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THE ESSENTIAL GUIDE TO ASTRONOMY

SKY & TELESCOPE

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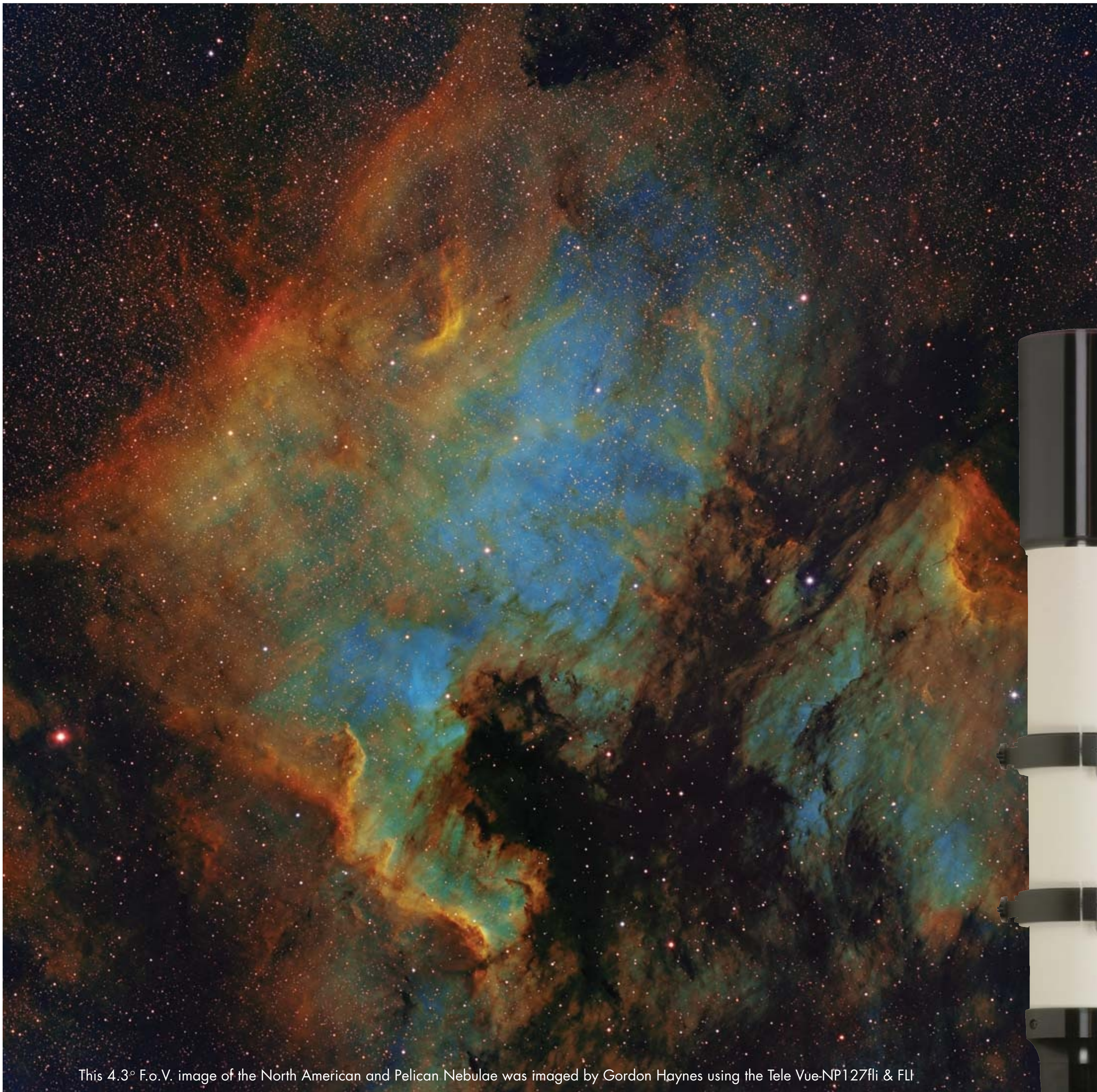
This 4.3° F.o.V. image of the North American and Pelican Nebulae was imaged by Gordon Haynes using the Tele Vue-NP127fli & FLI

April 2015

SKY & TELESCOPE

VOL. 129, NO. 4

On the cover:
The Dawn spacecraft will investigate Ceres for several months, providing the first close-up of this mysterious dwarf planet.

COVER ILLUSTRATION: CASEY REED

FEATURES

OBSERVING APRIL

S&T TEST REPORT

ALSO IN THIS ISSUE

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April 2015 Digital Extra

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- **The Herschel Sprint**
  Take on this observing challenge and let us know how you fare.
- **Explore the WorldWide Telescope**
  Use WWT for fun, research, and outreach — an interactive universe awaits!

Photo Gallery

Image by Bob Franke

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ONLINE PHOTO GALLERY

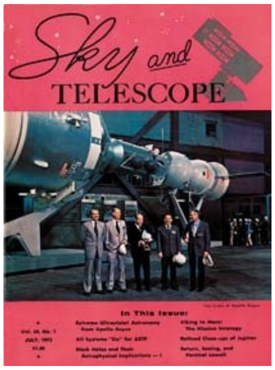
John Vermette captured Comet C/2014 Q2 (Lovejoy) in January 2015 in Tuscon, Arizona.

Decades on the Shelf

ONE DAY RECENTLY, I was cleaning out my mother's attic when I came upon a large, dust-covered cardboard box. Inside, neatly arranged, lay several dozen issues of *Sky & Telescope* that my brother, John, had saved in the mid-1970s when he was a teenager. Standing there in that dark, cramped space, cobweb strings dangling from the roof beams, I traveled back to another era: Apollo-Soyuz, the first Space Shuttle flight (in air), the Viking lander on Mars.

Of course, some *S&T* readers put my brother to shame when it comes to preserving past issues. Two long-time *S&T* contributors, Roger Sinnott and Dennis di Cicco, have preserved every single issue since they began subscribing in 1957 and 1963, respectively, and I've heard from other readers who've done the same. Why save so devotedly?

"It's great reference material," Dennis says. "Techniques even 40 or 50 years old are still applicable or spark ideas." Roger concurs: "Old articles on how to set up, use, and get the most out of a telescope contain valuable, timeless advice. For those who grind and polish their own mirrors and lenses, those old issues contain a wealth of exotic optical designs worth trying."



The crew of Apollo-Soyuz graced the cover of the July 1975 issue.

Observing articles also remain timeless. "A galaxy or star cluster that Walter Scott Houston described seeing with his 10-inch reflector in the 1950s will look pretty much the same in a 10-inch today," Roger says. "The laws of optics guarantee it!"

And then there's nostalgia, naturally. The old advertising is fun to look at, and many amateur astronomers surely enjoy revisiting the observation, project, or photo that they themselves once contributed to the magazine. Most pointedly perhaps, subscribers conserve back issues because *S&T* has been right there with them through the flowering and maturity of one of their foremost passions, which the magazine itself might have first kindled. If they toss out those issues, they'd be tossing out a part of themselves.

For my brother, as for many young would-be astronomers, *S&T* indeed provided formative inspiration. John saved every penny of his allowance the summer before 9th grade to buy a 4¼-inch Edmund Scientific reflector for $75. He went on later to found a company that uses lasers to measure material deformation and strain. His biggest client over the years? NASA.

"I loved my *S&T*s every month," John recalls. "They allowed me to dream — to dream about space and the future. *S&T* opened my mind to the incredible work of huge numbers of people, to study the skies, to develop tools, and to understand the physics. I still love it."

Why have *you* saved your old *S&T*s? We'd love to hear from you at **letters@skyandtelescope.com**. ✦

Peter
Editor in Chief

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The Essential Guide to Astronomy

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ONE HALF OF THIS IMAGE WAS TAKEN WITH A $2,499 ESPRIT
THE OTHER WAS TAKEN WITH A SCOPE THAT COST TWICE AS MUCH
Actually, the other telescope cost **more** than twice as much as the Esprit, but that's not really the point. The point is, do you see twice as much performance on one side of the page than the other? Take a close look. Are the stars twice as pinpoint? Is the color doubly corrected?
We don't think so.
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Spin: How Sure Are We?

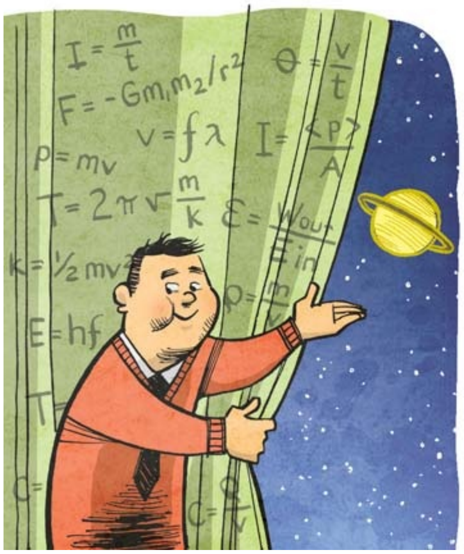
The news brief "First Direct Exoplanet Spin Measurement" (*S&T*: Sept. 2014, p. 18) gives the impression that the rotation of Beta Pictoris b bolsters the hypothesis that the more massive a planet is, the faster it rotates. Beta Pic b's surface, or cloud tops in this case, might move at a faster clip than Jupiter's (25 km/s vs. 13 km/s), but that doesn't mean Beta Pic b rotates faster than Jupiter, or even than Earth; for that determination we need to know the exoplanet's size. Beta Pic b has 11 times Jupiter's mass, but do we know its size at all?

Jim Baughman
West Hollywood, California

Editor's Note: *Beta Pic b isn't a transiting planet, so we can't easily determine its radius. However, with some calculations based on direct imaging, the astronomers estimated that the exoplanet is 1.65 times the size of Jupiter. This implies that the length of day is only 8 hours, whereas Jupiter's day is 10 hours, supporting the team's argument.*

Bring Back the Fun

Bert Probst made some good points about introducing people to astronomy in his Focal Point "Winning Converts to the Cause" (*S&T*: Oct. 2014, p. 86). My suggestion is, if you know someone who is not interested in the science of astronomy, you might want to introduce him or her to *astronomizing*, a word I like to use to describe the aesthetic side of skygazing — in other words, a recreation similar to earthly sightseeing. This is especially enjoyable when something is changing right before your eyes, such as the mountain shadows on the crescent Moon. I can watch that again and again. And then there are occultations. My favorite was the occultation of a star by Saturn and its rings.



S&T: LEAH TISCIONE

Years ago I acquired a used Celestron 5-inch Schmidt-Cassegrain. It came with all the accessories, but I don't use the tripod or the electric drive. Instead, I just place it on a picnic table with its equatorial wedge and enjoy the show through the eyepiece. I don't do occultation timings or any other measurements: I just like to watch. I'm a retired physics professor, but I prefer to separate the *science* of astronomy from the *fun* of astronomy. All of the new gadgets are great for serious astronomers, but I think they can be imposing to beginners and perhaps turn them off to astronomy. Maybe we should get back to basics, downplay all those gadgets, and focus on showing people the fun of the hobby instead.

William DeBuvitz
Mendham, New Jersey

As a retired science educator, I have grave concerns about both what is being taught in schools today and how it's being taught. The frustration I have is that there seems to be no regard for age-appropriateness. Scientific ideas and concepts appropriate for older students are creeping into requirements for younger students, making it harder for them to learn.

Once while teaching my students about solids, liquids, and gases, I used the standard model: to show a gas, I drew dots far apart on the board. I looked at my students and saw blank faces. I asked, "What do you think is between these particles?"

Hands went up quickly. "Air" was the answer.

"How many agree?" I asked.

Almost all agreed.

Things aren't always as simple as we think they are.

There needs to be a change in our culture to help make science as fun and interesting as it should be. The American Association for the Advancement of Science and the National Science Teachers Association have together created a two-volume *Atlas of Science Literacy* (**www.project2061.org/publications/atlas**), which lays out the learning benchmarks K–12 students can successfully hit in order to build up their understanding of a particular topic, from the solar system to how scientific inquiry works. These are the best guidelines for what is appropriate at each age level, and I recommend them to anyone writing science curricula. Maybe *S&T* could also have age-appropriate ideas or activities as part of the magazine.

Herb Hoyack
Mechanicsville, Maryland

Daytime Observing

I enjoyed Chris Dalla Piazza's article "Stars & Planets in Broad Daylight" (*S&T*: Oct. 2014, p. 36). For many years I've also observed during the day. I use an 8-inch Celestron with standard setting circles and a permanent mount that's polar aligned. I normally set up the telescope between 11 a.m. and 4 p.m., so that the Sun is well above the horizon before I start the hunt. So far I've seen 62 stars, four of them double, along with the planets Mercury, Venus, Mars, Jupiter, and Saturn. The fainter, 5.1-magnitude member of the double Albireo is the faintest star that I've seen during the day so far.

Both Albireo (magnitudes 3.1 and 5.1) and the double Lambda Ori (magnitudes 3.6 and 5.5) required a very clear blue sky to separate the pairs. In terms of planets, Mercury and Venus are perfect to look at when

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they're near the zenith and show really nice crescents as they pass between Earth and the Sun. A brilliant white Venus or Sirius against a deep blue sky is a sight to see.

Dave Partyka
Oberlin, Ohio

In his article on daytime astronomy, Dalla Piazza's comment on "pushing the envelope" by using doubles to find fainter stars in the daytime took me back to the early 1990s. I had purchased a Celestron Classic 8. Although not a Go To scope, it had adequate setting circles and a Vernier scale on the right ascension circle, which enabled me to quickly locate an object in the night sky. That being so easy, I started looking for planets and bright stars in the daytime and eventually got curious about finding a personal best.

I was surprised to find that I could see a star as faint as magnitude 6.8 while the Sun was still above the horizon. Starting with Arcturus ($14^h\ 15^m\ 39.6^s$ +19° 10′ 57″), I slewed east to Xi Bootis ($14^h\ 51^m\ 23.2^s$) after getting a good focus on Arcturus. The double Xi Boo is roughly 6′ lower in declination, so no declination adjustment was necessary. Xi Boo's companion is a 6.8-magnitude star 5.7″ from the primary. The pair is high in the sky just before sunset in early July. With today's Go To scopes, this is no longer as great a challenge, but some readers might want to give it a try this summer.

Jim McCormick
Victor, Idaho

Don't Skimp on Print

I just wanted to comment on your use in the print magazine of weblinks to "online extras," which leaves behind thousands of inmates such as me. Not all readers have internet available, and we truly rely on snail mail as our only access to outside contact. As extremely important as the internet is in today's technological society, assuming readers can go online cuts both prisoners and other "offline" readers out of the loop and makes us feel isolated, that people have forgotten that we exist. There are about 500 inmates here. Snail mail is my only connection with the outside world.

Mail call. I scan the magazine and then pass it along, to make sure that all get to experience the privilege of reading *S&T*.

Steven Lewis, #133282
Randall L. Williams Correctional Facility, Pine Bluff, Arkansas

For the Record

✸*The Atmospheric Dispersion Corrector (*S&T*: Jan. 2015, p. 33) is manufactured by Astro Systems Holland, not Pierro-Astro, and is available at* **www.astrosystems.nl**.

✸*In the February 2015 Deep-Sky Wonders column, there are two image errors: (1) Abell 24 is north of Zeta Canis* Minoris, *not Zeta Canis Majoris as shown in the chart on page 56; (2) on page 58, Douglas's Triangle is not the three stars in the middle of the image but the three stars that combine to create the top "star" in that triangle. A zoomed-in image of the triangle and a corrected chart appear on* **http://is.gd/errata2015**.

75, 50 & 25 Years Ago

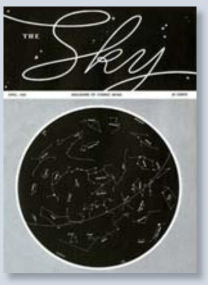
Roger W. Sinnott

April 1940

Wayward Neptune "[Recently] I computed the motion of Neptune by Cowell's method, step by step, from 1780 to 1938. [The] attractions by the other planets [I evaluated] with the aid of the Hollerith machines of the Watson Astronomical Computing Bureau at Columbia University. . . .

"[Neptune's ecliptic] latitudes since 1846 could not possibly be represented by an orbit in which Pluto's attraction was omitted. . . . The mass of Pluto found by this determination is 1/400,000 of the sun's mass. This practically equals the mass of Venus, and is about 82 per cent of the mass of the earth."

Dirk Brouwer (Yale University Observatory) pioneered the use of punch-card tabulating machines before the advent of modern computers. But in the 1980s astronomers realized Pluto was too puny to tug noticeably on Neptune, sparking speculation that another Planet X, an unseen dwarf star nicknamed Nemesis, or even the attraction of the Milky Way's center was involved. Today most dynamicists believe small errors in Neptune's observed position before 1911 created the illusion of the additional gravitational force.



April 1965

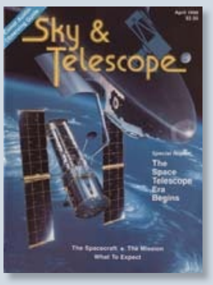
Damon Cameras "A new photographic sky patrol program has been started at Harvard Observatory with modern cameras. This is a revival, on a greatly modified plan, of the famous sky patrol that Harvard director E. C. Pickering began nearly 80 years ago. . . .

"The clear aperture of the Damon lenses is 1.71 inches, corresponding to f/8.1. The useful field on 8-by-10 plates is 30 by 40 degrees. [The] size of the circle that contains 80 percent of the light of a star image is 15 microns on the optical axis, and 20 at the edge of the field. . . . We wanted a rugged camera needing little maintenance, rigid and stable enough to keep its overall alignment [and] make unguided exposures of up to two hours."

Hector C. Ingrao's article is a classic for its nuts-and-bolts details of the Damon patrol cameras, in use through 1989. The cameras contributed 12,381 astronomical plates to Harvard's vast collection. Numbering a half million, the plates are now being digitized as a resource for future research (more in next month's issue).

April 1990

Mini Hubbles "[I'm not saying] it was a mistake to build the Hubble Space Telescope at all. [But] it was a mistake to sell HST to Congress and to the public as the space telescope for the rest of the 20th century. It was a mistake to push HST ahead of more modest space telescopes that could have been flying earlier. If we had even one imaging telescope in the 1-meter class, looking at the sky with 0.1-arc-second resolution, many of the discoveries that HST will make might have been made 10 years sooner."



On the eve of the space telescope's launch, Freeman J. Dyson (Institute for Advanced Study) was offering his perspective on HST.

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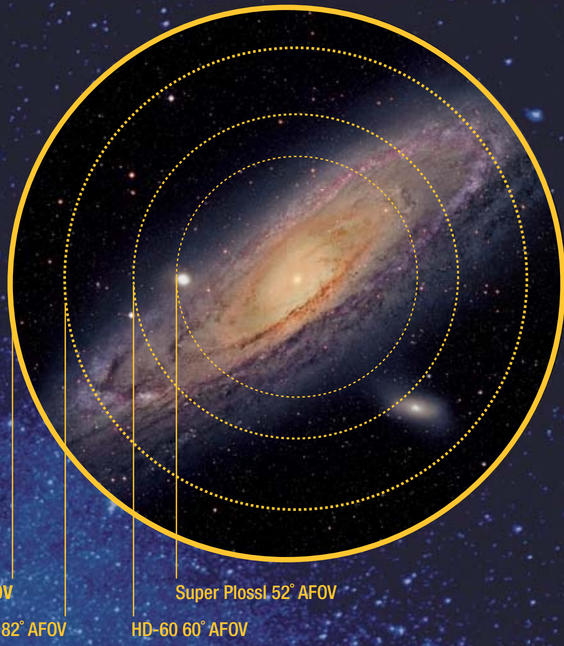

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EARTH | Give-and-Take Origin for Oceans?

Earth suffered heavy bombardment early in its history, potentially both tearing away and adding to its primordial atmosphere and water content.

NASA GSFC / CONCEPTUAL IMAGE LAB

Planetary geologists have long debated where Earth's water originated. Has it been here from the outset, as our planet came together, or was it imported later on?

Even if Earth assembled from chunks of water-rich primordial matter, the titanic impact that ripped into our infant planet and led to the Moon's formation would have melted Earth's crust and mantle to great depth, driving off water as superheated steam — along with any primordial atmosphere that might have existed.

If that happened, then late-arriving comets could have replenished what was lost. The total volume of water on Earth is about 1.4 billion cubic kilometers (330,000,000 mi^3), and it would take a few thousand comets, each 50 km (30 miles) across, to deliver all that. Such a barrage would have been likely early in solar system history, during the *late heavy bombardment* (LHB) between 4.1 and 3.8 billion years ago. Many dynamicists now think the LHB was triggered by an abrupt shifting of the giant planets' orbits.

However, early results from ESA's Rosetta mission (*S&T*: Aug. 2014, p. 20) put a damper on cometary delivery. As Kathrin Altwegg (University of Bern, Switzerland) and colleagues report December 10th in *Science,* the ratio of deuterium to hydrogen in Comet 67P/Churyumov-Gerasimenko's water is 3½ times that in Earth's oceans. This deuterium excess supports the growing suspicion that comets didn't deliver the bulk of Earth's water.

Meanwhile, new computer modeling suggests that asteroid impacts could have both removed and increased Earth's allotment of volatiles. Calculations by Hilke Schlichting (MIT) and two colleagues at Hebrew University suggest that thousands of small impacts would strip away Earth's primordial atmosphere much as the Moon-forming impact would, by each ejecting a localized pocket of gas irretrievably into space. It'd take tens of thousands of these events to blast away the entire atmosphere, Schlichting and colleagues report in February's *Icarus*. A bombardment of that magnitude likely occurred during the LHB.

One way to safeguard a water-rich future would be to stash lots of the stuff deep down in Earth's mantle. That's the thinking of Wendy Panero and Jeffrey Pigott (Ohio State University), who envision that Earth's constant cycling of massive crustal slabs could have preserved large amounts of water in the mantle rocks and then, eventually, returned it to the surface.

Panero and Pigott discovered tiny flecks of the silicate mineral ringwoodite in a diamond that formed at great depth. The most common mineral in Earth's lower mantle is perovskite, a silicate whose crystalline structure can't store many stray hydrogen atoms (which end up in water). But lots of hydrogen can be stashed in ringwoodite, which exists in a broad layer about 500 to 800 km down. The hydrogen got there thanks to slabs of water-rich oceanic basalt forced down into the mantle along subduction zones. The team suggested December 17th at the American Geophysical Union that a Pacific Ocean's worth of water remains locked up down below. To form its oceans, Earth might have simply regurgitated water that's been stored for eons in its mantle.

However, geophysicists think that plate tectonism might not have started until Earth was already a billion years old — by which time any primordial water was likely long gone. So perhaps Earth's oceans were imported after all, predominantly from water-rich asteroids.

■ **J. KELLY BEATTY**

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

MARS | Curiosity Finds Organics . . .

On December 16th, team members with NASA's Mars Science Laboratory reported the detection of methane and other organic compounds on Mars.

Organics are molecules made up of carbon atoms linked to other elements. They can arise both biologically and abiotically, such as by raining down from space as micrometeoritic dust. Organics would break down fast in the hostile Martian environment, destroyed by solar UV rays or by the strongly oxidizing soil, so scientists have struggled to detect them.

Curiosity's organics detection comes from the Cumberland sample, which the rover drilled on May 19, 2013. The compound identified is chlorobenzene (C_6H_5Cl), at a level at least four times the upper levels inferred from previous samples. It's unclear whether the compound is actually present in the rock as chlorobenzene or as something else, such as benzilic acid ($C_{14}H_{12}O_3$), that's transformed by the roving lab's processing.

The methane detection came with a surge in atmospheric levels in November 2013. Planetary scientists have debated methane's presence on Mars for decades, and Curiosity's iffy detection in 2012 — which placed an upper limit of 1.3 parts per billion by volume (ppbv) — didn't help. But in fact methane *is* there. "We were completely surprised, we suddenly saw 5½ ppbv methane," says Chris Webster (JPL). "It was an Oh My Gosh moment."

A week later it had risen to 7 ppbv; a month later it was still 7 ppbv. A fourth test 3 weeks after that detected 9 ppbv. Then 6 weeks later, it had completely disappeared.

The average over the 2-month period is 7.2 ± 2.1 ppbv, about 10 times the average background level, the team reported December 16th at the American Geophysical Union and in *Science*.

The signal's sudden appearance and disappearance, coupled with the low background levels and wind patterns, suggest that the methane came from a small, localized source either within Gale crater or just outside and to the north of it. It could either come from a modern source or be ancient methane leaked from a subsurface reservoir. The team will monitor methane levels and work with India's Mars Orbiter Mission to try to catch another spurt.

■ **CAMILLE M. CARLISLE**

. . . and Studies Mars's Dry-out

Samples taken from two drill holes on Mars support the idea that the Red Planet lost a whole lot of water early in its history.

Mars had wet conditions in the first few hundred million years of its existence. But the planet had turned cold and dry by 3 billion years ago. Scientists investigate what happened in part by looking at the ratio of hydrogen (H) to its heavier form, deuterium (D). The D:H ratio leans more in favor of deuterium if the parent world loses a lot of hydrogen (and, therefore, water) to space.

The D:H ratio in Mars's atmosphere today is roughly 6 times the average in Earth's oceans. But primitive mantle material in a Martian meteorite called Yamato 980459 has a ratio similar to Earth's.

Scientists with NASA's Curiosity rover investigated Mars's water loss by drilling into clay minerals that solidified in standing water roughly 3.8 billion years ago. They found that the water released from the heated samples had a D:H ratio three times that of Earth's. The value is higher than expected for early Mars, Paul Mahaffy (NASA Goddard) and colleagues report December 16th in *Science*.

If the samples reflect the planet-wide D:H levels at that time, then Mars has lost to space 100% to 150% as much water as it currently has in its surface and subsurface.

But if the planet has multiple water reservoirs that have been isolated from one another for a long time — such as ice embedded in sediments that hasn't interacted with the atmosphere — then the samples only reveal how much water that particular reservoir lost. NASA's MAVEN orbiter will reveal whether the current atmospheric loss rates imply the same history of loss for the planet.

■ **CAMILLE M. CARLISLE**

COSMOLOGY | BOSS Ruler for the Universe

Astronomers have announced the most precise standard ruler yet for cosmological distances. The Baryon Oscillation Spectroscopic Survey (BOSS) covered 25% of the sky over the past 7 years as part of the Sloan Digital Sky Survey (SDSS). The goal: detect the imprint of primordial sound waves, called *baryon acoustic oscillations*, which sloshed around the primordial universe's plasma and left their mark in the distribution of matter in the universe.

This mark appears in huge statistical samples as galaxies' slight preference to lie 500 million light-years apart. Although BOSS's final data analysis isn't expected until later this year, the 85% of the data already analyzed confirms the primordial sound waves' fingerprint to 10 sigma, or having a 1 in 10^{23} chance of being a fluke.

BOSS detected ripples by looking at populations of relatively nearby galaxies, divided into two groups whose light has traveled for 3.5 billion and 5.7 billion years, respectively, and by looking at more distant quasars, whose light has traveled 11 billion years to Earth. These two data sets sandwich the era when the universe's expansion began accelerating.

Normally, astronomers need to calculate distances to these objects using their redshifts. But that requires models of how fast the universe is expanding. On the other hand, if astronomers know how big the primordial ripples should be (found in cosmic microwave background fluctuations), and they measure how big the ripples appear on the sky, they can measure the distance directly. These distances are now known to an accuracy of 1%, BOSS scientists announced at the winter American Astronomical Society meeting in Seattle. Alternatively, you can forgo the cosmic microwave background measurements and just calculate relative ripple sizes at different distances to see how quickly the ruler expands over cosmic time. Both measurements agree with the leading cosmological model, including a constant dark energy.

■ **MONICA YOUNG**

IN BRIEF

Quasar Shuts Down. Over the course of 10 years, the supermassive black hole powering a once-brilliant quasar seems to have stopped gobbling down gas. Black holes must make the transition from active to dormant status at some point, since nearby supermassive black holes are all quiescent, but such transitions are rarely spotted. Stephanie LaMassa (Yale) and colleagues reported December 5th on arXiv.org that SDSS J015957.64+003310.5 exhibited radically different spectra when measured 10 years apart, with the more recent spectrum missing the broad emission lines characteristic of a voraciously accreting black hole. The quasar had also dimmed to one-tenth its former brightness. It is the brightest and most distant of about a half dozen active galactic nuclei (AGN) that have been caught in this short transition phase. These AGN are overturning the conventional wisdom that differences in AGN appearance stem solely from our viewing angle; instead, an AGN's evolution might play a role.

■ **SHANNON HALL**

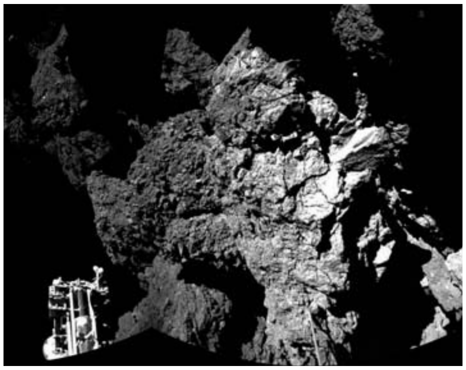
Stars' Spins Show Their Ages. Astronomers have expanded their ability to date stars using stellar spins. Young stars rotate rapidly, have more spots, and flare more often; old stars rotate slowly and have fewer spots. *Gyrochronology* uses starspots to clock stars' rotation periods and thereby determine their ages, but it's only been used on cool, low-mass stars younger than 1 billion years. Now, Søren Meibom (Harvard-Smithsonian Center for Astrophysics) and colleagues have spin-dated 30 low-mass stars in the 2.5 billion-year-old cluster NGC 6819. The stars followed a simple sequence, with more massive stars spinning faster. This suggests that at ages greater than 2 billion years, measuring a low-mass star's rotation period leads directly to its age, with a precision of about 10%, the team said on January 5th at the American Astronomical Society and in *Nature*. The results also confirm that solar-type stars' periods increase with the square of their age, a relation put forward by Andrew Skumanich in 1972.

■ **JOHN BOCHANSKI**

MISSIONS | Philae Landed in a Hole

Scientists with ESA's Rosetta mission are still unsure where their lander, Philae, has come to rest after its bumpy landing on November 12th (*S&T*: Feb. 2015, p. 12). The team has executed an intensive photographic search with the orbiter and hopes to find the lander in those images once they're downloaded and analyzed.

The patchwork view Philae sent back of its new home before running out of power shows the lander to be sitting in a hole, surrounded by a number of cliffs. This is a good thing: the science team thinks these cliffs and their shadows could act as a shield against the extreme environment that will arise when the comet surges to life near perihelion. One cliff showcases layers of ice and dust, with linear fracture patterns and materials that could be loaded with pristine organics. "This was the material we were desperately looking for," says Jean-Pierre Bibring (Institut d'Astrophysique Spatiale, Orsay, France).



ESA / ROSETTA / PHILAE / CIVA

Philae's first view of the comet's rugged surface (a composite of two frames) shows one of the lander's three legs at left.

The steep incline shortens the amount of sunlight reaching Philae's solar-cell panels to only 4½ hours during each 12½ rotation, delaying the backup battery's recharging. But the wake-up only requires 15 to 20 watts, so the team is optimistic about the lander's prospects.

■ **EMILY POORE**

MAVEN Finds New Particles, Ion Plume

NASA's MAVEN mission has discovered a new population of particles in Mars's upper atmosphere. It's also found a plume of particles escaping from the planet's pole, confirming atmospheric loss is happening today. Team members presented the preliminary results at the American Geophysical Union on December 15th.

The Solar Wind Ion Analyzer found that a fraction of charged solar wind particles manage to dive fairly deep into Mars's upper atmosphere by playing a chameleon game. Mars's ionosphere should deflect the solar wind. But the team found that about 1/500 of the particles bombarding the Martian atmosphere show up about 200 km above the planet's surface — less than 1/10 the altitude where they're normally stymied. Plus, they don't show up in the region between these two layers.

What's likely happening is this: upon arrival, some solar wind particles steal electrons from the uppermost atmosphere, thereby transforming to neutral particles. Unlike ionized particles, neutrals can pass through the ionosphere and any magnetic fields with impunity. They're therefore able to drill deep into the Martian atmosphere, sailing unencumbered until the atmosphere grows denser and there's more stuff to run into. Then they again do a charge exchange with atmospheric particles, becoming ions again.

Using these flip-flop ions, researchers can track what the solar wind is doing high above while the spacecraft is in the atmosphere below, giving them an instantaneous look at what's going on in the solar wind, how much energy it's dumping into the upper atmosphere, and how the atmosphere responds. That'll be a huge help with MAVEN's mission, which is to understand the drivers of atmospheric loss on Mars.

The Suprathermal and Thermal Ion Composition instrument also detected a plume of ions at Mars's pole, created by ions heated and escaping from the upper atmosphere. It's unclear which of the various processes at work in Mars's atmosphere is stripping the ions away. ✦

■ **CAMILLE M. CARLISLE**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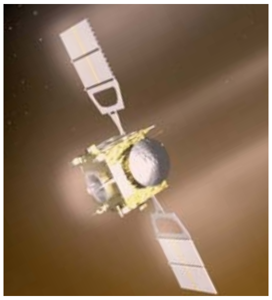
Farewell to a Friend

After a tremendously successful mission, Venus Express has orbited its last.

IT'S TIME TO SAY GOODBYE, and thanks, to a friend who has served us well. For me the friendship began in 2006 with a letter from the European Space Agency (ESA) informing me that I had been selected as a member of the Science Team for the Venus Express mission. This was a dream come true. I had been fascinated with "Earth's twin" at least since the 5th grade when I read Isaac Asimov's novel *Lucky Starr and the Oceans of Venus,* which described epic battles and exotic aquatic creatures.



I soon learned that this fantasy had been obsolete since 1961, when Mariner 2 — the first successful mission to another planet — had proved Venus far too hot to host oceans or surface life. The harsh reality dashed Venusian water-world fantasies but raised delicious new questions: What happened to take these twin worlds down such different paths? What could we learn from this about the life stories of Earth-like planets? Further spacecraft results hinted that Venus was likely once cooler and wetter. We began to see it as a place where planetary climate had gone off the rails, into the hot zone.

The plucky European spacecraft arrived in April 2006 and orbited for eight great years, providing our first continuous, detailed observations of the cloud-shrouded planet. It revealed a vibrant world of constantly shifting cloud patterns, immense tornado-like vortices dancing chaotically around the poles, intense bursts of lightning, and seemingly active volcanism.

We knew we were living on borrowed time. Venus Express had long since exceeded its originally expected mission lifetime, and all last year it had been running low on the fuel to power its thrusters. The last phase of the mission was focused on dynamic and variable phenomena, both on the surface, where we used the infrared spectrometer to scan for volcanic activity, and in the upper atmosphere, where we monitored the changing abundance of sulfur dioxide above the clouds.

Doing science to the end, we tried some risky maneuvers we would not have dared attempt earlier in the mission. In June and July of last year we performed a series of "aerobraking" experiments, lowering the orbit to an altitude of 80 miles (130 kilometers), well into the thin uppermost atmosphere. Changes in spacecraft motion allowed us to compute the density of the air, which we found was surprisingly variable and more strongly affected by time of day than expected. New data like these help us build better climate models for Venus — and for Earth.

We had hopes that the mission might last longer, but the spacecraft's orbit had been decaying. We planned a series of 10 daily rocket burns for the last week of November to raise the orbit. These could have kept the spacecraft safe until February, when another series of burns could have kept it going until June. The suspense came from the fact that we didn't really know how much fuel was left. It was like running on fumes with your gas tank's warning light on, except we knew when we ran out there would be no roadside assistance.

On November 28th, during one of these rocket burns, the spacecraft stopped communicating normally and suddenly seemed unable to maintain proper orientation with its antenna focused on Earth. Venus Express was still alive, still sending out telemetry, but we never established a good communication link, and it soon became clear that its fuel had run out, and there was nothing more to be done. On December 16th, ESA announced that the mission was over. Sad but proud emails darted among the science and engineering teams, with congratulations on an amazing mission and reminders of the years of data analysis still to be done.

It really is like saying goodbye to a friend after so many years of making plans, sending instructions, receiving photos and data, losing and regaining contact, worrying over problems, crossing our fingers, and rejoicing when everything is okay. After years of this, you get attached.

Sometime around the end of January the spacecraft was expected to plunge into the atmosphere, falling in pieces, corroding and melting, toward the searing surface.

Goodbye, Venus Express. Please tell Venus that we'll be back. ✦

__David Grinspoon__ is an astrobiologist and author at the Library of Congress. Follow him on Twitter at @DrFunkySpoon.

Dawn Arrives at Ceres

Emily Lakdawalla

NASA's spacecraft enters into orbit around the largest asteroid in the main belt.

It was once called a planet, and then it was demoted. Long passed over for larger solar system targets, this dwarf planet remains mysterious, with an unknown composition and origin. But the mystery won't last long: this year, a long-voyaging spacecraft is finally paying the neglected world a visit.

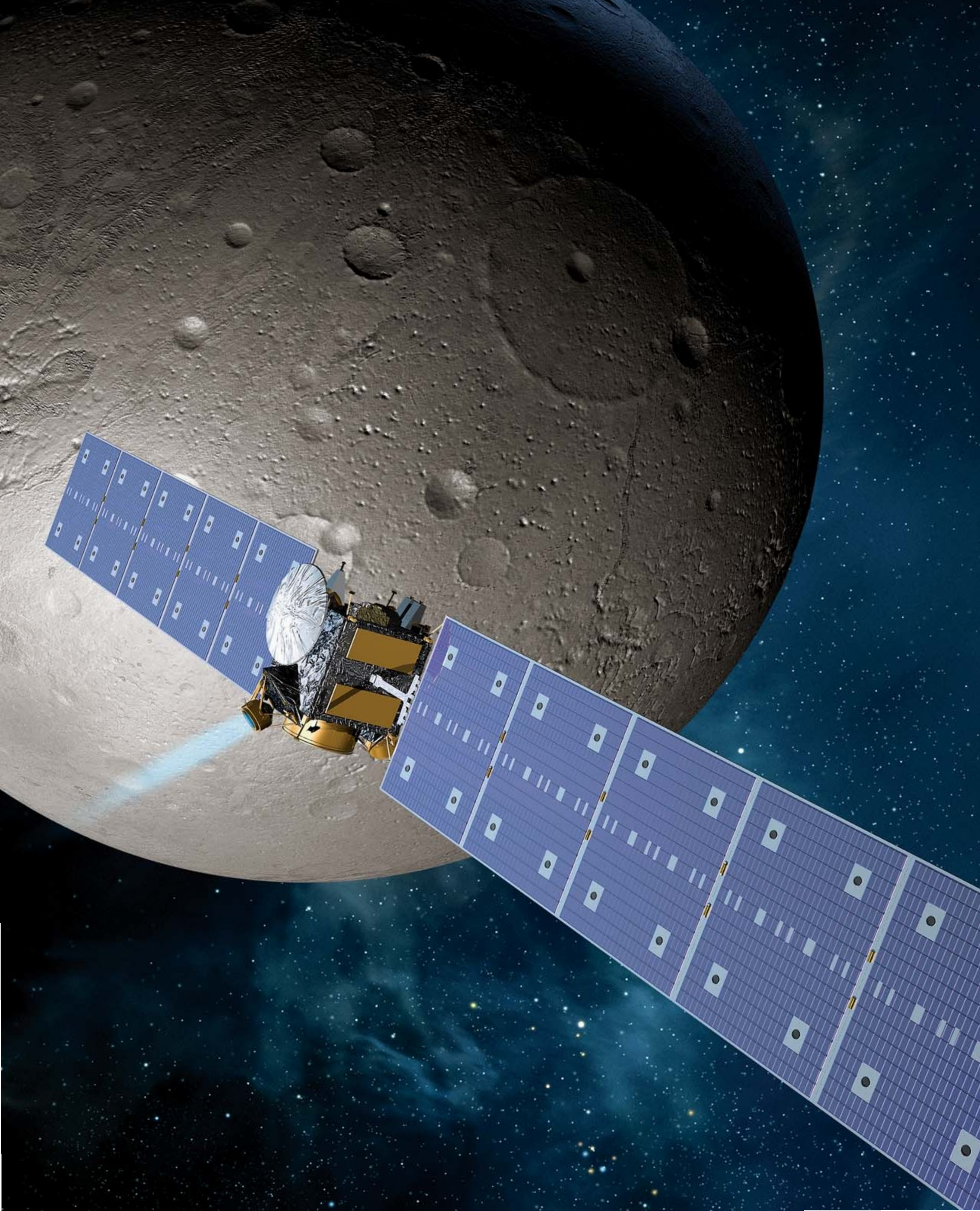
I could be discussing Pluto, but I'm not. Ceres, the first-discovered and largest of the asteroids, is the second target of NASA's Dawn mission. When it arrives at Ceres, Dawn will become the first spacecraft ever to orbit (not just fly by) two worlds beyond Earth.

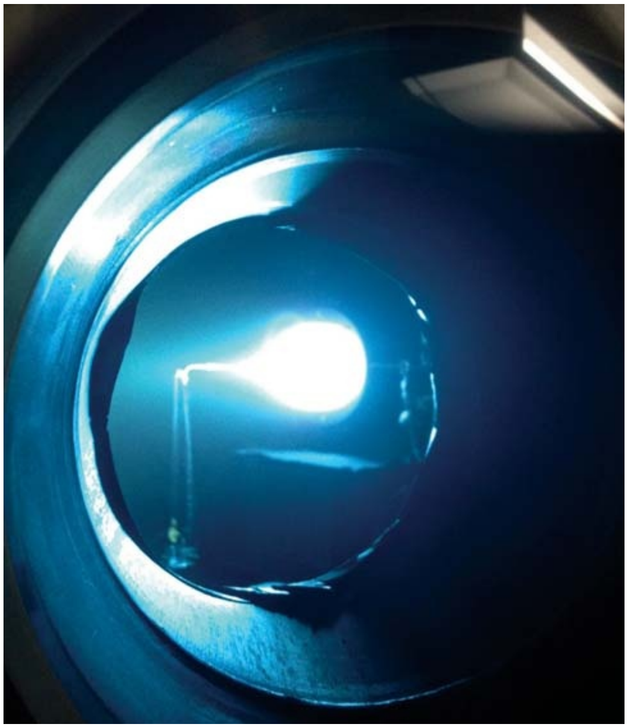
Dawn is a little spacecraft with a huge wingspan. The spacecraft's small cubical body can mostly hide behind its 1.5-meter (5-foot) dish antenna, but its solar panels stretch nearly 20 meters from wingtip to wingtip. Dawn needs huge solar panels for two reasons. One is distance. Out at Ceres' orbit within the main asteroid belt, the Sun shines only 13% as strongly as it does on Earth. Only two solar-powered missions operate at greater distances from the Sun than Dawn does: the European Space Agency's Rosetta, in orbit around Comet 67P/Churyumov-Gerasimenko, and NASA's Juno, on its way to Jupiter.

The Sun gives Dawn electricity for free, electricity that Dawn can use to accelerate xenon ions to enormous speeds, 7 to 10 times faster than the speed of exhaust from traditional chemical engines. At maximum thrust, each of Dawn's three ion engines expels a miniscule 3.25 milligrams of xenon per second. The resulting thrust

DAWN APPROACHES NASA's Dawn spacecraft bears down on Ceres, the largest main-belt asteroid in the solar system, in this artist's illustration.

ILLUSTRATION BY CASEY REED





NASA / JPL-CALTECH

FULL THROTTLE Although Dawn's xenon ion engine (shown here in the lab) produces a small amount of thrust, that thrust built up over time, eventually propelling the spacecraft to a velocity of about 11 kilometers per second.

is only 91 millinewtons, the same force with which a single sheet of paper weighs on your hand. It's now even less (down to less than 30 millinewtons), for as Dawn's solar separation increases, the solar panels produce less electricity and the engines less thrust. But the patient and near-continuous work of the electrically accelerated ions has propelled Dawn into the record books: it has achieved more change in speed under its own power than any previous spacecraft (10.7 kilometers per second, or 23,900 mph, by the time it gets to Ceres).

It's Dawn's ion propulsion system that makes the mission's two-world navigational feat possible. Having opened our eyes to the marvels of Vesta (*S&T*: Nov. 2011, p. 32), the little spacecraft that could is homing in on a world like none we've seen before. Its size, roundness, and water-rich composition make it seem a kin of Pluto, yet it orbits among the scattered lumpy asteroids. Is it a protoplanet? An escaped Kuiper Belt object? What, if anything, can it tell us about how the solar system formed?

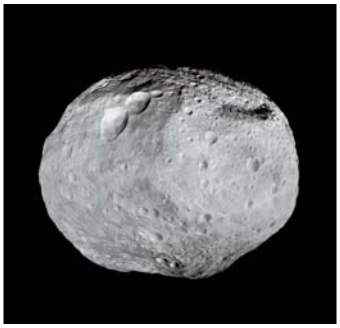
Vesta Success, Flywheel Failure

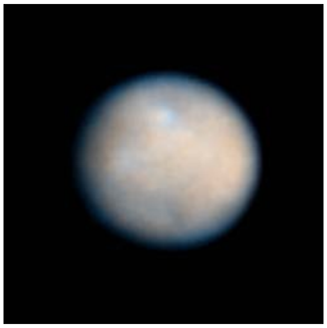
Dawn launched from Earth in September 2007 and received a boost from a Mars flyby in February 2009. It settled into orbit at Vesta on July 16, 2011, and kept the asteroid company for about a third of its year, until September 5, 2012. Then, Dawn departed Vesta — a rare feat. Only one other mission that has ventured beyond the Moon has ever departed from its deep-space orbital destination: the first Hayabusa mission (also ion-powered), which rendezvoused with Itokawa in September 2005 and departed that December to return to Earth.

Dawn transformed Vesta from a smudge of light into a world with complex geology. Its measurements confirmed that the asteroid has separated into a denser, perhaps metal-rich core and a less-dense rocky mantle and crust. This differentiation is a major driver of internal geology, and planets and moons that are differentiated are also usually round and would therefore be classified as dwarf planets. But after it differentiated, Vesta suffered not just one but two enormous impacts, both near the south pole, which left huge scars on Vesta's three-dimensional shape. An enormous mountain sticks out of its south pole, and its equator is girdled with rhythmic troughs, fossil waves from an impact that nearly blew Vesta apart.

One of the most intriguing features Dawn saw at Vesta was so-called "dark material" in splotches and sprays found across much of its surface (but not inside the largest south polar impact basin, Rheasilvia). That dark material contains hydrated minerals and might be carbon-rich. Neither of those types of compounds would have formed where Vesta now orbits, so the dark material probably represents stuff that originally formed much farther away, perhaps beyond Neptune. Any such material that hit Vesta should also have struck Ceres and all the other asteroids.

Given Dawn's advanced propulsion system, it's ironic that the Ceres mission was jeopardized by one of humanity's oldest technologies: the wheel. In June 2010, on





HUBBLE VS. DAWN Even Hubble can only resolve fuzzy images of Ceres and Vesta. Shown from left to right are Vesta as seen by Hubble in 2010, a mosaic of Vesta as seen by Dawn, and Ceres in a visible-UV composite from Hubble's view in 2003 and 2004.

approach to Vesta, Dawn lost one of its four reaction wheels. These devices permit the spacecraft to maintain its orientation in space, to keep its solar panels facing the Sun, its dish antenna pointed at Earth, and its instruments aimed at science targets. Because reaction wheels are spun using electricity generated by the solar panels, pointing with reaction wheels is essentially without cost to the mission — unlike the spacecraft's rockets, which have a limited supply of hydrazine to power them.

After the loss of the first reaction wheel, the mission scrambled to conserve hydrazine and preserve the three remaining reaction wheels by using them sparingly. They completed the Vesta mission with three wheels, but a second one ground to a halt as they prepared to depart Vesta in August 2012. Dawn could travel to Ceres without reaction wheels, but it would be impossible to complete the Ceres mission as planned without them: there was simply not enough hydrazine to accomplish all of the required turns.

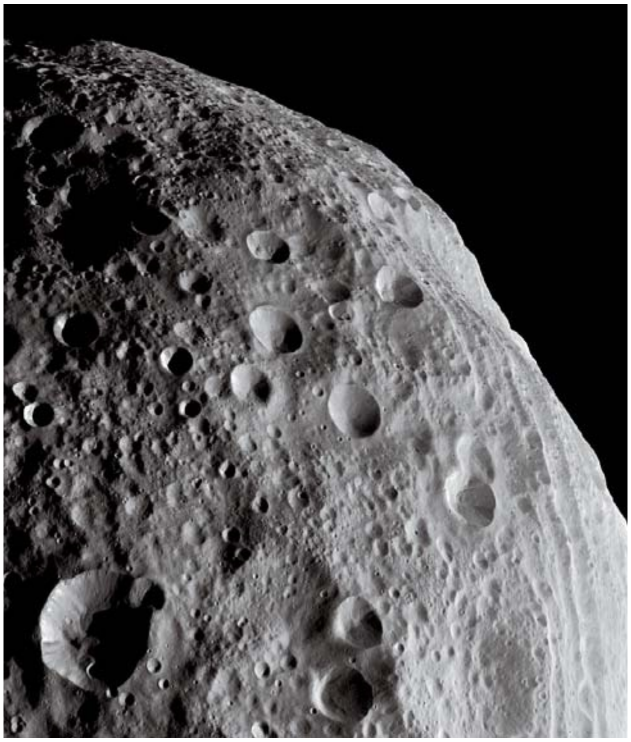
After herculean effort, the mission's earthly planners succeeded in finding a way for Dawn to complete its Ceres to-do list with no reaction wheels at all. They had to make some compromises: Dawn will not turn to talk to Earth as frequently as it did at Vesta, and will image Ceres only 9 times as it approaches, compared to the 23 imaging sessions it performed on approach to Vesta. But the spacecraft will actually gather more science data at Ceres than in the original plan. Simply by being more patient and waiting a little longer to gather observations, mission planners will be able to acquire everything they promised to at Ceres, including full-color global maps and detailed gravity data.

Another Kind of Water World

Ceres is a very different object from Vesta; we know that already, even without visiting it. A key insight into Ceres is its density. Vesta has a bulk density nearly identical to that of silicate rock. Ceres is 80% larger but only two-thirds as dense as Vesta. Yet Ceres is too large for it to have much porosity (unlike smaller asteroids, which can have lots of void space, resulting in low density). There is only one plausible explanation: Ceres contains a substantial amount of water ice.

Given the mass and dimensions of Ceres, and assuming initial proportions of elements like those found in meteorites, geophysicists Tom McCord (now at Bear Fight Institute) and Christophe Sotin (University of Nantes, France) simulated how Ceres would have evolved over time, from a newly condensed mixture of materials to the modern day, 4.6 billion years later. They found that Ceres almost certainly differentiated, its materials separating into a rocky core and watery mantle. Depending on how much of its water is incorporated into the crystal structures of its rocky minerals, its water could compose anywhere from 17 to 27% of its mass. The upper few kilometers of Ceres might always have been too cold for differentiation and so would have remained a mixture of ice and rock. But it's likely that there was a liquid internal ocean for some part of its history, and it's possible that such a liquid layer persists today.

But if this story were true, would there be evidence of it on the surface? Ceres' surface would always have been frozen solid, but as the body's primordial heat escaped, the dwarf planet would have cooled, its ocean slowly freezing solid from the top down. A primitive exterior could hide an evolved interior. On the other hand, any amount

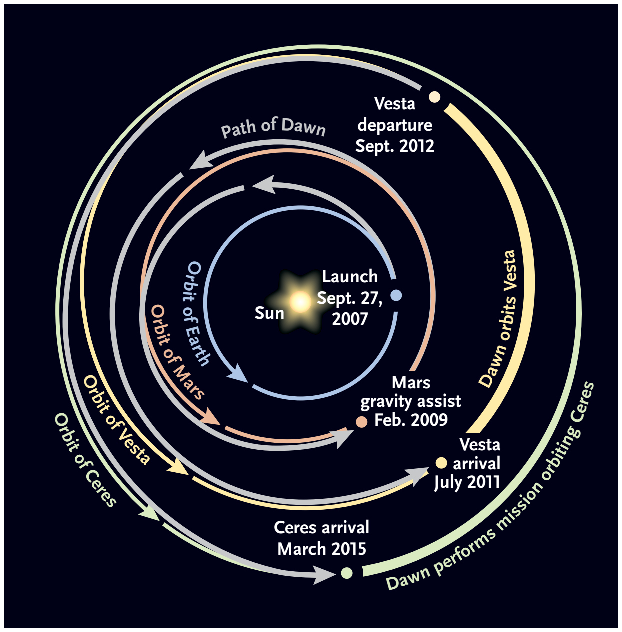


NASA / JPL-CALTECH / UCLA / MPS / DLR / IDA

VESTA'S BELT Deep grooves wrap around the asteroid Vesta's circumference, likely created by the reverberation from the impact that excavated the Rheasilvia basin at the south pole.

Ceres and Vesta Fast Facts

Parameter	Ceres	Vesta
Mean Radius (km)	476	263
Mass (kg)	9.39×10^{20}	2.59×10^{20}
Density (kg/m^3)	2,075	3,455
Rotation Period (Earth hours)	9.075	5.342
Semimajor Axis (a.u.)	2.76	2.362
Eccentricity	0.079	0.0895
Inclination (degrees)	10.6	7.14
Mean Albedo	0.10	0.40



S&T: GREGG DINDERMAN

DAWN'S INTERPLANETARY VOYAGE Using ion-propulsion thrusters and a gravity assist from Mars, Dawn traveled nearly four years to reach Vesta. It's cruised another 2½ years to reach Ceres.

of rock in Ceres' crust would make it significantly denser than an icy mantle below it, which would be an unstable arrangement. Most likely, a primitive crust would founder and sink into the mantle, generating a fresh new surface on the asteroid.

An internal ocean could also drive very active surface geology. Ice is less dense than water, so as Ceres cooled and its subsurface ocean froze, the internal pressure would multiply as this material swelled and tried to take up more space. That internal pressure would have to be relieved somehow. The crust could have cracked in order to allow the mantle to expand, forming planetary stretch marks as a series of parallel fractures, like those we see today on Saturn's moon Dione. If such fractures propagated deep enough to open a conduit to the surface for the pressurized ocean, we could see frozen flows of cryovolcanic material, made of the mineral-rich stuff that once circulated deep within the body. In fact, with its icy composition and differentiated interior, Ceres will likely look much more like the moons of Jupiter or Saturn than it will look like Vesta.

Today, Ceres' surface is too hot for ice to be stable anywhere except, possibly, at the poles. If there ever was ice exposed at the surface, it has sublimed away. Any dust or rocky material that was once buried in the ice would remain on the surface, coating it in a darker, gunky lag deposit made of rocky silicates and organic material. But ice could be very close to the surface. Before it ran out of cryogen in 2013, the European Space Agency's infrared space telescope Herschel made the surprising discovery of water vapor in the space around Ceres — but only at some longitudes, and not at every point in Ceres' orbit. How ice seems to make a patchy, transient water-vapor atmosphere is a new mystery for Dawn to try to solve.

And there's spectroscopic evidence for water's action on Ceres' surface rocks, in the form of minerals never seen on other asteroids: potentially brucite or another hydroxide, and carbonates. The only other places in the solar system where we have observed carbonates are Mars and Earth.

A Pioneer Expedition

Most of the questions driving Dawn's investigation of Ceres are pretty basic, befitting the first reconnaissance of a new world. What covers its surface? How is its interior layered? What is its geologic story? Where and how did it form? Could there ever have been life there?

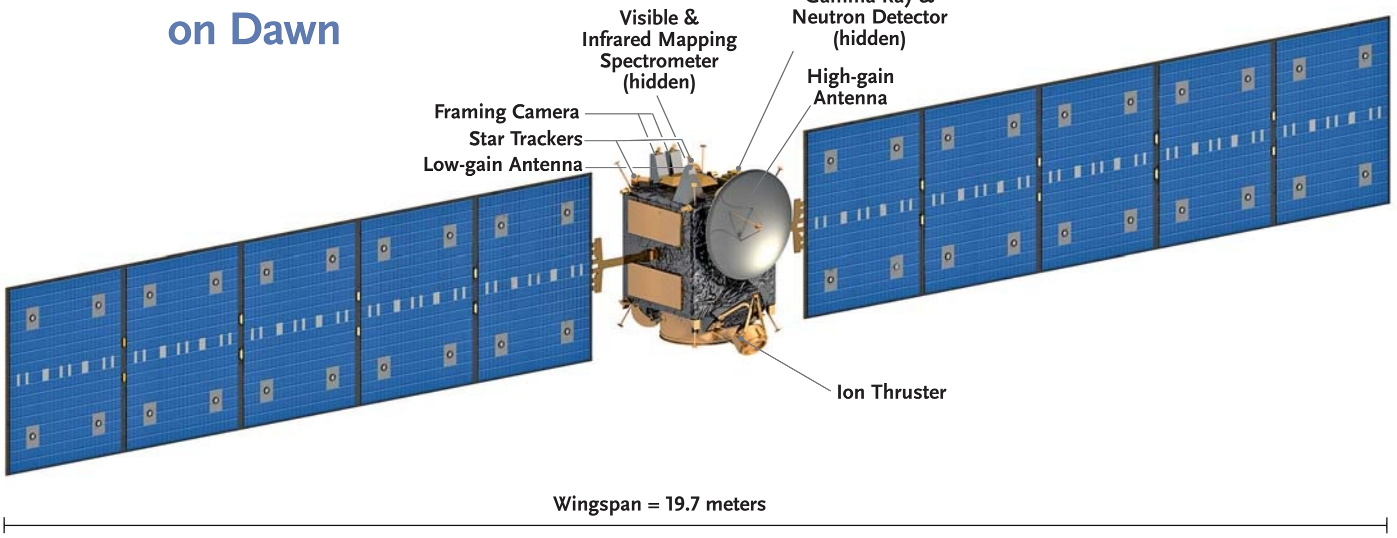
To answer these questions, Dawn will perform a survey of Ceres almost identical to the one it did at Vesta. With its Framing Camera, it will map all of Ceres in full color at medium resolution, and all of it in monochrome at higher resolution. It will gather the data to create a global infrared map with its Visible and Infrared Mapping Spectrometer at low resolution, and some locations at higher resolution. It will also photograph the limb of Ceres against the sky to develop detailed shape models. In a three-month low orbit, Dawn will use its Gamma Ray and Neutron Detector (GRAND) spectrometer to map the distribution of different elements, and radio tracking to measure the gravity field.

Dawn's observations of the shape and gravity of Ceres will significantly narrow the range of possible structures for Ceres' interior, which will, in turn, tell us which of the possible stories for Ceres' geologic history are more probable than others.

One of the most intriguing questions that Dawn could answer is: where did Ceres form? Until recently, scientists assumed that most of the objects in the solar system, particularly the large ones, have been where they are now since their formation. But we now know that giant planets can migrate, and their migrations wreak havoc with the motions of the solar system's smaller denizens.

Ceres has lots of water, so it can't have formed too close to the Sun. Could it have formed farther away than it is now? Its density overlaps with those of trans-Neptunian objects; researcher Bill McKinnon (Washington University in St. Louis) has gone so far as to suggest that Ceres formed in the Kuiper Belt and was transported to the inner solar system by the same dynamical process that populated the Trojan points of the giant planets' orbits with icy bodies. Olivier Mousis (now at University of Franche-Comté, France) and Yann Alibert (University of Bern, Switzerland) proposed an intermediate history: perhaps Ceres' rocky center formed in the asteroid belt, but it accreted an icy envelope later as it caught up smaller Kuiper Belt bodies that drifted into its path. The ques-

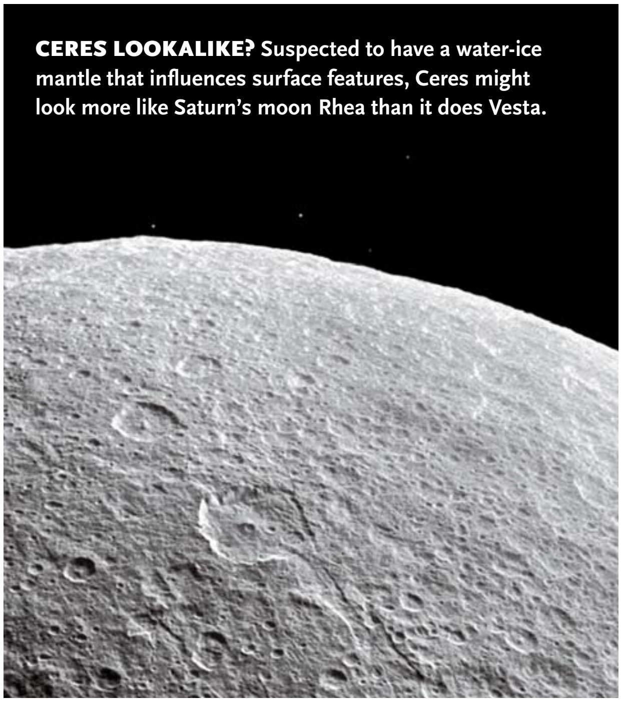
Science Instruments on Dawn



TRAVELING LIGHT Dawn has a comparatively small, but successful, payload. Its monochrome Framing Camera has seven color filters and one panchromatic filter to extract as much detail as possible when mapping asteroid surfaces. The Visible and Infrared Mapping Spectrometer detects wavelengths from 250 to 5000 nanometers, covering a wide range of signatures, and its Gamma Ray and Neutron Detector maps elements' distributions across the asteroids' surfaces. CASEY REED, SOURCE: NASA / JPL-CALTECH / UCLA / MCREL

tion of where Ceres formed could be settled with help from GRAND measurements of the ratio of radioactive potassium to thorium. Potassium is more easily evaporated away than thorium, so the ratio between these two elements can change depending on the temperatures an object has experienced in the past — and, therefore, where an object hails from.

Each of these potential histories could leave its signature in the composition of Ceres' surface and the patterns of its geologic features. For instance, several of the possible stories for Ceres suggest times in its history when it would have needed to change in size. Ice expands as it freezes, and minerals in silicate rocks exposed to liquid water change to other minerals with lower densities than the original ones. If Ceres expanded, we should see *extensional tectonic features* on its surface such as fissures and fractures, possibly even signs of volcanism.

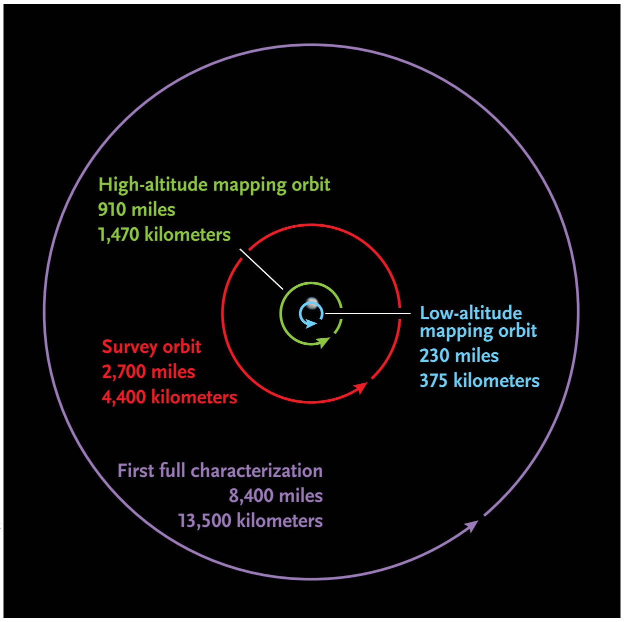


CERES LOOKALIKE? Suspected to have a water-ice mantle that influences surface features, Ceres might look more like Saturn's moon Rhea than it does Vesta.

NASA / JPL-CALTECH / SPACE SCIENCE INSTITUTE

Even if Dawn does not reveal extensional tectonic features, we should be able to detect subsurface ice through the shapes of craters: ice flows over geologic time even if it remains solid, so craters on an ice-rich body should have a relaxed appearance like those on Saturn's moons Tethys or Rhea. If Ceres has features like this, it will be the only place we've ever seen them where the geology wasn't driven by the tidal forces exerted by a neighboring planetary body. Even Pluto and Charon — to be visited by New Horizons in July this year — will have tectonics that are dominated by the forces that the members of that binary world system exert on each other.

But there's also the possibility that Ceres will keep its secrets hidden. Maybe these changes happened so long ago that they've been obscured by dust and space weathering. Some of the features that Dawn spotted on Vesta that were originally thought to be volcanic — including the splotches and wisps of dark material on the asteroid's surface — are now thought to be organic-rich material brought in later by impacts, completely unrelated to Vesta's internal geology. Whatever exogenic processes we see on Vesta, we should also see on Ceres.



SOURCE: NASA / JPL-CALTECH, S&T: GREGG DINDERMAN

SCIENCE ORBITS Dawn will conduct four different orbits around Ceres, spiraling down from the outermost to the innermost over a few months.

What we do know about Ceres is that it is large, it is unmistakably round, and it is brighter in some places than in others. Those three facts make it very likely that Ceres has an exciting story to tell.

Looping an Asteroid

Dawn's science plans for Ceres are very similar to the survey it performed at Vesta, with a few tweaks. Dawn began its approach observations of Ceres in January 2015. The very first images Dawn acquires during approach will be similar in quality to Hubble's of this little world, and they will only get better from there.

As Dawn approaches, it will take nine sets of photos of Ceres while also searching nearby space for possible moons. These will include perform two "rotation characterizations," where it will watch Ceres through one complete 9-hour day, imaging the entire globe with both camera and spectrometer in visible and infrared bands.

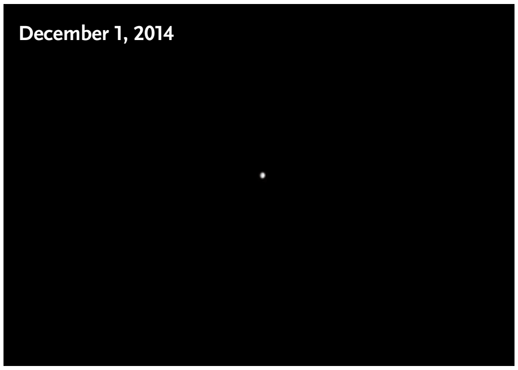
Dawn will arrive in its first science orbit in late April, a polar one at an altitude of 13,500 kilometers (8,400 miles), with a leisurely orbital period of 15 days. That's far enough away for Ceres to still fit comfortably within the Framing Camera's field of view, around 700 pixels across. Dawn will watch Ceres rotate through three complete Cerean days, thoroughly characterizing its three-dimensional shape. Once its orbit takes it to Ceres' nightside, it will repeat the observation, capturing what will be an exciting set of images of Ceres in a crescent phase.

It will take a month for the gentle pressure of Dawn's ion engines to shift it down to its survey orbit altitude of 4,400 km, where the spacecraft will spend three weeks acquiring global maps with camera and spectrometer. Another six weeks of orbit adjustment will take it to its high-altitude mapping orbit, circling Ceres once every 19 hours at an altitude of 1,470 km. A 12-orbit cycle will carry Dawn over every inch of Ceres' surface. From this high-altitude orbit, Dawn will cover Ceres six times — once looking straight down, and the rest at a variety of angles in order to measure what may be subtle topographic rises and falls.

Finally, Dawn will perform its last orbital shift, descending to a low-altitude mapping orbit only 375 kilometers above the surface, about the same as the International Space Station's orbit above Earth. Here, its GRAND spectrometer will be able to most strongly sense the sparse neutrons emanating from Ceres' surface; over time, their energies and locations will tell the Dawn team about the distribution of chemical elements.

While GRAND is mapping the surface, Dawn will also stay in nearly continuous contact with NASA's Deep Space Network. From tiny shifts in Dawn's orbital speed as it circles Ceres, the mission team will be able to map Ceres' gravity field, looking for clues to its internal structure. Dawn will also acquire image data — the highest resolution of the mission — during the lowest orbit, but the focus of this phase is composition and gravity mapping.

In low-altitude mapping orbit, Dawn will prolong its hydrazine supply by switching to a "hybrid mode" of pointing, where it will use its two remaining functional



DECEMBER: NASA / JPL-CALTECH / UCLA / MPS / DLR / IDA; JANUARY: NASA / JPL-CALTECH / UCLA / MPS / DLR / IDA / PSI

LAND HO! Ceres was a dot to Dawn's Framing Camera at a distance of three Earth-Moon separations (*far left*). When the distance closed to match the Moon-Earth system, Dawn saw mottling and a bright spot.

NASA / JPL-CALTECH

ONLY SO SERIOUS Dawn chief engineer and mission director Marc Rayman (JPL) smiles at the camera on the mission's launch day in 2007.

reaction wheels in combination with hydrazine thrusters to point itself. Hybrid mode will also extend Dawn's life as long as possible. But if, at any point, one of its remaining two reaction wheels fails, it will complete its mapping mission on hydrazine thrusters only.

Regardless of whether the reaction wheels survive until mission's end, Dawn should be left with just a few kilograms of hydrazine propellant when its work in the low-altitude mapping orbit is complete. The orbit is a stable one and the spacecraft will never crash into Ceres. It is possible that NASA will extend Dawn's mission: more time for GRAND in low-altitude orbit will improve its maps, and will fill in gaps in high-resolution imaging.

Had the reaction wheels not failed, Dawn could have finished the Ceres mission with sufficient xenon to depart and travel to a third asteroid destination (although who knows whether it would have). Sadly, that is now out of the question. But there should be no regret. Dawn will remain the first spacecraft ever to rendezvous with, orbit, and completely map two alien worlds. And if all goes according to plan, its results will surely be spectacular. ✦

Keep up to speed on the mission with mission director Marc Rayman's Dawn Journal: http://dawnblog.jpl.nasa.gov.

S&T *Contributing Editor* ***Emily Lakdawalla*** *is senior editor and planetary evangelist for The Planetary Society. She writes about space science and exploration at* **www.planetary.org**. *She thanks Marc Rayman, Carol Raymond, and Andy Rivkin for their assistance with this article.*

WorldWide

Take a virtual and interactive tour of the universe.

What famous observatory has no lens and no mirror? In centuries past, such primitive institutions could be found worldwide, until the 17th century invention of the telescope revolutionized the meaning of the word "observatory."

Now the modern age has its own version of an observatory sans telescope: the internet. The wealth of online astronomical data grows every day, drawing from spacecraft as well as ground-based observatories around the globe. And there's a portal through which anyone can access these data: the WorldWide Telescope (WWT).

Alyssa Goodman & Curtis Wong

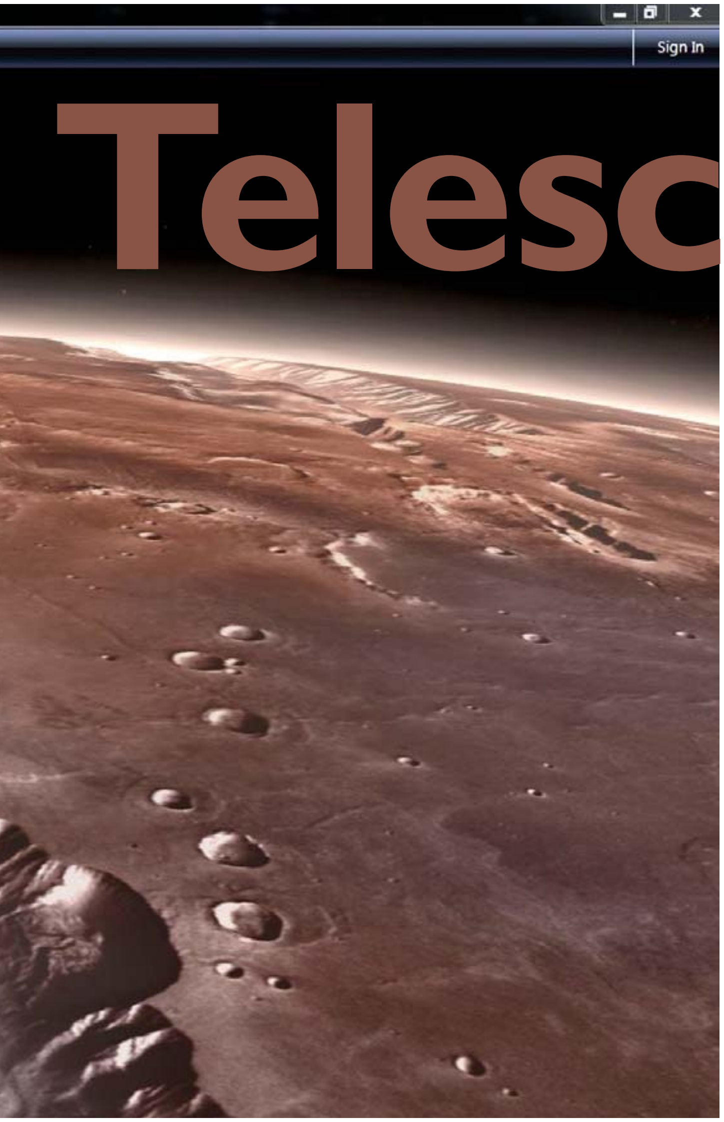
This software runs on web browsers, on Windows as a desktop application, or on other platforms altogether — including planetariums across the country. WWT accesses the amazing online treasure-trove to provide beautiful all-sky imagery at dozens of wavelengths, as well as close-ups of popular celestial targets. Users can find additional information on individual objects by following links to diverse databases, ranging from Wikipedia to NASA's Astrophysics Data System (the repository for most astronomical literature published since the 1800s).

Basically, WWT functions as an interactive web browser for the sky. And best of all, it's free.

A Virtual Observatory Is Born

One of astronomers' first uses of the internet was as a remote-observing tool, enabling them to access telescopes

Telescope



EXPLORE THE COSMOS Fly through Valles Marineris in the 3D Mars environment (*left*) before zooming out to explore stars in the solar neighborhood listed in the Hipparcos catalog (*top right*). Keep scrolling, and soon you'll soar outside the Milky Way, passing through some of the nearly 1 million galaxies drawn from the Sloan Digital Sky Survey (*bottom right*). All screenshots are from WWT.

on distant mountaintops and space satellites. Over the decades, data exchange over the web became commonplace, and as detector technologies continued to improve and telescopes became more powerful, the astronomy community realized the potential for creating a set of interconnected data and research tools. The ultimate goal: create the best "observatory" the world has ever seen.

In 2001 the National Science Foundation funded the creation of a framework that would evolve into today's U.S. Virtual Astronomical Observatory. Related virtual observatory efforts have appeared in countries around the world. The effort's backbone is the International Virtual Observatory Alliance (IVOA), an organization that creates standards for all astronomical data. Though largely invisible to practicing astronomers, the group's work is critical to making data universally accessible. For example, most astronomical images come in a Flexible Image Transport System (FITS) format; IVOA standards put in place a decade ago help astronomers using different types of software search for, view, and exchange these images.

Today, in spite of funding woes in the U.S. and worldwide, the Virtual Observatory has created a set of free astronomical resources that are arguably more coordinated and accessible than in any other field of science. But granting the public access to those resources requires a different kind of effort. Enter the WorldWide Telescope.

Building the WorldWide Telescope

Growing up in Los Angeles, amateur astronomer and coauthor Curtis Wong tried to explore the amazing sky

DENNIS DI CICCO

WWT@HARVARD From left to right, Patricia Udomprasert, director of the WWT Ambassador program, coauthor Alyssa Goodman, astronomer Owen Gingerich, and coauthor Curtis Wong take a moment to explore the universe at a large-screen kiosk in the lobby of the Harvard Science Center.

presented in magazines like *Sky & Telescope*. But between city lights and smog, he could only see the Moon, a few planets, and some nebulae with his 60-mm refractor. But what he really wanted was a gigantic telescope, a dark sky, and maybe even an expert by his side to explain the view.

Years later Wong found himself working at Microsoft Research with big data computer scientist Jim Gray and astronomer Alex Szalay (Johns Hopkins University). Gray and Szalay were producing software to archive, organize, and visualize Sloan Digital Sky Survey (SDSS) data. When the pair wrote a seminal paper envisioning "The World-Wide Telescope, an Archetype for Online Science," Wong realized that all the elements were in place to realize his childhood dream.

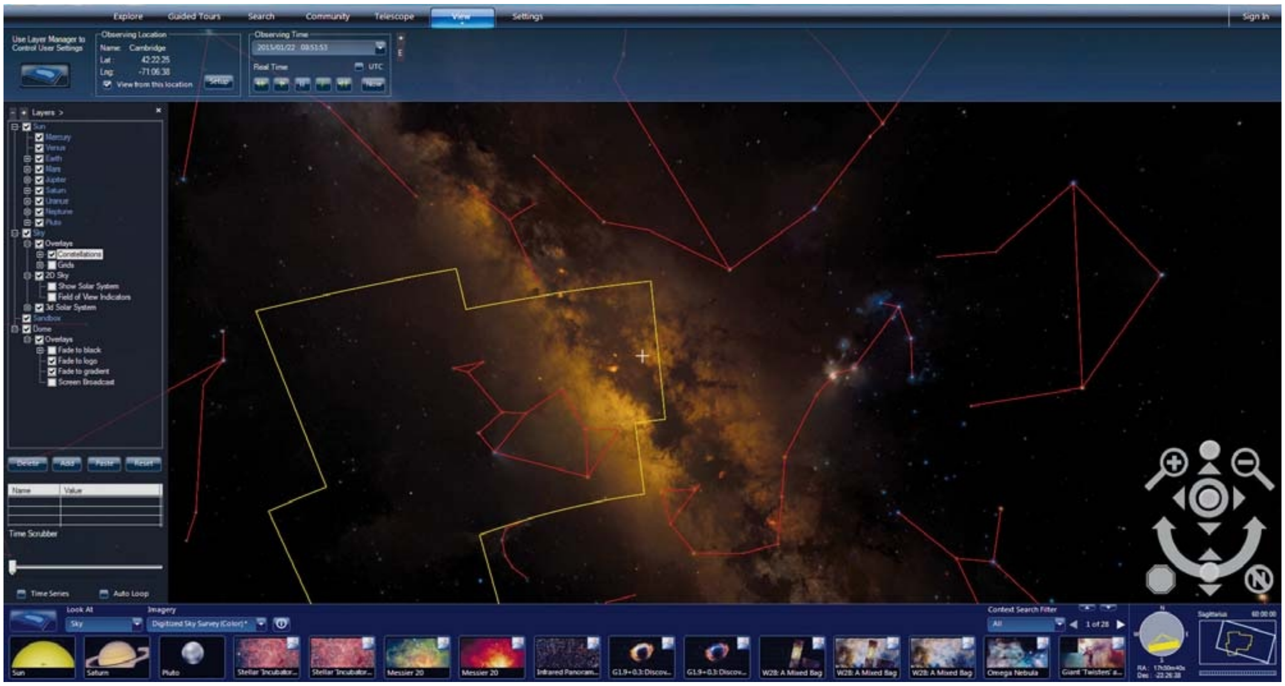
Wong presented his ideas at a 2005 astronomy visualization conference, where he befriended professional astronomer and coauthor Alyssa Goodman. When he finally got the go-ahead to make his project a reality in 2006, Goodman and other astronomers advised him on its content and usability. During the next two years Wong collaborated with software architect Jonathan Fay, an amateur astronomer himself, to build the software; Wong designed the experience and Fay developed the code.

After Gray was lost at sea during a 2007 sailing trip, Wong and Fay retitled the project WorldWide Telescope to honor the computer scientist's vision for online astronomy. Launched at a 2008 TED conference, the software was featured in *Sky & Telescope* that same year (Sept. 2008, p. 44). Former *S&T* editor Stuart Goldman explained in an accompanying blog post the best way to explore WWT: "Watch the introductory tours to learn your way around the program — and then left- and right-click on everything!" That's still good advice, even more so now than in 2008.

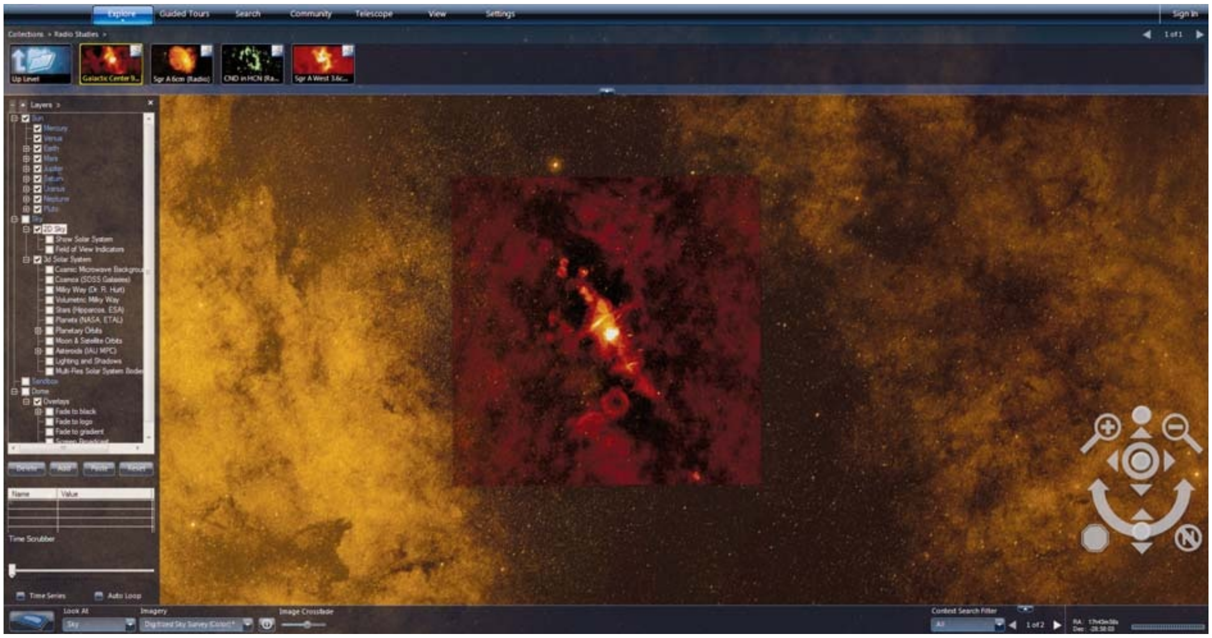
Tour the Universe

Today's amateur astronomers are blessed with a wide variety of tools to display the night sky. WWT offers the same functions as other planetarium software, but with unique quality and breadth. The images in the program's database capture the sky in more than 85 different wavelengths — most of these far beyond the spectral window of the human eye.

WWT opens with the night sky as seen from your location. The 1-trillion-pixel view seamlessly stitches together



NIGHT SKY WWT opens to show the celestial view from a given time and location, seamlessly stitched together from thousands of Digitized Sky Survey images. Constellation patterns are overlaid by default.



IN DIFFERENT LIGHT WWT enables users to explore images in multiple wavelengths. This view shows our galaxy's center imaged in 90-cm radio waves overlaid on a visible-light view from the Digitized Sky Survey.

thousands of images from the Digitized Sky Survey, an all-sky photographic atlas. Users can zoom in from a 60-degree field of view to a high-resolution close-up of the wisps in the Veil Nebula. Users can also look at the same image in two wavelengths, comparing, for example, the Horsehead Nebula in visible-light and infrared images.

Start playing with the controls of the WWT desktop application and a range of options opens up. Simulate eclipses as viewed from Earth or space, or fly to the Moon to view the Lunar Reconnaissance Orbiter's high-resolution images and elevation maps. Travel to Mars and fly through Valles Marineris, or see the distribution of more than 500,000 asteroids tracked by the Minor Planet Center.

Then zoom out from the solar system and fly through the roughly 118,000 neighborhood stars drawn from the Hipparcos catalog. Keep zooming out and you'll pass through nearly 1 million SDSS galaxies and glimpse the universe's large-scale structure. Right-clicking on any star, planet, or galaxy will reveal deeper information on that object from multiple online sources.

But WWT isn't meant just for solo use. Users of the Windows desktop application can also create and share guided sky tours, saving their path through the program as if a virtual camera were recording the experience. These tours look like videos and can include musical scores, narration, additional imagery, and hyperlinks. But unlike with videos, users can interact with the tour as they experience it, exploring a particular topic in detail before picking up right where they left off.

Astronomers and educators have already created dozens of sky tours spanning topics from the very general, such as *Astronomy for Everyone*, to educational tributes highlighting the work of important astronomers, including *John Huchra's Universe* and *Galileo's New Order*.

The latter tour debuted on the 400th anniversary of Galileo's observations of Jupiter and uses the desktop application's 3D solar system environment to recreate the astronomer's revolutionary observations. The tour juxtaposes the movement of Jupiter's moons, which move back and forth in almost a straight line over time, against Galileo's drawings from *Sidereus nuncius*. To illustrate Galileo's realization that these observations confirmed the Copernican model of a heliocentric solar system, the sky tour shows the moons as viewed in the plane of the sky, as well as in three dimensions using modern images from NASA orbiters.

Full functionality, especially of WWT's 3D environments, requires the Windows desktop application, but the browser-based version performs most of the program's basic functions. Some of the interactive tours that rely on the 3D environments are also only accessible to users of the desktop application, though they are available in video form on the WWT Ambassadors website and on YouTube.

Multiplatform, Multidevice, Multiscreen

While WWT was initially created as a Windows desktop application, Microsoft Research soon made the software available in a limited, browser-based version accessible from nearly any operating system and device. And as technologies continue to develop, WWT has become available on more than just computer screens.

Find WWT on the big screen at planetariums such as the Adler Planetarium in Chicago and the California Academy of Sciences in San Francisco. Or bring WWT to your backyard, using the software to slew your telescope to celestial targets as you view multiwavelength data on your screen. If you would rather stay inside, plug in an Xbox controller and immerse yourself in "on-world" experi-

INTERACTIVE LEARNING The WorldWide Telescope Ambassador program brings the astronomy software and associated curricula to a sixth-grade classroom.

WWT AMBASSADORS

ences such as a rover's view of the Martian surface. With red/blue glasses handy, you can even get the view in 3D.

Perhaps the ultimate experience is to view WWT through Oculus Rift, a headset that plunges you into a virtual reality. (The consumer version of the headset might become available in 2015; so far, only preliminary versions have been released.) WWT offers a virtual tour of the International Space Station (ISS), where you can hover just outside while the Earth rotates below. ISS Commander Chris Hadfield took it for a spin at a 2014 TED conference. His only criticism? The ISS would not have that many Soyuz capsules docked at one time.

Rallying the Troops

Multiple studies have shown that students learn more from interactive tools than from traditional learning materials, and kids and adults alike love using WWT — "Cooler than *Call of Duty*," proclaimed one sixth-grade student. So the software makes an ideal platform for astronomy education and public outreach.

To that end, the WWT Ambassadors (WWTA) Program trains active researchers ranging from advanced undergraduates to tenured faculty, as well as retired astronomers. About 100 PhD-level Ambassadors have brought WWT into a wide variety of educational environments over the past few years: creating sky tours, presenting at science fairs and conventions, and aiding in-classroom research. Since kids learn to operate the WorldWide Telescope astonishingly quickly, Ambassadors' primary role is to bring deeper physics, math, chemistry, and engineering knowledge to bear on students' questions. Ambassadors may answer questions online or in classrooms where teachers are using WWTA curricula.

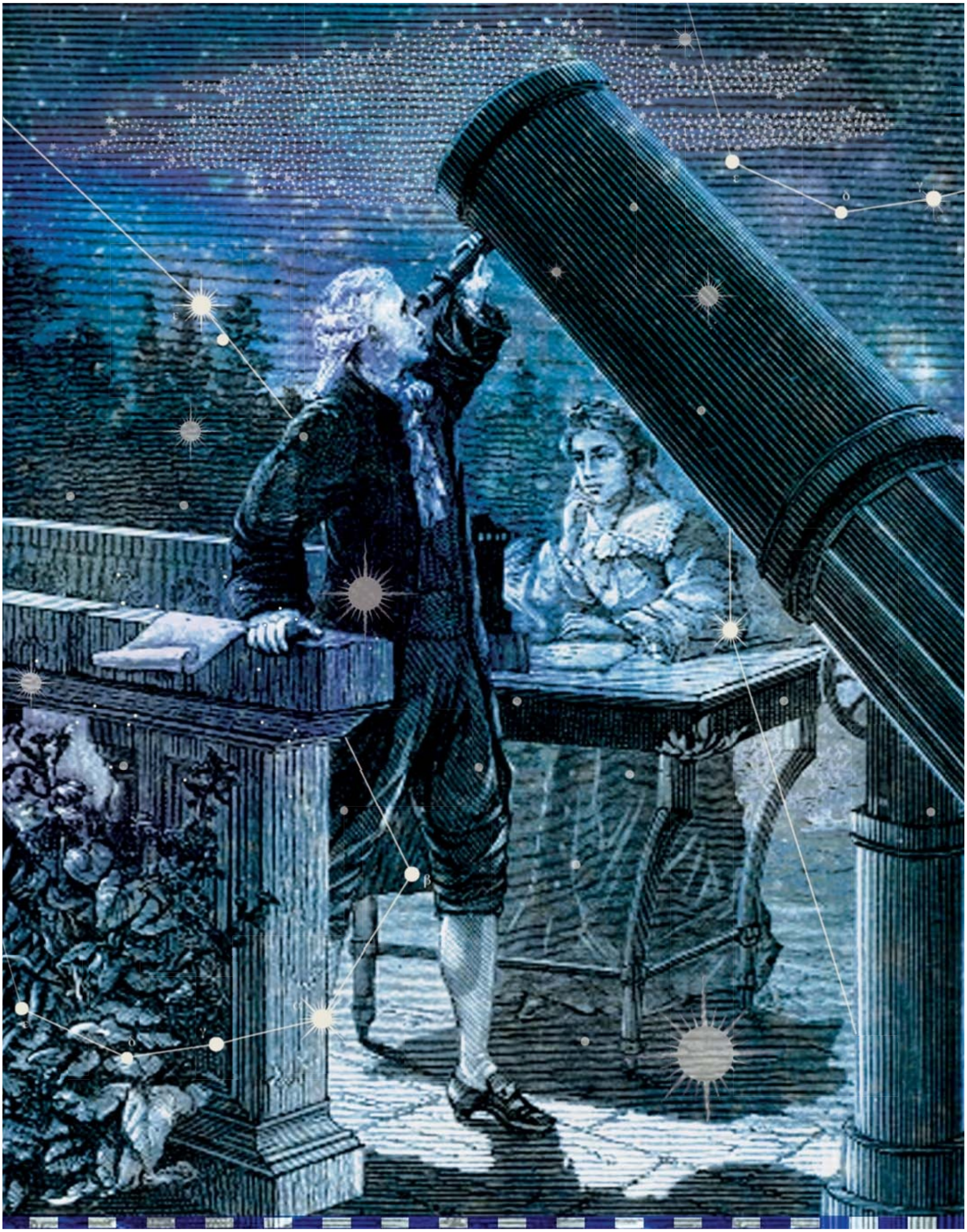
For instructions on how to use WWT and to access WWT sky tours, go to is.gd/worldwidetelescope.

WWT has recruited Ambassadors throughout the U.S. and in countries such as Poland, China, and India. If you are interested in bringing WWTA to your area or becoming an Ambassador yourself, we encourage you to contact us via the WWTA website (**wwtambassadors.org**).

The Ambassador program isn't the only direction WWT is growing. In 2015 WWT's code will become open source. The software is already free to download, but making the code open source means it will also become available to the general public to modify. Those working at universities, high schools, museums, or planetariums can go far beyond creating sky tours, changing the code itself to expand and enhance its capabilities, or even incorporating it into their own programs.

WWT's goal has always been to augment professional research while also engaging the general public. Now individuals and institutions with similar goals can leverage WWT to make their mutual ambitions a reality. ✦

__Alyssa Goodman__, a Harvard University astronomy professor and Smithsonian Institution research associate, and __Curtis Wong__, Principal Researcher at Microsoft Research, have collaborated on the WorldWide Telescope and other astronomy visualization and education projects for the past 10 years.



S&T PHOTO ILLUSTRATION: PATRICIA GILLIS-COPPOLA. HERSCHEL IMAGE: WIKIMEDIA

William Herschel's Extraordinary Night of Discovery

Mark Bratton

Recreating the legendary sweep of April 11, 1785

There's little doubt that William Herschel was the most significant astronomer of the 18th century. His accomplishments included the discovery of Uranus, infrared radiation, and four planetary satellites, as well as the compilation of two extensive catalogues of double and multiple stars. His most lasting achievement, however, was his exhaustive search for undiscovered star clusters and nebulae, a key component in his quest to understand what he called "the construction of the heavens." In Herschel's time, astronomers were concerned principally with the study of solar system objects. The search for clusters and nebulae was, up to that point, a haphazard affair, with a total of only 138 recorded by all the observers in history. Even the celebrated Charles Messier, responsible for the discovery of 40, regarded nebulae as nuisance objects to be avoided during the search for comets.

By contrast, William Herschel systematically searched for nebulae, using the most powerful telescope in existence up to that time, an 18.7-inch speculum reflector. Between 1783 and 1802, he surveyed the sky on 401 nights, conducting 1,112 sweeps and cataloguing 2,500 separate objects, almost all of them original discoveries. He surveyed almost the entire sky north of –33° declination, and published three catalogues of objects in 1785, 1789, and 1802. These catalogues were the forerunners of J. L. E. Dreyer's *New General Catalogue of Nebulae and Clusters of Stars*, printed in 1888.

Herschel's interest in nebulae was piqued by two developments. One was his systematic examination of the clusters and nebulae catalogued by the French comet hunter, Charles Messier, in 1782 and 1783. Herschel's 6.2-inch ("7-foot") and 12-inch ("Small 20-Foot") reflectors were superior to any of Messier's telescopes, and he was delighted to discover that many of the objects that Messier considered "nebula without stars" were resolved clearly with his instruments. As we will see, he did make occasional errors in interpretation, despite the superior optics; for instance, he thought that the planetary nebula M57 was a ring of stars.

The other factor contributing to Herschel's interest was the success of his sister, Caroline, in her study of the sky. He had built her a small telescope, encouraging her to search for double stars and comets. She located Messier objects and more, occasionally finding star clusters and nebulae that had escaped the French astronomer's eye. Over the course of a year of observing, she discovered about a dozen star clusters and galaxies, occasionally noting in her logbook: "Messier has it not!" William realized that if Caroline could find new objects with her small telescope, a larger instrument, deliberately designed to search the skies, would reveal many more. In 1783, he embarked upon the construction of his 18.7-inch aperture, 20-foot telescope, the most effective instrument of its era.

William Herschel, 1738-1822

Caroline Herschel, 1750-1848

S&T ARCHIVES (2)

William's telescope, the so-called Large 20-Foot, was ready in the fall of 1783, but because he was working alone and the instrument was somewhat difficult to use, initial results were disappointing. In mid-December 1783, he modified his search method. First, he set up the telescope as a transit instrument, aiming it at the meridian. He hired an assistant to slowly raise and lower the telescope by 2–3° of declination while the sky's diurnal motion brought new stars into the field of view. He used an eyepiece with a magnification of 157× and a 15′ 4″ field of view. When necessary, he used a higher magnification to confirm his sightings. Typically, he studied the sky for an hour or more at a time, pausing only when clouds intervened or he needed to reset the telescope for some other reason. Each one of these sessions was called a "sweep"; a typical night involved three or four sweeps.

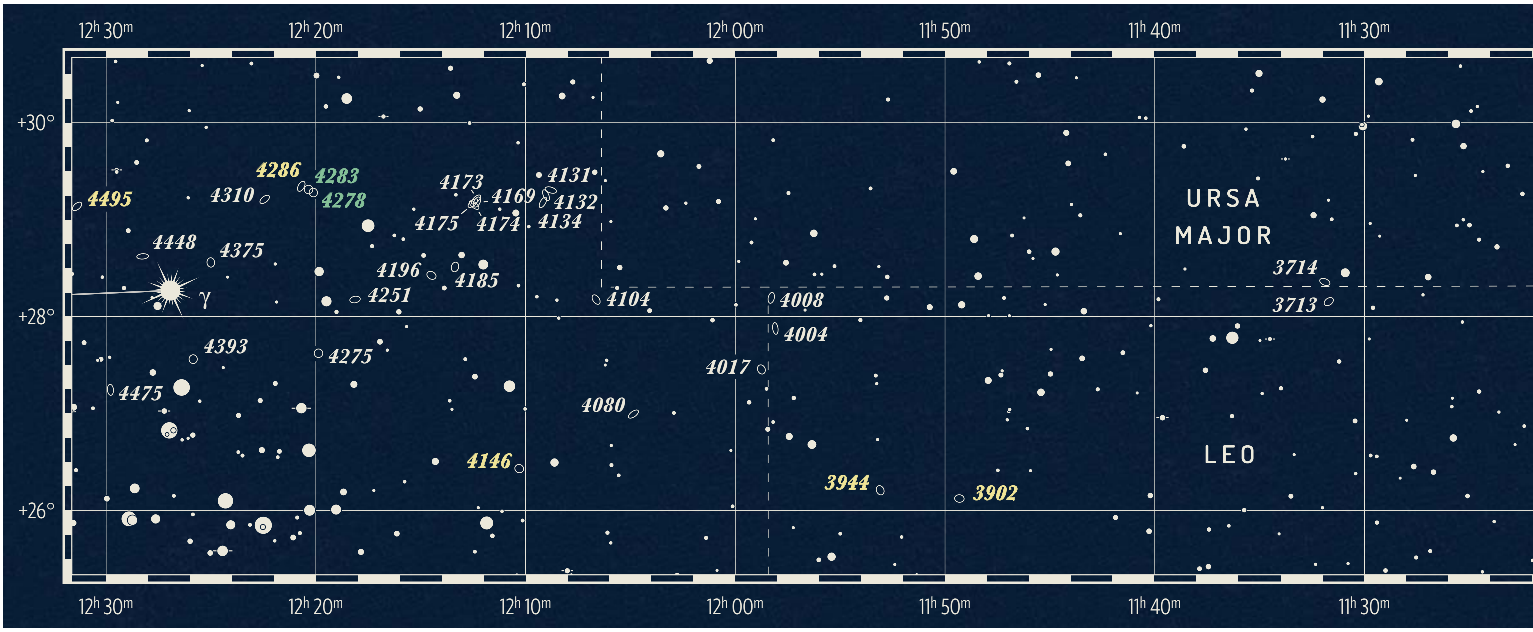
William's second modification to his method was his employment of Caroline, who recorded in a register the positions and other details of the discoveries he made at the eyepiece. She used John Flamsteed's catalogue (volume 3 of the *Historia Coelestis Britannica*) to identify reference stars. This allowed William to spend all his time at the telescope. These changes in strategy bore immediate results. The small team soon found that the sky was teeming with undiscovered star clusters and nebulae, waiting to be revealed.

Fully half of Herschel's discoveries were made in 1784 and 1785. He ardently searched on every clear night and even when conditions were far from ideal. He often discovered a dozen objects in a single night; on some nights, he noted many more. By spring of 1785, he and Caroline were closing in on 1,000 new objects. But on April 11, 1785, they enjoyed a night of discovery never approached nor equaled in the annals of visual astronomy.

The sweep that night began near the modern-day border between Leo and Leo Minor, at approximately $10^h\ 00^m$ RA, with the north-south sweep covering about 2½ degrees, centered at about +28° declination (epoch 2000.0). The first object encountered was not only the faintest of the night, but one of the faintest in Herschel's entire catalogue. **NGC 3196** is a high surface brightness, lenticular galaxy, so very small and remote that William described it as "extremely faint, a little extended, a little doubtful." Care and patience are needed to pick up this 14th-magnitude fuzzy; it's situated immediately west of a quite dim field star, which may help in locating it. The galaxy's high radial velocity implies a distance of about 675 million light-years.

Herschel next encountered a loose quartet of galaxies: **NGC 3245**, **NGC 3265**, and **NGC 3277** in Leo Minor, and **NGC 3274** in Leo. The first three galaxies are part of a group associated with NGC 3254 immediately to the north, discovered by Herschel a month earlier. A glowing oval of light oriented north-south, NGC 3245 is the brightest of the three objects. NGC 3274, a fuzzy elongation to the south of NGC 3245, is likely a small spiral galaxy with an irregular outer structure.

Close to twenty minutes passed before Herschel came upon another loose clump of galaxies. **NGC 3380**, **NGC 3400**, **NGC 3414**, **NGC 3418**, and **NGC 3451** all have similar radial velocities and likely form a gravitationally bound system about 60 million light-years away from us. Visually, NGC 3414 is the brightest and most interesting of the group, displaying a bright core with faint, bar-like extensions embedded in a hazy outer envelope. The extensions flare slightly as the distance from the core increases, and it's possible that this is a polar ring galaxy. Its peculiar extensions caught the attention of Halton



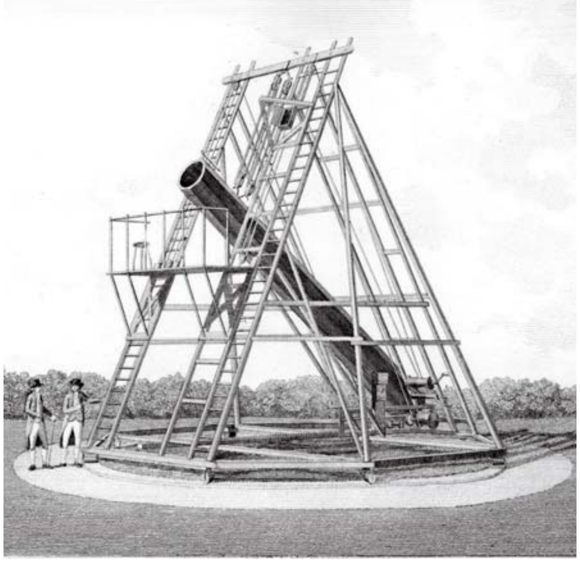
ALL CHARTS S&T: GREGG DINDERMAN

Arp; he catalogued the galaxy as Arp 162 in his *Atlas of Peculiar Galaxies* (1966).

Herschel encountered the last of the Leo Minor galaxies just a few minutes later. **NGC 3486** and **NGC 3510** probably form a wide physical pair, but morphologically they are quite different from each other. NGC 3486 is a large, graceful, multi-arm spiral that appears quite ethereal visually; the bright core is surrounded by a grainy outer shell with ill-defined edges. NGC 3510 is a wispy, low surface brightness object that Herschel described as "faint, much extended, 1.5′ long but very narrow." Almost 1° south of this object is the close pair **NGC 3504** and **NGC 3512**. Both galaxies are bright (11th and 12th magnitude, respectively), and large-aperture telescopes will show the bar and inner structure of NGC 3504 well. Two low surface brightness arms emerge from the bar to form a pseudo ring around it.

A harbinger of things to come next occurred as Herschel encountered three faint members of a distant galaxy cluster. **NGC 3527**, **NGC 3550**, and **NGC 3552** are among the brightest members of the Abell 1185 galaxy cluster in Ursa Major, some 400 million light-years away from Earth. Herschel classified all three as very faint. NGC 3527 is a face-on barred spiral, while NGC 3550 and NGC 3552 are both ellipticals. Two condensations, very likely companion galaxies, appear in the outer halo of NGC 3550, one to the northeast, the other to the southwest. In a medium-aperture telescope, these objects appear as faint, unresolved extensions, but observers may be able to resolve the companions in large-aperture instruments.

Another gap of 20 minutes followed before Herschel came upon another wide physical pair. **NGC 3713** (in Leo) and **NGC 3714** (in Ursa Major) are both faint, though condensed, objects lying about 300 million light-years away



THE LARGE 20-FOOT TELESCOPE. The configuration of Herschel's reflector changed with time; this engraving, published by the astronomer in 1794, shows the system of pulleys manipulated by an assistant to adjust the declination.

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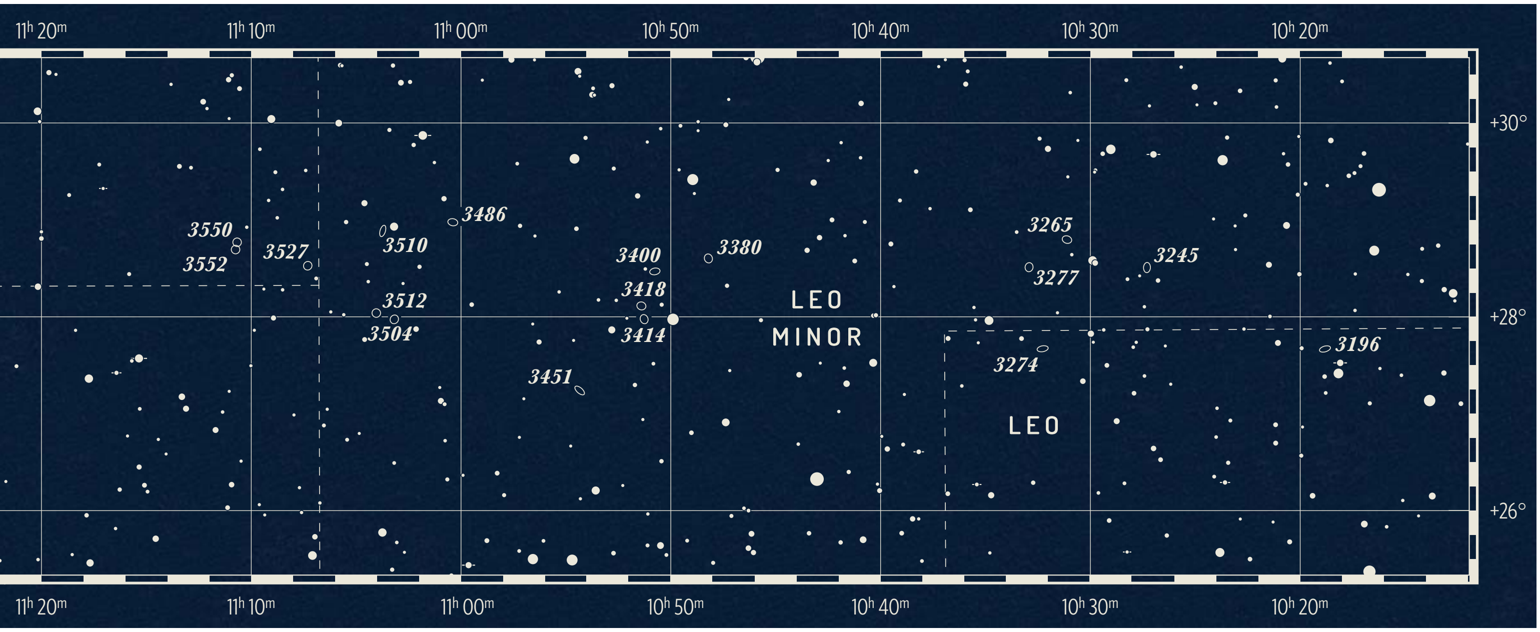
from us. William had difficulty resolving NGC 3714 and described it to Caroline as "extremely faint. 240 (magnification) left it doubtful."

Up to this point the Herschels had had a productive night, recording 19 new nebulae at a steady pace. Things were now about to get quite busy, though, as William was about to discover 25 objects in less than 40 minutes.

The first three discoveries were **NGC 4004**, **NGC 4008**, and **NGC 4017**, all part of a large, loose group of galaxies. NGC 4004, shining at magnitude 13.6, is a

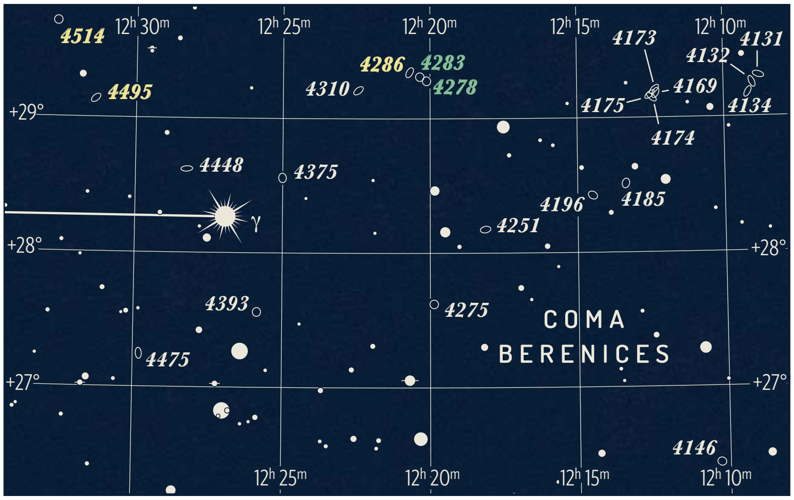


peculiar spiral with mottled and distorted arms. Large-aperture telescopes may reveal some of this structure. A fainter, elliptical companion, IC 2982, lies immediately west of NGC 4004, though it was not detected by Herschel. NGC 4008 is a brighter, though uninspiring lenticular object. NGC 4017, paired with NGC 4016, presents as an intriguing barred spiral that may be interacting with an irregular companion. Herschel may have seen some structure in NGC 4017, calling it: "Faint, pretty large, extended, brighter towards the following side." Together, these two galaxies are also known as Arp 305.

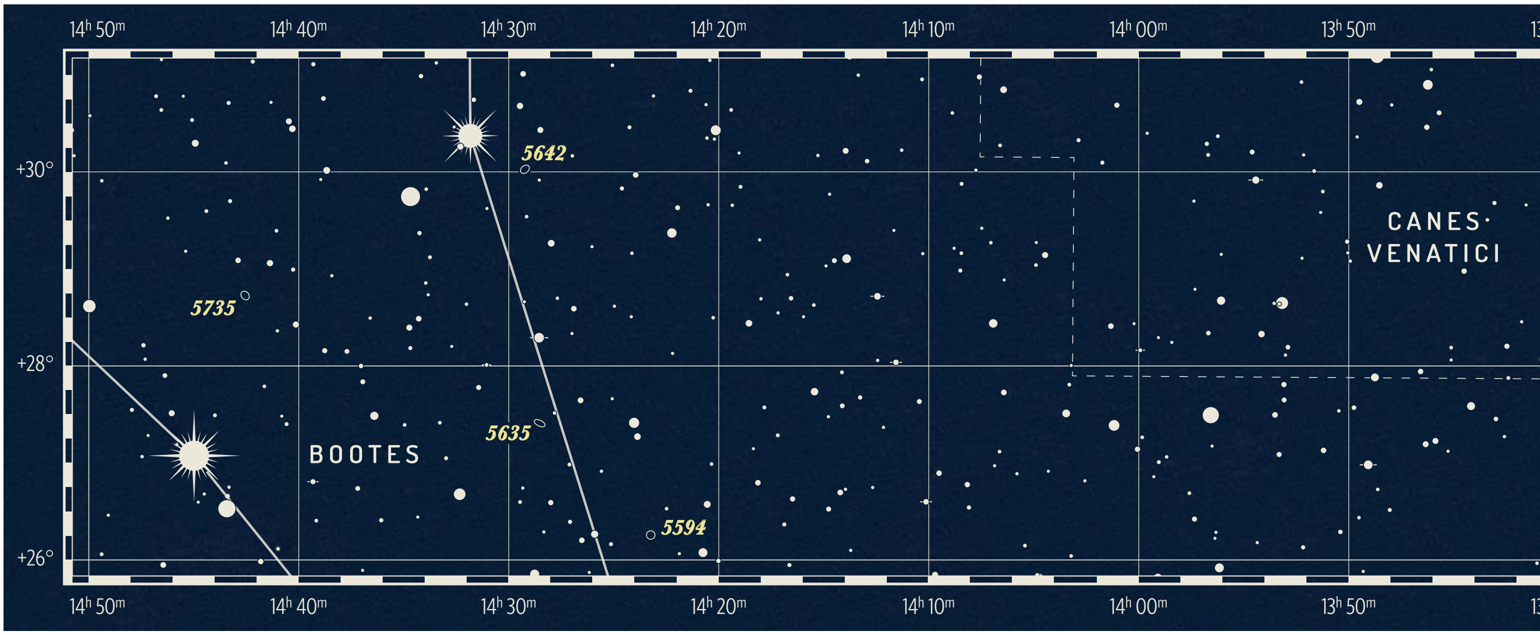
After chalking up **NGC 4080** and **NGC 4104** in modern Coma Berenices, things became hectic for the Herschels. Two compact quartets came into view in quick succession. The first was a linear triplet formed by **NGC 4131**, **NGC 4132**, and **NGC 4134**. The brightest and most southerly object was the inclined, multi-arm spiral NGC 4134. The other two galaxies were fainter and in the register, Caroline wrote, "Two of three, the place is that of II. 371 [NGC 4134]. Both very faint, much extended. A 4th suspected." This fourth object may have been MCG +5-29-24, a faint galaxy with an elongated, relaxed spiral form, immediately east-northeast of NGC 4132.

Less than four minutes later, the Herschels recorded all four members of what is now known as the **Hickson 61 galaxy group**. The description of the faintest three objects reads, "Three of a quartile. The place is that of II. 372 [NGC 4173]. All very faint, very small and all within 3′." **NGC 4169**, probably the easiest to spot of "the quartile," is a lenticular galaxy that creates an oval glow in the field of view. **NGC 4173**, the largest, but also the most challenging target in the group, may not be a true member, as its radial velocity is almost 3000 km/s less than that of the other galaxies.

Sweeping south, William came upon another wide physical pair of galaxies, **NGC 4185** and **NGC 4196** — and something of a mystery as well. Herschel noted a third object, **NGC 4209**, which he described as "faint, pretty small." Yet, no galaxy exists at the recorded position. Conventional wisdom assumes that NGC 4209 duplicated the observation of NGC 4185, even though Herschel described that galaxy as "faint, large, brighter to the middle." The NGC authority Wolfgang Steinicke equates NGC 4209 with a faint star at the recorded position. Considering that William might have been rushing things at this point (recording ten nebulae in only four minutes), it's easy to imagine him mistaking a faint star for a small nebula. According to Dreyer's *The Scientific Papers of Sir*



COMA BERENICES. Objects labeled in yellow were discovered during Herschel's previous sweeps. Green labels mark objects he inadvertently duplicated in his catalogue.

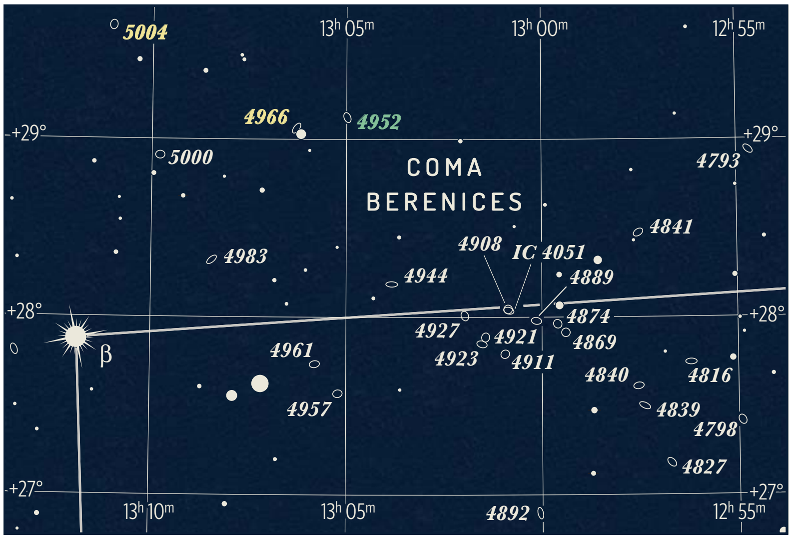


William Herschel, the Herschels recorded the position of NGC 4209 as crossing the meridian 1 minute 18 seconds of time after NGC 4196, just 2 minutes to its north. One minute six seconds of time following, and about 15 minutes south, of NGC 4196 lies the faint galaxy NGC 4211, discovered by Édouard Stephan and described in the *New General Catalogue* as "very faint, extremely small, much brighter to the middle." It's difficult to reconcile the discrepancy in declination, unless William or Caroline made a recording error, but could NGC 4211 be Herschel's missing object?

Two more objects followed quickly — the bright lenticular galaxy **NGC 4251** and the face-on spiral **NGC 4275**. Sweeping north, Herschel fell into confusion again. He recorded two fairly bright galaxies, **NGC 4278** and **NGC 4283**, thinking they were new objects. However, one month earlier in a sweep two degrees to the north, he had already come upon these two galaxies, as well as a fainter one to the east, NGC 4286. The Herschels didn't notice their error because the two sweeps relied on different field stars as reference points.

Five more galaxies followed in quick succession: **NGC 4310**, **NGC 4375**, **NGC 4393**, **NGC 4448**, and **NGC 4475**. For modern observers, two stand out. NGC 4448 is a bright, barred galaxy with an inner ring structure that may be visible in very-large-aperture telescopes (8- to 10-inch scopes will reveal a glowing oval, with features faintly articulated), while NGC 4393 is a large, low surface brightness spiral with very faint, nebulous knots scattered across its spiral arms.

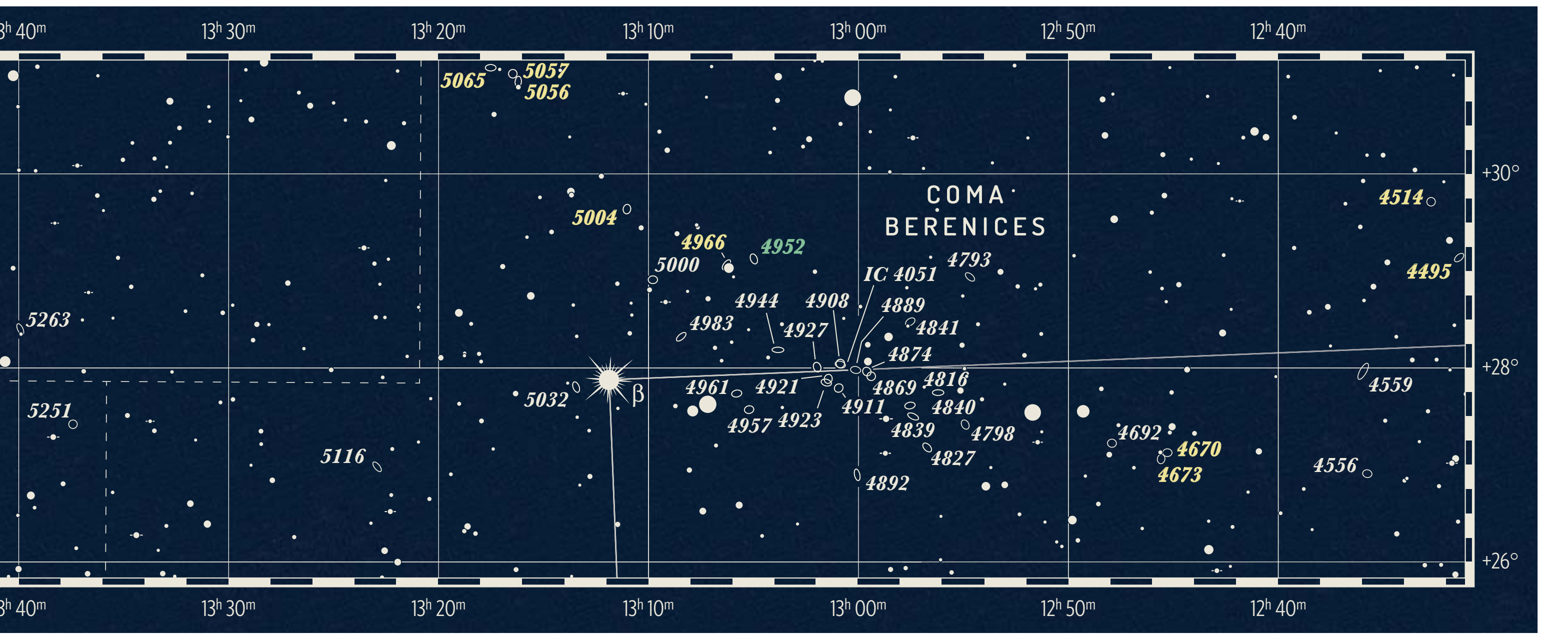
William next observed **NGC 4556** and **NGC 4559**. While NGC 4556 appears nondescript, NGC 4559 has the distinction of being a large spiral galaxy, the brightest object recorded that night. William described it as "very



COMA CLUSTER. Herschel spotted NGC 4952, 4966, and 5004 in earlier sweeps of Coma Berenices. Even so, a wealth of galaxies awaited discovery on April 11, 1785.

bright, very large, much extended north preceding, south following, 10 or 12′ long, four stars in it." A large aperture instrument reveals the elongated form and the spiral sweep of the arms.

William was now on the verge of sweeping through the heart of the Coma Cluster of galaxies, **Abell 1656**. Skimming the northeast outskirts of the cluster the previous month, he had discovered NGC 4952 and NGC 4966 on March 13th. Now he approached the cluster from the west, where **NGC 4692**, a small and faint elliptical, stood in isolation from the group as a whole. He followed this discovery with the bright spiral **NGC 4793**, a non-Coma Cluster galaxy almost two degrees to the north. Swinging to the south, he picked up another Abell 1656 member,



NASA / ESA / K. COOK (LAWRENCE LIVERMORE NATIONAL LABORATORY, USA)

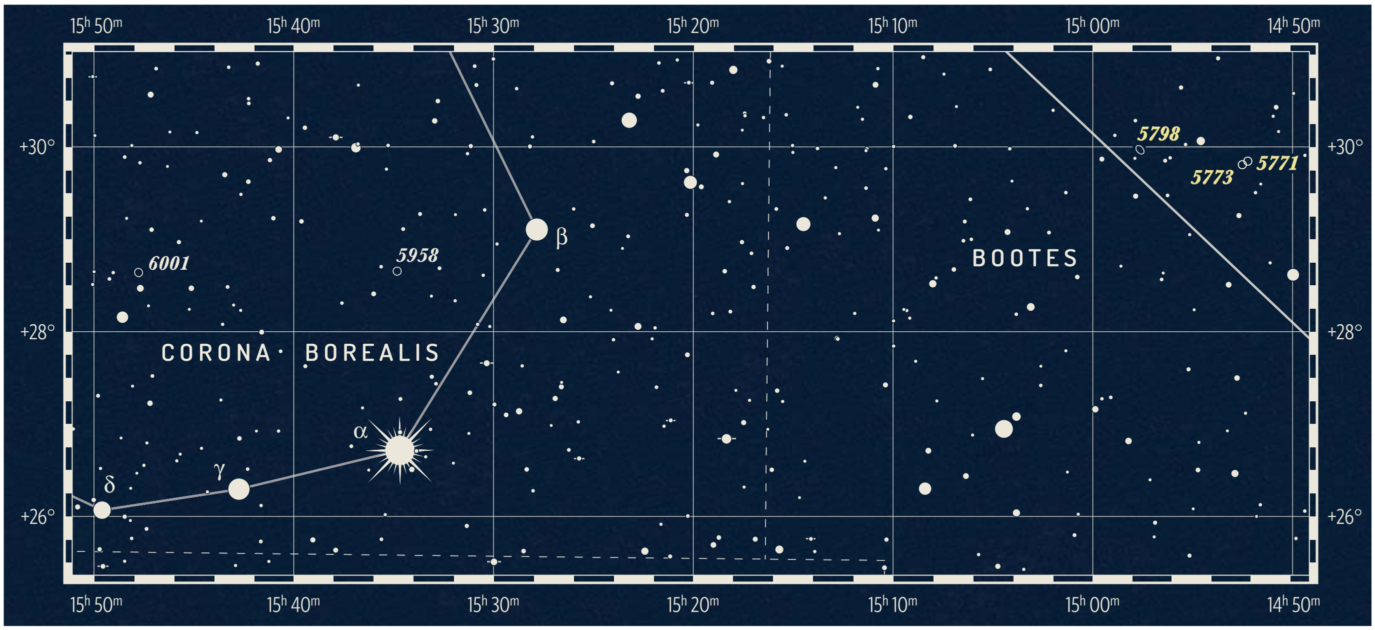
The face-on barred spiral galaxy NGC 4921 in Abell 1656 displays a bright core surrounded by a large low surface brightness halo.

NGC 4798, and things once again became busy for the observing team. Fifteen cluster members were recorded during the next eight minutes. **NGC 4816**, **NGC 4827**, **NGC 4840**, and **NGC 4841** all appear similar visually; they're classed as either lenticular or elliptical galaxies, with NGC 4841 having a very slightly smaller and fainter companion immediately northeast. **NGC 4839**, a giant elliptical galaxy, measures as one of the largest in the cluster. William laconically described all these galaxies as "faint, pretty large."

Swinging into the heart of the Coma Cluster, William noted two galaxies that present modern observers with an intriguing viewing challenge. **NGC 4869** and **NGC 4874** were recorded together and described as, "Two. The time taken between them." Both were recorded as class II objects (faint), though visually, NGC 4874 appears larger and brighter. A much fainter object, NGC 4872 appears embedded in the outer halo of NGC 4874 to the southwest. Until recently, it was presumed that NGC 4872 was the galaxy described by William. The confusion stems from Heinrich d'Arrest's explorations of this same region in 1864. Observing two galaxies at the same position, d'Arrest concluded that the faint NGC 4872 was William's discovery; he thus recorded NGC 4874 as a new object.

A little more than 1° south of NGC 4874, William observed **NGC 4892**, an edge-on spiral galaxy located well away from the main concentration of the cluster; visually, it appears as an extended oval of subtle light, just following two brighter field stars.

IC 4051, another victim of mistaken identity, lies just east of **NGC 4889**. It now seems clear that IC 4051, a discovery credited to Guillaume Bigourdan and Hermann Kobold in Dreyer's *Second Index Catalogue*, and NGC 4908, credited to Heinrich d'Arrest, are one and the same object — Herschel's Class III object III 363. To confuse matters even more, in his *General Catalogue*, John Herschel equated III 363 with a galaxy he discovered, h1510 (NGC 4894), an error carried over into Dreyer's *New General Catalogue*. As Dreyer noted, "This region is so very crowded that it is not easy to identify a very faint nebula." All editions of *Uranometria 2000.0* plot NGC



4908 as a separate object, immediately north of IC 4051, but observers wishing to view the correct Herschel object should locate IC 4051, the southernmost object in a chain of four galaxies.

Three more Herschel discoveries stand south of IC 4051. **NGC 4921** is the largest and most brilliant of the three, a face-on barred spiral with a bright core in a diffuse outer spiral structure. Immediately south-southeast of it shines **NGC 4923**, a concentrated lenticular galaxy. The third object is **NGC 4911**, a high surface brightness, compact spiral. Northeast of NGC 4921 is the edge-on lenticular galaxy **NGC 4927**. A roughly similar distance to its northeast is another lenticular, the slightly larger and more luminous **NGC 4944**. William described the galaxies together as, "Three. The two following pretty near each other. The south preceding about 8′ distance. The time is that of the two."

At this point, William left behind the main concentration of the Coma Cluster, though a few of its outliers remained to be recorded in the register. The first of these, the aforementioned **NGC 4952**, was another case of a previously discovered object being identified as a new one when a different reference star was used to determine its position. But a look 1½° to the south of NGC 4952 revealed another Coma Cluster member, the elliptical galaxy **NGC 4957**. To its northeast was a much closer spiral galaxy, **NGC 4961**.

The final three outlying Coma Cluster members, arrayed around the bright star Beta (β) Comae, were all described as very faint objects. **NGC 4983** is the smallest of the trio; in photographs, it shows a probable barred spiral with a bright core and a faint outer disk. **NGC 5000** and **NGC 5032** are nearly face-on barred spiral galaxies with inner ring structures.

The pace now slowed dramatically for the Herschels as observable objects thinned out considerably. Three widely separated faint galaxies came into view: **NGC 5116**, **NGC 5251**, and **NGC 5263**. Of the three, NGC 5263 may be the most appealing target, a small nearly edge-on galaxy to the east of the spectacular globular cluster M3. One can imagine William's sense of relief as the large, bright cluster came into the eyepiece, a brilliant object appearing after a hectic night of observing dozens of fainter objects.

Herschel was now entering a section of sky that he'd swept on May 17th of the previous year, recording the large, loose globular NGC 5466 as well as the faint galaxies NGC 5635 and NGC 5735. He found nothing new this night until, more than 90 minutes later, he spotted **NGC 5958**, then **NGC 6001**, two small, faint face-on spiral galaxies in Corona Borealis. The long night of discovery was at an end.

As the accompanying table shows, the final tally was remarkable, with 74 objects recorded during the marathon session. Perhaps we should pause to acknowledge the remarkable persistence and determination of Caroline,

One Amazing Night: Herschel's Spring Success

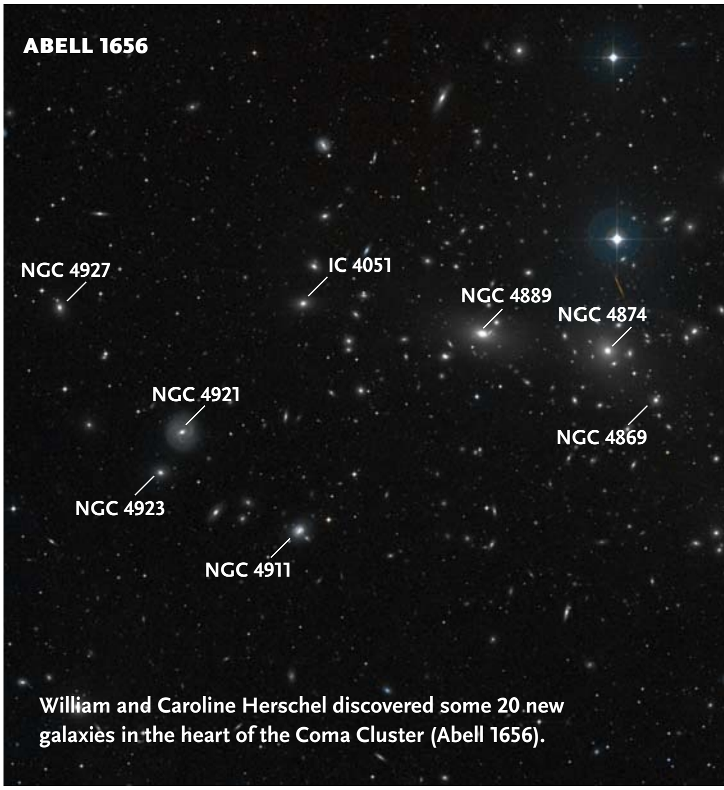
NGC	Herschel No.	Con	Mag (v)	Size	RA	Dec
3196	III 348	Leo	14.9	0.3′ × 0.2′	10^h 18.8^m	+27° 40′
3245	I 86	LMi	10.8	3.2′ × 1.8′	10^h 27.3^m	+28° 30′
3265	III 349	LMi	13.5	1.3′ × 1.0′	10^h 31.1^m	+28° 48′
3274	II 358	Leo	12.6	2.1′ × 1.0′	10^h 32.3^m	+27° 40′
3277	II 359	LMi	11.7	1.9′ × 1.7′	10^h 32.9^m	+28° 31′
3380	II 360	LMi	12.7	1.7′ × 1.3′	10^h 48.2^m	+28° 36′
3400	II 361	LMi	13.4	1.3′ × 0.8′	10^h 50.8^m	+28° 28′
3414	II 362	LMi	10.9	3.5′ × 2.6′	10^h 51.3^m	+27° 59′
3418	II 363	LMi	13.4	1.4′ × 1.1′	10^h 51.4^m	+28° 07′
3451	II 364	LMi	13.1	1.7′ × 0.8′	10^h 54.4^m	+27° 14′
3486	I 87	LMi	10.5	7.1′ × 5.2′	11^h 00.4^m	+28° 58′
3504	I 88	LMi	11.8	2.7′ × 2.1′	11^h 03.2^m	+27° 58′
3510	II 365	LMi	12.3	4.0′ × 0.8′	11^h 03.7^m	+28° 53′
3512	II 366	LMi	12.9	1.6′ × 1.5′	11^h 04.1^m	+28° 02′
3527	III 350	UMa	13.9	1.0′ × 0.9′	11^h 07.3^m	+28° 32′
3550	III 351	UMa	13.2	1.0′ × 1.0′	11^h 10.7^m	+28° 46′
3552	III 352	UMa	14.5	0.6′ × 0.5′	11^h 10.7^m	+28° 42′
3713	II 367	Leo	13.3	1.2′ × 0.8′	11^h 31.7^m	+28° 09′
3714	III 353	UMa	13.3	0.5′ × 0.4′	11^h 31.9^m	+28° 21′
4004	III 354	Leo	13.6	1.8′ × 0.6′	11^h 58.1^m	+27° 53′
4008	II 368	Leo	11.8	2.5′× 1.3′	11^h 58.3^m	+28° 12′
4017	II 369	Com	12.7	1.8′ × 1.4′	11^h 58.8^m	+27° 27′
4080	III 355	Com	13.9	1.2′ × 0.5′	12^h 04.9^m	+27° 00′
4104	II 370	Com	12.2	2.6′ × 1.5′	12^h 06.7^m	+28° 10′
4131	III 356	Com	13.3	1.3′ × 0.7′	12^h 08.8^m	+29° 18′
4132	III 357	Com	14.0	1.1′ × 0.3′	12^h 09.0^m	+29° 15′
4134	II 371	Com	13.1	2.2′ × 0.9′	12^h 09.2^m	+29° 11′
4169	III 358	Com	12.3	1.8′ × 0.9′	12^h 12.3^m	+29° 11′
4173	II 372	Com	13.3	5.0′ × 0.7′	12^h 12.3^m	+29° 13′
4174	III 359	Com	13.6	0.8′ × 0.3′	12^h 12.5^m	+29° 09′
4175	III 360	Com	13.4	1.8′ × 0.4′	12^h 12.5^m	+29° 10′
4185	II 373	Com	12.3	2.6′ × 1.9′	12^h 13.4^m	+28° 31′
4196	II 374	Com	12.9	1.2′ × 0.9′	12^h 14.5^m	+28° 25′
4209	II 375	Com	—	Non-existent	12^h 15.4^m	+28° 28′
4251	I 89	Com	10.6	3.6′ × 1.5′	12^h 18.1^m	+28° 11′
4275	II 376	Com	12.8	0.8′ × 0.7′	12^h 19.9^m	+27° 37′
4278	I 90 = II 322	Com	10.2	4.1′ × 3.8′	12^h 20.1^m	+29° 17′

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.

One Amazing Night: Herschel's Spring Success

NGC	Herschel No.	Con	Mag (v)	Size	RA	Dec
4283	II 323 = II 377	Com	12.1	1.5′ × 1.5′	$12^h 20.4^m$	+29° 19′
4310	II 378	Com	12.3	2.2′ × 1.2′	$12^h 22.4^m$	+29° 13′
4375	II 379	Com	13.0	1.6′ × 1.4′	$12^h 25.0^m$	+28° 34′
4393	III 361	Com	12.2	3.2′ × 3.0′	$12^h 25.9^m$	+27° 34′
4448	I 91	Com	11.2	3.9′ × 1.4′	$12^h 28.3^m$	+28° 37′
4475	III 362	Com	13.5	2.0′ × 1.0′	$12^h 29.8^m$	+27° 15′
4556	II 380	Com	13.2	1.2′ × 1.0′	$12^h 35.8^m$	+26° 55′
4559	I 92	Com	10.0	10.7′ × 4.4′	$12^h 36.0^m$	+27° 58′
4692	II 381	Com	12.8	1.3′ × 1.3′	$12^h 47.9^m$	+27° 13′
4793	I 93	Com	11.9	2.8′ × 1.5′	$12^h 54.7^m$	+28° 56′
4798	II 382	Com	13.2	1.2′ × 0.9′	$12^h 54.9^m$	+27° 25′
4816	II 383	Com	12.8	1.3′ × 1.1′	$12^h 56.2^m$	+27° 45′
4827	II 384	Com	12.8	1.4′ × 1.3′	$12^h 56.7^m$	+27° 11′
4839	II 386	Com	12.1	4.0′ × 1.9′	$12^h 57.4^m$	+27° 30′
4840	II 385	Com	13.9	0.7′ × 0.7′	$12^h 57.5^m$	+27° 37′
4841	II 387	Com	13.1	1.6′ × 1.0′	$12^h 57.5^m$	+28° 29′
4869	II 388	Com	13.8	0.7′ × 0.7′	$12^h 59.4^m$	+27° 55′
4874	II 389	Com	12.2	1.9′ × 1.9′	$12^h 59.6^m$	+27° 58′
4889	II 391	Com	11.9	2.9′ × 1.9′	$13^h 00.1^m$	+27° 59′
4892	II 390	Com	13.8	1.3′ × 0.3′	$13^h 00.1^m$	+26° 54′
IC 4051	III 363	Com	13.2	1.0′ × 0.9′	$13^h 00.9^m$	+28° 00′
4911	II 392	Com	13.2	1.4′ × 1.3′	$13^h 00.9^m$	+27° 47′
4921	II 393	Com	12.3	2.5′ × 2.2′	$13^h 01.4^m$	+27° 53′
4923	II 394	Com	13.7	0.8′ × 0.8′	$13^h 01.5^m$	+27° 51′
4927	III 364	Com	13.8	0.8′ × 0.6′	$13^h 02.0^m$	+28° 00′
4944	II 395	Com	12.9	1.7′ × 0.6′	$13^h 03.8^m$	+28° 11′
4952	II 396 = III 303	Com	13.0	1.8′ × 1.1′	$13^h 05.0^m$	+29° 07′
4957	II 397	Com	13.1	1.2′ × 1.0′	$13^h 05.2^m$	+27° 34′
4961	II 398	Com	12.8	1.6′ × 1.1′	$13^h 05.8^m$	+27° 44′
4983	III 365	Com	14.0	1.1′ × 0.7′	$13^h 08.5^m$	+28° 19′
5000	III 366	Com	13.4	1.7′ × 1.4′	$13^h 09.8^m$	+28° 54′
5032	III 367	Com	12.8	2.1′ × 1.1′	$13^h 13.5^m$	+27° 48′
5116	III 368	Com	12.9	2.0′ × 0.7′	$13^h 22.9^m$	+26° 59′
5251	III 369	Boö	13.9	0.7′ × 0.7′	$13^h 37.4^m$	+27° 25′
5263	III 370	CVn	13.4	1.6′ × 0.4′	$13^h 39.9^m$	+28° 24′
5958	II 399	CrB	12.7	1.0′ × 1.0′	$15^h 34.8^m$	+28° 39′
6001	III 371	CrB	13.7	1.0′ × 1.0′	$15^h 47.8^m$	+28° 39′

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.



William and Caroline Herschel discovered some 20 new galaxies in the heart of the Coma Cluster (Abell 1656).

POSS-II / STSCI / CALTECH / PALOMAR OBSERVATORY

Visit Skypub.com/herschelsprint for the entire listing of Herschel's night of discovery.

who faithfully recorded positions and descriptions for each and every object, writing them down in her register with a quill pen! Unfortunately, William didn't recognize the cluster of nebulae he'd discovered, even though he recorded 23 of them. Discovery of the Coma Cluster is generally credited to Heinrich d'Arrest, who noted the group of faint nebulae in 1865.

Accepting that NGC 4209 doesn't exist, and that William had discovered NGC 4278, NGC 4283, and NGC 4952 previously, that still gave the Herschels a total of 70 newly discovered galaxies, an unprecedented accomplishment, and one never equaled by any of the 72 nineteenth-century visual observers who subsequently contributed to Dreyer's *New General Catalogue*. The only observer to come close was John Herschel, who recorded 38 new objects, 34 of them in the Large Magellanic Cloud, on December 23, 1834. Even more remarkable: there are 7,093 independent objects in the *New General Catalogue*, eliminating duplicate entries, nonexistent objects, and entries associated with single, double, or multiple stars. Fully one percent of those 7,000+ objects were discovered on one night, April 11, 1785, by one of the greatest visual observers of all time. ✦

Mark Bratton is the author of The Complete Guide to the Herschel Objects *(Cambridge University Press, 2011).*

In This Section

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

William Herschel discovered barred spiral galaxy NGC 4911 on April 11, 1785 (page 34).

OBSERVING

Sky at a Glance

APRIL 2015

3 **NIGHT:** Algol shines at minimum brightness for roughly two hours centered at 10:37 p.m. EDT (7:37 p.m. PDT); see page 53.

4 **DAWN:** Today's lunar eclipse will only just reach total before sunrise for the western half of North America, during deep night across the Pacific, and in the evening in eastern Asia. The partial phase is visible everywhere in North America except parts of Maine and the Canadian Maritimes; see page 50.

8 **DAWN:** Saturn shines about 3° from the waning gibbous Moon for North America.

10–12 **EVENING:** Venus blazes about 3° from the Pleiades in the constellation Taurus.

19 **DUSK:** Mercury and very faint Mars are visible near the thin crescent Moon soon after sunset; bring binoculars.

20 **DUSK:** Look for a light sliver of crescent Moon in the west, where it pins the corner of a quadrilateral formed with Venus, Aldebaran, and the Pleiades.

22 **ALL NIGHT:** The somewhat weak Lyrid meteor shower is best observed in North America from about 11:00 p.m. to dawn on this night.

27 **EVENING:** The waxing gibbous Moon shines about 5° from Regulus for North America.

30 **DUSK:** Mercury makes its best evening apparition of 2015 this week and next, low in the west-northwest. Look for it about 2° to the lower left of the Pleiades in evening twilight.

Planet Visibility

SHOWN FOR LATITUDE 40° NORTH AT MID-MONTH

Planet	◀SUNSET	MIDNIGHT	SUNRISE▶
Mercury	W Visible April 18 through May 17		
Venus	W NW		
Mars	W Visible through April 20		
Jupiter	S	NW	
Saturn		SE	S SW

Moon Phases

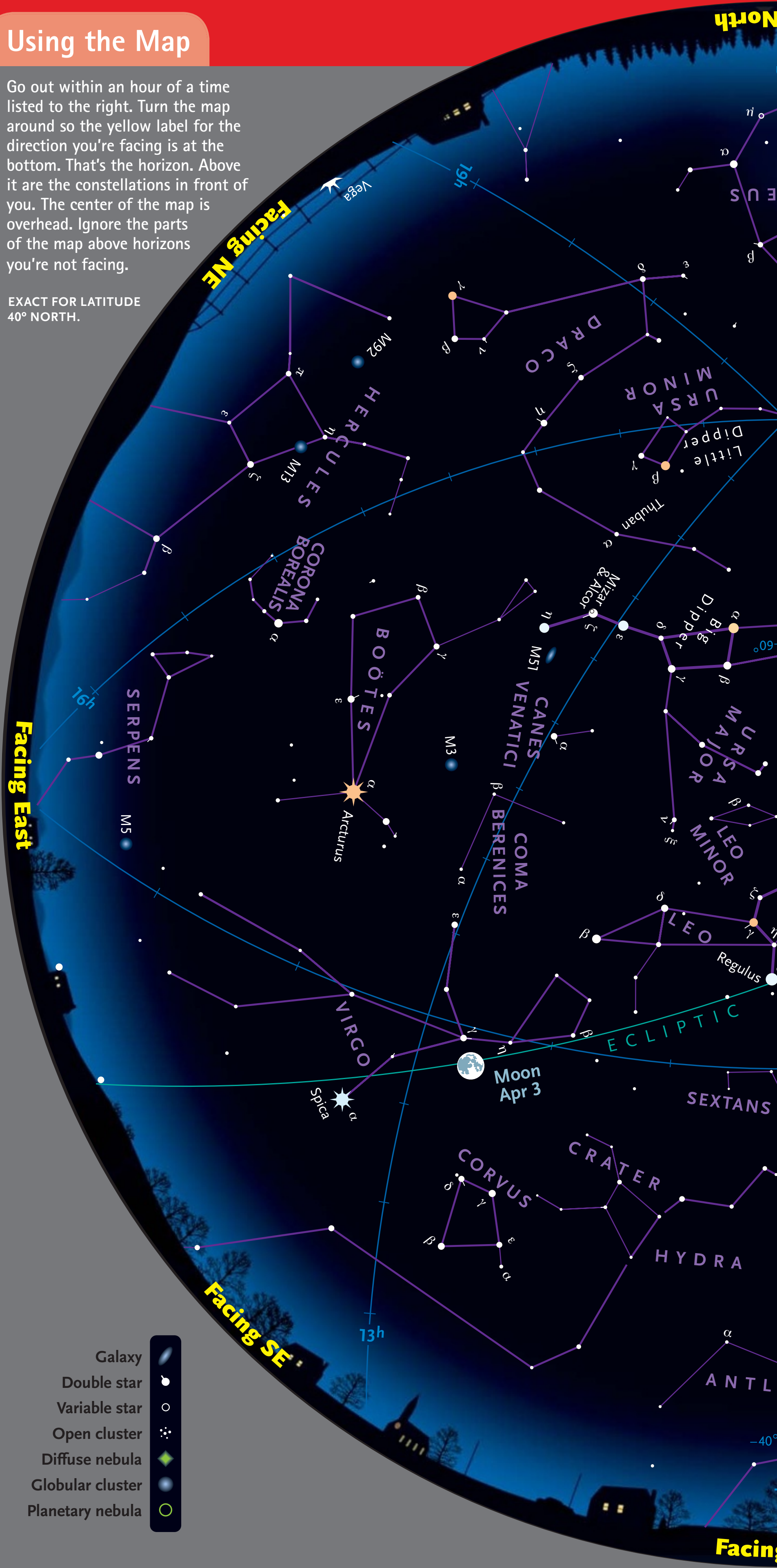
Full April 4 8:05 a.m. EDT	Last Qtr April 11 11:44 p.m. EDT
New April 18 2:57 p.m. EDT	First Qtr April 25 7:55 p.m. EDT

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.



Gary Seronik

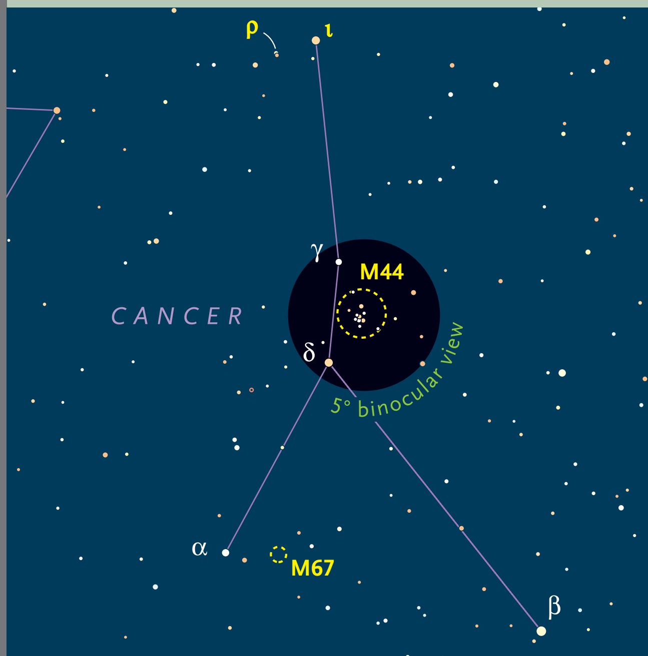
Treats in Cancer

For such a small and indistinct constellation, Cancer has more than its share of binocular treats. The Crab can lay claim to two nice open clusters and a couple of good double stars.

Let's start with the constellation's finest object, **M44** – also known as the Beehive Cluster. One of the very best binocular clusters, M44 features a couple dozen stars sprinkled over an area as wide as two full Moons. In 10×50s, it's a lovely sight, rivaled in the northern sky only by the Pleiades. Whenever I look at M44, my eye is drawn to a miniature version of the constellation Corvus near the cluster's center. Do you see it?

Two binocular fields south-southeast of the Beehive lies the constellation's other binocular cluster, **M67**. Although it lacks the grandeur of its neighbor, M67 is an easy find. My 10×50s show it as a slightly grainy, elongated patch of light with a 7.9-magnitude star marking its northeast extremity.

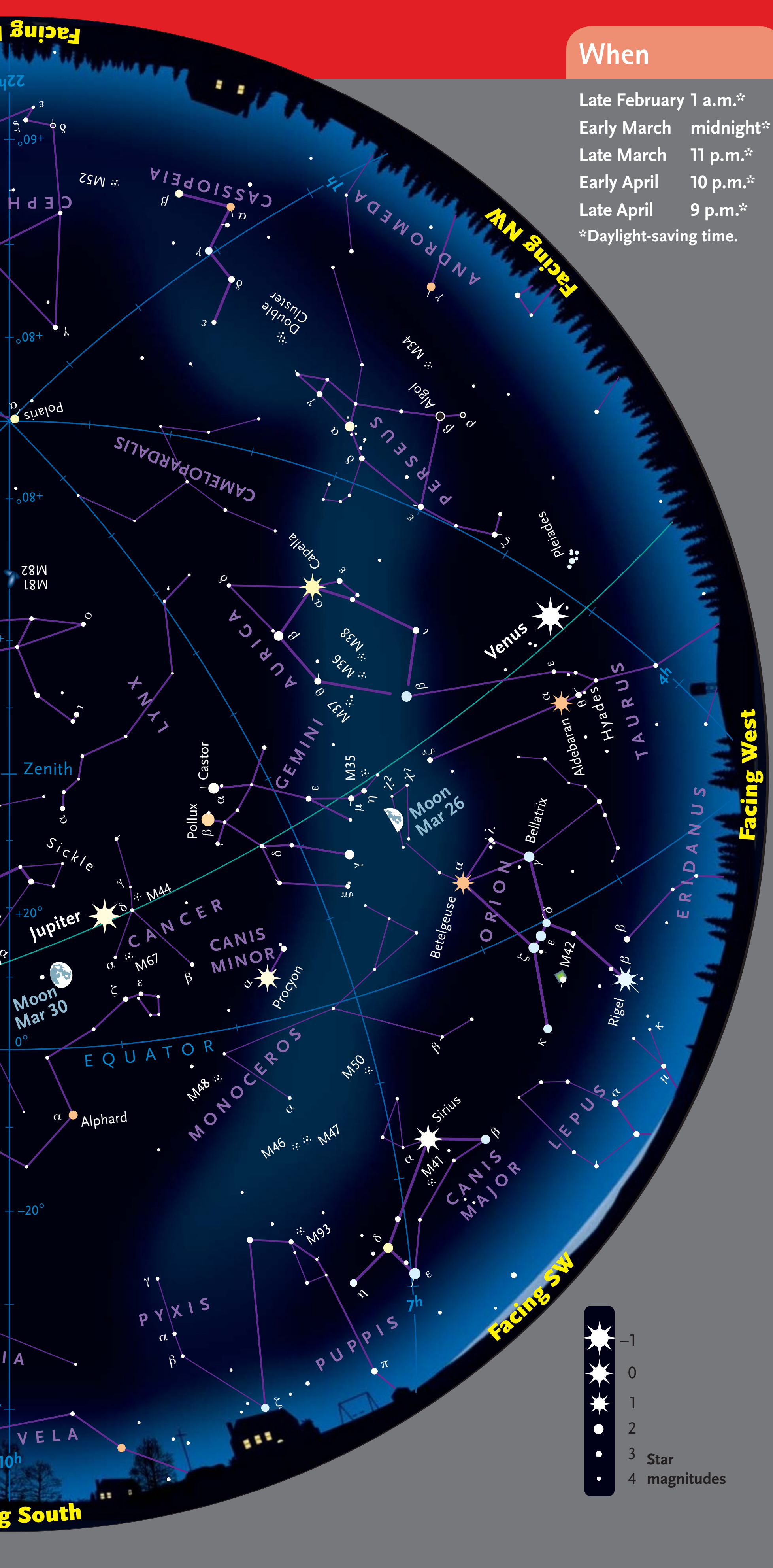
Northern Cancer has two fine binocular double stars, **Iota** (ι) and **Rho** (ρ) **Cancri**. Rho is the easier of the two, as both component stars are bright (magnitude 5.9 and 6.3) and are separated by a generous 278 arcseconds. Interestingly, the northern star of the pair (also known as 55 Cancri) was one of the first discovered to have an exoplanet. Compared with Rho, nearby Iota is a challenging target. I find it a difficult split in tripod-mounted 10×50s because the primary is 10 times brighter than the secondary (magnitudes 4.0 and 6.5, respectively). To make matters worse, the stars are separated by only 30 arcseconds. I would wager splitting Iota is all but impossible in 7× binoculars. ✦



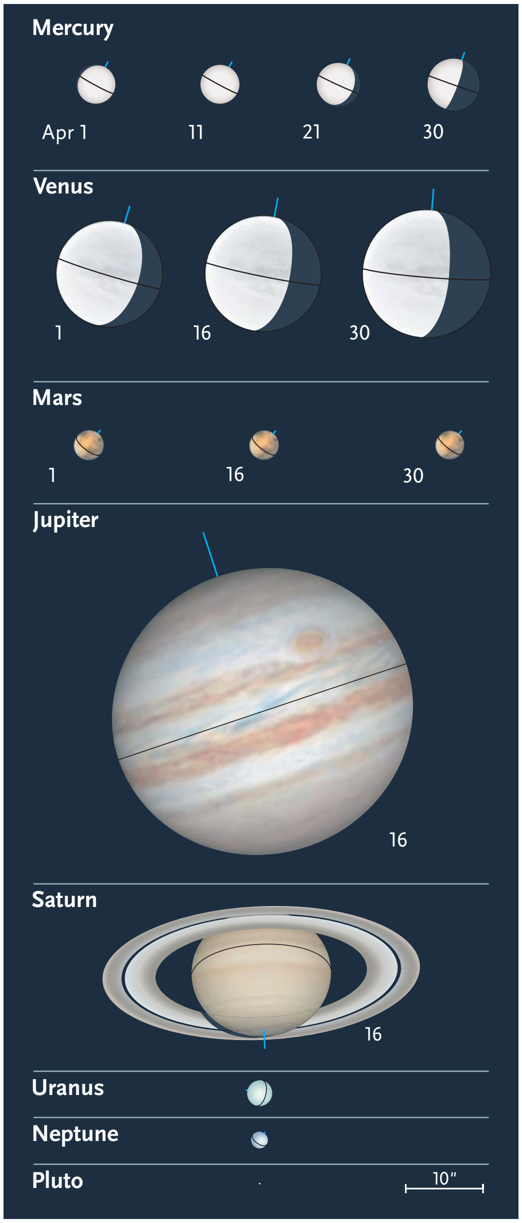
When

Late February	1 a.m.*
Early March	midnight*
Late March	11 p.m.*
Early April	10 p.m.*
Late April	9 p.m.*

*Daylight-saving time.



Planetary Almanac

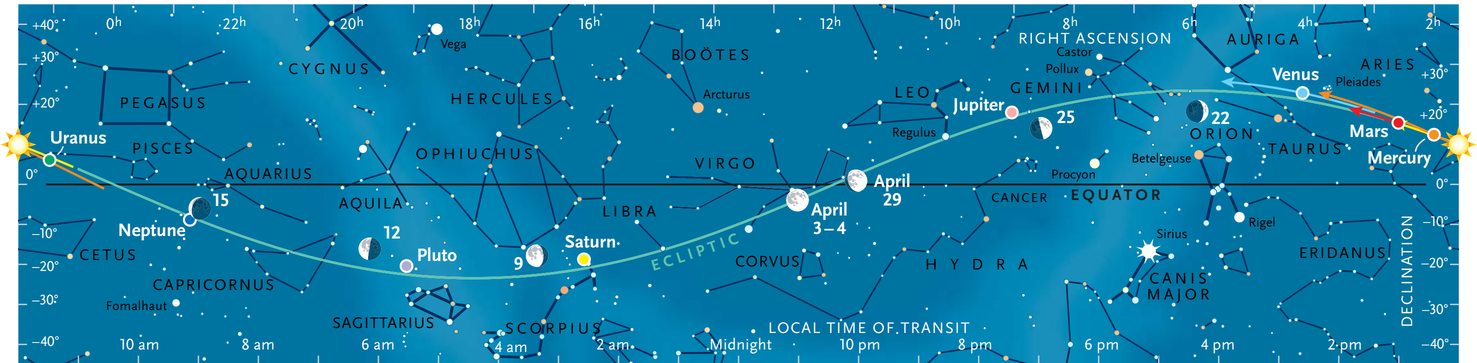


Sun and Planets, April 2015

	April	Right Ascension	Declination	Elongation	Magnitude	Diameter	Illumination	Distance
Sun	1	0^h 39.5^m	+4° 15′	—	–26.8	32′ 01″	—	0.999
	30	2^h 27.0^m	+14° 32′	—	–26.8	31′ 46″	—	1.007
Mercury	1	0^h 08.7^m	–1° 09′	9° Mo	–1.1	5.0″	95%	1.335
	11	1^h 20.5^m	+7° 43′	1° Ev	–2.2	5.0″	100%	1.331
	21	2^h 38.0^m	+16° 32′	12° Ev	–1.3	5.6″	87%	1.210
	30	3^h 41.6^m	+22° 02′	19° Ev	–0.5	6.6″	59%	1.011
Venus	1	2^h 58.1^m	+17° 51′	37° Ev	–4.0	13.8″	78%	1.207
	11	3^h 45.9^m	+21°21′	38° Ev	–4.0	14.6″	75%	1.142
	21	4^h 35.0^m	+23° 58′	40° Ev	–4.1	15.6″	71%	1.072
	30	5^h 19.7^m	+25° 27′	42° Ev	–4.1	16.6″	68%	1.007
Mars	1	1^h 51.9^m	+11° 22′	19° Ev	+1.4	4.0″	99%	2.362
	16	2^h 34.4^m	+15° 11′	16° Ev	+1.4	3.9″	99%	2.418
	30	3^h 14.7^m	+18° 14′	12° Ev	+1.4	3.8″	100%	2.464
Jupiter	1	9^h 00.9^m	+17° 59′	122° Ev	–2.3	41.5″	99%	4.755
	30	9^h 03.3^m	+17° 47′	94° Ev	–2.1	38.0″	99%	5.193
Saturn	1	16^h 11.6^m	–18° 56′	126° Mo	+0.3	17.8″	100%	9.347
	30	16^h 05.8^m	–18° 37′	156° Mo	+0.1	18.4″	100%	9.046
Uranus	16	1^h 02.8^m	+6° 01′	9° Mo	+5.9	3.4″	100%	20.989
Neptune	16	22^h 42.6^m	–8° 59′	47° Mo	+7.9	2.2″	100%	30.645
Pluto	16	19^h 05.5^m	–20° 30′	100° Mo	+14.2	0.1″	100%	32.662

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-April; 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

The Pilgrim's Way

Venus and Jupiter lead us on a journey through spring skies.

"Whan that Aprill with his shoures soote
The droghte of March hath perced to the roote,
And bathed every veyne in swich licour,
Of which vertu engendred is the flour;
Whan Zephirus eek with his sweete breeth
Inspired hath in every holt and heeth
The tendre croppes, and the yonge sonne
Hath in the Ram his half cours yronne,
And smale foweles maken melodye
That slepen al the nyght with open ye
(So priketh hem nature in hir corages)
Thanne longen folk to goon on pilgrimages..."

— Chaucer, "The General Prologue,"
The Canterbury Tales

Venus shines in Auriga above Taurus

JOHN LEMLEUX

No beginning in literature is more uplifting than that of *The Canterbury Tales*. It takes on even more incantatory power today by being in Middle English (though considerable translation is necessary — the "shoures soote" are "showers sweet"). The astronomical reference in these lines even needs a little explanation. As April arrives, the Sun is astrologically about halfway through Aries the Ram. Though Chaucer wrote over 600 years ago, even then the Sun was really — astronomically — in the constellation Pisces at the beginning of April.

It's the final line in the quote above, however, that serves as the springboard for our spring adventures in this column: April is the time for astronomers to go on pilgrimages (in Chaucer's pronounciation, "pil-grim-MAH-jez") in the sky.

Pilgrimages in the spring sky. After winter's cold has kept us indoors, April is the time to step out and seek the treasures of the heavens.

The month-name "April" is believed to come either from Aphrodite (the Roman Venus) or from "aperture" (an opening — that is, of the natural year). This month is always an opening for spring stargazing, but in 2015, it's also the month of the planet Venus. Venus dominates the western sky after nightfall, sitting in the midst of Taurus — but also, more broadly, in the midst of the departing throng of Auriga, Orion, Gemini, Canis Minor, and Canis Major. So this is one of our pilgrimages — to visit Venus and to adore, finally in more comfortable weather, the beauties of the descending winter constellations.

Another scene currently infiltrated by a bright planet is the region of Gemini, Leo, and Cancer, in which Jupiter now resides. Not far from Jupiter is one of two delectable naked-eye clusters in the spring constellations that are definitely worth visiting: Cancer's M44, the Beehive Star Cluster; see page 45. But on the other side of Leo — in fact, anciently regarded as the tuft of Leo's tail — is the Coma Star Cluster. Five members of the Coma Cluster are brighter than magnitude 5.5, and about a dozen brighter than 6.5 spread irregularly over about 5° of sky. In quite dark skies the cluster is surprisingly prominent to the naked eye, but in light pollution you'll need binoculars to detect and enjoy it. You'll find the Coma Cluster about halfway between bright Beta (β) Leonis (Denebola) and Alpha (α) Canum Venaticorum (Cor Caroli).

A bright star pilgrimage. A brighter and special pilgrimage, around the entire sky, is one to see the greatest number of 1st-magnitude and brighter stars visible at one time. Soon after nightfall, observers around latitude 40° north can still view Sirius, Rigel, Aldebaran, and Betelgeuse low in the west; Capella, Pollux, and Procyon higher in the west; Regulus, Arcturus, and Spica from the south to the east sky; and Vega, rising in the northeast.

An extragalactic pilgrimage. If you want a telescopic pilgrimage, a great one heads for April's galaxies. One rousing route starts high in the north with odd couple M81 and M82 in Ursa Major, then runs under the Big Dipper to arrive at noble M51. From there, for tougher but marvelous fare, you can travel down to the wonderland that most observers enter about 5° west of 3rd-magnitude Epsilon (ε) Virginis — the Realm of Galaxies. ✦

Encounter at Aldebaran

Venus takes us on a grand tour of Taurus.

On April 4th, western North America, the Pacific, and eastern Asia experience a total lunar eclipse with a total stage that lasts around 10 minutes. Most of the rest of North America can view the partial phases as dawn brightens; see page 50.

April features up to five bright planets in the evening hours. Venus dominates the western sky for several hours after sunset. Mercury appears low in twilight after mid-month, and for a few days, acts as a guide to finding dim Mars near it. Jupiter shines prominently high in the south at dusk. Saturn rises in the south-east in the late evening and is highest before dawn.

DUSK AND EVENING

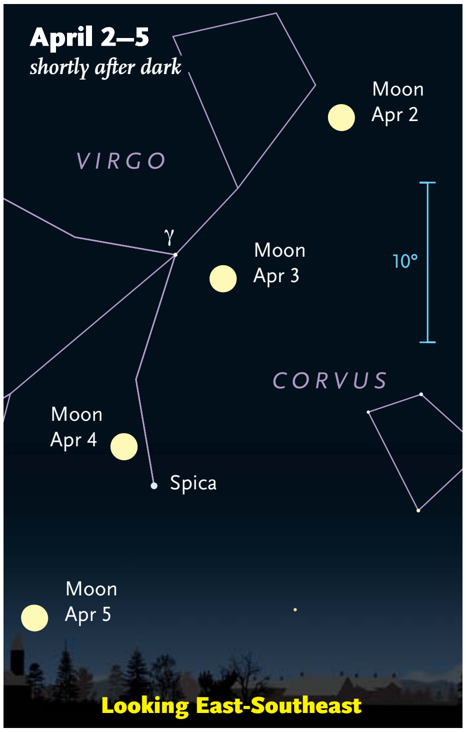
Venus shines at magnitude –4.1 for most of April and continues to brighten. This yellow-white beacon climbs a little higher with each passing week for viewers at mid-northern latitudes, eventually appearing more than a third of the way up the western sky at sunset. It stays up long after dark; the interval between sunset and Venus-set increases from about 3 hours to 3½ hours during April as seen from around latitude 40° north.

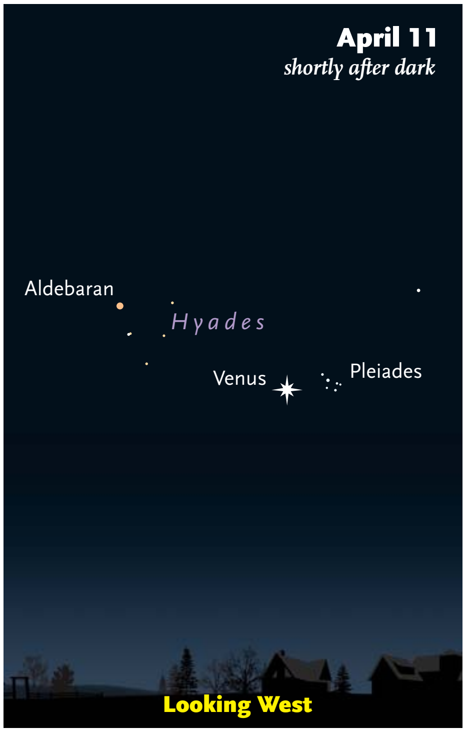
Especially lovely this month is Venus passing by the Pleiades, the Hyades, and Aldebaran. Venus starts April some 12° below the Pleiades; it shines only 2° or 3° to their left by the 11th and 12th, and about 7° upper right of Aldebaran on April 19th. Then, on April 20th and 21st, the crescent Moon joins Venus, Aldebaran, and the bright Taurus clusters in beautiful arrangements. By month's end, Venus is nearing Beta Tauri (Elnath).

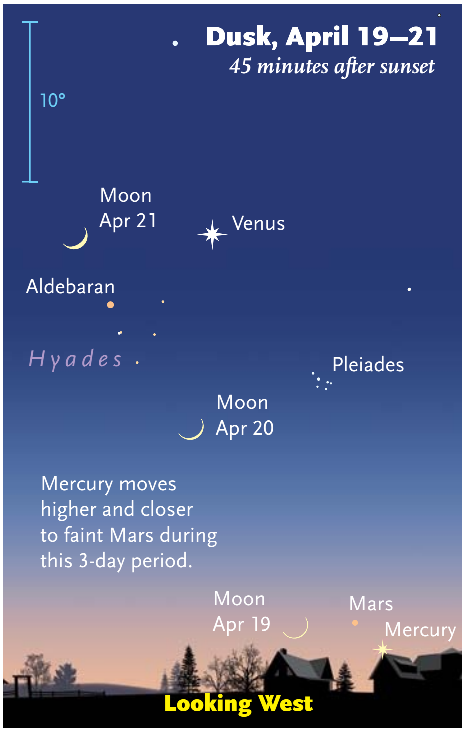
Telescopes show the angular diameter of Venus grow from less than 14″ to more than 16″ tall in April, while its gibbous phase shrinks from 78% to 68% sunlit.

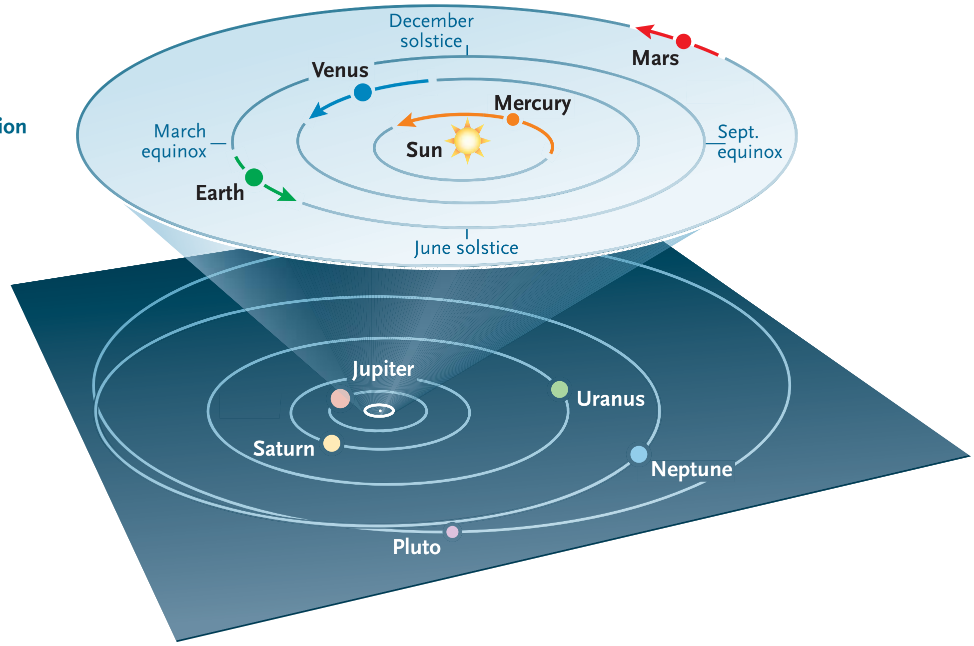
Mercury is at superior conjunction with the Sun on April 10th, but moves rapidly out into the evening sky — far to the lower right of Venus — in the following three weeks. By April 19th, Mercury, shining at magnitude –1.4, should be visible to the unaided eye (with difficulty) very low in the west-northwest about 45 minutes after sunset. That same night, look also for an extremely thin crescent Moon, hardly more than 1 day old for North America, less than a fist-width at arm's length to the left of, and slightly higher than, Mercury.

Mars, much fainter at magnitude +1.4, is finally sinking down into the sunset after eight months of hanging fire. Binoculars or a telescope show it just a few degrees to the upper left of brighter Mer-









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

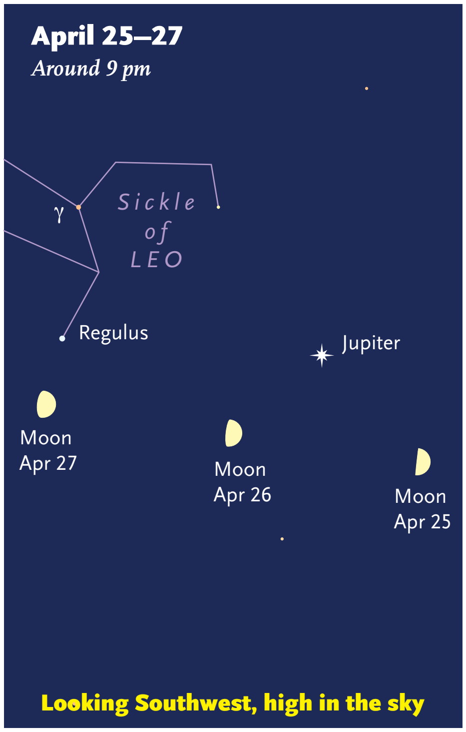
cury by April 19th. Mars and Mercury are closest together on the 22nd, when Mars is 1.3° to Mercury's lower left. Telescopes won't show much of either at that point of the month. Mars is a round speck 4″ wide, while Mercury is more than 5″ wide and slightly gibbous.

Jupiter beams in the south at dusk. Although it dims a bit more during April, from magnitude –2.3 to –2.1, it's high at nightfall and grandly positioned in dim Cancer the Crab, between Gemini and Leo. It halts its retrograde motion (movement westward relative to the background stars) on April 8th, when it's still 5° east of M44, the Beehive Star Cluster. Jupiter moves only very slowly east during the rest of the month.

By the end of April, when Jupiter is still setting as late as 2 or 3 a.m. daylight-saving time for viewers at mid-northern latitudes, it's only two months away from an epic conjunction with Venus on July 1st. Jupiter's disk shrinks from 41″ to 38″ in diameter during April.

LATE EVENING TO DAWN

Saturn rises in the second half of the evening, earlier and earlier, so by the end of the month, it appears around 9:30 p.m. daylight-saving time. The ringed planet brightens from magnitude +0.3 to an impressive +0.1 this month, rivaling Arcturus and Vega in brightness, on its way to a May 23rd opposition. Saturn is slowly retrograding, just north of the stars forming the head of Scorpius. As the month begins, it's less than a degree north of Nu (ν) Scorpii (Jabbah), and as the month ends it's well over a degree north of Beta (β) Scorpii (Graffias). Both stars are fine telescopic doubles.



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

Saturn's splendid rings remain tilted at more than 24° from edge-on, almost their maximum possible, which accounts for the planet's unusual brightness this year. Saturn is highest in the south before morning twilight.

Pluto is in northern Sagittarius, far east of Saturn and still several months away from opposition. **Neptune** rises around the start of morning twilight,so is not well placed for observations this month. **Uranus** reaches conjunction with the Sun on April 6th. Wait a few months to see all of them.

MOON PASSAGES

The full **Moon** is eclipsed before dawn on April 4th and shines about 3° from Spica that evening for North America. A fat waning gibbous Moon rises less than 3° from Saturn late in the evening on April 8th. On April 19th, the waxing crescent poses with Mercury and dim Mars very low in the dusk. The Moon hangs well to the lower left of the Pleiades the next evening, and floats well to the left of Venus and close to Aldebaran on April 21st. It's not very near Jupiter on April 25th and 26th but appears a little closer to Regulus on the 27th. ✦

A Barely Total Lunar Eclipse

On the morning of April 4th, the Moon skims just inside Earth's umbra.

As it did last October, the eclipsed Moon on April 4th will decline in the west as dawn brightens for most North Americans. Keith Lisk of Waverly, Ohio, took 21 shots at 4-minute intervals during the October eclipse using an 80-mm lens. He increased the exposure during the last 8 frames as the eclipse deepened to totality (the last 4 frames).

KEITH LISK

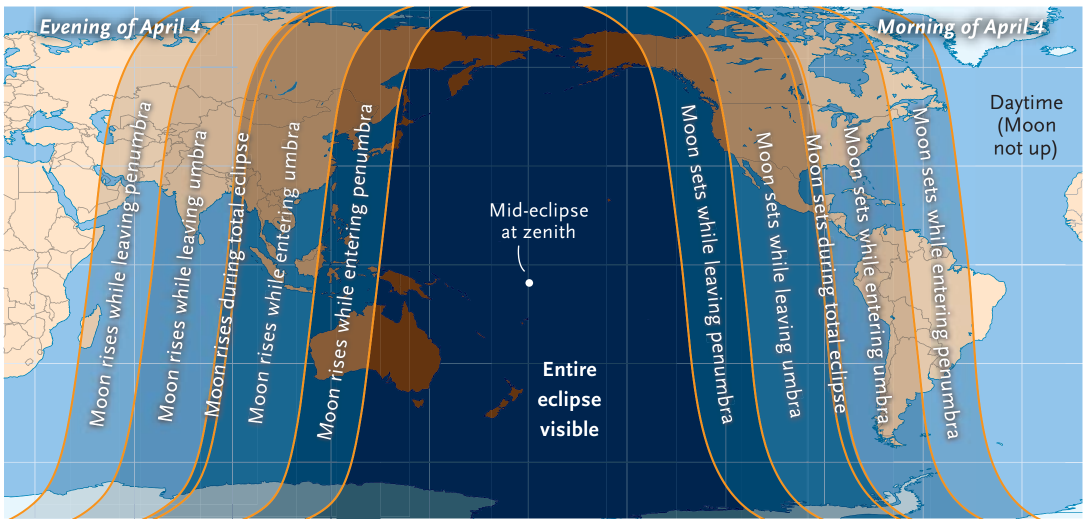
The next total eclipse of the Moon will greet early risers before or during dawn on Saturday morning, April 4th, across much of North America. It will be the third in the current "tetrad" of four total lunar eclipses coming at half-year intervals.

In one way, this eclipse will be a lot like the one last October 8th. Most North Americans will again need to get up early and look low in the west as dawn brightens. And again, the farther west you are the better — more so this time, because the eastern half of the continent misses the total phase of the eclipse completely.

But in another way it will be different. The eclipse will be just barely total and only for about 10 minutes. You may even get the impression that it never becomes quite total at all. The Moon's north-northeastern limb will be so slightly inside the umbra (the central portion of Earth's shadow) that it will remain much brighter than the deep red we can expect across the rest of the Moon's face.

The map below, and the diagram and timetable on the facing page, tell what to expect at your location and when. Near the West Coast, you'll see the total phase of the eclipse happen fairly high in a dark sky long before sunrise. Skywatchers farther east will find dawn brightening and the Moon sinking low in the west around totality. For easterners, the Moon sets (and the Sun rises) during the partial phase before totality begins. New England misses this one altogether.

If you're in Hawai'i or New Zealand, the eclipse hap-



For your location, see if the Moon will set (or rise) during any stage of the eclipse. Because an eclipsed Moon is always full, the Sun rises (or sets) at almost the same time on the opposite horizon. This means that a lunar-eclipse moonset or moonrise always happens in a very bright sky.

pens deep in the night and high in the sky. For Australia, Japan, China, and Southeast Asia, it comes on the evening of April 4th local date.

Stages of the Eclipse

A total lunar eclipse has five stages, with different things to watch for at each.

The first *penumbral* stage begins when the Moon's leading edge enters the pale outer fringe of Earth's shadow: the penumbra. But the shading is so weak that you won't see anything of the penumbra until the Moon is about halfway across it. Watch for a slight darkening to become apparent on the Moon's celestial southeast side. The penumbral shading becomes stronger as the Moon moves deeper in.

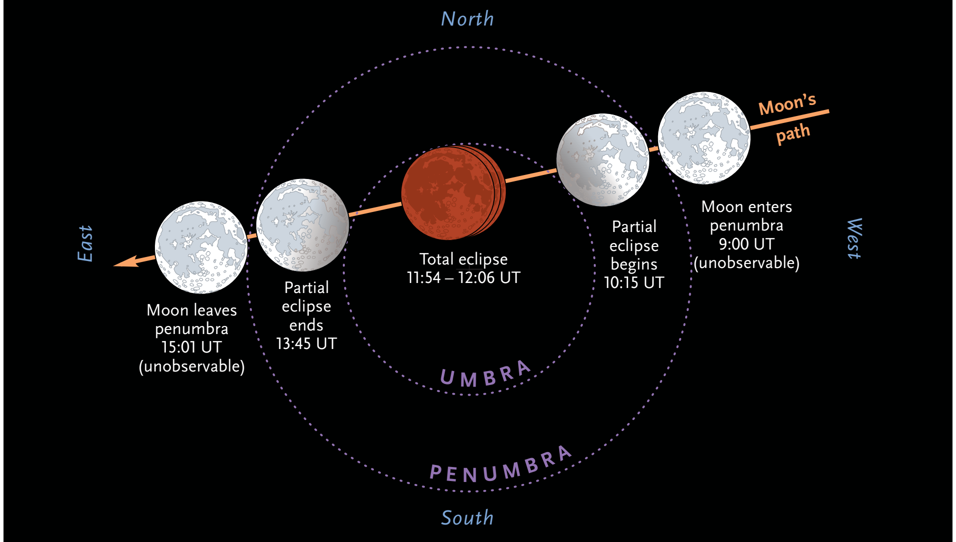
The second stage is *partial eclipse*. This begins much more dramatically when the Moon's leading edge enters the umbra, where no direct sunlight reaches. With a telescope, watch the umbra's edge engulf one lunar feature after another as the night around you deepens. Eventually just a final bright arc remains outside the umbra, while the rest is already showing a foreboding reddish glow.

The third stage is *total eclipse,* beginning when the last of the Moon slips into the umbra. But this depends on how the umbra's edge is defined! The edge is hazy, and in a grazing instance like this, its

Take a fairly long exposure, and even a partially eclipsed Moon shows the red-lit land in the umbra of Earth's shadow.

JOHNNY HORNE

Total Eclipse of the Moon, Morning of April 4, 2015



Eclipse event	EDT	CDT	MDT	PDT
Penumbra first visible?	5:35 a.m.	4:35 a.m.	3:35 a.m.	2:35 a.m.
Partial eclipse begins	6:15 a.m.	5:15 a.m.	4:15 a.m.	3:15 a.m.
Total eclipse begins	7:54 a.m.	6:54 a.m.	5:54 a.m.	4:54 a.m.
Mid-eclipse	—	7:00 a.m.	6:00 a.m.	5:00 a.m.
Total eclipse ends	—	7:06 a.m.	6:06 a.m.	5:06 a.m.
Partial eclipse ends	—	—	7:45 a.m.	6:45 a.m.
Penumbra last visible?	—	—	—	7:25 a.m.

adopted definition is critical enough that the U.S. Naval Observatory's *Astronomical Almanac* lists totality as lasting 12.3 minutes, while Fred Espenak's *Fifty-Year Canon of Lunar Eclipses* says 8.6 minutes.

Most of the Moon is sure to glow some shade of intense orange or red. The red light shining onto the Moon is sunlight that has skimmed and bent through Earth's atmosphere; it's from of all the sunrises and sunsets that ring our world at any given moment.

Two factors affect a lunar eclipse's color and brightness. The first is how deeply the Moon goes into the umbra; the umbra's center is much darker than its edges.

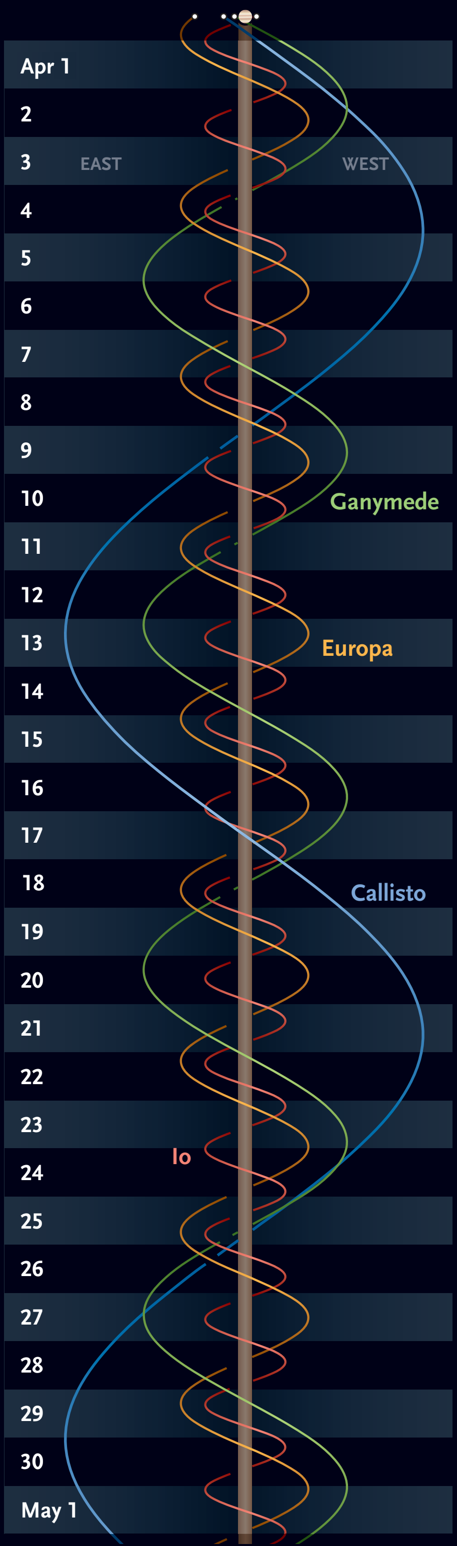
The other factor is the state of Earth's atmosphere along the sunrise-sunset line. If the air is very clear, the eclipse is bright. But when a major volcanic eruption has recently polluted the stratosphere with thin global haze, a lunar eclipse will be dark red, ashen gray, or occasionally almost black.

In addition, blue light that is slightly refracted through, and tinted by, Earth's ozone-rich upper atmosphere can also add to the scene. These blue rays can create a subtle mix of changing colors, especially near the umbra's edge. Time-lapse videos may also show large "flying shadows" in the umbra, caused by changing cloud-shadowing effects around the sunrise-sunset line as Earth moves and turns.

And then, as the Moon continues eastward along its orbit, events replay in reverse order. The Moon's edge re-emerges into sunlight, ending totality and beginning stage four: a partial eclipse again.

When all of the Moon escapes the umbra, only the last, penumbral shading is left for stage five. By about 45 minutes later, nothing unusual remains at all.

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.

Mutual Events of Jupiter's Moons

Jupiter's Galilean satellites continue to eclipse and occult each other in April. But the average depth of these events is diminishing, as the satellites' orbital planes edge away from the Sun and Earth. From April onward, North America (or part of it) gets only six more events in which the shadowed satellite, or the blend of two during a mutual occultation, should fade by at least 0.5 magnitude while Jupiter is visible in a dark sky.

Deep Mutual Events of Jupiter's Moons for North America

Date (UT)	Event	Start UT	End UT	Mag. drop
April 12	2e3	1:41	1:50	1.0
14	1e2	1:28	1:33	0.6
18	4o3	1:28	1:37	1.0
19	2e3	4:59	5:08	1.1
21	1e2	3:43	3:48	0.6
28	1e2	5:58	6:03	0.6

Under "Event," satellite 1 is Io, 2 is Europa, 3 is Ganymede, and 4 is Callisto; *o* means occults, and *e* means eclipses.

For instance, from 1:41 to 1:50 April 12th UT (9:41 to 9:50 p.m. April 11th EDT), Europa casts its shadow onto Ganymede, dimming it by 1.0 magnitude at mid-eclipse. Judge Ganymede's brightness carefully against the brightnesses of the other moons.

For the complete list of all these events visible from around the world, sortable by your location, see **skypub.com/jovianmutualevents**. There you'll also find links to the global campaign to time them photometrically, in order to refine our knowledge of the slight but important ongoing changes in the Jovian satellites' orbits.

The next series of mutual events won't start until 2020, when Jupiter begins to reach the opposite side of its 12-year orbit.

Other Action at Jupiter

Jupiter is already nice and high as soon as night falls in April, but it shrinks from 42″ to 38″ wide this month.

Any telescope shows Jupiter's four big Galilean moons. Binoculars usually show at least two or three, occasionally all four. Identify them using the diagram at left.

All of the April interactions between Jupiter and its satellites and their shadows are tabulated on the facing page. Most are easy to watch with an amateur telescope.

Mutual events among the satellites themselves are listed above.

And here are the times, in Universal Time, when the Great Red Spot should cross Jupiter's central meridian. The dates, also in UT, are in bold. (Eastern Standard Time is UT minus 5 hours; Eastern Daylight Time is UT minus 4 hours.)

March 1, 9:50, 19:46; **2,** 5:41, 15:37; **3,** 1:32, 11:28, 21:24; **4,** 7:19, 17:15; **5,** 3:11, 13:06, 23:02; **6,** 8:58, 18:53; **7,** 4:49, 14:44; **8,** 0:40, 10:36, 20:31; **9,** 6:27, 16:23; **10,** 2:18, 12:14, 22:10; **11,** 8:05, 18:01; **12,** 3:57, 13:52, 23:48; **13,** 9:44, 19:39; **14,** 5:35, 15:31; **15,** 1:26, 11:22, 21:18; **16,** 7:13, 17:09; **17,** 3:04, 13:00, 22:56; **18,** 8:51, 18:47; **19,** 4:43, 14:39; **20,** 0:34, 10:30, 20:26; **21,** 6:21, 16:17; **22,** 2:13, 12:08, 22:04; **23,** 8:00, 17:55; **24,** 3:51, 13:47, 23:42; **25,** 9:38, 19:34; **26,** 5:29, 15:25; **27,** 1:21, 11:17, 21:12; **28,** 7:08, 17:04; **29,** 2:59, 12:55, 22:51; **30,** 8:46, 18:42; **31,** 4:38, 14:34.

April 1, 0:28, 10:23, 20:19; **2,** 6:15, 16:10; **3,** 2:06, 12:02, 21:58; **4,** 7:53, 17:49; **5,** 3:45, 13:40, 23:36; **6,** 9:32, 19:28; **7,** 5:23, 15:19; **8,** 1:15, 11:11, 21:06; **9,** 7:02, 16:58; **10,** 2:53, 12:49, 22:45; **11,** 8:41, 18:36; **12,** 4:32, 14:28; **13,** 0:24, 10:19, 20:15; **14,** 6:11, 16:07; **15,** 2:02, 11:58, 21:54; **16,** 7:50, 17:45; **17,** 3:41, 13:37, 23:33; **18,** 9:28, 19:24; **19,** 5:20, 15:16; **20,** 1:11, 11:07, 21:03; **21,** 6:59, 16:54; **22,** 2:50, 12:46, 22:42; **23,** 8:37, 18:33; **24,** 4:29, 14:25; **25,** 0:20, 10:16, 20:12; **26,** 6:08, 16:03; **27,** 1:59, 11:55, 21:51; **28,** 7:47, 17:42; **29,** 3:38, 13:34, 23:30; **30,** 9:25, 19:21.

These times assume that the spot will be centered at System II longitude 221°. Any feature on Jupiter appears closer to the central meridian than to the limb for 50 minutes before and after transiting.

A light blue or green filter slightly boosts the contrast of Jupiter's reddish, orange, and tan markings.

Asteroid Occultation

On the night of April 14–15, an 8.9-magnitude star in Virgo near Spica will be occulted by the asteroid 595 Polyxena, magnitude 12.3, along a path from Newfoundland and Maine through southern Ontario, Michigan, and Nebraska to northern California. The star should vanish for up to 8 seconds around 7:29 UT for Newfoundland and 7:34 UT for the West Coast.

For more precise time predictions, a track map, finder charts for the star, and more, see **asteroidoccultation.com/IndexAll.htm**.

Lyrid Meteors

The half year from January 7th to July 7th has remarkably few meteor showers compared to the other half of the year, for no known reason but chance. Only the April Lyrids and the May Eta Aquariids make it onto lists of major showers, while nine or ten rich meteoroid streams intersect the other side of Earth's orbit.

And the Lyrids are "major" only if you stretch the definition. Their typical peak zenithal hourly rate (the number you could count under a very dark sky with Lyra near the zenith) is about 15 or 20. That's enough to be clearly a shower if you watch for more than a half hour while the peak is happening (the peak may last just a fraction of a day). But it's a far cry from the 90 to 120 per hour expected on the moonless late nights coming up for the August Perseids and December Geminids this year. The Lyrids showed a brief surge to a ZHR of 90 in 1982, but not since.

The peak night this year should be April 22–23. The waxing crescent Moon sets early. The shower's radiant, between Lyra and the Keystone of Hercules, is high in the sky from about 11 p.m. until dawn. ✦

Minima of Algol

Mar.	UT	Apr.	UT
3	13:34	1	5:48
6	10:24	4	2:37
9	7:13	6	23:26
12	4:02	9	20:15
15	0:52	12	17:05
17	21:41	15	13:54
20	18:30	18	10:43
23	15:20	21	7:32
26	12:09	24	4:21
29	8:58	27	1:10
		29	22:00

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

Phenomena of Jupiter's Moons, April 2015

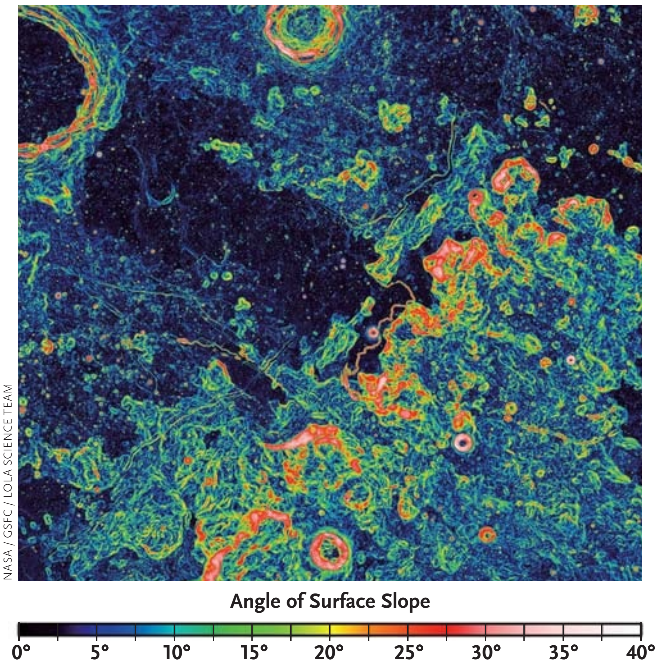
Apr. 1	3:14	IV.Sh.I
	7:57	IV.Sh.E
	9:36	I.Tr.I
	10:40	I.Sh.I
	11:53	I.Tr.E
	12:57	I.Sh.E
	17:05	II.Tr.I
	19:16	II.Sh.I
	19:58	II.Tr.E
	22:09	II.Sh.E
Apr. 2	6:55	I.Oc.D
	10:19	I.Ec.R
Apr. 3	4:04	I.Tr.I
	5:09	I.Sh.I
	6:21	I.Tr.E
	7:26	I.Sh.E
	11:14	II.Oc.D
	16:19	II.Ec.R
Apr. 4	1:22	I.Oc.D
	2:35	III.Oc.D
	4:48	I.Ec.R
	6:15	III.Oc.R
	7:07	III.Ec.D
	10:47	III.Ec.R
	22:31	I.Tr.I
	23:38	I.Sh.I
Apr. 5	0:48	I.Tr.E
	1:55	I.Sh.E
	6:19	II.Tr.I
	8:34	II.Sh.I
	9:12	II.Tr.E
	11:27	II.Sh.E
	19:50	I.Oc.D
	23:17	I.Ec.R
Apr. 6	16:59	I.Tr.I
	18:06	I.Sh.I
	19:16	I.Tr.E
	20:23	I.Sh.E
Apr. 7	0:27	II.Oc.D
	5:37	II.Ec.R
	14:18	I.Oc.D
	16:24	III.Tr.I
	17:45	I.Ec.R
	20:01	III.Tr.E
	21:01	III.Sh.I
Apr. 8	0:38	III.Sh.E
	11:27	I.Tr.I
	12:35	I.Sh.I
	13:44	I.Tr.E
	14:52	I.Sh.E
	19:33	II.Tr.I
	21:52	II.Sh.I
	22:25	II.Tr.E
	23:50	IV.Oc.D
Apr. 9	0:45	II.Sh.E
	4:42	IV.Oc.R
	8:46	I.Oc.D
	10:59	IV.Ec.D
	12:14	I.Ec.R
	15:48	IV.Ec.R
Apr. 10	5:55	I.Tr.I
	7:04	I.Sh.I
	8:11	I.Tr.E
	9:21	I.Sh.E
	13:41	II.Oc.D
	18:55	II.Ec.R
Apr. 11	3:14	I.Oc.D
	6:18	III.Oc.D
	6:43	I.Ec.R
	9:58	III.Oc.R
	11:06	III.Ec.D
	14:46	III.Ec.R
Apr. 12	0:22	I.Tr.I
	1:33	I.Sh.I
	2:39	I.Tr.E
	3:50	I.Sh.E
	8:48	II.Tr.I
	11:11	II.Sh.I
	11:40	II.Tr.E
	14:03	II.Sh.E
	21:41	I.Oc.D
Apr. 13	1:12	I.Ec.R
	18:50	I.Tr.I
	20:01	I.Sh.I
	21:07	I.Tr.E
	22:18	I.Sh.E
Apr. 14	2:55	II.Oc.D
	8:13	II.Ec.R
	16:09	I.Oc.D
	19:40	I.Ec.R
	20:10	III.Tr.I
	23:46	III.Tr.E
Apr. 15	1:01	III.Sh.I
	4:38	III.Sh.E
	13:18	I.Tr.I
	14:30	I.Sh.I
	15:35	I.Tr.E
	16:47	I.Sh.E
	22:03	II.Tr.I
Apr. 16	0:29	II.Sh.I
	0:55	II.Tr.E
	3:21	II.Sh.E
	10:38	I.Oc.D
	14:09	I.Ec.R
Apr. 17	7:46	I.Tr.I
	8:59	I.Sh.I
	9:45	IV.Tr.I
	10:03	I.Tr.E
	11:16	I.Sh.E
	14:31	IV.Tr.E
	16:10	II.Oc.D
	21:15	IV.Sh.I
	21:31	II.Ec.R
Apr. 18	1:57	IV.Sh.E
	5:06	I.Oc.D
	8:38	I.Ec.R
	10:05	III.Oc.D
	13:45	III.Oc.R
	15:06	III.Ec.D
	18:46	III.Ec.R
Apr. 19	2:15	I.Tr.I
	3:28	I.Sh.I
	4:31	I.Tr.E
	5:44	I.Sh.E
	11:19	II.Tr.I
	13:47	II.Sh.I
	14:11	II.Tr.E
	16:39	II.Sh.E
	23:34	I.Oc.D
Apr. 20	3:07	I.Ec.R
	20:43	I.Tr.I
	21:56	I.Sh.I
	23:00	I.Tr.E
Apr. 21	0:13	I.Sh.E
	5:26	II.Oc.D
	10:49	II.Ec.R
	18:02	I.Oc.D
	21:35	I.Ec.R
Apr. 22	0:00	III.Tr.I
	3:36	III.Tr.E
	5:01	III.Sh.I
	8:37	III.Sh.E
	15:11	I.Tr.I
	16:25	I.Sh.I
	17:28	I.Tr.E
	18:42	I.Sh.E
Apr. 23	0:35	II.Tr.I
	3:05	II.Sh.I
	3:27	II.Tr.E
	5:57	II.Sh.E
	12:31	I.Oc.D
	16:04	I.Ec.R
Apr. 24	9:39	I.Tr.I
	10:54	I.Sh.I
	11:56	I.Tr.E
	13:11	I.Sh.E
	18:42	II.Oc.D
Apr. 25	0:07	II.Ec.R
	6:59	I.Oc.D
	10:33	I.Ec.R
	13:57	III.Oc.D
	16:55	IV.Oc.D
	17:37	III.Oc.R
	19:05	III.Ec.D
	21:47	IV.Oc.R
	22:45	III.Ec.R
Apr. 26	4:08	I.Tr.I
	5:03	IV.Ec.D
	5:23	I.Sh.I
	6:25	I.Tr.E
	7:40	I.Sh.E
	9:51	IV.Ec.R
	13:52	II.Tr.I
	16:23	II.Sh.I
	16:44	II.Tr.E
	19:15	II.Sh.E
Apr. 27	1:27	I.Oc.D
	5:02	I.Ec.R
	22:36	I.Tr.I
	23:51	I.Sh.I
Apr. 28	0:53	I.Tr.E
	2:08	I.Sh.E
	7:59	II.Oc.D
	13:26	II.Ec.R
	19:56	I.Oc.D
	23:30	I.Ec.R
Apr. 29	3:54	III.Tr.I
	7:31	III.Tr.E
	9:01	III.Sh.I
	12:37	III.Sh.E
	17:05	I.Tr.I
	18:20	I.Sh.I
	19:22	I.Tr.E
	20:37	I.Sh.E
Apr. 30	3:09	II.Tr.I
	5:41	II.Sh.I
	6:01	II.Tr.E
	8:33	II.Sh.E
	14:25	I.Oc.D
	17:59	I.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 is gradual, taking up to several minutes. Predictions courtesy IMCCE / Paris Observatory.

Faulting the Lunar Crust

Subtle cracks and creases betray shifts in the lunar landscape.

DAVID STOREY



NASA / GSFC / LOLA SCIENCE TEAM

Top: The Apennine Front consists of towering peaks along the southeastern margin of Mare Imbrium. Sunlight gleams from stark fault scarps where slabs of rim dropped toward the basin floor. *Above:* A map from the LOLA altimeter on NASA's Lunar Reconnaissance Orbiter shows that slopes in this region can exceed 30°.

Fifty years of deep-space exploration have revealed this fundamental truth: impact cratering is far and away the most common geologic process on solid bodies in our solar system. But faulting is high on the list too.

Our planet's crust is cut by thousands of faults, most resulting from the movement of the 100-kilometer-thick slabs of brittle rock that form Earth's crust. Most faults either slide these crustal plates horizontally past each other (California's San Andreas Fault comes to mind) or into each other, such as where the Pacific Ocean's Nazca Plate dives under the continent of South America.

By contrast, the Moon displays only a handful of obvious faults — and none was caused by plate movements. The Moon's most famous fractures are **Rupes Recta** (the classic Straight Wall) in southeastern **Mare Nubium** and **Rupes Cauchy** in northeastern **Mare Tranquillitatis**. In both cases one side of the mare's surface has dropped down a few hundred meters compared to the other.

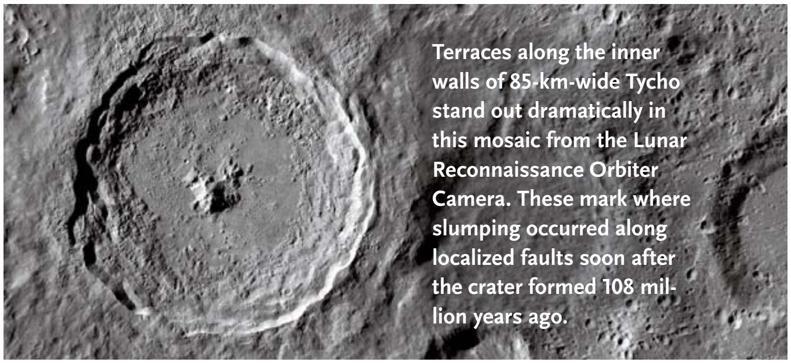
But thousands of other lunar faults abound that we never think of as such. Impact craters larger than about 15 km wide initially had walls too steep to be held in place by the strength of the lunar rocks. So huge slabs of the inner walls broke away and slid down as large blocks, creating giant concentric terraces. These movements occurred along fault planes that are often visible today as bright scarps just below crater rim crests. Look for them along the tops of the inner walls of **Copernicus**, **Theophilus**, **Tycho**, and other large "fresh" craters.

Telescopic observations made before the Space Age suggested that the slopes of these rim crests are inclined as much as 40° to 50°. Thanks to altimetric data from the Lunar Reconnaissance Orbiter (LRO), it's now possible to measure these slopes much more accurately. The steepest ones are generally 35° to 40°, implying that the narrow scarps along rim crests are even steeper. You can search for these by looking for ribbons of shadow hugging the rim crests of craters, after the Sun has locally risen high enough to illuminate more gently sloping topography.

The biggest faults on the Moon occur on the rims of the biggest craters. For example, the **Montes Apenninus** (Apennine Mountains) mark the edge of the 1,160-km-wide Imbrium Basin. Like a crater rim, this towering arc has a steep side facing the interior of the basin and a gentler slope gradually radiating outward. The 600-km-long Apennines rise more than 4 km above the adjacent **Mare**

Imbrium. This inner face, called the Apennine Front, is the top of a deep fault formed when the floor of the original Imbrium basin subsided. The fault probably slices 30 to 40 km down into the crust, curving inward with depth.

Another giant impact-generated fault scarp is visible as the inward face of the **Rupes Altai**, a mountain arc that rims the Nectaris basin and lies about 200 km southwest of **Mare Nectaris** itself. Most other nearside basins are too old to have retained their rims' fault-faced scarps.



Terraces along the inner walls of 85-km-wide Tycho stand out dramatically in this mosaic from the Lunar Reconnaissance Orbiter Camera. These mark where slumping occurred along localized faults soon after the crater formed 108 million years ago.

NASA / GSFC / ARIZONA STATE UNIV.

Stealth Faulting

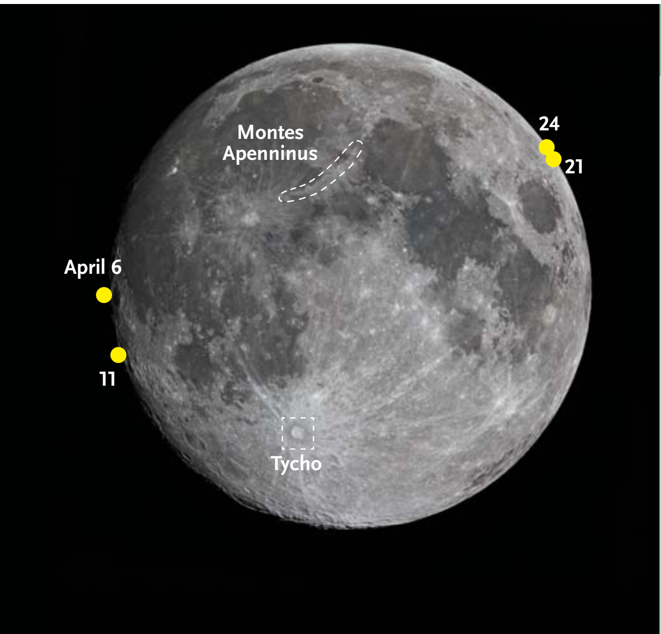
An unexpected class of lunar faults show up as the low, sinuous ridges (*dorsa*) common in all maria. The most famous of these, informally named **Serpentine Ridge**, runs north-south for about 350 km along the eastern edge of **Mare Serenitatis**.

For a long time these features were called "wrinkle ridges," which described how we thought they formed. As with some mountains on Earth, geologists thought wrinkle ridges resulted from horizontal compression that caused folding. On Earth, the compressional force is due to collisions between plates, and the mountain ranges thus created are a few hundred kilometers wide and 5 to 10 km high. But the Moon's wrinkle ridges are very different, typically only about 5 to 20 km wide and just 100 to 300 m high. With slopes of only a few degrees, they can be easily observed only with low angles of illumination.

The mare ridges in Mare Serenitatis imply that these ridges formed due to a combination of folding and faulting. Imagine going back in time to watch the evolution of a just-formed impact basin, 500 km across. In time, lava flows erupt from the heavily fractured floor and fill the basin to a depth of 4 or 5 km in the middle, thinning to nothing at the outer margins. All that added mass causes the basin's interior to sag, squeezing the now-solid pile of lava into a depression of smaller radius. This compression perhaps creates some folding concentric with the basin margin, but most of the volume reduction involves low-angle faults that thrust adjacent layers of lava over one another. Few of these faults actually breach the surface, but the ones at shallow depth trigger compressional folding in the topmost layers of lava — creating wrinkle ridges.

Curiously, LRO altimetry data show that the inward-facing sides of many mare ridges are 50 to 200 m lower than their outer sides. This agrees with evidence from old Apollo ground-penetrating radar scans. Intriguingly, concentric mare ridges also occur at about the same relative distance from a basin's center as do the inner rings of basins not inundated with lava (such as Orientale). And we see the same thing on a smaller scale where mare ridges mark the rims of buried impact craters, such as the one just south of **Lambert** in Mare Imbrium.

So mare ridges appear to be triggered by underlying topography of one kind or another. Keep a lookout for these and other faulty features when you're next eyeing the lunar landscape through your telescope. ✦



The Moon • April 2015

Phases		Distances		Librations
FULL MOON April 4, 12:06 UT		Apogee 252,284 miles	April 1, 13^h UT diam. 29′ 26″	Krasnov (crater) April 6
LAST QUARTER April 12, 3:44 UT		Perigee 224,330 miles	April 17, 4^h UT diam. 33′ 6″	Rydberg (crater) April 11
NEW MOON April 18, 18:57 UT				Vashakidze (crater) April 21
FIRST QUARTER April 25, 23:55 UT		Apogee 251,706 miles	April 29, 4^h UT diam. 29′ 30″	Boss (crater) April 24

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

S&T: DENNIS DI CICCO

Spring's Hit Parade

A blood-red gem and a misty bird of prey top the charts.

Judy Schmidt reprocessed this Hubble mosaic of M82 to draw out the background clusters and stippled star field.

NASA / ESA / THE HUBBLE HERITAGE TEAM (STSCI/AURA) / JUDY SCHMIDT

I'm guilty. Like many other observers, I spend much of my time on challenges, but little on showpieces of the night sky — except when I'm showing them to others. So, this month, let's focus on celestial treasures that are among the best in their class and well-placed for observers at mid-northern latitudes throughout April and May. I've had fun revisiting them, and I hope you will too.

Among the galaxies, I believe **Messier 82** best fulfills the prerequisites for this article. It's a spectacular galaxy in its own right, and its neighbor **Messier 81** makes any field of view large enough to include both galaxies a real treat to behold. The pair is lovely and quite nicely framed through my 130-mm refractor armed with a wide-angle eyepiece that gives a magnification of 63×. It's amazing how much detail M82 shows when I take time to study it carefully. The galaxy's hallmark dust lanes slant across its cigar-like profile, carving it into vaguely triangular sections. M81 shows a tiny, very bright nucleus embedded in a large, bright, oval core that's mantled in a faint halo. A dim star is superimposed on the south-southeastern fringe of the core, and another (south-southwest of the first) tacks down the galaxy's halo.

Pretty as this scene is, don't miss the chance to observe M82 at higher magnifications. Boosting the power to 117×, I find the galaxy's complex structure considerably easier to discern. I was pleasantly surprised to see that Supernova 2014J was still visible against the galaxy when I sketched M82 for this article on March 18, 2014. Most of M82's supernovae are obscured by dust clouds and escape detection, especially at visible wavelengths.

M82's tortured appearance is probably due to a past encounter with massive M81 and the ongoing torrent of star formation triggered by it.

My "best in show" for planetary nebulae is **Messier 97**,

The author's sketch of M97 as viewed through her 130-mm refractor shows how the object earned the nickname "Owl Nebula".

the Owl Nebula. Through 15×45 image-stabilized binoculars, the Owl is fairly easy to see as a little round patch of mist. M97 and three stars form a pattern that reminds me of an upside-down Southern Cross (Crux). The nebula marks the figure's eastern corner, and the stars shine at 7th and 8th magnitude.

The Owl Nebula is quite evident in my 130-mm scope at 23×. It appears round and grey, and it has fairly uniform surface brightness. A 12th-magnitude star perches just off its north-northeastern edge. With a bit of attention, the dusky eyes that give the Owl its name aren't difficult to discern at 63×; at 91× the nebulosity between the eyes looks brighter than the sides of the Owl's face. Contrast between light and dark areas is often exaggerated on my sketches because I draw them using a dim, red light.

M97's central star has a visual magnitude of 15.8. Some folks claim that it can be seen with an 8-inch scope, while others say that a substantially larger telescope is needed. Let's put that to a test. Try to observe the central star for yourself, and let me know what size scope and what magnification you used, as well as any conditions that affected your observation. Positive and negative sightings are both welcome. I'll report the results next year when we can see the Owl again.

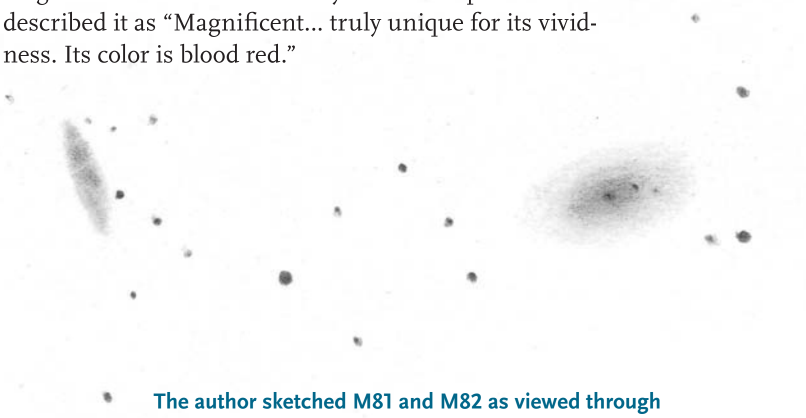
Those with large telescopes should try for PGC 34279 (MCG +09-19-014), a little 15.7-magnitude galaxy located 3.8′ south-southeast of M97's center. A 14th-magnitude star rides on its northeastern flank. The galaxy has been observed with scopes as small as 14.5 inches in aperture. Together with M97, PGC 34279 makes an intriguing target for astrophotographers.

For our multiple star, let's visit Zeta (ζ) Ursae Majoris, better known as **Mizar**. Its two visual components make up the first physical pair discovered with a telescope. In 1617 Benedetto Castelli, calling Mizar "one of the most beautiful things in the sky," asked his friend Galileo to look at it. Galileo's remarks describe an unequal pair with a 15″ separation. Leos Ondra's fascinating quest for the story behind Mizar's discovery can be read in full at **http://www.leosondra.cz/en/mizar/**.

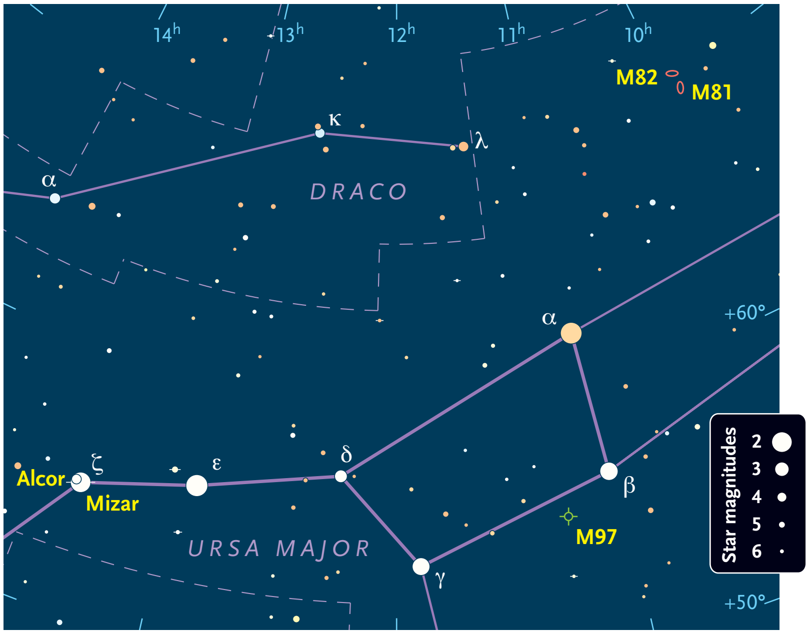
With good vision and a moderately dark sky, you can see 4th-magnitude **Alcor** near Mizar. Observed by Galileo, this pair is within reach of any modern telescope. The three stars shine nearly pure white in my 105-mm refractor at 47×; they're the brightest stars in the field of view.

Each star of the Mizar pair has a close companion detected by telltale signs in its spectra, making Mizar a quadruple system. In the March 2010 *Astronomical Journal*, Eric E. Mamajek and colleagues announced the discovery of a red dwarf companion to Alcor. Only 1.1″ from Alcor, the companion was imaged using the 6.5-meter MMT telescope in Arizona. The authors also employed modern astrometric data to explore the relationship between Mizar and Alcor. They suggest that Mizar and Alcor form a probable sextuple system, making it the second-closest sextuplet to us after the Castor system, at 82 and 53 light-years, respectively. Neil Zimmerman and colleagues independently discovered Alcor's companion and reported it in the February 1, 2010 *Astrophysical Journal*.

Among the carbon stars, I give my nod to beautiful, deeply reddish orange **Y Canum Venaticorum**. In his 1877 book *Le Stella*, spectroscopy pioneer Father Pietro Angelo Secchi called this ruddy star "La Superba." He described it as "Magnificent… truly unique for its vividness. Its color is blood red."



The author sketched M81 and M82 as viewed through her 130-mm refractor at 63×.



Y CVn is the second-brightest carbon star, topped only by autumn's 19 Piscium (TX Psc). In fact, both stars are variable with almost the same maximum brightness, so you could arguably say they vie for first place. Y CVn is a pulsating star that slowly expands and contracts. Although you can usually spot it in a dark sky, you'll need binoculars or a telescope to enjoy its color. Carbon stars are red giants with atmospheres rich in carbon-bearing molecules that absorb blue light, making them look redder than ordinary giants. If you have trouble seeing color in the stars, this is definitely one for you to try.

My globular cluster of choice is **Messier 3**. Through my 18×50 image-stabilized binoculars, M3 is ensconced in a right triangle of stars. The cluster displays a moderately faint halo about 10′ across that looks a bit grainy. The globe becomes suddenly brighter about halfway in, then intensifies dramatically toward the center, where dwells a brilliant point of light. In my 130-mm refractor at 48×, this beautiful cluster spans about 15′. The halo is resolved into stars, and the outer core appears partly resolved. At 117× the outer halo seems loosely populated, while the inner halo and outer core wear a sprinkling of somewhat brighter stars over a fainter mob. The core is a blaze that brightens toward the center, and it's accented with several star-specks competing with its glare.

M3 holds a whopping 300,000 stars and lives 33,000 light-years away from us.

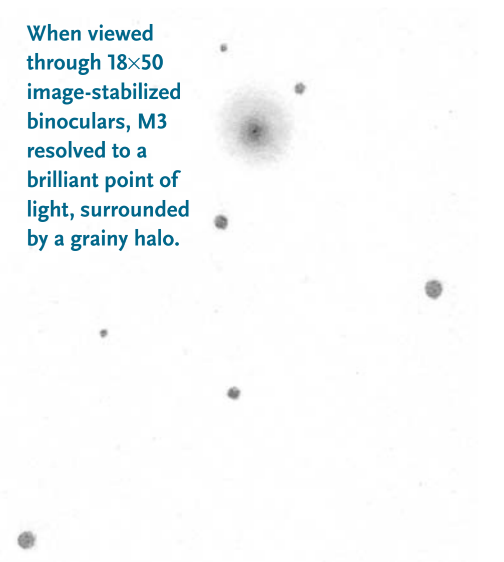
For an open cluster, I've chosen the **Coma Star Cluster** (Melotte 111). How can you beat a cluster that's as big across as 10 full Moons? Looking up on a nice night, I can see about 10 stars, and there's a vague impression of fuzziness in the area. Observers under dark skies have reported seeing two dozen stars. Few telescopes can encompass the entire cluster, so this is one for binoculars. Through my 10×30 image-stabilized binoculars, most of the bright stars seem to outline a fancy vase with inwardly curved sides. The main body sports about 20 bright and 30 dimmer stars, while a sparse area south of the vase adds 5 bright and 15 faint suns. The brightest gem within the apparent boundaries of the cluster is golden Gamma (γ) Comae in the far-northern reaches of the cluster, but it's actually a foreground star. Can you see color in any of the other stars?

If you're now asking "Why didn't she choose…?", tell me about your nominees and perhaps we can do this again next year. ✦

Sue's Spring Hits

Object	Con	Type	Mag(v)	Size/Sep	RA	Dec.
M81	UMa	Spiral galaxy	6.9	26.9′ × 14.1′	9^h 55.6^m	+69° 04′
M82	UMa	Starburst galaxy	8.4	11.2′ × 4.3′	9^h 55.9^m	+69° 41′
M97	UMa	Planetary nebula	9.9	3.5′	11^h 14.8^m	+55° 01′
Mizar/Alcor	UMa	Double star	2.2, 3.9/4.0	14.4″/11.8′	13^h 23.9^m	+54° 56′
Y CVn	CVn	Carbon star	4.9–5.9	—	12^h 45.1^m	+45° 26′
M3	CVn	Globular cluster	6.2	18′	13^h 42.2^m	+28° 23′
Coma Star Cluster	Com	Open cluster	1.8	5°	12^h 25.1^m	+26° 07′

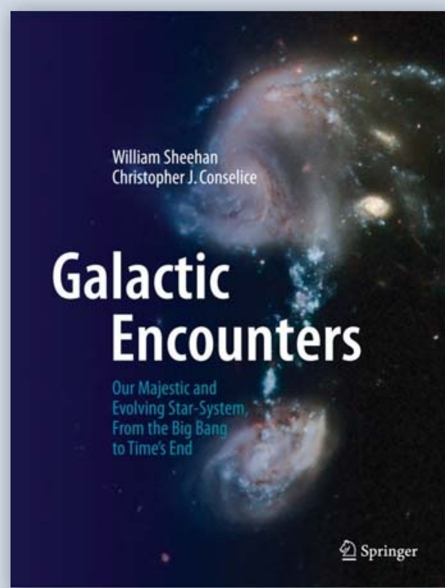
Angular sizes and separations are from recent catalogs. Visually, an object's size is often smaller than the cataloged value and varies according to the aperture and magnification of the viewing instrument. Right ascension and declination are for equinox 2000.0.


When viewed through 18×50 image-stabilized binoculars, M3 resolved to a brilliant point of light, surrounded by a grainy halo.

Our Place in the Universe

Galactic Encounters: Our Majestic and Evolving Star-System, From the Big Bang to Time's End

William Sheehan and Christopher J. Conselice
Springer, 2015
385 pages, ISBN 978-0-387-85346-8, $44.99, hardcover.



IF *GALACTIC ENCOUNTERS* IS an example of the type of book William Sheehan and Christopher Conselice can produce together, I hope they're planning on more collaborations in the future.

At first glance, *Galactic Encounters* appears to be a college reader; its hardback heft led me to expect problem sets at the end of every chapter. But this is really less a textbook and more the telling of a tale. Sheehan and Conselice have written a sweeping history of the study of galaxies by European and American astronomers — how these men and women came to grips with the unknown, the unseen, and the observationally abstruse. Indeed, a more appropriate subtitle for this work would have been "***A History of Our Understanding of*** *Our Majestic and Evolving Star-System*," as most of the book isn't about galactic science *per se*, but about the long process of evaluating scientific evidence, starting with Messier's lists of nuisance nebulae (1771, 1780, and 1784). Only slowly did astronomers recognize that Messier's fuzzies represented a diversity of objects; his final list included nebulae, globular and open clusters, and some 42 galaxies — spiral, lenticular, elliptical, and irregular — all of which offered evidence as to the origin of our own galaxy, the Milky Way.

This is history filtered through often heroic, but sometimes miserable, biography — of Messier, Herschel(s), Parsons, Bond, Huggins, Barnard, Hale, Shapley, Leavitt, Hubble, and others. Drawing on letters, journals, professional publications, and personal anecdotes, Sheehan and Conselice breathe new life into these astronomers, humanizing them with details taken from their quotidian domestic and professional lives. Indeed, my reading experience was lengthened, yet enriched, as I fell into every rabbit hole the authors dug for me. I played William Herschel's Symphony No. 8, picked up a volume of Walt Whitman's poetry, and read Christopher Marlowe's *The Tragical History of Doctor Faustus*, all the while contemplating the connections to the history of galactic science.

The book concludes with several chapters on the current state of research on galaxy formation, dark matter, and dark energy. For me, however, the climax of the story came much earlier, when astronomers realized that the distribution of O and B stars revealed the structure of our own galaxy. The intensity of work done to map the Perseus and Orion Arms comes across clearly in the prose of Sheehan and Conselice, but the tale is made even more poignant with the description of visual astronomer W. W. Morgan's "complete personal crisis," the timing of which prevented him from being fully credited with the discovery of the Milky Way's spiral arms. Finding our place in the galaxy must have been rewarding for him, but it came at a very dear price.

Galactic Encounters is available as an e-book, but I hope Springer finds a way to release it as a paperback as well. While the current layout does great service to the illustrative charts and photographs, the story is so readable and engaging that it seems a shame not to reach for an even wider reading audience. ✦

S&T *Observing Editor* ***S. N. Johnson-Roehr*** *loves reading even more than she loves astronomy.*

Night Flight

Astronomy Aboard SOFIA

After two decades of trials and tinkering, the Stratospheric Observatory for Infrared Astronomy (SOFIA) is finally flying high.

J. Kelly Beatty

"First Class" here isn't exactly posh — the cloth-covered seats date from the 1980s, it's cold and noisy, and there's no food service or even hot coffee. But that's not why I've boarded this repurposed Boeing 747SP aircraft. On tonight's red-eye over the Pacific Ocean, it's all about the in-flight entertainment: a chance to see the universe in ways that just aren't possible from the ground.

SOFIA, the Stratospheric Observatory for Infrared Astronomy, soars to altitudes at or above 12 kilometers (39,000 feet). From these heights, above 99% of the atmosphere's infrared-blocking water vapor, the craft's compact, 2.5-meter (100-inch) telescope can be trained on targets in the "warm universe" — anything from nearby asteroids to star-forming regions in remote galaxies.

NASA acquired this 747SP in 1997 from United Airlines, which in turn had bought it in 1986 from the now-defunct airline Pan Am, which had flown it since 1978. The gleaming white fuselage is still emblazoned with *Clipper Lindbergh*, the plane's original name, but nothing of the once-opulent interior remains. It took nearly a decade and $800 million for contractors to gut the interior and install the telescope, which was fabricated by the German Aerospace Center (DLR), NASA's partner for this

NASA's Stratospheric Observatory for Infrared Astronomy takes off from Palmdale, California, at sunset to begin a full night of astronomical observations. NASA / CARLA THOMAS project (*S&T*: October 2010, p. 22). Day-to-day operations are managed for NASA by Universities Space Research Association (USRA).

The telescope itself is open to the air at high altitude and hidden behind a thick bulkhead that isolates it from the crew compartment. The telescope looks out through a gaping, 5.5-by-4.1-meter (18-by-13½-foot) hole in the aircraft's port (left) side. It can tilt up and down to elevations from 20° to 60° above horizontal. Pointing in azimuth is done by turning the whole airplane. A sliding door covers the opening until it's time to observe, and a spoiler on the hole's leading edge reduces turbulence.

Jutting from the bulkhead into the pressurized cabin are the telescope's focal plane, a massive counterweight, and FORCAST, a beefy Cornell-built camera that records a small patch of sky 3.2 arcminutes square. FORCAST is equipped with 13 mid-infrared filters spaced in wavelength between 5 and 40 microns, or about 10 to 80 times the wavelength of visible (green) light. It also has six grating prisms ("grisms") to spread the incoming infrared light into spectra. Liquid nitrogen keeps the detector array cryogenically chilled, so that its own infrared glow doesn't overwhelm its view of the sky.

Instrument scientist Andrew Helton runs through the night's target list with me:

• U Monocerotis, a dying supergiant star, is an RV Tauri type of pulsating variable. Observers want to know more about the shells of dust that it has ejected.

• VY Canis Majoris, a red hypergiant star with 40 times the Sun's mass, is sometimes cited as the largest star known, larger than the orbit of Jupiter. Its past eruptions can be analyzed by recording the faint shells of cool dust surrounding it. "A difficult observation," Helton cautions.

• NGC 3501, an edge-on spiral galaxy in Leo, will be scanned to see how much dust has settled to its midplane versus how much is distributed above and below the disk.

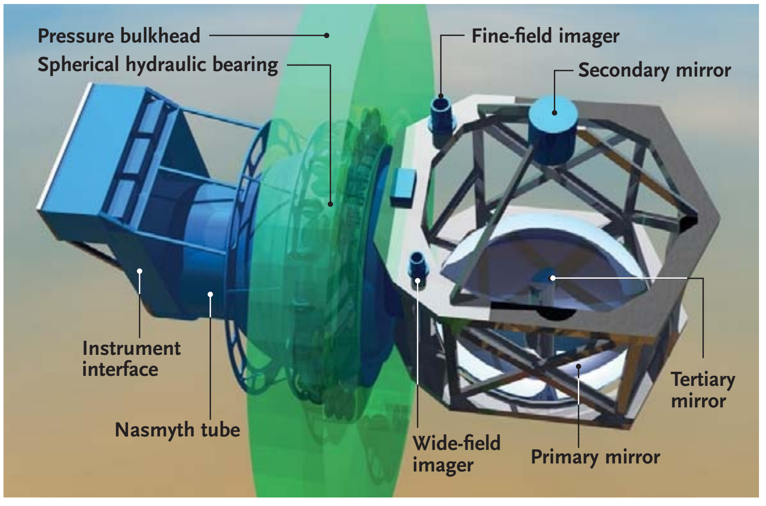
• Asteroid 2 Pallas is on the list for two reasons. This reddish object serves as a calibration target, and Franck Marchis (SETI Institute), who's aboard, also wants to probe the dust layer on its surface.

• The night's main attraction is the Cigar Galaxy (M82) and specifically SN 2014J — the brightest supernova in decades — blazing in its disk. Astronomers had captured the outburst with another instrument on a prior SOFIA flight, but tonight a trio of observers led by William Vacca (USRA) hopes to record an emission line at 11.9 microns. This is from doubly ionized cobalt atoms in the blast wave; cobalt is a decay product from the radioactive nickel-56 synthesized in the stellar explosion, and this decay keeps supernova shells glowing brightly for months after they explode.

Vacca says it's a challenging observation: look for the cobalt emission too soon after the star explodes, and the supernova's expanding shell will be too opaque; look

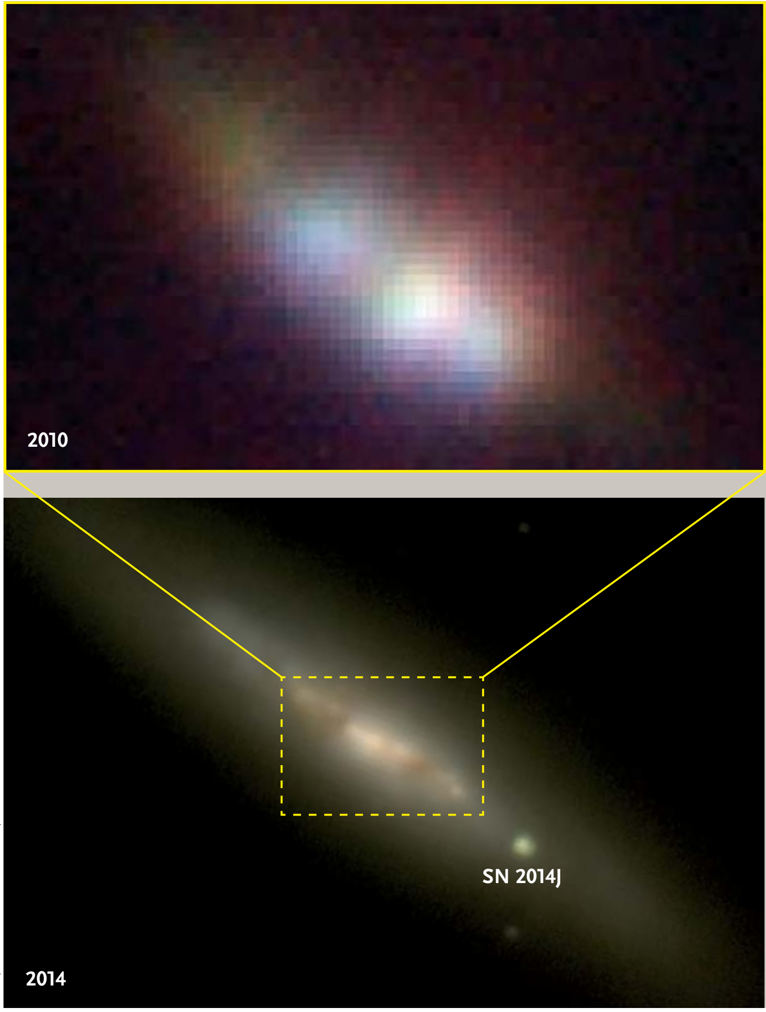
NASA / JIM ROSS

NASA / TOM TSCHIDA



DAVID BLACK / ROSIE BUHRLEY

Top: A jet airplane with a huge rectangular opening in its fuselage is an unlikely sight. This view of SOFIA over remote California terrain was taken during test flights in 2010. *Middle*: The telescope looks out through a 5½-by-4-meter (18-by-13½-foot) opening in the fuselage, which is covered by a huge sliding door until the plane reaches high altitude. A thick bulkhead separates the telescope compartment from the passenger cabin and incorporates a huge spherical bearing, shock absorbers, and gyroscopes to control the telescope's motion.



NASA / FORCAST SCIENCE TEAM / FLITECAM SCIENCE TEAM (2)

Science From SOFIA

SOFIA's telescope is modest compared to the giants at modern ground-based observatories, but those are limited to viewing only in a few near-infrared wavelengths due to atmospheric absorption. Meanwhile, infrared-sensing space telescopes such as Spitzer and Herschel, having run out of cryogenic coolant, can no longer record the longer-wavelength radiation from very cold cosmic sources.

That leaves SOFIA in a unique position to collect images and spectra throughout the infrared spectrum: at wavelengths from 1 to 1600 microns. Since the plane's "first light" flight in mid-2010, astronomers have used it to probe scores of targets. U.S.-funded research takes up 80% of the flight hours, while German astronomers get 20%. SOFIA's instruments are typically used in rotation, each getting bolted to the telescope for several flights before mechanics switch it out for another.

Eight reports of early science results from the flying observatory were showcased in a special 2012 issue of *Astrophysical Journal Letters.* More recently, both FORCAST and FLITECAM were used to record Supernova 2014J, and over the next year astronomers will use SOFIA to study a wide range of planetary atmospheres, interstellar clouds, protoplanetary disks, and ejected matter from novae and supernovae.

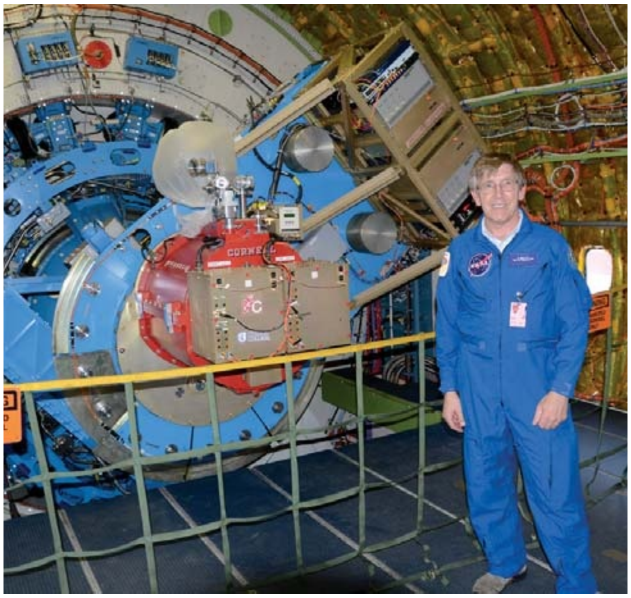
Upper left: **The heart of the Cigar Galaxy, M82, was an early target for SOFIA and its FORCAST camera at wavelengths of 20, 32, and 37 microns.** ***Left:*** **The near-infrared view of M82 — and Supernova 2014J — captured by the FLITECAM instrument.**

too late, and the cobalt will have spread out too far and become too dim. "We're hoping it's the right time," he says. The flight plan calls for SOFIA's telescope to stare at SN 2014J for nearly 3 hours.

Take-off is scheduled for 6:37 p.m. I settle into one of the vintage first-class seats as the Sun lingers over the western horizon. But murmuring in the cabin signals that something is amiss. Soon flight director Randy Grashuis gathers everyone and delivers the bad news: there's an errant flap sensor in the cockpit display. The flap itself is OK, but the sensor is dead. Unless a replacement is found fast, tonight's flight will be scrubbed.

"Not again!" I groan.

My efforts to ride SOFIA go back to 2011, when I'd watched three chances come and go. Too much rain foiled the first attempt, and a schedule mismatch scuttled the second. For the third try, I headed to SOFIA's home base, NASA's Dryden Aircraft Operations Facility in Palmdale, California, and completed all the requisite preflight training for that evening's flight. Then it snowed — *in the Mojave Desert!* The flight was canceled because DAOF, understandably, has no snowplows.



S&T: J. KELLY BEATTY

The author poses with the business end of SOFIA's telescope: the bulkhead, Cornell's half-ton FORCAST camera/spectrometer, and a counterweight at top center containing racks of electronics.

SOFIA was grounded the following year for a series of equipment and electronics upgrades. Undaunted, I strapped in for a flight in March 2013. But an hour after takeoff, low oil-pressure warnings in two engines forced an early return to Palmdale.

In three years of trying, I am 0-for-5 — and now my Flight Attempt Number 6 isn't going well either.

Fortunately, standing idle on the tarmac nearby is one of NASA's *other* 747s, one once used to ferry Space Shuttles piggyback across the country. Mechanics raid its cockpit for the needed part and make the swap in record time. The plane's tires finally lift off the runway at 8:56 p.m. — just minutes before the flight would be scrubbed.

Time Management

We're airborne, but we've lost nearly 2½ hours of flying time — and compromises must be made. While the mechanics were preoccupied with the flap sensor, science flight planner Karina Leppik and copilot Wayne Ringelberg had huddled tensely around a computer display of possible reroutings. Their eventual Plan B preserves the observations of VY CMa, Pallas, and SN 2014J, along with an hour of staring at Arcturus as a calibration target. Losing out, tonight at least, are U Mon and NGC 3501.

The plane makes a beeline for the coast and, after threading a narrow corridor between restricted airspaces, heads out over the Pacific Ocean for the first of five long legs that will take until nearly dawn to complete. Everyone settles in for the all-nighter ahead.

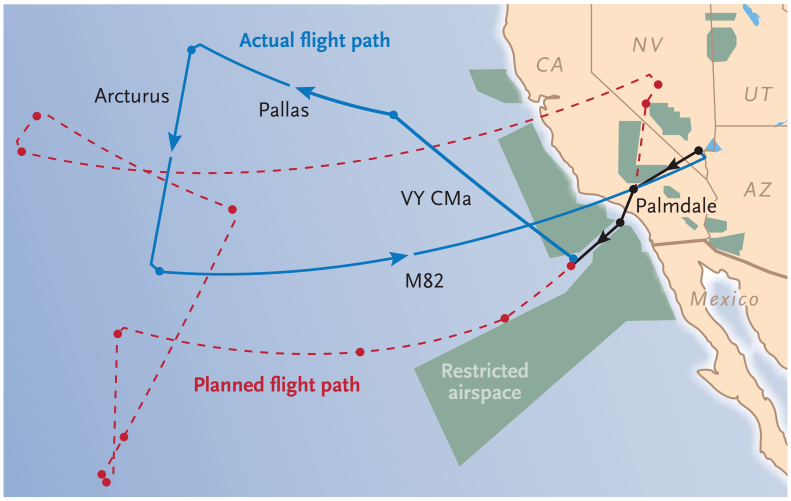
After passing through about 30,000 feet, Grashuis makes the call to slide open the giant barrel door in the fuselage. I expect to hear a deep-throated *whoosh* or feel some vibration to signal that stratospheric air is rushing past a huge hole in the plane's side at Mach 0.85. But nothing like that happens — in fact, the only indication that the door really *has* opened is a graphic on one of the computer monitors.

A glance aft at the big bulkhead shows the focal plane, counterweight, and FORCAST moving slightly, up and down, side-to-side. But in reality the 17-ton telescope's pointing is rock-solid, steadied to 0.35 arcsecond in some modes; the gentle nodding actually betrays the slight pitch, yaw, and roll of the plane around it.

The 2.7-m primary mirror has an effective aperture of 2.5 m because of its large secondary and other factors, and the overall optical path is f/20. The atmospheric seeing out the door typically limits resolution to 2 to 4 arcseconds even at altitude. That would be a problem for a visual observer back on Earth, but deep in the infrared, it's less than the diffraction limit for a telescope of this size at wavelengths greater than 15 microns.

We zigzag our way over the open ocean, completing the VY CMa and Pallas legs. There's a deceptive calm in the cabin, as 13 scientists and operators stare intently into their consoles. Tight time constraints mean the observing

S&T: J. KELLY BEATTY

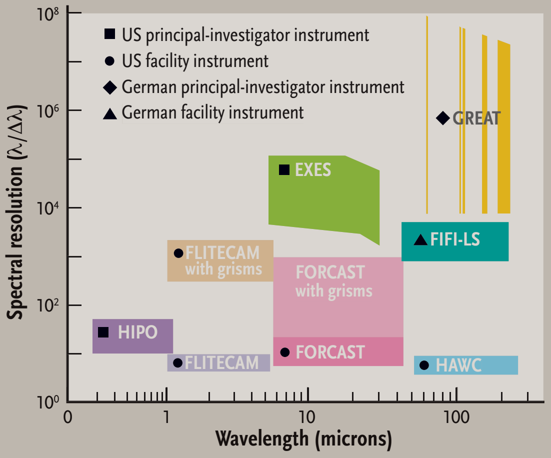


S&T: LEAH TISCIONE, SOURCE: USRA / KARINA LEPPIK

S&T: J. KELLY BEATTY

Top: **Science flight planner Karina Leppik and copilot Wayne Ringelberg work out a new flight plan after takeoff was delayed by more than 2 hours. *Middle*: Because the telescope stares out the port (left) side of the fuselage, SOFIA's pilots must execute a convoluted flight plan to put all the night's targets within view. This plot shows the original itinerary (red) and the abbreviated routing (blue) necessitated by a delayed takeoff. Green polygons denote restricted airspace. *Bottom:* Parked near SOFIA's hangar is one of two 747 aircraft that NASA once used to ferry Space Shuttle orbiters across the country.**

SOFIA's Instruments: Eyes on the Infrared Sky



Abbrev.	Name	Institution	Wavelengths (microns)
EXES	Echelon-Cross-Echelle Spectrograph	UC Davis	4.5 – 28 μ
FIFI-LS	Field Imaging Far-Infrared Line Spectrometer	Univ. of Stuttgart	50 – 200 μ
FLITECAM	First Light Infrared Test Experiment Camera	UC Los Angeles	1 – 5 μ
FORCAST	Faint Object Infrared Camera for the SOFIA Telescope	Cornell University	5 – 40 μ
GREAT	German Receiver for Astronomy at Terahertz Frequencies	Max Planck Institute	60 – 200 μ
HAWC	High-resolution Airborne Wideband Camera (ready in 2016)	Jet Propulsion Lab.	50 – 240 μ
HIPO	High-speed Imaging Photometer for Occultations	Lowell Observatory	0.3 – 1.1 μ

Astronomers flying on SOFIA can make their observations using one of several instruments designed to probe different parts of the infrared spectrum. Two additional instruments are under construction. In the chart, *Spectral Resolution* denotes how finely the target's infrared spectrum is recorded.

S&T: LEAH TISCIONE, SOURCE: NASA / USRA

sequences have to be accomplished quickly and efficiently. "It's a completely new way to observe," one first-time researcher tells me, "with a level of anxiety and nervousness I've never had before."

Four hours into the flight, we turn eastward for the long stare at M82. The recast flight plan has preserved almost all of this critical observation, because FORCAST will need every photon it can get to detect the weak cobalt emission line. In the end, however, even 140 minutes of dedicated staring wasn't enough. "Unfortunately, the supernova wasn't detected," Vacca admits. "It's simply a case of the line being too weak to detect with a smallish telescope in the presence of the atmosphere's strong background — even from SOFIA."

By now we've cleared the coastline, and the predawn lights of Las Vegas twirl below as SOFIA makes the turnaround that leads back to Palmdale. I head to the surprisingly cramped cockpit to watch the pilots execute the final approach. We land in darkness, with dawn's early glow just breaking in the east.

SOFIA FAST FACTS

- One of 45 747SP aircraft built; only 14 are still flying
- Maiden flight: April 26, 2007; first light: May 26, 2010
- Wingspan (196 feet) exceeds length (185 feet)
- Mass at takeoff: 696,000 pounds (315,700 kg)
- Range: 6,625 nautical miles (12,270 km)
- Mission duration: 7 to 9 hours (12 hours maximum)
- Port door: 5.5 by 4.1 m (18 by 13.5 feet)
- Telescope: 34,000 pounds (15,500 kg); f/19.7 optics
- Primary mirror: Schott Zerodur; 2.7 m (oversize) f/1.3

Riding Out Some Turbulence

The pilots and crew make it look easy, but getting SOFIA to this point has been far more challenging than originally envisioned. The project began back in 1997, but the repurposed plane didn't make its initial test flight until mid-2007, and its telescope finally feasted on starlight while airborne three years later. Paul Hertz, who heads NASA's astrophysics program, didn't declare SOFIA fully operational until June of last year.

Soon afterward the plane was flown to Hamburg, Germany, for six months of "heavy maintenance" performed by Lufthansa Tecknik and DLR. Technicians removed the engines and stripped away panels to check for corrosion and cracks in the 36-year-old airframe. Science flights are again happening regularly now, and more than 70 observing proposals are queued up for 2015.

Observers appreciate SOFIA's ability to let them ride along with their experiments and fine-tune filter settings and exposure times on the fly. The plane's mobility also makes it possible to observe any target on the celestial sphere — as demonstrated during a two-week stint in 2013 when it flew to New Zealand to concentrate on the far-southern sky — or to capitalize on targets of opportunity such as SN 2014J.

But it's a very expensive operation, with an $80 million budget in fiscal year 2014. That's more than $100,000 per hour of actual research at altitude. "Unlike a space mission," Hertz explains, "SOFIA doesn't get cheaper to operate after launch." In fact, despite the unique capabilities that a flying observatory affords, some astronomers question whether SOFIA's scientific productivity will ever justify the $1.1 billion development cost — more than three times the original estimate.

As one measure of the project's uncertain standing,

NASA / CARLA THOMAS

The 747's cockpit, updated from the 1978 original, is an orderly array of gauges and controls for the plane's operation.

last year the Obama administration proposed mothballing the plane for an undefined period beginning in fiscal 2015 as a part of overall budget-tightening at NASA. The space agency even started looking for other agencies to take over SOFIA's operation. But supporters in both the House and Senate countered with $70 million in extra funding to ensure that NASA keeps the flights coming for another year. DLR officials were understandably relieved.

However, the scrutiny continues. In July 2014, NASA's Office of Inspector General investigated the program's operational challenges and recommended 10 changes. For example, the OIG found there's not enough planning for future technological upgrades, no mechanism for rescheduling missed opportunities (such as the U Mon and NGC 3501 targets on my flight), and a backlog of undelivered observations after flights are over (example: Marchis is still waiting for his Pallas data).

Meanwhile, Hertz plans to launch a "senior review" of the SOFIA program this year. Outside experts will look at ways to maximize the science return. "Hours cost money," Hertz explains, "and the right choice might be to fly fewer hours." They'll also explore ways to restructure AURA's operations contract, which expires next year. Most critically, they'll assess SOFIA's scientific relevance when judged against other agency programs and funding needs.

But Hertz also emphasizes that SOFIA gives astronomers regular access to a little-explored slice of the electromagnetic spectrum. Seven instruments are in the observational rotation now, and two more (one German, one American) will be in the mix by the end of next year. "We have not stopped moving forward," he insists. With luck — and steady funding — this one-of-a-kind flying observatory will still be soaring into the stratosphere 20 years from now. ✦

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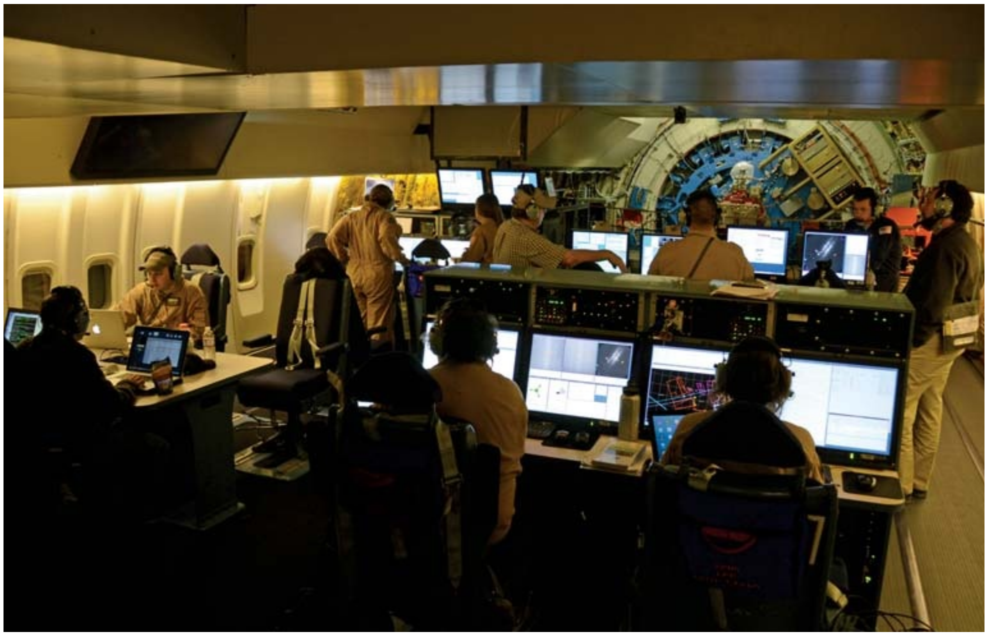
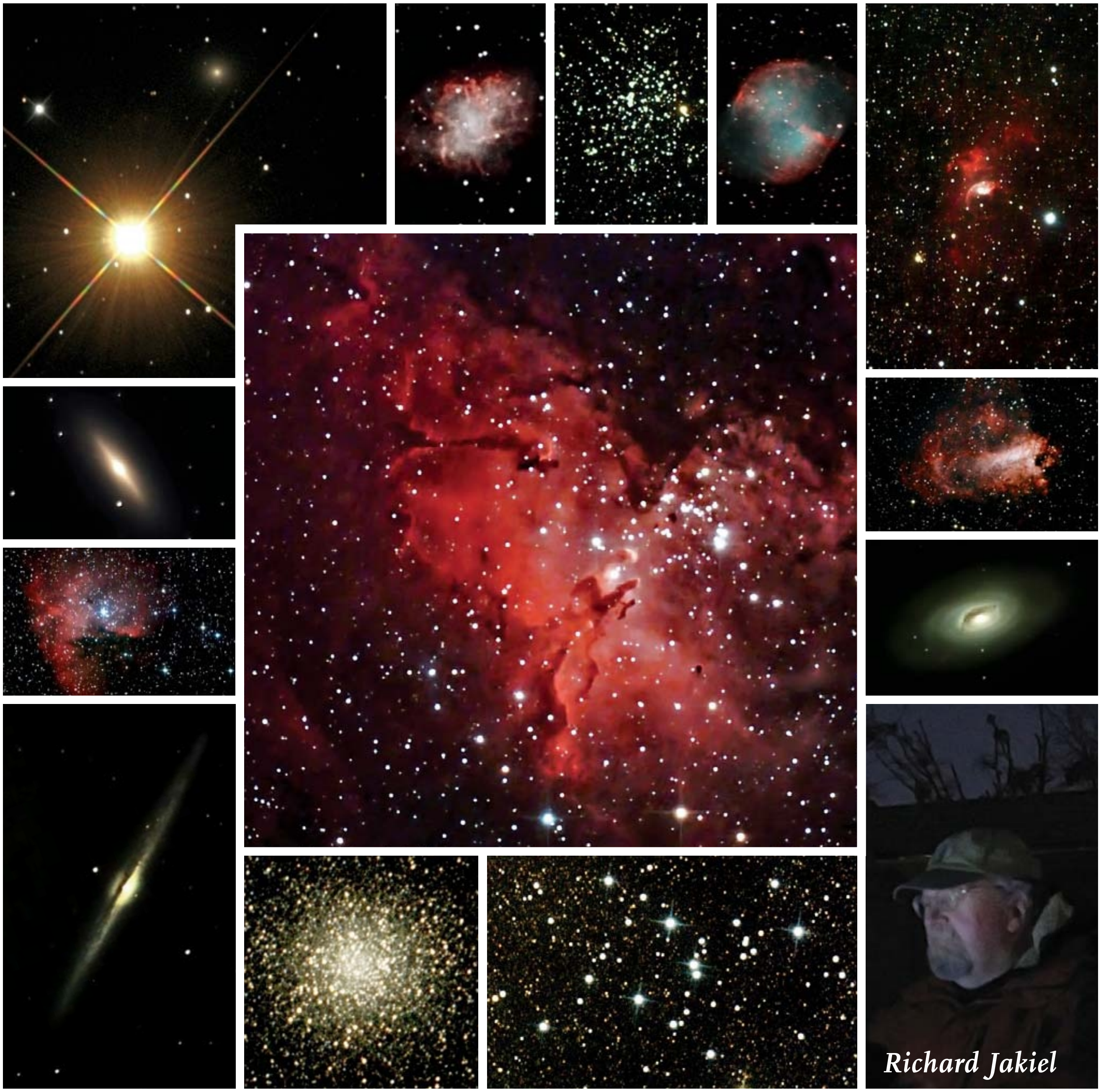
*Senior editor **Kelly Beatty** made his first flight on SOFIA's predecessor, NASA's Kuiper Airborne Observatory, in 1988.*



S&T: J. KELLY BEATTY (2)

The aircraft's roomy but cold and noisy cabin has workstations for four specific tasks: the flight manager and science planner (seated at lower right); astronomers (far left); telescope operators (just left of center); and instrument control (right of center). Everyone faces aft toward the pressure bulkhead and telescope compartment (upper right). Some astronomers choose to come aboard to oversee their observations. The lucky ones get to take their data early and then catch up on sleep after SOFIA turns to view other targets.

Backyard **DSLR** Imaging



Get the most out of your imaging from any location with these helpful tips.

While digital SLR cameras continue to change the landscape of astrophotography, many amateurs are unaware of their ability to capture good astrophotos from under suburban light-polluted skies. Author Richard Jakiel shares the techniques he uses to record images like those above under the light domes of suburban Atlanta, Georgia.

UNLESS OTHERWISE NOTED, ALL IMAGES ARE COURTESY OF THE AUTHOR.

DSLR images clockwise from upper left corner: NGC 404, M1, M52, M27, NGC 7635, M17, M64, author Richard Jakiel, M7, M22, NGC 4565, NGC 281, NGC 3115. Center: M16.

Like many imagers, I live under the pervasive glow of urban light pollution, where the closest dark-sky site requires a substantial drive. But rather than limit my imaging to those rare nights I can make the trip, I've learned to mitigate many of the problems of my location to take respectable images with my DSLR and a variety of telescopes of many targets once thought out of my reach. Whether you're starting out in astrophotography with one of these readily available cameras or have been shooting for some time, the tips shared here can help you take impressive photos of galaxies, nebulae, and star clusters with a DSLR and telescope from the comfort of your own neighborhood.

Settings for Astronomy

Plenty has been written about the strengths and versatility of DSLR cameras. The latest models incorporate high-sensitivity, low-noise CMOS detectors that rival the performance of many CCDs used in dedicated astronomical cameras. But unlike CCD cameras, DSLRs are equally at home taking everyday photos as well as long exposures of faint galaxies attached to the back of your scope.

To get the most out of your photos taken under any sky, some changes to the basic camera settings will greatly increase the quality of your images. The first setting to choose for astrophotography with your DSLR is the manual mode in your camera. This allows you to control important features including exposure length and color balance. For deep-sky imaging, you'll most often be using the "bulb" exposure, which allows you to keep the shutter open longer than 30 seconds. This is necessary to record all but the brightest objects visible to the naked eye.

Next, be sure to set your camera to save images in "RAW" format. This is a proprietary format (saved with the extension NEF in Nikon cameras, while Canons use CR2) in 16-bit format that preserves all the light you recorded. Other file formats (particularly JPEG) compress your images to save space and introduce unsightly artifacts. You'll need to use the software that came with your camera or another image-processing program to convert your RAW files into other file formats, but the additional quality is worth it.

Now examine your camera's ISO setting. This is similar to the gain setting on video cameras; the higher the value you use, the more sensitive your camera will be and the shorter the exposure you'll need. The latest DSLR models boast extremely high ISO settings — in some this can be in excess of 50,000! But there is a cost. While it's tempting to image at these extremely high values, this approach adds noise and also reduces the dynamic range of your image. Star colors are washed out, and the image appears noisy. I recommend using an ISO setting of 400 to 800 as a good compromise to preserve colorful star clusters and planetary nebulae, while selecting higher values when capturing galaxies and nebulae.

S&T: SEAN WALKER

Besides your camera, you'll need at least two other accessories to take photos through your telescope. A T-ring adapter replaces the lens on your camera and connects it to the focuser on your telescope, while a digital intervalometer (left) allows you to program and shoot multiple exposures.

Calibration: Half the Work

A large part of taking good astrophotos with a DSLR is using good calibration frames. These are called *dark, bias,* and *flat-field* images, and they're used to reduce unwanted thermal and optical effects in your images.

Due to the electronic nature of CMOS (and CCD) sensors, the longer you expose the sensor to light, the warmer the detector gets. This creates thermal artifacts that build up in your photo, which appear like static or noise in photos exposed longer than a few seconds. Dark frames are photos taken of the same duration and temperature as the images of your target, but with the camera or telescope covered to record only the thermal signal in your image. These frames are then subtracted from your

Much light pollution comes from local sources. Porch lights, streetlights, and headlights all can add to the problems in your images. The author sets up his equipment where all nearby lighting sources are blocked from shining directly into his telescope.

Bright Galaxies for Urban Imagers

Object	Constellation	Mag(v)	RA	Dec.
M31	And	3.4	0^h 42.7^m	+41° 16′
NGC 253	Scl	7.6	0^h 47.6^m	–25° 17′
NGC 891	And	9.9	2^h 22.6^m	+42° 21′
M77	Cet	8.8	2^h 42.7^m	-0° 01′
NGC 2403	Cam	8.5	7^h 36.9^m	+65° 36′
M81	UMa	6.8	9^h 55.6^m	+69° 04′
M82	UMa	8.4	9^h 55.8^m	+69° 41′
M65	Leo	8.5	11^h 18.9^m	+13° 05′
M66	Leo	9.0	11^h 20.2^m	+12° 59′
M100	Com	9.4	12^h 22.9^m	+15° 49′
M84	Vir	9.3	12^h 25.1^m	+12° 53′
M86	Vir	9.2	12^h 26.2^m	+12° 57′
M64	Com	8.5	12^h 56.7^m	+21° 41′
M51	CVn	8.1	13^h 29.9^m	+47° 12′

By shielding his equipment from direct lighting and shooting only when the object was in the darkest part of his backyard sky, the author managed to capture this deep, colorful image of M33 using an 8-inch f/3.9 Newtonian astrograph and twelve 10-minute exposures.

pictures, making them appear less noisy. Most DSLRs today have very little dark current, so imagers often skip this calibration frame.

Bias frames record the fixed-pattern noise inherent in all digital detectors and are taken at the very fastest shutter speed you have. These are likewise subtracted from your photos, as they help to reduce uneven banding seen when you stretch an image to reveal faint details during post-processing.

The last calibration frame is the flat-field image. This is a snapshot of an evenly illuminated surface that records the vignetting of your lens and dust motes on the detector that plague virtually every optical system but are more pronounced when shooting under light-polluted skies. When properly applied, flat-field calibration can greatly reduce if not eliminate these optical effects.

Flat-field images can be recorded in various ways using the darkening sky during twilight or with an evenly illuminated screen. No matter how you choose to take your "flats," they need to be recorded in the *exact* same optical configuration used for imaging during an entire evening. It's important to have your telescope focused before taking flats so that you accurately record the location of any dust motes, and you should not rotate the camera for the rest of the night.

Flat-field images should also be exposed to have the highest-level register at about ⅓ to ½ of the histogram display. This is a graph feature in your camera that shows brightness levels and is plotted from left (black, or no signal) to right. Consult your camera's manual to see how to display the brightness histogram on your particular model.

Once you've recorded all these calibration frames, consider picking up an additional computer program that can apply them to your photos. Although you can capture your images in your DSLR with only the addition of a cable release and the camera's Bulb setting, you'll need a dedicated astronomical processing software program to properly calibrate and adjust the images.

Managing Your Sky

With all the preparation done, you're ready to start imaging. Spend a little time determining where the best part of your sky is. Light pollution not only washes out the sky, it also introduces unusual background hues and brightness gradients that can be tough to deal with. To top it off, light pollution is never uniform across the sky; instead it's more concentrated in the form of light domes rising up from the horizon. But a little bit of strategy will usually mitigate these problems. Set up your scope in a location that best blocks local sources of light and shoot in the direction away from the most intense light domes.

When imaging in urban skies, try to plan your evenings to shoot multiple targets that best utilize both your local conditions and your time throughout a night. Take advantage of your chosen targets' path across the sky by planning to image them only when they are away from light domes, or when they are simply highest. This lets you avoid following a single subject as it goes from a dark spot in your sky and into a brighter area later in the evening. While this approach might spread your acquisition of a particular target over multiple nights, you'll get better images overall.

Even when avoiding light domes, there will still be some light pollution in your images that lightens the entire frame. This brightness effectively decreases the signal-to-noise ratio (SNR) in your photos, limiting how long you can actually expose your individual pictures before reaching the sky limit where there is no benefit to exposing longer. When shooting with a DSLR, this occurs when the detector becomes saturated or the sky background gets very bright. You can find the sky limit by taking a series of progressively longer exposures at your chosen ISO and then examining the photo histograms. If the plot of the histogram begins at about the middle of the graph, you should try a shorter exposure.

The best way to work around the sky limit at your location is to take many exposures of the same object and combine (or stack) them into a single image later. This increases the SNR in your photo, allowing you to record fainter details in your images while greatly reducing the noise compared to single exposures.

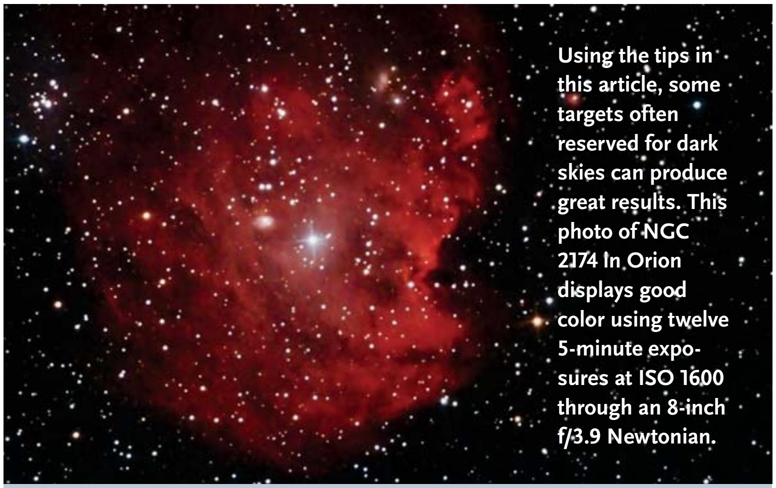
The actual gain in signal when stacking multiple images is equal to the square root of the number of frames stacked. For example, if nine 5-minute exposures are stacked, the relative gain in SNR is only $\sqrt{9}$, or 3. So the resulting stack is effectively what you'd record in a single 15-minute exposure. When imaging from urban locations, stacking will be the technique that adds the most to the quality of your images.

Battling Gradients

As mentioned earlier, you'll always be recording gradients in your images when shooting from suburban locations. To really maximize your efforts, consider purchasing a light-pollution suppression (LPS) filter. These filters use interference technology to block most wavelengths associated with common forms of urban light pollution while passing most of the photons from deep-sky objects, increasing the contrast in your images by up to a factor of three.

Still, despite these best efforts, gradients will show up in your images and can present a real processing challenge. Fortunately, most astronomical image-processing programs include tools to effectively deal with these problems. Processing suites such as *MaxIm DL* (**www.cyanogen.com**), *PixInsight* (**http://pixinsight.com**), and others include tools to correct gradients. A useful technique to correct gradients using *PixInsight* can be found in the September 2014 issue, page 68.

While there is no true substitute for dark skies, you don't always need to be under pristine skies to take great deep-sky astrophotos or improve your imaging technique. With a little understanding of your DSLR camera and the effects of light pollution, a great deal can still be done under less-than-ideal conditions that let you end up with some impressive results. ✦



Using the tips in this article, some targets often reserved for dark skies can produce great results. This photo of NGC 2174 In Orion displays good color using twelve 5-minute exposures at ISO 1600 through an 8-inch f/3.9 Newtonian.

Bright Nebulae for Urban Imagers

Object	Constellation	Mag(v)	RA	Dec.
NGC 281	Cas	—	0^h 52.8^m	56° 37′
M76	Per	9.9	1^h 42.4^m	+51° 34′
M1	Tau	8.4	5^h 34.5^m	+22° 1′
M42 (and M43)	Ori	3.0	5^h 35.4^m	–5° 27′
NGC 2174	Ori	—	6^h 9.7^m	+20° 30′
M8	Sgr	5.8	18h 3.8^m	–24° 23′
M16	Ser	6.0	18^h 18.8^m	–13° 47′
M17	Sgr	6.9	18^h 20.8^m	–16° 11′
M57	Lyr	8.8	18^h 53.6^m	+33° 2′
M27	Vul	7.3	19^h 59.6^m	+22° 43′
NGC 6888	Cyg	—	20^h 12^m	+38° 21′
NGC 7635	Cas	—	23^h 20.7^m	+61° 12′
NGC 7662	And	8.3	23^h 25.9^m	+42° 33′

Even from heavily light-polluted skies, bright star clusters like the famous Double Cluster (NGC 869 and NGC 884) punch through sky glow, making great targets through almost any telescope.

Richard Jakiel is an experienced observer and astrophotographer living in a suburb of Atlanta, Georgia.

Build the Art Swivel

Here's a great alternative to traditional altazimuth designs.

I'M STRUCK BY how frequently different telescope makers arrive at similar solutions when confronted with similar problems. Remember Chuck Lott's "pseudo-ball" telescope mount that I featured in the December 2013 issue? By coincidence, just as that issue was going to press, I received an e-mail from Art Gamble of Wichita Falls, Texas, describing a remarkably similar design. His implementation was a little different, but the root of the idea — a ball-and-socket mount utilizing a segmented "ball" — was the same. Like Chuck, Art was looking for a way to improve on the conventional altazimuth mount.

The difficulty with ball-and-socket mounts is finding a rigid ball of the necessary size. It's probably the main reason the design isn't as popular as it could be, given its utility. "My goal was to build a mount for my 90mm f/8.8 refractor that operated like a ball-and-socket, but without the ball," Art says. The solution that he, Chuck Lott, and a few others arrived at is making a virtual ball from several plywood arcs.

As Art Gamble's wife Sara demonstrates, a ball-and-socket mount can be an excellent choice for a small refractor like their 90mm f/8.8.

ART GAMBLE

When you sit down to build one, the first questions to arise are how many arcs, and how big do they need to be? Experimentation led Art to conclude that five or six arcs are optimal to ensure that the "ball" would always have several points of contact with the socket. The dimensions of the individual arcs depend on the diameter of the telescope tube and the size of the socket base. The ball should be big enough to enclose the rear of the telescope tube and have enough extra material to ensure a rigid structure. Once you settle on the approximate size of the ball, you can select a suitable base and then determine the dimensions of the ball segments. "I came up with a simple formula: multiply the diameter of the base ring by 0.572 to calculate the radius of the arc segments," Art says. The arc sections for his scope have a radius of 6½ inches, which, when assembled, simulate a ball 13 inches in diameter.

Art cut each arc from ¼-inch plywood, though larger scopes would obviously benefit from thicker wood. "I made a template of stiff, thin cardboard and traced the shape on the plywood, which I cut on a band saw, leaving about ⅛ inch of extra material," he recalls. Next he stacked the segments and clamped them together for final shaping. "I used a combination belt and disk sander to refine the pieces and ensure uniform curves."

The mount segments were finished with several layers of clear polyurethane, including the edges that slide against the rim of the socket. The socket is simply the top of a 5-gallon plastic bucket reinforced on the bottom with a disk of ¾-inch plywood. The base is affixed to a sturdy surveyor's tripod. Although the bucket has a bit of flexibility, this actually turns out to be a benefit since it helps ensure good contact with the ball.

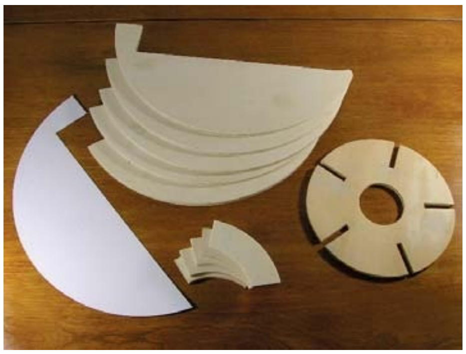
One of the problems of a ball-and-socket mount when used with refractors like Art's (and small Cassegrains) is that the eyepiece ideally should be positioned as near the center of the ball as possible. However, doing so results in a front-heavy configuration. To cope with the imbalance, Art cast an 8-pound lead counterweight and affixed it to the rear of the ball.

The mount's "socket" is simply the top of a plastic 5-gallon bucket. A cast lead 8 lb. counterweight ensures that the front-heavy scope is properly balanced.

Although making a ball-and-socket mount like the Art Swivel requires a bit of extra effort, the advantages are significant. A convenient eyepiece position is one of the key benefits — you can rotate the eyepiece to any angle needed for comfortable viewing. "Following objects at high magnification is easier thanks to the steadiness of a setup that has only one moving part," he reports. "My aim in building this telescope was to produce a prototype that could be scaled up for use with a much larger reflector. I'm hoping that my results inspire other ATM's to take the ball, so to speak, and run with it!"

Readers wishing to learn more about Art's Swivel mount can e-mail him at artgam1946@gmail.com. ✦

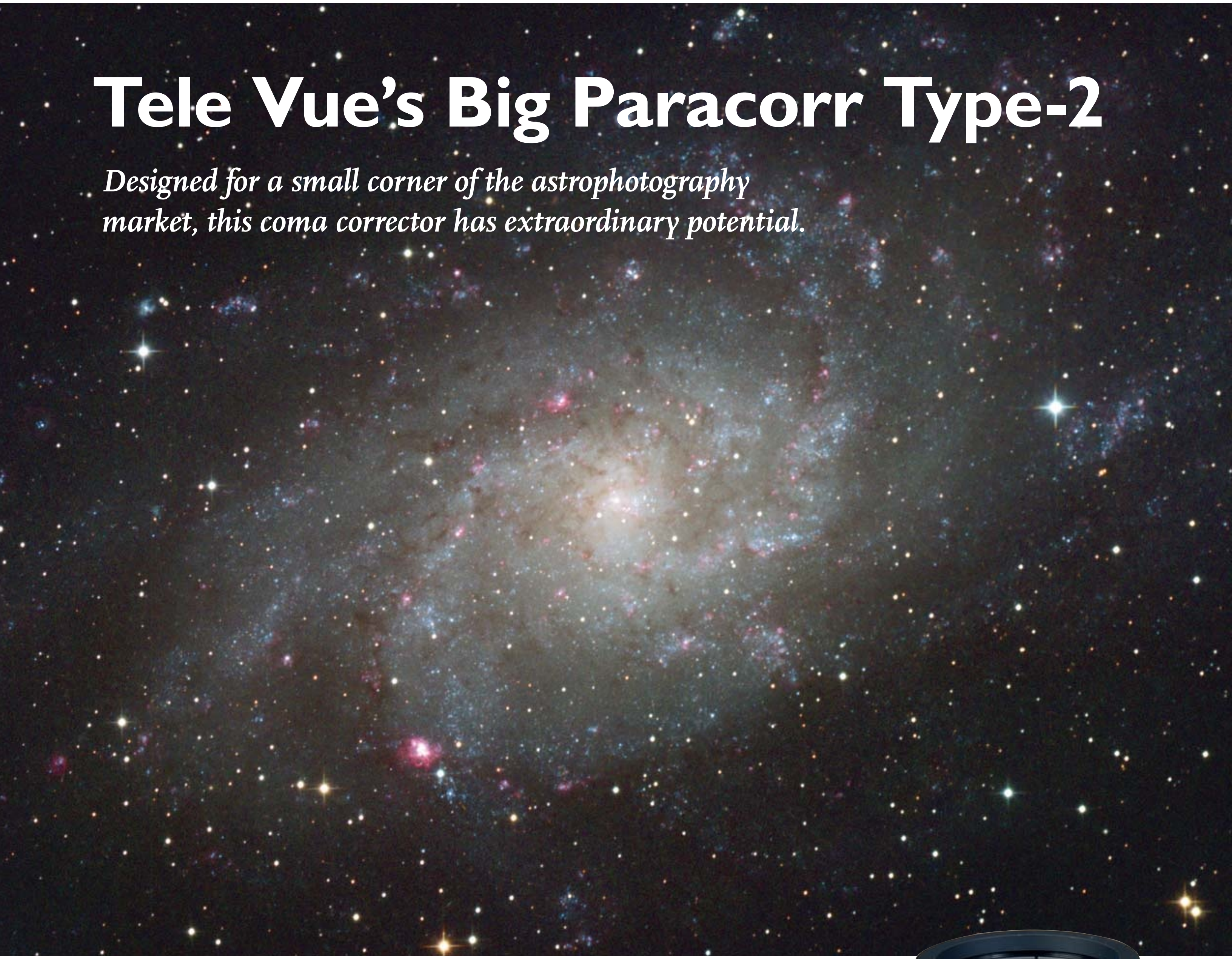
Contributing editor ***Gary Seronik*** *is an experienced observer and telescope maker. You can contact him via his web site, www.garyseronik.com.*



ART GAMBLE (2)

The swivel mount's wood parts are shown here with the cardboard template used to make the arc segments for the virtual ball.

 Dennis di Cicco



Tele Vue's Big Paracorr Type-2

Designed for a small corner of the astrophotography market, this coma corrector has extraordinary potential.

Tele Vue Big Paracorr Type-2

US price: $1,095, televue.com

Tele Vue's Big Paracorr was key to transforming the author's 12-inch f/5 Newtonian reflector into a first-class optical system used for the astrophotography with this review. The image above of the grand spiral galaxy M33 was assembled from 40-minute exposures through red, green, and blue filters with a CCD camera fitted with a KAF-16803 chip. All color astrophotographs with this review were processed by the author's colleague Sean Walker.

ALL PHOTOS BY THE AUTHOR

WHAT WE LIKE:

Extraordinary coma correction for fast Newtonian reflectors

Excellent coverage of large-format CCD chips

The potential to make top-notch astrophotography more affordable

WHAT WE DON'T LIKE:

It is currently of interest mainly to do-it-yourselfers

During my years of testing astronomy equipment, I've worked with some of the world's finest telescopes designed for astrophotography. (And feel free to substitute the word "expensive" for "finest" in that sentence, if you'd like.) I've used telescopes made by Officina Stellare, PlaneWave, Takahashi, and Tele Vue, as well as top-of-the-line equipment from Celestron, Meade, Star-Watcher, Stellarvue, and others. The astrophotos with this review, however, weren't made with any of them. Rather, they were taken with a 12-inch Meade LightBridge Dobsonian that I bought used for $500. All I did was add Tele Vue's new Big Paracorr Type-2 coma corrector to the scope and, voilà, I had imaging performance that was on par with the best astrographs I've tested.

The devil, they say, is in the details, and there are definitely some between "add Tele Vue's Big Paracorr" and "voilà." The most significant involve fitting the telescope with a 3-inch focuser that would accept the Big Paracorr and attaching the tube assembly to an equatorial mount suited for astrophotography. I also upgraded the scope's secondary mirror to a larger one that provided better field illumination for imaging. Except for this mirror, I made all the parts for these modifications, but they could have easily been done with parts available commercially. I'll come back to this scope later, but for now let's look at the real reason I could turn a onetime Dobsonian reflector into a world-class astrograph — the Big Paracorr.

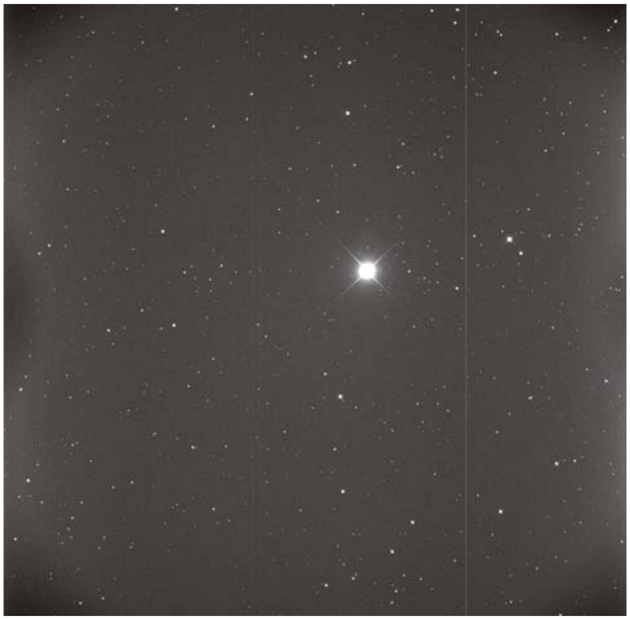
Why a Coma Corrector

At the close of the 19th century, photographic plates were replacing the eye as astronomy's workhorse detector. Telescopes were essentially becoming giant camera lenses, and the never-ending quest for bigger telescopes shifted from refractors to reflectors having parabolic primary mirrors — a trend that culminated with the completion of the 200-inch (5.1-meter) Hale Telescope in the late 1940s. Parabolic mirrors are also at the heart of Newtonian reflectors familiar to all amateur astronomers today even if we hear the name Dobsonian (derived from the style of mounting) more often than Newtonian.

Tight star images and fine resolution are possible with the Big Paracorr as apparent in this image of the globular cluster M15 assembled from sets of 12 1-minute exposures made through red, green, and blue filters.

Newtonians with parabolic primaries have many advantages, but they suffer from coma. This inherent optical aberration distorts stars into seagull-like flares that grow larger as they appear farther from the center of the telescope's field of view. Visual observers tolerate coma by moving objects to the center of the eyepiece field where images appear sharp. But coma is a curse for astrophotographers striving to capture pinpoint stars across big fields. The problem becomes worse as the imaging detector grows larger, and it grows worse for mirrors having shorter focal ratios (lower f/numbers), which are desirable for astrophotography. This holds true regardless of the mirror's aperture. For example, any f/3.3 parabolic mirror (the focal ratio of the primary in the 200-inch Hale Telescope) produces acceptable star images across a field less than half an inch in diameter. Fortunately, wider fields are possible if a multi-element, coma-correcting lens is introduced near the telescope's focal plane.

Designed mainly for astrophotographers, the Big Paracorr has optional spacers and adapters to couple it with many DSLR and astronomical CCD cameras. But there is also an optional adjustable top that allows the corrector to be used visually with a wide range of Tele Vue eyepieces.



The author's first images with the Big Paracorr were with a 16-inch f/3.2 parabolic mirror mounted in a plywood tube that he made years earlier to test other coma correctors. The "first-light" image here is an uncalibrated 10-second exposure of the star field around Polaris showing pinpoint stars across the frame of the large-format KAF-16803 CCD. Some vignetting is apparent in the corners of the frame, but the shadowing at left is due to the Paracorr extending into the setup's light path, an unavoidable artifact of the tube's layout.

Yerkes Observatory astronomer Frank E. Ross was America's foremost astronomical lens designer in the early 20th century. He developed some of the first coma correctors, including ones for the 200-inch telescope that gave well-corrected fields about 3 inches in diameter. Later correctors designed by Charles G. Wynne provided even larger fields.

Commercial coma correctors for amateur astronomers have come and gone over the years, and a handful exist today that are designed for telescopes with 2-inch focusers. Some are made for visual observers, some for astrophotographers, and some for both. I've tested several, including one a few years ago that prompted me to build an 8-inch f/3.3 Newtonian for astrophotography with DSLR cameras having APS-size sensors. The results were acceptable enough for me to start work on a 12-inch f/4 Newtonian, but I stopped after upgrading my astronomical CCD camera and DSLRs to models with sensors that were too big for the field coverage of the coma corrector.

Until Tele Vue introduced its Big Paracorr Type-2, the only current source of coma correctors capable of adequately covering large-format detectors such as the popular KAF-16803 CCD from ON Semiconductor (formerly Truesense Imaging, which was formerly Kodak) was Astrosysteme Austria (ASA). Like the Big Paracorr, even ASA's smallest corrector, which is based on a Wynne design, needs a 3-inch focuser.

Enter the Big Paracorr Type-2

Building on the success of the 2-inch Paracorr Type-2 (one of this magazine's Hot Product picks for 2011), Tele Vue's Paul Dellechiaie designed the 3-inch Big Paracorr Type-2 for use with CCDs as large as the KAF-16803 and parabolic mirrors as fast as f/3. It was introduced at last year's Northeast Astronomy Forum in April, and a few months later I borrowed one of the first production models for testing.

The Big Paracorr has an extremely generous 80 millimeters of back focus (a third more than ASA's correctors), allowing ample room for attaching all the astronomical CCD cameras and filter wheels that I'm familiar with, as well as all DSLRs. In many cases there is even enough back focus with the Big Paracorr to squeeze in a low-profile off-axis guider.

The Big Paracorr moves the telescope's original focal plane outward a bit more than 72 millimeters (an engineering drawing showing all the relevant spacings is available on Tele Vue's website). As with the coma correctors that Ross designed for the 200-inch telescope, the Big Paracorr slightly increases a telescope's effective focal length, with a corresponding increase in f/ratio. For the Big Paracorr this magnification increase is 1.15×, meaning that an f/3 mirror effectively becomes an f/3.45 imaging system.

Were it not for my experiments with coma correctors in the past, the Big Paracorr would have been a challenging product to test given the rarity of fast Newtonians with 3-inch focusers, not to mention ones set up for long-exposure imaging. But I had a 16-inch f/3.2 parabolic mirror configured as a Newtonian in a plywood "tube," albeit one that wasn't intended for an equatorial mount. Nevertheless, I modified its focuser to accommodate the 3-inch Paracorr and simply propped up the tube in my driveway so I could shoot the field around Polaris where the sky's slow diurnal movement allowed minute-long exposures with minimal star trailing.

My first exposures with a CCD camera having a KAF-16803 CCD were remarkable. Despite the crudeness of the setup, the Big Paracorr yielded perfectly round, virtually pinpoint stars across the frame. Vignetting was minimal in all but the very corners, and there was no discernible change in focus for exposures made through clear, red, green, and blue filters.

Plans immediately began swirling in my head for turning the 16-inch into a telescope for astrophotography, but a much faster way to test the Paracorr for long-exposure imaging was to modify my old 12-inch Light-Bridge Dobsonian. While I did this as a temporary test

Long-exposure tests were done with the Big Paracorr fitted to a 12-inch Meade LightBridge reflector that is described in the text. The scope's pedigree is apparent during a "photo op" the day it was attached to a Paramount ME II (reviewed in the September 2014 issue, page 38). In practice, however, the scope was wrapped in a light shroud and fitted with a tube extension that prevented stray light from reaching the Paracorr's front lens located just inside the wall of the telescope's tube. The working setup towered over the author who is nearly 6 foot 4 inches (193 cm) tall.

Visit is.gd/Pacacorr to see more of the author's images made with the Paracorr.

Despite the Big Paracorr's lenses being relatively near the telescope's focal plane, exposures are remarkably free of ghost images and haloes even when very bright stars are in the field. This 30-minute shot of the Pleiades was through a blue filter.

Some long-exposure tests with the 12-inch reflector and Big Paracorr were with a CCD camera having a KAF-8300 chip. Because this CCD is smaller than the KAF-16803, vignetting is insignificant, and this view of the sinuous nebula VDB 142 in Cepheus was processed without a flat-field calibration.

Full-resolution images (left and right) cut from the corners of an uncalibrated 1-minute exposure of the Pleiades (center) made with a KAF-16803 CCD show the quality of the star images as well as the darkening caused by vignetting at the very corners of the chip. From corner to corner the KAF-16803 covers an imaging circle spanning 52 millimeters.

setup, in hindsight it wouldn't be a crazy idea to consider a LightBridge fitted with the Big Paracorr as a permanent astrograph from the outset. This isn't a story about telescope making, so I'll skip the details, but it's worth noting that modifications costing me less than $200 ($165 of which was for the 4-inch secondary mirror from Agena AstroProducts, **agenaastro.com**), produced a telescope that made the images accompanying this review. It's something I certainly think about when I compare my results with those I've obtained while testing commercial astrographs priced well north of $10,000.

Notes from the Field

As mentioned above, I don't know of any commercially available big Newtonians that have fast f/ratios and are made for long-exposure astrophotography. So there's no way for me to address how the Big Paracorr will perform with specific telescopes people are going to use it with (which is another way of saying that, for now, deep-sky astrophotography with the Big Paracorr is mainly in the hands of do-it-yourselfers). That said, my field notes will still be of interest to people considering the Big Paracorr for imaging.

The filtered exposures used to assemble the color images with this story were all done with a fixed focus — I did not refocus the telescope when switching between filters. I simply set my initial focus shooting through the green filter. I could, however, obtain ever-so-slightly tighter star images for the red and blue filters by tweaking the focus. In a perfect world I might have done that, but in the practical world I found it unnecessary.

Because my test setups were only meant to be temporary, I cut a few corners when modifying the tube assemblies for the 16- and 12-inch mirrors. As such my cameras ended up never being perfectly square to the scopes' optical axes. And while I could achieve good optical collimating, it too was never perfect in either setup. Regardless, I performed various tests that proved to me the Big Paracorr can form nice, tight, round star images across the full frame of a KAF-16803 CCD. Close examination of images showed that the first sign of degraded focus was a tiny elongation of star images (which mimicked poor guiding) followed by the expected bloating of stars as the focus became worse.

There is little question that I'm excited by the potential of the Big Paracorr. It clearly raises the imaging performance of humble Newtonian reflectors with fast primary mirrors to a level that can compete with today's elite astrographs having exotic optical designs. And it also opens up a world of possibilities for "old-school" astrophotographers like me who got started in this hobby because we could build (and afford) the telescopes we used. ✦

Dennis di Cicco has been writing about equipment in the pages of Sky & Telescope *for more than 40 years.*

Kelly Beatty

Gallery

◂ HEART OF THE SOUL

Steven Coates

This false-color portrait of the Soul Nebula, IC 1871 in Cassiopeia, reveals the tortured shapes carved by fierce, ionizing winds from recently formed stars embedded in the cloud.

Details: *Explore Scientific ED127mm with QSI 683wsg-8 CCD camera. Total exposure was 10 hours through Astrodon narrowband filters.*

▾ PERFECT FIREBALL

Brett Abernethy

A brilliant sporadic fireball skewers Orion early last December 20th, lighting up Mount Rundle and the snow-covered shoreline of nearby Johnson Lake in southern Alberta.

Details: *Canon EOS 5D Mark III DSLR with Zeiss 21-mm lens. Total exposure was 49 seconds at f/4 and ISO 3200.*

Gallery showcases the finest astronomical images submitted to us by our readers. Send your best shots to gallery@SkyandTelescope.com. See SkyandTelescope.com/aboutsky/guidelines for more information.

◄ **COMET LOVEJOY: JUST PASSING THROUGH**

Chris Schur

A tempting tease for visual observers, Comet Lovejoy (C/2014 Q2) sported a short tail (lower right) while gliding among the riches of Orion, Taurus, and Eridanus. **Details:** *Modified Canon Rebel XTi DSLR camera with 17-mm lens. Total exposure was 1¾ hours at f/5.6, ISO 800, taken from Payzon, Arizona.*

► **NGC 7331**

Larry Van Vleet

Sometimes called a Milky Way twin, this pretty spiral galaxy lies in Pegasus about 50 million light-years away and displays intense star formation around its center. **Details:** *PlaneWave CDK20 astrograph with Apogee U16M CCD camera. Total exposure was 25 hours through Astrodon color filters.*

►▼ **WINTER SKY FROM A DESERT INN**

Amirreza Kamkar

The Sangi caravansary in central Iran once served as a rest stop for travelers. Its ruins frame bright constellations and Jupiter (at top) as seen in January 2014. **Details:** *Canon EOS 5D Mark II DSLR camera with 15-mm fisheye lens. Mosaic of two images, each exposed for 20 seconds at f/3.5, ISO 3200.*

▼ **TRIANGULUM TREAT**

Steven Coates

Messier 33, the Triangulum (or Pinwheel) Galaxy, is peppered with crimson-hued pockets of ionized hydrogen that mark regions of intense star formation. **Details:** *Explore Scientific ED127mm with QSI 683wsg-8 CCD camera. Total exposure was 6.8 hours through Astrodon color filters.* ✦

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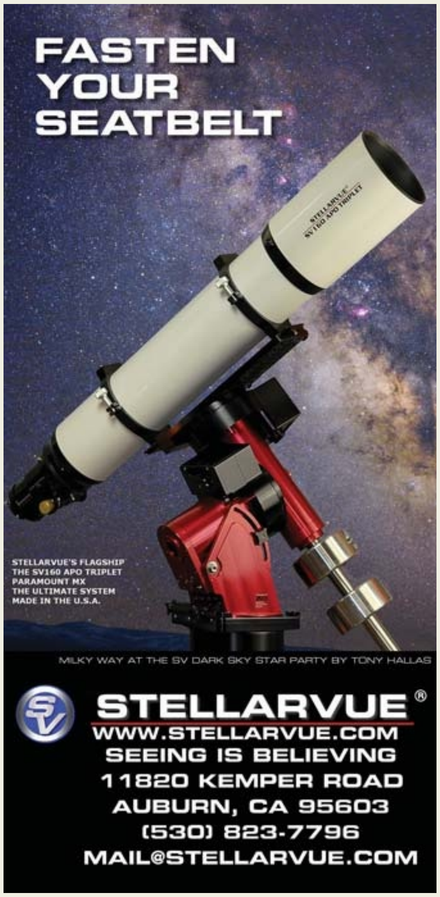

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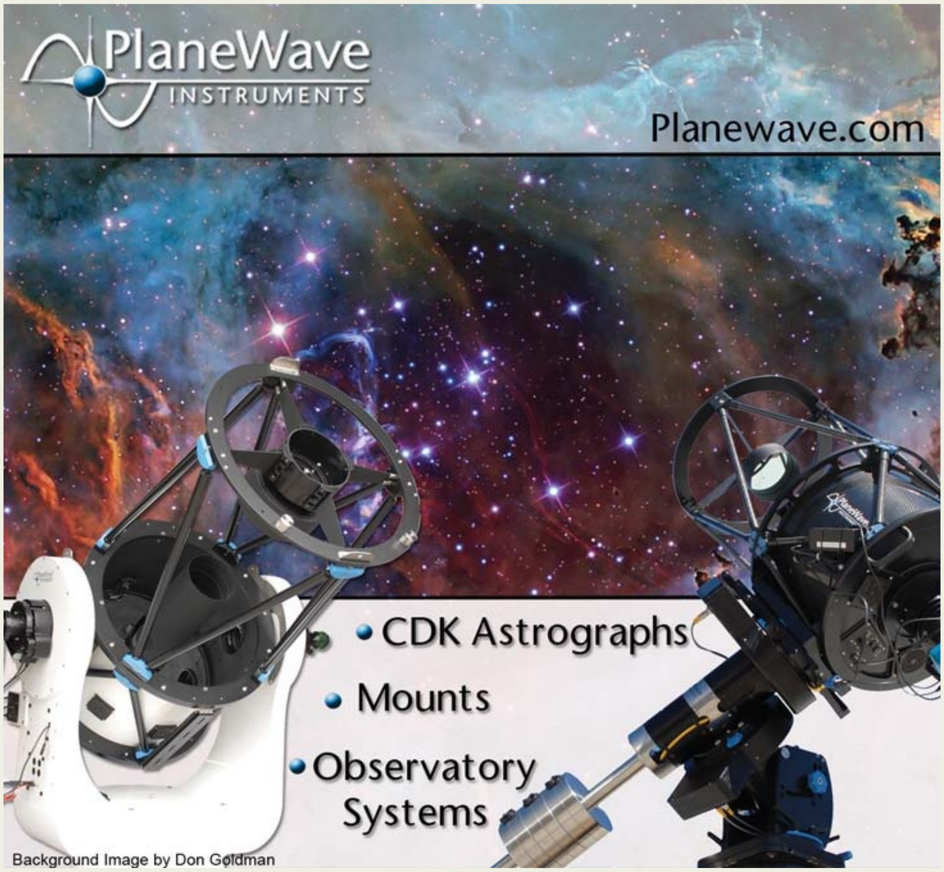

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Seeing Uranus in Antiquity?

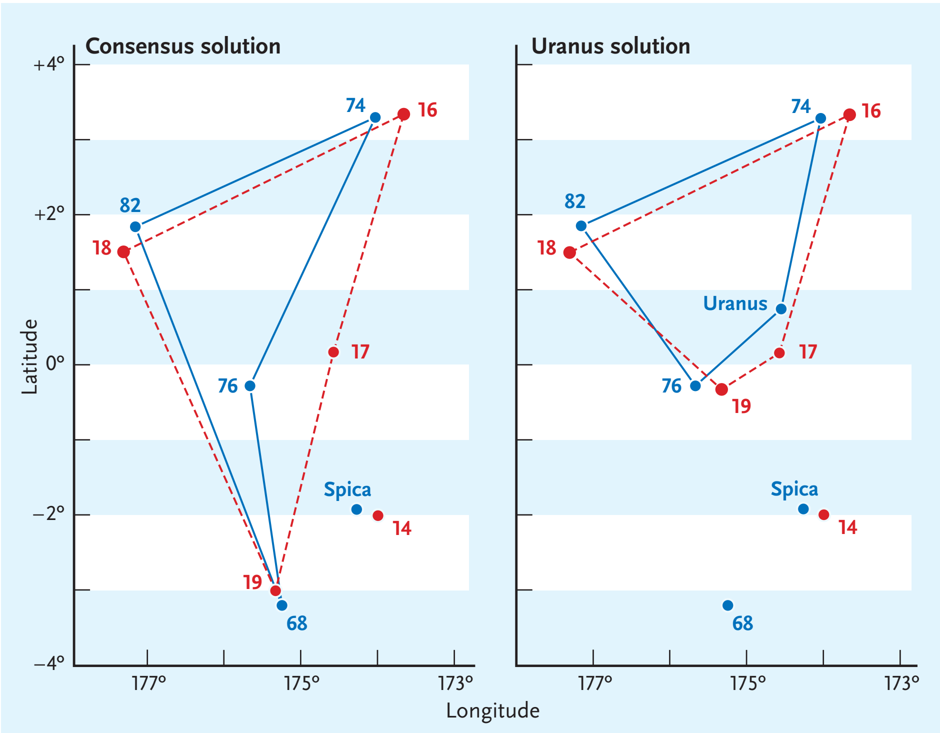
An amateur astronomer's hypothesis about what Hipparchus saw c. 128 BC

An unusual passion gripped me when ancient manuscripts became more readily available on the internet: the search for inadvertent observations of then-unidentified planets and asteroids. But when it came to my study of the star catalog included in the *Almagest*, Ptolemy's 2nd-century AD astronomical treatise, I encountered a huge problem: the identity of the star catalog's author was (and is) still unknown. Alas, none of the theories as to its origins has proved to be entirely convincing.

Contrary to the claims of Ptolemy (c. AD 90–168), the epoch of the *Almagest* star catalog doesn't coincide with the year AD 137. As a consequence, some scholars have proposed that the catalog he claims as his own is actually that of Hipparchus of Nicaea (c. 190–120 BC), with its longitudes increased by 2° 40′.

Several indices allow us to fix the time that Hipparchus's catalog was created to about 128 BC, and I was delighted to see that, around that time, Uranus could be found in the bottom right corner of a quadrilateral defined by that planet plus (Flamsteed numbers) 74, 76, and 82 Virginis. This location is of invaluable importance, because all versions of the *Almagest* note the presence of a quadrangle formed by four stars with magnitudes ranging from 4.3 and 6.0 in the left thigh of the Virgin (3° northeast of Spica). The faintest of these four stars, 17 Virgo (or Uranus according to my hypothesis), marked the lower right corner of the quadrangle.

Experts generally agree that this quadrilateral was formed by the four stars identified in the *Almagest* as Virgo 16, 17, 18, and 19 (Flamsteed 74, 76, 82, and 68 Virginis). But experts also concur that this stellar quartet doesn't form a very convincing quadrangle. In the accompanying figure, I've marked the stars of the *Almagest* in red, the "real" stars in blue. The figure compares the quadrilateral as envisioned by scholars of the star catalog to one incorporating Uranus as Hipparchus could have observed it, with 19 Virgo equated with 76, rather than 68, Virginis.



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The position of Uranus is for April 9th, 128 BC, the date of its ecliptic conjunction with Virgo 17 according to the so-called Arabic versions of the *Almagest*. As its perihelion took place only seven years earlier, the planet was close to its maximum brightness of magnitude 5.4. Moreover, its great elongation from the Sun (159° E) and its northern declination (+3°) would have allowed Hipparchus to spot it from the island of Rhodes at a comfortable zenithal distance of 33°. And, as the figure shows, the quadrilateral formed by Uranus with 74, 82, and 76 Virginis looks much more realistic than one formed with 68 Virginis.

The reconstruction of the star pattern described by Hipparchus two millennia ago not only confirms him as the author of the *Almagest*'s star catalog but also awards him credit as the first observer of our solar system's seventh planet. We may never be able to find definitive proof of Hipparchus's observations of Uranus, but passion and a diligent reading of ancient evidence can perhaps lead us closer to the truth.

The British *Journal for the History of Astronomy* published a fuller version of this story in its November 2013 issue. ✦

***René Bourtembourg** is a Belgian amateur astronomer. His interest in ancient astronomy led him to identify the very first observation of an asteroid by astronomer Charles Messier in 1779.*

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