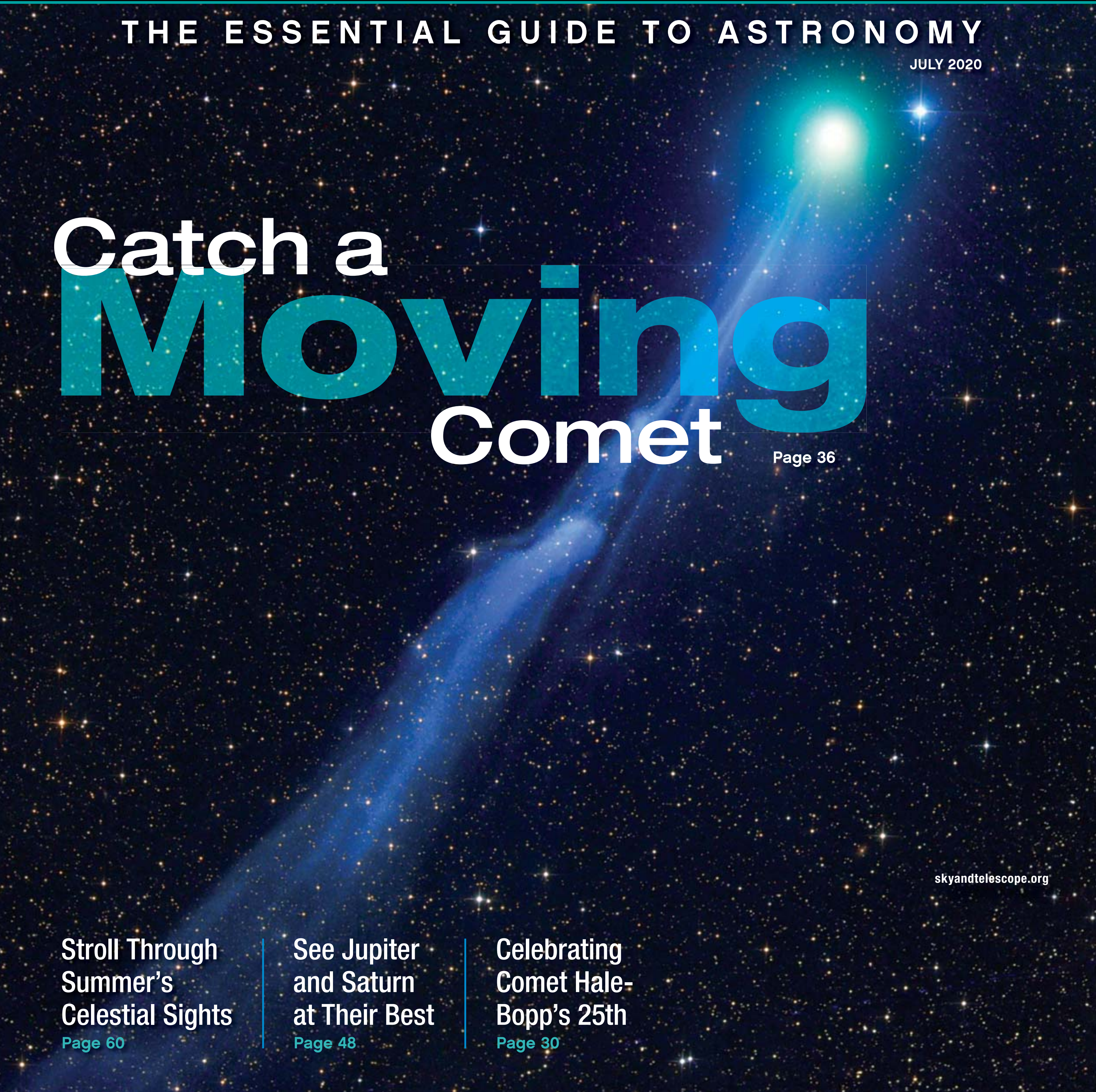
SKY & TELESCOPE

THE ESSENTIAL GUIDE TO ASTRONOMY

JULY 2020



Catch a Moving Comet

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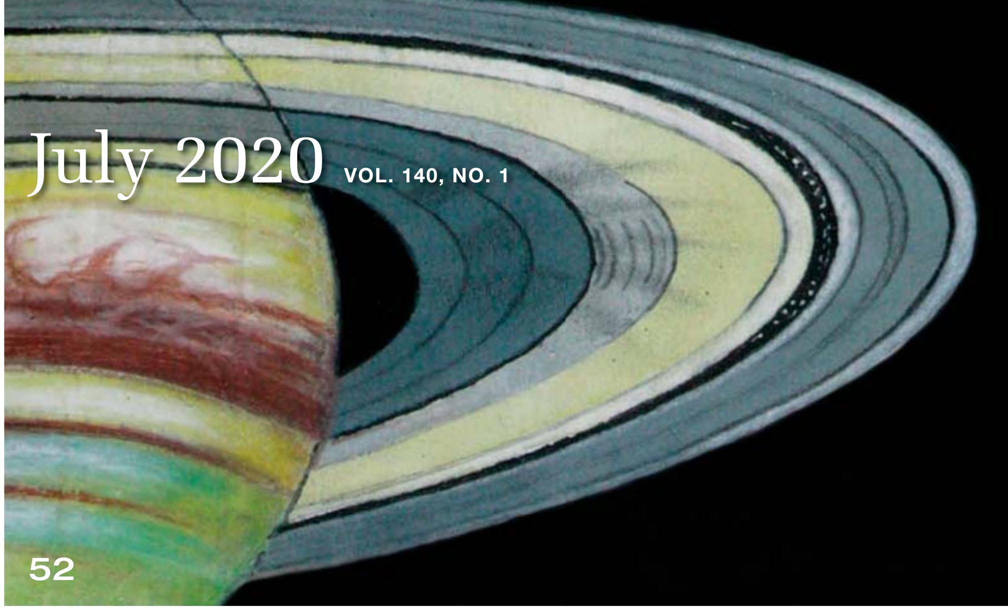

STEPHEN JAMES O'MEARA

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Comet Lovejoy (C/2014 Q2) seen from Austria in 2015
PHOTO: GERALD RHEMANN

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The Caprice of Comets

IF THERE'S ONE THING you never want to say about a newly discovered comet, no matter how glorious its prospects appear to be, it's: "Wow, this could be the comet of the century!" Whether or not you believe in tempting fate, it's a fool's errand. Too many hyped-up comets en route to the inner solar system have fizzled, like winter's much-anticipated first snowstorm arriving as rain. Their very names stick in the craw of dedicated comet lovers: Kohoutek. Austin. ISON.

"But some have turned out to be phenomenal," you might counter. True enough. Names of those comets also remain fixed in the minds of those who treasure these dirty snowballs from afar. Bennett. West. Hyakutake. Hale-Bopp.

The uncertainty inherent in comet outcomes puts an astronomy magazine like *S&T* in a bind. We don't want to miss the boat, but we don't want to go down with a sinking ship either. So, as we were putting this issue together, we asked ourselves: How should we deal with the latest Comet ATLAS?

Discovered on December 28th by the robotic Asteroid Terrestrial-impact Last Alert System survey, Comet ATLAS (C/2019 Y4) will reach perihelion on May 31st. We knew that would be just after subscribers receive this issue.

Comet ATLAS as seen at about 5:52 UT on April 15th

SEAN WALKER / MDW SKY SURVEY

So, we wondered, should we continue with our plans to make this our comet issue? If ATLAS turned out to be another "Great Comet," it would be fabulous timing to have this edition arriving in mailboxes and on the newsstand just as ATLAS blossomed.

But what if it wilted?

In the end, we decided to keep to comets. We start with a news story about the interstellar comet 2I/Borisov (page 8). Ken Hewitt-White then reminisces about the mid-1990s Hale-Bopp, the last "Great" comet viewable from the Northern Hemisphere (page 30). Gerald Rhemann, who took the cover shot, provides valuable tips on comet astrophotography (page 36). And Paul Signorelli describes the sneaky way he retrieved his stolen astrocamera just in time to capture Comet Halley on its return in 1986 (page 84).

We knew, though, that we had to play it safe with ATLAS. And lo and behold, in mid-April as I write this, the comet has begun to fragment. To the ancient Greeks, Atlas, the Titan condemned to shoulder the celestial sphere for eternity, was a symbol of endurance. But poor Comet ATLAS may not last much longer.

It's one of the paradoxes of comets: After hurtling through space for billions of years, they can fall apart within days. The tipping point comes after they cross the so-called snowline about 3 a.u. from the Sun, when their water ice begins to vaporize.

So let's just called ATLAS *a* comet and not *the* comet, shall we?

Peter

Editor in Chief

SKY&TELESCOPE
The Essential Guide to Astronomy

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Stars in the City

Ken Pilon captured this image of the January 2019 lunar eclipse from his ninth-floor city balcony.

Ken Pilon's Focal Point (*S&T:* Feb. 2020, p. 84) surprised me. There were no examples of the purported good images taken from his ninth-floor city balcony. There wasn't even a link to a website with his images. I sure would have liked to see some.

Richard Lighthill • La Pine, Oregon

Ken Pilon replies: *I am so glad that you want to see a few of my photos. I just completed a new website on the very same subject, astro-imaging from an urban balcony,* **https://is.gd/thewhitezone**.

I found Ken Pilon's article fascinating and encouraging. For years, I have been observing from the driveway of my townhouse complex. The only semi-dark skies available are in the north and west. But I made it work using the same techniques as Ken, particularly selecting star clusters for most of my imaging objects.

Then, in December of 2018, I started using the observatory at Garvey Ranch Park, located in very urban Monterey Park, right next to Los Angeles. It allows our club members to observe every Wednesday night, weather permitting. The ease of use of the facility, particularly no equipment setup, increases observing time. However, there is an athletic field right next to the observatory with lots of floodlights.

The more I observe the more I see, and as long as I keep my expectations reasonable, I can see a lot!

Dave Nakamoto • Azusa, California

Jack and the Moon Giants

The letter from Jim Michnowicz (*S&T:* Feb. 2020, p. 6) noted his observation of a "Lunar Tiki God" near the Fra Mauro region of the Moon. As he mentions, this is an example of pareidolia — the tendency to perceive a recognizable object in a visually ambiguous image.

Many others have reported such Moon illusions, but the undisputed "King of Lunar Pareidolia" is Jack P. Swaney. During the early 1980s, in a series of letters to *Fate* magazine, Swaney reported detecting dozens of huge, artificial structures on the Moon using his amateur telescope. They reveal a bewildering assortment of objects, including a construction crane, a bridge, a pipe, and even a kewpie doll.

One of my favorite observing projects is to examine these "Swaney Objects" with my 8-inch Schmidt-Cassegrain. After years of careful telescopic scrutiny, I can't find any convincing evidence for the existence of any of them. Either Swaney has a more active imagination than I do, or extraterrestrials have secretly removed these objects to eliminate all evidence of an alien presence on the Moon.

Frank Ridolfo
Bloomfield, Connecticut

Resolving Power

Robert Dick (*S&T:* Feb. 2020, p. 8) points out that our eyes have better horizontal resolution than vertical resolution. I first noticed this when I found that I could see a sailplane towline in the sky when it was well below the resolution limit computed by standard telescope equations using my eye's lens as the objective's size. Subsequently, I read that our eyes wiggle horizontally all the time. While normally this is too small to detect, I had an acquaintance with vision so poor I could see his eyes wiggling back and forth.

If one imagines an image projected on a grid of sensors, be they pixels or cells in the eye, and further imagines moving the image by tiny amounts, greater detail can be inferred by which sensors turn on and off. The eye-brain system does this in real time.

There might be an application of the mirror-movement systems that currently combat air turbulence to a new kind of telescope that increases resolution by wiggling the objective and measuring the effects on an image sensor. For example, this could increase a space telescope's resolving power without a larger objective.

Tom Wright
San Diego, California

Sabrina Garvin replies: *According to adaptive optics lab director Donald Gavel (University of California, Santa Cruz), this method, known as Drizzling, is often used by the Hubble Space Telescope. Hubble imagers move the telescope by a fraction of a pixel to gain more spatial information about an object. Astronomers originally developed the technique to help create the Hubble Deep Field images.*

Driveway Spectrum

I was very interested in Jerry Oltion's article (*S&T:* Feb. 2020, p. 32) regarding a simple reflection spectrograph. A few years ago, I did a similar experiment with a cheap 1,500-line-per-inch Hilger & Watts diffraction grating placed in front of a 100-mm lens on my DSLR camera, which I pointed down at the solar reflection off a sewing needle.

A needle spectrum

The diffraction grating wasn't quite parallel with the needle, so the resolution was poor. Nevertheless, this experiment is well worth trying again.

Kevin J. Kilburn
Manchester, England

The Little Scope That Could

I bought my nephew a telescope many years ago. He quickly lost interest, and it sat in a basement for more than two decades under extreme temperature and humidity conditions. A few years ago, I decided to resurrect it, clean it up, buy some hardware for it, and take a look at the night sky. To my surprise, I saw the rings of Saturn and was ecstatic. Then, I purchased some additional hardware to record what I was observing. The image wasn't as dramatic as the first scope I peered through (my industrial arts teacher's Questar back in the early '60s, when I was in eighth grade), but it was still very cool! The real wonder is seeing the Sun's reflected light from Saturn having taken 71 minutes to reach Earth through 60 mm of ground glass.

Ed Huff
Tucson, Arizona

S&T Appreciates You

I have been subscribed to *S&T* for more than 40 years with only a few interruptions on my end since an initial gift from my parents while in middle school. This most recent renewal involved a bit of hesitation on my end. Why bother renewing a subscription when I may not have the time to read my monthly magazine? Should I continue experiencing the guilt in having an issue or two neglected in their plastic sleeve for a month or longer after arrival?

I renewed my subscription to thank the *S&T* editors, employees, and contributors of this iconic publication. Their efforts and enthusiasm continue to spark the interest in observational astronomy of not only those whose first exposure was a gift issue of *S&T* but also to keep alive the interest of long-time subscribers. I hope that *S&T* continues to serve as much of a magnet to talented contributors, as it does to keep its subscribers committed to the magazine's success.

R. S. Marvin
Farmington Hills, Michigan

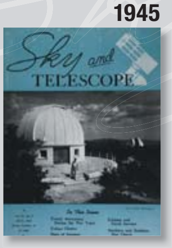
FOR THE RECORD

● In the graph of the Orientale basin (*S&T:* Apr. 2020, p. 53) the average elevation is in meters not kilometers. The correct graph can be seen on our new website **https://is.gd/Errata2020**.

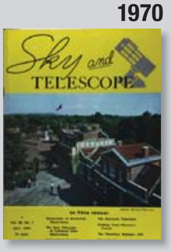
SUBMISSIONS: Write to *Sky & Telescope*, One Alewife Center, Cambridge, MA 02140, USA or email: letters@skyandtelescope.org. Please limit your comments to 250 words; letters may be edited for brevity and clarity.

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

1945



1970



1995

KEVIN KILBURN

◖ **July 1945**

Corona Revealed "By far the most striking results obtained by French astronomers during the war are those by Bernard Lyot and his collaborators on the Pic du Midi. The coronagraph has an aperture of about eight inches and a focal length of over 13 feet, and is used with a . . . monochromatic filter . . .

"Films covering a total duration of 92 hours fail to confirm actual motions in the corona reported by some observers [during total eclipses] — no moving streamers are observed. The corona as a whole seems to pulsate, however, getting brighter and fainter over large segments. [Before] Lyot built his coronagraph we had to wait for an eclipse of all of the sun before we could even hope to see the corona."

◖ **July 1970**

Microbe on the Moon "[A] microorganism accidentally carried to the moon three years ago in Surveyor 3's camera has been recovered from inside the camera that was brought back to Earth by the Apollo 12 crew in November, 1969. The microorganism has been identified as *Streptococcus mitis,* a harmless species often found in the human respiratory tract. Apparently it survived the Surveyor launch, the three-day journey under vacuum conditions to the moon, and 950 days in the hostile lunar environment.

"Captain [Frederick] Mitchell and his team spent five months in studying Surveyor 3 camera parts retrieved from the moon. The microorganism was found in a small bit of polyurethane foam which was used as insulation in circuit boards inside the camera housing. [Air Force microbiologists] placed the cubic millimeter of foam in a bacterial culture medium (Thioglycollate broth) at 37° C.

"The first signs of life were observed after four days of incubation . . . and on the next day 'the tube was turbid with growth.'"

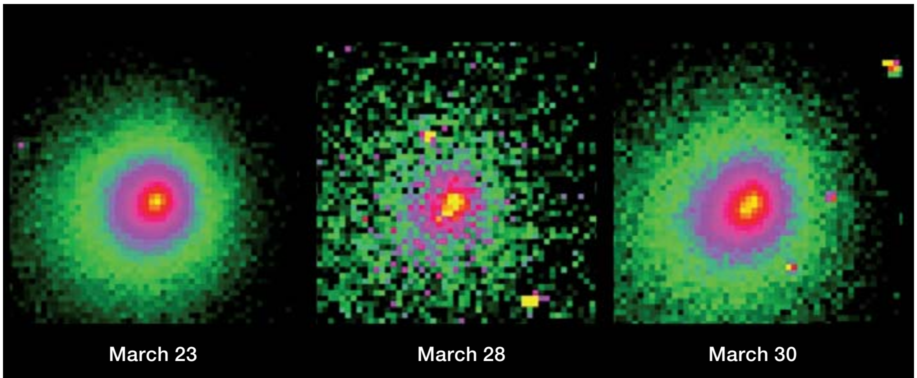
◖ **July 1995**

Origin of Comets "A team of four astronomers led by Anita Cochran (University of Texas) has exploited the Hubble Space Telescope to detect hints of a large population of extremely faint objects orbiting the Sun beyond Neptune.

"[They] combined 34 Hubble images of a single field, 4 arcminutes on a side . . . They identified and removed the field's stars and galaxies, then combined the images again with two kinds of relative offsets. [Dozens] more objects were found in . . . an excess far beyond that expected by chance. . . .

"This statistical excess implies that many thousands of objects . . . await discovery in every square degree of sky along the ecliptic. . . . Their discovery thus strengthens the belief that the Kuiper Belt is the dominant source of short-period comets."

Today's thinking shifts the bullpen of periodic comets to the scattered disk, a broader, less stable region also just beyond Neptune.



Hubble images show Comet Borisov fragmenting in late March.

SOLAR SYSTEM

Is Interstellar Comet 2I/Borisov Breaking Up?

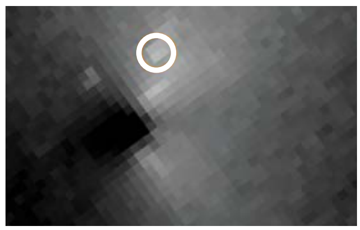
THE INTERSTELLAR COMET designated 2I/Borisov, discovered on its way into the solar system in 2019 (*S&T:* Jan. 2020, p. 10), began shedding chunks in late March — more than three months after its closest approach to the Sun.

Two analyses of Hubble Space Telescope images taken between March 23rd and 30th show fragments drifting from the comet.

Analysis of the images shows a small piece of the comet breaking off and floating slowly away, David Jewitt (University of California, Los Angeles) and colleagues found. The fragment was bright and only 180 km (112 mi) from the comet's core at the time Hubble took the images.

What's more, after processing the same Hubble images to increase the contrast between the core and the coma around it, Bryce Bolin (Caltech) and colleagues spotted a second piece farther out, floating away at more than 0.5 m/s. The two results were posted to *The Astronomer's Telegram* on April 2nd and April 3rd, respectively.

While the fragment that Jewitt's team observed is about as bright as the comet's core, he thinks this is due more to its icy surface than its size. Its mass, he estimates, is likely less than 1% of the whole comet, which would make the split more like a side mirror dropping off a car than the whole car falling apart. The piece that Bolin reports is likewise small, no more than 100 meters across based on its visibility.



▶ A more involved analysis shows a second fragment farther out from the core.

While the data provide evidence that the comet is undergoing a fragmentation event, Bolin cautions that the event hasn't yet destroyed the nucleus. "When comets catastrophically disrupt, their brightness drops very, very quickly . . . we're not seeing that with Borisov," he explains.

The timing is strange, because comets are most likely to fragment when nearest the Sun; however, Comet Borisov has been close enough for sunlight to vaporize ices from its surface for the past six months. That said, fragmentation was still possible in late March, when it was still 2.6 a.u. from the Sun.

Bolin says the comet appears to have been little altered when it arrived at our solar system, despite eons traveling through interstellar space. But it may have a narrow escape on the way out.

■ JEFF HECHT

● Read additional details at https://is.gd/borisovbreakup.

SOLAR SYSTEM

Why Have Parts of Mercury's Landscape Collapsed?

CHAOTIC TERRAIN, an unexplained type of landscape on Mercury, might be the legacy of vast amounts of volatile materials that were once stored deep underground.

For decades, planetary scientists have thought this weird terrain was collateral damage from the impact that made the Caloris Basin on the exact opposite side of the planet. The impact could have set off massive seismic ripples that raced around the world, meeting on the opposing side to jumble the landscape.

But in a new study, Alexis Rodriguez (Planetary Science Institute) and colleagues suggest that the terrain achieved its chaotic look because of wholesale collapse. Easily vaporized elements stored underground escaped gradually; once enough of these materials had gone, the landscape deflated. If so, then volatiles existed relatively recently on Sun-baked Mercury. The findings, based on observations made by NASA's Messenger spacecraft, appear in the March 16th *Scientific Reports*.

The researchers present crater analyses to support their claim. Crater counts provide a proxy of age, enabling the researchers to estimate the chaotic terrain's age at 1.8 billion years old — at least 2 billion years *younger* than the Caloris Basin. Also, ejecta rays from recent craters disappear in some areas of chaotic terrain, which aligns with the idea that the ground-collapse events occurred in geologically recent times.

Furthermore, the team found terrain with similar texture in regions other than the one directly opposite the Caloris Basin. These smaller areas don't appear to be related to large impacts.

GALAXIES

Knife Edge Galaxy Throws Astronomers for a Loop

IN 2006, AMATEUR ASTRONOMER R. Jay GaBany obtained an iconic image of NGC 5907. Using his observatory, he captured an eye-catching double loop of diffuse starlight wrapping around the edge-on galaxy, also known as the Knife Edge Galaxy. The image appeared in the December 10, 2008, *Astrophysical Journal* as part of a team effort led by David Martínez-Delgado (Astronomical Calculation Institute, Germany). In addition to a known elliptical feature — most likely a tidally disrupted dwarf galaxy — GaBany's image clearly shows a second loop.

Then the Dragonfly telephoto array (*S&T:* May 2019, p. 64), which excels at detecting low-surface-brightness features, failed to see the second loop. Pieter van Dokkum (Yale University) and collaborators published these results in the October 1, 2019, *Astrophysical Journal Letters*.

But Ignacio Trujillo (Institute of Astrophysics of the Canary Islands, Spain), who contributed to the 2008 paper, counters that the Dragonfly team uses a nonstandard method to quantify the depth of their images. "They [do] not reach particularly deep low-surface-brightness levels," he claims, much to the annoyance of van Dokkum.

Now, Oliver Müller (University of Strasbourg, France) and colleagues have observed the galaxy with the 1.4-meter Milanković telescope in Serbia. And they, too, failed to see signs of the second loop, as they write in the December 2019 *Astronomy & Astrophysics*.

Martínez-Delgado argues that at least some of the Milanković images were taken when the galaxy was at relatively low elevation, hampering the detection of extremely diffuse features. "Their data cannot shed light on this controversy and are still consistent with shallow images taken by tens of amateurs with very modest equipment in the last decade," he says.

Unfortunately, the raw data from the 2006 image were lost in a hard-drive crash and cannot be reprocessed independently. But Martínez-Delgado says more follow-up observations by his team are in progress. "I'll give a suitable answer [to the criticism] in a refereed publication soon," he says. Adds Trujillo: "I am confident that the mystery will be finally solved later this year."

■ **GOVERT SCHILLING**

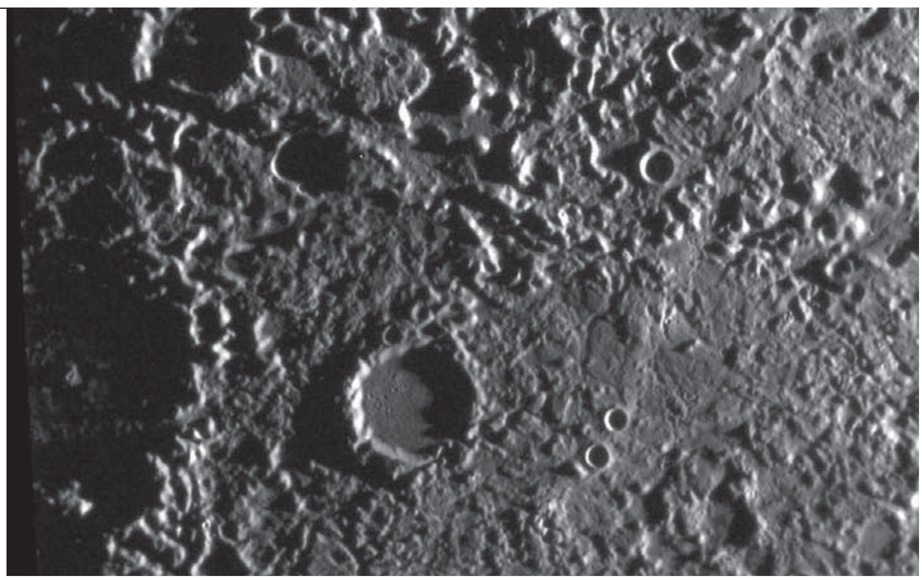
▶ *Top:* R. Jay GaBany captured a double loop around NGC 5907. *Bottom:* Later images, including this one from the Dragonfly telephoto array, fail to show the second loop.

This suggests that volatile-rich materials might be stored deep within large areas of the planet's crust.

"It's fascinating work and I think it will spur quite a lot of research," says David Blewett (Johns Hopkins University Applied Physics Laboratory).

Confirmation of whether volatile-rich materials still exist underground — and what they are — could come from the BepiColombo spacecraft, due to arrive at the innermost planet in 2025.

■ **JAVIER BARBUZANO**

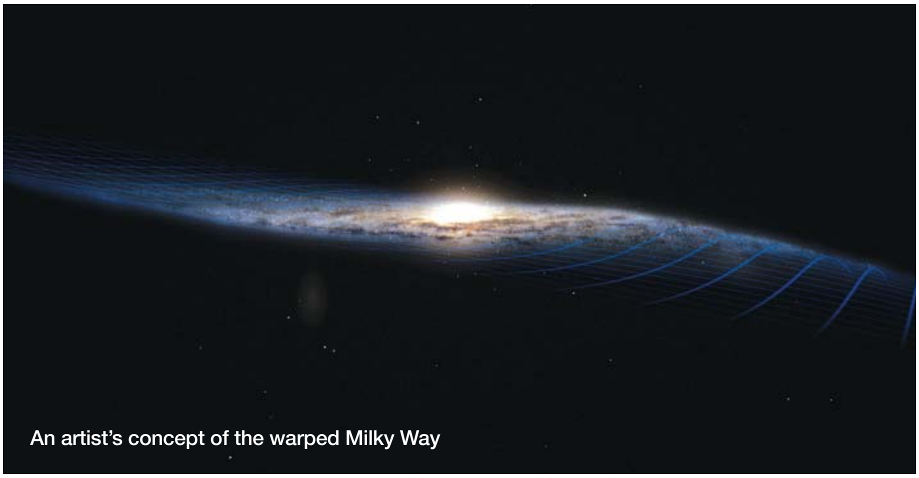


▶ NASA's Messenger spacecraft captured this close view of chaotic terrain. The area in the image is 248 km across.

TWO LOOPS: D. MARTÍNEZ-DELGADO ET AL. / *THE ASTROPHYSICAL JOURNAL* 2008; SINGLE LOOP: VAN DOKKUM ET AL. / *ASTROPHYSICAL JOURNAL LETTERS* 2019; MERCURY TERRAIN: NASA / JHU-APL / CARNEGIE INSTITUTION OF WASHINGTON

GALAXIES

How Fast Does the Milky Way's Warp Whirl?



An artist's concept of the warped Milky Way

STEFAN PAYNE-WARDENAAR

ASTRONOMERS HAVE KNOWN for decades that, while the inner part of the Milky Way is flat as a very thin pancake, gases in the outer edges warp out of the galactic plane. The stars in the outskirts follow suit, riding like boats up and down the wave. Now, scientists have measured those vertical motions, using the European Space Agency's Gaia satellite to gauge how quickly the warp whirls around the Milky Way. The results appeared online March 2nd in *Nature Astronomy*.

Gaia is mapping the positions and motions of more than a billion Milky Way stars (*S&T:* Aug. 2018, p. 9), and last year scientists used its data to precisely chart the warp's shape (*S&T:* Nov. 2019, p. 12). With the new study, Eloisa Poggio (National Institute of Astrophysics, Italy) and colleagues again turned to Gaia to see how that warp *precesses*, or turns, around the center.

Poggio and colleagues measured the vertical motions of more than 12.6 million giant stars from the Gaia catalog, which gave the researchers insight into the motions of the warp itself. They found that the warp is turning *prograde*, in the direction of the galaxy's rotation, at a speed of about 10 km/s per kiloparsec away from the galactic center. Out at the Sun's location, the warp is precessing at 80 km/s — so our Sun, which goes around the galactic center at some 230 km/s, is fast outpacing the wave it rides. While the Sun takes some 220 million years to circle the galaxy, the warp takes about 600 or 700 million years.

Yet the warp is turning considerably faster than some theories would have us expect. Despite some uncertainty in the measurements, the results are certain enough to indicate that the warp hasn't always been there. A recent interaction with a dwarf galaxy — already suggested by several other lines of evidence — could have temporarily whacked our galaxy out of a flatter state of existence.

■ MONICA YOUNG

IN BRIEF

Margaret Burbidge, 1919–2020

Astronomer Margaret Burbidge, who celebrated her 100th birthday last year, has passed away. An early fascination with the stars combined with a talent for mathematics — as well as a stubbornness that enabled her to overcome prejudice — ultimately led to a fruitful career. Most famously, together with her husband, Geoffrey Burbidge, and collaborators Fred Hoyle and William Fowler, Burbidge published the seminal paper "Synthesis of the Elements in Stars." The study outlines how stars forge elements via fusion in their cores, cementing the idea that most of the elements around us originated in the stars. Read the fascinating story of her life and work in the July 2019 issue of *Sky & Telescope* or online at **https://is.gd/MargaretBurbidge**.

■ MONICA YOUNG

2020 Star Party Status

Several clubs and organizations have cancelled or postponed star parties and other events due to the COVID-19 pandemic. In many cases, organizers are still in the process of making a decision on how and when to hold a given event. We are providing an updated calendar of upcoming North American star parties and events: **https://is.gd/starparties2020**. We'll update the page weekly as the pandemic continues.

■ SABRINA GARVIN

Starlink: An Update

On March 18th, aerospace company SpaceX sent its sixth batch of 60 Starlink satellites into the sky, bringing the total number of Starlinks in low-Earth orbit to 360. SpaceX is thus well on its way to having a working network of thousands of broadband internet–providing satellites (*S&T:* Mar. 2020, p. 14). On January 6th, the company launched an experiment, dubbed DarkSat, with a dark coating to dull reflections. But studies show that the satellite — while notably fainter — is not faint enough to avoid causing problems for sensitive, wide-field professional telescopes, such as the upcoming Vera C. Rubin Observatory. But a dark coating is not the only trick up the engineers' sleeve. "SpaceX has been aggressively pursuing multiple solutions," says Kelsie Krafton (American Astronomical Society), who helps coordinate talks between SpaceX and professional astronomers. SpaceX's incremental approach to manufacturing makes it adaptable, she adds, so potential solutions can be continually incorporated, tested, and improved upon. Tony Tyson (University of California, Davis), an astronomer with the Rubin Observatory, agrees: "SpaceX is taking this seriously and is committed to solving the problem," he says. Separately, on March 30th SpaceX's only major competitor, OneWeb, filed for Chapter 11 bankruptcy protection. OneWeb had already launched 74 of its satellites; they, and the radio spectrum they've claimed, will likely be sold as part of the bankruptcy proceedings.

■ MONICA YOUNG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COSMOLOGY

Mysterious X-ray Signal Goes Missing

THE ABSENCE of a mysterious X-ray signal — which could have provided evidence of dark matter — is causing as much controversy as its detection did.

In 2014 two teams discovered a slight surplus of X-rays with energies around 3,500 electron volts (3.5 keV) in observations of galaxies and galaxy clusters. Astronomers had few ready explanations, and some of them suspected that a dark matter particle candidate known as the *sterile neutrino* could produce the extra photons when it decayed. However, some observations, such as one of the Perseus Cluster, failed to turn up a similar signal.

Joining the hunt, Christopher Dessert (University of Michigan) and colleagues examined 752 X-ray images of the Milky Way's halo taken with the XMM-Newton satellite. Selecting only observations of empty regions of sky between 5° and 45° from the galactic center, they amassed a year's worth of exposure time.

Dessert's team finds no evidence of a signal at 3.5 keV, the researchers report in the March 27th *Science*. Furthermore, by calculating how many X-rays they would receive from sterile neutrino decay, the team eliminates this neutrino as a dark matter candidate.

However, astronomers involved with the original detection remain unconvinced. Esra Bulbul (Center for Astrophysics, Harvard & Smithsonian) contends that the researchers did not accurately account for the instruments' background. And Alexey Boyarsky (Leiden University, The Netherlands) raises the stakes further: He *has* detected the 3.5 keV signal in a subset of the very same XMM-Newton observations of the Milky Way.

While Dessert and his team plan to extend their technique to search for dark matter candidates at other energies, Bulbul looks to up-and-coming X-ray telescopes to settle the debate. "We are almost there," she says.

■ MONICA YOUNG

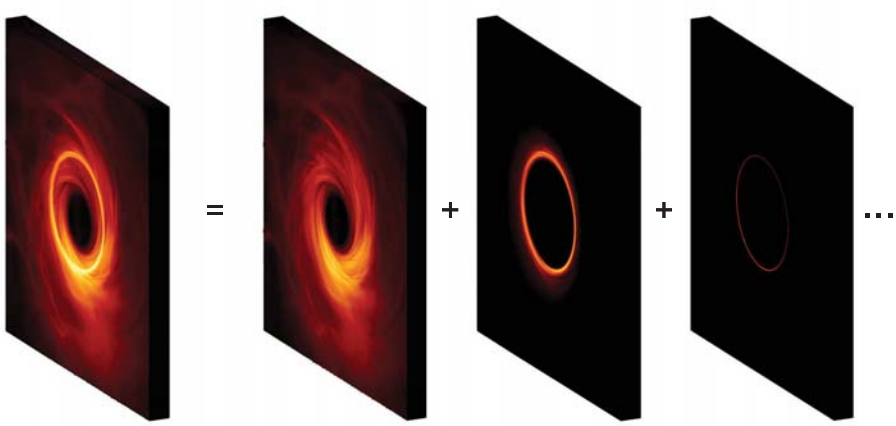
BLACK HOLES

Rings of Light Could Reveal Black Hole Properties

NEW CALCULATIONS REVEAL that a telescoping cascade of rings around black holes could shed light on these enigmatic objects.

Last year, the Event Horizon Telescope (EHT) team released the now-iconic image of a black hole's silhouette at the center of the galaxy M87 (*S&T:* Sept. 2019, p. 18). Within the bright halo around the "shadow" is the *photon ring*, which marks the closest circuit light can make around the black hole without plunging into it.

But it turns out, the photon ring is not a single ring. It's an infinite series of concentric "subrings," each one thinner than the one just outside it. The photons that trace out the subrings are temporary hostages of the black hole, their trajectories diverted by its gravity. A photon winds up in a particular subring based on how many times it circles the black hole before escaping to reach us. The more loops completed, the thinner the subring, and the closer it lies to the event horizon in the image.



▲ This artist's concept shows how several subrings (at right) combine to make the photon ring surrounding the black hole in M87 (simulation at left).

Work by a team at Harvard's Black Hole Initiative and their colleagues shows that *very long-baseline interferometry*, the method that the EHT team used to capture the black hole image, can trace the thickness, shape, and brightness of each subring. This signature reveals how the black hole warps spacetime around itself, which in turn depends on the black hole's mass and spin. Studying the subrings could not only give us a new way to "see" the gravitational landscape, but it could also tell us the two properties that define a black hole, Michael Johnson (Center for Astrophysics, Harvard & Smithsonian) and colleagues explain in the March 18th *Science Advances*.

While exploration of black holes' photon rings remains out of reach for the current EHT, the network of telescopes could expand to space. Even then, though, astronomers wouldn't image more than the first couple of subrings. Nevertheless, combining space telescopes with ground-based radio dishes could reveal what the black hole is doing to the surrounding spacetime as it whirls around.

■ CAMILLE M. CARLISLE

● **To view an animation of a photon ring and read additional details, visit https://is.gd/photonring.**

GEORGE WONG (UIUC) AND MICHAEL JOHNSON (CFA)

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 by Ashley Gerard Davies

Io the Volcani Rosetta St

Giant eruptions and vast lava fields cover Jupiter's tempestuous inner moon.

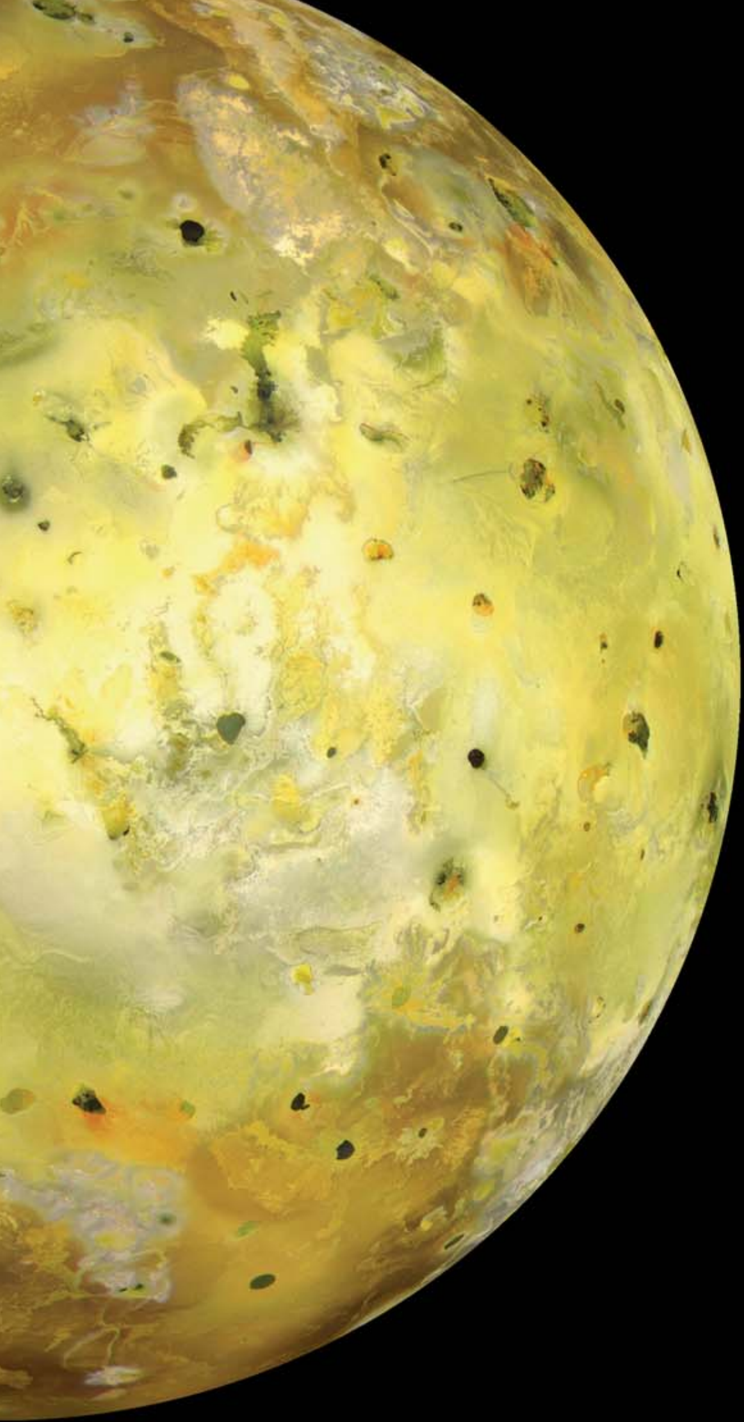
Most planets in the solar system have moons, but giant Jupiter has perhaps the most extraordinary satellite of all — the volcanic wonderland Io, a world made for superlatives. Its hundreds of active volcanoes erupt huge volumes of hot lava. Lava flows cover areas the size of small countries on Earth. And although it's almost exactly the same size as Earth's Moon and just as much a target for impactors, Io's surface looks nothing like the ancient, heavily cratered lunar landscape — in fact, Io's surface has no impact craters at all: The incredible level of volcanic activity constantly renews the surface and quickly buries all evidence of impacts.

Voyager 1 photo of Io

The most astonishing thing about Io, however, is that it is volcanic at all. When the worlds of the solar system first formed, radioactive isotopes were incorporated into their interiors. As these isotopes decayed, the interiors heated up and, in many cases, fueled surface volcanism. Over time, though, this heat was lost to space. Small bodies lose heat faster than large ones, so, for example, Earth's Moon has no active volcanoes while the larger Earth has plenty. Most scientists therefore expected Io to be volcanically dormant — a cold, frozen ball quietly whirling around Jupiter.

But the primary source of Io's internal heat is not radioactive. Instead, this heating comes from the gravitational tug of war between Jupiter, Io, and two other moons — Europa and Ganymede. Caught in an orbital resonance, the satellites pull at one another as they pass, kneading their interiors and warming them.

Io is in the sweet spot for the most extreme heating. The flexing of Io melts part of the rocky interior and ultimately



manifests at the surface as breathtakingly intense volcanism. Io's volcanoes radiate so much energy in the infrared that astronomers can observe many of these individual eruptions using telescopes on Earth.

Io is therefore one of the most restless, mesmerizing worlds in the entire solar system. And because it is the most dramatic and extreme example we have of tidal volcanism, Io also may help us understand what's going on inside other moons, such as Europa and Enceladus, where tidal forces may power hydrothermal vents in the subsurface ocean. It might even illuminate what's inside faraway exoplanets.

The Discovery of Io's Volcanism

I have been fascinated by Io ever since I was a schoolboy, when astronomers first discovered its giant volcanic plumes stretching hundreds of kilometers into the sky. These images from NASA's Voyager 1 spacecraft revealed a surface unique in the solar system, both in terms of color and morphology. But it was really the follow-up Galileo mission that unveiled Io's surface in unparalleled detail, both at visible and infrared wavelengths. The visible images showed a multi-colored surface unlike anything else in the solar system. These colors speak volumes about the composition of the surface, which is dominated by yellow sulfur and white sulfur dioxide, the latter as frost. Red deposits, ranging from small, wispy streaks to huge annular plume deposits more than 1,000 km (600 miles) across, are most likely sulfurous volcanic gases escaping from silicate lavas as they erupt onto the surface. Because the red sulfur reverts quickly to yellow sulfur, the presence of these deposits indicates sites of active resurfacing.

◀ **SULFUROUS MOON** This color mosaic combines images from the Galileo spacecraft's near-infrared, green, and violet camera filters to approximate what the human eye would see — although processing aficionados debate the best combination. Black, brown, green, orange, and red regions are volcanic centers of different types and ages.

▼ **IO IN VISIBLE AND IR** On its way through the outer solar system, the New Horizons spacecraft looked at Io with three cameras. Fine details in a plume from Tvashtar Paterae appear in black and white *(left)*, while the visible-light color image *(center)* highlights the contrasting colors of the lava and plume. But the infrared composite *(right)* shows Tvashtar's true splendor. At least 10 fainter volcanic hotspots also dot the nightside.

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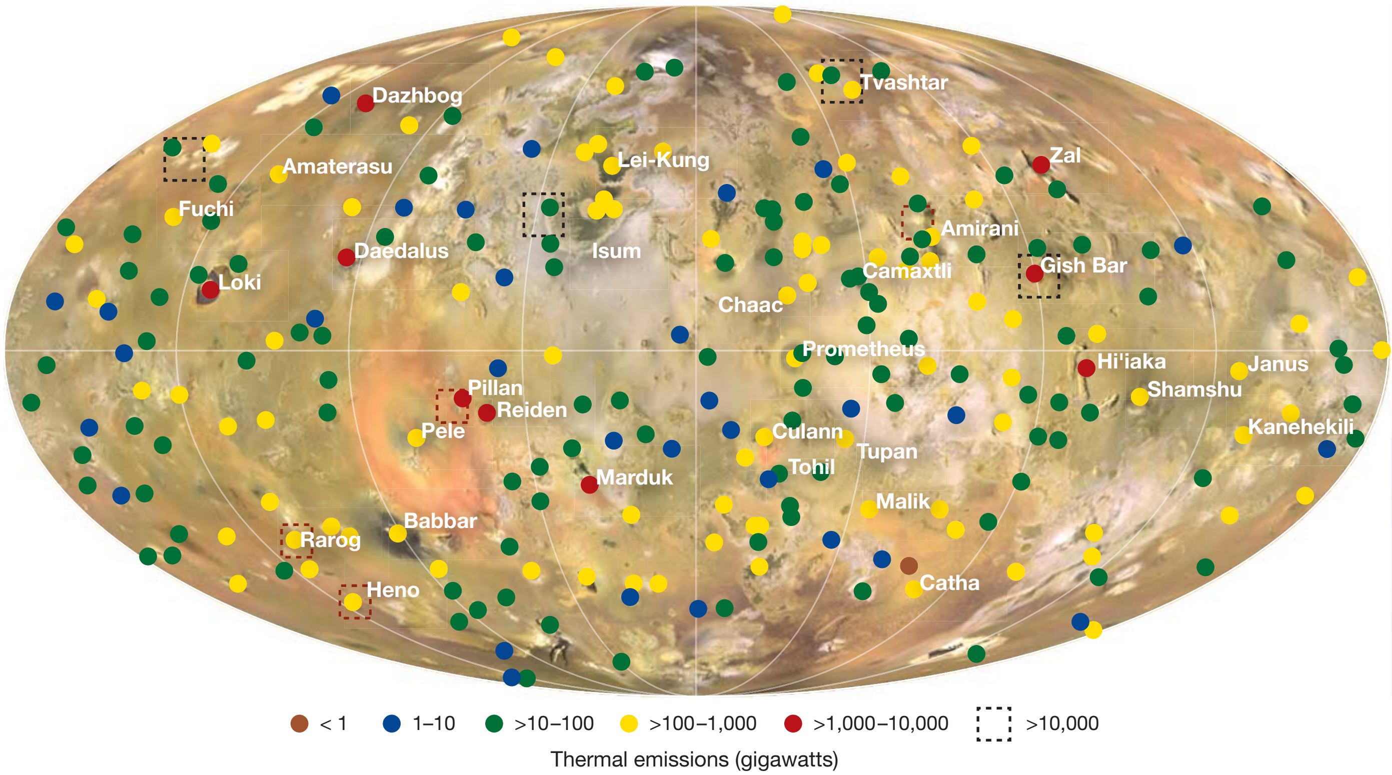
VOYAGER 1'S VIEW: NASA / JPL; IO: NASA / JPL / UNIVERSITY OF ARIZONA; IO THREE WAYS: NASA / JHU APL / SWRI



▲ **VOLCANOES GALORE** Scientists have detected more than 250 active or recently active volcanoes on Io, color-coded here by their thermal emission. Loki Patera (red dot at far left) is the most powerful. Dotted squares mark transient outbursts. The central longitude marks the anti-jovian point.

Extensive silicate lava flows of different ages cover millions of square kilometers of Io's surface. The youngest are black; older surfaces fade to grey before eventually blending into the background. Io is also dotted with volcanic depressions (called *paterae*), similar in appearance to collapse calderas found on Earth. Many paterae have dark, low-albedo floors of silicate lava. In total, these fresh lavas cover only about 2% of Io's total surface area, but they emit more than half of Io's thermal energy.

It is therefore in the infrared that Io is most spectacular. The hundreds of volcanic eruptions glow brightly, revealing the magnificent scale of Io's volcanism. As a volcanologist with experience interpreting remote-sensing observations of eruptions, I joined Galileo's Near-Infrared Mapping Spectrometer (NIMS) team and dove into these infrared wonders in the 1990s and early 2000s. NIMS could detect thermal emission from lava at the moment it was first exposed on the surface until it had cooled down by well over 1000K. Watching these observations return, and embarking on the adventure to understand what the data told us about the individual eruptions and their place in the broader picture of Io's origin and evolution, was one of the greatest thrills of my career.

Since Galileo, we've relied primarily on adaptive optics–enhanced telescopes on Earth. The most notable are the Keck and Gemini North telescopes on Mauna Kea, Hawai'i, both of which are equipped with adaptive optics (AO) that yield spatial resolutions equivalent to much of the data collected by Galileo's NIMS. But to this day, the Galileo data continue to reveal new insights into Io's extraordinary volcanoes, too. Together, these observations unmask Io's volcanic marvels.

Volcanic Eruptions on Io

The power emitted from Io's volcanoes spans an astonishing six orders of magnitude. The smallest identified thermal source, in terms of size and emission, is about 100 meters across and outputs about 0.2 gigawatt of heat. While small for Io (as far as we can tell from existing data), this is still equivalent to some of the largest terrestrial effusive eruptions in recent years, such as Iceland's Holuhraun in 2014-2015. At the other end of the power scale, Io's largest eruptions output tens of terawatts for short periods of time.

Io's eruptions, characterized by what appears to be high-temperature, low-viscosity silicate lava (think Kilauea, Hawai'i), are familiar to a terrestrial volcanologist, but Io's volcanoes operate on a much larger scale than their terres-

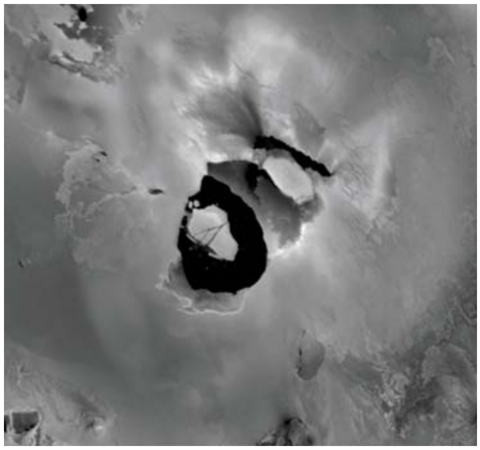
Epic Eruptions

The lava fountains at Fimmvörðuháls during the 2010 Eyjafjallajökull eruption in Iceland emitted roughly **1 GW** of heat at their peak. The Rarog and Heno Paterae volcanoes emitted **10,000 times** more than that during eruptions on August 15, 2013.

A. G. DAVIES ET AL. / *ICARUS* 2015

trial contemporaries. Take lava lakes, for example. Rare on Earth, an active lava lake is the top of a column of magma connected to a magma source. They are interesting volcanological phenomena. Terrestrial lava lakes, associated with high-temperature, low-viscosity basalt (again, think Kilauea) and lower-temperature, more viscous phonolite (such as Mount Erebus in Antarctica), are typically tens of meters in diameter.

But Io has Loki Patera. Located on the moon's permanently Jupiter-facing side, Loki Patera is Io's most powerful persistent volcano. The patera is 180 km across, about the length of Delaware. The dark, lava-covered floor of the patera has an area of 21,500 km^2 (8,300 mi^2), twice the area of Los Angeles County. The volume of lava needed to be exposed and cooled every year to support the extraordinary power output is huge — about 100 km^3 (20 mi^3).

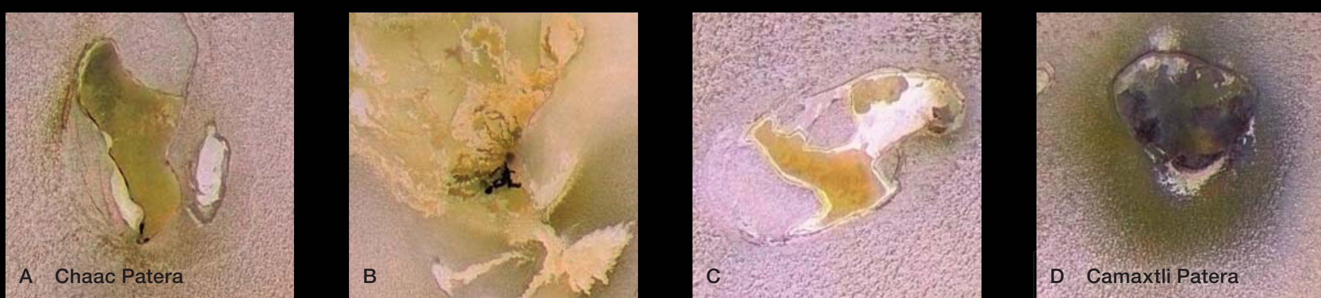


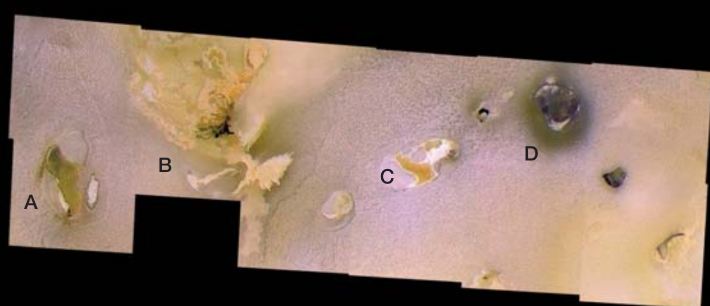
◀ **LOKI** A sea of lava under a thick crust fills the floor of the giant volcano Loki Patera, surrounding the central island like a hot moat.

Loki Patera's thermal emission varies depending on how the patera's surface renews itself. On the massive lava lake — a lava sea, really — a crust forms at the surface. Over time, the crust thickens, and the surface cools. Eventually, the crust becomes so thick that it founders, sinking into the molten magma beneath. This newly exposed lava then starts to cool and solidify, forming a new crust. Gradually, this foundering progresses around the patera, and around a central "island" that rises above the area being resurfaced. I mapped this progression over part of the patera floor using NIMS data, and others have done it since using large, ground-based telescopes. Subsequent, extraordinary Io occultation data obtained by Katherine de Kleer (then University of California, Berkeley) and colleagues using the Large Binocular Telescope Interferometer have shown that, at least during 2015, the resurfacing took place progressively in *two* directions around the island — both clockwise and counterclockwise.

Lava lakes on Io may be as rare as on Earth — we've only confidently identified a few. Pele is the best example and the closest Io analog so far to terrestrial basalt lava lakes. Escaping gas breaks up Pele's crust and causes the lava to roil. Sulfur and SO_2 gases escape at high velocity, carrying along silicate particles and forming a giant eruption plume that dramatically paints the surface of Io red. Another feature on Io — Janus Patera — may also contain a lava lake, as it exhibits similar thermal behavior to that of Pele. Janus Patera lacks a Pele-like persistent, sulfur-rich plume, though.

While Io's most common volcanic feature is the patera, extensive lava fields also cover large expanses of Io's surface. Between the Voyager and Galileo missions — 16 years — lava flows spread to cover more than 3,400 km^2 at Prometheus. The Amirani lava field is more than 300 km long. The newest, warmest areas of the lava flows at Lei-Kung Fluctus cover





PATERA CHAIN This 12-image Galileo mosaic *(right)* shows several ionian paterae, from Chaac Patera (green-floored on left) to Camaxtli Patera (dark depression in upper right). The irregular depressions often correspond to active volcanic centers and are similar to terrestrial collapse calderas. The mosaic spans 850 kilometers.

LOKI PATERA: NASA / JPL / USGS; CHAIN OF PATERAE: NASA / JPL / UNIVERSITY OF ARIZONA

IO PUTS EARTH TO SHAME Io is less than 30% Earth's size, but it boasts volcanoes that are dramatically larger and more powerful than those on our planet. Icons are not to scale.

Sizes: Small but Mighty

Earth radius 6,378 km

Io radius 1,821 km

The largest lava lake on Io is ***more than 250 times wider*** than the largest lava lake on Earth.

Nyiragongo (0.7 km across)

Loki Patera (180 km across)

Eruption Rates (in cubic meters/second)

	Earth	Io
Pahoehoe flows	**5** Kilauea (avg)	**67.5** Prometheus (avg)
Lava lake	**5** Kupaianaha	**300** Pele (avg)
Open channel flows	**1,000** Mauna Loa	**40,000** Pillan, 1997
Io outburst	No equivalent	**500,000** Loki region, 1990

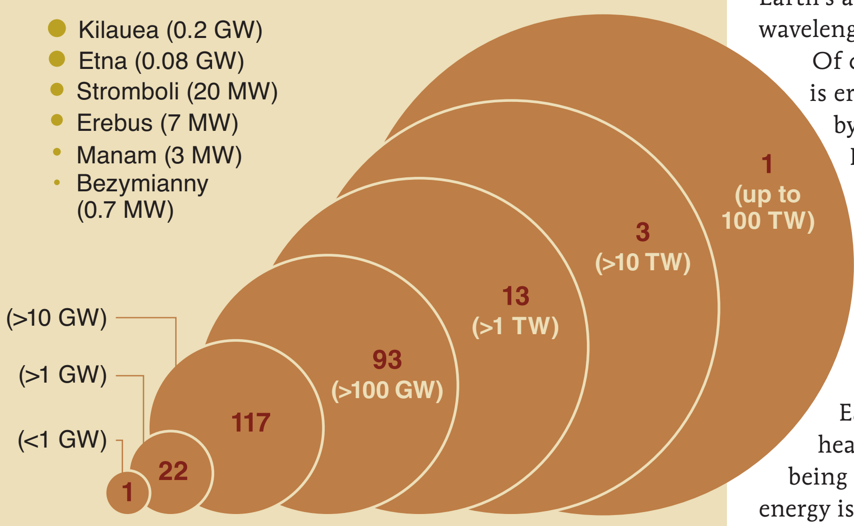
Power Radiated

Brown numbers indicate the number of ionian volcanoes in each class. The smallest source detected on Io radiates about 0.2 GW.

Earth

- Kilauea (0.2 GW)
- Etna (0.08 GW)
- Stromboli (20 MW)
- Erebus (7 MW)
- Manam (3 MW)
- Bezymianny (0.7 MW)

Io



some 55,000 km^2, and combined with the adjacent flows at Isum the entire area exceeds 100,000 km^2, larger than Portugal. Even if these lava flows are only 10 m thick, this represents an erupted volume of 1,000 km^3, about double the volume of Lake Erie.

Io's largest, most powerful, and rarest eruptions are voluminous outpourings characterized by lava fountains that feed extensive, thick lava flows. At the height of these outburst eruptions, Io's global infrared radiance at 4.8 microns more than doubles. During such an event at Heno Patera in 2013, more than 13 km^3 of lava erupted in less than a week — enough to bury the island of Manhattan, New York, to a depth of 220 m. Over the entire duration of the 1980 eruption of Mount St. Helens, Washington, the total erupted volume was about 1.25 km^3. At the peak of the Heno Patera eruption, the volume of lava erupted may have reached 10^5 cubic meters per second. This is more than 100 times the peak volume erupted by Mauna Loa in Hawaiʻi during its last eruption in 1984.

Such voluminous eruptions took place in the distant pasts of Earth (flood basalts), the Moon (mare flows), Mars (Athabasca Valles), and Venus (creating vast lava plains), thus helping shape the surfaces of these bodies as we see them today. Little is known about how these eruptions actually behaved, how long they lasted, and how exactly they emplaced their huge lava flows. On Earth, we can only examine the final deposits and infer the eruption mechanisms, but on Io we can directly observe these eruptions as they happen, giving us a glimpse of events that long ago rocked our own world.

The Glow from Below

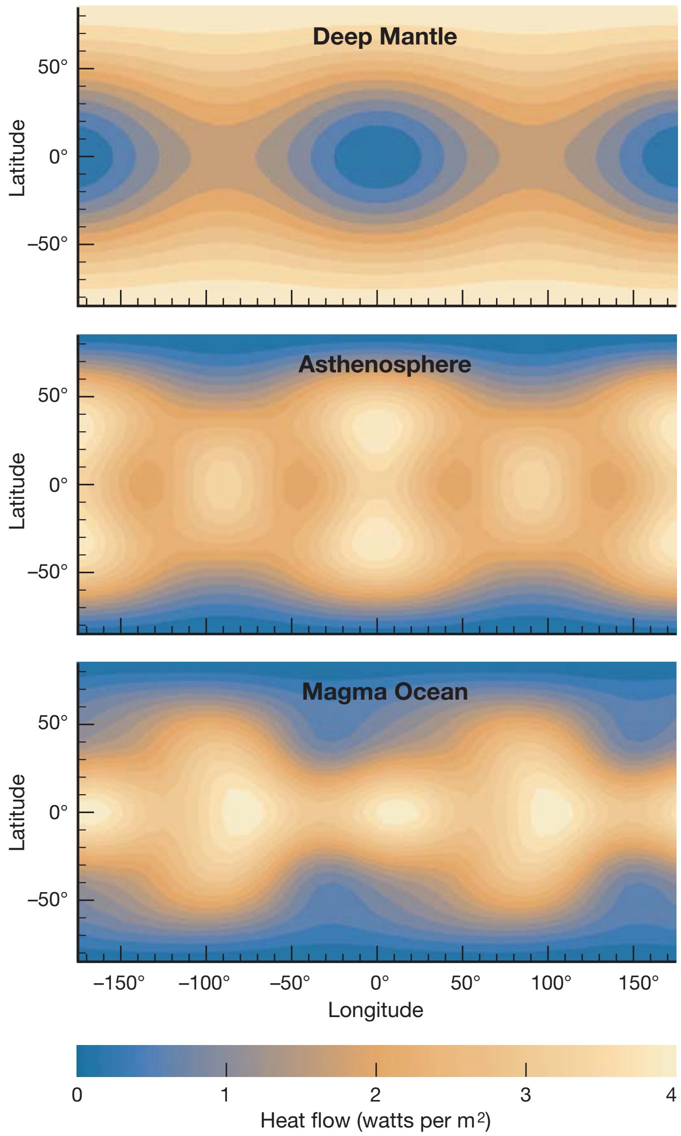
While it is instructive to examine these and other eruptions on Io to understand the physical and volcanological processes taking place, the larger value of these eruptions lies in understanding Io's total *heat flow*. As a result of internal and solar heating, Io is a relatively warm body in cold space. The heat radiates from the warm surface into the coldness of space. Io's overall heat flow is about 2.5 W/m^2, about 30 times Earth's average. This radiated heat is best detected at infrared wavelengths.

Of course, the hottest areas on Io's surface (where lava is erupting) radiate a lot more energy than areas heated by the Sun or warmed by heat conducted up through Io's crust. Much of Io's volcanic heat flow emanates from paterae. Loki Patera makes up the lion's share of this, responsible on average for about 10% of Io's *total* heat flow, and about 20% of Io's *volcanic* heat flow.

It is the distribution of heat flow across Io's surface, rather than the distribution of volcanoes, that may reveal what Io's interior looks like. Just like on Earth, Io's heat flow is not uniform. Models of interior heating depend not only on how much tidal energy is being pumped into the system, but also exactly where this energy is deposited and dissipated, and that depends, in turn,

TERRI DUBÉ / S&T, SOURCE: THE AUTHOR; EARTH ICON: SERHII SMIRNOV / THE NOUN PROJECT; MOON ICON: LOGAN / THE NOUN PROJECT; VOLCANO ICON: LAYMIK / THE NOUN PROJECT; OPEN CHANNEL FLOW ICON: PEPPER CURRY / THE NOUN PROJECT

POSSIBLE HEATING PATTERNS The pattern of heat flowing out of Io's surface should depend on where tidal energy is pumped into the moon's interior. If most of the energy is deposited in the deep mantle *(top)*, we'd expect more heat coming out of the moon's poles than we would if it's concentrated at the top of the upper mantle *(middle)* or in a magma ocean just beneath the crust *(bottom)*.

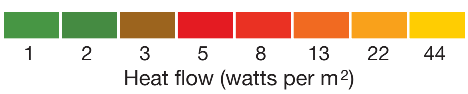


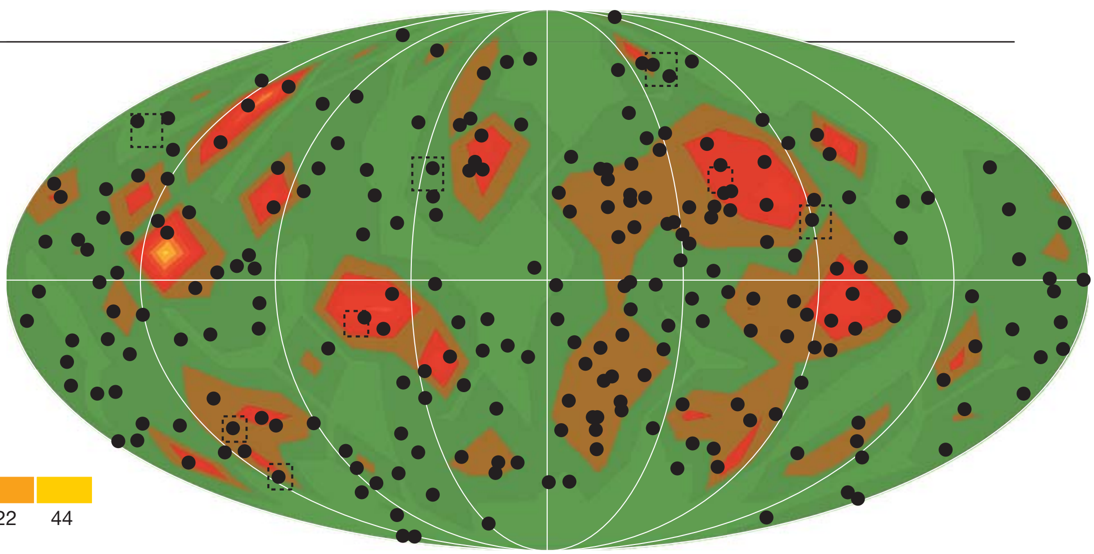
on the composition and state of Io's interior. If most of the energy is deposited deep in the mantle, then models predict that Io's polar heat flow would be enhanced. If deposited in the shallower *asthenosphere* — a layer between the top of the mantle and the solid lithosphere above — we expect that Io would exhibit enhanced heat flow at lower latitudes, with the peaks at two areas not far from the locations on the surface that directly face toward and away from Jupiter, called the *sub-* and *anti-jovian points*.

Reality differs from these simple predictions. As expected, observations based purely on volcanic heat flow suggest that there is a mixture of deep and shallow heating. But there appears to be a longitudinal shift in the expected asthenospheric model peaks, which are shifted about 45° eastwards from the sub-jovian point, and about 60° eastwards from the anti-jovian point. Furthermore, although Galileo observations suggested Io's poles are anomalously warm, it's unclear why — it could be because of the surface material's thermal inertia or conductive properties, or the result of deep internal heating in the mantle, which would shunt heat to the poles.

Understanding Io's heat flow — and by extension, how tidal heating actually works as a planet-altering process — will require mapping Io's global volcanic and internal heat flow and determining the state of Io's interior. An indication of the state and degree of interior melting is the erupting lava's composition. And here we come to the limits of available data: We don't actually know the precise composition of Io's dominant, silicate lavas, or if composition varies with location. Our current data are too contaminated by the presence of sulfur and SO_2, which mask the characteristic

FOLLOW THE HEAT Io's heat flow shows several hotspots (redder regions), which are not always synonymous with high concentrations of volcanoes (black dots). The average "background" heat flow — that not from volcanoes — is just shy of 1 W/m² and is an estimate, not a direct measurement.





HEAT FLUX: ISAMU MATSUYAMA / UNIV. OF ARIZONA AND KECK INSTITUTE OF SPACE STUDIES; HEAT FLOW: A. G. DAVIES ET AL. / *ICARUS* 2015 spectral fingerprints of silicate minerals.

With the right data, we could study fresh lava's composition using both eruption temperature and spectra. Basalt erupts at a lower temperature than more magnesium-rich *ultramafic lavas*, the presence of which would indicate a high degree of mantle melting. Now, differentiating between eruption temperatures of hot basalt (about 1500K) and even hotter ultramafic lava (say, 1800K) is not easy, because the hot surfaces cool so fast on Io that within a few seconds 1800K surfaces will be at basalt eruption temperatures. But it is not impossible to tell them apart, so long as image data meet key criteria: They are obtained quickly, and at multiple wavelengths simultaneously; the data are not saturated; and the observation exposure time is fast — a fraction of a second — so as to "freeze" the cooling action. Volcanic processes that enable us to take such images include lava fountains and the streams flowing through lava tubes, if we can observe them through skylights in the roof of the tube.

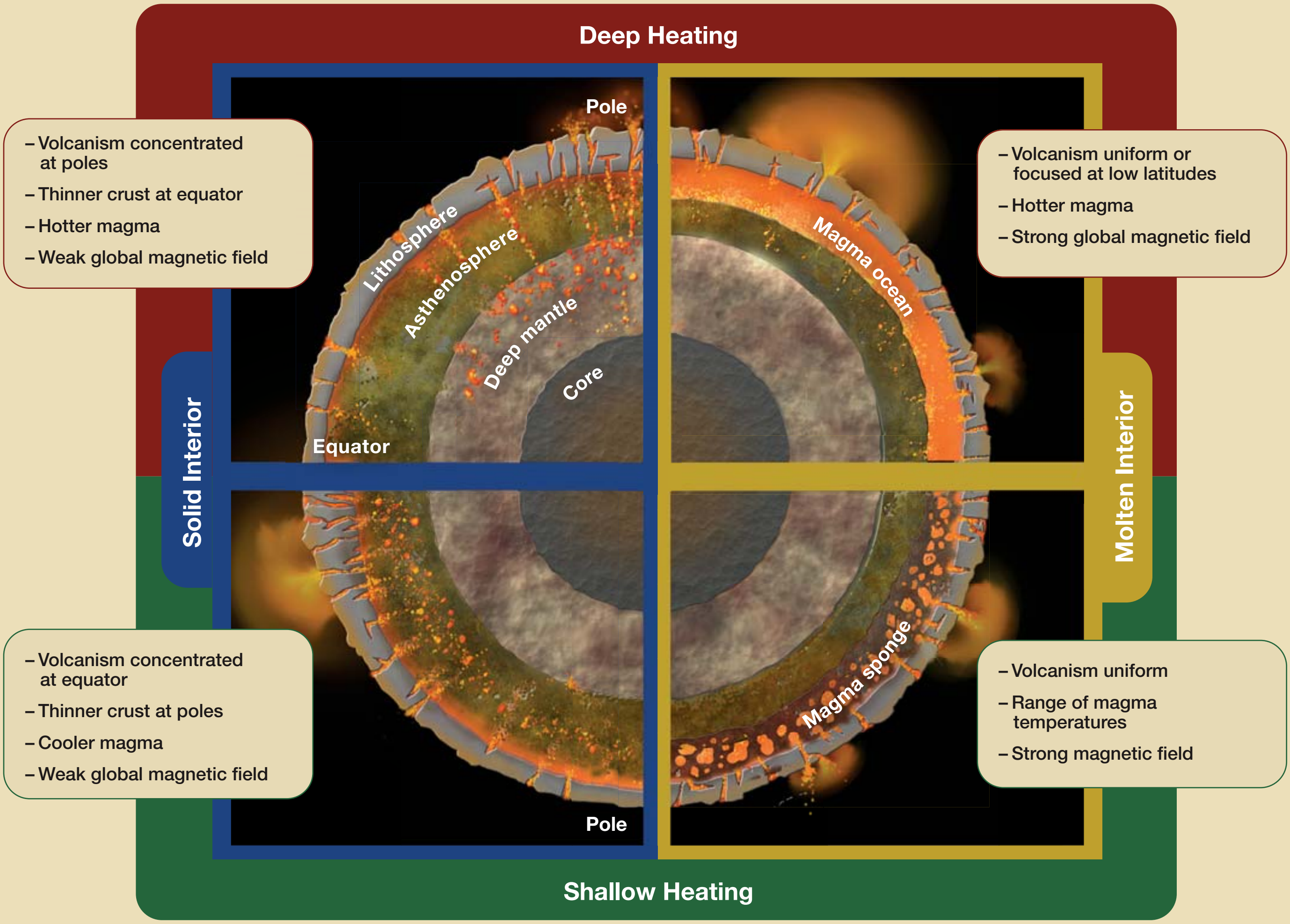
We can also determine composition by looking for particular absorption features in infrared spectra that reveal the chemical signatures of specific minerals in Io's lavas. Basalt, for example, would have more silica than ultramafic lava. Happily, Io has abundant fresh, warm lava flows that are free of sulfurous frosts.

All we need is to get close enough to Io to make the necessary observations.

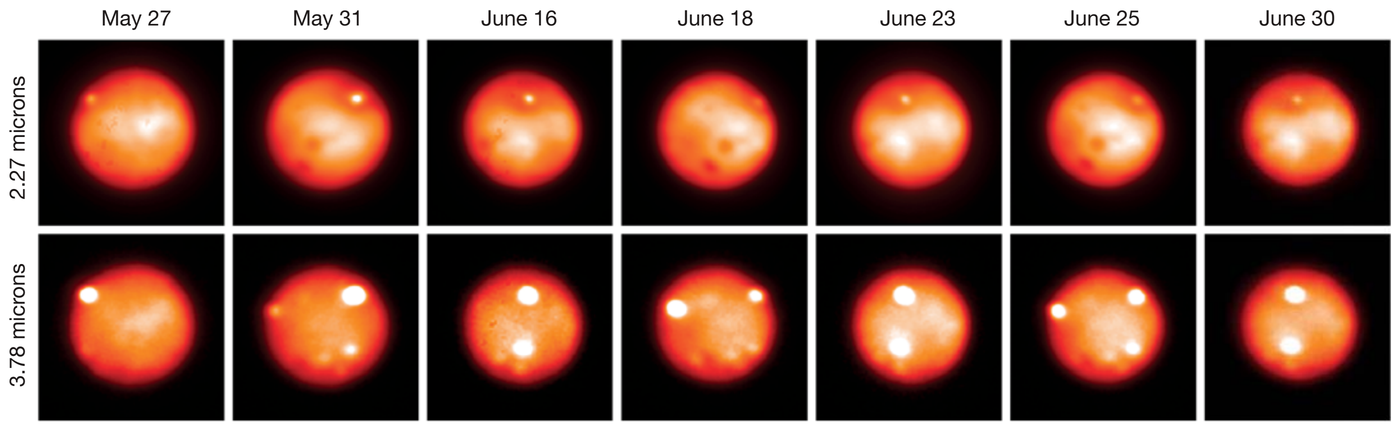
Back to Io?

So, Io is intensely volcanic — but the story doesn't stop there. Combined with the discovery of lifeforms that thrive without sunlight (*S&T:* Jan. 2020, p. 34), the discovery of Io's active volcanoes heralded a revolution in planetary science. No longer was the habitable zone within the solar system confined to the relatively narrow band defined by solar insolation. Now, the conditions for sustaining life — liquid water, food, and volcanic (rather than solar) heat — were governed not

▼ **WHAT LIES BENEATH** Scientists don't know what Io's interior looks like. It could have a thinner crust in certain locations, or even a global *magma sponge* layer. Spacecraft measurements of the moon's magnetic field and how the world wobbles and changes shape as it orbits Jupiter would help scientists rule out possibilities.



CHUCK CARTER AND JAMES TUTTLE KEANE / KECK INSTITUTE FOR SPACE STUDIES



▲ **VISIBLE FROM EARTH** The Gemini North telescope captured these infrared images of ionian eruptions in spring 2018. Isum Patera is the only hotspot in the top row; it appears at the same location in the bottom row. The bright hotspot south of Isum Patera is Marduk Fluctus. The one west of Isum Patera in some images is Loki Patera.

only by distance from the Sun, but also by orbital dynamics.

This opened the possibility of environments capable of supporting life inside Europa and Ganymede, into which energy is also being pumped via the same tidal resonance as in Io (although to a lesser degree), as well as in Saturn's Enceladus, Tethys, and Dione. Could volcanism be taking place at the bottom of the deep Europan ocean, generating an environment that could support life? And what about inside plume-rich Enceladus, where Cassini chemical data indicate that hydrothermal vents probably exist (*S&T:* Aug. 2017, p. 10)? The discovery of exoplanets in orbital resonances, such as Trappist-1's seven planets, also emphasizes the importance of understanding just how tidal heating works.

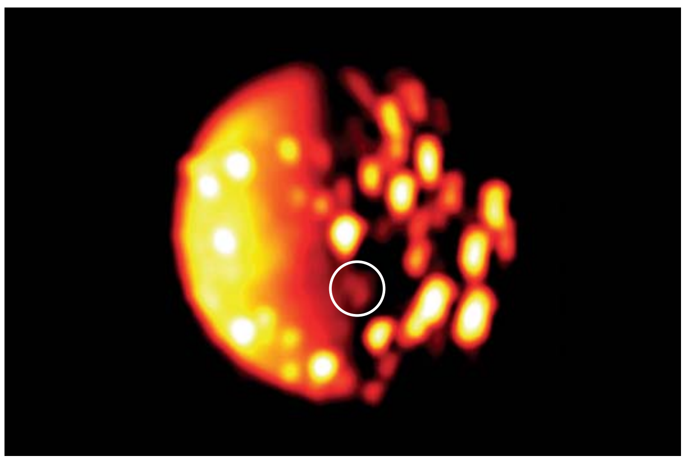
But we have now reached the limit of what existing Io data can tell us. While ground-based telescopes of increasing power and capability continue to obtain astonishing data on the location and magnitude of individual eruptions, it is impossible to obtain the polar observations needed to accurately map the moon's heat flow. NASA's Juno spacecraft is making polar observations of Io at ultraviolet, visible, and infrared wavelengths, but, while a handful of new hotspots have been discovered, the instruments onboard cannot map the heat flow from Io's non-volcanic areas.

What is needed is a new mission dedicated to Io. One potential mission, the Io Volcano Observer (IVO) proposed by Alfred McEwen (University of Arizona) and others, would essentially "follow the heat." In a highly inclined orbit around Jupiter, IVO would regularly pass Io as the spacecraft crossed the jovian equatorial plane, determining the nature of Io's crust and upper mantle and the evolution of Io's orbit. It would also measure the magnetic field induced inside Io as it moves through Jupiter's own field, to determine if Io has a global magma ocean. Building on decades of data analysis, specially designed imagers would constrain the lava's eruption temperature, measure lava composition, identify minerology, and map surface temperatures across Io's entire surface.

In summary, then, Io is key to understanding the process of tidal heating — how heat is deposited within a planetary body, and how it is transported to the surface. Although existing and future telescopes will continue to obtain data to better understand some of the volcanic processes taking place, the big questions — regarding internal structure, heat flow magnitude and distribution, and lava composition — can only be comprehensively answered by a new Io-dedicated mission. Only then can we pull aside the curtain to fully appreciate Io's elegant planetary ballet as it is tugged and twisted by the other bodies in the orbital resonance, all choreographed by the immutable laws of physics.

■ **ASHLEY GERARD DAVIES** is a research scientist at NASA's Jet Propulsion Laboratory in Pasadena, California, and can't quite believe he's actually paid to tramp about on erupting volcanoes.

▼ **JUNO'S VIEW** This infrared view of Io's southern hemisphere from the Juno spacecraft reveals a new hotspot (circled) that could be a previously undiscovered volcano. Brighter colors indicate higher temperatures.



IO CHANGES: K. DE KLEER ET AL. / *ASTRONOMICAL JOURNAL* 158:29 (2019); JUNO VIEW OF IO: NASA / JPL-CALTECH / SWRI / ASI / INAF / JIRAM by Emily Lakdawalla

Three Missions Head for

The summer of 2020 will see three spacecraft launch toward the Red Planet, each one with distinct objectives.

Next year, Earth invades Mars. Launch opportunities to Mars only happen once every 26 months, and during the next window — which spans this July and August — three spacecraft are set to begin their journeys. If everything goes well, in early 2021 they'll deliver two orbiters, a lander, and two rovers to Mars, joining the six orbiters, one lander, and one rover that already operate there.

Robotic spacecraft have orbited Mars continuously since 1997. The numerous missions have produced global maps of albedo, topography, and composition, finding evidence for abundant shallow subsurface ice and a distant past of long-term environments suitable for life. NASA seeks to take the next step with its Perseverance rover, going beyond the search for habitable environments to the search for life itself.

Perseverance won't launch alone. Two other launches represent efforts to expand the exclusive club of agencies that have achieved successful missions at Mars beyond NASA, ESA, and India. The United Arab Emirates will launch an orbiter to Mars, and China's plans are even more ambitious. Both missions, if successful, would mark historic firsts for their respective countries.

China's Aspirations

China's bold plans for its first Mars mission involve an orbiter, lander, and rover. No other agency has attempted more than an orbiter on its first mission. China has already demonstrated capability for deep-space navigation with Chang'e 2, which it piloted out of lunar orbit and on to a rendezvous with asteroid 4179 Toutatis. China also placed a lander and rover on the Moon on its first attempt with Chang'e 3 (*S&T:* June 2020, p. 34).

However, landing on Mars is far more difficult than on the Moon because of the planet's atmosphere, which is thick enough to burn up an incoming spacecraft with frictional heating (therefore requiring an aeroshell and heat shield for entry) but too thin to slow a spacecraft by parachute alone (therefore requiring both parachutes and landing rockets).

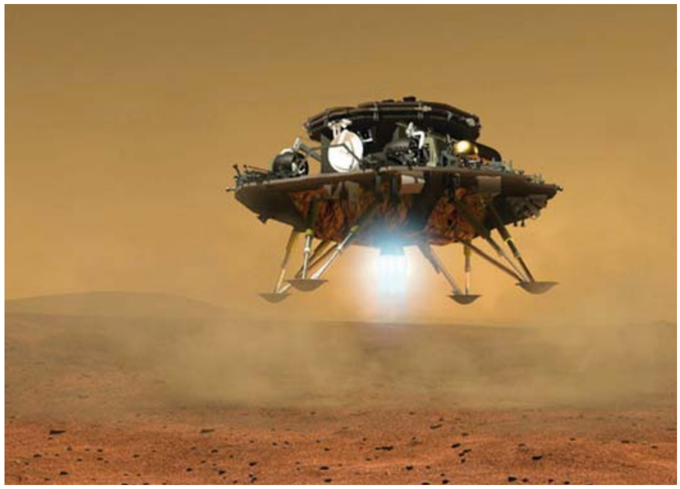
Like the Viking missions did, China's Mars mission (provisionally designated Huoxing 1, or "Mars 1") will probably place the entire spacecraft stack in orbit and then use the orbiter to perform reconnaissance of landing sites. The landing site will be in one of two northern-hemisphere regions selected for safety more than science. The orbiter has a hefty payload, including two cameras and a spectrometer for surface mapping, a radar instrument for detecting subsurface water ice, and a magnetometer and particle analyzer for studying the space environment.

The 240-kilogram, solar-powered rover is twice as heavy as China's lunar rovers and a third the mass of Spirit and Opportunity, but it's only a quarter of Perseverance's weight. It carries ground-penetrating radar, a multispectral camera, weather instruments, and a magnetic-field instrument. The nominal mission is 90 Martian days, but if the Chinese

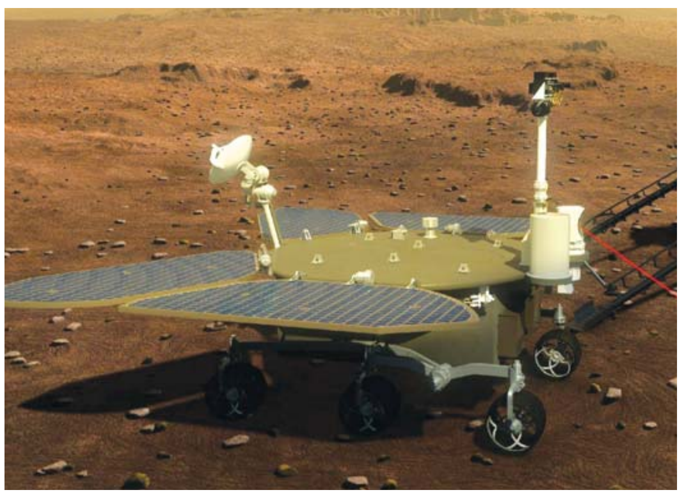
TRACKS: NASA / JPL-CALTECH / MSSS: LANDER/ROVER AND SOLAR PANELS: XINHUA NEWS AGENCY (3)

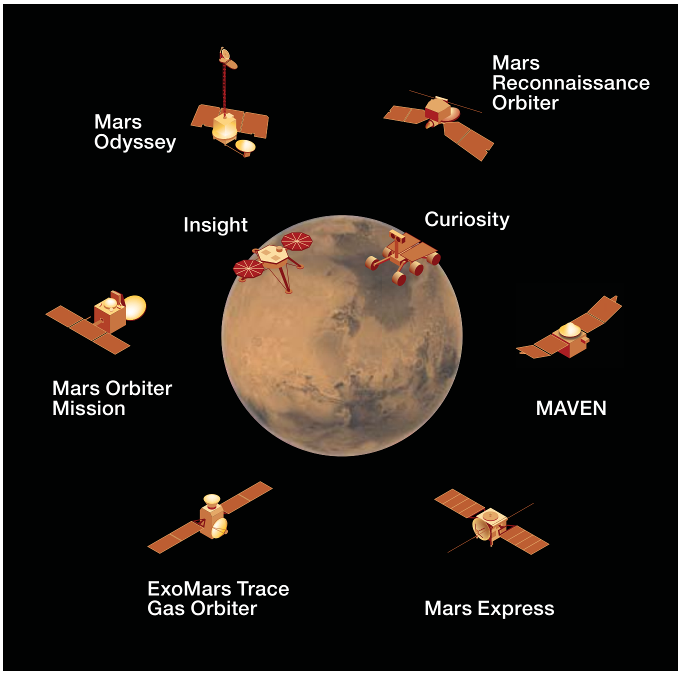
MARS

▼ **DESCENT** Retro rockets will help slow the lander once parachutes and air cushions (not seen here) have already been deployed.



◀▼ **CHINA'S MISSION** At *left*, an artist's concept of China's Mars mission shows the rover ready to roll. Solar panels are folded up on the rover's back and will unfold upon deployment *(below)*.





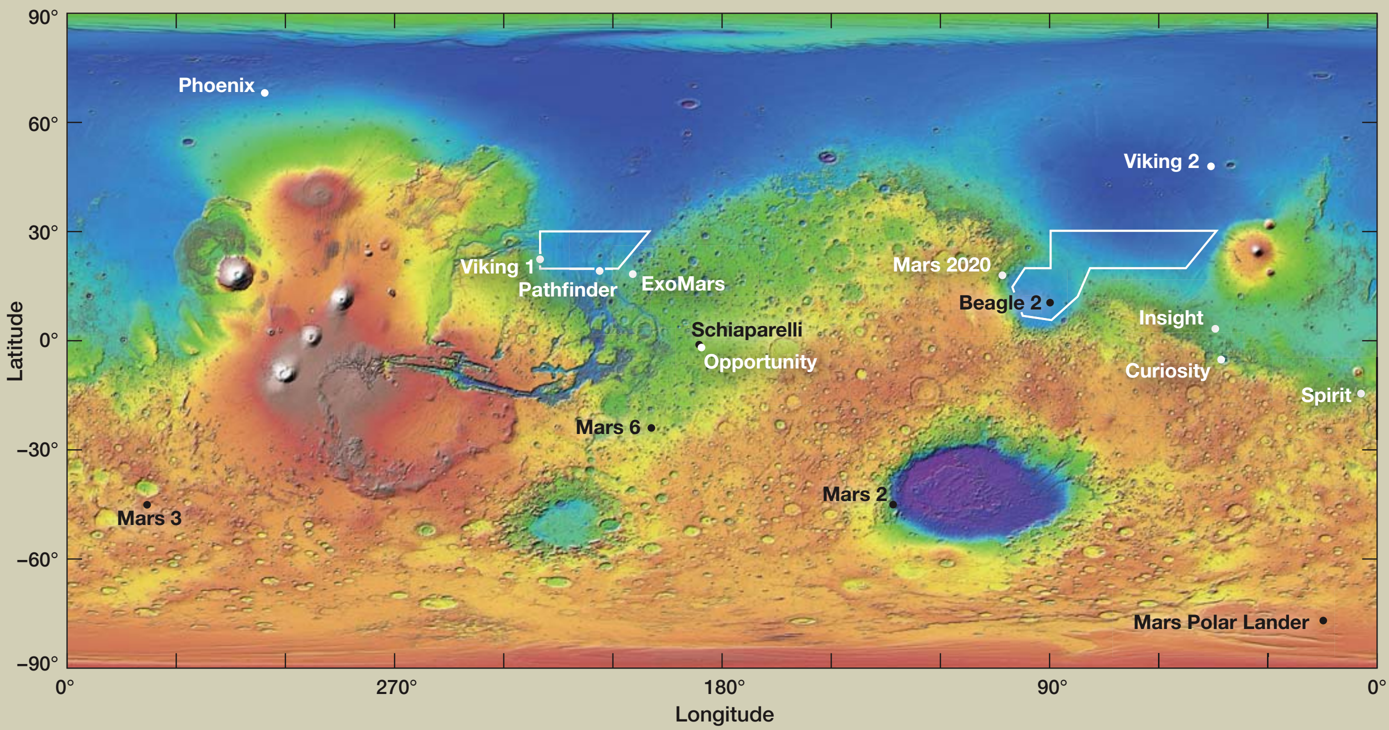
▲ **RED PLANET ROBOTS** Mars hosts a fleet of craft that are operational as of March 2020, including NASA's Insight lander and Curiosity rover as well as six orbiters: India's Mars Orbiter Mission, the European ExoMars Trace Gas Orbiter and Mars Express missions, and NASA's Mars Odyssey, MAVEN, and Mars Reconnaissance Orbiter.

lunar rovers' longevity is any guide, not to mention Spirit and Opportunity's experience with solar panel-cleaning events, China's Mars rover could last much longer.

The rover's mission all depends, of course, on a successful landing. If everything works, China has long-term ambitions to conduct a robotic Mars sample return, currently planned for launch in 2028. Even if the rover isn't successful, the orbiter alone stands to provide excellent science data. The sharp-eyed capability of the orbiter's High Resolution Camera is comparable to the sharpest eye in orbit today, the HiRISE camera on NASA's Mars Reconnaissance Orbiter (MRO).

As NASA's spacecraft is long past its design lifetime, a successful Chinese orbit insertion would provide backup for, and eventually replacement of, NASA's capability — provided we can use it. While the ESA has been strengthening its ties with China, NASA is not allowed to enter into bilateral agreements with the country. The restriction comes from the so-called Wolf Amendment to the U.S. bill that provides funding to the Departments of Commerce and Justice, Science, and Related Agencies. Under current law, NASA won't be able to turn to China to fill the gap if MRO bites the dust, at least not without FBI certification and Congressional notification. China has typically published all of its lunar data about a year after acquisition, so unless Congress acts, NASA researchers who want to use the Mars orbiter's observations may have to wait for the proprietary period to expire.

▼ **LANDING ON MARS** A topographical map of Mars shows the locations for past and future missions. (The UAE's Hope mission is an orbiter so does not appear here.) Successful past and current missions are shown in white; failed missions are shown in black.



MISSIONS AT MARS: GREGG DINDERMAN / *S&T*; MARS ILLUSTRATION: PE3K / SHUTTERSTOCK.COM; LANDING SITES: E. LAKDAWALLA; BASEMAP: MOLA SCIENCE TEAM / NASA GODDARD

United Arab Emirates' Hope

The United Arab Emirates is taking a different approach to its first Mars mission than China. China's all-in-one survey orbiter has a general mission to develop base maps and survey the Martian weather and space environment to further the country's exploration plans. In contrast, the Emirates Mars Mission, named Al-Amal or Hope, is tightly focused on answering a specific set of science questions.

The mission seeks to advance Mars climate and weather science beyond the current state of the art. By taking advantage of public data and international expertise from 50 years of Mars exploration, the team is jumping right into making scientific contributions to our understanding of the Red Planet's atmosphere.

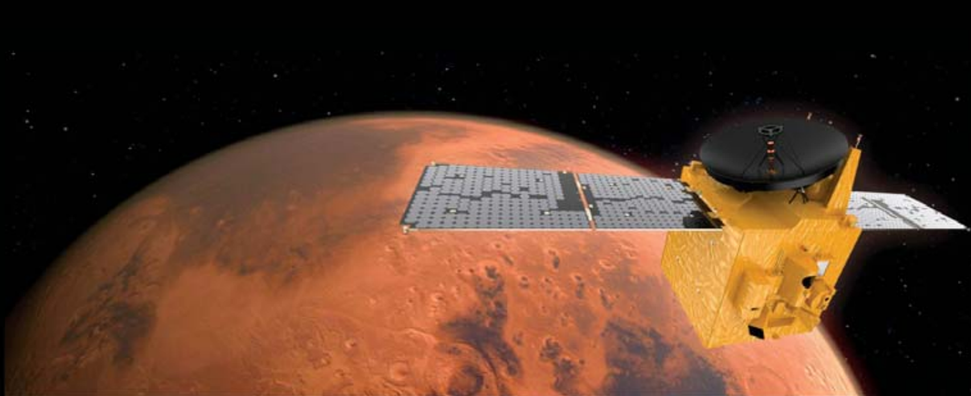
To accomplish that end, the 1,500-kilogram orbiter will carry three remote-sensing instruments — a multiband camera and infrared and ultraviolet spectrometers — to a wide, elliptical orbit (22,000 by 44,000 kilometers, or 14,000 by 27,000 miles) around Mars. This is far more distant than other orbiters; the closest it comes to Mars is just inside the orbit of the moon Deimos.

From this remote viewpoint, Mars will rotate more slowly under the orbiter, enabling the instruments to take long looks at the development and evolution of global weather patterns. The data should be highly complementary to closer-in, atmosphere-focused satellites like NASA's MAVEN and ESA's ExoMars Trace Gas Orbiter, providing valuable global context for their more detailed views.

The mission is part of a long-term national effort to shift the country from an oil-based economy to an expertise-based one.

For the United Arab Emirates, Hope has a second set of worldly goals that are equally as important as the scientific ones: The mission is part of a long-term national effort to take the country from an oil-based economy to an expertise-based one.

The UAE only established its space agency in 2014, and Hope is its first interplanetary spacecraft. The team is building it with help and training from experienced international partners, in the process developing a cohort of talented young Emirati engineers and scientists. The average age of its science team members is 27, and 80% of the science team is women. (While approximately 25% of American planetary scientists are women, on average they make up only 16% of NASA mission science teams.) With an overwhelmingly youthful population, the UAE hopes that its aptly named mission will inspire young people at home and elsewhere in the Middle East to envision a future of pride and achievement in science and technology.



◀ **ARABIC ORBITER** The United Arab Emirates' Hope mission will investigate the Red Planet's atmosphere and weather patterns from a farther-out orbit than other orbiters.

▼ **WORKING ON HOPE** Images of the orbiter in a cleanroom show testing proceeding as planned.

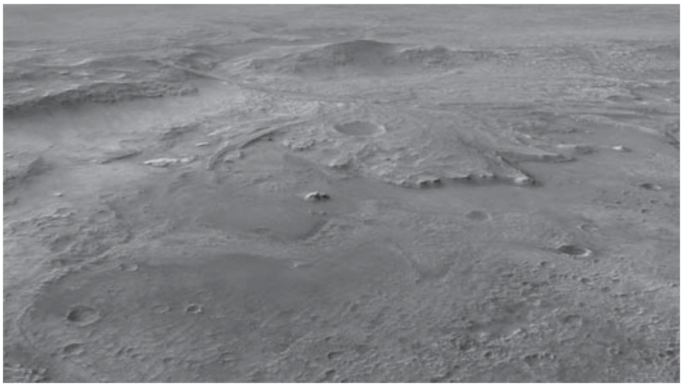
ARTIST'S CONCEPT AND ENGINEERS WORKING ON HOPE: MOHAMMAD BIN RASHID SPACE CENTER; HOPE PANELS UNFOLDED: SULTAN ALNEYADI / TWITTER

Mars & Earth: Fraternal Twins

NASA's Perseverance represents a dramatic shift in Mars exploration strategy, made possible by two decades of missions that include NASA's Mars Global Surveyor, Mars Odyssey, and Mars Reconnaissance Orbiter, and ESA's Mars Express. These missions have yielded the insight that Mars and Earth started out as very similar planets but diverged between 3½ and 4 billion years ago. Those insights were confirmed and expanded on by the rovers Spirit, Opportunity, and Curiosity, which ground-truthed the orbiters' data and found conclusive evidence for past watery and potentially life-supporting environments on Mars.

Before their divergence, both Earth and Mars were actively volcanic, possessed voluminous carbon dioxide–dominated atmospheres, and experienced a water cycle. But then Mars's magnetic dynamo shut down, removing its shield against solar radiation. The much smaller planet quickly lost most of its atmosphere (*S&T:* July 2018, p. 14). Indeed, MAVEN and ExoMars Trace Gas Orbiter are studying the still-ongoing loss of Martian air.

Volcanoes continued dumping noxious gases into the sky for a while longer, so the last stages of Mars's watery history featured rare, acidic rainfall on cold deserts. At present, the surface environment is powerfully oxidizing and unshielded from solar radiation — challenging conditions for life to thrive in. Any life on Mars must be sheltered, perhaps underground (*S&T:* Jan. 2020, p. 34), from this harsh environment. Nevertheless, life originated on Earth sometime before 3½ billion years ago. Since Mars had similar conditions at similar times, shouldn't life have begun there as well?



▲ **AIMING FOR JEZERO** The rim of the 45-km-wide Jezero Crater passes across the top of this image, just visible in this perspective view. Breaking through the rim is an ancient river delta. Perseverance will aim for the flat crater floor to the east of the delta, in the foreground of the image. Amateur imager Seán Doran created this perspective view by combining imaging data from the Mars Reconnaissance Orbiter with a digital terrain model.

Unfortunately, that era of Earth's history is nearly inaccessible because rocks of such great age are rare. The few that exist have been dramatically transformed through billions of years of plate tectonics, weathering, and erosion.

But the arid surface of Mars is far better preserved than Earth's. As rovers traverse Martian sites containing ancient rocks that formed in wet environments, scientists plan not only to search for evidence of past life on Mars, but also to learn more about the conditions that existed back when life began on Earth.

▼ **SEARCH FOR LIFE** *Left:* In this artist's rendition, NASA's Perseverance studies a Mars rock outcrop. At the end of the robotic arm, a Raman spectrometer named SHERLOC will look for carbon-containing compounds. *Right:* The Mars Helicopter will accompany Perseverance to Jezero Crater. Although the craft is primarily a technology demonstration, it does carry cameras and can photograph future traverse areas during its brief flights.

Similar Rovers, Divergent Approaches

Perseverance looks a lot like its predecessor, Curiosity. But its instruments are new, and its mission has different goals. Curiosity was, literally, a Mars Science Laboratory, performing sensitive analyses on rock samples within its belly while on the Martian surface. By contrast, Perseverance has no such interior lab. Instead, it will obtain and document samples for future return to Earth for deeper analysis.

Perseverance will be the heaviest rover ever to land on Mars: At 1,050 kilograms, it's 17% heavier than Curiosity. Much of that weight is in instruments. Compared with Curiosity, Perseverance has upgraded science cameras (now with zoom capability!) and weather sensors. Its arm-mounted Planetary Instrument for X-ray Lithochemistry (PIXL) improves on Curiosity's element-sensing Alpha Particle X-Ray Spectrometer. The wide-field-of-view engineering cameras Perseverance will use for navigating its environment are dramatically better than Curiosity's. And its ground-penetrating Radar Imager for Mars's Subsurface Experiment (RIMFAX) is a dramatic upgrade of underground imaging technology.

Of all of the new instruments, perhaps the most exciting are the two Raman spectrometers: one in the rover's mast-mounted SuperCam and one mounted at the end of the robotic arm called the Scanning Habitable Environments with Raman and Luminescence for Organics and Chemicals (SHERLOC). Raman spectrometers allow sensitive detection of carbon-containing compounds — including ones of biological interest. SuperCam, which also encompasses an upgraded version of Curiosity's ChemCam rock-zapping laser, will help the Perseverance team determine which rocks might be biologically interesting from a distance. SHERLOC will obtain close-up, high-resolution images of rock targets using a copy of the Curiosity Mars Hand Lens Imager.

For this mission to be successful, it's not only the landing that must go well. Perseverance will stress the aging network of NASA's data-relay orbiters. Curiosity already routinely uses ESA's ExoMars Trace Gas Orbiter for communications. This takes a little pressure off of Mars Odyssey and Mars Reconnaissance Orbiter, and it also provides ESA with valuable experience in data relay for their future ExoMars lander. Relief in the form of a new NASA orbiter that's capable of providing communications relay for landed missions will not arrive at Mars until at least 2027.

NASA's Perseverance represents a dramatic shift in Mars exploration strategy.

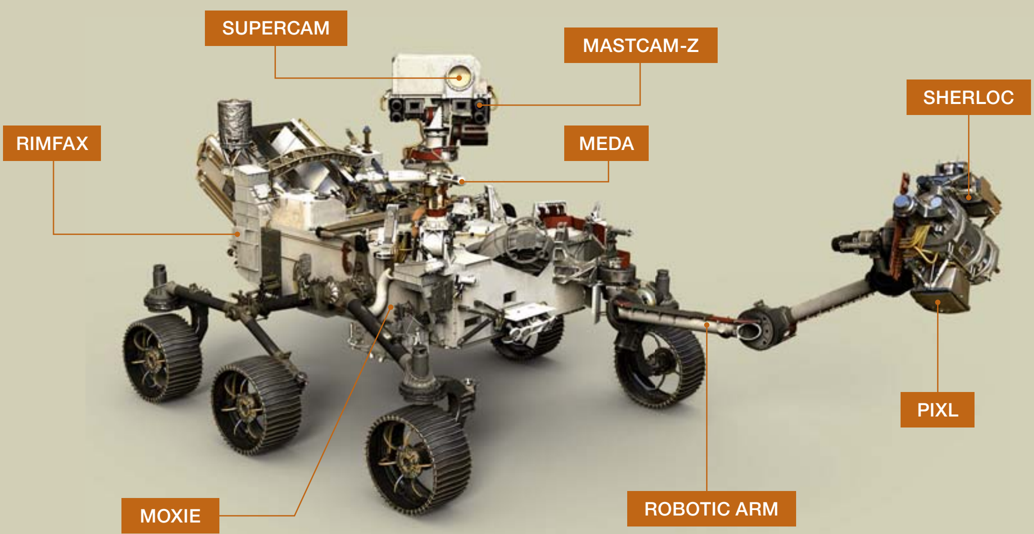
Perseverance: Sample Grabber

Perseverance will land in nearly the same way that Curiosity did. On February 18, 2021, during local afternoon, it will enter the atmosphere and begin its "7 minutes of terror." A heat shield will slow its descent, then a parachute will slow it further. Finally, it will lower itself gently to the surface on cables attached to a rocket-powered jetpack, cutting the cables after touchdown to allow the jetpack to fly away and land at a safe distance.

Engineers have upgraded the landing technology with terrain-relative navigation: The spacecraft has extra cameras and onboard processing capability to figure out where hazardous spots like big rocks and sand traps lie within the landing ellipse, and it can steer around them to land on a safe spot.

By 2021, we may have three simultaneously operating weather stations on Mars: Curiosity, Insight, and Perseverance all carry meteorological experiments. Perseverance also has an instrument that will test ways to generate oxygen from Mars's thin carbon dioxide atmosphere.

NASA / JPL-CALTECH



▶ A LOAD TO CARRY Perseverance will carry 23 cameras, including seven specifically for scientific purposes, and a sample-caching system, which will package and lay aside samples for a later mission to pick up and carry home. It also carries five instruments designed to explore the history of water and chemistry in the ancient lake basin.

ExoMars: A Mission Delayed

▲ **ROVER GROUNDED** A reduced-scale model of Franklin roves a Mars-like terrain in preparation for the second leg of the ExoMars mission, now set for launch in 2022.

Another mission was originally intended for the 2020 flight window: ExoMars, a joint mission between the European Space Agency and the Roscosmos agency in Russia, would have put the Rosalind Franklin rover on the Red Planet's surface in 2021 as well. However, parachute problems put the mission behind schedule, causing the team to delay to a 2022 launch.

Like Perseverance, the Rosalind Franklin will be on the lookout for life, but it will take a different tack to the search for biosignatures. Rather than caching samples for future study, Franklin will drill as deep as two meters into Mars, retrieving samples to analyze in the lab within its belly. It will study each sample using infrared and Raman spectrometers, before using lasers to zap it into gases for analysis with an organic-sniffing gas chromatograph mass spectrometer.

Team scientists hope that the rover's deep drill will provide access to rocks that have been shielded from the oxidizing atmosphere and space radiation. If Mars has life in the form of microbes living beneath the surface, there is a faint but nonzero possibility that ExoMars could discover it immediately, without the need for future missions to recover and return samples.

ESA's Rosalind Franklin rover is much smaller than Perseverance, comparable to the size of NASA's earlier rovers Spirit and Opportunity. Unlike NASA's rovers, though, Rosalind Franklin will not bounce to a safe landing inside airbags. Rather, it will ride down to the surface atop a Russian-built lander.

Once it rolls off the lander, Rosalind Franklin will visit Oxia Planum, a flat plain along the eastern edge of Chryse Planitia. There is abundant evidence that rivers once flowed across this landscape toward a northern sea. The rocks are slightly older than those at Jezero and contain minerals that formed in liquid water, but what kind of water? The rocks may well have been inundated by the salty waters of the northern ocean, a different environment than Jezero's closed lake basin.

Rosalind Franklin will be in a hurry: Its nominal mission lasts only a third of a Martian year. Over a traverse path of 1.5 km, the team hopes to drill as many as six holes. The scientists plan to drill to more than one depth at each place to compare the condition of near-surface rocks to those underground.

After landing, Perseverance will find itself inside a crater named Jezero. At Jezero, the mission's goal will be "to explore the history of water and chemistry in an ancient crater lake basin and associated river-delta environments to probe early Martian climates and search for life." In particular, the team hopes to sample rocks that contain *biosignatures*, evidence for the existence of ancient life (see next page).

Jezero Crater, which is 45 kilometers in diameter, once held a lake that could have been as deep as 250 meters (820 feet). When the lake was full of water, two river systems emptied into it, depositing a thickly layered, spread-fingered river delta. The crater, delta, river, and river source regions have all been mapped by dozens of planetary geologists poring over every data set that every Mars orbiter has to offer. These regions contain a wide variety of rocks that geologists would dearly love to sample.

A detailed plan for Perseverance's scientific traverse has already been hashed out. The rover will land on a flat section of the crater floor to the east of the delta, possibly atop some volcanic rocks that filled the crater after the lake dried up. A lava rock sample, if returned to Earth, could be radiometrically dated to pin down when in Mars's history the water activity ended.

Before drilling their first sample, though, team members will execute a number of shakedown activities, which should include the flight of the first-ever Martian helicopter. The helicopter is an experimental technology that doesn't need to work for the overall mission to be considered successful. But it could, like the Pathfinder's Sojourner rover did back in 1997, pave the way for future exploration. The helicopter might provide the most dramatic moments (after landing) of the early phases of the new Mars mission.

The minicopter weighs only 1.8 kg and has twin counter-rotating carbon-fiber blades that span 1.2 m. It will drop off the bottom of the rover, then wait until the rover has driven a safe distance away before it begins to operate, popping up in brief flights as long as 1½ minutes. Each flight will take its cameras high enough to photograph potential traverse areas, then it will land and recharge for another go a few days later. It's designed to fly up to 5 times, but one bad landing could end its mission more quickly.

Once the rover acquires its first sample, the team will drive to some rocks in the delta area. Geologists understand deltas very well. Consequently, they know exactly how they want to traverse Jezero's delta for samples. They've zeroed in on locations that will answer questions about Mars's history while also maximizing the opportunity to sample rocks that preserve biosignatures.

The team plans to sample at the base and surface of the delta, at the ancient lake shoreline (there may be several such shorelines), and up on the crater rim. If all goes to plan, the rover will reach the rim by the end of the nomi-

ALTEC

▼ WHAT ARE BIOSIGNATURES?
The hunt for ancient life on Mars involves the search for *biosignatures*, or signs of life. Perseverance will conduct this search on the ground as well as cache samples for later return to earthbound labs.

Organics: All life on Earth is made of carbon-containing compounds, but they form in the absence of life, too. Perseverance will be able to tell if organics are present, but not which ones.

Isotopes: Atoms of an element always contain the same number of protons but can have differing numbers of neutrons. Certain biological processes prefer one isotope over another, but only labs on Earth can measure their abundance.

Minerals: Some minerals on Earth are uniquely associated with life. Perseverance can find these minerals, but only if they're abundant. Samples could yield better results on Earth.

Chemicals: Metabolic processes often have a chemical signature, and the rover can make rough detections of such chemical changes. Labs on Earth could do better but returned samples will be smaller and less numerous than what the rover can explore in situ.

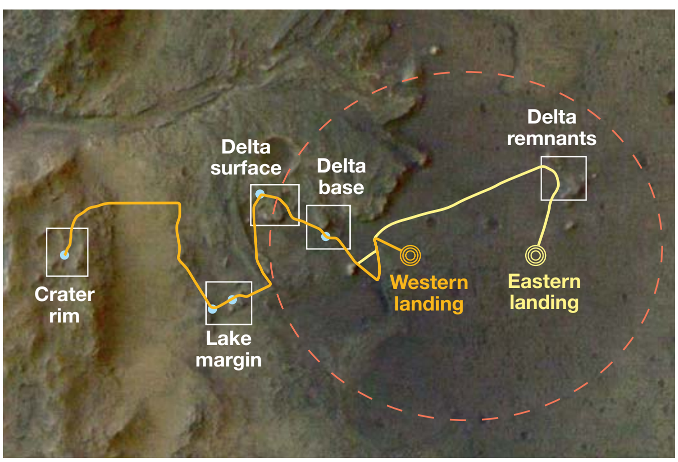
Small-scale structures: Perseverance will be able to detect ancient cellular life in the form of fossils, molds, or casts. When samples are returned to Earth, labs will offer better resolution.

Large-scale structures: Microbial life on Earth built mats, stromatolites, reefs, and other large structures. NASA's rover will be able to see these structures if they're on the surface.

nal mission, one Mars year (687 Earth days) after landing. The goal is to collect and cache at least 20 distinct samples within that time.

If the rover is still in good shape and continues beyond the nominal mission, the team could drive on to study the surrounding bedrock, which supplied the sediment that built the delta. The rover has the ability to store up as many as 23 additional samples during that exploit.

▼ MISSION SCENARIOS The Perseverance rover will land in Jezero Crater on February 18, 2021 (landing ellipse in red). This map, made in 2018, shows some possible drive paths for the rover, depending on whether it lands in the eastern side of the ellipse (yellow) or western side (orange). While the actual path may end up differing significantly, the exercise helped the science team understand what a successful primary mission for the rover might look like.



BIOSIGNATURE: EMILY LAKDAWALLA / T. DUBÉ; HEXAGONS: FIREOFHEART / SHUTTERSTOCK.COM; FUTURE PATHS: PATHS: SANJEEV GUPTA AND BRIONY HORGAN; BASEMAP: ESA / DLR / FU BERLIN / EMILY LAKDAWALLA

What's Next?

NASA and ESA recently have begun negotiating the scope of each agency's involvement in the collaboration that will retrieve the rock samples. Perseverance will drop them in caches along its path, carefully selecting and documenting their locations to make them straightforward to locate again.

The current plan is for two follow-up missions to launch in 2026. An Earth-return orbiter, arriving in 2027, would act as a communications relay. Then in 2028, a separate sample-retrieval mission would bring a lander and rover to the surface. The rover (possibly with Perseverance's help) would fetch and deliver the samples to the lander. The lander would in turn load up the Mars ascent vehicle, which would then carry the samples to orbit in 2029. The Earth-return orbiter would retrieve the sample capsule, sending it on its way to Earth by 2031.

With human exploration on the horizon, caching Mars rock samples in hermetically sealed containers is crucially important. When humans finally arrive, they will carry with them a large bio-burden of microbes, with much more potential to contaminate Mars than previous robotic landers have had. If we discover life on Mars, it'll be important to have confidence that it isn't an Earthly contaminant but really is a Mars native. The cached samples, whenever they get picked up, will help.

■ **EMILY LAKDAWALLA** is a planetary scientist and solar system specialist for The Planetary Society. Her first book, *The Design and Engineering of Curiosity: How the Mars Rover Performs Its Job*, was published in March 2018.

 by Ken Hewitt-White

A quarter of a century after its discovery, this big, bright comet remains vivid in memory.

I'll never forget the night of August 19, 1995, when I first saw Comet Hale-Bopp. The wee wisp that would become one of the most impressive celestial sights in living memory had been caught independently a month earlier by Alan Hale and Thomas Bopp. I wanted to be the first on my astronomical block to see it.

Netting Hale-Bopp would be no easy task, since it was still only a 10th-magnitude fuzz ball languishing at the bottom of the Sagittarius Teapot. Because my rural British Columbia home was barely north of the 49th parallel, I knew I'd have to aim my 17.5-inch Dobsonian low in the south, where the comet was bound to be ensnared in the branches of a nearby Ponderosa pine. I selected a wide-field eyepiece. It took a few minutes to identify the globular cluster M69 and, 2½° to the northwest, the dim globular NGC 6624. Halfway between them, just where Hale-Bopp should be, I beheld an out-of-focus tree trunk. I waited — my eye glued to the eyepiece. Long moments later, a tiny nebulosity emerged in the space between two boughs. "Gotcha!" I cried aloud.

One Month Earlier . . .

The Teapot rides higher over the southern United States. On the Saturday night of July 22–23, 1995, Alan Hale was working with his 16-inch reflector at home in Cloudcroft, New Mexico. An experienced comet observer, Hale had viewed 71P/Clark earlier that evening and was waiting for Comet d'Arrest to rise. To pass the time, he trained his scope on the Sagittarius globular cluster M70 and spotted a small,

A Discoverer's Perspective

It was a beautifully clear July evening in 1995. I was listening to a couple of songs from the band R.E.M. (including "Man on the Moon") as I prepared to head outside for some routine comet observing. I had no way of knowing that less than an hour later I would be stepping into the pages of history. The discovery I made that night (at the same time as Thomas Bopp) would eventually become one of the 20th century's Great Comets and end up being viewed by more people than any other comet in history.

To say the comet changed my life would be a vast understatement. Three years earlier I had successfully completed my doctoral degree with a thesis on exoplanets, but an extremely tight job market together with the responsibilities of raising two young sons made prospects for secure long-term employment problematical. Indeed, I was facing the very real possibility of having to abandon my lifelong desire for a career in astronomy.

But all that changed during that single fateful hour. For the next few years, I was quite the celebrity both within scientific circles and in the wider world. I gave numerous interviews and talks, often in the company of Thomas Bopp. On one particularly memorable evening, my family and I had a private comet-viewing session at the U.S. Naval Observatory in Washington, DC, with Vice President Al Gore and his wife, Tipper. At a conference I had the opportunity to meet Richard West, discoverer in 1976 of the eponymous comet. We engaged in a playful "argument" over who had the best comet — each of us taking the position that the other's comet was better.

I also enjoyed a professional career, of sorts, thanks to the discovery. For a few years I maintained an active program for tracking comets and near-Earth asteroids. Some of my astrometric measurements of Comet 81P/Wild 2

WEI-HAO WANG

GREATNESS IN THE SKY Comet Hale-Bopp impressed skywatchers the world over when it was at its brightest in the spring of 1997. It was discovered 25 years ago on the night of July 22–23, by Alan Hale and Thomas Bopp. Neither observer imagined that the faint object they spotted in their scopes would eventually become a rare Great Comet.

Celebrating Hale-Bopp

▲ **HALE-BOPP BY HALE** This image of the Great Comet of 1997 was taken by Alan Hale on April 1, 1997. Hale photographed the comet from his home near Cloudcroft, New Mexico, where he became the first human to see the object on July 23, 1995.

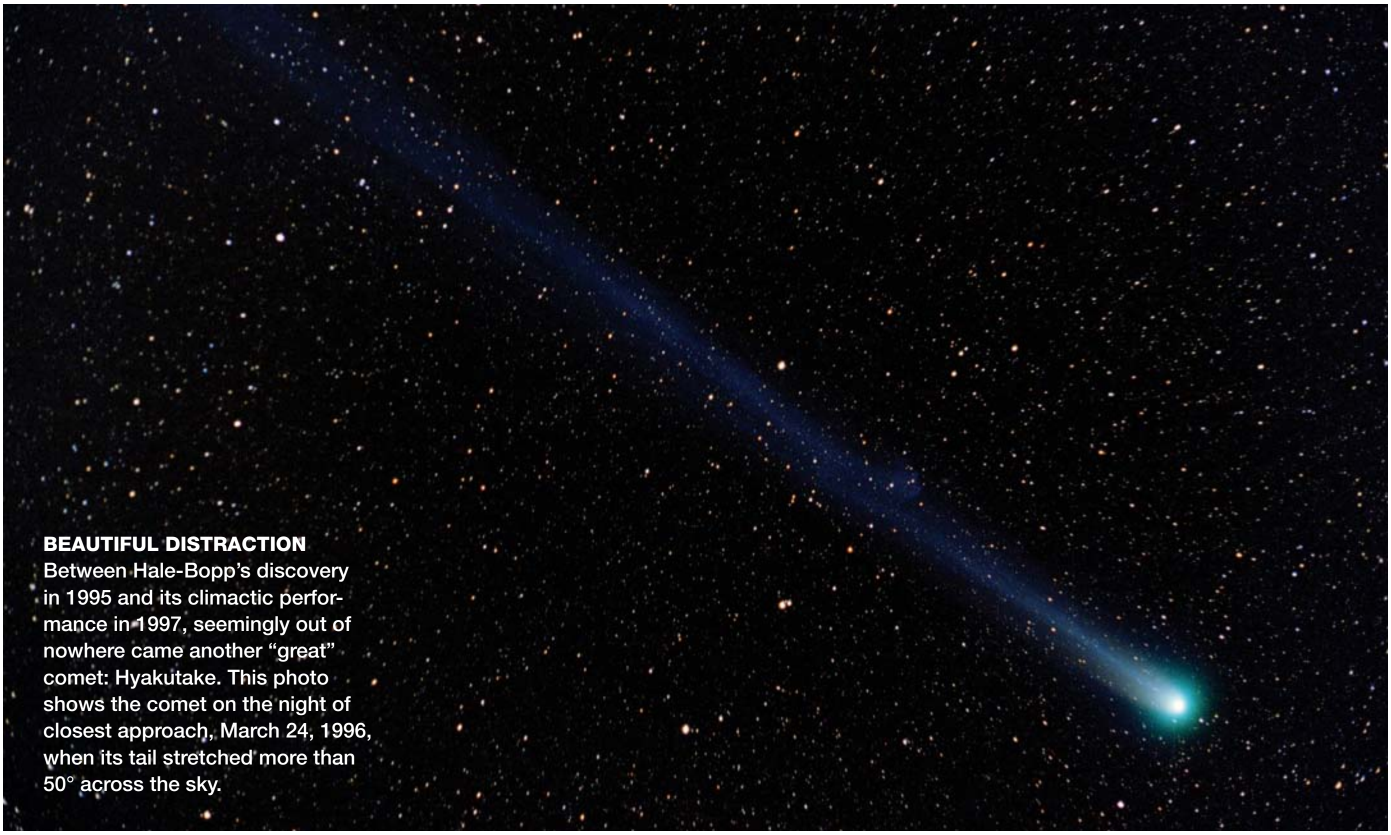
proved crucial in navigating the Stardust mission to its successful encounter with that object in 2004. I also became active within the commercial space community and taught online university classes for several years.

I am grateful that the discovery gave me the opportunity to accomplish some things beyond science. In 1999 I had the privilege of leading a delegation of Americans on a "science diplomacy" trip to Iran to view the total solar eclipse that year, with a follow-on visit the next year. I still remain in touch with friends I made in Iran during those visits. Inspired by these experiences, I developed a project called Earthrise. Its mission is to use astronomy and space as a tool for building bridges between nations and cultures. In 2009 I was officially recognized by the U.S. Congressional Medal of Honor Society for these efforts.

My current project, Ice and Stone 2020, is an online program available for teachers and students worldwide keying on the fact that this year marks not only the 25th anniversary of the discovery of Hale-Bopp but also the 50th anniversary of my first comet observations.

I continue to observe comets with the same telescope I used to discover Hale-Bopp all those years ago, and via remote imaging with the Las Cumbres Observatory. As of this writing, I've tallied 674 comets! Perhaps there will come a time when I stop doing all this, but that time has not yet come. I hope I have at least one more Great Comet to enjoy before all is said and done.

–Alan Hale



BEAUTIFUL DISTRACTION Between Hale-Bopp's discovery in 1995 and its climactic performance in 1997, seemingly out of nowhere came another "great" comet: Hyakutake. This photo shows the comet on the night of closest approach, March 24, 1996, when its tail stretched more than 50° across the sky.

▲ **HALE-BOPP IN CYGNUS** *(Left)* Taiwanese astrophotographer Wei-Hao Wang captured this view of the comet on March 10, 1997, as it made its way through the Milky Way in northern Cygnus. **A COMET OF TWO TAILS** *(Right)* Like many comets, Hale-Bopp sported two distinct tails — a broad, amorphous dust tail and a narrow, blue-tinted ion tail, as presented in this photograph taken by Bill Roberts on April 4, 1997.

GARY SERONIK

10.5-magnitude blur roughly 15′ eastward. By the onset of twilight, Hale had detected the telltale motion of what was surely a comet. The burning question was: Had he snagged it before anyone else?

The answer was yes, but just barely. At virtually the same moment as Hale, Thomas Bopp was also eyeing M70 at an informal star party in the Arizona desert, some 90 miles south of Phoenix. Bopp was using a friend's 17.5-inch Dobsonian reflector telescope when he noticed a faint, fuzzy interloper slowly chasing M70 through the field of view. Bopp had never observed a comet before, but after checking his star charts and then detecting motion in the object, he realized he was onto something.

Meanwhile, Alan Hale had emailed the world clearing-house for comet discoveries, the Central Bureau for Astronomical Telegrams (CBAT). Tom Bopp returned home as quickly as possible and also dispatched a telegram to CBAT. The next morning, CBAT supplied the amazing news both men wanted to hear — they'd won the cometary lottery. On July 23rd, IAU *Circular* 6187 alerted the world to a new comet designated C/1995 O1. But that was all. No fanfare — C/1995 O1 was just like many similarly faint comets discovered each year. The hyphenated moniker "Hale-Bopp" was added a few days later. And that was that.

Then the data starting coming in. The newfound object was 7.2 astronomical units (a.u.) from the Sun, well beyond the orbit of Jupiter, making it unusually bright for such a great distance. Indeed, it was the most remote comet ever found with amateur telescopes. Perhaps not surprisingly, then, measurements indicated the ghostly glow could develop into a Great Comet. Alan Hale and Tom Bopp had won a bigger prize than they'd initially realized. Precisely how big, though, no one knew for certain.

Duds from Space

I was somewhat skeptical about the "Great" part of the description. Hale-Bopp wouldn't reach perihelion until April 1, 1997, leaving lots of time for it to fizzle into insignificance, as many comets do. Borrowing a line from Shakespeare's *Hamlet* about an unlikely ghost, my pessimistic mantra was: "Tush, tush, 'twill not appear."

My outlook had been tainted by the Curse of Kohoutek, a dull play that folded on opening night. Comet Kohoutek was discovered by Czech astronomer Luboš Kohoutek on March 7, 1973, and — subsequently heralded the "Comet of the Century" — was expected to dominate the northern sky at the end of the year. As a young show presenter at the H. R. MacMillan Planetarium in Vancouver, British Columbia, I was thrilled when the director asked me to staff a "comet desk" to field inquiries from the public and media. Unfortunately, the fab phenom failed to live up to its advance billing, and the overhyped Comet of the Century decayed into the dud of the decade. Although astronomers considered Kohoutek a moderately impressive specimen (4th-magnitude, nice tail), I couldn't see it through all the egg on my face.

▲ **B&W BEAUTY** This photo emphasizes Hale-Bopp's brilliant coma and the intricate, braided structure of its delicate ion tail. Dennis di Cicco recorded this view with an f/1.5 Celestron Schmidt camera on March 27, 1997.

Frustrated to the max, I formulated Ken's Comet Law: Early-discovery comets are potential time bombs of disappointment. After Kohoutek, my "law" was bolstered by other icy visitors, Halley's Comet chief among them. No amount of caution from planetarium staff could prevent the most famous comet in history from becoming a massive public downer. In 1990, Comet Austin was another fiasco that made my planetarium life miserable. And, post-2000, who can forget the utterly forgettable Comet ISON (C/2012 S1)? Magazines of every stripe hyped it to the hilt. "ISON blazes into glory" screamed one headline. "All eyes are on ISON for a show 4 billion years in the making" made me cringe. Naturally, ISON was DOA.

Some Showstoppers

Despite the frequent disappointments, the cometary brigade wasn't completely without big, bold exceptions. Over the past half century, Northern Hemisphere observers of a certain age (including yours truly) have been fortunate enough to marvel at four truly newsworthy comets. Curiously, all four reached their peak during spring.

Comet Bennett zoomed northward in March 1970 to rise tail-first in the predawn sky, its nucleus outshining Deneb. Bennett became a feathery, circumpolar exclamation mark for several weeks. In March 1976, Comet West, another tail-first morning riser, was even brighter and sported a broad, curving

A Comet for City Dwellers

When I was a young boy and first started exploring the night sky, the word "comet" was synonymous with "disappointment." Like so many others, I eagerly anticipated the December 1973 appearance of Comet Kohoutek, and the much-hyped 1986 return of the best known of them all, Halley's Comet. Thankfully, the whole comet situation eventually improved in spectacular fashion.

I got my first look at Hale-Bopp on a chilly night in August 1995 while attending the annual Mount Kobau Star Party. This was only one month after Alan Hale and Thomas Bopp had made their discovery. When I spotted the comet that night on Kobau, it had shifted only 4° from where Hale and Bopp had initially sighted it.

Here's what I wrote in my observing notebook for August 24th: "One possibly noteworthy sight was Comet Hale-Bopp, low in the south in Sagittarius, near Delta Sagittarii and the globular cluster NGC 6624. The comet was small and indistinct in my 8-inch." Even now I chuckle when I read that "possibly noteworthy" remark.

Fast forward to 1997. It's February 22nd and I'm up at 5 a.m. hoping to glimpse the rapidly brightening Hale-Bopp from my downtown Vancouver apartment. The odds aren't great. The comet is low in the northeast, and a full Moon is making the city sky glow even brighter. Plus, I'm in my living room. Luckily, it has a window facing the right direction. I opened the curtain and looked out. To my utter astonishment, there was the comet! It seemed only a touch fainter than nearby Deneb in Cygnus. I excitedly set up my 3.5-inch Questar telescope on the windowsill to have a better look. The view was amazing — when I examined the bright head of the comet, I saw what looked like a fountain of material emanating from the nucleus itself. I'd never seen a feature like that before — and to think I was doing so from the living room of a downtown apartment. Who would have dreamed such a thing possible?

That morning was the first of many dawn encounters with Hale-Bopp. Paying a visit to the comet simply became part of my morning routine. In my journal for March 10th, I pondered the future. "Will this be the best comet of my life? As I write this at 6 a.m., I can still see the comet against a blue predawn sky. Amazing." That same day, I was able to see it again12 hours later in the evening sky. And though the views of Hale-Bopp I got from a dark-sky site a few weeks later were unquestionably much more spectacular, it's those early morning apartment visits that I recall most fondly. It was enough for me to finally forgive Halley and Kohoutek.

–Gary Seronik

fan of dust. We knew of its arrival months in advance, yet West was largely ignored by the media, a victim of indifference so soon after the Kohoutek debacle. Twenty empty years elapsed before Comet Hyakutake barreled in on less than two months' notice. An astral ghost train of incredible length, it roared silently overhead in March 1996. Then, the following spring Hale-Bopp provided a breathtaking encore.

▲ **THE BIG ONE** Comet Hale-Bopp proved to be one of the most spectacular comets of the 20th century, in no small part because of its unusually large nucleus, estimated to be as large as 40 kilometers in diameter.

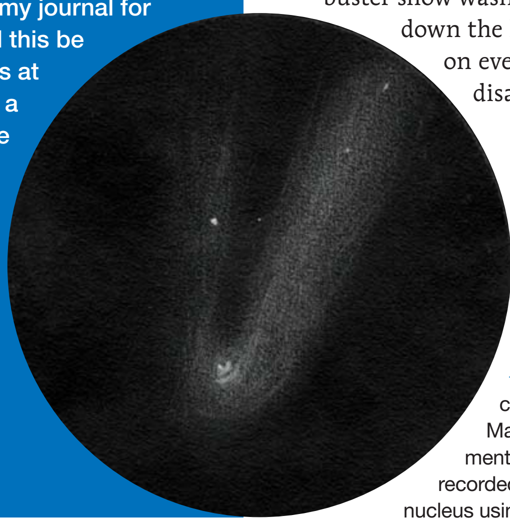
A decade later, in January 2007, Comet McNaught (C/2006 P1) blossomed into a brilliant wonder — over the Southern Hemisphere. It showed only briefly in the north. McNaught aside, though, it was Hale-Bopp that made the biggest impact between 1970 and 2020.

Prime-Time Perfect

Right from the start, Hale-Bopp was unusual. Sporting an absolute magnitude of –1, it was intrinsically the brightest comet to pass inside Earth's orbit since the 16th century. Early scrutiny by the Hubble Space Telescope indicated a nucleus 10 to 40 km in diameter, and a report in this magazine by Edwin L. Aguirre (*S&T:* Nov. 1995, p. 21) stated that throughout the weeks following discovery Hale-Bopp's "nuclear region underwent fluctuations almost every night." The activity continued, unabated, right up to perihelion.

Although the comet's telescopic appearance hadn't improved much prior to its disappearance behind the Sun in December 1995, it was recovered unexpectedly early on February 1, 1996, at which point its brightness had improved to magnitude 8.8 — better than anticipated. Throughout the summer and fall of 1996, the comet grew steadily, albeit rather slowly. Veteran comet watchers cautioned that a blockbuster show wasn't guaranteed. As Hale-Bopp headed down the homestretch in early 1997, the question on everyone's mind was, will we be dazzled or disappointed?

We needn't have worried. Even though Hale-Bopp came no nearer to Earth than 1.3 a.u. (ten times the distance of Hyakutake), it benefited from impressive physical properties (bigger and more dust-rich than Hyakutake) plus a delightful confluence of timing and



◀ **DAWN VISITOR** Gary Seronik made this pencil sketch of Comet Hale-Bopp on the morning of March 14, 1997, from the window of his apartment in downtown Vancouver, British Columbia. He recorded the "shells" surrounding the comet's pseudonucleus using his 3.5-inch Questar telescope.

SEAN WALKER

placement. The vernal equinox (March 20th), the comet's closest approach (March 22nd), its maximum elongation (approximately 45°), and farthest northern declination (nearly 46°) all occurred within a few days of one another. Stargazers at mid-northern latitudes were treated to a circumpolar spectacle for several weeks — a situation reminiscent of Comet Bennett nearly three decades earlier. Moreover, during this period the comet shifted from being primarily a morning object to an evening one just as the Moon did the reverse. On the evening of the full Moon (March 23rd), with Hale-Bopp peaking, North Americans were awarded a 92% partial lunar eclipse. The lucky observers (me included) who lived in the Pacific time zone were delighted to have the blackout occur at the optimum hour for viewing the comet.

All these factors ensured that the Big Show played to packed houses for its advertised run. By the end of its record-breaking apparition, Hale-Bopp had surpassed magnitude 0 for two months. It remained a naked-eye object for more than 18 months, until late 1997, by which time it had descended far into the southern sky, where it remains to this day.

Comet Tales

I have so many fond memories of Hale-Bopp: glimpsing it naked eye as I counted Perseid meteors in August 1996; a predawn peek from a jetliner near the end of a redeye flight in January 1997; and, amid weeks of rain and snow, catching the comet between scudding clouds on the evening of the spring equinox through the window of a busy restaurant!

Three nights after the restaurant sighting my wife and I watched the lunar eclipse and Hale-Bopp perform a heavenly pas de deux. What a unique and awesome performance! A copper-colored disc hovered above our stand of Ponderosa pines in the south while the two diaphanous tails of the comet skirted the Milky Way in the north.

At nightfall on April 4th a cold wind of increasing power drove us indoors. We turned off every light in the house and gazed through our north-facing living room window as Hale-Bopp, a silver siren set against a black backdrop of Andromeda stars, descended ever-so-gently behind moonlit firs. We felt like we had box seats to the evening's cometary curtain call.

As twilight ebbed on April 10th, Hale-Bopp lit up the stage with a terrific supporting cast. The comet's gossamer dust tail, fanning across Perseus, had ensnared the Demon Star, Algol. The V-shaped Hyades cluster had captured a four-day-old Moon, and the lunar crescent was creeping toward Aldebaran. Taking to our telescopes around 9:30 p.m., we saw Aldebaran wink out behind the earthlit lunar limb. Then we turned to the comet. In my big Dob the nucleus was a headlight of magnitude –1 cocooned in aqua-tinged hoods. From this flowed the tenuous tails: one a curving fan of dust; the other an ion streak. And thanks to some ethereal lighting, the scene got even better. An aurora swelled over the north horizon, grew stunningly luminescent, and sprouted green rays near the comet. A rolling ribbon materialized out of thin air, mingled with the comet's tails, and dissolved back into space. Sublime.

Gone, But Not Forgotten

The Great Comet of 1997 lives on in the memories of all who saw it. For its two discoverers, July 23, 1995, was a date to cherish. To this day, Alan Hale remains grateful for the way in which the comet helped advance his career in space science (see sidebar, page 30). Tom Bopp, who worked in the construction industry, once remarked that his life became a lot more interesting post-discovery. Unfortunately, Tom passed away in 2018, at the age of 68.

The comet bearing the names Hale and Bopp will outlast us all. Back in 1997, Richard M. West (of Comet West fame) looked ahead to the present day: "Just over two decades from now, in 2020, [Comet Hale-Bopp] will be 43 a.u. from the Sun and, assuming a diameter of approximately 20 km, the apparent magnitude of the nucleus will be around 29 to 30."

The hibernating Hale-Bopp is in it for the long haul. About 12 centuries will pass before the distant inert iceberg reaches aphelion some 370 a.u. from the Sun; 12 additional centuries will elapse before it returns.

In the end, Comet Hale-Bopp made a stronger impression on the lay public than any other recent comet and was likely the most widely viewed comet in human history.

All the top-tier comets I described earlier came and went in less than three decades. Alas, there hasn't been a celestial blockbuster since 1997. A quarter century has elapsed between Hale-Bopp's discovery and the present day, yet on average there should be a crowd-pleasing comet for Northern Hemisphere skywatchers once every 10 to 20 years.

Time's up!

■ Contributing Editor **KEN HEWITT-WHITE** has observed more than 200 comets between 1967 and 2020.

KEN HEWITT-WHITE

▶ **INDOOR COMET** The author and his wife, Lynda, enjoyed a stunning view of Hale-Bopp from their darkened living room on April 4, 1997. The photo was shot near the end of astronomical twilight as the brilliant comet descended in the north-northwestern sky.

Comets are perhaps the oddest denizens of the solar system. Most appear with little warning, put on a modest show, then race back to the Oort Cloud, not to be seen again for many, many years (see page 30). Part of their allure is that each is unique and doesn't always follow predictions about its brightness and activity. Some, like 17P/Holmes, defy conventional wisdom and unexpectedly attain naked-eye visibility even when located relatively far from the Sun. Others fail to live up to their advance billing, with some inevitably disintegrating as they near our star.

◀ **WHIZZING BY** Recording many short exposures and stacking the results registered on the comet's nucleus produces a sharp image of PanSTARRS (C/2015 ER61) against a field of trailed stars. In this case, the author recorded exposures through individual LRGB filters, resulting in colored star trails.

All this uncertainty is part of the challenge that has kept me actively photographing comets for more than 30 years.

Dirty Iceballs

These dusty chunks of ice and gravel are leftover material from the formation of our solar system. When a comet passes close to the Sun, the comet's surface can warm enough to sublimate its frozen gases, producing an expansive atmosphere known as the *coma*. Brighter comets typically develop a tail or sometimes two. One tail, comprising gases that stream away from the direction of the Sun, is called the *ion tail*. Such tails usually appear bluish and can display fast-moving knots that change appearance over short timespans.

The other tail commonly seen in comets is made of small dust grains and gravel-sized particles that trail behind the comet along its orbital path and are slowly pushed away from the Sun by solar radiation. These *dust tails* are generally colorless and often appear featureless, though some contain visible striations.

On rare occasions a comet may develop an *antitail* that appears as a spike projecting sunward from its coma. This feature is an optical illusion resulting from our Earth-based perspective. The antitail consists of dust grains trailing behind the comet along its orbital path.

Different Comets, Different Approaches

Photographing most comets is more challenging than either deep-sky or planetary imaging. Although comets are solar system objects, they can't be imaged the same way as, say, Jupiter or Mars. A comet's nucleus as seen from Earth is never large enough to be resolved as anything more than a point source. Indeed, comets rarely (if ever) display sub-

CATCH a Moving Comet

Photographing these icy visitors often requires a special approach.

PASSING BY Comets are fast-moving targets that often present unique photographic opportunities. This image of 21P/Giacobini-Zinner as it passed the Rosette Nebula was assembled using the technique described in the article.

arcsecond details in their inner-coma, so you don't need to shoot them with long focal-length optics as you would a planet. Instead, comet photographers typically use deep-sky techniques such as long exposures, stacking multiple images and processing the results to display the wide range of brightnesses in the coma and tail.

On very rare occasions a truly great comet swings through the inner solar system, producing a huge tail spanning tens of degrees or more. You can image these using the most basic photographic setup of a camera with a wide-angle lens on a tripod. A single, short exposure of less than 30 seconds can produce fantastic results. Comets such as these appear every decade or so, but with very little warning. The last one to grace our skies was Comet McNaught (C/2006 P1) in 2007, which was best seen from the Southern Hemisphere.

Most comets are far more modest in appearance and as such require a unique imaging approach to be photographed successfully. The problem is that comets move relative to the background stars. This motion is particularly apparent when they are nearest to the Sun and Earth. An exposure of around 5 minutes with the camera tracking the stars results in an image with nice round stars, but a comet stretched into a blurry streak.

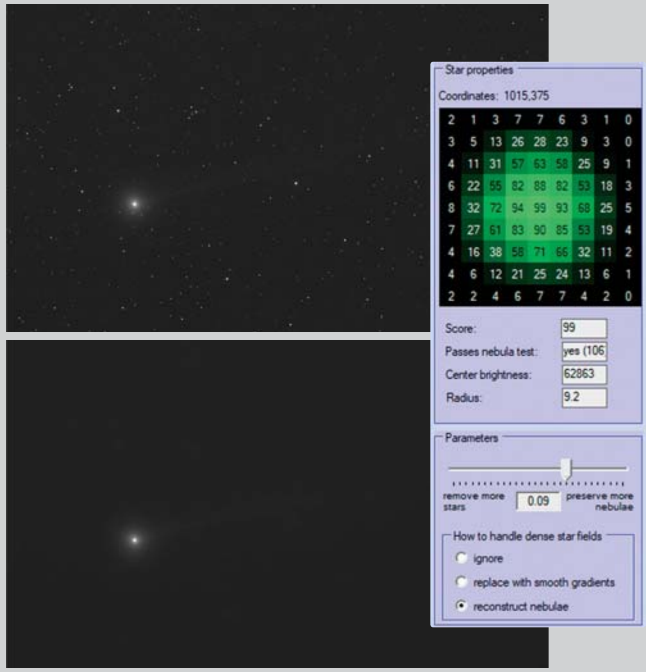
One solution is to track the comet with a telescope equipped with a guidescope and an autoguider that is locked onto the comet. Another approach for those with advanced computerized mounts is to program the mount to track the comet's apparent motion rather than the stars. Both techniques produce photos with a sharp comet nucleus but a field of trailed stars. While acceptable, some find these results aesthetically disappointing. After all, we usually can't *see* a comet moving against the stars when we observe it visually.

ALL IMAGES BY THE AUTHOR

Freeze Frame

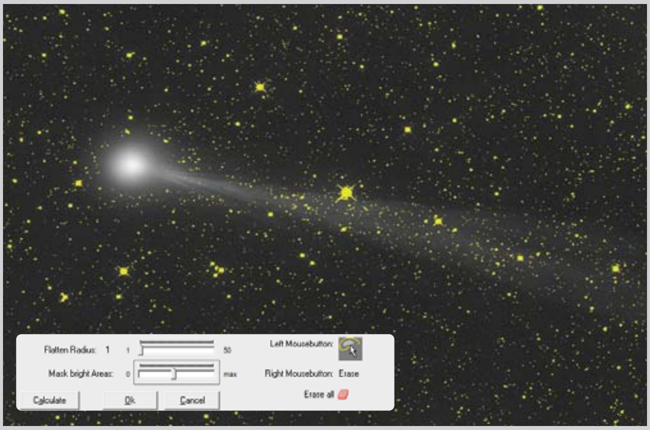
With a bit of planning we can create a photo that "freezes" the comet's motion relative to the background stars. It involves taking many short exposures that are just long enough that the comet's nucleus doesn't trail in a single shot, and neither do the stars. The results are then combined in software to produce a deep image of the comet against a background of pinpoint stars.

First, with your rig set to track the stars, make a series of test images to determine the longest exposure you can make

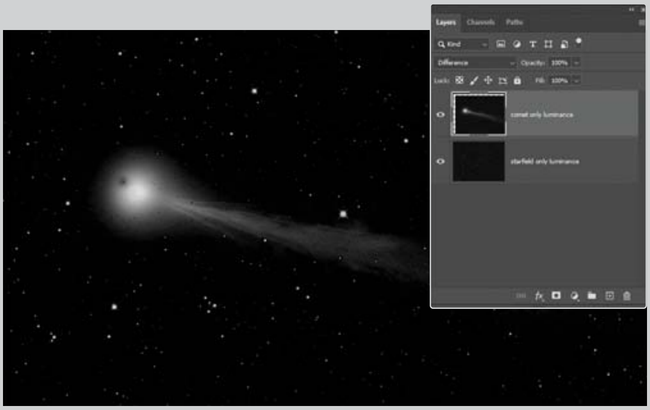


▲ **REMOVING STARS** The PC software program *Straton* automatically removes stars from most image files, including FITS files. You can fine-tune the aggressiveness of the program by adjusting the Parameters slider at lower right.

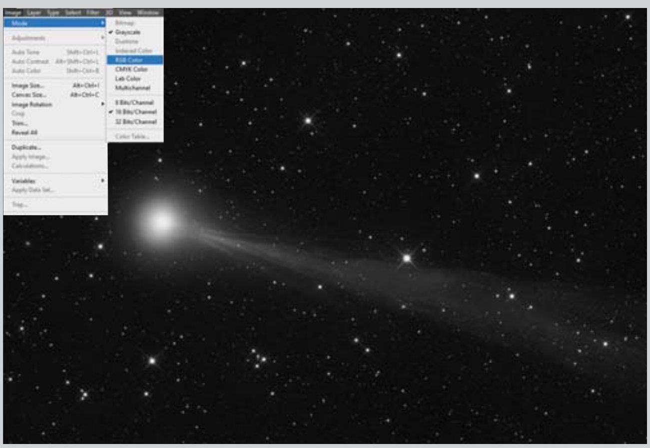
▲ **STARLESS COMET** Once the stars have been successfully removed from the aligned FIT files, imagers shooting through monochrome cameras equipped with color filters can combine the images into a starless color composite using their favorite astronomical image-processing program. The author uses *MaxIm DL 6*.



▲ **CLEANING THE STAR FIELD** Use the Variable Flatten tool in the free PC software *Fitswork* to mask the stars in the registered star-field images. Adjust the Mask Bright Areas slider at the bottom left of the screen to mask the stars before applying the filter.



▲ **RECOMBINATION** Putting all the color and luminance images together is best accomplished in *Adobe Photoshop*. Start with the luminance images by copying the comet-only picture and pasting it into the star-field photo. Change the comet layer blending mode to Difference, then move the layer until the comet nucleus in both layers cancels out. When both are aligned, change the comet layer blending mode to Lighten and merge the two layers.



▲ **PREPARING FOR COLOR** Convert the recombined luminance image's color space from Grayscale to RGB Color before pasting in the color images.

before the comet's motion becomes apparent. This value is highly dependent on both the comet's speed as well as the pixel scale of your imaging setup. For example, a telescope and camera combination producing an image scale of several arcseconds per pixel will permit longer exposures than one having 1-arcsecond resolution.

Once you've determined the exposure length, start your series of images. I prefer to shoot with monochrome cameras and color filters, so I set my equipment to take several sets of L, R, G, and B exposures, one after another. But the method works just as well with one-shot-color cameras (including DSLR and mirrorless cameras). The technique doesn't require a long total integration time, particularly when the comet displays small-scale details in its ion tail. These details, often appearing as knots, kinks, or streamers, will be rapidly moving down the ion tail and will limit how many frames you can combine before blurring the ion tail in your stacked result. When kinks and knots are visible in my test exposures, I usually bin my CCD camera 2×2. This lets me take shorter images by increasing the camera's sensitivity. It also limits how much these details shift in a single LRGB image series. All of this movement further constrains how many exposures I can combine into a single composition, so I rarely shoot more than a half-hour or so of data.

Putting It All Together

When you've acquired your individual frames, the next step is to assemble them into a final composite. The procedure is similar to that used for deep-sky imaging. Start by calibrating all the images in an astronomical image-processing program using dark frames and flat-field exposures (I prefer *MaxIm DL 6*). Save these individual calibrated exposures as you would for any deep-sky image. Next, align each calibrated image on the nucleus of the comet and save it with a new name such as "atlas01 comet.fit." Then perform a second alignment of the calibrated exposures, but this time aligning on the stars, and save it with a modified title to reflect this action, for example: "atlas01 stars.fit."

The big challenge in freezing a comet's motion in an image series is to create an isolated picture of the comet that can then be reinserted into a photo of just the star field. There are several methods for removing stars from an astrophoto with computer software, and I prefer the inexpensive PC program *Straton* (**zipproth.com/Straton**). It's written primarily for narrowband image-processing but works just as well for comet photography.

To remove the stars with *Straton*, open your image series using File > Open. If you've shot with a monochrome camera and color filters, process each set of images separately. Color camera users should split each image into separate red, green, and blue images before loading them into the program, and process the colors separately.

Next, select Tools > Remove stars from this image. In a minute or two, the result displays the comet without any stars in the field. If the program removed the comet's nucleus, you can reload the image and adjust the Parameters slider on the bottom right toward "preserve more nebulae." If that doesn't work, then you can restore it by holding the control key (Ctrl) and left-clicking on the comet. Once you've determined the proper setting, perform the same action on all your individual images. I prefer to do this manually, rather than using the batch setting, because the program may still remove the comet on a few exposures. When completed, save the image using File > Save As from the pull-down menu. *Straton* will automatically add "withoutStars" to the end of the file name.

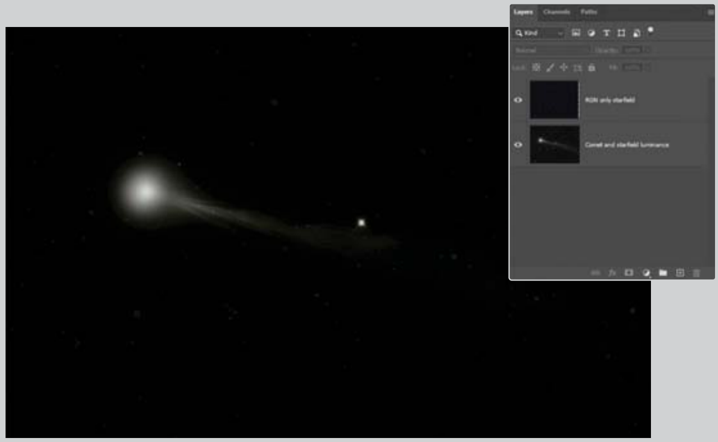
You can now stack your sets of starless, comet-registered images with any astronomical image-processing program. I create a luminance image and an RGB image, open both in *MaxIm DL 6,* and process with the Digital Development tool to perform a non-linear stretch. I save the results as 16-bit TIF files, which I'll combine later in *Photoshop.*

Next, you have to process the star-field data. This time you need to remove the comet as it moves relative to the stars in each exposure. For this I prefer a free program called *Fitswork* (**https://is.gd/fitswork**). Begin by opening one of the images aligned on the field stars (atlas01 stars.fit). Select Processing > Background Flatten > Variable Flatten from the pull-down menu at the top of the screen.

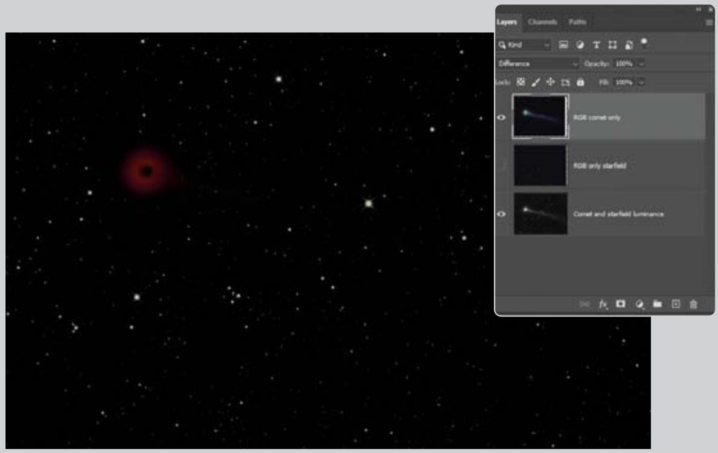
A new window opens where you can protect the stars and deep-sky objects from the tool's action using the Flatten Radius and Mask Bright Areas sliders. You should usually only need to increase the Mask Bright Areas slider, which highlights everything in the image that will be masked as yellow. Right-click the mouse to remove any mask that appears over the comet nucleus. When you're satisfied with the mask preview, click the Calculate button, followed by the OK button, and then save the result. Repeat this action for each image and then combine the results into a single FIT file (or luminance and RGB images when shooting LRGB sets). Stretch the results to create scaled TIF files just like the ones you made for the starless comet files earlier.

The next step is to create the final LRGB composite in *Adobe Photoshop*. Open all four TIF files and start by selecting the luminance star-field image. Usually there's a tiny spot of the comet's nucleus remaining in the photo, which you can use as the registration point for the other layers. Convert the color space from Grayscale to RGB by choosing Image > Mode > RGB Color from the pull-down menu. This is necessary so that the color layers added later will, in fact, appear in color.

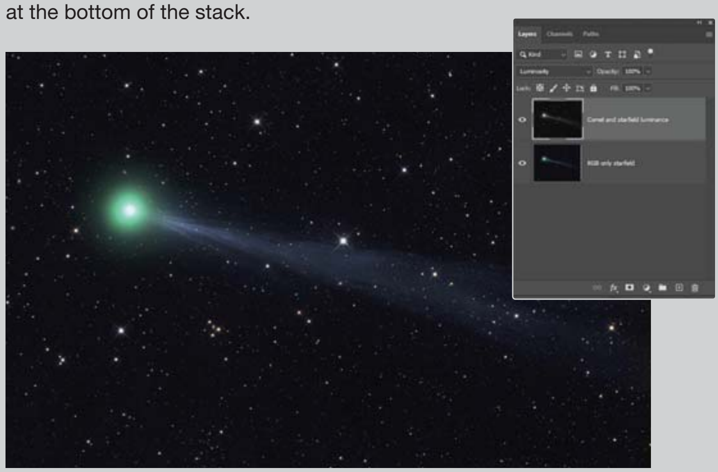
Select and copy the starless comet luminance image using Edit > Copy from the pull-down menu. Next, click on the luminance star-field image and select Edit > Paste, which will place the starless comet image on top of the star field. Open the Layers window (Window > Layers) and change the layer blending mode from Normal to Difference and use the Move tool to nudge the starless comet image until the nucleus lines up with the tiny spot in the star-field image. When the layer is in position, change the layer blending mode from Difference to Lighten. The comet then appears in all its glory in the star field. Lastly, use Layer > Flatten Image to combine these layers.



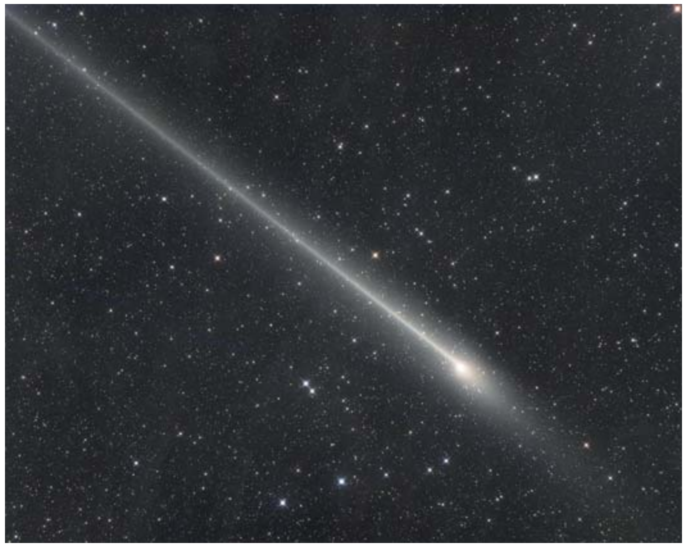
▲ **ADDING COLOR STARS** Copy and paste the RGB star-field image and align it to the luminance image below by changing the color star-field layer blending mode to Difference, then nudge it into place with the Move tool. When perfectly aligned the stars turn black, and you can change the layer blending mode to Normal.



▲ **COLOR COMET** Adding the starless comet image to the working stack is done in a similar way — paste it on top of the color star-field layer and change the blending mode to Difference. Be sure to hide the color star-field layer by clicking its "eye" icon in the layer window so that you are aligning the color comet layer to the luminance layer at the bottom of the stack.



▲ **SHUFFLING LAYERS** The final step is to change the order of the layers so that the luminance is above the color layer, then changing its blending mode from Normal to Luminosity.



◀▲ **UNIQUE VISITORS** Comet ATLAS (C/2019 Y4) appears with a strong, greenish coma on March 19th, whereas Comet PanSTARRS (C/2011 L4) had both a dust tail and antitail back on May 27, 2013.

Now add the color by clicking on the color star-field image, copying it, and pasting it onto the luminance image. Change the layer blending mode to Difference and move this layer until it cancels out the majority of the stars — the brightest stars will appear black with a light halo equal on all sides when the layer is perfectly aligned. Once satisfied with the positioning, change this layer's blending mode to Normal and rename the layer "RGB star field."

Now select the color starless comet image and paste it on top of the layered photo. Align it using the Difference blending mode, but hide the color star-field layer by clicking the "eye" icon to the left of the layer so that you're aligning the comet to the luminance layer. Once aligned, turn on the color star-field layer and change the color comet layer blending mode to Lighten. Combine these two color layers by clicking on the top layer, selecting the options in the top right of the layer window, and choosing Merge Down. You now have two layers — one RGB color and another, deeper luminance image. I prefer to apply the luminance to the color layer, so I drag the bottom luminance image above the color layer in the Layers window and change its blending mode from Normal to Luminosity. The result is a colorful, stationary comet frozen in time among a field of sharp stars. The last step is to select Layer > Flatten Image from the pull-down menu and you're done.

▶ **A MOMENT IN TIME** The final result is an image with the comet appearing as if it were captured during a single moment of time. This example of Comet PanSTARRS (C/2015 ER61) was made on June 4, 2017 using 12 minutes of data recorded through a luminance (L) filter, and 5 minutes each of red, green, and blue exposures. Compare this result with the same data registered on the comet on page 36.

Final Thoughts

Much of this technique's success depends on your equipment choices. Some comets tend to stay close to the horizon, which limits the time available before the comet sets or the Sun rises. Telescopes with fast focal ratios combined with high-sensitivity detectors permit collecting as much data as possible in a short timespan. And a mobile setup increases your opportunities to capture these unpredictable visitors from the edge of the solar system.

Comets are fast-evolving objects that can dramatically change appearance on short timescales. Their rapid movement through the inner solar system presents a constantly changing perspective for imagers. Each tail of volatile gas and dust interacting with the solar wind offers a celestial show unlike anything else in the night sky, which is why photographing comets is so rewarding.

■ **GERALD RHEMANN** chases comets in both the Northern and Southern Hemispheres. Visit his website at **astrostudio.at**.

1 EVENING: The month opens with Jupiter and Saturn shining 6° apart above the southeastern horizon. Look toward the south to see the waxing gibbous Moon less than 2° from Beta (β) Scorpii.

4 EARTH is at aphelion, farthest from the Sun for 2020, at a distance of 152,095,295 kilometers.

5 EVENING: The Moon, just past full, joins Jupiter and Saturn to form a triangle between Sagittarius and Capricornus.

11 DAWN: High above the southeastern horizon the waning gibbous Moon and Mars are less than 6° apart, while lower on the eastern horizon a mere 1° separates Venus and Aldebaran.

14 ALL NIGHT: The mighty gas giant, Jupiter, arrives at opposition (see pages 46 and 50).

17 DAWN: Look toward the east to see the waning crescent Moon, Venus, and Aldebaran in a shallow arc 6° long.

20 ALL NIGHT: Saturn, the magnificent ringed planet, reaches opposition (see pages 46 and 50).

22 DUSK: The very thin waxing crescent Moon is 3° from Regulus, Leo's lucida. Spot the pair low on the western horizon.

28–29 ALL NIGHT: The Delta Aquariid meteor shower is expected to peak. Best viewing is in the early hours of the morning after the waxing gibbous Moon has set.

29 DUSK: The waxing gibbous Moon is 5° from the red supergiant Antares, the heart of the Scorpion.

31 DUSK: The month closes with the fattening Moon, Jupiter, and Saturn forming a line 19½° long in the southeast.

— DIANA HANNIKAINEN

▲ Saturn's rings extend for 282,000 kilometers (175,000 miles) but are extremely thin, only around 10 meters (30 feet) thick in most places. This natural-color image looking northward through the rings is a mosaic of images taken by Cassini when the spacecraft was some 725,000 kilometers from the planet.
NASA / JPL-CALTECH / SPACE SCIENCE INSTITUTE

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

NASA / LRO

MOON PHASES

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

FULL MOON

July 5
04:44 UT

LAST QUARTER

July 12
23:29 UT

NEW MOON

July 20
17:33 UT

FIRST QUARTER

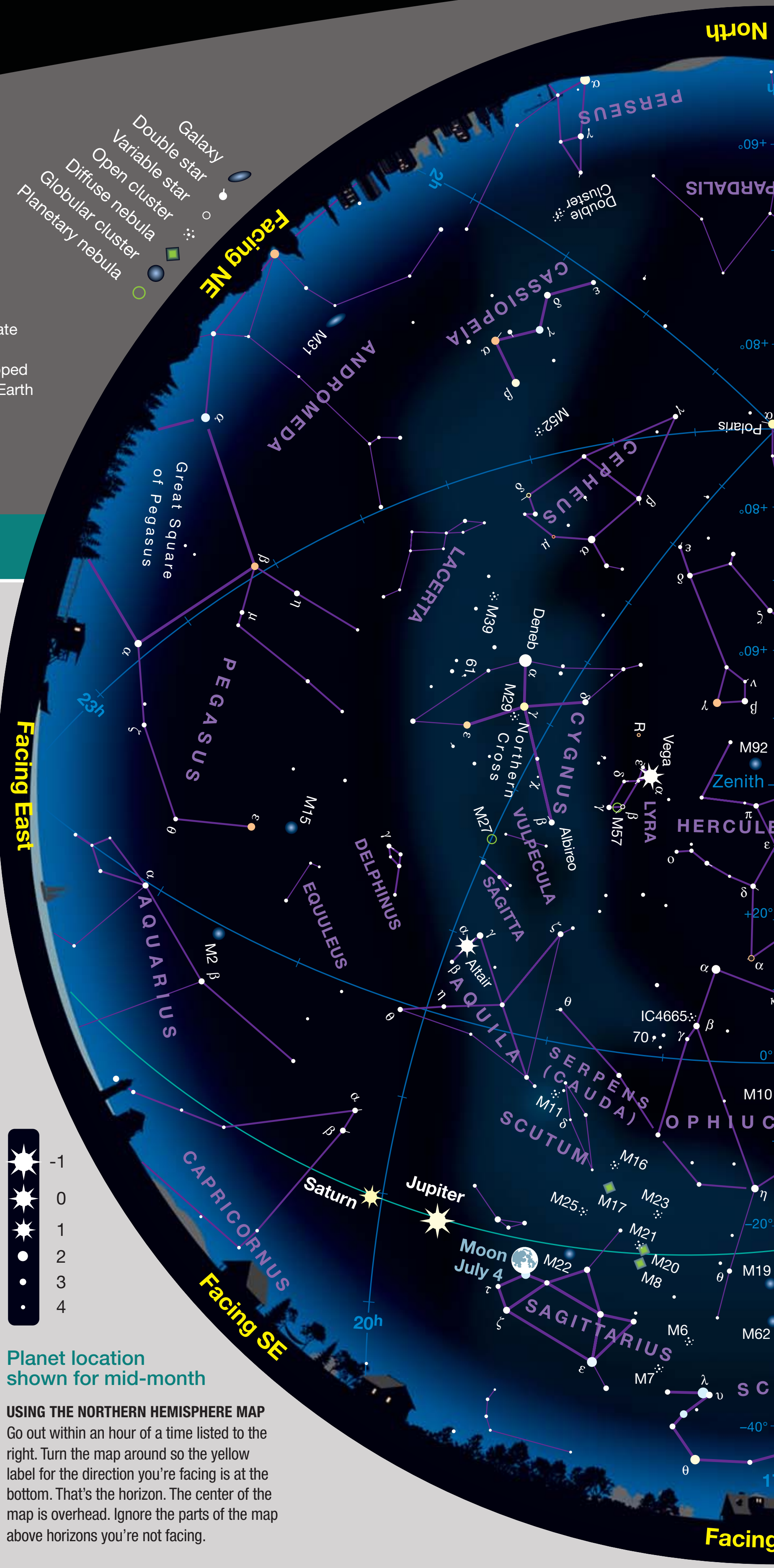
July 27
12:33 UT

DISTANCES

Apogee	July 12, 19h UT
404,199 km	Diameter 29′ 34″
Perigee	July 25, 05h UT
368,361 km	Diameter 32′ 26″

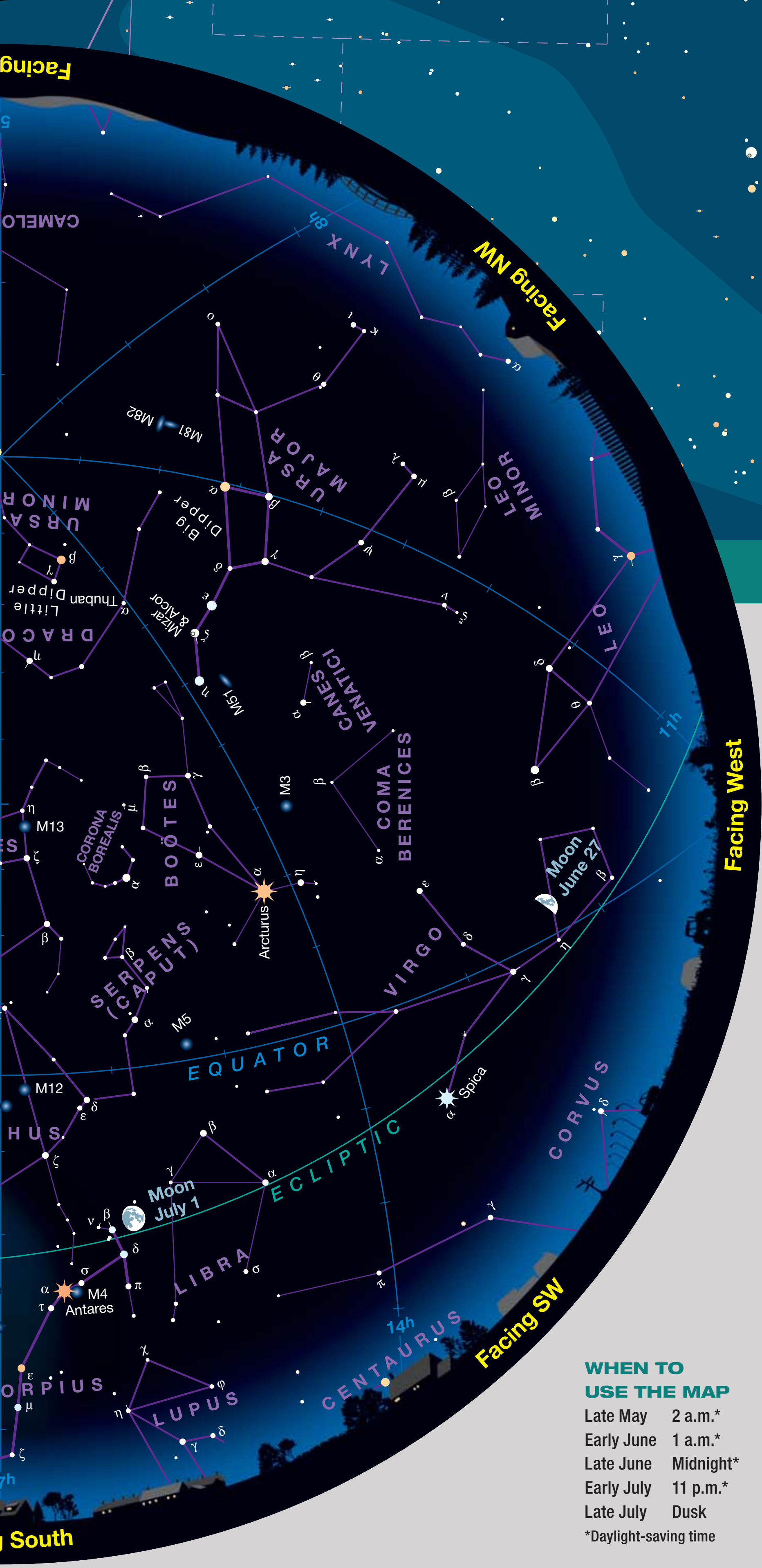
FAVORABLE LIBRATIONS

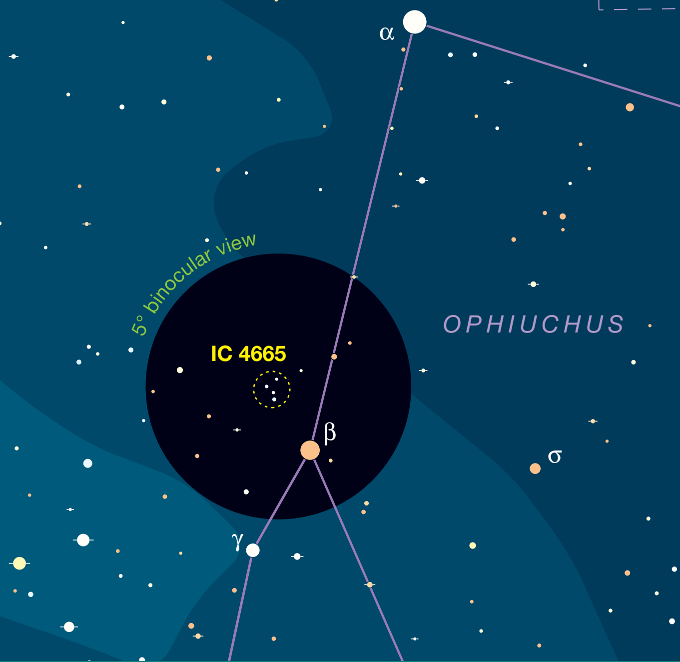
- Mare Australe July 2
- Mare Smythii July 4
- Mouchez Crater July 13
- Pascal Crater July 14



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.





WHEN TO USE THE MAP

Late May	2 a.m.*
Early June	1 a.m.*
Late June	Midnight*
Early July	11 p.m.*
Late July	Dusk

*Daylight-saving time

Binocular Highlight by Mathew Wedel

A Classic Rediscovered

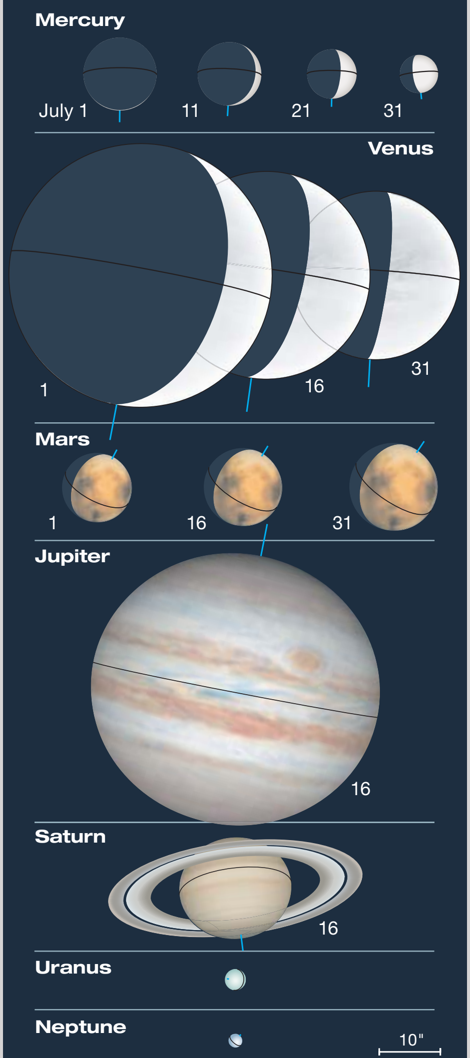
No list of showpiece open clusters would be complete without **IC 4665** in the constellation Ophiuchus, the Serpent Bearer. The cluster's easy to find, just a little more than 1° northeast of the star Beta (β) Ophiuchi. At 4th magnitude it's visible to the naked eye under dark skies, so you'd think that the cluster would have been discovered and cataloged early in the era of telescopic astronomy — and if so, you'd be half right.

IC 4665 was indeed discovered early . . . and often. Swiss astronomer Jean-Philippe Loys de Cheseaux seems to have been the first to log it in 1745. Johann Elert Bode discovered it independently in 1782, and in 1783 William and Caroline Herschel discovered it once again. But despite all this early attention, the cluster didn't make it into any of the great astronomical catalogs of the day. In fact, it wasn't added to the *Index Catalogue* until 1908 after a *fourth* "discovery," when Solon Bailey of Harvard College Observatory spotted it on a photographic plate. IC 4665 just might hold the dubious record for longest interval between telescopic discovery and formal cataloging in either the *NGC* or the *IC*.

IC 4665 is a young open cluster, only about 40 million years old. It lies roughly 1,100 light-years away, just a little bit closer than the Orion Nebula, and it may give us an idea of what that object will look like in another few million years. Unfortunately, we can't compare the nebula and the cluster directly, as they lie on opposite sides of the sky. But go have a look at IC 4665 anyway, even if you've seen it before. By now, rediscovering this celestial gem is something of an astronomical tradition.

■ The night sky is truly endless if you forget which objects you've previously observed — not that MATT WEDEL would know anything about that.

PLANET VISIBILITY (40°N, naked-eye, approximate) **Mercury:** visible at dawn starting on the 17th • **Venus:** serves as the brilliant Morning Star all month • **Mars:** a brightening pre-dawn object all July • **Jupiter and Saturn:** rise in the evening and transit around 1 a.m. local daylight-saving time.

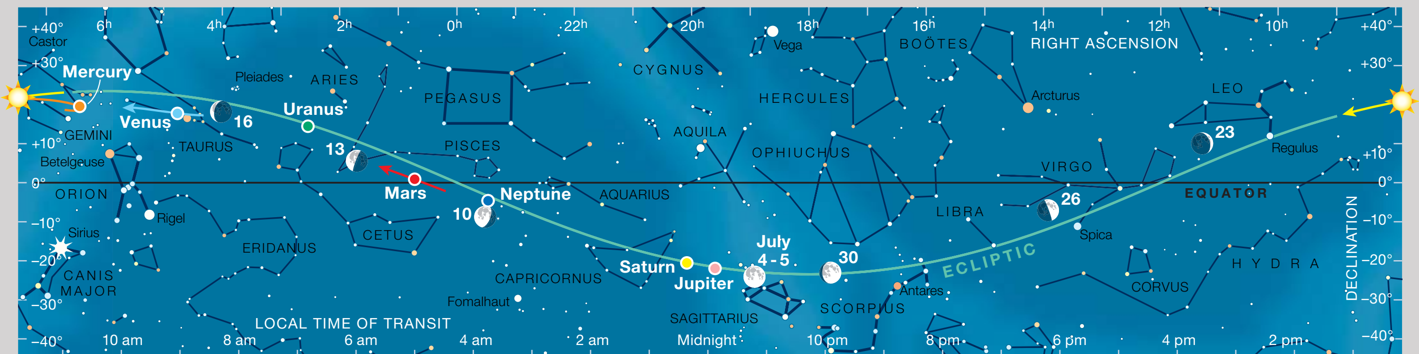


PLANET DISKS have south up, to match the view in many telescopes. Blue ticks indicate the pole currently tilted toward Earth.

July Sun & Planets

	Date	Right Ascension	Declination	Elongation	Magnitude	Diameter	Illumination	Distance
Sun	1	$6^h\ 40.7^m$	+23° 06′	—	–26.8	31′ 28″	—	1.017
	31	$8^h\ 41.6^m$	+18° 16′	—	–26.8	31′ 31″	—	1.015
Mercury	1	$6^h\ 40.2^m$	+18° 40′	4° Mo	—	12.0″	1%	0.562
	11	$6^h\ 22.3^m$	+18° 47′	14° Mo	+2.6	10.4″	10%	0.644
	21	$6^h\ 36.6^m$	+20° 27′	20° Mo	+0.4	8.1″	33%	0.829
	31	$7^h\ 29.2^m$	+21° 32′	17° Mo	–0.8	6.3″	66%	1.072
Venus	1	$4^h\ 18.1^m$	+17° 13′	34° Mo	–4.7	43.1″	19%	0.387
	11	$4^h\ 33.2^m$	+17° 23′	40° Mo	–4.7	36.7″	28%	0.455
	21	$4^h\ 58.3^m$	+18° 13′	43° Mo	–4.6	31.6″	36%	0.529
	31	$5^h\ 30.6^m$	+19° 11′	45° Mo	–4.6	27.5″	42%	0.606
Mars	1	$0^h\ 10.4^m$	–2° 17′	98° Mo	–0.5	11.4″	84%	0.818
	16	$0^h\ 42.4^m$	+0° 45′	104° Mo	–0.8	12.8″	85%	0.730
	31	$1^h\ 10.3^m$	+3° 20′	110° Mo	–1.1	14.5″	86%	0.647
Jupiter	1	$19^h\ 42.6^m$	–21° 39′	166° Mo	–2.7	47.3″	100%	4.170
	31	$19^h\ 26.6^m$	–22° 19′	162° Ev	–2.7	47.2″	100%	4.175
Saturn	1	$20^h\ 08.0^m$	–20° 24′	160° Mo	+0.2	18.4″	100%	9.054
	31	$19^h\ 59.0^m$	–20° 53′	170° Ev	+0.1	18.4″	100%	9.009
Uranus	16	$2^h\ 31.1^m$	+14° 23′	74° Mo	+5.8	3.5″	100%	20.057
Neptune	16	$23^h\ 26.9^m$	–4° 45′	123° Mo	+7.8	2.3″	100%	29.362

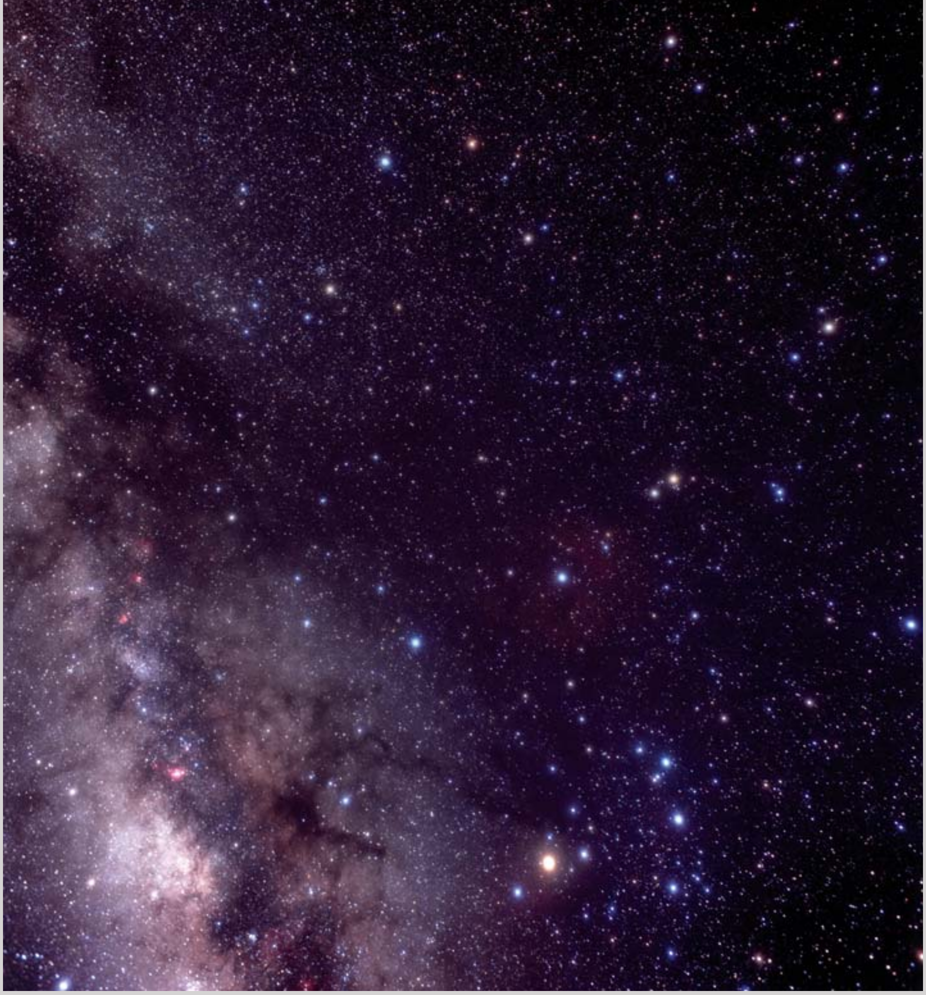
The table above gives each object's right ascension and declination (equinox 2000.0) at 0^h Universal Time on selected dates, and its elongation from the Sun in the morning (Mo) or evening (Ev) sky. Next are the visual magnitude and equatorial diameter. (Saturn's ring extent is 2.27 times its equatorial 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-July; 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 Treasures

This sprawling summer constellation is full of interesting sights.



▲ **ASTRIDE THE MILKY WAY** Ophiuchus is home to several fine clusters, numerous nebulae, and a couple of nearby stars. Use our Northern Hemisphere Sky Chart on pages 42-43 to identify the constellation and brightest deep-sky objects visible in this photo.

Satan stood
Unterrified and like a comet burn'd
That fires the length of Ophiuchus huge
In th' Artick sky, and from its horrid hair
Shakes pestilence and war.
— John Milton, Paradise Lost

The great English poet John Milton chose well with the phrase "Ophiuchus huge." The Serpent-Bearer was always large, and modern constellation boundaries have it stretching from nearly +15° to –30° in declination and from roughly 16h to 19h in right ascension. But size isn't everything. It's the incredible variety and richness of deep-sky attractions in Ophiuchus that is our main topic this month.

Plenty of globulars and a few overlooked open clusters. Ophiuchus's seven Messier globular clusters outnumber the six in Sagittarius, despite the latter's prime position in the thick of the Milky Way. None of the Ophiuchus globulars is a match for Sagittarius's majestic M22, to be sure, but the middle of the Serpent Bearer does offer two reasonably bright globulars a mere 3° apart: M10 and M12. Also impressive are M19 and the southernmost Ophiuchus Messier, M62. All four are brighter than 7th magnitude.

Have you observed the few large and bright open clusters in Ophiuchus? One of them is part of a 3°-wide pairing (just like M10 and M12). However, the Ophiuchus open cluster's mate is slightly over the border in Serpens Cauda. This "S-O Double Cluster" is located midway between Theta Serpentis (Alya) and 72 Ophiuchi. It features Ophiuchus's lovely NGC 6633, shining at magnitude 4.6. The cluster's 27′ diameter includes at least 30 stars, the brightest of which is magnitude 7.7. The Serpens half of the pair is 5.1-magnitude IC 4756. This cluster is approximately 52′ wide and contains at least 80 stars. Under dark-sky conditions, the S-O Double Cluster is a pair of naked-eye patches within a narrow tongue of Milky Way, west of the dark Great Rift. Binoculars show both objects nicely.

A little beyond the end of that Milky Way tongue is IC 4665, a rather sparse open cluster that's almost a degree wide and glows with a total magnitude of 4.2. It's most easily found by looking slightly more than a degree northeast of Beta Ophiuchi (Cebalrai). As it happens, the region east of Beta is a wonderland of interesting objects.

70 Ophiuchi and Barnard's Star. One of those objects is 70 Ophiuchi, a double star only 16.6 light-years from Earth. (That's virtually the same distance as Altair, which is 16.7 light-years away.) This double consists of a yellow, magnitude-4.2 primary and a red, magnitude-6.0 secondary. The two stars revolve around each other in just 88 years, with a maximum separation of 6.8″ coming up in 2024. 70 Ophiuchi is the easternmost point in a tiny triangle of naked-eye stars. The one about 1° northwest of 70 Ophiuchi in the triangle is 4th-magnitude 67 Ophiuchi, and the star 1.5° southwest is 4.5-magnitude 68 Ophiuchi.

By coincidence, less than 3° northwest of 70 Ophiuchi is another of our nearest stellar neighbors: Barnard's Star. Glowing faintly at magnitude 9.5, Barnard's Star's proximity is second only to the Alpha Centauri system, and it's the star exhibiting the greatest proper motion across the heavens.

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

AKIRA FUJII

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

A Month of Oppositions

Jupiter, Saturn, Pluto, and Pallas are all at their best in July.

July is one of the most exciting months for planet watchers this year. Jupiter and Saturn are paired at their biggest and brightest all night; Mars rapidly gains size and brightness and is visible for the second half of the night; and Venus burns at its most brilliant as it passes through the Hyades and leaps out of morning twilight.

ALL NIGHT

Jupiter reaches opposition on July 14th, followed by **Saturn** on the 20th. The two mighty gas giants are both retrograding (moving westward with respect to the background stars) and on the 3rd Saturn edges back into Sagittarius, where Jupiter currently resides. Since Jupiter is moving faster than Saturn, the separation between the two planets increases from about 6° to more than 7½° during the month.

Jupiter shines at magnitude –2.7 almost all July but briefly peaks at –2.8 around opposition. Saturn brightens from magnitude 0.2 to 0.1 for a few weeks around opposition. Jupiter swells to its largest diameter for the year (47.6″) and offers a wealth of detail visible even in fairly small telescopes. Saturn's disk diameter peaks at 18.5″ this month while its rings span 42″, with their tilt increasing slightly to nearly 22°. In early July, Jupiter and Saturn transit the meridian at 2:00 and 2:30 a.m. local daylight-saving time, respectively, and about 11:45 p.m. and 12:20 a.m. at month's end. By late July the two planets set well before sunrise.

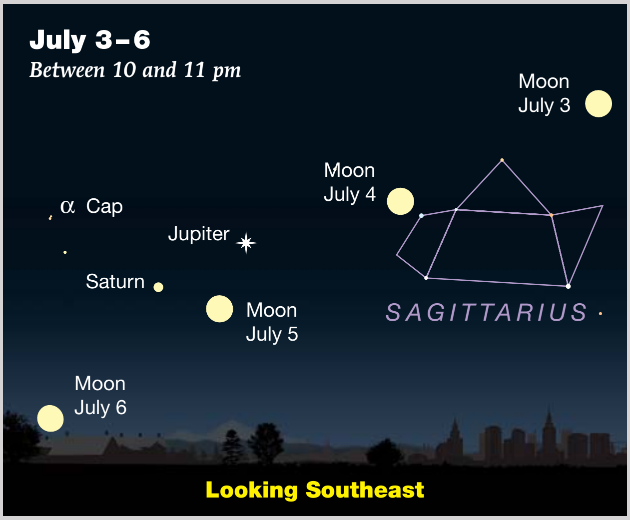
Pluto reaches opposition in Sagittarius on July 15th, when it glows dimly at magnitude 14.3. (For a finder chart, turn to page 48.) A fourth notable world at opposition this month is the asteroid **Pallas**. It reaches this milestone on the 12th, when it peaks at magnitude 9.6 in western Vulpecula.

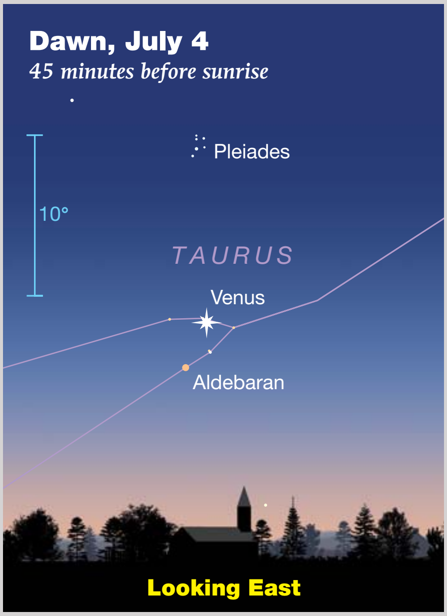
MIDDLE OF NIGHT TO DAWN

Mars dramatically increases in brightness again this month, improving from magnitude –0.5 to –1.1. The apparent diameter of the Red Planet grows from 11.4″ to 14.5″, making it a bit larger than it appears during unfavorable, aphelic oppositions. Yet Mars still has three more months to brighten and enlarge before its perihelic opposition in October.

At the start of July, Mars rises around 12:30 a.m. local daylight-saving time — 1½ hours before Jupiter culminates. At the end of the month, Mars comes up about 11:15 p.m.

Mars reaches the meridian after sunrise in early July, but roughly half an hour before sunrise in late July. On the 11th, Mars ventures north of the celestial equator for the first time since last October, making it respectably high for observers at mid-northern latitudes when the planet nears the meridian. The campfire-colored world drifts north-eastward from Pisces through a corner of Cetus in early July, before re-entering Pisces at the end of the month.





▶ 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.

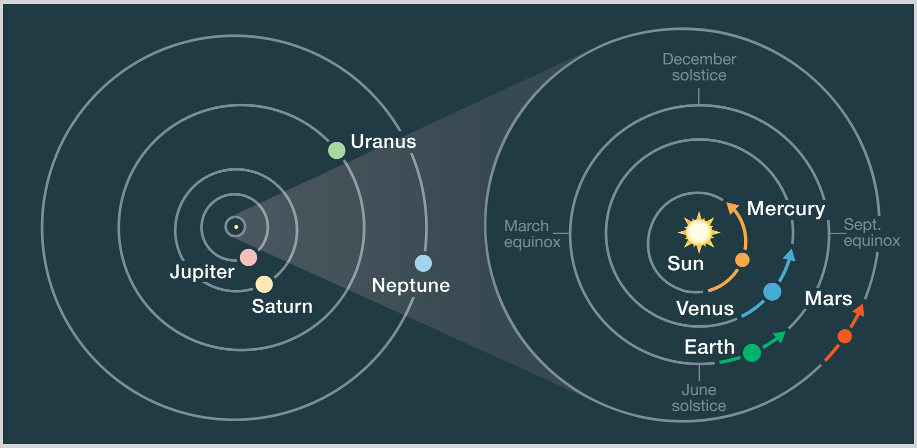
Neptune rises roughly one hour before Mars this month, and **Uranus** follows the Red Planet by about one hour. Like Mars, the two outer planets are still several months from their respective oppositions.

PRE-DAWN AND DAWN

Venus flames to its brightest and veritably rockets up from morning twilight for observers at mid-northern latitudes during July. Venus's lead on the Sun increases from 2 hours to 3¼ hours during the month, and the planet's sunrise altitude leaps from 21° to 35° — the steepest monthly climb in its 8-year cycle of recurring appearances. And the brilliance of Venus during July makes it easy to see with the naked eye at sunrise, or even shortly after in a very clear sky. The queenly Morning Star blazes at magnitude –4.7 for much of the month before tapering off a tiny bit to –4.6.

The sight of Venus is especially thrilling in the first half of July as it marches through the Hyades and passes 1° north of Aldebaran on the morning of the 11th.

A scope shows Venus's crescent waxing from 19% to 43% illuminated as its disk shrinks from 43″ to 28″ diameter during the month. The planet reaches greatest illuminated extent (47.4 square arcseconds) on the 10th.



ORBITS OF THE PLANETS

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

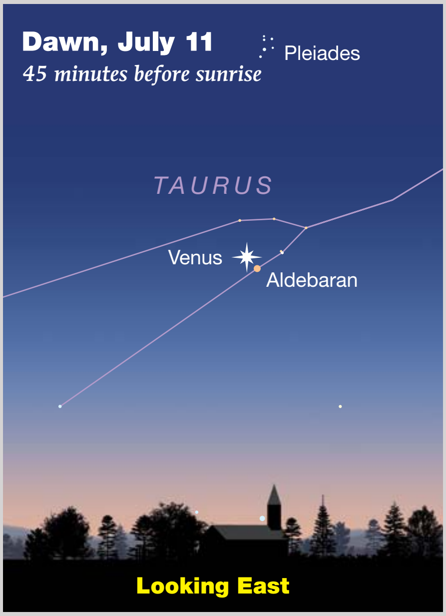
Mercury is at inferior conjunction on June 30th and doesn't reappear in the dawn sky until around July 17th, when it shines at magnitude 1.1 and rises 1¼ hours before the Sun. The tiny planet reaches greatest elongation (22° west of the Sun) on the 22nd. By then Mercury has brightened nearly a full magnitude to 0.2 but is only 37% illuminated and has an angular diameter of just 7.8″.

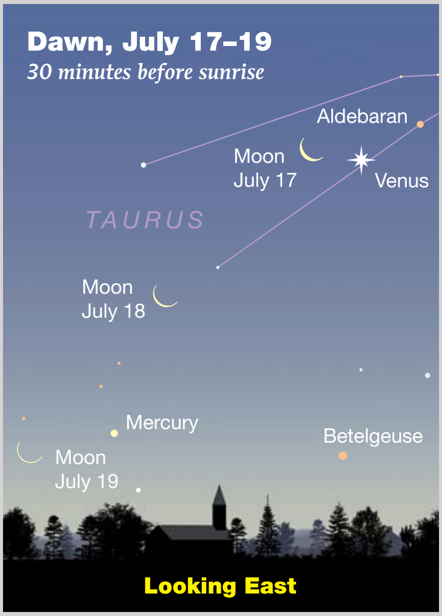
EARTH AND MOON

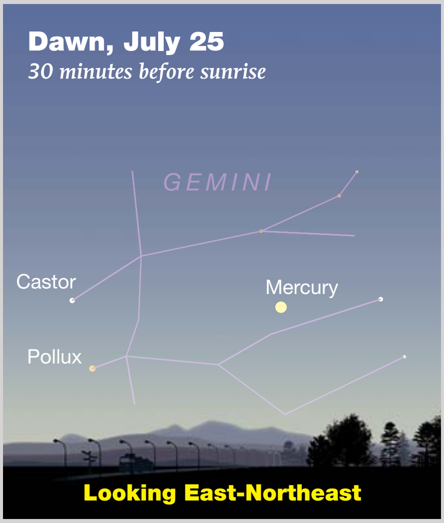
Earth reaches *aphelion* (its greatest distance from the Sun) at 7:35 a.m. EDT on July 4th when our home planet is 94,507,635 miles from the Sun.

The **Moon** is at Full at 12:44 a.m. EDT on July 5th and undergoes a penumbral eclipse too slight for the eye to detect. Mid-eclipse occurs at 12:30 a.m. EDT on July 5th. The Moon makes a long curving line with Jupiter and Saturn on the 4th, and the following evening it forms a wonderful, compact equilateral triangle with the two planets. At dawn on the 17th, a waning lunar crescent is just a few degrees left of Venus, with Aldebaran nearby. A very thin Moon is left of Mercury 30 minutes before sunrise on the 19th.

FRED SCHAAF teaches astronomy at both Rowan University and Rowan College in southern New Jersey.







Pluto by Way of Jupiter

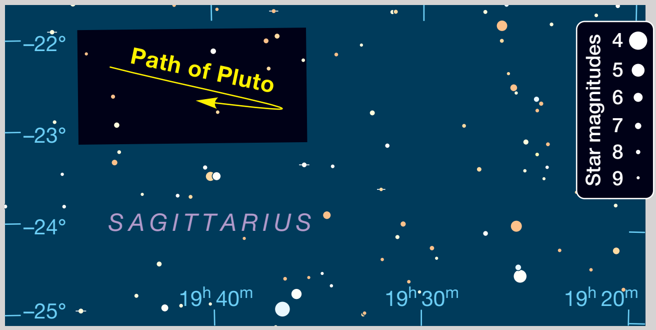
Two bright planets and one "former planet" reach opposition this month.

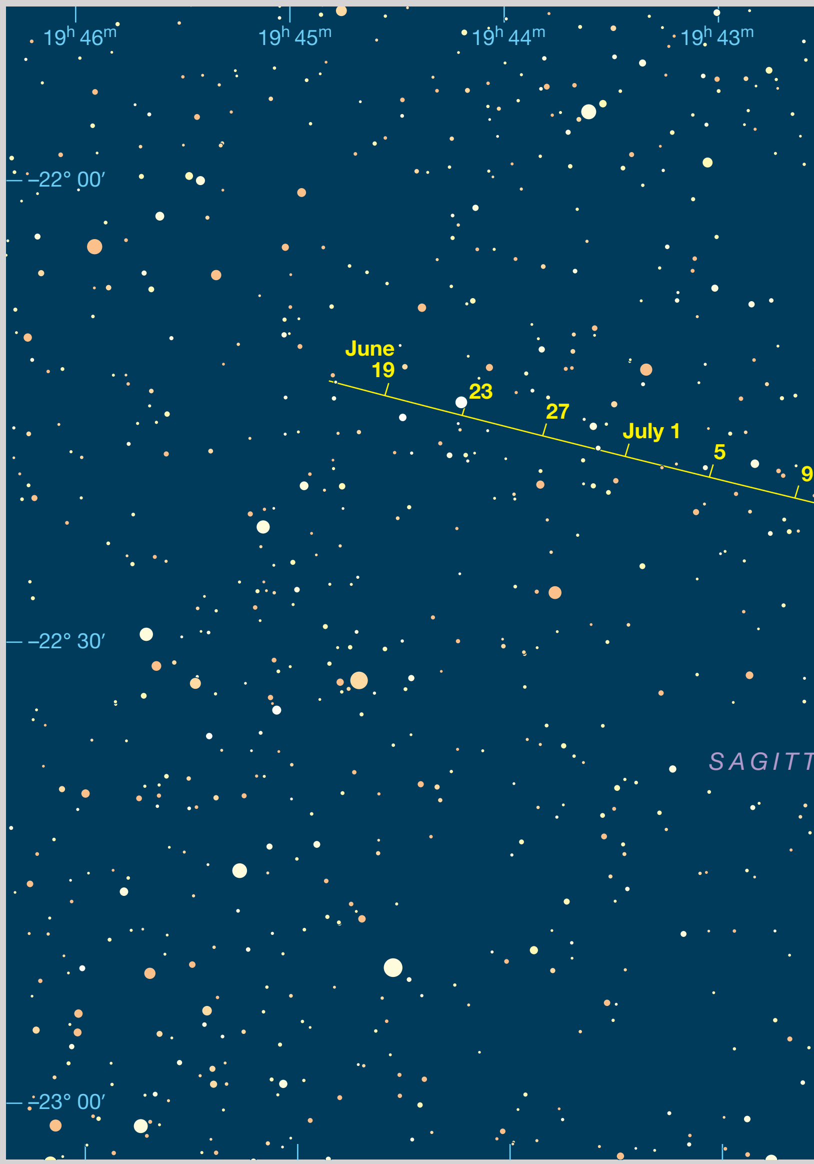
If you've never seen Pluto before, you're in luck this month. Yes, the 14.3-magnitude blip will require at least an 8-inch telescope, but Jupiter will point the way. The disparate worlds met in a close conjunction on June 30th and remain less than 1° apart most of July. Jupiter is at opposition on the 14th, and Pluto on the 15th. Saturn's in the game too and reaches opposition on the 20th.

We usually think of Jupiter as a distant world, but at mid-month Pluto is nearly 5 billion kilometers from Earth — eight times farther than Jupiter. And though it's faint now, Pluto won't grow any brighter in our lifetime. Its eccentric orbit whisks it farther from the Sun with each passing year, and when it reaches aphelion in 2114 the frostbitten orb will have faded to magnitude 16.

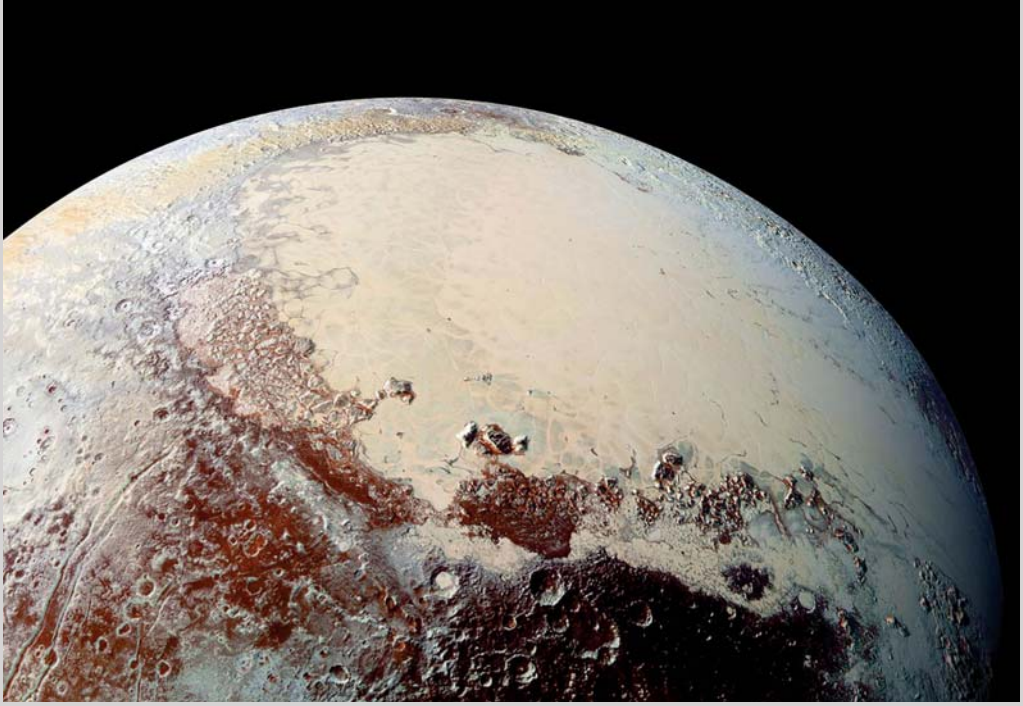
Pluto toddles along at the rate of about 87 arcseconds per day in mid-July. That's sufficiently fast for attentive observers to notice its motion relative to the background stars in the space of just 24 hours. To avoid a bright Moon, plan your Pluto foray between July 10th and 26th. Using the charts presented here, start at Jupiter, star-hop to Pluto's vicinity, then switch to higher magnification. Since nothing distinguishes the dwarf planet from similarly faint field stars, the enjoyment comes from the hunt and appreciating what you're looking at.

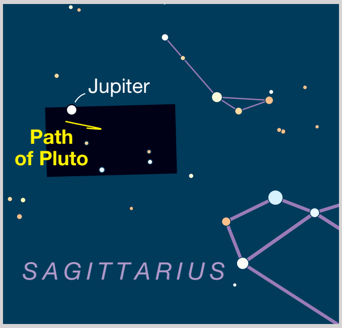
Pluto may look like a mundane pinprick of light in telescopes, but thanks to spectacular close-up images beamed to us by NASA's New Horizons probe we can envision a sphere 2,377 kilometers in diameter, or about two-thirds the size of our Moon. However, Pluto is much more reflective because of its icy surface and bounces back 72% of the light it receives from the Sun, compared with only 12% from the Moon. In fact, Pluto is nearly as reflective as brilliant Venus.

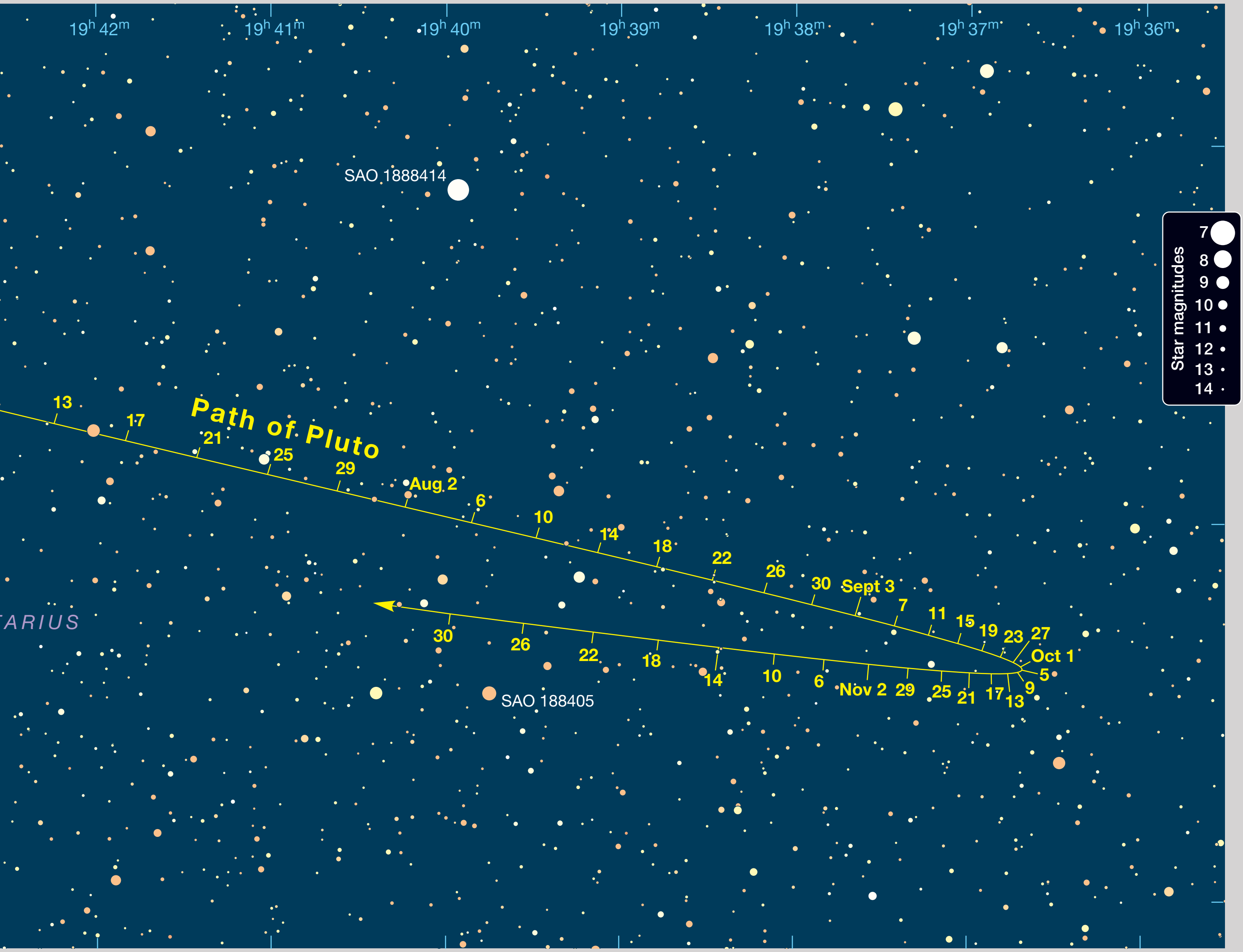




▶ This high-resolution image of Pluto captured by NASA's New Horizons spacecraft combines blue, red, and infrared images. The bright expanse is the western lobe of the "heart," informally called Sputnik Planitia, a region rich in nitrogen, carbon monoxide, and methane ices.







NASA / JHU APPLIED PHYSICS LABORATORY / SWRI

UK planetary imager Damian Peach recorded this detailed view of Jupiter on June 3, 2019. Many of the features shown here are accessible in mid-sized backyard telescopes when seeing conditions are steady.

Opposition Mates

SATURN AND JUPITER HANG LOW in eastern Sagittarius like summer apples ripe for picking. Unfortunately for observers at mid-northern latitudes, both planets will frequently suffer from poor seeing conditions arising from their southern declinations.

Jupiter presents a wealth of telescopic detail, including most famously the Great Red Spot. Although the GRS has shrunk noticeably in recent decades, its color has deepened to a gorgeous pink-red. A 4-inch scope at 150× should easily coax it into view.

The North Equatorial Belt (NEB) often appears rusty red and densely textured, but the South Equatorial Belt (SEB) presents a split appearance with two thinner, parallel bands separated by a pale zone, resembling an ice cream sandwich. Occasionally, the SEB will completely disappear, as it did in 2010.

At first glance Jupiter's equatorial zone (EZ) might appear blank, but if you attune your eye to look for low-contrast features you're likely to discern one or more *festoons* — grayish-blue wisps that look like windblown chimney smoke.

A 6-inch or larger telescope running at 200× can reveal the disks of all four Galilean moons. At opposition their apparent diameters are: Europa, 1.0″; Io, 1.2″; Callisto, 1.6″; and Ganymede, 1.8″. Observe often enough and you'll soon be able to tell which moon is which by size alone! (Check out the Action at Jupiter section to find out when the GRS transits and to keep up with the phenomena of the Jovian moons.)

While Jupiter hands out telescopic goodies at every turn, Saturn makes a single, sublime statement with its rings. The northern side of its rings is tipped 22° this season — just enough for the planet's southern limb to peek out from under the ring plane for the first time since 2014.

A 6-inch telescope will readily show Cassini's Division, a narrow gap that separates the outermost A ring from the bright, wide B ring. The innermost C ring (or Crepe Ring) is translucent, like dusty glass. Look for it projected against the planet's disk, just inside the B ring.

The planet's globe presents a muted, butterscotch-colored atmosphere, but be vigilant — sometimes enormous storms erupt out of nowhere, like the monster that bubbled up in 2010-11.

Saturn has 82 known moons, but only a few are within reach of backyard telescopes. With a 6-inch you'll be able to see Titan, Rhea, Tethys, Dione, and Iapetus. An 8- to 10-inch instrument will add Enceladus and Hyperion.

Use our Saturn Moon tool (**https://is.gd/SaturnMoons**) to track down the five brightest Saturnian satellites.

Action at Jupiter

AT THE START OF JULY, Jupiter rises around 9 p.m. local daylight-saving time and transits the meridian at 2 a.m., when it's well-placed for telescopic viewing. On July 1st the planet gleams at magnitude –2.7 and presents a disk 47″ in diameter.

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

All the July interactions between Jupiter and its satellites and their shadows are tabulated on the facing page. Find events timed for late at night 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.)

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

July 1: 1:56; 11:52; 21:47 **2**: 07:43; 17:38 **3**: 3:34; 13:29; 23:25 **4**: 9:21; 19:16 **5**: 5:12; 15:07 **6**: 1:03; 10:59; 20:54 **7**: 6:50; 16:45 **8**: 2:41; 12:36; 22:32 **9**: 8:28; 18:23 **10**: 4:19; 14:14 **11**: 0:10; 10:06; 20:01 **12**: 5:57; 15:52 **13**: 1:48; 11:43; 21:39 **14**: 7:35; 17:30 **15**: 3:26; 13:21; 23:17 **16**: 9:13; 19:08 **17**: 5:04; 14:59

18: 0:55; 10:51; 20:46 **19**: 6:42; 16:37 **20**: 2:33; 12:29; 22:24 **21**: 8:20; 18:15 **22**: 4:11; 14:07 **23**: 0:02; 9:58; 19:53 **24**: 5:49; 15:45 **25**: 1:40; 11:36; 21:31 **26**: 7:27; 17:23 **27**: 3:18; 13:14; 23:09 **28**: 9:05; 19:01 **29**: 4:56; 14:52 **30**: 0:47; 10:43; 20:39 **31**: 6:34; 16:30

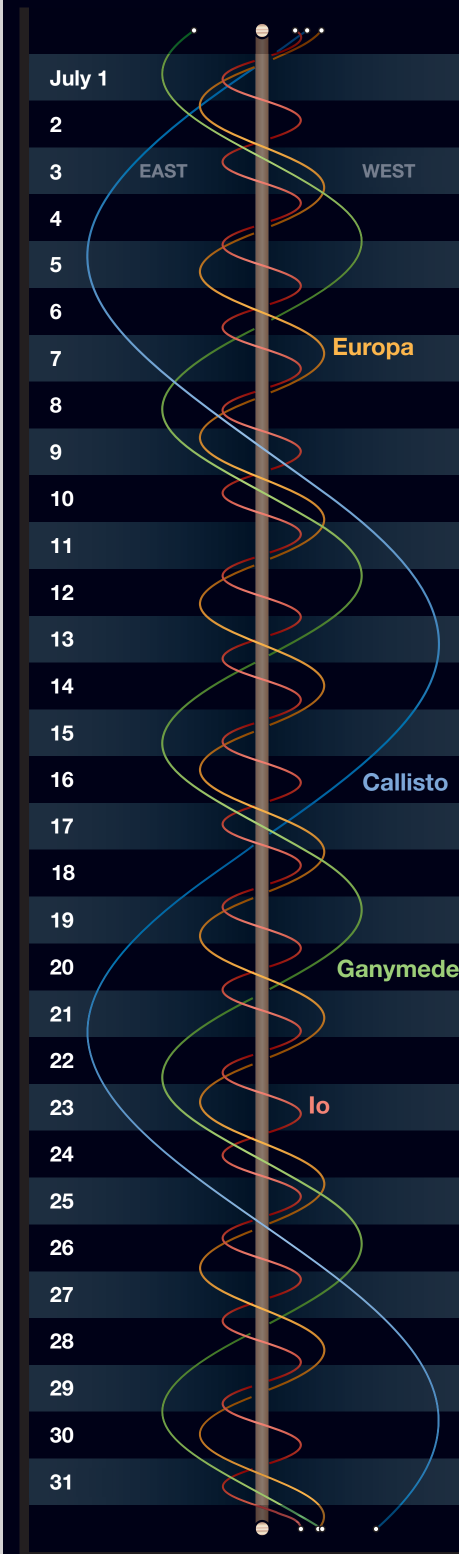
These times assume that the spot will be centered at System II longitude 334° on July 1st. If the Red Spot has moved elsewhere, it will transit 1²/₃ minutes earlier for each degree less than 334° and 1²/₃ minutes later for each degree more than 334°.

Phenomena of Jupiter's Moons, July 2020

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

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.

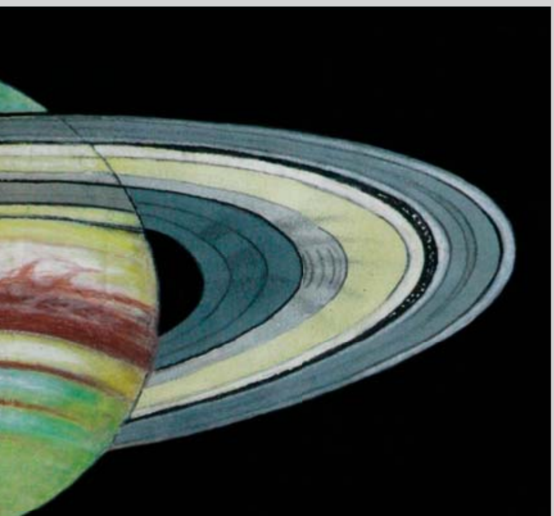
A Mystery in Saturn's C Ring

Have observers witnessed upheavals in the Crepe ring?

In 1890, the philosopher and educator William James wrote: "Round about the accredited and orderly facts of every science there ever floats a sort of dust-cloud of exceptional observations, of occurrences minute and irregular and seldom met with, which it always proves more easy to ignore than to attend to."

The history of visual planetary observing provides no better example of James's maxim than a series of controversial observations of Saturn's C ring that were unfolding about the time he penned those words.

The March 1887 issue of the British journal *The Observatory* contained breaking news from the Belgian astronomer François Terby of the University of Louvain. During the previous month he had detected "dark masses" in Ring C through his 8-inch refractor.



During a 1992 observing run at the Pic du Midi Observatory Stephen O'Meara glimpsed delicate blotches in the C ring that were not as narrow as the ephemeral spokes in the adjacent B ring.

STEPHEN JAMES O'MEARA

Anomalies in the C ring had also caught the attention of one of Britain's leading lunar and planetary observers, Thomas Gwyn Elger. Using an 8.5-inch Newtonian reflector on February 16, Elger noticed a pronounced difference in the brightness of the ansae of Ring C. In the April issue of *The Observatory* he also reported:

> *On February 25, though the* f *[following] ansa of the dark ring was very dusky, it was perfectly distinguishable, while the* p *[preceding] ansa was noted as unequally dark, certain parts of its surface appearing quite black. On the following night, with excellent definition, the* p *ansa exhibited on its inner margin three or four large re-entering angles, like the teeth of a saw, the space between this jagged outline and the ball being perfectly black. . . On March 18, between* 9^h *and* 10^h *(with a superb image of the planet, showing Encke's division as a hair-line on the ansa of ring A) the* f *ansa of the obscure ring was a sombre but easy object, while the* p *ansa again exhibited a serrated border. . .*

Elger noted that this strange aspect was not without precedent. William Stephen Jacob, the director of the Madras Observatory in India, had seen the inner edge of the C ring appear irregular "like the fold of a curtain" on one occasion in 1852 through a 6.2-inch refractor.

The *Monthly Notices of the Royal Astronomical Society* published two lengthy reports by Elger of his Saturn observations during 1887 and 1888. These accounts contain detailed descriptions of extraordinary appearances in the C ring — the frequent unequal brightness of the ansae, the presence of amorphous dusky patches, and the occasional scalloped appearance of its inner edge.

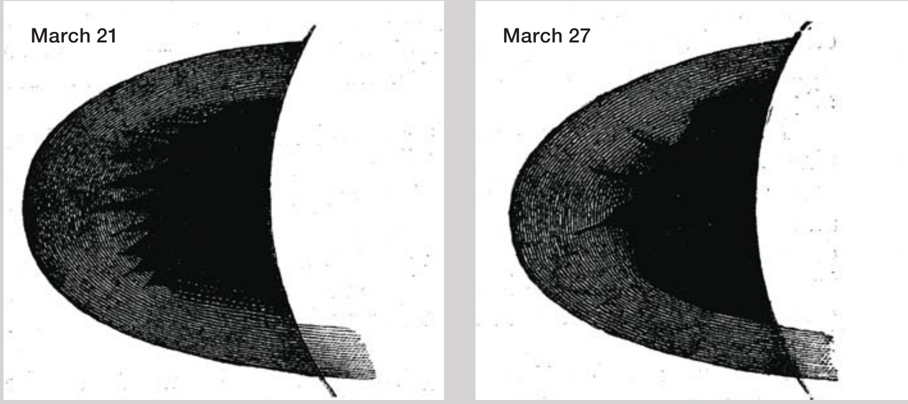
There was no shortage of corroboration from experienced observers. The Reverend Phillip Kempthorne of Wellington College and Major Harry Watson, observing from Newbridge, Ireland, both noted similar phenomena.

The Belgian astronomer Paul Henri Stroobant saw a pair of prominent dark notches in the western ansa of the C ring on April 30, 1890, using the 15-inch refractor at Royal Observatory in Brussels.

Observing with a 10-inch reflector from Malta, the Reverend T. H. Foulkes reported than on May 20, 1896, the C ring ". . . did not possess its usual uniform appearance, but was decidedly 'lumpy.' I counted six or seven of these darker shadings, which seemed to have a tendency to circular formation. . . Though this planet has been observed by me for the last 25 years, I have never before seen this curious formation." Six nights later he claimed that ". . . the crape [sic] ring presented a strange and beautiful appearance in the ansæ . . . which seemed to be all mottled with swarming tiny spots, granulated."

These reports were greeted with widespread skepticism and became the subject of acrimonious debate. One of the leading lights of the British Astronomical Association, William Frederick Denning, noted that the anomalies ". . . were not seen at many observatories where such features, if real, could hardly have escaped detection."

Many critics attributed the peculiar appearances in the C ring to the effects of atmospheric turbulence. Elger countered that they ". . . were invariably seen to greater advantage in proportion to the goodness of the night for observing purposes. . ."



▲ Thomas Gwyn Elger depicted strange serrations on the inner edge of Ring C on two nights in March 1888.

Ironically, one of the most prominent skeptics of Ring C anomalies, Lick Observatory astronomer Edward Emerson Barnard, may have provided the most compelling evidence that they had a basis in reality. On the night of November 1-2, 1889, Barnard watched Saturn's satellite Iapetus emerge from behind the globe of the planet and slowly pass through the shadow cast by the translucent C ring. Using a 12-inch refractor under excellent seeing conditions, he made 80 estimates of Iapetus's fluctuating brightness to determine the C ring's structure and optical density. The fixed brightness of the nearby moons Tethys and Enceladus served as references.

McDonald Observatory astronomer James Bryan published a painstaking review of Barnard's data in the October 2007 issue of the *Journal of Astronomical History and Heritage*. He found that Barnard's light curve contains a curious shadow that ". . . appears to be consistent with observations of transitory dark markings on the C ring in the late 1880s . . . Apparently, a condition existed in the inner ring system on 1-2 November 1889 that does not, for whatever reason, exist now."

Bryan speculated that the shadow might have been cast by a "spoke," the radial streaks that appear in the B ring, even though NASA's Voyager and Cassini spacecraft never recorded these ephemeral features in Ring C. In the faint C ring, visual observers might perceive radial spokes as the indentations and serrations described in the 19th-century reports.

The Cassini spacecraft recorded several clouds of ejecta produced by the impact of meter-sized meteoroids with particles in Ring C. Far too small in scale to be detected with any telescope, these events seem to be encounters with compact streams of Saturn-orbiting material derived from the prior breakup of larger bodies rather than random collisions with single objects.

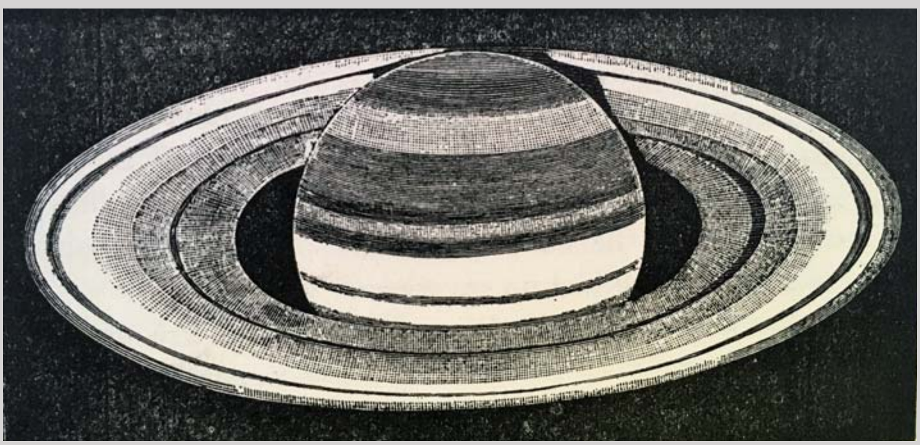
Cassini images revealed the presence of vertical ripples or warps in the C ring and in the even more tenuous innermost D ring. According to Jeffrey Cuzzi of NASA's Ames Research Center, a leading expert on the rings of Saturn, these corrugated structures ". . . suggest that Saturn's D and inner C rings were tipped relative to its equator several times over the last millennium, and as recently as a few decades ago. Impacts by rubble streams produced by disrupted objects are the most likely cause."

I can't help but wonder if the strange appearances in the C ring reported late in the 19th century were produced by a series of unusually intense bombardments. There are tantalizing clues of others.

In 1913 and 1914 the French astronomers Georges and Valentin Fournier at the Jarry-Desloges Observatory in Algeria found Ring C appearing "granular" and of varying intensity with dusky knots and brighter areas. In 1992 the eagle-eyed observer Stephen James O'Meara glimpsed a pair of "dark interludes in brightness" in Ring C through the 1-meter Cassegrain reflector at the Pic du Midi Observatory (*S&T:* Jan. 1993, p. 20). These delicate features were ". . . slightly darker features against a relatively dark ring, more blocky and broad" than the arced wisps of the B ring spokes and required averted vision to see.

Visual observers of Saturn seldom give the C ring more than a passing glance. The observational record suggests that it deserves careful inspection, particularly while the rings are favorably tipped at opposition this month.

▼ This widely reproduced lithograph accompanied François Terby's 1887 report of anomalous dusky patches in the western (left) ansa of the C ring.

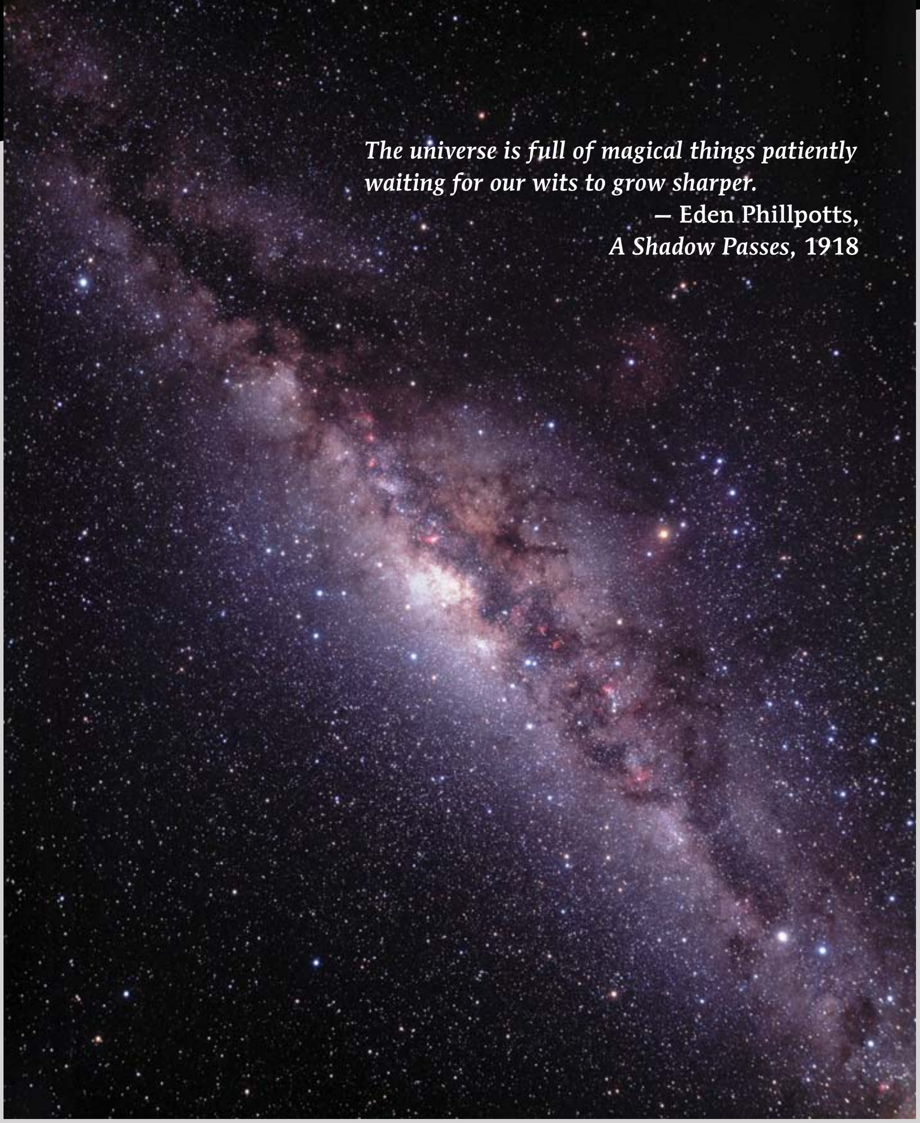


TERBY DRAWING: THE OBSERVATORY; ELGER DRAWING: ROYAL ASTRONOMICAL SOCIETY

■ Contributing Editor **THOMAS A. DOBBINS** was awarded the Donald E. Osterbrock Prize of the American Astronomical Society Historical Astronomy Division in 2017.

Magical Things

Planetary nebulae sprinkled along the Milky Way beckon observers outside on warm summer evenings.



▲ Midyear in the Northern Hemisphere means the summer Milky Way is well placed for viewing in the evening sky. Deep-sky observers can spend a lifetime among the rich assortment of star clusters and nebulae scattered across the galactic bulge in Scorpius and Sagittarius. They are prominent in this view by Japanese astrophotographer Akira Fujii.

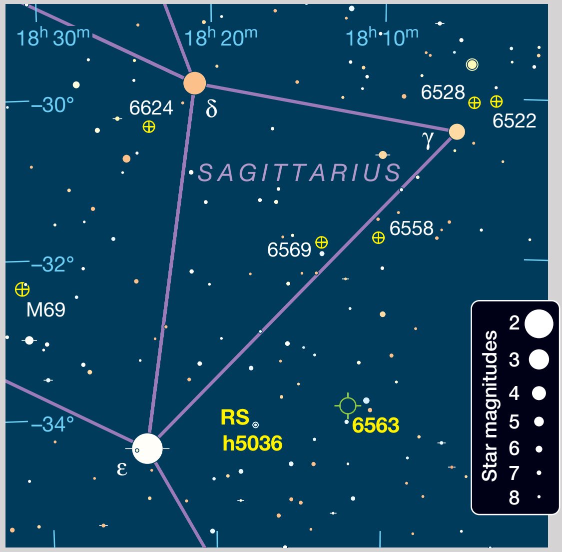
Planetary nebulae are fascinating deep-sky beauties. We've learned that aged stars, initially one to eight times the mass of our Sun, form planetary nebulae by shedding material at different speeds and times. But the specific processes leading to their bewildering variety and intricate structures are still a matter of debate. Only 3,000 or so planetary nebulae are known in our galaxy, yet large numbers of them have been identified in galaxies as far-flung as the Virgo Cluster. These extragalactic planetaries aid in determining distances to their host galaxies, while the distances to most of the planetaries in our own backyard remain poorly known.

Let's drop in on some less-visited representatives of these wondrous objects draped along the summer Milky Way, as well as their chance comrades in the sky.

Starting in southern Sagittarius, we'll star-hop our way to **NGC 6563** and pause at an interesting star along the way. From Epsilon (ε) Sagittarii (also known as Kaus Australis), sweep 1.4° west-northwest to a 6th-magnitude star, which is both the brightest in the area and the primary of the quadruple **h5036**. The three companions are visible at low power and range from magnitude 8.7 to 10.2. Look for two of the attendants a spacious 1.3′ northeast of the primary, and the third one less than half as far to the east. Making things even more interesting, the primary star is the eclipsing binary **RS Sagittarii**, with a period of 2.4 days. Normally magnitude 6.0, the binary dims once by about 0.3 magnitude and a half cycle later by 0.9 magnitude as its stars alternately pass in front of each other as seen from Earth.

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.

Returning to our star-hop, make a second leap of the same length and direction to reach another 6th-magnitude star. NGC 6563 lies 15′ east-southeast of this star, making a trapezoid with it and two 7th-magnitude stars farther south. Through my 105-mm (4.1-inch) refractor at 87×, this planetary nebula is fairly small, faint, and roundish. There is a minor improvement in contrast with a narrowband nebula filter, but the nebula stands out much better with the use of an O III filter. Through my 10-inch reflector at 115×, NGC 6563 is round and ¾′ across with uniform surface brightness. It's enshrined in a little triangle of three 12th- and 13th-magnitude stars, the closest one north and the others northwest and southeast. Boosting the power to 213× and adding an O III filter reveals that the nebula is oval and



▲ *Left*: A short star-hop from Kaus Australis, the southernmost star in the Sagittarius Teapot asterism, will lead you to the interesting planetary nebula NGC 6563 floating in a rich star field. North is up in this 8′-wide view.

tipped about 60° east of north. There's a slightly brighter arc along the northern edge and a more subtle brightening on the opposite rim.

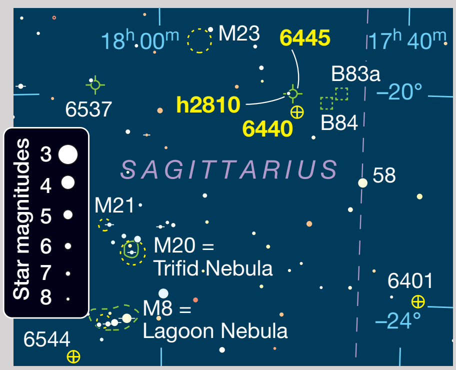
Farther north in Sagittarius, the planetary **NGC 6445** sits 22′ north-northeast of the globular cluster **NGC 6440**. Even at 17× in my little refractor, NGC 6440 is an easily visible, little hazy patch 1.8° northeast of the pale-yellow star 58 Ophiuchi. At 47× the planetary nebula joins the scene as a small, fairly faint spot with the wide double star **h2810** about 5′ to its east. The double has a 7.6-magnitude primary with a 10.4-magnitude companion a bit west of south. At 87× NGC 6445 is about 40″ long, roughly oval, and leans north-northwest. The north-northwestern edge appears brighter and has a faint star a short distance beyond. The globular cluster still shares the field of view. It spans 2.3′ and grows much brighter toward the center. NGC 6440 adorns the middle of an 11½′-long line of 11th- and 12th-magnitude stars, two to the cluster's north-northwest and two off the opposite side.

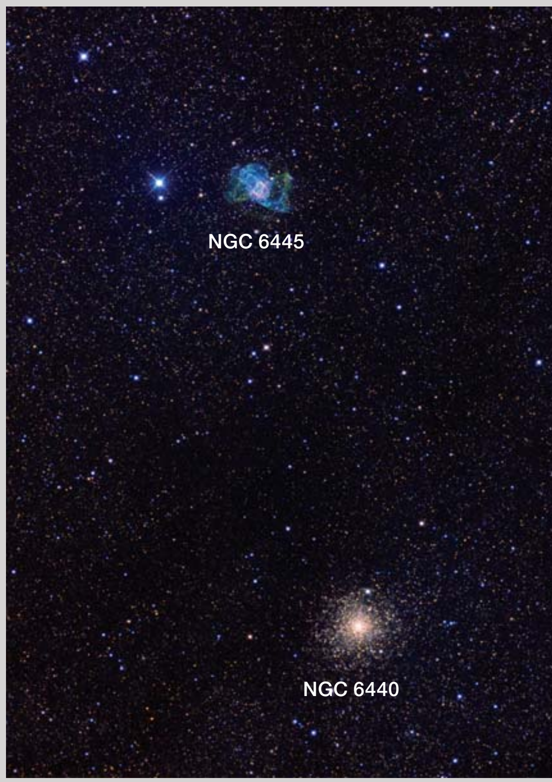
Arizona amateur Frank Kraljic says that through his 10-inch reflector at 112×, NGC 6445 resembles a slightly top-heavy, hollowed-out, rectangular box. The northern and southern walls are distinctly brighter, with the former shorter but more intense. There are hints of faint extensions reaching out from the perimeter of the nebula. Kraljic tells me that an O III filter worsens the view, but a narrowband filter enhances contrast of the planetary's walls. In addition, he finds NGC 6445's interior to be darker in its northern half.

Next, we'll move northward to Lyra, where the planetary nebula **NGC 6765** resides with its neighbor **Messier 56**, a globular cluster. Let's start with M56, which is brighter and reasonably straightforward to locate 1.7° west-northwest of the star 2 Cygni. Even with my 15×45 image-stabilized binoculars, M56 is an easily noticeable hazy patch with a broadly brighter center and a faint star off the western side. The cluster is quite pretty through my 105-mm refractor at 87×. Its 1¾′ core is mottled, bright, irregular, and surrounded by a star-spattered halo that fades away near the western star. A magnification of 127× pulls out a few stars in the core. My 10-inch scope at 166× shows an irregular, partly resolved core and a nice mixture of faint to fairly bright stars scattered across the cluster.

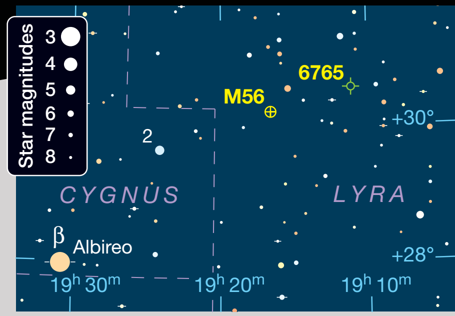
A 6th-magnitude orange star lies

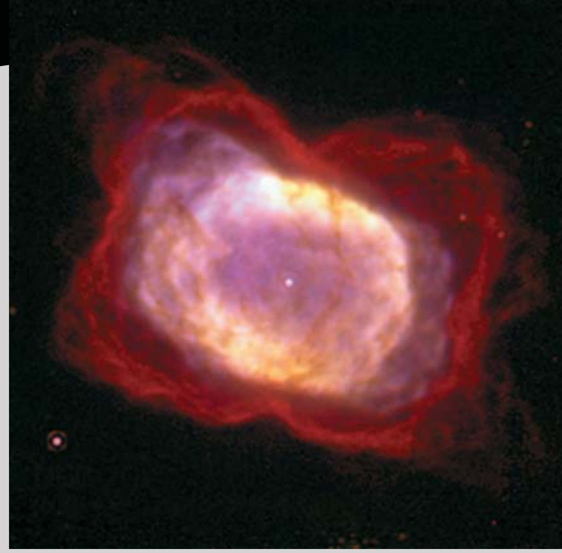
▶ Visible even in small telescopes, NGC 6445 shares the field in low-power views with the brighter globular cluster NGC 6440 just 22′ to its south-southweest.





NGC 6563: ADAM BLOCK / MOUNT LEMMON SKYCENTER / UNIVERSITY OF ARIZONA; NGC 6445 AND NGC 6440: MIKE SIDONIO





▶ This visible and infrared image from the Hubble Space Telescope captures small-scale detail in the planetary nebula NGC 7027 that can't be seen in backyard telescopes, but the large-scale features are visible to the keen-eyed observer with a 10-inch scope.

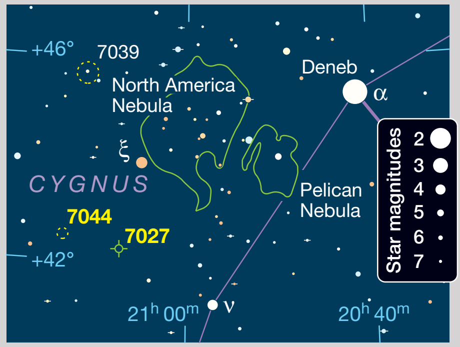
26′ northwest of M56, and NGC 6765 is 1° west from there. It's a very faint planetary for my little refractor at 87× and increasing the power to 122× helps more than any nebula filter. The planetary appears elongated north-northeast to south-southwest and is about ½′ long. An O III filter is much more helpful with my 10-inch reflector. At 219× NGC 6765 displays a patchy bar that's brightest at the northern end. There seems to be a faint haze around the bar, especially to the east. The nebula spans about 35″ through my 10-inch scope and 40″ through my 14.5-inch.

Our final planetary nebula is **NGC 7027** in Cygnus. It's parked at the right angle of a triangle that it makes with Xi (ξ) Cygni and the open cluster **NGC 7044**. Through my little refractor at 87×, the cluster is a hazy ball with two faint stars in the eastern side. My 10-inch scope at 118× reveals a lovely diamond-dust cluster with many very faint stars enmeshed in a misty glow 4½′ across.

NGC 7027 is an aqua nebula with a tiny bright center in my 105-mm scope at 47×, while at 127× with an O III filter, I see it as an oval tipped northwest. Through my 10-inch scope at 213×, the nebula has a striking bluish green color. It shows two distinct lobes separated by a narrow lane and surrounded by a faint halo. The northwestern lobe is larger with a minute bright spot in its western edge. The southeastern lobe is a bit dimmer and elongated east-northeast to west-southwest. At 299× the color is not as strong, but the nebula appears wonderfully complex. The halo becomes prominent and the division between the lobes even more distinct. The area surrounding the intense spot is quite bright. The spot itself is nonstellar and remains bright when viewed through an eyepiece with an O III or narrowband filter, attesting to its nebular nature.

The planetaries showcased here give us just a little taste of the varied forms these nebulae take, intriguing forms that place planetary nebulae among the many magical things in our universe.

■ Contributing Editor **SUE FRENCH** wrote this column for the July 2009 issue of *Sky & Telescope*.



A Midyear Hunt for Magical Things

Object	Type	Mag(v)	Size/Sep	RA	Dec.
NGC 6563	Planetary nebula	11.0	48″	18h 12.0m	–33° 52′
h5036	Multiple star (h5036 C, D)	8.7, 10.2	22.4″	18h 17.7m	–34° 05′
RS Sgr	Double star (h5036 A/B)	6.0, 9.5	39″	18h 17.6m	–34° 06′
NGC 6445	Planetary nebula	11.2	44″	17h 49.2m	–20° 01′
NGC 6440	Globular cluster	9.3	4.4′	17h 48.9m	–20° 22′
h2810	Double star	7.6, 10.4	44″	17h 49.6m	–20° 00′
NGC 6765	Planetary nebula	12.9	40″	19h 11.1m	+30° 33′
Messier 56	Globular cluster	8.4	8.8′	19h 16.6m	+30° 11′
NGC 7027	Planetary nebula	8.5	18″ × 11″	21h 07.0m	+42° 14′
NGC 7044	Open cluster	12.0	7′	21h 13.1m	+42° 30′

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.

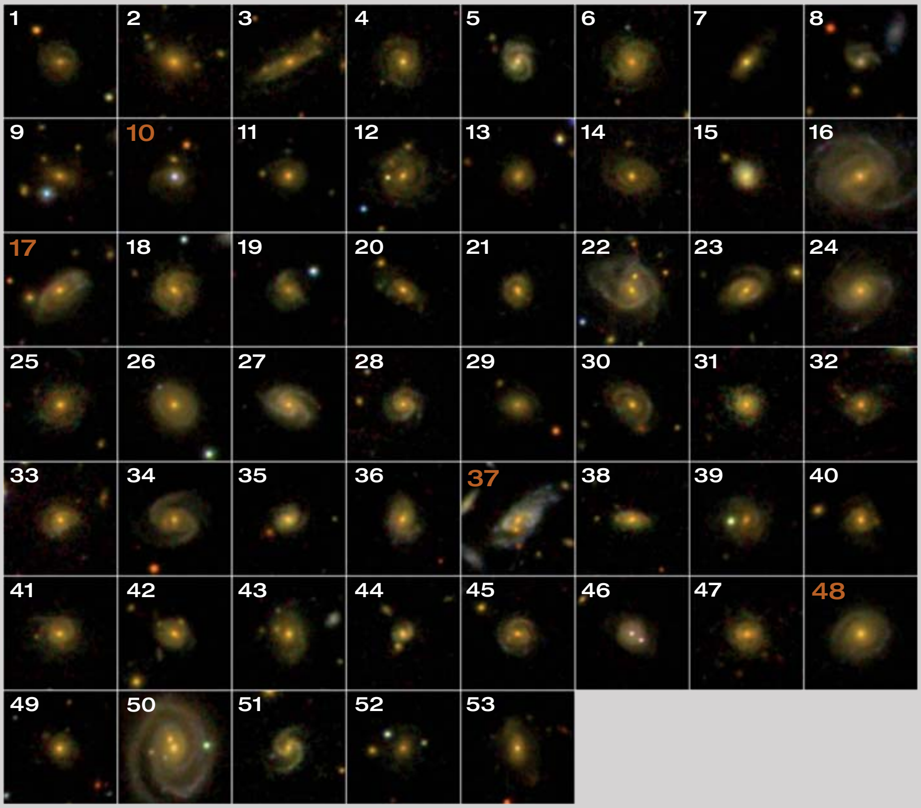
WILLIAM B. LATTER (SIRTF SCIENCE CENTER / CALTECH) AND NASA / ESA

Super Spiral Galaxies

Astronomers recently identified a new category of spiral galaxy. Read on to find out how to observe them.

The volume of published information is staggering. In my field of medicine alone more than 900,000 articles were published in 2018. Millions of studies in diverse fields are reported annually in many thousands of journals, recording the painstaking procedures whereby research progresses. It's a rarity when a revolutionary breakthrough — such as the detection of the Higgs boson — occurs in an established discipline, and it's even more rare for a whole new category of object to emerge.

So when I came across a paper in 2016 by Patrick Ogle of Caltech and his colleagues describing a new class of spiral galaxy, it was a *big* surprise. Surely, by now, astronomers had sorted out all the subtypes of galaxies. How could anything have escaped the myriad surveys and intense scrutiny of the Hubble Space Telescope and ten-meter-class reflectors? But there they were, hiding in plain sight.



▲ **A MENAGERIE OF SUPER SPIRALS** The photomontage shows all 53 superluminous spiral galaxies in the paper by Ogle and colleagues. The four discussed here are labeled in red.

Discovery of Super Spirals

Ogle and his team trawled through the NASA/IPAC Extragalactic Database as part of an ongoing research project to determine its completeness. They selected galaxies with redshifts less than 0.3 (i.e., light left them less than 3.5 billion years ago) and luminosities more than eight times that of the Milky Way. These criteria, intended to "capture the rarest, most luminous galaxies," yielded 1,616 objects. Further culling based on quantity and quality of data resulted in a sample of a couple hundred bright and massive galaxies. Most of the galaxies were ellipticals, but to the team's surprise, 53 were spirals. They dubbed the latter superluminous spiral galaxies, or super spirals.

The super spirals range from 30 to 340 billion solar masses and from 180,000 to 437,000 light-years in diam-

PATRICK OGLE ET AL. / *THE ASTROPHYSICAL JOURNAL* 2016

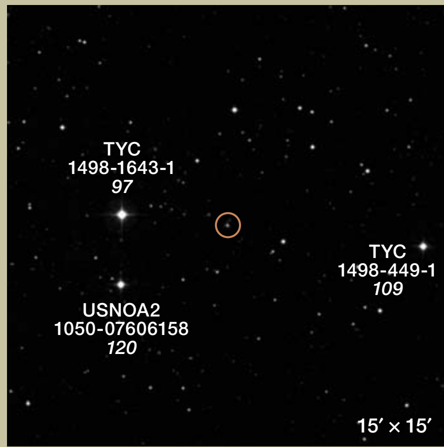
Superluminous Spirals

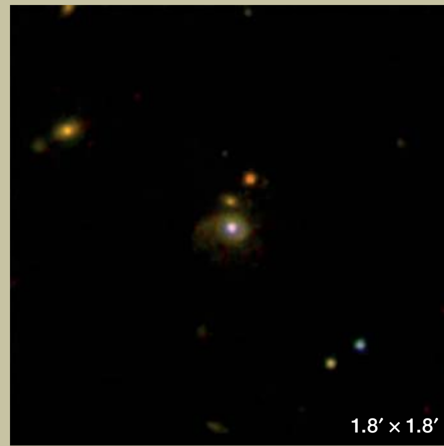
Ogle Number	Object	Redshift (z)	Light-travel time (Gl-y)	Diameter (kl-y)	Mag(v)	RA	Dec.
10	2MASX J15430777+1937522	0.23	2.8	214	16.9	$15^h\ 43.1^m$	19° 38′
17	2MASX J11535621+4923562	0.17	2.1	294	16.1	$11^h\ 53.9^m$	49° 24′
37	2MASX J16014061+2718161	0.16	2.1	268	16.3	$16^h\ 01.7^m$	27° 18′
48	2MASX J13435549+2440484	0.14	1.8	198	15.9	$13^h\ 43.9^m$	24° 41′

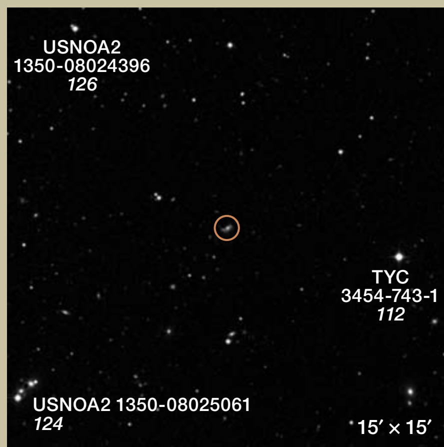
Magnitudes are calculated from SDSS g and r values. Sizes are from recent catalogs. Visually, an object's size is often smaller than the cataloged value and varies according to the aperture and magnification of the viewing instrument. Right ascension and declination are for equinox 2000.0. Light-travel times are computed from redshifts according to current cosmological models. Galaxy names incorporate full coordinates.

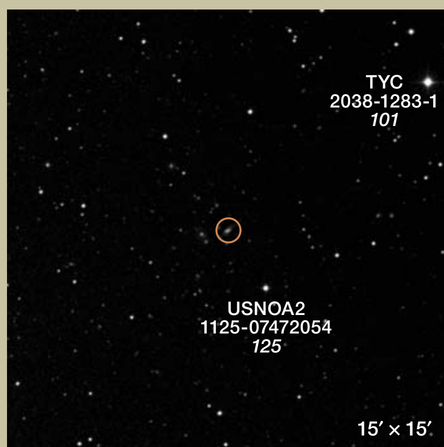
eter. This means that the largest spirals in the sample exceed our Milky Way by up to 14 times in luminosity and four to five times in size. The closest is 1.2 billion light-years away and the farthest 3.5 billion. Super spirals spin much faster than their smaller counterparts — some rotate three times as fast as the Milky Way — which is likely attributed to extremely massive halos.

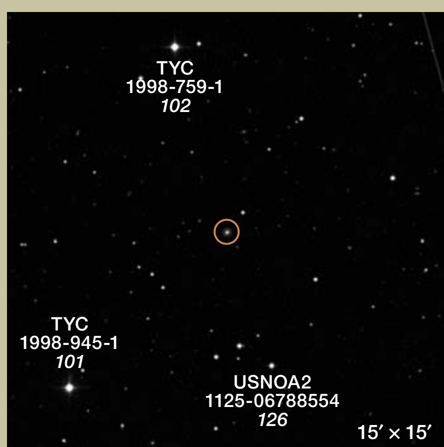
They're a heterogeneous group and include six active galactic nuclei (AGN): four Seyferts and two quasars. Four super spirals exhibit double nuclei or stellar bulges, signatures of merging activity. Nearly one-fifth of the group appear to be brightest cluster galaxies, a distinction usually reserved for ellipticals. Some instead are isolated in space. Several display signs of tidal interaction — shells, extended arms, and disturbed morphology. Starburst activity is present in several, and the star-formation rate of the whole sample is very high, ranging from 5 to 65 solar masses per super spiral per year. By contrast, our Milky Way converts 1 solar mass of material into stars every year. In addition, the five most rap-

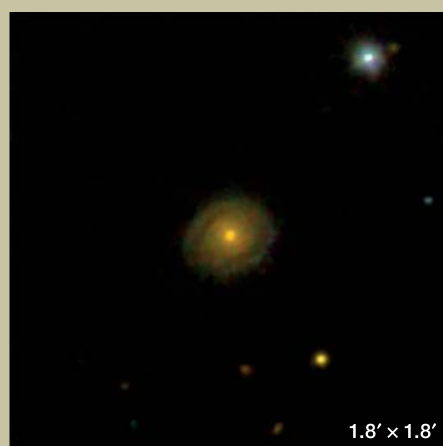












▶ **HOW TO FIND THE SUPER SPIRALS** The left-hand column shows *POSS-II* finder images of the super spiral fields, while the images in the right-hand column are SDSS close-ups of the galaxies. Image dimensions are noted, as are the names and magnitudes of select stars.

Number 10 *(Top)* The author observed this quasar at the 2018 Texas Star Party and saw only the nucleus.

Number 17 *(Second from top)* A brightest cluster galaxy, this super spiral is also a Seyfert. Other cluster members are visible in the image, but at the Texas Star Party the author only spotted the super spiral.

Number 37 *(Second from bottom)* Another brightest cluster galaxy, this super spiral sports a binary nucleus and displays a disturbed morphology. As with Number 17, other cluster members are visible in the image.

Number 48 *(Bottom)* The brightest of the four super spirals observed, this one is also the third smallest in the Ogle sample.

idly star-forming super spirals are all smaller than the group median.

The high rate of star formation in galaxies this massive is certainly curious — normally they'd be populated with old and red stars. Ogle and his team studied various factors that contribute to the star-formation rate, such as cold gas accretion rates through the halo, accretion shocks, as well as the density of the intergalactic medium. They speculate that super spirals could be a remnant population of massive disk galaxies that somehow still maintain active star formation, i.e., the cold gas supply that eventually becomes stars isn't cut off for some reason. One scenario proposes that when this gas supply is eventually quenched, super spirals evolve into lenticulars or ellipticals. Identifying fossil giant disks devoid of star formation around lenticular or elliptical galaxies would support this theory.

Based on their sample, the team estimates that there are about 60 super spirals per cube of 3.3 billion light-years on a side, which is only 6% of the space density of elliptical galaxies of the same luminosity. This makes super spirals very rare. In fact, they're so rare that even the most powerful cosmological simulations don't have the capacity to predict how many super spirals there should be nor how they form.

> This means that the largest spirals in the sample exceed our Milky Way by up to 14 times in luminosity and four to five times in size.

Observing Super Spirals

What can amateurs expect to view in the eyepiece? Fortunately, by definition, at 8 to 14 times the luminosity of the Milky Way super spirals are relatively bright. This makes them 2.5 to 3 magnitudes brighter than what a galaxy similar to ours would be if placed at the same distances.

In addition, AGNs give a boost to visibility — the halos of these galaxies are much fainter than their cores. In some cases, amateurs may see only the quasar or Seyfert nucleus (as I did with one of the objects I observed).

Just one of the 53 galaxies in Ogle's sample was previously cataloged in a familiar source: Number 50 in the list is CGCG 122–067. The rest either have Sloan Digital Sky Survey (SDSS) or Extended 2 Micron All-Sky Survey (2MASX) designations — not exactly tip-of-the-tongue monikers. The sample's magnitudes range from 15.9 to 16.9, potentially making all of them accessible to a 20-inch reflector. Visual inspection of the photomontage of SDSS images on page 57 shows that every galaxy has a moderately bright nucleus and about two-thirds have discernible spiral structure. For amateur-size instruments the *National Geographic Society — Palomar Observatory Sky Survey* (*POSS*) is a much better gauge of visibility. Several of the larger galaxies, such as numbers 16, 22, and 50, should show spiral structure in large-aperture reflectors.

In moderately poor observing conditions at the 2018 Texas Star Party I turned my 32-inch f/4 reflector on four super spirals. **Number 10** in Ogle's list is a quasar, which I saw merely as a 17th-magnitude stellar object, with no sign of the surrounding galaxy. It reportedly has the highest star-formation rate of the group, but this may be overestimated from the infrared heating effect of its active nucleus.

Number 17 is the brightest galaxy in a cluster identified and cataloged by Ogle and collaborators (OGC 0586). This super spiral is also classified as a Seyfert galaxy, in which the active nucleus is partially obscured due to viewing angle. In the eyepiece of the 32-inch, some traces of the galaxy extensions were visible to the northwest and southeast. I'm sure I'd spot some additional cluster members in better conditions with prolonged inspection, but I didn't this time.

Number 37 in Ogle's list is also a brightest galaxy in a cluster. This super spiral sports a binary nucleus, one central and one offset, indicating a likely merger between a larger and a smaller galaxy. It also displays a markedly disturbed morphology with tidal arms and tails splayed to the northwest and southeast, but the *POSS-II* image only hints at them. At the Texas Star Party, I saw only the central portion of the 16th-magnitude galaxy, inclined at a position angle of about 130°. I also spotted several other members of the host cluster, GMBCG J240.41924 +27.30444. In fact, the two ellipticals around 50″ east and east-southeast of the super spiral actually appeared brighter.

The last source I observed in the hour or so I spent on super spirals at the star party was the nondescript **Number 48** in the list. At magnitude 15.9, it was the brightest of the four I viewed. It was also the third smallest of Ogle's sample at slightly less than 200,000 light-years across. The SDSS image clearly shows the surrounding galaxy, but in the *POSS-II* image that's all but washed out. There was no hint of outer spiral arms in the eyepiece of the 32-inch, and it would likely take perfect conditions to tease them out at the galaxy's 1.8 billion light-year distance.

I plan to spend more time on this project. I hope to dissect Number 50, the closest superluminous spiral galaxy at 1.2 billion light-years, with the apparent largest size of about 35″ × 30″, and Number 11, the most distant at 3.5 billion light-years. All but a few of these goliaths are in the Northern Hemisphere sky between 8 and 17 hours of right ascension. Next time you have access to a large reflector try adding a new type of super galaxy to your collection.

■ **DAVE TOSTESON** chases deep-sky objects in between keeping up on all the latest medical developments.

FURTHER READING: To read the original paper go to **https://is.gd/ogle_apj** (Ogle, P. M. et al., "Superluminous Spiral Galaxies," *The Astrophysical Journal*, Vol. 817, p. 109, 2016).

 by Jerry Oltion

A Tourist's G
to the Sum

Roam the summer skies and revel in this collection of fine objects in and around Sagittarius.

There's an old story about a bunch of miners wintering in a cabin. They have a joke book, but everybody has read it so often they've memorized it, so when someone wants to tell a joke they just call out the page number.

Summer's "big, bold, bright, and beautiful" highlights are a bit like that. I just have to say "page 67" and anybody with a copy of *Sky & Telescope's Pocket Sky Atlas* will have enough information for an entire night of observing.

Indeed, in the summer I spend more time on that page than on any other. Why? Because page 67 contains Sagittarius, and Sagittarius contains the core of the Milky Way. When we look in that direction, we're looking right into the Grand Central Station of our galaxy — the gravitational hub around which everything else revolves. Globular clusters hover around it like bees around a hive, nebulae (both bright and dark) abound, and the sky is thick with stars.

Toward the Center

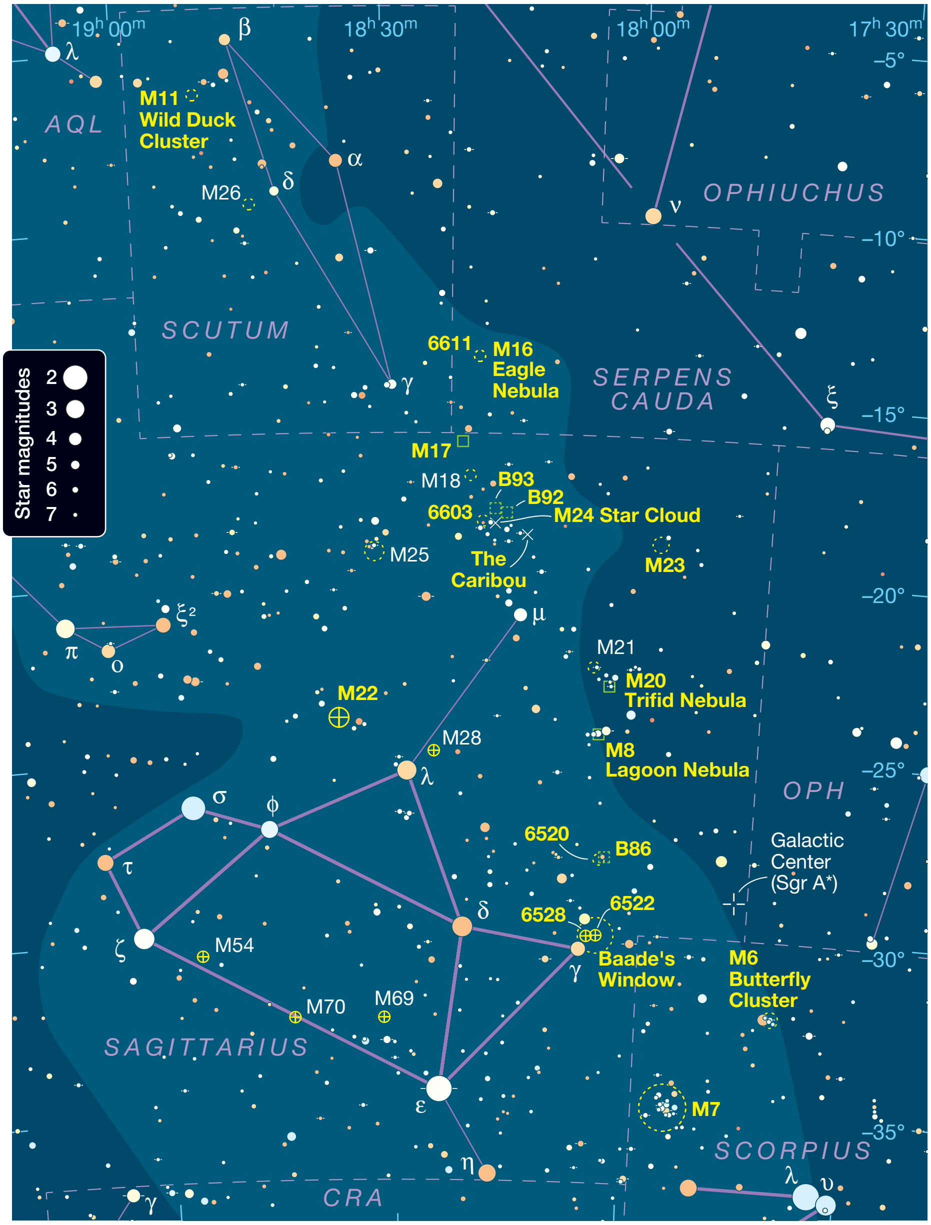
Let's make our first stop right at the very heart of the galaxy, lying some 26,000 light-years away. Normally we wouldn't be able to see it through all the intervening gas and dust, but in the 1940s German astronomer Walter Baade discovered that there's a small gap in the clouds that let him peer all the way to the core. That gap is called **Baade's Window** in his honor.

Baade's Window is easy to find: It's just off the spout of the Sagittarius Teapot, centered on the globular cluster **NGC 6522**. The area is about 1° across, but you won't see any obvious boundaries. Instead what you'll see is a field of view so packed with stars that if NGC 6522 weren't there for scale, you'd swear you were looking at a high-magnification view of a globular cluster. The stars that you can resolve are mostly closer than the galactic core, residing in our own Orion Spur or the Scutum-Centaurus Arm that sweeps across between us and the core. But the hazy glow that doesn't resolve is the light from millions of stars in the core itself.

You'll likely notice another globular cluster in the same field of view, just east of NGC 6522. **NGC 6528** is smaller and dimmer (despite their official magnitude listings in the table on page 66), but still quite easy to spot even against the

SPLASH OF STARS The globular cluster Messier 22 in Sagittarius lies at a distance of around 10,000 light-years from Earth. It's one of the brightest globulars in the sky.

M22: ESA / HUBBLE / NASA; ALL IMAGES BY THE AUTHOR UNLESS OTHERWISE NOTED



background glow. These two clusters are 11–12 billion years old, which make them two of the oldest globulars known.

Lying 2° directly north of Baade's Window you'll find the compact open cluster **NGC 6520**. While this is a nice object in its own right, with its young blue stars standing out against the yellower stars deeper toward the galactic core, the main attraction here is **Barnard 86** just a smidgen to the west. B86 is a dark nebula that's so dense no stars are visible through it. The few stars you can see against the blackness are in the foreground. It's clouds like this that mask the core of the galaxy from our view in all but Baade's Window.

Follow the Steam

From here the logical course is to simply follow the "steam" of the Milky Way rising out of the spout of the Teapot. But if you do that you'll miss **M6** and **M7** — two great open clusters just over the border in Scorpius. They're visible to the naked eye under a dark sky and are glorious in binoculars or a wide-field telescope.

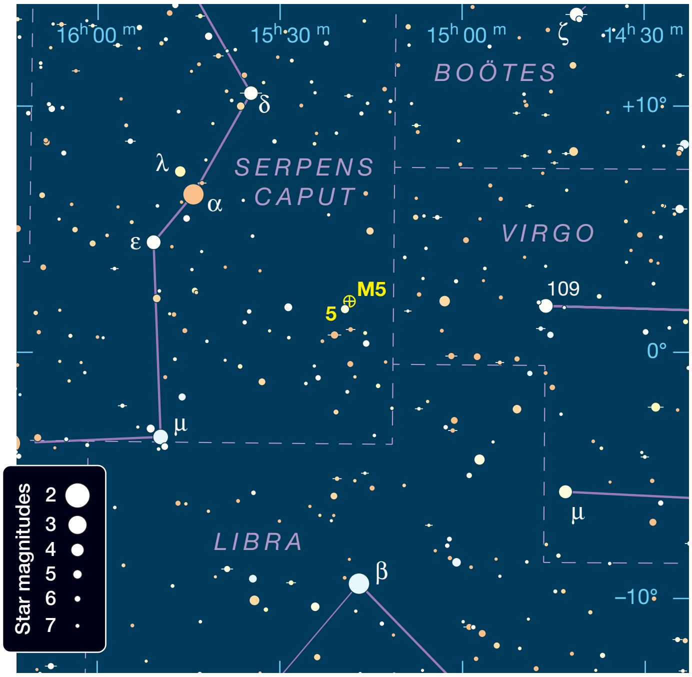
Of the two, M6 is my favorite. It's smaller than M7, but richer and more delicate. It's often called the Butterfly Cluster, for reasons that are obvious in binoculars but less so in telescopes. Its stars appear bright blue and conspicuous, arranged in a wide oblong that suggests the wings of a butterfly. There's even a fairly obvious V of stars that form the butterfly's antennae.

M7 is bigger and showier than M6 and so bright it's easily spotted without optics. The Alexandrian astronomer Ptolemy mentioned it as early as 130 AD and described it as "a little cloud following the stinger of Scorpius." Commonly known as Ptolemy's Cluster, its stars are brighter and more widely spaced than in M6, but similar in number (about 80). The reason for that is distance: At 800–1,000 light-years, M7 is only about half as far as M6.

As long as we're in the neighborhood, we should stop by **M4**, a globular cluster in Scorpius a little more than 1° west of Antares. At a distance of 7,000 light-years, M4 is one of the nearest and brightest globular clusters in the sky. But at declination –26° it's close to the horizon for Northern Hemisphere observers. M4 is well worth a look, though, since it's probably the easiest globular to resolve into individual stars all the way to the core. In fact, there's an obvious chain of stars running right through it. The cluster is just a smidgen bigger than the Moon, so use low to medium power. M4 is disappointing in twilight or in light-polluted sky, but it's glorious in full darkness.

Globulars Galore

Sagittarius, Scorpius, and Ophiuchus are all lousy with globular clusters. Not surprisingly, Charles Messier picked all the low-hanging fruit, so all the brightest have Messier numbers. One of my favorites is **M5** next door in Serpens. Why? Because I discovered it by naked eye long before I'd tracked down all the Messier objects. I was looking into Serpens Caput through a gap in some trees when I saw what looked like a fuzzy star. I got out the binoculars and had a look, and sure enough, a fuzzy star! In a telescope it resolves into one of the richest globular clusters in the sky.



M5 is actually marginally brighter than M13, the great Hercules cluster. The Serpens globular has a tight core that's so packed with stars it's difficult to resolve, but the outer reaches break into thousands of stars. The cluster lies around 24,500 light-years away and spans about 165 light-years, making it one of the largest known.

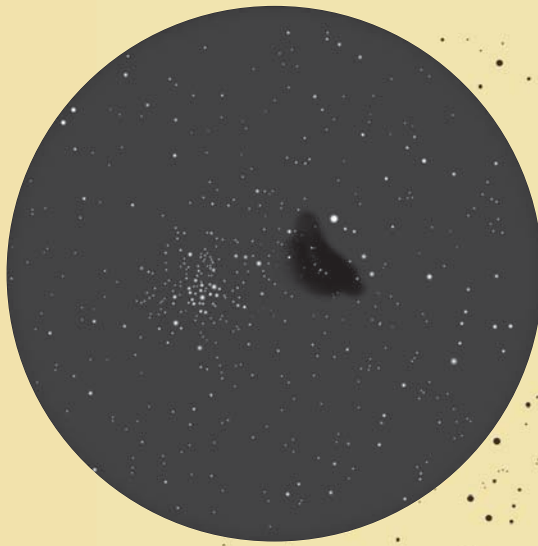
The bright star near M5, **5 Serpentis**, is a nice double. Its 5th- and 10th-magnitude components are separated by 11″. The faintness of the companion makes this a bit of a challenge, but I'm able to split it easily in an 8-inch scope, and I bet it's doable at half that aperture.

Compare M5 to **M22**, just 2.5° northeast of Kaus Borealis, the top star of the Teapot in Sagittarius. M22 is even brighter and bigger than M5, but that's due to its relative proximity rather than its intrinsic size. At a distance of 10,000 light-years, it's less than half as far away as M5, which makes resolving its individual stars a little easier. The cluster's looser core also helps with that.

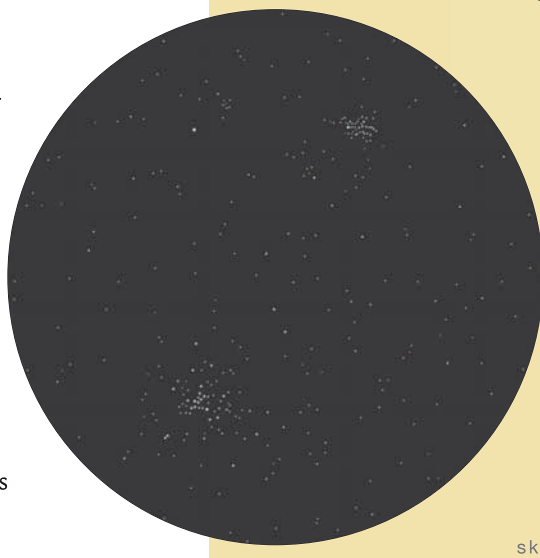
Dive into Nebulae

I could fill an entire article with globular clusters, but there's so much more to see! Let's finally take that stroll up the steam rising out of the Teapot, starting with **M8**, the Lagoon Nebula. If the Orion Nebula is the luminary of winter, the Lagoon is its summer counterpart. It's easy to spot by naked eye and is glorious in binoculars. With the Lagoon you get a twofer: There's a large, bright emission nebula and an associated open cluster embedded within it. A nebula filter greatly increases the extent of the glowing gas, at the expense of the cluster. The nebula is

▲ **PEERING TOWARD THE CENTER OF THE MILKY WAY** Baade's Window offers a peek into the core of our galaxy, with a couple of globular clusters thrown in for spice. FOV=20°
All sketches have north upwards.



▲ **NGC 6520 AND BARNARD 86** An open cluster nestles with an ink spot in space. FOV=30′



◀ **M6 AND M7** Both of these open clusters, the Butterfly and Ptolemy's, are visible to the naked eye under dark skies. FOV=6° 20′

split in two by a dark lane, which is the "lagoon" in its name. Stars are being formed here, so stick around a few dozen millennia — it will only become more impressive with time.

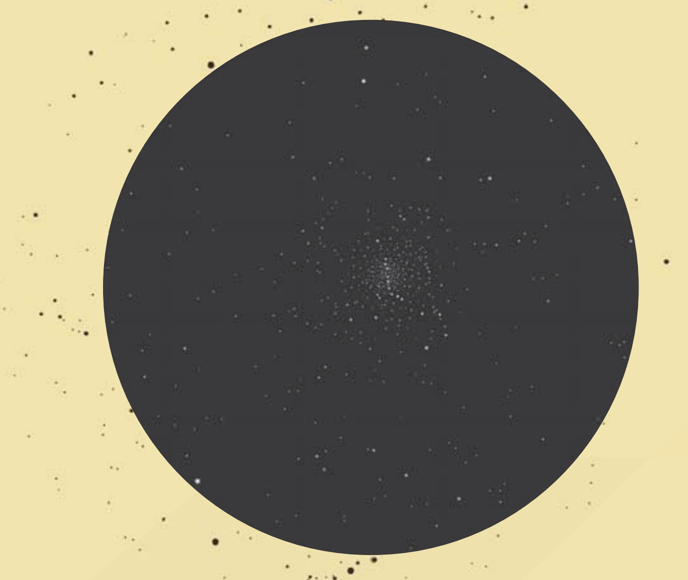
You can't look at the Lagoon without moving north 1.5° to **M20**, the Trifid Nebula. Its listed magnitude of 6.3 is deceptive; this nebula is spread out enough to have a fairly low surface brightness, but with a little aperture and/or a nebula filter it stands right out. It, too, comes in two parts: the emission nebula with the three-vaned dark lane in front of it that gives it its name, and a reflection nebula just to the north of that. In photographs the emission nebula is bright red while the reflection nebula is pale blue, yet to the eye in a relatively large-aperture telescope, it looks just the opposite.

Why is that? I have a theory: Because our eyes are much more sensitive to blue-green than to red light, when we just barely begin to perceive color we see it as green. The red emission nebula is brighter than the blue reflection nebula, so our brains interpret it as green, which makes the other one red in comparison.

There's a bonus at the heart of the emission nebula: The central star is a triple. Another reason to call it the Trifid!

Rather than continue straight up through the steam, let's shift a little to the right to catch an underappreciated open cluster, **M23**. With all the other spectacular sights around, M23 is often overlooked, but in any other part of the sky it would be the showcase object — and I believe it should be here, too. M23 is a beautiful cluster, filled with streams of stars, including one that leads to a 6.5-magnitude star at the northwest edge of the cluster. M23 is about the same size as the Moon, so it's great in binoculars or in a telescope at low power. But this cluster continues to reward every increase in magnification until it overfills the field of view. Spend some time here!

▼ **M4** One of the closest and brightest globular clusters, in telescopes M4 has a distinctive string of stars running through it. FOV=45′



Celestial Creatures

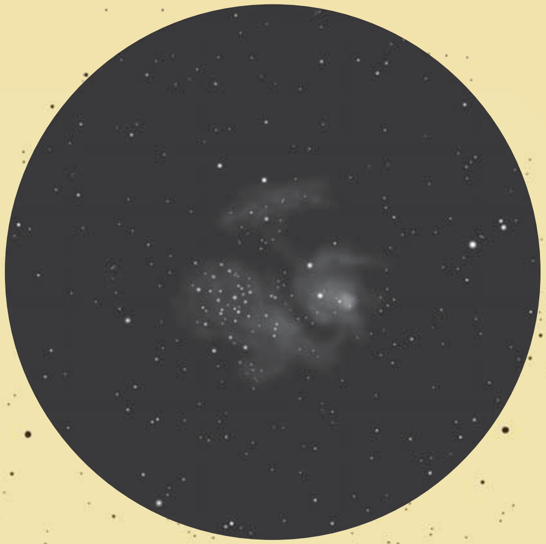
Diving back into the Teapot's steam we come to **M24**, the Great Sagittarius Star Cloud. This is a huge patch of Milky Way that stands out from behind the intervening dust and gas much like Baade's Window. It's easy to spot with the naked eye and is glorious in binoculars. In all but the widest-field telescopes it extends beyond the field of view, but that's okay; it's great fun to drive around in this thick cloud of stars. You'll find two distinct dark nebulae, **Barnard 92** and **Barnard 93**, forming what I call the "coal miner's lungs," and a tiny cluster within the cluster of objects, **NGC 6603**.

You'll also find an asterism that I call the **Caribou**. It's made up of a couple of obvious arcs of stars that form the rump and back and neck of the animal, with its head down as if cropping grass, and another distinct arc of stars with forward-facing spurs that looks for all the world like a rack of antlers. This is one of those asterisms that you can't unsee once you've seen it. It's not just a deer; it's a caribou!

As long as we're looking at celestial animals, let's move on up the steam cloud to **M17**, the Swan Nebula. This is a large, obvious swatch of brightness against a rich stellar background, with a curved extension rising from its western end. In the inverted field of a Newtonian telescope it looks for all the world like a duck floating on a pond. Wait . . . a duck? Not a swan? Nope. The neck is too short to be a swan. It's a duck. But we call it the Swan Nebula because . . . just because.

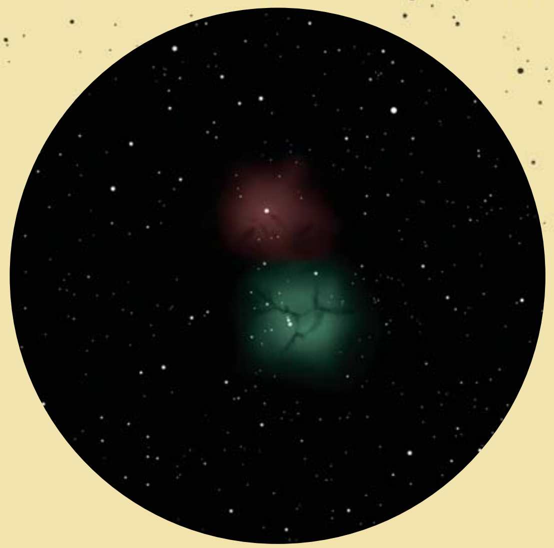
Put a nebula filter on this one and you'll see a lot more nebulosity surrounding it. Now it's a duck in a fog bank.

Onward north and veering slightly west some 2° you'll find **M16**, the Eagle Nebula. This one looks sort of vaguely eaglelike in photographs, but in a telescope you're just going to see a patch of nebulosity at the northern end of an



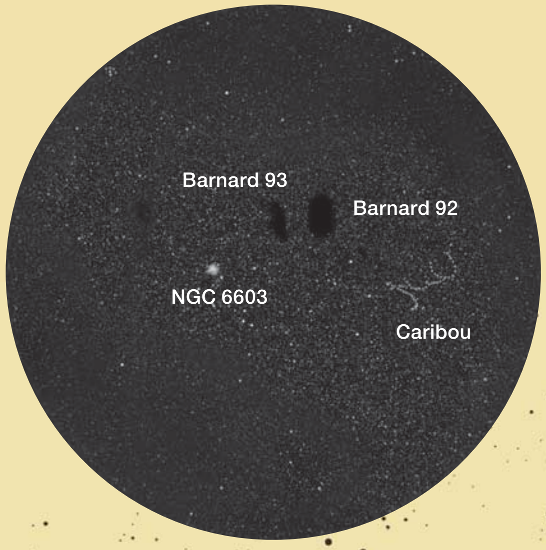
◀ **M8** The Lagoon Nebula is the summer's showpiece emission nebula and open cluster. FOV=50′

▶ **M20** The Trifid Nebula needs dark sky and a nebula filter, or plenty of aperture. With a big enough telescope you'll see subtle colors, but they'll be the reverse of reality! FOV=35′



◀ **M23** This open cluster is often ignored in favor of nearby gems, but it's a jewel in its own right. FOV=1° 10′

▶ **M24** This star cloud contains many excellent sights, including the open cluster NGC 6603, the dark clouds Barnard 92 and 93, and the Caribou asterism (turn the page around to see the Caribou right-side-up). FOV=3° 20′



◀ **M17** This nebula looks more like a duck than a swan to me. Would you agree? FOV=1°

▶ **M11** The Wild Duck Cluster is a sparkling spectacle in any telescope. FOV=20′

S-shaped asterism of stars, the upper half of which is the cluster **NGC 6611**. Under any kind of light-polluted sky, you might see only the cluster until you try a nebula filter.

The Hubble Space Telescope's famous Pillars of Creation image was taken here, just at the southern edge of the cluster. I've tried to see the Pillars in a telescope, but it has proven elusive even in my 20-inch.

We'll end with one more animal: **M11**, the Wild Duck Cluster. This is an open cluster 11° northeast of the Eagle Nebula and nestled into a curve of bright stars at the border of Scutum and Aquila. Composed of several hundred visible stars (and many more fainter ones) all packed into a spot of sky smaller than the Moon, M11 is one of the most impressive open clusters in the sky. A single bright star dominates the field, and the rest are arranged in a rough square whose V-shaped edges apparently led 19th-century British astronomer William Henry Smyth to declare that it resembled "a flight of wild ducks."

I've seen a lot of geese fly in V-formation, but not so many ducks. But who wants to go off on a wild goose chase? So the "wild duck" it is.

You will note that there's plenty more steam rising out of the teapot. I'll leave that remaining steam for you to investigate on your own. But I'll just provide one last bit of direction: "page 62."

■ Contributing Editor **JERRY OLTION** hopes someday to study pages 48 and 49. Contact Jerry at **j.oltion@gmail.com**.

FURTHER READING: For more "big, bold, bright, and beautiful" objects, see Jerry Oltion's articles for other seasons: *S&T:* May 2018, p. 22; *S&T:* Oct. 2018, p. 28; and *S&T:* Jan. 2020, p. 62.

Summer's Splendors

Object	Designation	Type	Mag(v)	Size/Sep	RA	Dec.
Baade's Window	Core of Milky Way		4	~1°	$18^h 03.6^m$	–30° 02′
	NGC 6522	Globular Cluster	9.9	9.4′	$18^h 03.6^m$	–30° 02′
	NGC 6528	Globular Cluster	9.6	5′	$18^h 04.8^m$	–30° 03′
	NGC 6520	Open Cluster	7.6	5′	$18^h 03.4^m$	–27° 53′
Barnard 86	B86	Dark Nebula	Dark!	5′ × 5′	$18^h 03.0^m$	–27° 52′
Butterfly Cluster	M6	Open Cluster	4.2	33′	$17^h 40.3^m$	–32° 16′
Ptolemy's Cluster	M7	Open Cluster	3.3	75′	$17^h 53.8^m$	–34° 47′
	M4	Globular Cluster	5.4	36′	$16^h 23.6^m$	–26° 32′
	M5	Globular Cluster	5.7	23′	$15^h 18.6^m$	+02° 05′
	5 Serpentis	Double Star	5.1, 10.1	11″	$15^h 19.3^m$	+01° 46′
	M22	Globular Cluster	5.2	32′	$18^h 36.4^m$	–23° 54′
Lagoon Nebula	M8	Emission Nebula / Open Cluster	6.0	40′ × 30′	$18^h 03.8^m$	–24° 23′
Trifid Nebula	M20	Emission / Reflection Nebula	6.3	20′ × 20′	$18^h 02.3^m$	–23° 02′
	M23	Open Cluster	5.5	25′	$17^h 56.9^m$	–17° 23′
	M24	Star Cloud	4.6	120′	$18^h 17.0^m$	–18° 36′
Barnard 92	B92	Dark Nebula	—	15′ × 9′	$18^h 15.6^m$	–18° 14′
Barnard 93	B93	Dark Nebula	—	5′ × 9′	$18^h 16.9^m$	–18° 04′
	NGC 6603	Open Cluster	11.1	4′	$18^h 18.5^m$	–18° 24′
The Caribou		Asterism	—	30′	$18^h 13.0^m$	–18° 48′
Swan Nebula	M17	Emission Nebula	6.0	20′ × 15′	$18^h 20.8^m$	–16° 11′
Eagle Nebula	M16	Emission Nebula	6.4	35′ × 28′	$18^h 18.6^m$	–13° 58′
	NGC 6611	Open Cluster	6.0	8′	$18^h 18.7^m$	–13° 48′
Wild Duck Cluster	M11	Open Cluster	5.8	11′	$18^h 51.1^m$	–06° 16′

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.

QHYCCD's New 60-Megapixel Camera

CMOS detectors are the future of astroimaging, and the new QHY600M camera is giving us a state-of-the-art taste of that future today.

▲ The QHY600M camera comes with an AC power supply, a full complement of cables, a 2-inch nosepiece, and a set of spacers that allow expanding the back-focus distance between the nosepiece and the camera's CMOS detector up to an additional 17 millimeters in increments as small as ½ mm.

ALL PHOTOS BY THE AUTHOR

QHYCCD's QHY600M Camera

U.S. Price: $5,000

qhyccd.com

What We Like

Extraordinary image resolution

Fast readout

Short back focus

What We Don't Like

Difficulty achieving quality flat-field calibration.

THERE'S A LOT TO TALK ABOUT with the new QHY600M camera from QHYCCD, so let's jump right in. And the first thing there's a lot of is pixels – 62,393,796 of them, according to the spec sheet for Sony's IMX455 back-side illuminated, full-frame, CMOS sensor, with slightly more than 61 million of them active imaging pixels. To put that into a bit of personal perspective, I got my start in digital astrophotography about 30 years ago with several cameras built around the TC211 CCD sensor made by Texas Instruments. It was small but still boasted nearly 32,000 pixels. Just one square millimeter of the QHY600M's chip contains more than twice that many pixels.

All those pixels translate into a chip capable of extraordinary image resolution. In theory, the QHY600M can resolve about 133 line pairs per millimeter. If we spin the clock back a few decades, that kind of resolution would typically outperform Kodak's Technical Pan film, the last great heartthrob for amateurs in the days of emulsion-based astrophotography. The QHY600M is the kind of camera many amateurs have long wished for — the resolution of fine-grain film coupled with the sensitivity of modern digital detectors. But, as the saying goes, sometimes we should be careful what we wish for. Hold that thought for now.

Hardware

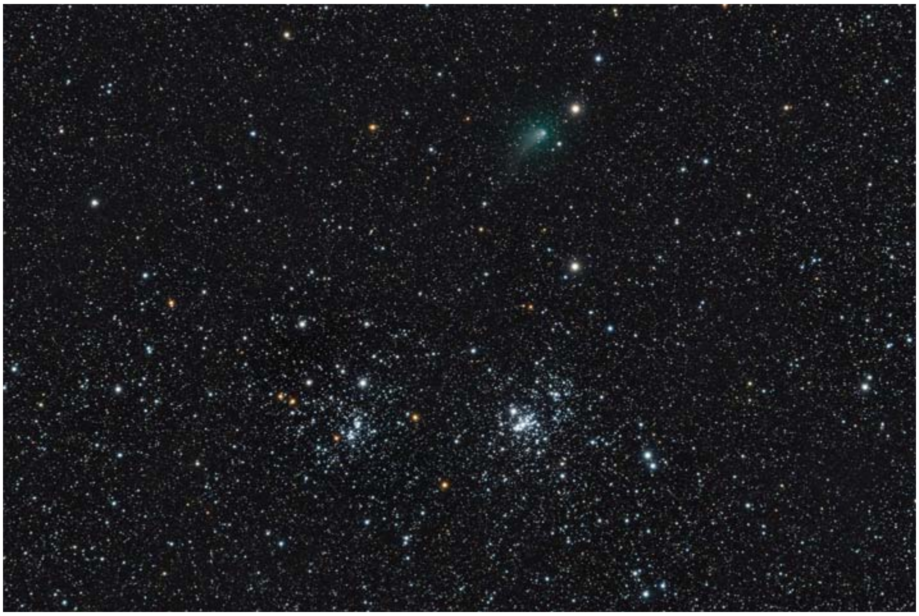
The QHY600M's vital specifications are listed in the camera manual, which can be downloaded for free from the company's website (**qhyccd.com**), so I'll only highlight a few here. The camera body reminds me of a large beverage can. It's 3½ inches (90 mm) in diameter, 7 inches long, and weighs 2 pounds (0.9 kg). The chip is set back only 17½ mm from the front of the camera body, but this distance increases to a minimum of about 26 mm when the mounting ring and 2-inch nosepiece are in place. An included set of spacers allows stretching this setback an additional 17 mm in ½-mm increments — a nice feature for anyone needing critical back focus in an optical system.

I tested the QHY600M paired with its mating QHYCFW3 filter wheel, which comes with two carousels; one for nine 50-mm-round filters and the other for seven 50-mm-square filters. The round filters I tested are really too small for this setup. While there was only slight vignetting at the corners of the frame, reflections from the filter edges often marred images and complicated the process of flat-field calibrations. Experience has shown that 50-mm-square filters are better suited for chips as large as the one in the QHY600M.

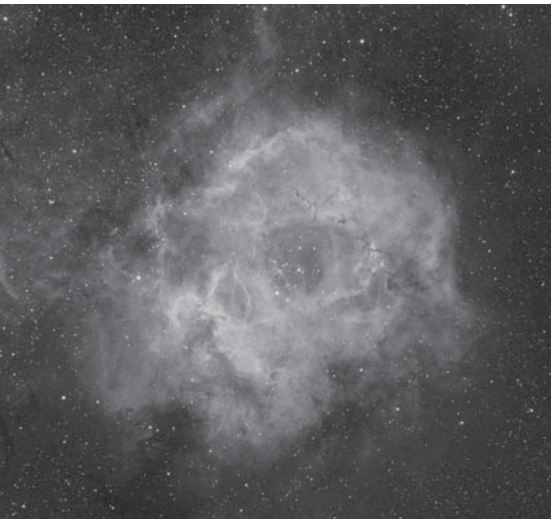
▲ *Left:* The camera's Sony IMX455 back-side illuminated (BSI) sensor contains more than 61 million 3.76-micron active imaging pixels in a 24-by-36-mm array, which is the benchmark size of a frame of 35-mm film. The camera does not have a mechanical shutter, so dark frames have to be made with a telescope's aperture covered. *Right:* The author tested the QHY600M camera with its mating QHYCFW3 filter wheel shown opened in this view. It comes with separate carousels for seven square and nine round 50-mm filters. As mentioned in the accompanying text, the round filters are a bit too small for the QHY600M camera. The filter wheel is 10 inches in diameter, weighs 3.7 pounds, and with its 2½-inch nosepiece consumes about 1 inch of back focus.

While the filter wheel is capable of stand-alone operation, my setup powered and controlled it via a single, short cable connected to the camera. Everything ran with just a 12-volt DC power cord and a USB 3.0 cable connected to the camera. The supplied USB cable is only 2 meters (6½ feet) long, but with a little juggling at the telescope I could keep my computer close enough to the camera to not need any extensions. A pending Professional version of the camera supports two 10-gigabit optical fiber connections, which offer fast image downloads and cable lengths spanning up to 300 meters. My USB 3.0 connection allowed frame downloads of slightly less than 5 seconds on a Windows 10 laptop and around 15 seconds on an older system running Windows 7.

The filter wheel comes with a 2½-inch nosepiece, since a 2-inch would certainly cause significant vignetting. Many modern astrographs have focusers large enough to accommodate the nosepiece, but it may present a problem for older setups. Fortunately, I have the ability to machine custom adapters, which I had to do for three of the telescopes I used.



▶ Comet C/2017 T2 was captured last January 29th as it passed by the Double Cluster in Perseus. This image was assembled from sets of 2-minute exposures made through RGB filters with a Tele Vue NP101is refractor and the QHY600M camera binned 2×2. Light pollution at the author's location severely limits exposure times made with broadband filters.



▲ Images here and on the facing page were made with the QHY600M shooting through a hydrogen-alpha filter. This view of the Rosette Nebula is a 60-minute exposure.

QHY600M Software

Software installation on PCs running Windows 7 and higher is relatively straightforward and involves downloading the latest drivers from the company's website. One is a native driver for the camera and another is for people running the camera as an ASCOM device with third-party programs such as *MaxIm DL*. I had a couple of stumbles with the Windows 7 laptop.

Initially, everything worked when I connected to the camera with *MaxIm DL 6,* but a failed attempt to run the camera with a previously installed version of QHY's *SharpCap* program resulted in nothing working until I deleted and reloaded the drivers. The problem was likely caused by me overlooking a detail in the manual about installing an updated version of the dynamic-link library file in the *SharpCap* program folder. Regardless, after getting everything working again with *MaxIm DL*, I stuck with it as my operating software. QHY says that the camera can also be used with its own "basic" deep-sky imaging program *EZCAP_QT*, which is available for free on its website.

While on the topic of software, I should note that FITs image files from the QHY600M may tax some image-processing programs, since each full-resolution image is a whopping 117-megabyte file. Yup, each image. Nine dark frames chew up more than a gigabyte of computer memory, and even a casual evening shooting celestial objects along with the usual calibration frames can consume 5 to 10 GB of disk space. Furthermore, not all image-processing programs can quickly (or even successfully) perform multiple-image operations such as stacking when individual files are this large.

Notes from the Field

I could write a lot about my experiences with the QHY600M, since it was my first extensive astronomical imaging with a CMOS (I accumulated more than 700 exposures while testing the camera). There are certainly differences when compared to using a CCD camera, but instead of diving too deeply into the details, I'd rather point you to Richard Wright's excellent article, "Changing of the Guard," in last May's issue, page 30. I agree with Richard's assessment that the current state of astronomical CMOS imaging isn't at the same level as CCD imaging, but it seems to be rapidly getting there. And to drive that point home, Richard mentioned amplifier glow in the corner of images as being a significant CMOS issue, but the QHY600M, which arrived in my hands shortly after Richard was putting the final touches on his article, has zero amplifier glow.

The QHY600M's two-stage thermoelectric cooler is capable of dropping the sensor's temperature at least 35°C below the ambient air temperature. The cooler has a built-in safety feature that completely shuts the camera down if the cooler runs too long at 100% power. During cold winter nights it only took a few minutes for the camera to reach my typical operating temperature of –25°C (the cooler quickly ramps up to 100% cooling when first turned on, then cycles to lower power once the set-point temperature is reached).

As warmer springtime evenings arrived, however, the cooler often ran at 100% power for too long, tripping the safety feature. The camera automatically resets itself after a few minutes rest, but I then had to manually reconnect it to the computer and begin the cooling process again. This even happened on nights when the cooler could maintain the –25°C temperature with only about 60% power, but still initially ran at 100% for too long. The solution on these nights was to drop the temperature in small steps — a simple but still time-consuming process.

Although I didn't perform critical tests, the QHY600M certainly seems to be a sensitive camera. A full-resolution, unfiltered, 3-minute exposure of the open star cluster M67 through a 4-inch telescope recorded stars fainter than magnitude 18.5. That's close to the limits I reached during the mid-1990s using an SBIG ST-7 camera with a Kodak KAF-400 CCD shooting 4-minute exposures on a 16-inch telescope. This is an impressive result given the shorter exposure and much smaller aperture used with the QHY600M.

That said, long exposures with the camera had an overall appearance of being noisier than those done with a

▼ The photogenic region around the iconic Flame and Horsehead nebulae in Orion was assembled from a set of nine 10-minute, back-to-back exposures.

CCD. My colleague Sean Walker, who processed the deep-sky images with this review, noticed this as well. It was especially true of images made through a hydrogen-alpha filter. We don't have apples-to-apples examples, however, so I don't want to put too much emphasis on our observation.

I feel the jury is still out on what will be the best way to calibrate CMOS images, but I did note a couple of differences compared to my usual way of working with CCDs. The first is that dark frames should be made with the same sensor temperature and exposure time as the light frames they are used to process. The typical method of scaling CCD darks did not work well with this CMOS sensor. And dark frames made a few days before or after light frames also didn't work as expected. This would be an issue for those of us who build dark-frame libraries in the course of our normal workflow.

In the best of times, I find making high-quality flat-field calibration frames challenging, especially when it involves shooting through narrowband filters. I had better luck shooting flats with a relatively low signal, rather than the usual ones I use with CCD images that have pixel values of at least half of a pixel's full-well capacity. Also, I found it better to shoot flats at the camera's full resolution and downsize them for processing astronomical images that were made with the camera binned 2×2, rather than shooting flats binned 2×2.

Under a Microscope

When I initially set up the camera indoors, making test exposures with a Nikon camera lens, I was astounded by the QHY600M's image quality. Snapshots of equipment at the far end of my darkened workshop were filled with almost unimaginable detail. The QHY600M is indeed a full-frame camera with remarkable sensitivity and the resolution of fine-grain film that many of us wished for years ago. But these attributes have a downside, since I soon discovered that the camera's sensitivity and resolution were putting my imaging systems under a virtual microscope.

▲ Three hours of total exposure captured the nebulosity in central Auriga, including IC 410 at bottom and the Flaming Star Nebula, IC 405, at upper right.

Over the course of testing the camera, I used four astrographs that perform well with cameras fitted with Kodak KAF-16803 CCDs having 9-micron pixels. The resolution of the QHY600M's 3.76-micron pixels, however, revealed that three of them had off-axis star images that really weren't that great. The setup that delivered the best star images across most of the chip was the 4-inch f/5.4 Tele Vue NP101is refractor used for all the celestial images in this review.

And there were other issues that arose because of the QHY600M's extraordinary resolution. One is the need to have the chip absolutely square to a telescope's optical axis to achieve maximum performance. This is true for any large-format sensor, and fortunately the chip in the QHY600M was notably square to the camera body. But most imaging setups involved adapters that can wiggle around, and even a tiny wiggle can cause star images to appear of uneven quality across the QHY600M's chip.

The same goes for telescopes that change focus as nighttime temperatures drop. One of the scopes I used typically has to be refocused every half hour or so during the springtime evenings when shooting with a KAF-16803 CCD camera. But the QHY600M revealed obvious focus changes during the course of a single 10-minute exposure because of the camera's resolution. Tracking was also an issue, since even tiny guiding errors were made obvious by the camera's resolution. And there were other, more subtle issues that cause me to rethink the way my imaging setups performed when subjected to the scrutiny afforded by the camera.

The solution for many of these issues is to simply use the camera binned 2×2, which created pixels that are effectively 7½-microns square. That's still better resolution than the KAF-16803's 9-micron pixels, but it was enough to mask some of the issues mentioned above. And, as an added benefit, the image files were reduced to a far more manageable 31 megabytes each — something my computer hard drives, image-processing software, and I myself all appreciated.

I've been in the astrophotography game long enough to remember well all the things that confounded amateurs as the hobby was switching from emulsion-based to CCDs. To a lesser degree, that is happening again as we transition to CMOS detectors. But the ride will likely not be as bumpy this time, and if you want to get a head start on learning what the future will be like, I can recommend the QHY600M camera; it's a bit of the future today.

■ **DENNIS DI CICCO** spends a lot of clear nights testing equipment from his backyard observatory in Boston's western suburbs.

A Virtual Convention

North America's largest astronomy show goes online.

Many North American amateur astronomers look forward to the annual deep dive into our hobby that is the Northeast Astronomy Forum (NEAF). Usually held in Suffern, New York, during early April, the event is the biggest astronomy trade show in North America. Due to the COVID-19 pandemic, this year's event has been pushed back until September 12-13, with the Northeast Astro Imaging Conference (NEAIC) following on September 13-14. But on Saturday, April 4th, while most of us were sheltering at home, event organizers produced an excellent Virtual NEAF experience online at **neafexpo.com**, with more than eight hours of streaming content. Presentations included Jani Radebaugh describing the Dragonfly rotorcraft mission to Saturn's moon Titan (**dragonfly.jhuapl.edu**), Alex Young discussing the latest from the Parker Solar Probe (**parkersolarprobe.jhuapl.edu**), and our own Senior Editor Kelly Beatty previewing several upcoming solar eclipses.

Much of the virtual experience was remarkably similar to attending the talks and booths at NEAF in person, without the added background din to contend with. At the end of the day, door prizes were awarded, with the grand prize of an Explore Scientific 16-inch ES Dobsonian presented to James Ventling.

Although the main event is delayed until late summer, many vendors still took the opportunity to introduce new products. So, as we continue to hunker down in our homes and wait out the virus, here is a selection of the latest gear to whet your appetite in anticipation for the big show in Suffern this September.

—SEAN WALKER

Atik Cameras (**atik-cameras.com**) rolls out two new camera models. The Atik ACIS 7.1 features a Sony IMX428 CMOS sensor with 4.5-micron pixels in a 7.1-megapixel-array capable of 30 frames per second at full resolution. The second instrument is an addition to the QSI line of CCD cameras (**qsimaging.com**).The QSI 6162 incorporates the popular KAF-16200 CCD detector boasting a 16-megapixel array of 6-micron-square pixels and is available with several options, including a built-in off-axis guider. Prices start at $8,110.

Atik ACIS 7.1

QHYCCD (**qhyccd.com**) launches its QHY268C color CMOS APS-C-format camera (starting at $2,099). The unit is designed around a Sony Exmor 26-megapixel, back-illuminated, color CMOS detector with 3.76-micron-square pixels. The camera includes two-stage thermo-electric cooling and QHY's proprietary thermal noise reduction technology to produce images free of amp glow. See our review of the QHY600M model on page 68.

QHYCCCD QHY268C

Celestron (**celestron.com**) announces its revolutionary StarSense Explorer alt-azimuth telescope series, featuring push-to pointing aided by a smartphone and free *StarSense Explorer* app that plate-solves the sky using your device's camera. For more details, see our April issue, page 63.

Celestron StarSense Explorer

Sky-Watcher Evolux 82ED

Sky-Watcher USA (**skywatcherusa.com**) highlights several telescopes and accessories. First is its introduction of the Evolux series of doublet ED refractors for astrophotographers on the go, starting with the 72ED and 82ED models. Both utilize an f/6.5 focal ratio and a 2.4-inch rotating focuser that accepts an optional 0.85× reducer/flattener. Next up is Sky-Watcher's AZ-EQ6 mount that can operate in both equatorial and alt-azimuth modes ($2,170). The AZ-EQ6 uses belt drives and "Freedom Find" encoders to ensure accurate Go To slewing and smooth tracking. The mount's saddle plate accepts both Vixen-style and the newer Losmandy-D dovetail bars. Sky-Watcher also showed off the SolarQuest tracking mount for small solar telescopes ($399). This lightweight alt-az mount includes the patented HelioFind solar finder and built-in GPS to help you aim at the Sun and accurately track it for hours on end. The mount accepts Vixen-style dovetail bars and can carry instrument loads of up to 11 pounds.

Sky-Watcher SolarQuest

Meade Instruments (**meade.com**) has a few interesting offerings, including the LXPS 18 Portable Power Supply ($209). This 222-watt-hour lithium-ion battery pack can power most Go To telescopes and other mounts and multiple electronic devices at the same time. It features a 110V AC inverter, five USB charging ports (including two USB-C ports), and three 12-volt DC outlets. The company also announced 10×56 Masterclass Pro ED Binoculars ($469). These waterproof binoculars combine extra-low dispersion (ED) glass elements, fully multi-coated optics, and BAK-4 prisms with integrated field-flatteners to produce sharp images across the entire visible field. The Masterclass series can focus as close as five feet and come with a nylon case and quick-release harness.

Meade Masterclass-Pro 10×56 Binoculars

Tele Vue (**televue.com**) adds a new accessory in support of its growing night vision observing line of equipment noted in the March issue, page 57. The 67mm conversion lens is designed to maximize the true field of view of the company's 55-mm Plössl eyepiece when paired with the TNV-14 White Phos Gen 3 Night Vision Monocular. This lens screws into the internal threads of the 2-part eye guard housing of the eyepiece. Additional details are pending.

Tele Vue 67mm TNV Conversion lens

Software Bisque (**bisque.com**) promoted several intriguing products, including TheSky Fusion, a mountable control computer for your imaging system (see February, p. 73). Bisque also displayed the Paramount Apollo 500 Robotic Alt-Az Mount (detailed in the March issue, p. 57), and *TheSky Imaging* software bundle (June, p. 71).

Software Bisque TheSky Fusion

NEAF 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.

The STEM Spyglass Project

How to make a small, very inexpensive refractor.

These small, lightweight, simple scopes are a hit with children.

FOR THE LAST COUPLE OF YEARS, Merry Edenton-Wooten and her husband, Wayne Wooten, have been building telescopes and sending them to schools in Puerto Rico. These are unpretentious little spyglasses made with simple achromatic objective lenses and eyepieces scavenged from binoculars. They're small, lightweight, durable, easy to use, and provide great views of the Moon, Jupiter's moons, and bright clusters like the Pleiades. Thanks to an erect-image roof prism, they're even good for terrestrial use. To top it off, these little scopes are simple to build and cost only about $25 in parts.

You can make one for a budding astronomer you know.

The parts are simple: 1) An achromatic objective lens of about 30-mm diameter with a 200- to 300-mm focal length. (The Wootens use Surplus Shed's PA1048 [**surplusshed.com**], which is a 32-mm objective with a 260-mm focal length.) 2) A length of 1¼-inch PVC pipe. 3) A pipe coupling to act as a dew shield (and to give the spyglass more of a telescope look — an important consideration in making it appeal to kids). 4) A can of black spray paint. 5) The roof prism and eyepiece from the left half of a pair of Ozark Trail 8×21 binoculars.

▼ The parts for this small refractor are simple and easy to assemble. The tube and coupling can be made pretty with contact paper.

Because Merry runs Draco Productions (**dracoproductions.net**), a long-standing maker of solar filters, they also include a solar filter with every spyglass.

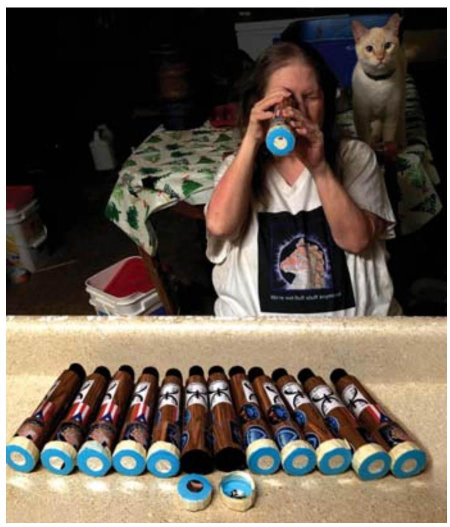
As of this writing, the Ozark Trail binoculars retail for a whopping $7.86 at Walmart. The 32-mm objective lens is $14.50. The pipe and coupling are just a couple of dollars. You'll also need some masking tape and glue.

To assemble the spyglass, first spray-paint the inside of the pipe and coupling black. Then wrap tape around the circumference of the objective lens until it fits snugly inside the pipe. Put the lens right at the end and make sure it's square, with the crown (the curved side) facing outward. Use a couple of drops of glue to hold it in place. Put the coupling over it and snug it down tight.

The binoculars need to be disassembled and the rubber coating cut off the left side. (Use the left side, so you can keep the right side that retains its focusing ability from about 10 feet to infinity to use as a monocular, or as a finder.) Once you've sliced off the rubber, exposing the metal tube that holds the optical components, you'll need to remove the objective lens and cut off the central hinge flange. File it smooth, then wrap masking tape around the tube until it fits easily inside the PVC pipe. You'll push and pull to focus the telescope, so you want it snug but not tight.

Slide the roof prism/eyepiece combination into the PVC pipe . . . and look through it! The eyepiece is a relatively high-quality Kellner, and the view through it is surprisingly good. And with the larger diameter and longer focal length of the Surplus Shed objective lens, the spyglass produces about 26×, as opposed to the binoculars' original 8×. The objective is about five times the diameter of your eye's pupil, so it gathers about 25 times more light and lets you

▼ Merry Edenton-Wooten checks out a batch of scopes ready for delivery to schools in Puerto Rico. Denali the cat supervises the operation.



ALL IMAGES BY WAYNE WOOTEN

▲ The Moon photographed through one of the spyglass scopes. Although there's some chromatic aberration, the view is pretty decent considering the $25 the scope costs to build.

see down to about 9th magnitude. That's a lot of stars!

Twenty-six power is a bit much for handheld optics, so Merry and Wayne drill a hole in the middle of the tube and tap ¼×20 threads so the spyglass can be mounted on a standard camera tripod.

All this would be for naught if the telescope didn't perform well, but when asked what a person can see through this scope, Wayne replies, "Everything Galileo saw, you'll see better. Sunspots (when a filter is used), lunar craters and maria, the phases of Venus, the moons of Jupiter, easy double stars, and bright nebulae and clusters all look nice for a project costing less than $25!"

I suspect some people are wondering why the guy who wrote an entire article warning buyers away from small "hobby killer" refractors would promote this spyglass project. I do it because this scope promises only what it can deliver. There's no false advertising here: This spyglass is an introductory scope that won't disappoint. And as Wayne says, "It's a great way to get started in tinkering with optics on a budget."

For complete building instructions, visit the Wootens' Facebook page at: **https://is.gd/STEMspyglass**.

■ Contributing Editor **JERRY OLTION** welcomes your project submissions. Contact him at **j.oltion@gmail.com**.

CENTAURUS A

David Doctor

This deep image of the peculiar galaxy NGC 5128 in Centaurus shows a faint halo of stars extending to the top right and bottom left of the frame. Several pinkish star-forming regions are visible in the galaxy's curved dust lanes. North is towards the right.

DETAILS: *Astro Systeme Austria ASA 500 Newtonian astrograph with FLI ProLine PL16803 CCD camera. Total exposure: 35 hours through LRGB filters.*

◁ ULTRAVIOLET VIEW

Richard Schrantz

Normally appearing as a featureless ball in visible light, Venus reveals dark and light cloud patterns in this image recorded at ultraviolet wavelengths.

DETAILS: *10-inch Newtonian reflector with Imaging Source DMK 21AU04 video camera. Stack of 1,200 video frames recorded through a Schuler UV filter.*

▽ GALAXIES GALORE

Kfir Simon

Spiral galaxies NGC 4151 (left) and NGC 4145 in Canes Venatici are relatively close to us at about 62 and 68 million light-years distant, respectively. That's close when compared to the hundreds of much more distant galaxies seen throughout the field.

DETAILS: *16-inch f/3.75 Dream Astrograph with Apogee Alta U16M CCD camera. Total exposure: 5½ hours through LRGB filters.*

Gallery showcases the finest astronomical images that our readers submit to us. Send your best shots to gallery@skyandtelescope.org. See **skyandtelescope.org/aboutsky/guidelines**. Visit **skyandtelescope.org/gallery** for more of our readers' astrophotos.

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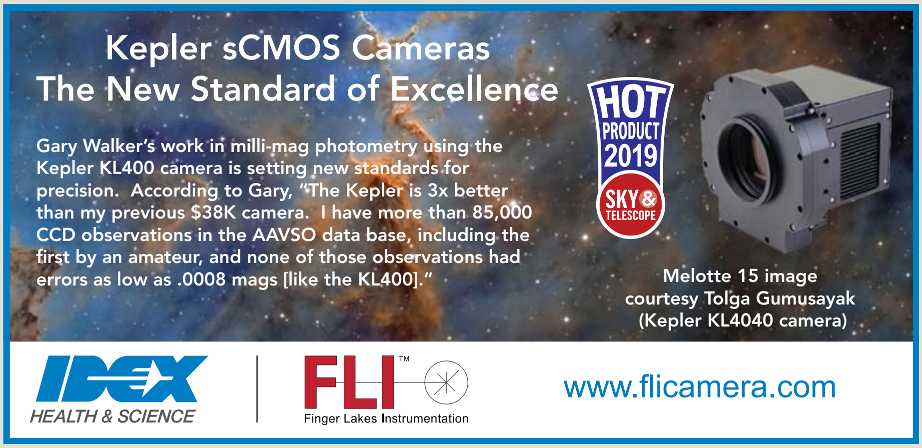
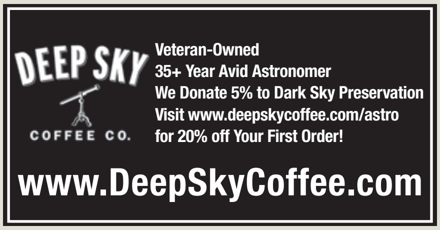
CAMERAS (cont.)



ACCESSORIES (cont.)

MISCELLANEOUS



OBSERVATORIES/DOMES

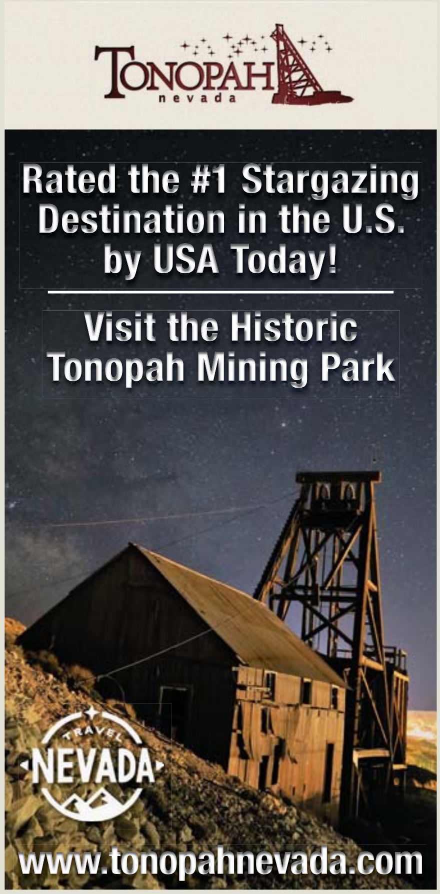
OBSERVATORIES/DOMES (cont.)

OPTICS

SOFTWARE

TELESCOPES

TRAVEL



CLASSIFIEDS

SOUTHWEST NEW MEXICO: Casitas de Gila Guesthouses. Dark skies, great accommodations; power, wifi, and pads available. casitasdegila.com/astronomy.html. 575-535-4455.

FOR RENT: 3BR/2BA furnished home in ARIZONA SKY VILLAGE PORTAL, AZ. Specatcular observing/birding! irkitzman@gmail.com www.arizona-dreaming.com 520-203-8500

ASTRONOMY EQUIPMENT FOR SALE: "Enough to outfit a University Department!" Many items still new in box. Examples: Meade LX200, Celestron CPC 1100 XLT and astronomical Binoculars. Astrophotography Accessories: Nikon Cameras, Mounts, Computerized Systems and Programs. Complete professional Inventory List & Photos available. "Everything but the Dome!" Private Owner Estate. Call 267-373-8074 or email doug.tiger@yahoo.com

DEEP SKY COFFEE: World-class coffee to fuel late night observation sessions! Veteran-owned; 35-year avid astronomer; 5% donated to Dark Sky Preservation and PTSD research. 20% off first purchase at: www.DeepSkyCoffee.com/astro

MIRADOR ASTRONOMY VILLAGE: https://www.skythisweek.com.info/mirador.htm. Contact David Oesper at davedarksky@mac.com 608-930-2120

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INSIDE This Issue

Specialty astronomy equipment dealers and manufacturers are an important resource for amateur and professional astronomers alike — patronize our advertising dealers in this issue and enjoy all the benefits of their expertise.

Product Locator

AD INDEX

Event Calendar

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

~~June 5–7~~ **CANCELLED**
RASC GENERAL ASSEMBLY
Vancouver, BC, Canada
ga2020.rasc-vancouver.com

June 11–14
BOOTLEG SPRING STAR PARTY
Harmon, IL
facebook.com/bootlegastronomy

~~June 13–20~~ **CANCELLED**
GRAND CANYON STAR PARTY
Grand Canyon, AZ
https://is.gd/GCSP2020

June 17–20
BRYCE CANYON ASTRO FESTIVAL
Bryce Canyon National Park, UT
https://is.gd/brca_astrofest

June 17–21
ROCKY MOUNTAIN STAR STARE
Gardner, CO
rmss.org

June 18–20
WISCONSIN OBSERVERS WEEKEND
Hartman Creek State Park, WI
new-star.org/index.php?Itemid=82

June 18–21
CHERRY SPRINGS STAR PARTY
Coudersport, PA
cherrysprings.org

~~June 20–24~~ **CANCELLED**
GOLDEN STATE STAR PARTY
Bieber, CA
goldenstatestarparty.org

July 19–24
NEBRASKA STAR PARTY
Valentine, NE
nebraskastarparty.org

~~July 21–25~~ **CANCELLED**
TABLE MOUNTAIN STAR PARTY
Oroville, WA
tmspa.com

~~July 21–26~~ **CANCELLED**
OREGON STAR PARTY
Indian Trail Spring, OR
oregonstarparty.org

August 4–7
ALCON 2020
Albuquerque, NM
alcon2020.info

August 13–16
STELLAFANE CONVENTION
Springfield, VT
stellafane.org/convention

August 14–18
ALMOST HEAVEN STAR PARTY
Spruce Knob, WV
ahsp.org

August 14–23
SUMMER STAR PARTY
Plainfield, MA
rocklandastronomy.com/ssp.html

August 15–23
MERRITT STAR QUEST
Loon Lake, BC
merrittastronomical.com

• For an up-to-date listing, including coronavirus-caused cancellations, visit **https://is.gd/starparties2020**.

MICHAEL QUINN / NPS

The author took this shot of Halley's Comet on January 2, 1986, using hypered Kodak Tech Pan 2415 film — and his recently recovered Schmidt camera.

An Inconvenient Theft

Just before Halley's Comet returned in 1986, the author's Schmidt camera was stolen. How he got it back is quite a story.

IN 1984 I PURCHASED an 8-inch Celestron Schmidt camera for use with my C14 scope, which I keep in my observatory in Colorado. I planned to use the camera to photograph Halley's Comet during its 1986 apparition for the International Halley Watch project.

During testing, I discovered the camera was out of focus, so I had to return it to the manufacturer for adjustment. The repair took much longer than I thought it would, and I began to wonder if I'd have it back in time for Halley's return.

I phoned the manufacturer to find out its status and learned that they'd shipped it back weeks before. (Why they never alerted me, I don't know.) To avoid porch pirates, they'd sent it to a consignment agent, but as it turns out, the agent had moved away. I suspected that porch pirates had taken the instrument after all, or that the new occupant of the receiving facility (a residential house) might have signed for the camera and simply kept it. The manufacturer sent me a copy of the trucking record indicating that the delivery had indeed taken place on a certain date.

So I went to the delivery address and knocked on the door. A man about 30 years old answered. When I asked him about the instrument, he said he didn't know anything about it. But his body language and shifty eyes told a different story. I knew he was lying.

I left and drove about a block away, parked, and watched his house. About 15 minutes later the man came out, got into his car, and headed into downtown Colorado Springs. I followed him at a distance, but somehow he "made" me. Perhaps he recognized my old red-and-white Volkswagen van from when I'd initially parked outside his house. In any case, he sped away.

Then I noticed I was right in front of a pawn shop, so I pulled over and went inside. There it was, my Schmidt camera, in a glass display case right on the counter!

I immediately called the police. When they arrived at the shop, I showed them the purchase and repair records as my proof of ownership. They told me they had to take the camera in as evidence. I said I needed it as soon as possible because time was running out — the comet was coming. They shrugged and said if all checked out I could have it in about a week.

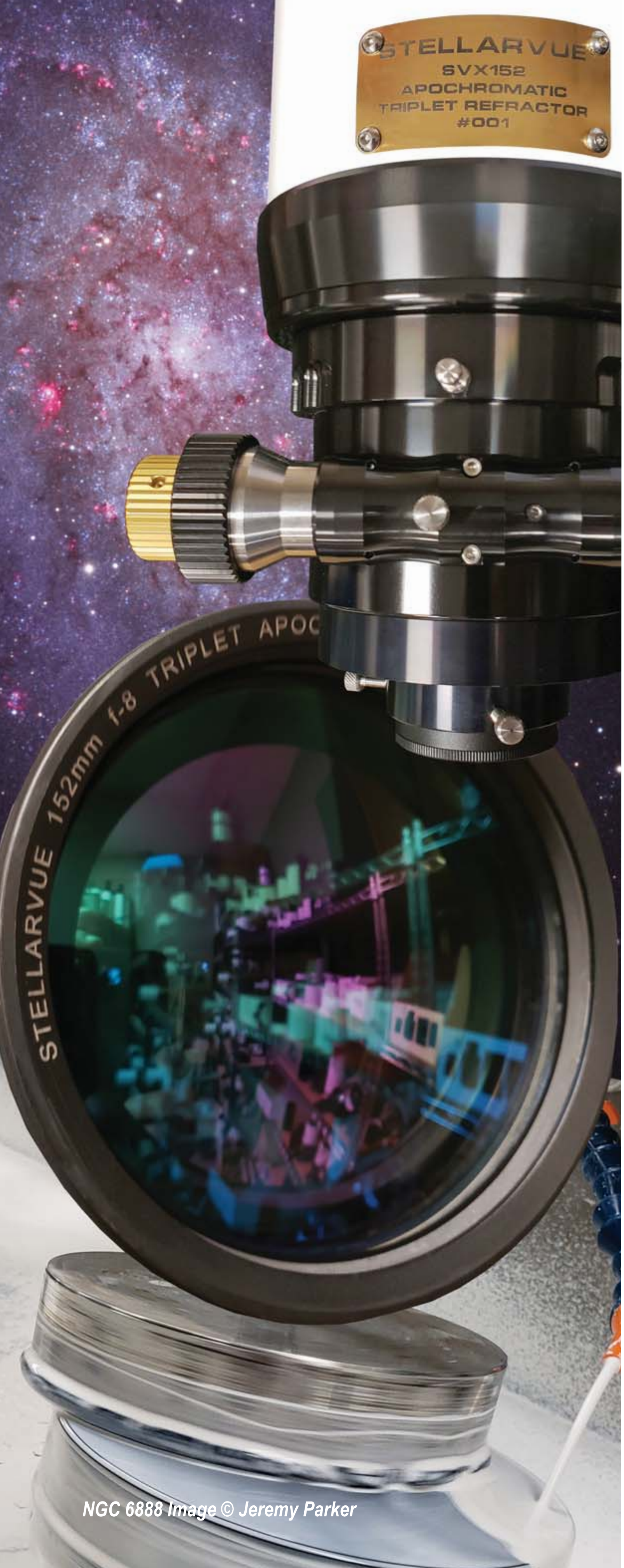
Fortunately, I got it back in time to set it up in my observatory and fully test it. In the end, I was able to capture the photo seen above using the camera. The image later appeared in *Looking Back: Amateur Adventures with Halley's Comet 1985-1986*, a book by David Deskins.

As is recorded in the Office of the District Attorney for El Paso County, Colorado, the police charged the suspect with fraud, and he was fined.

Even after all these years, I still use the camera. It remains vulnerable to theft, but appropriate security measures are in place.

■ **PAUL SIGNORELLI** is a retired electronics engineer who worked on space programs. Since 1984 he has operated Las Brisas Observatory (**https://is.gd/LasBrisas**). He also runs amateur radio station W0RW from his observatory.

PAUL SIGNORELLI



NGC 6888 Image © Jeremy Parker