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SKY & TELESCOPE

THE ESSENTIAL GUIDE TO ASTRONOMY

APRIL 2022

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Water Worlds

WHEN WE LOOK UP at the night sky, we don't tend to think of oceans. Deep, blue seas exist down here, not up there. Yet if what we suspect about certain moons in our solar system is true, then oceanic worlds might be ubiquitous, not just in our planetary system but in many others.

Astronomers think that at least six moons in the outer solar system conceal water oceans beneath their frozen crusts. These include Jupiter's moons Europa, Ganymede, and Callisto — the subject of Ben Skuse's cover story on page 14 — as well as Saturn's moons Titan and Enceladus, and Neptune's Triton. Ariel and Miranda, two moons of Uranus, are among other bodies beyond Mars that might shelter subsurface seas, too. But we haven't collected enough data on those satellites yet to feel as confident about them as we are about the other six.

Could one or more of these watery orbs harbor life? For our entire history as a species, we've not known whether we're alone in the universe. It's a simple yes-or-no question, but so far we've been unable to answer it. That's what makes the two upcoming missions to Jupiter's moons that Skuse discusses in his feature so rousing: They might bring us tantalizingly close to answering that age-old query.

▲ Might the nearest aliens inhabit the icy underworld of Jupiter's moon Europa?

NASA / JPL-CALTECH / SETI INSTITUTE

Any living things in those shadowed oceans wouldn't be able to breathe fresh, sunlit air on a spring morning, say, or float beneath a star-spangled night sky — there's neither air nor sky under a thick blanket of ice. But they could thrive nevertheless, perhaps thanks to hydrothermal vents like those that sustain a wide array of creatures in the pitch black thousands of feet down in our own oceans.

It's unlikely that the two missions Skuse describes — NASA's Europa Clipper and the ESA's Jupiter Icy Moons Explorer (JUICE) — will directly determine whether any Jovian moons host organisms. But the spacecrafts' observations will help us consider that and other compelling mysteries: If someday we find alien life, will it use the same biochemistry as life on Earth does, or something different? If the same, would we be able to tell if it represented a wholly independent origin of life? How does non-life become life? When conditions are right, does life arise as a matter of course, or is it an exquisitely rare phenomenon?

Such questions fire up astrobiologists, who will be waiting breathlessly for results from the Europa Clipper and JUICE missions. Answering one or more of them would truly be, in a manner of speaking, Earth-shaking.

Peter

Editor in Chief

SKY & TELESCOPE
The Essential Guide to Astronomy

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

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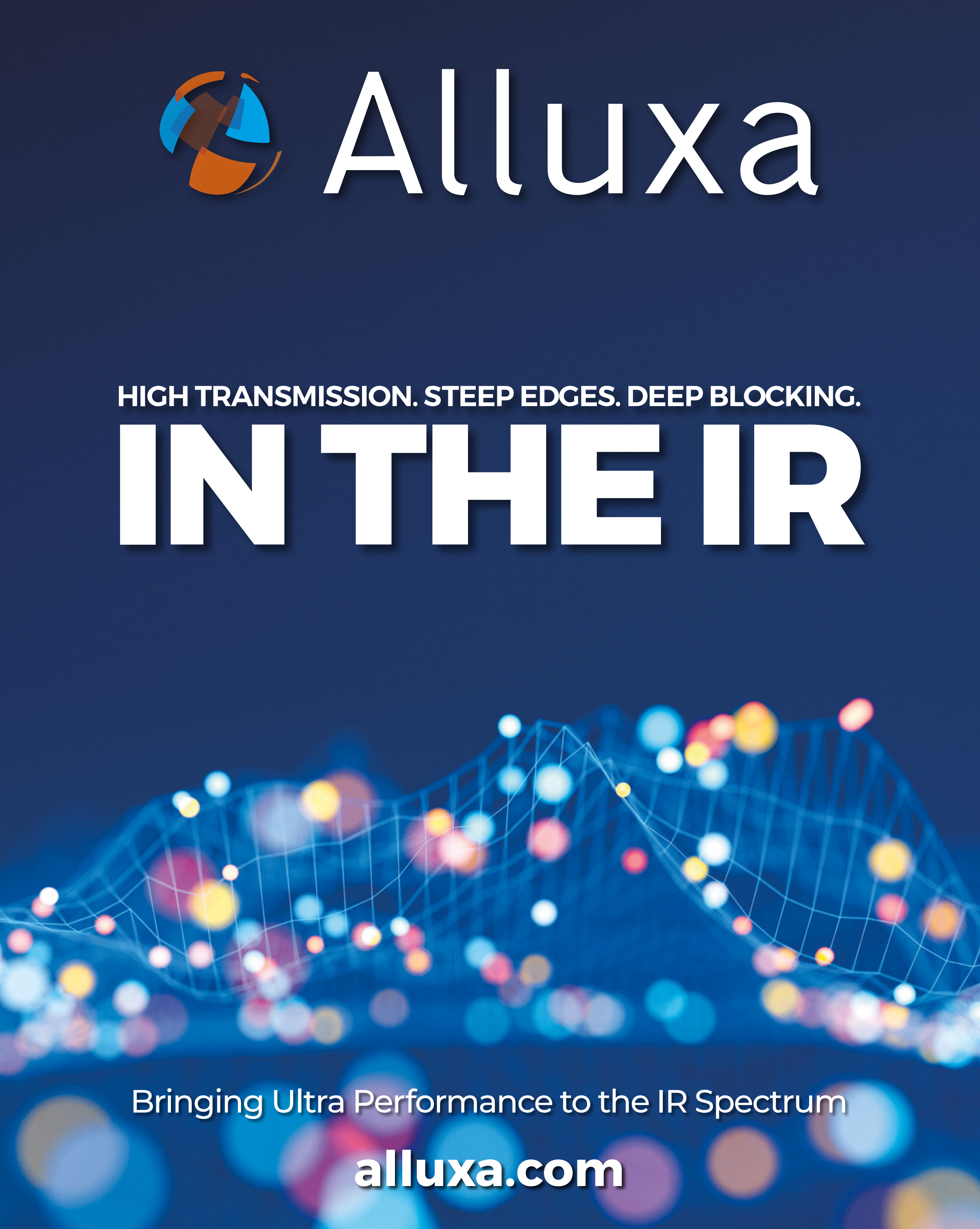
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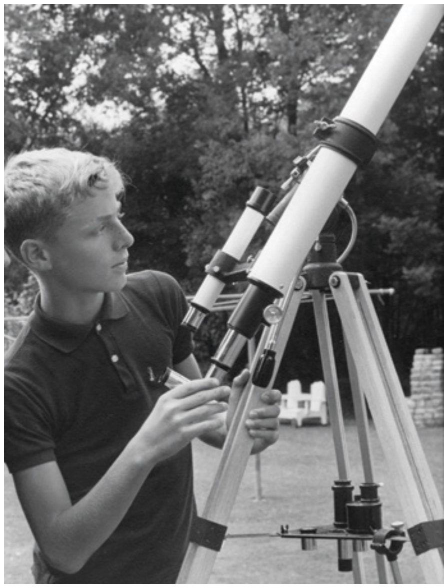
Matching Lafayettes

As a subscriber for many years, I was delighted to learn in "Coming Full Circle" (*S&T:* Nov. 2021, p. 84) that one of my favorite authors/editors, Dennis di Cicco, had the same connection to the 2.4-inch (60-mm) Lafayette refractor as I had. I got mine when I was in high school around the same time he did (1960–1961). I also remember, like it was yesterday, the first time I saw Saturn.

I used to read *Sky & Telescope* from cover to cover at the library when I was 12 or so. That telescope and my interest in science led me to a PhD in physics and a 42-year career as a chief scientist at four different research labs. I am semi-retired now, but I still consult on projects for one of the labs. Glad to know Dennis di Cicco and I started on the same scope. I've never seen it mentioned before. Thank you for bringing back those long nights when I was a teenager! I've since graduated to other telescopes, but this one holds a special spot.

Rich Tansey • Reno, Nevada



▲ *Left:* A young Dennis di Cicco inspects his 2.4-inch Lafayette refractor. *Right:* Rich Tansey's version of the scope, which is still in use after 55 years.

Dennis di Cicco replies: *It's nice to know that another person with a long connection to* Sky & Telescope *started out with the same 60-mm Lafayette refractor. Mine was a slightly early birthday present in July 1963 so that I could view the solar eclipse on July 20th. I still have distinct memories of my first view of Saturn, which happened when I turned the scope to the bright "star" that appeared next to the full Moon at the beginning of August.*

The scope has served me well in a variety of applications over the years — many of them being as a guide scope on larger instruments. As the scope approached its 50th birthday, I got interested in restoring it to nearly as original condition as possible, and I began searching for "parts scopes" on eBay. One that I obtained from a fellow on Long Island was so original that it still has excelsior packing in the wooden carrying case.

Here's to more years of us both enjoying our Lafayette telescopes!

Returning to Old Projects

I have long enjoyed the amazing material in *S&T*. Dennis di Cicco's "Coming Full Circle" was particularly touching. I, too, had a similar full-circle event last year when I finally finished a telescope that I started 50 years ago.

Fifty-one years ago, during the fall I turned 16, I had a bit of time and found myself drawn to building a telescope. So I found an 8-inch (20-cm) piece of glass and a book on telescope making and went through the steps. Through autumn the Andromeda Galaxy got lower and lower in the west, and I realized, as much as I wanted to see it through my own telescope, it was not going to happen. Other opportunities started to appear and, while I felt that I had not really gotten the mirror as good as I could have, I realized I had to put it away. I bought a small suitcase from the thrift store for 50¢ and tucked the mirror away. I knew the mirror holder, truss tube, and mount would all have to be easily transportable as I'd be moving soon, so I drafted out, in my mind, a system I thought I could afford, build, and transport. And then I moved on.

Well, during a lifetime of distractions and 22 moves, that little suitcase has gone with me every step of the way. Every fall, as Andromeda sank farther into the west, I thought about the telescope I wanted to build. This year, I got the suitcase out. Much to my delight and amazement, the f/6 mirror tested pretty darn good. So I went to the hardware store and bought the parts needed to build the telescope. I finally screwed it all together, just as I had been thinking of doing every fall for a lifetime.

Then, early on the morning of July 12, 2021, I used the telescope for the first time. It worked! I observed Jupiter, Saturn, Mars, Venus, the Moon, and . . . wait for it . . . the Andromeda Galaxy, too!

Thanks again for telling this age-old story of how we are all touched by our youthful selves. And thank you for giving me (and thousands more) a lifetime of wonderful monthly reading in *S&T*.

Bill Kahn
Weddington, North Carolina

Approaching a Telescope

Reading "Coming Full Circle," I started thinking about the mindset folks bring to a telescope or to an astronomy club.

Charles Spurgeon, an English pastor who lived in the mid-to-late 19th century, wrote in his book *Morning and Evening*, "The glory of the setting sun excites our wonder, and the solemnity of approaching night awakens our awe." That's the word: awe — wonder, excitement, anticipation.

However humble the telescope, it enables us to consider the vast expanse of the universe and the size and speed of those little workhorses, photons, whizzing through space to reach Earth. One can gaze at an image of Saturn and get lost in the utter amazement of the physics of light traversing space to enter the telescope, the eye, and beyond, or should I say within, as the human brain processes the almost unfathomable and incomprehensible. It's when the awe starts to ebb that I suspect many a scope ends up in a closet, missing all the light that it cannot see.

Ed Huff
Tucson, Arizona

Public Observing with Kids

Reading Alan Rifkin's quip about the youngster who dropped Rifkin's treasured eyepiece in the mud in "The Art of Sidewalk Astronomy" (*S&T:* Dec. 2021, p. 84) reminded me of my all-time favorite public observing story.

While waiting for the sky to darken, I pointed my 14-inch (35.5-cm) Dobsonian at Venus. My first "customers" were a 7- or 8-year-old lad and his dad. I told the boy that he would see the planet Venus. After a quick peek in the eyepiece, the lad turned to me and, in a rather loud voice, said, "That's not Venus you DUMMY, that's the Moon!" Quite a number of participants were within earshot, and I will never forget the look of embarrassment on the father's face!

Gregory Habas
Georgetown, Texas

Shakespeare and the Pleiades

I was pleased to receive a copy of the December 2021 issue of *S&T*, in which I read, among others, the fascinating article "Seeing the Seven Sisters" by Fred Schaaf. The scientific description of the star cluster interspersed with literary and mythical lore made it a nice reading experience. I would like to add one more literary anecdote related to the Pleiades. In Shakespeare's play *Henry IV, Part 1*, in Act I, Scene II, lines 13–16, Falstaff says to Prince Hal, "for we that take purses go by the moon and the seven stars, and not 'by Phoebus, he that wand'ring knight so fair'." In other words, to measure the suitable time for stealing purses, they go by the Moon and the Pleiades, not the movement of the Sun.

Tapan Kumar Mukherjee
West Bengal, India

SUBMISSIONS: Write to *Sky & Telescope*, One Alewife Center, Suite 300B, Cambridge, MA 02140, USA or email: letters@skyandtelescope.org. Please limit your comments to 250 words; letters may be edited for brevity and clarity.

75, 50 & 25 YEARS AGO by Roger W. Sinnott

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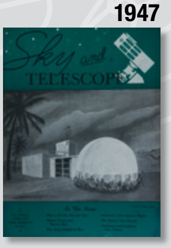
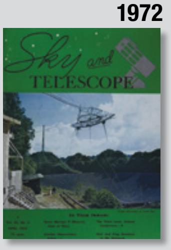


1972



1997

◖ April 1947

Stars Indoors "Not far from the southwest corner of the island is the Polytechnic Institute of Puerto Rico, surrounded by magnificent mountain scenery . . .

"On this rich earth, breathing this friendly air, are those who turn their eyes to the sky. It is to such a group of students, in such a background, that a unique new educational opportunity will soon be offered. The [institute] last month broke ground for its proposed Hall of Earth, Air, and Sky. In this building will be housed a miniature planetarium . . ."

The enthusiastic author, Armand N. Spitz, wasn't well known at the time. But in just a few years he began selling his simplified star projectors to schools and museums that could not afford the elaborate ones from Zeiss. When Spitz died in 1971, Charles Federer wrote that at least four-fifths of all planetariums in North America had Spitz projectors.

◖ April 1972

Dry Ice? "Astronomers have debated for many years whether Mars' white polar caps are frozen water or frozen carbon dioxide. During the past two decades, the weight of opinion has tended increasingly toward CO_2. . . .

"A decisive identification of frozen CO_2 in the Martian south polar cap has now been reported by Harold Larson and Uwe Fink of the Lunar and Planetary Laboratory, University of Arizona, from their work [using] the 90-inch Steward Observatory reflector on Kitt Peak. . . .

"[N]o spectral features of water ice were found . . . Hence Drs. Larson and Fink believe that there was at least 100 times as much carbon dioxide as water in the cap at the time of their observation. The essential absence of water could be either seasonal or permanent."

Thanks to spacecraft visits in the last 30 years, we now have a more nuanced picture. In each hemisphere's winter, its polar cap has a top layer of frozen CO_2 that tends to hide a larger amount of water ice underneath.

◖ April 1997

Faraway Globulars "When the Hubble Space Telescope stared at a nondescript patch of sky in Ursa Major for 100 hours in 1995, it predictably turned up what astronomers think are the most distant galaxies yet seen . . . Now the record-breaking image has provided researchers with the most distant globular star clusters known.

"Many researchers have concentrated on the Deep Field's elongated objects in the hope of learning about galaxy evolution. But Rebecca A. W. Elson [and colleagues] instead homed in on the equally important . . . 'point' sources. Eleven of these starlike dots hover around a recognizable elliptical galaxy. [T]hese pinpricks' colors and feeble magnitudes (from 28th to 30th) are suggestive of globular clusters at a distance of more than one billion light-years."

◀ The James Webb Space Telescope lifts off early morning on December 25th.

SPACE

The James Webb Space Telescope Launches

AT LAST! After more than two decades of development, cost overruns, a 2005 redesign, and brushes with Congress, the James Webb Space Telescope (JWST) launched on an Ariane 5 rocket on December 25th from the Guiana Space Center in French Guiana.

The first and second stages set JWST on a path toward a halo orbit around the Sun-Earth L_2 Lagrange point, 1.5 million kilometers (1 million miles) from Earth in the anti-sunward direction. Mission controllers reported the payload in good health post-launch.

The infrared space telescope will take 30 days to enter its final orbit, but deployment occurred while it was still en route. On January 4th, the team finished deploying the telescope's tennis court–size sunshield. This structure, which consists of five layers of a lightweight material called Kapton, is critical to the telescope's operations, as it helps cool the observatory down to below 50K (-223°C or -370°F). The next crucial step followed days after, as 132 actuators helped unfurl the 18 gold-plated beryllium mirror segments that make up the telescope's 6.6-meter (21.7-foot) primary mirror. On January 8th, NASA announced that the deployment phase was complete. Now, the team will commission the telescope and its instruments for about five months after the telescope arrives at L_2. Science operations should begin mid-year.

JWST will push forward our understanding of the universe at wavelengths from 0.6 to 28.3 microns, performing observations that can only be done in space. A joint project between NASA, the Canadian Space Agency, and the European Space Agency, JWST will answer key questions for a new generation of astronomers. It will witness the formation of galaxies in the early universe, study the birth of stars and planetary systems, and explore exoplanet atmospheres, as well as observe solar system bodies.

While JWST has a minimum lifetime of five years, NASA issued a statement post-launch saying that the mission has enough fuel to support "significantly more than a 10-year science lifetime."

■ **DAVID DICKINSON**

JWST LAUNCH: ESA / CNES / ARIANESPACE; PARKER SOLAR PROBE ILLUSTRATION: NASA / JOHNS HOPKINS APL / BEN SMITH

SOLAR SYSTEM

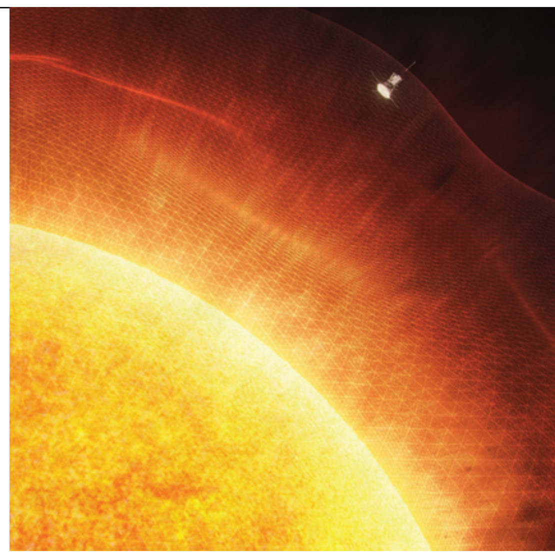
Parker Solar Probe "Touches" the Sun

NASA'S PARKER SOLAR PROBE (*S&T:* Nov. 2020, p. 20) entered our star's atmosphere on April 28, 2021, "touching" the surface of the Sun. The probe slipped past a critical boundary known as the *Alfvén surface*, entering a region of space where the Sun's crackling magnetic field has a tight hold on the plasma and governs its movements.

The probe actually entered this magnetized atmosphere a total of three times, explains Justin Kasper (BWX Technologies, Inc. and University of Michigan), principal investigator of the probe's particle-detecting Solar Wind Electrons Alphas and Protons (SWEAP) instruments. Kasper led a study on the crossings in the December *Physical Review Letters*.

The first time Parker passed the Alfvén surface, it flew through the solar atmosphere for about five hours. Even as it continued flying toward the Sun,

▶ In this artist's concept, the Parker Solar Probe hovers above a hilly boundary known as the *Alfvén surface*.



GALAXIES

A Tiny Galaxy Has a Giant Black Hole

AT THE CENTER OF Leo I, a dwarf galaxy about 100,000 times less massive than our own, astronomers have discovered a black hole nearly as big as the behemoth at the core of the Milky Way.

"My first reaction was total disbelief," recalls María José Bustamante Rosell (now at University of California, Santa Cruz), who led the study in the November 10th *Astrophysical Journal*.

Her team examined the integrated light of stars in Leo I to measure how their typical speeds vary throughout the galaxy. In doing so, they noticed extreme motions around the center — a telltale sign of the strong, concentrated gravitational pull of a black hole. By their estimate, the core of Leo I weighs in at around 3 million times the mass of the Sun, though the value could range from 1.3 million to 5.3 million solar masses. For comparison, the Milky Way's central black hole contains 4.3 million Suns.

Leo I is a dwarf spheroidal galaxy, which means that it is a small but massive group of stars. Though dwarf spheroidals are probably very common, they are so dim that astronomers have only discovered a few.

There are at least two ways for such a small galaxy to end up with a supermassive black hole: The galaxy might

Dwarf galaxy Leo I

have started out larger, before the Milky Way's gaseous halo ripped away most of its star-forming material. Or there might have been runaway mergers of stellar-mass black holes. The first option would not leave enough of the galaxy behind, while the alternative, piece-by-piece growth wouldn't have built a supermassive black hole in time.

There are caveats. "Leo I could very well be a weird one-off," Bustamante Rosell notes. Astronomers will have to look for more black holes in dwarf spheroidals to be certain something really strange is going on. If it is, then a crucial piece may be missing from what we know about how galaxies form or how black holes are born — or maybe even both.

According to Mark den Brok (Leibniz Institute for Astrophysics Potsdam, Germany), who was not involved in the study: "This [result] might lead to a paradigm change."

■ ASA STAHL

though, it popped back out — only to submerge again more deeply when it was at its closest approach. That time it exited after just half an hour. Then, on its way outward, the spacecraft once again skimmed beneath the surface for more than an hour.

"[The Alfvén surface] has to be wrinkly," Kasper says. "It's not fuzzy — it's well-defined while we're under it — but the surface has some structure to it." So while the probe sees a smooth change in conditions while crossing the boundary, *where* the boundary is can change.

Subsequent passes should also take the probe within the solar atmosphere, shedding light on the origin of the solar wind and the heat source of the million-degree corona. The probe's insider view may also give scientists insight into *switchbacks*, ubiquitous magnetic twists in the solar wind (*S&T:* Apr. 2020, p. 10). The new observations suggest switchbacks may be associated with *magnetic funnels* that form between the giant convection cells in the Sun's boiling plasma.

As the Parker Solar Probe continues its spiral toward the Sun, solar activity is also ramping up, promising additional insights.

■ MONICA YOUNG

WIKISKY

IN BRIEF

Primordial Grains from Asteroid Ryugu

Laboratory tests showed that the sample that the Hayabusa 2 spacecraft grabbed from the carbon-rich asteroid 162173 Ryugu is the most primitive ever collected. (Previous missions have returned samples from the Moon, Comet 81P/Wild 2, and rocky asteroid 25143 Itokawa.) Two teams published reports on the Ryugu sample in *Nature Astronomy* on December 20th. Toru Yada (Japan Aerospace Exploration Agency) and colleagues found the particles to be extremely porous and dark, with an *albedo* (reflectivity) of only 2%. They also detected infrared absorption signatures of organic and hydrated compounds. In the second study, Cédric Pilorget (University of Paris-Saclay) and his group confirmed these detections, finding additional signatures from volatile-rich species. Such species would have vaporized if they spent too much time close to the Sun, suggesting the compounds formed farther out in the solar system. They were probably already present when the grains first coalesced out of the protoplanetary disk. "These two papers are really fundamental," says Deborah Domingue (Planetary Science Institute), who was not involved in the study, "establishing that this is a highly primitive body."

JEFF HECHT

Read more details at https://is.gd/Ryugusample.

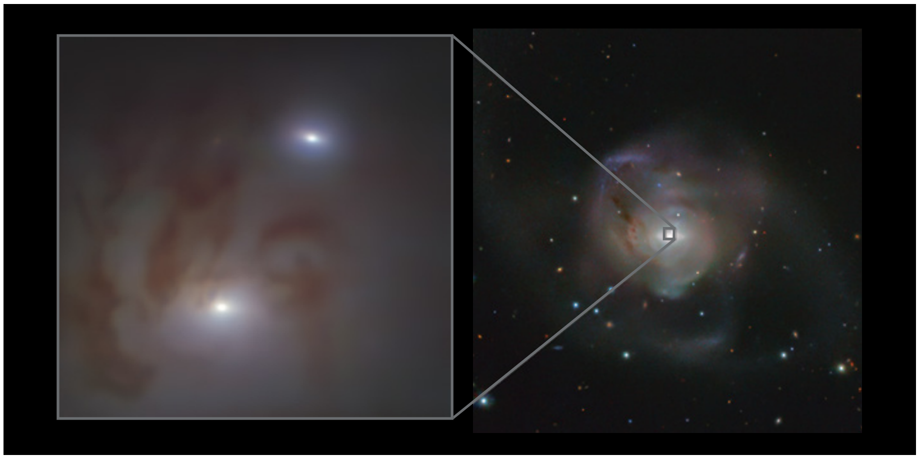
New X-ray Explorer

NASA's Imaging X-ray Polarimetry Explorer (IXPE) lifted into an equatorial low-Earth orbit on December 9th. The $214 million mission specializes in *polarization*, a largely unexplored property of X-rays by which astronomers can gain insight into the structures and processes at work in enigmatic astrophysical objects such as supernovae, magnetars, and feeding black holes. IXPE has three identical telescopes sitting on an extended boom, each with a set of 24 nested cylindrical mirrors that focus X-rays grazing along their surfaces. The telescopes measure the arrival time, location, energy, and polarization of each incoming photon. IXPE will set its eyes on some 40 X-ray sources during its first year; a second year will be dedicated to follow-on observations. "It's a new toolkit for astronomy and astrophysics," says principal investigator Martin Weisskopf (NASA MSFC). "I can't wait to see it at work."

■ DAVID DICKINSON

BLACK HOLES

Nearest Supermassive Black Hole Pair Discovered



▲ This image shows close-up (*left*) and wide (*right*) views of the two bright nuclei of NGC 7727, each of which harbors a supermassive black hole.

ASTRONOMERS HAVE IDENTIFIED and "weighed" the nearest dual supermassive black hole in a galaxy 89 million light-years away.

In a study to appear in *Astronomy & Astrophysics*, a team led by Karina Voggel (Observatory of Strasbourg, France) presents evidence that a previously discovered double nucleus at the center of the slightly distorted galaxy NGC 7727 harbors two supermassive black holes some 1,600 light-years apart. That's close enough for them to collide within just 250 million years or so.

Using the Multi Unit Spectroscopic Explorer (MUSE) on the European Southern Observatory's Very Large Telescope in Chile, the team measured the bulk stellar motions in the two nuclei. The spread of velocities indicates that the black holes have 154 million and 6.3 million solar masses, respectively.

"This is a nice piece of work and a very trustworthy way of determining the black hole masses," comments Peter Barthel (University of Groningen, The Netherlands).

The duo is one of a growing number of supermassive black hole pairs that astronomers have found. Since galaxies grow via mergers and most large galaxies host supermassive black holes, we can expect to see many such pairs, but they can be hard to find. Voggel points out that the more massive black hole in NGC 7727 doesn't show any current activity, so it would have gone unnoticed if not for the velocity measurements carried out with MUSE.

"Due to these hidden black holes, some of which may be outside of the centers of galaxies, the overall number of supermassive black holes could be up to 30% higher than previously assumed," Voggel notes.

■ **GOVERT SCHILLING**

SPACE

What Comes after the International Space Station?

AS NASA PREPARES to retire the International Space Station (ISS) by 2030, it will also support a transition to commercial operations in low-Earth orbit. This recommendation comes as part of an audit that the NASA Office of Inspector General released on November 30, 2021.

The station has hosted a continuous human presence in space since November 2, 2000, and it has served as a key platform for scientific studies in fields ranging from human physiology to Earth observation to high-energy astrophysics. But the station is showing its age. Most notably, multiple cracks and additional undiscovered leaks along the interior of the Service Module Transfer Tunnel, which connects to one of the areas where crew live and work, have raised concerns about the station's structural integrity.

The report thus details the plan for a controlled deorbit, which will take place over several years beginning between 2026 and 2028. (In the event of an emergency, the reentry timeline could accelerate to about six months.) Deorbiting the station will cost about $1 billion (roughly the same as one year's maintenance), to be split among the international partners.

The audit acknowledges that research on the long-term effects of living in space, essential to future missions, will not finish before the ISS's demise. Other outposts will therefore have to continue to advance the work.

▲ The International Space Station, as viewed from the Space Shuttle

To that end, NASA has selected three companies to develop plans for commercial stations in low-Earth orbit, including Blue Origin ($130 million), Nanoracks LLC ($160 million), and Northrop Grumman ($125.6 million).

Axiom Space is another player in commercial low-Earth orbit. The company plans to send at least one module to the ISS in late 2024, which will detach and form its own small space station by 2028.

For years, the ISS has silently slid overhead in the night, a reminder of humanity's outpost in space. With preparation, that human presence may continue for decades to come.

■ **DAVID DICKINSON**

Read the full report at https://is.gd/ISSaudit.

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STARS

Stellar Remnant at the Heart of "The Cow"

A TITANIC EXPLOSION in a remote galaxy that occurred in June 2018 was most likely the birth cry of a neutron star or a black hole, according to a detailed analysis of high-energy X-rays captured from the fading blast.

Discovered by the Asteroid Terrestrial-impact Last Alert System (ATLAS) and cataloged as AT2018cow, the explosion occurred in a spiral arm of the inconspicuous galaxy CGCG 137-068, which is 200 million light-years away in Hercules. But this was no regular supernova: "The Cow," as it was nicknamed, brightened much faster and was much bluer and more luminous than any exploding star observed before.

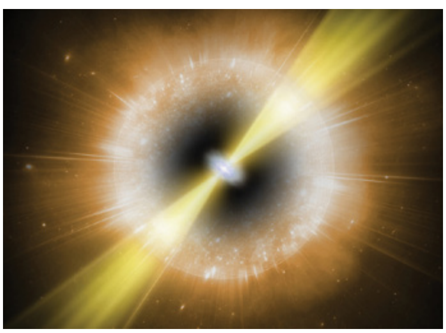
Astronomers have found similar "fast blue optical transients" (FBOTs) in archival data, but they saw the Cow in real time. It was by far the most luminous FBOT observed.

On December 13th in *Nature Astronomy*, a team led by Dheeraj Pasham (MIT) argued that a compact object lies at the core of the blast. Pasham and colleagues analyzed two months' worth of high-energy X-ray data collected by NASA's Neutron Star Interior Composition Explorer (NICER) X-ray telescope aboard the International Space Station. The astronomers found a rapid flickering (224 cycles per second), from which they estimated that the size of the X-ray emitting region is no larger than 1,300 kilometers (810 miles) across.

This size rules out an extended gaseous envelope, as well as a black hole more massive than 850 Suns. The slightly irregular flickering likely arose from a rapidly rotating accretion disk, though it's unclear whether the material orbits a neutron star or black hole.

"The authors have done a thorough job exploring different options," says Chryssa Kouveliotou (George Washington University), who was not involved in the study. "I think it is still too early to call what the spinning object is. We probably need to observe more such systems to make a final decision."

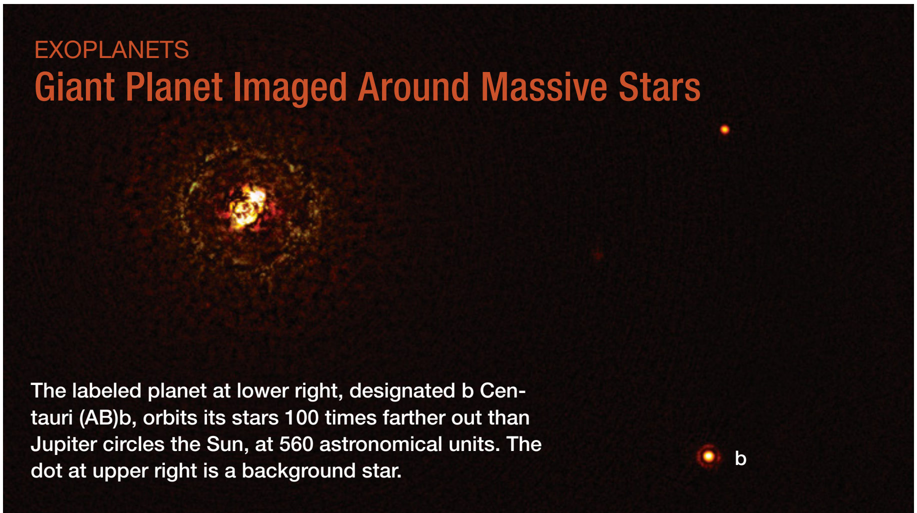
■ GOVERT SCHILLING



▲ An artist's impression of the mysterious burst dubbed AT2018cow

EXOPLANETS

Giant Planet Imaged Around Massive Stars



The labeled planet at lower right, designated b Centauri (AB)b, orbits its stars 100 times farther out than Jupiter circles the Sun, at 560 astronomical units. The dot at upper right is a background star.

ASTRONOMERS HAVE IMAGED a giant planet around a massive pair of stars collectively known as b Centauri. The discovery in the December 9th *Nature* challenges our notions of how planets form.

Markus Janson (Stockholm University) and colleagues saw the planet in observations taken in 2019 and 2021 as part of the B-star Exoplanet Abundance Study (BEAST). The real kicker, though, was an observation taken two decades earlier as part of a different project. Including the latter observation enabled the researchers to confirm that the planet is both moving with the b Centauri system and orbiting its central stars. The stars together are up to 10 times the mass of the Sun, making this system the most massive known to host planets.

The planet, dubbed b Centauri (AB)b to denote that it circles both stars, has one of the widest known orbits, comparable to that of Sedna in the outer solar system. But the planet's mass, deduced from the glow leftover from its formation, is between 9.3 and 12.5 Jupiters — over a million times more massive than the far-out Kuiper Belt object.

The mass-orbit juxtaposition puts planet formation scenarios to the test. Astronomers think giant planets form via *core accretion*, in which smaller grains stick together, merging their way up to planet sizes before attracting a gaseous outer layer.

But if a planet forms too far out, there won't be much gas for it to attract. This is especially true around massive stars, whose intense radiation quickly dissipates gas. Then again, since disks disperse from the inside out, perhaps a wide-orbiting planet has more time to grow.

It's also possible that material collapsed suddenly in a process known as *gravitational instability*.

Previous studies of less massive stars have shown that bigger stars tend to host bigger planets in wider orbits. However, exoplanet expert Joshua Winn (Princeton) cautions that we need more exoplanets orbiting truly massive stars to draw firm conclusions.

■ MONICA YOUNG

STAR AND PLANET: ESO / JANSON ET AL. / *NATURE* 2021; EXPLODING STAR: NATIONAL ASTRONOMICAL OBSERVATORY OF JAPAN

WHAT LIES BENEATH THE ICE? The Europa Clipper spacecraft will explore Europa's icy geology, as well as look for leaks from its subsurface ocean.

Ocean Underworlds

Two missions launching soon will take a close look at some of our best bets for finding alien life in the solar system — Jupiter's icy moons.

NASA / JPL-CALTECH

Ask any amateur astronomer and they will likely tell you that of all the planets in the solar system, Jupiter holds a special place in their heart. But for me and many others, the gas giant itself plays second fiddle to the Galilean moons merrily dancing around it. Even when viewing them through wobbly binoculars for the umpteenth time, there's still a giddy rush of joy in seeing energy and movement in the sky as the moons change position, in having the ability to track the moons' orbits, and in knowing I'm viewing the same scene and following the first steps that helped Galileo Galilei more than 400 years ago come to the conclusion that the universe doesn't revolve around us.

For showing that worlds can orbit other bodies, not just Earth, the Galilean moons — Io, Europa, Ganymede, and Callisto — played a key role in humanity's realization that our tiny rock is just a small part of something much, much bigger. But this might not be the only profound truth they harbor. Though all their surfaces seem harsh and barren, Jupiter's four large moons might just offer hope of finding other life in the solar system.

During their 1979 Jupiter flybys, NASA's twin Voyager spacecraft swept past the Galilean satellites, snapping pictures that revealed hugely diverse worlds, from the bristling volcanic activity of Io to the dead cratered surface of Callisto. But it was the images of Europa that would lead scientists to wonder about potential alien life. Europa's terrain was riddled with wide, brown, crack-like streaks — the first visible hint that something might be going on below the surface.

Twenty-seven years later, NASA's Galileo mission began taking measurements of Jupiter's magnetosphere near Callisto and Europa. After analyzing the data, scientists found something startling. The periodic planetary magnetic field felt by the moons due to Jupiter's rotation was inducing weaker magnetic fields at Europa and Callisto. The only way this could happen was if the moons contained a huge amount of conductive material, and the best match to the data was liquid salt water. With gravity measurements from Europa backing up the magnetic field results, scientists tentatively concluded that Europa and Callisto — and later, Ganymede as well — likely host ocean underworlds beneath their protective icy shells.

The Key Ingredients

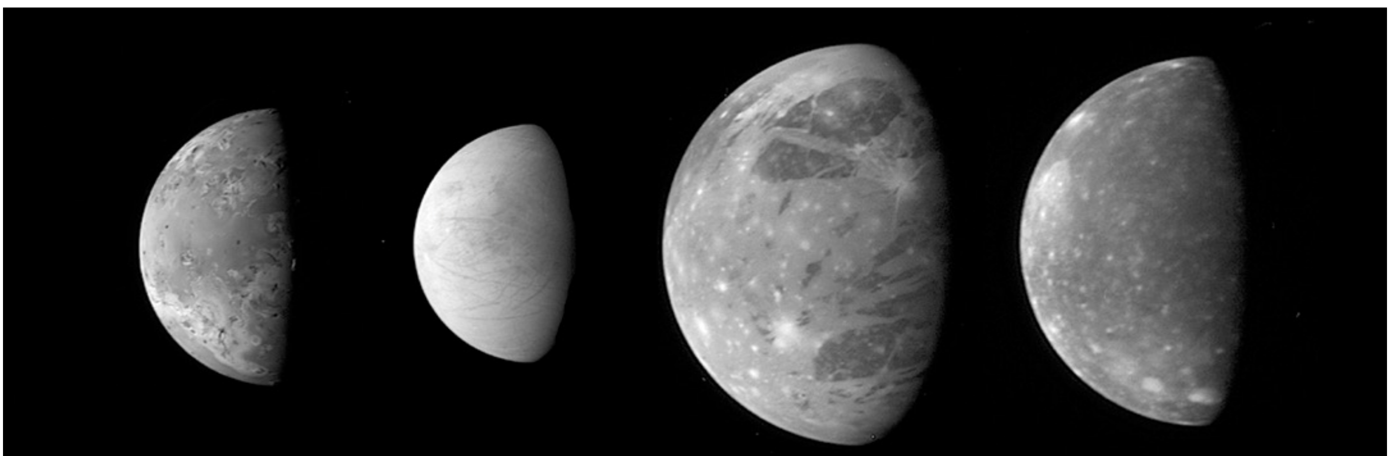
Why this discovery was important is simple: no water, no life (at least, as we know it). Among other key properties, water is essential because it is an amazing solvent. More substances dissolve in water than in any other liquid, meaning it enables important nutrients to pass into a cell and toxic substances such as waste products to be shuttled out.

Given water's key life-giving role, Io — the closest moon to Jupiter and the most volcanically active body in the entire solar system — represents the longest shot among the Galilean moons for hosting extant life. Blasted by radiation from Jupiter, any liquid water that might have existed on Io in the distant past was stripped from the surface long ago; only places such as the moon's subsurface lava tubes might still host a habitable environment.

Discarding Io (and Jupiter itself, plus the 75 other smaller Jovian moons) leaves just three hopes for finding life in the Jovian system: Europa, Ganymede, and Callisto. All three are thought to have an abundance of liquid water beneath their icy shells. How do we whittle down the contenders to give us the best chance of finding life?

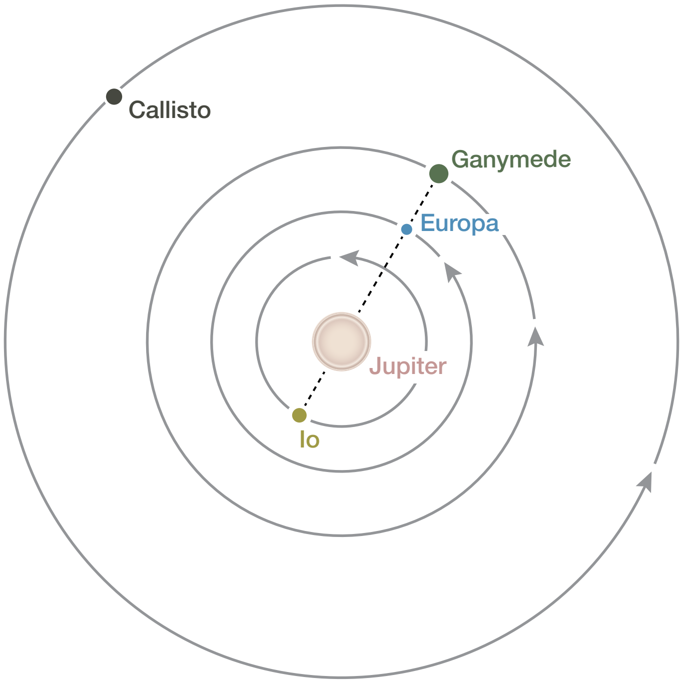
To answer this question, we need to get to the nub of what is absolutely essential to life here on Earth. And when we do, the list is surprisingly short. Given enough time, life appears to only need water, a source of energy, and a handful of essential elements.

On our world, most life ultimately takes its energy from the Sun, which is not an option on a distant ocean world covered by a thick layer of ice. But some *extremophiles* are known to harvest their energy from hydrothermal vents deep underwater (*S&T:* Jan. 2020, p. 34). Some scientists even think life on Earth originated around such vents. With a

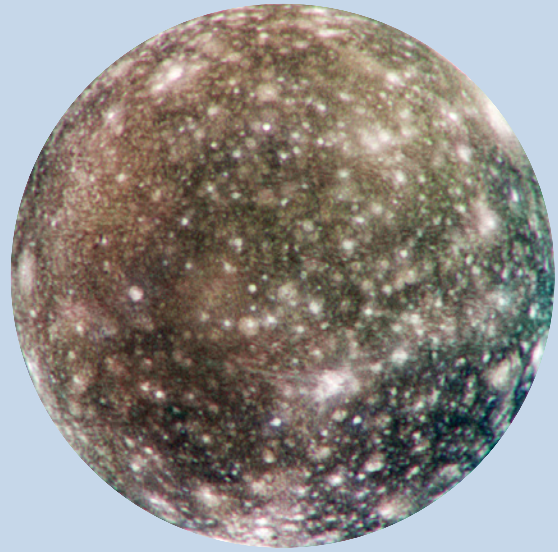


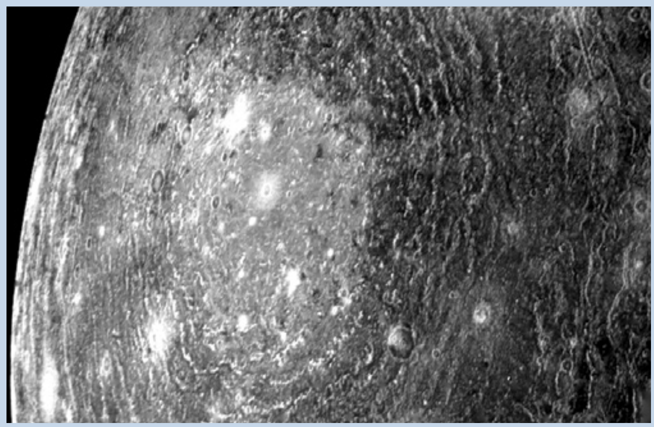
ALL IN THE FAMILY The Pluto-bound New Horizons spacecraft took these images of the Galilean satellites during its 2007 flyby. The images are scaled to the moons' relative sizes and placed in order of distance from Jupiter, left to right: Io, Europa, Ganymede, and Callisto.

NASA / JHU APL / SWRI



▲ **RESONANCE** The Galilean moons orbit Jupiter closely, and the three inner satellites travel in resonant orbits: For every orbit Ganymede completes, Europa completes two and Io four. When Europa and Ganymede are closest to each other, Io is always on the opposite side of Jupiter.





▲ **CALLISTO** *Top:* This color image from the Galileo spacecraft shows bright impact scars on the dark surface of Jupiter's most distant Galilean moon.

▲ **BIG SMACK** *Bottom:* Voyager 1 snapped this image of a 300-km-wide impact basin on Callisto in 1979. The multiple rings that surround the basin indicate that the surface is less dense and stiff than, say, the crust of the Moon.

suitable energy source to heat their cores, these moons too could host vents teeming with life.

In terms of essential elements, there are six that make up 98% of most life here on Earth: carbon (C), hydrogen (H), nitrogen (N), oxygen (O), phosphorus (P), and sulfur (S), or CHNOPS for short (pronounced "schnapps," like the liqueur). If the icy Galilean moons show signatures of these elements and have a way to produce energy, it's a fair bet they could host life.

Callisto: The Dead Surface

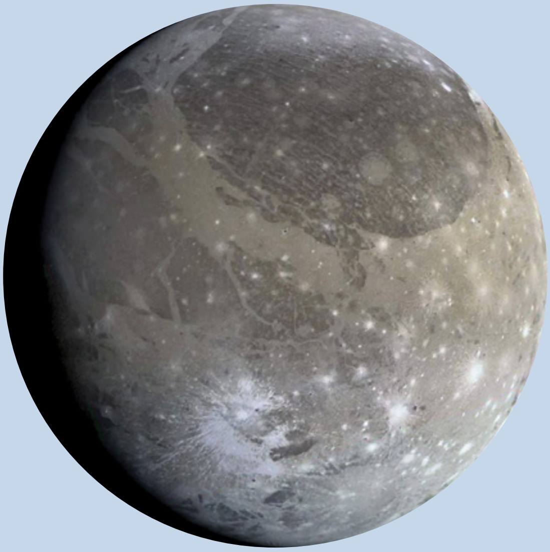
When we assess what we know about each of the three icy Galilean moons, Callisto stands out as a rank outsider in the "potential for life" pecking order. Its rocky, icy surface is the oldest and most heavily cratered in the entire solar system, with no large mountains and no evidence of volcanic or tectonic activity.

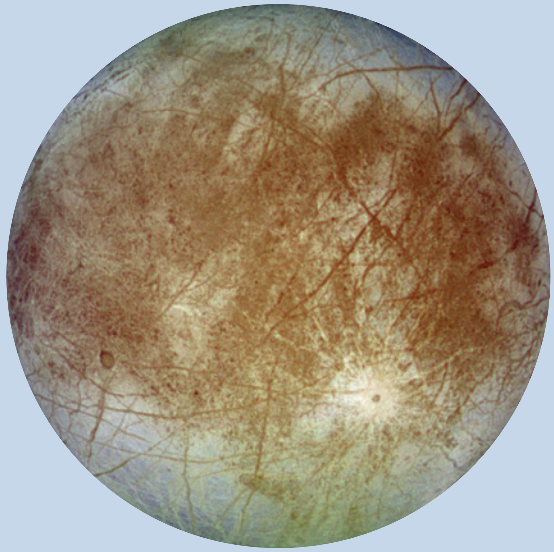
In large part, Callisto's dead appearance stems from a lack of energy. Just as the Moon's gravitational tug creates ocean tides here on Earth, the Galilean satellites experience tidal forces from Jupiter. In their slightly elliptical orbits, these moons are pulled by time-varying gravitational forces that stretch and squeeze them as they move closer and farther away from their host planet, like pinching a tennis ball from the top and bottom with one hand and then from the sides with the other repeatedly. This constant bulging in different directions causes friction, which creates internal heat.

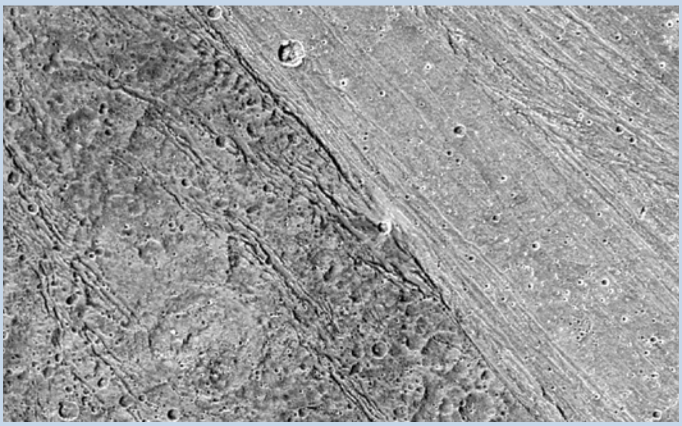
Io, Europa, and Ganymede gain an extra energy boost from their huge gravitational influence on one another, due to being in *resonant orbits* around Jupiter. Ganymede's 7.2-day orbit is two times Europa's 3.6-day orbit, which in turn is twice Io's 1.8-day orbit. This synchronization reinforces Jupiter's gravitational tug, creating much bigger tidal effects. Being the farthest from Jupiter and not being part of the resonant gang means Callisto experiences little tidal heating. As a result, the case for Callisto's ocean receiving enough energy to support life is weaker.

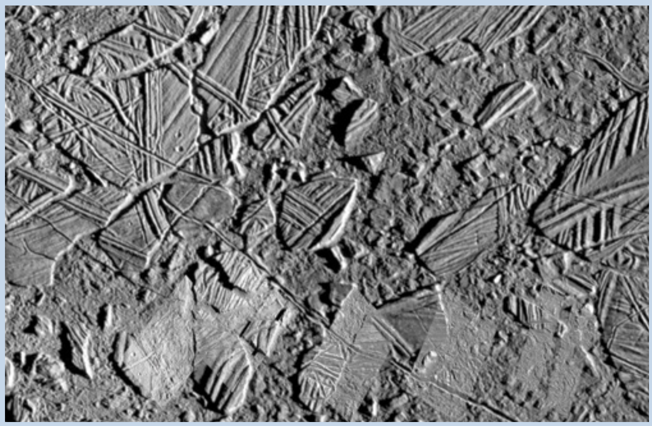
What's more, Callisto might not even have a subsurface ocean. "We can interpret Callisto's gravity [measurements] to be consistent with an ocean," says planetary scientist Wil-

DIAGRAM OF MOONS' ORBITS: *S&T* DIAGRAM; CALLISTO GLOBE: NASA / JPL / DLR; IMPACT ON CALLISTO: NASA / JPL









▲ **GANYMEDE** *Top:* This color composite shows Jupiter's largest moon as seen by the Galileo spacecraft. Ganymede has a complex surface, its darker, heavily cratered regions striated by lighter, more pristine regions that might be due to past cryovolcanism.

▲ **TERRAIN BOUNDARY** *Bottom:* The ancient, dark terrain of Nicholson Regio (left) lies alongside the smoother Harpagia Sulcus. Perhaps the bright regions have been smoothed by tectonic processes?

▲ **EUROPA** *Top:* This Galileo image shows the smallest of Jupiter's ocean moons in approximately natural color. The myriad lines are fractures in the crust, some stretching more than 3,000 km long.

▲ **CHAOS** *Bottom:* In several places on Europa, ice appears to have broken up, shifted, and even tipped over in a surrounding liquid or slush that then refroze as a solid but brittle surface. This mosaic shows the Conamara Chaos region.

liam McKinnon (Washington University). "But it also could simply have a core that is sufficiently lumpy that it gives the very weak gravity signal that Galileo saw." And perhaps the magnetic measurements come from the moon's ionosphere, mimicking a conductive subsurface ocean, he adds. "We simply don't know."

Despite these doubts, Callisto is not completely ruled out. It hosts a rich store of essential elements, revealed by carbon dioxide, hydrogen, and oxygen detected in its thin atmosphere. In addition, its putative dark ocean could be heated to some extent by the decay of radioactive elements in the moon's core. "I think it's very mysterious," says planetary scientist Olivier Witasse (European Space Agency). "This moon, which seems to be dead from the geological point of view, could be interesting in terms of habitability."

Ganymede: The In-Betweener

Witasse is the project scientist of ESA's Jupiter Icy Moons Explorer (JUICE) mission, which will launch in 2022 and travel for almost seven and a half years to reach the Jovian system. JUICE will peer over Callisto and Europa, as well as Jupiter itself. But the mission's main goal is to interrogate the

GANYMEDE GLOBE: NASA / JPL / TED STRYK / CC BY-NC-ND 3.0; TERRAIN ON GANYMEDE: NASA / JPL / DLR; EUROPA GLOBE: NASA / JPL / DLR; EUROPA'S SURFACE: NASA / JPL habitability of Ganymede from above.

Bigger than Mercury, Ganymede is the largest moon in the solar system. Its surface has a split personality. Darker regions are heavily cratered like Callisto, suggesting they have not changed in billions of years. Lighter regions look geologically younger, like Europa, with puzzling geology and fewer craters. Scientists have proposed many explanations for these lighter regions' features. For instance, McKinnon and his colleagues have suggested that liquid water flooded rifts in the surface and subsequently froze over, relandscaping Ganymede. Others have touted the idea that these regions stem from tectonic activity. These and other explanations point to Ganymede's subsurface ocean being internally heated at some time, though McKinnon warns: "It's not a presently active world as far as we can tell."

The most interesting aspect of Ganymede is its mysterious magnetic field. Ganymede is the only moon — and one of only three solid bodies in the solar system (alongside Mercury and Earth) — to generate its own global magnetic field. Might this field make Ganymede habitable? "It could do," says Michele Dougherty (Imperial College London), principal investigator for JUICE's J-MAG magnetometer instrument. "I mean, Earth's magnetic field protects it from the most energetic particles from the solar wind, and so it's part of what's helped make Earth habitable over a long period of time."

For Dougherty, though, Ganymede's magnetic field is more important as one of several tools to probe the subsurface ocean's habitability — for which there is a key sticking point. Given Ganymede's size, some predictions suggest that pressures might force water at the bottom of the ice-topped ocean to form another ice layer in a different phase at the seafloor, sandwiching the ocean and making it difficult for heat from the mantle to leach through in the form of potentially life-supporting hydrothermal vents. More recent predictions point to there being several liquid layers, the deepest of which may be in direct contact with the seafloor.

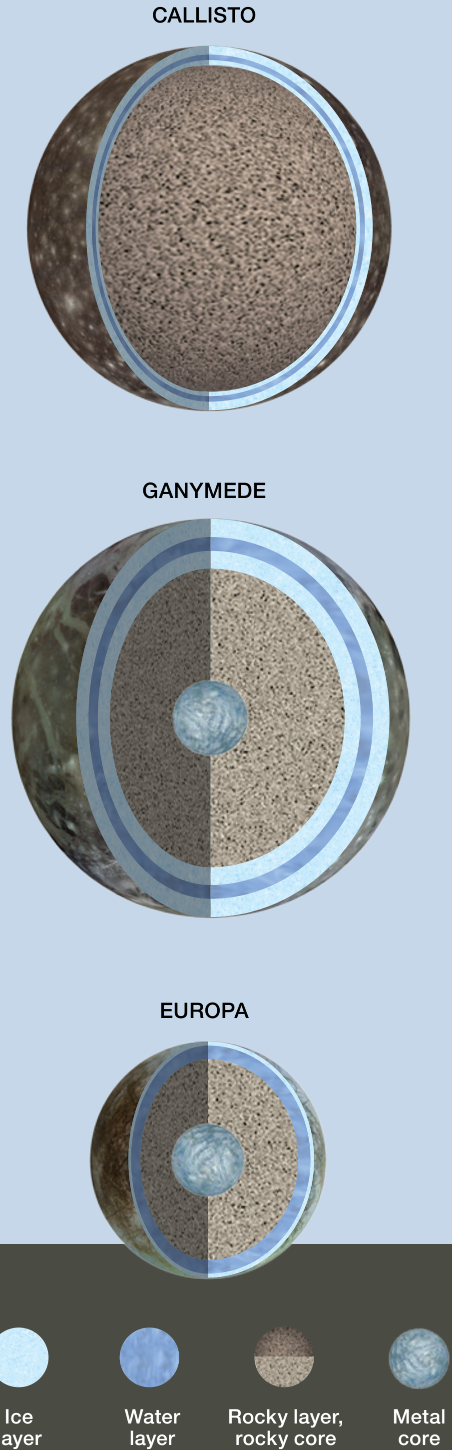
"What my instrument will do is measure the size of the currents that are flowing in the ocean," says Dougherty. Both Jupiter's daily rotation and Ganymede's monthly circuit create magnetic variations that will produce unique effects, depending on the ocean's thickness and salinity. "We're going to be able to separate out how deep the ocean is from what its salt content is."

Orbiting Ganymede for nearly a year, JUICE will also take detailed measurements of the moon's rotation rate, gravity field, and how much the surface warps due to tidal forces. Mission scientists will then compare these data with different predictions of Ganymede's composition. "We'll get the answer with JUICE," Witasse asserts.

Europa: Chaos and Geysers

If that answer is that the moon does indeed have a layer of liquid water in direct contact with the seafloor and hot mantle, Ganymede might provide one of the most fertile environments in the solar system. Yet confirming life deep

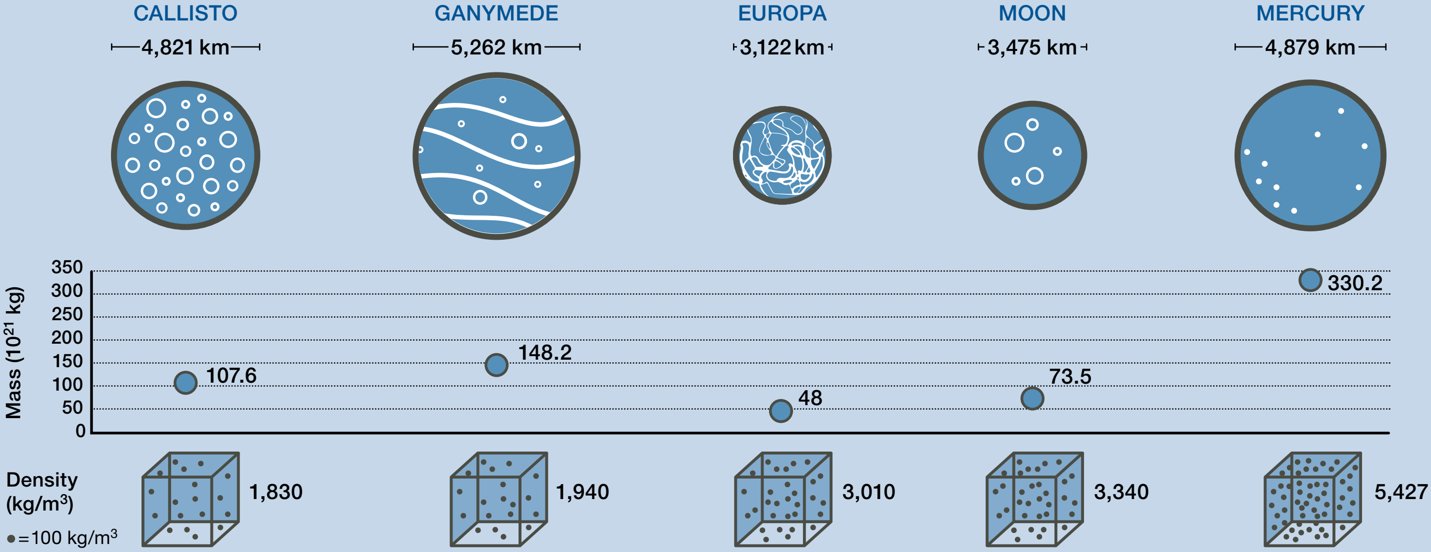
OCEAN WORLDS Jupiter's three icy Galilean moons are some of the largest satellites in the solar system and appear to have subsurface seas. If they also have energy sources (such as hydrothermal vents) and the right chemical combinations, they might be habitable.



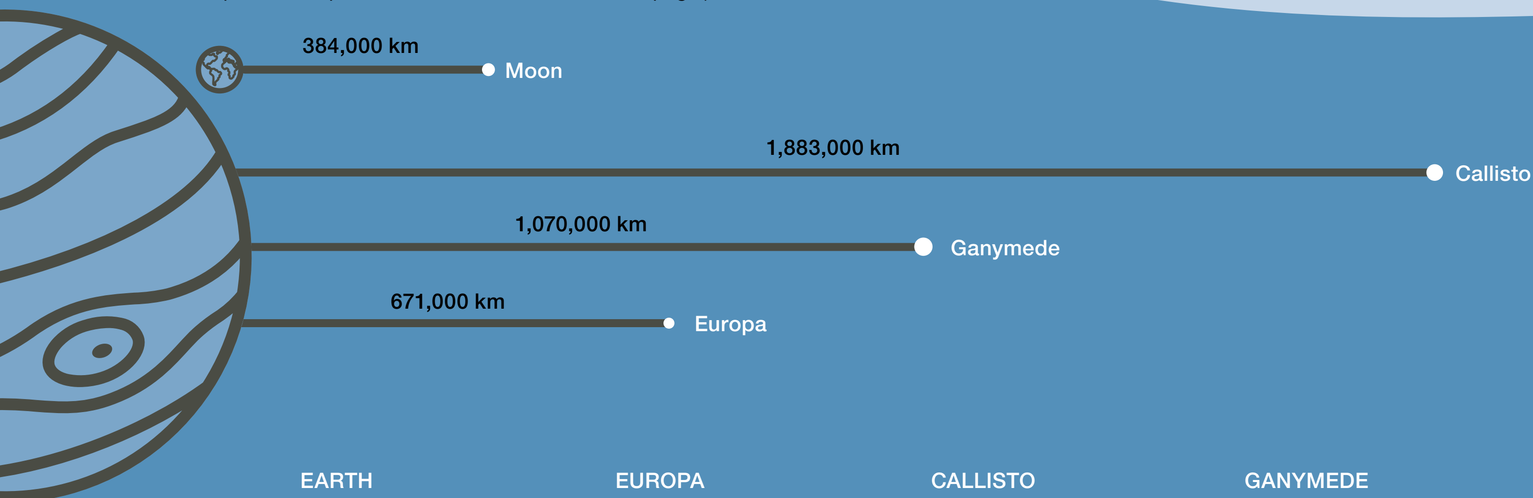
WATER LAYERS Researchers estimate that Callisto's *hydrosphere* (ice plus liquid water) makes up about 10% of the moon's radius. Ganymede's is a whopping 25%, while Europa's is 15%. Earth's oceans span less than a tenth of a percent of our planet's radius.

GREGG DINDERMAN / S&T, SOURCES: STEVEN VANCE / JPL AND DOUG ELLISON, EMILY LAKDAWALLA, BOB PAPPALARDO / CC BY 3.0

NO SMALL FRY Ganymede, the largest moon in the solar system, beats out Mercury in size, with Callisto not far behind. But both satellites are far less dense than the Iron Planet or even Earth's Moon. Europa, just smaller than the Moon, has only a slightly lower density than our satellite.

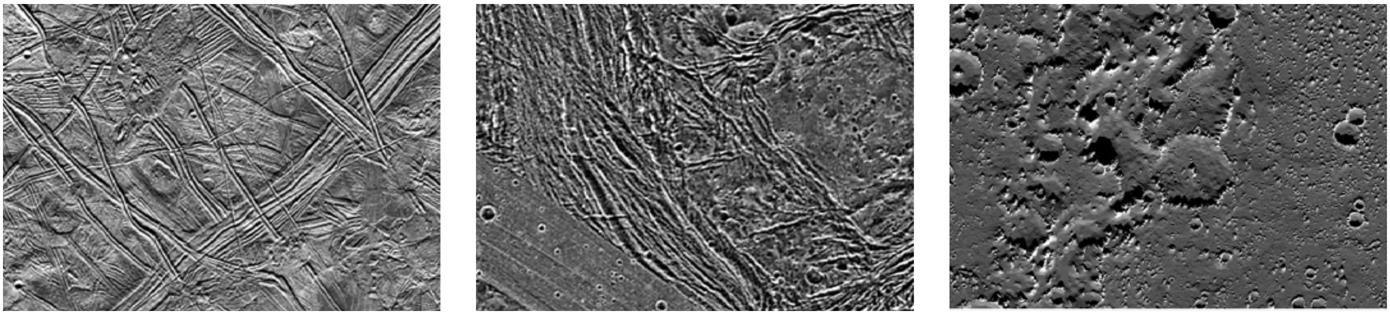


CLOSE KIN In kilometers, the Moon lies closer to Earth than the Galileans do to Jupiter. But in terms of the host planet's size, the Galileans are much closer: Ganymede lies 15 Jupiter radii away, whereas the Moon lies 60 Earth radii away. (Distances are shortened by a factor of 5 with respect to the planets' sizes, in order to fit on the page.)



HOW MUCH WATER? Estimates vary, but the Galilean oceans could easily be 25 times deeper than the average depth of Earth's seas. (Earth's deepest point is 11 km, in the western Pacific's Mariana Trench.)

INFOGRAPHIC: TERRI DUBÉ / S&T; EUROPA ICON: KAYLA VALENCIA / THE NOUN PROJECT; JUPITER ICON: VICTORULER / THE NOUN PROJECT



▲ **THREE WORLDS** The surfaces of Europa, Ganymede, and Callisto *(left to right)* show different degrees of tectonic and geologic activity, as well as cratering. An unknown dark material covers Callisto's pockmarked surface. Europa's surface looks the youngest, but just how young is it?

below layers of water and ice would be a challenge, to say the least. "In the case of Ganymede and Callisto, their ice shells appear to be very thick, quite old, and thus don't provide much of a window into the ocean below," says astrobiologist Kevin Hand (Jet Propulsion Laboratory).

This is why Hand and other scientists working on NASA's Europa Clipper are pinning their hopes on Europa. The spacecraft, which launches in the mid-2020s, will join JUICE in the Jovian system to begin its 40 to 50 close sweeps over Europa at the start of the next decade.

Europa has two key advantages for life detection over its Galilean siblings. First, it has a relatively thin ice shell — roughly tens of kilometers thick, as opposed to a hundred or more for Ganymede and Callisto — through which liquid water and biosignatures might spew. Second, evidence strongly suggests Europa's ocean is in direct contact with the seafloor. This means the deepest recesses of Europa's ocean world may be dotted with hydrothermal vents. But if not, Hand says that even water leaching through mineral-laden rocks might be enough to spark and sustain life.

And he should know. Hand took part in an expedition that sent acclaimed film director James Cameron on a record-breaking dive down to the depths of the Mariana Trench in 2012. As part of the expedition, a robotic vehicle descended to a region called Sirena Deep, where cameras captured a rocky outcrop covered in peculiar filaments. "These filaments are basically dead ringers for microbial mats," says Hand. "We think that this microbial population feeding on nutrients coming out of rocks is what then feeds a larger biosphere." The same process may have kickstarted and maintained microbes on Europa.

Further work by Hand suggests life on Europa could be more exciting than one-celled microbes. Observations and experimental evidence indicate that charged particles raining down on Europa from Jupiter's magnetic field are creating oxygen and other oxidants on the surface. Hand thinks that if these chemical modifiers are somehow delivered to the ocean below and get dissolved into the water, they could essentially power more complex organisms. "That's a big 'if,'" he says. "But I've published some numbers showing that you could get up to enough oxygen within Europa's ocean such that, not only could microbes exist, but multicellular life could also potentially survive."

Though tantalizing, all of this is moot if we cannot confirm life on Europa. Luckily, signs on the surface suggest there may be ways for Europa Clipper and JUICE to peer into the depths below. For example, an important and unique surface feature is Europa's *chaos regions*, explains planetary geophysicist Lynnae Quick (NASA), who is co-investigator on the Europa Imaging System aboard Europa Clipper. "These are areas where Europa's ice shell has broken up into plates to form humongous icebergs in an ice–slush water matrix," she says. Directly below these icebergs and slush might be Europa's subsurface ocean. In such regions, sea salts, organics, and other telltale materials could get churned up onto the surface, ready to be spied by JUICE or Europa Clipper's spectral imagers.

Another promising avenue of investigation is Europa's cryovolcanism. On Europa and other outer solar system bodies harboring dark oceans, conditions are so cold that ice can act like rock and liquid water as lava to produce frigid versions of the fiery volcanism we see on Earth (*S&T:* Aug. 2020, p. 32). Galileo images hinted that in certain regions on Europa, water seeps through the ice shell and then spreads like lava, eventually solidifying and forming smooth areas on the surface (just as McKinnon

◀ **MICROBIAL MATS** An expedition found these strange, filamentary life forms on outcrops at Sirena Deep, more than 10 km below the ocean's surface.

TERRAIN COMPARISONS: NASA / JPL / DLR; MICROBIAL MATS: K. HAND ET AL. / *DEEP SEA RESEARCH* 2020 predicted for Ganymede). And in 2013, a team led by planetary astronomer Lorenz Roth (now at KTH Royal Institute of Technology, Sweden) announced it had used Hubble data to spot potential cryovolcanic eruptions, sending plumes of water vapor roughly 200 kilometers into space. Further hints of huge plumes spewing out of different locations were reported in 2016.

Europa Clipper team members are crossing their fingers that the spacecraft spots one of these chilly eruptions. "We've seen these beautiful chaos regions, we've seen what appear to be smooth cryolava flows on Europa's surface," says Quick. "But I hope that we're actually able to catch geyser-like plumes in the act." Tempering expectations, she warns that the huge plumes reported by Roth and others might be the exception rather than the rule. "It could be that most are 20 to 30 kilometers tall," she explains. Moreover, plumes may not even originate from the Europan ocean, instead erupting from shallow pockets of briny water in the ice shell. "We're at a point where we have to plan for anything."

McKinnon, who is a member of the sounding radar teams for both JUICE and Europa Clipper — jokingly given the acronyms RIME (Radar for Icy Moons Exploration) and REASON (Radar for Europa Assessment and Sounding: Ocean to Near-surface) — is circumspect about the evidence for, and chances of, spotting plumes on Europa. However, he says that Europa Clipper offers the best hope of finding plumes if they do indeed exist. "We'll be passing really close by, and if there's any kind of even small eruptions from the surface, it will show up in the data." Better yet, if a larger geyser happens to erupt on one of the spacecraft's close approaches, Europa Clipper has instruments to "taste" the vapor as it flies through the thin spray, just as Cassini did with Enceladus' plumes (though Europa Clipper's instruments are far better equipped to analyze the kind of complex chemistry that would suggest life).

Of course, from their vantage point high above the surface, Europa Clipper and JUICE are highly unlikely to provide incontrovertible proof that life lies below the icy Galileans' surfaces. For that, we need a lander. "You've got to get down to the surface and grab a chunk of material and put that through instruments that are specifically designed to search for complex organics and various parameters that can help us assess whether or not we've actually found life itself," says Hand.

Hand — who was heavily involved in the conceptualization of Europa Clipper and is now co-investigator on the spacecraft's mass spectrometer instrument — is co-leading a pre-project team to do just that. The Europa Lander concept, if approved, will dig up samples shielded from damaging radiation about 10 centimeters beneath the surface and then analyze them in a miniature onboard laboratory to look for biosignatures.

And if signs of life are found, what then? Drill down to seek it out, of course! Already, NASA mission concepts are exploring weird and wonderful technologies to dive through the ice shell and explore the ocean underworld — including a swarm of tiny robotic fish and a larger, instrument-laden robotic snake.

Other icy worlds in the solar system — such as Saturn's moons Titan and Enceladus, Neptune's moon Triton, or even Pluto — may yet prove to offer a better chance of finding alien life in our backyard. But for now, the icy Galilean moons seem like some of our best bets. In decades to come, who knows, we may be watching in awe as a serpent robot makes first contact with a Europan squid.

BENJAMIN SKUSE is a science writer based in Somerset, United Kingdom.

FURTHER READING: For a deeper dive into the dark oceans of the solar system and beyond, read Kevin Hand's new book *Alien Oceans: The Search for Life in the Depths of Space*.

▶ **DIVING DEEP** The Sensing With Independent Micro-swimmers (SWIM) mission proposal would deploy centimeter-scale robotic fish into an icy moon's subsurface ocean. Each fish would carry its own sensing and communication systems.

NASA / JPL-CALTECH

Markarian's

HUNTER WILSON

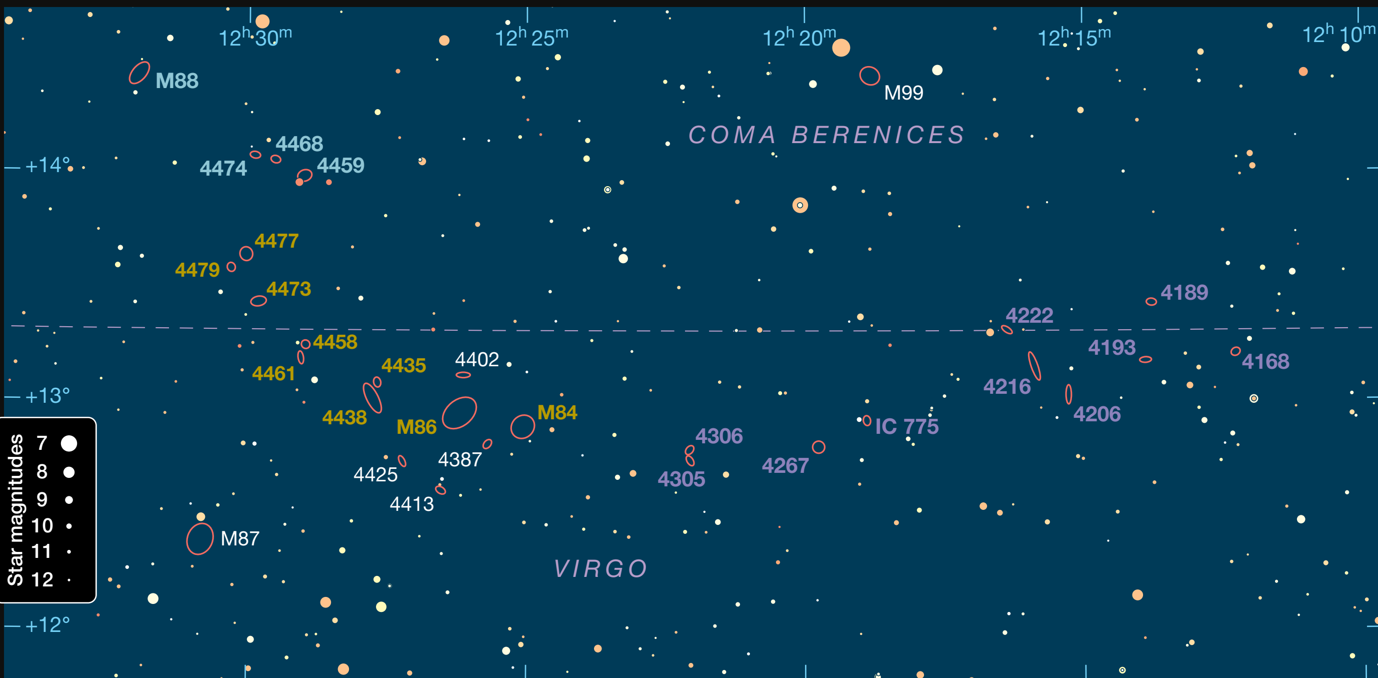
Step into the Virgo Cluster to observe this amazing line-up of galaxies.

Armenian astronomer Beniamin Markarian published a paper in 1961 in which he speculated that eight prominent galaxies in the Virgo Galaxy Cluster are approximately the same distance from us. He showed statistically that the galaxies aren't a "chance projection" and probably do form a true physical system. Ever since, this eye-catching string of galaxies has been informally known as Markarian's Chain.

A familiar lament among astronomers is that measuring distances to cosmic sources is exceedingly tricky, even controversial at times. And this is true also for the galaxies in the Chain — 60 years later we're still not exactly sure how far away they are. Different methods yield different distances, and the more I dug into the professional literature, the more the Chain became a ragged bunch distance-wise. However, recent studies show the estimates converging. We do know, though, that at least seven of the galaxies appear to move coherently through space, and so we'll take it that Markarian's Chain *does* form an actual, curved line of bright galaxies.

The Virgo Cluster is the nearest large aggregation of galaxies and subtends an angle of about 8° across the sky. With somewhere between 1,300 and 2,000 members, it also contains more spiral galaxies than is typical for a cluster this large. The Virgo Cluster has three main concentrations centered on M49, M86, and M87. The latter stole the limelight in 2020 when the Event Horizon Telescope team revealed to the world that they'd imaged the supermassive black hole at its core (*S&T:* Sept. 2020, p. 18). The presence of the three subclusters suggests a dynamic gravitational and molecular gas environment — in fact, unusually for a galaxy cluster, it has a relatively large number of galaxies still forming stars. Even fleetingly (on cosmic scales), the mere existence of a string of bright galaxies that are approximately the same distance from us is pretty extraordinary.

Marvelous Chain



◀ **THE GREAT CHAIN . . .** The eight galaxies that form the eye-catching Markarian's Chain are surrounded by several other Virgo Cluster members. Anchoring the Chain are the ellipticals M84 and M86, which Charles Messier discovered in March 1781. North is up in all images unless otherwise noted.

▲ **. . . AND BEYOND** You can extend the collection of the eight Chain galaxies to the west and east for even more observing fun. The objects are color-coded according to location: Chain (orange), Western Extension (purple), Eastern Extension (light blue). Note that NGC 4479 isn't one of Markarian's original eight galaxies.

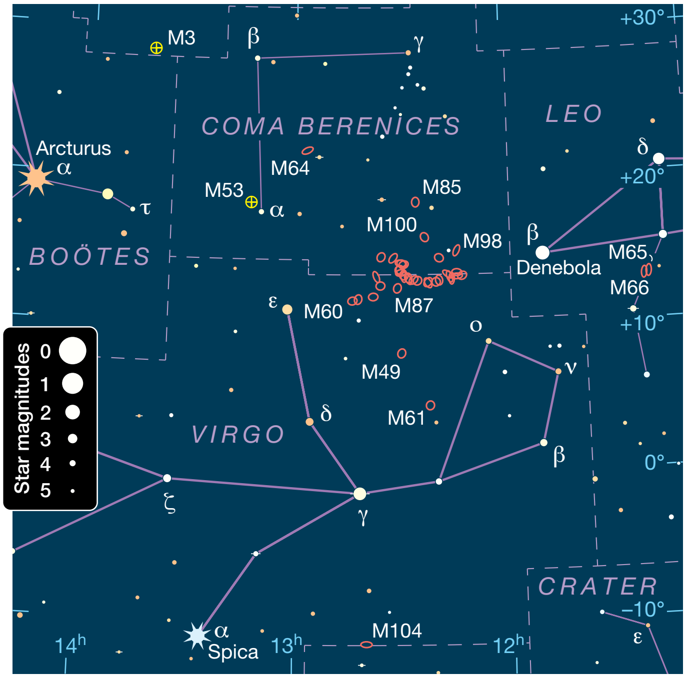
Contemplating the Chain

I observed Markarian's Chain with my 8-inch and 28-inch scopes from my semi-dark backyard. The 8-inch made it possible to see the entire Chain, which spans about 1.5° east to west. However, because the galaxies appear rather faint from my backyard, they didn't stand out very well at the low power required; I saw them much more clearly at higher magnifications. I also had one spectacular night at a dark site with the 28-inch, which is reflected in my sketches on pages 26 and 27.

M84 is the westernmost galaxy of the Chain and is the second brightest of the bunch. At magnitude 9.1, it's visible in my 80-mm finder, and delightful in larger scopes even though there's not much to see beyond its softly glowing, slightly oval shape. I noted a bright core and ill-defined edges, and the galaxy's apparent size grows with either a larger telescope or darker sies. In spite of being one of the nearest and brightest examples, M84 looks like most other ellipticals when viewed in the eyepiece.

Although not a visible feature, a ragged dark lane of dust bisects M84's core. Seen only in the infrared, it shows well in the Hubble Space Telescope image (page 24). M84 is also known for two (possibly three) supernovae observed since 1957. This is unusual for an elliptical galaxy and may indicate a population of younger stars, perhaps related to the dust lane.

Slewing east from M84 we encounter **M86**, the brightest member of the Chain at magnitude 8.9. It's apparently falling toward the center of the Virgo Cluster from "behind," which means it's moving through the Cluster toward the Milky Way at around 240 km/s (that's nearly 540,000 mph!). With the possible exception of M90, this gives M86 the highest blueshift of any Messier galaxy. Studies using the Chandra X-ray satellite show a tail of gas that's been stripped from the galaxy, highlighting its motion through the cluster. The mechanism producing the tail is *ram pressure*: Galaxy clusters are filled with an intra-cluster medium of hot gas — if a galaxy moves



◀ **IN THE HEART OF THE CLUSTER** Markarian's Chain is worthy of full exploration in its own right, but it also serves as a handy launching pad for venturing forth into the Virgo Galaxy Cluster.

▼ **DUSTY LANES** By measuring the motion of the gas and stars at the core of the elliptical galaxy M84, astronomers were able to estimate the mass of the supermassive black hole lurking within to be about 1.5 billion solar masses. This Hubble Space Telescope image combines visible and infrared exposures and shows only the central region of the galaxy.

ESA / HUBBLE / NASA

through this medium fast enough then this hot gas environment can strip gas and dust from it. M86's trajectory through the Virgo Cluster doesn't necessarily mean it will merge with the Milky Way in the distant future — it's still gravitationally bound to the Cluster — but it helps to illustrate the likely temporary nature of Markarian's Chain as a coherent structure.

In a suburban sky, M86 looks much like M84 — a round glow. However, in darker conditions its outer reaches have a distinct oval shape extending southeast to northwest that — along with its bright core — are its defining visual features. I've been impressed by how elongated M86 appears in darker skies, and its distinctive shape is made even more apparent by a quick comparison with its much rounder neighbor, M84. These two galaxies make a memorable sight together, and M84's appeal is boosted even more by its proximity to M86. My 28-inch draws out several smaller and fainter non-Chain NGC galaxies — four to the south and one to the north.

Depending on the quality of your observing site you may see these NGC galaxies along with M84 and M86 as an oval subgrouping of galaxies in the Chain, with M86 at its center. Or, you might see a face looking back at you.

Marvelous Markarian's Chain

Object	Type	Surface Brightness	Mag(v)	Size	Dist. (M l-y)	RA	Dec.
M84/NGC 4374	Elliptical	13.0	9.1	6.5′ × 5.6′	57.1	$12^h\ 25.1^m$	+12° 53′
M86/NGC 4406	Elliptical	13.2	8.9	8.9′ × 5.8′	61.3	$12^h\ 26.2^m$	+12° 57′
NGC 4435	Barred Lenticular	12.5	10.8	2.8′ × 2.0′	54.8	$12^h\ 27.7^m$	+13° 05′
NGC 4438	Lenticular	13.6	10.2	8.5′ × 3.2′	53.8	$12^h\ 27.8^m$	+13° 00′
NGC 4458	Elliptical	13.1	12.1	1.7′ × 1.6′	54.1	$12^h\ 29.0^m$	+13° 14′
NGC 4461	Barred Lenticular	12.8	11.2	3.5′ × 1.4′	56.1	$12^h\ 29.1^m$	+13° 11′
NGC 4473	Elliptical	12.8	10.2	4.5′ × 2.5′	54.5	$12^h\ 29.8^m$	+13° 26′
NGC 4477	Barred Lenticular	13.1	10.4	3.8′ × 3.5′	56.8	$12^h\ 30.0^m$	+13° 38′
NGC 4479	Barred Lenticular	13.0	12.4	1.5′ × 1.3′	58.8	$12^h\ 30.3^m$	+13° 35′

Angular sizes and distances 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.

Toward the middle of Markarian's Chain we come upon **NGC 4435** and **NGC 4438**, a wonderful pair of interacting galaxies that would be worth the time to track down even if they weren't part of the scene. Often referred to by their nickname, The Eyes, they're also known as Arp 120. These two are not only interacting with each other — NGC 4438 also had a close encounter with M86 about 100 million years ago. A remarkable bridge of cold gas connects NGC 4438 with M86 and raises the question of whether that interaction is responsible for NGC 4438's distinctive tidal tails. Computer simulations suggest, though, that the tails are due not only to a close interaction with NGC 4435 but also to ram pressure from NGC 4438's motion through the cluster, again highlighting the dynamic nature of the Virgo Cluster.

This is usually where I'd say "too bad we can't see any of this" — but this time we can! The tidal tails of NGC 4438 are indeed visible under a dark sky and are rather amazing in the 28-inch scope. They're nearly invisible from my backyard, but they make a long drive to a dark site worth it all on their own. You'll need a fairly large scope — I'll guess that a 12-inch might do the trick.

I see the tidal tails much like they're depicted in photographs (e.g., below right), with the exception that the tails look considerably wider in the eyepiece. The northeastern tail is especially fabulous with its sharp change of direction. The southwestern tail has a gentle curve and seems to get a little wider towards its end, then quickly narrows and disappears. Long exposures show the two tails are actually connected in a subtle loop (just visible in the image), but that feature is too faint for me to detect.

The central regions of both galaxies are similar in size, shape, brightness, and orientation, which inspires their nickname. This effect is particularly noticeable under a less pristine sky or in smaller scopes. The main difference I see is that NGC 4438's core has a slightly longer extension toward the southwest. All in all, this wonderful galaxy pair is the gem of Markarian's Chain and would be a highlight anywhere in the sky.

The Chain contains another pair of galaxies that seem to be even closer together than The Eyes but appear mismatched by comparison. **NGC 4461** looks like it could swap places with NGC 4435 due to its similar brightness, shape, and orientation, while **NGC 4458** is smaller, round, and less conspicuous compared to NGC 4438. Although NGC 4458 and NGC 4461 are interacting, there are no tidal tails to show for it, so what you see in photos is much like what you'll see in the eyepiece of your scope.

Nonetheless, this pair is special simply because of its proximity to The Eyes. Where else can you see two bright sets of close galaxy pairs together like this?

Compared to the rest of the Chain, the elliptical galaxy **NGC 4473** appears to be a bit lonely. However, it harbors a 120 million-solar-mass black hole, so it's not uninteresting. Visually, it's a 10.2-magnitude glow elongated nearly due east-west with a bright core, and it stands up well to mild light pollution. Like most of the northern half of the Virgo Cluster, this galaxy is located just over the border in Coma Berenices.

Also in Coma is 10.4-magnitude **NGC 4477**, which anchors the easternmost end of the Chain. I note that it has a central bar sporting a small, bright core surrounded by a fairly circular and much fainter galactic disk, which needs a dark sky to see well. It has a 12.4-magnitude companion galaxy, **NGC 4479**, which isn't considered part of the Chain, even if they're at comparable distances. In any case, their apparent pairing helps highlight the relative solitude of NGC 4473.

I originally intended to observe just the eight galaxies mentioned in Markarian's 1961 paper, but as soon as I looked at my star chart it was apparent that the curved line of Markarian's Chain can be extended at each end, more than doubling its overall length. I found these additional targets impossible to ignore.

Western Extension

The galaxies on the western side of the main Chain aren't all as bright or even generally at the same distances as the main eight (on the whole they lie farther away, with some exceptions). But they do lengthen its graceful east-to-west arc some 2° or so by adding another seven galaxies that end in a wonderful clump of three edge-on galaxies. Unofficially extending the Chain does two things. First, it effectively marks the curving midline of the Virgo Cluster, making it easier to galaxy-hop from one side of the Virgo Cluster to the other. Secondly, it's fun. Works for me!

Proceeding westward from M84, we arrive at **NGC 4305** and **NGC 4306**, which are faint enough that I could barely detect them from my backyard with the 28-inch scope.

ALSON WONG

▲ **THE EYES** The pair of interacting galaxies, NGC 4435 and NGC 4438, gained their nickname thanks to their striking similarities as viewed through a telescope. A similar pair sits just to the east.

Indeed, they're the two toughest galaxies to see in either the real or "expanded" Markarian's Chain.

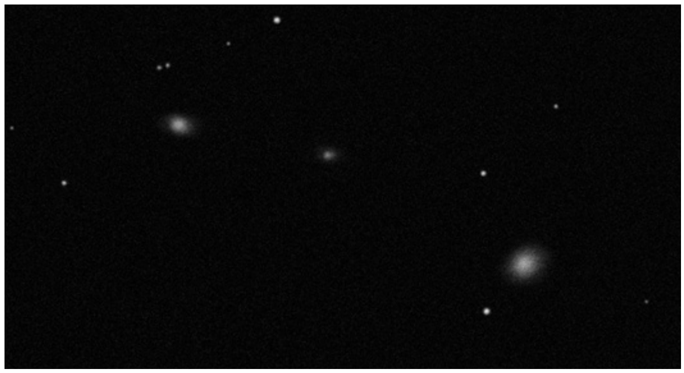
In the eyepiece NGC 4305 shows a bright core with a stellar nucleus and a smooth spiral disk but no spiral arms. NGC 4306 is a barred lenticular that has a barely discernible nucleus. They look much the same size at first glance and appear slightly closer together than NGC 4458 and NGC 4461 farther east in the Chain. Distance estimates show the pair to be either just outside the Cluster or at its outer edge.

On the other hand, **NGC 4267** *is* counted among Virgo Cluster members and is approximately at the same distance as the Chain galaxies (if maybe a bit closer). Like NGC 4306, it's classified as a barred lenticular, and I see a moderately bright, round core with a surrounding circular glow.

In the same low-power field of view is **IC 775**, which is about six to seven times farther than the Chain galaxies and is therefore well beyond the Virgo Cluster. Small and faint, it's easy to overlook, but it has the virtue of continuing the westward curve of the extended Chain.

NGC 4206, **NGC 4216**, and **NGC 4222** are a really cool trio of edge-on galaxies that look fabulous in a large scope. Unfortunately, they're faint. They fit nicely into a fairly high-power field of view, though — plus on a really good night you might catch a few even fainter galaxies in the same field. NGC 4216 is both the largest and brightest of the three and is the most eye-catching. It has a bright core and an extended central disk as well as a faint dark lane. The small, 15th-magnitude galaxy PGC 39247 lurks just west of its northern tip. At more than 500 million light-years in the distant background, the PGC object lies well outside the Virgo Cluster.

NGC 4206 is a subtle, narrow streak, appearing about half as long as NGC 4216. It has a slightly brighter central region but lacks a dust lane. NGC 4222 is a bit smaller and thinner yet, but with neither a central brightening nor a



▲ **EXPLORING THE EXTENSIONS** (*Top*) The author observed, from left to right, NGC 4222, NGC 4216, and NGC 4206 with his 28-inch scope at 155×, 253×, and 408× under a sky that measured 21.9 with a Sky Quality Meter. A rare and beautiful sight, this is a lovely bookend to the western extension of the Chain. At the other end, NGC 4459, NGC 4468, and NGC 4474 cap the eastern extension (*bottom*).

Beniamin Egishevich Markarian (1913–1985)

Armenian astronomer Beniamin Markarian was born on November 29, 1913 (December 12, 1913, in the Gregorian calendar) in Shulaver (today Shahumyan in Georgia). He graduated from Yerevan State University in 1938 with a degree in mathematics, and after a stint lecturing embarked on postgraduate studies. World War II interrupted these endeavors (Markarian was called into army service), but he successfully defended his thesis in 1944 under the supervision of the doyen of Armenian astronomy, Viktor Ambartsumian.

In 1946 Ambartsumian founded Byurakan Observatory on Mount Aragats, a half-hour drive northwest of the Armenian capital, Erevan. Markarian started work there at the outset of operations in the capacity of senior researcher and focused on the spectroscopy of white dwarfs and stars in open clusters. However, in 1965, Ambartsumian delegated a project to Markarian to search for faint blue galaxies that exhibited strong ultraviolet emission. Using the 1-meter Schmidt telescope at Byurakan (at right, under the dome in the foreground), Markarian obtained spectra of thousands and thousands of galaxies. By the end of the project he had examined more than 2,000 photographic plates, each one containing about 15,000 objects, yielding some 1,500 objects with an ultraviolet excess. A similar ambitious survey followed in 1978.

Markarian held several prestigious positions, including serving as president of the International Astronomical Union Commission on Galaxies (1976–1979). He never traveled outside the Soviet Union, but his colleagues continued his work at places such as Mount Palomar, and they also published a posthumous catalog of galaxies. Objects that Markarian first identified now bear his name.
—DIANA HANNIKAINEN

SKETCHES: HOWARD BANICH (2); OBSERVATORY: RITA WILLAERT / CC BY 2.0

ALL TOGETHER NOW This is a composite view of Markarian's Chain as the author saw it through his 28-inch scope. Each galaxy is portrayed individually as he sketched it both from his backyard and from a deep-sky site. He then assembled the sketches into this seamless view of the entire group. Magnifications ranged from 155× to 408×.

HOWARD BANICH

dark lane. When I first observed this triplet from my backyard, I didn't see NGC 4222 initially — so it's definitely the faintest of the three. (It's also bisected by the Virgo-Coma Berenices border, which looks neat in star charts!) There are no apparent additional gravitational interactions among these three objects, besides those which result from them being members of the Virgo Cluster.

Farther west are three more galaxies — **NGC 4193**, **NGC 4189**, and **NGC 4168**. I could have included them in this expanded version of Markarian's Chain, but I was so taken by the dramatic trio of edge-on galaxies as a natural ending point that I didn't feel the need to go on. You might, though, so give them a shot.

Eastern Extension

Let's slide over to the other end of the Chain and explore what we find at its eastern end.

You could take the beautiful spiral **M88** as a possible northeastern extension of the Chain. I detected its subtle spiral arms on a great night with the 28-inch scope, but under a less dark sky the arms were invisible, and I could only make out M88's overall shape and bright core. M88 has likely only recently arrived at the Virgo Cluster (highlighted by ram-pressure stripping of gas along its leading, western edge) and will make its closest approach to the gravitational center of the cluster 200 to 300 million years from now.

Maybe **NGC 4459** is an even better choice to extend the eastern end of the Chain. A lenticular galaxy that shows evidence of ongoing star formation, NGC 4459 has a bright core and looks fairly round in the eyepiece. It also has two rather bright neighbors just to its northeast, **NGC 4468** and **NGC 4474**, which together — as yet another trio of apparently close galaxies — provide an eastern counterpart to the western triplet of NGC 4206, NGC 4216, and NGC 4222.

Choosing between the delightful spiral M88 and this attractive trio, I prefer to consider the latter bunch as the northeastern end only because it gives the unofficially extended Chain a slightly lopsided, pareidolic grin.

So, wow — this is a lot of galaxies! But the Chain – original or extended — only scratches the surface of the overall cluster. Although Markarian's Chain is a jewel in the Virgo Cluster, it can also offer multiple jumping-off points to explore the many other highlights of this vast but nearby conglomeration of island universes.

There's a lot to see out there.

■ Contributing Editor **HOWARD BANICH** thinks Markarian's Chain is the real deal — more or less. He can be reached at **hbanich@gmail.com**.

FURTHER DATA You can find tables for the galaxies in the Eastern and Western Extensions here: **https://is.gd/ExtensionsData**.

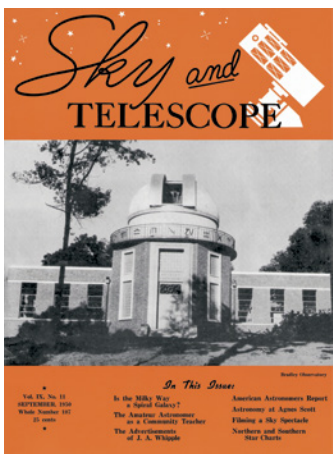
The Past, Present, and Future of College Observatories

Even in an era of big science and big budgets, small facilities still have an important role to play.

"Is the Milky Way a Spiral Galaxy?" That was the question posed on the cover of the September 1950 issue of *Sky & Telescope*. The query underlying that article may seem quaint today, but other cover stories that month, like "The Amateur Astronomer as a Community Teacher," feel as timely as ever. Perhaps the most surprising item in that issue, though, was an article entitled "Astronomy at Agnes Scott," which described Bradley Observatory, a brand-new facility built on the campus of a small women's college in Decatur, Georgia. Most readers likely hadn't even heard of the school, and yet it was now home to a 30-inch telescope — the largest in the southeastern U.S.

The Georgian building housing the instrument still stands today and, more than 70 years later, continues to bustle with research, teaching, and community gatherings. The fact that this dramatic structure came to be built in Decatur at a cost equivalent to more than $1 million today speaks to how large an impact the telescope was expected to have on those who peered through its eyepiece.

Agnes Scott College isn't the only small school with big, cosmic dreams. Similarly significant investments were, and continue, to be made at small colleges and universities across the country, suggesting that such facilities have something unique to offer even in the modern era of orbiting telescopes and grand national observatories. Perhaps modest college observatories can occupy an important place in the astronomical landscape as the public and local faces of astronomy. This role is especially important at colleges that serve underrepresented populations, like women's colleges and Historically Black Colleges and Universities (HBCUs). Such observatories provide a pathway into science and give both students and the community a way to experience the universe directly. The three institutions we highlight in this article share similarities in their size, their diverse student populations, and their early and continuing dedication to astronomical research and education.



▶ **COVER STORY** Agnes Scott College's Bradley Observatory was featured on the cover of *Sky & Telescope* in September 1950, the year the facility was dedicated.

Looking Back to the Future

College observatories in the U.S. were largely built in the 19th and 20th centuries, but their intellectual and architectural heritage can be traced to much earlier edifices in Europe. That continent's first observatories were associated with churches and states. These early buildings, and the work done within their walls, "brought glory" to the state, says Michael Lynn, a historian at Purdue University Northwest in Indiana. "The grandeur of the building was meant to reflect the grandeur of the state that funded it," says Lynn. Large national observatories arguably follow in this tradition today, minus some grandeur and plus lots of technology.

But while governments and religious organizations undergirded many of these European observatories, quite a few of the structures nevertheless existed on college and university campuses. As with modern institutions, work carried out at these early school-based centers played a critical role in giving students something astronomical to do with their newly acquired algebra and trigonometry skills. By 1800, at least 130 observatories existed in western Europe, according to Lynn.

In the U.S., most universities and colleges are privately funded and aim to contribute

OPEN SKIES The Bradley Observatory dome is opened at twilight for a night of observing. The observatory was dedicated in 1950, and the observing plaza in the foreground — which contains a scale model of the solar system — was added in 2000.

AGNES SCOTT COLLEGE / BILLY HOWARD

to both research and public education. That was true at Vassar when it was established in 1861 as a women's college in Poughkeepsie, New York. The school's push for an observatory began with Maria Mitchell, the first female professor of astronomy. Under her purview, in 1865 the school installed the third-largest telescope in the country — a 12⅜-inch whopper of a refractor, now on display at the Smithsonian Institution's National Museum of American History in Washington, DC. The observatory that originally housed that scope was, in fact, the very first building completed on the Vassar campus. Mitchell's love of teaching, and the high enrollment in astronomy in the years she taught there, set a pattern echoed at Agnes Scott College in the 1940s, where 25% of undergraduates were enrolled in astronomy classes.

Mount Holyoke, a women's college in Western Massachusetts, also claims an observatory as its oldest academic building. The John Payson Williston Observatory was built in 1881, just in time to observe the 1882 transit of Venus. Today it hosts a vintage Alvan Clark 8-inch refractor and a 24-inch Ritchey-Chrétien reflector.

Astronomy was a required course of study in Mount Holyoke's early days, but female students were nevertheless largely relegated to the traditional role of collecting data, not analyzing them. However, by the early 20th century, some of the work performed at Williston Observatory by women astronomers helped open doors to academic jobs that might have remained closed. Thanks to the observatory's collaborations with institutions like Harvard College in Cambridge, Massachusetts, these women astronomers had also acquired connections that may have otherwise been out of reach in the discipline's "old boys' club." Today, students at Agnes Scott, Mount Holyoke, and Vassar train at modern facilities and go on to wield those skills with larger telescopes.

▲ **TAKING THE HIGH GROUND** The John Payson Williston Observatory stands at the highest point on the campus of Mount Holyoke College in South Hadley, Massachusetts. Dating to 1881, the observatory's original 8-inch Alvan Clark equatorial refractor telescope is still in use today.

Vassar and the Class of 1951

In recent years, Vassar has added to its original arsenal of instruments with a new on-campus observatory. In 1997, the class of 1951 sponsored construction of a new building and the installation of a 32-inch reflector, which is one of the largest telescopes in the state. The 32-inch sits alongside a 20-inch reflector, each housed in its own dome at the Class of 1951 Observatory. When the public visits, people like to peer at the Moon, or planets that pop, like Saturn, which looks like a tiny, perfectly rendered painting. "I think there is

▼ **AN EARLY START** Vassar's observatory was the first academic building completed on campus, thanks to a push from Maria Mitchell. Its original refracting telescope, used both for research and education, is now on display at the Smithsonian Institution's National Museum of American History in Washington, DC.

VASSAR COLLEGE OBSERVATORY: COLLIN KNOPP-SCHWYN; JOHN PAYSON WILLISTON OBSERVATORY: MOUNT HOLYOKE COLLEGE ARCHIVES AND SPECIAL COLLECTIONS a strange phenomenon now where the public is so exposed to digital astronomical images, they don't realize you can actually see something similar with your own eye," says Colette Salyk, Assistant Professor of Astronomy. "It's always a revelation for them the first time they see it."

The school also employs around a dozen students annually to collect data, following in Maria Mitchell's footsteps. "She was famous for getting students involved in the research," says Debra Elmegreen, Professor of Astronomy on the Maria Mitchell Chair.

This involvement is possible in part because modern instruments were added to the older telescopes. "We have a scientific-grade CCD and computerized observing tools, so we're able to do cutting-edge science," says Salyk. "There's really no substitute for hands-on observing when it comes to learning how to deal with real data."

With a telescope on campus, any student who wants to learn can. That's not necessarily true in the wider world. A small number of national facilities are supplanting the larger network of more diminutive telescopes that once dotted the U.S. As a result, fewer projects get observing time, and even fewer students get direct observing experience or even see an observatory in person. Since many research telescopes sit on far-flung mountaintops or are in orbit, working with them usually involves remote logins, or analyzing data that magically appears in an email inbox. "Mountaintop observing is becoming a thing of the past," says Elmegreen.

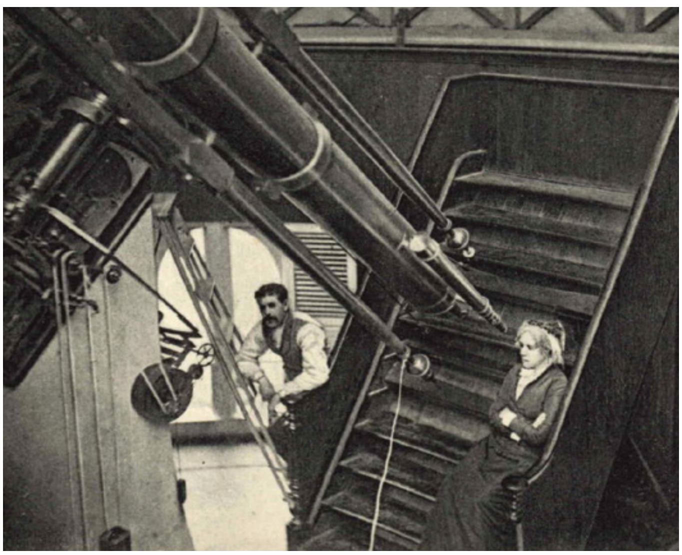
That means once-necessary skills — knowing how to spend all night slewing, calibrating, and integrating — aren't as useful. "On the other hand, if students have no experience with hands-on observing, they may take all data as 'truth' without having an understanding of how the data are obtained and what could potentially go wrong in that process," says Salyk. "So I think it becomes crucially important to give a glimpse of what's happening behind the scenes at telescopes, so they can be appropriately skeptical users of data in the future."

In addition to offering hands-on experience, college observatories can also whip up enthusiasm that distanced, impersonal astronomy can't. "Just to sit in front of a computer all the time and say, 'We got this data from the Hubble Space Telescope. Isn't that wonderful?' — it's hard to motivate students that way," says Elmegreen. "Most observational astronomers got into astronomy because, like everyone else, they loved looking up at the sky when they were kids." But when astronomy is reduced to tapping keys on a laptop, investigating the wonders of the night sky starts to feel like performing finance calculations, or parsing numbers for a social-media company. An accessible, on-campus observatory can keep students interested and motivated to use their skills to understand the universe.

The utility of small college observatories, though, goes beyond training or motivating students. It's also about scientific results. After all, not every astronomical project demands a dry-desert behemoth. Some research projects just require regular observations sustained over long periods of time. "I think we'll always need that," says Elmegreen.

At Vassar, the observatory collects light curves from supernova explosions, cataclysmic variable stars, and asteroids. The 32-inch is part of the Kilodegree Extremely Little Telescope Follow-Up Network (KELT-FUN) and has directed its gaze at exoplanet candidates to help determine whether the suspect systems actually have planets. The scope also serves as an

▼ **PIONEERING PROFESSIONAL** Maria Mitchell, shown here at the eyepiece end of the Vassar College Observatory refractor sometime after 1865, was the first woman to become a professional astronomer in the U.S. A talented observer, she also shared an appreciation of the "beauty and poetry" of astronomy.



▼ **LOOKING TO THE LIGHT** The Vassar College Class of 1951 Observatory was completed in 1997. Like many small college observatories dotting the U.S., it's actively engaged in frontline research. The observatory's telescopes are part of the Kilodegree Extremely Little Telescope Follow-Up Network (KELT-FUN).

MARIA MITCHELL AT VASSAR: WIKIMEDIA COMMONS / PUBLIC DOMAIN; CLASS OF 1951 OBSERVATORY: ROBERT BENSON / VASSAR COLLEGE official follow-up instrument for NASA's Transiting Exoplanet Survey Satellite (TESS) mission (*S&T:* March 2018, p. 22).

Better Late than Never

When it was founded in 1889 as Decatur Female Seminary, Agnes Scott College (as it became in 1906) didn't have an on-campus observatory. That changed in 1950, thanks to the passion of a new faculty member named William A. Calder. Calder had studied at Harvard under Harlow Shapley, a seminal astronomer who participated in early 20th-century debates about the size of the universe and the extent of the Milky Way.

In 1947, while looking for a telescope for the institution that had recently hired him, Calder noticed an ad for a 1930s vintage, 30-inch Cassegrain reflector in the magazine *Popular Science*. "I wanted an observatory for the people," he said in an interview for the *Atlanta Journal Constitution* given at the time of his retirement from Agnes Scott College in 1971. "There are many observatories throughout the world, on mountain peaks, etc., but I thought one in a major city for the public wouldn't hurt."

Calder convinced the College to nab the 30-inch and, as a result, a small liberal arts women's college suddenly hosted the largest telescope in the southeast, at a time when few women went into the sciences at all. The observatory underwent a major renovation in 2000 to celebrate its 50th anniversary, which included introducing computerized tracking and control for the 30-inch and the addition of the 70-seat Delafield Planetarium.

The grand scope is still used for public astronomy. With your eye up to its eyepiece, the massive tube angled in front of you, you can even see the subtle pink hues of the magnificent Orion Nebula. Out front, in the granite tiles of the plaza through which neighborhood residents, school-aged kids, and political science majors all pass, there is a scale-model, geometric representation of the planets and the Sun.

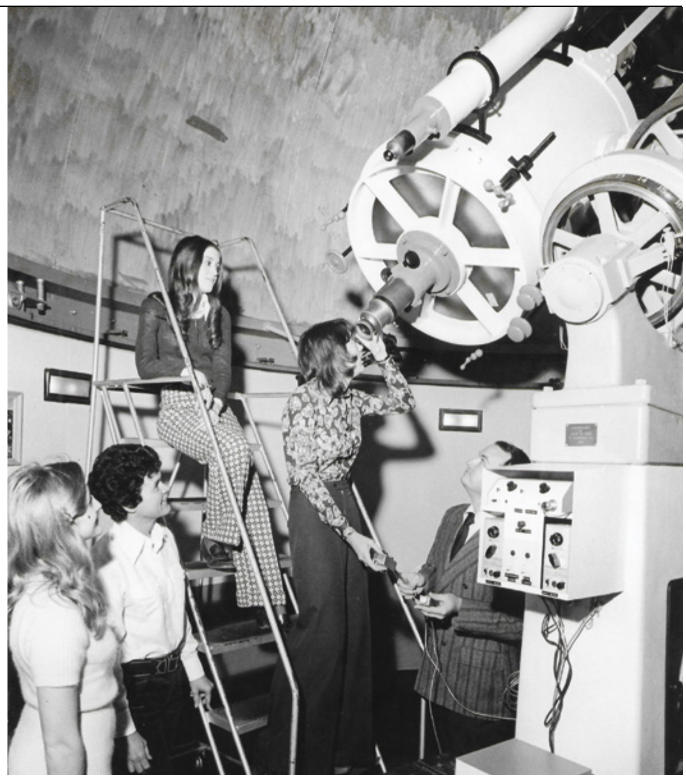
The Bradley Observatory (as it was named in 1950) at Agnes Scott College is also part of the Southeastern Association for Research in Astronomy (SARA), a consortium of mostly smaller schools that have banded together to remotely operate three 1-meter-class telescopes. From within Bradley Observatory's walls students can log in, gather data on exoplanet transits and variable stars, and be part of a full-on remote research collaboration — and then go on to look at Jupiter's moons with their own eyes, getting both aspects of the experience that the Vassar professors believe to be so important.

Making Progress

Agnes Scott College is situated near downtown Atlanta, and its observatory faces the encroachment of city lights, which limits the kinds of research possible. It is partly for that reason that new telescopes have been built farther and farther afield — including those serving smaller colleges. Norfolk State University (NSU) in Virginia, an HBCU, is one example. Carlos Salgado, a professor of physics, has been the lone astronomer at NSU in recent years, working half-time there. "Everybody likes to know about astronomy," says Salgado. "It is an easy way to get students interested in science."

The expansion of the NSU astronomy program started in 2001 with the refurbishment of the school's on-campus,

▶ **USED TELESCOPE** William A. Calder acquired the 30-inch Beck Telescope for Agnes Scott College in 1947, after he spotted the instrument being advertised for sale in *Popular Science*. Once Bradley Observatory was built, the scope had a permanent home and has been used for research and outreach for the past 71 years.



▼ **MAN WITH A MISSION** William Calder served as Professor of Astronomy at Agnes Scott College from 1949 to 1971. In addition to acquiring the Beck Telescope for the college, he oversaw the construction of Bradley Observatory, and the growth and popularity of astronomy both at the college and in greater Atlanta, by founding the Atlanta Astronomy Club in 1947.

WILLIAM CALDER AND BECK TELESCOPE: AGNES SCOTT COLLEGE ARCHIVES (2)

120-seat planetarium. Then came National Science Foundation funding and construction of the Rapid Response Robotic Telescope (RRRT), now operational at Fan Mountain Observatory in Covesville, Virginia, some 240 kilometers (150 miles) northwest of the NSU campus. "The RRRT was originally built to study gamma-ray burst afterglows," says Salgado, "and is now part of the SkyNet Robotic Telescope Network."

Like historical observatories, the RRRT has multiple goals, including training, research, and collaboration. The telescope is now used by students at NSU, University of Virginia, and the wider SkyNet community. Had the observatory been built earlier, it might have been located on campus in the middle of light-polluted Norfolk. In this sense, the NSU model is very modern. With Salgado's efforts to reach out to both the campus and broader communities, even a remote facility tells students that the sky is theirs, too, even if they don't see very many astronomers who look like them.

Having built a NASA-supported program that began offering an astronomy minor in 2003, and supporting a significant education and public-outreach program, Salgado has helped remedy inequities that could contribute to Black students' underrepresentation in astronomy. He points out, "As the result of our high-school teacher training, the Virginia Beach public school system now offers a class in astronomy."

Yet HBCUs are conspicuously missing from the **collegerank.net** online list, "The 35 Best College Astronomy Observatories." While it's impressive that current and former women's colleges make the cut (Agnes Scott and Vassar colleges land in the #19 and #27 spots, respectively), HBCUs like North Carolina A&T State University, the University of the Virgin Islands, and NSU do not. But they do have observatories that can make a big difference in the lives of students and the community. In 2014 Jedidah Isler, a graduate of the NSU physics program, became the first African-American woman to receive a PhD in astrophysics from Yale University. And the first NSU physics major to graduate with an astronomy minor, Cassy Smith, got her PhD in astronomy from Georgia State University in 2015.

An Ongoing Mission

How have these observatories, old and new, remained relevant in an age when high-resolution astronomical images are released daily? How can a 100-year-old telescope in a brick building at a small liberal arts college compete with the latest NASA or ESA instruments orbiting Earth? Simple. By opening their doors to visitors of all ages from the community to answer their questions and fulfill a longing for personal connection. By providing real, hands-on experiences to students, and a place to carry out research and outreach activities. And by putting the discoveries made both near and far into a larger historical and societal context.

▲ **AFTERGLOW OBSERVATORY** The Rapid Response Robotic Telescope (RRRT) of Norfolk State University is located at Fan Mountain Observatory in Covesville, Virginia. The clam-shell dome in the foreground houses a 24-inch Ritchey-Chrétien telescope that can be aimed at a target in a matter of seconds.

College observatories also serve what may be an even greater purpose, eliciting what Ukrainian education researchers Galina Zhukova and Tetiana Bulgakova call "planetary and cosmic thinking" — an awareness of the scale of the universe and how Earth and the individual fit in. "They expand a person's worldview from a regional and even planetary scale to the perception of the self as a product of cosmic processes," the scholars wrote in a 2019 *Philosophy and Cosmology* journal article. Even Maria Mitchell, who was famously quantification-focused in her work and in her teaching style, appreciated the more nebulous benefits of the field. "We especially need imagination in science," she once said. "It is not all mathematics, nor all logic, but it is somewhat beauty and poetry."

Small observatories at colleges and universities bring together students, faculty, and their surrounding communities to show them the math, logic, beauty, and poetry of the universe. We may now be sure the Milky Way is a spiral galaxy, but plenty of unanswered questions remain for generations to come.

■ **CHRIS DE PREE** and **SARAH SCOLES** are co-authors of *Astronomical Mindfulness: Your Cosmic Guide to Reconnecting with the Sun, Moon, Stars and Planets*. De Pree also served as the Charles A. Dana professor of astronomy at Agnes Scott College and director of the Bradley Observatory for 25 years.

▶ **STARS, INDOORS** Bradley Observatory's 70-seat planetarium is used for teaching and outreach at monthly open-house events. In this photo, visitors prepare for a planetarium show. The same space hosts live music events twice a year for the William A. Calder Concert Series.

FAN MOUNTAIN OBSERVATORY: UVA / EDWARD MURPHY; PLANETARIUM INTERIOR: AGNES SCOTT COLLEGE / TOM MEYER

SAGA SATELLITES by Shannon Hall

An *Unusual* Home

A new survey hints that the Milky Way might be an outlier — with broad implications for our understanding of the universe.

THE MILKY WAY Smears of galactic starlight and dust hang over a private game reserve in Namibia, a sight familiar to those under dark skies. But is the environment our Milky Way provides typical of galaxies its size?

Marla Geha didn't want to get her hopes up. She was poring over images of distant dwarf galaxies, surrounding hosts similar to our own Milky Way, when she realized that the dwarfs looked surprisingly different from the ones in our backyard. It was the first hint that the most-studied galaxy in the universe — our own — might not be as typical as previously thought.

"Whenever I see a result, I basically try and figure out what ways it could be wrong before getting excited," says Geha (Yale). "I think I've been hurt too many times."

But it didn't take long before she realized that this was no mistake. The dwarf galaxies imaged as part of the Satellites Around Galactic Analogs (SAGA) Survey are studded with young, brilliant, blue stars. That's a far cry from the old, red stars in the faint satellites circling our galaxy.

Apart from the Magellanic Clouds (which are large, recent arrivals), all 60-some known dwarfs around the Milky Way are dead — and have been for at least 1 billion years. The same story is true around Andromeda, where only two of the galaxy's 30-odd satellites are currently forming stars.

Such a stark contrast could be a problem. Much of our knowledge about galaxy formation and even cosmology is based on our understanding of the Milky Way's satellites. Most of these small galaxies are also crowded with dark matter, making them useful laboratories for studying the mysterious substance. "There have been hundreds of papers written about the Milky Way satellites and using them to infer big things," Geha says. But if the Milky Way's satellites aren't the norm, then many of those conclusions might need a rethink.

Enter SAGA, with the goal to observe satellites around 100 Milky Way analogs — galaxies comparable in brightness and environment to our own home. To do so, the team must reach beyond the Local Group, studying galaxies as far as 100 million light-years away (well beyond the Virgo Cluster) in order to provide the cosmological and statistical comparison that would place the Milky Way in context.

▲ **MILKY WAY SIBLING** Hosts like this spiral galaxy look like our own, but their dwarf retinue does not.

"I've always thought it was a fantastic idea," says Andrew Wetzel (University of California, Davis), who is not directly involved with the project. "So I've always been a big supporter of it . . . because I think it's doing really essential work."

The early results are both reassuring and intriguing. The total number of satellites around Milky Way–like galaxies matches our own, suggesting that we might not need to rethink some basics of galaxy formation.

But the fact that our satellites host old stars while the SAGA satellites are often bustling with birth presents theorists with a conundrum — one that might shed light on a range of astronomical mysteries.

PJ-mode Observing

Roughly 20 years ago, Geha and her colleague Risa Wechsler (at the time both graduate students at the University of California, Santa Cruz) dreamed of scouring the skies for satellite galaxies beyond the Milky Way and Andromeda.

Together, they make the perfect team. Wechsler (Stanford) is the theorist who simulates galaxies by mixing concoctions of dark matter, ordinary matter, and dark energy in her computer programs. Geha is the observer who searches for those galaxies using some of the world's largest telescopes.

In 2011, once they had settled into full professorship positions, they applied for funding to turn their dream into reality. And then again, each successive year, until they were finally successful in 2014. It's no wonder Wechsler calls the project her baby.

But even after the duo received funding and added members to their team, they faced challenges and even criticism from their colleagues.

The main issue is that while there are publicly available images of Milky Way–like galaxies and their surroundings, it can be impossible to decipher the true satellites — of which only two to five might be visible — from the thousands of background galaxies crowding the image. Measuring the distance to every single galaxy using spectroscopy would take far too many nights on a telescope, critics said. But at first, the team had no alternative.

"It took a lot of perseverance," Wechsler says. "At the beginning of the survey, we just had to brute-force it." They collected spectra for every single object within several systems to measure distances and find the true satellite galaxies.

But they had no intention of continuing that way; the early groundwork enabled them to develop techniques to winnow galaxies down to a more manageable list of candidates. And now the team knows a key trick: Distant galaxies will appear both redder and smaller.

Both facts are not news to astronomers. When dealing with objects in the distant universe, astronomers have long relied on a source's *redshift*, which quantifies how much an object's light has been stretched to longer, redder wavelengths by cosmic expansion. The more distant an object, the more redshifted its spectrum. And that's true for its appearance as well: More distant galaxies will look redder, a trick that enabled the team to cut down the candidates by about half.

"But the real secret is to look at the size of the galaxy," says SAGA team member Yao-Yuan Mao (Rutgers University).

More distant objects will also look smaller, which sounds obvious but is far from easy to measure. Because the team looks at incredibly dim galaxies (roughly 1 million times fainter than the faintest star visible to the naked eye), the outskirts of those galaxies will be so diffuse that it's almost impossible to measure the galaxy's true size. It wasn't until the Dark Energy Camera in Chile came online that astronomers could accurately gauge a galaxy's size, enabling the SAGA team to cut down the candidates from a few thousand to a few hundred per host galaxy.

With that more manageable list in hand, the team made use of the Anglo-Australian Telescope (AAT), the MMT Observatory in Arizona, the Palomar Observatory in California, the Southern African Large Telescope, and the Keck Observatory in Hawaiʻi to measure distances and unveil the true satellites.

◀ **PANDEMIC OBSERVING RUN** COVID-driven changes to observing regimens meant that Geha targeted satellite galaxies from the relative comfort of her living room — using four computer screens and two laptops, all while her five-year-old sat on the couch in remote kindergarten.

MILKY WAY SIBLING: SDSS; PANDEMIC OBSERVING: MARLA GEHA

In 2017, they finally published the results on eight systems. In February 2021, the tally rose to 127 satellites around 36 Milky Way–like galaxies. Each system of satellites is named after an iconic literary work or its main characters, including Gilgamesh, *Catch-22*, and Harry Potter. *The Lord of the Rings*, so far, has secured two spots with systems named after Frodo and Bilbo.

Since the 2017 study, the work has mostly been smooth sailing — except, of course, for the global pandemic. In the early days of COVID-19, most professional telescopes shut down. And even when astronomers were able to return to work by observing from the comfort of their living rooms, they faced unique hurdles.

Geha, for example, has spent 25 nights on the AAT since the start of the pandemic. To do so, she had four computer screens and two laptops set up in her living room on cobbled-together furniture — all while her five-year-old sat on the couch in remote kindergarten.

Her days would begin at 3 a.m. and run until dinner. "It's a mental fatigue, it's a marathon," Geha says. After a week, she wouldn't let herself drive. "You have to make sure not to operate heavy machinery outside of the telescope itself — just because it's so exhausting and so tiring."

But now, the team is finally close to its goal of 100 systems, with more than 300 satellites among them. "I'm just over the moon," Wechsler says.

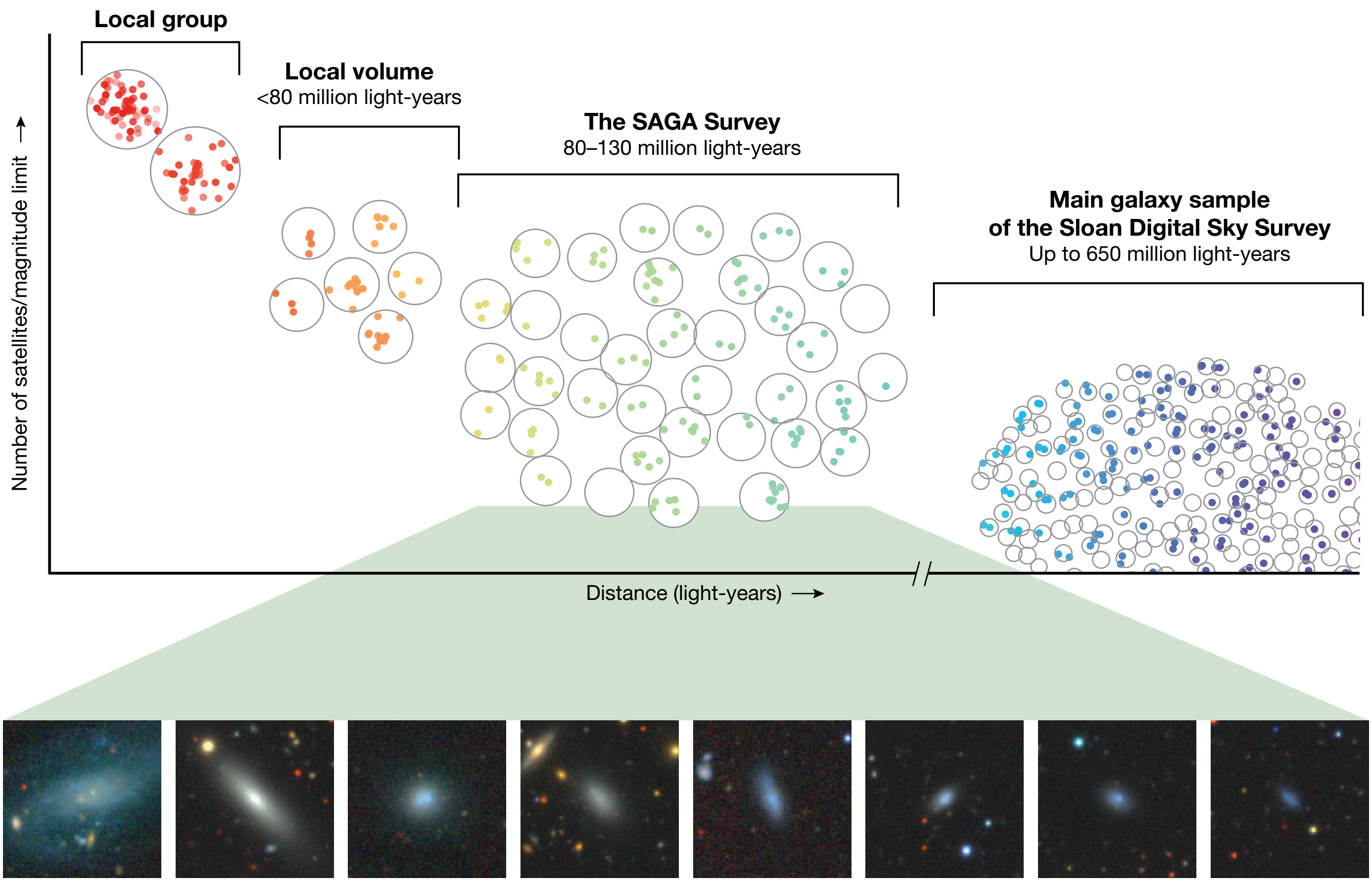
Counting Galaxies

At first take, these systems do resemble our own, at least in the number of satellites per big galaxy. And that's reassuring.

Astronomers have long mused over the number of satellites — or more specifically, the drastically *low* number of satellites — that swirl around the Milky Way. More than two decades ago, computer simulations predicted that the Milky Way's neighborhood should host hundreds or thousands of tiny companions. And yet at the time, we had only discovered a dozen. (We've since pushed that number up to roughly 60.)

It was a worrying conundrum that might have meant we were missing an important piece to the puzzle. Perhaps we didn't understand how galaxies evolve. Or maybe dark matter was even more exotic than we imagined.

Luckily, astronomers have since found the missing puzzle piece: The smallest satellites simply can't hold onto the gas that forms stars (*S&T:* Oct. 2016, p. 12). The Milky Way is embedded within a cloud of dark matter that extends well beyond the iconic spiral disk. Within this *halo* are mini-halos,



▲ **VISIBILITY** Finding Milky Way analogs requires imaging galaxies to large distances. But as distance increases, astronomers can't see as many dwarfs for a given brightness limit. SAGA's aim is to image satellites around 100 Milky Way siblings between 80 million and 130 million light-years away. The thumbnails at bottom show a selection of SAGA satellites. (Each box is 1 arcminute on a side; host galaxies are not shown.)

NUMBER OF SATELLITES OBSERVABLE VS. DISTANCE: YAO-YUAN MAO (RUTGERS); SAGA THUMBNAILS: Y.-Y. MAO (RUTGERS), WITH IMAGES FROM LEGACY SURVEYS / D. LANG (PERIMETER INSTITUTE) the biggest of which host our satellite galaxies. But once a mini-halo drops below a certain halo mass, it can no longer form stars. Such dark matter clumps will be invisible to the world's best telescopes — thus explaining why we haven't detected troves of them.

Although astronomers haven't quite homed in on the exact mass below which satellites become dark, many agree that we've found the answer to the so-called *missing satellites problem*, at least for the Milky Way. But astronomers have wondered whether our galaxy might be an oddity.

Now the SAGA results verify that isn't the case. Milky Way–like galaxies across the universe appear to also host few substantial satellite companions. Specifically, they host zero to nine, while the Milky Way hosts five and Andromeda hosts nine within the survey's luminosity limit.

"We can rest easy knowing that these solutions probably work in the rest of the universe and not just the Milky Way," says SAGA team member Erik Tollerud (Space Telescope Science Institute).

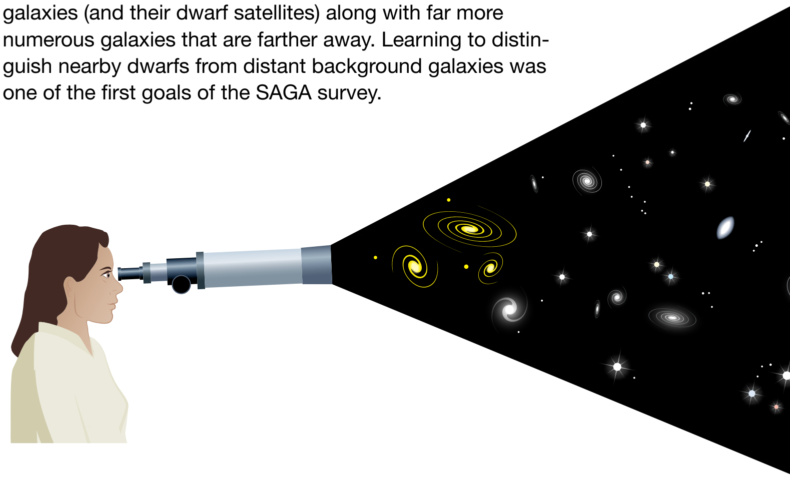
The numbers don't simply provide a sanity check — they might also reveal the nature of dark matter. Most cosmologists think that dark matter particles are "cold," meaning they move slowly. Because of this, they coalesce easily to create scores of mini-halos, the biggest of which host dwarf galaxies. But both warm dark matter (which moves faster) and self-interacting dark matter would not come together as well, resulting in far fewer dwarf galaxies. Ultimately, SAGA data will help differentiate between these hypotheses.

A Detective Story

But although the satellites might match in number, they don't in appearance. Roughly 85% of the 335 satellites that SAGA has detected are actively making stars, while the same can be said for only two (the Magellanic Clouds) of the five comparable satellites around the Milky Way and for two of the nine around Andromeda.

The question is why.

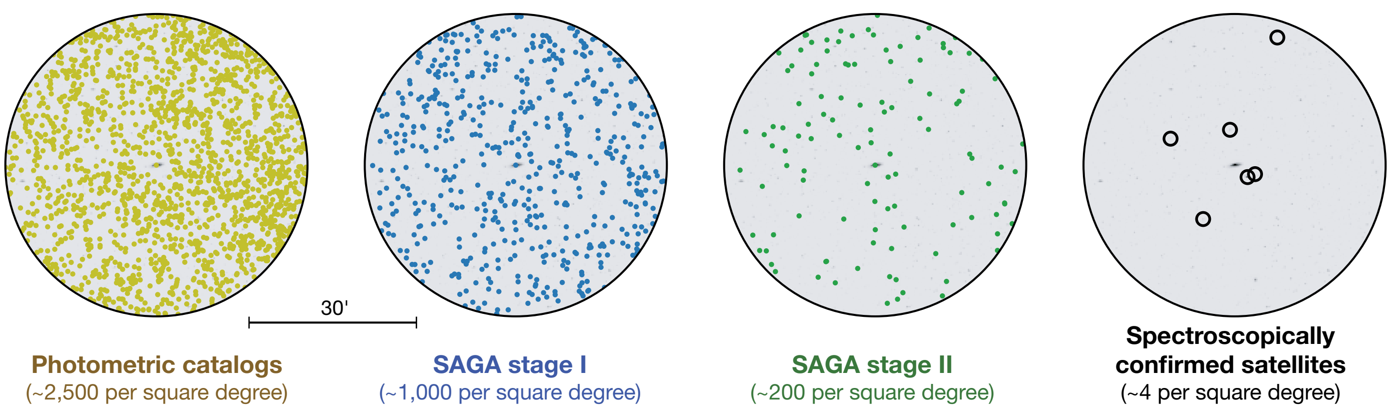
▼ **FIELD OF VIEW** When observers look at a telescope's field of view, they're actually looking into a cone-shape region of the universe. In this cone will be a few nearby galaxies (and their dwarf satellites) along with far more numerous galaxies that are farther away. Learning to distinguish nearby dwarfs from distant background galaxies was one of the first goals of the SAGA survey.



"It's kind of a new toy — a totally new set of data that we didn't have access to before," Mao says. Already, astronomers have started to speculate on the difference, which might have to do with our dark matter halo.

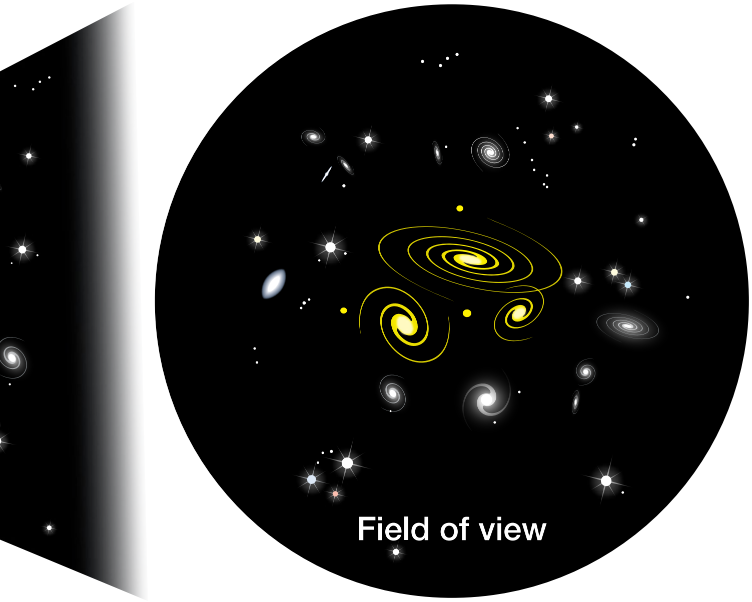
Just like other galaxies, the Milky Way's halo hosts a sea of diffuse, hot gas. Much as you feel Earth's atmosphere "pushing" against you as you ride your bicycle down the street, dwarf galaxies traveling through a large galaxy's halo face a headwind from the hot gas suffusing it. That headwind, also known as *ram pressure*, can easily remove the cold, star-forming gas from dwarf galaxies and thus halt star formation.

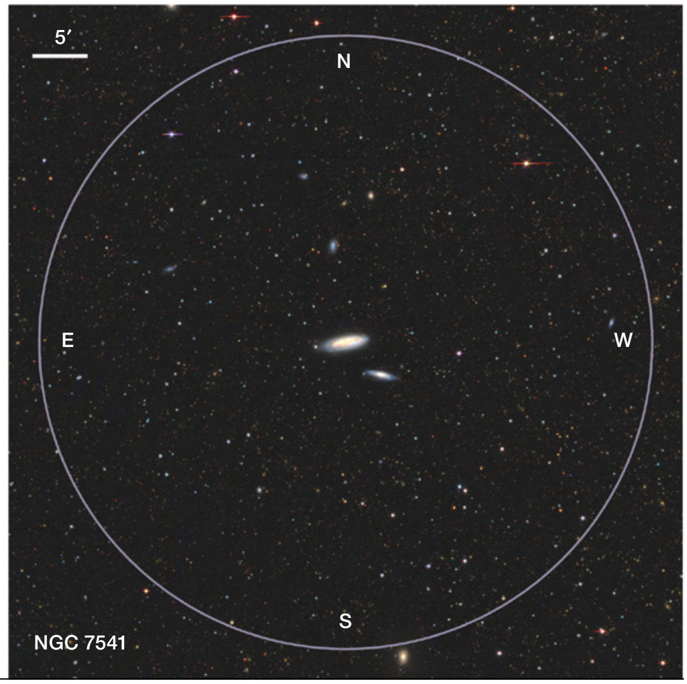
If the Milky Way has a larger dark matter halo than we previously thought, then it could hold onto enough hot gas to explain why all of our galaxy's satellites are barren. That hypothesis could have big implications for the future colli-



▲ **TARGET SELECTION** To narrow down which galaxies in each field of view are actual satellites of the Milky Way–like host (the field shown here is around NGC 7541), the SAGA team first employed simple cuts based on galaxies' colors. The second version of the survey (SAGA II) was able to use more sophisticated criteria to select galaxies for spectroscopic follow-up. The result: Zero to nine satellites hover around each SAGA galaxy.

FIELD OF VIEW: GREGG DINDERMAN / S&T; TARGET SELECTION: Y.-Y. MAO (RUTGERS), WITH IMAGES FROM LEGACY SURVEYS / D. LANG (PERIMETER INSTITUTE)





▲ **CATCH-22** To capture the satellites around NGC 7541, pictured here, the survey included an area with a diameter of 1 degree around the host. This large field of view encompasses most of the galaxy's dark matter halo and the satellites within it. However, most of the galaxies pictured here are distant background galaxies. (The galaxy and its satellites are dubbed "Catch22" in the SAGA catalog.)

sion between the Milky Way and Andromeda, which would happen very differently if our galaxy is actually more massive than we think.

Or maybe Andromeda is in on the secret. M31, like the Milky Way, has a dearth of star-forming satellites. It's possible that instead of being independent systems, the two galaxies share one large dark matter halo — with a bunch of hot gas deadly to tiny companions. The SAGA team members specifically avoided close pairs of galaxies like that of the Milky Way and Andromeda, so at the moment we have no analog with which to test the idea. But perhaps if astronomers can study similar duos in the future, they might find only quenched satellite galaxies as well.

Then again, the discrepancy could have to do with our galaxy's unique history. If our satellites fell into the Local Group much earlier, then our hot, gaseous halo would have had longer to act on them. Unfortunately, we don't know how long ago most satellites were swept up by the Milky Way.

Lastly, it's possible our satellites are snuggled up so close to the Milky Way that our halo can more efficiently remove their gas. It's hard to tell if that's true in the SAGA systems, where we don't have full three-dimensional pictures.

All these hypotheses assume that the answer lies in our halo. But Andreea Font (Liverpool John Moores University, UK), who was not involved in the survey, thinks another mechanism might be the culprit. "There are many ways you can kill a galaxy," she says.

Ram-pressure stripping is favored in the case of the Milky Way, but other physical mechanisms can also diminish a dwarf galaxy's reservoir of star-forming gas. Tides from galaxy clusters can strip it away. Other dwarfs can jostle a dwarf about so that it loses its gas. And plenty of processes can ionize gas, keeping it so warm that it can't form stars.

There is no clear answer yet. And some theorists do wonder if there is an observational bias. Since many galaxies that are quenched tend to be fainter than star-forming galaxies with the same mass, astronomers might have missed them. But Geha says that SAGA can pick up faint satellites in this mass range.

"I think it's really exciting," says Alyson Brooks (Rutgers University). Brooks is not involved in the SAGA project directly, but she has already started to compare the current generation of computer simulations to the newest results. "For decades, we have had our own Milky Way and our nearest neighbor Andromeda to compare our simulations to and try to figure out if we understand galaxy evolution, and who knows if they are biased."

A Dark Future

These early results have prompted a never-ending list of hypotheses, follow-up questions, and planned observations.

To start, the SAGA team would like to better understand the influence that a Milky Way–like galaxy has on its satellites. Dwarf galaxies as large as the Magellanic Clouds, for example, should create new stars for a very long time, and yet we see similar SAGA satellites that have ceased forming stars if they are close to a massive galaxy like the Milky Way.

"The SAGA satellites are all influenced by their parent Milky Way," Geha says. "The question is, how much?" To find the answer, the team plans to obtain high-resolution

SATELLITES AROUND NGC-7541: Y.-Y. MAO (RUTGERS), WITH IMAGES FROM LEGACY SURVEYS / D. LANG (PERIMETER INSTITUTE) spectra of the dwarfs they found. These data will help enable researchers to determine how the star-formation rate might have been impacted as the satellite fell toward the host galaxy. Projected distances will also show whether star-formation rates change with distance from the host. This is a question that Brooks is already addressing from a theoretical standpoint by simulating the evolution of dozens of Milky Way–like galaxies and their satellites.

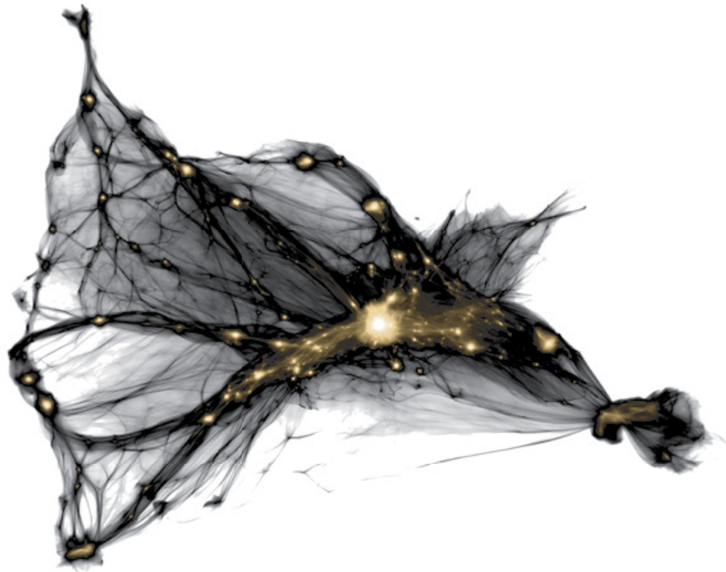
And Geha would like to expand the survey to other kinds of systems, too. "Now that we have this toolbox, we're going to apply it everywhere," she says. The team wants to look at galaxies of similar sizes to the ones in SAGA but in any environment. That includes not only galaxies in isolation but also galaxies that reside in Local Group–like systems, which could reveal whether any special features of the Milky Way's system are related to its close contact with Andromeda.

The survey will surely help address open questions about galaxy evolution, but the SAGA team is hopeful that the data will also provide a new window on dark matter.

Astronomers have deduced that dark matter exists within our own galaxy and others based on the excessive speeds of galaxies' stars, which move far too fast to stay bound if the gravity of visible matter is all that's holding a galaxy together. The SAGA galaxies are too far away to measure the velocities of their individual stars, but astronomers can measure velocities for clusters of stars and large regions of hydrogen gas within the galaxies. Then they use those measurements to estimate how quickly a galaxy spins around.

"Having a new data set to apply that to is really enticing," Tollerud says. "And to ask whether the hundreds of papers that have been written on [dark matter] in the Milky Way also apply to the larger universe."

But the findings won't simply point to the existence of dark matter; they will also hint at dark matter's nature.



▲ **SEEING THE UNSEEN** Astronomers compare SAGA observations to predictions from cosmological simulations. In this visualization of one such simulation, clumps and filaments of dark matter (black areas) serve as the scaffolding for the formation of cosmic structures such as stars, galaxies, and galaxy clusters (bright areas). The simulated Milky Way–like halo is the large yellow-white object near the center.

Already, Wetzel is running simulations that vary dark matter's characteristics to see if they create observable differences in the number of dwarf galaxies or in their properties, such as the orbital speeds of their stars.

"The SAGA observations are and will continue to be a very useful data set to compare [to] any such model — be it a vanilla, cold-dark-matter model or some more exotic alternative," Wetzel asserts. "It's quite a useful observational benchmark."

■ **SHANNON HALL** is an award-winning freelance science journalist. She'd like to nominate "Samwise" for a SAGA name.

▲ **STAR-FORMING VS. QUENCHED** SAGA satellites are more likely to be star-forming *(top row)* than not *(bottom row)*. The former tend to be bluer in color due to light from newer, more massive stars. These representative examples all have roughly the same stellar mass (10 million Suns' worth).

GALAXY/DARK MATTER SIMULATION: Y.-Y. MAO & RISA WECHSLER, VISUALIZATION: RALF KAEHLER; DWARF GALAXY THUMBNAILS: M. GEHA, WITH IMAGES FROM LEGACY SURVEYS / D. LANG (PERIMETER INSTITUTE)

1 DAWN: Venus, Saturn, and Mars climb in the east-southeast in brightening twilight. As the month progresses, Venus teases itself away from the other two planets.

4 DAWN: Mars and Saturn grace the east-southeastern horizon a mere ½° apart. Check in on this duo the next morning, too, as they're even closer. (Turn to page 46 for more on this and other events listed here.)

4 EVENING: Look toward the west to see the thin lunar crescent hanging in Taurus about 4° from the Pleiades.

8 EVENING: High in the southwest, the waxing crescent Moon, Castor, and Pollux form an isosceles triangle in Gemini.

9 EVENING: The first-quarter Moon aligns with Gemini's bright lights, where it sits some 5° left of Pollux.

16 DAWN: An eye-catching string of planets comprising Jupiter, Venus, Mars, and Saturn adorns the east-southeastern horizon at twilight.

19 MORNING: The waning gibbous Moon poses in Scorpius, around 6° right of Antares.

22 MORNING: The Lyrid meteor shower peaks. Watch for meteors both this morning and next — even though the waning gibbous Moon will hamper viewing somewhat.

25 DAWN: Look toward the southeast to see the waning crescent Moon, Saturn, and Mars arranged in a triangle, while Venus and Jupiter lurk lower in the east.

26 DAWN: The Moon now hangs almost midway between Venus and Mars.

27 DAWN: Low in the east, the thin waning lunar crescent forms a tight triangle with Jupiter and Venus.

29 DUSK: Make sure you don't miss the delightful sight of Mercury lower left of the Pleiades; they're very low in the west-northwest, so catch them before they set.

30 DAWN: The dazzling duo of Jupiter and Venus rise in the east, with less than ½° separating the pair.

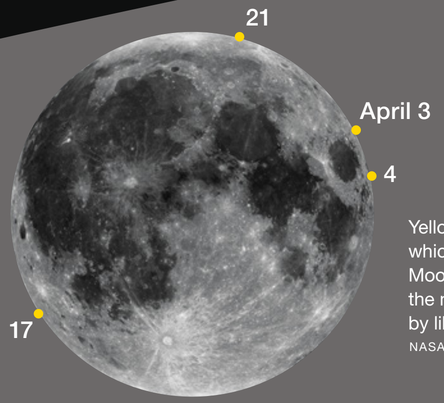
30 A PARTIAL ECLIPSE OF THE SUN is visible in the southeast Pacific and southern South America (see page 50).
— DIANA HANNIKAINEN

Get up early on the morning of April 30th to catch the close pairing of Jupiter and Venus in the east. This photo, taken in November 2017, shows a similar event. ALAN DYER

APRIL 2022 OBSERVING

Lunar Almanac

Northern Hemisphere Sky Chart



Yellow dots indicate which part of the Moon's limb is tipped the most toward Earth by libration.

NASA / LRO

MOON PHASES

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

NEW MOON
April 1
06:24 UT

FIRST QUARTER
April 9
06:48 UT

FULL MOON
April 16
18:55 UT

LAST QUARTER
April 23
11:56 UT

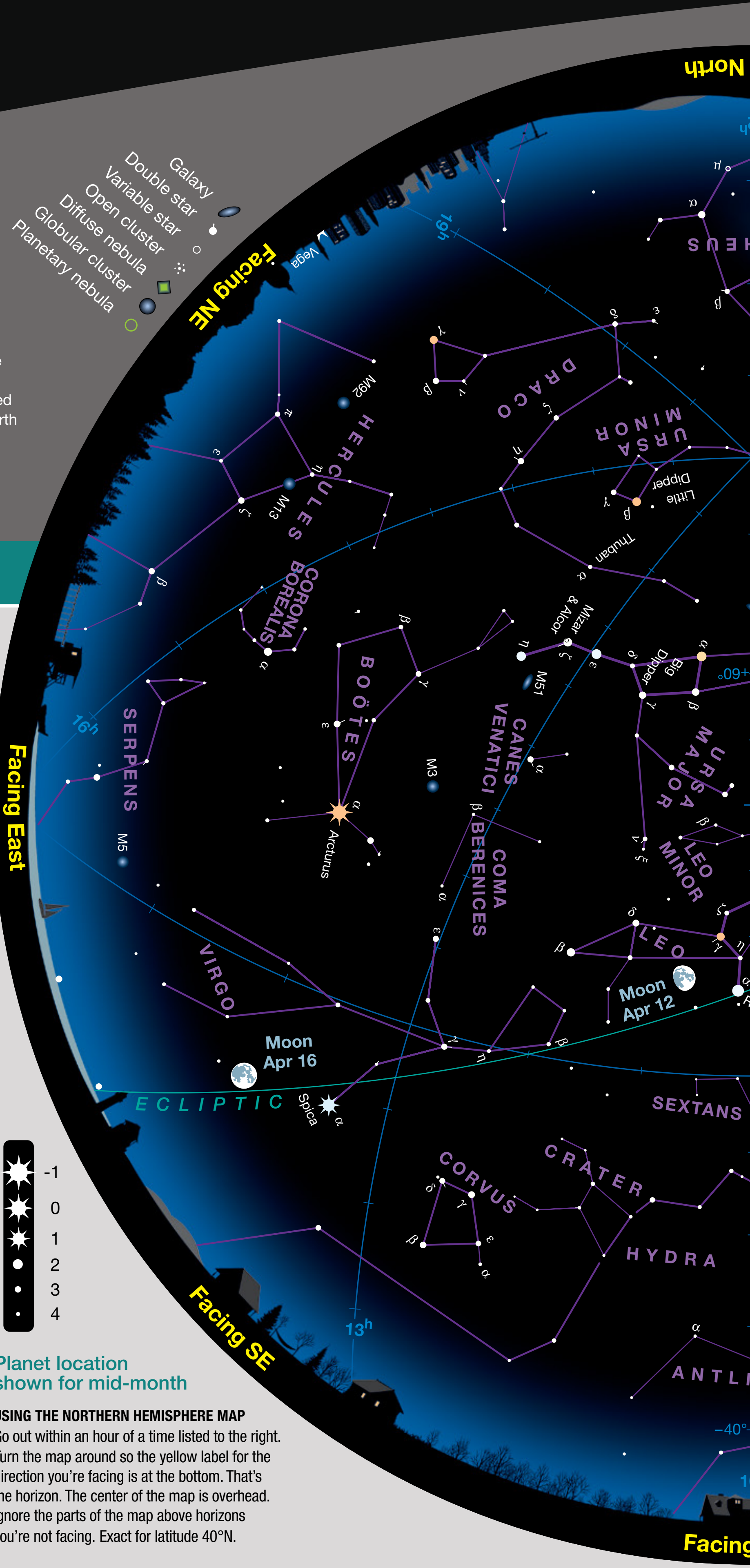
NEW MOON
April 30
20:28 UT

DISTANCES

Apogee 404,436 km	April 7, 19^{h} UT Diameter 29′ 33″
Perigee 365,145 km	April 19, 15^{h} UT Diameter 32′ 44″

FAVORABLE LIBRATIONS

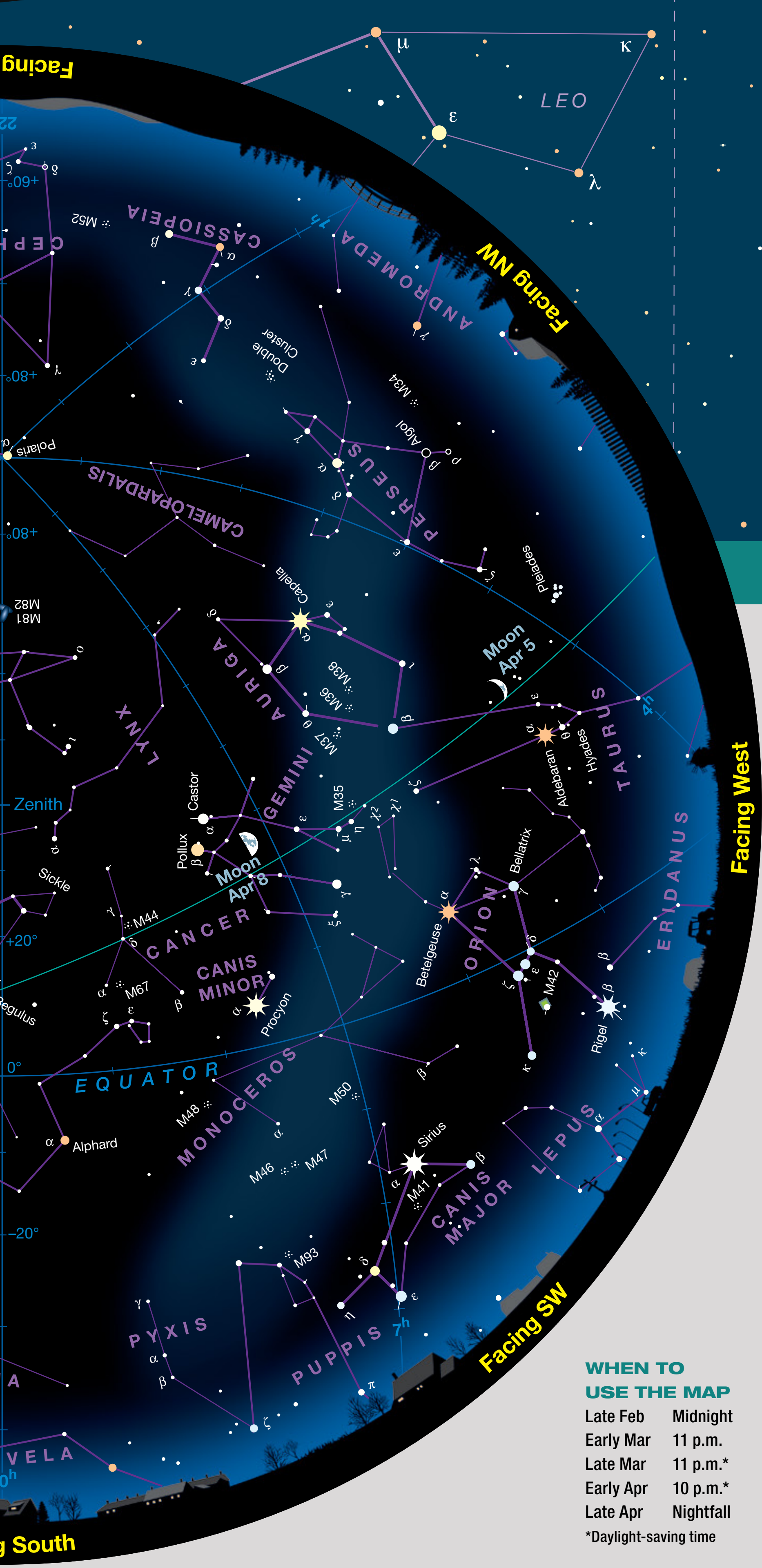
- Lyapunov Crater — April 3
- Mare Marginis — April 4
- Shaler Crater — April 17
- Gioja Crater — April 21

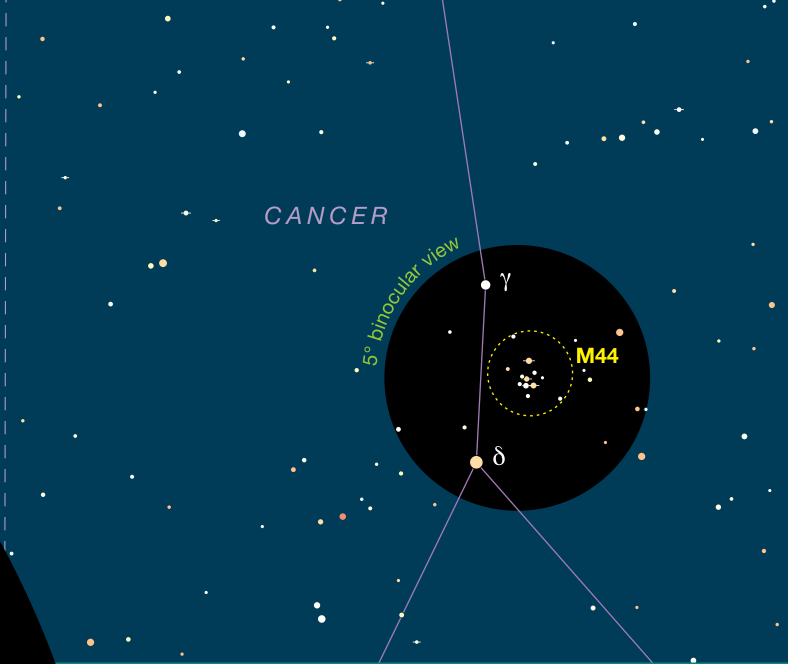


Planet location shown for mid-month

USING THE NORTHERN HEMISPHERE 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. The center of the map is overhead. Ignore the parts of the map above horizons you're not facing. Exact for latitude 40°N.





Binocular Highlight by Mathew Wedel

A Charming Cluster in Cancer

Our target this month is one of the finest open clusters in the northern sky: **Messier 44**, in Cancer, the Crab. Cancer is not one of the more striking constellations. In fact, the 3.1-magnitude cluster is brighter than any of the individual stars in the Crab. That leads to the bizarre circumstance that, under moderate light pollution, it can occasionally be easier to spot M44 than the named stars of the constellation. As can be seen in the chart at left, a handy shortcut in those circumstances is to aim approximately halfway between Pollux, or Beta (β) Geminorum, and Regulus, or Alpha (α) Leonis, to find the cluster.

M44 sits just west of a pair of stars aligned north-south: 4.7-magnitude Asellus Borealis, or Gamma (γ) Cancri, and 3.9-magnitude Asellus Australis, or Delta (δ) Cancri. These are the "northern and southern donkeys" that the ancients envisioned eating from the trough of M44, which they accordingly knew as Praesepe, or "manger" in Latin. A more modern nickname is the Beehive, which certainly fits the cluster's swarm of stars, some of which are resolvable by the naked eye under clear, dark skies.

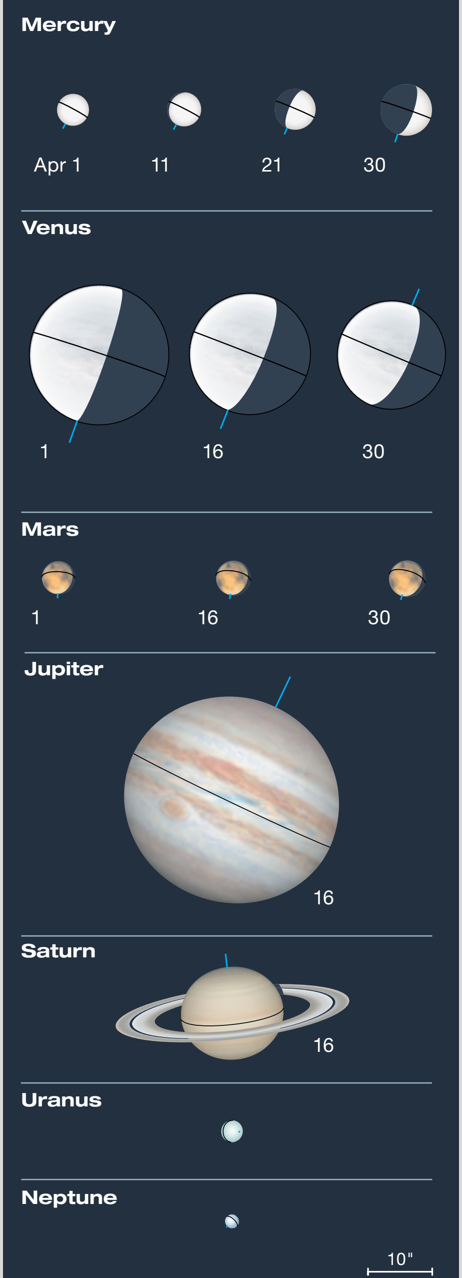
The metaphors of manger and beehive both evoke the messiness of living systems, but when I look at M44 in binoculars, I tend to see stars laid out in an almost geometric grid, like a well-planned city seen from above. That mathematical fancy is enhanced by the rectangular dark lanes spaced around the central core of the cluster. M44 can conjure such detailed visions because it's so close to us, only about 600 light-years away. Go look with fresh eyes and see what images the cluster brings to mind.

■ **MATT WEDEL** believes that a dedicated observer can never see the same cluster twice — there's always more to them.

WHEN TO USE THE MAP

Late Feb	Midnight
Early Mar	11 p.m.
Late Mar	11 p.m.*
Early Apr	10 p.m.*
Late Apr	Nightfall

*Daylight-saving time



▲ **PLANET DISKS** are presented north up and with celestial west to the right. Blue ticks indicate the pole currently tilted toward Earth.

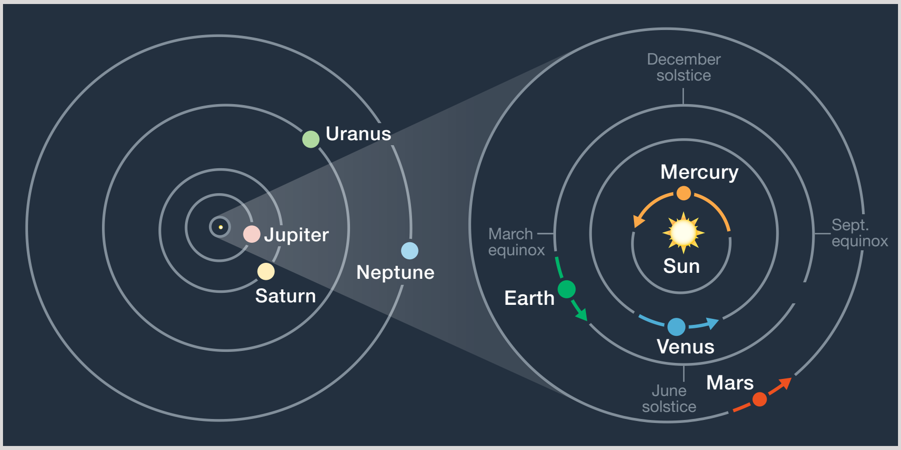
▶ **ORBITS OF THE PLANETS** The curved arrows show each planet's movement during April. The outer planets don't change position enough in a month to notice at this scale.

PLANET VISIBILITY (40°N, naked-eye, approximate) **Mercury** emerges from the Sun's glare on the 11th and is visible at dusk • **Venus** and **Mars** visible at dawn all month • **Jupiter** visible at dawn low in the east-southeast all month • **Saturn** visible at dawn all month.

April Sun & Planets

	Date	Right Ascension	Declination	Elongation	Magnitude	Diameter	Illumination	Distance
Sun	1	0^h 40.2^m	+4° 20′	—	–26.8	32′ 01″	—	0.999
	30	2^h 27.8^m	+14° 36′	—	–26.8	31′ 46″	—	1.007
Mercury	1	0^h 34.7^m	+2° 20′	2° Mo	–1.9	5.0″	100%	1.347
	11	1^h 49.3^m	+11° 36′	9° Ev	–1.5	5.3″	94%	1.261
	21	3^h 00.9^m	+19° 14′	18° Ev	–0.7	6.4″	65%	1.054
	30	3^h 47.8^m	+22° 45′	21° Ev	+0.3	8.0″	36%	0.838
Venus	1	21^h 47.1^m	–12° 27′	46° Mo	–4.4	21.7″	55%	0.769
	11	22^h 29.2^m	–9° 30′	45° Mo	–4.3	19.7″	60%	0.846
	21	23^h 11.5^m	–6° 00′	44° Mo	–4.2	18.1″	64%	0.923
	30	23^h 49.7^m	–2° 29′	43° Mo	–4.1	16.8″	67%	0.991
Mars	1	21^h 27.4^m	–16° 16′	52° Mo	+1.1	5.2″	92%	1.805
	16	22^h 11.7^m	–12° 38′	55° Mo	+1.0	5.5″	91%	1.716
	30	22^h 52.0^m	–8° 52′	58° Mo	+0.9	5.7″	90%	1.635
Jupiter	1	23^h 28.5^m	–4° 30′	20° Mo	–2.0	33.4″	100%	5.903
	30	23^h 52.4^m	–1° 59′	42° Mo	–2.1	34.7″	100%	5.676
Saturn	1	21^h 37.7^m	–15° 09′	49° Mo	+0.9	15.8″	100%	10.524
	30	21^h 46.3^m	–14° 31′	75° Mo	+0.9	16.5″	100%	10.099
Uranus	16	2^h 44.2^m	+15° 31′	18° Ev	+5.9	3.4″	100%	20.661
Neptune	16	23^h 39.0^m	–3° 30′	32° Mo	+7.9	2.2″	100%	30.765

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. equals 149,597,871 kilometers, or 92,955,807 international miles.) For other timely information about the planets, visit **skyandtelescope.org**.



Direct from the Dipper

A famous signpost guides you to stellar delights.

LOOKING NORTH Both the Big Dipper and Little Dipper appear in this image. During April evenings, the Big Dipper points downwards, toward the north horizon.

AKIRA FUJII

April is when the Big Dipper is positioned highest above the horizon in the early evening and at dusk. The iconic asterism is so well known that it's easy to forget that it's only the brightest portion of the constellation Ursa Major, the Great Bear. April is also when the Pointers in the Big Dipper's Bowl aim downward to Polaris, the North Star.

If you look at our Northern Hemisphere map (pages 42 and 43), you'll find that extending the long axis of the Big Dipper far to the right (west) guides you to zero-magnitude Capella, in Auriga. April evenings are also when the brightest winter constellations are last visible. Taurus, Orion, and Canis Major all drop into the Sun's afterglow, while a few more winter groupings — Auriga, Gemini (starring Pollux and Castor), and Canis Minor (starring Procyon) — hang on through May.

But what about the three brightest stars of spring? Arcturus, Regulus, and Spica all stand in geometric relation to the Big Dipper, which helps us identify them. The famous formula for locating Arcturus and Spica is to start with the curve of the Big Dipper's Handle and take "the arc to Arcturus," then drive a "spike to Spica" (the spike being a straight line).

Our all-sky map suggests that proceeding south from the Big Dipper will take you to Leo, the celestial Lion, with its Sickle asterism that includes Regulus (see the March issue, page 45). In practice it's a little tricky (and hard on your neck) to gaze directly from the Dipper to Leo if you're at mid-northern latitudes. That's because the *zenith* (the point in the sky directly overhead) lies between the two star groups — you literally have to bend over backwards to reach Regulus from the Big Dipper no matter if you're facing north or south!

The April sky map also shows that Regulus and the Sickle are oriented north-south, very close to the 10^h line of right ascension and, therefore, the meridian. But if you follow the meridian north past Polaris, you'll find another constellation skimming the horizon. This star pattern is the fairly dim constellation Cepheus, the King, which looks like a little house with a pointy roof. You'll need clear and dark skies to detect Cepheus when its low on the horizon during April evenings.

Interestingly, Leo's Sickle and Cepheus lie in exactly opposite directions, with the Pointer Stars of the Big Dipper roughly midway in the vast gap between them. Those Pointers are 1.8-magntiude Alpha (α) and 2.4-magnitude Beta (β) Ursae Majoris, otherwise known as Dubhe and Merak, respectively. Normally you'd expect these to be the two brightest stars in the constellation, but they're not. Dubhe ranks #2 — very slightly dimmer than Epsilon (ε) — and Merak is only #5.

Almost everyone knows that you can find the Pole Star, Polaris, by extending a line northward from the Pointer stars. But do you know how to find Thuban? Thanks to the effects of *precession* (the wandering of Earth's rotational axis), this 3.7-magnitude star in Draco, the Dragon, closely marked the north celestial pole around 5,000 years ago — it was the pole star when the Great Pyramids in Egypt were being built. To locate Thuban, select the two brightest stars in the Bowl of the Little Dipper, Beta and Gamma (γ) Ursae Minoris (the so-called Guardians of the Pole), then run a line from them to Mizar at the bend in the Big Dipper's Handle. You'll find Thuban about midway between the Guardians of the Pole and Mizar. A few thousand years ago, that would have been handy to know!

■ **FRED SCHAAF** welcomes your letters and comments at **fcschaaf@gmail.com**.

To find out what's visible in the sky from your location, go to skyandtelescope.org.

Mercury Makes Good

A fine showing for the innermost planet is just one highlight in a busy month.

MONDAY, APRIL 4

The **Moon** visits the **Pleiades** cluster in Taurus roughly once a month. But the very best meet-ups are the ones that feature a thin lunar crescent in a reasonably dark sky, which happens in the early evening in spring and the early morning in summer. The reason a thin crescent is best is simple: The collection of stars that make up the Pleiades' mini-dipper shape mostly shine around 4th magnitude, which is faint enough to be overwhelmed when the lunar disk is more than 50% illuminated, at least so far as the naked-eye view is concerned.

That's why this evening's event is so appealing — the Moon is less than four days old and just 14% lit as it sits just 4° below left of the cluster. The pair will make for a fine, early-evening naked-eye sight, but if you use binoculars the view really gains luster. Not only will you catch more Pleiads, but you'll also get to enjoy seeing earthshine gently illuminating the "dark" portion of the Moon.

TUESDAY, APRIL 5

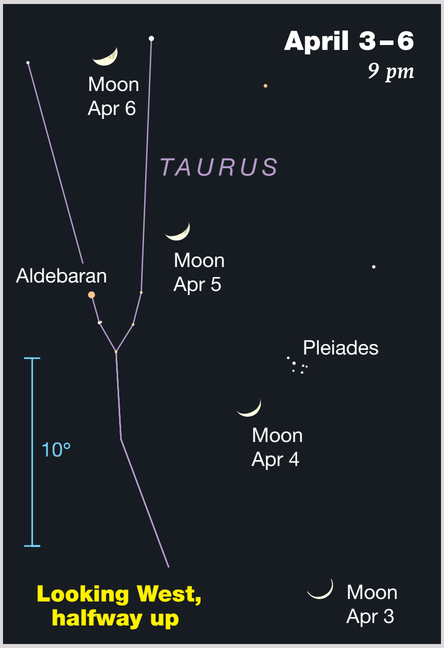
The morning sky is the place to be in April as four naked-eye planets subtly shift positions on a daily basis. The first highlight of the month's series of dawn delights is a close pairing of **Mars** and **Saturn** on the 5th. Mars's eastward motion has been bringing it nearer and nearer to Saturn, and on this date it sits a mere 24′ below the ringed wonder. That's slightly less than one Moon diameter, which means the two can be seen together in a small telescope used at moderate magnification. Such a view will show Saturn's magnificent rings and render Mars a tiny, ruddy disk. Interestingly, both planets are very nearly the same brightness, with Saturn shining at magnitude +0.9 and Mars at +1.0. But you certainly don't need a telescope (or even binoculars) to enjoy this pairing — an alarm clock is likely the only piece of gear required since the best time to look is around 5:30 a.m. (local daylight time), before twilight brightens the sky too much.

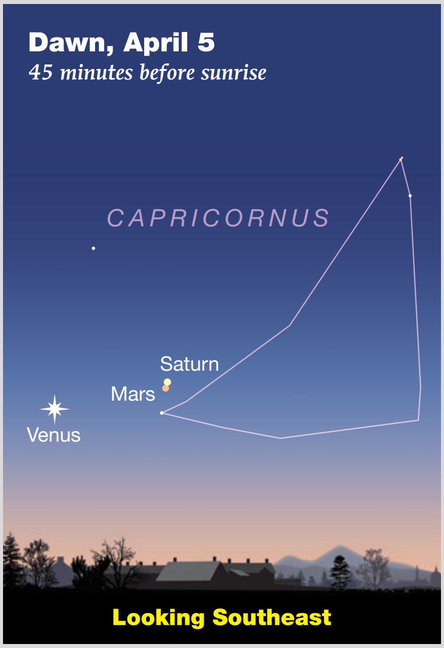
MONDAY, APRIL 18

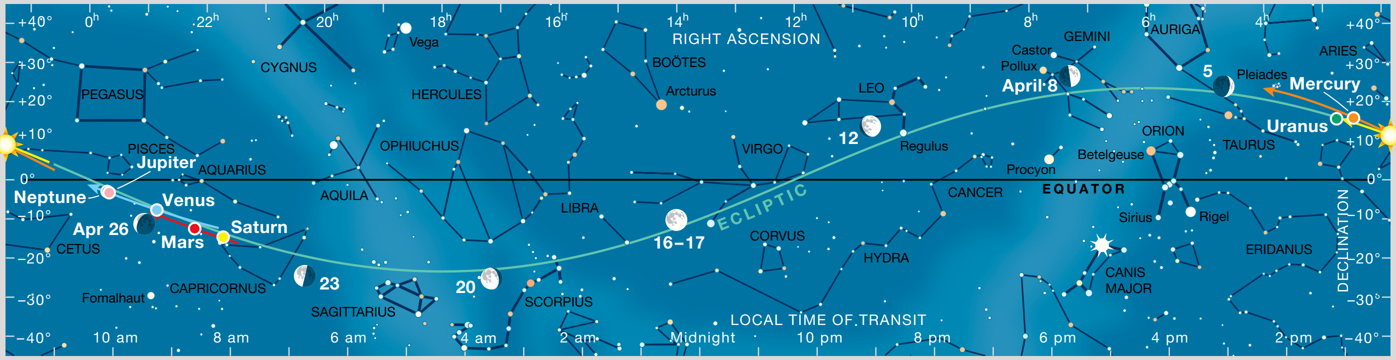
There's something irresistibly eye-catching about a set of evenly spaced bright planets strung out in a line. And that's exactly what we have at dawn today. Starting from the horizon and proceeding up and to the right, you get **Jupiter** (magnitude –2.1), **Venus** (–4.2), **Mars** (+1.0), and **Saturn** (+0.9). Obviously, this delightful configuration didn't spring up overnight — the quartet has been in some sort of "line" since Jupiter emerged from solar conjunction at the start of the month — but the gaps between the planetary dots are most equal on this morning.

The line is nearly 32° long, which means if the planets were perfectly spaced each would be separated from its neighbor by a little less than 11°. So, are they? Plus or minus ½°, yes! The exception is Mars and Saturn, which have only 9° between them. But given that they're the faintest of the foursome, their deviation from perfection seems a little less obvious. This is one of those sky sights that is purely for naked-eye enthusiasts — even binoculars will

▶ These scenes are drawn for near the middle of North America (latitude 40° north, longitude 90° west). European observers should move each Moon symbol a quarter of the way toward the one for the previous date; in the Far East, move the Moon halfway.







▲ The 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 illuminated). "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.

diminish the experience. And it'll be fascinating to watch the planets rearrange themselves over the coming weeks.

FRIDAY, APRIL 29

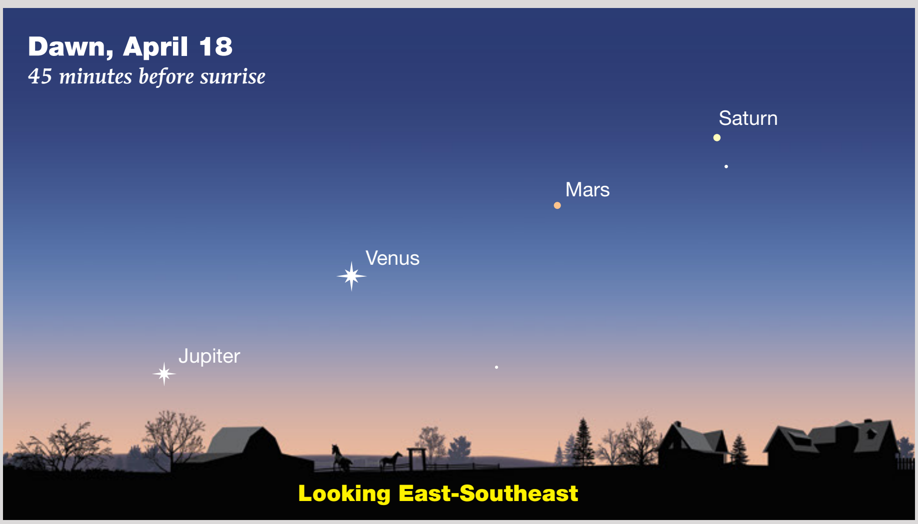
Mercury has seven elongations in 2022, and this one is the best. Not only does the planet reach its greatest altitude for observers at mid-northern latitudes, but, conveniently, it does so in the evening sky. If you've never managed to spot the swift-moving planet before, now's about as good a chance as you're going to get. Mercury is at magnitude +0.3 and hovers nearly 14° above the west-northwestern horizon at the end of *civil twilight*, when the center of the Sun is 6° below the horizon. But if you wait a little longer and let twilight fade a bit more, you'll not only be able to spot Mercury more easily, but the sight will be enhanced with a bonus addition: the **Pleiades**. By coincidence, this evening the little world is positioned below left of the cluster, less than 1½° from Alcyone, the brightest Pleiad. Get your binoculars out for the most rewarding view, though a small, low-power telescope will also show the planet and cluster together well. On this evening Mercury sets roughly 10 minutes after the end of *astronomical twilight*, when the Sun is 18° below the horizon and night truly begins.

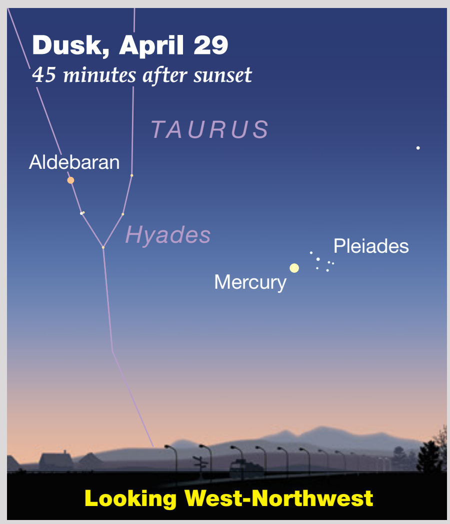
SATURDAY, APRIL 30

Events in the dawn sky reach their climax this morning when the two brightest planets (usually, that is — Mars occasionally outshines Jupiter) have a close encounter. Ascending **Jupiter** and descending **Venus** meet and sit side by side less than ½° apart. (They'll be at their absolute closest at 21 UT, when just 14′ separate the pair.) Both planets rise at roughly 4:20 a.m. local daylight time — just as astronomical twilight begins. Venus outshines Jupiter by a full two magnitudes, which means it's more than six times brighter.

This is a wonderful naked-eye sight, but once again I'd be tempted to get out a scope and enjoy the rare chance to see both worlds in the same telescopic field. It's in that arena that Jupiter has an advantage over Venus: It's bigger! Indeed, giant Jove presents a disk that's almost exactly twice as large as its gleaming neighbor. If the weather fails you, check again the following morning (May 1st) when they'll be only slightly farther apart.

■ Consulting Editor **GARY SERONIK** never misses a chance to catch a mercurial Mercury appearance.





Run With the Asteroids

Three small-scope minor planets highlight the month.

If you enjoy chasing asteroids, this is your month. Three reach opposition in April and are bright enough to follow in small telescopes: 8 Flora, 10 Hygiea, and 15 Eunomia. They share the same pocket of sky in the Hydra-Virgo-Libra region, making it easy to catch them all in a single observing session. Although in the eyepiece they're indistinguishable from stars, knowing a little about each asteroid helps us appreciate their hidden individuality.

This is a particularly good opposition for Hygiea (Hi-JEE-uh), a dark, carbonaceous asteroid compositionally similar to Ceres and located in the outer region of the main asteroid belt. Normally 10th magnitude, Hygiea reaches magnitude 9.3 at opposition on the 28th, providing an infrequent opportunity to glimpse it with binoculars from a dark-sky location.

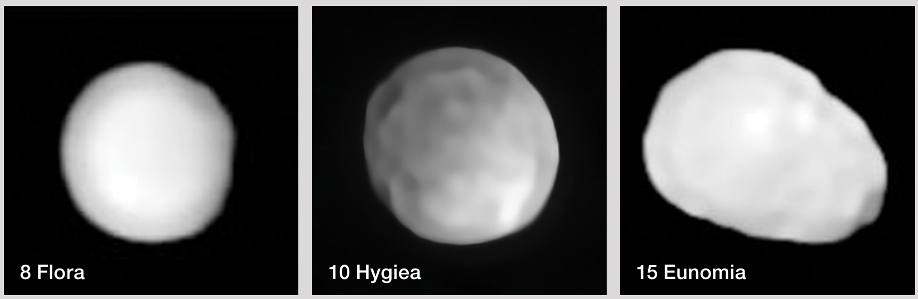
Hygiea has a diameter of 434 kilometers (270 miles), which makes it the fourth largest asteroid after Ceres, Vesta, and Pallas. Its impressive size and nearly spherical shape have some astronomers considering reclassifying it as a dwarf planet. Simulations suggest that more than 2 billion years ago a collision with an object in the 75–100-km size range may have fully shattered Hygiea, with the resulting fragments coalescing and consolidating into the spherical body we see today.

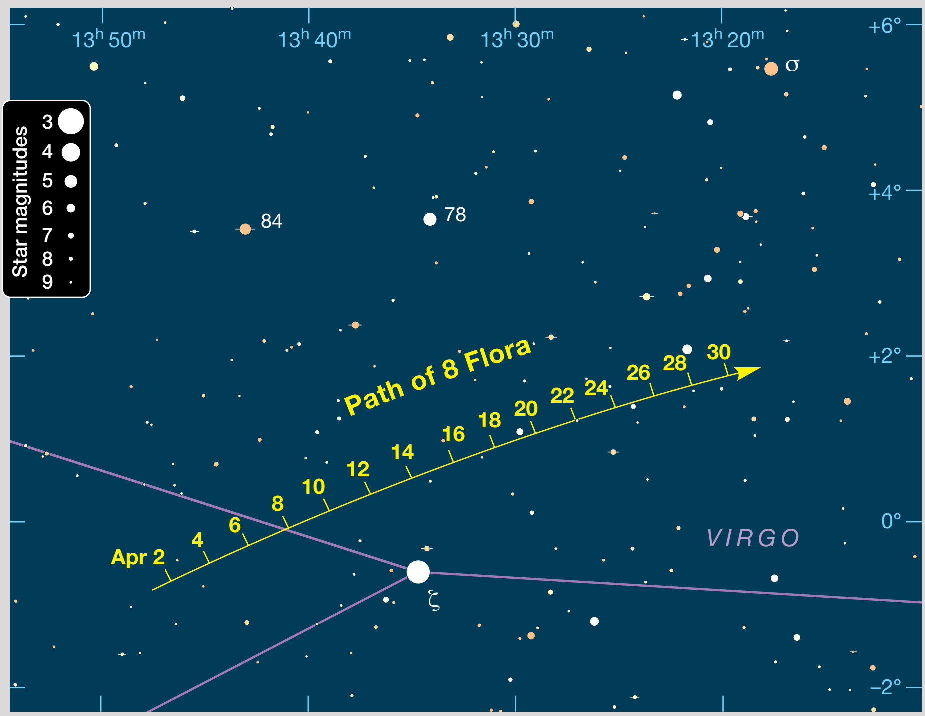
The spectral signatures of our other two asteroids indicate they're made of denser stuff — silicates and iron-nickel. Flora orbits within the inner region of the asteroid belt at an average distance of 2.2 a.u., compared to 3.1 a.u. for Hygiea and 2.6 a.u. for Eunomia. Flora's composition implicates it as a possible source for the LL (low-iron, low metal) chondrite meteorites, an uncommon stony type that accounts for about 9% of observed meteorite falls. With a diameter of 146 km, it's large for an inner asteroid but will only brighten to magnitude 9.8 during this season's distant opposition on April 12th. During more favorable apparitions, Flora brightens to magnitude 8.0 when it's closest to Earth.

British astronomer John Russell Hind (of Hind's Crimson Star fame) discovered Flora on October 18, 1847, but it was John Herschel who proposed naming it after the Roman goddess of flowers and spring. Appropriately, its appearance this year puts it nicely in sync with the season. Puttering westward across central Virgo, it passes 1.1° north of 3.4-magnitude Zeta (ζ) Virginis on the night of April 12–13.

Flora spins once every 12.8 hours and, like Uranus, rotates tipped on its side, with an axial tilt of 79° (give or take 10°). Past impacts have chipped away at the asteroid to create the Flora

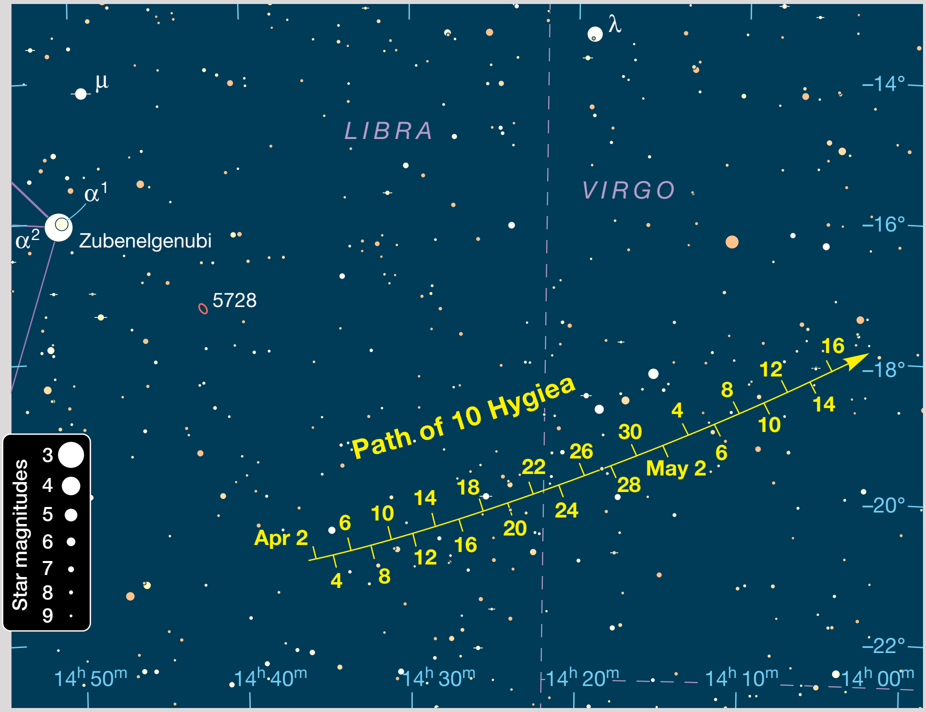
▼▶ The images below, captured by the SPHERE instrument on the ESO's Very Large Telescope, reveal each asteroid's general shape and some surface features. Hygiea could eventually be reclassified as a dwarf planet because it satisfies the definition, including possessing a spherical shape. (For all finder charts, the position of the asteroids is plotted for 0^h UT.)

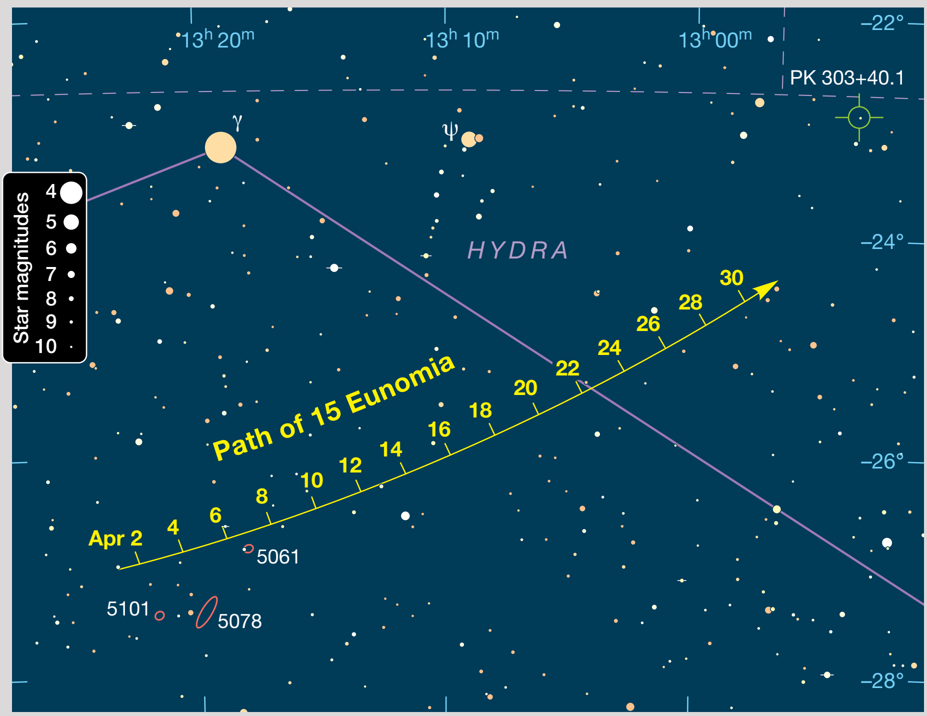




ASTEROIDS: ESO / P. VERNAZZA ET AL. / MISTRAL ALGORITHM (ONERA / CNRS) (3) family of objects, which has more than 13,000 members — one of the largest asteroid groups known. A 2017 *Astronomical Journal* paper by David Vokrouhlický, William F. Bottke, and David Nesvorný suggests that the family "may be the primary source of present-day LL chondrite-like Near Earth Objects as well as Earth/Moon impactors." When you point your scope at this stellar speck, one of its many offspring may be closer than you think!

Eunomia (you-NO-me-uh) reaches opposition on April 16th at magnitude 10.0. It stays within 5° of 3rd-magnitude Gamma (γ) Hydrae until the end of the month, making the star a convenient jumping-off point. Eunomia's potato-shaped figure spans 270 km, making it the second-largest stony or "S-type" asteroid after Juno. As with Flora, Eunomia's 2022 opposition is a distant one. However, in 2024 it will be much closer and reach magnitude 8.1. Despite Eunomia's relative remoteness this time, the smallest of telescopes will still show it with ease.





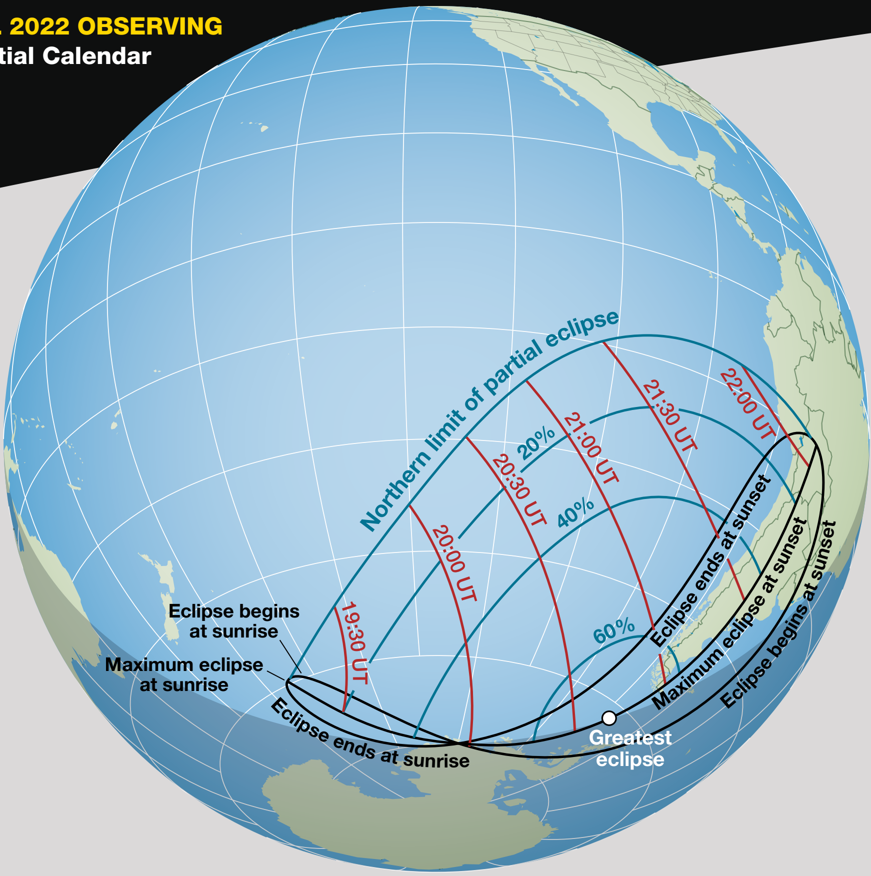
R CVn: An April Mira

IF YOU FOLLOW the arc of the Big Dipper's Handle to Arcturus (as described by Fred Schaaf on page 45), consider stopping along the way at the red pulsating variable star R Canum Venaticorum (R CVn). It reaches maximum brightness at mid-month when it tops out around magnitude 7.5 to 7.7 — easily within reach of ordinary binoculars.

R CVn is a Mira-type star that cyclically expands, contracts, and expands again every 329 days. Mira variables shine brightest when their outer envelopes contract and heat up. When they balloon outward again, the stars cool and fade.

Sometime in late September, R CVn should dim to magnitude 12 before its next round of contraction. You'll need a 4-inch telescope to see it when it's faintest. But if you add this star to your observing list now, you'll be able to appreciate how dramatically its light diminishes between now and the end of summer.

For a detailed chart that includes comparison stars, visit **aavso.org** and type "R CVn" into the Pick a Star box, then click Create a Finder Chart.



First Eclipse of 2022

SKYWATCHERS ACROSS SOUTHERN South America, the southeastern Pacific Ocean, and a smidgen of Antarctica can witness a partial solar eclipse during the late afternoon or early evening hours of April 30th. Greatest eclipse occurs in the Southern Ocean northwest of the Antarctic Peninsula, where the Moon will obscure 54% of the Sun at 20:41 UT, shortly before sunset. In Ushuaia, the capital of Tierra del Fuego, Argentina, the eclipse reaches maximum, with 52% of the Sun covered, just 10 minutes before sunset. In neighboring Punta Arenas, Chile, maximum eclipse (also 52%) occurs 24 minutes before sundown. The Sun's low altitude combined with the region's mountainous topography and coastal expanse should make for dramatic photos.

Farther north, in populous Santiago, the Moon takes its first nibble of Sun at 20:33 UT (4:33 p.m. CLT), with maximum solar obscuration of 28% at 21:37 UT (5:37 p.m. CLT). Sunset occurs 27 minutes later while the eclipse is still in progress.

You can find detailed information for any location by visiting Xavier Jubier's interactive eclipse page at **https://is.gd/april2022partial**.

Minima of Algol

Mar.	UT	Apr.	UT
1	8:27	1	21:30
4	5:17	4	18:19
7	2:06	7	15:08
9	22:55	10	11:58
12	19:45	13	8:47
15	16:34	16	5:36
18	13:23	19	2:25
21	10:13	21	23:14
24	7:02	24	20:03
27	3:51	27	16:53
30	0:41	30	13:42

These geocentric predictions are from the recent heliocentric elements Min. = JD 2457360.307 + 2.867351E, where E is any integer. They were derived by Roger W. Sinnott from 15 photoelectric series in the AAVSO database acquired during 2015–2020 by Wolfgang Vollmann, Gerard Samolyk, and Ivan Sergey. For more info, see **skyandtelescope.org/algol**.

Action at Jupiter

AFTER A MONTH-LONG ABSENCE, Jupiter has reappeared in the dawn sky to begin a new apparition. On April 1st it shines at magnitude –2.0 from eastern Aquarius and attains an altitude of just 7° at sunrise. The telescopic observing prospects for Jupiter improve modestly by month's end, when the planet rises at about 4:20 a.m. local daylight time and climbs to about 17° above the east-southeastern horizon by sunup.

Any telescope reveals the four big Galilean moons, and binoculars usually show at least two or three. The moons orbit Jupiter at different rates, changing positions along an almost straight line from our point of view on Earth. Use the diagram on the facing page to identify them by their relative positions. All the observable interactions between Jupiter and its satellites and their shadows are tabulated on the facing page. Find events timed for when Jupiter is at its highest.

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 Daylight Time is UT minus 4 hours.)

April 1: 7:36, 17:31; **2**: 3:27, 13:23, 23:19; **3**: 9:15, 19:10; **4**: 5:06, 15:02; **5**:

▲ Perseus is setting in the northwest during early evening hours in April. Every 2.7 days, Algol (Beta Persei) dips from its usual magnitude 2.1 to 3.4 and back. Use this chart to estimate its brightness in respect to comparison stars of magnitude 2.1 (Gamma Andromedae) and 3.4 (Alpha Trianguli).

ECLIPSE DIAGRAM: GREGG DINDERMAN / S&T, SOURCE: FRED ESPENAK

0:58, 10:54, 20:49; **6**: 6:45, 16:41; **7**: 2:37, 12:33, 22:28; **8**: 8:24, 18:20; **9**: 4:16, 14:12; **10**: 0:08, 10:03, 19:59; **11**: 5:55, 15:51; **12**: 1:47, 11:42, 21:38; **13**: 7:34, 17:30; **14**: 3:26, 13:21, 23:17; **15**: 9:13, 19:09; **16**: 5:05, 15:00; **17**: 0:56, 10:52, 20:48; **18**: 6:44, 16:39; **19**: 2:35, 12:31, 22:27; **20**: 8:23, 18:18; **21**: 4:14, 14:10; **22**: 0:06, 10:02, 19:57; **23**: 5:53, 15:49; **24**: 1:45, 11:40, 21:36; **25**: 7:32, 17:28; **26**: 3:24, 13:19, 23:15; **27**: 9:11, 19:07; **28**: 5:03, 14:58; **29**: 0:54, 10:50, 20:46; **30**: 6:42, 16:37

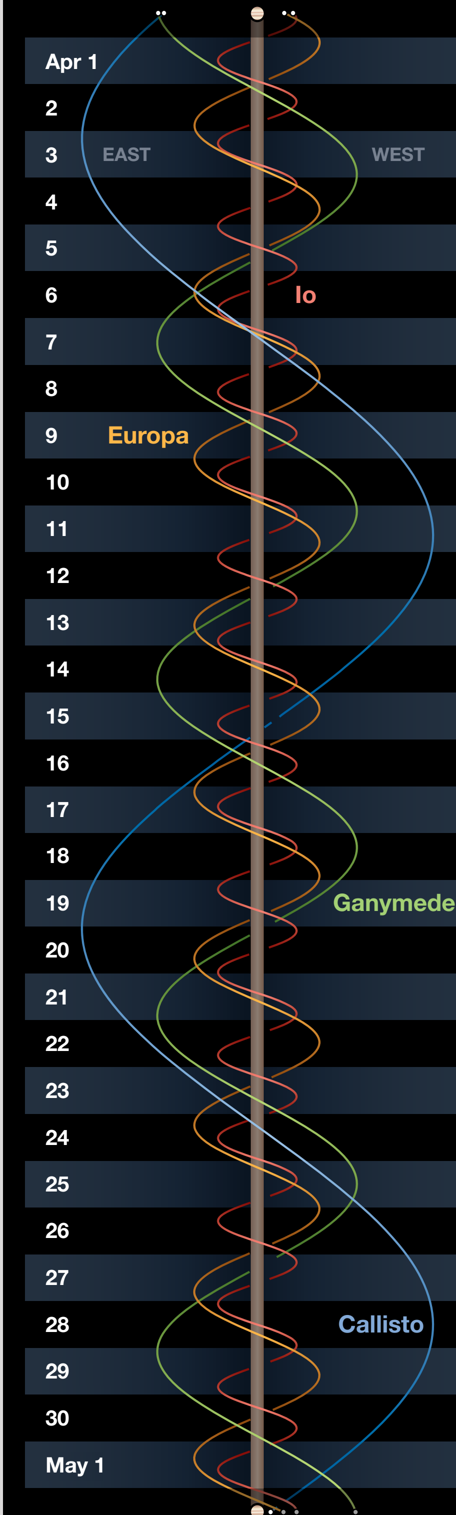
These times assume that the spot will be centered at System II longitude 16° on April 1st. If the Red Spot has moved elsewhere, it will transit $1\frac{2}{3}$ minutes earlier for each degree less than 16° and $1\frac{2}{3}$ minutes later for each degree more than 16°.

Phenomena of Jupiter's Moons, April 2022

Apr. 1	2:20	I.Oc.R
	20:50	I.Sh.I
	21:18	I.Tr.I
	21:40	II.Ec.D
	23:05	I.Sh.E
	23:33	I.Tr.E
	23:40	III.Sh.I
Apr. 2	1:19	II.Oc.R
	1:37	III.Tr.I
	3:00	III.Sh.E
	4:58	III.Tr.E
	18:04	I.Ec.D
	20:51	I.Oc.R
Apr. 3	15:18	I.Sh.I
	15:48	I.Tr.I
	16:23	II.Sh.I
	17:25	II.Tr.I
	17:33	I.Sh.E
	18:04	I.Tr.E
	19:07	II.Sh.E
	20:10	II.Tr.E
Apr. 4	12:33	I.Ec.D
	15:21	I.Oc.R
Apr. 5	9:47	I.Sh.I
	10:18	I.Tr.I
	10:57	II.Ec.D
	12:02	I.Sh.E
	12:34	I.Tr.E
	13:37	III.Ec.D
	14:43	II.Oc.R
	19:09	III.Oc.R
Apr. 6	7:01	I.Ec.D
	9:52	I.Oc.R
Apr. 7	2:29	IV.Sh.I
	4:15	I.Sh.I
	4:49	I.Tr.I
	5:34	IV.Sh.E
	5:42	II.Sh.I
	6:30	I.Sh.E
	6:52	II.Tr.I
	7:04	I.Tr.E
	7:55	IV.Tr.I
	8:26	II.Sh.E
	9:36	II.Tr.E
	11:05	IV.Tr.E
Apr. 8	1:30	I.Ec.D
	4:22	I.Oc.R
	22:44	I.Sh.I
	23:19	I.Tr.I
Apr. 9	0:15	II.Ec.D
	0:59	I.Sh.E
	1:34	I.Tr.E
	3:42	III.Sh.I
	4:08	II.Oc.R
	6:08	III.Tr.I
	7:00	III.Sh.E
	9:27	III.Tr.E
	19:59	I.Ec.D
	22:53	I.Oc.R
Apr. 10	17:12	I.Sh.I
	17:49	I.Tr.I
	19:01	II.Sh.I
	19:27	I.Sh.E
	20:04	I.Tr.E
	20:18	II.Tr.I
	21:45	II.Sh.E
	23:01	II.Tr.E
Apr. 11	14:28	I.Ec.D
	17:23	I.Oc.R
Apr. 12	11:41	I.Sh.I
	12:19	I.Tr.I
	13:32	II.Ec.D
	13:56	I.Sh.E
	14:35	I.Tr.E
	17:32	II.Oc.R
	17:38	III.Ec.D
	23:37	III.Oc.R
Apr. 13	8:56	I.Ec.D
	11:53	I.Oc.R
Apr. 14	6:09	I.Sh.I
	6:50	I.Tr.I
	8:21	II.Sh.I
	8:24	I.Sh.E
	9:05	I.Tr.E
	9:44	II.Tr.I
	11:04	II.Sh.E
	12:27	II.Tr.E
Apr. 15	3:25	I.Ec.D
	6:24	I.Oc.R
	12:13	IV.Ec.D
	15:17	IV.Ec.R
	18:51	IV.Oc.D
	21:51	IV.Oc.R
Apr. 16	0:38	I.Sh.I
	1:20	I.Tr.I
	2:50	II.Ec.D
	2:53	I.Sh.E
	3:35	I.Tr.E
	6:55	II.Oc.R
	7:43	III.Sh.I
	10:37	III.Tr.I
	11:00	III.Sh.E
	13:54	III.Tr.E
	21:54	I.Ec.D
Apr. 17	0:54	I.Oc.R
	19:06	I.Sh.I
	19:50	I.Tr.I
	21:21	I.Sh.E
	21:39	II.Sh.I
	22:05	I.Tr.E
	23:10	II.Tr.I
Apr. 18	0:22	II.Sh.E
	1:52	II.Tr.E
	16:22	I.Ec.D
	19:24	I.Oc.R
Apr. 19	13:35	I.Sh.I
	14:20	I.Tr.I
	15:50	I.Sh.E
	16:07	II.Ec.D
	16:35	I.Tr.E
	20:19	II.Oc.R
	21:39	III.Ec.D
Apr. 20	4:04	III.Oc.R
	10:51	I.Ec.D
	13:54	I.Oc.R
Apr. 21	8:04	I.Sh.I
	8:50	I.Tr.I
	10:18	I.Sh.E
	10:59	II.Sh.I
	11:05	I.Tr.E
	12:36	II.Tr.I
	13:41	II.Sh.E
	15:18	II.Tr.E
Apr. 22	5:20	I.Ec.D
	8:25	I.Oc.R
Apr. 23	2:32	I.Sh.I
	3:20	I.Tr.I
	4:47	I.Sh.E
	5:25	II.Ec.D
	5:35	I.Tr.E
	9:43	II.Oc.R
	11:43	III.Sh.I
	15:00	III.Sh.E
	15:05	III.Tr.I
	18:19	III.Tr.E
	20:50	IV.Sh.I
	23:42	IV.Sh.E
	23:48	I.Ec.D
Apr. 24	2:55	I.Oc.R
	4:57	IV.Tr.I
	7:36	IV.Tr.E
	21:01	I.Sh.I
	21:50	I.Tr.I
	23:15	I.Sh.E
Apr. 25	0:05	I.Tr.E
	0:17	II.Sh.I
	2:01	II.Tr.I
	3:00	II.Sh.E
	4:42	II.Tr.E
	18:17	I.Ec.D
	21:25	I.Oc.R
Apr. 26	15:29	I.Sh.I
	16:20	I.Tr.I
	17:44	I.Sh.E
	18:35	I.Tr.E
	18:42	II.Ec.D
	23:06	II.Oc.R
Apr. 27	1:41	III.Ec.D
	4:59	III.Ec.R
	5:17	III.Oc.D
	8:30	III.Oc.R
	12:45	I.Ec.D
	15:55	I.Oc.R
Apr. 28	9:58	I.Sh.I
	10:51	I.Tr.I
	12:12	I.Sh.E
	13:05	I.Tr.E
	13:36	II.Sh.I
	15:27	II.Tr.I
	16:19	II.Sh.E
	18:07	II.Tr.E
Apr. 29	7:14	I.Ec.D
	10:25	I.Oc.R
Apr. 30	4:26	I.Sh.I
	5:20	I.Tr.I
	6:41	I.Sh.E
	7:35	I.Tr.E
	8:00	II.Ec.D
	12:29	II.Oc.R
	15:44	III.Sh.I
	18:59	III.Sh.E
	19:32	III.Tr.I
	22:42	III.Tr.E

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

Jupiter's Moons



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

◀ Unlike most other lunar features, crater rays are best seen at or near full Moon.

SEAN WALKER / S&T

Crater Rays — Mysterious No More

Understanding these bright features can add further enjoyment to your lunar observing.

Well into the 20th century, the first sentence of many articles describing lunar rays stated that their origins were enigmatic. This was due to our poor understanding about these bright, filamentary streaks radiating from many young lunar craters. That perception began to change with Ralph Baldwin's transformative 1949 book, *The Face of the Moon*. Baldwin was the first to convincingly make the case for the impact origin of lunar craters by asteroids and comets (rather than volcanic eruptions), with the rays being material ejected during crater formation. A decade later, legendary lunar scientist Eugene Shoemaker published the first ballistic analysis of lunar impacts and the resulting emplacement of ray-forming ejected rocks. Since then, Apollo 12 astronauts collected samples of a ray from Copernicus, and scientists have even studied rays on other worlds. It's safe to say that rays are no longer completely mysterious, though some of their features aren't fully understood.

Both Baldwin and Shoemaker noticed that rays are most conspicuous from craters like **Copernicus** and **Tycho** having youthful characteristics, such as crisp rims and a lack of superposed impact craters. They also recognized that **Eratosthenes** and other craters have fainter rays, while most have no visible rays at all. This implies that rays disappear over time, a fact that Shoemaker and his colleagues at the U.S. Geological Survey used to identify the youngest epoch of lunar history — the Copernican era spanning from about 1.1 billion years ago to the present day. Only craters formed in this period were believed to have visible rays.

The best-known rays are the nearly Moon-girdling ones radiating from Tycho. These are best seen at full Moon, which led some to theorize that rays are flour-like deposits of bright highlands material with no topographic expression. But following Baldwin, Shoemaker recognized that embedded within these bright rays were many small, elongated craters. He interpreted these as secondary craters, created by low-velocity impacts of ejecta from the primary crater and consistent with rays being fragmented and pulverized rocks.

High-resolution images from NASA's Lunar Orbiter and subsequent spacecraft revealed that many secondary craters occur in clusters and chains, indicating that they were formed by clumps of debris, rather than solid boulders. Additionally, the horizontal component of the ejecta's velocity carried smaller particles, creating downrange deposits of dunes and herringbone patterns of fine, bright debris. In most cases these secondaries and other ray deposits are too small to observe telescopically. However, when examining the floor of **Pitatus**, you can see Tycho ejecta as V-shaped white splotches with clusters of secondary craters on their uprange sides.

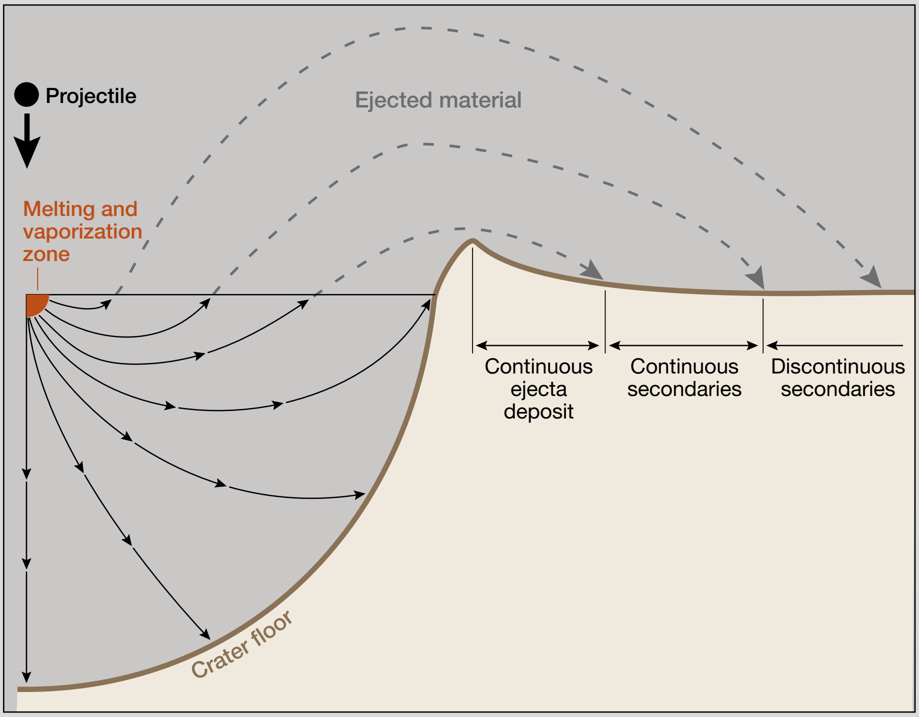
Careful studies show that material excavated and ejected from the initial impact event changes in thickness and character with increasing distance from the originating crater. The nearest ejecta is thick, contributing to the height of the crater rim itself. It then rapidly decreases farther from the rim, reaching the level of the original terrain at about one crater radius away. This inner annulus is called the *continuous ejecta deposit*. Beyond that is an area of abundant secondary craters in clusters and chains — the zone of *continuous secondaries*. Then, stretching hundreds of kilometers from larger craters is a zone of *discontinuous secondaries*, often isolated craters rather than clusters of secondary impacts. These are formed by high-velocity blocks of ejecta shot out from near the center of the primary crater. Because these projectiles impact at high angles, the resulting secondaries are nearly circular and difficult to distinguish from small, primary craters.

Major discoveries about rays have come from multispectral imaging. By comparing the spectra of rays at two near-infrared wavelengths, Jennifer Grier and her colleagues at the University of Arizona could identify the *maturity* of a lunar ray. Maturity describes the degree of space weathering that affects the microscopic character of minerals found in the ray. Over millions of years, cosmic rays, solar wind, and micrometeorites darken ray material by creating iron grains and glass-bonded soils on exposed surfaces. Immature rays radiating from young craters haven't been exposed to these effects for long and still appear bright.

Space weathering reduces the brightness, so all rays ultimately disappear. The rate of fading depends on the thickness of the ray. Small secondary craters have shallow ray deposits, which disappear faster than the thicker rays produced by large cratering events.

Multispectral imaging provides a second critical type of information about rays. In 1985, Carle M. Pieters and her colleagues at Brown University imaged lunar rays at near-infrared wavelengths to determine if some are bright because they are immature or because they contain intrinsically bright lunar highland material.

The team discovered that the bright ray from Copernicus that streaks north across **Mare Imbrium** near **Pytheas** contains abundant highlands material, as well as some immature mare material excavated by secondary cratering. Lunar geologist B. Ray Hawke and colleagues at the Pacific Regional Planetary Data Center continued this research, recognizing that some crater rays are made of bright highlands material. Other rays are the pulverized and fractured target material now exposed to space weathering, and some rays are the product of both mechanisms. Thus, there are compositional rays, immaturity rays, and combination rays. But all rays are really produced by secondary craters and their deposits. Some craters previously considered to be Copernican in age have compositional rays and may be considerably older.



▲ The dynamics of crater excavation are illustrated above. At the point of impact, surface rocks are melted and vaporized. Crustal materials are then pushed downward and away, flowing along curved paths where some are ejected when reaching the surface. Boulders and debris near the impact point are ejected first at high velocity and high angles, traveling farthest and forming discontinuous secondaries and dunes. Forces pushing more downward excavate debris from greater depths, ejecting it at lower angles and velocity. That debris is then deposited at the rim and as the continuous ejecta deposit, leaving the deepest rocks at the top of the rim.

The next time the Moon is full (or nearly so), start with Tycho's long streaks that cross **Mare Serenitatis** and **Mare Nectaris** (at **Rosse**). Then jump halfway across the Moon to the familiar triangle of rays from Copernicus (particularly the composition ray near Pytheas), **Kepler**, and **Aristarchus**. More challenging are the faint rays from **Langrenus** near the Moon's eastern limb. Look south for the 32-kilometer-wide **Petavius B**; its oblique-impact origin is indicated by a ray-exclusion zone to the crater's north. As a final challenge, trace the bright ray from **Glushko** at the western limb that passes northeast of **Krafft** and **Seleucus** and continues north of the Aristarchus Plateau — a 1,000-km-long ray!

■ Contributing Editor **CHUCK WOOD** observes the lunar rays every time he turns his telescope on the full Moon.

▶ Apollo 12 astronauts photographed this oblique view showing many secondary craters along the ray near Pytheas (middle) pointing back towards Copernicus (top). South is up.

IMPACT DYNAMICS: *S&T* ILLUSTRATION, SOURCE: Z. XIAO ET AL.; COPERNICUS SECONDARIES: NASA / JSC / ASU

Image Stacking Demystified

This basic technique is one of the most powerful tools for noise-free astrophotos.

Almost as soon as you start capturing the night sky with your camera, you'll encounter the mysterious term *stacking*. "How many images did you stack?" "How long are the subs in that stack?"

I remember having my own misconceptions about the subject of stacking when I got started, and I still meet experienced astrophotographers who are fuzzy on the details of how the technique works. But stacking is actually simple to understand once you have a solid grasp of the problem you're trying to solve. It's really all a matter of signal and noise.

The author captured this photo of the North America Nebula in Cygnus. The final, noise-free result presented here is a stack of 60 2-minute exposures made with a Canon 60Da DSLR camera and a 200-mm f/2.8 lens.

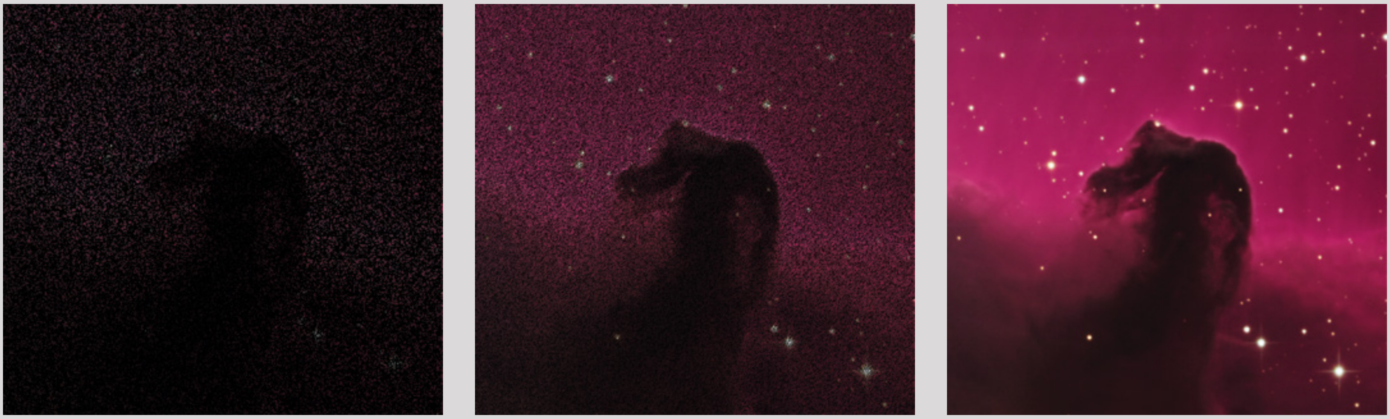
A Light Rain

Photography is all about light — the term literally means "writing with light." Plentiful light produces high-quality photos, while low light levels yield noisy images unless you increase the exposure time in order to record more light. A significant part of noise we see in low-light images is called *shot noise*. It's important to bear in mind that this noise is not something that gets *added* so much as something that's *missing*.

At the risk of oversimplifying the situation, imagine a light drizzle of rain that peppers your driveway with a splattering of wet spots, as opposed to a good downpour that leaves the pavement nice and evenly wet. Now imagine instead of raindrops we're talking about photons, and you'll get the idea. A good downpour of photons makes for a clean, smooth image, but collecting just a few photons renders only bits and pieces of an image — those missing bits and pieces are what we call shot noise.

There is only one solution to shot noise, and that's to capture more light. We can do this by increasing the aperture of our lens, by adding more exposure time, or both. When it comes to astrophotography, we usually need a great deal of light to record the faint detail we seek, be that the Milky Way stretching across the sky or the barely there glow of a distant galaxy. How long do you need to expose for a good image? That, my friend, is the $64,000 question! The answer depends on how bright your target is and how much light your optics can collect.

It turns out that photography is largely an exercise in signal processing. The light we receive is termed the *signal*.



▲ As this series of images demonstrates, increasing the "signal" improves the quality of the result. The leftmost frame shows that only a little light yields a dark image with plenty of noise (missing signal). Moving right, additional light fills in and overpowers the noise, resulting in a pleasingly smooth image. (The complete, final image is presented below.)

The more light we have, the stronger the signal. For example, if a single pixel on the camera's sensor records 10,000 photons of light, then we can represent the signal as 10,000. Note that the signal is the quantity of light we record — not the length of the exposure. This is a crucial point. More time doesn't produce better images, more *light* does. In other words, the signal created by a short exposure of a bright target can be the same as the signal generated by a long exposure of a faint target.

A Shot in the Dark

Shot noise is also quantifiable — it's simply the square root of the signal value. For our previous example of a signal value of 10,000, the shot noise would be 100, which is 1.0%. The longer we expose, the more signal we get, but we also get more shot noise. At first this may sound counterintuitive. But what happens is that the signal increases faster than the shot noise, and eventually we get a better signal-to-noise ratio (SNR). So, if our signal value is 20,000 instead of 10,000, the shot noise would be only 0.7%, which is proportionately quite a bit less.

In fact, as we collect more light, we're not reducing the shot noise. Rather, we're improving the SNR. The lefthand graph on page 56 shows this relationship. Starting from the left side, you can see the noise increases with signal and early on the noise is overwhelming. Soon, however, the signal overtakes the noise and begins to climb much more rapidly.

The image below serves as a useful illustration of the key point that signal is the total light collected at each pixel, not simply the base exposure time. In this photo, the Flame Nebula (at bottom left) is very bright, so that region of the image has a lot of signal, and just a little exposure time will yield a good SNR. The area around the Horsehead Nebula is fainter — if you want the image to be smooth here, you'll need more signal than was needed for the Flame Nebula, which means a longer exposure. And to bring out details in the dark region below the Horsehead, you'll have to use an even longer exposure.

Stacking the Deck

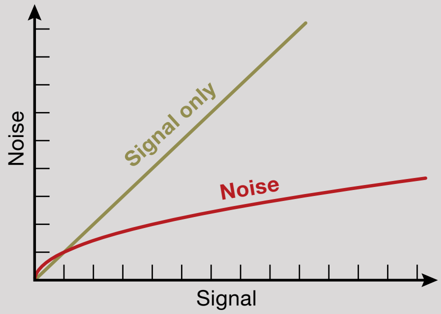
All this finally brings us back to the problem that stacking solves. You might expect the solution to the challenge of

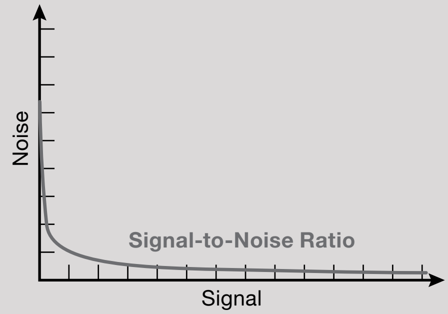
▲ One of the author's favorite images is this portrait of the notoriously dim Horsehead Nebula in Orion. To achieve the exceptionally smooth results presented here, he digitally combined some 200 30-second subframes.

producing a healthy SNR is to simply take one very long exposure. Unfortunately, there are a couple of practical considerations that get in the way. The ability of your mount to track perfectly during a sufficiently long exposure is a big one. Bigger still is that skyglow and light pollution will saturate a long-exposure image long before you've captured enough photons from that galaxy far, far away. And that's not even considering the airplanes and satellites that will inevitably pass through your targeted field.

So, instead of taking one very long exposure, we take many shorter ones. These short exposures are often called *subexposures*, *subframes*, or just *subs*. Once they're collected, you align and combine them digitally with software, such as *DeepSkyStacker* (available for free download at **deepskystacker.free.fr**), to create an "image stack" — effectively one long exposure. But keep in mind stacking doesn't brighten your target, it just makes the SNR better for a smoother image. A high SNR allows you to stretch or brighten the stacked image later with image-processing software (such as Adobe *Photoshop*, or similar) and still get a pleasing, low-noise result.

The graph above right shows how the noise is supposed to decrease with the number of images in your stack. You reduce the effective noise by half each time you double the number of subexposures. This graph can be slightly misleading, though. It suggests that after a dozen or so exposures you're getting very little return for additional subs. That's true. But, remarkably, the shape of the curve looks the same if each exposure is 1, 5, 30, or 60 minutes long! However, I promise that an image made from a dozen 5-minute exposures will be significantly smoother than one made with twelve 1-minute exposures. Stacking works by increasing the total *signal*, not by simply increasing the number of sub-exposures.





▲ *Left:* Signal and noise both increase the longer you collect light, but the noise increases at a slower rate, as the square root of the signal. That relationship is at the heart of why gathering more light improves the signal-to-noise ratio (SNR). *Right:* As this graph shows, increasing the number of subframes improves the SNR. However, it's important to note that the shape of the curve remains the same regardless of the exposure time for the individual subframes. Remember: It's not the number of subframes that improves the SNR, it's the total amount of light collected.

By now you might be wondering how short can your individual exposures be? Are 100 1-minute exposures as good as 20 5-minute subs? In theory, yes — both yield a total exposure time of 100 minutes. In practice however, we have to take into account other noise sources, including contributions from the camera itself. Individual exposures need to be long enough that the faintest details you're trying to capture register enough photons to rise above the noise floor of your camera. How long that is depends entirely on your specific camera model, your choice of lens, and even how warm or cold the night is.

There's no quick-and-easy recipe for creating appealing night-sky images. Experimentation is key. But by understanding how stacking works, you can begin to appreciate its benefits and take advantage of its powerful ability to help create deep and detailed astrophotos.

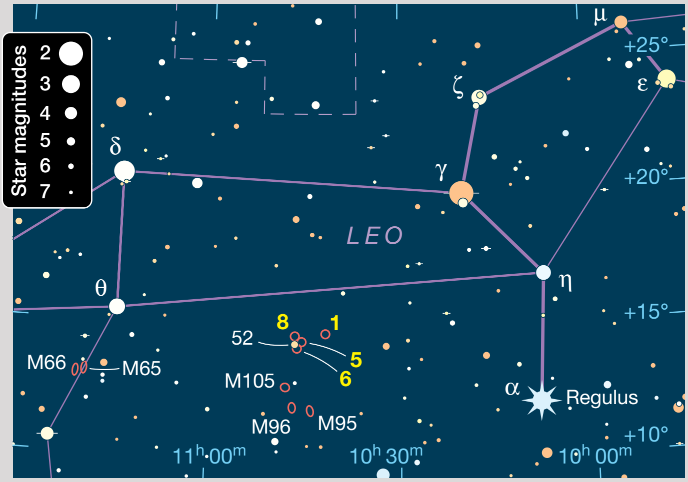
■ **RICHARD WRIGHT** has been capturing images for more than two decades. By day he is a software engineer specializing in computer graphics technologies.

▲ A single 5-minute exposure (left half) of M51, the Whirlpool Galaxy, shows some detail in brighter areas. However, stacking 40 subframes (right) improves the SNR of the darker areas, where sufficient light takes longer to accumulate.

GRAPHS: S&T / SOURCE: RICHARD WRIGHT (2)

Observing Large Quasar Groups

If you have a big enough scope, you might seek these objects of the early universe.



▲ **UNDER THE LION'S BELLY** Look for the quasars described here around the 5.5-magnitude star 52 Leonis.

One of the pillars of current cosmology is the *cosmological principle*. It holds that at large enough scales any observer would see a homogeneous distribution of matter from every point — the universe would look *isotropic*, or the same in all directions. There should be no preferred position and no central point of view.

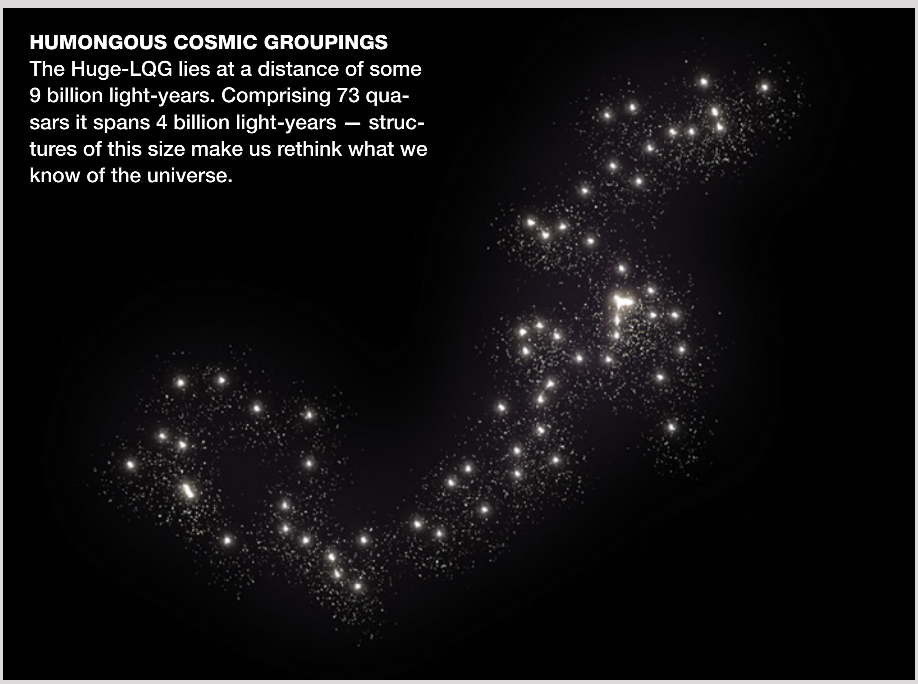
Another pillar is the prevailing theory that describes the universe: the *lambda cold dark matter* (ΛCDM) model, also known as the "standard model." It states that the universe is composed of baryons (what all visible matter is made of); cold dark matter that interacts only through gravity; and a repulsive force causing the universe's expansion to accelerate (see, e.g., *S&T:* Mar. 2022, p. 14). The model predicts the maximum size of structures allowed within such a universe — but recent discoveries of ultralarge formations may jeopardize this model.

Amateurs with large telescopes have an exciting opportunity to view members of a group of objects at the center of this controversy.

The Early Years

In 1982 Adrian Webster (University of Cambridge) published data on a group of four quasars that appeared associated and carry similar redshifts of about 0.37. Through statistical analysis he determined how likely such a gathering would be compared to random distribution. At the time these four quasars, spanning 300 million light-years, was the largest known structure. Seven years later David Crampton (then at Dominion Astrophysical Observatory) and his colleagues identified 23 quasars clustered at a redshift of 1.1. That same year, Margaret Geller and John Huchra (Harvard Center for Astrophysics) introduced the world to an even bigger formation: a "Great Wall" of galaxies and galaxy clusters stretching for up to 750 million light-years in its longest dimension. But it was only 15 million light-years thick. Shortly thereafter, in 1991, Roger Clowes (University of Central Lancashire) and Luis Campusano (Universidad de Chile) found 13 quasars at a redshift of 1.3 that stretched across 1.9 billion light-years.

Since then, complexes of superclusters of galaxies called Great Walls have vied with groups of quasars for the title of "Largest Structure in the Universe." The Large Quasar Groups, or LQGs, are usually located within but at the periphery of galaxy clusters. The portions of the clusters they inhabit appear bluer than the average, suggesting an increased star-formation rate consistent with gravitational disturbance by tidal interactions between member galaxies. These interactions have "turned on" the quasars by feeding their quiescent, central supermassive black holes with gas, dust, and stellar matter. The beacons of light we see from the newly activated quasars divulge their otherwise invisible environments.

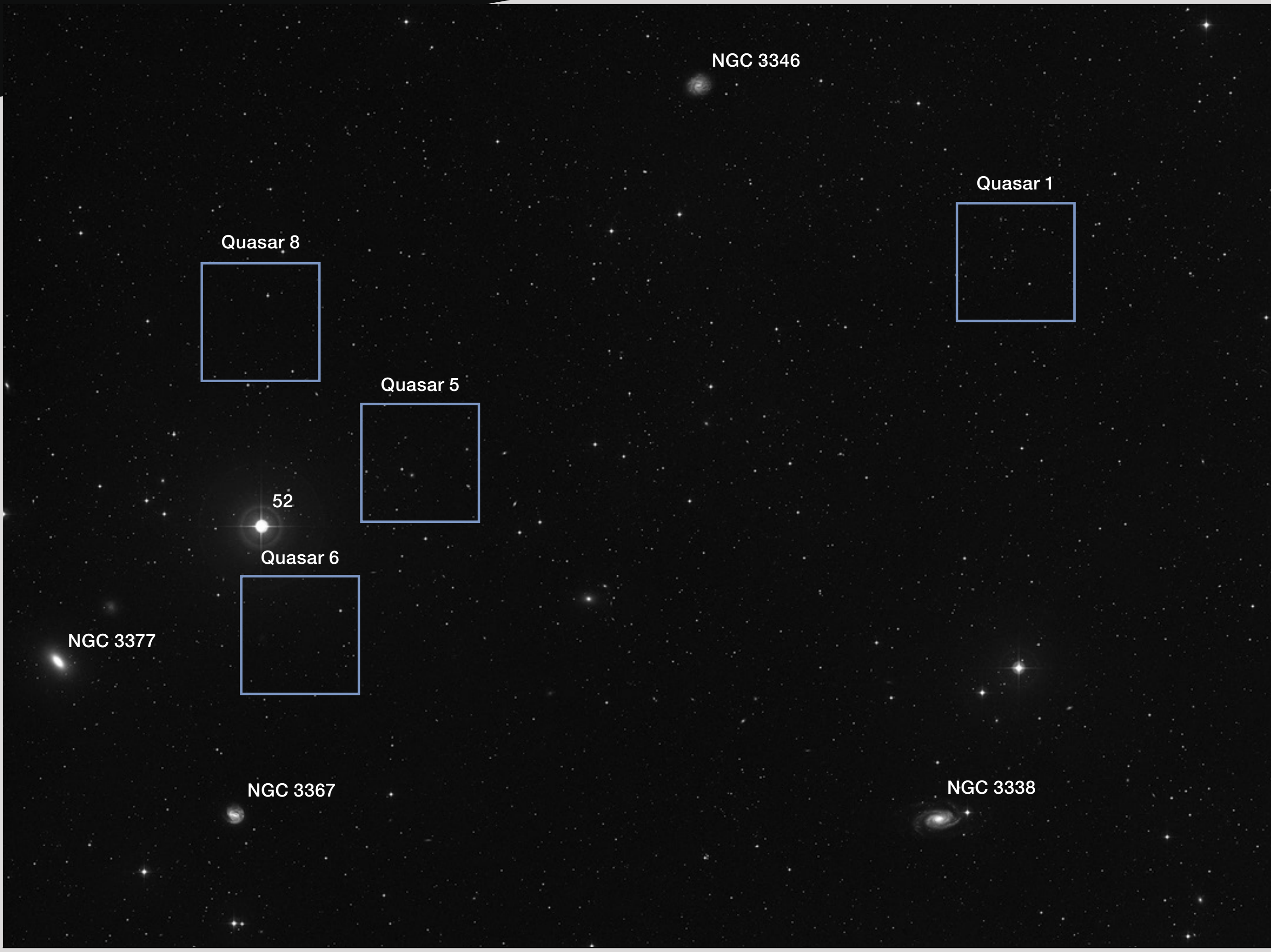


HUMONGOUS COSMIC GROUPINGS The Huge-LQG lies at a distance of some 9 billion light-years. Comprising 73 quasars it spans 4 billion light-years — structures of this size make us rethink what we know of the universe.

PABLO CARLOS BUDASSI /

Great Walls of Galaxies

In 2003, scientists used data from the Sloan Digital Sky Survey (SDSS) to iden-



POSS-II / STSCI / CALTECH / PALOMAR OBSERVATORY

tify a massive entity that they named the Sloan Great Wall. At 1.4 billion light-years in length, it was two times larger than the Great Wall, which pushed the limits of ΛCDM theory. Since then other Great Walls of galaxies, LQGs, as well as gamma-ray bursts are outlining what are, if the data confirm them, structures up to 10 billion light-years in diameter. The trouble is that none of these should exist.

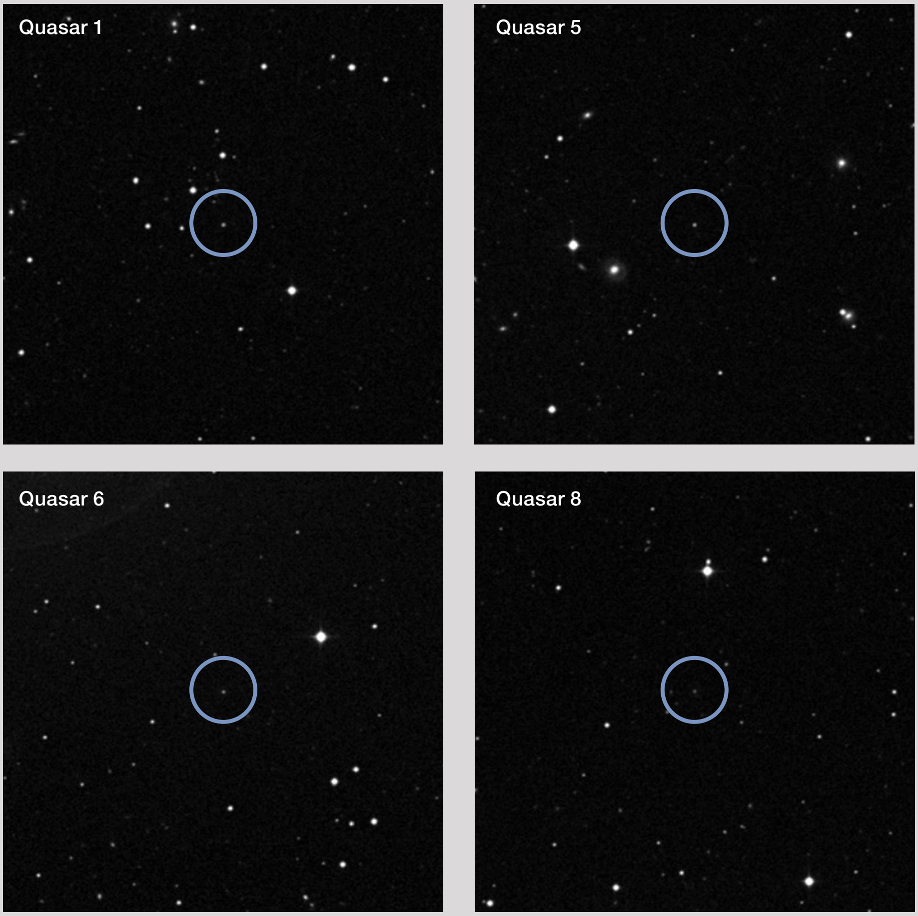
In 2010, another team of astronomers published limits for entities compatible with the then-current understanding of ΛCDM: Their length should be less than 1.2 billion light-years. The Sloan Great Wall mildly exceeds this (though not in volume), and theorists scrambled to fit it into their constructs. If it had been the single largest structure in the universe — and just happened to be in our cosmic backyard — the theory may have been safe.

But in 2013 Clowes and his colleagues announced the discovery of what they dubbed the Huge-LQG, a collection of 73 quasars clustered at a mean redshift of 1.27 that stretches 20° by 10° across Leo. At four billion light-years in its longest dimension, this group was three times too large to fit into standard cosmology models, and some scientists wondered if it disproved the cosmological principle. For context, the 3.4×10^{18} solar masses contained in the Huge-LQG are equivalent in mass to 1,300 Coma Clusters or 20 Sloan Great Walls. Sifted from the Sloan database of 105,000 quasars, it may be the largest LQG (the SDSS sampled only one quarter of the sky).

Faraway Quasars

Object	Number	Mag(v)	Light travel time (Gyr)	RA	Dec.
SDSS J104520.62+141724.2	5	18.5	8.9	10^h 45.3^m	+14° 17′
SDSS J104604.05+140241.2	6	18.9	8.9	10^h 46.1^m	+14° 03′
SDSS J104624.25+143009.1	8	19.0	9.2	10^h 46.4^m	+14° 30′
SDSS J104139.15+143530.2	1	18.2	8.7	10^h 41.7^m	+14° 36′

The quasar numbers refer to the position in the table in the Clowes et al. paper (published in *Monthly Notices of the Royal Astronomical Society* in 2013). Right ascension and declination are for equinox 2000.0.



◀▲ **QUEST FOR QUASARS** You'll need access to a large scope and dark skies to catch a glimpse of these distant objects. If you manage to spot them, remind yourself that you're looking at only a few elements of a vast formation in the early universe. North is up and each image is 10′ × 10′.

POSS-II / STSCI / CALTECH / PALOMAR OBSERVATORY (4)

At least four other datasets have challenged the standard model within the last few years. All of them hint at structures at near-gigaparsec (3.26 billion light-years) dimensions. These include quasar polarization vectors; directional flow of dark matter, or so-called cosmic flows; supervoids; and ultracompact radio sources. In 2013, gamma-ray bursts were used to map the Hercules-Corona Borealis Great Wall, defining an entity twice as large as any seen before.

A 2016 discussion of the Huge-LQG's compatibility with the ΛCDM model concluded that it was *just possibly* concordant, though its rarity made it a statistical stretch. Going further, in 2018 a team performed computer simulations of randomly distributed quasars and showed that about 10% resulted in similar groupings to the Huge-LQG. Theoretical and observational astronomers are working closely to refine observations of these structures, while debating their impacts on existing theory. The most extreme possibility hints that a new set of principles is needed to explain the discordant findings, a case that if true guarantees employment to the next generation of cosmologists.

Observing Quasars

I've been interested in observing quasars since the 1980s and have seen several at redshifts greater than 5.3. But it was not until I learned about the Baryon Oscillation Spectroscopic Survey, an international collaboration to map objects in the early universe, that I considered quasar groups or clusters important targets. My attention was drawn to Clowes' discovery of the Huge-LQG and the brightest quasars in that study, which had a magnitude of 17.8. Using my 32-inch f/4 reflector from my home in rural Minnesota in good conditions, I can readily see to that level. For my observations, I made a list that included images of 14 of the 73 Huge-LQG quasars, all readily visible on *National Geographic Society — Palomar Observatory Sky Survey* red plates.

I noticed on almost all the *POSS2* images that galaxy groups either surrounded the quasar or were just off to the side. This fact correlated with Clowes' comments about the quasars being in or at the periphery of the clusters, and how gravitational effects could activate them. I made finder charts using *Megastar*, and from my home I set up to observe at about 3:30 a.m. CST on November 26, 2016. The temperature hovered several degrees below freezing, and in 90 minutes I was able to see only a trio of quasars with visual magnitudes of 18.5, 18.9, and 19.0. In Clowes' paper they were #5, #6, and #8, all clustering within 18′ of 52 Leo, a 5.5-magnitude star on a line connecting Theta (θ) and Alpha (α) Leonis. Quasar #8, for instance, is surrounded by eight faint galaxies on the *POSS2* red plate. Although I didn't see the galaxies that night, in perfect conditions I should have. (I concluded a quartet of quasars when I spotted #1 in Clowes' list, an 18.2-magnitude object, several years later at the 2018 Texas Star Party.)

On November 27th, the morning held a thick blanket of fog. Hoarfrost covered computer screens and grass and trees. It was beautiful but totally incompatible with Huge-LQG observing. My goal had been to observe a sample of the 73 Huge-LQG quasars, including some of the faintest, to show that *all* may be visible. Coincidentally, two other LQGs that Clowes found sit just a few degrees away from the Huge-LQG bunch. Amateurs with large reflectors can view these stealthy beacons of change and follow theorists wrestling with new data about the universe's structure — all while pondering these profound questions.

■ **DAVE TOSTESON** is looking forward to traveling more in retirement, both here on Earth and throughout the universe.

Building an Ultra-portable Dobsonian

Here's a lightweight reflector that fits in your carry-on luggage.

I live in a forest. The only view of the sky I get from my house is a tiny notch above my roof, viewable from my driveway. To make matters worse, my sky is badly light polluted. So every telescope I've made has to fit into my car for the drive out of town and be at least tolerably easy to set up and take down in the dark.

I also dream of traveling to the Southern Hemisphere to see the part of the sky inaccessible from my home latitude of 44° north. Somehow, I don't think I'll be taking my 12½-inch binocular scope on an airplane, though. Nor do I trust baggage handlers with a classic Dobsonian or even a refractor in a padded case. What I need is a scope with enough aperture to be useful that packs into a box I can carry onboard.

A Seed Is Planted

In my October 2016 Astronomer's Workbench column I wrote about an amazing travelscope built by Dutch telescope maker Roel Weijenberg. It sported an 8-inch f/4 mirror yet fit into a box only 9.25″ × 10.5″ × 3.9″ on a side — a box made up of the scope's own ground board and rocker box. The moment I saw it I knew I wanted to build one myself, but it took me several years to do it.

Why so long? I had to work up my courage! So many elements had to fit perfectly with so many others that the entire process seemed fraught with peril. I eventually set to work and kept track of the many design decisions I had to make along the way. It's those decisions, many of which apply to any telescope-making project, that I want to share with you now. It's my hope that this story will demonstrate how a methodical approach to telescope making can see you

BIG AND LIGHT The assembled 9½-inch, airline-compatible travelscope awaits dusk on a mountaintop.

through just about any project. Hopefully it will inspire you to try building a telescope of your own, if not this design (which I wouldn't recommend as a first-time project) then some other, and it will help you figure out how to make everything work together.

I'm the kind of telescope maker who stands in the shop and stares at my scrap wood pile until I see a piece of plywood that will make a good start, and off I go. This is why a travelscope seemed so daunting — I could just envision making some nifty part that would work fine on a normal scope but wouldn't fit in the box with everything else. I did way more thinking on this scope than with any of my others, and I even drew a bunch of pencil sketches of the most difficult parts before building them. Even so, I rebuilt a lot of components when I came to others that wouldn't fit with what I'd already made.

◀ **COMPACT OBSERVING KIT** The entire scope, eyepieces, finder, collimator, and flashlight all fit within the 12¾″ × 12¾″ × 6″ box.

Getting Started

The first design element was the mirror. I had several 9½-inch (240-mm) mirror blanks that I'd gotten through a Cloudy Nights classified ad, so I chose one as the starting point. I already had a bunch of foot-long, ⅜-inch-diameter (9.5-mm) aluminum tubes that I'd bought several years ago in anticipation of building a travelscope, and I figured I would use three sections per truss, which meant three-foot trusses. A little math told me I should make the mirror f/4.

While I ground and polished the mirror, a machinist friend (Hi, Mike Curtin!) made a set of truss connectors for me. They screw together, and the threaded parts stick out half an inch at either end of the tubing, at least for the middle section. That added an inch to the length of the tubes, so I originally figured I'd need one of the box's interior dimensions to be at least 13″ to hold the trusses. I had a bunch of ½″ Baltic birch plywood left over from other projects, so I decided to build the box out of that, which made the longest outside dimension 14″.

Another dimension was dictated by the size of the secondary ring. I planned to use a 24-mm, 68° eyepiece for my widest field (the best you can do with 1¼″ eyepieces), which would give me a 1.6° true field of view. That meant the secondary ring's inside diameter needed to be at least 0.9″ bigger than the mirror to avoid vignetting, so I made the inner diameter 10½″. Since I figured the ring should be at least half an inch thick to be sturdy enough, that made its outer diameter 11½″. Add a quarter inch so it would fit easily in the box, and that made the box's minimum inner dimension 11¾″, and an outer dimension of 12¾″.

I arbitrarily chose to make the box 6″ high internally to start with, which meant 7″ high externally. That gave me a box with outside dimensions of 12¾″ × 14″ × 7″.

Truss Considerations

To accommodate the mirror's focal length and the design's 36-inch-long trusses, I had to mount each pole on top of the mirror cell, rather than on the side of it, and I also had to place the focal plane 7″ out from the optical axis. That would require a larger secondary mirror than the 1½″ one I had on hand, but I couldn't see a better solution . . . until someone pointed out that there was no need to arrange the trusses lengthwise in the box. Instead, I could lay them diagonally,

▼ **INNOVATIVE CURVES** *Left:* Everything packs tightly inside the scope's carry case. The wavy seam between the top and bottom of the box matches the curve of the altitude bearings and provides three points of contact for the base. *Right:* The primary mirror is protected with a microfiber cloth and a foam-core cover. The truss segments fit into the lid at an angle to save space.

ALL IMAGES COURTESY OF THE AUTHOR

▲ **PLENTY OF SPACE** When packed up, the secondary ring rests on the altitude bearings, leaving room for eyepieces, the focuser, a flashlight, and a bag of miscellaneous hardware.

which meant they could be way longer than 13″. And that meant I could place the focal plane closer to the outside of the secondary ring and use my smaller secondary mirror.

So I added ½″ to the end segments of each truss, bringing the total truss length to 37″ while keeping each segment 13″ long (including the connectors).

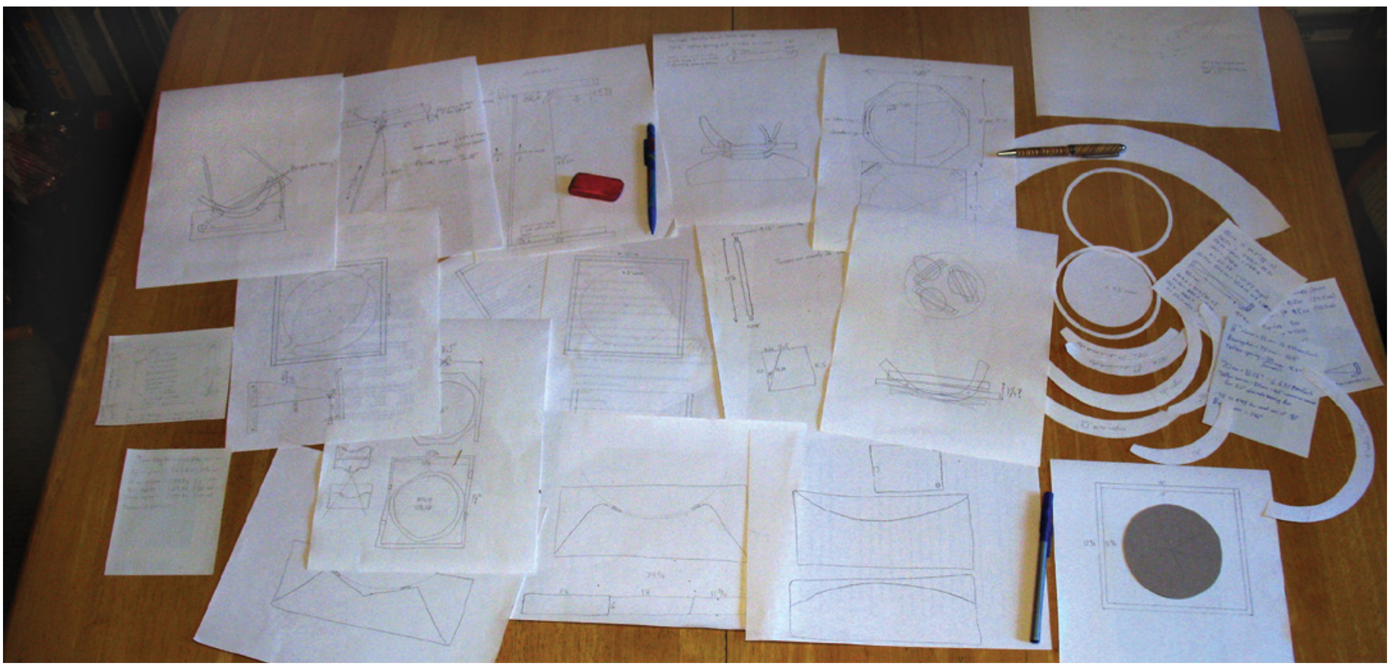
Even with the longer trusses, I still had to attach them to the top of the mirror cell. Of course, the truss connection points also needed to lie outside of the light path. All this meant making the mirror cell larger than the mirror. Fortunately, with the 11½″ secondary ring dictating the size of the box, I could make the mirror cell 11½″ across, too, giving me plenty of space for truss mounts.

An octagonal cell gave me flat edges for mounting the altitude bearings and still kept the corners of the box free to store eyepieces. At first, I thought I could make 10″-radius altitude bearings, which would put the center of rotation very close to the balance point, but when I realized I could store the trusses in the box at an angle, I was able to cut the box down to 12¾″ square, which was a big attraction. Doing that meant I could only use an 8″ radius on the altitude bearings, though, which would put the scope's center of rotation below the center of gravity, making the scope top-heavy. That meant I would need some kind of bungee system or counterweight to balance the finished scope.

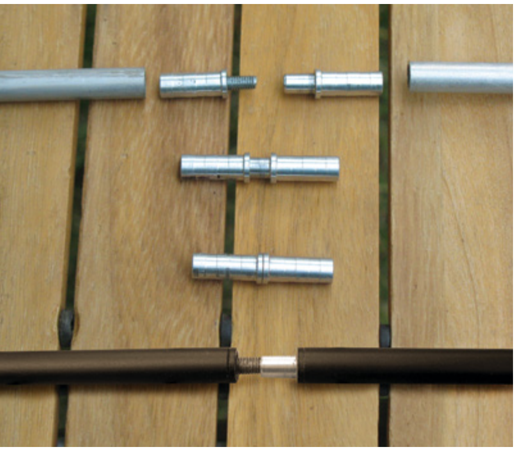
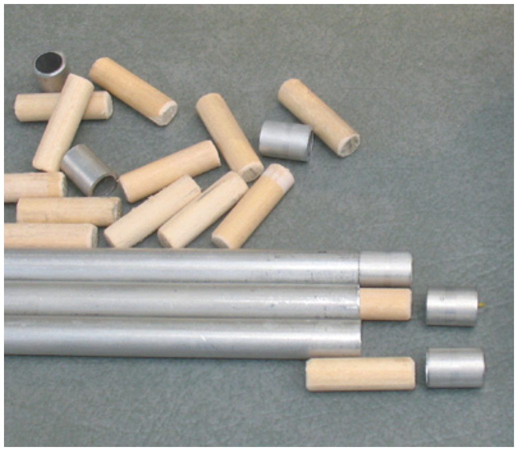
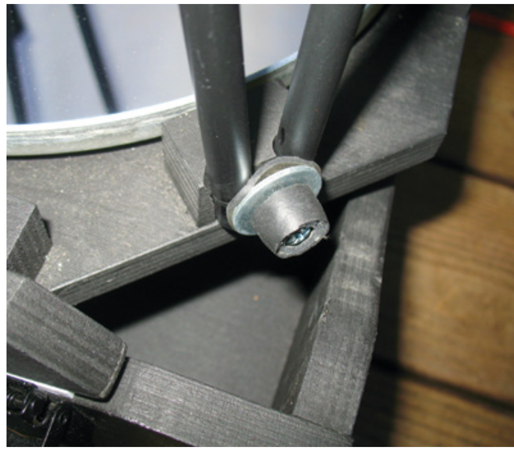
Because I was making the primary mirror cell octagonal, I made the secondary ring octagonal, too. That let me mount the trusses inside the corners of the octagon, which I think looks nicer than mounting them on the outside.

A Shrinking Rocker Box

I had already made the box 14″ long but hadn't made the cutouts for the altitude bearings in the sides yet, so I still could shorten it. I then had to decide how to cut the seam between the top and bottom halves. The altitude bearings would define part of the seam, but how high should they be? The front of the mirror cell needed to clear the bottom of the box when the scope was aimed toward the horizon, and at the same time I needed to cut low on two corners and on the center of the opposite side so the lid would rest on three points when it served as the ground board. I drew all sorts of funky zigzags, then realized none of them could be cut without leaving big



▲ **NOTES AND REVISIONS** When designing his travelscope, the author did all his sketches in pencil. The eraser got quite a workout.

▲ **TRUSS CONNECTIONS** *Left:* The truss poles screw together with custom-made connectors, forming eight, three-foot-long trusses. *Center:* After a forehead-slap moment, the author realized there was room in the mirror box to allow extending the trusses half an inch on each end. Wooden dowels glued inside the tubing provide sufficient strength. *Right:* A bolt through a fender washer and a piece of inner tube hold the trusses in place. A rubber hose over the bolt head provides grip. Assembling the scope requires no tools.

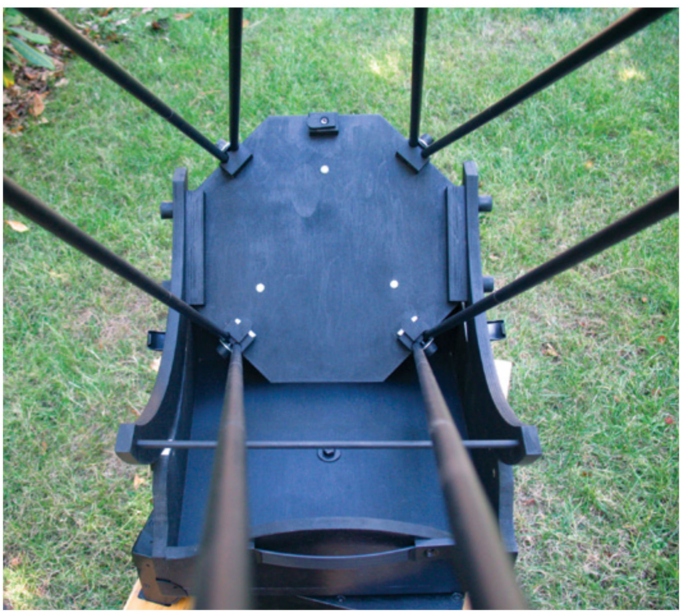
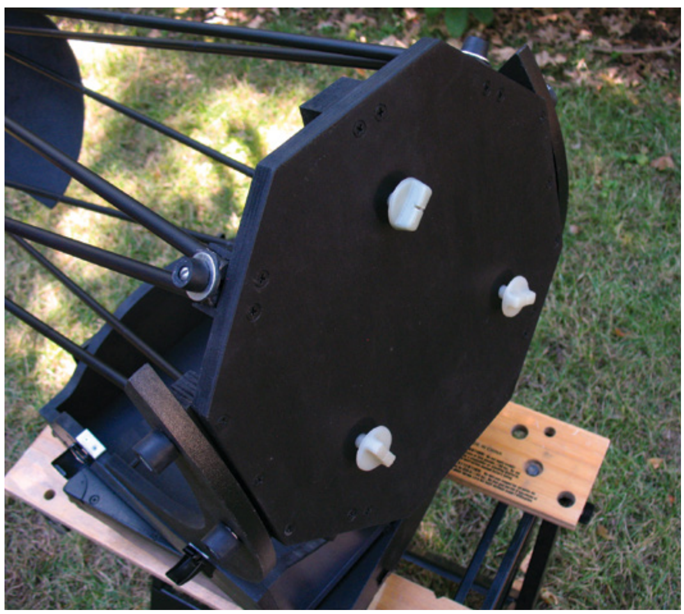
gaps where I would have to drill holes in order to change the angle of a jigsaw blade. I needed to make curvy lines so I could cut them in one smooth go.

I still had to fill the gap between the top and bottom halves of my box with ⅛″ closed-cell neoprene foam to seal it tight and refine the fit. I glued the foam to the bottom side of the box lid. The foam makes a great vibration damper since this piece serves as the scope's ground board. I also used a big square of the same foam to make a light baffle opposite the focuser. It's the first thing in the box when I pack up, and it provides a nice, cushy bed for everything else to rest on.

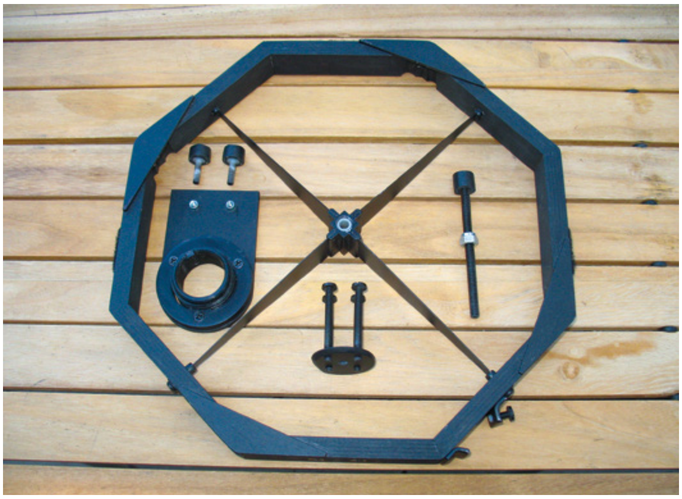
My original focuser design was just a simple push-pull tube like what John Dobson used in his telescopes. But once I figured out exactly where the focal plane was, I had another friend (Hi, Robert Asumendi!) 3D-print a lightweight helical focuser for me. It's the perfect design for a travelscope, for which space is a precious commodity.

After figuring out the major parts of the scope, I assembled everything and fiddled with its balance. I didn't want to add unnecessary extra weight to a box I will have to carry through airports, so I experimented with various bungee setups, eventually discovering that two sets of #33 rubber bands tied end to end and used on both sides of the mount worked beautifully. In cold weather rubber bands lose some of their strength, so I carry a bag of extras to fine-tune their pull.

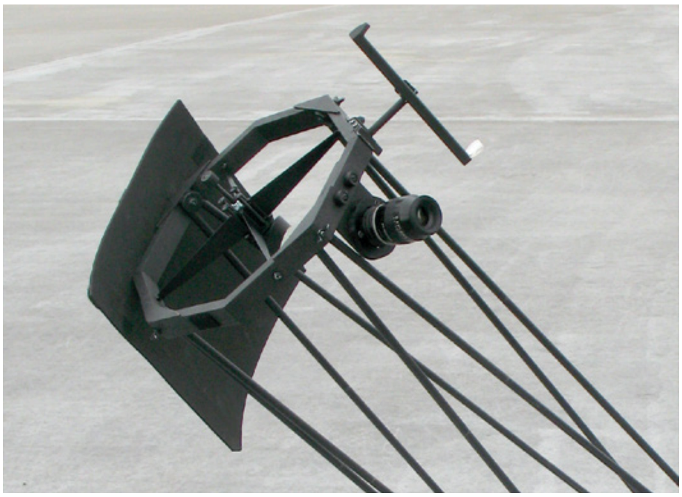
The eyepiece is such a significant portion of the front end's

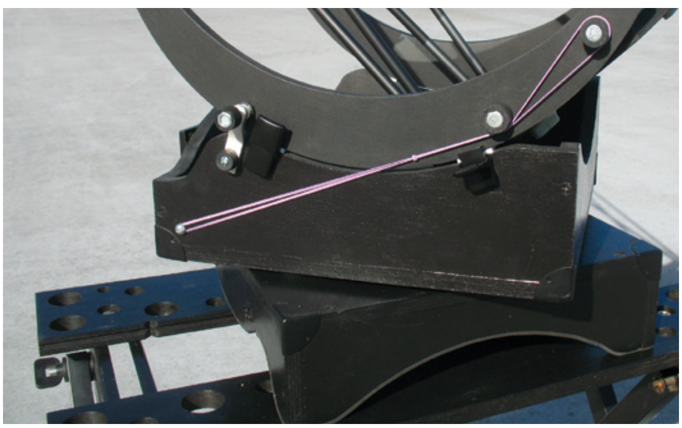
▲ **SIMPLE SUPPORT** *Left:* The primary mirror (absent in this photo) rests on the ends of three nylon bolts. Teflon pads support the mirror radially on its lower edge. *Right:* The primary mirror collimation bolts are simply nylon toilet seat bolts. When the scope is packed for transport, the bolt heads fit between the spider vanes of the secondary ring.



▲ **SECONDARY RING** The 3D-printed helical focuser and secondary mirror both screw on to the ring with lightweight nylon bolts.



▲ **SECONDARY ASSEMBLED** The entire secondary ring weighs less than most eyepieces. The black neoprene foam light baffle also acts to pad the inside of the box when the scope is packed for transport.



▲ **ELASTIC BALANCE** Two #33 rubber bands tied end to end provide the right amount of tension for balancing the scope. Note the brake near the front of the rocker box used to lock the scope in place while swapping eyepieces.

weight that the scope would head for the zenith whenever I removed one. That meant I needed a clutch system to hold the scope in position. Again, I tried various designs, from wedges to spring clamps to magnets, but I eventually realized that a simple screw on an arm would do. Tightening the screw pushes a piece of grippy rubber against the side of the altitude bearing, and the scope stays put.

Making It All Fit

Although the scope was working well, I hadn't yet figured out how to pack it all in the box. I'd assumed the primary mirror in its cell would go in the bottom, then the secondary cage on top of that, followed by the altitude bearings, with eyepieces in the corners and the focuser disassembled to lie flat inside the arc of the altitude bearings. But that arrangement proved inefficient — 6 inches of internal space vanished pretty quickly. The collimation bolts sticking out the bottom of the mirror box wasted half an inch of depth, and the altitude bearings got in the way of everything. Also, I was worried about all that irregular stuff resting on the primary mirror, even with some padding in between.

So, I played with other arrangements, eventually realizing I could stack the altitude bearings on top of one another around one side of the box, then put the secondary cage on top of those, and that would leave me four big gaps in between the spider vanes to hold some eyepieces, the focuser, finder, the bag of parts, spare rubber bands, etc. The secondary mirror goes into a form-fit case that sits in the corner opposite the altitude bearings, and everything else packs neatly in between the spider vanes or in the other corners. Two of the eyepieces fit so snugly you'd swear I designed everything around them, but it was just luck.

With everything packed that way I gained so much room I had an extra inch of space between the primary mirror and the trusses (which mount diagonally two layers deep inside the lid). So, I cut the box down to 6″ high, to its finished dimensions of 12¾″ × 12¾″ × 6″. That still leaves room for a generous primary mirror cover that fits snugly against the trusses and holds everything tight.

One thing I learned on this project is that travelscopes aren't simple scopes. In fact, the smaller you make them, the more complicated they become. This scope takes me about 25 minutes to set up, which is 5 minutes longer than it takes to set up my 20″. But this scope will fit under an airplane seat, which is where I intend to put it . . . on a flight to the Southern Hemisphere as soon as possible.

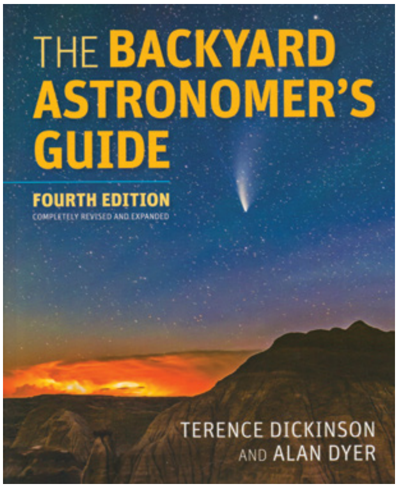
■ Contributing Editor **JERRY OLTION** plans to spend a lot of time looking at the Magellanic Clouds someday soon. And 47 Tucanae. And the Jewel Box. And . . .

FURTHER READING Many of the telescope-making concepts referenced in this article can be found in *The Dobsonian Telescope* by David Kriege and Richard Berry, which can be purchased in our online store at **shopatsky.com/products/dobsonian-telescope**.

A Crowning Achievement

THE BACKYARD ASTRONOMER'S GUIDE, 4TH ED.

Terence Dickinson & Alan Dyer
Firefly, 2021
416 pages, ISBN 978-0-2281-0327-1
US$49.95, hardcover



AFTER READING THROUGH the fourth edition of this classic, which first appeared in 1991, I can't believe I hadn't picked up this book before now. Lavishly illustrated, it's an essential and virtually complete guide to amateur astronomy today, with coverage of observing basics and equipment selection as well as two chapters on astrophotography. The sections on naked-eye phenomena and observing are excellent, as are those aimed at users of binoculars, telescopes of all kinds, and, finally, cameras.

While this book is great for beginners and experts alike, I wouldn't classify it as ideal for *absolute* beginners. Right away when discussing sky phenomena, it states that the Moon is 90 degrees from the Sun at first quarter. There's no introduction to celestial measurement systems. As such, for the complete novice I'd recommend Dickinson's *NightWatch: A Practical Guide to Viewing the Universe*, which the authors freely admit is a prequel to *The Backyard Astronomer's Guide*.

Dickinson and Dyer break their material down into sections on getting started, selecting and using the right gear, and observing guides for naked-eye, binocular, deep-sky, and solar system objects. The chapters are structured such that you can easily jump around. In fact, the first one I read was a new chapter for this edition that Ken Hewitt-White, a *Sky & Telescope* contributing editor, wrote on observing the Moon. The chapter is fantastic, and I plan to borrow liberally from it when I do my next outreach event that involves the Moon.

Hewitt-White also contributes brand-new chapters on binocular and telescope targets. There are also new sections on dark-sky reserves and astrotourism. All told, the 4th edition boasts 48 additional pages over the 3rd, as well as new photographs and up-to-date star charts. It also includes a foreword by MIT astrophysicist, author, and exoplanet expert Sara Seager.

The Backyard Astronomer's Guide is a joy to read for novice and veteran amateurs alike. The equipment review sections are current, and instead of vague, abstract guidelines, the authors describe current brands and models as well as highlight their strengths and weaknesses. This includes telescopes, mounts, eyepieces, and a plethora of accessories.

As an advanced imager, I applaud the authors for suggesting early on that photography should be last on a beginner's journey. "Don't start your hobby there," they caution. They wisely suggest that novices begin with visual observing and a modest investment in gear until they get their feet under them. Having spent many years in product development and tech support for a company that makes astrophotography hardware and software, I can say with confidence that this is solid advice.

The two chapters on astrophotography are straightforward, practical, and aim to cover everything as well as can be done in a limited space. The material leans toward doing astrophotography on a tripod or with a tracking platform, then graduating to putting a camera on a telescope. For more advanced astrophotographers, there's guidance on using dedicated CCD or CMOS cameras with filters.

The Backyard Astronomer's Guide is a joy to read for novice and veteran amateurs alike.

The image-processing content shows a bias towards DSLR/mirrorless-camera workflows. I found this to be a reasonable approach, because fitting such a huge topic into two chapters is arguably impossible. Truly, putting a camera on a tripod is the best and most prudent way to get started.

The book wraps up with some useful appendices on niche topics such as polar alignment, testing and collimating optics, and more.

Altogether, while I've read many books that go into greater detail on all aspects of amateur astronomy or astrophotography, none has been as much fun to read in a very long time as *The Backyard Astronomer's Guide*.

■ Contributing Editor **RICHARD S. WRIGHT, JR.** is a software developer and engineer specializing in graphics and imaging technologies. See his First Exposure article about image stacking on page 54 of this issue.

Sky-Watcher's Heritage 150P Dobsonian

This moderately priced beginner's telescope offers much more than just a great set of features.

▲ The Sky-Watcher Heritage 150P is a 150-millimeter (5.9-inch) f/5 Dobsonian telescope that ships fully assembled and ready to use. It's also lightweight and compact, with a base 38 cm (15 in) in diameter and a height of just 56 cm (22 in) with the tube retracted, as seen on the facing page.

Sky-Watcher Heritage 150P Tabletop Dobsonian

U.S. Price: $280 • Skywatcherusa.com

What We Like

Great general-purpose beginner's telescope

Compact design for transportation and storage

Ready (and easy) to use out of the box

What We Don't Like

Open tube allows bothersome light scatter in the eyepiece under some observing conditions.

WHAT'S THE BEST TELESCOPE for a beginner? It's a question I've been asked hundreds of times. But as every observer knows, there's no one-size-fits-all answer any more than there's an answer to what's the best vehicle for a person with a new driver's license. Is the budding celestial explorer interested only in visual observing? What about imaging? Are there special considerations for transporting and setting up the telescope? Is there adequate space for storing it? What about the cost?

Sometimes the people seeking advice on a first-time telescope do have specific needs, but the majority of them I've talked with want a "general-purpose" scope. And other than a don't-break-the-bank cost, many want a scope that a young person can carry, set up, and operate. Given those requirements, the Sky-Watcher Heritage 150P Dobsonian would seem like an ideal telescope. And after several weeks of testing it late last autumn and early winter, I do indeed feel it's a great first scope. Furthermore, the optical-tube assembly (OTA) can easily be removed from its Dobsonian

ALL IMAGES COURTESY OF THE AUTHOR

base and attached to a small, motorized mount that adds tracking and Go To pointing, making it a reasonably powerful instrument even for seasoned observers. But more about that later.

At the heart of the Heritage 150P Dob is a 150-mm (5.9-in) f/5 parabolic mirror with a 750-mm focal length. I grew up with a generation of amateur astronomers who rightly considered a 6-inch telescope an instrument for serious observers. At the time a friend let me borrow his 6-inch f/8 Newtonian reflector (a Criterion RV-6), and I still vividly remember many of the objects I observed with it that helped fuel my lifelong love of visual observing. During the course of testing the Heritage 150P that we borrowed from Sky-Watcher for this review, I revisited a number of those objects, and many appeared even better than I remembered them from the past. This scope has plenty of aperture for revealing hundreds of deep-sky objects, as well as detail on the Moon and planets, and for splitting tight double stars.

Out of the Box

Given that the Heritage 150P is shipped fully assembled, it arrived in an impressively small and light box. The Dobsonian base is only 38 cm (15 in) in diameter, and with the OTA's front end retracted, the whole telescope stands just 56 cm (22 in) tall. It weighs just 10½ kilograms (23 pounds), light enough for most anyone to set up on a moment's notice. There's a tight-fitting dustcap for the front of the tube, and because the eyepiece holder is outside the solid portion of the tube, when the OTA is retracted it forms an essentially dust-proof enclosure for the optics. A very nice feature.

It took me longer to unwrap the two included eyepieces than it did to attach the red-dot finder, which is all

▲ The telescope's front end is very robust and maintained excellent optical alignment in the weeks that the author repeatedly extended and retracted it during testing.

I needed to do before using the scope. While the included "SUPER" eyepieces are of unstated optical design, they are of decent quality. The 25-mm eyepiece yields 30× magnification and a field of view 1¾° across, and the 10-mm delivers 75× with a ¾° field.

Also included with the telescope is a collimation cap that fits into the eyepiece holder to aid in checking and aligning the optics. The scope arrived almost perfectly collimated. What little tweaking was needed was easy

▲ As explained in the accompanying text, nearby house lights reflecting off the aluminized sides of the secondary mirror caused significant scattered light in the eyepiece during some of the author's tests. Adding a small piece of black photographic masking tape cured the problem.

to do during daylight thanks to the cap, a centering dot on the primary mirror, and very good collimation instructions with clear diagrams in the user's manual. The scope's front end is robust, with a solid three-vane spider assembly for the secondary mirror, which I suspect will rarely, if ever, need adjustment. The collimation tweaking I did was with the thumbscrews on the primary-mirror cell, which are easily reached while you're looking through the collimation cap.

The Heritage 150P is billed as a tabletop telescope, but when it's placed on a standard-height table, the eyepiece can become a bit too high for a typical standing adult when the scope is aimed at moderately high elevations. Something about the height of a barstool would be better support for the scope. If you can tolerate kneeling on the ground beside the telescope, the eyepiece is readily accessible at all but the lowest telescope elevations. And while it wasn't terribly elegant looking, I did much of my observing with a pair of overturned 5-gallon plastic buckets from Home Depot — the scope sitting on one and me sitting on the other.

▼ A 6-inch-long, Vixen-style dovetail bracket is permanently mounted at the telescope's balance point, allowing users to adjust the scope's balance when swapping in heavy eyepieces. The dovetail mount also makes it easy to detach the scope from its Dobsonian base and use it with other mounts.

My first time out with the scope began in strong evening twilight, when I could still catch sight of Venus from the end of my driveway. The planet was low in the west and the atmosphere very turbulent, but I could still easily make out the planet's half-lit disk in the 25-mm eyepiece. As darkness deepened, I swung the scope to Saturn, whose rings and the moon Titan were easy to see at 75× despite the still rather mediocre atmospheric seeing. Jupiter was next and a bit higher. Several belts and the Great Red Spot were reasonably apparent at 75×.

The real observing prize, however, was the nearby Moon, just a day past first quarter. I spent a lot of time picking out features using both eyepieces. Adding my own Meade 2× TeleXtender, which boosted the 10-mm eyepiece to 150×, gave excellent views along the deeply shadowed terminator during fleeting moments of stable seeing conditions. All these views were contrasty and free of obviously scattered light despite the scope's open tube and bright moonlight.

That, however, changed when I moved the scope to a table on the back deck of our house for a look at some of the star clusters scattered along the Milky Way between Cassiopeia and Auriga rising in the east. All of a sudden there was a large, bright arc of light in the eyepiece field that overpowered the view. Removing the eyepiece and looking into the focuser revealed the culprit — light from a kitchen window to my side was reflecting off the aluminized edge of the secondary mirror (see photo at bottom of page 67). Blocking the window light with a piece of cardboard solved the problem that night, but later I wrapped black photographic tape around the edge of the secondary mirror that's visible from the eyepiece holder. An even better long-term solution would be to fashion a small shroud from black cloth that could be placed around the open end of the tube. Ideally, this scope would be used in a place free of local terrestrial lights, but those locations are often difficult to find in a suburban environment.

▲ Readily accessible thumbscrews on the primary-mirror cell make it easy to collimate the optics (if necessary). Adjacent to each large collimating thumbscrew is another, smaller one used for locking the mirror's position once it's aligned.

The scope's helical focuser has a somewhat loose feel but still allows precise focusing even at high magnifications. The single-arm Dobsonian base moves smoothly and is very stable, with vibrations damping out after only a second or two when moving or focusing the scope. It's easy to make small adjustments to the friction controlling the altitude motion using the hand knob on the altitude axis. This was especially useful when I used some of my own heavy eyepieces that changed the balance of the OTA. Aiming the scope at low and moderate elevations allows enough leverage to move the scope smoothly in azimuth by pushing on the OTA's front ring. At very high elevations I often opted to move the azimuth by putting my hands on the mount itself.

I was impressed enough with the views through the Heritage 150P that I decided to attach the OTA to a small Go To mount so I could hunt down some of the fainter deep-sky targets that are challenging to find in my suburban sky with just the scope's red-dot finder.

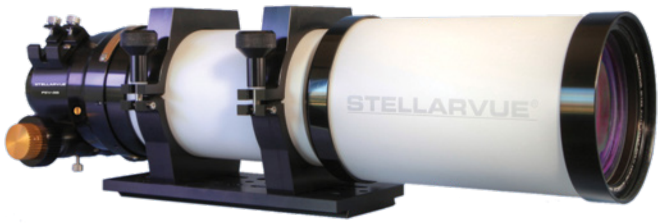
(My star-hopping skills are getting a bit rusty after decades using Go To scopes.) The switch to a Go To mount was easy thanks to the scope's Vixen-style dovetail bracket permanently attached to the balance point of the OTA. But therein lies the rub: Since the eyepiece is fixed relative to the dovetail bracket, the scope works best on an altazimuth Go To mount because the eyepiece remains as easily accessible as it is with the scope on its Dobsonian base. On a German equatorial mount, however, in some parts of the sky the eyepiece and finder end up positioned under the OTA, where they are extremely difficult to look through. To be used effectively on a German equatorial mount, a Newtonian reflector needs to be in tube rings so users can rotate the eyepiece to a comfortable observing position. Proper-size tube rings could easily be added to the Heritage 150P since the scope's balance point is located on the solid portion of the 7-inch-diameter tube.

◀ A tight-fitting dustcap helps seal the retracted telescope tube from dust, especially since the opening for the eyepiece holder remains outside the solid portion of the tube.

After weeks of observing with the telescope I have only good things to say about the Heritage 150P Dob, other than the easily fixed issue of occasional light reflections off the edge of the secondary mirror. It really fills the bill as a great general-purpose scope for a beginner, as well as for anyone who might want to observe on a moment's notice with what I still consider an aperture well suited for serious observing.

■ Despite having a backyard observatory with larger telescopes, on clear evenings **DENNIS DI CICCO** often chose to step out on his deck for some spur-of-the-moment observing with the Heritage 150P Dobsonian.

▲ Although the telescope can be fitted to a variety of mounts, it works best on altazimuth mounts (left) because the eyepiece, which is fixed relative to the dovetail mounting bracket, remains easily accessible as the telescope is pointed around the sky. This is not the case for German equatorial mounts (right), in which the eyepiece and finder can end up under the telescope tube when pointed to some parts of the sky.



▲ 4-INCH APOCHROMAT

Stellarvue adds a new model to its extensive line of SVX apochromatic refractors. The SVX102D ($2,195) is a 102-mm (4-inch) f/7 doublet apochromat that pairs a super-low-dispersion element with a rare-earth lanthanum element to produce sharp, color-free views. The tube weighs roughly 4 kilograms (9 pounds) and measures 54½ centimeters (21½ inches) long with its dew shield retracted, 67 cm fully extended. The SVX102D comes with a 3-inch-format, dual-speed focuser and includes both 2- and 1¼-inch eyepiece adapters with non-marring compression rings. Purchasers can upgrade the focuser to a Starlight Instruments 3-inch Feather Touch Focuser at additional cost. Each scope purchase comes with an aluminum lens cap, a pair of CNC-machined mounting rings, and a dovetail finder mounting base.

Stellarvue
11802 Kemper Rd., Auburn, CA 95603
530-823-7796; stellarvue.com

▲ COMA CORRECTOR

Orion Telescopes & Binoculars now offers a dual-use field corrector for its Newtonian telescopes. The Orion 2″ Photo-Visual Coma Corrector for Newtonians ($129.99) corrects coma and field-curvature aberrations inherent in fast Newtonian reflectors, resulting in pinpoint stars in wide-field eyepieces and cameras alike. Designed to correct reflectors with focal ratios between f/3.5 and f/6, the unit fits into 2-inch focusers and adds a mild 1.1× magnification factor to your optical system. The corrector performs best with about 75 mm of backfocus. Its 2-inch eyepiece holder is replaced with the included M48-to-T-thread adapter for imaging. An additional 20-mm spacer ring is required for optimal performance with DSLR cameras, and other spacers are needed for use with mirrorless or astronomical cameras.

Orion Telescopes & Binoculars
89 Hangar Way, Watsonville, CA 95076
831-763-7000; telescope.com

◀ COMPACT GUIDER

iOptron expands its imaging support with an autoguiding package for most small- to mid-sized tracking mounts. The iGuider Autoguider System ($218) pairs the company's iGuider Mini Guiding Scope with its iGuider 1 Camera to produce excellent guiding accuracy for short- to medium-focal-length imaging systems. The iGuide Scope includes a 30-mm f/4 achromat that mates with iOptron's CEM26, GEM28, CEM40, and GEM45 mounts and can be used on other telescopes with standard finderscope dovetail saddles. The iGuider 1 Camera is built around a 1.2-megapixel CMOS detector with 3.75-micron-square pixels in a 1,280 × 960 array, resulting in a resolution of 6.44 arcseconds per pixel. The iGuider supports pulse guiding and comes with a 2-meter USB 2.0 cable to connect with your control computer.

iOptron
6F Gill St., Woburn, MA 01801
781-569-0200; ioptron.com

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A Plate-Solving Finder

Get spot-on pointing with equipment you may already own.

SEVERAL OF MY observing buddies use Go To telescopes. One of their key measures of a good night is whether or not the computer puts their target objects in the field of view. They're always fiddling with the alignment: sometimes starting over from scratch, often retraining the scope after they center an object, or even nudging a tripod leg to make the computer's internal star map match reality. If targets are completely out of the field of the eyepiece, they're "lost in space."

What if you could get your Go To scope to put an object dead center in the eyepiece every time? Sure, recent-generation scopes with plate-solving technology will photograph the sky, figure out where they're pointed, and center the scope on the target, but what about those millions of previous-generation scopes still in use? Are they left out of the plate-solving revolution?

Thankfully, no. Virginia amateur Robert Capon, last seen in these pages with his incredibly compact travel scope (*S&T:* Jan. 2021, p. 74), has figured out a way for people with previous-generation Go To scopes to join the party. And if you're an astrophotographer, you might very well be able to do it with equipment you already have on hand.

Rob says, "Virtually every astrophotography program today can plate-solve and recenter after a slew. I'm using a ZWO ASiair Plus for astrophotography, but popular programs like *The SkyX*, *N.I.N.A.*, and *SharpCap* also work."

The trick is to mate the software and camera with a guidescope or finderscope that provides an optimal-sized field of view. Rob's first attempt, using a Svbony SV165 Mini Guider Scope 30mm/120mm F4 he bought for about $50 and his wide-format ZWO ASI294MM camera, provided way too wide a field of view. It put thousands of stars in the field, combined with distortion in the corners, so the software was

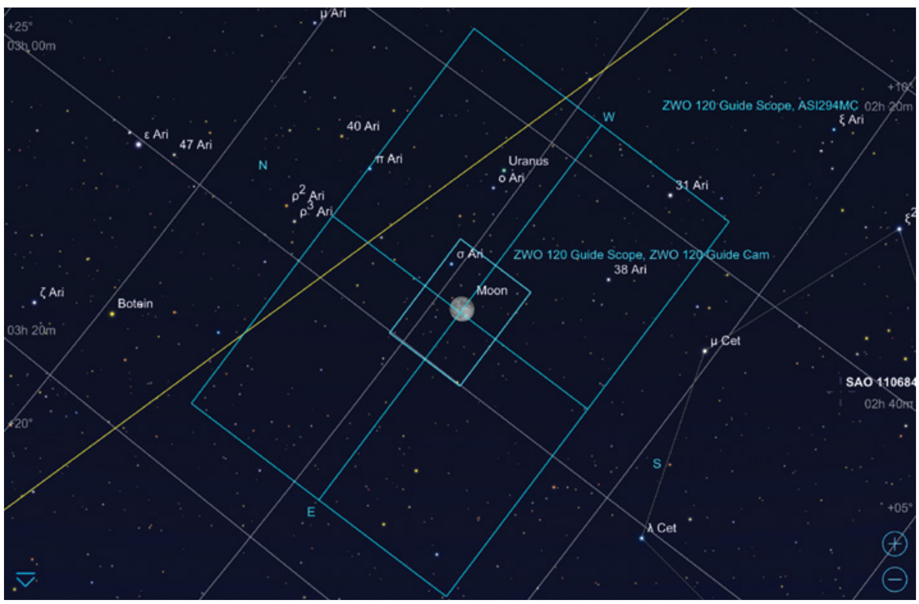
▲ The ASiair Plus computer easily fits on the side of the telescope and communicates wirelessly with a smartphone or tablet for telescope control.

unable to recognize the images. Switching to an inexpensive ZWO ASI120MM-S guide camera with a much smaller chip solved the problem. That scope and camera combination has a suitable 2.3°-by-1.7° field of view, which results in reliable plate-solving. To keep the finder from dewing up, Rob added a homemade dew shield.

To operate the computerized auto-centering finderscope, Rob mounted both the finder and ASiair Plus mini-computer on small finderscope dovetail brackets, connected the computer to the mount's external control port, and issued his Go To commands from his tablet, with the ASiair Plus set to plate-solve and recenter after each slew.

It's reasonably fast. It takes a couple seconds to shoot the image, another couple to download the image to the com-

▼ *Left:* Rob Capon's plate-solving finder is a simple, easy solution for exact Go To pointing. *Right:* The blue rectangles in this *SkySafari* screen shot show the field of views of the two cameras Rob tried. The wider field contained too many stars for the software to plate-solve, but the narrower field was just right.



ALL IMAGES COURTESY OF ROBERT CAPON

puter, 5 to 10 seconds for the computer to solve the star field, another couple of seconds to adjust the telescope's aim, then a repeat exposure, download, and plate-solve to confirm its new position. The whole process takes less than 30 seconds, probably less time than it would take to manually find and center an object that was outside the field of view.

This system should work on any mount that can communicate with a computer. Rob uses it on three different mounts: a Losmandy GM811G, a Meade LX65, and a Sky-Watcher AZ-GTI operating in both alt-az and equatorial modes.

Rob reports that "This thing works so well you don't even need a real 2-star alignment. You can level your scope and go north (Meade home position) or go in the counterweight down position (equatorial scope pointing towards the North Celestial Pole). Then do a 1- or 2-star alignment where you accept the telescope's choice of stars without even centering them. (Simply press the 'OK' button when you're in the vicinity of the star doing your 2-star alignment.) When you try this, you'll miss your targets by a mile, but the computerized finder will still recenter it for you."

When Rob is imaging, he's automatically plate-solving with the computer and his camera through the main telescope, so there's no need for the finder in that case. Two of his mounts have dual finder saddles, so he'll often go out with two OTAs: an 80-mm Stellarvue refractor doing electronically assisted astronomy and an 8-inch Meade Schmidt Cassegrain for visual. In that case, the Stellarvue is centering the telescope, and Rob can enjoy visual astronomy with the Meade.

The computerized, auto-centering finderscope centers objects in the field of view every time. As Rob says, "Even with very dim visual objects, I know where to look for them in the eyepiece: dead center!"

For more information, contact Rob at **rscapon@gmail.com**.

■ Contributing Editor **JERRY OLTION** has built many finders, but none as independent as this.

▷ STELLAR SISTERS

Drew Evans

Despite its nickname, the Pleiades open cluster (M45) contains far more than seven stars. This middle-aged cluster of stellar siblings is passing through a dense cloud of interstellar dust, producing the bluish nebulosity in this deep image.

DETAILS: *William Optics Gran Turismo 81 refractor with ZWO ASI2600MM Pro camera. Total exposure: 13.7 hours through LRGB filters.*

▷▷ HIDDEN GALAXY IN THE GIRAFFE

Daniel Feller

Intervening gas and dust along the plane of the Milky Way in Camelopardalis dims the light from the distant spiral galaxy IC 342. Feller combined many long exposures to reveal the galaxy's numerous reddish star-forming regions.

DETAILS: *Meade LX200 12-inch ACF telescope with ZWO ASI1600MM camera. Total exposure: 35 hours through Hα and RGB filters.*

▽ LEONARD'S TAIL

Gerald Rhemann

A complex series of kinks and knots decorated the tail of Comet Leonard (C/2021 A1) after the tail experienced a disconnection event on the evening of December 26th.

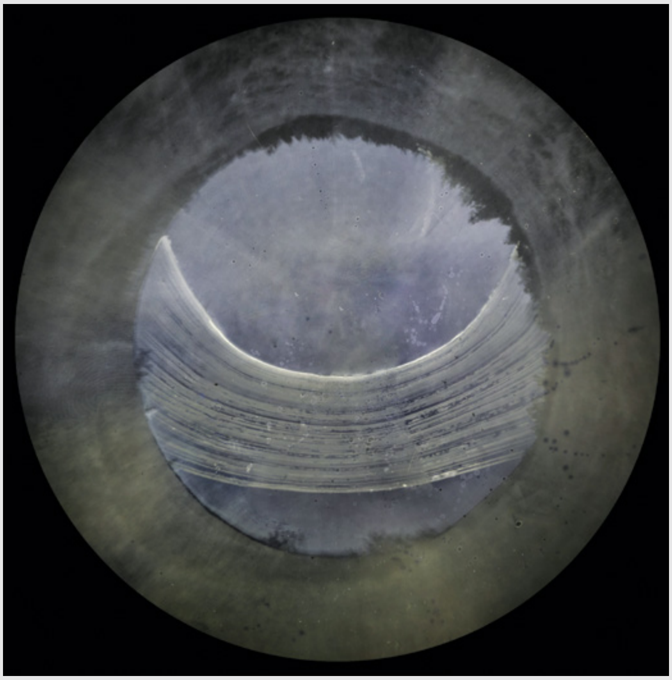
DETAILS: *Officina Stellare Veloce 200 AT astrograph with QHY600M CMOS camera. Mosaic of two panels, each exposed for 6⅔ minutes through LRGB filters.*

STELLAR HARVEST

Sheldon Faworski

The Milky Way from Sagittarius (middle) to Aquila (top left) stands high above a farm in Elizabeth, Illinois.

DETAILS: *Canon EOS 5D Mark II DSLR camera with 20-mm lens at f/2.5. Total exposure: one minute at ISO 1600.*



◁ ANKARA DAYS

Cem Özkeser and Seda Baştürk

This 360° solargraph shows the Sun arcing across the entire sky over Ankara, Turkey, starting on June 21, 2021, and ending on December 16th.

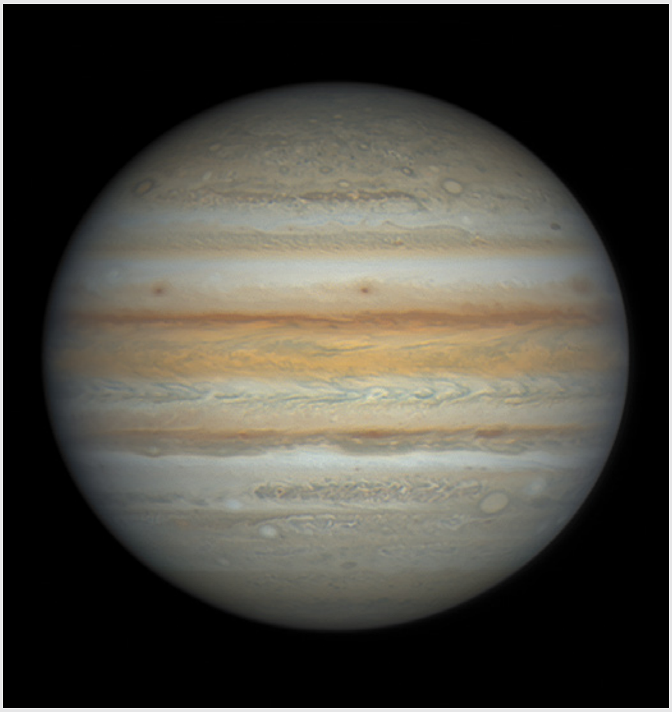
DETAILS: *Eleven cylindrical canisters with 0.3-mm pinholes and black-and-white photographic paper. Total exposure: 179 days.*

▽ MERCURY AND LUNA

Sérgio Conceição

The statue of the Roman god Mercury atop the Edificio La Giralda in Badajoz, Spain, appears to reach for the full Moon in the early evening of June 24, 2021. This regionalist-style building is a replica of another monument with the same name in Seville, Spain.

DETAILS: *Canon EOS R6 camera with 400-mm lens. Total exposure: 1⁄40 second at f/5.6, ISO 2500.*



△ SWIRLING ATMOSPHERE

Enrico Enzmann

Jupiter sports an unusually colorful Equatorial Zone bordered by brownish North and South Equatorial belts. Red Spot Junior appears pale though still reddish at lower right.

DETAILS: *Astrosysteme Austria ASA500 Cassegrain with ZWO ASI290MM video camera. Stack of multiple video frames recorded through RGB filters.*

▷ HIGH-FLYING ECLIPSE

Petr Horálek

Lucky umbraphiles intercepted the shadow of the Moon over Antarctica during the total solar eclipse of December 4, 2021. This image captures both the eclipsed Sun and its shadow racing over the icy land and sea below.

DETAILS: *Canon EOS 6D and Ra cameras with Samyang 24-mm and Tamron 70-to-200-mm lenses. Stack of 48 exposures at either f/2.0, ISO 400, or f/2.8, ISO 800.*

▽ JAMES WEBB AND SCULPTOR

Samit Saha and Soumyadeep Mukherjee

Aboard the Ariane 5 rocket, the James Webb Space Telescope passes NGC 253, the Sculptor Galaxy, at lower left as it heads toward its final destination at the L_2 Lagrange point 1.5 million kilometers (932,000 miles) from Earth.

DETAILS: *Nikon 5600 camera with Samyang 135-mm lens. Composite of 40 exposures, each 2 seconds at f/2, ISO 500.*

◁ DIAMOND RING

Petr Horálek

Delicate streamers within the solar corona are revealed in this composite image of the final moments of the total solar eclipse on December 4, 2021. The planet Mercury is visible in upper right.

DETAILS: *Canon EOS Ra Mirrorless camera with Tamron 70-to-200-mm lens. Composite of 28 exposures of varying lengths at f/2.8, ISO 800.*

▽ A YELLOW NEBULA

Gerald Rhemann

The Toby Jug Nebula, IC 2220, in Carina is a rare example of a yellowish reflection nebula produced by the red giant star HD 65750 at its center.

DETAILS: *Astro Systeme Austria N12 astrograph with ZWO ASI6200MM Pro CMOS camera. Total exposure: 12⅘ hours through Hα and LRGB filters.*

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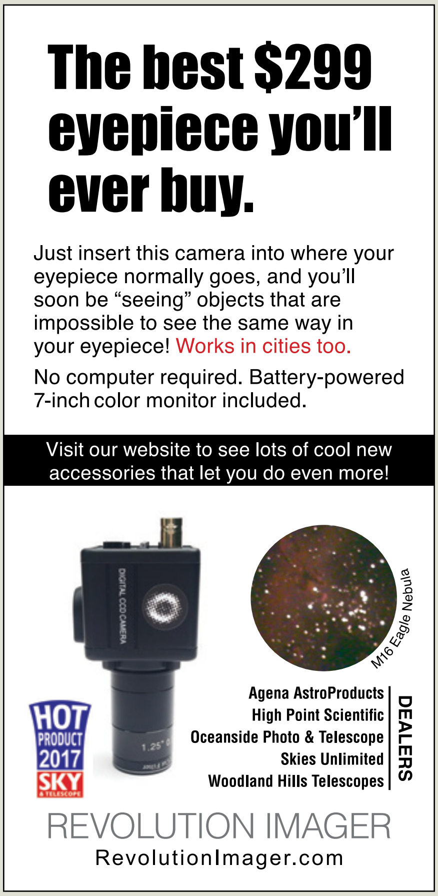

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Saving Apollo 16

Fifty years ago this month, one man's timely phone call averted disaster — or so he might have thought.

THE WIND-WASHED dusk sky above San Francisco Bay was immaculately cloudless that night — April 16, 1972. As twilight deepened, a fetching celestial tableau emerged high in the west: the crescent Moon perched within kissing distance of lustrous Venus.

It's an odd thing. Whenever Venus gleams alone, it begets only tepid interest. Yet if the Moon snuggles alongside, curiosity spikes. Callers ring planetariums and observatories, asking for the name of the bright "star" by the Moon.

There's also a third scenario, one far rarer and more intriguing. It's when Venus and Luna rendezvous mere hours after humans, with much hoopla, set out toward the latter body.

That's what ensued on this April day, when Apollo 16 roared off from Cape Kennedy. You can probably guess the errant presumption made by those who, with memories of the televised launch fresh in their minds, mistook Venus for something else entirely.

I arrived at Oakland's Chabot Observatory before sunset, aspiring to capture the conjunction on film. It was Sunday, a day off for staff, so the place was blissfully free of interruptions.

A half hour past sunset, a ringing phone startled me. A woman, breathless over the spectacle above, asked, "Is the bright star beside the Moon really Apollo 16?" When I told her it was Venus, she countered, "Are you sure?"

"Quite certain," I replied. "Just you watch. Over the next hour, the Moon will drift slowly away from Venus."

After I hung up, the phone rang again within seconds. Another query of the same sort, followed immediately by another. And another. Two hours later I'd fielded roughly 100 calls, monopolizing the line to such a degree that numerous callers no doubt heard a busy signal.

Moreover, and most curiously, I sensed a consistent caller reaction: skepticism or outright disbelief when I explained that Venus, not Apollo, was the luminary of interest. This sentiment was not quite unanimous, however, owing to one unforgettable gent who went off on a completely different tack.

"Thank goodness I got through!" he shouted frantically when I answered. "You've gotta do something, and quick, otherwise the astronauts are doomed!"

"How so?" I inquired.

He said excitedly that, in looking up from his backyard, he noticed Apollo approaching very close to the Moon.

"Ah, but that's not . . ." I tried to interject.

"The way it's headed, it'll soon hit the Moon's pointy end, puncture the capsule, and bleed out all their air!"

Here was an obvious teachable moment. But with so much to explain — for instance, why lunar cusps don't pose a navigational hazard — and mindful that myriad other people were trying to ring the observatory, I opted to punt.

"Hey, you're right! I'll contact NASA headquarters immediately. Thanks for your call." [*click*]

On occasion over the years, I've second-guessed my response to that sincere but agitated fellow; he deserved a proper and respectful explication. Nevertheless, the Apollo 16 mission ended successfully and safely. So perhaps there's solace in hoping he may have felt a small measure of hero's pride in his ever-so-prompt forewarning. Maybe in his mind, if not for him, Apollo 16 might still be impaled on the Moon's northern cusp.

■ MARK GINGRICH was, in 1972, a part-time student assistant at what is now the Chabot Space & Science Center in Oakland, CA. Due to the volume of phone calls that night, he never did photograph the conjunction.

LEAH TISCIONE / S&T


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We've been there when the seeing is perfect and when it's soup. That's why at Sky-Watcher we're constantly striving to produce top-quality precision products for our customers — with unmatched value, backed by service you can trust.
Because when you can trust in your gear, you can focus on your passion.
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