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SKY & TELESCOPE

THE ESSENTIAL GUIDE TO ASTRONOMY

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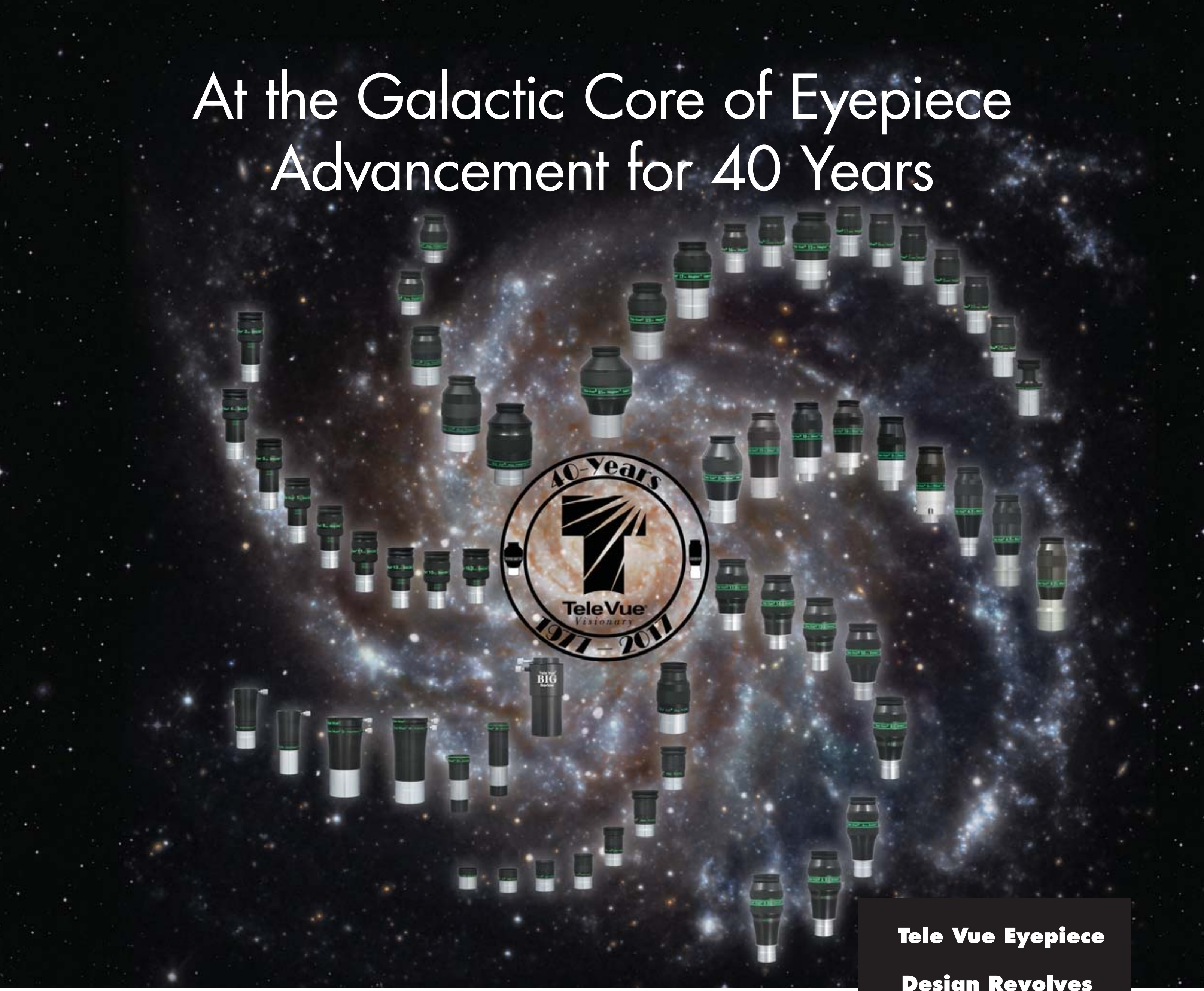
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Artist's concept of the early universe's voracious star formation
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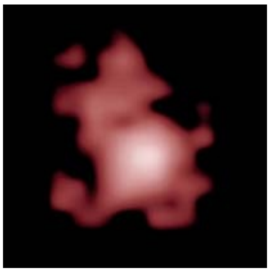
Clear Skies

IMAGINE IF SPACE WERE OPAQUE. There'd be no such thing as optical astronomy, and *S&T* likely wouldn't exist. (Heaven forfend!)

Fortunately, outer space is crystal clear. It's so transparent that we can see right across the universe. This is an astonishing fact. We can't look with our eyes alone into our own oceans because of their opacity, or into our own forests because of the trees. Yet with the help of our finest telescopes, we can perceive objects billions of light-years away.

This equates, of course, to billions of years back in time. Somehow it seems impossible from our perspective that light, the fastest thing in the cosmos, takes any time at all to travel somewhere. But because of the unimaginable distances involved when contemplating the early universe, photons can take a sizeable fraction of its age to reach us. This, too, is astonishing. Every time we use a telescope, we're time traveling, and sometimes very, very far into the past.

The firmament's translucency — in both space and, in a sense, time — works both ways, naturally. A hypothetical observer on a distant planet could look our direction and see the Milky Way as it appeared long ago. With advanced-enough technology, could that observer even focus in on Earth? Why not? Even as we're taking in, say, NGC 1275, a galaxy about 225 million light-years away, an observer there could be admiring the supercontinent Pangaea, which existed on our planet 225 million years ago.



Hubble image of GN-z11, the most distant galaxy known to date

NASA, ESA & G. BACON (STSCI)

I digress. *Our* observers, namely professional astronomers, are using that remarkable quality of space, that splendid emptiness, to look back more than 13 billion years in the past to a time when galaxies first formed. In images like the one at left, those primordial galaxies might be mere splotches of a few pixels, but *there they are*.

If that doesn't play enough with your mind, consider this: Those same astronomers are trying to peer far enough in space and back in time to discern when galaxies *run out*. As James Geach writes in his article on page 14, "what we'd really like to know is when we *stop* seeing galaxies." Astronomers know there was a time before galaxies existed. Can they, in essence, wind the clock back far enough that the first galaxies begin to vanish from the view?

Astronomy offers countless opportunities for such head-spinning contemplation. And yet it's not fantasy. This is real. That galaxy-free period is out there, and we might soon see right up to its very edge.

Peter

Editor in Chief

SKY&TELESCOPE
The Essential Guide to Astronomy

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Brilliant green auroral curtains danced over Akranes, Iceland, during a display on October 21, 2017.

Aurora Observations Wanted

Our team at the University of Jena is compiling a new catalog of ground-based aurora observations from the 19th and 20th centuries. We will use these to compare the auroral oval's size with direct measurements of Earth's magnetism (surface field strength and position of the geomagnetic pole) made since the early 19th century. Then we'll use historical aurora observations to reconstruct Earth's magnetic field at earlier times and compare our results with other reconstructions.

Please send us your aurora observations either as written descriptions (in English) or as pictures, noting the location and the date of your observation and, if possible, the time, direction, height, and color of the auroral display. We'll send results of the study to everyone who contributes, and they'll all be mentioned by name in the catalog (unless they prefer to opt out of getting this acknowledgement). Please use the email address **wagner.d@uni-jena.de** or mail your observations to us at Astrophysical Institute and University Observatory, Friedrich Schiller Universität Jena, Schillergässchen 2, 07745 Jena, Germany.

Daniel Wagner & Ralph Neuhäuser
Jena, Germany

Close Encounters

I was startled to read that Gliese 710 will pass within 16,000 astronomical units of the Sun (*S&T:* Dec. 2017, p. 12), yet there was no mention of possible disruptions of orbits of the major bodies within our solar system.

Since this star will clip the Oort Cloud inside the aphelion of the putative, Neptune-size, and as-yet-optically-unverified "Planet Nine," it seems to me the potential for great catastrophe exists. Surely someone is doing the math on the possibility that, after Gliese 710 passes (with any planets it might possess), our solar system as we know it will have ceased to exist.

Jim Baughman
West Hollywood, California

Monica Young replies: The longer, original version of Shannon Hall's story (**https://is.gd/zUu3dC**) notes: "Luckily, Gliese 710 isn't terribly massive. In fact, it's about 60% as massive as the Sun. Unluckily, it's moving relatively slowly. So [dynamicist Eric] Mamajek, unsure of what the star's effect on the Oort Cloud might be, did a quick back-of-the-envelope calculation. He found that it sits at the border between a star that has a negligible effect and one that can stir up the inner Oort Cloud enough to send comets our way."

Diversifying "Gallery"

While I appreciate the many, wonderful images in Gallery each month, I cannot help but notice the paucity of ones from women. It might be symptomatic of the dearth of women in astronomy in general (most of my astronomy club's members are male). Or it might be that women are less likely to submit their images. For whatever reason, I'd like to encourage more submission of images across the gender spectrum. If you know a woman who's interested in photography, encourage her to keep at it. And to the women who read this: Astronomy needs you. Please share your images!

Katrina Ince-Lum
Toronto, Ontario

Science with Backyard Scopes

I have a bone to pick with Govert Schilling, regarding his contention (*S&T:* Nov. 2017, p. 84) that "Gone are the days when an astronomer would do his research at the eyepiece of a telescope in his backyard . . ."

Maybe we amateurs don't do "big science," but our collective backyard telescopes have made substantial contributions, even as late as the most recent eclipse. Big science would be incomplete without us.

Tom Sales
Somerset, New Jersey

Honoring Ewen Whitaker

I heartily endorse the hope expressed by Charles Wood (*S&T:* Dec. 2017, p. 52) that a crater should be named to honor Ewen Whitaker (1922–2016), whose contributions to original lunar research are legendary.

As a young amateur fascinated with the exploration of the Moon, I hesitated

DEAN STRINGER

to write to Whitaker to ask a technical question about the lunar craters created when the S-IVB stages of Saturn rockets slammed into the Moon — but I mailed the letter anyway.

Whitaker sent me back a thoughtful, non-condescending reply, along with a Polaroid print of an Apollo 16 orbital image showing one of those craters to illustrate his point.

Besides his extensive, wonderfully original research, Whitaker's 1999 book *Mapping and Naming the Moon: A History of Lunar Cartography and Nomenclature* is a classic.

Perhaps the IAU's officials will find a suitable crater near the one named for Whitaker's longtime collaborator Gerard Kuiper. They should also consider naming a crater after David William Glyn Arthur, a colleague of Whitaker, whose contributions to selenography are likewise fundamental.

Bill Pohnan, Jr.
Streamwood, Illinois

Seeing Things in Orion

They say "familiarity breeds contempt," and that probably captures my perception of the Orion Nebula (*S&T:* Dec. 2017, p. 32) — which I've been observing and showing to guests for more than 50 years, starting with a 2-inch refractor. Yet, absent guests, it hasn't featured in my observing routine for years — despite now having a 55-cm Dobsonian reflector and mercifully dark skies. This article brought home to me, in such wonderful detail, that I can (and should) take a completely new look at it.

Paul Dawson
Olancha, California

▲ The iconic Orion Nebula, seen here with south up, appears to harbor a ghost among the tangle of red filaments near its left edge.

WES ATCHISON

In February 2016 I took my best-ever image of the Orion Nebula. The combination of the camera's mounting angle and my scope's orientation caused the image to be rotated by 180° from the usual north-up view. I discovered that if you look at M42 this way, there's a vague human form — or what I tell my friends is "Wes's Ghost" — on the nebula's left side. I thought this was some artifact of my imaging setup until I saw the M42 article. If you turn those images upside down, the "ghost" is there in all of them. Has anyone else ever noticed this?

Charles "Wes" Atchison
Sanger, Texas

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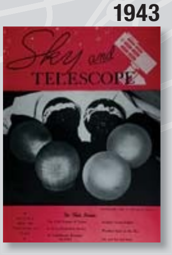
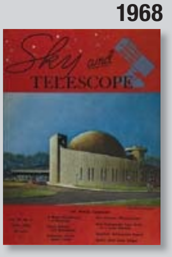
75, 50 & 25 YEARS AGO by Roger W. Sinnott

1943



1968



1993

◖ **April 1943**

Thorium in the Sun "A search for the rare radioactive element, thorium, in the sun — begun in 1938 but delayed by insufficient experimental laboratory work — has now proved fruitful. According to a Science Service report, Dr. Charlotte E. Moore, of Princeton Observatory, and Dr. Arthur S. King, of the spectroscopic laboratory at Mt. Wilson, find that the strongest laboratory lines of the ionized element coincide with hitherto unidentified lines in the solar spectrum."

Since then observers have found thorium in other stars and, a decade ago, in the Ursa Minor dwarf galaxy (a member of the Local Group that's 225,000 light-years away). Thorium's importance lies in its unusually long half-life: 14.05 billion years. Comparing its abundance to that of other heavy elements, such as uranium, could yield an independent estimate of a galaxy's age.

◖ **April 1968**

First Pulsar "An extraordinary object in the constellation Vulpecula has been reported by A. Hewish and his coworkers at Cambridge University's Mullard Radio Astronomy Observatory in England. Last July they began operating a large new antenna array . . .

"Soon they noticed that signals which seemed at first to be weak sporadic interference were being detected [4 minutes earlier each day, implying that] an extraterrestrial source was passing through the antenna's fixed reception pattern. The signals, when present, consisted of a series of pulses each lasting about 0.3 second and repeated every 1.337 seconds. . . .

"Whatever the physical nature of this strange emitter is, it must be very compact. . . . The source can be no larger than the planet Mercury, and may be much smaller!"

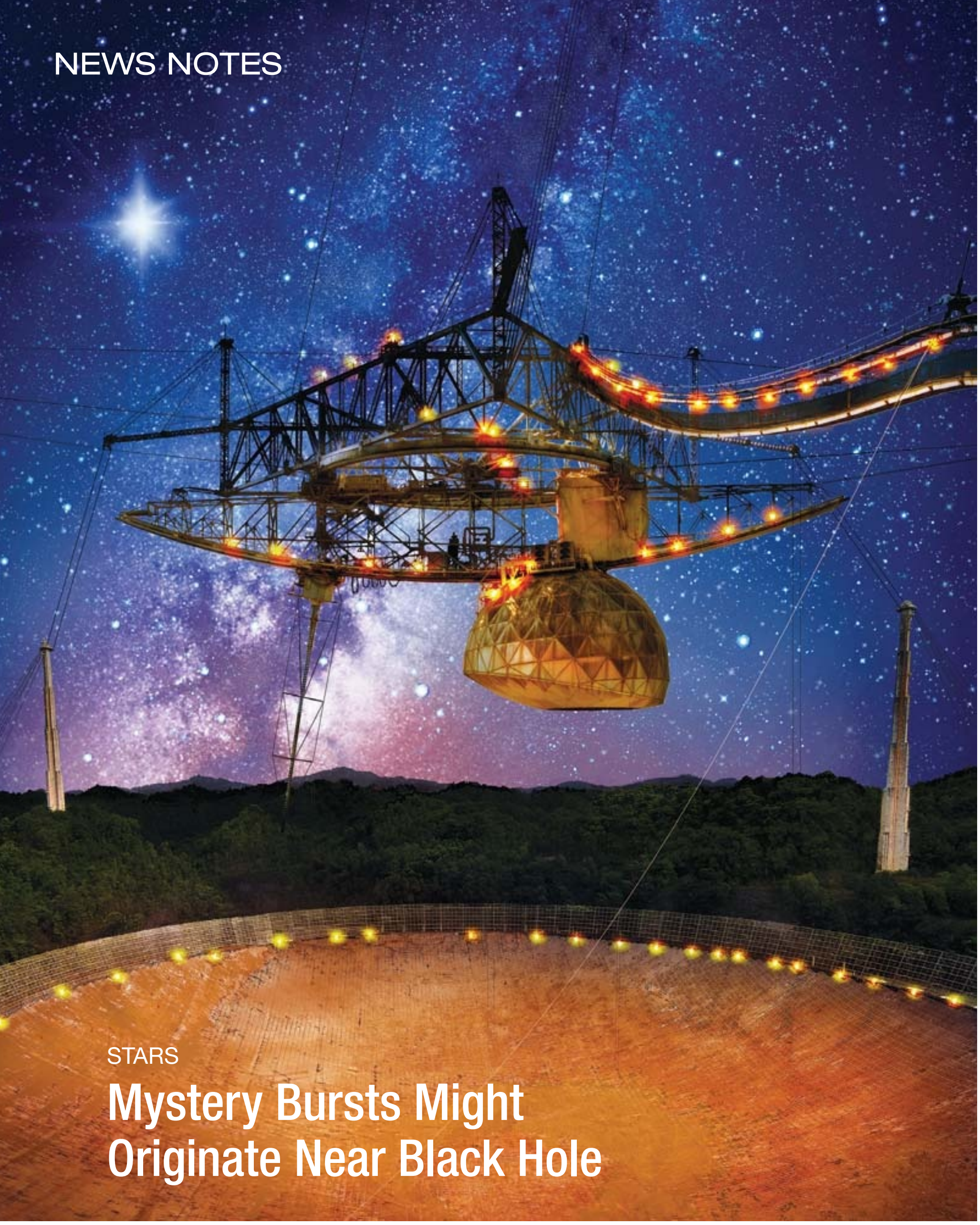
The second author of Antony Hewish's paper was graduate student Jocelyn Bell, who had first noticed the odd signal and recognized its importance. Yet the 1974 Nobel Prize for work related to the discovery of pulsars went to Hewish and Martin Ryle instead — a source of controversy ever since.

◖ **April 1993**

Big Bang "[In 1990] NASA's Cosmic Background Explorer (COBE) satellite established that the spectrum of the microwave background radiation is nearly that of a pure blackbody, as the Big Bang theory says it should be. Now the qualification 'nearly' can be dropped. . . .

"At the January AAS meeting, John C. Mather (NASA-Goddard Space Flight Center) presented a new spectrum derived from hundreds of millions of COBE measurements [that is] indistinguishable from the theoretical curve for a 2.726° Kelvin blackbody. . . . 'The universe has passed its toughest test yet, as far as the Big Bang theory is concerned,' says Mather."

COBE's results were the death knell of the steady-state theory, the Big Bang's main contender.



STARS

Mystery Bursts Might Originate Near Black Hole

▲ This photo illustration shows the 305-meter Arecibo telescope and its suspended support platform of radio receivers. The starburst at upper left marks FRB 121102's location.

BRIAN P. IRWIN / DENNIS VAN DE WATER / SHUTTERSTOCK.COM

NEW OBSERVATIONS SHOW that a source of repeating radio-wave flashes, first detected in 2012, is embedded in a potent magnetic field, perhaps that of a massive black hole.

So-called *fast radio bursts* can generate as much energy as 500 million Suns in only a few milliseconds. Astronomers have detected about 30 of them so far, but they think as many as 10,000 sources might flash each day.

In 2016 astronomers announced that one of these bursts, FRB 121102, had flared several times, making it the only fast radio burst known to repeat. In the years since, it has erupted more than 200 times, enabling astronomers to finally tie the source to a star-forming region in a dwarf galaxy 2.4 billion light-years away (*S&T*: Sept. 2017, p. 12).

New observations of polarized radio emission, reported January 11th in *Nature* and announced at the American Astronomical Society meeting in Washington, D.C., suggest the repeated bursts come from an environment with an unusually strong magnetic field. As such, the source might be a young neutron star in the vicinity of a massive black hole, whose strong field could alter the neutron star's emissions.

Daniele Michilli (University of Amsterdam) and colleagues used the Arecibo Observatory in Puerto Rico and the Green Bank Telescope in West Virginia to detect the bursts at higher frequencies than before, measuring the polarization of the radio waves. They found that the radio waves were almost entirely *linearly polarized*, which means the waves were almost all oscillating in the same plane. Moreover, this polarization had been strongly twisted in a signature known as *Faraday rotation*, which occurs when light passes through a magnetic field. In this case, the waves' polarization is so twisted, it suggests the magnetic field around the source is at least 100 times stronger than the average magnetic field in the Milky Way. The only known source with such a strong polarization signature is a pulsar near Sagittarius A* — the supermassive black hole at the center of our galaxy.

In addition, the shortest burst lasts less than 30 microseconds, suggesting that the source is as small as 10 km across, the typical size of a neutron star.

So the fast radio burst could be a neutron star near a massive black hole. But this answer poses another question: Why would the two objects be so close together? "Presumably that would not just be a coincidence," says Jason Hessels (University of Amsterdam).

Michilli and his team members agree that other scenarios could give rise to this odd fast radio burst.

"It's likely that it would be very young and if it's very young, it's quite possible that it could still be in some kind of cocoon, [like] a supernova remnant," Hessels says. But that hypothesis isn't perfect either. The remnant would have to be a million times brighter than the Crab Nebula, the brightest remnant in the Milky Way. Another idea involves outflows from black holes.

With a number of wide-field radio telescopes coming online this year and next (*S&T:* July 2016, p. 24), astronomers will soon be detecting more fast radio bursts — and perhaps more repeating ones — which will help them get a better handle on these enigmas.

■ SHANNON HALL

SOLAR SYSTEM

Next New Horizons Target Has a Moon

NEW ANALYSIS FROM the New Horizons team suggests that the spacecraft's next target, a Kuiper Belt object known as 2014 MU_{69}, might have a moon. The object was already thought to be a binary, so this brings the party members to three. Planetary scientists presented the preliminary results at the meeting of the American Geophysical Union in New Orleans.

New Horizons will fly 3,500 km (2,200 mi) from 2014 MU_{69} on January 1, 2019. Initial views, to be obtained in September 2018, won't resolve the object — it won't be until after the flyby that we'll begin to see high-resolution images of its surface. Data will continue trickling in through 2019 and most of 2020. Meanwhile, New Horizons will also be exploring 30 other Kuiper Belt objects from much greater distances through 2021.

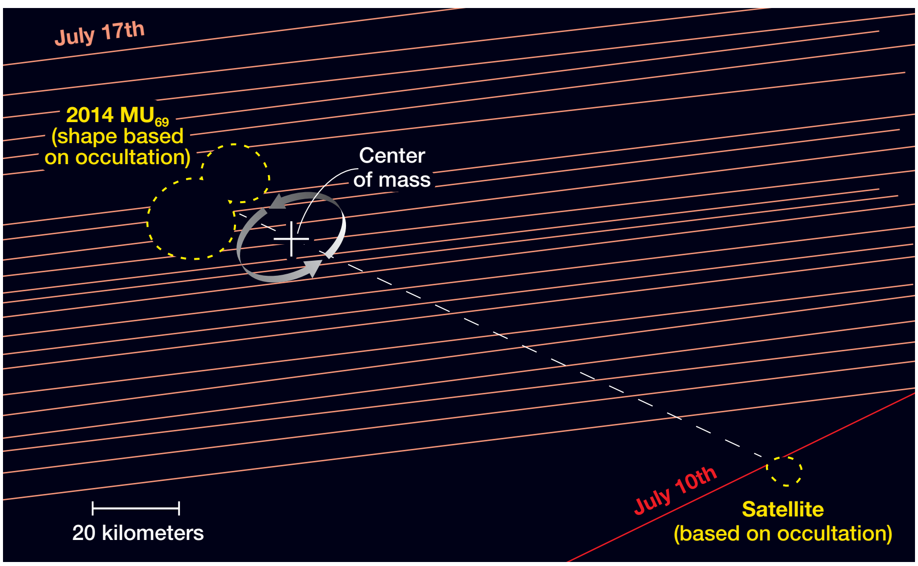
In preparation for the flyby, the team deployed observers across the globe to monitor occultations on June 3rd, July 10th, and July 17th (*S&T:* Oct. 2017, p. 11), as 2014 MU_{69} passed in front of three different stars. The team caught a blip during the second event, then struck gold with the third occultation, as five of 24 observers caught the star blinking out of view.

Analysis of the third event showed that the object could be a binary (*S&T:* Nov. 2017, p. 9). But the plot thickened when the team took another look at the blip recorded during the second occultation. A new analysis, which includes observations of 2014 MU_{69}'s orbit around the Sun using data from the Gaia mission, suggests the blip is evidence for a third member of the system: a much smaller moon orbiting at a larger distance from the closer binary.

"This is probably a sign that the object itself was not a collisional fragment. We think [2014 MU_{69}] was made like this," says Marc Buie (Southwest Research Institute). However, he cautions that the three-body explanation isn't a final result; further observations could change the scientists' conclusions. Regardless of how many pieces the little world consists of, it will shed light on the planet-forming environment of our system's earliest years.

■ MONICA YOUNG

▼ Colored chords mark the path of background stars as seen from different telescopes on three different days. The blank spaces on those lines indicate the few seconds when 2014 MU_{69} blocked the light from the star.



NASA / JHUAPL / SWRI / JAMES TUTTLE KEANE

● To see what we can expect from the New Horizons mission in the coming months, go to https://is.gd/newhorizonstimeline.

SOLAR SYSTEM

`Oumuamua: Tumbling & Silent

AFTER THE DISCOVERY of what proved to be an object from interstellar space (*S&T:* Feb. 2018, p. 10), astronomers at observatories worldwide scrutinized this unique visitor before it zipped out of the inner solar system, never to return. Those measurements confirm that `Oumuamua (or 1I/2017 U1, as it's officially cataloged) is a rocky, modestly red object about 200 m (700 ft) long.

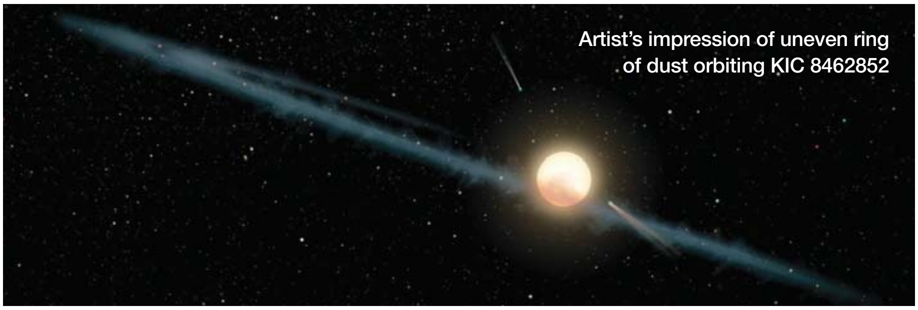
The object also displayed surprisingly wild swings in brightness of up to 2½ magnitudes — a factor of 10! — that argue for a length at least five times its width.

Such a dramatic light curve should easily yield a rotation period, but initial reports of a 7- or 8-hour spin rate proved premature. Instead, multiple teams have deduced that the object appears to be in an "excited rotational state," that is, spinning along more than one axis.

Such tumbling is rare among our solar system's asteroids and comets. Comet 1P/Halley is one of the exceptions, driven by assorted gas jets from its nucleus. But `Oumuamua shows no hint of outgassing, and the chance that it struck something in our solar system prior to its discovery seems impossibly remote. Most likely, it had a rough time escaping its system of origin. If so, its tumbling has already lasted a long time and will likely last longer still.

Meanwhile, Breakthrough Listen — the initiative to find signs of intelligent life in the universe — funded an effort to eavesdrop on any radio waves `Oumuamua might be broadcasting. Researchers didn't *expect* to pick up alien communications from this interloper, but they wanted to check anyway. Their observations on December 13th using the Robert C. Byrd Green Bank Telescope in West Virginia didn't turn up any radio beacons or other transmissions.

■ J. KELLY BEATTY


Artist's impression of uneven ring of dust orbiting KIC 8462852

STARS

New Observations of Boyajian's Star

NEW DATA ON KIC 8462852, also known as Boyajian's Star (*S&T:* June 2017, p. 16), show that dust — not an alien megastructure — is causing its mysterious behavior. Results will appear in the *Astrophysical Journal Letters*.

Tabetha Boyajian (Louisiana State University) and colleagues reported the star's discovery in 2016 in archived Kepler data. The star dipped in brightness by up to 22% for several days at a time. Long-term observations also showed the star fading over the years.

To obtain round-the-clock observations that could catch the star as it was dipping, Boyajian launched a Kickstarter campaign to secure funding for observations with the Las Cumbres Observatory (LCO), a network of 0.4-m robotic telescopes around the globe.

In May 2017 the team caught the first real-time change, a minor event that obscured 1% of the star's light. The star's blue light dimmed slightly more than redder wavelengths during the event, indicating that whatever material is involved, it's not solid. That's a strike against the unlikely idea of "alien megastructures" around the star.

Instead, the data suggest cosmic dust, 1,000 times smaller than the smallest grains of sand, is the culprit. Since the star's light exerts radiation pressure that would easily blow such small grains out of orbit, any dust near the star must have arrived there recently, perhaps from a swarm of comets, asteroids, or a dusty planetesimal. Dust that has been ejected to greater distances might dim the star over longer time scales.

Most dust-producing objects would orbit the star. Based on the estimated orbit, Boyajian and colleagues have predicted that the next set of dips should occur in June 2019.

■ JOHN BOCHANSKI

EXOPLANETS

Metal-enriched Stars Host Closer Planets

IRON-RICH STARS are more likely to have planets on closer orbits, Robert Wilson (University of Virginia) announced at the Washington, D.C. meeting of the American Astronomical Society. This unexpected result could help reveal how planets form.

Stars and their planets form out of the same natal gas cloud, which leaves its impression on a star's *metallicity*: the abundance of elements heavier than hydrogen and helium. Previous studies have shown that metallicity plays a role in planet formation, but it's unclear how.

Wilson studied 282 confirmed and candidate Kepler planets, using spectroscopic measurements from the Sloan Digital Sky Survey to reveal each star's iron abundance, a proxy for its total metallicity. To Wilson's surprise, the stars richest in iron host planets on scorchingly close orbits of about 8 days or less, while stars with lower iron abundances have planets on farther-out orbits.

The results point to different histories for the two types of systems. A higher abundance of heavy elements might affect how planet-forming disks form and evolve.

■ MONICA YOUNG

BOYAJIAN'S STAR: NASA / JPL-CALTECH; KEPLER-90: NASA / WENDY STENZEL

EXOPLANETS

Neural Network Finds Two Earth-Size Planets

A UNIQUE COLLABORATION between an astronomer and a Google engineer has led to the creation of a kind of artificial intelligence known as a *neural network* (*S&T:* Dec. 2017, p. 20). Set on data from the Kepler mission, the algorithm discovered two new Earth-size planets, one of which is part of the first eight-planet system outside our own.

Neural networks are loosely based on connections between neurons in the brain. Each "neuron" is a simple mathematical formula that acts like a switch, turning on when it recognizes a certain pattern. Each set of neurons passes its results on to the next layer.

By combining layers, Christopher Shallue (Google Brain) built an algorithm that can identify exoplanet transit signatures in stellar light curves. It learned how by training on a set of

GAMMA-RAY BURSTS

Did Colliding Neutron Stars Choke Their Own Jet?

THE NEUTRON-STAR SMASHUP that LIGO detected last year might point toward a new class of sources.

A quick burst of gamma rays followed the first-ever gravitational-wave detection of merging neutron stars, known as GW170817. Some astronomers heralded this event as definitive proof that neutron-star collisions cause *short gamma-ray bursts* (GRBs), high-energy flashes less than 2 seconds long.

Artist's concept of failed-jet scenario

NRAO / AUI / NSF / D. BERRY

A short GRB would have sent a gamma-ray-emitting jet toward Earth. But in a study to be published in *Nature*, Kunal Mooley (University of Oxford, UK) and colleagues report radio-wave observations that don't match this simple jet scenario. Instead, the data add to a growing argument that this source is anything but typical of short GRBs (*S&T:* Feb. 2018, p. 32).

GW170817 posed a problem from the beginning. This event was 10,000 times dimmer than other short GRBs. Many astronomers thought that might be because the jet was facing slightly away from Earth, but others proposed that the jet had choked on surrounding debris. To test these scenarios, Mooley and colleagues tracked GW170817's radio afterglow for more than 100 days after the collision.

If the jet were simply pointed in another direction, Mooley's team would have detected its signature as a sudden increase in radio waves. Instead, they saw a gradual brightening. They interpret the radio glow as a cocoon surrounding the smashup: If the jet failed to punch through the material kicked out in the merger, it would have transferred most of its energy to the debris, pushing it outward into a bubble-like structure.

The cocoon model also jibes with new Chandra X-ray Observatory data reported January 18th in *Astrophysical Journal Letters*, which show that X-rays from the event continue to brighten.

If this scenario holds up, GW170817 could mark an entirely new class of GRBs. But the debate rages on: Several papers in the pipeline argue that a successful, off-axis jet can better explain the latest data, returning this event to its status as a typical short GRB.

■ SHANNON HALL

15,000 Kepler light curves previously studied by humans. Andrew Vanderburg (University of Texas, Austin) then ran a preliminary sample of 670 stars through the standard pipeline to identify signals to feed to the algorithm. The neural net caught two rocky planets, Kepler-90i and Kepler-80g, both having roughly 14-day orbits. The discovery appears in the January 18th *Astronomical Journal*.

Kepler-90i is the eighth planet discovered in its tightly packed system. Kepler-80g is the sixth planet in its system, orbiting its star in resonance with four of its companions. The resonance keeps the orbits stable, even though they're more compressed than Kepler-90's. Neither planet offers a pleasant place to live: Surface temperatures are 710K (820°F) and 420K, respectively.

Eventually, Shallue and Vanderburg want to expand their project to study all 150,000 stars in the Kepler field, but they'll proceed with caution. A neural network is only as good as it was taught to be; it can't generalize what it has learned in the same way humans can.

■ MONICA YOUNG

◀ Kepler-90i is the third planet from the left in this artist's illustration of its scrunched system. All eight planets would fit within Earth's orbit.

IN BRIEF

Meteoroids Explode from the Inside

Space rocks breaking up in Earth's atmosphere might be their own Trojan horses. Spurred by an attempt to understand why the 2013 Chelyabinsk meteoroid fragmented so easily, Marshall Tabetah and Jay Melosh (both at Purdue University) simulated the rock's interaction with the surrounding air as it dove through the atmosphere. The key was the meteoroid's porosity, which hadn't been included in previous simulations. Asteroids are more like piles of coarse gravel than solid boulders. As one of these rocks shoots through the atmosphere, a bow shock forms around it, with piled-up air in front and a vacuum in the wake. This setup creates something of a suction effect, with the high-pressure air in front shooting through the rock's fractures to fill the vacuum behind. The air's infiltration breaks the meteoroid apart from the inside out. The team's paper appeared December 11th in *Meteoritics & Planetary Science*.

■ CAMILLE M. CARLISLE

Exoplanet Loops Over Star's Pole

Reporting December 18th in *Nature*, Vincent Bourrier (Geneva University Observatory, Switzerland) and colleagues have found that the Neptune-mass exoplanet GJ 436b orbits around its star's poles rather than its equator. The default in planet formation is for worlds to coalesce from a dusty disk of gas around a newborn star's middle, a consequence of the conservation of angular momentum. Furthermore, huge planets close to their parent stars "should" be on circular, equator-aligned orbits due to tidal interactions. But GJ 436b is wonky: The team's 3D mapping of the planet's trajectory, coupled with measurements of the star's rotation, reveal that the gaseous world is following an elongated orbit that passes over the star's pole. This setup suggests that an outer, unseen exoplanet might have driven GJ 436b inward to its current location. The migration would also have exposed the planet's atmosphere to more starlight and might have triggered GJ 436b's comet-like atmosphere.

■ CAMILLE M. CARLISLE

GALAXIES

Ordered Galaxies in Chaotic Early Universe

ASTRONOMERS EXPECTED that most galaxies living among the chaos of the infant universe would be turbulent and disorganized free-for-alls. But new observations have revealed surprisingly mature galaxies when the universe was only 800 million years old.

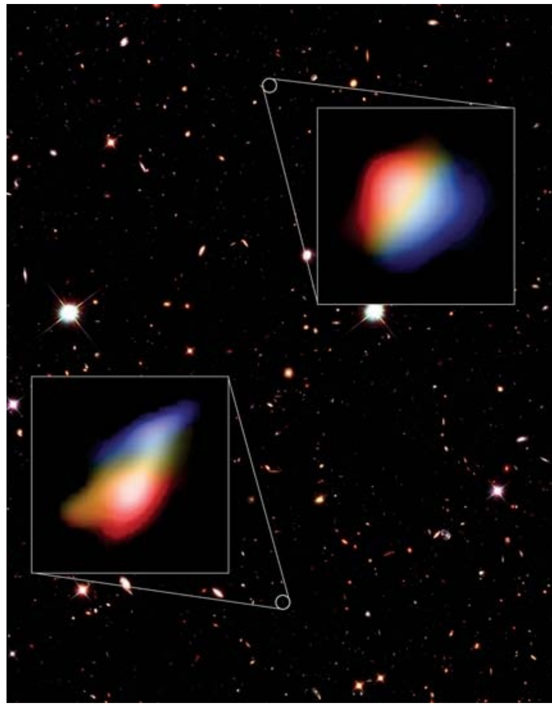
Renske Smit (University of Cambridge, UK) and colleagues report in the January 11th *Nature* that two galaxies have already settled into rotating disks, suggesting rapid evolution right after they were born.

Smit and colleagues first found the two galaxies in deep Spitzer Space Telescope images, then followed up using the Atacama Large Millimeter/submillimeter Array (ALMA), a network of radio dishes high in the Atacama Desert in Chile. ALMA's incredible resolution enabled the astronomers to measure radiation from ionized carbon — associated with forming stars — across the face of these diminutive galaxies.

These observations show galaxies forming 20 Suns' worth of stars every year, more than is typical for that time period. In fact, they look more like the fluffy disks typically seen at so-called *cosmic noon*, the universe's adolescent period of star formation and galaxy growth. That implies rapid evolution, as cosmic noon occurred more than 2 billion years after these two galaxies existed. (They probably don't have spiral arms, though, as such features take more time to form.)

Simulations had predicted that it's possible for some galaxies to evolve more quickly than their peers do, notes Nicolas LaPorte (University College London), but this is the first time it's actually been observed.

■ MONICA YOUNG



▲ This data visualization shows the velocity gradients across two young galaxies, indicating that they've already settled into rotating disks.

OBITUARY

Comet Discoverer Thomas Bopp (1949–2018)

THOMAS JOEL BOPP, codiscoverer of Comet Hale-Bopp, died January 5, 2018, in Phoenix, Arizona, from liver cancer. He was 68 years old.

Bopp's name will forever be linked to that of his friend and colleague Alan Hale. But the observers didn't know each other before they became inadvertent partners in one of the greatest comet discoveries of the 20th century.

On the night of July 22, 1995, Bopp was out stargazing with friends. Alan Hale, a professional astronomer, was at his home in New Mexico. Both men spotted the fuzzy object within 5 minutes of each other and sent messages to Brian Marsden at the Central Bureau for Astronomical Telegrams.

Their names were attached to Comet Hale-Bopp (C/1995 O1), which ultimately brightened to magnitude –1 near its perihelion on April 1, 1997 — a stunning evening object seen by more than two-thirds of all Americans.

As his fame grew, Bopp left his job due to a heavy schedule of public appearances. He and Hale were media darlings, appearing on TV and in newspapers and magazines. Along with other accolades, Bopp was awarded an honorary doctorate from Youngstown State University. But the discovery also brought tragedy, when Bopp's brother and sister-in-law were killed in a car accident after spending a night photographing the comet.

Bopp was born in Denver, Colorado, on October 15, 1949, and grew up in Youngstown, Ohio. Introduced to the sky by his father, Bopp received his first telescope (a 4-inch reflector) when he was 10 years old. But he didn't start deep-sky observing until after he left the Air Force in 1972.

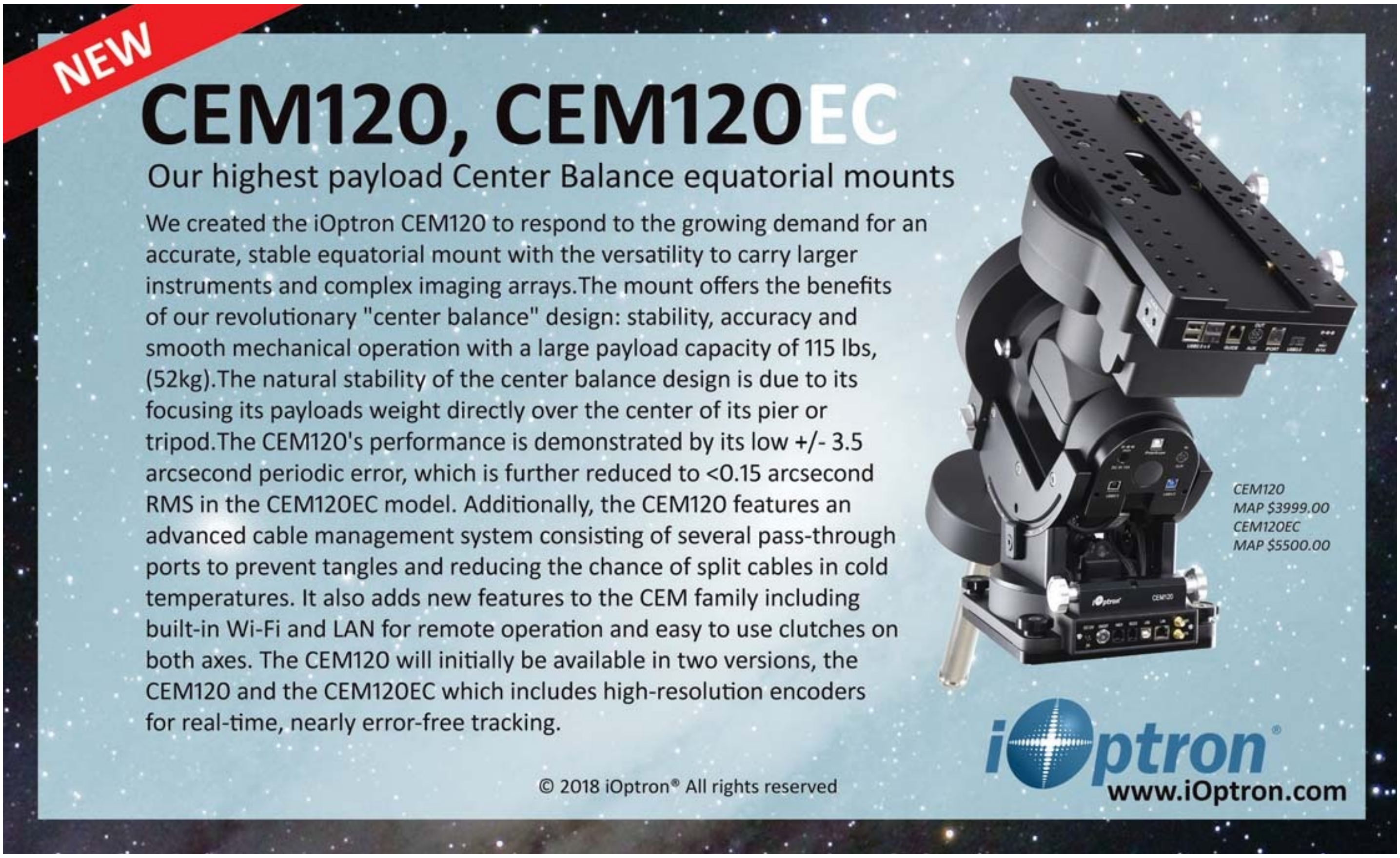
Bopp and his family moved to Glendale, Arizona, where he met Jim Stevens, another local amateur astronomer. The two became friends and spent weekends observing with Stevens' 17.5-inch Dobsonian reflector. It was on one of those trips — while looking at M70 through the big Dob — that Bopp chanced upon the comet.

Bopp continued to pursue his passion for stargazing until his death. He is survived by his daughter, April Bopp-Esch, along with a granddaughter, three sisters, and two brothers.

■ CAROLYN COLLINS PETERSEN

● **To read more about Thomas Bopp's life and see additional images, visit https://is.gd/boppobit.**

BOPP: KEVIN GILL; YOUNG GALAXIES: HUBBLE (NASA / ESA), ALMA (ESO / NAOJ / NRAO), P. OESCH (UNIV. OF GENEVA) & R. SMIT (UNIV. OF CAMBRIDGE)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The First Galaxies

Astronomers are traveling backwards in time to observe our universe's early history.

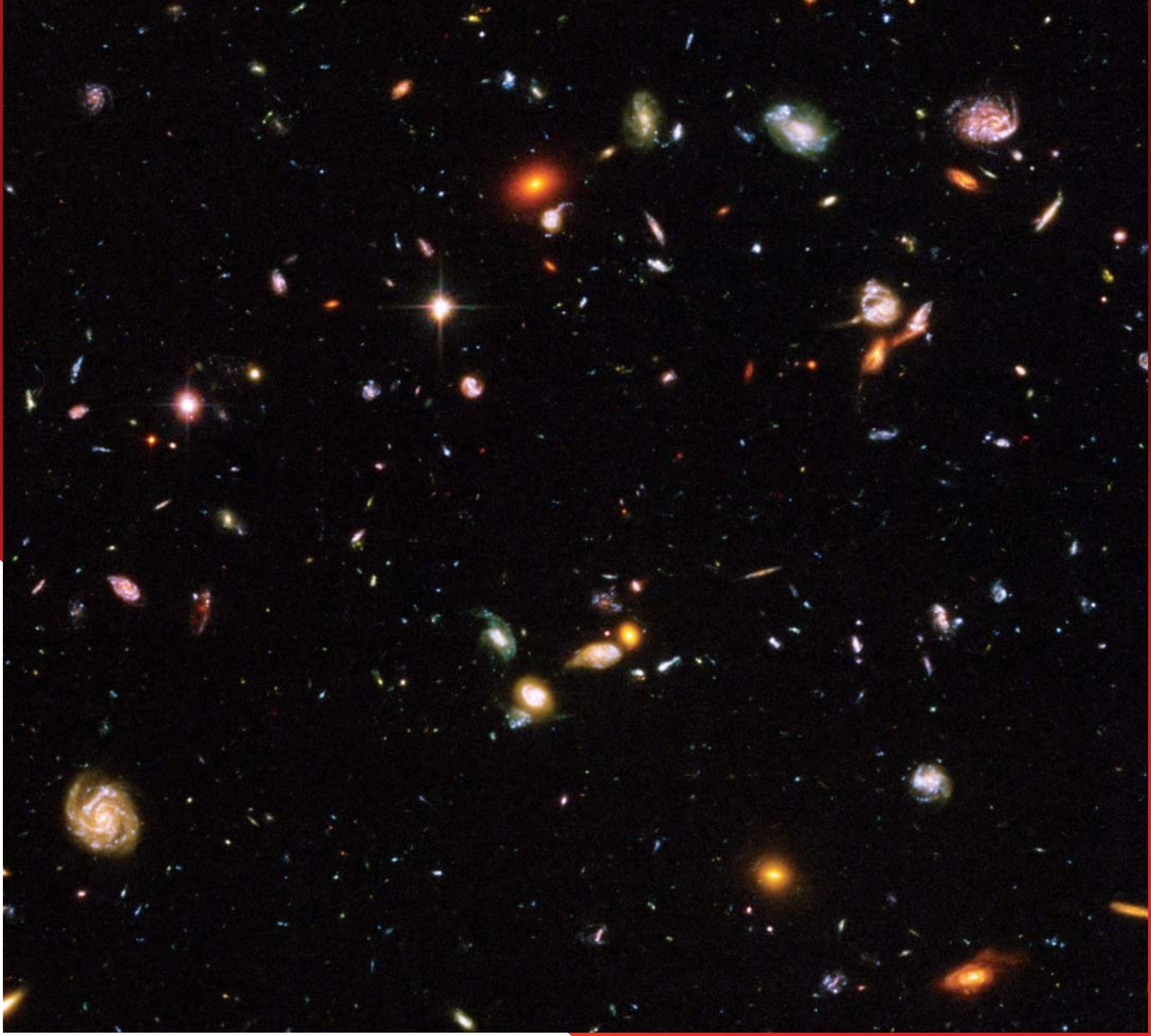
There's a certain exhilaration in hunting for the most distant galaxies in the universe. It's that feeling of pushing back the boundaries. Seeing a bit farther than anyone before you.

But I bet if you ask most astrophysicists who study the formation and evolution of galaxies, it's not the distance in space that excites them, but the distance in time. Electromagnetic radiation travels at a finite speed, and the light emitted by distant galaxies can take billions of years — large fractions of the age of the universe — to reach us. We see those distant galaxies as they were in the past, at the moment the light left them. Our ultimate goal is to detect the light emitted by the first galaxies: the cosmic dawn.

Remarkably, we're getting close. Any long-exposure image will reveal a universe teeming with galaxies; current estimates put the total number of galaxies around the trillion mark. As the sensitivity of CCD cameras improves and the size of telescopes increases, it has become routine for deep astronomical surveys to detect galaxies seen at a time when the universe was a small fraction of its current age.

These infant galaxies are much too far away for light-years to be a useful metric. Rather than thinking in distance units, we use the galaxies' *cosmological redshift* (see box on page 17) as a proxy for their distance.

The universe — space itself — has been expanding ever since it came into existence in the Big Bang. The wavelength of an electromagnetic wave traveling through the expanding universe will stretch so that blue light emitted by a distant galaxy will have become red light by the time we detect it. The amount the wavelength has stretched tells us how much the universe has expanded since the photon began its journey. If we know the history of the expansion (since space



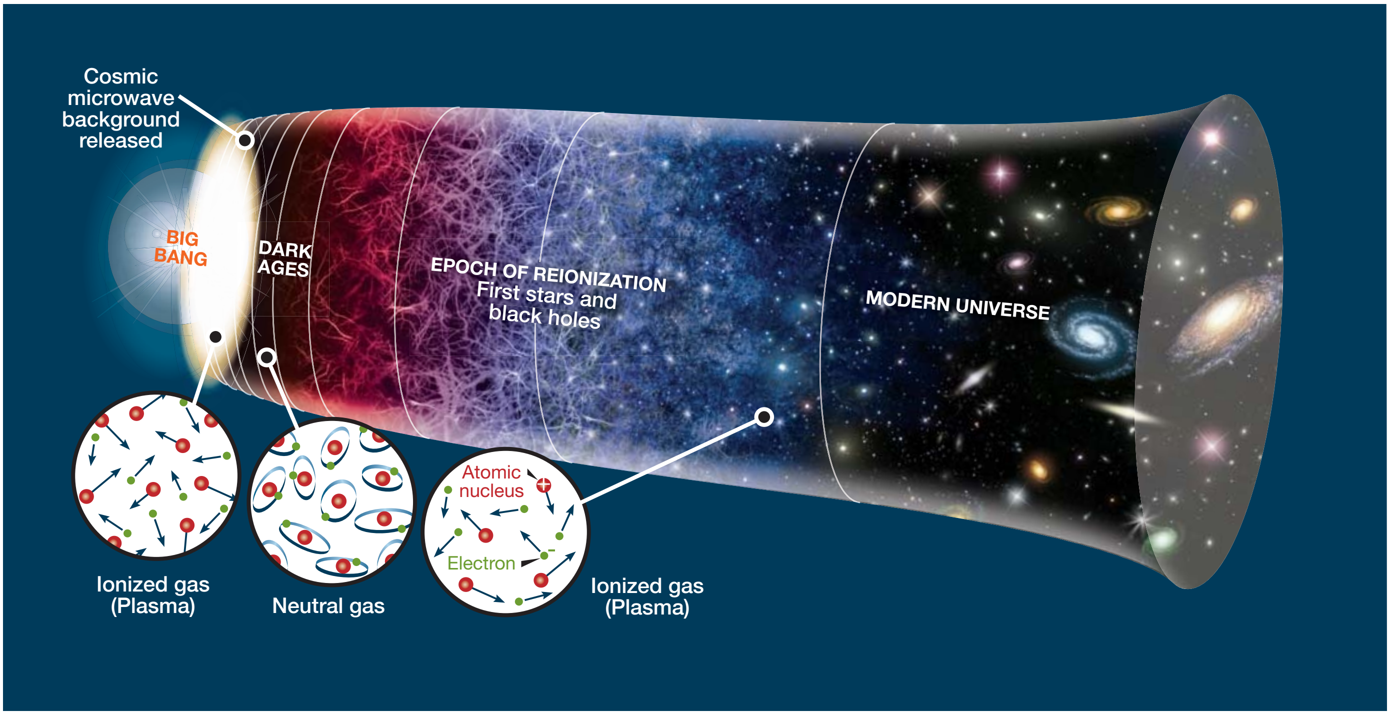
hasn't grown at a steady rate), then we can use redshift to say something about how far away that galaxy is and how far back in time we are seeing it.

Although we have observed galaxy formation over most of the history of the universe, we still don't know how galaxies first formed. We have models and simulations, but not the observations to test them. This is why we need to see the earliest galaxies. In fact, what we'd really like to know is when we *stop* seeing galaxies.

Cosmic Dropouts

Measuring the redshift of very distant galaxies isn't easy. They're faint, and typically we need to disperse the small amount of light we do detect into a spectrum, thinning it out like butter spread over hot toast, in order to see how much light we receive at each wavelength. The spectrum allows us

▲ **GOING DEEP** The Hubble Ultra Deep Field, a 1 million-second exposure of a tiny region of sky in Fornax, contains nearly 10,000 galaxies. The well-defined ellipticals and spirals are relatively nearby; the smallest, reddest galaxies in the image above are among the most distant known.



▲ **HISTORY OF THE UNIVERSE** The period after the Big Bang, when charged particles trapped photons, gave way to the the Epoch of Recombination, when particles combined into atoms and released the photons we now know as the cosmic microwave background. Soon after that, in the Epoch of Reionization, higher-energy emissions from the first stars began once again stripping electrons off hydrogen atoms.

LEAH TISCIONE / S&T

to identify key features, such as the spike-like emission lines of excited hydrogen gas, to determine precisely how much those lines have redshifted.

If we want to hunt for the first galaxies, we need a lot of light-collecting area — that is, a big telescope — and a sensitive spectrograph. Still, there are far too many galaxies to measure the spectrum of each one. Technological advances are helping to solve that problem (*S&T:* Mar. 2018, p. 11), but astronomers still commonly save time by narrowing down the search, preselecting those few galaxies in an image of thousands that are likely to be the most distant ones.

In the 1990s astronomers developed a deceptively simple and economic method to do just that, identifying galaxies at very high redshift using images alone. The trick works because galaxies, and the wider intergalactic medium, contain a lot of neutral hydrogen gas. This gas is very efficient at absorbing photons with wavelengths below 91.2 nanometers. This means that the spectrum of a typical galaxy in the distant universe has a pronounced dip, or "break," at that wavelength. At wavelengths below this so-called *Lyman break*, neutral hydrogen gas, either in the galaxy itself or in the intervening medium, absorbs most of the photons.

In practice this means that we can use a filter that only lets through wavelengths of light *below* the Lyman break and compare it to an image of the same patch of sky filtered to only allow wavelengths *above* the Lyman break. Some galaxies appear to "drop out" of the shorter-wavelength filter — they are simply too faint to detect in the bluest band.

Now, the clever bit is when cosmological redshift comes into the picture. In more distant sources, the observed position of the Lyman break redshifts to longer wavelengths. That means that a more distant galaxy will disappear at a longer wavelength than a closer galaxy will. So, as we try to chase the galaxies to higher and higher redshifts, we can turn to different combinations of filters. The filter in which a galaxy vanishes from view gives a pretty strong clue as to the galaxy's *photometric redshift*, even without a spectrum; spectroscopy can later provide unambiguous confirmation.

But this method for determining redshift, now more generally referred to as the *dropout technique*, has a catch: Distant sources of light are also faint. So, although the technique is efficient, astronomers still need an exceptionally sensitive instrument and very deep observations to find the earliest galaxies. Without question, the instrument that has allowed us to best exploit the dropout technique — and given us the clearest glimpse of the earliest galaxies — is the Hubble Space Telescope. Hubble's Deep Fields are tiny windows onto the distant universe, keyholes that the telescope has spent millions of seconds staring through to reveal thousands of galaxies in small patches of sky no larger than 1% of the angular area of the full Moon. Some of those galaxies appear merely as clumps of a few pixels, nearly lost amid the noise. Nevertheless, those pixels represent light from some of the earliest galaxies we know about, and they have allowed us to start piecing together the picture of galaxy formation within half a billion years of the Big Bang.

Cosmological Redshift

Redshift compares the observed wavelength of light with its wavelength when it was emitted. Hydrogen, for example, can emit light at 121.6 nm, but in a faraway galaxy we observe that line at redder wavelengths due to *Doppler shift*.

By comparing the two wavelengths — emitted and observed — *cosmological redshift* tells us the size of the universe today relative to the size of the universe then.

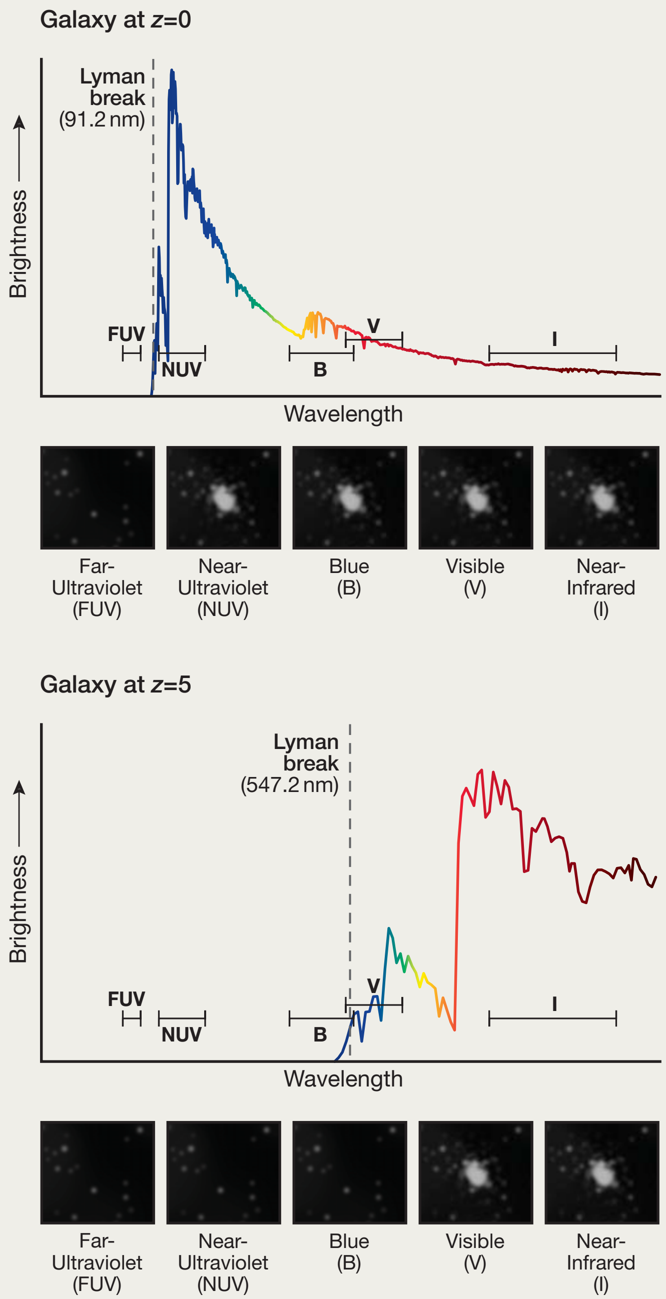
Here's the equation that describes this:

$$z = \frac{\lambda_{\text{observed}}}{\lambda_{\text{emitted}}} - 1$$

where λ is the wavelength.

Galaxies very near the Milky Way have a redshift of nearly 0, which means that the wavelengths we observe are about the same as those originally emitted. (Gravitational attraction also drives relative motions between galaxies, but any resulting shifts in wavelength are unrelated to the universe's expansion and hence to the galaxies' distances.)

The wavelengths of light from a galaxy with a redshift of 1 (that is, emitted in a universe roughly half its current age) will double by the time they reach us. A galaxy in the early universe, at a redshift of 10, will have had its light stretched by a factor of 11, pushing ultraviolet wavelengths to much longer (redder) wavelengths, near the infrared part of the spectrum.



COSMIC DROPOUTS Splitting light from a typical galaxy into its component colors results in a spectrum like the one shown at top, spanning far-ultraviolet to near-infrared wavelengths. Neutral hydrogen gas absorbs light emitted below the so-called Lyman break at 91.2 nanometers. Thanks to the break, examining the light at different filters reveals the distance to faint, faraway galaxies without actually having to measure their spectra. Because the expansion of the universe stretches the wavelengths of light traveling through it, the wavelength at which the Lyman break is observed shifts redward, so that the galaxy becomes unobservable at shorter wavelengths.

Cosmic Dawn

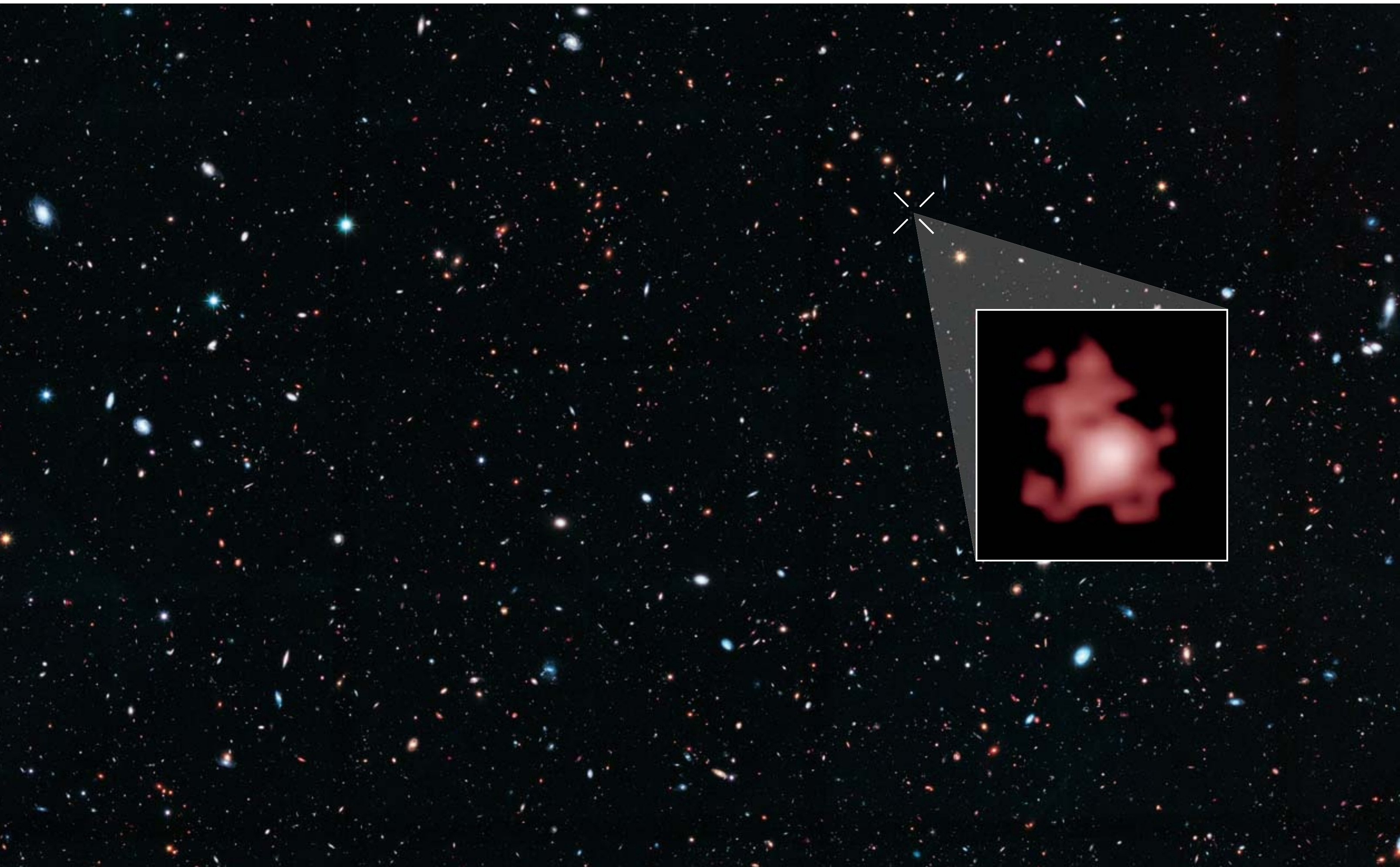
Besides the obvious prize of discovering the most distant object, why do we really care about finding the first galaxies? Because they are the missing piece of our picture of galaxy formation. We don't know how or exactly when the first galaxies ignited, or what their properties were, and that's frustrating. To rectify the situation, we must explore the earliest frontier of galaxy formation.

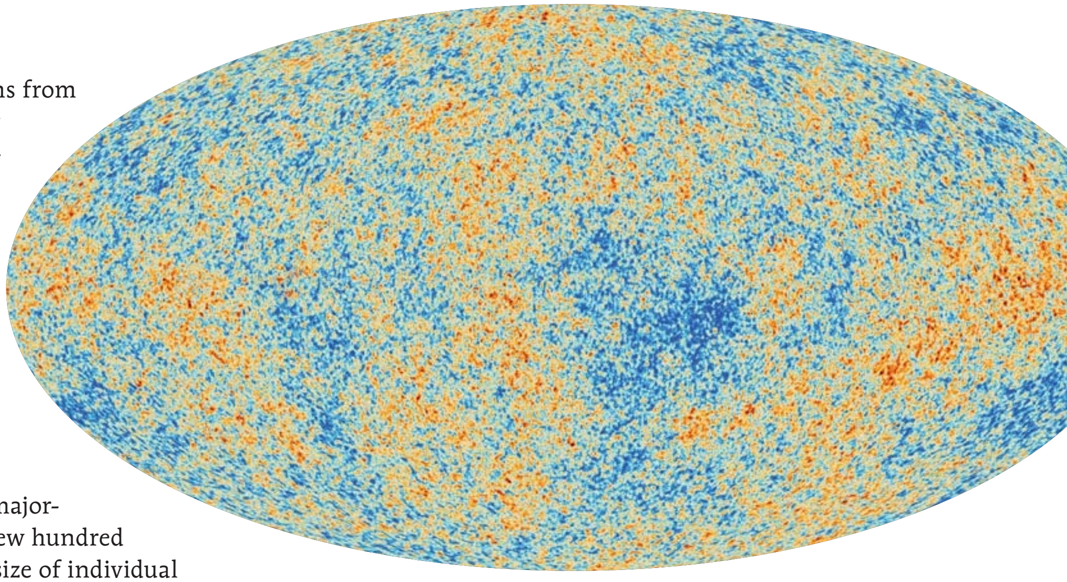
For the first few hundred thousand years of cosmic history, there were no atoms in the universe, just a hot broth of particles and photons. But about 370,000 years after the Big Bang, in what is known as the *Epoch of Recombination*, the universe cooled sufficiently for free electrons to bind to protons, transitioning the cosmos from a totally ionized phase to one that was electrically neutral. At this point most of the normal matter in the universe was in the form of neutral hydrogen atoms.

This vast medium wasn't smooth. Gravity had teased the subtle density fluctuations present at the start of the universe into thicker filaments and clumps, where dark matter and gas had gradually pooled and coagulated to form the seeds of the first galaxies.

At some point, a few hundred million years after the Epoch of Recombination, the first stars in these proto-galaxies flashed into life and streamed ionizing starlight into the universe around them. Some of this radiation was energetic

What did these reionizing galaxies look like? Observations show that when they were bursting into life, the majority of these galaxies were small, just a few hundred light-years across. These young galaxies also had quite low masses, perhaps less than 1% of the Milky Way's mass.





▲ **EPOCH OF RECOMBINATION** As the universe cooled enough to allow electrons and positively charged nuclei to come together into neutral atoms, the space between stars was freed of the ionized plasma that trapped light. Photons escaped, free to roam the universe as what is known as the cosmic microwave background. The Planck telescope's view of this radiation shows us the universe at 370,000 years of age.

enough to again start stripping electrons from the hydrogen atoms in the surrounding intergalactic medium. As galaxy formation took hold, bubbles of ionized gas grew around new galaxies, spreading outward like some sort of disease. After another 500 million years or so, a time period known as the *Epoch of Reionization*, the universe's neutral hydrogen was almost totally turned into plasma.

What did these reionizing galaxies look like? Observations show that when they were bursting into life, the majority of these galaxies were small, just a few hundred light-years across — comparable to the size of individual star-forming regions in the Milky Way and its companions, such as 30 Doradus (Tarantula Nebula; *S&T:* Nov. 2017, p. 24). These young galaxies also had quite low masses, perhaps less than 1% of the Milky Way's mass. Simply not enough time had yet passed for large numbers of stars to form out of the gas reservoirs, or for lots of galaxy mergers to take place. Nevertheless, observations of dropout galaxies show that the average rate of star formation ramped up quickly in these small, low-mass galaxies, starting half a billion years after the Big Bang, if not earlier.

We also have some evidence that galaxies were settling into rotating disks at quite early times. But rather than sedately spinning, Milky Way–like pinwheels, which became prevalent more than a billion years later, early disk galaxies were probably quite clumpy and turbulent.

One of the most important differences between very high-redshift galaxies and those we see in today's universe is in the chemistry of their interstellar medium. Our Sun formed from a gas cloud composed mostly of hydrogen and a bit of helium but "polluted" with heavier elements, known to astronomers as *metals*, that formed in previous generations of stars. Without metal enrichment of the interstellar medium, neither our planet nor the people on it could have formed. But these metals take time to build up: They are made inside stars during nuclear fusion, in supernova explosions, and in other extreme cosmic events. So we expect the first galaxies to be "metal poor" compared to the Milky Way (see page 22).

A lack of metals would mean that these galaxies should also contain relatively small amounts of interstellar dust, which tends to absorb starlight. The ionizing radiation from massive stars would escape the galaxies more easily, making the reionization process quite efficient.

◀ **FARTHEST GALAXY** In 2016 Hubble revealed the infant galaxy GN-z11, a galaxy that existed just 400 million years after the Big Bang and is the most distant galaxy known to date. The background image shows the GOODS-N project, which combines images of a small square of sky in Ursa Major from the Hubble, Spitzer, and Chandra space telescopes, along with data from ground-based telescopes.

FARTHEST GALAXY: NASA, ESA, AND G. BACON (STSCI); PLANCK MAP: ESA / PLANCK COLLABORATION

Moreover, the stars that formed from the metal-poor gas would be metal-poor themselves. Metals absorb ultraviolet photons, which is one reason why metal-poor stars tend to emit lots more of this high-energy light compared to stars today. Observations of some of the earliest star-forming galaxies reveal gas containing oxygen and carbon atoms that are missing more than one electron. Ultraviolet light must have stripped these electrons, which means that much of the starlight escaping from early galaxies was in the form of high-energy photons. These observations again point to an efficient reionization process and a quick cosmic dawn.

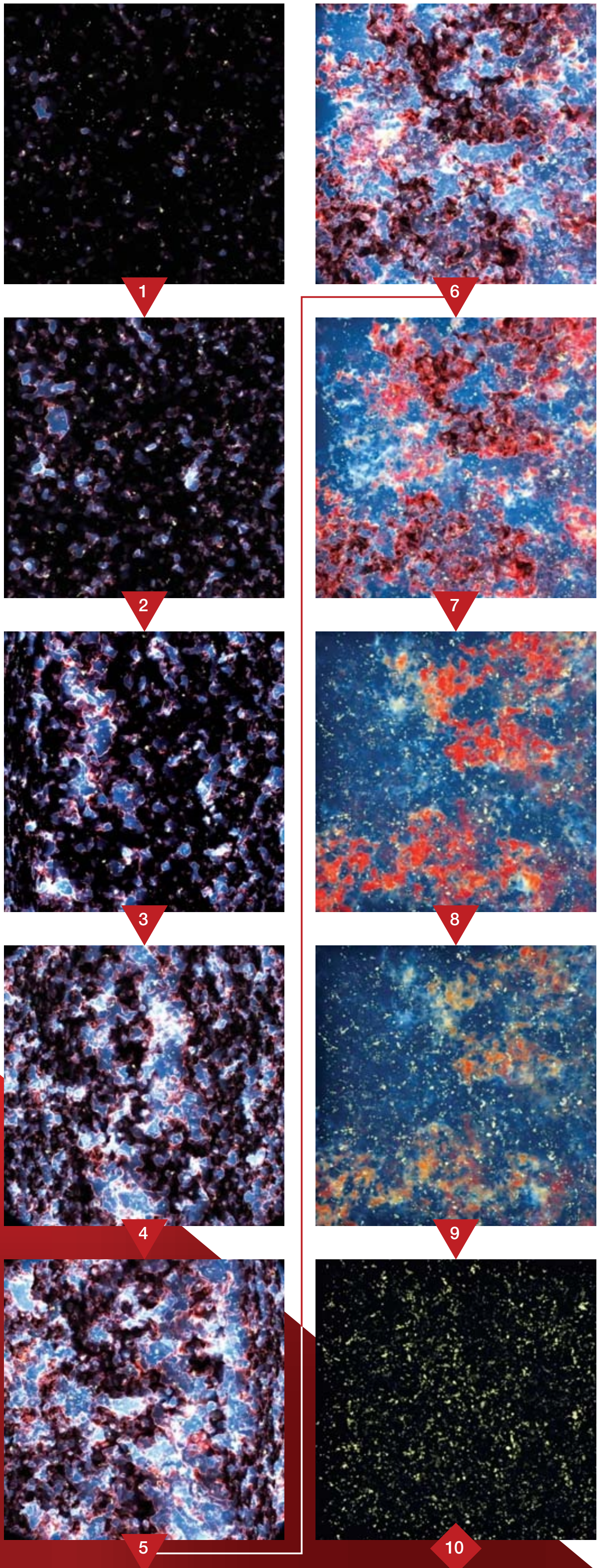
Pulling Back the Veil

Hubble's observations have taken us far, but astronomers are gearing up for two new telescopes that will help us see back even further in time. One is the James Webb Space Telescope (JWST), due to be launched in 2019.

"We have squeezed out every last drop of what the Hubble Space Telescope has to offer," explains Renske Smit (University of Cambridge, UK), a hunter of distant galaxies. "But the fact is, Hubble is limited in how far it can look back in time due to the wavelength range that it can see. The light from the very first stars is redshifted too far into the infrared, out of Hubble's view."

"JWST's uniquely designed infrared capabilities will allow us to look back beyond where Hubble has seen," Smit says.

On the ground, we can look forward to the next generation of 30- to 40-meter megatelescopes. One of these — the European Extremely Large Telescope (ELT) — is now being built some 3,000 meters (10,000 feet) up in the Atacama Desert in Chile. The ELT's huge segmented primary mirror



◀ **SLICES OF REIONIZATION** The first galaxies and their stars lit up the early universe, kicking electrons away from hydrogen nuclei in what is known as the Epoch of Reionization, between 400 million and 900 million years after the Big Bang. What was once a neutral medium between the stars gave way once more to ionized plasma. (The universe remains ionized today, but its much lower density allows photons to still travel freely.) These slices come from a Swiss cheese–like simulation of the process.

provides the collecting area that will enable astronomers to detect starlight and ionized gas in galaxies at cosmic dawn.

JWST and ELT will provide an important next step, but there is a facility online that is already revolutionizing our view of the early universe: the Atacama Large Millimeter/submillimeter Array (ALMA). Sited 2 kilometers higher than ELT, on the Chajnantor Plateau in the Atacama Desert, ALMA is a collection of 66 radio antennas that act as one telescope via interferometry to deliver unprecedented sensitivity and exquisite resolution at wavelengths between about 300 microns and nearly 4 millimeters. ALMA can detect the thermal glow of interstellar dust heated by starlight, as well as emission from cooler gas clouds, even in the most distant galaxies.

One of ALMA's breakthroughs has been to show that the first generation of stars quickly enriched the universe with heavy elements, a development that surprised some astronomers. ALMA has detected light emitted by ionized oxygen and interstellar dust granules in galaxies as far back as a redshift of 8.4, just 600 million years after the Big Bang. These elements can only have been created in and dispersed by stars, yet this was a time when reionization was still in progress — the lights hadn't all been turned on yet. ALMA has also observed the telltale glow of a unusually massive amount of starlight-heated dust — 2.5 billion Suns' worth — in a galaxy at redshift 7, just 200 million years later.

How heavy-element enrichment happened so quickly is one of the key questions for studies of the first galaxies. The answer underpins much of our understanding of the subsequent 13 billion years of galaxy evolution.

Forget Starlight

There's a new way of studying the Epoch of Reionization that's exciting astronomers. Instead of looking at the galaxies, we're trying to detect the signature of the first stars' ignition in the stuff between the stars: the intergalactic medium.

A gas of neutral atomic hydrogen will emit radio waves due to a quantum effect called *hyperfine splitting*. According to the laws of quantum mechanics, the electron and proton in a hydrogen atom can either have the same spins or opposing ones. Atoms with electrons in aligned spins will occupy a state with marginally higher energy than atoms in the opposite, anti-aligned state. Occasionally, an electron's spin can flip, and the atom will release the energy as a photon. Because the energy transition is so small, the photon has a very low energy: We detect it at a frequency of 1.4 gigahertz, corresponding to a wavelength of 21 centimeters.

The gas surrounding galaxies at cosmic dawn is essentially a huge sea of neutral atomic hydrogen, so it releases these

REIONIZATION: M. ALVAREZ (HTTP://WWW.CITA.UTORONTO.CA/~MALVAREZ), R. KAEHLER & T. ABEL; RED GRADIENT: HARDIK PETHANI / GETTY IMAGES

▲ **OBSERVING EXTREMES** This visualization shows the European Extremely Large Telescope, currently being built in the Atacama Desert in Chile. Its segmented primary mirror will span 39 meters, making the ELT the largest visible/infrared telescope on Earth. Its large collecting area will allow it to image aspects of galaxies at cosmic dawn.

radio waves. But like all distant sources of light, the 1.4 GHz signal is redshifted by cosmic expansion. By the time the radio waves reach us, they are at much lower frequencies, around 100 MHz or so for gas at the Epoch of Reionization. The signal is also extremely faint, drowned out by radio emission from sources both within our own Milky Way (such as the Crab Nebula) and in other galaxies. The combination of low radio frequency and weak signal has made detecting neutral hydrogen in the early universe challenging with previous generations of radio telescopes.

But experiments are now under way to record this primordial radio signal and use it to map out reionization. Telescopes such as the Low-Frequency Array (LOFAR), a network of radio receivers spread across Europe, and the new Canadian Hydrogen Intensity Mapping Experiment (CHIME) in British Columbia, are not only trying to detect the radio signal from distant neutral hydrogen, but they're also measuring its fluctuations in brightness, which tell us how reionization actually happened.

As the first galaxies radiate out bubbles of ionized hydrogen, the radio signal from neutral hydrogen should weaken and ultimately vanish. The various sizes and distribution of these bubbles will imprint themselves on the radio signal, enabling us to compare different scenarios for how reionization might have proceeded — without having to detect starlight at all.

It's been less than 100 years since we realized there were galaxies outside the Milky Way. The century after that discovery has seen a journey backward in time as we attempt to understand the origin of galaxies, including our own. Technological advances have allowed us to read this story in the increasingly faint and long-wavelength light coming from the edge of the observable universe. The search for the first galaxies and the Epoch of Reionization is the final (or is it the first?) chapter of that story. What will the next century bring? Well, we've only skimmed the book; now, it's time to appreciate it in detail.

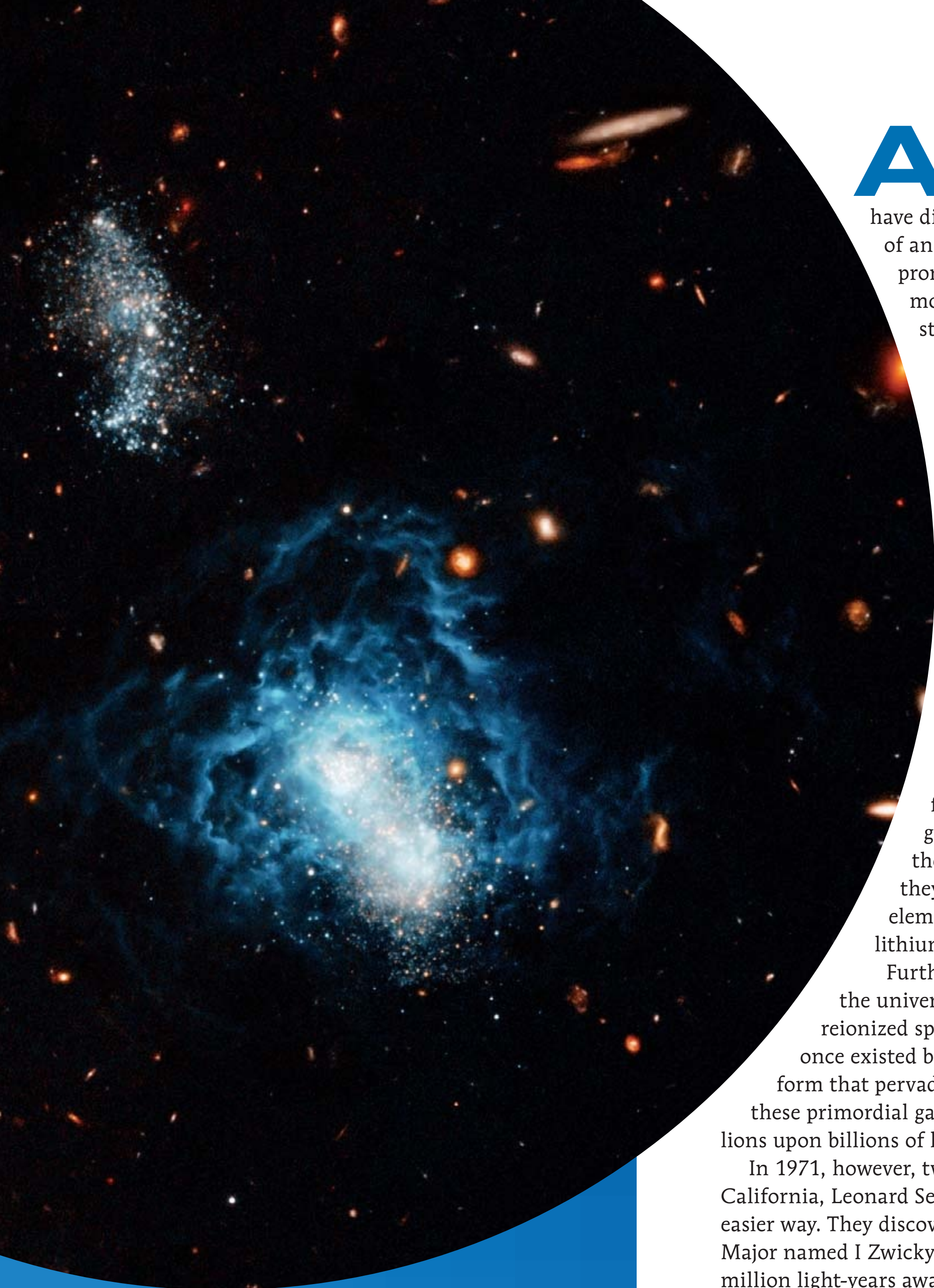
▲ **CAPTURING GALAXIES' SOULS** The Atacama Large Millimeter/submillimeter Array (ALMA) records ionized gas and dust in galaxies in a universe as young as 600 million years old. Its observations have revealed that the first galaxies' stars rapidly enriched the universe with metals.

■ **JAMES GEACH** is an astronomer and Royal Society University Research Fellow at the University of Hertfordshire in the United Kingdom.

 by Ken Croswell

Star-making dwarf galaxies with just a trace of oxygen provide insight into the nature of the first galaxies, how they spawned their stars, and even the Big Bang itself.

The Little Galaxie That Can



Astronomers often pursue extremes: the biggest, the brightest, the farthest, the oldest. Recently observers have discovered the most extreme members of an already extreme celestial class that promises to teach us much about the cosmos: small blue galaxies that spawn new stars yet possess scarcely any oxygen.

A galaxy without oxygen is like a forest without fallen leaves. Massive stars create lots of oxygen during their bright but brief lives, then hurl the element into space when they explode. So it's no surprise that within a billion light-years of Earth, astronomers have spotted fewer than ten extremely oxygen-poor star-forming galaxies.

These galaxies have somehow survived for eons without acquiring much oxygen. Such oddballs are telling us some fundamental things about the early universe, because these galaxies resemble the first ones that ever arose. Primordial galaxies were also small, and because they formed soon after the Big Bang, they should have consisted of the three elements it created: hydrogen, helium, and lithium — with little if any oxygen.

Furthermore, the first galaxies changed the universe. Radiation from their hottest stars reionized space, transforming the neutral gas that once existed between the galaxies into the ionized form that pervades space today. Alas, no one can see these primordial galaxies in detail yet, because they're billions upon billions of light-years distant.

In 1971, however, two British-born astronomers in California, Leonard Searle and Wallace Sargent, found an easier way. They discovered that a much closer galaxy in Ursa Major named I Zwicky 18 has almost no oxygen. A mere 60 million light-years away, the galaxy is a lot easier to study than its distant cousins. Indeed, we now have beautiful Hubble images that show it to be a splotchy blue dwarf galaxy brimming with gas and rambunctious young stars. Yet its abundance of metals — elements heavier than hydrogen and helium — is just a few percent of the Sun's.

"We realized that these galaxies are very, very, very metal-deficient and hence probably the closest proxies to primordial

S

BLUE BACKGROUND: HARDIK PETHANI / GETTY IMAGES; I ZWICKY 18: NASA / ESA / A. ALOISI (ESA / STSCI)

▲ **PRIMORDIAL PRETENDER** Despite hosting a collection of newly formed stars, the dwarf galaxy I Zwicky 18 (larger blue object) has an anemic level of star-produced oxygen. It appears here with a companion called Component C (upper left), which might be a separate galaxy.

galaxies," says Trinh Thuan (University of Virginia), who has spent decades hunting for more in the hopes of finding a galaxy so extreme it has no oxygen at all. The search is worth it, because these curious systems also carry news from the very first minutes of the universe's life.

Fresh Air

Oxygen is an excellent element to study in star-forming galaxies. Of all the metals in the universe, oxygen is the most abundant. Oxygen is also the second most common element in Earth's air (after nitrogen) and its interior (after iron). In most stars, however, oxygen produces few spectral lines, making its abundance difficult to gauge. But when hot stars ionize interstellar gas, oxygen atoms in the gas glow at visible and near-ultraviolet wavelengths that astronomers can detect. Comparing the strengths of these emission lines with those of hydrogen reveals oxygen's abundance relative to hydrogen, the most common element in the universe.

Astronomers often express abundances using a scale on which the hydrogen level is always 12. This scale is logarithmic, so 11 means an element is one-tenth as abundant as hydrogen, 10 means the element is one-hundredth as abundant as hydrogen, and so on. The Milky Way is far bigger and brighter than most other galaxies, and its many stars have blessed it with lots of oxygen — good news for those of us who like to breathe it. Surprisingly, the Sun's exact oxygen abundance is controversial, but it is probably around 8.76. If so, the Sun has 1 oxygen nucleus for every 1,740 hydrogen nuclei.

Because stars create oxygen, galaxies with fewer stars have lower oxygen levels. For example, the Milky Way's two brightest satellite galaxies — the Large and Small Magellanic Clouds — have oxygen abundances around 8.35 and 7.95, respectively, giving them levels that are 39% and 15% solar. I Zwicky 18, the long-time champ among oxygen-deprived star-making galaxies, has an oxygen level of only 7.17. That's just 2.6% of the solar value.

In the Milky Way's disk, gas makes up 99% of interstellar matter and dust 1%. In I Zwicky 18, however, dust accounts for a mere 0.001% of interstellar matter.

These galaxies have proved to be so rare that I Zwicky 18 remained the most oxygen-poor star-forming galaxy known for three decades. Eventually, however, it lost its crown to a blue galaxy three times farther away in Eridanus. The galaxy, named SBS 0335-052W, is part of a larger, oxygen-poor system and is creating new stars. In 2005, Yuri Izotov, Natalia Guseva (Main Astronomical Observatory, Kiev, Ukraine), and Thuan proclaimed this upstart galaxy the new champion. It has an oxygen level of 7.13.

Blue But Not New

Astronomers once suspected that I Zwicky 18 might be a galactic infant, having formed all of its stars recently. Indeed, the galaxy derives its blue hue from bright, massive newborn stars, which wouldn't have had time to enrich their surroundings with oxygen.

Deeper observations, however, have revealed much older stars. Now astronomers think that the galaxy stands out from the pack because nearly metal-free gas is falling onto it from beyond. This incoming gas diluted the galaxy's own, lowering the oxygen level and triggering the rash of starbirth that lights it up today. This idea also explains why the galaxy, though only somewhat less luminous than the Small Magellanic Cloud, has a sharply lower oxygen level.

In 2012, Riccardo Giovanelli (Cornell University) and colleagues used a new technique to find a new type of oxygen-poor star-forming galaxy: a dwarf in Leo much dimmer than I Zwicky 18 that likely owes its paucity of oxygen simply to a dearth of stars that create the element. The astronomers found the little galaxy's hydrogen gas before they saw its stars, picking up its 21-centimeter radiation (see page 14) with the Arecibo radio telescope. The galaxy has the same low level of oxygen as I Zwicky 18, so the astronomers christened the dwarf Leo P, the "P" standing for "pristine."

Leo P is a mere 5 million light-years away. That puts it just beyond the edge of the Local Group, the collection of more than a hundred nearby galaxies — most of them dwarfs much dimmer than the Magellanic Clouds — which two giant galaxies, the Andromeda Galaxy and the Milky Way, govern. In fact, Leo P is the nearest oxygen-poor star-forming galaxy ever found. Emitting less than 1% as much light as I Zwicky 18, Leo P is also one of the least luminous galaxies ever seen engaged in starbirth; most galaxies this dim have run out of gas and lost their ability to make stars. Yet the little galaxy has certainly been around a long time, because Hubble has detected in it RR Lyrae stars, metal-poor pulsators that are more than 10 billion years old. The galaxy's secret? It has wisely avoided giants like our own Milky Way, which steal gas from smaller galaxies.

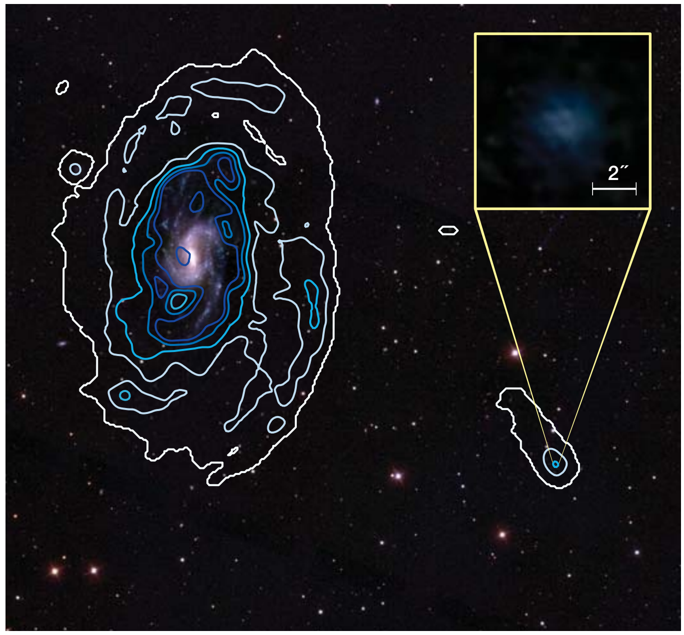
Leo P faces two challenges in trying to raise its oxygen level: It has few stars to forge the element and lacks the gravitational clout to hold on to it when they do. "It's tough being a little galaxy," says Kristen McQuinn (University of Texas, Austin). She estimates that Leo P has lost 95% of the oxygen that its stars created, because when they blew up, they shot the element away so fast the galaxy couldn't retain it.

In 2015, another galaxy first came to attention via its radio-emitting gas. When Alec Hirschauer, John Salzer (Indiana University), and colleagues examined an optical spectrum, they discovered the galaxy was a record-breaker. "It was obvious that it was very metal-poor," Salzer says. "My first reaction was: Well, we'd better be really sure of this." A second spectrum confirmed the first, yielding an oxygen level of only 7.02. Because this galaxy lies in Leo Minor, the Lesser Lion, the discoverers dubbed the dwarf Leoncino, which is Italian for "little lion."

◀◀ IS THAT A GALAXY? In 2012, astronomers discovered the closest oxygen-poor star-forming galaxy, Leo P (the P is for "pristine"). It lies just beyond the fringe of the Local Group of galaxies and has the same oxygen abundance as I Zwicky 18 but is much smaller and fainter.

◀ LITTLE LION The galaxy AGC 198691, nicknamed Leoncino, has an oxygen abundance of only 7.02 and abounds with gas. It's one of the most oxygen-poor star-forming galaxies known.

LEO P: NASA / ESA / KRISTEN MCQUINN (UNIV. OF TEXAS, AUSTIN); LEONCINO: NASA / A. HIRSCHAUER & J. SALZER (INDIANA UNIV.) / J. CANNON (MACALESTER COLLEGE) / K. MCQUINN (UNIV. OF TEXAS, AUSTIN); LITTLE CUB: IMAGE: SDSS COLLABORATION, CONTOURS: T. HSYU ET AL. / *ASTROPHYSICAL JOURNAL LETTERS* 2017



▲ BARELY THERE The Little Cub satellite (zoomed-in image inset) of NGC 3359 isn't much to look at in optical and infrared wavelengths. It has 100 times more gas than stars, though, and shows up in radio observations of neutral hydrogen (contours).

In 2016, Tiffany Hsyu (University of California, Santa Cruz) and her colleagues spotted a small blue galaxy in Ursa Major they named the Little Cub for its location in the constellation representing the Great Bear. This galaxy might orbit the beautiful barred spiral NGC 3359, and the interaction between the two galaxies might have sparked the birth of stars in the smaller galaxy. Its oxygen level is 7.13.

"These oxygen-poor galaxies give us a good idea of what star formation might have been like in the early universe, because the early universe was much more metal-poor than the universe we live in today," Hsyu says. The smallest star-forming galaxies, such as Leo P, lack oxygen for the same reason the first galaxies after the Big Bang did: They haven't made many stars. Even in larger dwarf galaxies like I Zwicky 18, where infalling gas has diluted native gas, star-forming conditions should mimic those in the primordial galaxies.

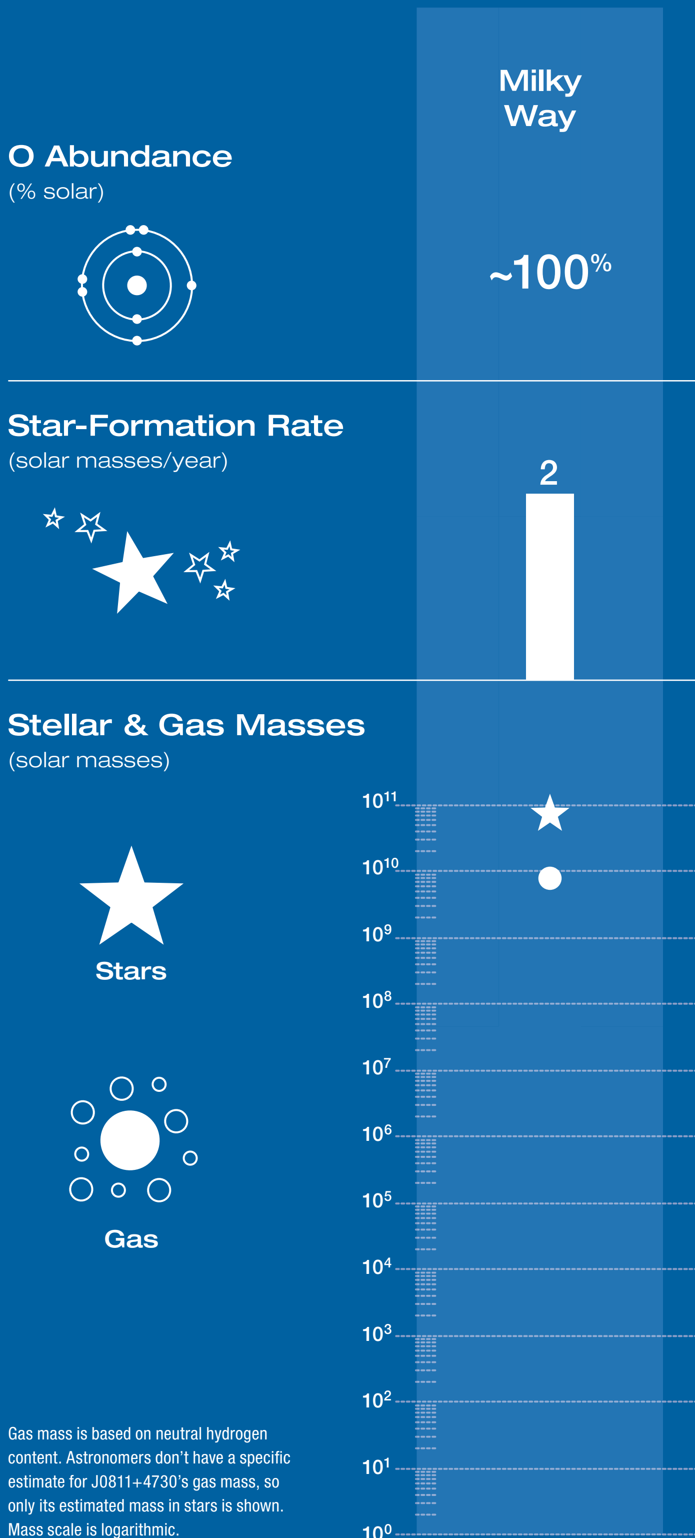
The galaxies certainly abound with the chief requirement for star formation: gas. In the Milky Way's disk and bulge, stars outweigh the gas, but in Leo P it's the other way around. In Leoncino, the gas is 50 times more massive than the stars, and the Little Cub has 100 times more gas than stars. These galaxies possess so little oxygen in part because they've converted so little of their gas to stars.

Despite all their gas, oxygen-poor galaxies have precious
(continued on page 28)

▲ **STELLAR NURSERY** Massive stars make oxygen, littering their natal neighborhoods and stars born there. This false-color Hubble image of the Carina Nebula shows oxygen in blue, hydrogen and nitrogen in green, and sulfur in red. Oxygen glows primarily where young stars have carved out the clouds.

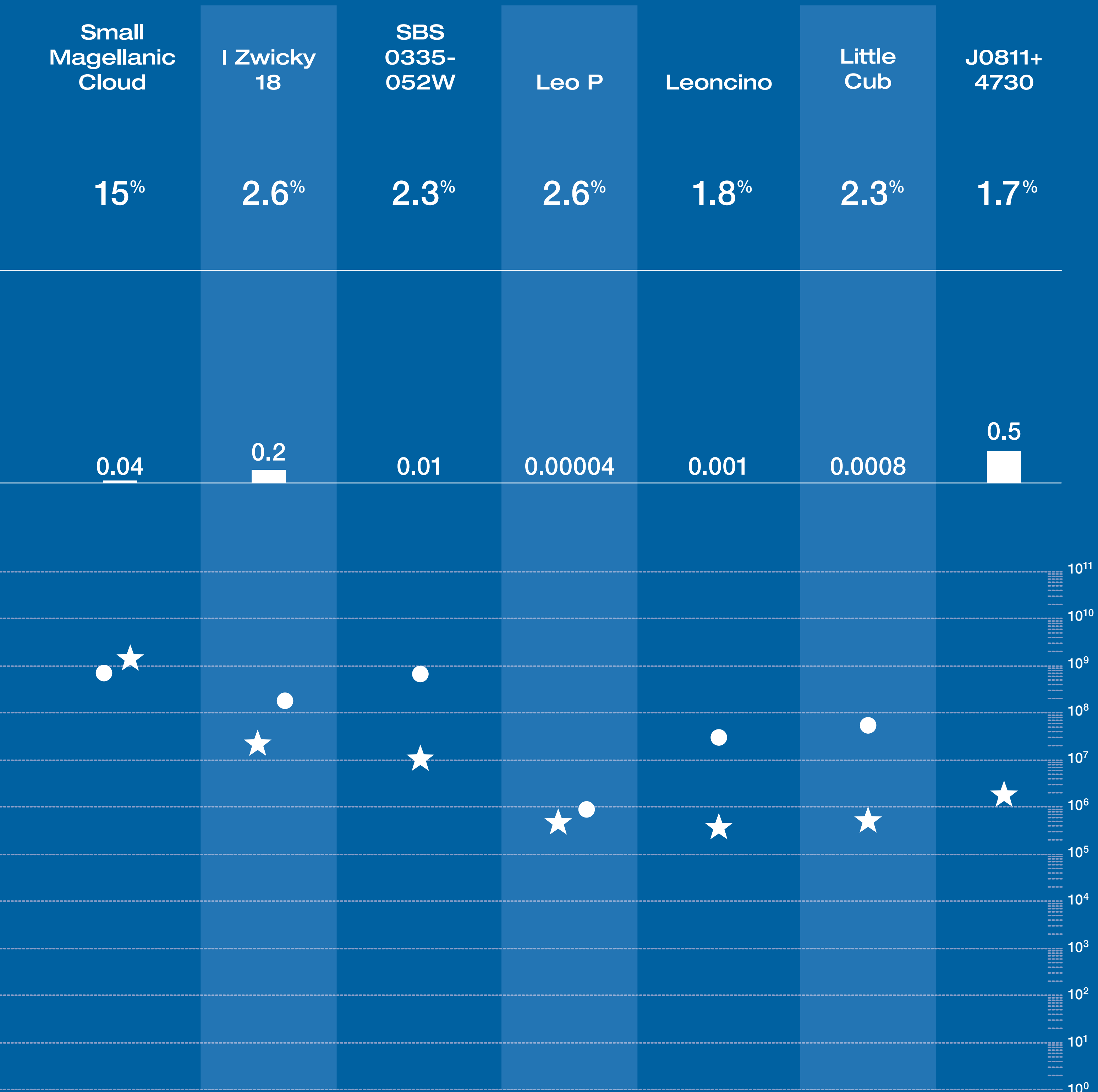
CARINA: NASA / ESA / M. LIVIO / HUBBLE 20TH ANNIVERSARY TEAM (STSCI); BLUE BACKGROUND: HARDIK PETHANI / GETTY IMAGES

Galaxy Scorecard



Gas mass is based on neutral hydrogen content. Astronomers don't have a specific estimate for J0811+4730's gas mass, so only its estimated mass in stars is shown. Mass scale is logarithmic.

Shown below are parameters for our home galaxy, one of its small neighbors (the Small Magellanic Cloud), and the oxygen-poor galaxies discussed in the article. Solar values serve as the benchmark for the oxygen abundances, and masses are approximate to within a factor of 10. Although the dwarfs churn out fewer stars per year than the Milky Way (second row), they also have a lot less mass to work with (bottom). The Milky Way's gas mass here includes the disk and bulge.



(continued from page 25)
little of another ingredient important in the Milky Way's star formation: dust. That's not surprising, because dust grains consist mostly of carbon, oxygen, magnesium, silicon, and iron, all of which are products of stars and are therefore scarce in these galaxies. In the Milky Way's disk, gas makes up 99% of interstellar matter and dust 1%. In I Zwicky 18, however, dust accounts for a mere 0.001% of interstellar matter.

When it exists, dust affects star formation. Dust grains darken star-forming clouds, shielding them from harsh radiation, and also promote star formation by emitting far-infrared radiation, which carries heat away from gas clouds. So do carbon and oxygen atoms. Cooler clouds have less thermal pressure, a force that counteracts gravity and can prevent a cloud from collapsing and becoming a star. Thus, with a shortage of dust and carbon and oxygen atoms to cool them, gas clouds in oxygen-poor galaxies may have to be more massive in order for gravity to take over and force collapse, giving rise to a greater proportion of massive stars. The same thing presumably happened in the universe's first galaxies.

Dust grains also serve as platforms on which atoms can meet one another and make molecules, such as molecular hydrogen, the most abundant molecule in the Milky Way's gas. Big clouds of molecular hydrogen fuel many of our galaxy's star-forming regions. No one has ever detected any molecular gas in a galaxy as oxygen-poor as I Zwicky 18.

What Is Dust?

Cosmic dust grains are small particles that range in size from about 10 to 100 nm. They're mostly silicate- or carbon-based and form in the atmospheres of aging red giant stars and in supernovae. Dust absorbs light with wavelengths similar to or smaller than its grain size, then re-emits it at infrared wavelengths. Its presence shields interstellar molecules from high-energy radiation and enables protostars to radiate away excess energy.

NOAO / AURA / NSF / N. SMITH (UNIVERSITY OF ARIZONA)

A New Record-Breaker

In 2017, Izotov and Thuan's team discovered the current champion: a starburst galaxy in Lynx that's 620 million light-years distant — 10 times farther than I Zwicky 18 — bearing the prosaic name J0811+4730. The blue galaxy spawned 80% of its stars during the past few million years, and its oxygen abundance is a mere 6.98, the lowest ever seen. That's just 1.7% the level of oxygen in the Sun.

Still, the galaxy emerged only after the astronomers searched a million spectra from the Sloan Digital Sky Survey. Thuan once hoped to find truly primordial galaxies containing no oxygen at all, but he now wonders whether he'll ever succeed. "It's very, very difficult," he says. "I've spent nearly 40 years of my professional life trying to find these things, but so far to no avail."

Perhaps, he adds, an ancient generation of massive stars showered the whole universe with metals, setting a minimum oxygen level in any galaxy that arose. As a result, galaxies with much less oxygen than the current record-breaker simply might not exist.

Little Galaxies, Little Particles

With all the new discoveries, the field is blossoming. That may be good news not just for astronomers but also for particle physicists, because these galaxies could reveal how many types, or "flavors," of neutrinos there are.

Neutrinos are tiny neutral particles that whiz through space — and our bodies — at nearly the speed of light. Hence their name: *Neutrino* means "little neutral one" in Italian. Physicists recognize three flavors: electron, muon, and tau. If a fourth flavor exists, however, it would have affected the nuclear reactions during the universe's first three minutes and raised the amount of helium the Big Bang produced.

But how much helium did the Big Bang actually make? We can't look to Earth for the answer, because the scant helium we have here has nothing to do with the Big Bang. Instead, the lighter-than-air gas that lifts blimps and balloons stems from the radioactive decay of heavy elements such as thorium and uranium.

In contrast, most of the helium on the Sun's surface did come from the Big Bang. Unfortunately, countless stars that lived and died before the Sun's birth also contributed.

▲ **ONE MORE FOR LEO** The dwarf galaxy DDO 68 (also known as UGC 5340) is a ragged collection of stars and gas clouds. At 40 million light-years away, it's one of the closer oxygen-poor star-forming galaxies. This image combines visible and infrared observations.

NASA / ESA

Astronomers could try and subtract the stellar contribution from the amount of helium the Sun was born with — about 27% by weight — and thereby extrapolate all the way back to the Big Bang abundance.

"*Extrapolate*: We hate that word," says Evan Skillman (University of Minnesota). Far better to measure the helium level in star-making galaxies so pristine their chemical composition almost reflects that of the early universe. "It's really the only way we have to estimate the primordial helium abundance," he says. In these galaxies, new stars emit ultraviolet light that strips electrons from helium atoms in the interstellar gas; electrons that rejoin the helium atoms create spectral lines revealing the element's abundance. In contrast, the many dim dwarf galaxies that orbit the Milky Way, some of which have still less oxygen, provide no such information because they lack both gas and hot young stars (*S&T:* Mar. 2017, p. 16).

Past measurements of I Zwicky 18 and its kin have found that helium made up a quarter of the chemical elements emerging from the Big Bang, but different astronomers derive slightly different numbers. In 2014, Izotov and Thuan's team obtained a primordial helium abundance of 25.5%, which is so high it suggests the number of neutrino types is more likely to be four than three. But Skillman's team favors a lower primordial helium level, around 24.5%, which implies three neutrino flavors, in accordance with standard physics.

Now, having spotted three new oxygen-poor star makers in just the past three years, astronomers have three more chances to derive the primordial helium abundance. If that number comes in on the high side, physicists should be seeking a fourth type of neutrino. Thus these odd little galaxies might tell us not only what the first galaxies looked like but also how many flavors of "little neutral particles" there are zipping through the cosmos.

■ **KEN CROSWELL** earned his PhD for studying a decidedly oxygen-rich galaxy, the Milky Way. His book about our galaxy, *The Alchemy of the Heavens*, was a *Los Angeles Times* Book Prize finalist. He has also written for *National Geographic*, *New Scientist*, and *Scientific American*.

Star-Forming Galaxies with the Lowest Oxygen Levels

Galaxy	Constellation	Oxygen Abundance (hydrogen = 12)*	Approx. Distance (light-years)
J0811+4730	Lynx	6.98	620 million
Leoncino	Leo Minor	7.02	40 million?
SBS 0335-052W	Eridanus	7.13	190 million
Little Cub	Ursa Major	7.13	60 million?
I Zwicky 18	Ursa Major	7.17	60 million
Leo P	Leo	7.17	5 million
DDO 68	Leo	7.20	40 million

*Oxygen abundances are generally the average of the values for multiple regions within a single galaxy. Question marks indicate a notably high uncertainty in distance.

The Snake in Spring

Step into the serpent's curves to explore the Hydra I Galaxy Cluster.

THE WATER SNAKE IN THE SKY
Hydra slithers some 100° across the night sky. Its heart, Alphard, or Alpha (α) Hydrae, beats in the western reaches of the constellation. The Hydra I Cluster is almost directly below Nu (ν) Hydrae, about halfway along an arc between Mu (μ) and Xi (ξ) Hydrae (see chart on p. 32).

PHOTO: BABAK TAFRESHI; CONSTELLATION DRAWING: HEVELIUS

On clear April evenings, the splashy winter constellations slide toward the western horizon, and deep-sky enthusiasts are itching to dive into the galaxy-rich fields of Virgo, Leo, and Coma Berenices. These constellations, along with Canes Venatici and Ursa Major, headline 32 of the 40 Messier galaxies. But farther south and less explored, the winding constellation of Hydra, the Water Snake, uncoils across 100° of the sky and contains its own bonanza of galaxies.

At a distance of 165 million light-years, the Hydra I Cluster (also known as Abell 1060) is one of the nearest rich galaxy clusters beyond the Virgo Cluster. Physically, the two clusters display a striking resemblance. Hydra I is three times as distant as the Virgo cluster, but its apparent size is ⅓ as large. So their linear dimensions are nearly the same. And each cluster contains 50 galaxies within two magnitudes of their dominant members, M87 in Virgo and NGC 3311 in Hydra, both supergiant ellipticals with comparable absolute magnitudes.

Redshift surveys have demonstrated that the cluster is remarkably isolated in space, with no foreground galaxies and a huge void in the background out to a distance of 400 million light-years. This allows for easy identification of cluster members to fainter magnitudes based on redshift. The NASA-IPAC Extragalactic Database lists upwards of 350 known members in a 5° region.

John Herschel discovered nine of the central galaxies that carry NGC designations in March 1835 and 1836 during his survey of the southern sky from the Cape of Good Hope. In 1835, he observed the cluster on three consecutive sweeps (slowly swinging the scope up and down several degrees while pointing due south) with his 18-inch speculum reflector in an attempt to accurately determine positions. But timing the closely spaced meridian transits while recording the altitude was difficult as the flurry of galaxies drifted by. As a solution, he made carefully drawn sketches in both years but realized "in each diagram only 7 were seen and laid down, yet there are in reality at least 9 in the whole group."

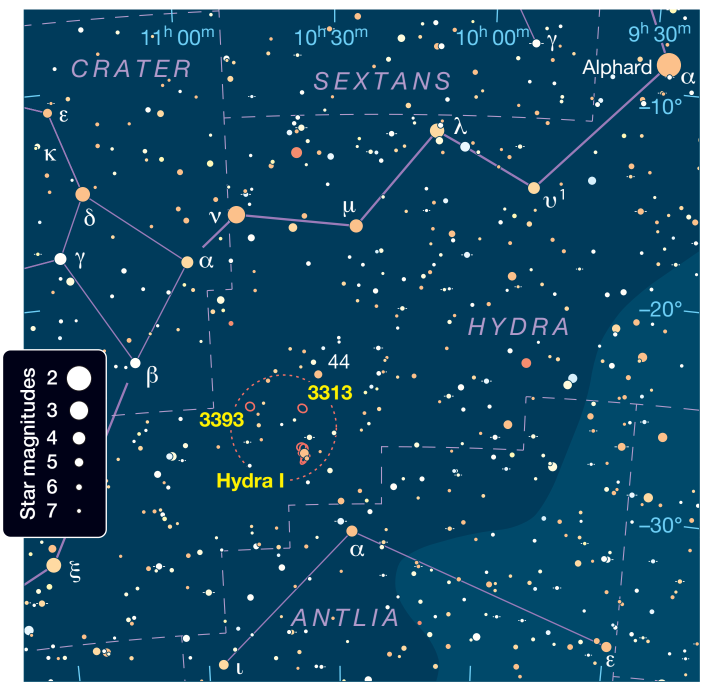
Hydra I just made the southern cut-off limit (–27° declination) of George Abell's 1958 catalog of 2,712 rich galaxy clusters, yet it's still accessible to mid-northern observers. And a large aperture isn't a requirement; several 11.5- to 12.5-magnitude members are within reach of a 6- to 8-inch scope. But to minimize the effects of poor seeing and reduced transparency close to the horizon, make your observation when the cluster is highest near the meridian — about 11:00 p.m. at the beginning of April and an hour earlier around the new Moon at mid-month.

The core of the Hydra I Cluster forms a wide isosceles triangle with 4th-magnitude Alpha (α) Antliae and 5th-magnitude 44 Hya. The cluster is slightly under 4° from either star, lying just to the east of a line connecting the two stars. The main drag of the cluster's core is easy to follow as it forms a 20′ chain passing between 4.9-magnitude HD 92036 and 6.7-magnitude HD 91964. You'll find half a dozen brighter NGC galaxies, but the glare from these stars can be an annoyance, so use medium or high power and isolate them outside the eyepiece field whenever possible. My descriptions are based on observations through a 13.1-inch reflector using 166× and 214× from dark sites in both northern California and tropical Costa Rica.

Let's start with **NGC 3309** and **NGC 3311**, which form an impressive pair at the heart of the cluster. NGC 3309, an 11.6-magnitude elliptical, is strongly condensed with a conspicuous 40″ core encased in a slightly elongated 1.2′ halo leaning northeast. NGC 3311, just 1.7′ east-southeast, is similar in size and magnitude but more broadly concentrated with no distinct nucleus. Using averted vision, its tenuous outer envelope grows to nearly 2′ in diameter with a 13.5-magnitude star sandwiched between the halos of the two elliptical galaxies.

NGC 3311 is a colossal cD-type (central dominant) galaxy with a distended diffuse halo composed of stars and debris cannibalized from nearby satellite galaxies. It commands a swarm of roughly 16,000 globular clusters, one of the largest

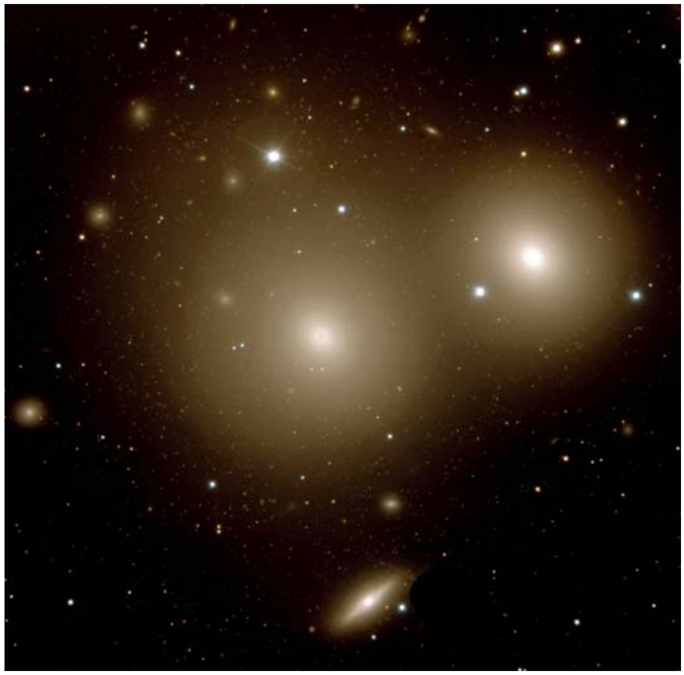
▼ HYDRA I FINDER CHART Find the cluster nestled between Mu, Nu, and Xi Hydrae and Alpha Antliae. Two outliers, NGC 3313 and NGC 3393, lie slightly north and northeast, respectively, of the cluster core.



Naming Abell clusters

Abell galaxy clusters are often abbreviated as "ACO [Number]" for the Abell-Corwin-Olowin 1989 update, so another name for Abell 1060 is ACO 1060.

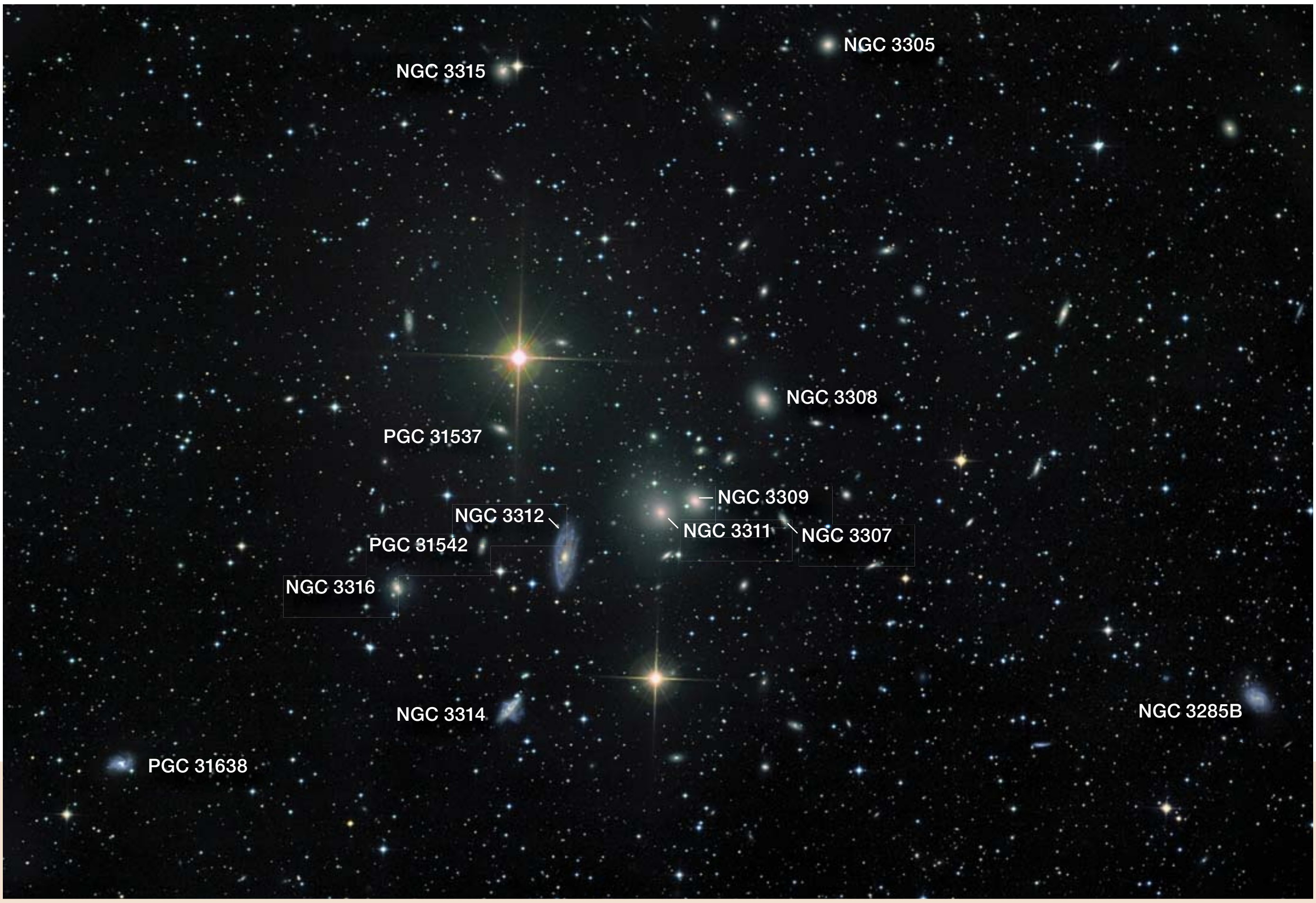
▶ **THE COLOSSUS IN THE CLUSTER** NGC 3311, in the center of this image, is by far the largest galaxy in the cluster and presumably hosts a supermassive black hole. What makes this galaxy even more remarkable, though, is the swarm of some 16,000 globular clusters in its halo, the largest collection of its kind known to date. To the right lies cluster member NGC 3309, another large elliptical galaxy, although less massive. The dark shadow at the bottom of the image is the spectrograph's guide probe.



known collections, and is predicted to harbor a behemoth black hole that weighs in at several billion solar masses.

NGC 3308, a 12th-magnitude lenticular (S0-type) with a weak bar, lies 6′ northwest of NGC 3309. The slightly oval halo spans 1′ diameter and holds a small bright nucleus. **NGC 3307**, just 5′ west of NGC 3309, is a much tougher catch. Even in my 18-inch this 14.5-magnitude barred lenticular was only a uniform ashen glow, perhaps 24″ by 18″.

The largest spiral in the cluster is 11.9-magnitude **NGC 3312**, symmetrically placed southeast of the central pair. In excellent conditions the relatively large, misty halo spans 2′ by 0.7′ north-south and encloses a roundish core that brightens to a stellar pip. An 18-inch scope should show a ragged



▲ **THE CLUSTER IN THE COILS** The Hydra I Galaxy Cluster, consisting of more than 100 members, lies some 165 million light-years away in a rather isolated corner of space.

NGC 3311: GEMINI OBSERVATORY / AURA; HYDRA I CLUSTER: J. PÖPSEL / S. BINNEWIES / CAPELLA OBSERVATORY halo due to long veins of dust that trace the winding spiral arms, as well as **PGC 31542**, a small 14.3-magnitude galaxy less than 4′ to its east.

NGC 3316, just 8′ east-southeast of NGC 3312, is a barred lenticular about a magnitude fainter than the previous galaxies (except for NGC 3307 and PGC 31542). Its 40″ round halo brightens gradually to a nearly stellar center. **NGC 3314** forms the southern vertex of an equilateral triangle with NGC 3312 and NGC 3316. This moderately bright spindle is tilted northwest in a 3:1 ratio with a major axis of 1.5′. A 13.5-magnitude star is pinned to its northwest tip.

The Hubble Space Telescope image of NGC 3314 seems to show a spectacular collision of two spirals, but in fact this cosmic trompe l'oeil is created by a nearly perfect line-of-sight superposition. The face-on galaxy lies a few tens of millions of light-years in front of the inclined spiral, and there is no evidence of a real physical interaction. Visually, though, even a large telescope will reveal only the brighter background spiral.

Want to tackle a stiffer challenge? **PGC 31537**, a pale 14th-magnitude smudge, is nearly lost in the glare of the 5th-magnitude star HD 92036 a mere 3.5′ away. With the star firmly planted off the north edge of the field, I glimpsed a ghostly oval, roughly 25″ in length and half as wide.

Let's check out some cluster members outside the crowded downtown region. Slide 18′ east-southeast of NGC 3314 to 13th-magnitude **PGC 31638**. Images show a disrupted spiral, but visually it was just an amorphous patch about 40″ across with a 13.5-magnitude star barely off the southwest edge. Continue another eyepiece field in the same direction and you'll arrive at **NGC 3336** in the eastern outskirts of the cluster. This 12th-magnitude spiral showed a diffuse 1′ halo with a weakly brighter central hub.

NGC 3285, another 12th-magnitude spiral, resides in the cluster's western suburbs. Look for it 37′ due west of NGC 3308 and 7′ southwest of 7.4-magnitude HD 91551. A moderately faint 60″ × 45″ halo is tilted west-northwest and rises broadly to a quasi-stellar nucleus. **NGC 3285B**, a dimmer barred spiral 18′ to its southeast, only revealed a slightly out-of-round 1′ diaphanous halo.

NGC 3315 is found 13′ north of HD 92036 and close to the east of a 10th-magnitude star. This small fuzz-ball

Hydra I Cluster Components

Object	Type	Mag(v)	Size	PA	RA	Dec.
NGC 3309*	E3	11.6	1.9′ × 1.6′	31°	$10^h\,36.6^m$	–27° 31′
NGC 3311*	E/S0	11.7	2.3′ × 2.1′	19°	$10^h\,36.7^m$	–27° 32′
NGC 3308*	SAB(s)0	11.9	1.7′ × 1.3′	32°	$10^h\,36.4^m$	–27° 26′
NGC 3307	SB(r)0/a pec	14.5	0.9′ × 0.3′	28°	$10^h\,36.3^m$	–27° 32′
NGC 3312*	SA(s)b pec	11.9	3.3′ × 1.3′	175°	$10^h\,37.0^m$	–27° 34′
PGC 31542	SB(s)0	14.3	0.9′ × 0.3′	167°	$10^h\,37.3^m$	–27° 34′
NGC 3316*	SB(rs)0	12.7	1.3′ × 1.1′	36°	$10^h\,37.6^m$	–27° 36′
NGC 3314*	Sab	12.8	1.5′ × 0.7′	143°	$10^h\,37.2^m$	–27° 41′
PGC 31537	SB0	13.8	1.0′ × 0.4′	72°	$10^h\,37.3^m$	–27° 28′
PGC 31638	SB(s)d pec	13.2	1.5′ × 0.7′	94°	$10^h\,38.6^m$	–27° 44′
NGC 3336*	SAB(rs)c pec	12.2	1.9′ × 1.5′	123°	$10^h\,40.3^m$	–27° 47′
NGC 3285*	SB(s)a pec	12.0	2.6′ × 1.3′	108°	$10^h\,33.6^m$	–27° 27′
NGC 3285B	SAB(r)b	13.1	1.5′ × 1.1′	43°	$10^h\,34.6^m$	–27° 39′
NGC 3315*	E/S0	13.4	1.1′ × 1.0′	80°	$10^h\,37.3^m$	–27° 11′
NGC 3305*	E0	12.8	1.1′ × 1.1′	–	$10^h\,36.2^m$	–27° 10′
IC 2597*	E4	11.8	1.5′ × 1.2′	4°	$10^h\,37.8^m$	–27° 05′
PGC 31588	Sc	14.0	0.9′ × 0.8′	97°	$10^h\,37.8^m$	–27° 07′
NGC 3313*	SB(r)b	11.4	3.9′ × 3.2′	55°	$10^h\,37.4^m$	–25° 19′
NGC 3393*	(R')SB(rs)a	12.2	1.8′ × 1.5′	48°	$10^h\,48.4^m$	–25° 10′

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

▲ **NGC 3314: A CELESTIAL TROMPE L'OEIL** Even though it might look as if these two spiral galaxies are interacting, they're in fact at a distance of tens of millions of light-years from each other. The background galaxy is associated with the Hydra I cluster, and it is just serendipitous alignment that places the foreground galaxy directly in the line of sight.

NGC 3314: NASA / ESA / HUBBLE HERITAGE (STSCI / AURA) ESA / HUBBLE COLLABORATION / W. KEEL (UNIVERSITY OF ALABAMA); NGC 3393: NASA / ESA / HUBBLE HERITAGE TEAM (STSCI / AURA)

extended 25″ and brightened modestly to the center. Another 15′ west of NGC 3315 is **NGC 3305**, a slightly brighter 13th-magnitude elliptical (E0-type) of similar size. A 13th-magnitude star is only 1.5′ west, and using higher power it resolved into a close pair.

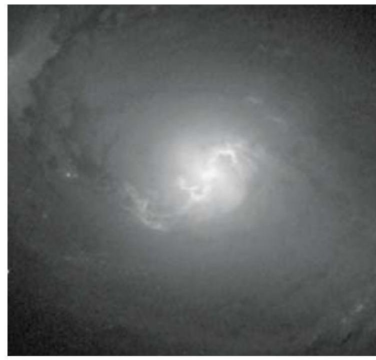
Return to NGC 3315 and shift some 9′ northeast to the 12th-magnitude elliptical **IC 2597**. In photographs, an extended gauzy envelope stretches 2.5′, but I only noted the brighter 1′ central hub, which is strongly concentrated. Prolific comet hunter Lewis Swift is credited with discovering IC 2597 in 1898 at the age of 78. But perusing E. E. Barnard's logbooks I found that he had run across this galaxy eight years earlier while comet hunting with the 12-inch refractor at Lick Observatory.

IC 2597 is the brightest member of Hickson 48, a compact quartet that fits in a 5′ circle. **PGC 31588**, just 2.5′ south, is a dim circular patch about 40″ diameter with no distinct core. A 14.5-magnitude star dangles off its southeast edge. The remaining two members are inconspicuous scraps (magnitude 15.4 and 16.0) about 2′ northwest of IC 2597 and were barely detectable in my 18-inch scope. Two of the four have somewhat discordant redshifts, so it's uncertain if the quartet is gravitationally bound.

Let's head out from the central region of the cluster and climb 1.8° due north of IC 2597 to **NGC 3313**, which glows at a respectable magnitude 11.4. The galaxy is sharply concentrated with a small intense nucleus embedded in a 1.5′ pallid halo. NGC 3313 is a photogenic face-on barred spiral with a prominent inner ring and a pair of graceful outer arms, though these were too low in surface brightness to detect.

Now scan 2.5° east of NGC 3313 for 12th-magnitude **NGC 3393**, at the very northeastern periphery of the cluster. The galaxy forms a shallow arc with a pair of 9th- and 11th-magnitude stars just east of it. An oval halo, perhaps 40″ in diameter, displayed a bright round nucleus and a dim star at its northwest edge.

The spiral galaxy NGC 3393 has long been known to contain an active galactic nucleus (AGN), classified as a Seyfert 2, that's powered by a supermassive black hole (SMBH). But in 2011, Harvard-Smithsonian astronomer Giuseppina Fabbiano and collaborators used observations from the Chandra X-ray Observatory to resolve the AGN into two peaks of X-ray emission separated by only 0.6″ on the plane of the sky.



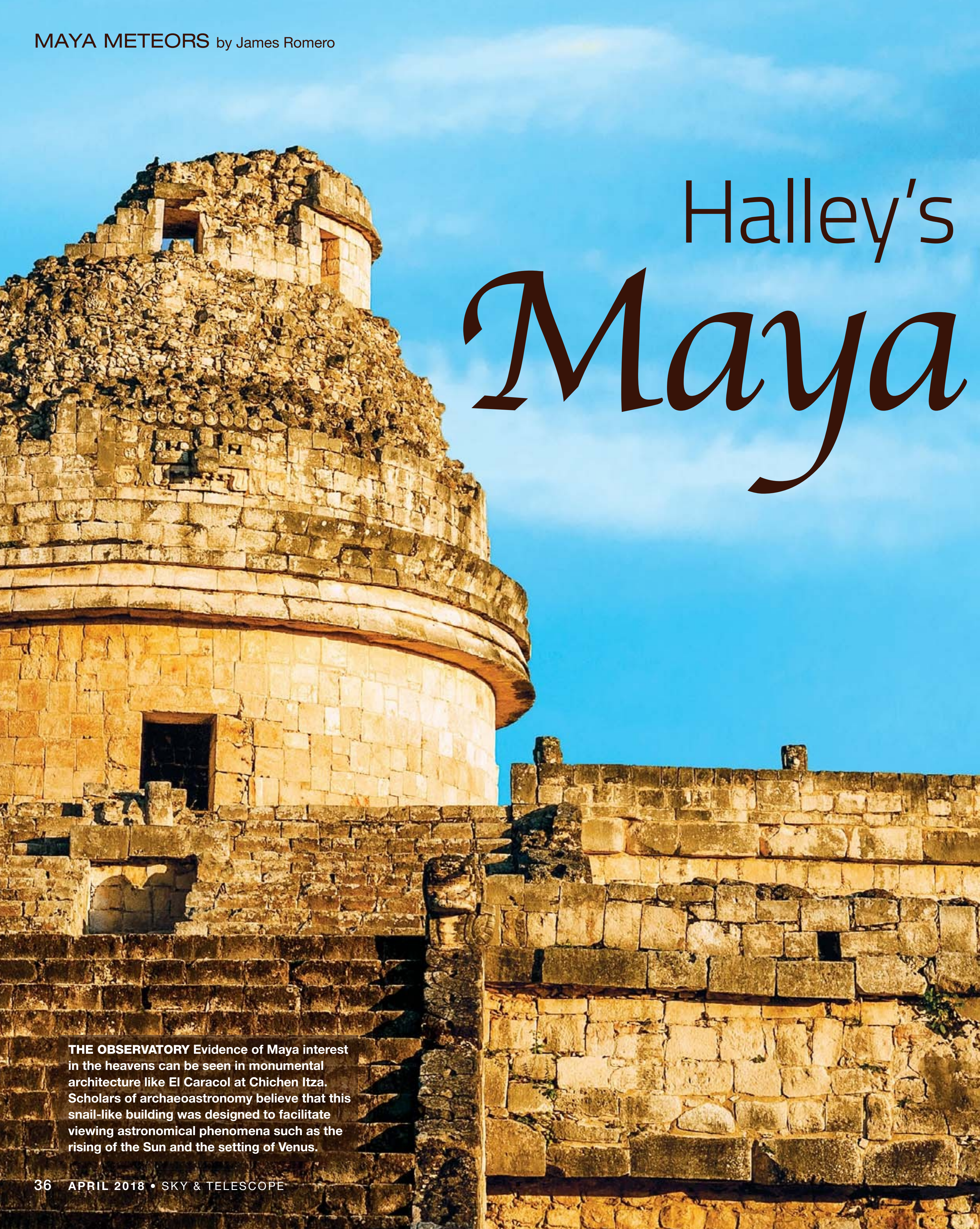
▲ **NOT ONE, BUT TWO** It's recently been shown via X-ray observations that NGC 3393, a spiral galaxy very similar to our own, houses two supermassive black holes, the result of a likely merger a billion years or so ago. At a distance of some 160 million light-years, this would be the closest example of a double supermassive black hole. Look for NGC 3393 in the northeastern outskirts of the Hydra I cluster.

This provided strong evidence that NGC 3393 houses two SMBHs less than 500 light-years apart — the nearest known example and the first discovered in a spiral galaxy. The SMBHs are likely the remnant of a merger that occurred a billion or more years ago. One day in the future their final collapse into a single black hole will be announced by the release of gravitational waves rippling across space.

On a grander scale, Hydra I is just one of a half-dozen Abell clusters and several smaller groups that spread into the constellations Antlia, Vela, and Centaurus, forming the Hydra-Centaurus Supercluster (*S&T:* April 2002, p. 101). If you're feeling adventurous, take a plunge into the southern sky — you'll find plenty to explore the next clear April night.

■ Contributing Editor and deep-sky fanatic **STEVE GOTTLIEB** has completed a 40-year project to observe the entire NGC (7,500+ objects), but still finds his list of new targets ever expanding. His detailed observing notes are available at **astronomy-mall.com/Adventures.In.Deep.Space**.

Halley's Maya



THE OBSERVATORY Evidence of Maya interest in the heavens can be seen in monumental architecture like El Caracol at Chichen Itza. Scholars of archaeoastronomy believe that this snail-like building was designed to facilitate viewing astronomical phenomena such as the rising of the Sun and the setting of Venus.

Comet & *Kings*

Did a spectacular, once-in-a-millennium meteor shower prompt the crowning of a king?

It's the evening of April 10, AD 531, in the city of Caracol, a regional political center located within the foothills of the Maya Mountains. The Moon set a few hours earlier, and a blanket of stars, concentrated overhead into a wispy Milky Way, is prominent in the pre-morning twilight. Suddenly, a brilliant shooting star streaks across the sky. Almost immediately, another star falls from the heavens, and then another.

What follows is one of the most impressive celestial displays in living memory. Unbeknownst to those witnessing the meteor shower from Caracol, the Earth is passing through a giant cloud of interplanetary detritus left behind by Comet 1P/Halley, our most famous recurring icy visitor, in a series of near passes in the preceding centuries. For two hours, bright streaks of light rain down from the heavens above the Maya Mountains, producing one of the most intense meteor showers of the first millennium.

For the residents of Caracol, this shower wasn't just a once-in-a-lifetime spectacle. The heavens had spoken and political change was in the air. Four days after the shower, the people recognized K'an I, known as Lord Jaguar, as the new king, succeeding his father, Yajaw Te' K'inich I. The royal ascension was accompanied by familiar ceremonies during which the new king's blood was a sacrificed to the gods as the sacred Maya beverage *saka*, made of maize and wild honey, was passed around.

We know about this series of events not from an ancient scripture, but thanks to a recent paper published in *Planetary and Space Science* by astronomer David Asher (Armagh Observatory) and Maya scholar J. Hutch Kinsman, who claim to have found the first evidence of meteor shower observation and recording anywhere in the Western Hemisphere.

The Maya Classic period ran from around AD 250–900. During this time, an empire encompassing some 50–75 city-states spanned the modern Central American countries of eastern Mexico, Guatemala, Belize, El Salvador, and Western Honduras. However, despite the range and longevity of this New World civilization, piecing together its story has proven tricky. All but four of the Maya's ancient books, known as *codices*, were destroyed by the Spanish after their arrival in the 16th century. Adding together the content of the surviving codices, plus all hieroglyphic inscriptions recovered from stone monuments (*stelae*), panels, painted murals, and portable objects (such as bones, shells, and ceramic vases), provides

▲ **DECIPHERING THE PAST** Scholars have carefully transcribed the glyphs on ancient Maya monuments, many of which have been lost to looters and developers. This drawing records what remains of Monument 6, which was found in Tortuguero (present-day Tabasco, Mexico).

just a couple of thousand date entries across the entire seven centuries of the Classic period. Events recorded on these dates mark not just the accession of kings, but also the births and deaths of important people and conquests of one city-state over another. We can also find astronomical information relating to Venus, and both solar and lunar eclipses, in these records. However, scholars have found no evidence of any meteor showers among the historical remnants.

Asher, a solar system modeler with an interest in the history of astronomical observations, considers this lacuna a bit strange, as records of meteor showers have been recovered from ancient Chinese, Korean, Japanese, and various European civilizations. In addition, based on their records of lunar and planetary movements, the Maya certainly had the capability to predict such celestial phenomena. “Did the records just disappear with much of the Maya book records,” Asher wondered, “or are there still clues we are missing?”

Asher has experience with meteor showers, having used the spectacular 1966 Leonid outburst, the biggest and most impressive of the 20th century, to predict the arrival time of subsequent displays in 1999, 2001, and 2002. Together with Robert H. McNaught, he achieved this with a computer program developed to model the trails of material shed by a comet and calculate when Earth’s travels around the Sun would cross them in the future. When they input the data for Comet Tempel-Tuttle, the parent comet for the Leonids, the shower predictions were accurate to a few minutes.

Asher’s interest in the Maya and their historical records came about only relatively recently following a chance encounter with Kinsman, a man who spends his time looking to the past rather than upwards. (Kinsman originally studied physics but has focused on the Maya for the last 20 years.) At their first meeting, Kinsman brought up the mysterious absence of shooting star records in the Western Hemisphere. (“It was a fascinating lecture,” recalls Asher.) By 2015 the two scholars had begun working together to address the missing Maya meteors.

Asher’s experience with the Leonids proved that with sufficient knowledge of a comet’s past location one could predict when the Earth would pass through its remnant trails later on. And if they knew the exact dates of meteor outbursts visible to the ancient Maya, perhaps they could spot indirect evidence of their impact in the recovered Maya events calendar. In terms of which comet to choose, the close proximity of Halley to Earth’s orbit during the Maya mid-Classic period made a strong argument for looking for evidence related to its Eta Aquariid showers, which

◀ **EXPANSIVE CULTURE** The Maya civilization spread across a large piece of Mesoamerica, including the Yucatán Peninsula and the mountains of the Sierra Madre region (present-day Mexico, Guatemala, and Belize). The city-states of the Maya Classic period (c. AD 250–900), which boasted populations as large as 120,000, produced most of the stone monuments and historical records that we have today.

MAP: LEAH TISCIONE / S&T

were recorded by ancient Chinese astronomers as far back as 74 BC.

Asher and Kinsman applied the Leonid model to simulate meteoroid-sized particles attributed to Comet Halley's passages from as early as 1404 BC in order to identify years when meteor outbursts might have been seen on Earth. After validating their approach by post-predicting observations in the ancient Chinese texts, they compared the same outburst dates to the surviving Maya record of notable dates.

They got 30 hits.

"Whilst some of them will be coincidences," Asher admits, "there are many more matches in or just after key meteor outbursts than you would expect to see by chance alone."

The recorded events that most commonly corresponded to Eta Aquariid displays were royal accessions, events that could easily be planned to coincide with or occur near the date of a meteor shower. For the shower in AD 531, Kinsman and Asher showed that the intensity of this burst resulted from Earth encountering particles released by Comet Halley during three previous passages (AD 295, 374, and 451). The relatively recent deposition of detritus by the comet meant there had been little time for dispersion, ensuring densely packed trails that could cause an intense outburst. The result was a shower Asher believes would have been spectacular, perhaps even to the extent of the incredible Leonid meteor storm of 1833, during which estimates have suggested 24,000 meteors were observable during an astounding nine-hour display. This celestial show was described at the time by Yale College Professor Denison Olmsted as "a constant succession of fire balls, resembling sky rockets, radiating in all directions from a point in the heavens," and if a similar shower had occurred in clear skies above the Maya city-states, it would have been impossible to ignore.

The calendar entry for AD 531 might itself provide additional evidence for a meteor-shower-inspired coronation, as it includes not just the ascension event, but also the number of days that had passed since new Moon. This lunar tracking isn't uncommon in the Maya records, but in the case of this entry, the age of the phase was inscribed incorrectly. Kinsman and Asher interpret this error to mean that the

The Venus Table

BY S. N. JOHNSON-ROEHR

A large part of the Dresden Codex, the oldest and the best preserved Maya manuscript, is dedicated to astronomical and calendrical data. These data include solar and lunar eclipse predictions based on observable lunar phases, as well as tables for tracking the cycles of Venus, Mars, and Mercury.

Six pages of the Dresden Codex are dedicated to the observable phases of Venus, beginning with the folio shown here. Credit for deciphering the so-called Venus Table goes to Ernst Förstermann, director of the Royal Library (now the Saxon State Library), who in 1901 worked out that the numbers inked in red across several pages of the codex were identical, and that they added up to 584. Recognizing that this number was almost identical to the synodic period of Venus (583.92 days, the time it takes for Venus to return to the same position as seen from Earth), Förstermann determined that the red numbers — 236, 90, 250, and 8 — marked four significant points in the planet's cycle: its morning heliacal rising; its disappearance at superior conjunction; its first evening rise; and its disappearance at inferior conjunction.

▲▼ **SKY TRACKERS** Despite a paucity of records related to meteor showers that might indicate otherwise, the Maya were keen observers of the night sky. Some of their astronomical knowledge was recorded in the Dresden Codex, a Maya history and astronomy treatise inked on paper made from the inner bark of a species of fig.

◀ **STONE METEORS** Tortuguero's Monument 6 includes a glyph depicting the AD 562 star war between the cities Tikal and Caracol. The droplets streaming from the glyph for "star," which resembles a pair of cartoon eyes, may represent the Eta Aquariid meteor shower.

> "There are many more matches in or just after key meteor outbursts than you would expect to see by chance alone."

inscribed age of the Moon referred to the date of the intense Eta Aquariid event, not the ascension itself. That is, the calendar noted a lunar age of 8 days (the age of the Moon during the meteor outburst on April 10th), not 12 days (the date the king was crowned).

"It appears that the Maya were back-calculating mythological events using calculations of the sidereal year that appear to have accurately targeted the Eta Aquariid meteor shower," says Dr. Michael Grofe, an archaeoastronomy specialist from the Maya Exploration Centre who wasn't involved in the project. "Kinsman and Asher make a compelling argument that the Maya both observed and predicted the Eta Aquariid meteor shower, and that the dates of the accession of Maya kings and queens, among other notable events, were timed to coincide with this astronomical phenomenon."

While AD 531 provides the most convincing match, Asher and Kinsman's date matches provide other tantalizing possibilities. A modest outburst in AD 511 was followed nine days later by the ascension to the throne of a six-year-old queen, known as the Lady of Tikal. However, not all matches led to scenes of celebration. In AD 562 a major battle between rival cities Tikal and Caracol followed an Eta Aquariid outburst by slightly less than three weeks. The battle, which resulted in Tikal's conquest and subsequent disappearance from the historical record for the next 120 years, is depicted in the record with a hieroglyph that looks a lot like a star showering Earth with liquid droplets. This evocative glyph led archaeologists to refer to this and similar devastating battles as *star wars*. Losing a star war often signaled the end, or at least the near erasure, of the defeated city-state. Archaeologists have noted that star wars tended to occur in the dry season (November to January) and typically began near the date of the appearance or disappearance of Venus. But could a star war also be prompted by a meteor shower?

An additional interesting match concerned not dust-induced meteors but Halley's Comet itself, which made its second-closest known approach to Earth on April 1, AD 374. About one month after the comet's passage, the Maya record shows the royal ascension of Teotihuacan ruler Spearthrower Owl (Atlatl-Cauac), whose hieroglyph and iconic representations clearly depict an owl holding an *atlatl*, a spear-throwing tool with stars, or "celestial darts," attached. It may be that Spearthrower Owl, who was responsible for the establishment of non-Maya rule over Tikal and other Maya city-states in AD 378, based his ascension on the passage of Halley's Comet in AD 374.

"The scale of some of these events organized close to major showers supports the idea the Maya were able to calculate the length of the sidereal year, and in all probability kept track of and observed Eta Aquariid meteor showers and outbursts," says Kinsman. While some of the connections seem speculative, we are gaining more knowledge of the Maya daily through the study of their hieroglyphs, monuments, and codices. "We hope this collaboration can run and run," adds Asher, who now wants to apply the same technique to other comets and meteor showers that could have commanded the ancient Maya from the heavens. Short of revealing clear textual or archaeological evidence, this type of collaboration represents the best chance of understanding observations of meteor showers by the Maya.

■ **JAMES ROMERO** is a UK-based planetary and solar system science writer who has written for *Science News* and *New Scientist* magazines. A geology graduate and very amateur astronomer himself, he also organizes large public science festivals in the UK at Imperial College London. You can follow him on twitter **@mrjamesromero**.

FURTHER READING: For a more detailed discussion of Maya records and the Eta Aquariid outbursts, see the original paper published in volume 144 of *Planetary and Space Science* (**arxiv.org/abs/1707.08246**).

OBSERVING
April 2018

2 DAWN: Look toward the south-southeast above the Teapot in Sagittarius to see Mars hovering about 1° below Saturn, then scan right toward the Moon to spot Jupiter hanging in Libra, the Scales.

7 DAWN: It gets crowded above the Teapot in Sagittarius as the waning gibbous Moon floats some 1½° above Saturn and a little more than 4° above and right of Mars.

8 EVENING: Algol shines at minimum brightness for roughly two hours centered at 11:24 p.m. EDT (8:24 p.m. PDT); see page 50.

17–18 NIGHT: Witness Saturn rising in the east-southeast around 1 a.m. local time and marvel at the fact that the ringed planet is at aphelion, the farthest it has been from the Sun since 1959.

18 EVENING: A delicate sliver of the waxing crescent Moon is cradled by the Hyades; less than 2° separates the Moon from Aldebaran, and an occultation is visible in parts of northern Canada.

22 EVENING: The first-quarter Moon is in Cancer, some 2° to 3° below the fuzzy Beehive Cluster (M44); use binoculars to distinguish individual cluster members.

ALL NIGHT: The peak of the normally sparse Lyrids meteor shower occurs during the North American daytime, but try to catch a glimpse of meteors originating between Hercules and Lyra, especially after midnight as the Moon nears the horizon.

24 EVENING: The Moon has now rolled into Leo and trails Regulus by some 3° as they travel together through the night toward the west.

30 EVENING: Jupiter and the full Moon vie for prime position in Libra.

The Moon pays a visit to Sagittarius, the Hyades, Cancer, Leo, and Libra this month.
SEAN WALKER / *S&T*

APRIL 2018 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					

LAST QUARTER
April 8
7:18 UT

NEW MOON
April 16
1:57 UT

FIRST QUARTER
April 22
21:46 UT

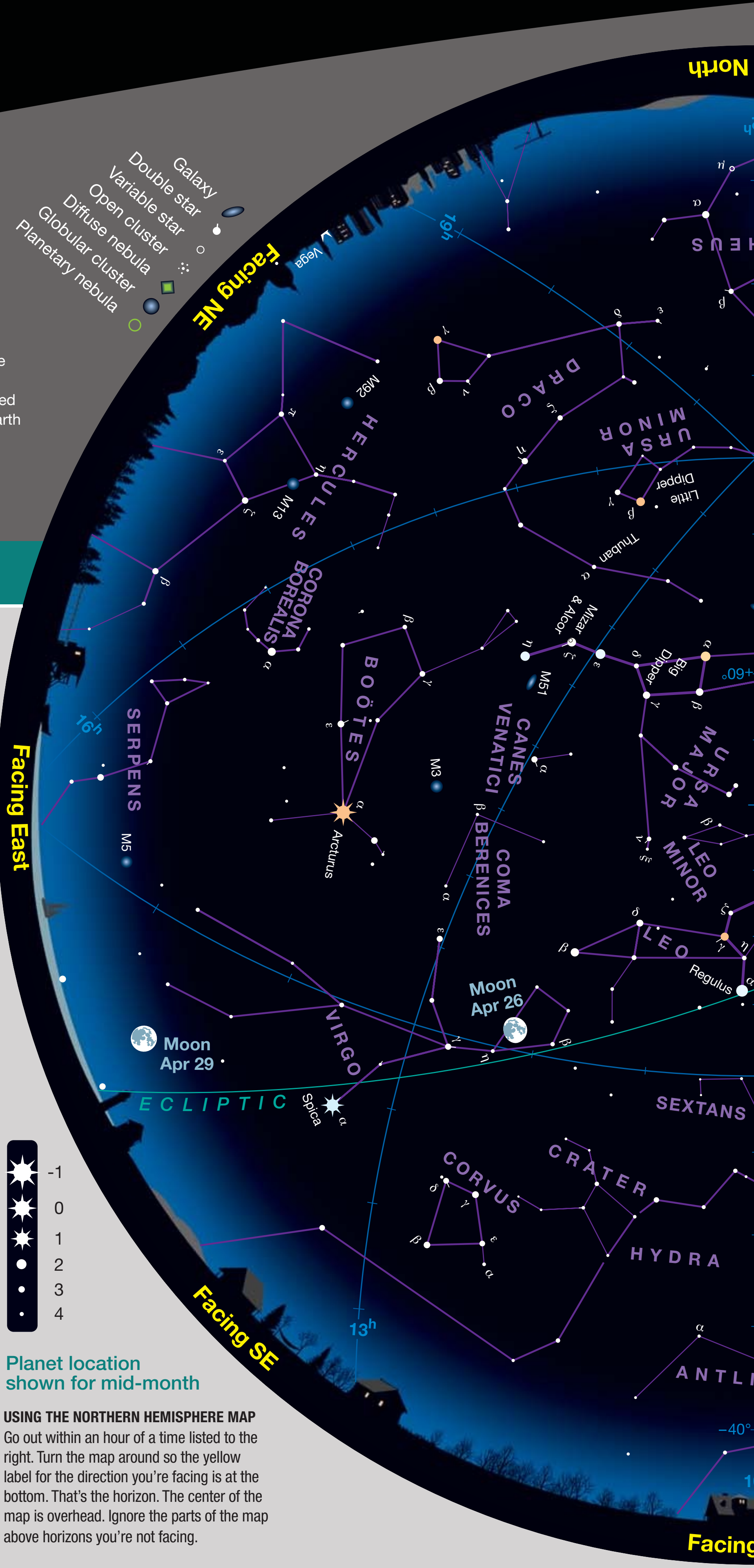
FULL MOON
April 30
00:58 UT

DISTANCES

Apogee	April 8, 06h UT
404,144 km	Diameter 29′ 34″
Perigee	April 20, 15h UT
368,714 km	Diameter 32′ 25″

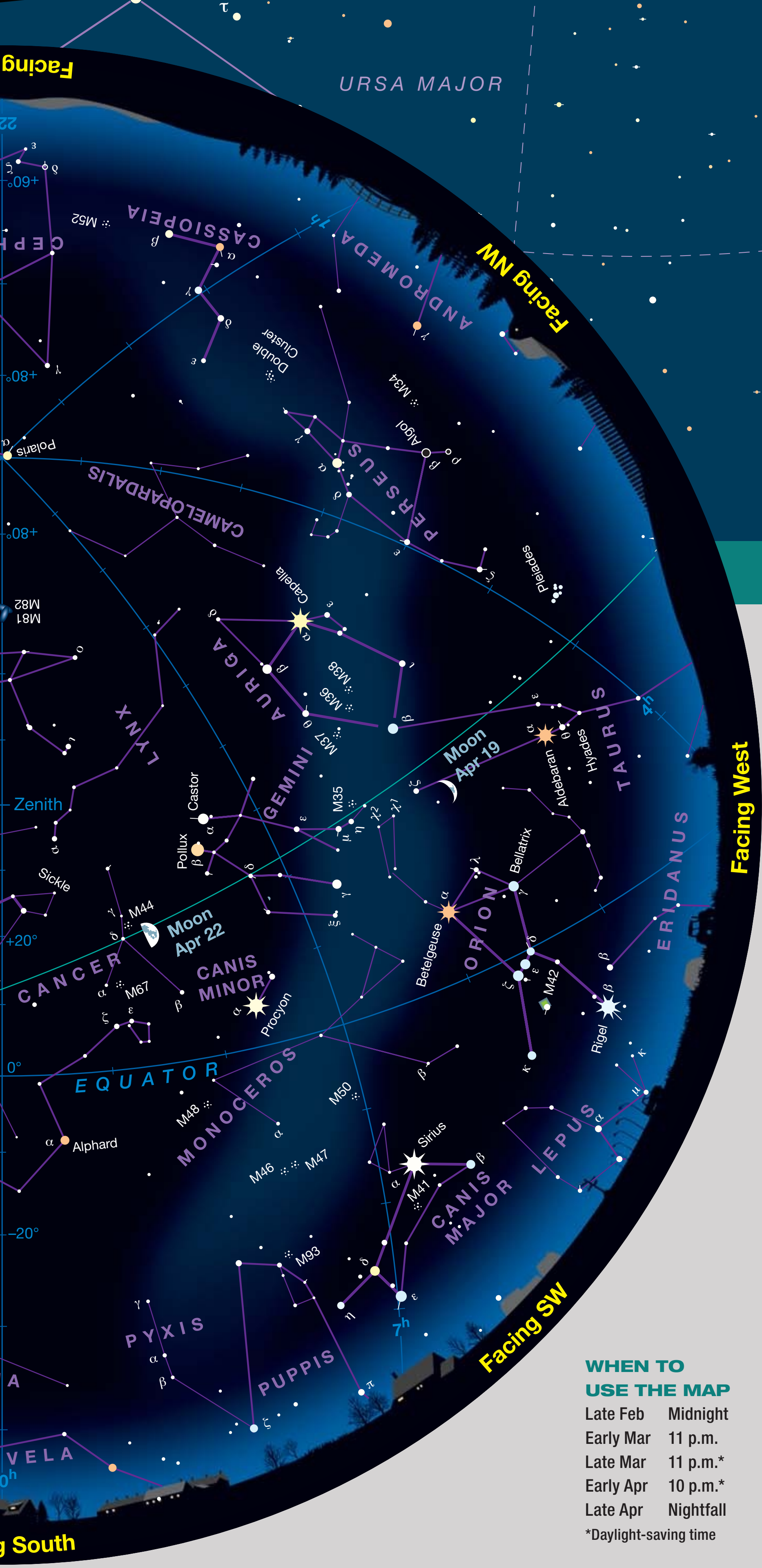
FAVORABLE LIBRATIONS

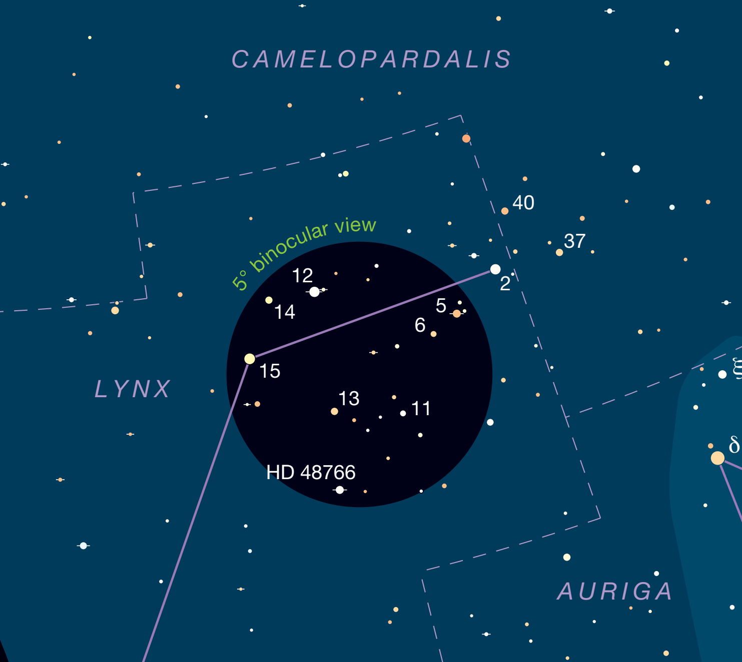
- Vasco da Gama Crater — April 11
- Eddington Crater — April 13
- Humboldt Crater — April 25
- Jeans Crater — April 29



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.





Binocular Highlight by Mathew Wedel

Fields of Gold

The constellation Lynx is in a weird in-between situation. It's far enough from the plane of the Milky Way to have few clusters, but not far away enough to have many bright galaxies. The constellation has zero Messier objects and only one Caldwell, NGC 2419, one of our galaxy's most distant globular clusters. It is not a rewarding binocular target.

That's not to say that Lynx has nothing to offer for binocular observers. The northwest corner of the constellation, near the borders of Auriga, the Charioteer, and Camelopardalis, the Giraffe, is home to a lovely field of stars spread over roughly 6°. On the east side, the stars 12, 14, and 15 Lyncis form a wide isosceles triangle. A couple of degrees south-southwest of that triangle, the stars 11 and 13 Lyncis and HD 48766 form another triangle, although I can't help but see them as a miniature version of the constellation Coma Berenices. And a few degrees to the west, 5 and 6 Lyncis form a line pointing to a nearly perfect equilateral triangle bounded by 2 Lyncis and 37 and 40 Camelopardalis.

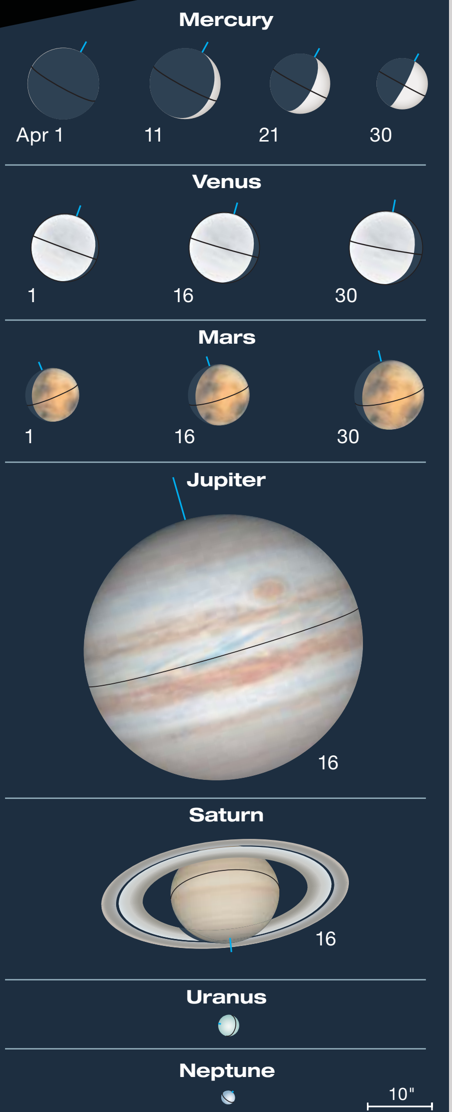
As far as I know, the stars in this field aren't physically related, beyond the mutual gravitational attraction that we all share. A significant majority of them are *G*- and *K*-type yellow and orange giants. The only exceptions are 2, 11, and 12 Lyncis and HD 48766, all *A*- or *F*-type main sequence stars. The colors of the giant stars are subtle, but to me all the more rewarding when I do detect them. It's useful to be reminded of this deceptively simple fact: that we can tell the temperatures of the stars, divine their compositions, and read their histories and fates from nothing more than the color of their light.

■ **MATT WEDEL** is on a quest to rehabilitate the underdog constellations. Go, Lynx!

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



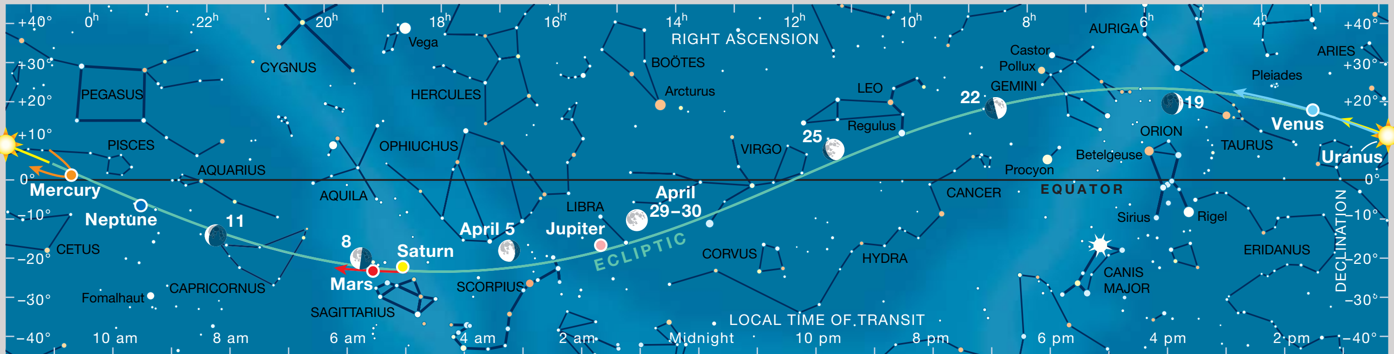
PLANET DISKS have south up, to match the view in many telescopes. Blue ticks indicate the pole currently tilted toward Earth.

PLANET VISIBILITY: Mercury: hidden in the Sun's glow all month • **Venus:** visible at dusk • **Mars:** visible at dawn • **Jupiter:** rises mid-evening, visible until sunrise • **Saturn:** rises near midnight, visible until sunrise

April Sun & Planets

	Date	Right Ascension	Declination	Elongation	Magnitude	Diameter	Illumination	Distance
Sun	1	$0^h\ 40.3^m$	+4° 20′	—	–26.8	32′ 01″	—	0.999
	30	$2^h\ 27.9^m$	+14° 37′	—	–26.8	31′ 46″	—	1.007
Mercury	1	$0^h\ 40.6^m$	+7° 36′	3° Ev	—	11.2″	1%	0.601
	11	$0^h\ 18.9^m$	+2° 39′	15° Mo	+2.6	11.0″	10%	0.609
	21	$0^h\ 24.2^m$	+0° 43′	25° Mo	+0.9	9.4″	29%	0.714
	30	$0^h\ 50.3^m$	+2° 20′	27° Mo	+0.3	8.0″	44%	0.844
Venus	1	$1^h\ 55.1^m$	+11° 17′	20° Ev	–3.9	10.6″	94%	1.578
	11	$2^h\ 42.4^m$	+15° 42′	22° Ev	–3.9	10.8″	93%	1.541
	21	$3^h\ 31.2^m$	+19° 28′	25° Ev	–3.9	11.1″	91%	1.498
	30	$4^h\ 16.7^m$	+22° 08′	27° Ev	–3.9	11.5″	89%	1.455
Mars	1	$18^h\ 34.0^m$	–23° 33′	93° Mo	+0.3	8.4″	88%	1.108
	16	$19^h\ 09.0^m$	–23° 16′	100° Mo	0.0	9.6″	88%	0.973
	30	$19^h\ 39.0^m$	–22° 47′	107° Mo	–0.3	11.0″	88%	0.853
Jupiter	1	$15^h\ 20.4^m$	–17° 06′	139° Mo	–2.4	42.6″	100%	4.625
	30	$15^h\ 08.6^m$	–16° 18′	170° Mo	–2.5	44.6″	100%	4.416
Saturn	1	$18^h\ 37.4^m$	–22° 16′	92° Mo	+0.5	16.7″	100%	9.976
	30	$18^h\ 38.0^m$	–22° 16′	121° Mo	+0.4	17.5″	100%	9.516
Uranus	16	$1^h\ 45.1^m$	+10° 18′	2° Ev	+5.9	3.4″	100%	20.894
Neptune	16	$23^h\ 06.9^m$	–6° 41′	41° Mo	+7.9	2.2″	100%	30.699

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



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

Springtime Skies

Spring ushers in special sights of stars, planets, and more.

Spring is a time of sap stirring in trees and ASAP (pronounced *ay-sap* — meaning "as soon as possible") stirring in human beings.

But spring isn't just a season of greatest vitality, it's a season of greatest variety. It's a time of tulips and tornadoes, of blossoms and (in early spring) blizzards. So let's explore three different kinds of celestial sights that are unique to spring skies.

TAMAS LADANYI

The few but fine 2nd-magnitude stars of spring. The dearth of 2nd-magnitude stars in the traditional constellations of spring is really surprising. At least, that's true if you don't include the six 2nd-magnitude stars of the Big Dipper (which, for many of us, are circumpolar) or stars too far south to see well from around latitude 40° north. If you do that, you find that out of what I count to be 71 stars between magnitude 1.5 and 2.5 in all the heavens, only four of them are in the traditional spring constellations.

You can probably think quickly of the three 1st-magnitude stars of spring: Arcturus, Spica, and Regulus. But what are the four 2nd-magnitude luminaries? They are Alpha (α) Hydrae (Alphard), Gamma (γ) Leonis (Algieba), Beta (β) Leonis (Denebola), and Alpha (α) Coronae Borealis (Alphecca) — with magnitudes of 1.99 (Alphard), 2.01 (Algieba), 2.14 (Denebola), and 2.22 (Alphecca). Delta (δ) Leonis (Zosma) at magnitude 2.56 just misses being in this category. But is Alphecca's constellation Corona Borealis, the Northern Crown, really a constellation of spring? Or does it belong to early summer (Alphecca's epoch J2000.0 RA is $15^h\ 35^m$)? If Alphecca doesn't count, then spring's tally of 2nd-magnitude stars is only three.

Alphard, whose name means "the solitary one," is the orange lonely heart of Hydra, the Sea Serpent, and is in a large, dimly starred region of the heavens. Algieba is one of our finest double stars, its golden magnitude-2.2 and -3.5 components currently 4.4″ apart. Denebola marks the tail of Leo, though the tuft used to be the big loose cluster of Coma Berenices, Berenice's Hair. And Alphecca, also known as Gemma, is indeed the brightest gem in the semicircle of the Northern Crown.

Steep planets at nightfall in springtime. Around the spring equinox, the angle of the zodiac is quite steep with respect to the western horizon at nightfall. This places the Moon and the planets as high as possible for a given elongation from the Sun. Last spring, as it does every 8 years, Venus passed its maximum north of the Sun (slightly more than 8°) at inferior conjunction. Back in 2001 this helped me see Venus with the naked eye at both ends of one night — and see the crescent Venus without magnification (through an eye-centered pinhole to eliminate the diffraction spikes or rays of Venus). Last year ($2 \times 8 = 16$ years after 2001) I was able to see Venus at both ends of the same day — this required optical aid, though — and to observe it in a small telescope shortly before sunrise, virtually right at the moment of inferior conjunction.

Best in spring: six out of six amazing comets. I feel that a "great comet" may be most basically defined as one of 2nd magnitude or brighter when visible outside of twilight. If so, then all four such comets for the Northern Hemisphere in the past 50 years were best seen in March and April: Comet Bennett in 1970, Comet West in 1976, Comet Hyakutake in 1996, and Comet Hale-Bopp in 1997. But my two other most fascinating comets of the past 50 years have been Comet Halley in March–May 1986 and Comet IRAS-Araki-Alcock in May 1983, the latter of which I'll discuss here in next month's column.

■ **FRED SCHAAF** lives on the edge of the New Jersey Pinelands Reserve (with no lights for about 10 miles to his east).

Mars, Saturn, and the Teapot

Early in the month, the two planets congregate by the Teapot; by the end of the month, Mars slips away from Saturn.

Brilliant Venus appears higher in the west-northwest each dusk as April advances. Brightening Jupiter starts rising ever earlier in the evening — and at last this month comes up before Venus sets. In the hours after midnight, Mars and Saturn rise as a strikingly close, bright pair at the start of the month, but then grow increasingly far apart as April progresses.

DUSK

The altitude of **Venus** at sunset increases from about 18° to 24° during April for observers around latitude 40° north. The lapse between sunset and Venus-set grows from about 95 minutes to 130 minutes this month. Nevertheless, the brightest planet remains at magnitude –3.9, and its disk, roughly 90% lit, grows from only about 10½″ to 11½″ in April.

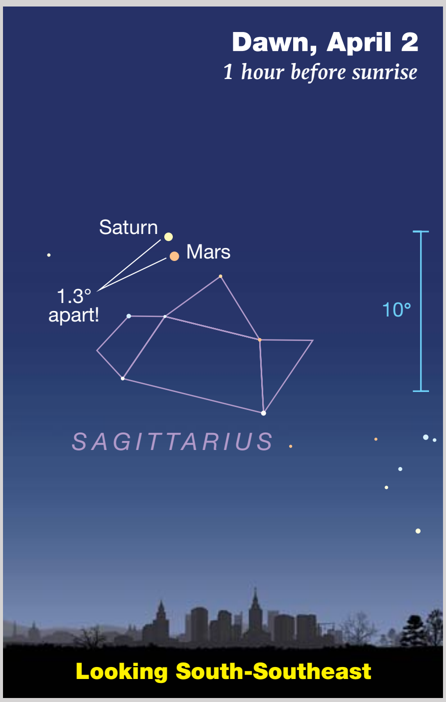
Venus passes 3.5° to the lower left (south-southeast) of the Pleiades on April 24th. At nightfall on April 27th, the planet is poised directly — and almost exactly halfway — between the Hyades and the Pleiades.

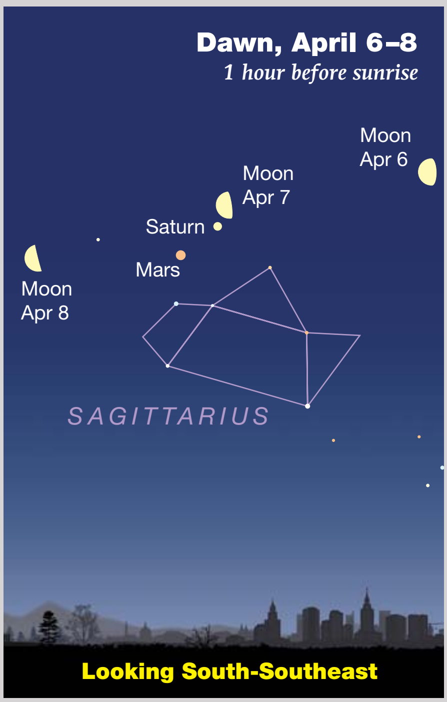
Uranus is lost in the solar glare below Venus early in April, then reaches conjunction with the Sun on April 18th.

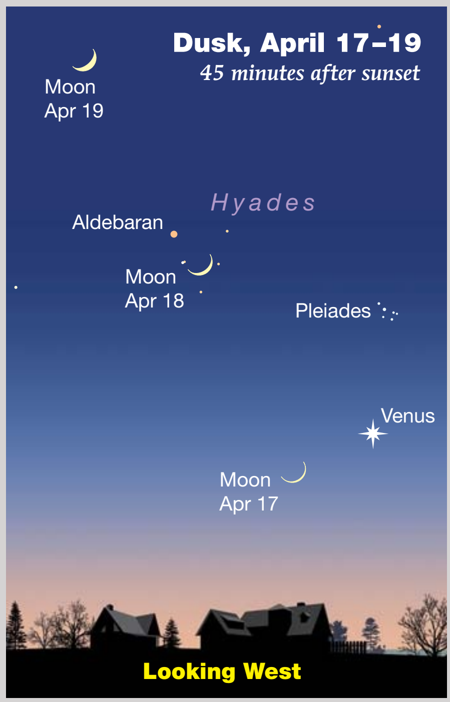
EARLY EVENING TO DAWN

Jupiter is impressive indeed as it comes up in the east-southeast about 3 hours after sunset as April opens and little more than half an hour after sunset by month's end. Jupiter's magnitude improves from –2.4 to –2.5 in April, which is still a lot less bright than the light of Venus at the opposite end of the sky. On the other hand, Jupiter is now far more interesting than Venus in telescopes, about four times wider and its clouds loaded with detail. Jupiter's equatorial diameter increases from about 42½″ to 44½″ during the month.

Look for the bright lamp of Jupiter slowly retrograding in low and lowly Libra. The planet is highest around 3:30 a.m. daylight-saving time in early April and around 1:30 a.m. in late April. Mighty Jupiter will reach opposition,







● To find out what's visible in the sky from your location, go to skypub.com/almanac.

shining all night at its brightest and biggest, on May 8–9.

MIDNIGHT TO DAWN

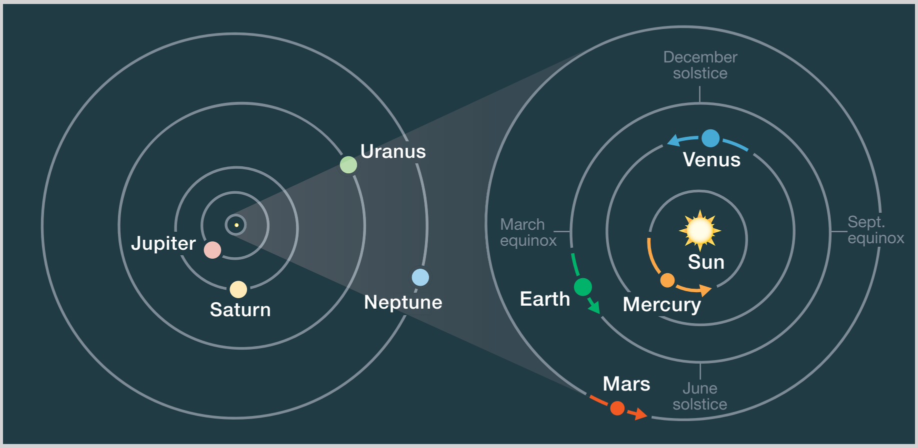
Mars and **Saturn** are a glorious couple in the opening days of April when they rise close together around 2:15 a.m., and are highest just after sunrise. They are a minimum of 1.3° apart at dawn of April 2nd, but essentially are as close together on the mornings before and after. On the day of minimum separation Mars is magnitude +0.3 and Saturn +0.5, orange-gold and rich gold in hue, respectively. Their equatorial diameters are about 8½″ for Mars and 17″ for Saturn, with the superbly tilted rings spanning about 2½ times the size of Saturn's globe.

Mars and Saturn have their encounter just a few degrees to the upper left of Lambda (λ) Sagittarii (Kaus Borealis), the top star of the Teapot of Sagittarius. But Mars races on eastward away from Saturn during April, increasing the gap between them to 2° on April 5th, a little more than 5° on April 12th, and more than 14° on April 30th. During April, Saturn brightens from magnitude +0.5 to +0.3, but Mars kindles from +0.3 to –0.4, veritably doubling in brightness. The apparent width of Mars swells from 8½″ to 11″ during April, bringing some surface features into range of medium-size telescopes on nights of excellent "seeing."

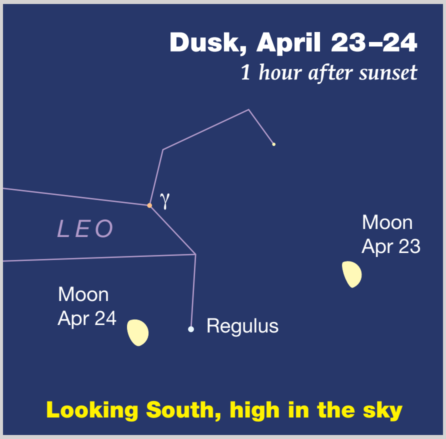
By the way, dauntingly dim **Pluto**, magnitude +14, is 1.4° north of Mars on the morning of April 26th.

By the end of April, Mars still rises well after midnight, in fact not long after 1:30 a.m. By month's end, Saturn appears above the east-southeast horizon at roughly 12:15 a.m.

Something awesome to note is that on the North American night of April 16–17 Saturn, at almost the same time it begins retrograde (westward) motion, reaches aphelion (farthest from the Sun in space) for the first time in 30 years. Saturn then lies 10.07 a.u. from the Sun (only a tad closer than in 1959). That is slightly more than 1 a.u. farther than Saturn will be at its next perihelion (closest to Sun in space) in 2032.



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.



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

DAWN

Mercury spends the month going from inferior conjunction with the Sun on April 1st to a greatest western elongation of 27° on April 29th. But this is the lowest morning apparition of Mercury in 2018 for viewers at mid-northern latitudes. Even when highest at month's end, Mercury is less than 10° above the horizon even at sunrise.

MOON PASSAGES

The Moon is fat waning gibbous when it is around 5° upper right of Jupiter on the morning of April 3rd. The Moon is nearing last quarter when it's less than 2° upper right of Saturn (itself less than 3° upper right of Mars) at dawn on April 7th. The slender waxing lunar crescent is almost 6° left of Venus at nightfall on April 17th and within the Hyades 24 hours later. The waxing gibbous Moon is some 3° left of Regulus at nightfall on April 24th. The Moon is full on the North American evening of April 29th and joins Jupiter in Libra.

■ FRED SCHAAF had his first view of a very blue Uranus in a telescope as a teenager over half a Uranus orbit ago.

April Showers

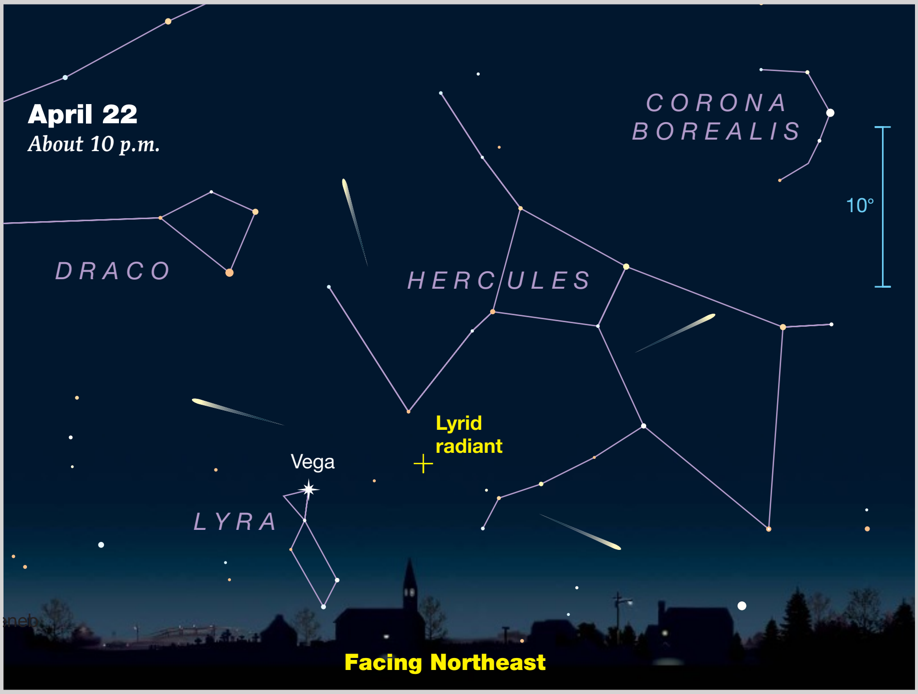
The Lyrids, the capricious meteors of spring, are predicted to peak on April 22nd.

A Lyrid meteor streaks through the sky above Rio Arriba, New Mexico.

Humans have been following the Lyrid meteor shower since 687 BC; at least, Duke Zhuang, who ruled the Chinese State of Lu from 694 to 662 BC, noticed that the "stars fell like rain" in the middle of a spring night that year. Despite the poetic history of the shower, however, the Lyrids can be something of a minor event, with just 18–20 meteors visible per hour at peak under good (dark, clear) conditions. But meteor fans are ever hopeful, watching intently for an outburst like the one in 1922 that graced the skies above Poland with 300–600 meteors per hour, or more recently, when North America was showered with a "modest" 250 meteors in a single hour in 1982.

The Lyrid meteor shower traces its origins to Comet Thatcher (C/1861 G1), a long-period comet discovered by A. E. Thatcher on April 4, 1861, as it passed through the head of Draco (the comet was independently discovered by Carl Wilhelm Baker). Early studies of the Lyrids suggested that the shower's dramatic outbursts might be linked to the proximity of Comet Thatcher to Earth, but since the comet orbits the Sun only once every 415 years, its return to our region of the solar system can't explain the outbursts, which follow a roughly 12-year cycle. T. R. Arter and I. P. Williams (University of London) have analyzed outburst data thoroughly and suspect that the outbursts may have been caused by fragmentations of Comet Thatcher's nucleus. The fragments, gravitationally perturbed by major planets, now follow 12-year orbits (Arter and Williams admit that "no totally convincing explanation for the observed periodicity has been found," though). The shower hasn't produced much drama since 1982, and this year's peak hour isn't favorable for North America.

MIKE LEWINSKI



▲ Lyrid meteors may appear anywhere in the sky. If you can trace a meteor's track backward to a point of apparent origin near Vega in Lyra, you'll know you've spotted a Lyrid.

GREGG DINDERMAN / S&T

But one never knows, and the new quarter Moon falls on April 22nd, so the morning hours won't be disturbed by moonlight. The shower's radiant is in eastern Hercules, 8° southwest of brilliant Vega. This means that it's low at dusk for observers at mid-northern latitudes, hovering just above the northeastern horizon. Visibility, and thus meteor counts, should improve as the radiant climbs higher and the Moon sets after midnight.

Moon Occults Nu Geminorum

ON THE NIGHT of April 20–21, the waxing crescent Moon, about 30% lit, occults 4th-magnitude Nu (ν) Geminorum. Nu's a double, possibly multiple, star system, with a blue giant B6-type primary. This is an easy split for small scopes. A 90-mm reflector at 50× will separate the 8th-magnitude secondary from the lucida without problems. But Nu Gem A and B themselves are both very tight double (or even triple) stars, which leads to some uncertainty about the stars' spectral classes.

The broad occultation path covers the southern half of North America and all of Central America, but for those in the west, this is an evening twilight event. Phoenix, for instance, sees the occultation begin just 45 minutes after sunset. Conditions should be better toward the east, where it will be darker, but the Moon will be lower. For Jacksonville, Nu's reappearance on the dark limb comes with the Moon at an altitude of only 10°.

Timetables for the event for cities and towns along the path are available from the International Occultation Timing Association (**lunar-occultations.com/iota/iotandx.htm**), but here are some preliminary timings:

Phoenix, *disappearance* 7:45 p.m., *reappearance* 8:51 p.m. MST; **El Paso,** *d.* 8:55 p.m., *r.* 9:58 p.m. MDT; **Dallas,** *d.* 10:08 p.m., *r.* 10:57 p.m. CDT; **Huntsville,** *d.* 10:22 p.m., *r.* 10:47 p.m. CDT; **Jacksonville,** *d.* 11:23 p.m., *r.* 11:57 p.m. EDT.

What's in a Name?

◗ We prefer to make our comets more cozy by using their common names: Comet McNaught, Comet Thatcher, Halley's Comet, the Great Comet of 1811 . . . But astronomers follow a different set of rules when referring to these icy travelers. In 1994, the International Astronomical Union (IAU) codified a system meant to eliminate confusion caused by duplicate names. Let's look at Comet Thatcher's official designation, C/1861 G1 (Thatcher), to explain the rules.

The most common prefixes for comet designations are *C* and *P*. A preceding *P* means you're looking at a periodic comet (any comet with an orbital period of 200 years or less). The number attached to the *P* reveals the order of discovery. For instance, Comet 1P/1882 Q1 (Halley) is so-called because it was the first comet determined to be periodic. These numbers are assigned after a comet's second perihelion passage, which (ideally) confirms the object's periodicity.

A preceding *C* is used for non-periodic comets, or comets with periods longer than 200 years. Comet Thatcher rounds the Sun every 415 years, so its designation begins with a *C*. If you see an *X*, you'll know that the comet's orbit couldn't be calculated. If you see an *I*, you'll know you've got an interstellar object (the IAU added *I* to the system last year after the discovery of 1I/2017 U1 ('Oumuamua) in October).

Thatcher's *1861* is straightforward — that's the year of discovery. The *G* tells us that the comet was discovered in the first half of April (January = *A*+*B*; February = *C*+*D*; March = *E*+*F*; April = *G*+*H*; and so on). The *1* lets us know that this was the first comet discovered in the *G* period. And, of course, we wrap up the designation with the last name of the discoverer or the object's coziest call sign.

Speaking of Gemini . . .

ON THE NIGHT of April 28–29, the asteroid 20 Massalia will hide a 10th-magnitude star in the Twins for observers in the southeastern United States. This Classically inspired location seems appropriate for this event: Massalia's designation comes from the Greek name for Marseille, one of the cities from which the asteroid was discovered. (French astronomer Jean Chacornac and the Italian astronomer Annibale de Gasparis both spotted the asteroid on September 19, 1852.) At 160 km × 145 km, Massalia is one of the largest members of its eponymous family, a group of stony, silicaceous asteroids with similar orbital elements and compositions. In this case, 20 Massalia is the indisputable head of the clan. The smaller members of the family are actually fragments of Massalia, ejected by a cratering event large enough to do some damage, but not so great as to thoroughly destroy the parent.

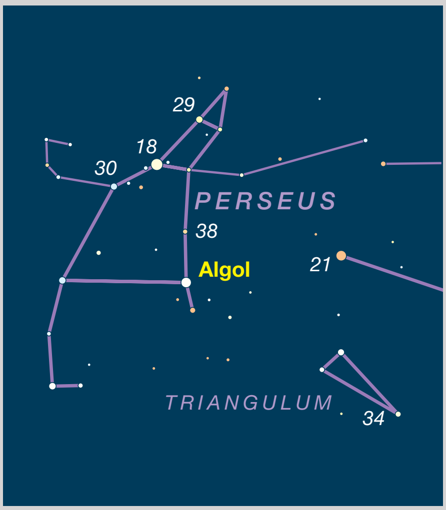
As Massalia passes in front of the magnitude-10.2 star TYC 1357-02401, their combined light will drop to 10.9 (Massalia's magnitude) for a maximum of 4.7 seconds. This dip in brightness will occur within a couple of minutes of $1^h\,18^m$ UT on April 29th (9:18 p.m. EDT April 28th), just before the end of astronomical twilight for Florida.

About a week before the event, more precise predictions and a path map will be available from Steve Preston's minor-planet occultation website (**asteroidoccultation.com**). For advice on timing occultations and reporting observations, see **asteroidoccultation.com/observations**. Occultation enthusiasts can join an online discussion group at **groups.yahoo.com/neo/groups/IOTAoccultations**.

Minima of Algol

Mar.	UT	Apr.	UT
2	20:43	3	9:45
5	17:32	6	6:34
8	14:22	9	3:24
11	11:11	12	0:13
14	8:00	14	21:02
17	4:50	17	17:51
20	1:39	20	14:40
22	22:28	23	11:29
25	19:17	26	8:18
28	16:07	29	5:07
31	12:56		

These geocentric predictions are from the heliocentric elements Min. = JD 2445641.554 + 2.867324E, where E is any integer. For a naked-eye comparison-star chart and more information about Algol and its history, see **skyandtelescope.com/algol.**



▲ Every 2.7 days, Algol (Beta Persei) dips from its usual magnitude 2.1 to 3.4 and back. Use this chart to carefully estimate its brightness with respect to the convenient comparison stars of magnitude 2.1 (Gamma Andromedae) and 3.4 (Alpha Trianguli).

Action at Jupiter

JUPITER OPENS THE MONTH in Libra, shining at magnitude –2.4. The gas giant has all but reached opposition (the night of May 8–9) and it shows. By mid-April the planet beams at a glorious magnitude –2.5, its brightest for the year. As it edges closer to Earth and to opposition, Jupiter's equatorial diameter increases from 43″ to 45″.

Jupiter is an all-night show now. On April 1st, it rises around 10:30 p.m. local time — just a few hours past sundown — but appears earlier with each passing evening. It rises within minutes of sunset on the 30th. On that date, it transits about 1:30 a.m. and is visible until dawn.

Any telescope shows Jupiter's four big Galilean moons, and binoculars usually show at least two or three. Use the diagram on the facing page to identify them at any date and time.

All of the April 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 in the early morning hours.

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

March 1, 9:36, 19:31; **2,** 5:27, 15:23; **3,** 1:18, 11:14, 21:10; **4,** 7:05, 17:01; **5,** 2:57, 12:52, 22:48; **6,** 8:43, 18:39; **7,** 4:35, 14:30; **8,** 0:26, 10:22, 20:17; **9,** 6:13, 16:08; **10,** 2:04, 12:00, 21:55; **11,** 7:51, 17:47; **12,** 3:42, 13:38, 23:33; **13,** 9:29, 19:25; **14,** 5:20, 15:16; **15,** 1:12, 11:07, 21:03; **16,** 6:58, 16:54; **17,** 2:50, 12:45, 22:41; **18,** 8:36, 18:32; **19,** 4:28, 14:23; **20,** 0:19, 10:15, 20:10; **21,** 6:06, 16:01; **22,** 1:57, 11:53, 21:48; **23,** 7:44, 17:39; **24,** 3:35, 13:31, 3:26; **25,** 9:22, 19:17; **26,** 5:13, 15:09; **27,** 1:04, 11:00, 20:55; **28,** 6:51, 16:47; **29,** 2:42, 12:38, 22:33; **30,** 8:29, 18:25; **31,** 4:20, 14:16.

April 1, 0:11, 10:07, 20:02; **2,** 5:58, 15:54; **3,** 1:49, 11:45, 21:40; **4,** 7:36, 17:32; **5,** 3:27, 13:23, 23:18; **6,** 9:14, 19:10; **7,** 5:05, 15:01; **8,** 0:56, 10:52, 20:47; **9,** 6:43, 16:39; **10,** 2:34, 12:30, 22:25; **11,** 8:21, 18:17; **12,** 4:12, 14:08;

13, 0:03, 9:59, 19:54; **14,** 5:50, 15:46; **15,** 1:41, 11:37, 21:32; **16,** 7:28, 17:24; **17,** 3:19, 13:15, 23:10; **18,** 9:06, 19:01; **19,** 4:57, 14:53; **20,** 0:48, 10:44, 20:39; **21,** 6:35, 16:31; **22,** 2:26, 12:22, 22:17; **23,** 8:13, 18:08; **24,** 4:04, 14:00, 23:55; **25,** 9:51, 19:46; **26,** 5:42, 15:37; **27,** 1:33, 11:29, 21:24; **28,** 7:20, 17:15; **29,** 3:11, 13:07, 23:02; **30,** 8:58, 18:53.

These times assume that the spot will be centered at System II longitude 288°. If the Red Spot has moved elsewhere, it will transit 1⅔ minutes earlier for each degree less than 288° and 1⅔ minutes later for each degree more than 288°.

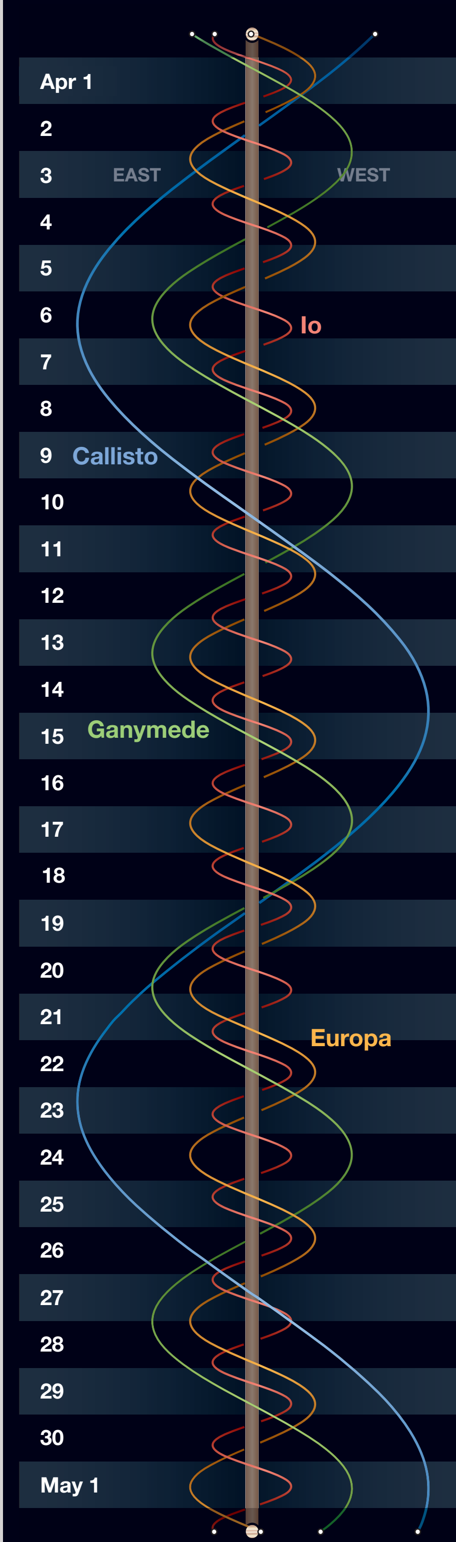
Features appear closer to the central meridian than to the limb for 50 minutes before and after transiting.

Phenomena of Jupiter's Moons, April 2018

Apr. 1	1:09	I.Sh.E
	1:19	III.Sh.I
	1:57	I.Tr.E
	3:04	III.Sh.E
	4:59	III.Tr.I
	6:02	III.Tr.E
	20:07	I.Ec.D
	23:05	I.Oc.R
Apr. 2	4:17	II.Ec.D
	8:07	II.Oc.R
	17:28	I.Sh.I
	18:16	I.Tr.I
	19:37	I.Sh.E
	20:24	I.Tr.E
Apr. 3	14:35	I.Ec.D
	17:31	I.Oc.R
	22:27	II.Sh.I
Apr. 4	0:03	II.Tr.I
	0:43	II.Sh.E
	2:11	II.Tr.E
	11:56	I.Sh.I
	12:42	I.Tr.I
	14:06	I.Sh.E
	14:50	I.Tr.E
	15:26	III.Ec.D
	17:13	III.Ec.R
	18:51	III.Oc.D
	19:56	III.Oc.R
Apr. 5	9:03	I.Ec.D
	11:57	I.Oc.R
	17:34	II.Ec.D
	21:16	II.Oc.R
Apr. 6	6:24	I.Sh.I
	7:09	I.Tr.I
	8:34	I.Sh.E
	9:17	I.Tr.E
Apr. 7	3:32	I.Ec.D
	6:24	I.Oc.R
	11:44	II.Sh.I
	13:12	II.Tr.I
	14:00	II.Sh.E
	15:20	II.Tr.E
Apr. 8	0:53	I.Sh.I
	1:35	I.Tr.I
	3:03	I.Sh.E
	3:43	I.Tr.E
	5:17	III.Sh.I
	7:02	III.Sh.E
	8:25	III.Tr.I
	9:27	III.Tr.E
	22:00	I.Ec.D
Apr. 9	0:50	I.Oc.R
	6:52	II.Ec.D
	10:26	II.Oc.R
	19:21	I.Sh.I
	20:01	I.Tr.I
	21:31	I.Sh.E
	22:09	I.Tr.E
Apr. 10	16:29	I.Ec.D
	19:16	I.Oc.R
Apr. 11	1:01	II.Sh.I
	2:21	II.Tr.I
	3:17	II.Sh.E
	4:29	II.Tr.E
	13:49	I.Sh.I
	14:28	I.Tr.I
	15:59	I.Sh.E
	16:36	I.Tr.E
	19:24	III.Ec.D
	21:10	III.Ec.R
	22:15	III.Oc.D
	23:20	III.Oc.R
Apr. 12	10:57	I.Ec.D
	13:43	I.Oc.R
	20:10	II.Ec.D
	23:35	II.Oc.R
Apr. 13	8:18	I.Sh.I
	8:54	I.Tr.I
	10:28	I.Sh.E
	11:02	I.Tr.E
Apr. 14	5:25	I.Ec.D
	8:09	I.Oc.R
	14:19	II.Sh.I
	15:29	II.Tr.I
	16:34	II.Sh.E
	17:37	II.Tr.E
Apr. 15	2:46	I.Sh.I
	3:20	I.Tr.I
	4:56	I.Sh.E
	5:28	I.Tr.E
	9:14	III.Sh.I
	10:59	III.Sh.E
	23:54	I.Ec.D
Apr. 16	2:35	I.Oc.R
	9:27	II.Ec.D
	12:43	II.Oc.R
	21:15	I.Sh.I
	21:46	I.Tr.I
	23:25	I.Sh.E
	23:54	I.Tr.E
Apr. 17	18:22	I.Ec.D
	21:01	I.Oc.R
Apr. 18	3:36	II.Sh.I
	4:37	II.Tr.I
	5:51	II.Sh.E
	6:45	II.Tr.E
	15:43	I.Sh.I
	16:12	I.Tr.I
	17:53	I.Sh.E
	18:20	I.Tr.E
	23:21	III.Ec.D
Apr. 19	1:08	III.Ec.R
	1:35	III.Oc.D
	2:41	III.Oc.R
	12:50	I.Ec.D
	15:27	I.Oc.R
	22:45	II.Ec.D
Apr. 20	1:51	II.Oc.R
	10:12	I.Sh.I
	10:38	I.Tr.I
	12:21	I.Sh.E
	12:47	I.Tr.E
Apr. 21	7:19	I.Ec.D
	9:53	I.Oc.R
	16:53	II.Sh.I
	17:45	II.Tr.I
	19:09	II.Sh.E
	19:54	II.Tr.E
Apr. 22	4:40	I.Sh.I
	5:04	I.Tr.I
	6:50	I.Sh.E
	7:13	I.Tr.E
	13:13	III.Sh.I
	14:58	III.Sh.E
	15:07	III.Tr.I
	16:11	III.Tr.E
Apr. 23	1:47	I.Ec.D
	4:19	I.Oc.R
	12:02	II.Ec.D
	14:59	II.Oc.R
	23:08	I.Sh.I
	23:30	I.Tr.I
Apr. 24	1:18	I.Sh.E
	1:39	I.Tr.E
	20:16	I.Ec.D
	22:45	I.Oc.R
Apr. 25	6:10	II.Sh.I
	6:53	II.Tr.I
	8:26	II.Sh.E
	9:01	II.Tr.E
	17:37	I.Sh.I
	17:56	I.Tr.I
	19:47	I.Sh.E
	20:05	I.Tr.E
Apr. 26	3:19	III.Ec.D
	6:00	III.Oc.R
	14:44	I.Ec.D
	17:11	I.Oc.R
Apr. 27	1:20	II.Ec.D
	4:07	II.Oc.R
	12:05	I.Sh.I
	12:22	I.Tr.I
	14:15	I.Sh.E
	14:31	I.Tr.E
Apr. 28	9:13	I.Ec.D
	11:37	I.Oc.R
	19:28	II.Sh.I
	20:00	II.Tr.I
	21:43	II.Sh.E
	22:09	II.Tr.E
Apr. 29	6:34	I.Sh.I
	6:48	I.Tr.I
	8:44	I.Sh.E
	8:57	I.Tr.E
	17:11	III.Sh.I
	18:24	III.Tr.I
	18:56	III.Sh.E
	19:30	III.Tr.E
Apr. 30	3:41	I.Ec.D
	6:03	I.Oc.R
	14:38	II.Ec.D
	17:14	II.Oc.R

Every day, interesting events happen between Jupiter's satellites and the planet's disk or shadow. The first columns give the date and mid-time of the event, in Universal Time (which is 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.

Engimatic Lava Tubes

Challenging to spot, some lunar rilles might someday shelter astronauts from harm.

Lunar craters have undeniable appeal when seen through a telescope, but eventually you'll want to explore the subtle details found splayed across the Moon's vast lava plains. High on my list are *sinuous rilles,* snakelike "riverbeds" that sometimes meander across the maria for hundreds of kilometers. They're worth studying because one of them might someday serve as a habitat for visiting astronauts.

This is an old idea, dating back to the 1960s and early 1970s, when geologists realized that these winding features weren't formed by flowing water but by flowing lava. Dale Cruikshank (now at NASA Ames Research Center) and I were among those who proposed this explanation. We'd noted how fluid eruptions from Hawai'ian volcanoes tend to develop channels that efficiently transport lava downslope.

Splashes of lava solidify along the edges of these channels and gradually build levees that in some cases grow to span the flow's entire width. This insulating cap keeps the lava underneath from radiating heat away quickly, allowing it to flow further. Pieces of the roofs of some tubes collapse, creating "skylights" that expose torrents of hot lava flowing below.

Future astronauts might descend into a hollow, long-frozen lava tube on the Moon to gain shelter from cosmic rays and small impact events, and to moderate the extreme temperature swings (300°C or 540°F) that the surface endures over a 29½-day-long lunar diurnal cycle.

More Common than Thought

Among a comprehensive census of 195 sinuous rilles compiled by Debra Hurwitz while a graduate student at Brown University (see **lpi.usra.edu/lunar/rilles**), only six are known to have skylights. It seems that most channels were too wide for roofs to form and be supported.

Unfortunately, these six skylights are relatively tiny. The largest are only about 100 m wide, far too small for even the best telescopes to spot. Areas between lines of skylights should be uncollapsed lava tubes — in theory, at least.

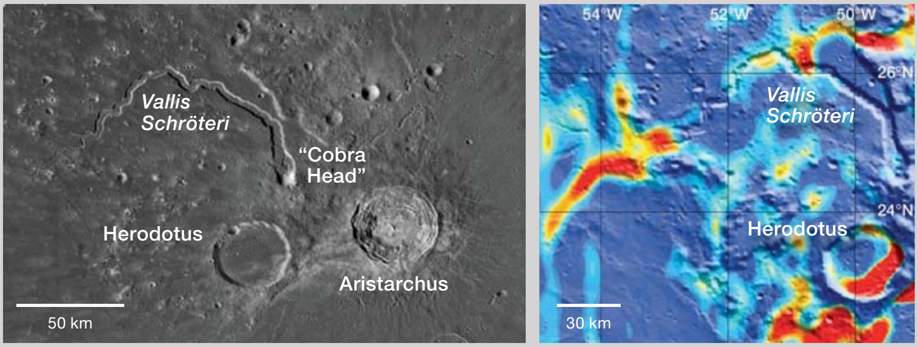
Two teams have recently used different geophysical measurements to provide more direct evidence that such tubes exist. Loïc Chappaz (Purdue University) and six colleagues analyzed the very precise measurements obtained by NASA's twin Gravity Recovery and Interior Laboratory spacecraft. Since a lava tube is empty space, it's detectable as a tiny deficit of mass. The Chappaz team delicately tweaked GRAIL's data to find indications of 11 lunar tubes — some extending beyond sinuous rilles, some between skylights, and some with no surface expression at all.

Among the most conspicuous is an extension beyond the end of the "mega-rille" **Vallis Schröteri** (Schröter's Valley). The researchers model this tube as being 60 km long, 3.75 km wide, and an amazing 600 m tall. It apparently starts near the end of Schröter's Valley and extends out to the southwest under younger lavas that overlap the edges of the Aristarchus Plateau.

They identified another lava tube near two large rilles in the western Marius Hills. That's where spacecraft imagery revealed a 65-m-wide skylight, evidence for a relatively recent collapse. The tube continues 60 km past the end of the surface rille and apparently is

DALE CRUIKSHANK

▲ An opening or "skylight" on Mauna Ulu in Hawai'i reveals molten rock flowing through a lava tube just below the surface. Numerous lunar rilles likely have hidden lava tubes as well.



▲ *Left:* The "mega-rille" Vallis Schröteri (Schröter's Valley) snakes across the lunar surface for hundreds of kilometers. *Right:* New results from GRAIL spacecraft data suggest that a hollow tube (red band left of center) extends below the surface beyond the rille's southwestern end.

much broader than the 400-m-wide channel seen on the surface.

The final large gravity anomaly found by Chappaz's group appears to connect the southern ends of **Rima Sharp** and **Rima Mairan** in Sinus Roris. Then it continues to the north end of a bizarre "braided rille" (likely a complex lava tube) due south of the 40-km-wide crater **Mairan**.

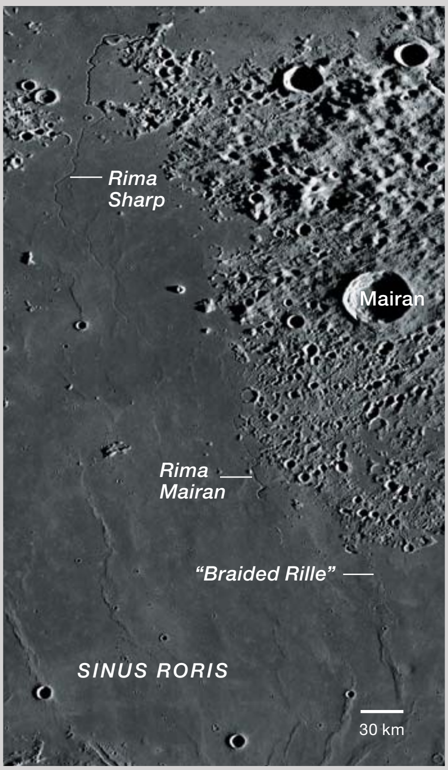
It seems strange that one tube would connect all of these lava channels around Sinus Roris, for this kind of linking doesn't happen on Earth. It's also perplexing to find tubes so much wider than the surface rille. In terrestrial cases, the tube is just a roofed channel — so they're the same width.

The Japanese lunar orbiter Kaguya has provided confirmation of tubes in the Marius Hills. Kaguya's Lunar Radar Sounder generates radio-wave pulses that penetrate tens to hundreds of meters into mare lavas, and then records echoes reflected from subsurface layers. Tesuya Kaku (Japan Aerospace Exploration Agency) and colleagues have detected numerous linear voids near the Marius Hills rilles that they believe come from the floors and ceilings of lava tubes.

Would these make suitable habitats for astronauts? Perhaps not. All of the lava tubes that I've entered had floors littered with collapsed roof blocks and stalactites hanging from their ceilings. Such sharp rocks and surfaces could make walking difficult or easily puncture an inflatable habitat or spacesuit. And access through a partially collapsed skylight could be tricky. It might be necessary to use a winch to get astronauts and their equipment into and out of an underlying tube.

Elusive Quarry

Usually less than 1 km wide, lunar rilles are challenging to observe. Those with roofs (lava tubes) are even more difficult to detect, unless they have skylights — but even then it will be a struggle to glimpse them.



▲ The lunar rilles Rima Sharp and Rima Mairan snake along the eastern shore of Sinus Roris and might be part of an interconnected regional network of ancient lava tubes.

Still, the areas where they occur are readily observable. Easiest is the western end of Schröter's Valley, the widest lunar rille. You'll need a telescope with at least 3 inches of aperture; look 12 or 13 days after new Moon (March 29–30, April 12–13, or April 28–29 this season).

The nearby Mairan and Sharp rilles are both narrower than 1 km and would be nearly impossible to visually observe — except that parts of their lengths run nearly north to south. This means that, after local sunrise (likewise 13 days after new Moon), their eastern walls cast shadows onto their floors that appear like narrow black lines in the maria. Use 150× to 200× and a scope with a 6-inch or larger aperture to explore the area.

On the same night that you search for Schröter's Valley and the rilles in Sinus Roris, slide farther south along the terminator to the **Marius Hills**, a collection of nearly 200 volcanic cones, domes, and rilles. Although too narrow to resolve visually, the rille and its associated skylight and lava tubes occur near the middle of this mass of mounds.

Not all rilles are in the maria. Using Lunar Reconnaissance Orbiter images, Pascal Lee (SETI Institute, Mars Institute) found that **Philolaus**, a young, 70-km-wide crater poleward of the western end of Mare Frigoris, has many small rilles and some skylights on its floor. These formed in impact melt that must have flowed after being ejected upward and then falling back to the surface. The rilles are too small to be observed, but the nearly 20-km-long patch of smooth impact melt can be glimpsed on the eastern floor of the crater.

As you observe the Marius Hills and the Sharp and Mairan rilles, imagine what it would be like to live in one of their tubes — with a skylight providing night views of an inky-black sky littered with stars.

■ Contributing Editor **CHUCK WOOD** singed his eyebrows in 1971 while photographing a lava-tube skylight in an active flow on Kilauea in Hawai'i.

PHOTOS: NASA / LUNAR RECONNAISSANCE ORBITER; COLOR PLOT: CHAPPAZ *ET AL* / *GEOPHYSICAL RESEARCH LETTERS*

Into the Lion's Den

It's deep, it's dark, but this nighttime hideaway is also full of galaxies.

The den of the celestial lions, Leo and Leo Minor, is adorned with the ashen light of myriad far-flung galaxies awaiting our admiration. Since Leo is far and away the more recognizable of these starry felines, let's begin our pursuit of their deep-sky wonders by prowling through his share of the den.

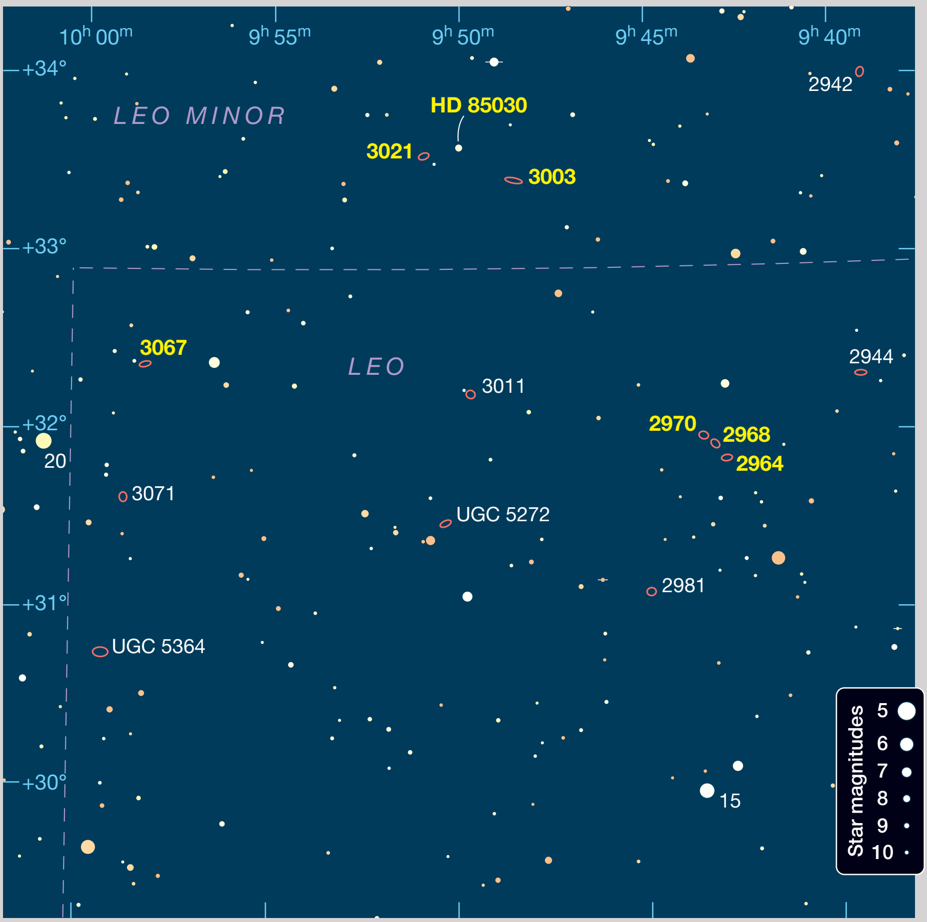
Leo's iconic feature is the sickle-shaped asterism that marks his head and heart, but some skygazers picture it as a backward question mark. Our initial leonine quarry is a galaxy trio north of the Sickle, composed of **NGC 2964**, **NGC 2968**, and **NGC 2970**. You'll find them arrayed along a shallow arc, with each galaxy smaller and dimmer as you work your way from southwest to northeast.

The brightest member of the triad is NGC 2964, perched 1.9° north of the 5.6-magnitude star 15 Leonis. In my 130-mm refractor at 37×, the galaxy bares a brighter heart and crowns a distinctive arrangement of eight 9th- to 12th-magnitude stars that outline an 18′-tall shark fin. At 63× NGC 2964 becomes an east-west oval covering roughly 2′ × 1′. NGC 2968 materializes 6.2′ to the northeast, watched over by a 12th-magnitude star roosting 3.6′ north-northeast. At 102× NGC 2968 looks oval and points back toward NGC 2964, which brightens moderately toward the center. Using averted vision, NGC 2970 joins the scene as a little, fuzzy dot 2.9′ east of the 12th-magnitude star. My 10-inch reflector at 115× coaxes out a small, concentrated core within NGC 2968.

This galaxy triplet is thought to be a true group. A neutral-hydrogen bridge connects NGC 2964 and NGC 2968, while a tail reaches out to NGC 2970. The local motions of these galaxies and their relative nearness to us conspire to make redshift-based distances unreliable. Only NGC 2964 has a significant number of redshift-independent distance determinations. Using their mean as a value would place the trio at 62 million light-years. Experienced astro-imagers have captured visible material around NGC 2970 that may stem from past galaxy-galaxy interactions.

Crossing the border into Leo Minor, we'll find **NGC 3003** 21′ west-southwest of the 7.9-magnitude star HD 85030. The galaxy appears slender and very faint in the 130-mm scope at 48×. At 102× its brightest region spans 2′ and slants a bit north of east. Pallid extensions run farther west than east and stretch the length to perhaps 5′. Through the 10-inch scope at 166×, the galaxy's face seems slightly patchy.

In the 130-mm refractor's 48× view, NGC 3003 shares the field with a little fuzzy spot snugged against an 11th-



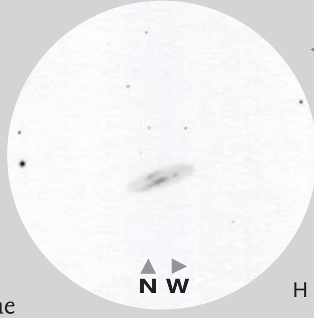
magnitude star. This is **NGC 3021**, which rests 12′ east-southeast of HD 85030. At 117× its 1′ oval gently brightens toward the center and doesn't reach the 11th-magnitude star near its east-southeastern tip. My 10-inch scope at 166× reveals another stellar attendant, a 14th-magnitude sun northeast of the galaxy's center and tight along its edge.

NGC 3003 and NGC 3021 are considered members of a loose galaxy group designated USGC U268, given a distance of 78 million light-years in the NASA/IPAC Extragalactic Database. Another group member, **NGC 3067**, lies 43′ northwest of pale yellow, 5.4-magnitude 20 Leo Minoris and past the border into Leo. I stalked this galaxy one night with my smaller refractor, a 105-mm scope. At 47× a 25′-long zigzag of six stars sprawls across the field, with NGC 3067 near its westernmost star. At 87× the oval galaxy leans east-southeast and exhibits uniform surface brightness. In the 10-inch reflector at 115×, NGC 3067 covers roughly 2′ × ⅔′. At 166× its center is broadly but only slightly brighter, while the tips are dimmer.

We'll find our next trio of galaxies making a nearly equilateral triangle in Leo Minor. **NGC 3245** and **NGC 3277** form the triangle's southern side, while **NGC 3254** marks its northern point. A bright, widely spaced double star sits between the southern galaxies, although it's only an optical (unrelated) pair. **ΟΣΣ 105** (STTA 105) comprises two yellow-orange stars, the standoffish companion a full 134″ southwest of its primary.

With the 130-mm refractor at 37×, NGC 3245 is easily visible as an oval glow north of the western end of a long wavy line of field stars that includes the double ΟΣΣ 105. Dimmer NGC 3277 bears a round face with a more luminous center. At 63× NGC 3245's north-south oval grows progressively brighter toward the middle, and NGC 3254 emerges as a gauzy strand stretched northeast-southwest. At 102× NGC 3245 is 2′ long and half as wide, harboring a brighter oval interior and tiny, bright core. NGC 3277 has a diameter of about 1′, while the ghostly glow of NGC 3254 is maybe 4′ long, with a brighter, elongated interior. The 10-inch reflector at 213× adds a stellar or nearly stellar nucleus to each galaxy.

The three galaxies above belong to the NGC 3245 group, about 75 million light-years distant. **NGC 3245A** is sometimes listed among the group's members. Its exceptionally thin needle of light lies 8.8′ north-northwest of NGC 3245. Although I couldn't see it with my 15-inch reflector, others have reported success with scopes as small as 12 inches in aperture.



◀ NGC 3067 is detectable in small refractors as a slight smudge tipped west-northwest. Larger scopes, such as the 27-inch f/4.2 Newtonian reflector used to complete this sketch, should reveal brightening at the galaxy's center as well as a few luminous H II regions.

Our final prey is the galaxy cluster WBL 258, whose designation comes from a 1992 paper published in the *Astronomical Journal* by Richard A. White and colleagues. WBL 258 is credited with nine galaxies at a vast remove of 305 million light-years, eight of them in the *New General Catalogue of Nebulae and Clusters of Stars*.

NGC 3158 is the cluster's brightest member, and the easiest catch through my 130-mm scope. The galaxy is visible at 37× as a very small, very faint, round smudge that's brighter in the center.

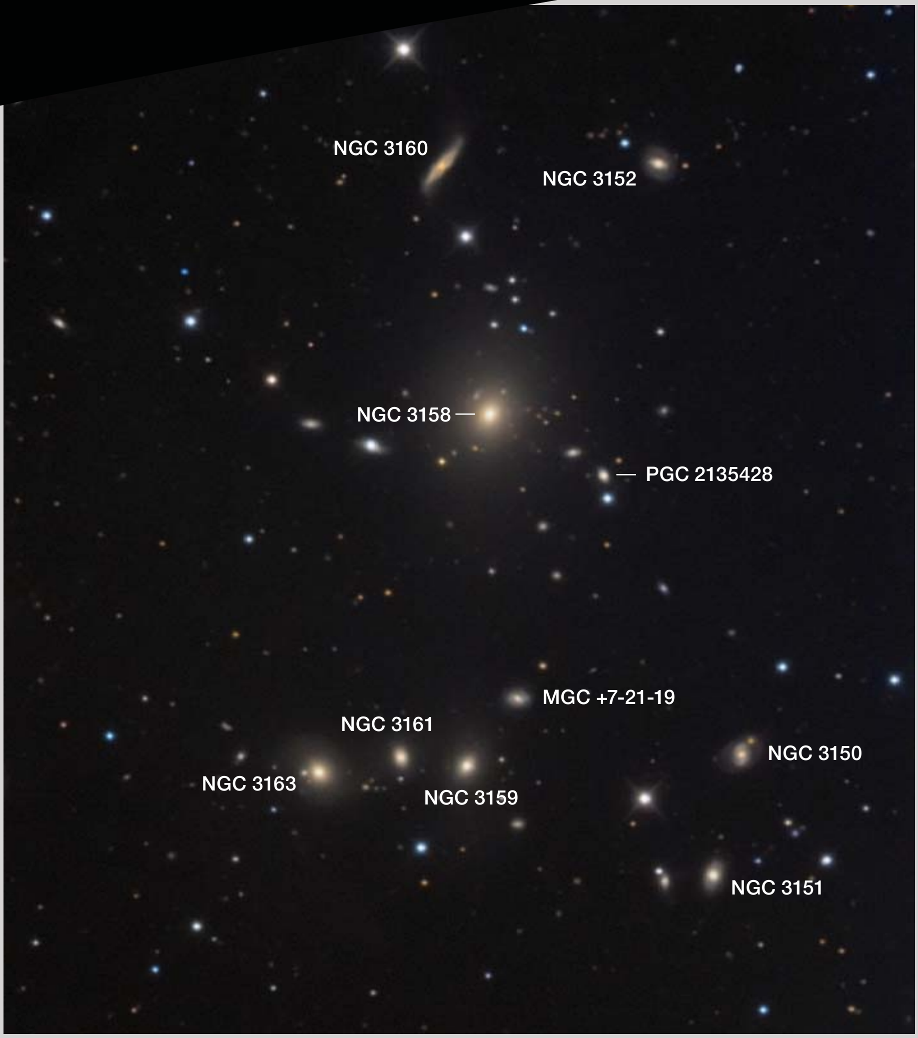
Galaxies in Lion Territory

Object	Type	Mag(v)	Size	RA	Dec.
NGC 2964	Spiral galaxy	11.3	2.9′ × 1.6′	$9^h\ 42.9^m$	+31° 51′
NGC 2968	Irregular galaxy	11.7	1.9′ × 1.3′	$9^h\ 43.2^m$	+31° 56′
NGC 2970	Elliptical galaxy	13.6	0.8′ × 0.7′	$9^h\ 43.5^m$	+31° 59′
NGC 3003	Spiral galaxy	11.9	5.8′ × 1.3′	$9^h\ 48.6^m$	+33° 25′
NGC 3021	Spiral galaxy	12.1	1.6′ × 0.9′	$9^h\ 51.0^m$	+33° 33′
NGC 3067	Spiral galaxy	12.1	2.4′ × 0.8′	$9^h\ 58.4^m$	+32° 22′
NGC 3245	Lenticular galaxy	10.8	2.9′ × 1.1′	$10^h\ 27.3^m$	+28° 30′
NGC 3277	Spiral galaxy	11.7	1.9′ × 1.7′	$10^h\ 32.9^m$	+28° 31′
NGC 3254	Spiral galaxy	11.7	4.5′ × 1.2′	$10^h\ 29.3^m$	+29° 29′
ΟΣΣ 105	Double star	7.0, 8.2	134″	$10^h\ 29.9^m$	+28° 35′
NGC 3245A	Barred spiral	13.9	3.6′ × 0.3′	$10^h\ 27.0^m$	+28° 38′
NGC 3158	Elliptical galaxy	11.9	2.0′ × 1.8′	$10^h\ 13.8^m$	+38° 46′

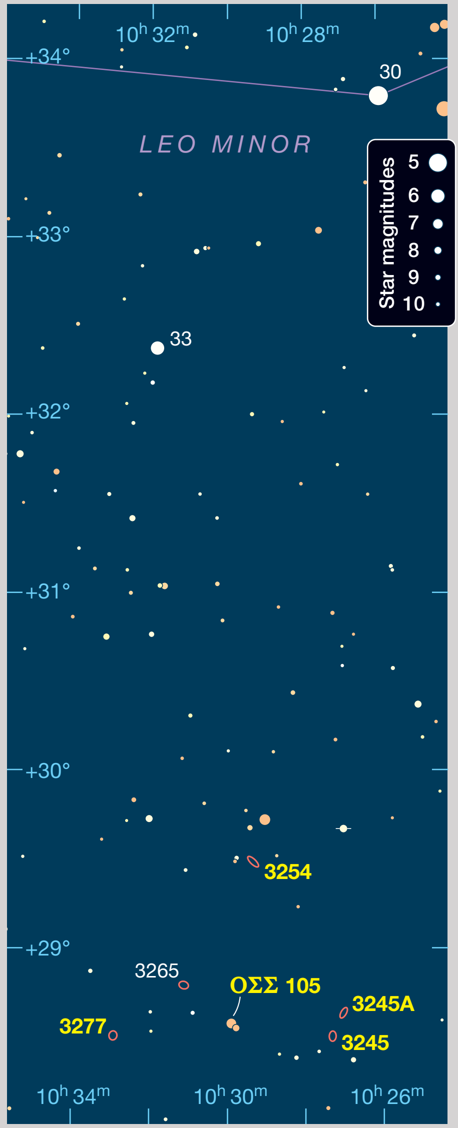
Angular sizes and separations are from recent catalogs. Visually, an object's size is often smaller than the cataloged value and varies according to the aperture and magnification of the viewing instrument. Right ascension and declination are for equinox 2000.0.

▲ The trio NGC 2964, NGC 2968, and NGC 2970 are thought to be a true galaxy group. In the LRGB image above, which represents a total of 22 hours, 24 minutes exposure time, the luminous bridge connecting NGC 2968 and NGC 2970 is visible.

SKETCH: UWE GLAHN; TRIO: BERNHARD HUBL



▲The light from NGC 3158, the brightest member of this eponymous galaxy group, takes about 325 million years to reach Earth. William Herschel spotted NGC 3158 and NGC 3163 in 1787, but the group's dimmer galaxies weren't dug from the deep until almost a century later.



At 117× its bright interior takes up a relatively large part of the galaxy, which spans about 1′. A very faint spot is also visible in the field. Boosting the magnification to 164× confirms its identity as **NGC 3163** (magnitude 13.3), and I can also glimpse **NGC 3159** (13.6). These smaller galaxies can be detected largely due to their comparatively bright cores. An extremely faint star hangs between and south of the pair, and a 12th-magnitude star sits a few arcminutes west of NGC 3159.

My 10-inch reflector at 213× exposes several more galaxies. Closely flanked by roundish NGC 3163 and oval NGC 3159, **NGC 3161** (13.5) is fairly faint with uniform surface brightness. Its bosom buddies hold brighter hearts, and NGC 3159 lists northwest. The 12th-magnitude star west of NGC 3159 forms a short isosceles triangle with two dim galaxies, **NGC 3151** (13.8) to the southwest and more elusive **NGC 3150** (14.6) to the west-northwest. North of NGC 3158, two stars 3.7′ apart bracket **NGC 3160** (14.1), a slim galaxy tilted northwest. Only 4.1′ due west of NGC 3160, **NGC 3152** (14.2) is a very small, very faint glow.

The view in the 10-inch scope also includes two non-NGC galaxies. At first I thought there were three, but the easily visible, starlike object that I'd taken for MCG +7-21-25's core turned out to be a true star superimposed on the core. On the other hand, tenuous **MCG +7-21-19** (15.0) is discernible, but it's a very tough catch 1.6′ northwest of NGC 3159. With a lower magnitude but higher surface brightness, **PGC 2135428** (15.3) seems to be a tiny spot 2.5′ west-southwest of NGC 3158 and a scant 26″ north of a 13.6-magnitude star. It's a great eye-teaser for those who enjoy a real challenge.

The celestial lair where lions dwell, its walls softly silvered with galaxies and sparkling with tiny gems, is a fine place to spend a clear spring night. Give it a try!

■ Contributing Editor **SUE FRENCH** fears no lions, celestial or otherwise.

JOHN DWYER

Sky-Watcher's Stargate 18-inch Dobsonian

The Stargate truss-tube Dobsonians are billed as the largest mass-market telescopes available. Is the 18-inch model worthy of the hype?

Stargate 18-inch Dobsonian

U.S. Price: $5,999 ($6,999 as tested with Go To motor drives)

skywatcherusa.com

What We Like

Excellent optics

Optional drive offers accurate pointing and tracking

Overall performance

What We Don't Like

Abysmal instruction manual for telescope assembly

AFTER TESTING SKY-WATCHER'S 18-inch Stargate truss-tube Dobsonian for several months late last year, it's easy to understand why deep-sky observers proclaim that aperture is king. Objects that appear faint and ill-defined in smaller scopes take on a whole new dimension in an 18-inch. Many globular clusters are transformed from small, fuzzy glows into brilliant spheres of sparkling stars. Lots of planetary nebulae appear large and bright enough to show obvious structure not seen with smaller apertures. And the fields surrounding many familiar deep-sky objects are filled with a multitude of faint background stars lending 3D-like perspectives.

◀ The Sky-Watcher Stargate 18-inch with SynScan motor drives for Go To pointing and tracking is a big telescope, standing more than 7 feet tall when pointed at the zenith. While the author set up the telescope by himself, the process would be far easier with two people.

ALL PHOTOS PROVIDED BY THE AUTHOR

▲ The Stargate comes with a 9×50 straight-through finder and a 2-inch, two-speed focuser with extension tubes/adapters for 2- and 1¼-inch eyepieces. As explained in the accompanying text, the author typically observed with the Tele Vue Paracorr coma corrector pictured here.

It was apparent how much I liked the Stargate when I quickly found myself looking forward to each clear night as an opportunity to observe rather just one to work on a product review. While the telescope ended up being one I truly enjoyed, and one I can strongly recommend, the review process didn't start out that way. But let's save that part of the story for later in this review and begin with the good stuff.

Although I'm no stranger to using large telescopes, especially at star parties, my own recreational deep-sky observing is usually done with a 12-inch f/5 Dobsonian. As such, the 18-inch Stargate was a significant step up. In addition to having 2¼ times more light grasp than the 12-inch, the Stargate's longer focal length (1,900 mm versus 1,524 mm) offered noticeably more magnification for a given set of eyepieces. By itself, this longer focal length would have yielded 25% more magnification. But because the Stargate is an f/4.1 Newtonian and suffers more from coma than the 12-inch f/5, I did most of my Stargate observing with a Tele Vue Paracorr coma corrector that increased the Stargate's effective focal length by a factor of 1.15×. And this meant a 43% increase in magnification for the same eyepiece used with the Stargate compared to my 12-inch Dob.

The Stargate ships with 2-inch 28-mm and 1¼-inch 10-mm eyepieces of decent quality. They yield 68× with a 49-arcminute field of view and 190× with a 15-arcminute field, respectively.

There is also a Cheshire eyepiece collimation tool, which is very good for checking the scope's optical alignment. Due to the length of the instrument, however, collimating the optics with the included tool is best done with two people — one looking through the Cheshire eyepiece while the other adjusts the collimation screws on the primary-mirror cell. I aligned the optics with a HoTech SCA laser collimator (**hotechusa.com**) that allowed me to tweak everything without additional help. And the good news is that once collimated, the scope held its alignment well.

I also used my own Tele Vue eyepieces that I keep handy with my 12-inch scope. These ranged from a 35-mm Panoptic that yielded (with the Paracorr) 62× and a field slightly more than 1° across, to a 7-mm DeLite giving 308× and an 11-arcminute field. I also had some exceptionally memorable

▶ The Stargate Dobs have noteworthy primary mirrors made from fused glass. The 18-inch has a front plate (about ¾ inch thick) and back plate separated by a dozen ribs surrounding a central hollow core. As such the 3½-inch-thick mirror weighs only about 30 pounds and acclimates to ambient temperatures much faster than a solid disk of glass would.

▶▶ In the workshop, the author's Foucault test of the primary mirror shows no sign of "print through" from the supporting rib structure. There is a slight hint of a central depression due to the hollow core, but it falls completely within the shadow of the secondary mirror and is of no consequence. The mirror is an overall well-corrected paraboloid with subtle artifacts typical of machine-polished optics. It delivered excellent performance at the eyepiece.

views with a 21-mm Ethos, which gave almost the same field of view as the Panoptic, but at an impressive 103×.

First Night Out

My first night under the stars with any telescope is usually reserved for just getting a feel for what it's like to set up and use the equipment — serious observing isn't typically on the agenda. As such I picked a spot on the walkway outside my garage where the sky is, unfortunately, heavily obscured by the house and surrounding trees.

While I set up the scope by myself, it would be far easier with two people. The base with its optional motor drives weighs about 66 pounds (30 kg). But it's the optical assembly (a.k.a. "the tube") that presents the biggest challenge. Complete with the side cradles attached to the primary-mirror assembly, the tube weighs almost 100 pounds, and it's quite awkward for one person to lift and position on the base. But I still found this easier to do than to assemble the tube beginning with the primary-mirror assembly (by itself a 60+ pound unit) placed on the base. The problem here for one person is trying to get the secondary-mirror cage attached to the top of the six truss poles while they are pointing 7 feet above the ground and flailing around.

As twilight receded down the western sky, I pointed the Stargate to brilliant Vega high overhead. Although I'm well over 6 feet tall, I could just reach the eyepiece when standing on a 9-inch-high step stool. At 196× Vega appeared dazzlingly bright with four razor-sharp diffraction spikes extending across my 18-arcminute-wide field of view. Boosting the magnification to 308× and racking the eyepiece from one side of focus to the other revealed diffraction patterns suggesting that the optics in this scope were very good, but Vega was really too bright for a good star test, so I nudged the scope to the northeast to look at Epsilon Lyrae, the famous Double-Double.

▲ With the threat of rain in the forecast, the author spread out the parts of the Stargate on his garage floor before beginning the assembly process.

Moving my eye from the Stargate's 9×50 finder to the 308× eyepiece provided me with a dramatic, in-your-face example of the advantages that a big aperture brings to many types of observing. The tightly spaced components of this pair of double stars were cleanly resolved with a wide gap of dark sky between the tight pairs. And all four stars were surrounded with neat sets of diffraction rings. I've seen this kind of clearly resolved separation at similar magnifications with smaller, high-quality telescopes, but there were added dimensions to the view in the Stargate. Each of the four stars vividly displayed its own delicate hue — something that is far more subtle with smaller apertures. And there was a multitude of faint background stars that go mostly unnoticed in smaller scopes, giving a truly three-dimensional feel to the scene. It was now obvious that the optics were indeed very good.

With my appetite whetted for more, I decided to engage the motor drives and attempt the necessary star alignment for Go To pointing and tracking even though I hadn't yet gone through the manual for Sky-Watcher's SynScan drive system. Following instructions that scroll across the hand control, and after a few false starts (mainly because of accidentally pushing the wrong buttons on the hand control), I got the drive working, and I grabbed a star chart to see what interesting objects were within

◀ *Far left:* The two sections forming each of the scope's six truss poles have solid, screw-together connections at their centers. This keeps the length of the individual pieces very manageable for transport and storage. *Left:* The truss poles fit into numbered connections on the primary- (seen here) and secondary-mirror assemblies, and lock in place with a captive clamp and hand lever. As such, no tools are needed to assemble the optical tube.

my limited view of the sky. Despite my less-than-ideal alignment, the Go To pointing was very good and tracking was likewise good. Thus began a very enjoyable evening of observing.

And It Gets Better

If I considered that first night good, then the second night was nothing short of spectacular. By then I'd made a trip to the local outlet for Harbor Freight Tools and picked up a small furniture dolly for $8 and a two-tier step ladder, on sale for $20. With a couple of pieces of scrap wood I supported the assembled Stargate on the dolly and could easily roll it in and out of my garage. Furthermore, as the image on page 62 shows, it was an easy matter to lift each leg on the base about ½ inch and slide a brick under it, putting the scope on a solid footing free of the dolly. After leveling the base and marking which leg belonged on which brick, I marked the location of the bricks with a few pieces of tape on the driveway. On subsequent nights it took only a few minutes to roll the scope out of the garage and have it ready for observing. This may sound stupid, but because I didn't have to disassemble the scope to transport and store it, it was as easy to use in my driveway as any grab-and-go scope I've tested.

By the second night I'd also gone through the SynScan manual and had a better handle on the best way to do star alignments and, in general, use the drive's features. The hand control has the typical catalogs of objects that are available with modern Go To systems, including the Caldwell catalog. There is, however, no listing of named deep-sky objects, so if you're looking for the Ring Nebula, you'll have to find it by either its Messier number (M57) or its designation in the New General Catalogue (NGC 6720).

From an operational standpoint, the drive worked very well. When slewing the telescope at the higher speeds, there's a somewhat annoying lag in the response to pressing the slew buttons, but this goes away at slower speeds, making it easy to center objects in the finder and telescope eyepiece. Since the power jack for the motors moves as the scope turns in azimuth, you have to be mindful of having enough slack in the power cord for the scope to turn. There is a cord-wrap feature that helps by preventing the scope from continuously slewing in one direction, but I never figured out exactly when it would activate. This is no big deal, but it can be a bit surprising when you expect to have the scope slew only a short distance

▲ *Left:* The Stargate's ribbed secondary mirror is made of molded glass to help reduce weight and speed temperature acclimation. *Right:* Lightweight plastic covers for the primary and secondary mirrors help keep the optics protected and dust-free when the scope is not in use.

from one object to the next but then find the azimuth motion reverse direction and turn nearly 360° to get back to the general area where you were just looking.

There are a few subtle differences between the SynScan system and other Go To scopes I've used, but overall I was very pleased with its operation and features. I've not used a lot of Dobsonian scopes with Go To pointing, but I found this one to be very accurate, and the tracking excellent. Furthermore, you can disengage the motor clutches on both axes and move the scope manually to any part of the sky and reengage the clutches and resume observing without having to re-initialize the drives. A very nice feature.

▲ The SynScan hand control has illuminated buttons and is typical of many of today's Go To systems. The author found it easy to master.

Why the Rocky Start?

With so many positive things going for the Stargate, you're probably wondering why I said earlier that this review didn't start off well. The answer can be summed up in three words — the instruction manual. Regardless of what I might intuitively know about setting up telescopes, for the sake of a review I always follow the step-by-step instructions in the manual. I can't recall assembly instructions worse than those for the Stargate. In addition to easily recognized mistakes such as referring to the secondary-mirror assembly as the primary-mirror assembly, there are misidentified parts mentioned in the text that make the assembly procedure confusing. But even worse are the diagrams, many of which are riddled with errors. There are mislabeled diagrams; diagrams with missing labels; and diagrams mentioned in the text that simply don't exist. The worst of these errors involved the novel cable system used for the altitude drive, so the manual will be less of a problem for people who don't purchase a Stargate model with drives. But I found the Go To pointing and tracking to be so valuable that I would strongly recommend people consider getting the scopes with motor drives.

After working through the scope's frustrating assembly procedure, I worried that things were going to get even worse. When I initially unpacked the telescope from its four large shipping boxes there was a prominent slip of paper with the bold headline "Attention." It directed me to the Sky-Watcher website to download the latest version of the SynScan firmware and install it *using instructions in the manual*.

This is rather common for today's computerized scopes, but I was dismayed to see that the latest version of the firmware was dated more than six months before the Stargate was shipped to me for review, and the version of firmware in my hand control was even older. An update was clearly needed to keep the review accurate, but I certainly wasn't looking forward to another round of step-by-step instructions in the manual.

But here's the punchline: The whole procedure went precisely as described in the SynScan manual and took about

▲ As described in the text, the author found this $8 furniture dolly an excellent way to move the fully assembled scope over hard surfaces, including on a lengthy trek down his street to a neighbor's yard to view an occultation by Neptune's moon Triton last October 5th. It was a simple matter to lift each of the scope's three legs just enough to slip bricks under them, creating a solid base for the scope to sit on.

Here's a sneak peek of the new night-vision system we'll be reviewing in the coming months. It was awarded a Hot Product in last January's issue (page 35) and is seen here on the Stargate with an optional iPhone adapter. It was used for the "snapshot" at far right of the planetary nebula NGC 7662 in Pegasus, better known as the Blue Snowball Nebula. Deep-sky astrophotography with an iPhone — we do live in interesting times….

▲ *Left:* The altitude drive for the Stargate SynScan models uses a wire-cable system visible in this view of the telescope base. It worked very well but had to be disconnected from the telescope tube in order for the tube assembly to be removed from the base. *Right:* Electrical connections for the SynScan drives are straightforward and well-marked. Furthermore, the cable connectors for the azimuth motor and encoder are slightly different, making it impossible to attach them incorrectly, even in the dark.

10 minutes! The only hurdle was the required serial connection between the computer and hand control to do the update. Since the hand control needs to be plugged into the scope and powered on for the update, that meant bringing a computer to the scope, and it's been years since any of my laptop computers has included a serial connection. I had to use a USB-to-serial adapter, which was no big deal.

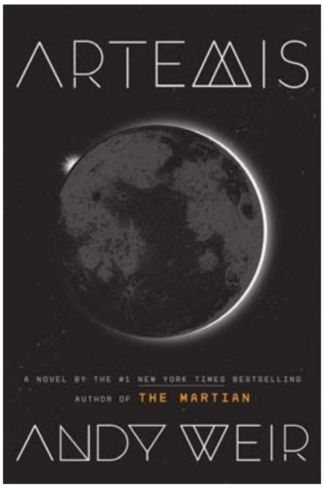
Memories of the bumpy road traveled to get from opening the telescope's shipping boxes to first light with the Stargate 18-inch SynScan instantly faded into the background when I had that first look at the Double Double mentioned earlier. And were it not for writing this review, it would have probably stayed that way. The Stargate turned out to be a wonderful instrument to use. As with any big telescope, there are special considerations that go with storing, moving, setting up, and taking down the Stargate. But if you're prepared for them, then I can strongly recommend this telescope. It really is that good.

■ DENNIS DI CICCO has been writing about astronomical equipment in the pages of *Sky & Telescope* for more than 40 years.

Of Heists, Lies & Truth

ARTEMIS: *A Novel*

Andy Weir
Crown, 2017
320 pages, ISBN 9780553448122
$27.00, hardcover.



FROM THE AUTHOR OF *The Martian* comes another high stakes extraterrestrial adventure. Its billing as a "heist on the Moon" doesn't quite encapsulate the entirety of *Artemis* — it's part heist, but it's also part whodunit and part hard science fiction, all told through the eyes and past emails of the main character, Jazz.

A compelling read, *Artemis* displays Weir's penchant for getting the science right. From detailing how the difference in gravity affects lunar residents and visitors, to time delays in interacting with Earth's internet, to the delightfully complicated solutions with limited resources *The Martian* presented so well, it's clear that Weir took the time to find explanations that would obey our universe's laws of physics — without getting lost in the minutiae and miring the novel's pace.

Weir creates a working economy, society, and currency that are both internally consistent and fascinating to follow through to their logical completion. Refreshingly, Artemis, the lunar colony and setting of the novel, is run not by a utopian United States exploring the vastness of space for the sake of knowledge, but rather by Kenya, thanks to a clever economist. It feels completely different from the perspective of other science fiction novels while at the same time seems absolutely normal because that's just how this world is.

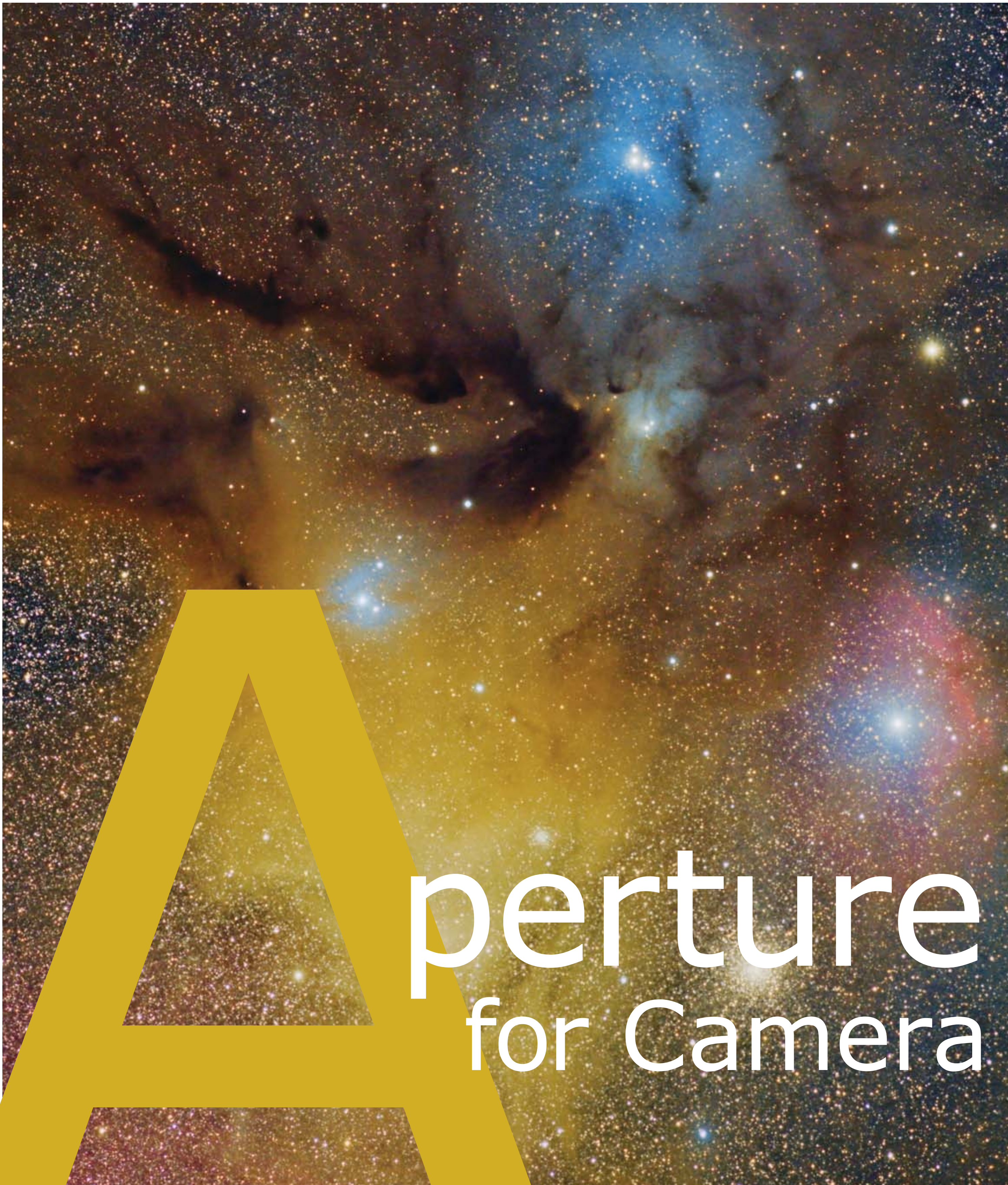
. . . it's part heist, but it's also part whodunit and part hard science fiction, all told through the eyes and past emails of the main character, Jazz.

In large part, this normalcy is achieved by the book's underachieving lead, Jazz. While she has an astronomical intellect, Jazz has no aspirations of being part of the intelligentsia. Instead, she runs a small smuggling ring in her low-paying porter job, consorts with denizens of the Artemesian underbelly, and dreams of having enough money to pay her debts and join the EVA Guild. Jazz lies to herself throughout the novel about what does and doesn't matter to her, which at times makes the characterization feel false and clumsy — a woman's experience told through the eyes of a man. But in the end, that falseness adds authenticity, because this novel is as much about codes of ethics and how they frame our experience as it is about a heist.

Although the falseness and clumsiness of Jazz has the ring of truth to it, Weir's inclusion of a tertiary romantic subplot adds nothing to her characterization. The lead in *The Martian* had no such subplot, and I was left wondering if he thought that Jazz needed a romance just because she's a woman, as if her attitude towards love is the indicator of her brokenness. As she heals, her attention to romantic love returns. It's a shame, because the shift in her relationship with herself and her father was plenty to signal that healing without the addition of a romantic love.

What Weir does well, of course, is craft a heist. A heist with a perfect solution that only the most brilliant brain with exactly the right skills could come up with — and since it's Weir, you know something goes wrong. It's thoroughly delightful, refreshing, and well worth a read if you enjoyed *The Martian* (and perhaps even if you didn't). Oh, and I didn't see the end coming until, well, the end. Of course, all the clues were there . . .

■ Digital Content Strategist **JANINE MYSZKA** is often found with her nose in a book — when she isn't managing the S&T social media accounts, that is.



Aperture for Camera

Masks Lenses

Here's a novel way to make your camera lens perform like a high-quality refractor.

Once upon a time I had two hobbies: photography and astronomy. I had a telescope for observing, and I had a camera for taking photographs. These two interests lived separately and grew for years before they came together, mostly because I had good photographic gear long before I had good astronomy gear. When the two merged, it didn't seem to be something entirely new; it was just that now my photography extended beyond birds, animals, and landscapes to also include astronomical objects.

All those years ago, I thought you had to use a telescope for astrophotography. But really all you need to get started is an off-the-shelf DSLR camera, some quality lenses, and the ability to have them track the sky. In fact, this avenue of astrophotography is so compelling to me that, even with high-quality astrographs, astronomical CCD cameras, and exotic filters at my disposal, I still frequently return to my DSLR and its lenses to capture certain targets.

When it comes to wide-field astrophotography, well-corrected astrographs with focal lengths less than about 400 mm are extremely rare and generally astronomically expensive. But one of the enduring appeals of the DSLR is the wide range of interchangeable lenses available. It's much easier to find quality DSLR lenses ranging from 400 mm all the way down to 8-mm fisheye lenses covering a 180° field of view.

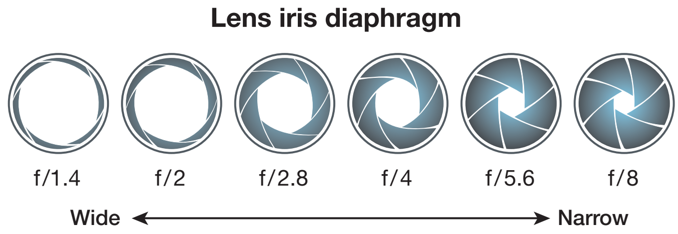
There is a reason for this, of course. The shorter the focal length (and wider the field of view), the more difficult it is to control optical aberrations, especially away from the center of the image. The camera-lens folks have got this figured out, and highly sophisticated lens designs using multiple elements abound. And due to the immense size of the photography market, they can be had relatively cheaply. These lenses make excellent optics for astrophotography as well!

There is a caveat or two when using a camera lens for the night sky. Stars, being point sources of light, are an acid test for lens quality and sharpness. While stars in the center of the field of view might be round and sharp, those near the edges or corners of the frame often appear as elongated streaks, distorted into "seagull" shapes, or simply out-of-focus, multicolored blobs. It takes a critical eye to spot this in a daylight image, but in a star field the aberrations stand out like a sore thumb.

The typical mitigation for this is to stop the lens down. It's well known in the photography crowd that, say, a 200-mm f/2.8 lens doesn't perform at its peak sharpness until you stop it down to f/4 or f/5.6. The exact adjustment varies from lens to lens, and there are websites aplenty with test charts for various lenses from different manufacturers.

Increasing the focal ratio ("stopping down the lens") decreases the opening through which the light enters the camera and restricts the amount of light that's focused onto the image sensor. It does so by blocking the edges of the lens using only the central region of the lens where the sharpness and aberration control are at their best.

Typically the light gets reduced using a 6- or 8-bladed diaphragm within the lens assembly, though some high-end lenses use more. Usually the blades have straight edges, which create spikes or rays (one for each blade) radiating from a



▲ **INTERNAL STOPS** The diaphragm in a camera lens is designed to reduce the amount of light entering the lens, but it can produce diffraction spikes around bright stars.

◀▲ **NO SPIKES** Author Richard S. Wright, Jr. describes his novel approach to creating lens masks that eliminate the diffraction spikes caused by internal iris diaphragms. He used the Canon EOS Rebel 3Ti DSLR above with a 200-mm f/2.8 lens stopped down to f/4 using a modified lens cap aperture mask to shoot the colorful Rho Ophiuchi region in Scorpius on the facing page.

UNLESS OTHERWISE NOTED, ALL PHOTOS BY RICHARD S. WRIGHT, JR.; DIAPHRAGM: LEAH TISCIONE / *SKY & TELESCOPE*

point source of light. This diffraction from a stopped-down lens is glaringly apparent in an image filled with bright stars. In some high-quality lenses, the blades' edges are curved to reduce this effect.

Diffraction spikes can sometimes add "sparkle" to what would otherwise be a lackluster image. When I first started astrophotography through a camera lens, I liked this effect. But over time I found that spikes tend to get in the way of the real subjects shot through my 200- or 300-mm lens, cutting across subtle nebulae and detracting from an otherwise fine image. When you see these spikes, it's a dead giveaway that the image was taken through a camera lens. Most of the time I prefer to see the four diffraction spikes typically seen in images captured through a Newtonian reflector — or none at all, as you'd get with a refractor.

My Simple Solution

The cause of these spikes is well known, and I'm certainly not the first to find them objectionable or to want to eliminate them. One easy way to do this is to purchase a set of step-down rings that thread onto the front of your camera lens to allow the use of smaller lens filters. I looked at this at first but quickly found that the cost can really add up when buying specific-sized rings for each lens I own, as well as needing several additional sizes to achieve the f/ratios I desire. I then figured out a more economical alternative.

Replacement plastic lens caps are both cheap and abundantly available online. It's a simple matter to purchase several lens caps and then bore them out to the correct aperture with a drill press and a few hole-saw bits (like the ones used to cut into a wooden door to install a knob or lock). I ordered several caps to experiment with and a 50-mm hole-saw bit. Note: When ordering lens caps, try to find ones that use small plastic clips, rather than a clip system that uses springs.

▲ **DIFFRACTION DISTRACTION** Images that include bright stars or planets, such as this shot of IC 4592 with the interloping planet Mars at lower left, exhibit strong diffraction spikes because the 200-mm was stopped down from f/2.8 to f/4 using its internal diaphragm.

The spring system takes up most of the area that needs to be bored out and won't work for this project.

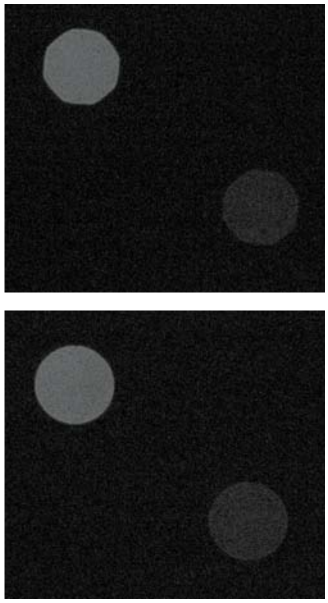
While cutting a lens cap is relatively straightforward, remember that the hole has to be right in the center of the cap. Finding the center is pretty easy — my son R. Stephen, who is much more mechanically inclined than I am, used a set of calipers to scratch three circles of the same diameter as the lens cap at about 120° intervals, using the outer edge of the cap as the center point of the circles. The scratched lines naturally intersect at the approximate center of the cap. This is particularly helpful if you're using a hole-saw bit that uses a central pilot bit.

We then used the drill press with a few "C" clamps to hold the caps firmly in place with the cap centered and made

▲ **CENTERING** The aperture should be precisely centered in the cap, or you may end up with distorted or flared stars in your images. The center was quickly determined using a set of calipers described in the article.

SAFETY FIRST Using a hole-saw drill bit and a drill press, it only takes seconds to cut through the plastic cap. Be sure to secure the cap in place.

two test aperture masks, one that turned my Canon 300-mm f/4 lens into a sharper f/6 system, and one to stop down my 200-mm f/2.8 into a sharper f/4 system. I hit the fresh cut with a little fine sandpaper to remove any burrs that could potentially add any unwanted diffraction spikes, and I was ready to test them out.



▲ **ROUND STARS** The improvement in star shapes using the lens cap masks is apparent even when focusing. Out-of-focus stars display an octagonal shape when using the internal iris of the 300-mm lens (top), while the same field above using the lens cap mask displays clean, round stars.

Do they work? You bet they do! Images shown at the bottom of this page were taken with the Canon 300-mm lens. The left photo was taken with the lens set to f/5.6 using the internal diaphragm, while the other was taken with the diaphragm fully open but with the lens stopped down to f/6 using the test aperture mask. It worked just as well as I'd hoped — the second photo appears to have been shot with a small refractor, rather than with a camera lens.

One important point to remember when using an external aperture mask is to make sure the camera's internal aperture diaphragm is open all the way; otherwise, the blades will still introduce diffraction spikes in the optical path even when you've put on the circular mask.

Another clear illustration of the effect of the lens's internal aperture blades can clearly be seen when focusing. The out-of-focus stars appear as octagons due to the lens's internal diaphragm, while the stars shot using the aperture mask show a much more "refractor-like" appearance. It's worth mentioning that a top-quality camera lens operating at full aperture won't exhibit diffraction spikes, but its overall sharpness is visibly reduced, and edge aberrations, often appearing as elongated or even V-shaped stars when operating "wide open," are still often compromised; in all forms of photography, there are tradeoffs to be made.

Amateurs with access to a machine shop (or a friend with one) can also purchase inexpensive aluminum lens caps and mill them out to the specific aperture sizes needed to achieve more precise focal ratios. Hole-saw drill bits come in a limited range of sizes, so you'll need to calculate the f/ratio produced by a particular bit simply by assuming the new hole is your clear aperture. For instance, with the aperture mask in place, my 200-mm camera lens now operates as if I am imaging through a good quality 50-mm f/4 refractor (as we typically denote telescopes by their clear aperture, whereas camera lenses are listed by their focal length). The tradeoff here is you'll need to take longer exposures to acquire the same signal-to-noise ratio, but if you have to stop down your lens to reduce edge aberrations, you're already making this compromise anyway.

The proof, they say, is in the pudding. I've since made several lens-cap aperture masks for all my camera lenses to use with my modified DSLR. This simple improvement is both easy and inexpensive. No more "starburst" diffraction spikes for me!

■ **RICHARD S. WRIGHT, JR.** is a software developer for Software Bisque, and writes a monthly blog on imaging for *Sky & Telescope* readers at **https://is.gd/3yZO2K**.

▲ **BEFORE AND AFTER** Compare these shots of reddish IC 434 (which includes the Horsehead Nebula) and the Flame Nebula to its lower left. Both views were captured through the same 300-mm f/4 lens, but the shot at left used the lens's internal iris stopped down to f/5.6. The image at right used a lens-cap mask producing an f/ratio of 6. Note the distinct improvement in star quality, particularly the bright star Alnitak between the two nebulae.

A Lens to Grind

With skill and patience, this rare project is greatly rewarding.

▲ Lütfü Çakmak and his homemade refractor share a beautiful mountain observing site.

WHEN PEOPLE TALK about homemade telescopes, we almost always talk about reflectors. Making mirrors is so much easier than making lenses, hardly anybody even considers the latter. A decent refractor requires at least two lenses, which means four highly accurate surfaces, three of them convex.

But Turkish ATM Lütfü Çakmak is no stranger to crazy projects. He has already made two Cassegrain scopes, which require convex secondaries, and he was part of the "100 Telescopes in 8 Days" project in which 100 amateurs ground mirrors and built telescopes in just over a week (*S&T:* Nov. 2009, p. 68). So when his friend Jerry Wright sent him a pair of 92-mm lens blanks he bought at a Stellafane swap table, Lütfü was off and running.

The first order of business was deciding what type of lens pair to make. There are many different styles, ranging from oil-filled to cemented to air-spaced doublets. Jerry helped again with an f/10 Fraunhofer design, which is air spaced and relatively simple to make.

Armed with the parameters of the lenses he needed to grind, Lütfü built a turntable out of a car's windshield-wiper motor and set to work. While the turntable provided rotation, Lütfü hand-held the lens blanks against the grinding tool (which for two of the four surfaces could be the other lens blank) and let the grit wear away the glass.

His lens blanks were considerably thicker than the f/10 design called for, so much of the initial grinding involved simply removing glass. For that he ground the flint and crown elements against each other using coarse grit. He noticed that the flint glass wore away about twice as fast as the crown did, revealing that not only was there a difference in refractive index between the two pieces, but a significant difference in hardness as well.

Fortunately the lens surfaces only need to be spherical, not parabolic, which makes the job easier than it might be, but three of those surfaces have to be convex. How do you test a convex surface for accuracy?

By making a matching concave surface first, of course. Lütfü used plate glass for those, and was able to test their focal length and sphericity with a Ronchi test and a Bath interferometer. When he got them just right, he ground the convex surfaces to match. (That means he actually ground seven curved surfaces, but who's counting?)

One complication that mirror makers don't face is that you have to protect each surface of the lens while you're grinding the other side. Lütfü's method

LÜTFÜ ÇAKMAK (5)

From Glass Blanks to Lens Elements

◗ These are the raw materials for the lenses: a crown and a flint blank.

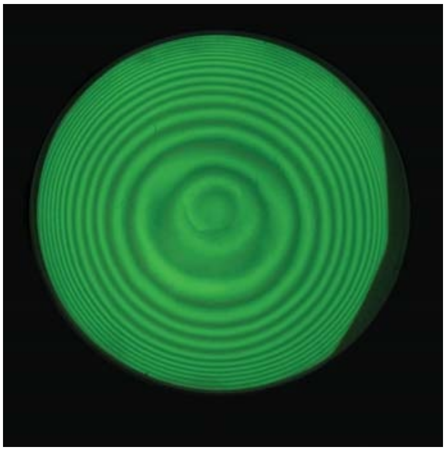
Facing page, left: Lütfü ground the lenses on a small turntable in his living room.

Facing page, right: The finished lenses look flawless.

was to rest each surface in its matching plate-glass tool with a soft paper towel between the two, then tape the lens and plate glass together. Then he could work on the exposed surface without fear of scratching the other.

Testing was a simple matter of placing his convex surface inside the concave reference surface and looking for interference fringes under monochromatic light. (Fluorescent or laser light sources work well for this.) With spacers between the surfaces you get a bull's-eye pattern, and by pressing on the edge of the lens and watching which direction the fringes move, you can tell whether your curve is too shallow or too steep. The number of fringes reveals how far off it is — each fringe is half a wavelength of light. The spacing of the fringes grows wider and wider as the lens surface approaches the same curvature as the test surface. When they match, the bull's-eye goes away.

Lütfü also had to watch out for "wedge," a difference in thickness between one side of a lens element and the other. He could grind down the thick side, but he had an overall target thickness he had to hit, so he had to stay on top of the wedge right from the start and not let it get out of hand. Even so, he overdid one correction, which led to a spot that wouldn't polish out, forcing him to go back to fine grinding to regularize the surface again. That made his lens just a smidgen too thin,



▲ Testing the convex surfaces was done by looking at interference fringes with a matching concave surface of known quality.

but fortunately he had about 1 mm of tolerance, so he was okay.

The turntable was relatively small, and it was wintertime when he set to work, so Lütfü did all the grinding in his living room. "I owe thanks to my wife for her patience," he says. "It wasn't nice to listen to the turntable's noise!"

After two months of grinding and polishing, Lütfü had two beautifully finished lens elements. Then he had to build the telescope to hold them. He chose a 105-mm PVC pipe for the OTA and had a machinist make a Delrin lens cell to fit it. He baffled the inside with 1 mm-thick cardboard circles, using Nils Olof Carlin's design in which no part of the tube wall is visible from the focal plane. Rings cut from the tube ensured that the baffles stayed perpendicular. He bought a focuser and a star diagonal from Surplus Shed (**surplusshed.com**) and had his machinist make a Delrin adapter to fit the focuser to the tube.

Refractor lens elements need to be precisely spaced in order to work together properly. Lütfü's required shims of exactly 0.11 mm at the edge, ideally made of brass, but he couldn't find any stock of the right thickness so he made do with cardboard.

After he assembled everything and had his first look, Lütfü reports, "When I looked at the sky through my homemade refractor, I was amazed. I loved it more than the 10- or 15-inch Newtonians or the 10- and 12-inch Cassegrains that I had made." The image is crisp and clear, with hardly any color fringing even on bright objects. Lütfü has not had the lenses anti-reflection coated, but he gets no ghosting or internal reflections. In short, the finished telescope is everything he had hoped for. And Lütfü has joined the elite of the elite in ATMing: He has made a refractor, literally from scratch.

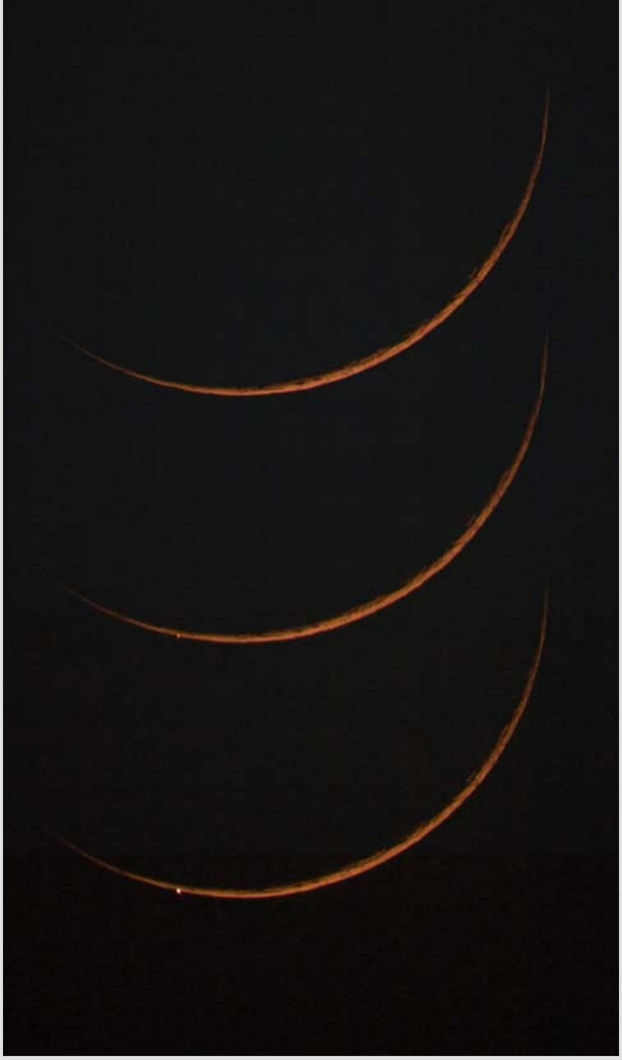
For more information about this and Lütfü's other projects (in Turkish), visit **https://is.gd/eep4SQ**.

■ Encouraged by Lütfü's success, Contributing Editor **JERRY OLTION** has acquired a set of lens blanks. Now he just needs a box of moxie and he can get started.

BEAUTY NEAR THE BELT

Terry Hancock & Walter Holloway

Alnitak (below center), the easternmost star in Orion's Belt, anchors a rich region of nebulosity that features the broad glow of IC 434, with the Horsehead Nebula (Barnard 33) silhouetted against it, and the Flame Nebula (NGC 2024) at bottom center. North is toward left. **DETAILS:** *Takahashi FSQ-130ED astrograph and QHY367C CCD camera with hydrogen-alpha and LRGB filters (rendered in monochrome). Total exposure: 6.9 hours.*



◁◁ FANTASY IN ORION

Paolo Moroni

The Orion Nebula (Messier 42) and, to its immediate north, Messier 43 (sometimes called De Mairan's Nebula) are must-see showpieces in any telescope.

DETAILS: *Sky-Watcher Esprit ED80 apochromatic refractor and Moravian Instruments G2-8300 CCD camera with Astronomik LRGB filters. Total exposure: 12.2 hours.*

◁ MERCURY MEETS THE MOON

YuWen Chang

The predawn occultation of Mercury by an ultrathin crescent Moon on September 19, 2017, was just 5° above the horizon as seen from Hsinchu City in Taiwan. Frames are 1 second apart.

DETAILS: *Vixen VC200L astrograph and Canon EOS 700D DSLR camera set to ISO 400. Exposures: 1.3 second.*

▽ FLASHY AURORA

Matt Skinner

After some poor weather, the skies cleared over Palmer, Alaska, on the morning of December 14, 2017 — just in time for a mottled auroral display and a dazzling Geminid fireball.

DETAILS: *Canon EOS 5D Mark III DSLR camera set to ISO 1600 with 24-mm lens. Exposure: 15 seconds.*

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

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August 6–12, 2018

Join astronomer and former *S&T* editor Steve O'Meara for this combo safari/star-gazing tour in Botswana. Observe lions, elephants, and other wildlife by day — and the Magellanic Clouds, Eta Carinae Nebula, and more by night. Stay in luxurious field camps. Optional extension to Victoria Falls.

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March 26–April 2, 2019

Join Finnish-American *S&T* editor Diana Hannikainen on this cushy tour from Helsinki to Lapland in search of the gorgeous aurora. Enjoy Finnish and Sami culture and cuisine, stargaze with a local astronomer, stay in glass igloos, take a reindeer safari and Finnish sauna, and more.

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Drug Companies Fear Release of the New AloeCure

Big Pharma stands to lose billions as doctors' recommend drug-free "health cocktail" that adjusts and corrects your body's health conditions.

by David Waxman
Seattle Washington:

Drug company execs are nervous. That's because the greatest health advance in decades has hit the streets. And analysts expect it to put a huge crimp in "Big Pharma" profits.

So what's all the fuss about? It's about a new ingredient that's changing the lives of people who use it. Some call it "the greatest discovery since penicillin"!

The name of the product is the AloeCure. It's not a drug. It's something completely different. And the product is available to anyone who wants it, at a reasonable price. But demands may force future prices to rise.

TOP DOC WARNS: DIGESTION DRUGS CAN CRIPPLE YOU!

Company spokesperson, Dr. Liza Leal; a leading integrative health specialist recommends AloeCure before she decides to prescribe any digestion drug. Especially after the FDA's stern warning about long-term use of drugs classified as proton pump inhibitors like **Prilosec®, Nexium®, and Prevacid®**. In a nutshell, the FDA statement warned people should avoid taking these digestion drugs for longer than three 14-day treatment periods because there is an increased risk of bone fractures. Many people take them daily and for decades.

Dr. Leal should know. Many patients come to her with bone and joint complaints and she does everything she can to help them. One way for digestion sufferers to help avoid possible risk of tragic joint and bone problems caused by overuse of digestion drugs is to take the AloeCure.

Analysts expect the AloeCure to put a huge crimp in "Big Pharma" profits.

The secret to AloeCure's "health adjusting" formula is scientifically tested Acemannan, a polysaccharide extracted from Aloe Vera. But not the same aloe vera that mom used to apply to your cuts, scrapes and burns. This is a perfect strain of aloe that is organically grown under very strict conditions. AloeCure is so powerful it begins to benefit your health the instant you take it. It soothes intestinal discomfort and you can avoid the possibility of bone and health damage caused by overuse of digestion drugs. We all know how well aloe works externally on cuts, scrapes and burns. But did you know Acemannan has many of other health benefits?...

HELPS THE IMMUNE SYSTEM TO CALM INFLAMMATION

According to a leading aloe research, when correctly processed for digesting, the Aloe plant has a powerful component for regulating your immune system called Acemannan. So whether it's damage that is physical, bacterial, chemical or autoimmune; the natural plant helps the body stay healthy.

RAPID ACID AND HEARTBURN NEUTRALIZER

Aloe has proved to have an astonishing effect on users who suffer with digestion problems like bouts of acid reflux, heartburn, cramping, gas and constipation because it acts as a natural acid buffer and soothes the digestive system. But new studies prove it does a whole lot more.

SIDE-STEP HEART CONCERNS

So you've been taking proton pump inhibitors (PPI's) for years and you feel just fine. In June of 2015 a major study shows that chronic PPI use increases the risk of heart attack in general population.

UNLEASH YOUR MEMORY

Studies show that your brain needs the healthy bacteria from your gut in order function at its best. Both low and high dosages of digestion drugs are proven to destroy that healthy bacteria and get in the way of brain function. So you're left with a sluggish, slow-to-react brain without a lot of room to store information. The acemannan used in AloeCure actually makes your gut healthier, so healthy bacteria flows freely to your brain so you think better, faster and with a larger capacity for memory.

Doctors call it "The greatest health discovery in decades!"

SLEEP LIKE A BABY

A night without sleep really damages your body. And continued lost sleep can lead to all sorts of health problems. But what you may not realize is the reason why you're not sleeping. Some call it "Ghost Reflux". A low-intensity form of acid reflux discomfort that quietly keeps you awake in the background. AloeCure helps digestion so you may find yourself sleeping through the night.

CELEBRITY HAIR, SKIN & NAILS

Certain antacids may greatly reduce your body's ability to break down and absorb calcium. Aloe delivers calcium as it aids in balancing your stomach acidity. The result? Thicker, healthier looking hair…more youthful looking skin… And nails so strong they may never break again.

SAVE YOUR KIDNEY

National and local news outlets are reporting Kidney Failure linked to PPI's. Your Kidney extracts waste from blood, balance body fluids, form urine, and aid in other important functions of the body. Without it your body would be overrun by deadly toxins. Aloe helps your kidney function properly. Studies suggest, if you started taking aloe today; you'd see a big difference in the way you feel.

GUARANTEED RESULTS OR DOUBLE YOUR MONEY BACK

Due to the incredible results people are reporting, AloeCure is being sold with an equally incredible guarantee.

"We can only offer this incredible guarantee because we are 100% certain this product will work for those who use it," Says Dr. Leal.

Here's how it works: Take the pill exactly as directed. You must see and feel remarkable improvements in your digestive health, your mental health, in your physical appearance, the amount inflammation you have throughout your body – even in your ability to fall asleep at night!

Otherwise, simply return the empty bottles with a short note about how you took the pills and followed the simple instructions and the company will send you...Double your money back!

HOW TO GET ALOECURE

This is the official nationwide release of the new AloeCure pill in the United States. And so, the company is offering our readers up to 3 FREE bottles with their order.

This special give-away is available for readers of this publication only. All you have to do is call TOLL-FREE **800-747-1925** and provide the operator with the Free Bottle Approval Code: JC025. The company will do the rest.

Important: Due to AloeCure's recent media exposure, phone lines are often busy. If you call and do not immediately get through, please be patient and call back.

SKY&TELESCOPE

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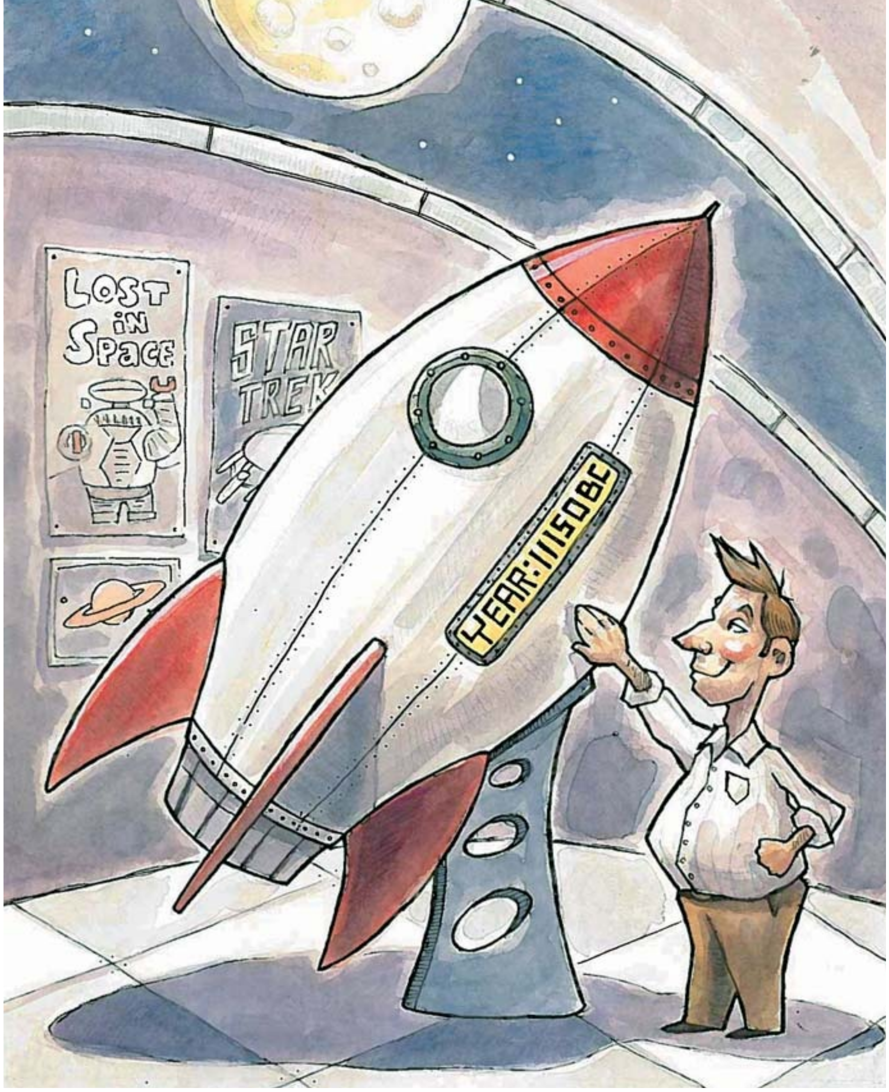
My Plastic Spaceship

A boy's lofty dreams are realized, though not quite as he'd imagined.



AS A YOUNGSTER in the late 1960s and early '70s, one of my grandest dreams about being a grownup was living in the Space Age. I fantasized about flying cars and vacations on the Moon while devouring endless episodes of *Space 1999*, *Star Trek*, and *Lost in Space*. Our nation was still sending men to the Moon when a trip I took to the planetarium in the first grade sealed the deal and left me with a hunger that I'd never satisfy.

Today, alas, there is virtually no chance I will ever drive a flying car or vacation on the Moon. But I have my own spaceship, an enormously capable one. It can carry me on voyages through the solar system, across the galaxy, and even into intergalactic space. It's also a time machine. With it I can travel to the distant past, to an age when dinosaurs walked the Earth or, with some effort and care, to a shadowy period before our planet even existed.

You see, at some point in my adult life I became an astrophotographer. Like many who are serious about such a passion, I've built my own observatory under the dark skies of a remote location — in my case in South Florida. My observatory is my spaceship. It's one of those domes that folds over and slides to the side, and the whole thing consists of the same plastic material that comprised my children's backyard playhouses.

Many a night I have lain down on the floor beneath my dome and stared up through the opening, as if through a portal into outer space. At such times, the equipment in the center of my ship warbles and clicks in the faint glow of red lights pulsating with the implied power of my mighty craft. Our galaxy arches overhead, and occasionally a fellow traveler flies by, be it a streaking meteor, a comparatively slow-moving satellite, or an airplane with other travelers heading to a more terrestrial destination. My course is celestial, though, and to the music of Enya or some sci-fi soundtrack I sail off across an ocean so vast few can comprehend it.

It's also a time machine. With it I can travel to the distant past, to an age when dinosaurs walked the Earth or, with some effort and care, to a shadowy period before our planet even existed.

I am made of stardust, I think as I marvel at how my craft's machinery collects and records photons a million years old or more. I ponder the duality that to me they are ancient in years beyond counting, while from their perspective they were created a moment ago by some star many light-years away and only just spanned this immense distance.

Is it this crisscross of time streams that gives rise to the fabric of the universe? Am I the universe too, the dust or ashes of dead stars assembled here on Earth in such a way that I can reflect upon the universe, and myself, in such a fashion?

Yes, I have a spaceship, and it's more powerful than I ever imagined as a boy.

■ **RICHARD S. WRIGHT, JR.**, is a software developer at Software Bisque. See his article on aperture masks on page 66 of this issue.

JASON ABBOTT

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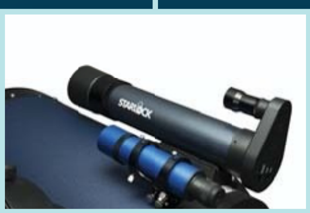

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This large telescope can be easily broken down and moved. With the LX600 Split Fork design, you can quickly separate the OTA from the mount, which allows for easier setup and transportation!

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