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SKY & TELESCOPE

THE ESSENTIAL GUIDE TO ASTRONOMY

JANUARY 2021

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THE ESSENTIAL GUIDE TO ASTRONOMY

BOB KING

January 2021

VOL. 141, NO. 1

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ON THE COVER

Barred spiral galaxy NGC 1398
PHOTO: ADAM BLOCK / MOUNT LEMMON SKYCENTER / UNIVERSITY OF ARIZONA

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Find out what the sky looks like for your time and place. You can also print the chart as a handout.
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New Year's Resolutions

THE TURN OF A NEW YEAR is a good time to turn over a new leaf. With this is mind, we're introducing three new columns and a few other changes with this issue. Collectively, they will help optimize our observing coverage and ensure we're reaching the broadest range of readers. They should also make clearer the stepped approach our observing section takes, from naked eye to binoculars to telescope to *big* telescope. Plus, we're launching a new pro-am column. To wit:

Evenings with the Stars (page 45): This new column replaces Under the Stars. Fred Schaaf will still write it, but he'll concentrate on naked-eye stargazing. No binoculars or telescopes here, nor planets or moons — they're covered further on. Fred will direct his gaze solely at constellations and their stars.

Sun, Moon & Planets (page 46): We're also sharpening the focus of this long-running column. Rather than describe what all the planets as well as the Sun and Moon are up to, we'll zero in on a few standout celestial events each month. Consulting Editor Gary Seronik will tackle this job. To Fred Schaaf, we extend our deepest thanks and gratitude for so ably writing this column for 28 years.

STEVECOLEIMAGES / GETTY IMAGES

Suburban Stargazer (page 54): With many of our readers today coping with some degree of light pollution, this new bimonthly column, built along the lines of the newly retired Deep-Sky Wonders, will showcase deep-sky observing opportunities viewable from the city out to the suburbs. Long-time Contributing Editor Ken Hewitt-White will compose this one.

First Exposure (starting next issue): Written by multiple authors, this new department will alternate every month with Suburban Stargazer. As more and more hobbyists find themselves becoming interested in astrophotography, this piece will provide tips and tricks to help beginner imagers capture their first shots with basic equipment.

Pro-Am Conjunction (page 57): With the AAS now our parent organization, it's the perfect time to start reporting on the ever-increasing number of fruitful collaborations between professional and amateur astronomers. Observing Editor Diana Hannikainen will write this bimonthly column. She's ideally suited for the task, having worked as a professional astronomer in high-energy astrophysics for more than a decade before joining *S&T*.

Lastly, we swapped positions of the planet orbits diagram (now in Planetary Almanac) and the ecliptic chart (now in Sun, Moon & Planets).

Otherwise, all remains the same as you've come to expect it in *S&T,* including lots of dark-sky-site content. We hope you appreciate these enhancements — which, unlike most New Year's resolutions, we intend to keep.

Peter

Editor in Chief

SKY&TELESCOPE
The Essential Guide to Astronomy

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

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Impressive Handmade Eyepieces

Thanks to Jerry Oltion's article about building "Homemade Eyepieces" (*S&T:* Sept. 2020, p. 74), I scrounged four 35-mm binocular objective lenses and arranged them per his instructions. I placed the objectives in a metal tube (from a junked variable-power binocular), which sits in a PVC adapter that I shortened and joined to a standard eyepiece barrel. The resulting eye relief is significant, just as Jerry Oltion said, so I added a tall eyecup made from black foam sheeting that slips over the metal tube. It also helps shield the view from unwanted light sources. Quite frankly, I didn't think that the eyepiece's performance would impress me, but was I ever wrong! It had great light transmission, was sharp across the entire field of view, and didn't cause any eye strain. Now, if I could only find four 50-mm lenses . . .

Randy Strauss • Papillion, Nebraska

▲ Randy Strauss made this eyepiece *(left)* from four binocular objective lenses. A PVC adapter and eyepiece barrel help it sit nicely in his telescope *(right)*.

Matchstick Quick Fix

I doubt I am the first person to come up with this idea, but I stick a matchstick into the fine focus knob of my Crayford focuser.

It provides precise and vibration-free adjustment and makes a huge difference compared to turning the knob with both my finger and thumb. This way, I only need to touch it lightly with one finger. While using this matchstick, I can easily focus a star, even at high magnification.

I decided to try this because I had just started out in planetary imaging, and I needed something to improve my focus. But my new electric focuser was eight weeks away, while the opposition of Mars was in four!

Bill Wood
Melbourne, Australia

▶ The addition of a simple matchstick greatly improved this focuser.

BILL WOOD

A Moving Geosat

It was fun to read Steve Daubert's remarks about observing and photographing geostationary satellites in "Observing Geosat Flares" (*S&T:* Oct. 2020, p. 36). I made this discovery by accident decades ago. I was at a star party in Colebrook, Connecticut, hosted by the Astronomical Society of New Haven, looking through various telescopes to see what the more experienced amateurs had to offer. When I stopped at one to peer through the eyepiece, I must have moved it slightly from its previous target because what I saw blew me away.

There was a spaceship traveling steadily through the stars! No doubt about it. Contact!

I quickly motioned to the telescope's owner and called out to other observers to take a look. It took me an instant to infer that I was looking at a geosat. Since the telescope was tracking, it looked like the satellite was moving rather than the stars around it. Of course, the irony here is that the satellite is not moving in the sky relative to an observer on the ground.

It would be fascinating to work out the geometry of this kind of observation, but I'm not up to it. I'm happy just to have had the experience, and I encourage everyone to have their own close encounter with a distant geosat.

Joel Marks
Milford, Connecticut

Memories of M57

Reading the first paragraph in Howard Banich's fine article "The Ring and I" (*S&T:* Sept. 2020, p. 58) reminded me of my first look at M57 with my new 4-inch (102-mm) Criterion reflector in 1955. I was 12 years old and so proud that I'd found it that I ran up the steps to tell my mother and asked her to come down and look. Then I heard a crash. I looked back at the sidewalk and saw to my horror that the telescope had fallen over. Upon impact with the sidewalk, the focuser had punched through the tube, and the eyepiece was rolling down the street.

My mother never saw M57 that night. I eventually was able to repair the damage and get a few more years of enjoyment out of the telescope, including "discovering" Saturn. Wow!

Bill Dellinges
Apache Junction, Arizona

A Region by Any Other Name

While reading "The Andromeda Outback" by Ken Hewitt-White (*S&T:* Sept. 2020, p. 62), I sensed that I knew that region but under a different name. I opened my copy of *Field Book of the Skies* by William T. Olcott, Margaret W. Mayall, and R. Newton Mayall and turned to their entry on Andromeda. There was Ken Hewitt-White's Andromeda Outback, a little pattern of stars they called Gloria Frederika or Frederik's Glory. A Google search revealed that this grouping was named in 1787 by Johann Bode in honor of Frederick the Great of Prussia, who had died the previous year.

David A. Rodger
North Vancouver, British Columbia

A Timely Observing Project

I was just studying *S&T*'s wonderful Laminated Moon Map and 350-piece Moon Puzzle, along with Antonín Rükl's fabulous *Atlas of the Moon*, to finally learn the Moon well enough to spend an hour or two casually observing without constantly checking the map. I came upon a feature I had never noticed before: Palus Epidemiarum, the Marsh of Epidemics. It's an irregularly shaped lava plain in the Moon's southwest quadrant between and directly below Mare Humorum and Mare Nubium. Palus Epidemiarum includes craters Ramsden and Capuanus, as well as Rimae Ramsden, Rima Hesiodus, and other interesting features. It's a busy area of the Moon. Check it out!

P. J. Tramdack
New Castle, Pennsylvania

Residential Sky Village

In "It Takes a Village" (*S&T:* Oct. 2020, p. 84), Christopher Smythies encourages the founding of sky villages. Toward that end, we are working to create a residential astronomy community where people won't have to own property to live there. Mirador Astronomy Village (**miradorastrovillage.org)** will include a cohousing community, apartments, a shared house, and an RV park. Both full- and part-time residents will have the opportunity to provide astronomy experiences for our visitors and guests in exchange for pay or reduced monthly rent.

David Oesper
Dodgeville, Wisconsin

We Love the Lagoon!

I want to thank you for Howard Banich's "Swimmin' in the Lagoon" (*S&T:* Aug. 2020, p. 20). It's the most engaging writing about astronomy I've ever read. Well, perhaps some of Timothy Ferris's metaphoric paragraphs come close.

I read the article while comparatively viewing an image I captured of M8 from my humble 5.5-inch (140-mm) Schmidt-Newtonian Comet Catcher. I wish that I'd been able to read it while that image was stacking live onscreen. My first priority is to reread the article with the Lagoon Nebula above me.

Thank you so much for the effort and the art that brought M8 back into my heart and soul.

Gary Shaw
Auburn, Maine

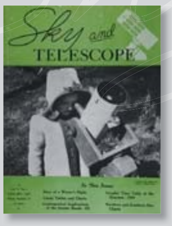
FOR THE RECORD

- In "Observing Geosat Flares" (*S&T:* Oct. 2020, p. 40), the correct direction of travel of the anti-solar point at night is east to west.
- "Mars at its Most Magnificent" (*S&T:* Oct. 2020, p. 47) should state that asteroid 8 Flora will be 130,000,000 km (80,778,255 miles) from Earth on October 31st.

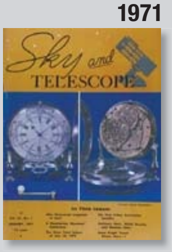
SUBMISSIONS: Write to *Sky & Telescope*, One Alewife Center, Suite 300B, Cambridge, MA 02140, USA or email: letters@skyandtelescope.org. Please limit your comments to 250 words; letters may be edited for brevity and clarity.

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

1946



1971



1996

January 1946

Plastic Lenses? "Optical plastics have been developed almost entirely under the impetus of wartime necessity; the story . . . has now been released . . . For the Army, a plastic 3-power anti-tank telescope with a 6-inch eye relief and 1-inch exit pupil proved a boon possible of immediate production in large quantity. . . .

"These optical plastics researches have been carried out under . . . Dr. Theodore Dunham, Jr., on leave from Mount Wilson Observatory. Although elements of plastic cannot be used for the precision required in astronomical instruments, the future may bring further improvements . . ."

Since they can be mass produced from a mold, plastic lenses have found wide use for eyeglasses and some low-cost camera lenses. But plastic scratches easily and changes with age. In large telescopes, glass is still king.

January 1971

X-ray Frontier "Early in 1960, rocket scientists at the U. S. Naval Research Laboratory obtained the first X-ray picture of the sun. . . . Now more than 40 discrete sources of celestial X-rays are known, as well as a diffuse X-ray background that covers the sky almost uniformly. . . .

"[But with] the first Small Astronomy Satellite (SAS-A) scheduled for launching December 12, 1970, [astronomers] expect to find hundreds of additional X-ray sources . . . The measurements of known and new X-ray sources are to include position, intensity, energy spectrum, and variations in strength from minutes to months."

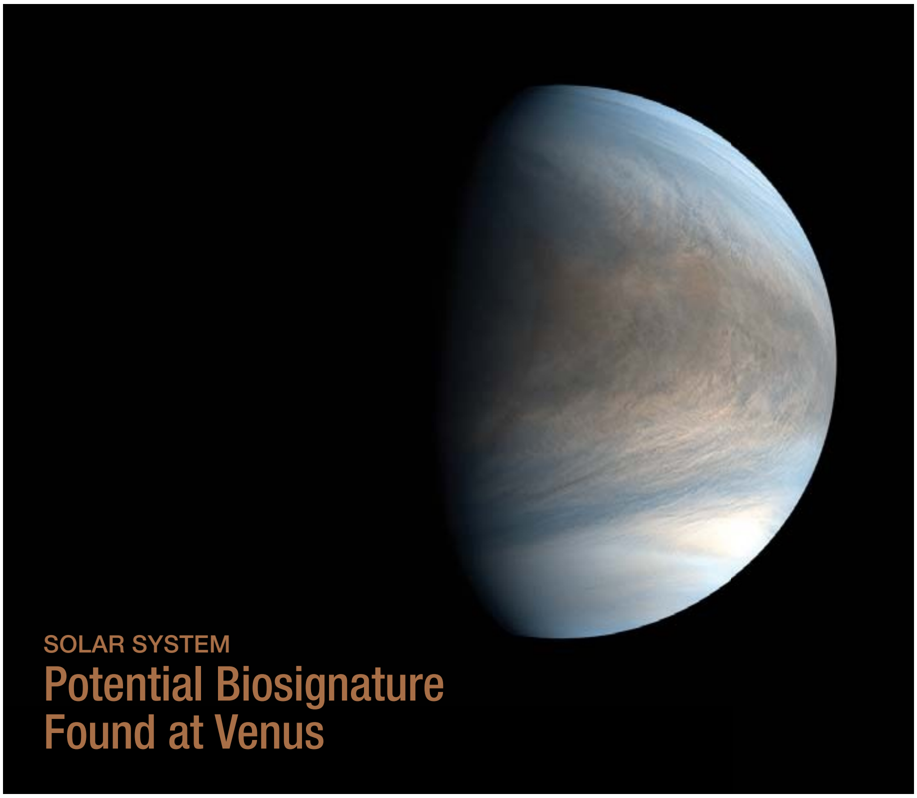
Renamed Uhuru once in orbit, this highly successful mission truly launched X-ray astronomy.

January 1996

Alien Eavesdroppers "Can spacecraft discern the existence of an intelligent civilization on our planet? From close range it's rather easy: reconnaissance satellites routinely spot all manner of structures and city lights from orbit. But distant spacecraft have to use less direct means. . . .

"NASA's Wind spacecraft . . . carries instruments for monitoring the solar wind [and one] detector, called Waves, [and] is sensitive to radio emissions [at] shortwave bands from 1 to 14 megahertz (MHz). [Signals from Earth] are most obvious when the spacecraft looks down on the planet's nighttime hemisphere [and they] leak outward into space.

"The spacecraft records a cacophony of transmissions at each wavelength. But a specific station can be identified if its broadcast occurs at an otherwise quiet time . . . Waves and its 15-meter-long antennas could detect Earth's radio broadcasts only as far away as the asteroid belt. By contrast, our strongest signals, from the phased-array radars of ballistic-missile warning systems, carry for many light-years across interstellar space."



SOLAR SYSTEM

Potential Biosignature Found at Venus

▲ Akatsuki captured ultraviolet light from Venus's dayside in this 2016 image.

AN INTERNATIONAL TEAM of researchers, led by Jane Greaves (Cardiff University, UK), has announced the detection of *phosphine* — a gas potentially associated with life — in the relatively cool cloud decks of Venus.

Astronomers have previously found phosphine surfacing from the depths of Jupiter and Saturn, where the high-pressure, hydrogen-rich, and intensely hot environments provide the right conditions to make the molecule. But anaerobic microbes produce it in less extreme places on Earth, too.

As reported September 14th in *Nature Astronomy*, Greaves and her colleagues observed Venus first in 2017, with the James Clerk Maxwell Telescope (JCMT), then again with the Atacama Large Millimeter/submillimeter Array (ALMA) in 2019. They found a chemical fingerprint of phosphine at a wavelength of 1.123 millimeters, at which the molecule absorbs thermal radiation coming from clouds lower in the planet's atmosphere.

The team investigated numerous possible abiotic sources for phosphine, including geological activity, meteorite impacts, and lightning. Although the detection indicates only trace amounts of the gas, around 20 or 30 parts per billion, none of the scenarios explored could account for it.

PHOSPHINE AS BIOSIGNATURE

In its pure form, phosphine is a colorless, odorless gas made up of one phosphorus and three hydrogen atoms. It is flammable at room temperature and highly toxic, which is why it is produced mainly as a fumigant and occasionally used as a chemical weapon.

But in the 1990s, Dietmar Glindemann (University of Leipzig) showed that it was also a naturally occurring part of Earth's anaerobic biosphere. His research led to the discovery of phosphine-producing microbes.

Quantum astrochemist Clara Sousa-Silva (MIT) and colleagues researched the compound's potential as a biosignature gas on rocky exoplanets as part of the All Small Molecules project. It was this work that caught Greaves's attention; the theorists and observers joined forces in December 2018.

Phosphine absorbs light at other wavelengths, too, but the spectral transition that Greaves's team observed with JCMT and ALMA is by far the easiest absorption line to see from Earth.

Looking into Venus's atmosphere to find the subtle signature was not easy, though, as the planet is bright and almost fills ALMA's field of view. Anita Richards (Manchester University), the team's ALMA liaison, helped Greaves's team with the long and intricate process of data reduction.

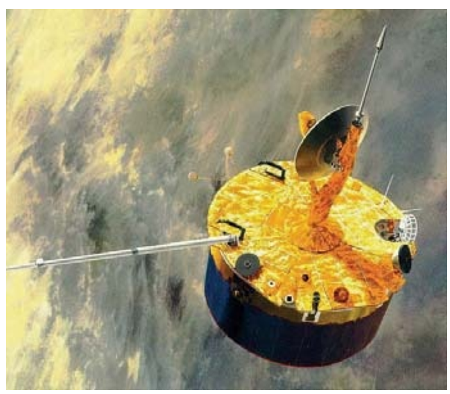
When the result first came out, David Grinspoon (Planetary Science Institute), who was not involved in the project, predicted it would be contentious. "People will look very critically at this, as they should," he said. "We don't want to jump to the wrong conclusion about something this important." (Read more from Grinspoon on page 15.)

CONFIRMING PHOSPHINE

The team is confident in the analysis but agrees that additional observations are needed. As the discovery is based on the detection of a single absorption line, additional spectral lines would verify phosphine's presence.

However, the thickness of the Venusian atmosphere and the general propensity for molecular signals to get tangled up with each other both hinder remote detections — and make a good case for a mission to our sister planet.

A direct observation made within the atmosphere would be ideal because the



▲ Pioneer Venus hovers above the planet in this illustration.

UV IMAGE OF VENUS: JAXA; PIONEER VENUS: NASA signal could be amplified. Moreover, in-situ instruments could identify multiple wavelengths at which the molecule absorbs light.

There are several proposals for missions to Venus, but not all of them would be able to detect phosphine. Two of NASA's four Discovery Program finalists, DAVINCI+ and VERITAS, would send missions to Venus as early as 2026. VERITAS would carry instruments with high spatial resolution but moderate spectral resolution — probably not good enough to see phosphine.

DAVINCI+, on the other hand, would carry an entry probe that would measure the atmosphere's composition as it floats down to the surface. The tunable laser spectrometer the probe will carry could in theory detect phosphine.

The European Space Agency's EnVision orbiter, proposed for launch in the early 2030s, would have a mass spectrometer in its payload, but it's unlikely that it would be able to detect the gas.

In addition, NASA's Venus Flagship Mission Study has proposed a combined orbiter-balloon-lander mission, which could launch in the 2030s if approved. "The balloon will explore the cloud layer for two months, with specific instruments designed to detect biological material if present," says Colin Wilson (Oxford).

A spacecraft could arrive at Venus even sooner with a private venture: Rocket Lab, an aerospace manufacturer and smallsat launch service provider, has announced that it is planning a Venus mission that could fly by 2023.

While future exploration will provide more definitive evidence, legacy data from NASA's Pioneer Venus mission, which launched in 1978, appear to support phosphine's presence.

That mission's entry probe carried a neutral mass spectrometer, which analyzes gases in situ to suss out their elemental composition. In a new analysis of the 42-year-old data, Rakesh Mogul (Cal Poly Pomona) and colleagues find evidence of phosphine, as well as other molecules such as methane and ammonia. The study was posted on the arXiv astronomy preprint server.

NASA GODDARD

▲ Artist's concept of the DAVINCI+ mission's probe descending through Venus's atmosphere

TIME WILL TELL

As for whether the phosphine on Venus is really a biosignature, that remains to be seen. For starters, even in the relatively cool cloud decks, life would still have to endure an environment that's around 90% sulfuric acid.

"My gut tells me an unknown photochemical process is going on," says team member William Bains (MIT). "I think the chances of there being life on Venus are very small."

Indeed, chemistry labs across the globe are already investigating possible inorganic production routes, to see if anything besides life could account for the molecule's presence in Venus's atmosphere.

Sousa-Silva is similarly cautious. "My science tells me the detection is true, but it's pretty wild," she says. "I hope that everyone will get their models running and try and find alternatives that explain this."

"I have reached the limits of my knowledge," she adds, "and I welcome the rest of the scientific community to join in the fun."

■ ARWEN RIMMER

● Read more: https://is.gd/phosphine.

IN BRIEF

More Underground Lakes on Mars

New analysis of data from the European Space Agency's Mars Express orbiter strengthens the case for super-salty lakes under Mars's south polar cap, first discovered in 2018 (*S&T:* Nov. 2018, p. 8). Sebastian Lauro (Roma Tre University, Italy) and colleagues reported the result September 28th in *Nature Astronomy*. Using a new analysis technique on 134 radar images taken over 10 years, the researchers not only confirmed the probable presence of an underground lake, they found that it has friends: The "large body of water [is] encircled by patchy water pools or wet areas of smaller extent," they write. The largest putative lake is about 20 by 30 kilometers (12 by 19 miles); the smaller patches appear as 5- to 15-kilometer-wide spots. The nature of the lakes remains a matter of speculation: To maintain liquids in a place where temperatures might reach as low as 150K (-120°C or -190°F), the water would have to be a hypersaline brine. Other researchers argue in favor of an additional heat source such as volcanism. Regardless of how liquids exist, the evidence for sub-ice liquid-water ponds has grown strong.

■ EMILY LAKDAWALLA

Read more: https://is.gd/Marslakes.

Amateur Discovers Kilometer-Wide Asteroid

Amateur astronomer Leonardo Amaral was scanning the skies on the night of August 27th when he picked up cosmic interloper 2020 QU_6, a kilometer-size asteroid. Amaral used a 12-inch reflector at the Observatório Campo dos Amarais near São Paulo, Brazil, recently upgraded to a stabler mount via a $8,443 Shoemaker NEO Grant from the Planetary Society. The asteroid's size is surprising given that astronomers have cataloged most large objects. However, Amaral's Southern Hemisphere vantage point gave him an edge, since the southern sky is sparsely covered by automated surveys. The asteroid orbits the Sun once every 3.4 years on an orbit that poses no current threat to Earth. It passed within 40 million kilometers (24 million miles, or more than 100 times the Earth-Moon distance) on September 10th.

■ DAVID DICKINSON

Read more: https://is.gd/2020QU6.

ASTRONOMY & SOCIETY

Wildfires Threaten Observatories

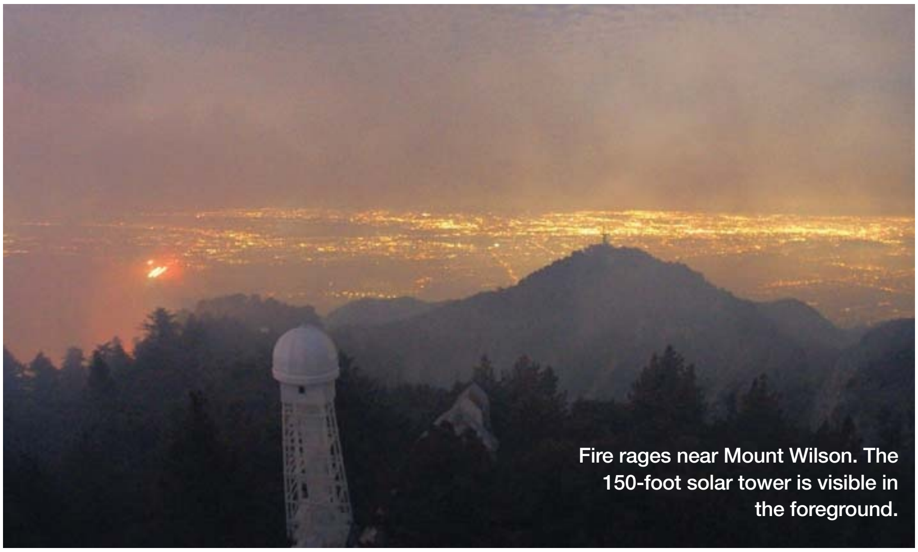
TWO HISTORIC OBSERVATORIES, Lick and Mount Wilson, have survived the worst U.S. wildfire season on record. The fires also threatened amateur observatories in the region — and devastated one of them.

The Santa Clara Unit (SCU) Lightning Complex Fire swept across the area east of San Francisco Bay, coming dangerously close to the Lick Observatory domes on August 19–20.

"We are tremendously thankful to the firefighters from all over California, whose courageous actions saved Lick Observatory," says director Claire Max.

The observatory, founded in 1876, escaped major damage, and no one was injured. However, a few residences — including the home of astronomer Edward Emerson Barnard — were lost.

Then in September, the massive Bobcat wildfire bore down on the historic Mount Wilson Observatory, founded in 1904 by George Ellery Hale. Local radio and television transmission towers, located on the peak and worth $1 billion, were also at risk. On the afternoon of September 15th, the fire approached within 150 meters (500 feet) of the observatory complex. By nightfall the worst had passed, though the fire took several more weeks to contain.



Fire rages near Mount Wilson. The 150-foot solar tower is visible in the foreground.

Fires also affected amateur observatories. Some escaped with smoke damage, such as the Sierra Remote Observatories. Others were not so lucky: The Tri-Valley Stargazers, an astronomy club in Livermore, California, lost their main observatory building to the same SCU Lightning Complex wildfires that came so close to Lick.

The Hidden Hill Observatory, donated to the club in 1983, was used for observing, research, astrophotography, and outreach events. Recently, the Tri-Valley Stargazers had even finished a two-year renovation project, including improvements to the building and equipment upgrades. When fire swept through the area, the club lost almost everything, including most structures and two custom-built telescopes.

However, the landowners made it out safely, and their home escaped the blaze. A small dome also survived unscathed. And within a month the Tri-Valley Stargazers had raised more than $30,000 to rebuild the observatory, likely another two-year project.

"I am overwhelmed by the support we've received so far from the community and from fellow stargazers throughout the world," says club president Roland Albers.

■ DAVID DICKINSON & SABRINA GARVIN

THE SUN

The Solar Activity Cycle Has Stabilized

SOLAR CYCLE 25 IS HERE, and predictions suggest that the next decade of the Sun's activity will mimic the last one — halting a four-decade downward trend.

The historical sunspot record shows an 11-year cycle, as the number of sunspots (and other solar activity) increases and then decreases again over that timeframe. While the timing is steady, the cycle varies in strength, and the Sun's behavior the last couple of decades has puzzled astronomers.

In September, NASA and the National Oceanic and Atmospheric Administration (NOAA) cosponsored the Solar Cycle 25 Prediction Panel. The international group of scientists declared December 2019 to be solar minimum, which in turn marks the beginning of Cycle 25. The scientists must average the sunspot number over 13 months to smooth out the Sun's variability, hence the delay between solar minimum and the announcement.

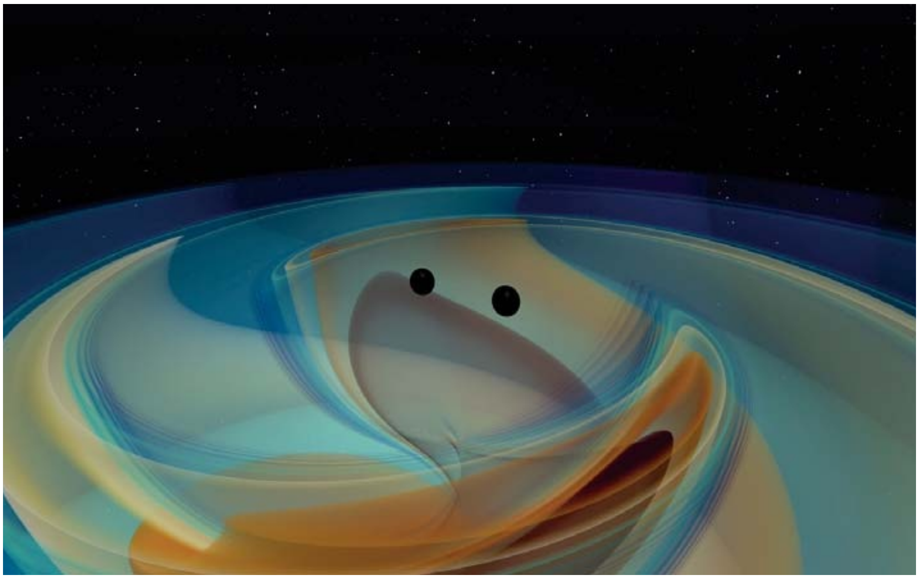
The panel also announced a consensus on forecasts for Cycle 25 — unlike the panel for Cycle 24, which was split. The current panel predicts the next peak in activity will come in July 2025, with 115 sunspots. That prediction, while weaker than average, is almost exactly the same as what actually occurred in Cycle 24: Activity peaked in April 2014 with 114 sunspots.

Cycle 25 should thus interrupt the trend of decreasing activity that has been going on for more than 40 years. Cycle 24 was the weakest cycle in 100 years (*S&T:* Nov. 2013, p. 10), and some had even speculated that the Sun could be approaching a largely sunspotless period. But the Cycle 25 forecast contradicts the notion that we are headed for a more profound change in solar magnetic activity.

HPWREN / MOUNT WILSON OBSERVATORY

BLACK HOLES

Most Massive Black Hole Merger Yet



▲ Gravitational waves radiate from two merging black holes in this simulation of GW190521.

THE LIGO AND VIRGO gravitational-wave detectors registered a brief burst of spacetime ripples on May 21, 2019, that confirms the existence of intermediate-mass black holes. It also provides astrophysicists with new insights on the growth of these cosmic gluttons.

The signal, cataloged as GW190521, originated when two black holes, 66 and 85 times the Sun's mass respectively, merged into a 142-solar-mass behemoth — the heaviest black hole ever found via gravitational waves. The analysis appears in the September 4th *Physical Review Letters*.

According to astrophysical wisdom, supernova explosions cannot produce black holes so massive. The progenitors would have suffered from a process called *pair instability*, which blows the star apart without leaving anything behind. So at least the 85-solar-mass black hole (and possibly the 66-solar-mass one as well) must have formed another way — perhaps through an earlier merger event.

The end result is the first reliable detection of a black hole with more than 100 (but less than 1,000) solar masses. Such intermediate-mass black holes (IMBHs) fill the gap between stellar-mass black holes and the supermassive versions found in galaxy cores. According to an accompanying report in the September 1st *Astrophysical Journal Letters*, GW190521 confirms that IMBHs can form via mergers — and that they might even be the missing link in supermassive black hole formation.

Crowded places such as globular clusters might allow series of mergers to take place. But Jay Strader (Michigan State University) points out that this process isn't likely to make supermassive black holes, because individual collisions tend to kick their merger products out of the very environment where additional mergers can occur. "My guess is that GW190521-like objects are not related to supermassive black hole formation," Strader says.

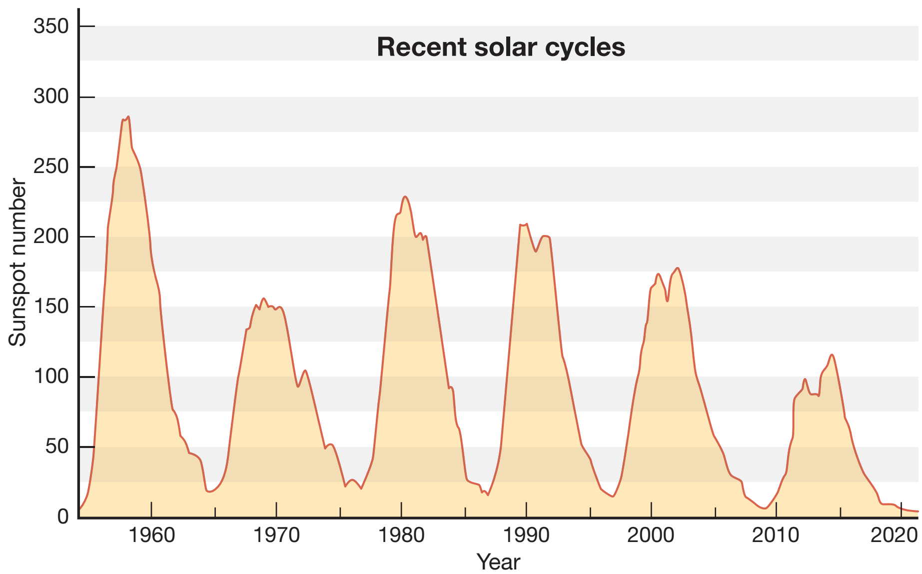
Jenny Greene (Princeton) agrees that all formation mechanisms have challenges. "No chance we will be lucky enough that all IMBHs could be formed via one process," she says. "That said, if we can determine that a series of black hole mergers can work, we have learned something very important."

■ **GOVERT SCHILLING**

Key to the new predictions was a realization that the Sun's hemispheres behave independently. In fact, Cycle 24 was weak in part because the northern hemisphere peaked two years before the southern one did.

Instead, monitoring the Sun's polar regions — specifically, the strength of the magnetic field there — turns out to be crucial to understanding how the next cycle will transpire. "The models we have the most confidence in have evolved significantly in the last decade," says panel co-chair Lisa Upton (Space Systems Research Corporation).

■ **MONICA YOUNG**



▶ Daily sunspot number for the past six cycles

COSMOLOGY

Hubble Images Reveal Dark Matter Problem

ASTRONOMERS STUDYING IMAGES of massive galaxy clusters have uncovered a potential problem with dark matter.

In the September 11th *Science*, Massimo Meneghetti (National Institute of Astrophysics, Italy) and colleagues present a new way of visualizing unseen dark matter in galaxy clusters — and their results contradict cosmological expectations.

Theorists have long known that dark matter isn't smooth. Instead, like a botched baking project, the dark matter halos that surround galaxies and clusters have lumps, or as astronomers term them, *subhalos*.

Simulations specify how many subhalos we might expect around the galaxies in a cluster. Some of them could have stars and be faintly visible as dwarf galaxies, while others might be entirely dark. In any case, most of them would be difficult to observe.

Meneghetti's team came up with a way around that. Because galaxy clusters are so massive, they act as gravitational magnifying glasses, lensing the light from background galaxies into arcs or multiple images. A galaxy cluster's mass may create images separated by several tens of arcseconds, but a subhalo in just the right place in the cluster might create additional images separated by less than a few arcseconds.

The team used detailed images and data from the Hubble Space Telescope and the European Southern Observatory's Very Large Telescope in Chile to examine several galaxy clusters and count the number of those small-scale lenses that subhalos make. Then they looked at what cosmological simulations predict.

To the researchers' surprise, the simulations predict far fewer halos than observed by a factor of 10. Try as they might to explain the difference, there were no easy answers.

Frank van den Bosch (Yale), who was not involved in the study, calls the results "potentially groundbreaking."

▲ An artist's impression shows small-scale dark matter clumps in MACS J0416.1–2403 *(left)*, compared to a visible image of the galaxy cluster *(right)*.

"The authors address all the 'obvious' candidates for what might explain this," he says. "I agree with them that none of them seem to be able to reconcile the large discrepancy found." He expects that follow-up studies would examine the abundance, structure, and other properties of dark matter lumps.

■ **MONICA YOUNG**

SOLAR SYSTEM

The Origin of Earth's Water

WE MAY FINALLY HAVE FOUND the missing source of most of Earth's water in a rare class of meteorites called *enstatite chondrites*.

These rocks come from the part of the protoplanetary disk in which the terrestrial planets formed. While the meteorites' composition resembles Earth's, astronomers had presumed them too dry to supply water. But a new analysis including the most pristine samples known shows that the original population could have supplied more than enough water to fill our oceans, Laurette Piani (University of Lorraine, France) and colleagues report in the August 28th *Science*.

Astronomers think Earth and the other terrestrial planets formed too close to the young Sun for water to condense. While water could have condensed out near Jupiter, beyond the snow line of the young solar system, it would have had to take a roundabout route to Earth. The leading candidate for water delivery in this scenario had been *carbonaceous chondrite asteroids* — rocky leftovers of the protoplanetary disk that formed beyond Jupiter. But these asteroids fail a crucial fingerprint test: They don't have the same ratio of isotopes as Earth's material does. Enstatite chondrites, on the other hand, have isotopic compositions that are nearly identical to those of Earth and the Moon. "We consider enstatite chondrites the best analog we have for Earth's building blocks," says Piani.

◀ An enstatite chondrite meteorite on display at the Royal Ontario Museum

Piani's team analyzed 13 samples of enstatite meteorites, finding traces of water that account for 0.08%–0.5% of the rocks by weight, with meteorites altered the least since their formation carrying the most water. That may not sound like much, but it adds up: Piani's group suggests enstatite chondrites could have supplied all the water in the mantle and most of the oceans, with the rest coming from wet asteroids.

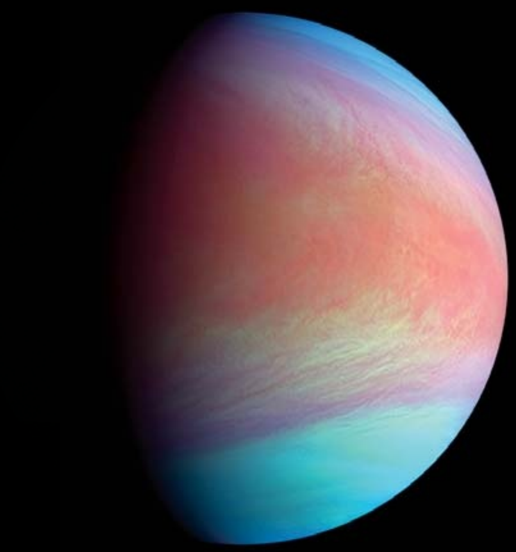
While enstatite meteorites provide water a more straightforward route to Earth, future research must address how the water originally came to be in rocks forming so close to the Sun.

■ **JEFF HECHT**

GALAXY VISIBLE VIEW: ESA / HUBBLE / NASA / HST FRONTIER FIELDS; ACKNOWLEDGEMENT: MATHILDE JAUZAC (DURHAM UNIV., UK AND ASTROPHYSICS & COSMOLOGY RESEARCH UNIT, SOUTH AFRICA) AND JEAN-PAUL KNEIB (ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE, SWITZERLAND);DARK MATTER VIEW: ESA / HUBBLE / M. KORNMESSER; ENSTATITE CHONDRITE: WIKIMEDIA COMMONS / CC BY 3.0

Venus Surprise

Will phosphine be the "Mars rock" of our sister planet?



▲ Japan's Akatsuki spacecraft captured this false-color image of Venus's dayside on July 23, 2016.

SCIENTISTS HAVE REPORTED phosphine, a candidate biosignature gas, on Venus! (See page 10.) Exciting, but what does this mean?

There are three possible outcomes. Least likely is that it turns out to be genuine evidence for life. But we can't rule this out and indeed must take it seriously as a viable hypothesis while we investigate further. That's worthy of excitement and wonder.

Barring life, phosphine may point to unknown chemistry in the Venusian atmosphere. This is important to understand if we hope to use biosignature gases to infer the possible presence of life on exoplanets.

Or, the detection could be shown to be false, as scientists scrutinize, repeat, and supplement the detection methods with further, less ambiguous techniques. The team that published this finding did careful, rigorous work, but it was a tricky analysis, and new research will confirm or reject it.

We've had false alarms before. A famous one was the "Mars rock" — the evidence for microfossils in the Martian meteorite ALH84001, reported in *Science* in 1996. Though now widely regarded as a misinterpretation, the "Mars rock" episode forced us to think about possible life on early Mars. Many skeptics suddenly began saying, "Why not?" Out of this came a massive boost for both astrobiology research and Red Planet exploration.

The same could happen for Venus. Indeed, I believe we'll soon see several new spacecraft launched to explore the clouds, atmosphere, and surface, to better understand the geology, climate, evolution, and maybe even past or present biology.

There's more than one way to look at the question of life on other planets. This is good since we know nothing about extraterrestrial life. We think we know that life needs water, organic matter, and energy. But it's worth noting that Earth, the only living world we know, has some rare properties that could also be key to life's emergence.

Our planet is active and self-renewing. Life here relies on two giant heat engines: the restless, overturning interior, which constantly feeds new minerals and gases to the surface; and the sunlight-driven churning of our atmosphere, which circulates those gases and erodes those rocks, ever exposing fresh surfaces and fueling the geochemical cycles upon which life feeds.

Venus, too, has a geologically active surface fed by a restless interior engine and a thick, dynamic, solar-driven envelope. In our solar system, arguably only Venus and Earth share these qualities (although Titan gets an honorable mention).

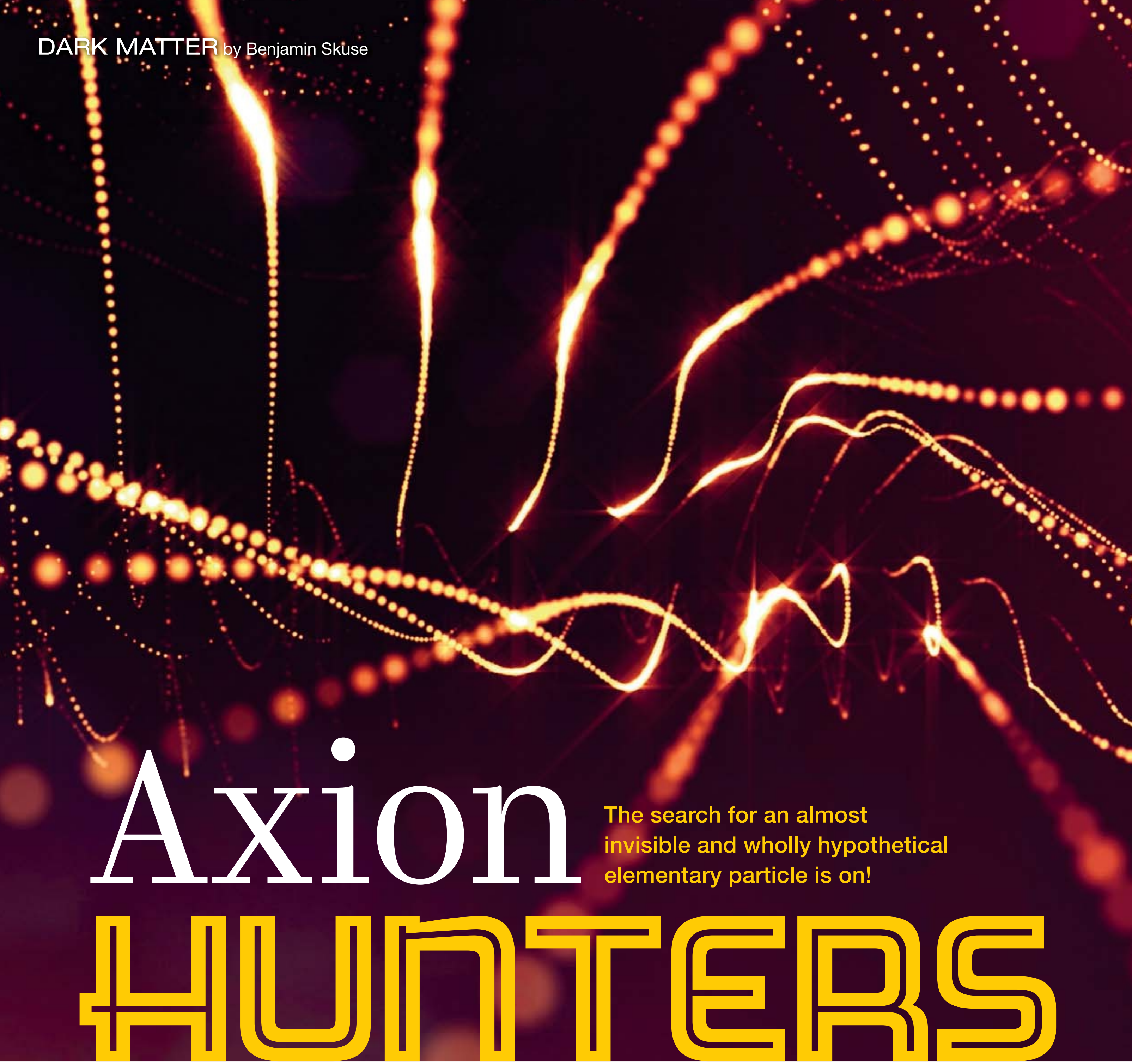
This is why I've long pushed the idea of a possible biosphere in Venus's cool clouds. It's not just the relatively moderate conditions, potential nutrients, and energy sources, and not just strange mysteries such as the "unknown ultraviolet absorber" that acts almost like a photosynthetic pigment, hungrily sucking up more than half the solar energy reaching the planet.

It's that rare liveliness of the Venusian atmosphere, which suggests to me that perhaps something could have evolved to take advantage of that fertile environment. Recent model results showing that Venus was likely habitable on the surface for most of its history provide a compelling origin story for life, which may have ended up as "climate refugees" in the clouds.

If the phosphine holds up, then clearly we need to go and investigate. Even if it doesn't, the finding is shining a bright spotlight on this underexplored and mysterious realm. It is forcing scientists to reexamine their assumptions and to once again ask, "Why not?"

■ Contributing Editor **DAVID GRINSPOON** is the author of *Venus Revealed: A New Look Below the Clouds of Our Mysterious Twin Planet*.

 by Benjamin Skuse



Axion HUNTERS

The search for an almost invisible and wholly hypothetical elementary particle is on!

Dark matter: It's the elephant in the astrophysical room. Astronomers think it makes up about 84% of all the mass in the universe. And they're bending over backwards to find it.

"Some days I'm doing pencil-and-paper theory, other days it's simulations, and still others I'm analyzing astrophysical or laboratory data," muses Benjamin Safdi (University of Michigan). "To be honest, I'm not completely sure how to classify researchers like myself . . . perhaps 'dark matter hunters' is an appropriate term."

Safdi and others like him are unusual in the physics community, where experts rarely straddle the boundaries between experimental, observational, and theoretical research. But their "Renaissance man" approach is born out of necessity: Decades of expensive and drawn-out experiments have come up empty, so scientists need creative new ideas for directly detecting dark matter.

For some, this means building more complicated and sensitive lab experiments and space-based searches in a last-ditch attempt to discover the most popular dark matter

GOLDEN WIND / SHUTTERSTOCK.COM

candidate, *weakly interacting massive particles* (WIMPs; *S&T:* Aug. 2017, p. 28). On the French–Swiss border at CERN's Large Hadron Collider (LHC), for example, physicists have been wielding the famous Higgs boson — discovered at the particle smasher in 2012 — to probe whether it decays into WIMP particles. And right now, about a mile underground in an abandoned gold mine in South Dakota, the LUX-ZEPLIN experiment is being installed. A vat containing 7 tons of xenon, LUX-ZEPLIN is designed to capture bursts of light from WIMP and other particle collisions. Its superior size and sensitivity compared to its predecessor experiments, LUX (Large Underground Xenon) and ZEPLIN (Zoned Proportional Scintillation in Liquid Noble Gases), offer hope of finally exposing WIMPs — if they exist.

For a growing number of other dark matter hunters, though, the fact that a range of WIMP detection experiments have seen nothing shows that it's time to focus on other possibilities. And an experiment deep below the Gran Sasso massif in Italy recently bolstered their arguments, galvanizing the hunt for a different dark matter candidate: axions.

Though a WIMP would be at least the mass of a proton — "massive" in particle physics terms — and an axion perhaps one hundred billionths of the mass of the tiny electron (or even much less), in many ways WIMPs and axions are similar. Like WIMPs, axions are proposed to have formed in the early universe and only very weakly interact with normal matter. In addition, either one of them could potentially explain dark matter in a way that forms a clean extension to the Standard Model of particle physics, without having to completely rewrite fundamental laws.

But many scientists think it is now time for WIMPs to exit stage left and allow axions to step into the limelight.

An Omnipresent Particle?

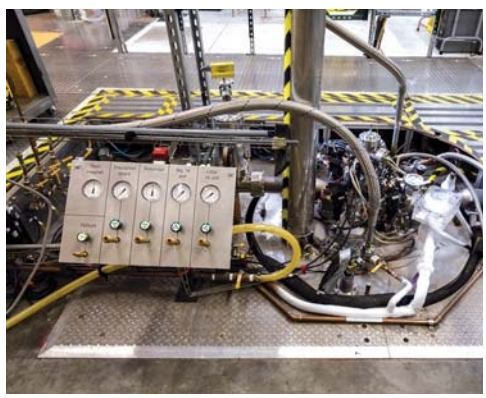
Axions were first theorized in the late 1970s independently by Steven Weinberg and Frank Wilczek. They are the consequence of an idea that solved a problem — the *strong CP problem* — in a part of the Standard Model of particle physics known as *quantum chromodynamics* (QCD). Weinberg initially called the new hypothetical particle the "Higglet," but it was Wilczek's suggestion of "axion" — named after a laundry detergent that had caught his eye at the supermarket a few years before — that stuck.

Theory predicts these *QCD axions* pervade space like the cosmic microwave background, and that they should very weakly interact with ordinary matter and be very light. But, frustratingly, theory does not predict exact values.

However, a few years after QCD axions were first proposed, Pierre Sikivie (University of Florida) and others realized that there is a range of masses and interaction strengths that would make them add up to the missing matter in the universe. It is around this band of values that researchers currently focus most of their efforts.

To find a miniscule hypothetical particle that has no electric charge and that rarely interacts with the universe we see is a challenge, to put it mildly. Theory suggests one of the few ways to catch an elusive axion red-handed is with magnetic fields, which can change axions into photons and back again. In their photon form, researchers can measure the light's frequency, which relates directly to the axion mass.

Dark matter hunters pursue two broad lines of investigation based on this idea: building powerful magnets that induce axion identity-swapping here on Earth,



ADMX *Left:* Physicists use the Axion Dark Matter Experiment to search for axions by moving two rods inside a cavity (cavity is gold chamber at bottom of cutaway). The rods' placement determines the cavity's resonant frequency, which then makes it sensitive to different wavelengths. *Below:* ADMX physicists examine the experiment *(top)*, which normally is lowered into the bore of the superconducting magnet at their feet *(bottom)*.

ADMX CUTAWAY: ADMX COLLABORATION; EXPERIMENT AND PHYSICISTS: MARY LEVIN / UNIVERSITY OF WASHINGTON; ADMX IN GROUND: MARK STONE / UNIVERSITY OF WASHINGTON

The Strong CP Problem

Axions are an attempt to solve the *strong CP problem*, a strange dilemma in which two fundamental nuclear forces don't act the same way. The weak nuclear force breaks what's called *charge-parity symmetry*, which essentially states that switching from matter to antimatter will create the mirror image of the original physical process. But the strong nuclear force *follows* CP symmetry, even when involving the same kind of particles that violate the symmetry in weak interactions. The problem seems to be the value of a constant in the strong force equations. Physicists realized in the 1970s that if this constant is instead a field permeating space, it could solve the strong CP problem. The axion is the particle of that hypothetical field.

and searching nature's sources of magnetic fields in space for telltale signs of the chameleon-like phenomenon.

Earthbound Investigations

A leading experiment offering hope for finding axion dark matter on Earth is the Axion Dark Matter Experiment (ADMX) at the University of Washington. Started in 1995 based on a detection scheme proposed by Sikivie, ADMX hunts for axions that could be showering Earth every second from the wider universe. The experiment aims to switch these axions to microwave photons via a supercooled magnet whose magnetic field is about 150,000 times stronger than Earth's. If axions do exist and the instrument is tuned to precisely the right wavelength, its cavity will resonate, amplifying the signal so that ultra-sensitive quantum electronic detectors can pick it up.

Another promising line of investigation for axion hunters is to search for axions from the Sun. These axions could be produced within the Sun and other stars through high-energy X-ray photons switching identity to axions when they interact with charged particles in the stellar plasma. Solar axions would not explain dark matter — only primordial axions produced in the early universe and now permeating space could do that. But finding the solar version would prove axions exist.

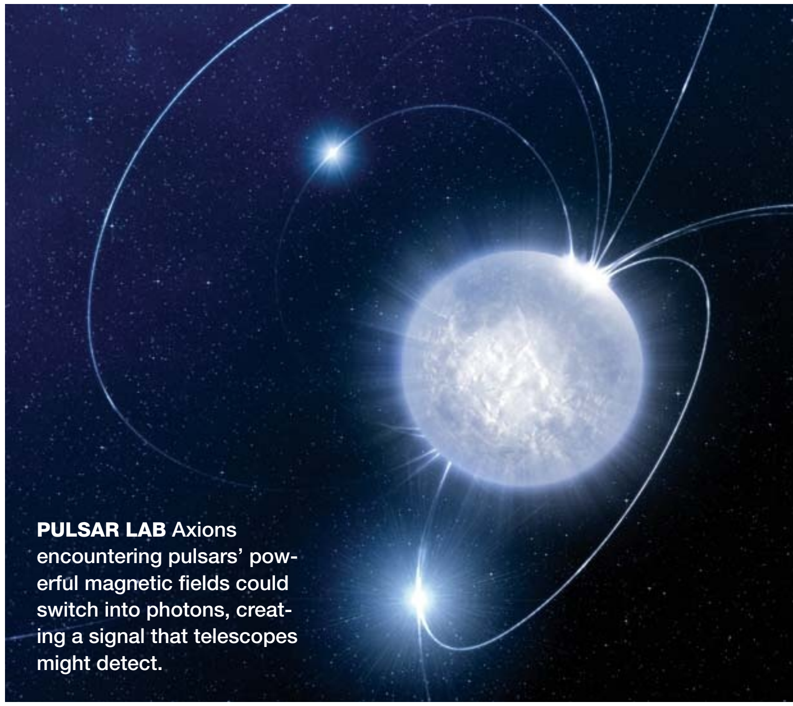
Most of these experiments are based on a design, again first proposed by Sikivie, that uses specially built telescopes

Many researchers have turned to scouring the vast natural laboratory of outer space for hints of this tiny hypothetical elementary particle.

called *helioscopes*. The CERN Axion Solar Telescope (CAST), for example, is essentially an extremely good X-ray telescope that points at the Sun, but whose lens cap never comes off. It consists of two 10-meter-long tubes and a strong magnetic field generated by an upcycled LHC prototype magnet, intended to reconvert solar axions back to photons. Each magnetic pipe leads to an X-ray telescope and photon detector that records faint flashes of X-ray light. If any photons appear, they are likely solar axion chameleons.

CAST has been searching for axion signals by following the Sun for 1.5 hours at both sunrise and sunset since 2003. Though the team has found no signal, "some of the strongest limits on the properties of axions arise from CAST," says Safdi. Promising even tighter limits and possibly even detections, CAST's proposed successor — the International Axion Observatory (IAXO) — may be a game-changer, he adds.

Scientists are also intrigued by recent results from another kind of experiment. XENON1T is a giant, sensor-lined tank, buried beneath the mountains of central Italy. Inside its relatively modest 3.2 tons of xenon, dark matter



PULSAR LAB Axions encountering pulsars' powerful magnetic fields could switch into photons, creating a signal that telescopes might detect.

ESO / L. CALÇADA

hunters captured an unexpected excess of particle interactions. WIMPs were immediately ruled out as the culprit, leaving three possibilities: contamination inside the experiment, neutrinos exhibiting a new property, or, most excitingly, solar axions. Confirmation will have to wait until first results from XENON1T's successor experiment, XENONnT, which at the time this article went to press was scheduled to go live late in 2020.

Searching Outer Space

Though new experimental ideas and upgrades to existing ground-based searches promise to explore even more potential masses and interaction strengths, Earth-based hunts may simply not be up to finding the elusive axion without more information on its makeup. This is one reason many researchers have turned to scouring the vast natural laboratory of outer space for hints of this tiny hypothetical elementary particle.

"I think the largest [stable and continuous] magnetic field that we can create on Earth is about 45 teslas," explains Richard Battye (University of Manchester, UK), referring to the 35-ton device at the National High Magnetic Field Laboratory in Florida. "But, for example, you can get 10^{11} T in a pulsar — even though it's a long way away and you have less control over it, it's a massive signal."

Pulsars are the highly energetic leftovers from massive stars' explosive deaths: rapidly spinning, magnetized neutron stars sending narrow beams of light in opposite directions like cosmic lighthouses. Battye is interested in these pulsars' *magnetospheres*, a region of space encircling the pulsar where charged particles are trapped by the gargantuan electromagnetic field — the perfect place for axions to flip to photons.

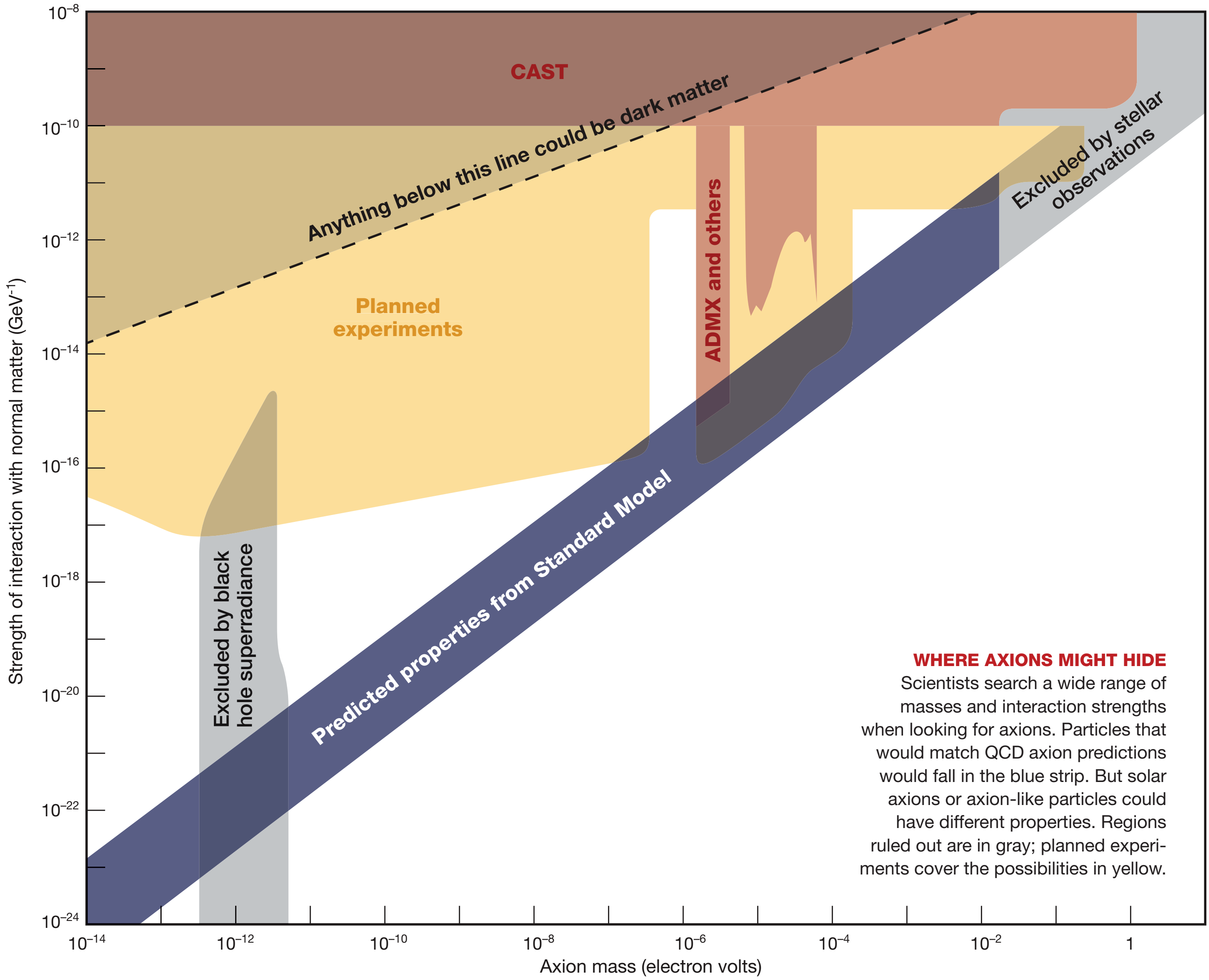
In an ideal world, astronomers would only need look for an anomalous spike in the spectrum of light emanating from a pulsar to discover the axion's mass. But in reality, they need to model the precise dynamics of the pulsar's evolution in order to predict what the signal would look like — no mean feat when the nearest pulsars are hundreds of light-years from Earth. Battye is currently sifting through the last 12 years of the UK's Jodrell Bank Observatory archive of pulsar measurement data to see if he can constrain axion mass this way. In a parallel study, Safdi is searching nearby neutron stars with instruments like the Green Bank Telescope in West Virginia for similar signals.

The axions that would produce these signals would originate from outside the pulsar or neutron star, and their wavelengths would be found somewhere in the radio part of the electromagnetic spectrum. But Safdi is also pursuing an idea that the hearts of neutron stars themselves are high-energy axion factories. Like the solar axions CAST is hunting, when these axions exit the neutron star and enter the surrounding magnetosphere, some would transform to X-ray photons. Recently, Safdi and colleagues searched seven nearby pulsars for these characteristic photons. In the reams of data from XMM-Newton and Chandra space telescopes, they found hints of the elusive particle. Ongoing efforts center on confirming the discovery.

Black Hole Clues

Though observing pulsars and neutron stars for hints of axions seems far removed from the aforementioned ground-based lab experiments, almost all of these studies rely on magnetic fields spontaneously converting axions to normal photons. Are there other ways we can observe these mysterious hypothetical particles? Masha Baryakhtar (New York University) is one of a number of researchers exploring a completely different idea: *black hole superradiance*.

First proposed by Soviet physicist Yakov Zel'dovich in 1971, black hole superradiance is an effect in which a particle or wave grazing a spinning black hole can extract energy and



WHERE AXIONS MIGHT HIDE Scientists search a wide range of masses and interaction strengths when looking for axions. Particles that would match QCD axion predictions would fall in the blue strip. But solar axions or axion-like particles could have different properties. Regions ruled out are in gray; planned experiments cover the possibilities in yellow.

GREGG DINDERMAN / *S&T*

angular momentum as it passes. If axions exist with the right range of masses then, like a speaker amplifying a sound wave, superradiance will spontaneously and exponentially grow the number of axions around the black hole. Their numbers will balloon from zero to a few percent of the black hole's mass in just a few years. And these axion clouds will form states around the black hole that look similar to electron orbitals in a hydrogen atom, earning such black holes the term *gravitational atoms*.

"Gravitational atoms are huge — hundreds of kilometers across — and can contain astronomical amounts of axions, up to 10^{80}!" remarks Baryakhtar. But for the black hole, forming a gravitational atom takes a heavy toll. As the axions sap the black hole's energy, there quickly comes a point when it is no longer spinning with enough energy to induce superradiance. This rapid spin-down effect is key for Baryakhtar: She can plot the mass and spin of known black holes and compare this to what she would expect if superradiance spins black holes down. The black hole masses and spins that superradiance allows are directly related to the axion mass. If a black hole exists that is spinning too fast for a given axion mass, she can rule out that axion mass. She and her colleagues have already used this technique to exclude a range of axion masses.

Though Baryakhtar is currently refining this technique and adding new black hole measurements as they come in with the aim of further tightening the constraints on axion mass, she has her eye on a more direct way of identifying axions from black holes: gravitational waves.

Researchers at the Laser Interferometer Gravitational-Wave Observatory (LIGO) twin sites in Washington and Louisiana, alongside scientists based at LIGO's European cousin Virgo in Italy, have so far confidently witnessed 10 events in which two black holes collide and merge, as well as one binary neutron star merger and dozens more candidate events. Since the first detection in 2015 that proved gravitational waves' existence, these ripples in spacetime have been used to gain a deeper understanding of the sizes and nature of black holes and neutron stars, to gauge how common black holes are in the galaxy and universe, and to test whether the speed of light and gravity are the same (spoiler alert, they are!).

Baryakhtar thinks scientists could soon wield gravitational waves to identify gravitational atoms as well. A gravitational atom could produce gravitational waves in two ways. First, in a direct parallel to electrons in an atom, axions could fall from higher energy states to lower ones. In an everyday atom, an electron making this transition emits a photon. But in the gravitational atom, the axion would emit a gravitational wave. Second, unlike electrons, axions are their own antiparticle, so two axions from the same energy level can annihilate to produce gravitational waves. "This doesn't happen in a regular hydrogen atom," says Baryakhtar. "But it's the most common source of gravitational waves in gravitational atoms."

With a potentially colossal number of axions at any one energy level in a gravitational atom's axion cloud, the gravitational-wave signal could be large and easy to spot.

"So far there have not been any positive signals that could potentially be coming from gravitational atoms, so we are mostly thinking about how to properly use these searches to place constraints on axions," she says. "But I think it is a very promising direction and expect the prospects to improve as LIGO and Virgo achieve even more incredible sensitivity to gravitational waves."

Future detectors like ESA's three Laser Interferometer Space Antenna (LISA) spacecraft promise even more sensitivity to axion-derived gravitational waves, if axions exist. And the outlook for other axion hunting methods is just as bright. With a large swathe of axions' potential parameters still unexplored, researchers are throwing the book at the problem using acronym-heavy Earth-based detectors such as IAXO, ABRACADABRA (A Broadband/Resonant Approach to Cosmic Axion Detection with an Amplifying B-field Ring Apparatus), MADMAX (Magnetized Disc and Mirror Axion Experiment), and CASPER (Cosmic Axion Spin Precession Experiment). At the same time, scientists are leveraging increased understanding of stellar evolution to further constrain axion parameters. They will also soon wield the power of the Square Kilometre Array (SKA) radio telescope to search for signals from the elusive particles.

"Right now, there is a bit of a Wild West mentality," says Safdi. "It really is an exciting time . . . any of these searches could lead to a discovery."

BENJAMIN SKUSE is a science writer based in Somerset, United Kingdom.

An Axion or Axion-like Particle?

Axion-like particles are, unsurprisingly, just like axions: They are predicted to be very light and weakly interacting, and they perform the same photon identity–swapping as axions. The difference is that, instead of being motivated by QCD, they fall out of the equations of different versions of string theory and other particle physics frameworks that go beyond the Standard Model. This means they do not solve the strong nuclear force conundrum that axions do. Efforts to find axion-like particles and axions often overlap.

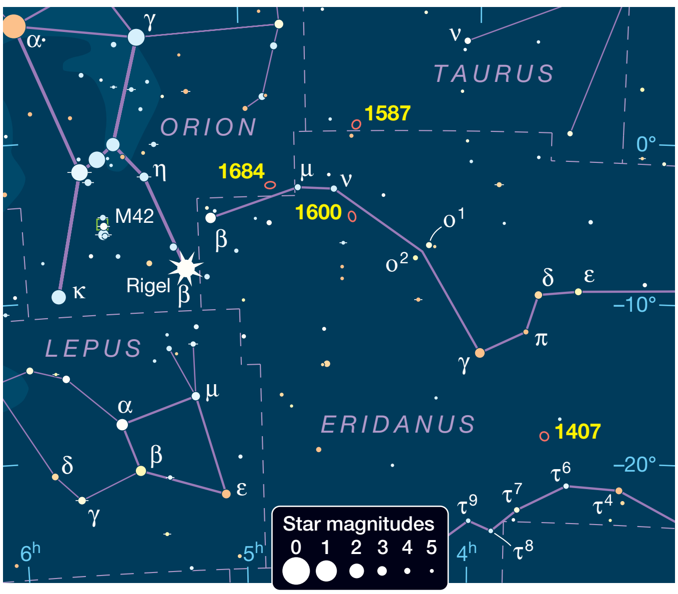
Should a promising particle be discovered, calculations will soon reveal if it solves the strong CP problem and is therefore a QCD axion, or not and instead an equally intriguing axion-like particle. Its mass and interaction strength will quickly answer whether it can account for some or all of the universe's dark matter.

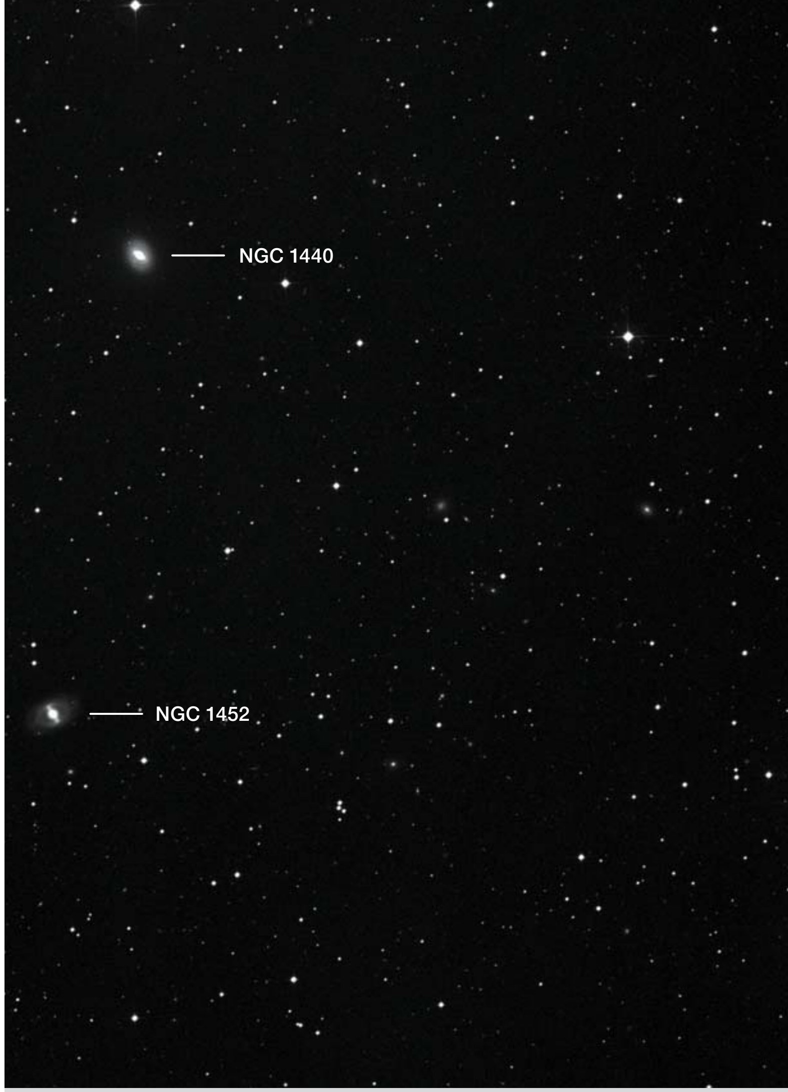
Winter's Galaxy Groups

Head off the beaten path to expand your January observing list.

To northern observers, the January sky with its iconic constellations might be the most familiar of celestial landscapes. Darkness falls early allowing most of us to enjoy hours of observing without missing too much (or any!) sleep. The winter evening sky is dotted with bright stars — the largest collection of first-magnitude stars we find anywhere in the heavens. Cold, crisp air makes them glitter like diamonds, encouraging us to step out and look up. Scattered among the familiar constellations are some of the most treasured objects visible in a backyard telescope. Amateur astronomers know them well and love them dearly.

You probably don't think of galaxies when you consider observing targets for January nights, but hidden among the nebulae and star clusters of the winter constellations are a number of galaxy groups worthy of attention. The dozen groups I've selected for this tour all consist of four or more galaxies that lie within 1° or so of the group's brightest member, and all contain objects that are within the reach of an 8-inch telescope under a dark sky. The groups' fainter members will challenge you, providing a test of your optics, your skills, and your determination. These galaxies are quite distant, averaging about 230 million light-years, and the farthest we'll visit is nearly 430 million light-years away.



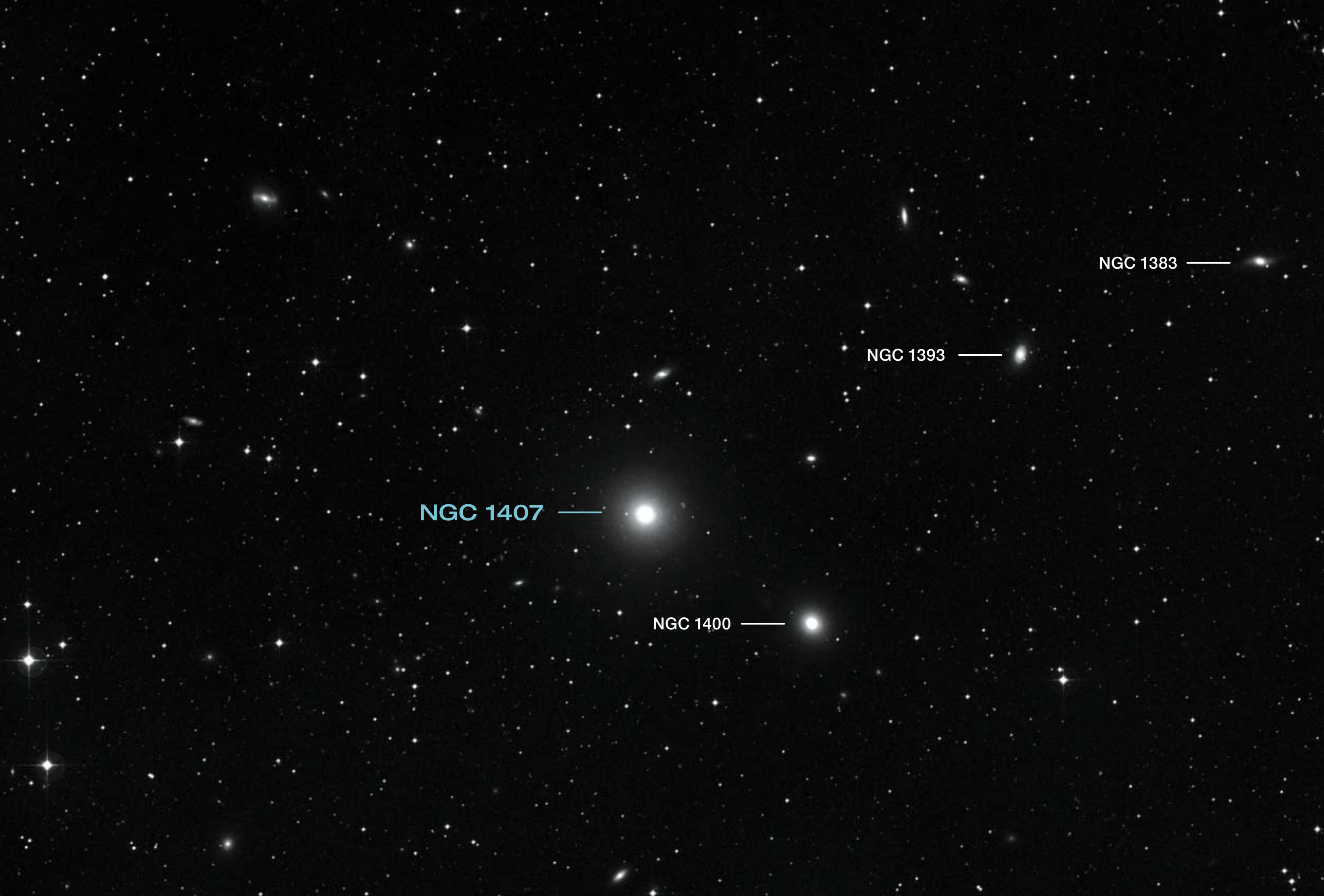


NGC 1407

Let's begin in Eridanus where **NGC 1407** anchors a group of galaxies with a few members brighter than 13th magnitude. The field lies in a bend in the celestial river midway between Tau (τ) Ceti and Alpha (α) Leporis, or about 8¾° almost due south of Delta (δ) Eridani. The group is dominated by NGC 1407 and **NGC 1400**, the two forming a bright pair about 12′ apart. Several fainter galaxies in the immediate vicinity just barely overflow a 1° eyepiece field of view.

The NGC 1407 group is a subgroup of the larger Eridanus Cloud. Of great interest to astronomers, it's an example of a *fossil group*, which is essentially a large isolated elliptical galaxy that results from an extensive merger of all the galaxies within a small group. With NGC 1407 we're perhaps seeing a giant elliptical galaxy in the making, caught in the act of cannibalizing a number of dwarf galaxies in its vicinity.

There are two bright members of the NGC 1407 group with interesting identity discrepancies. (This happens quite often; see "The NGC 2340 Tangle" sidebar on page 27 for details on another mix-up.) Contributing Editor Steve Gottlieb explains how **NGC 1440** was assigned four NGC numbers (**https://is.gd/gottlieb_ngc**). William Herschel discovered this 11.5-magnitude barred spiral on October 6, 1785. He recorded it again on September 20, 1786, but introduced an error of 1° in declination. His son, John Herschel, observed the object twice and agreed with German astronomer Arthur Auwers that both of William's observations were of the same target. Jean Louis Emil Dreyer, compiler of *The New General Catalogue*, recognized the probable duplication, but gave it two NGC designations anyway: NGC 1440 and NGC 1442.



American astronomer Francis Leavenworth reported the object again in 1886, but this time due to a 2′ error in right ascension it yet again was given a new designation: NGC 1458. Another detection attributed to Leavenworth — NGC 1430 — is also probably the same object.

NGC 1452 has a multiple identity as well. This 11.8-magnitude barred spiral was discovered by William Herschel in 1785 and rediscovered by Leavenworth in 1886. Again due to discrepancies in reported positions, Dreyer assumed Leavenworth's find was of a new object and assigned it the designation NGC 1455.

In a straight line northwest of NGC 1407 are two moderately bright spirals. Twelfth-magnitude **NGC 1393** is about 24′ from NGC 1407, and the edge-on 12.5-magnitude **NGC 1383** is another 15′ farther along.

Galaxies in Groups

Object	Type	Surface Brightness	Mag(v)	Size	RA	Dec.
NGC 1407	Elliptical	12.9	9.7	4.6′ × 4.3′	$03^h\ 40.2^m$	–18° 35′
NGC 1600	Elliptical	12.5	10.9	2.5′ × 1.7′	$04^h\ 31.7^m$	–05° 05′
NGC 1587	Elliptical	12.7	11.7	1.7′ × 1.5′	$04^h\ 30.7^m$	+00° 40′
NGC 1684	Elliptical	13.5	12.0	2.2′ × 1.7′	$04^h\ 52.5^m$	–03° 06′
NGC 2274	Elliptical	12.5	12.1	1.2′ × 1.1′	$06^h\ 47.3^m$	+33° 34′
NGC 2340	Elliptical	12.5	11.7	1.8′ × 1.2′	$07^h\ 11.2^m$	+50° 10′
NGC 2389	Spiral	13.9	12.9	2.0′ × 1.4′	$07^h\ 29.1^m$	+33° 52′
NGC 2487	Barred spiral	14.2	12.5	2.6′ × 2.1′	$07^h\ 58.3^m$	+25° 09′
NGC 2513	Elliptical	13.3	11.6	2.5′ × 2.0′	$08^h\ 02.4^m$	+09° 25′
NGC 2563	Spiral	13.3	12.2	2.1′ × 1.5′	$08^h\ 20.6^m$	+21° 04′
NGC 2749	Elliptical	12.7	11.8	1.7′ × 1.4′	$09^h\ 05.4^m$	+18° 19′
NGC 2795	Elliptical	13.2	12.8	1.4′ × 1.0′	$09^h\ 16.1^m$	+17° 38′

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.

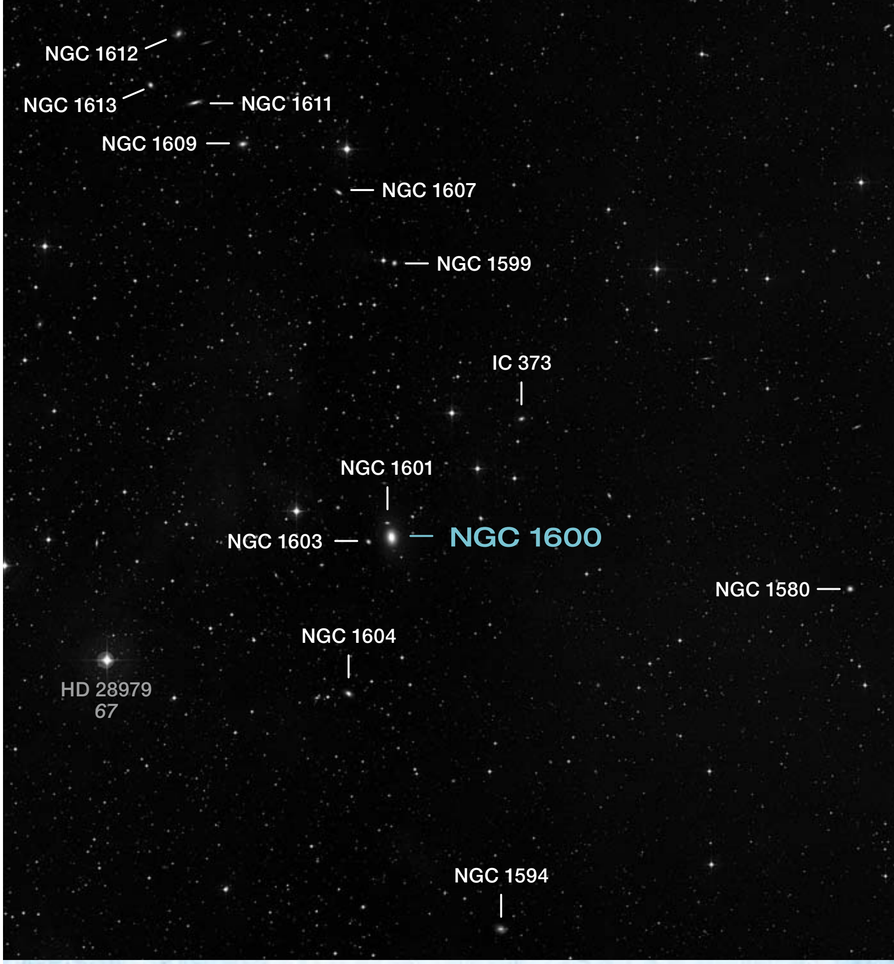
NGC 1600

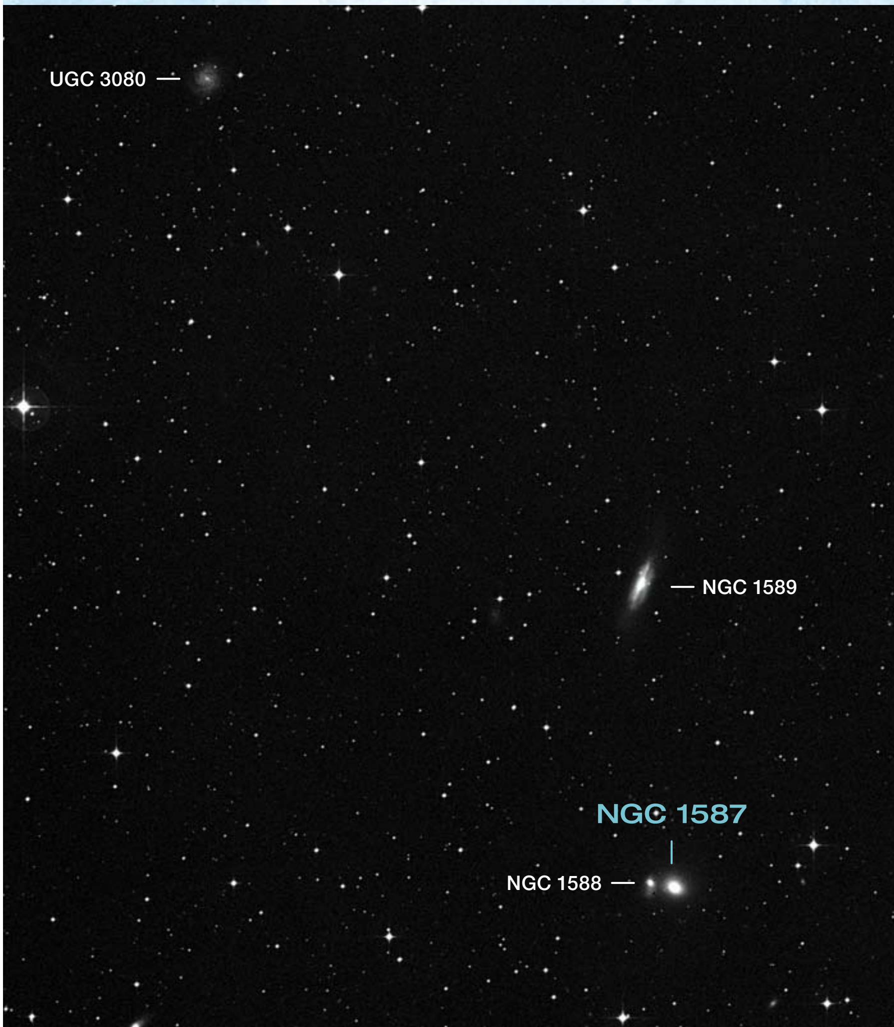
In the northern part of Eridanus, about 11° west-northwest of Rigel and 2° southwest of Nu (ν) Eridani, is **NGC 1600**, the brightest galaxy in a collection that contains 12 additional galaxies brighter than 14th magnitude. NGC 1600 itself is an 11th-magnitude elliptical with two close companions: **NGC 1601** and **NGC 1603**. Apparently, neither William Herschel, who discovered NGC 1600 in 1786, nor John Herschel, who observed the field four times, made any mention of the companions. Their discovery was left to George Johnstone Stoney observing at Birr Castle in 1849. See if you can detect them. NGC 1601 lies about 1.5′ north-northeast and NGC 1603 sits 2.5′ almost due east of NGC 1600.

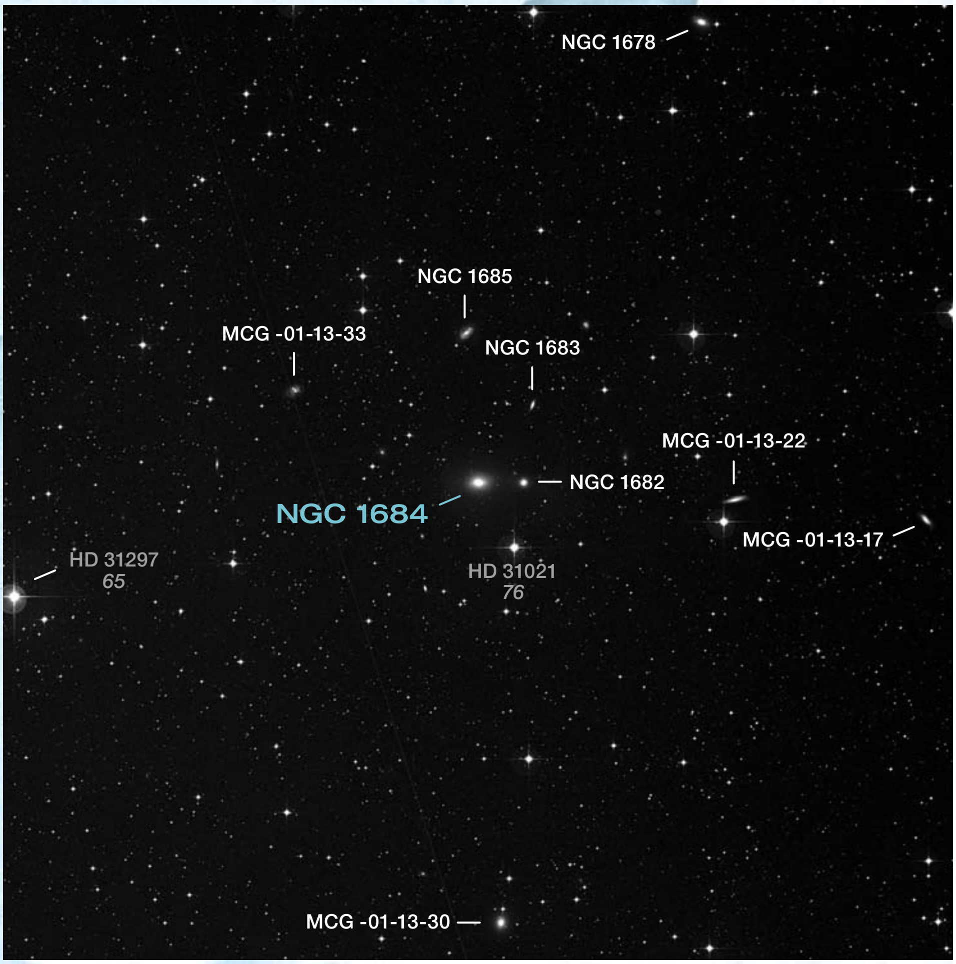
NGC 1600 is quite a bit brighter than the other members of its group at similar distances, suggesting that it, too, might be a fossil group galaxy and its neighbors might be fated to be cannibalized. To round out the set, look for the 13.7-magnitude lenticular **NGC 1604** some 17½′ to the south-southeast, the 13.0-magnitude barred spiral **NGC 1594** located 44′ to the south-southwest, the 13.5-magnitude spiral **NGC 1580** lying 50′ nearly due west, the 13.9-magnitude barred spiral **IC 373** found 19′ to the northwest, and the face-on 13.7-magnitude spiral, **NGC 1599**, situated 30′ to the north. Extending farther to the north-northeast lies a string of five galaxies stretching out to my arbitrary 1° boundary. The string includes the elongated lenticular **NGC 1607**, the oval lenticular **NGC 1609**, the spindle-shaped **NGC 1611**, and the two barred spirals **NGC 1613** and **NGC 1612**. These galaxies all range in magnitude from 13.2 to 13.7.

NGC 1587

Taurus is home to **NGC 1587** and three neighboring galaxies brighter than 14th magnitude — look for this quartet about 45′ northwest of 4.9-magnitude 45 Eridani. Both ellipticals, NGC 1587 at magnitude 11.7 and **NGC 1588** at magnitude 12.9, form an interacting binary pair. NGC 1587 is noteworthy for having one of the highest rotation rates known for an elliptical of average luminosity. One scenario proposes that NGC 1587 is the product of a merger with another galaxy, and its high rotation rate is the consequence of that interaction. About 12′ north of the bright pair is **NGC 1589**, an 11.8-magnitude spiral seen nearly edge-on. The open-faced spiral, **UGC 3080**, about ½° north-northeast of the pair, barely makes the cut due to its low surface brightness. Large-scope owners may just detect the slightest hint of spiral structure, as well as several fainter galaxies that dot the field.



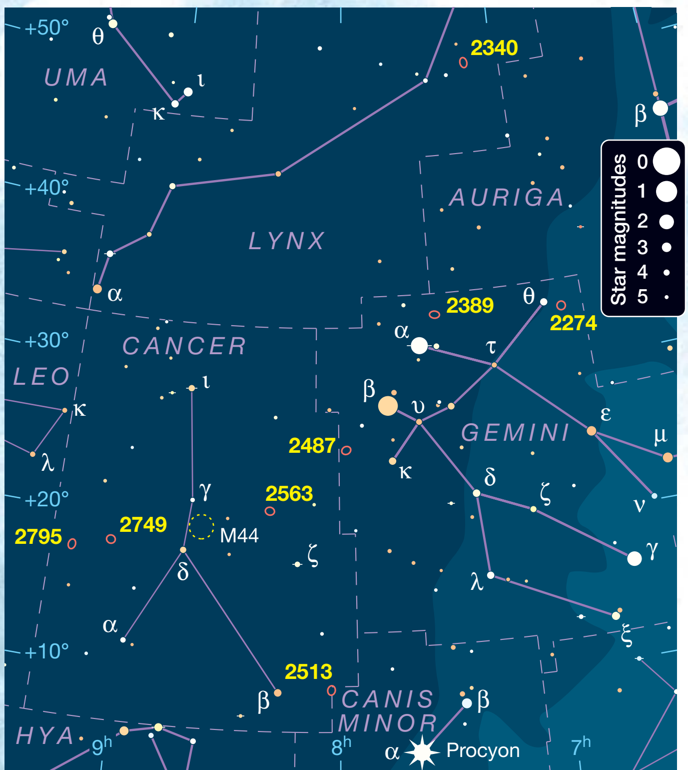




NGC 1684

The 12th-magnitude elliptical **NGC 1684** lies just across the border in Orion, some 1.7° east of Mu (μ) Eridani. It forms a pair with the smaller elliptical **NGC 1682** a little less than 3′ to its west. NGC 1682 is fainter, but its stellar core makes it stand out. **NGC 1685**, about 9½′ to the north, and **NGC 1683**, a little less than 6′ to the northwest, complete the inner part of the group. Both are faint and may be quite difficult to detect.

NGC 1678, a 13.2-magnitude spiral with an 11.7-magnitude star just off its western edge, lies about ½° to the north-northwest of this inner group. Four more galaxies in the field are within range of larger scopes. Along a line extending nearly ½° west of NGC 1684 we first come to **MCG -01-13-22** seen edge on and then **MCG -01-13-17**, which is also elongated. Turning south of NGC 1684 a little more than 27½′ brings you to the spiral, **MCG -01-13-30**, while the barred spiral **MCG -01-13-33** is 13′ east-northeast of the inner group.

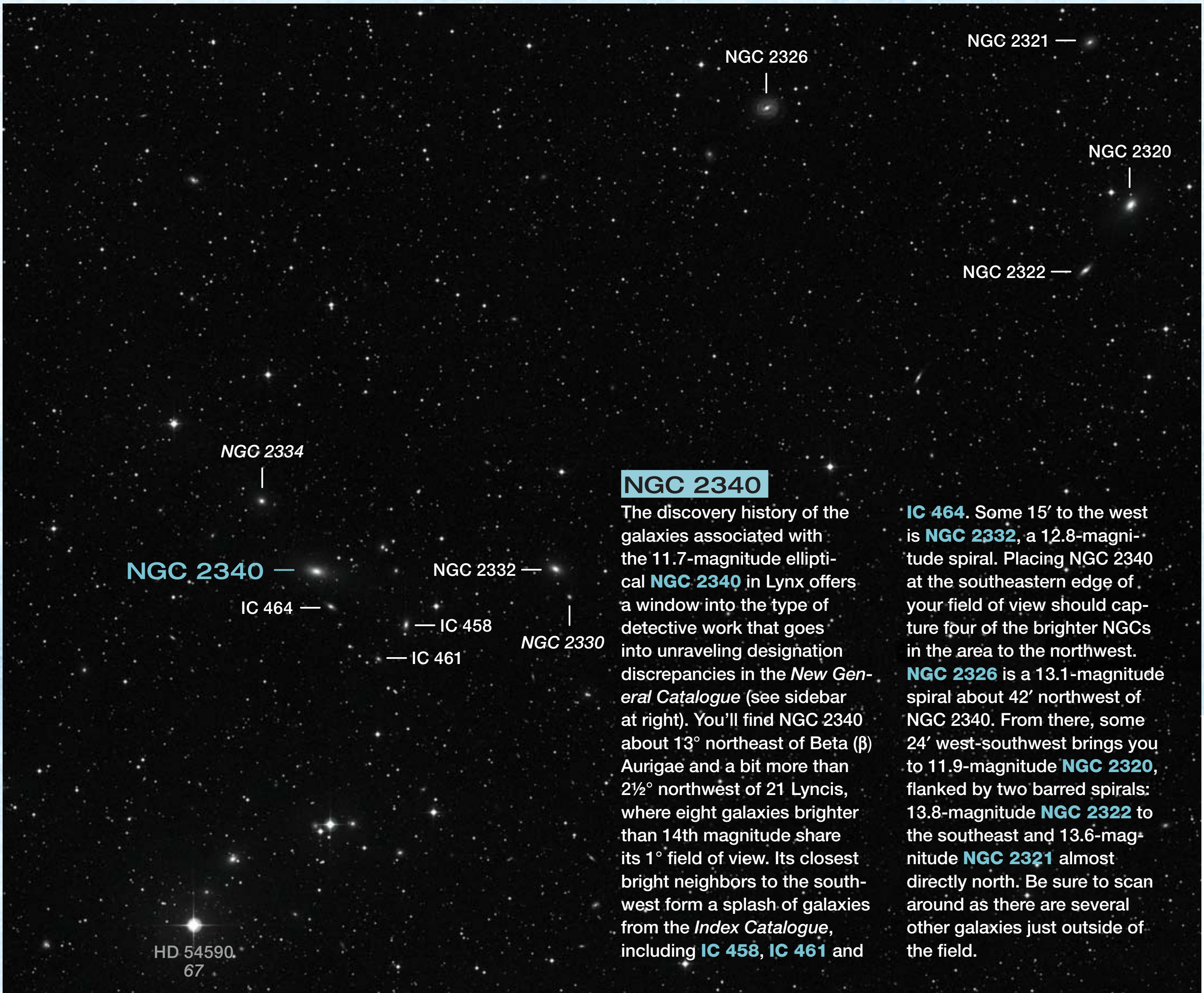


NGC 2274

About 1.2° southwest of Theta (θ) Geminorum, **NGC 2274** (not shown) outshines its close neighbor **NGC 2275** by more than one magnitude. American astronomer Harold Corwin notes that the two galaxies are reversed in the *Morphological Catalogue of Galaxies*. The *NGC* and the *Uppsala General Catalogue* correctly identify NGC 2274 as the southern and brighter of the two. About 45′ to the east is a group of five NGC galaxies arranged in an arc. The three brightest, **NGC 2289**, **NGC 2290**, and **NGC 2291**, are of similar magnitude, although NGC 2289, with its greater surface brightness, sticks out more.

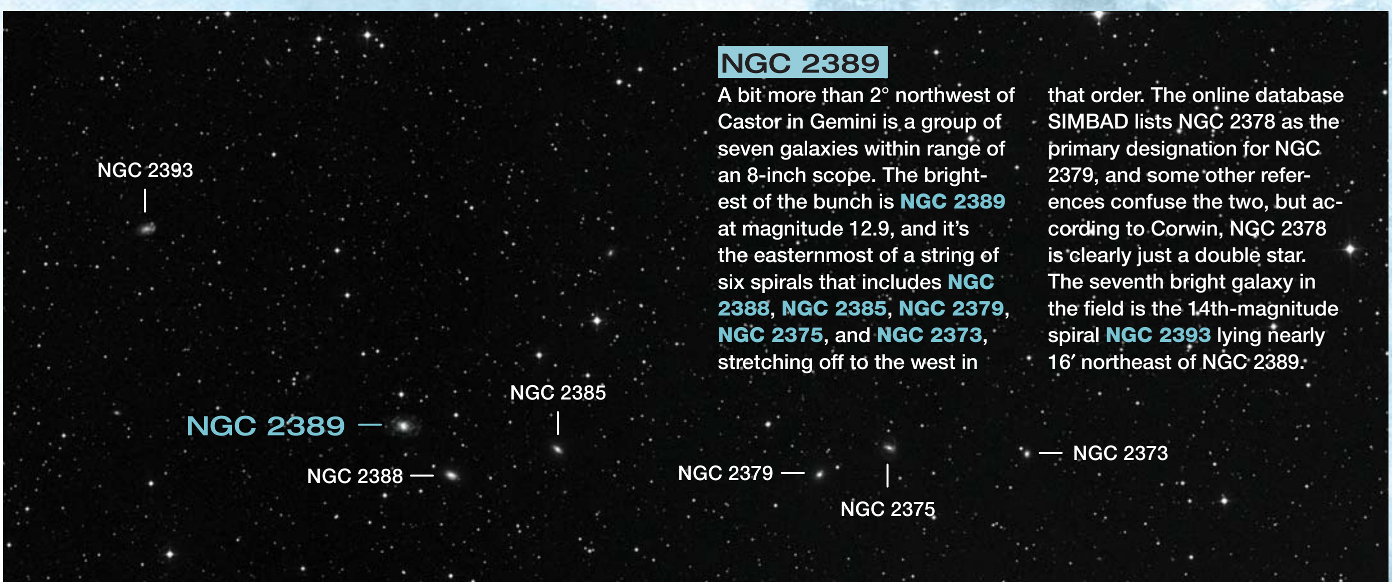
Catalog Abbreviations

Astronomical catalogs abound, but they often have rather long and unwieldy titles. Hence, observers revert to convenient abbreviations. They'll refer to "NGC" objects listed in the *New General Catalogue*, and the catalog itself is often simply reduced to "the NGC." The same goes for the *Index Catalogue* (IC), the *Morphological Catalogue of Galaxies* (MCG), and the *Uppsala General Catalogue* (UGC), among many others.



NGC 2340

The discovery history of the galaxies associated with the 11.7-magnitude elliptical **NGC 2340** in Lynx offers a window into the type of detective work that goes into unraveling designation discrepancies in the *New General Catalogue* (see sidebar at right). You'll find NGC 2340 about 13° northeast of Beta (β) Aurigae and a bit more than 2½° northwest of 21 Lyncis, where eight galaxies brighter than 14th magnitude share its 1° field of view. Its closest bright neighbors to the southwest form a splash of galaxies from the *Index Catalogue*, including **IC 458**, **IC 461** and **IC 464**. Some 15′ to the west is **NGC 2332**, a 12.8-magnitude spiral. Placing NGC 2340 at the southeastern edge of your field of view should capture four of the brighter NGCs in the area to the northwest. **NGC 2326** is a 13.1-magnitude spiral about 42′ northwest of NGC 2340. From there, some 24′ west-southwest brings you to 11.9-magnitude **NGC 2320**, flanked by two barred spirals: 13.8-magnitude **NGC 2322** to the southeast and 13.6-magnitude **NGC 2321** almost directly north. Be sure to scan around as there are several other galaxies just outside of the field.



NGC 2389

A bit more than 2° northwest of Castor in Gemini is a group of seven galaxies within range of an 8-inch scope. The brightest of the bunch is **NGC 2389** at magnitude 12.9, and it's the easternmost of a string of six spirals that includes **NGC 2388**, **NGC 2385**, **NGC 2379**, **NGC 2375**, and **NGC 2373**, stretching off to the west in that order. The online database SIMBAD lists NGC 2378 as the primary designation for NGC 2379, and some other references confuse the two, but according to Corwin, NGC 2378 is clearly just a double star. The seventh bright galaxy in the field is the 14th-magnitude spiral **NGC 2393** lying nearly 16′ northeast of NGC 2389.

NGC 2487

Gemini is also home to **NGC 2487** and **NGC 2486** (not shown), which form a bright pair near the Gemini-Cancer border. The field also contains the 13th-magnitude barred spiral **NGC 2498**. About 52′ southwest of NGC 2498 is the 8th-magnitude star HD 64682, and 3.7′ northwest of that is the barred spiral UGC 4099; see if you can detect its subtle dumbbell shape.

The NGC 2340 Tangle

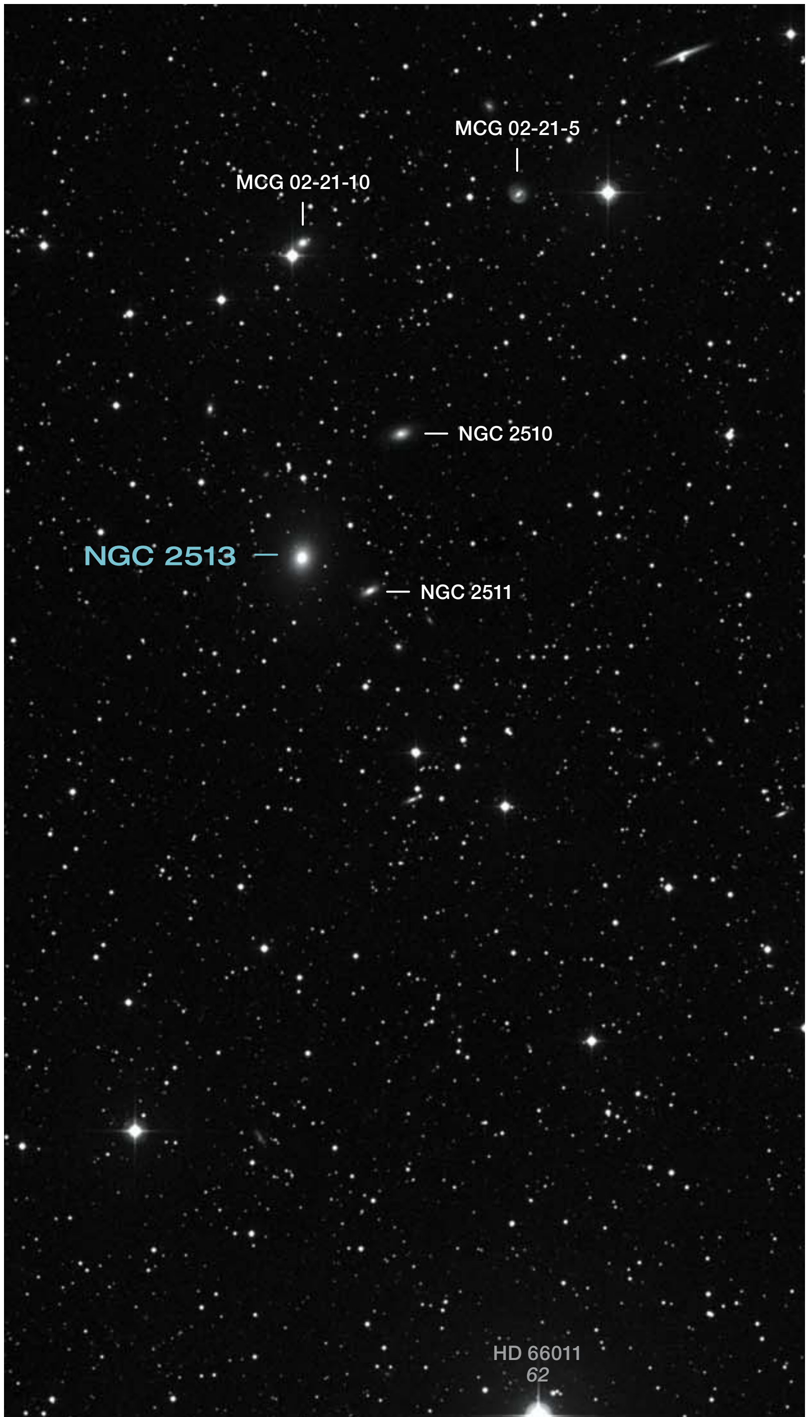
Unraveling the mysteries regarding some NGC/IC designations can be as fascinating as it is frustrating. One example is NGC 2340 and the galaxies surrounding it. The data for this group is marred by a number of inaccuracies in positions, questionable assumptions, and missing data.

William Herschel's visits to the area probably resulted in duplicate observations of the galaxy we now know as NGC 2340, which ended up causing some confusion over the identity of neighboring NGC 2332. His son, John, however, apparently detected both objects, and the discovery of NGC 2332 is credited to him.

The identities of the pair are reversed in the *Revised New Catalogue of Nonstellar Astronomical Objects* (*RNGC*) and in the *MCG,* which can further confuse modern observers. Lord Rosse observed the field in 1851, but his notes are rather sparse, and frustratingly he didn't include his sketches in a monograph published in 1861. However, in his notes of three different visits to the area, Lord Rosse identified a number of galaxies. And while his observations provide ample evidence for nine galaxies, Dreyer chose to assign NGC numbers to just four of them.

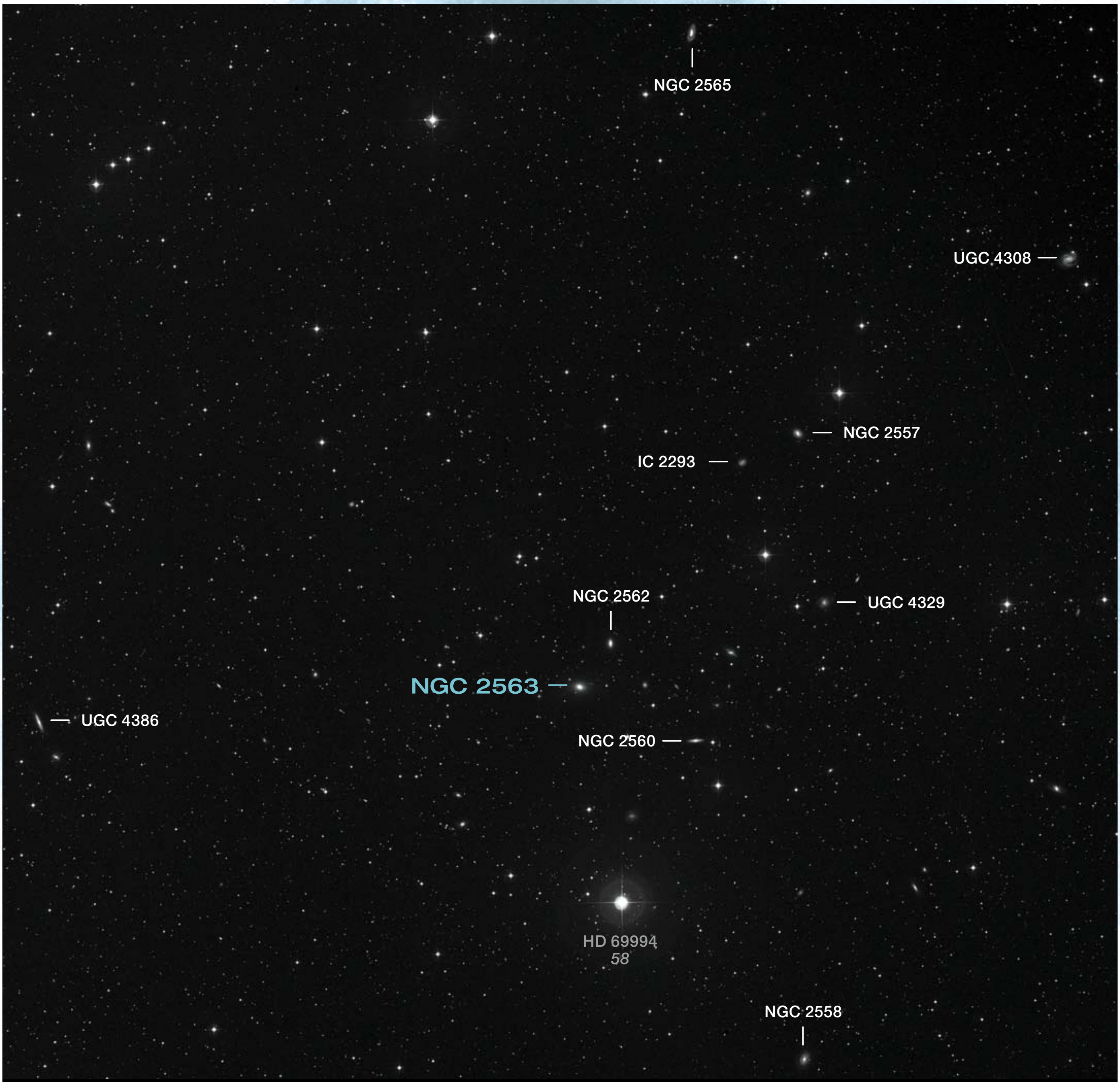
French astronomer Guillaume Bigourdan visited the region in 1885, but his observations weren't published in full until after the *NGC* went to print. The two nebulae that Bigourdan recorded turned out to be stars, but Dreyer assigned these objects NGC numbers anyway. Consequently, American astronomer Harold Corwin has suggested the possible equivalence of NGC 2330 with IC 457 and NGC 2334 with IC 465 (see image on page 26), but other researchers (among them Malcolm Thompson) disagree.

Visit Corwin's webpage **https://is.gd/ngc-notes** for a more complete discussion.



NGC 2513

Cancer is home to four galaxy groups. The first lies on the border with Canis Minor, 3½° west of Beta (β) Cancri. **NGC 2513** is the brightest in a small group that contains some challenging targets. William Herschel discovered NGC 2513 in 1786, while two of its neighbors — **NGC 2511** and **NGC 2510** — were spotted by Bindon Stoney in 1851. My 18-inch Dob picked up a few other galaxies in the field. A few more nearly defied detection, appearing as nothing more than "lumpy darkness," a term that captures well the sensation when you can just sense the presence of objects that you can't make out. I also detected the barred spiral **MCG +02-21-5**, the elliptical **MCG +02-21-10**, and the compact galaxy **CGCG 59-32** (also known as Markarian 1208; not shown).

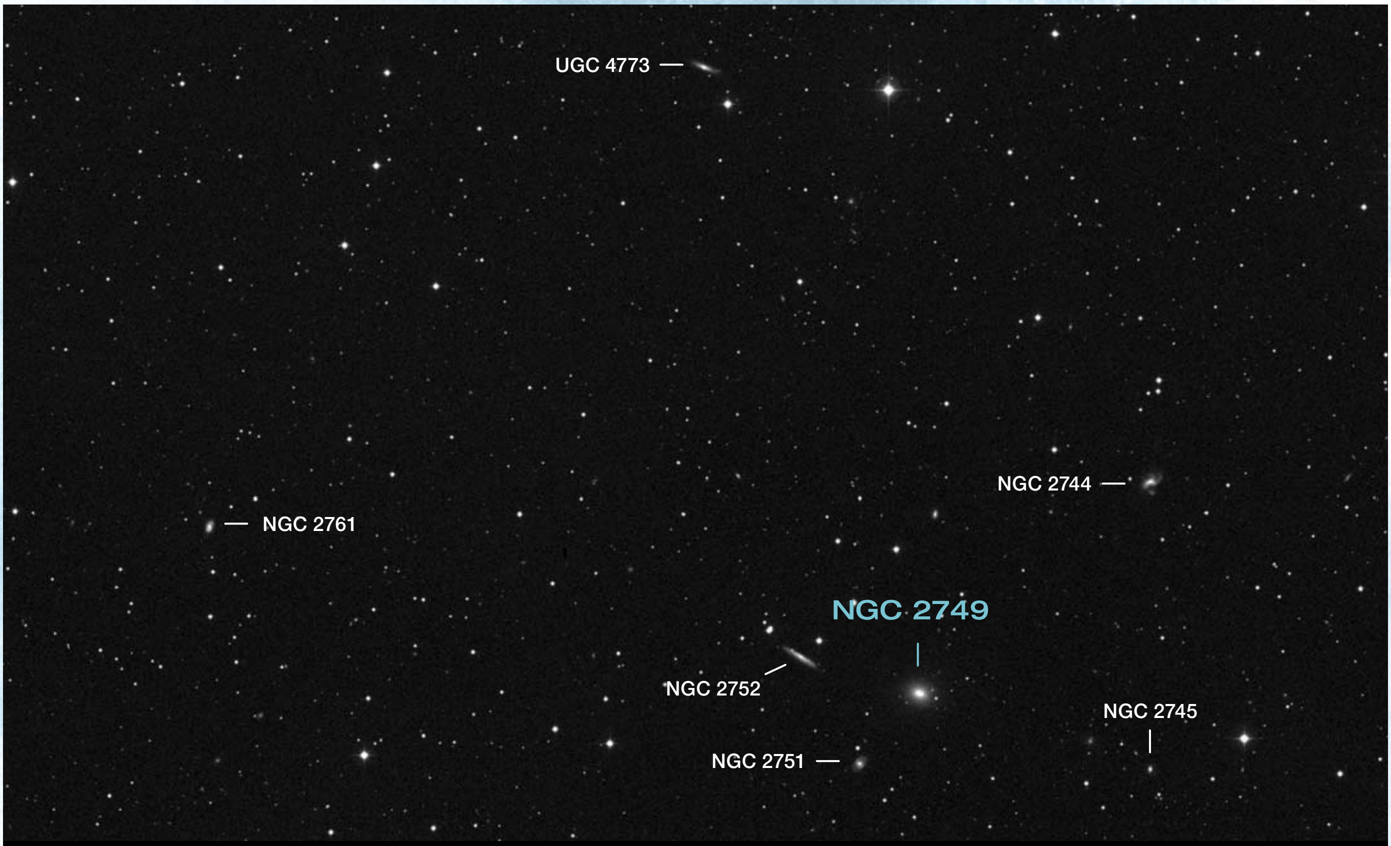


NGC 2563

The collection of galaxies known as the Cancer Cluster isn't really an organized cluster at all but rather a loose association of discrete groups with very different velocities. The area is quite "spiral rich" — spiral galaxies make up about 70% of the group's members. **NGC 2563**, a 12.2-magnitude lenticular located about 4½° west-northwest of the Beehive Cluster (M44), is the brightest of the group. It forms a pair with **NGC 2562**, another lenticular, about 4½′ to the northwest.

The area is dotted with moderately bright galaxies, including eight brighter than 14th magnitude and lying within 1° of NGC 2563. Only four of these made it into the *NGC*. **NGC 2560** sits 11.3′ to the southwest and close to a 10th-magnitude star. A farther 30′ south-southwest is **NGC 2558**, a 13th-magnitude spiral. Going back to NGC 2560 and heading some 28½′ to the north-northwest is the barred lenticular **NGC 2557** at magnitude 13.2, with **IC 2293**, a 14th-magnitude spiral, sitting 5.6′ to its southeast. **NGC 2565**, a 12.6-magnitude barred spiral, is at the limit of our boundary, north-northeast of NGC 2563.

The region provides a good opportunity to explore beyond the *NGC/IC* too. Three more galaxies in this central part of the Cancer Cluster have UGC designations and should be visible in modest-aperture scopes. **UGC 4329** is located 23′ west-northwest of NGC 2563. It's a 13.6-magnitude spiral seen nearly face on. **UGC 4308** is a 12.8-magnitude barred spiral about 58′ northwest of NGC 2563. A surface brightness of 12.9 helps in detecting the edge-on galaxy **UGC 4386** some 48′ east of NGC 2563.



NGC 2749

A little less than 5° east of Delta Cancri, **NGC 2749** is the brightest galaxy in our next set. The 11.8-magnitude elliptical dominates a collection of six companions that fit in a 45′ field of view. Close by to the northeast is the 13.7-magnitude edge-on barred spiral **NGC 2752** and to the southeast the 14.3-magnitude spiral **NGC 2751** — its relatively high surface brightness makes spotting it easier. Another object with enough surface brightness to be detectable is the tiny, nearly stellar **NGC 2745**, which lies 10.5′ southwest of NGC 2749.

Shifting our view 13.5′ northwest of NGC 2749 brings us to the double galaxy system **NGC 2744**. Its small companion 0.4′ south of its center isn't visible. Even the principal galaxy, a barred spiral, appears faint. A little more than ½° east-northeast of NGC 2749, **NGC 2761** is another faint member with a relatively high surface brightness rendering it detectable as a small, round spot. Perhaps the most elusive object in this field is the faint and slender edge-on galaxy **UGC 4773**. I could barely see the 13.7-magnitude sliver that lies about 28½′ north-northeast of NGC 2749 in my 18-inch Dob.

NGC 2795

Our last stop is a challenging foursome some 2.6° east-southeast of the NGC 2749 group. The 12.8-magnitude elliptical **NGC 2795** (not shown) forms a pair with **NGC 2794**, a 13.2-magnitude barred spiral. Images reveal that they outshine a smattering of close-by, faint, mostly anonymous galaxies, but in backyard telescopes even the two principals are faint and somewhat difficult. Fourteenth-magnitude **NGC 2797**, situated 7.3′ northeast of NGC 2795, appears small and round and makes a pair with an 11.9-magnitude star about 3′ to its southwest. The fourth member is the 13.2-magnitude spiral **IC 2454**, 11½′ north of NGC 2795.

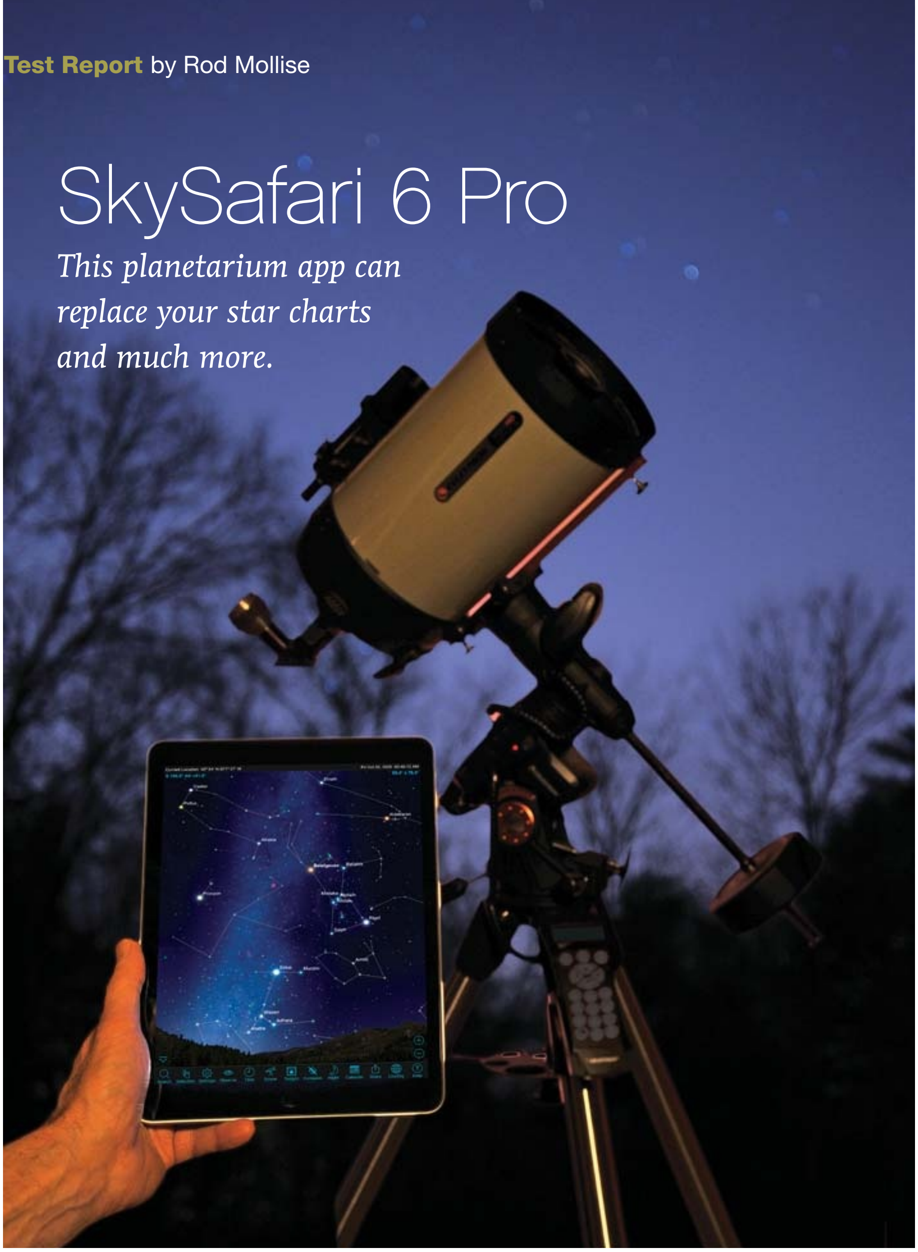
There's a tendency, I think, for observers to get comfortable with a cache of favorite objects, and there's no doubt that a typical January hit list is overloaded with the star clusters and nebulae that populate our own corner of the Milky Way. For some observers finding galaxies in the January sky might be a unique experience. It's a satisfyingly challenging departure from the routine that's perhaps enhanced a bit by exploring not just other galaxies but groups of galaxies at a single glance.

I'm always moved to flights of fancy when viewing other galaxies — contemplating the unimaginably vast real estate contained in those tiny, faint smudges of light and their countless stars, planets, moons, asteroids, and comets. Life? Who knows. The idea is rather mind-blowing, and that's why I've recommended straying from the usual January targets. To paraphrase Robert Frost: There were two paths through the winter sky tonight, and we chose the one less traveled. And that makes all the difference.

■ Contributing Editor **TED FORTE** enjoys the dark skies of his retirement home in southeastern Arizona. Observing the entire *New General Catalogue* accessible from his observatory with his 30-inch Dobsonian is just one of his many observing goals.

SkySafari 6 Pro

This planetarium app can replace your star charts and much more.



◀ The powerful smart-device app *SkySafari Pro 6* includes everything you need at the telescope, including 100 million stars, millions of deep-sky objects, and much more. With an optional Wi-Fi adapter, it can even let your smartphone replace the Go To controller on most computerized telescopes and mounts.

SkySafari 6 Pro

Simulation Curriculum
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What We Like

Smooth operation even with older devices

More feature-rich than most Go To hand paddles

What We Don't Like

Additional steps required to access information

Reconnecting to mount

WHEN COMPUTERIZED TELESCOPES entered the amateur market in the 1990s, I imagined one day there'd be a Go To telescope hand control with a color screen and a built-in set of star charts. Simply click on an object on a sky map and the scope would go there. At least one manufacturer did introduce something like that, but it was obsolete almost before it came to market thanks to smartphones and tablets running powerful apps like *SkySafari*.

Now in its sixth iteration, *SkySafari* is available for both iOS and Android devices as a full-featured planetarium app that displays a fairly realistic depiction of the night sky. Publisher Simulation Curriculum offers three tiers of the app. *SkySafari 6 AR* ($2.99) includes 120,000 stars and a selection of 222 of the best objects to view in the night sky. A more advanced Plus version costs $14.99 and includes 2.5 million stars and 32,000 deep-sky objects as well as 7,000 asteroids, comets, and satellites.

For this review we chose to look at the full *SkySafari 6 Pro*, which boasts a lot more objects and features. So much more, in fact, that I was initially skeptical about how it would compare to similar software for PC and Macintosh desktop computers (there's also a Mac desktop version available for $59.95). But I also wanted to see how the app performs compared to Go To hand paddles.

The Universe in Your Pocket

The first thing you'll notice when you open the app is its beautiful rendition of the night sky. Whether on a phone or on the larger screen of a tablet, *SkySafari*'s depiction of the night sky is attractive and fairly realistic, which is particularly helpful when observing under light-polluted skies. It even includes about 20 different horizon panoramas to choose from to enhance the "real" experience.

SkySafari's sky isn't just beautiful; it's accurate. Take the onscreen appearance of nebulae. The sky is depicted like a deep nightscape image of the Milky Way, with colorful nebulae visible. As you zoom into an area, the view transitions to red/blue color composites of the brighter nebulae and galaxies created from the second Palomar Sky Survey. In addition, it also includes an outline of the brighter extent of gas clouds, star clusters, and galaxies. These outlines (or isophotes) are often useful when observing and straining to make out the shapes of these dim objects.

Of course, excellent graphics don't mean much if they cause performance issues. Fortunately, that isn't a problem with *SkySafari Pro*. Response is quick

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◀ The app presents an attractive and fairly realistic rendition of the sky and horizon, with many options to select a foreground of your choice. Below are examples of *SkySafari Pro 6*'s appearance on an iPhone 6, while at left is its look on an iPad mini. Using the app on a tablet gives more room for text and menu items; otherwise its performance and content are the same.

and amazingly smooth, even using older devices, as I discovered when panning around the sky on my somewhat elderly 64GB iPhone 6. Using the app on Android devices is just as good.

Operation of the basic program is intuitive since it works like most other smart-device applications. You touch and drag the sky to navigate, touch to select objects or menu items, and pinch two fingers onscreen to zoom in and out. Scroll the ribbon-style menu along the bottom of the screen left to reveal numerous choices. While the program can be operated in basic fashion immediately, there are many options and menus, so there's a bit of a learning curve. Simulation Curriculum provides a comprehensive manual on its website at **skysafariastronomy.com**.

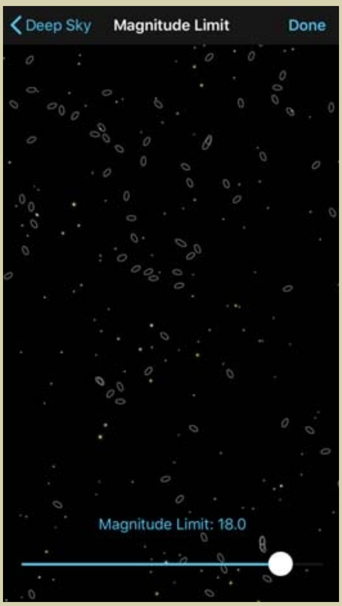
Basic Operation

Despite being packed into a smartphone, this is a big, sprawling program with many useful features. However, the place many of us begin when evaluating astronomy software is, "How many objects does it have?"

SkySafari Pro 6 is no slouch in that department, placing more than 100 million stars and 4 million deep-sky objects at your fingertips. Closer to home, it includes 770,000 solar system objects — in addition to the planets, and comets, the apps database includes *every* asteroid with a known orbit, and it adds new ones as they are confirmed. You can set the limiting magnitude of the faintest objects displayed using a slider in the Settings menu.

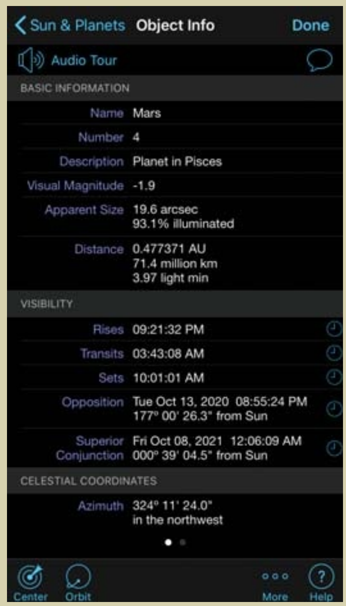
Admittedly, most amateur astronomers aren't going to have much use for 20th-magnitude galaxies or even dimmer rocks in the solar system. For most of us, the NGC catalog, brighter comets, and a few prominent asteroids are enough. Astrophotographers, however, often like to identify asteroids and

▲ A ribbon menu at the bottom of the screen allows access to functions such as setting past or future dates and times of the sky display. You can adjust the limiting magnitude of displayed objects and stars with sliders in the Settings menu.



▲ There's no lack of stars and deep-sky objects in *Sky Safari Pro 6*. Here the app displays 18th-magnitude galaxies in a small area of the sky. While you can adjust the limiting magnitude in the Settings menu, the closer you zoom into a field, the fainter it will display.

▲ Searching for objects returns a lot of information (the page scrolls down containing more facts and history), with additional options like object centering, and, for more prominent targets, an image and an audio tour.



▲ A page of more detailed information is available by swiping right from the object information page. This is included in the main info page when operating the app on a larger tablet device.

other moving objects in their images. Activating Show Asteroids in the Solar System menu makes it fairly easy to quickly look them up. I cranked the limiting-magnitude slider all the way to its maximum setting, and despite many more tiny dots appearing in the app, it didn't seem to slow the performance of the app much.

Having tons of objects isn't very useful, though, if you can't easily access the one you want. The search function in *SkySafari* is excellent. Touching Search on the ribbon menu brings up a list of object groups. For example, clicking Sun & Planets opens up a list of our major solar system denizens (including the 5 dwarf planets). Selecting Mars yields a picture of the planet, a brief text description (scroll the page up for much more), and a set of options including centering the planet on the app's display and a Go To command that slews your telescope to it if it's connected. Swiping right brings up a page of detailed data.

If you don't feel like scrolling through groups of objects, you can type the common name or designation of the target of your choice into the search field at the top of the screen. The app isn't finicky about search terms; typing M1, M 1, or "Crab," all returned the Crab Nebula, Messier 1. Testing the search function on less popular catalogs was equally impressive — every object I looked for in the van den Bergh (vdB) catalog came up immediately.

Diving Deeper

Prominent objects include audio tours. These well-executed sound files give an

▲ Simulation Curriculum offers an optional Wi-Fi adapter to connect your phone or tablet to a Go To telescope or mount. Some manufacturers sell their own adapters that work just as well and, in some cases, even better. The author used Celestron's SkyPortal WiFi module to connect *SkySafari Pro 6* to his telescope mount, which completely replaces the mount's Go To hand paddle.

overview of the selected target. Surprisingly, these aren't limited to planets and Messier objects; many interesting deep-sky objects from the NGC catalog also feature these audio tours.

These professionally narrated audio tours average about a minute in length and do a good job of covering the basics. They include details such as the location of an object, its appearance in a telescope or binoculars, and a little of the science regarding it. They are so interesting that I haven't yet grown tired of listening to them and make it a point to find new ones I hadn't encountered before.

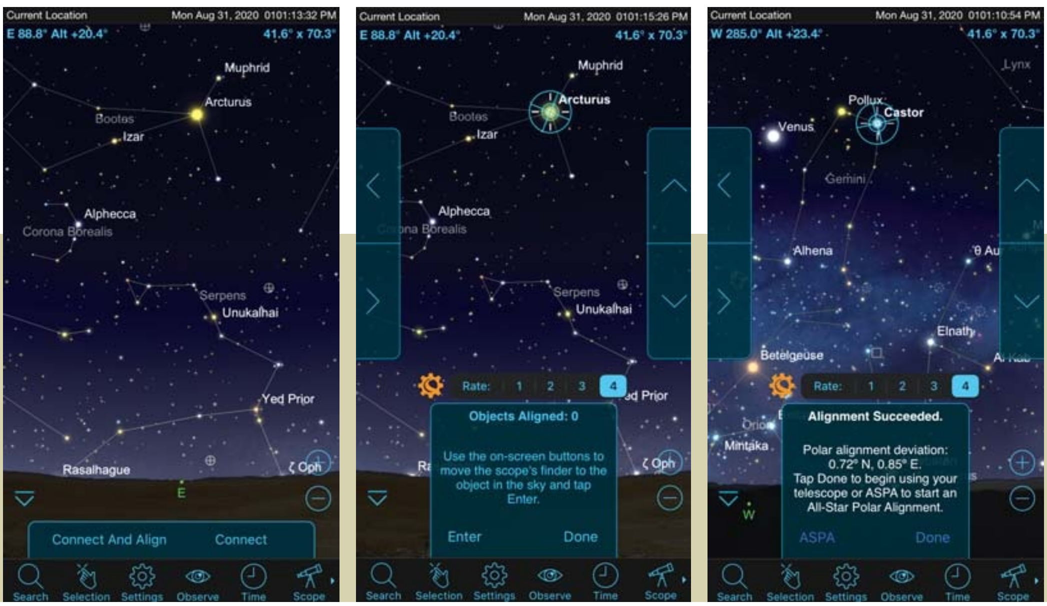
You can also access an onscreen object's information by touching it and choosing the Selection option from the ribbon menu. This brings up a context menu with Object info and several other options. I'd have preferred that the context menu appear as soon as I touched an object onscreen rather than having to do an extra step.

Go To Control

Years ago I was showing my university astronomy students how to use a paper planisphere to identify the stars and constellations, when one pulled out her smartphone, held it up to the sky, and said, "I can do that with my iPhone!"

Like my student's app, *SkySafari Pro 6* can take advantage of a phone's built-in accelerometer. Select Compass on the ribbon menu, hold the phone up, and the app will track the sky. Point toward Hercules, for example, and that constellation will be centered onscreen.

If my smartphone were to become the telescope hand control I'd imagined years ago, I'd have to connect it to a telescope. The app can do that, but exactly how depends on your particular scope or mount. The easiest way is by using an instrument with built-in Wi-Fi like Celestron's Evolution series of Schmidt Cassegrain telescopes. But if your telescope doesn't have Wi-Fi, the company offers its WiFi III Wireless Control Package at additional cost that will work with almost any recent telescope mount or integrated system. It



▶ Aligning your Go To telescope with *SkySafari Pro 6* is easy. *Left:* After connecting to the mount, select Scope on the ribbon menu and then choose Connect And Align. *Middle:* SkySafari then instructs you to center four stars, beginning with two in the east. *Right:* When complete, *SkySafari* gives Celestron users the option of running the All-Star Polar Alignment (ASPA) procedure.

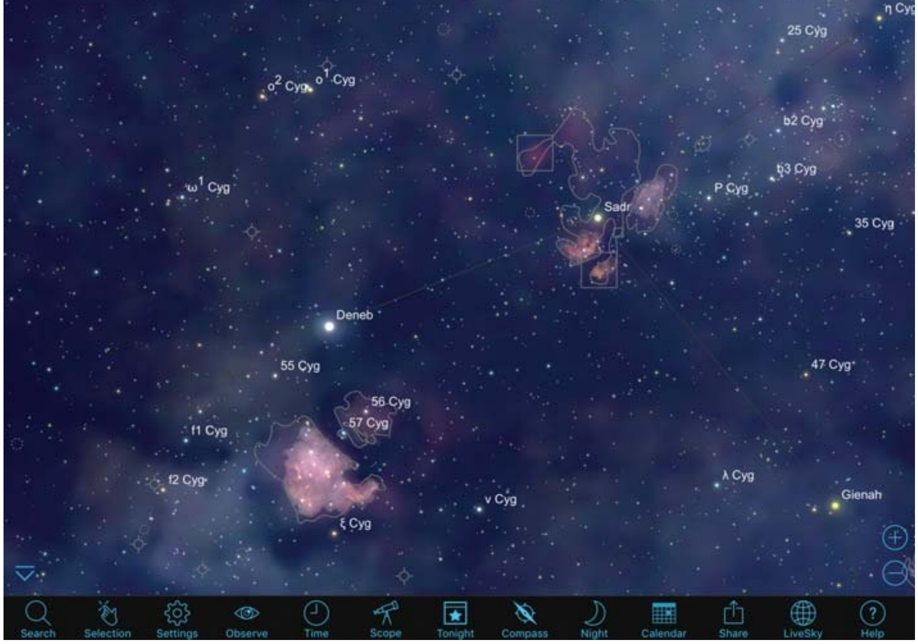
consists of a small rechargeable electronics box and a serial or USB cable to connect to the telescope hand control.

I used a Celestron SkyPortal WiFi module with an Advanced VX mount. The strength of this gadget is that it doesn't connect to the mount's hand paddle — it completely replaces it.

Connecting via the SkyPortal Link is simple. It appeared in my iPhone's list of networks, I selected it, brought up SkySafari Pro, and touched Connect And Align in the Telescope menu display. The app instructed me to place the scope in its home position pointing north, and then had me center two stars in the east and two stars in the west in my finderscope followed by fine adjustments in the main scope using onscreen direction buttons.

The resulting Go To alignment was every bit as good as one done with the mount's hand control. I'd touch GoTo in the telescope menu or the Object info page, and the scope would immediately slew to the chosen target. Objects were nearly perfectly centered in the eyepiece from one side of the sky to the other. The one thing I found slightly difficult was using onscreen direction keys with no tactile feedback. Nevertheless, it wasn't difficult to center objects.

The only problem I experienced was the time, about 20 seconds, for *SkySafari* to reconnect to the mount when I let my iPhone go into sleep mode. Other than that, I was thrilled with how well scope control worked. I felt like I'd finally got what I'd wished for so long ago: a Go To hand control with a full color, interactive star map.



▲ Outlines of nebulae, sometimes referred to as isophotes, can be a big help when observing dim gas clouds, and *SkySafari* does a good job of rendering them.

Observing Lists and Logs

One thing I've found is that without a list of interesting deep-sky objects to observe, I won't see much of anything. Another great feature in *SkySafari Pro 6* is its Observe section in the ribbon menu. Selecting it brings up a context menu with several options for observers. Want to build an observing list? You might not need to start from scratch. Choosing Observing Lists gives the options of creating a custom list or importing one from an online repository. While there are not a huge number of lists online, those available are quite good and include large numbers of objects to keep you busy observing for hours.

▶ Slew the telescope to targets by selecting the object onscreen, touching the Scope menu option, and then hitting GoTo.

If you don't find a list that appeals to you, just select Create New Observing List to make your own. Once you've named the list, you can add objects by selecting them onscreen and choosing Add to Observing List in the Selection menu. Alternatively, you can search for an object and use the More menu on the search results page to add it to the observing list.

While observing, I try to log all my observations. My logbooks from the past are not just useful but are a pleasure to browse years later. With *SkySafari Pro 6,* I can have them in my pocket at all times. The app contains this handy section in the Selection menu. Simply touch Create New Observation, and a log opens with a large comments section, and allows you to input other pertinent details, like the instrument used, atmospheric seeing conditions, limiting magnitude, and sky-quality-meter values.

If you'd prefer to keep your log in the cloud, choose Live Sky from the ribbon menu, log onto this Simulation Curriculum website, and save your log entries there. You can even share them with other users. All of this is just a sampling of what the app can do for observers.

I can sum up *SkySafari Pro 6* simply: This powerful app is on a par with or better than most desktop planetarium programs and more convenient to use than any of them. The older I get, the more I tend to simplify the astronomical side of my life and now prefer putting my phone in my pocket to lugging a laptop into the backyard or observing field. Especially since using *SkySafari* doesn't mean giving up any of its power and features. It gives renewed meaning to the phrase "putting the universe in the palm of my hand."

■ Contributing Editor **ROD MOLLISE** can often be found scanning the skies from his backyard in rural Alabama.

Looking for Ice IN THE DARK

Several tiny spacecraft are launching to tell us more about the water ice that lurks in shadowed craters on the Moon.

Flashlights help us find our way through pitch-black forests or a house that's just lost power. But researchers want to use a flashlight in another way: to find and characterize water ice in one of the darkest, coldest places in the solar system — the Moon.

Astronomers already know that patches of ice exist on the lunar surface at both the north and south poles. Hidden from direct sunlight and thus extremely cold, these regions are where ice delivered by comet impacts and other processes can gradually accumulate and survive on geologic time scales. The distribution of water ice in these *cold traps* varies between the poles, from place to place, and even within a single deposit.

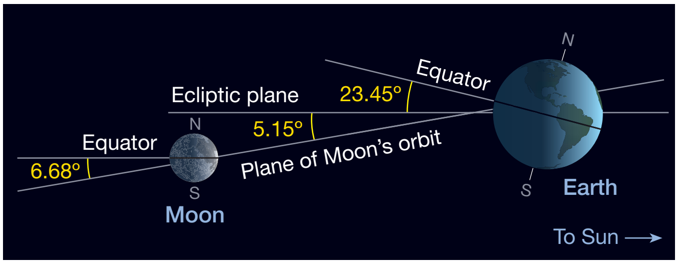
But scientists know little about this ice. To explore these frozen regions, Barbara Cohen (NASA Goddard) leads the Lunar Flashlight mission, a CubeSat about the size of a box of detergent that will fly to the Moon in late 2021. The probe will scan dark craters near the lunar south pole to better understand deposits of water ice there. It's one of several to be carried aboard Artemis 1, the first (and uncrewed) trip of NASA's new astronauts-to-the-Moon program. Other upcoming probes will also investigate lunar ice, helping to pave the way for the first NASA-built Moon rover and, perhaps, the eventual development of a cislunar economy.

Ground Truth

Water on the Moon is not a new idea. In pretelescopic times, people speculated that the lava plains called *maria* (Latin for seas) actually were seas. In the early 20th century, William H. Pickering even penned wildly speculative articles about vegetation and insect migrations in the crater Eratosthenes and wrote of "The Snow Peaks of Theophilus."

In 1952, geochemist Harold Urey noted that because the Moon's spin axis is tilted a mere 1½° from the axis of its orbit around the Sun, *permanently shadowed regions* (PSRs) should exist at the lunar poles, in which frozen water molecules and other volatile compounds might be present. In

▼ **SUNLESS SECRETS** Located almost exactly at the Moon's south pole, the crater Shackleton has a rim 21 km (13 miles) across that's bathed in near-constant sunlight — and a floor that never sees even a glint of it. A new generation of spacecraft will soon probe such permanently shadowed regions for the abundant water ice that scientists think lies hidden from view.



▲ **LOCKED IN PLACE** The near-vertical orientation of the Moon's spin axis to the ecliptic plane creates pockets of permanent sunlight and nighttime on the floors of craters near the lunar poles.

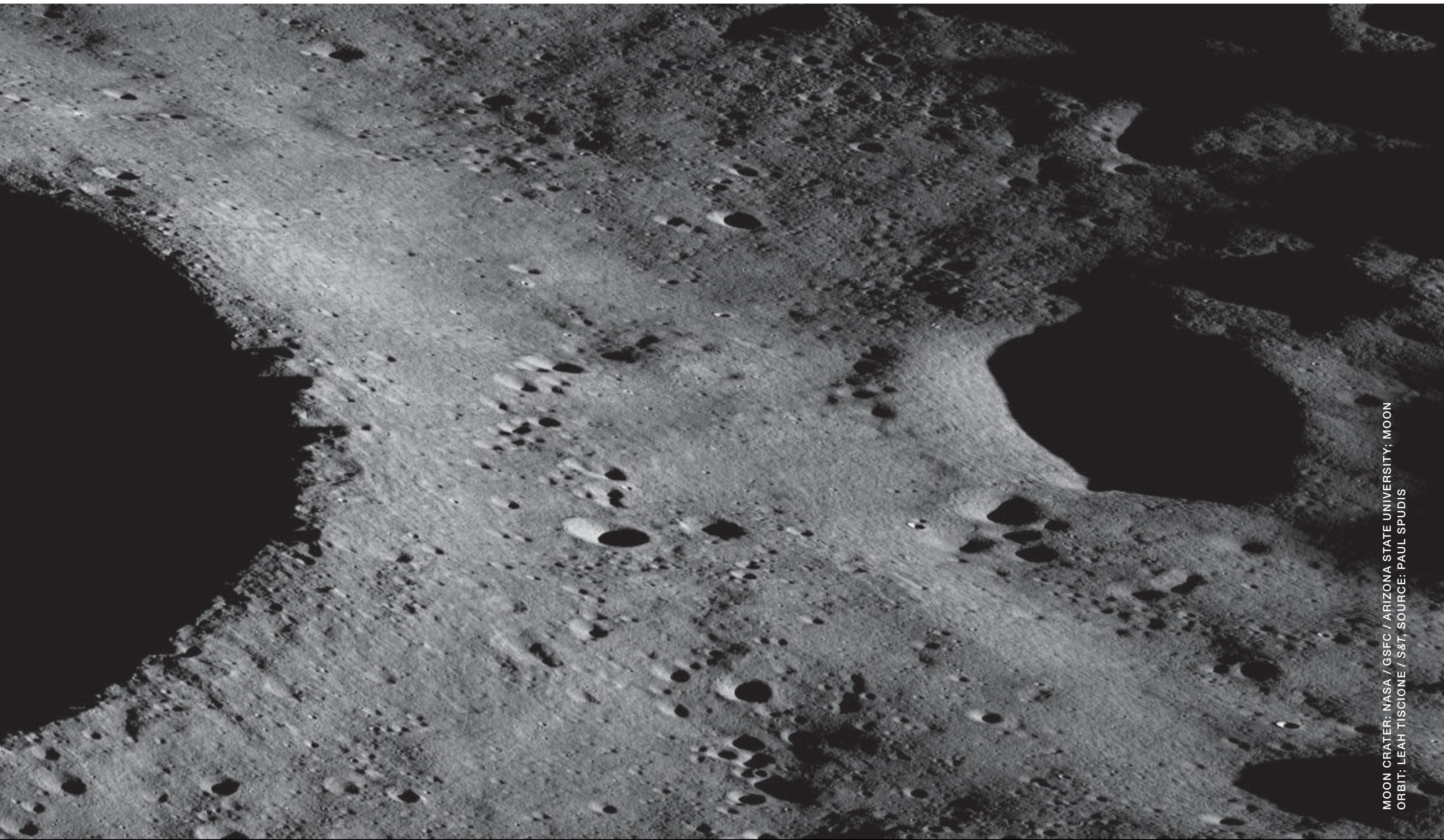
1961, Caltech scientists Kenneth Watson, Bruce Murray, and Harrison Brown extended that idea, suggesting that "water is actually far more stable on the lunar surface [than other volatiles] because of its extremely low vapor pressure at low temperatures and that it may well be present in appreciable quantities in shaded areas in the form of ice."

Space missions eventually proved they were right. In 1994, the Clementine orbiter confirmed that PSRs do exist on the Moon, pinging some with radio waves. The signals came back strong enough to indicate that among the polar rocks were likely deposits of water ice, which reflects radio energy more strongly than rock does. Four years later, an orbiter called Lunar Prospector found more evidence, indirectly detecting hydrogen atoms (presumably in water molecules) on and just below the surface. In a strange denouement, however, when the team deliberately crashed the craft into a PSR, they detected no water in the ejecta.

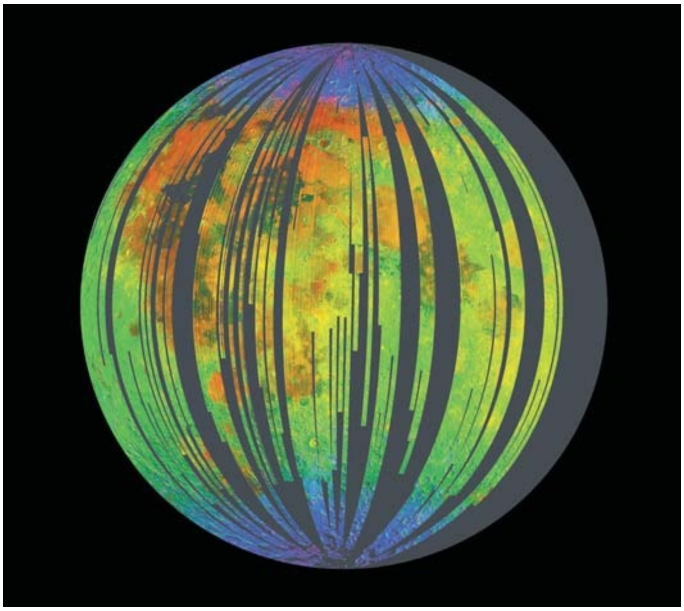
More than a decade would pass before the next leaps in lunar-ice research. During flybys of the Moon in 1999 and 2008, respectively, NASA's Cassini and Deep Impact spacecraft found tantalizing evidence for water on the lunar surface as they sped by.

By November 2008, India's Chandrayaan 1 satellite had arrived in lunar orbit, observing the terrain below with a suite of 10 experiments. Two of those, including the NASA-funded Moon Mineralogy Mapper (M^3), detected the spectrum of water-bearing compounds on the surface, and an instrumented probe released by the orbiter persistently detected whiffs of water vapor before it slammed into the Moon.

Then, on October 9, 2009, a NASA team deliberately crashed a Centaur rocket body into Cabeus, a large crater situated close to the Moon's south pole. The Lunar Crater Observation and Sensing Satellite (LCROSS) trailed the empty rocket stage in order to observe the ensuing plume of debris, which rose some 16 kilometers (10 miles). LCROSS kept recording data until it too slammed into the crater's



MOON CRATER: NASA / GSFC / ARIZONA STATE UNIVERSITY; MOON ORBIT: LEAH TISCIONE / S&T, SOURCE: PAUL SPUDIS



◀ **ICY FROSTING** This composite map, made at three infrared wavelengths by a NASA spectrometer aboard India's Chandrayaan 1 spacecraft, uses blue to denote small amounts of water and hydroxyl (OH) on the surface of the Moon. Their abundance clearly increases nearer the north and south poles.

floor. During the Centaur's impact, NASA's Lunar Reconnaissance Orbiter recorded a momentary flash and kept an eye on the temporary cloud of material. Its findings electrified the planetary-science community: Water ice and other volatiles were clearly detected.

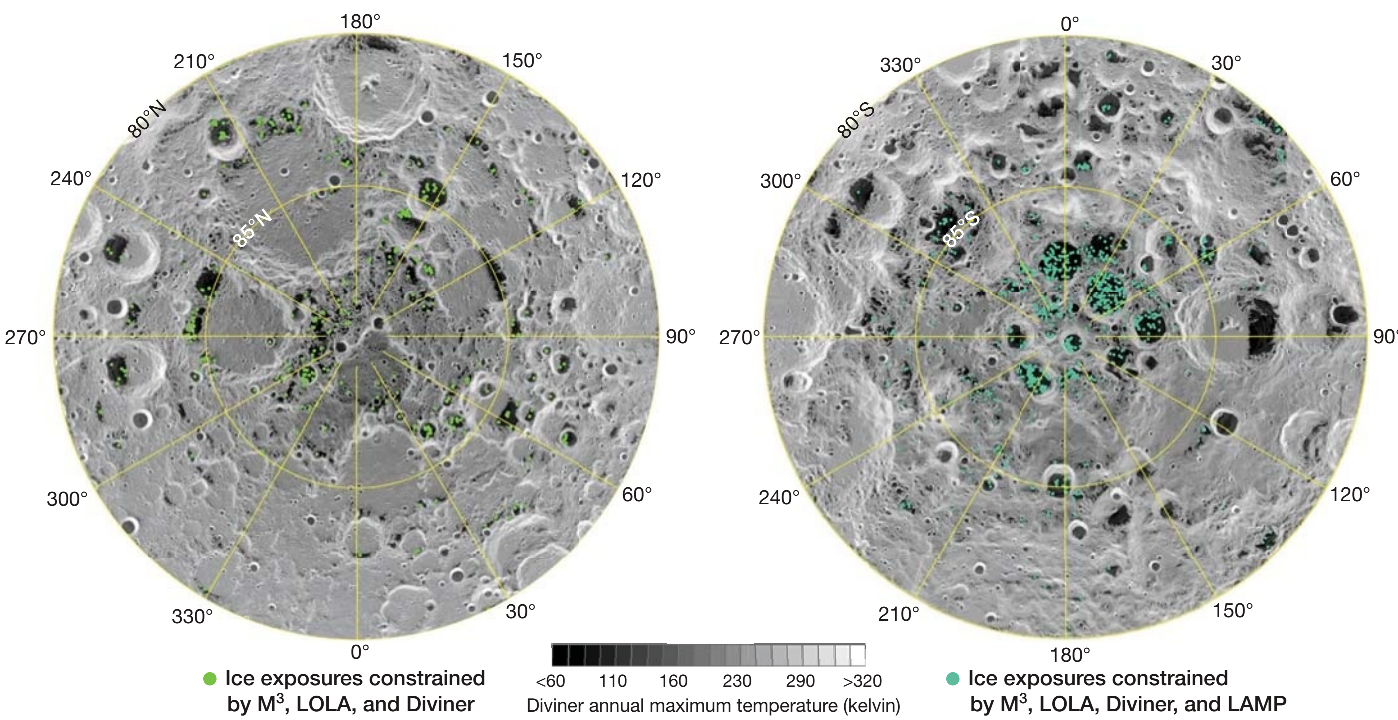
Nearly 10 years later, Shuai Li (University of Hawai'i) and colleagues combed more carefully through M³'s data and found spectroscopic evidence of light reflecting off water ice in many PSR locations surrounding the lunar poles. While less than 4% of the total sunless surface exhibits the spectral features of water ice, here and there up to 30% ice (by mass) might be mixed with the dusty regolith.

"Nobody believed there would be useful information in data collected from PSRs," Li explains. After all, how can you get reflectance spectra from a place without light? But Li decided to look after Apollo 15 astronaut Dave Scott told him that the Moon's rough topography can scatter light into shadows. Studying data with such weak signals was arduous, but the researchers found what they were looking for.

Meanwhile, other scientists using new laboratory techniques found trapped water inside Apollo samples from the Moon (*S&T:* Aug. 2018, p. 26). The Apollo-era paradigm of a bone-dry Moon was dead.

The Moon's Water Cycle

Water molecules have accumulated in shadowed regions over eons through direct deposit by other bodies, such as comets,



▲ **TREASURE MAPS** Colored dots show where water ice exists in the floors of permanently shadowed craters within 10° of the Moon's north *(left)* and south poles. These dots represent positive detections using a combination of instruments on the Lunar Reconnaissance Orbiter and Chandrayaan 1 spacecraft. Curiously, the coldest crater floors don't always have ice deposits — one notable example is the large crater Amundsen, on the 90° longitude line at the south pole. A closer look at the south pole is on the facing page.

and from volcanic gas that still leaks from the lunar interior. Water ice bonds tightly to bits of lunar dust and rock a few centimeters below the surface. Micrometeorite impacts release the water into the Moon's barely-there exosphere; sunlight's warmth and the solar wind can also send the molecules hopping about the lunar surface or launch them into the exosphere. Some molecules migrate randomly to PSRs, where the water apparently remains stable. The craters are very cold, about −240°C (−400°F).

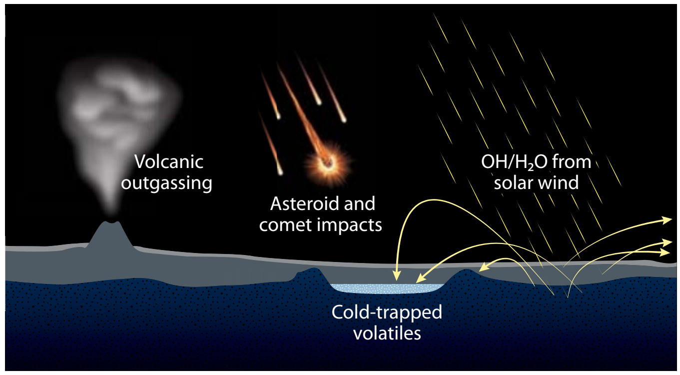
Ariel Deutsch (then at Brown University) and colleagues extended the analysis of Li's team by estimating the ages of craters near the lunar south pole. Most of the permanently shadowed real estate lies within 20 large craters at least 3.1 billion years old that contain patchy deposits of surface-exposed ice. But, puzzlingly, some ancient craters that should have ice deposits do not, possibly having baked during a reorientation of the Moon's spin axis and a resultant wandering of the lunar poles long ago.

Another mystery is why only about a quarter of 100 younger craters, all less than 15 km wide, show detectable exposures of water ice on their hidden floors. This ice is perhaps less ancient, having been delivered relatively recently by micrometeorites (instead of larger impactors in the distant past) and by the solar wind stirring up water molecules elsewhere on the surface. Or perhaps the water originated in some of the large ancient craters nearby. Some researchers suggest that the ice in both older and younger craters should be roughly the same age, because much older ice would have been destroyed over time by impacts and other causes. No one knows for sure.

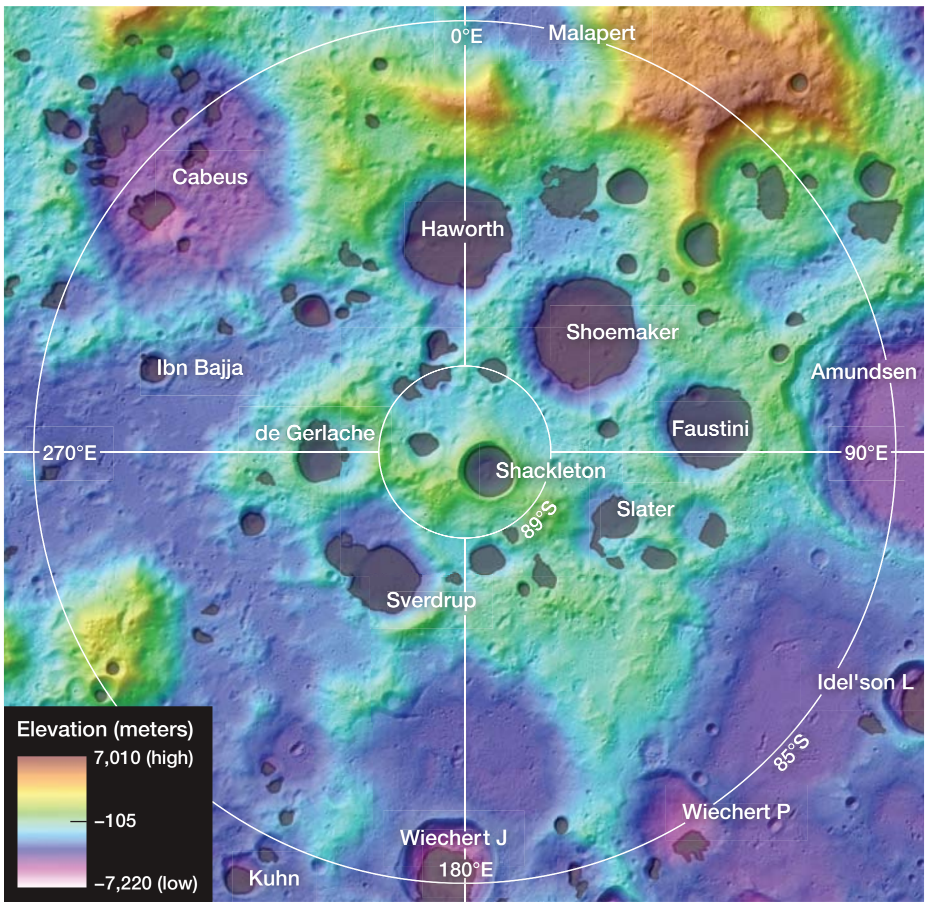
There's a lot we don't know. Says Deutsch: "What are the origins of the ice? What processes are responsible for the delivery, modification, and destruction of ice, and what are the relative strengths of these processes? What is the physical form of the ice (thickness, abundance, texture, etc.)? How does ice vary with depth [and] on lateral length scales?"

There may even be more icy craters than scientists have suspected. Lior Rubanenko (Stanford) and colleagues evaluated the depth and slope of thousands of lunar craters and found that the ones near the south pole are up to 50 meters shallower than equivalent sites closer to the equator. The likely culprit? Water ice filling the bottoms. Strangely, the shallowing trend does not hold with north-polar-region craters.

All told, Rubanenko and colleagues suggest that there might be up to 100 billion metric tons of lunar water ice — roughly the volume of Lake Tahoe, and much higher than others have estimated.



▲ **CRYO-CACHING** Water can reach the Moon's surface via the impact of water-rich asteroids or comets, the escape of gas from its deep interior, or the interaction of energetic solar-wind particles with lunar rocks. Over time, much of this water vapor migrates to permanently shadowed areas near the lunar poles, where it freezes on contact with the frigid surface and forms deposits.



▶ **WHERE THE DARK IS** A shaded-relief topographic map of the terrain within 5° of the Moon's south pole reveals how many craters have deep floors that are hidden from direct sunlight (gray shading). Note that some floors (such as in Cabeus at upper left) are only partly in permanent shadow.

LUNAR COLD-TRAP PROCESSES: GREGG DINDERMAN / S&T; SOURCE: KEVIN CANNON; SOUTH POLE MAP: JULIE STOPAR & HEATHER MEYER / LUNAR & PLANETARY INSTITUTE

The Next Wave of Exploration

Researchers might not have to guess much longer, as a trio of pint-size spacecraft are being readied to hitchhike to the Moon as secondary payloads on NASA's Artemis 1 mission. One of them is Lunar Flashlight, which the Jet Propulsion Laboratory touts as "the first CubeSat to reach the Moon, the first planetary CubeSat mission to use green propulsion, and the first mission to use lasers to look for water ice."

Barbara Cohen explains that scientists largely agree that lots of water ice lies just *under* the surfaces of PSRs. But Lunar Flashlight is looking for something slightly different: surface water ice. "There are multiple lines of observation that are consistent with water ice frost at the surface," she says. "But each observation could also be explained by other properties. Lunar Flashlight will be the final verification that it is or isn't water ice frost — if it is abundant enough for us to observe."

Using four near-infrared lasers, Lunar Flashlight will record the reflectivities and crude spectra of both ice-free rock and ice itself. Three craters have caught Cohen's eye: Haworth, Shoemaker, and Faustini. Though they are similar in size and lie next to one another at the south pole, the amount and distribution of water ice in each is different. This is puzzling.

Related investigations await two other CubeSats set to fly on Artemis 1. Morehead State University's Lunar IceCube will use an infrared spectrometer to look for water in all its forms across a swath of the Moon, trying to understand, among other things, how water and other volatiles move. Arizona State University, meanwhile, will fly LunaH-Map very low over the Moon, to do more precise neutron spectroscopy.

"The three missions represent the first ad hoc constellation of SmallSats fielded to study the Moon," says Benjamin Malphrus, who leads the Morehead State team. Each craft uses a propulsion system and trajectory specific to its mission, which is why Lunar Flashlight will be the first of the CubeSat trio to reach the Moon.

Working with a CubeSat requires "a whole collection of tweezers," jokes LunaH-Map's lead mechanical engineer, Joe DuBois (Arizona State University). "It's like working on a cell phone or something." The CubeSat is about a quarter the size of the "small" satellite DuBois cut his teeth on in the 1990s, and its computer is not even twice the size of a Rubik's cube. This means the assembly area is small, too — just a few tables and computers behind glass so visitors can see the work proceed. Only about three or four people are physically working on LunaH-Map, DuBois says.

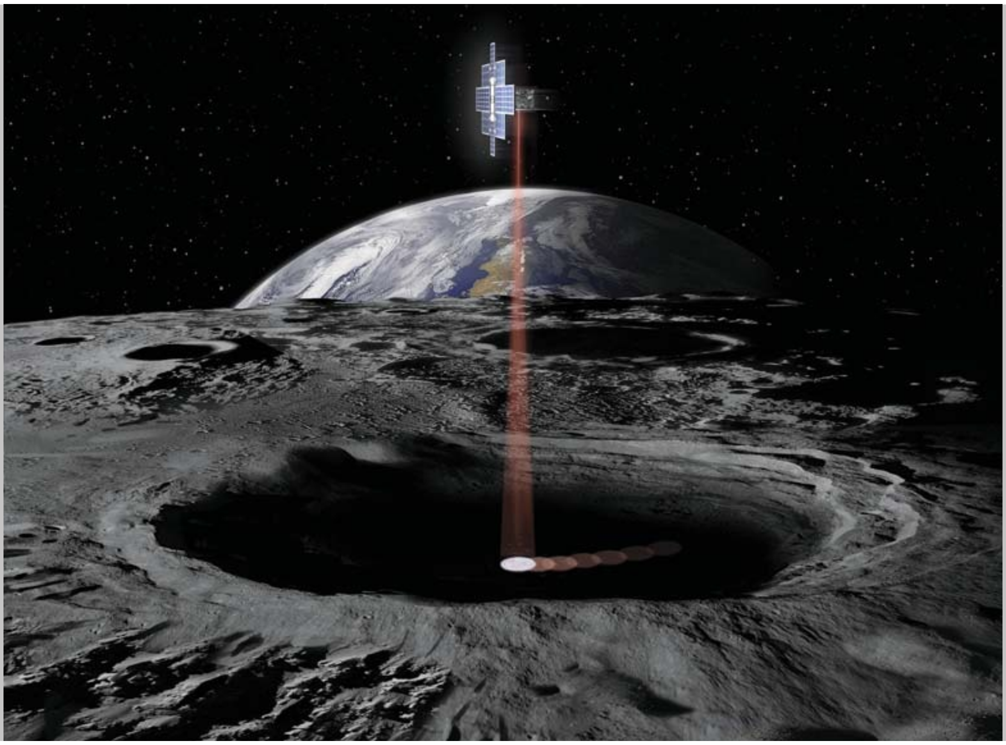
Although these satellites are small, they can be intimidating, admits Craig Hardgrove (Arizona State University). "There is no playbook to look towards for guidance." But the potential of these missions to pioneer new approaches to solar system exploration is exciting. "I think maybe we, along with all the other planetary CubeSat developers, are writing [the playbook] now."

Shining Some Light on the Problem

Then there's the mission named for a creature that doesn't like the cold but, on the Moon, will seek it out.

NASA's Volatiles Investigating Polar Exploration Rover (VIPER) is slated to launch in late 2023 and be delivered to the lunar south pole by the Griffin lunar lander. Engineered

▶ **CUBESATS** *Left:* NASA's Lunar Flashlight will use lasers at four near-infrared wavelengths to illuminate permanently shadowed regions near the lunar south pole and record the reflected pulses for evidence of water ice lying atop the surface. *Center:* IceCube's infrared spectrometer will measure the distribution of water and other volatiles across the entire lunar globe (not just shadowed areas) as a function of time of day, latitude, and the age and composition of the Moon's rock-and-dust regolith. *Right:* The LunaH-Map spacecraft will record neutrons coming from the lunar surface that have interacted with hydrogen atoms (presumably in water molecules).



NASA / JPL

for a 100-day mission, the fully robotic rover will be NASA's longest-running mobile lunar mission yet and will hunt for ice on or below the surface in selected southerly PSRs.

The solar-powered VIPER will be big: golf-cart size and weighing 430 kilograms (950 pounds). On board will be three spectrometers and a 1-meter-long drill to sample regolith and ice. With headlights and a camera, VIPER will provide dramatic, close-up views of *luna incognita* — the never-before-seen interior of areas that have not witnessed sunlight in eons. The lighting conditions and extreme temperature variations between sunlit and dark areas, swinging between –243°C and 27°C (–405°F and 80°F), present significant engineering challenges.

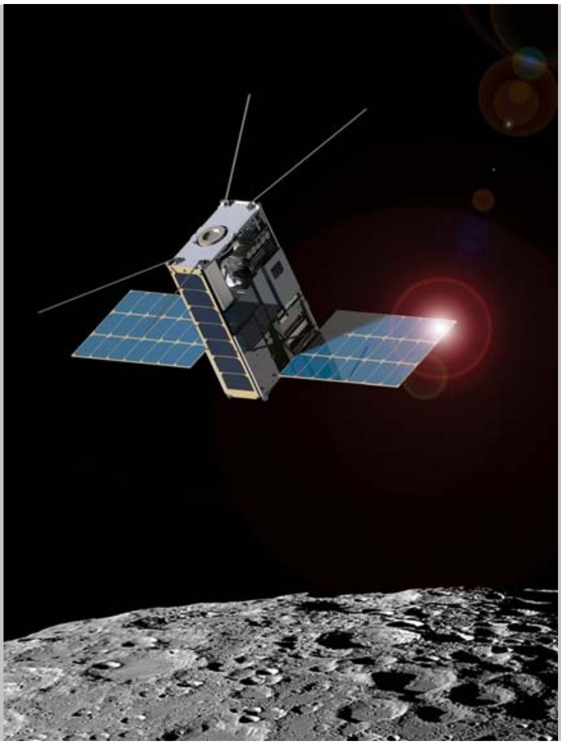
So, too, the ground itself. It's unclear just how loose or compacted the terrain will be, so VIPER, as mission planners write, "can drive sideways or diagonally, spin in a circle and move in any direction without changing the way it's facing." If it gets stuck, the rover will even be able to move each wheel independently to free itself.

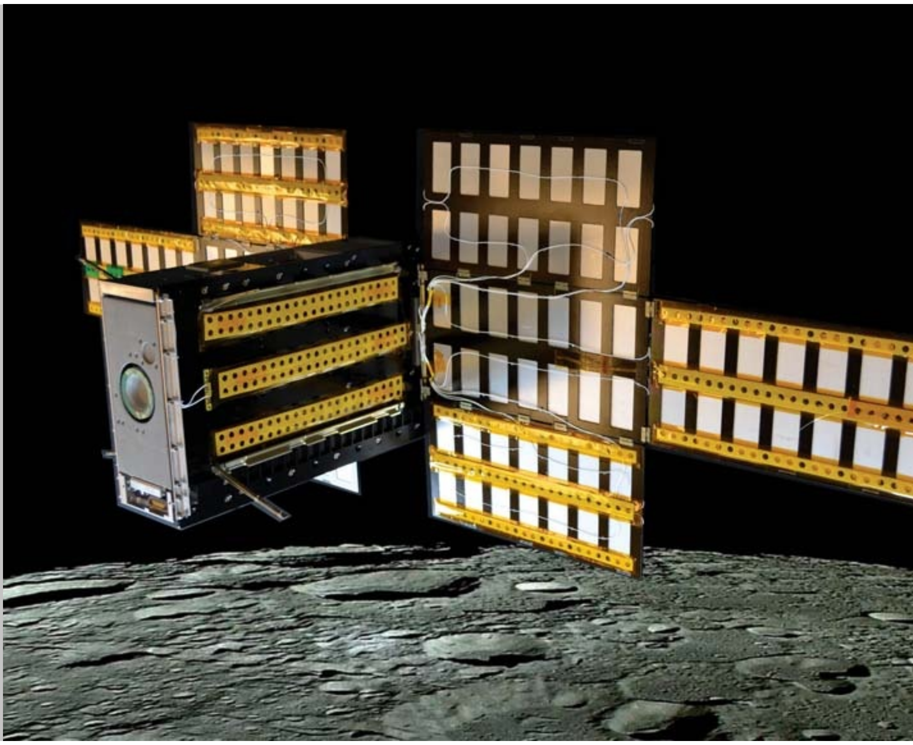
The rover will be told where to go, then get there on its own. With the need to recharge batteries and avoid extended dark, cold spells, VIPER will drive to higher terrain when it needs sunlight.

The trio of spectrometers are "absolutely killer instruments," says Richard Elphic (NASA Ames Research Center), team leader for VIPER's Neutron Spectrometer System. The NSS acts like a bloodhound, he explains. Like a bloodhound, the instrument will keep its nose close to the ground, in this case a meter or two above the regolith. Because the hydrogen in water has a strong effect on neutron flux, the rover will sniff out changes in hydrogen abundance and help clarify how ice's distribution changes with topography, temperature, lighting, and other factors.

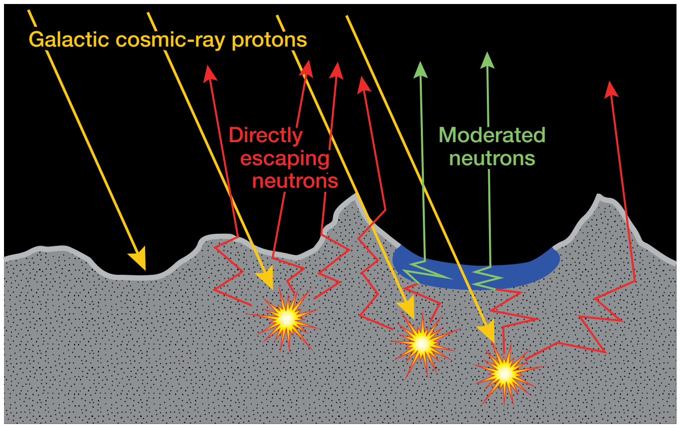
VIPER project manager Daniel Andrews (also NASA Ames) says that prior missions "answered the big dumb binary question" about whether there was water ice or not on the Moon. But "we didn't make great quantifiable measurements. We need a better understanding of the volatiles at the polar regions." If scientists can get such measurements at the south pole, then they will be able to extrapolate at least somewhat to the north pole.

▲ **ROVER INVESTIGATION** NASA's Volatiles Investigating Polar Exploration Rover, or VIPER, is a mobile robot that will roam around the Moon's south pole looking for water ice using neutron spectroscopy.





ICECUBE: MOREHEAD STATE UNIVERSITY; LUNAH-MAP: LUNAH-MAP / ARIZONA STATE UNIVERSITY; LUNAR ROVER: NASA AMES / DANIEL RUTTER



◀ **WHAT NEUTRON SPECTROSCOPY DETECTS** Cosmic rays constantly strike the Moon and liberate neutrons, which either get absorbed or scattered by interactions with rocks before escaping to space. But the neutrons lose a bit of energy if they glance off hydrogen atoms before leaving — hydrogen that's very likely bound up in molecules of water. So by recording these less-energetic "moderated" neutrons, scientists can map the extent and abundance of water-ice deposits in the top meter or so of the lunar surface.

The rover will land in an "unbelievably cold" and "very strange, never-seen-before region" that may have very little resemblance to the Moon we think we know, says Andrews. Already mission planners are sifting through thousands of candidate landing sites and traverse patterns, factoring in science needs, access to sunnier terrain, temperatures, sight lines with Earth for communication, and obstacle avoidance.

We'll learn more about such mission needs from a smaller rover called MoonRanger, under joint development by Carnegie Mellon University and CMU-spinoff company Astrobotic. Set to arrive in 2022, it will test navigation, communications, and mapping tools before VIPER lands.

This large-scale lunar exploration effort — joined as well by China (*S&T:* June 2020, p. 34) and other countries — would not be happening if not for the combined allure of scientific discovery and natural resources.

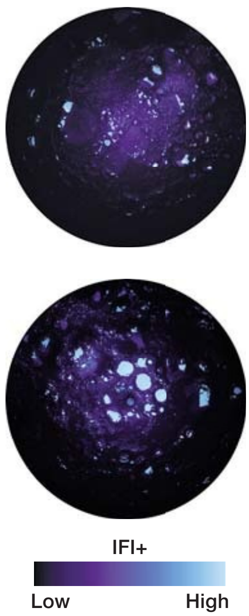
The cache of water and other volatiles stored at the lunar poles will provide valuable information about the creation and evolution of the terrestrial planets, including Earth, says Deutsch. "If we don't have the opportunity to study these records in detail, we lose access to the most accessible and potentially most complete record of the processes that have delivered and modified volatiles in the inner solar system."

Understanding the timing and processes for the deposition of surface and subsurface lunar water ice can also help us understand impact rates over time, Cohen points out.

But although science is in many ways driving the lunar revival, it might be economic activity and even settlements that translate to further progress. Researchers are also studying which deposits would be best for *in situ resource utilization*, processed for crew consumption or rocket fuel.

"On Earth, we've learned a tremendous [amount] about geologic processes and materials in the course of exploring for resources," says Kevin Cannon (Colorado School of Mines). "I think scientists should welcome economic prospecting and development of these ices, because it will result in them getting more data, samples, and new findings than they ever could have hoped for with scientific exploration alone." Given that there might be trillions of metric tons of ice present, it won't be gone any time soon, he adds.

Somewhere, W. H. Pickering may be smiling. There are no blizzards in Theophilus, but there are places on the Moon locked in a kind of interplanetary winter. It's a season that heralds breakthroughs for our understanding of the Moon.

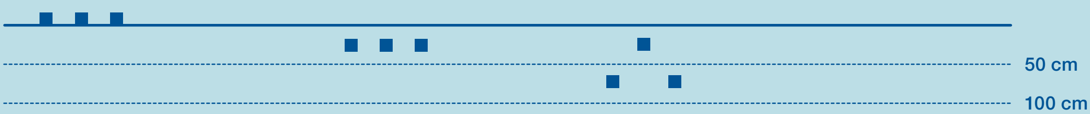


▶ **WHERE'S THE ICE?** These maps show the *ice-favorability index* (IFI), a predictive assessment of which regions near the lunar poles contain the most favorable ice deposits for future mining operations. They apply desired characteristics such as older crater ages, ice stability closer to the surface, and higher areal fraction of cold traps — but not ease of access. North pole on top.

■ **CHRISTOPHER COKINOS** is coeditor of the anthology *Beyond Earth's Edge: The Poetry of Spaceflight*. He teaches at the University of Arizona and is writing a book about the Moon.

WHERE IS THE ICE?

NASA scientists use four categories for where to look for ice on the Moon.



Surface region
Soils on the surface where ice is expected to be stable, such as in permanently shadowed craters

Shallow region
Soils where ice is expected to be stable within 50 cm (20 in) of the surface

Deep region
Soils where ice is expected to be stable at depths of 50–100 cm (20-40 in)

Dry region
Soils where no ice is expected within the top 100 cm (40 in)

NEUTRONS ESCAPING MOON: GREGG DINDERMAN / *S&T*, SOURCE: LUNAH-MAP / ARIZONA STATE UNIVERSITY; MOON MAPS: KEVIN CANNON & DANIEL BRITT / UNIVERSITY OF CENTRAL FLORIDA

OBSERVING
January 2021

The Pleiades twinkle above wintry trees, with Aldebaran (bottom right) and Capella (top left) completing the picture.
P-M HEDÉN

1 DUSK: Jupiter and Saturn are a little more than 1° apart as they grace the southwestern horizon after sunset. The pair become more conspicuous as they sink lower in deepening twilight.

2 EARTH passes through perihelion, its closest point to the Sun for 2021, just 3% nearer than at aphelion in July.

2 EVENING: The waning gibbous Moon rises in the east-northeast in Leo. Follow it as it climbs higher, with Regulus some 4° right.

3 ALL NIGHT: The brief Quadrantid meteor shower peaks at around 9:30 a.m. EST. Best viewing is between midnight and dawn, especially for western North America, but the waning gibbous Moon will interfere (see page 48).

10 DUSK: Jupiter, Saturn, and Mercury form a tight triangle as they set together in the west-southwest. Catch this sight before they sink out of view. Bring binoculars.

11 DAWN: The thin lunar crescent and Venus rise in the southeast with less than 4° separating them. Make sure you see this pretty sight before sunrise washes it away.

11 DUSK: A mere 1½° separates Jupiter and Mercury as they set in the west-southwest.

14 EVENING: Algol shines at minimum brightness for roughly two hours centered at 11:12 p.m. PST; see page 50.

17 EVENING: Algol shines at minimum brightness for roughly two hours centered at 11:01 p.m. EST (8:01 p.m. PST).

20 EVENING: Algol shines at minimum brightness for roughly two hours centered at 7:50 p.m. EST.

20 EVENING: The first-quarter Moon and Mars are about 6° apart high above the southwestern horizon. If you have binoculars, you should spot Uranus 1½° lower left of the Red Planet (see page 47).

23 EVENING: High above the southwestern horizon the waxing gibbous Moon is in Taurus, some 4° above Aldebaran.

26 EVENING: The almost-full Moon is now in Gemini, with Pollux roughly 7° upper left.

29 EVENING: Closing the circle, the Moon, one day past full, is again in Leo with 4° separating it from Regulus.
— DIANA HANNIKAINEN

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						

LAST QUARTER
January 6
09:37 UT

NEW MOON
January 13
05:00 UT

FIRST QUARTER
January 20
21:02 UT

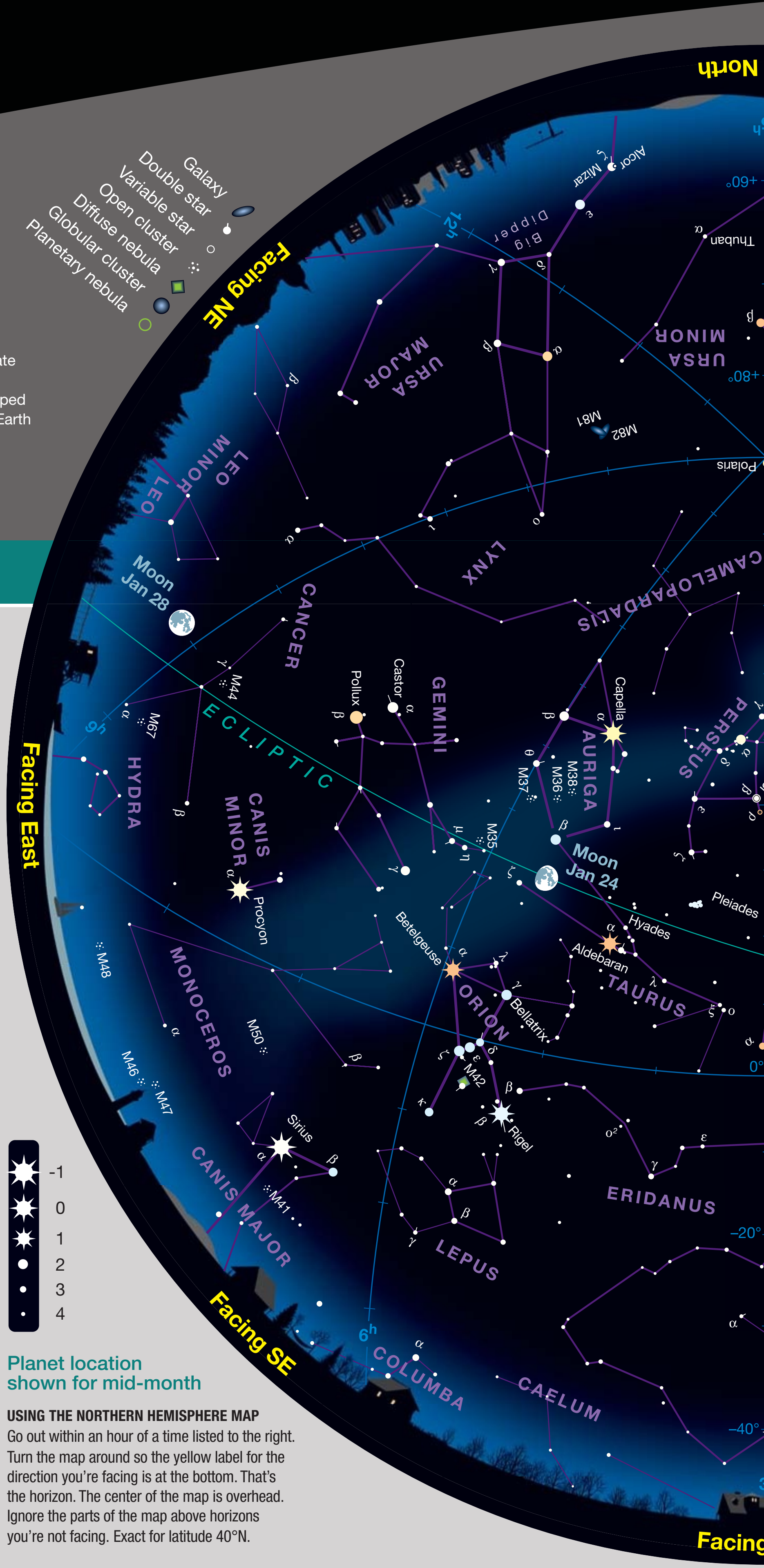
FULL MOON
January 28
19:16 UT

DISTANCES

Perigee	January 9, 16^h UT
367,389 km	Diameter 32′ 32″
Apogee	January 21, 13^h UT
404,360 km	Diameter 29′ 33″

FAVORABLE LIBRATIONS

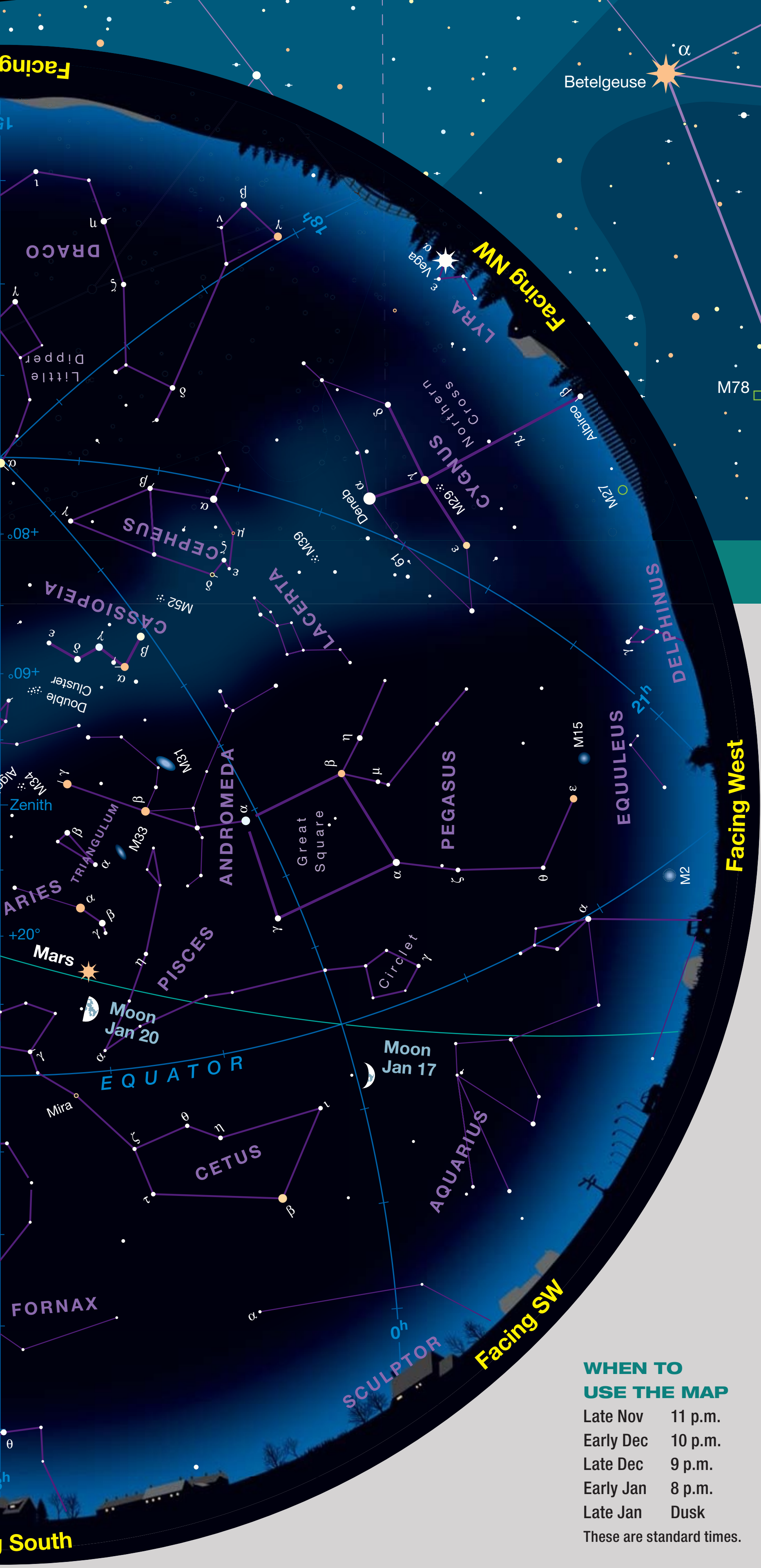
• Inghirami Crater	January 3
• Kircher Crater	January 8
• Bel'kovich Crater	January 19
• Pingre Crater	January 31

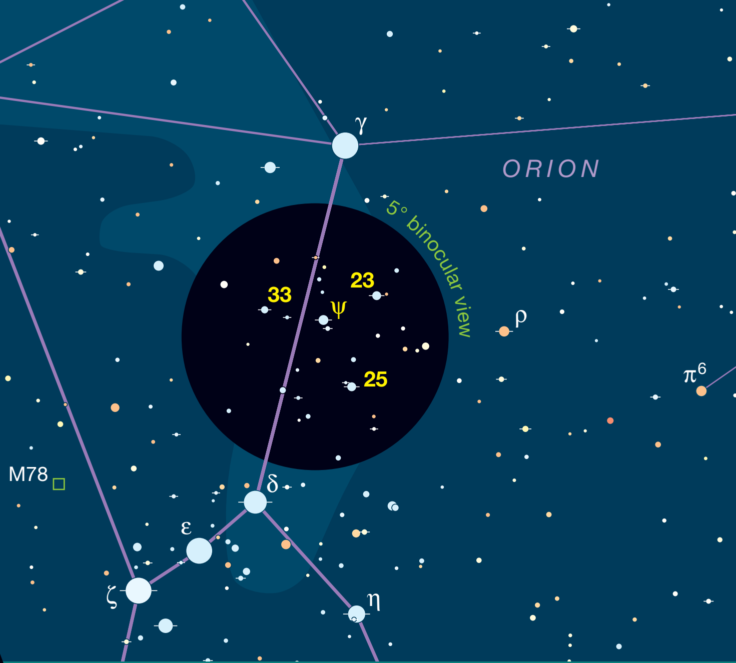


Planet location shown for mid-month

USING THE NORTHERN HEMISPHERE MAP

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





Binocular Highlight by Mathew Wedel

The Fires of Youth

I blame binoculars for my interest in the anatomy of the Milky Way. It was only after I fell in love with binocular observing that I realized how many large-scale structures of the galaxy require wide fields and low magnifications. Among my favorites are *OB* associations — groups of hot, young *O*- and *B*-type stars that are thought to have been born from the same giant molecular cloud.

The constellation Orion, the Hunter, is positively clotted with *OB* associations. You already know some of them: Orion's Belt, Sword, and the new stars being born from the Orion Nebula are all subsets of the Orion OB 1 association. Another subset, Orion OB 1a, hasn't reached the same level of fame, but it's an eminently worthy subject for binocular observation.

To observe Orion OB 1a, look about 3° northwest of Delta (δ) Orionis for a swarm of stars, roughly 4° across. Specifically, the Y-shape formed by **23**, **25**, **Psi (ψ)**, and **33 Orionis** is an easy-to-find "gateway" to Orion OB 1a. Looping around these stars is a donut of several dozen 6th-, 7th-, and 8th-magnitude stars, which appears less dense near Psi Orionis. The star 25 Orionis sits in a tight little knot of neighboring stars, and it's of particular astrophysical interest: This big, hot, fast-rotating star is burning its fuel 10,000 times faster than our own Sun, and it's therefore destined to blow itself apart in the not-too-distant future.

Given their size, proximity, and inherent fascination, I think *OB* associations will only attract more interest from amateur observers going forward. Unfortunately, few popular works exist on the subject. One useful entry point is Danish observer Allan Dystrup's "Classic Rich Field" project (**https://is.gd/ADystrup**). Happy hunting.

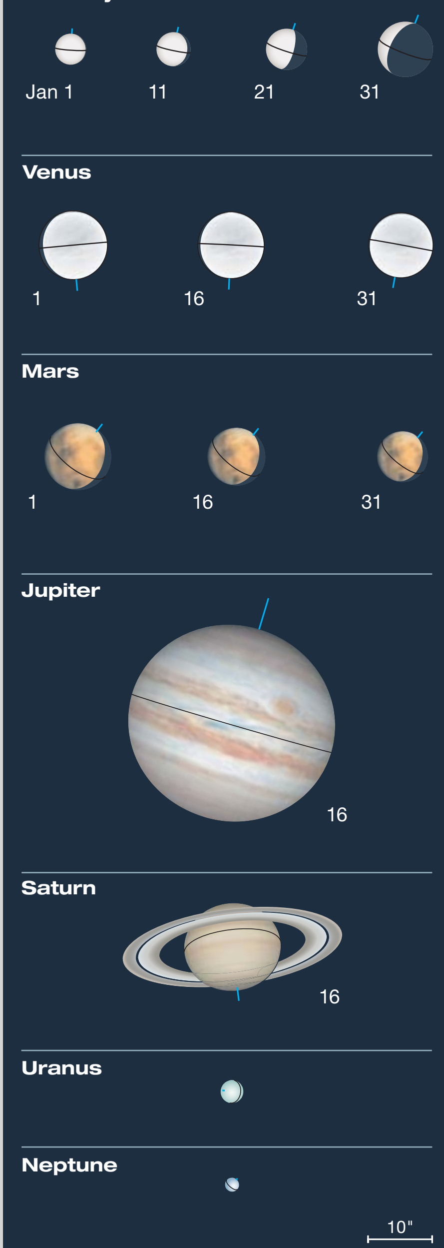
■ MATT WEDEL enjoys trying to fit the structure of the galaxy into his mostly structure-less brain.

WHEN TO USE THE MAP

Late Nov	11 p.m.
Early Dec	10 p.m.
Late Dec	9 p.m.
Early Jan	8 p.m.
Late Jan	Dusk

These are standard times.

PLANET VISIBILITY (40°N, naked-eye, approximate) **Mercury:** visible at dusk after the 8th • **Venus:** loses altitude at dawn but remains visible throughout January • **Mars:** transits at dusk and sets around 1 a.m. • **Jupiter:** can be seen at dusk until the 16th • **Saturn:** visible at dusk until the 7th.



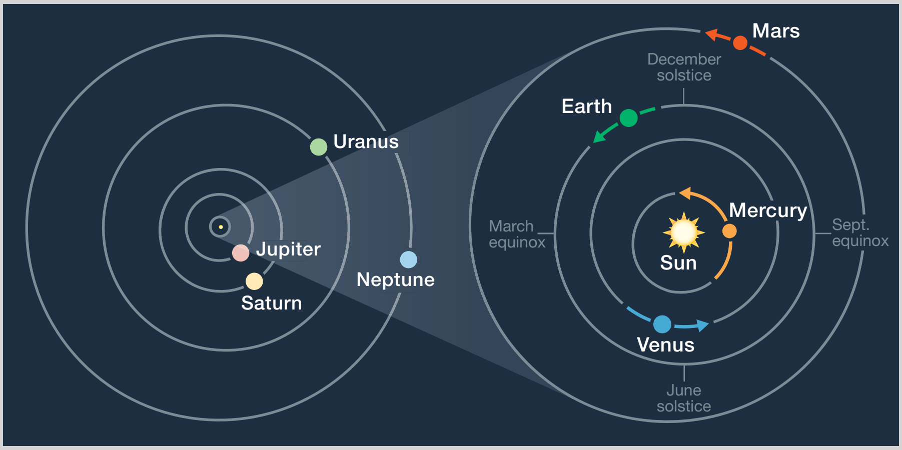
▲ **PLANET DISKS** have south up, to match the view in many telescopes. Blue ticks indicate the pole currently tilted toward Earth.

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

January Sun & Planets

	Date	Right Ascension	Declination	Elongation	Magnitude	Diameter	Illumination	Distance
Sun	1	$18^h 45.7^m$	–23° 01′	—	–26.8	32′ 32″	—	0.983
	31	$20^h 54.0^m$	–17° 27′	—	–26.8	32′ 28″	—	0.985
Mercury	1	$19^h 16.8^m$	–24° 23′	7° Ev	–1.0	4.8″	98%	1.390
	11	$20^h 26.5^m$	–21° 12′	13° Ev	–0.9	5.3″	90%	1.264
	21	$21^h 26.6^m$	–15° 51′	18° Ev	–0.8	6.4″	68%	1.050
	31	$21^h 51.2^m$	–11° 04′	15° Ev	+0.7	8.6″	23%	0.783
Venus	1	$17^h 17.2^m$	–22° 25′	20° Mo	–3.9	10.7″	94%	1.560
	11	$18^h 11.6^m$	–23° 11′	18° Mo	–3.9	10.5″	95%	1.594
	21	$19^h 06.0^m$	–22° 46′	16° Mo	–3.9	10.3″	97%	1.624
	31	$19^h 59.7^m$	–21° 11′	13° Mo	–3.9	10.1″	98%	1.650
Mars	1	$1^h 39.2^m$	+11° 14′	107° Ev	–0.2	10.4″	89%	0.899
	16	$2^h 05.5^m$	+13° 54′	98° Ev	+0.1	9.0″	89%	1.038
	31	$2^h 35.5^m$	+16° 34′	91° Ev	+0.4	7.9″	89%	1.182
Jupiter	1	$20^h 19.6^m$	–20° 05′	22° Ev	–2.0	32.9″	100%	5.994
	31	$20^h 48.5^m$	–18° 22′	2° Mo	–2.0	32.5″	100%	6.070
Saturn	1	$20^h 14.7^m$	–20° 14′	21° Ev	+0.6	15.2″	100%	10.900
	31	$20^h 29.3^m$	–19° 27′	6° Mo	+0.6	15.2″	100%	10.961
Uranus	16	$2^h 17.0^m$	+13° 15′	101° Ev	+5.7	3.6″	100%	19.565
Neptune	16	$23^h 19.5^m$	–5° 32′	53° Ev	+7.9	2.2″	100%	30.512

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



Orion's Magnificent Seven

Winter's best-known constellation is also its brightest.

WINTER LIGHTS Orion the Hunter stands out even amongst the many bright stars of the winter sky. The constellation's distinctive three-in-a-row Belt, along with Betelgeuse and Rigel, make it easy to identify.

AKIRA FUJII

I experienced my first evenings with the stars — that is, *real* outings of marveling and learning — in the winter in which I turned six years old. The first constellation I discovered that winter is still my favorite. It's also the one that almost everyone considers finest of all: Orion the Hunter.

The brightest constellation. There are only two constellations other than Orion that contain two stars of 1st-magnitude or brighter. These are the far-south groupings Centaurus (the Centaur) and Crux (the Southern Cross). But neither of these has the visual appeal of Orion. Crux is very small, and its cross shape lacks the crucial middle star. The main pattern of Centaurus contains many rather bright stars but is large and sprawling. In contrast, Orion's seven principal stars include +0.2-magnitude Rigel, +0.4-magnitude (usually) Betelgeuse, and five stars of roughly 2nd magnitude: Bellatrix, Alnitak, Alnilam, Mintaka, and Saiph. Together, they make Orion the most concentratedly brilliant constellation of all.

Compare Orion's seven stars to the same number making up the Big Dipper. This extremely famous *asterism* (an unofficial pattern of stars) contains no suns of 1st magnitude or brighter, a half-dozen 2nd-magnitude lights, and a single 3rd-magnitude star. Of course, the Big Dipper catches our attention because it so closely resembles such a well-known implement, a pan or ladle. But Orion represents the most familiar and interesting of all shapes to us: the human body.

Contrasting Betelgeuse and Rigel. No other constellation's brightest two stars provide so strong a color contrast as blue-white Rigel and orange-yellow Betelgeuse. Most people can notice the difference in these hues by glancing back and forth between the stars with the naked eye.

This month also provides the unusual opportunity to compare the colors of Betelgeuse and Mars. As our star chart (on pages 42-43) shows, both objects are visible together during evening hours. What's more, the Red Planet is currently in the same brightness range as Betelgeuse.

I've called both the star and the planet "campfire-colored." Robert Burnham, Jr., in his classic *Burnham's Celestial Handbook*, used a different descriptor. He wrote, "The exotic word *padparadscha*, used in India to designate the rare orange sapphire, might be an appropriate name for Betelgeuse."

The only first-magnitude star that varies greatly in brightness. Amazingly, last winter Betelgeuse unexpectedly dimmed so much that some observers estimated it to be as faint as magnitude 1.8. That's very slightly dimmer than the Hunter's other shoulder-star, Bellatrix, and two of the stars in his Belt. But historically Betelgeuse may also have been uncharacteristically bright at times. The great astronomer John Herschel wrote in December 1852 that Betelgeuse was then "the largest star in the northern hemisphere." In this context, "largest" meant "brightest," suggesting a magnitude of –0.1 or better — equalling golden Arcturus in Boötes. Former *Sky & Telescope* editor in chief Joseph Ashbrook also estimated Betelgeuse to be magnitude –0.1 at its most luminous during a period spanning 1937 to 1975.

Orion on the meridian. The blazing stars of Orion are near the meridian around 9 p.m. at month's end. Remarkably, the second and third brightest stars of winter (Capella, in Auriga, and Rigel, respectively) transit the meridian at almost exactly the same time.

■ **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.

Goodbye Jupiter and Saturn (and Mars)

A trio of prime telescopic planets reaches notable milestones.

FRIDAY, JANUARY 1

Going, going, going . . . . As the month opens, **Jupiter** and **Saturn** remain tightly paired low in the southwest at dusk, but they're slowly drifting apart while they set earlier and earlier. The duo is separated by just 1¼° this evening and are going to be a particularly striking sight in binoculars or a small, low-power telescope, both of which should add a couple of Jupiter's moons to the scene. (Look for Callisto, and perhaps Ganymede and Io, to the planet's left.) The gas giant pair will remain within 2° of each other until the 8th.

MONDAY, JANUARY 4

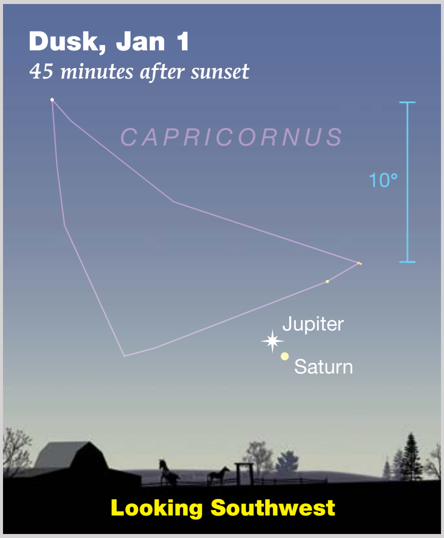
This date marks a significant milestone in the current **Mars** apparition. For the first time since last June, the Red Planet's disk will span less than 10″. So what? Although it's largely an arbitrary distinction, most Mars-watchers regard crossing the 10″ threshold as the point at which significant surface detail is no longer readily visible in moderate-size telescopes. In many respects this event marks the conclusion of the 2019–20 Mars season for all but the most dedicated planetary observers. And given its decline in prominence — Mars is just one-tenth as bright as it was at its peak last October — the winding down of the planet's remarkable run is obvious even to the naked eye.

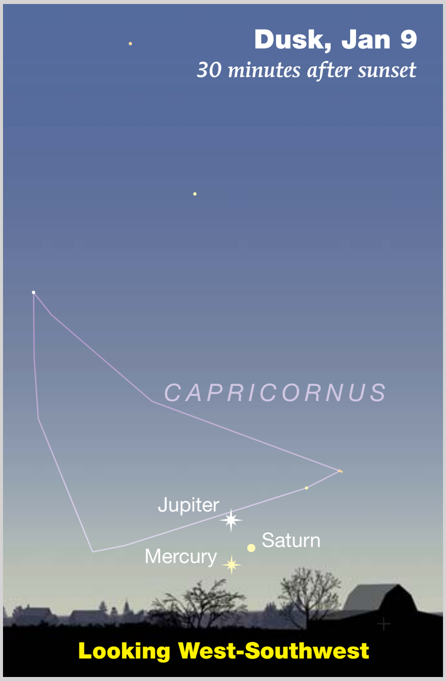
Although it's a diminished telescopic target, Mars isn't going away anytime soon. It will continue to adorn the evening sky through July but won't be in conjunction with the Sun until October — that's when the current apparition finally concludes and a new one begins. We'll have to wait until September 2022 before the Martian disk once again exceeds 10″.

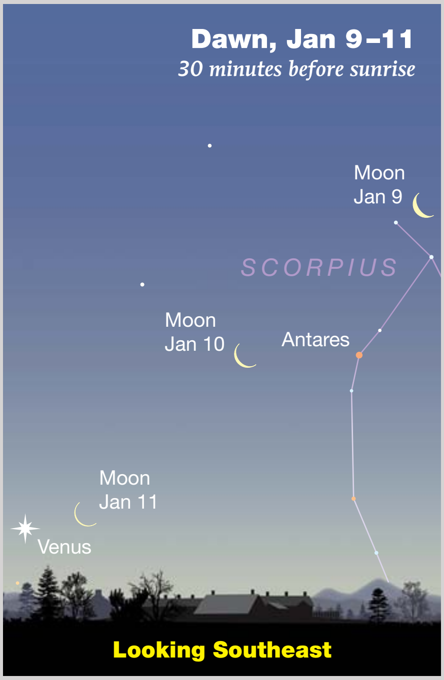
SATURDAY, JANUARY 9

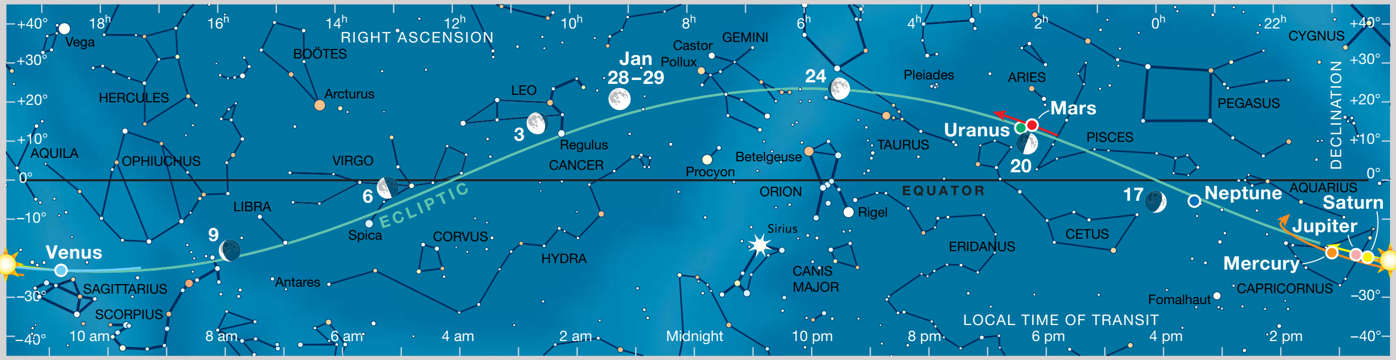
Very low in the west-southwest during evening twilight there's a planetary three-for-one, as Jupiter and Saturn are joined by Mercury to form a tight right triangle. Mercury is a bit more than 1½° from Saturn, which itself is roughly 2¼° from Jupiter. Given their very low altitude, it's likely you'll need binoculars (and a very clear sky) to see all three objects, with Saturn being the faintest and most difficult to pick out. On the following night (the 10th), Mercury will be halfway between the other two planets, and then on the 11th it will pull up alongside Jupiter.

▼▶ 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.







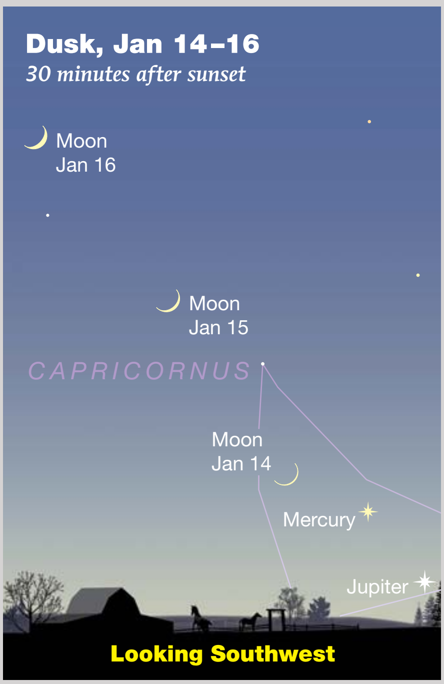


▲ The Sun and planets are positioned for mid-January; the colored arrows show the motion of each during the month. The Moon is plotted for evening dates in the Americas when it's waxing (right side illuminated) or full, and for morning dates when it's waning (left side illuminated). "Local time of transit"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

MONDAY, JANUARY 11

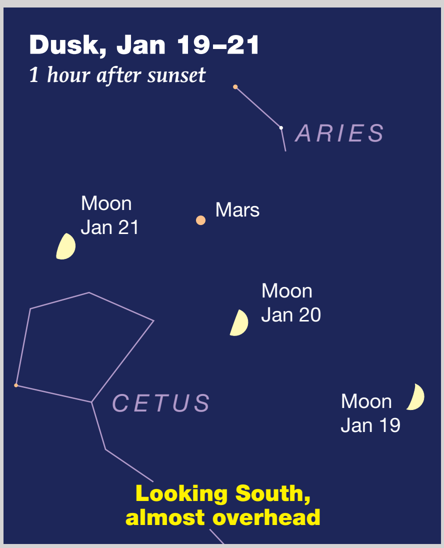
There are two essential truths to every **Moon-Venus** conjunction. First, they always involve a crescent Moon, thanks to the fact that Venus never strays terribly far from the horizon at dawn or dusk, which is where the Moon hangs out as either a waning or waxing crescent. Second, the encounters are reliably beautiful — and the closer, the better.

For this morning's pairing, the Moon is positioned less than 4° right of Venus, which gleams impressively at magnitude –3.9. That's close enough, however, for both objects to fit into the field of view of ordinary binoculars. The lunar crescent will be razor-thin — just a bit more than 3% illuminated, which makes seeing earthshine very easy. The one caveat to this show is that both objects will be low in the southeast and rise just one hour before the Sun. Worth getting up early for, though!



WEDNESDAY, JANUARY 20

This evening the first-quarter Moon hangs roughly 6° below Mars, high in the south. The later you look, the closer the two objects will appear, since the Moon is closing in on the Red Planet and will pass as near as 3° to its south at 4:50 a.m. EST on the 21st. Unfortunately, that's long after moonset, even for observers on the West Coast. Still, the contrast between the silvery-gray Moon and peachy-orange Mars is striking to the unaided eye even when the two objects are slightly farther apart.



As a bonus, binocular users should set aside a little time to catch **Uranus** positioned just a bit more than 1½° south-southeast of Mars. At magnitude 5.8, Uranus is easy to identify because it's the brightest dot of light that close to and south of Mars. (There's a magnitude-5.7 field star 42′ northwest of Mars, but its location means it's hardly likely to be mistaken for Uranus.) A scope will easily reveal the planet's tiny disk. If you have cloudy weather this particular night, don't fret. Uranus will be within 2° of Mars from the 18th to the 22nd, inclusive.

SATURDAY, JANUARY 23

Today **Saturn** is in conjunction with the Sun. For naked-eye observers, the ringed planet will become visible once again at dawn in the latter part of February, though binocular users will be able to pick it out sooner.

THURSDAY, JANUARY 28

Jupiter and Saturn have been together since their historic close pairing in December, so it's not surprising that they're both in conjunction with the Sun within a few days of each other. Although Jupiter reaches this point five days later (on the 28th), you'll likely spot it emerging at dawn first because it's 10 times brighter than Saturn.

■ Consulting Editor **GARY SERONIK** has been watching the night sky for five decades and is author of the book *Binocular Highlights*.

Sky Highlights for 2021

A full year of observing enjoyment awaits.

For our January Celestial Calendar installment, we've decided to present a "sneak-peek" selection of some of the most interesting celestial highlights for 2021. (Each event will be described in greater detail in upcoming issues.)

The coming year has its share of excitement, with several fine eclipses, the return of a few modestly bright periodic comets, and the usual assortment of meteor showers and eye-catching conjunctions.

January 3: The **Quadrantid meteor shower** peaks around 6:30 a.m. PST (14:30 UT). The timing of the peak means the display favors skywatchers on the West Coast and in Alaska. Unfortunately, light from the waning gibbous Moon in Leo will blot out many of the fainter meteors.

March 4: **Vesta**, the brightest and second-most massive asteroid, reaches opposition 1¼° northeast of 3.3-magnitude Theta Leonis, in the tail of Leo. At magnitude 6.0, Vesta is bright enough to be glimpsed by keen-eyed observers without optical aid from a dark sky. Binoculars will make the asteroid an easy catch.

The limb of the eclipsed Moon pokes out from the umbra in this photo captured during the April 15, 2014, total lunar eclipse. This view is similar to how the Moon will appear at maximum eclipse during November's partial lunar eclipse.

BOB KING

March 5: **Mercury** and **Jupiter** are just 21′ apart, low in the east-southeast at dawn. On this date, Jupiter will shine at magnitude –2.0, and Mercury at magnitude +0.1.

March 10: A thin, waning crescent **Moon** joins the planetary trio of **Mercury**, **Jupiter**, and **Saturn** in morning twilight. The group will span about 14°.

April 2: Jupiter's innermost moon, **Io**, passes just 0.5″ south of the 5.9-magnitude star **44 Capricorni** around 5:20 a.m. CDT. The event occurs with Jupiter low in the southeastern sky and favors observers in the middle of North America. (From locations in Central America and northern regions of South America, Io occults the star.)

April 25: **Mercury** (magnitude –1.6) and **Venus** (–3.9) are a little more than 1° apart very low in the western sky during evening twilight.

April 26: **A perigean full Moon** (popularly called a "supermoon"), occurs tonight. The Moon is full at 11:31 p.m. EDT (3:31 UT, April 27th) and reaches *perigee* (when it's closest to Earth) a little less than 12 hours later, at a distance of 357,377 km (222,063 miles).

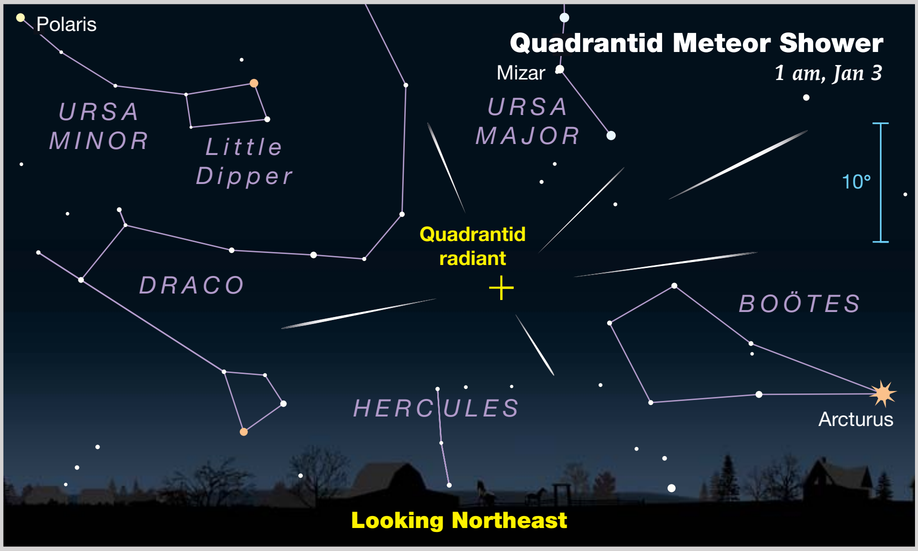
May 12: **Venus** and a very thin crescent **Moon** are only 1° apart, low in the west-northwest at dusk.

May 26: A **total lunar eclipse** is visible from western North America, though many other locations will be able to see at least part of the event. Because the Moon's northern limb is barely inside the Earth's umbra, totality will be relatively bright and brief, lasting from 4:11 a.m. to 4:26 a.m. PDT (11:11 to 11:26 UT). As it happens, this night also presents another "supermoon." The Moon is full (at 11:15 UT) a little more than 9 hours after reaching perigee, 357,310 km from Earth.

June 10: An **annular solar eclipse** is visible in Canada, Greenland, and Russia. The path of annularity crosses mostly remote locations (including the North Pole) except at its southern end along the north shore of Lake Superior, where maximum eclipse occurs at sunrise. Early risers in the northeastern U.S. will see a dramatic sunrise with roughly 80% of the Sun covered by the Moon. Greatest eclipse (lasting 3 minutes 51 seconds) occurs at 10:42 UT.

June 23: Observers across North America can see **Mars** (magnitude 1.8) smack-dab in the middle of the **Beehive Cluster (M44)** in Cancer, low in the northwestern sky at dusk. Use binoculars or a small, wide-field telescope to view this conjunction.

June 25: Skywatchers in the western half of North America can watch the nearly full **Moon** occult the 2nd-magnitude star **Nunki** (Sigma Sagittarii), in



▲ This month's Quadrantid meteor shower will be hampered somewhat by light from a waning gibbous Moon, which rises in the early evening on January 2nd. Given the timing of the display's peak, the best time to look will be in the predawn hours of January 3rd.

BOB KING

2021 Returning Comets

Comet 7P/Pons-Winnecke makes a favorable return in 2021 and may reach magnitude 10 in the morning sky as it shuttles from Aquarius to Piscis Austrinus during mid- to late June. Comet-watchers expect this to be its best apparition in several decades. You can begin searching for the comet in northern Ophiuchus as early as April.

Comet 6P/d'Arrest has a moderately favorable return in 2021 and could brighten to magnitude 9 at its peak in late August and September as it travels from southern Ophiuchus into Sagittarius.

Comet 67P/Churyumov-Gerasimenko returns to the inner solar system. This year's apparition is similar to the one it had in 1982, when the comet reached 9th magnitude and grew a pretty tail. On the night of perihelion (November 2nd) it's well placed for viewing, positioned 3° southwest of Pollux, in Gemini. Back in 1982, watching the comet evolve inspired me to track every future comet within my telescope's reach.

▲ Comets as spectacular as last summer's NEOWISE (C/2020 F3) are the exception rather than the rule. The much more common fainter comets require telescopes to see — including the trio of periodic comets highlighted above.

Shortly after Jupiter occults 44 Capricorni on April 2nd, the star passes just 0.5″ north of the Jovian moon Io, as seen in this simulation.

the early morning hours.

July 11: The thin, waning crescent **Moon** shines 5° right of **Venus** and **Mars**, which are separated by 1° low in the western sky at dusk. On the 12th, Venus and Mars are a scant ½° apart and shine at magnitudes of –3.9 and 1.8, respectively.

August 2: **Saturn** is at opposition.

August 12: The **Perseid meteor shower** peaks in the predawn hours. The waxing crescent Moon won't spoil the view because it sets around 10 p.m. local daylight time on the 11th. There might be a few extra meteors visible, courtesy of Comet Chacornac (C/1852 K1). On August 12th around 4:22 UT, the Earth will pass very close (15,000 km) to the comet's dust tail. The radiant for the resulting meteors lies in south-eastern Cetus near the star Pi Ceti.

August 18: The variable star **Mira** (Omicron Ceti) will be at or near its maximum brightness of magnitude 3.

August 19: The waxing gibbous **Moon** occults **Nunki** (Sigma Sagittarii) for observers in the southernmost U.S., Central America, and northern South America.

August 19: **Jupiter** is at opposition.

August 22: This morning features a **Seasonal Blue Moon**, that is, the third full Moon in a season that contains four. This is the original (and largely forgotten) definition of the Blue Moon as outlined in the *Maine Farmers' Almanac*.

September 14: **Neptune** is at opposition.

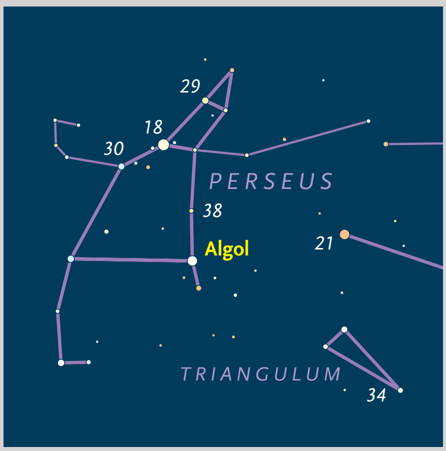
November 4: **Uranus** is at opposition.

November 19: A near-total **lunar eclipse** occurs this morning, visible from the Americas, northern Europe, east Asia, Australia, and the Pacific. A full 97.4% of the Moon will dip into Earth's umbral shadow. The remaining 2.6% of the southern limb will glow brightly, giving the Moon the appearance of Mars with a polar cap. First umbral contact is at 2:19 a.m. EST (7:19 UT); greatest eclipse is at 4:03 a.m.; and the Moon exits the umbra at 5:47 a.m.

November 27: **Ceres** is at opposition and shines at magnitude 7.0 in Taurus. The asteroid spends November crossing the Hyades and on the night of November 4-5 passes just a few arcminutes south of Aldebaran.

December 5: **Jupiter**, **Saturn**, **Venus**, **and the Moon** form a spectacular 50°-long line in the western sky in twilight. Over the following three evenings, the Moon will visit each planet in turn. Towards the end of December, Mercury joins the gathering.

December 14: The **Geminid meteor shower** peaks around 2 a.m. EST (7 UT), which is nearly ideal for North American viewers. Unfortunately, the waxing gibbous Moon (80% illuminated) will spoil the show until it sets at around 3 a.m. local time. For a few hours before morning twilight, there should be some excellent, moonfree meteor watching.



▲ Perseus is positioned at the zenith during evening hours in January. Every 2.87 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

Dec.	UT	Jan.	UT
3	6:54	3	19:55
6	3:43	6	16:44
9	0:32	9	13:33
11	21:21	12	10:22
14	18:10	15	7:12
17	14:59	18	4:01
20	11:49	21	0:50
23	8:38	23	21:39
26	5:27	26	18:29
29	2:16	29	15:18
31	23:05		

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**.

STELLARIUM

Action at Jupiter

THE JUPITER OBSERVING SEASON is ending. At the start of January the planet is low in the southwest and sets 1h 45m after the Sun. On January 1st, Jupiter shines brightly at magnitude –2.0 and presents a disk 33″ in diameter. By the 16th, however, Jupiter is unobservable to the naked eye and a poor telescopic target. (The planet is in conjuction with the Sun on January 28th.)

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

All the observable January interactions between Jupiter and its satellites and their shadows are tabulated below. Find events timed for dusk 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 Standard Time is UT minus 5 hours.)

December 1: 3:55, 13:51, 23:46; **2**: 9:42, 19:38; **3**: 5:34, 15:30; **4**: 1:26, 11:22, 21:17; **5**: 7:13, 17:09; **6**: 3:05, 13:01, 22:56; **7**: 8:53, 18:48; **8**: 4:44, 14:40; **9**: 0:36, 10:32, 20:27; **10**: 6:23, 16:19; **11**: 2:15, 12:11, 22:07; **12**: 8:03, 17:58; **13**: 3:54, 13:50, 23:46; **14**: 9:42, 19:38; **15**: 5:34, 15:29; **16**: 1:25, 11:21, 21:17; **17**: 7:13, 17:09; **18**: 3:05, 13:00, 22:56; **19**: 8:52, 18:48; **20**: 4:44, 14:40; **21**: 0:36, 10:31, 20:27; **22**: 6:23, 16:19; **23**: 2:15, 12:11, 22:06; **24**: 8:02, 17:58; **25**: 3:54, 13:50, 23:45; **26**: 9:42, 19:37; **27**: 5:33, 15:29; **28**: 1:25, 11:21, 21:16; **29**: 7:13, 17:08; **30**: 3:04, 13:00, 22:56; **31**: 8:52, 18:47

January 1: 4:47, 14:43; **2**: 0:39, 10:34, 20:30; **3**: 6:26, 16:22; **4**: 2:18, 12:14, 22:09; **5**: 8:05, 18:01; **6**: 3:57, 13:53, 23:48; **7**: 9:44, 19:40; **8**: 5:36, 15:32; **9**: 1:28, 11:24, 21:19; **10**: 7:15, 17:11; **11**: 3:07, 13:03, 22:59; **12**: 8:55, 18:50; **13**: 4:46, 14:42; **14**: 0:38, 10:34, 20:30; **15**: 6:26, 16:21; **16**: 2:17, 12:13, 22:09

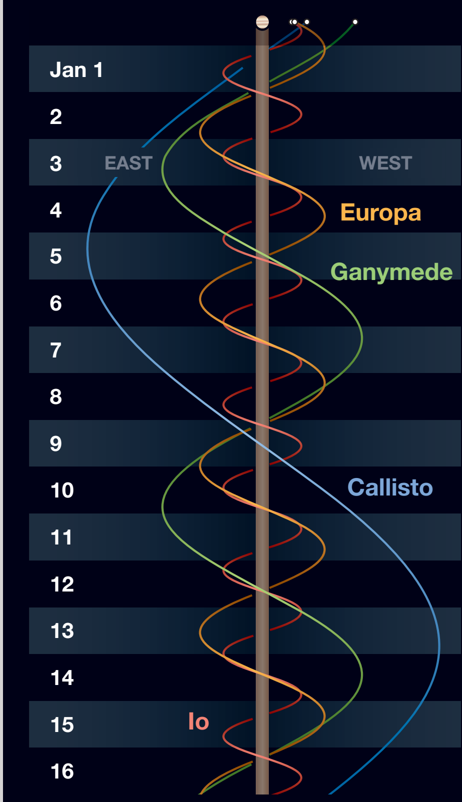
These times assume that the spot will be centered at System II longitude 349° on January 1st. If the Red Spot has moved elsewhere, it will transit $1\frac{2}{3}$ minutes earlier for each degree less than 349° and $1\frac{2}{3}$ minutes later for each degree more than 349°.

Phenomena of Jupiter's Moons, January 2021

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

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.

To this day observers report the unpredictable phenomenon known as the blue clearing. Spacecraft views like the above image from the European Space Agency's Rosetta probe conclusively prove that it is an illusion arising in the atmosphere of Earth rather than that of Mars.

The "Blue Clearing" on Mars

This legendary phenomenon is a product of Earth's atmosphere rather than the Red Planet's.

Late in September 2020, the renowned observer Stephen O'Meara reported that he was enjoying unusually clear views of Martian surface features through a blue filter. His remarks called to mind reports of a strange atmospheric veil on Mars that endured well beyond the dawn of the Space Age.

Early in the 20th century a number of astronomers began to photograph the planets through color filters. In the United States this work was conducted by Carl Otto Lampland and Earl C. Slipher at Lowell Observatory, Robert Trumpler and William Wright at Lick Observatory, and Frank Ross at Mount Wilson Observatory. Russian astronomers Aristarkh Belopolsky and Gavriil Tikhov undertook similar investigations at Pulkovo Observatory.

Mars displayed the most dramatic differences in appearance through color filters. In red, orange, and yellow light the planet's albedo features — the bright "continents" and dusky "seas" in 19th-century parlance — stand out boldly. In the blue region of the spectrum around wavelengths shorter than 450 nanometers, Mars often appears uniformly bright and devoid of features except for diffuse clouds and hazes near the morning and evening limbs, as well as in the regions above the polar caps. This bland appearance was attributed to the presence of a mysterious "violet layer" composed of aerosols or exceedingly fine particles of dust or ice high in the tenuous Martian atmosphere that selectively absorbs or scatters light of short wavelengths.

The violet layer was regarded as a permanent feature of the Martian atmosphere until 1937. For a period of several days around the date of opposition that year, Slipher's blue-light photographs, which required much longer exposures than in red light, captured the planet's conspicuous albedo features Syrtis Major and Sabaeus Sinus so clearly that he reported that they might have been mistaken for images taken through a yellow filter. He attributed this strange transient clarity to the sudden disappearance of the violet layer.

In the decades that followed, Slipher and many other Mars observers reported additional "blue clearings" that varied in intensity and lasted from a few hours to several days. According to Slipher, ". . . there is definite tendency for pronounced blue clearings to occur more often near opposition."

Looking for these events by carefully examining the planet through a Wratten 47 (blue-violet) filter became standard practice for several generations of dedicated visual observers. The reddish surface materials of Mars reflect only 5% to 7% of incident blue light. Combined with the fact that the sensitivity of the human eye falls off in this region of the spectrum, the excessive dimming of the planet's image through this dense filter made

◀ Earl C. Slipher of Lowell Observatory was first to record distinct albedo markings on Mars in blue light. This "blue clearing" became a phenomenon to watch for each apparition.

MARS: ESA; SLIPHER: TERENCE SPENCER

observations very challenging.

Blue clearings display a very puzzling characteristic — they are seldom localized, but usually occur over the entire visible hemisphere of the planet or were sometimes reported as a planetwide phenomenon. This is hard to reconcile with mundane meteorological explanations like the evaporation of aerosols or the settling out of dust particles. Even more confounding is the fact that the absorption or scattering of short wavelengths of light in the Martian atmosphere should decrease the brightness of the planet's polar caps, yet they stand out very clearly in blue and violet images.

Slipher reported that photographs taken on the same date at different locations around the world showed stark differences in the violet layer, ranging from virtual opacity to nearly complete transparency. In his classic 1962 book *Mars: The Photographic Story*, he recounted that "The 1956 observations showed plainly that the state of the blue clearing differed widely at Lowell Observatory [Arizona], Lamont-Hussey [South Africa], and Mount Stromlo [Australia], where observations were made on the same night."

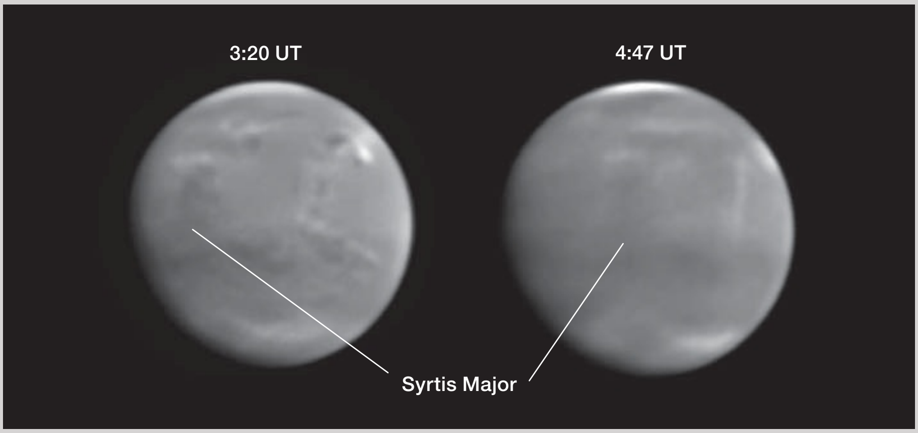
In 1967 Carl Sagan and James Pollack presented very convincing arguments that blue clearings originated in the atmosphere of Earth rather than Mars. They noted that the intrinsic differences in the reflectivity of the albedo features on the Martian surface are reduced at short wavelengths. Consequently, their outlines, which stand out so boldly in red and orange light, are very subdued in blue and violet light. Turbulence in Earth's atmosphere further reduces this contrast, which is invariably more pronounced at short wavelengths. Sagan and Pollack contended that blue clearings were simply occasions when the seeing improves sufficiently to permit the albedo features to be discerned more clearly visually or photographically, despite their muted contrast in blue light.

Seeing conditions vary from place to place and often change rapidly at any given location. This handily accounts for the seemingly sudden disappearance and reappearance of the violet layer over an entire hemisphere of Mars, as well as the profound differences in intensity reported from different observing sites on the same date.

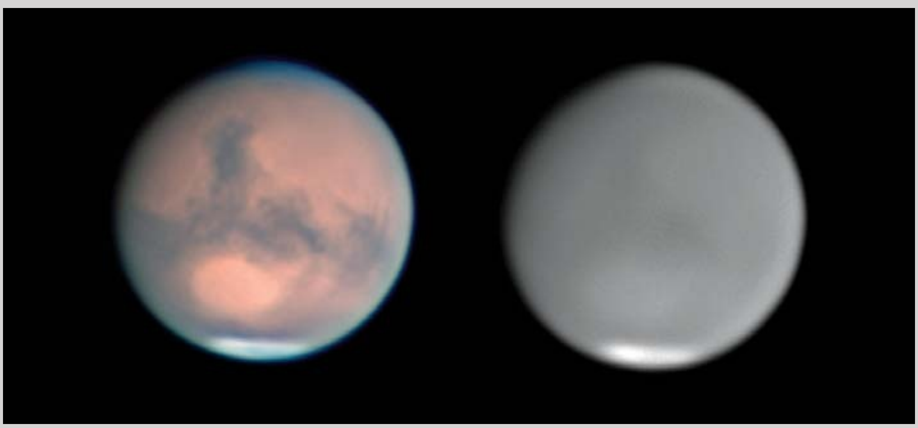
The purported tendency of blue clearings to occur near opposition may be attributable simply to the fact that Mars is at its closest to Earth at such times and has the maximum apparent size, making it easier to record low-contrast surface features than when the planet is more distant. Sagan and Pollack noted that blue clearings tend to be reported when the largest and most easily visible dark markings are located near the center of the disk. In addition, Mars is often at its highest in the sky around the time of opposition, increasing the odds of good seeing.

Belief in the violet layer was shattered when the Mariner 6 and 7 spacecraft took close-up photographs of the planet's topographic features through color filters in 1969. The clarity of the images was not perceptibly diminished in blue light. The veritable armada of spacecraft that followed has failed to detect the presence of any violet layer.

To my surprise, more than a handful of observing handbooks published in recent years perpetuate the myth of the violet layer and blue clearings. Perhaps to some, partaking of the mysterious can be more gratifying than solving a mystery.



▲This pair of Mars images, recorded with a 10-inch telescope through an Astronomik blue filter on the evening of February 8, 2008, shows the dramatic effect of a slight deterioration of atmospheric steadiness. At left, very steady seeing clearly revealed Syrtis Major. When the air became more turbulent nearly an hour-and-a-half later, the feature was almost invisible.



▲Though months past opposition, Mars still presents a sizable disk this month. The planet typically displays a bland disk in blue light (right) but watch for particularly steady seeing conditions in order to identify albedo markings through a blue filter (left).

SEAN WALKER / S&T (2)

■ Contributing Editor **TOM DOBBINS** often observed Mars through a Wratten 47 filter in hopes of observing the fabled blue clearing.

◄ **SUPERNOVA AFTERMATH** The Crab Nebula is a supernova remnant — a roiling cloud of shredded ejecta expanding from an exploded sun. The light from that stellar paroxysm 6,300 light-years away reached Earth on July 4th, 1054. Almost eight centuries later, in 1844, a sketch of the faint, irregularly shaped haze by Irish nobleman William Parsons, the Third Earl of Rosse, featured spindly filaments resembling the legs of a crustacean — hence the name Crab Nebula.

RON BRECHER

Taking on Taurus

Even under bright city skies, the Bull contains celestial sights worth seeking.

Welcome to Suburban Stargazer, our new bimonthly column dedicated to deep-sky observing in light-blighted backyards. I live in a small Canadian burg, a few blocks north of several brilliantly illuminated car dealerships. Believe me, I know the challenges and frustrations of city scoping. Like many of you, I can't always pack up and hit the highway in search of pristine skies. More often, I'm stuck at home. So, when the sky clears above my suburban yard, I set up one or two scopes and make the best of it.

I hope you'll join me as I track down various double stars, all kinds of clusters and nebulae — even the odd galaxy. Thanks to today's affordable quality telescopes and accessories, you can observe many celestial treasures in a compromised sky. Indeed, the number of faint fuzzies accessible from town just might surprise you.

So, let's turn off the porch light and get out there!

Taurus Up Front

The constellation Taurus, arguably the zodiac's most fearless figure, got a raw deal. Only the front portion of the big bad Bull is depicted on star maps — his rear end (mercifully for us) is lost in space. It's the region around Taurus's head and horns we'll be exploring in this debut installment of Suburban Stargazer.

The Bull's head is outlined by the **Hyades**, a vast, 4°-wide, V-shaped star cluster. The grouping is dominated by 0.8-magnitude **Aldebaran**, or Alpha (α) Tauri, although it's merely a foreground star and not a true cluster member. The reddish-orange sun symbolizes a bright bloodshot eye, while 3.5-magnitude **Epsilon (ε) Tauri** marks the other, less menacing eye.

I always enjoy sweeping across the sprawling Hyades Cluster using a scope at low magnification. But one wee Hyad, easily found halfway between Aldebaran and Epsilon, pays dividends at high power. It's a binary cataloged as **Σ559** (Struve 559) that sports identical 7.0-magnitude stars exactly 3″ apart. The far-off headlights of Σ559 resolve in my 8-inch f/6 Newtonian reflector at 135×. Nice!

The Bull's extra-long horns extend eastward from the Hyades. The southern horn goes from Aldebaran to 3.0-magnitude **Zeta (ζ)**, the northern one from Epsilon to 1.6-magnitude **Beta (β)**, or Elnath. Within that region are two 6th-magnitude open clusters. A diagonal line connecting Aldebaran to Elnath intersects both of them.

The first cluster, **NGC 1647**, is located on the western flank of the Taurus Milky Way, 3½° northeast of Aldebaran. At the correct spot, a finderscope will pick up two yellow-orange markers 5′ apart. The 6.0- and 7.5-magnitude stars point to our glittery prize immediately northward. In my 8-inch Dob at 50×, NGC 1647 is a moderately attractive catch. I count maybe 60 members, all but one fainter than magnitude 8.5, spread across 40′. Northeast of the cluster's center is a pretty tandem named **AG 311**, which features 8.9- and 9.3-magnitude stars separated by 33″.

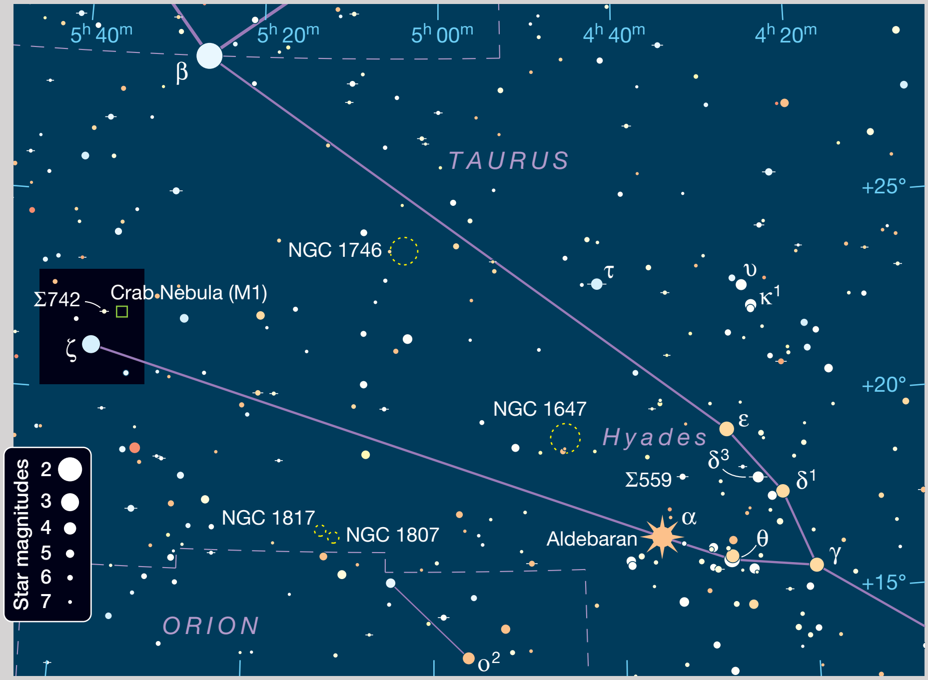
This distinctive double, plus numerous fainter pairs, jazz up the loose group.

Our 2nd specimen, **NGC 1746**, is situated deeper in the Milky Way, almost halfway from NGC 1647 to Elnath. My 8-inch captures some five dozen stars in two batches spanning 40′. Most obvious is a coarse scatter of at least 40 blue-white dots, again all but one dimmer than magnitude 8.5. The spray includes another delicate duo, **AG 313**, with 9.4- and 10.0-magnitude components 19.7″ apart, southwest of the cluster's center. A sharply bent "fence" of five 7th- and 8th-magnitude orange stars borders NGC 1746 along its eastern side. Bumping up the magnification to 135×, I notice something odd where the fence bends 90°. There, at NGC 1746's eastern extremity, is a 10′-wide clump of perhaps 20 very faint pinpoints. Recent research suggests this subgroup (possibly the object labeled NGC 1758 in some star atlases) might be a separate, more distant cluster.

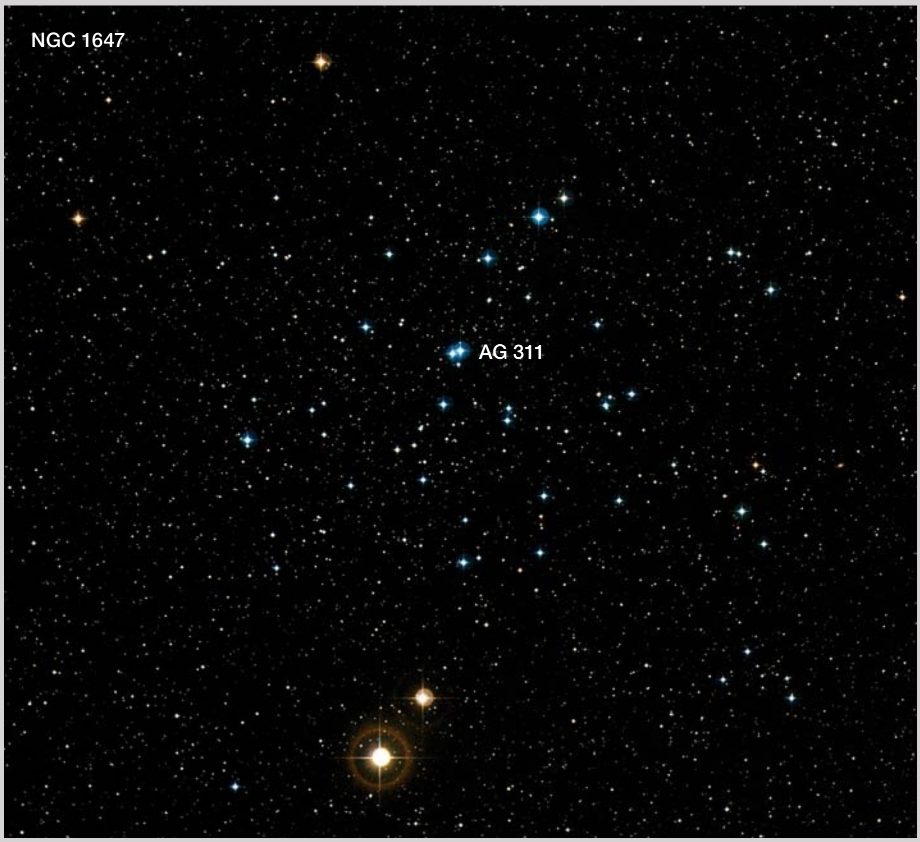
A Cosmic Crustacean

Near the tip of the Bull's southern horn is a truly famous fuzzy — the Crab Nebula, **M1**. This much-studied jewel is the remnant of a supernova that illuminated the night sky on July 4, 1054. English astronomer John Bevis discovered the nebulous wreckage in 1731. When French comet hunter Charles Messier observed the tiny mist in 1758, he was intrigued by its comet-like appearance. The "comet imposter" would become the initial entry in Messier's now famous catalog of deep-sky objects.

M1 is a 1° hop northwest from Zeta Tauri. But if you follow Ken's patented "Zeta Zig-Zag to the Crab," you can double your fun. From Zeta, go 18′ west to a double called **Σ740**. The generously spaced pair shine at magnitudes 9.0 and 9.9, 21.7″ apart, which makes them easy to resolve at low magnification. Next, turn northward almost 50′ to the binary **Σ742**. Its tight, 7.1- and 7.5-magnitude components are only 4.2″ apart but split beautifully at 100×. Finally, it's a ½° nudge westward to the cosmic crustacean.

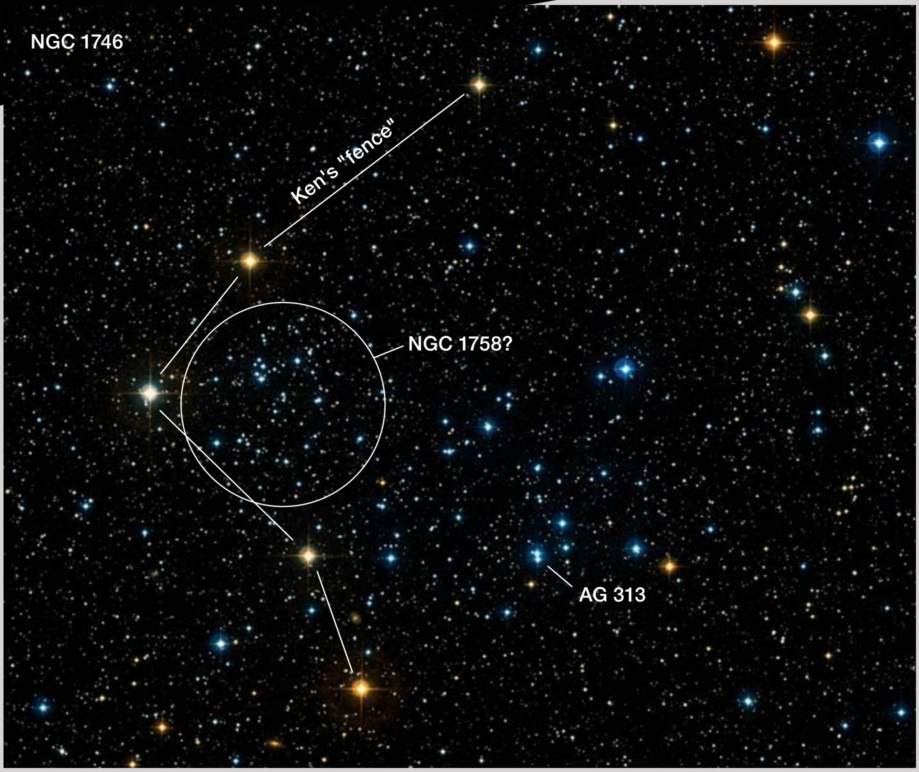


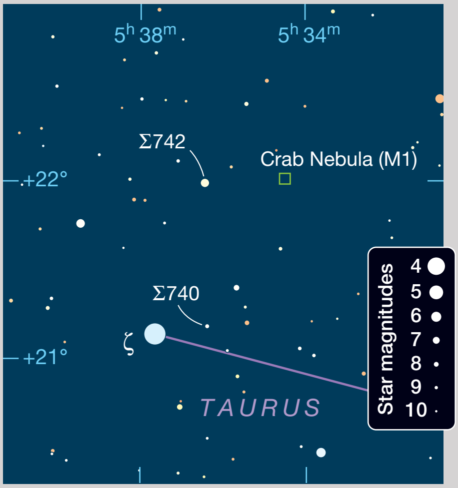
▲ **BETWEEN THE HORNS** The Bull's head and horns highlight the eastern half of the constellation Taurus. The head is symbolized by the huge Hyades Cluster, dominated by brilliant Aldebaran, only 65 light-years away. Two open clusters and the famous Crab Nebula are found in the area of sky between the horns.



▲ **MODEST TAURUS TREASURE** About 1,700 light-years from Earth, NGC 1647 is easy to locate a few degrees northeast of Aldebaran. Of the roughly 200 relatively faint cluster members, several dozen can be spotted in small backyard telescopes, including the attractive double star AG 311.

POSS-II / STSCI / CALTECH / PALOMAR OBSERVATORY





▲ **ONE TARGET, TWO CLUSTERS** The cluster identified as NGC 1746 is likely two clusters located at different distances. Based partly on historical observations, the bright, sprawling western portion of NGC 1746 is also (confusingly) designated NGC 1750, while the faint eastern portion is sometimes called NGC 1758.

The Crab glows modestly at magnitude 8.4, but its light is spread over a 6′ × 4′ area. The result is a low-contrast cloud that can be a challenge to detect in city telescopes. A couple of entries in my observing logbook from 20 years ago illustrate the difficulty and reward of fishing for faint fuzzies in a light-polluted setting: *M1 in Taurus: 4¼″ f/6 Newtonian, 50×: a slightly oval smudge. 100×: a bigger smudge!*

The next entry was more detailed:

10″ f/5.5 Newtonian, 116×: dim, diffuse, egg-shaped, oriented NW-SE, brighter at NW end, dimmer at narrow SE end (facing Zeta). 150×: nebula is a thick, blurry letter S. No filters used.

For city observers, light-pollution filters generally are a boon, but when it comes to the Crab, the situation is complicated. A broadband light-pollution filter or a narrowband Ultra-High Contrast (UHC) filter boosts the contrast between M1 and the background sky. However, the overall view (especially with a UHC) is darker. And the view in a doubly ionized oxygen (O III) filter is so dim that I don't recommend it. In fact, I prefer Crab fishing sans filter. My 8-inch, working unfiltered at 41×, pleasingly frames Zeta Tauri, a resolved Σ740, and the pale nebula. Your conditions might be worse than mine, so I encourage you to experiment with whatever filters you have.

January Is Taurus Time

I observed the Crab in the predawn late in the summer, when Taurus was halfway up the eastern sky. The positioning was perfect for the motions of my alt-az Dobsonian. M1 was a vertical hop from Zeta Tauri, and the clusters between Aldebaran and Elnath were a low-power horizontal slide from either star. For most readers, approximately the same orientation occurs at nightfall in mid-January, when there'll be no evening moonlight to spoil the view.

Eastern Taurus awaits. So, never mind the city lights — grab the Bull by the horns the first chance you get!

■ Contributing editor **KEN HEWITT-WHITE** studies the night sky from southwestern British Columbia.

Suburban Treasures in Taurus

Object	Type	Mag(v)	Size/Sep	RA	Dec.
Σ559	Double star	7.0, 7.0	3.1″	04h 33.5m	+18° 01′
NGC 1647	Open cluster	6.4	45′	04h 45.9m	+19° 06′
AG 311	Double star	8.9, 9.3	33.0″	04h 45.9m	+19° 10′
NGC 1746	Open cluster	—	—	05h 03.8m	+23° 46′
AG 313	Double star	9.4, 10.0	19.7″	05h 04.6m	+23° 39′
M1	SNR	8.4	6′ × 4′	05h 34.5m	+22° 01′
Σ740	Double star	9.0, 9.9	21.7″	05h 36.4m	+21° 11′
Σ742	Double star	7.1, 7.5	4.2″	05h 36.4m	+22° 00′

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.

◀ At the AAVSO's annual meeting held in November 1918, Annie Jump Cannon, Henrietta S. Leavitt, and Edward C. Pickering (clustered in the second and third rows at center) were among those in attendance.

AAVSO

A Century and Counting of Variable Stars

Have a hankering to get involved in research? Join the AAVSO.

Hundreds of years ago, the line between professional and amateur astronomers was fuzzy. Think of the great William Herschel. A musician and composer by training, he became fascinated with astronomy, built telescopes, and made discoveries still discussed today (such as the planet Uranus).

By the 1800s, growing demand for larger, more costly light-collecting mirrors went hand in hand with an increasingly rarefied environment of participation. Astronomy began closing itself off from those outside of professional circles — a trend compounded in the 20th century with the advent of satellites and ever-larger telescopes atop mountains. Professionals largely work in academia, while amateurs peer at the heavens from their backyards. Rarely the twain meet.

However, some astronomers on both sides work to bridge this gap. These intrepid individuals and organizations think that pros and ams have a lot to offer each other. In this new bimonthly column, we'll explore many kinds of pro-am collaborations. We hope that their examples will inspire you to join in — because science at its heart is DIY.

Our First Guest: the AAVSO. By the second half of the 19th century, pros had trouble keeping up with the data streaming in due to newly developed observing techniques, such as photography and spectroscopy. Institutes increasingly relied on the amateur community for observations of variable stars. Answering a call in the August 1911 issue of *Popular Astronomy* entitled "What an Amateur Can Do," lawyer and amateur astronomer William Tyler Olcott founded the American Association of Variable Star Observers (AAVSO) in November that year — and it's still going strong today.

AAVSO's mission is to "enable anyone, anywhere, to participate in scientific discovery through variable star astronomy." Its primary treasure is a vast database of long-term *light curves*, which trace the brightening and fading of various variable stars back more than a century. Amateurs provide the majority of these data. Knowing the long-term variability of stars enables astronomers to put episodic patterns or snapshot observations into larger context. Long baselines are also essential for making predictions of interesting behaviors.

The professional-amateur interface. Pros nowadays are stretched too thin between too many specialized projects and scrabbling over dwindling resources. Those shiny behemoths atop mountains? Many researchers only get a few hours *total* of observing time. Luckier ones might get a couple of nights. Hence, professional analyses are often based on a smattering of datapoints, which can lead to ambiguity. But the universe is dynamic. The only way we'll catch its surprises is with programs such as those championed by the AAVSO.

Also, since there are only so many nights per year, and so many projects to fulfill, the large telescopes are mainly reserved for cutting-edge science, pushing the envelope on faint and distant targets. In this competition, brighter sources can lose out. When Betelgeuse curiously dimmed at the end of 2019, AAVSO provided the crucial photometry.

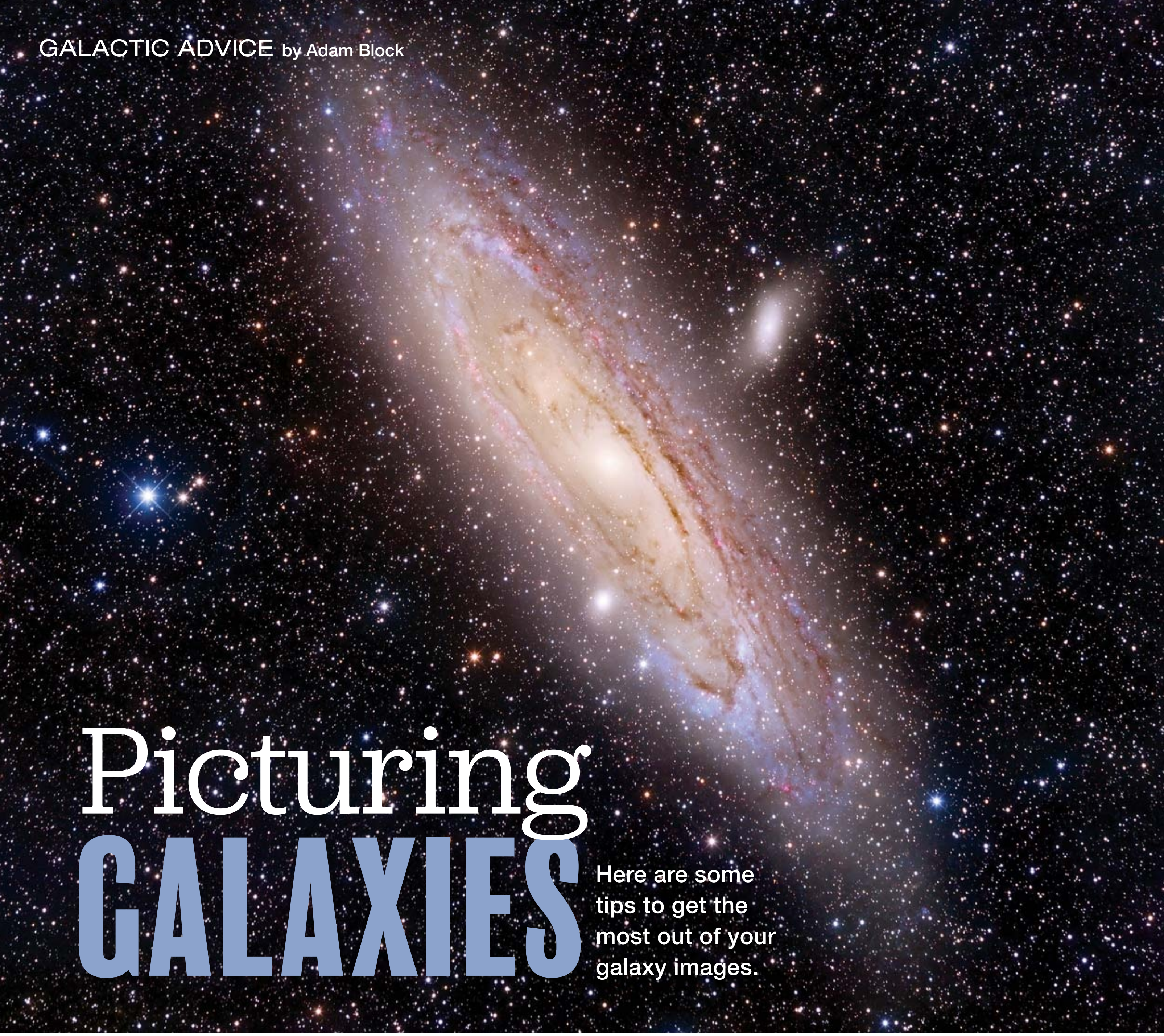
What can you do? If you'd like to participate in this august body's valuable mission, go to **aavso.org** and sign up. You can request a mentor who'll shepherd you in your first forays into the wonderful world of variable star observing. The AAVSO, via its helpful staff, provides rigorous training.

Depending on your interests, skills, and equipment, you can participate in a variety of programs through the AAVSO's observing sections, which include eclipsing binaries (e.g., Algol), long-period variables (e.g., Mira), and even exoplanets. Interested in spectroscopy? You can get involved in that, too.

You don't have to make the connection with pros on your own — AAVSO staff will act as liaison. Amateurs now work with international researchers across the globe and, increasingly, participate in data analysis. "The non-professional community are essential collaborators for the acquisition of data," says Stella Kafka, executive director of the AAVSO. "Amateurs *enable* research."

The line between pro and am astronomers is again happily fuzzy.

■ Observing Editor DIANA HANNIKAINEN works on both sides of the pro-am line.



Picturing GALAXIES

Here are some tips to get the most out of your galaxy images.

▲ **NEARBY SHOWPIECE** Producing aesthetically pleasing images of galaxies requires exercising restraint. Although we have the tools to increase contrast, color saturation, and sharpness, resisting the urge to go overboard with any of these tools allows the true nature of the subject to shine through. This fine example of M31 in Andromeda preserves the galaxy's bright nucleus while enhancing its bluish outer arms.

ALL IMAGES COURTESY OF AUTHOR

Beyond the Milky Way, there are a seemingly limitless number of galaxies that stretch to the edge of the observable universe. Except for all but the nearest dozen or so, their great distances from us make them appear maddeningly small and faint. Additionally, the combined glow of their stars results in objects that appear with low contrast, color, and detail, making galaxies a challenge to render in our images.

Most galaxies are significantly brighter in their centers compared to their outer extremes. Spiral galaxies that are undergoing a period of vigorous star formation tend to have bluish arms, with yellowish or colorless halos consisting of older stellar populations, pinkish H II regions, and reddened areas where dust attenuates starlight. Elliptical galaxies are dominated by older, red stars imparting a golden hue. This palette is fairly ubiquitous in the universe, and these simple truths shape the techniques I use to depict them in deep astrophotos. Here are some ways I approach the many different types of galaxies to produce colorful, detailed portraits that retain a pleasing appearance.

▲ **DISTANT BUT DETAILED** The Whirlpool Galaxy, M51, together with its interacting companion NGC 5195 in Canes Venatici, is much farther from us than M31 but displays many high-contrast features in larger instruments, including complex dust lanes, colorful regions of vigorous star formation, and a bright core. In many ways, each galaxy is unique and requires a different approach to achieve a faithful representation.

Squeezing the Dynamic Range

Let's start by contrasting two relatively nearby spiral galaxies — M51, the Whirlpool Galaxy in Canes Venatici, and M31 in Andromeda. Even though M51 is more than 10 times farther than M31, as a starburst galaxy the Whirlpool presents a rich, varying color palette with a bright disk. It and its companion galaxy, NGC 5195, appear as a tapestry filled with high-contrast features, including dark dust lanes and colorful H II regions. On the other hand, M31 is a very challenging target despite its closer proximity. Its bright nucleus appears virtually featureless in raw, unprocessed images, while its outer disk lacks the bright H II regions and strong color differentiation that's seen in M51. Nevertheless, M31 does contain subtle detail within its nucleus, and its outer disk displays muted color variations that require particular attention to tease into visibility. While applying processing techniques that modify these fundamental elements of M31, the question becomes: How far from the truth should a rendering stray to better present features of color and detail that are normally difficult to see?

The dusty details hidden within M31's central bulge are hard to see due to the sheer luminosity of the stars found there. Compressing this brightness range with non-linear stretching can help reveal them, but this completely removes a significant feature of M31 by making the nucleus appear to be nearly the same brightness as the galaxy's outer disk. A galaxy processed in this way starts to take on a different identity that strays far from the subject's actual appearance. Indeed, an audience unfamiliar with M31 might easily walk away believing this is how the galaxy normally appears. But with few exceptions, galaxies tend to have brighter nuclei than disks or outer halos. By exercising restraint when applying the process, I retain more of M31's essence and produce what I consider a more natural appearance. Of course, it isn't natural at all. Aesthetic astro-image processing is a blend of what is and what we want things to be, with a careful balance between the two.

In the wide-field image of M31 on page 58, the galaxy's outer arms are not strongly saturated in bluish light in a way they might appear with other spiral galaxies like M51. However, by increasing the contrast in the B channel of the image while operating in Lab color space in my preferred image-processing software, I can enhance the bluish star formation in the outer disk, but only to the degree that is still strongly correlated with the original data. M51's blue disk and M31's blue features are very different. These kinds of considerations are specific to processing galaxies based on the fundamental characteristics of these objects.

▲ **COLORLESS CORE** Allowing non-linear processes to equally affect the bright and faint regions in a galaxy can often lead to grayish, colorless nuclear regions, as in this example of NGC 7217 in Pegasus. You can avoid this problem by keeping the brightest areas in the galaxy from becoming saturated early in your workflow.

Care with Dust Lanes

Inclined spiral galaxies such as NGC 4698 in Virgo offer a different kind of challenge. Galaxies like it require colossal processing restraint with regard to its dust lanes. Another fact about galaxies is that any intervening foreground dust both attenuates and reddens the stellar light that shines through it.

We all have an evolutionary preference for high-contrast imagery, which leads to a nearly irresistible urge to increase the contrast in our images, especially with intrinsically low-contrast objects such as spiral galaxies. But the casualties of increasing contrast are the color variations and fluctuations in brightness within their dust lanes. Common processing techniques such as raising the black level, unsharp masking, and high-pass filters all increase the contrast and detail of a galaxy's dust lanes. But too much contrast reduces the dust lanes to an opaque, colorless, black etching across the subject. This increases the visibility of details within the dust lanes, but at the cost of the object's natural appearance. My approach would be to again exercise extreme restraint while applying these powerful tools to retain the truths of NGC 4698's appearance while enhancing prominent features. Galaxies don't really have inky-black dust lanes.

▲ **FLATTENED** In the two examples of M31 above, the image at left suppresses the brightness of the galaxy's core in order to better display its inner dust lanes, removing a key aspect of the galaxy. The image at right preserves this important detail, while still permitting the dust to be seen.

Retaining Color

One of the biggest challenges when processing galaxy imagery is retaining color in the central regions. Increasing the brightness and color in a galaxy while maintaining a smooth look in the fainter regions of the field often produces a near-colorless nucleus. The key to maintaining color in the core of a galaxy is to preserve it early in the processing workflow. Color can appear diluted when the brightness of an image exceeds 80% of the maximum value. This is due to how our eyes and brain perceive brightness and color. While there often is a colorless core in many galaxies, this should generally be the size of a typical star in the image. Not long ago, the digital development process (DDP) was the go-to tool used to manage this difficult area in most galaxies. Today, there are far more facile and powerful tools, such as HDRMultiTransform in *PixInsight,* that compress the dynamic range in an image while allowing for small-scale enhancements in the bright regions.

Star Treatment

Without exception, galaxies appear to float behind a foreground of stars residing in our own Milky Way. Quite often the stars are uniformly distributed across the field and play a lesser role in the final composition. The galaxy (or galaxies) is the focal point of the image, and, to the degree that processing choices affect the stars, I may permit them to be modified by the same processes, or in some cases, I may create masks to shield them from these effects targeting the main subjects of my picture.

Sometimes it's easy to become overly concerned with retaining star colors in the final composition even when those decisions negatively affect the appearance of the galaxy. Examples in which this can happen include galaxies seen through prominent arms of the Milky Way, such as NGC 6946, NGC 6674, and IC 342. In such cases, it's often a better approach to de-emphasize the stars in these fields so that the galaxy isn't competing with them for the viewer's attention. The exception is when a star (or group of stars) is very bright, you can use it as a balancing weight within the framed composition. This is usually done by placing your galaxy at one side of the image frame with the star (or stars) at the opposite end. Using these stars as a compositional element, it then becomes important to retain as many attractive qualities of the stars as possible.

Noise Reduction

Due to their faintness, galaxies present challenges in managing the amount of noise reduction applied to an image. Many nebulae have smooth brightness and color transitions across large areas. The faintest portions of these nebulous regions may look like the background sky itself and, often in the interest of contrast, are made to appear very dark without taking away from the overall impact of the image. By comparison, all but the nearest galaxies are smooth objects with small highlights of color and detail. Even modest noise-reduction techniques can adversely impact these elements. But the

▲ **OVER CONTRAST** *Top:* Increasing the contrast of dust lanes in a galaxy may be appealing but can lead to loss of color and other details in the image. *Bottom:* This picture of NGC 4698 avoids this tempting step, allowing other interesting details in the galaxy like the golden tone of reddened starlight in its dust lanes to shine through.

faintest outer extents of galaxies are often exciting features that we would like to highlight in our images and that require significant noise reduction. Some examples include arc-like shells or stellar streams that hint at ancient acts of galactic cannibalism. The difficulty is creating the selections or masks that apply a smooth transition from the high-signal areas where little or no noise reduction is required.

One of the easiest and most powerful techniques I employ is to simply magnify and process images at 200% or greater while working with noise-reduction tools. At this scale, I can see if I've made a reasonable choice with any given process, or if I've gone too far. A galaxy with a silky smooth outer halo and sharp, small-scale features in the brighter portions (including H II regions and foreground stars) can make a jarring transition for the eye to follow and forces the viewer to concentrate on the imager's processing choices, rather than the galaxy itself.

◀ **JARRING TRANSITIONS** Another minor detail to be aware of is the transition between areas that require noise reduction and the regions surrounding stars. In this close-up, the pixelated noise surrounding each star will draw viewers' attention, forcing them to focus on this minor oversight in the final image.

An edge-on spiral galaxy that illustrates this point well is NGC 5866 in Draco. Without applying strong non-linear compression and selective noise reduction, it would be impossible to see its narrow dust lane, yellowish core, and bluish arms simultaneously with its complex outer halo. With these considerations the otherwise featureless Spindle Galaxy is transformed into an edge-on galaxy with a visible history of galactic interaction with large tidal tails and shells.

A Good Plan

One final approach I use when processing galaxy imagery is to take inventory of all the interesting attributes and details in my subject early on. In most cases, significant details and features within a galaxy should be visible in the calibrated but unprocessed data in its linear form. If, later in processing, details and colors emerge that were not initially evident in the raw data, then there's a good chance these details are simply artifacts introduced by the processing. Additionally, by noting real features early in your plan, you can make processing choices better suited to reaching a final result that renders all of them well.

COMPOSITIONAL BALANCE Usually stars play a minor role in a galaxy image and don't require special treatment. The exception is when some bright stars, like the ones north of NGC 5792, play a supporting role in the composition. In such cases, it's often beneficial to retain their color and not have them appear as over-exposed dots.

▲ **BEST OF BOTH** Edge-on spiral galaxy NGC 5866 is surrounded by faint star streams that suggest a complex history of galactic cannibalism. Although known as the Spindle Galaxy due to its appearance (left), a simple non-linear stretch (middle) brings out these star streams, but at the expense of its inner spindle-like dust lane. Careful use of *PixInsight*'s HDRMT tool with special attention to the transition between the outer areas and the inner details helps to tell the entire story of this fascinating galaxy (right).

One question I often receive when delivering an image-processing workshop after discussing image calibration is, "How do you know what to do next?" The answer is somewhat akin to Ansel Adams's technique of previsualization. While Adams stressed the importance of imagining what he wanted the final print to reveal about a subject before entering the darkroom, I approach galaxy processing based on my initial inventory of interesting features. Each subsequent processing decision both enhances some aspect of an image's attributes while protecting others so that they do not suffer in their appearance or visibility.

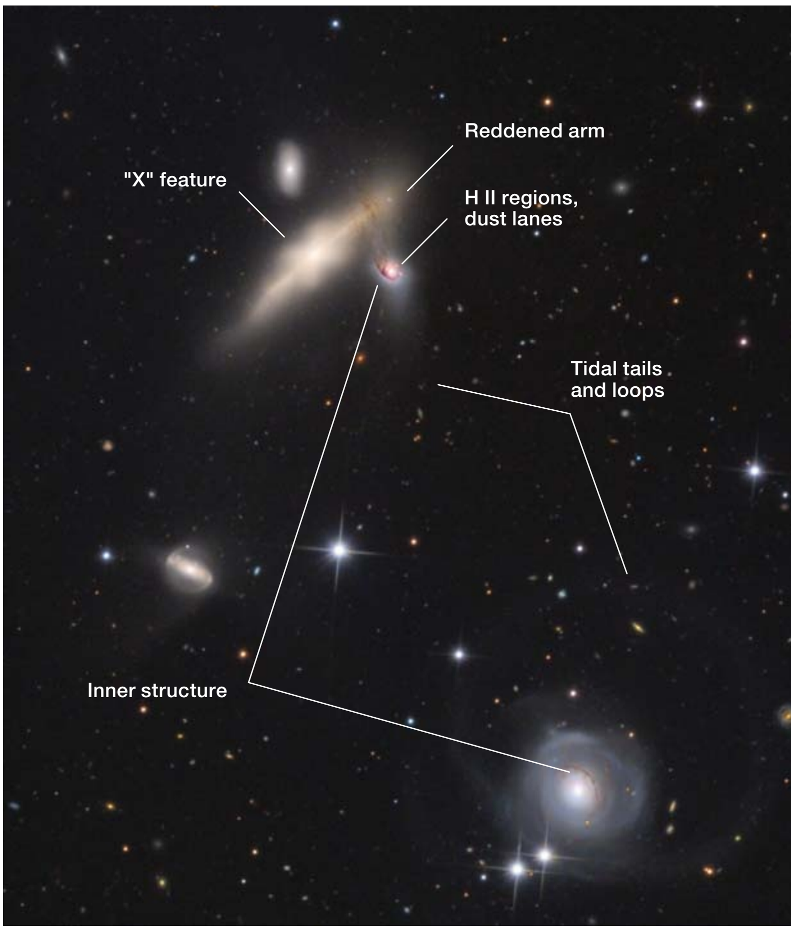
Galaxies are particularly well suited to this way of thinking. For example, I note a wealth of information while examining my unprocessed images of the lenticular galaxy NGC 128 and its neighbors in Pisces. A short list of interesting features to highlight includes:

1: Faint outer tidal tails (and stellar streams around nearby NGC 125).
2: The X-shaped nucleus of NGC 128.
3: Dust clouds extending from NGC 127 crossing in front of the northern extent of NGC 128.
4: The same dust from NGC 127 makes NGC 128 redder on this portion of the galaxy.
5: Small-scale details in both the nucleus regions of NGC 127 and NGC 125.

Carefully monitoring these details during each processing step informs the final picture. As experienced processors know, it's all too easy to introduce artifacts along the way. In a sense, the galaxies themselves tell me what to do next.

Galaxies are by far the most numerous deep-sky objects to observe in astrophotography. Each has its own features and characteristics. Even if you don't adopt all of the ideas presented here, the attention you give to them will certainly help raise awareness of what is in your hard-won data and bring your own imaging to a higher level.

■ **ADAM BLOCK** is a world-renowned astrophotographer based in Tucson, Arizona, and founder of the University of Arizona's Mount Lemmon SkyCenter.



▶ **PLAN OF ATTACK** A great method when approaching any image is to make note of important details before beginning the work. This galaxy group in Pisces, including NGC 128 (top left), NGC 127 to its right, and NGC 125 (bottom), boasts a number of interesting features I set out to highlight before beginning any digital-darkroom enhancements.

The Schiller *Enterprise*

The story of one man's inspired attempt to recast the constellations of mythology with biblical figures

The constellations seem to have been purposely named and delineated to cause as much confusion and inconvenience as possible. Innumerable snakes twine through long and contorted areas of the heavens where no memory can follow them; bears, lions and fishes, large and small, confuse all nomenclature.

John Herschel (1792–1871)

For centuries, the most popular fusion of the starry night sky and the visual arts appeared in the remarkably beautiful depictions of the constellations found in many wonderful celestial atlases. However, in the first few decades of the 17th century, depictions of the night sky mirrored the different goals of science and religion. In the same century in which the Protestant Reformation pitted competing versions of Christianity against each other, a second reformation was simultaneously taking place in astronomy, triggered by Galileo's telescopic discoveries. Both reformations are reflected in a tale of two atlases, and the profound effects those works introduced into the visualization of science and religion.

Bayer and *Uranometria*

As the 16th century came to a close, the state of the art for celestial cartography was a work entitled *De le stelle fisse* (*On the Fixed Stars*) by Alessandro Piccolomini (1508–1578). Published in 1540, it depicts 47 of the 48 classical constellations listed by Ptolemy. For reasons not known to us, Johann Bayer (1572–1625) decided it was time for an update. He not

ORION REPLACED At first glance it's difficult to see the familiar form of Orion in this chart from Julius Schiller's *Coelum Stellatum Christianum* (The Starry Christian Heavens). That's because Saint Joseph has replaced the hunter from mythology, and the view is from the "outside" of the celestial sphere looking in — note the orientation of the three "belt" stars. Schiller's atlas sought to repopulate the heavens with Christian characters and symbols.

ALL CHARTS: THE MENDILLO COLLECTION; BACKGROUND PAPER TEXTURE: ILOLAB / SHUTTERSTOCK.COM only wanted to show far more stars, but he also wanted to portray the mythological figures long associated with each constellation. Advances in publishing would also allow Bayer to replace Piccolomini's crude woodblock renderings with spectacular images made possible by copper-engraved printing plates. Bayer published his *Uranometria* (Measure of the Heavens) in Augsburg in 1603. But who was Johann Bayer?

It's a sad commentary, indeed, when virtually all that's known about someone comes from the engraving on a tombstone. Such is the case with Bayer, who is buried in a Catholic cemetery in Augsburg, Germany. The epitaph, as translated by astronomy historian Basil Brown, tells us that Bayer trained in law and served as the equivalent at the time of attorney general to Augsburg. His fame comes neither from his successful advocacy for that municipality nor from an impressive body of brilliant legal opinions still taught to this day in the schools of law in Europe and America. His day job left no legacy comparable to that of his nocturnal hobby.

Bayer's *Uranometria* is probably the most enduring contribution to astronomy by a nonprofessional. In it he depicted all 48 ancient constellations in a series of full-page engravings. To these he added one last engraving that depicted 12 new constellations, groupings of Southern Hemisphere stars recorded by Dutch navigators while on their great journeys of exploration.

Of the 140 stars available, Bayer used 121 to define the southern skyscape, introducing Musca (the fly), Chamaeleon (an exotic creature about to eat the fly), Piscis Volans (a flying fish), Dorado (a fish now associated with a swordfish), Phoenix (to honor the famous birds of mythology), Grus (often associated with a flamingo), Tucana (honoring the South American bird), Indus (the Native American hunter, and the only human in the sky), Hydrus (the small water snake, below Indus), Pavo (the peacock, in mythology Hera's pet bird), Apus (the bird of paradise found in New Guinea), and Triangulum Australe (the southern triangle).

Bayer also adopted the scheme introduced by Piccolomini of identifying stellar brightness by using Greek letter desig-

A FAMILIAR FORM The constellation Orion as presented in *Uranometria* by Johann Bayer. The handwritten notations along the right side of the chart were made by the atlas's owner, who plotted the progress of a naked-eye comet visible around Christmas in 1652.

nations, which is still in use today. For example, the brightest star in Orion is Alpha (α) Orionis (Betelgeuse), shown in the hunter's left shoulder in the illustration on page 65. Interestingly, this particular copy of *Uranometria*, from 1639, wasn't stored in a library, but actually used by a keen observer of the great naked-eye comet of 1652. The Christmas comet's path is marked with handwritten notes, as the object passed by Rigel upwards toward the lion's skin.

Unfortunately for Bayer, his milestone atlas appeared just seven years before Galileo's *Sidereus nuncius* (1610), which described the wonders revealed by the newly invented telescope. Almost overnight, *Uranometria* became obsolete.

Schiller's Great Enterprise

At the same time that the telescope drove a revolution in astronomy, religion experienced its own upheavals. To oppose astrological belief and to counter Protestant iconoclastic furor during the Thirty Years' War (1618–1648), an effort was undertaken to rebrand the celestial landscape by replacing the constellations of mythology (so beautifully rendered by Bayer) with saints and biblical symbols. The force behind this daring initiative was Julius Schiller (c. 1580–1627), Bayer's friend, professional colleague, and fellow astronomy enthusiast.

Schiller's remarkable and audacious plan was to rename and reimage all 60 astronomical constellations. Ptolemy's Northern Hemisphere figures would be replaced by saints from the New Testament, while the constellations of the southern sky would appear as icons from the Old Testament. For the pivotal groupings of the zodiac, the 12 Apostles of Christ would supplant the 12 pagan signs and myths. The effort involved was enormous, and *Coelum Stellatum Christianum* (*The Starry Christian Heavens*) was published in 1627.

The image on page 64 shows Saint Joseph, Schiller's biblical replacement for the group of stars associated with Orion. In Bayer's *Uranometria*, Orion's famous three belt stars align from lower left to upper right, as they appear in the night sky. Schiller, however, portrays those same stars from upper left to lower right, as if seen from outside the celestial sphere (God's-eye view). This perspective in itself was not revolutionary, since celestial globes had long used that external format. Schiller's bold move was to break the association of Orion's stars with a reprehensible, womanizing pagan in favor of the ultimate role model of husband and father. And the figure's props were changed as well. The club and trophy lion's skin are gone, replaced with the tools of a humble carpenter.

Schiller didn't always employ a scheme based on morality (as with the Orion/Saint Joseph pair) — geometrical patterns offered visually appealing options as well. In the images on the facing page, we see Cygnus, the Swan, from *Uranometria* transformed into Saint Helen, holding the cross upon which Jesus died. So obvious is the stellar pattern that Cygnus today is often referred to as the Northern Cross. Schiller cleansed Zeus's various sexual exploits that are embedded in the Cygnus mythologies by employing the Roman Emperor Constantine's saintly mother.

Fixing the Zodiac

Schiller wasn't the first to reimagine the heavens. Previously the focus had always been on the 12 constellations of the zodiac — the signposts along the celestial superhighway (the ecliptic) where the Sun and planets are found. The zodiacal constellations were also the foundation stones of astrology, a belief system opposed by all manner of religious leaders, from Saint Augustine (353–430) to Martin Luther (1483–1546). Giordano Bruno (1548–1600) proposed to change the names of the 12 zodiacal signs to those of the 12 moral virtues. While that scheme died with him at the stake, famed Jesuit author and orator Jeremias Drexel (1581–1638) took up the cause. However, it was Schiller (whom Drexel mentored) who pushed the concept to visual reality.

The 12 constellations of the ancient zodiac offered a ready-made target for replacement by the numerically equivalent Apostles. Why would that be so? The number 12 was an important number for many groups documented in the Bible (for example, the Twelve Tribes of Israel), and today it is omnipresent in everyday life (12 inches to a foot, 12 items in a dozen, and, most notably, 12 months in a year).

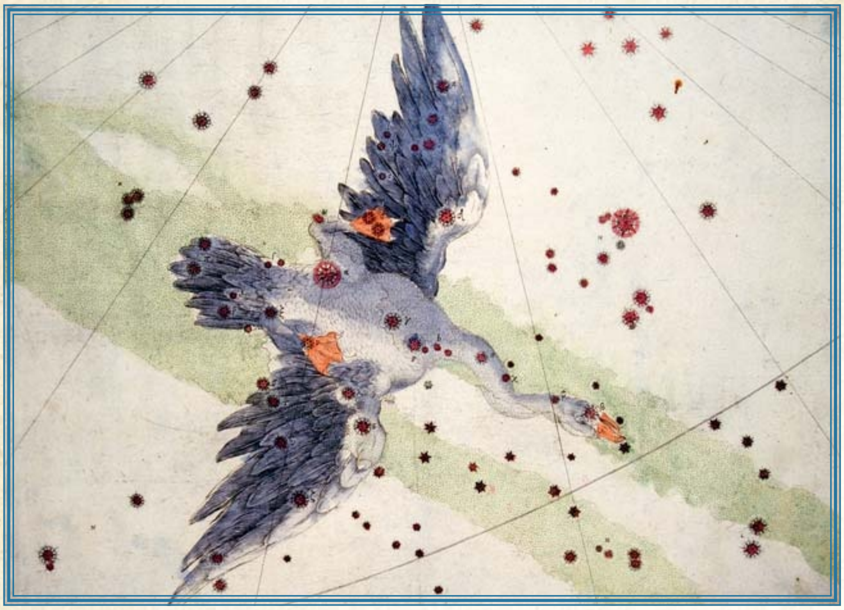
With his plan in place, Schiller could now repopulate the entire celestial sphere with his biblical choices. Using the first-ever translation of Schiller's Latin text, by Aaron Shapiro (Boston University), we can perceive Schiller's methods when it came to the 12 signs of the zodiac. "And so Saint Peter the Apostle, Shepherd of Christ's flock, has taken for himself the constellation of Aries, first of the Zodiac, and according to *Uranometria*, the first of all constellations."

Then, case by case, the 11 remaining signs became saint-by-saint constellations. Schiller started by grouping brothers together (Peter and Andrew for Aries and Taurus; James the Greater and John the Evangelist for Gemini and Cancer), and ended with the twelfth sign (Pisces) occupied by Saint Matthias, himself the replacement of the perfidious Judas Iscariot. Schiller also assigned a symbol to each apostle's image. Saint Peter, for example, holds the keys to Heaven. For the remaining 11, Schiller turned to the apostle's martyrdom, often described in gory detail.

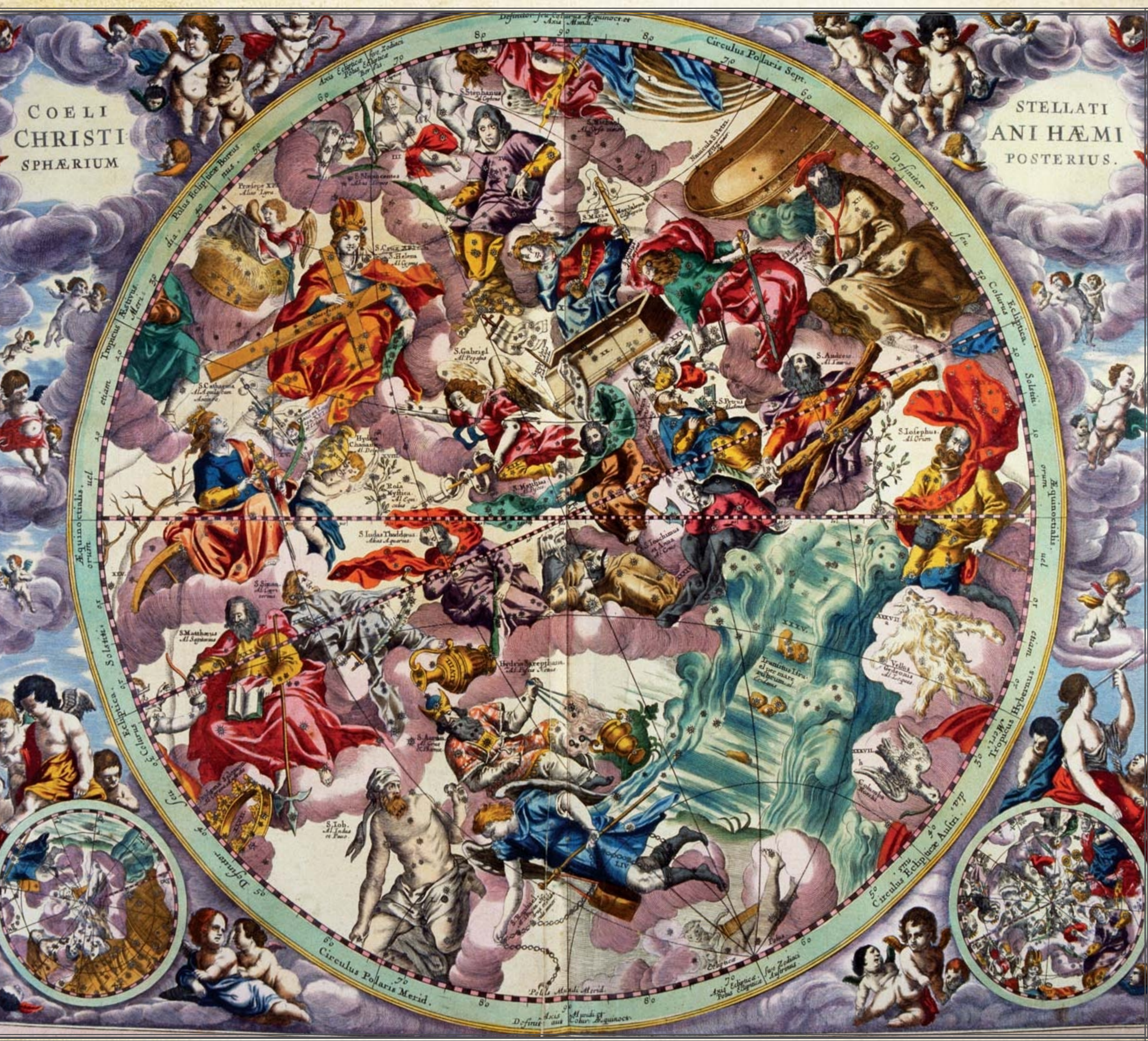
For constellations beyond the zodiac, Schiller sometimes offered moral connections (as with Orion and Saint Joseph), and occasionally geometrically convenient ones (Cygnus and Saint Helen). Each constellation pair in *Coelum Stellatum* included a thoughtful explanation. A spectacular visual summary of the overall scheme for the Northern Hemisphere is shown on pages 68 and 69, using plates from the magnificent atlas, *Harmonia Macrocosmica*, by Dutch–German cartographer, Andreas Cellarius (1661).

Going South

Having converted each of Bayer's 48 classical Northern Hemisphere constellations to his Christianized versions, Schiller



◀▼ OF SAINTS AND SWANS The constellation Cygnus (left image) from Bayer's *Uranometria* appears with its biblical replacement of Saint Helen and the Cross (below). The left-right reversal (internal versus external viewpoint) is particularly clear in this pair of charts.



▲ **A CHRISTIAN SKY** This plate from the *Harmonia Macrocosmica* of Andreas Cellarius (1661) showing the constellations of the Northern Hemisphere is populated with biblical figures and illustrates Schiller's approaches to celestial cartography. The left-to-right inversion arising from its "God's-eye view" is obvious when you look to the upper left to see Saint Helen holding the Cross — Schiller's "revised" rendering of Cygnus.

addressed Plate #49 in *Uranometria* — the cluster of 12 new constellations Bayer added for the Southern Hemisphere.

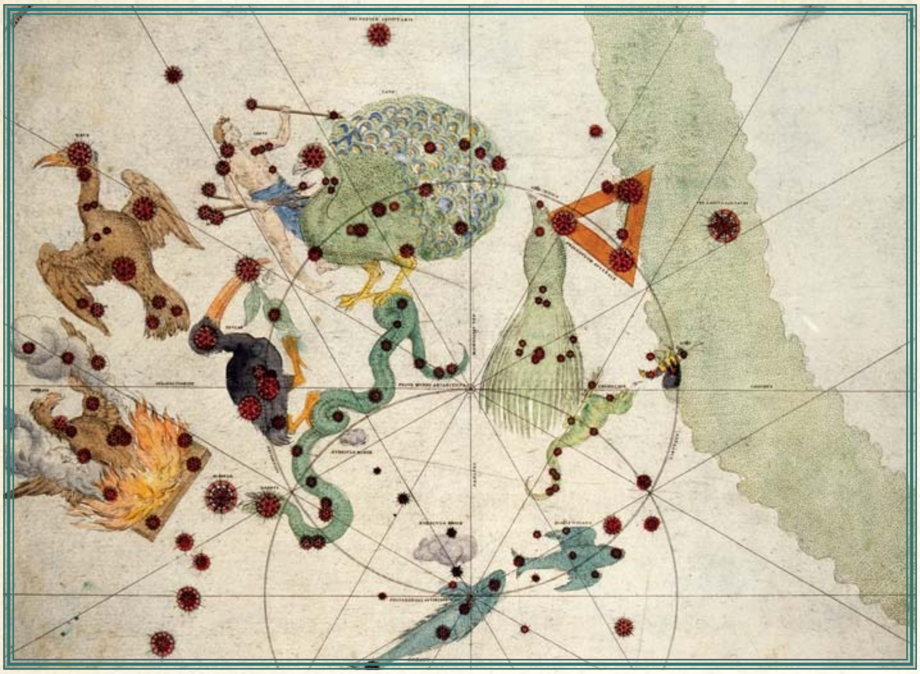
While adding biblical nomenclature to the southern sky, Schiller avoided a full 12-for-12 replacement scheme he used with the zodiac. Instead, he combined Bayer's 12 southern constellations into a concise set of five, with one full page devoted to each. Thus, Aaron is in the area of Grus, Job occupies the space near Indus, Eve is near Triangulum Australis, Abel lies near Piscis Volans, and Saint Raphael the Archangel is near Tucana. Saint Raphael is Schiller's only New Testa-

▲ **FAMILIAR FIGURES** The same region of sky as presented by Bayer features the constellations that are well known to most readers.

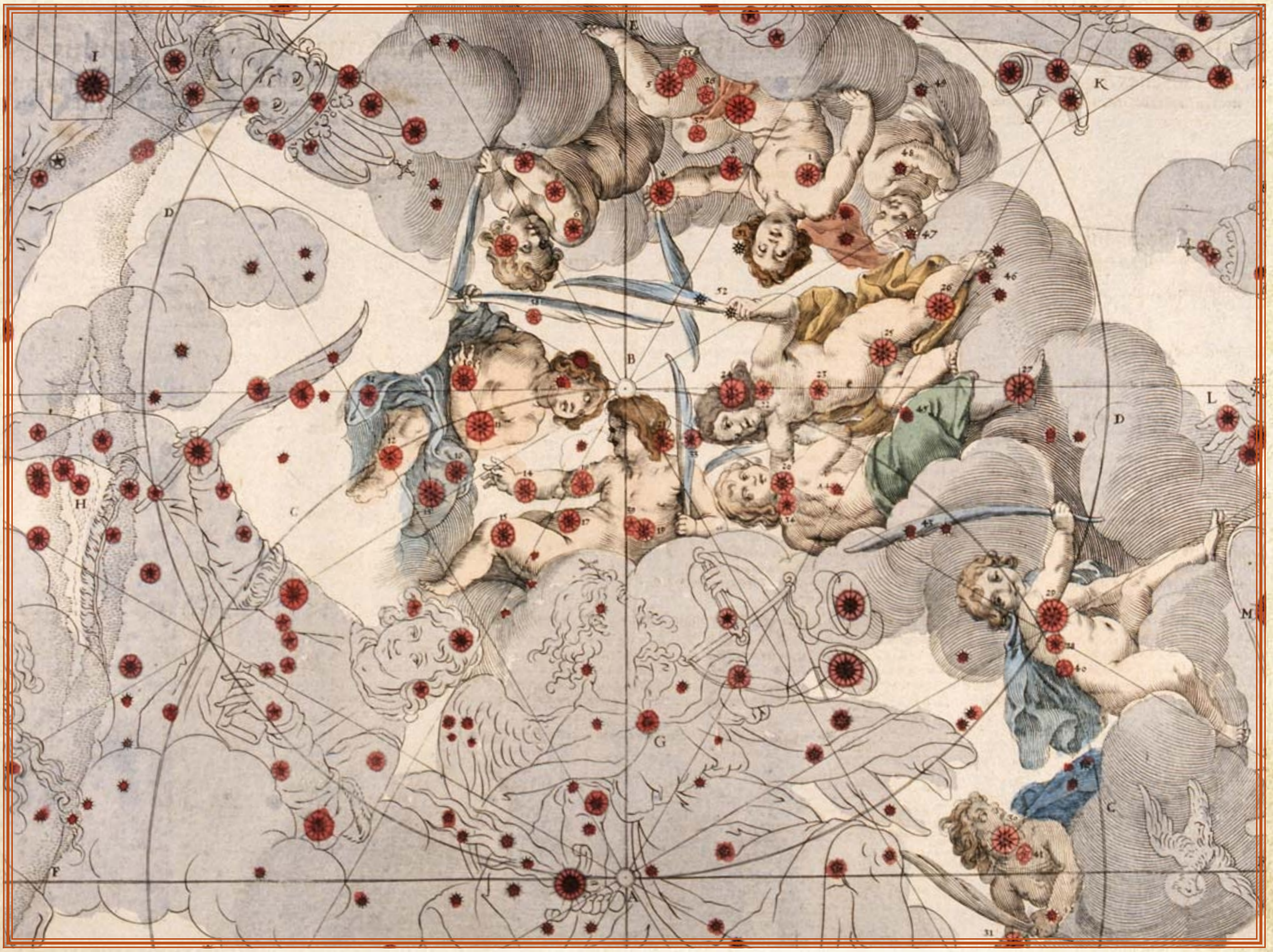
ment figure in the Southern Hemisphere. However, for his summary image (shown on page 70) that can be compared with Bayer's, Schiller portrays four highly animated pairs of angels surrounding the south pole. Schiller's decision to bypass a 12-for-12 replacement (and Bayer's thoughts about this choice) remains to be explained.

Hevelius's Review

Of course, Schiller's scheme ultimately failed to gain acceptance. Why? Johannes Hevelius (1611–1687) provides insight.



◀▼ **SOUTHERN STARS** The set of constellations introduced by Johann Bayer for the south celestial pole region are shown at left, and the replacement images offered by Schiller's religious theme are presented below.



Hevelius built a great observatory in Danzig (now Gdansk, Poland) equipped with instruments he designed and assembled. With these capabilities he became a major force in astronomy as he observed sunspots, published maps of the Moon, and chronicled the passages of comets. He's thus a worthy 17th-century authority to go to for a contemporary professional assessment of Schiller's scheme.

Hevelius observed so many new stars that he ultimately produced an atlas, *Firmamentum Sobiescianum* (published in 1690), that offered many additional constellations — seven still in use today. By his own account, he struggled with the question of how to name them. The choices, as he saw them, were to use Christian names and adhere to Schiller's plan, or to come up with his own. Hevelius devoted five full pages of the preface to his atlas defending his rejection of Schiller's nomenclature so as to avoid the accusation that he might not be a good Christian astronomer. We can follow his reasoning clearly (again, via Shapiro's translation):

> *Indeed necessity demands that we Christians root out utterly all those things which take their origin from the pagans and all those which incline toward idolatry . . . for it seemed at the beginning, before I considered the matter more deeply, that it would also have been glorious for me if I had followed in his* [Schiller's] *footsteps.*

Then came the inevitable "but," followed by a list of reasons. First was a fear of obscurity:

> *All my work would be in vain: in the sixty years since* [Schiller's atlas], *no astronomer has found any occasion, either in formal written work or letters, disputations or dissertations, to follow Schiller's opinion on the names of the constellations.*

Second, Hevelius was concerned with the practical matter of selling his new atlas:

> *Another reason is that even though the Starry Christian Heavens is widely available, nevertheless it is not universally convenient and marketable, and worse it is owned by very few among the learned. No globe has ever been made using Schiller's method.*

Third, he just wanted to vent his frustration about Schiller's nomenclature:

> *It is annoying, bothersome, and tedious.*

His conclusion is as relevant today as it was for astronomers in the 17th century:

> *Since human life is precious and brief, we have to spend our time rather in acquiring a more perfect understanding of the matters not yet satisfactorily detected in Astronomy than in overwhelming the memory with new inventions of terminology and names (except as is necessary).*

Hevelius carried the day — a complete victory!

No subsequent celestial cartographer ever attempted to add constellations to a new sky atlas using names from the Bible. Subsequent efforts *were* made to politicize the heavens by replacing the 12 signs of the zodiac with the coats of arms of dynastic European families, but those initiatives failed as well.

While Hevelius was a Protestant, the objections he offered were not theological but, rather, scientific and practical.

Final Thoughts

The Starry Christian Heavens was the first atlas to be published after the invention of the telescope, and thus contained many additional stars not included in Bayer's *Uranometria*. It also appeared at a crucial moment, during the birth of modern science. If Schiller's initiative had succeeded, the 2006 demotion of Pluto would have seemed like a minor change in nomenclature by comparison!

It seems reasonable to consider the Schiller enterprise as simply an act of personal piety. But beyond that, it amounted to a strong Catholic rebuff to elements of the Reformation. Martin Luther greatly diminished the roles of saints as intermediaries between Christians and their God. Some of his followers ("Iconoclasts") pushed such teachings to acts of physical violence against imagery highly valued by Catholics. *The Starry Christian Heavens* extended that concept to the stars. In an act of celestial iconoclasticism, Schiller destroyed the zodiacal signs of the ancient sinners, while simultaneously promoting the use of saints strategically placed between Earth and Heaven.

The constellations and the artworks depicting them provide a remarkable, enduring example of the connections between art, mythology, religion, and astronomy. Old and new, they tell stories of discovery and wonder, linking themes in science, the humanities, and belief, through visualizations that provide pathways to understanding our place in the universe.

■ **MICHAEL MENDILLO** is a professor of astronomy at Boston University where he heads a research group that studies the upper atmospheres of Earth, the major planets, moons, comets, and exoplanets. He also has the largest privately held collection of antiquarian astronomical charts, maps, and atlases used in celestial images exhibitions and for his studies in the history of astronomy.

Support for this article was provided, in part, by Boston University through its Center for Space Physics. Material presented comes from a book-length manuscript in preparation entitled *Saints and Sinners in the Sky: Exploring Connections between Astronomy, Art and Religion in Western Culture.* The author is grateful for valuable discussions and comments offered by Professor William Carroll at Boston University, and for significant help with images by Joei Wroten of the Center for Space Physics at Boston University.

Dome Homes for Your Telescopes

This month we've assembled a listing of companies that specialize in observatory domes for sale in the North American marketplace. When you're contemplating that backyard observatory, keep these products in mind to make your telescope's home dry, secure, and protected from the wind. (Prices listed do not include crating and shipping costs.)

APHELION DOMES

Located in British Columbia, Canada, Aphelion Domes offers several sizes of clamshell-style domes ranging from 7 to 12 feet in diameter (starting at $11,750). Its fiberglass and resin observatories allow your telescope access to the entire sky, or they can be partially opened to shield your instrument from excessive wind or light trespass. Additional options include motors and computer interfacing.

Aphelion Domes
22061 64th Ave.
Langley, BC, Canada V2Y 2N8
604-534-1958; apheliondomes.com

ASH MANUFACTURING

For more than 50 years, Ash Manufacturing, based in Plainfield, Illinois, has specialized in custom-manufactured aluminum domes for amateur and professional facilities (including many schools, universities, and colleges). Ash can produce a world-class facility with domes ranging from 8 to 30 feet in diameter to suit most any size instrument and built precisely to fit the customer's specific needs. Additional options include on-site installation and motorization kits. Email for a brochure and more information.

Ash Manufacturing Company
P.O. Box 312
Plainfield, IL 60544
815-436-9403; ashdome.com

ASTRO HAVEN

The company founded by the inventor of the clamshell observatory continues to produce and expand upon its innovative design. Astro Haven Enterprises, in California, offers fiberglass clamshell observatory domes in 7- to 20-foot configurations. These are available with advanced functions, including independent shutter control using servo-driven linear actuators and belt drives, as well as dome rotation. Prices available upon request.

Astro Haven Enterprises
P.O. Box 3637
San Clemente, CA 92674
949-215-3777; astrohaven.com

EXPLORADOME

ExploraDome features polyethylene plastic structures in 8- and 11-foot models rotomolded as a single piece, significantly reducing assembly time. Prices start at $1,421.80 for the 8-foot ExploraDome. Additional offerings include aluminum-framed polyethylene building structures, expansion bays, rotation kits, and computerized controls.

ExploraDome
62824 250th St.
Litchfield, MN 55355
800-328-7659; explora-dome.com

NEXDOME

NexDome in Canada produces a lightweight, modular 8-foot ABS plastic dome with Solarkote UV protective hardened coatings starting at $1,699. NexDome is designed to break down into small, manageable sections that can be shipped anywhere in North America for a fraction of the cost of competing products. The company also carries a full line of accessories including expansion bays, rotational motors, rain and cloud sensors, and telescope piers.

NexDome
109 - 1585 Broadway St.
Port Coquitlam, BC, Canada V3C 2M7
604-421-2835; nexdome.com

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OBSERVA-DOME

Another long-time astronomical manufacturer, Observa-Dome has nearly 60 years of experience producing 2.5- to 7-meter (8.2- to 23-foot) aluminum structures customized to suit each location's environmental requirements and building codes. The company's unique bi-parting shutter domes can be closed within seconds and are designed to withstand winds of up to 175 mph. Call for pricing and additional options.

Observa-Dome
371 Commerce Park Dr.
Jackson, MS 39213
601-982-3333; observa-dome.com

PIER-TECH

Located in Bartlett, Illinois, Pier-Tech makes 14½-foot or larger domes manufactured from interlocking galvalume-coated metal sheeting with an aluminum frame. Additional options include a range of coating colors, sub-building structures, motorization, elevating telescope piers, and an ASCOM-compatible automation system. Contact the company for pricing and additional details.

Pier-Tech
1251 Humbracht Cir. #G
Bartlett, IL 60103
630-841-6848; pier-tech.com

SKYSHED OBSERVATORIES

SkyShed offers the POD 6.6-foot half-dome starting at $1,895 (dome only) as well as the POD MAX 12.5-foot traditional fiberglass dome. The POD is a double-walled polyethylene structure that is UV-resistant and designed to last decades in extreme weather conditions. Customers can choose from an extensive line of base structures. The Staffa, Ontario, company also carries a full line of accessories, including expansion bays, hardened-foam insulated wall panels, and telescope piers. Visit its website for full pricing and shipping details.

SkyShed
3404 Perth Road 180 RR # 2
Staffa, Ontario, Canada N0K 1Y0
519-272-9081; skyshedpod.com

TECHNICAL INNOVATIONS

With nearly 30 years of experience, Technical Innovations in Orlando, Florida, produces a range of resin-coated fiberglass dome observatories to fit most users' needs. Its product line spans from the fully automated 40-inch RoboDome, to the 15-foot ProDome with a generous aperture width (prices start at $5,995). In addition, the company provides numerous accessories such as rotation and shutter motors, dome tracking, and a computerized interface. See its website for more details and pricing.

Technical Innovations
1271 La Quinta Dr. #6
Orlando, FL 32809
407-601-1975; homedome.com

1 Ash-Dome 14.5-foot model
2 Astro Haven 18-foot model
3 NexDome with building and expansion bay
4 Observa-Dome 7-meter fast-tracking dome
5 Pier-Tech PTD1
6 SkyShed POD MAX with expansion bays
7 Technical Innovations PD10 ProDome

2


4


6


3


5


7

The Trekking Pole Travel Scope

Never leave home without it!

ON A TRIP TO SOUTH AMERICA a year or so ago, Washington, DC amateur astronomer Robert Capon made the decision to travel light, leaving his portable telescope at home. That proved to be a mistake, as the southern sky was spectacular, but all he had to appreciate it with was his 8×42 binoculars.

He did take his Ruta Locura Yana carbon-fiber trekking poles, though, and while hiking under that beautiful sky he began to wonder if he could design a travel scope that would use the trekking poles for struts. He says, "The goal was to design and build a portable telescope that would be rugged, and so small and light that I would never be tempted to leave it behind."

He settled on a 114-mm (4½″) f/4 mirror, which just fit into a Pelican 1120 Protector Case. That turned out to be an ideal housing. It's lightweight yet very rugged, and the plastic is easy to drill and shape with a Dremel tool, plus it holds screws well. The inside is filled with pluck foam, which is perfect for custom-fitting cavities to protect all the parts in transit.

▲ Robert Capon carries his ultra-compact, ultra-lightweight travel scope.

Mounting the trekking poles was fairly straightforward. Rob carved two channels out of the lip of the Pelican case just inside the handle. That provided 2.6″ of spacing between the poles and allowed the use of the handle supports for additional stability. He secured the poles in place with hose clamps.

The mirror cell uses the Pelican case itself for its rear element and three drilled and countersunk wooden squares for the mirror's support points. Pan-head bolts are glued to the wood, and the squares are glued to the mirror. Bolts run out the back of the case for collimation. Springs around the screws keep the mirror firmly in place, although Rob added lock screws as well by drilling and tapping the Pelican case.

He wanted everything but the poles stored in the case, which meant going with a minimalist focuser. Some rummaging around in his astronomy parts box turned up a Celestron 1.25″ visual back, which he mounted upside-down on a ¼″ plywood square. The visual back threads were cut off to lower the focuser's profile. That holds the eyepiece securely, and focus is achieved by simply loosening the set screw and moving the eyepiece in and out. If the focal point is outside the eyepiece's travel range, the truss lengths can be adjusted where they attach to the Pelican case.

The secondary mirror is on a single stalk that bolts to the wooden focuser platform. Rather than clamp the trekking poles on the upper end, Rob added two 6″ lengths of carbon fiber rod that slip snugly inside the ends of the trekking poles, so the entire assembly can be slid into place in a moment using trekking pole splice joints. With the secondary removed, the focuser/secondary assembly also fits into the lid of the Pelican case, with the secondary mirror tucked in beside it. A trimmed spindle case for a 50-pack of DVDs makes a fine protector for the primary mirror.

Rob mounted a finder bracket to the side of the case and uses a low-profile red-dot finder so it will fit in the case along with everything else. There's just enough room for a 25-mm eyepiece

▶ The travel scope sets up easily and provides an excellent observing experience.

▶▶ Everything but the trekking poles and tripod fits inside the Pelican case.

ROBERT CAPON (4)

tight against the focuser board, and a collimation eyepiece, Moon filter, screwdriver, hex wrench, and even a mini planisphere complete the package. And here's a bonus: When it's set up, the case's lid acts as an accessory tray.

The scope has two mounting options: a short Vixen-style dovetail rail (Sky-Watcher S20550) mounted to the side, and a tripod quick-release plate on the bottom. Because the telescope is so light (3 pounds, 4 ounces), you can mount it on any tripod sturdy enough for a DSLR camera. Rob's Koolehaoda H-50 Mini Tripod weighs in at 2 lbs and matches the travel scope for portability.

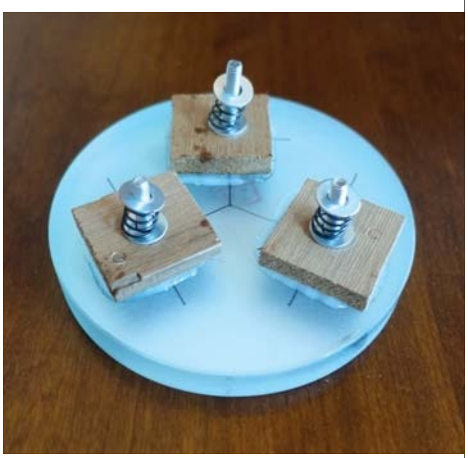
The result is an excellent optical instrument. The case and poles are so rigid that settling time is basically zero, and aiming and observing with it are a breeze. When packed, the case is just 8.4″ × 6.7″ × 3.9″. As Rob says, "That's small enough to ensure that I never leave it behind!" It's also inexpensive: less than $100.

This might very well be the smallest travel scope ever built, at least for its aperture. If not, it's a close contender, and well worth considering for your next vacation.

For more information, contact Rob at **rscapon@gmail.com**.

■ Contributing Editor **JERRY OLTION** also hopes to take a travel scope to view the southern sky sometime soon.

▼ The primary mirror is held in place with three bolts simply glued to the back of the mirror. Wooden blocks provide a greater gluing surface.



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Actual number of copies of single issue published nearest to filing date: 46,922. G. Copies not Distributed. Average number of copies each issue during preceding 12 months: 8,514. Actual number of copies of single issue published nearest to filing date: 11,129. H. Total (sum of 15f and 15g). Average number of copies each issue during preceding 12 months: 57,321. Actual number of copies of single issue published nearest to filing: 58,051. I. Percent paid. Average percent of copies paid for the preceding 12 months: 99.3%. Actual percent of copies paid for the preceding 12 months: 99.9%. 16. Electronic Copy Circulation: A. Paid Electronic Copies. Average number of copies each issue during preceding 12 months: 13,755. Actual number of copies of single issue published nearest to filing date: 13,249. B. Total Paid Print Copies (Line 15c) + Paid Electronic Copies (Line 16a). Average number of copies each issue during preceding 12 months: 62,234. 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▷ THE EYE OF MARS

Oleg Bouevitch

The dusky albedo feature at the lower right resembling a giant eye is known as Solis Lacus. Near the top of the planet's disk, the massive volcano Olympus Mons appears as a brighter orange circular area.

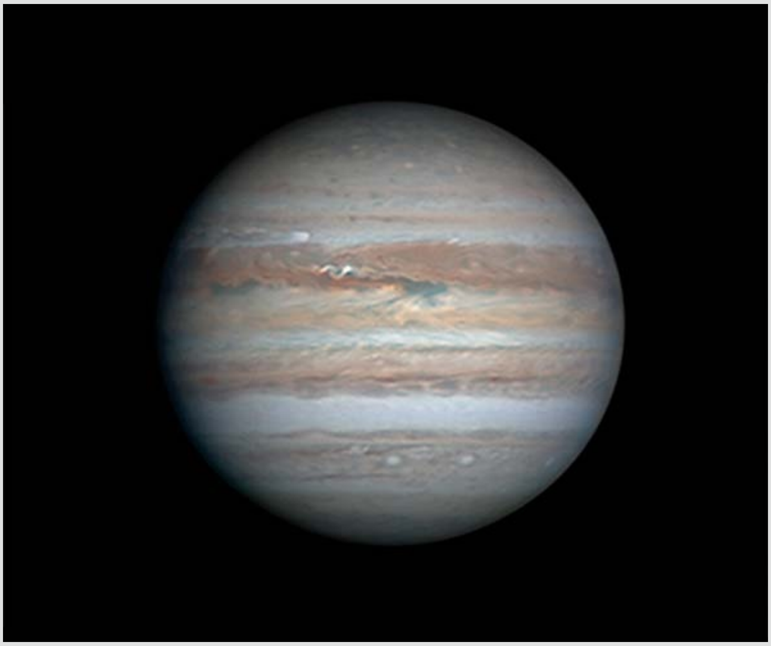
DETAILS: *Celestron EdgeHD 14-inch Schmidt-Cassegrain with ZWO ASI290MM video camera. Stack of multiple video frames taken through RGB filters.*

▽ THE SERPENS-AQUILA RIFT

Ted Wolfe

This immense complex of molecular dust known as LDN 673 in Aquila holds enough material to produce hundreds of thousands of new stars.

DETAILS: *PlaneWave 12½-inch CDK with SBIG STL11000 CCD camera. Total exposure: 12 hours through LRGB filters.*



◁ **UNUSUAL STORMS**

Clyde Foster

Two bright, transient storms were visible on Jupiter in early September. At top left, the North Temperate Belt outbreak leaves a wake of material trailing to the left, while another storm appears as a whitish sinuous wave in the darker North Equatorial Belt.

DETAILS: *Celestron C14 Schmidt-Cassegrain telescope with ZWO ASI290MM video camera. Stack of multiple video frames taken through Baader RGB filters and recorded on the evening of September 13, 2020.*

▽ **THE FLYING DRAGON**

Kurt Zeppetello

Sharpless 2-114 is a faint, nebulous shock front in Cygnus that resembles the fabled fire-breathing winged lizards of medieval lore.

DETAILS: *Astro-Tech AT115EDT refractor with ZWO ASI1600MM-Pro camera. Total exposure: 15½ hours through RGB and hydrogen-alpha filters.*

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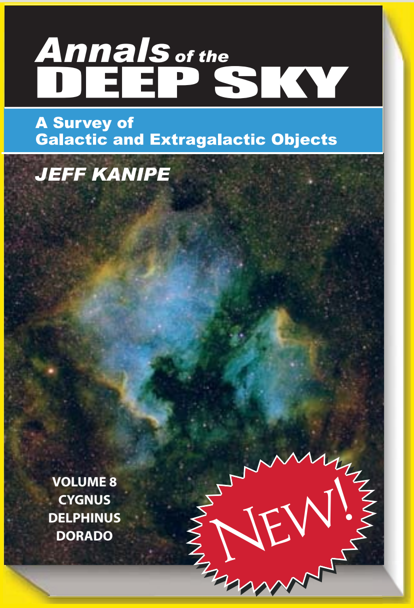

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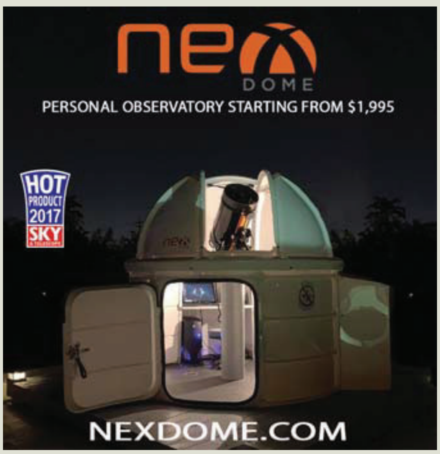

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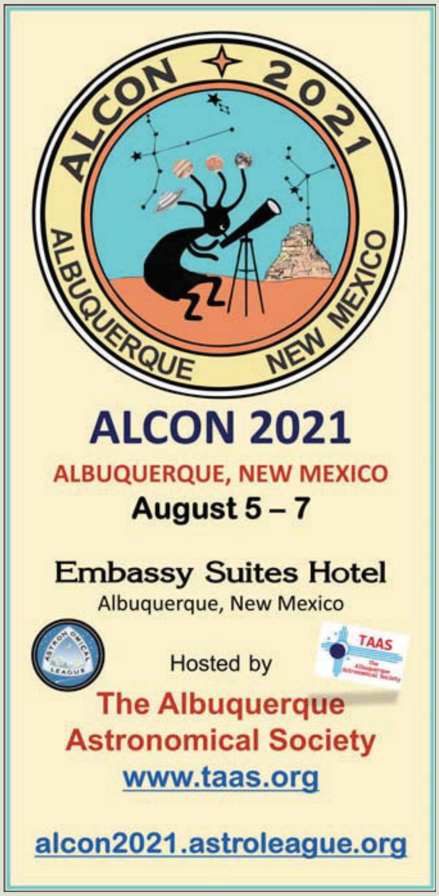

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INSIDE This Issue

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

Product Locator

BINOCULARS

Sky-Watcher USA (Pages 8-9)
SkyWatcherUSA.com
310-803-5953

CAMERAS

Diffraction Limited (SBIG Aluma) (Page 79)
diffractionlimited.com/AC4040
613-225-2732

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310-803-5953

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AD INDEX

Event Calendar

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

February 8–14
WINTER STAR PARTY
Scout Key, FL
https://is.gd/WinterStarParty2021

April 7–10
MIDSOUTH STARGAZE
French Camp, MS
rainwaterobservatory.org/events

April 10–11
NORTHEAST ASTRONOMY FORUM
Suffern, NY
rocklandastronomy.com/neaf1.html

May 15
ASTRONOMY DAY
Events across North America
https://is.gd/AstronomyDay

May (date not yet determined)
TEXAS STAR PARTY
Fort Davis, TX
texasstarparty.org

June 5–12
GRAND CANYON STAR PARTY
Grand Canyon, AZ
https://is.gd/GCSP2021

June 9–13
ROCKY MOUNTAIN STAR STARE
Gardner, CO
rmss.org

June 10–13
CHERRY SPRINGS STAR PARTY
Cherry Springs State Park, PA
cherrysprings.org

August 1–6
NEBRASKA STAR PARTY
Valentine, NE
nebraskastarparty.org

August 3–7
TABLE MOUNTAIN STAR PARTY
Oroville, WA
tmspa.com

August 3–8
OREGON STAR PARTY
Indian Trail Spring, OR
oregonstarparty.org

August 5–8
STELLAFANE CONVENTION
Springfield, VT
stellafane.org/convention

August (date not yet determined)
SUMMER STAR PARTY
Plainfield, MA
rocklandastronomy.com/ssp.html

October 9
ASTRONOMY DAY
Events across North America
https://is.gd/AstronomyDay

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

Corona Virus

How the coronavirus (one word) has wrecked the plans of those who have the two-word kind

The *Paul Gauguin* was perfectly positioned for totality during the total solar eclipse of November 14, 2012, the last time the author saw the Sun's corona from that ship.

AS I WRITE THIS, I have mixed emotions. I'm disappointed that I have to sit out the December 14, 2020 total eclipse of the Sun, which I was planning to experience just after sunrise in the South Pacific Ocean. But I'm also relieved that my wife and I won't be boarding a cruise ship while the COVID-19 pandemic is still raging.

This was going to be my 15th totality, and I was really looking forward to it after getting skunked by unseasonably bad weather at the last one on July 2, 2019. For that eclipse, also in the South Pacific — it's a big target, and the Moon's umbral shadow hits it frequently — we were sailing on the *Paul Gauguin*, a small but luxurious vessel that was on its fifth expedition to totality since 2005. We'd been on two of those earlier voyages, all four of which managed to find clear skies or a well-placed hole in the clouds.

July 2, 2019 dawned clear, but as the initial phase of the eclipse progressed, the temperature of the ocean air dropped below the dew point, and thick clouds materialized out of nowhere. Every time our captain turned the ship toward a Sun glint on the water, it vanished before we could reach it. We were soon overcome with a sinking feeling — the last thing you want on a cruise ship! — that we weren't going to see the solar corona, and indeed we didn't. The first-time eclipse chasers among us weren't all that upset, because it still got eerily dark (and they didn't really know what they were missing). But those of us who had witnessed the glory of totality before were miserable.

December 2020 offered a chance to restore the *Gauguin*'s reputation for successful eclipse-chasing. When the pandemic exploded in March and much of the world went into lockdown, I wasn't worried about an event still nine months away. But when cases surged in June, it became clear that the pandemic would be with us for a long time. Then, in mid-July, the *Gauguin* embarked on its first international cruise in months — only to return to port two days later after a passenger tested positive for the novel coronavirus. Inevitably, the ship's sixth rendezvous with the Moon's shadow was soon canceled.

I used to tell people who'd never seen a total solar eclipse that it's not so much about science as about beauty and awe. And I'd assure them that once they'd experienced one, they'd join the ranks of eclipse chasers — we call ourselves *umbraphiles* — and do anything they could to see another. More recently, I'd joke that the "corona virus" was what causes umbraphilia.

Now that the coronavirus has effectively canceled the December 2020 eclipse for nearly everyone except some residents of Chile and Argentina, I don't find my joke funny anymore. Nor will I ever again suggest that eclipses aren't so much about science. After all, it's science that enables us to predict with astonishing precision when and where such events will occur. And if the leaders of all the nations on Earth had taken science seriously, we'd have better contained the coronavirus and prevented a lot of unnecessary suffering and death, and I'd likely be en route to notching my 15th total solar eclipse.

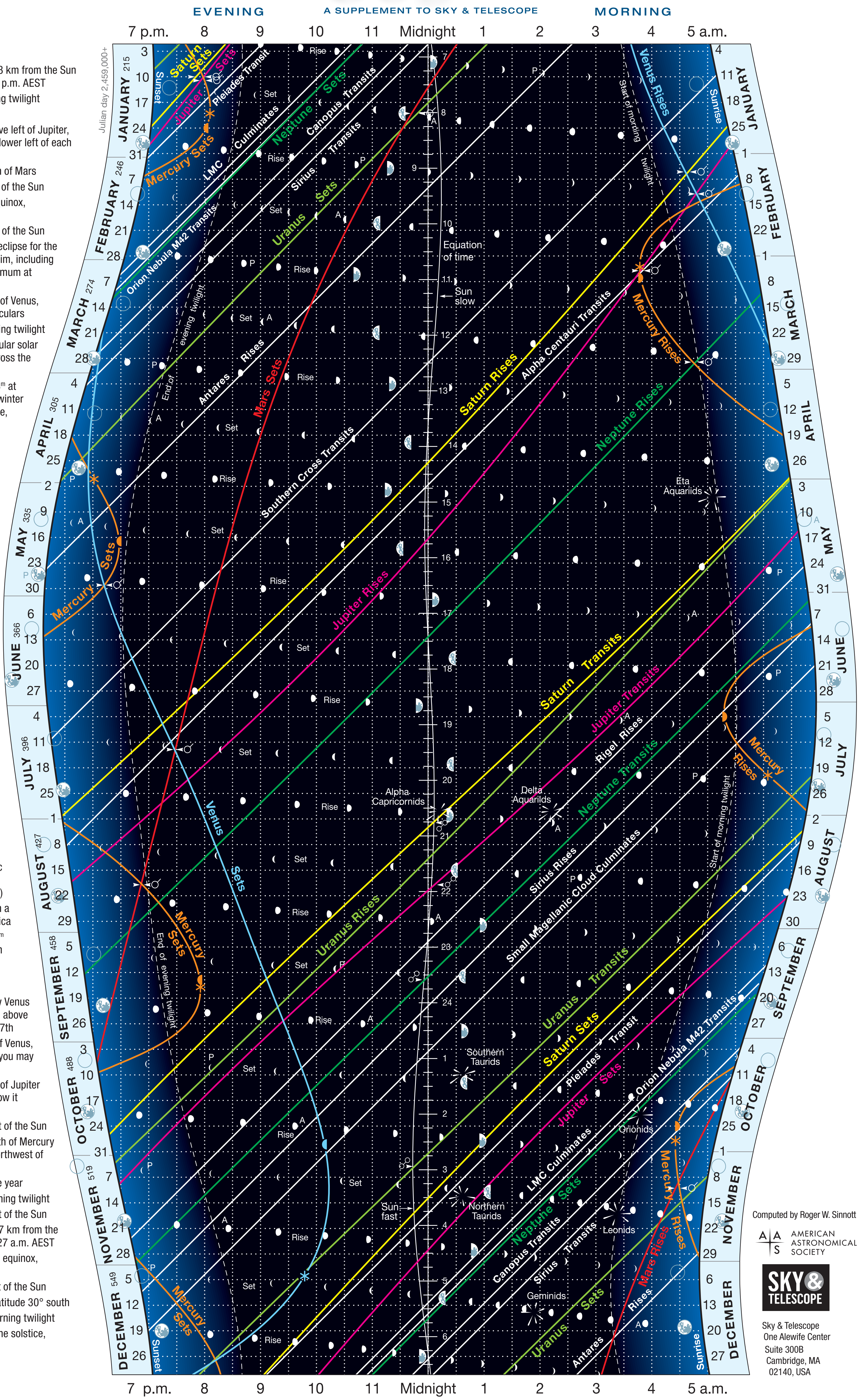
■ Senior Contributing Editor **RICK FIENBERG** is Press Officer of *S&T*'s parent organization, the American Astronomical Society. He served as editor in chief of this magazine from 2000 to 2008.

ANTONIO DELLE MONACHE / PAUL GAUGUIN CRUISES

Skygazer's Almanac 30°S 2021

FOR LATITUDES NEAR 30° SOUTH

A SUPPLEMENT TO SKY & TELESCOPE



EVENING SKY

- Jan 2 Earth is 147,093,163 km from the Sun (perihelion) at 11:51 p.m. AEST
- Jan 3 Latest end of evening twilight
- Jan 9 Latest sunset
- Jan 11 Mercury is 1.5° above left of Jupiter, with Saturn 2.3° to lower left of each (use binoculars)
- Jan 20 Uranus is 1.6° south of Mars
- Jan 24 Mercury is 19° east of the Sun
- Mar 20 Fall begins at the equinox, 7:37 p.m. AEST
- May 17 Mercury is 22° east of the Sun
- May 26 A barely total lunar eclipse for the Pacific Ocean and Rim, including Australia, with maximum at 11:19 UT
- May 29 Mercury is 0.5° left of Venus, but low — use binoculars
- Jun 7 Earliest end of evening twilight
- Jun 10 Earliest sunset; annular solar eclipse in a path across the Arctic Ocean
- Jun 21 Shortest day, $10^h\ 13^m$ at latitude 30° south; winter begins at the solstice, 1:32 p.m. AEST
- Jul 13 Mars is 0.5° above left of Venus
- Jul 22 Venus and Regulus are 2.2° apart
- Jul 30 Mars and Regulus are 0.6° apart
- Aug 2 Saturn is at opposition tonight
- Aug 19 Mercury is just 0.2° above Mars this evening; Jupiter is at opposition tonight
- Sep 5 Venus and Spica are 1.7° apart tonight and tomorrow
- Sep 14 Mercury is 27° east of the Sun; Neptune is at opposition tonight
- Oct 16 Venus and Antares are 1.5° apart tonight and tomorrow
- Oct 29 Venus is 47° east of the Sun
- Nov 4 Uranus is at opposition tonight
- Nov 19 Partial lunar eclipse for Australia (at nightfall), the Pacific Ocean, and South America (near dawn)
- Dec 4 Total solar eclipse in a path across Antarctica
- Dec 22 Longest day, $14^h\ 05^m$ at latitude 30° south

MORNING SKY

- Feb 6 Saturn is 0.7° below Venus on the 6th, and 0.7° above left of Venus on the 7th
- Feb 12 Jupiter is 0.5° left of Venus, but they are so low you may need binoculars
- Mar 5 Mercury is 0.5° left of Jupiter on the 5th, 0.5° below it on the 6th
- Mar 7 Mercury is 27° west of the Sun
- Mar 30 Neptune is 1.5° north of Mercury on the 30th, 1.5° northwest of it on the 31st
- Jul 1 Latest sunrise of the year
- Jul 4 Latest onset of morning twilight
- Jul 5 Mercury is 22° west of the Sun
- Jul 6 Earth is 152,100,527 km from the Sun (aphelion) at 8:27 a.m. AEST
- Sep 23 Spring begins at the equinox, 5:21 a.m. AEST
- Oct 25 Mercury is 18° west of the Sun
- Dec 3 Earliest sunrise at latitude 30° south
- Dec 9 Earliest onset of morning twilight
- Dec 22 Summer begins at the solstice, 1:59 a.m. AEST

Computed by Roger W. Sinnott

AMERICAN ASTRONOMICAL SOCIETY

SKY & TELESCOPE

Sky & Telescope
One Alewife Center
Suite 300B
Cambridge, MA
02140, USA

Conjunction (appulse) · Greatest elongation · Greatest illuminated extent · Opposition · New Moon · First Quarter · Full Moon · Last Quarter · A Apogee · P Perigee · Waxing (moonset) · Waning (moonrise)

Skygazer's Almanac 30°S 2021

FOR LATITUDES NEAR 30° SOUTH

What's in the sky tonight?

When does the Sun set, and when does twilight end? Which planets are visible? What time is moonrise?

Welcome to the *Skygazer's Almanac 2021,* a handy chart that answers these and many other questions for every night of the year. This version is plotted for skywatchers near latitude 30° south — in Australia, southern Africa, and the southern cone of South America.

For any date, the chart tells the times when astronomical events occur during the night. Dates on the chart run vertically from top to bottom. The time of night runs horizontally, from sunset at left to sunrise at right. Find the date you want on the left side of the chart, and read across toward the right to find the times of events. Times are labeled along the chart's top and bottom.

In exploring the chart, you'll find that its night-to-night patterns offer many insights into the rhythms of the heavens.

The Events of a Single Night

To learn how to use the chart, consider some of the events of one night. We'll pick January 10, 2021.

First find "January" and "10" at the left edge. This is one of the dates for which a string of fine dots crosses the chart horizontally. Each horizontal dotted line represents the night from a Sunday evening to Monday morning. The individual dots are five minutes apart.

Every half hour (six dots), there is a vertical dotted line to aid in reading the hours of night at the chart's top or bottom. On the vertical lines, one dot is equal to one day.

A sweep of the eye shows that the line for the night of January 10–11 crosses many slanting *event lines*. Each event line tells when something happens.

The dotted line for January 10–11 begins at the heavy black curve at left, which represents the time of sunset. Reading up to the top of the chart, we find that sunset on January 10th occurs at 7:06 p.m. *Local Mean Time*. (All times read from the chart are Local Mean Time, which can differ from your civil clock time by many minutes. More on this later.)

Note that Saturn, Mercury, and Jupiter all set within a few minutes of 8 p.m., so they are close together in the sky, but they'll be hard to spot so soon after sunset. Moving to the right we see that the Pleiades transit the meridian at 8:28 p.m., meaning the famous star cluster is at its highest in the sky. Then twilight ends at 8:40, marking the moment when the Sun is 18° below the horizon and the sky is fully dark.

At about 10:02 the Large Magellanic Cloud culminates (another way of saying it transits). Then the two brightest nighttime stars, Canopus and Sirius, transit at 11:03 and 11:25, respectively. Transit times of such celestial landmarks help us follow the march of constellations during the night.

Running vertically down the midnight line is a scale of hours. This shows the sidereal time (the right ascension of objects on the meridian) at midnight. On January 10–11 this is $7^{h}\ 21^{m}$. To find the sidereal time at any other time and date on the chart, locate the point for the time and date you want, then draw a line through it parallel to the white event lines of stars. See where your line intersects the sidereal-time scale at midnight. (A star's event line enters the top of the chart at the same time of night it leaves the bottom. Sometimes one of these segments is left out to avoid crowding.)

Near the midnight line is a white curve labeled *Equation of time* weaving narrowly right and left down the chart. If you regard the midnight line as the previous noon for a moment, this curve shows when the Sun crosses the meridian and is due north. On January 10th the Sun runs slow, transiting at 7 minutes past noon. This deviation, important for reading a sundial, is caused by the tilt of the Earth's axis and the ellipticity of its orbit.

At 12:07 a.m. the red planet Mars sets, and we can infer that it has been visible in the sky all evening. Dim Uranus sets at 12:28. Then at 1:59 Antares, a star we usually associate with later seasons, climbs above the southeastern horizon.

At about 2:52 we notice a small Moon symbol, and the legend tells us it is a waning crescent, rising. The first hint of dawn — the start of morning twilight — comes at 3:36. Then brilliant Venus rises at 3:50. The Sun finally peeks above the eastern horizon at 5:10 a.m. on Monday morning, January 11th.

Other Charted Information

Many of the year's most important astronomical events are listed in the chart's left-hand margin. Some are marked on the chart itself.

Conjunctions (close pairings) of two planets are marked by a ☌ symbol on the

Local Mean Time Corrections

Adelaide	+16	Melbourne	+20
Brisbane	–13	Perth	+18
Canberra	+4	Sydney	–4
Cape Town	+46	Johannesburg	+8
Durban	–3	Port Elizabeth	+18
Harare	–4	Pretoria	+8
Asunción	–10	Rio de Janeiro	–7
Buenos Aires	+54	Santiago	+43
Montevideo	+45	São Paulo	+6

planets' event lines. Here, the symbol indicates the night when the planets appear closest in the sky (at appulse), not just when they have the same ecliptic longitude or right ascension.

Opposition of a planet, the date when it is opposite the Sun in the sky and thus visible all night, occurs roughly when its transit line crosses the Equation-of-time line (*not* the line for midnight). Opposition is marked there by a ☍ symbol. For instance, Saturn reaches opposition on the night of August 2–3 this year.

Moonrise and *moonset* can be told apart by whether the round limb — the outside edge — of the Moon symbol faces left (waxing Moon sets) or right (waning Moon rises). Or follow the nearly horizontal row of daily Moon symbols across the chart to find the word *Rise* or *Set*. Quarter Moons are indicated by a larger symbol. Full Moon is always a large bright disk whether rising or setting; the circle for new Moon is open. *P* and *A* mark dates when the Moon is at perigee and apogee (nearest and farthest from Earth, respectively).

Mercury and *Venus* never stray far from the twilight bands. Their dates of greatest elongation from the Sun are shown by ◗ symbols on their rising or setting curves. Asterisks mark when their telescopic disks have the greatest illuminated extent in square arcseconds. For example, this occurs for Mercury on the evening of January 20th and for Venus on December 4th.

Meteor showers are marked by a starburst symbol on the date of peak activity and at the time when the shower's radiant (point of origin) is highest in the night sky. This often occurs just as morning twilight begins. (Note that our predicted peak of the Southern Taurids, a sparse and ill-defined shower, falls a few weeks earlier than in recent years.)

Julian dates can be found from the numbers just after the month names on the chart's left. The Julian day, a seven-digit number, is a running count of days beginning with January 1, 4713 BC. Its first four digits this year are 2459, as indicated just off the chart's upper left margin. To find the last three digits for days in January, add 215 to the date. For instance, on January 10th we have 215 + 10 = 225, so the Julian day is 2,459,225.

Rising or Setting Corrections

South Latitude	Declination (North or South) 0°	5°	10°	15°	20°	25°
10°	0	8	16	24	33	43
15°	0	6	12	19	26	33
20°	0	4	8	13	18	23
25°	0	2	4	7	9	12
30°	0	0	0	0	0	0
35°	0	2	5	7	10	13
40°	0	5	10	16	22	29
45°	1	8	17	26	37	49
50°	1	12	25	39	54	72

Note that the Julian day does not change to this value until 12:00 Universal Time (UT). In Australia, 12:00 UT falls during the evening of the same day (at 10 p.m. Australian Eastern Standard Time, AEST). Before that time, subtract 1 from the Julian day number just obtained.

Time Corrections

All events on this southern version of the *Skygazer's Almanac* are plotted for an observer at longitude 135° east and latitude 30° south. However, you need not live near McDouall Peak, South Australia, to use the chart. Simple corrections will allow you to get times accurate to a couple of minutes anywhere in the world's south temperate latitudes.

To convert the charted time of an event into your civil (clock) time, the following corrections must be made. They are given in order of decreasing importance.

• **DAYLIGHT-SAVING TIME ("SUMMER TIME").** When this is in effect, add one hour to any time read from the chart.

• **YOUR LONGITUDE.** The chart gives the *Local Mean Time* (LMT) of events, which differs from ordinary clock time by many minutes at most locations. Our civil time zones are standardized on particular longitudes. Examples in Australia are 150°E for the eastern states (which use Australian Eastern Standard Time, AEST), and 142.5°E for the central state and territory (an odd value that puts the minute hands of their clocks 30 minutes out of joint with most of the rest of the world).

If your longitude is very close to your standard time-zone meridian, luck is with you and your LMT correction is zero. Otherwise, to get standard time *add 4 minutes* to times obtained from the chart for each degree of longitude that you are *west* of your time-zone meridian. Or *subtract 4 minutes* for each degree you are *east* of it.

For instance, Melbourne, Australia (longitude 145°), is 5° west of its time-zone meridian (150°). So at Melbourne, add 20 minutes to any time obtained from the chart. The result is standard time.

Find your Local Mean Time correction and memorize it; you will use it always. The table below at left has the corrections, in minutes, for some major cities.

• **RISING AND SETTING.** Times of rising and setting need correction if your latitude differs from 30° south. This effect depends strongly on a star or planet's declination. The declinations of the Sun and planets are listed each month in *Sky & Telescope*.

If your site is *south* of latitude 30°S, an object with a south declination stays above the horizon *longer* than the chart shows (it rises earlier and sets later), while one with a north declination spends less time above the horizon. If you are *north* of 30°S, the effect is just the reverse. With these rules in mind, you can gauge the number of minutes for correcting a rise or set time using the table above left.

Finally, the Moon's rapid orbital motion alters lunar rising and setting times slightly if your longitude differs from 135°E. The Moon rises and sets about two minutes earlier than the chart shows for each time zone east of central Australia, and two minutes later for each time zone west of there. Observers in southern Africa can simply shift the Moon symbol a third of the way to that for the following date. Those in South America can shift it about halfway there.

Skygazer's Almanac 2021 is a supplement to *Sky & Telescope* Magazine, One Alewife Center, Suite 300B, Cambridge, MA 02140, USA, skyandtelescope.org.

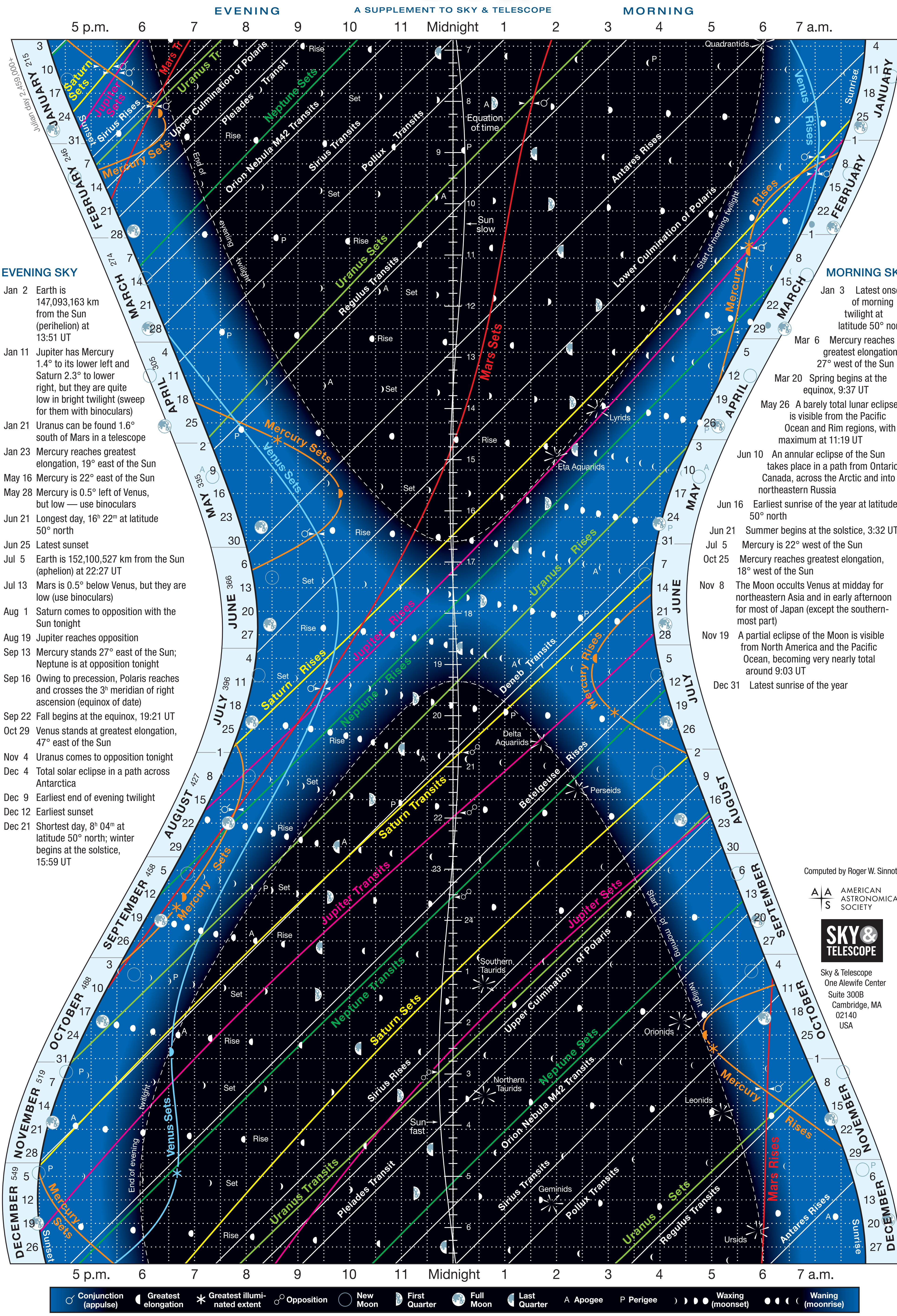
SKY & TELESCOPE

AAS AMERICAN ASTRONOMICAL SOCIETY

Skygazer's Almanac 50°N 2021

FOR LATITUDES NEAR 50° NORTH

A SUPPLEMENT TO SKY & TELESCOPE



EVENING SKY

Jan 2 Earth is 147,093,163 km from the Sun (perihelion) at 13:51 UT

Jan 11 Jupiter has Mercury 1.4° to its lower left and Saturn 2.3° to lower right, but they are quite low in bright twilight (sweep for them with binoculars)

Jan 21 Uranus can be found 1.6° south of Mars in a telescope

Jan 23 Mercury reaches greatest elongation, 19° east of the Sun

May 16 Mercury is 22° east of the Sun

May 28 Mercury is 0.5° left of Venus, but low — use binoculars

Jun 21 Longest day, 16ʰ 22ᵐ at latitude 50° north

Jun 25 Latest sunset

Jul 5 Earth is 152,100,527 km from the Sun (aphelion) at 22:27 UT

Jul 13 Mars is 0.5° below Venus, but they are low (use binoculars)

Aug 1 Saturn comes to opposition with the Sun tonight

Aug 19 Jupiter reaches opposition

Sep 13 Mercury stands 27° east of the Sun; Neptune is at opposition tonight

Sep 16 Owing to precession, Polaris reaches and crosses the 3ʰ meridian of right ascension (equinox of date)

Sep 22 Fall begins at the equinox, 19:21 UT

Oct 29 Venus stands at greatest elongation, 47° east of the Sun

Nov 4 Uranus comes to opposition tonight

Dec 4 Total solar eclipse in a path across Antarctica

Dec 9 Earliest end of evening twilight

Dec 12 Earliest sunset

Dec 21 Shortest day, 8ʰ 04ᵐ at latitude 50° north; winter begins at the solstice, 15:59 UT

MORNING SKY

Jan 3 Latest onset of morning twilight at latitude 50° north

Mar 6 Mercury reaches greatest elongation, 27° west of the Sun

Mar 20 Spring begins at the equinox, 9:37 UT

May 26 A barely total lunar eclipse is visible from the Pacific Ocean and Rim regions, with maximum at 11:19 UT

Jun 10 An annular eclipse of the Sun takes place in a path from Ontario, Canada, across the Arctic and into northeastern Russia

Jun 16 Earliest sunrise of the year at latitude 50° north

Jun 21 Summer begins at the solstice, 3:32 UT

Jul 5 Mercury is 22° west of the Sun

Oct 25 Mercury reaches greatest elongation, 18° west of the Sun

Nov 8 The Moon occults Venus at midday for northeastern Asia and in early afternoon for most of Japan (except the southern-most part)

Nov 19 A partial eclipse of the Moon is visible from North America and the Pacific Ocean, becoming very nearly total around 9:03 UT

Dec 31 Latest sunrise of the year

Computed by Roger W. Sinnott

AMERICAN ASTRONOMICAL SOCIETY

SKY & TELESCOPE

Sky & Telescope
One Alewife Center
Suite 300B
Cambridge, MA
02140
USA

Skygazer's Almanac 50°N 2021

FOR LATITUDES NEAR 50° NORTH

What's in the sky tonight?

When does the Sun set, and when does twilight end? Which planets are visible? What time does the Moon rise?

Welcome to the *Skygazer's Almanac 2021,* a handy chart that answers these and many other questions for every night of the year. This version is plotted for skywatchers near latitude 50° north — in the United Kingdom, northern Europe, Canada, and Russia.

For any date, the chart tells the times when astronomical events occur during the night. Dates on the chart run vertically from top to bottom. The time of night runs horizontally, from sunset at left to sunrise at right. Find the date you want on the left side of the chart, and read across toward the right to find the times of events. Times are labeled along the chart's top and bottom.

In exploring the chart you'll find that its night-to-night patterns offer many insights into the rhythms of the heavens.

The Events of a Single Night

To learn how to use the chart, consider some of the events of one night. We'll pick January 10, 2021.

First find "January" and "10" at the left edge. This is one of the dates for which a string of fine dots crosses the chart horizontally. Each horizontal dotted line represents the night from a Sunday evening to Monday morning. The individual dots are five minutes apart.

Every half hour (six dots), there is a vertical dotted line to aid in reading the hours of night at the chart's top or bottom. On the vertical lines, one dot is equal to one day.

A sweep of the eye shows that the line for the night of January 10–11 crosses many slanting *event lines*. Each event line tells when something happens.

The dotted line for January 10–11 begins at the heavy black curve at left, which represents the time of sunset. Reading up to the top of the chart, we find that sunset on January 10th occurs at 4:20 p.m. *Local Mean Time.* (All times on the chart are Local Mean Time, which can differ from your civil clock time by many minutes. More on this later.)

Note that Mercury, Saturn, and Jupiter set in rapid succession near 5:30 p.m., so they must be together in the sky. But this occurs so soon after sunset that they will be very hard to see. Moving to the right, we see a dashed line marking the end of evening twilight at 6:17 p.m. This is the time when the Sun is 18° below the horizon and the sky is fully dark.

The red planet Mars transits the meridian at 6:35, meaning it is due south at its high point in the sky — a good time to study it in a telescope. Then at 6:44 Sirius, the brightest nighttime star, rises. At 6:56 dim Uranus transits.

Polaris, the North Star, reaches upper culmination near 7:37. This is when Polaris stands directly above the north celestial pole (by 39′ or 38′ this year), a good opportunity to check the alignment of an equatorial telescope.

The Pleiades star cluster in Taurus transits the meridian at 8:26, followed by the Orion Nebula, Messier 42, at 10:14 and Sirius at 11:23. Transits of such celestial landmarks help remind us where the constellations are during the night.

Running vertically down the midnight line is a scale of hours. This shows the sidereal time (the right ascension of objects on the meridian) at midnight. On January 10–11 this is $7^h\ 23^m$. To find the sidereal time at any other time and date on the chart, locate the point for the time and date you want, then draw a line through it parallel to the white event lines of stars. See where your line intersects the sidereal-time scale at midnight. (A star's event line enters the top of the chart at the same time of night it leaves the bottom. Sometimes one of these segments is left out to avoid crowding.)

Near the midnight line is a white curve labeled *Equation of time* weaving narrowly right and left down the chart. If you regard the midnight line as the previous noon for a moment, this curve shows when the Sun crosses the meridian and is due south. On January 10th the Sun runs slow, transiting at 12:08 p.m. This deviation, important for reading a sundial, is caused by the tilt of the Earth's axis and the ellipticity of its orbit.

Mars, having been up all evening, finally sets at 1:43 a.m. The bright star Regulus transits at 2:46. As the wee hours continue, Antares, a star we usually associate with a later season, rises at 5:28.

The first hint of dawn — the start of morning twilight — comes at 5:58 a.m. The crescent Moon comes up at around 6:27, as does brilliant Venus at 6:49. The Sun finally peeks above the eastern horizon at 7:55 a.m. on Monday morning, January 11th.

Local Mean Time Corrections

Amsterdam	+40	Manchester	+8
Belfast	+24	Montreal	–6
Berlin	+6	Moscow	+26
Bordeaux	+62	Munich	+14
Bremen	+24	Oslo	+17
Brussels	+44	Ottawa	+3
Bucharest	+16	Paris	+51
Budapest	–16	Prague	+2
Calgary	+36	Quebec	–15
Copenhagen	+10	Regina	+58
Dublin	+25	Reykjavík	+88
Geneva	+35	St. John's	+1
Glasgow	+16	Stockholm	–12
Halifax	+14	Toronto	+18
Hamburg	+20	Vancouver	+12
Helsinki	+20	Vienna	–5
Kiev	–2	Warsaw	–24
London	0	Winnipeg	+29
Lyons	+41	Zurich	+24

Other Charted Information

Many of the year's chief astronomical events are listed in the chart's evening and morning margins. Some are marked on the chart itself.

Conjunctions (close pairings) of two planets are marked on the chart by a ☌ symbol on the planets' event lines. Here, conjunctions are considered to occur when the planets actually appear closest together in the sky (at appulse), not merely when they share the same ecliptic longitude or right ascension.

Opposition of a planet, the date when it is opposite the Sun in the sky and visible all night, occurs roughly when its transit line crosses the Equation-of-time line (*not* the line for midnight). Opposition is indicated there by a ☍ symbol. For instance, Saturn reaches opposition on the night of August 1–2 this year.

Moonrise and *moonset* can be told apart by whether the round limb — the outside edge — of the Moon symbol faces right (waxing Moon sets) or left (waning Moon rises). Or follow the nearly horizontal row of daily Moon symbols across the chart to find the word *Rise* or *Set*. Quarter Moons are indicated by a larger symbol. Full Moon is always a large bright disk whether rising or setting; the circle for new Moon is open. *P* and *A* mark dates when the Moon is at perigee and apogee (nearest and farthest from Earth, respectively).

Mercury and *Venus* never stray far from the twilight bands. Their dates of greatest elongation from the Sun are shown by ◗ symbols on their rising or setting curves. Asterisks mark the dates when their disks in telescopes show the greatest illuminated extent in square arcseconds. For example, Mercury does so on the evening of January 20th and Venus on December 4th this year.

Meteor showers are marked by a starburst symbol at the date of peak activity and the time when the shower's radiant is highest in the night sky. This is often just as twilight begins before dawn. (Note that we've adjusted the predicted peak of the Southern Taurids, a sparse, ill-defined shower, to fall somewhat earlier in the year.)

Julian dates can be found from the numbers just after the month names on the chart's left. The Julian day, a seven-digit number, is a running count of days beginning with January 1, 4713 BC. Its first four digits this year are 2459, as indicated just off the chart's upper left margin. To find the last three digits for evenings in January, add 215 to the date. For instance, on the evening of January 10th we have 215 + 10 = 225, so the Julian day is 2,459,225. For European observers this number applies all night, because the next Julian day always begins at 12:00 Universal Time (noon Greenwich Mean Time).

Rising or Setting Corrections

North Latitude	Declination (North or South) 0°	5°	10°	15°	20°	25°
60°	1	11	23	36	53	80
55°	0	5	10	16	23	32
50°	0	0	0	0	0	0
45°	0	4	8	13	18	24
40°	1	8	15	23	32	43
35°	1	10	20	31	44	68
30°	1	12	25	39	54	72
25°	1	15	30	46	64	84

Time Corrections

All events on this *Skygazer's Almanac* are plotted for an observer at longitude 0° and latitude 50° north, a reasonable compromise for the countries of northern and central Europe. However, you need not be on a boat in the English Channel to use the chart. Simple corrections will allow you to get times accurate to a couple of minutes anywhere in the world's north temperate latitudes.

To convert the charted time of an event into your civil (clock) time, the following corrections must be made. They are given in decreasing importance:

• **DAYLIGHT-SAVING TIME (OR "SUMMER TIME").** When this is in effect, add one hour to any time that you obtain from the chart.

• **YOUR LONGITUDE.** The chart gives the *Local Mean Time* (LMT) of events, which differs from ordinary clock time by a number of minutes at most locations. Our civil time zones are standardized on particular longitudes. Examples in Europe are Greenwich Mean Time (or Universal Time), 0°; Central European Time, 15°E; and Eastern European Time, 30°E. If your longitude is very close to one of these (as is true for London), luck is with you and this correction is zero. Otherwise, to get standard time *add 4 minutes* to times obtained from the chart for each degree of longitude that you are *west* of your time-zone meridian. Or *subtract 4 minutes* for each degree you are *east* of it.

For instance, Copenhagen (longitude 12.5° east) is 2.5° west of the Central European Time meridian. So at Copenhagen, add 10 minutes to any time obtained from the chart. The result is Central European Standard Time.

Find your local-time correction and memorize it. In the table at below left are the corrections from local to standard time, in minutes, for some major cities.

• **RISING AND SETTING.** Times of rising and setting need correction if your latitude differs from 50° north. This effect depends strongly on a star or planet's declination. (The declinations of the Sun and planets are listed in *Sky & Telescope*.)

If your site is north of latitude 50°, then an object with a north declination stays above the horizon longer than the chart shows (it rises earlier and sets later), while one with a south declination spends less time above the horizon. At a site south of 50°, the effect is just the reverse. Keeping these rules in mind, you can gauge roughly the number of minutes by which to correct a rising or setting time from the table above.

Finally, the Moon's rapid orbital motion alters lunar rising and setting times slightly if your longitude differs from 0°. The Moon rises and sets about two minutes earlier than the chart shows for each time zone east of Greenwich Mean Time, and two minutes later for each time zone west.

For reprints (item SGA21E, $5.95 each) or to order a similar chart for latitude 40° north or 30° south, go to: shopatsky.com/resource-materials/calendars-almanacs

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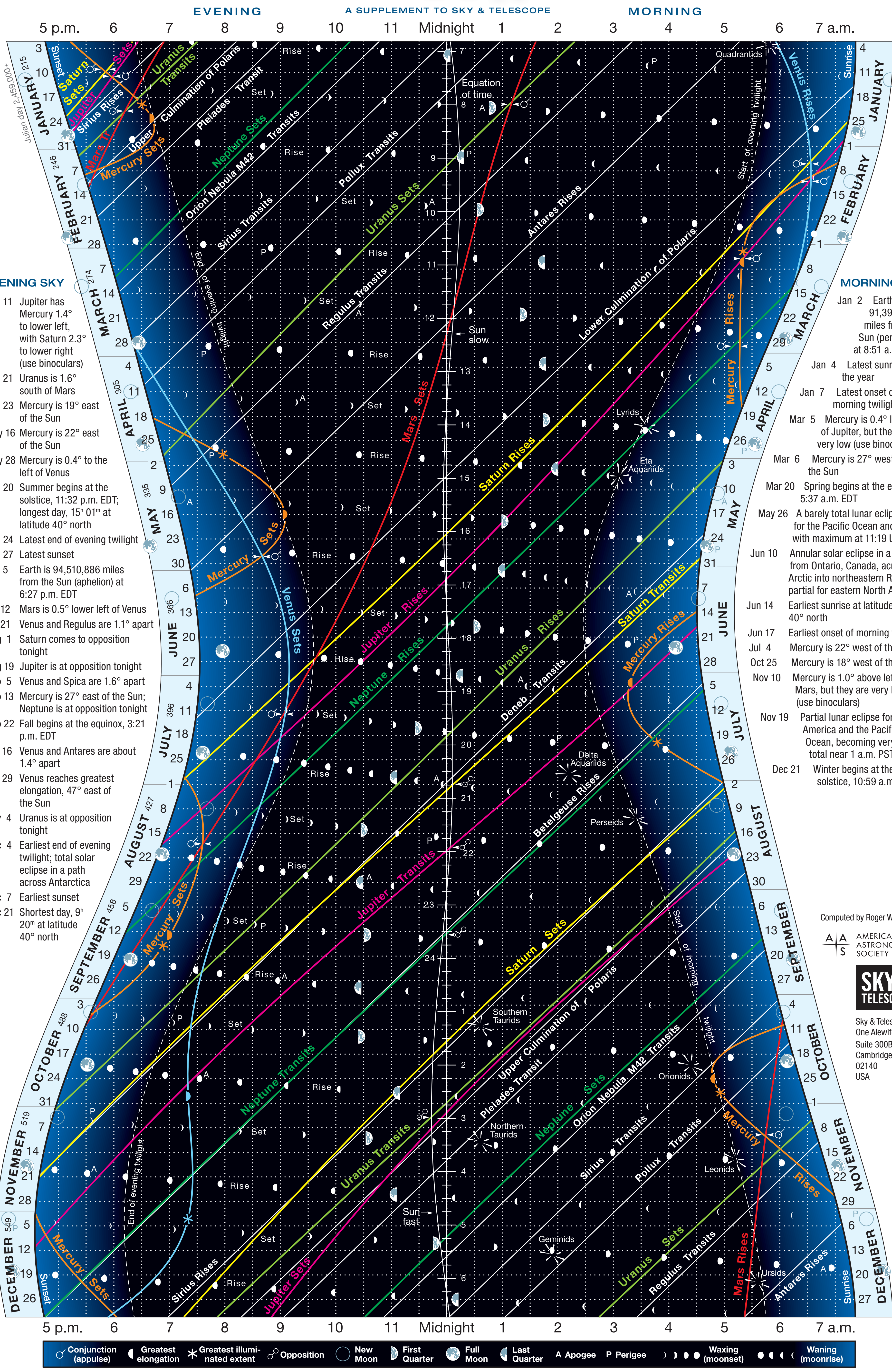
SKY & TELESCOPE

AMERICAN ASTRONOMICAL SOCIETY

Skygazer's Almanac 40°N 2021

FOR LATITUDES NEAR 40° NORTH

A SUPPLEMENT TO SKY & TELESCOPE



EVENING SKY

Jan 11 Jupiter has Mercury 1.4° to lower left, with Saturn 2.3° to lower right (use binoculars)

Jan 21 Uranus is 1.6° south of Mars

Jan 23 Mercury is 19° east of the Sun

May 16 Mercury is 22° east of the Sun

May 28 Mercury is 0.4° to the left of Venus

Jun 20 Summer begins at the solstice, 11:32 p.m. EDT; longest day, 15ʰ 01ᵐ at latitude 40° north

Jun 24 Latest end of evening twilight

Jun 27 Latest sunset

Jul 5 Earth is 94,510,886 miles from the Sun (aphelion) at 6:27 p.m. EDT

Jul 12 Mars is 0.5° lower left of Venus

Jul 21 Venus and Regulus are 1.1° apart

Aug 1 Saturn comes to opposition tonight

Aug 19 Jupiter is at opposition tonight

Sep 5 Venus and Spica are 1.6° apart

Sep 13 Mercury is 27° east of the Sun; Neptune is at opposition tonight

Sep 22 Fall begins at the equinox, 3:21 p.m. EDT

Oct 16 Venus and Antares are about 1.4° apart

Oct 29 Venus reaches greatest elongation, 47° east of the Sun

Nov 4 Uranus is at opposition tonight

Dec 4 Earliest end of evening twilight; total solar eclipse in a path across Antarctica

Dec 7 Earliest sunset

Dec 21 Shortest day, 9ʰ 20ᵐ at latitude 40° north

MORNING SKY

Jan 2 Earth is 91,399,454 miles from the Sun (perihelion) at 8:51 a.m. EST

Jan 4 Latest sunrise of the year

Jan 7 Latest onset of morning twilight

Mar 5 Mercury is 0.4° left of Jupiter, but they are very low (use binoculars)

Mar 6 Mercury is 27° west of the Sun

Mar 20 Spring begins at the equinox, 5:37 a.m. EDT

May 26 A barely total lunar eclipse for the Pacific Ocean and Rim, with maximum at 11:19 UT

Jun 10 Annular solar eclipse in a path from Ontario, Canada, across the Arctic into northeastern Russia; partial for eastern North America

Jun 14 Earliest sunrise at latitude 40° north

Jun 17 Earliest onset of morning twilight

Jul 4 Mercury is 22° west of the Sun

Oct 25 Mercury is 18° west of the Sun

Nov 10 Mercury is 1.0° above left of Mars, but they are very low (use binoculars)

Nov 19 Partial lunar eclipse for North America and the Pacific Ocean, becoming very nearly total near 1 a.m. PST

Dec 21 Winter begins at the solstice, 10:59 a.m. EST

Computed by Roger W. Sinnott

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SKY & TELESCOPE

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Skygazer's Almanac 40°N 2021

FOR LATITUDES NEAR 40° NORTH

What's in the sky tonight?

When does the Sun set, and when does twilight end? Which planets are visible? What time does the Moon rise?

Welcome to the *Skygazer's Almanac 2021,* a handy chart that answers these and many other questions for every night of the year. It is plotted for skywatchers near latitude 40° north — in the United States, the Mediterranean countries, Japan, and much of China.

For any date, the chart tells the times when astronomical events occur during the night. Dates on the chart run vertically from top to bottom. The time of night runs horizontally, from sunset at left to sunrise at right. Find the date you want on the left side of the chart, and read across toward the right to find the times of events. Times are labeled along the chart's top and bottom.

In exploring the chart you'll find that its night-to-night patterns offer many insights into the rhythms of the heavens.

The Events of a Single Night

To learn how to use the chart, consider some of the events of one night. We'll pick January 10, 2021.

First find "January" and "10" at the left edge. This is one of the dates for which a string of fine dots crosses the chart horizontally. Each horizontal dotted line represents the night from a Sunday evening to Monday morning. The individual dots are five minutes apart.

Every half hour (six dots), there is a vertical dotted line to aid in reading the hours of night at the chart's top or bottom. On the vertical lines, one dot is equal to one day.

A sweep of the eye shows that the line for the night of January 10–11 crosses many slanting *event lines*. Each event line tells when something happens.

The dotted line for January 10–11 begins at the heavy black curve at left, which represents the time of sunset. Reading up to the top of the chart, we find that sunset on January 10th occurs at 4:54 p.m. *Local Mean Time*. (All times on the chart are Local Mean Time, which can differ from your clock time. More on this later.)

We see that Saturn, Mercury, and Jupiter all set in quick succession around 6 p.m. This means they are fairly close together in the sky, as described in the column of text left of the chart. But they may be hard to see so soon after sunset.

At 6:18 p.m. the bright star Sirius rises. Then at 6:31 a dashed line shows that twilight technically ends. This is when the Sun is 18° below the horizon and the sky is fully dark.

The red planet Mars transits the meridian at 6:34, meaning it is due south and "riding high," an excellent time to study it in a telescope.

At 7:36 Polaris, the North Star, has its upper culmination. It then stands directly above the north celestial pole (by 39′ or 38′ this year), a good time to check the alignment of an equatorial telescope.

The famous Pleiades star cluster transits at 8:25 p.m., followed by the Orion Nebula (10:13) and Sirius (11:22). Transit times of such celestial landmarks help us keep track of the march of constellations across the night sky.

Running vertically down the midnight line is a scale of hours. This shows the sidereal time (the right ascension of objects on the meridian) at midnight. On January 10–11 this is $7^h\ 24^m$. To find the sidereal time at any other time and date on the chart, locate that point and draw a line through it parallel to the white event lines of stars. See where your line intersects the sidereal-time scale at midnight. (A star's event line enters the top of the chart at the same time of night it leaves the bottom. Sometimes one of these segments is left out to avoid crowding.)

Near the midnight line is a white curve labeled *Equation of time* weaving narrowly right and left down the chart. If you regard the midnight line as noon for a moment, this curve shows when the Sun crosses the meridian and is due south. On January 10th the Sun runs slow, transiting at 12:08 p.m. This deviation, important for reading a sundial, is caused by the tilt of the Earth's axis and the ellipticity of its orbit.

After being visible all evening, Mars finally sets at 1:22 a.m. The wee hours continue, and at 4:41 Antares rises. This is a star we usually associate with a much later season of the year.

The first hint of dawn — start of morning twilight — comes at 5:45 a.m. A beautiful crescent Moon rises around 6:01, as does Venus at 6:12. The Sun finally peeks above the horizon at 7:21 a.m. on January 11th.

Other Charted Information

Many of the year's chief astronomical events are listed in the chart's evening and morning margins. Some are marked on the chart itself.

Conjunctions (close pairings) of two planets are indicated by a ☌ symbol on the planets' event lines. Here, conjunctions are considered to occur when the planets actually appear closest in the sky (at appulse), not merely when they share the same ecliptic longitude or right ascension.

Opposition of a planet, the date when it is opposite the Sun in the sky and thus visible all night, occurs roughly when its transit line crosses the Equation-of-time line (*not* the line for midnight). Opposition is marked there by a ☍ symbol, as for Saturn on the night of August 1–2.

Moonrise and *moonset* can be told apart by whether the round limb — the outside edge — of the Moon symbol faces right (waxing Moon sets) or left (waning Moon rises). Or follow the nearly horizontal row of daily Moon symbols across the chart to find the word *Rise* or *Set*. Quarter Moons are indicated by a larger symbol. Full Moon is always a large bright disk whether rising or setting; the circle for new Moon is open. *P* and *A* mark dates when the Moon is at perigee and apogee (nearest and farthest from Earth, respectively).

Mercury and *Venus* never stray far from the twilight bands. Their dates of greatest elongation from the Sun are shown by ◗ symbols on their rising or setting curves. Asterisks mark their dates of greatest illuminated extent in square arcseconds. For example, this occurs for Venus on the evening of December 3rd this year.

Meteor showers are marked by a starburst symbol on the date of peak activity and at the time when the shower's radiant is highest in the night sky. This is often just as morning twilight begins. (Note that we've moved the peak of the Southern Taurids, a sparse, ill-defined shower, to a little earlier in the year.)

Julian dates can be found from the numbers just after the month names on the chart's left. The Julian day, a seven-digit number, is a running count of days beginning with January 1, 4713 BC. Its first four digits this year are 2459, as indicated just off the chart's upper left margin. To find the last three digits for evenings in January, add 215 to the date. For instance, on the evening of January 10th we have 215 + 10 = 225, so the Julian day is 2,459,225. For North American observers this number applies all night, because the next Julian day always begins at 12:00 Universal Time (6:00 a.m. Central Standard Time).

Time Corrections

All events on this *Skygazer's Almanac* are plotted for an observer at 90° west longitude and 40° north latitude, near the population center of North America. However, you need not live near Peoria, Illinois, to use the chart. Simple corrections will allow you to get times accurate to a couple of minutes anywhere in the world's north temperate latitudes.

Rising or Setting Corrections

North Latitude	Declination (North or South) 0°	5°	10°	15°	20°	25°
50°	0	7	14	23	32	43
45°	0	3	7	10	14	19
40°	0	0	0	0	0	0
35°	0	3	6	9	12	16
30°	0	5	11	16	23	30
25°	0	8	16	24	32	42

To convert the charted time of an event to your civil (clock) time, the following corrections must be made. They are mentioned in order of decreasing importance:

• **DAYLIGHT-SAVING TIME.** When this is in effect, add one hour to any time obtained from the chart.

• **YOUR LONGITUDE.** The chart gives the *Local Mean Time* (LMT) of events, which differs from ordinary clock time by a number of minutes at most locations. Our civil time zones are standardized on particular longitudes. Examples in North America are Eastern Time, 75° W; Central, 90°; Mountain, 105°; and Pacific, 120°. If your longitude is very close to one of these (as is true for New Orleans and Denver), luck is with you and this correction is zero. Otherwise, to get standard time *add 4 minutes* to times obtained from the chart for each degree of longitude that you are *west* of your time-zone meridian. Or *subtract 4 minutes* for each degree you are *east* of it.

For instance, Washington, DC (longitude 77°), is 2° west of the Eastern Time meridian. So at Washington, add 8 minutes to any time obtained from the chart. The result is Eastern Standard Time.

Find your time adjustment and memorize it. The table below left shows the corrections from local to standard time, in minutes, for some major cities.

Local Mean Time Corrections

Atlanta	+38	Los Angeles	–7
Boise	+45	Memphis	0
Boston	–16	Miami	+21
Buffalo	+15	Minneapolis	+13
Chicago	–10	New Orleans	0
Cleveland	+27	New York	–4
Dallas	+27	Philadelphia	+1
Denver	0	Phoenix	+28
Detroit	+32	Pittsburgh	+20
El Paso	+6	St. Louis	+1
Helena	+28	Salt Lake City	+28
Honolulu	+31	San Francisco	+10
Houston	+21	Santa Fe	+4
Indianapolis	+44	Seattle	+9
Jacksonville	+27	Tulsa	+24
Kansas City	+18	Washington	+8
Athens	+25	Lisbon	+36
Baghdad	+3	Madrid	+75
Beijing	+14	New Delhi	+21
Belgrade	–22	Rome	+10
Cairo	–8	Seoul	+32
Istanbul	+4	Tehran	+4
Jerusalem	–21	Tokyo	–19

• **RISING AND SETTING.** These times need correction if your latitude differs from 40° north. This effect depends strongly on a star or planet's declination. (The declinations of the Sun and planets are listed monthly in *Sky & Telescope*.)

If your site is *north* of latitude 40°, then an object with a north declination stays above the horizon *longer* than the chart shows (it rises earlier and sets later), whereas one with a south declination spends less time above the horizon. At a site *south* of 40°, the effect is just the reverse. Keeping these rules in mind, you can gauge the approximate number of minutes by which to correct a rising or setting time from the table above.

Finally, the Moon's rapid orbital motion affects lunar rising and setting times if your longitude differs from 90° west. The Moon rises and sets about two minutes earlier than the chart shows for each time zone east of Central Time, and two minutes later for each time zone west of it. European observers can simply shift each rising or setting Moon symbol leftward a quarter of the way toward the one for the previous night.

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