DEEP-SKY WONDERS: The Plowman's Galaxies
PAGE 54

STELLAR ARCHAEOLOGY: The First Stars
PAGE 58

TEST REPORT: The Explore FirstLight Dob
PAGE 30

SKY & TELESCOPE

THE ESSENTIAL GUIDE TO ASTRONOMY

JUNE 2020

CHINA

The Next Space Power?

Page 34

skyandtelescope.org

Hop Around the Pinwheel Galaxy
Page 14

Treasures of the Sharpless Catalog
Page 22

CONTENTS

SKY&TELESCOPE
THE ESSENTIAL GUIDE TO ASTRONOMY


June 2020 VOL. 139, NO. 6

22

RON BRECHER

FEATURES

14 A Galaxy-Hop Around M101
Join the author as he explores the Pinwheel Galaxy and surrounding objects. *By Alan Whitman*

22 Treasures of the Sharpless Catalog
Sample some of the delights in the first comprehensive catalog of nebulae. *By Ron Brecher*

Cover Story:

34 China Launches to Center Stage
A bold series of successful and proposed missions are catapulting China to prominence in space. *By Andrew Jones*

58 Stellar Archaeology
Astronomers are illuminating the universe's early days by studying chemical patterns in the oldest stars. *By Brian Ventrudo*

66 Exploring the Deep Sky with Video
With a little tech, you can see farther *and* share the view. *By Rod Mollise*

OBSERVING

41 June's Sky at a Glance
By Diana Hannikainen

42 Lunar Almanac & Sky Chart

43 Binocular Highlight
By Mathew Wedel

44 Planetary Almanac

45 Under the Stars
By Fred Schaaf

46 Sun, Moon & Planets
By Fred Schaaf

48 Celestial Calendar
By Bob King

52 Exploring the Moon
By Charles A. Wood

54 Deep-Sky Wonders
By Sue French

S&T TEST REPORT

30 Explore Scientific's FirstLight 8-inch Dobsonian
By Ken Hewitt-White

COLUMNS / DEPARTMENTS

4 Spectrum
By Peter Tyson

6 From Our Readers

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

8 News Notes

57 Books by *S&T* Authors

71 New Product Showcase

72 Astronomer's Workbench
By Jerry Oltion

74 Gallery

84 Focal Point
By Joe Ulowetz

ON THE COVER

China's Long March 5 rocket launches from Hainan Province.
PHOTO: JOHN SHI

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China's Dream

EVER SINCE THE MOON LANDINGS a half century ago, the U.S. has enjoyed preeminence in space exploration. It has sent probes to all planets in the solar system and placed robots on the surface of Mars eight times, among many other signal achievements.

Other space agencies besides NASA have accomplished great feats during that time as well, of course, most notably those of Russia, the European Union, and Japan. And in recent years, new spacefaring hopefuls have entered the arena, including India and the United Arab Emirates.

But one country arguably harbors aspirations to supplant all other nations, including the U.S., in the exploration and use of space: China. And some analysts believe it has the drive and the resources to do so. As Andrew Jones makes clear in his cover story on page 34, the Celestial Empire has plans for an impressive array of space missions through the 2020s and beyond.

The U.S. last put a man on the Moon in 1972. Since NASA retired the Space Shuttle in 2011, it has struggled to build its replacement spacecraft. It relies on Russia to send American astronauts to the International Space Station, or ISS (at more than $80 million a seat). Successive U.S. administrations have waffled in their space aims, pushing for the Moon, then Mars, then the Moon again.

The Chang'e 4 lander on the Moon's farside

CNSA / CLEP / DOUG ELLISON

China, meanwhile, appears to be dead-set on its chosen course. As stated in a November 2019 report to Congress by the U.S.-China Economic and Security Review Commission, the People's Republic has "a single-minded focus and national-level commitment to establishing itself as a global space leader." The report quotes President Xi as declaring that his country's "space dream" is to "explore the vast universe, develop aerospace enterprises, and build a strong aerospace country."

While it got a comparatively late start, China has rapidly caught up to other top spacefaring nations. In 2013, just 10 years after it launched into orbit its first taikonaut (yes, that's the term), China became only the third country to soft-land a spacecraft on the Moon. Last year, a second Chinese spacecraft, Chang'e 4, alighted on the Moon's farside — a first for any nation.

Accomplishing firsts seems to be central to China's strategy. The country plans to construct a Chinese space station even as the ISS ages, its future uncertain. If it succeeds with current proposals, the People's Republic might be the first nation to return a sample of Mars regolith to Earth and to erect a crewed research station on the Moon.

So which nation will predominate in space 50 years from now? It might just be China.

Peter
Editor in Chief

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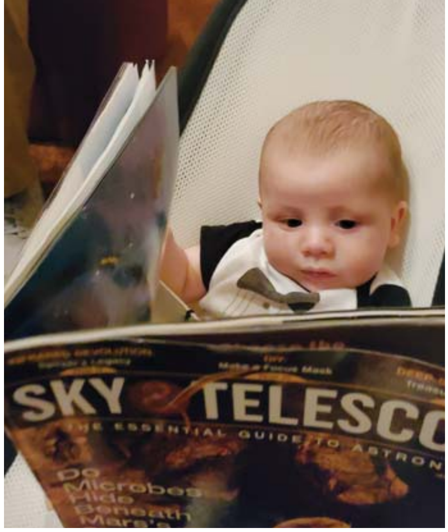
Young Astronomy

I want to thank you and the AAS for making *S&T* the premiere magazine for astronomy. I'd also like to introduce perhaps your youngest reader, Calvin, our grandson, who is 3 months old. It's never too early to get started in astronomy.

Paul L. Livio
Torrance, California



▶ Three-month-old Calvin has a gander at our January 2020 issue.

CALVIN AND PAUL LIVIO

Micro Martians

Thanks for the engaging article "The Martian Underground" (*S&T:* Jan. 2020, p. 34). It's likely that any life on Mars today can only survive deep underground and, as with subterranean organisms here, must be exceedingly diverse in respect to energy sources and metabolic adaptations. The most tantalizing question is whether it's DNA-, RNA-, and protein-based, like terrestrial life, or if it has an alternate biochemistry. If it is similar, that raises questions as to where it originated, and if it could be the result of past cross-contamination between the two planets. Conversely, if putative Martians exhibit significantly different biochemistries, it would imply that they originated independently. Either way, the answers would have profound implications as to how and where life originated and how common it is in the universe.

Klaus Brasch
Flagstaff, Arizona

Lunar Inversion

I have been enjoying *S&T* since the late 1970s and never felt the need to write in until reading the letter from Ed Wagner (*S&T:* Feb. 2020, p. 6).

Ed, you're not alone! For about the past 30 years, 99% of all Moon images I have seen in pictures or videos appear "reversed." Try as I might, I cannot get the little hillocks to turn into craters, even though I know they are craters and should be depressed. Forty years ago, I did not have this problem. While watching the Apollo 11 lunar-landing videos as a youngster, I saw craters as craters.

Until Ed's letter, I thought I was the only one with this issue. Now, I also wonder how many others may have struggled with this problem. However, despite the hillocks, I enjoy observing the wonderful beauty of God's astronomical creation and, occasionally, I see craters!

Scott Alford
St. James, Missouri

I read Ed Wagner's letter with interest. This reversal often happens to me, particularly when looking at an image for the first time. I haven't experienced the reversal through the eyepiece, though. Sometimes, I rotate the page or look at the image with light coming from a different direction. It doesn't always work!

Other times, I can make the reversal happen just through concentration, flipping between domes and craters.

It's an interesting phenomenon and sometimes exasperating. I know of one other person who has noticed it, too.

James Edgar
Melville, Saskatchewan

I frequently notice this "reversed topographical relief" when viewing photos of lunar and Martian craters. When this occurs, I rotate the photograph 180°, look away, and then look back. This inevitably resets my brain to the proper topographical relief perspective.

Many years ago, I gave a presentation, using a slide projector, of images of Martian landforms that were recently received from a spacecraft orbiting Mars. I was surprised when about 10% of the audience was unable to perceive the Martian craters normally but instead saw reversed relief. To correct this, I removed the slides from the tray, flipped them 180° (front to back), and replaced them in the tray. This corrected the inverted depth perspective for those individuals.

Alas, about 10% of the audience that previously were able to correctly perceive the Martian craters now saw a reversed relief image instead!

Frank Ridolfo
Bloomfield, Connecticut

As a geologist who has worked with Landsat and other types of aerial imagery throughout my career, what Ed experienced is a common phenomenon.

When working with hard copy images, a cure for this "reversal" is to physically turn the image upside down and view it from the opposite direction. This fixes the image for me most of the time. When it doesn't work or if I am viewing digital images and can't physically turn them, then I force myself to think about the direction of the light.

It's not easy to "flip the image" once your brain has locked onto a particular view, and I commend Ed for having success most of the time. As a last resort, take a break and come back to the image or scope after some time. The brain may self-correct after the break.

Thomas Jones
Spring, Texas

The optical phenomenon described by Ed Wagner is called pseudocopic vision. It is described in Richard L. Gregory's book *Eye and Brain*.

There is also an optical instrument known as a pseudoscope that reverses depth perception. I have seen this phenomenon a few times with a 5-inch Maksutov-Newtonian.

Spurious resolution, however, though not as common, is responsible for some of the reports of the "canals" seen on Mars. Spurious resolution is usually seen in out-of-focus photographs. Human eyes and brains can be easily fooled (as any magician will tell you).

Rodger Gordon
Nazareth, Pennsylvania

A Twist of Terminology

As a physics major in college, I learned that the small wooden circle mounted on legs with two telescopes at different angles and a prism at the center is a spectroscope, an instrument that records is a spectrograph, and a spectrometer measures a wavelength.

Jerry Oltion (*S&T:* Feb. 2020, p. 32) omits the spectrometer, but identifies the instruments in the article with the terminology from the standpoint of a physicist.

Through an apparent accident of history, astronomers do not use the standard physics terminology. Instead, what Jerry and I call a spectrograph, they call a spectrometer. This is one of many instances where one field of science uses different terminology than another.

I wonder when the usage of the words for spectrometer and spectrograph were confused, and what other astronomy terms also experienced this mix-up.

Mark Trueblood
Sonoita, Arizona

FOR THE RECORD

We published a photo essay on micrometeorites by Ted Kinsman (*S&T:* Feb. 2020, p. 14), which included discussion of his collection methods and scanning electron microscope images of micrometeorites he had gathered. Before we published the photo essay, a NASA meteorite scientist carefully reviewed the text and images for accuracy, and we published only the images he thought clearly showed micrometeorites.

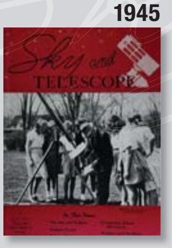
However, since publication we have received skeptical responses from readers familiar with this field. Subsequently, we contacted two additional micrometeorite experts for their opinion. Both inform us that, although the author's collection method has merit for finding micrometeorites melted by their passage through the atmosphere (called cosmic spherules), almost all the samples shown in the images are likely terrestrial contaminants.

The takeaway, every source tells us, is that sorting out imposters from true micrometeorites is immensely challenging. Despite the author's efforts to remove anything of terrestrial origin, the specialists we contacted don't think he was successful. Therefore, we the editors are flagging Kinsman's article as likely inaccurate. We will consider publishing a separate micrometeorite article informed by these lessons at a later date.

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

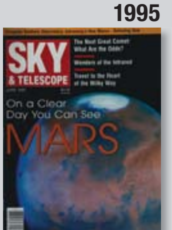
75, 50 & 25 YEARS AGO by Roger W. Sinnott

1945



1970

1995



June 1945

Speed of Light "'Among the distinguished observers who have measured the velocity of light, an implicit faith in its constancy seems to have prevailed. But other writers, comparing the published observations, have interpreted the apparent differences as secular and periodic variations.'

"So comments Harold D. Babcock [reviewing a reanalysis of past results by] N. E. Dorsey, formerly of the U. S. Bureau of Standards. . . . [Dorsey] finds that there is no indication of any progressive change in the velocity, the best value for which he determines as 299,773 kilometers per second (in a vacuum) plus or minus 10 kilometers a second."

In 1983, international agreement fixed the speed of light at 299,792.458 kilometers per second. So it is no longer subject to remeasurement and in effect defines the kilometer.

June 1970

Comet Bennett "Everyone in mid-northern latitudes who viewed Comet Bennett in early April agrees that it has been the finest comet for them in many years. Its great brilliance, long tail, and convenient location in the dark predawn sky tempted some watchers to compare it with such historic objects as Donati's Comet of 1858 and Halley's Comet of 1910. . . .

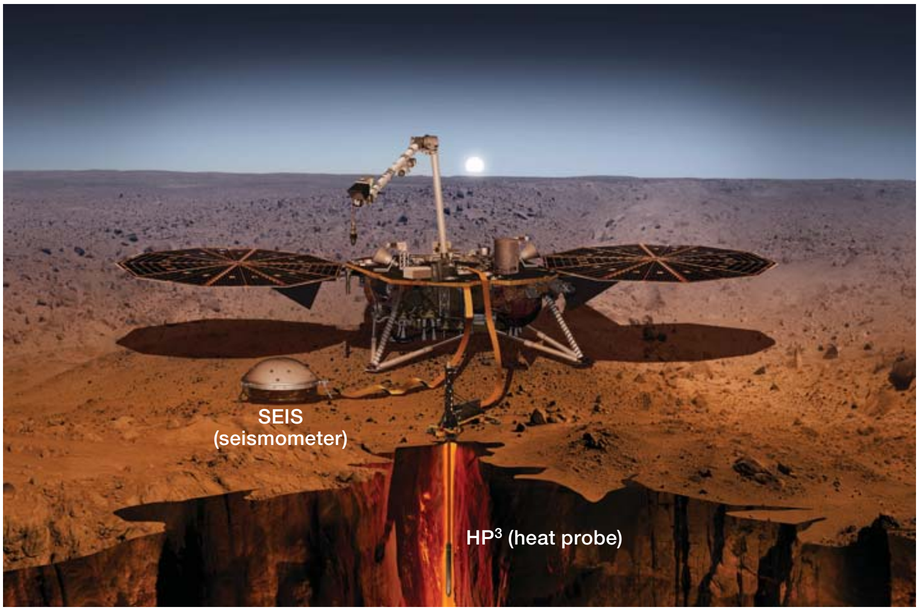
"[Bennett's] Type II or dust tail was 19 degrees long to the naked eye on April 8th, according to John E. Bortle at Stamford Observatory in Connecticut. That same morning, the slender Type I or gas tail was estimated by him as eight degrees long. . . .

"Using a 22-inch Maksutov telescope, Mr. Bortle detected spiral jets emerging from the nucleus, sometimes as many as five at once. During the first week in April he saw and photographed luminous hoods around the nucleus, resembling those in George P. Bond's classic drawings of Comet Donati."

June 1995

Sculptor Dwarf "Painstaking positional measurements on photographic plates spanning a half century have produced the latest results from a nascent astronomical industry: assessing absolute proper motions for [local galaxies. These are key to] unraveling the history of our galactic neighborhood, and obtaining 'test particles' to 'weigh' the Milky Way's dark halo. . . .

"Andrea E. Schweitzer (University of Wisconsin), Kyle M. Cudworth (Yerkes Observatory), and their colleagues [measured] stellar positions in the Sculptor dwarf spheroidal galaxy with respect to six distant background galaxies. By comparing South African plates from the late 1940s with those acquired in Chile throughout the last decade, the researchers assessed the average shift of more than 1,000 stars. The Sculptor dwarf's resultant proper motion — 36 arc milliseconds eastward and 43 northward per century — is the most precisely determined by this method to date."



▲ Artist's illustration of NASA's Insight lander, with its seismometer (under dome at left) and heat probe (center) deployed.

SOLAR SYSTEM

NASA's Insight Detects Marsquakes

MARS REGULARLY QUIVERS with barely discernible quakes due to fracturing in its crust as the interior cools. That's the takeaway from the first 10 months of observations by NASA's Insight lander.

Insight is the equivalent of a planetary X-ray, with instruments designed to reveal the Martian interior. The team reports results from some of these instruments in five papers published in the March 2020 *Nature Geoscience*.

Insight's seismometer, called the Seismic Experiment for Interior Structure (SEIS), had detected 174 seismic events as of the paper's writing. Most of these are tiny and shallow, but 24 propagate much deeper and have magnitudes between 3 and 4. That's still weak — you probably wouldn't feel them if you were standing on the surface.

These 24 marsquakes seem to come from deeper in the planet than earthquakes do, maybe 30 to 50 kilometers (20 to 30 miles) down instead of 5 to 10 km, says SEIS principal investigator Philippe Lognonné (University of Paris).

The quakes also lasted a long time, from 10 to 20 minutes each. For comparison, one of the longest earthquakes ever recorded on Earth lasted between 8 and 10 minutes, but most earthquakes are smaller and fade much faster, attenuating within tens of seconds as they travel through Earth's partially molten interior. Marsquakes' longer duration suggests seismic waves pass more easily through the Martian interior than Earth's. Lognonné says this indicates that Mars's upper mantle is less melted than Earth's is. But seismic waves fade more quickly on Mars than on the ultra-dry Moon, so the Martian crust might have a trace of moisture in it, he adds. For example, there may be thin films of water in the rocks' pores.

▶ A test using an engineering model shows how the Insight lander will use its robotic arm to press on "the mole" to help it dig.

Surprisingly, Insight hasn't seen any tremors stronger than magnitude 4. Because larger quakes carry information about what lies deeper down in the mantle, the team might have to rely more heavily on Insight's other instrument packages to probe the nature of the planet's core.

Signals from three of the 24 deep marsquakes were clear enough to trace them back to their sources. Two appear to have come from Cerberus Fossae, a set of steep troughs in the plains southeast of the dormant volcano Elysium Mons. The third comes from a bit farther east. Cerberus Fossae is a region of recent (within the last 10 million years) geological and volcanic activity. It's possible there's a magma chamber deep underground, which would contract as it continues to cool, causing the crust above it to crack. There's no evidence yet for magma plumes that could be to blame, but concentrations of radioactive elements might keep pockets of the subsurface warm.

While SEIS is yielding a slew of results, another Insight instrument is in dire straits. The Heat Flow and Physical Properties Package (HP^3), fondly known as "the mole," started digging in February 2019, intending to draw a string of temperature sensors underground to measure heat flow from the planet's interior. But the probe only made it some 35 cm (14 inches) down before it got stuck. A slew of tests determined that the soil there isn't as sandy as at other landing sites. Instead of falling back into the hole, providing traction for the probe as it dug, the soil clotted, leaving the mole with nothing to push against as it tried to hammer deeper.

The team is now prepping to do what it had hoped never to do, Bruce Banerdt (JPL) says: Use the lander's robotic arm to push the mole down. The researchers think that, if they can press the probe far enough to bring its top end level with the ground, friction might win out and enable the mole to keep digging.

■ CAMILLE M. CARLISLE

NASA / JPL-CALTECH (2)

SUN

European Solar Orbiter Launches

THE EUROPEAN SPACE AGENCY'S Solar Orbiter took to the skies on February 9th, the first space-science mission to launch in 2020. The orbiter joins a growing armada of solar telescopes, including the Parker Solar Probe (*S&T:* Apr. 2020, p. 10) and the ground-based Daniel K. Inouye Solar Telescope, which saw first light in January. Solar Orbiter will begin collecting data in May as it cruises toward the Sun, but full science operations won't begin until November 2021.

Solar Orbiter will be the first mission to image the Sun's poles. (Ulysses, a joint ESA/NASA mission, launched in 1990 to study the Sun's polar regions but didn't carry cameras.) With the help of three gravitational assists, one maneuver past Earth and two past Venus, the spacecraft will enter an initial orbit inclined 17° to the ecliptic plane. From this vantage point, Solar Orbiter will study the the Sun's extended atmosphere and the birthplace of the solar wind.

▲ An artist's impression shows the Solar Orbiter spacecraft approaching the Sun.

Several further gravity assists past Venus will gradually steepen the inclination, putting it at 33° by 2029. The closest pass by the Sun, at 0.28 astronomical unit, will take the spacecraft well inside Mercury's orbit.

Ten instruments are hitching a ride, including the NASA-contributed Heliospheric Imager, which will take the first high-resolution images of the Sun from up close. Other instruments include an X-ray spectrometer and telescope, two ultraviolet detectors, and an instrument to survey the Sun's magnetic fields. A Sun-blocking coronagraph named Metis will also make key observations of the inner corona.

This new mission overlaps with — and is complementary to — NASA's Parker Solar Probe. Parker studies the Sun from close up, but it can't image the Sun directly. Solar Orbiter will image the Sun from an inclination that allows study of the poles, offering a comprehensive view of the Sun's activity.

■ DAVID DICKINSON

SOLAR SYSTEM

Pluto's Icy Heart "Beats," Driving Planet-Scale Winds

SPUTNIK PLANITIA, a basin that makes up the left lobe of Pluto's "heart," may drive subtle winds over the entire dwarf planet, Tanguy Bertrand (NASA Ames Research Center) and colleagues suggest. They published their findings in the February *Journal of Geophysical Research: Planets*.

Among the many surprises Pluto presented to scientists was a global atmosphere. Hints on the surface, such as probable wind streaks west of Sputnik Planitia, reveal the thin atmosphere's impact. Bertrand and colleagues examined what could drive these winds using high-resolution climate simulations.

In what Bertrand's team nicknames Pluto's "heartbeat," nitrogen ice in Sputnik Planitia sublimates in Pluto's daytime and condenses back into ice at nighttime. However, because Pluto's spin is tilted with respect to its orbit around the Sun so that it's almost on its side, the northern edge of Sputnik Planitia is in constant daylight. As a result, the nitrogen there is constantly sublimating, inducing a southerly wind. Pluto's rotation deflects that wind slightly westward, until it nears the basin's mountainous western boundary, where it returns southward. At the southeastern edge of Sputnik Planitia, which lies closer to the part of Pluto under polar night, nitrogen condenses back into ice. Here, the winds turn northerly again, completing the counterclockwise spiral.

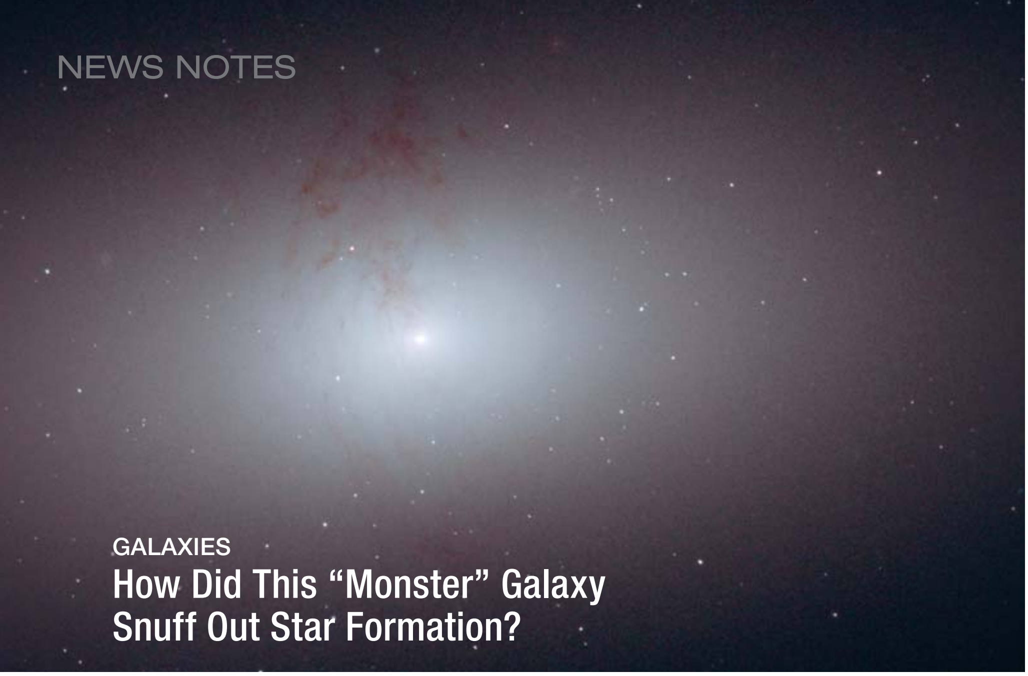
The simulations show that from Sputnik Planitia, nitrogen gas rises to higher altitudes, flowing from northern summer to southern winter. But just as an ice skater's spin slows when they spread their arms, Bertrand explains, the nitrogen molecules slow down as they move from north to south, because they're moving farther from the planet's rotational axis. As a result, high-altitude nitrogen ends up moving more slowly than the dwarf planet below it. The consequence is that the winds on Pluto blow westward, opposite the planet's rotation — a pattern unique among solar system worlds (except maybe Neptune's moon Triton).

▲ Sputnik Planitia, a 3-km-deep basin, makes up the left lobe of Pluto's "heart."

"Sputnik Planitia may be as important for Pluto's climate as the ocean is for Earth's climate," Bertrand said. William McKinnon (Washington University in St. Louis), who was not involved with the study, agrees that Sputnik Planitia is the "source and sink" of Pluto's atmosphere.

■ JULIE FREYDLIN

● **Watch simulations of Pluto's winds at https://is.gd/plutowinds.**



◀ This nearby massive galaxy, like XMM-2599, has shut down its star formation.

GALAXIES

How Did This "Monster" Galaxy Snuff Out Star Formation?

WITHIN THE FIRST several billion years of the universe, galaxies grew like newborns, turning gas into stars at fantastic rates. But astronomers have discovered one massive galaxy that furiously formed new stars only to abruptly quench starbirth altogether. The result could change how we think about galaxy evolution.

Ben Forrest (University of California, Riverside) and colleagues published follow-up observations of this monster galaxy, which was discovered in a larger survey, in the February 10th *Astrophysical Journal Letters*. The team took spectra using the Keck I telescope on Mauna Kea, Hawai'i, to measure the galaxy's stellar mass and its star formation history.

The galaxy, dubbed XMM-2599, already had five times the Milky Way's mass in stars just 1.8 billion years after the Big Bang. Such a gargantuan galaxy is by itself rare in the early universe, as most galaxies hadn't had enough time to produce so many stars. But some galaxies worked overtime, at least for a little while. Chemical fingerprints in the galaxy's spectrum indicate that, for a period of several hundred million years around 1 billion years after the Big Bang, XMM-2599 was forging more than 1,000 stars per year. (The Milky Way only produces about one or two stars every year.)

However uncommon, massive star-forming galaxies have been seen in both observations and simulations of galaxy evolution. But not only is XMM-2599 massive, all the data collected so far point to a complete shutdown of its star-formation factory. Astronomers have spotted only a few massive galaxies that have doused starbirth so early on in the universe. Moreover, simulations can't reproduce them.

Katherine Whitaker (University of Massachusetts, Amherst), who was not involved in the study, says this discovery highlights tensions between observations and computer models. "I don't know that we need to totally rethink models," she adds. "But these tensions are precisely what we need to identify and revisit the assumptions and prescriptions driving the simulations."

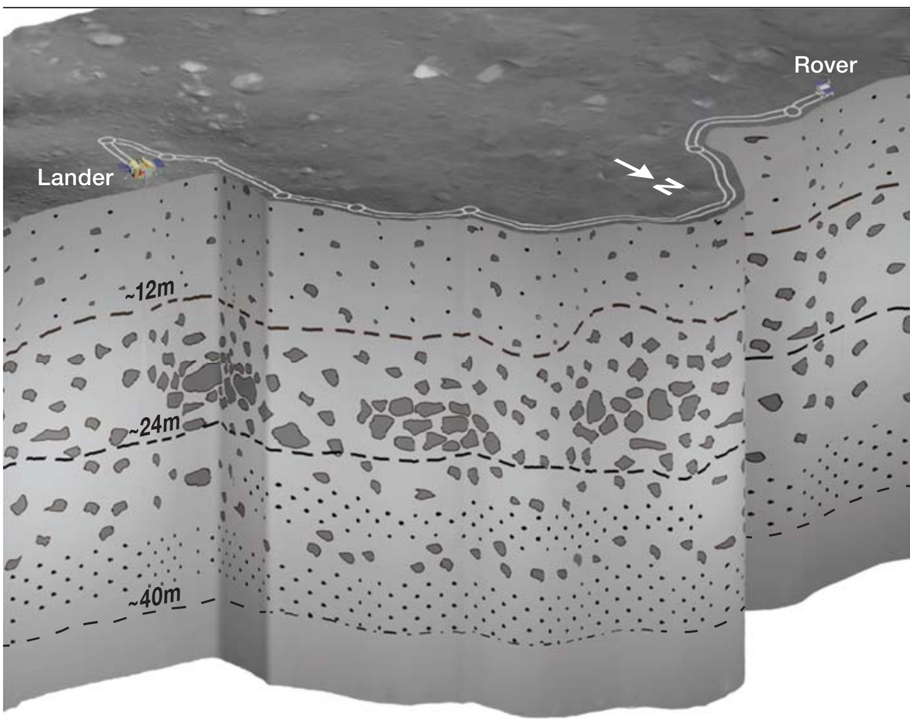
■ **MONICA YOUNG**

MOON

What Lies Beneath the Lunar Farside

CHINA'S CHANG'E 4 MISSION to the farside of the Moon is providing a look at the lunar subsurface. Data from the Yutu 2 rover's Lunar Penetrating Radar has revealed three discrete layers of regolith underneath the landing site in Von Kármán Crater in the vast South Pole–Aitken Basin.

Chunlai Li (Chinese Academy of Sciences) and colleagues published results



◀ The farside's subsurface can be divided into three units: Unit 1 (down to 12 m, or 40 feet) consists of fine lunar regolith, unit 2 (12 to 24 m) consists of coarser materials with embedded rocks, and unit 3 (24 to at least 40 m) contains alternating layers of coarse and fine materials.

GALAXY: NASA / ESA / R. FOLEY; MOON SUBSURFACE: CHUNLAI LI ET AL. / *SCIENCE ADVANCES* 2020

SOLAR SYSTEM

Arrokoth Details Reveal How Planets Form

FOURTEEN MONTHS AFTER New Horizons flew by Arrokoth (originally designated 2014 MU$_{69}$), mission scientists have concluded that the peanut-shaped object came together more gently than previously thought. The team presented the findings at the annual meeting of the American Association for the Advancement of Science and published three papers in the February 28th *Science*.

New Horizons data show that Arrokoth has remained largely untouched since its formation 4.5 billion years ago. The spacecraft's cameras reveal a uniform, deep-red surface that's relatively unmarred by craters. Spectra of reflected infrared light show the chemical fingerprints of methanol ice, a molecule commonly found in protoplanetary disks.

Most surprising, though, are multiple lines of evidence that Arrokoth's two lobes came together exceedingly gently. "There is no evidence that the merger of these two lobes was at all violent," says William McKinnon (Washington University in St. Louis).

◀ Arrokoth's deep red color and its unmottled and craterless surface support the notion of a gentle formation and a peaceful existence.

McKinnon and colleagues ran a series of computer simulations to test this peaceful scenario. To reproduce Arrokoth's appearance and characteristics, they found that the two bodies must have initially been orbiting each other and slowly merged, joining together at less than 4 m/s (9 mph) and likely at a slanting angle.

Arrokoth also sheds light on how planetesimals formed. In the *classic hierarchical model* of planet formation, dust gloms together into pebbles and planetesimals collide to make planets. But scientists have had difficulty explaining why pebble-size objects would fuse together rather than ricocheting off each other.

More recently, scientists have proposed that the *streaming instability*, in which gas in the protoplanetary disk would drag on pebble-size particles, could help bridge that gap. Like a line of cyclists riding against the wind, some pebbles plowing into the gas would drop behind, where they'd feel less drag. The resulting pebble "streams" would be gravitationally unstable, quickly collapsing into multiple massive objects — typically binaries or contact binaries, like Arrokoth.

Arrokoth's pristine nature represents an important piece of evidence supporting the streaming instability's role in planet formation, says New Horizons principal investigator Alan Stern (Southwest Research Institute): "I believe this is a game-changer."

■ JAVIER BARBUZANO

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from the first two lunar days (59 Earth days) in the February 26th *Science Advances*. The data show fine materials down to a depth of 12 meters (39 ft), with occasional larger rocks mixed in. Beneath that, down to 24 meters, the number of boulders increase. Further still, to a limiting depth of 40 meters, the regolith changes again to alternating layers of fine and coarse materials. Impact ejecta helped create these multiple layers, while other geological processes also played a role.

The Yutu rover of the 2013 Chang'e 3 mission (see page 34) also carried ground-penetrating radar, but it could only see down to a depth of about 10 meters. The more transparent farside suggests that its geological history differs from the Chang'e 3 landing site.

The current study only considers the first two lunar days of the Chang'e 4 mission, and also only deals with radar experiments conducted at 500 MHz. The team still needs to analyze data taken at the same frequency from further along the rover's path. Additional data taken at 60 MHz, which ought to penetrate deeper, remain difficult to analyze because of interference from the rover's metallic body.

With its recent missions, China has now established its expertise in ground-penetrating radar, according to Clive Neal (University of Notre Dame). Understanding the subsurface will inform not just the science of the Moon's structure and formation, but also its resource potential.

■ ANDREW JONES

ASA / JHU APL / SWRI

IN BRIEF

Bennu Features Named

The International Astronomical Union (IAU) has bestowed official names on 12 features on the asteroid 101955 Bennu. Team members on NASA's OSIRIS-REX mission (*S&T:* May 2020, p. 14), who have been mapping Bennu in detail over the past year, proposed the names to the IAU, the international authority for naming celestial bodies and their surface features. As the asteroid's name was itself inspired by the ancient Egyptian deity Atum, who is often depicted as the Bennu bird, the features' names are likewise related to mythological birds and bird-like creatures. The large boulder jutting out 21.7 meters (71 feet) from the asteroid's southern hemisphere is the most prominent feature to receive an official designation: Benben Saxum. The name comes from the primordial hill that first rose out of the dark waters in an ancient Egyptian creation myth. Atum, in the form of the Bennu bird, flew over the primordial waters before settling upon Benben to create the world.

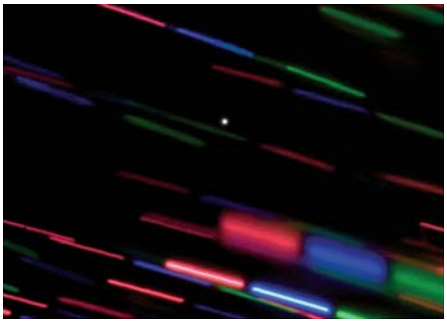
■ MONICA YOUNG

SOLAR SYSTEM

Earth's New (and Temporary) Mini-Moon

EARTH RECENTLY TOOK ON a brand new moon. Designated 2020 CD_3, it was discovered on February 15th by Catalina Sky Survey astronomers Kacper Wierzchos and Teddy Pruyne. At the time, the object was a 20th-magnitude pinpoint about 300,000 km (186,000 miles) from Earth. Combining brightness and distance information, astronomers estimated the asteroid's diameter at 6 to 12 feet (2 to 3.5 meters) — about as wide across as an elephant is tall.

Additional measurements soon revealed that the space rock wasn't orbiting the Sun, but rather was going around Earth — though only temporarily. Working the orbit backwards, astronomers concluded that Earth's gravity had snared the mini-moon several years ago. The asteroid went undetected for so long because it's tiny — and therefore faint — and because it orbits our planet in meandering loops of varying eccentricity and inclination.



▲ The new mini-moon, designated 2020 CD_3

Our sojourn with 2020 CD_3 will be brief: Astronomers expected the boulder to return to a solar orbit by April.

As with any Earth-approaching asteroid, there's always a small probability that it can come back to bite us — but that won't happen this time around. And while preliminary analysis from the JPL's Sentry project indicated a 3% probability of impact within the next century, we wouldn't have to worry even if it did collide with Earth. Objects this size typically fragment when they strike the atmosphere, so at worst it would land as numerous small meteorites.

Earth has had one other known mini-moon, 2006 RH_{120}, discovered by Catalina Sky Survey astronomer Eric Christensen. It dawdled in our neighborhood for about a year before getting the boot. The objects likely represent only a small fraction of the mini-moons Earth has captured and released since its youth.

■ BOB KING

IN BRIEF

Amateur Dennis Conti Wins Chambliss Award

The American Astronomical Society has conferred the Chambliss Amateur Achievement Award on Dennis Conti for "his outstanding observational, computational, and educational contributions to exoplanet studies." Conti, a computer scientist and amateur astronomer, has been heavily involved with the exoplanet community since 2016, when he helped coordinate a worldwide network of amateur astronomers. Together, they provided observations complementing a Hubble Space Telescope program searching for water in exoplanet atmospheres. More recently, Conti took the helm of a group of amateurs at the American Association of Variable Star Observers working with NASA's Transiting Exoplanet Survey Satellite (TESS). In this role, Conti contributes observations and trains and mentors other observers. He also contributed a key piece of TESS's object identification algorithm, which helps identify signals that are not really planets. Conti says the most thrilling discovery he has contributed to so far is the discovery and validation of the TOI-700 triple-planet system. This triplet includes the first habitable-zone Earth-size planet that TESS has identified.

■ DIANA HANNIKAINEN

Betelgeuse Rises Again

After declining in brightness to a record-breaking minimum (*S&T:* Apr. 2020, p. 10), Betelgeuse, the bright red giant sitting at Orion's left shoulder, finally began brightening again in late February. Edward Guinan (Villanova University) and colleagues report in *Astronomer's Telegram #13512* that the star bottomed out at magnitude 1.61 in mid-February. This low point occurred 420–428 days after the star's last minimum in mid-December 2018, when it had dimmed to magnitude 0.9 — part of a long cycle in brightness variations caused by turbulence below the star's surface layers. However, it remains unclear why the star dimmed so much this time around. In a related *Astronomer's Telegram #13518*, Robert Gehrz (University of Minnesota) and colleagues reported that at infrared wavelengths, Betelgeuse has remained "steadfast" over the past 50 years. The team suggests that the recent fading at visual wavelengths is therefore more likely due to "local surface phenomena," such as changes in the amount of foreground dust and gas belched out by the star along Earth's line of sight, or variations in surface temperature. The star may yet explode tomorrow or in the next 100,000 years, Gehrz and colleagues write, but the recent "fainting" episode is not a harbinger of the star's core collapse.

■ BOB KING

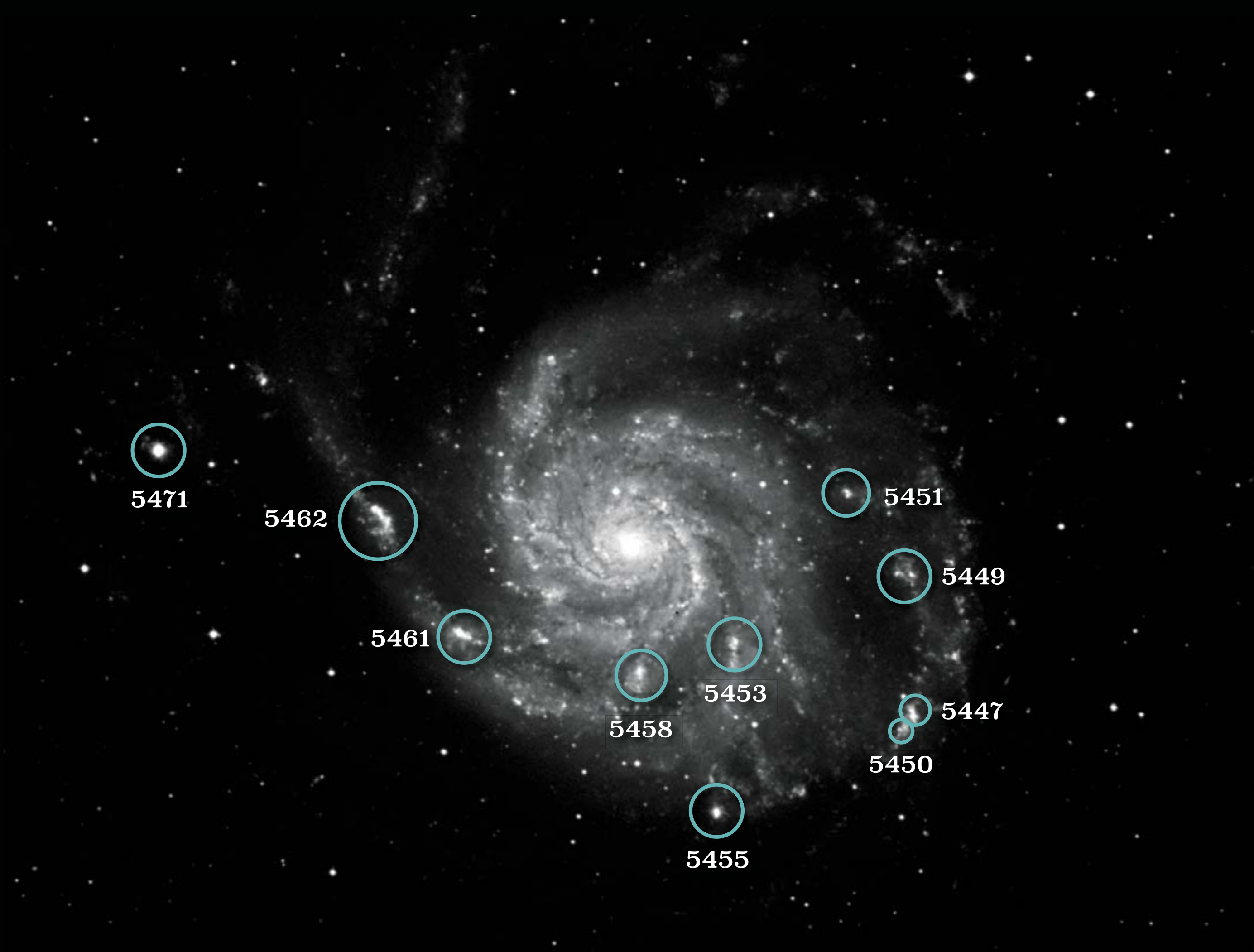
NASA 2021 Budget Proposal

The current administration has released its request for NASA's budget for the fiscal year of 2021, a proposal that emphasizes human exploration at the cost of several key programs. The space agency would receive $25.2 billion overall, but while this represents a 12% increase over the received budget in 2020, the majority of this increase would go toward the Artemis initiative, which aims to put people back on the Moon by 2024. Projects to build the Lunar Gateway, which would orbit the Moon, and a lunar lander, which would take astronauts to the surface, both received increases under the current proposal. In return, several science missions are zeroed out, including the Wide-Field Infrared Survey Telescope (WFIRST), the Stratospheric Observatory for Infrared Astronomy (SOFIA), NASA's Office of STEM Engagement, and two Earth science missions. The proposal would also suspend NASA's Near-Earth Object Surveillance Mission, a space-based infrared telescope that would hunt for potentially hazardous asteroids. Many of these missions have faced termination several times before, though, and managed to survive thanks to Congressional intervention.

■ DAVID DICKINSON

Read more budget details at https://is.gd/NASAbudget2021.

GEMINI OBSERVATORY



A Galaxy-Hop Around M101

BRIMMING WITH H II REGIONS The author tackled the H II regions in the spiral arms of M101, and on his first visit identified three knots. Two subsequent tours of the outer arms of the galaxy revealed a further seven knots.

POSS-II / STSCI / CALTECH / PALOMAR OBSERVATORY

Take a telescopic tour of the Pinwheel Galaxy and its neighbors.

I tear out many of the observing articles in *Sky & Telescope* to use as guides whenever a superb night might present itself, and I add them to my ever-thickening observing folder. But not every month offers a superb night at my latitude of 49° north, even though I live in the semiarid Okanagan Valley of southern British Columbia, on the drier and clearer eastern side of the Cascade Mountains. The June section of my observing folder contains several articles that I dip into often. This June will be no exception. I'll turn to some of my favorite articles on a stunning spiral galaxy in the far eastern reaches of Ursa Major: **M101**. Join me as we acquaint ourselves with this magnificent object and its surroundings.

Diving into M101's Spiral Arms

The June 1993 issue of *Sky & Telescope* featured the article "A Visual Tour of M101" by amateur astronomer Roger N. Clark, who used to observe at an excellent site in the Colorado Rockies. M101 is a spiral galaxy that displays a mixture of features associated with both non-barred and barred spirals. In addition, the inner arms form a ringlike structure. It's also one of three Messier galaxies that share the same nickname, the Pinwheel Galaxy; the other two are M33 and M99.

Work pressures prevented me from much serious observing in 1993, but I saved Clark's article with its accompanying image and six years later tackled the H II regions that appear as knots in M101's outer spiral arms. My 8-inch f/6 Newtonian at 116× revealed three of these knots: **NGC 5461** (the easiest of the three), **NGC 5462**, and **NGC 5455**. NGC 5461 and NGC 5462 were tiny fuzzies, while NGC 5455 looked stellar but was only intermittently visible. One night during a Messier marathon — not an event when you normally want to linger on objects, since the aim is to bag as many of the 110 Messier objects as quickly as possible in one night — I had my best view yet of M101 with an 8-inch scope (although Sue French saw as much with her 105-mm refractor at 127×). At 93× the Dob, with its freshly aluminized mirror, forced me to spend time on the galaxy because I could detect two barely discernible spiral arms and a fairly faint nucleus.

Then, in 2004, the June issue (again) featured an excellent article by Steve Gottlieb entitled "H II Regions Galore in M101." It again took a while before I could follow up on the article, but on a first-rate night five years later I finally got around to chasing down more of M101's knots. For this purpose, I used my backyard observatory's 16-inch f/4.5 Newtonian on an equatorial mount. On the first night, 152× revealed two prominent spiral arms plus sections of two faint arms. As I swept around the galaxy, I detected 10 knots and circled them on an unlabeled image. In the morning, I compared my markings to the H II regions and star associations identified on the image in Steve's article. To the three NGC knots that my 8-inch had shown in 1999, my 16-inch added **NGC 5450**, **NGC 5447**, **NGC 5471**, and **NGC 5458**.

I don't know whether the three unidentified knots that I saw in the galaxy were legitimate H II regions and star associations or not. But there were three knots in Steve's article that I hadn't seen by simply sweeping the galaxy. So, the following year I returned to M101 and — again referring to the image in Steve's article for star-hopping — I added **NGC 5453**, **NGC 5449**, and **NGC 5451**. All three were mere smudges and only occasionally detectable when the seeing steadied. NGC 5451 required 229×, but 152× sufficed for the other two. Sue French has observed seven of these star-forming regions with her 10-inch reflector — the last three were just beyond the grasp of a 10-inch.

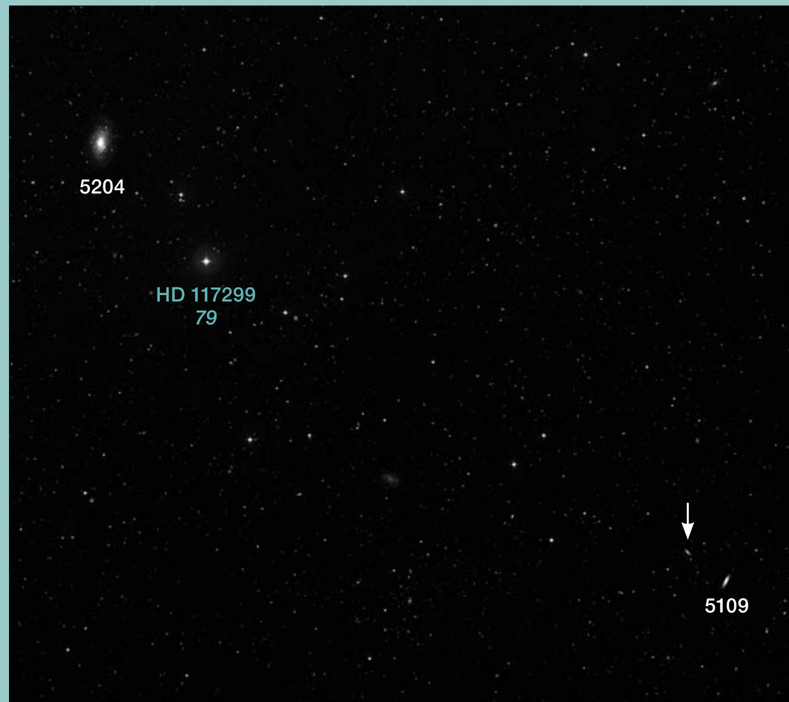
Galaxy-hopping Around the Pinwheel

The Astronomical League's Herschel 400 Observing Program (**https://is.gd/Herschel400**) that I completed with my 8-inch long ago includes three galaxies near M101 (NGC 5473, NGC 5474, and NGC 5631). And in the course of working my way around M101 to view the condensations in its spiral arms I came across several more nearby galaxies. Last year I decided to star-hop around the area in order to observe

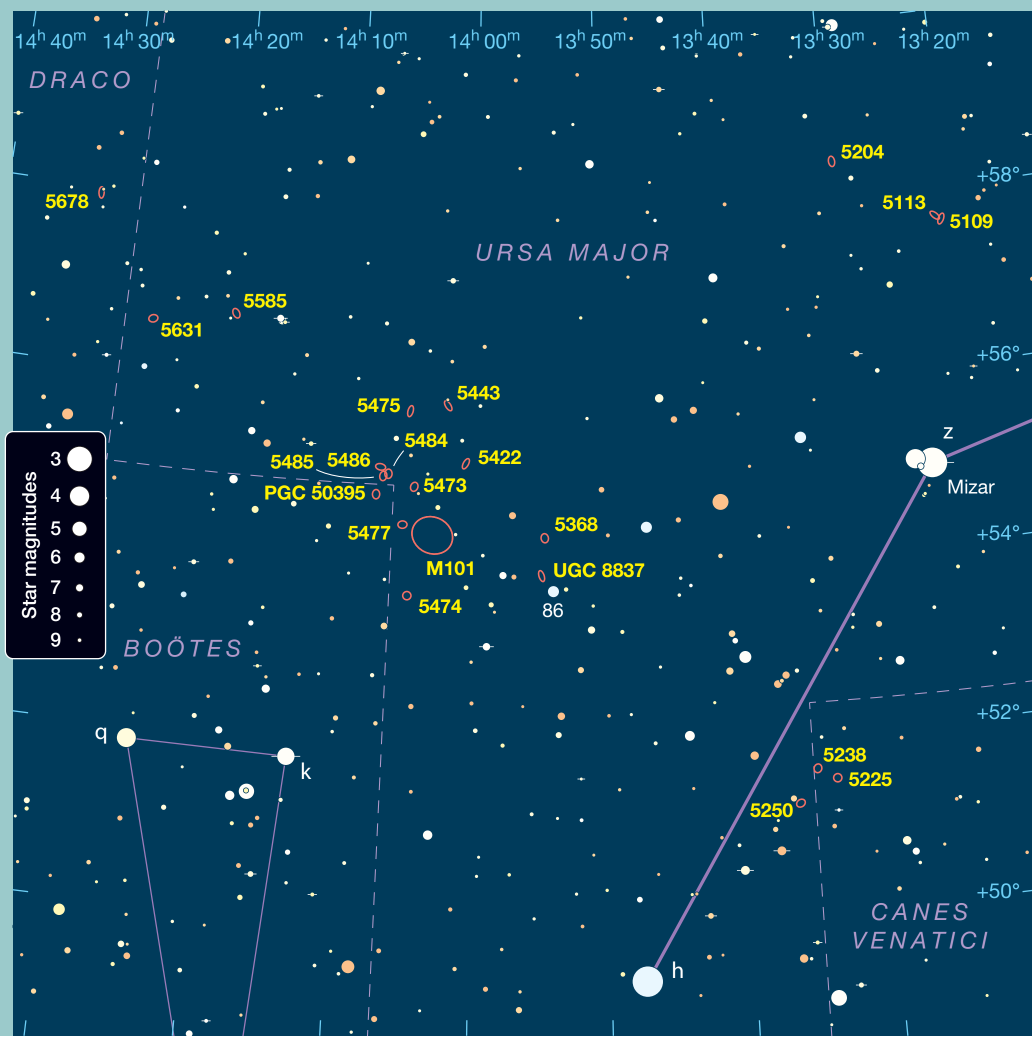
▲ **SPIRAL SPLENDOR** June nights bring this magnificent spiral galaxy in Ursa Major into prime evening position. But it's not alone. Follow the author as he explores the spiral arms of M101, and galaxy-hops around the Pinwheel in search of further interesting targets.

▼ **DISTORTED DWARF** A member of the M101 group of galaxies, NGC 5474 lies around 21 million light-years away and contains several billion stars (instead of the several hundred billion that the Milky Way counts as its own). Previous interactions with M101 might have contributed to this dwarf galaxy's odd look.

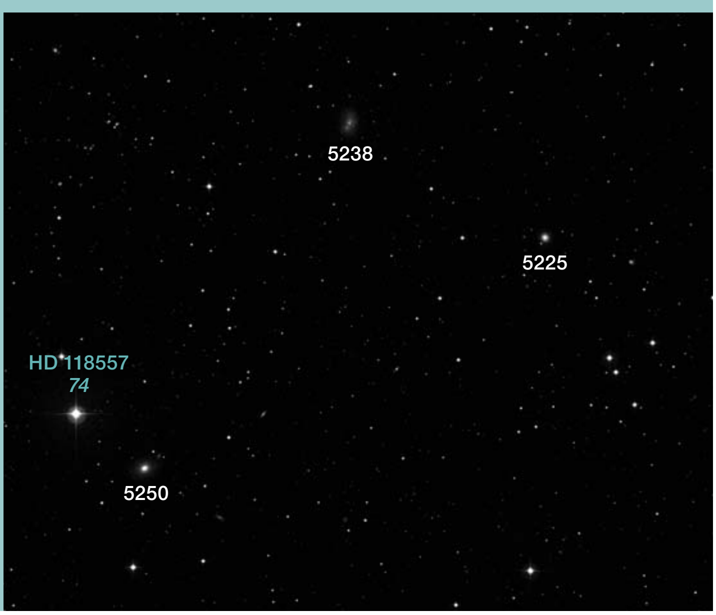
M101: MASIL IMAGING TEAM; NGC 5474: ESA / HUBBLE / NASA



THE PINWHEEL AND SURROUNDINGS The chart at right gives an overview of the area in space that M101 and its companions share (see page 43 to read more on Mizar). The accompanying POSS-II images show zooms of the central region of the chart, as well as of the clusterings of galaxies at top left, top right, and bottom right. The arrow in the image at top right of this page points to the galaxy that Herschel likely labeled NGC 5113. Nearby stars and their magnitudes (without decimals) are also labeled.



POSS-II / STSCI / CALTECH / PALOMAR OBSERVATORY (2)



POSS-II / STSCI / CALTECH / PALOMAR OBSERVATORY (2)

members of the M101 Group, a small group of galaxies that are gravitationally bound to M101, as well as the other more prominent galaxies nearby.

NGC 5474, both a member of the M101 Group and on the Herschel 400 list, is a spiral with a small core that is only a little brighter than the halo. Located about 44′ south-southeast of the center of M101, it's obvious at 76×. With my 8-inch at 93× it was large and amorphous with a brighter patch off-center. My 16-inch at 203× (which is the standard power I use for observing galaxies) gave a similar view but added a 16th-magnitude star on the face of the galaxy slightly offset from the core to the northeast.

NGC 5477, another member of the M101 Group, is a spiral with no discernible core located only 21′ east-northeast of the center of M101. It's very faint and very amorphous in my 16-inch.

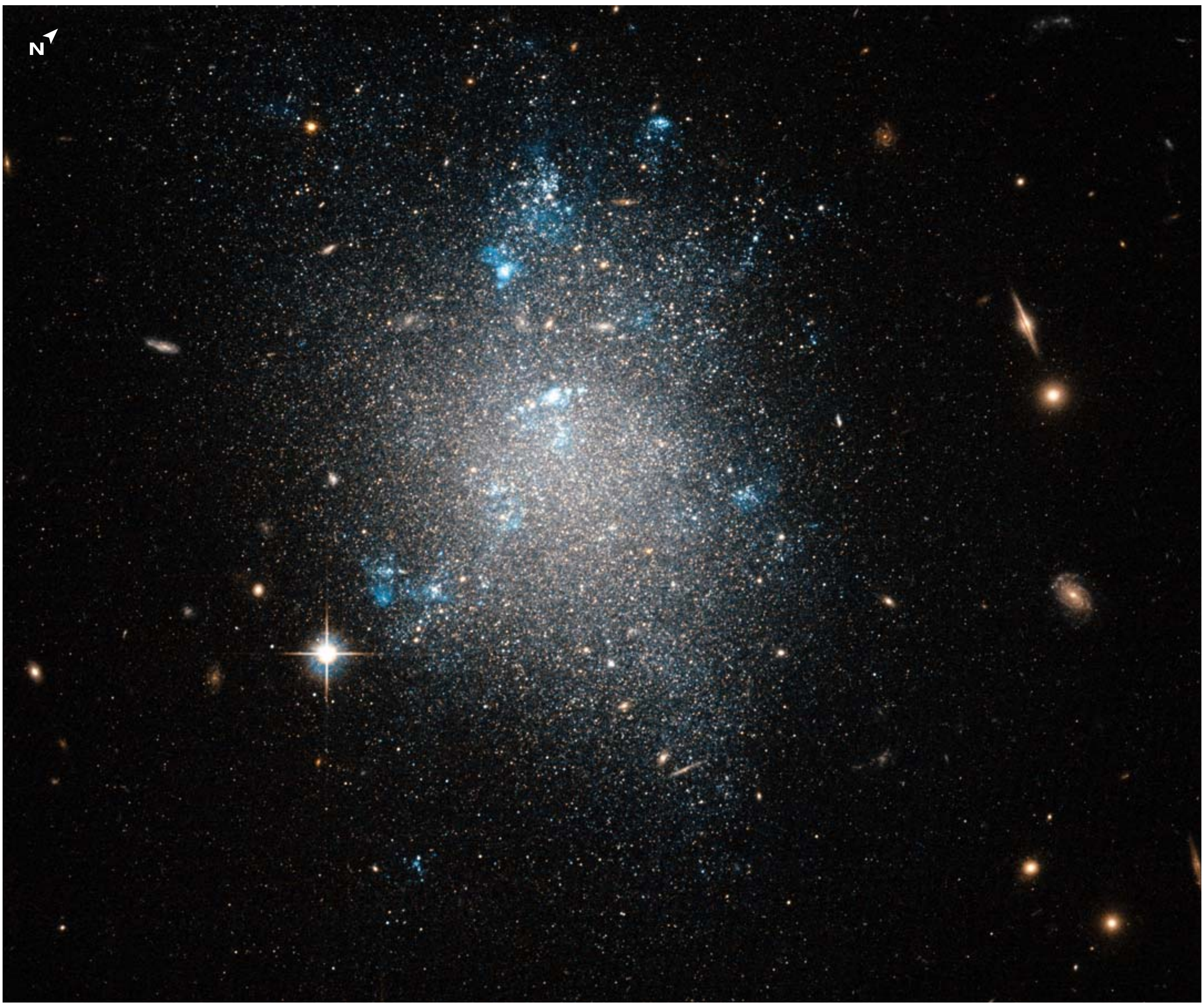
NGC 5473, despite sitting a mere 35′ north-northeast of M101's core, isn't a member of the M101 Group but is included in the Herschel 400 list. I saw this lenticular with my 8-inch at 93×. With the 16-inch, NGC 5473 is very bright at 76× (which is the low power that I use for star-hopping to targets) and shows a bright nucleus and a 14.3-magnitude star northeast of the nucleus.

A tight trio dominated by the lenticular galaxy **NGC 5485** (seen at 93× with my 8-inch) lies only one high-power field east-northeast of NGC 5473. In the 16-inch NGC 5485 is bright, fairly large, round, and brightens gradually toward the visible nucleus. Only 6′ to the north-northeast, the spiral **NGC 5486** is quite large, but it's faint and amorphous with a very faint nucleus. The magnitude-14.7 elliptical **NGC 5484** is small and very, very faint, but easy to find because it's only 4′ northwest of bright NGC 5485. **PGC 50395** lurks in the same high-power field of view, 13′ south-southeast of NGC 5485. This magnitude-13.8 lenticular wasn't included in the *New General Catalogue of Nebulae and Clusters of Stars* — although it's nonstellar it's very small, which is why it may have been omitted.

NGC 5585, an M101 Group spiral lying 3.3° northeast of M101, was obvious at 76×. With the 16-inch at 203× the galaxy is large, bright, and amorphous. At 114× it resembles an unresolved globular cluster.

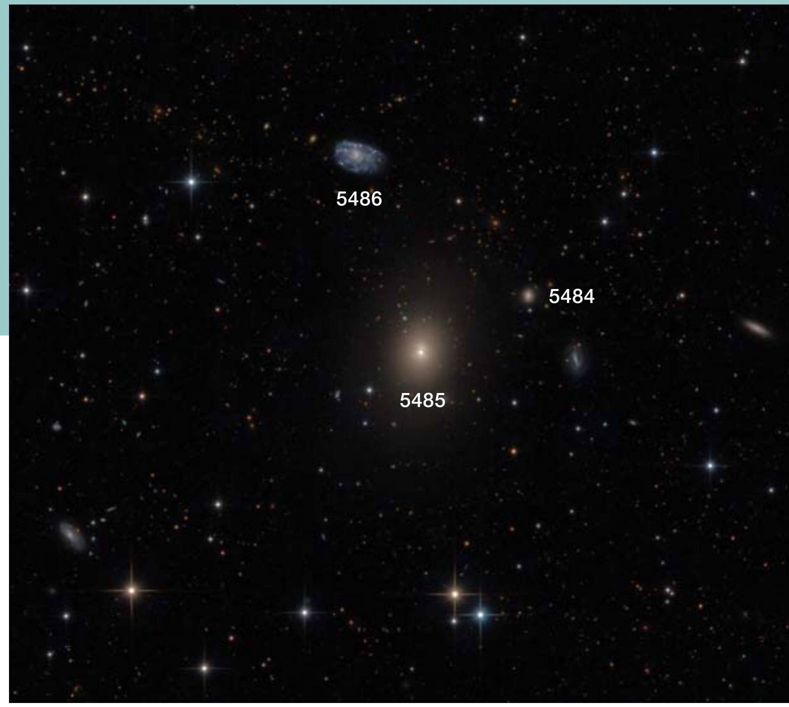
While here, we might as well observe NGC 5585's two bright neighbors, **NGC 5631** and **NGC 5678**. NGC 5631, lying just short of 1° east of NGC 5585, is in the Herschel 400 list and so — even though the galaxy is tiny — I saw it immediately with my 8-inch at 64×. At 203× it was small, round, and moderately faint with a faint nucleus. In the

▼ **IRREGULAR CONGLOMERATION** NGC 5477, another member of the M101 Group, exhibits bright nebulae all across the galaxy. The nebulae comprise glowing hydrogen gas and are the birthplace of new stars. Normally, the clouds of gas would glow pinkish red, but the selection of filters for this image makes these regions look blue or white. Look carefully: Can you see background galaxies peeking through NGC 5477?



ESA / HUBBLE / NASA

William Herschel also rated this beauty a Class-I object, and it was so obvious that I spotted it while simply sweeping around M101 at low power without specifically searching for a prize.



16-inch at the same power I described this lenticular as being bright with a very bright nucleus. How do you see it?

The spiral NGC 5678 is located 1.5° north-northeast of NGC 5631, just across the constellation line in Draco. In the 16-inch it's very obvious at low power as it's a Herschel Class-1 object, or in the "Bright Nebulae" category. After observing it at 203×, my logbook entry read "bright, large and oval, with a gradual brightening to a core holding a nucleus." I also saw the magnitude-9.6 star SAO 29187 (cataloged as Aitken 1106) just 2.5′ north-northwest of NGC 5678, a tight double 2.3″ apart, with magnitudes of 9.7 and 10.9.

Return to M101 to star-hop to an excellent group of three edge-on galaxies centered one low-power field to the north. The closest one to M101, the beautiful lenticular **NGC 5422**, has a bright, elongated core that holds a fairly bright nucleus in the 16-inch. The faint, very elongated halo has a ratio of about 4:1. William Herschel also rated this beauty a Class-I object, and it was so obvious that I spotted it while simply sweeping around M101 at low power without specifically searching for a prize.

NGC 5443, a barred spiral, is bright, large, and elongated at a ratio of 3:1 in the 16-inch. The core is also elongated and shows a nucleus. A 15th-magnitude star sits southwest of the nucleus, and a possible knot is perched northeast. NGC 5443 is very bright even at low power and can be seen with a much smaller aperture.

Through the 16-inch **NGC 5475** is bright, fairly large, edge-on, and elongated at a ratio of 5:1. Its small core displays a nucleus. This spiral is also very easy at 76×.

I believe these three bright edge-on galaxies should all be included in the Herschel 400 observing list. The list comprises targets simply based on catalog magnitudes and, as a result, many bright but — in my opinion — boring galaxies are in it, while numerous bright beauties like these three

▶ **TRIPTYCH** *(Top)* Three galaxy types are neatly represented in this celestial trio: NGC 5484 is an elliptical, NGC 5485 a lenticular, and NGC 5486 a spiral. The three appear to occupy the same corner of space, but in fact the first two lie at a similar distance of around 100 million light-years, while the latter is closer at around 72 million light-years.

▶ **ONE OR TWO?** *(Bottom)* NGC 5238 was once thought to be two interacting galaxies, but careful examination of the galaxy's rotation curve reveals that it's indeed a single object. This irregular galaxy is relatively close, located some 15 million light-years away in Canes Venatici.

NGC 5485: BERNHARD HUBL; NGC 5238: NASA / STSCI edge-ons were omitted. The Herschel 400 observing list was designed for the 6-inch Newtonians that amateurs commonly used decades ago, but these days most serious deep-sky observers opt for bigger instruments. I believe that the Herschel 400 list should be updated so that it actually offers the bright *and best* deep-sky objects beyond the Messiers for Northern Hemisphere observers.

NGC 5204, a spiral 3.5° north of Mizar, is a more distant member of the M101 Group. My 16-inch shows a large oval, elongated by 3:1. It's only a very little bit brighter in the middle, with a very faint nucleus. There are knots or faint stars at both ends of the long axis. Herschel classified it as Class IV, which corresponds to his category of "Planetary Nebulae, Stars with Burs, with Milky Way Chevelure, with Short Rays,

Galaxy-Hop Around M101

Object	Type	Mag(v)	Surface Brightness	Size	RA	Dec.
M101	Spiral	7.9	14.9	28.8′ × 26.9′	$14^h\ 03.2^m$	+54° 21′
NGC 5461	H II region	14.0	—	1.1′ × 0.4′	$14^h\ 03.7^m$	+54° 19′
NGC 5462	H II region	13.5	—	1.5′ × 0.6′	$14^h\ 03.9^m$	+54° 22′
NGC 5455	H II region	13.0	—	0.5′ × 0.5′	$14^h\ 03.0^m$	+54° 14′
NGC 5450	H II region	13.0	—	1.0′ × 0.5′	$14^h\ 02.5^m$	+54° 16′
NGC 5447	H II region	13.5	—	1.0′ × 0.2′	$14^h\ 02.5^m$	+54° 17′
NGC 5471	H II region	15.5	—	0.3′ × 0.3′	$14^h\ 04.5^m$	+54° 24′
NGC 5458	H II region	14.0	—	0.5′ × 0.3′	$14^h\ 03.2^m$	+54° 18′
NGC 5453	H II region	13.8	—	0.3′ × 0.3′	$14^h\ 02.9^m$	+54° 18′
NGC 5449	H II region	14.0	—	1.0′ × 1.0′	$14^h\ 02.5^m$	+54° 20′
NGC 5451	H II region	14.0	—	0.4′ × 0.4′	$14^h\ 02.6^m$	+54° 22′
NGC 5474*	Spiral	10.8	14.0	4.7′ × 4.7′	$14^h\ 05.0^m$	+53° 39′
NGC 5477*	Spiral	14.0	14.7	1.7′ × 1.3′	$14^h\ 05.5^m$	+54° 28′
NGC 5473	Lenticular	11.4	12.8	2.3′ × 1.7′	$14^h\ 04.7^m$	+54° 54′
NGC 5485	Lenticular	11.4	12.9	2.3′ × 1.9′	$14^h\ 07.2^m$	+55° 00′
NGC 5486	Spiral	13.2	13.6	1.7′ × 1.0′	$14^h\ 07.4^m$	+55° 06′
NGC 5484	Elliptical	14.7	13.3	0.5′ × 0.5′	$14^h\ 06.8^m$	+55° 02′
PGC 50395	Lenticular	13.8	13.0	0.9′ × 0.6′	$14^h\ 07.7^m$	+54° 48′
NGC 5585*	Spiral	10.7	13.9	5.8′ × 3.7′	$14^h\ 19.8^m$	+56° 44′
NGC 5631	Lenticular	11.5	12.5	1.7′ × 1.7′	$14^h\ 26.6^m$	+56° 35′
NGC 5678	Spiral	11.3	13.0	3.3′ × 1.6′	$14^h\ 32.1^m$	+57° 55′
NGC 5422	Lenticular	11.9	12.9	3.9′ × 0.7′	$14^h\ 00.7^m$	+55° 10′
NGC 5443	Barred spiral	12.3	13.2	2.7′ × 1.0′	$14^h\ 02.2^m$	+55° 49′
NGC 5475	Spiral	12.6	12.4	2.0′ × 0.5′	$14^h\ 05.2^m$	+55° 44′
NGC 5204*	Spiral	11.3	14.1	5.0′ × 3.0′	$13^h\ 29.6^m$	+58° 25′
NGC 5109	Spiral	12.9	12.6	1.7′ × 0.5′	$13^h\ 20.9^m$	+57° 39′
UGC 8837*	Barred irregular	13.4	15.1	4.6′ × 1.2′	$13^h\ 54.7^m$	+53° 54′
NGC 5368	Spiral	13.0	12.3	0.9′ × 0.7′	$13^h\ 54.5^m$	+54° 20′
NGC 5238	Irregular	13.3	14.1	1.7′ × 1.4′	$13^h\ 34.7^m$	+51° 37′
NGC 5225	Spiral	13.6	12.7	0.7′ × 0.7′	$13^h\ 33.3^m$	+51° 29′
NGC 5250	Lenticular	13.0	12.7	1.0′ × 0.9′	$13^h\ 36.1^m$	+51° 14′

The asterisk denotes M101 Group members. 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.

Remarkable Shapes, etc." The galaxy was obvious at low power during the star-hop.

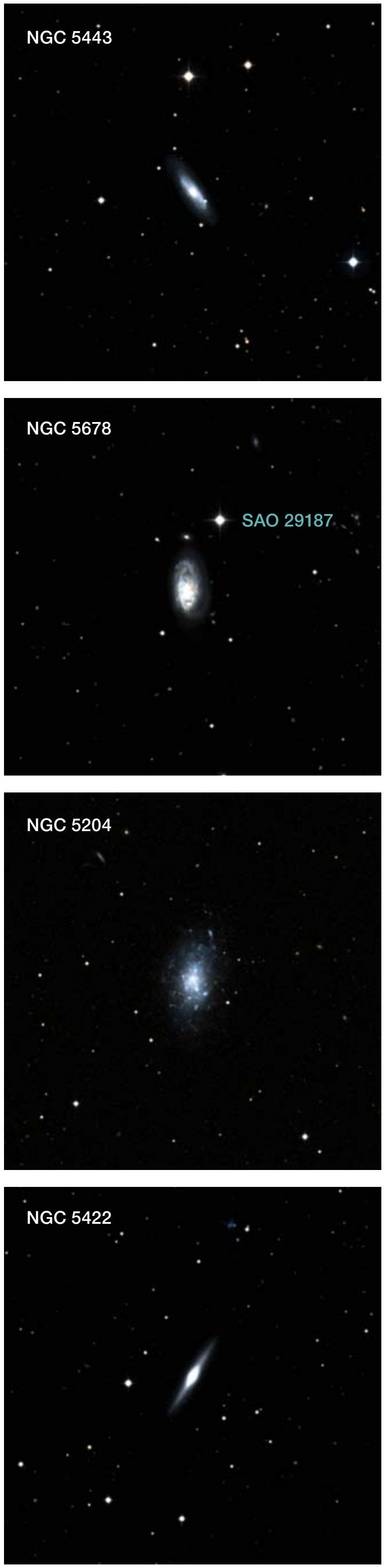
NGC 5109 is one of a close pair of galaxies 1.4° southwest of NGC 5204. The fainter of the two, indicated with an arrow in the image on page 16, is often designated NGC 5113. Gottlieb's excellent website (**https://is.gd/Gottlieb**) discusses the history behind NGC 5109 and NGC 5113. There's no visually detectable galaxy at Herschel's position for NGC 5113 (which he observed 11 months prior to NGC 5109). Astronomers studying the region later on concluded that a faint galaxy nearby was, in fact, the object that Herschel had actually observed. Gottlieb's entry notes that Harold Corwin (of the NGC/IC Project) leans toward NGC 5113 being the same object as NGC 5109. Images do show an elongated and mottled galaxy that is much fainter than NGC 5109 at the position at which the *Millennium Star Atlas* plots NGC 5113. This is the object that I observed, but I note in my master observing log that the faint galaxy should probably be identified as CGCG 294-034 rather than NGC 5113.

Along with all the NGC galaxies in this article, NGC 5113 is listed among William Herschel's 2,400+ deep-sky discoveries. It's very unusual for one of these galaxies to be difficult to see with my 16-inch. My experience in observing targets plucked from Herschel's full list has been that if there's a group of four or five galaxies in a tight clump on my atlas, all of them detectable with my 16-inch, Herschel usually noted only the one or two brightest. So I doubt that he had seen an object as challenging as the galaxy labeled NGC 5113.

I located the spiral NGC 5109 at 76× with some effort. At 203× it's fairly faint, elongated by 4:1, and has a somewhat brighter core along the long axis. The nucleus is barely discernible, and a very faint star sits at the southern tip of the galaxy. I could just detect the adjacent galaxy at magnitude 15.3, some 5′ northeast of its brighter companion.

UGC 8837, another member of the M101 Group, hides 1.3° west-southwest of M101. While at magnitude 13.4, it's 4.6′ long, which yields a surface brightness of just 15.1 magnitudes per square arcminute. With the 16-inch it was large, elongated, and extremely faint. This ghost was very difficult, but the position angle was correct, so I was confident I'd bagged it. A barred irregular galaxy, it's only 13′ northeast of a bright magnitude-5.7 star, 86 Ursae Majoris, which might be why it wasn't discovered by the great visual observers of the late 18th and 19th centuries. Then again, my notes say "not something that you would ever sweep up" with a 16-inch.

NGC 5368, in the same field as UGC 8337, 26′ to its north, was fairly bright in the 16-inch. It's small and round with a nucleus. I saw NGC 5368, a mixed spiral, immediately at low power during my star-hop.



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

◀ **MANY FLAVORS** The galaxies in this sample come in many shapes and orientations. These DSS images are approximately 13′ × 13′. The spirals are the most recognizable, but the edge-on lenticulars, such as NGC 5422, are curious to behold. Can you discern the different characteristics of M101's companions?

Concluding Trio

NGC 5238, a dwarf irregular galaxy 5° southwest of M101 in Canes Venatici, is very faint and amorphous and is possibly a member of the M101 Group. Adjacent **NGC 5225**, a much easier galaxy since I can spot it with low power, is in the same high-power field 15′ farther west-southwest of NGC 5238. A spiral, it's small and round and showing a nucleus. Just barely back across the border in Ursa Major, but also obvious in the same medium-power field of view ½° southeast of NGC 5225, the lenticular **NGC 5250** is fairly bright, very small, and round, with a nucleus.

I hope you enjoyed this visit to M101, the Pinwheel, and the survey of its companions. Maybe this June — or perhaps even next June, or one several years later — you'll take a peek for yourself.

■ Contributing Editor **ALAN WHITMAN** thanks the International Astronomical Union for minor planet 21330 Alanwhitman. This flying mountain will save his heirs the cost of a gravestone.

Treasures of the Sharpless Catalog

NEBULOUS SPLENDOR The Sharpless Catalog was the first exclusive listing of emission nebulae visible from the Northern Hemisphere. Many of the nebulae listed as several objects in earlier catalogs are grouped as single, larger objects. For example, NGC 7000 (top left) and IC 5070 (right) are together listed as Sh 2-117.

Sample some of the delights in the first comprehensive catalog of nebulae.

Like most astrophotographers today, my imaging adventures began on a well-trodden path of celestial showpieces, including the Andromeda Galaxy (M31), the Hercules Cluster (M13), and the Dumbbell Nebula (M27). I occasionally revisit these familiar landmarks to see how my imaging techniques have improved with time. But as my experience and skills developed, I began to look beyond the popular Messier list in search of new and exciting vistas to explore.

While the Messier and NGC catalogs guide us to many splendors for imaging with amateur equipment, other, more obscure compilations are available for those who want to delve into less familiar deep-sky objects. The Sharpless catalog is one such great resource for imagers in the Northern Hemisphere who want to embark on an "off-road" adventure.

A Catalog of Galactic Nebulae

Stewart Lane Sharpless (1926–2013) was a graduate student at Yerkes Observatory who helped with the calculations used to define the UBV photometric system that photographically classified stars according to their colors. This later expanded into the UBVRI system as photographic emulsion sensitivity in the mid-20th century became more responsive to red and infrared wavelengths. Sharpless focused on determining the true structure of the Milky Way Galaxy. In so doing, he estimated the distances to H II regions and hot, young star clusters. This work culminated in a paper published in 1952 with Don Osterbrock in which they conclusively established the spiral nature of our home galaxy.

Sharpless continued his research into the structure of the Milky Way when in 1953 he took a position at the United States Naval Observatory Flagstaff Station in Arizona. There he continued surveying and cataloging H II regions within the Milky Way. But he didn't use a telescope for this task. Rather, he pored through the available plates of the ongoing National Geographic Society – Palomar Observatory Sky Survey (NGS-POSS). This groundbreaking survey, begun in 1949 using the 48-inch Samuel Oschin telescope at Palomar Observatory in California, was the first to image the entire sky down to a declination of –27° in both blue and red light. Because emission nebulosity consists primarily of ionized hydrogen, which emits light at 656.28 nanometers, Sharpless concentrated his efforts on identifying and cataloging emission nebulae exclusively recorded on the red-sensitive Kodak 103a-E plates.

First published in the *Astrophysical Journal Supplement* in 1953, "A Catalogue of Emission Nebulae Near the Galactic Plane" contained 142 objects. Sharpless continued to add to his list as new plates became available. In December 1959, the second and final edition of the catalog appeared; it was titled "A Catalogue of H II Regions" and lists 313 entries. The second edition supersedes the first, prefacing each object with the designation "Sh 2."

Sharpless's goal was to produce a comprehensive catalog of every known emission nebula north of the southerly declination of –27°, although some objects in the catalog lie farther south. His quest focused primarily on H II regions, though his list contains some planetary nebulae and even several supernova remnants like the famous Crab Nebula (M1), designated **Sharpless 2-244**.

Targets for Any Scope

Today, the Sharpless catalog is one of the most comprehensive lists of emission nebulae in the sky for Northern Hemisphere astronomers and astrophotographers. It includes both bright and faint targets — objects suitable for most any telescope.

When I wrote previously about objects that tend to get ignored in favor of their brighter neighbors (*S&T:* Oct. 2018, p. 58), friends noted that I drew heavily from the Sharpless catalog. They're right — the list includes all the familiar bright nebulae visible in northern skies, as well as many faint obscure objects. It's exciting to go after the fainter members of this list, but you probably have unknowingly shot a few Sharpless objects already. Here are a few of my favorites.

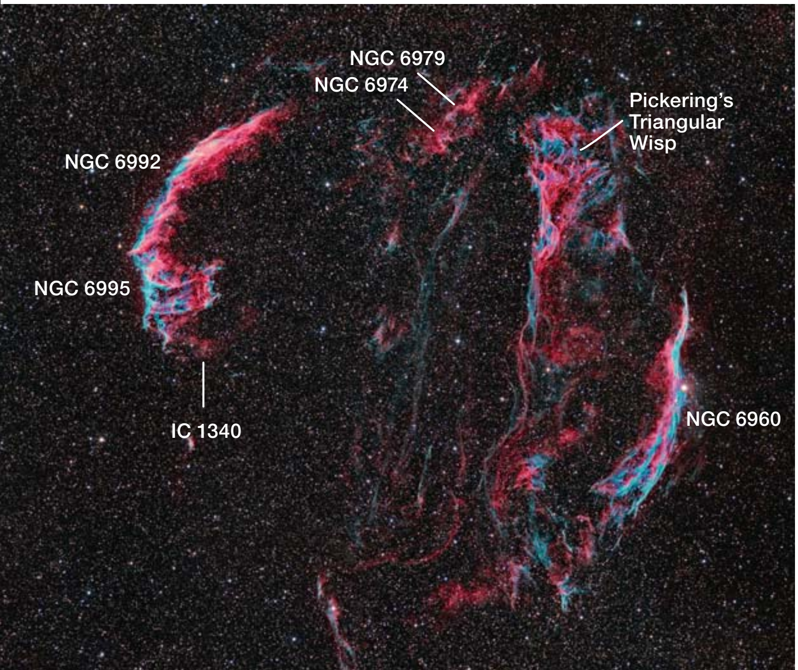
In the Wings of the Swan

I could spend the whole summer — maybe several — just imaging the Sharpless objects in Cygnus. This single constellation contains no less than 26 individual targets, including several showpieces such as the North America Nebula and Pelican Nebula complex (NGC 7000 and IC 5070) east of 1st-magnitude Deneb that make up **Sh 2-117**. Just over 3° to its west lies **Sh 2-119**, an equally large though faint nebula punctuated with several small, dark nebulae.

Almost 10° south of Sh 2-117 is the Cygnus Loop, **Sh 2-103**, which partly spills into Vulpecula. Sharpless

▼ **FAMILIAR FRIENDS** While the Sharpless catalog contains many faint objects, it was meant to be a comprehensive listing of all emission nebulae visible from the Northern Hemisphere. So it includes many well-known objects such as M1, the Crab Nebula, designated Sh 2-244 (below).

SOME REFLECTIONS The vast majority of nebulae that made the Sharpless list are exclusively emission nebulosity, which emits light at the red end of the spectrum. But several objects, including NGC 1977 at top (Sh 2-279) and M42 (Sh 2-281) seen below contain bluish reflection nebulosity.



▲ **SUPERNOVA UNITED** *(Left)* All the individual segments of the nearby Cygnus Loop supernova remnant (noted in the image) are included on the Sharpless list as Sh 2-103. **BIG PLANETARY** *(Right)* Sh 2-290 is one of the closest planetary nebulae visible from Earth, and the only Sharpless nebula in Cancer.

neatly combined the individual segments of NGC 6960, NGC 6992, NGC 6995, NGC 6974, NGC 6979, IC 1340, and Pickering's Triangular Wisp into Sh 2-103.

About 2° southwest of 2nd-magnitude Sadir (Gamma Cygni) is the Crescent Nebula (NGC 6888), cataloged as **Sh 2-105**. This complex nebula is produced by the stellar wind from the Wolf-Rayet star WR 136 at its center. The Crescent is another object that contains a bluish oxygen III (O III) component consisting of a gossamer shell seen along its outer edge.

Continuing about 3° farther along the imaginary line formed by Sadir and the Crescent brings us to **Sh 2-101**, the Tulip Nebula. This moderately bright emission nebula displays small dark lanes in deep exposures.

For a tough summertime challenge, look 3½° south of Sh 2-101 and try to image **Sh 2-98**. As one of the fainter Sharpless catalog members in Cygnus, it looks like a ghostly red smoke ring in a rich field of brightly colored stars. Like Sh 2-105, Sh 2-98's glow is caused by energy from a powerful Wolf-Rayet star, in this case WR 130.

In the northeastern corner of the constellation, **Sh 2-124** tends to be overlooked due to its proximity to so many better-known objects. Lying in a dense star field 3.5° northeast of IC 5146, the Cocoon Nebula, this little nebula is bisected by a wide, meandering dark lane.

Skipping farther south, the Eagle Nebula in Serpens is often referred to as M16, but Messier actually cataloged the open cluster at the Eagle's heart and didn't see the surrounding nebula. Sharpless includes this expansive nebulosity as **Sh 2-49**. Long exposures are required to reveal the extended "wings" of nebulosity that give the nebula its nickname, while larger instruments producing a higher pixel-scale are required to get good detail in the central pillars of dark nebulosity. Just 2° north of the Eagle and part of the same tenuous hydrogen cloud is **Sh 2-54**, which adds additional interest to wide-field photographs of the area.

Northerly Declinations

Targets in the summer Milky Way remain available to northern imagers as the nights lengthen during autumn. But you might also find yourself drawn towards other Sharpless treasures along the Milky Way in Cassiopeia, Cepheus, and Perseus.

One of the best-known deep-sky objects in this region is the Bubble Nebula, NGC 7635, denoted as **Sh 2-162** on the Sharpless list. This thin shell of nebulosity is found about 37′ southwest of the open cluster M52 and is being hollowed out by the strong stellar winds of the young star SAO 20575 within. The Bubble should reveal itself in relatively short exposures. Slightly more than 1° south-southwest of the Bubble Nebula lies the expansive Lobster Claw Nebula, **Sh 2-157**. The Lobster Claw contains a strong O III component and is particularly colorful when imaged through narrowband filters. A wide-field astrograph with a 4° field can frame both objects in the same field and make a nice composition that also includes another interesting nebula, NGC 7538, also known as **Sh 2-158**.

Heading west just over the border in Cepheus, 3⅓° to the northeast lies the Cave Nebula, **Sh 2-155**. This faint target is a

CLUSTERED GROUPING This image features four distinct nebulae near the border of Cassiopeia and Cepheus, including Sh 2-162; the Bubble Nebula (left); Sh 2-161 (top); Sh 2-158, the smaller, bright nebula at top right; and Sh 2-157 (bottom).

OVERSHADOWED Sh 2-119 in Cygnus is a complex object with dark nebulous detail usually passed over in favor of the nearby North America Nebula a little more than 3° to its west.

mix of emission, reflection, and dark nebulosity that makes for a wonderful multi-hued image but requires long exposures.

South-central Cepheus is home to the expansive nebula **Sh 2-131**, better known as IC 1396. This large emission complex is almost 3° across and is a fine autumn target for northern imagers using most any optic. It contains many dark nebulae as well as the well-known Elephant's Trunk Nebula, vdB142, a great target for big telescopes.

Slightly more than 4° northwest of Sh 2-131 is **Sh 2-129**, sometimes referred to as the Flying Bat Nebula. This faint emission nebula was revealed to host a large and even fainter bipolar nebula known as Ou4, the Squid Nebula, which consists entirely of doubly ionized oxygen nebulosity. Discovered just nine years ago by French astrophotographer Nicolas Outters, Ou4 is *exceedingly* faint. I needed more than 100 hours of exposure before I was satisfied with the result.

Targets for Long Nights

One of my favorite winter targets is the Sword of Orion, which contains two well-known objects that also grace Sharpless's list: the Great Nebula in Orion (M42), also known as **Sh 2-281**, and the Running Man Nebula (NGC 1977), which makes the catalog as **Sh 2-279**. While much can be said about these two famous clouds of glowing gas, both sport large- and small-scale details in camera lenses and large telescopes alike. As one of the brightest emission nebulae, Sh 2-281 is among the most photographed regions of the sky, beckoning to both beginners and seasoned astrophotographers.

Far north and straddling the borders of Camelopardalis and Perseus lies **Sh 2-205**, sometimes referred to as the Peanut Nebula. This large, faint nebula requires a wide-field camera and telescope combination producing at least a 3° field of view to record the entire object's irregular shape.

◀ **STELLAR WINDS** Another familiar object to deep-sky imagers is NGC 6888, the Crescent Nebula, cataloged as Sh 2-105 on the Sharpless list. This nebula is the product of a fierce stellar wind emanating from the Wolf-Rayet star at its center colliding with the surrounding molecular cloud that fills most of Cygnus.

◀ **HIDDEN GEM** *(Top)* Located in the northeast corner of Cygnus, Sh 2-124 is an emission nebula bisected by a prominent dark lane.

◀ **BONUS CONTENT** *(Middle)* The large, faint Flying Bat Nebula, or Sh 2-129, in southwestern Cepheus also hosts the extremely faint bipolar outflow Ou4, often called the Giant Squid.

◀ **WINTER TREATS** *(Bottom)* Another popular nebula during the winter months, supernova remnant IC 443 makes the catalog as Sh 2-248 (lower right), as well as the fainter, diffuse nebulosity of Sh 2-249 (IC 444) seen in the image at middle left.

For a more formidable challenge, aim your rig at the similarly sized and very faint supernova remnant **Sh 2-221** in Auriga. Although the hydrogen-alpha (Hα) signal in this target is relatively strong, long exposures through an O III filter will reveal teal-colored tendrils and a foglike haze surrounding this mostly red nebula.

While most of the fainter Sharpless objects lack common names, I refer to a few by the shapes they remind me of as I spend time processing their images. For example, **Sh 2-232** in Auriga reminds me of a jelly donut and so will forever be the Jelly Donut Nebula in my mind. This roughly 40′ circular nebula gives great results when imaged through an Hα filter. It also contains two snake-like dark nebulae, and a trio of prominent stars near its center. Smaller, brighter **Sh 2-235** is right next door to the southwest, enhancing the field of view. Astro-imagers with longer focal-length instruments targeting Sh 2-235 can reveal several orangish Herbig-Haro objects just off its southwestern edge, hinting at newly formed stars within.

Planetaries and Supernovae

Besides general emission nebulae, the Sharpless catalog includes quite a few nebulae produced during the final stages of a star's life cycle.

One excellent target is the Jellyfish Nebula, IC 443, found just east of the 3rd-magnitude star Propus in Gemini. Sharpless lists this complex nebula as **Sh 2-248.** It's a little less than 1° across, but if you use a wide-field astrograph, you can also sweep up the adjacent nebulosity of **Sh 2-249**. The Jellyfish is another example of a large supernova remnant that can appear as a striking, multi-colored image when shot through narrowband filters. Another interesting target is the large, faint planetary nebula **Sh 2-290** (Abell 31) found in southern Cancer. Estimated to be about 2,000 light-years distant, it's one of the closest and largest planetary nebulae, measuring 17′ in diameter. Sh 2-290 has a core dominated by teal-colored O III encased in a faint red hydrogen shell and wispy features visible in high-resolution images taken with larger instruments.

Plan Your Approach

Imaging targets from the Sharpless catalog is in some ways easier than photographing galaxies. While galaxies emit light across the visible spectrum, emission nebulae emit light at specific wavelengths that can be isolated from most sources of light pollution. This means that urban imagers equipped with narrowband filters will be rewarded with colorful results and rich details despite their bright skies.

Regardless of your sky's darkness, if you are using a monochrome camera, narrowband filters are a good option for imaging Sharpless objects. Hydrogen-alpha provides the predominant signal for most Sharpless objects, so imaging through an Hα filter is beneficial and can give you great results on its own or combined with O III- and S II-filtered images. Plan on gathering plenty of exposures for the particularly dim nebulae in the catalog — that will give you the best chance of revealing the faintest structures that your gear and sky conditions will permit. You can even achieve good narrowband images of bright emission nebulae under a gibbous Moon.

Extended nebulae in the catalog are best imaged with short-focal-length instruments combined with a large sensor. Shoot the faintest targets on the most transparent, Moon-free nights.

Conversely, longer focal lengths are helpful for the smaller targets. For objects that contain small-scale detail, nights of good seeing will produce the most satisfying results.

Additional Information

This article barely scratches the surface of this wonderful resource. If you'd like to delve deeper into the Sharpless catalog, perhaps the best place online today is Dean Salman's *The Best of the Sharpless Catalog* at **sharplesscatalog.com**. There you'll find a list of all 313 objects and their J2000 coordinates, as well as Dean's images of many Sharpless objects taken through color and narrowband filters.

Whether you prefer imaging showpiece targets or like to hunt for obscure treasures, think about consulting the Sharpless catalog. This comprehensive list of objects reveals the rich distribution of nebulosity within the Milky Way.

■ By night, **RON BRECHER** is a deep-space imager residing in Guelph, Ontario. Visit his website at **astrodoc.ca**.

Select Nebulae of the Sharpless Catalog

Object	Common Name	Constellation	Size	RA	Dec.
Sh 2-49	M16	Serpens Cauda	35′ × 28′	$18^h 19^m$	–13° 58′
Sh 2-54		Serpens Cauda	60′ × 30′	$18^h 18^m$	–11° 40′
Sh 2-98		Cygnus	15′	$19^h 59^m$	+31° 25′
Sh 2-101	Tulip Nebula	Cygnus	18′ × 10′	$20^h 00^m$	+35° 17′
Sh 2-103	Veil Nebula	Cygnus / Vulpecula	210′	$20^h 51^m$	+30° 55′
Sh 2-105	NGC 6888	Cygnus	18′ × 13′	$20^h 12^m$	+38° 21′
Sh 2-117	NGC 7000, NGC 5068	Cygnus	240′	$20^h 55^m$	+44° 13′
Sh 2-119	LBN 400	Cygnus	160′	$21^h 18^m$	+43° 56′
Sh 2-124		Cygnus	70′	$21^h 38^m$	+50° 21′
Sh 2-129	Flying Bat Nebula	Cepheus	110′ × 100′	$21^h 12^m$	+59° 57′
Sh 2-131	IC 1396	Cepheus	170′ × 140′	$21^h 39^m$	+57° 30′
Sh 2-155	Cave Nebula	Cygnus	50′ × 30′	$22^h 57^m$	+62° 37′
Sh 2-157	Lobster Claw Nebula	Cassiopeia	90′	$23^h 16^m$	+60° 02′
Sh 2-162	Bubble Nebula	Cassiopeia	15′ × 30′	$23^h 21^m$	+61° 12′
Sh 2-205	Peanut Nebula	Camelopardalis / Perseus	100′ × 30′	$03^h 56^m$	+53° 12′
Sh 2-221		Auriga	120′	$05^h 02^m$	+46° 21′
Sh 2-232	Jelly Donut Nebula	Auriga	40′	$05^h 42^m$	+36° 12′
Sh 2-235		Auriga	7′ × 5′	$05^h 41^m$	+35° 51′
Sh 2-244	Crab Nebula, M1	Taurus	6′ × 4′	$05^h 35^m$	+22° 01′
Sh 2-248	IC 443	Gemini	50′ × 40′	$06^h 17^m$	+22° 47′
Sh 2-249	IC 444	Gemini	8′ × 4′	$06^h 20^m$	+23° 16′
Sh 2-279	NGC 1977	Orion	20′ × 10′	$05^h 35^m$	–04° 52′
Sh 2-281	Orion Nebula	Orion	65′ × 60′	$05^h 35^m$	–05° 27′
Sh 2-290	Abell 31	Cancer	17′	$08^h 54^m$	+08° 55′

Angular sizes and separations are from recent catalogs. Right ascension and declination are for equinox 2000.0.

The Explore Scientific FirstLight 8" Dobsonian

This modestly priced Dobsonian is a solid performer.

▲ The Explore FirstLight 8″ Dobsonian is an easy-to-use starter scope or nice upgrade for the budding backyard astronomer. The compact unit weighs less than 50 lbs fully assembled.

ALL PHOTOS ARE BY THE AUTHOR

Explore Scientific First-Light 8″ Dobsonian

U.S. Price: $499.99

Telescope.com

What We Like

Good optics
Quick setup
Compact for storage

What We Don't Like

No optical finderscope
Slightly oversized spider hub
Errors in assembly instructions

EXPLORE SCIENTIFIC'S FIRSTLIGHT series offers telescopes of various sizes, mount designs, and optical configurations. Some are small, entry-level instruments — quickly set up, simply operated, and easily stored. For this review, we acquired a larger yet still user-friendly model in the FirstLight lineup: an 8-inch f/6 Newtonian reflector on a manually operated Dobsonian-style mount. The product arrived at my home in two well-packed, reinforced cardboard boxes. One squarish box was a "flat pack" of the various laminated particleboard pieces requiring assembly to make the Dobsonian rocker box. A longer box contained the optical tube assembly (OTA), which, at first glance, looked ready to go under the stars right out of the gate.

Some Assembly Required

The flat pack meant work! Anyone who's purchased u-build furniture like that from Ikea will recognize the procedure, though the provided wordless quick-assembly pamphlet guides you along. A detailed instruction manual exists online. Oddly, however, it isn't mentioned in the pamphlet. If you seek help on the scope's website (**https://is.gd/ESdob**), you'll be happy to know the link to the written instruction manual is cleverly hidden in a tab labeled "Extras."

Both assembly instructions contain errors. In the pamphlet, for example, the illustrated parts list shows two semicircular altitude bearings but suggests there are four by labeling each bearing "2×". Another head-scratcher, both in print and online, depicts the round base plate with four bolt holes when, in fact, there are six. The online manual begins by using both numbers and letters to identify the same components. Later, the parts aren't labelled at all. During each step of the instructions, we're forced to return to the early graphics to match letters and numbers to illustrated parts. Fortunately, assembly is essentially an intuitive exercise.

Two hours later, the entire scope was put together and I was itching to get it outside. I first verified that collimation of the OTA had survived shipping by analyzing a reflection of the primary mirror and its paper donut center mark using my peep-sight collimator inserted into the scope's focuser. The primary mirror is supported in a flotation cell with three large, easy-to-turn collimation screws. Its secondary mirror assembly sports a four-vane spider holding a substantial central hub with three collimating screws for manipulating the gimble mount on which the secondary mirror is cemented. Although Explore Scientific claims the secondary produced a 24% obstruction, the hefty hub is in fact 2½-inches wide — 31% of the primary's 8-inch diameter. A blockage of this size subtly diminishes the visibility of low-contrast planetary detail.

First Light for the FirstLight

I transported the 9½-kg (21-pound) combo of base plate and rocker box to my backyard patio. I then lifted the 11-kg OTA using the attached altitude bearings as handles. Some advice: Before placing the tube on the rocker box, ensure the inner lateral guides, one on each bearing, aren't too tight, or else the bearings won't fit onto the rocker base. I loosened the guides slightly with a 2-mm hex key. Also, because the guides slide along the inside of the rocker walls, the slightly loose fit will result in smoother altitude motion. (A tighter fit increases friction in altitude motion, if you prefer.) Be mindful that the altitude bearings rest on the rocker. You can rotate the OTA within adjustable tube rings to bring the focuser to a comfortable viewing position and even slide the tube forward and back to ensure best balance with all your eyepieces. But rotate the tube carefully or else it will literally twist off your rocker!

Inserting the supplied 25-mm "SuperPlössl" eyepiece in the focuser and aiming at a bright star resulted in an unexpected problem. I couldn't focus the image, even when the focuser was racked all the way out. The focal plane is positioned so far outside the OTA that a supplied 1½-inch-long "spacer sleeve" must be threaded onto the focuser for the use of almost any ocular. The crucial sleeve is pictured, but not identified, in the pamphlet. In the online manual, it's erroneously described as an optional accessory for special situations, such as "extreme" eyepieces. However, this extra back focus should allow the FirstLight to accommodate most any binoviewer on the market.

▲ The scope's mirror cell features three easily manageable collimating screws and three smaller locking screws. Note the textured metal surface on the altitude bearing (right), which permits smooth up-and-down motion.

After adding the sleeve, I focused the star and noticed some edge-of-field distortions typical of a fast Newtonian — nothing serious. Changing to my best-quality 9-mm eyepiece and centering the star in the 135× field, I was pleased to behold an Airy disk and diffraction pattern of reasonable symmetry inside and outside of focus, with no astigmatism evident. Tapping the tube results in a damp-down time of about three seconds — not bad.

The telescope's 2-inch rack-and-pinion focuser operates smoothly. A friction screw permits increasing or decreasing the sensitivity of the focusing motion, and two more knurled screws at the base of the focuser are for locking the motion if desired. On my unit, they didn't lock the motion at all, though the robust focuser has never slipped, even under the strain of my heaviest ocular. In both the 2-inch barrel and the included 1¼-inch adapter, two knurled screws push against a compression band to secure eyepieces without marring your eyepiece barrels — a nice touch.

For comfortable aiming and tracking, I sat on a stool, one hand on the front end of the tube and the other on an altitude wheel. The FirstLight produces reasonably smooth motion in both altitude and azimuth. The altitude bearings, covered by a strip of textured metal, glide easily atop Teflon pads. A central bolt at the base of the rocker box can be tightened or loosened to adjust tension in azimuth, though loosening the bolt too much introduces sloppiness. The only significant stickiness occurred when I targeted the area around the zenith — a notorious Dobsonian no-fly zone. Whenever I stubbornly tracked an object in the so-called Dobson hole,

▲ The 2½-inch-wide secondary mirror assembly features a robust central hub that's slightly bigger than the width (minor axis) of the secondary mirror itself. Its three collimating screws make adjustments easy. The tube's interior is evenly painted flat black throughout.

I needed "both hands on the wheel" to reduce any jerky azimuth motion.

There's another zenith issue to consider. The balance point for the OTA makes observing straight up potentially problematic. The tube's bottom end barely clears the base of the rocker box when the tube is balanced to support a lightweight eyepiece. But if you add an optical finderscope or heavy ocular (certainly if you add both), you'll have to rebalance the OTA downward to compensate for the extra front-end weight, or else risk the scope slowly slipping in altitude when aiming at low objects. Unfortunately, any amount of downward shift will result in the tube's bottom end hitting the rocker box when aiming high overhead.

Lots of Exploring

Most of my observing with the FirstLight took place in my suburban yard — latitude 49.2°. Although Jupiter and Saturn, temporarily stuck in the lowest point of the zodiac, crested a mere 20° above my south horizon, the scope delivered pleasing views of them at 135× to 175×. Examining Jupiter one especially calm June night, I noted several dark belts, plus two dusky festoons stretching diagonally across the planet's pale Equatorial Zone. The Great Red Spot was obvious despite its diminished size. Saturn was superb. Each ansae in the nearly wide-open ring system was cut by the dark thread of Cassini's Division. Saturn's oblate disc exhibited subtle shading in its northern hemisphere.

The Moon was a wonderland of detail. Surveying the lunar crescent at 50× with the 25-mm SuperPlössl, I couldn't miss the coal-black craterlets in Mare Crisium. At first quarter, doubling the magnification allowed me to trace several fine rilles in the Triesnecker region. Two nights later, I had no trouble spotting the sequence of large-to-small craterlets on the floor of my favorite crater, Clavius. The stepped terraces along the inner walls of Copernicus and Tycho were crisply delineated. A few evenings ahead of full Moon, Aristarchus gleamed at 200×. I detected the tortured terrain in the adjacent Schröter's Valley, plus the nearby volcanic pimples known as the Marius Hills. No budding lunaphile will be disappointed with the appearance of the Moon in this telescope.

Stepping out from the solar system, the FirstLight performed well on a variety of double stars. Operating at between 125× and 150×, the scope easily split the showcase binaries Castor in Gemini, Algieba in Leo, Porrima in Virgo, Almach in Andromeda, and the Double-Double in Lyra. I enjoyed resolving unequal tandems, such as Izar in Böotes, Rasalgethi in Hercules, Delta Serpentis, and Kappa Geminorum. Albireo in Cygnus and 24 Comae Berenices both displayed colors that were particularly vivid.

Globular cluster M13 in Hercules was surprisingly bright and partly resolved at 50×; at 135× it was immensely satisfying. The Ring Nebula, M57, in Lyra, was a delightful donut at high power. The Dumbbell Nebula, M27, in Vulpecula, resembled a fuzzy apple core, then morphed to appear as a diffuse, semi-transparent "planet" when spied through a UHC narrowband filter.

When away from city lights, I enjoyed low-power sweeps of the Milky Way through the scope. The Veil Nebula in Cygnus was amazingly distinct with the aid of a UHC filter. At 135×, again filtered, the scope captured the faint and fragile Crescent Nebula (NGC 6888), also in Cygnus. Due to its modest field of view, the SuperPlössl couldn't quite frame the entire Pleiades Cluster, but the 25-mm ocular showed the little red and blue double star inside the gorgeous group. The field-spanning Andromeda Galaxy boasted parallel dust lanes and two companion galaxies.

▲ Be careful when placing the OTA in the rocker box — the bearings merely rest on pads located on top of the box's curved upper surface. Care must also be taken when rotating or sliding the telescope tube within the tube rings or else the tube can become dislodged from the rocker box.

▲ Two plastic lateral guides, one affixed to the interior of each altitude bearing, fit inside the curved part of the rocker and slide against it as the scope is aimed higher or lower. The lateral guides on the author's test unit arrived too tight; loosening them allowed the bearings to fit properly and slide more freely. Note the Teflon pad (one of two) under the bearing. The textured metal strip lining the bearing provides smooth motion.

In my icy driveway on a frosty February night, the electronics-free Dobsonian suffered no operational limitations and continued to provide great observing experiences. The open clusters M36, M37, and M38 in Auriga each looked distinctly different at 50×. M35 in Gemini was particularly fabulous through the scope — a beady arc of light in the northern part of the cluster resolved into a chain of at least nine stars. M35's teensy neighbor, NGC 2158, was faint yet definite. At 135×, M46 in Puppis was a pale dusting of stars; a UHC filter revealed planetary nebula NGC 2438 within the cluster. And the Great Orion Nebula, M42, displayed broad wings of nebulosity through the unfiltered telescope. The tiny Trapezium energizing M42 sparkled cleanly at 50×.

Final Considerations

The FirstLight 8-inch Dob comes with a red-dot viewfinder, which is the weakest point of the package. This flimsy plastic unit-power spotter is inadequate for locating anything dimmer than bright stars. The limitation is made worse by a tinted viewscreen (think mild sunglasses) that attenuates the viewfinder's field. The first accessory I'd advise you to buy to improve the scope is a right-angle optical finderscope. But buyer beware:

▲ The telescope tube of the FirstLight 8-inch Dobsonian, as delivered, and when properly balanced, barely clears the base of the rocker box when pointed high up. Adding a heavy ocular (such as the author's 2-lb, 31-mm Tele Vue Nagler), and the resulting rebalance of the tube downward, causes the mirror-end of the tube to strike the base.

The mounting shoes (there are two, one on either side of the focuser) are of proprietary design, accepting only Explore Scientific finders.

Explore Scientific's online promotion confusingly claims this FirstLight can be converted into a Newtonian telescope. A subsequent statement tells us that the Newtonian OTA can be attached to an equatorial mount via "the included Vixen-style dovetail plate." No such accessory was in the kit I received. The promotional blurb also states that an ". . . included adapter helps observers use their smart device to capture and share images." Neither the quick-assembly pamphlet nor the online instruction manual refers to the adapter, which is appropriate because this accessory, too, wasn't in the kit. Pity. A smartphone adapter fully explained (and actually in the box!) would appeal to the growing number of people whose smartphones are also their cameras.

All quibbling aside, I wouldn't hesitate to recommend this telescope to anyone starting out in the hobby, or a novice wanting to upgrade to a bigger yet still uncomplicated and affordable aperture. Decades ago, when I was 17 and rapidly outgrowing my tiny 60-mm Tasco refractor, I acquired a friend's home-built, 8-inch Newtonian reflector — a long-focus monster on a massive steel mount and cinder-block base. I'm sure I would have preferred, had it existed, the compact FirstLight. It's not perfect, but it's good value for the money.

■ **KEN HEWITT-WHITE** enjoys observing the night sky from his home in suburban Chilliwack, British Columbia, Canada.

▶ The 2-inch rack-and-pinion focuser includes a knurled thumbscrew between the focusing knobs, allowing you to adjust the tension of the focus motion – helpful when employing a heavy eyepiece.

▶▶ Two locking screws located near the base of the focuser are intended to prevent slippage but did not seem to function on the review unit. A metric Vernier scale is inscribed on the drawtube. The supplied 25-mm eyepiece focuses at the 30-mm mark, or roughly 8 inches outside the telescope tube with the black "spacer sleeve" inserted between the drawtube and the 2-inch eyepiece holder.

 by Andrew Jones

In July 2020 at the Wenchang Satellite Launch Center on the island province of Hainan, engineers will be preparing one of China's largest rockets for takeoff. The Long March 5 has a payload capacity similar to the Delta IV Heavy, which has carried craft such as NASA's Parker Solar Probe into space. The payload for the Long March 5's launch this summer will be the country's first independent interplanetary mission, joining NASA's Mars 2020 rover and the United Arab Emirates' Hope Mars mission this year in heading for the Red Planet.

The go-ahead for launch of Huoxing 1 ("Mars 1") depended on the successful return-to-flight of the Long March 5 in late December 2019, following the second launch's failure in 2017. While there's certainly pressure to succeed, China's fate is in its own hands. That wasn't the case less than a decade ago, when its first interplanetary adventure rode on another nation's rocket. The first attempt to reach Mars was a small orbiter that piggybacked on Russia's 2011 Phobos-Grunt sample-return mission. But an upper stage failure meant both spacecraft failed to leave Earth orbit.

With Queqiao in place to facilitate communications, China was poised to do something never before attempted.

The upcoming Huoxing 1 mission will be much more complex, reflecting China's growth in both capabilities and ambitions. The mission will consist of both an orbiter — equipped with a suite of science payloads and medium- and high-resolution cameras, the latter comparable to HIRISE on NASA's Mars Reconnaissance Orbiter — and a small, 240-kilogram rover. With a design lifetime of 90 days, the rover seeks to discover the distribution of water ice under the Martian surface using ground-penetrating radar — an instrument that has never been deployed on Mars's surface. It will also carry its own laser-induced breakdown spectroscopy instrument, similar to that of Curiosity, as well as equipment to analyze the climate, magnetic field, and surface composition. The landing site is expected to be within Utopia Planitia, south of the Viking 2 lander. Assessing Martian morphology, geology, and climate are all major science goals of the mission.

Placing an orbiter around Mars would match India's stunning 2014 achievement, but sticking the rover landing would be spectacular: Only NASA has successfully operated on the Red Planet for more than a minute. That China is ready to make such an attempt demonstrates the huge strides its space program has made.

HOW DO YOU SAY IT?

Chang'e is pronounced "chahng-uh," where the "uh" is like the e in "her."

Lunar Learning Curve

While they do have an element of seeking international prestige and domestic support, China's space efforts also have clear science objectives and even far-sighted goals. These are apparent first in its long-game approach to the Moon. China's plans for the Moon are extensive and make use of accumulated engineering capabilities and technological achievements. It has already landed twice on the lunar surface and has four more missions in the works.

First came Chang'e 3, which landed in Mare Imbrium in 2013. Quietly and somewhat surprisingly, Chang'e 3 is still running. While the Yutu ("Jade Rabbit") rover lost roving ability after two lunar days and ceased operating completely in 2016, the solar-powered lander still wakes up every lunar daytime, protected from the extreme cold of the night by a radioisotope heater unit. Updates these days come not from China, but from radio amateurs, who pick up signals sent from the lander to ground stations. Only one of eight payloads — the Lunar-based Ultraviolet Telescope (LUT) — was reported working by 2017. Scientists have used LUT's data to put an upper limit on the amount of water within the tenuous lunar exosphere.

Despite a limited drive that totaled 114 meters (374 feet), the Yutu rover used its ground-penetrating radar to reveal a surprising number of layers within the first dozen meters or so of the surface. The result hinted at a more complex geological history than researchers had previously thought happened. However, a 2018 follow-up study by Chinese and Italian scientists calls the interpretation into question, suggesting that some of these layers are actually artifacts.

When preparing Chang'e 3, China also manufactured a backup. After the successful 2013 landing, engineers repurposed this backup, Chang'e 4, for a more ambitious feat.

The first clue as to what Chang'e 4's mission would be came in 2014 from the test mission Chang'e 5 T1, when the spacecraft returned a stunning image of the lunar farside and distant Earth. Then in May 2018 a communications relay satellite, named Queqiao ("Magpie Bridge"), was launched and sent into a halo orbit around the second Lagrangian point of the Earth-Moon system, tens of thousands of kilometers beyond the Moon. From this orbit, Queqiao is able to maintain a constant line of sight with both terrestrial ground stations and the lunar farside, which due to tidal locking never faces Earth.

With Queqiao in place to facilitate communications, China was poised to do something never before attempted: Chang'e 4 made the first-ever soft landing on the farside of the Moon in January 2019. The spacecraft descended automatically, avoiding hazards to set down on a relatively flat area of Von Kármán Crater within the massive South Pole-Aitken (SPA) Basin — a gigantic, ancient impact crater. Shortly after landing, Chang'e 4 deployed the 140-kilogram,

China Launches to Center Stage

A bold series of successful and proposed missions are catapulting China to prominence in space.

XIAO CHEN

LIFTOFF The Long March 5 rocket launches from Wenchang in December 2019.

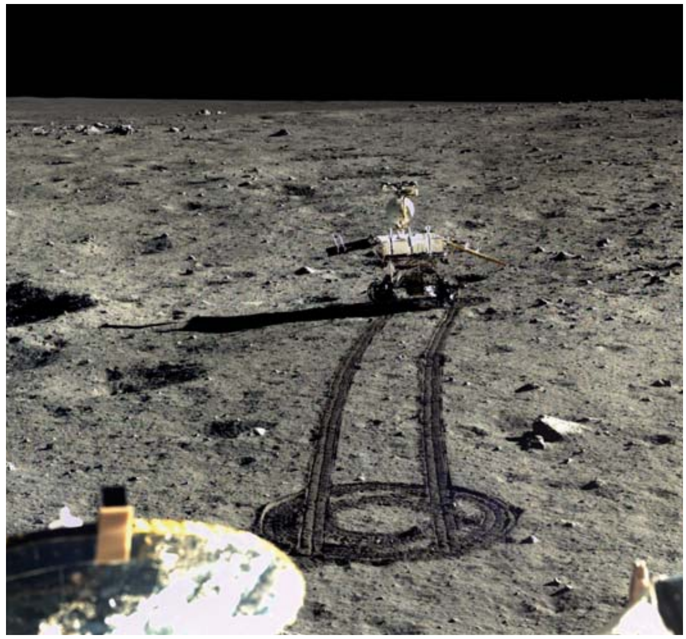
six-wheeled Yutu 2 rover on the surface.

The Chang'e 4 lander is equipped with a low-frequency radio spectrometer that takes advantage of its unique position on the lunar farside, where it's shielded from electromagnetic interference from Earth. This instrument will make unprecedented observations at frequencies blocked by Earth's atmosphere. A similar instrument, the Netherlands-China Low Frequency Explorer, flies aboard Queqiao. Both instruments could eventually detect neutral hydrogen in the cosmic dark ages that preceded the universe's first galaxies.

The lander also carries the Lunar Lander Neutron & Dosimetry experiment from Germany, which will measure the radiation environment. Those readings could be instructive for future crewed lunar missions.

The first major results returned from Chang'e 4, however, came courtesy of Yutu 2's Visible and Near-Infrared Imaging Spectrometer (VNIS), which detects light reflected off materials on the surface. Similar instruments are also aboard Chang'e 3 and the future Mars rover. In May 2019, Chunlai Li (Chinese Academy of Sciences, Beijing) and colleagues reported that VNIS readings suggest the presence of olivine and low-calcium pyroxene within the regolith near the landing site — materials that may originate from the Moon's mantle. A second study by Sheng Gou (also Chinese Academy of Sciences, Beijing) and others supports this claim. They conclude that lunar regolith and rock fragments likely contain materials excavated from the upper mantle by the impact that created the nearby crater Finsen.

Yutu 2 has also given us a look at the lunar subsurface. The first published results from the rover's Lunar Penetrating Radar 2 indicate three distinct layers of regolith extending to a depth of 40 meters below the surface and embedded with boulders of various sizes, providing a unique insight into the geological history of Von Kármán (see page 10).



▲ **INTREPID YUTU** This four-image mosaic from the Chang'e 3 lander shows the 1.5-meter-tall Yutu rover driving southward on the Moon on December 23, 2013.

Towards a Lunar Research Base

Chang'e 1 and 2, launched in 2007 and 2010, respectively, were orbiters that mapped the Moon — with the latter also performing a flyby of near-Earth object Toutatis in 2012. Chang'e 3 and 4 were landing and roving missions. Next up will be the third phase of China's lunar exploration project, initially conceived in the early 2000s: sample return. The Chang'e 5 mission, currently slated to launch in late 2020, aims to collect up to 4 kilograms from a site near Mons Rümker in Oceanus Procellarum on the Moon's nearside.

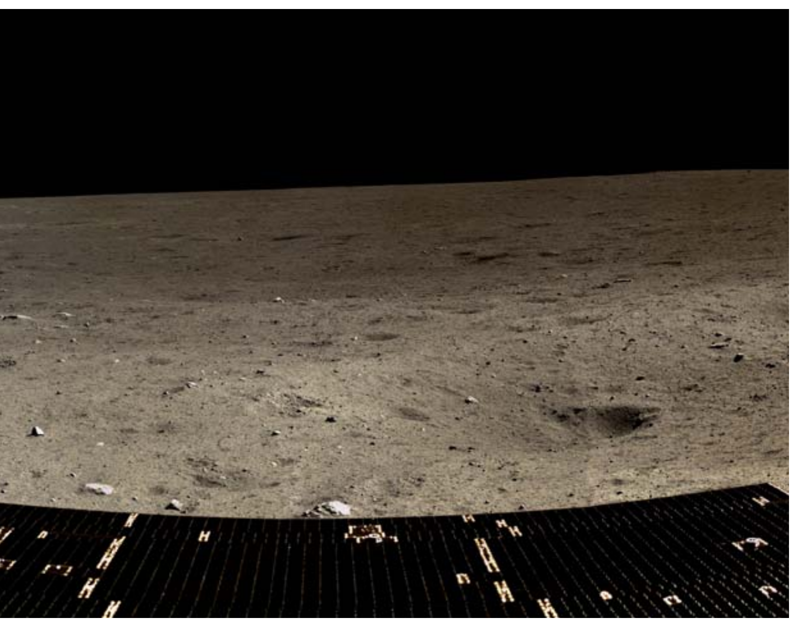
VIEW FROM CHANG'E 3 This section of a panorama taken three days after Chang'e 3's December 2013 landing shows the rover, Yutu, as well as a crater with bright rocks on its rim.

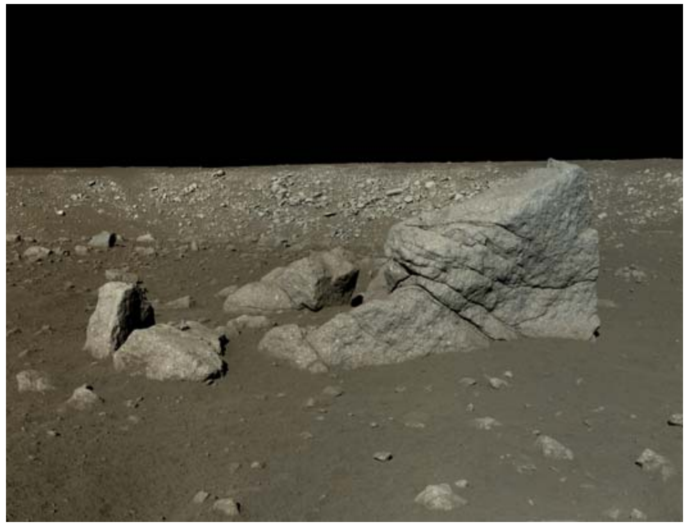
Rather than a direct sample return like the last such mission, the 1976 Soviet Luna 24, Chang'e 5 will employ a robotic lunar orbit rendezvous. An ascent vehicle will launch from the lunar surface and meet up with a waiting service module, which will then head back to Earth and release a return capsule. The capsule will land in the same area as China's crewed Shenzhou missions.

This otherwise unnecessary complexity has been taken as a signal that China is looking to use the mission to prove technologies for future crewed lunar missions, which could take place in the 2030s. If Chang'e 5 succeeds, the backup Chang'e 6 will target the lunar south pole. It will also carry the French Detection of Outgassing Radon instrument, which aims to study the transport of volatiles through the lunar regolith and in the lunar exosphere.

Following the success of its first set of Moon missions and the shift in international interest toward lunar exploration over the last 10 years, Chinese scientists and officials have been formulating an expanded project to explore our celestial neighbor. In the afterglow of the successful Chang'e 4 landing, China stated that prospective missions beyond Chang'e 6 will go ahead. These will attempt comprehensive exploration of the lunar south pole, including analysis of topography, composition, and the space environment. They will also test key technologies to lay the groundwork for the construction of a science and research base on the moon, Yanhua Wu, deputy head of the China National Space Administration, said in January 2019.

Slated for the mid-2020s, Chang'e 7 will consist of a relay satellite, orbiter, lander, rover, and hopping detector. Chang'e 8 will follow. Both missions will likely use the Long March 5 for transport. Chang'e 8 will test extraction of volatiles, in-situ resource utilization, and 3D printing on the Moon. These technologies will support future crewed lunar





▲ **PYRAMID ROCK** The Yutu rover visited this block of impact ejecta, called Long Yan (Pyramid Rock), southwest of the Chang'e 3 lander. The view is a six-image mosaic.

landings and resource utilization. The missions will also carry out unspecified biological experiments. Additionally, scientists may conduct a Very Long Baseline Interferometry experiment, combining data from Earth-based radio dishes with one on the relay satellite.

Into Deep Space

China's lunar engineering achievements have built a platform to journey deeper into the solar system. Members from the team behind these landings have been involved in preparing for the greater challenges posed by Mars, including the remote distance, a thin atmosphere (which demands an aeroshell and parachute system for entry), and a propulsive landing in a different gravity field. Meeting all these challenges is crucial to entry, descent, and landing.

With its 2020 Mars mission apparently set to go — China announced in November with a short, public propulsive test that its landing technology was ready — other projects are now under way. The next spacecraft in the pipeline has an ambitious, two-target mission. Tentatively named after Zheng He, the 15th-century eunuch admiral and explorer, the 10-year mission will visit a near-Earth asteroid (NEA) and then rendezvous with a main-belt comet.

The target for the first visit is 2016 HO_3, also known as 469219 Kamoʻoalewa, a roughly 40-meter-diameter NEA. The plan is to collect up to 1 kilogram of regolith and return this sample to Earth within three years of launch.

After dropping off a reentry capsule containing the samples, the spacecraft will then head for Mars, using a Red Planet flyby to set course for Comet 133P/Elst-Pizarro. The aim is to reach the comet ahead of its perihelion in 2030 and remain there for one year, carrying out remote-sensing and in-situ measurements. Such a mission would, in a few daring maneuvers, demonstrate the kinds of capabilities shown by the European Rosetta and Japanese Hayabusa missions.

▲ **FARSIDE** Chang'e 5 T1 took this image of the lunar farside and distant Earth in 2014, as it looped around the Moon in a test flight for future orbiter and sample-return missions.

Chinese scientists have opened a call to both domestic and international institutions for science payloads.

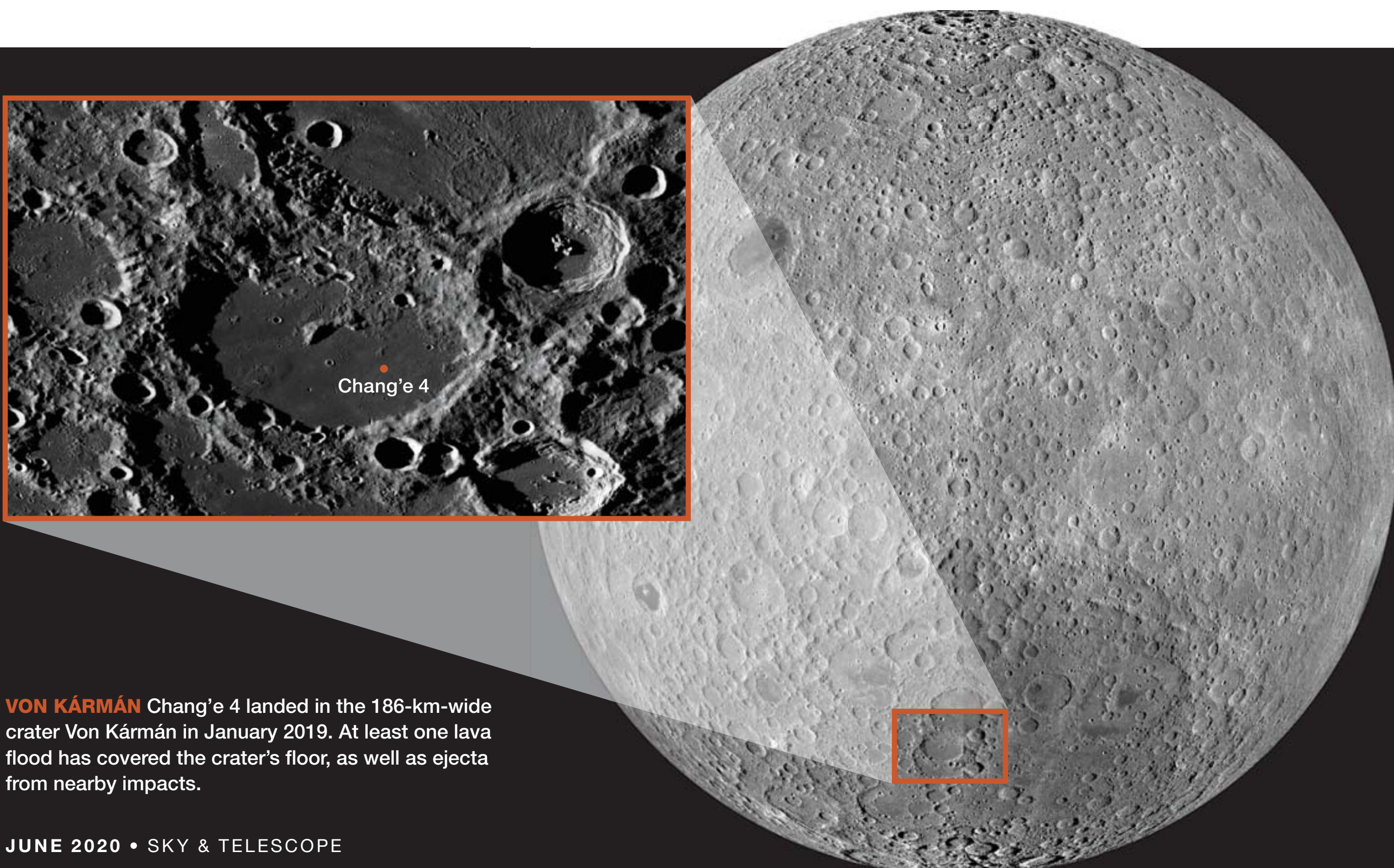
Another emerging target for China is an interstellar project along the lines of NASA's Voyager missions. Although there is no fortuitous planetary alignment such as that which provoked the Voyagers' Grand Tour of the outer solar system, two 200-kilogram Interstellar Heliosphere Probes will launch around 2024 and use flybys of Jupiter to target the head and tail of the heliosphere, respectively. The latter will also release an impactor during a Neptune flyby before flashing past a yet-to-be-determined Kuiper Belt object. Science objectives for the mission include determining whether the tail of the heliosphere is open or closed, studying the wall of hydrogen atoms at the heliopause, and investigating the processes that accelerate ions at the heliosphere's boundary to become anomalous cosmic rays.

After detecting more than a billion cosmic-ray events, DAMPE data showed more than the expected amount of particles with energies around 1.4 teraelectron volts – a possible signature of dark matter.

A dedicated mission to the outer solar system will come in 2030 with the planned launch of a Jupiter orbiter, which will follow the trail blazed by NASA's Galileo and Juno missions. It will target the Jovian moons, shedding light on how the lunar system formed. The mission is expected to be given the name Gan De, for the Chinese astronomer in the 4th century BC who made some of the most detailed early observations of Jupiter and, it is claimed, even observed Ganymede without optical aid.

The variety of missions and their capabilities and destinations — comets, asteroids, inner and outer planets, and even interstellar space — suggests that China is looking to match many of the exploration achievements of established space-faring nations. But, as demonstrated by the Chang'e 4 lunar

FARSIDE: CNSA; LANDING SITE: FARSIDE AND VON KÁRMÁN: NASA / GSFC / ARIZONA STATE UNIV.



VON KÁRMÁN Chang'e 4 landed in the 186-km-wide crater Von Kármán in January 2019. At least one lava flood has covered the crater's floor, as well as ejecta from nearby impacts.

farside landing, China is also working to surpass what's been done before.

Another example of that goal is China's planned second mission to Mars, tentatively launching around 2028-2030. This one is to be a sample return. The mission has the potential to be a major space first, depending on the progress of joint NASA and ESA plans for such a project. The deliverer of Martian samples could change history, should evidence of previous or extant life be discovered in the soil. Initial plans outline a one-launch mission using the in-development Long March 9, a super-heavy-lift launch vehicle comparable to the Saturn V. Alternate plans would send the landing and return segments separately.

Entry into Space Science

China has been a space-faring nation since 1970, when a Long March 1 lofted the country's first satellite. But space science is an area in which China is only just emerging. A first batch of four missions was approved early last decade, developed under the auspices of the Chinese Academy of Sciences and launched between 2015 and 2017.

The first in action was the Dark Matter Particle Explorer (DAMPE) space telescope. Also known as Wukong, or Monkey King, from the 16th-century novel *Journey to the West*, it launched in December 2015. Designed to detect high-energy gamma rays and cosmic rays, DAMPE's specific aim was to look for an indirect signal from the decay of a hypothetical dark matter particle.

After detecting more than a billion cosmic-ray events, DAMPE data showed more than the expected amount of particles with energies around 1.4 teraelectron volts — a possible signature of dark matter. While in itself not conclusive, the result opened a new avenue for dark matter research.

The mission also had a big impact domestically. "As the first Chinese astronomical satellite, the successful performance and the significant results of DAMPE highlight the country's rise in space science and have convinced the community that China is able to make significant contributions to astrophysics and space science," says Yizhong Fan, science

Astronomy & Space Science Launches

LAUNCHED

- **2007** — **CHANG'E 1:** Moon orbiter
- **2008**
- **2009**
- **2010** — **CHANG'E 2:** Moon orbiter, near-Earth asteroid flyby
- **2011**
- **2012**
- **2013** — **CHANG'E 3:** Moon lander (Mare Imbrium); **YUTU:** Rover (*traveled with Chang'e 3*)
- **2014** — **CHANG'E 5 T1:** Moon flyby
- **2015** — **DAMPE (WUKONG):** Dark matter
- **2016**
- **2017** — **HXMT (INSIGHT):** X-ray telescope
- **2018** — **QUEQIAO:** Orbiter (Earth-Moon L_2 point); **CHANG'E 4:** Moon lander (Von Kármán Crater); **YUTU 2:** Rover *(traveled with Chang'e 4)*
- **2019**

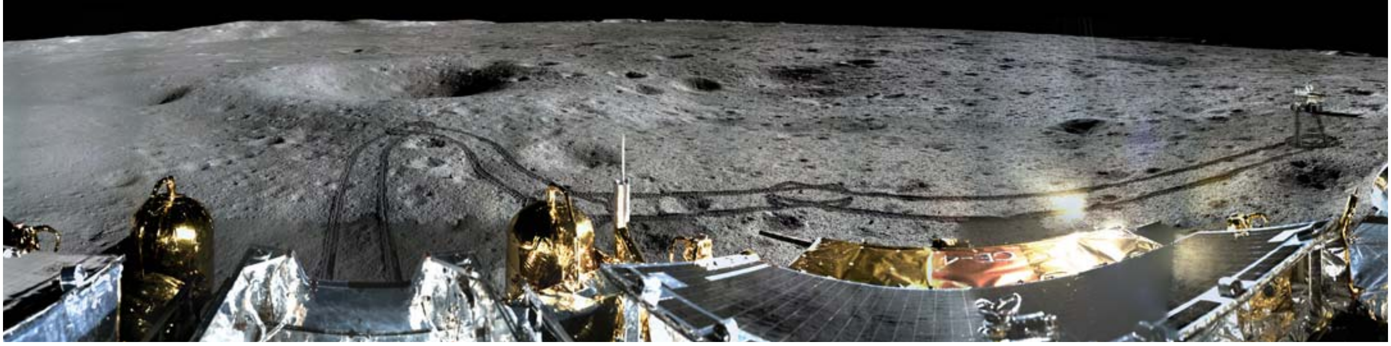
SCHEDULED

- **2020** — **HUOXING 1:** Mars orbiter and rover; **CHANG'E 5:** Moon sample return (Oceanus Procellarum)

PROPOSED, LAUNCH ORDER UNCERTAIN

- **2020s**
  - **SVOM:** Gamma-ray, X-ray, and visible-light observatory
  - **EINSTEIN PROBE:** High-energy transient phenomena
  - **ASO-S:** Solar observatory
  - **CHANG'E 6:** Moon sample return (south pole)
  - **CHANG'E 7:** Moon relay satellite, orbiter, lander, rover, and hopping detector
  - **XUNTIAN:** 2-meter space telescope
  - **CHANG'E 8:** 3D printing, resource extraction
  - **ZHENG HE:** Near-Earth asteroid sample return, comet rendezvous
  - **INTERSTELLAR HELIOSPHERE PROBES:** Heliosphere, Neptune impactor, Kuiper Belt
  - **MARS SAMPLE RETURN**
- **2030s** — **JUPITER ORBITER**

THE FARSIDE JPL's Doug Ellison assembled this panorama (half shown) of the lunar farside from approximately 120 images taken by the Chang'e 4 lander's Terrain Camera.



PANORAMA: CNSA / CLEP / DOUG ELLISON; TIMELINE: TERRI DUBÉ / S&T

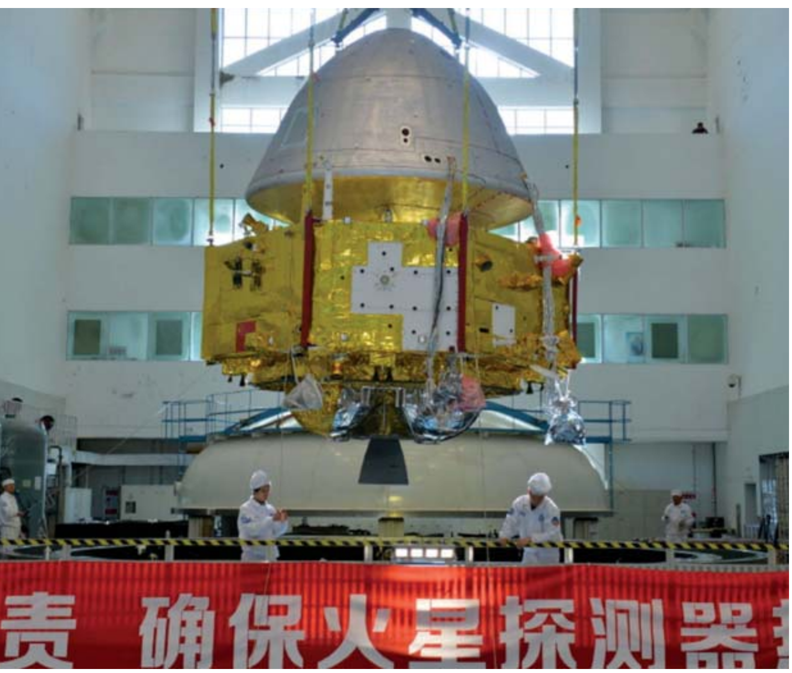
team head. “This certainty gives the government the confidence for organizing future explore missions.”

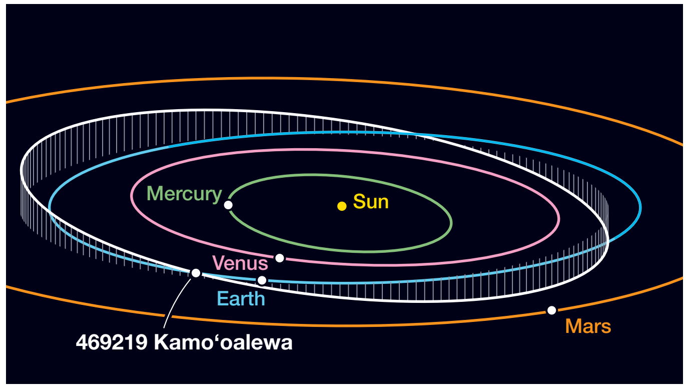
The next science missions weren’t astronomy-related. Shijian 10 was a retrievable satellite experiment, which in 2016 tested the growth of mouse embryos in the microgravity environment of low-Earth orbit. Then the Quantum Experiments at Space Scale, launched later that same year, made waves as the first quantum science satellite. It used the phenomenon of entanglement to test encrypted communications between China and Austria.

The final mission of the set was the Hard X-ray Modulation Telescope (HXMT), aka Insight, which launched in June 2017. Shortly after, it joined international follow-up observations of the GW170817 neutron star merger detected by LIGO (*S&T:* Feb. 2018, p. 32), setting a strict upper limit on X-rays produced by the event. In October 2019 the HXMT team also investigated the accretion disks around black hole and neutron star X-ray binaries. The observations verified a decades-old theory that structural changes in the accretion disks come from the radiation pressure of light. Since coming into operation, HXMT has returned more than 29 TB of scientific data.

The successful launch of these four missions helped win approval for a new batch of space-science projects that will begin launching in 2021. Some of these have a strong terrestrial focus, such as the Water Cycle Observation and the Magnetosphere-Ionosphere-Thermosphere Coupling Exploration missions. In addition, the Solar Wind Magnetosphere Ionosphere Link Explorer, a space-weather observatory, is a joint endeavor with the European Space Agency.

▼ **RED PLANET TEST** China’s Mars spacecraft enters its space environment testing in this image released in October 2019.





▲ **TARGET ASTEROID** China’s planned Zheng He spacecraft will visit the asteroid 469219 Kamo‘oalewa, which crosses Earth’s orbit. After it delivers its samples to Earth, it will continue outward via Mars to fly by Comet 133P/Elst-Pizarro in the main belt.

But other planned projects will continue forays into off-Earth astronomy. Three of these will focus on high-energy phenomena:

The Space-based Multi-band Astronomical Variable Objects Monitor, produced in collaboration with the French Space Agency, is a gamma-ray, X-ray, and visible-light observatory. Following launch in 2021, it will study the intensely powerful gamma-ray bursts thought to come from the death of certain kinds of stars.

Meanwhile, the 1,400-kilogram Einstein Probe should launch by the end of 2022 to look for short-lived, high-energy sources. These include gamma-ray bursts, supernovae, magnetars, and the electromagnetic counterparts of gravitational-wave events. With a large field of view, it will also monitor variable objects across the sky, such as accreting supermassive black holes at the centers of galaxies, and carry out an all-sky survey.

A third mission, the Advanced Space-based Solar Observatory, is also scheduled for 2022 and will study solar flares and coronal mass ejections.

If all this weren’t enough, the Xuntian 2-meter space telescope should launch in the mid-2020s. The Hubble-class instrument is designed to co-orbit with China’s planned modular space station and dock with it for occasional maintenance and repair.

Speaking at the Global Space Exploration Conference in Beijing in 2017, Ji Wu, then director of the National Space Science Center that oversaw China’s first space science missions, explained how he sees the country’s growing role in space. China, he says, has made a major contribution to the global economy. Now it will (once again) contribute to scientific knowledge with a new decade of exploration and discovery.

■ **ANDREW JONES** is a space journalist based in Finland who reports on China’s space-related activities in particular. Follow him on Twitter for insights into a far-reaching and expanding space program: **@AJ_FI**.

MARS MISSION: CNSA; ORBITS: LEAH TISCIONE / *S&T*

1 DUSK: The month opens with the waxing gibbous Moon in Virgo, with Spica some 6° to 7° below.

4 EVENING: The almost-full Moon is about 7° above Antares in Scorpius.

7 EVENING: The waning gibbous Moon, Jupiter, and Saturn form a shallow arc some 12° long above the southeastern horizon.

8 EVENING: The Moon has hopscotched over Jupiter and is now about 4° below Saturn.

13 DAWN: Catch the last-quarter Moon and Mars, less than 5° separating the pair, in the southeast before the Sun rises.

19 DAWN: The thin crescent Moon and Venus rise together just 1° apart (see page 49).

20 THE LONGEST DAY OF THE YEAR in the Northern Hemisphere. Summer begins at the solstice, 21:44 UT (5:44 p.m. EDT).

21 DAYTIME: Six days past apogee, the Moon will pass in front of the Sun, giving rise to an annular eclipse visible from central Africa and southern Asia. See page 50 for more information.

25 DUSK: Spot the growing crescent Moon a little more than 5° from Regulus in Leo.

28 DUSK: The first-quarter Moon, Spica, and Porrima form a triangle in Virgo.

30 DUSK: The month closes with the waxing gibbous Moon in Libra, some 2° to 3° from Zubenelgenubi, or Alpha (α) Librae.
— DIANA HANNIKAINEN

▲ The Sun is captured either side of midnight on the summer solstice from Pyhäranta (about 61°N) in western Finland. At latitudes farther north, the Sun doesn't set at all.
PEKKA PARVIAINEN / SCIENCE SOURCE

JUNE 2020 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				

FULL MOON

June 5
19:12 UT

LAST QUARTER

June 13
06:24 UT

NEW MOON

June 21
06:41 UT

FIRST QUARTER

June 28
08:16 UT

DISTANCES

Perigee	June 3, 04^h UT
364,366 km	Diameter 32′ 48″
Apogee	June 15, 01^h UT
404,595 km	Diameter 29′ 32″
Perigee	June 30, 02^h UT
368,958 km	Diameter 32′ 23″

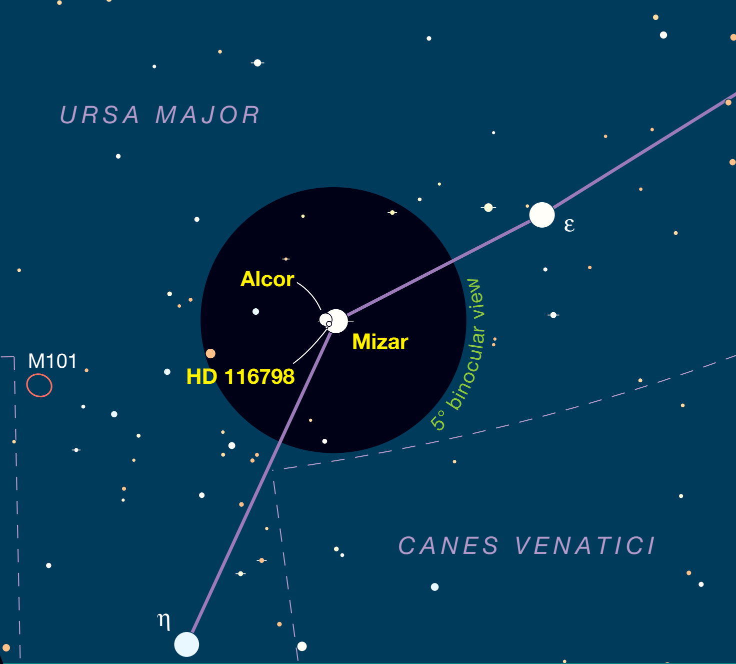
FAVORABLE LIBRATIONS

- Scott Crater June 3
- Helmholtz Crater June 4
- Gibbs Crater June 6
- Desargues Crater June 17

Planet location shown for mid-month

USING THE NORTHERN HEMISPHERE MAP

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



Binocular Highlight by Mathew Wedel

The Horse and Rider

I have shown **Mizar** and **Alcor** — the "Horse and Rider" in Ursa Major, the Great Bear — to hundreds if not thousands of people at star parties and outreach events. And for just that reason it never hurts to brush up on the fundamentals.

Mizar and Alcor are roughly 80 light-years away, but the parallax distance measurements have large margins of error. We are certain the two stars — or rather, the two systems — are moving together through space as members of the Ursa Major association. But after almost four centuries of study, it's still unclear if they're orbiting each other or not. If they are gravitationally bound, it's a long orbit, taking 700,000 years or more to complete.

I mentioned that Mizar and Alcor are systems, not single stars. Mizar is at minimum a quadruple-star system and Alcor is at least double. You probably already know about Mizar, since splitting the two brighter and wider components is a favorite trick with small telescopes or big binoculars. Mizar A and B are separated by 14″, which is doable with 20× tripod-mounted binos but very tough with any less magnification. If you haven't split Mizar, grab your big glass and see what you can do.

While you're in the neighborhood, check out **HD 116798**, a yellow-white star a bit south of the line between Mizar and Alcor. At magnitude 7.6, it should be visible without optical aid to the eagle-eyed and an easy catch in binoculars. In 1722, German theologian and scientist Johann Georg Liebknecht named the star Sidus Ludoviciana, thinking it to be a planet. Liebknecht was mistaken about that, but he studied both fossils and astronomy, so he's okay in my book.

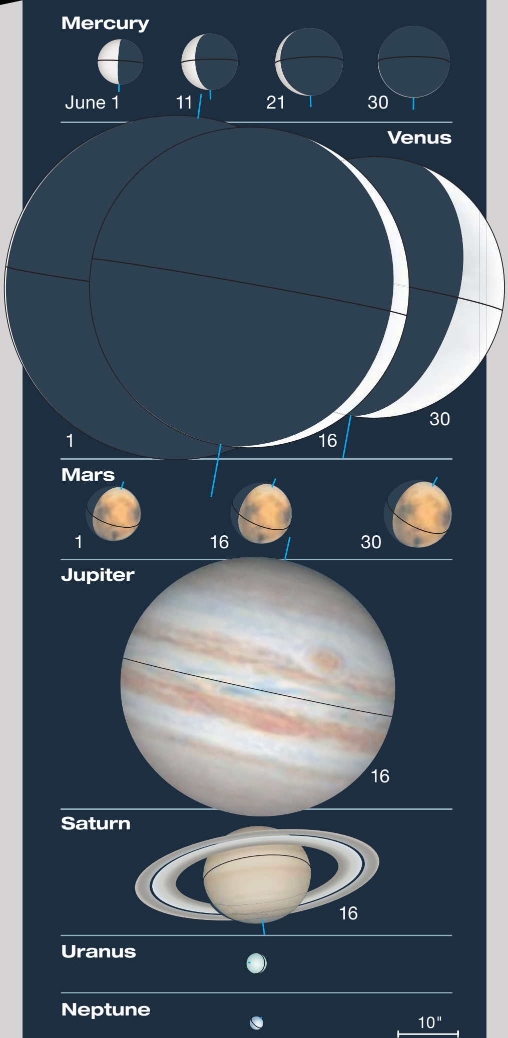
■ MATT WEDEL loves contemplating the night sky on dinosaur digs in Oklahoma and Utah. He's probably out there right now.

WHEN TO USE THE MAP

Late April	2 a.m.*
Early May	1 a.m.*
Late May	Midnight*
Early June	11 p.m.*
Late June	Nightfall

*Daylight-saving time

PLANET VISIBILITY (40°N, naked-eye, approximate) **Mercury:** visible at dusk through to the 14th • **Venus:** reappears at dawn on the 10th • **Mars:** a bright predawn object throughout June • **Jupiter and Saturn:** roughly 5° apart all month, rise in the late evening and climb high before dawn

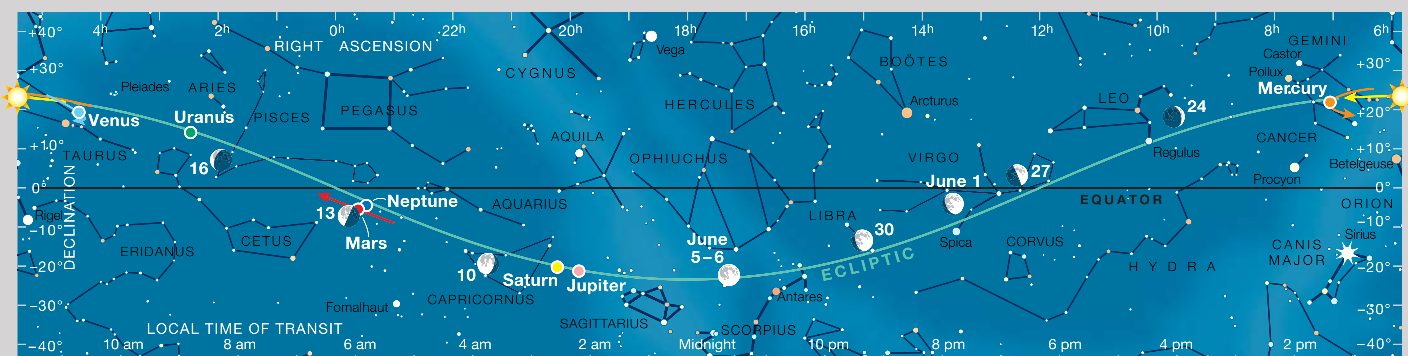


PLANET DISKS have south up, to match the view in many telescopes. Blue ticks indicate the pole currently tilted toward Earth.

June Sun & Planets

	Date	Right Ascension	Declination	Elongation	Magnitude	Diameter	Illumination	Distance
Sun	1	$4^h\ 36.4^m$	+22° 03′	—	–26.8	31′ 33″	—	1.014
	30	$6^h\ 36.6^m$	+23° 10′	—	–26.8	31′ 28″	—	1.017
Mercury	1	$6^h\ 17.0^m$	+25° 21′	23° Ev	+0.1	7.6″	45%	0.890
	11	$6^h\ 54.6^m$	+23° 15′	22° Ev	+1.1	9.4″	25%	0.713
	21	$7^h\ 00.7^m$	+20° 32′	15° Ev	+3.0	11.3″	8%	0.594
	30	$6^h\ 42.8^m$	+18° 47′	5° Ev	—	12.0″	1%	0.560
Venus	1	$4^h\ 54.5^m$	+23° 43′	4° Ev	—	57.6″	0%	0.290
	11	$4^h\ 30.0^m$	+20° 37′	11° Mo	–4.0	56.2″	2%	0.297
	21	$4^h\ 16.3^m$	+18° 13′	25° Mo	–4.5	50.2″	9%	0.332
	30	$4^h\ 17.2^m$	+17° 15′	33° Mo	–4.7	43.8″	18%	0.381
Mars	1	$22^h\ 58.8^m$	–9° 06′	88° Mo	0.0	9.3″	85%	1.009
	16	$23^h\ 35.7^m$	–5° 38′	93° Mo	–0.2	10.3″	84%	0.911
	30	$0^h\ 08.2^m$	–2° 30′	98° Mo	–0.5	11.4″	84%	0.824
Jupiter	1	$19^h\ 54.2^m$	–21° 04′	134° Mo	–2.6	44.7″	100%	4.413
	30	$19^h\ 43.1^m$	–21° 37′	165° Mo	–2.7	47.2″	100%	4.174
Saturn	1	$20^h\ 14.4^m$	–20° 01′	129° Mo	+0.4	17.8″	100%	9.343
	30	$20^h\ 08.3^m$	–20° 23′	159° Mo	+0.2	18.3″	100%	9.060
Uranus	16	$2^h\ 27.0^m$	+14° 04′	46° Mo	+5.9	3.4″	100%	20.489
Neptune	16	$23^h\ 27.4^m$	–4° 41′	94° Mo	+7.9	2.3″	100%	29.836

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



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

Ophiuchus and Friends

The celestial serpent bearer has plenty of interesting company.

It seems to me that Ophiuchus often gets a low rating from beginners for its supposed lack of observational thrills. It's true that the star pattern of the Serpent Bearer is big but rangy, with a large center that has no bright stars. And though the constellation's globular clusters are amazingly numerous, they're smaller and dimmer than the mighty globular blazes in neighboring Serpens, Hercules, Scorpius, and Sagittarius.

Perhaps it's true that Ophiuchus doesn't offer the brightest splashy wonders for small telescopes and novice observers, but the incredible variety of its attractions can help improve a beginner's observing skills and lead to a greater awareness of the diversity of deep-sky objects in the heavens.

Diversity? Next month we'll explore the constellation's collection of globulars, its two huge open clusters, its many fine double and multiple stars, its surprisingly prominent dark nebulae, and its pair of superb planetary nebulae. We'll also meet the second-closest star in the night sky.

But this month, let's meet Ophiuchus in the context of its remarkable connections to its constellation neighbors.

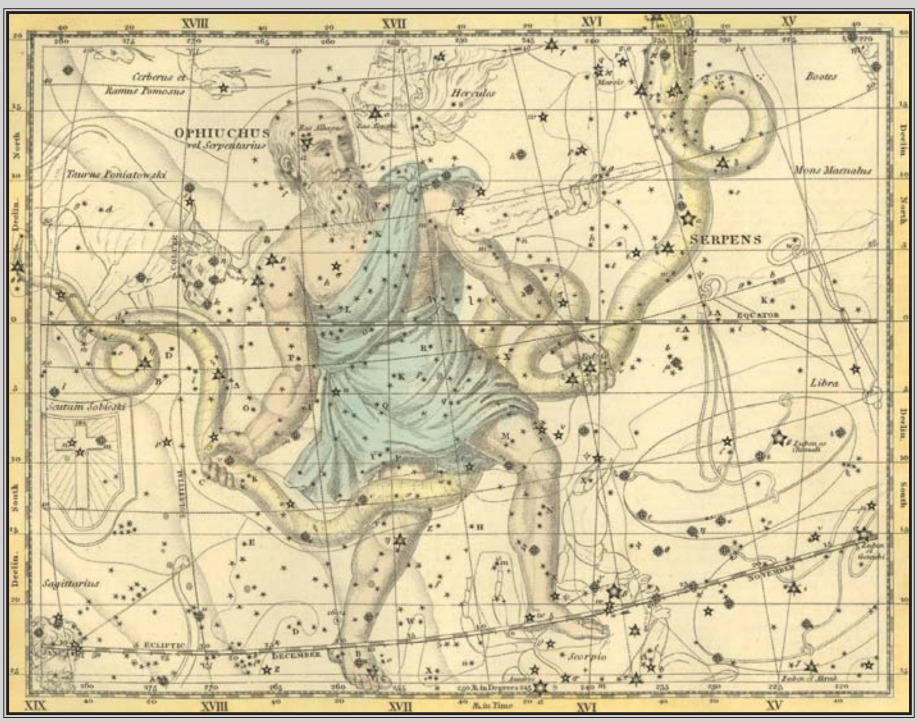
Ophiuchus and Serpens. Ophiuchus is a large, human figure pictured holding a snake: Serpens the Serpent. Of the 88 official constellations, Serpens is the only one separated into two parts by another constellation. To the west of Ophiuchus is the front part of the snake, known as Serpens Caput (the Serpent's Head), and to its east is Serpens Cauda (the Serpent's Tail). Combined, Ophiuchus and Serpens stretch all the way from Boötes to Aquila, with Ophiuchus's brightest star, 2nd-magnitude Rasalhague, slightly below a long, long line connecting Arcturus and Altair. If we counted the areas occupied by Ophiuchus and Serpens together as a single constellation, it would be by far the largest in the heavens.

This arrangement of Ophiuchus dividing Serpens in two is not just unique, it's visually striking. The interesting lights that go before and after Ophiuchus are Unukalhai (Alpha Serpentis) in Serpens Caput, and Alya (Theta Serpentis) in Serpens Cauda. Unukalhai is a magnitude-2.6 orange star and is a rough guide to the vicinity of M5, one of the grand globular clusters and a favorite of many observers. The 5.8-magnitude cluster is situated about 8° southwest of Unukalhai and just 20′ northwest of the golden, 5.1-magnitude star 5 Serpentis. And what about Alya? It's a beautiful, easy double star comprised of magnitude-4.6 and -4.9 components (both white, *A*5-type stars) a generous 22.3″ apart. Alya is also the very end of the Serpent's tail — a line of stars jutting into the dark Great Rift of the summer Milky Way.

Ophiuchus and Hercules. The Alpha stars of Ophiuchus and Hercules are Rasalhague and Rasalgethi, respectively. They're only 6° apart and mark the heads of the two big figures. Hercules is the most famous legendary strongman, while Ophiuchus is usually associated with Aesculapius, the god of medicine, whose snake-entwined staff remains a symbol of the medical profession today. Which constellation is bigger? The main pattern of Ophiuchus appears much larger, but Hercules includes an expansive region of dim naked-eye stars and occupies a significantly greater area. Even though Ophiuchus is the 11th-biggest constellation, Hercules ranks 5th.

Ophiuchus and Scorpius. The modern boundaries of the constellations have the Sun spending only one week in Scorpius but almost three weeks in Ophiuchus. Because of this, some have started calling Ophiuchus the 13th constellation of the zodiac.

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



▲ **SERPENT TAMER** This fanciful chart from Alexander Jamieson's 1822 *Celestial Atlas* portrays the constellations Ophiuchus and Serpens.

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

Venus Returns

The brightest planet emerges at dawn after a near miss with the Sun.

After inferior conjunction on June 3rd, Venus makes a fairly steep climb into morning twilight, appearing two hours before sunrise by month's end. Now rising in the evening, Jupiter and Saturn move 1° farther apart in June, but are both brightening and getting bigger as they approach their July oppositions. As for Mars, it rises after midnight but flames a half-magnitude brighter during June and grows large enough for major surface features to be glimpsed in moderate-sized telescopes.

DUSK TO LATE EVENING

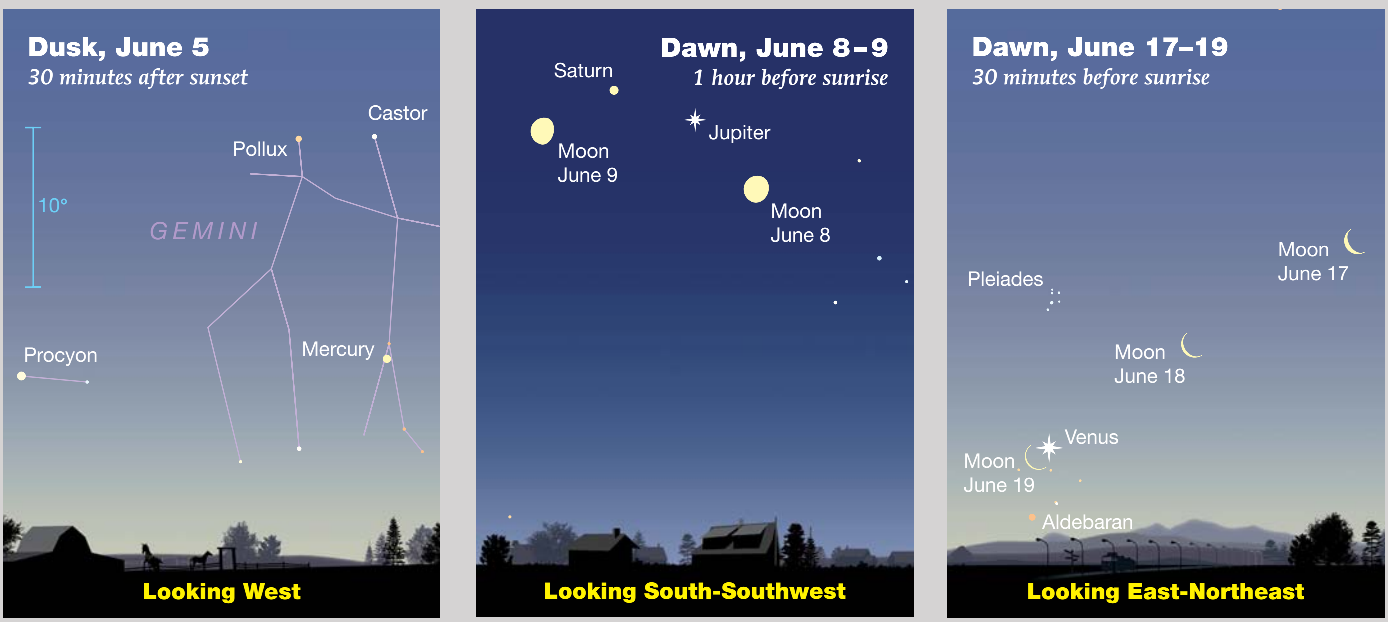
Mercury is the only planet visible as June's long evening twilight begins to fade. The innermost planet reaches a greatest eastern elongation of 24° from the Sun on the 4th. Mercury then shines at magnitude +0.4 and its 8″-diameter disk is less than 37% lit. The fleet little planet sets more than 1 hour and 45 minutes after the Sun during the first week of June. But Mercury's altitude and brightness quickly begin to decrease. On the 12th it shines at magnitude 1.3 well below Pollux and Castor, and a few days later it's too dim and low to glimpse without optical aid. Mercury reaches inferior conjunction on July 1st.

Jupiter and **Saturn** rise within about 15 minutes of each other in the hour before midnight as June begins but in the hour after sunset at the end of the month. Both worlds are slowly *retrograding* (moving westward) — Jupiter is a few degrees west of the Capricornus-Sagittarius border, and Saturn remains in Capricornus until it crosses into Sagittarius on July 3rd. The two gas giants begin June only 5° apart, and the gap between them grows to 6° by the end of June. They make for a splendid pair with Jupiter's blazing brightness increasing marginally from magnitude –2.6 to –2.7, and Saturn's from magnitude +0.4 to +0.2. Jupiter's feature-rich globe grows from 45″ to 47″, while Saturn's rings span 40″ and are tilted more than 20° from edge-on.

PRE-DAWN TO DAWN

Mars rises around 1:45 a.m. daylight-saving time as June opens, and shortly after 12:30 a.m. as the month closes.

▼▶ 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.

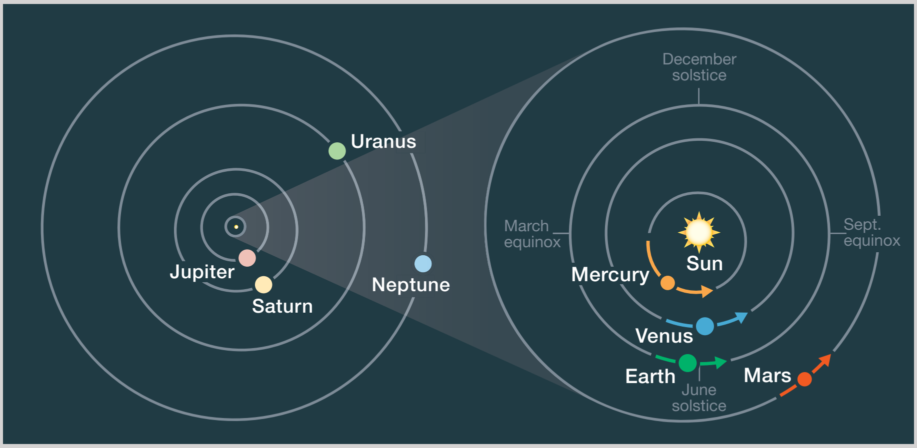


This means the planet is moderately high in the southeast when morning twilight begins to brighten the sky. Mars increases from magnitude 0.0 to –0.5 during June — its tiger-colored fire crossing from Aquarius to Pisces on the 24th. The planet reaches west quadrature (90° west of the Sun) on the 6th, so its gibbous disk will show a strong shadowed edge in telescopes this month. Mars's apparent diameter increases from 9.3″ to 11.4″ in June, the size at which it begins to show significant surface detail in medium-size instruments when seeing conditions are particularly steady.

Neptune glows at magnitude 7.9 just 1.6° northwest of Mars on the morning of June 13th, with the Moon just a few degrees east of the Red Planet. **Uranus** rises two hours later than Neptune but shines a full two magnitudes brighter.

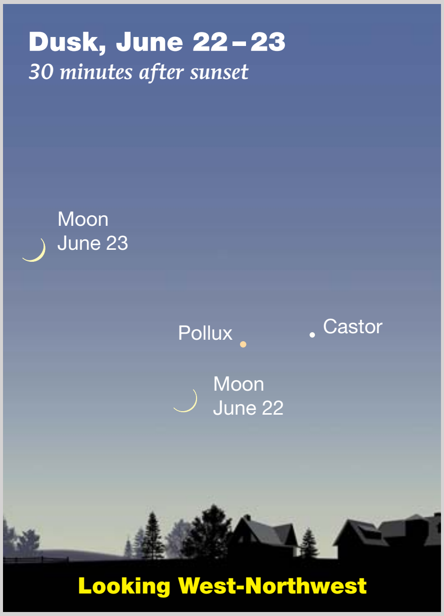
DAWN

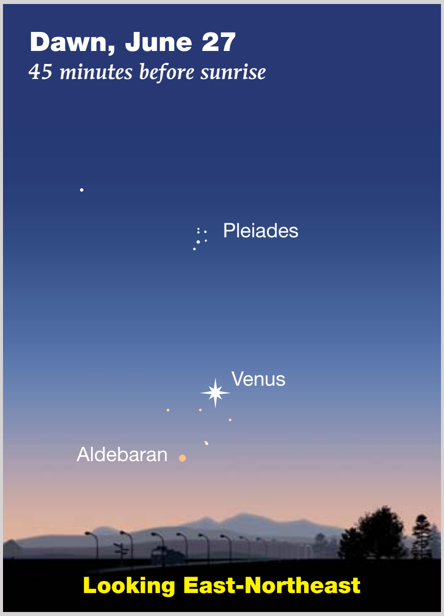
Venus technically doesn't exit the evening sky until it comes to inferior conjunction with the Sun at 18^h UT on June 3rd. Venus slips through the plane of Earth's orbit almost exactly two days after that date, so instead of transiting the solar disk (as it did in 2004 and 2012), it passes just half a solar diameter north of the Sun. The following weeks find Venus lofting steadily higher in morning twilight and brightening rapidly as its phase waxes from "new" to a thin crescent. On the 12th Venus rises about 45 minutes before the Sun, shines at magnitude –4.1, and features a disk that's 55″ wide and roughly 3% illuminated. By the 20th, the planet rises 80 minutes before the Sun, shines at –4.5, and has a 51″-diameter disk that's 9% illuminated. Venus ends the month clearing the east-northeastern horizon 2 hours before sunrise in a sky dark enough to appreciate it gleaming on the edge of the Hyades, in Taurus. By then the new morning star has brightened to magnitude –4.7, with a 44″-wide disk 18% illuminated.



ORBITS OF THE PLANETS

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





SUN AND MOON

The Sun reaches the June solstice at 5:44 p.m. EDT on the 20th, ushering in summer in the Northern Hemisphere and winter in the Southern Hemisphere. One day later, an annular eclipse of the Sun is visible across parts of Africa, Asia, and the western Pacific (see page 50 for details).

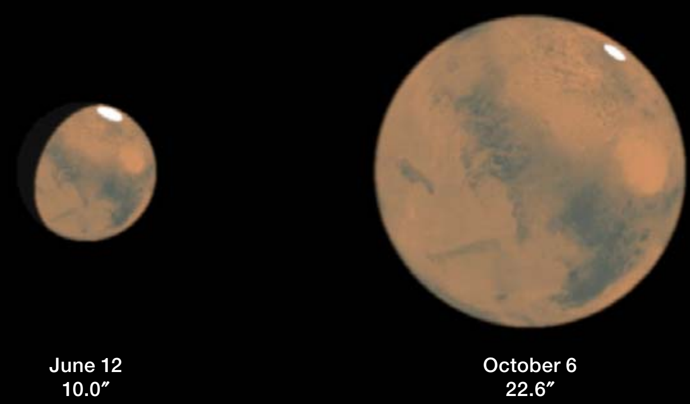
Observers in Europe, Africa, Asia, and Australia have an opportunity to watch the **Moon** undergo a weak penumbral lunar eclipse on June 5th. At dawn on the 8th, the waning gibbous Moon marks the westernmost point of a gentle curve with Jupiter and Saturn equally spaced along it. On the following morning the Moon has shifted position and now holds down the eastern end of that curve.

A spectacular close conjunction of the thin lunar crescent and Venus is visible low in the east-northeast around 30 minutes before sunrise on the morning of the 19th (the event is an occultation in parts of the Eastern Hemisphere — see page 49 for more). After the new Moon, the waxing lunar crescent reappears at dusk, and on the 22nd it's positioned below and to the left of Pollux and Castor, low in the west-northwest during twilight.

■ **FRED SCHAAF** teaches astronomy at both Rowan University and Rowan College in Gloucester County, southern New Jersey.

A Martian Sneak Peek

One of the best showings of the Red Planet in decades starts now.



South is up in this pair of illustrations showing the changing phase and diameter of the Martian disk as the planet grows to its maximum size when it's closest to Earth on October 6th.

Grab all the Mars you can this apparition. The Red Planet won't be this close to Earth again until 2035. Closest approach during the current apparition occurs on October 6th, when the tiny orb will swell to 22.6″. That's only 1.7″ less than at its perihelic opposition in 2018, which was less favorable for Northern Hemisphere observers due to the planet's southerly declination. This time Mars stands 31° farther north, where atmospheric turbulence and poor seeing typical of lower altitudes should have much less affect on the view.

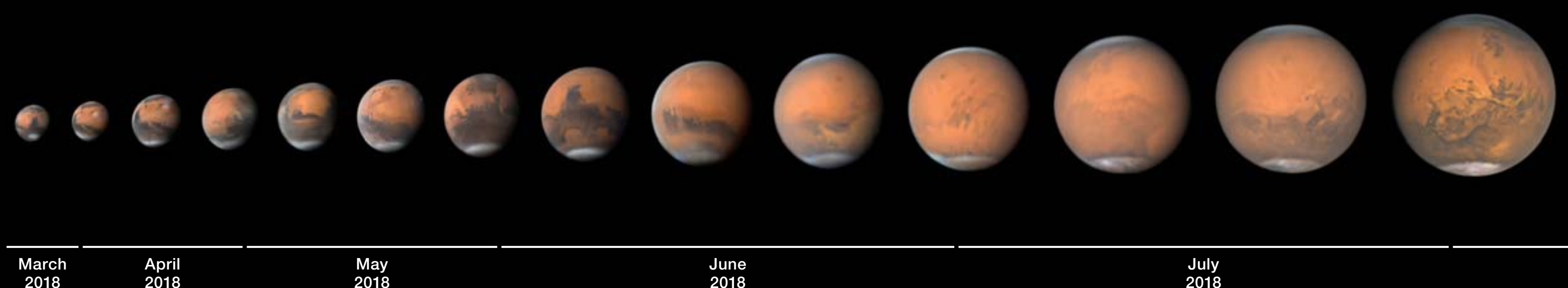
Longtime Mars observers know that every arcsecond counts, which is why I encourage you to rise at dawn this month and catch the planet when it's at its highest before sunrise. On June 12th, Mars grows to 10″ in diameter — the generally accepted minimum size at which useful observations can be made. While only half as large as it will be at opposition, now is the time to start getting acquainted with the planet's most prominent surface markings, called *albedo features*. Finding your way around Mars early will prepare you to make the most of the upcoming close approach.

The Martian South Polar Cap (SPC) should be prominent throughout June and appears glaringly white, like snow on a sunny day. Watch for the SPC to gradually shrink during the month as spring deepens in the planet's southern hemisphere. A 6-inch telescope used at 150× or greater should reveal the thumb-shaped Syrtis Major, the "wand" of Sinus Sabaeus, Mare Cimmerium's dark band, and the mottled blotch of Mare Erythraeum. Use higher magnification if seeing conditions allow it, and boost the contrast of these often-tenuous features with the help of an orange Wratten 21 or red Wratten 23a filter.

Patience is key. Eyeball the planet for at least 15 minutes (a half hour is better), and you'll often catch enough

UK imager Damian Peach created this sequence of Mars images during the planet's close 2018 apparition. North is presented up, and the sequence progresses from left to right with the earliest images on the left, the latest on the right. Notice that the disks photographed just prior to the July 31st closest approach have muted features, the result of a planetwide dust storm raging at the time.

MARS SIZE COMPARISON: GARY SERONIK / *S&T*, SOURCE: COELIX AND USGS



glimpses of surface details for your brain to "stack" into a coherent picture. If you take the time to capture what you see with a sketch, you'll learn to recognize even smaller details — a skill that will serve you well when Mars reaches opposition in October.

As seen from mid-northern latitudes one hour before sunrise, the planet stands some 28° high in Aquarius on June 1st and climbs to 39° by month's end. During that span, its ruddy disk grows from 9.3″ to 11.4″. June offers observers another advantage — a lower probability of those infamous Martian dust storms ruining the view. Every close Mars apparition, observers fear a giant dust storm will blow up and turn the planet into a featureless orange ball like it did for much of June and July 2018. I'm happy to report that the June 2020 Mars weather forecast calls for clear pink skies and settled conditions — at least according to the calendar of seasonal events compiled by Jeffrey D. Beish of the American Lunar and Planetary Observers (ALPO).

I've never regretted a Mars morning encounter even when poor seeing has roughened up the telescopic image. More often, calmer conditions prevail during twilight, and the brighter sky helps subdue the planet's glare. I like to wake with the birds and see the day bloom in quiet, dewy splendor while my eye roams across the dusty desert planet.

To see an interactive Mars map, visit our Mars Profiler at **https://is.gd/marsprofiler**. *S&T* will have additional Mars coverage in upcoming issues.

MOON: GARY SERONIK / S&T, SOURCE: STELLARIUM

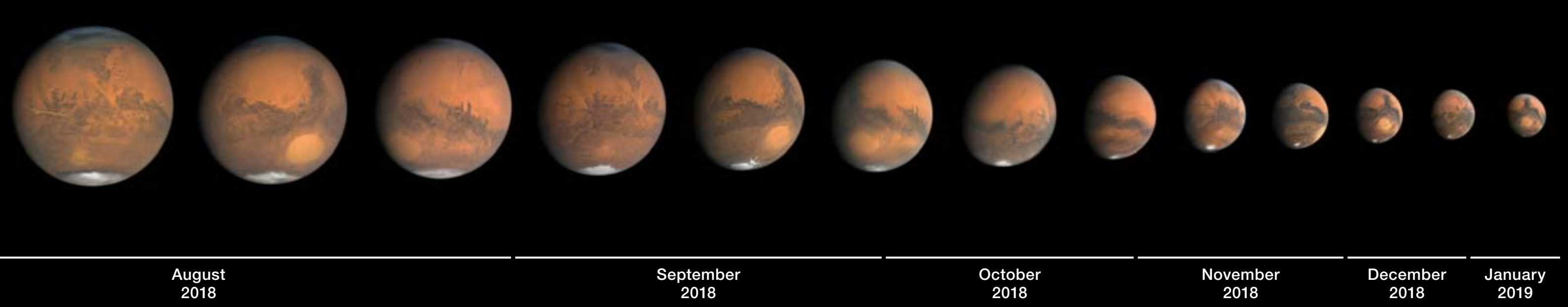
One Crescent Meets Another

▲ This illustration portrays the tiny crescent Venus re-emerging from behind the dark limb of the earthlit crescent Moon in morning twilight, as seen from Boston, Massachusetts.

NEWLY ARRIVED in the dawn sky after its June 3rd inferior conjunction, Venus will be occulted by the thin, waning crescent Moon on the morning of June 19th. The planet will be an 8%-illuminated crescent, 51″ in diameter. For most of North America, the two objects will simply present an attractive close conjunction. However, observers in northern and eastern Canada, Greenland, northwestern Europe, northern and central Russia, and northern Mongolia will get to see the entire occultation, albeit in daylight for most locations.

From St. John's, Newfoundland, Venus disappears behind the Moon's bright limb starting about 4:49 a.m. Newfoundland Daylight Time, and emerges at the dark limb at 5:41 a.m. with the Sun already up. East Coast observers in cities such as Boston, Massachusetts; Greenville, North Carolina; and Bangor, Maine will miss the immersion phase, which happens before moonrise. However, those locations will enjoy a fantastic view of the Venusian crescent emerging from behind the Moon's dark limb before sunrise, at around 4:07 a.m. EDT (as seen from Boston).

From northern Europe the entire event occurs after sunrise. While this will make the Moon's slender, ghostly crescent tricky to locate, spotting impressively brilliant Venus should be relatively easy. Use binoculars or a small telescope to find the planet 22° west of the Sun and then watch its tiny crescent meet the Moon's large, pale one.



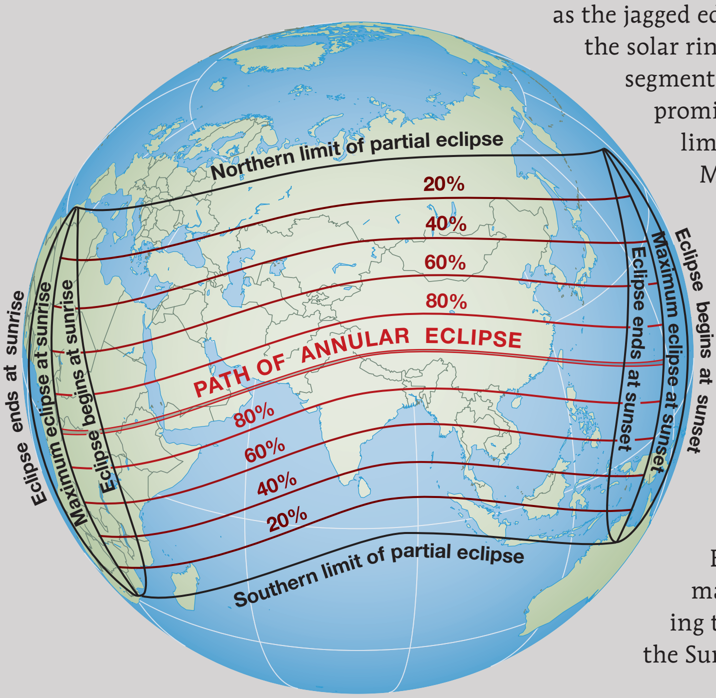
An African and Asian Annular

ON JUNE 21ST, the day after the June solstice, the Moon will pass in front of the Sun, producing an annular solar eclipse. The Moon will be just six days past apogee, with an apparent diameter 99.4% that of the Sun's — too small to cover the solar disk completely. So, instead of a total eclipse, observers will be treated to the dramatic sight of the silhouetted Moon encircled by a narrow annulus of sunlight.

The path of annularity varies from 21 to 85 kilometers wide and stretches from central Africa to Taiwan before departing solid ground for the Pacific Ocean. At the track's western end, observers will witness the fiery annulus for up to 82 seconds, low in the eastern sky shortly after sunrise. First contact is at 3:46 UT, greatest eclipse occurs at 6:40 UT, and the Moon vacates the solar disk at 9:34 UT. Visit Fred Espenak's website (**https://is.gd/June21eclipse**) to find viewing details for hundreds of individual locations.

▲ Fred Espenak captured this photograph of the annular eclipse of February 16, 1999, when the Moon covered 99.3% of the Sun's disk. This month's eclipse is a very close match, with the solar disk 99.4% obstructed.

▼ An annular solar eclipse takes place on June 21st. The central track, shown in red, crosses Africa, the Arabian Peninsula, and southern Asia.



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

During a typical annular event, brilliant points of sunlight called Baily's Beads shine through valleys along the edge of the Moon, flashing into view moments before and after maximum eclipse. But the fit between Moon and Sun this time is so tight that observers with safe eclipse glasses or properly filtered binoculars and telescopes should get extended views of the Beads as the jagged edge of the Moon breaks the solar ring into numerous short segments. Likewise, any bright prominences along the Sun's limb that appear as the Moon advances eastward across the solar disk should be easy to photograph and see in a telescope, provided you keep the blindingly bright portions of the Sun safely out of view.

I've witnessed two annular eclipses and saw brief glimpses of prominences and Baily's Beads, but what really made my jaw drop was seeing the Moon moving across the Sun in real time.

Action at Jupiter

AT THE START OF JUNE, Jupiter rises just before midnight local daylight-saving time and transits the meridian during morning twilight, when it should be a fine sight in telescopes. On June 1st the planet gleams at magnitude –2.6 and presents a disk 45″ in diameter.

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

All the June interactions between Jupiter and its satellites and their shadows are tabulated on the facing page. Find events timed for dawn twilight in your time zone, when Jupiter is at its highest.

Features on Jupiter appear closer to the central meridian than to the limb for 50 minutes before and after transiting. Here are the times, in Universal Time, when the Great Red Spot should cross Jupiter's central meridian. The dates, also in UT, are in bold. (Eastern Daylight Time is UT minus 4 hours.)

May 1: 6:39; 16:34 **2**: 2:30; 12:26; 22:21 **3**: 8:17; 18:13 **4**: 4:08; 14:04; 23:59 **5**: 9:55; 19:51 **6**: 5:46; 15:42 **7**: 1:38; 11:33; 21:29 **8**: 7:25; 17:20 **9**: 3:16; 13:12; 23:07 **10**: 9:03; 18:58 **11**: 4:54; 14:50 **12**: 0:45; 10:41; 20:37 **13**: 6:32; 16:28 **14**: 2:23; 12:19; 22:15 **15**: 8:10; 18:06 **16**: 4:02; 13:57; 23:53 **17**: 9:48; 19:44 **18**: 5:40; 15:35 **19**: 1:31; 11:27; 21:22 **20**: 7:18; 17:13 **21**: 3:09; 13:05; 23:00 **22**: 8:56; 18:52 **23**: 4:47; 14:43 **24**: 0:38; 10:34; 20:30 **25**: 6:25; 16:21 **26**: 2:16; 12:12; 22:08 **27**: 8:03; 17:59 **28**: 3:54; 13:50; 23:46 **29**: 9:41; 19:37 **30**: 5:32; 15:28 **31**: 1:24; 11:19; 21:15

June 1: 7:11; 17:06 **2**: 3:02; 12:57; 22:53 **3**: 8:49; 18:44 **4**: 4:40; 14:35 **5**: 0:31; 10:26; 20:22 **6**: 6:18; 16:13 **7**: 2:09; 12:04; 22:00 **8**: 7:56; 17:51 **9**: 3:47; 13:42; 23:38 **10**: 9:34; 19:29 **11**: 5:25; 15:20 **12**: 1:16; 11:12; 21:07 **13**: 7:03;

16:58 **14**: 2:54; 12:49; 22:45 **15**: 8:41; 18:36 **16**: 4:32; 14:27 **17**: 0:23; 10:19; 20:14 **18**: 6:10; 16:05 **19**: 2:01; 11:56; 21:52 **20**: 7:48; 17:43 **21**: 3:39; 13:34; 23:30 **22**: 9:26; 19:21 **23**: 5:17; 15:12 **24**: 1:08; 11:03; 20:59 **25**: 6:55; 16:50 **26**: 2:46; 12:41; 22:37 **27**: 8:33; 18:28 **28**: 4:24; 14:19 **29**: 0:15; 10:10; 20:06 **30**: 6:02; 15:57

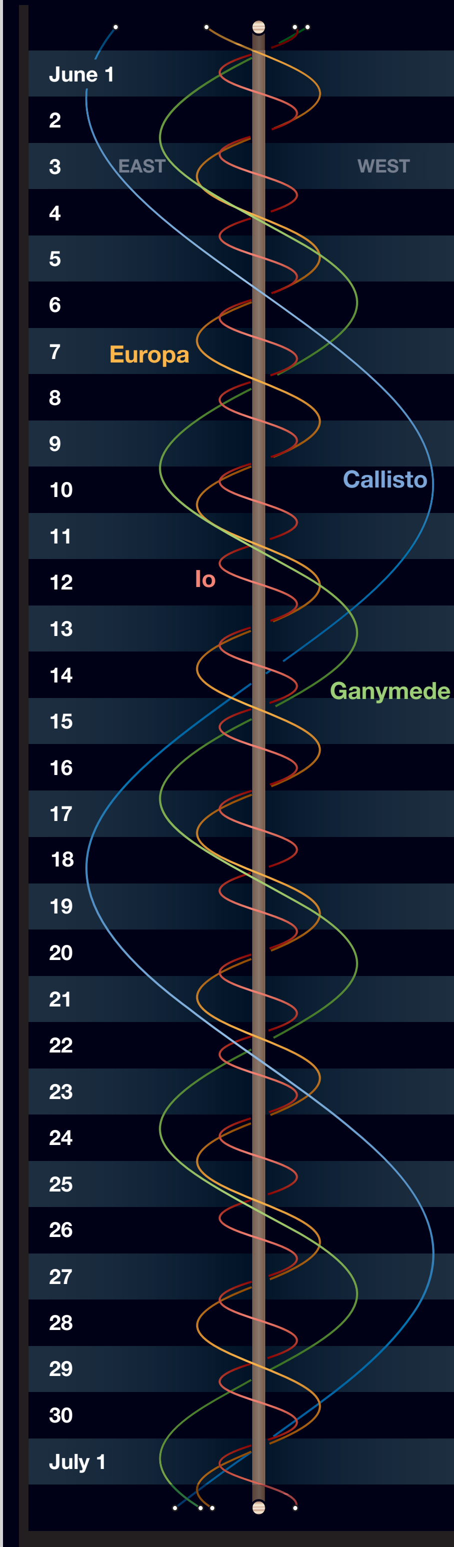
These times assume that the spot will be centered at System II longitude 333° on June 1st. If the Red Spot has moved elsewhere, it will transit $1\frac{2}{3}$ minutes earlier for each degree less than 333° and $1\frac{2}{3}$ minutes later for each degree more than 333°.

Phenomena of Jupiter's Moons, June 2020

Date	Time	Event
June 1	0:30	III.Oc.D
	0:49	II.Sh.E
	2:04	I.Oc.R
	2:42	II.Tr.E
	3:52	III.Oc.R
	20:05	I.Sh.I
	21:01	I.Tr.I
	22:22	I.Sh.E
	23:18	I.Tr.E
June 2	16:39	II.Ec.D
	17:20	I.Ec.D
	20:31	I.Oc.R
	21:22	II.Oc.R
June 3	14:34	I.Sh.I
	15:28	I.Tr.I
	16:50	I.Sh.E
	17:45	I.Tr.E
June 4	10:35	III.Sh.I
	11:21	II.Sh.I
	11:48	I.Ec.D
	13:05	II.Tr.I
	13:50	III.Sh.E
	14:06	II.Sh.E
	14:08	III.Tr.I
	14:57	I.Oc.R
	15:51	II.Tr.E
	17:29	III.Tr.E
June 5	9:02	I.Sh.I
	9:55	I.Tr.I
	11:19	I.Sh.E
	12:11	I.Tr.E
	18:30	IV.Sh.I
	22:16	IV.Sh.E
June 6	2:32	IV.Tr.I
	5:58	II.Ec.D
	6:17	I.Ec.D
	6:38	IV.Tr.E
	9:24	I.Oc.R
	10:33	II.Oc.R
June 7	3:31	I.Sh.I
	4:21	I.Tr.I
	5:47	I.Sh.E
	6:38	I.Tr.E
June 8	0:37	II.Sh.I
	0:42	III.Ec.D
	0:45	I.Ec.D
	2:14	II.Tr.I
	3:23	II.Sh.E
	3:50	I.Oc.R
	3:58	III.Ec.R
	3:59	III.Oc.D
	5:01	II.Tr.E
	7:21	III.Oc.R
	21:59	I.Sh.I
	22:48	I.Tr.I
June 9	0:16	I.Sh.E
	1:04	I.Tr.E
	19:13	I.Ec.D
	19:16	II.Ec.D
	22:17	I.Oc.R
	23:43	II.Oc.R
June 10	16:28	I.Sh.I
	17:14	I.Tr.I
	18:44	I.Sh.E
	19:31	I.Tr.E
June 11	13:42	I.Ec.D
	13:54	II.Sh.I
	14:33	III.Sh.I
	15:23	II.Tr.I
	16:39	II.Sh.E
	16:43	I.Oc.R
	17:35	III.Tr.I
	17:49	III.Sh.E
	18:10	II.Tr.E
	20:56	III.Tr.E
June 12	10:56	I.Sh.I
	11:41	I.Tr.I
	13:13	I.Sh.E
	13:57	I.Tr.E
June 13	8:10	I.Ec.D
	8:34	II.Ec.D
	11:09	I.Oc.R
	12:53	II.Oc.R
June 14	5:17	IV.Ec.D
	5:25	I.Sh.I
	6:07	I.Tr.I
	7:41	I.Sh.E
	8:24	I.Tr.E
	9:09	IV.Ec.R
	11:46	IV.Oc.D
	15:54	IV.Oc.R
June 15	2:38	I.Ec.D
	3:11	II.Sh.I
	4:31	II.Tr.I
	4:40	III.Ec.D
	5:36	I.Oc.R
	5:56	II.Sh.E
	7:18	II.Tr.E
	10:46	III.Oc.R
	23:54	I.Sh.I
June 16	0:34	I.Tr.I
	2:10	I.Sh.E
	2:50	I.Tr.E
	21:07	I.Ec.D
	21:52	II.Ec.D
June 17	0:02	I.Oc.R
	2:02	II.Oc.R
	18:22	I.Sh.I
	19:00	I.Tr.I
	20:39	I.Sh.E
	21:17	I.Tr.E
June 18	15:35	I.Ec.D
	16:28	II.Sh.I
	17:39	II.Tr.I
	18:28	I.Oc.R
	18:33	III.Sh.I
	19:13	II.Sh.E
	20:26	II.Tr.E
	20:59	III.Tr.I
	21:50	III.Sh.E
June 19	0:20	III.Tr.E
	12:51	I.Sh.I
	13:26	I.Tr.I
	15:07	I.Sh.E
	15:43	I.Tr.E
June 20	10:04	I.Ec.D
	11:11	II.Ec.D
	12:54	I.Oc.R
	15:12	II.Oc.R
June 21	7:19	I.Sh.I
	7:52	I.Tr.I
	9:36	I.Sh.E
	10:09	I.Tr.E
June 22	4:32	I.Ec.D
	5:44	II.Sh.I
	6:47	II.Tr.I
	7:20	I.Oc.R
	8:30	II.Sh.E
	8:39	III.Ec.D
	9:34	II.Tr.E
	12:31	IV.Sh.I
	14:07	III.Oc.R
	16:25	IV.Sh.E
	17:23	IV.Tr.I
	21:29	IV.Tr.E
June 23	1:48	I.Sh.I
	2:18	I.Tr.I
	4:04	I.Sh.E
	4:35	I.Tr.E
	23:01	I.Ec.D
June 24	0:29	II.Ec.D
	1:46	I.Oc.R
	4:20	II.Oc.R
	20:16	I.Sh.I
	20:45	I.Tr.I
	22:33	I.Sh.E
	23:02	I.Tr.E
June 25	17:29	I.Ec.D
	19:01	II.Sh.I
	19:54	II.Tr.I
	20:12	I.Oc.R
	21:47	II.Sh.E
	22:32	III.Sh.I
	22:41	II.Tr.E
June 26	0:19	III.Tr.I
	1:50	III.Sh.E
	3:41	III.Tr.E
	14:45	I.Sh.I
	15:11	I.Tr.I
	17:02	I.Sh.E
	17:28	I.Tr.E
June 27	11:57	I.Ec.D
	13:48	II.Ec.D
	14:38	I.Oc.R
	17:28	II.Oc.R
June 28	9:13	I.Sh.I
	9:37	I.Tr.I
	11:30	I.Sh.E
	11:54	I.Tr.E
June 29	6:26	I.Ec.D
	8:18	II.Sh.I
	9:01	II.Tr.I
	9:04	I.Oc.R
	11:05	II.Sh.E
	11:48	II.Tr.E
	12:37	III.Ec.D
	17:25	III.Oc.R
June 30	3:42	I.Sh.I
	4:03	I.Tr.I
	5:59	I.Sh.E
	6:20	I.Tr.E
	23:19	IV.Ec.D

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

Jupiter's Moons



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

Peering over the Limb

Spot evidence of these hidden farside features during favorable librations.

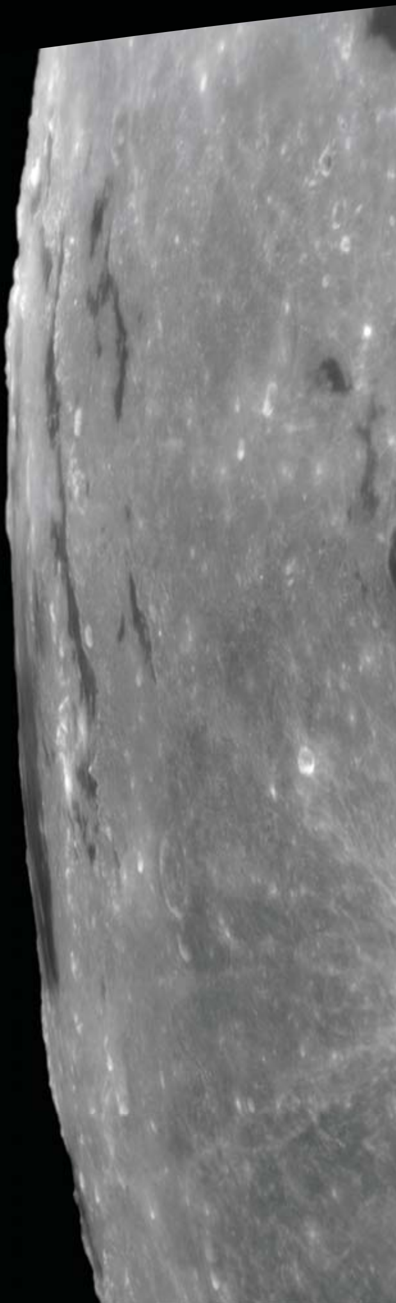
For observers, the Moon is like a circular billboard in the sky. We never see its entire back side from Earth, but with the subtle effects of the Moon's orbit known as *libration* (*S&T:* Sep. 2018, p. 52), we can peek a few degrees around its edge, allowing us to view nearly 60% of the Moon's surface. Within that just-around-the-edge zone, during favorable librations we can observe all of **Mare Orientale**, even though the mare itself lies beyond the western limb. Similarly, we can glimpse the limbward halves of **Mare Marginis** and **Mare Smythii**, both of which extend beyond 90°E.

Direct observation beyond the 6° to 7° width of the libration zone is impossible, but there have been several attempts to infer farside features before the Space Age. Nathaniel Shaler, an American geologist who studied the Moon, speculated in 1903 that **Montes Cordillera**, which appear as bumps on the Moon's western edge, could be the rim of a giant crater. Shaler was right. Lunar Orbiter 4 photographs revealed the full extent of the three-ringed Orientale impact basin that extends 10° to 15° beyond what Earthbound observers can view. Orientale is a very large basin indeed, with a small lake of dark mare lava in the middle – Mare Orientale.

In 1624, Giovanni Domenico Cassini observed very tall peaks on the limb near the lunar south pole. The indefatigable observer Johann Hieronymous Schröter rediscovered the peaks at the turn of the 19th century and named them the **Leibnitz Mountains**, —a designation they retained until 1971. Schröter didn't suspect that they might be the rim of a giant farside crater, but William Hartmann and Gerard Kuiper did. In their groundbreaking 1962 paper, "Concentric Structures Surrounding Lunar Basins," the pair recognized that nearside circular maria were mountain-edged impact basins. The Leibnitz Mountains are among the tallest on the lunar surface, so it's not surprising that the basin they partially enclose is the Moon's biggest impact feature, the South Pole–Aitken (SPA) Basin. Spanning around 2,500 kilometers, the entire SPA lies on the farside.

Schröter also discovered the **Doerfel Mountains**, west of the Leibnitz peaks. The Doerfels are another limb-hugging, tall range whose name is no longer officially recognized. Schröter and other observers attempted to carefully map the range, but none suggested they are the rim of a large crater. In 2018, amateur astronomer Jim Mosher definitively matched the highest peaks with high spots near the craters **Drygalski** and **Hausen**, situated right along the SPA rim. Along with the Leibnitz mountains, the Doerfels are the only parts of the giant SPA Basin that libration makes visible.

Shaler also initiated a separate attempt to identify features on the unobservable lunar farside by examining faint crater rays appearing to radiate from sources beyond the limb. Later, in the 1950s, Hugh Percy Wilkins and Patrick Moore repeated the exercise and proposed the existence of 9 farside ray craters. Each lay beyond the western limb and was situated in a long arc spanning from near the north pole to Mare Orientale and down to **Bailly** near the south pole. One proposed crater supposedly had rays converging near the nearside craters Bailly and **Inghirami**.



▲ This image of Mare Orientale seen on an evening of strong libration reveals the western rim of the Rook Mountains (Montes Rook) residing far beyond the limb.

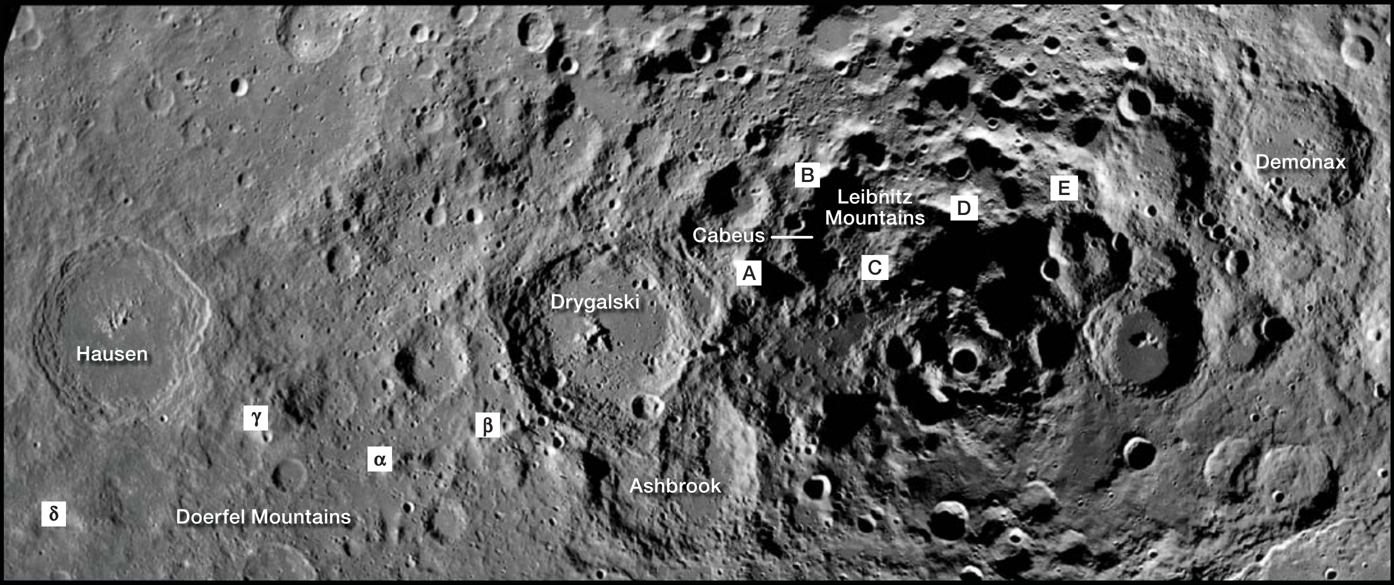
SEAN WALKER / S&T

Using NASA's Lunar Reconnaissance Orbiter Hapke-Normalized Color *QuickMap* overlay (**quickmap.lroc.asu.edu**), I don't see any of the rays Wilkins and Moore reported. However, I can find other farside craters whose rays extend onto the nearside. The best example are three rays from Ohm that extend 1,130 km across farside highland material and continue through the middle of **Russell**, as well

▼ Ejecta rays from the crater Giordano Bruno on the lunar farside extend to Alhazen crater east of Mare Crisium.

▼▼ This *QuickMap* image shows rays from the crater Ohm on the lunar farside, extending to Russell in western Oceanus Procellarum.

▼▼▼ The tall peaks of the former Doerfel and Leibnitz Mountains are labeled with Schröter's original designations. South is up.



NASA / GSFC / ARIZONA STATE UNIVERSITY (3)

as north and south of the crater. There are suggestions that the Ohm rays extend 150 km farther into **Oceanus Procellarum**. Finally, other rays to observe from a farside crater radiate from **Giordano Bruno** and extend at least 975 km to the crater **Alhazen**, east of **Mare Crisium**.

All of the rays and mountains described here are observable from your backyard with a small telescope, though the peaks will require a very favorable libration. You won't see very far onto the lunar farside, but you can observe features that mark major landforms otherwise completely speculative without spacecraft data.

■ Contributing Editor CHUCK WOOD often observes the libration zones.

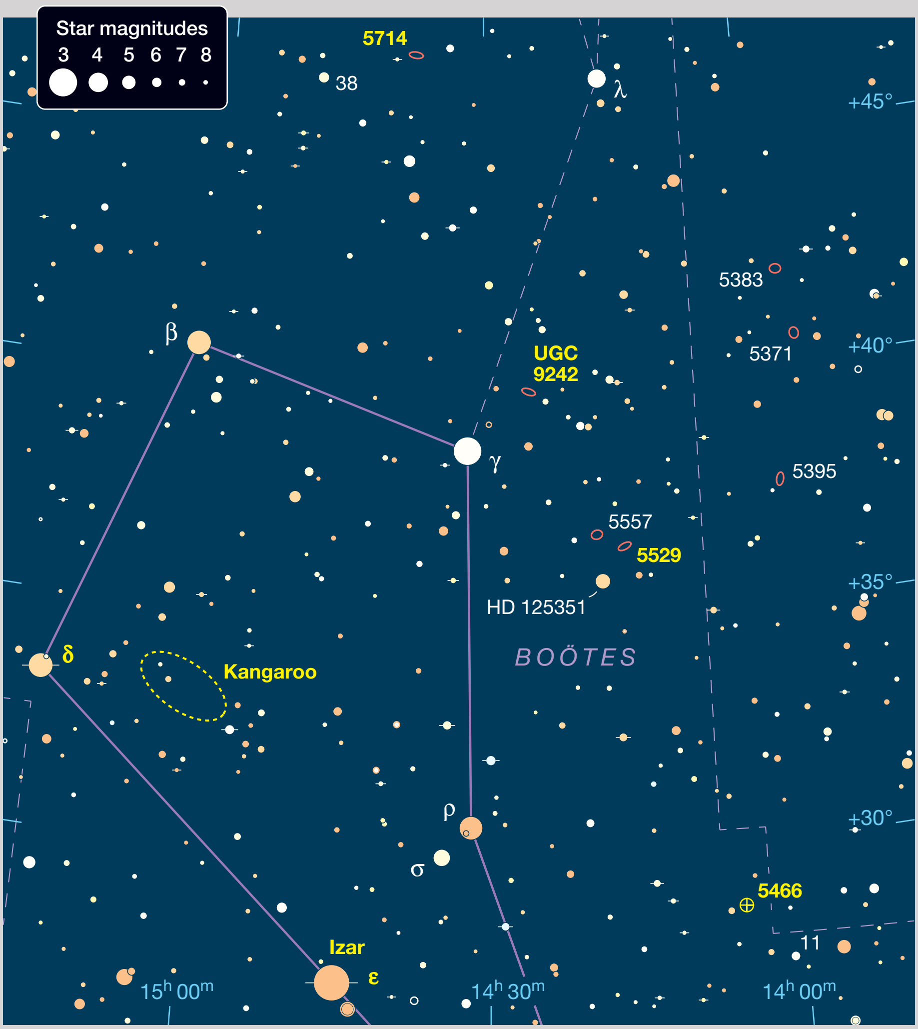
The First Plowman

Boötes is home to one globular cluster and many great galaxies.

And next Boötes comes, whose order'd Beams
Present a Figure driving on his Teams.
— Marcus Manilius, *Astronomica*

The name Boötes is often said to come from a Greek term meaning "ox driver." According to some tales, Boötes invented the ox-drawn plow to make the cultivation of crops easier. Proud of her son's creation, the goddess Ceres had Boötes placed among the stars. We can also see his creation in the nearby asterism of the Big Dipper, which is called the Plough in the British Isles.

Have you ever wondered how to pronounce Boötes? One accepted pronunciation is bo-OH-teez. For an expanded guide to the constellations and their pronunciations, visit **https://is.gd/constellations**.



We'll begin at **Delta (δ) Boötis**, a spacious double star whose components are widely parted by my 105-mm (4.1-inch) refractor at 17×. The deep-yellow primary is a giant star with a spectral type of G8, and the pale-yellow star following it across the sky is similar to our Sun. Despite the gulf between them, these stars form a true pair about 122 light-years away from us. Their angular separation on the sky tells us that they must be separated in space by at least 10 times the average Sun-Pluto distance.

Canadian amateur Dave Johns told me about a cute asterism he found 3.1° west of Delta. His **Kangaroo** spans 1.7° from nose to tail and makes a nice target for big binoculars or a small, wide-field telescope. My 18×50 image-stabilized binoculars show enough stars to see his shape, with the Kangaroo boinging his way east. My 105-mm scope at 17× nicely displays the 21 stars (magnitudes 7 to 11) that make up his outline. The Kangaroo's brightest star joins his foreleg to his body and shines with a golden hue.

Our next stop is the lovely double star **Epsilon (ε) Boötis**. It's commonly known as Izar, an Arabic word meaning girdle or loincloth, denoting the star's position in its constellation figure. William Herschel discovered the pair in 1779, describing it as "a very beautiful object." He called the brighter star "reddish" and the fainter one "blue, or rather a faint lilac." Friedrich Georg Wilhelm von Struve bestowed the name Pulcherrima (Most Beautiful) on this double, calling its stars "very yellow" and "very blue."

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

Through my 105-mm refractor at 122×, I see Izar's snug primary and secondary as gold and white, respectively, which matches their spectral types of *K*0 and *A*0. However, many observers see the secondary as bluish, a common color-contrast illusion experienced when a yellow, orange, or red star is seen close to a fainter star that's not strongly colored. The companion star is only 2.8″ north-northwest of its primary, and you may need a magnification of more than 200× to separate them when the seeing (atmospheric steadiness) is poor.

Farther west we come to **NGC 5466**, the only globular cluster in Boötes. Look for it 1.5° northeast of the 6th-magnitude star 11 Boötis. Although the cluster has a ghostly surface brightness, I can detect it through 15×45 image-stabilized binoculars. The globular appears fairly large through my 130-mm refractor at 23×. I estimate that it would just fill the space between two field stars (8th and 9th magnitude) about ½° to the cluster's north-northwest and 8.4′ apart. A 7th-magnitude, yellow-orange star sits 20′ east-southeast of the cluster. At 102×, NGC 5466 presents a slightly brighter core that's elongated north-south for 3¼′. The cluster remains fairly bright to a diameter of 5′ and then gives way to a gossamer halo. A few extremely faint stars pop in and out of view.

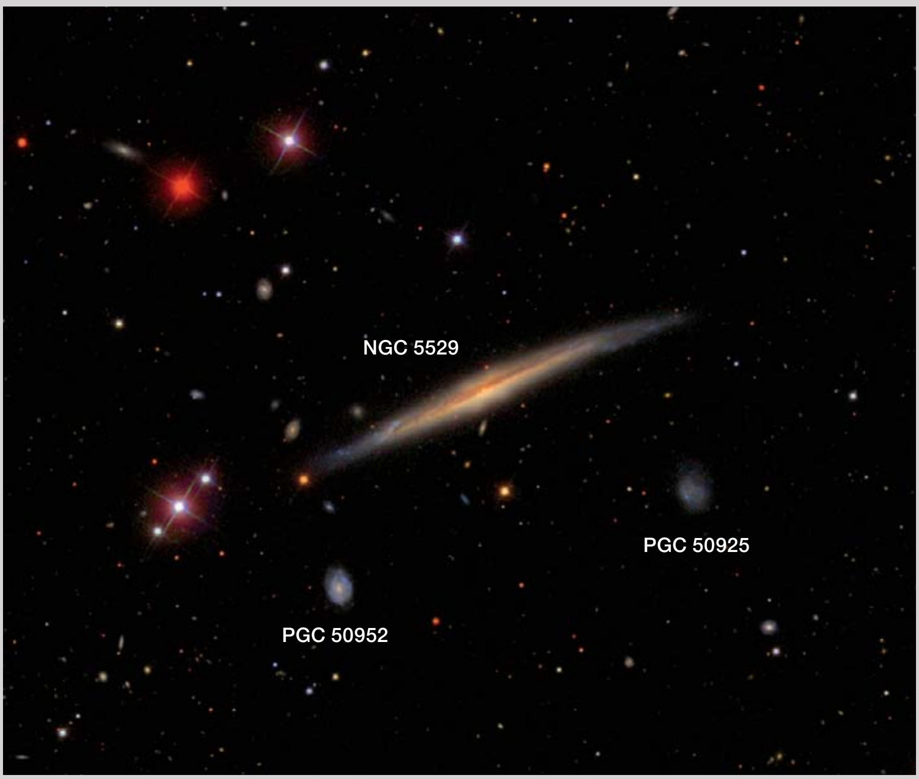
In my 10-inch reflector at 187×, NGC 5466 flaunts many chains of faint to very faint suns beading an unevenly bright haze, while isolated halo stars are set against a sable sky. Switching to my 15-inch reflector at 216×, NGC 5466 is a gorgeous, well-resolved, and very loose cluster with ragged edges. Many stars of varied brightness grace the cluster, some of the brightest hemming the star-dappled core and molding it into a 5′ triangle pointed southwest. A line of several stars dangles from the globular's southwestern fringe and trends south-southeast.

NGC 5466 is high above the plane of our galaxy, about 52,000 light-years from the Sun and 53,000 light-years from our galaxy's center. NGC 5466 sports a lengthy tail of tidal debris stripped from the orbiting cluster when it passed near the galactic center while plunging through the galaxy's disk. The tail's following arm extends at least 15° southeast, and the leading arm reaches across Canes Venatici and into Ursa Major. Part of the tail is kinky, and a 2012 study by Hanni Lux (University of Nottingham, UK) and her colleagues used its peculiar structure to probe the shape of our galaxy's dark matter halo.

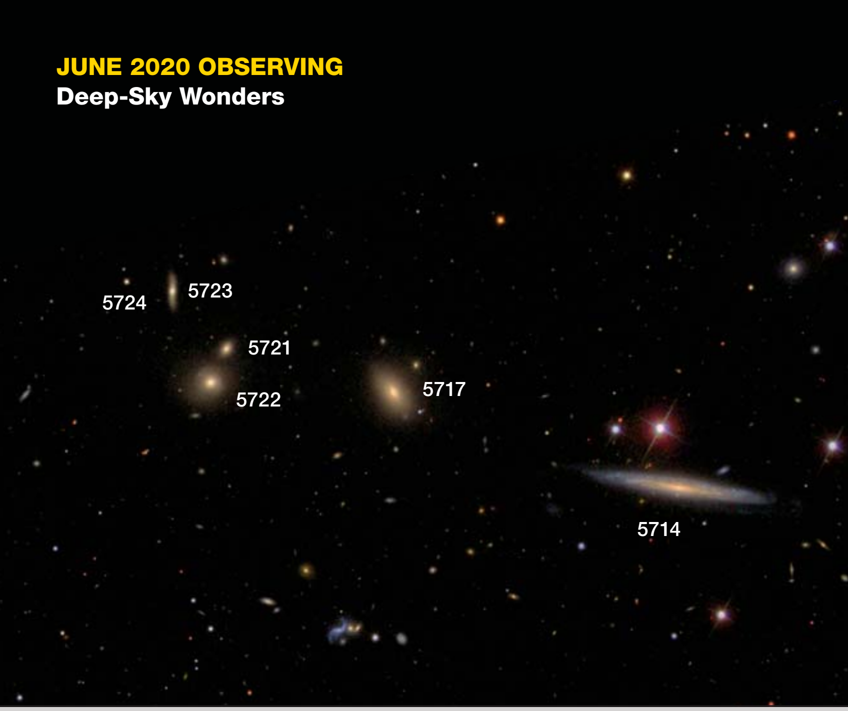
Now we'll call on the flat galaxy **NGC 5529**, which rests 52′ northwest of the 4.8-magnitude, yellow-orange star HD 125351. Flat galaxies are disk-like galaxies, seen edge-on, that appear at least seven times longer than wide.

NGC 5529 is faint, very slender, and grows brighter toward the center as seen through my 130-mm scope at 63×. It spans about 3′, running west-northwest to east-southeast. NGC 5529 is nestled in a distinctive star field that includes a short, three-star (magnitudes 10.9 to 13.5) line near the galaxy's eastern tip and a large, six-star zigzag topped by a 10th-magnitude beacon west of the galaxy. Folks with 16-inch or larger scopes should look for the galaxy's thin dark lane and the two dim companion galaxies to the south (PGC 50952 and PGC 50925).

Large-scope enthusiasts may also like to try the more challenging flat galaxy **UGC 9242**, located 1.8° northwest of Gamma (γ) Boötis. Whereas NGC 5529 is nine times longer than wide, UGC 9242 is a needle-thin 17 times longer than wide. With my 10-inch scope at 89×, I can just see its very dim, elongated core sprouting short fainter extensions. A 13th-magnitude star is perched 1.3′ southeast of its center. At 115× I see only 1.3′ of



SLOAN DIGITAL SKY SURVEY



this galaxy's 5.7′ length, a pin of light pointing east-northeast. Texas amateur Jimi Lowrey brought this super-thin galaxy to my attention. How much of its length can you see?

We'll end our tour with a compact sextet of galaxies 1.9° west-northwest of 38 Boötis. In my 130-mm scope at 164×, I can barely see three of these faint galaxies with averted vision (that is, by looking a little off to one side of each object). **NGC 5714** (magnitude 13.4) is just a slightly elongated blur, while **NGC 5717** (mag. 14.4) and **NGC 5722** (mag. 14.7) show only their tiny cores as extremely faint spots. Two 13th-magnitude stars 5.2′ north-northwest of NGC 5722 point right to the galaxy.

Through my 10-inch scope at 166×, NGC 5714 becomes a 1½′ streak tipped a little north of east with a slightly brighter, elongated core. A 12th-magnitude star hovering over the galaxy's northern flank guards a 13th-magnitude star to its east. This flat galaxy shares the field of view with NGC 5717 and NGC 5722. The former is a 1′ oval leaning northeast, which harbors a brighter core and starlike nucleus. NGC 5722 is small and round with an elusive, stellar nucleus.

My 15-inch reflector at 216× adds two fainter smudges to the group — **NGC 5721** (mag. 14.9) and **NGC 5723** (mag. 15.0). The final member of the sextet, **NGC 5724** (mag. 16.9), remained invisible to me. Can you spot it?

NGC 5717, 5721, 5722, and 5723 are each about 500 million light-years distant. NGC 5714 and 5724 are foreground galaxies 130 million and 260 million light-years away from us.

▲ Here's the author's impression of the NGC 5714 sextet as viewed through her 15-inch Newtonian reflector. She didn't see NGC 5724, the faintest member of the sextet.

■ Contributing Editor **SUE FRENCH** wrote this column for the June 2013 issue of *Sky & Telescope*.

Stars, Clusters, and Galaxies in Boötes

Object	Type	Mag(v)	Size/Sep	RA	Dec.
δ Boo	Double star	3.6, 7.9	109″	15^h 15.5^m	+33° 19′
Kangaroo	Asterism	—	113′ × 53′	15^h 00.9^m	+33° 09′
ε Boo	Double star	2.6, 4.8	2.8″	14^h 45.0^m	+27° 04′
NGC 5466	Globular cluster	9.0	9.0′	14^h 05.5^m	+28° 32′
NGC 5529	Flat galaxy	11.9	6.4′ × 0.7′	14^h 15.6^m	+36° 14′
UGC 9242	Flat galaxy	13.5	5.7′ × 0.3′	14^h 25.4^m	+39° 32′
NGC 5714 Sextet	Galaxy group	13.4–16.9	11.5′	14^h 38.5^m	+46° 39′

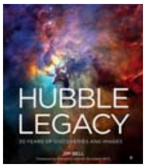
Angular sizes and separations are from recent catalogs. Visually, an object's size is often smaller than the cataloged value and varies according to the aperture and magnification of the viewing instrument. Right ascension and declination are for equinox 2000.0.

SLOAN DIGITAL SKY SURVEY (2)

A Wealth of Wonders

Our writers expand their (and our) horizons in an eclectic range of astro-centric books.

The authors whose work appears in our pages often take their ideas and interests further by writing books. Below are some recently published volumes by *S&T* contributors. *—The Editors of* Sky & Telescope



Jim Bell

Sterling Publishing, 2020

224 pages, ISBN 978-1-4549-3622-0

$27.95, hardcover

Hubble Legacy: 30 Years of Discoveries and Images

You can't flip through this stunning collection of Hubble images without pausing often to shake your head in awe. The accompanying text that Contributing Editor Jim Bell wrote is equally enriching. Altogether, this coffee-table book is a riveting celebration of the venerable space telescope's 30th anniversary (see *S&T:* Apr. 2020, p. 14).

Keith Cooper

Bloomsbury Sigma, 2020

336 pages, ISBN 978-1-4729-6042-9

$28.00, hardcover

The Contact Paradox: Challenging Our Assumptions in the Search for Extraterrestrial Intelligence

What do we mean by intelligence? How can we identify a signal if one is sent to us? How should we react if one is? In this book, the editor of the UK's *Astronomy Now* magazine addresses these and other questions about the past and future of SETI.

Bob King

Page Street Publishing, 2019

224 pages, ISBN 978-1-62414-896-5

$16.99, paperback

Urban Legends from Space: The Biggest Myths About Space Demystified

From "There's No Gravity in Space" to "Jupiter Is a Failed Star," Bob King, our Celestial Calendar columnist (see page 48), provides brief chapters in this delightful and useful book that debunks common myths and misconceptions with solid scientific evidence.

Dean Regas

Adams Media, 2020

256 pages, ISBN 978-1-5072-1381-0

$21.99, hardcover

100 Things to See in the Night Sky, Expanded Edition: Your Illustrated Guide to the Planets, Satellites, Constellations, and More

In this expanded edition, Dean Regas, Cincinnati Observatory astronomer and *S&T* contributing editor, offers 100 objects that you can see with the naked eye, binoculars, or a backyard telescope. Want to become an expert stargazer? Here's your guide.

Govert Schilling

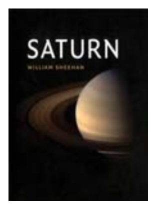
Firefly Books, 2019

240 pages, ISBN 978-0228102113

$49.95, hardcover

Galaxies: Birth and Destiny of Our Universe

Fascinated by those island universes we call galaxies? This handsomely illustrated volume by Contributing Editor Govert Schilling will supply all you need to know about everything from the Milky Way to the earliest galaxies known, from spirals to lenticulars, and from colliding galaxies to cosmic clusters.



William Sheehan

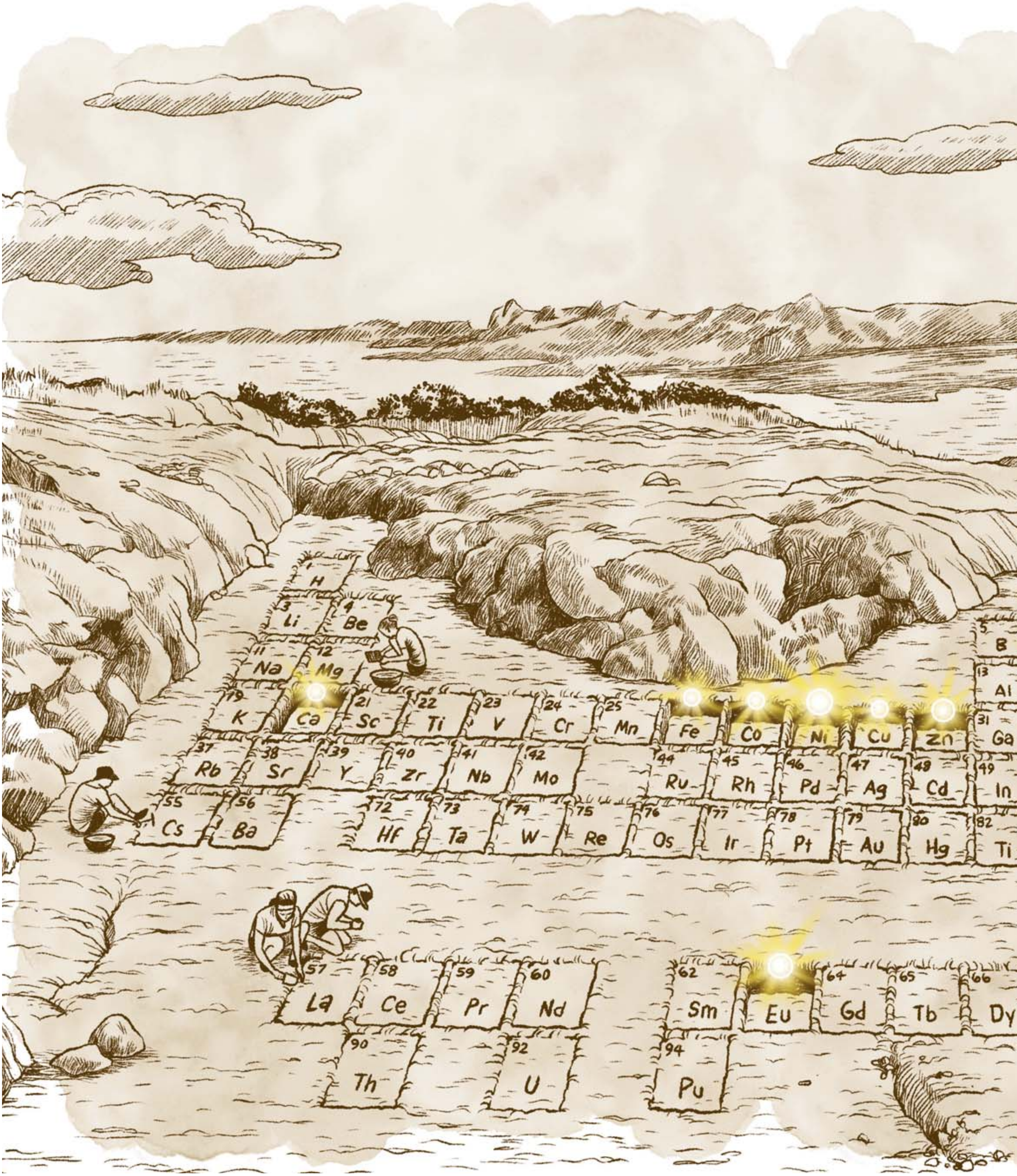
Reaktion Books, 2019

220 pages, ISBN 978-1-78914-153-5

$40.00, hardcover

Saturn

Everyone remembers their first view of Saturn in a telescope, and that initial wonder rarely dissipates. Here, Contributing Editor Bill Sheehan offers a gorgeously illustrated deep dive into everything that captivates us about the ringed planet. From the early investigations by Tycho Brahe and Galileo to the latest discoveries by the Cassini mission, Sheehan covers it all.



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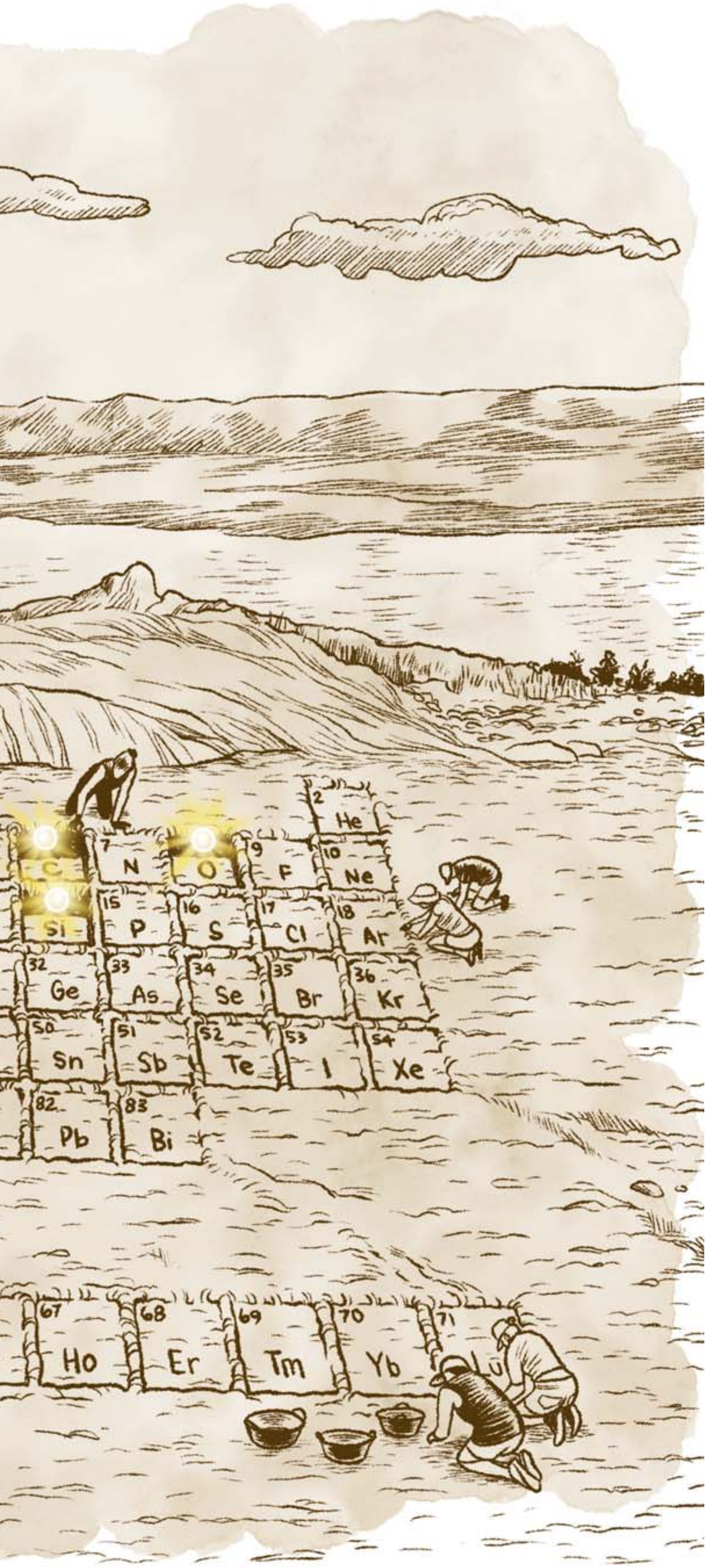


Stellar Archaeology

Astronomers are illuminating the universe's early days by studying chemical patterns in the oldest stars.

The first stars must have been a magnificent sight. Far brighter, hotter, and more massive than most stars that currently light the sky, they emerged after a period of relative darkness — about 100 million years after the Big Bang, aided by the gravitation of countless halos of dark matter. No large galaxies existed yet, nor did elements heavier than helium, save for a trace of lithium. But when the first stars ended their lives as immense supernova explosions a few million years later, they released heavier elements that helped form the next generation of stars.

These heavy elements, such as carbon, calcium, and iron, astronomers collectively call *metals*. Metals helped radiate away heat from collapsing clouds of hydrogen and helium gas, fostering the creation of less massive and longer-lived stars. The smallest of these second-generation *Population II* (Pop II) stars still exist in the Milky Way and in nearby dwarf galaxies. Their outer layers harbor traces of metals produced in the first stars, called (counterintuitively from a chronologist's view) *Population III*.

This presents astronomers with an opportunity to do archaeology — stellar archaeology. No current telescopes can look back more than 13 billion years to directly study the first stars. But astronomers can study the abundances and relative proportions of metals left behind by the first stars in the outer layers of the oldest surviving Pop II stars, much as earthbound archaeologists learn about ancient cultures by studying the artifacts they left behind. Using this approach, astronomers hope to increase our understanding of how the first stars evolved, how they generated the first elements heavier than lithium, and how the first galaxies formed.

Finding the Oldest Stars

Population II stars are not hard to find. A peek through a telescope at a bright globular cluster such as M13 presents the combined light of hundreds of thousands of these ancient stars. Many stars in the Milky Way's central bulge and immense but sparsely populated halo are also Pop II stars that formed some 10 billion to 13 billion years ago. Only a fraction of them formed immediately after the demise of the first stars.

Much younger *Population I* stars, by contrast, lie in the Milky Way's disk. They are relatively rich in elements such as iron and carbon, because they formed from interstellar mate-

LEAH TISCIONE / S&T

rial seeded by many generations of earlier stars. Our Sun is a Pop I star. It formed about 9 billion years after the Big Bang, time enough for heavy elements to enrich its natal cloud. Today about 1.5% to 2% of the Sun's mass comprises elements heavier than helium.

This fraction may sound low, but it's high compared with Pop II stars: Metals are less than a tenth as abundant in Pop II stars as they are in the Sun. The oldest Pop II stars have the lowest levels. This is the key assumption of stellar archaeology: The abundances of metals in the atmosphere of a star are a proxy for its age. The lower the abundance of metals such as carbon, iron, and calcium, the more likely it is that the very first stars produced these trace metals. Pop III stars, if they are ever observed, would have virtually no elements heavier than helium.

The first metal-poor stars were found by chance. In 1951, Joseph Chamberlain and Lawrence Aller (both University of Michigan) found the stars HD 140283 and HD 19445 had surprisingly low iron and calcium abundances. Astronomers often use a star's iron abundance as a gauge for its overall metal content. Subsequent studies of HD 140283 revealed an iron abundance about 1⁄300 that of the Sun. Sometimes called the Methuselah Star, this 7th-magnitude star is easily visible in the constellation Libra with a pair of binoculars.

Later sky surveys revealed hundreds of metal-poor stars. The HK and Hamburg/European Southern Observatory projects in the 1980s and 1990s recorded low-resolution spectra directly onto photographic plates, which astronomers then analyzed to find two absorption lines from calcium — the H and K lines at 397 nm and 393 nm.

The HK survey detected the first star with an iron abundance 1⁄10,000 solar, while astronomers found another star, HE 1327-2326 — until recently the most iron-poor star known — with the Hamburg/ESO survey. It has an iron abundance 500,000 times lower than the Sun's, which suggests it is one of the oldest stars yet discovered.

The more recent Sloan Digital Sky Survey and the SkyMapper survey of the southern sky have resulted in the discovery of many more metal-poor stars. Based at Siding Spring Observatory, SkyMapper uses a fully automated 1.35-meter modified Cassegrain telescope with six photometric filters to estimate the color and brightness of millions of stars. One of the filters overlaps with the Ca H and K lines to make a rough estimate of overall metallicity. Less absorption at these violet wavelengths suggests a metal-poor star, and astronomers measure higher-resolution spectra of such stars using larger telescopes. Detailed numerical models render the abundance of a particular metal from the measured strength of the absorption line, along with an estimate of the star's effective temperature and surface gravity. Screening excludes stars cooler than 4000K, because they have evolved to a stage in which convection dredges up metals from the core and contaminates the outer layers of the star.

Despite extensive searching, results to date show only about 30 stars with iron content less than 1⁄10,000 that of the

▲ **M13** Astronomers estimate that 20% of the stars in the globular cluster M13 are primordial Population II stars.

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

Sun. "Finding these stars is like searching for a needle in a haystack," says Anna Frebel (MIT) who discovered the low metallicity of HE 1327-2326 and other metal-poor stars. "An automated survey like SkyMapper gives us a bigger magnifying glass to look for these stars, but it's still hard work."

Iron-Poor Stars and the First Supernovae

As SkyMapper was commissioned, Frebel and her collaborators in 2014 discovered SMSS 0313-6708, a 15th-magnitude red giant with no detectable iron absorption. The missing signal

Understanding Stellar Populations

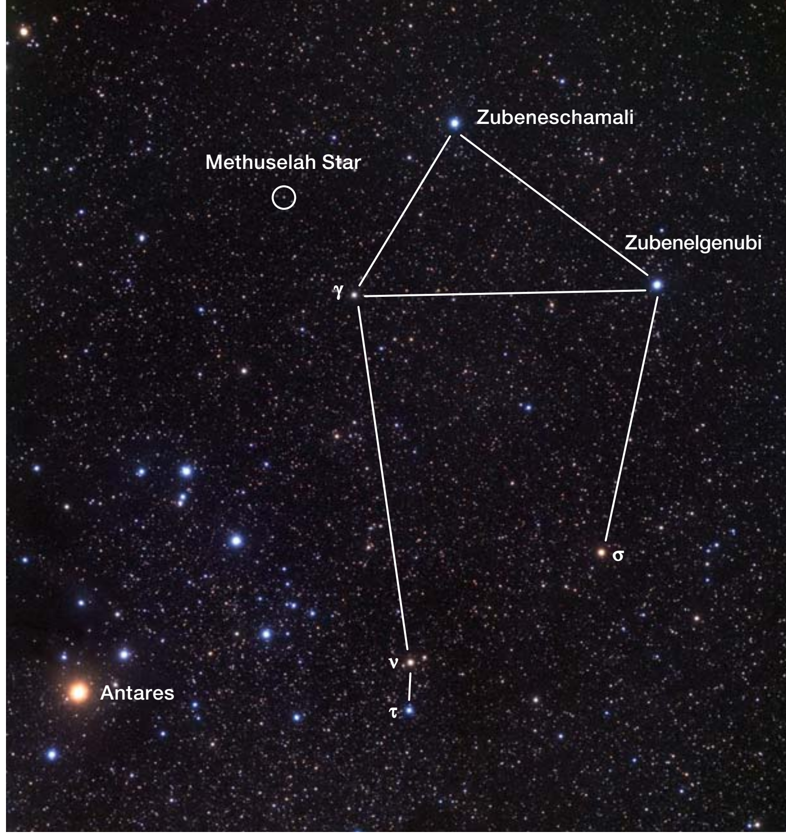
Astronomers, like most scientists, love to classify things. It was in this spirit that Walter Baade introduced the idea of stellar populations in the 1940s. He noticed bluer stars, which he called Population I, congregate in the spiral arms of the Milky Way and other galaxies, while redder Population II stars were found in and around the bulge of the galaxy, in the halo, and in globular clusters. Population I stars stay in the disk as they orbit the galactic center along fairly circular paths, while Population II stars in the bulge and halo can in some cases follow highly elliptical orbits around the center of the Milky Way and can shoot through the disk as well.

In the early 1950s, astronomers found Population I stars had much larger abundances of elements heavier than helium compared to Population II stars. That's suggested the star's iron fraction is at most 1/13 million that of the Sun. Spectroscopy also revealed weak absorption lines of carbon, magnesium, and calcium in this ancient halo star.

In 2019, Frebel's team found another iron-poor star, SMSS 1605-1443. It has the lowest measured iron abundance, at 1.6 million times less than solar. This star also has 100,000 times less calcium and magnesium compared to the Sun.

While these stars have just traces of iron, they feature a surprising overabundance of carbon. In the case of SMSS 1605-1443, for example, carbon is nearly 10,000 times more abundant than iron compared to the same ratio in our Sun. More recent observations of the iron-poor halo star J0815+4729 reveal a similar overabundance of oxygen compared to iron. These results surprised astronomers, because massive Pop III stars should die in spectacular supernovae explosions that eject large amounts of iron as well as lighter elements such as carbon, oxygen, magnesium, and calcium, all of which should find their way into the first Pop II stars.

So where did the iron go? One possibility suggests *mixing-fallback supernovae*. In this scenario, which might affect relatively small Pop III stars of 10 to 20 solar masses, mixing inside the collapsing core transports some heavy elements to the core's outer layers, where they are ejected in the explosion along with lighter elements such as carbon. But most of the heaviest end products of nuclear fusion in the core — such as iron, nickel, and zinc — would fall back into the black hole or neutron star formed at the star's core, explaining the relative lack of iron. A 2017 study by Ke-Jung Chen (National Astronomical Observatory of Japan) and colleagues made detailed computer simulations of mixing-fallback supernovae for Pop III stars. Using stars of 10 to 60 solar masses, they successfully explained the observed metal abundances in stars such as SMSS 1605-1443 and SMSS 0313-6708.



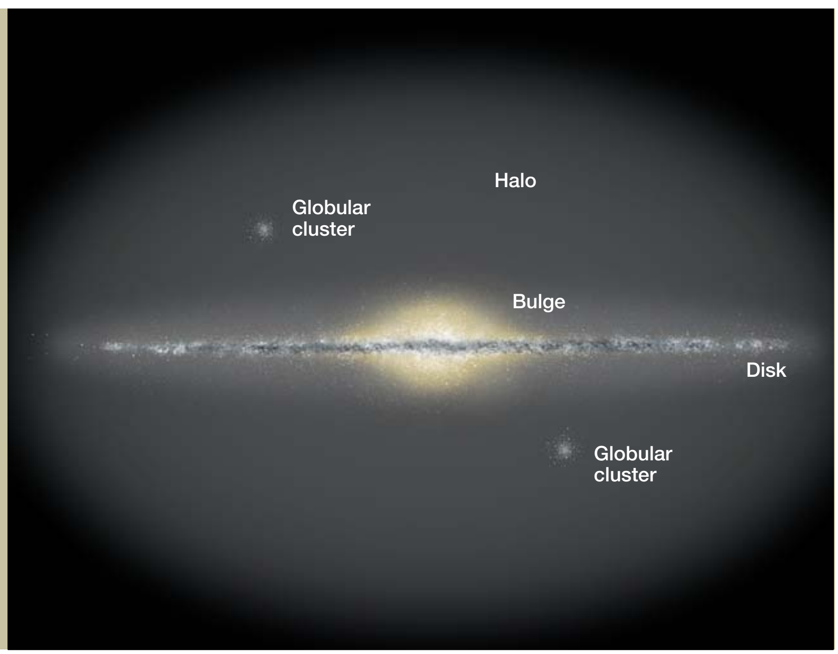
▲ **METHUSELAH STAR** Astronomers realized in the 1950s that the 7th-magnitude star HD 140283 in Libra has a surprisingly low level of iron.

Another explanation involves *pulsational pair-instability supernovae*, which would afflict Pop III stars of 100 to 140 solar masses. According to Stan Woosley (University of California, Santa Cruz), who has extensively modelled these supernovae, such stars first lose mass to stellar winds that might themselves be rich in carbon, nitrogen, and oxygen. Then they pulse violently as the dense soup of nuclei and gamma rays in their cores form pairs of electrons and

METHUSELAH STAR: AKIRA FUJII; GALAXY DIAGRAM: GREGG DINDERMAN / *S&T*

because Pop I stars, which are younger, formed from gas in the interstellar medium that was enriched by heavy elements ejected from many generations of dying stars. The Sun is a Pop I star, as are most other bright stars visible to the unaided eye. The older Pop II stars have far lower metal abundances than the Sun because they formed from less enriched material, earlier in the history of the universe. The 7th-magnitude star HD 140283 in Libra (see image above) is an example of a Pop II star.

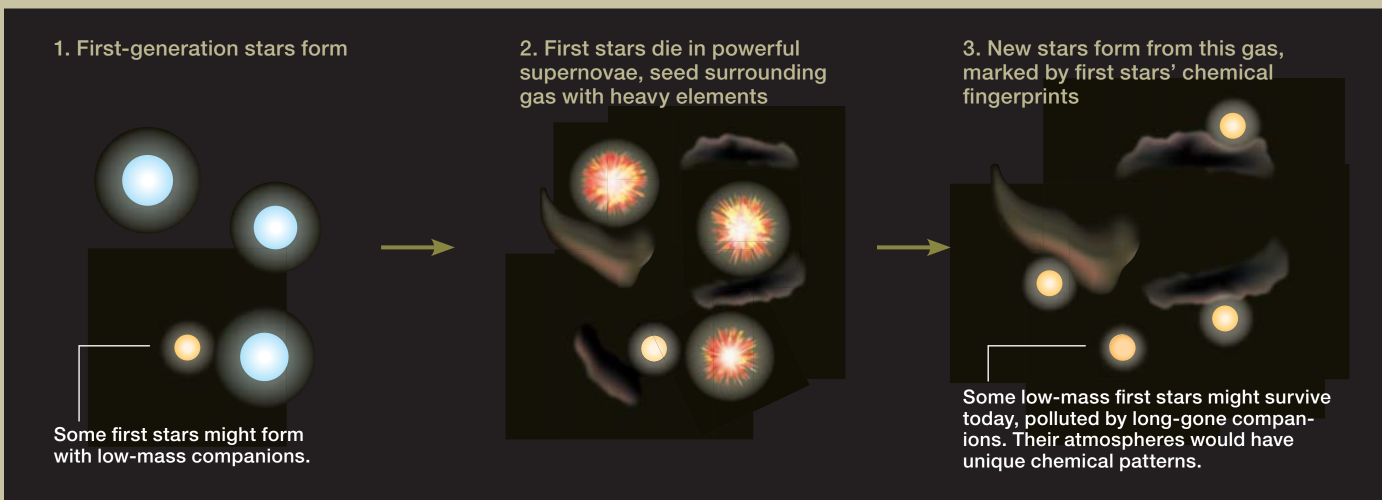
Astronomers introduced Population III stars as a concept in the 1960s. These stars have yet to be observed, but they would have no heavy elements because they formed out of primordial hydrogen, helium, and tiny traces of lithium only 100 to 200 million years after the Big Bang, before heavier elements existed.



positrons that self-annihilate, causing the core to partially collapse and rebound. They eject what was left of their hydrogen envelope and the outer part (maybe up to 5 to 10 solar masses) of their helium, along with appreciable C, O, Ne, and Mg. After the pulsations, the remainder of the star collapses to a black hole, capturing the iron remaining near the core. Very little of the iron — if any — escapes, and very little silicon and calcium.

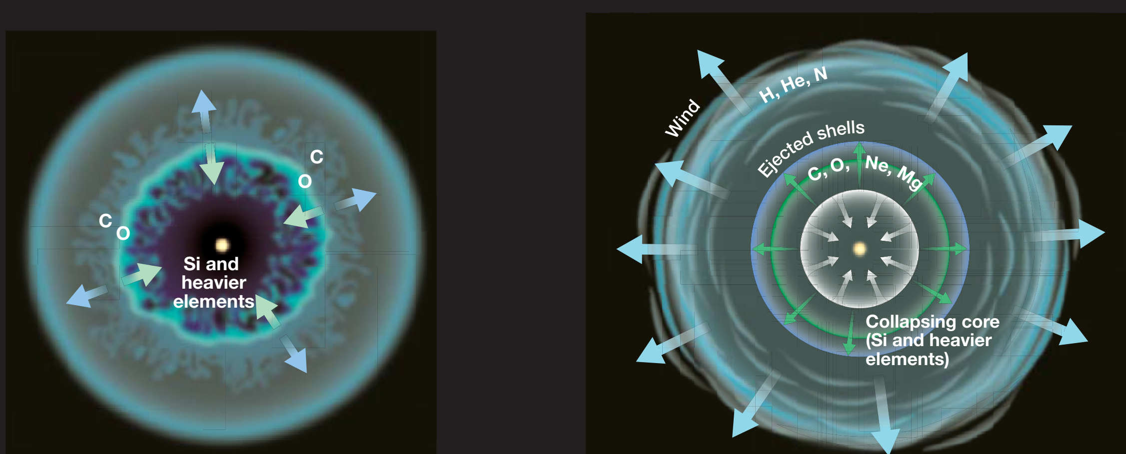
Explaining the overabundance of carbon in iron-poor stars got more complicated in 2019, when Rana Ezzeddine (then at MIT) and her collaborators measured UV absorption lines of zinc in HE 1327-2326 using the Cosmic Origins Spectrograph on the Hubble Space Telescope. In HE 1327-2326, zinc is not only present but six times more abundant than iron. Zinc is created from iron during supernova explosions, but standard mixing-fallback and pulsational pair-instability supernovae cannot produce such large amounts. Instead, the study suggests a significantly asymmetric supernova of a fast-rotating 25 solar-mass star would be energetic and unstable enough to power a pair of jets that would emerge from the core itself. The jets would pull up zinc from deep inside and eject it, even as most of the iron falls into the newly made black hole.

MAKING THE OLDEST STARS



THE FIRST SUPERNOVAE

Based on the chemical patterns in the oldest Population II stars, astronomers have suggested several possible ways the universe's first stars died.



GREGG DINDERMAN / S&T (2)

MIXING-FALLBACK: As the core explodes, the gravity of the newly formed neutron star/black hole drags on expanding ejecta, causing it to fall back and mix. The star ejects large amounts of carbon and oxygen, but elements heavier than silicon mostly end up in the compact remnant.

PULSATIONAL PAIR-INSTABILITY: Stars lose their outer layers over time and in a series of pulses, ejecting carbon, oxygen, and elements of similar atomic mass. Heavier elements are trapped in the core when it collapses.

Not to scale

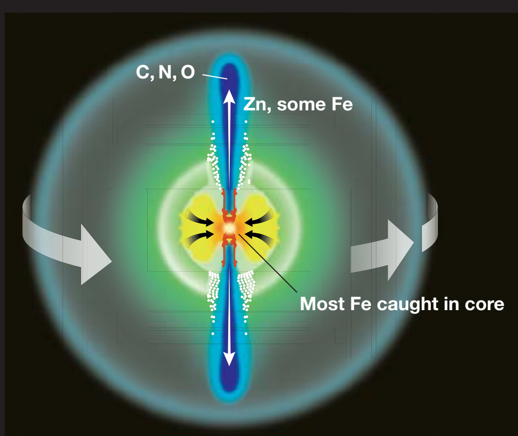
According to Frebel, a coauthor on the study, "In some ways, an asymmetric core-collapse supernova is a more natural explanation than mixing-fallback supernovae, while also explaining the zinc abundances in HE 1327-2326." In a press release after the study's publication, Ezzeddine suggested this result changes our understanding of how the first stars exploded. "This is the first observational evidence that such an asymmetric supernova took place in the early universe," she said.

The Origin of the Milky Way's Metal-Poor Stars

Most metal-poor stars discovered so far lie in the vast halo around the disk of the Milky Way. These 13-billion-year-old stars almost certainly predate the formation of the Milky Way as we know it today. But how did these stars come to arrive in our galaxy's halo, and where did they initially form?

Stellar archaeology suggests the answers to these questions lie in the kinematics of the dozens of dwarf spheroidal galaxies that surround the Milky Way. These tiny galaxies contain just a few thousand to a few million stars embedded within a more massive halo of dark matter that holds them together. They also have virtually no gas or dust, which means new star formation ended billions of years ago.

While computer simulations suggest the Milky Way has ingested many dwarfs in the past 10 to 12 billion years, it's been challenging to verify this observationally. However, stellar archaeologists have measured high-resolution spectra of a handful of the brightest stars in the closest dwarf galaxies. Results show the faintest galaxies, the so-called *ultra-faint dwarfs* (UFDs), have the lowest metallicities and the oldest Pop II stars. Metal-poor stars in UFDs such as Ursa Major II, SEGUE I, Boötes I, and Leo IV have abundances of Ca, Ti, Cr, and Zn remarkably similar to the most metal-poor stars in the halo of the Milky Way, suggesting they formed in a similar environment. "The chemical signatures in old stars in ultra-faint dwarf galaxies compared to those in the Milky Way halo is strong evidence that at least some of these stars in the halo came from ingested dwarf galaxies," says Frebel.



ASYMMETRIC, ROTATING: A rapidly spinning star explodes, and the energy and spin power jets that emerge from the core. The jets carry zinc and some iron up into the exploding star's outer layers, but much of the iron falls into the black hole.

UFDs also serve as sites for stellar archaeologists to investigate how Pop III stars generated the first elements heavier than iron. Massive stars create all the metals up to iron by fusion in their cores, but they only make small amounts of elements slightly heavier than iron — cobalt, nickel, copper, and zinc — before fusion shuts down and the star dies. Yet these elements clearly pollute the next generation of stars in significant amounts, so they must have been made somehow, along with even heavier elements.

Theory indicates that half the elements heavier than iron are produced through neutron capture in the so-called *r-process*, in which seed nuclei such as iron are bombarded by a huge flux of neutrons (roughly 10^{24} per cubic centimeter), then transmute into heavier elements in a cascade of energetically favorable nuclear reactions. The r-process happens in a matter of seconds, producing gold, rare earths like europium, and actinides such as uranium. It likely occurs in supernovae during the collapse and explosive re-expansion of the core, or during the cataclysmic merger of two neutron stars. In the present day, neutron star mergers may be a dominant source of r-process elements. But since many metal-poor stars have relatively low abundances of these elements, astronomers suspected that neutron-star mergers were irrelevant in the earliest days of star formation, possibly because of the long time it takes for such a merger to happen.

This view changed in 2016, when Alexander Ji (then at MIT) and his collaborators examined metal-poor stars in Reticulum II, a nearby UFD. They found very high abundances of r-process elements such as europium in seven of the nine stars observed, more than 100 to 1,000 times the abundance of these elements compared to stars in other UFD galaxies. It would take 1,000 supernovae to create these levels — an unlikely scenario in this tiny galaxy. Or they could be explained by a single merger of two neutron stars that polluted the environment. The neutron stars could have been the remnants of mid-sized, metal-free Pop III stars or very old Population II stars.

Coincidentally, Ji's study showed evidence of a neutron-star merger just before the Laser Interferometer Gravitational-Wave Observatory (LIGO) began to find gravitational waves from similar events (*S&T:* Feb. 2018, p. 32). "This is a really fantastic little galaxy that has changed our understanding of the field of nuclear astrophysics," Frebel says of Reticulum II. "It's a perfect example of how stellar archaeology plays at the top levels of astrophysics."

A Faint Hope

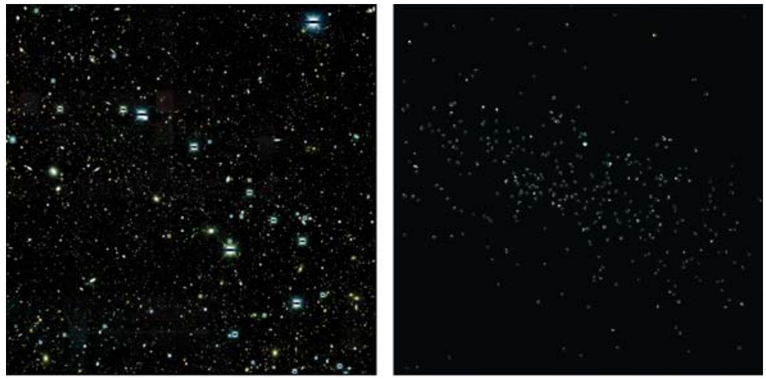
While most models of Pop III stars suggest they should have expired long ago, there remains a lingering uncertainty. Computer simulations in 2014 by Athena Stacy (then at University of California, Berkeley) and Volker Bromm (University of Texas, Austin) suggest that not all Pop III stars formed big and died quickly. Some less massive than the Sun may have formed in conjunction with a much higher-mass companion. If so, slow-burning and low-mass Pop III stars might remain nearby, although they would likely be quite rare and possibly contaminated by heavy elements from the interstellar medium or a companion star.

Would current techniques of stellar archeology allow us to find them? "These stars, if they exist locally, would be freaks of nature," says Frebel. "But we cannot yet exclude the possibility of their existence. I think we could recognize these stars if we measured them."

Bromm also believes we could recognize Pop III stars. It's unlikely such stars could masquerade as low-mass Pop II stars, he says — the chemical signature of the contamination they had experienced would be different. Yet he is not optimistic about finding them. "The chances to find these stars are fading because survey sizes are so large that, if low-mass Pop III stars existed, we should have found them by now," he says.

New projects such as the Canada-France-Hawaii Telescope's Pristine survey and results from larger ground-based telescopes will likely find even more metal-poor stars with interesting chemical signatures. The European Space Agency's Gaia mission is also helping link the chemistry of these ancient stars with their motions through the galaxy. Astronomers are already using such data to identify large groups of stars that are the likely remains of destroyed dwarfs (*S&T:* Mar. 2020, p. 34).

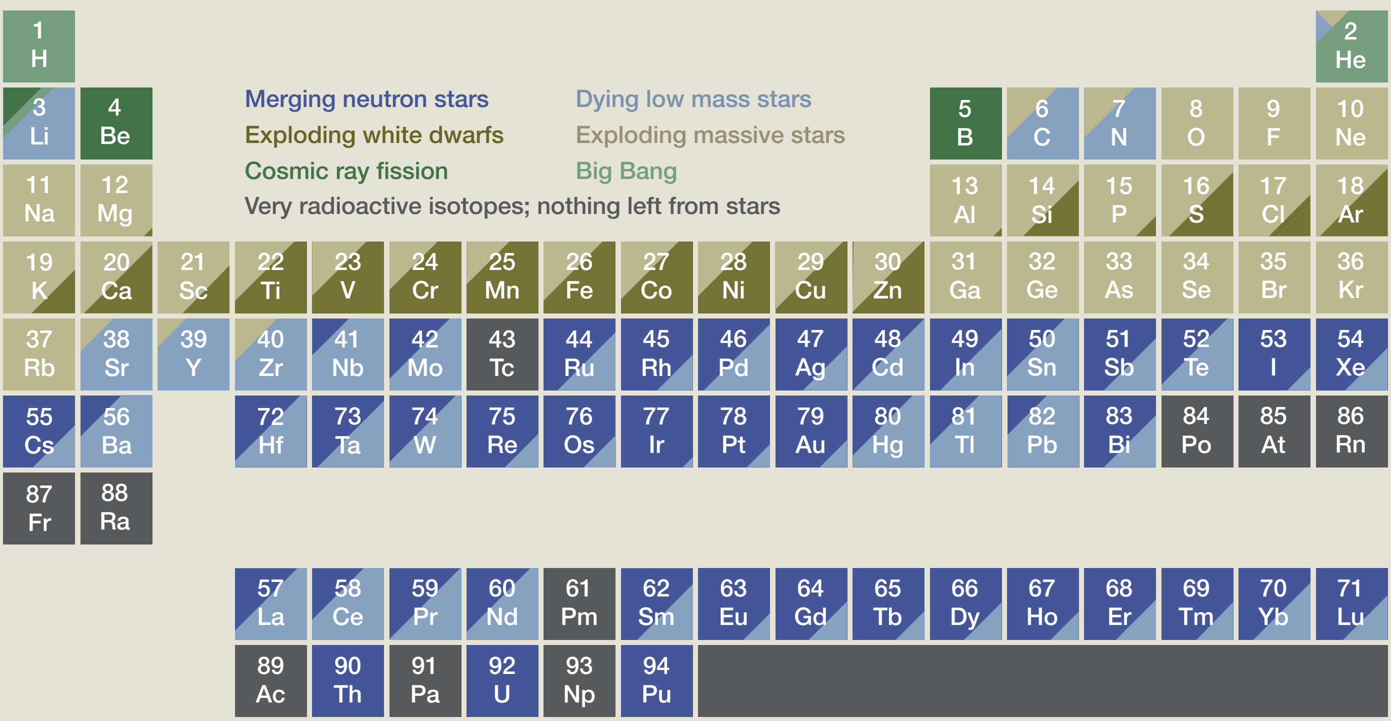
Like its earthbound counterpart, stellar archaeology is a challenging field. But when it comes to the night sky, the deeper you dig, the more you find.



▲ **RETICULUM II** Ultra-faint dwarf galaxies (UFDs) contain so few stars that they're difficult to spot. Foreground stars mask the UFD Reticulum II in a Dark Energy Camera image *(left, with brightest stars blacked out by bars)*. Only after blacking out all other visible matter can we see the stars that belong to the tiny galaxy *(right, stars' bubble appearance is a consequence of the image processing)*.

■ An erstwhile laser physicist and longtime stargazer with degrees in astronomy and applied physics, **BRIAN VENTRUDO** now observes and writes about stars of all ages from his home in Calgary, Canada.

▼ **ORIGINS OF THE ELEMENTS** The solar system's elements have different cosmic origins, with many of the heaviest made in neutron-star mergers (dark blue). Those in black are either artificially made or unstable on long time scales.



RETICULUM II: FERMILAB / DARK ENERGY SURVEY (2); PERIODIC TABLE: LEAH TISCIONE / *S&T*, SOURCE: JENNIFER JOHNSON / *SCIENCE* 2019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Exploring the Deep Sky With Video

With a little tech, you can see farther *and* share the view.

▲▲ **STRANGE NEW WORLDS** One of the great joys of video observing is being able to glimpse exotic objects in modest telescopes. One example is the relativistic jet in galaxy M87, the bright wisp near the galaxy's core, as shown in this Hubble Space Telescope image. The author's 8-inch scope "easily reveals" the feature with his video setup.

▲ **GEARING UP** The author prepares for a night of video astronomy with his 8-inch SCT. Although the extra equipment adds complexity to his setup, he finds the rewards more than worthwhile.

ALL IMAGES COURTESY OF THE AUTHOR UNLESS OTHERWISE NOTED; M87 JET: NASA / ESA / THE HUBBLE HERITAGE TEAM (STSCI / AURA)

Fifteen years ago, I was bored with amateur astronomy. I was tired of seeing deep-sky objects — galaxies, nebulae, and star clusters — as nothing more than faint blobs from my backyard. I wanted to go deeper into the night sky, too, to see more of everything, whether from home or from dark sites. A telescope larger than my 8-inch would have helped, but I didn't want to haul around a monster-sized Dobsonian reflector, much less pay for one.

Not long after my observing sailed into the doldrums, I found myself at an amateur astronomy conference in Nashville, Tennessee. The sky was more orange than black from thousands of streetlights surrounding our hotel. Yet, one brave enthusiast set up his telescope anyway to take us on a video tour of the summer sky.

The idea seemed laughable given the viewing conditions in the hotel parking lot; as if the light pollution wasn't bad enough, a full Moon was also lighting the sky. However, with the aid of a sensitive video camera, his 10-inch telescope revealed the globular star clusters M13, M5, and M22, plus many more, *and* it easily resolved them. Faint nebulae appeared on the display monitor too. You didn't have to squint through an eyepiece or use averted vision — there the objects were, big and beautiful. That night convinced me video was the cure for my observing blues.

Getting Video Eyes

There was more to that camera than just sensitivity. Normal video cameras only expose for 1/30 second — far too brief to pull in dim targets. By the late 1990s, however, manufacturers had broken through the 1/30-second barrier, and as the decade ended several astronomy-oriented companies were offering video cameras that could expose for as long as 15 seconds per video frame.

So, what kind of equipment do you need to get started in 2020? An astronomical video camera, of course, and unlike the 1990s, today you can choose from models that produce analog video or those that generate digital data. Digital cameras are more versatile and allow for easy interfacing with a computer. However, I believe it's still best to begin with an analog camera if your main goal is to see detail in deep-sky objects. In my experience, analog cameras are still more sensitive than their digital counterparts.

An analog camera can also be economical. The Revolution Imager (**revolutionimager.com**), for example, is a complete kit that includes a color CCD camera, small monitor, remote control, 0.5× focal reducer, battery power pack, cables, and a telescope adapter — all for less than $300.

I've tested one of the Revolution Imager kits, and while the camera's maximum exposure is only a little more than 5 seconds, it's quite sensitive and capable of easily showing more than can be seen with an eyepiece. I was amazed when the faint Horsehead Nebula in Orion showed up on the monitor despite the distinctly average skies over my backyard.

If you want to go à la carte, the main source of standalone astronomical video cameras is the Canadian company MallinCam (**mallincam.net**). While it offer a full line of digital models, it continues to sell analog units, including one I've used for years, the MallinCam Xtreme. Not only does it offer unlimited exposure times, its larger chip (compared to one found in the Revolution) makes framing objects easier. The video sensor is also cooled to reduce the effects of thermal noise. MallinCam's package includes cables, power supply, and a telescope adapter, but no monitor. While the cost for the Xtreme is about $1,300, that's still less than many dedicated astronomical cameras.

If you need to purchase a monitor for your chosen setup, be sure to pick one that's capable of displaying analog video. Most camera models output composite analog video, and while digital HDMI is the current video standard, many TVs and some monitors still feature analog inputs.

Even expensive video cameras have relatively small chips compared to DSLRs or astronomical CCD cameras. That's why it's vital to use a telescope with a short focal length to ensure the field of view is large enough to include a range of deep-sky objects. I've found 600 to 800 mm is a good focal length for most video work. I use an f/3.3 focal reducer with my 8-inch Schmidt-Cassegrain telescope (SCT) to bring its 2,000-mm focal length down to 660 mm — perfect for video. Suitable focal reducers are easy to find and often inexpensive. Because video detectors are quite small, the reducer's

▼ **PACKAGE DEAL** The economical Revolution Imager kit includes a color monitor, battery pack, color long-exposure video camera, focal reducer, cables, and remote control.

▶ **WIRED FOR VIDEO** A Go To telescope with video imaging equipment requires plenty of power and a seemingly endless number of cables and connections. A methodical approach during setup pays dividends when it comes to troubleshooting problems, should they occur.

edge-of-field optical performance usually isn't a concern.

There will be times when you'll want to record video for later study or to show friends. When I first started, I lugged a VHS recorder into the field, then later switched to a DVD recorder. Finally, I hit upon the solution I use now: a small, battery-powered digital video recorder (DVR). Such devices are available from a number of sources, including the retailers who carry the Revolution kit. Recorded video can be easily transferred to a computer for processing via the SD memory cards most DVRs use to store imaging data.

One final "accessory" that I find essential is a Go To telescope mount that will reliably point my telescope at deep-sky objects. You'll have enough to worry about setting up and operating the video gear without spending additional time trying to hunt down and frame faint targets on a small video chip. Fortunately, since exposures are typically less than 30 seconds long, you don't need a mount with especially accurate tracking, nor is guiding usually necessary.

Unlike conventional astrophotography, one item that's definitely optional for video astronomy is a computer. While some cameras can be controlled by PC or Mac software, most can also be operated with the buttons on the camera itself, or an accessory remote control.

Becoming a Video Star

Once you've got your gear, how do you use it? With your camera mounted to the telescope in prime-focus position (no eyepiece between the telescope objective and the camera) and a focal reducer in place if needed, begin by aiming the scope at a bright star. Take an exposure of 1 second with the gain/sensitivity of the camera set as high as it will go without turning the background sky solid white. Even if the scope is

◀ **GALACTIC WHIRLPOOL** Being able to clearly see the spiral arms in M51 from his suburban backyard was one of the author's first video thrills. The frame presented here is a 10-second exposure.

badly out of focus (which initially it probably will be) you should see your star on screen as a big blob. If nothing is visible, lengthen exposure to 2 or 3 seconds. Once you've acquired your target, adjust the telescope's focus until the star is as small as possible. Then increase the exposure until dimmer field stars become visible and refocus until they're sharp pinpoints.

Next? The universe is your oyster. I suggest beginning your video odyssey with the Messier list. No matter how light-polluted your skies, these bright objects will show amazing detail and will help you get a feel for setting the camera's various adjustments before moving on to fainter subjects.

When I began using video, I was content with impressing my friends with what the camera could do from so-so observing sites. Seeing the beautiful spiral arms of M51, the Whirlpool Galaxy, from my backyard any time I wanted, took a while to get over. While the experience wasn't quite the same as observing with an eyepiece, the electronic images streaming onto my monitor gave me a feeling of immediacy that conventional astrophotography lacks.

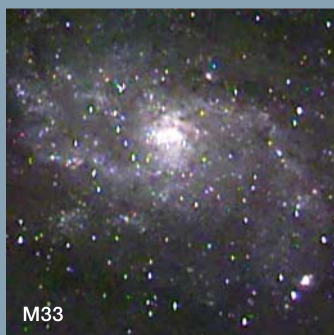
Eventually, it occurred to me that video might be a powerful tool for outreach. I'd long wished I could show visitors to my astronomy club's public nights the wonders of the sky beyond just the Moon and bright planets. Unfortunately, both kids and adults have a hard time seeing any deep-sky objects in a telescope. Eye placement can be difficult for anybody unaccustomed to looking into a scope, and dark adaptation is impossible in the presence of the bright white flashlights that inevitably show up at such events. I decided to see if video could help.

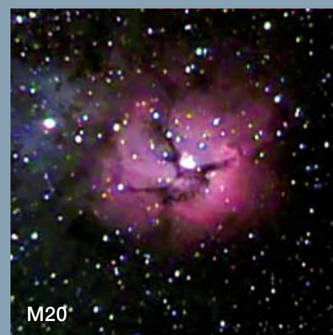
▶ **PICK AND PLAY** For those wanting a more customized solution, each piece of the video puzzle can be selected individually. One popular component is the MallinCam Xtreme, a color, cooled, long-exposure astro-video camera.

▶▶ **IN CONTROL** Most astronomical video cameras can be operated from the camera itself via a set of buttons or with a separate remote control, which makes bringing a computer into the field strictly optional.

VIDEO GALLERY

This collection of frame grabs shows what video astronomy is all about — seeing deeper in more detail than is typically possible with just an eyepiece. The objects themselves look far better in "real time," as the images are displayed at 30 frames per second, regardless of exposure times.





One early autumn evening, I hauled my 8-inch SCT, video camera, and a 19-inch monitor out to our club's public viewing site. By the time visitors began to pour onto the grounds, I had the magnificent Hercules globular cluster, M13, framed on the monitor and looking bright and beautiful. That evening I took guests on a tour of dozens of the best late summer deep-sky objects. Everybody could see them, and nobody had to wait in line. I still remember one little girl dragging her mother away from a big Dobsonian nearby and chirping, "Mommy, you can see it over here for real on TV!"

Diving into the Deep End

As rewarding and exciting as my experiences had been, the technology hadn't yet taken me deeper into the universe. That changed when I used my video rig at a dark-sky site for the first time. I'd been intrigued by an article I'd read online about observing groups of galaxies discovered by astronomer Paul Hickson. Known as Hickson Compact Groups (HCGs), the individual galaxies in these collections are generally faint (many at magnitudes of 16 and dimmer) and can be quite a

▲ **OFF-SCOPE GEAR** From left to right, the author's laptop computer, video display (a portable DVD player), and digital video recorder ready for an evening of fun. The cable switch box (far right) is used to send video output to either the display or the DVR.

challenge even for an amateur astronomer equipped with a large Dobsonian telescope. Could my relatively modest 11-inch SCT show any hint of these dim sprites? I placed a red filter over my monitor's screen so as to avoid annoying nearby observers and got to work.

Not only did my video camera reveal HCGs, it showed detail where there was detail to be seen. For example, the 16th- to 18th-magnitude members of HCG 20 displayed some haze and hints of tiny galactic disks. The dark sky at the site allowed me to increase my exposure times to a full 10 seconds and set the gain to near maximum, without making the resulting images excessively noisy or overexposed.

The next morning, I reviewed the video sequences I'd recorded and was astounded to discover my images showed essentially the same details as those captured by the famed 48-inch Oschin Schmidt Telescope at Palomar Observatory. There wasn't much in the observatory's online Digitized Sky Survey images that wasn't visible in my shots.

Video again proved its value when I used it for much of my observing during the Herschel Project (*S&T:* Aug. 2012, p. 60), my quest to observe the roughly 2,500 deep-sky objects discovered by Caroline and William Herschel. While I did some of the project visually, most had to be done from my backyard or the light-polluted skies at my club's site. Video easily brought home my quarry even under those compromised conditions. While I'd upgraded to the color MallinCam Xtreme by the time I was halfway through the Herschel Project, even my old black-and-white camera was able to grab the dimmest object on the list, the magnitude-16.4 galaxy NGC 4549.

◀ **DISTANT BEACON** *(Top)* Given that a magnitude-16.4 galaxy was little challenge for video, the author decided to collect supernovae in distant galaxies with his 8-inch SCT and video camera. This image shows a supernova that was discovered in M82 in 2014 (indicated).

◀ **FAR, FAR AWAY** *(Bottom)* Among the most distant objects the author has observed is the gravitationally lensed double quasar (QSO 0957+561 A/B) in Ursa Major. Although appearing as an unimpressive dot on the display screen (and in this image), the light reaching his video camera had been travelling across space for some 7.8 billion years.

Since such a faint galaxy was little challenge for video, I began to wonder just how far the technology could take me. Looking at my frame grabs, I noticed a horde of tiny, distant PGC and UGC galaxies. Might video transport me beyond them? Could I claim the mind-blowing, ultimate prize of quasars? These ancient objects are relics of the earliest epochs of the universe. Were they within reach?

They were, as I found out one evening at my favorite observing site, the Chiefland Astronomy Village near the dark Gulf Coast of Florida. I'd prepared for my observing run by making a list that included objects down to magnitude 17. Quasar after quasar appeared on my screen. At the end of the night, as I was covering the scope, I stopped and thought about what I'd seen. While the images weren't very exciting — quasars look much like stars in photographs — these objects have distances measured in *billions* of light-years.

Is there a downside to using video at the telescope? Sure. The technology might not be for you if you like to keep things simple in the field. You won't only be dealing with a computerized Go To telescope, but also with a video camera, a monitor, and all their associated cables and power requirements. Most of my video observing runs have been amazingly successful, but there have also been nights in which I spent hours troubleshooting equipment problems.

However, if you long to see detail in deep-sky objects from your backyard with a modest telescope, video can make that possible *and* show more than can be seen in an eyepiece on even the finest nights. Perhaps best of all, video can take you deeper into the cosmos than you may have ever imagined — even to the frighteningly distant realm of the quasars.

▼ **LOST IN THE LAGOON** One of the great pleasures of video astronomy is the ability to leisurely enjoy the sights (such as the Lagoon Nebula, M8) in complete comfort.

■ **ROD MOLLISE** is a retired engineer, author, and *Sky & Telescope* Contributing Editor. When he's not observing the deep sky from his backyard, Rod keeps busy teaching part-time for the physics department at the University of South Alabama.

◀ CAMERA TRACKER

Orion Telescopes & Binoculars now produces a compact camera tracker for nightscape photography. The Orion StarShoot Compact Astro Tracker ($279.99) is a palm-sized, lightweight-tracking module housing a DC servo motor that accurately follows the night sky at several speeds, including sidereal, 0.5× sidereal, solar, and lunar rates, to produce round stars in exposures up to several minutes long. The tracker attaches to your tripod via a ⅜ thread and supports a payload of up to 6.6 lbs. The unit is controlled through WiFi by the free *Tracker Console* iOS or Android smart device app and can take long-exposure and time-lapse image series. The StarShoot Compact Astro Tracker is powered by two AA batteries and includes an illuminated polar-alignment scope, a Vixen-style mounting plate with a ⅜ tripod mounting post, and a panoramic ball-head camera mount. Additional accessories, including SNAP shutter-release cables for several digital camera models, are available.

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

▶ IMAGING PACKAGE

Software Bisque announces a new software package for advanced astrophotographers. *TheSky Imaging* ($595) includes the professional edition of the company's powerful planetarium program *TheSky* complete with integrated camera control that operates most astronomical cameras, focusers, and filter-wheels on the market today. The program communicates with your equipment using the ASCOM-standard interface, as well as the company's own platform-independent X2 protocol. The suite also includes *TPoint* software, which models all the misalignments and flexure in your setup, ensuring accurate and reliable targeting across the entire sky. *TheSky Imaging* is compatible with Windows, MacOS, and Linux operating systems.

Software Bisque
862 Brickyard Circle, Golden, CO 80403-8058
303-278-4478; bisque.com

◀ ENHANCED OBSERVING

Explore Scientific now provides a complete observing package with its FirstLight 203mm Newtonian with EXOS2GT GoTo Mount ($1,099.99). This 8-inch f/4.9 Newtonian reflector features a sturdy 2½-inch Hexagonal rack-and-pinion focuser with extended travel to ensure that most any eyepiece can come to focus. Its EXOS2GT German equatorial Go To mount uses belt-driven stepper motors to yield smooth tracking of celestial objects. The StarTracker hand paddle includes 1-, 2-, and 3-star alignment routines and an internal database of more than 270,000 objects powered by eight D batteries. The telescope comes with 2-inch and 1¼-inch eyepiece adapters, a 25-mm 1¼-inch Plössl eyepiece, a red-dot finder, a universal smartphone camera adapter, and two 11-pound counterweights. See our review of the Dobsonian-mounted version of this telescope on page 30.

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

New Product Showcase is a reader service featuring innovative equipment and software of interest to amateur astronomers. The descriptions are based largely on information supplied by the manufacturers or distributors. Sky & Telescope assumes no responsibility for the accuracy of vendors' statements. For further information contact the manufacturer or distributor. Announcements should be sent to nps@skyandtelescope.org. Not all announcements can be listed.

◀ A peep-sight finder is surprisingly accurate. Note the bright target ring and bright perimeter around the peep hole, which help you find the finder finder at night.

Finder Finders

Here's a wide-field helper that puts you in the ballpark.

THOSE OF US WHO USE optical finders on our telescopes know the frustration of trying to figure out exactly what part of the sky the finder is pointed at. Optical finders are great for zeroing in on an object once you're in the right general area — you can often nail your quarry to within a few arcminutes if you know your target or the star field around it — but they're surprisingly difficult to aim anywhere near your objective to begin with. That's because optical finders don't have anything convenient to sight along. Like truss-tube Dobsonians or ball scopes, there's no structural component to use as a general aiming device.

Enter the "finder finder" — a simple sighting device that lets you aim the telescope in the right general direction before you look through the optical finder for your target.

One obvious solution would be to mount a red-dot finder alongside the optical finder, but that requires a second mounting bracket. And if you use multiple scopes, it requires a second bracket on each scope. Worse, because mounting brackets never seem to point exactly in the same direction, that means re-aligning two finders instead of just one when you change scopes.

I prefer mounting my finder finder right on the main finder's body. That way the two are always aligned. And I like making mine without electronics, so there are no batteries to die when I inevitably leave the switch on.

The simplest design is akin to a gunsight. If your finder has six adjusting screws, you have probably already discovered that you can get rough alignment by sighting across two screw heads. The screw heads are usually dark, however, and blunt, which makes aiming difficult.

You could paint the screws white, and that would help a little. You could glue small triangular caps to the screws and paint those white, which would help a little more. But the baseline, the distance between the screws, is really too short for much accuracy. You're better off putting a post all the way up front and either a post or a wedge in back. The longer baseline affords more angular precision, and if you align the components carefully when you glue them on the finder body, when you sight from one to the other you'll be looking down the finder's optical axis. Paint them white or use glow-in-the dark paint or tape to make them stand out.

A peep sight refines the concept a step further. A ¼-inch hole in back through which you must look forces your eye into the proper position, guaranteeing that whatever the front sight is aimed at is also what the main finder is aimed at. The front sight can either be another larger hole or a simple post. The important thing is to make the part you sight on (the center of the hole or the end of the post) the same distance from the main finder's optical axis as the peep hole you're looking through.

An even fancier refinement is a split-pupil finder. Described in our June 2013 issue (p. 66), and in more detail on my website at **https://is.gd/splitpupil**, a split-pupil finder involves a lens at the rear and a glowing arrow at the front. With your dilated eye, you look through the lens at the arrow while simultaneously looking over the lens at your target in the sky. The arrow must be placed at the lens's focal point, and the lens's center must be the same height

▼ A split-pupil finder finder takes a little getting used to, but once you learn how it works it's a joy to use.

ALL IMAGES BY THE AUTHOR

SHARE YOUR INNOVATION Do you have a telescope or ATM observing accessory that *S&T* readers would enjoy knowing about? Email your projects to Jerry Oltion at j.oltion@gmail.com.

above the main finder's optical axis as the tip of the arrow. The lens focuses the arrow at infinity, so it stays put when you move your head around, just as a Telrad, Rigel Systems QuikFinder, or other red-dot finders do with their glowing reticles.

With any of these designs, the goal is the same: Get the scope to within a few degrees of your target before looking through the optical finder to refine your aim. In many cases you'll discover that the finder finder is good enough on its own, but if not, you've got backup. (And when your optical finder dews up, you've got reverse-backup, too.)

Finder finders can save hours of frustration, and they're simple to make. Every optical finder should have one.

Contributing Editor **JERRY OLTION** is a finder fanatic.

▼ Right-angle finders are a bit more difficult to modify because the eyepiece is in the way, but there's usually room for a pair of posts or a peep sight on one side or the other.

SHARPLESS 2-25

Alex Roberts

The Lagoon Nebula (M8) in Sagittarius is one of only two emission nebulae visible to the unaided eye from mid-northern latitudes.

DETAILS: *Explore Scientific FCD100 Series 127mm Triplet ED APO refractor with QHY183M CMOS camera. Total exposure: 7.1 hours through Baader narrowband filters.*

▷ SHARPLESS 2-220

Ron Brecher

The energetic star Xi (ξ) Persei (lower right) fluoresces gas in the California Nebula, NGC 1499, in Perseus. Read Brecher's feature article about the Sharpless catalog on page 22 of this issue.

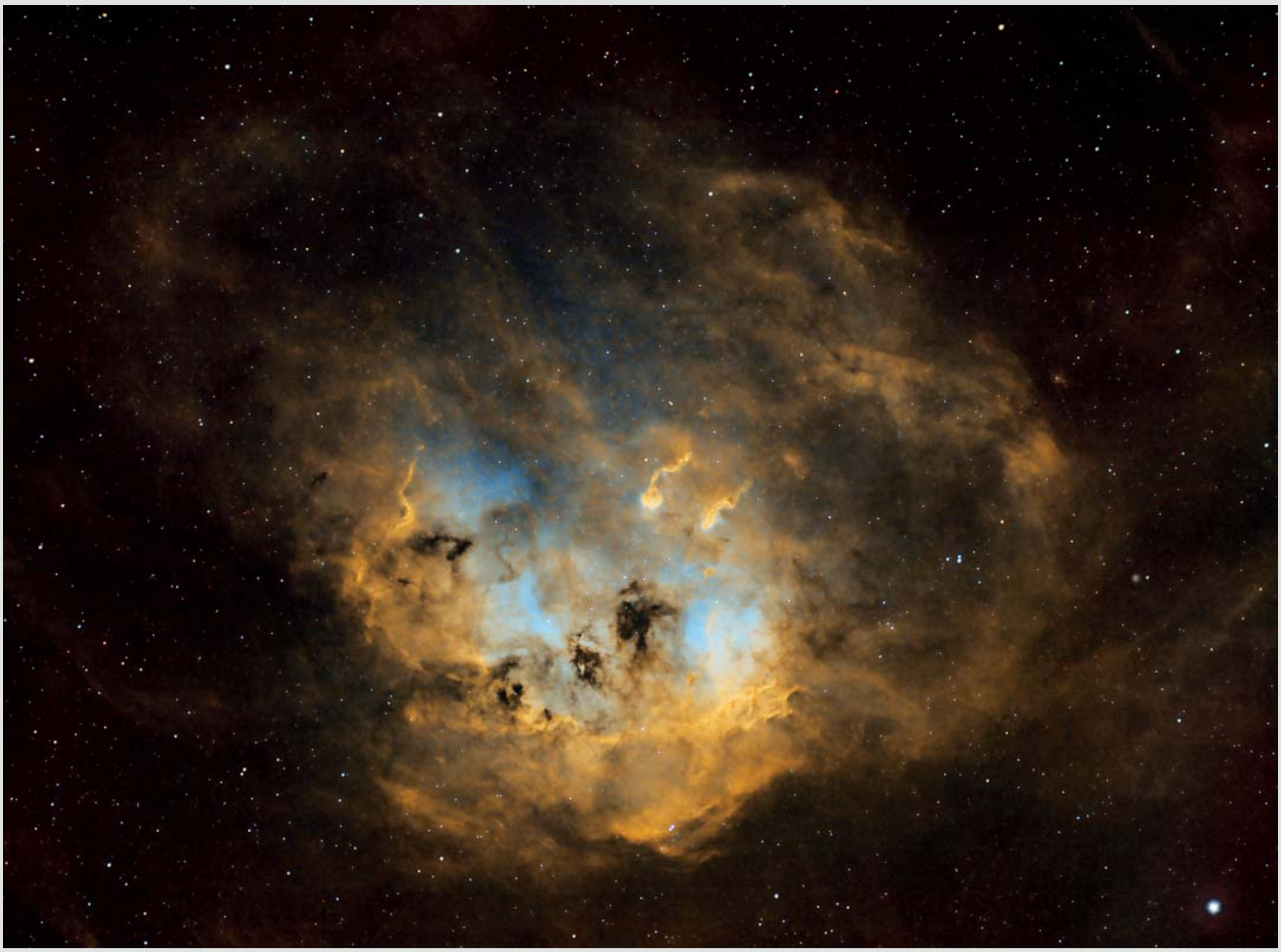
DETAILS: *Takahashi FSQ-106 ED IV astrograph with QHY367C CMOS camera. Total exposure: 12⅓ hours through an Optolong L-eNhance filter.*

▽ SHARPLESS 2-236

Peter Jenkins

Open cluster NGC 1893 in Auriga is in the process of slowly evaporating the surrounding nebulosity of IC 410. The two dense areas at center — often called the Tadpoles — likely conceal ongoing star formation.

DETAILS: *Officina Stellare Hiper APO 115 refractor with Atik Horizon CMOS camera. Total exposure: 6 hours through narrowband and RGB filters.*



SHARPLESS 2-273
Greg Gurdak
Hot, young stars within the open cluster NGC 2264 ionize the surrounding cloud of gas and dust in Monoceros, creating intricate structures such as the Fox Fur Nebula (center) and the Cone Nebula to its south.
DETAILS: *William Optics RedCat 51 astrograph with ZWO ASI1600MM Pro CMOS camera. Total exposure: 33⅓ hours through narrowband filters.*

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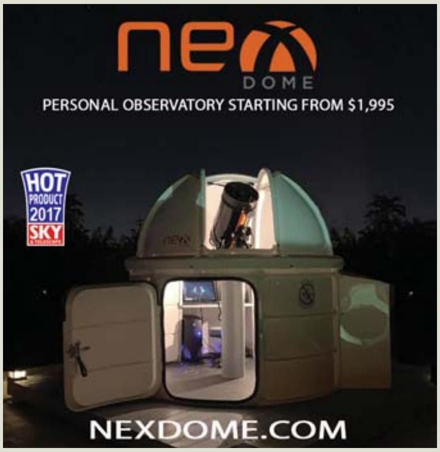

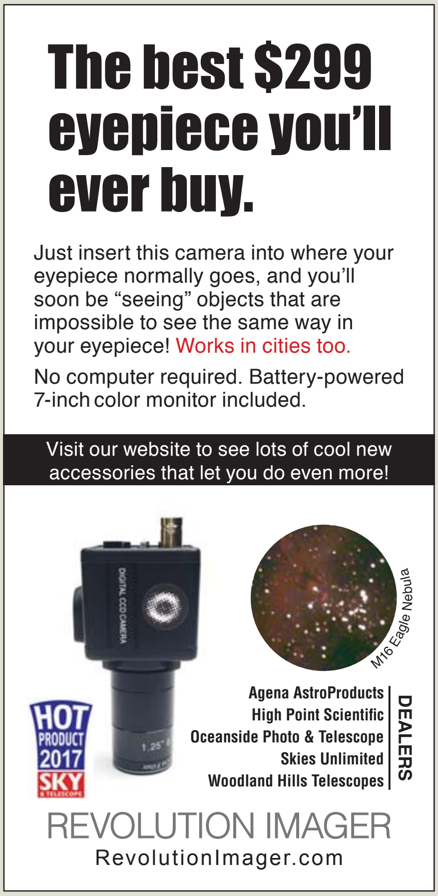

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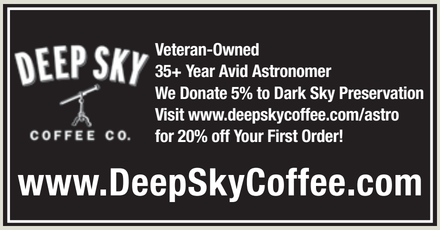

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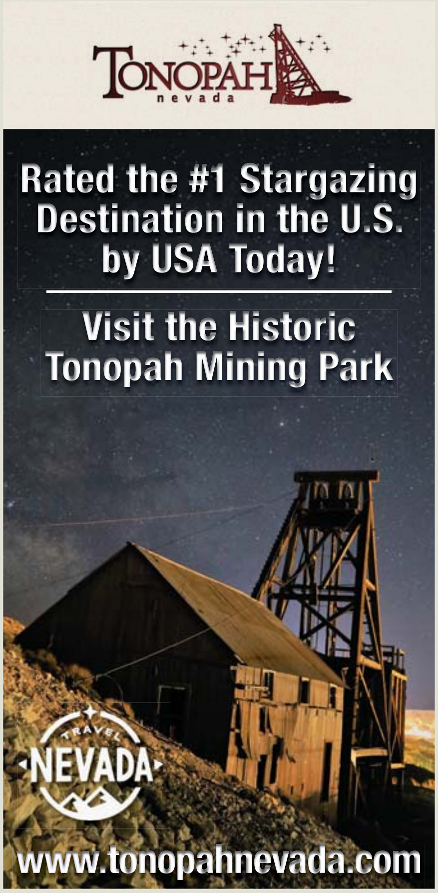

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MISCELLANEOUS

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MOUNTS

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TELESCOPES

iOptron (Page 65)
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AD INDEX

Astro Haven Enterprises 79
Astro-Physics, Inc. 80
Atik Cameras Ltd 13
Deep Sky Coffee 79, 80
Diffraction Limited. 73
DiscMounts, Inc.. 79
Doug Harr 80
Farpoint Astronomical Research. 78
Finger Lakes Instrumentation, LLC. 79
Hotel Las Islas in Baru (Aviatur) 73
iOptron. 65
Irene Kitzman 80
Knightware 80
Metamorphosis Jewelry Design 79
Michael P. O'Connor 80
Morrow Technical Services 78
NexDome 79
Nimax GmbH (Omegon). 5
Optic Wave Laboratories 79
Orange County Telescope, LLC 79
PreciseParts 78
Sky & Telescope 1, 3, 65, 73, 81, 83
Sky-Watcher USA 3
Software Bisque C4
Stellarvue. C3
Technical Innovations 78, 79
Tele Vue Optics, Inc. C2
Town of Tonopah Nevada Tourism 80
TravelQuest International 65
Willmann-Bell, Inc. 78

I Did Not Discover Planet 9

But for one dizzying day I couldn't rule out the possibility that I had.

I JUST WANT TO MAKE THAT CLEAR from the start: I didn't discover Planet 9, that hypothetical, super-Earth-size world posited to lie in the outer realms of our solar system. In fact, I didn't discover anything. But for one day I couldn't help but wonder: *Could it be?*

I live in suburban Chicago, where third-magnitude skies are a good night. But with just a moderate-size scope (9.25-inch SCT) and a good CCD camera, I can reach really faint objects that I could never have hoped for when I was limited to visual observing.

Pluto, for example, is easy to see at magnitude 14 with an exposure of a few seconds. If I increase the exposure to around 5 minutes, I can capture between magnitude 18 and 19 in good weather. I've imaged faint targets like the dwarf planet Eris many times.

But I wanted to push my limits. I thought it'd be really exciting to find Sedna. Roughly three times farther out than Neptune, that sizable planetoid travels far beyond the main Kuiper Belt and out toward the Oort Cloud. And Sedna is one of the six small worlds whose aligned, elliptical orbits are tilted about 20° off the ecliptic — collectively hinting that the large gravitational field of *something* is "herding" them.

Sedna's current brightness is magnitude 20.9, or about two magnitudes fainter than I've done before. Stacking my images might just let me go deep enough, I thought. So I spent two successive nights photographing Sedna's location. Then I stacked together the images taken each night and blinked the results, looking for any changes.

Nothing. I couldn't even convince myself that there might be a barely visible smudge. Unfortunately, I just couldn't go deep enough with my location and equipment. So I looked over the rest of the image, to see if maybe I had at least captured some other asteroid or maybe a variable star.

And that's when I noticed it.

Off near the edge of each image — but in slightly different locations — was a tiny dot that I estimated to be about magnitude 18. It hardly moved between the images, less than what I expected Sedna would do. That implied it was farther out than Sedna, but at magnitude 18 it must be large to be visible that far away — much larger than Sedna.

I knew of astronomers' predictions about Planet 9, but if it was as bright as magnitude 18 someone would have found it already. There really wasn't any chance that I was seeing it, right? Besides, they'd predicted it would lie in a patch of sky west of Orion, while Sedna was currently located in southern Taurus, which was . . .

. . . west of Orion.

My heart stopped. It couldn't be. It would have needed all previous surveys to have missed it. Impossible, right?

Probably, but I just couldn't walk away. I changed my imaging plans and dedicated a third night to re-imaging the field where Sedna lay.

And when I processed the new images: nothing. Apparently a pair of cosmic rays had hit my camera in nearly the same spot on two successive nights, making them look together like a slow-moving object.

So, in the end, I didn't discover Planet 9. But for 24 hours, I couldn't prove that I hadn't.

■ A software engineer during the day, **JOE ULOWETZ** uses his backyard observatory every clear night to study cataclysmic variable stars for the Center for Backyard Astrophysics (**cbastro.org**), plus other objects of interest.

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