INFRARED REVOLUTION:
Spitzer's Legacy
PAGE 18

DIY:
Make a Focus Mask
PAGE 30

DEEP-SKY WONDERS:
Treasures of Auriga
PAGE 54

SKY & TELESCOPE

THE ESSENTIAL GUIDE TO ASTRONOMY

JANUARY 2020

Do Microbes Hide Beneath Mars's Surface?

Page 34

skyandtelescope.org

GOING DEEP:
Fishing the Pisces Cloud
Page 58

Wander Through Winter's Splendors
Page 62

FORENSIC ASTRONOMY:
How Science Saved an Innocent Man
Page 26

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CONTENTS

SKY&TELESCOPE
THE ESSENTIAL GUIDE TO ASTRONOMY

January 2020 VOL. 139, NO. 1


62

FEATURES

OBSERVING

S&T TEST REPORT

COLUMNS / DEPARTMENTS

BILL BASHAM

ON THE COVER

Artist's concept of Martian microbes, inspired by Earth's
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Look Down

WHERE WOULD ASTRONOMY BE WITHOUT LIGHT? Save for a few rocks that have crashed to Earth or that we've managed to bring back from the closest bodies to us, most of what we've learned about the cosmos has come courtesy of electromagnetic radiation arriving from afar. Visible light, X-rays and gamma rays, ultraviolet and infrared radiation, microwaves and radio waves — all these forms of light have collectively enabled us to penetrate some of our universe's deepest secrets. See, for example, "Spitzer's Legacy" on page 18.

Yet, ironically, astrobiologists are itching to go where there's no light at all. The reason is to potentially answer one of the biggest cosmological questions of all: Does life exist elsewhere?

Many scientists would agree that one of the most likely places to find signs of extraterrestrial life is where darkness reigns — namely, belowground. If living things do exist beyond our planet, lightless zones such as the Martian subsurface or the deep oceans sheltered beneath the icy crusts of Europa and Enceladus might well harbor it.

Just scratching the surface: a 2-inch-deep hole drilled by the Curiosity Rover on Mars

As Javier Barbuzano writes in our cover story on page 34, we've known for decades that life on Earth can survive in total darkness. Entire ecosystems thrive in the ocean depths thousands of feet below the point where the last feeble rays of sunlight can reach. Similarly, microorganisms have been found doing just fine more than a mile underground.

In these stygian realms, photosynthesis, the basis of all life on the surface, is impossible. Instead, microbes at the base of the food chain have resorted to *chemosynthesis*, gaining their energy from chemical reactions. In some cases, this has allowed a menagerie of much larger organisms to exist, such as the giant tubeworms that cluster around hydrothermal vents on the seafloor.

Some scientists suspect that life on our planet might well have gotten its start in such sunless environs, rather than on the surface in, say, Darwin's "warm little pond." Maybe it began in a similar fashion on other bodies in our solar system and flourishes there to this day, awaiting our probes.

Just think: Light allows us to investigate objects and events right across the universe. Yet in all that inconceivably vast space, the spot where we're most likely to turn up evidence of other life forms is perhaps but a few tens of feet below the surface of our nearest neighbors. It's like pondering where on our enormous globe you might strike gold, when the most promising spot is right where you're standing.

NASA and other space agencies: Here's to going down.

Peter

Editor in Chief

NASA

Editorial Correspondence
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Fun with Names

Ted Forte's "Favorite September Sights" (*S&T:* Sept. 2019, p. 30) features a planetary nebula in need of a name. From what I see in it, NGC 6781 in Aquila could be called the "Hot Blue Alien." I see a face clearly: two eyes looking to the right, a thin nose in between, two eyebrows, and just a hint of a smile along the color boundary at lower right. Once I noticed those details, I cannot ignore them. Do others agree?

Gregg Paris • San Clemente, California

When someone discovers a comet, it's named after that person. Unfortunately, this is not the case for most deep-sky objects. So I would like to suggest that we give credit to those who first noted significant galaxies, clusters, and nebulae. In each of the following examples, most of which already have common names, the discoverer found only one object of each type (OC stands for open cluster, GC for globular cluster, and PN for planetary nebula):

Aratos' OC M44, Aristoteles' OC M41, Al Sufi's galaxy M31, Cacciatore's GC NGC 6541, Cassini's OC M50, de Chéseaux's nebula M17, Flamsteed's OC NGC 2244, Harding's PN NGC 7293, Caroline Herschel's galaxy NGC 253, Hodierna's galaxy M33, Hodierna's nebula M8, Ihle's GC M22, Kirch's OC M11, Kirch's GC M5, Koehler's OC M67, Lacaille's galaxy M83, de Mairan's nebula M43, Mechain's nebula M78, Mechain's OC M103, Peiresc's nebula M42, and Webb's OC IC 4756.

Glen Cozens
New South Wales, Australia

Getting the Light Right

Igor Palubski and Aomawa Shields's article on the factors to consider when determining if a planet orbiting a red-dwarf star could harbor life (*S&T:* Aug. 2019, p. 34) makes me wonder if we need to consider additional variables when determining where life can exist in the universe.

A point about the upper caption on page 37: Although a greater *fraction* of the radiation emitted by a red dwarf is indeed in the infrared range, the *total* amount of its infrared light is less — not more — than that emitted by hotter stars such as the Sun. The blackbody radiation diagram itself makes this comparison clear.

Douglas Warshow
Ann Arbor, Michigan

The first sentence in Palubski and Shields's article misleads readers by stating that the Sun is a "bright yellow star." That is not true, as every astronomer knows full well. The Sun is actually a pure-white star; it only gives the appearance of being yellow when viewed from ground level here on Earth.

Edward S. Craig
Bangor, Maine

Camille Carlisle replies: *This is a point of linguistic discomfort among astronomers. The Sun does appear whitish to our eyes, and solar astronomers will describe it thusly. But the Sun's emission peaks at a wavelength around that of visible yellow. So when discussing the Sun in the context of where it fits in with other stars, astronomers refer to it (and other* G*-type stars) as yellow.*

The H-Alpha Universe

I thoroughly enjoyed the article about the MDW Sky Survey (*S&T:* Oct. 2019, p. 20), and I wish Dennis di Cicco and Sean Walker success in completing such an amazing project! There have been professional hydrogen-alpha surveys in the past, but these have concentrated more on the galactic plane. A truly all-sky survey is bound to uncover a population of previously unknown planetary nebulae.

An equally interesting project would be an all-sky survey in the light of doubly ionized oxygen (O III), which would surely reveal many faint unknown nebulae. Indeed, amateurs have discovered hundreds of new planetaries in the past decade, and some of them are chronicled at **planetarynebulae.net/en**.

Sakib Rasool
Rochdale, United Kingdom

Nabbing Neptune

Thank you for the article "Cool Hunting" (*S&T:* Sept. 2019, p. 48)! It reminded me that, despite my being a stargazer for more than 40 years, I had never tried to spot Neptune. Possibly this was because it had long been low in the southern sky and didn't seem to be a promising object at all when observed from my latitude of +53½°.

But after reading the article, and with Neptune now at a more accessible declination of –6°, I decided to give it a try. The sky was a bit hazy on the evening of September 21st, and moderate light pollution from the small town where I live was obvious. But after some star-hopping with my 100-mm f/10 refractor, I found that tiny bluish dot.

Then I took a picture with my DSLR camera, which revealed a small dot

▲ A 13-second exposure at ISO 1600, shot using a 100-mm f/10 refractor, easily reveals bluish Neptune. Triton is just to its lower right.

NGC 6781: JOSEF PÖPSEL / BEATE BEHLE; NEPTUNE: KARL-LUDWIG ABKEN close to Neptune. What a surprise! I read the article again and followed the link to *Sky & Telescope*'s Triton Tracker app. After estimating the small dot's position angle and separation from Neptune, it was clear that the small dot was indeed Triton. Although I wasn't able to spot it with my eyes that night, it was a surprisingly easy target for my telescope and camera.

Karl-Ludwig Abken
Nordenham, Germany

Peace Officers in England

I confess to being a little bemused at recent correspondence (*S&T:* Nov. 2019, p. 6) regarding the potential danger posed to astronomers by police officers who might confuse the tube of a Dobsonian for something more sinister.

I have no wish to become politically involved in the ongoing U.S. gun-control debate, but I must say I am very grateful to be an amateur astronomer in England. We still do not have routinely armed police, and possession of a handgun is 100% illegal here. The most I might have to worry about is having my night vision ruined by a flashlight-wielding policeman who is unlikely to be concerned about the possibility of me having any kind of weapon. It's surely a different world over there.

Harold Mead
Somerset, United Kingdom

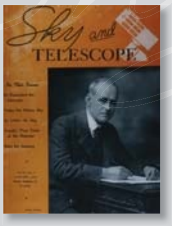
FOR THE RECORD

- The caption for Messier 52's image (*S&T:* Oct. 2019, p. 32) should have stated that 158 million years is the cluster's estimated age; its distance is about 5,000 light-years.
- "Transit Timetable" (*S&T:* Nov. 2019, p. 48) correctly lists the event's midpoint as 15:20 Universal Time; the time-zone-specific midpoints listed below it should also end in :20.

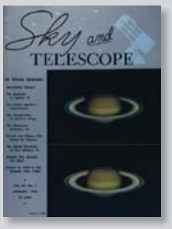
SUBMISSIONS: Write to *Sky & Telescope*, 90 Sherman St., Cambridge, MA 02140-3264, USA or email: letters@skyandtelescope.org. Please limit your comments to 250 words; letters may be edited for brevity and clarity.

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

1945



1970



1995

◖ January 1945

Spurious Perspective "In the Adler Planetarium there is a magnificent large model of the moon; when it is viewed from a distance of 20 to 30 feet, something about it appears very different from a telescopic view, and it must be [an] effect of spurious perspective involuntarily experienced in telescopic views.

"All of this emphasizes the foolishness of [asking], 'How far away does this telescope make the moon appear to be?' The answer to this question should be a polite but firm insistence that the telescope does not make the moon appear nearer; the perspective is all wrong. The only thing the telescope does is to magnify the naked-eye image of the moon. Talk about magnifying powers of 10,000 diameters to be used on the 200-inch telescope, 'thus bringing the moon up to only 24 miles from the earth,' is probably the maximum in telescoptical absurdity. . . .

"Unless astronomers assign themselves the task of stopping journalistic nonsense about astronomy, surely no one else is going to do the job."

Longtime columnist Roy K. Marshall was very much the "Science Guy" of his time.

◖ January 1970

Pulsar Periods "'Continuing observations of the times of arrival of the radio pulses from the pulsars visible from Jodrell Bank indicate that almost all [have rotation rates that are slowing down],' reports the British radio astronomer G. C. Hunt in *Nature* for December 6th.

"For 13 well-observed pulsars, he has derived the present rates of increase of period . . .

"The fastest changing pulsar is NP 0532 in the Crab nebula. . . .

"[But] Dr. Hunt calls particular attention to CP 0808 in Camelopardalis, whose period of 1.292241315 seconds has shown no sign of increase. . . . This conflicts with Thomas Gold's theory that the energy radiated by a pulsar is obtained at the expense of its rotational energy.

"To Dr. Hunt, CP 0808 suggests strongly that there must be another source from which the radiated energy is drawn, this source being either the magnetic field of the object or else its gravitational contraction."

Add to this "glitches," which are occasional sudden speed-ups observed in pulsars that are otherwise slowing down. Astronomers still struggle to model such changes.

◖ January 1995

Terrestrial Gamma Rays "The Burst and Transient Source Experiment (BATSE) aboard NASA's Compton Gamma Ray Observatory was designed to study gamma-ray bursts in space. Since its launch in April 1991 it has recorded more than 1,150 such events . . . But BATSE has also detected more than a dozen gamma-ray flashes from the *Earth*. First dismissed as spurious, these signals now appear to be quite real and may be associated with electromagnetic discharges in our planet's upper atmosphere.

"Gerald J. Fishman (NASA-Marshall Space Flight Center) and his colleagues reported that seven of the earthly gamma-ray flashes occurred under the watchful eye of a weather satellite, and in every case there was a large thunderstorm nearby. [Moreover,] airplane pilots and astronauts have reported seeing mysterious flashes of light streaking *upward* from the tops of thunderstorms. . . .

"To produce [gamma rays], the electric fields above storm clouds would have to accelerate electrons to energies of a million electron volts, making them some 30 times more powerful than the fields normally associated with lightning."

The Hubble Space Telescope obtained this image of Comet 2I/Borisov on October 12, 2019, when the object was 2.8 a.u. from Earth.

COMETS

Second Interstellar Visitor Discovered

ON AUGUST 30, 2019, an amateur astronomer discovered another interstellar object — the second after ‘Oumuamua (*S&T:* Feb. 2018, p. 10). This one’s a comet that will pass nearest the Sun and Earth in December.

Gennady Borisov captured Comet 2I/Borisov using a 0.65-meter telescope at the MARGO observatory near Nauchnij in Crimea, when it was about 3 astronomical units (a.u.) from the Sun. Unlike ‘Oumuamua, which was spotted after its perihelion, the new comet was still inbound. It comes closest to the Sun on December 8th, passing within 2 a.u. Its closest approach to Earth follows on December 28th.

What sets Borisov (and ‘Oumuamua) apart from solar system comets is the eccentricity of its orbit. Planets, asteroids, and comets have elliptical orbits, with eccentricities between 0 and 1. But Borisov’s eccentricity is more than 3, indicating a *hyperbolic orbit*. That is, it’s not gravitationally bound to the Sun. Moreover, its high velocity — which will reach a peak of 44 km/s (100,000 mph) at perihelion — precludes an origin within the solar system. The comet appears to be coming from Cassiopeia in the direction of the galactic plane.

Borisov was around 18th-magnitude at discovery, and early images showed a faint but distinct coma and the barest hint of a tail — cometary activity that ‘Oumuamua lacked (*S&T:* Oct. 2018, p. 20). By October, Borisov had reached 16th magnitude, and it’s expected to peak at 15th magnitude in December.

From early December through early January 2020, when Comet Borisov is expected to be brightest, it will travel about 0.8° per day, from the central part of Crater southward to Centaurus. The first 10 days of December will be best for amateur imaging and even visual attempts (using at least an 8-inch telescope under pristine skies) before the full Moon interferes on December 12th. Moon-free nights return on December 22nd.

In September, astronomers obtained spectra of Comet Borisov using the 4.2-meter William Herschel Telescope on La Palma, Spain, and the 8.2-meter Gemini North telescope on Maunakea, Hawai‘i. The object’s slightly reddish surface color, its 2-kilometer-wide nucleus, and the properties of its dust and gas resemble aspects of long-period solar system comets. The results appear October 14th in *Nature Astronomy*, and more observations are forthcoming.

■ **BOB KING & NOLA TAYLOR REDD**

● **Find a chart for Comet Borisov at https://is.gd/borisov.**

ASTRONOMY & SOCIETY

Nobel Prize Honors Exoplanet, Cosmology Discoveries

THE ROYAL SWEDISH ACADEMY OF SCIENCES has awarded the 2019 Nobel Prize in Physics to James Peebles (Princeton) and to Michel Mayor and Didier Queloz (both at the University of Geneva, Switzerland). The prize, which will be split in half, honors discoveries that offer new perspectives on our place in the universe.

Peebles is being honored for his theoretical contributions to our understanding of the Big Bang, as well as the role that dark matter and dark energy play in shaping our universe.

When Robert Wilson and Arno Penzias at the Bell Telephone Laboratories in New Jersey found a persistent buzz in their radio experiments — a discovery that won them the 1978 Nobel Prize in Physics — Peebles and his colleagues had already predicted the existence of background radiation. This radiation, they theorized, was initially trapped in the primordial soup of ions in the hot, early universe. But 370,000 years after the Big Bang, the soup had cooled enough to combine into neutral atoms, setting the photons free. This cosmic microwave background (CMB) now fills the universe.

Peebles worked for decades to understand tiny fluctuations in the CMB, which turn out to encode information about the universe’s earliest years. As astronomers were finding evidence for the existence of dark matter and dark energy in their observations of stars, galaxies, and galaxy clusters, Peebles

▶ James Peebles (*left*) shares the 2019 Nobel Prize in Physics with Michel Mayor (*center*) and Didier Queloz (*right*).

COMET: NASA / ESA / D. JEWITT (UCLA); NOBEL ILLUSTRATIONS: NOBEL MEDIA

SOLAR SYSTEM

20 New Moons Found Around Saturn

JUPITER MAY BE THE KING of the planets, but — right now, at least — Saturn is the king of moons. Astronomers Scott Sheppard (Carnegie Institution for Science), David Jewitt (UCLA), and Jan Kleyna (University of Hawai'i) have announced the discovery of 20 new moons circling the ringed planet, putting Saturn's total at 82 compared with Jupiter's 79. The moons are each around 5 kilometers (3 miles) in diameter.

The team used the 8.2-meter Subaru telescope atop Maunakea, Hawai'i, to find the moons. Sheppard had previously led a team in discovering 10 new moons around Jupiter, announced last year (*S&T:* Oct. 2018, p. 8), using the 6.5-m Magellan-Baade reflector at Las Campanas and the 4-m Blanco reflector on Cerro Tololo.

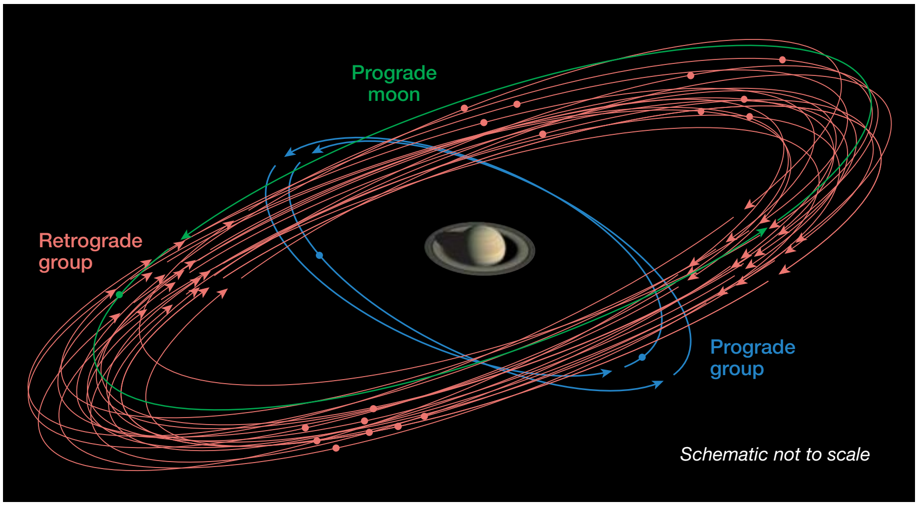
"Using some of the largest telescopes in the world, we are now completing the inventory of small moons around the giant planets," Sheppard explains. He and his colleagues are motivated by the window into the solar system's formation that these discoveries provide.

Saturn's outer moons can be roughly grouped into one of three clusters, dubbed the Norse, Inuit, and Gallic groups, according to the inclination of their orbits. Of the 20 new moons, 17 follow *retrograde* orbits and belong to the Norse group. The Norse group is diverse, but the orbits and inclinations of the newest moons suggest they all originated from the same parent body.

Three other moons are in prograde orbits, two orbiting at an inclination of 46° and one at an inclination of 36°. They belong to the Inuit and Gallic moon groups, respectively.

The Carnegie Institution for Science has held a contest to name the moons. Name suggestions, based on Norse, Inuit, and Gallic mythological giants, will go to the International Astronomical Union for a final decision.

■ MONICA YOUNG



▲ An artist's concept shows the 20 newfound moons orbiting Saturn.

was working to provide a solid theoretical framework for these concepts.

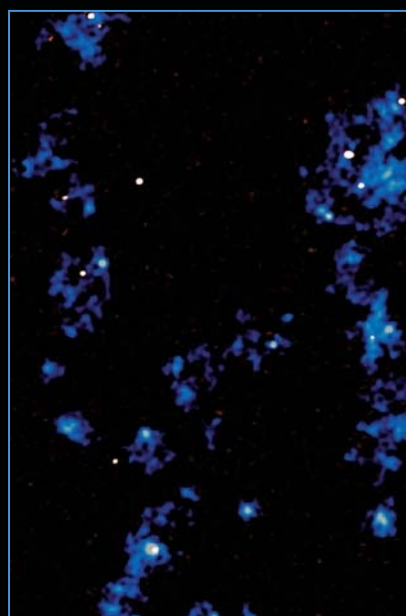
Mayor and Queloz will receive the other half of the Nobel Prize for their discovery of an exoplanet orbiting a Sun-like star, a hot Jupiter known as 51 Pegasi b. This gas giant, half the mass of Jupiter but half again as wide, zips around its star every four days and reaches temperatures of 1200K (1800°F). These properties made it far from the kind of exoplanet astronomers had expected to find. Nevertheless, it served as a proof of concept that ignited an exponential firestorm of exoplanet detections. More than two decades later, this worldwide effort has now collectively amassed more than 4,000 confirmed exoplanets.

■ MONICA YOUNG

Quasars Light Up Cosmic Web

Faraway galaxies act as flashlights, lighting up a piece of the *cosmic web* from when the universe was only about 2 billion years old. Computer simulations predicted this large-scale structure decades ago, yet the sparse gas bridging one galaxy cluster to another is difficult to detect directly. But in the October 4th *Science*, Hideki Umehata (RIKEN Cluster for Pioneering Research, Japan) and colleagues published an image (*right*) of a 3-million-light-year-long section of this gas. Using the Multi Unit Spectroscopic Explorer (MUSE) on the European Southern Observatory's Very Large Telescope in Chile, Umehata's team zeroed in on a distant collection of galaxies, collectively known as SSA22. These galaxies, bursting with newborn stars (white dots) and/or hosting a gas-guzzling black hole (not shown here), irradiate the sparse hydrogen gas that surrounds them. They light up two main filaments that run vertically through this image. The astronomers calculate that this region of the cosmic web contains a trillion Suns' worth of gas, fueling new stars and black hole activity.

■ MONICA YOUNG



SATURN ILLUSTRATION: SATURN IMAGE: NASA / JPL-CALTECH / SPACE SCIENCE INSTITUTE, STARRY BACKGROUND: PAOLO SARTORIO / SHUTTERSTOCK; COSMIC WEB: HIDEKI UMEHATA

BLACK HOLES

More Black Hole Mergers in LIGO Data

THE LIGO-VIRGO COLLABORATION has so far announced 11 detections of gravitational-wave surges based on data collected during its first two observing runs. Each surge comes from the merger of distant compact objects. Now, an independent team sorting through the public data archive has found seven additional black hole merger candidates.

Tejaswi Venumadhav (Institute for Advanced Study) and his colleagues developed their own data analysis pipeline to look specifically for black hole mergers. This is unlike the approach taken by the LIGO and Virgo collaborations, who look at data with "eyes wide open" to catch anything and everything, explains LIGO spokesperson Patrick Brady (University of Wisconsin, Milwaukee). The more focused approach provides greater sensitivity to spot quieter signals, Venumadhav said during a recent colloquium at Harvard University's Black Hole Initiative.

The seven merger candidates involved black holes with masses similar to those seen crashing together by the LIGO-Virgo Collaboration, roughly 20 to 40 solar masses. Also similar to the LIGO-Virgo mergers, most of the new candidates had small *effective spins*. The effective spin compares the speed and tilt of the two black holes' individual spins relative to each other and to their orbit around each other. If a system has an effective spin near zero, the most likely reason is that the two black holes either weren't spinning fast before the merger or they were spinning but were rolling on their sides relative to their orbit around each other.

However, one candidate, GW151216, bucks that trend. Its high effective spin might mean that, before the merger, the two black holes had similar masses and were whirling around each other like two upright tops on a table. Or, it could be that one fast- and upright-spinning black hole was more massive and thus "outweighed" its slower partner.

Artist's illustration of two black holes about to merge

The LIGO and Virgo collaborations have been discussing the results with Venumadhav's team for about a year, and Brady for one thinks the analysis is sound. The collaboration plans to release the second catalog of events around April 2020, which will include candidates found in the third observing run's first six months.

■ **CAMILLE M. CARLISLE**

● **Read about the newfound black hole mergers at https://is.gd/newmergers.**

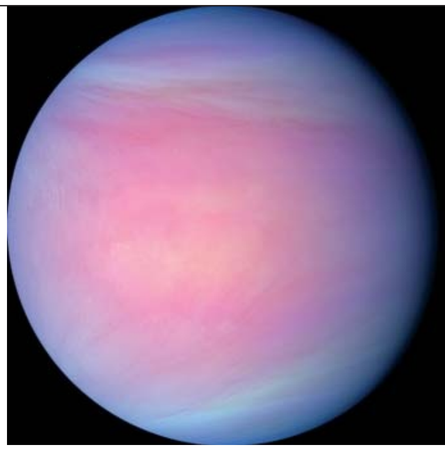
SOLAR SYSTEM

The Puzzling Clouds of Venus

JAPAN'S AKATSUKI SPACECRAFT has revealed previously unknown dynamics in the Venusian atmosphere, say scientists in two teams who presented their research at the joint meeting of the European Planetary Science Congress and the American Astronomical Society's Division for Planetary Sciences in Geneva, Switzerland.

The researchers' findings relate to the *superrotation* of Venus's upper atmosphere, which moves faster than the planet's surface turns. Venus takes 243 Earth days to complete a single rotation, but its atmosphere whisks around the planet in just four Earth days.

Kiichi Fukuya, Takeshi Imamura (both at the University of Tokyo), and colleagues used Akatsuki's Longwave Infrared Camera to observe cloud temperatures on the nightside as well as the dayside. These observations revealed mottling and streaks in the cloud cover, which the researchers tracked. While previous ultraviolet studies of the dayside had found that clouds tend to drift toward the poles, the infrared observations revealed that this trend reverses at night, when the clouds sometimes move equatorward instead.



▲ A false-color image shows what Venus looks like at infrared and ultraviolet wavelengths.

According to Imamura, the contrasting cloud motions could be associated with so-called *thermal tides*, planet-scale atmospheric waves generated when the Sun heats the uppermost cloud layer. The gas heats up and moves either toward higher altitudes or around to the cooler nightside. This process could accelerate equatorial cloudtops, goading them into superrotation.

Another factor plays a role in determining wind speeds, says a group of researchers led by Takeshi Horinouchi (Hokkaido University, Japan) and Yeon Joo Lee (Technical University of Berlin). They reported that the winds tend to be faster in the southern hemisphere than in the northern hemisphere. This difference could be linked to the distribution of a substance that absorbs ultraviolet radiation. As this "unknown absorber" affects how much heat the atmosphere takes in, variability in its abundance would also affect wind speeds.

■ **JAVIER BARBUZANO**

● **The BepiColombo spacecraft will briefly visit Venus in 2020. Learn what's in store: https://is.gd/Venus2020.**

BLACK HOLES: LIGO / CALTECH / MIT / AURORE SIMONNET (SONOMA STATE); VENUS: PLANET-C PROJECT TEAM

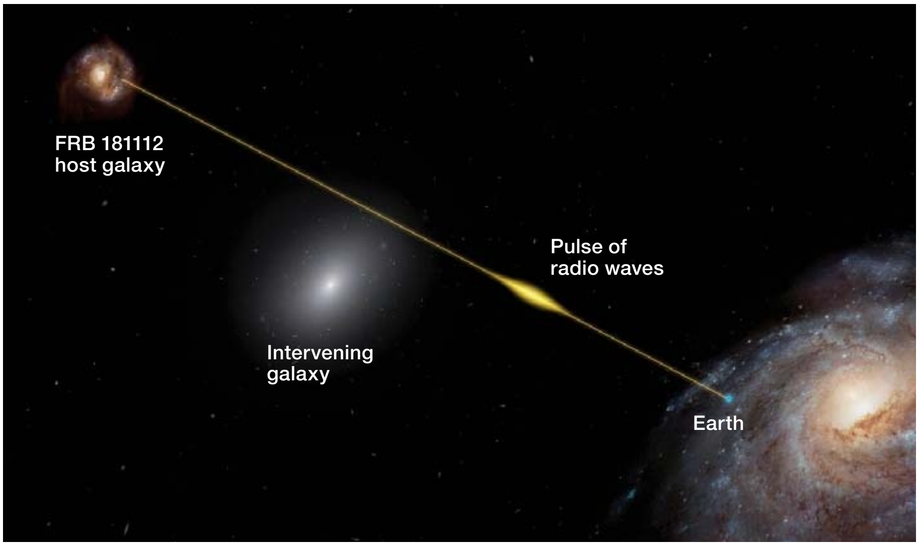
GALAXIES

Exotic Messenger Probes Galactic Halo

ASTRONOMERS UTILIZED a *fast radio burst*, a powerful 40-microsecond-long flash of radio waves, to evaluate the state of the nearly invisible gas around an intervening galaxy.

The mass of the hot, gaseous halo that surrounds most massive galaxies is often on par with the mass of all the stars in the galaxy itself. Yet it largely evades detection. It's both very hot — "cooler" clouds of some 10,000K (17,500°F) float within a hotter, million-degree atmosphere — and sparse, with only a couple hundred atoms within the space of a child's balloon. So astronomers observe the gas indirectly, by the way it absorbs the light of background sources.

Previous observations have suggested that halos tend to be turbulent, with high-density clouds embedded in the rarefied gas. Yet when astronomers reported in the October 11th *Science* that a powerful fast radio burst had passed through the halo of an intervening galaxy, they found that the radio waves seemed almost entirely undisturbed, indicating an unexpectedly calm and sparse halo.



▲ Astronomers utilized a 40-microsecond fast radio burst, designated FRB 181112, to probe a galaxy's outer reaches.

J. Xavier Prochaska (University of California, Santa Cruz) and colleagues probed the halo using FRB 181112, a fast radio burst detected by the Australian Square Kilometer Array Pathfinder. ASKAP immediately pinpointed the source to a specific location on the sky. As the powerful packet of radio waves traversed billions of light-years toward Earth, it had passed within 95,000 light-years of a foreground galaxy. That's close enough to pass through the galaxy's halo, but whatever medium the radio waves passed through barely made a dent in the signal.

The intervening galaxy has a central, supermassive black hole that's still somewhat active. It's possible that this black hole once pushed out jets of material that evacuated the inner halo. Or, it's also possible that the gas that some galaxies swim in is simply more serene than expected. The team plans to follow up on other fast radio bursts to test these scenarios in other galaxies.

■ MONICA YOUNG

IN BRIEF

Physicists Detect Black Hole Ringdown

A re-analysis of LIGO's first detection of gravitational waves reveals that scientists can pick up the shudder in spacetime that follows a black hole merger. This shudder, called the *ringdown*, is like the dying vibration of a struck bell. Physicists had typically looked for the ringdown signal long after a merger, but graduate student Matthew Giesler (Caltech), Maximiliano Isi (MIT), and their colleagues discovered that the ringdown could be detected right away. The key, they found, is to look for overtones, like additional tones in the ringing bell. Based on the ringdown's fundamental vibration and its overtones, the researchers calculated the black hole's mass and spin. They confirmed that these two parameters encapsulate everything you need to know about an astrophysical black hole, an idea known as the *no-hair theorem*. The team reports the results in the September 12th *Physical Review Letters* and in an upcoming *Physical Review X*.

■ CAMILLE M. CARLISLE

NASA Launches ICON to Explore Ionosphere

On October 10th Northrop Grumman's Pegasus XL rocket, ejected from the fuselage of a L-1011 Stargazer aircraft, lofted NASA's Ionospheric Connection Explorer (ICON) into low-Earth orbit. ICON will explore the boundary between Earth and space by studying the *ionosphere*, the region in Earth's atmosphere that's ionized by incoming sunlight. In the ionosphere, rarefied ions and electrons flow, their motions governed by winds, daytime heating and nighttime cooling, and solar activity. The movements of ions affect Earth's magnetic field, radio communications, the operation of low-Earth satellites, and many other aspects of Earth-space interactions. Slated for a two-year primary mission, ICON will characterize the ionosphere indirectly, by observing airglow, as well as directly via in situ measurements. ICON's launch came after a series of delays since its first scheduled launch from the Kwajalein Atoll in late 2017. The delays were due to problems with the Pegasus XL rocket, but ultimately the launch went off without a hitch. Science measurements will begin at the current minimum of solar activity, enabling scientists to focus on terrestrial drivers of space weather. If all goes well, ICON may observe solar maximum, too, when the Sun's activity — and its effect on Earth — is more variable.

■ DAVID DICKINSON

Read more about ICON's mission at: https://is.gd/ICONlaunch.

Mission to an Interstellar Object

It's time to visit a body from another star system — without leaving ours.

EVERYTHING WE THINK WE KNOW about the universe beyond our solar system has come from photons and a few grains of interstellar dust. But that near-complete material isolation is about to end. Our system apparently buzzes with objects from elsewhere in the galaxy. It's time to go out and meet one.

The existence of extraterrestrial comets isn't a surprise. We've known for decades that, unless there's something seriously wrong with our ideas about planet formation, they must exist. Building planets through gravitational accretion is messy. Planet assembly should be causing a constant exodus of bodies loosed from the grip of their home stars. If anything, it seemed a little strange that we hadn't seen something hurtling in from elsewhere in the galaxy.

That changed in late 2017 when we detected the bizarre extrasolar object ‘Oumuamua whipping through our solar system (*S&T:* Oct. 2018, p. 20). We didn't get a very good look, and ‘Oumuamua was just so weird — cigar-thin and seemingly accelerating mysteriously — that it didn't necessarily call out, “I'm a typical interstellar wanderer and there are many just like me.”

Now a second one has turned up. Found by Crimean amateur astronomer Gennady Borisov on August 30th, 2I/Borisov is already sporting a bit of a coma, so it seems much more like a “typical” comet (see page 10). Two objects detected in a short interval implies many more.

Could we launch a mission to intercept 2I/Borisov and do a close flyby or even grab a sample? There isn't time. These things come in and fly off fast, far too fast to be in permanent orbit around the Sun. But there will be more. The trick is to build and launch a spacecraft — a small and very fast spacecraft — that will be ready to spring into action when we spy another such interloper on a trajectory we can reach.

The European Space Agency's recently selected Comet Interceptor mission has this philosophy. It will wait in a stable orbit and then shoot off toward a suitable long-period comet. These are hard to catch, because once detected they quickly fly through the inner solar system and back out into the dark. Such an approach will be even more crucial for interstellar comets, which come in even faster.

It has to be done, though, and if one of the national space agencies doesn't take it on, it's a great opportunity for a zillionaire philanthropist to make history with a theatrical and scientifically rich exploration first.

It's a great opportunity for a zillionaire philanthropist to make history with a theatrical and scientifically rich exploration first.

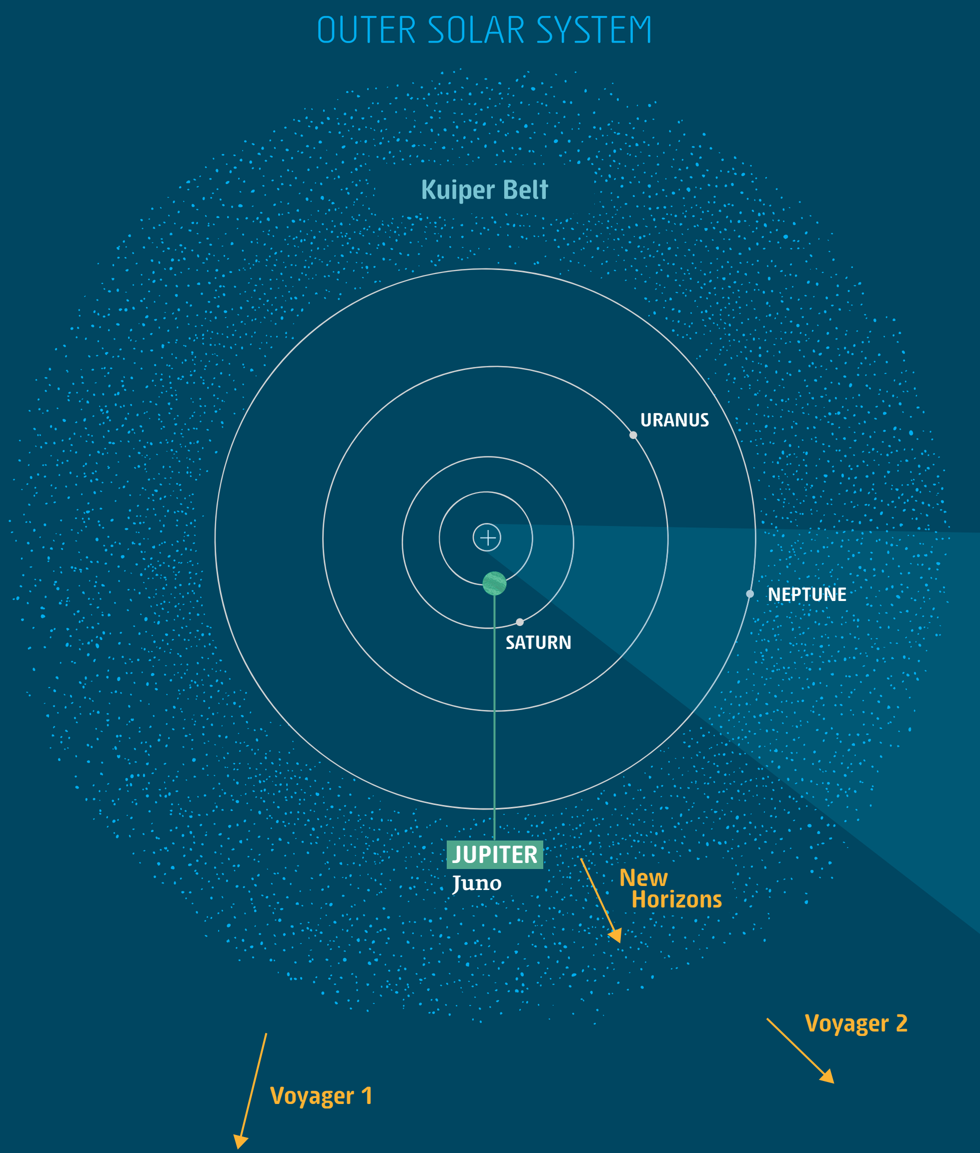
This is not how we usually do things: constructing a spacecraft when we haven't even found the target. But the merits of the approach became clear with the recent success of New Horizons at 2014 MU_{69}, also known as Ultima Thule (*S&T:* July 2019, p. 10). That was a fantastically rewarding encounter with a body that we hadn't discovered at the time of launch.

Just think: We can touch “other” star stuff. What are we waiting for?

■ Contributing Editor **DAVID GRINSPOON** is coauthor, with Alan Stern, of *Chasing New Horizons: Inside the Epic First Mission to Pluto*.

LEAH TISCIONE / S&T

Space Missions in 2020



Here's our digest of active space missions for 2020. Included are astrophysics, space weather, planetary, and solar and stellar observation missions; we omit missions that primarily observe Earth. Planet locations are marked for January 1, 2020. Mission statuses are current (to the best of our knowledge) as of September 2019. Those orbiting Earth are primarily categorized by research topic, which can be a bit subjective, and we've lumped all science projects aboard the International Space Station under "ISS." Also listed are planned launches, though these are always subject to change.

2020 is a Mars year. Four missions from four separate space agencies are looking to make the journey to the Red Planet in 2020, adding to the growing fleet of craft both on and orbiting Mars. China may also begin construction of its own space station in low-Earth orbit, and NASA's Osiris-REX mission will begin its asteroid sampling phase in mid-2020. Meanwhile, Japan's Hayabusa 2 sample-return mission is slated to return to Earth at the end of the year. Another big mission end: The Spitzer Space Telescope will shut down after 16 years (see page 18).

NOT TO SCALE

2019 Scheduled Launches

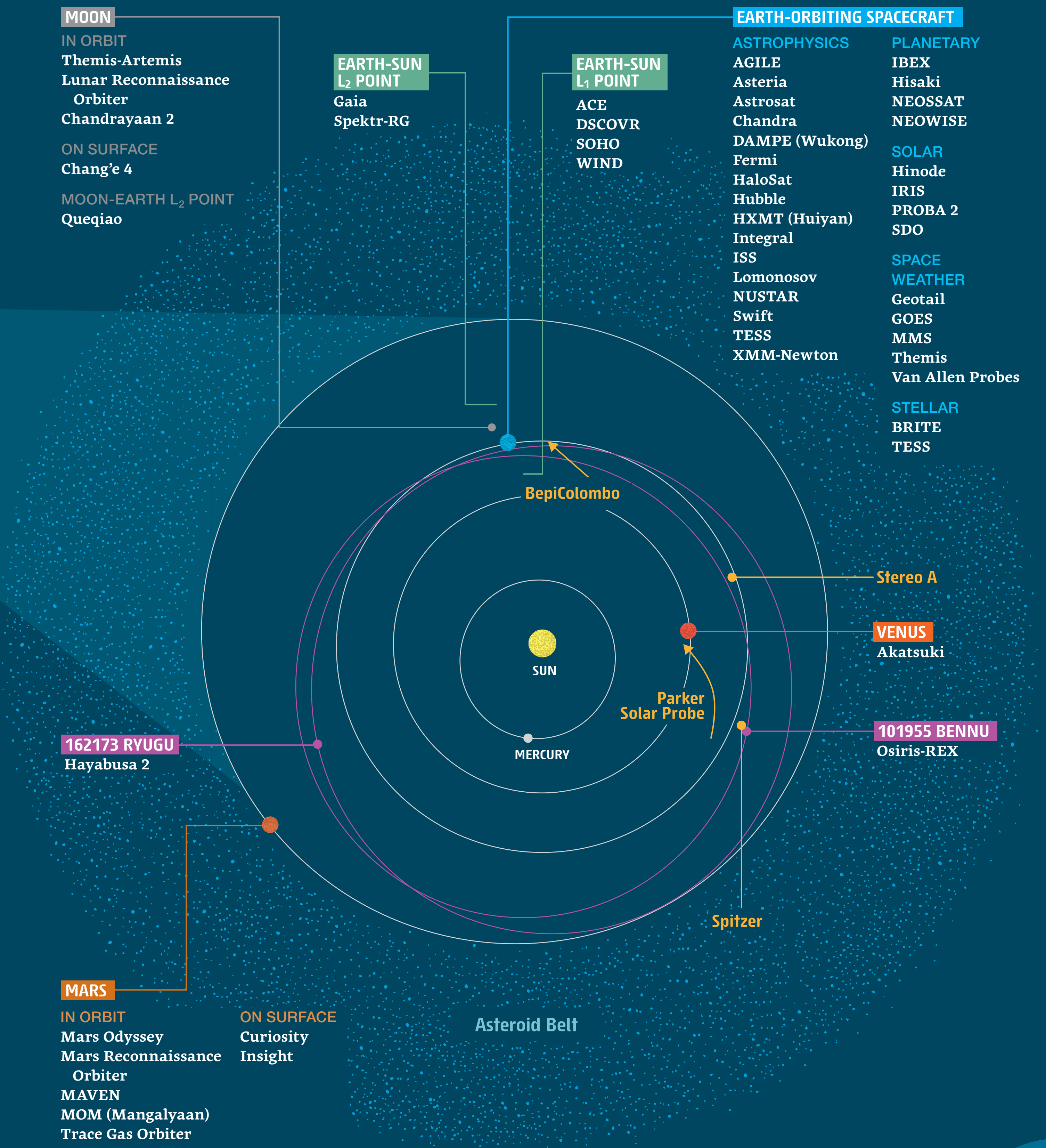
Chang'e 5 (*to Moon*)
Cheops (*exoplanets, Earth orbit*)
ICON (*space weather, Earth orbit*)

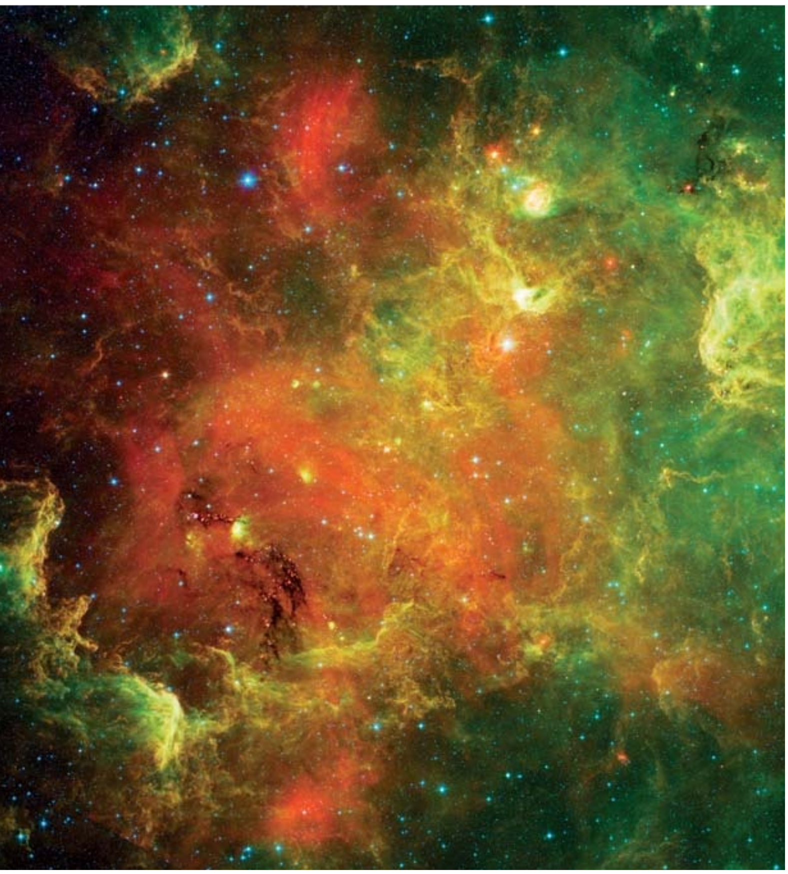
2020 Scheduled Launches

Solar Orbiter (*to Sun*)
Lunar Scout (*to Moon*)
Mars 2020 (*to Mars*)
ExoMars 2020 (*to Mars*)
Mars Global Sensing Remote Orbiter (*to Mars*)
Mars Hope (*to Mars*)

ROCKETS: OPHAT ANGWORAKUN / SHUTTERSTOCK.COM; PLANETS: MELOK / SHUTTERSTOCK.COM

INNER SOLAR SYSTEM





Spitzer's

NASA's premier eye on the infrared sky is shutting down after operating more than three times longer than designed.

On January 30, 2020, an era in astronomy will end. On this date, NASA's Spitzer Space Telescope will send us its final observations, finishing a remarkable, 16-year exploration of the universe at infrared wavelengths.

Spitzer is one of the four Great Observatories, a quartet of space telescopes launched by NASA in the 1990s and early 2000s to unveil the multiwavelength universe, from infrared to gamma ray. Originally known as the Shuttle Infrared Telescope Facility (SIRTF), the telescope concept came to life in 1971, when NASA was seeking payloads to fly on the Space Shuttle. Converted in 1984 to a free-flying observatory orbiting Earth, SIRTF underwent a series of (sometimes drastic) redefinitions before being launched as a Great Observatory into a heliocentric orbit in August 2003.

Although the public often latches onto Hubble (another Great Observatory) as the pinnacle of scientific discovery machines, astronomers already knew while planning Spitzer that there was at least as much to explore at infrared wavelengths as at visible ones. Infrared radiation pierces our galaxy's giant molecular clouds to reveal the dusty cocoons of forming stars. It also unveils distant galaxies heavily enshrouded in cosmic dust. Furthermore, because the universe's expansion stretches the light from distant galaxies to longer wavelengths, it is infrared, not visible light, that enables us to look back in time to the universe's first few billion years.

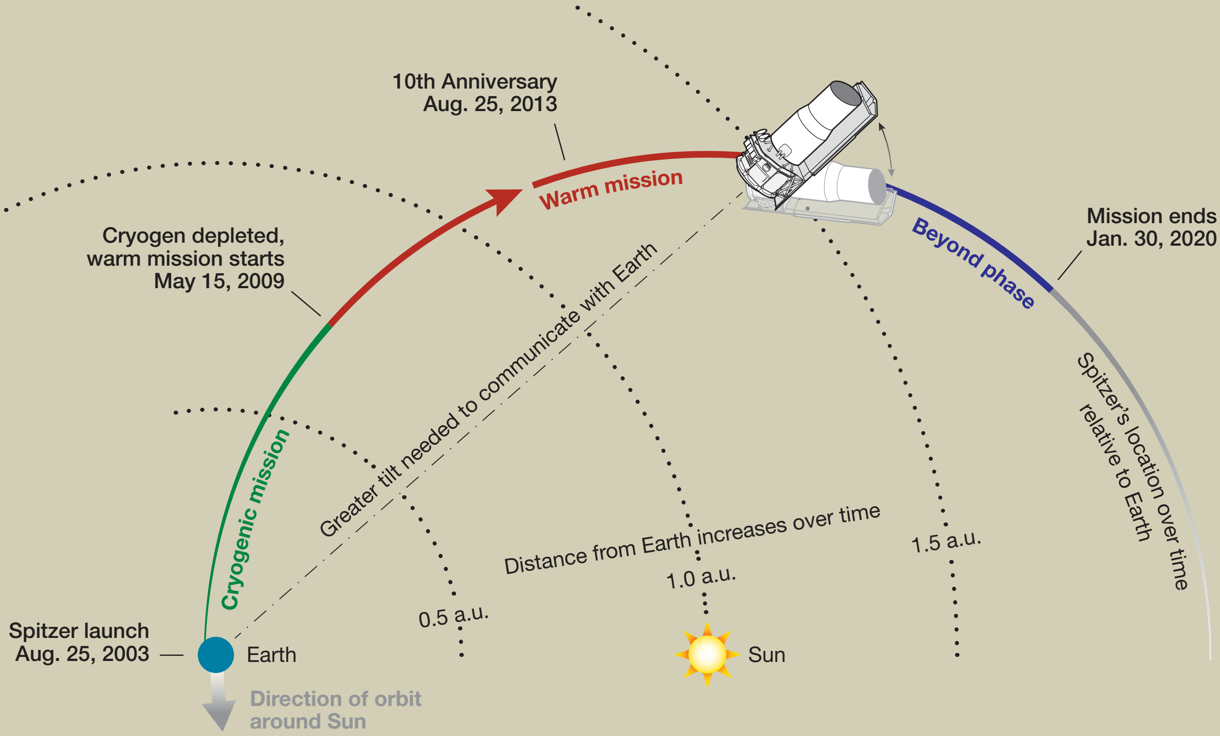
Still, back when mission planners were first envisioning what Spitzer would do, no planets were known to orbit stars other than the Sun, and the most distant objects known lay 10 to 11 billion years in the universe's past. Now, Spitzer has not only seen exoplanets crossing in front of their stars but also directly detected the glow from their heat and the chemical components of their atmospheres. We thought we were being bold in developing science programs to look back

◀ **VANISHING CONTINENT** The North America Nebula familiar to visual observers *(top)* disappears when viewed at infrared wavelengths with Spitzer *(bottom)*. Dark clouds become transparent, and the glow of dusty cocoons enveloping baby stars appears more prominent.

VISIBLE: DSS / D. DE MARTIN; INFRARED: NASA / JPL-CALTECH / L. REBULL (SSC / CALTECH)

Legacy

▼ **SPITZER'S JOURNEY** Spitzer trails behind Earth in its heliocentric orbit, moving farther from us with time. The space telescope operated with three instruments during its six-year cryogenic mission. During the subsequent "warm" and "beyond" phases of its mission, it has stayed cool by hiding in its solar panels' shadow, but it could only use one instrument at this higher temperature (about 27K). As the craft has pulled farther from Earth, the angle between its observing orientation and the one for pointing its antenna toward Earth for data downlinks has become more severe. The solar panels must now tilt away from the Sun beyond what mission planners designed the craft to handle.



11 billion years, but Spitzer has detected galaxies seen as they were more than 13 billion years ago, just a few hundred million years after the Big Bang. In short, Spitzer has greatly advanced our understanding of the universe.

Cosmic Chill

Spitzer originally observed mid- to far-infrared wavelengths, from 3.6 to 160 microns. For sensitive infrared observations from space, it is necessary to cool the telescope and the detectors to within shouting distance of absolute zero. Previous infrared instruments had launched cold, but the team took a different approach with Spitzer: SIRTF launched with most of the telescope at room temperature, then turned the spacecraft so that its solar panels shielded the telescope from sunlight and let it cool to less than 40 kelvin (–233°C) by radiating its heat into cold space. Radiative cooling is very effective in a heliocentric orbit, far from Earth's glow; only after this initial cooling did the liquid helium cryogen kick in to take the detectors to less than 2K.

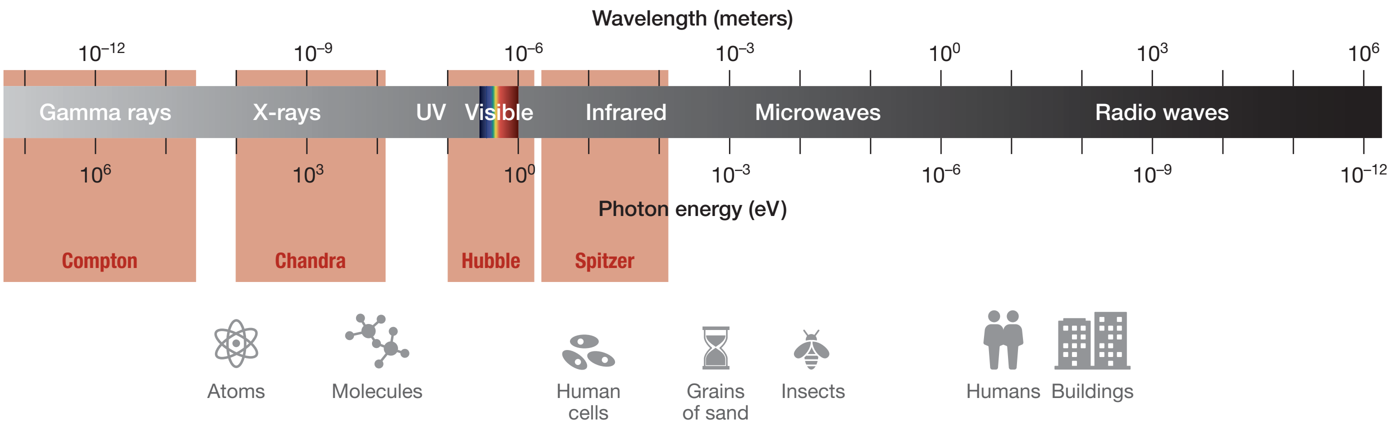
After the cryogen supply was exhausted in 2009, radiative cooling enabled Spitzer to continue observing in its two shortest wavelength bands, at 3.6 and 4.5 microns, with no loss of sensitivity. This second phase is known as Spitzer's warm mission.

The inherent sensitivity of a cryogenic telescope in space, which provides access to the entire infrared spectrum free of

Rechristened

The Shuttle Infrared Telescope Facility's name changed to Spitzer when the first scientific results were announced in December 2003. The name honors astrophysicist Lyman Spitzer, Jr., who in 1946 was one of the first to propose putting a telescope in space, and who tenaciously lobbied both NASA and Congress for a space telescope's development.

GREGG DINDERMAN / S&T, SOURCE: NASA / JPL-CALTECH



▲ **THE GREAT OBSERVATORIES** NASA's four premier space telescopes observed from the far infrared to gamma rays. The Compton Gamma-Ray Observatory shut down in 2000; the Neil Gehrels Swift Observatory and Fermi Gamma-ray Space Telescope now patrol that spectral range.

OBSERVATORIES INFOGRAPHIC: TERRI DUBÉ / *S&T*; ATOMS: CREATIVE STALL / THE NOUN PROJECT; MOLECULES: DELWAR HOSSAIN / THE NOUN PROJECT; HUMAN CELLS: TERRI DUBÉ / *S&T*; GRAINS OF SAND: DENNIS / THE NOUN PROJECT; INSECTS: VECTORSTALL / THE NOUN PROJECT; HUMANS: ADRIEN COQUET / THE NOUN PROJECT; BUILDINGS: UN·DELIVERED / THE NOUN PROJECT

the bright emission of the atmosphere or the telescope itself, allows the 33-inch Spitzer to be many times more sensitive than even a 10-m ground-based telescope operating at the same wavelengths. Spitzer's instruments exploited this gain by filling its focal plane with (what were then) large-format detector arrays. These arrays not only enabled efficient spectroscopy at wavelengths between 5 and 40 microns, but also allowed Spitzer to achieve both deep and rapid imaging surveys over fields of view comparable to or much larger than the angular size of the full Moon. These capabilities gave astronomers a valuable window on the universe, from star formation and exoplanets to the evolution of galaxies over cosmic time.

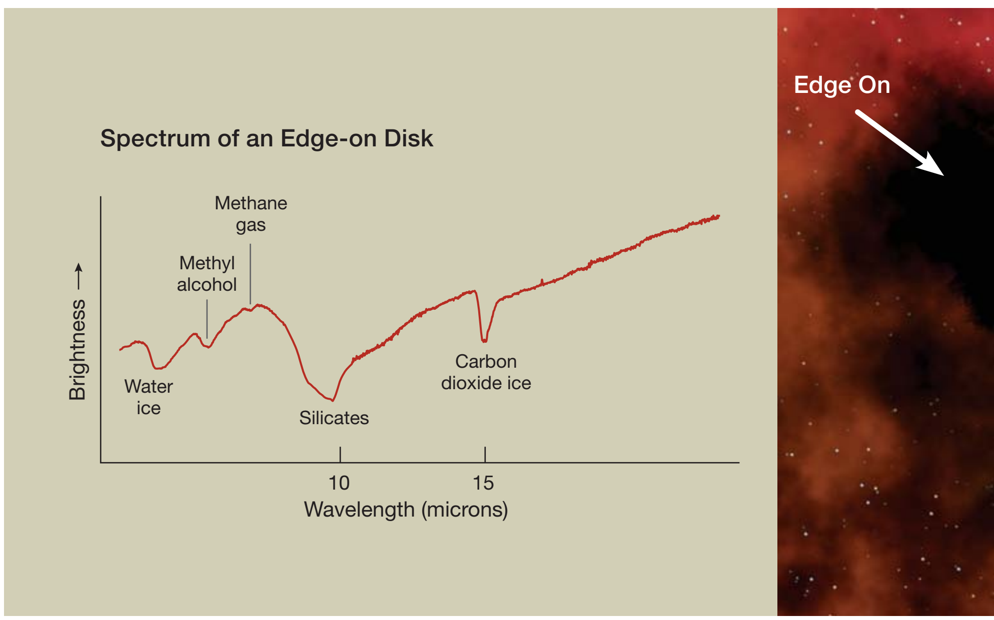
Formation of Stars and Planetary Systems

Although our Milky Way Galaxy came together some 13 billion years ago, stars have been forming throughout its history, from its first years through when the Sun and Earth coalesced some 4.6 billion years ago and to today. We now understand that, in most cases, a forming star gives birth to a planetary system.

Infrared observations can peer through dense interstellar dust clouds, which are opaque at visible wavelengths. They can also record the light emitted by objects which are too cold (below a few thousand degrees kelvin) to produce appreciable visible light. Spitzer's extensive studies of the formation and evolution of stars and planetary systems exploit both these qualities.

Starbirth begins when a portion of a dense interstellar cloud of gas and dust starts to collapse under its own gravity. The forming star passes through a number of stages, each of which has a characteristic appearance in the infrared, driven initially by the energy released by the infalling material and later by the onset of nuclear fusion. Even as the core bulks up and develops into a star, conservation of angular momentum dictates that some of the collapsing cloud forms a protoplanetary disk orbiting the star.

Spitzer's surveys have measured hundreds to thousands of young stars in each of these stages. Those observations have shown that the coagulation process that results in planets



▶ **COSMOCHEMISTRY** Spitzer observations of stars cocooned in dusty gas *(illustration, center)* have picked up several common compounds. Silicate minerals show up in spectra of protoplanetary disks seen edge on *(left, for protostar HH 46 IRS 1)*, whereas face on we have a clear view of the warm inner regions around the star *(far right, for AA Tauri)*.

begins within a few million years of the disks' formation.

Spitzer has also seen the very stuff that life as we know it depends on being absorbed into forming planetary systems. Spectra of face-on protoplanetary disks show us warm gas rich in water vapor within the central few astronomical units around the protostar. At the same time, looking edge-on through a cold disk we see absorption due to silicate dust, as well as the telltale signatures of frozen water and other ices that have condensed on the cold surfaces of the silicate grains. These icy grains might one day participate in the formation of habitable worlds.

Exoplanets

The study of exoplanets is one of the most exciting areas of contemporary astrophysical research. Astronomers have detected only a few dozen exoplanets directly, because it is very difficult to see the light from a planet in the glare of the nearby host star. But exoplanets are so common that many lie in orbits seen edge on, passing first in front of, then behind their stars from our perspective. This geometry gives Spitzer multiple ways to learn about alien worlds.

One of the most famous examples of this work is the Trappist-1 planetary system. Following up on ground-based observations that hinted at a peculiar system, a 20-day Spitzer campaign caught seven Earth-size planets transiting across the face of the faint red star Trappist-1 in 2016. Three of these exoplanets may lie in the star's habitable zone, where liquid water could exist stably on their surfaces.

Spitzer's precise timing of these worlds' transits enabled astronomers to determine that gravitational tugs exchanged by the planets changed the exact moment when each planet crossed in front of the star. The altered transit times in turn revealed the exoplanets' masses. As the planets' radii are known from how much starlight they block as they transit,

IC 417 in Auriga, infrared composite

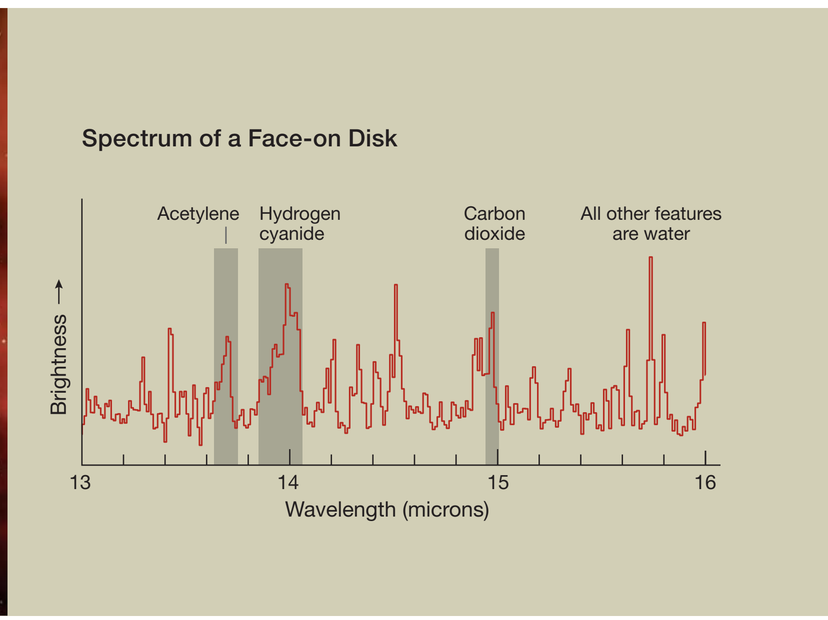
we thus also know the worlds' densities. This makes Trappist-1 perhaps the best characterized planetary system outside of the solar system.

Astronomers can also use Spitzer to study planets' heat signatures. If a planet glows brightly enough in the infrared, then when it passes behind its star Spitzer will detect a tiny drop in the system's emission, because the light of the planet is no longer seen. The depth of this eclipse tells us how much infrared radiation the planet emits. When combined with the planet's size, this measurement indicates the planet's temperature. Spitzer has measured planets as hot as 3000K and as cool as 700K, but it cannot reach down to Earth's temperature, which is about 300K.

Transiting systems can also tell us about exoplanet atmospheres. Spitzer's measurements can be combined with observations at shorter wavelengths to study the composition of an exoplanet's atmosphere and even to diagnose the presence of clouds or hazes. Spitzer eclipse measurements in five infrared bands between 3.6 and 16 microns show that the exoplanet GJ 436b, for example, has a much higher fraction of heavy elements in its gaseous atmosphere than does its host star. GJ 436b is about the size of Neptune, which, interestingly, shows a similar enhancement in heavy elements relative to the Sun.

In addition, we can study another aspect of a planet's atmosphere by observing the change in its brightness

PROTOPLANETARY DISK: NASA / JPL-CALTECH / R. HURT (SSC / CALTECH); EDGE-ON SPECTRUM: ADAPTED FROM A. NORIEGA-CRESPO ET AL. / *ASTROPHYSICAL JOURNAL SUPPLEMENT SERIES* 2004; FACE-ON SPECTRUM: ADAPTED FROM NASA / JPL-CALTECH / J. S. CARR AND J. R. NAJITA / *SCIENCE* 2008; IC 417: NASA / JPL-CALTECH



throughout its orbit as it shows us different fractions of its starlit side. This pattern, called a *phase curve*, shows how well the atmosphere redistributes the energy of absorbed starlight. When astronomers converted Spitzer's phase curve into a map of the temperature distribution for the Jovian-mass exoplanet HD 189733b, the map showed that the hottest spot on this exoplanet is not at the point where the star is directly overhead. Rather, the hotspot is displaced by about 30 degrees in longitude, likely due to winds of thousands of miles per hour transporting energy before it can be radiated away. Spitzer has seen similar offsets on other planets, including 55 Cancri e. In the case of the recently discovered super-Earth LHS 3844b, by contrast, the absence of such an offset, combined with the drastic drop in temperature from the dayside to the nightside, shows that this exoplanet has at most a very thin atmosphere. Although many telescopes have measured transits, Spitzer has stood almost alone in its ability to measure eclipses and phase curves.

The discussion above illustrates how scientists have used Spitzer and other telescopes to derive remarkably detailed information about exoplanets, even though they're never directly seen. The architectures of these systems differ from that of our own solar system. Indeed, if our familiar eight planets orbited a nearby star at the same distance they orbit the Sun, they would have gone undetected by most of the techniques used to date.

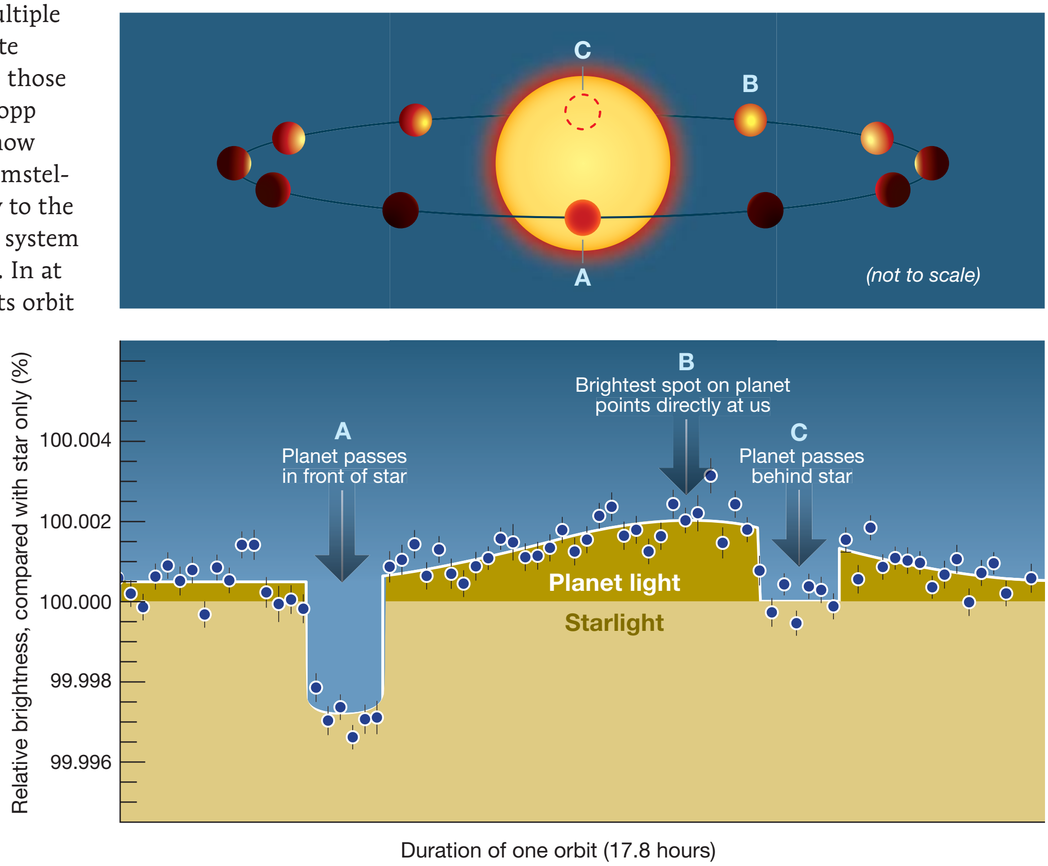
Nevertheless, there are remarkable similarities between our own solar system and exoplanetary systems. Systems with multiple planets are common. The silicate materials found often resemble those seen in comets, such as Hale-Bopp and Tempel 1. Many systems show evidence for two bands of circumstellar dust, corresponding roughly to the zodiacal dust in the inner solar system and the Kuiper Belt farther out. In at least one case, four giant planets orbit in the region between these two belts, just as Jupiter, Saturn, Uranus, and Neptune lie between the two solar system belts. Finally, collisions between 100 km-size asteroids in systems, inferred from transient increases in the dust orbiting the stars, are counterparts to the violent events that shaped our system's inner planets.

Thus, the evolution of the universe has led in many cases to conditions similar to those in our own system, including conditions that might be favorable to the development of life.

The Distant Universe

Spitzer has also observed beyond the stars and exoplanets of our own galaxy, reaching out to the billions upon billions of galaxies in the universe. Understanding how galaxies form and evolve has been a driving question in astrophysics for many decades. Infrared observations have been applied to this question in two separate domains: low and high redshifts. These domains split at a redshift of 3, corresponding to a lookback time of approximately 11.5 billion years.

With its enormous gain over prior missions in imaging sensitivity, predominantly at 24 microns, and its substantial spectroscopic capability, Spitzer has probed infrared-bright galaxies throughout the universe's last 11.5 billion years. For these galaxies, any infrared emission at wavelengths longer than 5 microns is generally the warm glow from dust heated by young stars. This radiation is a proxy for the number of young stars, and from this glow we can determine the



▶ **PHASE CURVE** When 55 Cancri e transits in front of its star (A in both orbit and light curve diagrams), the dip's size reveals the planet's diameter. When the planet moves behind the star, its infrared glow disappears (C), revealing its brightness. Together, the two dips tell astronomers the planet's temperature. However, the peak of the planet's light curve (B) is offset from its eclipse, indicating that the hottest point is not at high noon. That suggests strong winds redistribute the star's heat across the planet.

GREGG DINDERMAN AND LEAH TISCIONE / *S&T*, SOURCE NASA / JPL-CALTECH / UNIV. OF CAMBRIDGE AND NASA / JPL-CALTECH / L. KREIDBERG (CENTER FOR ASTROPHYSICS, HARVARD & SMITHSONIAN)

▶ **GALAXY IN INFRARED** The spiral arms of M81 in Ursa Major become more dramatic in this infrared composite *(top)*. Blue traces the distribution of stars, whereas green is radiation from hot dust. In visible light, the bulge is what catches the eye *(bottom)*.

INFRARED: NASA / JPL-CALTECH; VISIBLE: NASA / ESA / HUBBLE HERITAGE TEAM (STSCI / AURA)

star-formation rate. Combined with multiwavelength data from other instruments, these results show that star formation across the universe peaked between 2.3 and 3.8 billion years after the Big Bang and has been decreasing ever since. Astronomers refer to this period of rampant starbirth as cosmic high noon.

Swathed in dust, many of the distant galaxies we see are faint at visible wavelengths, even though they blaze in the infrared. As we look back in time, the concentration of galaxies that are oddly bright in the infrared skyrockets. These systems appear to be predominantly powered by vigorous star formation, with hundreds to thousands of solar masses of gas being converted each year into stars. The starbursts are almost entirely obscured by dust. Thus, the most active period of star formation in the universe is largely hidden from view in visible light and accessible only with infrared observations.

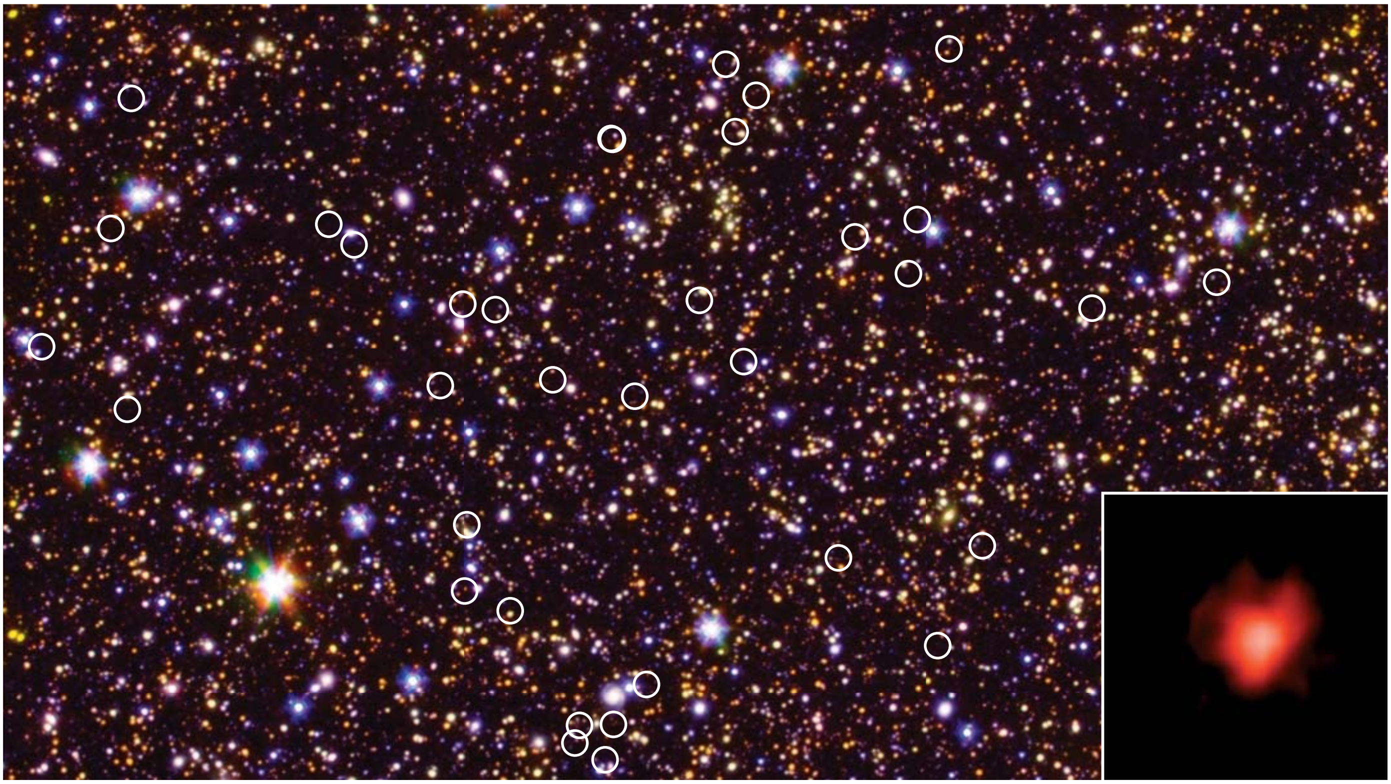
For far more distant galaxies, those with a redshift of 6 or greater (or a lookback time of 12.5 billion years or more), the galaxy's light has been stretched so much that the glow from star-heated dust is undetectable by Spitzer. For a galaxy at redshift 6, an observed wavelength of 4.5 microns corresponds to an emitted wavelength of 0.64 micron, which lies at the red edge of the visual band. Thus for high redshifts, Spitzer tells us not about the thermal emission from galaxies but about the visible light they emit.

This visible light comes from the galaxies' older stars. Because these older stars dominate a galaxy's stellar population, we can use their light to measure the total mass of stars in the galaxy.

Astronomers can also compare Spitzer observations to those by Hubble or ground-based instruments to extract the age of the stars producing the ultraviolet and visible light that's been redshifted to Spitzer's domain by cosmic expansion. Observations of one such galaxy, at a redshift of 9.11, indicate the stars are approximately 300 million years old.

Reaching into the Past

The basic tool used to discover galaxies with high redshifts is the *Lyman dropout technique* (*S&T:* Apr. 2018, p. 14). This method utilizes the fact that neutral hydrogen atoms become ionized when they absorb photons with wavelengths shorter than 0.09 micron. So the universe, which is suffused with neutral hydrogen gas, is effectively opaque to such photons. Thus, if an image obtained at 0.5 micron shows a galaxy that is not seen at 0.4 micron, we infer that the redshifted wavelength of hydrogen ionization falls between the two bands, at about 0.45 micron. From there, we can calculate that the galaxy has a redshift of approximately 4.



▲ **DISTANT GALAXIES** Every circle in this composite visible and infrared image marks a galaxy with a redshift of more than 7, corresponding to a lookback time of nearly 13 billion years. The inset is a Spitzer image of one of the galaxies. The main image is of part of the sky near the Draco-Ursa Major boundary, and most of the objects in the image are galaxies.

NASA / JPL-CALTECH / ESA / SPITZER / P. OESCH / S. DE BARROS / I. LABBE

Since the galaxy is observed at a lookback time of 13.2 billion years, the result suggests that this galaxy's star-formation episode occurred about 300 million years after the Big Bang.

These observations enable Spitzer to measure the growth of galaxies in two ways: by measuring how much mass is in galaxies at a given time, and by measuring how fast the galaxies are growing by forming stars. Comparing what we'd expect the stellar masses to be, based on the starbirth rates, with what we actually observe yields a gratifying confluence across more than 12 billion years of cosmic history. The strong agreement demonstrates that with Spitzer, Hubble, and large ground-based telescopes, we are indeed developing an accurate picture of the growth and evolution of galaxies in the universe.

Infrared Leaps

This wide-ranging scope of discovery is now coming to an end. Faced with a limited pool of funds, NASA has chosen to retire Spitzer because the high operating cost inherent to its mission design made it less attractive than other operating missions that were competing for the same funds.

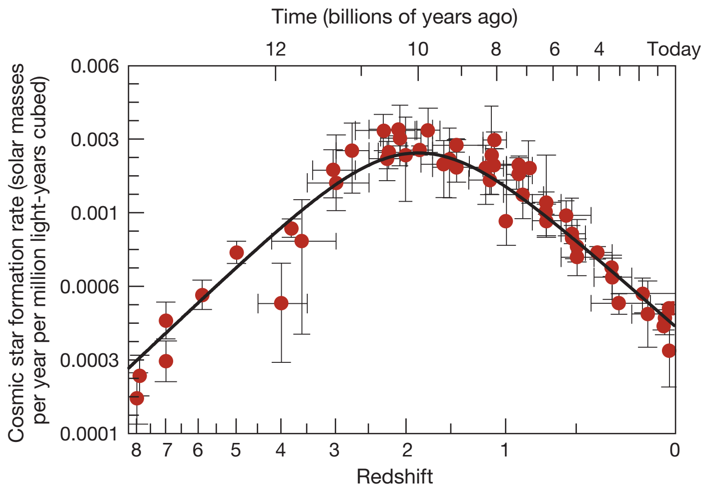
Because Spitzer was such a leap in capability compared to what had come before, it was able to lead the way in astrophysical exploration over the last decade and a half. This is the constant lesson of advances in technology that have driven astrophysics since the end of World War II. We saw this with the early infrared missions, with space observatories, with the twin Keck telescopes, and with the Very Large Telescope quartet in Chile, as well as with myriad other instruments, all of which, in one way or another, have probed the mysteries of the infrared universe. Doubtless we will continue to see it with future ground- and space-based telescopes, including the next major infrared facility, the James Webb Space Telescope, set to launch in 2021.

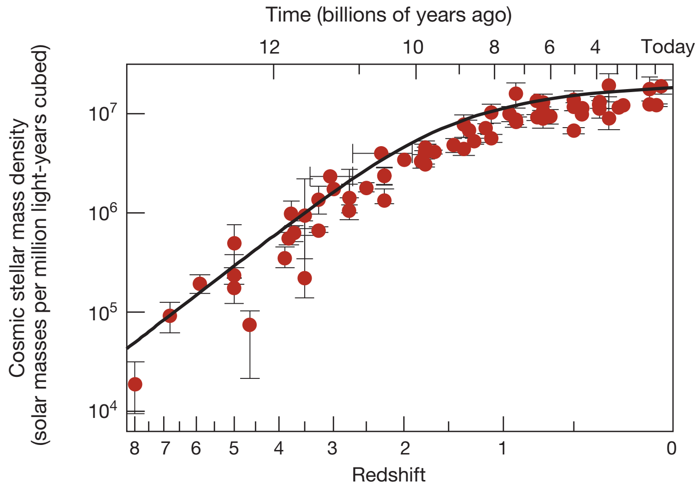
Even as Spitzer sends its final data back to Earth at the end of January 2020, commands will be sent to place the space-

The Farthest Galaxy Spitzer Can See

Spitzer's redshift limit is currently set by the heroic observation by Pascal Oesch (now University of Geneva) and his colleagues of a galaxy at a redshift 11.1. The detection required about 70 hours of Spitzer observations at 4.5 microns. We see this galaxy at a time when the universe was only 3% of its current age.

▶ **GALAXY GROWTH** Astronomers have tracked the history of star formation back 13 billion years *(top)*. Starbirth peaked across the universe approximately 10 billion years ago. When they add up all the star formation over time, astronomers can estimate the universe's bulk mass in stars *(black line, bottom graph)* — and this estimate agrees with observations of galaxies' buildup *(data points, bottom graph)*. The density drops as we look back in time because fewer stars had formed then.



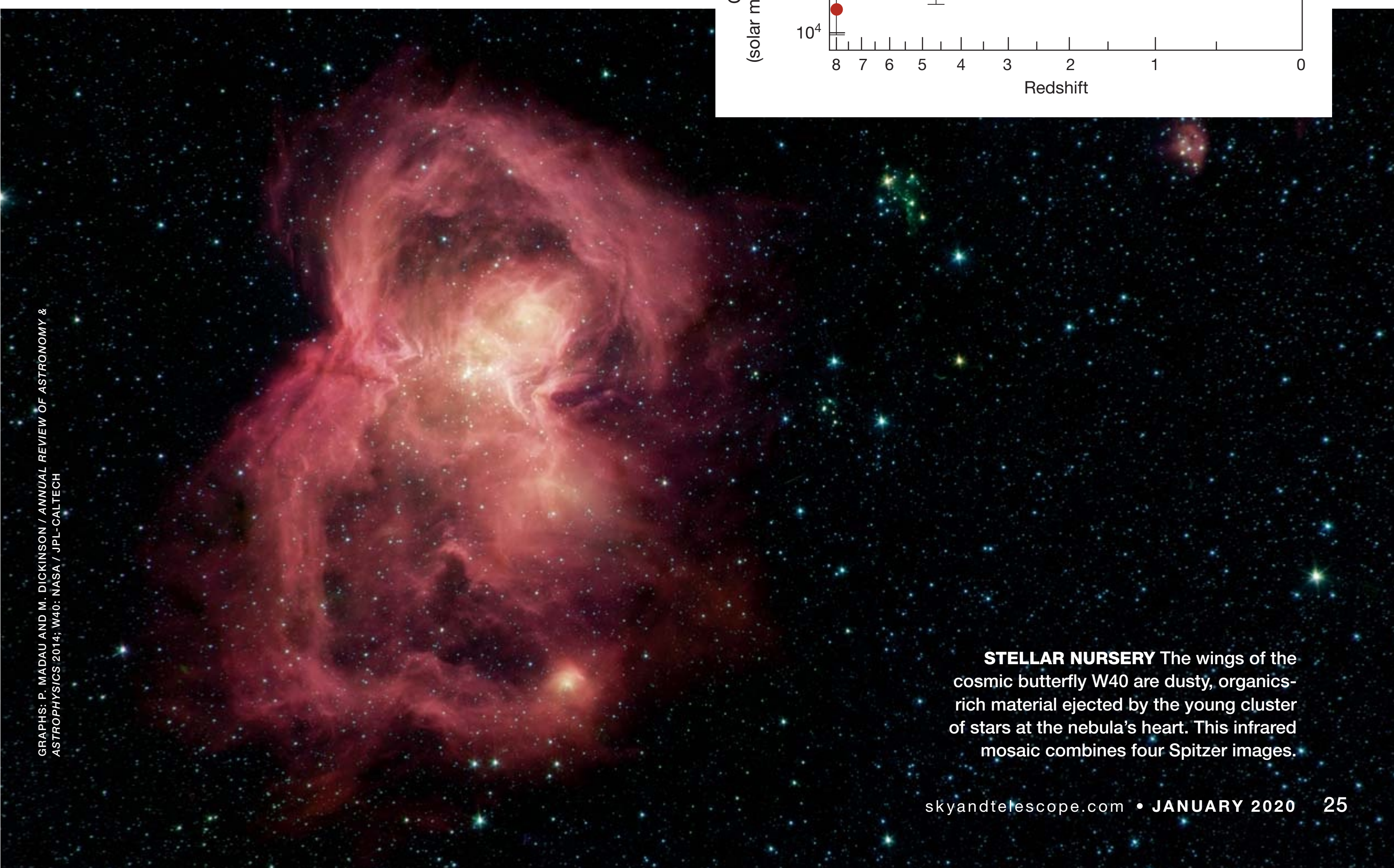


craft into a safe orientation and shut it down, leaving it to drift silently in an Earth-trailing orbit. As we bid it goodbye, we eagerly anticipate seeing the wonders of the universe unveiled by Spitzer further explored by future telescopes.

■ **MICHAEL WERNER** (Jet Propulsion Laboratory) has been project scientist for the Spitzer Space Telescope since 1983. **THOMAS SOIFER** (California Institute of Technology) has been the director of the Spitzer Science Center since 1997 and was a member of the Infrared Spectrograph science team for Spitzer from 1984 to 2012.

FURTHER READING: A more complete account of Spitzer science is given by Werner and Peter Eisenhardt in *More Things in the Heavens: How Infrared Astronomy is Expanding Our View of the Universe*. Princeton University Press, 2019 (see book review on page 57).

Read the Spitzer team blog: **spitzer.caltech.edu/explore/blog**



STELLAR NURSERY The wings of the cosmic butterfly W40 are dusty, organics-rich material ejected by the young cluster of stars at the nebula's heart. This infrared mosaic combines four Spitzer images.

GRAPHS: P. MADAU AND M. DICKINSON / *ANNUAL REVIEW OF ASTRONOMY & ASTROPHYSICS* 2014; W40: NASA / JPL-CALTECH

May 22, 1912. 3:21½

Shadow of a Doubt

In a historic Omaha court case, astronomical evidence played a key role in foiling an attempt to frame a man for attempted murder.

May 22, 1910. Computed time within one minute of 3:21½

◀▲ A 1910 trial in Omaha, Nebraska, hinged on two girls who saw a man matching the description of the accused carrying a suitcase bomb on their way home from church, where they had been photographed after a confirmation ceremony. William Rigge, astronomer at Creighton University, invalidated their testimony by analyzing the shadows in the photo and proving that it had been taken a half hour after the bomb was discovered. Rigge (in foreground, with watch) reenacted the scene precisely two years after the first photo, showing the shadow in the same location.

On December 9, 1910, attorney John Yeisner's client was on track to be convicted for attempted murder. Every piece of evidence seemed stacked against him. One can imagine the confusion in the Nebraska courthouse when Yeisner called his star defense witness to the stand. The 53-year-old man wasn't a doctor, an investigator, or a character witness for the accused.

He was an astronomer, clad in the formal garb of a Jesuit priest.

In a remarkable meeting of photography, cutting-edge science, and organized crime, Father William Rigge used astronomy to demolish the prosecution's case. With careful analysis of a shadow in a photograph, he dismantled the timeline presented by the police, invalidated the testimony of the prosecution's key witnesses, and put an innocent man on the path to freedom.

It was a stroke of luck that Rigge ended up in Nebraska at all. He had distinguished himself at Georgetown University's observatory in Washington, DC, and seemed poised to lead in the field of astronomy. But severe eyestrain prevented him from continuing his research, so the Jesuits reassigned him from the newly built 12-inch refracting telescope at Georgetown to fledgling Creighton University in Omaha, Nebraska.

Rigge's vision may have been impaired, but his spirit remained undimmed. He threw himself into enhancing and running Creighton Observatory and became a central member of the Omaha community, as well as an evangelist of astronomy and modern science. His outreach efforts included a widely publicized construction of a Foucault pendulum in an abandoned smokestack on Creighton's campus, organizing a faculty expedition to Georgia to witness the famed total solar eclipse of 1900, and hosting regular public viewing sessions through Creighton's 5-inch refracting telescope. He also published widely on topics designed to engage broader audiences, from perpetual calendars to upcoming eclipses and transits, as well as reviews of the newest developments in the field of astronomy.

A 1904 article Rigge published in *Scientific American* may stand out as his work of greatest consequence. While contemplating a photo of his observatory taken some years earlier, Rigge mused that pronounced shadows cast onto the front of the structure could offer the means to reconstruct when it was taken. Rigge worked through the riddle, calculated the precise moment the photograph was snapped, and went on to confirm his hypothesis by watching the expected tableau of shadows realign on the façade of the observatory when his projected date and time rolled around again in 1904.

The key to Rigge's method is that the daily course of the Sun from east to west and its north-south variation through the seasons yield only a pair of dates and a single time to which any given solar position can ever correlate, as shown on page 28. Rigge's breakthrough was realizing that pronounced shadows in a photograph can offer the means to reverse-engineer the Sun's position in the sky — and by extension, the exact date and time of the photograph's capture.

The key to Rigge's method is that the daily course of the Sun from east to west and its north-south variation through the seasons yield only a pair of dates and a single time to which any given solar position can ever correlate.

The public was fascinated by this revelation. Somewhere in the buzz of local media and the public lectures surrounding Rigge's newest work, his pioneering method lodged itself in the mind of an up-and-coming attorney named John Yeisner. And six years later, when a tough case looked to be at the brink of losing an innocent man his freedom, Rigge's methodological innovation would save the day.

The case began on May 22, 1910, when the police found and defused a suitcase bomb on the porch of Omaha's reigning political boss and racketeer. The police quickly fingered Yeisner's client, a mortal enemy of the politico, as their prime suspect. As the investigation grew, the prosecution found their ace in the hole: a pair of eyewitnesses. Two teenage girls claimed that they had seen the accused carrying a suitcase matching the bomb's description as they were on their way home after church that day. They could not see his face but recognized him by his clothes and distinctive limp.

Yeisner suspected that the supposed victim had planted the bomb on his own porch and then hired a look-alike to walk the streets with a dummy suitcase to make the suspect look guilty. But as the trial date approached, all looked lost — that is, until December 2nd, a week before open court, when Yeisner uncovered what would become the key piece of exculpatory evidence. He discovered that the teenage witnesses had been photographed after church on the day of the crime. The Sun had projected a prominent shadow across the church façade. The attorney had an inkling: Could this be the key to exonerating his client? He set out to find the astronomer who would help him find out.

Rigge leapt at the opportunity, excited by the prospect of bringing his method to bear

▶ William Rigge had a keen mind, a dry wit, and a passion for mathematical precision.

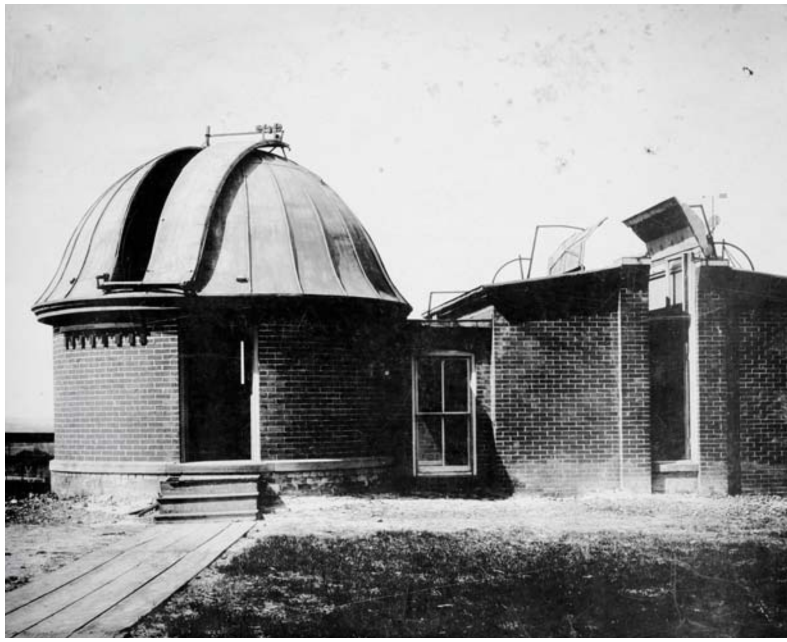
ALL PHOTOS COURTESY OF CREIGHTON UNIVERSITY in a court of law. He went to the church and redrew the profile of the shadow as shown in the photo. Working with a professional surveyor, he then measured the distance south, west, and upward to the roof corner that cast the shadow. He incorporated his collected measurements with data on latitude and longitude, ran trigonometric equations, and determined the exact position of the Sun in the sky at the time the photograph was taken. A quick check in an astronomical almanac yielded the moment the photo was captured on May 22nd. As Rigge entered the courtroom on that fateful December day, just a week after meeting Yeisner, he knew exactly when the photograph was taken. He announced without hesitation to the judge and 12 jurors that it was captured between 3:20.5 and 3:22.5 p.m.

Rigge had just blown up the prosecution's case. The police had discovered and defused the bomb at 2:50 p.m. Rigge's testimony meant the witnesses were claiming to have seen the defendant carrying the bomb after it was already safely in the hands of the police — a clear impossibility. The witnesses' testimony had to be thrown out. With no direct evidence to bolster their case, the prosecution was left with a hung jury.

The struggle, however, wasn't over for Rigge and the defense team. The prosecution pressed for a retrial. In the three months before the return to court, they attempted to intimidate and discredit Rigge. The lead detective and supposed victim visited Rigge's offices at Creighton repeatedly, trying to persuade him to abandon Yeisner's cause. At one point, they even presented a doctored photograph to Rigge, in an attempt to catch him in a contradiction.

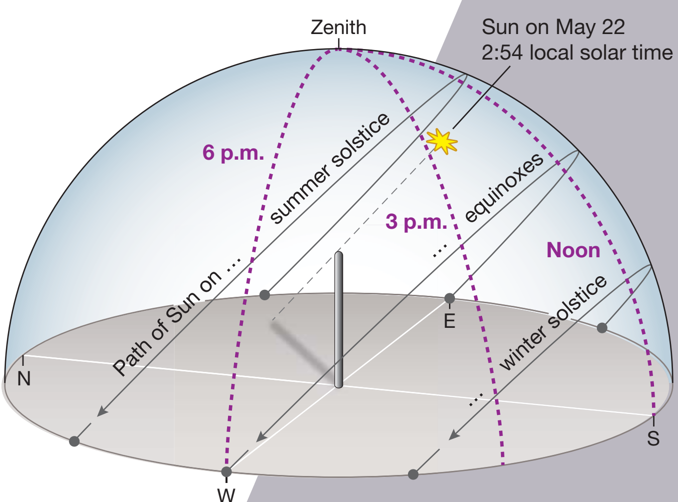
Rigge saw through the doctored photograph, and held his ground, like pioneering astronomers before him. He insisted that he had no interest in the guilt or innocence of Yeisner's client. But as an unbiased and professional scientist, he was confident that the testimony on which the case hinged was incorrect, and he wasn't going to be bullied. When the second trial began in March 1911, however, the prosecution was ready for him.

The lead prosecutor began to attack Rigge's methods and science in general, offering sarcastic asides to the jury during



▲ In a 1904 *Scientific American* article, Rigge proved that this photo was taken on May 2, 1893, at 3:06 p.m. Central Time. The position of the shadow on the window casing gave the time and narrowed the date to either May 2nd or August 11th. The state of the grass proved that it was May, and the clarity of the air and position of the weathervane matched meteorological records for 1893.

Shadow Science



A line from the tip of a shadow through the tip of the object that casts it points directly to the Sun. By definition, it's local apparent solar noon when the Sun is on the meridian, due south as seen from the North Temperate Zone. The Sun's hour angle (distance west of the meridian) determines the time of day, and its declination (distance north or south of the celestial equator) determines the time of year, or date.

To pin down a moment within a year, you need to know both the date and time. Ironically, it's quite easy to measure the time, the less significant of those numbers, because the Sun's east-west motion results primarily from Earth's rotation, roughly ¼° degree per minute, as users of non-tracking telescopes know to their sorrow. When measuring the time of photographs, Rigge was essentially using the structures in the photos as giant sundials, and a first-rate sundial is indeed accurate to

GREGG DINDERMAN / S&T

▲ Rigge used this 3-inch transit telescope to measure the positions of stars with sub-arcsecond accuracy, roughly 1,000 times better than needed for his shadow measurements. Creighton Observatory was Omaha's official timekeeper, using the transit times of standard reference stars to synchronize the public clocks.

a biting cross-examination. By referencing the inaccuracy of weather predictions as well as the mass hysteria surrounding the recent passage of Halley's Comet, he built an air of absurdity around the scientific method. The technique worked; at the second trial the jury convicted and sentenced Yeisner's client to 15 years in prison.

But Yeisner wasn't going to let an innocent man rot in prison. He appealed the sentence to the Supreme Court of the State of Nebraska, whose five judges were less susceptible to rhetorical flourishes than the local jury; they threw out the conviction on the basis of insufficient evidence.

The prosecution made one more attempt to discredit Rigge by hiring an independent astronomer, hoping that he would derive a different time for the photo. But the two results agreed within less than a half minute.

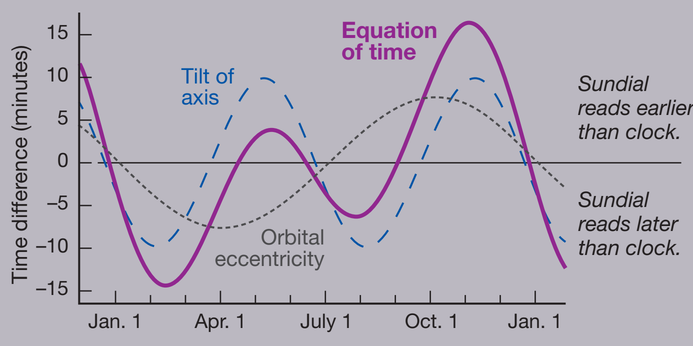
In the lead-up to May 22, 1912, two years after the day of the incident, Rigge wrote an article in the local newspaper inviting people to come to the church where the photograph was taken to see for themselves the veracity of his method. A group of students and journalists, as well as a photographer from the *Omaha Daily News*, took him up on his offer. As the promised shadow passed its expected point at 3:21.5 p.m., the photographer snapped a photo that matched the 1910 picture perfectly. Photos taken one minute earlier and later showed the shadow in visibly different positions. A piece congratulating Rigge was written up with great fanfare. Publications around the country and the world began to reprint the story, recounting how Rigge — and the discipline of astronomy — won a well-deserved victory on their day in court.

■ **JEFFREY DOBEREINER** is a science communicator and documentary TV producer, with a PhD in anthropology and a particular passion for space.

one or two minutes. The main error results from shadows' fuzziness, which is caused by the fact that the Sun is an extended object rather than a point source.

Determining the date is harder, because it results from Earth's revolution around the Sun, which is roughly 365 times slower than its rotation. Moreover, the Sun's declination changes very slowly near the solstices, as you can see on the ecliptic chart on page 44. Finally, the Sun reaches any given declination (except the extremes) twice a year, once on its way north and again on its way south. In the case of the church photo, of course, Rigge already knew the date ahead of time.

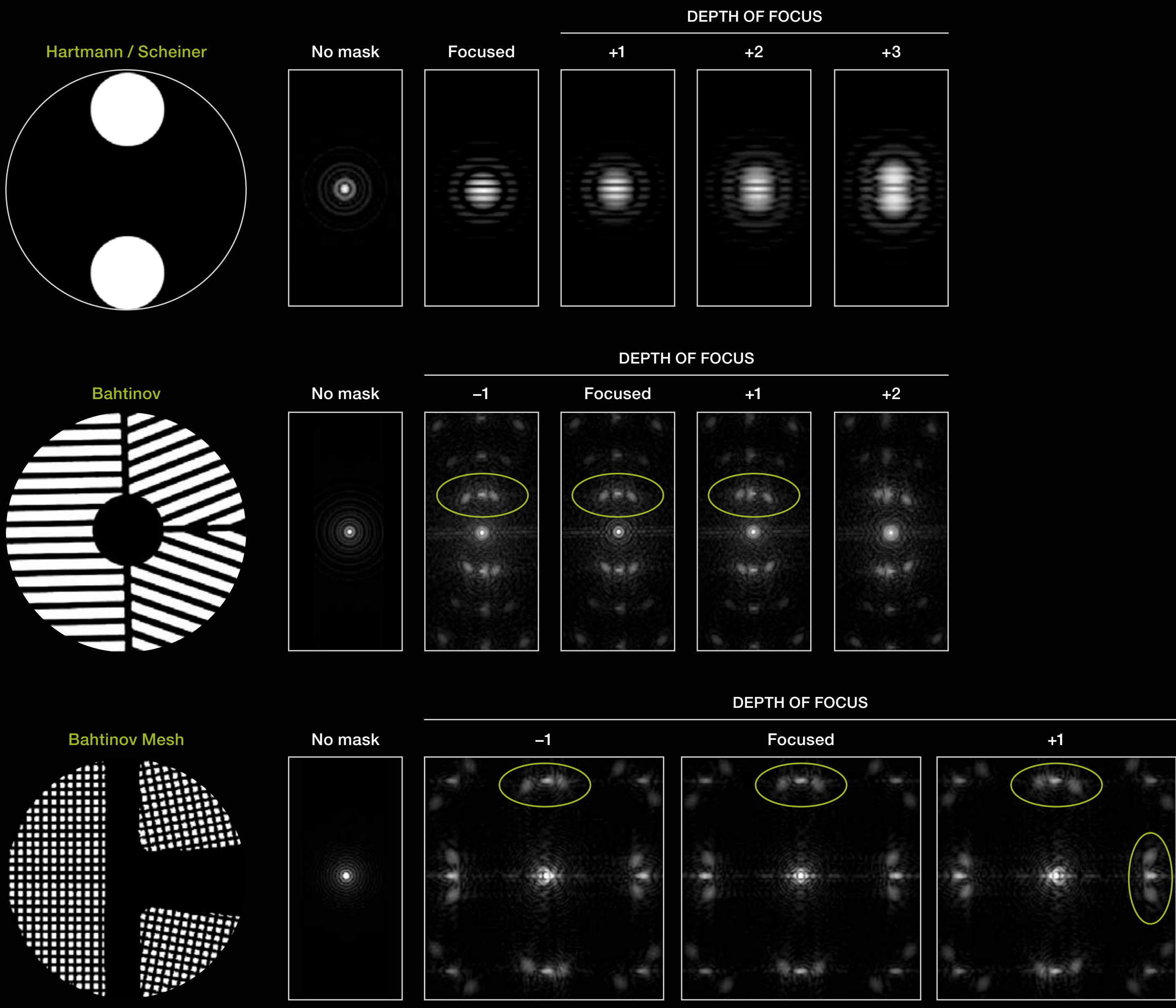
Having determined a local apparent solar time of 2:54 p.m. for the shadow in the church photo, Rigge then added 24 minutes because Omaha is 6° west of the center of its time zone, plus 3½ minutes for the equation of time, as shown at right.



▲ Earth rotates once every 23.934 hours. The extra 0.066 hour in the 24-hour day comes from the Sun's apparent motion through the stars, which is in turn caused by Earth's revolution around the Sun. Unlike Earth's rotation, the west-to-east motion due to revolution varies considerably depending on the season. That's due partly to the fact that Earth's orbit is not a perfect circle, and partly to the fact that its axis is tilted. This graph shows the two separate components and how they add up to form the *equation of time*, the difference between *apparent solar time*, as shown by sundials, and *mean solar time*, the basis of our civil time system.

MESH FOCUSING MASKS

This easy-to-assemble imaging aid can take the guesswork out of focusing.



Top row: A simple Hartmann mask helps to get close to focus, but stopping down the optical aperture significantly reduces the system's resolution compared to the unmasked stellar image, making it a challenge to see the slight oval shape when nearing the focus point.

Middle row: The popular Bahtinov mask normally works by producing diffraction spikes that appear symmetrical when the optic is in focus, but the spikes are only visible on the brightest stars. You can use fainter stars by balancing the first diffractive order images above or below the stellar image (circled). The optic is in focus when these side-by-side orders look evenly spaced.

Bottom row: Replacing the straight vanes of the Bahtinov mask with a 7-count mesh grid produces lateral diffraction detail. Not only are the first-order diffractive images apparent above and below the stellar image, the side dots can be employed for checking the mask alignment.

Focusing a telescope can take a great deal of fine-tuning and finesse. It's hard enough to focus a telescope or lens by eye, even though most eyes are somewhat forgiving. Once you're within the range of a half-diopter or so, the eye's internal process of focus accommodation automatically takes over, at least for young eyes. Of course, there are mechanical constraints that have nothing to do with the quality of the image viewed. For example, manually adjusting the focus knob causes the view to jiggle around the field. An image that jumps and shakes instead of standing still is impossible to focus, no matter how you measure success. Motorized focusers mostly solve these mechanical constraints — judgment of focus becomes nearly real-time, if the focusing action is slow enough.

Most solutions for visual observing, however, do not cover the full scope of the focusing problem. Astro-cameras possess no biological eye accommodation, making them even more difficult to focus. Poor focus can ruin an arduous exposure. Many imagers rely on computer software to aid in the process, employing metrics like the width and central brightness of a stellar image (known as the full-width at half-maximum, or FWHM) to determine quality of focus. Anyone familiar with these methods will no doubt continue to use them. But it's handy to have an independent way of checking the results, and it's even better to have a backup plan if software fails to deliver.

Dividing the Field

Imagers and observers alike use various tricks to determine perfect focus in an effort to convert the process from an exercise in judgment to a purely geometrical comparison. These methods have met with varying degrees of success; some work better than others.

One of the oldest is to place a device called a *Hartmann mask* or *Scheiner disk* over the telescope aperture that subdivides it into two smaller holes, producing two images of the same star that merge into a single image as you rack through focus. This method is repeatable if there's a way of recording the focuser's precise position and returning to the observed center of the pattern. The drawback to this mask is that it is very coarse. The Hartmann mask significantly reduces the resolution of the instrument, increasing the size of the *Airy disk* (the bright central core of a star's image formed by a lens or telescope) so much that it masks the shape of the star as it approaches best focus.

In the mid-2000s, Russian astrophotographer Pavel Bahtinov introduced a new type of focusing mask that soon spread throughout the imaging community. Bahtinov made a mask having three coarse diffraction gratings at shallow angles to one another. These gratings were angled in such a way as to induce an easily interpreted imbalance in position between the diffraction orders of the various grids in defocused images. This imbalance is visible in two ways. The first and most commonly used are long, overlapping (high-order) diffraction spikes that are centered only at the point of focus. The drawback to this approach is the diffraction spikes are only clearly visible on the brightest stars.

Bahtinov himself suggested a second method that works well on dimmer stars. Instead of concentrating on the main image of the star, use the first-order diffraction spots seen above or below the actual star image when using the mask. The monochromatic Fourier diffraction model seen on the facing page is slightly inaccurate as it doesn't show the first-order spots stretched into stubby spectra, but with dim stars the visible spectrum is very short. If you're focusing a camera through any color filter, monochromatic images of first-order spots are nearly perfect tools for achieving focus.

As alluded to earlier, the long diffraction spikes are great if you can see them. The first-order spots, on the other hand, are always there, making many more stars available for use as focusing targets. More importantly, you can employ a star in the direction of your telescope tube's lean angle to compensate for the effect of tube flexure at different points in the sky.

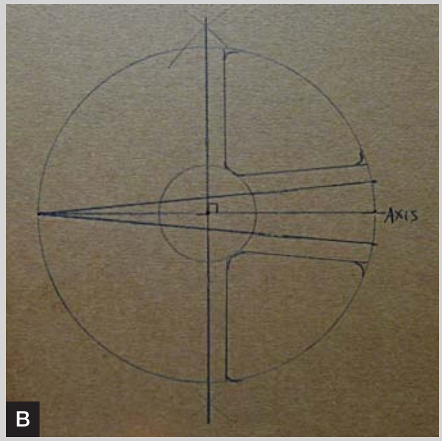
Mesh Mask Alternative

Nearly all amateurs who know about the Bahtinov mask have tried to fabricate one themselves by cutting long, straight plastic strips, and some have succeeded after painstaking effort. Whether or not they were successful, all agree that they don't want to attempt it a second time. Isn't there a straightforward alternative that doesn't involve such an extraordinary effort?

▼ Whether you're a visual observer or astrophotographer, focus masks can take some of the guesswork out of focusing under less-than-ideal conditions. Below is an easy-to-assemble 20° Bahtinov mesh mask for a 4-inch telescope that works well for both imaging and observing alike.

ALL IMAGES COURTESY OF THE AUTHORS

ASSEMBLE YOUR OWN MASK
(A) Plastic canvas can be found at most any craft store or online and can be cut with scissors. **(B)** Draw the pattern for your mask holes on a sheet of cardboard, being careful to place the registration lines of the two smaller holes at precisely the same angles relative to the larger aperture. The edges of the apertures don't need to be particularly neat, since they don't contribute to the image shift. **(C)** Assemble your mask with the mesh aligned to previously marked registration lines. **(D)** Remember that it's important that all three mesh screens are precisely aligned to your registration lines. **(E)** When completed, add three holes to install long nylon screws that will secure the mask to the front of your telescope or lens.



There is, though it produces a complicated image to interpret. The answer is to simply replace the long slits of the Bahtinov mask with a mesh grid, eliminating the need for any precision cutting while still producing a usable diffraction effect.

First, you need to find an inexpensive mesh that's rigid and sufficiently large enough to allow the first-order diffraction spots to appear between 10 to 30 arcseconds from the central peak. The grating relationship, which allows for calculating the diffraction angle based on the grating period and the wavelength of illumination, predicts this spacing for mesh periods of roughly 11 to 3.5 mm. An extensive search identified an ideal material known as *plastic canvas* that you can purchase online or at most hobby and craft stores. Plastic canvas is normally used to provide a backing for needlework through which brightly colored yarn can be strung to make simple pixel-like decorative patterns. We found it to be nearly perfect for our use — it's rigid, accurate, inexpensive, and easy to cut.

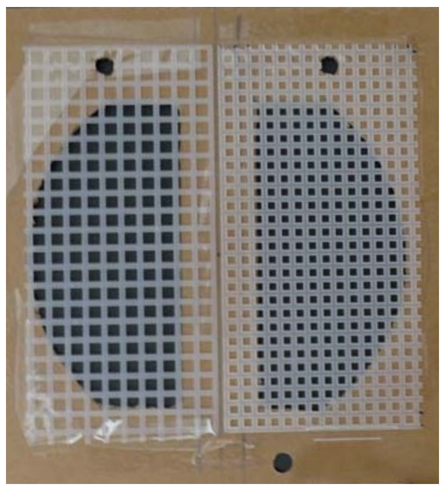
The three spots at the end of the first-order diffraction image are angled in the classic 40°, 12.7-mm period Bahtinov pattern. The outer spots of the triplet, which arise from the two angled areas of the mask, are separated by about 6 arcseconds. You should select a mesh period that will maintain at least this 6-arcsecond separation or a little bit more with the mesh mask, keeping in mind the pixel resolution at the effective focal length of the system. The tilt angle should be lower than 40° for finer meshes than the classic mask, or else the three spots appear too far apart for accurate judgment. For a 5- to 7-count plastic mesh (5 to 7 periods per inch), the best tilt angle is roughly 10° to 20°.

For example, with a 7-count mesh with two tilted regions diverted to ±10°, the triplet is separated by about 11 arcseconds, delivering two divided separations of 5.5 arcseconds each. For a generic 1,000-mm focal length imaging system, the first-order triplet is separated by twice 26 micrometers. Depending on the size of the camera's pixels, this may be tight or loose. A camera with 5-micron pixels has about 5 samples between the dots, and so should work fine.

Making a Mesh Mask

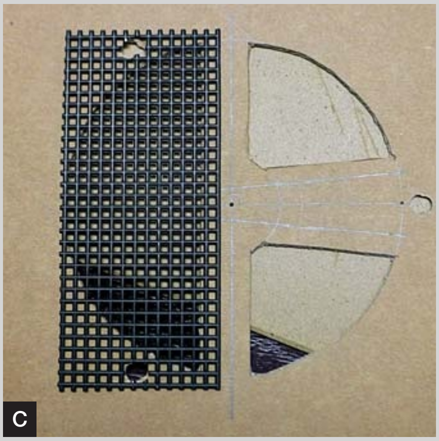
Assembling a mesh focus mask couldn't be simpler. Perforate a thin sheet of cardboard with the major holes that comprise the three large openings of the mask. There's no need to be particularly neat cutting the edges of these large holes, because they don't contribute to the desired linear diffraction. However, the alignment of the three mesh screens is important. The two smaller tilted regions must be mounted at the same opposite angles. An error in angle will result in a focus position with a systematic offset, producing slightly out-of-focus results.

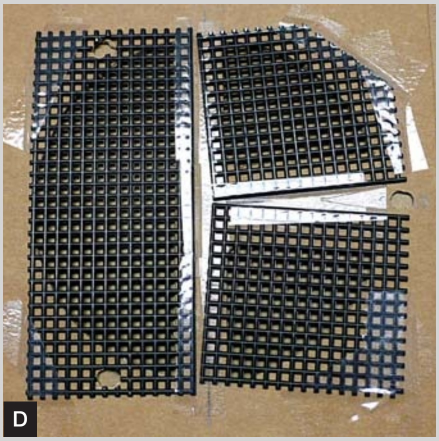
Using a mesh is not a kludge. They even have a built-in self-test for alignment accuracy: The first-order maxima in the spots seen horizontally from the main star will imme-

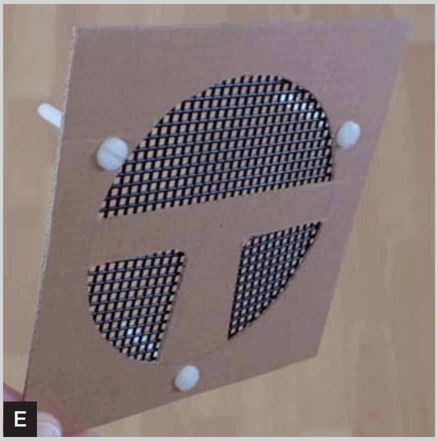


▶ Another excellent focus mask called the Oleshko two-frequency mask uses a bisected aperture with 5- and 7-count mesh grids.

▶▶ Assembling an Oleshko mask is even easier than crafting a Bahtinov. Simply abut 5- and 7-count plastic canvas along a single registration line.







diately display any mutual misalignment of the two smaller tilted regions.

Another advantage is that mesh masks are extremely easy to modify or repair. It's as simple as turning the grids over the holes or simply cutting out a new piece of plastic canvas.

Another diffractive focusing mask was popularized at roughly the same time as the Bahtinov mask. Although Andrei Oleshko's mask made less impact in the amateur community, it's equally sensitive and even easier to make with mesh.

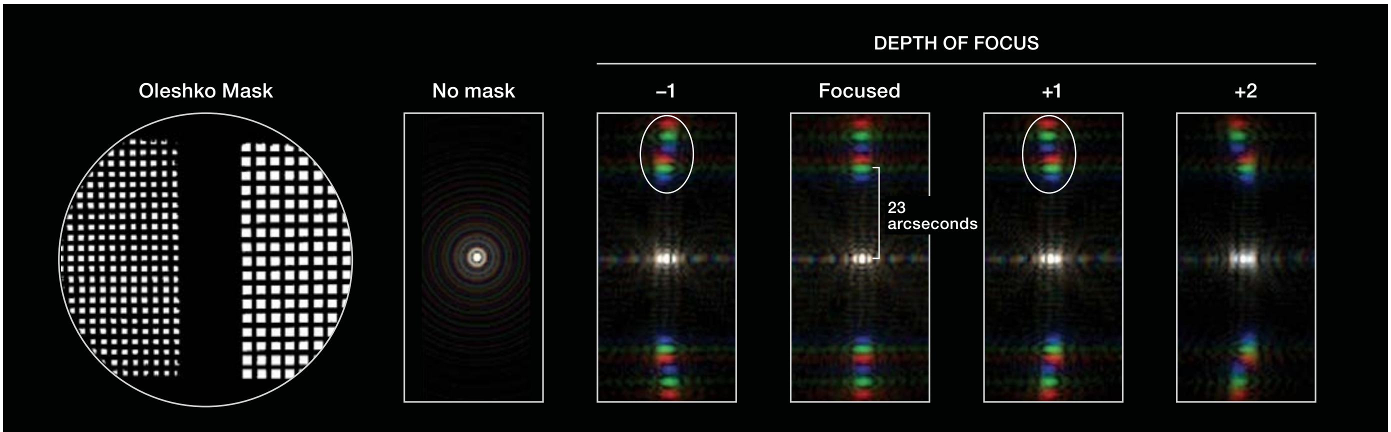
Using plastic canvas mesh, the most straightforward way of making one is to place a 5-count grating parallel to a 7-count grating over a mirror-image hole. The modeled color image below shows the way the Oleshko mask works. Because the 5-count grating wasn't available in black, it was constructed out of translucent plastic. A pleasant observation was that the transparency of the mask material makes little difference to the final image. Poorly focused light transmitted through the translucent material is scattered through such a wide angle that the translucent mesh works as effectively as black mesh.

Because strict alignment of any of these diffraction masks over the aperture isn't necessary, they can be loosely placed on the front of the telescope using long nylon screws. These don't attach to anything; they simply extend like fingers down over the edge of the tube. The complete structure is light and won't affect balance.

For visual use, diffractive masks require high power. At 560 nm, the 5- and 7-count meshes give first-order diffraction peaks separated by 32 and 23 arcseconds from the zeroth-order (in-focus) stellar image at the center. Given this scale, you can imagine Jupiter covering about half of the frames modeled here. To show deviations of spacing or linearity well enough, the magnification for small telescopes should approach 20× per centimeter of aperture. When focusing a camera, the spread of the diffracted first-order dots or spectrum separations should extend at least 7 to 10 pixels.

These masks are not magical. Because of many variables, including mechanical stability and atmospheric turbulence, focusing will still be a challenge. But it will be noticeably easier than simply viewing a dancing point of light and trying to decide where it's smallest and brightest.

■ **DICK SUITER** is the author of *Star Testing Astronomical Telescopes*. **BILL ZMEK** is the author of *Interferometry for Amateur Telescope Makers*. For more information on focusing masks, visit **https://is.gd/focusingmasks**.



The Oleshko two-frequency mask produces vertical spectra that line up when the optic is in focus.

 by Javier Barbuzano

The Martian Und

erground

Discoveries of life deep beneath Earth's surface are provoking scientists to wonder what might hide in the subsurface world of Mars.

NICOLLE R. FULLER / SAYO-ART LLC

In February of 1977, an oceanographic expedition studying hydrothermal vents at the bottom of the Pacific Ocean made a discovery that changed biology forever. Two kilometers deep, near a volcanic zone northeast of the Galápagos Islands, explorers onboard the deep-ocean submersible *Alvin* found four dense agglomerations of clams, mussels, crabs, anemones, and other creatures. Some of them were living among an alien-looking variety of tubular worms that vaguely resembled giant albino tulips. In awe, the researchers — probably inspired by the stark contrast with the barren seafloor beyond the vents — named the fourth, tubeworm-bedecked spot the "Garden of Eden."

At the time it was a mystery how this lush ecosystem could survive at such depth. Biologists had assumed that sunlight was the energy source that powered all life on Earth, effectively constraining the habitable zone to a thin layer on the planet's surface. Within that layer, photosynthetic organisms capture solar photons and use the energy to split water molecules. They then combine the hydrogen with carbon from the atmosphere to form sugars, releasing oxygen as a byproduct. In that scheme, all the other organisms, no matter how high up in the food chain, depended on the yield of these primary producers.

This deep biosphere [is] mainly populated by bacteria and other single-celled organisms called archaea, although recent research has also found fungal species and even animals.

But these giant tubeworms survive thanks to their ability to host *chemosynthetic* bacteria inside themselves. Like photosynthetic organisms on the surface, these bacteria also produce their own sugars, but instead of using sunlight — there is none 2 kilometers deep in the ocean — they obtain energy from chemical reactions. In this case they do it by oxidizing hydrogen sulfide present in the warm waters. Later research revealed that other types of chemosynthetic bacteria live freely inside and around the vents, occupying the bottom of the food chain in these isolated ecosystems.

This discovery showed that life is much more versatile and resilient than previously thought, opening the scope of where to look — and what to look for — when searching for life. It has led to the realization that, in our quest to find signs of life on Mars, maybe we've been looking in the wrong place.

From Underwater to Underground

It didn't take long for scientists to realize that one of the places they should be looking for chemosynthetic life forms was under their own feet. At first they piggybacked on commercial drilling and mining operations, then later on they explored caves and conducted their own drilling campaigns. By the early 1990s, researchers had collected enough evidence to show that Earth's crust is populated by a variety of microbes sustained by chemosynthetic organisms.

This *deep biosphere*, as it's called, extends from a few meters below the surface to several kilometers down, depending on the local conditions. It's mainly populated by bacteria and other single-celled organisms called archaea, although recent research has also found fungal species and even animals, such as nematode worms and tiny multicellular creatures called rotifers. In some places, where the conditions allow it, these communities can live in the pores and cracks of rocks up to 10 kilometers deep.

An expansion of scientific drilling projects in the last two decades has confirmed the findings and extended the range of subsurface environments where microorganisms can live, from the ancient continental crust to the younger and more

GIANT TUBEWORMS: NOAA OKEANOS EXPLORER PROGRAM, GALÁPAGOS RIFT EXPEDITION 2011 / CC BY 2.0; NEMATODES: GAËTAN BORGONIE / ELI, BELGIUM

▲ **HYDROTHERMAL TULIPS** Giant tubeworms (*Riftia pachyptila*) live among anemones and mussels at a deep-sea vent on the Galápagos Rift. This is one of the largest concentrations of *Riftia* found so far.

▲ **NEMATODES** Members of the species *Monhystrella parvella* inhabit a stalactite 1.4 km underground in the Beatrix gold mine in South Africa. Each nematode is a couple hundred microns long.

dynamic oceanic crust. This implies a huge diversity of living conditions, for the most part under high temperature and pressure, but also in the near-freezing environments under the polar ice sheets or basking in the heat of radioactive minerals.

Although life is pervasive underground, it's more austere than on the surface. The lack of sunlight and oxygen limits the energy supply. Subsurface organisms have slower metabolisms and are much less abundant than their surface counterparts. While one gram of surface soil can host more than 10 billion microbes, one gram of oceanic crust may contain only 10,000 cells, and continental crust one-tenth of that.

However, the volume of the deep biosphere is huge when compared to the surface world. Subsurface inhabitants therefore make up an important fraction of all life on Earth. "We've estimated that subsurface microbial life is about 10^{30} cells," says Tullis Onstott (Princeton University), a pioneer in the field who has been involved in subsurface-life research since the 1990s. "That's more than [the] stars in the visible universe and as many cells as in the surface world." Onstott's team estimates that subsurface life could represent around one-tenth of Earth's total biomass.

In order to subsist, chemosynthetic organisms — or *chemolithotrophs*, as they are called when they are able to extract energy from inorganic compounds — need to pair substances that can act as electron receivers and electron donors. When an electron jumps from the donor to the receiver, there is a small energy release these microbes can exploit. Luckily for them, many geological processes can provide this kind of chemical pair.

One example is the decay of naturally occurring radioactive elements within the rocks, such as uranium, thorium, or potassium. As these disintegrate, they emit high-energy particles that can break water molecules. This process, called *radiolysis*, releases huge quantities of hydrogen and reactive oxygen. Hydrogen is like a super food for microorganisms: It's so eager to donate electrons that even poor receivers such as sulfates can oxidize it, making it the ideal microbial fuel for the deep underground.

Another source of free hydrogen is *serpentinization*, a process in which iron-rich minerals react with water, filling the environment with leftover hydrogen that microbes can use. In some cases serpentinization can also produce hydrocarbons such as methane, another favorite meal for many microorganisms. Not only can they grab its hydrogen for food, they can also use it as a source of carbon.

Recent analyses have shown that underground dwellers are genetically diverse. There are even microbe species that are unique to the subsurface and cannot survive on the surface, raising important questions. Is subsurface life merely a result of what trickles down from the surface? How long have these species been evolving in the darkness? Could life have originated underground and then colonized the surface?

Both surface and subsurface life follow the same DNA blueprint, suggesting that life had a single origin, but it's not clear how or where it initially appeared. "There is much we don't understand about the origin of life on this planet," says Barbara Sherwood Lollar (University of Toronto, Canada), a geologist specialized in characterizing underground water reservoirs. "Certainly I don't think we understand yet the kind of environment where life first arose."

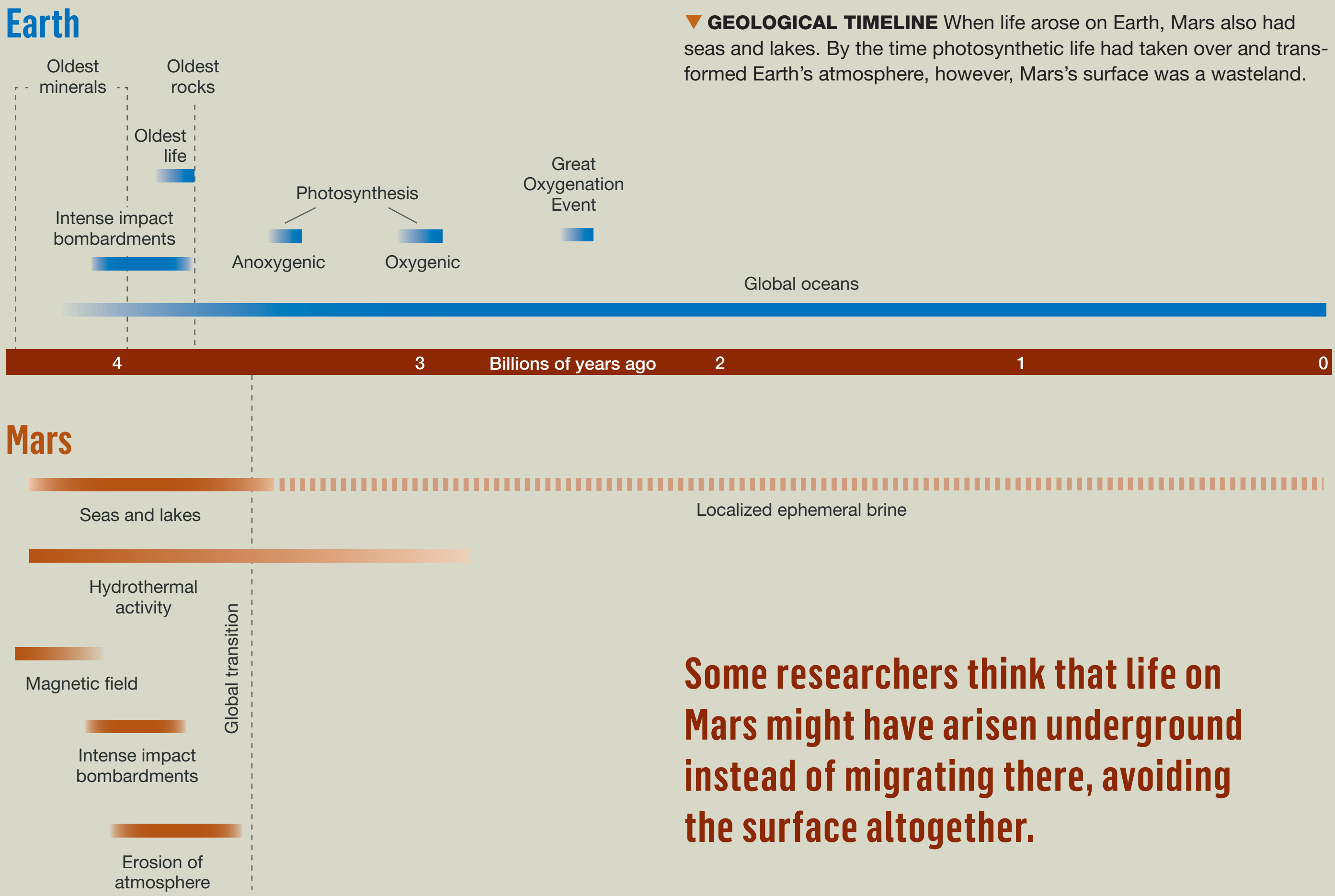
▲ **ANCIENT WATERS** Members of Barbara Sherwood Lollar's team take samples of water in rock fissures deep in Beatrix Mine in South Africa. The team has found evidence of life in this mine and others.

In 2013, Sherwood Lollar and her team discovered the oldest underground water ever found in Earth's crust, a thin network of veins 1.5 billion years old hidden 2.4 kilometers deep inside a mine in northern Ontario, Canada. This mineral-rich water contains the electron donors and receivers that organisms need to survive, showing that these habitable environments can be preserved over long time scales, something that could also happen on Mars. Sherwood Lollar and her collaborators have found signs of microbial life in the water, but although they are sure the life isn't a modern arrival, there is no way to say how long it's been there. It could have been isolated from the upside world for at least hundreds of millions of years.

MINING EXPEDITION: GAËTAN BORGONIE / ELI, BELGIUM; BACTERIA ICONS: BARBARA MARSILLAC, BR AND MAXIM KULIKOV / THE NOUN PROJECT

THE DEEP COMMUNITY

According to a 10-year study by the international Deep Carbon Observatory team, 70% of Earth's bacteria live underground.



▼ **GEOLOGICAL TIMELINE** When life arose on Earth, Mars also had seas and lakes. By the time photosynthetic life had taken over and transformed Earth's atmosphere, however, Mars's surface was a wasteland.

Some researchers think that life on Mars might have arisen underground instead of migrating there, avoiding the surface altogether.

But on other worlds, could pockets of underground life have originated independently from the surface?

"It's a question that is very important but we cannot address yet, whether or not life can originate in a subsurface environment," Onstott says. "When you think of Europa or Enceladus or any of the icy satellites and planets that exist out there that have subsurface oceans but never had a surface ocean, if life can originate in the subsurface then there's a chance that life exists there."

Even if humans cannot explore the oceans of Enceladus yet, there is a place within our reach that has potential for underground life: Mars.

Next Stop: The Red Planet

Although the Martian surface is currently inhospitable to life, various lines of evidence indicate that until about 3½ billion years ago, the Red Planet had surface water and an atmosphere (*S&T:* July 2018, p. 14). If life had time to appear on the surface during the billion or so years of clement conditions, then it might have also colonized the Martian underground, where conditions would have remained stable long after the surface became hostile. These life forms could have left fossils or other signs of their presence. Some scientists even think that this life could persist underground today.

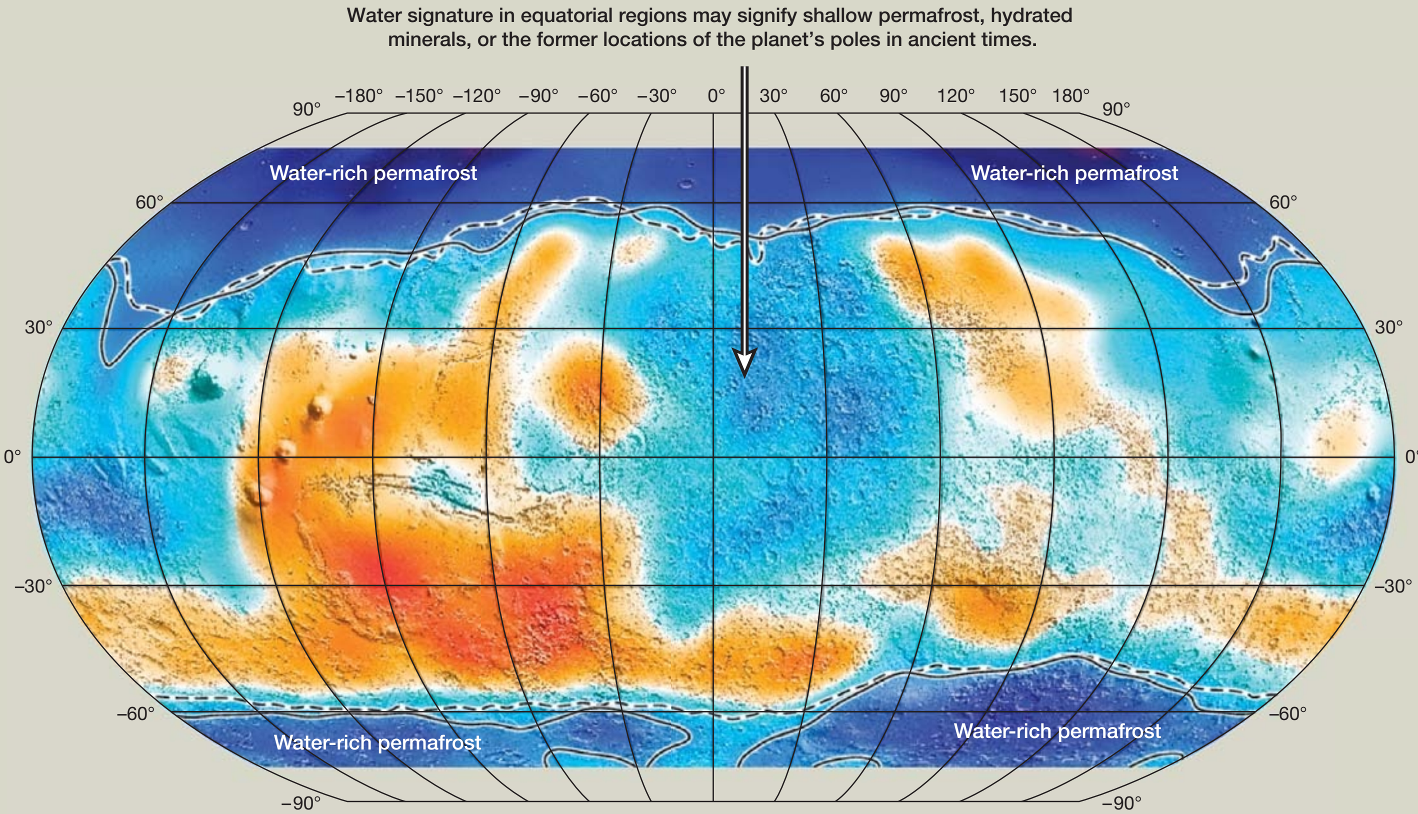
Recent studies suggest that the same geological processes that provide energy for subsurface microorganisms on Earth — serpentinization and radiolysis — occurred on Mars. NASA's Mars Odyssey spacecraft has found an abundance of the radioactive elements thorium, potassium, and uranium in the modern Martian crust. In eons past, these elements could have produced a global habitable subsurface several kilometers thick, thanks to radiolytically generated hydrogen. This could have provided enough chemical energy to support microbes for hundreds of millions of years, as long as there was enough water to split.

"There is no reason why you couldn't take the same organisms we find three kilometers down in South Africa and just teleport them to the subsurface of Mars, they would do just fine," says Onstott. "Deep below the surface [life] could be quite pervasive and quite active."

On the other hand, Mars might not have given life the chance to evolve on its surface. By current estimates, life appeared on Earth sometime prior to 3.7 billion years ago, roughly the same time that Mars's outer core stopped churning and the planet lost its magnetic field, exposing its atmosphere to the gusty solar wind. Photosynthetic life appeared on

GREGG DINDERMAN / *S&T*, SOURCE: J. R. MICHALSKI ET AL. / *NATURE GEOSCIENCE* 2018

▼ **UNDERGROUND WATER** This map from the ExoMars Trace Gas Orbiter shows hydrogen's distribution (bluer colors mean more hydrogen) in the uppermost meter of Mars's surface. Hydrogen might indicate water, water absorbed into the surface, or minerals formed in water.



ESA / I. MITROFANOV ET AL. 2018

Earth soon after, and by the time it became widespread enough to dramatically boost our atmosphere's oxygen content, Mars's surface had been a frozen and hyperarid desert bombarded by high-energy radiation for more than a billion years.

For this reason, some researchers think that life on Mars might have arisen underground instead of migrating there, avoiding the surface altogether. In their view, searching for evidence of life on the Martian surface is a biased approach fueled by what we see on Earth. Here, photosynthesizing surface life is extremely abundant, favored as it is by a protective atmosphere and magnetic field, a moderate climate, and easy access to water. One way or the other, scientists increasingly think that Mars research needs to shift its focus from the surface to the underground. Even if life got a foothold above ground, the harsh surface conditions might have wiped out any organic remains or other revealing signs, thwarting any life-searching missions based on surface features.

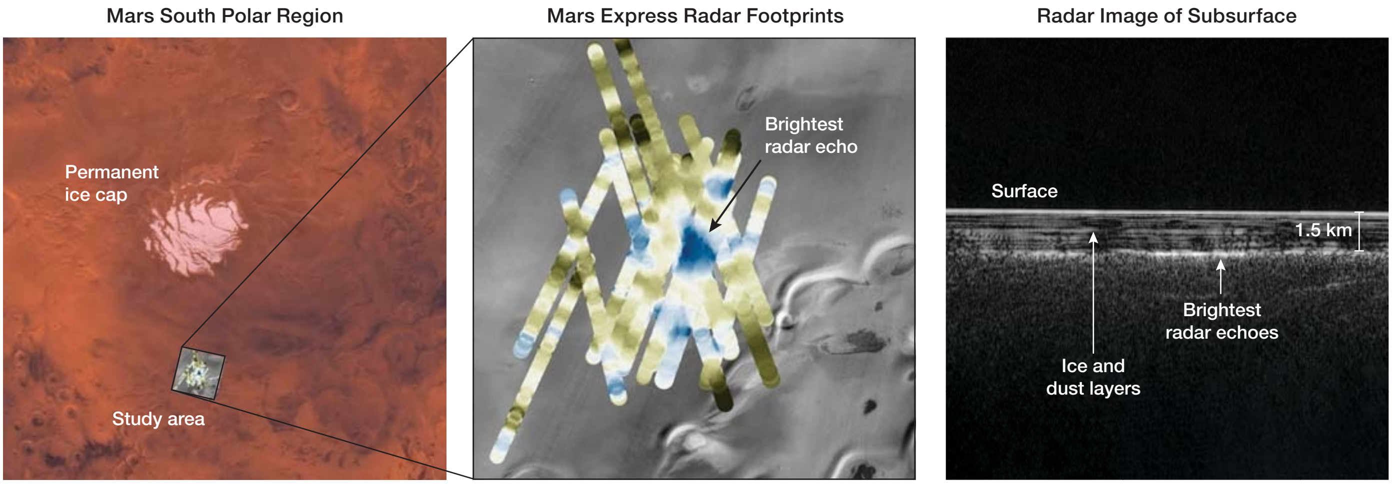
"Anything related to life, extinct or extant, leads us to the subsurface," says Vlada Stamenković (NASA Jet Propulsion Laboratory), an ardent advocate for subsurface Martian exploration. "It's clear that if we really want to understand if there ever was or is life on Mars, then we really have to dig into the subsurface and explore what's beneath."

Looking for Subsurface Life

Finding out if there is or has ever been underground life on Mars is not a straightforward proposition. First of all, we don't really know the physical properties of what lies below the surface. Things like temperature and water availability remain big unknowns. We only know there is a frozen layer close to the surface and a core that is probably still warm, making it likely that a temperate zone exists somewhere in between.

"These are reasonable conjectures, but we won't really know until we study Martian geophysics," says Ricardo Amils (Center for Astrobiology, Spain), who has worked extensively in characterizing southern Spain's Rio Tinto region, considered one of the best Martian analogs we have on Earth. Still, he's confident scientists need to look beneath the surface to fully assess the Red Planet's habitability. "If there is life on Mars it has to be in the subsurface, there is no doubt about that."

That's why NASA's Insight lander is an important first step towards the exploration of the Martian underground. The probe landed on Mars on November 26, 2018, carrying a seismometer, a thermal probe, and radio antennas, which together will reveal key aspects of Martian geophysics, such as the size and physical properties of the planet's core, mantle, and crust, as well as details about its inner heat flow.



▲ **SUBSURFACE LAKE?** Multiple passes by the European Mars Express orbiter reveal a highly reflective layer about 1.5 km below layers of ice and dust near Mars's south pole. Scientists suspect the 20-km-wide "anomaly" (blue triangle in radar footprints, center image) is a brine patch or lake. The righthand panel shows an example radar profile of the region.

ESA / NASA / JPL / ASI / UNIV. ROME, R. OROSEI ET AL. 2018

Another open question is the availability of liquid water below the surface. Orbiters have found that a frozen layer of soil and water ice called permafrost is common in the polar regions and covers large swaths of the rest of the planet, including equatorial areas. But little is known about what lies below. In July 2018, scientists using the MARSIS radar instrument onboard the European Space Agency's orbiter Mars Express announced they'd detected hints of liquid water 1.5 kilometers deep below the southern polar cap. While the finding remains controversial, researchers think that these are probably brines, bodies of water-soaked salt.

The detection would support the idea of an underground where high pressure and milder temperatures can make liquid water available. Although water's presence wouldn't mean life is present, it certainly would make things easier. "Life doesn't need a lot of water," says Amils. "Until now it was said that if there isn't liquid water there can't be life. Well, there is water."

Obviously, the most direct way to solve these questions is drilling, but current and future planned missions have limited digging capabilities. The Curiosity rover can grind just a few centimeters into the rock, and the upcoming European ExoMars 2020 rover will be able to drill up to 2 meters down. Insight, meanwhile, spent months stalled at a fraction of its 3-meter goal — still nowhere near where a deep biosphere might have existed.

"Mars exploration has been focusing so much on the surface that there has been very little investment in real subsurface exploration," says Stamenković, who is leading a concept design for a solar-powered Martian drill called Ares Subsurface Great Access and Research Drill (ASGARD), able to reach depths of at least 1 kilometer. Stamenković was recently part of a workshop hosted by the Keck Institute for Space Studies, where scientists and industry representatives discussed the future of underground Martian exploration. "We've realized that, actually, drilling technology has a lot to offer, there has been just little investment so far," he says. "As with many things on this planet, it's not the technology. It's the funding that is limiting."

However, Stamenković's optimism clashes with Onstott's experience chasing deep life. Even on Earth, he warns, drilling through frozen rock is an energy-intensive process that is prone to equipment failures and unexpected engineering challenges, from frozen pipes to broken drill bits.

For the time being, researchers will have to exploit other opportunities to study the Martian subsurface until drilling technologies become available. That means relying on indirect measurements and looking for certain features that are far less exciting than those uncovered by drilling kilometer-deep holes. Instead, researchers could look for exposed crustal rocks with unusual metal or carbonate accumulations, *biotextures* in rocks caused by interactions with microbes, or the buildup of organic molecules in fractures or fluid inclusions in rocks.

While the arguments for going deep in Martian exploration are sound and the possible outcomes fascinating, it seems that we will have to put our curiosity on hold. Even if indirect methods can reveal hints at what lies below the surface, only specialized instruments and drilling will provide definitive answers. Based on his experience, Onstott thinks that humans will not reach the Martian underground until after humans establish a base on Mars and need to access water below the surface for a permanent colony. "That's an important question for them," Onstott says. "When they access the water, will there be Martian organisms in it?"

■ Former *S&T* intern **JAVIER BARBUZANO** is a freelance writer based in Barcelona.

Read the story of the 1977 hydrothermal vents discovery at https://is.gd/1977ventsdisc.

OBSERVING
January 2020

A fireball streaks across the sky above ruins near the city of Damghan in Iran during the 2011 Quadrantids meteor shower.
BABAK TAFRESHI

3–4 ALL NIGHT: The short-lived Quadrantids peak for North America around 3 a.m. EST. The first-quarter Moon sets by 1:30 a.m. local time and won't interfere with best viewing opportunities that start about 2 a.m. (see page 48).

5 EARTH passes through perihelion, its closest point to the Sun for the year (just 3% closer than at aphelion in July).

7 DUSK: The waxing gibbous Moon is between the horns of Taurus, the Bull, only about 3° left of Aldebaran.

8 DUSK: The fattening Moon, still in Taurus, is less than 1° from Zeta (ζ) Tauri (for viewers in eastern North America).

10 FULL MOON (2:21 P.M. EST) A penumbral lunar eclipse is visible across most of Europe, Africa, and Asia. The Americas will have to wait until the summer, when a shallow event will be visible on the night of July 4–5 (see page 50).

13 EVENING: Algol shines at minimum brightness for roughly two hours centered at 10:46 p.m. PST.

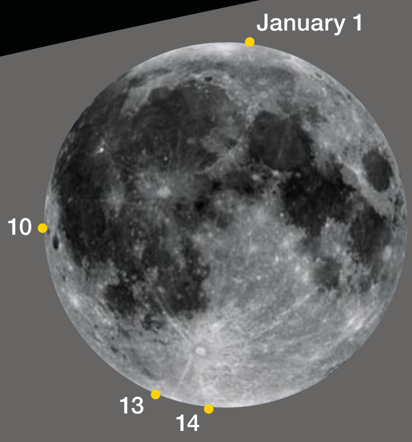
16 EVENING: Algol shines at minimum brightness for roughly two hours centered at 10:36 p.m. EST (7:36 p.m. PST).

19 EVENING: Algol shines at minimum brightness for roughly two hours centered at 7:25 p.m. EST.

20 DAWN: The waning crescent Moon, Mars, and Antares form a pretty triangle along the border between Ophiuchus and Scorpius before sunrise.

22 DAWN: A very thin lunar crescent rises in the southeast with Jupiter trailing it by around 6° — catch the pair before the Sun drowns out their delicate light.

27 EVENING: Some 6° separate Venus and the thin lunar crescent in Aquarius. Viewers with telescopes might spot Neptune less than ¼° from Venus.
— DIANA HANNIKAINEN



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	

FIRST QUARTER
January 3
4:45 UT

FULL MOON
January 10
19:21 UT

LAST QUARTER
January 17
12:58 UT

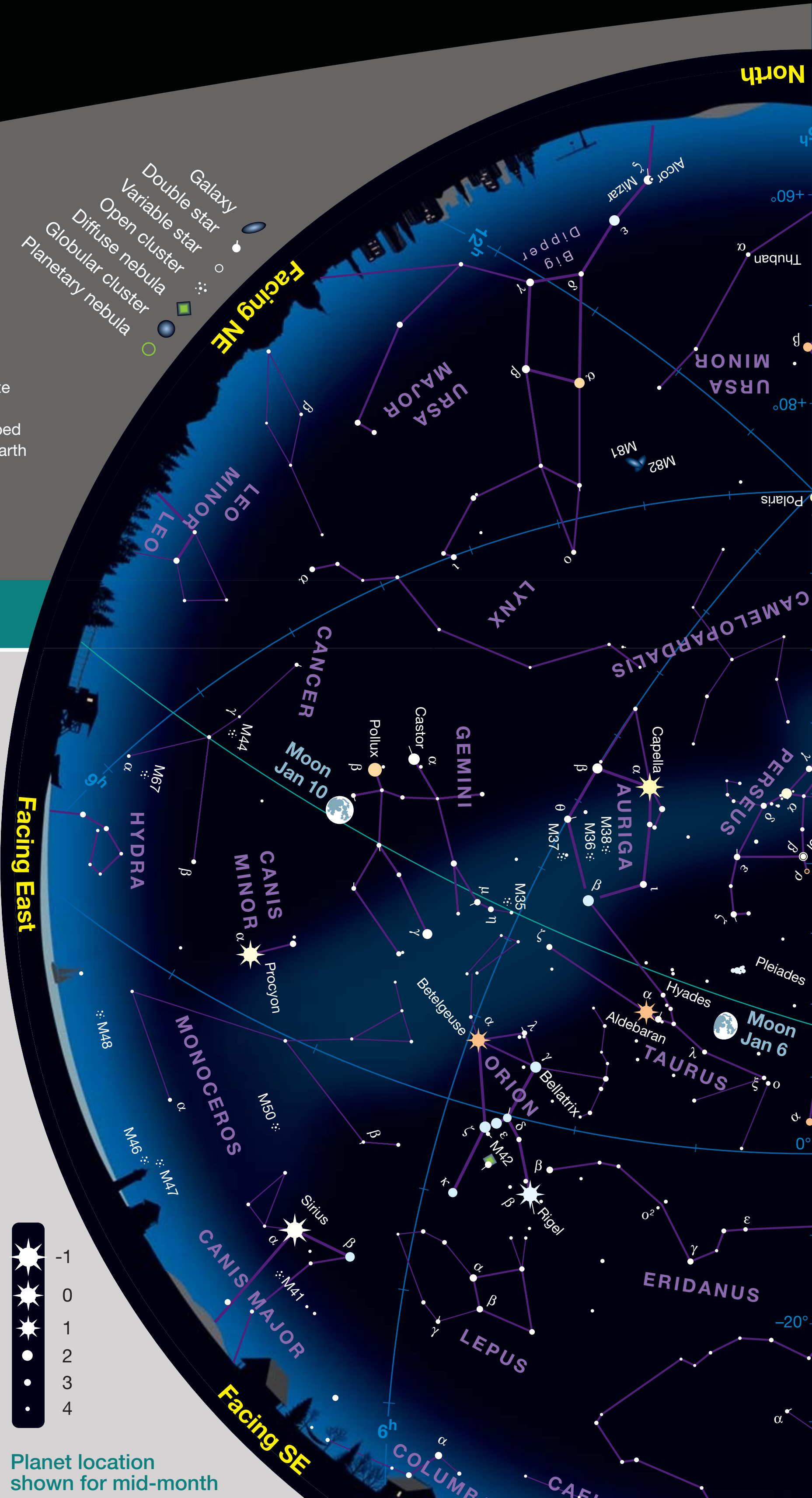
NEW MOON
January 24
21:42 UT

DISTANCES

Apogee	January 2, 2ʰ UT
404,580 km	Diameter 29′ 32″
Perigee	January 13, 20ʰ UT
365,959 km	Diameter 32′ 39″
Apogee	January 29, 21ʰ UT
405,393 km	Diameter 29′ 29″

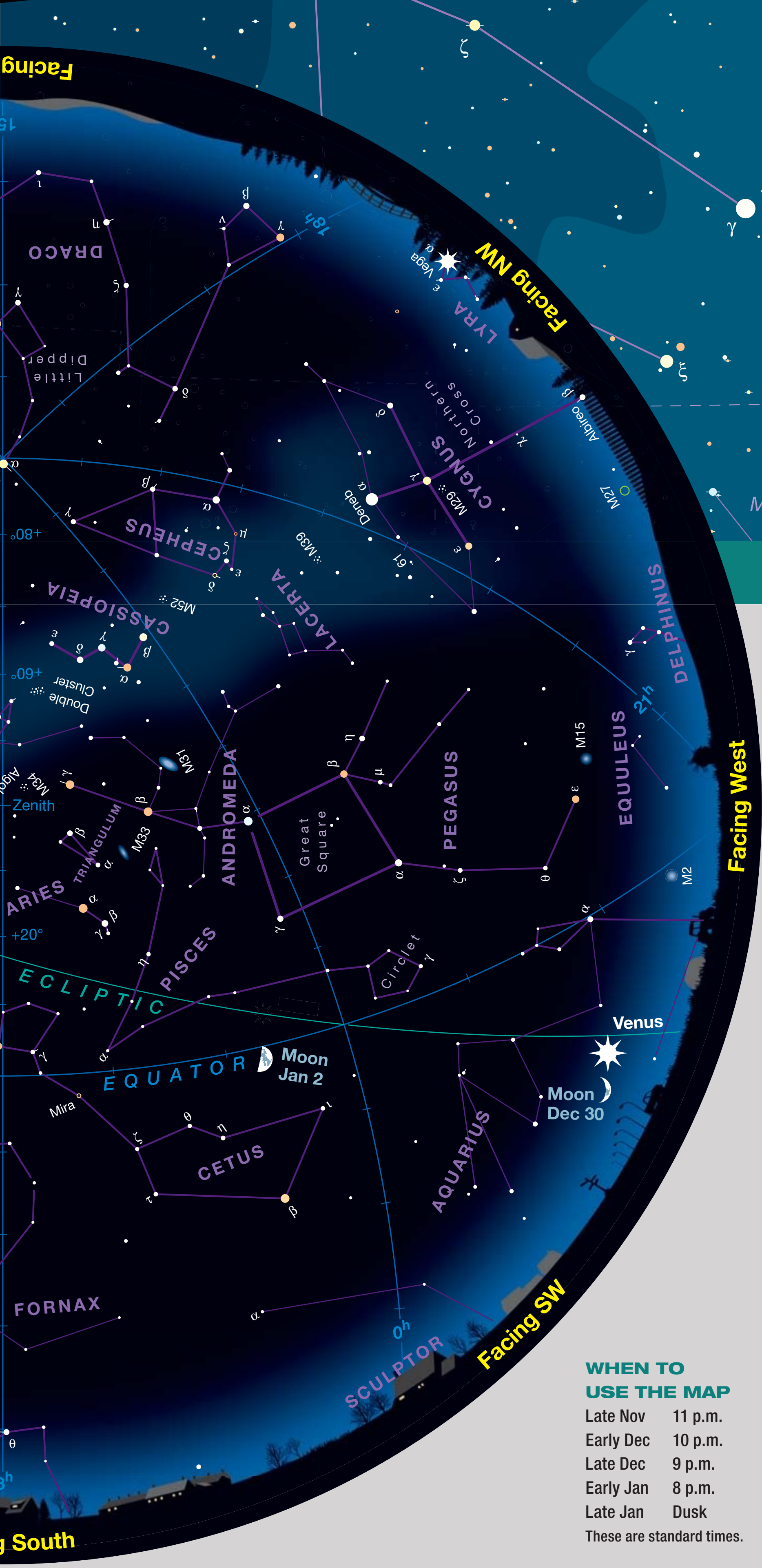
FAVORABLE LIBRATIONS

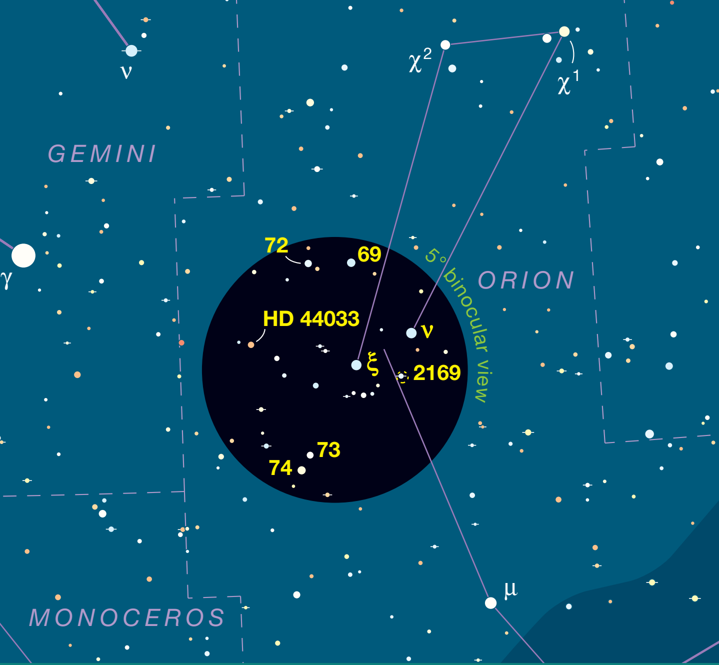
• Baillaud Crater	January 1
• Schluter Crater	January 10
• Hausen Crater	January 13
• Cabeus Crater	January 14



Planet location shown for mid-month

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





Binocular Highlight by Mathew Wedel

A Stellar Smorgasbord

Our destination this month lies in the northeastern reaches of Orion, the Hunter. Set **73** and **74 Orionis** near the south edge of your field of view, and **69** and **72 Orionis** near the north edge. You'll find yourself looking at a sprawling, complicated field with chains of bright stars, doubles, at least one cluster, and more besides.

Right away you'll notice an arc of bright stars running east-west like a lopsided smile, bounded by **HD 44033** in the east and **Nu (ν) Orionis** in the west. Just south of **Xi (ξ) Orionis**, four 6th- and 7th-magnitude stars make a miniature arc within the larger one. Just a bit to the west lies the open cluster **NGC 2169**. It's a small cluster, only about 5′ across as seen from Earth, but bright enough to show up even under moderate light pollution. At telescopic magnifications its stars spell out the number 37, hence its nickname, the "37 Cluster."

South of the arc, have a closer look at 73 and 74 Orionis. They look comparably bright, both about 5th magnitude, but that's an illusion. 74 Orionis is around three times as bright as the Sun and lies 65 light-years away. 73 Orionis is about 1,200 light-years away, but it's also more than 200 times brighter than its neighbor. I'm a sucker for cosmic odd couples like this, which remind us of the depths of the night sky.

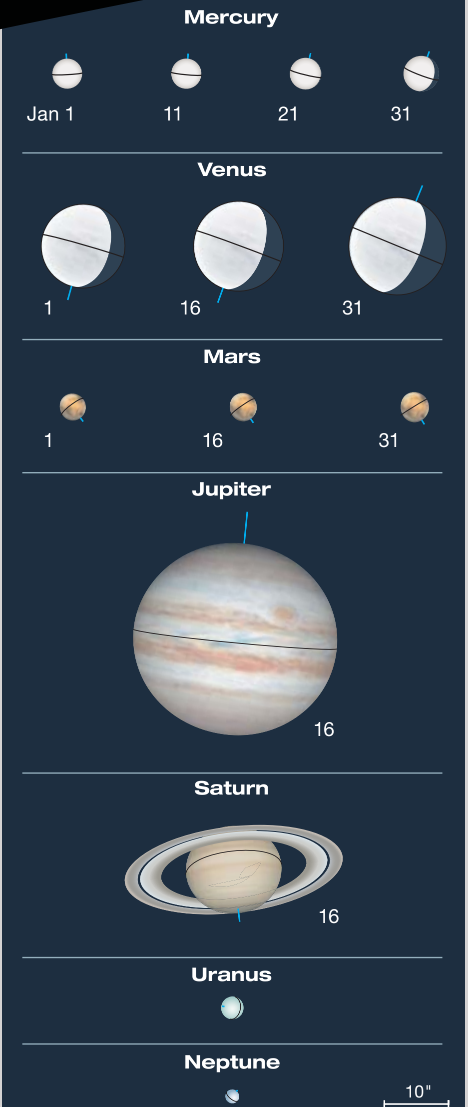
I haven't been shy about proposing new asterisms in this column, but I just can't make this field cohere into a neat picture. If we include 69 and 72 Orionis along with the bright arc, maybe there's a cross-eyed Cheshire Cat, or an upside-down toadstool? I'm really reaching here. A better solution is to stop trying to impose an order on Nature, and just take it all as it is.

■ "Just take it all as it is" is on MATT WEDEL'S bucket list (not checked off yet).

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.



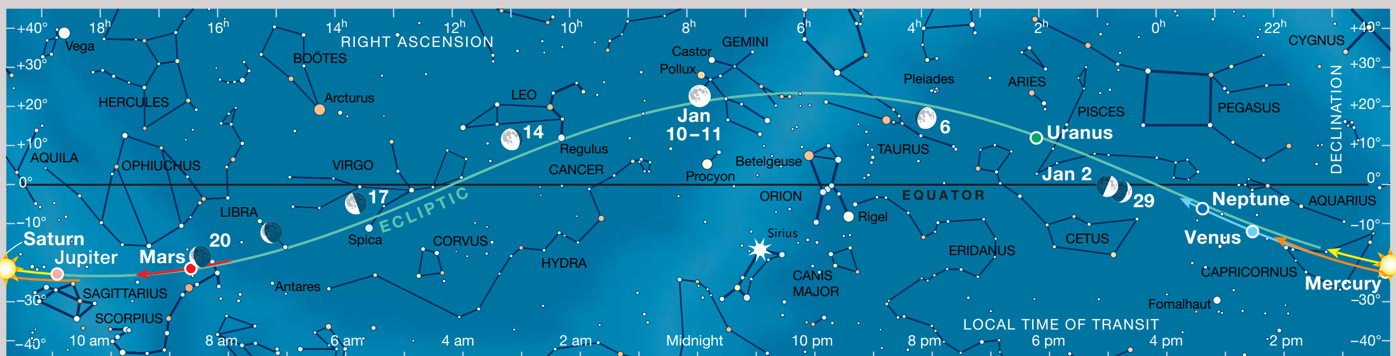
PLANET DISKS have south up, to match the view in many telescopes. Blue ticks indicate the pole currently tilted toward Earth.

PLANET VISIBILITY **Mercury:** very low at dusk starting on the 27th • **Venus:** visible at dusk, sets in early evening • **Mars:** visible at dawn • **Jupiter:** very low at dawn starting on the 12th • **Saturn:** hidden in the Sun's glow all month

January Sun & Planets

	Date	Right Ascension	Declination	Elongation	Magnitude	Diameter	Illumination	Distance
Sun	1	18^h 42.4^m	–23° 05′	—	–26.8	32′ 32″	—	0.983
	31	20^h 50.9^m	–17° 40′	—	–26.8	32′ 28″	—	0.985
Mercury	1	18^h 18.1^m	–24° 39′	6° Mo	–0.9	4.7″	99%	1.434
	11	19^h 28.5^m	–23° 51′	2° Ev	–1.4	4.7″	100%	1.429
	21	20^h 39.4^m	–20° 33′	7° Ev	–1.2	4.9″	98%	1.362
	31	21^h 47.3^m	–14° 46′	14° Ev	–1.0	5.5″	87%	1.212
Venus	1	21^h 08.7^m	–18° 21′	34° Ev	–4.0	13.1″	82%	1.278
	11	21^h 56.7^m	–14° 19′	36° Ev	–4.0	13.7″	80%	1.220
	21	22^h 42.5^m	–9° 40′	38° Ev	–4.0	14.4″	77%	1.160
	31	23^h 26.4^m	–4° 38′	40° Ev	–4.1	15.2″	74%	1.096
Mars	1	15^h 43.8^m	–19° 23′	42° Mo	+1.6	4.3″	96%	2.184
	16	16^h 26.1^m	–21° 29′	47° Mo	+1.5	4.5″	95%	2.073
	31	17^h 09.7^m	–22° 55′	52° Mo	+1.4	4.8″	93%	1.956
Jupiter	1	18^h 27.9^m	–23° 12′	3° Mo	–1.8	31.8″	100%	6.209
	31	18^h 57.3^m	–22° 45′	27° Mo	–1.9	32.5″	100%	6.074
Saturn	1	19^h 31.3^m	–21° 44′	11° Ev	+0.5	15.1″	100%	10.996
	31	19^h 46.3^m	–21° 10′	16° Mo	+0.6	15.1″	100%	10.976
Uranus	16	2^h 01.5^m	+11° 51′	97° Ev	+5.8	3.6″	100%	19.667
Neptune	16	23^h 11.3^m	–6° 20′	51° Ev	+7.9	2.2″	100%	30.538

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.com/almanac.



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). "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.

Silent Starlight

January's starry sky inspires a year of dreams and plans.

Silent sunlight, welcome in
There is work I must now begin
All my dreams have blown away
And the children wait to play
They'll soon remember things to do
When the heart is young
And the night is done
And the sky is blue

—Cat Stevens (Yusuf Islam), from *Silent Sunlight*

DENNIS DI CICCO

Welcome to the first of these columns for the potentially very inspiring year of 2020.

The song stanza quoted above is certainly inspirational, but for our purposes here we need to adapt a few of the lines. Silent starlight is as powerful in its own, somewhat different way, as silent sunlight is. And our hope is that the night we love is *not* done. To protect and regrow the night, however, there is work we — not just I — "must now begin."

Silent starlight. The mention of "silent sunlight" makes me think of sunlight pouring in through a window on a clear, sharp winter day, all quiet out-of-doors. Sunlight itself is silent — and so is the light of the multitude of suns, the stars — that shine in the night sky. On calm, windless winter nights we hear even fewer sounds, so the brilliance of Orion and the other winter constellations — the brightest of the year — has an even greater presence. Of course, we might occasionally hear loud cracking from something freezing up in the night, or the sounds of our footsteps crunching on ice or snow. But those kinds of sounds have a quality reminiscent of the sharp sparkling of stars, reinforcing the stellar beauty above.

A few years back I coined the term "vidience" as the counterpart in sight to what "audience" is in sound. A vidience is what we observers are collectively when we are stirred by the sights of a silent starry sky.

Start of the stars. Is January the best month to begin a year — or lifetime — of observing the stars? We really must factor in what times of the night are best in a given month. I continue to be fascinated with the fact that the brightest star, Sirius, is on the meridian almost exactly at midnight of January 1st, the first minute of the New Year. I've also written here before about how early evening in January brings us the hour Orion is rising and late evening the hour it's highest. Which of these ought to be called "Orion o'clock?"

The first step in dealing with these matters is using *sidereal time*, which is the time measured by the rotation of the Earth relative to the fixed stars rather than to the Sun.

The Heavens by Hours again. The liveliest, most memorable way to follow time by the stars is with the system of the Heavens by Hours, a system that has a name for each sidereal hour. This idea was originated by astronomical author and illustrator Guy Ottewell, with the first two hours of right ascension straddling the meridian at 1^h sidereal time and earning the name "the Andromeda Hour." Ottewell no longer does a print version of his legendary annual *Astronomical Calendar*, but you can get a more basic (and free) version for 2020 at his website **universalworkshop.com**. There you can also find how to purchase his deluxe Map of the Starry Sky and 2020 Zodiac Wavy Chart.

The hour of our January issue all-sky chart. It is, perhaps, the Pleiades Hour or the Perseus Hour at the time of our chart on page 42, because the lovely star cluster and the heroic constellation are both near the meridian. Orion is midway up the southeastern sky, with Sirius not far above the southeastern horizon at this hour. The group of bright constellations surrounding Orion almost fits within the east-to-southeast celestial pie slice in a pie of sky whose center is the zenith. Andromeda-Pegasus hangs down the western sky from near the zenith to near the horizon. And the departing Northern Cross of Cygnus stands upright on the west-northwestern horizon with Deneb at top.

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

To find out what's visible in the sky from your location, go to skypub.com/almanac.

Planetary Prelude

The first month of this year provides a foretaste of some of the amazing sights to come.

The year 2020 shapes up to be truly spectacular for the planets.

Jupiter and Saturn will pull close together in May, separate, and then come back together in December to have their tightest conjunction in centuries.

Also in 2020, Venus passes through the Pleiades near the apex of an outstanding evening apparition for observers at mid-northern latitudes. After that, brilliant Venus moves over into the morning sky for an almost equally excellent dawn display.

Finally, Mars in 2020 glides close past Jupiter and Saturn in March and in the fall will appear almost as bright and big in our sky as it was at the perihelic opposition of 2018. But this time Mars is 30° farther north and therefore much sharper in telescopes for observers at mid-northern latitudes.

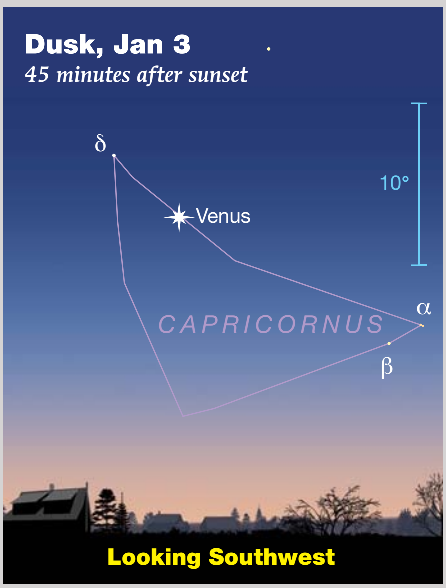
Which planetary sights can you view in this first month of 2020? As January progresses, Venus comes into sight higher and higher in the southwest at nightfall. Mercury pokes into visibility very low in the early evening twilight near month's end. But after Venus sets around mid-evening no bright planet is visible until several hours before sunrise, when Mars rises in Libra, Scorpius, or Ophiuchus. The last two bright planets follow Mars up at dawn but are only just emerging from the solar glare as January progresses: Jupiter around the second week of the month and Saturn, just barely for lucky binocular observers, at month's end.

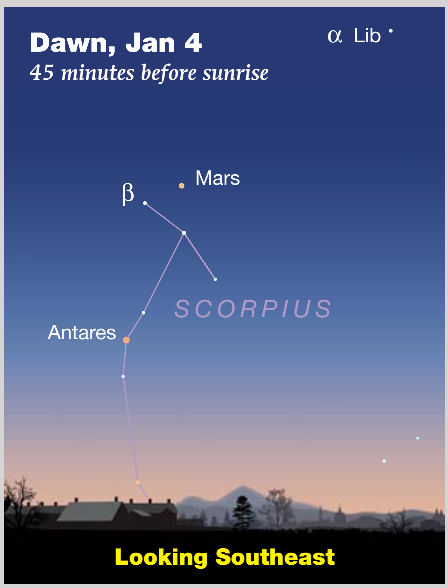
DUSK TO MID-EVENING

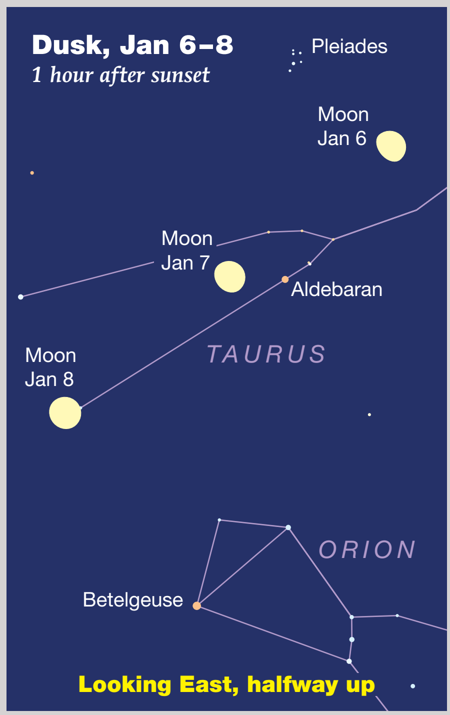
Venus has a dramatic increase in sunset altitude for observers at mid-northern latitudes this month. If you can already spot the planet's intense spark as the Sun drops below the horizon, you'll find it about 25° above the southwestern horizon on January 1st and about 34° high on the 31st. The interval between sunset and Venus-set increases from 2¾ hours to almost 3½ hours during January. You should be able to tell in your eyepiece that the planet has a gibbous phase that shrinks from 82% to 74% lit and a disk that enlarges from 13″ to 15″ during the course of January.

Venus spends the month tracking past Delta (δ) Capricorni (Deneb

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







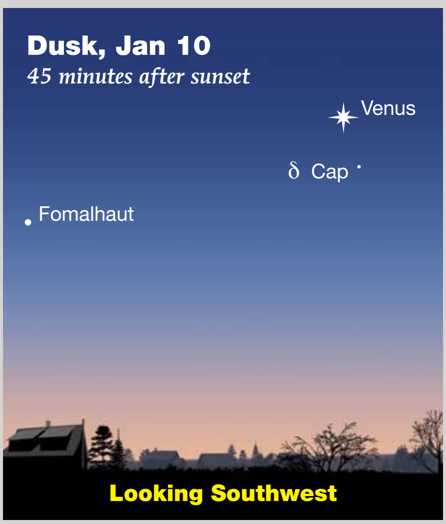
Algedi) and then entering Aquarius, where it has a very close encounter with **Neptune**. Almost 12 magnitudes fainter than Venus, Neptune's tiny disk is just 2.2″ wide and should be discernible in telescopes in good seeing conditions. That little aqua blip is only about 10′ lower right of Venus at nightfall on January 27th for viewers along the East Coast, with a little more distance separating the two planets for viewers farther west in North America.

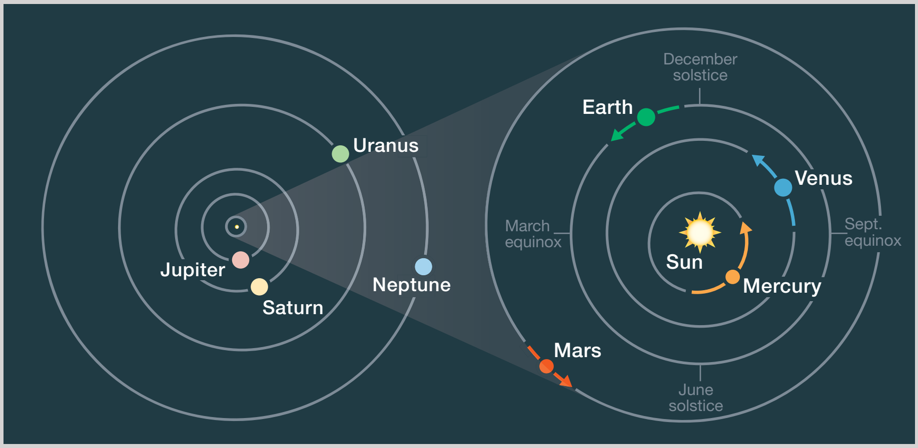
Uranus, two magnitudes brighter than Neptune, is high in the south in Aries at nightfall. Detailed finder charts for Uranus and Neptune are in the September 2019 issue and can also be accessed at **https://is.gd/urnep**.

Mercury goes through superior conjunction with the Sun on January 10th. It begins to come into view extremely low in the southwest about 30 minutes after sunset in the final days of the month. As January ends, Mercury shines at magnitude –1.0 and sets about 70 minutes after the Sun.

PRE-DAWN AND DAWN

Mars rises about three hours before the Sun in January and cuts an interesting path through Scorpius and Ophiuchus during the month. Mars begins the month and year some 4° to 5° upper right of the wide double star Beta (β) Scorpii (Graffias). The highlight of Mars's trek through the stars this month occurs on the mornings of January 17th

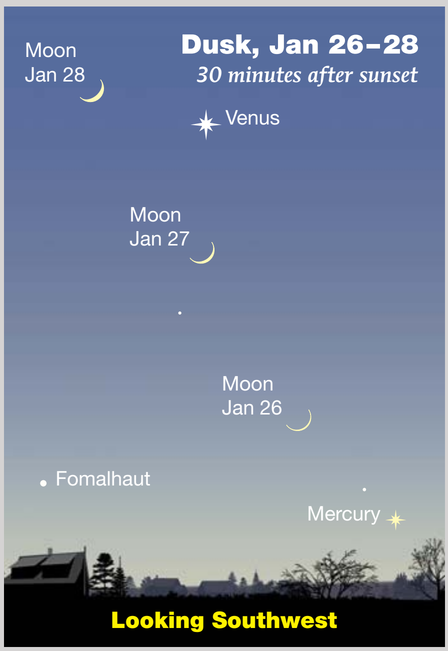




ORBITS OF THE PLANETS
The curved arrows show each planet's movement during January. The outer planets don't change position enough in a month to notice at this scale.

and 18th, when it passes less than 5° northwest of Antares, the heart of Scorpius. At this conjunction of the orange-gold planet and orange-gold star, Mars shines at magnitude 1.5, a half-magnitude dimmer than Antares. Mars brightens and grows slightly during January, but even at month's end its 93%-lit disk in telescopes is only 4.8″ wide.

Jupiter passed directly behind the Sun's disk at superior conjunction on December 27, 2019, and is only a few degrees from the Sun, lost in the solar glare, as 2020 begins. Not until the second week of January does Jupiter



become visible to the naked eye before sunrise. Magnitude –1.9 Jupiter comes up more than 1½ hours before the Sun as January ends.

Saturn makes a rare passage directly behind the Sun's disk on January 13th, reaching conjunction with the Sun just two hours after **Pluto** does. Saturn, shining at magnitude 0.6, may be visible to exceptionally well-placed binocular observers at month's end, rising about an hour before sunup.

EARTH AND MOON

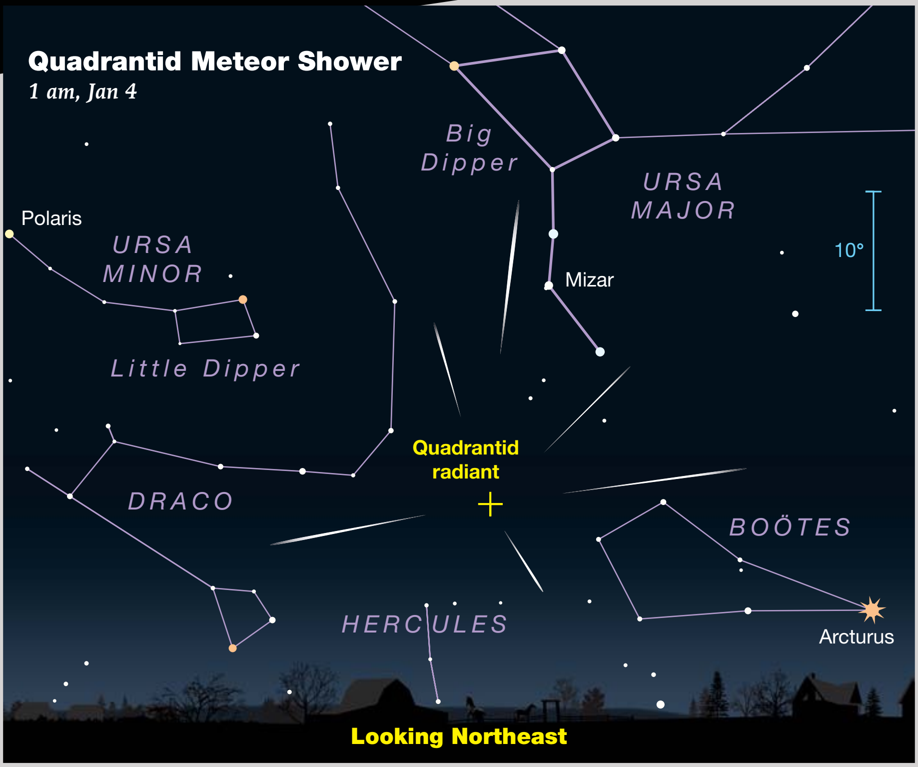
Earth arrives at perihelion, a minimum of 0.9832 a.u. from the Sun, at 8^h UT on January 5th.

The Moon is waxing gibbous and 3° to 4° left or upper left of Aldebaran at nightfall on January 7th. The Moon undergoes a penumbral eclipse, mostly visible in the Eastern Hemisphere on January 10th (see page 50 for details), and rises only a few degrees lower right of Pollux at nightfall that evening across North America. On the American morning of January 20th, the waning lunar crescent forms a compact pattern with Mars and Antares. At nightfall on January 27th, the waxing lunar crescent is some 6° below Venus, and the next night approximately the same distance upper left of Venus.

■ **FRED SCHAAF** had the 10-mile-wide asteroid 7065 Fredschaaf named after him in November 2016.

Catch the Quads

After a bright Moon slammed both the Perseids and the Geminids last year, January opens with the promise of an excellent show from the Quadrantid meteor shower.



The radiant for the Quadrantids is in northern Boötes. By 1 a.m. local time the radiant is well above the horizon for observers at mid-northern latitudes, with best viewing possibilities after 2 a.m. local time.

I like to think of the "Quads" as the shower without a home. Its meteors radiate from within the obsolete constellation Quadrans Muralis, the Mural Quadrant (which was a device once used to measure star positions). Joseph Jérôme de Lalande invented the figure in the 1790s using a handful of faint stars glimmering in the empty realm north of Boötes and south of Draco. Soon after, the quadrant made an appearance in several star atlases, including Johann Bode's *Uranographia*, and stuck around long enough to brand the Quadrantids when the shower was first recognized in the 1830s.

Alas, the constellation was not universally accepted and ultimately shown the door in the early 20th century. But it has bequeathed its name to the first meteor shower of the new year. The Quads peak on the night of January 3–4 with the best view in the early morning after about 2 a.m. local time until the start of dawn around 6 a.m. The focal point, or radiant, of the shower stands at the juncture of Hercules, Boötes, and Draco and climbs high in the northeast sky before first light.

While many meteor showers are active for several nights, the Quadrantids are famous for their fussiness, with a peak typically lasting only about 6 hours. If the radiant is well-placed during that time at your location, you could see up to 120 meteors per hour, according to the American Meteor Society. That's an idealized number assuming no Moon, the radiant at the zenith, and pristine skies.

Off-peak you'll see closer to 25 meteors an hour from a dark site. I caught the shower close to maximum under clear skies just once back in the 1980s. What a show! Meteors sparked about one a minute across the frigid pre-dawn sky, including a few fireballs, a classic Quadrantid characteristic. If you live in North America, 2020 is the year you've been waiting for. The International Meteor Organization (IMO) puts the peak at around 8^h UT on January 4th, or 3 a.m. Eastern Standard Time, favorable for North America. The first-quarter Moon sets by 1:30 a.m., leaving a blissfully black sky perfect for Quad-gazing.

My favorite way to enjoy a winter meteor shower is to crack open the squeaky folding chair and square it up in the driveway. As far as which direction to face, any works, but I like to look about 90° either side of the radiant for a nice mix of long- and short-trailed meteors. Once settled in I pull a big, wool blanket up to my chin and do nothing for the next hour or two but absorb the beauty of the stars and whatever meteors chance by.

If possible, face away from the worst light pollution to preserve night vision and maximize your meteor count. The majority of meteors are faint, so the darker the sky the more you'll see.

If you're planning on taking photos, get an *intervalometer* for your DLSR. The device presses the shutter button for you at preset intervals, so you don't have to maintain a frozen vigil at the camera. You can purchase one at camera shops or online outlets including eBay. Use a wide-angle lens with a focal length of 35 mm or less and start with an exposure of 30 seconds at f/2.8 and ISO 1600. Once activated, the intervalometer will snap one photo after another while you cozy away under that blanket. If you think frost or dew might become a problem, rubber-band a couple of chemical handwarmers around your lens and intervalometer. In an hour's time you will have tallied more than 100 images without even trying. Later, when you're indoors, you can swipe the frost off the camera back and click through your take to find (we hope!) a treasure or two.

Because the radiant lies at a declination of 50° north, it's circumpolar from many North American locations and visible all night. Be alert for Quadrantid *earthgrazers*, meteors that climb upward from the northern horizon and glow for many seconds as they skim the top of the atmosphere.

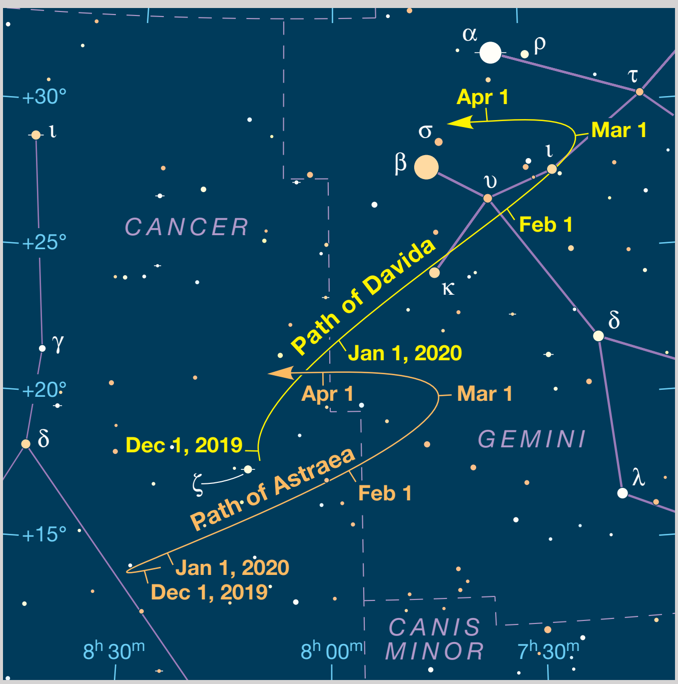
Unlike many meteor showers that originate from dust and debris sloughed off by passing comets, the Quads' parent body appears to be an extinct near-Earth comet discovered in 2003 called 2003 EH_1. Peter Jenniskens, an American astronomer and meteor researcher, has proposed that the Quadrantid stream evolved from the breakup of a much larger comet nucleus of which 2003 EH_1 is a remaining fragment (**https://is.gd/2003EH1**). Because the debris stream is narrow and Earth encounters the stream perpendicularly, the planet zips through the densest meteoroid braids in hours, which is why the peak is so brief.

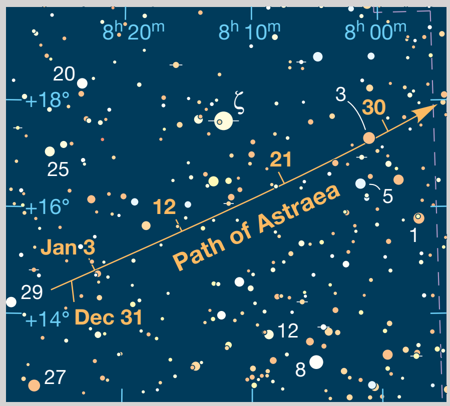
Hot Rocks for Cold Nights

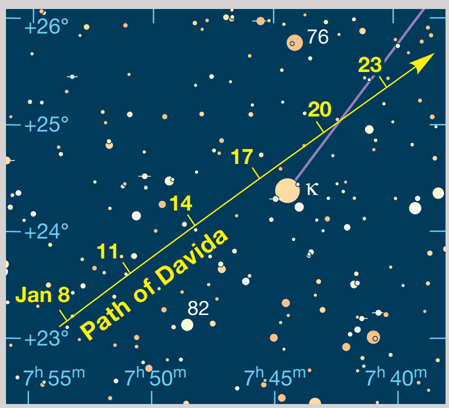
TWO BRIGHT ASTEROIDS ply the evening sky this month — **5 Astraea** and **511 Davida**. Davida reaches opposition on January 15th in Gemini and Astraea on the 21st in Cancer. Both shine around 9th magnitude and are glimpsable in binoculars from dark skies, but most of us will find a small telescope better suited to the task. Astraea, a large stony asteroid about 119 kilometers across, starts the month at magnitude 9.5, brightens to 8.9 at opposition and fades to 9.3 by month's end. Astraea was the fifth asteroid discovered after the familiar foursome of Ceres, Pallas, Juno, and Vesta. Those first discoveries came one after another between 1801 and 1807. Then 38 years went by without a single new object found. Many astronomers assumed that was all she wrote until Karl Ludwig Hencke, a German amateur, spotted a fifth on December 8, 1845, after searching steadfastly for *15 years* with a small achromatic refractor.

On the night of his discovery Hencke assumed the new object was a variable star since he'd swept the region many times before. He sent off an account of his new find to a Berlin newspaper. Several days later, Johann Encke of Encke's Comet fame, confirmed the object as a new "planet" after having observed it move against the fixed stars. Two years later, Hencke discovered his second asteroid, 6 Hebe.

These two almost back-to-back finds reenergized astronomers to begin hunting anew for asteroids. In the coming years, what had been a trickle of new objects became a torrent. In fact, so many new asteroids were discovered that astronomers abandoned calling them planets — the popular term at the time — and settled instead on *asteroid*, a word meaning "starlike." One man's persistence had paid off — Hencke unintentionally revolutionized our understanding of asteroids as minor solar system bodies compared to the more massive planets.







▶ The tick marks represent 0h UT; for North America, this time falls in the early evening (or late afternoon) of the previous date. The chart for Davida traces the asteroid's path one week prior to and one week after opposition.

Our second featured asteroid, 511 Davida, is a 290-kilometer-wide ball of carbonaceous goodness and one of the few that reveals a shape in ground-based instruments. Its reflectance spectrum indicates it's a Type C asteroid enriched in carbon. Unsurprisingly, its surface is considerably darker than Astraea's, with an albedo of about 0.06 versus 0.23. Type C asteroids are related to the CI and CM carbonaceous chondrite meteorites. They're more common in the outer part of the main asteroid belt, exactly where you'll find Davida, which takes its name from the late-19th, early-20th century American astronomer David Todd.

Davida begins the month at magnitude 9.9, brightens to 9.5 at opposition, and fades to 10 by month's end while embarking on a loop near the bright star Pollux in Gemini. You couldn't ask for an easier guide star. And what better sight on a cold January night than a carbon-rich asteroid soaking up sun like a turtle on a log?

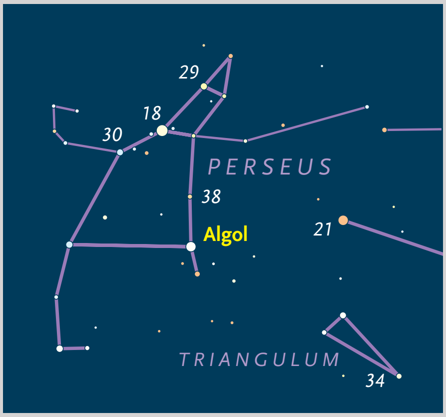
Penumbral Lunar Eclipse

SKYWATCHERS IN Europe, Africa, Asia, and western Australia will see a deep penumbral lunar eclipse on Friday, January 10th. The eclipse begins at 17:08 UT with maximum at 19:11 UT and conclusion at 21:12 UT. At maximum, 89.5% of the Moon will dip within Earth's outer, or penumbral, shadow. Observers should easily notice a "graying" of the Moon's southeastern limb about 20 minutes into the eclipse. All four of 2020's lunar eclipses are penumbral. Western Hemisphere observers will witness two of them, a shallow event on the night of July 4–5 and a deeper one in the early morning hours of November 29–30.

Minima of Algol

Dec.	UT	Jan.	UT
2	6:29	2	19:29
5	3:18	5	16:18
8	0:07	8	13:08
10	20:56	11	9:57
13	17:45	14	6:46
16	14:34	17	3:36
19	11:23	20	0:25
22	8:12	22	21:14
25	5:02	25	18:03
28	1:51	28	14:53
30	22:40	31	11:42

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.com/algol**.



▲ Perseus stands high in the northeastern sky in the evening. Every 2.7 days, Algol (Beta Persei) dips from its usual magnitude 2.1 to 3.4 and back. Use this chart to estimate its brightness in respect to comparison stars of magnitude 2.1 (Gamma Andromedae) and 3.4 (Alpha Trianguli). Algol remains near minimum for about 2 hours.

Action at Jupiter

JUPITER WAS VISIBLE LOW in evening twilight in the first week or two of December 2019 and in conjunction with the Sun on December 27th. Look for it to reappear very low in the dawn sky around January 12th.

When Jupiter is observable, 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 a nearly straight line from our point of view on Earth. Use the diagram at right to identify them by their relative positions on any given time and date.

All of the January interactions between Jupiter and its satellites and their shadows are tabulated on the facing page. Find events timed for Jupiter's brief period of twilight visibility.

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: 0:19, 10:14, 20:10; **2:** 6:06, 16:02; **3:** 1:58, 11:54, 21:49; **4:** 7:45, 17:41; **5:** 3:37, 13:33, 23:29; **6:** 9:25, 19:20; **7:** 5:16, 15:12; **8:** 1:08, 11:04, 21:00; **9:** 6:55, 16:51; **10:** 2:47, 12:43, 22:39; **11:** 8:35, 18:31; **12:** 4:26, 14:22; **13:** 0:18, 10:14, 20:10; **14:** 6:06, 16:01; **15:** 1:57, 11:53, 21:49; **16:** 7:45, 17:41; **17:** 3:36, 13:32, 23:28; **18:** 9:24, 19:20; **19:** 5:16, 15:12; **20:** 1:07, 11:03, 20:59; **21:** 6:55, 16:51; **22:** 2:47, 12:42, 22:38; **23:** 8:34, 18:30; **24:** 4:26, 14:22; **25:** 0:17, 10:13, 20:09; **26:** 6:05, 16:01; **27:** 1:57, 11:52, 21:48; **28:** 7:44, 17:40; **29:** 3:36, 13:32, 23:27; **30:** 9:23, 19:19; **31:** 5:15, 15:11

January 1: 1:07, 11:02, 20:58; **2:** 6:54, 16:50; **3:** 2:46, 12:42, 22:37; **4:** 8:33, 18:29; **5:** 4:25, 14:21; **6:** 0:17, 10:12, 20:08; **7:** 6:04, 16:00; **8:** 1:56, 11:51, 21:47; **9:** 7:43, 17:39; **10:** 3:35, 13:31, 23:26; **11:** 9:22, 19:18; **12:** 5:14, 15:10; **13:** 1:05, 11:01, 20:57; **14:** 6:53, 16:49; **15:** 2:45, 12:40, 22:36; **16:** 8:32, 18:28; **17:** 4:24, 14:19; **18:** 0:15, 10:11, 20:07; **19:** 6:03, 15:59; **20:** 1:54, 11:50, 21:46; **21:** 7:42, 17:38; **22:** 3:33, 13:29, 23:25; **23:** 9:21, 19:17; **24:** 5:12, 15:08; **25:** 1:04, 11:00, 20:56; **26:** 6:52, 16:47; **27:** 2:43, 12:39, 22:35; **28:** 8:31, 18:26; **29:** 4:22, 14:18; **30:** 0:14, 10:10, 20:05; **31:** 6:01, 15:57

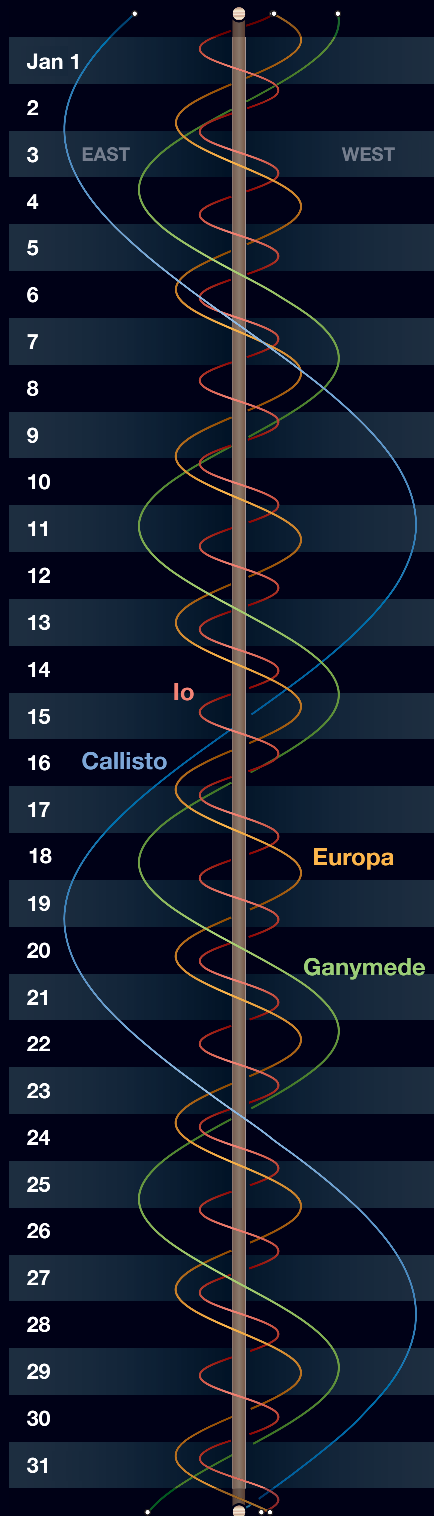
These times assume that the spot will be centered at System II longitude 322°. If the Red Spot has moved elsewhere, it will transit 1²/₃ minutes earlier for each degree less than 315° and 1²/₃ minutes later for each degree more than 315°.

Phenomena of Jupiter's Moons, January 2020

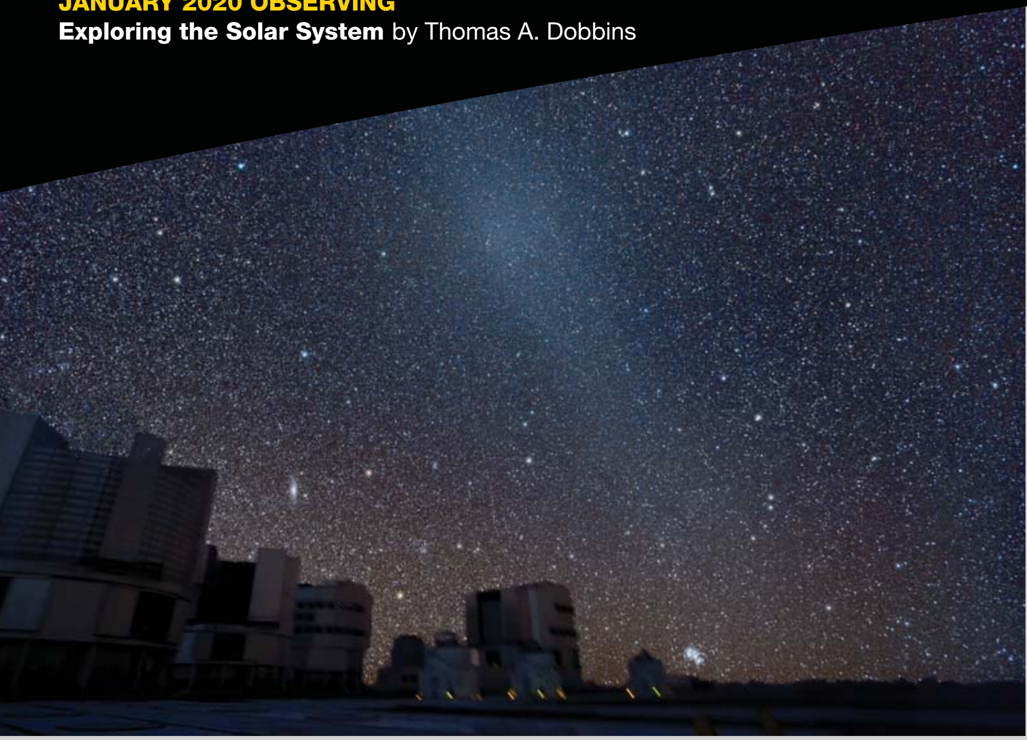
Jan. 1	15:19	I.Sh.I
	15:24	I.Tr.I
	17:33	I.Sh.E
	17:38	I.Tr.E
	21:00	II.Ec.D
	23:50	II.Oc.R
Jan. 2	9:19	III.Ec.D
	12:38	III.Oc.R
	12:38	I.Ec.D
	14:59	I.Oc.R
Jan. 3	9:48	I.Sh.I
	9:55	I.Tr.I
	12:02	I.Sh.E
	12:09	I.Tr.E
	16:02	II.Sh.I
	16:16	II.Tr.I
	18:42	II.Sh.E
	18:57	II.Tr.E
Jan. 4	7:07	I.Ec.D
	9:30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

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

Jupiter's Moons



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



◀ Reported to appear similar to but considerably fainter than the gegenschein seen at left, Kordylewski's clouds of dust reside 60° ahead of and behind the Moon in its orbital path.

The Kordylewski Clouds

Join the hunt for these enigmatic lunar attendants.

The most challenging observing targets in the solar system are located right in our cosmic backyard, yet they can't be seen through any telescope.

The path that led to their discovery six decades ago can be traced back almost two and a half centuries to attempts to solve the vexing "three-body problem" in celestial mechanics. In 1772 the mathematician Joseph-Louis Lagrange determined that a relatively small body that shares the orbit of a planet and lies 60° ahead or behind it will maintain its position for an indefinitely long period of time. These Lagrangian points are designated L4 (leading) and L5 (trailing). Forming a pair of equilateral triangles with the planet and the Sun, they are exceptionally stable because the gravitational attraction of the planet and the Sun on the small body just balance the centripetal force of its orbital motion.

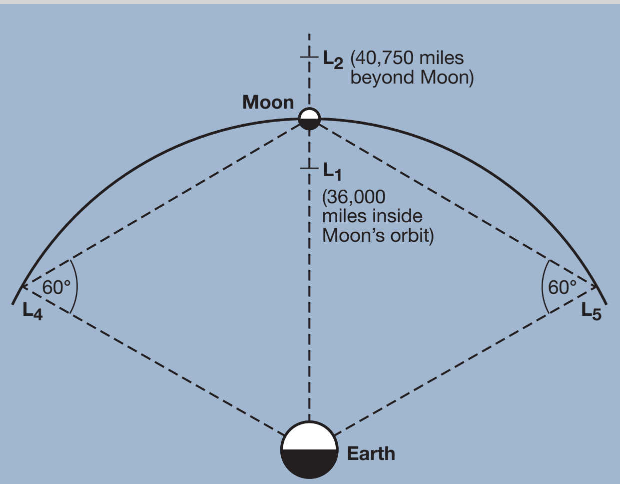
The Lagrangian points remained an abstract notion until the dawn of the 20th century, when astronomers discovered the brightest members of an entire family of asteroids that circle the Sun near the L4 and L5 points in Jupiter's orbit. Following a suggestion by Austrian astronomer Johann Palisa, these objects were named after famous heroes of the Trojan War, and to date more than 7,000 "Trojan" asteroids have been cataloged. They comprise almost one-fifth the mass of the main asteroid belt.

In 1951 the Polish astronomer Kazimierz Kordylewski, a specialist in celestial mechanics and the photoelectric photometry of variable stars, began a systematic visual search for "Trojan" bodies located at the L4 and L5 points of the Earth-Moon system using the 8-inch refractor of the Kracow Observatory. He looked for objects with a stellar appearance that would betray their nature by moving at the lunar rate — about ½° every hour — relative to the background stars.

Despite many nights at the eyepiece, Kordylewski failed to detect any suspects brighter than 12th magnitude, corresponding to objects about 20 meters in diameter with the same reflectivity as the lunar surface. Deep photographic surveys using a 20-inch Schmidt camera and a 24-inch reflector also proved disappointing.

Professor Josef Witkowski of Poznan University suggested to Kordylewski that he search for swarms of dust particles rather than discrete bodies. Far too tiny to be seen individually, if present in sufficient numbers these dust motes would be visible as a very faint nebulous patch. Without a contrasting expanse of surrounding dark sky to reveal its outlines, however, any cloud of sufficiently large dimensions would elude detection in

Five Lagrangian points exist for each three-body system. L_1, L_2, and L_3 (not shown, but on the far side of Earth at the Moon's distance) lie on a straight line drawn through the two large masses. Weak perturbing forces will knock objects at these points out of orbit. The stable L_4 and L_5 are the third points of two equilateral triangles drawn in the plane of the two large objects.



GEGENSCHEIN: ESO / Y. BELETSKY; LAGRANGIAN POINT DIAGRAM: LEAH TISCIONE / S&T

the narrow field of a telescope. It would be a classic case of being "too close to the forest to see the trees."

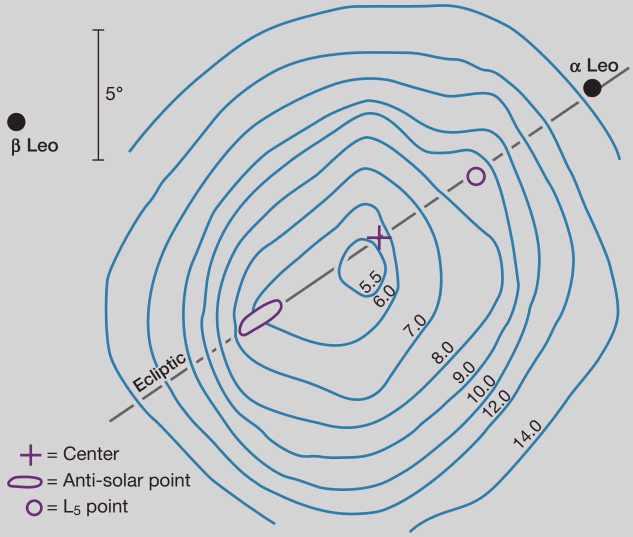
A special combination of circumstances is required for such a cloud to be observable. The Lagrangian point of interest has to be located well above the horizon to minimize the effects of airglow and atmospheric extinction. To provide a contrasting background, it must lie clear of the Milky Way as well as the band of the zodiacal light that runs along the ecliptic. It would appear brightest when nearly opposite the Sun, but at such times the Moon — only 60° away — is in a bright gibbous phase, so sightings are only possible before the Moon rises or after it sets to avoid a bright background sky awash with scattered moonlight.

Kordylewski hoped to find images of cloud satellites in the thousands of wide-angle patrol photographs taken at the Sonneberg Observatory in Germany over a period of three decades. Unfortunately, not a single one had recorded the L4 or L5 points when the Moon was below the horizon!

In October 1956 Kordylewski visited the Skalnaté Pleso Observatory in the Tatra mountains of Slovakia. From this dark, remote location, he managed to glimpse with his naked eye an exceedingly faint, diffuse patch of light about four times larger than the full Moon near the L5 point. It was one or two magnitudes fainter than the notoriously difficult *gegenschein*, the "counterglow" located directly opposite the Sun within the band of zodiacal light that is produced by the backscatter of sunlight from motes of interplanetary dust. Its changing location on successive nights confirmed that it was moving at the same rate as the Moon.

On an expedition to nearby Kasprowy Wierch mountain in the late winter through early spring of 1961, Kordylewski took 11- to 13-minute photographic exposures of the L5 region using a wide-field Leica camera equipped with a 50-mm f/1.5 lens. Although his films covered an area of 25° by 37°, the optical system's vignetting imparted uneven sky fog that was

▶ Kordylewski made this isophote diagram by photoelectrically scanning negatives obtained on March 6, 1961. The contour lines of increasing brightness are centered about 5° from the L_5 point.



LEAH TISCIONE / S&T

densest at the center of the image. To overcome this source of error he made four exposures on every night with the Lagrangian points at different locations relative to the center of the photograph.

The negatives were scanned with a microphotometer at the Wroclaw Observatory. This sensitive instrument measures the density of the films, allowing for the accurate plotting of contour lines that delineate regions of density. Deformations of these contour lines on all of the photographs revealed the presence of two oval clouds near L5. Measuring about 2° by 3° and separated by about 8°, the clouds were present in photographs of the constellation Leo taken on March 6 but absent in photographs of the same region taken two nights later when the Lagrangian point had moved into the constellation Virgo.

There has been no shortage of confirming observations over the years. In 1967 J. Wesley Simpson recorded the cloud satellites using instruments aboard NASA's Kuiper Airborne Observatory. Eight years later, J. R. Roach verified their presence using data acquired during 16 successive lunations with the Orbiting Solar Observatory 6. During the 1980s they were repeatedly captured on photographs taken with a battery of wide-field cameras by the Polish astronomer Maciej Winiarski from a dark site in the Carpathian Mountains.

Last year a team of Hungarian astronomers reported the most convincing evidence yet. Reflected sunlight is always polarized to some extent, so by using a linear polarizing filter that transmits only light with a particular direction of oscillation attached to a camera lens and CCD detector, they recorded a faint glow around the L5 point that was remarkably consistent with Kordylewski's observations six decades earlier.

There has also been no shortage of negative results, which led some astronomers to question the reality of the cloud satellites. In 1991 the Japanese Hiten space probe failed to detect a significant increase in dust particle density when it passed directly through L4 and L5. In 2010 astronomers Amanda Lowry and Dwight Russell reported that they didn't record any reddening of the light of background stars in the L5 region that would occur if the starlight had passed through even an exceedingly tenuous dust cloud.

The solution to this conundrum may be that the Kordylewski Clouds are variable. The feeble pressure that sunlight exerts will gradually sweep away any sub-micron grains of dust at the L4 and L5 points, suggesting that the debris shed by passing comets or ejected from lunar impacts periodically replenishes them.

If you have access to an exceptionally dark observing site and modern digital imaging equipment, the Kordylewski Clouds are well worth looking for. Just remember that you'll be straining to record something ephemeral that may not always be there!

■ This column marks Contributing Editor **TOM DOBBINS'** 50th article in *Sky & Telescope* in 33 years.

Auriga, the Charioteer

Some of the sky's finest nebulae and star clusters adorn this constellation.

Thou hast loosened the necks of thine horses, and goaded their flanks with affright,
To the race of a course that we know not on ways that are hid from our sight.
As a wind through the darkness the wheels of their chariot are whirled,
And the light of its passage is night on the face of the world.

— Algernon Charles Swinburne, *Erechtheus*, 1876

▲ Deep photographs show that NGC 1931, IC 417, IC 410, and IC 405 (top left, upper left, lower left, and lower right, respectively) are actually the brightest parts of a single nebula. The bright stars of asterism Melotte 31 shine between IC 410 and IC 405.

STEVE CANNISTRA

According to one myth, Erechtheus (or Erichthonius) was the mortal son of the Greek god Hephaestus. Erechtheus created the first four-horse chariot (quadriga) to ride beneath the heavens, which impressed the gods and earned him a place among the stars as the constellation Auriga.

We'll start our tour of Auriga's starry realm with **Melotte 31**. This elongated group of 35 stars spans 2¼° with golden 16 Aurigae at its center. In a suburban sky, Melotte 31 looks like a hazy glow to the unaided eye, but a rural sky may allow you resolve a few of its stars.

The group is easily visible through a finderscope, binoculars, or a small telescope at low power. The bright stars strung from 16 to 19 Aurigae are particularly eye-catching. *Sky & Telescope* Senior Editor Alan MacRobert has long referred to this cute asterism as the Leaping Minnow, while California amateur Robert Douglas calls it Auriga's Frying Pan. Despite the striking countenance of Melotte 31, its stars seem to be largely unrelated.

Melotte 31 is named for the British astronomer Philibert Jacques Melotte, who included it as one of the 245 objects listed in his 1915 *Catalogue of Star Clusters shown on the Franklin-Adams Chart Plates*. Melotte is also well-known for his discovery of Pasiphaë, one of Jupiter's moons.

Through my 105-mm (4.1-inch) refractor at 28×, the Minnow shares the field of view with the emission nebula **IC 410** and its embedded open cluster **NGC 1893**. This coarse gathering of suns is framed by a triangle of 9th-magnitude stars and ensnared in the eastern reaches of a gauzy mist. The cluster appears about 12′ across, while the nebula overspreads at least 19′. Boosting the power to 76×, I count forty 9th- to 13th-magnitude stars. The nebula is patchy and irregular, with a dimmer bay in its eastern side and dark blotch just west of the cluster's center.

NGC 1893 reveals 60 stars, and it doubles in size when seen through my 10-inch reflector at 70×. Many of the bright stars follow a pattern that reminds me of a pair of crossed candy canes, and the brightest star in the northeastern part shines with a golden hue. IC 410 stretches westward to a 9th-magnitude star near the cluster's edge and faintly beyond toward the nice double star **Espin 332**. The pair

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

consists of an 8.9-magnitude primary with a 9.5-magnitude secondary to its southwest.

Suspecting a small brighter spot in the nebula about one-third of the way from the golden star to the 10th-magnitude star at the center of the cluster, I zoomed in on the area with higher powers. They gave a much better view, and I could easily see a patch of enhanced brightness. A faint star rests inside and a dimmer one nuzzles the southern edge. This bright region marks the head of Simeis 130, one of IC 410's cometary nebulae. Nicknamed the Tadpoles, they are sites of denser gas and dust being eroded by stellar winds and radiation from the cluster. I didn't notice the head of the other Tadpole, Simeis 129, located 4′ northwest, nor did I see the Tadpoles' tails trailing away from the cluster. Can you?

About ¾° northwest of the Minnow, we find the eruptive variable **AE Aurigae**, a blue-white star that fluctuates irregularly between magnitude 5.4 and 6.1. This runaway star was ejected from the Orion star-forming complex approximately 2.5 million years ago. It's thought that a close encounter between two binary systems led to some star swapping that resulted in the eccentric binary Iota Orionis and two high-speed escapees, AE Aurigae and Mu Columbae.

AE Aurigae now serves as the chief source of illumination for the emission/reflection nebula **IC 405**, which it only chanced upon in astronomically recent times. The German astronomer Max Wolf noted that the nebular material surrounding AE Aurigae "looks like a burning body from which several enormous curved flames seem to break out like gigantic prominences." He thought this "flaming star" worth study, and its nebula thus became known as the Flaming Star Nebula.

With my 105-mm refractor at 17×, nebulous haze is fairly obvious near AE Aurigae and the 7.7-magnitude, pale-yellow star 8′ to its northwest. If you have a hydrogen-beta filter, IC 405 is one of the relatively rare objects you can add to its trophy case — but a narrowband filter can also be of help. In my

SEAN WALKER / S&T

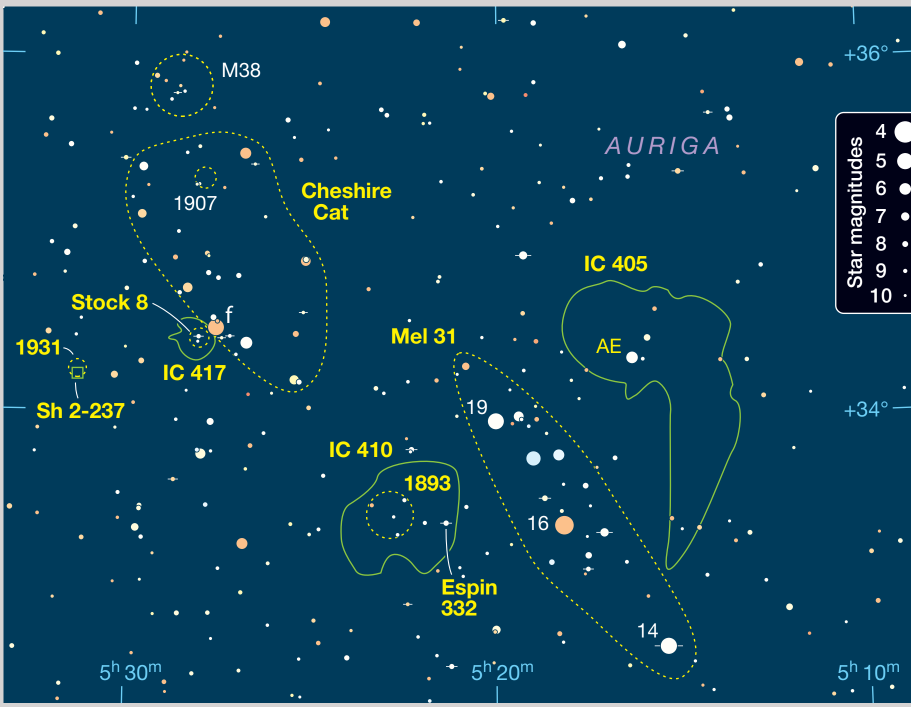
▶ The nebula IC 410 and its embedded star cluster NGC 1893 are gorgeous in this color image. The author saw the southern Tadpole (Simeis 130) through her 10-inch reflector, but not the fainter northern Tadpole, Simeis 129.

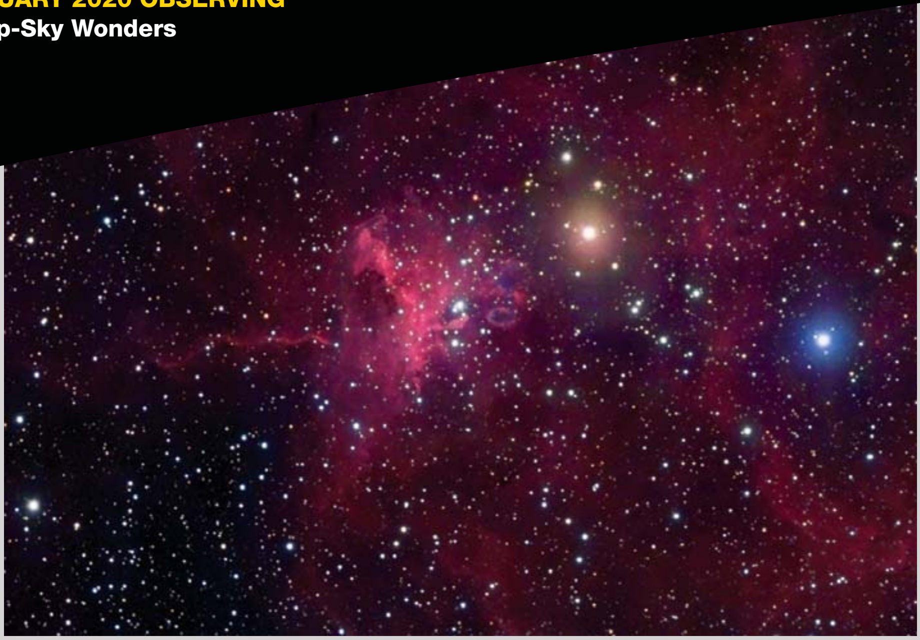
mirror-imaged view, I faintly see a 1½° J of nebulosity, especially when I scan east-west across it. The J dangles upside down in the sky, but only the bright region in its hook forms the Flaming Star Nebula.

Now lets move eastward to the 5th-magnitude star Phi (φ) Aurigae. Phi gleams in the smile of a 1.5° asterism that New York amateur Ben Cacace dubbed the **Cheshire Cat**. There are six stars in the wide grin, tipped north-northeast, and two eye stars to their west. Phi and the northern eye both glow yellow-orange in my 105-mm scope at 17×. Since the vanishing cat's dimmest star is magnitude 6.9, the asterism is an easy target for most binoculars.

The opulent open cluster Messier 38 decorates the northern corner of the Cheshire Cat's mouth. Splashy M38 and nearby, powdery NGC 1907 were featured in Ken Hewitt-White's "A Chariot Full of Clusters" (*S&T:* Mar. 2008, p. 55).

Off the lip of the Cheshire Cat, right next to Phi Aurigae, the open cluster **Stock 8** is wrapped in the nebulous cloak of **IC 417**. Through my 105-mm refractor at 47×, they appear as a hazy patch with several faint stars, the brightest one shining at 9th magnitude near the center. This star becomes a double (Σ707) at 76×, with the 11th-magnitude companion 18″ southeast of





▲ Open cluster Stock 8, together with the surrounding emission nebula IC 417, is visible in small telescopes under moderately dark skies.
▶ Sharpless 2-237 is so bright that it almost hides NGC 1931, its embedded star cluster.

the primary. The sparse cluster shows 11 stars and is elongated north-south about 6½′, while the nebula is a little longer and extends farther east of the cluster than west.

Stock 8 looks much richer when viewed through my 10-inch reflector at 118×. I see 35 to 40 moderately bright stars loosely strewn across 11′ of sky. IC 417 engulfs the more crowded regions of the cluster and covers about 8′.

Viewed through my little refractor at 47×, IC 417 shares the field with the smaller but much more obvious nebula **Sharpless 2-237**. The 11th-magnitude star nestled in its heart is almost overpowered by the glow of the nebula, but it shows up much better when I increase the power to 87×. It sits at the northwest corner of a 3½′ box that it forms with three dimmer stars. The nebula is very bright close to its star and fades sharply outward to a diameter of perhaps 3½′.

NGC 1931, the cluster associated with Sh 2-237, begins to emerge in my 10-inch scope at high power. The bright star is shown to be a quadruple, with the three brightest members arranged in a tiny triangle and the fourth component to their northeast. Several additional stars straggle south through west-southwest of the group.

The three clusters highlighted here are among the youngest visible in the sky. Their eldest members are a mere 4 million years old, and starbirth within them is still ongoing.

■ Contributing Editor **SUE FRENCH** wrote this column for the January 2010 issue of *Sky & Telescope*.

Chariot of Stars, Clouds of Fire

Object	Type	Mag(v)	Size/Sep	RA	Dec.
Melotte 31	Asterism	—	135′	$5^h 18.2^m$	+33° 22′
IC 410 / NGC 1893	Nebula / cluster	7.0	40′ × 30′	$5^h 22.6^m$	+33° 22′
Espin 332	Double star	8.9, 9.5	14.8″	$5^h 21.4^m$	+33° 23′
AE Aurigae	Bright Star	6	—	$5^h 16.3^m$	+34° 18′
IC 405	Bright nebula	—	30′ × 20′	$5^h 16.6^m$	+34° 25′
Cheshire Cat	Asterism	3.9	90′	$5^h 27.3^m$	+34° 52′
Stock 8 / IC 417	Cluster / nebula	—	15′	$5^h 28.1^m$	+34° 25′
Sh 2-237 / NGC 1931	Nebula / cluster	—	7′	$5^h 31.4^m$	+34° 15′

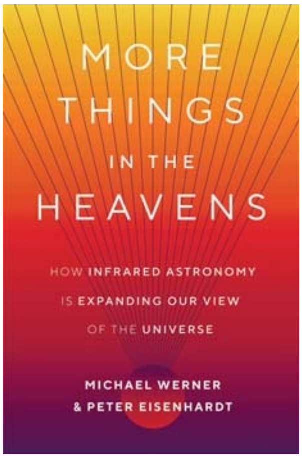
Angular sizes and separations are from recent catalogs. Visually, an object's size is often smaller than the cataloged value and varies according to the aperture and magnification of the viewing instrument. Right ascension and declination are for equinox 2000.0.

IC 417: SEAN WALKER / *S&T*; NGC 1931: MASIL IMAGING TEAM

Though She Be But Little, She Is Fierce

MORE THINGS IN THE HEAVENS

Michael Werner & Peter Eisenhardt
Princeton University Press, 2019
304 pages, ISBN 9780691175546
$35.00, hardcover.



SHAKESPEARE AFICIONADOS will recognize the title of Mike Werner and Peter Eisenhardt's new book as part of a famous line in *Hamlet* but may not immediately grasp what the book is about. The subtitle, "How Infrared Astronomy Is Expanding Our View of the Universe," is apt but incomplete. True, the book explores how observations at wavelengths longer than those of red light have revealed previously unknown celestial objects and phenomena, but the real focus of the story is NASA's Spitzer Space Telescope, which isn't mentioned on the cover at all.

I suspect this has something to do with Spitzer's living in the shadow of the Hubble Space Telescope, which is not just a household name but a cultural icon. If so, I hope this book will help Spitzer become better known, because the less famous orbiting observatory has transformed our understanding of planets, stars, and galaxies as fundamentally — if not as visibly (pun intended) — as Hubble. *More Things in the Heavens* makes this evident with well-written text and abundant color photos and illustrations accompanied by good, clear captions. The book is well edited and is printed on nice paper, but if you prefer digital you can download the ebook (ISBN 9780691191966), which will save you about $15.

Spitzer is a lot smaller than Hubble, sporting only an 85-centimeter-diameter mirror compared with Hubble's 2.4 meters. But what Spitzer lacks in aperture it more than makes up for in other ways. Hence the title of this review, also from Shakespeare (this time from *A Midsummer Night's Dream*) and also quoted in the book.

Werner and Eisenhardt, both at the Jet Propulsion Laboratory, have been involved with Spitzer for decades and know their subject intimately. (Werner is coauthor of the article on page 18.) After a whirlwind tour of the universe as seen in the infrared, they cover in detail every aspect of astronomy that Spitzer has touched, giving due credit to the scientists whose work they describe and, thankfully, presenting data in graphs that have been redrawn for a popular audience rather than being lifted straight from the pages of professional journals.

The authors are at their most enthusiastic when explaining research that wasn't even on the drawing board when Spitzer was conceived, such as studies of exoplanet atmospheres and active galaxies in the first billion years of the universe's existence. Some of their most beautifully written explanations of the science are contained in notes at the end of the book; I'd have preferred to see those in boxes adjacent to the relevant text so that more people would read them.

Two appendixes cover Spitzer's history from conception (as a telescope mounted in the Space Shuttle's cargo bay) to launch, as well as technical details of the spacecraft, its science instruments, the observing strategy, and the solar orbit that keeps the telescope and detectors at the icy temperatures required to maximize their sensitivity. Like so many NASA missions, Spitzer took decades to go from idea to reality, and I remember the journey well. When I was a graduate student at the Harvard-Smithsonian Center for Astrophysics in the 1980s, I helped write the proposal for what ultimately became Spitzer's workhorse instrument, the Infrared Array Camera (IRAC).

The timing of *More Things* is auspicious but slightly sad: Spitzer is scheduled to be decommissioned on January 30th. But don't be discouraged! Its data archive will be mined for years by a new generation of researchers, and the much larger James Webb Space Telescope, optimized for infrared observations, is on track for launch in 2021. The expansion of the universe is accelerating, and the expansion of our scientific understanding, thanks to infrared astronomy, is about to accelerate too!

■ Former *S&T* editor in chief **RICK FIENBERG** is press officer of the American Astronomical Society. He worked on one of the first digital cameras for infrared astronomy, a device that boasted a whopping 256 pixels.

Fishing in Pisces

The Pisces Cloud contains many faint galaxies — be prepared to probe deep to spot them.

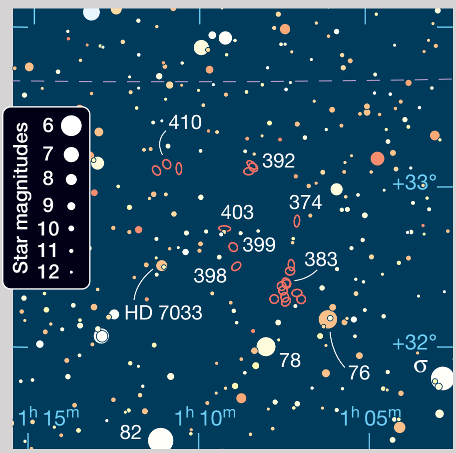
About 230 million light-years from Earth, on the edge of the Perseus-Pisces Supercluster, lies a string of elliptical galaxies known as the Pisces Cloud (or the Pisces Chain). Hovering around 13th magnitude, the brightest members of this group are accessible to an 8-inch telescope. Owners of large-aperture scopes might track down more than 50 galaxies within 1° of the group's brightest member, so this is a good area in which to test your mettle and push your optics.

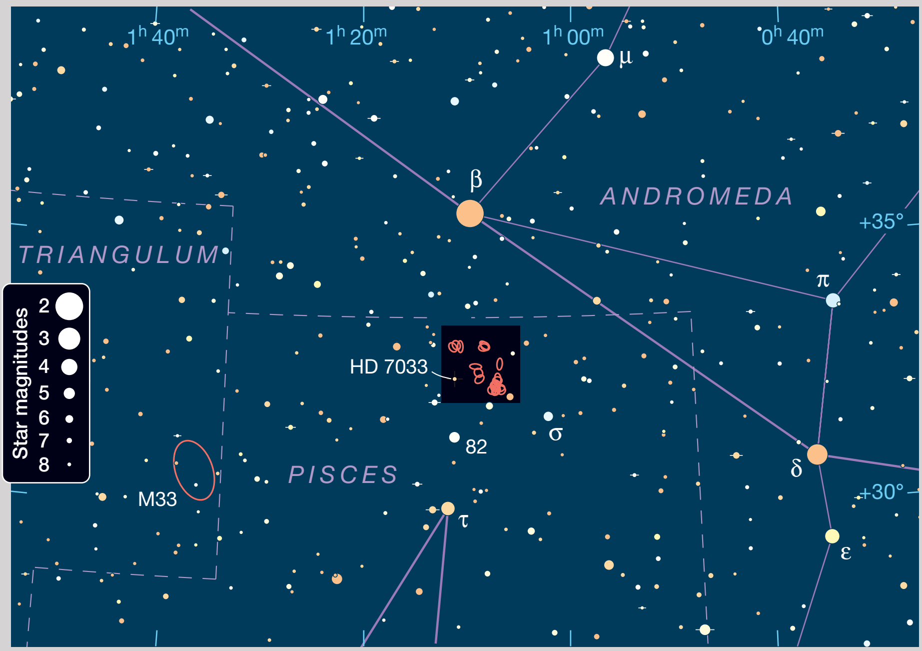
One of the things I find most intriguing about deep-sky observing is the sense of retracing the steps of the great visual astronomers of the past. This group of galaxies has an interesting history that begins on September 12, 1784, with William Herschel at Datchet in Berkshire, England. Herschel's Sweep 268 with the "large 20-foot" (18.7-inch aperture) reflector encompassed six objects in the area and included the brightest member of the group, **NGC 383**.

NGC 383 is a *radio galaxy*, an active galaxy that is very luminous at radio wavelengths. The core of the galaxy harbors a supermassive black hole and is the site of intense activity that acts as a launchpad for powerful jets. When these high-speed jets interact with the intergalactic medium, they give rise to bright radio emission via the *synchrotron process* (when relativistic charged particles, usually electrons, spiral in a magnetic field). However, none of this is visible through the eyepiece of a telescope. Instead, we see only a slightly elongated object with a nearly round bright core. Herschel assigned NGC 383 to his group II (faint nebulae).

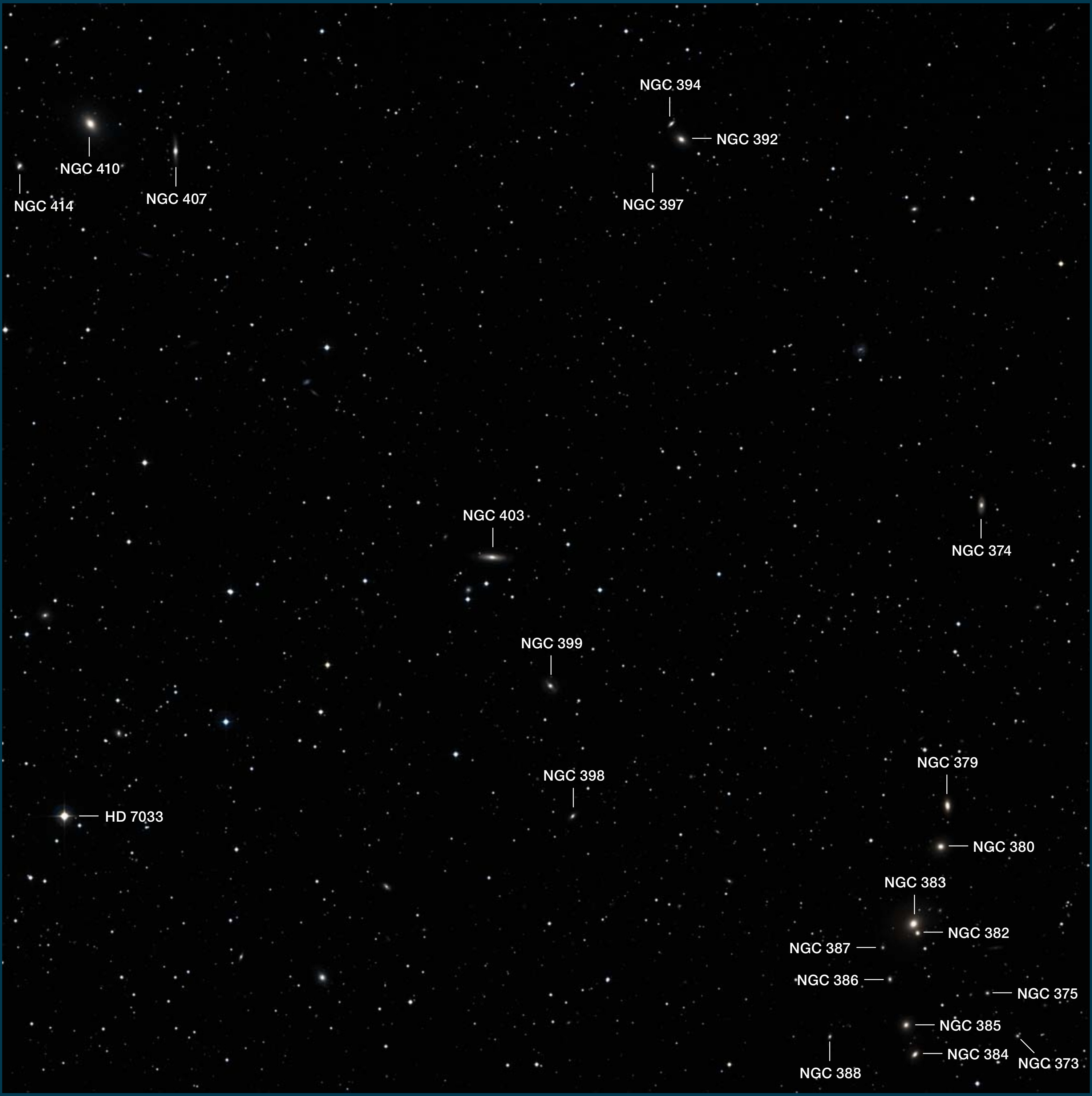
Herschel didn't record as a separate object NGC 383's small, round companion, **NGC 382**, about 30″ southwest of its core. That remained for the second wave of discovery that Irish engineer Bindon Stoney conducted at Birr Castle on November 4, 1850. Using the giant "Leviathan of Parsonstown," the 72-inch reflector built by William Parsons, 3rd Earl of Rosse, Stoney added five more objects to the then-known "nebulae" in the group. Later observations by other Birr Castle observers — Heinrich d'Arrest, Lawrence Parsons (son of William), Guillaume Bigourdan, R. J. Mitchell, Robert Ball, John Dreyer, and Herman Schultz — added another 10 objects to the group by 1886. Edwin Hubble and Milton Humason identified 25 galaxies

▼ **FINDER CHARTS** You'll find the Pisces Cloud in the northern reaches of the constellation that bears its name, northwest of M33, or the Triangulum Galaxy, and south of Beta Andromedae. The box in the finder chart below represents the area portrayed in the image at right. The chart below left shows the positions of the Cloud members in relation to nearby stars.





PISCES CLOUD IMAGE: POSS-II / STSCI / CALTECH / PALOMAR OBSERVATORY



DEEP FISHING Look for a string of what at first glance appears to be five elliptical galaxies to start your perusal of the Pisces Cloud. Upon closer examination, fainter galaxies within and north and east of the string will reveal themselves. Good observing conditions and large aperture will help. The area covered in this image is indicated by the box in the chart at left.

The Pisces Cloud

Object	Type	Surface Brightness	Mag(v)	Size	RA	Dec.
NGC 383	Lenticular	13.0	12.4	1.4′ × 1.4′	$01^h\ 07.4^m$	+32° 25′
NGC 382	Elliptical	12.4	13.2	0.7′ × 0.7′	$01^h\ 07.4^m$	+32° 24′
NGC 384	Lenticular	13.1	13.1	1.1′ × 0.9′	$01^h\ 07.4^m$	+32° 18′
NGC 385	Lenticular	12.9	13.0	1.1′ × 1.0′	$01^h\ 07.5^m$	+32° 19′
NGC 380	Elliptical	13.2	12.5	1.3′ × 1.3′	$01^h\ 07.3^m$	+32° 29′
NGC 379	Lenticular	12.9	12.9	1.4′ × 0.8′	$01^h\ 07.3^m$	+32° 31′
NGC 386	Elliptical	12.6	14.3	0.5′ × 0.4′	$01^h\ 07.5^m$	+32° 22′
NGC 387	Elliptical	13.6	15.5	0.4′ × 0.4′	$01^h\ 07.6^m$	+32° 23′
NGC 392	Lenticular	12.7	12.7	1.2′ × 0.9′	$01^h\ 08.4^m$	+33° 08′
NGC 410	Elliptical	12.7	11.5	2.4′ × 1.3′	$01^h\ 11.0^m$	+33° 09′
NGC 394	Lenticular	12.3	13.8	0.7′ × 0.4′	$01^h\ 08.4^m$	+33° 09′
NGC 397	Elliptical	13.7	14.8	0.7′ × 0.5′	$01^h\ 08.5^m$	+33° 06′
NGC 407	Lenticular	12.8	13.4	1.7′ × 0.4′	$01^h\ 10.6^m$	+33° 08′
NGC 414	Double system	12.9	13.8	0.8′ × 0.6′	$01^h\ 11.3^m$	+33° 07′
NGC 373	Elliptical	13.0	14.9	0.4′ × 0.4′	$01^h\ 07.0^m$	+32° 18′
NGC 375	Elliptical	13.0	14.5	0.5′ × 0.5′	$01^h\ 07.1^m$	+32° 21′
NGC 388	Elliptical	12.5	14.3	0.6′ × 0.3′	$01^h\ 07.8^m$	+32° 19′
NGC 374	Lenticular	12.7	13.4	1.3′ × 0.5′	$01^h\ 07.1^m$	+32° 48′
NGC 403	Lenticular	12.5	12.5	1.9′ × 0.6′	$01^h\ 09.2^m$	+32° 45′
NGC 399	Barred spiral	13.3	13.5	1.1′ × 0.8′	$01^h\ 09.0^m$	+32° 38′
NGC 398	Lenticular	13.4	14.5	0.8′ × 0.5′	$01^h\ 08.9^m$	+32° 31′

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.

as belonging to the Pisces group in their 1931 photographic survey of the area with the 100-inch Hooker telescope at Mount Wilson Observatory.

The galaxy group's popularity as an observing target was no doubt enhanced by its inclusion in Halton Arp's 1966 *Atlas of Peculiar Galaxies*. Arp compiled the catalog using photographs taken at Palomar Observatory with both the 200-inch Hale and the 48-inch Schmidt telescopes in the early 1960s. Listed as the core of the Pisces Cloud is Arp 331, one of several "strings of galaxies" in his catalog — Arp included eight galaxies in this string.

Located a little more than 3° south-southwest of Beta (β) Andromedae, or Mirach, the Pisces Cloud is an interesting stop between the Andromeda (M31) and Triangulum (M33) galaxies. A 10-inch scope will easily show a string of five elliptical galaxies in a roughly north-south line. A closer examination of the brightest object in the middle of that string should reveal its dual nature. This is the aforementioned NGC 383 and its smaller companion, NGC 382.

The galaxies in the Pisces Cloud are nearly all ellipticals or lenticulars and, as such, have little to no readily visible structure. Ellipticals are round or oval and typically have only slight brightness variations to mark their more concentrated centers. Most are composed primarily of old stars, with little or no ongoing star formation. Lenticulars are intermediate between ellipticals and spirals; they're more flattened than ellipticals but lack prominent spiral arms. At the distance of the Pisces Cloud, lenticulars are hardly distinguishable from their elliptical brethren.

The southern end of the string comprises **NGC 384** and **NGC 385**, a similar-looking pair of ellipticals with brighter cores. You may find it curious that Herschel didn't find these, as they can be detected in an 8-inch under optimum conditions. Herschel's innovative sweep method allowed him to systematically survey the sky, but it wasn't without its drawbacks. His method of overlapping sweeps left some gaps. According to Herschel expert and author Wolfgang Steinicke, the method effectively covered only 66% of the sky. Steinicke goes on to point out that Herschel discovered 66% of the objects above his horizon and theoretically detectable in his telescope. This match shows an incredible efficiency, so we must conclude that NGC 384 and NGC 385 just never fell within Herschel's field of view.

The northern end of the string is home to **NGC 380**, which is fairly bright and round with a bright core, and **NGC 379**, which is a little more elongated and a bit brighter overall.

High power should expose a fainter pair of galaxies to the east of the chain, between NGC 383 and NGC 385. **NGC 386** and **NGC 387** are both pretty faint and of similar size. NGC 386 is a little brighter; I need averted vision to see NGC 387 as anything more than stellar, even with a 30-inch telescope.

Herschel discovered three more galaxies on the same sweep as his other Pisces Cloud finds. Two of them, **NGC 392** and **NGC 410**, are considered official members of the Cloud. NGC 392, about 45′ north-northeast of NGC 383, is the brightest in a group of three galaxies. Its companions, **NGC 394** and **NGC 397**, are both rather small and faint. They're easily missed and weren't discovered until 1854 and 1866, respectively, both with the 72-inch at Birr Castle. This small trio is listed as KTG 3 in the *Isolated Triplets of Galaxies* catalog published in 1979 by Valentina Karachentseva and collaborators. NGC 410 forms a pair with **NGC 407** about 5′ to the west-southwest. Herschel described both as extremely faint and very small. NGC 410 is larger and rounder, while NGC 407 is rather elongated and considerably brighter toward the center. A third object about 4′ southeast of NGC 410 and designated **NGC 414** is actually two interacting compact galaxies (PGC 4254 and PGC 93079), but this small, faint spot of nebulosity doesn't reveal its dual nature in the eyepiece.

Three small NGC galaxies flank the southern end of the chain. About 6′ almost due west of NGC 384 is **NGC 373**. **NGC 375** is about the same distance northwest of NGC 385, and **NGC 388** lies 4′ east of NGC 385. All three are small, faint, round, and easily overlooked, often mistaken for stars. I use averted vision to pick them up. I can eventually hold NGC 375 with direct vision, but the other two remain elusive.

Extending the chain from NGC 379 almost due north by about 16.5′, we find **NGC 374**, a 13.4-magnitude lenticular between two 14th-magnitude stars that flank the galaxy to its northeast and southwest. The core is obscured by a foreground star, making it appear stellar.

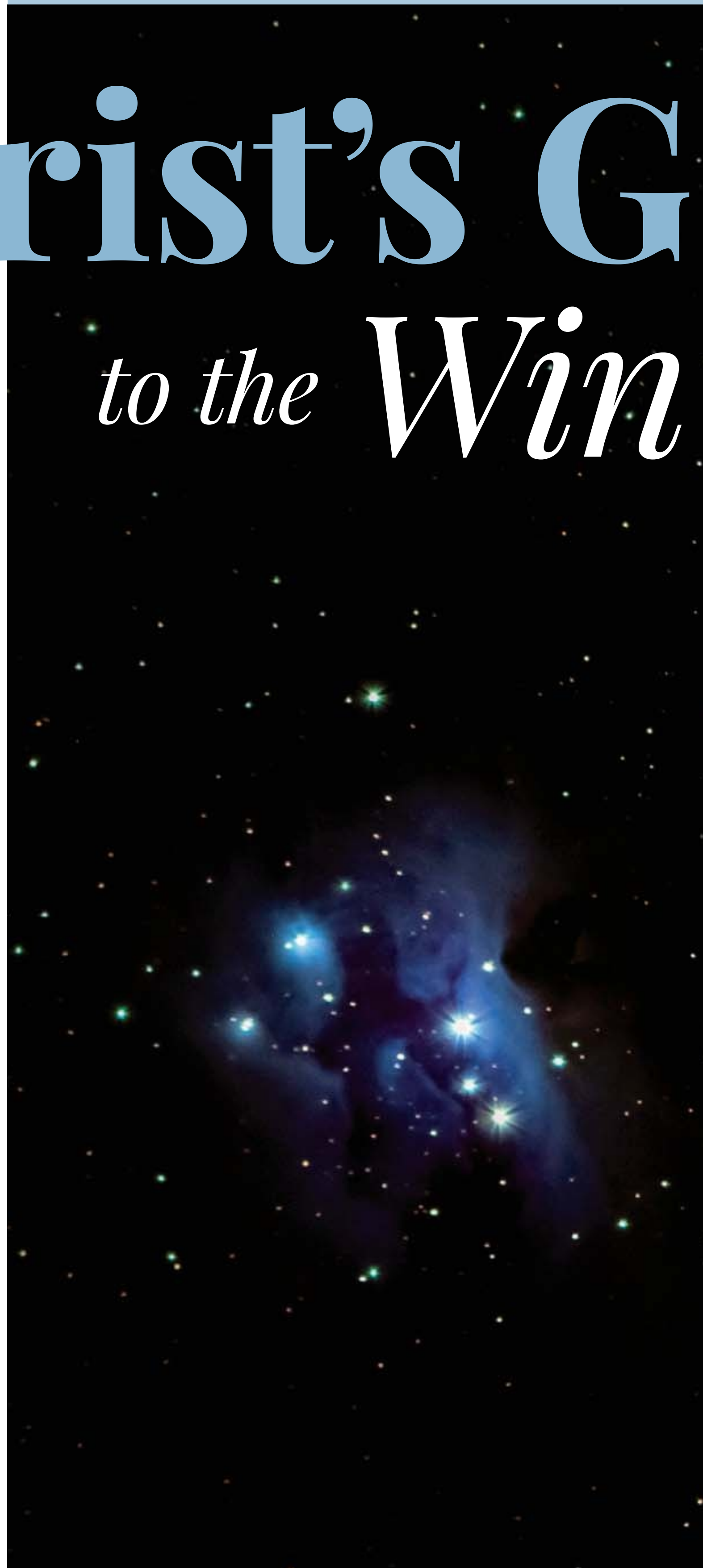
Three more objects complete our survey of NGCs within 1° of the Pisces Cloud's core. **NGC 403** lies about 30′ northeast of NGC 383. It's fairly bright and an easy catch compared to the 15th-magnitude galaxy 2′ to its southeast. It's elongated along the east-west axis and is very much brighter toward the center. About 8′ southwest of NGC 403 is the only spiral on our tour. **NGC 399** is rather faint, of even brightness almost to the core, and devoid of visible spiral structure. Another 7′ farther south is **NGC 398**, a small, round, averted-vision object.

> A fine hunting ground indeed. Part of the fun of exploring galaxy groups like the Pisces Cloud is in the sense of discovery and accomplishment.

The area surrounding NGC 383 contains several non-NGC galaxies that are within range of mid- and large-aperture instruments; my astronomy software identifies 26 non-NGC galaxies brighter than 16th magnitude, and 51 brighter than 17th magnitude within 1° of the group's core. A fine hunting ground indeed. Part of the fun of exploring galaxy groups like the Pisces Cloud is in the sense of discovery and accomplishment. You have the chance to test your skills against the famous observers who went before you. True, you have quite an advantage in knowing in advance that there *are* objects there to find, but still, imagine the pride of retracing their steps and perhaps even besting Herschel and the Birr Castle observers. Think of the bragging rights!

■ Contributing Editor **TED FORTE** enjoys retracing the steps of the great visual observers of the past from his backyard observatory outside of Sierra Vista, Arizona. He can be reached at **tedforte511@gmail.com**.

A Tourist's G to the Win

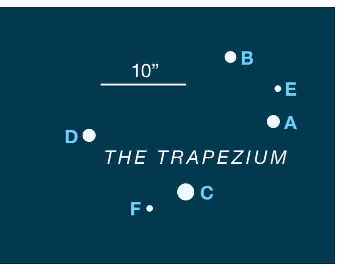


Jerry Oltion's ongoing series of nighttime favorites continues with a selection of winter's splendors.

Winter highlights? There are winter highlights? If you live in the Pacific Northwest [sic], as I do, the very concept may seem oxymoronic. But we do get a few clear nights throughout the winter, and when the clouds roll away and I actually get some sky, I don't waste a minute of it. No tracking down faint fuzzies for me; in the wintertime I go for the gusto, filling my night with the biggest, boldest, brightest, and most beautiful targets I can find.

Here are some of those glorious targets guaranteed not to waste your time.

First off, of course, is **M42**, the famous Orion Nebula. If you can only look at one item in the winter sky, this is it. The middle of the sword hanging from Orion's belt, this emission nebula is arguably the best one in the sky. It's visible by naked eye, although it just looks like a fuzzy star, but in binoculars or any telescope it's absolutely stunning. Big sweeping arcs of glowing gas and dust stretch outward and curve around like two hands cupping a precious jewel. That jewel is the **Trapezium**, a tight group of four stars, named A through D as shown at left. C, the brightest, is the powerhouse that makes the entire nebula glow.



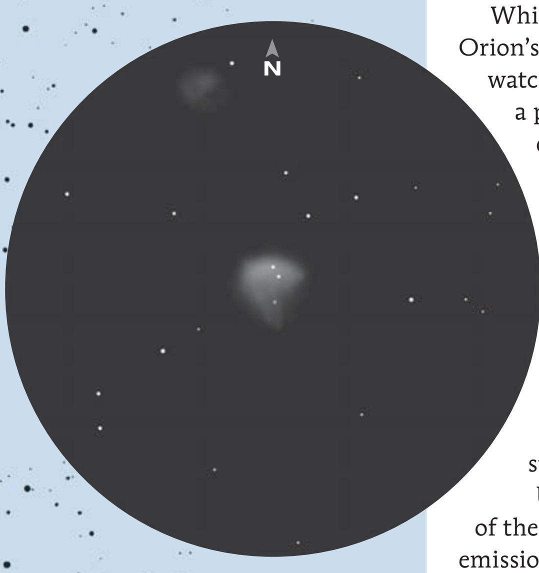
You can (and should!) spend hours studying the Orion Nebula. At low power you can see its overall structure as the birthplace of hundreds of brand-new stars (indeed stars are still forming there), and as you crank up the power you can zoom in on more and more structure within the nebula. A nebula filter (O III, Ultra-High Contrast, or even just a skyglow filter) will reveal even more.

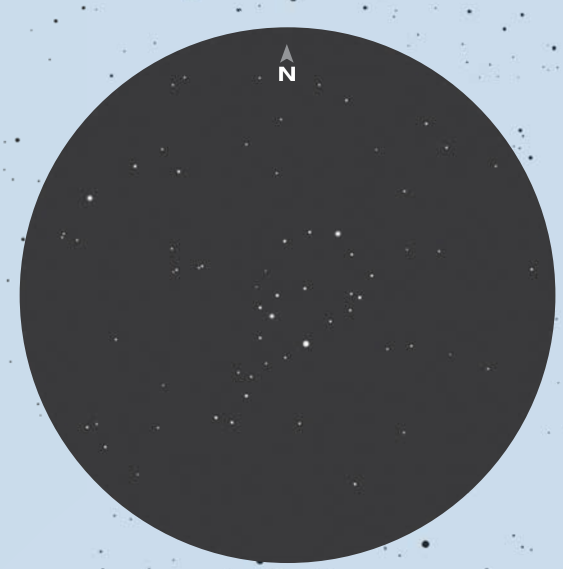
At high power (and unfiltered) the Trapezium gives up two more stars, the first relatively easy between the two that make up the narrow end of the skewed trapezoid, and the other much more difficult just outboard of the dazzling C star. You need good seeing and high magnification for this, but picking out the E and F stars of the Trapezium is always a kick.

uide
ter Highlights

WINTER'S SPLENDORS The iconic Orion Nebula, or M42, is a favorite and for many is probably one of the first nonstellar targets spotted in the telescope.

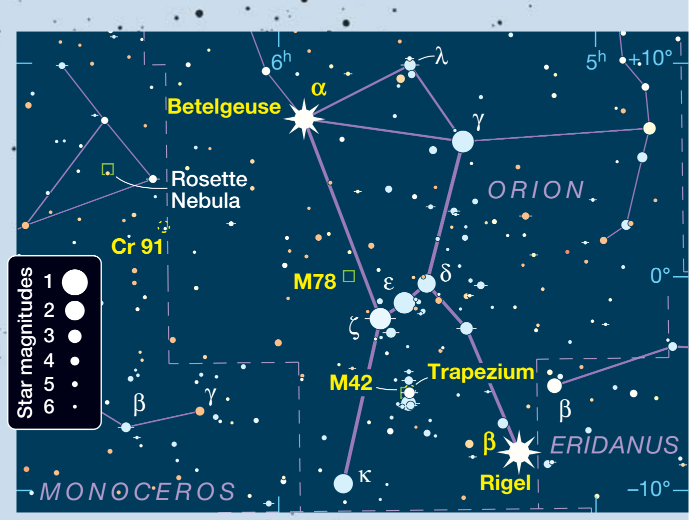
BILL BASHAM





▲ **BY ORION'S SIDE** M78 is one of the brightest reflection nebulae in the sky. FOV=35′

◀ **SMALL ANALEMMA** Not as complete as a proper solar analemma, Collinder 91 nevertheless forms a recognizable figure 8 in the sky. FOV=75′



While you're in the neighborhood, check out **Rigel**, Orion's lower right kneecap. It's big and bright — and fun to watch twinkle. When it's near the horizon, Rigel looks like a police car flashing red and blue. Turbulent air acts like dozens of prisms, splitting the starlight into its spectrum and flashing different wavelengths at you at random. In a telescope you'd swear the mothership was making a dive straight for you, lights ablaze.

When Rigel rises high enough to steady out, crank up the power and look for its binary companion less than 10″ away. The difference in magnitude is pretty extreme (0.3 and 6.8) and their separation is pretty tight, so the secondary will be just outside the glare of the primary. But if the seeing is relatively steady it's usually there as a distinct separate star.

Up alongside Orion's left side you'll find **M78**, one of the brightest reflection nebulae in the sky. M42 is an emission nebula, its gas glowing like a neon light, but M78 is simply reflecting starlight. You can see the two stars that are casting most of M78's light; they're off-center to the north end of the nebula. That end is the brightest, and the rest of the nebula trails away to the south in a cone shape that gives it a cometary appearance. There's a third, dimmer star near the nebula's southern edge. Stars are forming within this nebula, too. Most are still hidden within the gas and dust, but infrared studies have discovered nearly 200 young stars in several still-developing clusters.

As long as you're still in the neighborhood, check out Barnard 33, the Horsehead Nebula. Ha ha ha! Just checking to see if you were paying attention. The Horsehead Nebula is big and beautiful, but it's neither bold nor bright, and unless you've got a 12-inch scope or greater and dark, dark, really dark skies — and a hydrogen-beta filter — it's not likely to show up.

Collinder 91, on the other hand, stands out nicely about 9° to the east of M78. Not far from the Rosette Nebula (which you should also check out if you have dark skies), Collinder 91 is a fairly bright open cluster that also has the neat added property of having its stars arranged in a pattern that suggests something astronomical: an analemma.

What's an analemma? It's the pattern the Sun makes in the sky if you photograph it at the same time of day for an entire year. The Sun climbs up and down with the seasons due to Earth's axial tilt, but it also lags left and right as the Earth speeds up and slows down in its elliptical orbit. The combined effect of these two factors makes a big bowling-pin-shaped figure eight in the sky.

Collinder 91's major stars are arranged in just such a pattern. The narrow end of the analemma doesn't quite close the loop — it looks like the photographer still has a few weeks left to go — but the rest of it makes a remarkably good figure

JERRY OLTION (4)

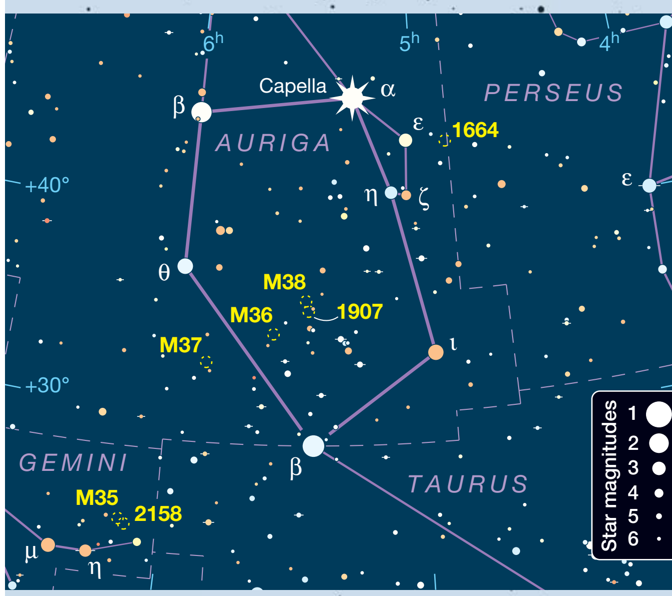
eight. It's a little more than ½° long, so it's best viewed at low power. I can even make it out in binoculars. I can also see it as an ampersand (&), or a musical treble clef, but I think it's coolest to think of it as an analemma.

The M-Thirty-Somethings are also reliable winter spectacles. I'm talking about the string of four open clusters that extend from the feet of Gemini into the circle of Auriga. They start with **M35** at Castor's toe and run through **M37** and **M36** to **M38** in the center of Auriga. (Yes, they're out of order. Talk to Charles Messier about that.) Of the four, my favorite is M35 because of little **NGC 2158** next to it. Both are open clusters, but while M35 is big and showy, NGC 2158 is much smaller and fainter. Seeing them both in the same field really provides a 3D effect, as NGC 2158 recedes way into the background. M38 also has a little cluster, **NGC 1907**, next to it.

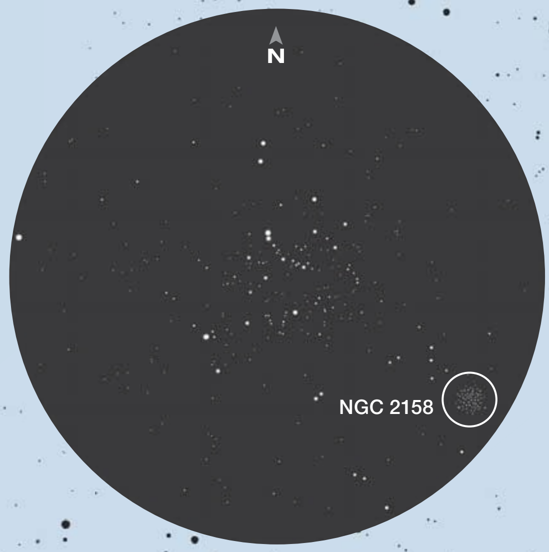
Moving on through Auriga to the west brings you to **NGC 1664**, also known as the Kite Cluster. This open cluster sports a loose diamond of stars that stands out well from the background, and an equally visible long tail that makes it look amazingly like a kite. There's even a smaller line of stars opposite the tail that looks like the kite string, and to the northwest there's a straight line of stars that could be the ground if the kite is flying along sideways. This is a must-see cluster any night it's up. I can also see this one as a manta ray gliding along over the ocean bottom.

Farther to the west of Auriga lies a wonderful naked-eye spectacle: the **Alpha Persei Cluster**, also known as Collinder 39 or Melotte 20. The constellation of Perseus is dominated by a wide scattering of blue-white stars, the brightest of which — Alpha (α) Persei itself, also known as Mirfak — anchors the center of the constellation. What's neat about this group is that it's a true cluster of stars; it's just so close to us (600 light-years) and it's old enough that it's scattered across several degrees of sky. Most of the stars you see here were born together 50 million years ago and are still moving through space together. This cluster is far too wide to appreciate even in binoculars; just lean back and admire this one by naked eye.

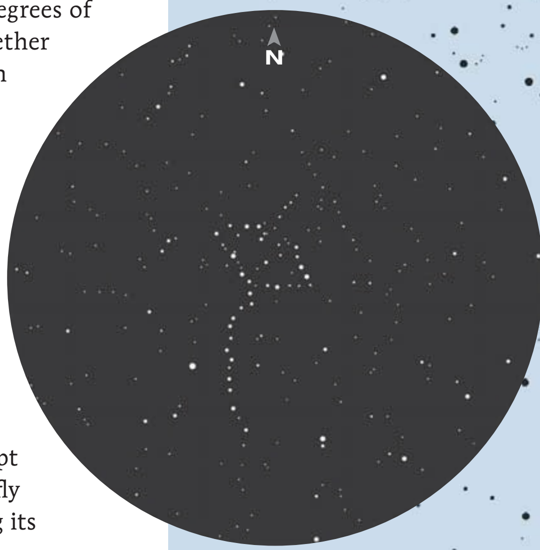
Moving farther north, just inside the middle bend of Cassiopeia's W, look for **NGC 457**, the Dragonfly Cluster, a gangly splotch of stars streaming away from two bright luminaries. This is one of those objects that always elicits an "Oh, wow!" at star parties, and it never fails to make me smile when I look at it myself. It's a gorgeous dragonfly fluttering around out there in space, with two big glowing eyes and wide-swept wings that sparkle just like the wings of a dragonfly in bright sunlight. This cluster also counts among its



▶ AT THE FOOT OF THE TWINS
M35 is bright and showy with a distinctive arc of stars in the middle, plus it has a fainter, more delicate companion, NGC 2158, to the southwest. FOV=1°



▼ CAN YOU SPOT THE KITE?
NGC 1664, the Kite Cluster, really does look like a kite swooping through the Milky Way. FOV=30′



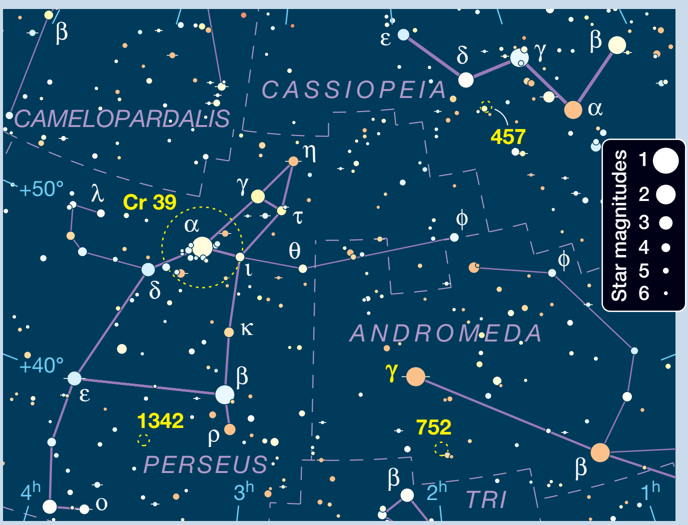
nicknames the Owl, the E.T., the Kachina Doll, and several others. Whatever you call it, you won't forget this one.

Moving back to the south of the Alpha Persei Cluster, look for **NGC 1342**, a loose, coarse, bright (magnitude 6.7) open cluster of about 60 stars elongated in an east-west orientation. I call this one the "Chipmunk Cluster" for reasons that will be obvious when you see it. It looks just like a chipmunk scampering out of the Milky Way right into your telescope. I'm sure this cluster is guaranteed to put a smile on your face, too. It's about ¼° across, so it looks good at low to medium power.

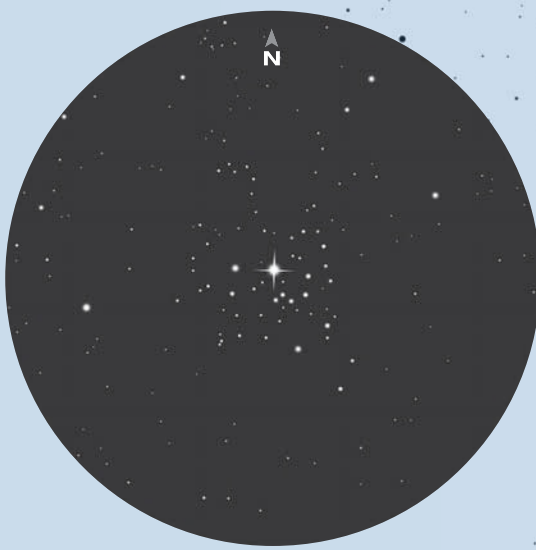
Farther to the west lies **Almach**, Gamma (γ) Andromedae. Almach is one of the prettiest doubles in the sky. It's a mini-Albireo, with a bright gold primary and a somewhat dimmer, bluer companion. Almach's two components' magnitudes are similar enough (2.3 and 5.0) and they're separated by enough distance (about 10″) that they're an easy split in almost any telescope. The colors are vivid enough to stand out under any conditions, even bad city skyglow.

Just 5° south of Almach lies a little-observed but quite nice open cluster, **NGC 752**. Also known as Caldwell 28, this is a bright, sparse, and very large open cluster more than 1° across. It's probably best in binoculars, but it's fun to cruise around in with a telescope to look at its many star chains, mini-clusters within the larger cluster, and doubles.

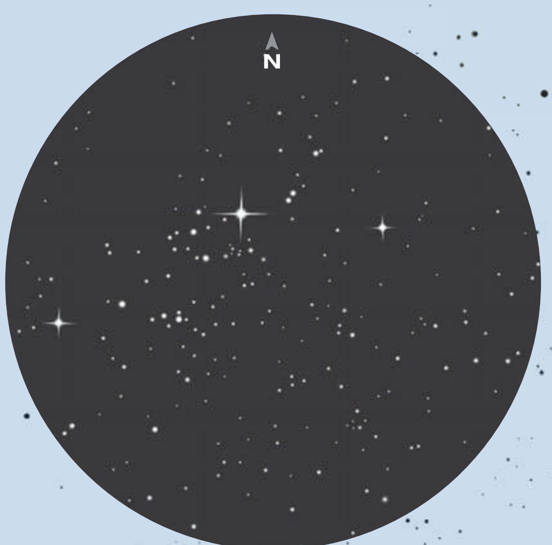
If you're going through these objects in order, things have moved a ways to the west now, and a few more gems are rising high enough in the southeast to enjoy. Let's drop all the way back down toward Orion, but skip off to the left of Canis Major, just above the rump of the dog, to **NGC 2362**. This is the Tau Canis Majoris Cluster, so named for the single bright star, Tau (τ) Canis Majoris, that dominates all the rest. Tau is assumed to be a true cluster star, which,

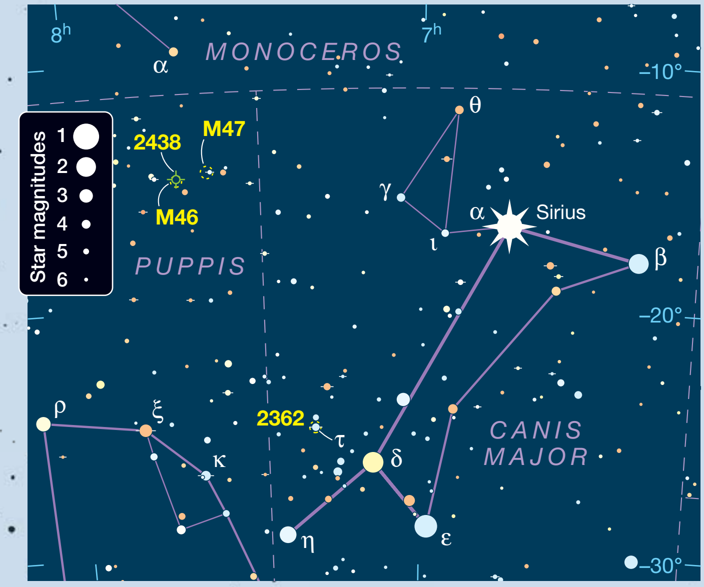


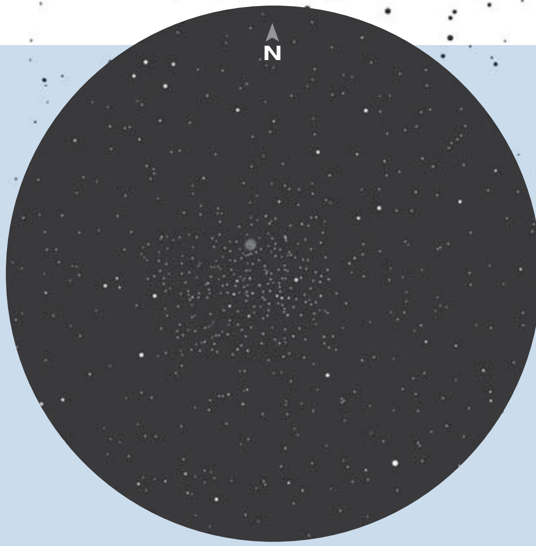
▼ **BRIGHT STAR AMONG MANY JEWELS** NGC 2362 is dominated by Tau Canis Majoris, a star possibly more than 100,000 times brighter than the Sun. FOV=20′



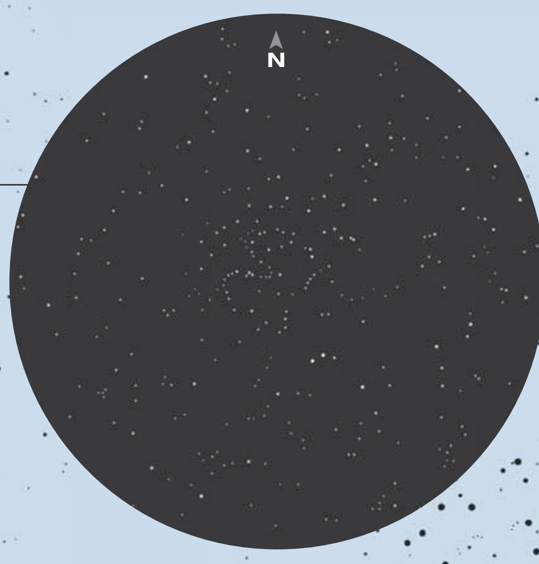
▼ **LARGE CLUSTER** The Alpha Persei Cluster is one of the closest and largest open clusters in the sky. This is too big for a telescope; enjoy it by naked eye. FOV=9°





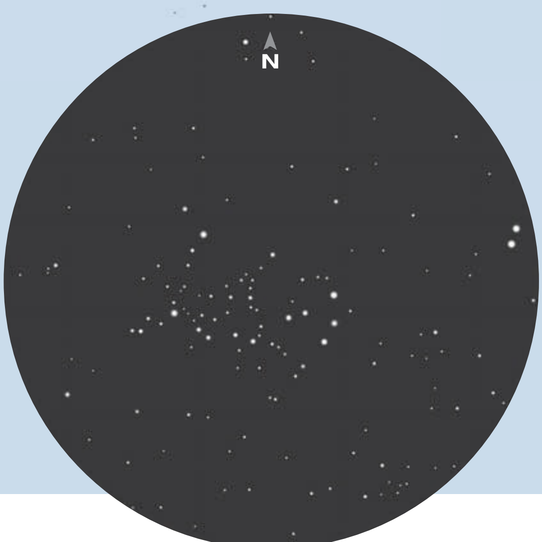


▲ **COMES WITH A BONUS** M46 is beautiful in its own right, but the planetary nebula in the foreground makes it a must-see object. FOV=75′



▶ **PRETTY IN BINOCULARS** NGC 752 boasts several gently curving arcs of stars. FOV=2°

▲ **OWL, E.T., OR DRAGONFLY?** To me, NGC 457 resembles a dragonfly with its two bright eyes and outstretched wings and body. What do you see? FOV=40′



◀ **NESTLED IN PERSEUS** I call NGC 1342 the Chipmunk Cluster for reasons that will be obvious when you flip the page around to give you the telescope view. FOV=40′

JERRY OLTION (6)

compared to the others, makes it very bright indeed, more than 100,000 times brighter than the Sun. The cluster itself is pretty, too, with a loose scattering of relatively bright stars surrounding the central luminary. Many of these stars are intrinsically bright, hot *O*- and *B*-type stars, which means they're relatively young (around 5 million years). Indeed, this is one of the youngest known clusters.

A little higher and to the east you'll find one of my favorite open clusters of all: **M46**. M46 is a beautiful dusting of delicate stars of magnitudes 10–13, but it comes with a bonus Easter egg: a planetary nebula directly in line with the cluster. The planetary nebula, **NGC 2438**, is relatively large and easy to spot under dark sky, and one of the cluster stars shines through to masquerade as the central star (which isn't visible itself in a normal-sized amateur scope).

The cluster stands out well in binoculars and is best appreciated at low power in a telescope . . . until you zoom in and see how many more stars appear. This is an eye-pleaser at any magnification, in any aperture. In fact, it's just visible to the naked eye under a dark sky.

While you're in the neighborhood, check out **M47**, a larger and coarser cluster about 1° to the west. It's close enough to fit in the same binocular field as M46.

You've probably noticed by now that the majority of the big, bold, bright, and beautiful objects of winter are open clusters. Why is that? Because in the winter we're looking outward toward the rim of the Milky Way, right down the length of the Orion Spur in which we live and into the Perseus Arm, both of which are full of clusters. Why no globular clusters? Because those hang out closer to the core of the galaxy, which is visible in the summer. Look for another article in six months dealing with some of those.

■ Contributing Editor **JERRY OLTION** enjoys pareidolia, as you can tell by the names he gives open clusters. Contact Jerry at **j.oltion@gmail.com**.

FURTHER READING: For more "big, bold, bright, and beautiful" targets, see Jerry Oltion's spring and fall collections in the May 2018 and October 2018 issues, respectively.

Winter's Splendors

Object	Designation	Type	Mag(v)	Size/Sep	RA	Dec.
Orion Nebula	M42	Emission nebula	4.0	65′ × 60′	$05^h\ 35.4^m$	–05° 27′
Trapezium	Theta^1 Orionis	Open cluster	4.7	18″	$05^h\ 35.3^m$	–05° 23′
Rigel	Beta Orionis	Double star	0.3, 6.8	9.4″	$05^h\ 14.5^m$	–08° 12′
	M78	Reflection nebula	8.3	8′ × 6′	$05^h\ 46.7^m$	+00° 03′
Analemma Cluster	Collinder 91	Open cluster	6.4	14′	$06^h\ 21.6^m$	+02° 20′
	M35	Open cluster	5.1	25′	$06^h\ 09.0^m$	+24° 21′
	NGC 2158	Open cluster	8.6	5′	$06^h\ 07.4^m$	+24° 06′
	M37	Open cluster	5.6	15′	$05^h\ 52.3^m$	+32° 33′
	M36	Open cluster	6.0	10′	$05^h\ 36.3^m$	+34° 08′
	M38	Open cluster	6.4	15′	$05^h\ 28.7^m$	+35° 51′
	NGC 1907	Open cluster	8.2	5′	$05^h\ 28.1^m$	+35° 19′
Kite Cluster	NGC 1664	Open cluster	7.6	18′	$04^h\ 51.1^m$	+43° 41′
Alpha Persei Cluster	Collinder 39	Open cluster	2.3	5°	$03^h\ 24.3^m$	+49° 52′
Dragonfly Cluster	NGC 457	Open cluster	6.4	20′	$01^h\ 19.5^m$	+58° 17′
Chipmunk Cluster	NGC 1342	Open cluster	6.7	17′	$03^h\ 31.7^m$	+37° 22′
Almach	Gamma Andromedae	Double star	2.3, 5.0	9.7″	$02^h\ 03.9^m$	+42° 20′
	NGC 752	Open cluster	5.7	75′	$01^h\ 57.6^m$	+37° 50′
Tau Canis Majoris Cluster	NGC 2362	Open cluster	3.8	6′	$07^h\ 18.7^m$	–24° 57′
	M46	Open cluster	6.1	20′	$07^h\ 41.8^m$	–14° 49′
	NGC 2438	Planetary nebula	10.8	1.2′	$07^h\ 41.8^m$	–14° 44′
	M47	Open cluster	4.4	25′	$07^h\ 36.6^m$	–14° 29′

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.

Meade's LX85 ACF

This new SCT package offers performance and portability at an attractive price.

▲ Meade's new LX85 mid-weight German equatorial Go To mount is offered with a variety of optical tube assemblies. We tested the mount paired with the 8-inch Advanced Coma-Free Schmidt-Cassegrain telescope seen above.

LX85 Series Telescope – 8-inch ACF

U.S. Price: $799 (mount)
$1,799 (with 8-inch ACF OTA)
meade.com

What We Like

Good pointing accuracy

Excellent optics

What We Don't Like

No power cable included

Insufficient user manual

AMONG THE MOST POPULAR telescope mounts today is the medium-capacity, computerized German equatorial mount (GEM). There are several reasons why, including their reasonable cost, good payload capacity, and general versatility — a solid equatorial mount is useful for a wide variety of optical tube assemblies. In the past Meade has produced several GEMs in this range, but the LX85 is the first new one in years, so I was interested to test its performance when paired with Meade's latest 8-inch Advanced Coma-Free (ACF) Schmidt-Cassegrain telescope.

The LX85 arrived in two large boxes. One contained the equatorial head, a 12-pound counterweight, a tripod with 2-inch diameter steel legs, the AudioStar hand controller, a compass, a CD with Meade's AutoStar Suite software, and a printed manual. The other box held the 8-inch ACF tube assembly and 8 × 50-mm finderscope, as well as the visual back, a 1¼-inch mirror star diagonal, and 25- and 9.7-mm Plössl eyepieces.

Assembling the LX85 mount and tripod is a simple task. The telescope connects to the mount with a Vixen-style dovetail bar and is secured with two bolts. It was never difficult to mount or dismount the relatively light 8-inch telescope, even in the dark.

The mount and telescope combo were, I had to admit, striking in appearance. However, looks aren't everything, and the only true test of a telescope system is under the stars, and that's where I ran into a little snag.

Meade didn't include a power cable with the mount. While I've accumulated several Meade AC power adapters over the years, the connector on this mount is slightly different. None of the cables I had worked. Meade was quick to send me a new power supply. Purchasers should be aware that the optional cable or power supply is a must-have item.

In the Field

One of the most desirable features of a medium-duty mount is its portability. Despite its stated 33-pound payload capacity, the LX85 mount weighs just

ALL PHOTOS BY THE AUTHOR

23 pounds without telescope or counterweight. I had no trouble carrying the assembled LX85 into the backyard. There, I oriented the tripod so the polar axis was pointed roughly north, installed the counterweight and 8-inch SCT, balanced the load, and plugged in the power supply. The large handle on the scope's rear cell is a real help in getting the tube mounted on the LX85.

A German equatorial mount needs to be aligned so its polar axis points to the celestial pole if it is to track the stars accurately. The LX85 doesn't come with a polar-alignment borescope to assist with this alignment, but one is available as an option. Without it, I performed a rough alignment by moving the mount until I could see Polaris centered in the hollow bore of the polar axis.

The next order of business was setting up the mount's Go To pointing. The included manual instructs users to line up pairs of arrow stickers on each of the mount's axes marking the mount's home position. When I tried lining up the marks for the declination axis, however, the locking lever bumped into a motor housing. That didn't seem correct, so I checked the pictures in the manual. It was evident that one of the marks was 180° from its proper position. This wasn't a serious problem since it was easy to align the mount by eye. Moving the tube by hand gave me a pretty good feel for the smooth motion provided by the ball bearings Meade uses on both axes.

Finally, I turned on the power and the AudioStar's red LED display came to life. Before beginning alignment, the LX85, like most Go To mounts, requires the time, date, location, and daylight savings time status to be entered with the hand control. Once input, the AudioStar instructed me to "Press 0 to align, or Mode for menu."

Choosing 0 brought up the Easy Align mode, in which the controller chooses two alignment stars, slews the telescope to them, and then you center the stars in the eyepiece. There are three other alignment options, including 1-Star Align, 2-Star Align, and 3-Star Align. In those modes, the user rather than the computer chooses the alignment stars. While my experience has been that it takes three stars to provide good accuracy over the entire sky, I was interested to see how the LX85 could do with an Easy Alignment.

The computer chose Arcturus in Boötes as its first target and began slewing to the star. When the scope stopped, Arcturus wasn't in the eyepiece but was only a degree or so away. I centered it in the 25-mm eyepiece (80×) using the hand paddle's direction buttons and clicked OK. The second star, Vega, was in the eyepiece when the scope stopped slewing — a good sign.

Pressing the Mode key brought up the Object menu where I entered "Deep Sky" and then "Messier". I input "M13", pressed Enter and Go To, and the telescope began slewing in the correct direction. When it stopped and I put my eye to the eyepiece, there was the globular cluster glowing dimly. Nice! How about M15, over in the east? In moments, the bright little cluster was in view. It was on the edge of the field, but it was there. I was off to a very good start.

Optical Performance

Accurate Go To pointing is great, but what really matters is how good objects look in the eyepiece when you get to them. Meade's ACF optical design less-

The LX85 8-inch ACF package includes an 8 × 50-mm finderscope, 9.7- and 25-mm Plössl eyepieces, a 1¼-inch mirror star diagonal, and a SCT-to-1¼-inch adapter.

▼ *Top:* The 8-inch ACF offers improved edge performance compared with a standard Schmidt-Cassegrain, producing round stars over a wide field. *Bottom:* In addition to the AudioStar input (HBX) and dec cable connection, the RA axis includes an ST-4-compatible autoguider port and an auxiliary port to connect Meade's optional focus motor.

ens the effect of coma, an optical aberration that makes stars toward the edge of the field look blurred and misshapen. Not only were objects sharp at the center of the field of view, but also toward the field edge. Jupiter, for example, showed a wealth of atmospheric detail at 209×, including small features within its belts and zones.

The visibility of details on a planet is a stringent test of the quality of a telescope's optics, and this scope showed itself to have optics as good as those of any 8-inch Schmidt-Cassegrain Telescope I've used. Naturally, deep-sky objects like globular clusters were subdued from my light-polluted backyard, but the ACF's sharp optics helped immensely while resolving star clusters. Messier 13 wasn't just a dim blur; it showed itself to be a globe of tiny stars.

◀ The AudioStar Go To controller includes a 30,000-object database with descriptive presentations and several alignment routines, though only the Easy Align mode is detailed in the manual.

Like most SCTs, the 8-inch ACF focuses by moving the main mirror when the focus knob on the scope's rear cell is turned. There was some focus shift as I moved back and forth through focus, but it was small and I estimated it to be less than 30 arcseconds.

As the evening progressed, I forgot I was working on a product review and just enjoyed myself visiting dozens of deep-sky favorites. At the end of my tour (AudioStar contains a list of ready-made sky tours), I took a break to see if a more accurate polar alignment would also improve the mount's Go To pointing accuracy. After additional tweaking, objects were close to the center of the 25-mm eyepiece at 80× and at least in the field of a 12-mm ocular at 160×. The improvement was enough that I strongly recommend the purchase of the optional polar-alignment scope.

Not only did the LX85 GEM display impressive Go To accuracy, it was also a quiet experience even at its top slewing speed of 4° per second. I was also impressed by the mount as it reached its targets. A rap on the telescope tube produced vibrations that died out in about three seconds, which I consider good.

Comfortable with the LX85's Go To performance, I explored the AudioStar's other features. Foremost is the reason for its name; it contains audio files for many of the objects in its library. When observing M13, for example, I was treated to a presentation on the star cluster. If you tire of hearing these mini lectures, the AudioStar can be set to deliver them on demand instead of automatically.

In addition to the guided tours, the AudioStar hand paddle includes nine selectable slewing speeds, a serial port for communications with a PC, a library of 30,000 targets, and even a built-in red flashlight.

Guiding Performance

Long-exposure deep-sky astrophotography is the most demanding test of a mount. The night I chose to shoot M13 wasn't perfect — there was plenty of haze and a fat Moon hanging in the east. But I wasn't looking to capture a beautiful portrait of the cluster. I just wanted to see how well the LX85 tracks.

After installing Meade's *AutoStar Suite* planetarium simulator on my PC laptop, I connected it to the LX85 using a Meade-compatible serial cable I had on hand. Once a connection was established, I was able to send the telescope to targets using the planetarium software. Clicking on a target onscreen

▼ *Left:* As delivered, lining up the home position markings on the declination axis causes the axis clutch lever to impact the motor box. *Right:* Turning the head 180° to match the illustrations in the manual (and Meade's website) allowed for successful Go To alignment.

would slew the LX85 to it in seconds. In addition to an optional Meade serial cable, for this you'll also need to provide your own USB-to-serial adapter.

Virtually every gear-driven telescope mount has some periodic error that can cause stars to trail during long exposures, and the LX85 is no different in this aspect. To compensate, the LX85 includes an ST-4-compatible autoguider port that permits users to attach a guiding camera. Even without fine-tuning the default settings in my camera's autoguiding software, the LX85 produced round stars in brief 60-second exposures as well as longer 5-minute shots. The periodic error of the mount was smooth and regular, and the guide camera and computer had no problem keeping it under control. Users can reduce tracking error further by recording the guide camera's corrections using the AudioStar's Permanent Periodic Error Correction (PPEC) feature. After recording a few minutes of guiding corrections, they can be stored and played back, reducing overall periodic error as well as the number of corrections necessary during an exposure.

Other than the minor issue of the misplaced home-position sticker, my only disappointment with the LX85 is its user manual. Both the printed and online versions are too brief and don't sufficiently explain all the mount's features. For example, while the LX85 offers several alignment modes, the manual doesn't describe anything other than the Easy Align procedure.

The Meade LX85 is one piece of equipment I was sorry to see go when it was time to return it to the manufacturer. It was a joy to use both for visual observing and photography. It also offers some advantages over similar mounts, particularly its amazing AudioStar computer. The excellent 8-inch ACF SCT was also a good match for the mount. If I were in the market for a medium payload GEM and OTA, I wouldn't hesitate to purchase the Meade LX85 8-inch ACF SCT package.

▲ *Left:* The LX85 includes a compass to help with rough alignment before darkness sets in. *Right:* Meade incorporates the Vixen-style mounting system into the LX85, permitting a wide variety of tube assemblies weighing up to 33 lbs to ride atop the mount.

■ Contributing Editor **ROD MOLLISE** likes the combination of a generous aperture and portability afforded by Schmidt-Cassegrain Telescopes. A great Go To system doesn't hurt either.

▲ While the mount includes a threaded bore to install an optional polar-alignment scope, moderately accurate Go To alignment is still achievable when roughly aligning the mount by sighting Polaris through the open bore.

▲ Five-minute autoguided exposures of the globular cluster M13 in Hercules showed round, sharp stars across the field of the author's APS-format DSLR camera.

Silvering Mirrors

An idea whose time has come . . . again.

WHEN *SKY & TELESCOPE* Contributing Editor Howard Banich decided it was time to recoat the mirror in his 28-inch telescope, he received a rude shock: It would cost about $2,000 to have it aluminized. Connecticut ATM Zane Landers faced a different problem: His local coater moved away, and he was reluctant to subject his pride and joy to the vagaries of the mail.

Both of them arrived at the same conclusion: Silver-coat the mirrors themselves.

Silver-coating used to be the only way it was done. But silvering was a finicky chemical process, and when aluminizing in a vacuum chamber came along, the convenience of having someone else do the coating, and more importantly the increased durability of the coating, quickly supplanted home silvering.

When you're looking at a cool two grand for a coating, though, the equation quickly becomes weighted toward economy. Plus, silver has one distinct advantage: It reflects 98% of the light that hits it, as opposed to aluminum's 89%. Howard and Zane and dozens more like them have begun to reevaluate silver as a coating of choice, and after some initial setbacks they have had some resounding success. You can too!

Silvering a mirror is a multi-part process, but each step is pretty simple. First you strip off the old coating, then you clean the mirror. Next, you sensitize it with a tin-based solution and finally coat it with a two-part silver solution, using two sprayers simultaneously.

Cleaning is by far the most difficult part, but it's not all that hard. You just have to be painstaking. You *must* get every bit of oil, dirt, or anything else off the surface of the glass or the silver won't stick. Howard starts by scrubbing with talcum powder mixed with a little distilled water, then rinses that off with distilled water. Then he uses the glass cleaner from the silvering kit and rinses again. He repeats those two steps, changing into a new pair of disposable gloves before each step. Be sure to never touch the mirror with bare skin, because even freshly washed skin is covered with oils.

The most common mistake is to not clean the sides of the mirror enough. Oils from your fingers as you were handling the mirror will work their way back onto the surface as you rinse off the top. You want the surface and the sides to literally be squeaky clean, and water should sheet off it rather than bead up when you rinse it.

Once you've got the mirror absolutely clean, you sensitize it with the tin solution. This goes on as a spray. You then spray on the two-part silvering solution. Within seconds of beginning the latter, the silver coating starts to form. If all goes as planned, you'll get a smooth, even silver coating.

Your first few attempts will probably not go well. It's hard to believe how much you need to clean the glass in order to get a perfect coating. But it's easy to remove the silver and try again, and each coating costs probably $10-$20 in chemicals. Practice makes perfect.

The expired chemicals aren't particularly dangerous, but you do need to collect and dispose of them properly. Fortunately, the same company that sells home silvering kits (Angel Gilding, **angelgilding.com**) also sells a clay-based cleanup and disposal kit that's safe and easy to use.

There's one last problem with silver: It tarnishes. You can only get a year or so out of an unprotected silver coating before it needs to be recoated. As cheap as the chemicals are, that's no big deal, but an anti-tarnish cloth made for silverware draped over the mirror will extend the life a bit. Even better, the Oregon ScopeWerks, a group of ATMs that Howard and I belong to, has been experimenting with protective coatings

▼ *Left:* The mirror must be squeaky clean before coating it. *Middle:* The two-part silvering solution is applied simultaneously using two sprayers. *Right:* With a little practice, you can achieve a near-perfect silver coating.

CLEANING MIRROR AND NEAR PERFECT COATING: HOWARD BANICH (2); SPRAYING SILVER: JERRY OLTION

▲ Insufficient cleaning will lead to areas that don't coat smoothly. This is most common at the edges of the mirror.

ZANE LANDERS

and have come up with a great one: A product called Midas Tarnish Shield (**https://is.gd/mtshield**) has proven, so far, to protect silver from tarnishing even under extreme exposure to sulfur compounds, which is silver's worst enemy, without noticeably affecting the mirror's figure. Angel Gilding has recently begun selling the same stuff under the name Angel Guard.

Howard and Zane and many others have become devotees of home silvering. As aluminizing and postage costs continue to rise, it seems likely that more and more people will switch back to this venerable old method. If you have a big mirror, or just want to undertake the entire telescope-making experience yourself, you might want to give it a try.

For more information, contact Howard Banich at **hbanich@gmail.com** or Zane Landers at **zdlanders@gmail.com**. Also check out articles by Howard, Peter Pekurar, and Rob Brown that go into much greater depth on the subject on their website at **https://is.gd/silvering**.

■ Contributing Editor **JERRY OLTION** once tried chrome spray paint, but that didn't work so well.

SHARE YOUR INNOVATION

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

◁ COMETARY ENCOUNTER

Gerald Rhemann

Comets ASASSN (C/2018 N2) and 260P/McNaught appear to almost cross tails in this ultra-rare conjunction on the evening of September 8, 2019.

DETAILS: *Astro Systeme Austria ASA 12-inch f/3.6 Newtonian Astrograph with Finger Lakes Instrumentation MicroLine ML16200 CCD camera. Total exposure: 50 minutes through LRGB filters.*

▽ NORTHERN GLOW

Barry Burgess

Ursa Major above and hay bales below frame faint greenish auroral curtains in Hants County, Novia Scotia, on the evening of September 1, 2019.

DETAILS: *Canon EOS 6D DSLR with 20-mm f/1.8 Rokinon lens at f/2.5. Total exposure: 30 seconds at ISO 3200.*

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△▽ **DIFFERENT PERSPECTIVES**

Terry Hancock

While attractive in visible light as seen above, emission and reflection nebulae M20, M8, and NGC 6559 (clockwise from top) appear more like three-dimensional hollows illuminated from within in the narrowband image below.

DETAILS: *Takahashi FSQ-130 astrograph with QHY367C CMOS camera. Total exposure: 10.5 hours (above), 15 hours through narrowband filters (below).*

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MISCELLANEOUS (cont.)

MISCELLANEOUS

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SKY&TELESCOPE

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.

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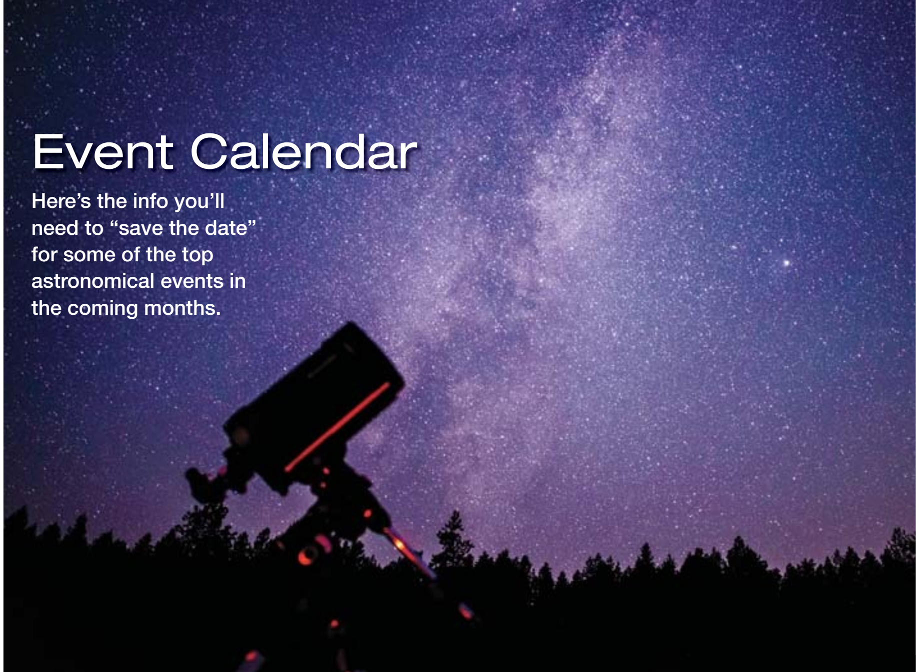


Event Calendar

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

February 17–23
WINTER STAR PARTY
Scout Key, FL
scas.org/winter-star-party

April 4–5
NORTHEAST ASTRONOMY FORUM
Suffern, NY
rocklandastronomy.com/neaf.html

April 22–25
MIDSOUTH STARGAZE
French Camp, MS
rainwaterobservatory.org/events

May 2
ASTRONOMY DAY
Events across North America
https://is.gd/AstronomyDay

May 17–24
TEXAS STAR PARTY
Fort Davis, TX
texasstarparty.org

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

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

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

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

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

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

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

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

September 26
ASTRONOMY DAY
Events across North America
https://is.gd/AstronomyDay

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

SCOTT CARNESS

Greeting the Queen of Night

Two friends linger late at a remote lake to savor a regal display.

BARRY BURGESS

THAT NIGHT, the trees surrounding the shoreline of Hidden Lake looked like an army of crowned kings, standing with arms interlocked. Halted at the water's edge, they seemed to be patiently waiting for a glimpse of a secret and solitary queen, who was about to pass before them. My friend and I also were in attendance, perched high above the treetops on a smooth, rocky bluff that overlooked the lake.

As darkness approached, day reluctantly gave way to night and its accompanying sounds in the surrounding swamps and forest. Not far off, a whip-poorwill called its name, while lonely tree frogs called out for a mate. The long, wide wings of a great blue heron creaked as it flew below us, searching for a place to land and hunt. In the distance, a chorus of pond frogs sang out a warning, perhaps to the heron, telling it their wetland was "too deep, too deep," while the coarse voice of a lone bullfrog croaked, "Go round, go round."

My friend asked, "When was the last time you looked *down* and saw a blue heron flying?"

Night in the wilderness does not descend from the sky, as it does in the city. It creeps out casually and quietly from the dark places where it lurks, waiting patiently for the sunlight to fade away. As night inched forward around us, soft and sudden glows flickered and faded from beneath the wings of busy fireflies.

Then she appeared, rising slowly over the treetops across the lake, as if ascending from some royal coffer out of sight beyond the intervening stand of forest. Perfectly round, timeless, as red as grass is green, enthroned on high, the undisputed queen of the night sky had arrived.

"Shall we howl?" my friend asked.

We only laughed. Perhaps we'd become too civilized to howl at something so powerful and beautiful.

Where the moonlight touched the rippling water below us, the lake came alive. A glimmering pathway of light danced across the surface from the shoreline beneath us, growing brighter as the Moon rose higher. Mosquitoes tested our resolve to stay and watch from our outcrop, even as they were hunted by hungry dragonflies, which in turn were pursued by bats.

> The loon's melancholy cry, unearthly yet unmistakable, only enhanced the harmony of the silent spectacle before us.

A single loon, black-hooded, white-breasted, and checker-backed, paddled into our view, immersed in that beam of celestial light that penetrated deep into Hidden Lake. The loon's melancholy cry, unearthly yet unmistakable, only enhanced the harmony of the silent spectacle before us.

We spoke few words, preferring the company of our private thoughts as the moonlight reached deep into new crannies in the rockface below.

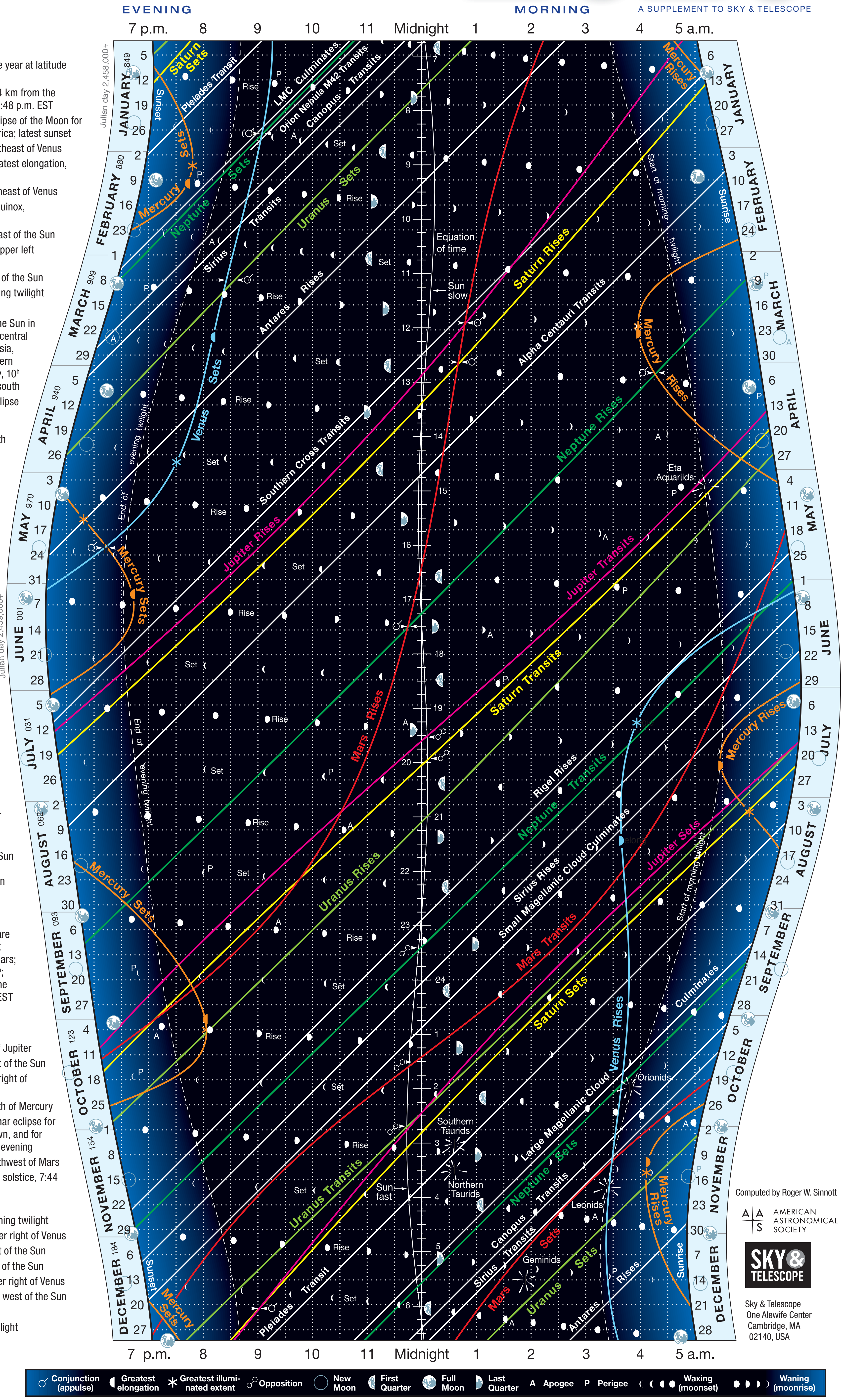
A long time later, we finally left our stone perch, but our adventure that night had not yet ended. We followed our Moon shadows on foot through the woods to our bicycles, which we'd left behind along the old railway bed. In the ashen moonlight, we pedaled a long way back to the car. Finally, we loaded the mountain bikes onto the roof rack and motored home to Kingston — far from the railway bed, the forested lake, and the Queen of Night.

■ **LARRY OAKLEY** lives in Kingston, Ontario, and is the author of *Inside the Wild* and *Inside the Wild 2*.

Skygazer's Almanac 30°S 2020

FOR LATITUDES NEAR 30° SOUTH

A SUPPLEMENT TO SKY & TELESCOPE



EVENING SKY

- Jan 4 Latest twilight of the year at latitude 30° south
- Jan 5 Earth is 147,091,144 km from the Sun (perihelion) at 5:48 p.m. EST
- Jan 10 Deep penumbral eclipse of the Moon for Asia and most of Africa; latest sunset
- Jan 27 Neptune is 0.5° northeast of Venus
- Feb 10 Mercury attains greatest elongation, 18° east of the Sun
- Mar 8 Uranus is 2.2° southeast of Venus
- Mar 20 Fall begins at the equinox, 13:50 p.m. EST
- Mar 24 Venus stands 46° east of the Sun
- May 22 Mercury is 0.9° to upper left of Venus
- Jun 4 Mercury is 24° east of the Sun
- Jun 7 Earliest end of evening twilight
- Jun 10 Earliest sunset
- Jun 21 Annular eclipse of the Sun in a narrow path from central Africa to southern Asia, China, and the western Pacific; shortest day, 10^h 13^m at latitude 30° south
- Jul 4 Slight penumbral eclipse of the Moon around midnight tonight for South America; Earth is 152,095,295 km from the Sun (aphelion) at 9:35 p.m. EST
- Jul 14 Jupiter comes to opposition
- Jul 20 Saturn reaches opposition
- Sep 11 Neptune is at opposition
- Sep 22 Spica is 0.3° upper left of Mercury; spring begins at the equinox, 11:31 p.m. EST
- Oct 1 Mercury is 26° east of the Sun
- Oct 6 Mars is nearest Earth, showing a disk 22.6″ across
- Oct 13 Mars comes to opposition tonight
- Oct 31 Uranus is at opposition
- Nov 30 Penumbral lunar eclipse for Australia this evening, and for South America this morning
- Dec 14 Total eclipse of the Sun in a path from the central Pacific Ocean across Chile and Argentina and into the South Atlantic
- Dec 21 Saturn and Jupiter are 0.1° apart, their first conjunction in 20 years; longest day, 14^h 05^m; summer begins at the solstice, 8:02 p.m. EST

MORNING SKY

- Mar 21 Mars is 0.8° right of Jupiter
- Mar 24 Mercury is 28° west of the Sun
- Apr 1 Mars is 0.9° above right of Saturn
- Apr 4 Neptune is 1.4° north of Mercury
- Jun 6 Weak penumbral lunar eclipse for Australia before dawn, and for southern Africa this evening
- Jun 14 Neptune is 1.6° northwest of Mars
- Jun 21 Winter begins at the solstice, 7:44 a.m. EST
- Jul 1 Latest sunrise
- Jul 4 Latest onset of morning twilight
- Jul 12 Aldebaran is 1° upper right of Venus
- Jul 23 Mercury is 20° west of the Sun
- Aug 13 Venus lies 46° west of the Sun
- Oct 3 Regulus is 0.2° lower right of Venus
- Nov 11 Mercury stands 20° west of the Sun
- Dec 3 Earliest sunrise
- Dec 8 Earliest morning twilight

Computed by Roger W. Sinnott

AMERICAN ASTRONOMICAL SOCIETY

SKY & TELESCOPE

Sky & Telescope
One Alewife Center
Cambridge, MA
02140, USA

Skygazer's Almanac 30° S 2020

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 2020,* 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 12, 2020.

First find "January" and "12" 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 12–13 crosses many slanting *event lines*. Each event line tells when something happens.

The dotted line for January 12–13 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 12th occurs at 7:05 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 both Saturn and Mercury set within a few minutes of the Sun, so we can cross them off tonight's observing list. Moving to the right we see that the Pleiades transit the meridian at 8:23 p.m., meaning the famous star cluster is at its highest in the sky. We see a tiny Moon symbol centered at 8:32, and the legend at the chart's bottom tells us the Moon is at waning gibbous phase, rising. Then twilight ends at 8:40, marking the moment when the Sun is 18° below the horizon and the sky is fully dark.

Venus sets at 9:14 p.m., and we can infer that the brilliant planet has up to now been sinking low in the western sky.

At about 9:57 the Large Magellanic Cloud culminates (another way of saying it transits). The Orion Nebula (Messier 42) transits at 10:10, and then the two brightest nighttime stars, Canopus and Sirius, transit at 10:58 and 11:20, 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 12–13 this is $7^{h}\ 26^{m}$. 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 12th the Sun runs slow, transiting at 12:08 p.m. This deviation, important for reading a sundial, is caused by the tilt of Earth's axis and the ellipticity of its orbit.

At 12:11 a.m. the faint planet Uranus sets. At 1:54 Antares, a star we usually associate with later seasons, climbs above the southeastern horizon. Then Mars comes up 3 minutes later.

The first hint of dawn — the start of morning twilight — comes at 3:37. Then the bright planet Jupiter rises at 4:14. The Sun finally peeks above the eastern horizon at 5:11 a.m. on Monday morning, January 13th.

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.

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

Conjunctions (close pairings) of two planets are marked by a ☌ symbol on the 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 July 20–21 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, and asterisks mark when their telescopic disks have the greatest illuminated extent in square arcseconds. For example, this occurs for Mercury on the evening of February 5th and for Venus April 28th.

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.

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 early this year are 2458, as indicated just off the chart's upper left margin. To find the last three digits for days in January, add 849 to the date. For instance, on January 12th we have 849 + 12 = 861, so the Julian day is 2,458,861.

Note that the Julian day doesn't 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. Eastern Standard Time, EST). Before that time, subtract 1 from the Julian day number just obtained.

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

Time Corrections

All events on this southern version of the *Skygazer's Almanac* are plotted for an observer at 135° east longitude and 30° south latitude. 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 Eastern Standard Time, EST), and 142.5° E for the two central states (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 2020 is a supplement to *Sky & Telescope* magazine.

For reprints (item SGA20S, $5.95 each postpaid) or to order a similar chart for north latitude 40° or 50°, contact
Sky & Telescope,
One Alewife Center,
Cambridge, MA 02140, USA.
Send an e-mail
to skyprodservice@
skyandtelescope.com,
or visit shopatsky.com.

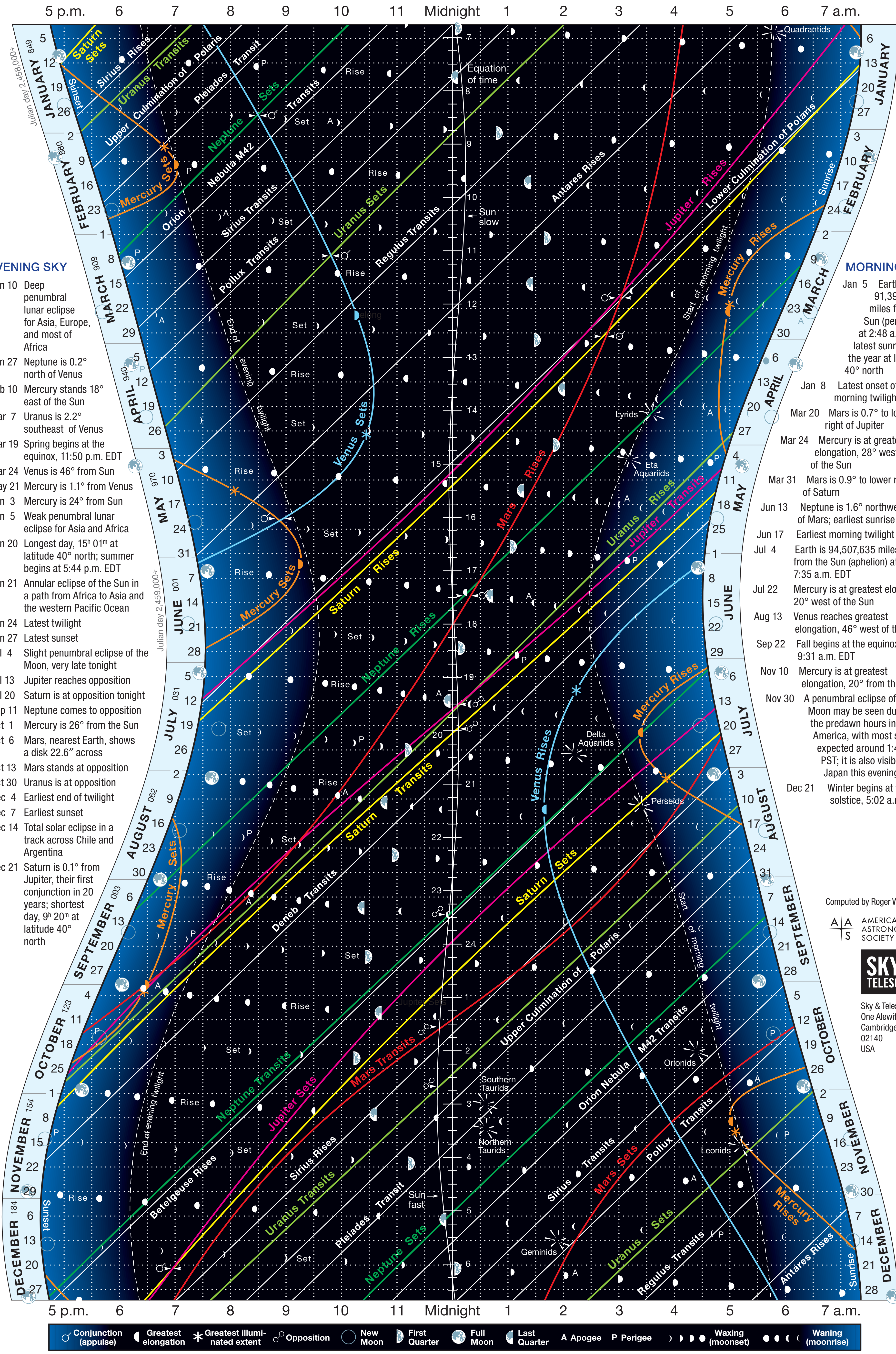
SKY & TELESCOPE

AMERICAN ASTRONOMICAL SOCIETY

Skygazer's Almanac 40°N 2020

FOR LATITUDES NEAR 40° NORTH

A SUPPLEMENT TO SKY & TELESCOPE



EVENING SKY

- Jan 10 Deep penumbral lunar eclipse for Asia, Europe, and most of Africa
- Jan 27 Neptune is 0.2° north of Venus
- Feb 10 Mercury stands 18° east of the Sun
- Mar 7 Uranus is 2.2° southeast of Venus
- Mar 19 Spring begins at the equinox, 11:50 p.m. EDT
- Mar 24 Venus is 46° from Sun
- May 21 Mercury is 1.1° from Venus
- Jun 3 Mercury is 24° from Sun
- Jun 5 Weak penumbral lunar eclipse for Asia and Africa
- Jun 20 Longest day, $15^h\ 01^m$ at latitude 40° north; summer begins at 5:44 p.m. EDT
- Jun 21 Annular eclipse of the Sun in a path from Africa to Asia and the western Pacific Ocean
- Jun 24 Latest twilight
- Jun 27 Latest sunset
- Jul 4 Slight penumbral eclipse of the Moon, very late tonight
- Jul 13 Jupiter reaches opposition
- Jul 20 Saturn is at opposition tonight
- Sep 11 Neptune comes to opposition
- Oct 1 Mercury is 26° from the Sun
- Oct 6 Mars, nearest Earth, shows a disk 22.6″ across
- Oct 13 Mars stands at opposition
- Oct 30 Uranus is at opposition
- Dec 4 Earliest end of twilight
- Dec 7 Earliest sunset
- Dec 14 Total solar eclipse in a track across Chile and Argentina
- Dec 21 Saturn is 0.1° from Jupiter, their first conjunction in 20 years; shortest day, $9^h\ 20^m$ at latitude 40° north

MORNING SKY

- Jan 5 Earth is 91,398,199 miles from the Sun (perihelion) at 2:48 a.m. EST; latest sunrise of the year at latitude 40° north
- Jan 8 Latest onset of morning twilight
- Mar 20 Mars is 0.7° to lower right of Jupiter
- Mar 24 Mercury is at greatest elongation, 28° west of the Sun
- Mar 31 Mars is 0.9° to lower right of Saturn
- Jun 13 Neptune is 1.6° northwest of Mars; earliest sunrise
- Jun 17 Earliest morning twilight
- Jul 4 Earth is 94,507,635 miles from the Sun (aphelion) at 7:35 a.m. EDT
- Jul 22 Mercury is at greatest elongation, 20° west of the Sun
- Aug 13 Venus reaches greatest elongation, 46° west of the Sun
- Sep 22 Fall begins at the equinox, 9:31 a.m. EDT
- Nov 10 Mercury is at greatest elongation, 20° from the Sun
- Nov 30 A penumbral eclipse of the Moon may be seen during the predawn hours in North America, with most shading expected around 1:43 a.m. PST; it is also visible from Japan this evening
- Dec 21 Winter begins at the solstice, 5:02 a.m. EST

Computed by Roger W. Sinnott

AMERICAN ASTRONOMICAL SOCIETY

SKY & TELESCOPE

Sky & Telescope
One Alewife Center
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USA

Skygazer's Almanac 40°N 2020

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 2020,* 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 12, 2020.

First find "January" and "12" 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 12–13 crosses many slanting *event lines*. Each event line tells when something happens.

The dotted line for January 12–13 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 12th occurs at 4:56 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 also note that Mercury has just set and that Saturn sets 1 minute after the Sun. We can cross those two planets off tonight's observing list. Moving to the right, we see that the brightest nighttime star, Sirius, rises at 6:13 p.m. in the deepening twilight. A dashed line shows that twilight technically ends at 6:32, the time when the Sun is 18° below the horizon.

The faint planet Uranus transits the meridian at 6:35, meaning it is due south and "riding high," an excellent time to look for it in binoculars. Not long after, at 7:15, a tiny Moon symbol appears on the dotted line, and the legend at the bottom of the chart tells us it is at waning gibbous phase, rising.

At 7:30 Polaris, the North Star, reaches upper culmination. This means it stands directly above the north celestial pole (by 39′ this year), a good time to check the alignment of an equatorial telescope.

Venus sets at 7:57 p.m., so we infer it has been shining brightly up to now, low in the western sky. At 8:20 the Pleiades star cluster transits, followed at 10:08 by the Orion Nebula, M42. Transits of such celestial landmarks help indicate when they are best placed for viewing.

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 12–13 this is $7^h\ 29^m$. 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 12th the Sun runs slow, transiting at 12:08 p.m. This deviation is important for reading a sundial. It is caused by the tilt of Earth's axis and the ellipticity of its orbit.

The red planet Mars rises at 4:03. It is followed up at 4:36 by Antares, 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. And this morning Jupiter rises at 6:32. The Sun finally peeks above the horizon at 7:21 a.m. on January 12th.

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 July 20–21.

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 Mercury on the evening of February 5th and for Venus on April 27th 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.

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 early this year are 2458, as indicated just off the chart's upper left margin. To find the last three digits for evenings in January, add 849 to the date. For instance, on the evening of January 12th we have 849 + 12 = 861, so the Julian day is 2,458,861. 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 at 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 (listed monthly on the Planetary Almanac page of *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.

For reprints (item SGA20R, $4.95 each postpaid) or to order a similar chart for latitude 50° north or 30° south, contact Sky & Telescope, One Alewife Center, Cambridge, MA 02140, USA; phone 800-253-0245. Send an e-mail to skyprodservice @skyandtelescope.com, or you can visit our online store at shopatsky.com.

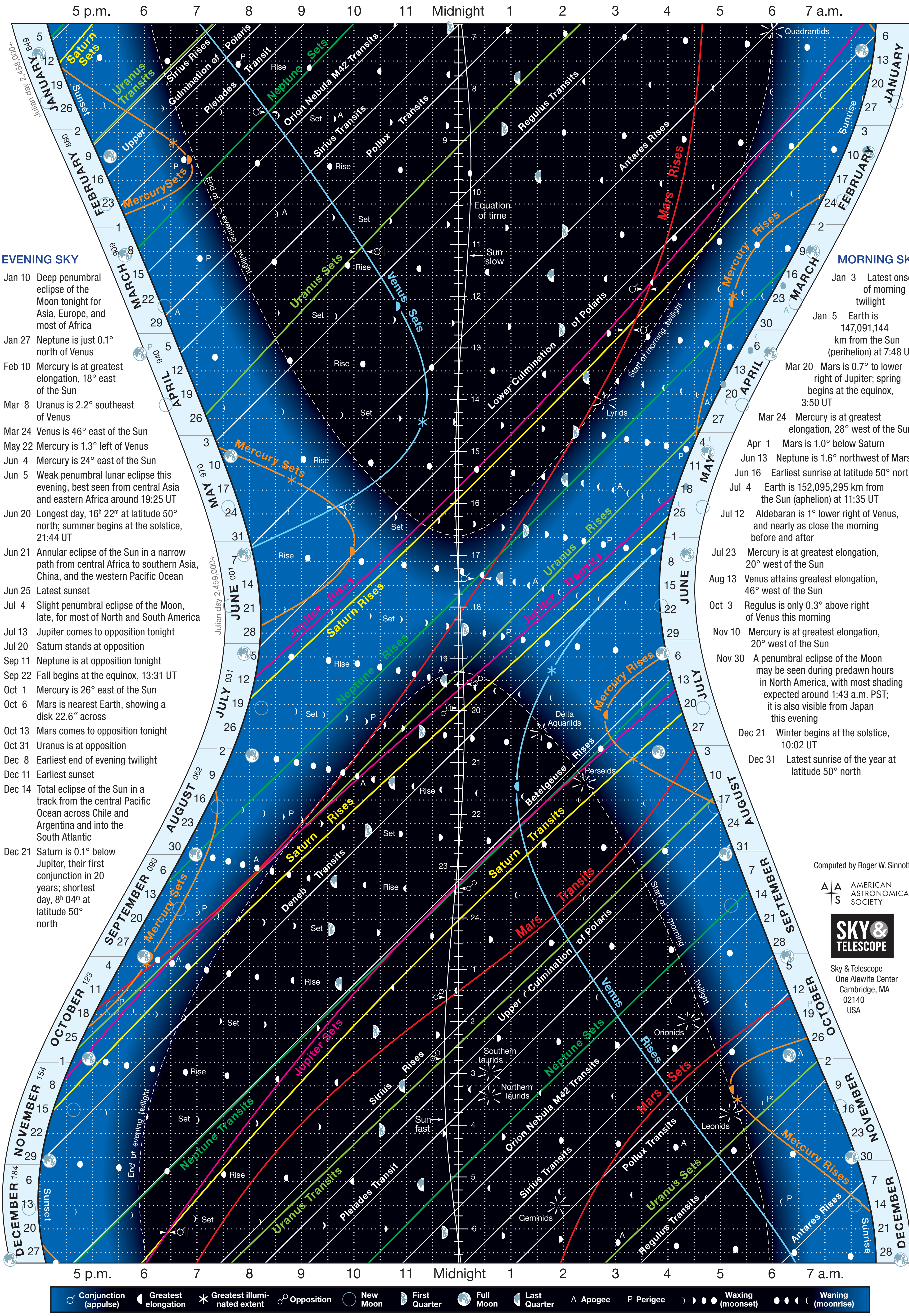
SKY & TELESCOPE

AMERICAN ASTRONOMICAL SOCIETY

Skygazer's Almanac 50°N 2020

FOR LATITUDES NEAR 50° NORTH

A SUPPLEMENT TO SKY & TELESCOPE



EVENING SKY

- Jan 10 Deep penumbral eclipse of the Moon tonight for Asia, Europe, and most of Africa
- Jan 27 Neptune is just 0.1° north of Venus
- Feb 10 Mercury is at greatest elongation, 18° east of the Sun
- Mar 8 Uranus is 2.2° southeast of Venus
- Mar 24 Venus is 46° east of the Sun
- May 22 Mercury is 1.3° left of Venus
- Jun 4 Mercury is 24° east of the Sun
- Jun 5 Weak penumbral lunar eclipse this evening, best seen from central Asia and eastern Africa around 19:25 UT
- Jun 20 Longest day, $16^h 22^m$ at latitude 50° north; summer begins at the solstice, 21:44 UT
- Jun 21 Annular eclipse of the Sun in a narrow path from central Africa to southern Asia, China, and the western Pacific Ocean
- Jun 25 Latest sunset
- Jul 4 Slight penumbral eclipse of the Moon, late, for most of North and South America
- Jul 13 Jupiter comes to opposition tonight
- Jul 20 Saturn stands at opposition
- Sep 11 Neptune is at opposition tonight
- Sep 22 Fall begins at the equinox, 13:31 UT
- Oct 1 Mercury is 26° east of the Sun
- Oct 6 Mars is nearest Earth, showing a disk 22.6″ across
- Oct 13 Mars comes to opposition tonight
- Oct 31 Uranus is at opposition
- Dec 8 Earliest end of evening twilight
- Dec 11 Earliest sunset
- Dec 14 Total eclipse of the Sun in a track from the central Pacific Ocean across Chile and Argentina and into the South Atlantic
- Dec 21 Saturn is 0.1° below Jupiter, their first conjunction in 20 years; shortest day, $8^h 04^m$ at latitude 50° north

MORNING SKY

- Jan 3 Latest onset of morning twilight
- Jan 5 Earth is 147,091,144 km from the Sun (perihelion) at 7:48 UT
- Mar 20 Mars is 0.7° to lower right of Jupiter; spring begins at the equinox, 3:50 UT
- Mar 24 Mercury is at greatest elongation, 28° west of the Sun
- Apr 1 Mars is 1.0° below Saturn
- Jun 13 Neptune is 1.6° northwest of Mars
- Jun 16 Earliest sunrise at latitude 50° north
- Jul 4 Earth is 152,095,295 km from the Sun (aphelion) at 11:35 UT
- Jul 12 Aldebaran is 1° lower right of Venus, and nearly as close the morning before and after
- Jul 23 Mercury is at greatest elongation, 20° west of the Sun
- Aug 13 Venus attains greatest elongation, 46° west of the Sun
- Oct 3 Regulus is only 0.3° above right of Venus this morning
- Nov 10 Mercury is at greatest elongation, 20° west of the Sun
- Nov 30 A penumbral eclipse of the Moon may be seen during predawn hours in North America, with most shading expected around 1:43 a.m. PST; it is also visible from Japan this evening
- Dec 21 Winter begins at the solstice, 10:02 UT
- Dec 31 Latest sunrise of the year at latitude 50° north

Computed by Roger W. Sinnott

AMERICAN ASTRONOMICAL SOCIETY

SKY & TELESCOPE

Sky & Telescope
One Alewife Center
Cambridge, MA 02140
USA

Skygazer's Almanac 50°N 2020

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 2020,* 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 12, 2020.

First find "January" and "12" 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 12–13 crosses many slanting *event lines*. Each event line tells when something happens.

The dotted line for January 12–13 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 12th occurs at 4:22 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 Saturn sets just 2 minutes after the Sun. We can cross it off tonight's observing list. Moving to the right, we see a dashed line marking the end of evening twilight at 6:18 p.m. This is the time when the Sun is 18° below the horizon and the sky is fully dark.

A tiny Moon symbol appears at 6:26, and the legend at the bottom of the chart shows it is at waning gibbous phase, rising. Ten minutes later Uranus transits the meridian, meaning this faint planet is due south at its high point in the sky — a good time to look for it in binoculars.

At 6:39 the brightest nighttime star, Sirius, rises in the southeast. Then at 7:31 Polaris, the North Star, reaches upper culmination. This is when Polaris stands directly above the north celestial pole (by 39′ this year), a good opportunity to check the alignment of an equatorial telescope.

Venus sets at 7:37, and we can infer that up to now this brilliant planet has been hanging low in the western sky. The Pleiades star cluster in Taurus transits the meridian at 8:21, followed by the Orion Nebula, Messier 42, at 10:09 and Sirius at 11:18. Transits of celestial landmarks tell when they are highest in the sky and 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 12–13 this is $7^h\ 28^m$. 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 12th the Sun runs slow, transiting at 12:08 p.m. This deviation, important for reading a sundial, is caused by the tilt of Earth's axis and the ellipticity of its orbit.

The bright star Regulus transits at 2:41 a.m. Then Mars rises at 4:36, followed by Antares, a star we usually associate with a later season, at 5:23.

The first hint of dawn — the start of morning twilight — comes at 5:58 a.m., and Jupiter pops into view at 7:10. The

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

Sun finally peeks above the eastern horizon at 7:54 a.m. on Monday morning, January 13th.

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 July 20–21 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 February 5th and Venus on April 27th 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.

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 early this year are 2458, as indicated just off the chart's upper left margin. To find the last three digits for evenings in January, add 849 to the date. For instance, on the evening of January 12th we have 849 + 12 = 861, so the Julian day is 2,458,861. 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 0° longitude and 50° north latitude, 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 East European Time, 30°. 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 below at 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 SGA20E, $5.95 each postpaid) or to order a similar chart for latitude 40° north or 30° south, contact
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