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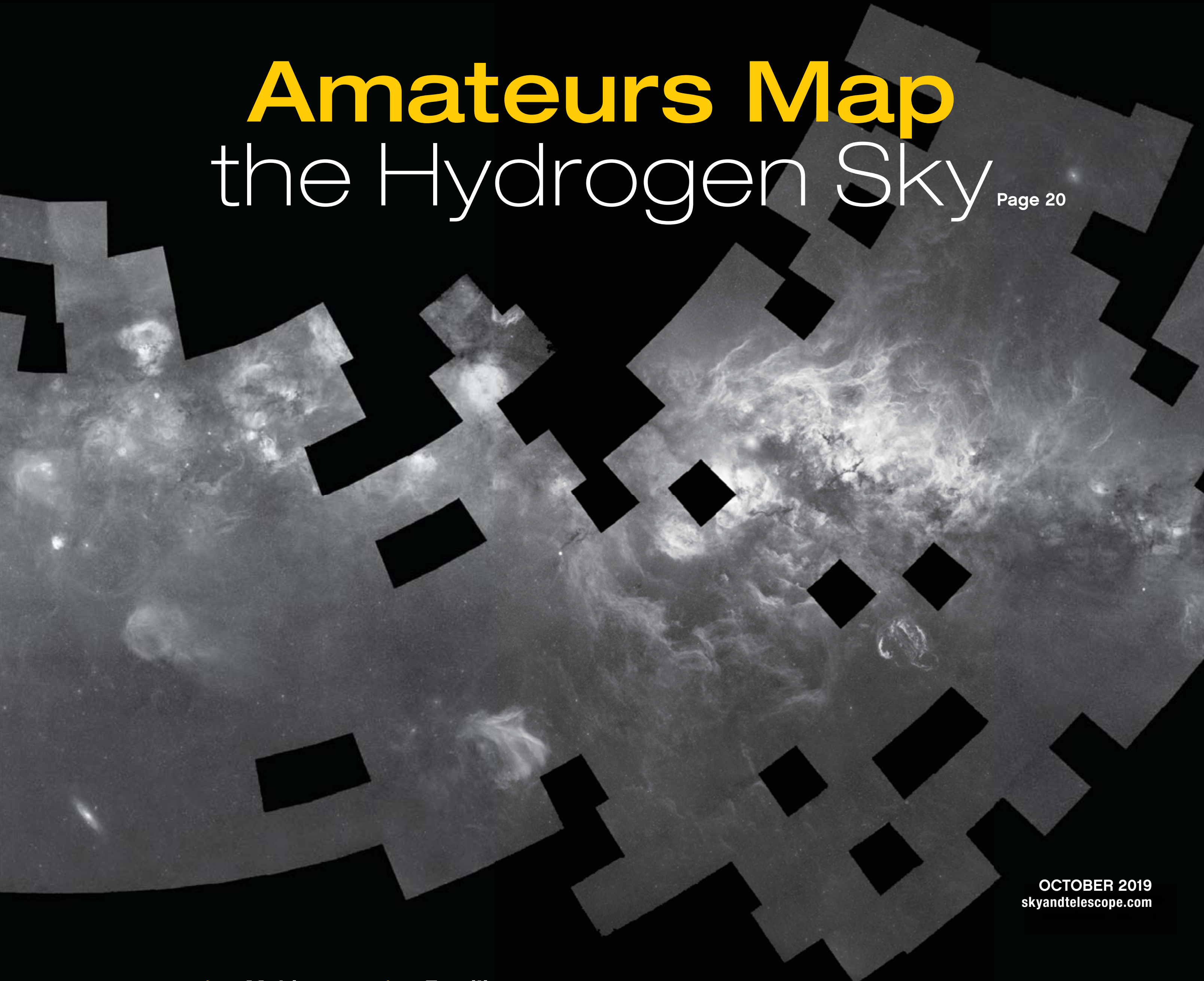
# SKY & TELESCOPE

THE ESSENTIAL GUIDE TO ASTRONOMY

## Amateurs Map the Hydrogen Sky

Page 20



OCTOBER 2019
skyandtelescope.com

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# SKY & TELESCOPE

THE ESSENTIAL GUIDE TO ASTRONOMY


T. A. RECTOR / UNIVERSITY OF ALASKA ANCHORAGE / H. SCHWEIKER / WIYN / NOAO / AURA / NSF



## ON THE COVER

The sky seen in hydrogen-alpha is replete with features.
MDW SKY SURVEY

## ONLINE

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Find out what the sky looks like for your time and place. You can also print the chart as a handout.
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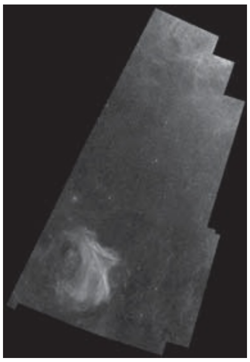
# Unfinished Symphony

**THERE'S SOMETHING MAGICAL** about experiencing a work in progress. You get a glimpse inside the active mind of the artist. Where was Rodin going with the various models for his never-completed sculpture *The Gates of Hell*? How did Thoreau's thinking evolve through the multiple drafts he wrote of *Walden*? Through such inquiry, we become virtual participants in the creator's thought process. In its very rawness, a partially realized work can seem more approachable to us, more human, sometimes even more hauntingly powerful — think Mozart's *Requiem*.

The mosaics we proudly present in our cover story beginning on page 20 are a case in point. (I say "proudly" because — full disclosure — two of the three friends behind these arresting images are long-time *Sky & Telescope* editors.) A quick glance at our cover reveals the unfolding, puzzle-piece nature of this ongoing project, which is called the MDW Hydrogen-Alpha Sky Survey after the first initials of the collaborators' surnames.



MDW SKY SURVEY

Diffuse nebula Sharpless 2-126 dominates this MDW survey image of Lacerta, the Lizard.

In these mosaics you're regarding the night sky not as you'd see it with the naked eye. Rather, it appears as you'd perceive it in the deep red light emitted by ionized hydrogen gas, which fills vast stretches of the interstellar medium. That wispy stuff is out there, and through the efforts of this survey you have the chance to observe it with 3-arcsecond resolution. Isn't that nebulosity ethereal?

On their website, **mdwskysurvey.org**, the project's triad of astrophotographers — Dennis di Cicco, Sean Walker, and the late David Mittelman — capture the project's essence: "It will be scientifically useful and aesthetically beautiful — a true blend of science and art."

That blend exemplifies what serious amateur astronomers, using today's advanced equipment, can do when they put their minds to it. The beauty you can see for yourself; the science is no less breathtaking. This is the first all-sky hydrogen-alpha survey of this depth and resolution. In fact, professional astronomers are already using the data in their research, with several adding the survey's team members as co-authors on scientific papers.

Of course, all science is a work in progress. So is technology: Just as the MDW survey supersedes what has come before, so will future surveys, relying on even more sophisticated cameras, allow for ever greater resolution. But at this moment, the MDW survey represents the cutting edge. In our era of instant gratification, it's refreshing to watch a tiny band of dedicated individuals take on an ambitious project knowing that it will take years to reach fruition.

Editor in Chief

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# The American Astronomical Society
# **Welcomes *Sky & Telescope*!**

All of us at the AAS are pleased and excited to assume ownership of *Sky & Telescope* and to welcome its readers to the AAS community. Many AAS members and elected leaders are long-time subscribers, and we're committed to sustaining the high standards you expect from *S&T*. We look forward to exploring the many opportunities presented by this new partnership, which we expect to benefit both the AAS and *S&T* in a wide variety of ways. Stay tuned!

**Megan Donahue**
**AAS PRESIDENT**

**AAS Board of Trustees & Strategic Assembly, AAS 234, St. Louis, MO, 9 June 2019**

We plan to make it easier for *S&T* readers to join the Society and to attend our meetings, especially our June meetings, which we anticipate expanding to include more amateur-focused content and involvement. Be on the lookout for announcements as these plans come together!

For more on the AAS, see **aas.org**.

## What is the AAS?

The major organization of professional astronomers in North America

Established in 1899, headquartered in Washington, D.C.

Its roughly 7,700 members also include physicists, mathematicians, geologists, engineers

**Its mission is to enhance and share humanity's scientific understanding of the universe**

Publishes the most-read and most-cited research journals in the field, including *The Astronomical Journal* and *The Astrophysical Journal*

Convenes two annual meetings, in January and June, and organizes topical meetings at other times throughout the year

Recently established a new Amateur Affiliate membership class for backyard astronomers who are advancing the field through scientific research on their own time.

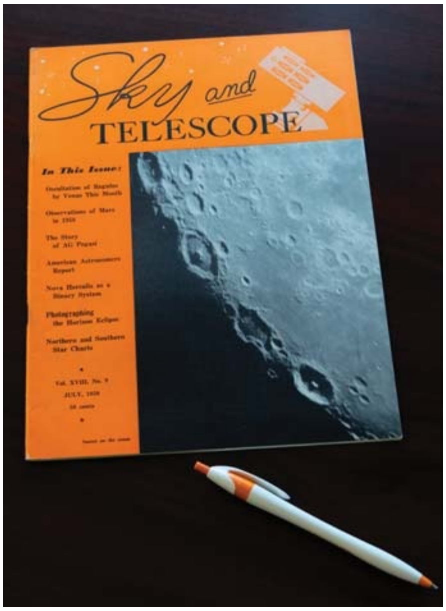
AMERICAN ASTRONOMICAL SOCIETY

SKY & TELESCOPE

## Still Gazing After All These Years

I received my July 2019 issue of your magazine today and couldn't help remembering a young boy two months short of his 15th birthday opening his first issue in July 1959. Pulling that magazine out of the yellow mailing envelope they came in back then was a thrill. Little did I know that the Moon looking back at me from that cover would be reached by Apollo 11 in just 10 more years. Observing then with a small 3-inch reflecting telescope led to bigger telescopes, a backyard observatory, and research work. Now in retirement housing and approaching 75 years of age, I'm still observing. What a wonderful ride it has been! Thank you, *Sky & Telescope*.

**James Hannon • Terryville, Connecticut**




▲ James Hannon has been observing and reading *S&T* for the past 60 years, ever since this image of the Moon graced its cover.

SEAN WALKER / S&T

## Hand-Me-Downs

In "Constellation Close-up: Centaurus and Crux" (*S&T:* Apr. 2019, p. 22), Tony Flanders considers how the southern constellation Centaurus came to be known to the ancient Greeks. His answer involving the precession of the equinoxes is only half the story.

In the early years of the 20th century, English astronomer E. Walter Maunder traced the traditional constellations back further than the ancient Greeks. He derived their origin by using the portion of the southern sky without ancient constellations. The size of that area defines the latitude where the original definers of the constellations (including Centaurus) lived, and the center point defines the time when they were named. Both these estimates are obviously crude ones.

Maunder concluded that these people lived between 36° and 40° north latitude within a few hundred years of 2700 BC. This precedes by quite a bit the ancient Greeks and is too far north for the Babylonians. The deepest answer to why the Greeks knew about the southern constellations was that they inherited the knowledge of them from much earlier times and merely translated preexisting names into Greek.

**D. Chris Benner**
**Williamsburg, Virginia**

**Tony Flanders replies:** *I agree that precession is only part of the story. There is little doubt that many of the Greek constellations were inherited from Mesopotamia and date back long before the Greek historical era. It's entirely plausible that Centaurus is among those, but I'm not aware of any concrete evidence to that effect. For more on the Mesopotamian origin of Greek constellations, see the articles by Craig Crossen in the March 2015 (p. 36), May 2016 (p. 24), and January 2018 (p. 66) issues of* Sky & Telescope.

## Moon Memories

Peter Tyson's "A Night to Remember" (*S&T:* July 2019, p. 4) reminded me of my experience with the Apollo 11 Moon landing. On July 20, 1969, I was in the military police stationed in Pusan, South Korea. I was on patrol with my sergeant that day, and for some reason we drove back to base. It turned out that he knew of the Moon landing, and I was lucky to watch it live on black-and-white TV. What a great memory! Thanks for reminding me.

**Dean Blau**
**Lake Balboa, California**

## Say It Ain't So, Joe

Bob King writes: "Supermoons are about 14% larger than the same Moon at apogee (dubbed a micromoon) . . ." (*S&T:* July 2019, p. 22). That 14% figure has been widely promulgated by both social and news media sites for at least the last three decades.

On February 19th the full Moon was at perigee, at a distance of 356,761 km from Earth. Its apparent diameter that night measured 33.5 arcminutes. On September 13th the full Moon will be at apogee, at a distance of 406,377 km from Earth. Its apparent diameter on that night will be 29.4 arcminutes. The difference in apparent size actually measures 12.2%.

So where did that 14% figure initially come from? As far as I can tell, it started with . . . *Sky & Telescope*!

In the October 1989 issue, on page 405, the "Moonwatcher's Corner" column explains how the difference in tidal force varies as the inverse cube of an object's distance. We then read: "This month the Moon is 14 percent closer at perigee than at apogee." I haven't been able to find any reference source citing the 14% value prior to that. My assumption is that the 14% figure was immediately accepted and has continued to be quoted to this day.

**Joe Rao**
**Putnam Valley, New York**

**Kelly Beatty replies:** *It depends on which way you do the division: 29.4 is indeed 87.8% of 33.5 (12.2% smaller). But Bob King's context was how much larger a Moon at perigee looks. Swapping the values so that the larger (perigee) apparent size is the numerator, the difference can indeed be a bit more than 14%.*

## Going Through a Break-Up?

In "The Allure of Betelgeuse" (*S&T:* May 2019, p. 34), I don't understand the characterization of Betelgeuse's rotation of 15 kilometers per second as being almost fast enough to break the star apart. The Sun takes about 25 days to complete a rotation at the leisurely rotational velocity of 2 km/s, but Betelgeuse, if we accept the diameter of 1.3 billion kilometers postulated in the article, would take a sluggish 8 years and 230 days to rotate once, hardly a fly-apart pace. Hot new giants rotate around 200 km/s.

But if we accept that Betelgeuse's rotational velocity is abnormally high, might this not be an indicator that the star is closer to the end of its life than we think? Owing to the conservation of angular momentum, each step in the fusion process (H→He, He→Be/C, C→Ne, etc.) causes the core to shrink, which bumps up the spin of the core. In H→He this process takes a long time, and core spin-up can be masked or even reversed by stellar drag effects. But once the star has entered its final burning steps, they happen with ever-greater speed, causing greater and greater spin, so only then would the core's increased rotation manifest itself in the outer layers of the star.

**Jim Baughman**
**West Hollywood, California**

**Craig Wheeler replies:** *I was too casual when I said in the article that the observed rotation was "close to break-up speed" without defining "close." Models show that the break-up speed for a star of the mass and radius of Betelgeuse is about 65 km/s. That means the observed rotation of 15 km/s is within about 25% of the break-up speed, but Betelgeuse is rotating safely below break-up, as physics demands. It's true that 8 years is sluggish in some sense and that hot new giants can rotate at about 200 km/s. The difference is that the latter are on the main sequence, while Betelgeuse has a large radius and hence a large lever arm for slinging matter, and gravity is relatively weak at that large distance.*

*You're also correct in saying that the inner core of the star will shrink as the star evolves and hence spin faster, like an ice skater pulling in her arms. Models show, however, that processes of transferring angular momentum from the core to the envelope are ineffective. The outer envelope gives little, if any, evidence of the rotation state of the core. The rotation of the envelope is a problem unto itself.*

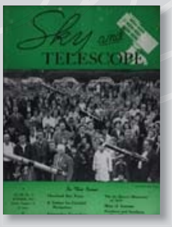
## FOR THE RECORD

• Due to an editorial error in "Insect Eyes on the Deep Sky" (*S&T:* May 2019, p. 64), the second and third sentences in the first full paragraph on page 69 should have been this single sentence: "On the other hand, Keck observations reveal that another newly discovered galaxy near NGC 1052, DF2, contains almost no dark matter at all, in spite of having a huge population of ultra-luminous globular clusters."

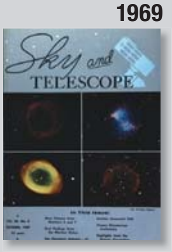
**SUBMISSIONS:** Write to *Sky & Telescope*, 90 Sherman St., Cambridge, MA 02140-3264, U.S.A. or email: letters@skyandtelescope.com. Please limit comments to 250 words; letters may be edited for brevity and clarity.

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

1944




1969




1994


### ◖ October 1944

**Double Meteor** "Many reports of successful observations of the Perseid meteors have been received. Everett A. Marsh, of Monkton, Md., writes: 'On the night of August 9th at 10:56 E.W.T. [Eastern War time], a very interesting and unique double meteor was observed in the constellation Camelopardalis, just about 11 degrees under the pole star and traveling in an east-to-west direction at relatively high velocity. The two meteors were about 4 degrees apart and (as near as could be observed) parallel to each other and horizontal to the northern horizon.

"'Both meteors appeared to enter the atmosphere at exactly the same time and the durations (estimated at 1½ seconds) were identical. Both were of about 1st magnitude. The color began as a deep yellow to red and faded to a light yellow. . . . No trains were observed without optical aid.' "

### ◖ October 1969

**Mariner Flybys** "[P]reliminary findings from the highly successful Mariner 6 and 7 missions have already made 1969 a banner year in the long history of Martian studies. . . . It is now well established that the surface pressure on Mars is only about a tenth of what astronomers had confidently believed around 1950. . . . Both radiometers worked well [and principal investigator Gerry] Neugebauer estimated that the surface temperature at Martian noon rises to +60° F., while during the night it falls below –100°. . . .

"An important conclusion announced by [ultraviolet spectrometer] experimenter C. A. Barth was the absence of molecular nitrogen. . . . If further analysis substantiates this finding, an element essential to life chemistry on Earth is seriously deficient in the Martian atmosphere."

*The October 1969 issue also presented 21 images from the double mission.*

### ◖ October 1994

**Comet Crash** "[F]or six days in July, . . . Comet Shoemaker-Levy 9 put on a spectacular display of cosmic fireworks. The Great Crash of 1994 left astronomers in open-mouthed awe. . . .

"In fact, after the first chunk of the comet smashed into Jupiter's atmosphere on July 16th, a secondary explosion of sorts ensued back on Earth during a press conference at the Space Telescope Science Institute in Baltimore. There the comet's discoverers, Eugene and Carolyn Shoemaker and David Levy, had been offering cautious predictions for the imminent event. But then observer Heidi B. Hammel rushed in with a near-infrared image fresh from the Hubble Space Telescope (HST). A huge dark feature stained the planet's southern hemisphere, an indication that the first large piece of comet had made a titanic splash. Hammel uncorked a bottle of champagne as the press corps roared its approval."

SOLAR SYSTEM

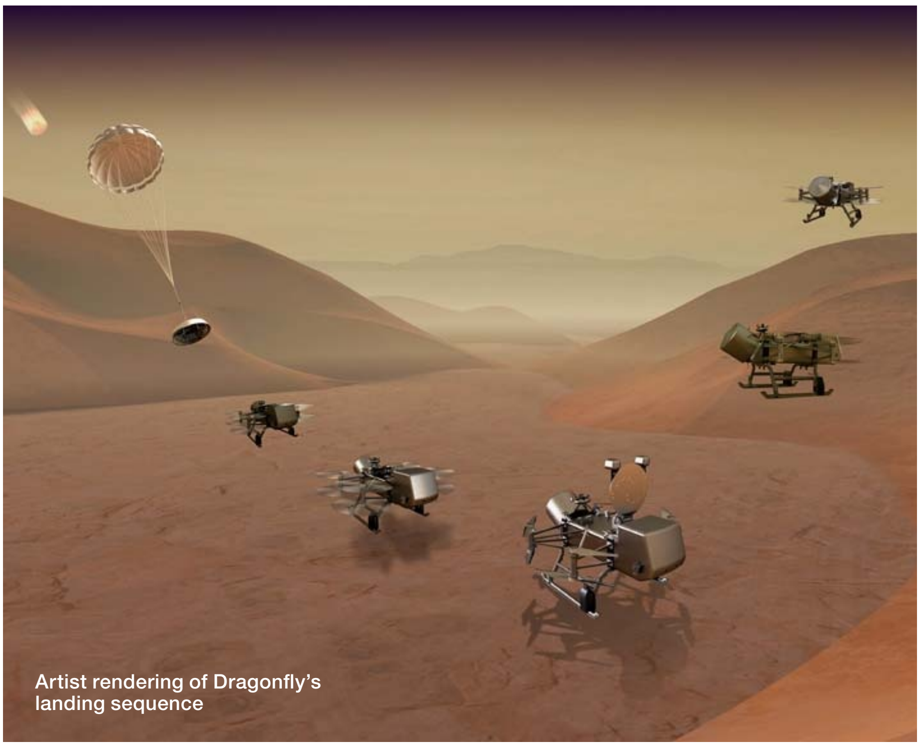
# NASA Announces Mission to Titan

**NASA'S NEW FRONTIER** missions have traveled to Pluto, Jupiter, and the asteroid Bennu. On June 27th, NASA announced that the fourth mission in this exploration lineup will head for Titan, Saturn's largest moon. Elizabeth "Zibi" Turtle (Johns Hopkins University Applied Physics Laboratory) will lead a team in designing and building Dragonfly, an eight-rotor, rover-size drone that will helicopter around the icy, eerily Earth-like world (*S&T:* Feb. 2019, p. 22).

Dragonfly will launch in 2026 for an eight-year trajectory through the solar system before it lands among Titan's sand dunes in 2034. From there, the drone will conduct dozens of reconnaissance flights, investigating the organics-based grains of the dunes before flying farther afield to approach and enter Selk Crater. A long-ago impact melted water ice there, which mixed with organic molecules, mimicking the ingredients for life — water, organics, and energy — that were present on early Earth. NASA's Cassini probe identified several outcrops where this prebiotic mixture exists right on the surface.

▲ Dragonfly in flight

The mission will land exactly one Titan year (29.5 Earth years) after the European Space Agency's Huygens probe descended through the moon's murky atmosphere in 2005. During the 2½ hours that Huygens survived on battery power, it provided a glimpse of a strangely familiar world. Even though the surface temperature hovers around –180°C (–290°F), Huygens imaged river-like channels carving through bright, icy terrain and emptying into a larger, darker area. The landing site itself resembled a dried-up lakebed.



Artist rendering of Dragonfly's landing sequence

But Dragonfly won't be going to the methane-filled lakes and rivers. The drone will arrive during northern winter, when the lake-covered north pole of Titan receives no sunlight; more importantly for communications purposes, there's no direct sightline to Earth. So Dragonfly will focus on solids instead of liquids in the "Shangri-La" dune fields in Titan's equatorial region. "The big outstanding question is the nature of solid surface materials," Turtle explains. "They hold the keys to understanding the prebiotic chemistry that's abundant on the surface of Titan."

Dragonfly will carry downward-looking and forward-looking cameras, a mass spectrometer for analyzing small batches of particles, and a neutron-activated gamma-ray spectrometer for investigating bulk surface composition. The drone will also carry meteorology sensors, to measure wind and other surface conditions, and a seismometer, to measure titanquakes and enable study of the moon's internal structure.

"We're doing innovation, not invention," Turtle explains. Many of these instruments have versions already sitting on the surface of Mars. But because the probe will fly instead of roll, it can cover far more ground than a rover would — more than 175 kilometers (109 miles) over a baseline mission of 2.7 years. That's nearly double the distance that all the Mars rovers combined have traveled to date.

Innovation also applies to the quadcopter-like mode of transportation. Flying on Titan is relatively easy: The moon's atmosphere is four times denser than Earth's air, while its gravity is only one-seventh that of our planet. However, Titan's distance from Earth and the ensuing time delays in communications mean that flights must be largely autonomous. Fortunately, self-flying drones are already commonplace on Earth, so it's just a matter of applying the technique to another world.

More than a decade from now, Dragonfly's innovative technology will let us explore this exotic world as we've never done before.

■ MONICA YOUNG

JOHNS HOPKINS APL (2)

# IN BRIEF

## Sun-Studying Missions Selected

NASA has selected two missions to study the Sun-Earth connection. The Polarimeter to Unify the Corona and Heliosphere (PUNCH) consists of four suitcase-size satellites known as microsats that will fly in formation in low-Earth orbit while investigating the solar wind as it leaves the Sun. The spacecraft will also track coronal mass ejections, the solar wind tsunamis that sometimes hurtle toward Earth, affecting satellite communications. PUNCH gains 3D information about these events by photographing sunlight that has become polarized as it bounces off electrons in the solar wind. Sharing PUNCH's ride to space, the two spacecraft that make up the Tandem Reconnection and Cusp Electrodynamics Reconnaissance Satellites (Tracers) will study the Sun-Earth connection a bit closer to home, focusing on the regions where the Sun's magnetic field interacts with Earth's field. NASA selected both missions for development and flight through its Heliophysics Small Explorers Program. They will cost no more than $165 million and $115 million, respectively, and will launch no later than August 2022.

■ MONICA YOUNG

**For more details about the missions, visit https://is.gd/Helio.**

## ESA's Comet Interceptor

The European Space Agency has selected a mission to accompany its exoplanet-hunting satellite, ARIEL, when it's launched in 2028. The Comet Interceptor will consist of three solar-powered spacecraft that will travel with ARIEL to Lagrangian point $L_2$ 1.5 million km (1 million miles) beyond Earth, on the opposite side from the Sun. The Comet Interceptor will wait there while looking for a target: either a new comet or perhaps an interstellar comet like 'Oumuamua. Once a target is identified, all three spacecraft will fly toward it together before separating to view it from different vantage points. Comets previously explored by spacecraft have returned again and again to the inner solar system, and solar heating has disturbed and altered their surfaces. The Comet Interceptor concept will enable scientists to explore a comet making its first trip toward the Sun; such an object could provide a pristine sample of the outermost reaches of the solar system.

■ MONICA YOUNG

**Find more mission details at https://is.gd/CometInterceptor.**

CSIRO

FAST RADIO BURSTS

## Two More Flashes' Host Galaxies Found

▲ ASKAP is one of the pathfinder radio arrays involved in homing in on the host galaxies of fast radio bursts.

**ASTRONOMERS HAVE HOMED IN** on the host galaxies of two non-repeating fast radio bursts (FRBs, *S&T:* July 2016, p. 24), and their homes are not what the teams expected.

Until recently, astronomers have only been able to identify the host galaxy of FRB 121102 — one of only two FRBs known to flash repeatedly. But on June 27th, Keith Bannister (CSIRO, Australia) and colleagues reported in *Science* that they had found the source of FRB 180924 — a millisecond-long flash that hasn't repeated — using the 36-dish Australian Square Kilometer Array Pathfinder (ASKAP). Then, on July 2nd, Vikram Ravi (Caltech) and colleagues announced that they'd narrowed down the galaxy hosting a second non-repeater, FRB 190523. Both teams triangulated the sources using radio interferometry.

In observations from the Dark Energy Survey, the Very Large Telescope and the Gemini South Telescope in Chile, and the Keck II Telescope in Hawai'i, Bannister and colleagues spotted the host galaxy, which appears to be lenticular in shape. Its light took 3.6 billion light-years to arrive at Earth. Spectroscopic measurements show little evidence of new stars forming; moreover, the burst appears to come from the galaxy's anemic outer reaches.

Meanwhile, Ravi's team used a 10-dish prototype for the upcoming Deep Synoptic Array at the Owens Valley Radio Observatory in California to quickly home in on FRB 190523. A deep image and spectroscopy of the field via the Keck I Telescope shows a Milky Way–size galaxy with a Milky Way–like star-formation rate (about one Sun per year). If the source is in this galaxy, then its radio waves have traveled more than 6 billion light-years to Earth. Their study will appear in *Nature*.

These findings are in stark contrast to the home of the repeating FRB 121102: a compact star-forming region in a dwarf galaxy (*S&T:* Sept. 2017, p. 12). Given its environment, some astronomers think its pulses might come from a newborn, highly magnetized neutron star known as a *magnetar*. However, the location of the non-repeating FRBs in galaxies with little or no star formation suggests that their sources are not associated with new stars, magnetars or otherwise.

"Interestingly, both host galaxies of FRB 180924 and FRB 190523 are more similar to each other than they are to the host of FRB 121102 (the repeater)," says Bannister. Different scenarios might apply to repeating and non-repeating bursts.

■ MONICA YOUNG

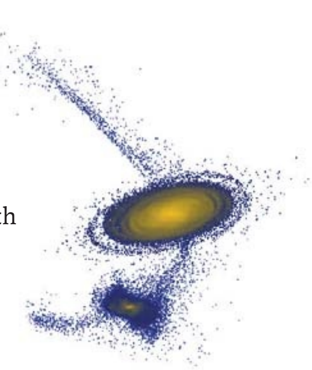
MILKY WAY

## Did a Newly Discovered Dwarf Do a Hit-and-Run?

**A CONTROVERSIAL STUDY** suggests that the dwarf galaxy Antlia 2, discovered in Gaia data (*S&T:* Mar. 2019, p. 11), had a long-ago run-in with the Milky Way.

Starting in 2009, Sukanya Chakrabarti (Rochester Institute of Technology) began fleshing out a theoretical scenario: The ripples that astronomers observe decorating our galaxy's outskirts (*S&T:* July 2015, p. 16) could have been initiated several hundred million years ago, when a dwarf galaxy smashed through the Milky Way. On June 12th, at a meeting of the American Astronomical Society, Chakrabarti announced that the dwarf galaxy Antlia 2 might be the guilty party.

The stars of Antlia 2 are spread surprisingly thin, suggesting that the dwarf might have tangled gravitationally with the Milky Way. Chakrabarti calculated its possible effects on our galaxy depending on how closely the two approached, while also considering a variety of galactic masses. Although neither galaxy's mass is well known, both their masses and their closest approach are critical to determine whether Antlia 2 could have had the gravitational strength to draw up ripples in the Milky Way's disk. The Sagittarius Dwarf Galaxy's tidal pull would have been insufficient, and the Magellanic Clouds haven't come close enough. Other dwarf galaxies that have been discovered are even less massive and/or farther away.



◀ One possible explanation for the ripples in the Milky Way's disk is a past collision with the dark dwarf galaxy Antlia 2.

But not everybody agrees that Antlia 2 is responsible for the Milky Way's ripples. Vasily Belokurov (University of Cambridge, UK) argues that the hit-and-run scenario only works if the galaxies are both on the more massive end of the spectrum *and* if Antlia 2 hit relatively close to our galactic center — a series of assumptions he calls improbable.

Fortunately, better measurements are forthcoming, as the next two data releases from the Gaia mission, expected in 2020 and 2021, will improve on the accuracy of earlier releases. The new data will provide the best test yet of whether this diminutive galaxy really restructured our galaxy's outer disk.

■ **MONICA YOUNG**

MILKY WAY

## Possible Evidence for Massive Dark Matter Clump

**A STELLAR STREAM** known as GD-1 might provide evidence of a dark-matter clump in the outskirts of the Milky Way, announced Ana Bonaca (Center for Astrophysics, Harvard & Smithsonian) on June 11th at a meeting of the American Astronomical Society. The finding will also appear in the *Astrophysical Journal* and, if it pans out, could help astronomers understand the nature of dark matter.

The GD-1 stream used to be a globular cluster, but gravitational interaction with the Milky Way, starting 3 billion years ago, pulled the group into a 30,000-light-years-long string of stellar pearls. Only, it turns out that some of the pearls are missing.

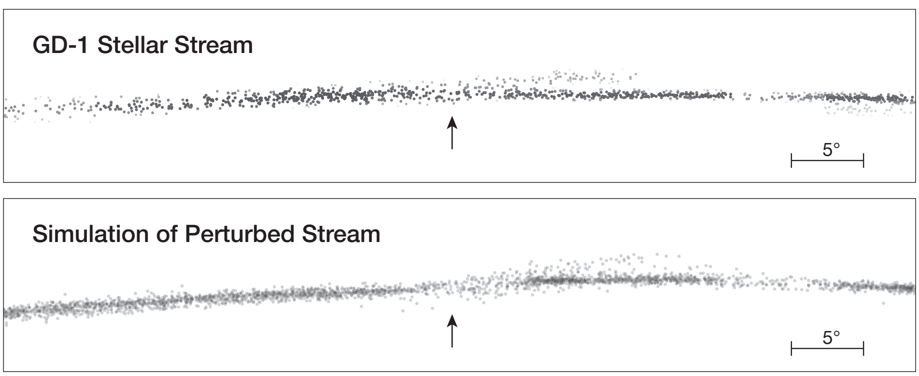
Data from the European Space Agency's Gaia satellite show two gaps in the stream, as well as a spur, where stars fly along on orbits slightly altered from the rest of the group. One of the gaps probably represents the location of the globular cluster before it dissolved under gravitational forces. But the cause of the other gap and the spur associated with it is unclear; simulations show that interactions with the Milky Way's disk or bar can't explain them.

Bonaca and colleagues propose that a massive but compact object punched through GD-1 about 500 million years ago. According to the group's simulations, the object would have been at least 5 million solar masses and less than 130 light-years across.

"What we infer about the mass and size of this object is consistent with something like a globular cluster," Bonaca acknowledges. "However, we have calculated the orbits of the known globular clusters, and they don't come very close to the stream." It's still possible that a cluster currently hiding within or behind the galactic plane could be responsible for GD-1's features. Alternatively, the mass could have been a starless clump of dark matter. Either way, the proposal should spur further study of the more than 40 other stellar streams discovered around the Milky Way to date.

■ **MONICA YOUNG**

▼ The stellar stream known as GD-1 has two gaps and a "spur." The central gap (arrow) and its associated spur could be explained if a dark matter clump punched through the stars.




GALAXY COLLISION: S. CHAKRABARTI; STELLAR STREAM: A. BONACA ET AL. 2019 / *ASTROPHYSICAL JOURNAL*

MOON

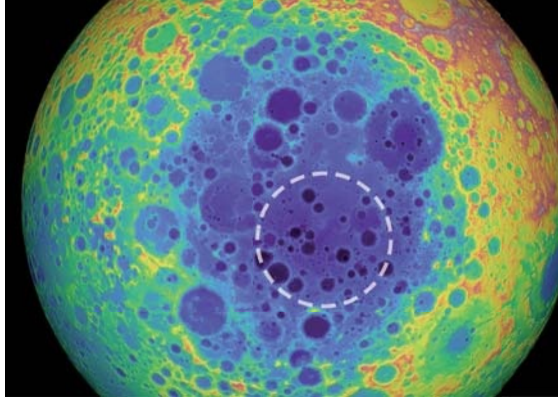
## Huge Mass Found Under Moon's Largest Basin

**NEW RESEARCH SHOWS** that a dense mass lies buried under the South Pole-Aitken Basin, hidden from view on the lunar farside. It might be the remains of the impactor that formed the basin.

Even though the South Pole-Aitken Basin spans roughly 2,400 km (1,500 miles), it isn't particularly obvious in spacecraft photos. Topographically, though, it's an unmistakable pit up to 13 km deep. Geologists have long suspected that the basin formed some 4 billion years ago in a slow, shallow, and oblique collision with an object roughly 200 km across.

Now a team led by Peter B. James (Baylor University) has identified a huge mass buried underneath the basin, based on analysis of topographic maps from NASA's Lunar Reconnaissance Orbiter and gravity data from NASA's Gravity Recovery and Interior Laboratory (GRAIL) mission. The team suggests that the primordial impactor's iron-rich core could have dispersed itself into the Moon's upper mantle. Alternatively, the dense mass could come from oxides left behind when the Moon's magma ocean solidified. The results appear in the May 28th *Geophysical Research Letters.*

Similar mass concentrations are found under many other lunar basins, but they usually have a bull's-eye structure, with a deeply buried ring of lower-density material sandwiched between a denser core and outer ring. But the massive blob buried at least 300 km under the South Pole-Aitken Basin has a different gravitational fingerprint. James and colleagues conducted simulations to show that, after striking the Moon with a glancing blow, the impactor's metallic core could have ended up as a lump beneath the basin — concentrated enough to create the



▲ A dashed circle shows the location of the huge mass buried under the South Pole-Aitken Basin in this topographical map of the Moon.

gravity anomaly recorded by GRAIL, but dispersed enough that it didn't sink en masse toward the lunar core.

The impact that created the largest and deepest basin on the Moon also redistributed the lunar crust, created magnetic anomalies all over the surface, and might even have affected the Moon's rotation. Dynamicists will now be investigating what role this massive, newly discovered lump might have played in altering lunar history.

■ J. KELLY BEATTY

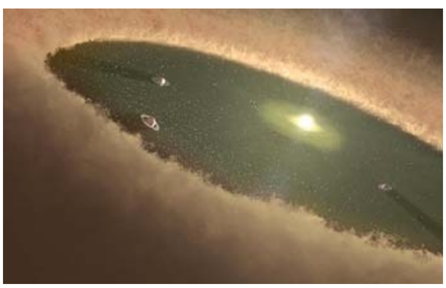
EXOPLANETS

## Youngest Confirmed Planet Discovered

**OBSERVATIONS OF THE YOUNGEST** confirmed exoplanet, the young hot Jupiter known as CI Tau b, suggest that it formed via gravitational collapse.

Christopher Johns-Krull (Rice University) and Lisa Prato (Lowell Observatory) presented the results of a new study led by Laura Flagg (also at Rice) at a meeting of the American Astronomical Society. Their work appears in the June 20th *Astrophysical Journal Letters*.

▼ An artist's concept shows several gas-giant planets orbiting near a young star surrounded by a protoplanetary disk.



Scientists have proposed two mechanisms to explain how large planets form: *core accretion*, in which a rocky core slowly attracts gas around it, and *gravitational instability*, in which portions of the disk collapse directly and rapidly into a planet. In the latter process, planets have higher temperatures and therefore glow more brightly at infrared wavelengths, so it's also known as the *hot start* model.

Planet formation scenarios can affect how astronomers interpret measurement of the planets themselves. For example, a young planet's infrared emission comes from the heat left over from its formation. Determining its mass requires knowing how quickly the planet came together.

The CI Tauri system, which is only 2 million years old, offers the opportunity to break this degeneracy. By combining the host star's radial velocity wobbles with a direct measurement of the planet's spectrum, the team was able to peg the planet's mass at 11.6 Jupiters without making any assumptions about the planet's formation scenario.

Between 2014 and 2018, the astronomers observed the system using the high-resolution Immersion Grating Infrared Spectrograph on telescopes at the McDonald and Lowell Observatories. In addition to detecting the chemical fingerprint of carbon monoxide from the planet, the team also measured its infrared brightness. The latter can be converted to a mass, depending on how quickly the planet formed.

By comparing the model-independent mass with the infrared brightness, the astronomers determined that the planet formed in a hot-start scenario.

The next question is, did this hot Jupiter migrate inward or form where it is now? The star's young age suggests the answer: "It's such a young system, it's hard to believe that it migrated in that quickly," says Prato.

■ STEVE MURRAY

SPA BASIN: NASA / GODDARD SPACE FLIGHT CENTER / UNIV. OF ARIZONA; PLANETS FORMING: NASA / JPL-CALTECH / T. PYLE

# ∞ PHOTOS WITHOUT ELECTRICITY

## MiniTrack LX3: Fully mechanical photography mount for cameras up to 3kg (105.8oz) (6.6 lbs).

Saslong Night - Sassolungo da Col Raiser (Italy) – Photo: Cristian Fattinnanzi

NEW

**Wide-field imaging, as depicted above, is possible with ease. The fully mechanical Omegon MiniTrack LX3 mount works just like a clock. No power necessary. No charging. No battery. Simply mount your camera onto the LX3 and wind it up. Easily capture wide-field images of the cosmos on your camera.**

### ✔ Clockwork mechanics

The mount works like a clock, with 60-minute tracking - all without power and batteries. You can also adjust the tracking speed according to your needs.

### ✔ Sleek and compact

Whether on a flight or on the next night-time excursion. The MiniTrack fits into every bag and still leaves room for a nice tripod or a second tele photo lens.

### ✔ Powerful spring system

The MiniTrack requires no counterweight, the spring system supports tracking. You can also adjust the tracking speed according to your needs.

### ✔ Brass Axel

The brass axle with integrated Teflon bearings ensures smooth and precise tracking.

### ✔ Integrated ¼-20" threading

The MiniTrack fits every photography tripod and features two ¼-20" threads. For example, you can connect a ball head to the MiniTrack and capture every part of the night sky.

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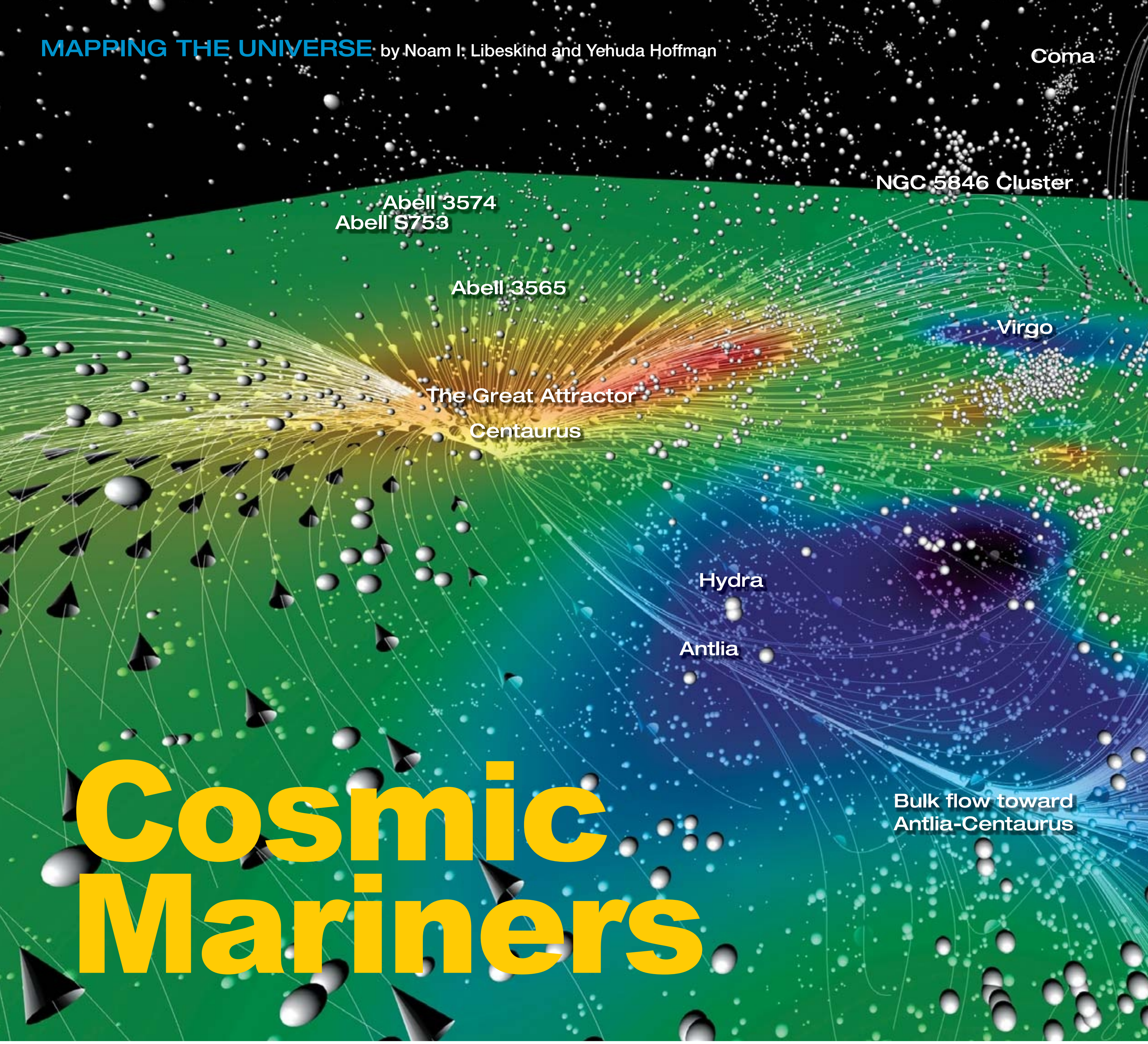



# Cosmic Mariners

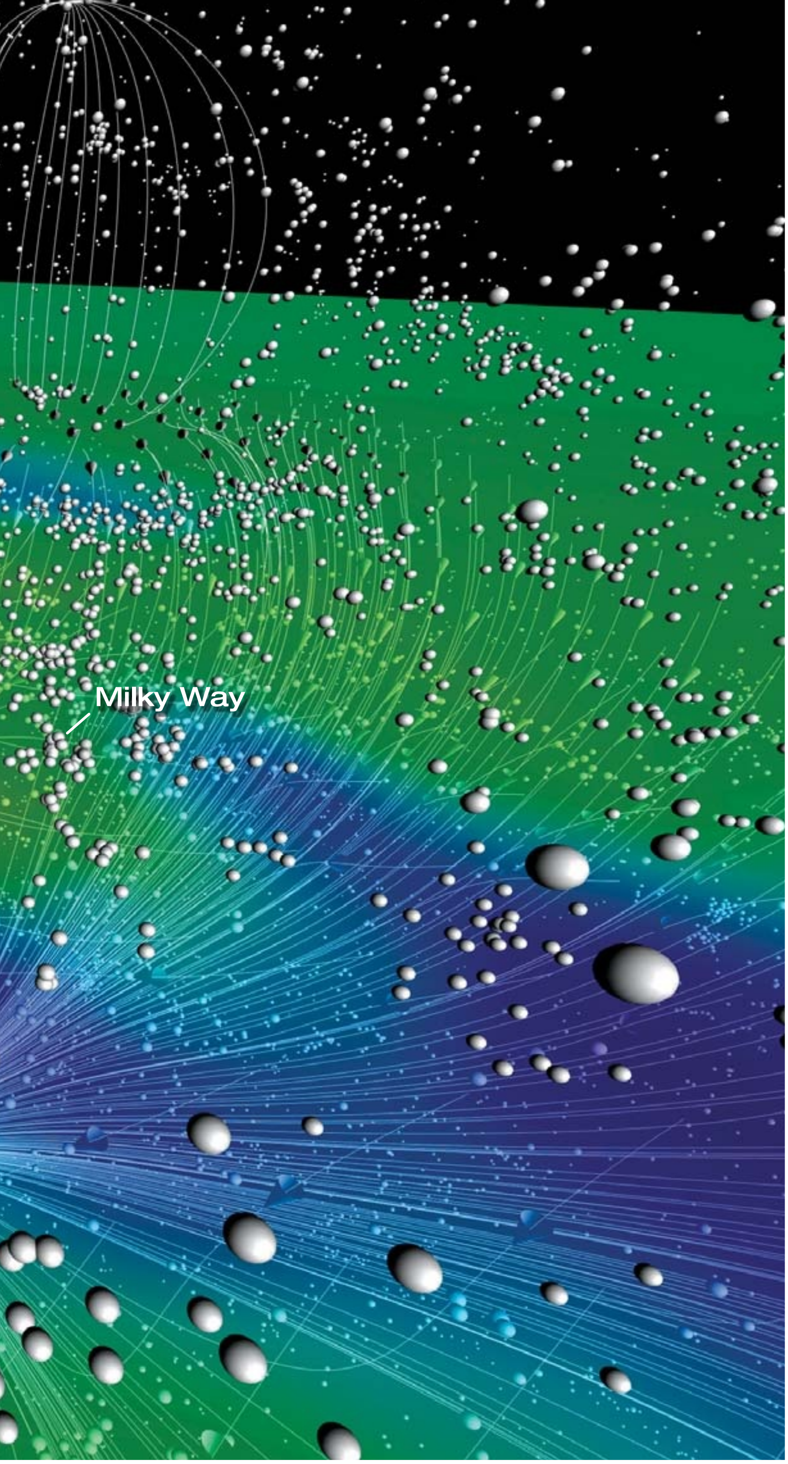
### Astronomers chart the vastness of space by tracking the currents that galaxies swim in.

"There's no such thing as a gravitational time machine!" belted out a voice across the hall. "You can't just reverse gravity!"

One of us (NIL) was lecturing on work that we and our collaborators had been developing, in which we tried to answer two simple questions: How did the Milky Way form, and why does it look the way it does? Our approach was rooted in observations of what's termed the *local neighborhood* — the immediate (relatively speaking) vicinity of our galaxy, out to some 100 million light-years. But instead of using telescopes, we were building galaxies in computers and then running time forwards and backwards to see how their appearance changed.

The lecture was in Tallinn, Estonia, at a meeting dedicated to the 100th birthday of Yakov Zeldovich, a towering figure in 20th-century physics and astrophysics. Besides helping to develop the Katyusha rocket and being an instrumental player in the Soviet Union's atomic bomb project, Zeldovich left an indelible mark on our understanding of the universe on its largest scales, including on how to map the cosmos.

H. M. COURTOIS ET AL. / *ASTRONOMICAL JOURNAL* 146:69 (2013)




▲ **COSMIC FLOWS** Each sphere in this wide-angle perspective represents a galaxy in the nearby universe. Arrows indicate the streamlines the galaxies follow, and colors correspond to a region's density (red for dense clusters, blue for voids).

LEAH TISCIONE / *S&T*, SOURCE: DANIEL POMARÈDE (CEA UNIVERSITÉ PARIS-SACLAY)

His school of thought produced some of the greatest luminaries in modern astrophysics, a number of whom are still active today, mostly spread across the Western world in a post-Soviet diaspora.

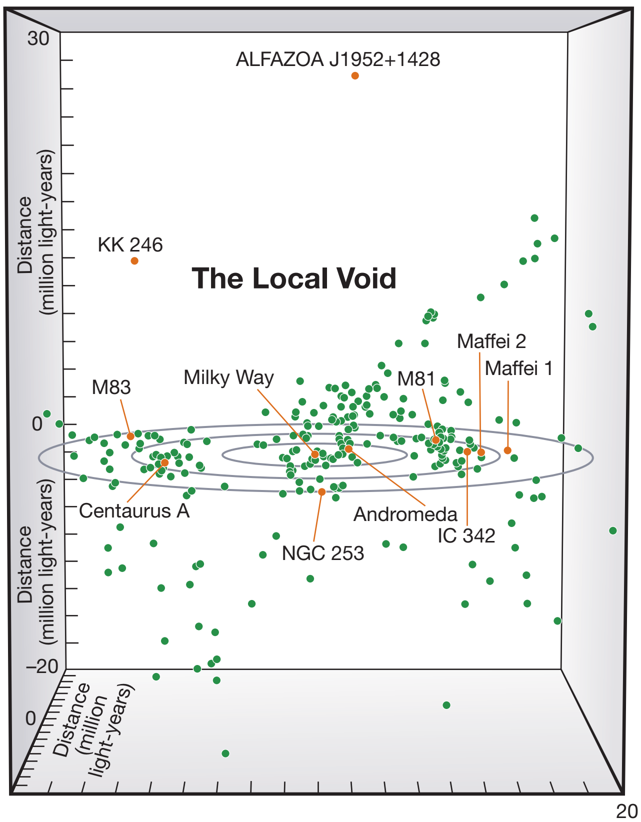
The voice berating our method came from Andrei Doroshkevich — a scion in the field who, now at more than 80 years of age, is one of the last of Zeldovich's living disciples. He had reason to complain: Gravity behaves in such a complex way that, with the exception of the most trivial situations, we cannot simply look at a galaxy now and predict precisely what it looked like at a previous time — Humpty Dumpty can never be put back together again.

But although we cannot yet reconstruct our galaxy's past this way, it turns out that with a little ingenuity, we can sidestep the impossibilities and truly turn back the gravitational clock in an attempt to map our galaxy's neighborhood.

## Nature vs. Nurture

One of the most fundamental questions in cosmology is how galaxies form and grow into the magnificent objects we see today. Just as with children, the answer is not merely a matter of genes; it's also one of environment. Our home galaxy, the Milky Way, lives very close to its sibling, the Andromeda Galaxy, and a smattering of smaller dwarf galaxies. This neighborhood of galaxies (which we call the Local Group) lies off the edge of the Virgo Cluster, a metropolis of some 2,000 galaxies about 50 million light-years away. In the opposite direction, a void abuts our location. Together with these and other clusters and voids, we are part of a vast, watershed-like conglomeration of galaxies that forms our cosmic nation.

To understand what made the Milky Way turn out the way it ultimately did, with its large spiral disk and rich collection




▲ **LOCAL SHEET** Seen in *supergalactic coordinates*, the Milky Way and its largest neighbors (labeled) occupy the Local Sheet, which abuts the Local Void. Circles mark 6.5 million, 13 million, and 20 million light-years.

of stars, we need to first map our galaxy's local environment. This work is called *cosmography*. Where is our galaxy? In which direction is it moving? Who are our cosmic neighbors? And how full of stars and galaxies is our neighborhood?

Making maps of the universe is not straightforward. For one, when you see two objects that look equally bright in the heavens, how do you know that one isn't in fact much brighter but much farther away? For another, since galaxies are so distant, it has taken the light they emitted a long time to reach us, sometimes billions of years. When you see a galaxy, you're actually looking at it in the past, as it was when it emitted the light you're seeing. But because the universe is expanding, that galaxy has moved farther away from you since then. So where are those galaxies now? How can astronomers even approach the question of building cosmographic atlases when the universe is expanding and galaxies today aren't exactly where we see them?

Luckily, mapping the universe isn't an impossible task. The expansion of the universe is well described by a simple empirical relationship known as the Hubble-Lemaître Law: The farther a galaxy is from us, the faster it's moving away.

There are two pieces to this relationship: distance and velocity. We determine galaxies' distances by finding one or more stars among the billions contained in a galaxy that have a known intrinsic brightness — such as Type Ia supernovae or Cepheids or stars "at the tip of the red giant branch." If one of these stars is fainter than another of the same type, it's farther away. Astronomers use these *standard candles* to measure the exact distance to the galaxies that host them (*S&T:* June 2019, p. 22).

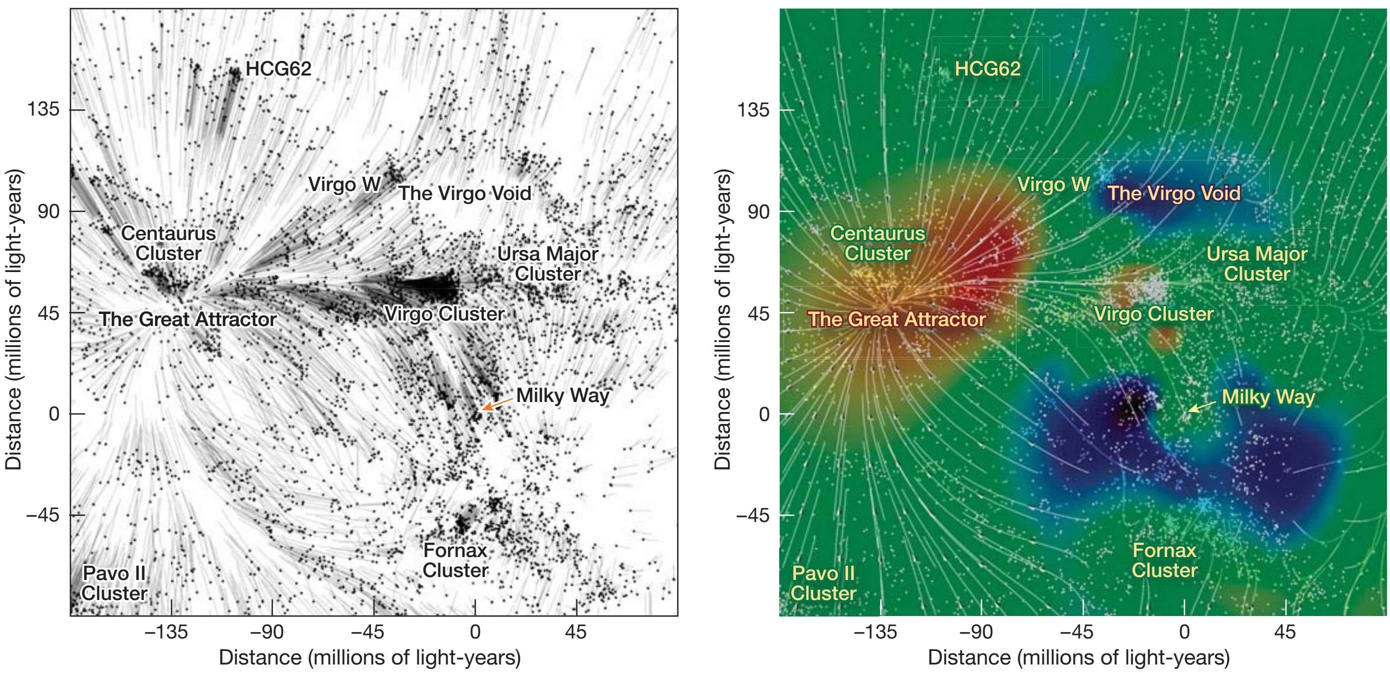
At the same time, observers measure the galaxy's velocity by splitting its light into a spectrum and observing the shift in the light's wavelengths caused by the galaxy's motion toward or away from us. This change is called a Doppler shift or (when the motion is away from us) the famous *redshift* to longer, redder wavelengths.

Knowing the distances to galaxies is critical for understanding how the galaxies are moving. Assuming the Hubble-Lemaître Law, a galaxy's distance should be all you need to figure out how quickly it's moving away — the galaxy is like a boat caught in the cosmic current, called the *Hubble flow*. Yet often galaxies move away faster or slower than expected for their distance. This movement is not some sort of new physics at work; it's due to cosmic structure. A galaxy's speed can deviate considerably from the Hubble flow when it's pulled off course by the gravitational attraction of a nearby dense region of matter, be it luminous or dark. This deviation is called the galaxy's *peculiar velocity* — peculiar because it doesn't conform to the uniform travel away from us caused by expansion.

## Go with the Flow

Peculiar velocities are key to mapping the local universe around the Milky Way, because they tell us how everything is connected. Unfortunately, they're hard to come by. We can only accurately determine peculiar velocities "locally," because the farther away a galaxy is, the more inaccurate a

▼ **FOLLOW THE FISH** *Left:* An analysis of thousands of galaxies' distances and velocities indicates how systems within about 100 million light-years of the Milky Way move. *Right:* The same plot but colored to show the density of matter, with flows simplified to the overall pattern. White dots are galaxies. Both diagrams are slices along the supergalactic plane, the coordinates centered on the Milky Way.




H. M. COURTOIS ET AL. / *ASTRONOMICAL JOURNAL* 146:69 (2013)

## THE GREAT ATTRACTOR

The first gravitational sink identified with cosmic flows was the Great Attractor. It's a concentration of galaxy clusters that lies between the Milky Way and the larger Shapley Supercluster. It was found by a gang of seven astronomers dubbed "The Seven Samurai" and led by Donald Lynden-Bell (1935–2018), one of the great astronomers of the past half century.

measure of its distance will be — and the more inaccurate the distance, the less sure we are of what the Hubble flow velocity for that galaxy should be.

Furthermore, the universe didn't bless every single galaxy with a standard candle as accurate as a Type Ia explosion. Only about 400 of the 40,000 or so supernovae we have observed in the billions of galaxies out there provide good, reliable distances. While there are other ways of measuring the distance to galaxies without supernovae, these methods tend to have errors of around 20% at great distances.

But it turns out that we don't need to precisely measure every galaxy's distance and motion in order to map the cosmic landscape. All the galaxies in a given volume of space inhabit the same gravitational environment, so they're all attracted toward the same concentrations of matter. Thus, charting only a fraction of the galaxies traveling along the currents in the cosmic ocean tells us the cosmography: You only need to measure the velocity of a few fish to know the speed of the entire school, and you only need to measure the motion of a few schools to infer where the hunting grounds are.

We can use this cosmographic approach on scales of hundreds of millions of light years, much larger than a single galaxy cluster. On these scales, deviations from the Hubble flow are small, and galaxies bob in relatively smooth currents — think of water gently flowing around a small obstacle. This is what's known as a *laminar flow*, as opposed to a *turbulent flow*, which is when a river rushes so fast that it foams and froths and creates eddies.

The broad-brush atlas of the heavens that we build with these smooth flows reveals quite a lot. We have charted the cosmic landscape out to distances of roughly half a billion light-years, using a mere 8,100 galaxies. These maps indicate that two structures dominate the local flow: an association of massive clusters of galaxies called the Shapley Supercluster, and an immense cosmic void coined the Dipole Repeller (*S&T:* May 2017, p. 8). Both lie about 650 million light-years away from the Milky Way, in almost diametrically opposing directions. One of us (YH) and colleagues also used the technique to discover that many features of the local universe actually belong to a much larger system called Laniakea, our home supercluster. Laniakea spans more than 500 million light-years and contains 100,000 galaxies.

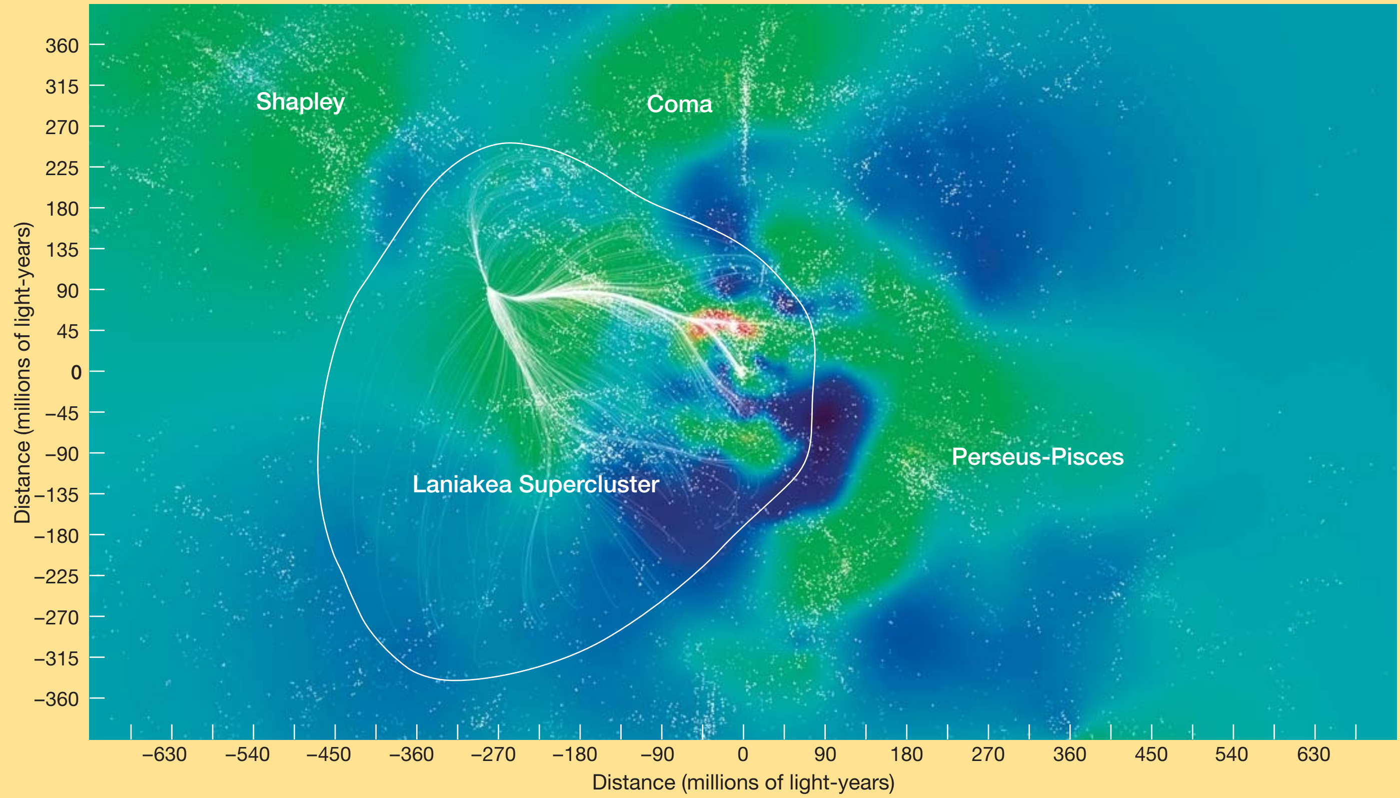
### The Gravitational Time Machine

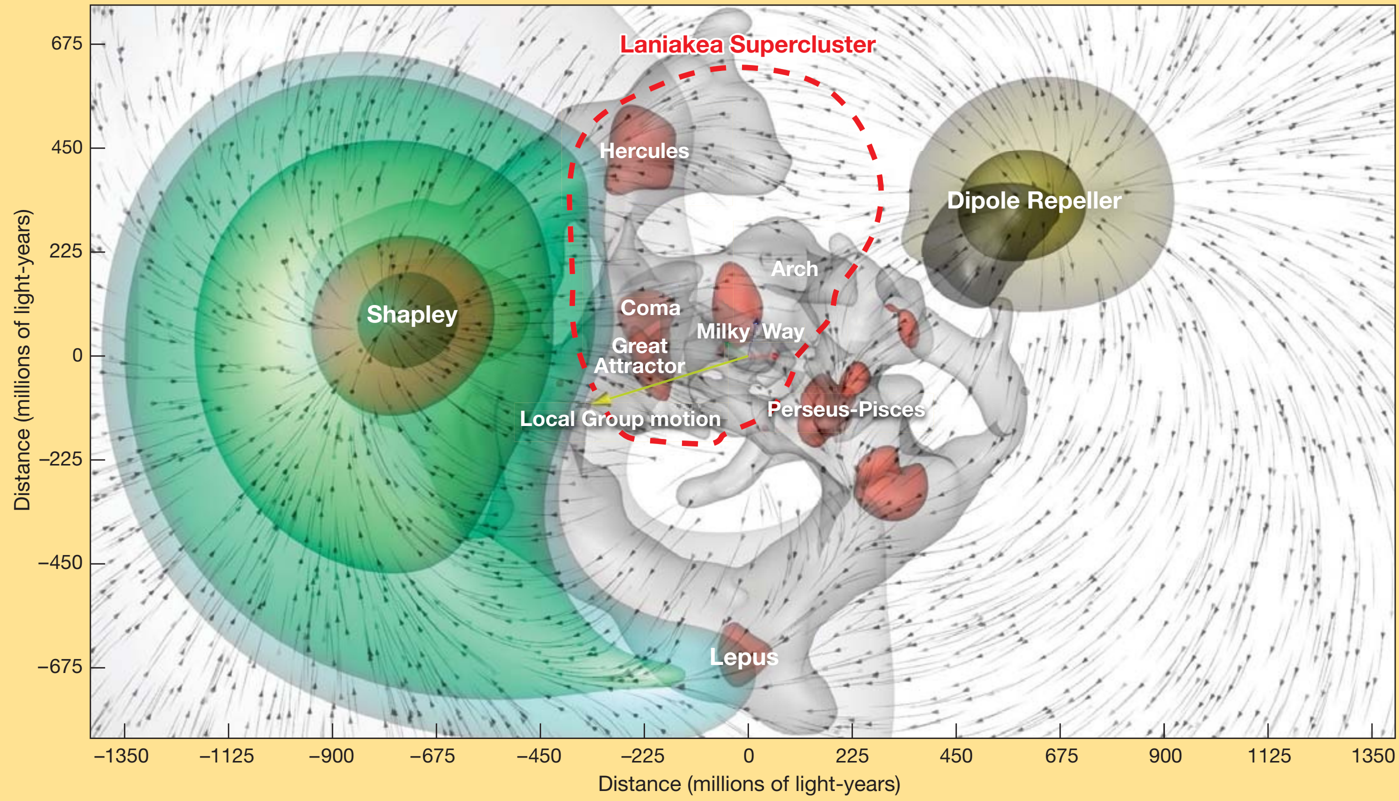
In laminar cases, it is fairly easy to trace the flow back in time, even all the way back to when the universe was young and galaxies had not yet formed. For example, if two galaxies are converging towards a common center, we may infer not only that there is some huge mass there that's attracting them, but that they were farther away from that common center in the past.

This time-traveling enables us to reconstruct what our section of the early universe once looked like, such that, under the influence of gravity, it would grow to produce the cosmographic landscape we observe today. We can then use this picture as the starting point of a computer simulation. Computer simulations allow us to fill in the blanks, to "guess" what the universe looks like on the scale of individual clusters, where galaxies' motions are too turbulent for us to infer the distribution of matter from peculiar velocities. In fact, Zeldovich and Doroshkevich were among the first to realize that reversing galaxies' paths in the heart of a cluster would be like trying to track footprints in the snow on a town square: easy to do for a few tracks right after snowfall, but an impossible task when half the town has gone to market.

**Reversing galaxies' paths in the heart of a cluster would be like trying to track footprints in the snow on a town square.**

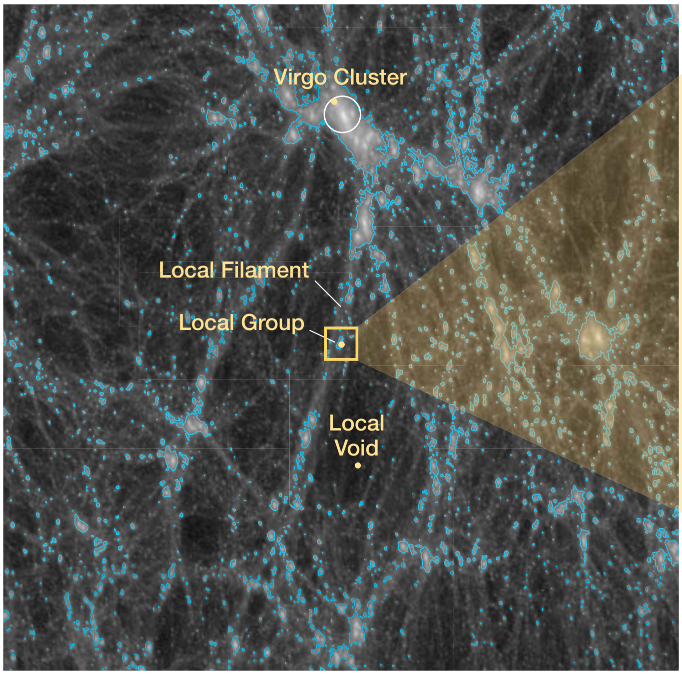
If you want to simulate gravity in a computer, it's not that hard. You fill an imaginary box with particles, arranged in some way. You then compute the gravitational force that each particle feels due to all the other particles and have the computer code move them accordingly. For example, if your initial setup is a uniform sea of particles with a big spherical blob in the center, then all the particles will feel a net attraction to the blob and collapse towards it. Gravity is the ultimate capitalist force: The rich get richer and the poor get poorer. By that we mean, the denser regions get more dense and massive as they attract more stuff, at the expense of the empty, less massive regions. It happens in a kind of gravitational avalanche. By today, most of the mass of the universe is concentrated in blobs — galaxies and clusters — whose density can be up to a few hundred times the mean density of the universe. This leaves behind vast, under-dense volumes whose typical density is about 10% of the mean (*S&T:* Feb. 2015, p. 20).

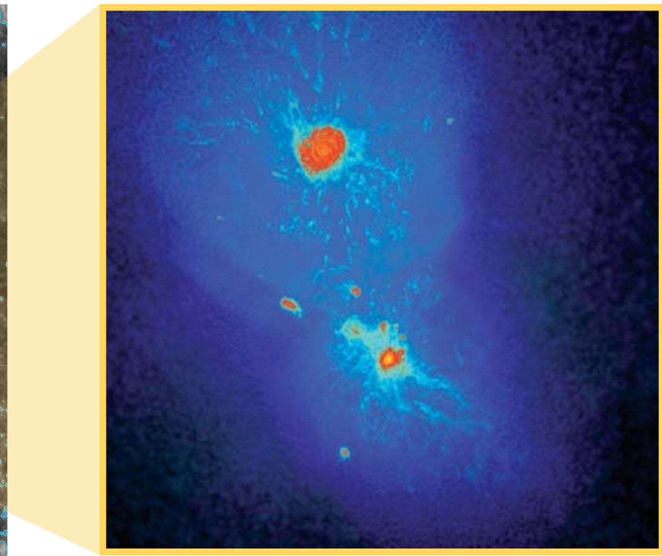



DANIEL POMARÈDE (CEA UNIVERSITÉ PARIS-SACLAY)

▲ **OUR COSMIC WATERSHED** Peculiar velocities indicate that the Milky Way lies on the outskirts of a vast supercluster, called Laniakea *(top, looking down on the supergalactic equator)*. This structure in turn lies between the Shapley Supercluster (an "attractor") and a gigantic void called the Dipole Repeller *(bottom, rotated 90° to look along the y-axis)*. Cosmologists have not fully charted the region between Shapley and Laniakea and so don't know their exact relationship yet.





**SIMULATED UNIVERSE** Simulations of large-scale structure can reproduce both our local cosmic structure *(left)* and the interactions of galaxies similar to the Milky Way and Andromeda *(right)*.

So, on large enough scales we can use our time-reversal machine to go back in time, reversing the evolution of a giant region of the observable universe from what it looks like today to the near-uniform sea of particles that was its initial state. Once at the beginning, we fill in the details that the large, gentle flows gloss over, by performing an educated guess on what's there. That's where computers come in handy. We then feed this smooth, nearly uniform early universe with our guesses into a computer and simulate forwards in time. In short, we go from the final state to the initial state, statistically fill in the details of what we missed, and then go forwards again.

These simulations all look similar on large scales and provide a good proxy to the real universe. They have to: They're built to reproduce galaxies' observed peculiar velocities and the underlying matter distribution, which is why we call them *constrained simulations*. But unlike our cosmographic maps, the simulations are not limited to the zoomed-out view. In the computer we are free to simulate down to whatever scale we want (computational limitations notwithstanding) and see how the galaxies move there.

What's remarkable is that on scales of roughly 10 million light-years — similar to the distances between individual galaxies — the virtual universes reproduced in our computers don't differ that wildly. That suggests that even with the rough, zoomed-out view that peculiar velocities provide, we can predict what the universe actually looks like on scales one-tenth as grand. By averaging many constrained simulations together, we are able to probe the movements of galaxies on these scales *and* simultaneously make some of the most accurate cosmographic maps in existence of the nearby universe.

Using this approach, we have been able to identify specific features hitherto unseen in the local universe. These features include bridges of dark matter, connections between clusters of galaxies, and voids that push galaxies outward — a network of structures that is commonly dubbed the cosmic web. Observers have also found such bridges, using the lensing effect the structures' gravity has on the light of galaxies behind them.

Certainly Doroshkevich and Zeldovich were right: Gravity, once it causes high-density regions to form, can never be reversed; the knot can never be untied. However, with good observational data and careful calculations, we can turn back the clock, not only creating rough maps of today's local universe but also reversing gravity to fill in the fine-grained details of the history of our galaxy's neighborhood. And someday, these charts of the cosmic currents will help us understand why the Milky Way looks the way it does.

We don't think Zeldovich, buried alongside other Russian giants such as Gogol, Chekhov, and Prokofiev in Moscow's Novodevichy Cemetery, would be turning in his grave. We hope that he would be pleased.

**NOAM LIBESKIND** is a computational cosmologist at the Leibniz Institute for Astrophysics Potsdam in Germany and a professor at the University of Lyon-1 in France. **YEHUDA HOFFMAN** is a professor of Physics at the Hebrew University of Jerusalem.

**Watch a detailed video on how cosmologists create maps of cosmic flows: http://irfu.cea.fr/cosmography.**

NOAM LIBESKIND (2)

# The MDW Sky Sur

The Moon isn't made of green cheese, and the Milky Way isn't a splash of mother's milk intended for Hercules. It's true that no one has believed these things for centuries. But many other astronomical truths have a far more recent origin. Take, for example, our understanding of spectacular deep-sky objects such as the Orion, North America, and Lagoon nebulae. Any budding amateur astronomer today will tell you these are glowing clouds of ionized hydrogen. And novice astrophotographers all know that it takes equipment sensitive to the red light of hydrogen-alpha emission to capture good images of them. But despite being common knowledge today, neither of these facts was known until well into the 20th century.

The first proof that nebulae could be clouds of gas rather than aggregations of stars too remote to be resolved visually came in 1864 when English amateur William Huggins pointed his 8-inch refractor and spectroscope at the Cat's Eye Nebula in Draco. It was, however, another six decades before

**An amateur sky survey would be a dream project, and it was also one now teetering on the edge of reality.**

physics explained that ionized hydrogen was responsible for most of the light coming from diffuse emission nebulae.

During the 1920s and '30s astronomers became increasingly aware that the deep red light of hydrogen-alpha emission (Hα for short) at a wavelength of 656.3 nanometers dominated these nebulae. Nevertheless, it wasn't until the latter half of the 1930s that photographic emulsions could record Hα well enough to efficiently explore the heavens in search of faint emission nebulae.

Armed with the latest photographic tools, astronomers rapidly added to the list of known nebulae, especially follow-

ALL IMAGES COURTESY OF THE MDW SKY SURVEY

# vey

A collaboration among three astrophotography friends is providing a dramatic new look at the glowing hydrogen spread across our Milky Way galaxy.

ing the National Geographic Society–Palomar Observatory Sky Survey completed in the 1950s with the 48-inch Oschin Schmidt telescope in southern California. During the 1980s, a second-generation survey done with the same telescope and state-of-the-art photographic technology revealed even more nebulae. Meanwhile, astronomers were increasing our knowledge of hydrogen spread throughout the Milky Way using other means, most notably radio astronomy.

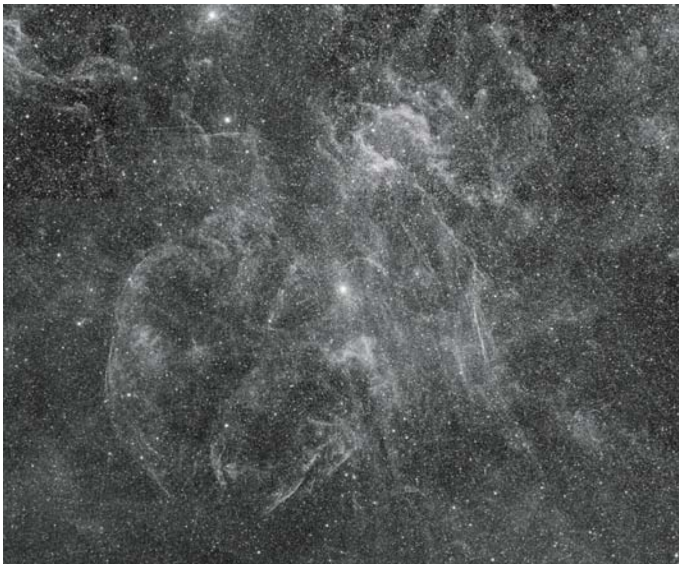
Amateurs were not far behind in exploiting the latest photographic advances to record deep-sky objects. During the 1980s and early '90s my *Sky & Telescope* colleagues and I were constantly amazed by photographs that readers sent in of faint nebulae, many of which were unknown in the days before the Palomar surveys.

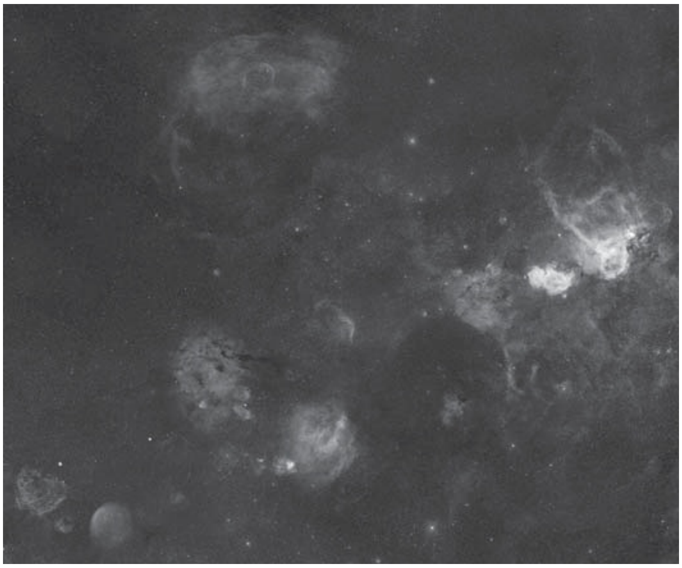
## The Digital Revolution

It's not news that the digital revolution has transformed astronomy, and especially astronomical imaging, in far more ways then there's room here to describe. This new technology offers more and better ways to study emission nebulae. Several early projects have provided a tantalizing picture of just how pervasive hydrogen emission is throughout our galaxy. Most notable among them are the Wisconsin H-Alpha Mapper (**astro.wisc.edu/wham-site/wham-sky-survey**), The Virginia Tech Spectral-Line Survey (**www1.phys.vt.edu/~halpha**), and The Southern H-Alpha Sky Survey Atlas (**amundsen.swarthmore.edu/SHASSA**).

There were also projects to map the sky in Hα light with short-exposure, small-scale digital images. The goal of the MDW Hydrogen-Alpha Sky Survey (MDW Sky Survey for short) is to take this to the next level, creating a detailed,

▲ This early mosaic stretching from northern Orion (left) to Vulpecula was made to highlight the survey's progress. It also shows the checkerboard coverage due to the autonomously controlled telescopes shooting optimally placed areas of sky rather than specific celestial targets.





deep Hα image of the entire night sky. It began not as a grand plan, but rather an evolution of the skills and common interests of three astrophotography friends — David Mittelman, myself, and Sean Walker (hence the MDW in the survey's name).

Soon after Sean joined the *Sky & Telescope* staff in 2000, he and I began working on a variety of imaging projects involving deep Hα images made from my backyard observatory in Boston's western suburbs. As the chips in affordable CCD cameras grew larger, we began experimenting with a branch of astrophotography that had long interested both of us — wide-angle imaging done with camera lenses.

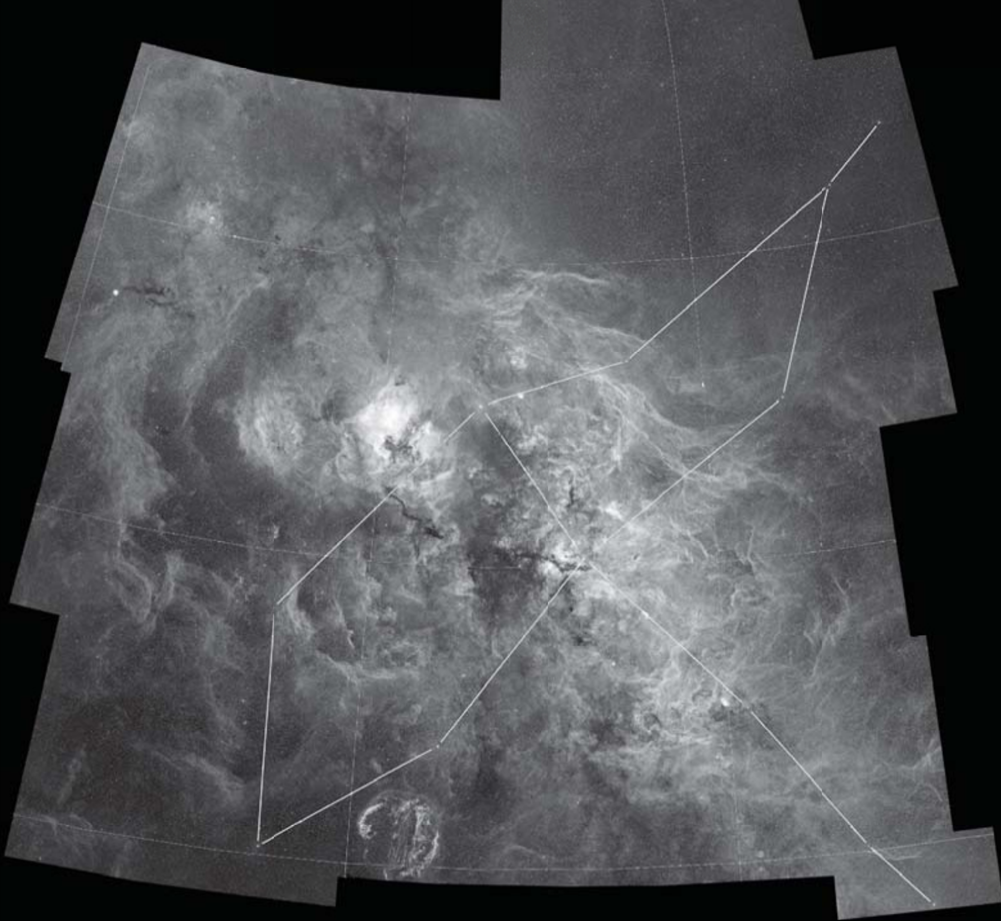
One ambitious project involved trying to capture any portion of the enormous but faint western edge of the Orion-Eridanus Superbubble, an emission feature almost unknown to amateur astrophotographers at the time. Success came on the first night. As our exposures made on subsequent nights panned haphazardly outward searching for the limits of what we could image, Sean began piecing the results together into a mosaic. With a few extra shots to fill in missing sections of the superbubble, the result proved interesting enough to appear as a story on wide-field imaging in this magazine's April 2009 issue, page 66.

Our next project was a more carefully planned mosaic of the Milky Way stretching from Puppis to Perseus. Made using a 110-mm camera lens, it covered more than 7,000 square degrees of sky with a resolution of about 17 arcseconds per pixel. The following year we made deeper mosaics of selected regions in this field using a 100-mm f/4 astrograph that increased the resolution to better than 5 arcseconds per pixel.

Around this time, and through overlapping circles of mutual friends, we connected with David Mittelman, who had a passion for astronomy dating to his days as a science major at Middlebury College. He had recently installed a pair of remotely operated telescopes at New Mexico Skies (**nmskies.com**). Most weeks the three of us would get together for an evening of talking shop and processing some of the latest images from the New Mexico scopes.

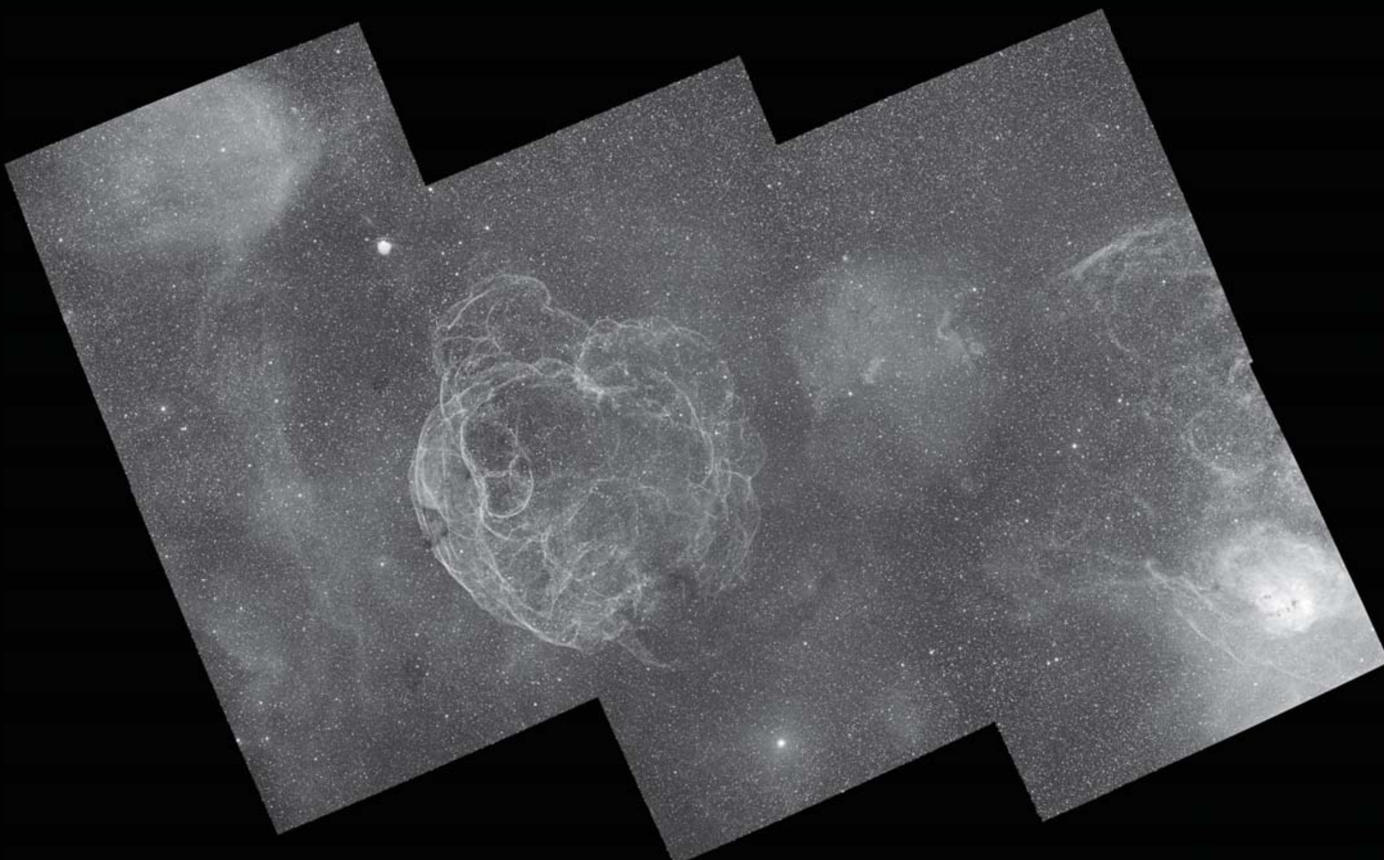
Dave became increasingly fascinated with the mosaics Sean and I were working on, including a new one of the Cygnus region made at a resolution of about 3 arcseconds per pixel. The resulting deep Hα image provided a dramatically new look at one of the sky's most targeted areas for wide-angle photographs. Not surprisingly, our conversations turned to what it would be like to photograph the entire *(continued on page 26)*

◀ *Top:* Located 15° southwest of the Veil Nebula, the supernova remnant G70.0-21.5 is larger than the Veil, but virtually unknown because it is so much fainter. This 8°-wide field straddles the Pegasus/Vulpecula border. The bright star in the field is 1 Pegasi. *Middle:* The Milky Way running from Auriga at lower left to the well-known Heart Nebula (IC 1805) in Cassiopeia at right contains many moderately bright emission features overlooked by astrophotographers. *Bottom:* Among the sky's most photographed deep-sky objects, the Veil Nebula in Cygnus is surrounded by fainter clouds of glowing hydrogen. The field is 14° wide.

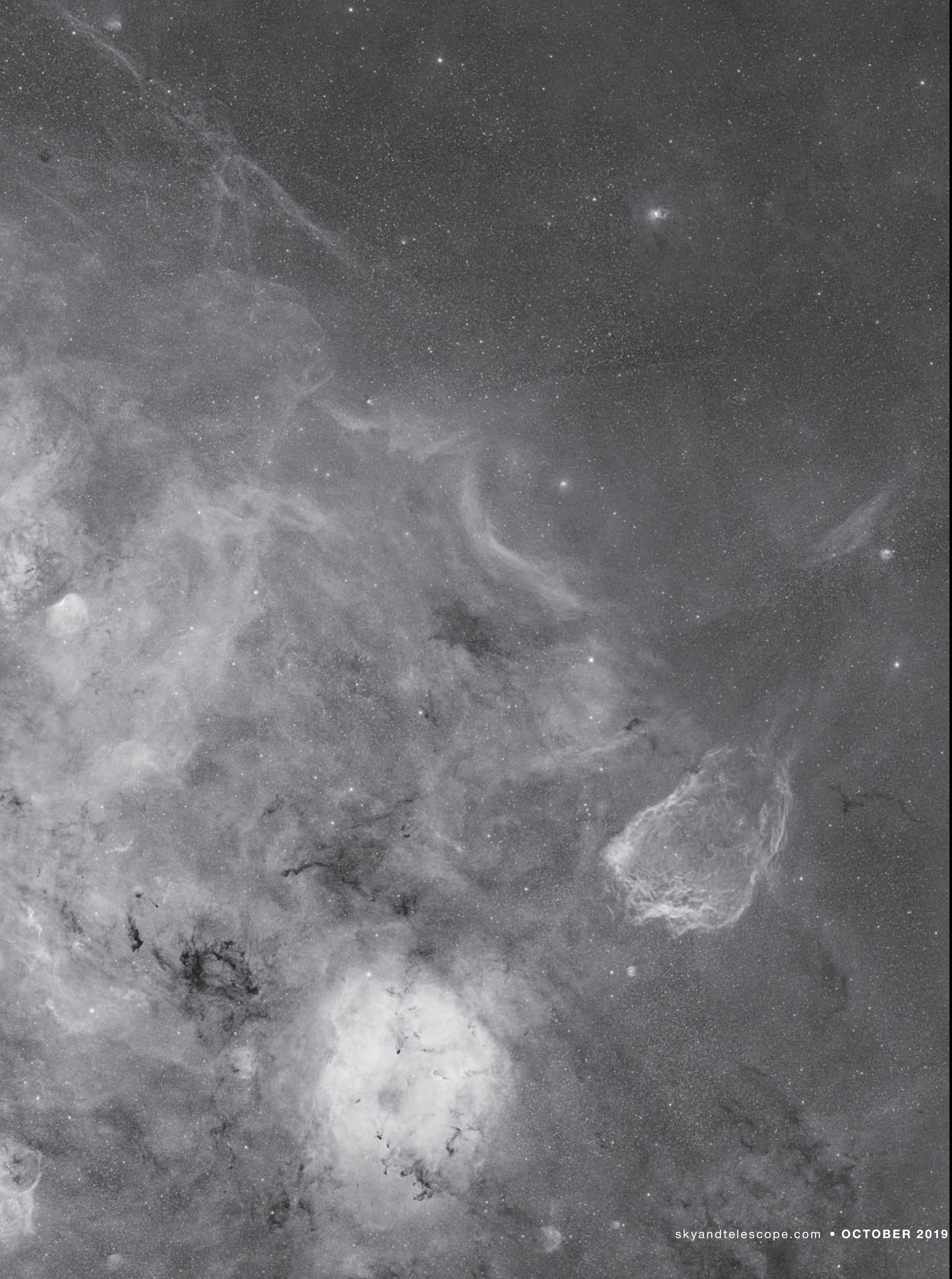


◀ Cygnus is home to many famous emission objects such as the North America and Veil nebulae. But deep exposures show that the whole constellation is awash with glowing hydrogen. The dark kidney-bean shaped feature at center is the Northern Coalsack. An image similar to this one provided inspiration for the survey.

▼ In the days of emulsion-based astrophotography, amateurs able to capture the large supernova remnant Simeis 147 in Taurus achieved major bragging rights, but today it's a rather routine object for wide-field digital imaging. This view has north to the right, with the bright nebula IC 410 in neighboring Auriga visible at bottom right. The prominent star is Elnath, Beta Tauri.



Scores of well-known nebulae pepper this swath of Milky Way crossing southern Cepheus from Cassiopeia at upper left to the Cepheus/Cygnus border at lower right, but they are merely the brightest islands in an ocean of hydrogen emission. One of the most prominent objects in this field is the nebula IC 1396 at bottom center on the facing page.



(continued from page 22)
Milky Way with deep Hα images, or, better still, the whole sky. Hardly original thoughts, but given the resources and experience of the three of us, and the proven technology of autonomously operated telescopes, an amateur sky survey would be a dream project, and it was also one now teetering on the edge of reality. During a discussion one evening, with hardly a pause in the conversation, Dave said, "Let's do it."

## Launching the Survey

Planning any project to photograph the whole sky involves a series of compromises. Because our main goal was to photograph faint Hα emission nebulae, we wanted an optical system with a fast f/ratio. We also wanted decent resolution, and that meant working with longer focal lengths, but as the focal length of an imaging system increases the area captured in each exposure grows smaller, meaning more exposures are needed to cover the sky. Our Cygnus mosaic was done with a focal length of 600 mm, and we decided that this was close to the upper limit of what would be practical.

After carefully testing several imaging setups, we settled on using a pair of the then-newly available Astro-Physics 130GTX refractors with their custom f/4.5 focal reducers that yielded an effective focal length of 585 mm. Equipped with FLI Proline 16803 CCD cameras, each scope captures a field of view roughly 3½° square with a resolution of 3.17 arcseconds per pixel. Considering the overlap needed to create a mosaic image, approximately 4,100 fields are required to cover the entire sky.

Because we are doing only Hα imaging, I modified each scope to use a fixed internal filter and FLI Atlas focuser. By doing away with a conventional filter wheel and focuser we

▼ The relatively bright but virtually unknown hydrogen cloud Sivan 2 in Cassiopeia is only a short hop from the Andromeda Galaxy. It was discovered as little more than a smudge on an H-alpha survey photograph made in the early 1970s by the French astronomer J. P. Sivan.

▼ This 11½°-tall image of Sivan 2 was created by combining survey exposures with RGB color images taken by Rogelio Bernal Andreo. The bright star at upper left is Schedar, Alpha Cassiopeia, while the open star cluster NGC 7789 is at upper right. North is up.

created a setup that is essentially sealed between the telescope objective and CCD detector, thus preventing dust from getting inside the telescope and causing image artifacts.

The scopes are mounted on a pair of Software Bisque Paramount MX+ German equatorial mounts in one of the roll-off-roof observatories at New Mexico Skies. They operate autonomously using the software package *ACP Expert* by DC-3 Dreams. Bob Denny, DC-3 Dreams founder, was especially helpful in creating an efficient method for loading our observing plans into *ACP Expert*. Since we are imaging each field for a minimum of 4 hours (done in blocks of three 20-minute exposures), there are more than 16,000 observing plans with almost 50,000 sky exposures loaded into the system. And this doesn't include nightly flat-field calibration frames and dark frames made on a regular basis.

After preliminary testing, the survey became fully operational in early 2016, and very quickly it was clear that results were exceeding our expectations. We were capturing Hα nebulosity virtually unknown to amateur astrophotographers. But just as enough data were accumulating to begin assembling small mosaics, there was the devastating news that Dave had been diagnosed with an aggressive form of brain cancer. The disease took his life the following May. You can read more about Dave and his lasting impact on astronomy at **sites.middlebury.edu/mittelmanastrophotography**.

▲ The two modified Astro-Physics 130GTX survey telescopes (described in the accompanying text) are currently housed in one of New Mexico Skies's roll-off roof buildings on the outskirts of Mayhill, New Mexico, at an elevation of 7,300 feet (2,225 meters).

## Survey Results So Far

As of this past summer, the survey has completed at least 4 hours of exposure for more than a third of the sky (more than 13,000 square degrees) accessible from the New Mexico site, and we are approaching a total of nearly 25,000 square degrees that have been imaged with at least 1 hour of exposure. The results continue to exceed expectations. As many of the images accompanying this story show, the survey is recording Hα nebulosity in parts of the sky traditionally overlooked by deep-sky photographers. Most of it is too faint to have been targets in the days of emulsion-based astrophotography, but much of it is well within reach of imagers using modest digital equipment today.

Along the way we've spotted dozens of objects that we've yet to identify in existing catalogs. Some, such as a faint but clearly obvious planetary nebula in Pisces, appear to be true discoveries, while others await further research. We've also turned up fascinating objects that remain almost unknown outside of a handful of professional research papers. These are potential targets for the new generation of wide-field astrophotographers working with modern astronomical cameras under dark skies.

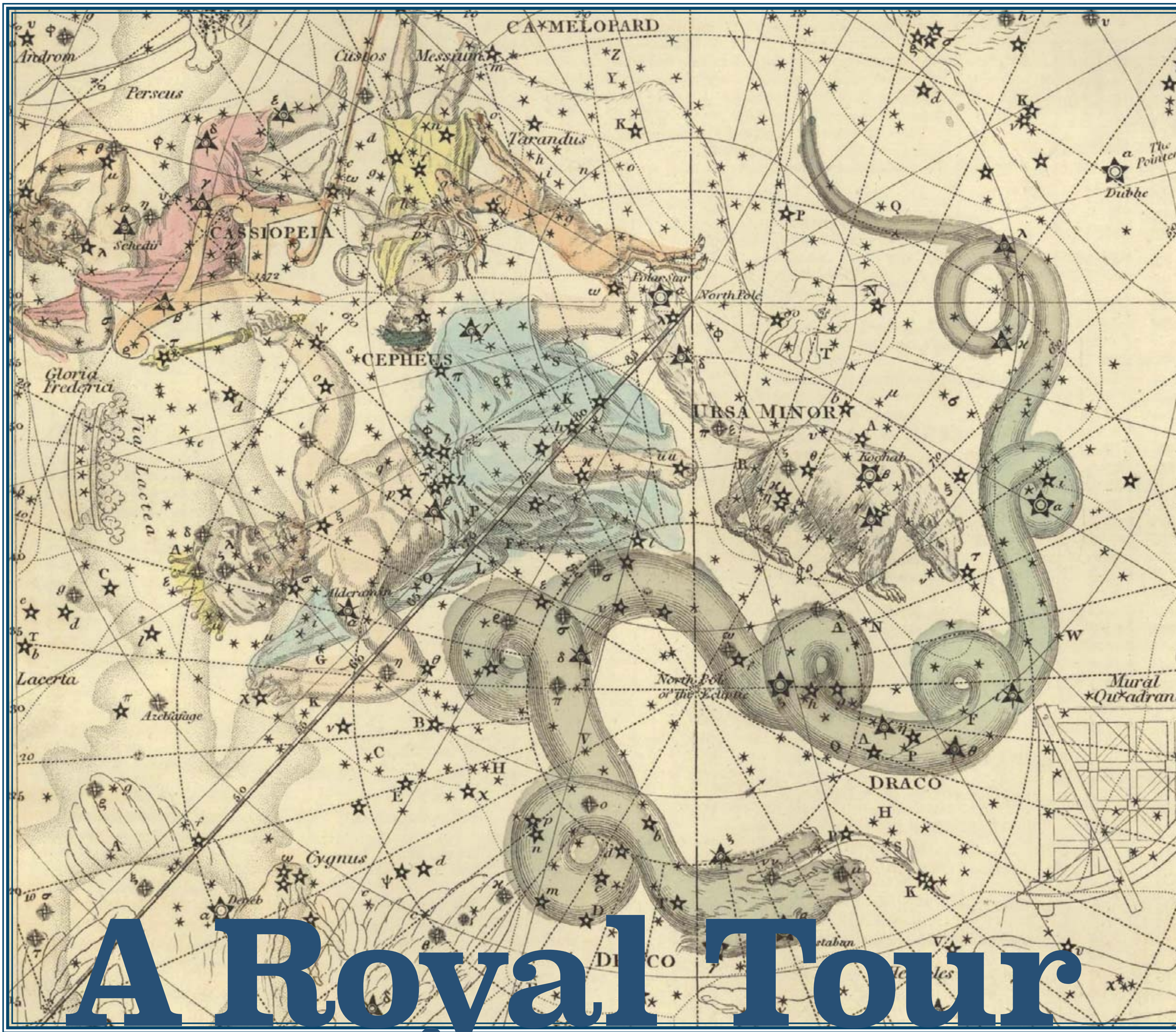
The survey has attracted the attention of professional astronomers, some of whom are using our data in their research. We believed this potential existed when we first considered doing a survey, but it's particularly rewarding to have it become a reality.

Once the survey is completed from the New Mexico site, we hope to follow through with our original plans of moving the telescopes to the Southern Hemisphere and finishing coverage of the entire sky. The southern Milky Way is especially rich in bright Hα nebulosity, so it's exciting to imagine what exists when we push to the limits we're reaching in the northern sky. Long-time astrophotographer John Gleason has been assembling deep Hα mosaics with a telescope in Australia (**astrobin.com/users/dvj**). And his work is fueling our enthusiasm for continuing the southern portion of the survey.

Our project has benefited from the support of many people. In addition to Bob Denny mentioned above, they include Roland and Marj Christen at Astro-Physics, the folks at Software Bisque, Mike and Lynn Rice and their team at New Mexico Skies, and especially the continuing support of the Mittelman family.

To see more of the survey results check out the website at **mdwskysurvey.org**. We continue to update the gallery section of the site with new material as we complete more coverage of the sky.

■ **DENNIS DI CICCO** began his career at *Sky & Telescope* in 1974, but his fascination with hydrogen-alpha nebulosity stretches back to the early 1960s.



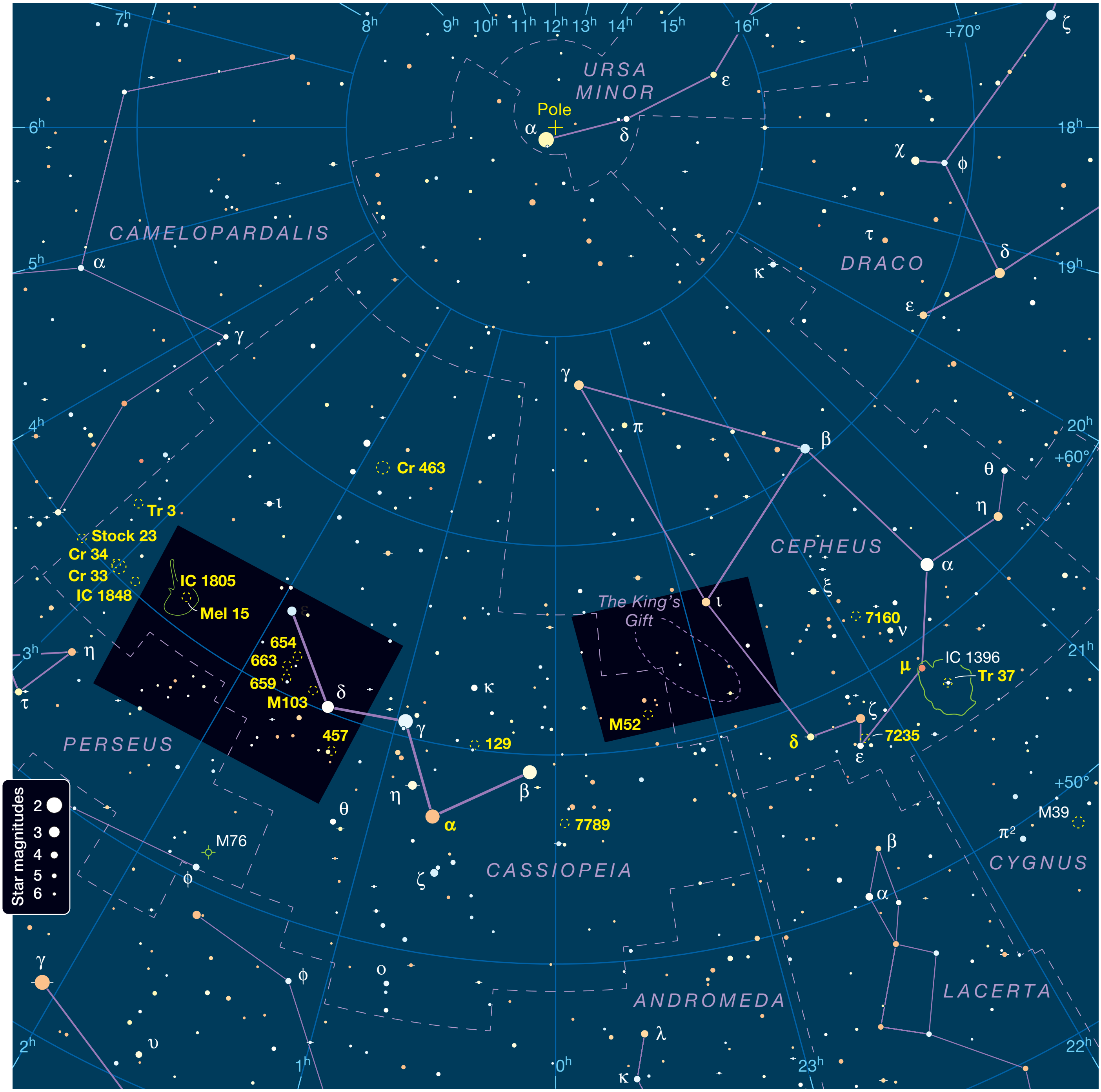

# A Royal Tour

Grab your binoculars to take a closer look at the overflowing coffers of the King and Queen of Aethiopia.

▲ **CELESTIAL CONGREGATION** Alexander Jamieson's *Celestial Atlas* was published twice in 1822, but the star maps in both editions were identical. Plate II depicted Cepheus with an upraised scepter and a crowned turban on his head, while Cassiopeia was shown seated on her throne. Nestled between the monarchs are representations of the now obsolete constellations Tarandus, the Reindeer, and Custos Messium, the Harvest Keeper.

ALEXANDER JAMIESON, *A CELESTIAL ATLAS* (1822) / UNITED STATES NAVAL OBSERVATORY LIBRARY / PUBLIC DOMAIN

In Greek mythology, Cepheus and Cassiopeia were the King and Queen of ancient Aethiopia and the parents of Andromeda. For boasting of her beauty, as well as that of her daughter, Cassiopeia was doomed by the god Poseidon to wheel around the pole star for eternity. Andromeda, even more unfortunate, was chained up as a snack for Cetus, the Sea Monster. Andromeda was rescued by Perseus, of course, but Cassiopeia still clings to her throne, following Cepheus


across the northern sky. That's a nice result for us, as these constellations are above the horizon nearly all year long from mid-northern latitudes. Poseidon must have been feeling lenient, since he allowed the royal couple to take their extravagant treasures with them into the heavens — as we're about to discover.

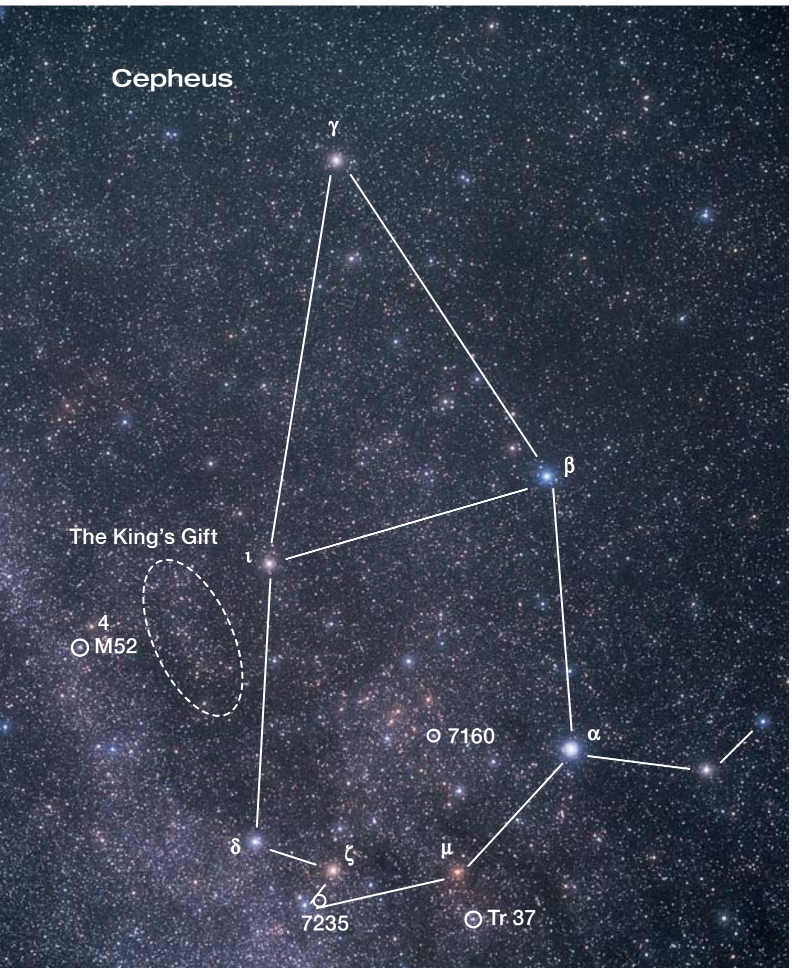
This is the fourth in a series of binocular tours of the Milky Way. In previous installments we covered the sky from Canis Major to Hydra (*S&T:* Dec. 2015, p. 32), Monoceros to Gemini (*S&T:* Mar. 2017, p. 30), and Perseus to Auriga (*S&T:* Jan. 2018, p. 60). As with the previous articles, I made the observations discussed here with 15×70 binoculars with a 4.4° true field of view. But almost all of these objects are rewarding at 10× or even 7×, and most will repay a visit with a telescope as well. Whatever instrument you have on hand, I'm certain that the celestial King and Queen have riches to match. So grab your favorite star-catcher and let's get going.

Cassiopeia is our ultimate goal, but we'll start with the more restrained adornments of her consort, Cepheus. Our launching point will be **Mu (μ) Cephei**, better known as

Herschel's Garnet Star. William Herschel described the star as having "a very fine deep garnet colour" in a 1783 paper, and it's indeed one of reddest stars visible to the naked eye. Mu Cephei is also one of the largest stars ever discovered. With a radius between 1,200 and 1,600 times that of our Sun, the Garnet Star would engulf the orbit of Jupiter if placed at the center of our solar system. This supergiant star is fusing helium to carbon, and in a few hundred thousand years it will blow itself apart in a supernova.

From death to birth: 1.5° south of Mu Cephei you'll find **Trumpler 37**, a very young star cluster. This sprawling field of suns is only 3 to 4 million years old, which means that our ancestors were making stone tools in Africa's Great Rift Valley when these stars were forming. At the center of the cluster, 6th-magnitude HD 206267 and 8th-magnitude HD 239729 form a nice binocular double. If you're under very clear, dark skies, see if you can pick out the gigantic but faint nebula IC 1396, in which Trumpler 37 is embedded.

▼ **A SIMPLE STRUCTURE** Though meant to represent a king, the stars of Cepheus could just as easily be used to build a house with a gabled roof. The riches here — Mu Cephei, Trumpler 37, NGC 7160, NGC 7235, and Delta Cephei — all reside in the lower story or cellar of this celestial domicile.




AKIRA FUJII

Scan from Trumpler 37 back past Mu Cephei and on for another 4° to find a tight, tiny cluster of stars: **NGC 7160**. The cluster is bright, at 6th magnitude, but very compact, with a diameter of just 5′ (arcminutes), so the individual stars are tricky to resolve even at 15×. So instead of zooming in, broaden out, and survey the sweep of bright stars scattered between Alpha (α) and Delta (δ) Cephei. This is the Cepheus OB2 Association, of which NGC 7160 is a part. Like other OB associations, Cepheus OB2 is full of hot, young, massive stars. The spiral arms of our galaxy are star factories, and Trumpler 37, NGC 7160, and the rest of Cepheus OB2 are the output of that ongoing process.

NGC 7160 lies about 2,600 light-years away, which is about the average for the brighter Messier, Caldwell, and NGC clusters. Our next target takes us farther out. Look just west of the line between Zeta (ζ) Cephei and Epsilon (ε) Cephei to find **NGC 7235**. NGC 7235 is about the same apparent size as NGC 7160 but much less bright, in part because it's about four times as distant at around 10,500 light-years. Whereas NGC 7160 — along with our own solar system — is part of the Orion Spur, NGC 7235 lies beyond, in the great Perseus Arm of the Milky Way. In comparing the two clusters, you're getting a glimpse of the larger structure of our galaxy.

While you're in the neighborhood and thinking about galactic structure, check out **Delta Cephei**, just 2.5° east-northeast of NGC 7235. Delta Cephei is a variable star, the prototype and namesake of the Cepheid variable class. As early as 1908, Henrietta Leavitt of Harvard College Observatory noted that Cepheid variables have a period-luminosity relationship, such that those with longer variability periods are intrinsically brighter than those with shorter periods. When Edwin Hubble observed Cepheid variables in the Andromeda Galaxy, this property allowed him to fix Andromeda's distance and thus establish that "spiral nebulae" are other galaxies, and not features inside the Milky Way. Delta Cephei is also of interest as a charming double star for binoculars and small telescopes. The secondary, a blue-white main-sequence star, lies 41″ (arcseconds) south-southwest of the yellow supergiant primary — a tight split for anything under 15×.

The next stop on the tour has no formal name that I've been able to discover, but in my notes I call it **"the King's Gift"**. Halfway between Iota (ι) Cephei and 4 Cassiopeiae you'll find a dense stream of stars running northeast to southwest, crowding an area about 5° long and 2° wide. In reality this is a group of unrelated stars scattered between 100 and 1,500 light-years away, but in mind it's a trove of jewels that Cepheus is presenting to Cassiopeia, hence my nickname for it.

It's time for us to attend the Queen as well, and our first stop in Cassiopeia is **M52**. This charming 7th-magnitude open cluster stands out as a distinctly bright patch in the dense Milky Way starfield. See if you can pick out a bright yellow *F*-type star near the western margin of the cluster.

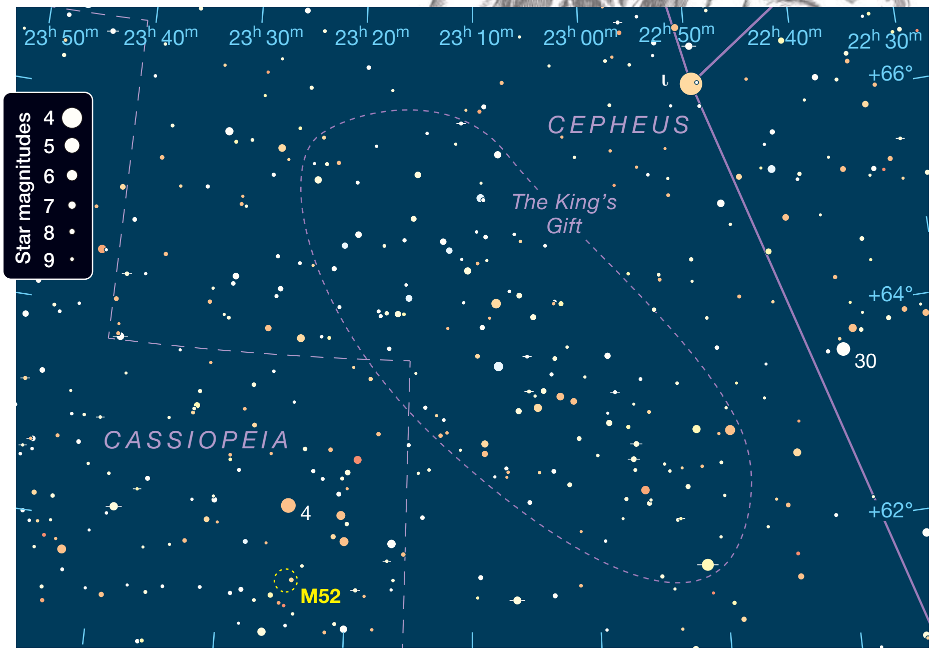
M52 has an estimated age of 158 million years, meaning that we're seeing stars that formed in the Late Jurassic Period, when *Allosaurus*, *Diplodocus*, and *Stegosaurus* roamed the American West.

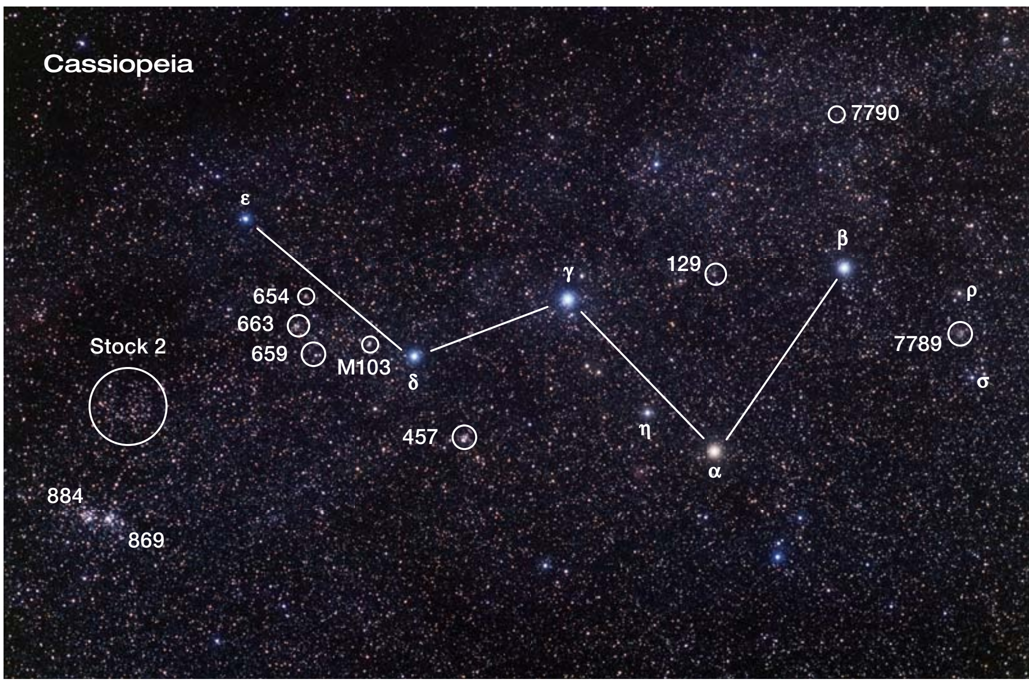
Now we'll take a small step in space, but a giant leap in time. A bit more than 6° southeast of M52, halfway between Rho (ρ) and Sigma (σ) Cassiopeiae, you'll find the sprawling wonder of **NGC 7789**. The cluster was discovered by Caroline Herschel in 1783, and it's also known as "Caroline's Rose" for its concentrically-curving loops and chains of stars. This is no bloom of youth, however — NGC 7789 is 1.7 billion years old, dating to a time when microbial mats were cranking out Earth's early oxygen atmosphere.

We'll follow the zig from M52 to NGC 7789 with a zag 5.5° to the northeast, to the bright cluster **NGC 129**. My early observing notes read, "compact, many stars, probably better than M103 under dark skies." Indeed, one of the enduring mysteries of Cassiopeia is how Charles Messier and his assistant, Pierre Méchain, managed to find nice but unexceptional clusters like M52 and M103 while overlooking so many brighter showpieces. NGC 129 was discovered by William Herschel in 1788, just five years after his sister discovered her eponymous rose. See if you can tease out a perfect triangle of 9th-magnitude stars at the center of the cluster.

We'll now drop a few degrees south to visit Schedar, or **Alpha Cassiopeiae**. Schedar is Arabic for "chest," and this queen's heart holds a secret: an 8th-magnitude companion 69″ to the west. The two form an optical double, only coincidentally aligned as seen from Earth, rather than a true binary. Schedar itself is a *K*-class orange giant. At 4–5 times the mass of the Sun, the star is destined to blow off its outer layers and form a planetary nebula before going into a long retirement as a white dwarf.

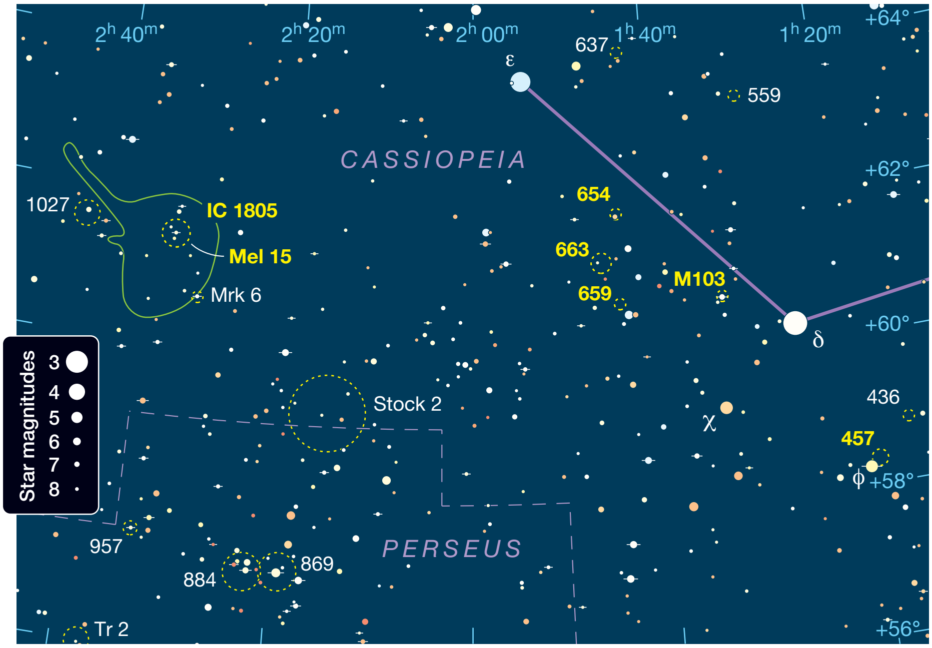
Our next stop is a perennial favorite for binocular and telescopic observers alike: **NGC 457**, the Owl or ET Cluster.




▶ **W IS FOR OPEN CLUSTER** About 106 of the galaxy's 1,100 open clusters lie within the bounds of Cassiopeia. The familiar W asterism (or M, if you prefer) of Cassiopeia makes a good starting point, as several clusters, including M103, NGC 663, NGC 654, and NGC 659, sparkle near her legs.

CASSIOPEIA IMAGE: AKIRA FUJII; CONSTELLATION DRAWING: JOHANNES HEVELIUS, *FIRMAMENTUM SOBIESCIANUM* (1687)




is **NGC 663**, full of hot, young *B*-type stars that are less than 10 million years old. Flanking NGC 663 are **NGC 654** and **NGC 659**, and a fourth cluster, **M103**, lies to the west, very close to Delta Cassiopeiae. We're looking quite far out here, between 6,300 and 8,200 light-years. NGC 663 appears biggest and brightest of the four because it is; with a diameter of 30 light-years it's roughly three times larger than any of the others.

Now let's compare NGC 663 with a similarly sized cluster that lies much closer. About 8° north of Epsilon you'll find **Collinder 463**. At almost 1° across and 5th magnitude, it's big and bright — and close, at only 2,300 light-years. Cr 463 lies in our own Orion Spur, and NGC 663 more than three times farther away, in the Perseus Arm. Like NGC 7160 and NGC 7235 in Cepheus, comparing these clusters lets you experience galactic distances for yourself.

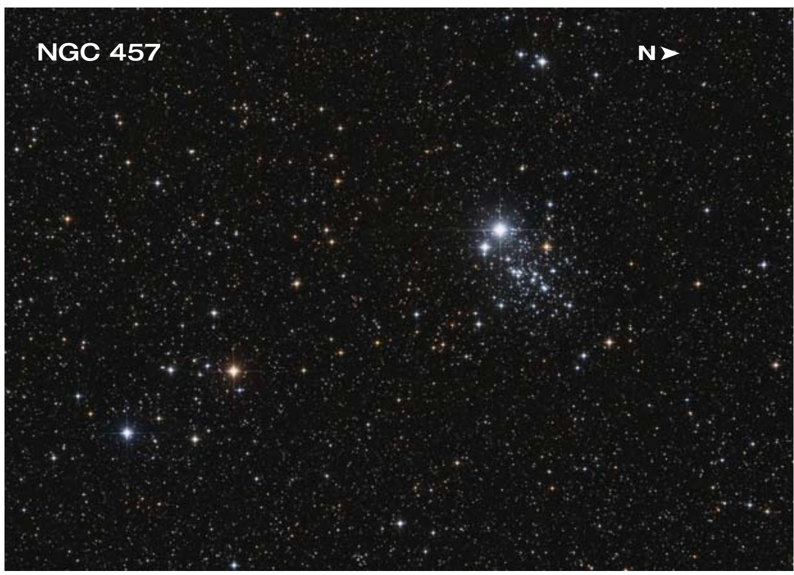
The traditional illustration of Cassiopeia seated on her throne ends with her feet just east of 3rd-magnitude Epsilon. But we're not quite done yet — a series of bright clusters runs to the east, and I like to imagine it as the long train of the queen's gown. We'll start with **IC 1805**, the Heart Nebula, and its embedded open star cluster, **Melotte 15**. As with Trumpler 37, we're looking here at bright young stars, whose intense radiation illuminates the remnants of the nebula that produced them. The same process is going on just a few

If we imagine the bright pair of Phi$^1$ ($\varphi^1$) and Phi$^2$ Cassiopeiae as eyes, the stars of the cluster form the body and limbs of the famous movie alien, or perhaps a very emaciated owl. Phi$^1$ and Phi$^2$ are separated by a generous 134″, making them an easy split even at low magnification. Both stars are aging, yellow supergiants, close in space to the cluster but probably not actual members.

We come now to one of the densest stretches of Cassiopeia for binocular observers. Southeast of the line between Delta and Epsilon Cassiopeiae is a gaggle of bright stars with four open clusters strewn among them. The biggest and brightest

▼ *Left:* The open cluster M52 lies 40 arcseconds south-southwest of Rho Cassiopeiae. Radiation from M52 takes about 158 million years to reach Earth, meaning that the light we see tonight left the cluster in the Late Jurassic Period. *Right:* Whether you see a cute extraterrestrial or an owl on the wing is up to your imagination, but either way, the pair of bright stars on the southeast edge of NGC 457 makes it easier to find this cluster 2° south-southeast of Delta Cas.

M52: STOCKTREK IMAGES / GETTY IMAGES; NGC 457: LORAND FENYES / STOCKTREK IMAGES / GETTY IMAGES

degrees east, where the young open clusters **IC 1848**, **Cr 33**, and **Cr 34** light up the Soul Nebula. Together, the Heart and Soul and their embedded clusters show the galaxy recycling itself, turning the ashes of dead stars into the blazing hearts of new suns.

To see an older product of that same process, look 3° northeast to find **Trumpler 3**, a tight little swarm of lights cupped inside a curving arc of brighter stars, like sugar in a spoon. Trumpler 3 is only 2,200 light-years away, one of our neighbors here in the Orion Spur. With an estimated age of 70 million years, it's still what astronomers consider a "young" open cluster, even though its light comes to us from the time of *T. rex* and *Triceratops*.

Our last stop is the cluster **Stock 23**, also known as Pazmino's Cluster, right on the constellation boundary with Camelopardalis, the Giraffe. Stock 23 might be a chance grouping rather than an open cluster, but whatever it is, it escaped detection for a long time. The first to note it was professional astronomer Jürgen Stock, who logged it around 1957, and it didn't come to widespread amateur attention before John Pazmino popularized it in 1977. This comparatively recent discovery illustrates two of my favorite facts about the sky: It's very big and very full. We're not going to run out of things to find and enjoy anytime soon.

As ever, this has been a galloping tour through just a handful of the best and brightest objects in Cepheus and Cassiopeia. Many more await, and I strongly suspect that some of them have yet to be discovered. I hope that you'll return to pay homage to the celestial King and Queen, and I'm certain that they'll richly reward your attention.

■ Cassiopeia was the first constellation Contributing Editor **MATT WEDEL** learned, and he still thinks of it as his celestial home base.

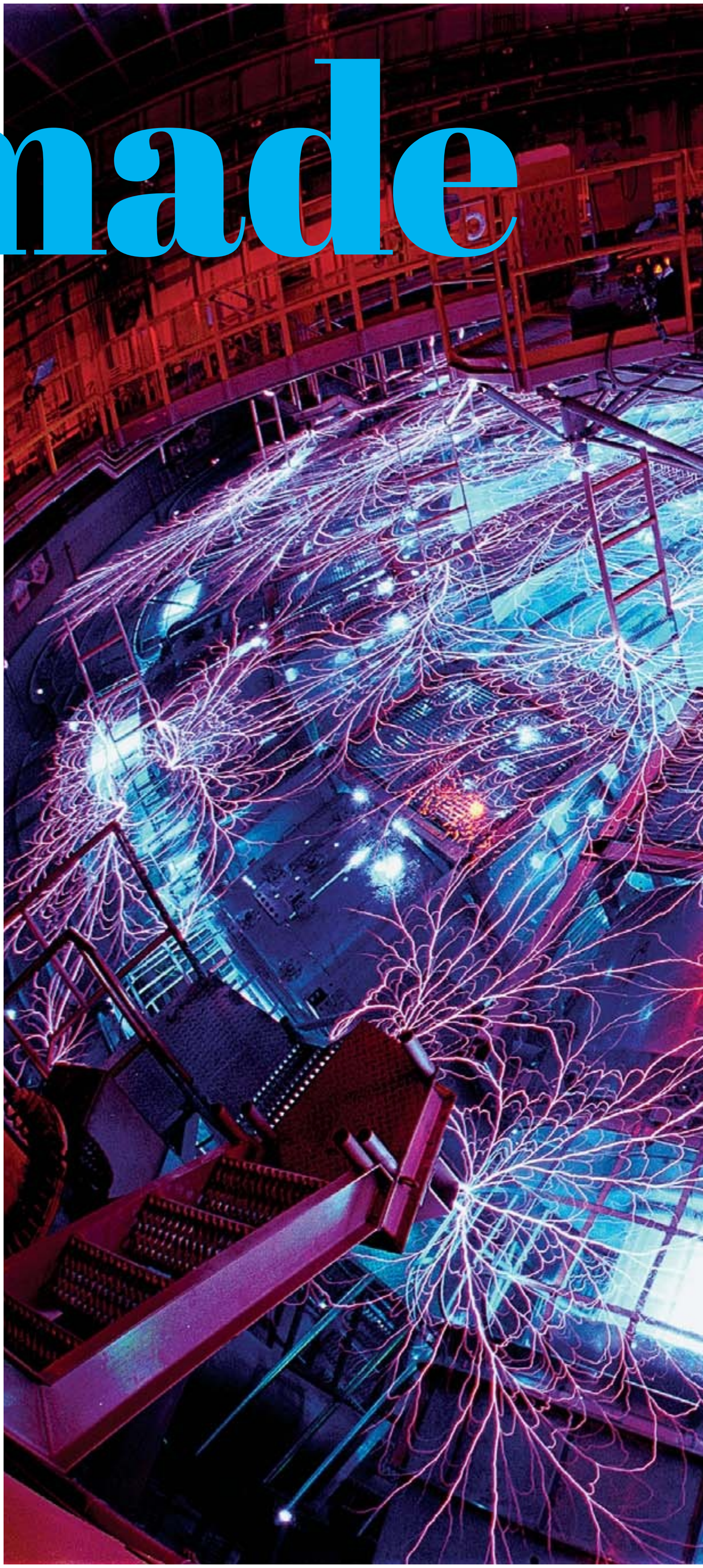
## Targets in Cepheus and Cassiopeia

| Object | Type | Mag(v) | Size | RA | Dec. |
|---|---|---|---|---|---|
| Mu Cephei | Supergiant | 3.4–5.1 | — | $21^h\ 43.5^m$ | +58° 47′ |
| Trumpler 37 | Open cluster | 3.5 | 90′ | $21^h\ 39.0^m$ | +57° 29′ |
| NGC 7160 | Open cluster | 6.1 | 7′ | $21^h\ 53.7^m$ | +62° 36′ |
| NGC 7235 | Open cluster | 7.7 | 6′ | $22^h\ 12.4^m$ | +57° 16′ |
| Delta Cephei | Cepheid variable | 3.5–4.4 | — | $22^h\ 29.2^m$ | +58° 25′ |
| The King's Gift | Asterism | — | 2° × 5° | $23^h\ 07.9^m$ | +64° 13′ |
| M52 | Open cluster | 6.9 | 13′ | $23^h\ 24.8^m$ | +61° 36′ |
| NGC 7789 | Open cluster | 6.7 | 16′ | $23^h\ 57.4^m$ | +56° 43′ |
| NGC 129 | Open cluster | 6.5 | 12′ | $00^h\ 30.0^m$ | +60° 13′ |
| Alpha Cas | Giant | 2.2 | — | $00^h\ 40.5^m$ | +56° 32′ |
| NGC 457 | Open cluster | 6.4 | 13′ | $01^h\ 19.6^m$ | +58° 17′ |
| NGC 663 | Open cluster | 7.1 | 16′ | $01^h\ 46.2^m$ | +61° 14′ |
| NGC 654 | Open cluster | 6.5 | 5′ | $01^h\ 44.0^m$ | +61° 53′ |
| NGC 659 | Open cluster | 7.9 | 6′ | $01^h\ 44.4^m$ | +60° 40′ |
| M103 | Open cluster | 7.4 | 6′ | $01^h\ 33.4^m$ | +60° 39′ |
| Cr 463 | Open cluster | 5.7 | 57′ | $01^h\ 45.8^m$ | +71° 49′ |
| IC 1805 | Emission nebula | 18.3 | 150′ | $02^h\ 33.4^m$ | +61° 27′ |
| Melotte 15 | Open cluster | 6.5 | 20′ | $02^h\ 32.7^m$ | +61° 27′ |
| IC 1848 | Open cluster | 6.5 | 18′ | $02^h\ 51.1^m$ | +60° 25′ |
| Cr 33 | Open cluster | 5.9 | 39′ | $02^h\ 59.3^m$ | +60° 24′ |
| Cr 34 | Open cluster | 6.8 | 24′ | $02^h\ 59.4^m$ | +60° 34′ |
| Trumpler 3 | Open cluster | 7.0 | 15′ | $03^h\ 11.8^m$ | +63° 15′ |
| Stock 23 | Open cluster | — | 29′ | $03^h\ 16.2^m$ | +60° 07′ |

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

 by Liz Kruesi

# Lab-made Stars



After centuries of reaching up to study the universe, scientists are making starstuff here on Earth.

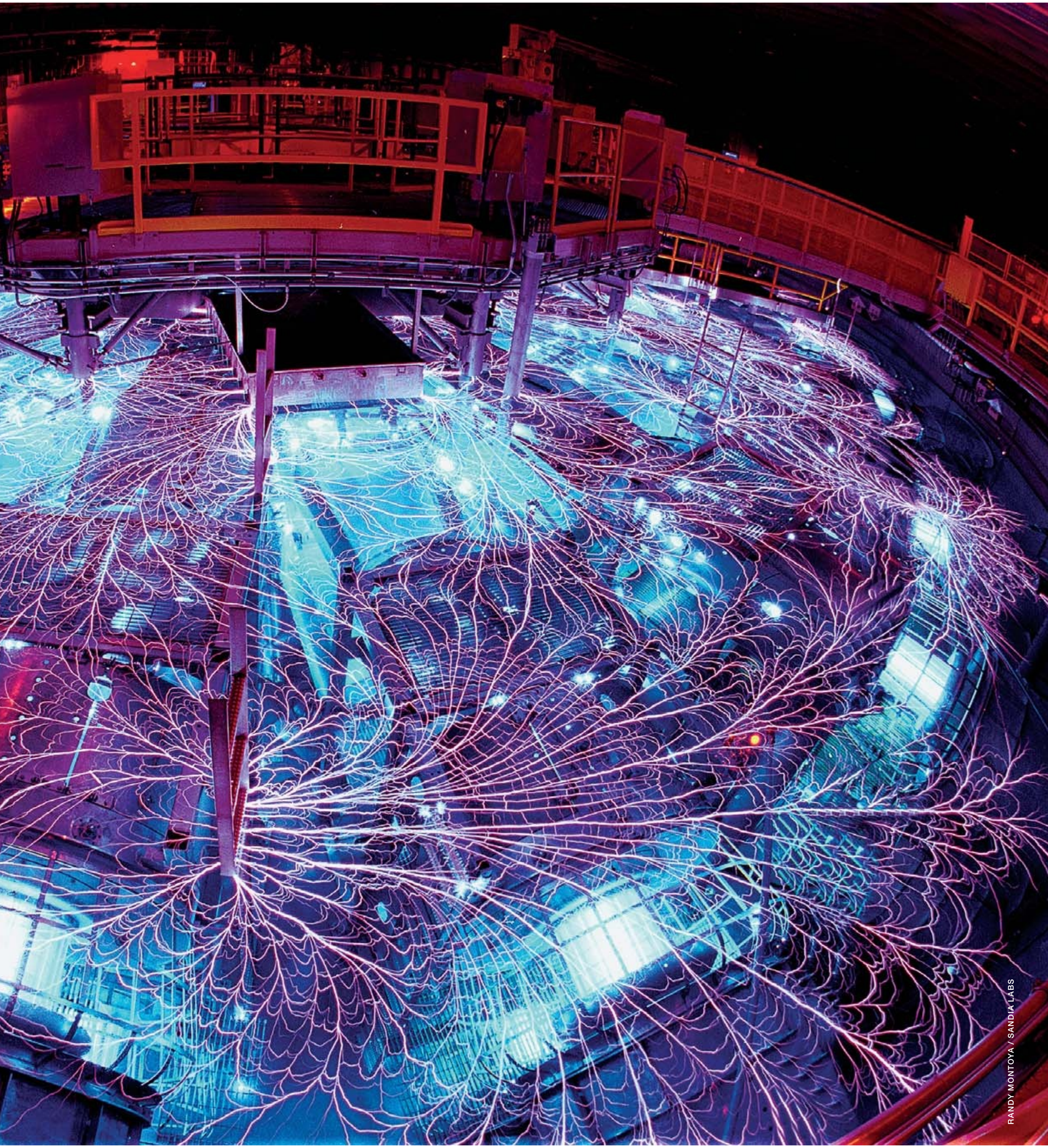
On April 14, 2010, a piece of a star lit up at a laboratory in Albuquerque, New Mexico. For more than 100 nanoseconds, the material, heated by a blast of X-rays, mimicked the ionized gas at the surface of a white dwarf star — in temperature and, more importantly, in density. The following year, an iron-magnesium foil converted to plasma for three nanoseconds at even higher temperatures and densities, mimicking the conditions that occur within our Sun. The goal was to test the ability of iron atoms deep inside the Sun to absorb the radiation produced at the core.

Every other area of science has a way to experimentally test theories. A physicist changes the magnetic field applied to a superconducting material to test how the field affects the material's properties. A geneticist hypothesizes that a particular gene affects a certain trait and studies mice with and without it. Experimental science is built on humans altering one variable while controlling others and observing what happens.

But while the field of laboratory astrophysics has been around for decades, originally to aid NASA space missions, astronomy overall has long been a complex mix of observations, theoretical predictions, and (more recently) computer simulations. Astronomers have always had to find their subjects in the cosmos, not the lab — stars of different colors, ages, and sizes, for example — and piece together how they relate to one another. They could work through the theory, but the only way to check the details was to use an observatory to detect examples.

The last decade has seen a new path. Since 2010, researchers have mimicked the stuff of stars dozens of times at

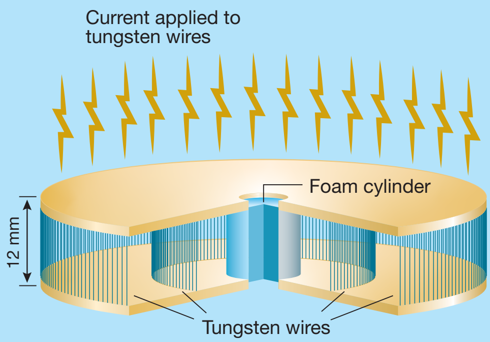
▶ **SPARKS FLY** Excess energy escapes from the huge pulse traveling through the Z machine to its target.



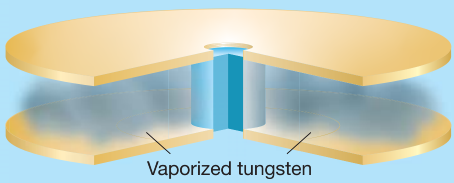
RANDY MONTOYA / SANDIA LABS

**HOW THE Z MACHINE WORKS** Hidden inside a vast vacuum chamber surrounded by a network of capacitors sits a tiny spool with which scientists recreate stellar plasma.

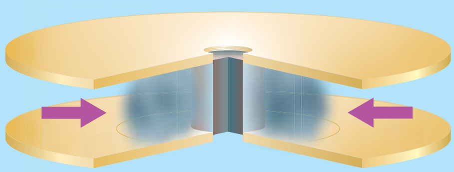
**1.** **A small cylinder threaded with tungsten wires waits in the Z machine.**



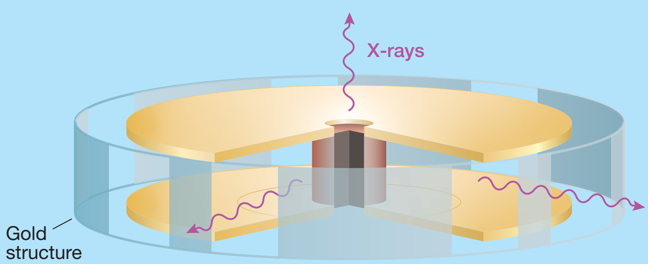

**2.** **A current surge through the wires vaporizes the tungsten. The plates above and below keep the plasma from expanding vertically.**




**3.** **The magnetic field created by the current forces the plasma to collapse inward, where it collides with a foam core.**



**4.** **The shock heats the foam, producing X-rays. These escape through holes in the gold structure around the target and hit experiments set in their path.**




GREGG DINDERMAN / S&T

Sandia National Laboratories' Z machine and other facilities like it. These studies are changing how astronomers parse the details of stars, by creating conditions that are identical to those found in stellar sites. And some things aren't matching up with expectations.

## A Flash and a White Dwarf

Until 2009, when Sandia physicist Jim Bailey visited the University of Texas in Austin to talk about his work, astronomers Don Winget and Mike Montgomery hadn't yet considered how laboratory experiments could aid their research. The UT astronomers study white dwarfs, the end state of most stars (including our Sun). But during Bailey's visit, Winget, Montgomery, and their graduate student Ross Falcon all independently looked at his data and realized that the plasma created at the Z machine looked familiar. Each of the three of them had the same thought, says Winget: "Holy crap, these really are white dwarfs." And that gave them an idea.

A white dwarf is what is left over after a normal star burns its inner fuel — first fusing hydrogen into helium, then helium to carbon and some other elements — and pulses off its outer gas layers. The remaining remnant is compact, about ⅔ of the mass of our Sun crammed into a sphere the size of Earth. It's typically made of carbon and oxygen with some surrounding leftover helium and hydrogen.

That the Sun will eventually become a white dwarf is an important enough motivation for understanding these stellar corpses. But they also contribute to astronomy in another way. White dwarfs that accumulate material from companions can become massive enough to undergo runaway nuclear fusion and blow up. The resulting Type Ia supernova is a brilliant flash that astronomers can see across vast distances and use to measure how fast our cosmos is expanding. Knowing white dwarfs' properties — their masses, their brightnesses, and how they work — is crucial to understanding the scale of our entire universe (*S&T:* June 2019, p. 14).

It turns out that astronomers who used white dwarfs' spectra to estimate the stars' masses had been underestimating those masses — the stars' most basic characteristics. "How wide their lines are," explains Montgomery, "gives us the surface gravity," and that provides a proxy for the star's mass. By mimicking in a lab the same densities and temperatures of that surface plasma and studying the lab version's spectrum, the researchers then had a benchmark to compare with light from distant white dwarfs. And they realized the interpretations were way off.

To create a white dwarf in a lab, hydrogen, helium, and carbon need to be bathed in 15,000-kelvin X-ray radiation. Here's how that works. When Sandia's Z machine is turned on, devices that hold charge, called capacitors, power up. All at once, they instantaneously release that charge — the scientists call it a *shot* — and a series of well-insulated cables directs the charge into a vacuum chamber and toward a cylinder the size of a spool of thread. Within that cylinder are hundreds of tungsten wires, each 12 mm long and thinner than a human hair. The current runs through those tungsten wires and heats them up so quickly that they vaporize into a hot, ionized gas — a plasma. That same current produces a magnetic field that forces the tungsten plasma to collapse toward the cylinder's central axis, the inner shaft of the spool. There sits a 6-mm-diameter piece of hydrocarbon foam. As the tungsten plasma falls toward the cylinder's axis, it runs into the foam. The impact generates X-rays.

It's these X-rays that researchers use to heat their experiments. Surrounding the tungsten-threaded spool is a gold cylinder, with several openings through which radiation can escape. The scientists place their sample in front of one of those openings. "What we want is for the X-rays to just stream through our sample," says Bailey. The radiation heats whatever the researchers set in its path. In some experiments, to keep the material from expanding as its temperature rises, it's tamped down, creating densities like those in stars.

UT's Center for Astrophysical Plasma Properties (CAPP) runs four or five experiments during each shot. For Winget and Montgomery's studies of white dwarf material, they set up a travel-mug-size vessel of gas between 30 and 35 cm away from the X-ray source. The X-rays stream into that gas cell and slam into the cell's gold back wall, which in turn also radiates X-rays, to bathe the sample fully in high-energy radiation. The scientists collect data on the wavelengths the gas absorbs and emits and what those spectral patterns look like.

They then compare the shapes of the spectral lines created in the lab to those from white dwarf stars. Interactions among particles in the plasma affect the shapes of the line widths, and so from the spectra they can learn how many particles are in a given volume. As the densities increase to stellar values, atoms are perturbed, and the width of the material's spectral lines changes.

The widths they're finding in their experiments differ from those seen in observations. "It's turning out that the theory is wrong by a fair amount," says Montgomery.

The higher, lab-measured density correlates directly to a higher measure of surface gravity, and thus mass, than astronomers had expected. "It means the masses of the white dwarfs are a little bigger," adds Winget — 10% to 20% bigger than the old theories predicted, actually. More massive stars cool more slowly, and temperatures are part of how observers calculate a white dwarf's age. Not only will the revised theory help astronomers better interpret the dwarfs they observe, he says, but it will help physicists understand what happens to matter at these extreme densities.

## Puzzling Interior

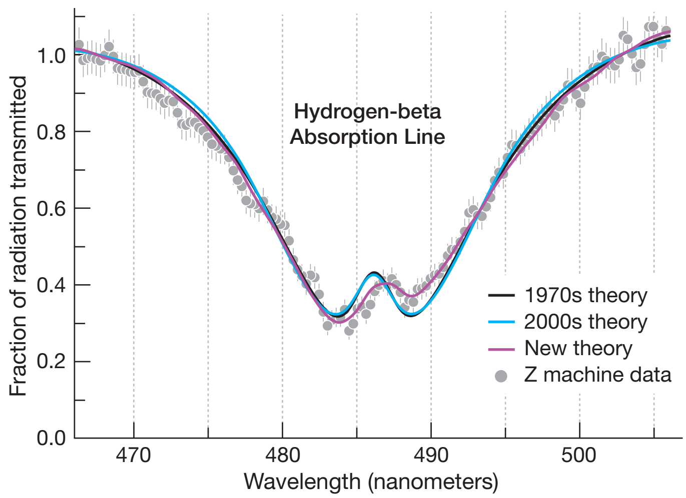
While Winget and Montgomery test the physics of plasma at white dwarf surfaces, Bailey's own work is to understand specifically how radiation propagates through a star's material. His experiments replicate conditions matching those deep inside the Sun, at the boundary where an inner region in which energy travels as radiation meets the roiling outer region, where convective cells of plasma carry energy to the

**If you increase the total opacity value of a star by, say, 10%, that means the star is 10% less luminous and therefore will live 10% longer.**

surface. The stellar characteristic he's studying is something called *opacity*, which describes how much radiation is blocked or absorbed by intervening matter.

"High opacity," says astrophysicist Aldo Serenelli (Institute of Space Sciences, Spain), "is like an insulating blanket." A star whose material has high opacity traps the heat from the star's furnace. A low opacity means a lot of that radiation can pass through the material. (A glass window, for example, has low opacity to visible light but high opacity to some ultraviolet wavelengths.)

Some chemical elements absorb or trap radiation more than others, which means a star's chemical composition affects how much light makes it through the stellar layers and to the surface. That also means a star's *luminosity* — the amount of energy it emits — relates to its ingredients' opacities. Therefore, says Serenelli, opacity affects how fast the star can burn its fuel and how long it lives. If you increase the total opacity value of a star by, say, 10%, that means the star is 10% less luminous and therefore will live 10% longer. The opacities are by far "the most sensitive aspect" in Serenelli's simulations of stellar interiors.




▲ **PLASMA SPECTRUM** The UT Austin team found that the hydrogen plasma they created with the Z machine (data points) did not absorb radiation quite the same way as previous theories (black and blue lines) had predicted it would. The discrepancy corresponds to a 10% to 20% difference in white dwarf masses, which could in turn change estimates of these stars' ages by up to a billion years.

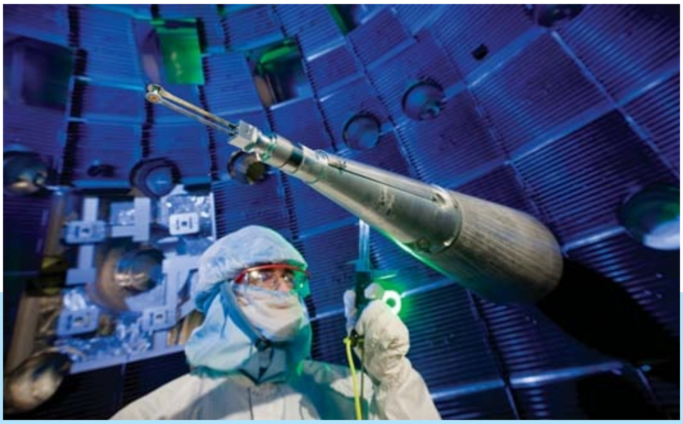
ROSS FALCON

Opacity is fundamental to how stars work, but our understanding of it is also incomplete. "All the opacities that we have been using since the dawn of stellar evolution [theory] rely completely on theoretical calculations, which have no experimental tests," says Serenelli, who has studied stars and their interiors for 20 years.

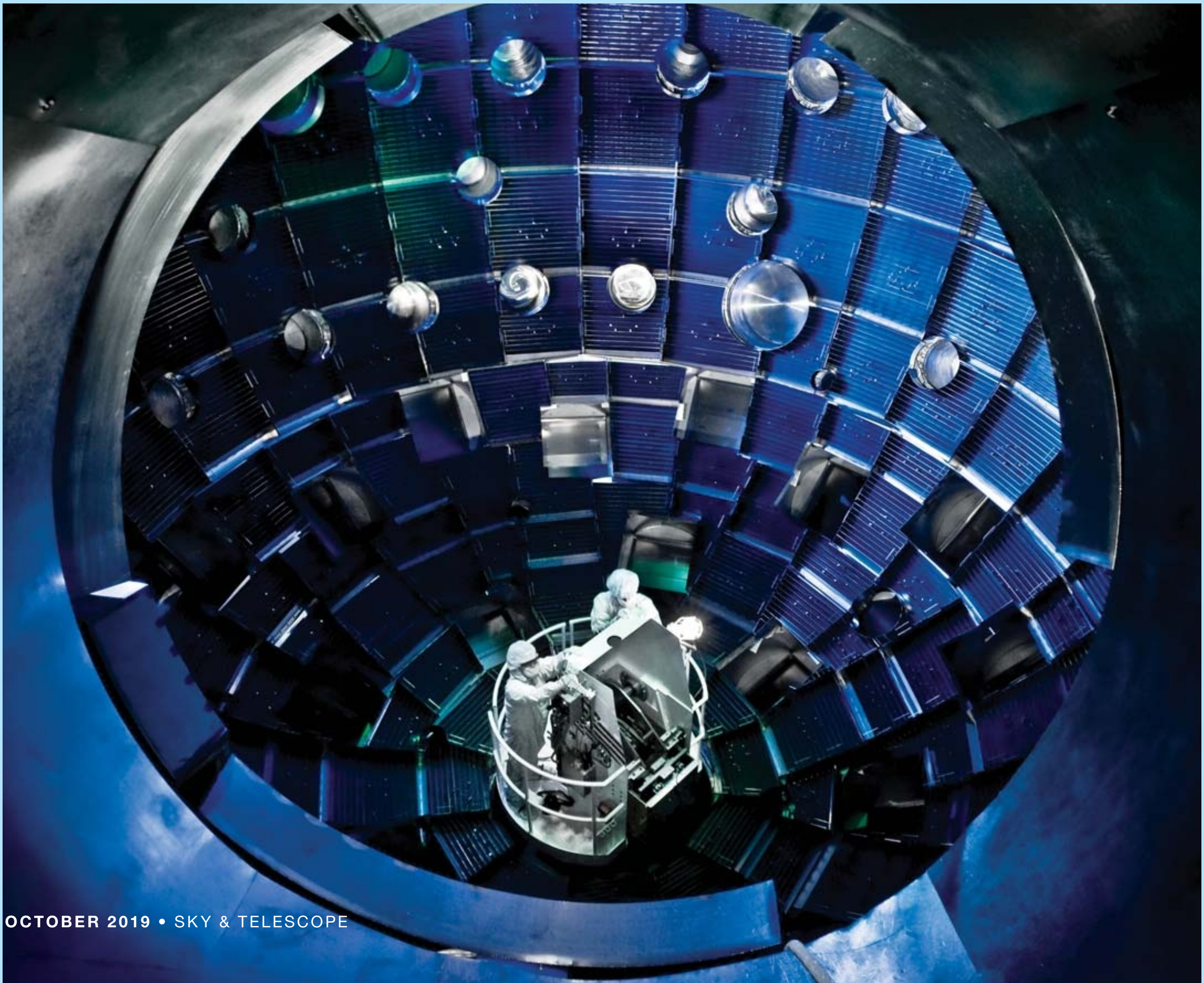
That is, until Bailey and colleagues began their work.

Serenelli has followed Bailey's opacity measurements since their results were published in a January 2015 *Nature* paper. That work revolved around the element iron. The researchers chose this element for several reasons. While stars are predominately hydrogen, helium, and other lighter chemical elements, heavier ones such as iron *are* also present. Hydrogen and helium easily ionize in the high-temperature and high-density environments inside a star, but iron has far more electrons and holds on to some of them. An atom absorbs radiation via its electrons, which transition to another energy level when they encounter a photon of the right wavelength. Because it still has so many electrons, an iron atom absorbs radiation more readily than lighter elements, and thus it has a major effect on the opacity of the Sun. In fact, iron accounts for about one-quarter of the opacity at the boundary layer between the radiative and convective zones.

Bailey's team uses the same shot at the Z machine as the white dwarf work, but the researchers place their foil target



**NIF** In the National Ignition Facility's roomy chamber, 192 lasers impinge upon a tiny target, with an accuracy equivalent to the diameter of a human hair. A positioning arm *(right)* holds the target.



LAWRENCE LIVERMORE NATIONAL LABORATORY (2) closer to the X-ray source — right on top of one of the holes in the cylinder, in fact — so that it reaches higher temperatures. ("They are closer to the campfire," quips Montgomery.)

Encasing the foil is a tamping material, to keep the super-heated-foil-turned-plasma from expanding. As the temperature and pressure rise, the plasma reaches a density similar to that within the Sun.

Bailey and his colleagues found that, depending on the specific wavelength measured, iron opacities were off from theory by anywhere between 30% and 400%. "Our experiment can't be matched by any known theory," he says. "We spent the next three years doing more experiments and doing every test that we could think of . . . to try to see if we could find anything wrong with the experiment." But they found no errors in their setup.

Bailey and his colleagues have now turned for insights to two elements on either side of iron on the periodic table, chromium and nickel, to see if the slight differences in the configurations of their electrons from that of iron change the results. The preliminary findings, published this year, suggest there's indeed something particular about iron: Although the data for chromium and nickel do disagree with the models, the discrepancy is not as severe. It's possible that current theoretical models aren't able to understand how the iron atoms' configurations of bound electrons are affecting radiation transport.

## Focus All the Lasers

About a thousand miles away, another powerful machine at another Department of Energy laboratory creates star-like conditions to test a crucial process: the nuclear reactions occurring in stellar cores.

The fact that a DOE laboratory is studying nuclear fusion isn't surprising. After all, both Lawrence Livermore National Laboratory (LLNL) and Sandia are firmly rooted in nuclear science as it relates to our country's security. Much of LLNL's laboratory data wasn't declassified and made accessible to civilian scientists until the early 1990s, four decades into its history. Now, the LLNL's National Ignition Facility (NIF), the world's largest and most energetic laser, opens 10% of its time to researchers wanting to do basic science. Bruce Remington (LLNL) leads this Discovery Science Program and says most of the projects pertain to astrophysics and planetary science.

NIF and Z are two of the most-used facilities for laboratory astrophysics work, because they're both able to reach the conditions of starstuff. "The details of how they heat and compress the matter are different," says Remington, "but the physics discussions are very similar."

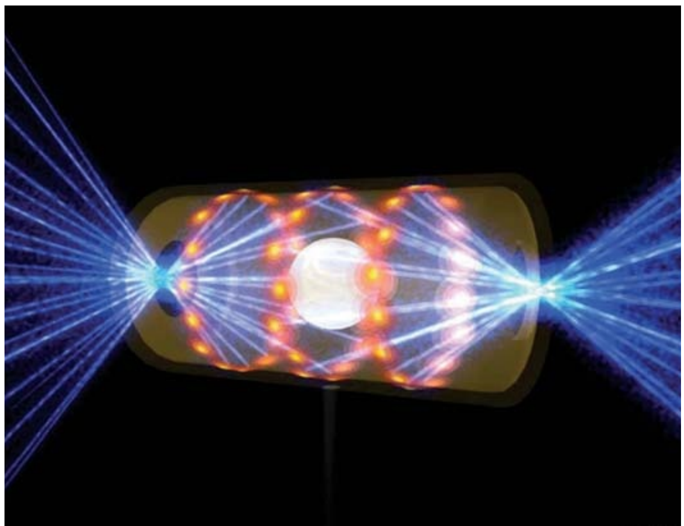
When NIF switches on, 192 lasers aim at a point at the center. What's at that center depends on what researchers want to zap. Sometimes the lasers focus directly on a spherical shell only a few millimeters wide, and other times that capsule is within a cylinder and the cylinder itself receives the radiation. In both cases, when the energy hits the surface of that shell, it vaporizes the shell's outer surface, which then expands rapidly. To conserve momentum, the inner surface collapses and compresses whatever is inside the shell.

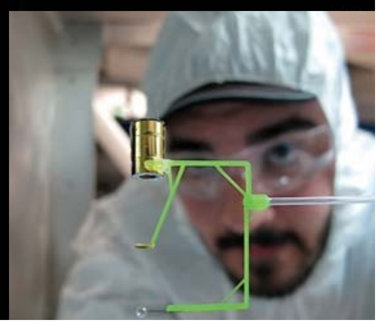
For nuclear astrophysicist Maria Gatu Johnson (MIT), inside that shell is helium-3 gas. (He-3 is a helium nucleus that's missing a neutron.) She and her colleagues are investigating a very specific reaction, which provides nearly half the energy in our Sun right now. They fill a tiny glass shell with He-3 and place it in the center of the 10-meter diameter NIF target chamber. In some experiments, that shell is 1.6 mm wide, and in others it's 3 mm wide. When the lasers hit the capsule's surface with about 2 megajoules of energy (the energy of a 2-ton truck hitting you at 45 m/s, or 100 mph), the gas collapses into a dense plasma and ignites. A burst of nuclear reactions lasting just a few nanoseconds follows.

The researchers capture the protons that stream from those reactions using a specialized detector placed 10 cm from the outburst. From the measured data, they can calculate the reaction rate, which tells them about the fusion outcomes, like the generated energy, the formed elements, and the emitted neutrinos.

## Evolve a Blast

Laboratory astrophysics projects at NIF aren't exclusively focused on nuclear reactions. Other researchers use the imploding plasma as a scaled-down model of what's happening in a supernova, to test how those stellar explosions work. Even though observational astronomers have found





**TINY TARGETS**
In the NIF's setup, laser beams enter through a capsule, called a *hohlraum*, and compress and heat the target within. Scientists modify the exact setup depending on what they're testing.

LAWRENCE LIVERMORE NATIONAL LABORATORY (2) thousands of exploding or exploded stars in the cosmos, theoretical astronomers can't yet perfectly simulate what nature provides. The computer models tend to be too symmetric and don't match observations of what Remington says looks like "a smeared-out porcupine." That's because there's a lot more going on in a supernova than what even today's supercomputers can handle.

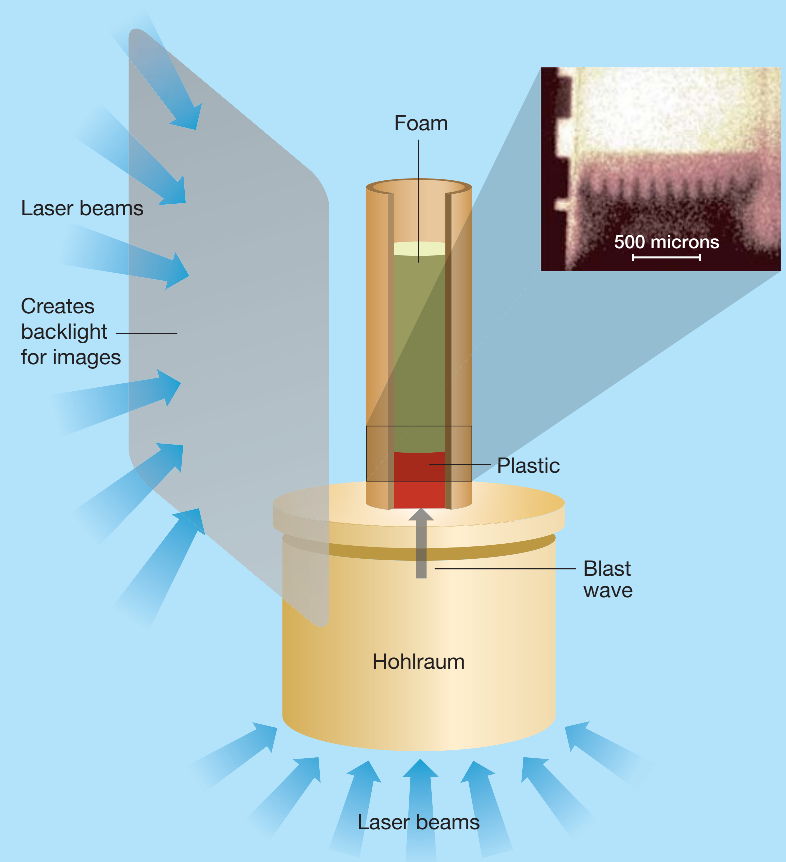
But in laboratory astrophysics, researchers can drill down to some of the detailed physics questions. For example, when modeling many astrophysical objects, including supernova explosions, astronomers often invoke fluid dynamics. When two different fluids — or plasmas, as is the case often in astronomy — meet and mix, they don't do so calmly. Instead, they're turbulent. Understanding how those instabilities evolve and affect the different materials is important for not just supernova explosions, but also for how stars form and even how galaxies interact. In the case of a supernova explosion, these instabilities could be responsible for why the heavy elements that are in the star's core (such as silicon) are counterintuitively farther from the center point of the explosion than the lighter elements in the star's outer layers (like hydrogen and helium).

Plasma physicist Carolyn Kuranz (University of Michigan) uses NIF to study hydrodynamic radiation instabilities in different densities of plasma. For her team's experiments, the 192 laser beams target a small open cylinder of gold, enter at the cylinder's bottom, and hit the interior walls, producing X-rays. That radiation sends a blast wave through another tube on top of the cylinder, which contains materials of two densities: a silicon dioxide foam atop a much denser plastic. The shock front slams into the two materials from the bottom and initiates mixing, just like in a supernova blast.

Supernova simulations don't incorporate mechanisms like heat conduction flowing between materials of different densities, because it would make the calculations even more intense. But Kuranz and her colleagues found that when energy moves through the plastic and foam, the rate of mixing decreases, and fewer instabilities form. "We're arguing that this needs to be included because it's really important to the dynamics," she says.

Collaborations like these lie at the intersection of plasma physics, nuclear physics, and astronomy and "are just there for the taking," Remington says. Far from being content to look up and study the cosmos, researchers have created the plasma that lies at the surface of a remnant star, initiated nuclear reactions like those that power the Sun, tracked how different materials interact in supernova blasts, and charted the details of radiation traveling through layers in the Sun. They are truly bringing the universe down to Earth.

■ **LIZ KRUESI** is a science writer who covers all things cosmic. She has also written five children's books.




**MIMICKING A SUPERNOVA** Scientists shoot lasers at a small gold hohlraum, triggering the launch of a blast wave into the overlying test cylinder. Inside the cylinder is a dense plastic topped by foam. As the blast wave crosses the interface between the plastic and foam, it creates comblike instability structures at the boundary *(inset)*. These structures are similar to those seen on a much larger scale in supernova remnants, where a star's ejecta slams into the much more diffuse medium around it *(below)*.

GREGG DINDERMAN / *S&T*, SOURCE: C. C. KURANZ ET AL. / *NATURE COMMUNICATIONS* 2018, SUPERNOVA REMNANT: X-RAY: NASA / CXC / MIT / D. DEWEY ET AL. AND NASA / CXC / SAO / J. DEPASQUALE, OPTICAL: NASA / STSCI


**2** **EVENING:** Algol shines at minimum brightness for roughly two hours centered at 9:23 p.m. EDT; see page 50.

**3** **DUSK:** The waxing crescent Moon and Jupiter are about 1½° apart in the southwest shortly after sunset, while Antares smolders some 10° to the pair's lower right.

**4** **DUSK:** Saturn, the Moon, Jupiter, and Antares extend along a shallow arc 34° long stretching from the south to the southwest as evening falls.

**5** **DUSK:** The first-quarter Moon and Saturn hover in Sagittarius between the Teapot's handle and the Teaspoon, some 2° separating the pair.

**17** **EVENING:** The waning gibbous Moon rises in Taurus about 2½ hours after sunset with Aldebaran some 3° to 4° to its right or upper right.

**19** **EVENING:** Algol shines at minimum brightness for roughly two hours centered at 11:15 p.m. PDT.

**21–22** **ALL NIGHT:** The moderate Orionids meteor shower peaks in the evening. The radiant, northeast of Betelgeuse, stands high by midnight local time. However, light from the last-quarter Moon will interfere somewhat. See page 48 for details.

**22** **EVENING:** Algol shines at minimum brightness for roughly two hours centered at 11:04 p.m. EDT (8:04 p.m. PDT).

**25** **EVENING:** Algol shines at minimum brightness for roughly two hours centered at 7:53 p.m. EDT.

**26** **DAWN:** The thinnest sliver of the almost-new Moon, Mars, and Porrima form a triangle in Virgo low on the eastern horizon just before sunrise. Binoculars will help.

**29** **DUSK:** Right after sunset, look toward the southwest to find the Moon, not quite 2 days old, and Venus less than 5° apart.

**31** **DUSK:** As at the start of the month, we again find the waxing crescent Moon and the two gas giants, Saturn and Jupiter, gracing the skies in the southwest after sunset.
— DIANA HANNIKAINEN

▲ The stars of Cassiopeia, Perseus, and Cepheus sprinkle across the Northern Hemisphere's autumn skies. VW PICS / UNIVERSAL IMAGES GROUP / GETTY IMAGES

## OCTOBER 2019 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 | 31 | | |

**FIRST QUARTER**

October 5
16:47 UT

**FULL MOON**

October 13
21:08 UT

**LAST QUARTER**

October 21
12:39 UT

**NEW MOON**

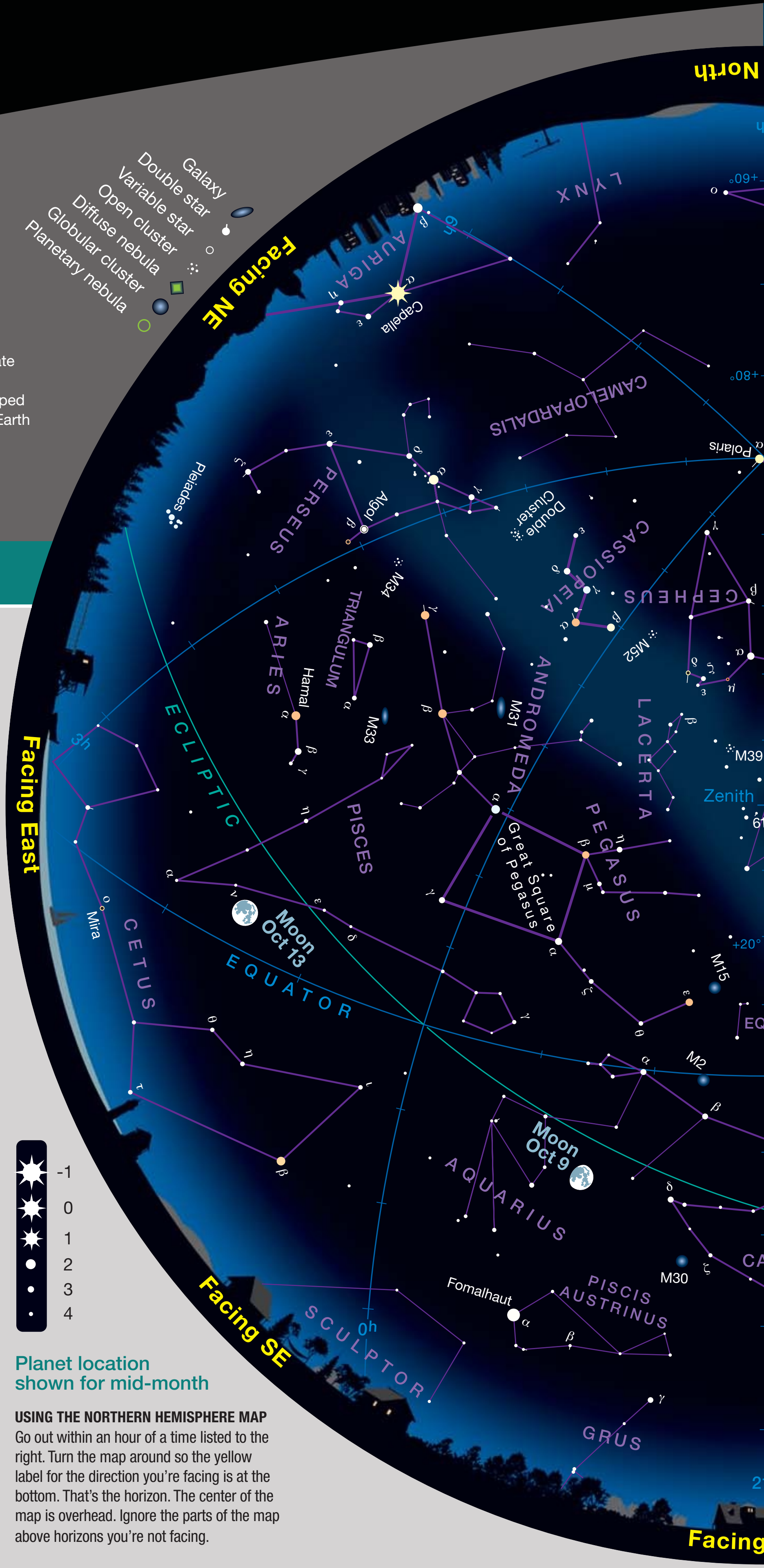
October 28
03:38 UT

**DISTANCES**

| | |
|---|---|
| Apogee | October 10, 18ʰ UT |
| 405,899 km | Diameter 29′ 26″ |
| Perigee | October 26, 11ʰ UT |
| 361,311 km | Diameter 33′ 04″ |

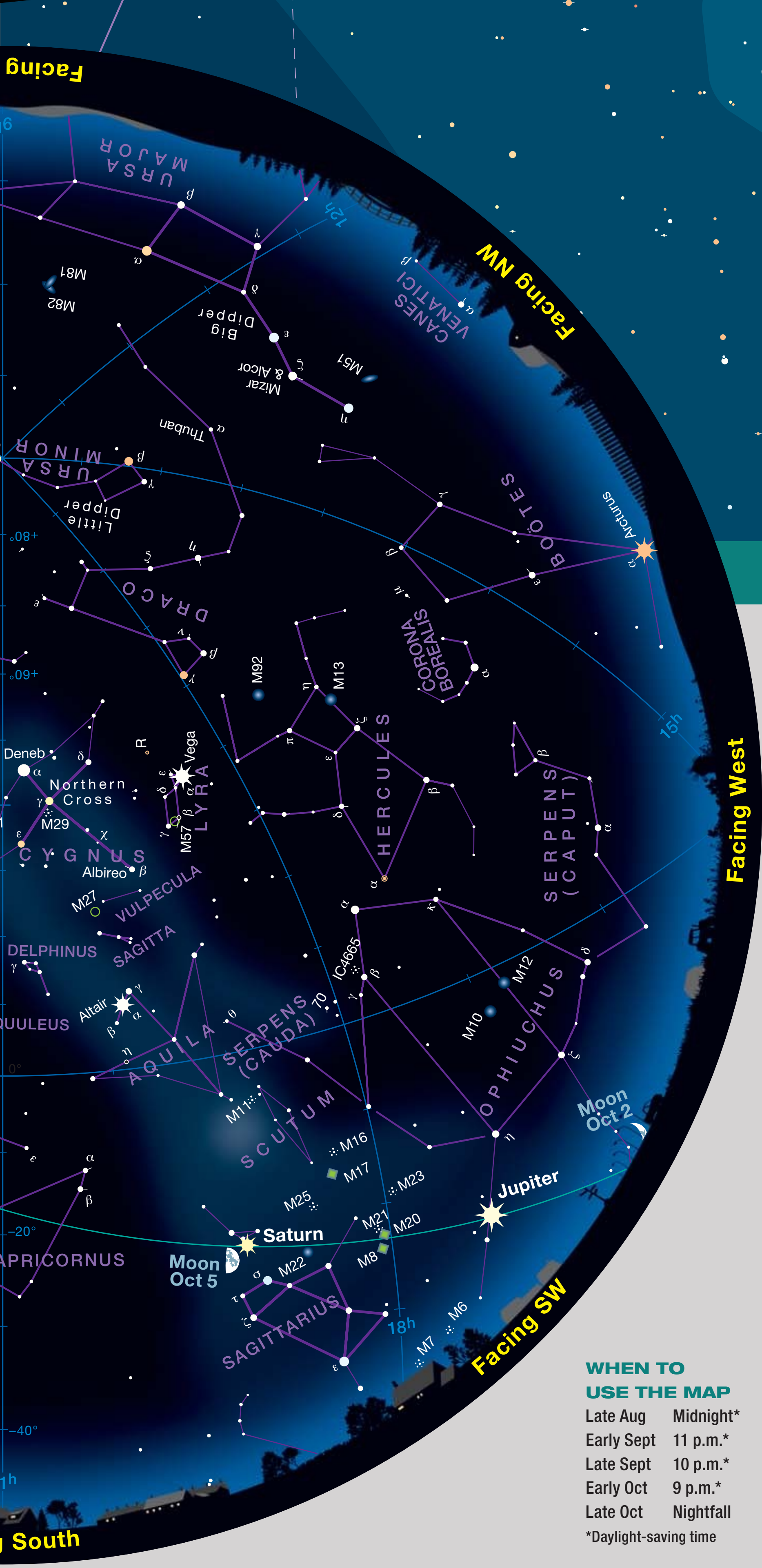
**FAVORABLE LIBRATIONS**

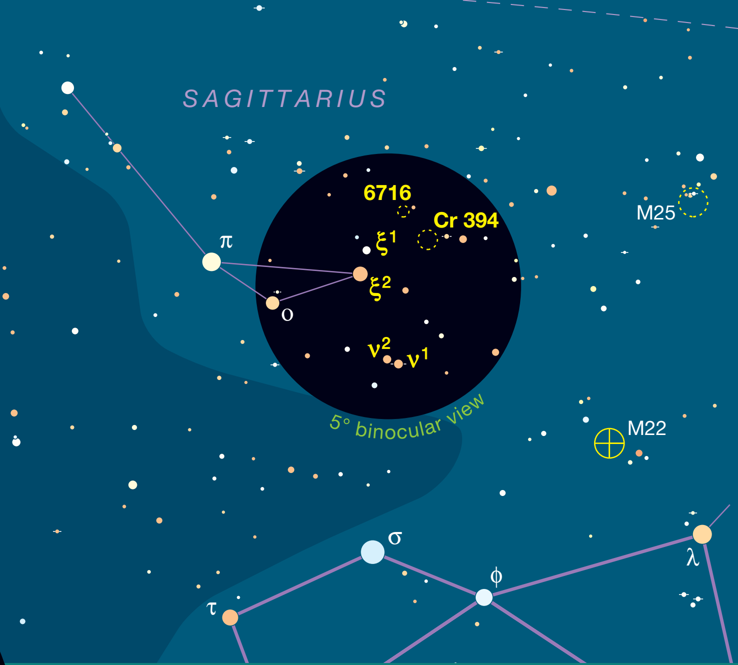
| | |
|---|---|
| • Byrd Crater | October 11 |
| • Pascal Crater | October 13 |
| • Boole Crater | October 14 |
| • Humboldt Crater | October 30 |




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

# Big and Small, Near and Far

My favorite observations allow me to make comparisons: similar objects at different distances, or objects of different sizes at the same distance. The “sugar spoon” asterism to the northeast of the Sagittarius “teapot” has an abundance of great objects to compare. Start with the stars at the lip of the spoon, **Xi$^1$ (ξ$^1$)** and **Xi$^2$ Sagittarii**. The brighter of the two, Xi$^2$ Sagittarii, is a *K*-type orange giant, 415 times as bright as our Sun, lying 370 light-years away. Xi$^1$ Sagittarii is a bit dimmer as seen from Earth, but that appearance is misleading. This *A*-type bright giant is more than 3,200 times as bright as the Sun, but it’s also more than five times farther out, at 2,100 light-years.

A couple of degrees to the south, the wide binocular pair of **Nu$^1$ (ν$^1$)** and **Nu$^2$ Sagittarii** offer a similar comparison. These *K*-type giants are almost the same apparent brightness, at magnitude 4.8 and 5.0, respectively, but they differ in distance by a factor of four, with Nu$^2$ at 270 light-years and Nu$^1$ at 1,100 light-years. Nu$^1$ Sagittarii is actually a supergiant, with a diameter 78 times that of our Sun and 4.5 times the size of Nu$^2$ Sagittarii.

One more comparison: about 1° northwest of Xi$^1$ Sagittarii you’ll find the open clusters **NGC 6716** and **Collinder 394**. These two clusters lie at similar distances, with Cr 394 at 2,300 light-years and NGC 6716 at 2,600 light-years. Cr 394 looks bigger because it is. With a diameter of 14 light-years, it’s twice the size of NGC 6716.

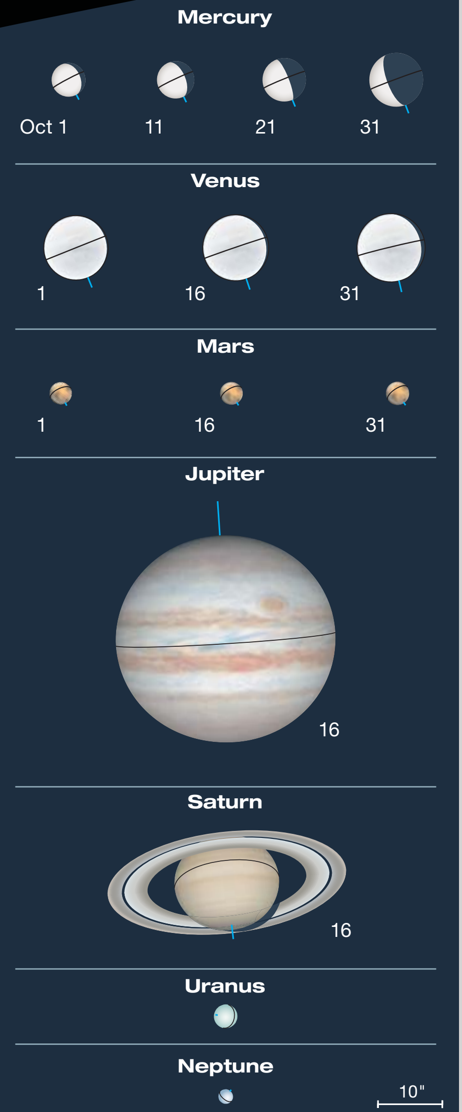
Quiz time: That’s six objects ranging from 270 to 2,600 light-years away. Can you find them all in order by distance?

■ **MATT WEDEL** is writing all of this down because there’s *way* too much of it to remember.

**WHEN TO USE THE MAP**

| | |
|---|---|
| Late Aug | Midnight* |
| Early Sept | 11 p.m.* |
| Late Sept | 10 p.m.* |
| Early Oct | 9 p.m.* |
| Late Oct | Nightfall |

*Daylight-saving time



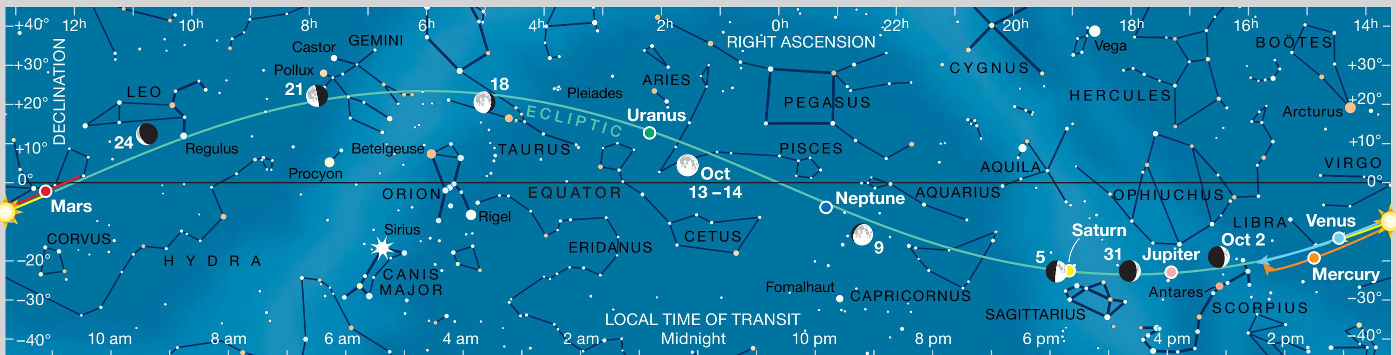

**PLANET DISKS** have south up, to match the view in many telescopes. Blue ticks indicate the pole currently tilted toward Earth.

**PLANET VISIBILITY** **Mercury:** hidden in the Sun's glow all month • **Venus:** visible at dusk all month • **Mars:** visible at dawn after the 14th • **Jupiter:** visible at dusk, sets early evening • **Saturn:** visible at dusk, sets mid-evening

## October Sun & Planets

| | Date | Right Ascension | Declination | Elongation | Magnitude | Diameter | Illumination | Distance |
|---|---|---|---|---|---|---|---|---|
| Sun | 1 | $12^h\ 26.7^m$ | –2° 53′ | — | –26.8 | 31′ 56″ | — | 1.001 |
| | 31 | $14^h\ 18.6^m$ | –13° 51′ | — | –26.8 | 32′ 13″ | — | 0.993 |
| Mercury | 1 | $13^h\ 36.3^m$ | –11° 06′ | 19° Ev | –0.2 | 5.3″ | 86% | 1.277 |
| | 11 | $14^h\ 28.0^m$ | –16° 53′ | 23° Ev | –0.1 | 5.8″ | 76% | 1.157 |
| | 21 | $15^h\ 12.9^m$ | –20° 58′ | 25° Ev | –0.1 | 6.8″ | 61% | 0.994 |
| | 31 | $15^h\ 37.5^m$ | –22° 18′ | 21° Ev | +0.4 | 8.4″ | 33% | 0.803 |
| Venus | 1 | $13^h\ 15.8^m$ | –7° 01′ | 13° Ev | –3.9 | 10.0″ | 98% | 1.664 |
| | 11 | $14^h\ 02.3^m$ | –11° 50′ | 15° Ev | –3.9 | 10.2″ | 96% | 1.636 |
| | 21 | $14^h\ 50.4^m$ | –16° 10′ | 18° Ev | –3.8 | 10.4″ | 95% | 1.604 |
| | 31 | $15^h\ 40.4^m$ | –19° 50′ | 20° Ev | –3.8 | 10.6″ | 94% | 1.569 |
| Mars | 1 | $11^h\ 53.1^m$ | +1° 49′ | 10° Mo | +1.8 | 3.5″ | 100% | 2.639 |
| | 16 | $12^h\ 28.5^m$ | –2° 05′ | 15° Mo | +1.8 | 3.6″ | 99% | 2.598 |
| | 31 | $13^h\ 04.3^m$ | –5° 57′ | 20° Mo | +1.8 | 3.7″ | 99% | 2.543 |
| Jupiter | 1 | $17^h\ 07.6^m$ | –22° 38′ | 71° Ev | –2.0 | 35.8″ | 99% | 5.507 |
| | 31 | $17^h\ 29.1^m$ | –23° 03′ | 46° Ev | –1.9 | 33.5″ | 100% | 5.892 |
| Saturn | 1 | $18^h\ 59.7^m$ | –22° 33′ | 97° Ev | +0.5 | 16.8″ | 100% | 9.880 |
| | 31 | $19^h\ 05.5^m$ | –22° 27′ | 68° Ev | +0.6 | 16.0″ | 100% | 10.368 |
| Uranus | 16 | $2^h\ 10.9^m$ | +12° 39′ | 167° Mo | +5.7 | 3.7″ | 100% | 18.854 |
| Neptune | 16 | $23^h\ 10.6^m$ | –6° 27′ | 144° Ev | +7.8 | 2.3″ | 100% | 29.121 |

**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-October; 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.

# Eternity Tonight

Can you "witness" eternity in an hour? Read on to find out.

*To see a World in a Grain of Sand*
*And a Heaven in a Wild Flower*
*Hold Infinity in the palm of your hand*
*And Eternity in an hour*

—William Blake,
*Auguries of Innocence*, c. 1807

A very small meteoroid could be considered both a "Grain of Sand" and a "World" (it has its own orbit around the Sun). The purple I saw in one of the components of Omicron$^2$ Cygni once leaped out at me the following day from a wild violet I saw blooming by the roadside — a hue of "Heaven" in a "Wild Flower."

But if we're looking for astronomical validations of Blake's lines above, what about "Eternity in an hour"? That's what you'll be reading here in this month's column — along with an astronomical connection to another line of Blake's: "Eternity is in love with the productions of time."

**From here to almost-eternity through your telescope.** Welcome to what I joked in last month's column would be "Eternity — Part 2!" (or, perhaps, "Eternity: The Sequel"?). In all seriousness, I want to show how two astronomical activities can gain for us what we might call pieces of real eternity. One activity is thinking about the monumental matters (and energies!) of astronomy. The other, perhaps even more potent, is the simple, direct act of observing astronomical sights.

Last month, I wrote that on any clear night we can step out and observe celestial objects astonishingly more ancient than humans, human institutions, or even the human species. We can see — with the naked eye — large structures of the Milky Way, a galaxy almost as old as our universe. But now let's consider the range across almost all of time that we can survey simply on the basis of how long it takes light to reach us.

We can see a meteor by light that left it much more recently than 1⁄1000 of a second ago. We can see the Moon's light from about 1⅓ seconds ago, the Sun's from 8 minutes ago, Neptune's from 4 hours ago, Vega's from 25 years ago, Deneb's from possibly a few thousand years ago — and, climbing in the east these October evenings, the Great Andromeda Galaxy's light from more than 2 million years ago. Amateur astronomers can even see quasar light from more than 5 billion years ago, before the Sun and Earth were born. But now stop and think about this: Consider that in one short observing session you can survey the full *range* of time from a microsecond-ago meteor to a 5-billion-year-past quasar. That at least approaches holding "Eternity in an hour."

LEAH TISCIONE / *S&T*

**The rural area on the edge of forever.** It's ironic that many of us need to drive for an hour or two into the countryside to stand on the edge of forever and view its wonders.

**The city on the edge of forever.** Last year we lost one of the most dynamic writers of the 20th century — Harlan Ellison. His script for an episode of the *Star Trek* TV series won a major screenwriting award in its original form — and even the greatly altered (Ellison would say greatly worsened) form of it that aired has often been voted by fans as the best episode of *Star Trek* ever. That episode is called "The City on the Edge of Forever," a great Ellison title referring literally to 1930s New York City reached by our characters from the future unwillingly through a time portal. But the poignancy of what they experience there (including being forced to let someone they loved die to save human history) reminds us with a shock of awe that we all really live, all the time, on the interface of now and forever.

**The love affair between eternity and the productions of time.** Does eternity really exist? Well, some physicists challenge the reality of time. Surely eternity cannot exist nor have meaning without the productions of time. And, conversely, eternity must be needed — or in some cases even longed for — by all the "productions of time": by planets, stars, galaxies . . . and especially human beings.

■ **FRED SCHAAF** welcomes your letters and comments at fschaaf@aol.com.

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

# Six Planets in the Evening

Venus has returned at dusk, and Mars reappears in the second half of October when it rises at dawn.

Early in dusk, Venus is still very low in the west for most of October. As the sky further darkens, Jupiter glows in the southwest and Saturn in the south-southwest. Not until the second half of the month does the final bright planet, Mars, rise at dawn and finally start to emerge from a long period of absence from the night sky.

## DUSK

**Venus** sets about a half-hour after the Sun as October starts and only about an hour after the Sun as the month ends. In telescopes, Venus, at magnitude –3.9 during the first half of the month and –3.8 during the second half, is almost fully lit but near its minimum angular diameter of 10″.

**Mercury** spends most of October not too far upper left of Venus and reaches a greatest eastern elongation of 24.6° from the Sun on the American evening of October 19th. But the little planet, close to zero magnitude all month, is a very difficult sight so low in twilight, never setting as much as an hour after the Sun. Mercury passes around 2½° below Venus on the evening of October 31st, very low in the southwest, and then falls and fades rapidly on its way to its marvelous transit of the Sun on November 11th.

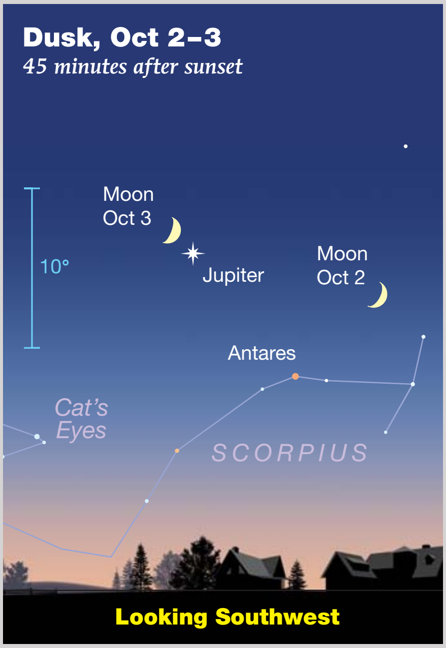
## DUSK AND EVENING

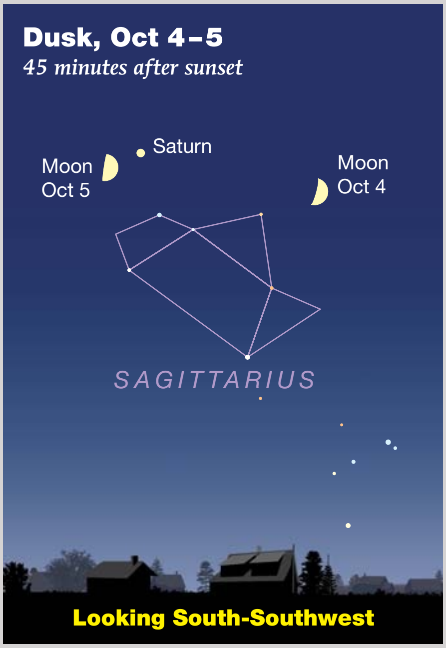
**Jupiter** fades a bit this month, from magnitude –2.0 to –1.9, and the interval between sunset and Jupiter-set decreases from about 3½ hours to 2½ hours. As twilight fades in early October, look for Antares to come into view, about a fist-width lower right of Jupiter. The giant planet continues to march slowly east against the background of stars in southeastern Ophiuchus.

**Saturn** is almost 30° high in dusk as October begins. The planet is at eastern quadrature (90° east of the Sun) on October 7th, so this is a month when Saturn's shadow is cast farthest to the side, giving the globe and rings their most three-dimensional appearance. The rings are tilted to a wide 25.2°. Saturn starts the month setting around midnight and ends the month setting not long after 10 p.m. The ringed planet dims a bit (from magnitude +0.5 to +0.6) and is now creeping eastward, away from the handle of the Teapot of Sagittarius.

## ALL NIGHT

**Uranus** reaches opposition on October 27th and therefore is above the horizon all night. The seventh planet glows at magnitude 5.7 in Aries and is bright enough to see with the naked eye in really dark skies. A medium-sized telescope shows the blue or blue-green of Uranus well and can reveal its 3.7″-wide disk. Finder charts for Uranus and Neptune can be found in the September issue and accessed at **https://is.gd/urnep**.




▶ 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.

**Neptune**, in Aquarius, was at opposition back on September 10th so is visible most of the night in October. Its 8th-magnitude disk, only 2.3″ wide, is now highest and best for telescopic observation in the late evening.

## DAWN

**Mars** has been lost in the solar glare since mid-July but returns to visibility in mid-October. The Red Planet rises only about 50 minutes before the Sun on October 1st, but about 1¾ hours before the Sun on October 31st. Mars currently shines at a meager magnitude 1.8, and its disk appears as small as that of distant Uranus. In comparison, one year from this month, the disk of Mars will appear about six times wider. That's when Mars reaches its next opposition, much better placed for observers at mid-northern latitudes than it was at its 2017 opposition.

October 7th is the day that Mars, now in Virgo, crosses southward over the celestial equator, and also the day the northern hemisphere of Mars experiences its summer solstice.

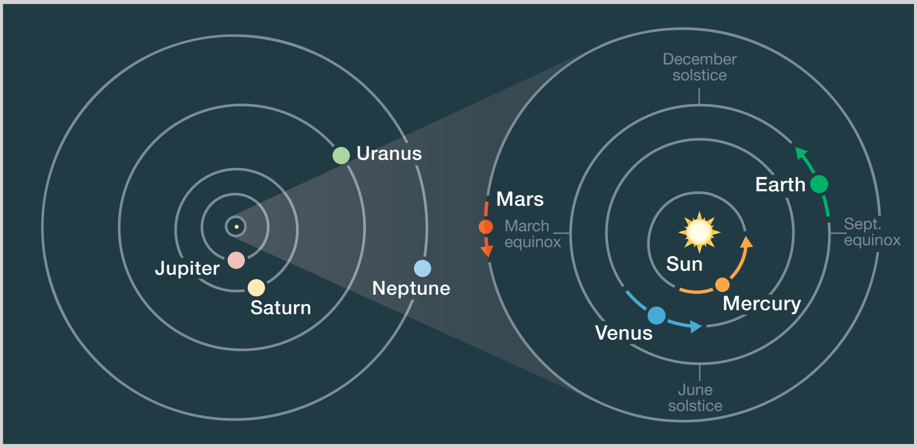
## MOON PASSAGES

**The Moon** is a waxing crescent well to the upper right of Antares on October 2nd. It's upper left of and marvelously close to Jupiter at nightfall of October 3rd. Just a few hours after its first quarter phase, the Moon is 2° or less lower left of Saturn at nightfall on October 5th.

The waning gibbous Moon rises not too far, some 3° or 4°, left of Aldebaran on the evening of October 17th. The Moon is at or near its last-quarter phase on the morning of October 21st, when it's almost perfectly lined up with Pollux and Castor. The waning lunar crescent is several degrees above Regulus on the morning of October 23rd. The Moon is a very thin crescent about 4° to 5° upper left of Mars at dawn on October 26th. In eastern North America, a near-record-old Moon might be glimpsed just above the eastern horizon about 30 minutes before sunrise on October 27th.

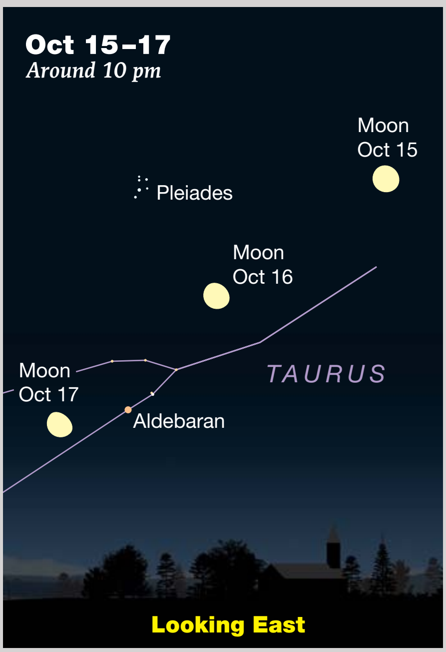
After sunset on October 29th, the waxing crescent Moon is just a few degrees upper right of Venus, down near the west-southwestern horizon. On October 31st, we get the second fine Moon-Jupiter pairing of the month, with the lunar crescent just a few degrees upper left of Jupiter at nightfall.

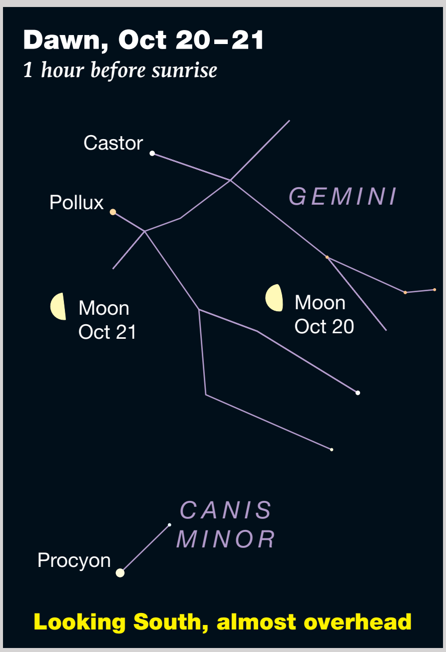
■ FRED SCHAAF has penned this column since 1993.

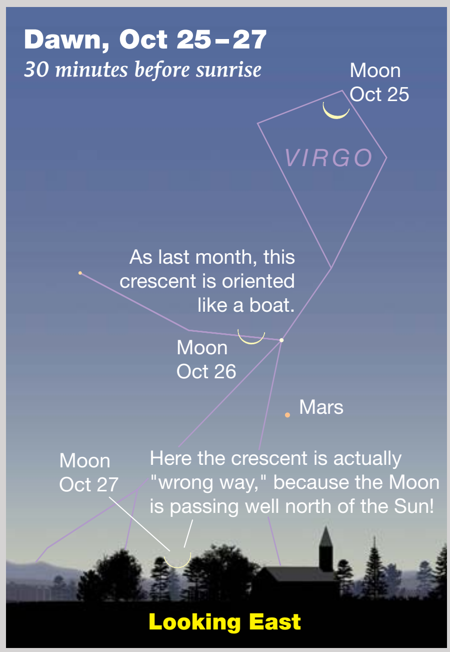



### ORBITS OF THE PLANETS

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



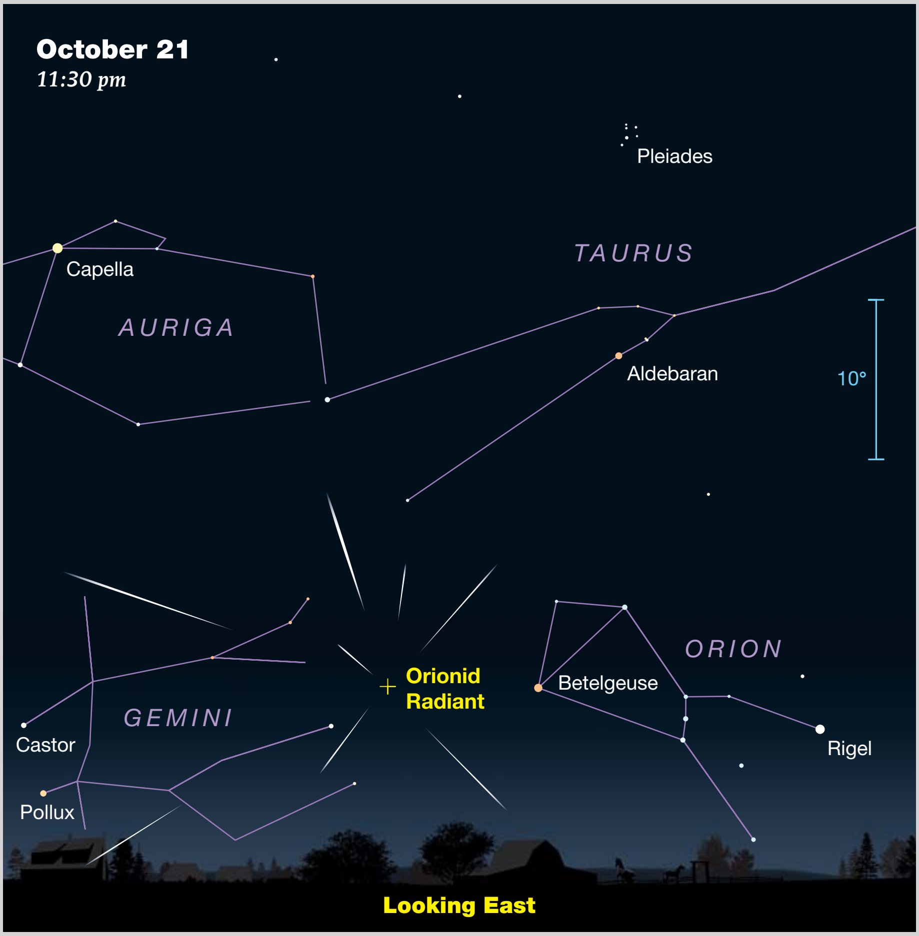
# October Is For Orionids

Even though observing conditions aren't ideal, you may see a few fireballs this month.

Twice a year, Earth travels through the trails of dust that Halley's Comet leaves behind when it passes through the inner solar system every 76 years. In May, Earth encounters the particle streams that mark the comet's multiple inbound paths; weather permitting, we witness the interaction as the Eta Aquariid meteor shower. In October, when Earth hits Halley's outbound paths, it's time for the Orionids.

The earliest record of a shower that can credibly be identified as the Orionids comes from the annals of the Sui dynasty in China, where historians noted "hundreds of meteors scattered in all directions" on the night of September 23 AD 585. Yet the location of the shower's *radiant* — the point in the sky from which a shower's meteors appear to emanate — wasn't determined until the 1860s, when astronomer Alexander Herschel included his observations of "luminous meteors" that originated near Nu (ν) Orionis in several annual reports for the British Association for the Advancement of Science.

Connecting the Orionids to their parent comet took more than a century longer, however. Chinese astronomers recorded observations of Halley's Comet as early as 239 BC, but the relationship between comet and shower wasn't clearly defined until 1983, when B. A. McIntosh (National Research Council Canada) and A. Hajduk (Astronomical Institute of the Slovak Academy of Sciences) co-authored a paper on Halley's meteor stream.




The radiant for the Orionid meteor shower is in Orion's raised club, which stands highest in the south before dawn.

Look for the Orionids to begin appearing in early October, with a predicted peak on the night of October 21–22. The shower has a *zenithal hourly rate* of 20, which means that under a dark, moonless sky you'd typically see about 20 meteors in an hour if the radiant was directly overhead. For the Orionids, the radiant is northeast of Betelgeuse, which rises about 10:30 p.m. daylight-saving time on the 21st. The radiant reaches a comfortable altitude by 11:30 p.m., but the waning crescent Moon, about 40% lit, rises just an hour after that. Typically, meteor viewing is better in the hours between midnight and dawn, but this year, it might pay to start watching in mid-to-late evening.

Even after the Moon clears the horizon, all is not lost. Meteors are more visible when you watch the sky 45°–90° away from the radiant, so if you look to the north and west, both the climbing radiant and Moon will be at your back. And though the peak falls on October 21–22, Orionids appear through November 7th or so. The slimming Moon will be less of a factor in the week following the predicted peak.

# Talk to the Fourth Rock

**MARS WAS IN CONJUNCTION** with the Sun — hidden behind our star from our vantage point on Earth — on September 2nd. It takes about six weeks for the Red Planet to pull out of the Sun's glow and return to visibility for earthlings. Fans of Mars will be happy to welcome it back into the dawn sky in mid-October, when its 1.8-magnitude light rises in an early twilight sky, about 1½ hours before sunrise.

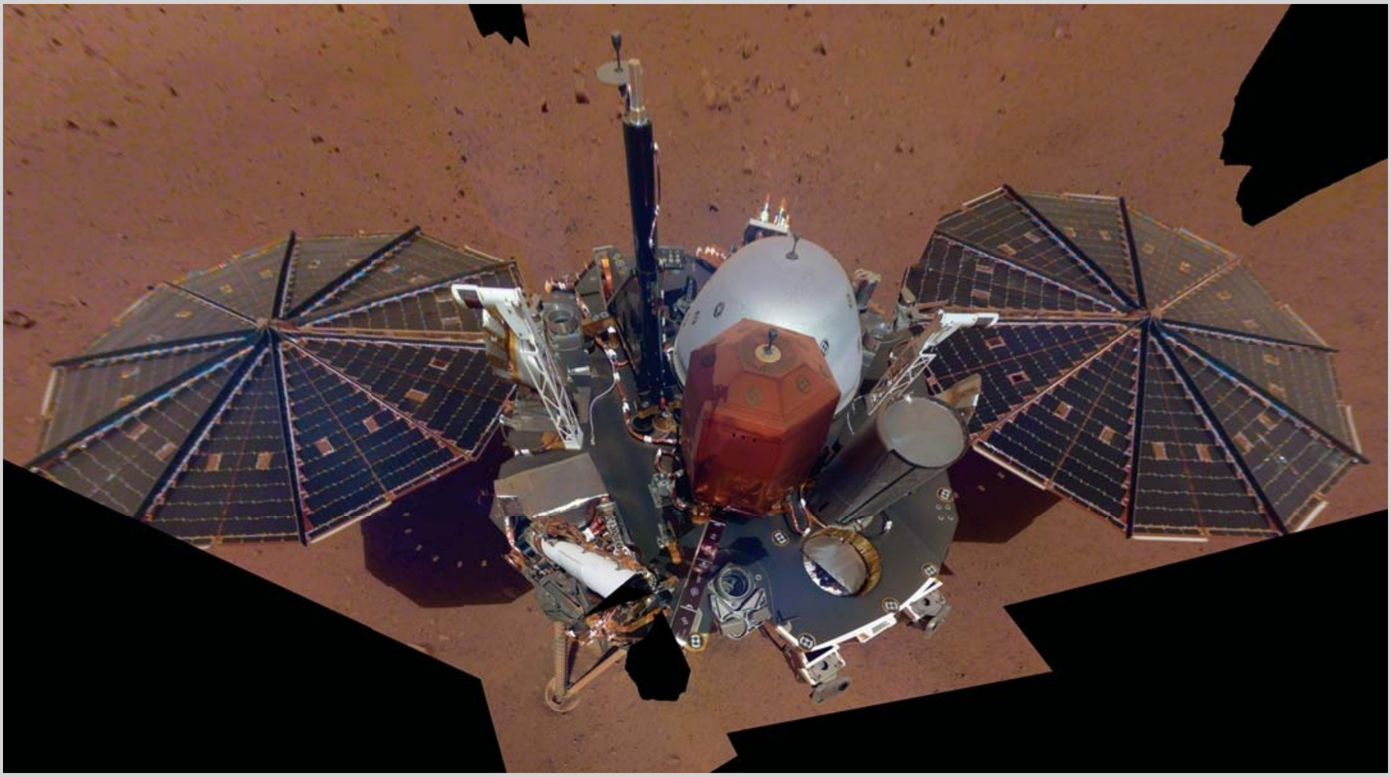
Be prepared to bring a telescope and lots of patience to your observing session since the planet won't clear the atmospheric murkiness near the horizon. Conditions improve with each passing morning, but even at the end of the month, Mars stands only 13° high in the east-southeast at the end of twilight. Mars remains a morning object until July 2020, when it finally begins rising before midnight daylight-saving time.

It takes Mars 687 Earth days to complete an orbit around the Sun (its *sidereal period*), but it takes almost 100 days beyond that to return to alignment with Earth and Sun. Thanks to the planets' different orbital rates, the Mars-Earth *synodic period* — the time it takes for an object to return to the same point in relation to another object — is 780 days. So Mars arrives at solar conjunction approximately every two years.

For amateur astronomers, solar conjunction means suffering Mars's absence from viewfinders and scopes for three or more months, waiting for the planet to escape the Sun's glow. For professional astronomers, particularly those working on Mars exploratory missions, the wait is shorter but perhaps felt more keenly. Every time Mars is hidden from Earth by the Sun, mission controllers at NASA's Jet Propulsion Laboratory encounter a two-week communications blackout, during which they're unable to send new instructions to rovers on and orbiters above Mars. To avoid data loss caused by charged solar particles, mission control sends two weeks' worth of instructions to Mars about a week ahead of the date of conjunction . . . and then takes a much-needed break or turns to work on other tasks.

NASA is well-practiced at this maneuver by now, and spacecraft are designed to run safely on autopilot for several days at a time. But this necessary break in communications does raise questions about crewed missions to Mars. Scientists have proposed a number of solutions to keep earthbound humans of the future in touch with their counterparts on Mars, including placing satellites equipped with ion thrusters in a special orbit around the Red Planet. The satellites would always be visible to both planets and so could serve as relay stations, but the feasibility of this and other solutions have yet to be thoroughly tested.

▼ NASA's Insight lander settled on the surface of Mars on November 26, 2018. This "selfie" is composed of 11 images taken by Insight's Instrument Deployment Camera, located on its robotic arm, on December 6, 2018.



NASA / JPL-CALTECH

## The Southern Taurids

The Taurids are a minor shower associated with 2P/Encke, a comet first observed by French astronomer Pierre Méchain in 1786. Encke has the shortest period (3.3 years) of any known periodic comet. Most of the time, Encke behaves like a cold asteroid; it becomes active only about 100 days before reaching *perihelion* (the closest point in its orbit to the Sun). Encke ejects the majority of its dust between the 10-day mark of its inbound journey and the 30-day mark of its outbound journey. Between those two points, the comet remains in a dormant state.

The dust trail left behind by Encke is broad, with distinct northern and southern branches that produce multiple meteor showers. This year, the Southern Taurids (produced by the southern branch of dust, as the name suggests) begin appearing around September 10th and continue through November 20th. Look for peak activity, with 5 meteors or so an hour, on the night of October 10th, three nights before full Moon.

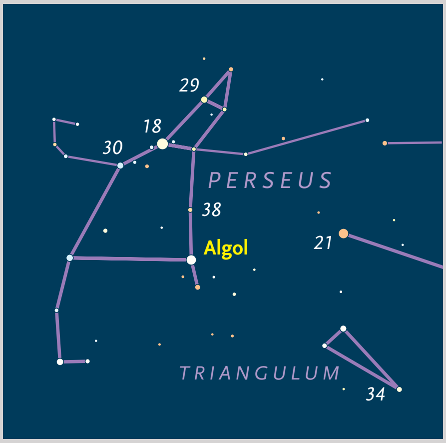
The southern particle stream is known for generating dramatic fireballs, and shower meteors with absolute magnitudes as bright as –17 have been recorded in the past. Such brilliant lights mean that some of the meteors could be very large indeed, with initial bodies perhaps 1 meter wide and masses reaching as much as 900 kg. The biggest and brightest fireballs have been heard to produce sonic booms that rumble like thunder as the sound waves descend to Earth.

The radiant of the Southern Taurids falls near the ecliptic, so though observers in the Northern Hemisphere are slightly better placed to watch the shower, activity will also be visible to those in more southerly locations. To determine if a meteor is a Southern Taurid, track its trajectory back to the point of origin. If it appears to emanate from an oval region approximately 20° × 10° centered on Xi (ξ) Arietis (just outside the bounds of Cetus, next to the Sea Monster's head) on October 10th, you've seen a shower meteor. The Northern Taurids pick up around October 20th, and as the Southern radiant moves into Taurus, it may be difficult to tell which branch of the meteor stream produced the light streak.

### Minima of Algol

| Sept. | UT | Oct. | UT |
|---|---|---|---|
| 1 | 12:28 | 3 | 1:23 |
| 4 | 9:17 | 5 | 22:12 |
| 7 | 6:05 | 8 | 19:00 |
| 10 | 2:54 | 11 | 15:49 |
| 12 | 23:43 | 14 | 12:38 |
| 15 | 20:31 | 17 | 9:27 |
| 18 | 17:20 | 20 | 6:15 |
| 21 | 14:08 | 23 | 3:04 |
| 24 | 10:57 | 25 | 23:53 |
| 27 | 7:46 | 28 | 20:42 |
| 30 | 4:34 | 31 | 17:30 |

These geocentric predictions are from the recent heliocentric elements Min. = JD 2445641.554 + 2.867324*E*, where *E* is any integer. For a comparison-star chart and more info, see **skyandtelescope.com/algol**.




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

## Action at Jupiter

**JUPITER IS AN EARLY EVENING** object this month, culminating before sunset. Look for its –2.0-magnitude light in the southwest as the sky darkens.

Any telescope shows the four big Galilean moons, and binoculars usually show at least two or three. In binoculars, the moons are all but indistinguishable from one another. They orbit Jupiter at different rates, changing positions along a straight line from our point of view on Earth. Use the diagram on the facing page to identify them by their relative positions.

All of the October 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 evening hours.

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

**September 1:** 9:21, 19:17; **2:** 5:12, 15:08; **3:** 1:04, 11:00, 20:55; **4:** 6:51, 16:47; **5:** 2:43, 12:39, 22:34; **6:** 8:30, 18:26; **7:** 4:22, 14:17; **8:** 0:13, 10:09, 20:05; **9:** 6:01, 15:56; **10:** 1:52, 11:48, 21:44; **11:** 7:40, 17:35; **12:** 3:31, 13:27, 23:23; **13:** 9:19, 19:14; **14:** 5:10, 15:06; **15:** 1:02, 10:57, 20:53; **16:** 6:49, 16:45; **17:** 2:41, 12:36, 22:32; **18:** 8:28, 18:24; **19:** 4:20, 14:16; **20:** 0:11, 10:07, 20:03; **21:** 5:59, 15:55; **22:** 1:50, 11:46, 21:42; **23:** 7:38, 17:34; **24:** 3:29, 13:25, 23:21; **25:** 9:17, 19:13; **26:** 5:08, 15:04; **27:** 1:00, 10:56, 20:52; **28:** 6:48, 16:43; **29:** 2:39, 12:35, 22:31; **30:** 8:27, 18:22.

**October 1:** 4:18, 14:14; **2:** 0:10, 10:06, 20:02; **3:** 5:57, 15:53; **4:** 1:49, 11:45, 21:41; **5:** 7:37, 17:32; **6:** 3:28, 13:24, 23:20; **7:** 9:16, 19:11; **8:** 5:07, 15:03; **9:** 0:59, 10:55, 20:51; **10:** 6:46, 16:42; **11:** 2:38, 12:34, 22:30; **12:** 8:26, 18:21; **13:** 4:17, 14:13; **14:** 0:09, 10:05, 20:01; **15:** 5:56, 15:52; **16:** 1:48, 11:44, 21:40; **17:** 7:36, 17:32; **18:** 3:27, 13:23, 23:19; **19:** 9:15, 19:11; **20:** 5:07, 15:02; **21:** 0:58, 10:54, 20:50; **22:** 6:46, 16:42;

**23:** 2:37, 12:33, 22:29; **24:** 8:25, 18:21; **25:** 4:17, 14:12; **26**: 0:08, 10:04, 20:00; **27:** 5:56, 15:52; **28:** 1:48, 11:43, 21:39; **29:** 7:35, 17:31; **30:** 3:27, 13:23, 23:18; **31:** 9:14, 19:10.

These times assume that the spot will be centered at System II longitude 315°. If the Red Spot has moved elsewhere, it will transit 1⅔ minutes earlier for each degree less than 315° and 1⅔ minutes later for each degree more than 315°.

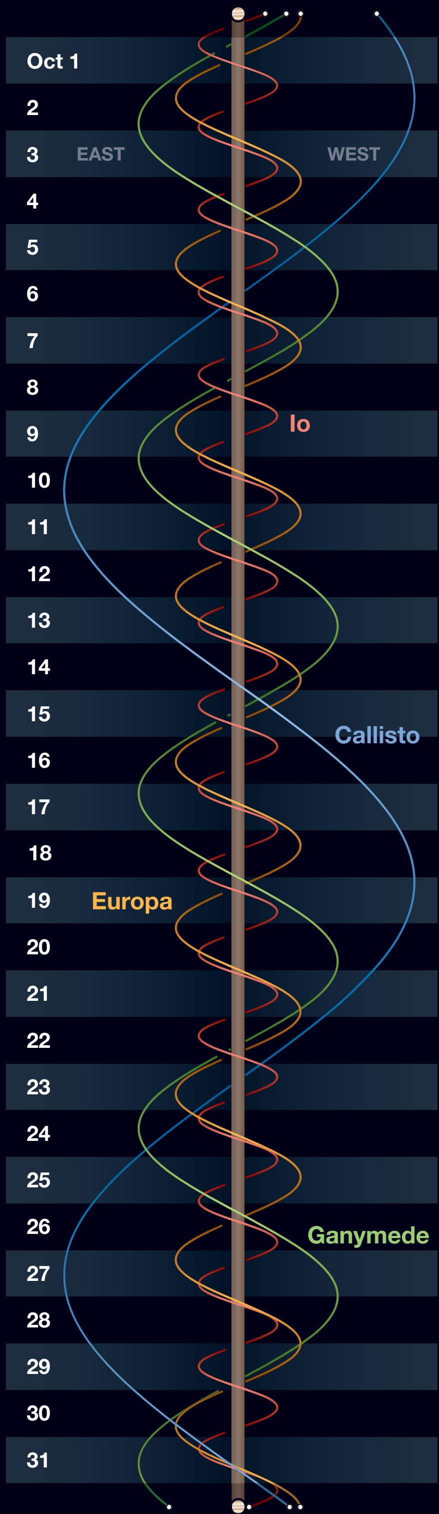
Use a filter opposite in color to the feature you're trying to highlight. Red filters can make bluish features easier to distinguish, and yellow filters can enhance contrast at the polar regions.

## Phenomena of Jupiter's Moons, October 2019

| | | |
|---|---|---|
| **Oct. 1** | 0:34 | III.Oc.D |
| | 3:09 | III.Oc.R |
| | 5:28 | III.Ec.D |
| | 8:08 | III.Ec.R |
| | 9:08 | II.Oc.D |
| | 13:20 | I.Tr.I |
| | 14:05 | II.Ec.R |
| | 14:32 | I.Sh.I |
| | 15:32 | I.Tr.E |
| | 16:44 | I.Sh.E |
| **Oct. 2** | 10:30 | I.Oc.D |
| | 13:57 | I.Ec.R |
| **Oct. 3** | 3:31 | II.Tr.I |
| | 5:56 | II.Sh.I |
| | 6:02 | II.Tr.E |
| | 7:50 | I.Tr.I |
| | 8:30 | II.Sh.E |
| | 9:00 | I.Sh.I |
| | 10:01 | I.Tr.E |
| | 11:12 | I.Sh.E |
| **Oct. 4** | 4:59 | I.Oc.D |
| | 8:26 | I.Ec.R |
| | 14:31 | III.Tr.I |
| | 17:05 | III.Tr.E |
| | 19:18 | III.Sh.I |
| | 21:56 | III.Sh.E |
| | 22:29 | II.Oc.D |
| **Oct. 5** | 2:19 | I.Tr.I |
| | 3:22 | II.Ec.R |
| | 3:29 | I.Sh.I |
| | 4:31 | I.Tr.E |
| | 5:41 | I.Sh.E |
| | 23:29 | I.Oc.D |
| **Oct. 6** | 2:54 | I.Ec.R |
| | 16:53 | II.Tr.I |
| | 19:15 | II.Sh.I |
| | 19:24 | II.Tr.E |
| | 20:49 | I.Tr.I |
| | 21:49 | II.Sh.E |
| | 21:58 | I.Sh.I |
| | 23:00 | I.Tr.E |
| **Oct. 7** | 0:10 | I.Sh.E |
| | 17:59 | I.Oc.D |
| | 21:23 | I.Ec.R |
| **Oct. 8** | 4:46 | III.Oc.D |
| | 7:23 | III.Oc.R |
| | 9:28 | III.Ec.D |
| | 11:49 | II.Oc.D |
| | 12:09 | III.Ec.R |
| | 15:18 | I.Tr.I |
| | 16:27 | I.Sh.I |
| | 16:40 | II.Ec.R |
| | 17:30 | I.Tr.E |
| | 18:38 | I.Sh.E |
| **Oct. 9** | 12:29 | I.Oc.D |
| | 15:52 | I.Ec.R |
| **Oct. 10** | 6:15 | II.Tr.I |
| | 8:34 | II.Sh.I |
| | 8:48 | II.Tr.E |
| | 9:48 | I.Tr.I |
| | 10:55 | I.Sh.I |
| | 11:09 | II.Sh.E |
| | 12:00 | I.Tr.E |
| | 13:07 | I.Sh.E |
| **Oct. 11** | 6:58 | I.Oc.D |
| | 10:21 | I.Ec.R |
| | 18:45 | III.Tr.I |
| | 21:20 | III.Tr.E |
| | 23:18 | III.Sh.I |
| **Oct. 12** | 1:11 | II.Oc.D |
| | 1:57 | III.Sh.E |
| | 4:18 | I.Tr.I |
| | 5:24 | I.Sh.I |
| | 5:57 | II.Ec.R |
| | 6:29 | I.Tr.E |
| | 7:36 | I.Sh.E |
| **Oct. 13** | 1:28 | I.Oc.D |
| | 4:50 | I.Ec.R |
| | 19:38 | II.Tr.I |
| | 21:53 | II.Sh.I |
| | 22:10 | II.Tr.E |
| | 22:47 | I.Tr.I |
| | 23:53 | I.Sh.I |
| **Oct. 14** | 0:27 | II.Sh.E |
| | 0:59 | I.Tr.E |
| | 2:05 | I.Sh.E |
| | 19:58 | I.Oc.D |
| | 23:19 | I.Ec.R |
| **Oct. 15** | 9:02 | III.Oc.D |
| | 11:40 | III.Oc.R |
| | 13:27 | III.Ec.D |
| | 14:32 | II.Oc.D |
| | 16:09 | III.Ec.R |
| | 17:17 | I.Tr.I |
| | 18:21 | I.Sh.I |
| | 19:15 | II.Ec.R |
| | 19:29 | I.Tr.E |
| | 20:33 | I.Sh.E |
| **Oct. 16** | 14:28 | I.Oc.D |
| | 17:48 | I.Ec.R |
| **Oct. 17** | 9:01 | II.Tr.I |
| | 11:12 | II.Sh.I |
| | 11:34 | II.Tr.E |
| | 11:47 | I.Tr.I |
| | 12:50 | I.Sh.I |
| | 13:47 | II.Sh.E |
| | 13:59 | I.Tr.E |
| | 15:02 | I.Sh.E |
| **Oct. 18** | 8:58 | I.Oc.D |
| | 12:17 | I.Ec.R |
| | 23:01 | III.Tr.I |
| **Oct. 19** | 1:38 | III.Tr.E |
| | 3:17 | III.Sh.I |
| | 3:54 | II.Oc.D |
| | 5:58 | III.Sh.E |
| | 6:16 | I.Tr.I |
| | 7:19 | I.Sh.I |
| | 8:28 | I.Tr.E |
| | 8:33 | II.Ec.R |
| | 9:31 | I.Sh.E |
| **Oct. 20** | 3:28 | I.Oc.D |
| | 6:45 | I.Ec.R |
| | 22:24 | II.Tr.I |
| **Oct. 21** | 0:30 | II.Sh.I |
| | 0:46 | I.Tr.I |
| | 0:57 | II.Tr.E |
| | 1:47 | I.Sh.I |
| | 2:58 | I.Tr.E |
| | 3:06 | II.Sh.E |
| | 4:00 | I.Sh.E |
| | 21:58 | I.Oc.D |
| **Oct. 22** | 1:14 | I.Ec.R |
| | 13:19 | III.Oc.D |
| | 15:59 | III.Oc.R |
| | 17:16 | II.Oc.D |
| | 17:26 | III.Ec.D |
| | 19:16 | I.Tr.I |
| | 20:09 | III.Ec.R |
| | 20:16 | I.Sh.I |
| | 21:28 | I.Tr.E |
| | 21:50 | II.Ec.R |
| | 22:28 | I.Sh.E |
| **Oct. 23** | 16:28 | I.Oc.D |
| | 19:43 | I.Ec.R |
| **Oct. 24** | 11:49 | II.Tr.I |
| | 13:46 | I.Tr.I |
| | 13:50 | II.Sh.I |
| | 14:22 | II.Tr.E |
| | 14:45 | I.Sh.I |
| | 15:58 | I.Tr.E |
| | 16:25 | II.Sh.E |
| | 16:57 | I.Sh.E |
| **Oct. 25** | 10:58 | I.Oc.D |
| | 14:12 | I.Ec.R |
| **Oct. 26** | 3:21 | III.Tr.I |
| | 5:59 | III.Tr.E |
| | 6:38 | II.Oc.D |
| | 7:17 | III.Sh.I |
| | 8:16 | I.Tr.I |
| | 9:13 | I.Sh.I |
| | 9:59 | III.Sh.E |
| | 10:28 | I.Tr.E |
| | 11:08 | II.Ec.R |
| | 11:26 | I.Sh.E |
| **Oct. 27** | 5:28 | I.Oc.D |
| | 8:41 | I.Ec.R |
| **Oct. 28** | 1:12 | II.Tr.I |
| | 2:46 | I.Tr.I |
| | 3:08 | II.Sh.I |
| | 3:42 | I.Sh.I |
| | 3:46 | II.Tr.E |
| | 4:58 | I.Tr.E |
| | 5:44 | II.Sh.E |
| | 5:54 | I.Sh.E |
| | 23:58 | I.Oc.D |
| **Oct. 29** | 3:10 | I.Ec.R |
| | 17:39 | III.Oc.D |
| | 20:01 | II.Oc.D |
| | 20:21 | III.Oc.R |
| | 21:16 | I.Tr.I |
| | 21:25 | III.Ec.D |
| | 22:11 | I.Sh.I |
| | 23:28 | I.Tr.E |
| **Oct. 30** | 0:10 | III.Ec.R |
| | 0:23 | I.Sh.E |
| | 0:25 | II.Ec.R |
| | 18:28 | I.Oc.D |
| | 21:38 | I.Ec.R |
| **Oct. 31** | 14:37 | II.Tr.I |
| | 15:46 | I.Tr.I |
| | 16:27 | II.Sh.I |
| | 16:39 | I.Sh.I |
| | 17:11 | II.Tr.E |
| | 17:58 | I.Tr.E |
| | 18:52 | I.Sh.E |
| | 19:03 | II.Sh.E |

Every day, interesting events happen between Jupiter's satellites and the planet's disk or shadow. The first columns give the date and mid-time of the event, in Universal Time (which is 4 hours ahead of Eastern Daylight Time). Next is the satellite involved: **I** for Io, **II** Europa, **III** Ganymede, or **IV** Callisto. Next is the type of event: **Oc** for an occultation of the satellite behind Jupiter's limb, **Ec** for an eclipse by Jupiter's shadow, **Tr** for a transit across the planet's face, or **Sh** for the satellite casting its own shadow onto Jupiter. An occultation or eclipse begins when the satellite disappears **(D)** and ends when it reappears **(R)**. A transit or shadow passage begins at ingress **(I)** and ends at egress **(E)**. Each event is gradual, taking up to several minutes. Predictions courtesy IMCCE / Paris Observatory.

## 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.

# Lunar Pareidolia

Our vivid imagination can make us see more than craters on the Moon.

▲ Patterns formed by the large lunar maria visible during full Moon suggest a man's face, a woman's profile, or even a leaping rabbit. How many can you see?

EDDIE TRIMARCHI

Our minds tend to seek out familiar patterns everywhere, trying to wrest order from ambiguity. According to the *Merriam-Webster Dictionary*, the tendency to perceive a specific, often meaningful image in a random or ambiguous visual pattern is known as *pareidolia*. Astronomers are familiar with many examples of pareidolia, such as seeing the shape of a continent in a nebula (see page 54), or a woman's profile in the maria visible at full Moon. Most constellations are themselves simply the standardized acceptance of ancient Greek pareidolic characterizations of star patterns as humans, animals, and even musical instruments. Recognizing such patterns helps us to navigate the night sky, aiding in how we communicate the locations of specific areas and events to one another.

Calling the dark maria as seen at full Moon a man, woman, or even a rabbit was common across many societies for thousands of years. Ancient Greek and later Arabic astronomers believed that the Moon was a smooth, mirror-like sphere and the maria to be reflections of Earth's oceans. The invention of the telescope did little to dispel these myths: On his 1647 map of the Moon, Johannes Hevelius compared the crater **Copernicus** to Earth's Mount Etna, a nearly circular volcano rising above the surrounding Mediterranean Sea.

Almost a quarter century later, improved telescope optics allowed Giovanni Domenico Cassini to represent **Promontorium Heraclides** on the west side of **Sinus Iridum** as the profile of a woman with hair streaming westward along the boundary between Mare Imbrium and Montes Jura. Fast-forward to the 1820s, when German observer Franz von Paula Gruithuisen reported seeing an area north of the crater **Schröter** that displayed nearly straight walls, with others branching off at 45° angles. Immersed in the romantic belief that life was nearly everywhere, he concluded that these features were a city as seen from above, naming it Wallwerk.

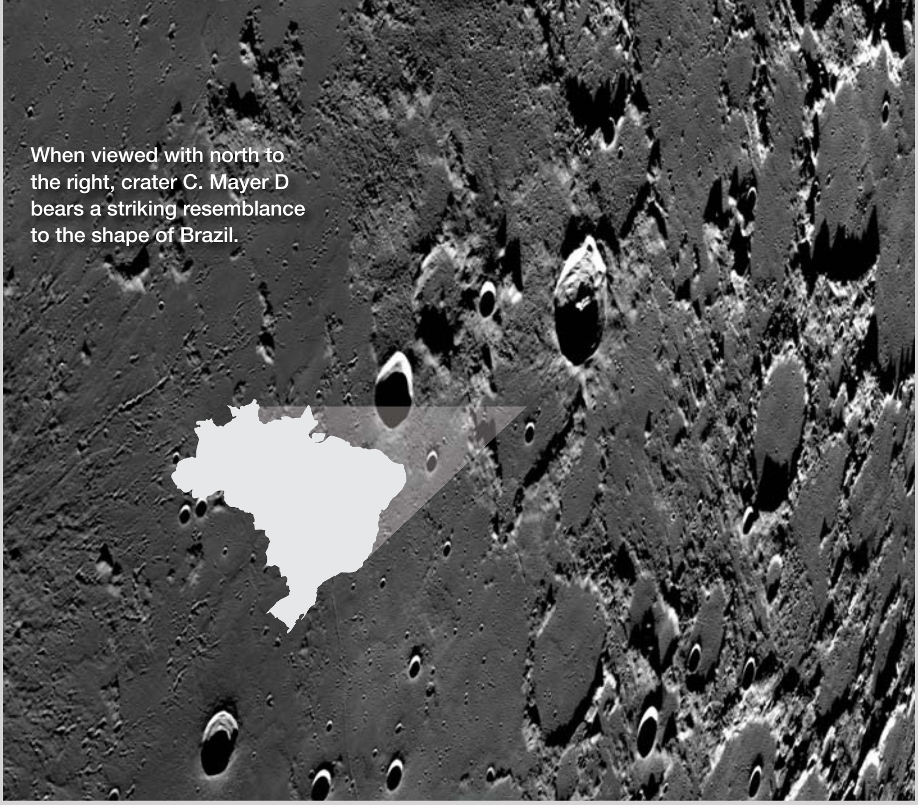
These examples distinguish between interpretations of observed features as real phenomena and recognition of just a similarity of shape. While Cassini didn't really think that Promontorium Heraclides was in fact the head of a giant woman, Hevelius did truly believe that Copernicus was a volcano. Likewise, Gruithuisen mistakenly thought his Wallwerk was indeed an artificial construction. Interpretations can be proved right or wrong with better information, but examples of pareidolia are imaginative comparisons that make observations more descriptively interesting.

Surprisingly, only a few lunar features have pareidolic nicknames. Perhaps the best known is the **Lunar X**, a conspicuous cross that appears on the terminator when the Moon is near first quarter phase. It's a fleeting apparition created by adjacent crater rims that catch the rising sunlight for only a few hours before the surrounding area is illuminated, causing the cross to vanish. The northeastern and southeastern walls of the 115-km-wide crater **Purbach** make the western half of the X, and the western rims of **La Caille** and **Blanchinus** comprise the eastern half.

A second, lesser-known cross is visible at full Moon when the floor of 41-km-wide **Plinius** is crossed by a broad X of bright material, with the central peak of the crater providing a bright central spot. And just west of **Rima Hyginus** and north of **Ukert** is the rarely seen **Lunar V**. This unofficial feature is harder to notice under sunrise conditions than the similar-sized Lunar X due to it being the southern rim of a crater that was nearly buried during the period of surging Imbrium ejecta 3.8 billion years ago.

What about other letters in the English alphabet? There are 24 additional letters for which pareidolic examples are rarely mentioned. The letter C is recognizable at sunrise for **Plato**, **Archimedes**, and many other large and small craters when sunlight reflects brightly from their western interior rims while the rest of the crater is in deep shadow. Many, many small craters on the maria each make a perfect O at full Moon; **Bessel** is an excellent example.

Probably there are some lunar Is and maybe even a B, D, L, or T, but frankly I am not very interested in them or the Xs, Vs, Cs, and Os. Examples of pareidolia tell us very little geologically and are nothing more than accidents of topography and illumination. But admittedly such standouts are a pleasure to stumble upon unexpectedly, at least for observers who use the Latin-derived alphabets common to Western Europe and its former colonies. I wonder if X is as satisfying for observers whose language is written in entirely different scripts or characters?

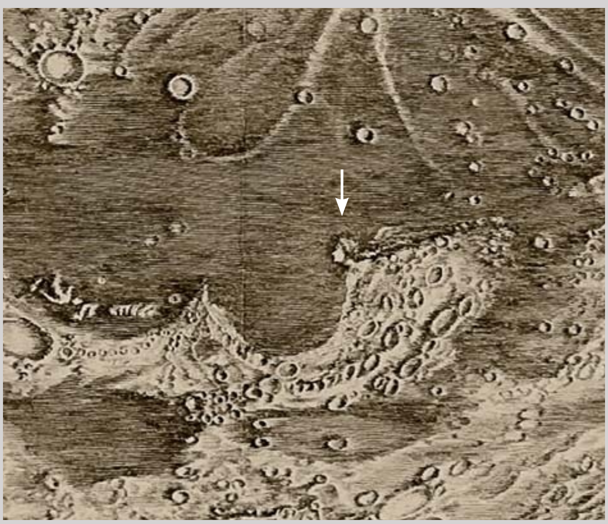


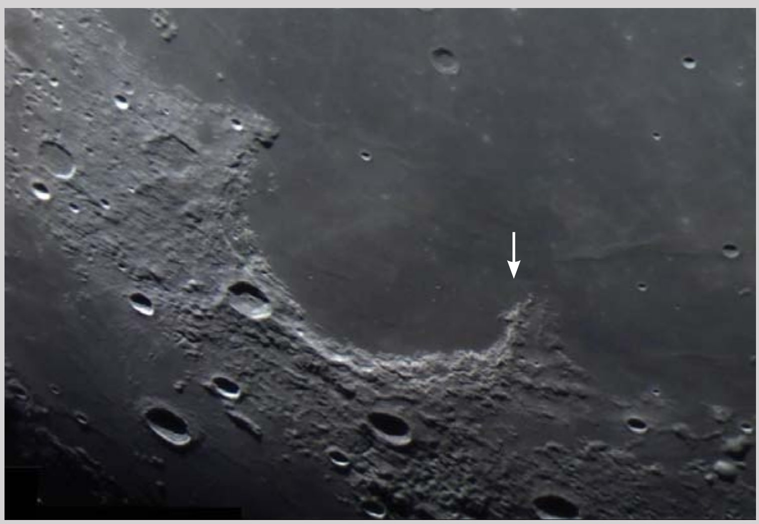
When viewed with north to the right, crater C. Mayer D bears a striking resemblance to the shape of Brazil.

There are a few instances of pareidolia that do bring geologic pleasure. For example, the **Valentine Dome** near the crater **Linné** is a volcanic structure appearing nearly flat and crossed by a rille that's often quite challenging to observe. And at least one other example of pareidolia always causes me to smile. Brazilian observer Ricardo Jose Vaz Tolentino noticed that the foreshortened view (turned so that north is at right) of the 65-km-wide lunar crater **C. Mayer D** is an uncanny match of the outline of Brazil — it even has a crater at the location of Brasilia. Now that's creative thinking!

■ Contributing Editor **CHUCK WOOD** often looks for Cassini's maiden when observing the Moon.

▼ Giovanni Cassini saw the profile of a woman in the hills of Promontorium Heraclides when he drew his 1679 map of the Moon. You can spot her when observing Sinus Iridum just a day or two following first quarter. South is up in both images.





CRATER C. MAYER D: NASA / LUNAR RECONNAISSANCE ORBITER; BRAZIL MAP: KELSEY CHISAMORE / THE NOUN PROJECT; MAP: GIOVANNI CASSINI / PUBLIC DOMAIN; PHOTO: SEAN WALKER / *S&T*

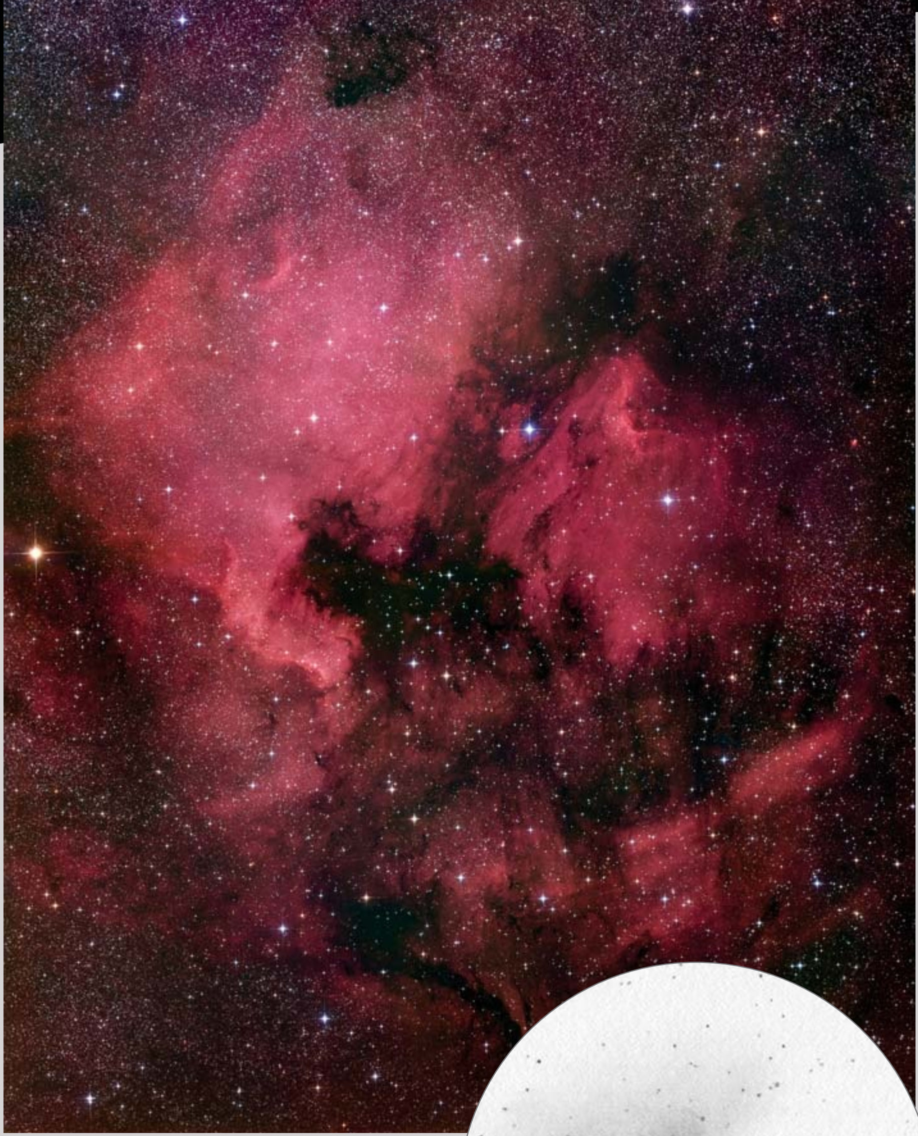
# Navigating North America

Knowing your geography puts you one step ahead in finding your way around this great nebula.

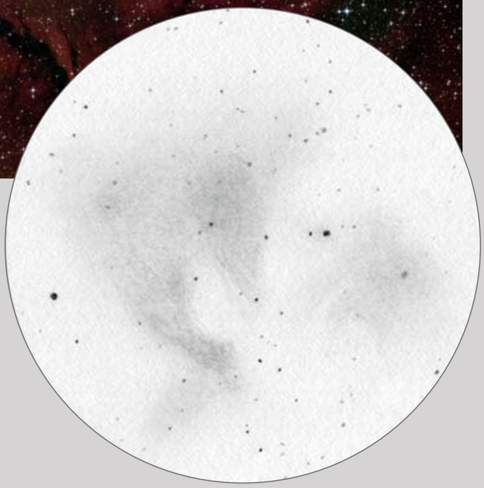
The North America Nebula is one of the most impressive nebulae glowing in our sky. This nebula's remarkable resemblance to the North American continent makes it better known by its common name — bestowed not by a resident of North America, but by German astronomer Max Wolf. In 1890 Wolf became the first person to photograph the North America Nebula, and for many years this remained the only way to fully appreciate its distinctive shape. With today's abundance of short-focal-length telescopes and wide-field eyepieces, we can more readily enjoy this large nebula visually.

The North America Nebula, **NGC 7000** or Caldwell 20, is certainly easy to locate. Just point your telescope to a spot in the sky about one-quarter of the way from 3.7-magnitude Xi (ξ) Cygni to Deneb. This will put you in the region of the celestial Gulf of Mexico. Be sure to use your lowest-power eyepiece. The nebula spans more than 2°, giving small telescopes a decided advantage. Even with modern eyepieces, large telescopes never show a wide enough field of view and must display the nebula a piece at a time.

**To celebrate 20 years of Sue French's stellar contributions to *Sky & Telescope*, we will be sharing the best of her columns in the coming months. We have updated values to current measurements when appropriate.**



▲ Connecticut amateur Robert Gendler made this mosaic of the North America Nebula and its environs with a Takahashi FSQ-106 f/5 refractor and SBIG STL-11000M CCD camera. North is up, and the field is 5° across. Note the dark oval of the Birds' Nest, 1 to 1½ inches from the top and just left of center. The image combines conventional color frames with others taken in hydrogen-alpha light to bring out fine structure in the nebula's predominantly red emission. For more about the technique, visit **robgendlerastropics.com**.



▶ For this sketch of a 3.6° field including the North America Nebula, Sue French used a 17× eyepiece on her 4.1-inch Astro-Physics Traveler — the same aperture employed for the digital image above.

NORTH AMERICA NEBULA: ROBERT GENDLER / STOCKTREK IMAGES / GETTY IMAGES

The pencil sketch reproduced above was made from the view through my 4.1-inch (105-millimeter) refractor at 17×. It shows the entire North America Nebula as well as the soft glow of **IC 5070**, the Pelican Nebula, off its East Coast (which lies westward on the sky). I'm often asked if the nebulae really look like this drawing. The answer is *yes* — if you view them the way they were sketched, in the dark with a dim red flashlight. Yet these nebulae aren't difficult to see. I've shared this view with many folks at public star parties. Few have trouble seeing NGC 7000, and most can see IC 5070. A third nebula, shy by nature, occupies much of the field. Do you see it? The Gulf of Mexico and the space between the East Coast and the offshore Pelican are filled by the dark nebula **LDN 935**.

I use a greenish O III filter to enhance the view at my moderately light-polluted observing site, but a narrowband filter works well too. Folks blessed with darker skies may find a filter unnecessary. Although I didn't try to sketch the wealth of stars that crowd the field, the view is impressive and even contains a few star clusters.

**NGC 6997** is the most obvious cluster within the confines of the North America Nebula. To me, it looks as though it's been plunked down on the border between Ohio and West Virginia. Putting 4.8-magnitude 57 Cygni at the western edge of a low-power eyepiece field should bring NGC 6997 into view. My 4.1-inch scope at 17× displays a dusting of very faint stars. At 47×, it's a pretty cluster, rich in faint stars, spanning 10′. Through my 10-inch reflector, I count 40 stars, mostly of magnitude 11 and 12. Many are arranged in two incomplete circles, one inside the other.

Is NGC 6997 actually involved in the North America Nebula? It's difficult to tell because the distances are poorly known. A journal article in 2004 puts NGC 6997 at around 2,500 light-years and adopts a value of approximately 3,300 light-years for the nebula. These figures are higher than those stated in many previous references. If valid, they identify the cluster as a foreground object. [Editor's note: Current figures place the North America Nebula at 1,800 light-years and NGC 6997 at 2,400 light-years away.]

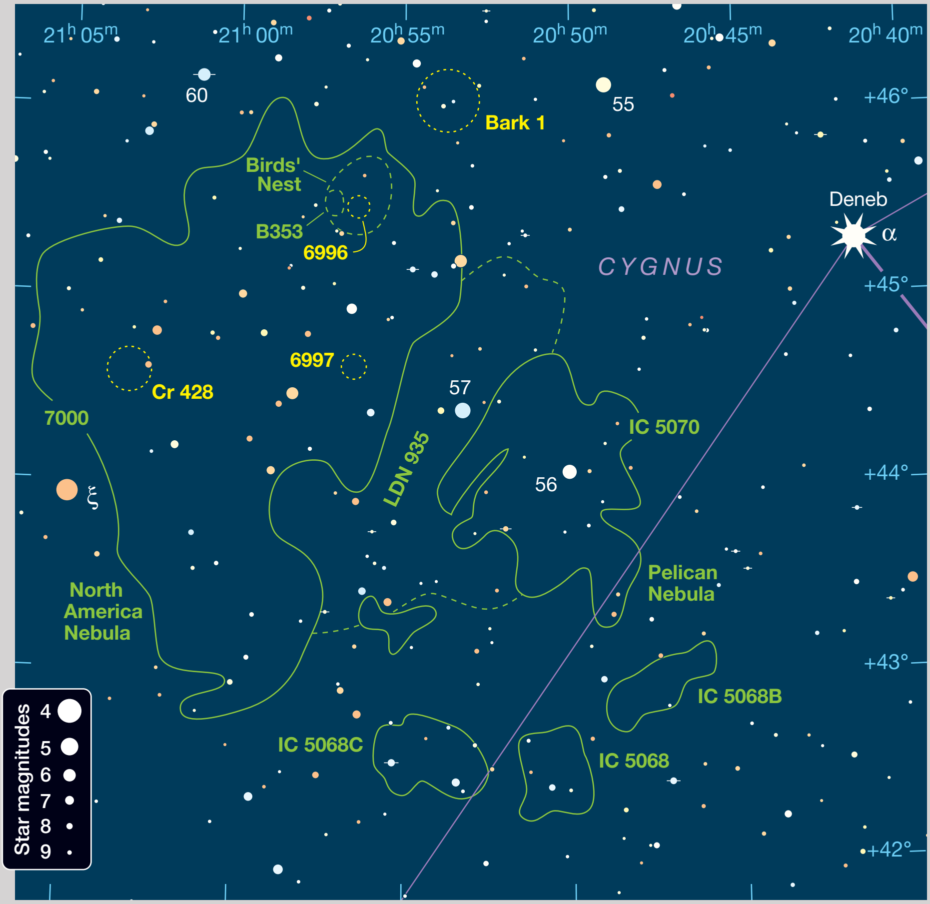
Dave Riddle, an avid deep-sky enthusiast from Georgia, brought the **Birds' Nest** to my attention. It has remained one of my favorite sights in this area ever since. The name comes from a 1927 article in *Popular Astronomy* magazine by Daniel Walter Morehouse. Entitled "A Ring Nebula (Dark) in Cygnus," it discusses an interesting feature visible in photographs of the North America Nebula. Morehouse commented that he had "been referring to this object for a number of years as 'The Birds' Nest' in the 'Hudson Bay' region." With my 4.1-inch scope at 47×, the dark rim of the nest is a 23′ oval ring running north-northwest to south-southeast.

The dark nebula **Barnard 353** forms the eastern border of the Birds' Nest, its inkiest section. I count 27 stellar "eggs" filling the interior of the nest. In my 15-inch Newtonian reflector, the center of the nest is crowded with stars. This area, or at least the southern part of it, makes up **NGC 6996**, a concentrated portion of the Milky Way enisled by the dark nebulae surrounding it.

NGC 6997 was discovered by William Herschel and NGC 6996 by his son John, both observing from England two centuries ago. Even though the positions given by father and son were fairly good, the two clusters have frequently been mixed up on atlases and in professional journals. Over the years, such notables as German astronomer Karl Reinmuth, French astronomer Guillaume Bigourdan, and U.S. astronomers Harold Corwin and Brent Archinal have untangled the identifications.

If the Birds' Nest is in Hudson Bay, then **Barkhatova 1** must be somewhere on Baffin Island. A pair of 7th-magnitude stars conveniently points straight to it, the more distant one golden and the closer one white. At 47×, my 4.1-inch scope shows a pretty dusting of 30 stars, moderately faint to very faint, with the brightest two in the southern part of the cluster. A large oval gap in the eastern side of the group harbors a lone, very faint star. A reddish star sits at the eastern side of Barkhatova 1, and a golden star rests beyond its western border. My 10-inch scope reveals about 60 stars within 20′.

We've visited the East Coast and Canada; now let's move over to northern Idaho, where we find **Collinder 428**. Putting 3.7-magnitude Xi Cygni at the southern edge of a low-power eyepiece field should bring this cluster into view. My little refractor displays a dozen faint



stars in 12′ with a 7th-magnitude star on the western edge. In my 10-inch reflector, the bright star appears orange and the star count doubles. The cluster looks somewhat like a fragment of the Milky Way isolated by a trapezoid of dark nebulae.

Three challenging patches of nebulosity lie south of the Pelican, roughly where you'd expect to find the northern coast of South America. The central patch is **IC 5068**, faint but definitely visible through my 4.1-inch scope with an O III filter. It looks blocky, with two 9th-magnitude stars in its eastern side: one near the northern corner, the other near the southern. Through my 15-inch scope, the dimensions are about ½° north-south and ⅓° east-west. The nebula's brightest star is south of center and shines at 7th magnitude.

Just to the northwest is a swath of nebulosity labeled **IC 5068B** on the software atlas MegaStar5. Harold Corwin of the NGC/IC Project [Editor's note: no longer extant] has tentatively identified this as IC 5067. It's just a vague presence in my small scope but fairly bright in the large one. As seen with an O III filter at 57×, it runs southeast to northwest for ¾° and is one-third as wide. A line of three 7th- through 9th-magnitude stars nearly parallels its northern edge. From east to west, they look blue-white, orange, and yellow when the filter is removed.

A third nebulous mass lies just east of IC 5068, and it is called **IC 5068C** in MegaStar5. I haven't managed to see this with my small scope, but it's visible in the 15-inch. What size telescope do you need to spot it? IC 5068C is about 25′ across and looks patchy, with a dimmer north-south band west of center. Two 7th-magnitude stars are widely spaced in its southern edge.

When next it's clear and your telescope beckons, why not go out and explore a continent?

■ Contributing Editor **SUE FRENCH** penned this column for the October 2004 Deep-Sky Wonders.

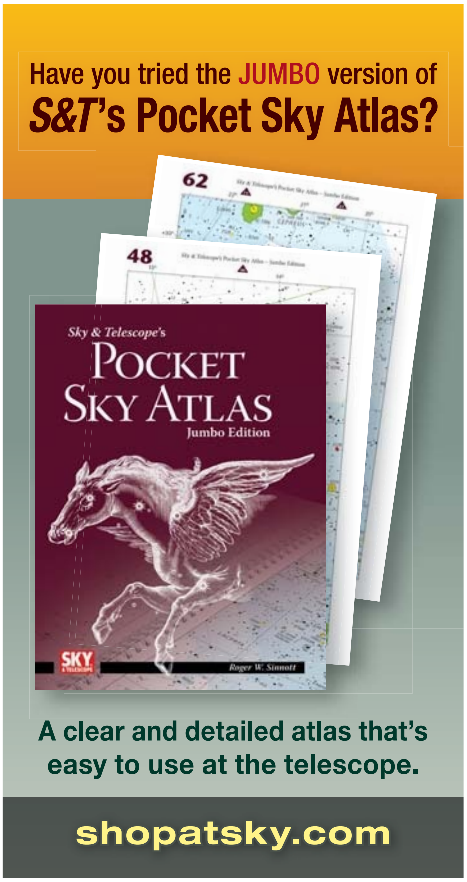
This "close-up" of the Pelican Nebula (IC 5070) represents a total exposure time of 22½ hours. The image was captured with a Tele Vue NP101is 100-mm f/5.4 apochromatic refractor with Hα, O III, and S II filters on an Astro-Physics AP900GTO CP3 mount.

CHRIS BARON / 500PX PLUS / GETTY IMAGES

## Field of Cygnus's North America Nebula

| Object | Type | Mag(v) | Size/Sep | RA | Dec. | *MSA* | *U2* |
|---|---|---|---|---|---|---|---|
| NGC 7000 | Emission nebula | 4 | 120′ × 100′ | $20^h$ $58.8^m$ | +44° 20′ | 1126 | 32L |
| IC 5070 | Emission nebula | 8 | 60′ × 50′ | $20^h$ $51.0^m$ | +44° 00′ | 1126 | 32L |
| LDN 935 | Dark nebula | — | 90′ × 20′ | $20^h$ $56.8^m$ | +43° 52′ | 1126 | 32L |
| NGC 6997 | Open cluster | 10 | 8′ | $20^h$ $56.5^m$ | +44° 37′ | 1126 | 32L |
| Birds' Nest | Dark neb., star cloud | — | 23′ × 18′ | $20^h$ $56.3^m$ | +45° 32′ | 1126 | 32L |
| Barnard 353 | Dark nebula | — | 12′ × 6′ | $20^h$ $57.4^m$ | +45° 28′ | 1126 | 32L |
| NGC 6996 | Star cloud | 10 | 5′ | $20^h$ $56.4^m$ | +45° 28′ | 1126 | 32L |
| Barkhatova 1 | Open cluster | — | 20′ | $20^h$ $53.7^m$ | +46° 02′ | 1106 | 32L |
| Collinder 428 | Open cluster | 8.7 | 13′ | $21^h$ $03.2^m$ | +44° 34′ | 1126 | 32L |
| IC 5068 | Emission nebula | — | 25′ | $20^h$ $50.3^m$ | +42° 31′ | 1126 | 32L |
| IC 5068B | Emission nebula | — | 42′ × 14′ | $20^h$ $47.3^m$ | +43° 00′ | 1126 | 32L |
| IC 5068C | Emission nebula | — | 25′ × 18′ | $20^h$ $54.2^m$ | +42° 36′ | 1126 | 32L |

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 columns headed MSA and U2 give the chart numbers of objects in the *Millennium Star Atlas* and *Uranometria 2000.0*, 2nd edition, respectively.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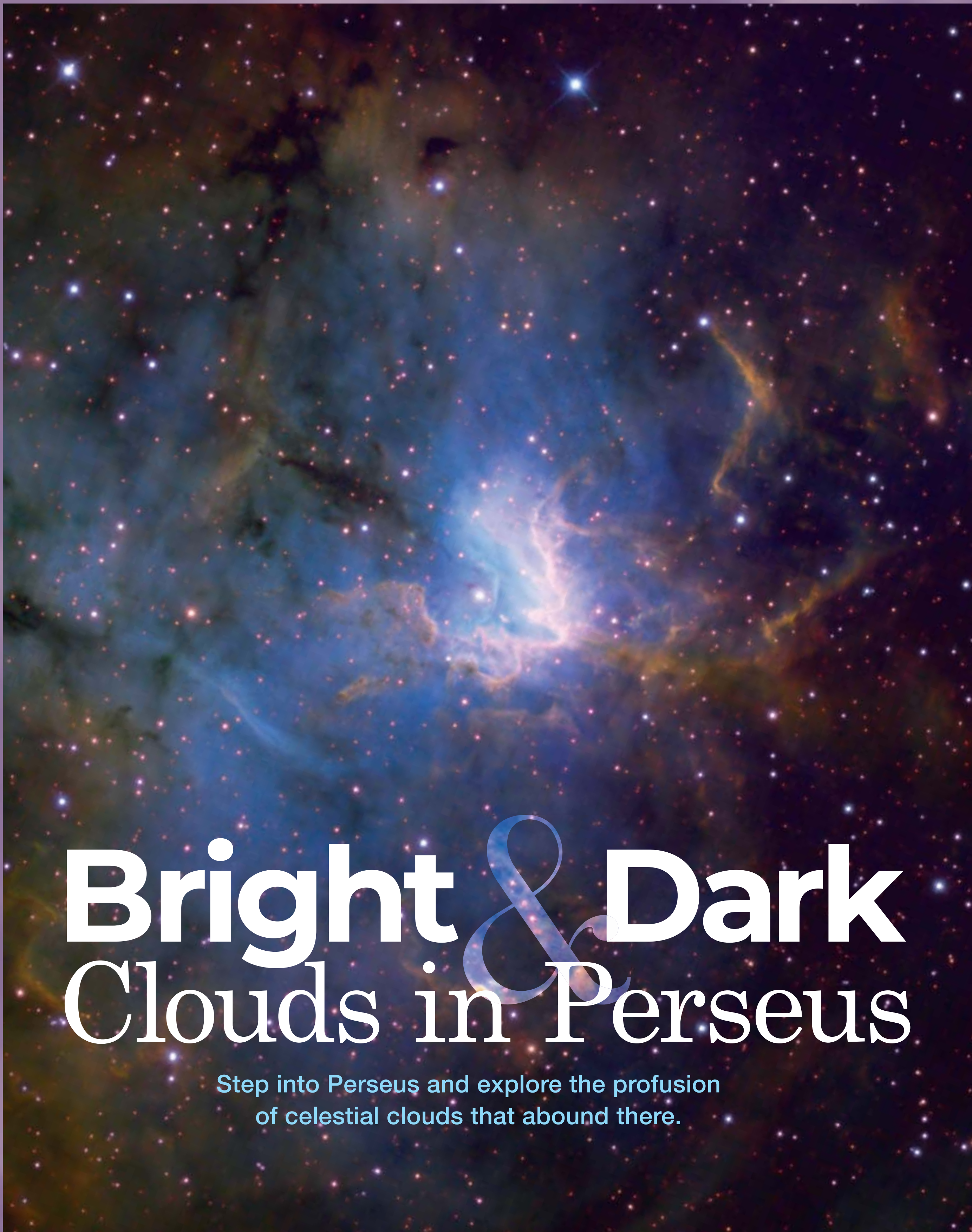


# Bright & Dark Clouds in Perseus

Step into Perseus and explore the profusion of celestial clouds that abound there.

NGC 1491: STOCKTREK IMAGES / GETTY IMAGES; BACKGROUND TEXTURE: PAUL SOUDERS / STONE / GETTY IMAGES PLUS

I began serious deep-sky observing in the late 1960s at a very dark observing site deep in the Kansas Flint Hills. My equipment at the time consisted of a 50-mm f/8 Tasco refractor and a 40-mm Kellner eyepiece that provided a magnification of 10× and covered an area of several degrees. I later found out that my site was only about 15 miles from where Walter Scott Houston (of longtime *S&T* fame) began his deep-sky observing. The advantage of the Flint Hills is that they're the highest and least populated topographical feature in the region. On nights when the fog settles below the hills and blankets surrounding cities, one obtains a dark sky of truly epic proportions! It was on such nights that I realized that I could see a number of what appeared to be huge dark nebulae stretching from Cygnus in the north down past either side of the Cepheus Star Cloud. The nebulae extended almost all the way to Polaris on the star cloud's eastern flank and curved into Cassiopeia, Camelopardalis, and Perseus on its western flank.

Being young at the time, I thought I had just made a magnificent discovery. But, at the library of the local university, I soon discovered that in 1962 American astronomer Beverly Lynds had already mapped a large number of nebulae using data from the National Geographic Society–Palomar Observatory Sky Survey. Lynds' *Catalogue of Dark Nebulae* improved and expanded on E. E. Barnard's work on individual dark nebulae. She also assigned ID numbers to larger structures that were an aggregation of several individually cataloged nebulae. In this I learned a valuable lesson in the pursuit of science: Excellent eyes and a quality site are still only useful if backed up by the diligent study of the latest astronomical research! I would later use many telescopes of various sizes and types as both an amateur and a professional astronomer, but I never forgot that this science we practice is primarily an exciting adventure to be enjoyed.

Let's embark on this adventure in the constellation of Perseus, and visit the profusion of nebulae that reside there.

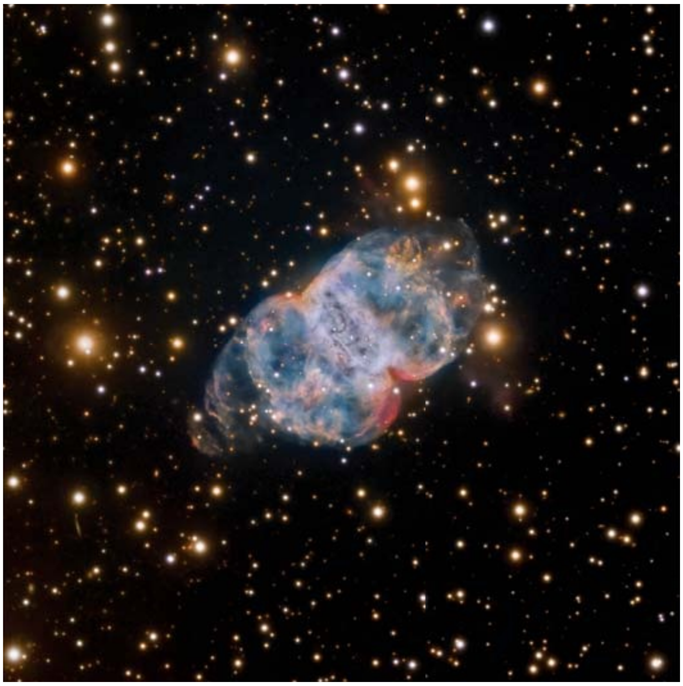
◀ **BRIGHT NEBULA** The constellation Perseus is a hotbed of a variety of different nebulae. One fine example is NGC 1491, a bright emission nebula that lies about 1° north-northwest of Lambda Persei. An 11.2-magnitude blue star illuminates the surrounding nebulosity.

## A Planetary and a Bright Nebula

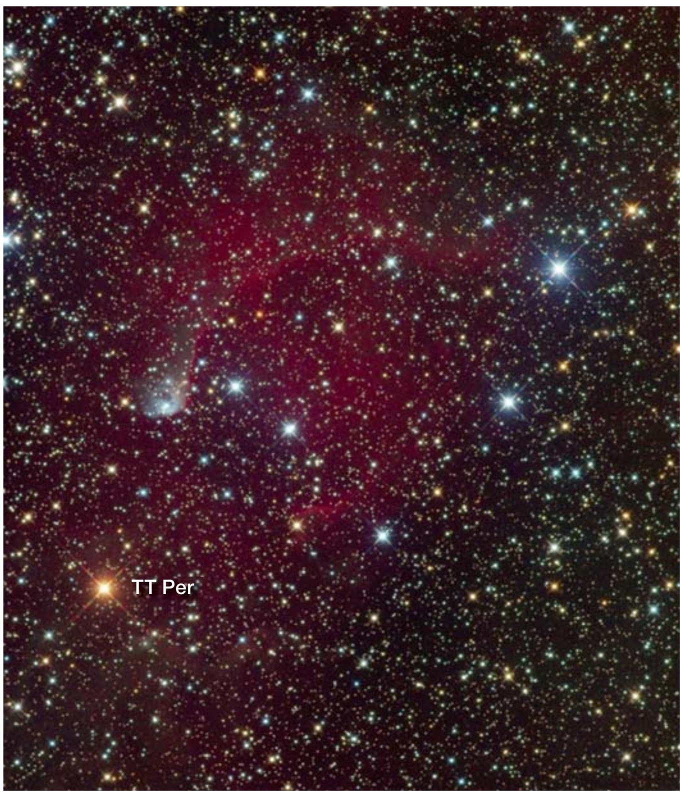
In the northwesternmost corner of the constellation we find **M76**, also known as NGC 650 and NGC 651, and by its nickname the Little Dumbbell Nebula (due to its resemblance to M27, the Dumbbell Nebula). This delicate planetary nebula was discovered in 1780 by French astronomer Pierre François André Méchain. You'll find M76 a little less than 1° north-northwest of Phi (φ) Persei and about 12′ (arcminutes) west-northwest of the 6.6-magnitude star HD 10498. The planetary nebula changes in appearance as telescope size increases. A small scope will tend to show one larger object, but as size and magnification are increased, the object breaks up into several separate brighter areas (hence the multiple NGC designations). These brighter patches are connected by an arc, and all these features reside within fainter general nebulosity. In the eyepiece, the southwestern lobe is somewhat brighter than the northeastern one.

Just 2½° north-northeast of M76 is the little-known bright nebula designated **LBN 640**. It's an intriguing object, in that under a perfect sky you might be able to pull out the entire 30′-sized object. You might also spot the smattering of 7th- to 9th-magnitude stars, including the reddish variable TT Persei, nearby. However, most of the time I've found that the easier part of this nebula is in its northeastern corner, an area around 5′ across peppered with stars ranging in magnitude from 11 to 13. Of course, it could just be that this part of the nebula is easier to detect due to the fainter stars — I'll let you be the judge!


▶ **JOURNEY THROUGH PERSEUS** The author takes us on a tour of bright and dark nebulae in Perseus. Use this chart to follow his itinerary. Note that the nebula symbols are not to scale. See the images on page 63 for zooms into the NGC 1333 and IC 348 regions.



▲ **THE LITTLE DUMBBELL NEBULA** M76, originally thought to be two separate emission nebulae, was assigned two NGC numbers: 650 and 651. Its nickname derives from its resemblance to the Dumbbell Nebula (M27) in the constellation Vulpecula. You'll most likely find the Little Dumbbell listed under any one of its designations.




▲ **LBN 640** Under ideal conditions, you might be able to tease out the full 30′ extent of this nebula, which floats ethereally in the northwestern corner of Perseus. The star TT Persei will guide your way to the nebula.

## The Eastern Outskirts

Let's slide across to 4th-magnitude Lambda (λ) Persei and from there continue about 1° northwest where you'll find the emission nebula **NGC 1491**. Discovered by William Herschel in 1790 and listed in his catalog as the 258th object in the "bright nebulae" category, NGC 1491 has a main band of nebulosity aligned almost north-south on the western side of an 11th-magnitude star. There's also a less distinct arc south of the band running east to west. See if you can tease out the many faint stars sprinkled in and around the main band. Slewing a little less than 6° east-southeast brings us to the open star cluster and bright emission nebula **NGC 1624**, also discovered by William Herschel in 1790 and listed as the 49th object in his "very large nebulae" category. The cluster is relatively poor, but the lack of a bright star allows this fine collection of 12th- and 13th-magnitude stars to shine. The nebulosity is also faint and envelops the open star cluster in a manner reminiscent of the Pleiades; however, in NGC 1624, the stars don't overwhelm the nebulosity.

Let's move on to some dark nebulae. Hopping about ¾° northwest of NGC 1624 takes us to **B20** — can you make out this dark nebula that's 1° × 1° in size? Next, slew some 4½° south to find **B15**. Need another reference point? Go to 53 Persei, and from there move east a little less than 2°. Even though the darkest part of B15 is only about 13′ across, rest assured that in the eyepiece the nebula as a whole is similar in size to B20.

The last object that we'll visit in this upper eastern corner is **Sh 2-216**, one of the closest planetary nebulae to Earth at a distance of around 530 light-years. Located some 2° east of B15, it's a large object, spanning 3° × 2°, and it's also rather faint. The planetary is best viewed using the "field sweeping" technique, and if you have one, an O III filter will help.

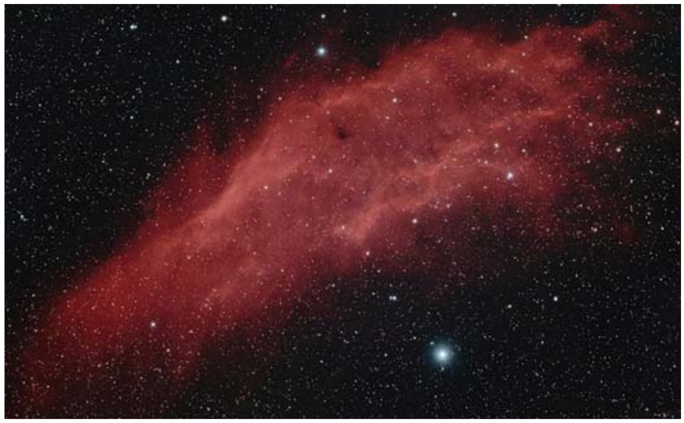
As we continue our journey counterclockwise through the constellation, from Sh 2-216 let's go some 4½° south to find **GN 04.41.8**, a mere 13′ southeast of the open star cluster Berkeley 68. This relatively small reflection nebula, only around 3′ across, is embedded with a number of faint stars. As with NGC 1624, the smattering of 11th- to 13th-magnitude stars doesn't overwhelm the faint nebulosity — on the contrary, the stars help in viewing the wispy cloud.

Continuing counterclockwise, we arrive at **NGC 1579** in the southeasternmost corner of the constellation. Discovered by William Herschel in 1788 and cataloged as the 217th object in his list of bright nebulae, this nebula is similar in appearance to M20 (also known as NGC 6514) — the Trifid Nebula in Sagittarius. In fact, NGC 1579 is often referred to as the Northern Trifid. Like the Trifid Nebula, NGC 1579 is generally a round nebula with patches of varying brightnesses and a number of dark lanes going through it. A 9th-magnitude star is associated with the brightest lobe, and almost a dozen stars down to 13th-magnitude are spread across the entire nebula. I note a three-dimensional effect when looking into this object due to looking past so many layers of faint clouds of dust and gas right into the heart of a stellar nursery.

Just 12′ to 13′ northeast of the center of NGC 1579 is the much fainter reflection nebula **IC 2067**, discovered by Welsh amateur astronomer Isaac Roberts in 1894 and reported in the *Second Index Catalogue of Nebulae and Clusters of Stars* published in 1908. The nebula is centered on a yellow star of 12th magnitude (and is similar to the fainter nebulosity just off of M20, if you've had the opportunity to observe this object).

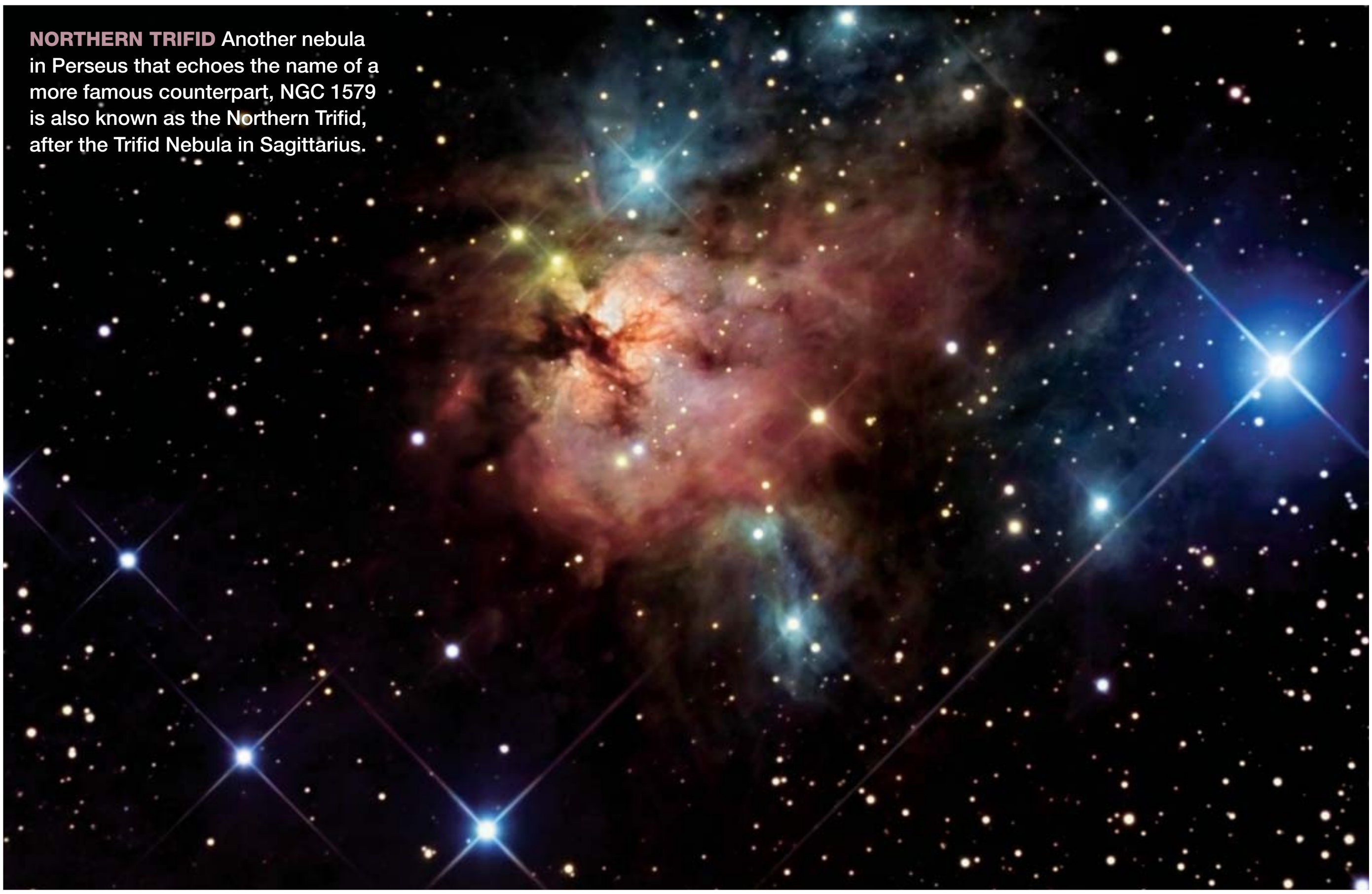
## Along Perseus's Leg

Next, let's slew back west and spend some time looking over the many fields of view of **NGC 1499**, also known as the California Nebula. This emission nebula was discovered by Barnard in 1885 using a 6-inch refractor at the observatory of Vanderbilt University. (Barnard studied astronomy and mathematics at Vanderbilt, and even though he never graduated, he was hired by the Lick Observatory in California just two years after he discovered NGC 1499.) You may have trouble seeing NGC 1499, but it's only a question of field of view. You typically can't see an object if you can't see where



▶ **YOUNG CLUSTER** *Top:* NGC 1624, in the northeastern corner of Perseus, is composed of a very young open cluster embedded in an emission nebula.

▶ **THE CALIFORNIA NEBULA** *Bottom:* Also designated NGC 1499, this delicate yet large nebula floats in Perseus's leg. You may need to employ the "sweeping technique" to snag this object.



**NORTHERN TRIFID** Another nebula in Perseus that echoes the name of a more famous counterpart, NGC 1579 is also known as the Northern Trifid, after the Trifid Nebula in Sagittarius.

NGC 1624: MASIL IMAGING TEAM; NGC 1499: HEWHOLOOKS / CC BY-SA 3.0; NGC 1579: STOCKTREK IMAGES / GETTY IMAGES it *isn't*: You have to have a field of view large enough to be able to know when you are on the object and when you have left it. If you do have a telescope with a large enough field of view (the nebula is more than 2½° long!), use the "field sweeping" technique and NGC 1499 should become quite evident. It's also best to keep 4th-magnitude Xi (ξ) Persei, or Menkib, out of the field so as not to ruin your dark-adapted eyes.

We'll leave NGC 1499 by exploring a gigantic dark nebula to which Lynds assigned the identification number 188. This behemoth starts with **LDN 1449** on the northwest end of NGC 1499, and you can follow the dark nebulosity up toward 3rd-magnitude Epsilon (ε) Persei before it curves east, then southeast, and finally ends at NGC 1579.

Recenter your telescope back to Epsilon and then nudge it southwest a little less than 2° and you'll find the reflection nebula **vdB 24**. You should see two curving chains of 10th- and 11th-magnitude stars. Where these chains approach each other in the center of the field, you'll find several small, bright nebulae in a wider area of fainter nebulosity. The star at the center of all this is the 10th-magnitude variable star XY Persei, and just off the bright nebula, some 2′ northeast, is an 11th-magnitude red star that may also be associated with the nebulosity. Returning to Epsilon and from there swinging 1½° north you'll come to a classical dark nebula, **LDN 1440**.

▲ **VDB 24** This faint, bluish reflection nebula — captured with the 4-meter Mayall Telescope at Kitt Peak National Observatory — lies northeast of NGC 1499. The nebula is illuminated by the variable star, XY Persei.

## The Grand Finale

To conclude our tour of nebulae in Perseus, we're going to head to a collection of some rather fantastic objects in one of the more complex regions in the sky. Two reflection nebulae, **IC 348** and **NGC 1333**, lie a smidgen less than 3½° apart in the southernmost reaches of the constellation. They bracket several dark nebulae, including **B1**, **B2**, **B3**, and **B4**. **B5** is in the outskirts, northeast of IC 348, and also associated with the region are **B202**, **B204**, and **B206**, which spill south into Aries. Lying on the border between Perseus, Aries, and Taurus, these clouds of gas and dust contribute to the Taurus dark cloud complex. Let's take a closer look at these objects and their companions.

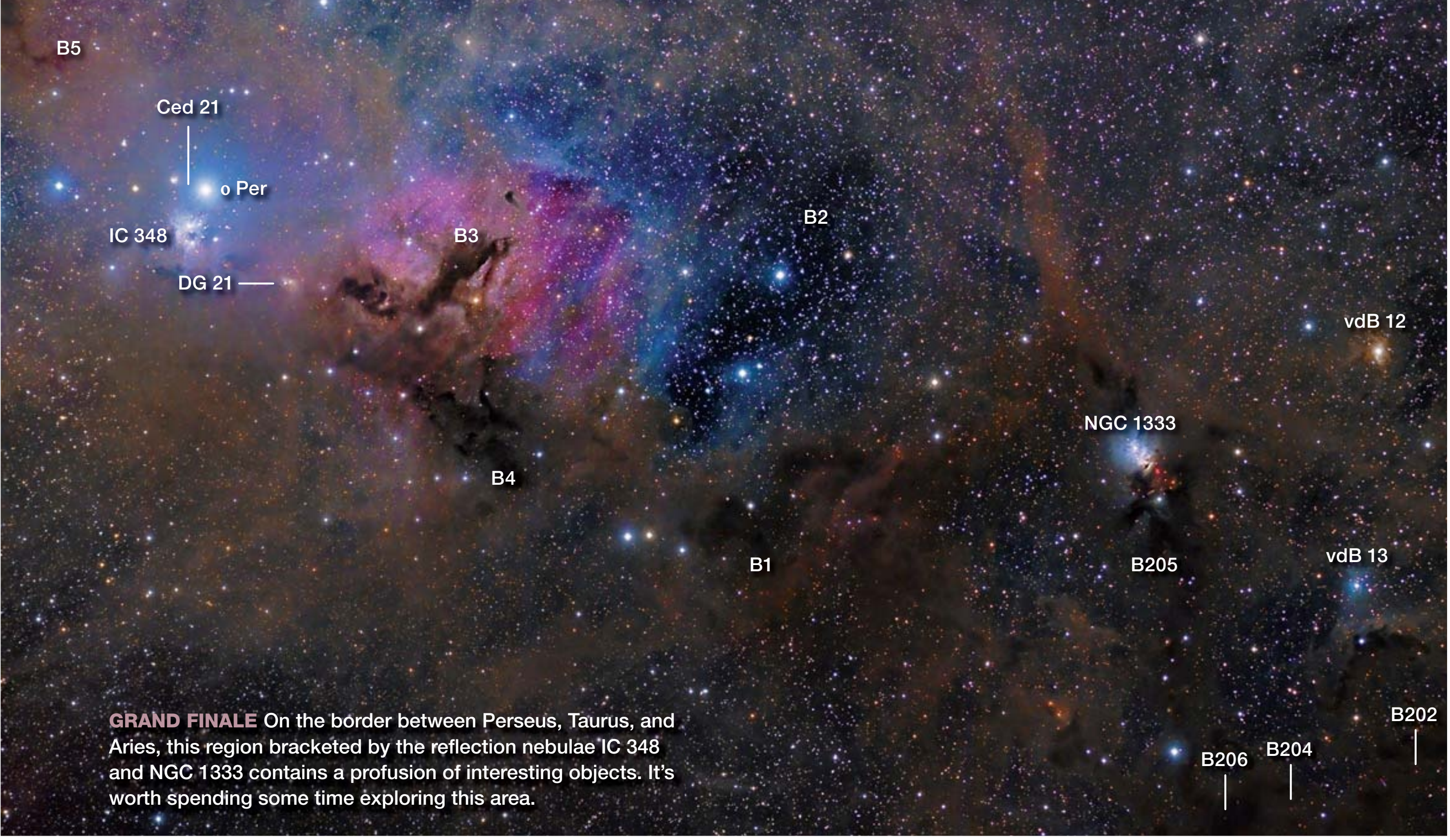
Start by locating 4th-magnitude Omicron (ο) Persei (also known as 38 Persei and Atik). South of this blue star is an open star cluster that you'll easily see is associated with a bright nebula — you've found the reflection nebula IC 348. This star-forming region, discovered in 1866 by American astronomer Truman Henry Safford, is somewhat overwhelmed by the presence of such a brilliant star a mere 8′ away.

Some 10′ north-northeast of IC 348 (and 5′ northeast of Omicron) is a faint double composed of a 14th-magnitude star and its 16th-magnitude sidekick — you should be able to spot the reflection nebula **Ced 21** here. Slewing around 1° northeast of Omicron, about three-quarters of the way in a direct line to Eta (η) Persei — also known as 42 Persei — will bring us to B5, which stretches into the upper left limit of this region.

Reorient yourself with Omicron, and we'll head into the main conglomeration of objects here. From Omicron, slide southwest about 25′ and you'll find a double star consisting of 11th- and 14th-magnitude components — these are associated with the faint nebulosity of the reflection nebula **DG 21**.

Continuing on our southwestern route we come to B4, a large dark nebula that has a protuberance at its northern edge, which is B3. Following an arc of 7th- to 9th-magnitude stars (HD 22418, the reddish HD 22360, and HD 22307) at the southwestern end of B4 brings you to B1. To its upper right you'll find B2, an elongated dark cloud peppered with a smattering of brighter stars. Before heading to our final stop, let's visit two reflection nebulae on the far western edge. Moving almost 2° west-southwest of the approximate center of B2 brings us to **vdB 12**, which is illuminated by the 7th-magnitude star HD 21110. About ¾° south you'll come to the pretty but challenging **vdB 13** (just over the border in Aries).

Let's finish our tour with a closer look at NGC 1333, an interesting object discovered by Eduard Schönfeld in 1855. The brightest part of NGC 1333, triangular in shape, surrounds a 10.5-magnitude star, HIP 16243. It extends to the southwest and can show some texture during periods of good seeing. As you slew your telescope farther southwest you will find various nebulous areas depending on the telescope used and the quality of your site and sky. A large telescope under ideal conditions may reveal some of the many Herbig-Haro (HH) objects in the area, bright areas of nebulosity associated with newborn stars that may be harboring nascent planetary systems. An example of possible protoplanetary disks in this region is **HH 12** on the southwestern edge of NGC 1333. At the outer edges of the nebulosity, south of NGC 1333 and HH 12, is a chain of Herbig-Haro objects that extends in a southeast-northwest direction. Included in the chain are **HH 7**, **HH 8**, **HH 9**, **HH 10**, and **HH 11**. On its own, some 4′ southeast of the chain, is **HH 5**. Bear in mind that Herbig-Haro objects are difficult targets because they're small. They're also faint. Many are often overlooked in nebula observing sessions because they don't always appear nebulous, but they're well worth




**GRAND FINALE** On the border between Perseus, Taurus, and Aries, this region bracketed by the reflection nebulae IC 348 and NGC 1333 contains a profusion of interesting objects. It's worth spending some time exploring this area.

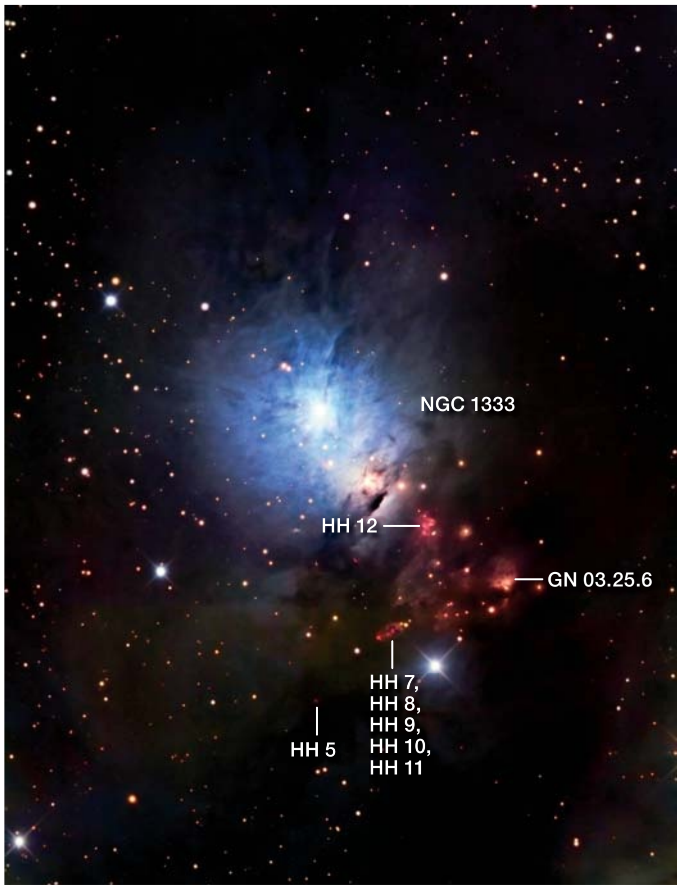
the effort. To wrap up, on the westernmost outskirts of these groupings is **GN 03.25.6**, a delicate reflection nebula.

You'll want to spend some time in the NGC 1333 area and generally in Perseus to see how many of its bright nebulous patches you can detect. Remember that much depends on the quality of the night sky. However, as you try to find each of the little bright objects, make sure you're not missing the 800-pound gorilla in the room: the dark nebulae! Perhaps the reason virtually all observing guides rank dark nebulae as the most difficult objects to find is that it's tough to see them when they're directly in the field of view. We're primed to see something "bright" or "faint," but we simply never appear to be prepared to see "dark!"

Well, you're going to see some "dark" in this region for sure, and you can enjoy it if you're prepared for the fact that that's what you're looking for. You'll learn a very important and valuable lesson in life mentioned by a sage of the past: "All that is gold does not glitter, Not all those who wander are lost." That's certainly the case with our wander through these bright and dark nebulae. This is a location to return to many times in order to get the most out of this type of object — bright, faint, nebulous, stellar, dark . . . Suddenly an area of sky that has often been considered empty is so full of objects that it's difficult now to keep track of them all!

■ **RICHARD P. WILDS** is the author of *Bright and Dark Nebulae: An Observer's Guide to Understanding the Clouds of the Milky Way Galaxy* (CreateSpace, 2017).

**FURTHER READING: See https://is.gd/perseusnebulae for a table of object data.**

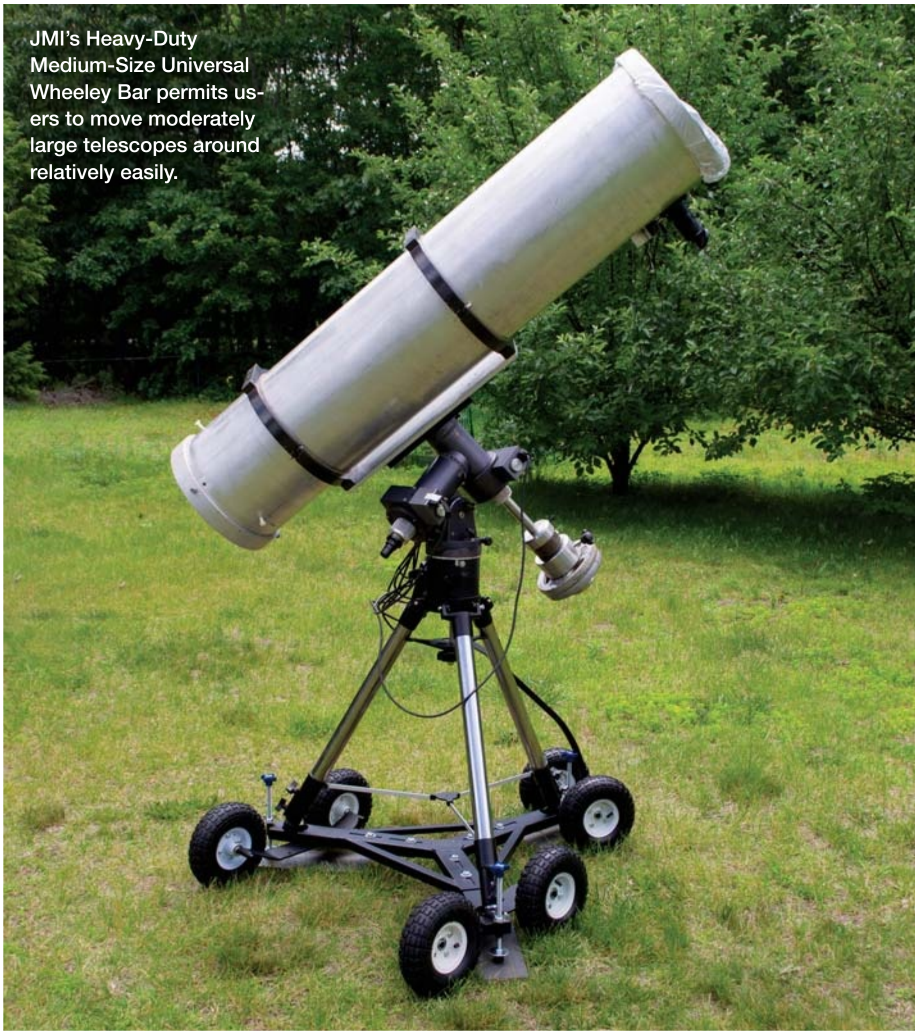



▲ **NGC 1333** You'll need the appropriate equipment and good observing conditions, but it might be worth trying to spot the fainter objects lying around NGC 1333. Use this image to guide you to their locations.

GRAND FINALE: JOHN DAVIS / STOCKTREK IMAGES / GETTY IMAGES;
NGC 1333: STOCKTREK IMAGES / GETTY IMAGES

# JMI Heavy-Duty Wheeley Bar

*This novel accessory helps you move your large scope with minimal effort.*



JMI's Heavy-Duty Medium-Size Universal Wheeley Bar permits users to move moderately large telescopes around relatively easily.

## JMI Heavy-Duty Medium-Size Universal Wheeley Bar

U.S. Price: $498 for the basic kit with 5-inch castors, $215 for 10-inch pneumatic large wheel and tow handle upgrade.
farpointastro.com

### What We Like

Solidly bears heavy telescope, mount, and tripod

Sturdy construction

### What We Don't Like

Wide turn radius

Rear wheels introduce steering error

**HAVING A PERMANENT HOME** for a big telescope is the dream of most dedicated amateur astronomers. The ability to have your scope ready for a night of observing or photography at a moment's notice is priceless. This is particularly true for those of us who live in climates where the weather can quickly change from good to bad and back again. Unfortunately, there are many obstacles that can prevent one from building that observatory — a custom structure is often a big investment beyond the reach of many. And those of us who rent probably can't put a permanent structure on our landlord's property.

Fortunately for those with access to a garage or large tool shed, there is a viable alternative to a dome or roll-off-roof structure: mobilizing your telescope with JMI's Wheeley Bars.

Wheeley Bars have been around for quite some time — Jim's Mobile Incorporated (JMI), a stalwart in the marketplace offering innovative products that solve problems unique to amateur astronomers, began producing models for tripod-mounted telescopes in the early 1990s. JMI was recently purchased by Optical Structures (which also acquired other time-tested innovators including Lumincon, Farpoint, and Astrodon, with the intention to continue to market and expand the offerings for amateurs).

As a longtime renter, I've used rolling telescope platforms for more than a decade and had eyed the Heavy-Duty Medium-Size Universal Wheeley Bar model with 10-inch pneumatic tires for quite some time. My yard in southern New Hampshire offers pretty good access to the sky, though I need to move my 12½-inch Newtonian reflector on a large equatorial mount across my yard to see the lowest stretch of the ecliptic, where all the major planets have been traversing for the past several years. Weighing more than 200 pounds with

▲ The north leveling foot of the Wheeley Bar doubles as the steering axle. Note the blue anodized bushing mentioned in the text.

ALL IMAGES: SEAN WALKER / S&T

counterweights, it's a bit too much to disassemble and move every clear night.

I arranged a loan of the platform to see how it would perform in my grassy yard. The model arrived in two well-packed boxes, one containing the main "Y" assembly with all the necessary hardware, the other containing six 10-inch tires, replacement axles, and a tow handle.

Assembly was very straightforward and only requires a crescent or socket wrench to completely assemble in less than 30 minutes. The instruction booklet included with the platform is well written, though be sure to pay attention to the photo that shows the blue anodized bushing when assembling the steering axle, or else you'll spend a good 5 minutes or more removing then replacing the 6-inch-long leveling foot that doubles as the steering pivot point.

The Medium-Size Universal Wheeley Bar is made of 3/32-inch powder-coated steel with ¼-inch stock for the axle supports. It accepts tripod leg diameters of up to 2⅜ inches, with an adjustable tip-to-tip distance between 34 and 42½ inches. It easily held my Millennium Mount attached to a Meade Field Tripod with the legs fully retracted.

▲ The steering wheels have a limited turning range due to the 10-inch pneumatic tires hitting the north foot plate of the Wheeley Bar assembly, resulting in a wide turning radius.

## Roll Out Observing

With everything assembled and ready to go, wheeling it out from my toolshed felt like I was rolling a Saturn V rocket onto the launch pad! The Wheeley Bar's six pneumatic tires looked impressive, as if I were moving much more weight than 200+ pounds. Pulling the unit out using the tow handle takes a little getting used to — it's a bit short for the job, forcing me to hunch over while pulling the scope in and out of my shed to my usual observing spot in the driveway. After a few observing sessions, I wondered if a longer tow handle was available (unfortunately not).

Pulling the scope around my yard to get to an area that offers the best view of the southern stretch of the ecliptic was relatively easy. My Meade Field Tripod feet sit well in the recessed openings on the Wheeley Bar, though as an added precaution, I secured each of the three tripod feet with a small bungee cord to avoid any unforeseen disaster when rolling the assembly over many bumpy spots in my yard.

I did encounter two issues that are due to the 10-inch Pneumatic Wheels upgrade. The first concerns the Wheeley Bar's steering mechanism. The design uses two wheels on an axle mounted to the pivot, which severely limits the turning radius of the unit. The wheels hit the frame after turning only about 35°, producing a very wide turning radius. If you have a lot of sharp turns between the place you store your scope and where you observe, you may want to consider the original 5-inch castors instead.

The second issue I experienced with the unit and its 10-inch pneumatic wheels has to do with the four rear wheels. Their layout is such that it places one tire in front of the other with an 8-inch gap between them. While this provides stability when rolling the scope around a bumpy landscape, it often caused the four back wheels to override the two steering wheels when trying to turn over grassy surfaces, forcing the scope to continue rolling straight ahead while trying to turn it left or right. This was sometimes rather frustrating, particularly in the dark when rolling my scope out to catch Saturn and Jupiter near opposition during the early summer months. I only encountered this issue on grass, and never when moving the Wheeley Bar over paved surfaces. One night I removed the two front wheels of each pair, given that they weren't necessary to bear the weight of my scope. This notably improved the steering in off-road conditions.

▶ Users may want to keep three boards or bricks handy to give the leveling feet a solid surface to crank down on.

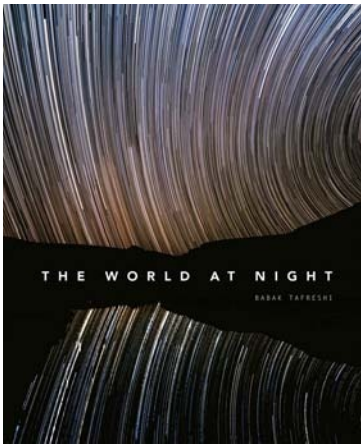
Clearance beneath the Wheeley Bar chassis is 2¼ inches, allowing it to pass over all the bumps and obstructions that often inhibited a competing scope platform I use. The leveling feet take a lot of screwing to secure your scope in its observing spot, but I found this could be mitigated by keeping three small boards or bricks handy to place under the feet when setting up on grass or dirt.

Once leveled, my scope was nearly as stable as if it were set up without a rolling platform beneath it.

Despite the inconvenience of its wide turn radius and occasional tracking error, I was pleased with the performance of the Wheeley Bar. If you have a large scope without the option of housing it in a permanent structure, then this is a good solution to get out under the stars much more frequently, particularly for users with short and direct distances to travel.

■ Associate Editor **SEAN WALKER** can often be found staking out the best locations in his yard to observe the planets.

## ▶ NIGHTSCAPE BOOK




*National Geographic* photographer Babak Tafreshi's latest book, *The World at Night: Spectacular Photographs of the Night Sky* ($40.00), showcases the photography of more than 40 members of the international photography group TWAN. Tafreshi curates the work to produce a collection of the most inspiring nightscape photography published to date. The book features more than 200 photographs, with commentary on the science, astronomy, and photography of each location interspersed with sections on astro-tourism, plus a specialist guide to night-sky photography that will help you capture your own gorgeous images of the heavens. Hardcover, 240 pages, ISBN 9781781319130.

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## ▲ FLUORITE DOUBLET

Takahashi announces the newest addition to its refractor lineup, the FC-100DZ ($2,850). This 4-inch f/8 apochromatic doublet pairs a fluorite element with a low-dispersion glass element with a high refractive index to provide sharp, color-free views across the visible spectrum. The optical tube assembly measures 59.5 cm (23.5 inches) long with a diameter of 95 mm. The telescope includes a retractable dew shield and a 2.7-inch rack-and-pinion focuser. The FC-100DZ accepts the optional FC-35RD photographic reducer ($1,060), making the instrument into an f/5.4 astrograph.

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

## ▲ LIGHT MOUNT

Sky-Watcher USA now offers a modular lightweight mount for visual and photographic use. The EQM-35 ($725) is a German equatorial mount capable of single- or dual-axis operation and weighs just 22.7 pounds. Its hybrid stepper motors produce slewing speeds of up to 1.8° per second, and its declination assembly can be replaced with a Star-Adventurer L-bracket or ball-head adapters, transforming the mount into a heavy-duty camera tracking system that can bear a load of up to 22 lb. Its SynScan Go To computerized hand controller includes more than 42,000 objects in its internal database and accepts ST4-compatible autoguiders. The mount includes an illuminated polar alignment scope, stainless-steel tripod, and two 7.5-lb counterweights.

**Sky-Watcher USA**
475 Alaska Ave., Torrance, CA 90503
310-803-5953; skywatcherusa.com

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# An Kythe the Mystery

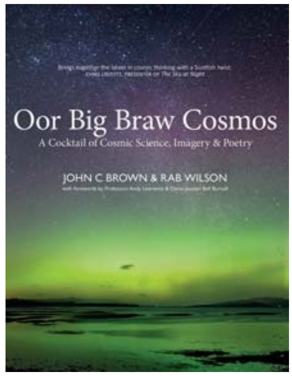
## OOR BIG BRAW COSMOS: *A Cocktail of Cosmic Science, Imagery & Poetry*

**John C. Brown and Rab Wilson**
**Luath Press Ltd, 2019**
**256 pages, ISBN 978-1-913025-05-2**
**US $45.00, UK £25.00, hardcover.**

**ASTRONOMER ROYAL FOR SCOTLAND** John C. Brown and distinguished Scots poet Rab Wilson have produced an unusual and thought-provoking exploration of the universe. With forewords by Andy Lawrence (University of Edinburgh) and Jocelyn Bell Burnell (Oxford University), *Oor Big Braw Cosmos: A Cocktail of Cosmic Science, Imagery & Poetry* brings together science and art to tell the story of our cosmos from a deliberately Scots perspective.

Written to be an accessible introduction to astronomy, *Oor Big Braw Cosmos* features photography from a number Scottish amateur astronomers, as well as illustrations by the American artist Lynette Cook. Though a legitimate guide to the universe — past, present, and future — what makes this book unique is its literary bent. As the title suggests, the Scots language makes frequent appearances in the text, so much so that the authors refer their readers to the Dictionary of the Scots Language (*Dictionar o the Scots Leid*) in the introduction. In addition, every chapter offers original Scots poems, penned by Rab Wilson. Wordplay meets science meets popular culture on every page.

The first half of the book details the history and structure of the universe, opening with a brief but lyrical explanation of the numbers and measures astronomers use to describe the cosmos. A succint review of the Big Bang in the first chapter is followed by a deeper exploration of planetary systems in the next. This is a good read, particularly if you've been meaning to catch up on current solar system science. Exoplanet science is always a moving target, but the authors provide a cogent summary of the methods used to search for new planets and descriptions of some of the more intriguing discoveries. Space art and poetry were put to good use in this section (look, for instance, for the "bricht unwavering steady licht" of the International Space Station).




Chapter 3 is dedicated to solar science, with a quick nod to Tlingit, Haida, and Tsimshian legends. A section on the Sun's atmospheric structure and space weather (solar flares, geomagnetic storms, and aurorae) is followed by several well-illustrated pages detailing the life and death of stars. This naturally leads into a discussion of star clusters, nebulae, and supernova remnants.

In Chapter 4, the authors go big, looking at galaxies and the large-scale structure of the universe. This is another colorful section, thoughtfully illustrated with Hubble Space Telescope photos and ground-based images captured by Scottish astrophotographers.

The fifth chapter beats as the true heart of the book; it's here that we get a direct look at some early Scots astronomers: James Gregory (the "Scottish Newton"); Alexander Wilson (solar structure); Thomas Brisbane (the world's first geomagnetic observatory); Mary Somerville (*The Mechanism of the Heavens* and *On the Connexion of the Physical Sciences*); Thomas Henderson (the first Astronomer Royal for Scotland); John Pringle Nichol (*The Architecture of the Heavens*); Charles Piazzi Smyth (the second Astronomer Royal for Scotland); James Clerk Maxwell ("What's the go o' that?"); and Williamina Fleming (curator of the Harvard College Observatory astrophotography plate collection).

Archaeoastronomy, with a focus on Neolithic structures in Scotland, as well as Scottish contributions to the analysis of sites like Stonehenge, is discussed in Chapter 6. Systems of modeling the universe, from Kepler to the planetarium to modern space art, are illustrated and explained.

Chapter 7 amplifies the authors' Scotland-inflected interactions with the cosmos. Particularly captivating is the use of high-latitude solarigraphs to reveal local weather variations. Musings on the coat of arms for the Astronomer Royal and observing in the north round out this section.

The book concludes with a few thoughts on the fate of the cosmos: the end of life on Earth and in our solar system, the fate of stars and galaxies, and, ultimately, the fate of the universe. An appendix includes suggestions for further reading, a map of Scottish sites of astronomical interest, and a cosmological timeline.

*Oor Big Braw Cosmos* has few weaknesses. It's easy to read (though you might have to learn a few Scots words), packed with images, and full of whimsical poems. If you have questions about the universe or Scotland's role in the history of astronomy, *Oor Big Braw Cosmos* will surely answer them.

■ Associate Editor **S. N. JOHNSON-ROEHR** once wrote an American History term paper on Scotland . . . and got away with it.

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# The "Binocrane" Parallelogram Mount

*Steady support is a must for binoculars.*

▲ The ends of a parallelogram remain parallel when the arms are raised or lowered.

**ANYBODY WHO'S TRIED** to hold up a pair of binoculars for more than a few minutes can tell you it's hard on your arms. And your neck. And your back. Binocular astronomers have it especially rough, since we have to look upward. While we're rubbing the crick in our necks after that first long observing session, we almost universally come to the same conclusion: We need a way to mount these things so we don't have to hold them up in our hands.

In my February 2018 column, I featured some nice binocular-mount designs, but I didn't mention one in particular that works exceptionally well — the parallelogram mount. Fortunately Colorado ATM Bill Kast has designed a beauty for us to consider.

Parallelogram mounts use a nifty trick of geometry: When you shift one side of a parallelogram, the other sides remain parallel. That means if you pin both the top and the bottom rails in place with the ends vertical, you can raise and lower the arms all you want and the ends will stay vertical. More to the point, the binoculars attached to brackets on the ends will remain level, so you don't have to tilt your head. A counterbalance compensates for the weight of the binoculars, so you don't even have to hold anything up. As Bill says, "This allows you to sit back in a reclining chair and gaze in comfort at objects all the way from the horizon to directly overhead."

Bill calls his mount the "Binocrane," a very apt name for it. Like a construction crane, it holds his binoculars on a rigid arm that can be raised and lowered at will.

Bill decided to build his out of aluminum tubing, both for strength and to minimize weight. And while designing it, he realized that he could extend the parallelogram outward in both directions from a central pivot point, allowing him to mount two pairs of binoculars at once. One end could carry a large high-power pair, while the other end could hold a smaller, low-power, wide-field model. As Bill explains, "Much like changing eyepieces in a telescope, this allows me to use different magnifications without dismounting and remounting binoculars."

Bill Kast's parallelogram mount makes binocular observing easy on the arms.

Bill calculated that all of the parts could be cut from a single 24″ × 24″ sheet of aluminum. The parallelogram bars would be constructed from two 1″ square by 5′ aluminum tubes. However, on his first try the arms proved too close together and his tripod was too flimsy. Bill says, "My first prototype wasn't an epic fail, nor was it an amazing success. So I went back to the drawing board and redesigned the tripod mount to accommodate a surveyor's tripod, and beefed up the end mounts, doubling the distance between the arms from 2 inches to 4 inches." He also added a third rail for extra strength and rigidity. The counterweight is suspended from all three beams rather than just the lowermost one, which distributes the load better. It also provides three more points of contact in the parallelogram structure, adding to its overall stability.

He tried a hand-driven angle bender to make the 90° bends required for the end brackets and the center uprights, but he found it impossible to make bends precise enough for all the mounting holes to line up. So he wound up using a quarter-inch-thick, 2″ × 2″

ALL PHOTOS BY BILL KAST

▲ *Top:* Photographers' pistol-grip ball-heads allow for easy aiming of the binoculars. *Bottom:* The heavy-duty central pivot is key to the Binocrane's success.

extruded aluminum channel and bolting his uprights to that.

This time the result was a resounding success. The Binocrane is stable as a rock, moves smoothly, and stays put when released.

The parallelogram structure provides a nice, steady platform for raising and lowering the binoculars and for swinging them around in azimuth, but how about tilting them up and down? For that, Bill uses two Dolica G100 pistol-grip ball-head camera mounts. They're plenty strong enough to hold even his 10-pound 25 × 100 binoculars at any angle, yet allow him instant freedom of motion simply by squeezing the grip.

Switching from one pair of binoculars to the other is simple: Just give the ones you're using a shove behind you and catch the other pair as it swings around in front of you. Thanks to PTFE bearings on the azimuth axis, the motion is smooth and easy.

Smooth and easy is the catch phrase here. The Binocrane makes binocular observing an all-night joy.

For more information, visit Bill's web page at **binocrane.com**.

■ Contributing Editor **JERRY OLTION** has used everything from a stick to the trunk lid of his car to steady binoculars, but he's seriously considering a Binocrane.

**BULLSEYE**

Daniel S. Schechter

The paths of the Sun and Moon perfectly intersected for slightly more than two minutes as seen in this timelapse captured over La Higuera, Chile, on the afternoon of July 2nd.

**DETAILS:** *Nikon D800 DSLR camera with 50-mm f/1.4 lens. Composite of 29 frames, with the image of totality exposed for two seconds.*

◁ POLAR BRUSH

Scott E. Lazerwith

The two broad equatorial "wings" seen in the solar corona extending toward the top right and bottom left are typically seen in an eclipse during solar minimum. Delicate polar streamers are visible in the top left and lower right of this image. South is at top left.

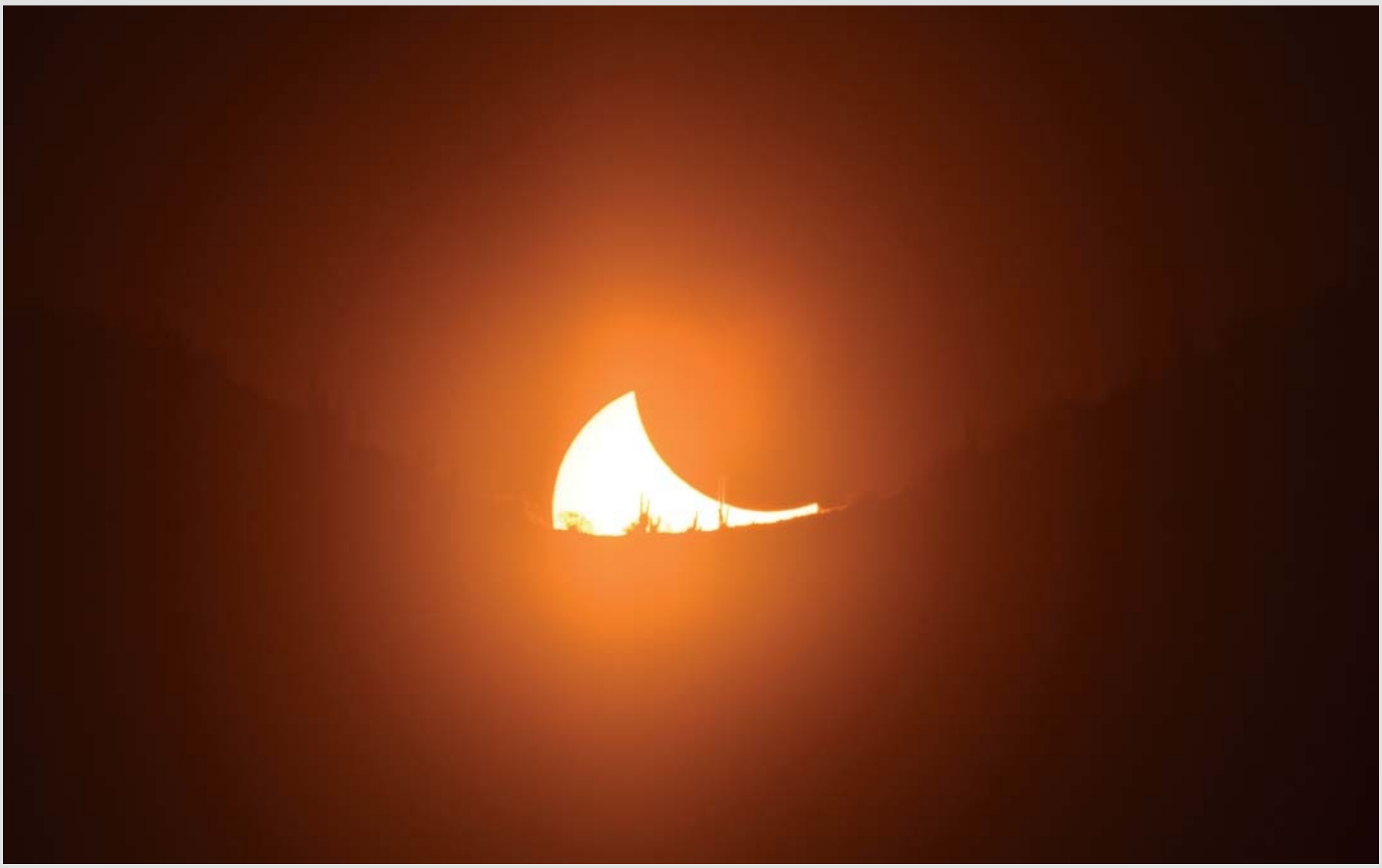
**DETAILS:** *Canon EOS Rebel T3i DSLR camera with 55-to-250-mm zoom lens at 250 mm. Total exposure: 1⁄20 second, ISO 200.*

▽ CACTI PHOTOBOMB

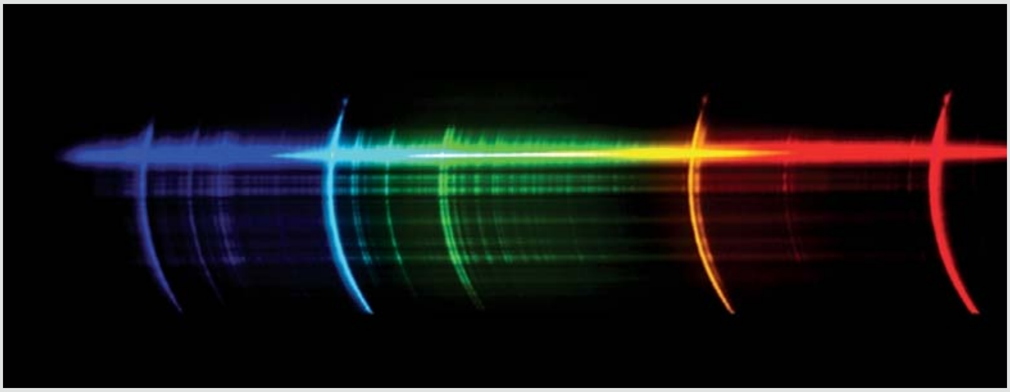
Randy Street

Several cacti scatter the light of the partially eclipsed Sun as it sets over Vicuña, Chile.

**DETAILS:** *Nikon D5500 DSLR camera with Nikkor 200-to-500-mm zoom lens at 500 mm. Total exposure: 3⁄5 second, ISO 400.*



◁ **SMARTPHONE TOTALITY**
Robert Smith
The eclipsed Sun appears to the right of the reflective dome of the 8.1-meter Gemini South Telescope at Cerro Pachón, Chile.
**DETAILS:** *Single frame taken from a time-lapse video recorded with an iPhone XR.*



◁ **FLASH SPECTRA**
Luis Manterola
The spectrum of the solar chromosphere seen during the final moments of the July 2nd eclipse displays several prominent emission lines.
**DETAILS:** *Canon EOS 70D DSLR with 8-inch Sky-Watcher Newtonian telescope and homemade spectrograph. Total exposure: 1⁄100 second, ISO 100.*

◁ **CRESCENT REFLECTIONS**
Wayne Squires
Internal reflections within the camera lens produced focused images of the partially eclipsed Sun as it's seen through a large cactus.
**DETAILS:** *Panasonic Lumix DMC-TZ110 camera with integrated zoom lens at 45 mm. Total exposure: 1⁄2000 second, ISO 125.*

**DIAMOND DAZZLE**
Andi Wolfe
The re-emerging photosphere is framed between two pinkish prominences, signaling the end of totality. **DETAILS:** *Canon EOS Mark VI DSLR camera with 100-to-400-mm zoom lens at 400 mm, f/5.6. Total exposure: 1⁄250 second, ISO 200.*

△ TOTALITY VALLEY

Callan Carpenter

The solar corona shines briefly above the surrounding hills at El Molle, Chile. Venus is also seen just above the horizon at center left.

**DETAILS:** *Canon EOS Mark III DSLR with 24-to-70-mm zoom lens set to 30 mm. Total exposure: 4 seconds at ISO 100.*

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**. Visit **skyandtelescope.com/online-gallery** for more of our readers' astrophotos.

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# The North Star Is Magic

*How and why I melted into goo at a star party*

**CAMILLE CARLISLE'S ARTICLE** *Secrets of Polaris* (*S&T:* Mar. 2019, p. 14) reminded me of one of my favorite observing experiences.

It was Public Night at the 2006 Shingletown Star Party in northern California, and I was just getting my 28-inch scope ready for observing. To align the tracking system on the north celestial pole, I began by finding Polaris in a low-power eyepiece, after which I planned to starhop to the NCP. But just as I got Polaris in the field of view, the public arrived.

"What you lookin' at?" came a voice out of the gathering darkness.

With the slightest hesitation I replied, "The North Star."

I'd almost said Polaris. But I thought calling it the North Star would make it more recognizable, and my hunch immediately proved correct.

"The North Star! Really? Wow, which one is it? Can we see?"

Somewhat puzzled by my questioner's enthusiasm, I invited him to have a look. More star partiers sauntered over, and before I knew it about 20 excited people had queued up for a view. The line was constant for the next hour.

Through the 28-inch, the North Star was actually quite a sight: sharp, bright, and beautiful, with its fainter companion star shining conspicuously nearby. The thin diffraction spikes coming off the primary star significantly enhanced the view. People oohed and aahed as if I were showing them a razor-sharp view of Saturn.

I was dumbfounded. I had no idea the North Star held such appeal.

While they waited, I told people in the line how the North Star lies at the end of the Little Dipper's handle, and that the two stars on the end of the Big Dipper's bowl point almost directly to the North Star. More oohs and aahs. The only disappointment I heard was one or two who were upset to learn that it isn't the brightest star in the sky.

The best part of this Public Night concerned a funny seven-year-old girl. She was funny, she told me, because her mom told her jokes. The girl was with several adults, and they stood in that long line — twice — to see the North Star. Each time she was transported by its beauty, and I was impressed.

Afterward my funny little friend skipped up to me and said, "I want to give you a hug!" I happily accepted, telling her she was very sweet. She bounced off with her companions into the dark, and I turned to the next person in line.

A few minutes later she was back, saying she had to give me another hug. I promptly melted into a puddle of goo. She was not only an adorable little girl but a fellow human being to whom I'd inadvertently bestowed a precious gift. Later I realized that she, and all whom Polaris dazzled that night, just as inadvertently gave me a gift: They reminded me that my mundane can be extraordinary to someone with new eyes.

At every public outreach since then, I've made it a point to call Polaris the North Star, and each time I've been gratified by people's response. Polaris is cool, but the North Star is magic.

■ Contributing Editor **HOWARD BANICH** is grateful to his funny friend and hopes she's still looking up.

LEAH TISCIONE / S&T


*SVX152T with Paramount MYT mount on New Stellarvue EVEREST Tripod*

*SVX152T Image ©Jon Talbot*