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SKY & TELESCOPE

THE ESSENTIAL GUIDE TO ASTRONOMY

OCTOBER 2020

All Eyes on MARS

Striking Close-ups & Observing Tips

Pages 12 & 48

skyandtelescope.org

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TWO EYES FOR THE GALAXY

Our insider tips for binocular astronomers

Scan for more info.

$1,399

Article No. 61493

The night may be dark and clear, or the band of the Milky Way may glisten above you. But to turn observing into an unforgettable experience, you need one thing above all: binoculars with outstanding optics. Brightsky binoculars provide wonderful views thanks to a cleverly-constructed optical system. Because it's not just what you see, but how well you see it that matters.

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A reliable companion on every tour: the body is made of magnesium, which makes it especially light, but also stable. The perfect basis for great journeys and experiences that are more exciting than a bus trip!

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Astro-binoculars are meant for just one distance: the view into infinity. Therefore, the single adjustable focusing is extremely practical, because it cannot be accidentally readjusted. You just have to point your binoculars at the sky, enjoy the experience, and not worry about anything else.

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Brightsky	Article No.		Price in $
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WxHxD in mm 450x220x190, weight 4.6kg (162.3oz) (10.1lbs)	61490	61491	**1,249.00**
Large binoculars 30x100	**45°**	**90°**	
WxHxD in mm 510x265x200, weight 6.8kg (239.9oz) (15.0lbs)	61492	61493	**1,399.00**

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A mosaic of about 1,000 images from the Viking orbiters
PHOTO: NASA / JPL / USGS

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PlaneWave™ INSTRUMENTS

NEW + NEW + NEW

PlaneWave Instruments is focused on vertical integration. We have been from the beginning. Design, optical production, fabrication, assembly, and quality control are all performed in-house by our expert team. PlaneWave even designs and builds our own robotic optics machines. Our approach and innovation allow us to create superior products and value for our customers. Over the last few years there was just one little issue: we had outgrown our facilities in California and in Michigan. It was time to reoptimize!

New Location: 2020 marks our first full year on PlaneWave's new 57-acre campus in Adrian, MI. We joined our MI and CA operations reducing overhead, gaining a larger campus, and providing countless opportunities to expand.

New Facilities: PlaneWave is evolving and growing. With new buildings, machines, and test equipment being added, we've been busily investing in the future for the last 12 months. The future is now!

New Pricing: Our increased capacity, reduced overhead, and manufacturing innovations allowed us to take a fresh look at pricing. We are proud to announce the results:

Product	Old Price	New Price	Savings
CDK12.5	$10,500	$8,500	$2,000
CDK14	$16,500	$12,500	$4,000
CDK17	$24,500	$19,500	$5,000
CDK20	$35,000	$29,500	$5,500
CDK300 (CDK12.5 & L-350)	$19,900	$18,500	$1,400
CDK350 (CDK14 & L-350)	$25,500	$22,000	$3,500
CDK400 (CDK17 & L-500)	$40,000	$37,000	$3,000
CDK500 (CDK20 & L-500)	$50,000	$47,000	$3,000

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Amateur Astronomy for All

MOST OF THE TIME we at *Sky & Telescope* ponder what's up there, in the sky. But sometimes we need to focus on what's down here, on Earth. Events can force us to consider our role in society, examine our values, decide what's important to us, and speak out. Now is such a time.

In recent months, the United States has been coming to grips yet again with the entrenched racism and inequalities in our society. At *Sky & Telescope*, we wish to state our unequivocal support for Black Lives Matter and related movements and initiatives to end systemic racism here and elsewhere in the world. We also support our parent organization, the American Astronomical Society, in its fight against racism in professional astronomy, and we pledge to address the same problem in amateur astronomy.

It's no secret that backyard astronomers are overwhelmingly white. Blacks and other minorities are seriously underrepresented in our ranks. In professional astronomy, people of color represent only 3% to 5% of physics and astronomy faculty at American universities, even as they compose about 30% of the U.S. population. The disparity may even be greater in amateur astronomy.

We take this imbalance to heart, because *Sky & Telescope* aspires to serve not just one segment of humanity but *all* of humanity. Our desire to share the wonders of the heavens with others encompasses everyone everywhere. We believe all people are captivated by the universe and its mysteries and should have the chance to observe it. Is there a person on this planet who hasn't had (or wouldn't have) the same "Wow!" reaction upon seeing Saturn for the first time in a telescope?

That caveat — "wouldn't have" — speaks volumes. It's easy to think that nothing embodies egalitarianism more than looking at the stars. Anyone can gaze up at the night sky; the Moon, planets, and stars do not discriminate but shine their light on all. Yet in reality, there's also inequality in stargazing. Not everyone who wants to observe the night sky actually can. Most underserved people live where light pollution is worst, and for them resources like time, adequate income, decent science education, and access to dark-sky sites or even basic observing equipment might not exist.

How can we at *S&T* begin to tackle this longstanding, deep-seated inequity in amateur astronomy?

We realize that addressing these issues must start with *S&T* itself: its print and web content, its staff and contributors, its mission and worldview. Listening is most important. In what ways are we unconsciously helping to perpetuate the status quo? What biases are we allowing to creep into our efforts? What barriers do we need to remove? How can we provide truly useful resources for the wider community?

Assessing how well we're doing will include gauging tangible results in terms of hearing from more voices and otherwise broadening our demographic. We're not talking about just public outreach and education, but active participation by people of color in amateur astronomy. From now on, we plan to be proactive rather than reactive (or, worse, unreactive) while understanding that the role of allies is to assist, not to tell how.

There's no quick fix. We're a small staff, and achieving genuine results on this front may take years. But we want our subscribers, web readers, supporters, and followers to know that our heart is in it, and we will commit time, funds, brainpower, and other resources to it over the long haul.

What do we have in mind? We'll make greater efforts to work with researchers, journalists, photographers, and illustrators who are people of color. We will con-

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tinue to post profiles of Black astronomers in the Famous Astronomers section of **skyandtelescope.org**. We're exploring the possibility of hosting or assisting sidewalk astronomy or a star party within underserved communities. We're also actively seeking a range of voices with experience in minority issues — Black astronomers, community organizers, members of underserved neighborhoods, and others — to guide us as we move forward.

In the meantime, we want to hear from you. If you or someone you know has felt uncomfortable attending an observatory night or star party in your area or otherwise taking that first step into astronomy, what most dissuades you? What needs to be done better, and how? If you're working on improving diversity and inclusion in the amateur astronomy community or in your local club, please contact us. What has worked? What hasn't?

Write to us at **editors@skyandtelescope.org** or c/o *Sky & Telescope*, One Alewife Center, Cambridge, MA 02140 USA (Attn: Astronomy for All). We welcome your ideas, comments, and suggestions, and we promise to read every email or letter we receive on this vital topic. All comments and contact information will be kept strictly confidential.

Thank you in advance for helping to educate us; we appreciate your time and effort.

Our doors are open to all. Please come in.

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SKY&TELESCOPE
The Essential Guide to Astronomy

Founded in 1941 by Charles A. Federer, Jr.
and Helen Spence Federer

Matching Astronomers

I have found my *doppelgänger*. When I showed the picture of Rod Mollise in "Exploring the Deep Sky With Video" (*S&T:* June 2020, p. 66) to my wife, she asked when had I sent in the article, and what telescope was I using. My sister-in-law was also fooled!

▲ *Left:* Donald Watts replicates the image of Rod Mollise from the June issue. *Right:* Rod Mollise prepares for a night of video astronomy.

So, we tried to duplicate the picture as closely as we could. Thanks for such a superb publication.

Donald W. Watts • Boise, Idaho

A Cable Solution

"Exploring the Deep Sky With Video" was of great interest to me. I've owned a Revolution Imager System R2 for almost two years. I use the video camera on my Celestron NexStar 8SE Schmidt-Cassegrain, Astro-Tech 72-mm refractor, and Coronado SolarMax II 60-mm solar telescope. So I was fascinated by all the images in that article.

The "Wired For Video" picture on page 67 shows the "seemingly endless number of cables" that are a staple of video astronomy. The wire situation was so intimidating that I refused to use my own video gear until I had a solution. I put the imager in a toolbox. All the cables are contained within the box — the only exception is the one connecting the camera to the telescope. I hope this picture inspires readers who are also intimated by the tangle of wires involved in video astronomy.

Greg Cisko
St. Charles, Illinois

▲ A toolbox and some ingenuity solve the cable situation.

CABLES: GREG CISKO

The Cloudtop Debate

According to June's Planetary Almanac (*S&T:* June 2020, p. 44), Venus began that month with an angular diameter of 57.6 arcseconds, a value consistent with most authoritative annuals. Pardon my nitpicky nature, but it's not true!

That value holds if the bare Venusian surface could be glimpsed. But our bedazzling empress of planets is swaddled in thick clouds, which, on June 1st, added 0.6 arcsecond of girth. Trifling as this may seem, it's a discrepancy measurable with a telescope and micrometer.

The scant few who discern with haze-piercing infrared or radar have good reason to abide by the status quo. Yet, in deference to the far more prevalent visual observers, shouldn't a planet's predicted size conform to what the eye perceives? Besides, the angular spans of Jupiter and its three kindred giants have always been defined by their cloudtops. Why is Venus treated differently?

Mark Gingrich
Mendocino, California

Roger Sinnott replies: *Brent Archinal and colleagues give 6,051.8 km for Venus's semidiameter in their paper,* **https://is.gd/Archinaletal**, *which we use to get 8.34 arcseconds as Venus's semidiameter (without clouds) at a distance of 1 astronomical unit. I've been using this value to calculate* S&T*'s almanac table since 1984! Before that, I used 8.41 arcseconds, which includes the clouds. In fact, that traditional value goes back to a paper by A. Auwers in* Astronomische Nachrichten *in 1891.*

I was simply following the Astronomical Almanac. *That way, we've always agreed on the published values. I'm sure Archinal's solid-Venus diameter has been refined several times since 1984, but not enough to change the adopted constant of 8.34 arcseconds.*

Martian Waves

I'm interested in the News Note, "NASA's Insight Detects Marsquakes" (*S&T:* June 2020, p. 8). How are the depth, distance, and direction of the sources of these quakes calculated? Also, is the magnitude scale for Mars the same as that for Earth?

Don Herron
Sugar Land, Texas

Camille Carlisle replies: *The News Note is an abridged version of the longer story* **https://is.gd/marsquakes**, *which goes into more detail, though I didn't dive deeply into the method. The team did use the same magnitude scale for the marsquakes as we do for earthquakes — so these are quite small temblors.*

In terms of how they did it: Well, it's not easy, because they only have one seismometer. On Earth, seismologists can triangulate using multiple seismometers at various locations. So, the team used a fair amount of extrapolation. However, the same principles hold on both planets: Different kinds of seismic waves, p and s waves, come from the same event but travel at different speeds. Therefore, the time between one type reaching a detector and the other tells *scientists how far away they were created. The depth is based on the wave frequency and the shape of the signal.*

Little Astronomers

It was a joy to see the photo of little Calvin with the magazine in front of him (*S&T:* June 2020, p. 6). It would be interesting to see him at a telescope a few years from now. I once tried to give a 3½-year-old a look through my telescope, but he couldn't hold his head still enough to see anything. Six months later, the reflexes in his neck and upper body had matured enough that he could get a good look at Saturn, and he said that it looked like a spaceship.

Keith Brescia
Falls Church, Virginia

Confounding Particles

In his letter "A Twist of Terminology" (*S&T:* June 2020, p. 7), Mark Trueblood wonders what other astronomy terms had been mixed up from one field of science using different terminology than another. After training as a chemist, I can testify that chemists refer to Mg(II) as doubly ionized magnesium, whereas astronomers define Mg II as singly ionized magnesium. When I started astronomy, I was deeply puzzled by H II regions. How could a hydrogen atom have lost two electrons?

Michel Bonnement
Courseulles-sur-Mer, France

Ludwig's Star

Johann Georg Liebknecht didn't give the name Sidus Ludoviciana to the star between Mizar and Alcor as stated in Mathew Wedel's "The Horse and Rider" (*S&T:* June 2020, p. 43). He named it Sidus Ludovicianum and Stella Ludoviciana in two different publications. Both names are Latin for "Ludwig's Star." Sidus Ludoviciana is an ungrammatical mix of the two created by accident by Joseph Ashbrook in "The Field of Mizar and Alcor" (*S&T:* Apr. 1957, p. 265).

Michael Covington
Athens, Georgia

The Editors reply: *This just goes to show that our Latin is not what it used to be. Another* S&T *gaffe that we promulgated is the definition of a Blue Moon, traced back to our March 1946 issue. We don't know whether to be flattered or mortified that we have such influence.*

FOR THE RECORD

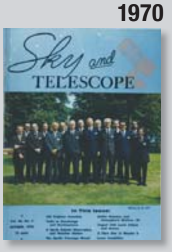
- In "Ophiuchus Treasures" (*S&T:* July 2020, p. 45), the correct number of Messier globular clusters in Sagittarius is seven.
- In "A Martian Sneak Peek" (*S&T:* June 2020, p. 48), the acronym ALPO stands for the Association of Lunar & Planetary Observers (**alpo-astronomy.org**).

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

October 1945

Big Bang "In line with the trend among popular science publications to comment on the atomic bomb, we must mention its relation to our field of science. Theoretical astrophysicists talked about one superlatively great atomic bomb (although not by that specific name) long before the war lords even thought of such a thing. It was the peace-loving Abbé Georges Lemaître, of Belgium, who 15 years ago envisaged the explosion of one giant primordial atom [that] produced the widespread debris we observe as the physical universe . . .

"The red shifts in the spectra of the galaxies may be interpreted to mean that these systems are receding from one another as they would from a center of detonation."

Lemaître's concept of an expanding universe slightly preceded that of Edwin Hubble, and most astronomers now favor the term Hubble-Lemaître Law.

October 1970

Uneclipsing Binary "The 9th-magnitude spectroscopic binary HD 168206 in Serpens consists of a Wolf-Rayet star and a *B*0 star, which move around their center of mass in a period of 29.6 days. The fact that this binary is also an eclipsing system was discovered in 1949 by Sergei Gaposchkin on Harvard patrol plates, [and it] became firmly established in variable star literature as CV Serpentis. . . .

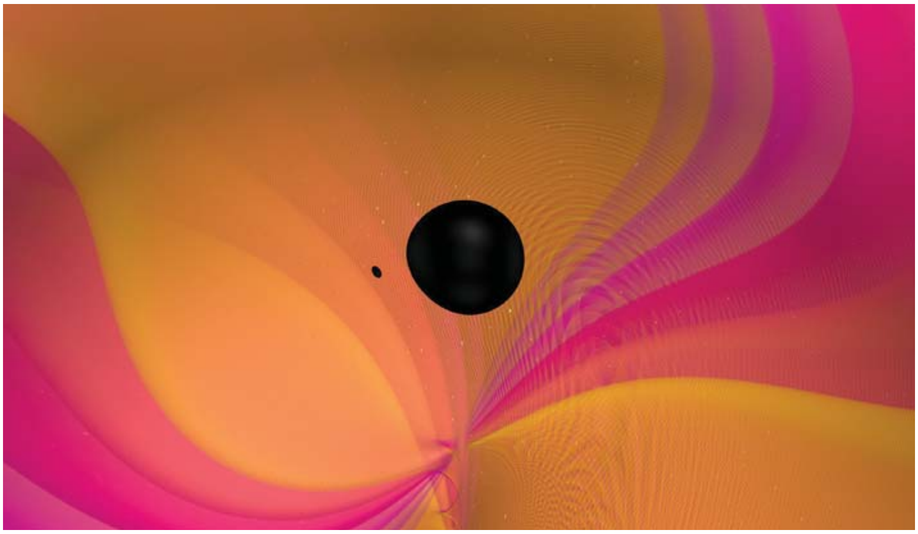
"Recently, a special set of photometric observations was undertaken by L. V. Kuhi and F. Schweizer to determine the light curve of CV Serpentis . . . Surprisingly, there was no indication whatever of variability! . . . The only explanation is that the system has stopped eclipsing. Drs. Kuhi and Schweizer suggest that the Wolf-Rayet envelope grew considerably during the years 1963 to 1968. The expansion would make the envelope less opaque, so at the time of primary eclipse no appreciable dimming of the *B* star would occur."

October 1995

Monster Comet "An inbound 10th-magnitude comet — first spotted July 22nd by Alan Hale and Thomas Bopp — may grow to rival the Great Comet of 1811. That's the guarded assessment of Brian G. Marsden (Central Bureau for Astronomical Telegrams), whose orbit calculations place the comet some 7 astronomical units from the Sun at the time of its discovery — beyond Jupiter and farther out than any comet discovered by amateurs until now.

"Traveling in a plane perpendicular to the ecliptic, the comet follows a highly elongated elliptical path with an aphelion more than 10 times that of Pluto's orbit. In these respects, as well as in its visibility long before perihelion, Hale-Bopp resembles the Great Comet of 1811, whose tail grew to 70° and stretched more than 1 a.u. in length."

Amateur astronomers would not be disappointed with Comet Hale-Bopp (C/1995 O1, see S&T*: July 2020, p. 30).*



GRAVITATIONAL WAVES

Gravitational Waves from a Mystery Object

ASTRONOMERS HAVE CAUGHT a black hole colliding with a companion that might be either the most massive neutron star or the smallest black hole ever detected.

Depending on neutron stars' structure, they should top out at between 2 and 3 solar masses before they collapse into black holes. So far, most neutron stars we know of weigh in at about 2 Suns or less. The vast majority of stellar-mass black holes, on the other hand, contain at least 5 solar masses. We've seen only a smattering of objects in between, a sparsely populated region scientists call the *mass gap*.

Now, the LIGO-Virgo team has reported in the June 20th *Astrophysical Journal Letters* the merger of a 23-solar-mass black hole with another object of 2.6 solar masses — smack in the middle of the gap.

The observations of the event, called GW190814, do not directly identify the smaller object. But some researchers, such as team member Philippe Landry (California State University, Fullerton), think it was likely a black hole. He explains that the neutron star crash witnessed in 2017 (*S&T:* Jan. 2018, p. 10) suggested that neutron stars are "reasonably soft" inside. They'd need very stiff interiors in order to survive at 2.6 solar masses without collapsing.

▲ Two black holes, one 9.2 times more massive than the other, emit gravitational waves before they inspiral and merge in this visualization.

Whatever the mystery object is, it and the more massive black hole make for the most mismatched gravitational wave-emitting duo. It's hard to explain the origin of two objects with such different masses in the same system.

Binary stars aren't likely to have had disparate-enough masses to make stellar corpses this different. Nor are globular clusters probable environments, because objects in these ancient star clusters tend to segregate by mass.

Better odds favor dense young star clusters, where binary systems may interact with each other to create more mismatched pairs. Even so, based on the available data, the team calculates that unequal mergers like this one appear to happen more often than they would have expected.

Interestingly, the gravitational-wave signal also revealed that the larger black hole basically wasn't spinning. (It dominates the gravitational-wave signal; scientists can't tell how fast the 2.6-solar-mass object spun prior to the collision.) "Low spin means that that 23-solar-mass black hole came from a single star," says team member Vicky Kalogera (Northwestern University).

The low spin has important implications for stellar evolution. As a star ages and swells, its rotation slows. If the core spins slowly, then the black hole it becomes when the star dies should also spin slowly. The large black hole in GW190814 supports this picture.

But X-ray measurements from black holes paired with massive stars suggest those black holes are spinning fast. Not enough gas has poured onto them from their companions to have spun them up, either. So why are they so different from their gravitational wave-producing counterparts?

In short, GW190814 challenges multiple paradigms — the mass gap, merger rates, and formation scenarios.

■ CAMILLE M. CARLISLE

X-RAYS

First All-Sky X-ray Map from EROSITA

THE EROSITA SPACE TELESCOPE, which launched in July 2019 (*S&T:* Nov. 2019, p. 9), has completed its first full sweep across the sky, mapping both hemispheres and cataloging more than 1 million X-ray sources.

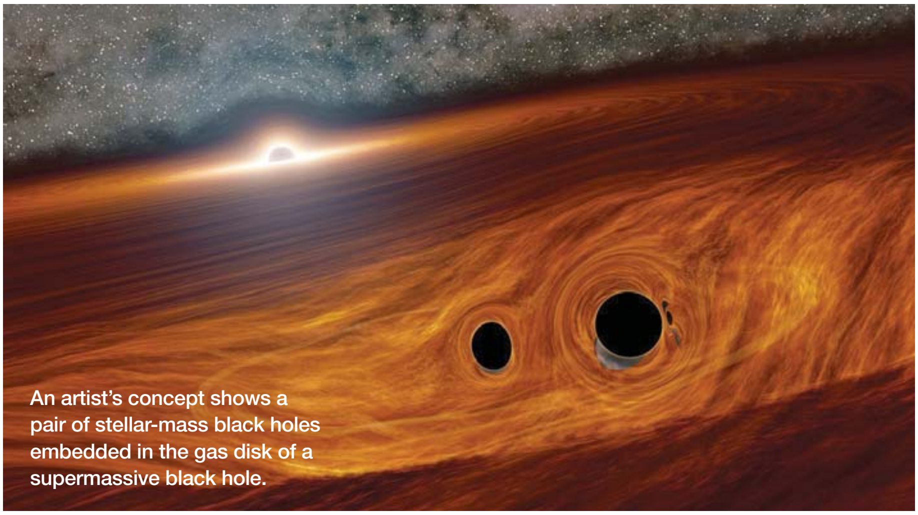
The EROSITA telescope flies on the Spectrum-Röntgen-Gamma spacecraft, a joint Russian-German mission. As the telescope rotates, it scans the X-ray sky with seven cameras, taking exposures of 150 to 200 seconds over most of the sky. (The poles have longer exposure times.) The images primarily record photon energies between 300 and 5,000 electron volts.

In half a year, EROSITA has already doubled the number of known sources collected since the start of X-ray astronomy in the 1960s. Only the hottest gases and the most extreme and active sources emit X-rays. While the telescope sees some stars (whose magnetic activity creates X-ray-emitting flares), most of the sources are active galactic nuclei, in which hot gases swirl into the maw

N. FISCHER / S. OSSOKINE / H. PFEIFFER / A. BUONANNO (MAX PLANCK INSTITUTE FOR GRAVITATIONAL PHYSICS) / SIMULATING EXTREME SPACETIMES (SXS) COLLABORATION

GRAVITATIONAL WAVES

Black Hole Collision May Have Caused Burst of Light



An artist's concept shows a pair of stellar-mass black holes embedded in the gas disk of a supermassive black hole.

BLACK HOLES DON'T EMIT LIGHT. Yet in a candidate gravitational-wave event recorded by the LIGO and Virgo detectors, dubbed S190521g, a flash of light appears to have followed the collision of two black holes. (The putative merger isn't officially confirmed yet; the LIGO-Virgo team is working on the paper now.)

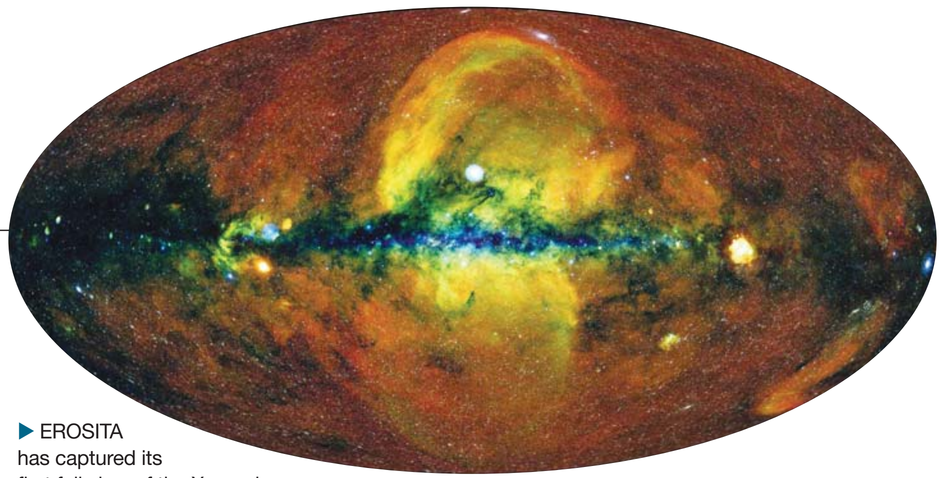
Matthew Graham (Caltech) and his colleagues have been following up on candidate events using observations from the Zwicky Transient Facility, looking for flares of visible light that might be associated with black hole mergers. Such a flare could be produced if two stellar-mass black holes collided in the vicinity of a supermassive one. The object they create could bulldoze its way through the disk of gas feeding the supermassive black hole, causing surrounding gas to heat up and brighten days to weeks after the merger.

In the June 25th *Physical Review Letters*, Graham's team says they've found evidence for exactly this kind of flare. Of the 21 candidate events the researchers investigated, one of them, S190521g, matched up with a peculiar month-long flare from the active galactic nucleus (AGN) J1249+3449. The flare showed no signs of changing color, as would be expected from a supernova blast that's expanding and cooling. Nor is it likely to come from the supermassive black hole's gas-guzzling activity, based on the AGN's past flickering. After a careful rundown of alternatives, the astronomers conclude that a merger-induced flare is the most likely explanation.

Given that the flare didn't last long, the team thinks that the merger kicked the black hole up and out of the disk. But the speed the researchers estimate it took from the merger isn't enough to escape the supermassive black hole. Instead, it should loop back through the disk and create a second flare in the next few years, the team says — a specific prediction that will be stunning if confirmed.

Ryan Chornock (Northwestern), who was not involved in the study, is excited by the team's result and agrees that the researchers did a good job ruling out normal supermassive black hole activity. "However," he warns, "AGN have a long history of surprising astronomers."

■ CAMILLE M. CARLISLE



▶ EROSITA has captured its first full view of the X-ray sky.

of supermassive black holes. Other X-ray sources include the hot gases released in supernovae explosions and the far more tenuous gas in and around our galaxy.

However, EROSITA's true quarry is galaxy clusters. The hot gas spread out in the vast space between galaxies emits X-rays. So by looking for extended X-ray-emitting blobs, mission scientists can find galaxy clusters from back when the universe was only half its current age. Clusters mark junctures in the cosmic web, so by plotting a large number of them over billions of years, astronomers can watch cosmic structures evolve over time. With more than 20,000 clusters spotted so far, the mission is on track to find more than 100,000 by the time its eight all-sky surveys are complete.

The mission has already begun a second round of sky-mapping and will ultimately combine eight maps to achieve unprecedented sensitivity to the whole X-ray sky.

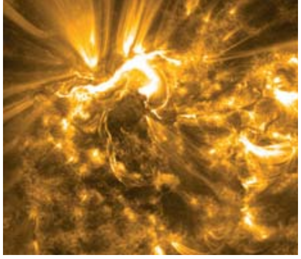
■ MONICA YOUNG

● **Explore close-up regions of EROSITA's all-sky map using the Worldwide Telescope at https://is.gd/EROSITA.**

BLACK HOLES: R. HURT (IPAC) / CALTECH; EROSITA: J. SANDERS / H. BRUNNER / ESASS TEAM (MPE) / E. CHURAZOV / M. GILFANOV (ON BEHALF OF IKI)

SUN

New Evidence for Nanoflares?



◀ Individual nanoflares release one-billionth the energy of more powerful flares, such as this one captured in 2012.

RADIO ASTRONOMERS have discovered that the quiet Sun is constantly emitting weak bursts of low-frequency radio waves. These bursts might help explain why the solar corona is much hotter than the visible surface.

Researchers have proposed several mechanisms that could transfer energy from the writhing magnetic fields at the surface into heat in its outermost atmosphere. One controversial idea is that *nanoflares*, smaller, more abundant siblings of the bright flares we see when the Sun is active, provide some or even all of the heat. However, nanoflares are too small and weak to see individually.

"I view nanoflares with a combination of horror and fascination," says solar physicist Hugh Hudson (University of Glasgow, UK). "The former because they are the subject of so much ill-justified hype, and the latter because the basic idea makes so much sense."

However, the bursts that Surajit Mondal (Tata Institute of Fundamental Research, India) and colleagues describe in the June 1st *Astrophysical Journal Letters* might eventually provide hard evidence that nanoflares exist.

The scientists analyzed radio images of the Sun taken on a particularly quiet day, November 27, 2017. Using the Australian Murchison Widefield Array, a network of radio antennas, the researchers picked up thousands of bursts of meter-wavelength radio waves from the Sun. Most bursts lasted less than a second, and they appeared throughout the solar corona, 100 times weaker than anything detected before.

Nevertheless, Hudson urges caution with the results, saying there may be other explanations for the data.

The next step is one for the theorists, who could calculate whether these radio emissions could correlate to enough nanoflare activity to heat the corona, explains Monica Bobra (Stanford University), who was not involved in the study. Rough estimates by Mondal's team show this to be the case, but the real test will come with formal computer simulations.

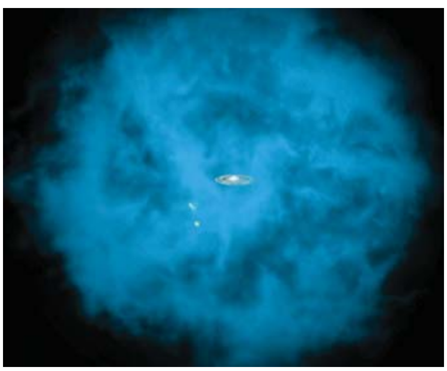
■ MONICA YOUNG

GALAXIES

The 10 Million-Degree Gas Around the Milky Way

ASTRONOMERS HAVE LONG KNOWN that a halo of sparse hot gas surrounds the Milky Way, most of it left over from our galaxy's formation — even though it evades all but a few forms of detection. Now, researchers think they've found even hotter halo gas, a discovery that will ultimately shed light on our galaxy's evolution.

At the June virtual meeting of the American Astronomical Society, Smita Mathur (Ohio State University) and Anjali Gupta (Columbus State Community College) presented new observations of distant quasars taken with the European Space Agency's XMM-Newton telescope. X-ray spectra of the quasars show that intervening halo ions have absorbed some of the photons. The high levels of ionization indicate that the gas must be searingly hot, near 10 million K — much hotter than typical halo gas.



▲ A giant halo of hot gas (blue) surrounds our Milky Way Galaxy and its small companions in this artist's concept.

Gas can't heat up that much as it falls into the Milky Way's halo; instead, supernova explosions or stellar winds could be flinging it out of the galaxy. This cycle of gas could drive star formation (or quench it) in the Milky Way.

Mathur and Gupta acknowledge that other explanations exist for the X-ray data they've collected, though they say the ultra-hot gas scenario fits the data best. But Dan McCammon (University of Wisconsin, Madison), who was not involved in the study, still notes concerns because, as he puts it, "We don't have very good instruments. So there isn't nearly as much data as we really need to untangle all the things that get added together along a line of sight."

Nevertheless, McCammon adds, "I do think they're quite possibly right." Ongoing and upcoming X-ray missions may put these results on firmer footing.

■ MONICA YOUNG

IN BRIEF

Fast Radio Burst with a Beat

Fast radio bursts (FRBs) are millisecond-long flashes of radio waves. While most FRBs are seen to only flash once, some repeat. Now, astronomers have found one repeater that bursts to a beat. FRB 180916 is the most active repeater in a catalog compiled by the Canadian Hydrogen Intensity Mapping Experiment (CHIME)/FRB Collaboration, having emitted 38 bursts in the 1½ years since its discovery. Analysis reported in the June 18th *Nature* suggests that the FRB's radio waves appear at rhythmic intervals. Roughly every 16 days, the source starts acting up, emitting about a burst every hour for a period of about five days. Then it's quiet for the next 11 days or so before starting up again. The cycle seems too long to be associated with the rotation of an object such as a neutron star, so the researchers speculate that an orbit around a stellar companion could be driving the beat. However, others have suggested that the source could be a lone magnetar, deformed by its own magnetic field and wobbling like a spinning top. Further observations will distinguish between these scenarios.

■ MONICA YOUNG

FLARE: NASA / SDO / AIA; GAS HALO: NASA / CXC / M. WEISS / OHIO STATE / A. GUPTA ET AL.

PRO-AM

Huge Circular Arc Spotted near the Big Dipper

A 30-DEGREE-LONG ARC lies splashed just outside the bowl of the Big Dipper, likely a pristine shock front expanding from a star that exploded some 100,000 years ago.

The thin, circular, and extremely faint trace of hydrogen gas spans a third of the northern sky, a record holder for sheer size. But it can't be seen visually; ultraviolet and narrowband photography captured the arc, as study coauthor Robert Benjamin (University of Wisconsin, Whitewater) reported in June at the virtual meeting of the American Astronomical Society.

Andrea Bracco (Ruđer Bošković Institute, Croatia) and colleagues happened upon the Ursa Major Arc when poring over the ultraviolet images archived by NASA's Galaxy Evolution Explorer satellite. The researchers were looking for signs of a straight, 2.5° filament that had been observed two decades ago — but they found out that that length of gas was less straight than they had thought, forming instead a small piece of a much larger whole.

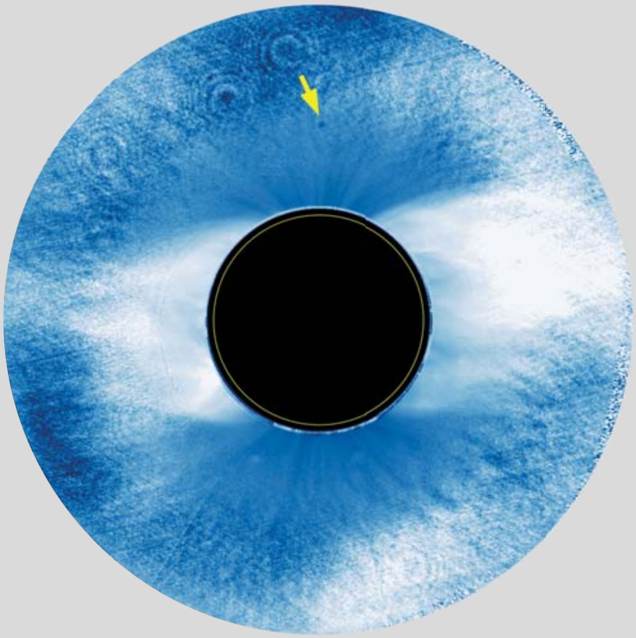
The team found unexpected confirmation of the feature in a hydrogen-alpha survey conducted by amateur astronomers David Mittelman (who died in 2017) and *Sky & Telescope*'s own Dennis di Cicco and Sean Walker. With the MDW Sky Survey, the amateurs are imaging the whole sky at 656.3 nanometers, the wavelength of light emitted by ionized hydrogen. In the process, they captured a circular arc that lines up "pretty much perfectly" with the ultraviolet data, Benjamin says.

Benjamin describes the curved feature as a thin, rippling shock front typical of supernovae, expanding away from a collapsed star at its center. Based on the gas's interaction with its surroundings, Benjamin and colleagues estimate that the arc is roughly 600 light-years away. The researchers report observations of the arc in the April issue of *Astronomy & Astrophysics*.

Interestingly, there are two well-known "holes" in interstellar material, termed the Lockman Hole and the Extended Groth Strip, that appear to lie within the bubble. These windows have given astronomers exceptionally unobscured views of intergalactic space. Given that the arc is so perfectly shaped, it's likely that some other explosive event had already cleared out the area when this supernova shock front passed through it, Benjamin says. Nevertheless, the explosion may have played a role in keeping these windows open.

■ MONICA YOUNG

The circular filament as seen in the MDW Sky Survey. See more stunning images of the H-alpha sky at **mdwskysurvey.org**.



ARC OF GAS: DAVID MITTELMAN, DENNIS DI CICCO & SEAN WALKER; VENUS PASSAGE: ALFRED DE WIJN & GUNTHER KÖNNEN

Venus Transits the Solar Corona

Sixteen years after Venus passed in front of the Sun in 2004, and eight years after its 2012 transit, Venus again passed near the Sun on the sky. This time, while Venus did not pass directly across the Sun's disk from our point of view, it did pass over the solar corona, coming within 13 arcminutes of the disk on June 3rd at 18:48 UT (2:48 p.m. EDT). Alfred de Wijn (National Center for Atmospheric Research) and Gunther Können (Royal Netherlands Meteorological Institute) recorded Venus's passage in front of the corona using the COSMO K-coronagraph (K-Cor) instrument at the Mauna Loa Solar Observatory in Hawai'i. K-Cor blocks the Sun's light to observe the corona, then further separates the corona's polarized light from the much more intense, but only weakly polarized, sky background. The brightness of the corona drops rapidly with distance from the solar disk, so the image here is scaled with a radially graded filter to improve the contrast. Venus won't pass so close to the Sun again until December 2109, eight years before the next transit of Venus in 2117.

■ ALFRED DE WIJN & GUNTHER KÖNNEN

View the video at https://is.gd/VenusCorona.

The Red Planet Revealed

A potpourri of images shot by the Mars Reconnaissance Orbiter showcases the planet's astonishing diversity of landforms.

Mars will be at its brightest and best in mid-October, when it comes to opposition. We thought of no better way to commemorate this close approach than to collect some of our favorite close-up photos taken by the Mars Reconnaissance Orbiter, which has circled the Red Planet since 2006.

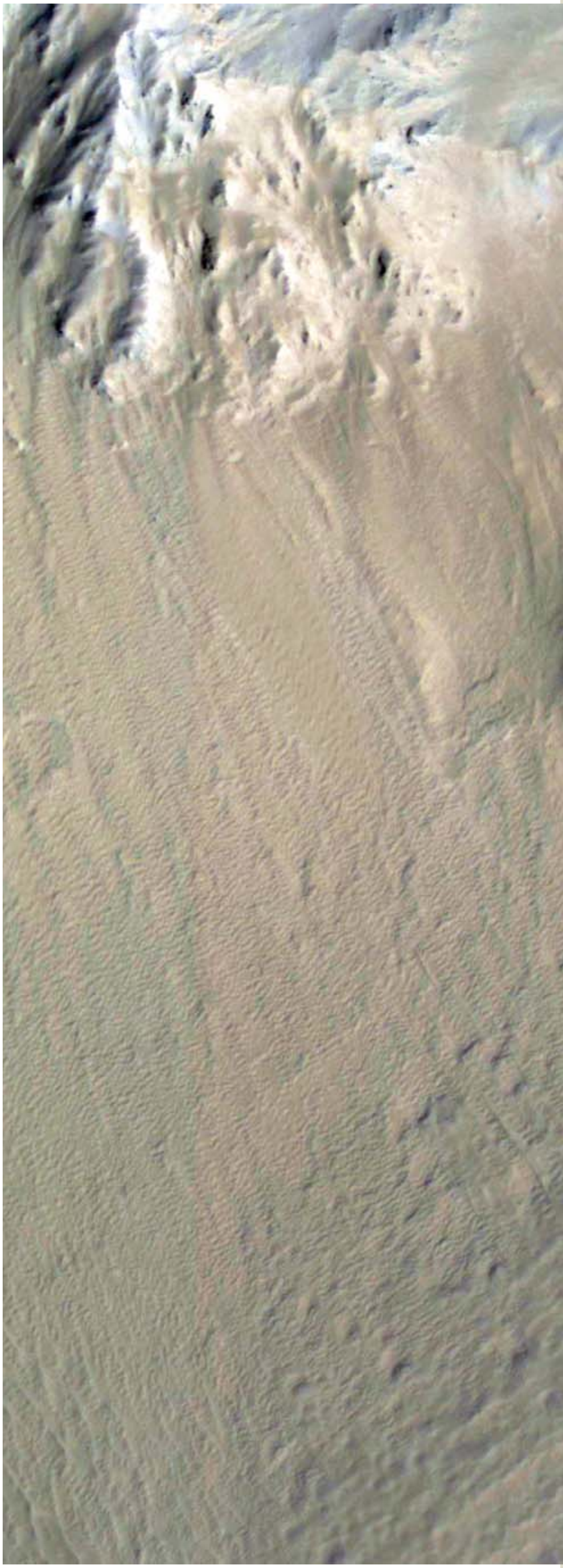
The spacecraft's High Resolution Imaging Science Experiment (HIRISE) is the most powerful camera we've ever sent to another planet. Its resolution is jaw-dropping: In images of surface swaths 6 kilometers (3.7 miles) wide, it can resolve features down to 1 meter (3.3 feet) across. And it can do so rapidly, acquiring images containing up to 28 GB of data in as little as 6 seconds. Altogether it's the largest optical telescope we've ever sent beyond Earth's orbit, but it also observes in near-infrared wavelengths. This helps scientists gather data on mineral groups that are present in the scenes it images.

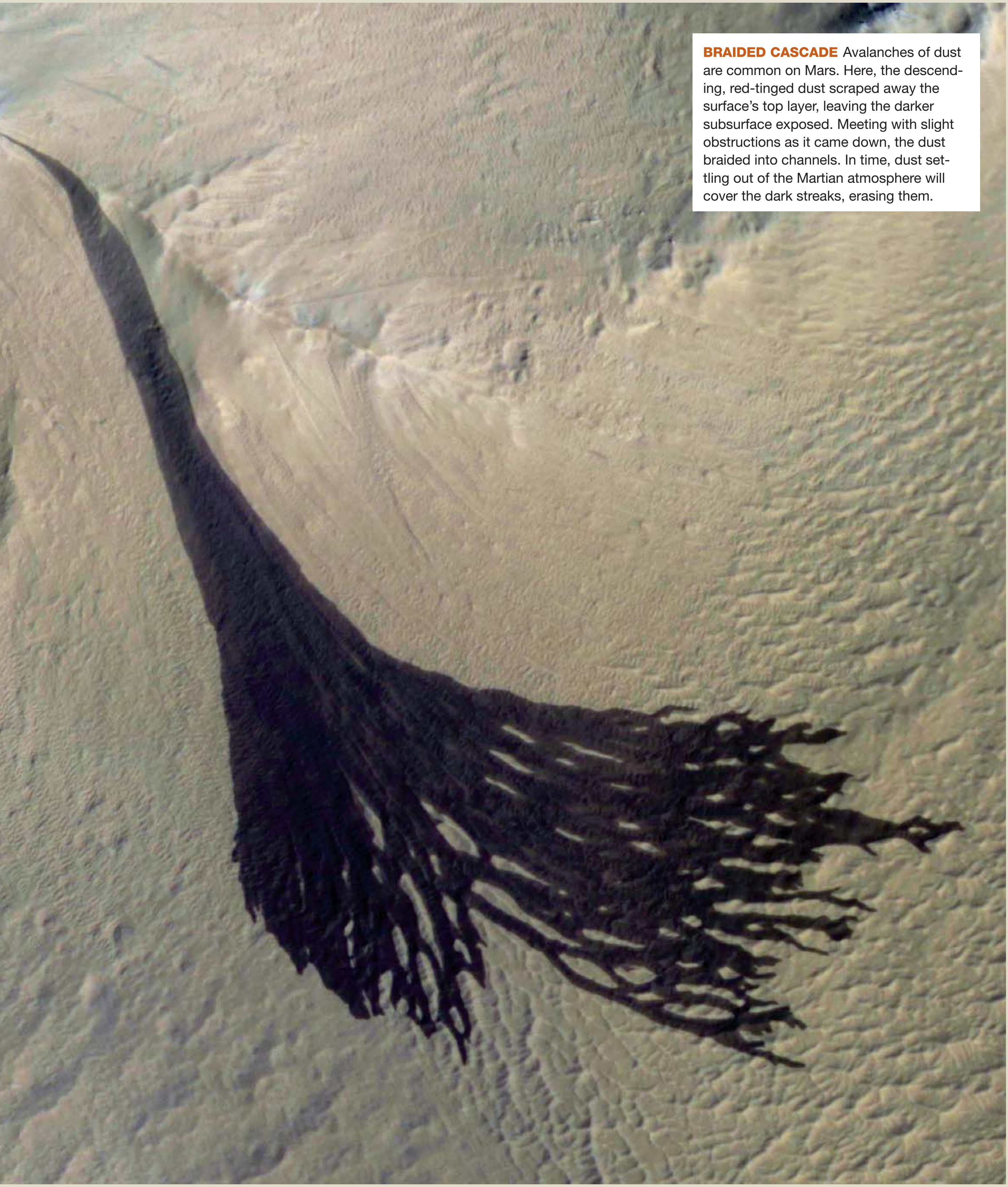
Scientists use HIRISE to study active surface processes on Mars and the evolution of its landscapes, as well as to help identify suitable landing sites for robotic and future human exploration. But the general public can also get a crack at it. Through the HiWish program, citizens can choose targets for the telescopic camera to photograph. For this reason, HIRISE is known as "the people's camera." The HIRISE team posts all acquired images to NASA's Planetary Data System (*S&T:* May 2018, p. 28), and they provide captioned images — from which all the pictures in this feature were chosen — that anyone, from educators to kids, can use in any way they wish.

We hope you savor our selection. But don't stop here: See the links below to explore Mars on your own.

■ Editor in Chief **PETER TYSON** wishes he could hike through some of these landscapes — with a really warm suit on.

FURTHER VIEWING:
HIRISE website: **uahirise.org**
HIRISE catalog: **uahirise.org/catalog**
HiWish: **uahirise.org/hiwish**



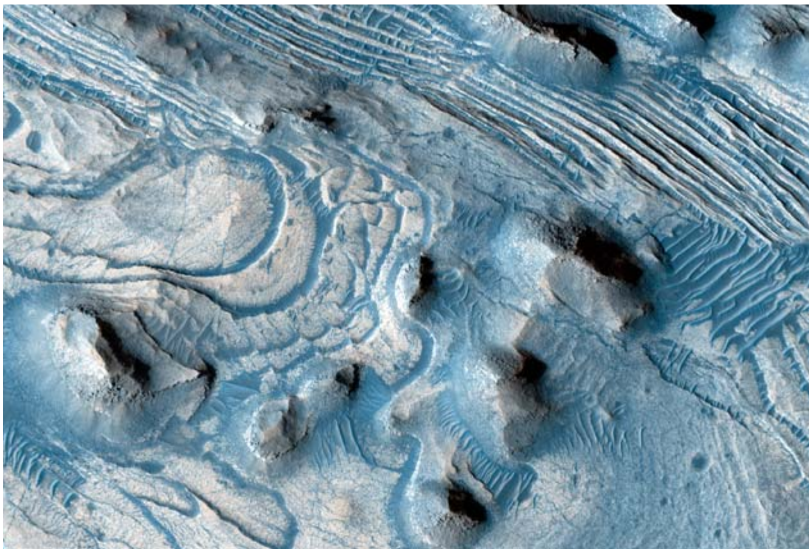


BRAIDED CASCADE Avalanches of dust are common on Mars. Here, the descending, red-tinged dust scraped away the surface's top layer, leaving the darker subsurface exposed. Meeting with slight obstructions as it came down, the dust braided into channels. In time, dust settling out of the Martian atmosphere will cover the dark streaks, erasing them.

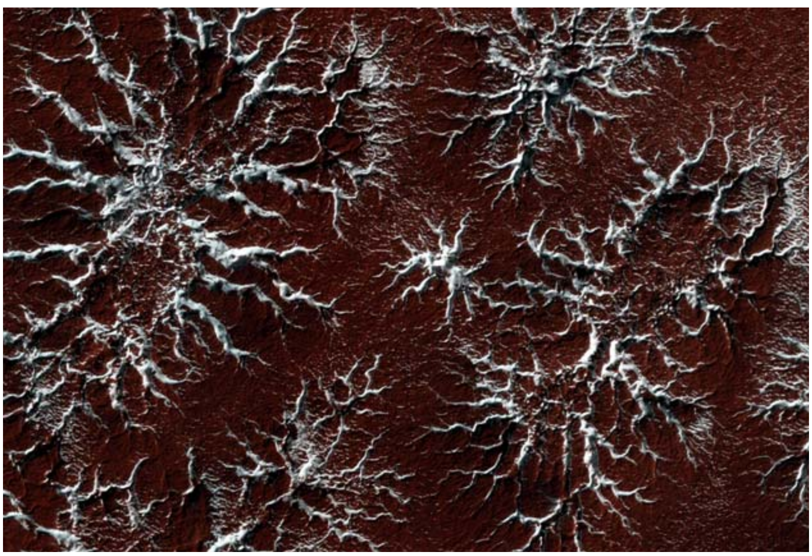
RIVER OF SAND Viewed in HIRISE infrared color, this fissure in southeastern Elysium Planitia looks like a wavy river flowing through a steep-walled canyon. But the ripples in the base of this cleft are dunes known as *transverse aeolian ridges*, or TARs. Careful monitoring of this region over years has shown no migration of the TARs, so the wind processes that created them might be on pause. The rift zone this gorge belongs to is part of a series of discontinuous fissures known as Cerberus Fossae.

▶ PATCHY CAP Carbon dioxide ice covers the Martian south pole, but sunlight ensures it's not uniform. The pits seen in this image form when the Sun heats the ice and causes it to *sublimate*, or change from solid directly to gas. Because the Sun never rises very high in the polar sky, steep slopes absorb more heat and sublimate faster, triggering the formation of pits that continue to expand, creating this otherworldly icescape.

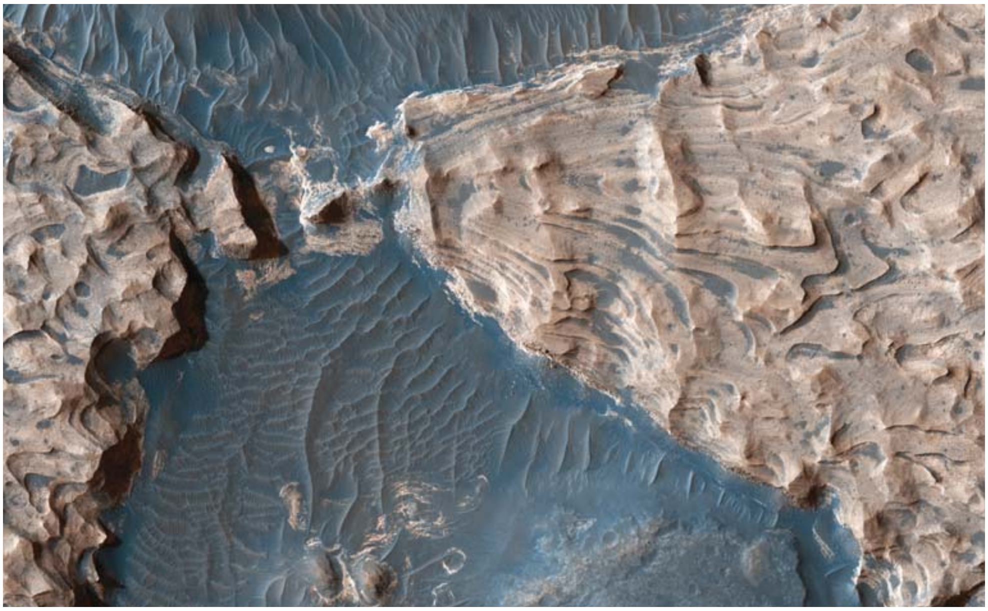
▶ COMPLEX TERRAIN There's a lot to keep a geologist busy in the landscape photographed here. It lies within Candor Chasma, a major canyon within Valles Marineris, the largest canyon complex in the solar system. The light-colored rock on the floor, formed ages ago by windblown or waterborne sediment, has been both folded and shifted along faults, giving it the curved, wavy appearance seen here. Careful mapping of the folds and faults will help scientists determine their origin, including whether water played a role in their formation.



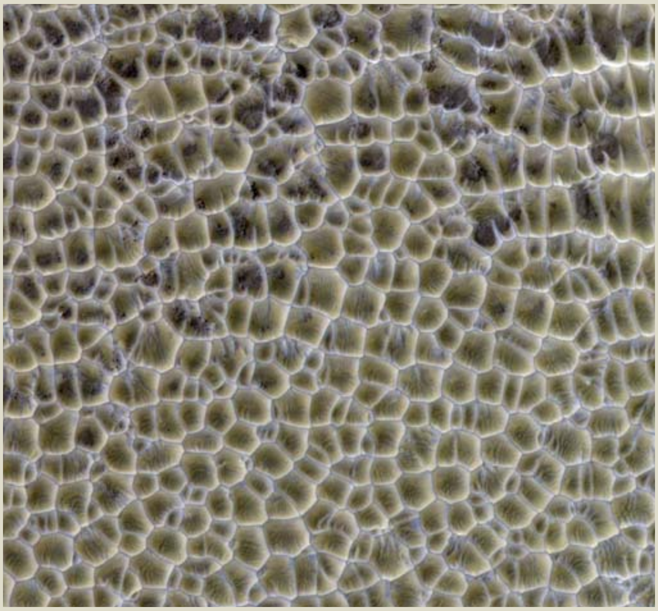
▶ SPIDERS ON MARS These channels of bright white carbon dioxide ice appear seasonally in the polar regions. In springtime, warming sunlight sublimates the dry ice, forming spider-like *araneiform* terrain. By summer, the ice will have vanished into the thin Martian air, leaving just empty channels in the brick-colored substrate.



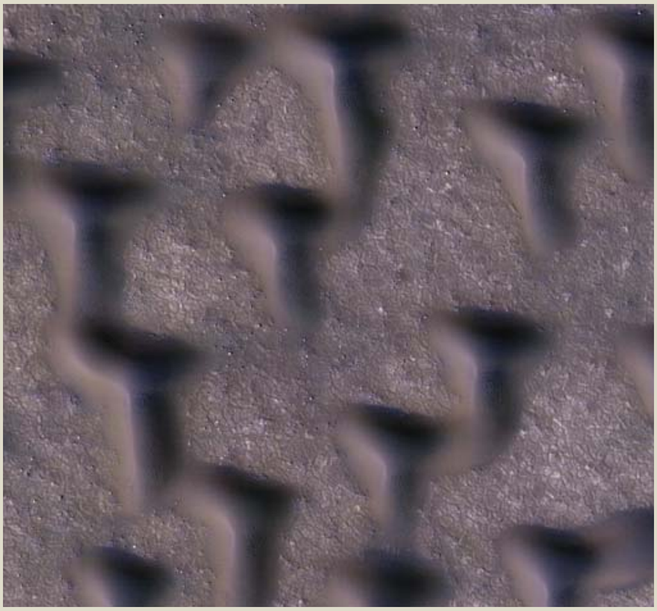
▶ WEATHERED BLOCKS Some landscapes on Mars can seem strangely familiar. These deeply etched layers of rock — mostly iron-oxide hematite and water-altered silicates — vaguely resemble desert landscapes of, say, the American Southwest. To geologists, they provide important clues that the ancient crater in which the stone lies was once a lake. Around the layered rock spread vast stretches of rippled, basaltic sand dunes. This scene is situated in Aram Chaos in the planet's southern highlands.



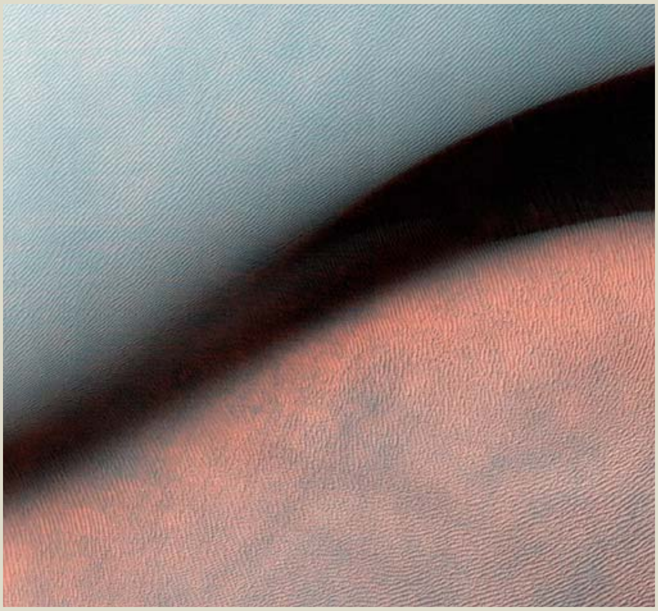
SERPENT OF DUST Like something alive, a dust devil scoots across the smooth plains of Amazonis Planitia. The length of its shadow indicates that this plume towers more than 800 meters (2,600 feet) into the Martian sky. The plume itself is about 30 meters wide and gets its sinuous shape from a westerly breeze.



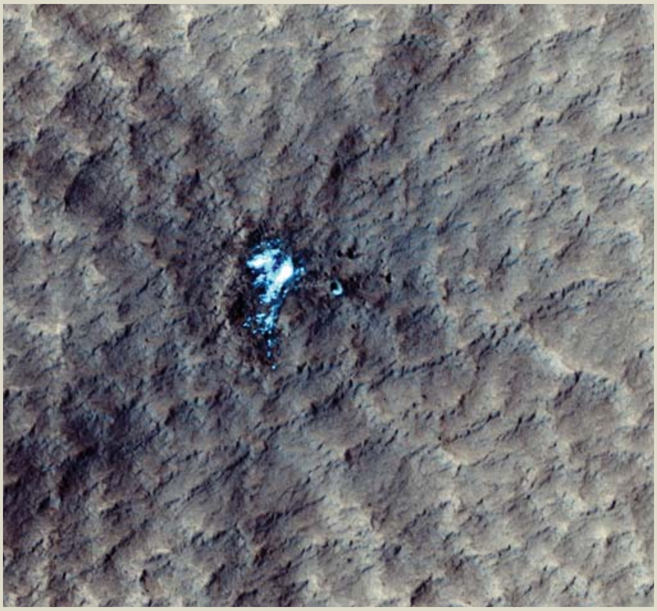
▲ **POLYGONAL PUZZLE** This view might remind one of a desiccated lakebed, but these are sand dunes. The polygons form when ridges of dunes intersect one another. In this image, the light comes from the upper left, and boulders and other debris can be seen in the base of some of the polygons.



▲ **HAUNTING ARMADA** In this enhanced-color view, a fleet of dunes appears to sail across a flat, boulder-strewn "sea" in the northern polar region. Typically, dune shapes on Mars serve as weathervanes, indicating the direction of the prevailing wind. But unlike classic *barchan*, or crescent, dunes, these T-shaped masses of basaltic sand enigmatically point in several directions.



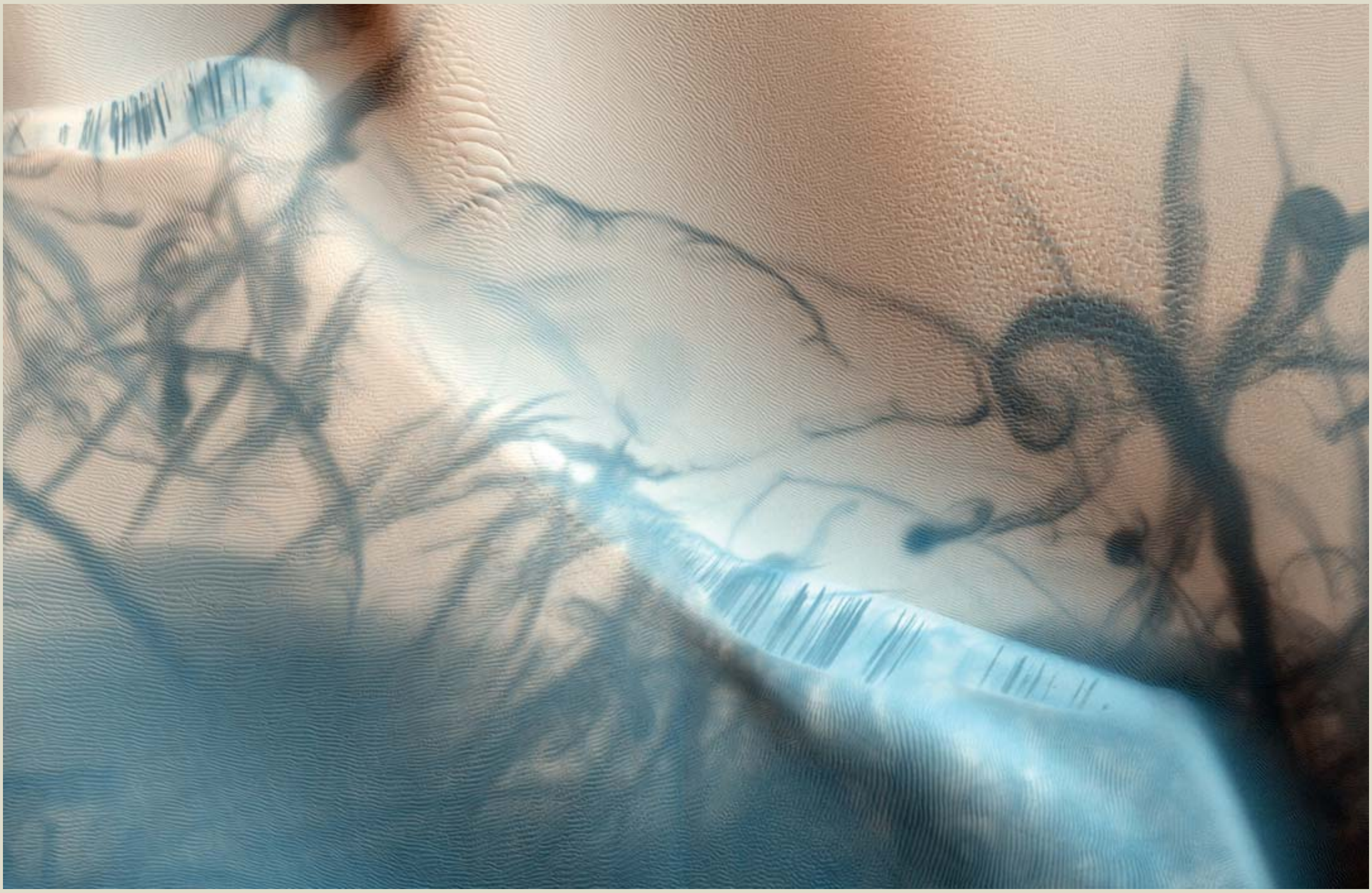
▲ **ABSTRACT MASTERPIECE** Scientists classify sandy landforms by the wavelength, or the length between crests. On Mars they recognize four classes: ripples (wavelength less than 20 meters), TARs (20–70 m), dunes (100 m to 1 km), and, finally, a mega-dune called a *draa* (greater than 1 km). This image is a close-up of a giant draa, with ripples stippling its precipitous faces. Relatively uncommon on Mars, draas likely take thousands of Martian years to form, possibly longer.

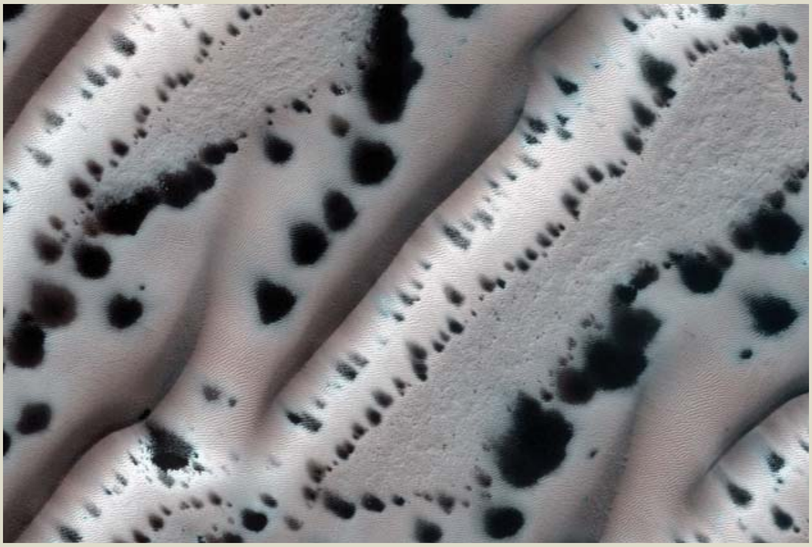


▲ **BLAST INTO THE BLUE** HIRISE has discovered more than 100 relatively recent impact craters on Mars. Some occurred *between* images taken of the same spot, offering valuable before-and-after scenarios. The impact zone of this one is about 800 meters wide. Most strikingly, the blast excavated right down to buried ice (blue), which surprised scientists with its pure, clean appearance. Such exposures of buried ice are rare — scientists have discovered only a handful.

▲ **SLEEK EDIFICE** This crescent-shaped dune (left in image) is known as a *barchan*. It forms when the wind blows in one direction, in this case east to west, over long stretches of time. By monitoring such dunes over years, scientists can follow the speed and manner of their creep across the surface, like tracking glaciers' progress on Earth.

▼ **MAKING TRACKS** Dust devils on Mars create their own calligraphy, scraping dust off the surface to reveal underlying darker materials. The twisters take shape from the sun-warmed surface's heat reradiating into the air. As the warm air rises, the devils spin and contract, much as figure skaters spin faster as they bring their arms into their sides.





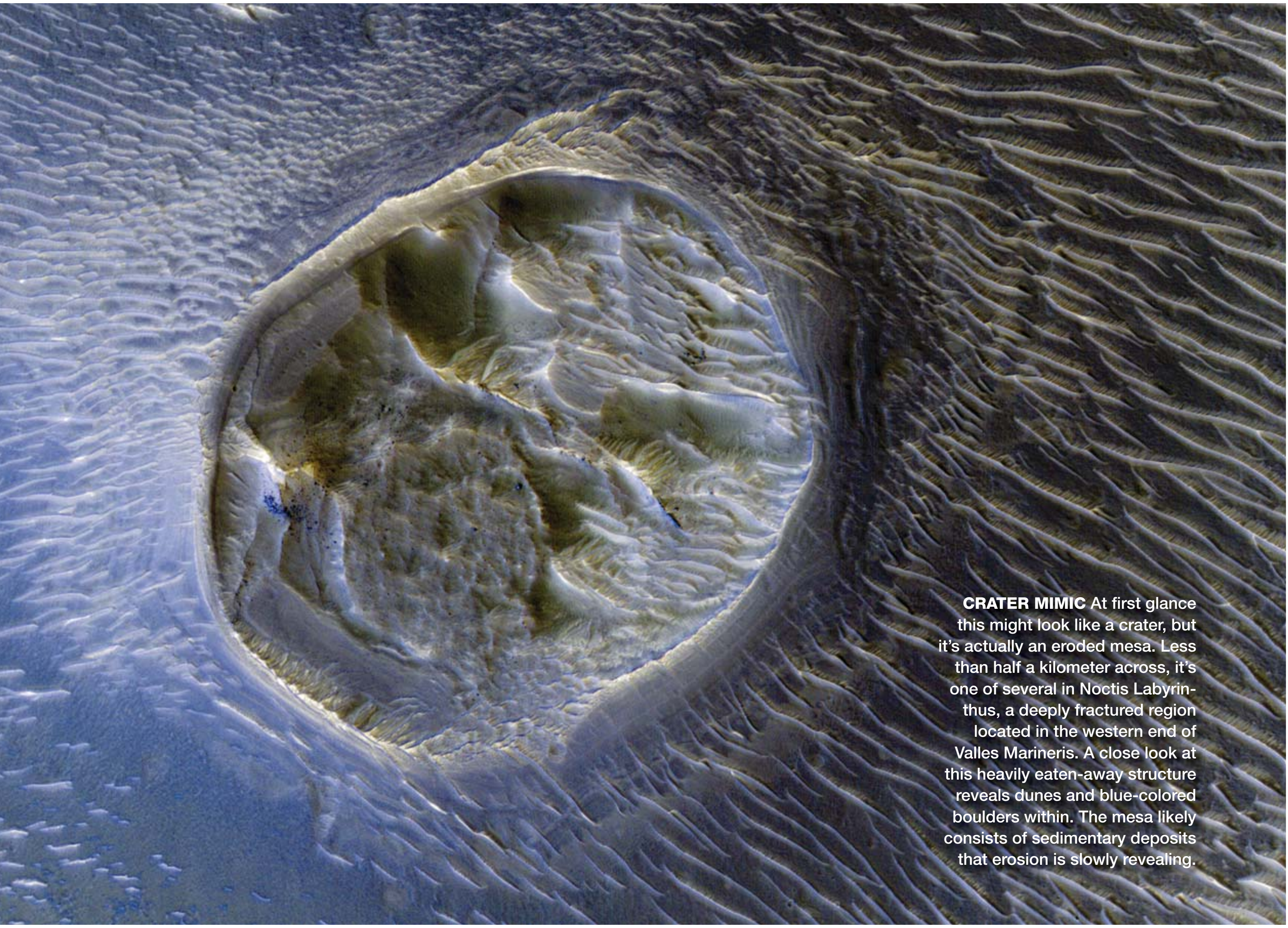
▲ **ANCIENT IMPACT** Some landscapes on Mars seem to be all about texture. The bumpy-looking surface surrounding this crater vaguely resembles reptilian skin. The crater lies west of Olympia Mensae in the Red Planet's high northern plains. (A *mensa* is a flat-topped prominence with cliffy edges, like a mesa on Earth.)

▲ **MARTIAN INK-BLOT TEST** We recognize the dunes and ripples, but what are the black blotches? They toy with the mind for an explanation of shape, pattern, consistency. What we're looking at is the result of sublimation of carbon dioxide frost in the late Martian winter. This jump from solid to vapor is complicated, resulting in the multifarious forms and patterns we see here, including grayish halos around some of the larger blotches.

SHADOWED GULLIES Deeply incised walls like this one characterize many craters in the Martian mid-latitudes. Of particular interest to scientists are seasonal changes, such as the color-enhanced blue deposits seen here in Gasa Crater. Captured in the early spring, the deposits are carbon dioxide frost that appeared the preceding winter.

◀ **DUSTY PLUNGE** HIRISE has serendipitously captured a number of avalanches at the very moment they occurred on the planet far below. Many of them, like this one, happen on sheer cliffs at the edges of layered deposits at the north pole. Here we're looking straight down a steep cliff, with white wispy tendrils indicating the direction of the fall. The reddish dust cloud is about 200 meters across. Studying such avalanches will help scientists determine what triggers them — seasonal temperature changes, wind gusts, or something else.

▶ **UNIFORM RANDOMNESS** Resembling brain matter, the ice cap at the north pole consists of thin coverings of carbon dioxide and water frost during the Martian winter. In spring, these low-lying hummocks, only about a meter in height, begin to disappear. By watching over time for tiny changes in such scenes, scientists can try to understand how this phenomenon occurs, which in turn can help them better understand climate and meteorological conditions at the north pole.



CRATER MIMIC At first glance this might look like a crater, but it's actually an eroded mesa. Less than half a kilometer across, it's one of several in Noctis Labyrinthus, a deeply fractured region located in the western end of Valles Marineris. A close look at this heavily eaten-away structure reveals dunes and blue-colored boulders within. The mesa likely consists of sedimentary deposits that erosion is slowly revealing.

HIRISE at a Glance

Type: Telescopic CCD camera

Size: 1.6 m long by 0.9 m in diameter

Primary Mirror: 0.5 m

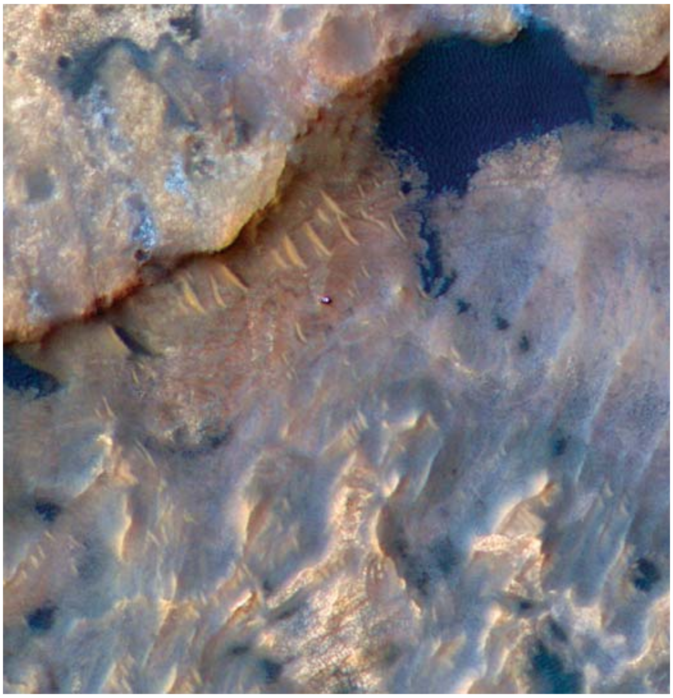
Focal Length: 12 m

Focal Ratio: f/24

Field of View: 1.14° x 0.18°

Resolution: up to 30 cm/pixel

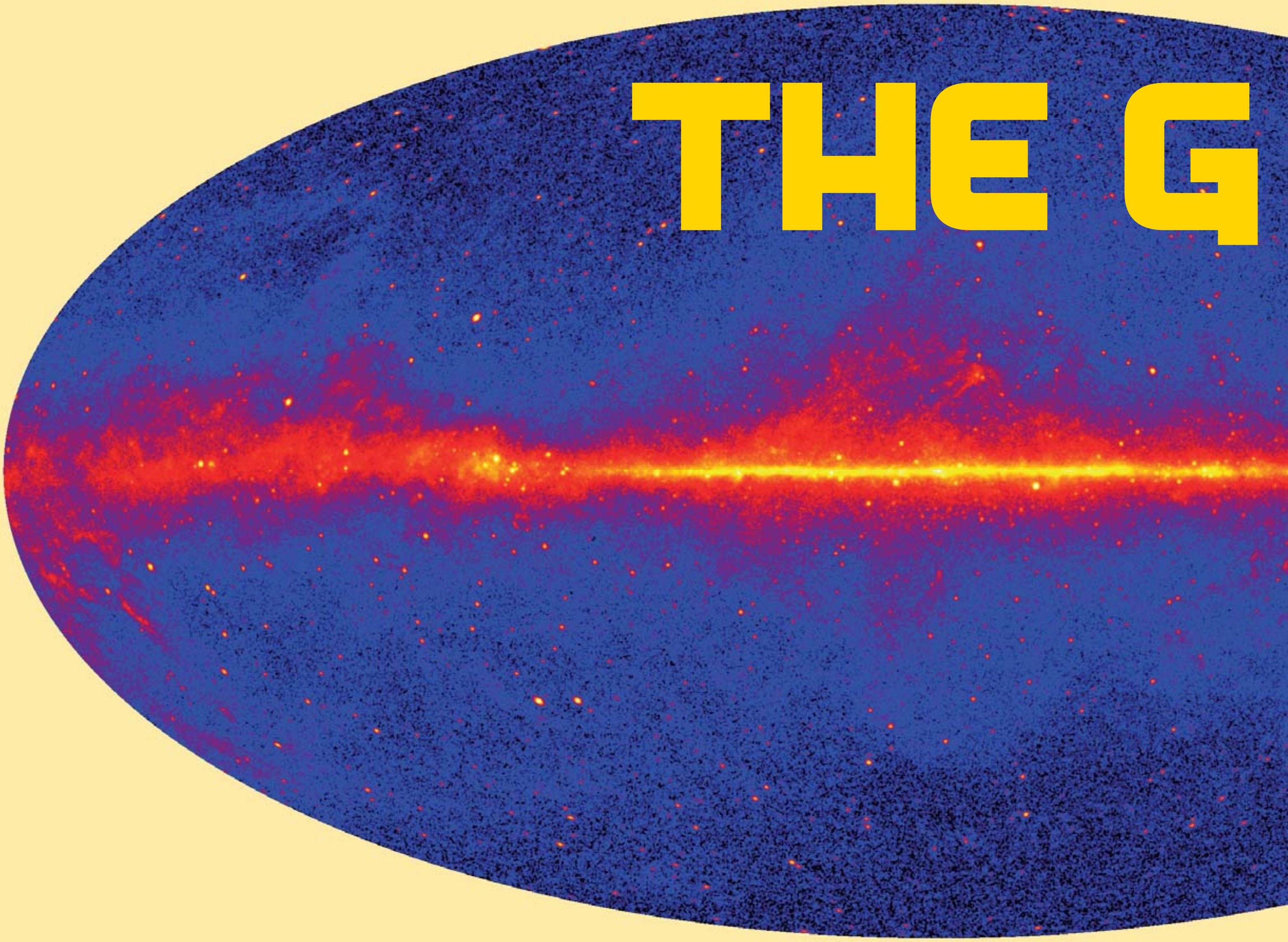
Altitude Operated: 200-400 km



▲ **LONELY EXPLORER** HIRISE captured this image of Curiosity on May 31, 2019, when the rover was investigating Woodland Bay, a clay-bearing area of Aeolis Mons in Gale Crater. Vera Rubin Ridge looms northwest of the rover, while to the northeast lies a dark pocket of rippled sand.

HIRISE CAMERA: NASA

THE G



NASA / DOE / FERMI LAT COLLABORATION

The highest energies of the electromagnetic spectrum reveal a cosmos replete with fantastic explosions and objects.

Imagine a universe where the glow from our Milky Way Galaxy dominates the sky, overpowering the light from individual stars, and where the Moon shines brighter than the Sun.

Imagine a universe so extreme that when two photons smash into each other they can actually form matter in the process, where a single explosion releases more energy in a few seconds than our Sun will in its entire lifetime, and where black holes accelerate tiny charged particles to nearly the speed of light in jets that span thousands of light-years.

This is the gamma-ray universe. Invisible to our eyes and beyond the reach of large, Earth-based telescopes such as Keck or VLT, gamma rays are emitted by the most exotic and extreme creatures in the cosmic zoo — pulsars, exploding stars, and gigantic, plasma-stream-shooting black holes. They give us a unique window into an energetic universe, one that we're still working to understand.

What Are Gamma Rays?

Most of the world that we experience is colored by the familiar rainbow of visible light — photons that have energies of just a few electron volts (eV). But gamma rays are a world apart from these everyday photons. Each individual gamma-ray photon has millions to billions of times more energy than a ray of visible light. With energies of millions (MeV) to billions (GeV) of electron volts, gamma rays rule the electromagnetic spectrum as the most energetic form of light.

AMMA-RAY UNIVERSE

▲ **THE GAMMA-RAY SKY** This map combines 10 years of Fermi observations at energies between 1 and 100 GeV. The color scale is logarithmic, from dark blue to yellow, with the brightest gamma-ray sources in yellow. The bar across the center is the Milky Way's disk. It shines brightly in gamma rays because of interactions between cosmic rays and interstellar gas. The isolated red and yellow dots across the sky are individual sources.

With their tremendous energies, gamma rays travel through the universe largely undisturbed by clouds of gas and dust. They also pierce normal mirrors, fly through lenses, and refuse to bounce off the nested mirrors that astronomers use to focus X-rays (*S&T:* Aug. 2019, p. 14). Gamma rays are thus notoriously hard to bring to a focus — in fact, we have yet to truly focus gamma rays, even in the laboratory. The best we can do is catch them one by one and try to trace them back to their sources in the sky.

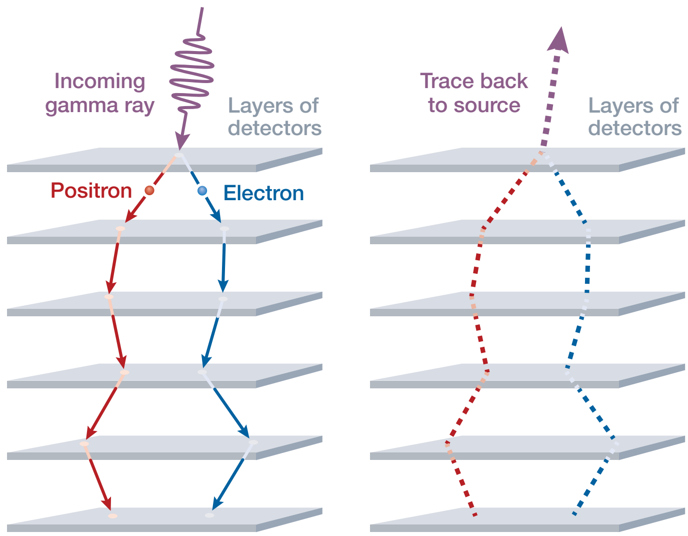
However, most gamma rays, after traversing the universe, stop cold when they interact with molecules in Earth's atmosphere. We can only detect signs of the most energetic gamma rays from the ground. For the rest, we have to send instruments into space. We do this with experiments that dangle under large helium balloons, with detectors strapped into rockets for short sub-orbital flights, or with free-flying satellites that orbit Earth for years, sending back data to ground-based researchers.

Since the first gamma-ray experiments in the 1960s, our ability to detect and image gamma rays has improved by more than a factor of 1,000. The most successful early mission was NASA's Compton Gamma-Ray Observatory (CGRO), part of the Great Observatories series of space telescopes. CGRO operated from 1991 to 2000 and, with its four instruments, surveyed nearly the entire stretch of the gamma-ray universe — an energy band roughly a million times "wider" and more than a million times more energetic than what Hubble can detect. By the mission's end, CGRO's EGRET instrument had cataloged 271 individual sources, including nearly 100 jet-shooting supermassive black holes called blazars, five pulsars, a very strong solar flare, the radio galaxy Centaurus A, and the Large Magellanic Cloud dwarf galaxy. Astronomers couldn't match the remaining 170 sources with objects studied at lower energies. They remained unidentified.

CGRO's instruments used a variety of techniques to capture and measure gamma rays, including scintillating crystals of dense materials such as sodium iodide. When an incoming gamma ray hits one of these crystals, an atom in the crystal releases an electron, which then strikes other nearby atoms, exciting additional electrons. When these electrons return to their ground state, they emit a flash of visible light. Devices called photomultipliers surrounding the crystals amplify the signal; with enough crystals, this method can also provide crude positional information to help locate the gamma ray's origin.

But the most accurate method to determine the direction of an incoming gamma ray is through *pair conversion*. When a gamma ray hits a dense material, it converts into a pair of oppositely charged particles — an electron and its antiparticle, the positron. The subsequent movement of these charged particles results in tracks that we can reconstruct to find the incoming direction of the original gamma ray. In this pair-conversion process, the energy (E) of the incoming gamma ray creates particle pairs with mass (m) according to Einstein's most famous equation: $E = mc^2$, where c is the speed of light.

Regardless of the type of instrument, the information from gamma-ray detectors must be read out electronically, fed into computers, and then reconstructed digitally. To complicate matters further, there are many extra signals created by background particles or by gamma rays originating on Earth. Astronomers must remove these spurious signals in order to recover the small fraction of the data that truly represents cosmic gamma rays. For example, at energies over 100 MeV, there is about 1 cosmic gamma ray detected for every 100,000 spurious signals! Searching for usable gamma-ray signals is therefore much like searching for needles in very large haystacks.



▲ **PAIR PRODUCTION** When a gamma ray hits a heavy nucleus in a dense material, such as lead, it converts into an electron and positron pair. These then travel through other layers that register their passage. Astronomers reconstruct the charged particles' paths to determine the gamma ray's incoming direction.

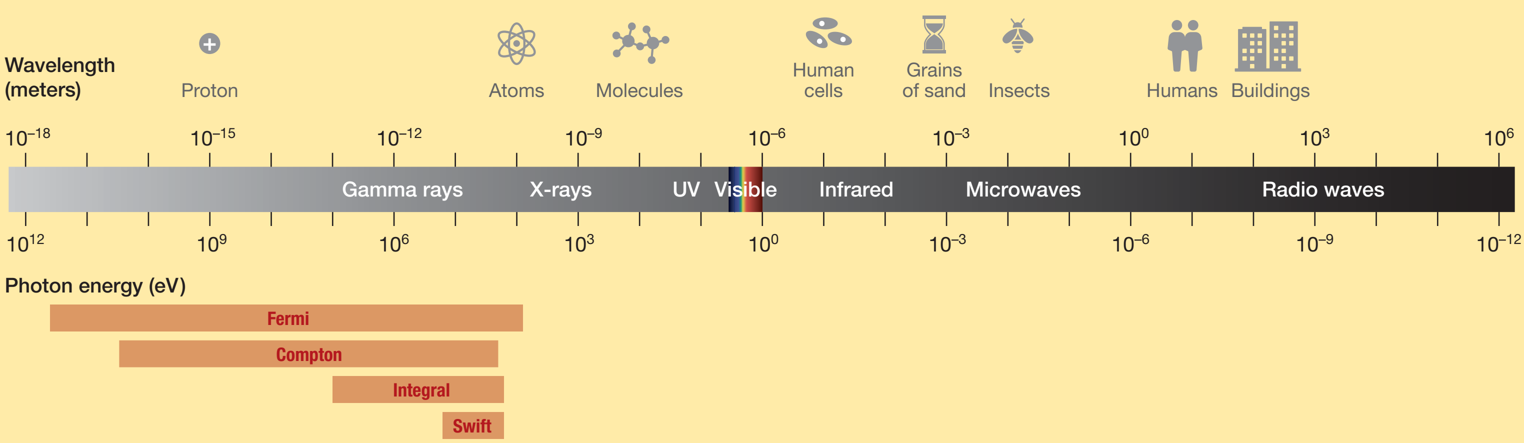
Sources of Cosmic Gamma Rays

On Earth, most of the light that we see or feel arises from things that are shining or glowing. The infrared light we feel as heat from a kitchen oven, the sunlight streaming through a window, and the ultraviolet light that penetrates clouds to produce sunburn, are examples of what scientists call *thermal radiation*. Thermal radiation is the characteristic light produced by something glowing at a specific temperature. The yellowish light from the Sun indicates that the solar surface is at a temperature of around 5800 kelvin. Lower-energy infrared light usually indicates temperatures of a few hundred kelvin. Ultraviolet light, which is more energetic than visible light, is often radiated by objects in space with temperatures of tens of thousands kelvin. Even some X-rays, seen from many astrophysical objects, come from gas glowing at millions of kelvin.

Only gamma rays are too hot to handle. In order for something to shine in gamma rays, the object would need a temperature of billions of kelvin. These conditions occur rarely, such as the instant that a star explodes. Almost all other cosmic gamma rays are *non-thermal* — they are not seen

ELECTROMAGNETIC RANGE AND PROTON: TERRI DUBÉ / S&T; ATOMS: CREATIVE STALL / THE NOUN PROJECT; MOLECULES: DELWAR HOSSAIN / THE NOUN PROJECT; HUMAN CELLS: TERRI DUBÉ / S&T; GRAINS OF SAND: DENNIS / THE NOUN PROJECT; INSECTS: VECTORSTALL / THE NOUN PROJECT; HUMANS: ADRIEN COQUET / THE NOUN PROJECT; BUILDINGS: UN-DELIVERED / THE NOUN PROJECT; PAIR PRODUCTION: GREGG DINDERMAN / S&T

▼ **GAMMA-RAY CATCHERS** Several space telescopes have observed the universe in gamma rays, including four notable recent missions: NASA's Compton, Fermi, and Swift space telescopes and the European Integral spacecraft. Some of the telescopes carried complementary instruments that observed lower wavelengths; for clarity, we've omitted those instruments' ranges here.



▲ **COMPTON** The Compton Gamma-ray Observatory seen from the Space Shuttle *Atlantis* during deployment. The lower dome on the spacecraft housed the instrument EGRET, which used the pair-production process to detect gamma rays. The other instruments utilized different kinds of scintillation detectors.

from something that is glowing or shining. Rather, gamma rays are created by the acceleration of charged particles, called *cosmic rays*, that are moving at very high speeds, often near the speed of light. When a charged particle accelerates or decelerates, it emits light. Faster acceleration (or deceleration) will produce higher-energy photons, and the most rapid changes produce gamma rays. The bright gamma-ray glow that we see from our own Milky Way Galaxy is likely created when cosmic rays crash into particles of interstellar gas and dust that are concentrated along the plane.

Decaying radioactive elements also produce gamma rays, as does a mechanism called *inverse Compton scattering*, in which visible or ultraviolet photons smash into relativistic electrons. The crash gives a million-fold energy boost to the incoming photon and transforms it into a gamma ray.

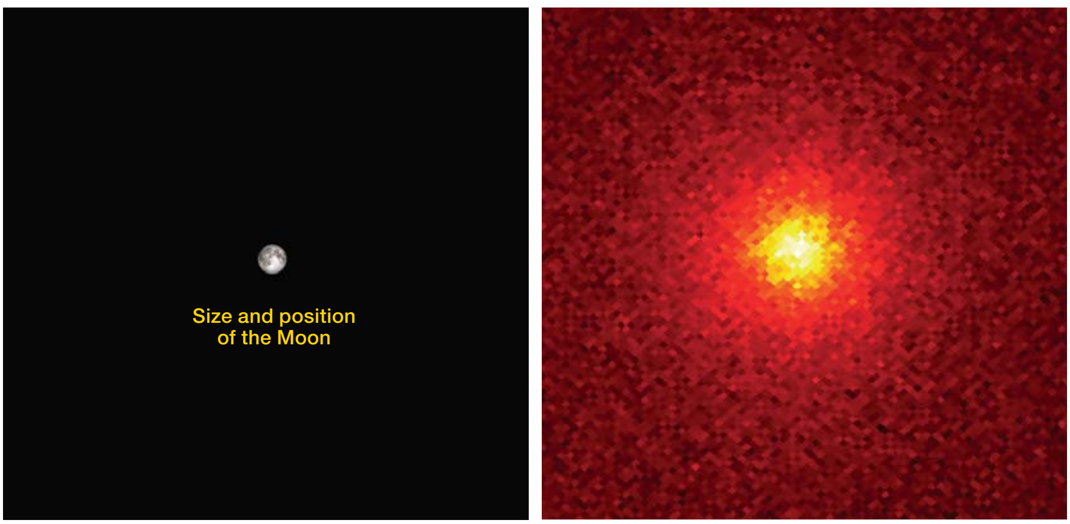
For cosmic objects, the extreme acceleration of charged particles needed to create gamma rays typically occurs in ultra-strong magnetic or gravitational fields. Astronomers therefore weren't surprised to detect gamma rays from blazars (which have bone-breaking gravitational fields near the black holes' event horizons) or pulsars (which have magnetic fields billions to trillions of times that of Earth). Yet we've now seen gamma rays from more mundane cosmic zoo denizens, such as novae, binary star systems, supernova remnants, and star-forming regions, confounding scientists and dramatically changing our understanding of their energetics.

Fermi's Discoveries

NASA's Fermi mission, launched into Earth orbit on June 11, 2008, has given us our most detailed view of the gamma-ray universe. Its two onboard instruments combine scintillating crystals and pair-conversion detectors to measure gamma rays over an extremely wide band: from 8 keV to more than 300 GeV. At the highest energies, Fermi has an angular resolution of about 0.1°. That would not be enough to resolve the largest craters on the Moon, but in gamma-ray astronomy it's as high-definition as we can currently get.

In 2010, Fermi detected gamma rays from V407 Cygni, a symbiotic binary system comprised of a white dwarf star and a red giant star about 500 times the size of the Sun. Astronomers have long observed visible-light outbursts from novae, caused by thermonuclear explosions on the white dwarf's surface. But no one expected to see strong gamma-ray emission that persisted for 15 days! Fermi's discovery of this emission from several novae revealed that the explosion's tremendous shock front accelerated particles trapped by magnetic fields to near light speed. When these highly relativistic particles smashed into the wind flowing out of the red giant, they created gamma rays. Seeing such strong gamma emission provided the first proof that magnetic fields in novae can approach the strength of those in their far more energetic supernova cousins.

Fermi also revealed gamma rays coming from star-forming regions. We usually think of these regions as dominated by nascent stars shining brightly at infrared wavelengths, cocooned within thick dust clouds that absorb most of their



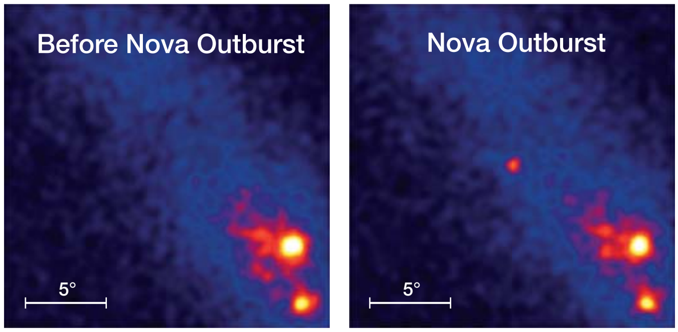
▶ **MOON IN GAMMA RAYS** This image from Fermi shows what the Moon looks like in gamma rays, specifically at energies above 31 million electron volts. The glow comes from cosmic rays hitting the lunar surface.

COMPTON TELESCOPE: NASA / MSFC; MOON IN GAMMA RAYS: NASA / DOE / FERMI LAT COLLABORATION visible light. However, starburst regions also include many massive stars that live relatively brief lives before detonating in supernovae. Supernovae create shock waves that accelerate charged particles to relativistic speeds. When these particles slam into nearby gas, they create gamma rays in a process similar to that which creates the Milky Way's bright gamma glow. The gamma-ray emission from star-forming regions teaches us about these shock waves and how they accelerate particles to such high speeds.

Based purely on their name, gamma-ray bursts (GRBs) are the most obvious target for gamma-ray astronomy. Astronomers have so far detected more than 5,000 of them with a variety of instruments. We think those longer than 2 seconds come from dying massive stars, while the shorter bursts come from two neutron stars crashing together. But we didn't have direct proof of the neutron-star scenario until August 17, 2017, when Fermi's Gamma-ray Burst Monitor (GBM) caught a short, relatively weak GRB at roughly the same time that gravitational waves rippled through detectors on Earth (*S&T:* Feb. 2018, p. 32).

We still don't know for sure what kind of object the merger produced. It should have created something of approximately 2.7 solar masses. This is smaller than conventional stellar-mass black holes (traditionally expected to be greater than 3 solar masses), yet it's too large to be a known type of neutron star (which typically top out at 2 solar masses). But based on detailed follow-up by thousands of astronomers worldwide, using data from more than 70 different instruments and observatories, we confirmed that crashes like this one could make at least half of the universe's supply of gold and several other elements heavier than iron. Thus although they may seem esoteric, gamma-ray bursts play a fundamental role in the development of the heavier elements and, by extension, rocky planets across the cosmos.

Gamma rays have also revealed entirely new features in our own galaxy, such as the Fermi Bubbles — almost symmetric, diffuse gamma-ray lobes stretching from near the Milky Way's center to out above and below the galactic plane. End to end, the bubbles span about 50,000 light-years (*S&T:* Apr. 2014, p. 26). The Fermi Bubbles match up with features seen in microwave sky maps (the "WMAP haze") and possibly also in X-rays, and they have well-defined edges. These results suggest that one or more events ejected energy into the region for a few million years but not much longer — perhaps repeated



▲ **V407 CYG** Fermi's Large Area Telescope saw no sign of a nova in 19 days of data prior to March 10, 2010. But data from the following 19 days *(right)* clearly show V407 Cygni blazing. The images show the rate of gamma rays with energies greater than 100 million electron volts, with brighter colors indicating higher rates.

◀▼ **FERMI** NASA's Fermi space telescope succeeded Compton. In the photo, the LAT instrument is the silver box on top. The cylindrical, foil-covered items in the center of the photo are some of the Gamma-ray Burst Monitor's 14 detectors.

FERMI PHOTO: NASA / GENERAL DYNAMICS ADVANCED INFORMATION SYSTEMS; FERMI ILLUSTRATION: NASA GODDARD SPACE FLIGHT CENTER; NOVA CAUGHT BY FERMI: NASA / DOE / FERMI LAT COLLABORATION outbursts from the supermassive black hole in the Milky Way's core. Although we have seen similar outbursts in other galaxies, we've seen none large enough in our own galaxy in the modern era. Without gamma-ray observations, we would have limited appreciation for just how violent our galaxy's center can be.

The Future of Gamma-ray Astronomy

With the publication of the fourth catalog of sources from Fermi's Large Area Telescope (LAT), we now know of more than 5,000 persistent gamma-ray sources spread across the entire sky. (GRBs generally only last a few seconds, so we don't include them in this tally.) Based on the first eight years of Fermi data, this catalog includes more than 3,000 blazars and nearly 240 pulsars. Along with NASA's Fermi mission, there are other satellites studying cosmic gamma rays at lower energies, including NASA's Neil Gehrels Swift Observatory and European missions such as Integral. Each has amassed its own collection of detections. With so many sources to study, gamma-ray astronomy has now become a mature field, contributing to studies of objects visible across the electromagnetic spectrum as well as via particle and gravitational-wave studies.

Approximately one-quarter of the objects in the fourth Fermi LAT source catalog are unidentified, i.e., not associated with objects visible at other wavelengths of light. Are these sources just fainter versions of the types of gamma-ray emitters with which we are already familiar? Or does some fraction of them represent entirely new classes of objects, going beyond the many new types of sources that Fermi has uncovered? It will take many more years of data and perhaps newer, more sensitive detectors to find out.

Possibly the biggest mystery that Fermi continues to study is the nature of dark matter. The Einsteinian heart of Fermi's LAT detector is the conversion of pure energy in the form of gamma-ray photons into particles with mass: an electron-positron pair. If you run this process in reverse and combine an electron with a positron, the particles annihilate, creating pure energy in the form of two 511 keV X-rays. Some scientists suspect a similar process should happen for dark matter particles, which are their own anti-particles in many theories. Since these types of theorized dark matter particles (often called "WIMPs" for Weakly Interacting Massive Particles; *S&T:* Aug. 2017, p. 28) are much more massive than electrons or positrons, we should see gamma-ray signals when they annihilate.

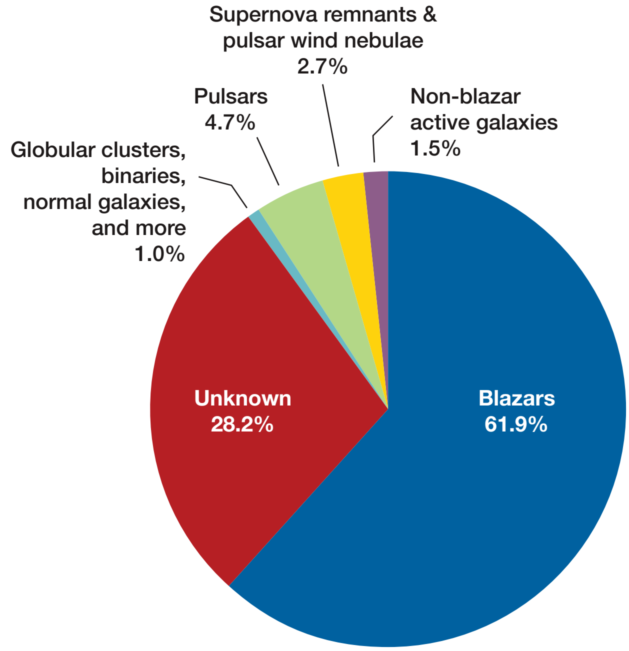
To date, Fermi has looked for dark matter signals in many regions of the sky, including the Sun, the center of the Milky Way Galaxy, and in dozens of external dwarf spheroidal galaxies. Astronomers have found a mysterious uptick of gamma rays coming from our galaxy's center, as well as the Andromeda Galaxy's. But they still debate whether the emission comes from dark matter or undiscovered pulsars. To date, no unambiguous signs of dark matter annihilation have been found. Do these heavy dark matter particles exist? Or are the physical theories that invoke these particles incorrect? We may have to wait for new generations of gamma-ray satellites and other types of instruments to illuminate the true nature of dark matter.

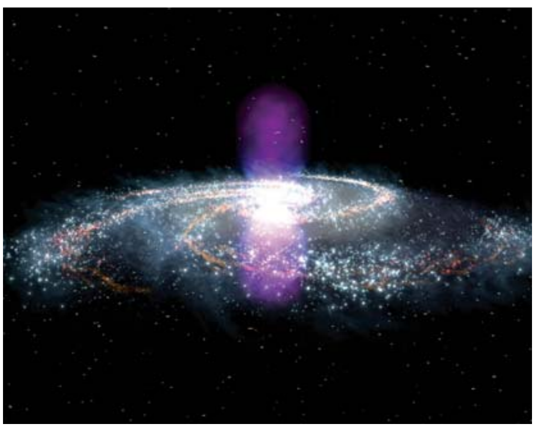
But while we are waiting, the gamma-ray observatories now orbiting Earth will continue to surprise us with discoveries of new sources, extreme behavior from familiar sources, and photons that link to other astronomical messengers to reveal more secrets from the high-energy universe.

■ **LYNN COMINSKY** is a professor of physics and astronomy at Sonoma State University and the director of EdEon, SSU's STEM learning center. When not in front of a computer, she is often found tending to all the critters at the Little H-bar Ranch in Petaluma.

The Fourth Fermi LAT Catalog

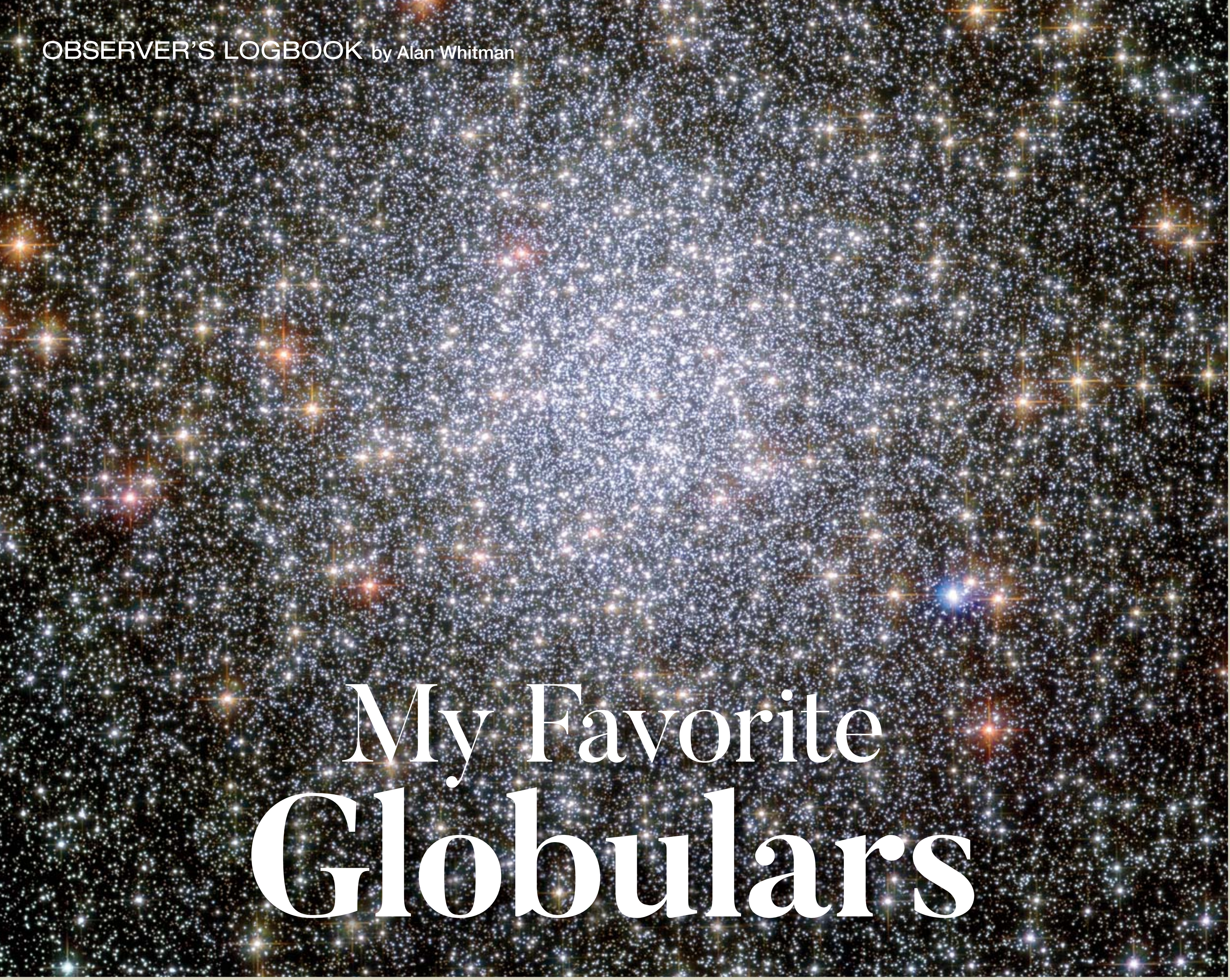
Total number of objects: 5,064





▲ **FERMI BUBBLES** Discovered in 2010 in gamma rays, two gargantuan lobes extend above and below our galaxy's disk. This artist's illustration shows just how big the Fermi bubbles are.

PIE CHART: GREGG DINDERMAN / *S&T*, SOURCE: IRFU / CEA; FERMI BUBBLES: NASA GODDARD SPACE FLIGHT CENTER



My Favorite Globulars

No matter your equipment or location, these impressive stellar collections offer something for everyone.

Globular star clusters are my favorite deep-sky objects. But what makes one a true showpiece? Size and magnitude are important, but there's much more when choosing favorites. I also take into account the degree of concentration, ease of resolution, the number and shape of any star chains, dark areas within the core, distinctive features, and other deep-sky objects ornamenting the field of view.

The observations presented here were made with 8-inch to 30-inch telescopes on excellent nights. But many of my most enduring memories were made with small scopes or binoculars, or under poor conditions. For example, during a pit stop en route to the 1983 Texas Star Party, with trucks rumbling by on the interstate and mosquitos swarming, I took out my 7×50 binoculars to look for Omega Centauri. My charts were buried under my stuff, but I knew the globular was somewhere below Spica. Sweeping southward, I found it within a minute. That first binocular view of the great globular is one that I'll never forget. At the TSP the Texans were generous with their big Dobs — but I preferred to patrol the southern horizon with my little 4.2-inch Astroscan, picking off globulars that I'd never seen before.

Here are my descriptions of my favorite globulars that I've observed throughout the decades in both Hemispheres, at remote star parties or in suburban backyards, with behemoth Dobs and with modest binoculars. I highlight the geographic locations and the variety of setups that I used in the hope that wherever you are and whatever equipment you might have, you too can enjoy these sights.

NASA / ESA / HUBBLE HERITAGE / STSCI / AURA / ESA / HUBBLE COLLABORATION

◀ The finest globular cluster, in my opinion, is **47 Tucanae**. A dense cluster, 47 Tuc has a prominent core that may harbor an intermediate-mass black hole (a class in between stellar-mass and supermassive black holes), with estimates ranging from around 1,400 to 3,700 solar masses. While in Australia, I enjoyed 47 Tuc with big Dobsonians almost every observing night (even if only briefly) because it's a circumpolar object from that location. Leading Australian amateur Andrew Murrell lent me his 20-inch Dob, and with it at 159× I'd place 47 Tuc just outside the field and watch *globular-rise*: The rich halo of uncountable stellar pinpoints would drift into view, the concentration of suns becoming ever greater until the magnificent yellow core appeared. Most observers see color in its dense core. Tony Buckley, my generous host on several Australian observing runs, has a 14.5-inch Dobsonian, and with it at 322× I could easily resolve the blazing core all the way across. A dark north-south lane appeared on the inner core's preceding edge, and an orange star lay just beyond the core's west-northwestern edge. At 136× numerous star chains appear in the halo. With a 30-inch Dob at the 2016 OzSky Star Safari in Coonabarabran, New South Wales, I could perceive many additional fainter stars.

All images are oriented so that north is up.

▲ **Omega Centauri** is brighter and larger than 47 Tuc, but since it's looser it isn't quite as overwhelming. It is, however, the Milky Way's most massive globular cluster. As with 47 Tuc, Omega Cen may host an intermediate-mass black hole in its core. This globular might even be the remnant of a dwarf spheroidal galaxy whose outer stars have been stripped by the Milky Way. The fact that a stellar designation was bestowed upon Omega Cen is curious — with the unaided eye, large and fuzzy Omega doesn't remotely resemble a star! After seeing it with Buckley's 14.5-inch at 136× I wrote in my logbook:

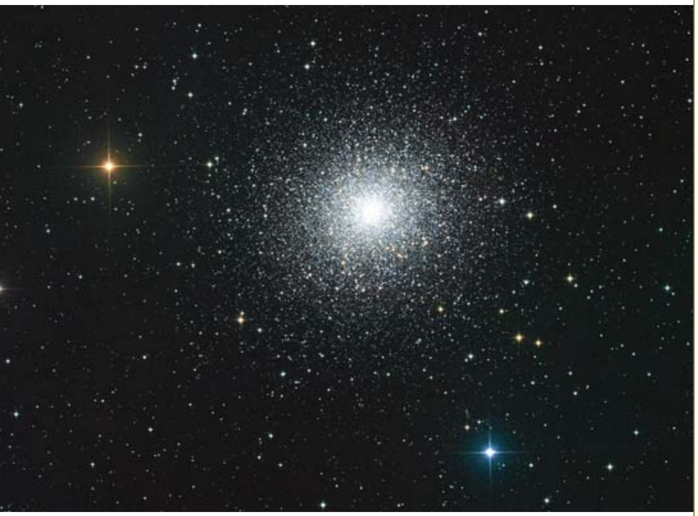
> *"Mesmerizing! It takes 1.6 fields to show all of the outliers. There are literally thousands of resolved stars — quite uncountable. The cluster is markedly oblate east-west. There are two adjacent dusky areas in the core arranged north-south where there are no resolved stars."*

In Coonabarabran the 30-inch Dob resolved stars all the way across these two darker areas.

▶ **NGC 6752** in Pavo ranks third in my estimation, and with its conglomeration of 11th-magnitude sparks, is obvious with the naked eye. Sailing on a cruise to Australia, I was observing from latitude 46°S while rounding New Zealand's South Island, and the Pavo Globular joined my short list of those I've seen with my unaided eye.

> *Murrell's 20-inch at 159×: "A very large, sparse outer halo, almost separated from the inner halo by a gap on the following side. The inner halo is crossed by seven long curving star chains, resembling mountain ridges which converge to a tiny central peak. The bright innermost core is surrounded by an outer core composed of faint stars. A red star is on the northeastern edge of the tiny innermost core. One degree southeast I saw the very tight group of four 12th-magnitude galaxies: NGCs 6769, 6770, 6771, and IC 4842. This observation of NGC 6752 was bittersweet because I knew that I could never again enjoy a first view of one of the sky's splendors — the Pavo Globular was my last!"*

OMEGA CEN: AKIRA FUJII; NGC 6752: ESO



▲ **Messier 13**, aka the Great Globular Star Cluster in Hercules, is another easy naked-eye object. M13 is neither the brightest nor the largest globular cluster, but it's arguably the most *distinctive* because of its striking curved star chains (Sue French calls them "a wonderful fireworks display frozen in time") and the Propeller (three somewhat darker lanes on the southeastern side of the core). M13's rich broad center also holds a curved dark lane across from the Propeller. My 8-inch Newtonian at 174× shows all four dark lanes, but they're subtle; at 203× six star chains become visible, four of them on the cluster's preceding side. Low power adds the 11.4-magnitude spiral galaxy NGC 6207 only 28′ northeast of the magnificent cluster.

My club's 10-inch Cave Astrola Newtonian shows hundreds of pinpoint stars at 254×, while my 16-inch Newtonian at 203× reveals an orange star at the center of M13's core.

Goldendale Observatory in Washington State with the 24.5-inch Cassegrain at 160×: "Bright stars on fainter stars on innumerable very faint stars on a mottled background!"

▲ Fifth-place **Messier 22** is the third brightest and the fourth largest on my list and can be partially resolved in a 60-mm refractor. With my 8-inch at 153× in excellent seeing, M22's halo was elongated 3:2 northeast to southwest, but the broad central concentration was round with a sharp edge. The cluster is resolved across the core, with a round underlying haze about 2′ in diameter. Nine star chains decorated the periphery, with a double tentacle in the southwest. There were at least 100 resolved stars distributed fairly equally across the globular within an 11′ diameter, plus many stars in the outer halo.

The 10-inch reveals the brightest orange star in M22, immediately following the core. In Australia I saw hints of other orange stars through the 14.5-inch, including a pair in the core. In a low-power comparison, M22 was only about one-quarter of Omega Centauri's area. My 16-inch at 174× unveiled two chevron-shaped dark lanes pointing south.

◀ **Messier 4** is the third largest cluster in my selection. The closest globular on my list at 6,500 light-years, it's also one of the easiest to resolve. The long north-south bar of stars through M4's loose core is one of the most distinctive features owned by any globular. From southern British Columbia (where M4 culminates at only 14°) the 10-inch resolved about 150 stars.

M4 was glorious in my 8-inch at 135× in southern Arizona, showing many star chains, a Y-shaped group northeast of the central bar, and the northern dark streak.

In Australia with the 14.5-inch at 322× there were two concentric arcs of stars on the preceding side of the halo, and an oval of stars crosses the central bar twice. An orange star lies where the southern side of the oval intersects the bar. The northern end of the bar trails off to the northwest.

The 25-inch Dobsonian at Chaco Observatory in New Mexico added an orange pair just southeast of the southern end of the bar at 206×. Some orange outliers peppered the view, but they might be field stars.

"Does any other globular cluster offer so many beautiful loops of stars?"

A much fainter globular cluster, NGC 6144, is included in a low-power field. Chaco's 25-inch resolved 15 stars (most of them forming an oval) on a slight background glow. About 12 additional stars are probably outliers since the area is conspicuously devoid of nearby stars, due to obscuration by the Antares Nebula.

M13: STEFAN BINNEWIES / JOSEF PÖPSEL; M22: ESA / HUBBLE / NASA; M4: ESO; M15: RON BRECHER; M5: FRANK SACKENHEIM / STEFAN BINNEWIES / JOSEF PÖPSEL

▼ At home at latitude 49° north **Messier 15** is the beauty that my 16-inch spends the second-most time on, right after M13. At 261×, an O III filter revealed the challenging 3″ planetary nebula Pease 1 hiding only 25″ north-northeast of M15's center. The 13th-magnitude prize requires a starhop within the globular (see *S&T:* Oct. 2000, p. 132).

Another of my club's members, Jim Failes, had an 8-inch Dynamax SCT that at 120× showed five arcing star chains and M15's impressive nucleus.

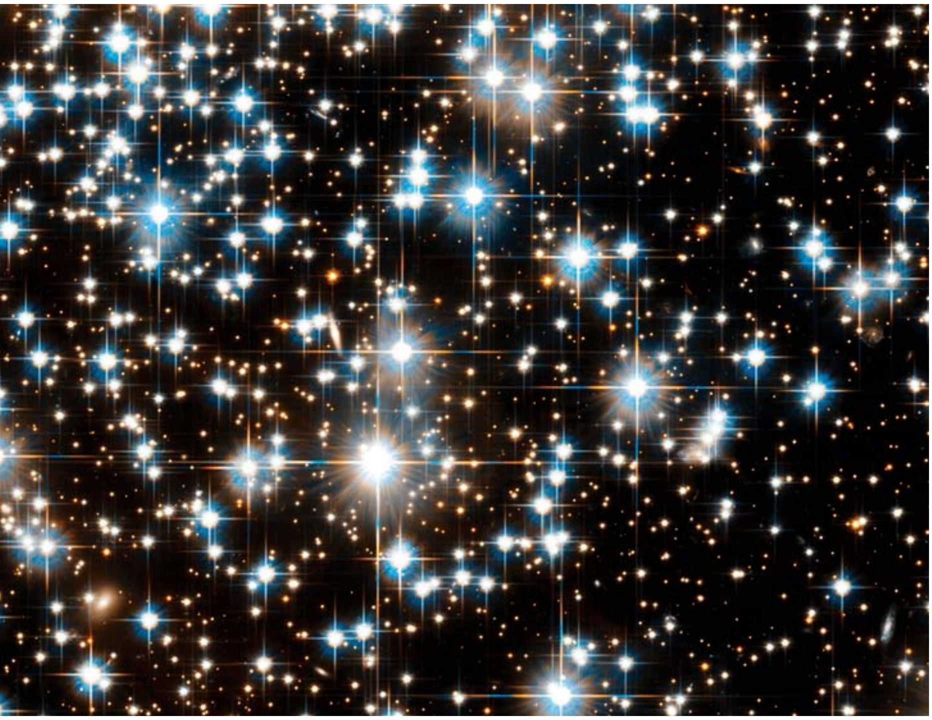
"There is a three-dimensional appearance to M15 — like the classic volcanic cone of Mount St. Helens before it blew."

Through Goldendale Observatory's 24.5-inch Cassegrain at 180× M15's core rises to an amazingly bright tiny nucleus, similar to that of the Pavo Globular, and dominated the view. A dark spot, only about 0.3′ in diameter, lies midway from the nucleus to the edge of the core. In a 25-inch Dob I noted that the nucleus is offset to the northern side of the teeming core.

▲ Eighth place goes to **Messier 5**, the brightest globular north of the celestial equator, and Concentration Class V (see Tipbox) like M13. My 8-inch shows far fewer stars in M5 than it does in M13 or M92, but my logbook entries made with 15-inch and larger scopes use words like "glory," "spectacular," and "superb." My finest view of M5 was on a pristine night with my 16-inch at 261×. The stars were crisp tiny points and were easily resolved right across the central globe with a fairly bright star near the center. A small dark vacancy lurks on the northeastern edge of the central mass, elongated northwest to southeast. The five main star chains arise on the northwestern side of the core, and then flow back around the core to the south through the east side of the halo.

Concentration Classes

In 1927, Harlow Shapley and his graduate student Helen Sawyer (later Sawyer Hogg) classified all known globular clusters according to apparent concentration of stars toward the center. The 12 classes, assigned Roman numerals (although some references denote them using Arabic numerals) range from I, which represents the highest concentration of stars toward the center, to XII, the most loosely packed of the globular clusters. The sample featured here represents all classes, with the exception of X and XII.



◀ In Ara, **NGC 6397**'s proximity makes it the fifth largest and tied for fourth brightest in my list. The *horizontal-branch magnitude* (the V-magnitude at which large numbers of stars start to become visible) is 12.9 — the brightest of any globular. All this makes the cluster obvious with the unaided eye and one of the easiest to resolve with small scopes.

Buckley's 14.5-inch at 136×: "Huge, loose, with bright stars and exceptionally long star-streamers. There is quite a 'tail' of stars in the following part of the halo, and this makes the cluster look quite elongated west to east. An orange star decorates the northern side of the loose core. A pleasure!"

The 30-inch at 202× revealed several hundred stars in the very large halo. The small core rises to a little clump of faint resolved stars.

Why haven't I ranked such a bright globular higher? Because it's a minor cluster that happens to be nearby, and its appearance in the eyepiece betrays that.

◀ **NGC 2808** in Carina is surprisingly large for its concentration category and resembles a pile of sand. My best view was at Coonabarabran with an 18-inch Obsession at 171×. The globular was well-resolved despite having a horizontal-branch magnitude of only 16.2, with a dense halo and a core that brightens toward the starlike nucleus at the center.

◀ I resolved **NGC 6541** in Corona Australis across the core with Buckley's 14.5-inch at 322×. The inner halo has one star chain preceding and several following. The outer halo stars are quite scattered and can be identified only by comparing the star density to surrounding fields.

At OzSky with the 30-inch at 202×: "It's well-resolved on top of a hazy background. The concentration increases rapidly to a small central pip, resembling M15."

▲ **Messier 2** has a dense core, but its long star streamers make it very unlike other Concentration Class IIs, such as M80.

Eight-inch SCT at 120×: "A cloud of many barely resolved faint stars, a dark lane northwest of center, and a rather rectangular appearance (somewhat like M92)."

In my 16-inch at 261× M2's core rises rapidly to a high bright mesa. Its outliers fill the 9′ field, and there are a great many magnitude-14 stars, making M2 more uniform in brightness than most globulars.

My club member Guy Mackie's evocative description with his 12.5-inch Dobsonian: *"The bright, granular core feeds streams of stars that flow through the halo and spill out onto the dark sky. . . . The west side of the halo has more of these star rivers, while the eastern end is more rounded; sort of looks like a jellyfish trailing tentacles behind."*

NGC 6397: NASA / ESA / H. RICHER / UNIV. OF BRITISH COLUMBIA; NGC 2808: DAVIDE DE MARTIN ESA/ HUBBLE / ESA / ESO / NASA PHOTOSHOP FITS LIBERATOR / DIGITIZED SKY SURVEY 2; NGC 6541: POSS-II / STSCI / CALTECH / PALOMAR OBSERVATORY; M2: RON BRECHER

▲ For Northern Hemisphere observers **Messier 92** is one of the most satisfying and distinctive globulars for moderate-sized scopes. With an 8-inch M92 is far superior to M5, for example. At 116× M92 presents a 3:1 rectangular outer halo running north-south, within which nestle a round inner halo and brilliant core, also round. At 244× there are 35 fairly bright stars, plus probably as many very faint stars that fade into and out of view as the seeing changes. The inner halo is 2′ in diameter, and the unresolved underlying haze is splotchy. The brightness jumps suddenly at the edge of the 40″-diameter core and then remains fairly constant across the star-studded core.

A 12-inch SCT at 220× added spiraling star streamers. The 16-inch at 366× unveiled hundreds of stars, and M92 no longer looked rectangular.

▲ Neighbors **Messier 10** and **Messier 12**, only a little more than 3° apart, are usually viewed in succession. The sum is greater than its parts, since M12 wouldn't make my list by itself.

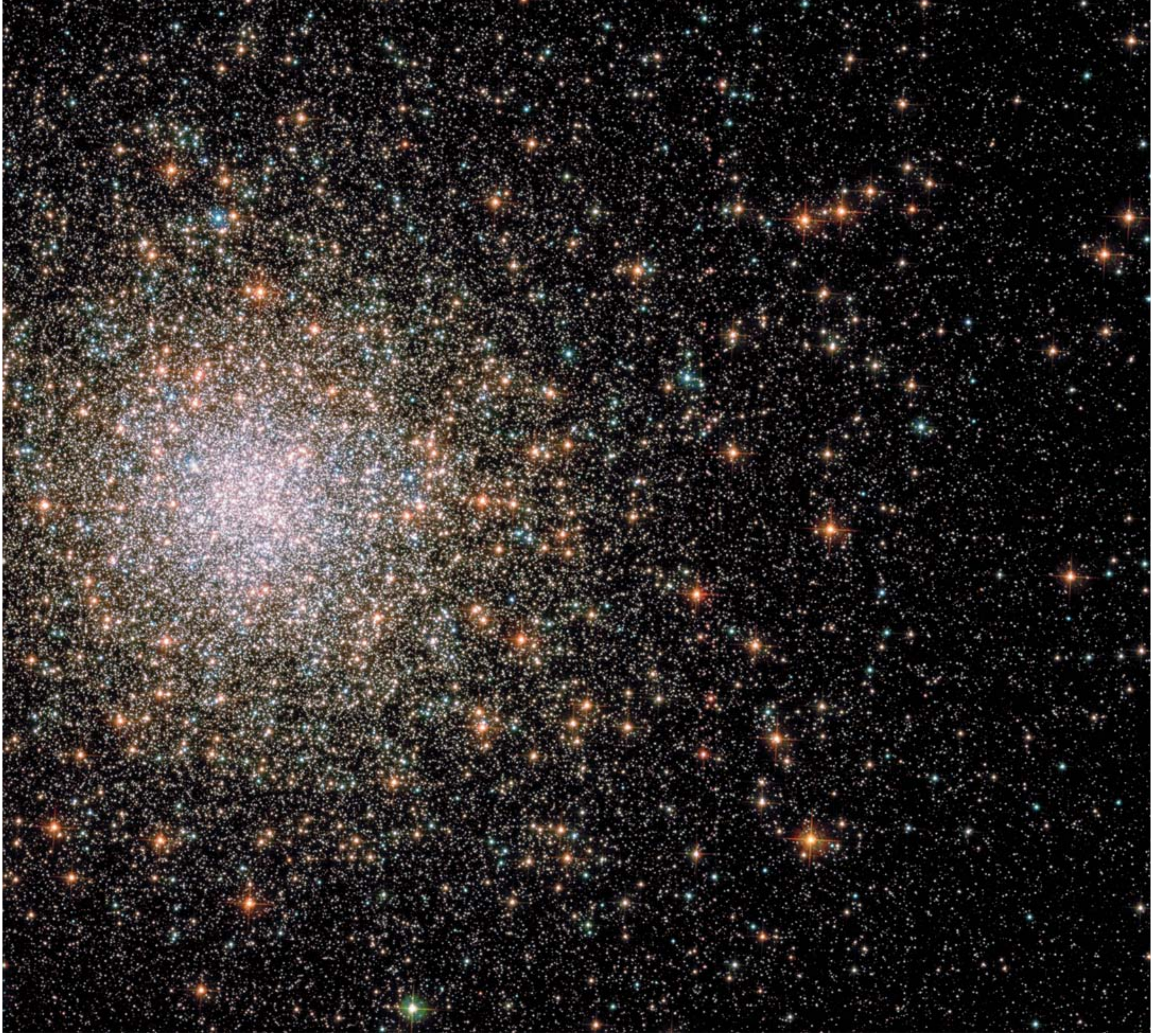
M10 (above) is a rewarding globular through my 8-inch at 244×. Through careful examination of star densities as M10 drifts across the field I can discern its full 15′-diameter outer halo, where some 50 stars are visible, including five long but sparse chains. I resolved another 40 stars in the inner halo and right across the 1.5′ core. The core brightness only increases gradually.

My 16-inch at 174× showed two long curved star chains, one north of the core and the other to the south, that jointly form a flattened reverse S. I easily resolved bright stars across the core, on a granular background. At 261× both the core and the halo showed resolved stars that all seemed to be magnitude 12 and 13, but there was a curious lack of fainter stars. Upping the power to 348× brought in the magnitude-15 sparks when the seeing allowed; but I just didn't spot any magnitude-14 stars!

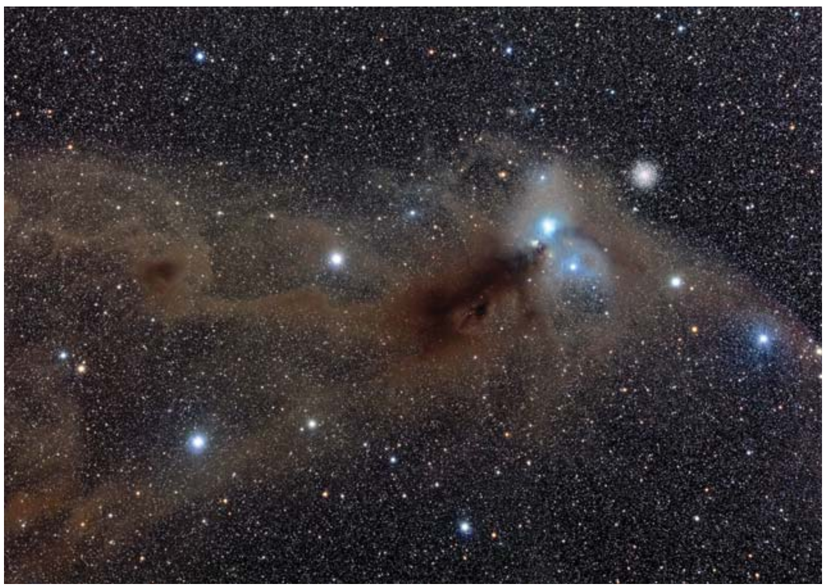
In looser M12 (right) the brightest stars are arranged in pairs or trios, giving it a strange appearance, like an open cluster overlying a globular. In my 16-inch at 229× M12 is well resolved right through the only slightly concentrated core, with about 50 bright stars on many faint ones. The halo consists of seven ragged star chains: three on the northern side, two on the western, and two on the southern. The core is elliptical in a ratio of 2:1, aligned east-west, and lies entirely on the northern side of the center of the halo. An orange star decorates the southern edge of M12's core.

▲ **Messier 55** is the best of the unconcentrated globulars. In a 13-inch Dob in Kentucky this cluster was huge, loose, and well-resolved with a multitude of sparkles on a prominent background glow.

M92: STEFAN BINNEWIES / JOSEF PÖPSEL; M10: RON BRECHER; M12: STEFAN BINNEWIES / RAINER SPARENBERG / JOSEF PÖPSEL; M55: JOSEF PÖPSEL



▲ Next up is **Messier 62**. At 202× with the 30-inch at the OzSky Star Safari, M62 was very dense with swarming stars. The concentration rises rapidly to a small, very bright pip that's strikingly offset to the southeast of the cluster's center. The Australian amateurs razzed me for wasting telescope time on such a *northerly* object, but M62 was 79° higher than I ever see it at home.



▶ The Sagittarius–Corona Australis border hosts one of the sky's most splendid complexes. **NGC 6723** is a fine, rather open globular with marvelous neighbors: the 55′-long dark nebula SL 40/41, the bright reflection nebula NGC 6726/7 with its embedded stars, the comet-shaped variable reflection nebula NGC 6729, the striking matched blue-white pair Brs 14 (separation 13″), and the matched yellowish binary Gamma CrA (separation 1.3″).

M62: ESA / HUBBLE / NASA / S. ANDERSON; NGC 6723: LORE KUN TAN / STARRYSCAPES.COM

▲ Columba's **NGC 1851** boasts the second-brightest center of any globular cluster, exceeded only by M15.

25-inch Dobsonian at 238× in Australia: "Excellent. Resolved throughout as the star density steadily increases to a tiny, resolved peak like M15's."

So why didn't the bright globular clusters Messier 3, NGC 362, Messier 19, NGC 3201, NGC 4833, NGC 6388, or Messier 28 make my list? Simply because none of them commanded attention in my eyepiece for long. As I said at the beginning, there's more to visual splendor than simply brightness!

As you've been reading, you've probably noticed that it's the far southern sky that holds many of the finest globular clusters. Any serious Northern Hemisphere amateur owes it to themselves to add viewing from the Southern Hemisphere with Big Glass to their bucket list. I hope that you'll also enjoy a view of many of these glorious sights no matter where you are.

■ Contributing Editor **ALAN WHITMAN** has observed 196 globular clusters, including 127 in the Milky Way. He thanks the generous Australian amateurs who enjoy showing Southern Hemisphere showpieces to Northern Hemisphere observers.

Favorite Globulars

Object	NGC No.	Constellation	Concentration Class	Mag(v)	Size	Distance (l-y)	RA	Dec.
47 Tuc	NGC 104	Tucana	III	4.0	50′	15,000	00^h 24.1^m	–72° 05′
Omega Centauri	NGC 5139	Centaurus	VIII	3.9	55′	16,000	13^h 26.8^m	–47° 29′
Pavo Globular	NGC 6752	Pavo	VI	5.3	29′	13,700	19^h 10.9^m	–59° 59′
Messier 13	NGC 6205	Hercules	V	5.8	20′	23,500	16^h 41.7^m	+36° 28′
Messier 22	NGC 6656	Sagittarius	VII	5.2	32′	9,800	18^h 36.4^m	–23° 54′
Messier 4	NGC 6121	Scorpius	IX	5.4	36′	6,500	16^h 23.6^m	–26° 32′
Messier 15	NGC 7078	Pegasus	IV	6.3	18′	34,200	21^h 30.0^m	+12° 10′
Messier 5	NGC 5904	Serpens	V	5.7	23′	24,800	15^h 18.6^m	+02° 05′
	NGC 6397	Ara	IX	5.3	31′	7,200	17^h 40.7^m	–53° 40′
	NGC 2808	Carina	I	6.2	14′	30,000	09^h 12.0^m	–64° 52′
	NGC 6541	Corona Australis	III	6.3	15′	21,500	18^h 08.0^m	–43° 42′
Messier 2	NGC 7089	Aquarius	II	6.6	16′	38,800	21^h 33.4^m	–00° 49′
Messier 92	NGC 6341	Hercules	IV	6.5	14′	24,500	17^h 17.1^m	+43° 08′
Messier 10	NGC 6254	Ophiuchus	VII	6.6	20′	14,000	16^h 57.1^m	–04° 06′
Messier 12	NGC 6218	Ophiuchus	IX	6.1	16′	18,300	16^h 47.2^m	–01° 57′
Messier 55	NGC 6809	Sagittarius	XI	6.3	19′	15,700	19^h 40.0^m	–30° 58′
Messier 62	NGC 6266	Ophiuchus	IV	6.4	15′	17,900	17^h 01.2^m	–30° 07′
	NGC 6723	Sagittarius	VII	6.8	13′	28,400	18^h 59.6^m	–36° 38′
	NGC 1851	Columba	II	7.1	12′	39,800	05^h 14.1^m	–40° 03′

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

POSS-II / STSCI / CALTECH / PALOMAR OBSERVATORY by Steve Daubert

Observing Geo

EYES IN THE SKY Earth is encircled by more than 500 satellites in geostationary orbit. Normally too faint to be seen without a telescope, under the right circumstances a geosat's solar panel directs sunlight earthward, allowing observers to witness the appearance of a bright new "star."

sat *Flares*

Autumn nights are ideal for spotting "stars out of place."

No one has observed a naked-eye supernova in our galaxy for more than 400 years. So, when I noticed a new, gold-tinted 2nd-magnitude star in Cetus last autumn, my first thought was, "It's about time!" As I watched this "star out of place," I let myself believe I was witnessing a bright galactic supernova, the likes of which no person alive has ever seen.

However, my special moment of discovery didn't last for long. The new star's position was shifting subtly against the stellar backdrop, and then it began to dim perceptibly. I let go of the excitement as my "supernova" faded to a reddish point and finally winked out. But what had I seen? In reality it was something much closer than a star — an object only 36,000 km (22,000 miles) away.

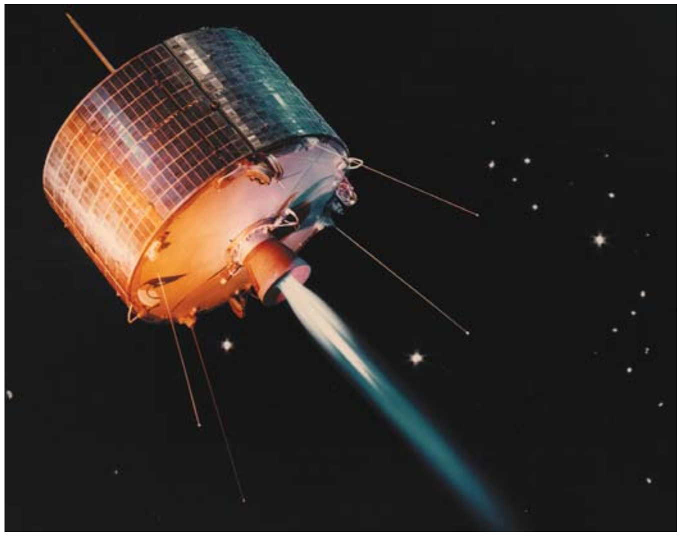
Stars Out of Place

Since the launch of Sputnik in 1957, skywatchers have witnessed the novelty of starlike apparitions coasting across the night sky — scores of artificial satellites including such recent luminaries as the International Space Station and the Hubble Space Telescope. Now we have trains of Starlink satellites from SpaceX proliferating toward numbers that threaten to overwhelm the night sky's stellar vista (*S&T:* March 2020, p. 14). Less frequently observed members of this family of artificial moons are the geostationary satellites, or *geosats*.

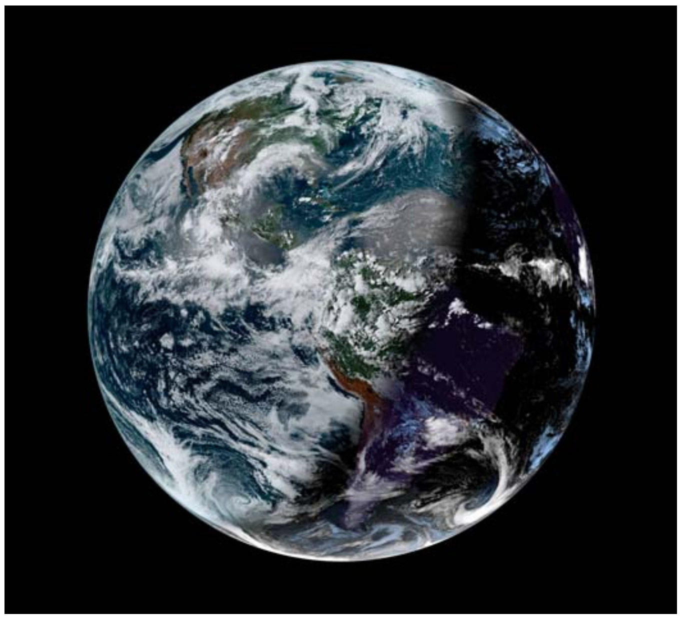
The idea of geostationary satellites first came to the public's attention in a 1945 article by Arthur C. Clarke that appeared in the magazine *Wireless World*. The concept is wonderfully elegant: Simply position a satellite at the distance where its orbital period matches Earth's rotation. This turns out to be at a height of 35,785 km. The object would then be "geostationary" — fixed above an assigned point on the surface below.

Beginning in the 1960s, many nations have launched payloads into this high orbit. The Clarke Belt, as the zone is called, now holds a greater mass of orbital equipment than all the other lower orbits combined. More than 500 active communication, meteorological, and navigation satellites now occupy slots in the Geosynchronous Earth Orbit (GEO) band. The first of these was Syncom 3, launched in August 1964. It was a small (71 × 39 cm) cylinder, weighing a little more than 11 kg (25 lbs). In recent years, however, geosats have increased dramatically in numbers and in size. The newest models are as big as a bus and carry solar panels thousands of square feet in area.

Visually, geosats are usually faint telescopic objects that appear at dusk and fade away at dawn, reappearing again the following night at the same point in the sky. But on occasion,



▲ **FIRST OF MANY** Launched from Cape Kennedy on August 19, 1964, Syncom 3 was the first geostationary satellite and was used to telecast the 1964 Summer Olympic Games from Tokyo, Japan. Later the satellite was operated by the U.S. Department of Defense for communications during the Vietnam War. Syncom 3 remains in orbit to this day, though it was deactivated in April 1969.



▲ **BIRD'S-EYE VIEW** Scores of geostationary satellites provide weather data, allowing detailed forecasts and monitoring of global climate trends. This image of Earth was captured on June 27, 2020, by GOES-16, operated by NASA and the National Oceanic and Atmospheric Administration. The satellite is positioned directly above the equator, at a longitude of 75.2° west.

GEOSAT IN ORBIT: ESA; SYNCOM 3: NASA; GOES EARTH VIEW: CIRA / NOAA the satellite's reflective solar panels direct sunlight earthward. On such occasions, for a lucky observer in the right location, a geosat can brighten by orders of magnitude, flaring to naked-eye visibility.

A Flash in the Night

Most readers have witnessed the startlingly bright appearance of an Iridium satellite. At times, these objects exceeded the brilliance of Venus. But now that the last Iridium has been deorbited, observing geosat flares is gaining popularity.

Geosat flares are quite different from either Iridium flares or the sequence of flashes produced by tumbling satellites. Instead of drifting across the starry background, geosat glints appear as fixed as actual stars, barely moving before fading away over a span of 10 to 15 minutes. In some cases, they brighten, disappear, then rebrighten before winking out for good. If you know when and where to look, you can see dozens of geosat flares over the course of a single evening.

Although geosats are faintly visible in telescopes all night long on every night of the year, their flares depend on a specific geometric alignment between the satellite, the Sun, and the Earth. This happens only a few nights per year. And as with Iridium flares, the visibility of geosat flares strongly depends on the observer's specific location.

Since the geosats are in equatorial orbit, they are seen from Earth along the great circle of the celestial equator (CE). However, their positions are displaced by parallax south of the CE for observers in the Northern Hemisphere, and north of the CE for those in the Southern Hemisphere. The amount of displacement depends on your latitude and is given in the table found on page 40.

◀ **GONE IN A FLASH** For two decades, catching an Iridium satellite flare was a favorite sport among skywatchers. However, the last of the 66 original Iridium satellites was deorbited in December 2019, bringing the era to a close. In this photo, a satellite flares to brightness then fades away in twilight, southeast of Altair in Aquila.

As the table also shows, geosat flares are visible only around the equinoxes. Each viewing cycle is divided into one phase for the Northern Hemisphere and one for the Southern Hemisphere, with a brief interval between in which Earth eclipses the Sun and no flares are seen. In Northern Hemisphere autumn, the first flares appear *after* the equinox, and as the flare season progresses they move eastward away from near the First Point of Aries, which is actually situated southeast of the Circlet of Pisces. In Northern Hemisphere spring, flares happen *before* the vernal equinox in March and appear east of the First Point of Libra (where the ecliptic and the celestial equator meet), southeast of Beta (β) Virginis. The position of the flares migrates westward toward that point until the end of the flare season.

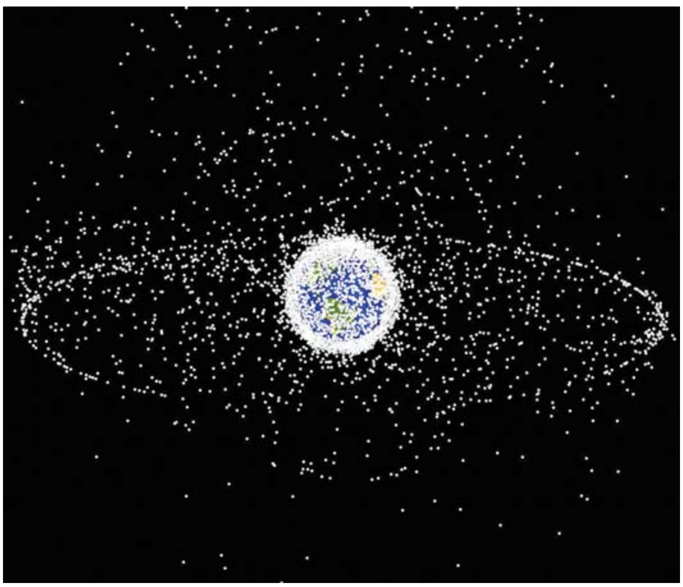
Playing the Angles

Over any location, the Clarke Belt geosats form an invisible band of solar panels stretching across the sky near the celestial equator from horizon to horizon. All the geosat solar panels remain aligned in the same general orientation facing the Sun. This means that, if we could see them, the geosats in the arc above would appear from our earthbound perspective to be pivoting in unison, completing one 360° revolution per day.

When the largest geosats flare, they rise to naked-eye visibility and rival the brightest stars. You can follow their fading for almost a quarter hour. And because they're stationary, you can observe geosats in a non-tracking telescope without having to constantly adjust its aim.

Geosat flares become visible starting with those low in the east at dusk. Over the course of the evening, as the antisolar point (the spot in the sky directly opposite the Sun's position) rises, geosats appear in succession, one after another, higher and higher in the sky.

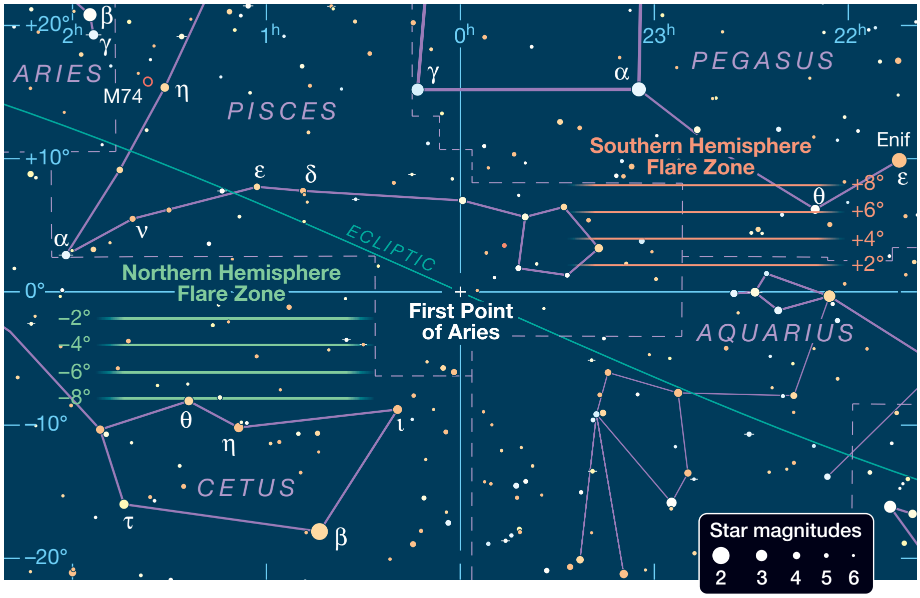
A night's display of geosat flares progresses with flares in the east at dusk, to dawn with flares appearing near the western horizon. Sometimes, there are no visible flares for a while;



◀ **EARTH'S RING** Conspicuous in this computer-generated plot showing objects in Earth orbit is the Clarke Belt of geostationary satellites, located at a distance of 35,785 km (22,236 miles) above the equator.

IRIDIUM FLARE: GARY SERONIK; SIMULATION: NASA ODPO

▶ **FLARE FINDER** This chart shows the predicted position of geosat flares during autumn. As noted in the text, geosat flares appear along a stretch of sky offset from the celestial equator by a specific declination, the amount of which depends on the observer's latitude.



other times, multiple flares may appear, like a cluster of ersatz stars in formation. You might catch a satellite "string of pearls" — a row of bright, equally spaced flares whose members appear in turn from the west and then disappear in the same order to the east.

Catching the Light

To prepare for a night of observing geosat flares, begin by consulting the table on page 40 to determine when the flare season peaks at your latitude. You can see geosats a few nights on either side of the date listed.

Next, you need to figure out where in the sky to look. Flares will appear in a zone that's opposite the Sun's position (the aforementioned anti-solar point) and offset from the celestial equator by the amount shown in the table. If, for example, you live at a latitude of 40° north, the autumn peak night would be October 7th, and the flare zone will lie 6.3° south of the celestial equator.

Now, look at the chart above and note the location of the celestial equator. You'll want to direct your attention at a zone with a declination of 6.3° south (between the –6° and –8° green tracks), and a few degrees east of the point where

Photographing Geosats

Photographing geostationary satellites is pretty easy for a couple of reasons. First, there are so many that it's almost guaranteed there will be several available at any time of night. Second, they're found along a narrow path near the celestial equator. From my location (at around latitude 42° north) they appear to cross the sky at about declination –6.5°.

You can photograph a geostationary satellite with any camera capable of taking exposures of several seconds or longer, and a regular tripod. Just about any lens will do, though you'll see individual satellites more clearly if you use a telephoto lens with a focal length of 100 mm or more. Set the lens to f/4 and the camera ISO to 1600, then focus your camera on a star. Next, aim at the correct declination for your latitude (see the table on the next page) and open the shutter for about 30 seconds. When you look at the resulting photograph, all the stars in your image will be trailed. However, you should have recorded several dots. These are geostationary satellites.

If you've ever photographed the Orion Nebula, chances are you also recorded quite a few geosats. Their orbit runs right across the lower part of Orion (as seen from the Northern Hemisphere) where several attractive nebulae reside, including M42. In a tracked photo, the satellites appear as horizontal streaks, as shown in the image at right.

—Sean Walker

MASIL IMAGING TEAM

▲ **LIGHT POLLUTION** For astrophotographers, geosats are a menace. They produce unsightly streaks across long-exposure photographs captured near the celestial equator, such as this 4½-hour exposure showing the region around NGC 2170 in eastern Monoceros.

the 0^h line of R.A. intersects the CE — the First Point of Aries. In the early evening, this zone will be near the eastern horizon. At around 1 a.m. (daylight-saving time) it'll be roughly due south, and at dawn near the western horizon.

Geosat Flare Visibility

Latitude	Autumn Peak	Spring Peak	Displacement*
+70°	Oct. 13	February 28	8.5° S
+60°	Oct. 12	March 1	8.0° S
+50°	Oct. 10	March 3	7.3° S
+40°	Oct. 7	March 6	6.3° S
+30°	Oct. 4	March 9	5.0° S
+20°	Oct. 1	March 12	3.5° S
+10°	Sept. 27	March 16	1.8° S
0°	*Eclipse zone: No flares visible*		
-10°	Sept. 19	March 24	1.8° N
-20°	Sept. 15	March 28	3.5° N
-30°	Sept. 12	April 1	5.0° N
-40°	Sept. 9	April 4	6.3° N
-50°	Sept. 6	April 7	7.3° N
-60°	Sept. 4	April 9	8.0° N
-70°	Sept. 3	April 10	8.5° N

*Displacement refers to north or south offset of the flare zone from the celestial equator for the listed latitude.

Another way to visualize the situation is to imagine that the anti-solar point is a searchlight beam moving along the string of satellites, illuminating one geosat (or several) at a time as it slowly sweeps from west to east during the course of the night. It's worth bearing in mind that the calculated flare point is, to some extent, only a guide to where you should look. Several factors working together can displace where a flare will brighten to visibility. The flares must appear along a track parallel to the celestial equator since that's where geosats orbit, but their solar panels aren't all aligned toward the Sun in exactly the same way, so the flare location can deviate by 15° east or west of the calculated position. That's why we observe flares in a "zone" rather than at a single spot.

During flare season, the passing display of geosats creates an incomparable vista. It's a spectacle that provides a good reason to host an all-night, flare-watching star party.

■ **STEVE DAUBERT** is a retired research scientist and author. His most recent book is *Between the Rocks and the Stars*.

FURTHER READING:
For flare predictions tailored to your location go to: **calsky.com/?geosat**

To see an interactive representation of Earth-orbiting satellites (including geosats): **http://stuffin.space**

A complete list of geosats is found here: **satsig.net/sslist.htm**

▲ **STREAKS AND GEOSATS** This photo was captured with a camera on a tripod. Diurnal rotation causes the stars to trail across the field, but geostationary satellites register as points of light since, by definition, their positions are fixed with respect to Earth's surface.

BOB KING

OBSERVING
October 2020

2, 3 DAWN: Venus and Regulus form a pair less than ½° apart on both mornings.

2 EVENING: This month is all about Mars (see pages 12, 46, 48, and 54). Look to the east to see the Moon, one day past full, rising in tandem with the Red Planet. Follow the pair throughout the night as they soar across the sky.

3 EVENING: Algol shines at minimum brightness for roughly two hours centered at 9:48 p.m. EDT.

6 EVENING: The waning gibbous Moon, in Taurus, is about 4½° left of Aldebaran.

6 EVENING: Mars is at its nearest to Earth and sports its widest disk until 2035.

10 MORNING: Look to Gemini to find the last-quarter Moon about 4° from Pollux.

11 MORNING: The waning crescent Moon is less than 2° from the Beehive Cluster (M44).

13 ALL NIGHT: Savor views of the Red Planet as it arrives at opposition.

14 MORNING: If you're in a dark location while taking in sights of Mars, look toward the east before morning twilight to see the zodiacal light. It should be visible to viewers at northern latitudes until the end of the month as a tall and dim pyramid of light stretching up through Cancer and Gemini into Taurus.

14 DAWN: Venus rises in the east with the thin lunar crescent in its wake.

20 EVENING: Algol shines at minimum brightness for roughly two hours centered at 11:40 p.m. PDT.

21 MORNING: The Orionid meteor shower peaks in the early hours (see page 52).

22 DUSK: The first-quarter Moon, Jupiter, and Saturn form a tight triangle in the south after sunset.

23 EVENING: Algol shines at minimum brightness for roughly two hours centered at 11:29 p.m. EDT.

26 EVENING: Algol shines at minimum brightness for roughly two hours centered at 8:18 p.m. EDT.

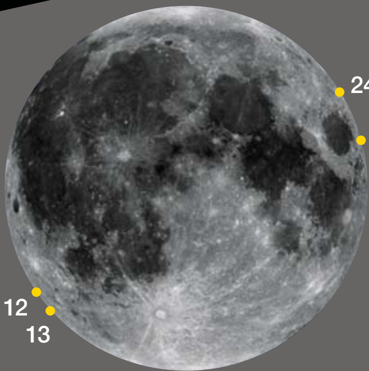
29 EVENING: Look toward the east-southeast to see the waxing gibbous Moon and Mars gleaming some 4° apart in Pisces.

31 EVENING: The month's second full Moon — or "Blue Moon" — rises on Halloween night.

— DIANA HANNIKAINEN

▲ If you're fortuitously positioned in the early hours of the morning on October 21st, you could be lucky to see Orionids flash against the backdrop of the zodiacal light. Don't forget to look for Venus rising in the east. BOB KING

OCTOBER 2020 OBSERVING
Lunar Almanac
Northern Hemisphere Sky Chart



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

NASA / LRO

MOON PHASES

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

FULL MOON
October 1
21:05 UT

LAST QUARTER
October 10
00:40 UT

NEW MOON
October 16
19:31 UT

FIRST QUARTER
October 23
13:23 UT

FULL MOON
October 31
14:49 UT

DISTANCES

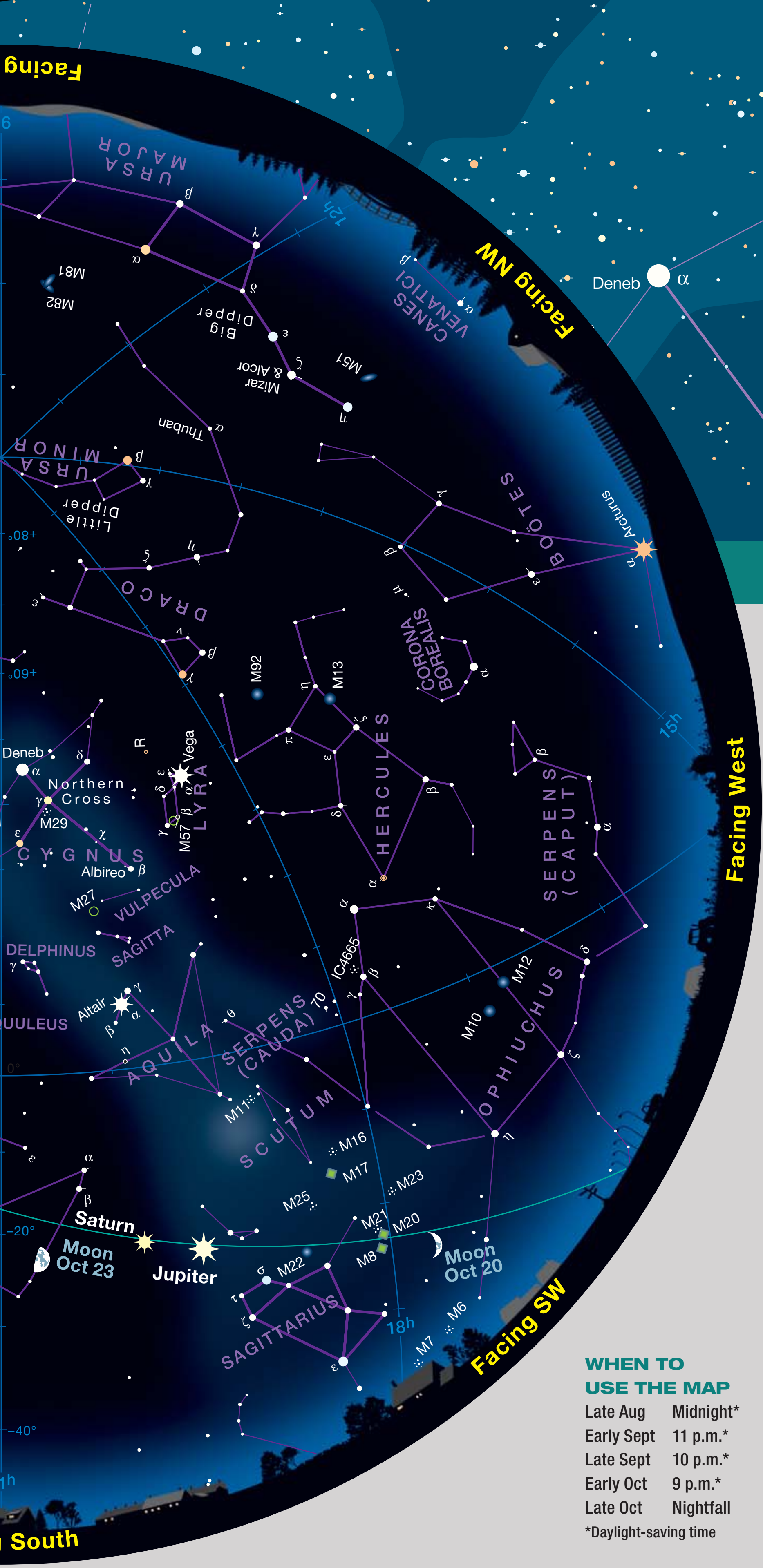
Apogee 406,321 km	October 3, 17^h UT Diameter 29′ 25″
Perigee 356,912 km	October 17, 00^h UT Diameter 33′ 29″
Apogee 406,394 km	October 30, 19^h UT Diameter 29′ 24″

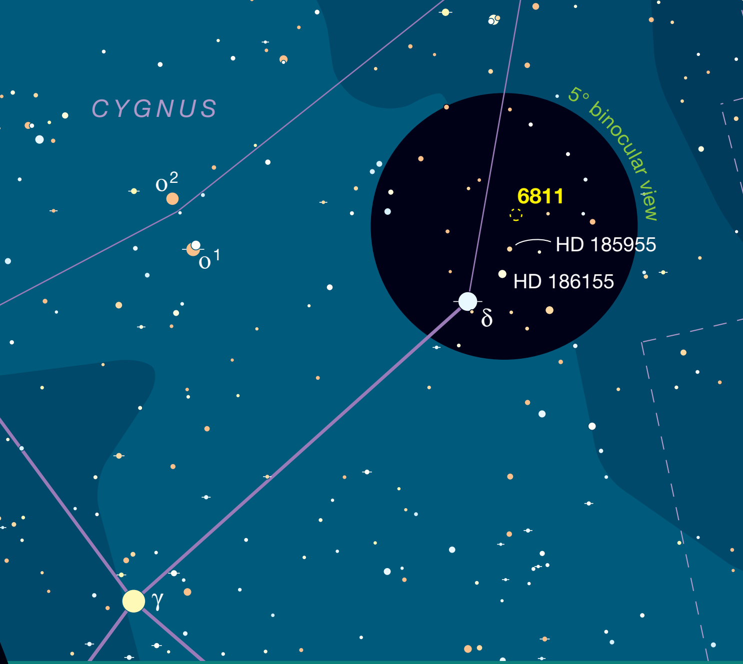
FAVORABLE LIBRATIONS

• Focas Crater	October 12
• Rydberg Crater	October 13
• Goddard Crater	October 22
• Boss Crater	October 24

Planet location shown for mid-month

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





WHEN TO USE THE MAP

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

*Daylight-saving time

Binocular Highlight by Mathew Wedel

One Billion Years

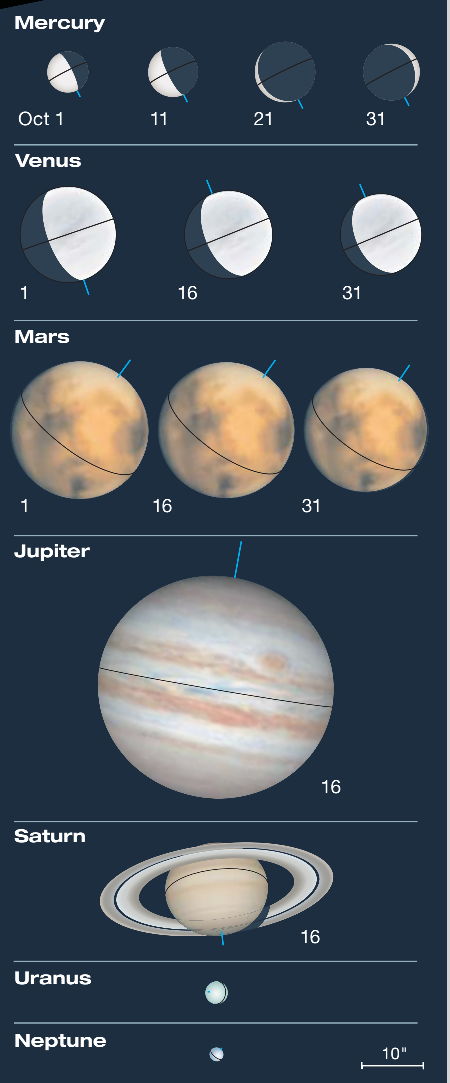
Chronological timescales of the universe are so colossal that a span of one billion years isn't particularly remarkable. Our own solar system is four-and-a-half times that old. Nevertheless, a billion is nothing to sniff at, and it's a nice round number to roll around in your head while you contemplate the night sky. And it's been rolling around in my head ever since I learned that the open cluster **NGC 6811** in Cygnus, the Swan, is around one billion years old.

NGC 6811 lies about 1¾° north-northwest of Delta (δ) Cygni, and is at the end of a northwest-trending line that includes Delta Cygni and the 5th- and 6th-magnitude stars HD 186155 and HD 185955. The cluster is big, but it's also oddly dim and diffuse — its brightest stars all extinguished long ago. Compounding this is the strange apparent hole at the center of the cluster. Most open clusters have a clutch of brighter stars toward their centers, but NGC 6811 doesn't. The total effect is a delicately beautiful cluster, but one that suffers under light pollution or poor transparency; try to observe it when it's high and the sky is clear.

Since NGC 6811 lies about 4,000 light-years away, the light we see now left it when ancient Egyptians had been building pyramids for centuries and the last woolly mammoths were dwindling to a quiet extinction on Wrangel Island in Siberia. That's a heady span of time, but it's still only four millionths of one billion. Confronting numbers like these occasionally puts our brand-new primate cleverness into its cosmic context. Next time you want to contemplate a billion, NGC 6811 is waiting.

■ **MATT WEDEL** is trying to use his binoculars as a lever to pry himself out of complacency before nature. So far, so good!

PLANET VISIBILITY (40°N, naked-eye, approximate) **Mercury:** hidden in the Sun's glare all month • **Venus:** is the brilliant Morning Star all month • **Mars:** rises around sunset, at opposition on the 13th • **Jupiter:** visible in the early evening • **Saturn:** culminates at dusk and sits 5° to 7° east of Jupiter.

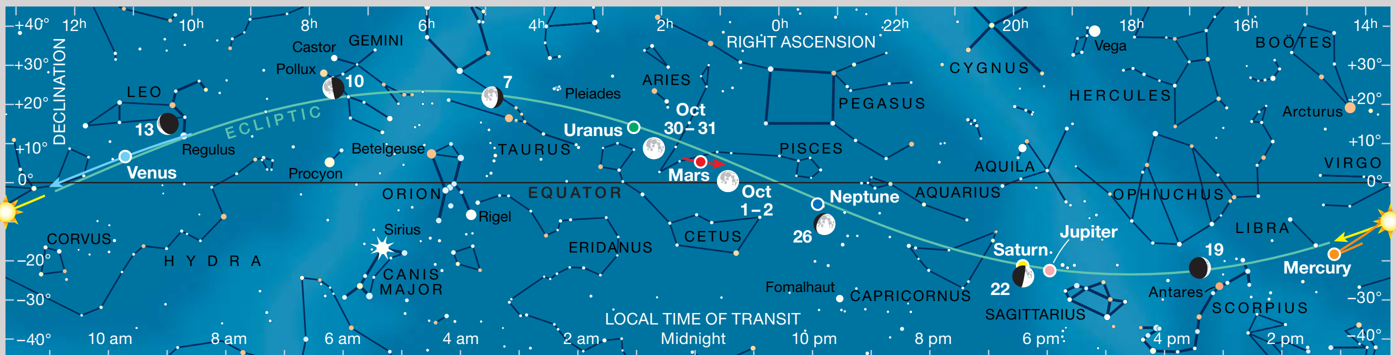


PLANET DISKS have south up, to match the view in many telescopes. Blue ticks indicate the pole currently tilted toward Earth.

October Sun & Planets

	Date	Right Ascension	Declination	Elongation	Magnitude	Diameter	Illumination	Distance
Sun	1	$12^h\ 29.4^m$	–3° 10′	—	–26.8	31′ 57″	—	1.001
	31	$14^h\ 21.5^m$	–14° 05′	—	–26.8	32′ 13″	—	0.993
Mercury	1	$14^h\ 01.8^m$	–15° 21′	26° Ev	0.0	6.7″	61%	1.001
	11	$14^h\ 29.3^m$	–18° 18′	23° Ev	+0.3	8.1″	39%	0.828
	21	$14^h\ 19.7^m$	–16° 25′	11° Ev	+2.8	9.8″	7%	0.683
	31	$13^h\ 41.2^m$	–9° 38′	11° Mo	+2.1	9.2″	10%	0.729
Venus	1	$9^h\ 59.3^m$	+12° 34′	40° Mo	–4.1	15.5″	72%	1.073
	11	$10^h\ 44.7^m$	+8° 52′	39° Mo	–4.1	14.6″	75%	1.140
	21	$11^h\ 29.7^m$	+4° 40′	37° Mo	–4.0	13.8″	78%	1.205
	31	$12^h\ 14.5^m$	+0° 09′	34° Mo	–4.0	13.2″	81%	1.265
Mars	1	$1^h\ 37.2^m$	+6° 08′	163° Mo	–2.5	22.4″	99%	0.417
	16	$1^h\ 18.7^m$	+5° 13′	176° Ev	–2.6	22.2″	100%	0.422
	31	$1^h\ 02.7^m$	+4° 43′	158° Ev	–2.2	20.2″	98%	0.463
Jupiter	1	$19^h\ 16.7^m$	–22° 42′	100° Ev	–2.4	40.5″	99%	4.864
	31	$19^h\ 29.5^m$	–22° 18′	73° Ev	–2.2	37.1″	99%	5.321
Saturn	1	$19^h\ 48.2^m$	–21° 26′	107° Ev	+0.5	17.2″	100%	9.661
	31	$19^h\ 51.7^m$	–21° 18′	78° Ev	+0.6	16.4″	100%	10.153
Uranus	16	$2^h\ 27.2^m$	+14° 03′	164° Mo	+5.7	3.7″	100%	18.823
Neptune	16	$23^h\ 19.0^m$	–5° 37′	146° Ev	+7.8	2.3″	100%	29.101

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



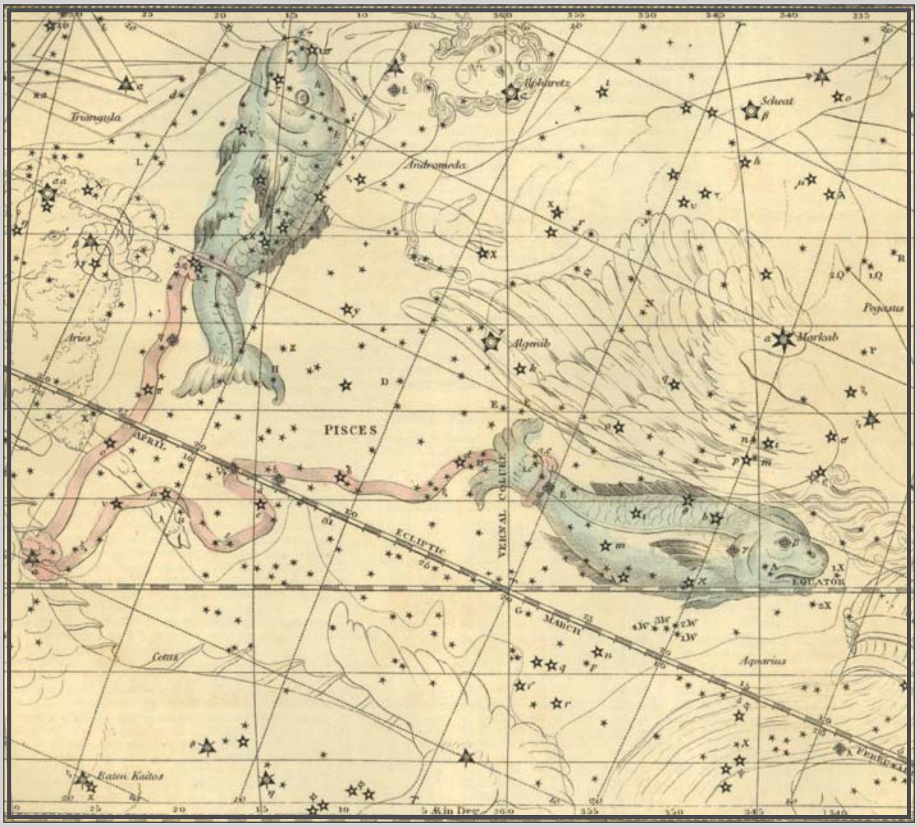
The Sun and planets are positioned for mid-October; the colored arrows show the motion of each during the month. The Moon is plotted for evening dates in the Americas when it's waxing (right side illuminated) or full, and for morning dates when it's waning (left side). "Local time of transit" tells when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

The Age of Pisces

There's something fishy going on in the October sky.

When the moon is in the Seventh House
And Jupiter aligns with Mars
Then peace will guide the planets
And love will steer the stars
This is the dawning of the Age of Aquarius

— From the song *Medley: Aquarius / Let the Sunshine In (The Flesh Failures)* featured in the 1967 musical *Hair*.



▲ **ONE FISH, TWO FISH** This chart shows the constellation Pisces, the Fishes, as presented in Alexander Jamieson's 1822 *Celestial Atlas*.

UNITED STATES NAVAL OBSERVATORY LIBRARY / PUBLIC DOMAIN

Astronomically, the Age of Aquarius won't begin until the vernal equinox point — where the Sun is found at the start of Northern Hemisphere spring — enters the boundaries of the constellation Aquarius, as established by the International Astronomical Union in 1930. According to the Belgian astronomer and mathematician Jean Meeus, that won't occur until AD 2597.

Highlights of Pisces. So, for the next several centuries, this important point on the celestial sphere is located in Pisces. What else of interest is found in the constellation? Pisces has no stars brighter than 4th magnitude and only one Messier object — the galaxy M74, one of the dimmest and most elusive objects in the Messier catalog. But Pisces does contain one of the very reddest naked-eye stars, several fine doubles, a nearby white dwarf, and, for the rest of the year, the ruddy planet Mars blazing at its best.

Double delights. Telescope users will enjoy Alpha (α) Piscium, with its 4.1- and 5.2-magnitude components separated by a mere 1.9″. Alpha also serves as the best comparison star for the great Cetus variable star Mira (Omicron Ceti) when it's near its peak, which it's expected to be this month. Also enjoyable in small scopes are the wide, nearly equal pair Psi[1] (ψ^1) Piscium and the colorful double Zeta (ζ) Piscium.

Seeing red. Pisces is imagined as two fishes, tied together with a cord and a knot; one fish extends northward to Andromeda, and the other reaches westward to Aquarius. The western fish includes a distinctive 7° by 5° loop of stars known as the Circlet. The easternmost star in the asterism is magnitude-4.9 (though slightly variable) TX Piscium. Under clear and reasonably dark skies, you might be able to detect the remarkable redness of this star with your naked eye. Wide-angle binoculars can contain the entire Circlet, and with such optical aid, the ruddiness of TX Piscium can be striking indeed. TX (also known as 19 Piscium) is a carbon star with a B-V color index of 2.5. Its distance from us is about 800 light-years, giving TX a very bright absolute magnitude of –2.2.

Van Maanen's star. Much fainter than TX is 12.4-magnitude van Maanen's Star, discovered by Adriaan van Maanen in 1917. The star is speeding across the sky with a proper motion of nearly 3″ per year. In the decades since its discovery, quite a few stars exhibiting greater proper motions have been found, but with a distance of only 14.07 light-years, van Maanen's Star still holds the title of the closest solitary white dwarf. (The white dwarf companions of Sirius and Procyon are nearer, at distances of 8.65 and 11.44 light-years, respectively.) The age of van Maanen's Star was once thought to be as much as 10 billion years, but recent research suggests it may only be about as old as our Sun.

To find van Maanen's Star you need a medium-size telescope and a detailed finder chart. But we can easily note its location on our Northern Hemisphere map (pages 42 and 43) — almost right on the ecliptic, a little more than 2° south of Delta (δ) Piscium.

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

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

Mars at its Most Magnificent

The Red Planet takes center stage, with Jupiter, Saturn, and Venus having supporting roles.

Mars rules October. Its ruddy beacon shines brighter and its globe is bigger than at any time until 2035. The Red Planet reaches opposition on the 13th, when it rises around sunset and travels across the sky all night.

Meanwhile, high in the south at nightfall are Jupiter (a touch dimmer than Mars) and Saturn — a bright pair whose separation is again starting to decrease. October is also a great time to spot Uranus, which is also at opposition.

The month's final highlight planet is lantern-like Venus, which passes very near Regulus and rises well before the start of morning twilight.

ALL NIGHT

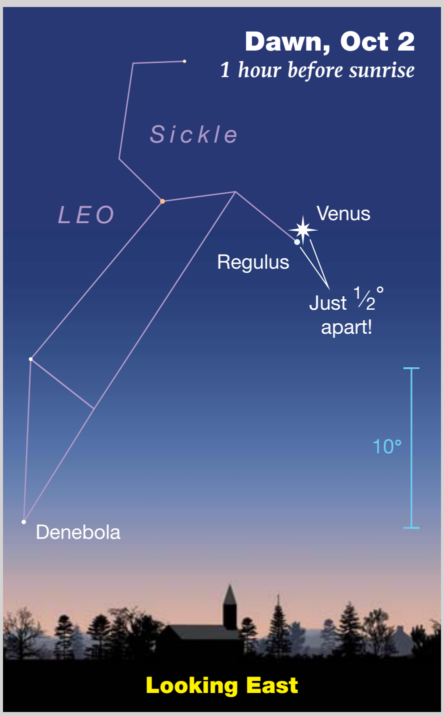
Mars is simply magnificent this month. Since 1988, the Red Planet has only appeared larger and brighter twice: in 2003 and again in 2018. But at both those oppositions Mars was much farther south. In fact, this time it's a full 31° farther north than it was in 2018, placing the planet more than twice as high on the meridian for observers at mid-northern latitudes.

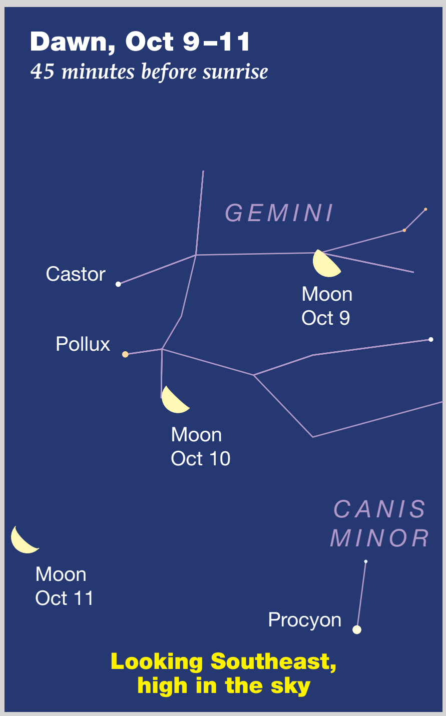
During October, Mars is retrograding in Pisces, about 5½° north of the celestial equator, where seeing conditions are likely to allow crisp telescopic views. Mars starts the month at magnitude –2.5, peaks for over a week at –2.6, then fades down to –2.2 by month's end. Its apparent diameter is more than 22″ for most of the month, shrinking slightly to 20″ by the 31st.

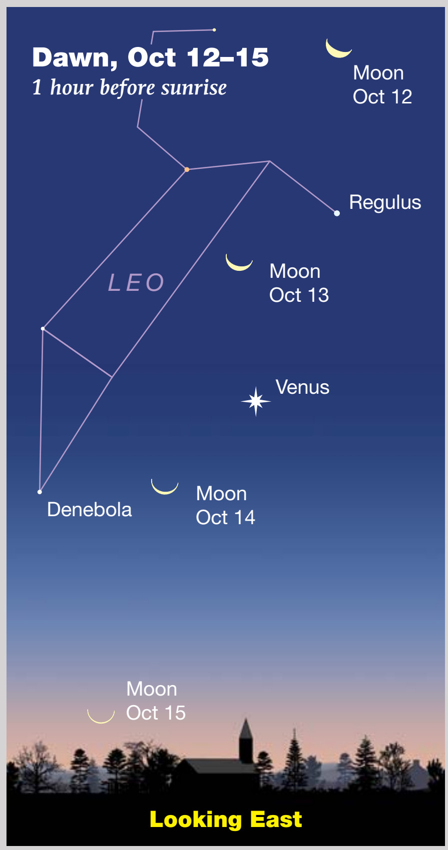
For detailed information about observing Mars during its very favorable 2020 apparition, turn to page 48.

Uranus is also its best in October. It reaches opposition in Aries on the 31st, when it shines at magnitude 5.7 and presents a disk 3.7″ wide. (See page 51 for a detailed finder chart.) **Neptune** is in Aquarius and crosses the sky three hours ahead of Uranus. If you're interested in hunting down Neptune, you'll

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

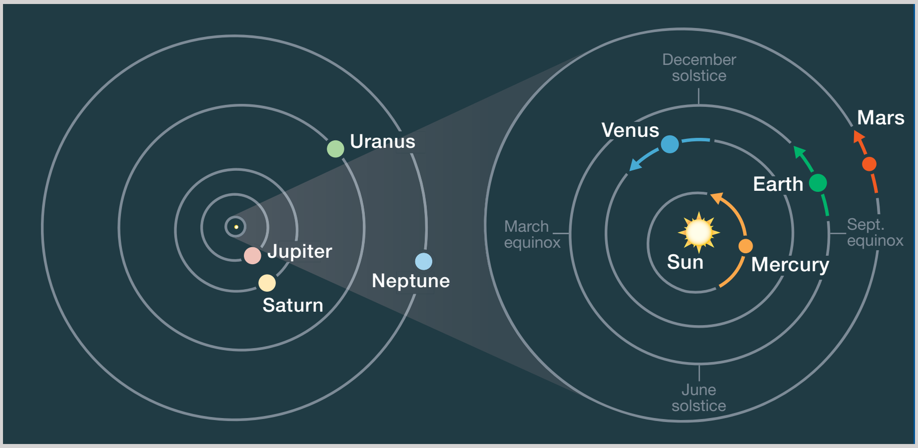






find a detailed chart on page 48 of the September issue.

This month, asteroid **8 Flora** is closer to Earth than at any time between 1980 and 2060. On October 31st, the magnitude-8.0 object is slightly more than 130,000 km away. On the 30th it can be found less than 10′ west of 3.5-magnitude Gamma Ceti. Flora reaches opposition on November 1st.



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

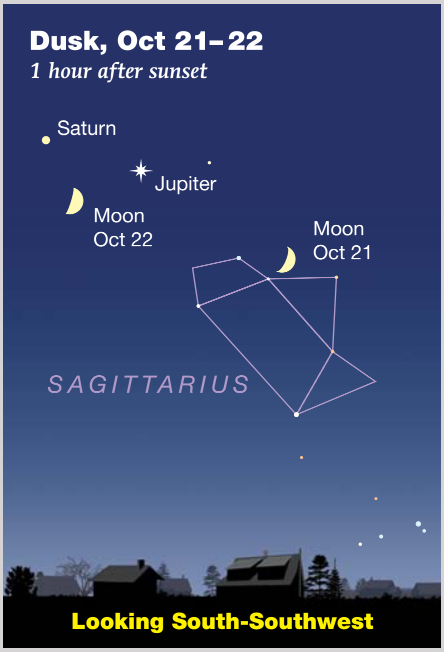
DUSK TO MIDNIGHT

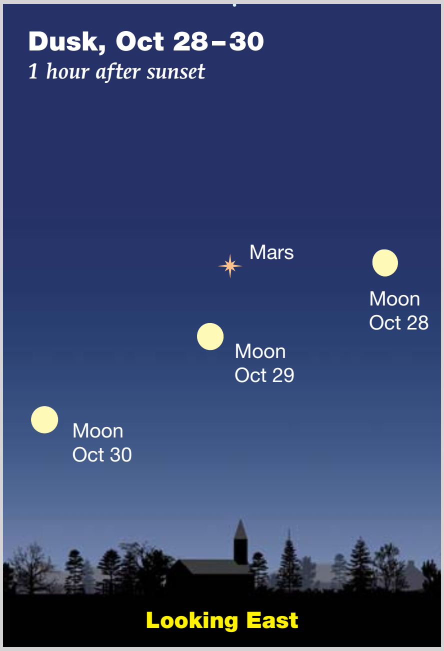
Jupiter and **Saturn** are at their highest due south at the end of evening twilight in early October, and around sunset by the end of the month. Between May and September, the two giant planets were retrograding (moving westward), and their separation increased from less than 5° to more than 8°. But in October, both planets are in eastern Sagittarius and in direct (eastward) motion. Faster Jupiter is closing in on Saturn, and by Halloween night the separation between them is reduced to 5.2°.

Jupiter dims a bit (from magnitude –2.4 to –2.2) during October and is a little fainter than Mars until the end of the month when the two are tied. Saturn fades a trace, from +0.5 to +0.6. Both Jupiter and Saturn remain prime targets for telescopes this month. Although Jupiter's equatorial diameter shrinks from 40″ to 37″ and Saturn's from 17.2″ to 16.3″, on steady nights observers can still enjoy views of Jupiter's clouds and Saturn's rings. Additional good news for observers is that Jupiter reaches *east quadrature* (90° east of the Sun) on October 11th and Saturn does on the 18th. In this position the planets cast their shadows farthest to the east of their disks, enabling better views of Jovian satellite eclipses, and enhancing the three-dimensionality of Saturn's globe and rings.

PRE-DAWN TO DAWN

Venus is two months past greatest elongation but still rises well over 3 hours before the Sun as October opens, and a little less than 3 hours after sunrise as the month closes. On the 2nd and 3rd, the magnitude –4.1 planet is roughly ½° from Regulus. They're closest at 18 UT (2 p.m. EDT) on October 2nd, when only 1⁄10° separates them. Venus's diameter decreases from 15.5″ to 13.2″ in October while its phase increases from 72% to 81%.

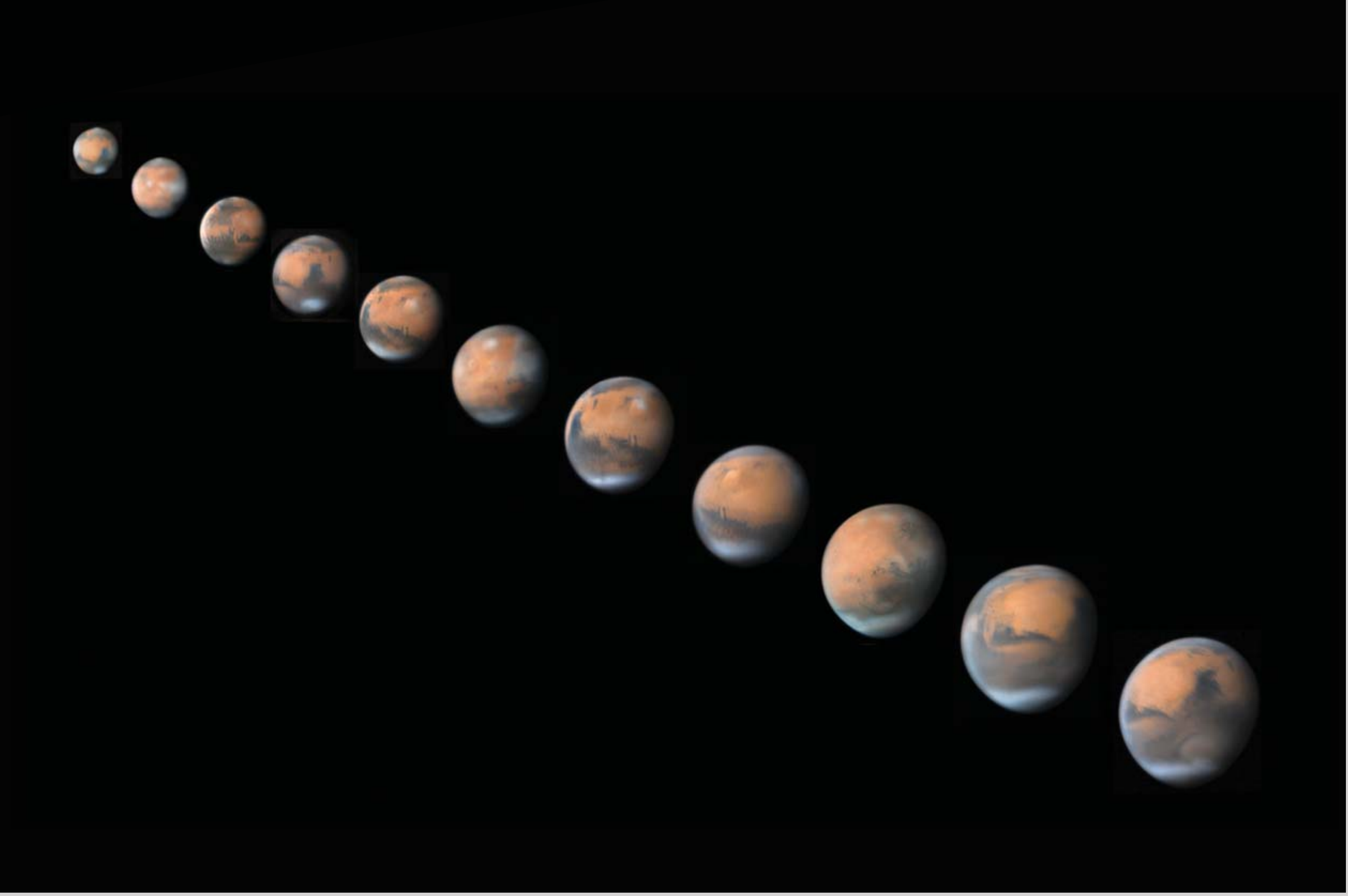




MOON PASSAGES

The **Moon** is full twice in October. On the 1st there's a Harvest Moon, and on the 31st, a Halloween "blue moon." The Moon is new on October 16th at 19:31 UT, and at 23:46 UT has its closest perigee of the year. On the night of October 2–3, the Moon passes extremely close to Mars and occults the Red Planet as seen from parts of South America, southwestern Africa, and Antarctica. The Moon is just a few degrees south of Pollux at dawn on October 10th. The waning lunar crescent is far above Venus on the 13th, and well to the lower left of the planet the next morning. At nightfall on the 22nd, a waxing lunar crescent forms a compact triangle with Jupiter and Saturn. At dusk on the 29th, the nearly full Moon is less than 5° below Mars.

■ **FRED SCHAAF** wrote his first book, *Wonders of the Sky: Observing Rainbows, Comets, Eclipses, the Stars and Other Phenomena*, 40 years ago.



A Great Year for Mars

The Red Planet won't be as good as this again until 2035.

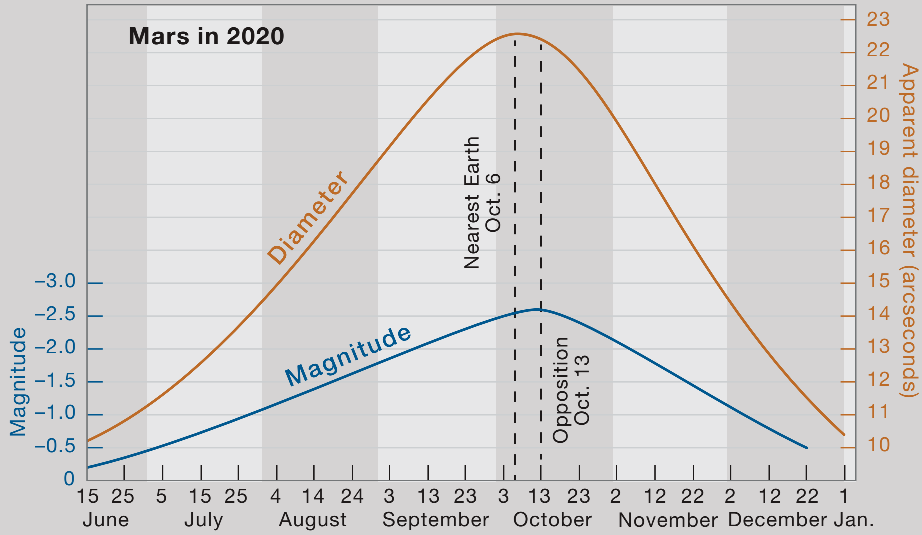
▲ UK planetary imager Damian Peach captured this sequence of images as the distance between Mars and Earth decreased during the 2018 apparition.

It's time to cash in those Mars chips. The Red Planet reaches one of its best recent oppositions on October 13th, when it will be just 62.7 million kilometers (39.0 million miles) from your front door — close enough to outshine planetary kingpin Jupiter, and large enough for satisfying telescopic views of the Martian surface.

Mars will actually be about 664,000 kilometers nearer on October 6th, when it has its closest approach to Earth. Martian perihelion occurred on August 3rd, and ever since the planet has been slowly moving away from the Sun, while at the same time Earth has been catching up in its orbit. The result is the October 6th "sweet spot" — a compromise between Mars's increasing solar distance and proximity to Earth.

Mars circles the Sun in a slightly elliptical orbit, and so its distance from Earth varies at each opposition. The two planets are at their closest when Mars's perihelion and opposition occur at roughly the same time. These so-called *perihelic* oppositions are when Mars shines exceptionally bright and presents a disk near its maximum size. Unfortunately for observers at mid-northern latitudes, the timing of these favorable oppositions often coincides with Mars sinking to the bottom of the ecliptic, where it's positioned very low in the sky. Poor seeing at low altitudes often muddies the view, making it difficult to discern surface details except on nights of nearly perfect steady seeing.

That's why the current opposition is so exceptional — it's a perfect balance between proximity and altitude. On October 13th Mars shines from Pisces



at a declination of slightly greater than +5°, which is a full 30° higher than during its 2018 opposition. Size-wise, the planet swells to 22.6″ this time at closest approach (on October 6th), compared with the 24.3″ it achieved during the last go-round. Get your scope tuned up and clean your eyepieces because Mars won't be this close again until 2035.

Surface highlights. The Martian south pole nods 20.4° earthward this opposition, offering spectacular views of the feature-rich southern hemisphere, including the South Polar Cap (SPC). Martian southern hemisphere summer began on September 3rd, so much of the cap's frozen carbon dioxide has vaporized into the planet's thin atmosphere. Still, on steady nights with a 6-inch or larger telescope used at high magnification, you should nevertheless be able detect a remnant of the SPC's former expanse.

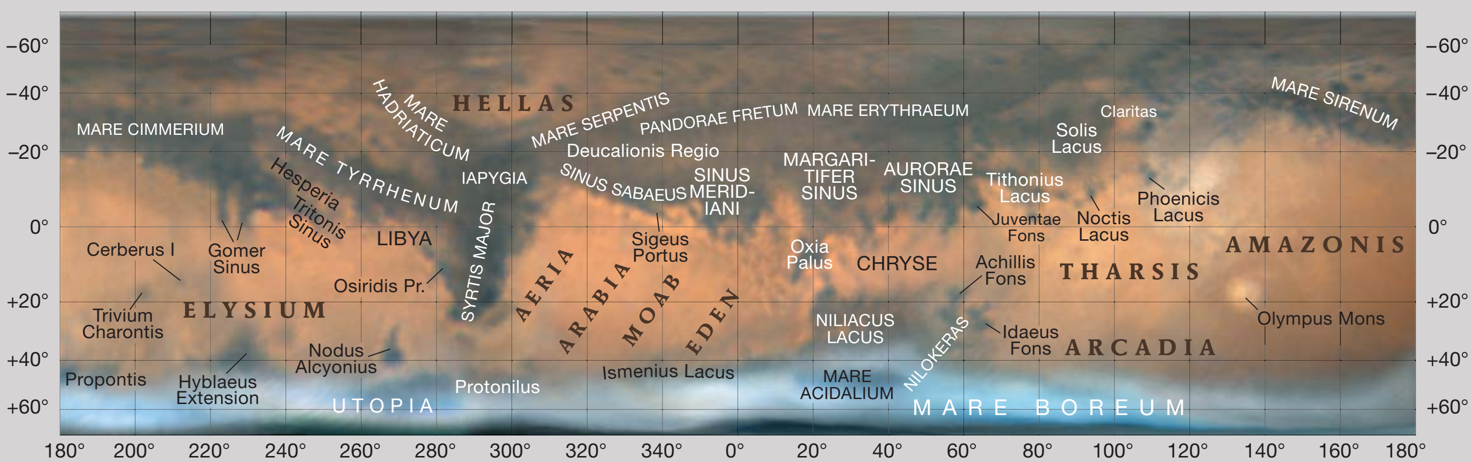
While the North Polar Cap (NPC) is tipped out of view it should be easy to spot the lens-shaped North Polar Hood (NPH), located along the northern limb of the Martian disk. Comprising clouds that huddle over the planet's north polar region in winter and early spring, the NPH is often so bright that beginning observers understandably confuse it with the NPC.

Martian surface markings make the planet both a joy and a challenge to explore. Mars rotates once every 24.6 hours, nearly the same rate as Earth. That means features drift 9.5° of longitude toward celestial east each passing night. So, if you observe the planet around the same time each night you'll notice that a given marking gradually slides eastward. Any marking seen on a particular night at a specific time will return to that spot at the same time 41 days later. An orange eyepiece filter (Wratten #21) will help the dark markings stand out better against the bright desert regions.

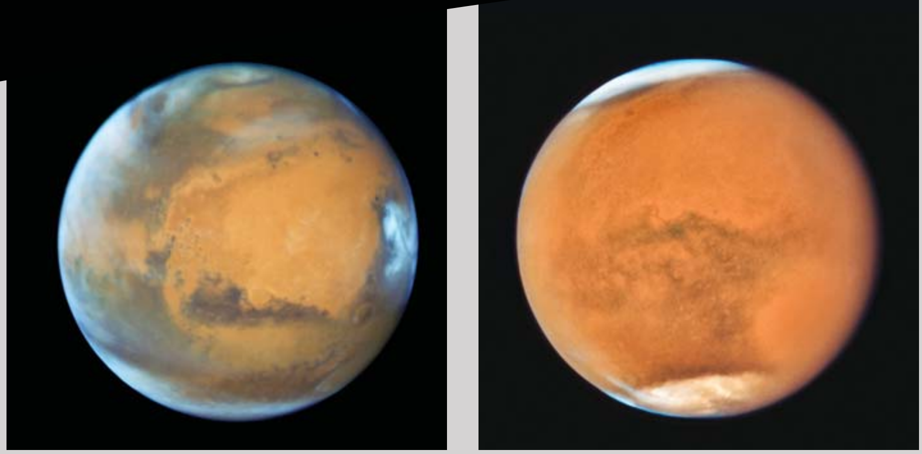
Let's take a quick tour of the most prominent features, starting with the thumb shape of Syrtis Major, an ancient shield volcano composed of dark basaltic rock. Like a low, thick branch extending from the trunk of a tree, Mare Tyrrhenum reaches to the south and west of Syrtis, ending at a bright gap called Hesperia, which separates it from the dark garland of Mare Cimmerium.

Follow the arc of Cimmerium and you'll arrive at a short, dark stripe called Mare Sirenum, the most prominent albedo feature on the planet's "boring" hemisphere, where easy-to-see formations are few and far between. A cursory glance may reveal nothing but a bland orange desert extending all the way to the NPH; however, if you look more carefully you might just spot one of the solar system's biggest volcanoes, Olympus Mons. Towering 25 kilometers above the surrounding desert and covering an expanse about the size of France,

▼ Use this map to locate key surface features on the Martian surface. South is presented up to match the orientation in Newtonian reflector telescopes, as well as refractors and Cassegrain instruments used without a right-angle diagonal.



GRAPH: GREGG DINDERMAN / S&T; MARS MAP: DAMIAN PEACH / GREGG DINDERMAN / S&T

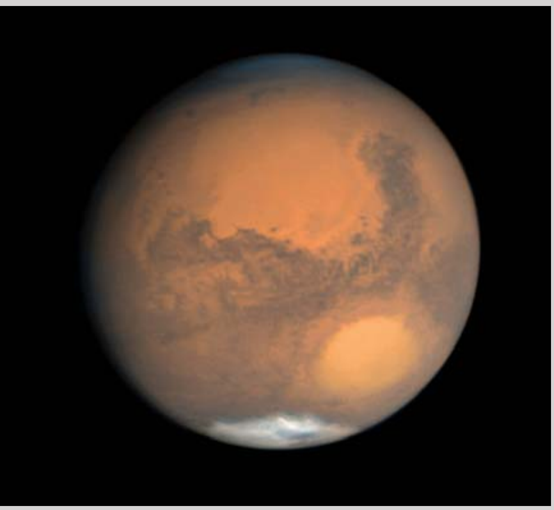


▲ This pair of Hubble Space Telescope portraits shows how the state of Mars's atmosphere drastically affects what we see. During the May 2016 opposition (*left*) many dark albedo features are visible; however, a global dust storm in July 2018 (*right*) partially obscures surface detail that stood out clearly several weeks earlier.

Olympus Mons is often topped with bright, white orographic clouds that give away the volcano's location.

Returning to Mare Sirenum, let's continue west. Get out your swimsuit because we'll soon arrive at Solis Lacus (Lake of the Sun), a prominent, circular dark patch that looks like a giant eye. Nearby Mare Erythraeum is blotchy and resembles the shape of Russia. Aurorae Sinus splays its fingers northward alongside a delightful Martian version of a soul patch called Margaritifer Sinus. While in the area, take a side excursion across the desert of Chryse, into the northern hemisphere to visit the prominent, mesa-like duo of Niliacus Lacus and Mare Acidalium. Despite being tipped away from us they're worth a look.

Besides Syrtis Major I also anticipate the appearance of Sinus Meridiani and Sinus Sabaeus, which blend together to resemble a marshmallow on a stick. A quick jaunt across Sinus Meridiani brings us to the great arch of Mare Serpentis branching east from Syrtis Major. Immediately south of Syrtis you'll find Hellas. Spanning some 2,300 kilometers, it's the largest impact structure on Mars. Even a 4-inch scope will show this enormous basin as a pale, round patch bounded by dark albedo features. At certain times of the year Hellas is coated with frost, transforming it into a misplaced faux polar cap.



▼ Several prominent Martian surface features appear in this image from August 2018 showing the face of the planet often regarded as the most interesting. The bright oval near the South Polar Cap is the Hellas basin; Syrtis Major, Sinus Sabaeus, and Sinus Meridiani are the most conspicuous dark markings.

Atmospheric features. Watch for isolated clouds as well as pale white limb hazes created by dust and dry-ice crystals scattering light high in the Martian atmosphere. Morning clouds form at the (celestial) east limb, evening clouds at the west limb. Violet and blue filters (Wratten #47 and #80) help enhance the visibility of these clouds.

As noted earlier, southern hemisphere summer began on Mars on September 3rd, so be on the lookout for the formation of dust storms, which tend to break out during this season. They can form in many places, but keep a close watch on Chryse, located between Margaritifer Sinus and Niliacus Lacus, and the region due south of Sinus Meridiani. If a feature you saw one night appears altered or disappears several nights later, a storm is the likely reason. A yellow filter (Wratten #8) shows dust clouds most clearly.

Mini moons. Mars has two tiny satellites: 10.7-magnitude Phobos and 11.8-magnitude Deimos. I observed them several times at favorable oppositions with an 11-inch telescope and an eyepiece fitted with an occulting bar. You can make your own by taping a tinsel-wide piece of aluminum foil to the eyepiece's field stop. (Basic designs such as orthoscopics and Plössls are best suited to this modification.) Use magnifications of 200× or greater, and position Mars behind the occulting bar. Seek the moons when they're at maximum elongation.

Although Deimos is fainter than Phobos, it orbits farther from the planet, which makes it easier to spot. At their greatest elongations this opposition, Deimos is about 67″ from Mars, while Phobos ventures just 20″ from the Martian disk. Were it not for the planet's overwhelming brilliance, both moons would be easy to see in a 6-inch scope. Most planetarium software will show the current locations of Phobos and Deimos.

On the evening of October 2nd, the nearly full Moon passes just 1° south of Mars, as if to herald the arrival of the most exciting phase of the Red Planet's current apparition. Settle in with your telescope and enjoy the show!

HELPFUL RESOURCES

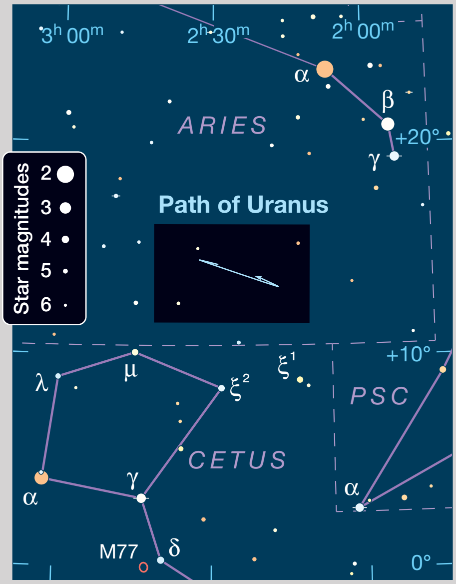
To find out which side of Mars is visible at any time use *S&T*'s Mars Profiler: https://is.gd/marsprofiler.

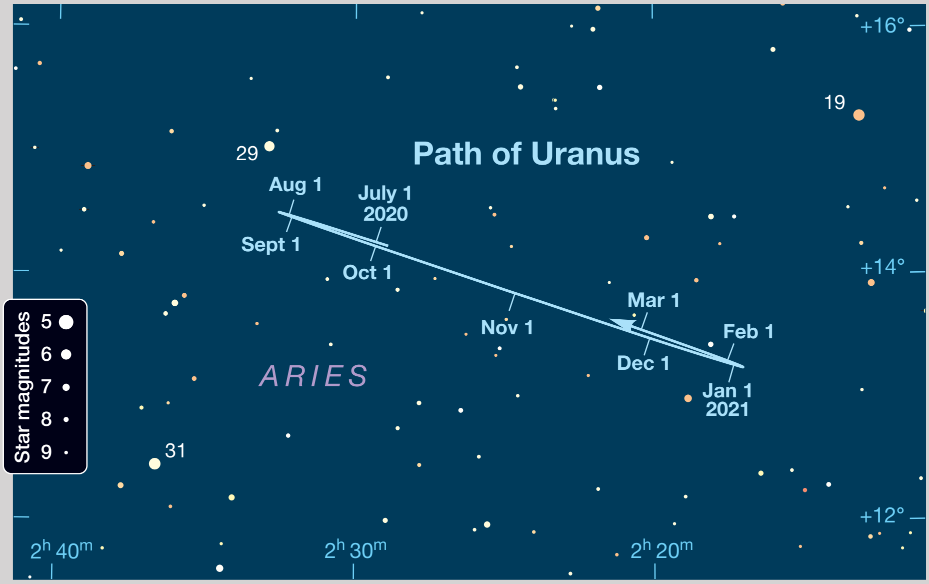
For the location of the two Martian Moons, visit: https://is.gd/MarsMoons.

Instructions for making an occulting bar are here: https://is.gd/OccultingBar.

HST MARS PAIR: NASA / ESA / STSCI; MARS DISK IMAGE: DAMIAN PEACH

Bag Uranus on Halloween Night





YOUR TRICK-OR-TREAT BAG could rustle with something extra special this Halloween. That night, Uranus comes to opposition in a barren region of sky in southern Aries. You can practically hear the wind whistle through the emptiness there and perhaps even imagine the ghost of William Herschel, the planet's discoverer, lifting a craggy finger to point the way.

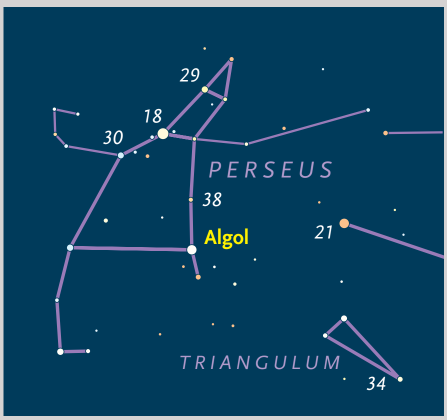
At magnitude 5.7, Uranus is easy to spot in binoculars even from the suburbs. The fact that so few stars populate the area makes this opposition ideal for a challenge attempted by few amateurs: finding the planet without optical aid.

From a dark, rural sky it's not too difficult to see stars slightly fainter than Uranus. Pick a night when there's no Moon and when the planet is near the meridian. A particularly good opportunity comes in the third week of October after moonset. That's when you can make use of a fortuitous alignment. Uranus sits roughly midway between 19 and 31 Arietis — stars with magnitudes nearly identical to that of the planet. Use averted vision to look for this line of stellar equals.

Uranus currently lies 2.8 billion kilometers from Earth. Although it's slightly less massive than Neptune, Uranus is 1,600 kilometers wider, making it the solar system's third biggest planet after Jupiter and Saturn. Through a 6-inch telescope at 75×, Uranus betrays its planetary nature with a telltale tiny disk 3.8″ across.

In a 10-inch or larger instrument under dark skies, you can pull in the planet's two brightest moons, Titania and Oberon (magnitudes 13.9 and 14.1, respectively). Use 250× or greater to discern these dim specks from the spillover glow surrounding the planet. Our Moons of Uranus tool will help you keep tabs on the planet's five brightest satellites: **https://is.gd/UranusMoons**.

Uranus is famous for its sideways tilt — its rotational axis is inclined 97.8° to the plane of its orbit. It makes me think of a dropped penny rolling away on the pavement. Snatch up this pale blue coin and tuck it into your treat bag on Halloween night.



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

Minima of Algol

Sept.	UT	Oct.	UT
2	12:53	1	4:59
5	9:42	4	1:48
8	6:30	6	22:37
11	3:19	9	19:25
14	0:08	12	16:14
16	20:56	15	13:03
19	17:45	18	9:52
22	14:33	21	6:40
25	11:22	24	3:29
28	8:11	27	0:18
		29	21:07

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

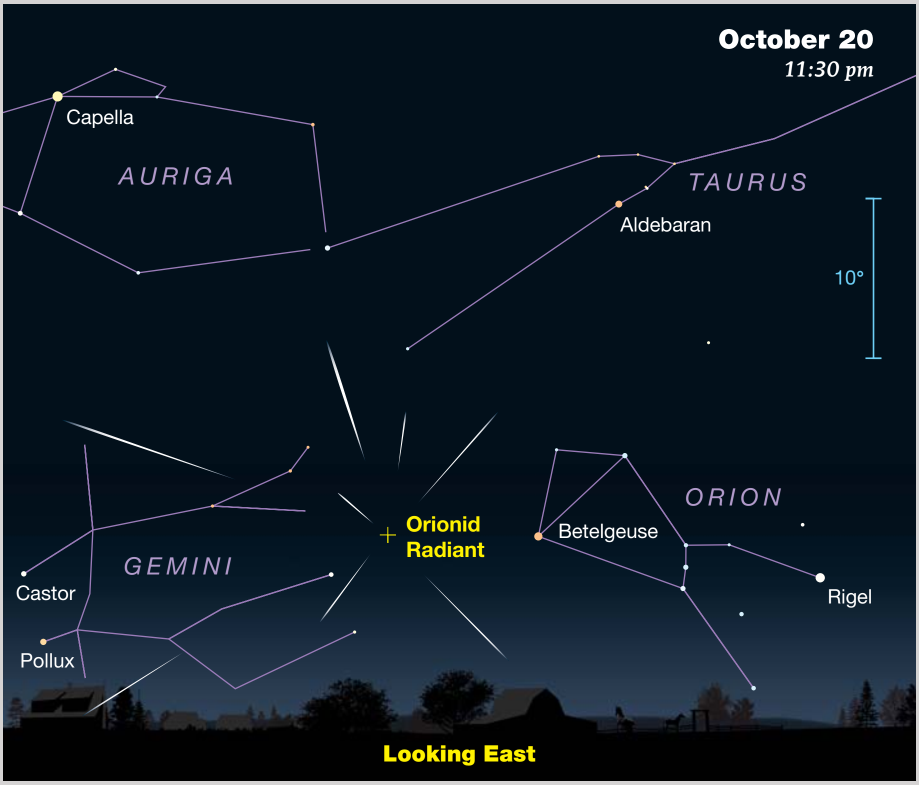
Orionids Peak

HALLEY'S COMET IS BACK! Well, not the *whole* comet — just little pieces of it. Earth intersects the orbital path of Mr. Halley's famous comet twice a year: first in early May, producing the Eta Aquariid meteor shower, and once again in autumn, when our planet crosses the comet's outbound leg, giving us the late-October Orionid display.

Each time, the planet plows through dust and cookie-crumb-sized debris boiled off the comet during its multiple trips to the inner solar system. Striking Earth's atmosphere at around 66 kilometers per second (148,000 mph), these fragments flare into meteors.

This year, the Orionids peak during the early morning hours of Wednesday, October 21st, when up to 15 meteors per hour will streak across the heavens, seemingly originating from Orion's upraised club (see the chart below). The peak is forecasted to occur around 6 UT (2 a.m. EDT). Thankfully, not a photon of moonlight will spoil this year's display, which begins around midnight local daylight-saving time and lasts until dawn, when the radiant climbs to the meridian.

Find a spot away from the neighbor's yard lights and relax on a reclining chair under a warm blanket while facing south or east. If you're patient, Halley's dust will make your night sparkle.



▲ The radiant for the Orionid meteor shower clears the east-northeast horizon at roughly 10:30 p.m. local daylight-saving time and reaches the meridian at 5:30 a.m., just before the start of morning twilight at mid-northern latitudes.

Action at Jupiter

AT THE START OF OCTOBER, Jupiter transits the meridian during twilight, at around 7:30 p.m. local daylight-saving time, when it's best placed for telescopic viewing. On October 1st, the planet gleams at magnitude –2.4 and presents a disk 40.4″ in diameter.

Any telescope shows the four big Galilean moons, and binoculars usually show at least two or three. Use the diagram on the facing page to identify the moons by their relative positions on any given date and time.

All the October interactions between Jupiter and its satellites and their shadows are tabulated on the facing page. Find events timed for early evening 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.)

September 1: 3:10, 13:05, 23:01; **2**: 8:57, 18:52; **3**: 4:48, 14:44; **4**: 0:40, 10:35, 20:31; **5**: 6:27, 16:22; **6**: 2:18, 12:14, 22:10; **7**: 8:05, 18:01; **8**: 3:57, 13:52, 23:48; **9**: 9:44, 19:40; **10**: 5:35, 15:31; **11**: 1:27, 11:22, 21:18; **12**: 7:14, 17:10; **13**: 3:05, 13:01, 22:57; **14**: 8:53, 18:48; **15**: 4:44, 14:40; **16**: 0:36, 10:31, 20:27; **17**: 6:23, 16:18; **18**: 2:14, 12:10, 22:06; **19**: 8:01, 17:57; **20**: 3:53, 13:49, 23:44; **21**: 9:40, 19:36; **22**: 5:32, 15:27; **23**: 1:23, 11:19, 21:15; **24**: 7:10, 17:06; **25**: 3:02, 12:58, 22:53; **26**: 8:49, 18:45; **27**: 4:41, 14:36; **28**: 0:32, 10:28, 20:24; **29**: 6:20, 16:15; **30**: 2:11, 12:07, 22:03

October 1: 8:02, 17:57; **2**: 3:53, 13:49, 23:45; **3**: 9:41, 19:36; **4**: 5:32, 15:28; **5**: 1:24, 11:19, 21:15; **6**: 7:11, 17:07; **7**: 3:03, 12:58, 22:54; **8**: 8:50, 18:46; **9**: 4:42, 14:37; **10**: 0:33, 10:29, 20:25; **11**: 6:20, 16:16; **12**: 2:12, 12:08, 22:03; **13**: 7:59, 17:55; **14**: 3:51, 13:47, 23:42; **15**: 9:38, 19:34; **16**: 5:30, 15:26; **17**: 1:22, 11:17, 21:13; **18**: 7:09, 17:05; **19**: 3:01, 12:56, 22:52; **20**: 8:48, 18:44; **21**: 4:40, 14:35; **22**: 0:31, 10:27, 20:23;

23: 6:19, 16:14; **24**: 2:10, 12:06, 22:02; **25**: 7:58, 17:53; **26**: 3:49, 13:45, 23:41; **27**: 9:37, 19:32; **28**: 5:28, 15:24; **29**: 1:20, 11:16, 21:11; **30**: 7:07, 17:03; **31**: 2:59, 12:55, 22:50.

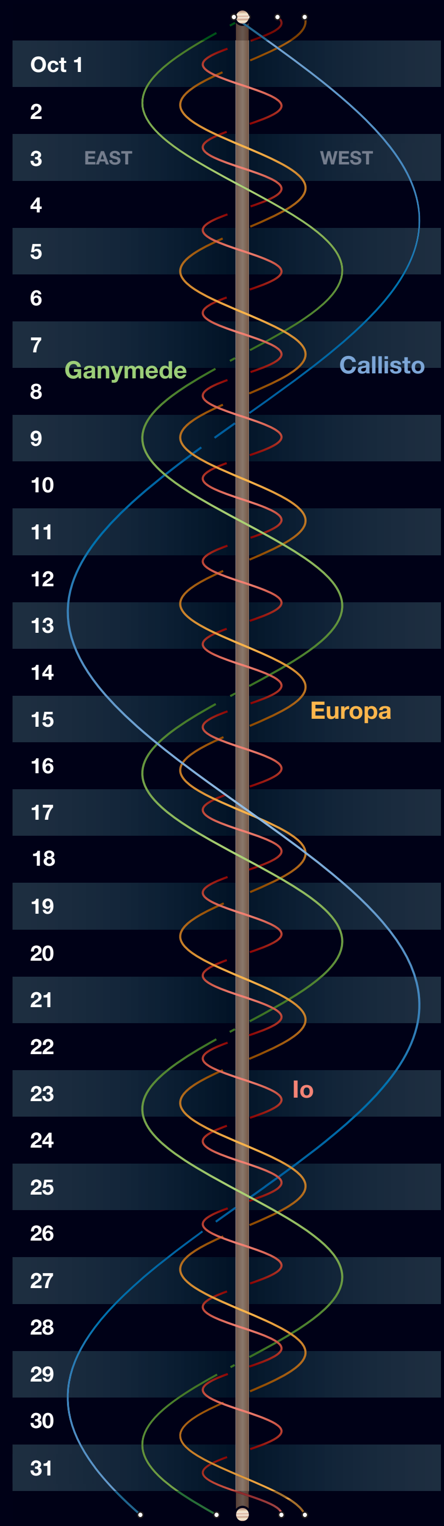
These times assume that the spot will be centered at System II longitude 342° on October 1st. If the Red Spot has moved elsewhere, it will transit 1²/₃ minutes earlier for each degree less than 342° and 1²/₃ minutes later for each degree more than 342°.

Phenomena of Jupiter's Moons, October 2020

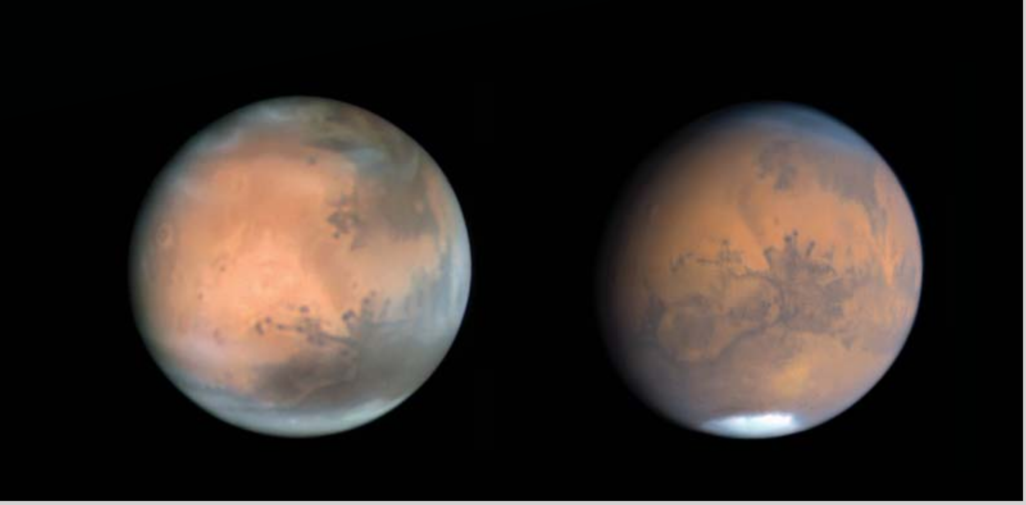
Oct. 1	0:27	I.Oc.D
	1:04	IV.Sh.I
	4:03	I.Ec.R
	5:29	IV.Sh.E
	10:31	II.Oc.D
	15:59	II.Ec.R
	21:49	I.Tr.I
	23:07	I.Sh.I
Oct. 2	0:05	I.Tr.E
	1:23	I.Sh.E
	18:56	I.Oc.D
	22:32	I.Ec.R
Oct. 3	4:41	II.Tr.I
	7:17	II.Sh.I
	7:28	II.Tr.E
	10:06	II.Sh.E
	16:18	I.Tr.I
	17:36	I.Sh.I
	18:33	I.Tr.E
	19:51	I.Sh.E
Oct.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

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

Jupiter's Moons



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



▲ Mars frequently changes, even from one apparition to the next. Note the dark features in the west and north of Solis Lacus (right image) that appeared during the intervening dust storm of 2018. Damian Peach recorded the two on June 5, 2016, and September 8, 2018, respectively.

The Changing Face of Mars

The Red Planet's shifting sands bring changes to the Martian landscape.

Golden lads and girls all must
Like chimney-sweepers come to dust.
— William Shakespeare, from *Cymbeline*

Mars reaches opposition on October 13th and at magnitude –2.5 will outshine nearly every other object in the night sky. With the Red Planet exhibiting a generously large disk of 22.4 arcseconds, observers will have a good opportunity to study its mysterious tapestry of dark and light markings.

In the early evenings this month, North American observers will be rewarded with a view of the most prominent dark marking, Syrtis Major, first recorded by the Dutch astronomer Christiaan Huygens on November 28, 1659. Later observers saw the same region as intensely blue-green and came to identify it as an actual Martian sea — a relic of perception that survives in other Martian nomenclature today.

Astronomers once thought Martian seas held water and even displayed marked changes in their outlines over time. During the last decades of the 19th century, the astronomical world was full of excitement about the "canals" made famous by the Italian astronomer Giovanni Schiaparelli after the opposition of 1877. Changes in the outlines of these dusky features were noteworthy enough to merit headlines in newspapers. The areas where differences were most often seen include the area of Libya, which forms a notch on the southeast side of Syrtis Major, and Solis Lacus on the other side of the planet, which sometimes appears round and at other times complex and elongated.

According to Schiaparelli, Libya was partly inundated by the neighboring sea in 1882 and 1884. Later, while observing with the great 77-centimeter (30-inch) refractor of the Nice Observatory, French astronomer Henri Perrotin found that the "land" had disappeared completely. Schiaparelli exclaimed:

> *"The planet is not a desert of arid rocks. It lives; the development of its life is revealed by a whole system of very complicated transformations, of which some cover areas extreme enough to be visible to the inhabitants of the Earth."*

It became clear by the end of the 19th century that the dark areas could not be true seas. For one thing, observers never saw specular reflections of the Sun within them. Astronomers adjusted, proclaiming them to be the dry beds of dead seas, while the perceived color changes were reinterpreted as marking the seasonal growth and fading of vegetation. Percival Lowell's ideas of an embattled civilization of Martians resorting to irrigation on a planetary scale influenced observers, as did his supple modifications of the existing nomenclature; he changed Schiaparelli's term *lacus,* meaning lake, to *lucus*, meaning grove or forest.

Rather oddly, Lowell seemed oblivious to the presence of Martian dust, believing the planet lay under perpetually clear skies. By failing to understand the opacity of dust in its atmosphere, he overestimated the latter's thickness by an order of magnitude. He also failed to appreciate that the usually regular and even outline of the planet's terminator was due to the smoothing presence of dust, and so thought that the surface must be remarkably flat and free of relief.

As the 20th century began, the vegetation theory marched on. Lowell Observatory astronomer Earl C. Slipher published pairs of images taken at different seasons, claiming proof of vegetation's existence on Mars. He emphasized the dark area Pandorae Fretum as especially susceptible to periodic strengthening and fading out, as if it went from spring and summer verdure to autumn and winter sere. Most astronomers of the time were so mesmerized by the claim that there was life on Mars that they did not consider the possibility that dust might have coated the region in the interval between the photographs.

At the opposition of 1954, when Mars was far south of the celestial equator, Slipher received National Geographic funding to mount a campaign to Bloemfontein, South Africa, in order to photograph Mars. His images seemed to bear witness to an enormous change. "Shortly after our observations began," Slipher wrote, "we discovered that a new dark area of considerable size had appeared in the desert regions of Mars . . . a little less than the size of Texas." However, whatever was going on was short-lived.

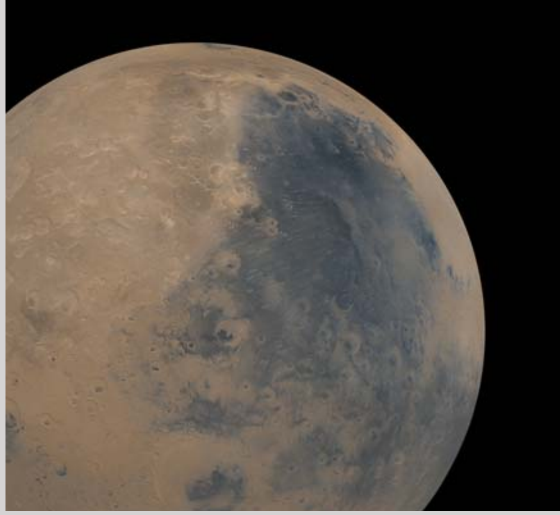
Following the Great Dust Storm of 1956, the new dark area vanished as quickly as it had come. This storm represented a turning point in the history of Mars interpretation. It was not the first large dust storm observed on the planet. But for the first time some astronomers — notably Dean B. McLaughlin of the University of Michigan — began to understand the planet's albedo changes in terms of the relentless movement of windblown sand and dust, seeing their shifting outlines as resembling the patterns of an Etch-a-Sketch board. Among the first converts to McLaughlin's theory was Yerkes Observatory astronomer Gerard P. Kuiper. Earlier a strong advocate of the vegetation theory, Kuiper completely changed his mind after 1956.

We now know, of course, that there is neither liquid water nor vegetation on Mars. There is, however, lots of sand and dust, as well as outcrops of weathered basalt (see our photo essay on page 12). There are also seasonal winds, capable of raising dust devils, regional dust storms, and planet-encircling storms.

A combination of warming and local topographic differences still seems to explain a subset of the storms. However, thanks to orbiting spacecraft imagery, we now know that many of the great summer storms actually have a distant origin, starting out along the tracks of seasonally repeating winter dust storms originating a hemisphere away. Plotting these tracks helps scientists better understand the way that dust alters the albedo features in places like Solis Lacus, Pandorae Fretum, and Libya.

Like the polar vortices of Earth, large cyclones develop in the polar regions of Mars, especially around the North Polar Cap during the northern hemisphere's cold winter. Some of these cyclones can become enormous. However, from Earth they are hard to study, because during much of autumn and winter northern latitudes are hidden beneath the clouds of the North Polar Hood.

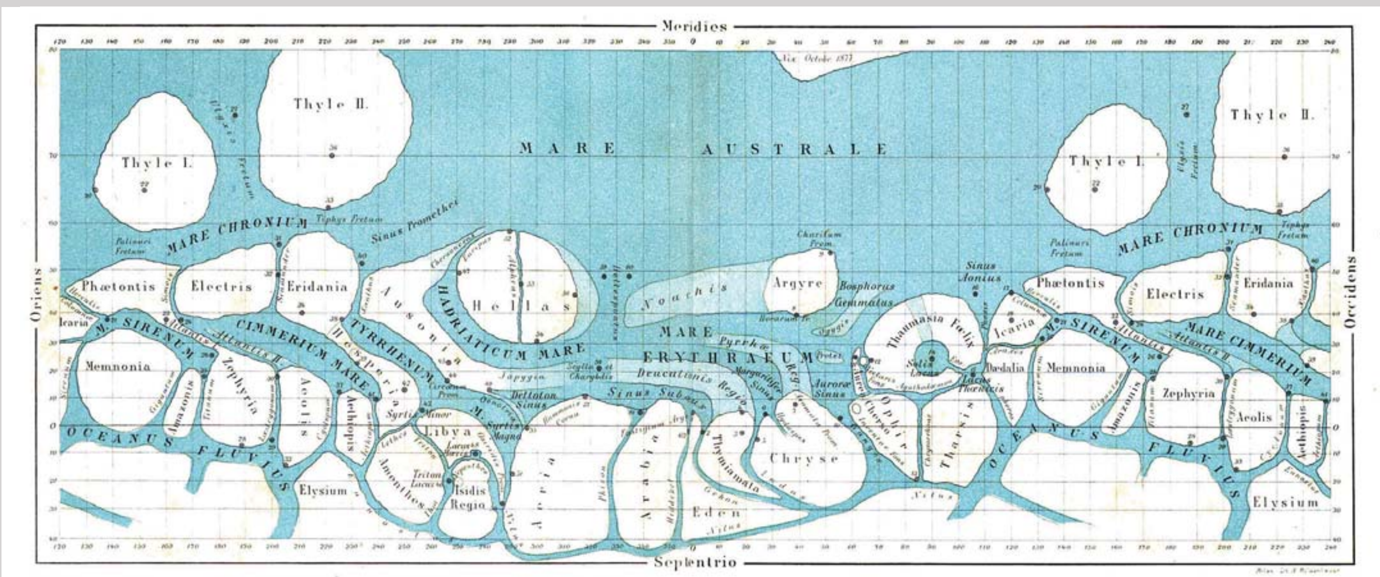
During the 2001 planet-encircling dust storm observed by NASA's Mars Global Surveyor, bands of dust originating in circumpolar cyclone activity began to move southward, picking up more dust as they went through Mare Acidalium and Chryse, and then along the equator into the Tharsis region. Bright Tharsis dust, injected into Solis Planum, caused the Solis Lacus albedo feature to change shape. Here, the dust was caught up in the strong winds of the subtropical jet and made its way across Noachis. Much of it would end up far to the east, piled up along the slopes of the Syrtis Major Planum shield volcano. For a time, the dust somewhat truncated that side of the Syrtis's dark, triangular form. Later, winds came and stripped most of that dust away. It finally settled within the ancient impact basin Isidis Planitia.



▲ Lighter dust fills Libya at top right, spilling into the dark area of Syrtis Major.

The Martian winds blow on, continuing to produce a phantasmagoria of changes that fascinate telescopic observers on Earth. What we are seeing are the ever-shifting shapes caused by wind and dust. But let's not entirely forget the changing shorelines of seas and vast tracts of vegetation grown during the last ebb of a dying race of Martians imagined by our predecessors.

■ Contributing Editor **BILL SHEEHAN** is co-author, with Jim Bell, of *The New Planet Mars*, coming soon from the University of Arizona Press.



▼ Giovanni Schiaparelli's 1878 map of Mars, featuring the first "canali." South is up.

SYRTIS MAJOR: NASA / JPL / USGS; MAP: WIKIMEDIA COMMONS / PUBLIC DOMAIN

Splashing Around the Dolphin

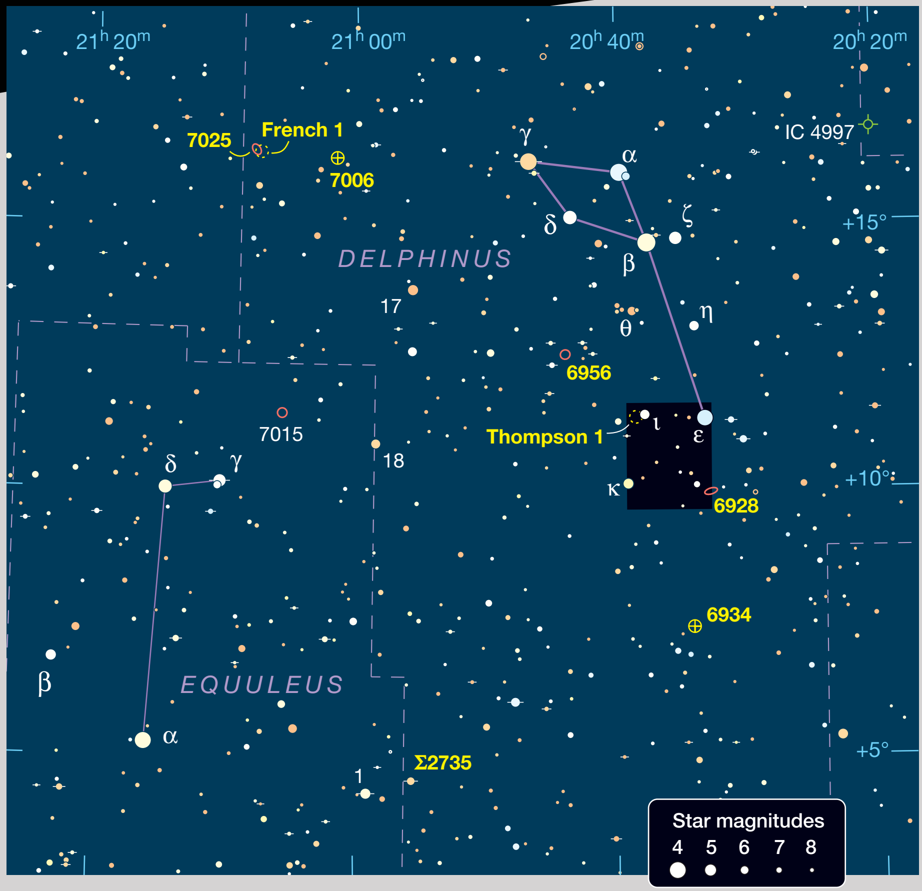
Tiny Delphinus holds a surprising variety of deep-sky objects.

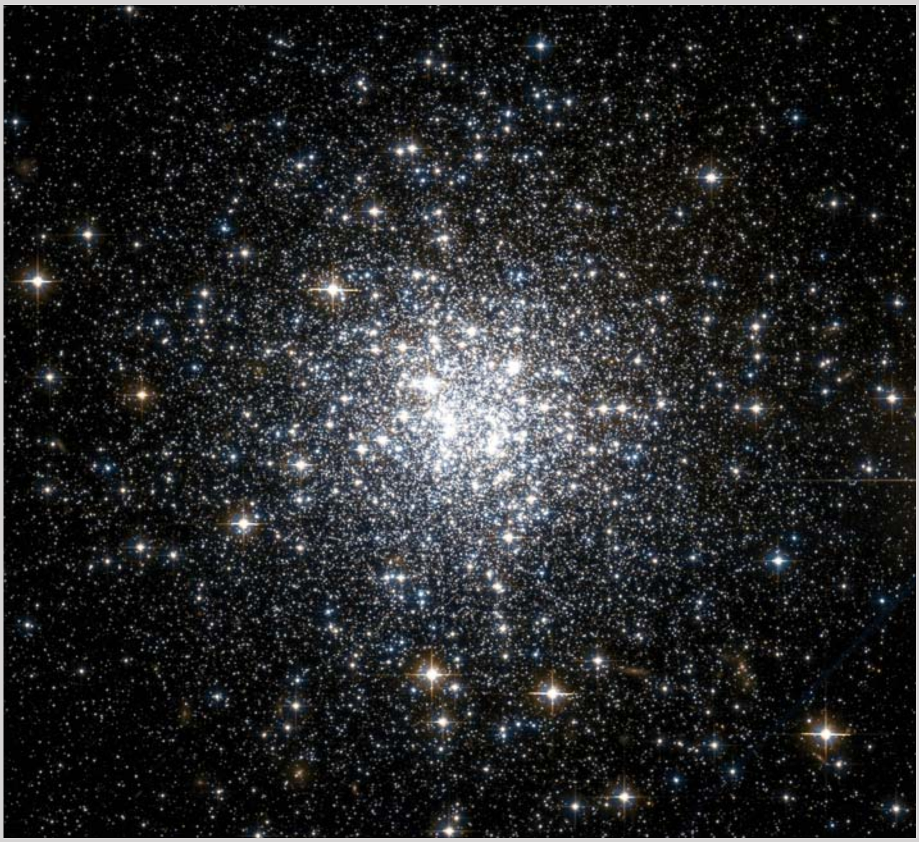
The autumn sky plays host to a flood of aquatic constellations that inundate the southeastern expanse of this month's all-sky star chart. Starting in the east and flowing toward the south, you'll see Cetus, the Whale; Pisces, the Fishes; Aquarius, the Water Bearer; Piscis Austrinus, the Southern Fish; Capricornus, the Sea Goat; and Delphinus, the Dolphin. The smallest of these constellations, Delphinus most resembles its namesake — a dolphin leaping playfully from the starry waters.

Let's first take to the water in far southeastern Delphinus, where we'll find the tight double star **Σ2735** sitting 53′ west-northwest of the star 1 Equulei in the neighboring constellation Equuleus, the Little Horse. The components of Σ2735 are only 2″ apart, but they're cleanly split through my 130-mm (5.1-inch) refractor at 117×. The 6.5-magnitude primary nuzzles a 7.5-magnitude companion a bit to the north of west. To me, the brighter star appears deep yellow and the secondary white.

Swimming 6.1° west-northwest, we come to **NGC 6934** (for more on globu-

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.





▲ NGC 6934 is the brightest globular cluster north of the celestial equator that's not in the Messier catalog. It's a fine spectacle through medium to large telescopes, though you'll never see it as well resolved as in this Hubble Space Telescope image.

ESA / HUBBLE / NASA

lar clusters, see page 28). This globular cluster is readily found by diving 3.9° south from Epsilon (ε) Delphini, the end of the Dolphin's tail. It's visible in my 12×36 image-stabilized binoculars as a softly glowing ball nestled against a 9th-magnitude star that makes it look elongated at a casual glance. The cluster's slightly oval form leans north-northeast as seen through my 105-mm scope at 153×. A few extremely faint stars sparkle in the halo, which encircles a broadly brighter core. In my 10-inch reflector at 219×, NGC 6934 appears 3′ across and partially resolved over a dappled haze. It grows to 4′ through my 15-inch reflector and glitters with many stars, including some at its very heart.

Next, we'll visit **NGC 6928**, the brightest of a small group of galaxies treading water 1.4° beneath the Dolphin's tail. No matter how large your telescope, I'm sure you'll find some of them challenging.

Only NGC 6928 is visible with my 105-mm refractor at 127×, its diaphanous spindle tipped east-southeast. A 6′ chevron of five similarly spaced, 12th-magnitude stars reaches northeast from the galaxy's eastern tip and then bends north-northwest.

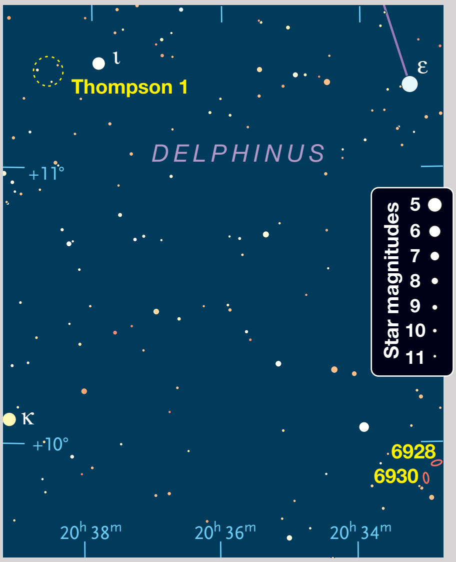
Through my 130-mm scope at 117×, I can easily distinguish a brighter, elongated core in NGC 6928 when I use averted vision. A faint star adorns the galaxy's northern flank. Boosting the power to 164×, I can catch, but not hold steadily, the roughly north-south glow of **NGC 6930**. It lies 3.8′ south-southeast of its companion and just north of the pointy end of a 2′ triangle of 10.2- to 12.6-magnitude stars.

Large-scope users should keep their eyes open for "extra" stars. NGC 6928 hosted a supernova that peaked at magnitude 15.3 in 2004. The previous year, NGC 6930 bore one perhaps a half magnitude fainter. Both galaxies are about 200 million light-years distant.

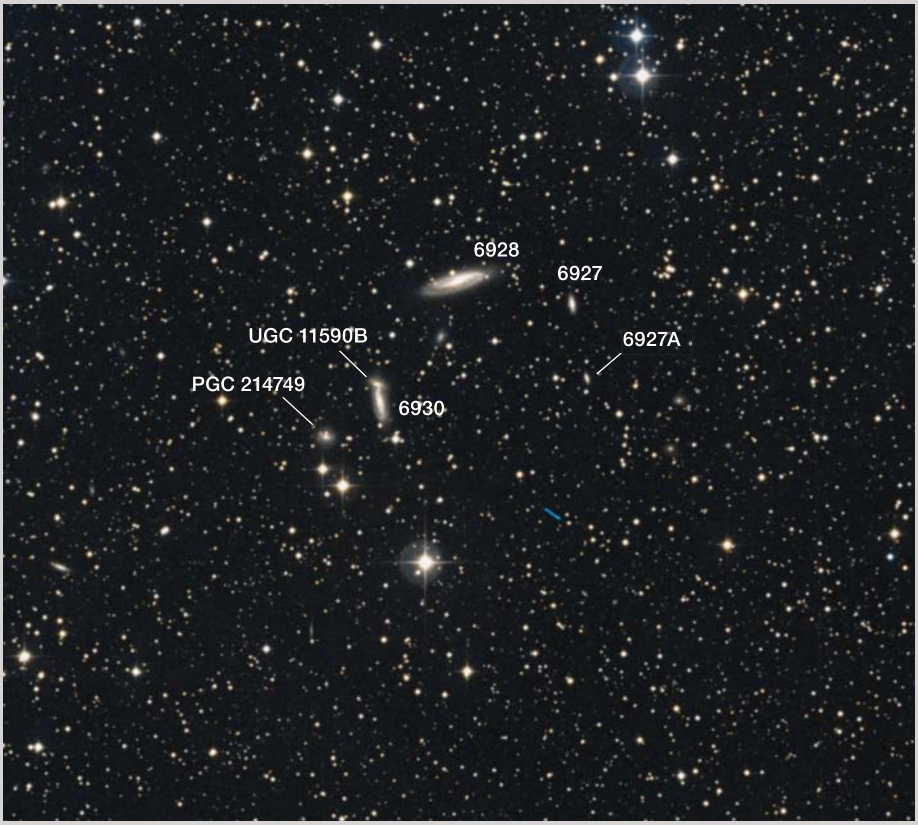
I can spot NGC 6928 at low power in my 10-inch scope, but the best view comes at 299×, which shows the mottled core growing brighter toward the center. The core of **NGC 6927** is visible as a very small, very faint spot 3.1′ west-southwest of its brighter cousin. While viewing at moderate powers, I noticed something 5.6′ west of NGC 6928 that looked tantalizingly like a nebula with a star involved. At 299× the star became a double accompanied by two more stars southeast and one north. Images of the area reveal a cute upside-down question mark of several stars that might look interesting when viewed through a large telescope.

In my 15-inch reflector, NGC 6927 becomes a small north-south oval, and I can glimpse three additional galaxies. At 247×, tiny **NGC 6927A** is dimly visible 2′ south of NGC 6927. A 15th-magnitude star lies off its southern tip, and a fainter one is visible to the north. **PGC 214749** is a very faint round patch 51″ north of the westernmost star in the triangle near NGC 6930. I occasionally see the glint of an extremely faint star on its northern edge. Identification of the galaxy is made simple by the fact that it makes a nice pie wedge with the triangle's stars.

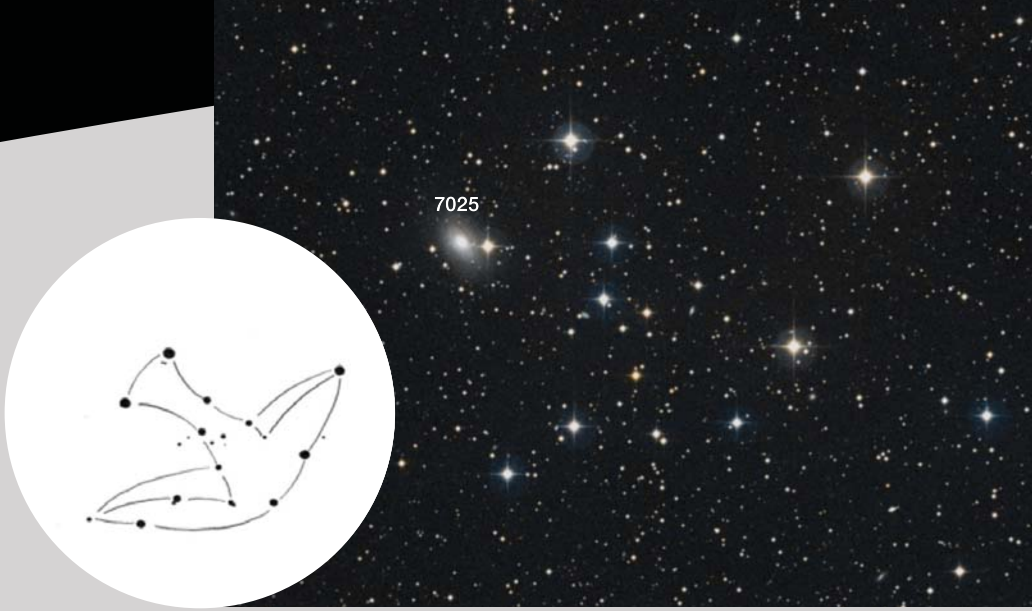
The third galaxy, **UGC 11590B**, teeters smack on the northern tip of NGC 6930, but I don't see it as a separate object. The slender profile of NGC 6930 comprises a faint halo, a brighter long



▼ NGC 6928, 6930, and 6927 are the brightest galaxies in their group at magnitudes 12.2, 12.8, and 14.5, respectively. Faint little NGC 6927A, at magnitude 15.2, is sometimes labeled as PGC 64924 or MCG 2-52-15.



POSS-I / STSCI / CALTECH / PALOMAR OBSERVATORY



axis, and a small oval core, while UGC 11590B merely looks like a brightening at its apex.

If you're looking for still tougher game, download an image of the surrounding area and use it to help you hunt down the plethora of faint galaxies that wade in these celestial waters.

Now we'll leap up to **Thompson 1**, whose three brightest stars are shown at upper left in the chart on page 57. This asterism was brought to my attention by Canadian amateur John Thompson. Through my 130-mm refractor at 63×, it shares the field with Iota (ι) Delphini, which glistens 10.4′ west-northwest. I count 13 stars, magnitude 10 to 13, in a distinctive, 5.7′-long triangle whose pointy end aims south-southwest.

Our next port of call is a galaxy that exhibits interesting structure. **NGC 6956** is a 1.5° voyage east-southeast from golden Theta (θ) Delphini. In my 105-mm refractor at 47×, it's a small hazy spot trying to hide in the glow of the 12th-magnitude star on its eastern edge. At 127×, the galaxy appears inclined north-northwest. My 10-inch scope at high power adds little, other than a faint double star just east of the superposed one. But my 15-inch reflector at 247× uncovers much more. NGC 6956 displays a faint oval halo, tipped a bit south of east, enveloping the elongated form seen in the smaller instruments. Its center harbors an oval core aligned north-south.

Another globular cluster, **NGC 7006**, floats 3.6° east of the Dolphin's nose. It's smaller and fainter than NGC 6934, but it's easily noticed at 37× through my 130-mm refractor, and it grows brighter toward the center. The cluster is about 2′ across and slightly elongated east-west. Two 14th-magnitude stars lie off the edge, a shade west of south, but no stars are resolved in the cluster.

Through the 15-inch reflector at 216×, NGC 7006 spans 3′ with a mottled core about half as large. Faint foreground stars graze the edge of the cluster approximately north, northwest, south, and east. Several extremely faint stars glimmer in the halo and some in the outer core.

▲ The photo above shows NGC 7025 hovering near the easternmost star of French 1. Turn the magazine 135° counterclockwise to see why this asterism is called the Toadstool. The sketch at left shows Finnish stargazer Jaakko Saloranta's impression of the Toadstool at 96× through his 8-inch telescope.

NGC 7006 is dimmer and more difficult to resolve than NGC 6934 largely because it's much farther away — 135,000 light-years compared to 51,000 light-years.

Sailing 1.4° east of NGC 7006, we come to **French 1**, a 13-star asterism of 9th- to 12th-magnitude stars. I call it the Toadstool, because it looks like a mushroom with its stem northeast and the 12.5′-wide cap southwest. Washed up against the foot of the Toadstool, we find a bit of celestial flotsam in the form of **NGC 7025**. Through my 105-mm refractor at 153×, this ashen galaxy shows a broadly brighter, slightly oval core encircled by a thin, faint, 45″-long halo tipped northeast. In the 15-inch reflector at 216×, it covers about 1½′ by 1′, its eastern flank guarded by a 13th-magnitude star and its western flank by the golden star at the base of the Toadstool.

For such a small constellation, Delphinus certainly holds a wealth of deep-sky objects. I hope some of them will make a big splash with you.

Delights of the Celestial Dolphin

Object	Type	Mag(v)	Size/Sep	RA	Dec.
Σ2735	Double star	6.5, 7.5	2.0″	$20^h\ 55.7^m$	+4° 32′
NGC 6934	Globular cluster	8.8	7.1′	$20^h\ 34.2^m$	+7° 24′
NGC 6928 (group)	Galaxy	12.2	2.2′ × 0.6′	$20^h\ 32.8^m$	+9° 56′
Thompson 1	Asterism	9.0	5.7′	$20^h\ 38.5^m$	+11° 20′
NGC 6956	Galaxy	12.3	1.9′ × 1.3′	$20^h\ 43.9^m$	+12° 31′
NGC 7006	Globular cluster	10.6	3.6′	$21^h\ 01.5^m$	+16° 11′
French 1	Asterism	7.1	12.5′	$21^h\ 07.4^m$	+16° 18′
NGC 7025	Galaxy	12.8	1.9′ × 1.2′	$21^h\ 07.8^m$	+16° 20′

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.

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

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DOUBLE VISION

Here's a great way to boost your imaging output when conditions are favorable.

▲ **TWO "EYES" ON THE SKY** Canadian astrophotographer Ron Brecher gets nearly twice as much exposure time with every target by piggybacking a Takahashi FSQ-106ED astrograph atop a Sky-Watcher Esprit 150 triplet apochromatic refractor. The larger scope images with a monochrome QHY16200A CCD camera, while the smaller FSQ records the same field with a QHY367C Pro color CMOS camera.

For most astrophotographers, clear skies can be infrequent and brief, particularly in the summer months when astronomical darkness lasts just a few hours. Setting up the equipment, recording calibration frames, and refocusing periodically all consume precious time and further reduce how much light we can capture in a single night. And if you have to travel to escape bright skies, you can lose even more valuable hours. So, what can you do to maximize your output on those rare nights when the stars do beckon? Here's a novel approach that can double your output.

Taking inspiration from the rock band Foreigner's classic rock song "Double Vision," I recently installed a pair of telescopes and cameras on my equatorial mount so that both can simultaneously accumulate images. It takes some planning, but a dual-scope imaging setup can vastly increase your output. Here's how to do it.

It's All About the Mount

As with any astrophotography, several pieces of hardware need to work together efficiently in a tandem imaging setup. At minimum, you'll need a solid tracking mount, two imaging telescopes, two cameras, and a control computer. Most setups will also require two electronic focusers and an autoguiding setup consisting of a guide camera attached to a guidescope or an off-axis guider.

First let's consider the mount. Regardless of whether you're using small refractors or large astrographs, a solid tracking mount is the key to a reliable dual-imaging platform. Your mount will be holding a lot of extra mass and will still need to be able to track precisely. I suggest keeping the total weight well below the manufacturer's stated limit, or else you may end up rejecting lots of poorly tracked images, defeating the entire point of the two-scope configuration. Imagers with light-duty mounts can use two small refractors or even a pair of telephoto lenses — the key is accurate tracking.

Be sure to either weigh or look up the weights of the individual components and add them together. Include everything that will ride on your mount — don't forget the dovetail plates, clamps, tube rings, filter wheels, focusers, guidescopes, and electronic components. The total must be less than the maximum load capacity of your mount.

Optical Choices

The next consideration for a dual-scope imaging system is the optics themselves. You need to ask yourself what you

MOUNTED CONTROL A dual-scope imaging system needs more ports than typically available on standard laptop computers. The author controls the mount, both imaging cameras, an autoguiding camera, two electronic focusers, and a filter wheel through his Primaluce Eagle 3 computer, seen mounted between the two refractors.

want each scope to do. Some imagers use identical telescopes and matching cameras to maximize the total exposure time. An extreme example of this method is the Dragonfly array in New Mexico (*S&T:* May 2019, p. 64), which uses 48 similar cameras and lenses on two mounts to record 48× more exposure time per hour than would be possible with a single assembly! Others opt for two different telescopes with slightly different tasks, such as having one shoot luminance while the other telescope records color data that will contribute to the same image.

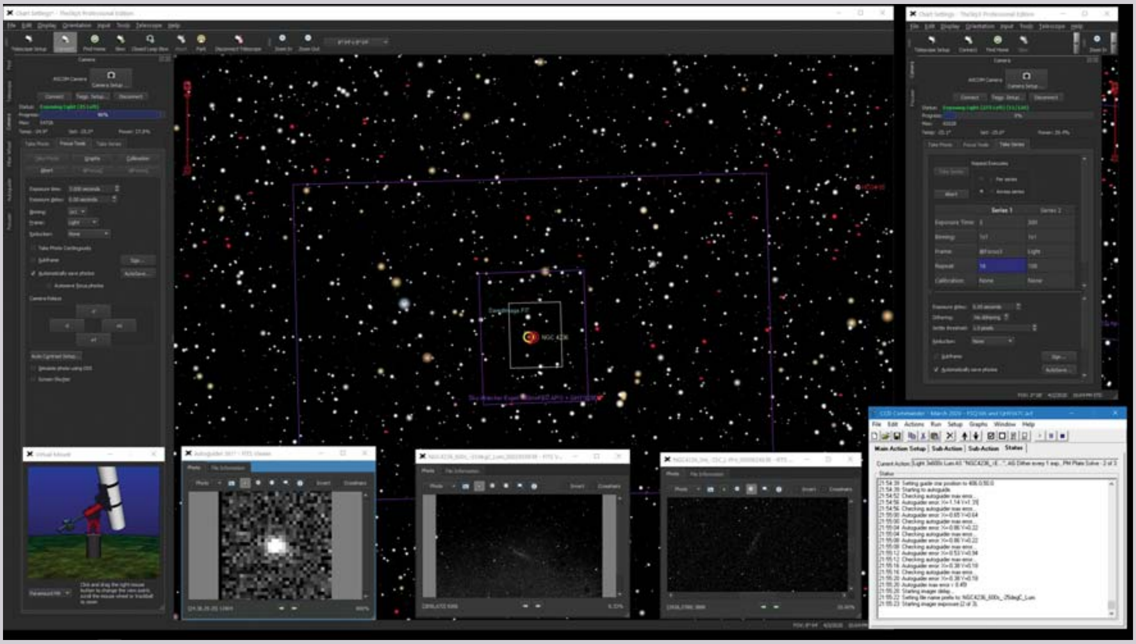
I've found that dual-scope imaging platforms are easier to put together using refractors rather than reflectors. One reason is that optical elements are more prone to shifting and flexure in a mirror telescope than in a refractor. Additionally, it's extremely difficult to align and stack star images from two scopes that produce diffraction spikes. Other compound optical designs, such as Schmidt-Cassegrain telescopes, sometimes suffer from mirror shift, which further complicates a dual-scope system.

For my setup, I use a Sky-Watcher Esprit 150 6-inch apochromatic refractor (*S&T:* Feb. 2020, p. 68) with a QHYCCD QHY16200A monochrome CCD camera to record high-resolution images with an image scale of about 1.1 arcseconds per pixel. While the Esprit acquires luminance (monochrome images with UV and IR wavelengths blocked) or narrowband images, a Takahashi FSQ-106ED paired with a QHY367C Pro one-shot color (OSC) camera records color images at 2.6 arcseconds per pixel.

This combination works well and solves a few of the challenges posed by a dual-telescope system. First, because our eyes perceive detail mainly in the *lightness* (brightness and contrast) of an image, I can add the color from the lower-resolution pictures taken with the 106-mm scope to the higher-resolution luminance from the 150 Esprit to achieve a high-resolution color result.

A second benefit is the Takahashi has a much larger field of view than the Sky-Watcher, making it relatively easy to aim both telescopes at the same field. There's usually no need to fine-tune the mounting of the two scopes to ensure the high-resolution instrument's field completely falls within the field of view of the wide-field instrument. This means

TEAM EFFORT Shooting deep-sky targets takes about half the time when using a dual-scope setup. As the FSQ-106ED recorded this wide-field image of the Running Man nebula with a QHY367C Pro color camera (top left), the Sky-Watcher Esprit 150 simultaneously captured luminance-filtered exposures with a monochrome QHY16200A CCD camera (bottom left). The right picture shows the result of combining both data sets.



BUSY PROGRAMS The system is controlled using two instances of *TheSkyX Professional Edition*. One copy of the software monitors the mount and controls the main camera and autoguider (left), while a second copy is open on the top right, controlling the color camera.

ZOOMING IN One novel benefit of imaging through a dual-scope system with different focal lengths is that the resulting images from both scopes offer distinct perspectives. *Left:* This wide-field shot taken with the FSQ-106ED of a region in Cygnus captures several interesting objects, including reflection nebula NGC 6914 (bottom right) and Simeis 57, the Propeller Nebula (top left). North is at left. *Right:* A closeup of NGC 6914 uses color from the wide-field image combined with high-resolution hydrogen-alpha data taken with the Sky-Watcher 150.

you don't have to utilize complex mounting hardware that permits tiny adjustments between the telescopes (a potential source of flexure).

Side-by-Side or Tandem Mounting?

With your mount and optics chosen, you next need to determine the best way to assemble everything. There are two common ways to attach a pair of telescopes to a single mount: side-by-side or with one scope piggybacked on the other.

Regardless of how you mount your equipment, proper balance is crucial to achieving good results (*S&T:* June 2019, p. 64). Flexure in the mounting hardware and the effects of gravity can lead to *differential flexure*, in which one telescope shifts slightly relative to the other. This can ruin every exposure from one scope, or even both if you're using a separate guidescope that might also flex relative to the two imaging scopes. Solid mounting hardware supplemented by some well-placed bungie cords can reduce or eliminate any differential movement. Troubleshooting flexure can take several nights of trial-and-error to determine the source of the problem and how to best address it.

Several manufacturers, including ADM Accessories (**admaccessories.com**), Losmandy Astronomical Products (**losmandy.com**), and Orion Telescopes & Binoculars (**telescope.com**), offer side-by-side saddle plates and tube rings.

Guiding Challenges

If you need to autoguide, consider using an off-axis guider (OAG), particularly if your telescopes have significantly different focal lengths. An OAG avoids the additional weight and reduces the risk of differential flexure that come with a separate guidescope. Placing the OAG in the longer focal-length instrument's optical path should produce round stars in both telescopes.

Dithering your exposures by randomly offsetting the field slightly between images may also require increasing the delay between the end of an exposure and the start of the next on the second camera. Otherwise the second camera may be recording an exposure when the dither movement occurs. This slight movement may not be visible in the lower-resolution images, if the offset is smaller than the pixel scale of your secondary imaging system.

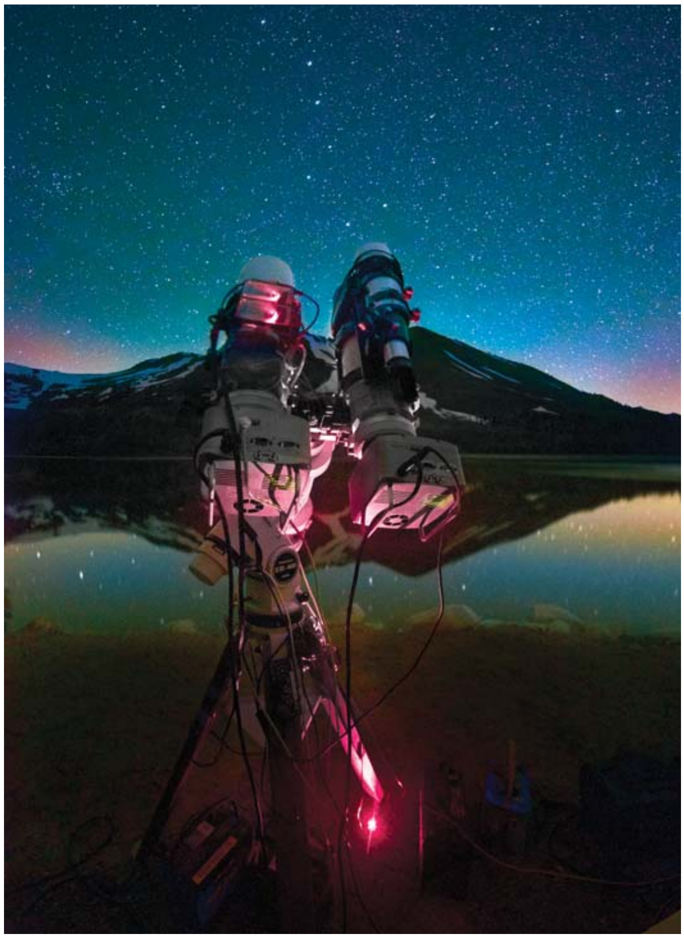
Adding a longer delay doesn't always work, particularly when the download speed differs significantly between the two cameras, or if the software takes more time than usual to dither the guide star or adjust focus. An additional software solution is required that I'll discuss shortly.

Control Management and Software

While everything mentioned so far can be operated through a laptop computer, there are additional considerations when assembling a dual-scope imaging platform that may be more than a laptop can handle.

Although not a lot of computing power is required for image acquisition, a dual-scope setup needs more power capabilities and ports for equipment connections than are typically available on a standard laptop. You'll need a lot of USB ports or an external, powered USB hub to connect your mount, two imaging cameras, their associated filter wheels, two motorized focusers, and possibly an autoguider. And when estimating your battery requirements for a night of portable imaging, remember that you may also need a dew-prevention system for each optic. Several companies offer small, integrated solutions that can be fitted to the telescope mount and controlled with a smart device, such as Software Bisque's Sky Fusion (**bisque.com**) or Primaluce Lab's Eagle control unit (**primalucelab.com**).

Even the control software is challenging when assembling a dual-scope setup. Most astronomical imaging software can operate a single camera, while some software suites like *MaxImDL* (**diffractionlimited.com**) and *TheSkyX Imaging Edition* permit users to control a secondary camera for autoguiding. If your mount is accurate enough to forgo guiding, then you can use this option to control your second camera and save the resulting images.



▲ **TANDEM MOUNTING** Another mounting option is to install both telescopes on a tandem platform. As seen here, imager Rogelio Bernal Andreo uses a pair of Takahashi FSQ-106 astrographs with two SBIG STL-11000M CCD cameras. Typically, he uses one scope to record color-filtered images while the other collects filtered luminance.

If you require autoguiding, there is another solution. The free open-source astronomical imaging software called *N.I.N.A.* (**nighttime-imaging.eu**) includes synchronized guiding and image downloads from multiple cameras. It works by launching two instances of the software to control each camera, though both copies communicate with each other and ensure that dithering occurs only when both imaging cameras are idle, and exposures begin again on both cameras once the mount has settled to the new position.

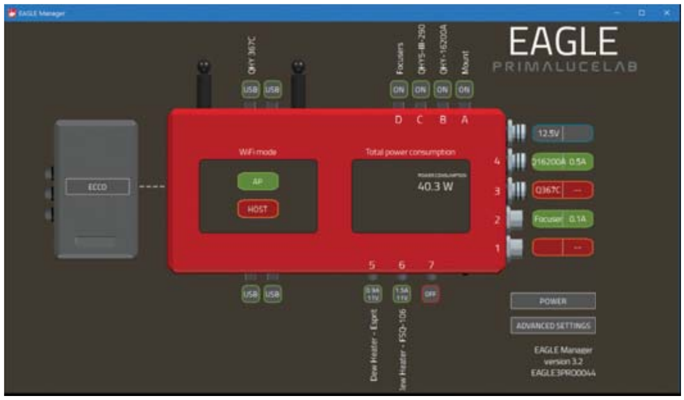
I prefer to simply run two instances of my camera control software. I use *TheSkyX Imaging Edition* to connect to my mount, monochrome camera, filter wheel, focuser, and the autoguider. I then launch a second instance and connect it to the OSC camera and its focuser. During an imaging session, the first instance of *The SkyX* runs all night, capturing images, autoguiding, and periodically refocusing the Esprit 150, while the second instance of the software controls my OSC camera, recording sub-exposures and periodically focusing the FSQ-106ED.

Processing the images from both scopes is just like processing the data from a single scope — simply calibrate all the images, then align and stack them together and proceed with your usual image-processing workflow.

Imaging Strategies

Once you've got your dual-scope imaging rig up and running, you can plan on acquiring much more data in a single night. With two identical telescopes and cameras, you can dedicate one scope to acquisition of color data while the other captures unfiltered luminance or even narrowband exposures. Or you can use one telescope to exclusively record narrowband images while the other scope focuses on recording broadband natural-color exposures. Each can yield a beautiful image in its own right, or they can be blended to impart natural-color stars to narrowband nebula images.

Using a dual-scope setup with telescopes of different focal lengths also offers the opportunity to present images from each telescope individually as two distinct perspectives, such as a wide-field and a complimentary closeup. Look for opportunities in which your low resolution, wide-field shots can make an attractive standalone picture. For example, NGC 6888, the Crescent Nebula in Cygnus, is beautiful either as a close-up portrait or set within the extensive nebulosity of the region. Many popular targets in the Milky Way offer "twofer" imaging opportunities.



▲ **DEVICE MANAGEMENT** The *Primaluce Lab Eagle 3 PC control panel* lets users manage its many power and USB ports on a smart device or computer via a WiFi connection. It also includes three RCA ports to connect dew heating strips that can each be remotely switched on or off as needed.

Regardless of the equipment you use, the number of clear, moonless nights is often the main limiting factor to completing an imaging project. Employing two telescopes simultaneously is an effective and efficient way to greatly increase the quantity of images recorded even in a relatively short night. It's only a little more challenging than using a single telescope, so maybe it's time to think about filling your eyes — or at least your cameras — with that double vision.

■ RON BRECHER is continually thinking of ways to improve his astro-imaging technique. Visit his website at **astrodoc.ca**.

▼ *Left:* Captured using the dual-scope system, this deep image of spiral galaxy NGC 4465 consists of nearly 22 hours of exposures recorded simultaneously. *Right:* Likewise, this richly colored photo of NGC 4236 uses more than 34 hours of total exposure taken in less than 19 hours over several nights.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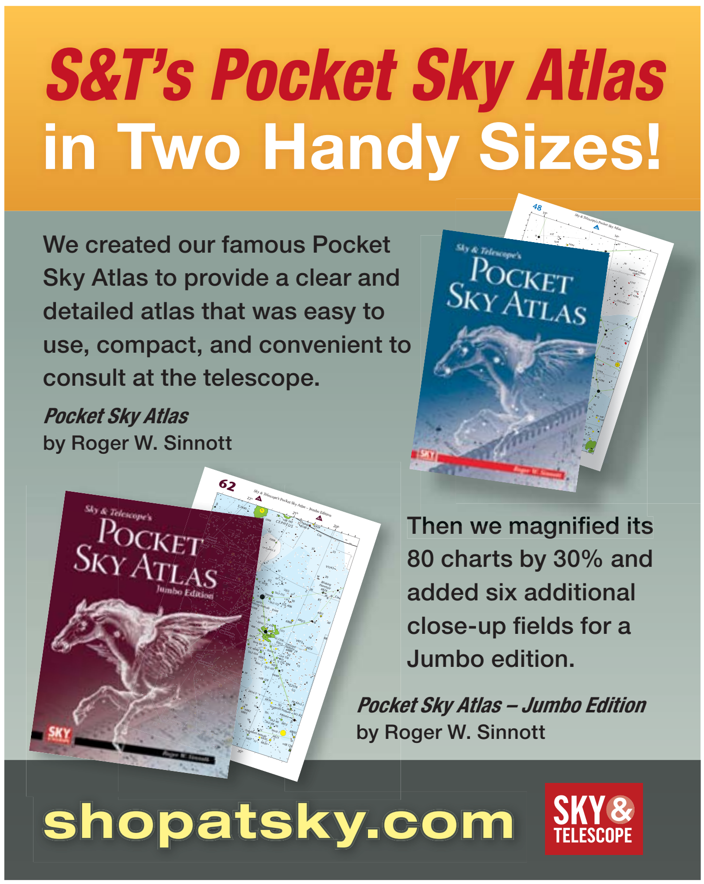
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Sky-Watcher's EQ8-R Pro Mount

This mid-heavyweight German equatorial mount is equally suited for use in the field or permanently installed in an observatory.

EQ8-R Pro Mount

U.S. Price: $4,050 (equatorial head and counterweights)

skywatcherusa.com

What We Like

Extremely solid mount

Accurate tracking and Go To performance

Very quiet slewing

What We Don't Like

Needs better software for remote operation and use with planetarium programs

◀ Sky-Watcher's new EQ8-R Pro German equatorial mount has a rated capacity of up to 110 pounds and is equally suited for use in a permanent observatory setting or assembled in the field for portable use.

ALL PHOTOS BY THE AUTHOR

"WHAT TELESCOPE DID YOU USE?" someone called out as one of our astronomy club members projected a photograph of the Dumbbell Nebula on the screen during a show-and-tell session. "That's not the question to ask," came the reply. "What you really should ask is what mount did I use?"

That unexpected response was so spot-on that now, more than 50 years later, it still rattles around in my head whenever I hear someone ask what telescope was used to create a stunning deep-sky image. As a beginning astrophotographer, I quickly learned that a telescope's mount and drive system played more of a role in creating a successful long-exposure photograph than did the scope's optics. And with few commercial options available back then, most of the leading astrophotographers — Clarence Custer, George Keene, Alan McClure, and Henry Paul, to name a few luminaries — were building their own equipment.

Times have changed. Driven by the increasing interest in deep-sky photography that began in the 1970s and accelerated into the 21st century fueled by digital imaging, today there's an abundance of excellent commercial mounts tailor-made for imaging setups, whether they be as lightweight as a camera and lens or as massive as the largest observatory astrographs.

One of the newest mounts to enter the mid-heavyweight category is the EQ8-R Pro from Sky-Watcher, a company with a reputation for making quality products with attractive price tags.

The EQ8-R Pro is rated for equipment weighing up to 110 pounds (50 kg). It's also massive itself, with the equatorial head alone tipping the scales at 57 pounds, and the counterweight shaft and a pair of 22-pound counterweights adding a total of 52 pounds more. The optional tripod/pier ($950 when ordered with the EQ8-R Pro) weighs 65 pounds, and even the adjustable footpads for the tripod legs are a hefty 4 pounds each. This stuff is all solidly made.

The most obvious benefit of this weight is stability. The EQ8-R Pro proved to be an exceptionally good platform for astrophotography. And while it should be a no-brainer to think that any mount good enough for long-exposure imaging would be good for visual observing too, it took a pandemic to make that point to me beyond a shadow of a doubt. More about that later.

You'll find a full list of specifications for the EQ8-R Pro on the Sky-Watcher website, so I'll mention just a few here. The mount requires a power source that delivers between 11 and 16 volts DC with at least a 3-amp capacity, which means it will run fine off of a car battery. There's an optional polar-alignment scope ($160) that bolts onto the mount's declination-axis housing. But I've become a big fan of electronic polar scopes such as the PoleMaster from QHYCCD or the iPolar from iOptron, since they are fast, accurate, and don't require you to be a back-bending contortionist to use them.

The EQ8-R Pro equatorial head has very robust adjustments for azimuth and especially altitude when doing polar alignment. They worked smoothly even when the mount was loaded with a telescope and counterweights, which is my preferred configuration when dial-ing in polar alignment to avoid possible changes due to flexure when weight is added or removed from a mount.

Sky-Watcher does not give a value for periodic error of the approximately 7-inch diameter, 435-tooth right-ascension worm gear. But I measured the error to be less than 6 arcseconds one night when viewing double stars with a calibrated reticle eyepiece. The tracking was very smooth and free of sudden jumps that might compromise guiding. I made several dozen 10-minute autoguided exposures without a single one showing guiding errors. And all but a few of my dozens of 2-minute unguided exposures were successful. I have no doubts that the mount will meet the demands of today's deep-sky photographers guiding manually (does anyone still do that?) or with an autoguider.

For people wanting to push the limits of unguided exposures, the EQ8-R Pro is available with a high-resolution Renishaw encoder on the right-ascension axis that should reduce periodic error well into the sub-arcsecond range. It's a $3,050 option.

▲ The author made this view of the Christmas Tree Cluster and Cone Nebula in Monoceros with a 200-mm f/3 astrograph and CCD camera. It was assembled from a dozen 10-minute autoguided exposures with the EQ8-R Pro mount.

Cables and Electronics

The EQ8-R Pro has an internal cable-management system for equipment mounted on a telescope. This can eliminate most loose wires hanging from a telescope that could snag on a moving mount. There are input ports on the fixed end of the polar-axis housing for power, USB 3.0 (connected to an internal USB hub), and RJ10, RJ12, and RJ45 modular jacks (the RJ45 jack is for 8-pin Ethernet cables). On the sky end of the telescope saddle there are three power output ports and four powered USB 3.0 ports, while the other end of the saddle has the corresponding output ports for the modular jacks.

As nice as this cable-management system is for electronic equipment on a telescope, the EQ8-R Pro does require some wires to be attached to the declination-axis housing, which is fixed relative to telescope moving in declination and also moves as the polar axis rotates. These are for the mount's main power input, SynScan hand control, autoguider input, and a USB cable if you want a hard-wire connection between the mount and a computer. Recently Sky-Watcher introduced a $65 WiFi

▲ *Left:* The mount's polar alignment can be precisely adjusted with heavy-duty controls on the azimuth and altitude motions of the polar axis. *Right:* While the EQ8-R Pro has an optional polar-alignment scope available, the author used its mounting cap screws to attach his QHYCCD PoleMaster to electronically dial in the mount's alignment.

adapter that replaces the need for the USB cable (see page 63 of last August's issue). The declination-axis housing also has the power on/off switch with a rather bright, red LED indicator, and a "snap" port for a remote-release cable that will operate Canon EOS cameras via the hand control or through the USB computer connection.

The SynScan hand control is the most straightforward way to operate the EQ8-R Pro as a standalone mount. But there are also free software apps that run on Windows computers and Android devices (for USB and WiFi connections to the mount) and iOS devices (for WiFi only). I tested only the Windows version running on a laptop.

The SynScan has most of the features and databases that have become pretty much standard fare for Go To telescopes. The manual does a good job explaining the hand control's setup and operation with one small exception that I encountered in the beginning. Initialization starts with entering date, time, and location, all of which remain in the controller's memory for future use with the exception of the time, which always defaults to 8 p.m. on power up. This means you only have to change the date and enter the correct time when you start the mount on another night, assuming your location is the same. If you're into luxury, there's a $175 GPS module that plugs into the SynScan controller and will update the necessary

◀ The SynScan hand control has illuminated buttons and a backlit LCD panel that's easily visible at night or in full daylight.

information each time you power up the mount.

Sky alignment of the mount begins by sending the mount automatically to its home position, which places the telescope above the polar axis and aimed at the celestial pole. And from there you perform a 1-, 2-, or 3-star alignment. The more stars you use, the better the Go To pointing accuracy is if the mount is only roughly polar aligned. Since most of my testing was done with the mount accurately polar aligned in my observatory, a 1-star sky alignment was always sufficient. Furthermore, since I usually shut down the mount with a park command, no alignment was needed when I powered up on the next night and resumed observing from the parked position.

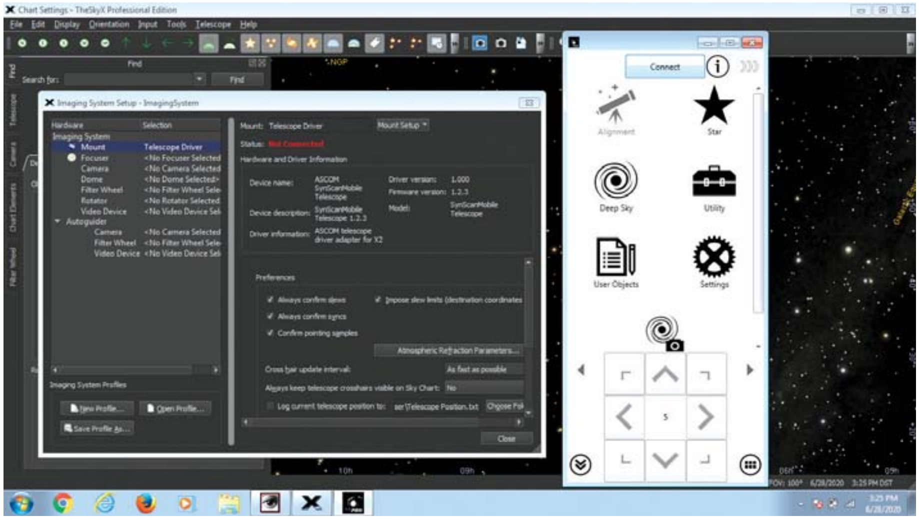
As for that bump in the road during my first sky initialization, it was the question "Renew H.P.O.?" that appeared on the SynScan display after I finished my star alignment. There was no mention of that in the manual. I simply selected "no" as my answer and went about my observing. Later I noodled out that H.P.O. stands for "home position offset," and it enters a correction (if needed) to correlate the aim of your telescope with the mount's fixed home position. This makes the mount's pointing very accurate when you start from the home position — an important feature if the mount is operated remotely.

The Windows app worked well, and it does offer some features that are not available with the hand controller. But by itself the app offered little advantage for observing over operating the mount from the SynScan controller. Furthermore, the controller has more catalogs of celestial objects and is thus better for Go To observing. One advantage of the app that I did use occasionally was the option of selecting Venus as a daytime alignment "star" when initializing the

mount if I wasn't starting from a parked position. The SynScan hand controller only lists stars for alignment, albeit many can be seen (and thus used) in a clear daytime sky, especially given the mount's accurate Go To pointing starting from the home position.

The app's real utility is its ability to allow control of the mount from a planetarium program. Indeed, it's the *only* way to do this, since there is currently no software for direct control of the mount from planetarium programs. The process of getting everything running is somewhat clunky, and the features, unfortunately, are limited.

I tested the app with Software Bisque's *TheSkyX* Professional running on my laptop. This required having the ASCOM Platform installed on my computer as well as installing the SynScan ASCOM driver that is available for free from the Sky-Watcher website. In a nutshell, I first launched the *SynScan Pro* app and connected it to the mount, and after completing a star alignment with the app I'd launch *TheSkyX* and connect it to the app. This let me select objects and issue slew-to commands to the mount from *TheSkyX.* But that's about all you can do. If you want to do something even as simple as nudging the scope to center an object, you have to toggle back to the app and use its move "buttons" rather than using controls in *TheSkyX.* Not exactly ideal.



▲ Operating the EQ8-R Pro from a computer requires launching the *SynScan* app (white box) and establishing a connection to the mount. Then it's connected as an ASCOM device to planetarium software such as *TheSkyX* shown here and tested by the author.

With some effort I was able to use this configuration to run the EQ8-R Pro remotely via the conventional method of connecting to the computer controlling the mount with remote-desktop software (*TeamViewer,* for example) running on another computer. Sky-Watcher's Kevin LeGore tells me that the company is working on software that will allow direct control of the EQ8-R Pro from planetarium software. That's good news, since in my opinion the EQ8-R Pro has all the mechanical features needed to make it a great mount for remote operation.

The mount performed extremely well during my tests, and I encountered only a few minor issues worth noting. One is that occasionally when sending the mount to the home position or when slewing between objects, a telescope can briefly point slightly below the horizon. This might present problems for optics that aren't fully restrained (think of a Dobsonian with a primary mirror in an unrestrained sling mount). Sometimes when using the hand control's direction buttons to center an object, the mount would briefly continue to move after I released a button. It was never an issue when guiding, only when using the faster centering slew speeds. I've also experienced this issue with other Go To mounts. It's mildly annoying, but not a showstopper.

Unlike most of the Go To mounts I've tested, the SynScan controller does not have a "synchronize" feature that lets you realign the pointing to a given object while observing. It does, however, have a nice feature, especially for a mount set up permanently, called "Pointing Accuracy Enhancement." It divides the sky into 85 small sections and remembers any corrections needed to center objects within a section and apply them to future Go To slews to that part of the sky. This would nicely compensate for telescope flexure that varied for different parts of the sky.

◀ Described in the accompanying text, the EQ8-R Pro has an internal cable-management system for power, USB 3.0, and modular-jack cables. Input ports (far left) on the fixed end of the polar-axis housing have corresponding outputs on the declination saddle (middle, only one end shown). The mount's power, autoguider, and computer USB connections (left) are on the side of the declination-axis housing.

The Pandemic Factor

How the coronavirus pandemic affected this test report would be an article in itself. But here's the short version. For this review we borrowed one of the first production models of the EQ8-R Pro from Sky-Watcher with the provision that it be returned for display at the Northeast Astronomy Forum (NEAF) in early April. With a relatively short schedule for testing, I set the mount on an existing pier in my backyard observatory, where I could quickly respond to New England's fickle winter weather. All went well, and the testing was finished by the beginning of April. But by then NEAF was cancelled because of the pandemic. There was no immediate way to return the mount given that the shipping boxes were locked up in *Sky & Telescope*'s shuttered offices.

With Massachusetts in a virtual shutdown, I suddenly had free time on my hands, which I used to dust off some back-burner astronomy projects, including modifying and testing several imaging setups. The EQ8-R Pro was the perfect platform for these projects, with its heavy-duty capacity, accurate pointing, and smooth tracking. I was only interested in image quality, so short, unguided exposures sufficed, and the mount handled them nicely.

But it was another project (one that had languished in the recesses of my thoughts for more than 40 years) that gave me the best appreciation for how well the EQ8-R Pro performs for visual observing. I spent many late spring and early summer nights using a home-made 6-inch refractor to follow in the footsteps of England's Admiral W. H. Smyth, observing the objects he viewed with a 6-inch refractor and described so poetically in his 1844 *Bedford Catalogue*. Many were double stars that required high magnifications, and having a solid mount that didn't jiggle when focusing was a real joy, and the accurate Go To pointing was a plus for identifying many of my targets.

I have little doubt that the EQ8-R Pro will satisfy the needs of astrophotographers and visual observers alike. And with the anticipation of updated software for control of the mount via third-party planetarium software, the EQ8-R Pro is sure to be a contender in the realm of mid-heavyweight mounts suitable for remote operation.

▲ The author's 6-inch refractor (made with parts cannibalized from other scopes) and the EQ8-R Pro helped launch an observing project that was more than 40 years in the waiting.

■ Senior Contributing Editor **DENNIS DI CICCO** often spends clear nights testing equipment from his backyard observatory in Boston's western suburbs.

◀ *Far left:* The optional tripod/pier for the EQ8-R Pro is a substantial piece of hardware, weighing 65 pounds. It can vary the height of the EQ8-R Pro's base between approximately 30 and 40 inches above the ground.

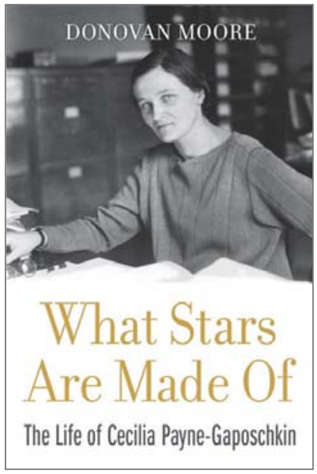
◀ *Left, top:* Adjustable footpads that assist with leveling the tripod/pier have a non-slip rubber ring on the base and a locking collar on the elevation jack screw.

◀ *Left, bottom:* Plastic pads and a center bolt (turned by the green hand knob at left) make for smooth operation of the EQ8-R Pro's azimuth motion when polar aligning the mount on the tripod/pier.

Discovering the Secrets of Stars

WHAT STARS ARE MADE OF: *The Life of Cecilia Payne-Gaposchkin*

Donovan Moore
Harvard University Press, 2020
320 pages, ISBN 9780674237377
$29.95, hardcover



SOMETHING WAS WRONG.

So Donovan Moore sets the stage, at the start of *What Stars Are Made Of*, for the story behind one of astronomy's greatest discoveries: that stars are overwhelmingly made of hydrogen and helium, with the heavier elements of planets and people little more than seasoning in the star soup. Moore's apt title for his biography of astrophysicist Cecilia Payne-Gaposchkin captures both her working out of the elemental makeup of stars and her strength of character, which propelled her into the firmament of professional astronomy.

Moore engagingly narrates Payne-Gaposchkin's path, which some people cautioned her from the outset was pointless for a woman. From its first stirrings to her discovery of star stuff and beyond, her exultant ambition to find things out shines through. "I shall never be lonely again," she once wrote. "Now I can think about science!"

Quotations from autobiographical notes and from her friends, family, and colleagues inform Moore's chapters.

> What stars are made of is crucial to astrophysics and cosmology. What scientists are made of is no less fundamental.

The result is a lively personal picture, studded with vignettes of numerous famous and influential figures. We share joyful first realizations that she was "develop[ing] the spirit of a scientist" — and the unhappy one that a woman's path to becoming an astronomer must start, at least in her case, with leaving England. She did — for Harvard, and Harlow Shapley. I was struck by how serendipity brought together Payne-Gaposchkin's experimental rigor, learned at the University of Cambridge's Cavendish Laboratory, with Harvard Observatory's vast collection of stellar spectrograms. It was a meeting that fate would not ignore.

From there it was all Payne-Gaposchkin herself, convinced that she had something big by the tail, illustrating Pasteur's dictum that "chance favors only the prepared mind."

The book's title encapsulates her 1925 doctoral thesis on quantifying the elements in stars. It was a bravura performance, which has been called "the most brilliant PhD thesis ever written in astronomy." Payne-Gaposchkin upended the entrenched *uniformitarian* view of stars as hot versions of planets, including multiplying hydrogen's share in the stellar recipe by a million!

Moore emphasizes her drive to follow the science to its indisputable conclusion: "Once I worked for 72 hours straight without sleep." Confident as always, Payne-Gaposchkin conceded to pressure from colleagues only by couching her findings as "almost certainly not real" — but only after boldly asserting them. Even so, their significance was widely discounted until Henry Norris Russell (of *Hertzsprung-Russell diagram* fame) verified them four years later.

One might suspect sexism in how astronomers remained unconvinced until *a man* had verified Payne's findings. But as Moore points out, any lone PhD candidate calling for a wrenching paradigm shift, one based on fiddly conjuring with spectrograms and the unfamiliar *Saha ionization equation* (developed in 1920 by Indian astrophysicist Meghnad Saha), would be sailing into stiff winds. Recognition did eventually come, though, and Russell explicitly acknowledged Payne-Gaposchkin's prior work.

Of numerous influences in her life, two stand out in Moore's telling: Arthur Eddington at Cambridge, inspiring and informing her decision to become an astronomer ("he . . . opened the door of the heavens to me"); and the not entirely benevolent Shapley, who exploited Payne-Gaposchkin's gender even as he mentored her. Nevertheless, she thrived: After earning Radcliffe College's first astronomy PhD, she remained at Harvard for a career that culminated quite satisfactorily, as scientist and as department chair, though Moore devotes relatively few pages to this greater part of her life.

What stars are made of is crucial to astrophysics and cosmology. What scientists are made of is no less fundamental to the human endeavor of science. Anyone fascinated by astronomy, scientific discovery, or the sociology of science should find appeal in this fascinating and illuminating story of what stars — Cecilia Payne-Gaposchkin among them — are made of.

HOWARD RITTER is a hematologist by day and astrophysics spectator by night.

An 8-inch f/3.3 Masterpiece

Some works of art are worth the wait.

WHEN HOWARD BANICH HEARD that the Tele Vue Paracorr provides good field correction down to f/3.5, his first impulse was to grind an f/3.5 mirror and see how well it really worked. He overshot a little and wound up with f/3.3, but as he says, "What the heck, the mirror was an experiment anyway. The biggest thing I learned is that f/3.3 is way more difficult than f/4." But yes, the Paracorr worked well even at that fast focal ratio, so Howard set out to build a scope around his new mirror.

That was about 25 years ago. Three mounts and one refiguring later, the scope is finally a joy to observe with.

His first mount was a basic Dobsonian, but it was so short that it was more of a tabletop scope than a serious observing scope. Its diminutive size inspired its second incarnation as a travel scope, with a secondary cage on one end and a primary mirror cell on the other end of a single arm that pivoted at the balance point. That mount was a failure, too, in that the one-armed attachment put too much stress on the altitude bearing for it to handle, and it also torqued the azimuth bearing so both axes were stiff.

The third time is often the charm, though, and in this case that certainly proved true. Howard went back to a more traditional two-bearing Dobsonian altitude motion, but he built it into a beautiful, tall rocker box that not only puts the scope at a comfortable viewing height but also houses the entire optical tube assembly for storage.

The OTA is a 30-inch length of Hastings aluminum irrigation tubing with the ends rolled for extra rigidity and comfort. One nice thing about an f/3.3 system is that Howard could leave a lot of extra tube up front for additional light baffling and still have a relatively short scope. He also lined the inside of the tube with 2-mm black EVA foam sheeting, using two-sided carpet tape to hold it in place. The extra tube length and dark interior provide excellent contrast at the eyepiece.

One problem with such a short OTA is that it doesn't provide as much leverage as a longer scope would, so Teflon on laminate makes the bearings too stiff. Howard solves that problem by using only one Teflon pad per bearing and using roller bearings for the other contact points. Aluminum strips and an aluminum plate give the roller bearings a hard surface to ride on and provide just the right amount of friction with the single pad of Teflon per bearing.

◀◀ Howard Banich's 8" f/3.3 telescope is as functional and fun as it is beautiful.

◀ The optical tube assembly fits completely inside the rocker box, and the finder and Sky Commander controller store away inside the base extender.

HOWARD BANICH (2)

▲ The azimuth bearing uses two roller bearings and one Teflon pad to achieve smooth motion with such a short lever arm. The altitude bearings have one roller and one Teflon pad each.

HOWARD BANICH

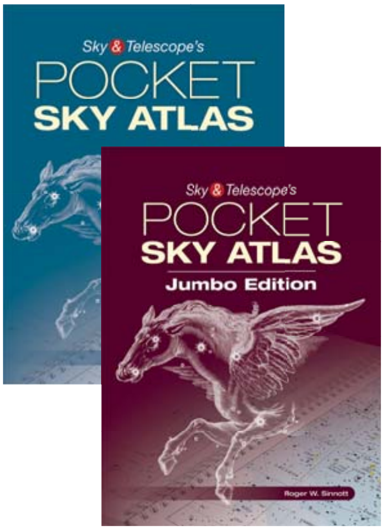
The rocker box looks at first glance like it might be metal, but it's actually just half-inch plywood stained black. It's cheap, lightweight plywood — another experiment to see if its lighter weight than the more traditional Baltic birch would compromise the scope. It didn't, but Howard reports that it was difficult to work with because of all the voids that were exposed when making cuts.

When he finished the scope, he discovered that it was still too short for comfortable viewing. Also, the scope was a bit top-heavy. So he built a wide base extension out of two more circles of inexpensive plywood and some 2 × 4s. He didn't stain them because he wanted the scope's base to be easier to see in the dark. And bonus: The space inside holds the plastic bin to store the finder, Sky Commander, its base, and power cord.

Sky Commander? Uh-huh. Even with the extender, bending down to look through a Telrad or even a right-angle finder was a literal pain. So Howard installed digital setting circles, and now finding stuff is a breeze.

Perhaps not surprisingly, a scope this beautiful and easy to use became the favorite scope of Howard's wife, Judy. They both enjoy using the scope whenever they get the chance. Howard says, "The smooth movements this third incarnation provides, along with the easily accessible eyepiece, make observing as pleasant and rewarding as I'd hoped. Finally."

■ Contributing Editor **JERRY OLTION** appreciates function first, but a beautiful form is a close second.



◀ UPDATED SKY ATLASES

Sky & Telescope has published new editions of our popular *Pocket Sky Atlas* ($24.95 for the 6 × 9-inch version and $41.95 for the 8 × 11-inch Jumbo edition). Both feature 80 charts covering the entire celestial sphere, with more than 30,000 stars down to magnitude 7.6. The atlases also contain 1,500 carefully chosen deep-sky treasures, including all galaxies brighter than magnitude 11.5, globular clusters brighter than 10.5, planetary nebulae brighter than about 12, all leading bright and dark nebulae, and all of the popular Herschel 500 list. Also indicated are good visual double stars, significantly variable stars, and a selection of deep-red carbon stars. In addition, both atlases include 10 close-up charts of several dense regions in the Milky Way and other interesting regions of the sky. Each atlas is printed on water-resistant paper, and the Jumbo edition includes a hard cover. 136 pages, spiral bound. ISBN 978-7350644-0-6; Jumbo Edition ISBN: 1-735064-41-3

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▲ DELUXE FINDER

Tele Vue updates its premier unit-power finder, the Starbeam with Quick Release base for Tele Vue telescopes ($275). Starbeam uses a red dot illuminator combined with its generous 40-mm glass lens to let you see the unamplified natural sky with a 10-arcminute collimated "red star" superimposed on the field. The unit's unique flip mirror permits comfortable viewing of the field lens at most any angle. The addition of the Tele Vue Quick Release Backet and Tele Vue Dovetail allows you to move the finder to another telescope or to store it without worrying about realignment. The dovetail is compatible with mounting shoes produced by Orion Telescopes & Binoculars and Sky-Watcher. The Starbeam finder includes knurled X-Y adjustment screws for precise alignment.

Tele Vue Optics
32 Elkay Dr., Chester, NY 10918
1-845-489-4551; televue.com

▲ SUPER-WIDE BINOS

Orion Telescopes & Binoculars unveils an unusual pair of binoculars. The Orion 2×54 Ultra Wide Angle Binoculars ($149.99) allow you to see sprawling star fields in the Milky Way and entire constellations at once. The optics are based on a modified Galilean design that includes extra lens elements to enhance the field of view and reduce aberrations compared with standard Galilean optics. Its 36° field of view and low magnification bring out stars about 1.2 magnitudes fainter than is possible with the naked eye, adding a new experience to meteor observing or seeing the extensive tails of bright comets. The interpupillary distance ranges from 60 to 81 mm, and each eyepiece focuses individually. The binoculars include individual lens and eyepiece covers and a nylon carrying bag.

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

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

DARK NIGHT IN THE PYRENEES
Jean-Francois Graffand
This scene of the Milky Way with bright Jupiter (right) is among the winning photos of the International Dark-Sky Association's Capture the Dark contest. See all the winning images at **https://is.gd/IDAcontest**.
DETAILS: *Modified Canon EOS 6D DSLR camera with 15-to-30-mm zoom lens. Total exposure: 20 seconds at f/2.8, ISO 10000.*

◁ COMET . . . MERCURY?

Andrea Alessandrini

The innermost planet has a tail! Mercury's closeness to the Sun and pressure from solar radiation combine to push neutral atoms away from the planet, causing a tail-like structure of mostly sodium atoms to trail away from the rocky world.
DETAILS: *Stellarvue SV66 refractor with Pentax K-3 II DSLR at ISO 1000. Total exposure: 7 minutes through an Edmund Optics 589-nanometer filter.*

▽ A RING OR A ROSE

Douglas Struble

This deep image of M57, the Ring Nebula, reveals its rarely seen outer shell, which was expelled from the central star centuries before the familiar bright inner ring more commonly seen.
DETAILS: *Explore Scientific ED 165-FPL53 and ED152 refractors with ZWO ASI1600MM-Pro and ASI1600MM-Cool CMOS cameras. Total exposure: 30½ hours through LRGB and narrowband 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.

BRILLIANT VISITOR
Kerry-Ann Lecky Hepburn
Comet NEOWISE (C/2020 F3) blazes through the dawn sky over Toronto, Ontario on July 5th.
DETAILS: *Canon EOS 6D DSLR camera with 100-to-400-mm lens at 160 mm. Panorama of several 1-second exposures at f/7.1, ISO 3200.*

△ DISAPPEARING ATLAS
Chris Schur
While predicted to put on a good show at the end of May, Comet ATLAS (C/2019 Y4) broke apart in mid-April, producing the elongated, diffuse nucleus seen above.
DETAILS: *Orion 10-inch f/3.9 Newtonian Astrograph with SBIG ST-10XE CCD camera. Total exposure: 72 minutes through LRGB filters, recorded on April 21.*

▷ INNER COMA
Debra Ceravolo
This high-magnification view of Comet NEOWISE (C/2020 F3) shows the greenish tint of cyanogen gas, several bow shocks of dust near the coma, and its bifurcated tail.
DETAILS: *Ceravolo 300 Astrograph at f/9 with SBIG Aluma 384 CCD camera. Total exposure: 3 minutes through RGB filters.*

▽ STANDING TALL

Constantine Emmanouilidi

This composite of Comet NEOWISE (C/2020 F3) includes 30 stacked 20-second exposures to better reveal vertical striations within its dust tail.

DETAILS: *Sony A7S Mirrorless camera with 70-to-200-mm zoom lens at 150 mm. Total exposure: 10 minutes recorded in Rodokipos, Greece on the morning of July 11th.*

▽ NOCTILUCENT NEOWISE

Jamie Cooper

The comet treated observers in the United Kingdom to a twin display on the evening of July 11th as it paired with shimmering waves of noctilucent clouds, seen here from Llanwddyn, Wales.

DETAILS: *Canon EOS 6D DSLR camera with 200-mm lens. Total exposure: 10 seconds at f/3.2, ISO 640.*

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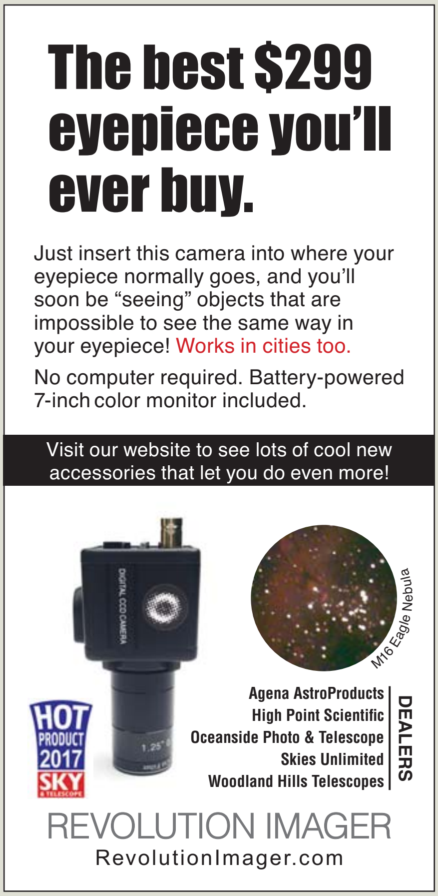

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ASTRO-PHYSICS 180 mm STARFIRE REFRACTOR: For sale is an Astro-Physics 180 mm EDT f9 Starfire refractor. Price includes refractor, guide scopes, other refractor accessories, eyepieces, and filters. Price, photos, and accessory list are available by emailing wallerfj@entermail.net

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

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FOCAL POINT by Christopher Smythies

It Takes a Village

Twenty-one amateurs form an observing community with plans to reach out to the public.

LEAH TISCIONE / S&T

FOR AMATEUR ASTRONOMERS living in the often-cloudy Seattle area, as I do, a dark-sky site within a few hours' drive is a dream. In 2018, 21 of us in the Pacific Northwest decided to make that dream a reality by establishing Goldendale Sky Village. Located on 30 acres of remote prairie land outside the town of Goldendale in south-central Washington, the site has Bortle Class 2 skies, a low horizon, few neighbors, and a view of Mt. Hood to boot.

We've organized the site into small telescope fields surrounded by lots. The shared fields promote social interaction, while the lots offer places to situate private observatories for in-person or remote use. Ultimately, we hope to share this new site with as many stargazers as possible, wherever they live.

We've completed what is perhaps the hardest part: finding the ideal parcel of land and the right people to get things started. Now we're working to improve basic infrastructure. This includes upgrading a ¾-mile-long access road to handle RV traffic, clearing a four-acre central telescope field, and building a network of gravel roads. We're working on a clubhouse and composting toilets. We have access to beamed broadband internet, and we plan to set up a rainwater-collection system and solar-powered battery exchange. So, not only will we be getting our photons from the sky but also our web, water, and electricity. A true sky village!

Transitioning from the basics to a must-see destination for dark-sky pilgrims is a process that we hope will take on a life of its own once the village's essential concepts are proven sound. The key is getting more people who love the night sky involved.

To this end, we aim to invite both the Seattle Astronomical Society and the Portland-based Rose City Astronomers to hold star parties at our village. If these events prove popular, we would explore the idea of holding our own annual, statewide star party. We also intend to conduct open houses, outreach to surrounding communities, and summer educational programs both on site and online. We hope these activities will attract new members beyond the original 21, whose capital contributions would help us further develop the village. This includes funding the Goldendale School of Astro Imaging (as we're calling it) and perhaps even a large-aperture telescope.

Looking ahead, we might even connect virtually with classrooms anywhere in the world and ideally bring the wonders of a dark sky to underserved students and others who have seen only the brightest stars and planets, if that. We would also encourage the founding of other sky villages around the U.S. or even in the Southern Hemisphere. A reciprocal agreement among such sites would make it much easier for people to travel from one to another.

In short, we have no shortage of dreams! The challenge is to move beyond our initial concept and realize these additional hopes in time. It's a lofty goal, but we'll keep forging ahead. Given the rising enthusiasm everywhere for all things related to astronomy, Goldendale Sky Village feels like an enterprise whose time has arrived.

■ **CHRISTOPHER SMYTHIES** is a board-certified neurosurgeon who practices at Multicare Tacoma General Hospital in Tacoma, Washington.

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