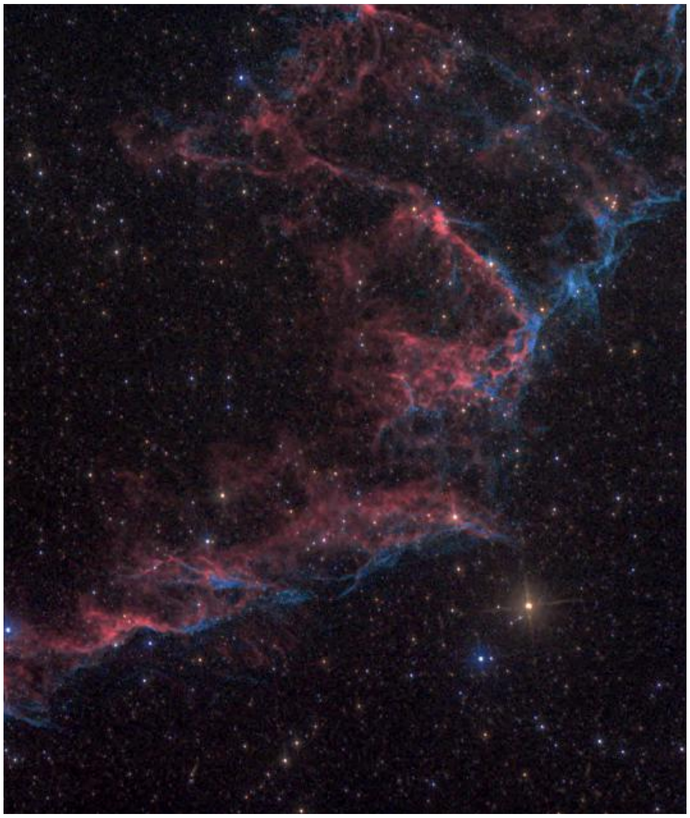
Computerized astronomy is in a constant state of change, and some of the biggest changes are just ahead. Laptop PCs and Macintoshes are still the best choices for the amateur astronomer; there are plenty of programs for them, and interfacing one to a telescope is easy. But modern devices — smartphones and tablets — are coming on strong, and I think my astronomy laptop will soon be obsolete. I'll hate to see it go, but wired astronomy has come a long way since the Commodore 64 days, and I can hardly wait to see where it's going next. ✦

S&T *contributing editor* ***Rod Mollise*** *writes an entertaining astronomical blog at* ***http://uncle-rods.blogspot.com****.*

Split-Star Processing with ImagesPlus

Blair MacDonald

Reveal more nebulosity in dense star fields with this clever technique.



ALL PHOTOS ARE COURTESY OF THE AUTHOR

IN ASTROPHOTOGRAPHY, it can sometimes be difficult to see the forest for the trees. Extended nebulosity within the Milky Way's dense star fields can often be obscured by the sheer number of bright stars in the area. Stretching an image to bring out this colorful gas also increases the outer extremities of star images (known as "star bloat") caused by scattered light within your telescope, further complicating matters. So how can we address this issue? The answer is to approach both the stars and nebulae in our images separately.

Imagers have long used masks and other special techniques in *Adobe Photoshop* to combat star bloat, and now

Although much of astrophotography is about imaging the stars, sometimes they require special attention to avoid overpowering other objects such as nebulae and galaxies. Author Blair MacDonald describes a technique in *ImagesPlus* to prevent excessive star bloat in his deep photograph of NGC 6992, the Eastern Veil Nebula, to reduce the stars dominance in the result at right.

the creator of *ImagesPlus* has added several features to help deal with this astronomy-specific issue. Of particular interest is a new tool that enables you to split the stars and nebula into separate images, allowing you to then process the two individually before recombining them into your final result. Here's how you can integrate this novel technique into your workflow to get the most out of your deep-sky CCD or DSLR images.

Combatting Star Bloat

A typical photograph of the Eastern Veil nebula, NGC 6992 (shown on the facing page), is a good example of a target where numerous stars dominate an image, detracting from the visibility of extended nebulosity in the area. Using typical stretching techniques, the colorful supernova remnant is overpowered by the myriad stars in the field. Here's how we can use a fundamentally different approach to the data in *ImagesPlus 5.75a* **(www.mlunsold.com)** to improve the image.

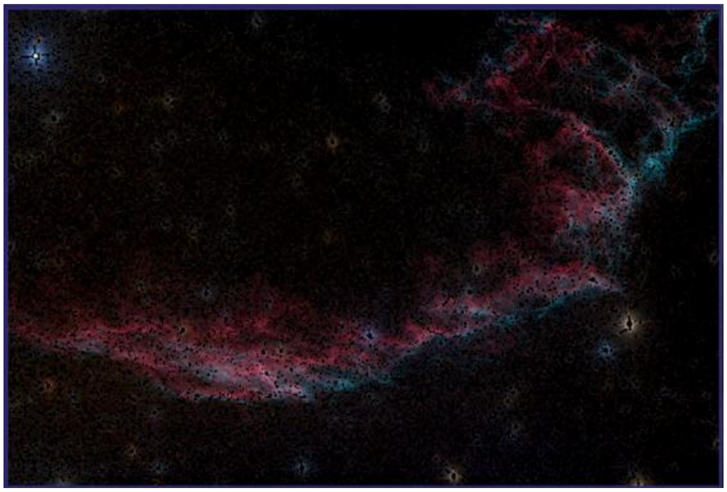
Begin by reducing your image data with the standard workflow of calibrating and combining your individual exposures into a "raw" unstretched result. When you have your raw color image, try stretching the result to limit the star bloat. This may mean not "pushing" your data to its limit to reveal the faintest wisps of nebulosity at this stage. I prefer to use the ArcSinH function (Stretch / ArcSinH), which provides excellent control of the light and dark areas of the image. Most of the adjustments I make using this tool are a combination of moving the BkGd. Min (Background Minimum) slider to the right to raise the black levels, while also dragging the Power slider toward the left to compress the dynamic range and increase the visibility of faint nebulosity in my image.

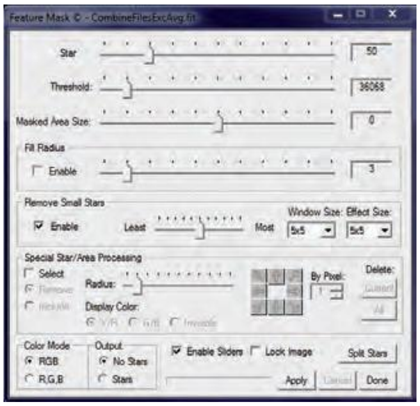
Mask and Separate the Stars

Next, I'll make a mask by selecting Special Functions / Mask Tools / Feature Mask ©. A new window opens, where I'll make my adjustments to first create my star mask. The dialog offers several controls to mask as many stars as possible while preserving the detail in the nebula.

Start by moving the Star slider to the right to mask out the largest bright stars. Move the slider in small increments, because the tool may select some of the brightest nebula details as well. If your mask begins to encroach on the surrounding nebula, move the Threshold slider to limit the tool's aggressiveness. The Star slider sets the maximum diameter of stars that will be masked and the Threshold slider tells the tool how much something should resemble a star to be masked from the image.

If many halos are still visible around the small-to-mid-sized stars after adjusting the Star and Threshold sliders, then move the Masked Area Size slider to the right to slightly increase the size of the mask. This will leave the smallest stars and some of the largest extended halos around the biggest stars still to be removed. Next, click



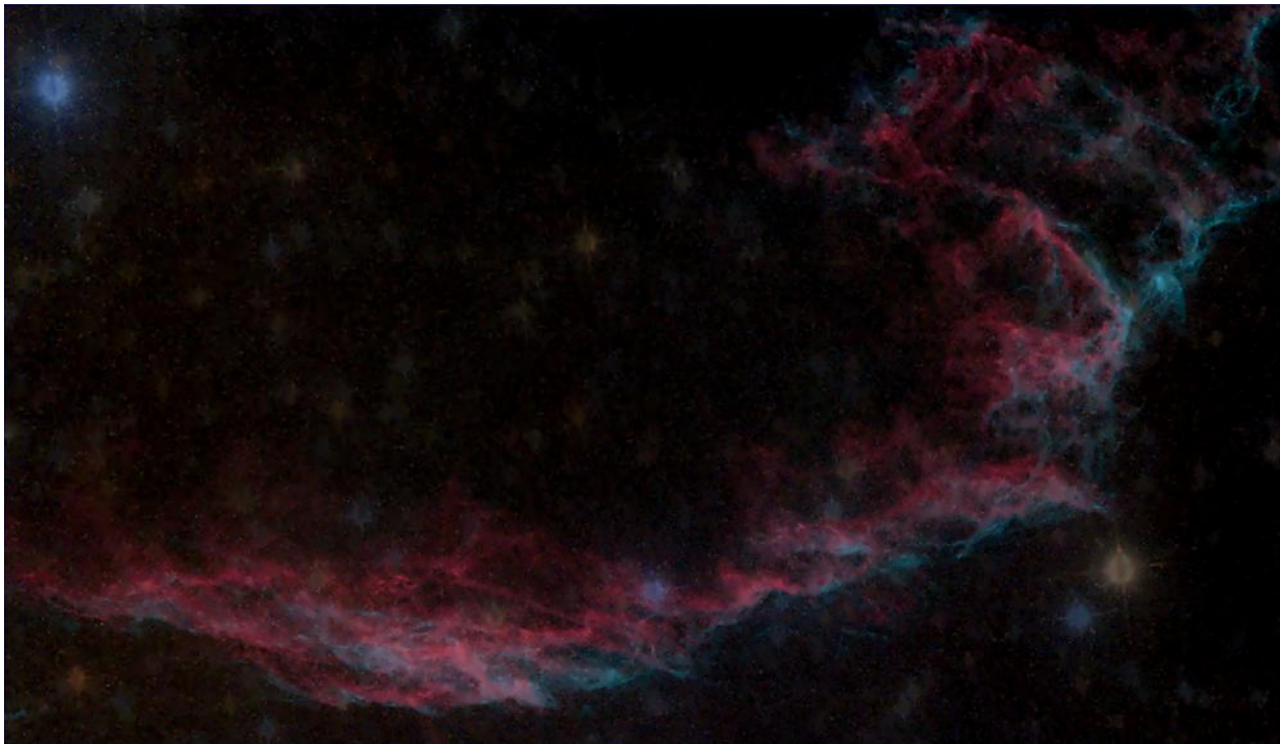


To mask stars in the software *ImagesPlus*, use the Feature Mask © tool in the pulldown menu (shown at *left*), and move the Star slider to the right to select more stars in your image. In a few seconds, the masked areas will appear black in your image (*above*). You can expand the star mask by moving the Masked Area Size slider to the right.

the Enable box in the Remove Small Stars section of the tool and move its slider to the right to mask the smallest stars in your photo. You can increase or decrease the Window Size and Effect Size settings if necessary, but note that increasing these values will cause some blurring of the image.

Finally, check the Enable box in the Fill Radius section and click the Apply button at the bottom right to fill the areas left by the star mask. In a few moments your mask will be generated. If the filled data is too bright, this means your mask isn't set properly yet. To fix this, move the Fill Radius slider to the right to darken the fill. The image should present sharp nebula detail and some stellar halos; if any of the halos are still overly bright you can remove them by clicking the Select box in the Special Star/Area Processing option. This is a handy feature that enables you to select areas manually for removal. Use the Radius slider in this section to increase the masked area.

At this point you should save this mask in FITS format using the Luminance Mask tool (Special Functions / Mask Tools / Luminance Mask) and close both the new mask and your color image. You can then apply this mask to the photo by reopening the raw image and selecting the Process History window (Open Operators / Process History).



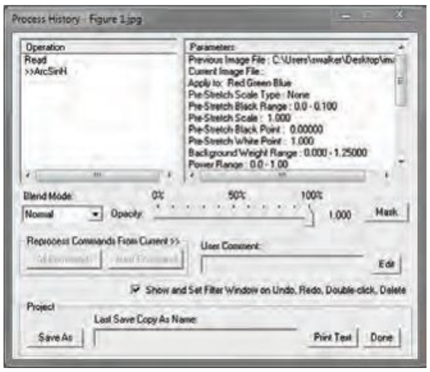
After applying the Feature Mask, your image should appear like the color photo above. You can also create a monochrome mask using the Luminance Mask tool that can be applied later in your workflow.

When the window opens, first re-stretch the image using the ArcSinH, then click the Mask button, and a window titled Mask Surface opens. At the bottom of this tool, select Mono Image in the Mask Type section, then press the Load button at the bottom right. This allows you to import the Luminance Mask FITS file you had saved, and apply it to your image. With this mask applied, you can then fine tune the ArcSinH stretch before moving on to the next step by simply double-clicking the listing in the Operation section of the Process History window.

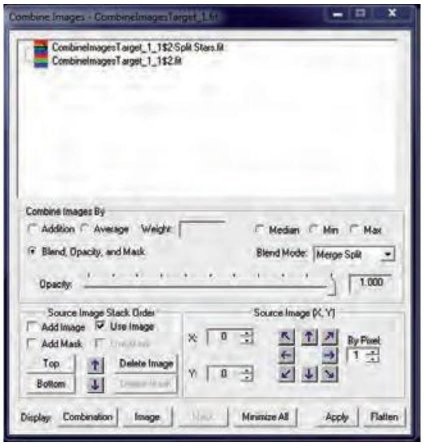
Now we'll use the Feature Mask © tool again to split the image into a star only and a starless nebula image. Adjust the sliders in the Feature Mask © window to mask all the stars again as we did to create the Luminance Mask. Once everything is set, click the Split Stars button at the bottom right of the window and instantly your image will be split into two separate images: one with only the stars and another with just the nebulosity with your target and background sky.

Now you can further stretch and sharpen the nebula

Applying your Luminance Mask is accomplished by using the Process History tool (*near right*). With your color image open, click the Mask button, and the Mask Surface window appears (*far right*). Click on the Mono Image tab in the Mask Type section, then click the Load button and select your luminance mask file.



image, and make other enhancements, without bloating the stars. In this case, I prefer to first address any uneven field illumination, such as vignetting or light pollution gradients, and then use the Micro Curves tool (Stretch / Micro Curves) to gently boost the nebulosity, followed by a slight increase in saturation. I usually only concentrate on increasing the saturation in the star image to show off the many hues of blue, yellow, and red that are often lost using other processing techniques.



Recombine your stars and nebula using the Blend Mode, Opacity, and Masks tool. Select Merge Split in the Blend Mode section and adjust the Opacity slider until you're satisfied with your result, then click the Flatten button.

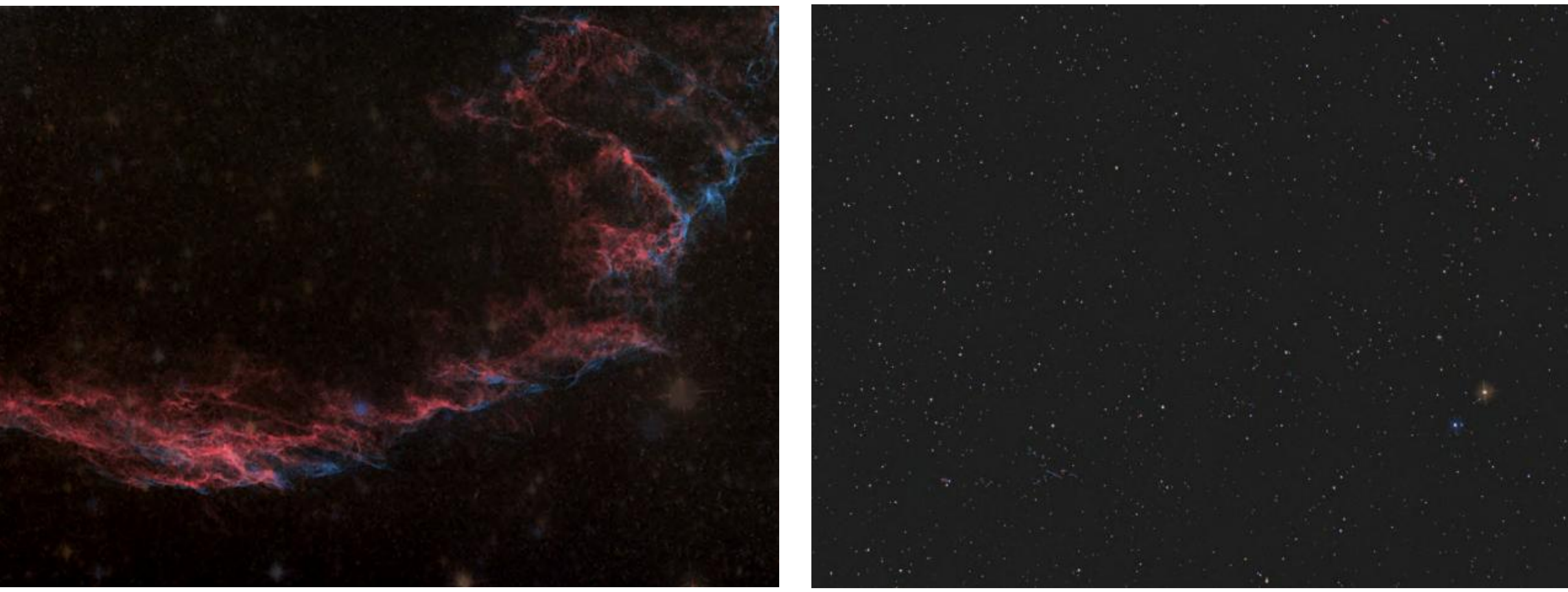
Recombining the Result

When you're satisfied with your work, you can combine the two images using Special Functions / Combine Images Using / Blend Mode, Opacity, and Masks. First, the Combine Images Setup dialog window opens, where you can retitle the combined result, and change its size if desired. Click OK, and in a moment a new image opens, along with the Combine Images window. To merge the two images together, click the carrot to the right of the Blend Mode option at right and select Merge Split. You can adjust the opacity of the layers using the Opacity slider, or switch which image is at the top of the stack to modify the blend of the two images. I prefer to have the image with the split stars on top, but you can move which image is at the top of the stack to get different results. Finally, click the Flatten button at the bottom right of the window to complete the merge, and then save your results.

Your final image should display rich star colors and much more nebula detail than your initial stretched image did.

Split-star processing makes it possible to stretch an image much more than is possible using other techniques. It's especially useful for objects located within the Milky Way's rich star fields. The feature-mask tool makes this type of processing easier with simple integration onto the *ImagesPlus* workflow. It has the potential to produce stunning images with a few simple mouse clicks and yields much better results than reducing the size of the stars after the fact. It also allows for more effective sharpening as the technique enables you to sharpen nebulae without producing unwanted artifacts around the stars, and it makes it easier to accomplish other processing such as noise reduction. The only real downside to using the tool in your image-processing workflow is that it works so well you'll be reprocessing all your older images again! ✦

***Blair MacDonald** is a member of the Royal Astronomical Society of Canada. He photographs the night sky from the dark skies of rural Nova Scotia.*



Clicking the Split Stars button in the bottom right corner of the Feature Mask © window produces two images, one with only your target nebula (*left*), and the other with the bright stars (*right*). You can then process the images individually before recombining them into the final result.

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TWINKLING SISTERS
Robert Fields and Terry Hancock
Even in a telescope, it's extremely difficult to see the extended wisps of bluish reflection nebulosity that appear in this image of the Pleiades (M45). But the cluster's brightest stars are easily seen without optical aid.
Details: *Takahashi FSQ-106N and Epsilon-180ED astrographs with QHY11 and SBIG STL-11000M CCD cameras. Total exposure was 3⅔ hours through color filters.*

◂ **BARRED SPIRAL**

Gerald Rhemann

NGC 1365 in Fornax is a nearby barred spiral galaxy visible in small telescopes. Deep images reveal thin dust lanes and small, pinkish star-forming regions in the galaxy's main spiral arms.

Details: *12-inch ASA N f/3.8 Astrograph with FLI Micro-Line ML8300 CCD camera. Total exposure was 10⅔ hours through color filters.*

▾ **DUSTY PERSPECTIVE**

José Joaquín Pérez

The thick dust of dark nebula LDN 1622 in Orion appears in stark contrast to the surrounding pinkish hydrogen gas of Barnard's Loop.

Details: *Orion Optics AG12 Newtonian astrograph with SBIG STL-11000M CCD camera. Total exposure was 7.5 hours through color filters.*

▲ **SHORES OF A LUNAR SEA**

Richard Hill

Dark lavas of Mare Humorum at right are bordered by an arc of the large craters Gassendi, Mersenius, Cavendish, and Vieta (seen from top right to middle left).

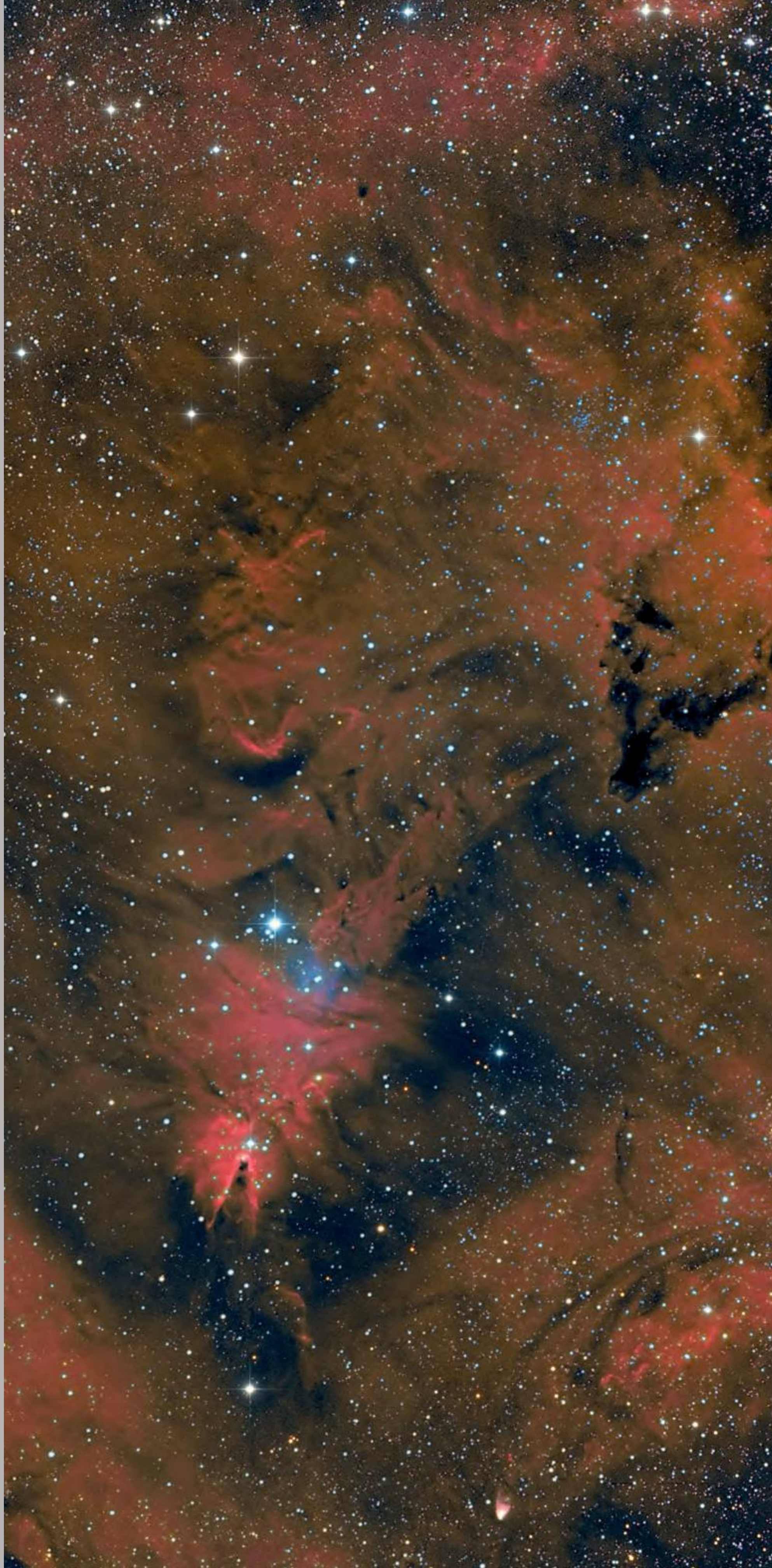
Details: *TEC 8-inch f/20 Maksutov-Cassegrain telescope with Celestron Skyris 274M video camera. Stack of 500 frames.*

► **CONE AND CLUSTER**

Robert Fields

The Cone Nebula (lower left) is a dense pillar of gas and dust which shares the same designation as the open star cluster NGC 2264 to its north.

Details: *Takahashi FSQ-106N astrograph with SBIG STL-11000M CCD camera. Total exposure was 8 hours through Astrodon filters.* ✦



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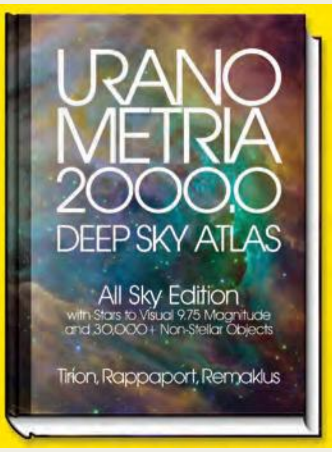

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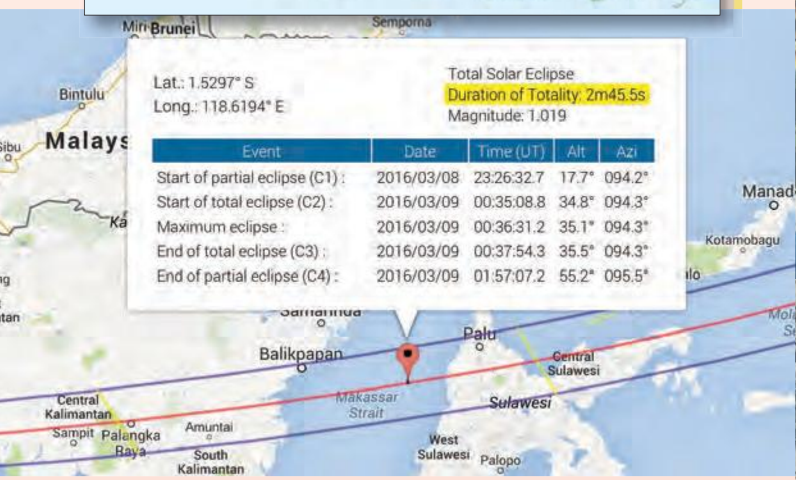

Lat.: 1.5297° S
Long.: 118.6194° E

Total Solar Eclipse
Duration of Totality: 2m45.5s
Magnitude: 1.019

Event	Date	Time (UT)	Alt	Azi
Start of partial eclipse (C1) :	2016/03/08	23:26:32.7	17.7°	094.2°
Start of total eclipse (C2) :	2016/03/09	00:35:08.8	34.8°	094.3°
Maximum eclipse :	2016/03/09	00:36:31.2	35.1°	094.3°
End of total eclipse (C3) :	2016/03/09	00:37:54.3	35.5°	094.3°
End of partial eclipse (C4) :	2016/03/09	01:57:07.2	55.2°	095.5°

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Robert Naeye has been *Sky & Telescope's* Editor in Chief since 2008. Previously he was Senior Editor at *Sky & Telescope* and Senior Science Writer for the Astrophysics Science Division of NASA's Goddard Space Flight Center. Robert is the author of two books: *Through the Eyes of Hubble: The Birth, Life, and Violent Death of Stars* and *Signals from Space: The Chandra X-ray Observatory.*

CST# 2065380-40

Greg Bryant has been Editor of *Australian Sky & Telescope* since 2006 and a Contributing Editor to *Sky & Telescope* since 2001. He has also been involved with the publication of an Australian annual astronomy yearbook since the early '90s and science writing for the Australian Research Council's Centre of Excellence for All-Sky Astrophysics. A keen amateur astronomer for more than 30 years, Greg most recently teamed up with Insight Cruises for their successful 2012 Total Solar Eclipse tour in Australia. In 2000, the International Astronomical Union named asteroid 9984 Gregbryant in his honor.

David Tholen, Ph.D. is an astronomer at the Institute for Astronomy of the University of Hawaii (IfA), who specializes in planetary and solar system astronomy. Winner of the American Astronomical Society Division for Planetary Science's Urey Prize in 1990, Dr. Tholen and his students have discovered many near-Earth asteroids, the most famous being Apophis, which will make an extremely close approach to the Earth on April 13, 2029.

For more info: 650-644-5812 or Info@InsightCruises.com

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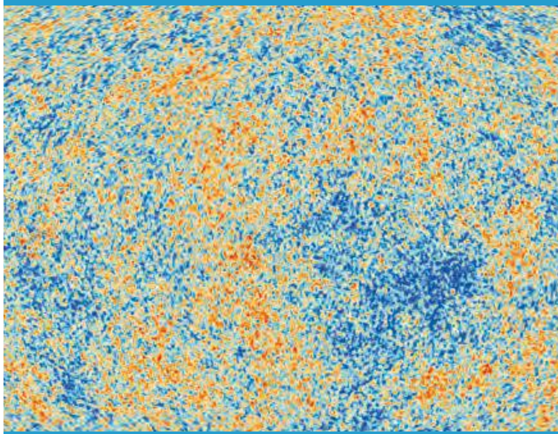

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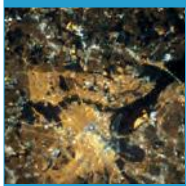

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Setting Expectations

The author has learned to live with astronomy's annoyances.

My interest in astronomy, like my relationship with my wife, is maturing. Just as I no longer get annoyed by my loving wife's habit of recounting all the annoying things about me that annoy her, I have learned to accept amateur astronomy's annoyances. These annoyances include the following:

1. Can't-miss astronomical events always happen at the most ungodly times.

Who's in charge of these things? Don't they realize that for me to support this hobby, I have to get up in the morning and actually work? Also, why don't they schedule these events during the weekends, or better yet, when I'm on vacation? The June 2012 Venus transit happened on a weekday. I called in sick. My boss saw my images on Facebook. The following day, a memo was waiting for me.

2. What you think you'll see is *not* what you'll get.

The images taken from space telescopes and observatories always set newbies up for a fall. Glorious images of nebulae lead us to expect to see high-def images in our eyepieces; what visual observers actually get are black-and-white smudges. The first time I saw the Andromeda Galaxy in my 6-inch reflector, I thought my telescope's mirror was dirty. And then we have objects where only averted or peripheral vision will work. Look, but don't look directly. It's like being allowed to eat but not to taste. What's up with that?

3. It's always going to be inverted.

Or it will be a mirror image if you've got a refractor. Either way, it does nothing but add disorientation insult to image-disappointment injury. This is what I always say to people who think that I use my telescope for more "illicit" pursuits. "Dude, I have a reflector, the image will be upside down. What's the point?" To which they will respond, "Why don't you just turn your scope around then?" Dante got it wrong in *Inferno*. There are no nine levels of hell — just nine levels of stupidity. And this suggestion belongs to the tenth.

4. Occultations.

This term needs some urgent rebranding. And it doesn't help that some of my armchair-astronomer friends insist on calling a solar eclipse an occultation of the Sun by the Moon. The term "occultation" has connotations of devil worship — no wonder so many people confuse astronomy with astrology. Which by the way, is the number two question I always get asked during public viewings: "What's your astrological sign?" It's like asking a Hindu whose burger tastes better, McDonald's or Wendy's.

If what's your astrological sign is my second-most asked question during public viewings, what's numero uno? My relationship with amateur astronomy, like my relationship with my wife, has matured. So now I don't get annoyed anymore when people ask me, "Do you believe in aliens?" I just smile and give them my standard Carl Sagan reply: "The universe is too big, man. If we were alone, it'd be an awful waste of space." Then I ask them to step away from the telescope please, and let the next one in line take a peek. If they don't budge, I point them to my wife holding a baseball bat. ✦

Gary B. Andreassen is the Public Relations Officer of the Astronomical League of the Philippines. His astronomical goal is to do a free telescope outreach for all the schools in his area by the end of 2014.

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