ADVENTURE:
A Mason-Dixon Venus Transit
PAGE 28

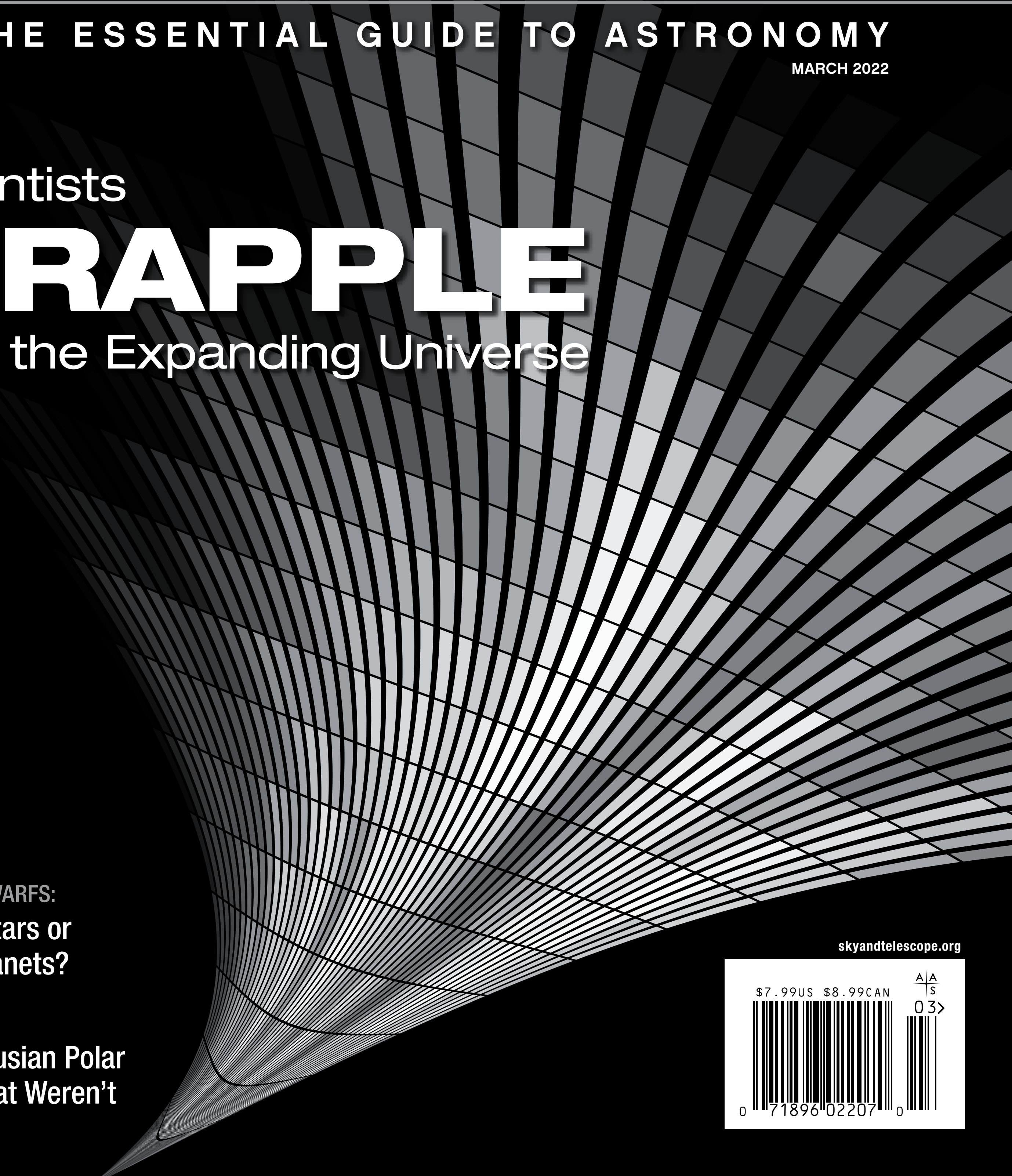
OBSERVING:
Herschel Highlights
PAGE 22

ASTROIMAGING:
Break Bad Photoshop Habits
PAGE 58

SKY & TELESCOPE

THE ESSENTIAL GUIDE TO ASTRONOMY

MARCH 2022



Scientists GRAPPLE with the Expanding Universe

Page 14

BROWN DWARFS:

Failed Stars or Giant Planets?

Page 34

The Venusian Polar Caps That Weren't

Page 52

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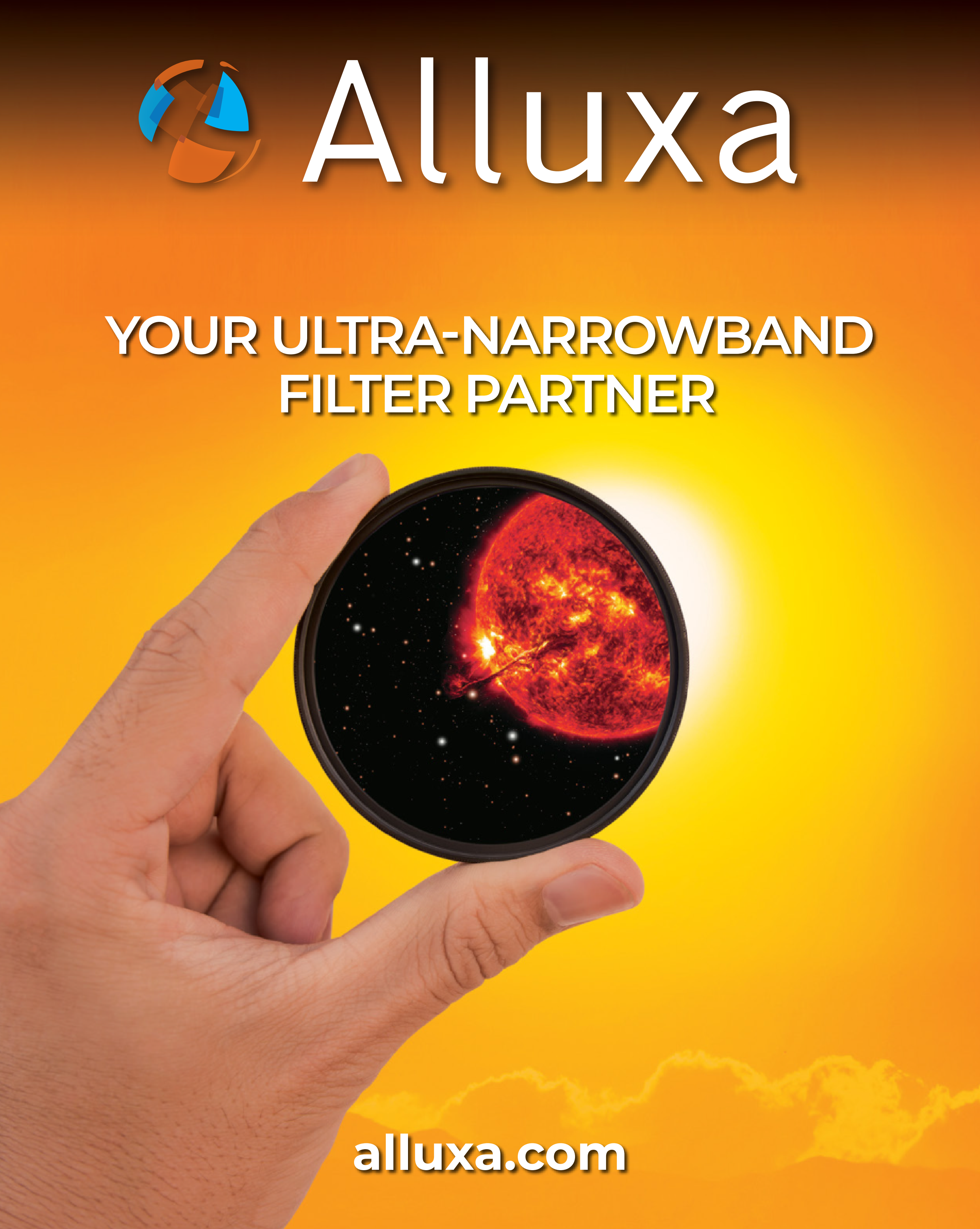
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CONTENTS

SKY & TELESCOPE
THE ESSENTIAL GUIDE TO ASTRONOMY

March 2022 VOL. 143, NO. 3

FEATURES

Cover Story:

14 The Hubble Constant: Tension and Release
The difference between measurements of the current cosmic expansion rate is a growing crisis in cosmology. What could alleviate the tension? *By Arwen Rimmer*

22 William and Caroline Herschel's Big Night
Follow in the footsteps of the duo's most productive night: April 11, 1785. *By Ted Forte*

28 Mason and Dixon's Great Venus Adventure
A pair of well-known surveyors got their start trying to solve one of the biggest questions in astronomy.
By Ted Rafferty

34 The In-Betweeners
Discoveries of brown dwarfs and exoplanets are complicating our definitions of which is which.
By Caroline Morley

58 Breaking Bad *Photoshop* Habits
Getting the best results from this popular software might mean unlearning how to use it.
By Alan Dyer

OBSERVING

41 **March's Sky at a Glance**
By Diana Hannikainen

42 **Lunar Almanac & Sky Chart**

43 **Binocular Highlight**
By Mathew Wedel

44 **Planetary Almanac**

45 **Evenings with the Stars**
By Fred Schaaf

46 **Sun, Moon & Planets**
By Gary Seronik

48 **Celestial Calendar**
By Bob King

52 **Exploring the Solar System**
By Thomas A. Dobbins

54 **Surburban Stargazer**
By Ken Hewitt-White

57 **Pro-Am Conjunction**
By Diana Hannikainen

S&T TEST REPORT

66 **PrimaLuceLab Eagle4 Pro Imaging Control Station**
By Johnny Horne

COLUMNS / DEPARTMENTS

4 **Spectrum**
By Peter Tyson

6 **From Our Readers**

7 **75, 50 & 25 Years Ago**
By Roger W. Sinnott

8 **News Notes**

12 **Cosmic Relief**
By David Grinspoon

70 **New Product Showcase**

72 **Astronomer's Workbench**
By Jerry Oltion

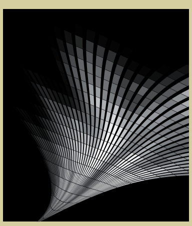
74 **Gallery**

83 **Event Calendar**

84 **Focal Point**
By Evan Hilgemann

TERO HIRVIKOSKI

ON THE COVER



Just how fast *is* the universe expanding?

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Cloudy Nights

CLOUDS ARE THE BANE of astronomers. They can shut down a night of stargazing — or a week. Even scattered ones can ruin your observing plan. In the most excruciating instance, they can dash hopes of witnessing totality during a solar eclipse you traveled half the world to see.

The irony is thick: With a clear night sky, you can see for light-years, yet cumulus just overhead can trip you up at the very start of such a visual marathon. Clouds can do the same at the other end. As Tom Dobbins remarks in his article about Venus on page 52, even though our twin is the brightest planet in the sky, it's a "bitterly disappointing" sight for visual observers because of its all-encompassing and largely featureless clouds. When looking at the second rock from the Sun, your sight of the finish line is unobstructed for tens of millions of kilometers, only to be blocked at the tape.

The same thing happens with far more distant exoplanets and brown dwarfs, the subject of Caroline Morley's article on page 34. As she notes, the clouds and hazes that often enshroud these two kinds of extrasolar worlds can absorb light at all wavelengths, denying us clues about the molecular composition of their atmospheres.

▲ Jupiter's clouds *make* the view, as seen strikingly in this Juno spacecraft image. But in many other instances in astronomy, clouds just get in the way.

NASA / JPL-CALTECH / SWRI / MSSS / KEVIN M. GALL

More commonly, the aerosol sheaths of these far-off orbs only partially obscure our view, so we can still get *some* idea of what their air contains. And the clouds themselves can tell stories of a world's weather over time, just as they can on Jupiter and other gas giants in our solar system.

All the same, clouds can frustrate exoplanet researchers just as much as they can backyard astronomers. That's why professionals are beside themselves with anticipation for the James Webb Space Telescope, set to launch only weeks from now as I write this. JWST's extreme sensitivity at infrared wavelengths will help astronomers cut through the veils of many exoplanets and brown dwarfs and measure the molecules they've been hiding.

Doing so will help us answer the question at the heart of Morley's piece: What exactly *are* brown dwarfs? Are they failed stars or giant planets? JWST will address much more than this question, of course, including whether any exoplanet atmospheres offer conditions that might support life.

One thing JWST will *not* do, though, is look at Venus — the telescope's protective sunshield will block the inner solar system from its view. So our sister planet's clouds will continue to hinder both our sight and our insight.

Peter

Editor in Chief

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Out of the Park

I'm a bit of a low-tech Dobsonian guy, but I clung to every well-written word of Paul H. Geithner's story "Building the James Webb Space Telescope" (*S&T:* Nov. 2021, p. 20).

Calling this thing a telescope doesn't do it justice because it represents so much more. We threw every great technological advancement we had into an idea chamber, flipped a switch, and out popped the pinnacle of human achievement.

Nothing this grand has taken place since that giant leap more than 50 years ago. It's a privilege for us low-tech little leaguers to watch the genius professionals hit this home run above the all-star outfield, out of the park, and into the realm of newborn galaxies and much more.

Roger Sargent • Albion, Pennsylvania

▲ Engineers evaluate the fully assembled James Webb Space Telescope before its launch, which is scheduled for December 22nd, as this issue goes to press.

80 Years of Observing Tips

Sky & Telescope's 80th-anniversary issue [November 2021] brought me back. I took up astronomy as a freshman in high school in 1955. I was 13, and my first telescope was a 2.4-inch (60-mm) Unitron on an alt-azimuth mount, which I bought with the money I made on a newspaper route.

I discovered *Sky & Telescope* at about the same time and have been getting it since then, 66 years. In 1966, I upgraded to a clock-driven 4-inch (102-mm) Unitron with an equatorial mount.

All this time, I kept *Sky & Telescope* as my encyclopedia and guide. It has informed and sustained me in my amateur status even while I was traveling internationally as an architect. *S&T* is my gateway to the universe.

My greatest moments were closely following Comet Shoemaker-Levy 9's (D/1993 F2) collision with Jupiter. *Sky & Telescope* prepared me for the event, and I actually excused myself in the middle of a dinner party to do my observations. I saw one of the impacts! I ran down to get everyone and showed them Jupiter in my telescope. I also made a series of sketches at the time and submitted them to the Association of Lunar and Planetary Observers. It was the high point of my observing career, all thanks to my long-time reading of *Sky & Telescope*.

Jeffrey Heller
San Francisco, California

Recalling a Golden Age

"A Golden Age for Amateur Astronomy" (*S&T:* Nov. 2021, p. 14) was a thoroughly enjoyable piece of writing — absolutely thrilling. It brought me back to my own beginnings when I looked at Vega through my mom's binoculars during the summer of 1960. You could not have chosen two more qualified authors than William Sheehan and Klaus Brasch. Carolyn and Gene Shoemaker and I observed with Bill on one of the final nights of our time at Palomar Observatory's 18-inch (0.46-meter) Schmidt telescope. But Klaus and I have known each other since our days at the Royal Astronomical Society of Canada's Montreal Centre in the early 1960s. As I read, the years faded away and there I was, standing beside all those who have helped make my own journey among the stars a happy one.

David H. Levy
Vail, Arizona

I very much enjoyed "A Golden Age for Amateur Astronomy." This article brought back many memories from my first telescope (a 60-mm Tasco refractor). It was a Christmas present from my parents back in grade school in the 1960s. This mediocre scope opened up the wonders of the solar system to me.

During this time, my love of astronomy included courses in solar and galactic astronomy at Riverview High School's planetarium [in Sarasota, FL] taught by Whitney Robinette [as well as] several more courses at the University of South Florida and Louisiana State. I would spend hours in the libraries reading *S&T* and eagerly anticipating the next issue.

One of my all-time favorite astronomy books is *All About Telescopes* by Sam Brown (*S&T:* Sept. 1968, p. 176). This manual has a wealth of information on designing, building, and testing telescopes and optics. Even now, I'm always delighted when reading this book. Unfortunately, my desire for a larger scope had to wait until after I completed my education and had adequate funds.

Years later, after a bachelor's degree in engineering, a permanent job, a new house, marriage, and paying off some

NORTHROP GRUMMAN

debt, I was able to purchase a shiny new 8-inch (20-cm) Celestron Powerstar II in the 1980s. This telescope opened the entire universe to me, especially since it had an accurate clock drive, which enabled me to get into astrophotography.

Nick Funk
Fairhope, Alabama

I loved this article. The November issue fell open at "A Golden Age for Amateur Astronomy," and I sat down and read it all, which is not the norm. It's such a great article. Like Bill Sheehan, I was 15 when I bought a secondhand 4.25-inch Edmund Scientific "Palomar Junior." Like many other amateurs, I have had a Cave 8-inch Newtonian, an orange Celestron C8, a 10-inch (25-cm) Meade LX200, and a Celestron NexStar 11 Schmidt-Cassegrain. Later still, I got an 18-inch NightSky Dobsonian. I had many great times at star parties and with members of the Austin Astronomical Society. Those experiences were the treasures of a lifetime. But after retirement, I found myself fading out of the hobby.

That all changed when I bought a Unistellar eVscope eQuinox this summer. This telescope has been a revolution in my passion for astronomy. It weighs around 20 lbs and has no cables, controller, or place to put an eyepiece, nor does it need any of that. Quite surprisingly, it makes imaging effortless, with little post-processing needed. I routinely print 11×14 images for my walls. I foresee a revolution coming comparable to when the Celestron C8 displaced the Cave reflectors in the 1970s.

Jack Estes
Boerne, Texas

Looking Forward

Howard Banich's article "Arc of an Amateur" (*S&T:* Nov. 2021, p. 58) really intrigued me because it reminded me of my journey in amateur astronomy, which began in 1970. I often reflect on the changes in this hobby and how we adapt. While there are certain constants, sometimes we get drawn into the times, and they change us.

As I approach the golden years of my own life, I also look at what I can do in this hobby. I want to make sure I get as much in as I can before it is too late.

The really important thing to remember is that it's not about how large your telescope is, or even how much one has seen, but whether we are enjoying what we are doing and sharing it with others. Make sure to find time to enjoy the amazing people along the way, too. Get out and become involved in a club, and go to star parties and meet new people. That is the future of our hobby.

James Paulson
Medicine Hat, Alberta

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

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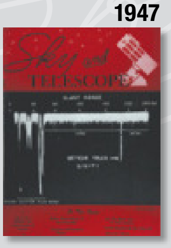
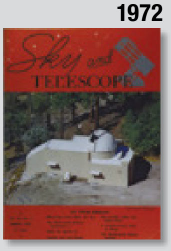


1972



1997

◖ March 1947
Lunar Craters "Among curious notions that have haunted astronomical thought, few are more phantastic than that which would explain the facial appearance of the moon by the fall of a hundred thousand meteorites and comets. . . . One seems to be in dreamland when he pictures the lunar heavens alive with flying blocks of stone . . .

"Maedler, Nasmyth and Carpenter, Moreaux, W. H. Pickering, and Goodacre, all have favored some form of volcanic theory, though not insisting on a single igneous agency. . . . And the moon itself provides a multitude of witnesses whose testimony . . . is a mighty *No.*"

The Apollo missions would finally convince astronomers that most lunar craters are due to impacts.

◖ March 1972
Leonid Meteors "As far as the writer knows, there are no records at all of the Leonids from the 9th century or earlier. Why is this? Did the orbit of the Leonid swarm undergo some drastic change about that time, making collision with the earth possible for the first time? . . .

"[T]here are many references to a spectacular Leonid shower in A.D. 902, on or about October 12-13. The best account comes from Islamic Spain, [where] 'there was seen in the sky an innumerable mass of stars, which were dispersed like rain, and [they] were cast off to right and left. . . .'

"One of our group, A. T. Gerard, has pointed out what may be a still earlier observation of the Leonids. It reads as follows: 'In the year of the Incarnation of our Lord 900 there appeared a marvelous sign in heaven. For the stars were seen to flow from the very height of heaven to the lowest horizon, well nigh as though they crashed one upon the other.' Radbod, who was the author, was elected Bishop of Utrecht in the Netherlands in 899 [and was perhaps] the first to see and record the Leonids."

This report came from D. J. Schove of St. David's College.

◖ March 1997
Carl Sagan "As president of The Planetary Society, Carl fostered Russian/American dialogue in order to achieve mutual understanding and lessen the chances of nuclear winter — the planetary catastrophe he researched and feared most. . . .

"Carl's advocacy of exobiology was considered disreputable by some scientists and drew criticism, further fueled by their jealousy of his public renown. I recall, with some shame, publically poking fun at Carl's idea of floating life forms in Jupiter's atmosphere. . . . Nonetheless, Carl practiced science with rigor. . . .

"We astronomers — amateur, armchair, professional — are fortunate that such an eloquent spokesman for science should have come from our midst."

Astronomer Clark R. Chapman paid tribute to his former teacher. Sagan died in December 1996.

ASTRONOMY & SOCIETY

Astronomers Announce Priorities for Next Decade and Beyond

WHEN THE NATIONAL ACADEMY OF SCIENCE released the Decadal Survey on Astronomy and Astrophysics, it unveiled long-awaited marching orders for the next decade and beyond.

The 614-page report, titled "Pathways to Discovery in Astronomy and Astrophysics for the 2020s" (Astro2020 for short), relied on advice from 867 white papers, several public information-gathering sessions, and 13 expert panels to form its recommendations. (Due to a COVID-related delay, these recommendations start in 2022.)

Rather than simply prioritizing missions for development, as previous surveys have done, Astro2020 advocates the creation of a "Great Observatories Mission and Technology Maturation Program." This program would guide technological advancement before committing to specific mission concepts, avoiding delays like the ones the James Webb Space Telescope experienced.

The first mission concept to enter the maturation program will be a space telescope with a mirror at least 6 meters (20 feet) wide. This choice compromises between two mission concept proposals that went into the decadal survey: the at-most 4-meter Habitable Exoplanet Survey (HabEx) and the Large Ultraviolet Optical Infrared (LUVOIR) Surveyor, which was proposed in 8-meter and 15-meter configurations. This flagship mission caps out at $11 billion through the first five years of operation, with launch in the early 2040s.

Next on the wish list are X-ray and far-infrared observatories. These missions will enter the maturation program in the 2030s and will be funded at the $3–5 billion level.

"This is a visionary road map for the future of discovery," says Grant Tremblay (Center for Astrophysics, Harvard & Smithsonian), a member of the Lynx X-ray Observatory team. "The committee has shown an achievable and maximally ambitious path toward a new constellation of Great Observatories."

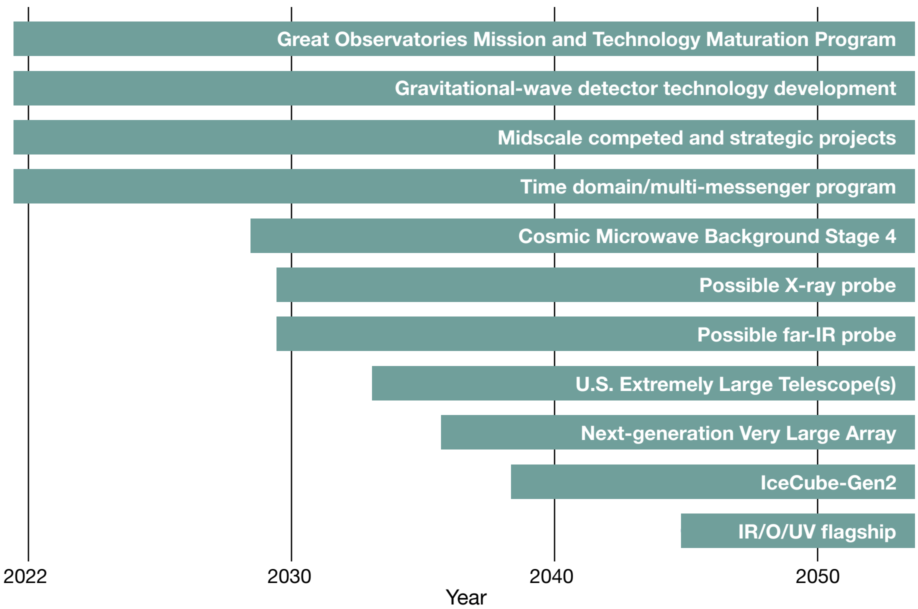
Astro2020 also gave high priority to the development of at least one Extremely Large Telescope, the Cosmic Microwave Background Stage 4 Observatory, and the next-generation Very Large Array radio telescope, as well as continued funding for gravitational-wave and neutrino astronomy.

This survey focused not only on facilities but also on people. The report notes "abysmal" racial diversity among astronomy faculty that has remained largely unchanged since the 1980s, and calls for investment in workforce diversity as well as guarantees that policies are in place to deal with harassment, discrimination, and misconduct.

■ **DAVID DICKINSON**

Read more at https://is.gd/Astro2020.

▼ The Astro2020 report recommended this timeline for medium and large programs and projects.



SOLAR SYSTEM

NASA's DART Launches for Asteroid Collision

A SPACECRAFT BUILT during pandemic hardships has successfully departed Earth on a one-way trip to an asteroid. NASA's Double Asteroid Redirection Test (DART) launched early on November 24th and will crash head-on into Dimorphos, the moonlet of near-Earth asteroid 65803 Didymos, in September or October 2022.

If DART and Dimorphos were billiard balls of infinite strength and elasticity, the outcome of this impact would be easy to predict: The spacecraft would bounce off almost as fast as it hit, and the moon would slow by a tiny amount.

But Didymos and Dimorphos are almost certainly loosely agglomerated piles of gravel with a lot of empty space. The lack of cohesion among particles might allow the swift-flying spacecraft to penetrate deeply into the surface, compressing it instead of bouncing off, reducing the collision's effectiveness.

On the other hand, the energy DART imparts will mobilize Dimorphos particles, launching them off of the super-low-gravity asteroid moon. Each fragment will carry some of Dimorphos's momentum with it. Scientists predict the slowing effect of the flying ejecta will rival that of the head-on impact.

An Italian-built CubeSat named LICIACube will separate from the carrier craft before the impact to watch the high-speed crash from a safe distance,

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SETI

The True Nature of Proxima Centauri's Candidate ET Signal

THE SIGNAL was the closest we've come to thinking we had found intelligent alien life. Discovered as part of a 10-year initiative to find technosignature in nearby star systems, Breakthrough Listen Candidate 1 (or BLC1) appeared to come from Proxima Centauri, the nearest star to the Sun.

But in a pair of articles published on October 25th in *Nature Astronomy*, team members concluded that the signal is of human origin.

BLC1 is the only signal to date that checked the most important boxes for alien origin. It was narrowband — a tone purer than any natural process could produce — and no known electronics on Earth intentionally transmit at that frequency. It also persisted over several hours. What really made BLC1 exciting, though, was that its frequency changed, drifting exactly as if it were being emitted by something moving within the Proxima Centauri system.

But when Breakthrough Listen observed Proxima Centauri again in 2020 and 2021, BLC1 had disappeared.

After checking for human-made interference from space and around the observatory itself — and coming up dry — the team tried a new strategy: They searched for "lookalikes," BLC1-like signals detected when the telescope was pointing somewhere else.

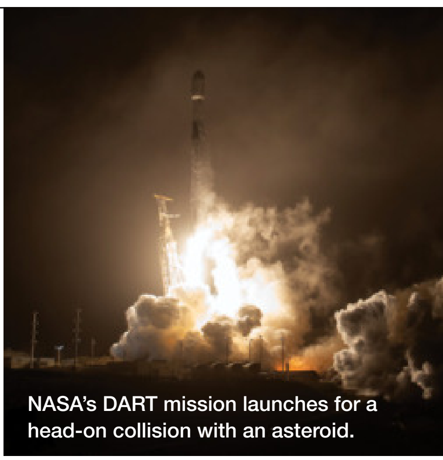
▲ The Australian Parkes radio telescope, also called by its Wiradjuri name Murriyang, detected the signal of interest from Proxima Centauri.

Searching their data on hundreds of other stars, the team turned up a few dozen signals that drifted as BLC1 did, though around different frequencies. Critically, these signals also appeared in off-source observations taken for calibration. A single electronic device interfering with itself could explain these signals, the team found.

The new tools Breakthrough Listen developed are essential to the search. "We are really much more capable than we were a few years ago," says Michael Garrett (University of Manchester, UK), who wasn't involved in the study. "If there is a signal out there, we're getting closer to being able to detect it."

And since Breakthrough Listen has only searched thousands of stars out of their goal of a million, plenty of opportunities remain.

■ ASA STAHL



NASA's DART mission launches for a head-on collision with an asteroid.

DART LAUNCH: NASA; PARKES: CSIRO / A. CHERNEY

observing the spray of ejecta and possibly the impact crater. Back on Earth, astronomers will also watch the system, carefully monitoring the light curve to determine if Dimorphos's orbital period around Didymos changes as expected.

In performing the first-ever experiment in changing an asteroid's velocity, DART will deliver valuable lessons toward that inevitable time in the future when we need to move an asteroid away from a population center.

■ EMILY LAKDAWALLA

IN BRIEF

An 'Oumuamua Analog?

When interstellar object 1I/'Oumuamua was first spotted tumbling through the solar system (*S&T:* Feb. 2018, p. 10), we'd never seen anything like it. Among many unexplained oddities was its shape: With an aspect ratio of 6:6:1, it was basically an otherworldly pancake. But at the Division for Planetary Sciences meeting in October, Ari Heinze (now at University of Washington) reported preliminary results for an asteroid, 2016 AK_{193}, that behaves remarkably like 'Oumuamua: It tumbles like the interstellar object did, and it seems to be just as elongated to boot. Unlike 'Oumuamua, though, this asteroid is not a new arrival; it has probably been going around the Sun for billions of years. Follow-up observations will take some patience, since 2016 AK_{193} won't come close enough to observe again until 2029, Heinze says. Still, the asteroid's mere existence is intriguing. Its current near-Earth orbit is unstable over 100 million years, Heinze notes. So it's possible this object used to belong to the main belt before a gravitational encounter redirected it, and that nudge might even have precipitated its reshaping. More and better observations will help us understand this object's past.

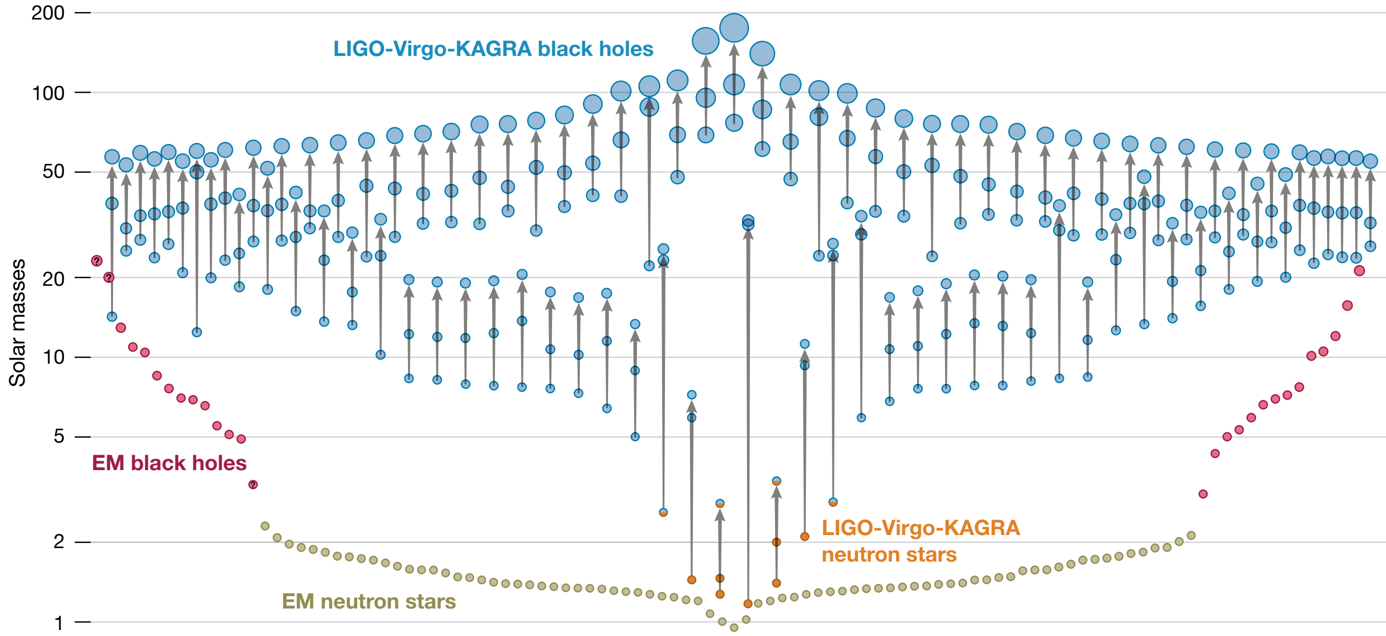
■ MONICA YOUNG

Read more at **https://is.gd/ssanalog**.

Russia Conducts Anti-Satellite Test

A Russian missile struck a defunct satellite early morning on November 15th, forcing those aboard the International Space Station (ISS) to take protective measures. The crew sat out close debris passes in docked spacecraft in case departure became necessary. The U.S. State Department and U.S. Space Command confirmed and condemned the test later that day, as did NASA. Roscosmos, the Russian space agency, issued a brief statement maintaining that the safety of the ISS crew remains their main priority. At the time of the test, there were 10 humans in space, all in low-Earth orbit: seven aboard the ISS (four from NASA, two from Roscosmos, and one from the European Space Agency) and three aboard China's Tiangong space station. Other nations have also performed anti-satellite tests, including China, the U.S., and India. The current Outer Space Treaty bans the use of nuclear weapons in space but not anti-satellite tests.

■ DAVID DICKINSON



▲ Scientists have now detected 90 gravitational-wave events. The dots indicate the masses of the objects that merged and of the object they created. (Pink and yellow dots are detections from electromagnetic observations.)

BLACK HOLES

Third Gravitational-wave Catalog Released

THE INTERNATIONAL TEAM associated with three gravitational-wave projects has unveiled results from their latest observing run, adding 35 new events and raising the total number to 90.

The catalog includes compact objects caught colliding between November 2019 and March 2020. This run included both Europe's Virgo and the U.S.-based LIGO detectors. The Japanese KAGRA project joined the fun for the campaign's last two weeks.

Of the 35 pairs in the newest catalog, 32 were black hole mergers. There were also two neutron star–black hole collisions and one event of indeterminate type: It might have been a black hole gnashing a neutron star, but chances are the smaller object was a tiny black hole 2.8 times the Sun's mass.

In a separate publication, the LVK Collaboration analyzed 76 of the most reliable events, upending some expectations about black holes as a population.

Astronomers had predicted that they wouldn't see objects between roughly 3 and 5 solar masses, and there *is* a drop in the number of objects just above 2 solar masses. But the gravitational-wave data don't show a hard upper edge, nor does this putative gap appear to be totally empty.

Astronomers had also thought that stars large enough to make black holes between 50 and 120 solar masses should tear themselves apart, leaving no remnant when they die. But the observations reveal black holes in this region, too: Although the latest gravitational-wave data do show a drop-off above 40 Suns or so, it's not precipitous.

The detectors will return for a fourth observing run in late 2022, when further upgrades may increase the number of detections by a factor of three.

■ CAMILLE M. CARLISLE

JUPITER

The Roots of the Great Red Spot Run Deep

NASA'S JUNO MISSION has obtained measurements that finally say just how far down the Great Red Spot goes. The deep roots of the centuries-long storm could be a clue to its longevity.

Previous work using the microwave radiometer aboard NASA's Juno spacecraft demonstrated the storm was still going strong 240 kilometers (150 miles) below the cloudtops. Now, a study in the October 28th *Science* puts a bottom limit to its depth. Juno scientist Marzia Parisi (JPL-Caltech) led an effort utilizing two passes that had the spacecraft zipping right over the Great Red Spot. The team also analyzed data from another 10 passes.

The spacecraft's path changed ever so slightly over the cyclone because of the uneven distribution of mass in the clouds below. By measuring deviations to Juno's expected path to within 0.01 millimeter per second, Parisi and colleagues showed that the Great Red Spot

JunoCam captured this image of Jupiter's south temperate belt and Great Red Spot on Dec. 30, 2020.

EXOPLANETS

Did We Find a Planet in Another Galaxy?

PLANETS ABOUND in the Milky Way. They probably do in other galaxies, too, but the usual techniques can't reach far enough to tell. Using an innovative method, Rosanne Di Stefano (Center for Astrophysics, Harvard & Smithsonian) and colleagues announced a possible extragalactic exoplanet in *Nature Astronomy* on October 25th.

In X-ray binaries, a black hole or neutron star siphons material off a companion star. Infalling material heats up until it emits X-rays. This hot inner region is small enough that a planet passing in front of it could block most or all of the radiation.

Di Stefano and collaborators set out looking for such a signal, examining observations of 238 X-ray binaries in three nearby spiral galaxies: M51, M101, and M104 (the Whirlpool, Pinwheel, and Sombrero galaxies).

The hunt struck gold 28 million light-years away in the Whirlpool Galaxy. There, the bright M51-ULS-1 system hosts a compact stellar remnant feeding off of a massive, bright-blue star, surrounded by an X-ray-emitting region some 50,000 kilometers (30,000 miles) across.

During the team's observations, the X-rays dropped dramatically, staying dim for three hours before returning to baseline. The dip was symmetric and appeared the same across frequencies,

▲ A box shows the location of the X-ray binary system in the Whirlpool Galaxy (M51) that might host an exoplanet, 28 million light-years from Earth.

X-RAY: NASA / CXC / SAO / R. DI STEFANO, ET AL.; OPTICAL: NASA / ESA / STSCI / GENDLER

as expected from a solid body crossing the field. Di Stefano's team concludes the transiting object was probably smaller than Jupiter and in a wide orbit.

Scott Wolk (also at Center for Astrophysics), who wasn't involved in the study, applauds the results but cautions, "For this to actually have been a planet would be incredibly lucky." The chance of catching a transit in the 2,624 lightcurves examined so far is on the order of a million to one.

But those chances depend on how common planets are in such systems; this result might not be so unexpected. "We need more discoveries to make a real comparison between observations and theory," Di Stefano adds.

While we may never know if a planet caused this particular dip in X-rays, the observations provide a proof of concept that Di Stefano and colleagues hope to use for future discoveries, both in other galaxies and in the Milky Way.

■ MONICA YOUNG

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extends 500 km down at most.

"Most of the scientific community was thinking the Great Red Spot was shallow," Parisi says. "We were surprised that it goes so deep."

Despite shrinking over the past few decades (*S&T:* Apr. 2002, p. 24), the Great Red Spot is still wider than Earth's diameter. So the storm itself is somewhat pancake-shaped — just a thicker one than scientists had expected. For context, Jupiter's stripes, the brown-red belts and whitish zones, extend much deeper, down to about 3,000 km, or about 4% of the way to the center.

Nevertheless, the unexpected depth means that the pumpkin-colored vortex is rooted well beneath the cloud layer as well as the water and ammonia condensation layers below that, and certainly well beyond the reach of sunlight. This depth will be something scientists need to consider as they puzzle over the mechanisms that could drive the storm.

■ MONICA YOUNG

Read more about other Jupiter storms at https://is.gd/GRSdeep.

MOONS

Did a Piece of the Moon Become a Quasi-satellite?

THE MOON has orbited Earth for billions of years, but *quasi-satellites* travel in phase with our planet around the Sun for only a few hundred years. Now the first detailed observations of the quasi-satellite 469219 Kamoʻoalewa suggest that it (and perhaps others) might actually come from the Moon itself.

Discovered in 2016, Kamoʻoalewa is both the closest and smallest known quasi-satellite and comes within range of large telescopes every year. Benjamin Sharkey (University of Arizona) and colleagues have observed it over the past five years using the Large Binocular Telescope and the Lowell Discovery Telescope, and reported their results on November 11th in *Nature Communications Earth & Environment*.

Data collected at visible and infrared wavelengths showed that Kamoʻoalewa reflects more light at longer wavelengths (1.5 to 2.5 microns), making it more like the samples collected during the Apollo missions than other near-Earth asteroids and meteorite samples.

The similarity with lunar samples suggests that Kamoʻoalewa might be a chunk of the Moon, perhaps blasted away by an asteroid impact. In addition to its color, the object's eccentricity and orbital inclination are also quite small for what is typical of captured objects. Kamoʻoalewa's slow speed near the Earth-Moon system, less than a quarter of typical near-Earth asteroids, also supports a Moon origin.

Kamoʻoalewa's close approaches to Earth offer unique possibilities in the future. The quasi-satellite comes close enough that the China National Space Administration has designated it the target for a complex mission to collect and return samples from an asteroid. Plans call for launch in 2024.

■ JEFF HECHT

Interstellar Stowaways

Could microorganisms travel between the stars?

AGE-OLD SPECULATION that life might hitchhike between planets revived in the 1980s with our discovery that meteorites from Mars occasionally pelt Earth. Add to that the discovery of extremophile species that can withstand huge extremes of temperature, desiccation, and radiation. However unlikely such an origin might seem for planetary life, we have to weigh it against the (still completely unknown) probability that life can readily spring from the native chemistry of a young world.

As I've discussed (*S&T:* Mar. 2018, p. 14), we've recently detected objects entering our solar system from other star systems. Those fleeting visits naturally make me wonder about interstellar *panspermia*, the phenomenon by which — it's hypothesized — life might spread between worlds orbiting different stars. Now two new studies have me thinking afresh about this.

One study involves small earthworms, *Pontodrilus litoralis*, that burrow into beaches, mudflats, and other coastal habitats around the world. Birds don't carry them, so how do they travel across oceans? Keryea Soong of Taiwan's National Sun Yat-sen University and two colleagues found that these little guys are adept at tunneling into, and living off of, driftwood, so they can float from place to place, munching on their rafts to stay alive.

The other study is titled "Panspermia in a Milky Way–like Galaxy." A team of Chilean, Korean, and French scientists used sophisticated models to simulate four steps of a hypothetical process: ejection of spores from planets, gravitational escape from stellar systems, transit between stars, and survival of spores across interstellar distances. The team concludes that life is more likely to originate in new stellar systems than be shuttled between the stars. However, they also admit that both probability estimates depend critically on unknown quantities.

◀ Tardigrades, or water bears, such as the one seen here in a colored scanning electron micrograph, are one of our planet's most resilient creatures. Could such microorganisms survive a journey among the stars?

STEVE GSCHMEISSNER / SCIENCE PHOTO LIBRARY

Driftwood transport works between islands here because tiny critters can drift on timescales that are short compared to their life expectancy. But to take evolutionary advantage of an interstellar dissemination vector, natural selection would require multiple generations using impact explosions to loft spores from planet to planet.

I've tried (on the back of an envelope) to model creatures that can evolve to do so. You'd need spores to be spread widely enough on a planet, and survive for long enough, to have a decent chance of being carried to another world after the next impact event. I couldn't make it work, and I doubt nature could either.

Spacefaring bugs, then, would have to accidentally evolve in a way that makes them fit for interstellar travel. Some of the hardiest Earth organisms — think tardigrades or extremophilic bacteria — can last for a few years desiccated and irradiated in space. But could anything survive for *millions* of years in such conditions? Our limited experimental data suggest that, even though the extreme cold of space might greatly increase survival against radiation damages, much shorter survival times are likely.

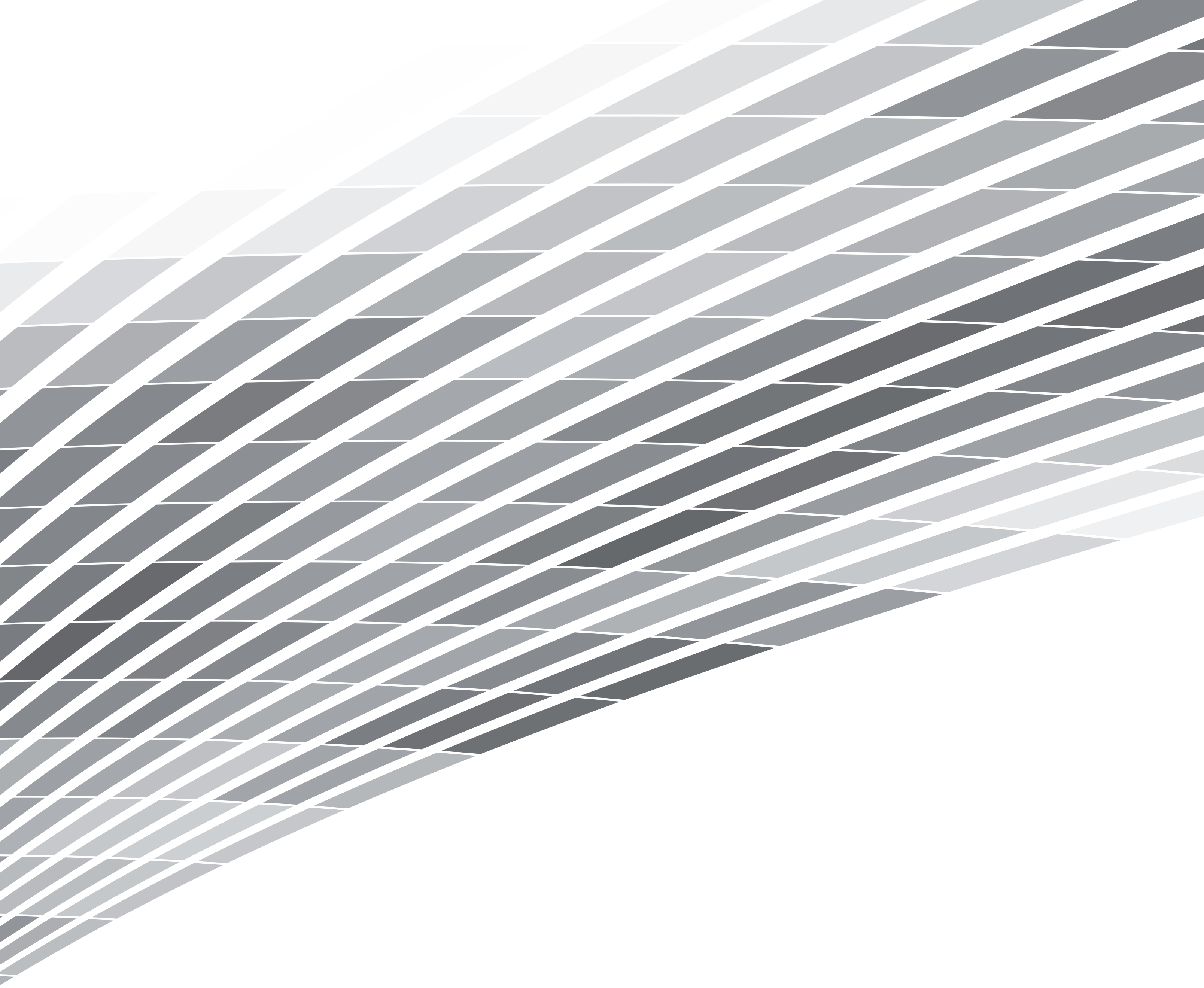
So, could our universe be full of life that has spread naturally over time from star to star, hiding like worms in driftwood, inside ejected rocks? Ultimately, we're still comparing unknowns. It seems more likely that life forms indigenously, and that's where I'll place my bets for now. But until we find some examples of ET life and learn how and if we're related to it, we have to allow for the intriguing possibility of life drifting throughout the galaxy on interstellar flotsam.

■ Contributing Editor **DAVID GRINSPOON** is an astrobiologist at the Planetary Science Institute.

 by Arwen Rimmer

The Hubble Constant:
Tension and Release

The difference between early- and late-universe measurements of the current cosmic expansion rate is a growing crisis in cosmology. What could alleviate the tension?



GURGEN BAKHSHETYAN / SHUTTERSTOCK.COM

The current theory of how the universe works is called the *lambda cold dark matter* (ΛCDM) model. It starts with the Big Bang, assumes that Einstein's general theory of relativity (GR) is just fine, and posits that the universe is composed primarily of three things: (1) dark energy, a repulsive pressure described by the constant Lambda (Λ); (2) cold dark matter (CDM); and (3) ordinary matter.

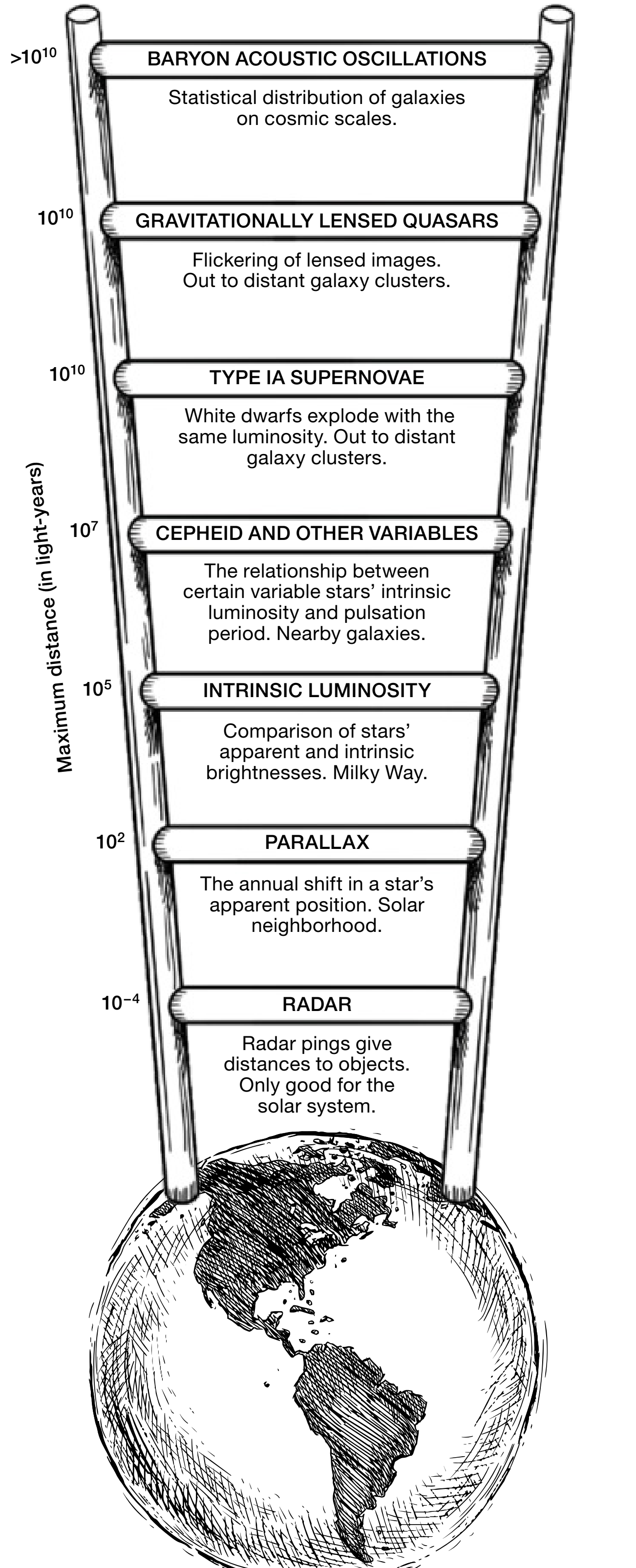
People call ΛCDM the "standard model" of cosmology because it is relatively simple and makes good sense of phenomena such as the cosmic microwave background (CMB), the way galaxies cluster, and much more. It has been around since the 1980s, even before two independent teams confirmed in 1998 that the expansion of the universe is accelerating due to dark energy, not slowing down as expected. ΛCDM is a good working model, and most astronomers accept it.

Which makes it a bit awkward that different methods of measuring the universe's current expansion rate, called the *Hubble constant* or H_0 (pronounced "H-naught"), don't match.

The issue is between two categories of measurements, one more direct than the other (*S&T:* June 2019, p. 22). The problem even has a name: the Hubble tension. Wendy Freedman (now at University of Chicago) and her colleagues reported the first reasonably precise direct measurements of the current expansion rate in 2001 (yielding a value of about 72 km per second per megaparsec, with an uncertainty of 11%). Then the Planck team announced the first high-precision indirect measurements in 2013 (about 67 km/s/Mpc, with an uncertainty of less than 2%). Many cosmologists assumed that these two very different approaches would eventually converge on the same number — but so far they haven't.

A Cosmic Rewind

The traditional way of measuring H_0 involves a *cosmic distance ladder*, in which astronomers use a variety of methods to mea-



▲ **THE COSMIC DISTANCE LADDER** Astronomers use several methods to measure distances, some of which are shown here. Cepheids can pick up where parallax no longer works, for example, and Type Ia supernovae and lensed quasars extend beyond Cepheids.

sure distances to increasingly farther objects. The first rung is geometric parallax, the most direct method of determining distances. The next rungs use the luminosity of *standard candles*, such as nearby Cepheid variable stars and more distant Type Ia supernovae. Astronomers climb these rungs to galaxies farther and farther out, then measure the speed with which those galaxies are moving away from us to calculate the current expansion rate of the universe. These are often called *local*, or *late-time* measurements.

One of the largest collections of distance-ladder studies comes from Adam Riess's group at the Space Telescope Science Institute. Using observations of supernovae and Cepheids in a project dubbed SH0ES (Supernovae, H_0, for the Equation of State of Dark Energy), the team's latest work gives a current expansion rate of 73 km/s/Mpc.

This kind of direct measurement is a cosmic rewind, starting here on Earth and measuring progressively outward and backward in time. But indirect measurement techniques use the primordial fluctuations, starting at the *epoch of recombination* when the first neutral atoms formed. This time period is important in cosmic history because it's the furthest back that we can see. The CMB is a picture of this early epoch; before that, everything was an opaque plasma.

Amazingly, from an image of the CMB, astronomers can derive the universe's composition: 4.9% baryons, 26.4% cold dark matter, and 68.7% dark energy. Then astronomers combine that composition with the standard model to predict the next 13.8 billion years, producing a universe that looks like the one we live in today.

Another indirect method involves *baryon acoustic oscillations* (BAO), the permanent imprint of the sloshing primordial plasma. As reionization dawned, waves traveling through the plasma "froze in." Thanks to that imprint, the lumps in the plasma that eventually evolved into galaxies are now slightly more likely to lie 480 million light-years apart than at other separations, based on data collected by the Sloan Digital Sky Survey (SDSS). When astronomers compare the size of the BAOs based on the CMB with the size from galaxy distributions, they can calculate a value for the expansion rate of the universe (67 km/s/Mpc).

So we have the direct methods, which try to measure the distances to late-time objects, and the indirect (or early-time) methods, which make inferences from the characteristics of the primordial universe. Like two sides of the same coin, "these two things should give the same answer," says cosmologist Licia Verde (University of Barcelona, Spain). "And it is very close, considering we are threading a needle from the other side of the universe."

Still, more precise measurements and larger data sets have only made the discrepancy starker. This "crisis in cosmology" has forced astronomers to ask big uncomfortable questions — both about the veracity of local calculations and about the limits of the ΛCDM model itself. Currently, there are two main approaches scientists are taking to try and solve the tension: astrophysical and cosmological.

LADDER: LEAH TISCIONE / *S&T*; EARTH: VERY_VERY / SHUTTERSTOCK.COM

Freedman thinks the root of the Hubble tension lies with Cepheids, which are younger than red giants and therefore occupy crowded star-forming regions.

Astrophysical: Are Cepheids the Problem?

Some scientists say uncertainties in distance-ladder measurements, what they call *systematics*, could cause the discrepancy. Even something small would compound on each rung, making the ultimate measurement of H_0 less reliable and creating tension where there is none.

In a recent study, Edvard Mörtsell (Stockholm University, Sweden) and colleagues analyzed the Cepheid method used by Riess's SH0ES collaboration. While Cepheid stars *are* a standard candle (*S&T:* Dec. 2021, p. 12), Mörtsell's team found that one of the ways astronomers typically calibrate their luminosities might be flawed.

There are lots of different ways that astronomers must characterize stars before figuring out how far away they are. One of the variables is how much dust is between us and them, and what that dust is made of. Traditionally, scientists have used a number to represent the typical amount that dust dims and reddens a star's light, and then used that number to calculate the star's true luminosity.

"The way it's been done before is that [astronomers] just assume that you can make the same correction for all Cepheids, regardless of the galaxy that they are in, which is basically saying that dust has the same properties everywhere," Mörtsell says. "But we know that this is not true. We know that there are lots of variations in how dust looks in different galaxies."

His group found that when they replaced the dust constant used in distance-ladder calculations with a value that can vary from galaxy to galaxy and then calculated H_0, they obtained a number much closer to the CMB calculation. But the gap isn't closed completely. Mörtsell suggests this is because there is probably more than one problem with the Cepheid method.

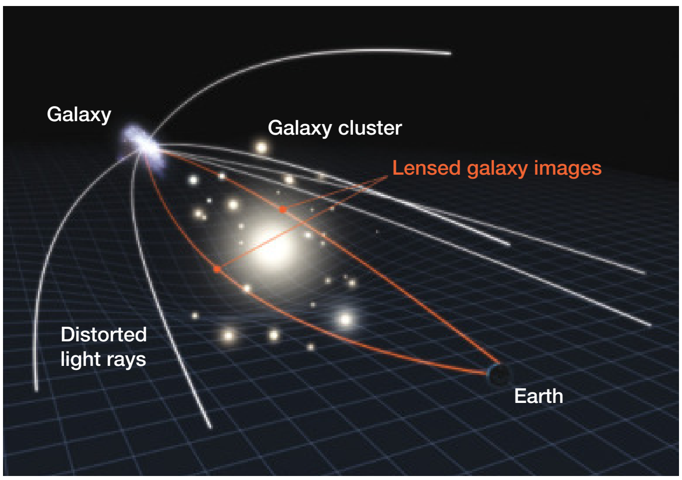
Other recent work has also raised concerns about Cepheids. In 2019 Freedman and her team measured the peak brightness of the populations of red giant stars in more than a dozen nearby galaxies and used that value as a standard candle to reckon their distances. In 2021 her team bolstered their results, cross-checking their luminosity measurements with five different approaches. The H_0 value the researchers get from the red giants is 69.8 km/s/Mpc — notably closer to the value derived from the CMB than the one calculated from a combination of Cepheids and supernovae.

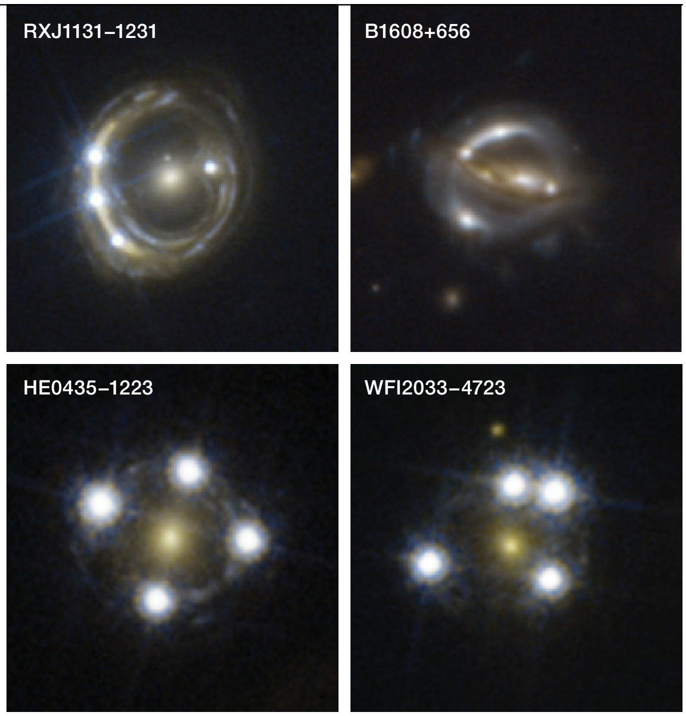
Like Mörtsell, Freedman thinks the root of the Hubble tension lies with Cepheids, which are younger than red giants and occupy crowded star-forming regions. It may be that things like dust and other stars are throwing off measurements.

Astrophysical: New Methods

Systematics could be the source of the tension. But it seems strange that different sources of error would throw off local

▼▶ **GRAVITATIONAL LENSING** *Below:* When a cluster sits at exactly the right spot between us and a distant galaxy, the cluster's gravity bends the distant galaxy's light around the cluster as though the cluster were a lens, magnifying the light and redirecting it toward us. Observers then use the resulting distorted images to learn about the distant galaxy. (Scales here are exaggerated.) *Right:* Hubble images of lensed quasars studied by the H0LiCOW collaboration.





GRAVITATIONAL LENSING DIAGRAM: NASA / ESA / L. CALÇADA; GRAVITATIONALLY LENSED IMAGES: NASA / ESA / S. H. SUYU (MPIA, TECHNICAL UNIV. OF MUNICH, ASIAA) / K. C. WONG (UNIV. OF TOKYO) measurements in the same direction. Why aren't some local studies measuring a Hubble constant *lower* than 67?

This is why the community is interested in finding other, independent ways of measuring H_0. Two promising new methods have already had interesting early results: gravitational waves and gravitational lensing.

Gravitational-wave facilities like LIGO, Virgo, and KAGRA watch for cosmic collisions, including neutron star mergers, which send out blasts of electromagnetic particles along with transient ripples in spacetime. Having multiple messengers from singular events lets astronomers make a one-rung distance measurement to the point of origin, turning gravitational-wave sources into standard sirens.

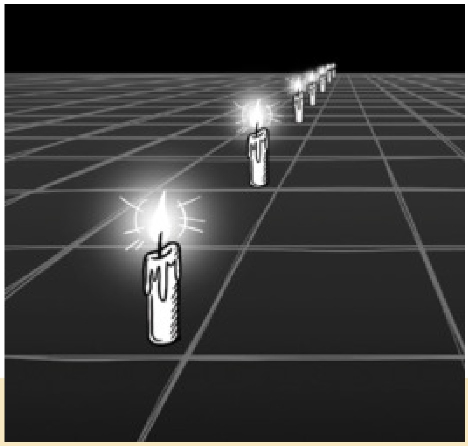
So far, astronomers have only been able to use gravitational waves to make a few such measurements of H_0. They calculated a value around 70, with an uncertainty range that overlaps both early- and late-time numbers. Within five years, the detectors will hopefully have gathered enough data for a much more precise value.

Unlike gravitational waves, which pass us by in a fraction of a second, gravitational lensing is a more permanent phenomenon. The theory is simple: We find flickering quasars that have a conveniently placed galaxy between us and them. The intermediary galaxy acts like a lens, magnifying the quasar's light and breaking it into multiple images, like a spacetime mirage. Although the images originate from the same place, they flicker out of sync because the light from the quasar refracts around the lens galaxy, taking paths of different lengths to reach us. Astronomers can use these delays to measure the quasar's distance.

Sherry Suyu (Max Planck Institute for Astrophysics, Germany) started a program to measure the distances to lensed quasars, dubbed H0LiCOW (H_0 Lenses in COSMOGRAIL's Wellspring). They looked at data from six different quasars, using a combination of space- and ground-based telescopes, and calculated an H_0 of about 73 km/s/Mpc.

But accurate measurements of the images' travel times depend on knowing the distribution of mass within the closer, lensing galaxy, which is tricky. This is why H0LiCOW and related groups are already preparing for a much larger study when the Vera C. Rubin Observatory comes online in 2023. They will also receive time on the James Webb Space Telescope (JWST) to better characterize the lensing galaxies.

Suyu is optimistic about the utility of the technique. "Gravitational lensing has an advantage because it is based



◀ **STANDARD CANDLE** A source of a specific intrinsic brightness will look fainter the farther away it is. Astronomers use several kinds of sources as standard candles to estimate distances across the observable universe.

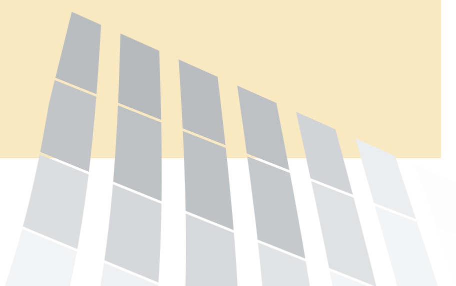
Distance by Any Measure

Space lacks perspective: Two stars can appear to be the same size and brightness, but in reality one can be much brighter and farther away than the other. This is where known quantities, either of brightness, size, or loudness — known respectively as *standard candles*, *standard rulers*, and *standard sirens* — come into play. Astronomers use them as the jumping-off point when reckoning cosmic distances.

Candles A standard candle is an astrophysical object of known brightness. Because the relationship between distance and perceived brightness is well understood, if you know the class of the object you are looking at, you can tell how far away it is by measuring its luminosity. Henrietta Swan Leavitt discovered the first standard candle — Cepheid variable stars — more than a century ago. Today there are many phenomena that astronomers can use to measure cosmic distances in this way, including Type Ia supernovae, gravitationally lensed quasars, and planetary nebulae.

Rulers A standard ruler is an astrophysical object of known size. If you already know how big something is, but you don't know how far away it is, simple trigonometry can tell you. All you need is to determine how big the object looks in the sky from your perspective, known as the angular diameter. Baryon acoustic oscillations are the main standard rulers in use right now. They indicate that matter in the universe is distributed in an uneven density pattern, such that galaxies are more likely to be about 480 million light-years from each other.

Sirens A standard siren is a source of gravitational waves of known intensity, or amplitude. The merger of two compact objects, like neutron stars or black holes, emits ripples in spacetime that shrink in amplitude as they travel. Assuming that general relativity is valid and that our detectors are well-tuned, that ripple will arrive at Earth with the distance it has traveled already encoded into it, with no need for complex distance-ladder calculations.



LEAH TISCIONE / *S&T*

“Gravitational lensing has an advantage because it is based on simple geometry and well-known physics. . . . GR has not yet failed us, so I think lensing won’t, either.” —SHERRY SUYU

on simple geometry and well-known physics,” she says. “It just relies on general relativity, which has so far passed all the various tests. GR has not yet failed us, so I think lensing won’t, either.”

In a few years, the groups working on gravitational-wave and gravitational-lensing observations will have enough data to give very accurate, independent measurements of H_0. If they find it to be around 67, this will vindicate CMB-based measurements. If they get around 74, then this will not only vindicate groups such as Adam Riess’s SH0ES collaboration but also provide strong evidence that something is missing from ΛCDM and new physics is needed.

If, on the other hand, these approaches find a value between the two extremes, as Freedman has, or they each find wildly different numbers, then it will still be anyone’s guess as to what’s going on.

Cosmological: Is ΛCDM Wrong?

The standard model is a concordance stratagem, meaning it’s what cosmologists agree to use right now. If the model is even a bit wrong, this could in turn cause calculations based on early features, such as the CMB and BAO, to get the current expansion rate a bit wrong in turn.

The Planck satellite gave us the gold-standard measurement of the CMB, with its final data release in 2018. But regardless of the elegance of the results, there is always room for improvement. Several instruments, the South Pole Telescope (SPT) among them, are currently observing the CMB with higher resolution and sensitivity than ever before.

“This gives us the capacity of testing predictions, both of the standard cosmological model and alternative models,” says SPT collaboration member Lloyd Knox (University of California, Davis). “So far, everything we have found is consistent with ΛCDM.”

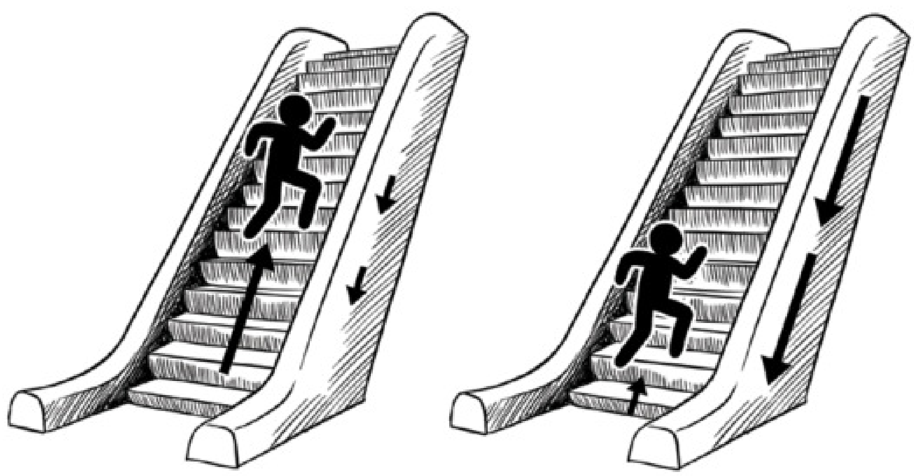
The SPT survey of the CMB will be completed in the next few years. Cosmologists expect it to deliver a more conclusive test of the exponential growth spurt in the universe’s earliest moments, called inflation, and a better understanding of dark matter and dark energy. Any surprises in these data could be evidence that the standard model is flawed.

Theorists have suggested a lot of different tweaks to the ΛCDM model to fix the discrepancy between direct and indirect measurements. Corrections after the epoch of recombination have mostly fallen out of favor because they are inconsistent with both observations of BAO and supernova data. So if something is wrong, many think it’s likely something to do with conditions in the primordial plasma universe, back before the CMB photons were released.

Adjusting elements of the early plasma, such as the properties of tiny particles called neutrinos or of primordial magnetic fields (*S&T:* Sept. 2021, p. 22), or varying fundamental physical constants, changes what’s called the *sound horizon*. The sound horizon is the maximum distance that a sound wave could have traveled before recombination occurred. We can’t look back any earlier than recombination with electromagnetic radiation, so the pre-recombination period is a mysterious period of time, uncharted territory that’s perfect for exploring new physics.

One of the possibilities is called *early dark energy* (EDE). This is a class of theories in which dark energy’s properties are not constant but evolve over time, creating more dark energy in the pre-recombination period and less at later times than cosmologists have traditionally assumed existed. Sunny Vagnozzi (University of Cambridge, UK) uses an illustration to show how uncertainties around the sound horizon lie at the heart of EDE solutions:

“Say I give you a certain amount of time to run the wrong way up an escalator, and you only make it to a certain point,” he says. “That’s the sound horizon. Now, say I speed up the escalator, and I give you the same amount of time. You’re going to run up a smaller distance. Imagine the speed of the escalator is the universe expanding. That’s why people are looking at early dark energy. For a small amount of time,



LEAH TISCIONE / S&T

▶ **EARLY DARK ENERGY** Increasing dark energy in the primordial universe would prevent sound waves from traveling as far, similar to the effect of trying to run up an escalator when the speed is increased.

just before recombination, it can speed up the universe, and sound waves will travel 7% less" — which would make the expansion measurements match.

By speeding up the escalator of the universe's early expansion, EDE theories lower the sound horizon, which in turn leads to a higher H_0 that's more in line with late-universe measurements.

"The thing is, though, that if you change the way in which dark energy behaves, you could make the way the universe evolves, like the number and size of galaxies, completely off," warns Vivian Poulin (now at University of Montpellier, France).

Astronomers will soon determine the true number and sizes of galaxies at high redshifts using the JWST. The resulting data will either lend credence to the ΛCDM assumptions about how the universe came to be or open up the field to competing possibilities.

But emerging evidence from Weikang Lin (Shanghai Jiao Tong University, China) and colleagues suggests that early-time solutions cannot by themselves fix the problem.

"Observations from the CMB are thought to be highly dependent on early physics," Lin says. "So we tried to find a way to use the information from the CMB in a way that wasn't sensitive to what happened before recombination."

Lin and his team used the sound horizon measured from the CMB and BAO to determine how much the universe expanded right after the CMB was released — a size change that depends on the density of matter, not pre-recombination physics. They refined their estimate of matter's density using supernovae not calibrated with Cepheids. Then they calculated H_0 in various ways, all of which approximately matched Planck's final value. The result suggests that fiddling with early-universe physics won't solve the discrepancy.

Maybe Einstein's GR is not the correct theory of gravity for cosmological scales.

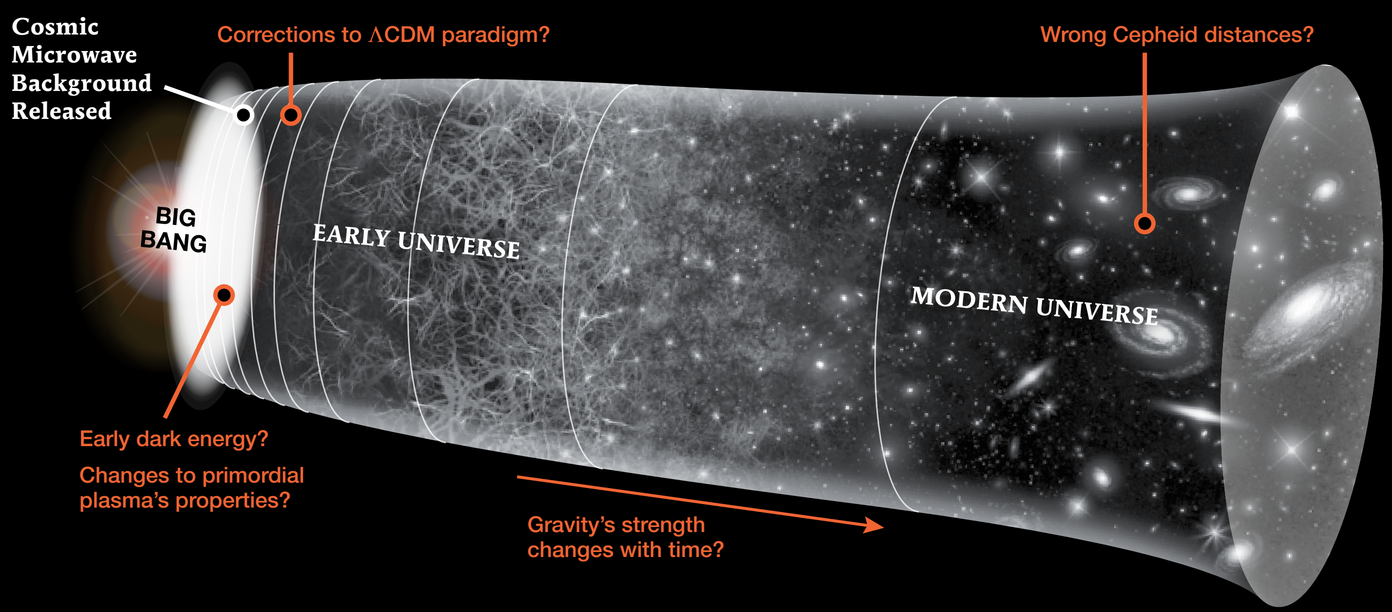
But if both early- and late-time corrections to ΛCDM are disfavored, does that mean that the Hubble tension is definitely the result of systematics? Vagnozzi says not necessarily.

"For it to be purely the result of mistakes from all the different independent groups would seem almost like a conspiracy," he says. "I think the literature is converging towards a big picture where neither late-time physics or early-time physics alone can solve the tension. Personally, I think the answer might be a combination of the two."

A Second Tension

One aspect of ΛCDM that theorists have been playing with for decades is gravity. Perhaps, in the same way that Newtonian physics works fine on Earth but not for describing extreme gravitational environments, maybe Einstein's GR is not the correct theory of gravity for cosmological scales.

S&T ILLUSTRATION



WHERE'S THE PROBLEM? Astronomers have suggested many solutions to the conflict between estimates of the current cosmic expansion rate. Those discussed in the article are shown here.

Joan Solà Peracaula (University of Barcelona, Spain) explores ways in which gravity might behave differently than we thought.

"The discrepancies in H_0 measurements are not the only problem for ΛCDM," he notes. Astronomers are also finding fewer galaxy clusters than expected, a problem called the *sigma-8 tension* (*S&T:* May 2014, p. 10).

"From what we can see, the universe is not as clumpy as the standard model predicts," he explains. "And I wondered, what if both of these problems are caused by the wrong theory of gravity?"

Solà Peracaula's group started with an alternative theory of gravitation called Brans-Dicke, first proposed in 1961, in which the gravitational constant (G) is actually variable. The researchers suggest that the strength of gravity at cosmological scales could become bigger over time, so that fewer, denser galaxy clusters would form — as observed.

Stronger gravity also makes local measurements of H_0 bigger, because in the standard cosmological model, the expansion rate is proportional to the gravitational constant.

To understand this, think of spacetime as a trampoline. Mass causes the trampoline to shrink, while dark energy expands it. Gravity is analogous to the stiffness of the trampoline. Modified gravity theories suggest that perhaps the trampoline is made out of different material in different places, at different times. If G is changeable, the push and pull between mass and dark energy will be more dynamic and could allow for the expansion of the universe to fit with the values of H_0 seen at different points in spacetime.

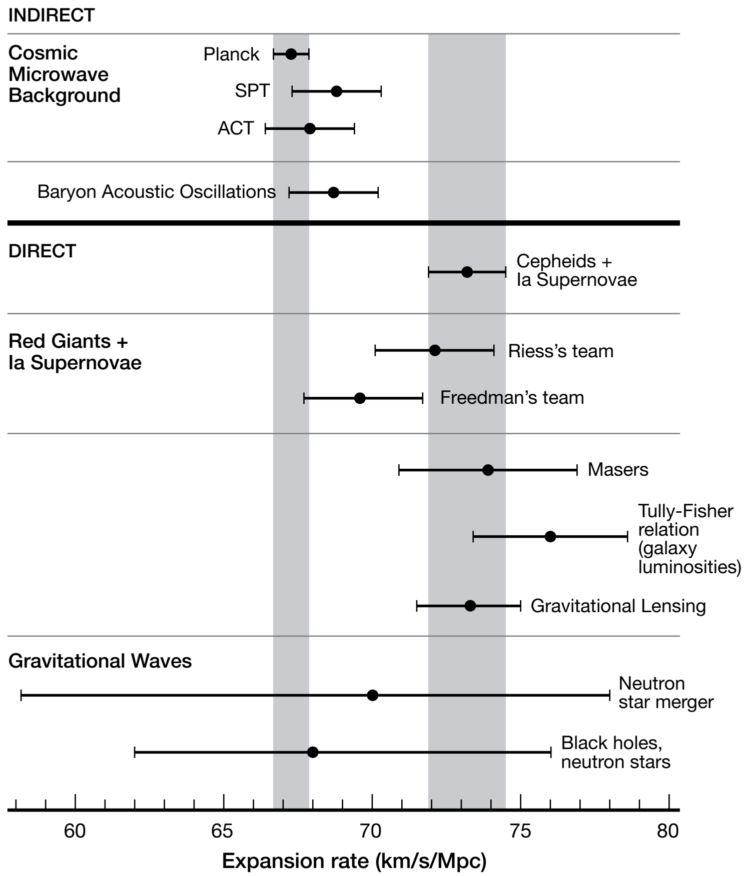
The Rubin Observatory promises to shed light on this second tension by giving us more and better data on the mass and composition of large-scale structures. If it turns out that there are as many galaxy clusters as ΛCDM predicts, then skeptics will have less ground to stand on. But if the observations continue to play out as they have, with the universe looking unexpectedly smooth, then this "tale of two tensions" may indicate we need a new theory of gravity.

The New Perihelion of Mercury

It's possible that one of the above-mentioned theories, observations, or experiments may eventually lead to the unraveling of the Hubble tension. But it is also possible that the answer may come from an unexpected source, requiring a leap forward in our understanding of physics. Take the story of Mercury's orbit.

The slow reorientation of Mercury's orbit around the Sun is not quite right when compared with the prediction from Newton's laws. Urbain Le Verrier first recognized this as a problem for astronomy in 1855. Lots of interesting solutions were proposed, but unfortunately, they caused more problems than they solved. This 19th-century crisis in cosmology wasn't resolved until Einstein's theory was applied to our solar system more than 50 years later: It turns out the Sun's mass creates a well in spacetime that drags on Mercury and gradually changes its motion.

Hubble Constant Measurements



▲ **THE GREAT DIVIDE** Measurements based on observations of the early universe (indirect, top) indicate a lower cosmic expansion rate for the modern universe than most measurements of later cosmic times (direct, bottom). Recent work by Wendy Freedman's team provides an intriguing exception, as do estimates based on gravitational waves.

S&T DIAGRAM, SOURCES: E. DI VALENTINO ET AL. / *CLASSICAL AND QUANTUM GRAVITY* 2021 AND THE LIGO, VIRGO, AND KAGRA COLLABORATIONS / ARXIV:2111.03604

In many ways, the Hubble tension feels like the new perihelion of Mercury. It could be that a mundane solution, like replacing a constant with a varying quantity or adjusting distance estimates for Cepheids, will make the problem go away. But it could also be that we need another GR moment, another cosmic epiphany. Where the solution will ultimately come from, no one can yet say.

■ **ARWEN RIMMER** is a writer and musician in Cambridge, England.

FURTHER READING: For a comprehensive overview of potential solutions to the Hubble tension, read the 2021 *Classical and Quantum Gravity* review by Eleonora Di Valentino and others: **arxiv.org/abs/2103.01183**. (Warning: It's 134 pages long.)

ONE ASTOUNDING NIGHT by Ted Forte

William and Caroline Herschel's Big Night

Follow in the footsteps of the Herschels' most productive night: April 11, 1785.

Of all the great visual observers of the past, Sir William Frederick Herschel (born Friedrich Wilhelm Herschel), was undoubtedly the most prolific. His telescopic discoveries include the planet Uranus and two of its moons (Titania and Oberon), as well as two of Saturn's moons (Mimas and Enceladus). Herschel's earlier observations focused on double stars, and he's credited with identifying 848 pairs. The three volumes of his *Catalogue of Nebulae and Clusters of Stars* (first published in 1786, with other editions appearing in 1789 and 1802) contain 2,500 entries, of which 2,363 are discrete, nonstellar, deep-sky objects.

Herschel began his systematic search for nebulae in 1783 from his home in Datchet (Berkshire, England) using a telescope of 18.7-inch aperture — known as the Large 20-Foot — that he built for this purpose. He devised a method of scanning the sky that he called *sweeps*. His earliest efforts, however, proved rather inefficient, prompting him to experiment with a different approach. The technique he employed on his 46th sweep in December 1783 proved effective, and it became his standard practice going forward.

Herschel observed sitting in a chair on an adjustable platform at the Newtonian focus of the Large 20-Foot, while an assistant moved the scope vertically with pulleys and ropes. With the telescope aimed at the meridian for many hours, the assistant would slowly raise and lower it by about 2° in declination, and thus a large rectangular area of sky was cov-

▲ **THE BOX** Hickson 61, a tight grouping of four galaxies, can fit into the same medium-power field of view. You can likely catch sight of the brightest of the foursome, NGC 4169, with an 8-inch, but you'll need a larger-aperture scope to add the remaining three. Starting from top and moving clockwise, the galaxies are ordered as follows: NGC 4173, NGC 4169, NGC 4174, and NGC 4175. The rightmost bright star in the image is magnitude-7.5 HD 105771.

TERO HIRVIKOSKI

ered as new objects drifted into the field of view. He'd call out his observations to his sister Caroline, who'd be sitting at a desk at a window nearby, recording the data in *sweep books*. (For more on the history of this night of observation, see page 34 in the April 2015 issue of *Sky & Telescope*.)

During the period from 1783 through 1802, Herschel performed searches on 616 nights, and he discovered new nebulae on 394 of them. He conducted 1,112 sweeps covering about 90% of the sky visible from his location. Herschel found most of the nonstellar objects accredited to him between 1784 and 1787. His nightly tally of discoveries exceeded 20 objects on 19 separate occasions.

◀ **DYNAMIC DUO** Caroline Herschel was instrumental in her brother's astronomical endeavors. Caroline would jot down William's observing notes as he called them out from his perch at the telescope. This engraving represents a time preceding the Large 20-Foot operations. You can read more on the Herschels' historic discoveries in, e.g., Wolfgang Steinicke's *Observing and Cataloguing Nebulae and Star Clusters.*

Yet one remarkable night stands out more than any other.

An Extraordinary Night

Overnight on April 11, 1785, Herschel recorded 74 new objects: Seventy-two were picked up on sweep number 396 and two more on sweep 397. When Herschel encountered a new nebula or cluster, he would assign it to one of seven classes he'd conceived, based on its visual characteristics. He gave each object a sequential number, with each class having its own series. On that night, Herschel listed eight of them as his Class I (Bright Nebulae, catalog numbers 86–93), 42 as Class II (Faint Nebulae, numbers 358–399), and 24 as Class III (Very Faint Nebulae, numbers 348–371).

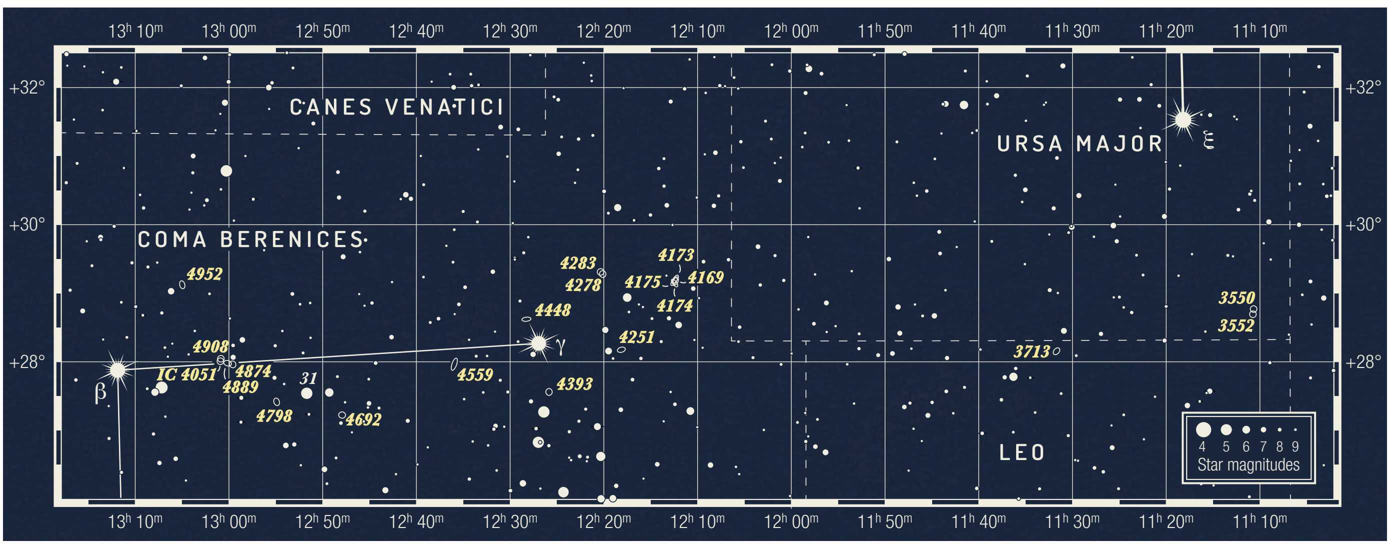
All the objects discovered were galaxies, except for the one he recorded as II 375, subsequently listed in the *New General Catalogue of Nebulae and Clusters of Stars* as **NGC 4209**. But it's probably a star or a duplicate observation of NGC 4185. (A few uncertainties still linger about the identities of some of the NGC objects.) While the majority of that night's finds lie in Coma Berenices, six other constellations are also represented.

Reliving this marvelous night has become a popular observing challenge. Called the *Herschel Sprint*, the *Herschel Hustle,* and even the *Herschel Marathon*, the idea is to observe all 74 objects during a single dusk-till-dawn session.

To recreate Herschel's experience as accurately as possible, choose a spring evening with a waxing crescent moon about two to three days old. Herschel's 18.7-inch mirror, made of speculum metal, was less reflective than a modern aluminized glass mirror. I would suggest that a scope of 15 or 16 inches would best approximate his instrument's light grasp. In any case, at least a 15-inch aperture is likely required to reliably detect all the objects Herschel discovered that night (but you can spot quite a few with smaller scopes as outlined below).

Modern eyepieces will also present a challenge to the purist. Herschel's standard eyepiece had a focal length of 39 mm, yielding 157× in the 18.7-inch scope, and a field of view of 15′ 4″. Observers may have to choose between replicating either the magnification or the field of view, but not both.

To faithfully duplicate Herschel's procedure, don't employ a clock drive. Instead, keep the telescope fixed at the meridian, moving it only in declination. Nearly five and a half



▲ **AN EXTRAORDINARY NIGHT** Even if you don't participate in the full Herschel Hustle, pursuing a subset of targets — such as the ones discussed here — should give you a flavor of what William and Caroline Herschel experienced on that astounding night of discovery, April 11, 1785.

WILLIAM AND CAROLINE: DETLEV VAN RAVENSWAAY / SCIENCE SOURCE; GALAXY ILLUSTRATION: MELOK / SHUTTERSTOCK.COM hours will elapse between the transits of the first and last objects. Around mid-March, the first object transits at around 11:45 p.m. and the last at around 5:10 a.m. for an observer at mid-northern latitudes. Attempting the list in April is more manageable, with transits beginning at around 9:40 p.m. and ending at 3:10 a.m.

For most readers, all the objects are above the horizon by sunset in April. If you're willing to observe as soon as your targets are high enough (instead of on the meridian), you could start at the end of twilight and look in on every galaxy in as few as three hours or so. Anyone who tackles the Herschel Hustle can download a certificate from the Astronomical League, while members of the League who actually complete the challenge in one go can apply for a more official award (see **astroleague.org/content/herschel-hustle**).

The Herschel Hustle is well worth attempting even if you stretch the effort out over several nights. The list contains some intriguing targets, and interesting histories inform the modern designations of several.

A good 4-inch scope under a dark sky will reliably show at least a dozen of the galaxies in the list. Twice that number are visible in an 8-inch, and a 10-inch scope will show about 45. However, as mentioned above, you might need a 15-inch aperture instrument to see all the objects reliably. Most of my explorations have been with an 18-inch Dobsonian, and unless otherwise noted, my descriptions refer to the view in that telescope.

◀ **THE LARGE 20-FOOT** Herschel experimented with various designs and configurations of his telescopes. One innovation was to add a system of pulleys handled by an assistant that would move the telescope in declination.

Cream of the Crop

For observers who just want to sample the best of the list, a few objects stand out. **NGC 4559**, for instance, is a must-see. This large, eye-catching spiral galaxy located around 2° east of 4.3-magnitude Gamma (γ) Comae (a star we'll be using as the starting point for several targets) has a bright core and a hint of spiral structure. The 18-inch shows an elongated object with a faint extension to the southeast that's set off

▲ **GALAXIES GALORE** You can start your own astounding night of observations by scoping out NGC 4559, a glorious spiral galaxy in Coma Berenices.

LARGE 20-FOOT: ROYAL ASTRONOMICAL SOCIETY / SCIENCE SOURCE; STARS ILLUSTRATION: MELOK / SHUTTERSTOCK.COM; NGC 4559: KPNO / NOIRLAB / NSF / AURA / JEFF HAPEMAN / ADAM BLOCK by an obscuring dust lane. Three stars are involved at the galaxy's southeastern end. In my 30-inch scope, I detect a fainter northern arm and two emission knots, designated IC 3551 and IC 3555. I didn't spot the other knots associated with this galaxy that have IC designations.

Lying some 27′ northeast of Gamma Comae, **NGC 4448** is a barred spiral with a prominent, oval-shaped core that's easily within reach of an 8-inch scope. A fainter, oval ring surrounds the core that I can just detect a tantalizing hint of with the 30-inch. Can you see it?

Go back to Gamma Comae and from there slew 1.9° west to find **NGC 4251**, a spindle-shaped lenticular galaxy with a bright, elongated core. Just 1½° northeast of the galaxy is Hickson 61. This is one of my favorite Hickson groups and is sometimes called The Box because of the rectangular arrangement of its four bright members: **NGC 4173**, **NGC 4169**, **NGC 4174**, and **NGC 4175**. NGC 4173, the edge-on spiral that forms the northern corner of the box shape, is a foreground object since it lies at one-third the distance of the other three. In angular size, it's the largest galaxy in the group. An interesting side note is that German astronomer Heinrich Louis d'Arrest "discovered" two other nebulae close to The Box but outside of the group that Herschel saw. However, those two objects — NGC 4170 and NGC 4171 — apparently don't exist. It's quite possible that poor seeing blurred some nearby stars, misleading d'Arrest to log them as nebulous objects.

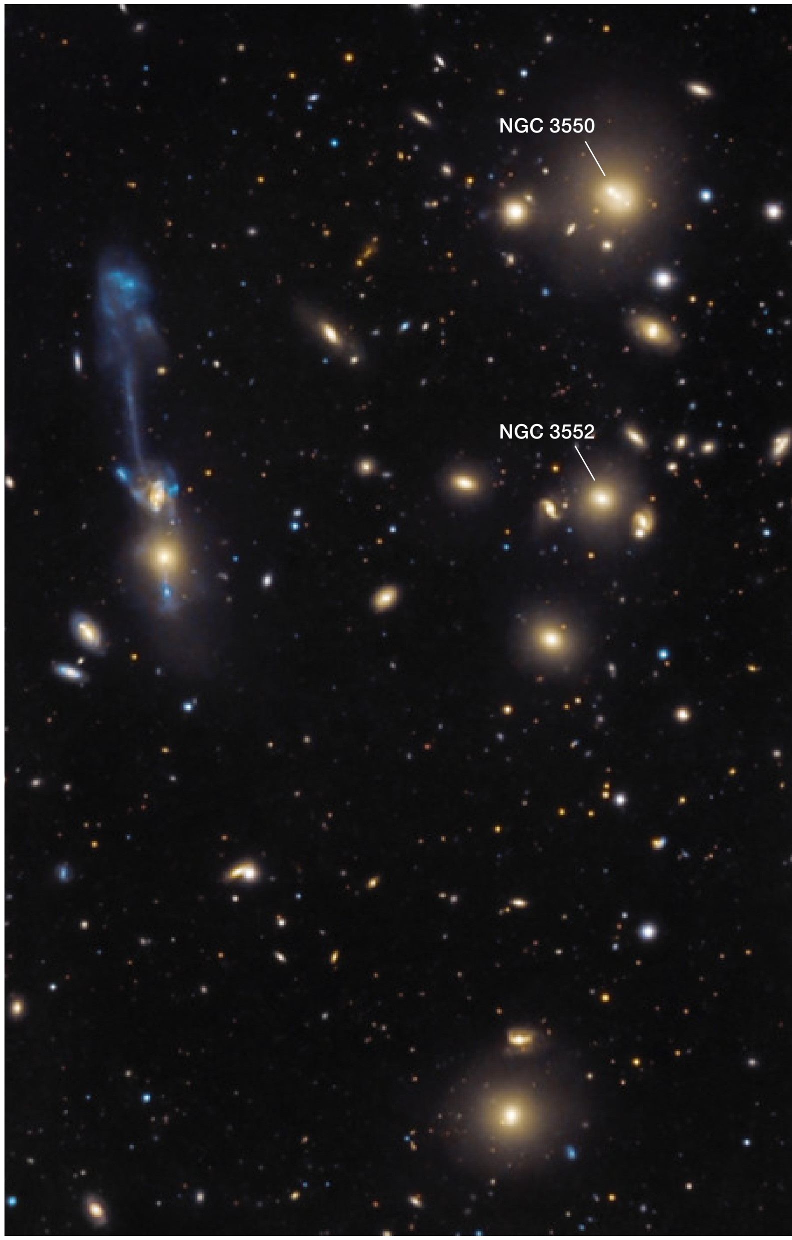
Another object that's visible in an 8-inch scope is the elliptical galaxy **NGC 4278**, which is the most prominent member of a trio that includes **NGC 4283** and NGC 4286. You'll find all three 1¾° northwest of Gamma Comae. Herschel discovered NGC 4278 and NGC 4283 twice. The first time he came across these targets during sweep 387 on March 13, 1785, he recorded them as II 322 and II 323 (along with the third galaxy III 300, NGC 4286). When Herschel encountered the pair again on April 11, 1785, he assumed they were new and logged them as I 90 and II 377.

Let's step away from Coma Berenices for a while and head toward the southernmost reaches of Ursa Major where we find **NGC 3550** and **NGC 3552** — two of the brightest galaxies in Abell 1185, a rich galaxy cluster that lies about 500 million light-years away. Herschel saw them as very faint and very small and even noted that he wouldn't have picked up the more southerly object, NGC 3552, had it not been close to the more prominent NGC 3550. I saw NGC 3550 fairly easily in the 18-inch, while NGC 3552 was considerably more difficult and not always distinct, but rather immersed in a haze of very faint nebulosity. My 30-inch can separate NGC 3552 from adjacent MCG 5-27-4 lying some 42″ to the southwest, which Herschel didn't note. This galaxy is most likely the object that French astronomer Camille Guillaume Bigourdan found 100 years after Herschel's discovery and should probably be designated NGC 3553. Since Bigourdan confused his discovery with NGC 3552, doubt lingers as to which new object he observed. These galaxies are about 3¼° southwest of Xi (ξ) Ursae Majoris.

Duplicitous Duos

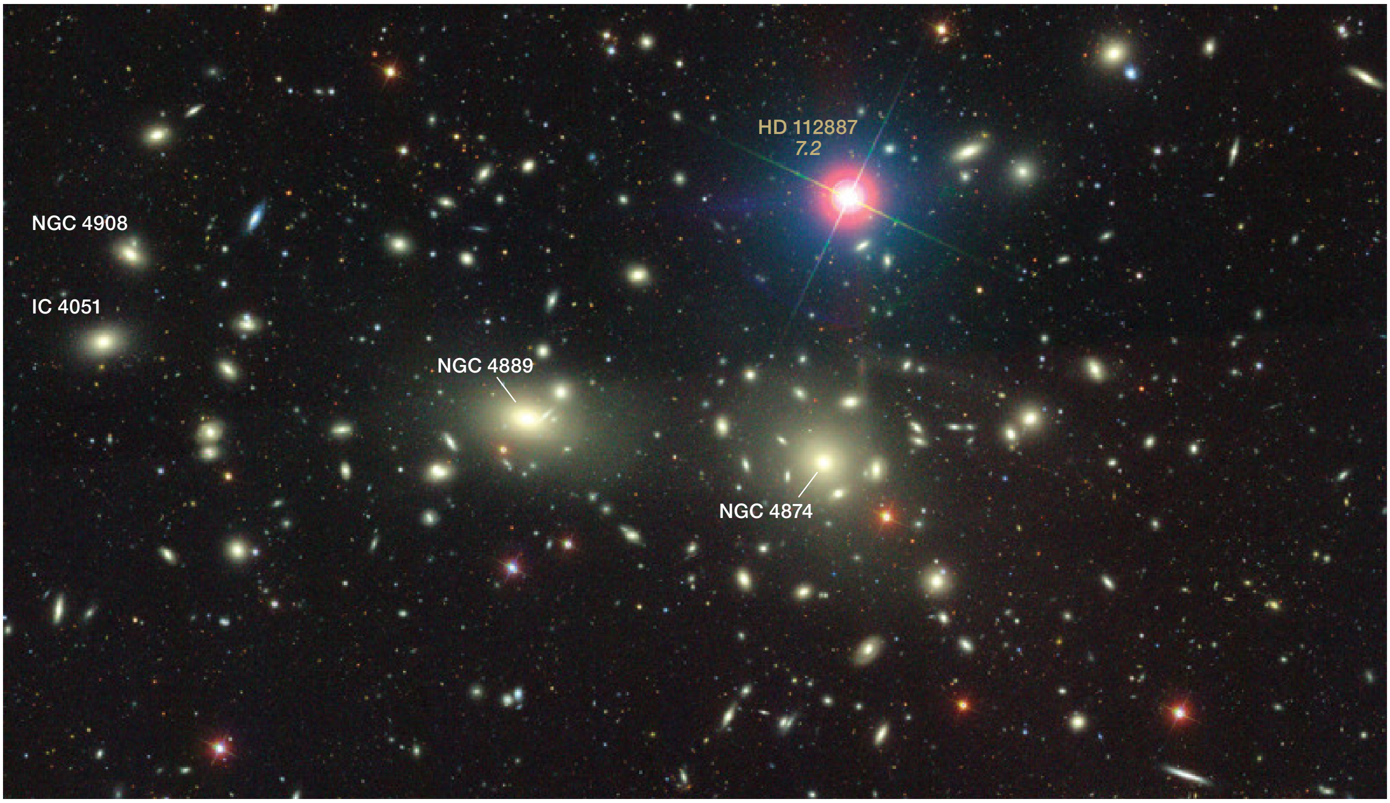
Among the objects that Herschel discovered on this remarkable night, uncertainties remain about the identities of several, and there are duplications worth noting.

Many of the galaxies Herschel swept up on April 11, 1785, belong to the Coma Cluster and count among the brightest members of that group of more than 1,000 galaxies. Of the 20 or so that he identified that night, the easiest to bag are **NGC 4889** and **NGC 4874**, which together comprise the core of the rich cluster. Your starting point is 4.2-magnitude Beta (β) Comae, and from there you'll slide 2⅔° due west to find this duo.



▲ **COSMIC CHAOS** Abell 1185 teems with galaxies of all shapes and sizes, many of which are drifting alarmingly close to one another. Several galaxies have already been ripped apart. Arp 105 (in the left-hand side of the image) is the result of a collision between a spiral and an elliptical, and the bluish feature stretching northward is a plume of ejected stars.

NICK PAVELCHAK



▲ **CLUSTERING IN COMA** The behemoths NGC 4874 and NGC 4889 anchor this humongous cluster of galaxies in Coma Berenices. The two galaxies are interacting, and astronomers have spotted some 22,000 globular clusters associated with the Coma Cluster (Abell 1656), some of which have formed a bridge connecting the pair.

DUSTIN LANG / SDSS COLLABORATION

The equivalence of NGC 4889 with NGC 4884 is fairly well established. On April 6, 1864, d'Arrest was exploring the group of galaxies at the heart of the Coma Cluster when he discovered the smaller companion to NGC 4889. John Louis Emil Dreyer (compiler of the *New General Catalogue of Nebulae and Clusters of Stars)* assigned it the NGC designation 4886. A year later, on April 22, 1865, d'Arrest observed the pair again but didn't recognize them. The objects he recorded that night were assigned NGC 4884 (duplicating NGC 4889) and NGC 4882 (duplicating NGC 4886).

A similar situation to that of NGC 4278 involves **NGC 4952**, some 1.9° northwest of Beta Comae. Astronomer and historian Harold Corwin believes that NGC 4952 is likely a rediscovery of NGC 4962, which Herschel recorded on March 13, 1785. There's nothing at the position of NGC 4962. Corwin notes that Herschel's position for NGC 4966, discovered the same night as NGC 4962, is off by 1′ in right ascension and 2′ in declination. By applying a similar offset to Herschel's position of NGC 4962, Corwin notes that it aligns with that of NGC 4952.

Popping into Leo, just below the border with Ursa Major you'll find **NGC 3713** about 5¾° southeast of Xi Ursae Majoris. It may be the key to unraveling a long-held mystery concerning NGC 3927, an object that d'Arrest recorded on April 27, 1864. Again, there's nothing at d'Arrest's position, and the object was assumed to be lost or nonexistent. *Sky & Telescope* Contributing Editor Steve Gottlieb has suggested that d'Arrest actually found NGC 3713 but registered a 20′ error in right ascension, a scenario Corwin agrees with (see **https:/is.gd/astronomy_mall** and **haroldcorwin.net/ngcic** for more on these and other historical aspects of NGC and IC objects).

Back in Coma Berenices, d'Arrest came upon NGC 4702 on March 4, 1867 — but it's most likely **NGC 4692**. This galaxy lies 53′ west-southwest of 4.9-magnitude 31 Comae. There's nothing at d'Arrest's position; Corwin concludes that this was a duplicate observation of NGC 4692 with a 1′ error in right ascension. It's also worth noting that many catalogs incorrectly equate NGC 4692 with IC 823, which Bigourdan discovered on April 17, 1885. IC 823 is, in fact, most likely a star.

Similarly, d'Arrest's discovery of NGC 4797 on April 21, 1865, is almost certainly **NGC 4798**, which you'll find 44′ east-southeast of 31 Comae. Corwin notes that the two positions that d'Arrest gives for NGC 4798 and NGC 4797 are very close indeed (separated by a mere 5′ in declination). If d'Arrest actually saw two different objects, they would have made a striking pair, and he most likely would have commented on the sight (which he didn't). Gottlieb adds that while d'Arrest measured the position of NGC 4798 on two nights, he didn't observe it on the night that he logged NGC 4797.

For the designations of the pair of galaxies **NGC 4908** and **IC 4051**, confusion and disagreement abound in sources and catalogs alike as to which is which. The two similar-looking objects lie 2.2′ apart in the Coma Cluster, with the slightly larger, brighter galaxy south-southeast of the of the smaller, fainter one. Herschel cataloged one of these objects as III 363, but it's somewhat unclear which of the pair he saw. German astronomer Hermann Kobold shares the co-discovery of IC 4051 with Bigourdan even though their individual assignment of the NGC and IC objects are reversed: Kobold assumed that the fainter of the two galaxies was Herschel's object while Bigourdan assumed the opposite. The issue is further confused by d'Arrest's recorded position for NGC 4908 (listed in the *New General Catalogue*), which falls between the two objects but is closer to the fainter one. John Herschel, William's son, muddled the situation even more by conflating III 363 with NGC 4894. Corwin and Gottlieb both conclude that Herschel (the elder) would have seen the brighter, more southeasterly object. My solution is to just observe them both and accept the designations most commonly assigned. Thus, Herschel's object is the one most often listed as IC 4051 if, as seems quite likely, he noted the more prominent of the two galaxies.

And lastly, ¾° south-southwest of our old friend Gamma Comae we find **NGC 4393**, an object that's often conflated with IC 3323, which Corwin confirms is a foreground star. Sometimes the star is associated with IC 3329, but this more correctly applies to a knot within NGC 4393.

The few errors and duplications that we find in this list — in fact, in the entire Herschel catalog — hardly detract from the incredible accomplishments of this remarkable observer. Certainly, I am not alone in my admiration for him and for being more than a little awed by his many achievements.

April 11, 1785, is perhaps the most extraordinary night in a long list of Herschel's extraordinary nights of observing. After all, it just may be the most productive night in the history of visual astronomy. One can only imagine the excitement of that session as the sweep books filled up with new acquisitions. Resolve to retrace Herschel's steps that night and you might sense a tiny bit of his excitement and gain an added appreciation for what was a golden age of visual astronomy.

■ Contributing Editor **TED FORTE** enjoys reliving the discoveries of the great visual observers of the past from his backyard in southeastern Arizona.

Herschel's Highlights

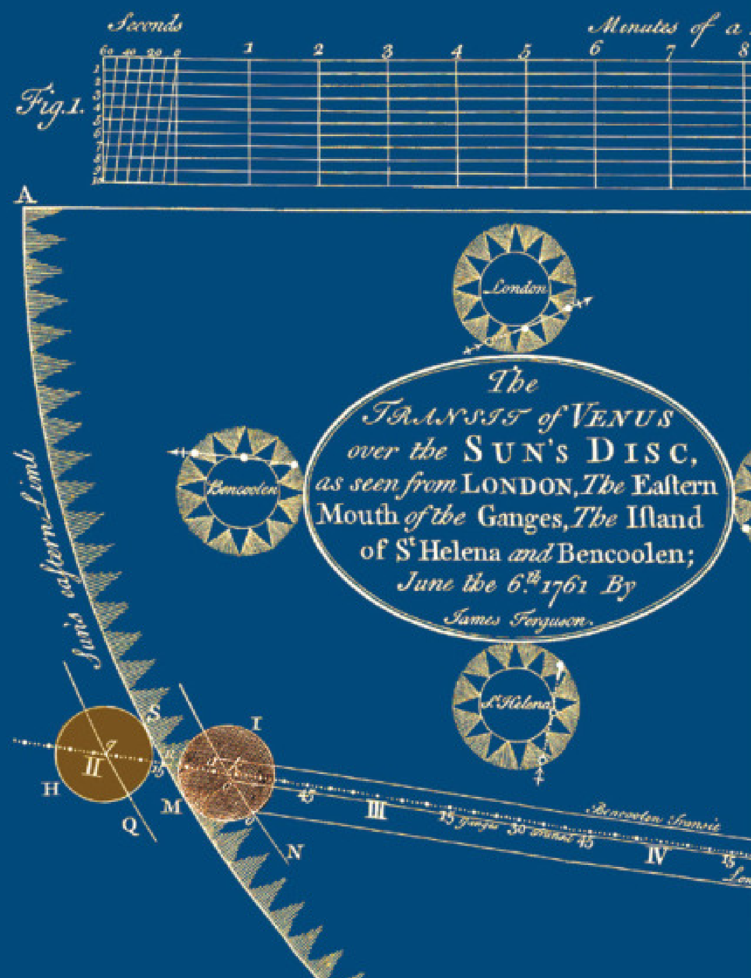
Object	Herschel Class	Type	Surface Brightness	Mag(v)	Size	RA	Dec.
NGC 4209	II 375	Stellar	—	11.3	—	$12^h 15.7^m$	+28° 28′
NGC 4559	I 92	Spiral	14.0	10.0	10.7′ × 4.4′	$12^h 36.0^m$	+27° 58′
NGC 4448	I 91	Barred spiral	12.8	11.1	3.9′ × 1.4′	$12^h 28.3^m$	+28° 37′
NGC 4251	I 89	Lenticular	12.4	10.7	3.6′ × 1.5′	$12^h 18.1^m$	+28° 10′
NGC 4173	II 372	Barred spiral	14.2	13.0	5.0′ × 0.7′	$12^h 12.3^m$	+29° 13′
NGC 4169	III 358	Lenticular	12.6	12.2	1.8′ × 0.9′	$12^h 12.3^m$	+29° 11′
NGC 4174	III 359	Spiral	11.4	13.4	0.6′ × 0.3′	$12^h 12.4^m$	+29° 09′
NGC 4175	III 360	Spiral	12.8	13.3	1.8′ × 0.4′	$12^h 12.5^m$	+29° 10′
NGC 4278	I 90	Elliptical	13.1	10.2	3.8′ × 3.8′	$12^h 20.1^m$	+29° 17′
NGC 4283	II 377	Elliptical	12.9	12.1	1.5′ × 1.5′	$12^h 20.3^m$	+29° 19′
NGC 3550	III 351	Peculiar	13.2	13.3	1.0′ × 1.0′	$11^h 10.6^m$	+28° 46′
NGC 3552	III 352	Elliptical	13.8	14.5	0.7′ × 0.7′	$11^h 10.7^m$	+28° 42′
NGC 4889	II 391	Elliptical	13.3	11.5	2.9′ × 1.9′	$13^h 00.1^m$	+27° 59′
NGC 4874	II 389	Elliptical	13.1	11.7	1.9′ × 1.9′	$12^h 59.6^m$	+27° 58′
NGC 4952	II 396	Elliptical	13.1	12.4	1.8′ × 1.1′	$13^h 05.0^m$	+29° 07′
NGC 3713	II 367	Lenticular	13.0	13.2	1.2′ × 0.8′	$11^h 31.7^m$	+28° 09′
NGC 4692	II 381	Elliptical	13.1	12.6	1.3′ × 1.3′	$12^h 47.9^m$	+27° 13′
NGC 4798	II 382	Lenticular	13.1	13.2	1.2′ × 0.9′	$12^h 54.9^m$	+27° 25′
NGC 4908	III 363	Elliptical	12.9	13.6	0.8′ × 0.6′	$13^h 00.9^m$	+28° 02′
IC 4051	—	Elliptical	13.3	13.2	1.2′ × 0.9′	$13^h 00.9^m$	+28° 00′
NGC 4393	III 361	Barred spiral	14.4	12.1	3.2′ × 2.9′	$12^h 25.9^m$	+27° 34′

Angular sizes 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.

GALAXY ILLUSTRATION: MELOK / SHUTTERSTOCK.COM

Mason and Dixon's Great Venus Adv

A pair of well-known surveyors got their start trying to solve one of the biggest questions in astronomy.



SCIENCE SOURCE / SCIENCE SOURCE

Charles Mason and Jeremiah Dixon are best known for their 18th-century survey of a disputed territorial boundary. Their names are attached to the Mason-Dixon Line, which partially defines the present-day border between the states of Pennsylvania, Maryland, Delaware, and West Virginia. What is less well known is that the pair were selected for this task thanks to their earlier involvement in an astronomical endeavor to determine the distance between Earth and the Sun.

Johannes Kepler's third law of planetary motion, published in the early 1600s, described the relative size of the solar system. His calculations expressed the radius of each planet's orbit as a ratio of Earth's orbit. For example, Mercury's orbit is 0.389 times the radius of Earth's and Saturn's is 9.51 times. However, the *absolute* size of the solar system remained a mystery — Kepler's ratios didn't reveal the actual distances between solar system bodies. But by determining the physical distance between just two solar system bodies, such as Earth and the Sun, all other distances could be calculated using Kepler's ratios.

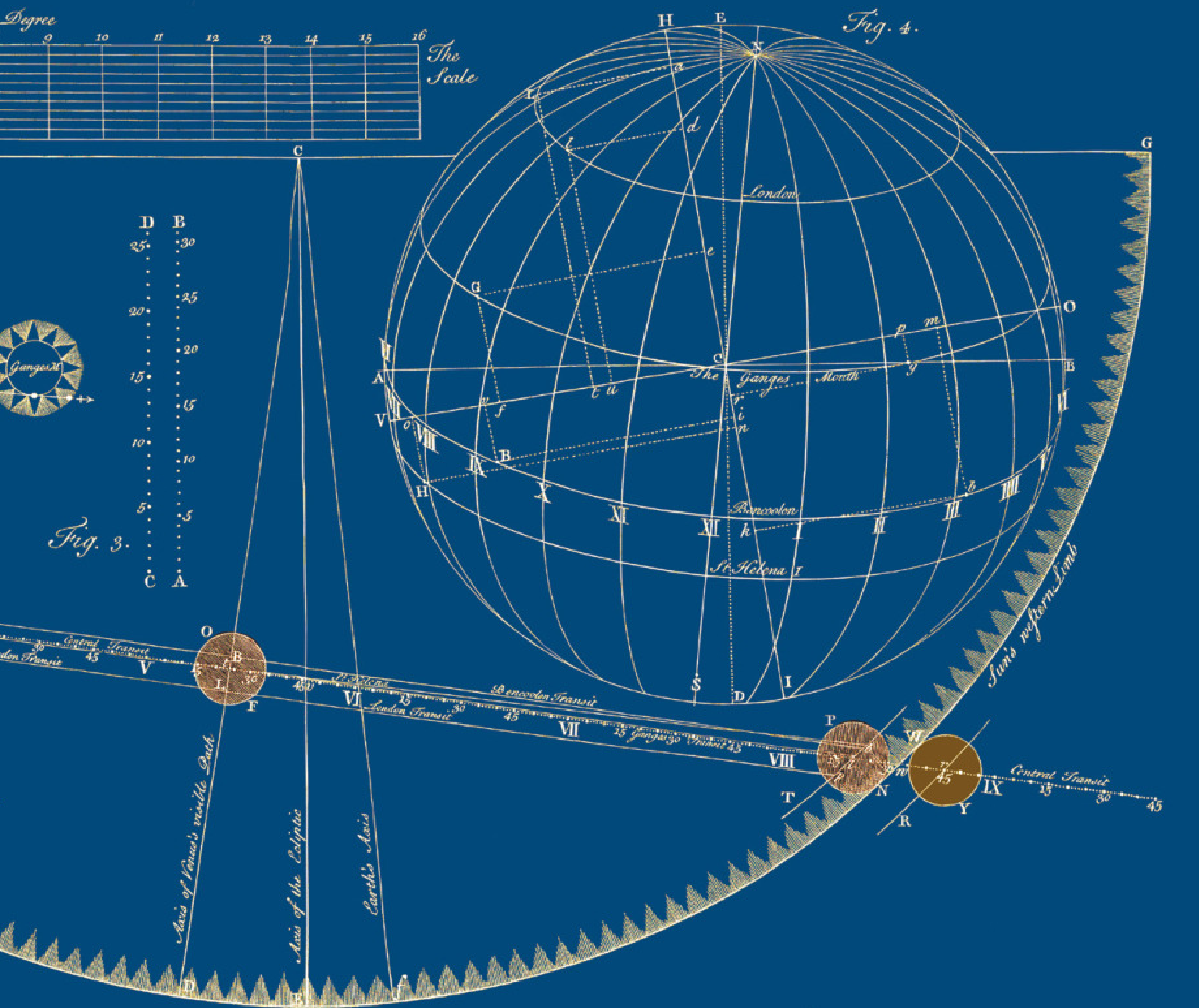
A Question of Angles

In the 18th century, the *parallax method* was believed to be the best available for establishing astronomical distances. To measure a parallax angle, astronomers had to observe a target from two widely separated locations and gauge the apparent shift in that object's position against a fixed background reference — usually the stars. The farther the object is from the background and the closer it is to Earth, the larger the apparent parallax shift and the greater the accuracy of the measurement.

Early attempts to capture the parallax shift of Mars against background stars failed. During favorable oppositions, Mars typically only approaches to within 0.37 a.u. of Earth, rendering the resulting angle too small to measure precisely. Similarly, observing Mercury crossing the face of the Sun didn't yield useful results: During the transit Mercury is too far, at around 0.61 a.u. from Earth, and it's also too close to the background reference (the Sun). In 1677, Edmond Halley suggested that the June 6th, 1761, transit of Venus might offer a good chance for a precise measurement of parallax shift. Compared with Mercury, Venus has the advantage of being both closer to Earth (at only 0.28 a.u.) and farther from the Sun.

enture

VENUSIAN PATH Scottish astronomer James Ferguson drew this diagram showing the path of the 1671 transit of Venus across the Sun as viewed from London, the eastern mouth of the Ganges in India, the island of St Helena, and Bencoolen, Sumatra. Charles Mason and Jeremiah Dixon set sail for Bencoolen but were forced to stop short and observed the event at the Cape of Good Hope in South Africa.



Astronomers could apply several methods to observe the Venus transit. One was to simply time how long it took for the planet to cross the entire solar disk. Another was to measure the north-south location of the apparent path Venus traced across the Sun. A third technique was to note the time it took for the preceding and following limbs of the Venusian disk to cross the limb of the Sun either at the start of the transit or as it ended.

Among the countries that took up Halley's challenge, England planned two transit expeditions to the Southern Hemisphere (see, e.g., *S&T:* June 2012, p. 28). Astronomer Nevil Maskelyne led one expedition to the island of St. Helena in the southern Atlantic Ocean, and Charles Mason, once assistant astronomer at the Royal Greenwich Observatory, was in charge of another to Bencoolen, Sumatra, on the eastern edge of the Indian Ocean. For his excursion, Mason selected Jeremiah Dixon as his assistant. Dixon, then 27 years old, was an amateur astronomer recommended to Mason by a Fellow of the Observatory (possibly John Bird).

Mason and Dixon's equipment for observing the transit included a pair of Gregorian reflectors made by prolific telescope maker James Short, and a pendulum astronomical clock built by James Ellicott. To determine both the local time and the latitude of their observing station, they also brought an astronomical quadrant of one-foot radius, supplied by the aforementioned Bird.

To measure the positions of Venus's path across the solar disk, as well as the apparent diameters of Venus and the Sun, Mason and Dixon utilized a Dollond divided object-glass micrometer that attached to the front of one of the telescopes. The object glass of the device had two halves that could be shifted linearly relative to each other by operating a pair of long rods — one to adjust the separation of the lens halves, and the other to rotate the micrometer. The separation between the limb of the Sun and Venus could be measured by noting the micrometer readings.

◀ **BRASS BEAUTIES** Mason and Dixon used a pair of Gregorian reflectors made by James Short to observe the 1761 transit of Venus. Each instrument had a focal length of two feet (61 cm) and speculum metal primary mirrors that were likely 4½ inches (114 mm) in diameter.

Sailing to Venus

Mason and Dixon's voyage to Sumatra seemed ill-fated from the start. The pair arrived at Portsmouth, England, where their ship was moored in late November 1760. Due to poor weather and problems readying their vessel, the *HMS Seahorse*, they didn't leave port until January 8, 1761. Even with favorable winds, the expedition would need more than a little luck to reach Bencoolen in time for the June transit.

▲ **LITTLE BLACK DOT** This photo of the June 6, 2012, transit was captured exactly 251 years after Charles Mason and Jeremiah Dixon watched Venus cross the Sun. In that time, a Venus transit has morphed from being a matter of great scientific interest to a mere curiosity.

To further complicate matters, the Seven Years' War between England and France was raging. Although both sides agreed not to interfere with astronomers destined for the transit, the 34-gun French frigate *L'Grande* attacked the *Seahorse* on January 10th before the English ship had even left the English Channel. Several items on the *Seahorse* were destroyed or thrown overboard (including a generous quantity of beer, water, and four hogsheads) to make room for firing the ship's guns. The French attempted to board the *Seahorse* three times before they were forced to retreat. In the battle, 11 members of Mason and Dixon's crew were killed outright and 37 wounded (many mortally). The damage was so extensive that the ship had to return to Portsmouth for repairs.

Mason, realizing that they might not reach Bencoolen in time for the Venus transit, wrote to the Royal Society suggesting they sail for the eastern Mediterranean instead, the nearest location where the entire event could be observed. However, the Royal Society was determined to gather observations from a Southern Hemisphere location, and since a large number of Northern Hemisphere expeditions were already planned, the society insisted the pair's destination remain Bencoolen.

By February 3, 1761, the *Seahorse* was repaired and ready to depart again. On April 27th — less than six weeks before the transit — the expedition had sailed only as far as the Cape of Good Hope in South Africa. Mason, Dixon, and the captain of

GREGORIAN REFLECTOR: HISTORY OF SCIENCE MUSEUM, UNIVERSITY OF OXFORD; VENUS TRANSITING THE SUN: GARY SERONIK the *Seahorse* knew it was impossible to reach Sumatra in time, so they decided to stop short and set up their equipment in Cape Town. The location was a compromise that would cost the astronomers dearly, since the 6½-hour transit would begin 3½ hours before local sunrise on June 6th.

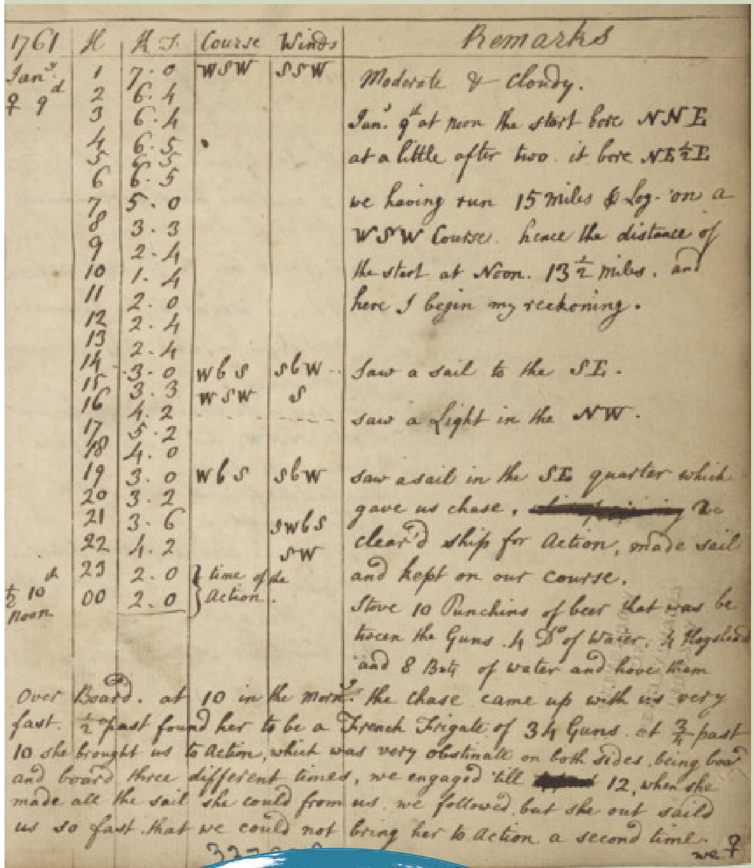
Having found a suitable site for their simple observatory, Mason and Dixon took their instruments ashore on May 2nd. They set up the pendulum clock and astronomical quadrant in order to determine crucial data for their transit measurements: their latitude and local time. To do so they needed to measure the Ellicott clock's *going* — the rate at which the clock was running fast or slow. They discovered it was slow by 2 minutes and 17 seconds per sidereal day. They could have adjusted the clock's rate by altering the length of the pendulum, but in practice simply taking the difference into account when reducing the data would accomplish the same thing. Between May 4th and June 5th, the pair observed on 13 nights in order to refine their position and the clock's going.

Transit Day Arrives

On the morning of the transit, the Sun rose into thick haze and low clouds. The scientists first spotted Venus 13 minutes after sunrise, but because the Sun was so close to the horizon, the view was poor. Around one hour after sunrise, Mason began using the Dollond micrometer on one of the reflectors at a magnification of 120×. He measured the distance between "the Sun's farthest limb from Venus' farthest limb (that is, the Sun's northern limb from Venus' southern limb.)"

Recording the time for each measurement was a task that probably fell to Dixon. It's also likely that he read and recorded the offset of the micrometer's object glasses so Mason could remain at the telescope's eyepiece. In total, the pair took 15 limb measurements, as well as four of the Sun's diameter and three of Venus's diameter to determine the apparent radii of both objects. (Mason also reported that he did not see a Venusian satellite.) He took his final observation of Venus's location on the face of the Sun about 35 minutes before the planet reached the solar limb. (You can see a representation of the transit at the HM Nautical Almanac Office website, which features an animation of the event as seen from Cape Town at **https://is.gd/1761transit**.)

As Venus exited the Sun's disk, both Mason and Dixon recorded the times when the planet's lead-


1761 | H | K F | Course | Winds | Remarks

Jan.d 9

Moderate & cloudy.
Jan. 9 at noon the start bore NNE
at a little after two it bore NE½E
we having run 15 miles & log. on a
WSW Course hence the distance of
the start at Noon. 13½ miles. and
here I begin my reckoning.
Saw a sail to the SE.
saw a light in the NW.
Saw a sail in the SE quarter which
gave us chase, [redacted] we
clear'd ship for Action, made sail
and kept on our course.
Stove 10 Punchins of beer that was be
tween the Guns. 4 D° of water, 4 Hogsheads
and 8 Butts of water and hove them
Over Board. at 10 in the morn. the chase came up with us very
fast. ½ past found her to be a French Frigate of 34 Guns. at ¾ past
10 she brought us to action, which was very obstinate on both sides, being board
and board three different times, we engaged 'till [redacted] 12, when she
made all the sail she could from us. we followed, but she out sailed
us so fast that we could not bring her to action a second time.

time of the Action

▶ **KEEPING TRACK** *Top:* This page from Mason's logbook details the attack on their ship by the French frigate *L'Grande*. The loss of life and damage to the expedition's vessel, the *Seahorse*, required a return to port and, ultimately, prevented the astronomers from reaching their planned destination.

▶ **DESTINATION VENUS** *Bottom:* The map presented here shows the approximate route Mason and Dixon took between Portsmouth, England, and Cape Town, South Africa, and their return from Cape Town to Portsmouth via St. Helena. Also shown is the route to their initial destination of Bencoolen, Sumatra.

▲ **DISTANT DIGS** Mason and Dixon described their Cape Town observatory as "circular, the radius of which [was] 6½ feet in the clear; the height of the circular wall 5½ feet; the roof conical, and moveable, (made of board) a lid in it of 3 feet breadth, to open, which was easily turned to any part of the heavens, as the whole top moved freely." This photo shows a model of the observatory made by Martin Saville for a 2012 exhibition at the Bowes Museum in the town of Barnard Castle, England.

ing and following edges crossed the solar limb, each observer peering into the eyepiece of one of the reflectors. With no one free to read the time from the clock, they probably recorded their observations using an "eye and ear" method in which both noted the time, and then counted off the seconds by the ticks of the clock as they watched Venus cross the solar limb. Their results differed considerably. Dixon timed Venus's leading edge making contact with the limb of the Sun four seconds earlier than Mason and observed Venus exiting the solar disk two seconds earlier. This was significantly greater than the one-second accuracy Halley thought possible.

Mason and Dixon remained in Cape Town for nearly two more months after the transit to continue testing the clock's going, refine their previous latitude measurements, and determine their longitude. For the latter task, they used the Gregorian reflectors to time eclipses of Jupiter's satellites, which they did 17 times. On October 3rd they finally packed up their equipment and set sail on the *Mercury* for St. Helena to meet with Nevil Maskelyne.

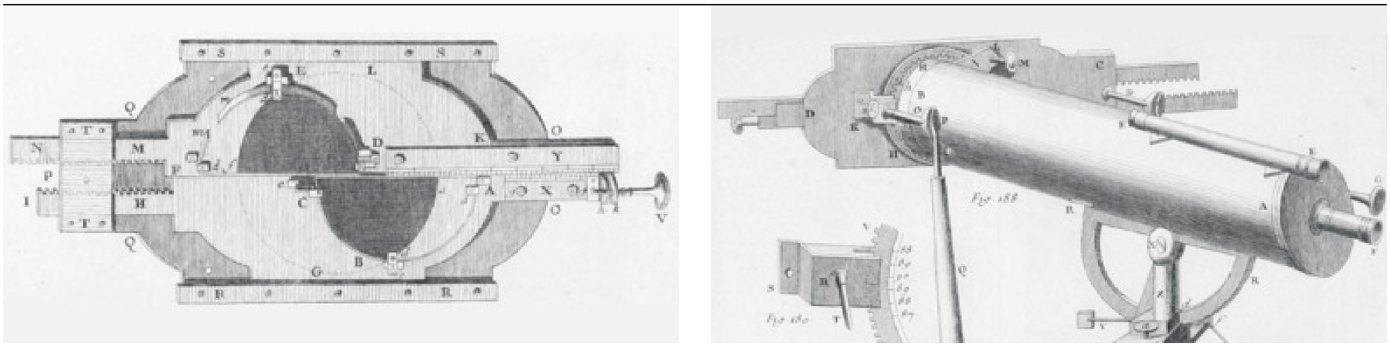
An Observation with Gravity

Although Maskelyne had had no trouble reaching St. Helena, on the day of the transit brief breaks in the clouds only permitted quick measurements that proved unusable. Maskelyne was also interested in the performance of the clock he'd brought from England. Built by John Shelton, the device had been tested at Greenwich, where its going was found to be slow by 11 seconds per day. However, when it was set up at St. Helena, Maskelyne found it to be slow by nearly two minutes per day. He attributed this difference to the oblate spheroid shape of the Earth — the effects of gravity on the pendulum clock differed from location to location.

After Mason and Dixon's arrival at St. Helena on October 16th, Maskelyne decided to test the Ellicott clock that the pair had used at Cape Town. Reciprocally, the trio wished to see what effect a different location would have on the Shelton clock. And so, while Mason remained behind to assist Maskelyne, on October 28th Dixon sailed back to Cape Town, arriving on November 25th with Maskelyne's Shelton clock. Dixon found that it ran nearly 30 seconds faster per day at Cape Town than at St. Helena, whereas Mason and Maskelyne found that the Ellicott clock ran close to 59 seconds a day slower at St. Helena than at Cape Town. The results confirmed Maskelyne's suspicion that the pendulum clocks were affected by local differences in Earth's gravity.

Dixon departed Cape Town on December 15th and returned to St. Helena on December 30th. On January 27, 1762, Mason and Dixon sailed for England on separate ships, both arriving at Plymouth on April 7, 1762.

The pair's observations were published in the Royal Society's *Philosophical Transactions*. Of course, the parallax



▲ **A GLASS DIVIDED** These illustrations from Jérôme Lalande's 1792 volume of *Astronomie* show the front and back of a Dollond divided object-glass micrometer. The scale labelled Y on the left illustration is for measuring the offsets of the two object-glass halves and below it, labelled X, is the Vernier. The right illustration shows the unit mounted on the front of a Gregorian reflector. The observer could rotate the micrometer by turning a rod, fitted with a flexible coupling. A similar rod on the right side controls the offset of the object-glass halves.

MODEL OF OBSERVATORY: THE BOWES MUSEUM: DRAWING OF TELESCOPE AND OBJECT-GLASS MICROMETER: U.S. NAVAL OBSERVATORY LIBRARY of Venus couldn't be calculated with just one set of measurements — good results from at least one other geographic position were required. Although the event was observed from some 150 locations, amateurs using poor equipment and who failed to accurately determine the local time and location provided most of the data, rendering most of the results useless.

A parallax estimate was eventually obtained by pairing Mason and Dixon's measurements with the best from the Northern Hemisphere, but the results had a large scatter. The root of the problem was that none of the methods utilized proved sufficiently accurate. This was the case not only for the 1761 Venus transit, but also for those in 1769, 1874, and 1882. Using parallax to determine a good value for the astronomical unit had to wait until the 20th century, when the asteroid Eros passed within 0.27 a.u. of Earth during its opposition of 1900–1901, and within 0.17 a.u. during its opposition of 1930–1931.

A Final Transit

Although the Venus transits failed to yield the desired outcome, the efforts of Mason and Dixon didn't go unnoticed. A little more than a year and a half after returning to England, the pair signed the contract that would keep them in America for four years and ten months, between 1763 and 1768, to do the work that would eventually bear their names. (A full account of the survey of the Mason-Dixon Line can be found in Edwin Danson's book *Drawing the Line*).

Mason and Dixon returned to England from America in October 1768, and, early in 1769, the Royal Society contracted them to observe the June 6, 1769, transit of Venus. This time, however, they would not team up. Mason was sent to Cavan, Ireland, while Dixon voyaged above the Arctic Circle to Hammerfest, Norway. Mason was able to observe the transit, but Dixon was clouded out.

After the 1769 transit, Dixon moved back to Cockfield, northeastern England, where he was born. He died there at the age of 45 on January 22, 1779. Mason returned to the Royal Greenwich Observatory to continue unfinished work from before the 1761 transit on German astronomer Tobias

▲ **DRAWING A LINE** As their reward for their work on the transit of Venus, Mason and Dixon travelled to America to survey a disputed territorial boundary. The result of their efforts became known as the Mason-Dixon Line, as shown in the map above.

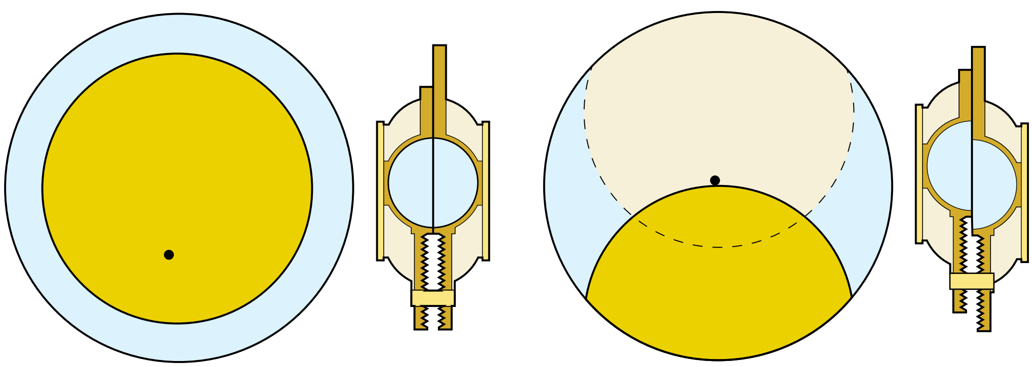
Mayer's lunar tables. Mason used the tables to determine longitude by the lunar distance method, and the Board of Longitude rewarded him £1,317 for his work. However, by 1786, he felt his scientific efforts were underappreciated, particularly by Maskelyne, who by then had become the Astronomer Royal. So, Mason departed England for America in July 1786, accompanied by his wife and eight children. He died on October 25th of that year at the age of 58, only a few weeks after arriving in Philadelphia.

Although Mason and Dixon's Venus expeditions failed to produce astronomically useful results, their efforts and willingness to risk their lives in pursuit of science ultimately led them to America, where they surveyed the border for which they will be forever linked and remembered.

■ **TED RAFFERTY** is a retired astronomer who worked for the U.S. Naval Observatory for 32 years.

OBJECT GLASS USE DIAGRAM: GREGG DINDERMAN / *S&T*, SOURCE: AUTHOR ORIGINAL; MASON-DIXON LINE: GREGG DINDERMAN / *S&T*

▶ **A MATTER OF OFFSET** Mason used a Dollond divided object-glass micrometer mounted on the front his telescope. The left half of this diagram shows Venus (small black dot) on the face of the Sun as it would have appeared with zero offset of the object-glass halves. The right pair of illustraions shows the farthest northern limb of the Sun superimposed on the farthest southern limb of Venus by adjusting the offset. Mason could then read the separation off the micrometer scale to gauge the planet's progress across the face of the Sun.



PLANET OR FAILED STAR? by Caroline Morley

THE IN-

Discoveries of brown dwarfs and exoplanets are complicating our definitions of which is which.

We humans love to categorize things. Before the detection of planets beyond our solar system, this was straightforward. The big ball of fusing hydrogen in the center of the solar system? A star, our Sun. The distant, giant, hydrogen-rich planets in the outer solar system? Gas planets. The little spheres of rock like the one we call home? Terrestrial planets.

But as new objects are found, our neat categories become more and more messy. Much like the discovery of the Kuiper Belt led to the demotion of Pluto to its dwarf-planet status, as we find more objects outside the solar system, we realize that many are not easily divided into the bins we initially chose.

Since the 1990s, astronomers have discovered thousands of objects that are neither stars nor planets, free-floating through space like stars but too low in mass to be considered stars. Scientists dutifully put them in another long-theorized category: *brown dwarfs*. But as we've discovered more brown dwarfs and exoplanets, researchers have noticed something quite interesting: The lowest-mass brown dwarfs and the highest-mass exoplanets can actually have the same masses! Suddenly the neat categories for dividing planets from stars have become much murkier . . . and so has our understanding of how they both form.

▲ **FAILED STAR OR GIANT PLANET?** This artist's concept depicts the brown dwarf 2MASS J22282889–431026, which observations suggest has gigantic, organized cloud systems in its atmosphere. At a temperature of 900K, its atmosphere could form clouds made of rock particles.

NASA / JPL-CALTECH

Between Planets and Stars

Brown dwarfs likely form the same way that stars do, collapsing from clouds of gas. The star-formation process most commonly makes stars significantly less massive than our own Sun. Above and below this most common mass, the number of stars dwindles. At the high-mass end, there are the massive, luminous blue stars, which catastrophically

BETWEENERS

explode when they die. At the low-mass end, there are the brown dwarfs.

The more massive an object, the higher the energy of its formative gravitational collapse, and the higher its initial temperature. Because brown dwarfs are lower in mass than stars, their interior temperatures are cooler; they never reach the temperatures and densities necessary in their cores to sustain normal hydrogen fusion.

Instead, if a brown dwarf is more massive than 13 times the mass of Jupiter, it will spend 100 million years or so fusing the tiny fraction of hydrogen with an extra neutron in its nucleus, called deuterium. After this spate of fusion ends, the brown dwarf then cools, waning in temperature for billions of years. How long cooling takes depends on the object's mass. So if we can measure a brown dwarf's age and temperature, we can estimate its mass.

Ages can be hard to measure, though. For many brown dwarfs, we know only that they must be younger than the age of the universe, about 13.8 billion years. We can estimate some brown dwarfs' masses with just that information and their temperatures. But astronomers have a clever trick for measuring younger ages. Stars form in groups, all born at about the same time before spreading out across the sky. New sky maps that include stars' speeds and directions allow us to trace some of them back to their birthplaces. If we connect a brown dwarf to its natal group, then we know it also has the same age as those stars.

Measurements of brown dwarfs in stellar groups have blurred the line between "failed stars" and planets. Many brown dwarfs have masses well under the 13-Jupiter-mass limit for deuterium fusion. Some, like PSO J318.5–22 and WISEA 1147, have masses between 5 and 10 Jupiter masses.

WHAT'S IN A NAME?

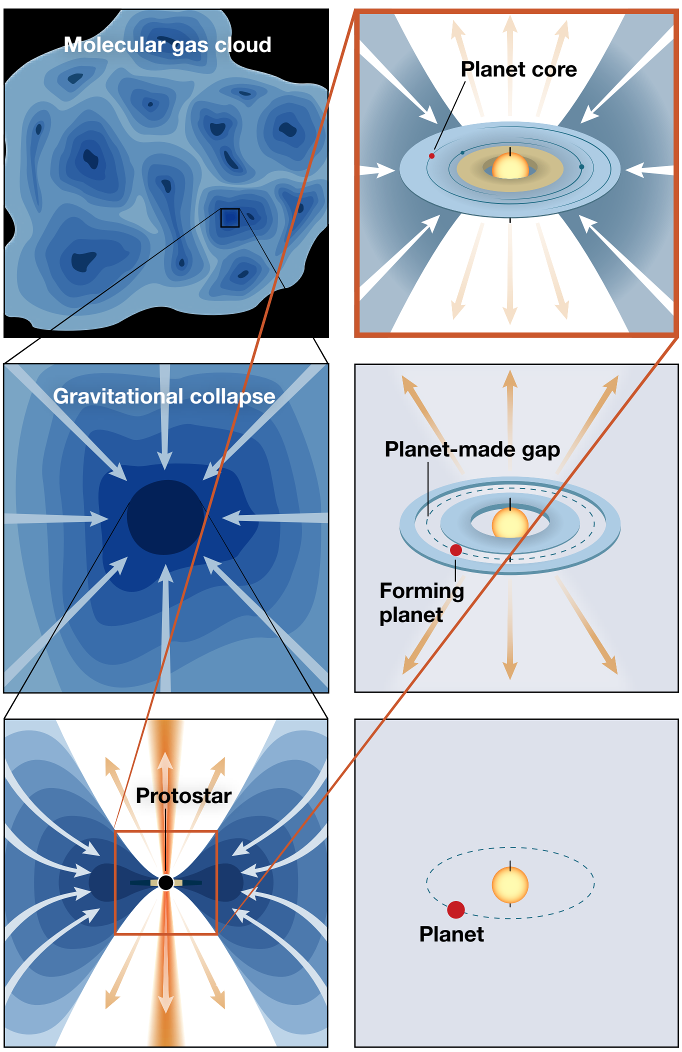
Astronomer Jill Tarter coined the term *brown dwarf* in her 1975 PhD thesis, without the intention of implying an actual color: At the time, it was impossible to determine what the then-theoretical objects' color temperature would be, so she chose brown because "brown was not a color." In fact, some brown dwarfs might actually look violet.

Meanwhile, we have discovered planets orbiting stars in those same young stellar groups. Those planets — like the four planets around HR 8799 or the planets in the debris disk of Beta Pictoris — have masses between 5 and 13 Jupiter masses. Thus, we find that young brown dwarfs and planets can actually have identical temperatures, ages, and masses.

This finding is a bit of a puzzle, because our long-standing picture of planets suggests they form differently from brown dwarfs. In most cases, to make a gas giant you likely first need to build a massive core, made of rocky and icy material that can stick together in a disk. As this core grows, it eventually becomes massive enough to start pulling in gases from the disk. Once this protoplanet reaches a certain mass — around 5 to 10 times the mass of Earth — runaway gas accretion begins. The planet quickly gobbles up all the gas in its orbit, carving a gap in the disk and rapidly growing to the size of a gas giant like Saturn or Jupiter. We actually see this process in action in very young (about 1-million-year-old) systems with the ALMA observatory, which has been taking exquisite images of gaps in disks where planets likely form (*S&T:* May 2020, p. 34).

Each discovery of a new planet-mass object complicates our categorization. Some "planets" orbiting far from their stars may actually have formed like brown dwarfs, from a collapsing cloud. Some free-floating brown dwarfs with planet-like masses may have formed like planets in a disk, only to be later flung out of their planetary system to float through space for eternity. Scientists don't yet have direct evidence for such an ejection process occurring, but figuring out if it has is a major goal of the coming decade of exoplanet science. To do so, we must tie the formation of planets and brown dwarfs to the properties we measure for them.

▼ **HOW STARS AND PLANETS FORM** Stars coalesce from collapsing clouds of gas (*left column*), but giant planets likely begin from a core within the disk surrounding the newborn star and then gather up gas along their orbits (*right column*). Astronomers suspect brown dwarfs follow the stellar chain of events.



GREGG DINDERMAN / S&T

Measuring the Properties of Exoplanets

When we break the light of brown dwarfs and exoplanets into infrared spectra, we see many of the same features. Dark regions reveal the presence of molecules, which absorb light at specific colors set by quantum mechanics within each molecule. The molecules we see depend on a number of atmospheric properties, including the composition. In general, the darker the absorption bands in the spectrum are, the more of the compound is present. The most common molecules we see in these worlds' atmospheres are water, carbon monoxide, and methane.

We can use these abundances to understand how a planet may have formed. When stars form, all the atoms present in the cloud collapse together: mostly hydrogen and helium (since they are most abundant in the universe), but also a whole array of other atoms, including carbon, oxygen, nitrogen, and iron. These atoms can be accreted in slightly different ratios depending on the gas available, but most stars in the solar neighborhood have quite similar compositions, close to that of the Sun. If brown dwarfs form via the same mechanisms, they should also have compositions similar to that of the Sun.

Planets instead accrete gas, rocks, and ice from the disk, because they form in the colder outer parts and not the center. Thus they can end up enhanced in materials present in rocks and ices: iron, magnesium, silicon, and oxygen in rocks; oxygen and carbon in ices. Jupiter's atmosphere is enhanced in many elements by a factor of about three compared with the Sun; Saturn, by a factor of about 10; and Uranus and Neptune by a factor of about 100. A key goal of exoplanet science is to measure abundances of different chemical species to understand where and how planets form. Measuring "planet-like" abundances in a free-floating brown dwarf would be a smoking-gun indication that the object actually formed in a protoplanetary disk around a star.

However, these measurements are complicated — sometimes thwarted! — by a key physical process: the formation of clouds and hazes.

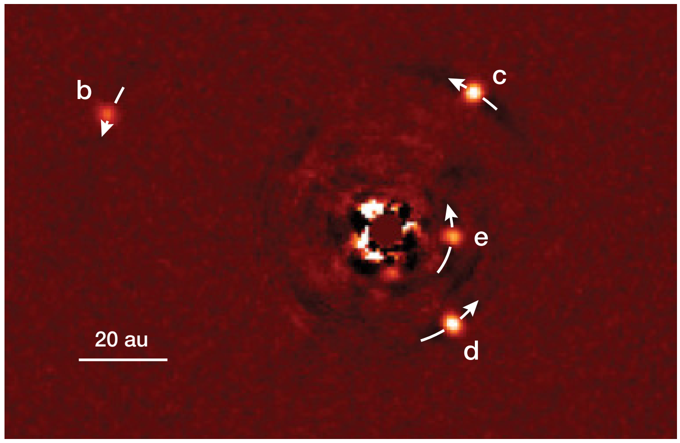
Clouds and Hazes

Look around the solar system and what do you see? Beautiful, swirling marbles, their portraits captured by spacecraft sent to catch a tantalizing glimpse while whizzing by or once caught into orbit, looking more closely with every revolution. The planets' atmospheres are each filled with layers of clouds and hazes, these aerosols shaping the worlds' appearances. Venus, for example, is enshrouded in a layer of deadly sulfuric-acid clouds, yellow and highly reflective, that help to make Venus among the brightest objects in the night sky. Jupiter instead has swirling bands of ammonia-ice clouds, colored by other chemicals in the atmosphere, and punctuated by a massive storm larger than Earth — its famous Great Red Spot.

To imagine faraway worlds and not imagine clouds would be to ignore the great lessons learned from our exploration of the solar system. Indeed, our first two decades of studying exoplanet and brown dwarf atmospheres have revealed a diversity of clouds that surpasses those found on worlds around the Sun.

While there are likely many differences between distant planets and our nearby neighbors, by far the most critical difference affecting the formation of clouds is the planet's temperature. At different temperatures, different materials condense. At high temperatures, almost everything is a gas, like in a star. At slightly cooler temperatures, materials that we know as minerals on Earth, like corundum — which forms rubies and sapphires — begin to condense into solids. At somewhat lower temperatures, silicates — which form many of the rocks on Earth — start to condense, creating a massive, planet-engulfing dust layer. At even cooler temperatures, materials like salts and sulfides solidify. At the coldest temperatures, ices like water and ammonia form.

Our solar system's giant planets all reside relatively far from the Sun and receive just a small amount of sunlight, enough to heat them to just 50 to 130 kelvin (–370° to –230°F). These cold temperatures mean that the clouds that form in the upper regions of their atmospheres (which are the only parts of the atmospheres we can see) are all made of ices: ammonia ice on Jupiter and Saturn, and methane ice on Uranus and Neptune.

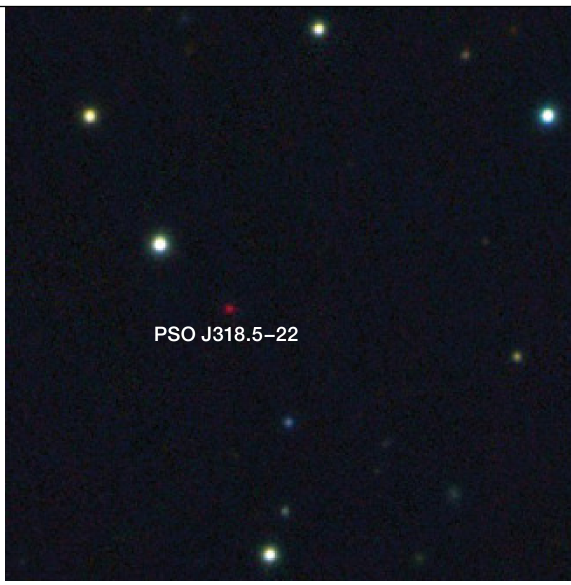


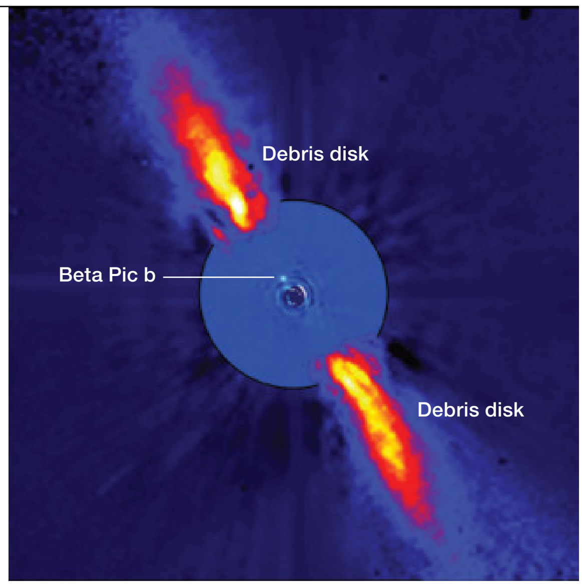
▲ **PLANETS ON THE MOVE** HR 8799 was the first planetary system that astronomers directly imaged. Each planet contains roughly 10 Jupiter masses. Observations over several years show the four planets moving (trajectories for 2009 to 2016 shown; image is from 2013).

Brown dwarfs and exoplanets have a much broader range of temperatures. Many of the exoplanets we have found are much closer to their host stars than our giants are to the Sun, making them much hotter — but in fact we know of planets covering the full range in temperatures, from icy (GJ 414 Ac, at 125K) to blazing hot (KELT-9b, at 4050K).

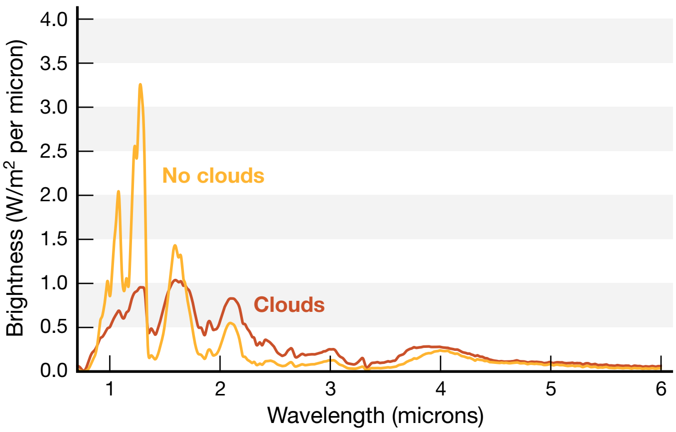
Complicating the picture, other materials also condense when planetary atmospheres are bombarded by ultraviolet radiation from their host stars. The UV light breaks up molecules such as methane in the upper atmospheres of exoplanets; these broken molecules then react with each other and

▶ **SAME BIRTHDAY** The free-floating brown dwarf PSO J318.5–22 (*left*) and the exoplanets around Beta Pictoris (*right*, only planet b is visible) both formed in the same stellar group about 23 million years ago — such a short span of time that a debris disk still surrounds Beta Pic.





HR 8799 PLANETS: A.-L. MAIRE / LBTO; PSO J318: N. METCALFE AND PAN-STARRS 1 SCIENCE CONSORTIUM; BETA PIC: ESO / A.-M. LAGRANGE ET AL.



▲ **CLOUD EFFECT** A brown dwarf's spectrum (colored lines) looks dramatically different depending on its clouds. Shown here are two possibilities for a theoretical, 1300K object: no clouds (yellow), with clear features around 1 micron, and thin iron and silicate clouds (red), which blot out those features.

can grow into larger organic molecules that condense, like the smog enveloping Los Angeles.

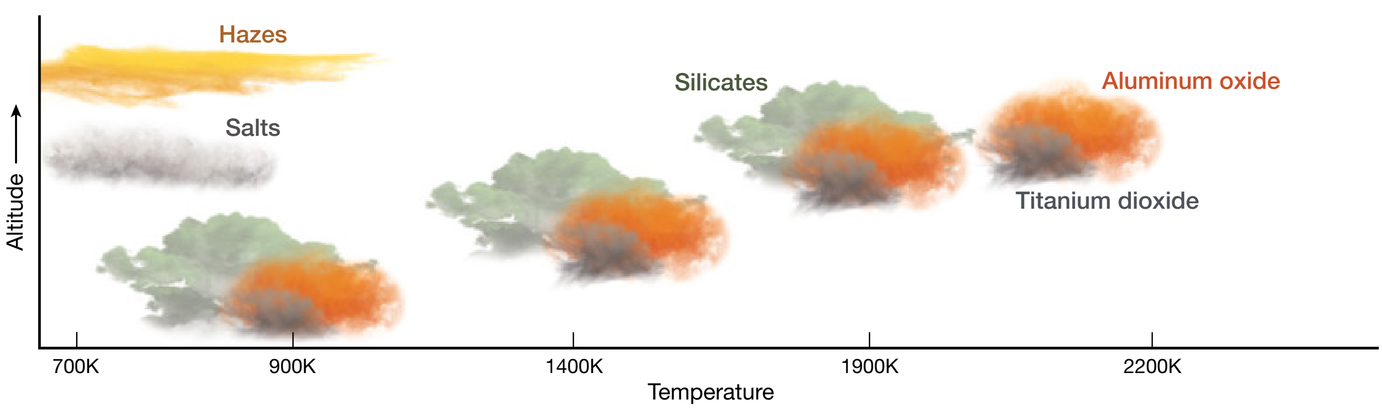
When clouds or hazes form, the appearance of a planet changes dramatically, like the transformation from a sunny morning to an afternoon thunderstorm. Instead of us being able to easily see molecular features, the clouds can obscure our view, absorbing light at all wavelengths. Some exoplanets have been found to be so cloudy or hazy that we cannot see any molecules through the clouds at all, thwarting our ability to measure the atmospheric composition. More commonly, clouds only somewhat obscure our view, decreasing the sizes of molecular features we detect and making it harder to extract information about how much of a given element or compound is there. To measure the compositions of planetary atmospheres precisely, we must first understand their clouds.

We've learned in recent years that the clouds on brown dwarfs and giant exoplanets appear to be very similar. Several brown dwarfs have infrared spectra that actually reveal an absorption feature from silicate cloud particles, darkening the spectra between 9 and 10 microns. Detecting this feature allows us to determine that there are specific minerals present in the atmosphere, like enstatite and quartz. In exoplanets, we see a similar trend based on a water absorption feature in hot Jupiter spectra: The water feature is mostly obscured — which means the clouds peak in thickness — at temperatures where silicate clouds should be plentiful.

One intriguing insight is that clouds appear to be thicker on lower-mass objects. Perhaps the clouds are more easily lofted to high altitudes when the force of gravity tugging them down is smaller. This physics means it's more challenging to measure the compositions of lower-mass objects than high-mass objects, because clouds obscure their spectra more.

Sometimes, we can even tell that storm systems on exoplanets and brown dwarfs vary over time, as we watch an object brighten and fade as it rotates. One such young world, VHS J1256–1257b, has thick silicate clouds that blanket much of the planet. Observations with the Hubble Space Telescope show that it varies up to 25% in brightness with each planetary rotation, getting fainter as darker cloudy regions come into view and brighter as clearer regions do. Understanding these variations allows us to trace weather on other worlds — not involving our own familiar water clouds, but instead planet-wide convection and circulation patterns that create storm clouds of dust.

Despite the excitement of studying these exotic worlds, we are perhaps most excited about observations of planets a little more familiar to us. The coldest free-floating planet known is the nearby gas giant WISE J0855–0714 (WISE 0855 for short), where the temperature averages about 250K, or −10°F: a moderately cold day in Minnesota. The world is cold enough for water ice to condense in its atmosphere, just like it does in Earth's upper atmosphere. WISE 0855 also appears to vary in brightness, changing by a few percent during its approximately 12-hour day. No direct proof yet exists of the ice clouds themselves, but the evidence so far is promising.



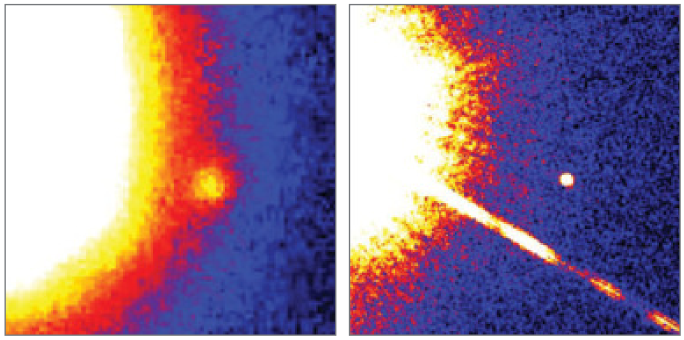
▲ **FORECAST** Clouds' altitudes and compositions depend in part on how hot their world's atmosphere is. Shown here are the condensates that scientists predict should form for a range of temperatures common on gas giants that orbit very close to their parent stars. Some brown dwarfs have these temperatures, too. Colors are ballpark examples of how the clouds might appear to the human eye.

SPECTRA: C. MORLEY ET AL. / *ASTROPHYSICAL JOURNAL* 2012; CLOUDS DIAGRAM: LEAH TISCIONE / *S&T*, SOURCE: PETER GAO / UNIV. OF CALIFORNIA, BERKELEY

With the upcoming James Webb Space Telescope (JWST; *S&T:* Nov. 2021, p. 20), we will probe infrared colors where water ice absorbs with a distinct pattern, allowing us for the first time to see clouds like our own on a planet light-years away.

In fact, WISE 0855 and other similarly cold brown dwarfs will offer some of the most anticipated observations with JWST. These objects provide a missing link: They have not just the masses of planets, but also temperatures nearing those of our own giants. Their atmospheres are complex, with cool temperatures that make chemical reactions creep to a halt. They are so cold that they are often nearly invisible at the near-infrared wavelengths with which we normally observe brown dwarfs.

Nonetheless, recent ground-based observations show that these objects are rapidly dredging molecules from deep within up to the parts of the atmosphere we can see, drastically changing their spectra from naïve expectations. JWST is extremely sensitive at infrared wavelengths, where cold objects glow brighter, so for the first time the telescope will let us precisely measure the objects' compositions — likely a combination of methane, ammonia, water, and more exotic species like phosphine. Then we can compare them directly to Jupiter, Saturn, Uranus, and Neptune. Whether some are relics of old solar systems torn apart, or simply the rarest outcome of the star-formation process, is yet to be seen.



▲ **THE FIRST BROWN DWARF** Discovered in 1994 at Palomar Observatory *(left)* and confirmed with the Hubble Space Telescope the following year *(right)*, the faint object Gliese 229 B was the first indisputable brown dwarf discovered. (Both are far-infrared images.)

Shaking Things Up

Despite our human tendency to categorize objects into tidy boxes, the past three decades have revealed a reality that is much more complex. Nature does not abide by the rules laid out by the International Astronomical Union, nor by the names we first give to objects we find in the sky. We now know that free-floating brown dwarfs come in miniature versions, with masses like those of the gas planets in our solar system. Gas-giant companions to stars come in many sizes, including supersize versions, with masses high enough to fuse deuterium like canonical brown dwarfs. But big questions remain: How did each object form? What is the lowest-mass object that forms from a gas cloud like a star? What is the highest-mass object that forms in a disk like a planet? Can we reliably tell the difference between objects formed by very different methods? Astronomers are still disentangling these puzzles.

By measuring the abundances of molecules across a broad swath of stars, brown dwarfs, and planets, we are starting to recognize patterns that trace their origins. We have nearly perfected the art of measuring stellar compositions, which tell us that stars in the solar neighborhood have a small range in elemental abundances, mostly like the Sun's. Brown dwarfs are more complex, with clouds making it more challenging to derive precisely what they're made of. Despite this,

▶ **JUPITER** This dramatic, enhanced-color image from the Juno spacecraft reveals the bright storm Oval BA (upper left), which is about the same size as Earth. Subtle changes in the light from the closest brown-dwarf binary suggest that the worlds might have belts, zones, and even vortex-dominated polar regions like those of Jupiter.

FIRST BROWN DWARF: PALOMAR IMAGE: T. NAKAJIMA (CALTECH) AND S. DURRANCE (JHU); HST IMAGE: S. KULKARNI (CALTECH), D. GOLIMOWSKI (JHU), NASA; JUPITER: NASA / JPL-CALTECH / SWRI / MSSS / RITA NAJM / CC BY there is evidence that most brown dwarfs have compositions similar to one another, with patterns in their spectra largely explained by their temperatures. Our picture fits together: Brown dwarfs likely form the same way stars do.

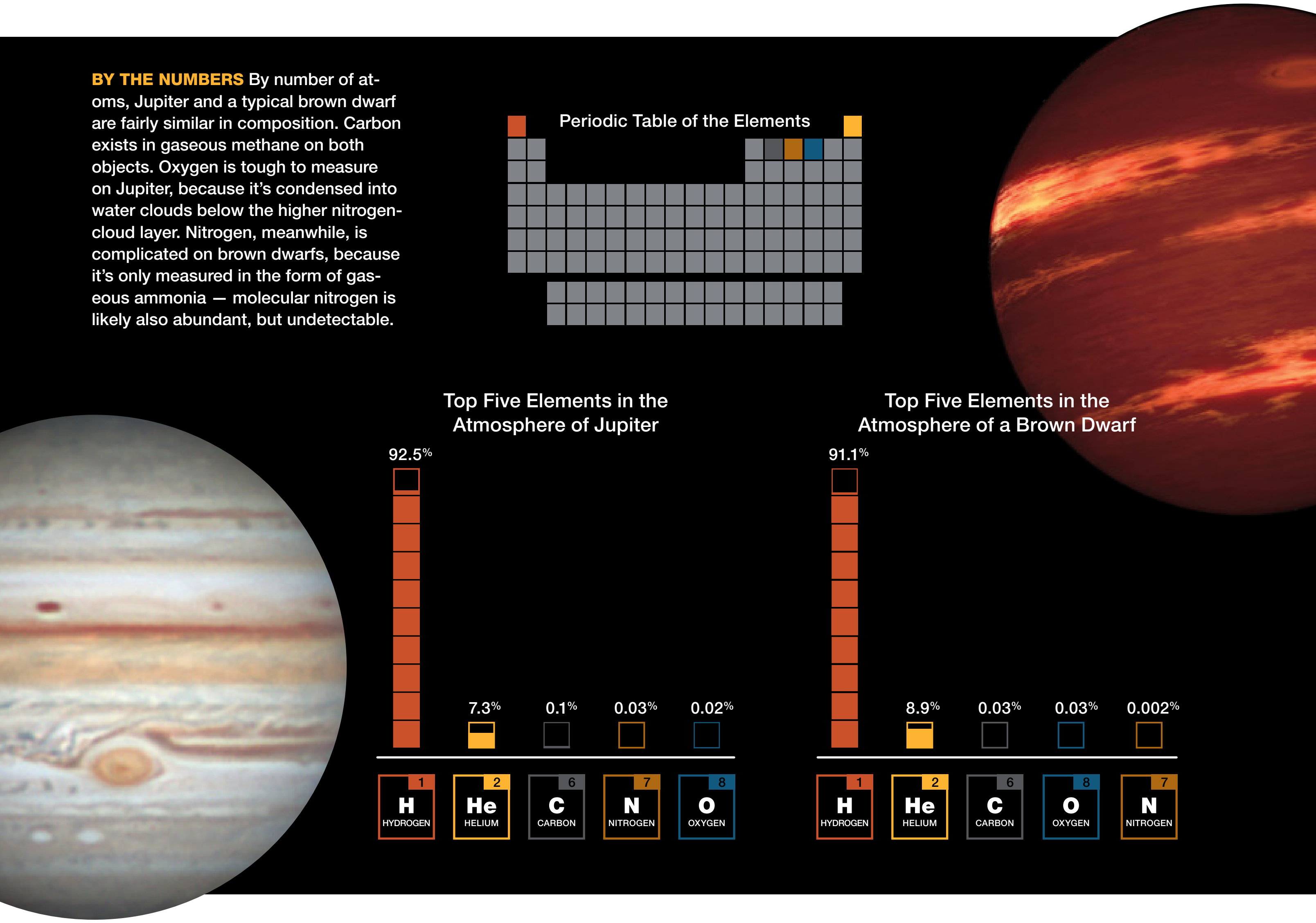
For the lowest-mass brown dwarfs — the free-floating planets — the picture that's emerging may be more complex. Many of the hot, young, low-mass brown dwarfs are cloudier than their high-mass counterparts, making their compositions even more challenging to determine. We also have not yet measured precise chemical makeups for the older, colder, free-floating planets, though with JWST we soon will, providing the most reliable comparisons to the solar system's objects to date.

And for the exoplanets themselves, we have much work to do. Exoplanet compositions are just barely in reach of current telescopes. Evidence so far suggests that exoplanets may have a wide range of oxygen abundances compared to stars, but other elements have remained largely out of reach. When JWST begins science operations, its enhanced sensitivity and wavelength range will enable us to measure molecules in a variety of exoplanet atmospheres and compare the results with both stars and brown dwarfs. Perhaps with this information, we will have clarity in our categories, with exoplanets appearing radically different from their stellar compatriots. Or, perhaps more likely, we will find new unanticipated complexities in the atmospheres of these faraway worlds.

NEIGHBORS

The third- and fourth-closest "star" systems to the Sun solely contain brown dwarfs: the binary WISE J1049-5319 (a.k.a. Luhman 16 AB) at 6.5 light-years, and WISE J0855-0714 at 7.3 light-years. But with an estimated mass of only 3 to 10 Jupiters, WISE 0855 would qualify as a free-floating planet.

■ **CAROLINE MORLEY** is an assistant professor of astronomy at the University of Texas, Austin. Her research focuses on understanding the atmospheres of exoplanets and brown dwarfs.



BY THE NUMBERS By number of atoms, Jupiter and a typical brown dwarf are fairly similar in composition. Carbon exists in gaseous methane on both objects. Oxygen is tough to measure on Jupiter, because it's condensed into water clouds below the higher nitrogen-cloud layer. Nitrogen, meanwhile, is complicated on brown dwarfs, because it's only measured in the form of gaseous ammonia — molecular nitrogen is likely also abundant, but undetectable.

TERRI DUBÉ / *S&T*; SOURCES: LUNAR AND PLANETARY INSTITUTE, M. R. LINE ET AL. / *ASTROPHYSICAL JOURNAL* 2017; JUPITER: SEAN WALKER / *S&T*; BROWN DWARF ILLUSTRATION: NASA / JPL-CALTECH

OBSERVING
March 2022

2 **DAWN:** A quartet of planets graces the southeastern horizon. Venus and Mars are separated by a smidgen less than 5° and guard the tighter duo of Mercury and Saturn, a mere 1° apart. You'll have to time this one carefully to catch all four worlds before the Sun rises. See page 46 for more on this and other events listed here.

3 **EVENING:** Algol shines at minimum brightness for roughly two hours centered at 9:17 p.m. PST (see page 49).

6 **EVENING:** Algol shines at minimum brightness for roughly two hours centered at 9:06 p.m EST.

8 **EVENING:** The waxing crescent Moon is prettily poised in Taurus between the Pleiades and Aldebaran.

12 **EVENING:** High in the south, the waxing gibbous Moon shines in Gemini around 3° from Pollux.

13 **DAYLIGHT-SAVING TIME STARTS** at 2 a.m. for most of the U.S. and Canada.

15 **EVENING:** Look toward the southeast to see the fattening Moon 4° upper left of Regulus.

19 **EVENING:** Watch as the waning gibbous Moon rises in tandem with Spica in the east-southeast; about 4° separates the pair.

20 **SPRING BEGINS** in the Northern Hemisphere at the equinox, 11:33 a.m. EDT (8:33 a.m. PDT).

23 **DAWN:** The waning gibbous Moon gleams some 2° above the Scorpion's heart, Antares. Look toward the south to catch this sight before sunrise.

25 **DAWN:** Venus, Mars, and Saturn rise in a compact triangle in the east-southeast.

26 **EVENING:** Algol shines at minimum brightness for roughly two hours centered at 8:51 p.m. PDT.

28 **DAWN:** Early risers will be greeted by the delightful sight of the waning crescent Moon hanging below Venus, Mars, and Saturn as the quartet rises in the east-southeast.

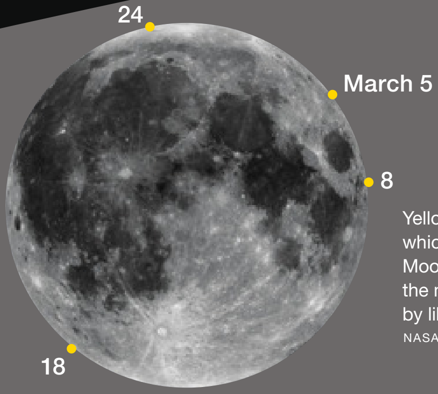
29 **EVENING:** Algol shines at minimum brightness for roughly two hours centered at 8:41 p.m. EDT.
— DIANA HANNIKAINEN

A fruit tree flaunts its flowering blossoms beneath Orion and bright Sirius near a village in the Alborz Mountains in northern Iran. Turn to page 48 to learn how you can try to catch a glimpse of Sirius in daylight. OSHIN ZAKARIAN

MARCH 2022 OBSERVING

Lunar Almanac

Northern Hemisphere Sky Chart



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

NASA / LRO

MOON PHASES

SUN	MON	TUE	WED	THU	FRI	SAT
		1	2	3	4	5
6	7	8	9	10	11	12
13	14	15	16	17	18	19
20	21	22	23	24	25	26
27	28	29	30	31		

NEW MOON
March 2
17:35 UT

FIRST QUARTER
March 10
10:45 UT

FULL MOON
March 18
07:18 UT

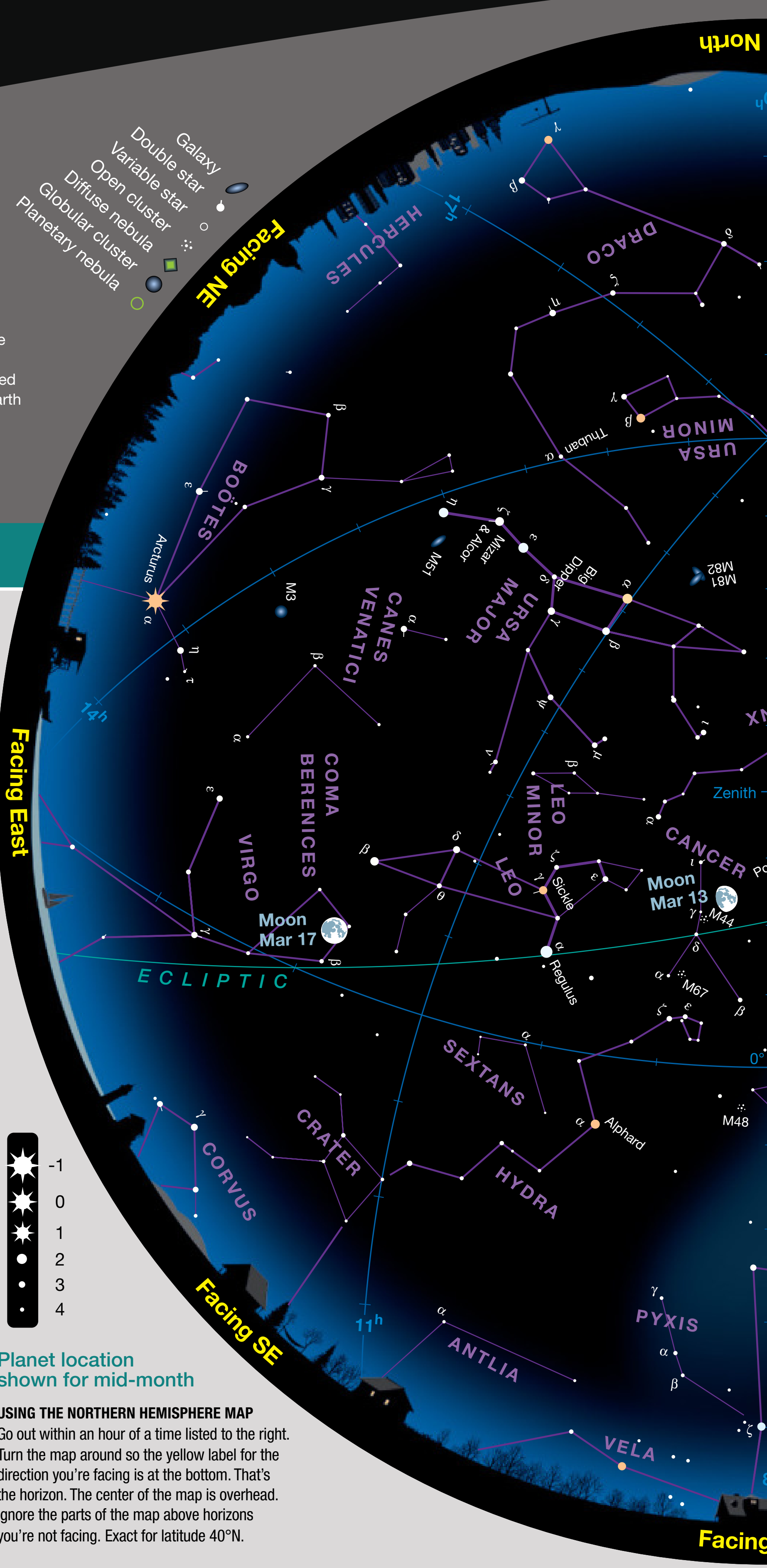
LAST QUARTER
March 25
05:37 UT

DISTANCES

Apogee	March 10, 23^h UT
404,268 km	Diameter 29′ 34″
Perigee	March 24, 00^h UT
369,760 km	Diameter 32′ 19″

FAVORABLE LIBRATIONS

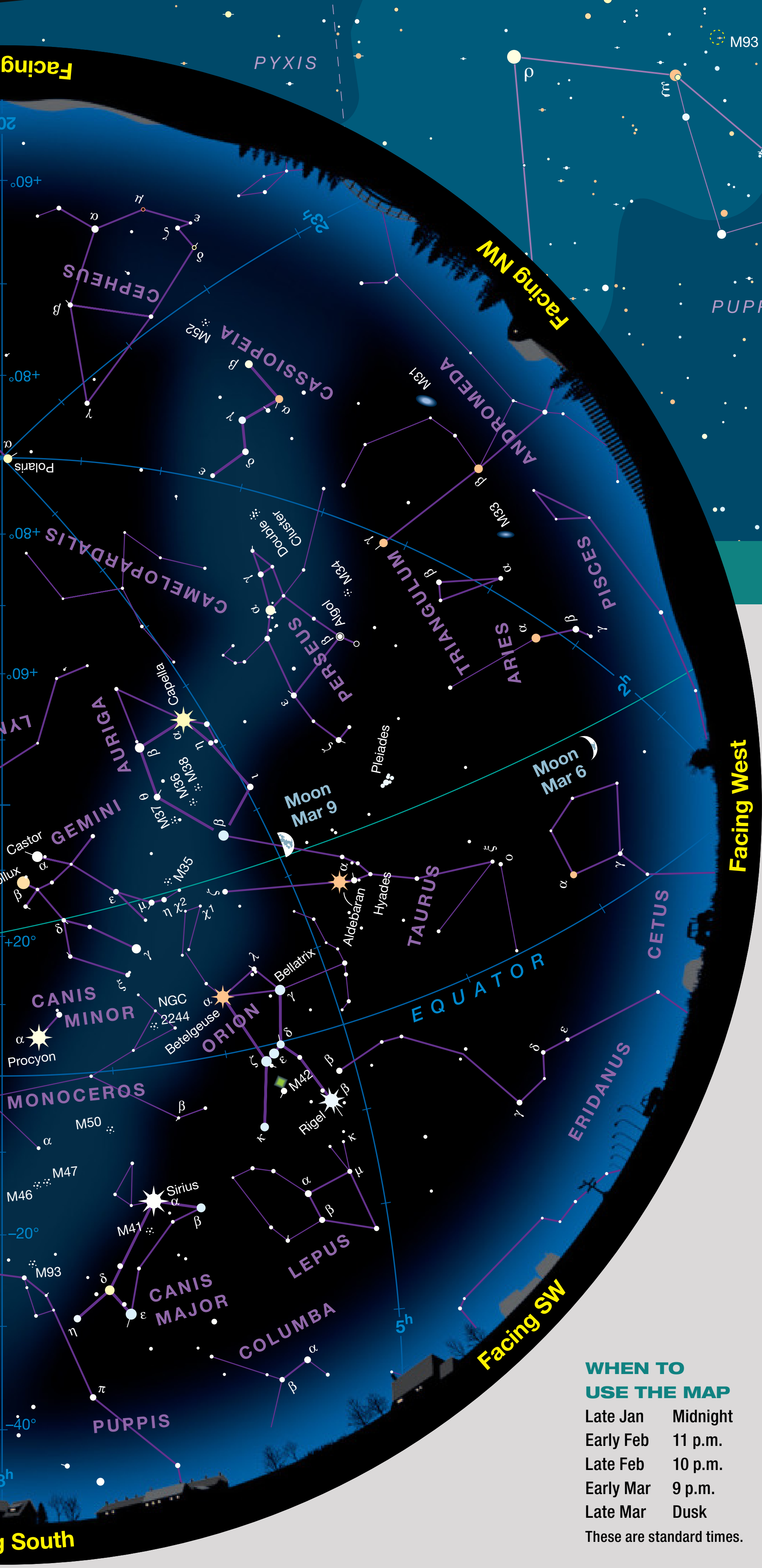
- Beals Crater — March 5
- Neper Crater — March 8
- Guthnick Crater — March 18
- Pascal Crater — March 24

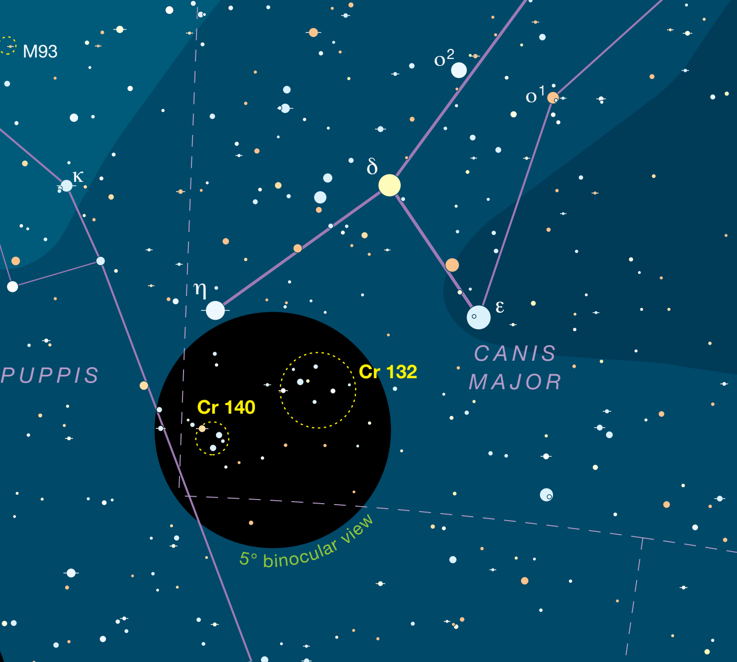


Planet location shown for mid-month

USING THE NORTHERN HEMISPHERE MAP

Go out within an hour of a time listed to the right. Turn the map around so the yellow label for the direction you're facing is at the bottom. That's the horizon. The center of the map is overhead. Ignore the parts of the map above horizons you're not facing. Exact for latitude 40°N.





Binocular Highlight by Mathew Wedel

Voyage of Discovery

Our targets this month are the open clusters **Collinder 132** and **Collinder 140** in the southeastern corner of Canis Major, the Great Dog. Follow the Dog's tail to its tip, Aludra, or Eta (η) Canis Majoris, and you'll find the two clusters south and southwest of the 2.4-magnitude star.

I vividly remember the first time I encountered these celestial gems. I was camping in Anza-Borrego Desert State Park in California, working my way through the winter Milky Way. My usual route from Canis Majoris into Puppis went a little farther north, but that night I decided to see what lay to the south. I stumbled into a wonderland of bright stars, clusters, and asterisms that ran from the tail of the Dog, then across Puppis and into Vela, the Stern and the Sails, respectively, of the ancient constellation Argo Navis.

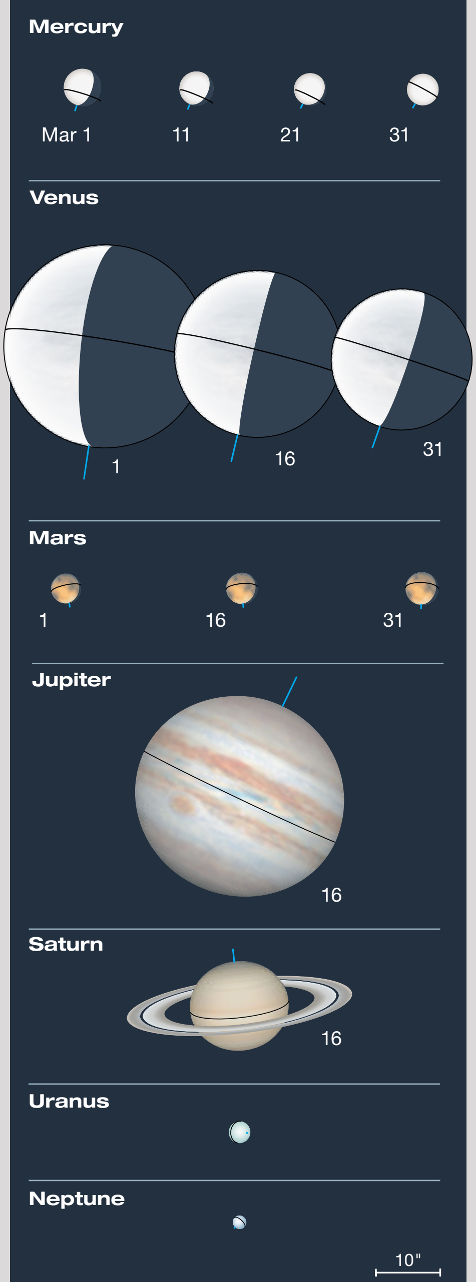
Collinder 132 and Collinder 140 were the heralds that greeted me on my voyage of discovery. Both clusters are big and bright in my 7×50 binos, and I can only assume that if they were farther north they'd be much more famous. Collinder 132 is the larger of the two, a swarm of distant suns that sprawls across 1.5°, punctuated by a handful of 6th-magnitude stars. Collinder 140 is much more compact, but equally bright, with a visual magnitude of 3.5. That cluster is dominated by a lovely chain of 5th- and 6th-magnitude stars that curls around at its southwestern end, like an upside-down, backwards question mark. Collinder 140 lies about 1,300 light-years away, and Collinder 132 is a few hundred light-years farther out. Both are part of the Orion Spur, a bridge of stars and clusters thousands of light-years long, which includes our own Sun. I hope you follow that stream on your own journey into the ocean of night.

■ As a constant daydreamer of undiscovered lands, MATT WEDEL is always up for a celestial adventure.

WHEN TO USE THE MAP

Late Jan	Midnight
Early Feb	11 p.m.
Late Feb	10 p.m.
Early Mar	9 p.m.
Late Mar	Dusk

These are standard times.



PLANET VISIBILITY (40°N, naked-eye, approximate) **Mercury** is lost in the Sun's glare all month • **Venus** and **Mars** visible at dawn all month • **Jupiter** visible at dawn low in the east-southeast starting on the 31st • **Saturn** emerges at dawn starting on the 8th.

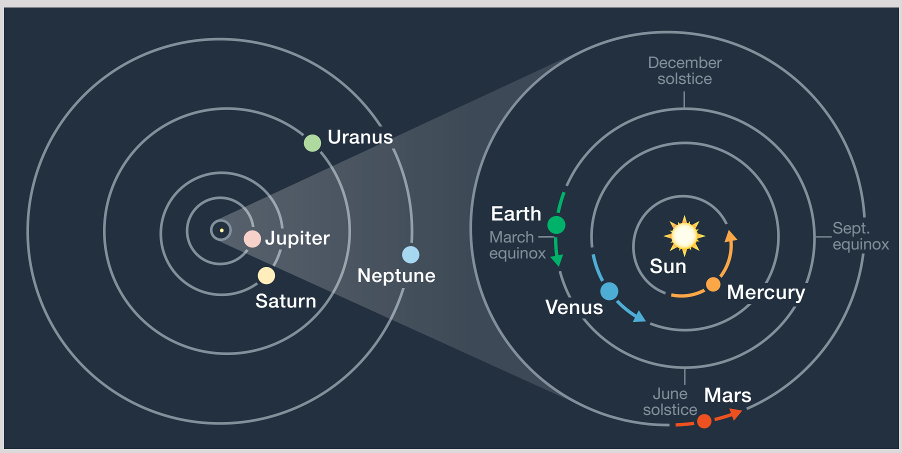
March Sun & Planets

	Date	Right Ascension	Declination	Elongation	Magnitude	Diameter	Illumination	Distance
Sun	1	$22^h\ 46.4^m$	–7° 48′	—	–26.8	32′ 17″	—	0.991
	31	$0^h\ 36.6^m$	+3° 57′	—	–26.8	32′ 02″	—	0.999
Mercury	1	$21^h\ 16.9^m$	–17° 16′	24° Mo	–0.1	5.9″	76%	1.148
	11	$22^h\ 15.9^m$	–13° 03′	19° Mo	–0.3	5.4″	85%	1.255
	21	$23^h\ 19.3^m$	–6° 45′	12° Mo	–0.7	5.1″	93%	1.328
	31	$0^h\ 27.6^m$	+1° 26′	3° Mo	–1.8	5.0″	99%	1.349
Venus	1	$19^h\ 45.8^m$	–16° 56′	45° Mo	–4.7	31.6″	38%	0.529
	11	$20^h\ 21.9^m$	–16° 17′	46° Mo	–4.6	27.6″	44%	0.605
	21	$21^h\ 01.5^m$	–14° 53′	47° Mo	–4.5	24.4″	50%	0.683
	31	$21^h\ 42.9^m$	–12° 42′	46° Mo	–4.4	21.9″	55%	0.761
Mars	1	$19^h\ 51.7^m$	–21° 49′	44° Mo	+1.3	4.7″	94%	1.996
	16	$20^h\ 38.6^m$	–19° 31′	48° Mo	+1.2	4.9″	93%	1.903
	31	$21^h\ 24.4^m$	–16° 30′	52° Mo	+1.1	5.2″	92%	1.812
Jupiter	1	$23^h\ 00.9^m$	–7° 22′	4° Ev	–2.0	33.0″	100%	5.970
	31	$23^h\ 27.6^m$	–4° 35′	19° Mo	–2.0	33.4″	100%	5.908
Saturn	1	$21^h\ 24.9^m$	–16° 07′	22° Mo	+0.8	15.4″	100%	10.822
	31	$21^h\ 37.3^m$	–15° 11′	48° Mo	+0.9	15.8″	100%	10.537
Uranus	16	$2^h\ 38.0^m$	+15° 02′	47° Ev	+5.8	3.5″	100%	20.380
Neptune	16	$23^h\ 34.8^m$	–3° 56′	3° Mo	+8.0	2.2″	100%	30.912

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

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

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



Spring Triangles

Three foes of Hercules bunch in the evening sky.

We can make use of parts of three constellations well placed on March evenings to locate a marvelous arrangement of rather compact triangles. We'll be using the front section of Leo, the Lion, the head and heart of Hydra, the Water Snake, and the cluster-filled center of Cancer, the Crab. On our Northern Hemisphere Map (pages 42 and 43), you can see that the center of Cancer and the head of Hydra are approaching the *meridian* (the imaginary line that joins north and south and passes directly overhead) and the bright, western half of Leo is not far behind. They're floating high in the southeast and south at map time.

▲ **CRABCENTRIC SKY VIEW** Cancer, the celestial Crab, is front and center in this chart from Alexander Jamieson's 1822 *Celestial Atlas*. Below the Crab is the head of Hydra, while Leo's head and front paws are to the left.

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

By the far the brightest of the three groupings is the front portion of Leo. I prefer the time-honored tradition that sees Regulus, Alpha (α) Leonis, as the heart of the noble Lion. That makes the large hook of stars that extends up (north) from Regulus the Lion's chest, head, and mane.

The hook asterism is also well known as the Sickle, a farming tool that has Regulus as the bottom of the implement's handle. The other bright star in the Sickle (or Lion's mane) is Algieba, Gamma (γ) Leonis. Algieba is best known as a beautiful double star in amateur telescopes, but to the naked eye their combined brightness equals a 2.1-magnitude point of light — just a trace dimmer than Polaris and only about half as bright as Regulus.

At magnitude 1.4, Regulus is the dimmest of all 1st-magnitude stars, but it's also the one closest to the *ecliptic*, the Sun's apparent path through the heavens and centerline of the zodiac. That makes Regulus the 1st-magnitude star that has the most frequent closest encounters with the Sun, the Moon, and the planets.

Let's use Regulus as our starting point for visiting some very interesting triangles. One of these is an almost-equilateral triangle that connects Regulus with 2nd-magnitude Alphard, Alpha Hydrae — the heart of Hydra — and the fairly dim but compact asterism that forms Hydra's head. Whereas Regulus is the blue-white heart of Leo, Alphard is the distinctly orange heart of Hydra. At magnitude 2.0, Alphard is almost identical in brightness to Algieba and Polaris.

A fascinating fact is that for observers near latitude 40° north, Alphard and Polaris have the same altitude but are in exactly opposite directions when Alphard reaches the meridian. That moment comes roughly two hours after the times listed on our March all-sky map. That same map shows that the mostly dim constellation Hydra is so expansive (the longest of all constellations, measured west-to-east) that its tail has not yet risen by the time its head crosses the meridian.

Regulus and the head of Hydra also form a triangle with the 3rd-magnitude heart of Cancer, M44, the Beehive Cluster. You can pin down its location with another triangle made up of Procyon, Hydra's head, and M44 itself.

Leo, Hydra, and Cancer have something more in common. In Greek legend, all three were adversaries vanquished by the most famous of strongmen, Hercules. Hercules killed the Nemean Lion and the Lernean Hydra. Cancer is reputed to have been a monstrous crab that Hera, the queen of the gods, sent to bite Hercules' toe. The hero kicked the crab from his foot all the way up into the heavens, where we see it today. And on March evenings, the constellation of Hercules is only now starting to rise in the northeast.

■ **FRED SCHAAF** observed both his first total eclipse of the Sun and his first great comet in March 52 years ago.

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

Planets Dance at Dawn

A quartet of solar system luminaries graces the morning sky.

WEDNESDAY, MARCH 2

March kicks off with a tight morning conjunction starring two planets traveling in opposite directions: **Mercury** and **Saturn**. The innermost planet is heading sunward as it concludes its first dawn apparition of 2022, while Saturn is slowly gaining altitude following its February 4th solar conjunction. And on the morning of the 2nd, substantially less than 1° (two Moon diameters) separates the pair as they rise together in the east-southeast.

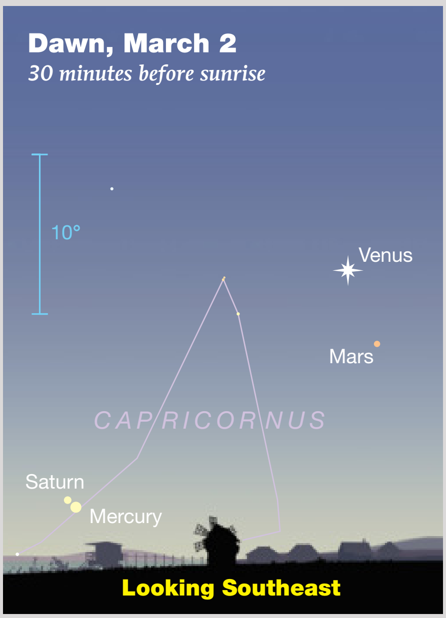
Once the two planets clear the horizon, it becomes a race against brightening twilight to spot them. Half an hour before sunrise, they're only about 3° up — and therein lies the challenge. You're going to need an unobstructed view (ideally, over water or an open field) and, more likely than not, binoculars. On the plus side, both objects are reasonably bright, with Mercury at magnitude –0.1 and Saturn a notch fainter at magnitude +0.8. This is a fitting final act to Mercury's morning appearance; you'll be able to catch it again at dusk starting around April 11th.

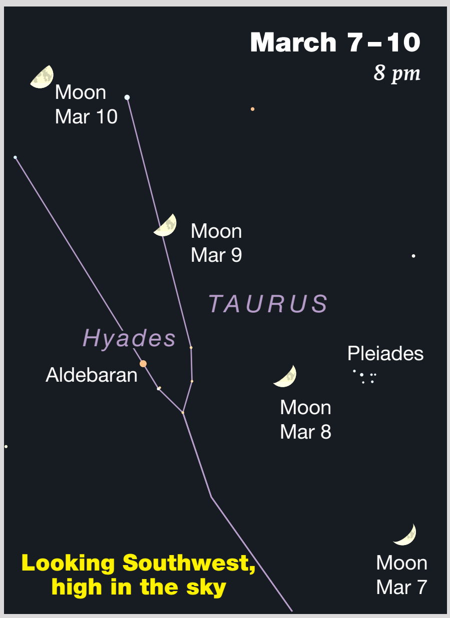
TUESDAY, MARCH 8

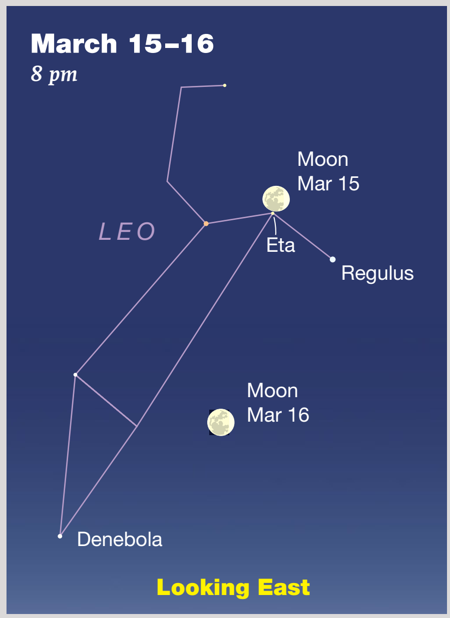
This evening the **Moon** is parked attractively between the **Hyades** and **Pleiades** clusters in Taurus. Because stargazing is a nighttime activity (to state the obvious), it often conflicts with other aspects of our lives, such as work and school. Even the most dedicated enthusiast can't always find time to soak up the starlight. That's why this evening's conjunction is so appealing — it's a perfect, quick-and-easy sight that you can enjoy before bedtime. Indeed, if you have a west-facing window, you don't even have to step outdoors to enjoy the waxing crescent Moon floating roughly 4° left of the Pleiades and 6° right of the Hyades.

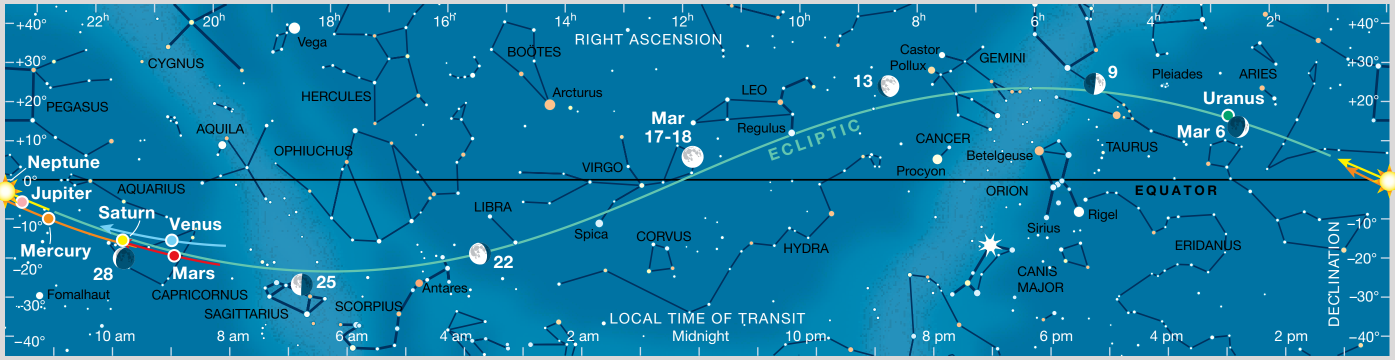
TUESDAY, MARCH 15

There's a lot going on in the morning sky right now as a group of naked-eye planets shift in and out of position with one another. Two of the more conspicuous participants in this dance are **Venus** and **Mars**. All month, the gap between them has been closing as Mars very slowly climbs higher and Venus gradually sinks lower. This morning they're at their closest, separated by a hair less than 4°. So leisurely is their pas de deux that they remain within 5° of each other for another 10 days! So, if the weather doesn't cooperate on this particular morning, you'll still have plenty of opportunities to see them together. The planetary pair are a bit of





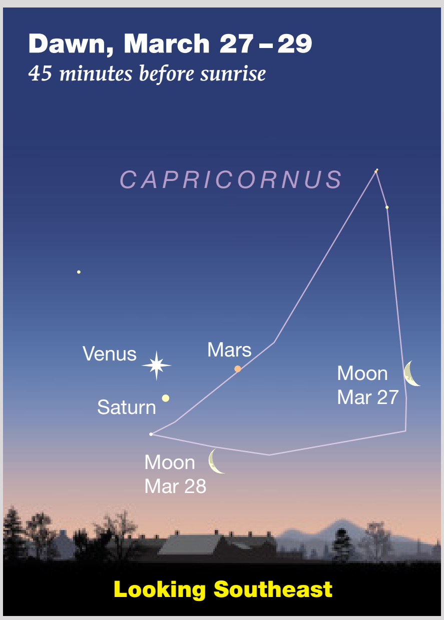




▲ The Sun and planets are positioned for mid-March; the colored arrows show the motion of each during the month. The Moon is plotted for evening dates in the Americas when it's waxing (right side illuminated) or full, and for morning dates when it's waning (left side illuminated). "Local time of transit"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

a brightness mismatch, though. Mars shines at magnitude 1.2, while Venus gleams at magnitude –4.6 — more than 200 times brighter than her ruddy dance partner.

Meanwhile, on the evening of the 15th, the **Moon** visits Leo, where it has two noteworthy encounters. First, observers in the eastern U.S. and Canada equipped with binoculars (or even better, a small telescope) can watch the dark limb of the waxing gibbous Moon eclipse 3.5-magnitude **Eta Leonis**. The exact time of the encounter depends on your location. From New York, it occurs in fading twilight at 7:51 p.m. EDT. More obvious this evening is the Moon positioned less than 4½° above left of **Regulus**, Leo's brightest star. That's the Leo pairing most of us will get to enjoy.



SUNDAY, MARCH 20

As described on page 50, today **Venus** reaches its greatest elongation from the Sun, sitting 47° west of our home star. You might suppose that "greatest elongation" is the best time to observe Venus since it's farthest from the Sun. However, it's really the planet's elevation above the horizon that determines how easy (or not) Venus is to see. For observers at mid-northern latitudes, that occurrence usually doesn't match the date of greatest elongation. Indeed, with the current Venus apparition, the brilliant planet was highest at dawn nearly a month ago, on February 23rd.

If you dig out our annual *Skygazer's Almanac* graph (distributed with the January issue), you can quickly see what's going on by looking at the line labelled "Venus Rises" on the right (morning) edge of the chart. You can also see how gradual Venus's descent toward twilight will be in the months ahead. I mention this because if you're a fan of watching the comings and goings of the naked-eye planets, you can't do better than this resource. That's why I always keep mine handy.

◀ 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.

FRIDAY, MARCH 25

The dawn dance of the planets reaches a new climax this morning as **Venus**, **Mars**, and **Saturn** find themselves arranged in a neat triangle. This moment of symmetry comes courtesy of Venus, which is shifting eastward quickly enough that the configuration of planets changes noticeably from one morning to the next. On this occasion the Morning Star is roughly 4° from Saturn and nearly 5° from Mars.

MONDAY, MARCH 28

If you had to pick one day out of the entire month to get up early, this would be it. A close pairing of planets, like the ones on the 2nd and 15th are lovely treats. Group together three planets, as on the 25th, and it's that even better. But throw in the **Moon** too? Well, even a non-early-riser like me is sure to get up before dawn. **Venus**, **Mars**, and **Saturn** are still arrayed in a triangle, though more of a right triangle than the nearly isosceles arrangement they had a few mornings ago. Completing this stunning scene is the attractively earthlit waning crescent Moon, shining below the planetary trio. Talk about a good morning!

■ Consulting Editor **GARY SERONIK** has been keeping an eye on the comings and goings of the Moon and planets for more than 50 years.

A Sirius Naked-Eye Challenge

March offers a golden opportunity for a daylight sighting of the night sky's brightest star.

A familiar winter-sky sight, Sirius, the Dog Star, anchors the constellation Canis Major, the Great Dog. But have you ever tried spotting Sirius in the daytime without optical aid? With careful planning it's possible.

As a kid I read that if you stood at the bottom of a deep well and looked up you could see the brightest stars in the daytime. Somehow it seemed to make sense — as if you could dark-adapt your eyes enough to claw stars from the blue. Sadly, it's a myth.

It all started with Aristotle back in the 4th century BC when he wrote: "The man who shades his eye with his hand or looks through a tube will not distinguish any more or less the differences of colors, but he will see further; at any rate people in pits and wells sometimes see the stars."

As with other things Aristotelian, it was passed on as true even by respected astronomers such as John Herschel and Robert Stawell Ball. We can only conclude they never actually tried the experiment themselves. Those who did, including German polymath Alexander von Humboldt and 20th-century astronomer and UFO researcher J. Allen Hynek, discovered the claim was false. Von Humboldt even went a step further and queried miners and chimney sweepers on the topic, with negative results.

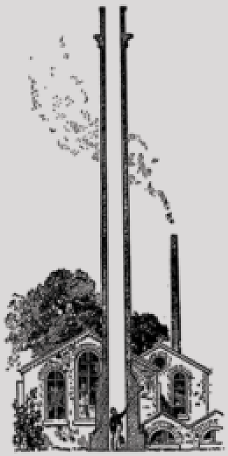
Hynek once took his astronomy class to a 72-meter-high (235-foot-high) smokestack. They assembled at the bottom early to dark-adapt while waiting for Vega to transit the aperture above. When they looked up at the critical time, no star appeared. Even binoculars failed to show anything.

But that's no reason to give up. There's at least one nighttime star you can see in daylight without optical aid: Sirius. And you don't need to crawl down a well or mineshaft to do so. At magnitude –1.5, Sirius is the brightest star in the night sky. Twice a year, in October at dawn and in March at dusk, the star reaches *quadrature*, when it crosses the meridian and stands highest in the sky at sunrise and sunset. This month quadrature occurs around March 27th.

On March 3, 2019, I successfully bagged Sirius in 10×50 binoculars, a full 20 minutes before sunset. Once found, I kept the star in view in the binoculars while walking a short distance to line Sirius up with the top of a spruce tree. Then I lowered the binos and waited. In the nick of time — just two minutes before sundown — a speck of light jumped from the blue sky. I was elated.

It was more than two weeks before the star's quadrature when I made this sighting. As a result, Sirius stood 6° lower than at its maximum altitude. But the extra separation between it and the Sun meant better contrast in a bluer sky, despite the marginal loss of light arising from the star's lower altitude.

Not surprisingly, the key to seeing Sirius in daylight is



◀ The caption for this illustration from the 1899 edition of Robert Stawell Ball's book *Star-Land* reads "How the stars are to be seen in broad daylight." Indeed, stars do shine in the daytime, but they're overwhelmed by the intense glare of the Sun and bright blue sky.

SIRIUS AT NIGHT: AKIRA FUJII

knowing exactly where to look and the time of local sunset. You can use an app such as *SkySafari* or *Star Chart* to find the star's position, but there's something appealing about doing it with a compass.

To pinpoint Sirius, you'll need to know its altitude and azimuth timed for at least 10 minutes before sunset so you can start searching early. I get these figures by using the free program *Stellarium*, which you can download at **stellarium.org**. Select your city and then set the clock to shortly before local sunset, which you can find from numerous sources, including **timeanddate.com**. In *Stellarium*, click on Sirius and its altitude and azimuth will appear in the upper left of your screen.

▲ The azimuth scale is typically found around the perimeter of a compass. Set it to match the azimuth of Sirius, then rotate the compass until the needle points north. The body of the compass will then be aligned with the star's azimuth position.

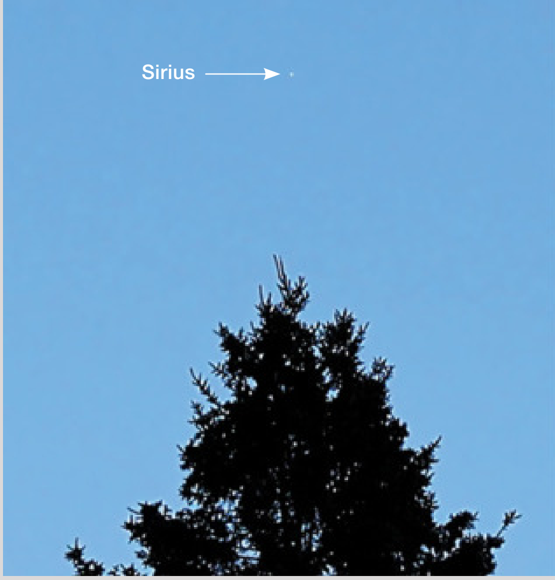
Now grab your compass and binoculars and head outside. Pick a spot with a good view to the south-southeast and with a prominent landmark in the foreground to line up with the star — a rooftop, utility pole, or tree will do the trick. Next, make sure your binoculars are pre-focused at infinity by aiming at the Moon (if visible) or a distant mountain. (If you plan ahead, you can pre-focus on a star the night before.) Without precise focusing, Sirius will blend right into the sky.

For the azimuth figure to be useful you have to take into consideration the fact that true north can differ from compass or magnetic north by several degrees, depending upon your location. That difference is called *magnetic declination*. You can find your site's current magnetic declination online at **magnetic-declination.com**. If it's just a degree or two (positive or negative) you can safely ignore it; otherwise, you have to adjust your compass accordingly or factor it into your azimuth calculation.

Rotate the outer dial of your compass so that Sirius's azimuth aligns with the index mark (the tick mark just outside the circle of readings) at the top of your compass. Next rotate the entire compass until the needle points north — your compass will now be aimed at the exact azimuth of the star. Finally, use your fist or fingers to estimate the altitude you got for Sirius. Ball your fist (vertically) and extend it at arm's length with the bottom touching the horizon and measure upwards. One fist height equals 10°.

Once you catch Sirius in your binoculars, note its position relative to your landscape reference point, then use your eyes alone. I saw the star flicker in and out of view two minutes before sundown and was able to briefly hold it steady at the one-minute mark. It was only at sunset that Sirius was obvious.

If you're older, you'll likely have trouble with pesky *floaters* — collagen deposits inside your eyes that look like dots or cobwebs floating across your field of vision. Try tipping your head left and right a few times to clear the floater. You might also find it helpful to regularly look away and relax your eyes by changing their focus. It's also worth trying a polarizing filter to darken the sky and increase contrast.



▲ The author photographed Sirius on March 3, 2019, one minute before sunset from Duluth, Minnesota, by using the tree to point to the star in the barren, blue sky. To see Sirius in daylight, haze-free conditions are a must.

Finding Sirius in March is a bit more challenging than in October when you can spot the star in morning twilight and follow it past sunrise. Either way, southern observers have the edge because the luminary is so much higher there than at mid-northern latitudes.

Good luck with your Sirius hunt!

BOB KING (2)

Minima of Algol

Feb.	UT	Mar.	UT
3	13:03	1	8:27
6	9:52	4	5:17
9	6:42	7	2:06
12	3:31	9	22:55
15	0:21	12	19:45
17	21:10	15	16:34
20	17:59	18	13:23
23	14:49	21	10:13
26	11:38	24	7:02
		27	3:51
		30	0:41

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

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

Debate Over Dichotomy

AS VENUS ORBITS the Sun, it swings from solar conjunction to greatest elongation and back again while cycling through Moon-like phases over a period of 584 days. This month, the planet reaches its greatest western elongation on the 20th at 21:35 UT (17:35 EDT), when it lies at a right angle to the Sun as seen from Earth. At *dichotomy* — as this arrangement is called — you'd expect the planet to appear exactly half-illuminated.

But you'd be wrong.

Two factors are at play. First, the eccentricities in the orbits of Earth and Venus can cause the theoretical moment of dichotomy to differ by more than two days from the time of greatest elongation. Eccentricity variations change the distance between the two planets, and thereby, the orbital position required to achieve the critical right angle. For the current Venus apparition, dichotomy occurs on March 21st, nearly 8½ hours after greatest elongation.

Then there's the Schröter Effect, first described by German astronomer Johann Schröter in 1793. He noticed that Venus usually appeared half-lit six days before evening elongations and six days after morning ones. Modern observations have shown that the deviation is closer to four days on either side of elongation. The cause of this difference remains unknown.

One study has shown that when we use our telescopes to view the terminator near the Venusian poles, our line of sight passes through a thicker cross-section of the planet's atmosphere. Therefore, due to light scattering, the polar regions appear brighter compared to the equatorial zone where the sightline is shorter. The difference makes the terminator appear slightly concave. While at first blush this explanation sounds convincing, it's problematic because atmosphereless Mercury also exhibits the same anomaly. Other studies have suggested that differences in aperture, atmospheric conditions, or even physiological or psychological differences among observers could play a role.

If you have a 4-inch or larger telescope, try looking for the Schröter Effect yourself this month. Time your dichotomy observing sessions for around 1 p.m. local daylight time, when the planet is nearest the meridian. That's when you should have the clearest, sharpest views possible.

Venus reaches greatest elongation again in June, 2023.

▲ Shahrin Ahmad of Kuala Lumpur, Malaysia, captured this view of Venus on October 27th, 2021 UT when 50.6% of the planet was illuminated. Greatest eastern elongation occurred on October 29th, while dichotomy took place a day earlier, on the 28th.

▼ The angle between the Earth, Venus, and the Sun is 90° during greatest elongation. At such time we would expect the planet to appear exactly 50% illuminated, but telescopic observations show otherwise.

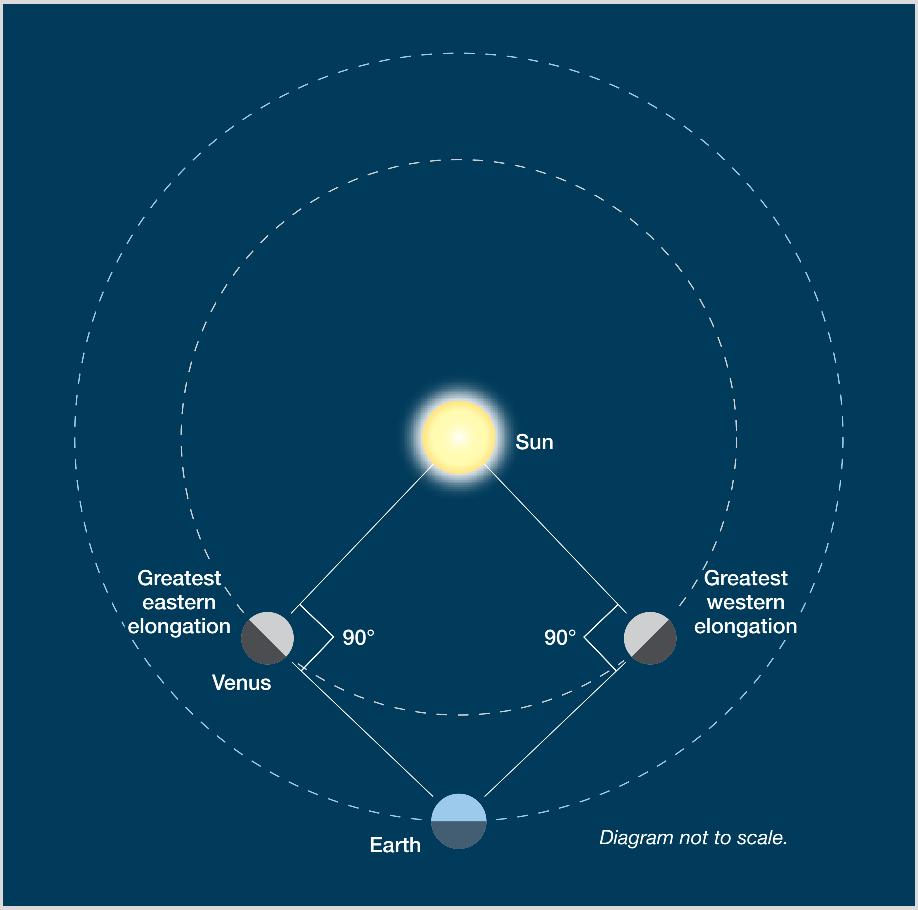


DIAGRAM: GREGG DINDERMAN / S&T

Aligning With the Equinox

▲ The Sun sets on West Adams Street in downtown Chicago on March 12, 2020. For several days around the equinoxes, the Sun rises nearly due east and sets nearly due west along the city's east-west grid of streets.

SPRING BEGINS on March 20th at 11:33 a.m. Eastern Daylight Time. On that date, day and night will be of roughly equal length across the planet, and the Sun will rise due east and set due west. These and other seasonally significant astronomical markers, such as the winter and summer solstices, were crucially important to our distant ancestors, who used the repeating motions of the Sun, Moon, and stars to measure the passage of time. These sky-watchers created numerous megalithic "observatories" that aligned with the Sun and possibly other celestial bodies at the equinoxes and solstices.

One of the most famous of these structures is Stonehenge, which was built in stages over hundreds of years beginning around 3000 BC. Key features appear to line up with the direction of sunrise at the summer solstice and sunset at the winter solstice. Other examples, such as the El Castillo pyramid at Chichén Itzá in Mexico's Yucatán, align with the equinoxes. For a few minutes on and around these dates the Sun casts a shadow in the shape of a serpent along a staircase that joins a snake-head sculpture at the pyramid's base.

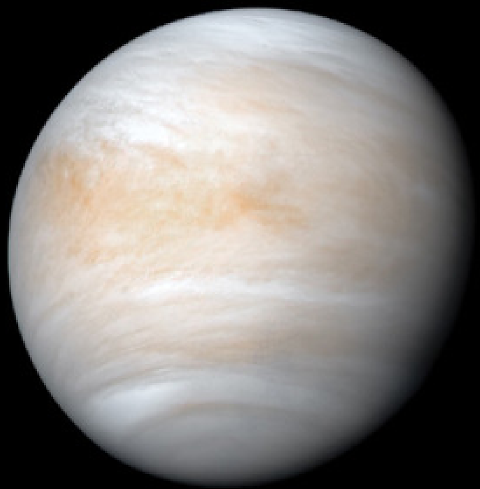
I wonder what the creators of these monuments would think of our modern cities, where the streets are commonly laid out along an east-west/north-south grid. Of the world's largest cities, Chicago, Illinois, is said to come closest to the perfect grid: From space it resembles an electronic circuit board. Cognizant of the city's rich symmetries, people have begun celebrating Chicagohenge at the spring and fall equinoxes in recent years. They gather on streets and watch the Sun rise or set at the bottom of deep skyscraper canyons. Some of the best viewing spots are between Kinzie and Madison streets in the heart of downtown. Not to be outdone, there's also a Manhattenhenge and Phillyhenge.

Does your town have streets aligned on an east-west axis? If so, maybe it's time to consider creating your own equinoctial henge with the help of your local astronomy club. These alignments still have a grip on the human imagination. Given the chance, most people are eager to make a celestial connection just as our distant ancestors did.

CHICAGOHENGE: TIM HARA; JUPITER: JOHN BOUDREAU

Action at Jupiter

Jupiter is in conjunction with the Sun on March 5th and essentially out of view all month. As a result, our regular tables showing the transit times of the Great Red Spot and Jovian satellite events aren't presented in this issue. They will return (along with Jupiter) next month.



◀ Venus in false color as seen by NASA's Mariner 10 spacecraft in 1974

NASA / JPL-CALTECH

Venusian Cusps, Caps, and Collars

Features near the poles of the hottest planet were once mistaken for polar caps.

For telescopic observers, the dazzling face of Venus is a bitterly disappointing sight compared with the richly detailed disks of Mars and Jupiter. The planet's surface is concealed from prying eyes by an unbroken canopy of clouds, overlaid by a thick haze. It's not unusual for experienced observers working with powerful instruments to find Venus utterly featureless. The few visible markings are almost invariably diffuse, ill-defined shadings of very low contrast.

The preeminent 18th-century Venus observer Johann Hieronymus Schröter failed to detect any markings for nine years, until in 1788 he was finally able to glimpse ". . . the ordinarily uniform brightness of the planet's disk to be marbled by a filmy streak." In 1890, Irish astronomer Agnes Mary Clerke lamented "What we see is a shell of clouds . . . The eye accordingly finds sure anchorage nowhere." It's no wonder that for more than three centuries observers reported wildly conflicting values for the planet's rotation period and axial tilt!

Early in the 19th century, keen-eyed German astronomer Franz von Paula Gruithuisen reported seeing brilliant spots visible near the horns or "cusps" of crescent Venus, persisting well into the planet's gibbous phase. These features varied in brightness, size, shape, and general outline from day to day and even from hour to hour.

Nevertheless, Gruithuisen compared these cusps to the polar caps of Mars, suggesting that they mark the location of the planet's poles of rotation. This proved to be a very lucky guess indeed. It was only when scientists bounced radar waves off the planet's surface in the 1960s that the rotational axis was finally established as being inclined by less than 3° from the orbital plane — not far off from Gruithuisen's estimate.

During the 1870s, confirmations of Gruithuisen's "cusp caps" trickled in from prominent observers, notably Hermann Carl Vogel and Wilhelm Oswald Lohse at Bothkamp Observatory, Étienne Trouvelot at Harvard College Observatory, and Camille Flammarion at the Juvisy-sur-Orge Observatory. Some observers even reported dusky collars surrounding the bright spots, further mimicking the Martian polar caps. Many suspected that the cusp caps were snowfields on lofty plateaus and attributed their changing visibility and appearance to variations in the density of the overlying clouds and haze.

A host of skeptics regarded the bright caps and dusky collars as optical illusions, often citing Walter Augustin Villiger's "artificial planet" experiments conducted at Munich Observatory during the 1890s. Villiger painted smooth, 2-inch-wide rubber balls white and had people view them through a 5-inch refractor while illuminating them with a spotlight. At several hundred meters the balls had same apparent size as Venus, and by shifting the location of the spotlight he could simulate the planet's phases. Many sketches of these featureless spheres by his test subjects bore an uncanny resemblance to drawings of Venus, replete with shadowy markings near the terminator and bright cusps.

Villiger certainly demonstrated the perils of assuming that features on Venus are real simply because they have been seen by independent observers. But the cusp caps and collars portrayed by his test subjects were never as prominent or well-defined as those in many actual depictions of the planet.

In 1927, Yerkes Observatory astronomer Frank Ross dispelled any lingering doubts about the reality of the cusp caps when he photographed them through ultraviolet filters with the 60- and 100-inch reflectors at Mount Wilson Observatory. Ross wrote that his striking images left "no doubt of the existence of these bright areas," which he characterized as "undoubted facts to be reckoned with."

We now have a better understanding

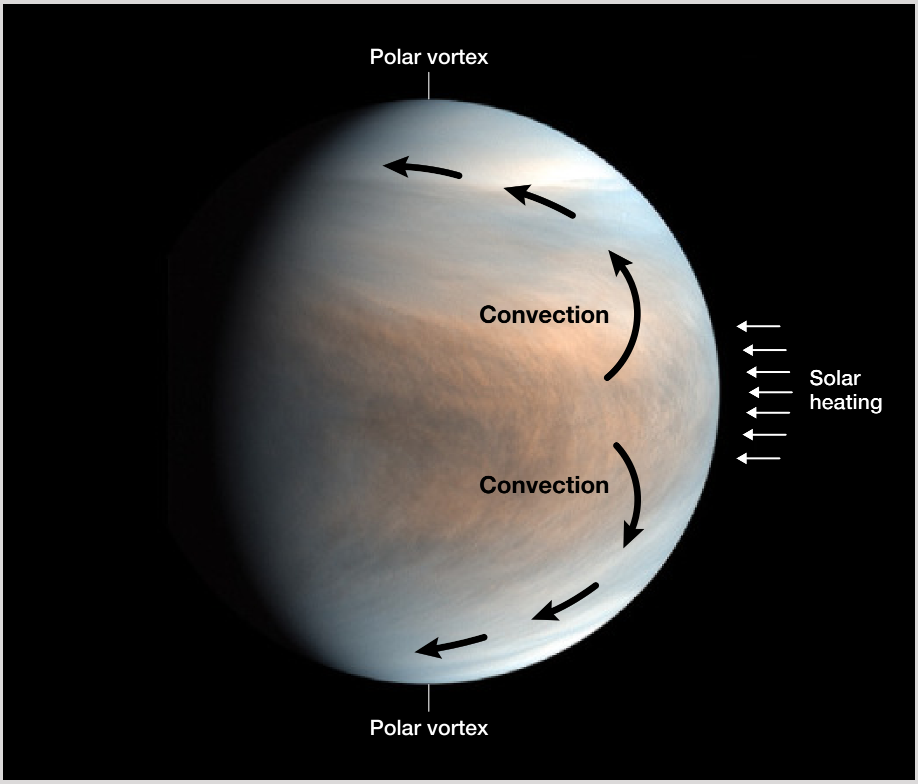
of how these features arise. Convection largely governs atmospheric circulation on Venus. Near the equator, the intense sunlight causes hot air to rise and flow toward the poles. These strong laminar winds extend to latitudes between 60° and 70°, where air starts to descend and flow back towards the equator beneath the visible cloud canopy. This region is the site of the dusky "cold collars," which appear narrow to earthbound observers due to foreshortening. At even higher latitudes, atmospheric circulation is dominated by the whirlpool pattern of powerful polar vortices, which are covered with bright cloud hoods. These features are the cusp caps.

In 1842, Gruithuisen wrote, "I find that spots were seen sometimes at both poles, at other times at one pole alone." This observation has also proved accurate. Recent ground- and space-based observations show that the speed and strength of zonal atmospheric currents on Venus can vary considerably and often show hemispheric inequalities. This discovery may account for the results of a 1958 statistical review by James Bartlett of 830 Venus observations made by members of the Association of Lunar and Planetary Observers from 1944 to 1956. Bartlett found that one or both cusp caps were visible in 54% of the observations: The south cap alone was seen 11% of the time, the north cap 7%, and both caps simultaneously 35%.

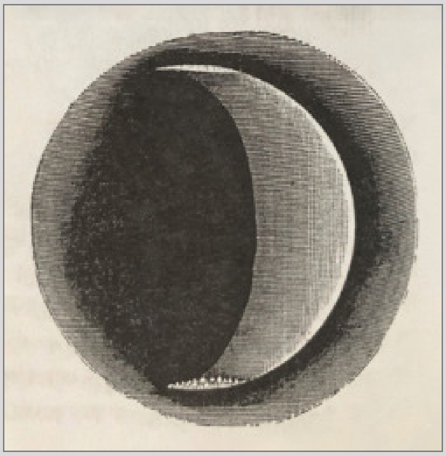
Cloud features on Venus stand out boldly in images recorded using a monochrome planetary camera and ultraviolet filter. They are usually subtle in visible light and always difficult to discern visually, unless steps are taken to reduce glare using a neutral-density filter or, better yet, a variable polarizing filter (*S&T:* Nov. 2020, p. 52). Color filters can also dramatically increase their visibility by boosting contrast. While most observers prefer the Wratten 38A violet filter, prolific British Venus observer Valdemar Axel Firsoff claimed that the combination of a green filter and a polarizing filter gives the best views. Imagers equipped with high-speed video cameras and an ultraviolet filter rountinely record the cusp caps.

The romantic visions of polar snows on Venus are banished forever. But following the ever-changing appearance of the cusp caps and cusp collars remains a rewarding opportunity to contribute to our understanding of the dynamic atmosphere of our closest planetary neighbor.

■ Contributing Editor **TOM DOBBINS** has occasionally glimpsed details in the clouds of Venus with the aid of filters but never without them.



▲ The pattern of atmospheric circulation on Venus is evident in this false-color ultraviolet image from the Japanese Akatsuki spacecraft. Convection from intense solar heating drives winds toward high latitudes, where a zonal flow parallel to the equator eventually predominates near the polar vortices.



▲ In 1878, French astronomer and artist Étienne Trouvelot depicted brilliant spots along the margin of the southern cusp cap that he imagined were snow-capped peaks.

▲ British observer David Graham made this rendering of gibbous Venus in 1988 showing the cusp caps while observing through his 6-inch refractor at 286×.

DIAGRAM OF ATMOSPHERIC CONVECTION: GREGG DINDERMAN / *S&T*, VENUS: JAXA / ISAS / DARTS

◀ **MISNAMED MARVEL** The term planetary nebula is a misnomer, as the objects have nothing to do with planets. These intricate and beautiful structures, as exemplified by NGC 2392, are in reality the ejected atmospheres of dying stars.

NASA / ESA / HUBBLE / CHANDRA / JUDY SCHMIDT

A Fuzzy Face in Space

A tiny celestial treasure lies nestled in one of the arms of the Gemini twins.

Castor and Pollux, the sibling soldiers of classical mythology, stand side by side to create Gemini, a constellation that rewards repeated telescopic exploration. During moonless evenings in early March, Gemini's rectangular star pattern crests near the zenith for mid-northern observers. I'm drawn to the eastern side of the rectangle in search of **NGC 2392**, popularly known as the Clown Face Nebula.

NGC 2392 is a *planetary nebula*. The term was coined by 18th-century observers who commented on the vaguely planetlike appearance of such objects in telescopes. However, a planetary nebula is formed when an aging red giant star becomes unstable and sloughs off its outer layers to create expanding shells of gas. As the ejected material balloons into space, a hot white dwarf — the remnant core of the original star — energizes the shed shells into luminescence.

The white dwarfs associated with planetary nebulae aren't very prominent, but some are bright enough to show in backyard telescopes. In the case of 9.1-magnitude NGC 2392, the 10.5-magnitude central star is as plain as the nose on a clown's face.

Getting There

Last spring, I studied NGC 2392 using three scopes: a 4¼-inch (108-mm) f/6 Newtonian, a 7.1-inch f/15 Maksutov-Cassegrain, and a 10-inch f/6 Dobsonian. The sky conditions were normal for my suburban yard, which has a limiting magnitude of 4.5 in the target area. Whoop-de-do.

My star-hop starting point was 3.5-magnitude **Delta (δ) Geminorum**, halfway down the eastern side of the Gemini rectangle. Yellowish Delta harbors an 8.2-magnitude companion — 76 times fainter — only 5.5″ to the southwest. My 4¼-inch Newtonian cranked up to 180× barely, but definitely, separated the feeble dot from the main star's glare. Very satisfying!

I reduced the magnification to 20× and hopped not quite 2° eastward to 5.3-magnitude 63 Geminorum, the brightest of seven stars forming an attractive ½°-wide crescent. Above the crescent, less than 0.8° north of 63 Geminorum, is a double star called **South 548**, whose 7.0- and 8.9-magnitude components, 35.3″ apart, are orangey-red and blue-white. South 548 was lovely in my little scope.

And 63 Gem itself is a tricky triple cataloged as **SHJ 368**. Its attendants are well spaced but dim. The B component, 43.0″ north-northwest, is magnitude 10.9, while C, nearly 2.2′ southwest of gleaming SHJ 368A, is magnitude 10.7. I needed 93× to capture the complete ABC. (A fainter star flickers between A and C but isn't part of the SHJ 368 system.)

I reduced to 20× again and focused the scope on 63 Gem, knowing that NGC 2392 was lurking in the same field of view, just 38′ southeast. Easy pickings, right? Not so fast. Spotting the Clown Face at 20× is difficult, as its misty disk is less than 1′ wide. Fortunately, said disk lies a mere 1.6′ south of an 8.3-magnitude star, HD 59087.

Initial Inspection

To prove that the star's shy neighbor was NGC 2392, I threaded a narrowband, doubly ionized oxygen (O III) filter onto the eyepiece. An O III filter blocks most light except for the radiation emitted by a planetary nebula. Filtered, HD 59087 was weaker, but the teensy nebulosity was stronger. When I removed the filter, the opposite was true.

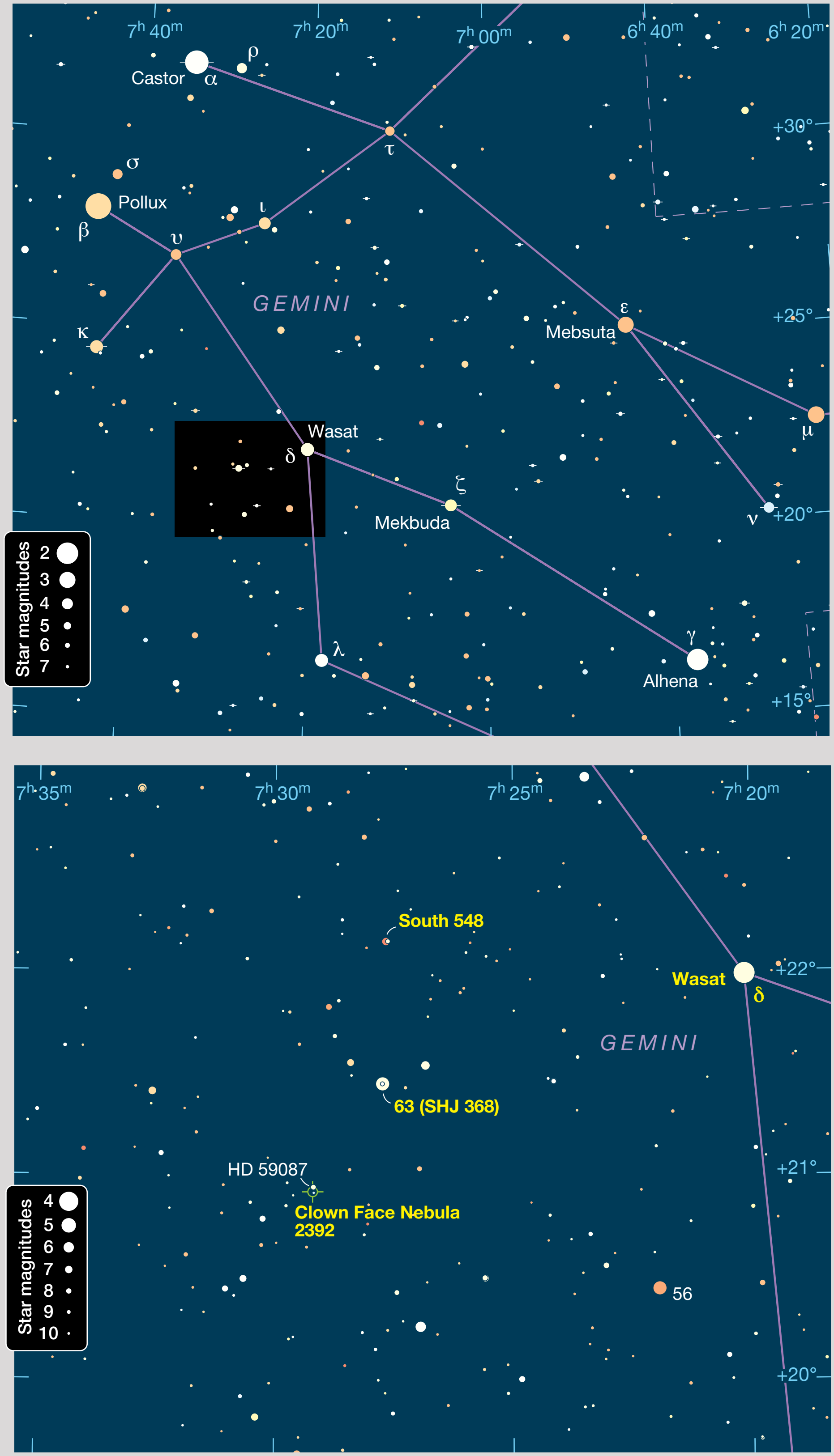
Identifying the smudge sans filter was easier with increased magnification. Using 40× when I shifted from 63 Gem snared the planetary every time — and the extra power clearly revealed the nebula's central star. Indeed, at 97×, I perceived a compact puff dominated by the central star. Adding a 2× Barlow for 194× produced a spherical haze roughly 30″ across that was diffuse at the edge and pinpoint-bright in the middle. HD 59087 was helpful for refocusing when needed.

Returning to 97× and attaching the O III filter made NGC 2392 crisply round, but it greatly diminished the central star. I switched to an Ultra High Contrast (UHC) filter, which isn't as severe as an O III. At 180×, the UHC delivered a big, well-defined disk with a central sun pleasingly visible. But beware: A filtered field at high power can be quite dark. Whenever I used the filters (particularly the O III), I had to cup my hands around the ocular to keep my eye sensitive to the dim and delicate scene.

Fiddling With Filters

For a bigger, brighter Clown Face, I deployed my 7.1-inch f/15 Mak-Cass. A 30-mm eyepiece generating 90× yielded a roundish haze, with the embedded central star still threatening to overpower it. Gazing directly at the star eliminated the delicate vapor. At 113×, the nebula was bigger and more diffuse. Adding the OIII filter darkened the sky significantly and eliminated the central star, leaving only a soft-edged disk. With the UHC, the disk was less sharply defined but the central star re-emerged.

Next, I upped the ante to 159× with the UHC in place. The nebula seemed unevenly bright, it didn't disappear under direct vision, and the central star persevered. Nice! Swapping out the UHC for the O III slayed the star. Despite that, I kept the O III and tried my luck at 300×. The result was a pale-grey "planet." The ghostly globe, around 35″ in diameter, was a bit mottled and slightly elliptical, its long axis pointing toward HD 59087 — still a boon for focusing. Nothing else was visible. With this combination of filter and magnification, the background was so dark I couldn't see the edge of the eyepiece field. I wanted more aperture, so I turned to my biggest bucket — the



▲ **FINDING THE FACE IN SPACE** The author's star-hop to NGC 2392 begins at 3.5-magnitude Delta (δ) Geminorum, which is located almost halfway from 1.2-magnitude Pollux to 1.9-magnitude Alhena, Gamma (γ) Geminorum. It continues through a pretty star field that includes 5.3-magnitude 63 Geminorum, then on to NGC 2392.

BOZO SMUDGE Known to amateur astronomers as the Clown Face Nebula, NGC 2392 is a small but prominent spring sky target that boasts a relatively bright (10.5-magnitude) central star. This fuzzy face in space smiles at us from a distance of some 5,000 light-years.

10-inch Dobsonian — and employed the UHC and O III filters with magnifications of 169× and 218×. Both filters presented a patchy disk. Again, the O III deleted the central star but mercifully spared Handy-Dandy 59087, my focus friend. I marginally preferred the UHC view, but I admit it's a matter of personal taste.

Fiddling with filters is a dark art on any night, but this March session was really cold. Picture it: numb fingers trying to thread an O III onto an eyepiece . . . patiently refocusing the field . . . nudging the scope at high power . . . losing the freaking target. Endless joy.

No filters? No problem!

Putting the filters aside, I boldly pushed the Dob to 436×. Wow! The Clown Face came to life. The mega-magnification generated a cottony, bluish-grey visage, the central star a pure-white nose. The face was egg-shaped, aligned north-south. To my eye, the southern portion glowed brighter than the northern parts. This agrees with images of NGC 2392, which show a bright patch on the southern edge (the Clown's forehead in my telescope's inverted view) and a dark area in the northern half (a dimpled chin). By comparing the size of the disk to the space between the nose and HD 59087, I estimated the oval nebula to span about 45″. That eyeball exercise led my averted vision to pick up an extremely tenuous halo around the disk. Surprisingly, neither the UHC nor the O III enhanced this barest hint of halo.

So, Gemini's cosmic Clown had the last laugh. In my backyard Dob at high power, it looked best unfiltered. Don't get me wrong. Narrowband filters work wonders at reviving pale planetaries sickened by polluted skies. But the Clown Face Nebula is healthy enough to stand out on its own. If your kit doesn't include filters, your views of NGC 2392 won't suffer much. All you need is a good telescope, relatively high magnification, and an eagle eye.

So, get after that face in space — and no clowning around!

■ Contributing Editor **KEN HEWITT-WHITE** observes every clear night but hasn't spotted a real circus clown in years.

Clown Jewels

Object	Type	Mag(v)	Size/Sep	RA	Dec.
NGC 2392	Planetary nebula	9.1	0.9′	$7^h 29.2^m$	+20° 55′
Delta Gem	Double star	3.5, 8.2	5.5″	$7^h 20.1^m$	+21° 59′
South 548	Double star	7.0, 8.9	35.3″	$7^h 27.7^m$	+22° 08′
SHJ 368AB	Double star	5.3, 10.9	43.0″	$7^h 27.7^m$	+21° 27′
SHJ 368AC	Double star	5.3, 10.7	2.2′	$7^h 27.7^m$	+21° 27′

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.

CHAD QUANDT

Bursts from Space

Help scientists get to the bottom of fleeting cosmic radio signals.

And now for something completely different. If you're a reader of this column, perhaps you've noticed that thus far we've showcased projects for you to undertake with telescopes in your backyard. But maybe you don't have a scope or the requisite recording equipment, or you can't readily get under dark skies. Yet you're yearning to contribute to scientific discovery. The good news is that for many endeavors, such as this one, you won't need a telescope. Heck, this project doesn't even deal with visual wavelengths! All you need is a computer with an internet connection.

FRBs

The radio universe has brought us many a wondrous thing, from revealing the origin of our universe to imaging supermassive black holes (*S&T:* Aug. 2020, p. 12). Lately, scientists have been blown away by *fast radio bursts*, or FRBs.

As their name implies, FRBs are *fast* (on the order of a few milliseconds) *bursts* (cataclysmic releases of energy) that we observe in the *radio* (the longest wavelengths in the electromagnetic spectrum). Since the first event detected in 2007, we've learned that they come to us from galaxies far, far away and that there are oodles of them. But what causes them?

"There are lots of things we don't fully understand about the cosmos," says Bryan Gaensler (University of Toronto). "But it's pretty rare that the universe serves us up something that's a total mystery." And it's important to get to the bottom of phenomena that elude us, because they can help us unveil fundamental aspects of the universe we don't understand.

In astronomy (as with all sciences) we learn about things incrementally, a bit like early morning fog evanescing to reveal a stunning landscape. "But, if anything, the fast radio burst story has gotten more puzzling and confusing as we've gathered more information about them," says Gaensler.

CHIME In

The Canadian Hydrogen Intensity Mapping Experiment (CHIME), a radio telescope located in British Columbia, is collecting data in order to understand FRBs. And it's stupendously productive: Every day it collects more data than all the internet traffic generated in Canada.

Despite having a powerful supercomputer, clever automated algorithms, and some 100 scientists working on the project, the CHIME team doesn't have the capacity to sift through all the signals coming in. You can help the team find and disentangle cosmic signals from the ubiquitous terrestrial ones. Humans are really good at pattern recognition, and your contribution to the "Bursts from Space" project is crucial. "Citizens provide the brain power needed to examine every possible fast radio burst and to decide which of these signals are genuine bursts," Gaensler says.

Currently, we mostly know of very bright FRBs; scientists still don't have a handle on how faint they can get. The CHIME team is counting on you to do better than the automatic software in catching the faint ones. You'll also be training the algorithm to recognize burst patterns it might be missing.

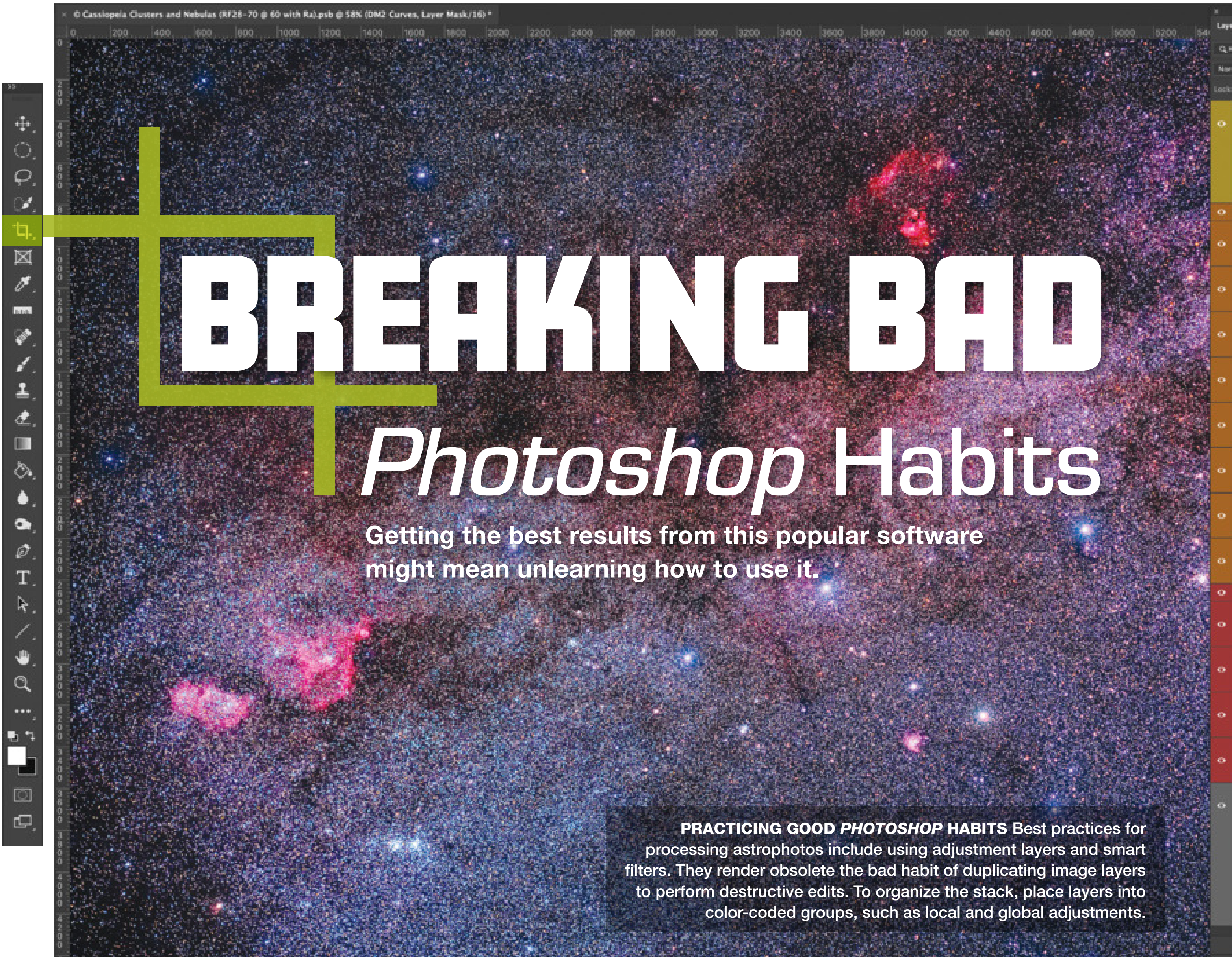
Ready to help the CHIME team solve the FRB mystery? Head to the project page: **zooniverse.org/projects/mike-walmsley/bursts-from-space**. Every Thursday at 14:00 UT, brand-new data fresh from the array will be available for you to peruse. Start by doing a couple of trial sessions in order to flex your pattern-recognition muscles. "The best way to train your eye, besides practice, is to check out the finds that other people are sharing on the Bursts from Space forum," advises Michael Walmsley (University of Manchester). The project FAQ page also has a lot of useful information.

Who knows, your eyes might be the very ones that pluck that crucial bit of info out of the data to help solve the FRB puzzle.

■ Observing Editor **DIANA HANNIKAINEN** used to observe the universe with radio telescopes.

THE CHIME COLLABORATION

▲ **CATCH A BURST** The CHIME radio telescope provides the data that might unravel the origin of FRBs. Now you can help scientists figure out if they're coalescing neutron stars or newborn magnetars . . . or something else entirely.



BREAKING BAD *Photoshop* Habits

Getting the best results from this popular software might mean unlearning how to use it.

PRACTICING GOOD *PHOTOSHOP* HABITS Best practices for processing astrophotos include using adjustment layers and smart filters. They render obsolete the bad habit of duplicating image layers to perform destructive edits. To organize the stack, place layers into color-coded groups, such as local and global adjustments.

Many astrophotographers use *Adobe Photoshop* at some point in their workflow. Chances are you learned it years ago and have never felt the need to make use of its new features and improved ways of editing images.

Gleaned from professional photographers trained by Adobe, here are my top tips for using *Photoshop* today. Most of the tips apply to versions of the program as far back as the decade-old *CS6*. If you use *Photoshop* anywhere in your image-processing workflow, I trust these tips will help you break your bad habits and produce better results with less work.

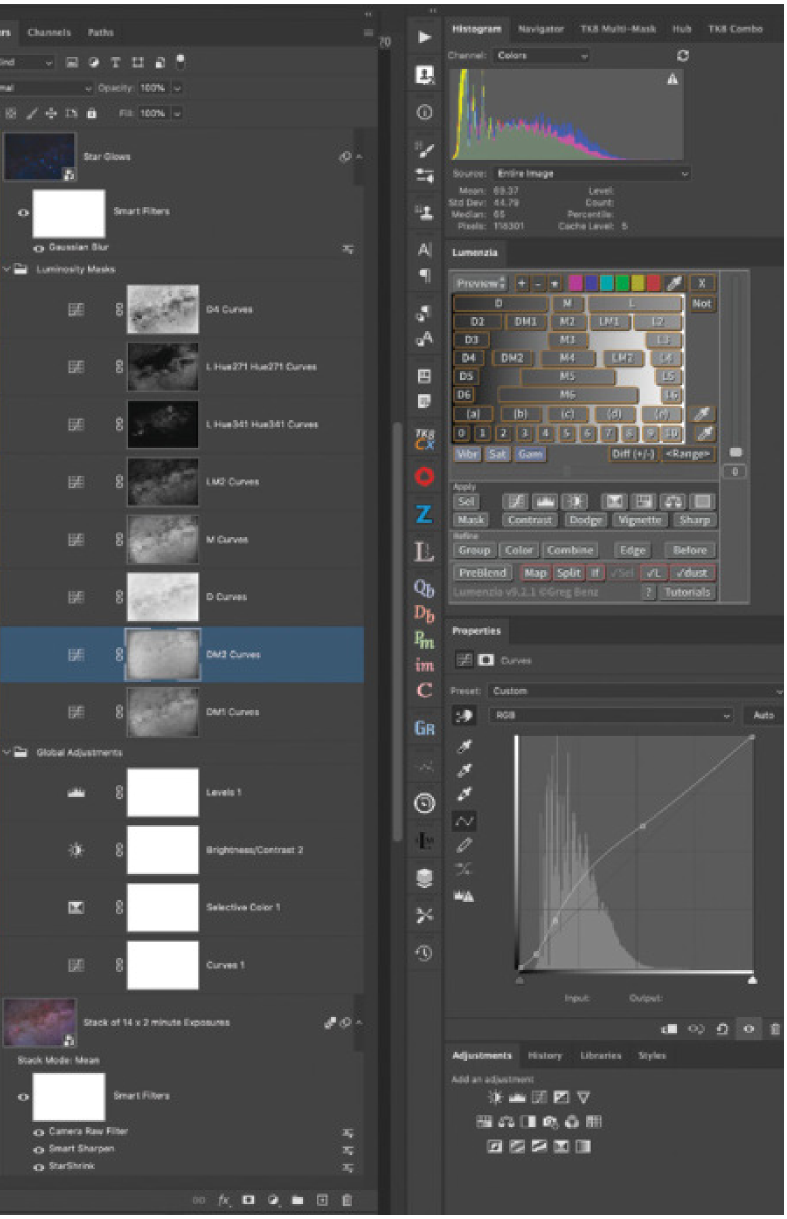
The Benefits of Good Habits

What are the bad old ways? A common offense is what I call “Duplicate and Destroy.” This is the habit of copying the background image layer, then applying a destructive adjustment or filter to that new layer. Then that new layer is copied to apply yet another destructive edit, and so on up the stack. At each step, pixels are irrevocably changed. Close the file, reopen it, and you can be stuck with a poor result and saying “I wish I hadn’t done that!”

Yes, the original image is preserved at the bottom of the layer stack, but reverting back to it requires throwing away all your work and starting over again. Destructive processing makes it impossible to edit any previous step, or to even know what those steps were. That’s especially true when, as I see many photographers do, they build up layers of carefully honed edits then commit the worst *Photoshop* sin of all, flattening all the layers. No!

Flatten is *Photoshop*’s “F” word. Flattening destroys all record of the work done to a photo, making it impossible to undo those changes. By preserving all the layers that make up a well-crafted picture, you can edit any aspect of it at any time

ALL IMAGES COURTESY OF THE AUTHOR



— perhaps next year, or just the next day — when you look at the image with fresh eyes and wonder, "What was I thinking?"

Non-destructive processing also allows you to inspect a picture days or months later and see exactly what you did to create it, so you can repeat your success.

Modern methods for using the program also make it quicker to use. You can tweak adjustments made previously, even several steps back, without having to redo your work from that point on. Non-destructive processing provides you with the freedom to play and experiment. You aren't forced to work in a linear progression, always worrying if you got a particular adjustment right before moving on.

#1: Preserve the Layered Master

To enjoy the stress-free benefits of non-destructive processing, always save your photos as 16-bit, layered master files in *Photoshop*'s native PSD format. Images larger than 2 gigabytes must be saved as PSB files, the program's "big" format. Both file types retain every element of an image — adjustment layers, smart objects, smart filters, and masks — allowing you to change your mind and re-edit at any time.

Use the layered master to export other versions that need to be flattened. That includes high-quality TIFFs for printing or publication, or lower-quality and down-sized JPGs for use on social media and for e-mailing. To create the latter, use Export As dialog under File > Export in the pulldown menu.

Long-time users tend to flatten their master images to save drive space — a bad habit from the days when hard drives cost hundreds of dollars for mere megabytes of storage. Terabytes of archival storage are now cheap; your time is not.

#2: Discover Adjustment Layers

Brightness, contrast, and color adjustments are the most common edits an astrophoto needs. Never apply those from the Image > Adjustments menu. These are destructive legacy functions that originated in *Photoshop 1.0* way back in 1990. Instead, add adjustment layers (Layer > New Adjustment Layer). This capability was introduced in *Photoshop 4* in 1996, yet some photographers still don't use it. Old habits die hard! Adjustment layers affect what an underlying image looks like without altering its pixels, preserving its original content.

Adjustment layers allow you to play with each tweak independently, to get the picture looking just right, either now or whenever you open the file in future. Adjustment layers are ideal for anyone afraid of commitment!

#3: Apply Smart Filters to Smart Objects

Ditto on smart filters, introduced in 2007 with *Photoshop CS3*. By converting an image layer into what Adobe calls a smart object, the original image is protected inside a "container" so no filter can alter its pixels, only the layer's appearance when viewed with the filter. For example, it's common to reduce noise and sharpen a photo by applying filters. Before doing so, convert the layer into a smart object, with Filter > Convert for Smart Filters. Any filter that gets applied can then be readjusted at any time. There's no longer a worry about adding too much or too little of a filter.

This also applies to third-party add-ons such as Russell Croman's excellent *StarShrink* and *GradientXTerminator* filters (**https://is.gd/CromanPS**), noise-reduction plug-ins including *Topaz DeNoise AI* (**topazlabs.com**), as well as my preferred choice, *ON1 NoNoise AI* (**https://is.gd/nonoiseai**).

#4: Don't Erase, Hide with Masks

Layer masks allow you to restrict an adjustment or a filter to selected parts of a picture, rather than to the whole thing.

Masks are also useful when blending several images into a single composite. For example, a photograph of a deep-sky object might be built up from multiple exposures — short ones for the brightest areas and long ones for the fainter outer regions. When blending these different exposures, never erase or delete parts of an image. If you do, those pixels are gone for good. Instead, apply a mask to hide the parts you don't want to use. Any area of a mask painted with black conceals what's on the associated layer, while the white area of a mask reveals. While this tip is basic *Photoshop* knowledge, even astrophotographers who know it well might not make use of the next tips for creating and editing the mask.

#5: Let the Software Do the Selecting

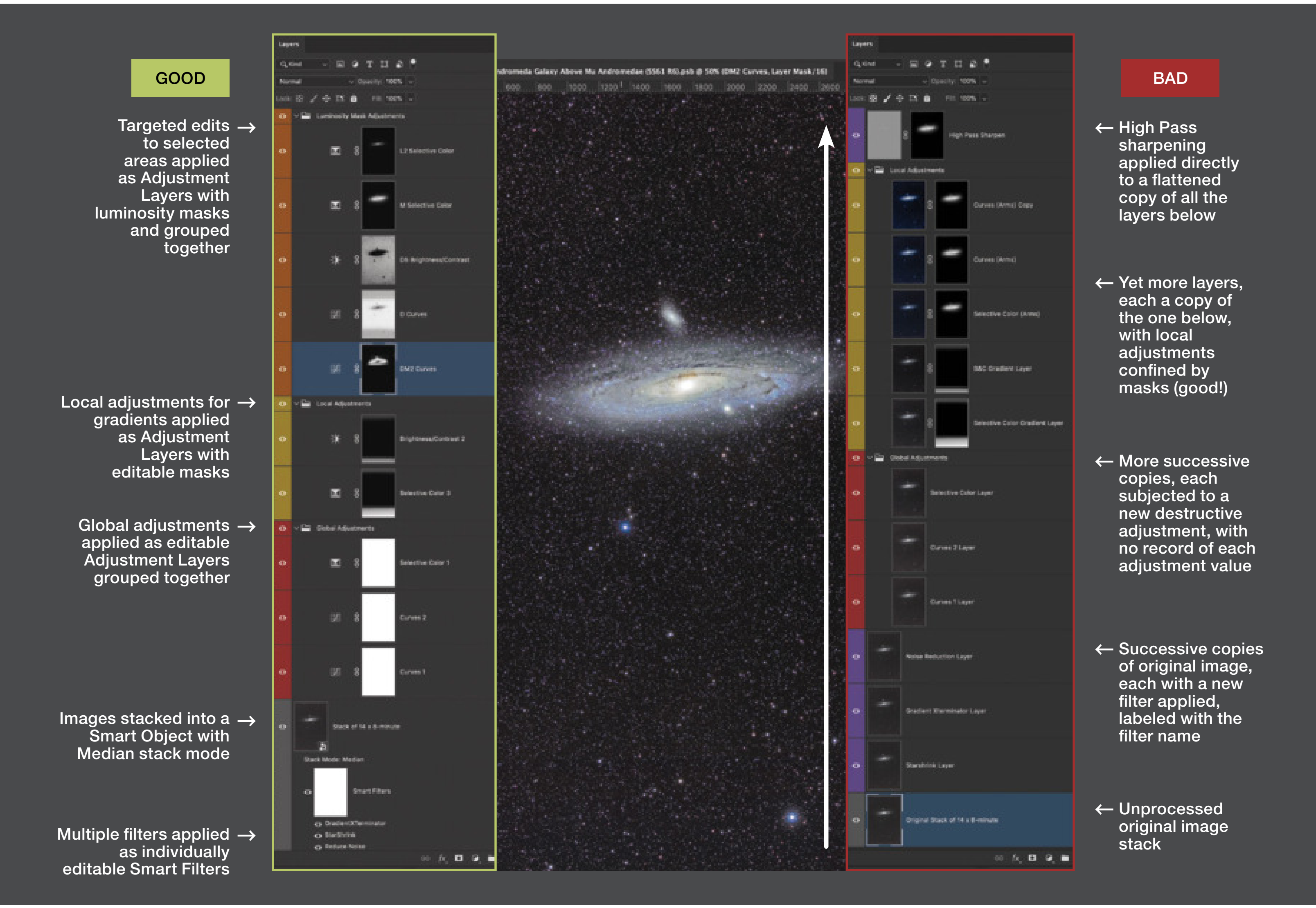
When blending two different exposures, a common practice is to freehand draw on a picture to select, say, the bright core of a nebula. *Photoshop* can do a better job making the selection. Use it to generate what's called a luminosity mask — one based on the brightness values in the photo.

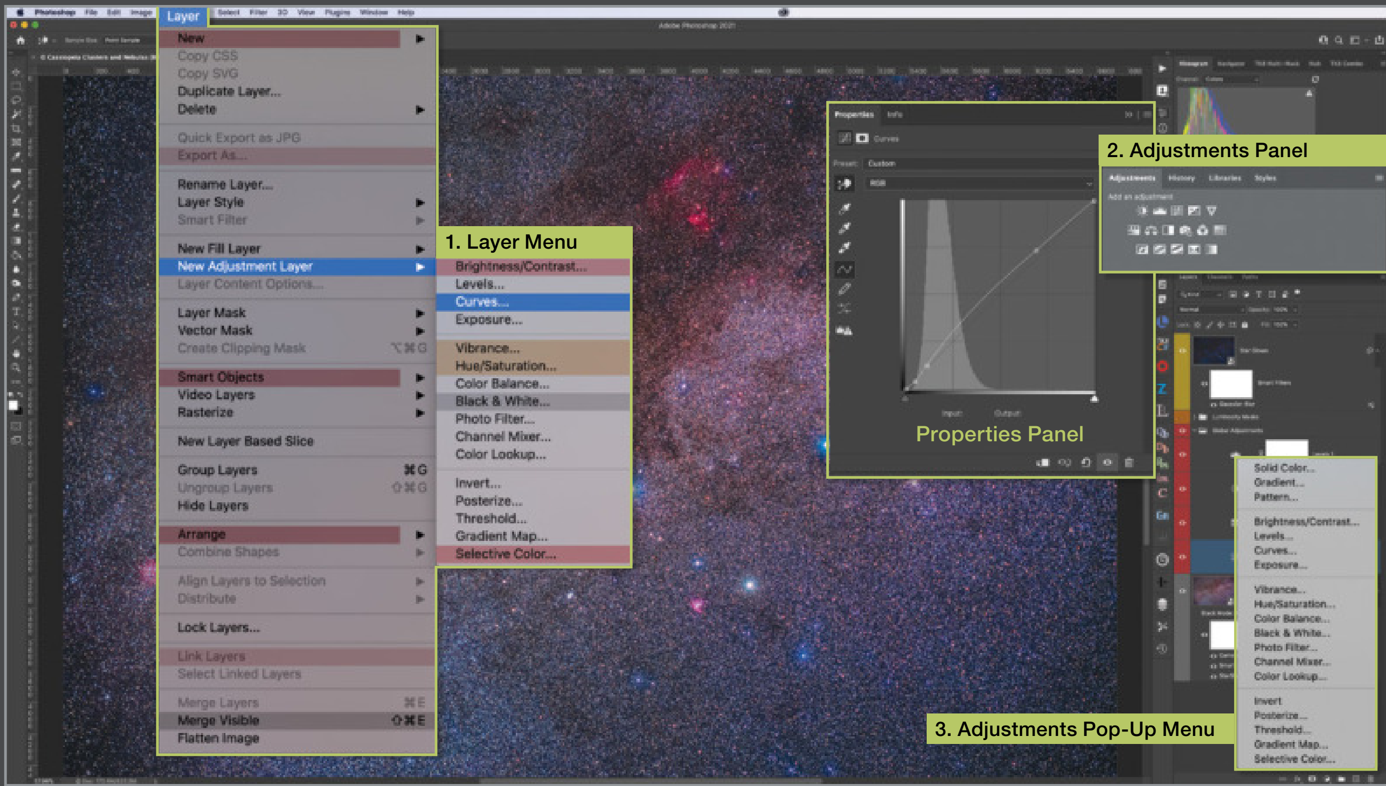
The easiest way automatically selects all the highlights. Click on the layer you wish to mask, then go into the Channels palette and click on the RGB channel while pressing the Command (on a Mac) or Control (in Microsoft Windows) keys. Now return to the Layers panel and, with the layer in question selected, hit the Add Layer Mask button at the bottom of the panel. Doing so creates a mask that reveals only the brightest parts of the picture. Whatever is revealed in the top layer hides whatever is below in the layer stack, as in the Orion Nebula example on page 62, where the short exposures of the bright core are placed above the long exposure set.

#6: Don't Blur a Mask, Use Properties

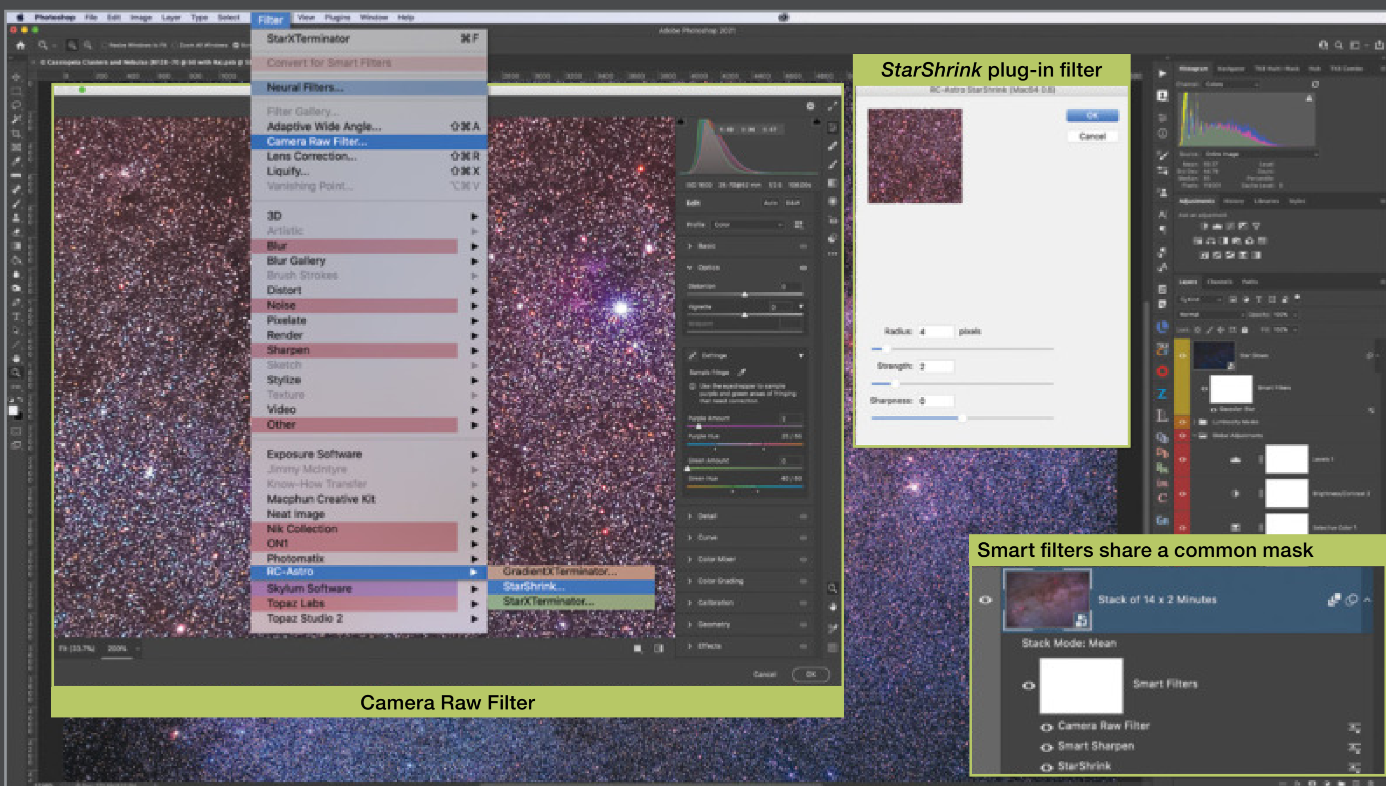
Even with accurate luminosity masks applied, seamlessly blending layers often requires masks with fuzzy edges. Don't select a mask, then apply a Gaussian Blur filter to it — that's a change you can't edit later. Instead, double-click on a mask to open up its Properties panel, a feature added in *Photoshop CS6*. One of the properties is Feather. Adjust the slider as needed. You can open the panel at any time to change the feathering.

▼ **GOOD VS. BAD HABITS** The old destructive way (right) starts with a base image, then duplicates it, each time applying a destructive edit. Nondestructive processing (seen at left) applies editable smart filters to and adjustment layers above the base layer, which remains untouched.

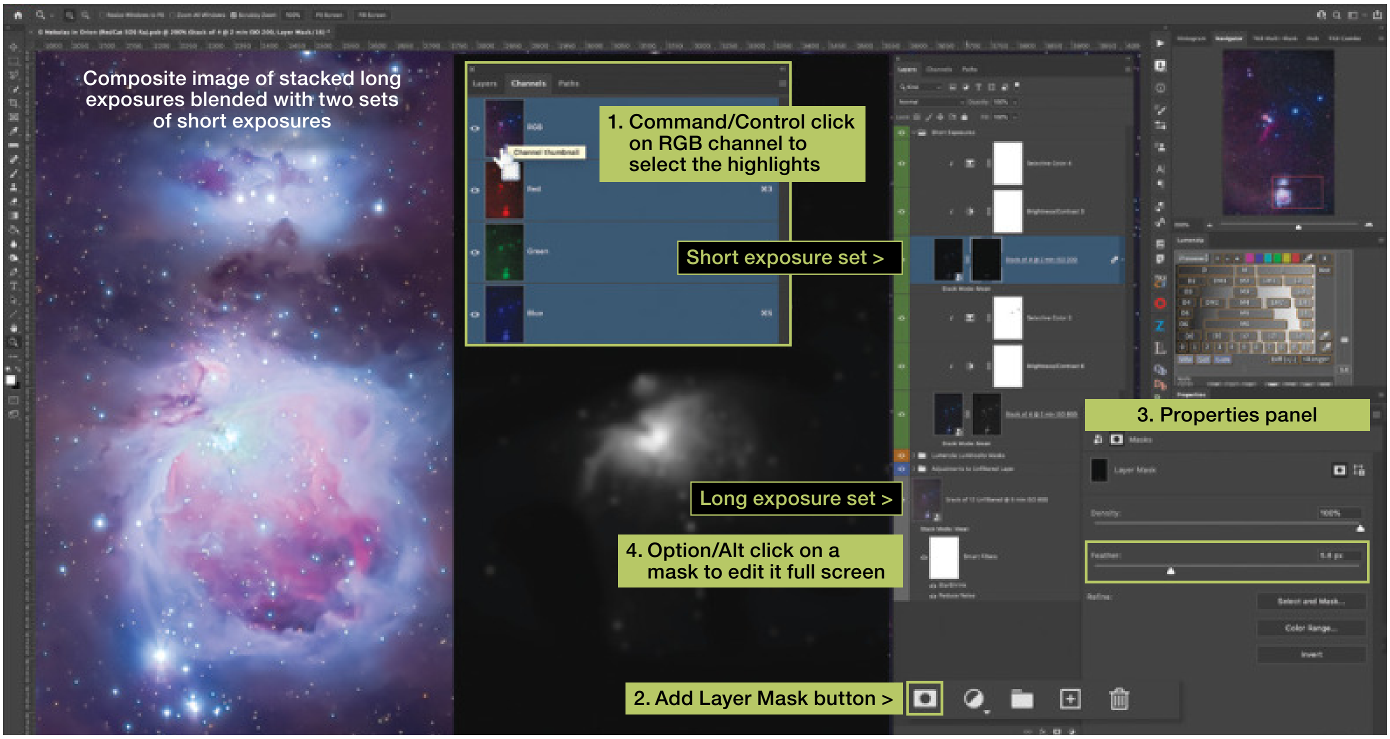




▲ **ACCESS TO ADJUSTMENTS** *Photoshop* often provides several different ways to access the same function. In this case, adjustment layers can be added either in the Layers menu (1), the Adjustments Panel (2), or the Adjustments pop-up at bottom (3).



▲ **APPLYING FILTERS SMARTLY** When filters are applied to smart objects, they become smart filters. Double-clicking on the filter name opens it and allows you to change its settings at any time. This image shows the useful Camera Raw applied as a filter, and Russell Croman's *StarShrink* filter.



▲ **MAKING MASKS** Command (Mac) or Control (Windows) clicking on a channel selects the highlights (1). Any mask added to a layer (2) reveals only those highlights. Feather the mask using the slider in the Properties (3) panel. You can then display the mask by Option (Mac) or Alt (Windows) clicking on the mask (4), making it easier to paint into.

#7: Add a Powerful Panel

This tip goes beyond breaking a bad habit to learning a new, advanced technique. As powerful as *Photoshop* is, its ability to easily create luminosity masks (such as using Select > Color Range) leaves a lot to be desired. That's where third-party developers have stepped in, taking advantage of the software's ability to run scripts.

Two of my favorite third-party scripts are *Lumenzia* from Greg Benz (**https://is.gd/lumenzia**) and *TK8* from Tony Kuyper (**goodlight.us/index.html**). Both permit one-click creation of complex masks, allowing you to select a narrow range of tones, a specific color, or a saturation value. Both panels have free "light" versions. Give them a try and be sure to watch the video tutorials offered by each supplier.

#8: Sharpen With Full Control

Here we combine several non-destructive methods to add sharpening, a frequent finishing touch in *Photoshop*. For this technique use the arcane keyboard shortcut Command+Option+Shift E (MacOS) or Control+Alt+Shift E (Windows) to create a "stamped" copy at the top of the stack of the underlying visible layers.

Now convert this layer into a smart object (right-clicking beside the image icon brings up a menu with this option). Then go to Filter > Other and select High Pass, setting the tool radius to 10 to 40 pixels. Don't worry, you can change this later. You get a gray mess until you change the Blend Mode (found in the Layers panel) from its default of Normal to Overlay, Soft Light, or Hard Light. Voila! Instant sharpening and contrast enhancement.

However, the result affects the entire picture. Use one of the mask-generation methods to add a mask to your High Pass sharpen layer to restrict its effect to areas you want. Typically, you would avoid sharpening stars and apply it just to structures such as dark dust lanes, as in the example shown on the facing page.

#9: Heal Without Hurting Pixels

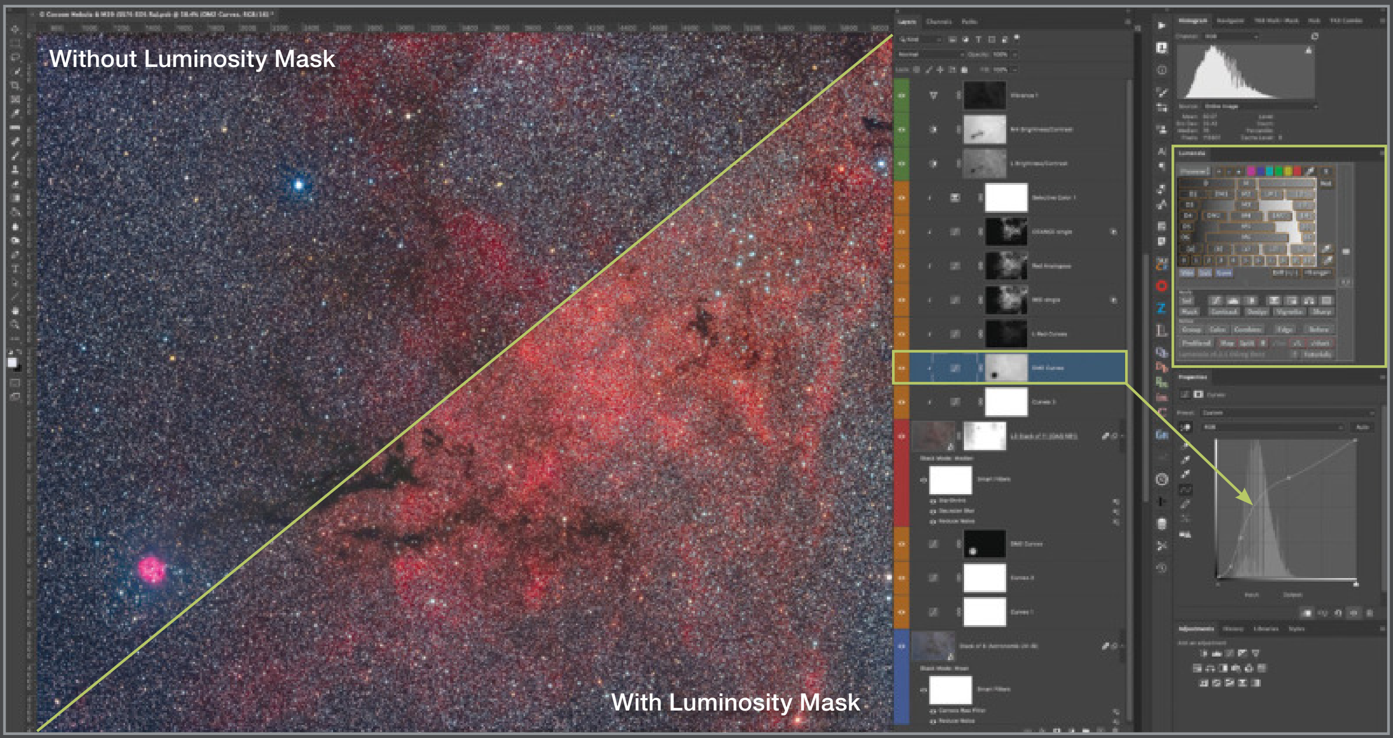
Inevitably, astrophotos contain flaws that need retouching. *Photoshop*'s Spot Healing Brush can do a great job, but don't apply it directly to your picture. In fact, if that layer is a smart object, you can't retouch it directly because it's protected.

Instead, add an empty layer (Layer > New > Layer) at the top of the stack. With Content-Aware and Sample All Layers checked in the toolbar, use the Healing Brush or Patch tools to cover up dust spots and other blights and blemishes with image content cloned from nearby.

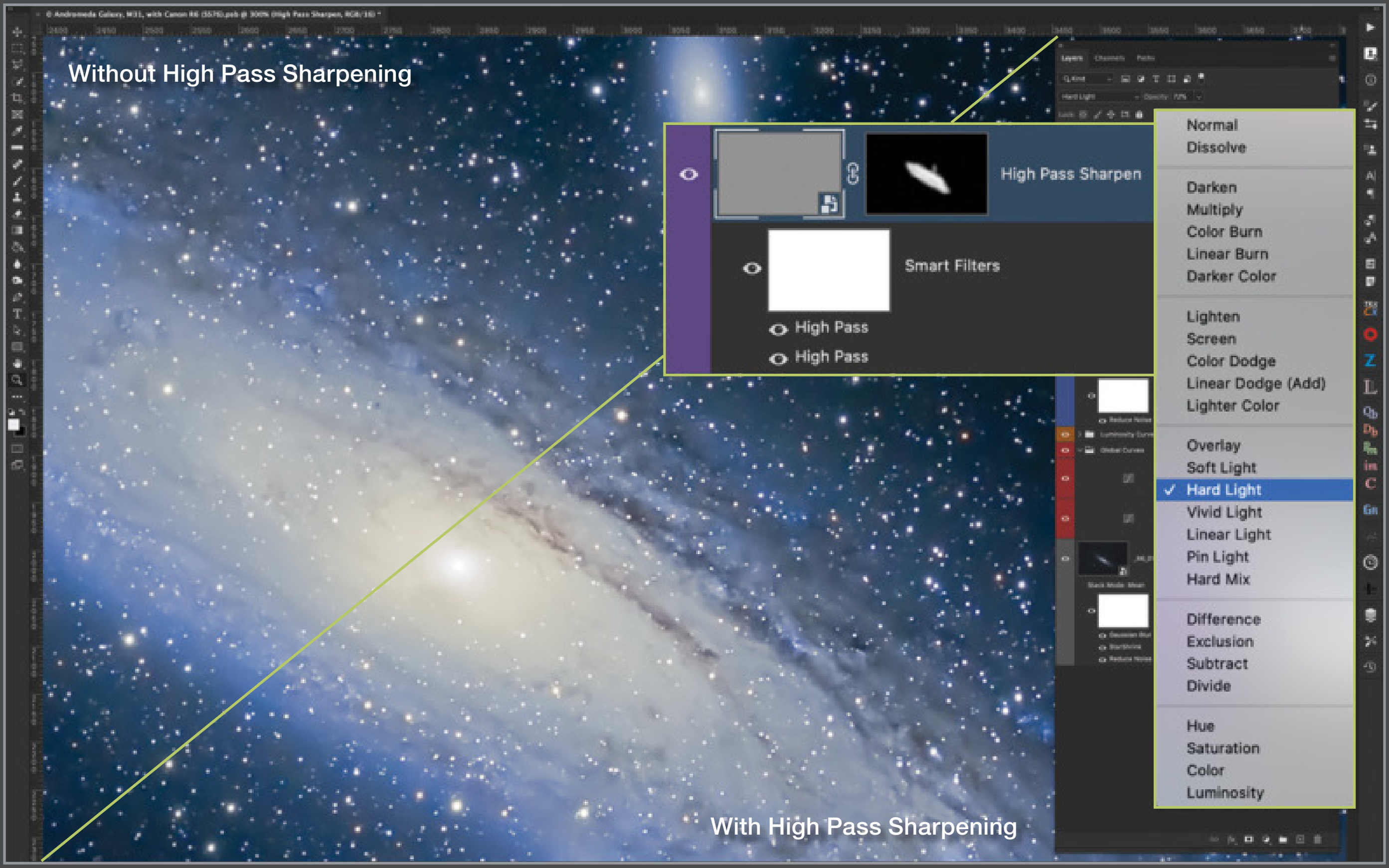
#10: Keyword and Catalog Your Images

As a final step in *Photoshop*, I always go into the image's metadata under File > File Info to fill in the Document Title, Author, and Copyright Status information. In the Description box I suggest also writing a caption, listing how the photo was shot, as a reminder to you, if no one else.

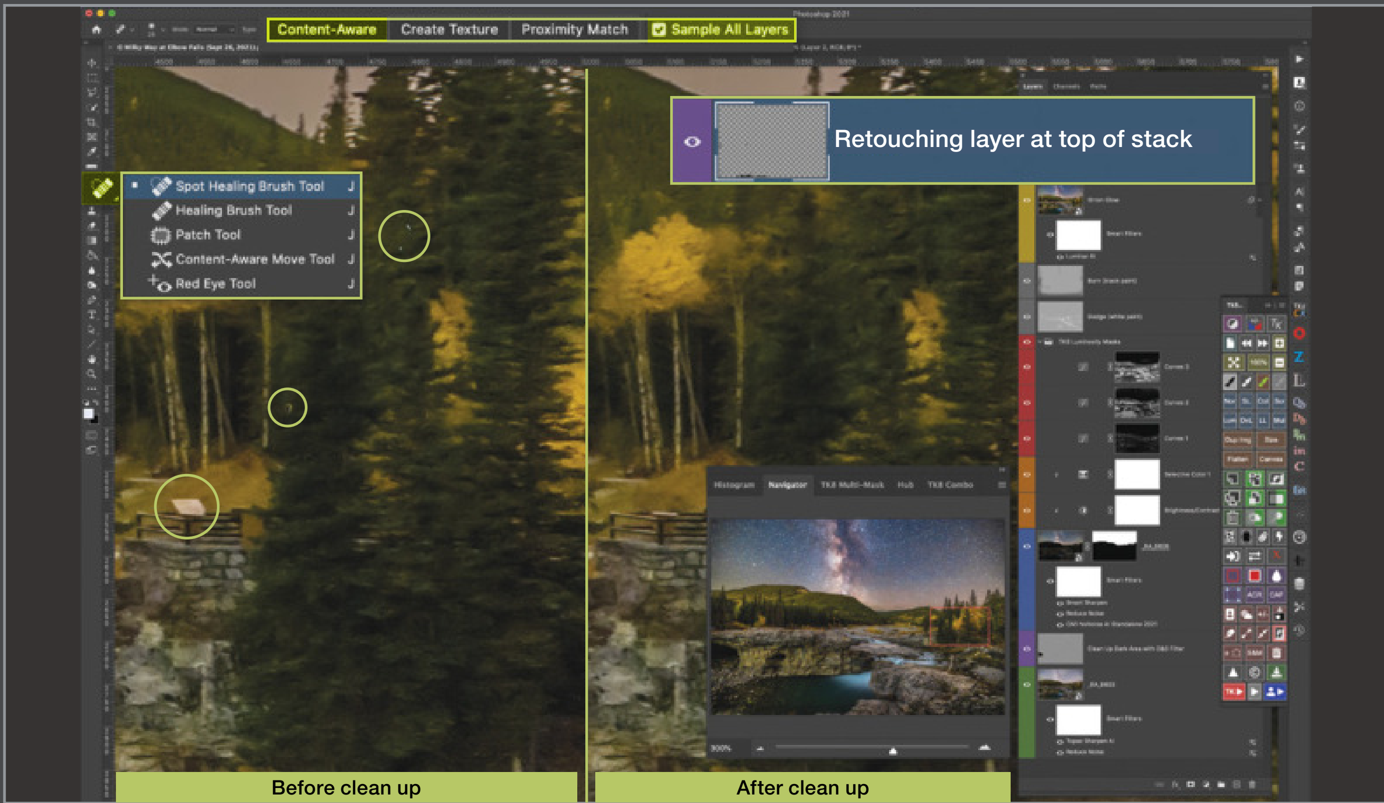
Be sure to also add information in the Keywords area. I'd suggest including the object name and catalog numbers,



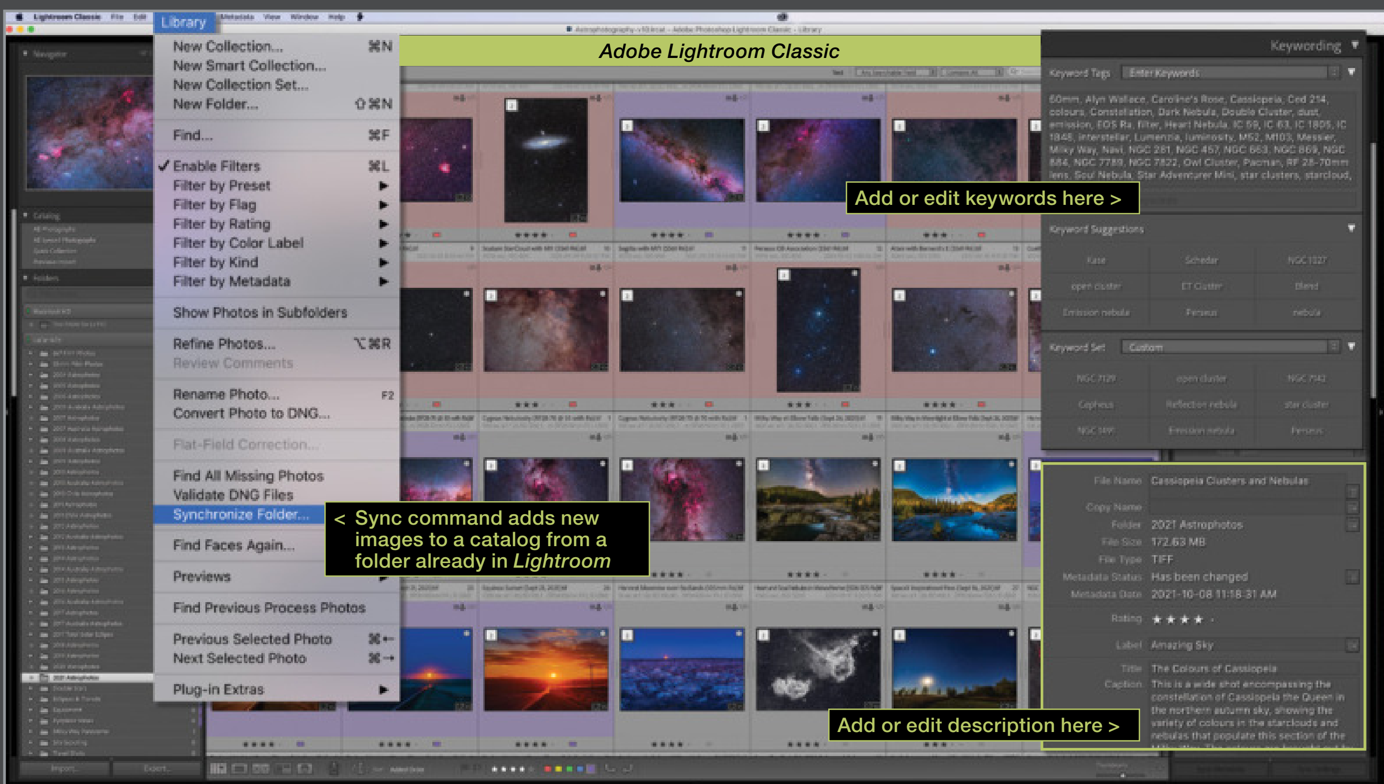
▲ **LUMINOSITY MASK PLUG-IN** *Lumenzia's* DM1 and DM2 masks select a range of tones from mids to darks — superb for bringing out faint nebulosity. This shows the difference a DM2 mask made with a single Curves layer applied to an image stack recorded through a narrowband filter.



▲ **NON-DESTRUCTIVE SHARPENING** Every aspect of a sharpening layer is editable: the size of the High Pass radius (two filters are applied here), the Blend Mode (changing the aggressiveness), the layer Opacity (affecting the strength), and the mask that controls where it applies.



▲ **CONTENT-AWARE CLONING** By confining retouching to a separate layer, you can edit or delete changes later if needed without altering or erasing the underlying pixels. This shows the *TK8 Cx* extension panel (right), with many functions useful for editing nightscape photos.



▲ **A FINAL STEP — CATALOGING** Using a digital asset manager program such as *Adobe Lightroom* to catalog keyworded photos does away with having to search through file folders looking for a particular image, ending another bad habit.

the class of object, its constellation, the telescope, and also the camera and filters used to photograph it — any terms by which you and others might want to search for it. All those metadata carry through to gallery websites such as 500px, Flickr, PhotoShelter, and SmugMug, though not to the popular AstroBin, nor to Facebook or Instagram.

Next, use Adobe's program *Lightroom Classic* (included with a *Photoshop* subscription) to add your pictures to its catalog by pointing *Lightroom* at the main drive and folders where you store your master photos, then importing them. Once *Lightroom* knows about a folder, to add images in the future just select Library > Synchronize Folder.

Lightroom makes it easy to search tens of thousands of files, or to create "smart collections" of photos automatically grouped by metadata values or the keywords you chose. If you don't wish to use *Lightroom*, then *ACDSee* or *Exposure X7* are good, low-cost alternatives.

By following these tips, you should be able to work smarter and save time by using *Photoshop* (and *Lightroom*) more easily and quickly to edit (and find!) your astronomical masterpieces.

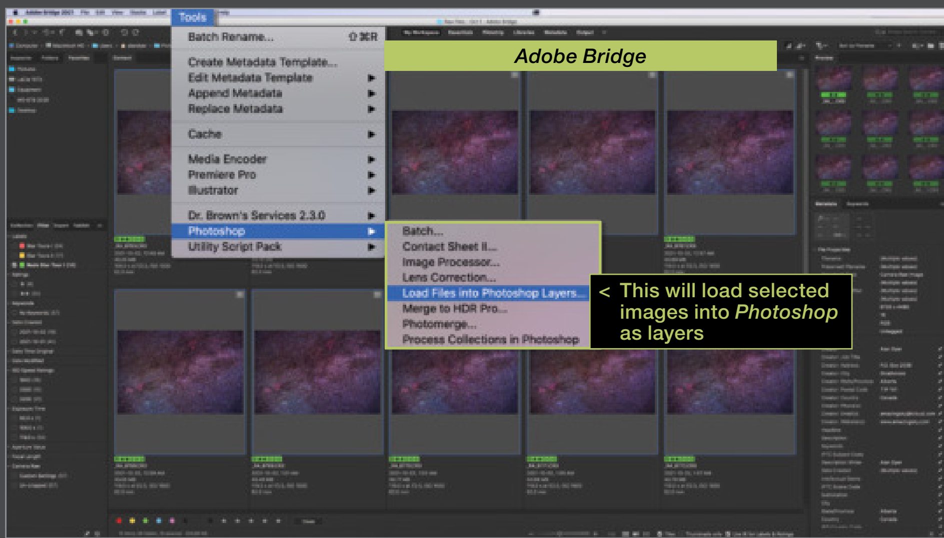
ALAN DYER is co-author with Terence Dickinson of the new fourth edition of *The Backyard Astronomer's Guide*. For more details, see **BackyardAstronomy.com**.

Can Photoshop Do That?

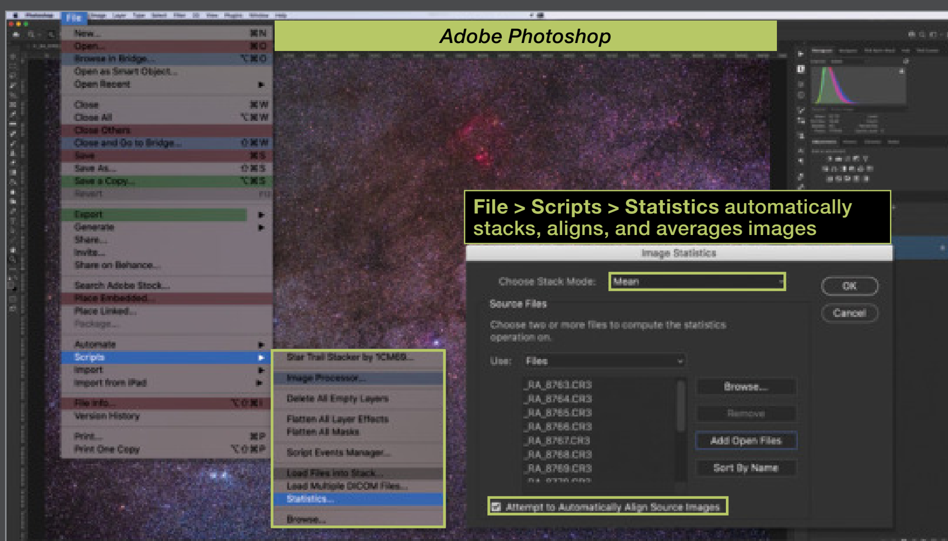
The usual practice for deep-sky image processing is to stack multiple exposures in order to reduce noise. Many photographers use a dedicated program for the task. But few realize that *Photoshop* can stack, align, and mathematically average photos, a function present since at least *CS6* from 2012, though only in the extended scientific edition. Starting in 2013, it's been included in all Creative Cloud versions of *Photoshop*.

The longhand way to stack images is to use *Adobe Bridge* to browse to and select the pictures, then choose **Tools > Photoshop > Load Files into Photoshop Layers**. After they load into *Photoshop*, select all the image layers and choose **Edit > Auto Align Layers**. Once aligned, select all the layers again and pack them into a smart object with **Layer > Smart Objects > Convert to Smart Object**.

Then go to **Layer > Smart Objects > Stack Mode** and choose either **Mean** (for the best noise reduction) or **Median** (to eliminate satellite trails). You can always change the stack mode later.



▲ **STARTING A STACK IN *BRIDGE*** The process begins in *Adobe Bridge*, an often underappreciated program included free with all versions of *Photoshop*. *Bridge* allows easy culling, labeling, rating, and transfer of sets of images over to *Photoshop*, in this case into a layered file.



▲ **SCRIPTED SHORTCUT** As an alternative, **File > Scripts > Statistics** will perform each stacking step automatically, using already open files (as here) or files selected from the dialog box. Choose Mean or Median. Then check the "Attempt to Automatically Align Source Images" box.

The PrimaLuceLab Eagle4 Pro

This ride-along imaging control station is much more than a tiny computer.

◀ In this photo, the PrimaLuceLab Eagle4 Pro appears mounted on the underside of a telescope, with its management app open on the author's iPad.

ALL IMAGES COURTESY OF THE AUTHOR

PrimaLuceLab Eagle4 Pro

U.S. Price: $2,195
primalucelabusa.com

What We Like

Reliable wireless remote control of astrophotography

Powers most every peripheral device

Small and sturdy

What We Don't Like

Requires many custom power cables

YEARS AGO, the only cable attached to an astro-camera was a shutter release cable. These days, astrophotographers typically deal with a bundle of USB cords leading from a computer to a cooled astronomy camera, filter wheel, autoguider, electric focus motor, a Go To mount, and maybe a dew controller or two. And that's not counting the wires needed to power many of these devices. Modern astrophotography makes most imagers "cable challenged," and I count myself among them.

But what if the imaging computer, power hub, and USB hub rode on the telescope, just like a finderscope? That would mean a single cable could power the whole works.

This is the idea behind the Eagle imaging control stations. The Eagle4 Pro is the flagship of four ride-along units offered by PrimaLuceLab of Italy. It's a rugged, compact computer with enough USB ports, power outlets, and mounting options to reduce most any messy run of cables. And everything attached to it can then be controlled with a single smartphone, tablet, or other remote computer. The company offers three other Eagle models for those with fewer devices to control.

Small but Mighty

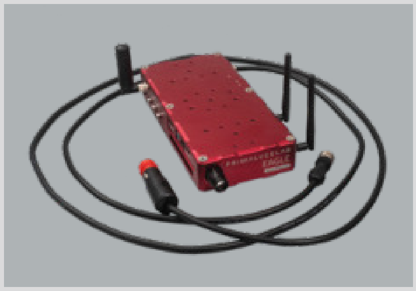
The Eagle4 Pro is housed in a red-anodized machined aluminum case with an array of mounting holes on the top and bottom. It features an Intel Quad Core i5 processor, 16 gigabytes of RAM, and a 480GB solid-state (SSD) hard drive. It has four USB 2.0 ports, four USB 3.0 ports, and a USB-C Thunderbolt 3 port. Additionally, there are seven 12-volt power-out sockets of three varieties.

The computer itself has no monitor, mouse, or keyboard (though you can add your own); instead, users with Apple or Android smart devices can connect to it via Wi-Fi. There is also an Ethernet port for a wired connection to a Mac or PC computer, or even straight into a router.

The Eagle4 Pro comes with a cigarette-lighter-style DC power cable and a bag of metric screws of various lengths and threads to facilitate mounting the unit. Cables to supply power to your accessories are purchased separately.

The online user manual states that the computer requires a regulated power supply, preferably one that provides 12.8 volts DC. The power supply must also provide sufficient current for all accessories plugged into the device. Following the very specific instructions in the manual, I powered our test unit with a regulated benchtop power supply. PrimaLuceLab offers a 12.8-volt, 14-amp AC to DC power supply for $185.

Built into the unit are two "Eagle Eye"



▲ PrimaLuceLab's Eagle4 Pro is the company's top-of-the-line imaging control station. The unit comes with a heavy 12-volt power cable with a standard cigarette-lighter plug and a bag containing lots of metric-threaded mounting screws (not shown).

▲ This side shows the "Eagle Eye" darkness sensor at left that measures sky brightness and alerts users when it's dark enough to begin imaging. Also shown are the four high-amperage 12-volt sockets described in the text. Each connection can be switched off and on remotely.

▲ The device is fitted with numerous connection ports. This side view shows its array of two USB 3.0 and four USB 2.0 ports as well as its two Wi-Fi antennae. The main power input connection is visible at right.

light sensors. Located at both ends of the casing, these measure the sky brightness to determine when it's dark enough to begin imaging. You can mount the sensor's objective lens at either end of the unit to ensure it's facing skyward, but be sure to activate the correct one in the *EAGLE Manager* program that comes preinstalled on the device.

Before mounting the device on your telescope, you first need to install your accessory drivers and control software. I accomplished this by simply plugging in a USB keyboard and mouse to the unit and a monitor into one of the HDMI sockets. In this configuration it operates just like a desktop computer. I used its Wi-Fi to connect to my home network, then downloaded and installed most all of the required software for my imaging gear and transferred a few additional programs with a flash drive.

I then plugged in all my accessories to the Eagle4 Pro to ensure all were operating properly before finally installing the device on my telescope.

After installing all my control software, there was just under 300 GB of free space remaining on the hard drive to store images. This is more than enough for a night of deep-sky imaging, but the large video clips used in lunar and planetary imaging easily fill the remaining drive space.

Mounting Up

The next step is to decide exactly where on your scope or mount the Eagle4 Pro will reside. Most any mounting configuration is made easy by the 23 metric-threaded mounting holes on its top surface and 31 on its underside. The included assortment of metric screws of various lengths ensure you'll be able to secure the computer close to the accessories it will control. PrimaLuceLab also offers a range of optional mounting clamps in matching red anodizing to connect to Losmandy- and Vixen-style dovetail bars.

The device measures 11.1 cm wide by 22.9 cm long and 3.8 cm thick (4⅜″ by 9″ by 1½″), allowing users to afix it most anywhere on a telescope or mount — even sandwiched between the main optical tube assembly and its finder or guidescope. The unit weighs just 1¼ kilograms (2 pounds, 12 ounces), which most modern telescope mounts should easily handle.

▲ *Left:* On the opposite side of the Wi-Fi antennae is the GPS antenna and its three 12-volt RCA accessory ports. Users can vary the voltage going to each port remotely, eliminating the need for an additional dew controller. Below the GPS is the main power switch and a reset button used to reboot the Wi-Fi connection if necessary. *Right:* This side of the device includes two HDMI ports as well as a high-speed USB-C Thunderbolt 3 port at lower left, two USB 3.0 sockets, and the Ethernet jack to hardwire the device to the internet for remote operation.

During my tests with several telescope and mount combinations, I was always able find a suitable spot to attach the device that didn't tug any wires as the scopes slewed around the sky.

Power Provisions

Not only is the Eagle4 Pro a tiny computer, it's also a robust power management system that includes seven electrical ports for various accessories, including focuser, camera rotator, imaging and guiding cameras, and dew heaters. Four of these ports have heavy-duty connectors located on one end of the housing. Two ports provide up to 8 amps and utilize custom female sockets, while the other two deliver up to 3 amps and accept male-threaded power connectors.

The cables that screw onto these four power outlets aren't included with the device. PrimaLuceLab offers a wide selection of suitable cables to fit a range of accessories and several popular digital camera bodies, priced from $39 to $89 each. You may need to spend some time on the company's website choosing which specific cables you need for your accessories.

Three additional power outlets on the long side of the housing are the familiar RCA-type sockets often found on dew-heater straps. The Eagle4 Pro control panel lets you vary the voltage sent to these dew-prevention ports, eliminating the need for a separate dew controller. Theses sockets can provide a maximum of 3 amps total.

▲ The Eagle4 Pro is shown mounted underneath the author's 8-inch Celestron RASA telescope. The unit powers the camera's thermo-electric cooling, two dew heaters, in addition to the imaging and autoguiding cameras. The author used ZWOptical's *ASILive* camera control to script imaging sequences in the background.

Untethered Control

PrimaLuceLab recommends using the free *Microsoft Remote Desktop* app to communicate with the Eagle4 Pro with Apple and Android devices, as well as with Apple and PC computers. However, newer tablets and smart devices are recommended. My decade-old iPad wouldn't accept the app, but a 6th-generation model installed it without issues.

The devices' extensive manual provides detailed instructions for each type of device connecting wirelessly to the device. There's also a thorough troubleshooting section, which helped me through an initial connection problem I experienced manually entering the unit's IP address.

To connect to the Eagle4 Pro after installing the app on your device, open the network settings and select the Eagle4 network. Then open *Microsoft Remote Desktop* and follow the onscreen instructions. I found that my iPad instantly connects when I launch the app, as long as I kept it as the default network in its Wi-Fi settings.

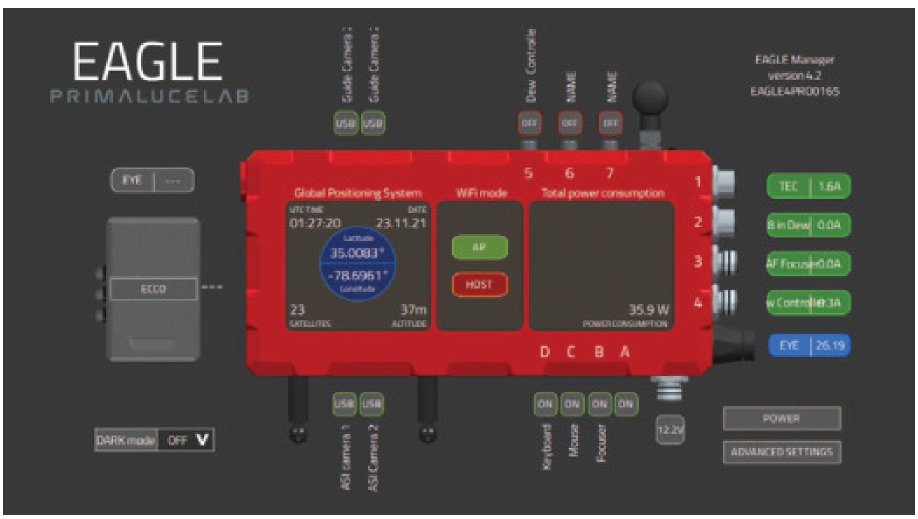
In the device's Windows 10 interface, right-clicking on the task bar at the bottom of the screen opens a dialog box with an option to "show desktop". After that point, it's just like operating a Windows operating system. On an iPad, use the onscreen keyboard and touch the "alt gr" and "tab" keys to toggle between the screens of your various device control programs. After the initial setup, you don't have to learn any complex new software to get up and running.

Because the Eagle4 Pro is a full Windows 10 computer, it isn't limited to controlling devices from a particular manufacturer. If there are PC-compatible software and drivers for your equipment, the computer can handle it.

Using the iPad, I could create folders on the Eagle4 Pro's hard drive to store image sequences and operate my capture and guiding software just like I could using a computer hardwired to the telescope. Connecting to it with my observatory desktop PC proved just as reliable.

The *EAGLE Manager* mentioned earlier is very simple and intuitive. I could activate and power up all my connected devices from the iPad screen and customize the names of each port. The program displays the status of each port, total power consumption, and other information provided by the GPS link.

The Eagle4 Pro's Wi-Fi range proved far-reaching. I had no problems controlling it from the downstairs room in



◀ The *EAGLE Manager* program provides control over each individual port on the device. The window at left displays the GPS-derived position of the observing site, which is updated automatically each time Eagle4 Pro is activated. The space at the right tracks the total power consumption. Clicking the "DARK mode" switch at lower left disables the lights on the device.

my observatory with one floor between my iPad and the device. I could wander about 23 meters (75 feet) away outside and retain a reliable connection. I only began encountering slow connection issues when I was inside my house and some 45 meters from the scope.

I filled most of the ports on the Eagle4 Pro when using the unit with my portable imaging setup. With a single power cable attached to the device, it provided electricity to the mount, two dew heaters (one for the imaging scope and another for a guidescope), the internal cooling fan on the main scope, and the thermoelectric cooler for my ZWO camera. The imaging camera and guide camera filled two USB ports. The ability to remotely switch off and on every port and vary the power going to the dew heaters is particularly handy as conditions change throughout the night.

In addition to deep-sky imaging, I often used the device for lunar and planetary imaging. The device's computer didn't lag when recording hundreds of video clips, all the while powering my equipment, though I filled the hard drive more than once per imaging session. To alleviate this minor inconvenience, I plugged an external 1-terabyte drive into one of the USB 3.0 ports and recorded videos directly to it.

▲ The fast writing speed of the Eagle4 Pro's solid-state hard drive made recording this scene of Mare Frigoris and the crater Plato a snap. The author used the Player One Astronomy Neptune-II camera reviewed in last month's issue at prime focus on a Meade 14-inch ACF telescope.

The Bottom Line

It's tough to appreciate the conveniences of a telescope control system like the Eagle4 Pro until you actually use one. With any imaging setup, the device is an immense space saver that shortens and consolidates all your electrical cords. And by moving the computer to a mountable box that you can control with a device that's likely in your pocket, it eliminates another cord to trip over in the dark.

For folks who regularly use cameras to collect photons on most clear, dark nights, the Eagle4 Pro offers outstanding performance, control, and convenience when using most any modern imaging devices. It can take a lot of the frustration out a night of imaging.

■ Contributing Editor **JOHNNY HORNE** is always interested in looking at products that make astronomy easier.

▼ *Left:* The Pleiades, M45, recorded with the Eagle4 Pro riding underneath the author's Celestron RASA 8 telescope seen on the facing page. *Right:* As with the image of M45, the device controlled all the equipment used to capture this image of NGC 1973, 1975, and 1977, collectively known as the Running Man Nebula. Twenty 180-second exposures were combined for this view shot through an 8-inch Astrotech Ritchey-Chretien working at f/5.3.

▲ QUINTUPLET ASTROGRAPH

Sharpstar Optics announces a new addition to its Askar line of apochromatic refractor astrographs. The Askar FRA500 Quintuplet Petzval Flat-Field Astrograph ($1,999) is a 90-mm f/5.6 refractor that incorporates a five-element objective lens with two elements made from extra-low-dispersion glass. The Petzval design produces a 55-mm image circle with 15.8 cm of back focus to accommodate most deep-sky cameras and filter wheels on the market today. The scope features a dual-speed, 3½-inch focuser to prevent vignetting. The optical tube weighs 5.2 kilograms (11½ lbs) and measures 45 centimeters (17.8 inches) long with its dew shield extended, 41 cm with it retracted. The Askar FRA500 comes with aluminum tube rings, a Losmandy D-style dovetail plate, a removable finderscope mounting shoe, and a four-piece conical extension tube.

Sharpstar Optics
Available in North America at Agena Astro
562-215-4473; agenaastro.com

▲ PORTABLE POWER

Explore Scientific now offers a compact power supply for observers. The Explore Scientific USB Power Bank with Red LED Flashlight ($139.99) is a rechargeable Lithium-Ion battery pack that produces 12 volts at 6 amps. It can power most telescope mounts and accessories through its barrel-style power port, and 5V at 2 amps via a USB power port. This small, rubber-armored power brick measures 5 × 9 × 16 centimeters (2 × 3.5 × 6.2 inches) and weights 0.6 kilograms (1.4 lb) and incorporates a handy red LED flashlight. The device can operate in temperatures between -4° to 140° Fahrenheit, and a 5-level indicator displays its state of charge. The power bank includes a male-to-male, barrel-style cord with 5.5 mm × 2.5 mm and 5.5 mm × 2.1 mm connectors, and an AC wall charger.

Explore Scientific
1010 S. 48th St., Springdale, AR 72762
866-252-3811; explorescientific.com

◀ PHOTOGRAPHIC NEWTONIAN

Orion Telescopes & Binoculars adds a new model to its series of astrograph reflectors. The Orion 8″ f/4 Newtonian Reflector ($699.99) features a 200-mm parabolic primary mirror made of low-thermal-expansion BK7 glass and sporting enhanced-aluminum coatings. The optical tube is 71 cm long (28 inches) and weighs 7¼ kilograms (16 lbs). The primary mirror cell incorporates a 12-volt cooling fan to reduce the time needed for the optics to reach thermal equilibrium. Also included are a 2-inch, dual-speed focuser with 2-inch extension, an 8 x 50 finderscope with quick-release mounting bracket, a pair of tube rings, a Vixen-style dovetail mounting bar, and a quick-collimation cap. An optional Baader MPCC Mark III coma corrector ($259.99) is recommended for optimal performance.

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

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Make a Laser-Finder Mount

Some finders are a pain in the back. Not this one.

▲ Laser finders are simple but effective.

ALL IMAGES COURTESY OF THE AUTHOR

NOT LONG AFTER I started doing astronomy, I wound up with back pain bad enough to send me to the doctor. It didn't take long to pinpoint the cause: bending my body to look into the finder on my equatorially mounted Newtonian scope. If you've got a German equatorial mount, you know what I'm talking about — the finder can wind up in some really awkward positions. Even a Dobsonian can require some contortions to reach the finder, which has led to many a backache in the morning.

Not long after I noticed the problem, I saw someone using a green laser to point out the constellations to someone else, and the answer was immediately obvious: Mount a laser to my scope and use it as a finder.

Laser finders are pretty common these days. Trouble is, the mount costs almost as much as the laser! You can blow a Benjamin on the whole setup, and that's a shame when you consider you can make the mount yourself for about five bucks.

How do you do it? Easy-peasy. Or should I say easy-PVC? Get a piece of PVC pipe that will hold the laser with some wiggle room for alignment. I make mine a couple inches shorter than the laser, but its length isn't critical. Cut a notch in the pipe so you can reach the "on" switch. Make the notch big and wide so you can get your cold index finger in there easily. If you wrap some sandpaper around another length of the same pipe and run it back and forth crosswise, you can sand a very nice-looking oval window.

Get six plastic screws (10 × 24 or 10 × 32 work well). Drill holes and tap threads for them at 120° intervals. Here's a neat trick: Stop tapping the threads before they're completely cut so the screws will remain snug in their holes. You can finesse this with quarter-turn advances of the tap until you get it just right, and it's worth the trouble. A snug screw won't back out. You want the screws loose enough to turn by hand, though, so you can adjust them in the field without tools.

For extra credit (and peace of mind), drill two holes near the back and run a thick string through so your laser's pocket clip will go over the string. That will keep the laser from falling out even if the screws do loosen in the night.

If your scope has a dovetail finder mount, put a dovetail on the bottom of your pipe. I stand mine off by an inch or so with a small block of wood to raise the finder above the secondary cage a bit, making it easier to reach. If you don't have a dovetail mount, consider making one. That way you can move the finder from scope to scope.

Important note: The commercially produced dovetails you find on many scopes are designed backwards. They load from the bottom, and the only thing keeping the finder from falling out is the clamping screw. Design yours better: Make it load from the front and put a stop on it so it can't slide all the way through. That way if the clamp screw loosens, your finder just loses its aim but doesn't fall out.

That's pretty much it. Paint it if you want. If you re-sand the finger hole after you paint it, you'll get a beautiful white ring around the "on" switch so you can quickly find it in the dark. (University of Oregon fans will recognize that "O.")

And now a word about laser etiquette: Have some. Green lasers have gotten a bad reputation in many circles, and for good reason. It only takes one inconsid-

▲ The laser's clip goes over the string, providing extra security in case the screws loosen in the night.

▲ You can make both halves of the dovetail mount at home. Be sure that the foot slides into the shoe from the front.

erate doofus to spoil a star party. Don't be that doofus. If you're in a group of people, don't go flashing your laser all around the sky. If someone is photographing nearby, make sure you don't laser-bomb their photo. Don't use an insanely bright laser. (Five milliwatts is plenty — and that's the legal limit in the U.S. anyway.) Don't shine it even close to anyone's head, or at any airplanes.

It should only take you a few brief flashes to zero in on your target. Used properly, a laser finder can be unobtrusive and extremely useful. And it can save you a lot of back pain.

■ Contributing Editor **JERRY OLTION** remembers when lasers were invented, and some wag called them "a solution in search of a problem." Contact Jerry at **j.oltion@gmail.com**.

ECLIPSE PEEK

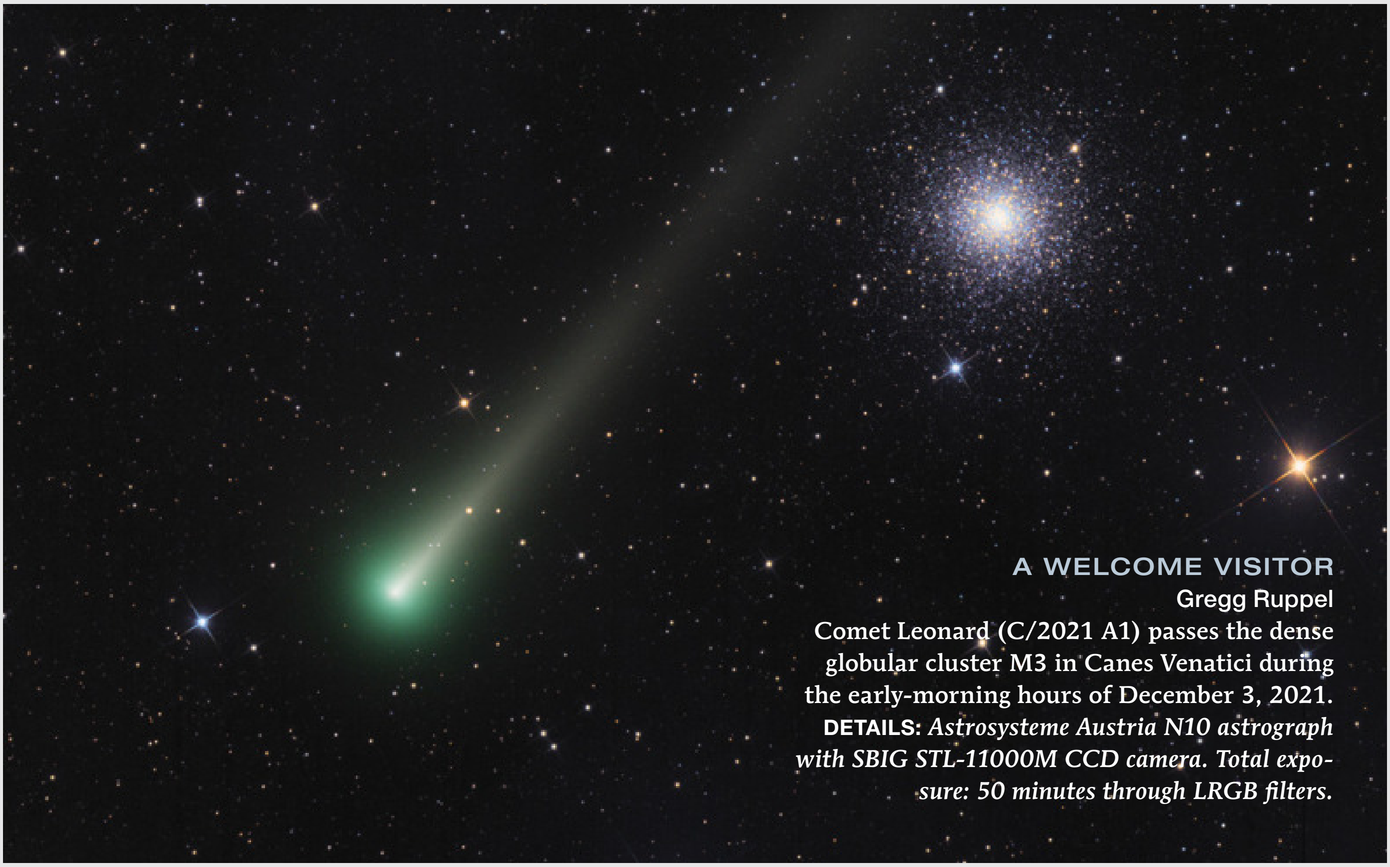
Amir Shahcheraghian

The partial lunar eclipse of November 19, 2021, slowly dims as the Moon edges deeper into Earth's shadow above the Sailor's Memorial Clock in Montreal, Quebec.

DETAILS: *Canon EOS 6D DSLR camera with 15-to-30-mm Tamron lens. Composite of 200 1-second exposures recorded at f/3.2, ISO 500.*

△ DISTANT SUPERNOVA
Dan Crowson
The bluish supernova SN 2021aefx appears to the lower right of the center of the spiral galaxy NGC 1566 in the southern constellation Dorado.
DETAILS: *PlaneWave CDK24 Corrected Dall-Kirkham telescope with FLI PL9000 CCD camera. Total exposure: 4 hours through LRGB filters.*

△ SILVER DOLLAR GALAXY
Gerald Rhemann
NGC 253 in Sculptor is a strong example of the so-called Sc class of spiral galaxies due to its small nucleus and dusty, loosely wound arms.
DETAILS: *Astrosysteme Austria ASA N12 astrograph with ZWO ASI6200MM Pro CMOS camera. Total exposure: 3 hours through LRGB filters.*



A WELCOME VISITOR
Gregg Ruppel
Comet Leonard (C/2021 A1) passes the dense globular cluster M3 in Canes Venatici during the early-morning hours of December 3, 2021.
DETAILS: *Astrosysteme Austria N10 astrograph with SBIG STL-11000M CCD camera. Total exposure: 50 minutes through LRGB filters.*

▷ UMBRAL COLORS

Damien Cannane

By combining several exposures of varying duration, Damien Cannane emphasized the subtle orange, yellow, and bluish hues of Earth's shadow cast on the Moon during the deep partial lunar eclipse of November 19, 2021.

DETAILS: *Celestron 8-inch Rowe-Ackermann Schmidt Astrograph with ZWO ASI183MC Pro CMOS camera. Stack of 90 bracketed exposures.*

▽ A NICE PAIRING

Mark Killion

This image frames last November's eclipsed Moon with the nearby Pleiades, M45. Killion processed the image with special care to duplicate the naked-eye appearance of the event when the Moon was deepest in Earth's shadow.

DETAILS: *Canon EOS Ra camera with Rokinon 135-mm f/2 lens at f/4. Total exposure: Composite stack of 30 images recorded at ISO 200.*

THE DARK TOWER

Gerald Rhemann

Intense ultraviolet radiation from nearby hot, young stars shapes this immense cometary globule silhouetted against the crowded star fields of Scorpius. North is to the right.

DETAILS: *Astrosysteme Austria N12 astrograph with ZWO ASI6200MM Pro CMOS camera. Total exposure: 4 hours through LRGB filters.*

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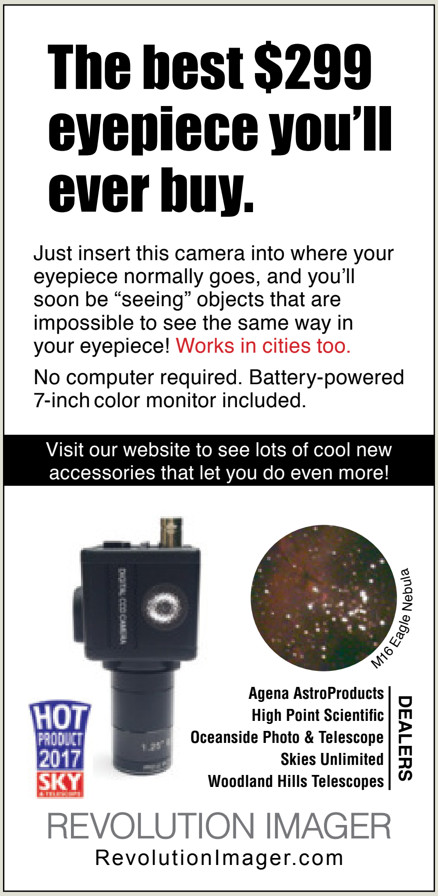

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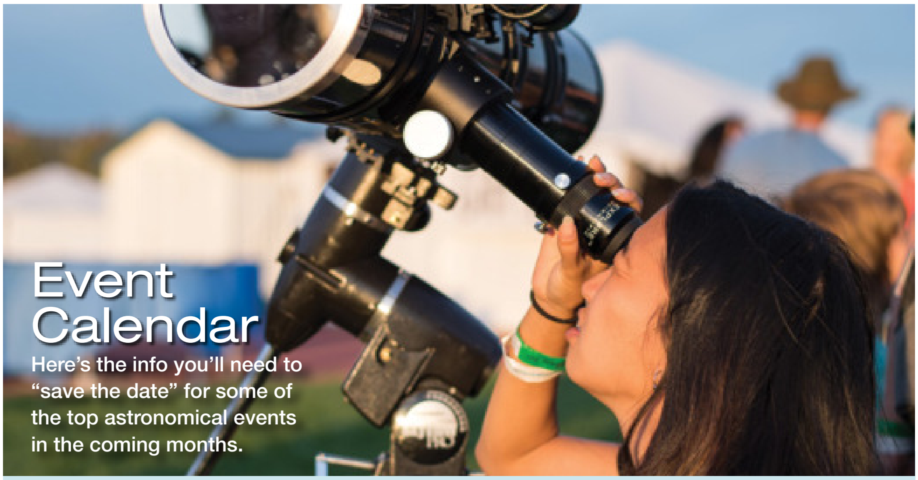

Event Calendar

Here's the info you'll need to "save the date" for some of the top astronomical events in the coming months.

January 31–February 6
WINTER STAR PARTY
Scout Key, FL
scas.org/winter-star-party/?y=2022

March 4–5
TRIAD STARFEST
Jamestown, NC
https://is.gd/tristar

April
GLOBAL ASTRONOMY MONTH
Everywhere!
https://is.gd/astrowithnoborders

April 9–10
NORTHEAST ASTRONOMY FORUM
Suffern, NY
neafexpo.com

April 22–30
INTERNATIONAL DARK SKY WEEK
Everywhere!
idsw.darksky.org

April 24–May 1
TEXAS STAR PARTY
Fort Davis, TX
texasstarparty.org

April 27–30
MIDSOUTH STAR GAZE
French Camp, MS
rainwaterobservatory.org/events

May 7
ASTRONOMY DAY
Everywhere!
https://is.gd/AstronomyDay

June 2–5
CHERRY SPRINGS STAR PARTY
Cherry Springs State Park, PA
cherrysprings.org

June 18–25
GRAND CANYON STAR PARTY
Grand Canyon, AZ
https://is.gd/GCSP2022

June 22–25
BRYCE CANYON ASTRO FESTIVAL
Bryce Canyon National Park, UT
https://is.gd/brca_astrofest

June 22–26
ROCKY MOUNTAIN STAR STARE
Gardner, CO
rmss.org

June 23–26
WISCONSIN OBSERVERS WEEKEND
Hartman Creek State Park, WI
https://is.gd/WIObserversWeekend

July 22–31
SUMMER STAR PARTY
Plainfield, MA
rocklandastronomy.com/ssp.html

July 24–29
NEBRASKA STAR PARTY
Valentine, NE
nebraskastarparty.org

July 26–31
TABLE MOUNTAIN STAR PARTY
Oroville, WA
tmspa.com

• For a more complete listing, visit https://is.gd/star_parties.

NASA / AUBREY GEMIGNANI

Let's Dance

Encountering old friends high overhead

THE BEST NIGHT of stargazing I've ever had was at a Boy Scout ranch in central Iowa when I was about 13 years old. It was a frigid weekend in January. The daytime high was only a few degrees above zero Fahrenheit, and the temperature dropped precipitously lower as the Sun set below a cloudless horizon — a rarity for a region more familiar in winter with overcast, gunmetal-grey skies.

My dad and I ventured out of our warm cabin not long after dinner. A short drive brought us to an isolated parking area next to a frozen lake, where we bundled up against the cold, loaded up on hand warmers, and set up a 10-inch Dobsonian atop a thin layer of snow. The chilled air left the atmosphere perfectly still, while low, forested hills blocked any nearby light sources. In short, it was an ideal night for astronomy.

With rapidly numbing fingers and toes we excitedly pointed our scope at the sky. The first object I remember observing was the Crab Nebula, M1. I'd searched fruitlessly for it from the light-polluted skies of my backyard in Omaha, Nebraska, so I was amazed this time when it instantly popped into the eyepiece. Even more mesmerizing was the Orion Nebula, M42, filling the eyepiece with intricate wisps and tendrils extending into ever more complexity and beauty.

Astronomy was frequently a part of other scouting trips, too. One of the adults in the troop, a Mr. Cinnamon, had a particular fondness for the hobby. On a rather more comfortable spring outing, I recall him reclining in a camp chair, pointing his binoculars straight up to look at the Pleiades, M45, and saying to no one in particular, "Hey there, ladies. Let's dance!"

It wasn't until another camping trip years later, this time as an adult during the COVID-19 pandemic, that I really began to understand what Mr. Cinnamon meant. With cases on the rise over Thanksgiving 2020, I left Los Angeles with my fiancée Kirsten for a camping trip in the California desert. Instead of the hills and plains of the Midwest that I'd enjoyed as a kid, we camped between an ancient lakebed and jagged mountain peaks, on ground covered in desert sage, cacti, and other chapparal plants.

A chill was in the air as the Sun set behind the western mountain range, and I donned extra layers while Kirsten retired to our tent. The overnight temperature would fall close to the freezing point that night.

As the sky darkened, I began to recognize many of the same celestial objects I'd first met decades ago. It's easy to feel lonely after months of lockdowns and extended time away from family and friends. But I realized that night in the desert that, once again, I was surrounded by my oldest companions.

> At the end of the night, I went dancing with the ladies one last time.

I spent time with Luna before she set in the west and said hello to Saturn and Jupiter. I went on the hunt with Orion, caught up with Cassiopeia, and listened to Lyra's beautifully silent music. At the end of the night, I went dancing with the ladies one last time and then clambered into the tent and contentedly dropped off to sleep.

■ **EVAN HILGEMANN** is a mechanical engineer at NASA's Jet Propulsion Laboratory and a telescope operator at Griffith Observatory, but he still thinks of himself as from Omaha, NE. He writes regularly on the exploration of Earth and space at **exploreandobserve.com**.

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Milky Way Image by Tony Hallas

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