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SKY & TELESCOPE

THE ESSENTIAL GUIDE TO ASTRONOMY

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November 2017 VOL. 134, NO. 5

ON THE COVER

A mosaic of Viking images shows Mars's Aram Chaos and environs.
NASA / JPL / USGS

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A New Cosmopolitanism

THERE'S NO BETTER WAY to see just how multinational astronomy and astrophysics have become in this century than to have a glance at a large, peer-reviewed research paper. At random, I recently chose as an example the journal article that describes the LIGO consortium's third detection of gravitational waves (*S&T:* Sept. 2017, p. 10).

Published in *Physical Review Letters* on June 2nd (see **https://is.gd/nAlfQ7**), this paper has more than a *thousand* authors. They hail from institutions all over the world. Beyond dozens from the U.S. and Europe, this includes affiliations in Australia, Brazil, Canada, China, India, Japan, Russia, South Korea, and Taiwan.

As our readers are well aware, numerous countries host first-rate astronomical observatories — on the ground, in the air, or in orbit. With its raft of premier eyes on the sky, Chile immediately comes to mind. Soon, South Africa and Australia will jointly host the Square Kilometre Array (see page 84). There are even observatories in Antarctica, a symbol of global participation if there ever was one.

Space exploration, too, is becoming more, well, planetary. As our cover story on page 14 details, the various missions to Mars set to launch in 2020 will feature the usual Big Three: the U.S., European, and Russian space agencies. But these will be joined by two comparative newcomers, China and United Arab Emirates, each of which plans to send its own spacecraft to the Red Planet.

▲ **United Arab Emirates engineers inspect the Hope spacecraft, set to launch Mars-ward in July 2020.**

MOHAMMED BIN RASHID SPACE CENTRE

Altogether, more than 70 nations today boast space agencies. Thirteen of those have launch capabilities, with a handful able to send humans into space. Astronauts flying under 18 different flags have visited the International Space Station, including one each from Belgium, Brazil, Denmark, Kazakhstan, Malaysia, the Netherlands, South Africa, South Korea, Spain, Sweden, and the United Kingdom.

Beyond signifying greater internationalism, this trend is emblematic of the essentially collaborative, inclusive, and universal nature of our kind's study of the heavens. We all share the same firmament, and the same desire to explore, discover, and understand. Jingoism doesn't — or shouldn't — come into it. When a space mission fails, it pains all of us, because we all lose. When it succeeds, we all win, as Neil Armstrong expressed so eloquently when he took humankind's first step onto another world.

This broadening of astronomy and space exploration to embrace more and more peoples is, like the expansion of the cosmos itself, speeding up. As our current golden age of astronomy advances, we welcome the diversity and wish clear skies for all.

Peter

Editor in Chief

SKY&TELESCOPE
The Essential Guide to Astronomy

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

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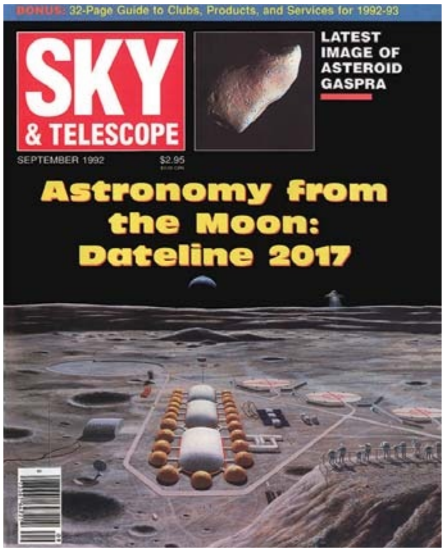
Wishing for the Moon

While looking through my archives I found the *Sky & Telescope* issue from September 1992. The cover story, by Paul Lowman, Jr., was a lengthy "letter" written from a lunar base on November 16, 2017. (In one of the letter's illustrations, on page 262, the author is gazing at the Moon's shadow on Earth during August 21st's solar eclipse.) As I flipped through the article, I was impressed — but sad at the same time — that a dream of establishing a lunar base has not yet become reality.

Andy Rokita
Wilmington, Delaware



Life Among the Stars?

I've noticed that astronomers tend to play up the chances of finding life elsewhere (*S&T:* Sept. 2017, p. 38) because of the sheer number of potentially habitable planets in our galaxy and the detection of the organic molecules required for living organisms. The numbers certainly look good, but as a molecular biologist I am more pessimistic.

Even the most primitive bacterium is vastly more complex than a mixture of its component chemical molecules. Its sophisticated system for information storage and transfer is prone to just enough error to allow evolutionary processes to occur. The probability of finding even these simple life forms elsewhere is tiny, in my view, leaving aside the (quite plausible) issue of life on Earth having been seeded from another part of the solar system.

If we combine this tiny probability with an even smaller chance of multicellular plants and animals evolving, let alone the emergence of human-like intelligence, then things *don't* look so good. I therefore urge astronomers to be more grounded (pardon the pun) in biochemical reality — but of course to keep looking for the evidence that will support or demolish these speculations.

Ed Zanders
Cambridge, England

Robert Gray mentions how he and his team adjusted the hydrogen emission frequencies they searched to allow for the blueshift caused by the Andromeda Galaxy's relative motion toward us. Shouldn't they have bracketed those frequencies in both directions to allow for the possibility that the transmitting race might have already compensated for that motion, so that the broadcast would be received here as the usual at-rest wavelength? If the senders were as advanced as assumed, surely they would have thought of that.

Dan Heim
New River, Arizona

Robert Gray replies: *To cover the possibility that signals aimed at our part of the Milky Way were Doppler-adjusted to arrive at the hydrogen rest frequency, we observed in a 125-kilohertz-wide spectral window, which seemed sufficient to cover various uncertainties. With 8,192 channels available, it was then possible to use channels only 15 Hz wide. And if the signals weren't Doppler-adjusted, we also picked a center frequency for our receiver to compensate for the motions of the two galaxies with respect to us and for motions across their disks. Our spectral windows also partly covered some other possibilities, such as signals adjusted to fall at hydrogen's rest frequency at the center of the Milky Way.*

By the way, my article mistakenly states that both M31 and M33 are moving toward us — but only M31 is doing that.

Sounds from Meteors

Regarding the origin of sound with meteors (*S&T:* July 2017, p. 12), an alternative explanation is the common phenomenon called *synesthesia*. This is a neurological process whereby the brain converts one type of sensory input into another. By the way, I heard my first meteor one early January morning while out on my paper route.

Craig Hohm, M.D.
Penn Yan, New York

Pass the Pasta

Just to be a bit persnickety, I'd like to point out something about the scientifically great picture titled "Pan: Saturn's Ravioli-Shaped Moon" (*S&T:* July 2017, p. 13). Hmm, *ravioli* is the Italian plural of *raviolo* ("little turnip"), so Pan is actually a "raviolo-shaped moon." But, hey, I don't blame David Dickinson — how many persons would know that? Meanwhile, I also got to read about "nuclear pasta" on page 19!

Carl Masthay
St. Louis, Missouri

Whither Helium?

A note about the discovery of helium (*S&T:* July 2017, p. 30): Jules Janssen and Norman Lockyer independently realized that one could observe the spectrum of the Sun's chromosphere without waiting for an eclipse by using two spectrographs (and they share a joint gold medal from the French Academy of Sciences for this). But Lockyer alone recognized the anomalous spectral line near sodium's strong D emission. There's a whole book about this saga, Biman Nath's *The Story of Helium and the Birth of Astrophysics*, and a very good book it is, too.

Virginia Trimble
Irvine, California

Dark (and Mysterious) Matter

Thanks, Leonidas Moustakas, for using one exclamation point in particular in your 8-page article on dark matter (*S&T:* Aug. 2017, p. 28). While exploring the

SKY & TELESCOPE

2MASS / UMASS / IPAC / CALTECH / NASA / NSF

◀ Messier 17, the Omega or Swan Nebula, has an unfamiliar shape when seen in this composite of three 2MASS infrared images.

possible reasons why we see stars moving rapidly in response to far more mass than we can detect visually, you conjectured, "One is that general relativity doesn't quite describe how gravity works on larger astronomical scales. This is certainly possible!" I keep thinking that dark matter and dark energy will turn out to be explained by different laws of physics on larger astronomical scales. This is a very long mystery novel, and I am looking forward to hearing about what is real and what is not.

Tom Kellogg
San Francisco, California

Seeing the Infrared

Howard Banich's review of Messier 17 includes an "infrared image" (*S&T:* Sept. 2017, p. 57). If so, how can it be displayed in RGB color, since an infrared image is a single spectral band and an RGB image (even a pseudo-colored one) requires three distinct spectral bands?

Steve Maas
Ransom Canyon, Texas

Kelly Beatty replies: *The Two Micron All-Sky Survey, or 2MASS, covered the whole sky at three near-infrared wavelengths that can pass through our atmosphere and reach the ground — but none of which are visible to the human eye. This important region of the electromagnetic spectrum lets us see deeper into dusty regions and reveals objects that are warm but not hot. To show the survey's results, the 2MASS images are usually represented in false color, with light recorded in the J infrared band (1.2 microns) shown as blue, H (1.6 microns) as green, and K (2.2 microns) as red. For a fuller explanation, see Michael Skrutskie's excellent feature article on the 2MASS effort in the July 2001 issue, p. 34.*

FOR THE RECORD

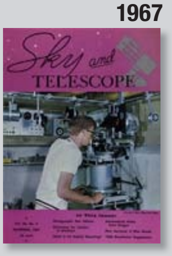
● Cassini recorded images of Enceladus's erupting geysers on November 21, 2009 (*S&T:* Sept. 2017, p. 23).

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

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

1942

1967



1992

November 1942

Nearest Neighbors "Alpha Centauri was among the first stars known to be double. [But a] discussion of this well-known star would not be complete without mention of its possible third component, Proxima Centauri. . . .

"We are . . . not quite sure that Proxima is really part of the system, although that seems probable; it is in any case self-luminous, though faint. On the other hand, even as our sister planets would be invisible [from] Alpha Centauri, so also any similar planets there would be invisible to us. If there be such, the perturbations of their orbits must be enormous and it would seem probable that the amounts of radiation they receive from the two luminaries at different times, and their consequent temperatures, would vary so greatly as to make the existence of life on them unlikely."

*So wrote Bernhard Dawson (La Plata Observatory, Argentina). Only last year, the European Southern Observatory reported that an Earth-like planet orbits 11th-magnitude Proxima (*S&T*: Dec. 2016, p. 10).*

November 1967

Ancient Observatory? "Nearly 5,000 years ago a city, now long-vanished, existed in Armenia on the bank of the river Metsamor, about 20 miles west of present-day Yerevan. At this site, Soviet archaeologists have been digging since 1965. . . . Miss E. S. Parsamian, of Burakan Observatory, told IAU Commission 41 (History of Astronomy) about these findings. . . .

"On a rocky hill are three ancient man-made platforms, all with a north-south orientation. One of these is of a triangular shape, with its apex pointing accurately south. Near the eastern face of this rock, four stars are carved, inside a trapezium that indicates an azimuth of 120 degrees. Miss Parsamian points out that this is the direction of the rising of Sirius."

The find spurred other megalithic studies in Armenia, including that of Stonehenge-like Carahunge (Zorats Karer) near the town of Sisian.

November 1992

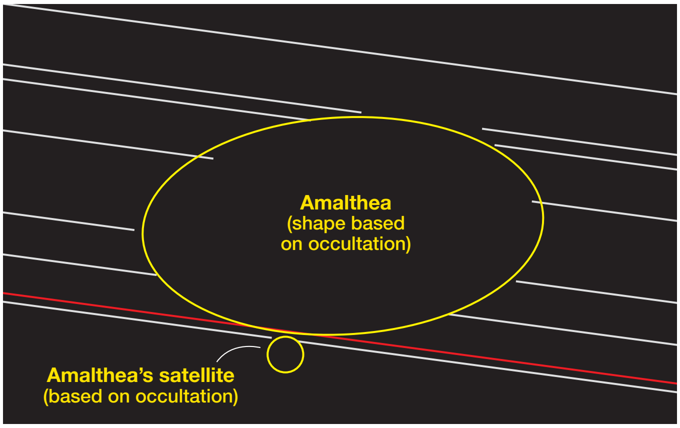
Vindication "The possible return of Comet Swift-Tuttle, the parent of the Perseid meteor stream, focused an unusual amount of attention on this year's Perseid shower. . . . The most exciting observation comes from a group of Japanese meteor watchers on the island of Okinawa. Between approximately 19:00 and 20:00 Universal time on [August 11th, they found] a zenithal hourly rate as high as 8,000! . . .

"According to Brian Marsden of the Central Bureau for Astronomical Telegrams . . . , 'It would appear that the material responsible for this burst was released rather recently by the comet, . . . but if Swift-Tuttle were to return now, . . . no one would be more surprised than I.'"

Marsden downplayed his own 1973 forecast, that the comet might return in late 1992. But it did —130 years after its discovery!

PRO-AM

Amateurs Find Asteroid's Moon



▲ These lines represent the projected paths of a 10th-magnitude star recorded by observers on March 14, 2017, as the star passed behind the asteroid Amalthea. Sam Insana in Gila Bend, Arizona, measured the red track, and the white line below it is actually two tracks close together. The yellow oval marks the asteroid's approximate shape; the small yellow circle just below it corresponds to the location of the potential moon.

A TEAM OF AMATEUR OBSERVERS, some armed with just 3-inch telescopes, found that the main-belt asteroid 113 Amalthea probably has a small companion.

Paul Maley, a retired NASA staffer and a key member of the International Occultation Timing Association, enlisted amateur observers in Texas to observe the March 14th occultation of a 10th-magnitude star by the 13th-magnitude asteroid.

As detailed in the Central Bureau for Astronomical Telegrams no. 4413, issued on July 12th, a "fence" of 10 observing sites spread across the occultation's predicted path yielded seven positive occultations and three "misses." One of those misses (red track in diagram), by Sam Insana in Gila Bend, Arizona, fell between five positive occultation tracks to his north and two to his south. The two southern ones, recorded by Dave Eisfeldt and Dick Campbell (both with the Central Texas Astronomical Society), appear to correspond to interruptions of the star's light by a moon. Other members of the team were Sam Deen, Wayne Thomas, Paul Facuna, Don Boyd, and Ted Blank (who set up four robotic cameras for the event).

Not to be confused with Jupiter's small moon of the same name, Amalthea orbits the Sun every 3.66 years in the inner part of the main asteroid belt, not far outside the orbit of Mars. It circles the Sun at an average of 2.37 astronomical units (355 million km) with an inclination of 5°. Discovered in 1871, it's about 50 km (30 mi) across and has a rocky "S-type" surface spectrum typical of bodies populating the inner main belt. Based on the lengths of each occultation record and how they line up in the plot, Amalthea must have a distinctly elongated shape.

The size of the satellite isn't known, though typically such companions are much smaller than their hosts. According to the definitive compilation by W. Robert Johnston, the census of asteroids with moons now includes 145 main-belt asteroids (8 with two each), 23 Mars-crossing asteroids (1 with two), and 63 near-Earth asteroids (2 with two each). Looking farther outward, Johnston's list includes 4 of Jupiter's Trojans and 82 trans-Neptunian objects.

Nor is it clear what kind of orbit the newfound companion might have. According to Daniel Green (Harvard University), small satellites around large main-belt asteroids typically have orbits roughly five times larger than their primary's diameter, which here would correspond to about 250 km. But the observed gap was far smaller, so perhaps the companion's orbital plane was seen nearly edge-on with the satellite near one of its conjunction points (rather than being far off to one side).

The whole claim to a satellite discovery rests on Insana's negative observation — take that away, and the two brief outages recorded by Eisfeldt and Campbell could simply be due to a large bump on Amalthea's surface. However, Maley says, "The Insana video has been checked over and over, as was his location, and the only conclusion that we can come to is that the miss is completely clean."

Confirmation of the discovery might not have to wait long. Although no one had previously observed a stellar occultation by Amalthea, four are predicted for next year — including an April 14th event with a track that crosses the northeastern U.S.

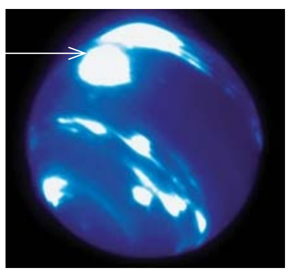
■ J. KELLY BEATTY

SOLAR SYSTEM

Huge Storm Rages on Neptune

ASTRONOMERS using the Keck Observatory have spotted a large storm complex on Neptune (shown), spanning at least 30° in both latitude and longitude and centered near the planet's equator. Some intrepid amateurs also detected the storm in the weeks preceding the Keck observations.

"Historically, very bright clouds have occasionally been seen on Neptune, but usually at latitudes closer to the poles," says Imke de Pater (University of California, Berkeley). "Never before has a cloud been seen at or so close to the equator, nor has one ever been this bright."



The cloud cover might form when methane condenses above a vortex anchored deep in Neptune's atmosphere. However, wind speeds on Neptune vary drastically with latitude, so it's unclear why such a vortex doesn't quickly break apart.

■ SEAN WALKER

AMALTHEA: LEAH TISCIONE / S&T, SOURCE: IOTA / BRAD TIMERSON; NEPTUNE: N. MOLTER / I. DE PATER (UNIV. OF CALIFORNIA, BERKELEY) / C. ALVAREZ (W. KECK OBSERVATORY)

MARS

Trojan Asteroids Might Come from Red Planet

▲ Artist's impression of an impact that excavated a piece of Mars's surface

TROJAN ASTEROIDS orbit ahead of and behind Mars in the stable regions where the gravitational pull of the Red Planet balances that of the Sun. While previous studies have suggested that these rocks might come from the asteroid belt, a study published in the July 17th *Nature Astronomy* points to an alternative source: Mars itself.

Of the nine Mars Trojans currently known, seven belong to a single cluster named for its largest member, 5261 Eureka. At least 1 billion years old and possibly the parent body of the cluster's asteroids, Eureka is known to be rich in olivine, a mineral rare in asteroids but common in the mantle of Mars as well as in Martian basins.

David Polishook (Weizmann Institute of Science, Israel) and colleagues used NASA's Infrared Telescope Facility to look at spectra of two other Trojans in the Eureka cluster: 2007 NS_2 (311999) and 2001 DH_{47} (385250). The light reflected off these asteroids also shows the characteristic absorption around 1 micron, implying olivine-rich surfaces.

Polishook's team then used numerical simulations to show that the olivine-rich Eureka cluster is more likely to have originated from Mars than to have been randomly captured from the asteroid belt. While it's easy for an impact to excavate and eject some of a planet's surface, moving those ejecta into a stable Trojan orbit requires a significant change in orbital energy. The simulations show that, to make this change, Mars itself would have to "jump" before settling into its current orbit, a possibility during the final stages of our solar system's planet formation.

■ DAVID DICKINSON

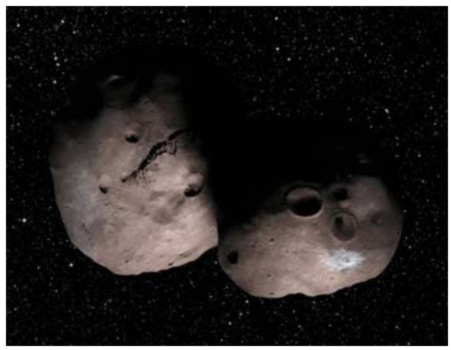
KUIPER BELT

Is New Horizons' Next Target a Binary Body?

THE QUEST IS ON to learn everything possible about the Kuiper Belt object (KBO) designated 2014 MU_{69} before New Horizons flies by at close range on January 1, 2019. And that effort got a huge boost when the notoriously dim (27th-magnitude) object passed in front of a dim star in Sagittarius on July 17th.

The occultation campaign's first two events, on June 3rd and July 10th, didn't see any blink-outs (*S&T:* Oct. 2017, p. 11). But on July 17th, five of the 23 observing teams recorded brief occultations of up to 1 second.

These teams, which included some experienced amateur observers, were arrayed about 4½ km (3 miles) apart along a "picket fence" perpendicular to the occultation's predicted path in remote parts of south-central Argentina. Given the separations of the five successful teams, 2014 MU_{69} has to be 20 to 30 km (12 to 18 miles) long. That's smaller than originally thought, so the surface material must be somewhat more reflective than the surfaces of the Kuiper Belt's usual denizens.



▲ What's the real shape of 2014 MU_{69}, a Kuiper Belt object that's 43.3 astronomical units (6.5 billion km) from the Sun? New studies suggest it's either highly elongated and up to 30 km long (*left*) or a binary body whose halves are each about 15 to 20 km across (*right*).

However, the occultation timings don't match the silhouette expected for a spherical object. Instead, campaign leader Marc Buie (Southwest Research Institute) reports, it could be highly elongated (like a skinny eggplant) or it might be a pair of objects, either touching or twirling around each other at very close range.

Corroborating observations come from Hubble Space Telescope observations carried out by Susan Benecchi (Planetary Science Institute) between June 25th and July 4th. She reports that 2014 MU_{69} showed little variation in brightness during the first observing run but that the changes became more pronounced later on. Benecchi says this is consistent with a double object; Buie prefers that option, too.

Meanwhile, negative results from the first two occultations (especially observations from NASA's SOFIA flying observatory on July 10th) build confidence that New Horizons' forthcoming target isn't ringed by impact debris, which would have posed a threat to the spacecraft as it whizzes by the rock at 13.7 km per second.

■ J. KELLY BEATTY

MARS: DAVID POLISHOOK / WEIZMANN INSTITUTE OF SCIENCE; KUIPER BELT: NASA / JHU APL / SWRI / ALEX PARKER

GALAXIES

Milky Way May Be Made with Swapped Gas

▲ The barred spiral NGC 4911, surrounded by galactic friends in the Coma Cluster.

HIGH-POWERED SIMULATIONS suggest that half of the material in the Milky Way could come from other galaxies. Although galaxies might look like pristine "island universes," exchanging stars and gas only when they crash into each other, stellar winds and supernovae regularly blow huge amounts of gas out of their host galaxies. This gas might rain back down, or it might escape into intergalactic space, where other galaxies can sweep it up.

Using the FIRE simulations (*S&T:* May 2017, p. 34), Daniel Anglés-Alcázar (Northwestern University) and colleagues took a closer look at these processes. The team watched the development of multiple systems, each with a different kind of galaxy in the middle. The simulations tracked gas particles as the gas flowed here and there, moving out of and back into individual galaxies, as well as between the central member and the ones surrounding it.

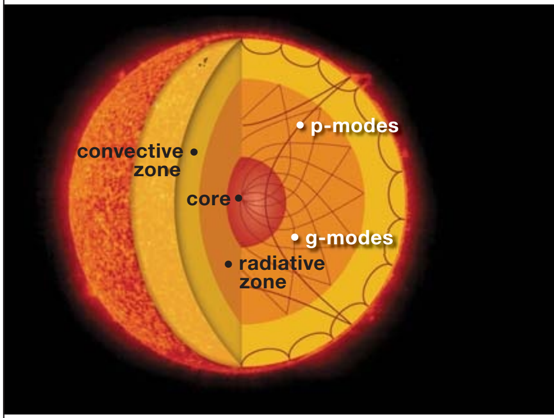
Previous work had suggested maybe 10–20% of the gas in a Milky Way–mass galaxy would come from other galaxies. Reporting in the October 1st *Monthly Notices of the Royal Astronomical Society*, the FIRE team's numbers are much higher: Somewhere between 20% and 60% of the gas in a modern Milky Way is "intergalactic" — stuff blown out of one galaxy and nabbed by another.

In today's universe, the team finds, the exchange of gas between galaxies via galactic-scale winds can even dominate how a big stellar metropolis acquires material. Once a galaxy's early years of formation have passed, gas swaps outstrip in importance the accretion of fresh, unprocessed gas and the recycling of the galaxy's own outflows. The simulations also suggest that a Milky Way-like system permanently chucks out a ton of gas, equivalent to the mass of all our galaxy's stars — that's in the range of tens of billions of Suns.

■ CAMILLE M. CARLISLE

SUN

Solar Waves Reveal Core's Spin



▲ Cutaway diagram of the Sun

SOLAR ASTRONOMERS might finally have detected the effect of gravity waves in our star's core, revealing that the Sun's central region rotates about four times faster than its outer layers.

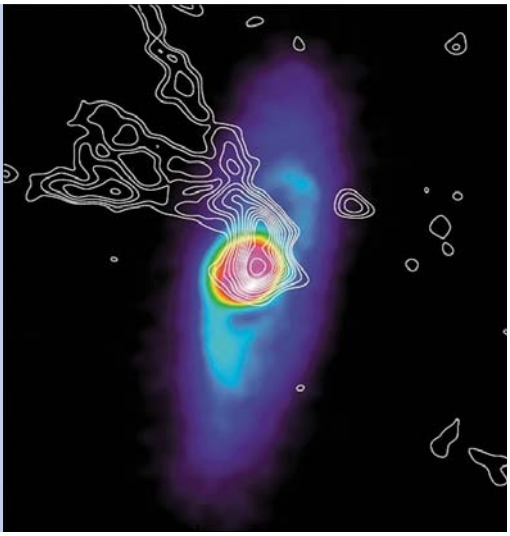
Astronomers have studied solar oscillations since the 1960s, but so far they've only detected acoustic waves, not gravity waves (called *g modes*). Gravity waves are a sloshing motion spurred by the turbulent convection that happens in the Sun's outermost layer. They don't survive long there, though — instead, they become trapped below, in the radiative zone and the core, where material moves in a way that doesn't erase them.

STARS

ALMA Sees New Star Launch Wind

◖ Observations from the Atacama Large Millimeter/submillimeter Array (ALMA), published in the July 2017 *Astronomy & Astrophysics*, reveal a still-forming star as it launches a wind from the edge of the disk that feeds it. The color gradient, corresponding to the intensity of 1.3-mm radiation, represents heat emitted from the dusty disk that surrounds the protostar BHB07-11 out to 80 a.u. A sparser envelope (outer blue regions) feeds the dense central disk. Other wavelengths tracing gas motions show a lopsided wind (white contours) blowing off the disk's edge, between 90 and 130 a.u. from the star. Astronomers knew that protostars must produce winds in order to carry away the infalling gas's native spin and enable accretion. But these observations are the first to identify the launch location as the region where infalling gas meets the disk's edge.

■ MONICA YOUNG



GALAXIES: NASA / ESA / HUBBLE HERITAGE TEAM (STSCI / AURA); ALMA: ©MPE; SUN: ESA / NASA

If solar physicists could detect gravity waves, then they could learn how fast the core rotates. (Acoustic waves pass through the core too quickly to be sensitive to its spin.) But every potential detection of gravity waves, going back to the 1970s, has not held up against further investigation.

Eric Fossat (Côte d'Azur Observatory, France) and colleagues now say they've unearthed this shy signal. The team dug through more than 16 years of data from the joint ESA/NASA Solar and Heliospheric Observatory (SOHO) spacecraft, launched in 1995 in part to look for g modes reverberating through the Sun. Counterintuitively, to find them, the researchers focused on acoustic waves that had moved through the core. Gravity waves change the Sun's internal structure and density, so their presence should affect the sound waves' travel time.

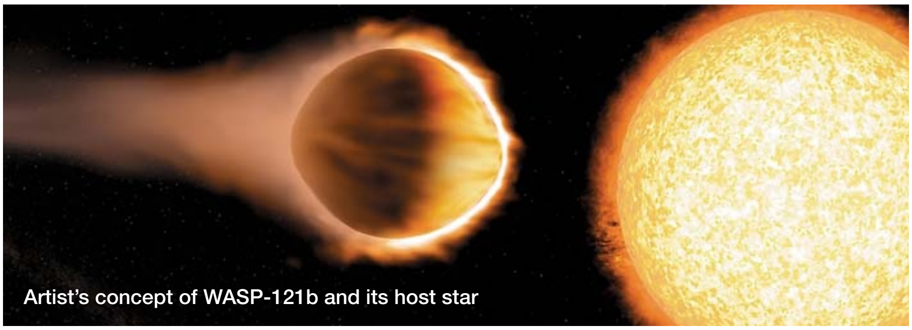
Careful analysis of more than 34,000 eight-hour chunks of acoustic-wave data uncovered what looks like the collective imprint of many gravity waves, Fossat's team reports in the August *Astronomy & Astrophysics*.

The gravity waves' frequency suggests that the core rotates every seven days. That's about four times faster than the radiative zone above it, and four to five times faster than the surface. Work using Kepler data suggests that many other stars' cores also rotate at different speeds than their outer layers. If the SOHO detection proves true, then it'll be one of the spacecraft's top discoveries.

■ CAMILLE M. CARLISLE

EXOPLANETS

Hot Jupiter Might Have Ozone-like Layer



Artist's concept of WASP-121b and its host star

ASTRONOMERS HAVE potentially detected a stratosphere in the atmosphere of the hot Jupiter WASP-121b. In a stratosphere, temperature *increases* with altitude — unlike the troposphere below it, where the temperature drops the higher you go. Earth has a stratosphere because of ozone, which absorbs the Sun's ultraviolet rays and heats up this atmospheric layer above it.

By watching the hot Jupiter pass behind its yellow *F*-type star with the Hubble and Spitzer Space Telescopes, Thomas Evans (University of Exeter, UK) and colleagues teased out light that came from the exoplanet. Although they couldn't resolve individual spectral lines in this light, the researchers were able to study the shape that multiple, mushed-together lines made. Among the shapes they uncovered is a bump in the exoplanet's spectra that they think is emission from water.

We should only detect emission from water molecules if the part of the upper atmosphere they're in is hotter than the gas that lies below — if the gas below were hotter, the water would absorb some of its glow, an effect not seen here. Thus, the team concludes in the August 3rd *Nature* that WASP-121b has a stratosphere. That result implies it has some sort of ozone-mimicking compound in its upper atmosphere, perhaps vanadium oxide (VO), although the team couldn't determine whether VO is present.

■ CAMILLE M. CARLISLE

EXOPLANET: ENGINE HOUSE VFX / AT-BRISTOL SCIENCE CENTRE / UNIVERSITY OF EXETER

IN BRIEF

■ BY DAVID DICKINSON

Goodbye, LISA Pathfinder

The LISA Pathfinder mission came to a quiet end, as planned, on July 18th. LISA Pathfinder launched in December 2015, entering an orbit 1.5 million km (1 million miles) sunward of Earth. The gravitationally tranquil environment enabled the spacecraft to keep two small cubes in freefall, nearly motionless with respect to each other. This technology demonstration was key to the upcoming Laser Interferometer Space Antenna (LISA) mission, which will listen for low-frequency gravitational waves such as those generated by merging supermassive black holes.

Saturn's Mysterious Magnetic Field

Saturn's magnetic axis aligns surprisingly well with its rotational axis. As NASA's Cassini conducted its dramatic Grand Finale dives between Saturn and its rings, the magnetometer onboard measured the planet's magnetic field. Its tilt is much smaller than 0.06°, which was the lower limit obtained prior to the Grand Finale. Magnetic and rotational axes are misaligned in other magnetically active planets; astronomers think such tilts help sustain those planets' internal dynamos. Saturn's good alignment suggests we don't understand its internal structure as well as we thought we did. The wobble of a misaligned magnetic field would also have revealed the rotation of the planet's core, and without that misalignment, scientists are still unsure of the true length of Saturn's day.

Sprites in Space

Six of "the world's smallest spacecraft," dubbed Sprites, piggybacked into low-Earth orbit on June 23rd. The spacecraft, each slightly larger than a postage stamp, weigh 4 grams each and contain solar panels, sensors, and communication equipment. Two of the Sprites were mounted on larger satellites named Venta and Max Valier; Max Valier carried another four Sprites in its cargo container for deployment as independent satellites. While communication with the Max Valier satellite has failed, halting the release of its Sprites, several ground stations have made contact with the Sprite mounted on the Venta satellite. The achievement is a small milestone for Breakthrough Starshot, which helped create the microsatellites as a test for building future interstellar travelers.

Chasing the Elusive 2014 MU_{69}

New Horizons' next target was hard to find and remains a bear to pin down, but persistence has paid off.

AS THE WORLD KNOWS, the New Horizons spacecraft spectacularly achieved its primary mission — to explore Pluto and its moons — in July 2015 (*S&T:* Oct. 2016, p. 14). But all along NASA managers had counted on visiting another object farther out in the Kuiper Belt. At launch in 2006, there was no known body it could reach, yet astronomers had sound statistical arguments for why they would find such an object during the decade-long trip to Pluto.

Except it almost didn't happen. Despite searching for years using the best telescopes on Earth, New Horizons team members failed to turn up a suitable second destination. One problem: The spacecraft was headed toward a region of sky packed with stars, and this made a dim Kuiper Belt object much harder to discover.

By 2014, New Horizons scientists realized they might not find their post-Pluto target by late summer, after which it would be too late. In desperation, they requested discretionary time on the Hubble Space Telescope. After an initial rejection and some tense back-and-forth, they gained a couple weeks' worth of Hubble observing time.

In June 2014, this investment paid off with the discovery of two targetable objects. One of those, now designated 2014 MU_{69}, became the spacecraft's next destination. On New Year's Day, 2019, this tiny world will become the most distant place ever visited by a robotic craft.

But identifying that distant blip was just the start of planning for this challenging encounter. The team needs to know the exact locations of both the spacecraft and the target, as well as something about the object's properties — size, shape, and surface reflectivity — to take all the planned images and spectra. And it'd be helpful to ensure that the target doesn't lie amidst a swarm of debris that might doom the spacecraft.

Fortuitously, the New Horizons team recently received some help from three faint stars that MU_{69} was predicted to pass directly in front of in early June to mid-July of this year. If the orbit for MU_{69} determined from the Hubble observations was correct, then well-positioned observers could watch each star's light blocked for a few seconds. Those cover-ups would, in turn, reveal the target's size and overall shape.

So the New Horizons team dispatched astronomers to observe the occultations (*S&T:* Oct. 2017, p. 11). The first event — visible on June 3rd from Argentina and South Africa — failed to catch the star's disappearance.

Finally, on July 17th, just over two years after the Pluto flyby, five observing teams in Argentina nailed it.

They tried again on July 10th with a dedicated flight over a remote stretch of the Pacific by NASA's SOFIA airborne infrared observatory. Again, no luck.

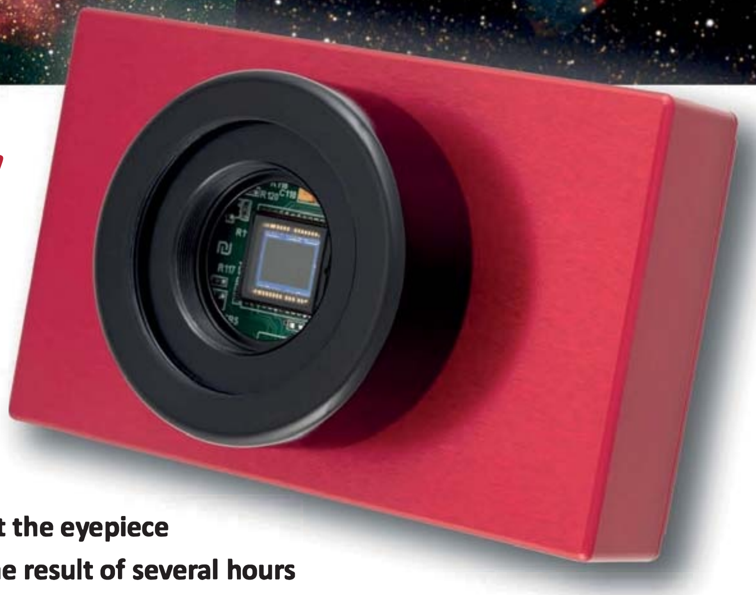
These negative results at least told us where the object *wasn't*, and they suggested that MU_{69} has no encompassing cloud of spacecraft-killing debris. But the thought that it might not be exactly on the predicted orbit, or might have properties very different from what we expected, was unsettling to those tasked with preparing for its one fleeting flyby.

Finally, on July 17th, just over two years after the Pluto flyby, five observing teams in Argentina nailed it. The results did more than refine MU_{69}'s orbit; they also hint that it's a supremely strange object, perhaps a double-lobed one (see page 9). It's another victory for the New Horizons team, and it promises the rest of us more frozen delights from the Kuiper Belt.

▲ 2014 MU_{69}, seen here with the New Horizons spacecraft in an artist's concept that may now need revision, has seriously challenged astronomers seeking to get a better fix on it.

NASA / JHUAPL / SWRI / ALEX PARKER

■ **DAVID GRINSPOON**, an astrobiologist at the Planetary Science Institute, is author of *Earth in Human Hands: Shaping Our Planet's Future.*



THE RACE TO MARS

Timing is everything in space exploration, and in 2020 the time will be right to launch an armada of explorers to the Red Planet in search of signs of life.

RED PLANET ROVING This artist's concept depicts NASA's Mars 2020 rover drilling into Martian rock. The rover is one of four government missions scheduled to launch toward the Red Planet in 2020.

NASA / JPL-CALTECH

Every 26 months, Earth and Mars hurtle close to each other in space, offering a short window during which a voyage to the Red Planet is as efficient a trip as possible. Apart from 2009, engineers have used each such window this century to send spacecraft to Mars. The next, in 2018, will see NASA launch its Insight robotic lander, aiming to study the planet's geological evolution.

But 2020 will be special. Here on Earth, a conflation of technological progress, exploration strategies, and delayed missions will mean that not one but four (or more) spacecraft will be rocketing to the Red Planet.

Not only are the usual suspects NASA and ESA sending missions in 2020, but first-time voyagers are going, too. The United Arab Emirates's Hope orbiter will join six other spacecraft already looping around Mars, as the first-ever mission to the Red Planet by an Arab country. Meanwhile, China will send its first independent mission to the Red Planet, a payload consisting of three elements: an orbiter, lander, and rover.

Outwardly, Mars is a dead red rock. So why the fascination? Why send so many spacecraft to the same planet? The plain truth is that Mars is Earth's most similar neighbor. Observations from previous missions suggest that this world once had a thicker atmosphere, flowing water, and all the ingredients necessary to sustain life. As a result, beyond the desire to physically set foot on a new world, the possibility of finding hidden alien life awakens the natural human urge to explore.

Dusting for Fingerprints

After a barren period following the 1976 touchdowns of the audacious Viking landers (an interval broken only by two doomed USSR missions), a concerted effort to reach the Red Planet began in the 1990s, later morphing into NASA's "follow the water" strategy (see page 16). Using the orbital lineups as opportunities, NASA — joined by other agencies — has since undertaken a series of missions designed to slice away, piece by piece, the mysteries of the Red Planet.

Mars Pathfinder and its tiny Sojourner rover gave this quest wheels, and NASA teams later followed up on their success by dropping two Mars Exploration Rovers — Spirit and Opportunity — onto the planet's surface in 2004 and a much larger third — Curiosity — in 2012. These latter three rovers have trundled across the surface uncovering compelling evidence that Mars might once have been able to harbor life.

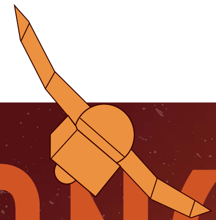
Yet this life — if it existed at all — was microscopic, perhaps only leaving the tiniest trace of its former existence. Although the Viking landers did test interesting samples suggestive of ancient life, their results were judged inconclusive — hardly surprising given that NASA conducted the mission nearly 20 years before the term "biosignature" had even been coined to describe evidence pointing to past or present life.

"It's actually really hard to tell what was made by life and what wasn't . . . unless you're looking at dinosaur bones," notes planetary scientist Briony Horgan (Purdue University), co-investigator on the Mastcam-Z camera system for NASA's Mars 2020 rover — the first NASA mission since Viking with the stated objective of seeking direct evidence for ancient life. This is why today's search takes a more holistic view. "You start with what was the type of environment you are in, what was the chemistry of that environment, and then — given that — what kind of life could survive here and what kinds of biosignatures would that life leave behind."

If found, these biosignatures will be subtle: "We look for shapes preserved in the rocks that are suggestive of the past presence or activity of life," says Kenneth Williford (Jet Propulsion Laboratory), Mars 2020's deputy project scientist. "And then we look for chemical disequilibria, organic matter, or biologically important elements distributed in a way that is correlated with those shapes in the rock."

A great example here on Earth of ancient life providing vestigial clues to its former existence is stromatolites. Stromatolites form from mats of photosynthetic bacteria that trap sediments and microbes, building layer upon layer until eventually they become dome-like rock structures, sometimes reaching basketball proportions. Modern ones are still developing in the shallow waters of the Bahamas and
(continued on page 18)

▲ **STROMATOLITES** These structures form when microbial mats catch sediment and build it up, layer by layer. Ancient stromatolites' unique combination of composition and structure provides some of the earliest records of life on Earth. Scientists would like to find similarly convincing fossils on Mars.



History of MARS MISSIONS

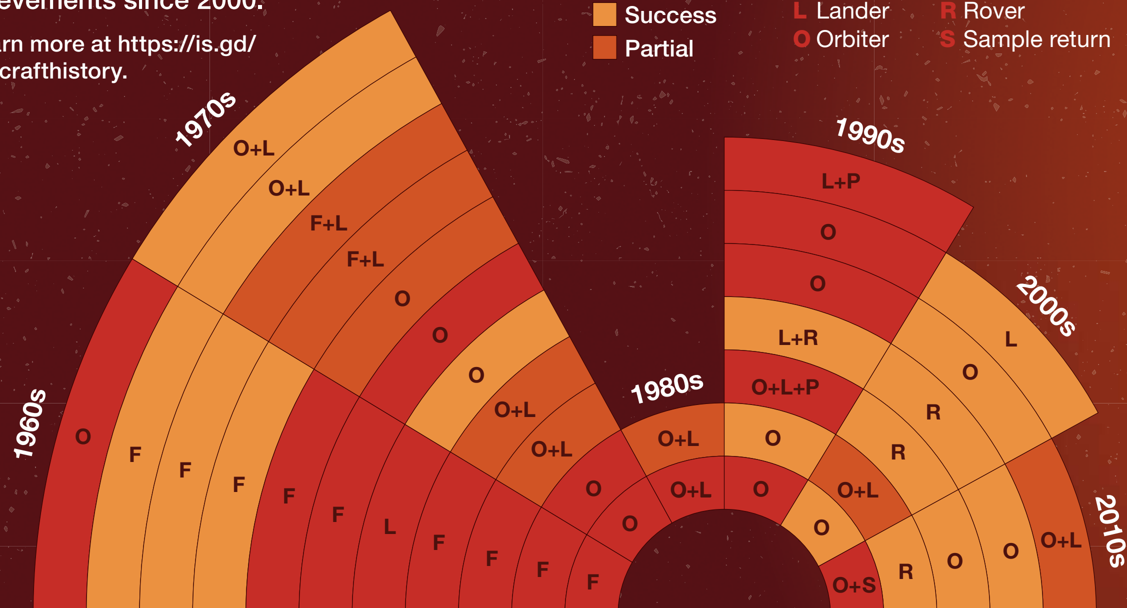
Camille M. Carlisle
Illustration by Terri Dubé

The spacecraft launching in 2020 build on more than a half century of exploration, much of it unsuccessful. A revamped, strategic approach by NASA fostered a string of achievements since 2000.

• Learn more at https://is.gd/marscrafthistory.

Success or Failure?

So far, humans have launched 42 missions to the Red Planet. Of those, 43% have failed, 38% succeeded, and 19% were partial successes. The low success rate has led scientists to joke about the "Martian ghoul."



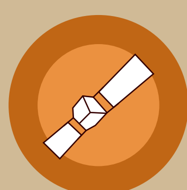
Mars Exploration
Missions and NASA Strategies

NASA began a "Follow the Water" strategy for its Mars Exploration Program in the early 2000s. The evolving approach includes ESA missions NASA has collaborated on. Although not formally part of the Mars Exploration Program, other projects (off-white) are joining the effort and are shown here for timeline completeness.

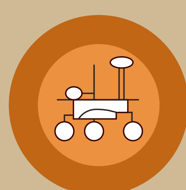
- Follow the water
- Prepare for human exploration
- Explore habitability
- Seek signs of life
- Not part of program

LAUNCH YEAR AND NAME
(F) Flown
(ID) In Development

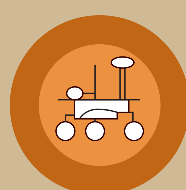
2001 (F)
Mars
Odyssey



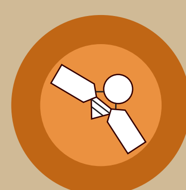
2003 (F)
Mars
Express



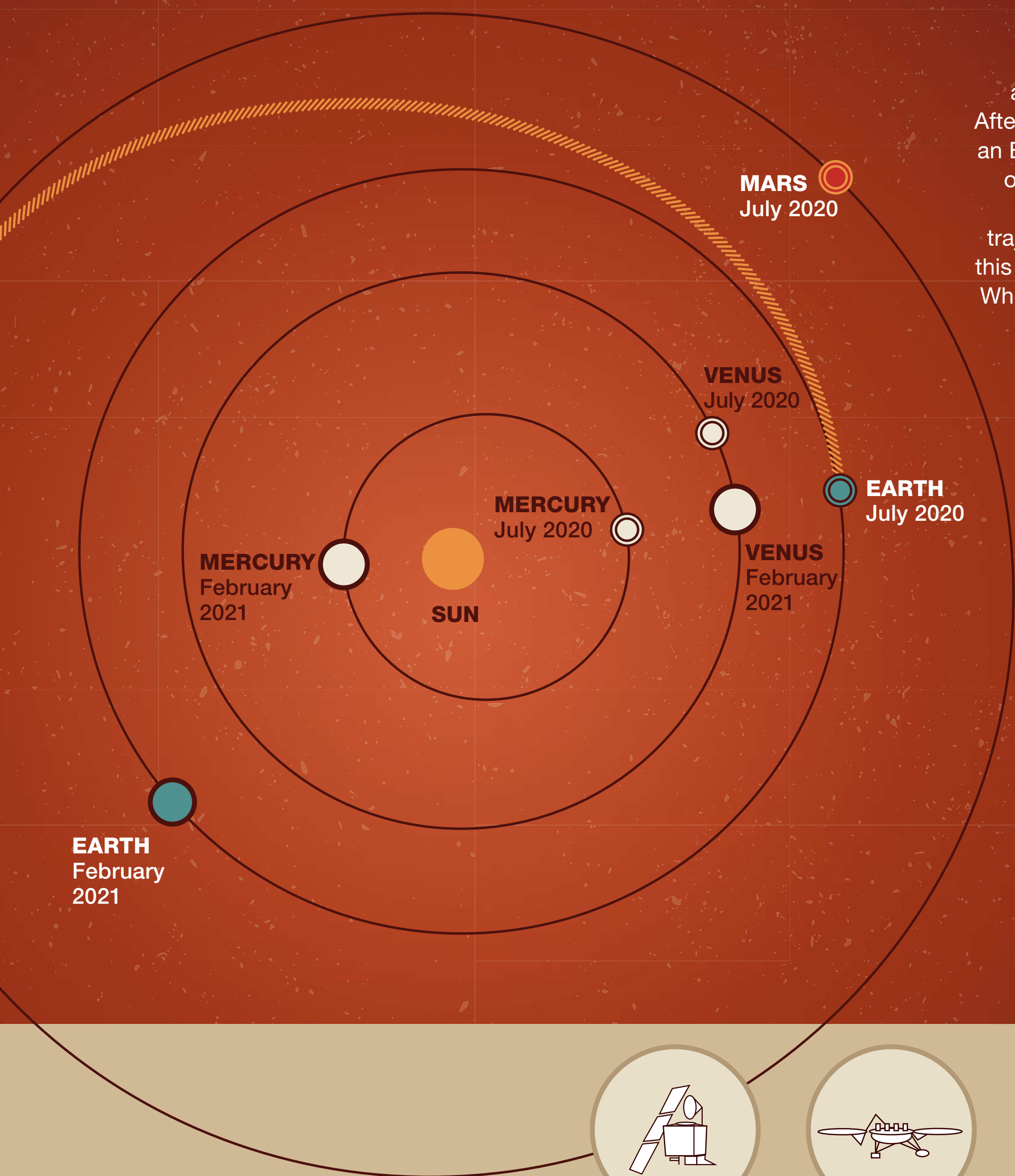
2003 (F)
MER
Spirit



2003 (F)
MER
Opportunity



2005 (F)
Mars Reconnaissance
Orbiter

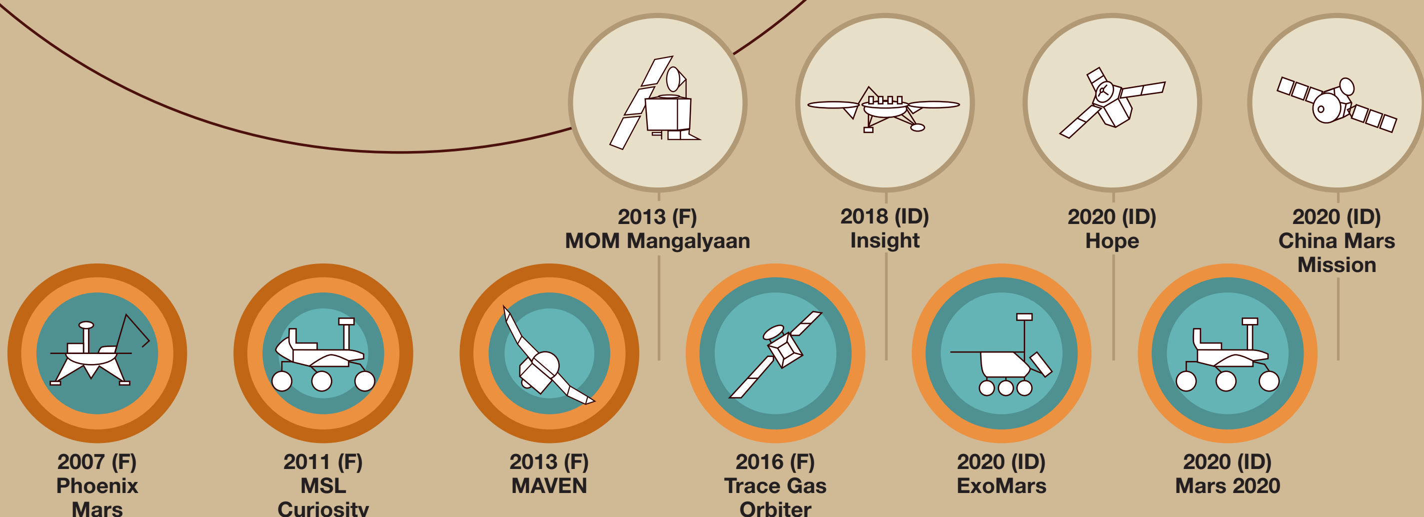


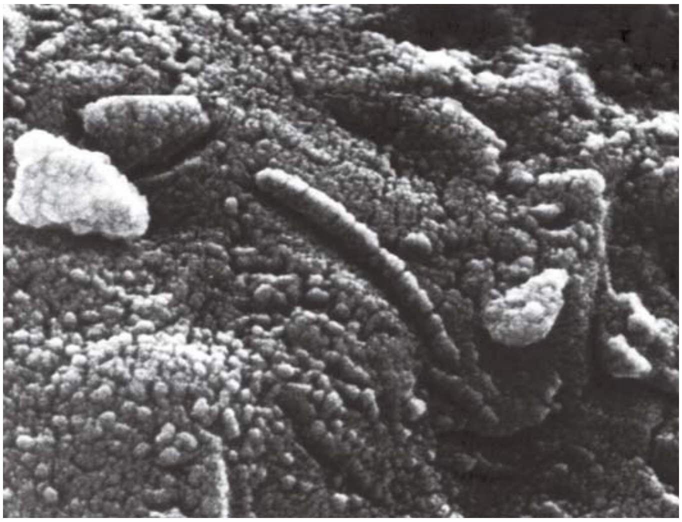
Flight Plan 2020

To minimize propellant, Mars-bound spacecraft take the most efficient path from Earth to Mars. Sitting on the launch pad, the spacecraft already orbits the Sun (with Earth). After it launches, it boosts itself out of an Earthlike orbit into a more elliptical one, with an aphelion that matches up with Mars's orbit. The craft's trajectory follows the outgoing arc of this ellipse (approximate path shown). When it reaches Mars, the spacecraft enters orbit or, if a lander, hits the planet "in a controlled way."

123,000
km/hr
Mars 2020 spacecraft's speed relative to the Sun at launch

64,000
km/hr
Mars 2020 spacecraft's speed relative to Mars at launch





▲ **LIFE FROM MARS?** These globule structures in the meteorite ALH 84001 are similar in texture and size to some made by bacteria on Earth. However, life isn't *required* to explain their formation.

▶ **CACHE CLOSEUP** The Mars 2020's CacheCam provides a top-down view into the rover's sample tube.

◀ **NASA'S MARS 2020** Based on the Curiosity rover design, Mars 2020 is about 3 meters long and 2.2 meters tall (10 feet and 7 feet, respectively), and it weighs less than a compact car.

▲ **NAVIGATING OBSTACLES** These images provide an example of what the navigation camera aboard NASA's 2020 rover sees. On the left is a pile of rocks as seen by the rover, from 15 meters (roughly 50 feet) away. The right-hand picture shows how camera data reveal the pile's 3D contours. Using the 3D information, the rover team can plan precise travel and arm movements.

(continued from page 15)
Australia, but ancient stromatolites date as far back as 3½ billion years, leaving behind a structure, trapped organics, and unusual chemical isotopes that together cannot easily be explained without life having been present.

Caching In

Loaded up with a panoply of instruments, the car-sized Mars 2020 rover should be able to detect any stromatolite-like Martian biosignatures. The most prominent of these instruments from the outside will be the rover's eyes: Mastcam-Z and Supercam, perched on a mast 2 meters above ground level. The former can take high-definition video, panoramic color, and 3D images of the Martian surface and features in the atmosphere. "Mastcam-Z will play a major role in helping to select the samples, as well as helping to characterize the geology and geological context of the landing site," says Mastcam-Z principal investigator Jim Bell (Arizona State University).

Meanwhile, Supercam will dissect organic compounds from a distance, identifying the chemical and mineral makeup of targets as small as a pencil point from 7 meters away. Supercam does this in part by using Raman spectroscopy — a technique whereby laser light is shone on a sample and the scattered light offers information about molecular vibrations inside the material, which scientists interpret to identify the sample's makeup. This versatile instrument also performs color imaging and visible and near-infrared spectroscopy.

Although used in chemistry labs across the world for decades to analyze the fingerprints of molecules, Raman spectroscopy is a new technology for the surface of Mars. And Mars 2020 will actually be carrying two of these spectrometers: Supercam on the mast and SHERLOC (Scanning Habitable Environments with Raman and Luminescence for Organics and Chemicals) on the robotic arm's turret. Also out on a turret is PIXL (Planetary Instrument for X-ray Lithochemistry), an X-ray spectrometer. It identifies chemical elements at a tiny scale. Both instruments are cutting-edge and are what geologists utilize when hunting for signs of past life in ancient rocks here on Earth.

Two other Mars 2020 instruments, from Spain and Norway, respectively, will contribute weather measurements and ground-penetrating radar. There's even one — MOXIE (Mars Oxygen In-Situ Resource Utilization Experiment) — aiming to produce oxygen from the Martian carbon-dioxide atmosphere. In future crewed missions, a MOXIE-like device could produce oxygen for propellant off the surface or for breathing.

But what has caused the most controversy and excitement is a new system for caching Mars rocks. "The rover might not be able to detect definitive biosignatures on its own," says Horgan. "Hence a core part of this mission is a follow-on sample return." The Mars 2020 rover will collect and hermetically seal about 30 tubes of surface material that its scientists deem likely to contain signs of life. These pencil-size samples will be left on the surface in a "depot" ready to be collected in the future.

METEORITE: NASA; SAMPLE VIEW: NASA / JPL-CALTECH; ROVER: NASA; ROCKS: NASA / JPL-CALTECH

▲ **EURASIAN MARS ROVER** ExoMars's standout feature is its drill (tall black cylinder), which will penetrate 2 meters beneath the surface.

Why go to the trouble of returning samples to Earth? One word: skepticism. A decade ago scientists probed a Martian meteorite (ALH 84001), found in Antarctica in 1984, and concluded that it contained microscopic fossilized evidence of bacteria. The resulting media attention even led to a statement from then U.S. President Bill Clinton in which he proclaimed: "If this discovery is confirmed, it will surely be one of the most stunning insights into our universe that science has ever uncovered." But when other teams scrutinized the results using every possible instrument and various independent labs, they found that the Martian rock's unusual features could all be explained without life.

"I think we'd be in the same situation, so we need to bring those samples back and run the best possible analyses on them," says Bell.

Drilling for Life

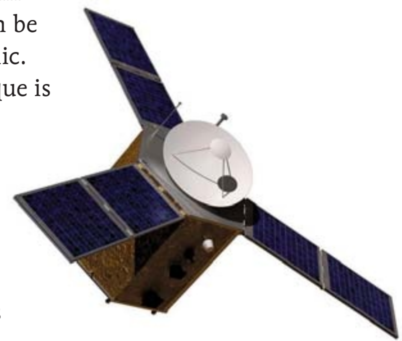
While caching and returning samples is universally acknowledged as the best solution to quelling skepticism, many think ancient life or its vestiges can only remain preserved deep below the surface. Sadly, Mars 2020 doesn't carry any deep digging tools. "The Martian atmosphere is extremely tenuous — the pressure is roughly one hundredth that of Earth — so radiation from the center of the galaxy and Sun penetrates unimpeded," explains Jorge Vago, project scientist on the ESA/Roscosmos mission to send the ExoMars 2020 rover to the surface of Mars. "This radiation acts like a million little knives that over millions of years cuts away the functional groups of the molecules you are trying to study, degrading them eventually beyond the point where you can recognize them."

To solve this issue, the ExoMars rover will carry the longest drill ever sent to the Red Planet, in order to tunnel a full 2 meters below the radiation-affected upper layers to more pristine rocks. "We think that it's going to be a big deal in terms of gaining access to better or more well-preserved samples for analysis," Vago enthuses.

The ESA/Roscosmos ExoMars mission is a two-part project to launch an orbiter and lander in 2016 and then a rover in 2020. With the first part of the mission being less than a stellar success (*S&T:* Feb. 2017, p. 10), whether the rover will land successfully or tragically crash is an open question. But if it does gently touch down on the Red Planet, ExoMars will be a highly capable machine, with a raft of instruments to rival Mars 2020's.

Like NASA's rover, it boasts cameras, infrared/visible and Raman spectrometers, and ground-penetrating radar. However, unfortunately bringing the deep drill means there is simply not enough room for a cache system. "It's very difficult to combine nice instruments, a large caching system, and a deep drill," notes Vago. "We tried, but found that it is almost impossible to do these three things on a single rover." Hence, ExoMars will have to rely on its onboard instruments' tests if it is to find evidence of life.

The best chance ExoMars has of finding these biosignatures is by detecting organics, carbon-based molecules that on Earth are the building blocks of life. This responsibility rests on the unique Mars Organic Molecule Analyzer (MOMA) instrument. MOMA will analyze organic molecules in much the same way as the Viking landers or Curiosity rover. Essentially it has a number of ovens to heat up Martian dirt. Any volatile materials will evaporate in the heat, at which point they can be extracted to see if they are organic. One problem is that this technique is plagued by *perchlorates* — salts that decompose when heated and oxidize the sample being studied. Results from such experiments in the past have proven inconclusive. However, the ExoMars team believes it has



▲ **EMIRATES' ENTRY** The UAE's Hope orbiter *(schematic above)* measures about 2⅓ meters wide by 3 meters tall (7¾ by 9½ feet) and, including fuel, will weigh about half again as much as NASA's rover. Here, engineers discuss disassembling the craft's sun shield baffle for inspection in the lab.

EUROPEAN ROVER: ESA / ATG MEDIALAB; UAE IMAGES: MOHAMMED BIN RASHID SPACE CENTRE

TOWARD A PERMANENT PRESENCE

NASA has had an active robot on the surface or in orbit at Mars since 1997.

solved the issue: "We also have a new way to extract organics, which is by using a large UV laser," says Vago. The laser flash-heats the sample so fast that these perchlorates don't have time to dissociate, meaning MOMA can extract and analyze the organics unimpeded.

New Contenders

Joining NASA and ESA in 2020, China plans to send an orbiter and surface mission as part of its rapidly expanding space endeavors. The still-unnamed project is the nation's second attempt to reach Mars: Its first, a joint endeavor with Russia, failed to leave Earth orbit in 2011. The details of the 2020 program are still shrouded in mystery, but what is known is that the rover will have six wheels and be roughly the same size as the Spirit and Opportunity rovers. Carrying four solar panels with an expected operational lifetime of three Martian months, the rover will tote 13 instruments, including a remote-sensing camera, ground-penetrating radar, and likely a host of spectrometers.

Speaking at a press conference, chief designer Zhang Rongqiao said that the goal of the mission is to study the planet's features, including its soil and atmosphere and the distribution of water and ice. It remains unclear if the Chinese mission will actively hunt for life, though the orbiter might be able to detect atmospheric methane.

The UAE Space Agency may only be three years old, but its scientists and engineers also have their sights set on arriving at Mars in 2021, to coincide with the 50th anniversary of the UAE's founding. Sporting an imager and two spectrometers, the car-size Hope orbiter aims to create the first global picture of Mars's climate, recording daily and seasonal changes in temperature, water vapor, and dust, as well as how the upper and lower atmospheric layers interact. It will also search for connections between today's weather and the ancient, hospitable one we think existed.

But the science is only one piece of a much larger strategy that the UAE is putting together, whose endgame is colonizing Mars by 2117. By reaching for this goal, the national space program is intended to make the UAE a hub of scientific innovation, reducing the country's dependence on oil by inspiring and enabling young Emiratis to enter careers in science and technology.

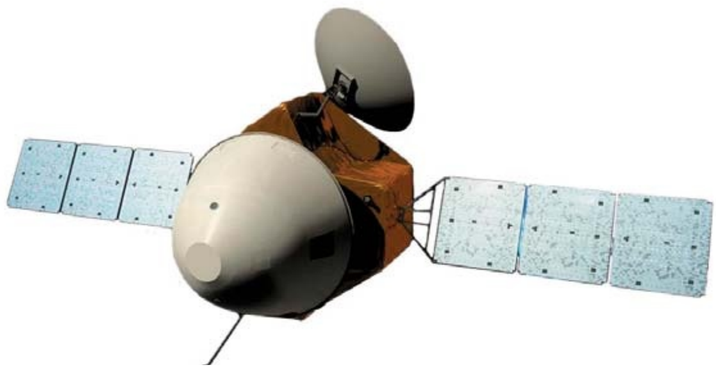
The private company SpaceX has lofty colonial ambitions for Mars, too, aiming to transport 1 million people to the planet in the next 50 to 100 years. The first step was to be an uncrewed Red Dragon spacecraft launch, also in 2020 and potentially landing somewhere in Arcadia Planitia. But recent statements by CEO Elon Musk suggest the Red Dragon's been nixed. It's unclear what will replace it, and when.

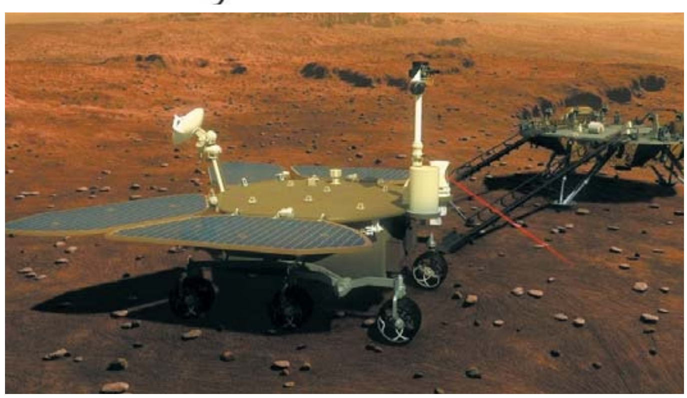
Although the dream of real-live people setting foot on Mars powers some (if not all) of these endeavors, current landing technologies can't make that happen. For example, NASA's methods rely on parachutes, airbags, and small retrorockets, but this would not cut the mustard for heavy, crewed missions to Mars, which will involve payloads roughly 20 times what Curiosity's descent technology can handle. Instead, some engineers are working on *supersonic retropropulsion* — firing thrusters to slow the craft when it's still traveling faster than sound. Although spacecraft have used retropropulsion to land on both the Moon and Mars at lower speeds, a vehicle's aerodynamics are completely different above Mach 1. It's unclear when this technology will have a chance to prove itself on Mars.

A Planet-size Time Capsule

Even if everything goes perfectly with these missions, the bad news for anyone hoping to find out if Martians once existed is that none of them is expected to find incontrovertible proof of past life. Simply put, the technology required is just too big to send to another planet. "We're just not there yet in terms of turning these super-sophisticated cutting-edge laboratories into instruments the size of a shoebox and putting them on a spacecraft," says Bell.

Searches for life present on Mars today will have to wait even longer. "When we say we will search for past or present life, what we really mean is that we concentrate on looking for signs of past life — from 3 to 4 billion years ago," explains





▲ **CHINA MISSION** China also plans to send an orbiter *(above)*, lander, and rover to Mars in 2020. The rover is in the foreground.

XINHUA (2)

GULLIES ON THE WALL This false-color image shows a crater wall in Utopia Planitia, with gully channels suggestive of water's activity. Some of the fractures resemble terrestrial ones that occur when ground ice is present.
NASA / JPL-CALTECH / UNIVERSITY OF ARIZONA

Vago. "I think if there is life on Mars now, it would have to be a couple of kilometers deep, and it would be a very expensive mission to drill to those depths."

If this is the case, then why not wait until society has developed the technology to determine if there is or isn't life on Mars once and for all? After all, part of the beauty of the Red Planet is that it is a planet-sized time capsule. "On Earth everything has been metamorphosed by burial and plate tectonics," says Horgan. "On Mars many of the rocks on the surface are in the exact place they were laid down 4 billion years ago — they're sitting there waiting for us to interpret them." Why rush?

Perhaps the reason comes less from the head and more from the heart. We want to know if we are not alone in the universe — and we want to know now. So hang waiting for technological advances: To steal from Tennyson, it is better to try and fail than never to try at all.

■ **BENJAMIN SKUSE** is a science writer based in Bristol, United Kingdom.

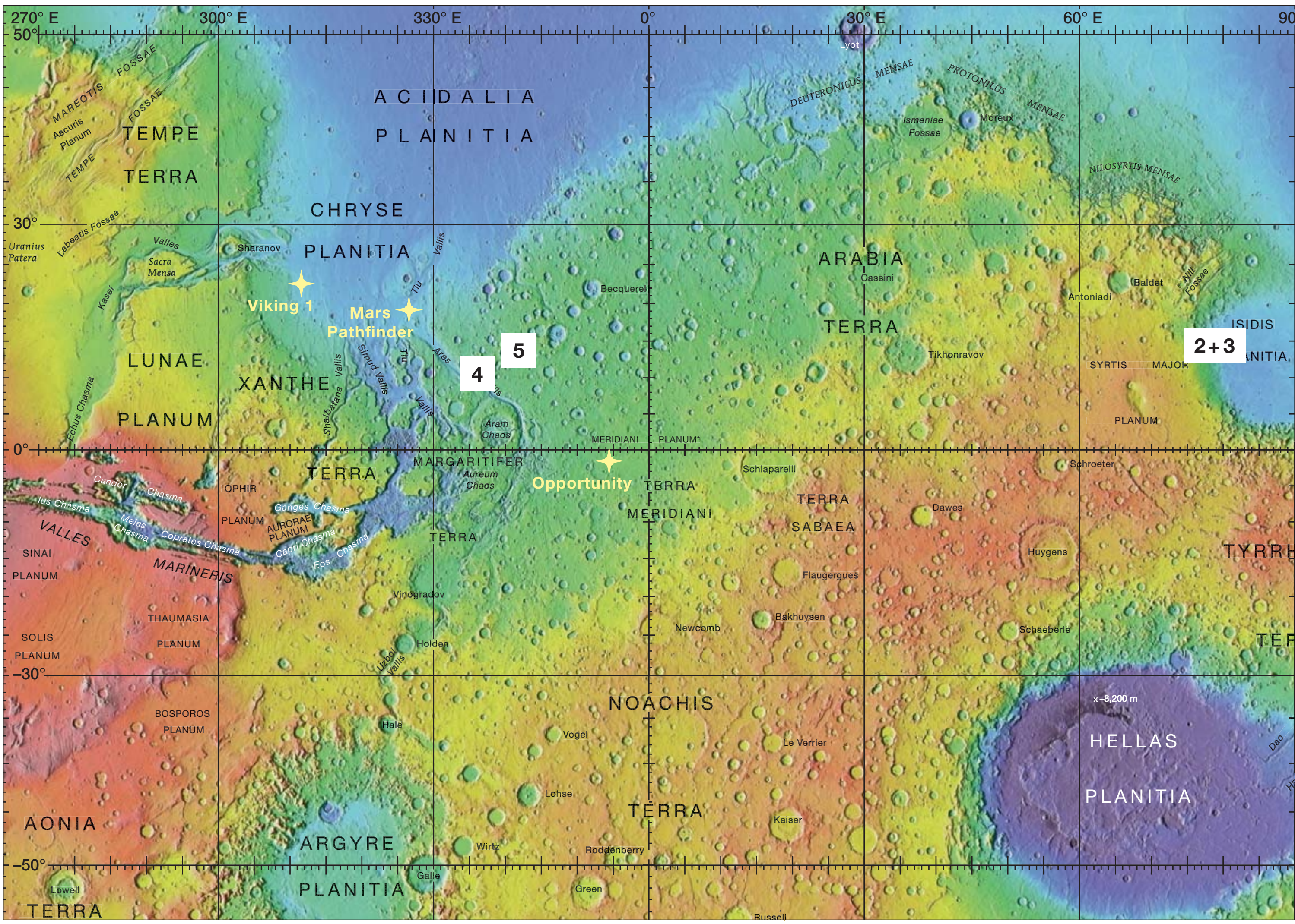
WHERE TO LAND?

While the Emirates Mars Mission has no intention of landing and the Chinese Mars Mission's landing site remains a secret (with officials only revealing it will touch down in the low latitudes of the northern hemisphere), NASA and ESA teams are busy whittling down where their spacecraft will land to a handful of contenders.

NASA **(landing ellipse 18 km × 14 km)**

1. Gusev – Mars rover Spirit found that mineral springs once burbled up from the rocks of Columbia Hills, specifically uncovering evidence that past floods might have formed a shallow lake inside this crater. "The minerals that precipitate out of those hot waters can trap microbes and organics, and help preserve biosignatures," says Horgan. "So astrobiologists are really excited about the chance to go back."

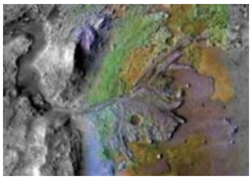
TOPOGRAPHIC MAP: U.S. GEOLOGICAL SURVEY



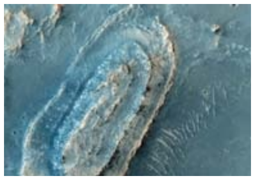
GUSEV: NASA / JPL-CALTECH / CORNELL; JEZERO: NASA / JPL-CALTECH / MSSS / JHU-APL; NE SYRTIS: NASA/JPL-CALTECH/UNIV. OF ARIZONA; OXIA PLANUM: NASA / MRO / HIRISE / OXIA PLANUM TEAM / LSSWG; MAWRTH VALLIS: ESA / DLR / FU BERLIN, CC BY-SA 3.0 IGO

1. Gusev

2. Jezero

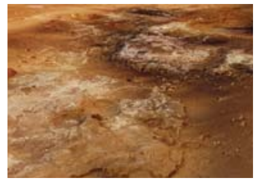


3. NE Syrtis



4. Oxia Planum

5. Mawrth Vallis



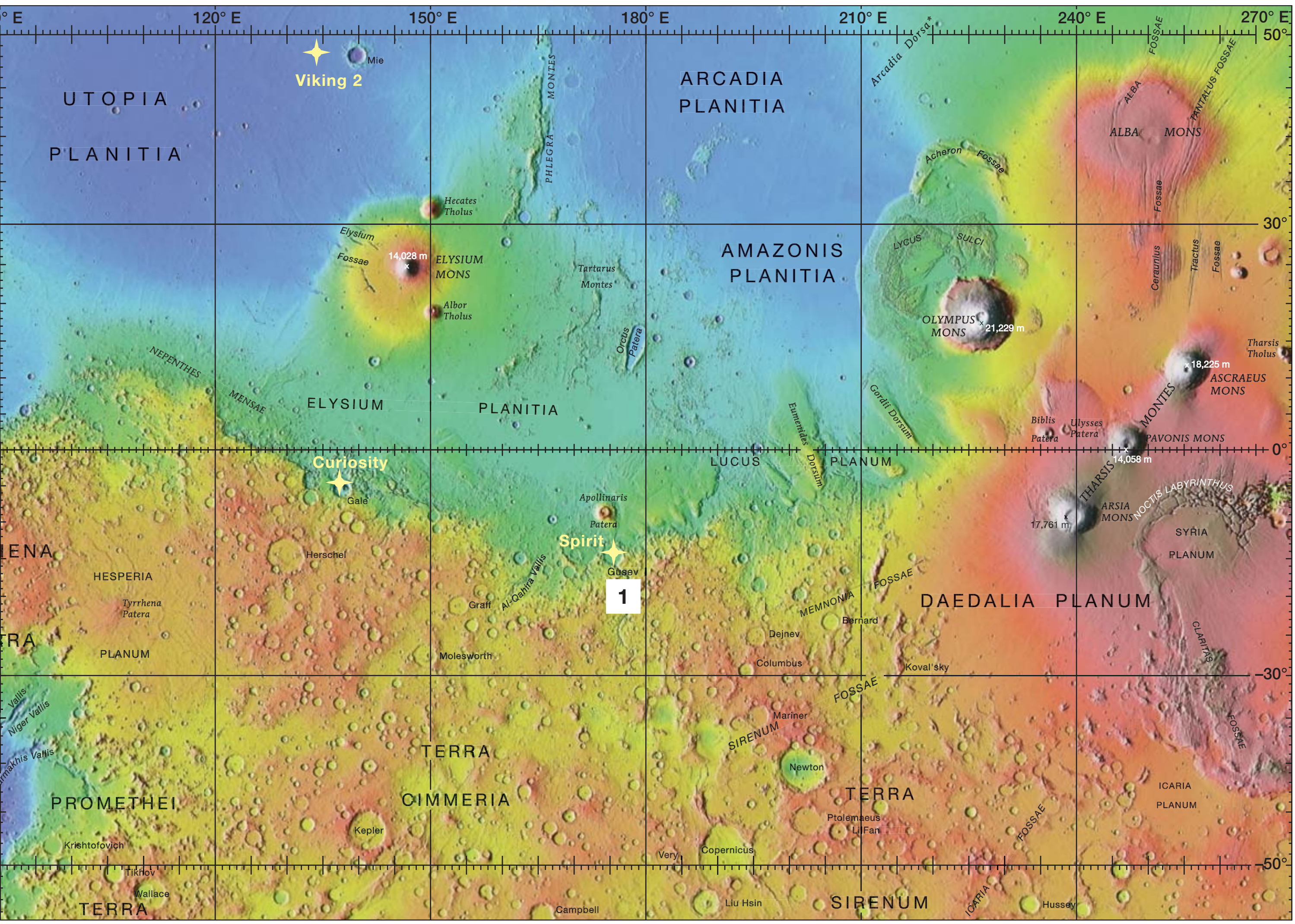
2. Jezero – This ancient crater contains evidence of a delta that formed when a river overran the crater's wall and flowed into it, creating a lake. Conceivably, microbial life could have lived in Jezero during one or more of the wet epochs the crater experienced. If so, signs of their remains might have been trapped in lakebed sediments.

3. Northeastern Syrtis Major Planum – Just upstream from Jezero, this broad plateau was once warmed by volcanic activity. Underground heat made springs flow and surface ice melt. "It's a layer cake stratigraphy of rocks containing all kinds of different minerals laid down in different environments," says Horgan. Some of these environments could have been ideal for microbes to flourish.

ExoMars (landing ellipse 104 km × 19 km)

4. Oxia Planum – This plain, covered in layers of clay-rich minerals, formed in wet conditions some 3.9 billion years ago and could have hosted microorganisms. The site features the remnants of a fan or delta near the outlet of Coogoon Valles, which might preserve biosignatures.

5. Mawrth Vallis – A few hundred kilometers away from Oxia Planum, Mawrth Vallis also contains layered, clay-rich sedimentary deposits, and hints at ancient localized ponds, subsurface aquifers, and possible hydrothermal activity. All of this could have provided the ideal conditions for life to thrive. Both sites lie just north of the equator and preserve a rich record of geological history from the planet's wetter past.



Treasures of the Tarantula

Researchers eagerly study a prodigious star-making factory in our galactic backyard.

I OFTEN LIKE TO GAZE at the Orion Nebula (Messier 42) from my home in Australia. Just 1,300 light-years away, it's the nearest region of massive star formation. It's also one of the closest *H II regions*, places where ultraviolet radiation from hot, young stars within a nebula ionizes the surrounding hydrogen gas.

After focusing on this eye-catching stellar nursery, I'll turn my attention 60° due south to the Large Magellanic Cloud (LMC). A satellite galaxy of our Milky Way, some 160,000 light-years away, it straddles the deep southern constellations Dorado and Mensa. Within it is the extraordinary H II region 30 Doradus, better known as the Tarantula Nebula. The region is clearly visible to the unaided eye as a bright, fuzzy spot in the LMC's northeast.

More than 600 light-years across, 30 Doradus boasts several young star clusters, vigorous star-forming regions, brightly glowing ionized gas, millions of stars (including the most massive known), and dark molecular clouds. If the Tarantula were as close to us as M42, we'd behold a staggering sight. Its glowing stars and filamentary tendrils of shining gas and dust would overflow the entire constellation of Orion, cast shadows at night, and be visible in daylight!

Yet 30 Doradus is much more than a southern-sky showpiece. It holds a significant place in our quest to understand the universe.

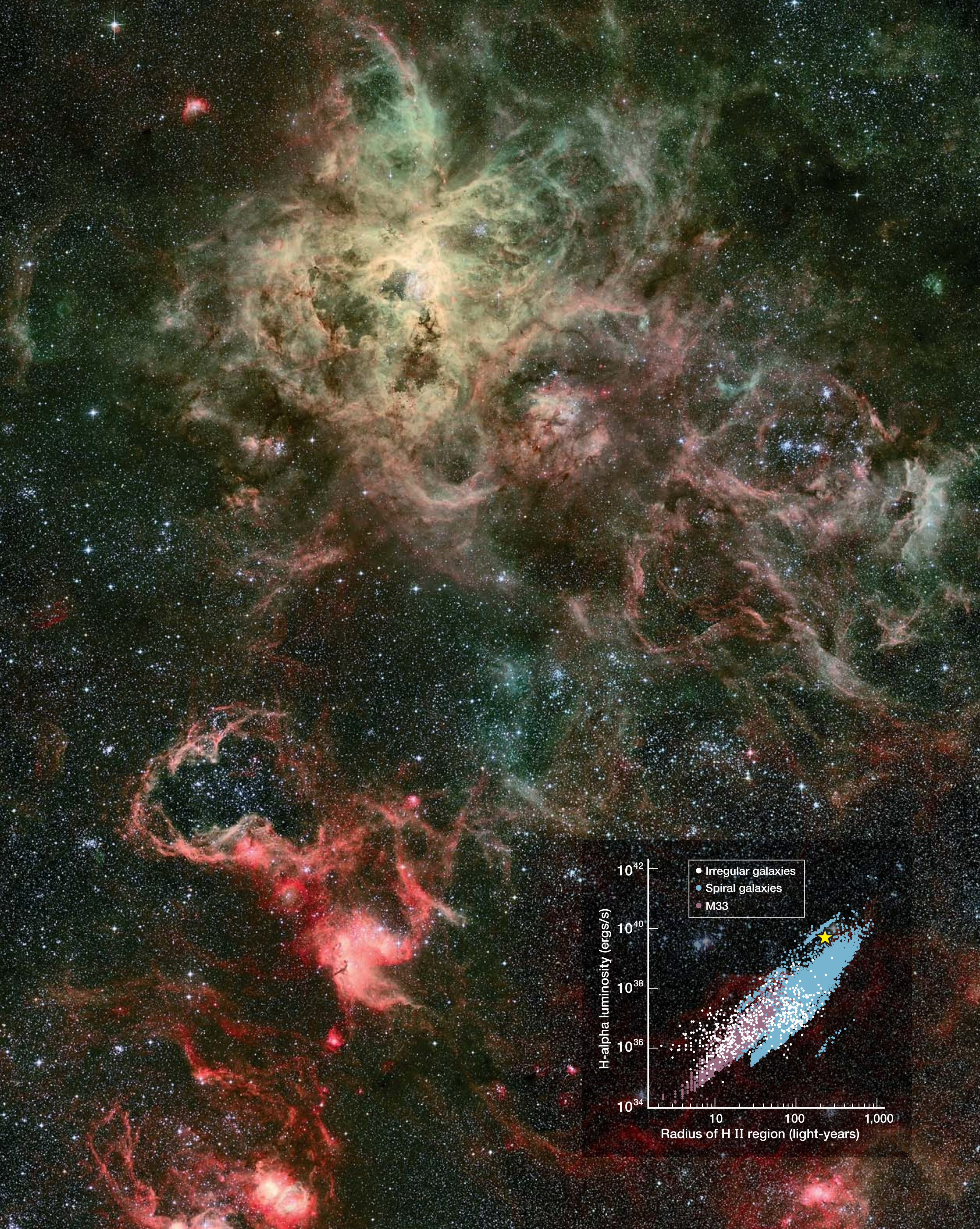
The Appeal of 30 Doradus

Galaxies are very much defined by regions of star formation, some so intense they're known as *starburst galaxies*. But most of these regions are unresolved in the best of telescopes. So astronomers' understanding of distant starbursts relies upon models underpinned by assumptions about what drives star formation, the limits that massive stars can reach, and how those stars influence the interstellar medium.

▲ **NEXT-DOOR GALAXY** The Large Magellanic Cloud, a dwarf galaxy of the Milky Way, is 160,000 light-years away. It's the home of the Tarantula Nebula (30 Doradus), set amid a complex of crimson-hued nebulae.

▶ **SPIDERY SPLENDOR** The Tarantula Nebula is a favorite of southern-sky astrophotographers. But it is equally prized by stellar researchers as a nearby and easily observed window on how star formation occurred in the early universe. This view measures 45 by 35 arcminutes. *Inset:* Gauged by its rate of star formation, the Tarantula Nebula (yellow star) has few peers, as shown in this plot of some 22,000 star-forming regions in nearby galaxies, including the well-studied spiral M33.

IMAGE: GERALD RHEMANN; FACING-PAGE IMAGE: ESO / ROBERT FOSBURY; GRAPH: LAURA A. LOPEZ ET AL. / *ASTROPHYSICAL JOURNAL* 2011



Irregular galaxies
Spiral galaxies
M33
H-alpha luminosity (ergs/s)
10^{42}
10^{40}
10^{38}
10^{36}
10^{34}
10
100
1,000
Radius of H II region (light-years)

We can only study the closest starburst regions in the detail needed to fully understand the life cycles of stars and what shapes galaxy evolution. Fortunately, 30 Doradus is right in our galactic backyard. Nolan Walborn (Space Telescope Science Institute) notes that this complex nebula would appear less than 1 arcsecond wide at the distance of the Virgo Cluster, 65 million light-years away, leaving us unable to resolve its individual stars.

However, it's not just the Tarantula's proximity that makes it appealing. Seen nearly face-on to us, it offers a clear picture of its internal layout. Similarly, because the LMC is well above the Milky Way's central plane, there's little foreground reddening and interference. In addition, the LMC's stars contain "metals" (all elements other than hydrogen and helium) at abundances about half those in our solar neighborhood but similar to the early universe's. This allows researchers to study star formation as it must have occurred long ago, at a rate many times what it is today.

In fact, when it comes to creating stars, 30 Doradus has few peers. A 2011 study led by Laura Lopez (University of California, Santa Cruz) compared it with all the H II regions in 70 galaxies within 100 million light-years. Based on its amount of hydrogen-alpha emission, a proxy for the rate of star formation, 30 Doradus ranks in the top 1% of 21,000 H II regions in 57 spiral galaxies, and it tops the 614 H II regions found in the study's 13 irregular galaxies by a factor of 10!

So it's hardly surprising that every major space-based telescope has targeted 30 Doradus, as have the Southern Hemisphere's big observatories. Two major programs dominate recent research efforts. The Hubble Tarantula Treasury Project (HTTP) dedicated 60 orbits of the orbiting observatory's time to record 30 Doradus from the near ultraviolet to the near infrared. In Chile, the VLT-FLAMES Tarantula Survey (VFTS) used one of the four 8.2-meter Very Large Telescopes to obtain spectra of some 900 massive stars.

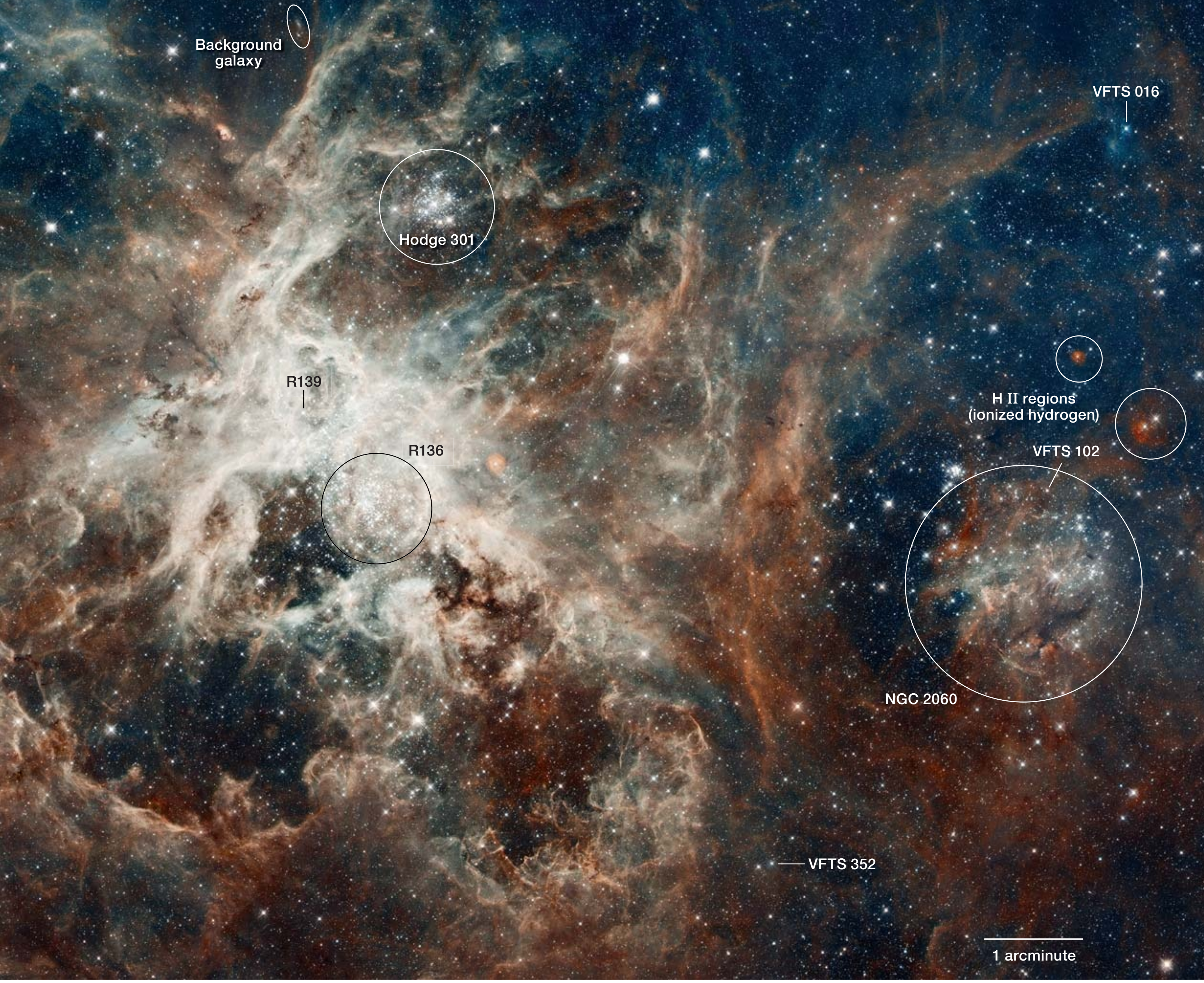
What's in the Tarantula Nebula

Object	Type	Description
NGC 2070	Star cluster	Massive cluster at heart of 30 Doradus; 130 light-years wide. Also known as Caldwell 103. Possible proto-globular?
Hodge 301	Star cluster	Oldest cluster in 30 Doradus; 25 to 30 million years old. Perhaps contributed to formation of NGC 2070.
R136	Star cluster	Portion of NGC 2070; believed to be less than 5 million years old
R136a	Stars	Dense knot within R136; 8 stars that range from 69 to 250 solar masses (most massive = R136a1)
R139	Binary star	Two *O*-type supergiants of 78 and 66 solar masses; most massive *O* binary yet discovered
VFTS 016	Star	Runaway star, first to be detected in 30 Doradus
VFTS 102	Star	Runaway star and fastest known rotator. Former companion perhaps now a pulsar?
VFTS 352	Binary star	"Overcontact binary" (its two components orbit so closely that their surfaces overlap)

These efforts allow astronomers to study individual stars within 30 Doradus, many smaller than our Sun. Studying their physical properties one at a time paints a picture of the population as a whole. Just as the Rosetta stone was the key to deciphering Egyptian hieroglyphs, so too is 30 Doradus seen as a unique laboratory to understand the processes involved in giant starburst regions.

▲ **STELLAR POWERHOUSE** *Left:* Compact and crowded, the star cluster R136 was once thought to be a single star within NGC 2070. Less than 5 million years old, it boasts scores of extremely hot and luminous super-suns in the *O* and *B* spectral classes. These stars produce most of the energy that makes the Tarantula Nebula visible. The area shown is about 35 light-years across. *Right:* A Hubble view of the same portion of R136 reveals intense ultraviolet emission from stars within the cluster.

LEFT: NASA / ESA / P. CROWTHER; RIGHT: ESA-HUBBLE / NASA / K. A. BOSTROEM



▲ **TREASURE MAP** The marriage of two Hubble near-infrared images with ground-based visible and hydrogen-alpha views yields this sweeping view of 30 Doradus and its surroundings. Key features are labeled and listed in the table. NGC 2070 comprises much of the left-hand complex.

NASA / ESA / ESO / D. LENNON, E. SABBI, ET AL.

Nature of the Beast

The star cluster NGC 2070, 130 light-years across, lies at the Tarantula's heart. *O*-type stars, the hottest and most luminous of all, are the rarest in our galaxy, with a population distribution of roughly 1 in 3 million. Yet NGC 2070 boasts some 2,400 *O* and *B* stars spread among a nest of sub-clusters, including the powerhouse called R136. The potent ionizing radiation from these stars collectively is 500 times greater than that from the Orion Nebula's hot, young suns. In fact, it creates the most active region of star formation in the Local Group of galaxies, which includes the Milky Way and more than 50 of its neighbors.

Researchers long believed that 30 Doradus was an evolved H II region with no major ongoing star formation. Then in 1992 observers spotted several protostars enshrouded in nebulosity. Further evidence came with the discovery of numerous infrared sources and intense radio emissions from OH radicals, a telltale sign of rapid starbirth. Today, we know 30 Doradus to be a region where star formation has taken place in multiple distinct epochs that continue to the present day.

The lack of red supergiants in R136, despite the large number of suitably massive stars, constrains the cluster to be less than 5 million years old. Further HTTP-based research led by Michele Cignoni (University of Pisa, Italy) shows that the star-formation rate peaked about 2 million years ago. This makes R136 notable: Few generations of stars we can observe are only a few million years old.

The oldest and second largest cluster is Hodge 301. Modelling led by Elena Sabbi (Space Telescope Science Institute), HTTP's principal investigator, suggests it formed 25 to 30 million years ago. Compared to nearby clusters, the level of reddening in Hodge 301 due to dust is relatively low and more uniform — probably because stellar winds and supernovae blasts have had time to blow through the cluster, cleansing the region of dust. How many supernovae? Perhaps 40 to 60, says Sabbi's team. Given the cluster's relatively old age, Cignoni and his colleagues believe that Hodge 301, and in particular its many supernovae, likely contributed energetically and chemically to the subsequent development of NGC 2070.

Monsters in the Lair

Massive stars play a major role in the evolution of the galactic environment. They create H II regions by ionizing large regions of gas and, after exploding as supernovae, enrich the interstellar medium with heavy elements. Because they radiate prodigiously at ultraviolet wavelengths, they're also thought to have been a major factor in the early universe's epoch of reionization (*S&T:* June 2017, p. 30).

Yet it's still unclear how big they can become. Stars with more than 100 solar masses usually hide deep within young, heavily congested star clusters. With lifetimes of only 2 to 3 million years, they're not around long enough for us to observe a lot of them. Suitable clusters for study in the Milky Way tend to be highly obscured by dust along our galaxy's midplane.

For decades astronomers thought R136 was a single star with a mass 2,000 to 3,000 times that of the Sun — but that's 20 to 30 times greater than stellar-evolution theory allows! By 1980, they'd resolved it into three components (denoted a, b, and c), but R136a was still well over the stellar-mass limit. Observations in the mid-1980s suggested that R136a was itself a dense cluster of at least eight stars, a notion confirmed in 1990 with Hubble's first scientifically significant image.

EARLY BLOOMER

Cataloged by Nicolas Louis de Lacaille as a diffuse nebula in 1751, 30 Doradus received its appellation 50 years later when Johann Bode included it in his *Uranographia* star atlas and accompanying catalog, in which he listed it as number 30 in Dorado.

Today, with a stellar population in the many hundreds of thousands, an estimated 3,000 stars of at least 3 solar masses, and perhaps 20,000 solar masses concentrated in its core, the R136 cluster is the densest concentration of stars in the Local Group. Nine of its stars weigh in at 100 Suns or more; at 250 solar masses, R136a1 leads the pack as the most massive star known. Where did all these behemoths come from? Could mergers of two or more smaller stars be responsible? Probably not, says Saida Caballero-Nieves (Florida Institute of Technology). "From what we know about the frequency of massive mergers," she explains, "this scenario can't account for all the really massive stars that we see in R136."

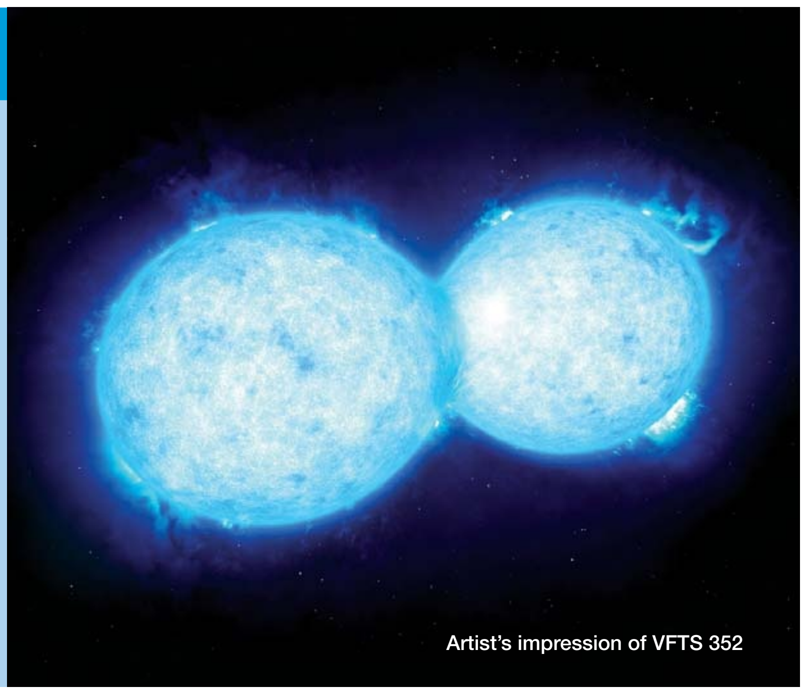
Fast Fliers

Not all massive stars in 30 Doradus reside in clusters — in fact, several have escaped their web. The first to be found, VFTS 016, came to light in 2006 when a team led by Ian Howarth (University College London) observed it with the 3.9-m Anglo-Australian Telescope. Particularly intriguing was its isolated location, more than 200 light-years from any cluster where such monsters tend to form and reside.

Stellar Mergers in 30 Doradus

Studies of massive stars suggest that some 40% of all *O*-type stars may interact with a nearby companion, and over half of those will lead to a "deep contact phase." An example in 30 Doradus is VFTS 352, comprising two very hot stars with their centers just 12 million kilometers apart — their surfaces overlap. Known as an "overcontact binary," VFTS 352 is one of just four *O*-type examples of such systems.

With a combined 57 solar masses, VFTS 352 is the most massive known overcontact binary and has the hottest components. Stars like this, sharing perhaps 30% of their material, are rare to catch because this phase in their lives is very short. If they eventually merge, the result might be a gigantic, faster-rotating superstar.



Artist's impression of VFTS 352

ESO / LUÍS CALÇADA

Chris Evans (Royal Observatory, Edinburgh) and colleagues found that VFTS 016 emits one of the strongest stellar winds known for an O-type star, implying that it's roughly 90 solar masses. VFTS spectra later ruled out that VFTS 016 has a massive companion.

How could such enormous stars reside in isolation? One idea is if a massive star in a binary system within the cluster explodes as a core-collapse (Type II) supernova, its surviving sibling might gain enough of a "kick" to be ejected from the cluster. Alternately, if a loosely bound binary encounters a third star at close range, that chance meeting could eject either the interloper or one of the binary's members from the cluster.

Danny Lennon (Space Telescope Science Institute) notes that R136 is young enough that the cluster's most massive stars have not yet exploded as supernovae. "This implies that the star must have been ejected through dynamical interaction," he explains. Walborn adds, "This is the first direct observation of the process in such a region."

To further investigate runaway stars, proper-motion studies provide the direction of escape in addition to the line-of-sight velocity. By combining a runaway's proper motion and line-of-sight velocity, astronomers can begin to deduce its probable origin. Determining the proper motion of stars 160,000 light-years away might seem impossibly difficult, but Hubble can measure the plane-of-sky motion of runaway stars typically moving at speeds of 100 km per second (200,000 mph) over a baseline of two decades. That's how Imants Platais (Johns Hopkins University) and colleagues identified two runaway stars, one of which (VFTS 285) seems to have been ejected from the cluster R136. Confirmation of their points of origin will come with further Hubble observations.

Binary system interactions can give stars more than just a kick. VFTS 102 is the fastest rotating star known: It spins at more than 600 km per second, nearly fast enough to be torn apart. Lurking nearby is the pulsar PSR J0537–6910 and an associated supernova remnant. Philip Dufton (Queen's University Belfast) and colleagues argue that VFTS102 was initially half of a two-star system so close together that gas from the companion spilled onto VFTS 102, causing it to spin up. After about 10 million years, the companion exploded as a supernova, leaving behind PSR J0537–6910 and giving VFTS 102 the kick needed to escape.

"This is a compelling story because it explains each of the unusual features that we've seen," says Dufton. "This star is certainly showing us unexpected sides of the short, but dramatic, lives of the heaviest stars."

Another study has found 17 other rapidly rotating O-type stars. All but four of them lie near the edges of the clusters NGC 2060 and NGC 2070, suggesting that these stars are in the process of escaping.

The Spider's Future

The LMC is a busy place, and 30 Doradus lies at the northern edge of a cold, dense, and massive interstellar cloud some 6,000 light-years long that seems destined to keep on producing stars. As for the Tarantula itself, Walborn notes that it should evolve into a giant "shell" H II region: The most massive stars within the core will go supernova and disappear, leaving behind the ionized region they created. But before violently ending their fast and furious lives, these stars will clear out the region's gas and dust with their powerful ultraviolet radiation, creating a completely evacuated cavity. All that will remain is an association of evolved, less-massive suns.

▲ **RUNAWAY STAR** VFTS 016, a blue-hot star 90 times more massive than our Sun, has escaped the R136 cluster and is hurtling across space at more than 100 km per second.

NASA / ESA / C. EVANS / N. WALBORN / ESO

While this is happening, the prominent filaments now seen in the outer parts of 30 Doradus are "star-formation fronts." There energetic outflows from the core are colliding with the surrounding dense clouds, triggering a new round of starbirth. Astronomers in the far future will find the region's most massive stars on its periphery rather than in the present core.

In a sense, say some researchers, we are witnessing the birth of a globular cluster. While open star clusters typically have tens to hundreds of stars, NGC 2070's number in the hundreds of thousands — as do globulars. These concentrated star-balls are ancient, typically as old as the galaxies they live in, and many questions remain regarding their formation.

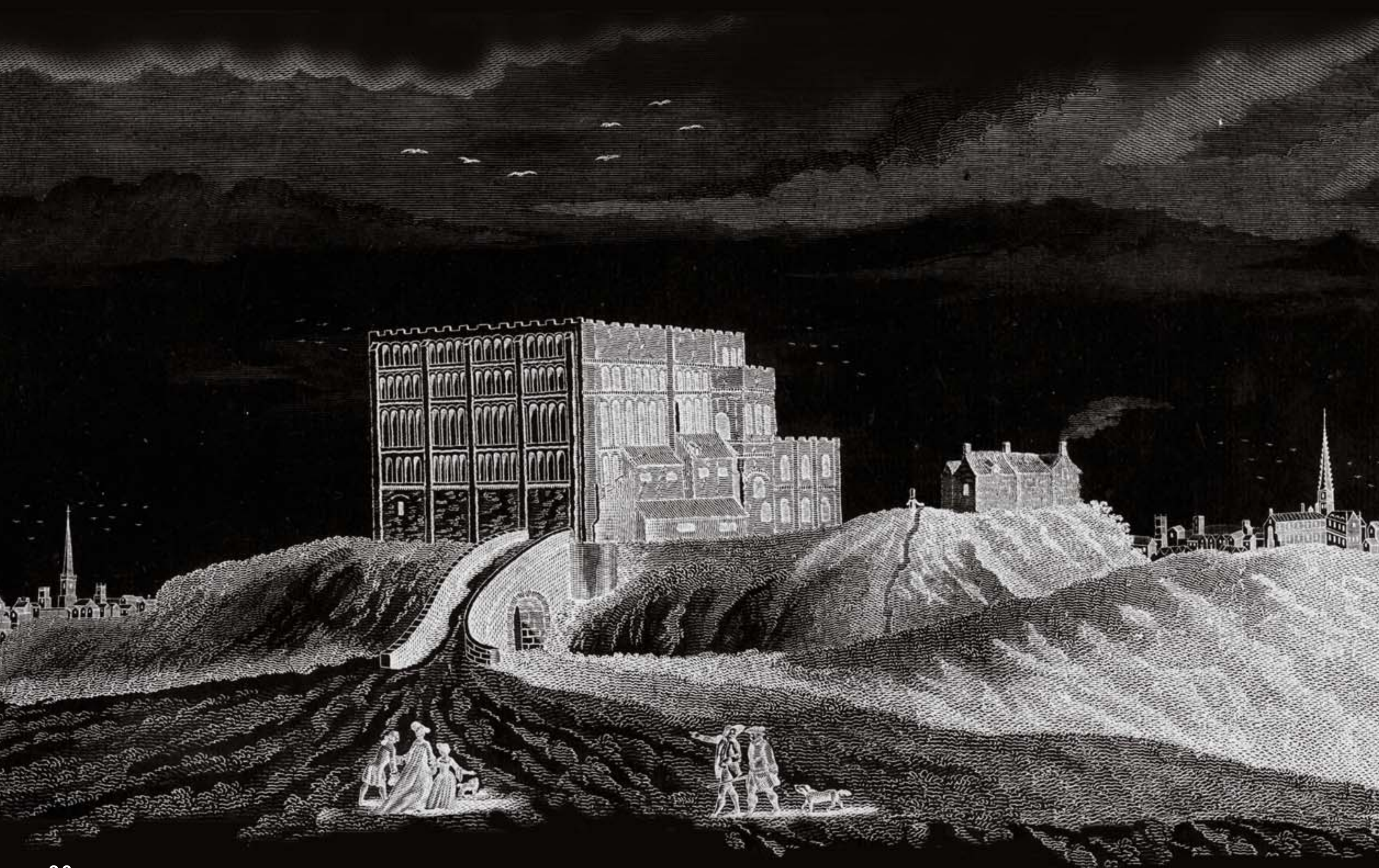
Whether NGC 2070 makes this transformation over the next 100 million years depends on whether it contains enough low-mass stars to keep the cluster bound once the massive stars have gone and the Tarantula's wispy filaments have dissipated. Walborn thinks the probable outcome is a low-mass globular. Given that eventual fate, 30 Doradus provides astronomers with a unique observational opportunity to comprehend what the early universe must have been like and how those first galaxies evolved through the life cycles of their stars.

■ Contributing Editor **GREG BRYANT** has been observing the Tarantula Nebula ever since the adjacent Supernova 1987A burst on the scene. He was Editor of *Australian Sky & Telescope* from 2006 to 2014.

For a video featuring discussion of the Tarantula's massive stars by researcher Paul Crowther, go to deepskyvideos.com/videos/other/tarantula_nebula.html.

The 1794 Volcano on the Moon

Sometimes an astronomical mystery seems very easy to solve. Perhaps too easy?



On the evening of March 7, 1794, William Wilkins took a stroll up Castle Hill in Norwich, England, to see if he could spot Mercury in the evening sky. *Wouldn't you know it! Cloudy in the west.* Then he looked up.

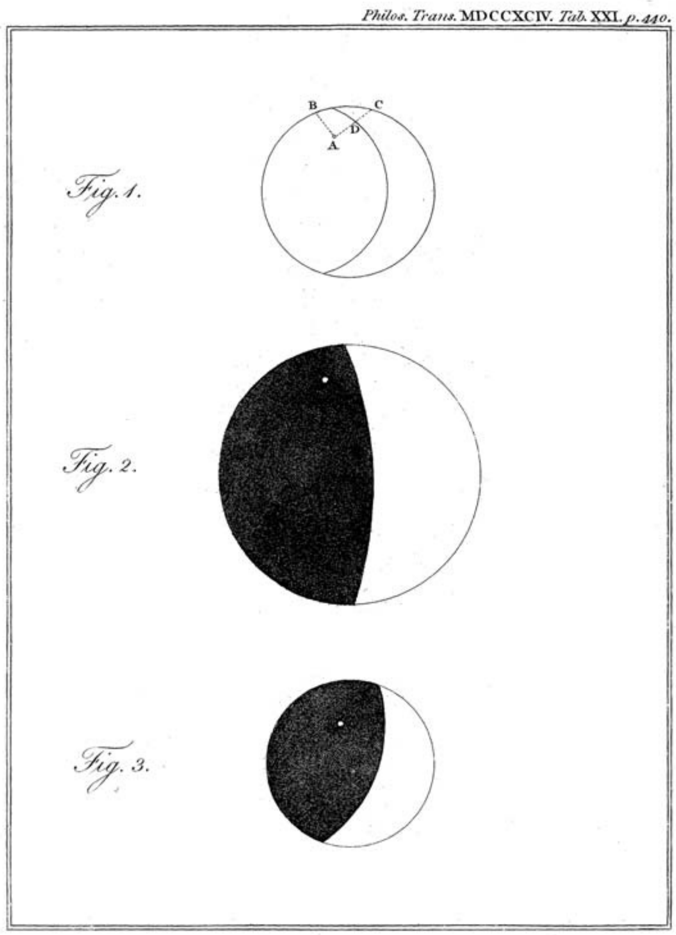
What he saw was a shock and surprise, one that stoked a mystery that has sputtered on for more than two centuries, helping to fuel tantalizing speculations about active events on our supposedly dead Moon.

Wilkins, 44, was an amateur astronomer. He had been inspired by William Herschel's discovery of Uranus — the first new planet since antiquity, putting astronomy in the headlines (Britain triumphs over French astronomers!) — just 13 years earlier. Like Herschel, Wilkins owned a reflecting telescope rather than the more common refractor. But unlike the famous ex-musician, Wilkins hadn't quit his day job. He was an architect, busy constructing a lighthouse with Argand lamps (oil lamps with big cylindrical wicks, the latest in high-intensity lighting). During the course of this work, he wrote "the goodness of my sight has often been remarked, in discovering vessels with the naked eye, which my companions could not discover but with the telescope." So he described himself in a letter to the astronomy professor Rev. Samuel Vince, lest there be any doubt about what followed:

> *. . . respecting the phænomenon I saw in the moon, on Friday the 7th of March, a few minutes before eight o'clock . . . I had been looking for that planet [Mercury] from the Castle-hill in Norwich, but was disappointed by a clouded horizon. I mention this merely as the reason of my being led to a more particular notice of the moon . . . having lost the first object of the evening's attention. When I saw the light speck, as shewn in the sketch* [at right], *I was very much surprised; for, at the instant of discovery I believed a star was passing over the moon, which on the next moment's consideration I knew to be impossible . . . I was, as it were, rivetted to the spot . . . and took every method I could imagine to convince myself that it was not an error of sight; and two persons, strangers, passed me at the same time, whom I requested to look, and they (may be, a little more ignorant than myself) said it was a star. I am confident I saw it five minutes at least . . . The whole time I saw it, it was a FIXED, STEADY LIGHT, except the moment before it disappeared, when its brightness INCREASED; but that appearance was instantaneous … I mentioned this soon afterwards to a gentleman of my acquaintance, who . . . conjectured this phænomenon to be some great volcanic convulsion in the moon, which induced me at that time to assist my memory with a sketch like what I have here sent you. I shall be obliged to you, Sir, if you will favour me with Dr. MASKELYNE'S opinion . . . .*

Enter the Astronomer Royal

Wilkins's letter went straight to the top. It appeared in the Royal Society's *Philosophical Transactions* as part of an investigation by England's Astronomer Royal, Nevil Maskelyne, titled "An Account of an Appearance of Light, like a Star, Seen in the dark Part of the Moon, on Friday the 7th of March, 1794." Here Maskelyne writes that soon after he learned about Wilkins, his own relation Sir George Booth and his wife paid him a visit at the Royal Observatory grounds in Greenwich. Lady Booth remarked that their servant, "who is curious for a person in his situation, and fond of looking at the stars, had some time before seen something extraordinary in the moon." When questioned by Maskelyne himself, the servant recalled that "some time ago, about six in the evening, he saw a light like a star, and as large as a middle sized star, but not so bright, in the dark part of the moon. He continued looking at it for a minute or more, dur-



◀ **OBSERVING SITE** Castle Hill in Norwich, England, as drawn in 1785, nine years before William Wilkins's fateful sighting (negative image). *Moon and Aldebaran:* Thanks to modern software, we can re-create the Moon's appearance from Norwich (with Aldebaran shown greatly exaggerated) at 6:57 p.m. local mean time March 7, 1794, as Aldebaran was just about to vanish from view. What's the chance that Wilkins really made his sighting one hour later? ***Above:*** Nevil Maskelyne published two people's drawings of their best recollection of where on the Moon they witnessed the naked-eye point. Wilkins, an amateur astronomer, was particularly careful; *Fig. 1* is from a sketch in which he attempted to specify the position of the "star" on the Moon by noting that the line BA = AD = DC. *Fig. 2* is what Wilkins drew for Maskelyne, "copying the moon's appearance from your scheme." *Fig. 3* is the same by another witness: Lady Booth's unnamed servant, the one "curious for a person in his situation."

ing which time it kept the same light, and he then lost sight of it by going in the house."

Maskelyne then tried to verify the time, which Lady Booth felt was later than six o'clock (around sunset). He met with a Thomas Stretton, who had also come forward. They went to where Stretton had stood in St. John's Square, London, and Maskelyne had him point out where he had seen the Moon "with respect to the opposite house and chimnies over which she appeared." Not the Astronomer Royal for nothing, Maskelyne describes how "with the help of a pocket compass and small wooden quadrant, I found the bearing of the place in the sky . . . to be 80° west of the magnetic south, or 56° west of the true south meridian, and the altitude 34°. Taking the moon's right ascension from the nautical almanac for the 7th of March . . . with the bearing abovementioned, and the latitude of St. John's Square taken 51° 31′," he calculated that the observation must have been made not far from eight o'clock, "and therefore the two observations agree as nearly together as can be expected."

Stretton must have pointed with remarkable accuracy, and Maskelyne's pocket compass must have been a good one too. Just a 14° pointing error could result in an hour's time error. But Maskelyne was making the most of this opportunity.

Star of the Show?

Suspiciously, an occultation of 1st-magnitude Aldebaran had begun about an hour earlier and ended a half hour earlier. The occultation was a near-grazing one. For Norfolk, as we can calculate quite precisely from our vantage in the 21st century, the star disappeared on the Moon's dark limb at 6:57 p.m. local mean time and reappeared from behind the bright limb at 7:33 p.m. LMT. (If Norwich was still using the older system of local apparent solar time, its clocks would have read 11 minutes earlier.) A half hour after the occultation ended, Aldebaran would have been plainly visible about half a lunar diameter to the Moon's right, off the bright limb.

But one hour *earlier*, Aldebaran was slowly skimming along the Moon's *dark* limb — at just the correct orientation of the

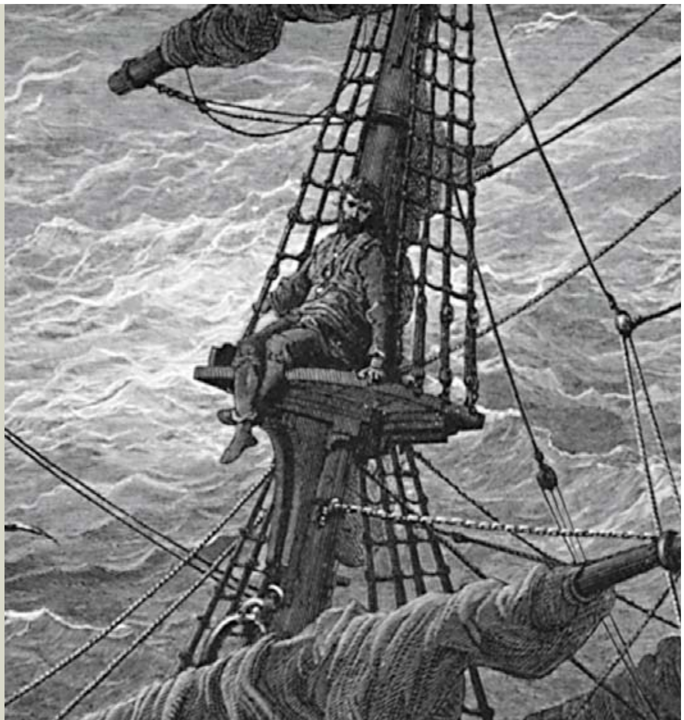
Wilkins's Star in Your English Class

◗ We have no busts or portraits of the observant Wilkins, and in 2013 his lighthouse at Orfordness (below right) was abandoned to the encroaching sea. But his star may be memorialized forever in Samuel Taylor Coleridge's *The Rime of the Ancient Mariner*:

The stars were dim, and thick the night,
The steersman's face by his lamp gleamed white;
From the sails the dew did drip—
Till clomb above the eastern bar
The hornèd Moon, with one bright star
Within the nether tip.

And with that evil omen, the ship's crew give the albatross-slaying Mariner a dirty look and drop dead, supernaturally.

Coleridge wrote the *Ancient Mariner* in 1797–98, just three or four years after the publication of Wilkins's sighting and Maskelyne's analysis. Coleridge was almost surely aware of these; he was an avid reader and devoured articles about every kind of natural curiosity. Maskelyne's report in the *Philosophical Transactions* created a stir, prompting a lengthy summary of the sighting in the more popular *British Critic* — which was, like the *Phil. Trans.* itself, one of Coleridge's regular reads.



▶ **SPOOKED** Samuel Taylor Coleridge's *Rime of the Ancient Mariner* went through countless editions in the 19th century; a particularly sumptuous one was illustrated by Gustave Doré. **Bottom**: Wilkins's recently abandoned lighthouse.

ENGRAVING: GUSTAVE DORÉ. LIGHTHOUSE: JOHN FIELDING mystery star so carefully noted by Wilkins!

And its sudden winking out, after shining steadily for at least 5 minutes, would of course have been the occultation itself.

Nevertheless, Maskelyne ruled out any connection between the Aldebaran occultation and the sighting. He concluded,

I shall make no conjectures on the cause to which this extraordinary phænomenon may be attributed; but only remark, that it is probably of the same nature with that of the light seen of late years in the dark part of the moon by our ingenious and indefatigable astronomer, Dr. HERSCHEL, with his powerful telescopes, and formerly by the celebrated DOMINIC CASSINI; although this has been so illustrious as to have been visible to the naked eye, and probably equal in appearance to a star of the third magnitude.

Those Disreputable TLPs!

Scientists in the late 18th century generally lacked the sophisticated understanding of statistics that any good scientist draws upon today. The statistician Thomas Bayes had introduced Bayes Theorem two decades earlier; it is the formal way to determine, among other things, what is "too unlikely a coincidence." But even an astronomer as illustrious as Maskelyne may not have considered his "priors." What was the prior likelihood that, right at the time of such a remarkable and seemingly impossible sighting — if the witnesses were wrong and the time was a few minutes before 7 instead of 8 or 6 — Aldebaran would have been right there along *with* the mystery "star"? What was the chance of such a coincidence given the rarity of bright-star occultations, much less one at just the correct place on the Moon's limb?

And yet, Wilkins says

I was very particular in my inquiries respecting the time, and called purposely on a neighbour [a Mr. R. Bacon, publisher of one of the Norwich newspapers] *to ascertain it with certainty; and found it a few minutes before eight o'clock, which I entered in my pocket journal; and on inquiry of Mrs. WILKINS, she says I left home at that time.*

Castle Hill was just 50 yards from his home, so he would have wasted little time getting there and back.

At 1st magnitude, Aldebaran is six times brighter than the 3rd-magnitude light that Maskelyne estimated for the lunar event. The glare of the Moon makes a star close to it look dimmer than it really is. But it's suspicious that none of the eyewitnesses seems to have mentioned a *second* star at the Moon that was at least as bright and eye-catching.

The dark limb would have been invisible to the naked eye; the Moon was a day short of first quarter (41% illuminated). So where exactly was the line between on the Moon and off the Moon? If the Moon's brilliance made it appear a little

◀ **NEVIL MASKELYNE** (1732–1811) was England's fifth Astronomer Royal, holding that illustrious office from 1765 to 1811.

WIKIMEDIA COMMONS / MAGNUS MANSKE

larger than reality to the naked eye, as often happens, might one misjudge that Aldebaran was inside the dark limb, rather than on it?

Quite possibly. In 1860 the famed observer Rev. T. W. Webb published a note in the *Monthly Notices* of the Royal Astronomical Society describing this effect and saying that it accounted for the famed Wilkins lunar volcano:

On the same evening there was an occultation of Aldebaran, which Dr. Maskelyne thought a singular coincidence, but which would now be acknowledged as the cause of [Wilkins's] phenomenon. . . . [T]he effect of irradiation [expansion of glare] upon an object out of focus is greater than might be supposed by those whose vision is perfect; of this I have been made aware through my own near sight, in consequence of which luminous spaces are enlarged at the expense of adjacent dark ones, to an extent which might hardly have been anticipated.

The term *Transient Lunar Phenomenon* (TLP) would not be invented for many years to come. Most reports of them refer to particular lunar features appearing unusually bright or hazy in a telescope. Their reality has always been questioned, and lunar astronomers today take essentially all such reports to be misobservations of features under changes of lighting (see the August issue, page 52). But the decade leading up to Wilkins's sighting was a heyday for TLP sightings, which were sometimes described outright as active lunar volcanoes. By 1794 astronomers were primed for them.

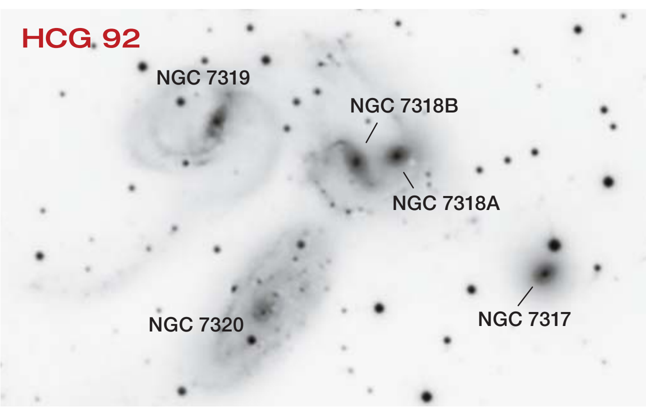
The TLP controversy, long considered nearly dead, gained a new gasp of life with a 2009 paper in *The Astrophysical Journal* titled "Transient Lunar Phenomena: Regularity and Reality" by Arlin Crotts. He wrote that judging from a 1968 NASA catalog of 579 TLP reports since 1540, statistics suggest that 80% were real, since 50% were seen near Aristarchus (the Moon's brightest white spot) and approximately 16% in Plato.

Nowadays, low-light video monitoring through telescopes occasionally catches actual, brief pinpoint flashes on the Moon's night side. These are small meteoroid strikes, and they appear at rates consistent with Earth's known meteoroid environment. Larger ones must also happen from time to time. But these flashes of white-hot vapor are gone in a moment in the lunar vacuum. The star that Wilkins saw shone unchanged for minutes — before winking away into more than two centuries of astronomical lore and legend.

■ **ANDREW LIVINGSTON** sees TLPs — Toronto's light-polluted skies — all the time. Alan MacRobert, Don Olson, David Dunham, David Herald, Leslie Morrison, and Tony Cook contributed to the Aldebaran investigation.

The Road Less Traveled

These nine compact galaxy groups show that stepping outside your comfort zone can be worth the effort.



▲ **BONUS GALAXY** Hickson Compact Group 92, more commonly known as Stephan's Quintet, lies about 280 million light-years from Earth in the direction of Pegasus. Four of the galaxies shown here — NGC 7317, NGC 7318A, NGC 7318B, and NGC 7319 — are true members of the interacting group. NGC 7320, on the other hand, is a foreground galaxy, shining only 40 million light-years away.

BOB & JANICE FERA

In 1982, Canadian astronomer Paul Hickson published a list of 100 compact galaxy groups selected from his systematic examination of the Palomar Observatory Sky Survey (POSS) red plates. In an attempt to avoid selection biases that might introduce statistical errors, Hickson applied specific criteria to collect the sample. His efforts resulted in a list of isolated associations of four or more galaxies with a brightness range within 3 magnitudes of each other and with a mean surface brightness greater than magnitude 26.0 per arcsecond of size. This translates to compact galaxy groups becoming more condensed as their members become fainter.

The collection of 100 Hickson Compact Groups (HCG) comprises a ready list of challenging targets for amateur observers that spans the northern sky (**https://is.gd/HicksonCatalog**). They range in difficulty from HCG 44 in Leo, which will yield easily to an 8-inch telescope, all the way to HCG 50 in Ursa Major, whose brightest member is around 19th magnitude! For those who enjoy ambitious observing projects, they have become almost iconic.

Observers who set themselves a goal of observing as many Hickson groups as they can are embarking on a journey that certainly qualifies as the path less traveled. Along the way, they're forced to hone their skills and push their optics.

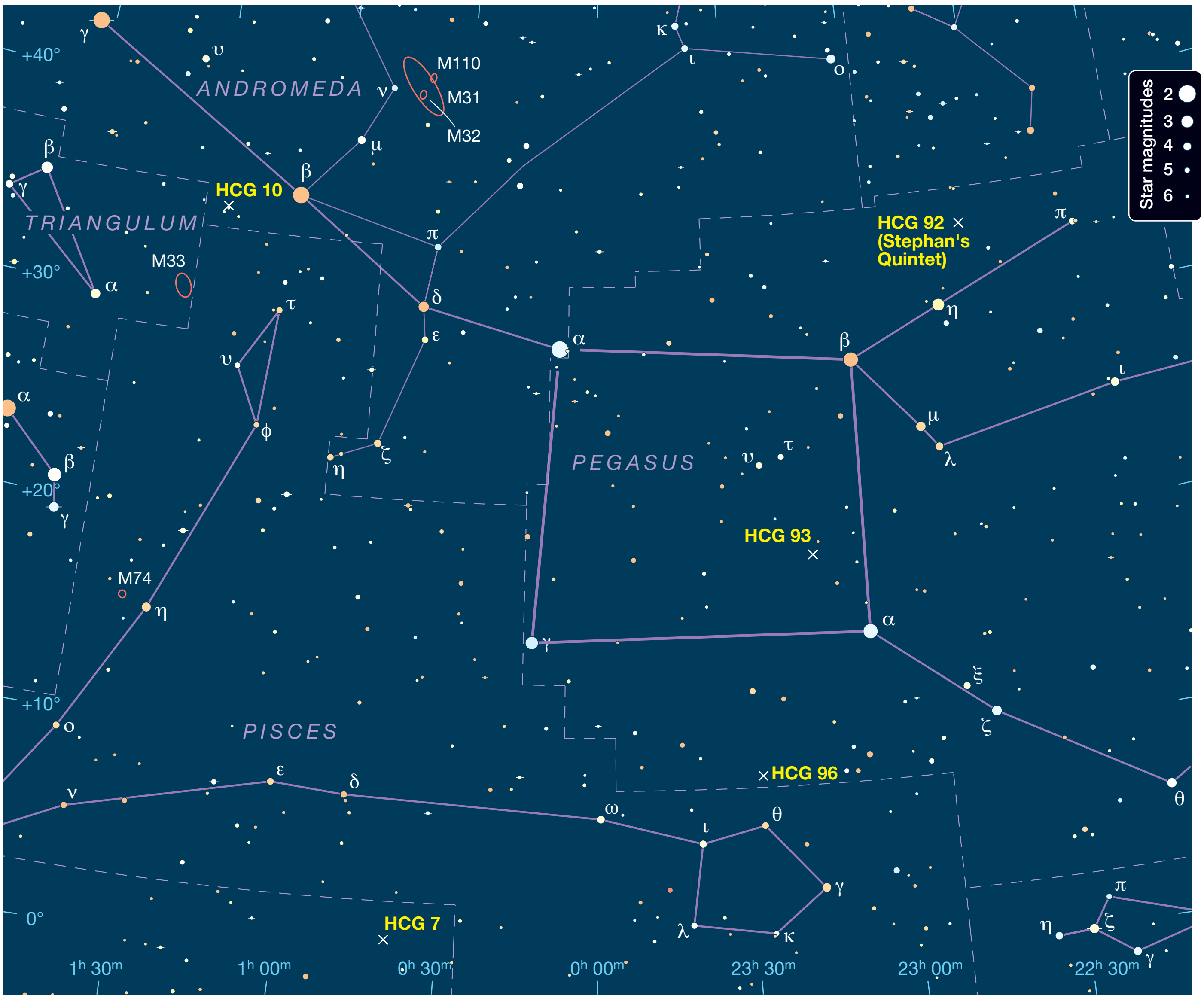
The November sky contains a large number of Hickson groups. For this tour, I've selected nine groups with a range of difficulty that offer most observers a realistic chance at successful detection. Success here is subjective, however. You may find it reasonable to deem detection of any part of the group, even the composite group as just a single object, as a success. The most demanding observers might accept nothing short of resolving all of the members into discrete components, and that will be a high hurdle to leap indeed. The aperture of your scope and the quality of your sky will, of course, limit what's possible, but all of the groups discussed here contain one or more members detectable with as small as an 8-inch telescope.

Pegasus

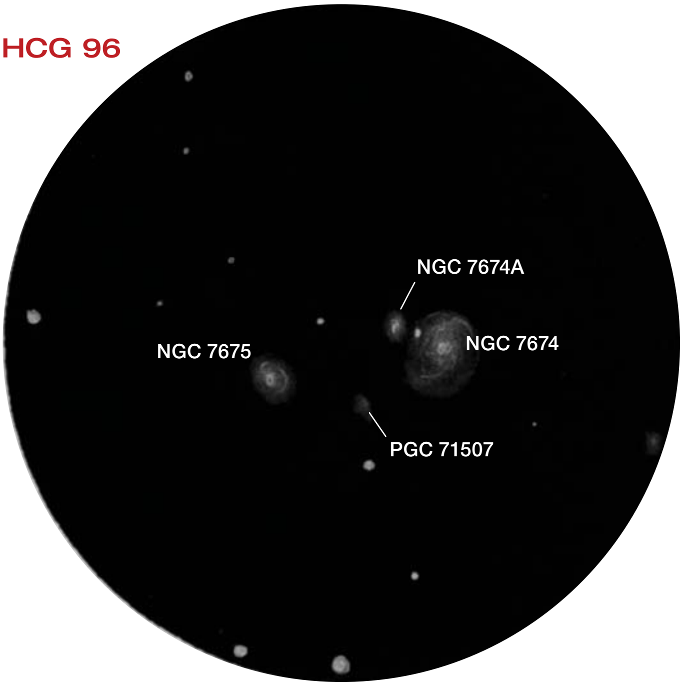
Stephan's Quintet (**HCG 92**) in Pegasus is one of the best-known groups on the list and an excellent place to start. Hickson sought to study tight groupings with discordant red shifts, and this group illustrates the situation well. The brightest galaxy here, **NGC 7320**, has a much lower red shift than its neighbors and based on that finding is considered to be a foreground object. The other members show evidence of gravitational interaction and are most likely in the process of merging. Recent research reveals that one member, **NGC 7318B**, is falling into the center of the group at an impressively high velocity (about 900 km/s), generating huge shock waves and bursts of X-rays.

HCG 92 was discovered on September 23, 1876, by Édouard Stephan using the 80-cm Foucault reflector from Marseilles, France. He described just four objects, being unable to resolve the pair of galaxies **NGC 7318A** and NGC 7318B separately. **NGC 7320C** was added to the group in the 20th century and has since been shown to be a true member of the interacting group.

The quintet is located a ½° south-southwest of NGC 7331. Moderate aperture will rather easily reveal three separate



HCG 96



▲ **WIDE RANGE** The four member galaxies of HCG 96 vary in difficulty; you may need to up the aperture to capture PGC 71507 and NGC 7674A. Dale Holt used a deep-sky video camera to direct the view of this dim object through his 20-inch f/3.7 reflector to a black-and-white monitor, making it more comfortable to sketch the galaxies.

objects. Most prominent is the combined glow of NGC 7318A and NGC 7318B, which appear as a single object to most observers. The largest patch of light, the "A" component of HCG 92, is NGC 7320. A 13th-magnitude star lies northeast of the bright core.

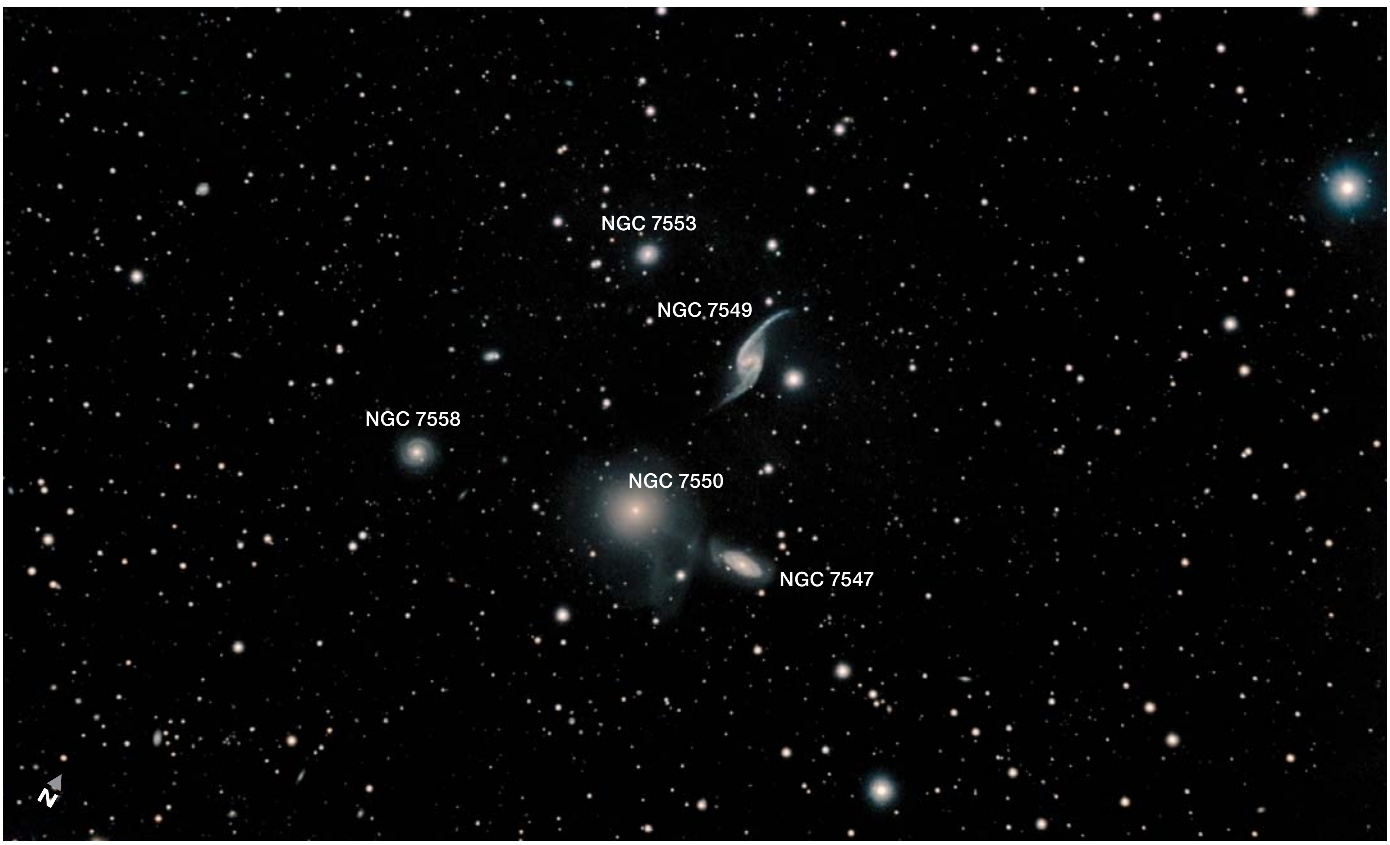
The third brightest member of the group is **NGC 7319**. Look for some wispy structure northeast of the brighter elongated patch of light. **NGC 7317** lies southwest of these three galaxies and has a stellar companion close to its core. To my eye, the galaxy looks a bit like a reflection nebula illuminated by that 12th-magnitude star.

Both NGC 7317 and NGC 7319 are classified as Seyfert II galaxies (as are several other galaxies on our tour). Seyfert galaxies have active galactic cores similar to quasars, but differ from their quasar cousins in that their parent galaxies are visible. Seyfert II galaxies are bright in infrared as well as visible wavelengths.

NGC 7320C lies about 4′ northeast of the group's center and is easily overlooked. It appears as a small, roundish spot of nebulosity that requires averted vision and concentration.

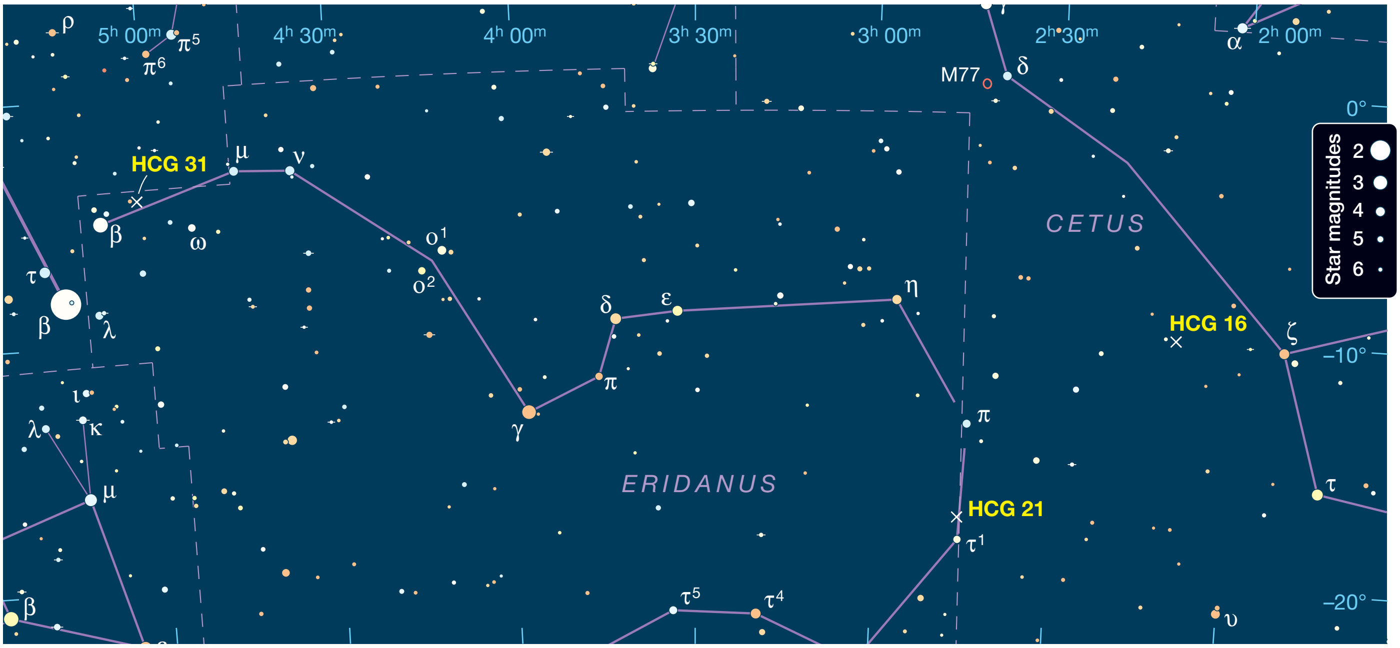
Pegasus is also home to **HCG 96**. This group's members exhibit a wide range of visual difficulty, with one member I consider relatively easy, as it stands out from its considerably more challenging neighbors. (This situation is quite typical of many Hickson groups.)

HCG 93



▲ **CHALLENGE GROUP** Three of HCG 93's member galaxies stand out in the eyepiece, but the group's fainter objects may require averted vision or imaging to detect. The elliptical galaxy NGC 7550 centers this image made through a 14-inch f/9.5 Schmidt-Cassegrain telescope.

HCG 96 SKETCH: DALE HOLT; HCG 93: ALSON WONG



Two galaxies dominate Hickson 96. Barred spiral galaxy **NGC 7674** is the brighter standout and ellipitcal galaxy **NGC 7675** is its fainter, smaller companion a bit more than 2′ to the east. Both appear round with brighter cores, and both might be seen in an 8-inch telescope.

It will take larger aperture and good conditions to detect the two faintest members, **NGC 7674A** (MCG +1-59-81) and **PGC 71507**, both of which lie between the brighter galaxies and appear as tiny patches of nebulosity.

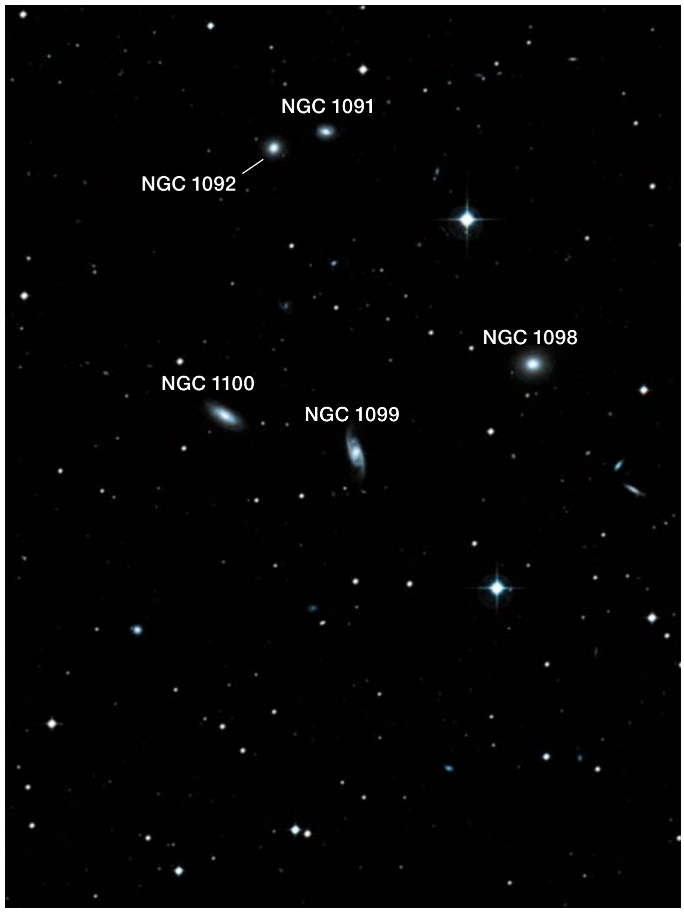
In another Pegasus group, **HCG 93**, three of the five member galaxies stand out fairly well. Elliptical galaxy **NGC 7550** is the brightest member; it's large and round, with a much brighter core than its companions. It contains a low-ionization nuclear emission-line region (LINER) type active galactic nucleus.

LINER galaxies are characterized by weak emission lines that have sparked debate among astronomers: Are these spectral emissions the result of supermassive black holes, or are they powered by star formation regions? Are giant shock waves the ionization mechanism, or is photoionization responsible? The jury's still out on all of this. The view in the eyepiece won't offer a clue as to the answer, but it's always fun to contemplate the physics of an object to add extra interest to your observing targets.

NGC 7549 lies about 5′ north of NGC 7550 and is similar in brightness but more elongated than its neighbor. Photographs show NGC 7549 to be a barred spiral sporting two graceful arms, one bright and one faint, but structure isn't apparent in the telescope.

NGC 7547, which lies 3′ west of NGC 7550, is about as bright as NGC 7549. Two faint circular spots round out the compact group. **NGC 7553** rests 4′ east of NGC 7549 and **NGC 7558** is 7′ southeast of NGC 7550.

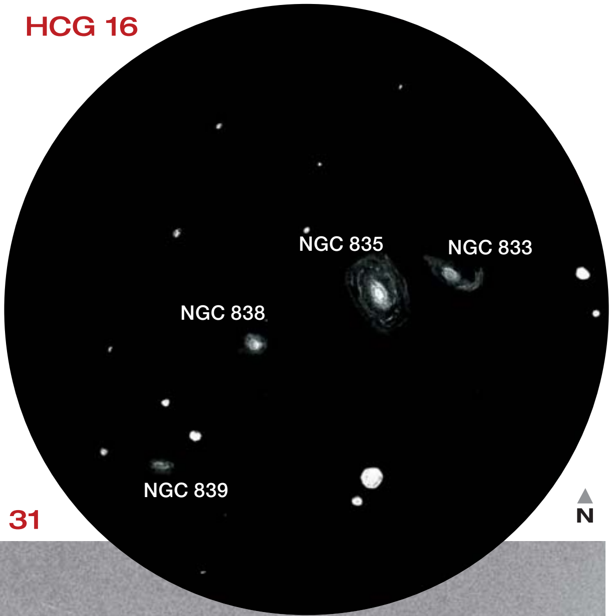
HCG 21



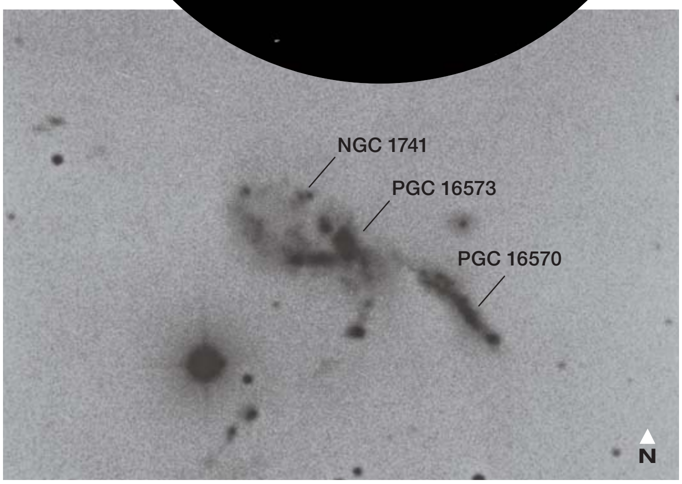
▲ **EXEMPLARY GROUP** This 30-arcminute-wide view offers a good comparison exercise in galaxy structure. Both NGC 1099, near the center of the image, and NGC 1100 are barred spirals viewed at slightly oblique angles from Earth. NGC 1092 is an elliptical, but a close look reveals NGC 1091 to be a spiral. NGC 1098? You're right — it's an elliptical.

POSS-II / CALTECH / STSCI / PALOMAR OBSERVATORY

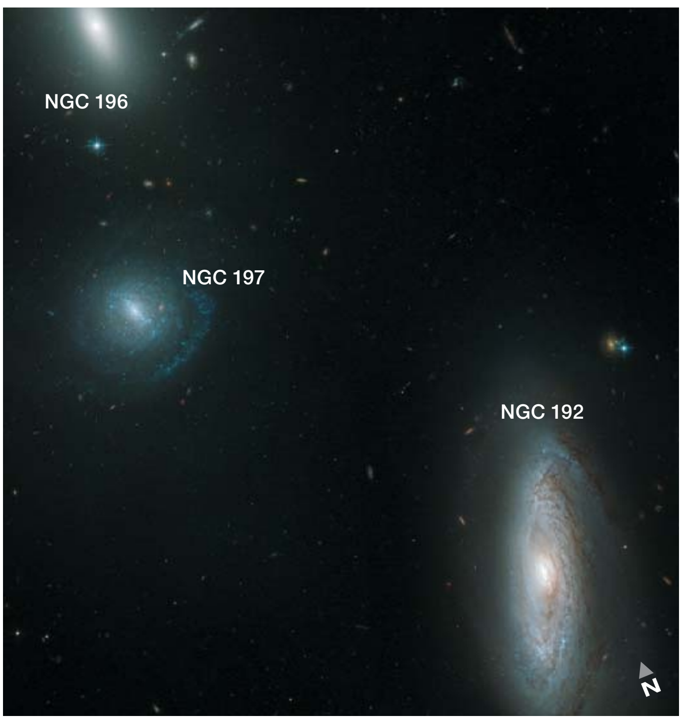
HCG 16



HCG 31



HCG 7



Eridanus

HCG 21 lies about 1° north of Tau (τ) Eridani and is comprised of five well-separated members. They make easy targets for large-aperture scopes, and the three more obvious members will show in an 8-inch in dark enough skies. **NGC 1099**, the brightest in the group, is a spiral that's worth examining closely for any hint of spiral structure extending away from a luminous core.

Only a little dimmer is **NGC 1100**, which lies about 5′ east-northeast of NGC 1099. Its lucent core anchors an elongated halo. **NGC 1098**, 7′ northwest of NGC 1099, looks like a very typical elliptical galaxy: round with a visible core. The last two members of the group, **NGC 1092** and **NGC 1091**, form a pair to the north. Look for two similar patches of fuzz that brighten toward their centers.

More challenging is **HCG 31**, which lies about 1° 35′ northwest of Beta (β) Eridani. I spotted two objects rather easily with my 18-inch scope. Most vivid is the combined light of **NGC 1741** and **PGC 16573**, which are unresolved. This mottled, oval patch is irregular in appearance. About a minute to the southwest, **PGC 16570** (some sources identify this as NGC 1741B) appears as a streak angled northeast-southwest. A circular patch 2½′ to the southeast is **IC 399**. The SIMBAD Astronomical Database (**simbad.u-strasbg.fr**) lists this as the "g" component of HCG 31, but few other sources include it in the group. No other members are seen.

Cetus

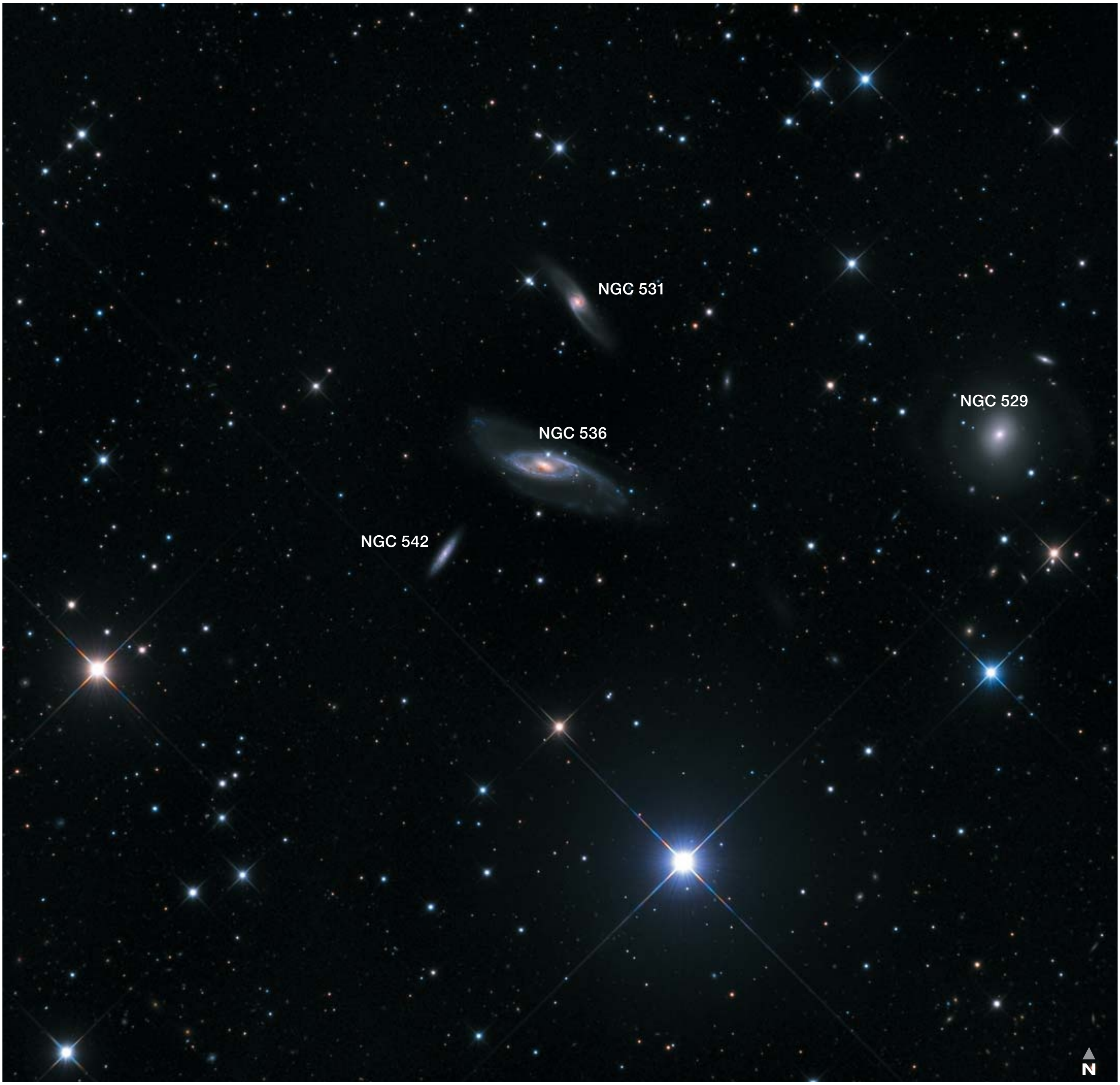
Cetus hosts two groups on our sampler tour, both quartets of relatively easily seen galaxies. **HCG 16** is 4½° degrees east of Zeta (ζ) Ceti. Its four members arc around a 9th-magnitude star. **NGC 835** is a mottled oval with a bright core and a hint of spiral structure in its fainter halo. **NGC 833**, nearly in contact to the west of NGC 835, is more elongated and angled east-west with a noticeable core. **NGC 838** lies about 4′ east of the pair and appears round with more obvious center.

The faintest member of the group is the spiral galaxy **NGC 839**, southeast of NGC 838. It's a bit elongated, angled

◀▲ **DOUBLE ENTRY** Top: With his 14-inch scope and deep-sky video set-up, Dale Holt was able to detect structure in what appears to be the central object of HCG 16, the face-on spiral galaxy NGC 835. **Middle:** Because compact galaxy groups frequently contain closely interacting galaxies, many of the entries in the Hickson catalog can also be found in Halton Arp's *Atlas of Peculiar Galaxies* (1966). Shown here is the red plate used to identify what Arp considered to be the "irregular clump" galaxies of Arp 259, which also make up the core of HCG 31.

◀ **SLOW AND STEADY** This "close-up" image of HCG 7, showing two spiral galaxies (NGC 192 and NGC 197) and a lenticular galaxy (NGC 196), comes to us courtesy of the Hubble Space Telescope. HCG 7, like many other entries in the Hickson catalog, appears to be remarkably calm for a group of interacting galaxies. Astronomers expect to see high rates of star formation in merging galaxies, but the production of HCG 7 members seems to have been relatively steady over time. It's possible that the galaxies have (and are still) producing stars with only endemic gas not affected by the gravitational forces of galactic mergers, but explanatory models for such a situation are still being worked out.

HCG 10



▲ **LOOK AWAY** Chasing down every member of Hickson 10 may prove difficult. NGC 531 boasts a surface brightness of only 13.6, making it a tough quarry in this galactic hunt. Don't expect to see the structure that this deep-sky image reveals to us. Use averted vision to detect the galaxy's subtle glow about 3 arcminutes north of NGC 536.

ADAM BLOCK / MOUNT LEMMON SKYCENTER / UNIVERSITY OF ARIZONA

east-west, and sports a condensed core. The group should be detectable in an 8-inch telescope.

Our other Cetus quartet is **HCG 7**. Located in the north-west corner of the constellation along the border with Pisces, it's a bit of a challenging star-hop. Look about 4° northwest of 4.8-magnitude 20 Ceti. The three brightest members form an eastward pointing triangle and the fainter fourth member lies within it. Along the western base of the triangle, **NGC 192** is elongated north-south and shows a visible core. To its north, **NGC 196** is a smaller oval with a much brighter core. **NGC 201** forms the apex of the triangle and is of lower surface brightness, nearly round, and mottled. **NGC 197** is a fainter round patch with a small, distinct nucleus.

Andromeda

HCG 10 in Andromeda is another quartet, but it's likely to yield only a pair or a triplet. With my 18-inch, I eventually saw all four members at 200×, but the fourth member eluded

• Visit **https://is.gd/HicksonGroups** for positions, surface brightnesses, and magnitudes of the objects discussed here.

me until I examined it in a scope with more aperture. The group is located 3.5° east-southeast of Beta Andromedae and just a little over 4° from M33.

The brightest member of the group, **NGC 536**, is elongated nearly east-west with a bright core. A faint star is involved to the northwest of the nucleus. Almost 9′ west is **NGC 529**, which is round with a bright core. **NGC 531** is the third brightest component, but has a lower surface brightness, so I found it to be the most difficult of the group. **NGC 542**, small and thin, angles almost northwest-southeast. It lies 2.5′ southeast of NGC 536.

Aquarius

Our sampler wraps up with **HCG 88**, about 15′ southeast of 4 and 5 Aquarii. It comprises a string of four galaxies that line up brightest to faintest on a northeast-southwest line.

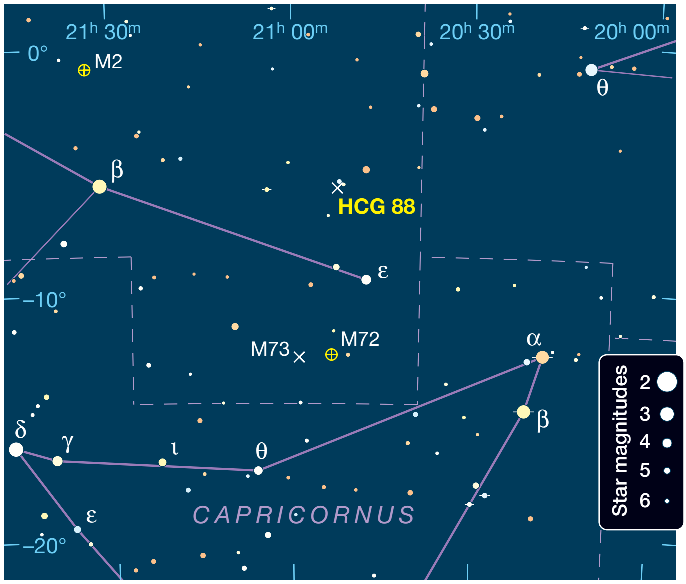
NGC 6978 stands at the northeast end of the string. It's elongated northwest-southeast and has a bright core. About 2½′ to the southwest is **NGC 6977**, which is round with a brighter core and a faint halo that, with averted vision, hints at structure. The third galaxy in line, **NGC 6976**, is smaller and fainter, but also round with a bright core. Last in line and faintest is **NGC 6975**, which is an averted-vision streak elongated nearly east-west.

Galaxy Hunters, Away!

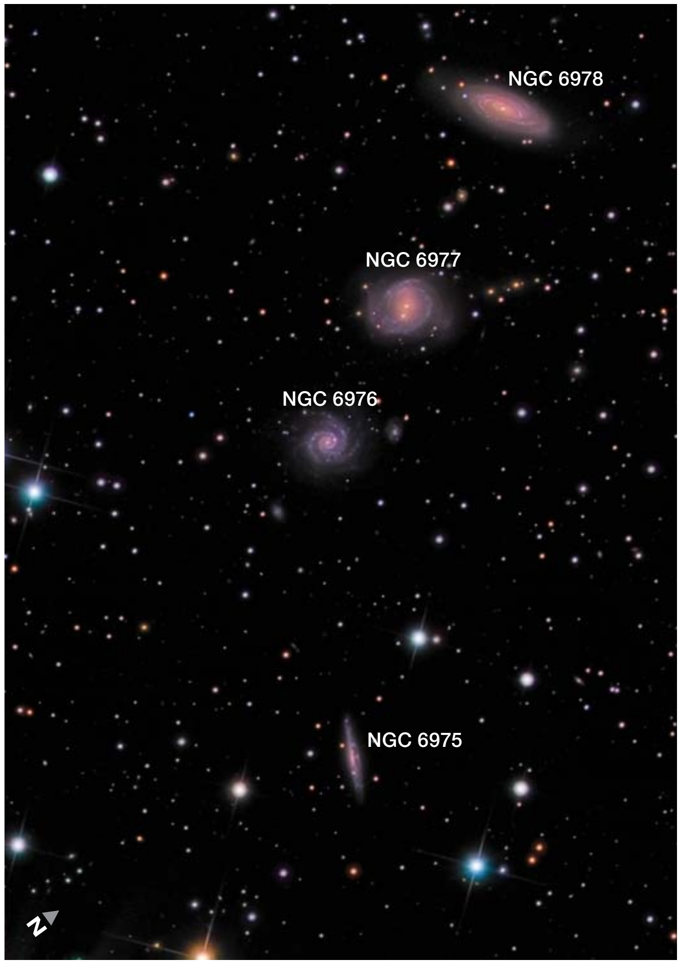
Many of the objects that comprise the Hickson Compact Groups are also contained in Halton Arp's *Atlas of Peculiar Galaxies* (**https://is.gd/ArpCatalog**) and exhibit the properties that make those objects so very compelling in the eyepiece. Evidence of interaction between the members, past or present, abounds. Gaseous streamers, warped disks and arms, violent starbursts and disturbed-looking dust lanes provide an endless array of interesting features that make these groups tantalizing targets in scopes of all sizes.

Sometimes the first reaction to a Hickson Compact Group will be to dismiss it as invisible. Some observers playfully use the words "lumpy darkness" to describe the vague impression of that "something" at the edge of detection that faint galaxy groups often display. It's here that experience and persistence along with good dark adaption are critical. While many Hickson groups will be beyond detection by most observers, you should never reject a group out of hand. The only realistic way to determine if a group can be seen is to actually look. The patient and determined observer of these systems will be well rewarded. Try them, and you're sure to conclude that the less-traveled road can make for a remarkable journey.

■ Contributing Editor **TED FORTE** is the operations director of Patterson Observatory in Sierra Vista, Arizona, and an officer of the Huachuca Astronomy Club. He writes a monthly astronomy column for his local newspaper, the *Sierra Vista Herald*.



HCG 88



▲ **DUCKS IN A ROW** The galaxies of HCG 88 conveniently form a line according to brightness. NGC 6978 and NGC 6977 hold the northwestern end of the line, NGC 6976 takes up the central position, and NGC 6975 faintly pins down the southwest end. Even with 18 inches of aperture, you're unlikely to detect any structure here. Look instead for circular fuzz patches that brighten toward the center.

KENT E. BIGGS

4 **DAWN:** Spica shines 4° right of Venus very low in the east-southeast. Bring binoculars. Faint Mars gleams some 16° above Spica.

5 **DAYLIGHT-SAVING TIME ENDS** at 2 a.m. for most of the U.S. and Canada.

5–6 **NIGHT:** The waxing gibbous Moon occults Aldebaran for much of North America and northern Europe; see page 51.

7 **NIGHT:** Algol shines at minimum brightness for roughly two hours centered at 10:56 p.m. EST; see page 51.

11 **MORNING:** Regulus is about 3° lower left of the just-past-last-quarter Moon as seen from North America. A few hours later the Moon occults Regulus in daytime for much of North America; see page 51.

DAWN: Find Jupiter 2° below the blaze of Venus, barely above the east-southeast horizon about 45 minutes before sunrise.

16 **DAWN:** The very slim waning crescent Moon hangs about 6° above Jupiter and 17° below modest Mars. Brighter Venus is 3° lower left of Jupiter.

17 **DAWN:** The hairline Moon, one day from new, forms a loose trio with Jupiter and Venus, quite low in the east-southeast. Bring binoculars and sharp eyes.

20 **DUSK:** The waxing crescent Moon poses nicely to the right of Saturn before they set in the southwest. Use binoculars to hunt Mercury 7° or 8° below the pair no more than 30 minutes after sunset.

24–25 **NIGHT:** Algol shines at minimum brightness for roughly two hours centered at 12:49 a.m. PST (3:49 a.m. EST).

27–28 **NIGHT:** Algol shines at minimum brightness for roughly two hours centered at 9:38 p.m. PST (12:38 a.m. EST).

28 **DUSK:** Look low in the southwest with binoculars to find Mercury and Saturn just 3° apart. Watch them close in on each other for the next 9 days.

The face-on spiral galaxy NGC 7674, also known as Markarian 533, is the brightest and largest member of the Hickson 96 compact galaxy group; see page 34.

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NOVEMBER 2017 OBSERVING

Lunar Almanac

Northern Hemisphere Sky Chart

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

NASA / LRO

MOON PHASES

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

FULL MOON
November 4
5:23 UT

LAST QUARTER
November 10
20:36 UT

NEW MOON
November 18
11:42 UT

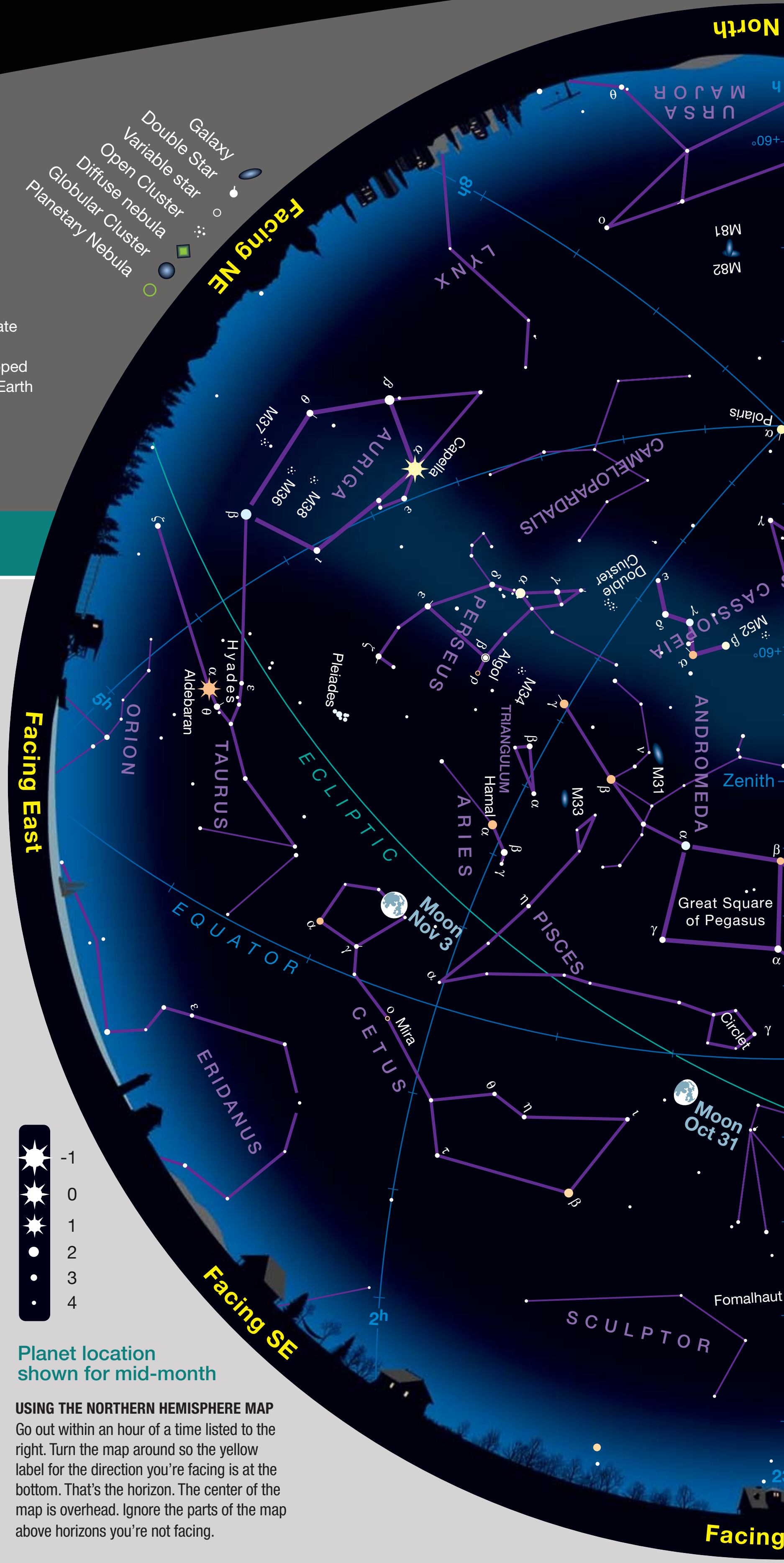
FIRST QUARTER
November 26
17:03 UT

DISTANCES

Perigree 361,438 km	November 6, 0^h UT Diameter 33′ 04″
Apogee 406,131 km	November 21, 19^h UT Diameter 29′ 25″

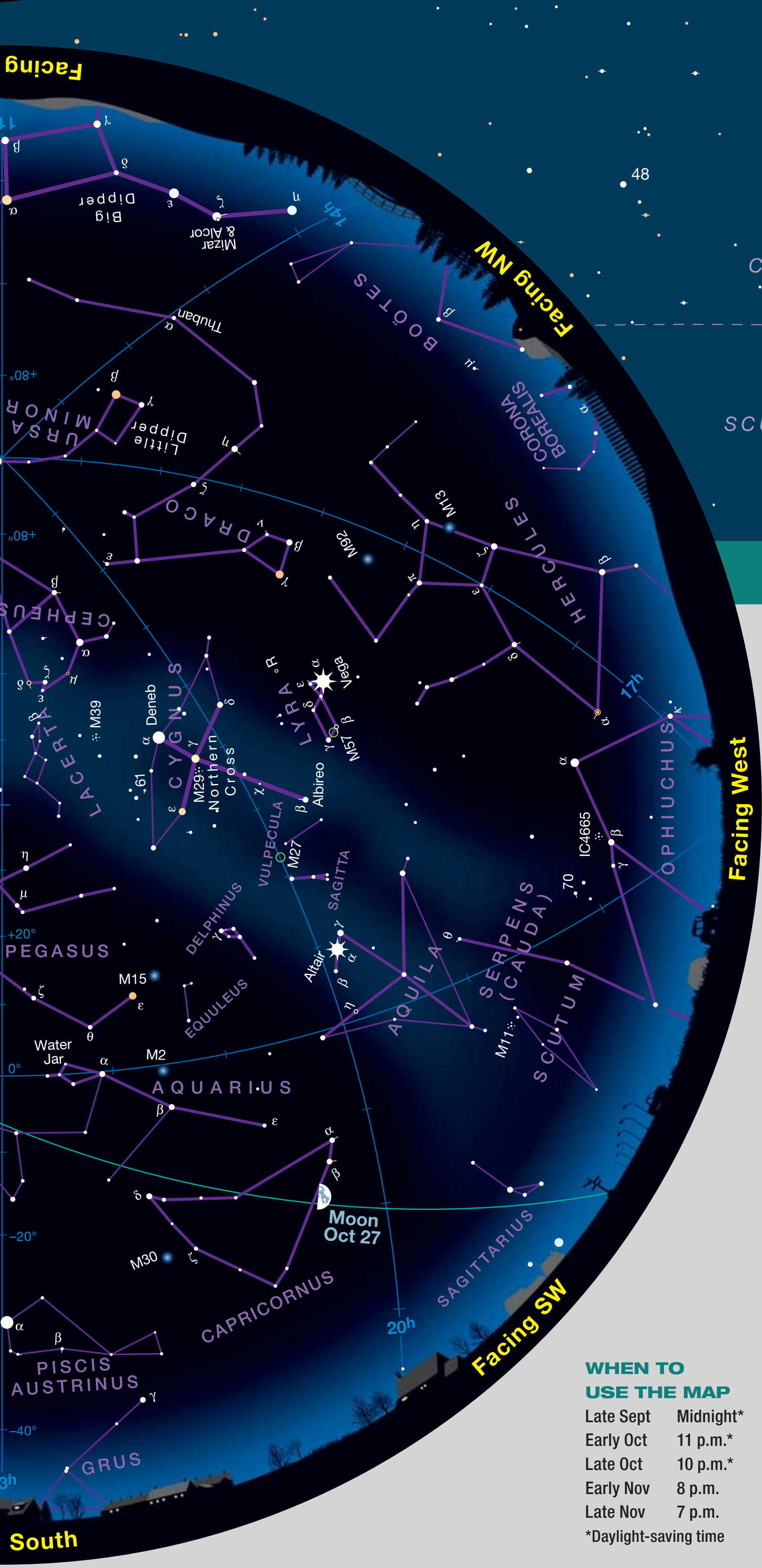
FAVORABLE LIBRATIONS

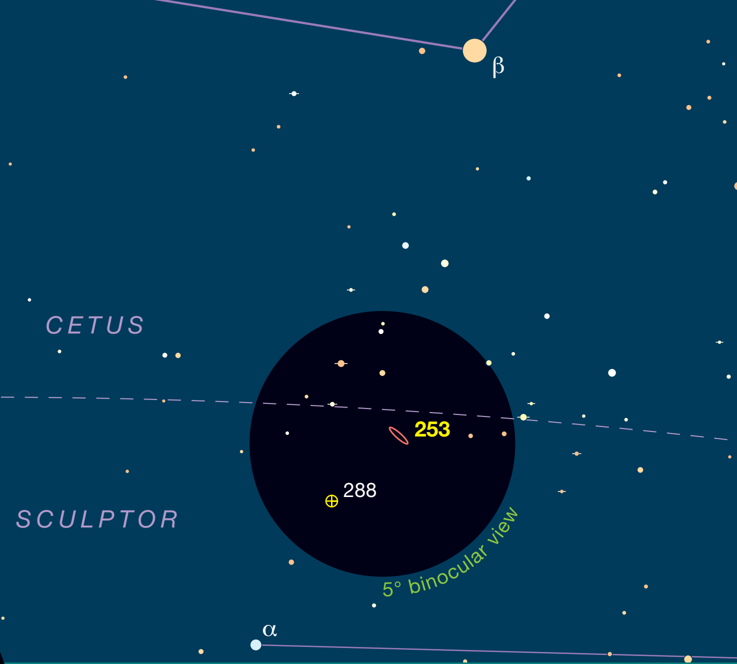
- Pascal Crater — November 5
- Mouchez Crater — November 6
- Scoresby Crater — November 7



Planet location shown for mid-month

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





Binocular Highlight by Mathew Wedel

The Silver Coin

I vividly remember the first time I saw **NGC 253**, the Silver Coin Galaxy (also known as the Sculptor Galaxy). I was in Big Bear Lake on a little weekend getaway with my family. Big Bear is isolated — at least by Southern California standards — high in the San Gabriel Mountains, full of trees, and not bad off in terms of light pollution. If you can get away from streetlights, you can see the Milky Way from the middle of town.

On the night in question, I was tired from an afternoon of swimming and hiking with my son, but still wanted to soak up a little starlight. I grabbed my binos and popped into the alley behind the lodge to see what was up. I was working on the Astronomical League's Deep Sky Binocular Observing Program, and NGC 253 was one of my last remaining targets.

My notes from that first observation hold up pretty well: "Outstanding, one of the best galaxies I've seen. Big, bright, obviously elongated, distinctly brighter in the western half." At magnitude 7.1, NGC 253 is indeed one of the brightest galaxies in the sky. Not only is it one of best binocular galaxies, eagle-eyed observers have spotted it with no optical aid whatsoever. And the western half does seem to be a bit brighter, as many photos and sketches attest. I suspect this is because the spiral arm on the west is in the foreground, whereas the eastern arm is receding behind the galaxy's famously dense dust lanes.

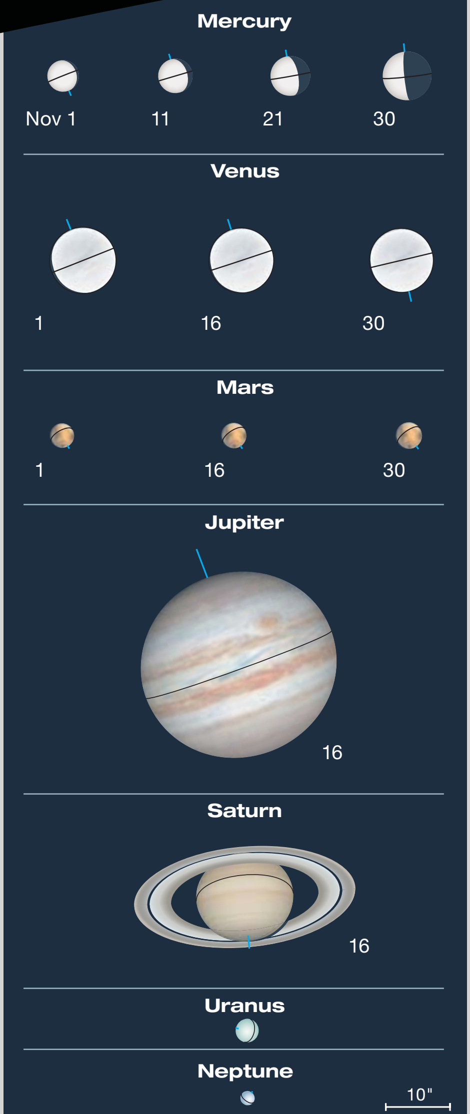
Since that first observation, I've had a good look at NGC 253 on dozens of occasions, and with instruments of all sizes. But somehow it just doesn't seem right if I'm not up in the mountains, surrounded by pine trees, holding binoculars. Sometimes first loves never quite let go.

■ **MATT WEDEL** is probably out in the dark somewhere, observing and making new memories.

WHEN TO USE THE MAP

Late Sept	Midnight*
Early Oct	11 p.m.*
Late Oct	10 p.m.*
Early Nov	8 p.m.
Late Nov	7 p.m.

*Daylight-saving time



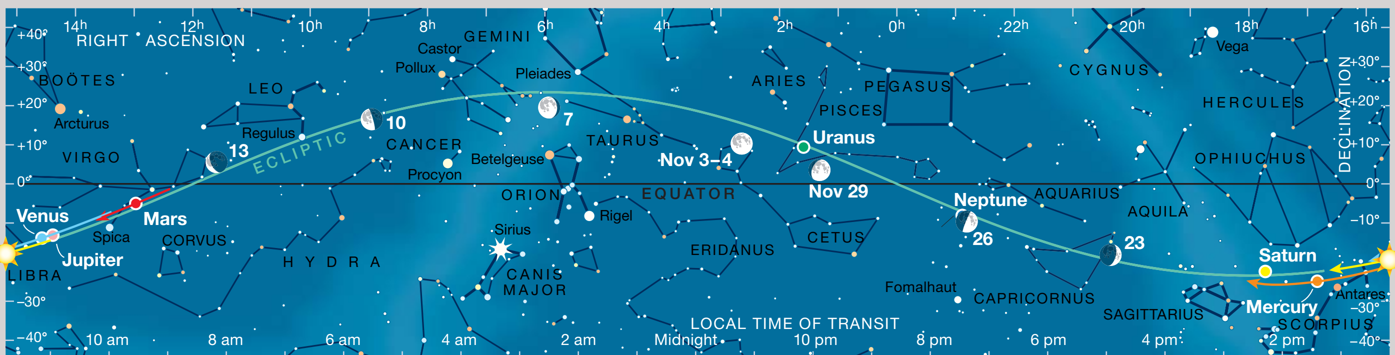
PLANET DISKS have south up, to match the view in many telescopes. Blue ticks indicate the pole currently tilted toward Earth.

PLANET VISIBILITY: **Mercury:** Mid-November through end, early dusk, low SW • **Venus:** All month, dawn, low ESE • **Mars:** All month, pre-dawn, E to SE • **Jupiter:** November 10 through end, dawn, low ESE **Saturn:** All month, dusk, low SW.

November Sun & Planets

	Date	Right Ascension	Declination	Elongation	Magnitude	Diameter	Illumination	Distance
Sun	1	$14^h\ 24.5^m$	–14° 20′	—	–26.8	32′ 14″	—	0.993
	30	$16^h\ 23.8^m$	–21° 36′	—	–26.8	32′ 26″	—	0.986
Mercury	1	$15^h\ 19.5^m$	–19° 48′	14° Ev	–0.4	4.9″	93%	1.359
	11	$16^h\ 19.8^m$	–23° 44′	19° Ev	–0.3	5.4″	85%	1.248
	21	$17^h\ 16.6^m$	–25° 38′	22° Ev	–0.4	6.2″	70%	1.080
	30	$17^h\ 52.1^m$	–25° 19′	21° Ev	–0.2	7.6″	44%	0.882
Venus	1	$13^h\ 22.3^m$	–7° 03′	17° Mo	–3.9	10.4″	96%	1.609
	11	$14^h\ 09.5^m$	–11° 39′	14° Mo	–3.9	10.2″	97%	1.636
	21	$14^h\ 58.2^m$	–15° 48′	12° Mo	–3.9	10.1″	98%	1.659
	30	$15^h\ 43.8^m$	–18° 58′	10° Mo	–3.9	10.0″	99%	1.676
Mars	1	$12^h\ 22.3^m$	–1° 10′	33° Mo	+1.8	3.9″	97%	2.406
	16	$12^h\ 57.1^m$	–4° 55′	39° Mo	+1.7	4.0″	96%	2.313
	30	$13^h\ 29.9^m$	–8° 17′	44° Mo	+1.7	4.2″	96%	2.215
Jupiter	1	$14^h\ 10.0^m$	–12° 02′	4° Mo	–1.7	30.7″	100%	6.430
	30	$14^h\ 34.1^m$	–14° 03′	27° Mo	–1.7	31.3″	100%	6.296
Saturn	1	$17^h\ 35.6^m$	–22° 20′	46° Ev	+0.5	15.5″	100%	10.729
	30	$17^h\ 48.8^m$	–22° 29′	20° Ev	+0.5	15.1″	100%	10.987
Uranus	16	$1^h\ 34.3^m$	+9° 12′	152° Ev	+5.7	3.7″	100%	19.032
Neptune	16	$22^h\ 52.2^m$	–8° 13′	108° Ev	+7.9	2.3″	100%	29.631

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-November; 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.

A Thrilling Trio

These three variable stars will hold your attention for nights on end.

Tracking variable stars requires meticulous observation habits, with careful attention paid to a single characteristic of a star, its brightness. Many amateur astronomers lean toward observing larger, richer, more detailed, or more colorful deep-sky objects, presuming that monitoring variable stars requires more work or more prolonged effort than they want to put out.

So people may be surprised to learn that three of the greatest amateur astronomers of the 20th century, all widely famed for their interest in more visually rich classes of astronomical objects, all widely treasured for their skilled and beautiful astronomical writing, were devoted, masterful, and passionate observers of variable stars.

Three men and three stars. These three great amateur astronomers are, in chronological order: William Tyler Olcott; Leslie Peltier; and Walter Scott Houston. This is a great time of year to ponder the topic of variable stars and what may have inspired the interest of these men in them. Our current sky offers the best evening visibility for the three most important, prototypical variable stars — all within a few hours of right ascension and within a few constellations of one another. The three variable stars are, west to east: Delta (δ) Cephei, the prototype of the Cepheid variable class; Omicron (ο) Ceti (Mira), the prototype of long-period or Mira variables; and Beta (β) Persei (Algol), the prototype of eclipsing binaries.

Let's take a closer look at these these three variable stars.

Delta Cephei, Mira, and Algol. I wrote about Delta Cephei in last October's installment of this column. This pulsating star drops in brightness from magnitude 3.5 to 4.4 and back to maximum in 5 days, 8 hours, and 48 minutes. It forms a small triangle with excellent comparison stars for its maximum and minimum, and it's also a gorgeous and easy orange and blue double star.

Delta heads a class of variable star known as "the Cepheids," which offered us a key to establishing distances in the universe. The variability of Delta Cephei was discovered in 1784 by astronomer John Goodricke. Goodricke lost his hearing after falling ill at age 5, but he received a solid education in mathematics and natural philosopy nonethless. He died of pneumonia at the age of 21, but not before proposing the correct explanation for the variability of Algol.

Mira is a long-period variable in the neck of Cetus, the Whale, that goes from one maximum to the next in about 332 days. Mira typically ranges from about 9th or 10th magnitude to 4th or 3rd magnitude, but it occasionally peaks at 2nd magnitude — and once even rivaled 1st-magnitude Aldebaran.

Mira is approximately 500 times the diameter of the Sun and so cool (for a star) that it has water vapor in its outer atmosphere. The star's variability was first noticed by German pastor David Fabricius back on August 13, 1596, but he seems to have believed it was a nova.

Algol marks the severed head of the monster Medusa in the grasp of Perseus. Algol dims from magnitude 2.1 to 3.4 over a period of 2 days, 20 hours, 48 minutes, and 56 seconds, with both the dimming and brightening taking about 5 hours each. Though Goodricke was the first to figure out Algol dims due to eclipses by its cooler companion star, the variability of Algol seems first to have been recorded by Italian astronomer Geminiano Montanari in 1667.

Next time: the 20th-century three. I've only just gestured at the accomplishments of Goodricke, Fabricius, and Montanari this month, but in next month's column, where we take further looks at awe, total solar eclipses, and more, we'll also discuss the "20th-century three" mentioned above and their love of variable stars.

■ Contributing Editor FRED SCHAAF was long ago struck by the wonder of variable stars.

At the Edge of the Day

All the bright planets congregate at either dusk or dawn this month.

For yet another month, all five bright planets congregate near dusk or dawn. They're not always easy to see, but they engage in some remarkable conjunctions, particularly when a few bright stars join the scene.

Mars is the most steadily present this month, rising a few hours before morning twilight. Then dawn brings us Venus (and Spica) in the first days of November. A week later bright Jupiter returns low in the east, where it passes an even brighter Venus in a low but close and spectacular conjunction.

In the second half of November, Mercury comes into view at dusk, very low in the southwest, for a rather poor apparition for observers at mid-northern latitudes. Departing Saturn follows Mercury down to set, and then there's a long wait before any bright planet enters the sky.

DUSK

Mercury might be first glimpsed with binoculars around November 17th, very low in the southwest 20 minutes after sunset. How early in the month can you spot it?

Mercury is at greatest elongation, 22° east of the Sun, on November 23rd, and in the last week of the month, moves a little higher in evening twilight. It's a bright magnitude –0.4 all the while, but in November's final days it begins to fade while still only 5° or 6° high 30 minutes after sunset. It closes the month at magnitude –0.2.

Saturn, even fainter at magnitude +0.5, starts the month moderately well up in twilight, setting about 2½ hours after the Sun. By the end of November, the ringed planet drops below the horizon little more than an hour after the Sun. Over the course of the month, Saturn sinks lower and lower, edging toward brighter Mercury. On November 24th, Saturn shines about 5° directly above Mercury. By the 28th, they're 3° apart and closing.

EVENING

Neptune reached opposition in September and is now highest — and so best observed — in early evening. This 7.9-magnitude world remains less than 1° from Lambda (λ) Aquarii.

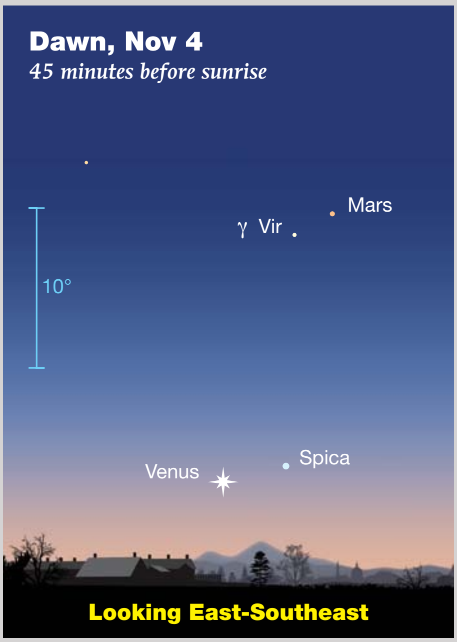
Uranus was at opposition in October and is now highest in late evening. At magnitude 5.7, Uranus shines eight times brighter than Neptune, which makes it an easier observing target. But it's hanging out in the dim constellation of Pisces, adding a level of difficulty to your star-hop. Even so, Uranus is well within reach of handheld binoculars.

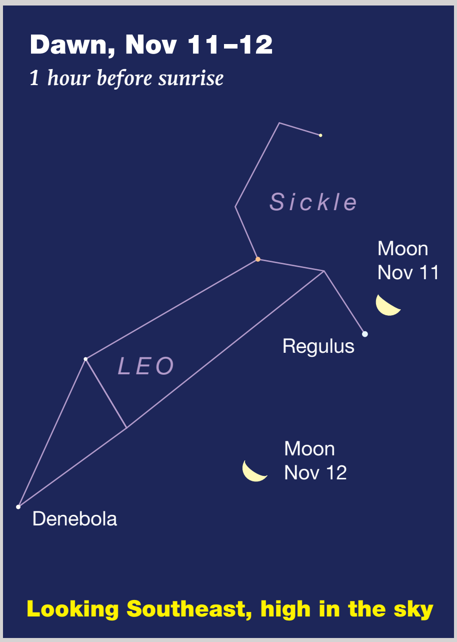
Finder charts for Uranus and Neptune can be found on pages 50–51 of the October issue.

EARLY MORNING

Mars leads the Sun in November, rising three to four hours earlier than our star. As it glides across a section of the long constellation Virgo, it remains dim and far away, its orange glow no brighter than magnitude 1.7.

On the morning of November 4th, Mars gleams orange just 3° upper right of the double star Gamma (γ) Virginis (commonly known as Porrima). By the 6th, the distance between the two closes to 2°; they remain close through the 9th. Look for the 1st-magnitude star Spica some 15° below this duo and **Venus** lower left of Spica before twilight transitions to sunrise.





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

On November 29th and 30th Mars makes its own pass by Spica, shining only 3° upper left of the brighter star.

Summer solstice occurs in the northern hemisphere of Mars on November 20th, but surface detail is unobservable as the planet is a tiny blob just 4″ wide in telescopes.

DAWN

Venus and **Jupiter**, the two brightest planets, pass each other low in the east at dawn this month, presenting a conjunction tight enough to remind us of the ultra-close pairings of 2015 and 2016.

Venus rises about 90 minutes before the Sun at the start of November but only about 45 minutes before the Sun by month's end. Venus blazes at magnitude –3.9 about 4° from Spica from November 2nd through 4th. The pair is low, though, less than 10° above the east-southeast horizon 45 minutes before sunrise. Venus shines about 100 times brighter than Spica.

Jupiter comes up too near sunrise to be seen in the opening days of November, but keep watch for it to the lower left of Venus. By the close of the month, the giant planet rises almost 2¼ hours before the Sun, offering a decent opportunity for observation.

Jupiter shines all month at its minimum brightness of magnitude –1.7 and at a nearly minimum apparent diameter of 31″. Still, that's almost exactly three times the 10″ width of almost fully illuminated Venus.

Be sure to bring your scope on the morning of the 13th; the two very different disks will fit in the same medium-power field of view at dawn. The globe of Venus shines only ¼° from the orb of Jupiter. After this conjunction at the border of Virgo and Libra, Jupiter rapidly moves farther to Venus's upper right, well into Libra.

MOON PASSAGES

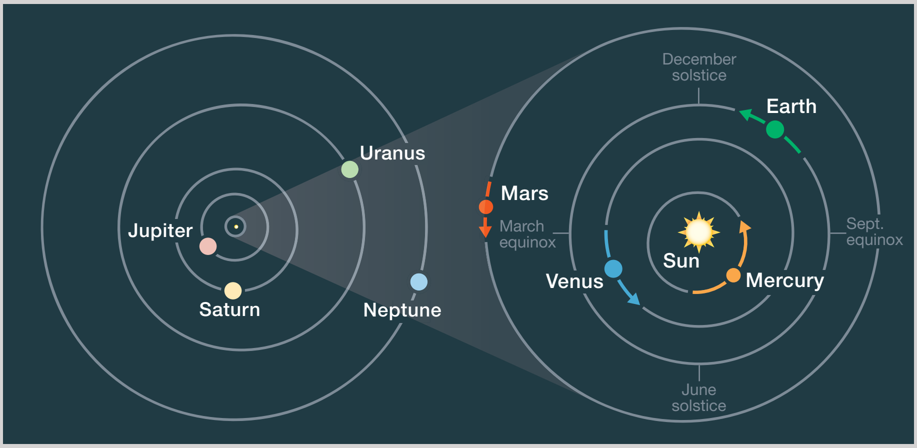
The **Moon**, just past full, occults Aldebaran on the evening of November 5th for much of North America. The Moon wanes to less than half lit by the time it occults Regulus in the daytime of November 11th for parts of North America; see page 51 for more on both occultations.

The waning crescent Moon is some 7° above Mars on the morning of November 14th. The next morning the Moon forms a pretty triangle with Mars and Spica, with Venus and Jupiter lower left of them. At dawn on November 16th the slimmer Moon is about 6° above Jupiter, which is then about 3° upper right of Venus.

A compact arc of Moon, Venus, and Jupiter occurs at dawn on November 17th, though with the Moon lowest and rising only a little more than an hour before the Sun. Look for the Moon with binoculars about 4° lower left of Venus.

In the evening sky, the thin waxing crescent Moon is 8° or 9° right of Mercury on November 19th, and just 3° right of Saturn on the 20th.

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



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

▲ 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.

The Poleward Trek of Comet ASASSN1

Heading far north, this telescopic target should be at its best in October and November.

▲ Comet ASASSN1, or more formally C/2017 O1, already showed a condensed nucleus and a lovely green coma when Rolando Ligustri took this image on July 22nd as the comet was crossing Cetus.

Comets often hug the dawn or dusk horizons frustratingly low in the twilight. And sometimes they're completely out of sight at their peak. The reason, of course, is that comets shine brightest when they're closest to the Sun in space. Not only is this when they're heated the most and release the most gas and dust, it's also where sunlight illuminates these sheddings the most intensely.

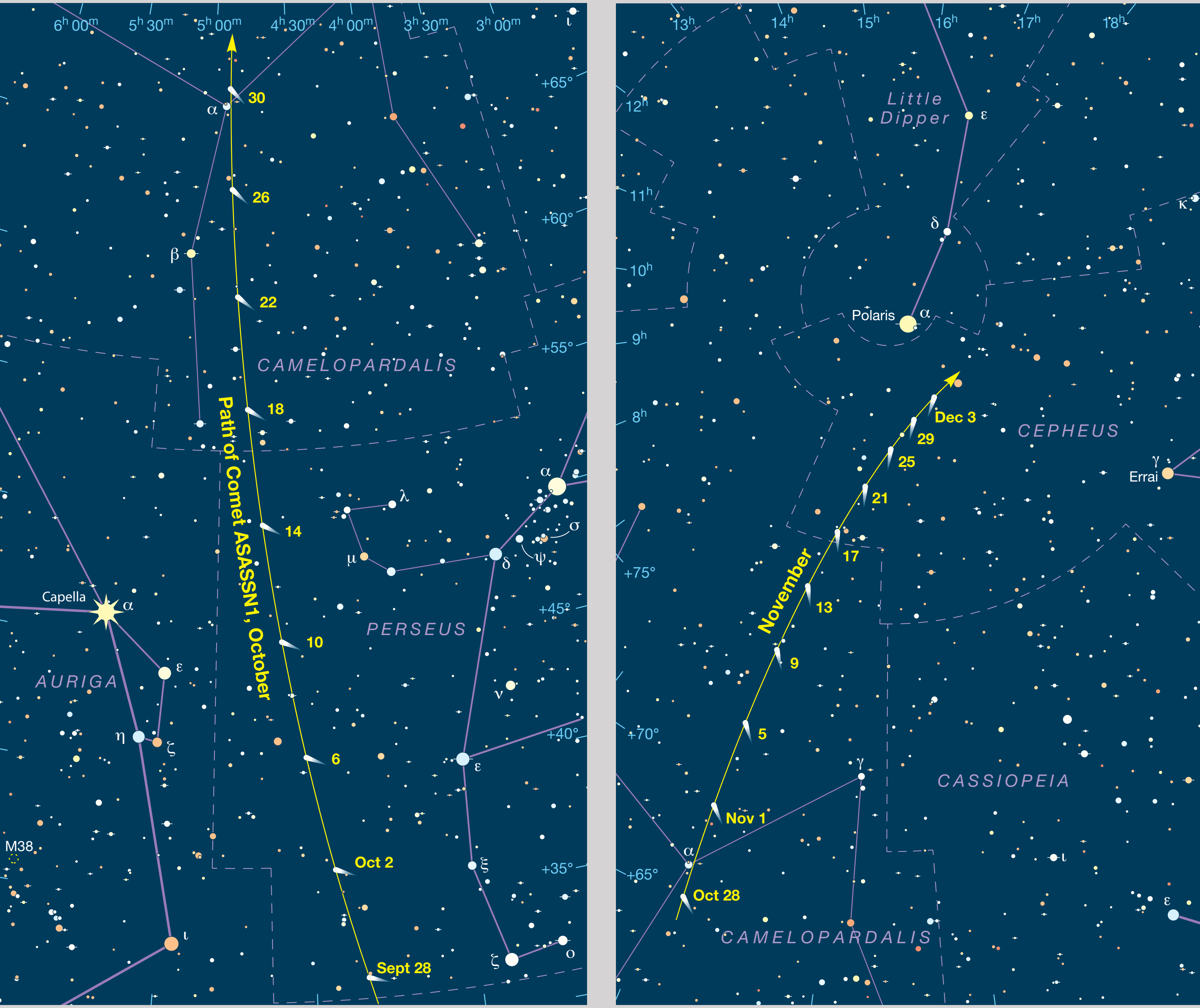
The newly found Comet ASASSN1 won't act like that. Formally named C/2017 O1, it was discovered by the All-Sky Automated Survey for Supernovae on July 19th at 15th magnitude. It brightened rapidly and is now high in the dark night sky for small-telescope users at mid-northern latitudes. It should glow at about 7th magnitude from early October through mid-November, and it could reach 6th in mid-October.

It will come only as near to the Sun as 1.5 a.u. (perihelion is October 14th), and Earth is coasting along more or less between it and the Sun — affording us a picture-window view of it against a backdrop of dark space.

Try binoculars if you have them, but expect to need a telescope. A diffuse thing like a comet is always less easily visible than a star of the same magnitude, especially through light pollution. In early August, ASASSN1 had a bright, condensed nucleus, a good sign that it may hold to its predicted brightness. It was not showing a tail, and with its distance from the Sun, it may never.

The comet travels northward between Perseus and Auriga for much of October, as shown at right. This part of the sky will be high in the east to northeast by late evening and passes overhead in the early-morning hours. The comet spends the rest of October and November trekking north through the dim polar wastes of Camelopardalis and northern Cepheus. By then it will be well up in early evening.

Can you see the comet's green color in your eyepiece? It's caused by hot diatomic carbon (C_2) fluorescing in the ultraviolet sunlight. I see at



▲ Comet ASASSN1 is excellently placed in a dark sky (for Northern Hemisphere observers) in late evening during October and by early evening in November. Assuming it doesn't punk out, as comets sometimes do, it should glow at about 7th magnitude in October and fade down to 9th by the end of November. The comet symbols (greatly exaggerated) are placed at 0:00 Universal Time on the dates indicated; in North America this is on the early evening of the previous date. The tails point in the direction away from the Sun.

least hints of green in most telescopic comets if they're bright enough to see at all without much difficulty. Your views may vary; color perception in dim light varies a lot from person to person.

About that deadly-sounding name: the All-Sky Automated Survey for Supernovae was not designed to find comets, and this is its first. But a comet discovery was hardly a surprise. The program's camera arrays in the Northern and Southern Hemispheres, with quartets of 400-mm f/2.8 lenses feeding large, top-of-the-line CCD detectors, can image the entire sky to 17th magnitude every two days. The project has found more than 500 supernovae in far galaxies, as well as many new cataclysmic variable stars, stellar flares, and tidal disruption events (when a star swings too near a galaxy's supermassive black hole and gets "spaghettified").

Anyone can use the program's data. At **asas-sn.osu.edu** there's a nifty tool that sifts through all of it and creates a light curve for any small spot on the sky you care to specify, such as an accurate star position. Results may take a few minutes to appear. (Stars brighter than 8th magnitude overexpose the detectors and cannot be usefully measured.)

▶ An automated array of ASASSN patrol cameras, with long dew shields, on Mount Haleakala, Hawai'i.

• For current news of Comet ASASSN1's behavior, and to see how your observations match others', see the Recent Observations box on the home page of the Comet Observation database, **cobs.si**, as well as updates at **skyandtelescope.com**.

The Taurids Are Back

HAVE YOU EVER SEEN a Taurid fireball? An unusually bright, unusually slow meteor on an October or November evening, sailing away from the general direction of Taurus or Aries as they climb the eastern sky?

The Taurid shower is unusual for several reasons. It's divided into two sub-branches, the Southern and Northern Taurids, with large, poorly defined radiants about 6° apart. The peak dates of the two branches are sometimes listed as November 5th and 12th, respectively. But both branches are so long-lasting — meaning the meteoroid streams are so wide — that they overlap greatly. In fact, recent video and visual plotting work indicate that the southern branch "probably reaches its peak about a month before the northern one," according to the 2017 Meteor Shower Calendar of the International Meteor Organization (IMO).

And because the radiant spots rise high in the east moderately early, evening skywatchers are not left in the fringes of the action as happens with most meteor showers, whose radiants only rise high in early morning hours.

The Taurids are sparse at all times, with zenithal hourly rates reaching only about 5 meteors visible per hour even under ideal conditions. But an unusually high proportion of these few are bright. Occasionally a Taurid fireball is long and dazzling enough for people to call the police to report a burning plane falling out of the sky.

In 2005 a sub-stream of unusually large Taurid meteoroids intersected Earth's orbit. These were the sizes of pebbles to small stones, rather than the sand grains to peas typical of most meteoroid streams, and the resulting "Halloween Fireballs" made the news. There's been no repeat of this outburst, but the name has stuck. Don't take it too literally; think Halloween plus or minus several weeks.

▲ A dazzling Taurid fireball streaked down to the left of Fomalhaut while Marko Korošec had his camera open to the sky over Brkini, Slovenia, early on the evening of October 30, 2015.

The Leonids

A more ordinary shower should peak on the mornings of November 17th and 18th, in the dark of the Moon this year. But the Leonids, a grand spectacle around the turn of this century, have since diminished into obscurity. The IMO is predicting a peak zenithal hourly rate of about 15, so prepare for quiet meteor watches.

If you want to do a useful, scientific meteor count for the IMO, you can read about how to do it, and where to report, at **imo.net/observations/methods/visual-observation/major/**. The IMO has overhauled its website since you may have last looked; check it out.

CAMERA ARRAY: ASASSN / OHIO STATE UNIVERSITY

Occultations of Aldebaran and Regulus

THE MOON IN NOVEMBER occults two 1st-magnitude stars for much of North America just six days apart. The first event happens mostly in early-evening darkness. The second takes place in broad daylight.

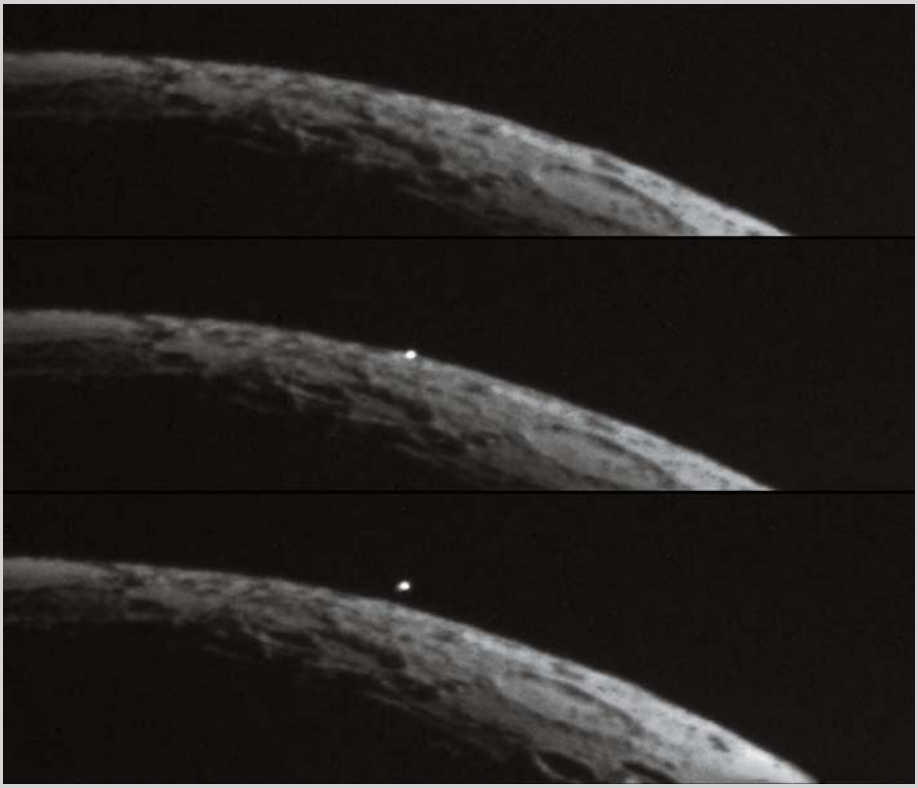
• **Aldebaran, November 5th.** The Moon will be just a trace past full and shining in the eastern sky around dinnertime when, for the eastern and central parts of the continent, its bright limb will creep up to and hide orange Aldebaran — a telescopic "fire on the Moon" in its final seconds. The star will reappear on the other side from behind the Moon's very thin dark sector (Luna is only 5% unilluminated) up to an hour or more later.

The farther west you are, the earlier and lower it happens. From Texas through Montana, the star will already be behind the Moon at moonrise; you'll only see the reappearance. Observers farther west miss out altogether.

Northern Europeans will see the occultation at a later hour: around the middle of the night of November 5–6.

• **Regulus, November 11th.** The following Saturday, telescope users from Georgia through British Columbia and points father south and west can try for the Moon occulting blue-white Regulus high in a (hopefully) blue sky. The Moon will be a day past last quarter. Again the star disappears on the bright limb and reappears on the dark limb, which will be invisible in the daytime blue. Good luck.

Complete timetables for both stars' occultations for hundreds of cities and towns are at **lunar-occultations.com/iota/bstar/bstar.htm**. Pay attention there to the altitudes listed for the Sun and Moon. The daytime sky around the Moon is deeper blue when the Moon is higher than the Sun, giving your telescope the best chance. The "CA" column tells the cusp angle where the star disappears or reappears: how many degrees from the Moon's north or south cusp the event occurs, so you'll know exactly where to look. For each star, the prediction page displays three long tables with less-than-obvious divides: for the disappearance, the reappearance, and the locations of cities.



▲ On July 25th, Shahrin Ahmad in Kuala Lumpur, Malaysia, took a telescopic video of Regulus emerging from behind the Moon's bright limb.

Minima of Algol

Oct.	UT	Nov.	UT
1	21:22	2	10:18
4	18:10	5	7:07
7	14:59	8	3:56
10	11:48	11	0:45
13	8:36	13	21:34
16	5:25	16	18:22
19	2:14	19	15:11
21	23:03	22	12:00
24	19:52	25	8:49
27	16:40	28	5:38
30	13:29		

Algol stays near minimum light, magnitude 3.4 instead of its normal 2.1, for about two hours. These predictions are from the heliocentric elements Min. = JD 2445641.554+ 2.867324*E*, where *E* is any integer. For a comparison-star chart, see **skyandtelescope.com/algol**.

USING A CHART WITH YOUR TELESCOPE

◖ You know that to find faint objects with your telescope, you need detailed, large-scale charts. But you also need to know the size and orientation *of your eyepiece view* as it appears on the charts, so that you can match star patterns in your eyepiece to star patterns on the paper or screen. Read how at **skyandtelescope.com/charts**. Then practice until it's routine.

If you know *exactly* where in your field of view a difficult faint fuzzy ought to be, you can detect things at least a magnitude fainter!

Jupiter – From Earth to Juno

Amateur astronomers are benefitting from — and adding to — Juno's observations.

As Jupiter's 2017 apparition draws to a close, we can look back over what has happened with the planet's dynamic, ever-changing cloudtops. Fortunately, ground-based observers have a powerful and exciting new ally. NASA's Juno spacecraft went into a looping, 53-day-long orbit around the solar system's largest planet on July 5, 2016 (*S&T:* July 2016, p. 18), and its "public outreach" camera, JunoCam, started imaging at the first *perijove* (closest approach to the planet) 7½ weeks later. Consequently, this has been a year in which professional and amateur ground-based observations have been more synergistic than ever before.

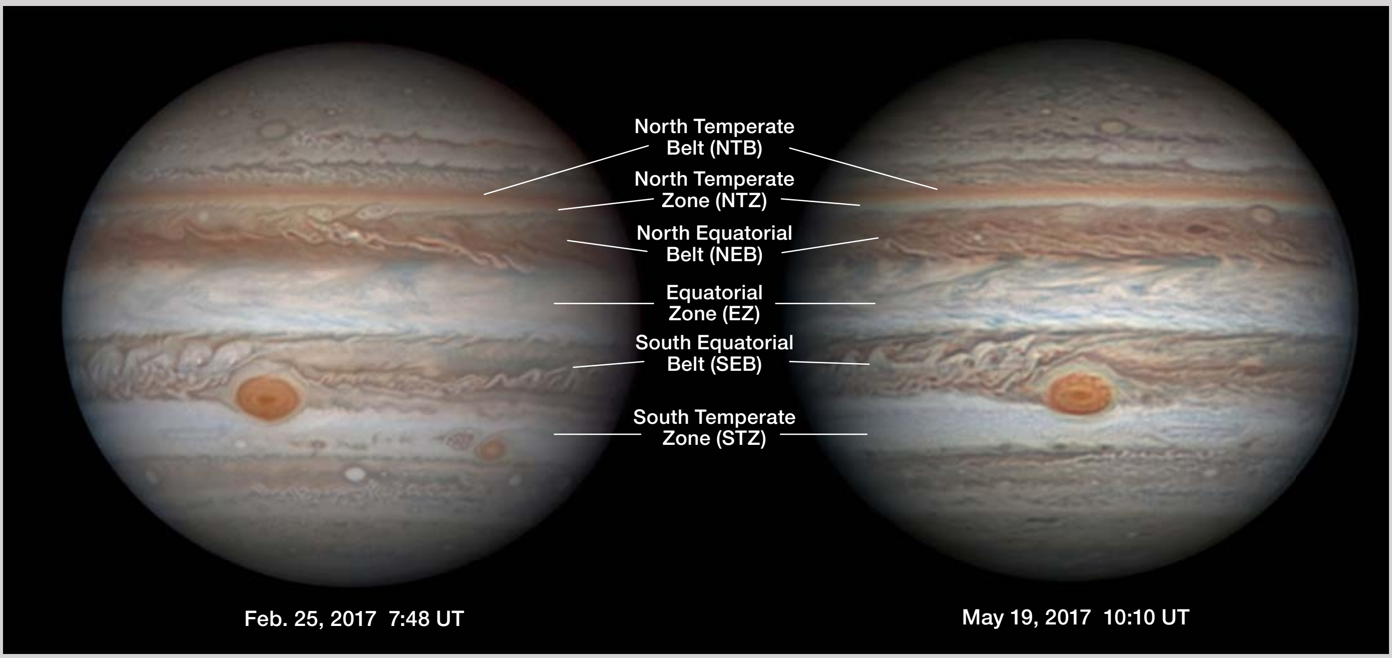
Jupiter's familiar banded pattern is due to intense winds that blow eastward and westward in jet streams at fixed latitudes. These set the boundaries between the planet's dark *belts* and the bright *zones*. The dark belts are cyclonic (low-pressure) bands, whereas the zones are regions of high pressure.

Close views of the clouds reveal the continuous streaming and swirling of fluid in motion, punctuated by eruptions of new white spots or streaks that mark convective thunderstorms. Sometimes, over a period of several months or years, dark belts can temporarily change their boundaries or fade (as white cloud condenses over the belt), but sooner or later they revert to normal. These changes are aspects of planet-encircling cycles within each belt that unfold over a year or more.

At the time of Juno's arrival, the planet's four most prominent belts were largely quiet. But since then, three have shown increasing activity, including major new cycles of disturbance in the North Temperate Belt (NTB) and North Equatorial Belt (NEB).

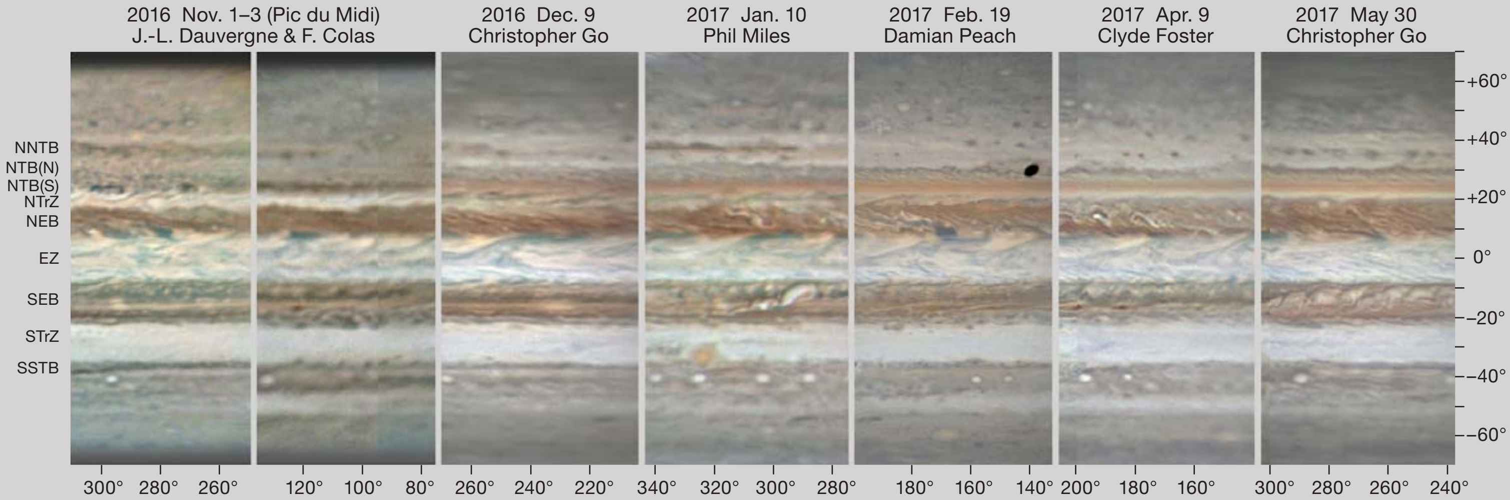
Monitoring Outbreaks

Cycles of activity in the NTB typically involve sudden outbreaks of brilliant, white cloud plumes along a very rapid jet stream on the NTB's southern edge. These are the fastest-moving features seen on the planet, and they are followed by a chaotically expanding disturbance that leads to a "revival" of the dark belt with a vivid orange southern component that observers term the



DAMIAN PEACH / CHILESCOPE TEAM: CHRISTOPHER GO

▲Two of the year's best ground-based images of Jupiter, taken by amateur astronomers, reveal a host of cloud features on the planet. Note, for example, the turbulent "wake" to the upper left of the Great Red Spot.



▲These reprojected images show changes in Jupiter's main belts and zones that occurred from November 2016 to May 2017. Initially, the North Temperate Belt (NTB) is in the throes of a violent outbreak of turbulence; from December onward, the belt "revives" with an orange southern component and dark gray northern component. Meanwhile, outbreaks of white "rifts" tear through the North Equatorial Belt (NEB) from January onward. The South Equatorial Belt (SEB) exhibits a new, bright rift in January's view and especially in May's.

NTB(S). These outbreaks sometimes occur at 5-year intervals, as they did in in 2007 and again in 2012.

This past year, given that the belt had faded again and the jet stream accelerated, observers anticipated another outbreak in late 2016 or early 2017. And it did occur — but when Jupiter was hidden from Earth during solar conjunction in late September. Glenn Orton (Jet Propulsion Laboratory) discovered the outburst in infrared images taken from Hawai'i on October 19, 2016, during Juno's second perijove. Although the spacecraft made no observations at that time, we could still identify and track the outbreak's four plumes in distant, low-resolution JunoCam images taken through October 14th.

Several amateurs immediately started imaging as well and successfully tracked the progress of the outbreak. Over the subsequent months, the orange NTB(S) appeared as expected — it's known as the "Big Red Stripe" on JunoCam's public website (**missionjuno.swri.edu/junocam**) — and the camera's dramatic images taken at successive perijoves showed the detailed cloud textures as the reviving belt matured.

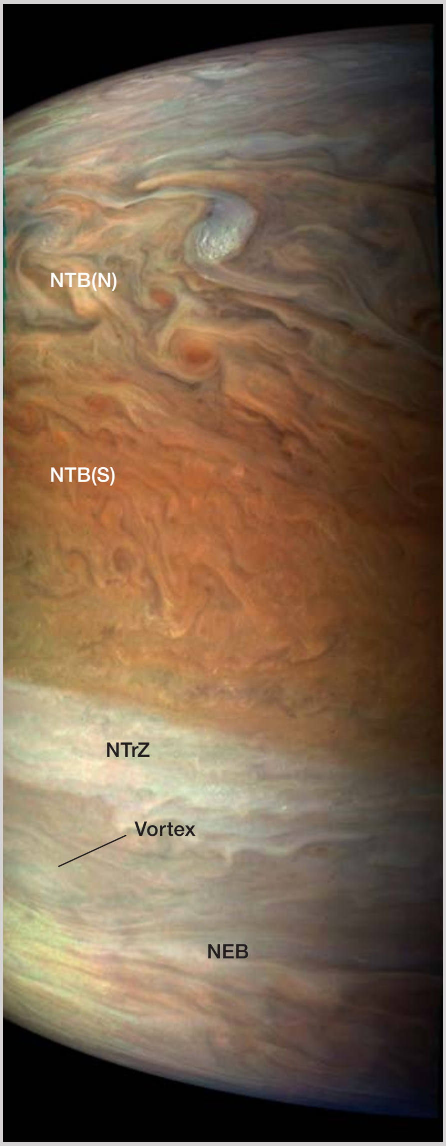
Cycles of activity in the North Equatorial Belt are quite different. They're marked by rapid broadening of the dark belt to the north, accompanied by outbreaks of convective white clouds known as "rifts." This sequence tends to occur at intervals of 3 to 5 years — the latest began in 2015 but fizzled out in early 2016, when it extended only halfway round the planet.

However, late last year, as the intense turbulence of the NTB outbreak spread southward, new rifts began to appear in the NEB. As seen in the sequence above, these proliferated to a remarkable extent and, in 2017, induced a full-scale broadening of the belt to the north.

These cyclic changes typically cause new features to develop in the expanded belt, and in fact we've observed both cyclonic brown ovals and anticyclonic white ovals. JunoCam has taken close-ups of the belt throughout all this activity, including recent snapshots of two of the newly formed vortices.

Making Waves

During these recent disturbances in the NEB, amateur observers have noted a series of large diffuse waves in the haze over the belt, which become visible in images recorded at near-infrared wavelengths sensitive to absorption by methane. Only once before, in 2000, have

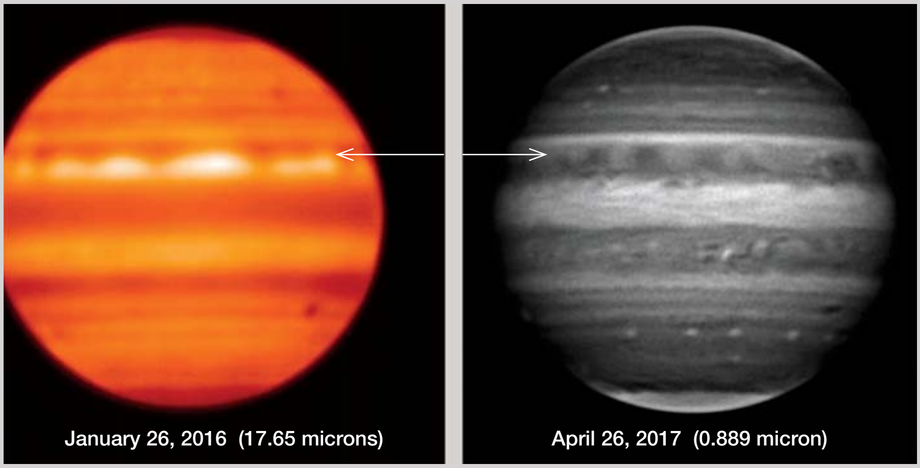


▶In this close-up of Jupiter as seen by NASA's Juno spacecraft near perijove, the cloud features are distorted by the extreme wide-angle view. The NTB has a dual personality: a turbulent northern half, designated NTB(N), and a calmer but strongly colored southern half, NTB(S). The very bright rift in NTB(N) is studded with tiny bright clouds casting shadows.

IMAGE SEQUENCE: MARCO VEDOVATO & JOHN ROGERS; JUNO IMAGE: NASA / SWRI / MSSS / GERALD EICHSTÄDT / JOHN ROGERS these waves been so conspicuous, and that likewise occurred during a NEB broadening event. They are striking in both amateur and professional infrared images. A team led by Leigh Fletcher (University of Leicester, UK) finds that the wave pattern is influenced by heat: The reflective haze looks thinner where the air is warmer. Perhaps some aspect of the disturbance in the "weather layer" of Jupiter's clouds generates the wave pattern seen in the overlying haze. In any case, the waves remained prominent during 2017, and tracking them using both amateur and professional images should help us to understand how they arise and propagate.

Meanwhile, the South Equatorial Belt (SEB) has not shown cyclic, planet-wide changes recently, but long-running convective storm activity has waxed and waned in more localized parts of it.

As with the planet's other major cloud belts, the SEB remained largely quiet throughout 2016, with only low-level convective activity in its usual location just west of the Great Red Spot (GRS). However, these storms have become much more extensive since February, and a new batch of similar storms appeared well away from the GRS last December 29th. So by mid-2017 the SEB was intensely disturbed around most of its length.



▲ Although not obvious in visible-light images, a large-scale wave pattern persisted over the NEB for most of 2017. Compare the right image, which uses a methane absorption band to accentuate high-altitude detail, and the view made at 17.65 microns, which shows hot spots in the cloud deck.

GLENN ORTON / SUBARU TELESCOPE; CHRISTOPHER GO

RESULTS FROM JUNO

NASA's Juno spacecraft has been sending back amazing images of Jupiter's ever-changing cloudtops. But its primary mission is to study the planet's magnetosphere and the high-energy particles trapped inside it. By carefully tracking the spacecraft, scientists are also mapping Jupiter's gravity field and using that knowledge to probe the structure of its interior and the character of its core.

You Call the Shots

Since JunoCam is intended primarily for public outreach, its imaging targets are being chosen by public vote. At the JunoCam website, amateur astronomers have been uploading their images of Jupiter, which the camera team uses to make up-to-date maps. Then the public gets not only to nominate "points of interest" but also to vote for the features that the spacecraft will image at the next perijove.

JunoCam makes images from wide-angle scans of the clouds directly below the spacecraft, which swoops close in, 3,500 km in altitude, at each perijove. So targets can be selected by latitude but not by longitude, because the location of a particular candidate "spot" depends on its often-variable drift in longitude. The amateur group JUPOS produces maps (found at **jupos.org**) that track all of the giant planet's atmospheric features as they drift east or west, and the author also produces a predictive map, to give the best possible estimate of which features will be observable at any given perijove pass.

Also, because JunoCam views the planet at such close range, it is important to put its images into a wider context using amateur images of the track taken close to the time of perijove. Several observers have made special efforts to obtain these, notably Clyde Foster in South Africa. Such images can show precisely how the dramatic cloudscapes seen by Juno fit into the ever-changing patterns that we can see from Earth.

JunoCam has obtained striking close-ups of several major features, including a pale but persistent cyclonic storm called the "STB Specter," which revealed superb circulation patterns. Close-ups have also covered long-lived anticyclonic ovals at latitudes ranging from 41°S (nicknamed the "String of Pearls") to 41°N and on July 11th, most dramatically of all, the Great Red Spot.

All the images, with preliminary processing by the camera team and with more advanced refinement by members of the public, can be viewed on the JunoCam website. It's well worth a visit — both to admire the striking cloud patterns found on Jupiter and to appreciate the rewarding results that such professional-amateur collaboration can achieve.

■ Veteran planetary observer **JOHN ROGERS** has served as Jupiter Section director for the British Astronomical Association since 1987.

Square Galaxies

Spend some time roping this herd of faint fuzzies in the Great Square of Pegasus.

One of the unmistakable stellar landmarks of the autumn sky is the Great Square of Pegasus, which you'll find cozied up to the meridian on this month's all-sky map. As Garrett P. Serviss writes in his ever charming book *Astronomy with an Opera-Glass*, the Great Square "at once attracts the eye, there being few stars visible within the quadrilateral, and no large ones in the immediate neighborhood to distract attention from it."

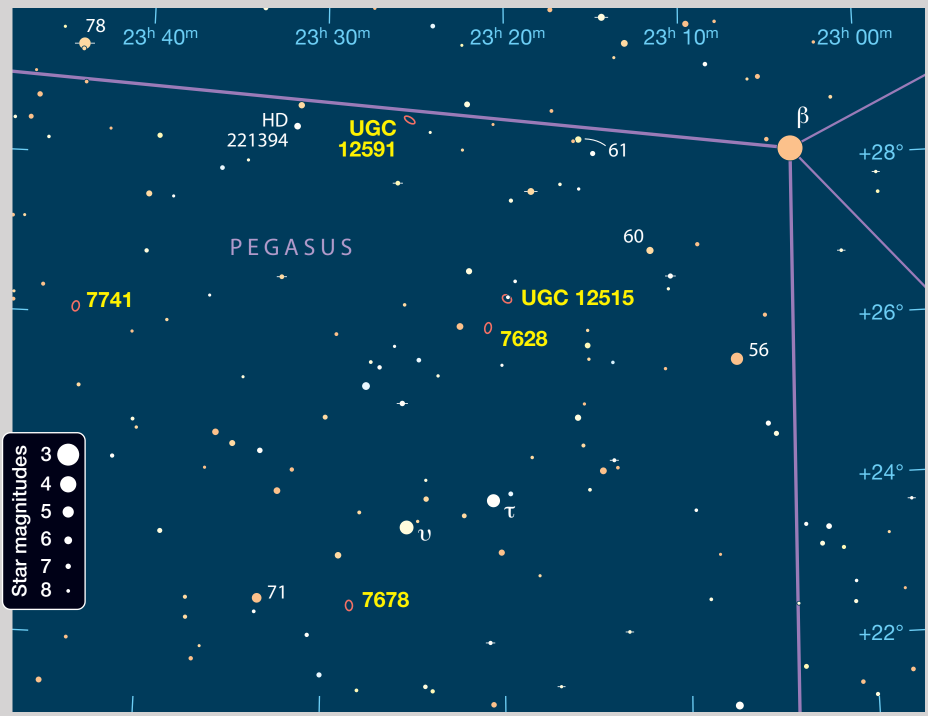
The Great Square corrals a herd of galaxies, little-known to most amateur astronomers. Let's round up a few of those that are a bit of a challenge for medium-sized telescopes from my semirural home. We'll start with one of the easier catches, **NGC 7678**, which is found 1.2° west of the pulsating red giant star 71 Pegasi (magnitude 5.3 to 5.6). This face-on spiral galaxy is about 140 million light-years away from us, yet bright enough to see even through my 130-mm refractor at 37×. Its filmy glow is neatly framed in a 2.4′-tall triangle of three stars, magnitudes 11 and 12. At 91× the roundish galaxy coffers a small, slightly enhanced core and fills much of the triangle.

Halton Arp included NGC 7678, which lies west of 71 Pegasi, in his *Atlas of Peculiar Galaxies* as an example of "spiral galaxies: one heavy arm." Deep-sky images make the heavy arm more apparent; in the eyepiece, the galaxy will offer a roundish glow with a slight brightening toward the core.

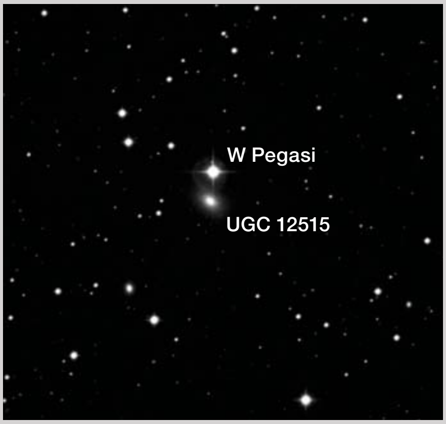
My 10-inch reflector at 166× shows NGC 7678 to better advantage, displaying a plump, 1½′-long oval that leans northeast. With averted vision, I see darker regions northeast and southwest of the core, indicative of dusky, inter-arm regions within the spiral.

Now we'll move on to shier game in the guise of the elliptical galaxy **NGC 7628**, located 2.2° north of 5th-magnitude Tau (τ) Pegasi and just 21′ west of a 6th-magnitude, yellow-orange star. Through the 10-inch scope at 115×, NGC 7628 is merely a faint little spot. At 166× the galaxy intensifies toward the center and makes a 1′-tall isosceles triangle with two stars to its south, magnitude 13.1 and 13.8, while at 213× it becomes slightly oval and spans roughly ½′.

NGC 7628 is included in our tour largely because it's good practice for our next target, which looks about the same size but has a slightly fainter magnitude and lower surface brightness. British amateur Mark Stuart pointed these galaxies out to me. He was looking at NGC 7628 and noticed that his star chart plotted another galaxy nearby, right next to a star. Stuart was quite



RICK JOHNSON



▲ The lenticular galaxy UGC 12515 snugs up to the variable star W Pegasi. The star, which has a period of 346 days and a magnitude range of 7.6 to 13, is dropping in brightness now, making this the ideal time to turn your scope toward this ghostly galaxy.

taken with the sight, proclaiming it a lovely, dimmer version of the Beta (β) Andromedae/NGC 404 pairing. Mark's discovery is the lenticular (lens-shaped) galaxy **UGC 12515**, which sits 26′ north-northwest of our previous galaxy.

In the 10-inch scope at 166×, UGC 12515 is only a tiny, roundish smudge seen with averted vision, just south of a reddish orange star. After familiarizing myself with the galaxy, I could faintly see it with direct vision. The galaxy is easier to see when it's pulled farther away from the star at 213×. Upping the magnification to 299×, it becomes a small oval leaning northeast. My 15-inch reflector at 216× reveals a ½′ × ⅓′ glow with a broadly brighter center.

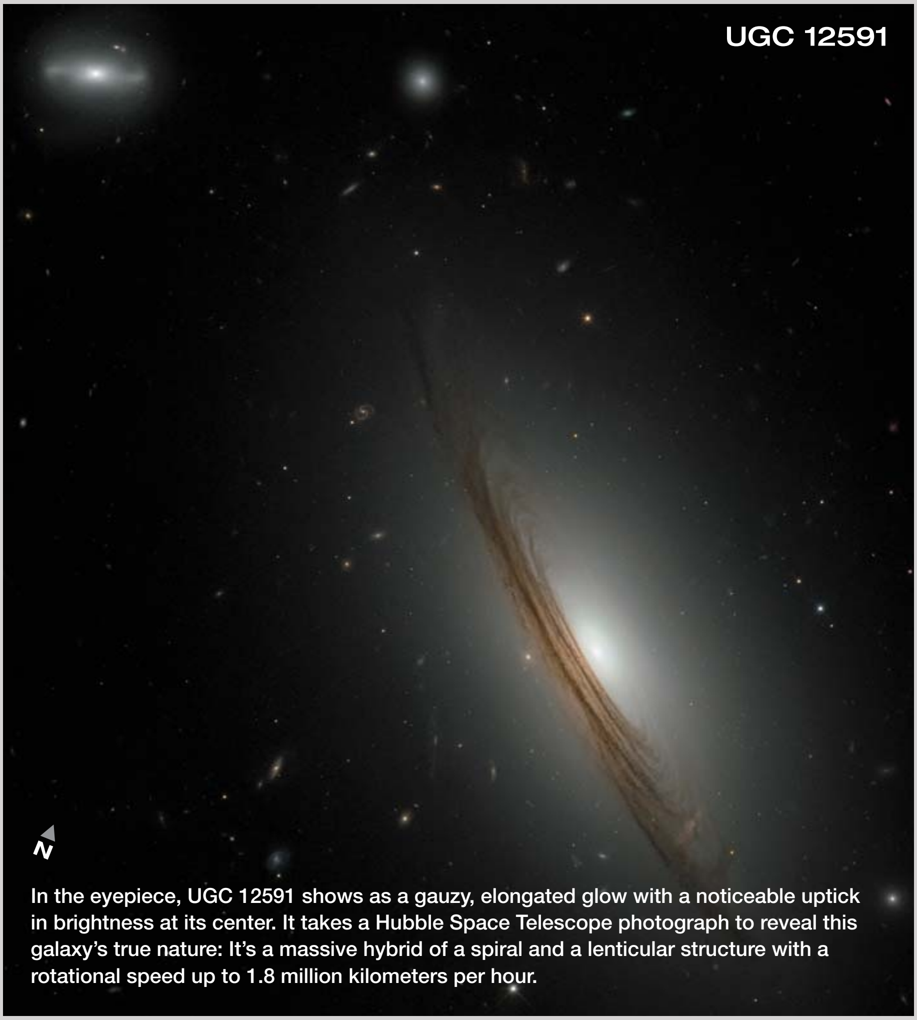
Beta Andromedae is known as Mirach, and the galaxy NGC 404 has been dubbed the Ghost of Mirach. The star cuddled up to UGC 12515 is the Mira-type variable W Pegasi, so perhaps we could call UGC 12515 the Ghost of W Pegasi. Since W Peg has a period of 346 days and a magnitude range of 7.6 to 13, sometimes the star takes on a ghostly pallor itself, too weak to flaunt its Mirach-like hue. W Peg is fading now, so the sooner you can observe it, the better.

Despite their apparent similarity in the sky, UGC 12515 is 340 million light-years distant, while NGC 7628 is half as far away. In reality, UGC 12515 is 2.7 times as luminous as NGC 7628.

Mark Stuart also pointed me in the direction of **UGC 12591**, which nuzzles the Great Square's northern border, 1.4° west of the 6th-magnitude star HD 221394. This UGC galaxy is more impressive than the last. Although very small and gauzy at 88× through the 10-inch scope, UGC 12591 is readily visible and holds a brighter center. Standing out better at 187×, this elongated galaxy bridges about 1′ and boasts a brighter oval center and a very tiny, bright nucleus. A 10th-magnitude orange star hangs 1.3′ south of its west-southwestern tip.

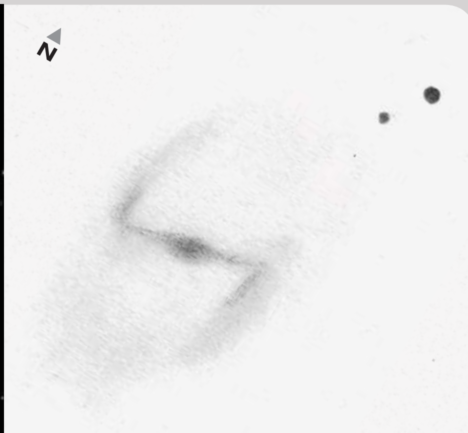
In the 15-inch scope, UGC 12591 seems to grow gently brighter toward the center at 133× and shows an abrupt drop in brightness along the south-southeastern flank at 192×. At 216× I can glimpse a little fuzz beyond the brightness drop, indicating the presence of a dark lane. A small, brighter core rests just above the northern side of the lane. As judged by comparing the length of the galaxy to the distance between the orange star and a 12th-magnitude star to the east, UGC 12591 appears roughly 50″ long and half as wide.

The morphology of UGC 12591 is considered an intermediate type between S0 galaxies (lenticulars with little or no spiral structure) and Sa galaxies (spirals with large bulges and tightly wrapped spiral arms). It's also



In the eyepiece, UGC 12591 shows as a gauzy, elongated glow with a noticeable uptick in brightness at its center. It takes a Hubble Space Telescope photograph to reveal this galaxy's true nature: It's a massive hybrid of a spiral and a lenticular structure with a rotational speed up to 1.8 million kilometers per hour.

UGC 12515: POSS-II / CALTECH / STSCI / PALOMAR OBSERVATORY; UGC 12591: ESA / NASA / HUBBLE SPACE TELESCOPE



NGC 7741 takes magnification well, revealing a wealth of detail with closer scrutiny. The author completed this sketch with her 15-inch reflector at 216×.

▲ NGC 7741 is a moderately bright face-on barred spiral, pinned at the north-northwest edge by a 10th-magnitude star. The central bar offers a strong brightening that runs east-west across the galaxy's center.

NGC 7741: ADAM BLOCK / MOUNT LEMMON SKYCENTER / UNIVERSITY OF ARIZONA; SKETCH: SUE FRENCH

one of the most massive spiral galaxies known, weighing in at 600 billion solar masses, as well as one of the fastest-spinning with a maximum rotational velocity of about 300 miles per second. This is another far-flung galaxy, 290 million light-years distant.

Our next goal is the face-on, barred spiral galaxy **NGC 7741**. There are no bright stars near enough to serve as a good guide, but if your telescope has an equatorial mount, you can drop 3.3° due south from the 5th-magnitude yellow-orange star 78 Pegasi. NGC 7741 is by far the brightest galaxy in the area. At 68× my 10-inch scope exposes the bar, which is this galaxy's most obvious feature. The bar is tipped south of east and points toward a 12th-magnitude star 3′ away. A golden, 10th-magnitude star perches 2′ north-northwest of the bar's center. At 115× this star gains a fainter companion to its south-southeast, while the bar grows a 2½′ halo that extends farther south than north.

NGC 7741 is a pretty galaxy through the 15-inch scope. At 102× the bar stands out quite well and grows brighter toward the center, and the halo stretches as far as the dimmer star of the north-northwestern pair. At a magnification of 216×, tantalizing details unfold. The eastern end of the bar hooks north, while the western end hooks south, and extending from each hook the sides of the galaxy are brighter. Overall, the halo is tilted north-northeast. I estimate a size of about 3¼′ × 1¼′, but the galaxy is rather insubstantial at the tips, so it's difficult to be precise.

According to *The de Vaucouleurs Atlas of Galaxies* (Buta, Corwin, and Odewahn, 2007), NGC 7741 can be considered a prototype of the SB(s)cd morphological type. This can be decoded as: spiral galaxy (S); spiral arms sprout from the ends of a bar (B(s)); little or no bulge and very open arms showing widespread resolution into large knots (cd).

From its apparent size, you might suspect that NGC 7741 is the closest galaxy in our tour, and you'd be correct. In fact, it's too close to us for redshift to give an accurate measure of its distance. The mean redshift-independent distance given in the NASA/IPAC Extragalactic Database (NED) is 46 million light-years. The surrounding field is liberally dosed with background galaxies. Intriguingly, very deep color images show one of them shining right through the galaxy's translucent façade.

On your next clear night, see if you can round up some of these challenging Square galaxies.

■ Contributing Editor **SUE FRENCH** enjoys perusing the skies of upstate New York with her husband Alan, a long-time amateur telescope maker.

Galaxies in the Great Square of Pegasus

Object	Surface Brightness	Mag(v)	Size/Sep	RA	Dec.
NGC 7678	13.2	11.8	2.2′ × 1.7′	23h 28.5m	+22° 25′
NGC 7628	12.7	12.7	1.1′ × 0.9′	23h 20.9m	+25° 54′
UGC 12515	13.1	12.9	1.4′ × 1.1′	23h 19.9m	+26° 16′
UGC 12591	12.8	12.9	1.7′ × 0.7′	23h 25.4m	+28° 30′
NGC 7741	14.0	11.3	4.4′ × 3.0′	23h 43.9m	+26° 05′

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.

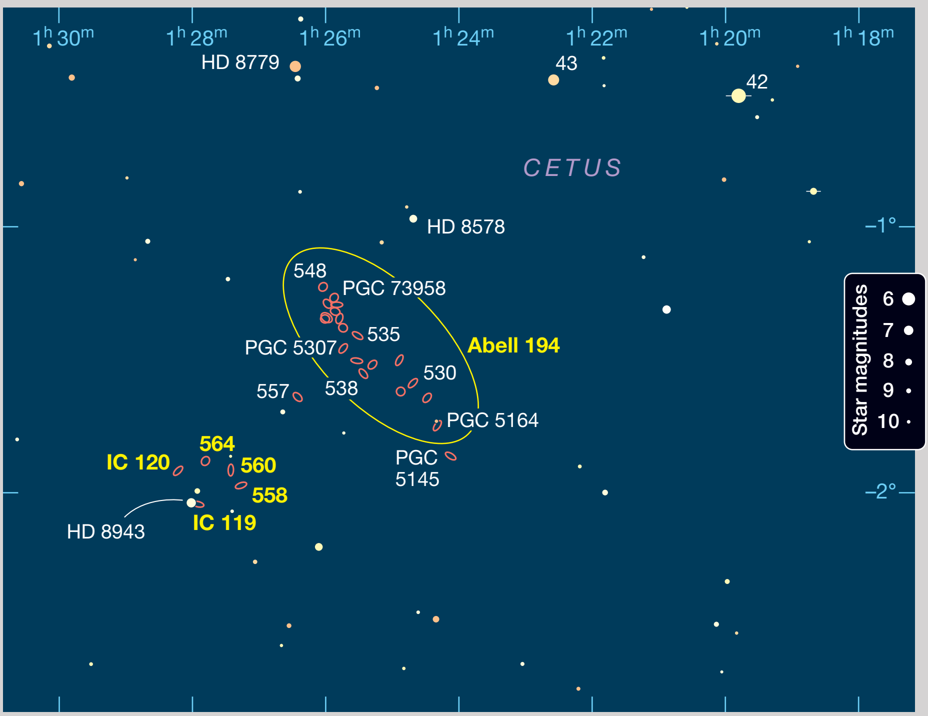
A Whale of a Galaxy Cluster

Reel in the denizens of Abell 194 — if those autumn skies ever clear.

I had to chuckle at last May's Going Deep column, which concluded by saying that the author, Howard Banich, "lives under the cloudy skies of western Oregon." Boy, can I relate to that! At my home in southwestern British Columbia, the November-through-March period is one long, soggy season. As with Howard's spring galaxies, my fall fuzzies are "a rare treat."

A case in point is the galaxy cluster **Abell 194** in Cetus, which I haven't revisited since I first explored it five autumns ago. My treatment here is the product of one 90-minute observation, during which I netted 18 cluster members (plus a few extras) with a 17.5-inch f/4.5 Dobsonian working at 222× and 285× (amid excellent sky transparency, but only moderately steady seeing). I hope the following overview, drawn from my observing log after impressions voice-recorded at the eyepiece, will convince you that Abell 194 is worth more than a single visit.

Most of our study area falls within a narrow, northeast-leaning swath of sky roughly 40′ long. The cluster's few prominent members are clumped near the northeast end, so let's begin there. To star-hop to that spot, first locate 3.6-magnitude Theta (θ) Ceti, then shift 7¾° northward to 6.5-magnitude 43 Ceti. Don't confuse that star with 5.8-magnitude 42 Ceti to the west or 6.4-magnitude HD 8779 to the east. Together the three dots form a 1⅔°-long row easily sighted in finderscopes. From the middle star (43 Ceti), drop southeast ¾° to 7.6-magnitude HD 8578, then another ½° into Abell 194. There, two elliptical galaxies, 4½′ apart and slanted northeast-southwest, await us.



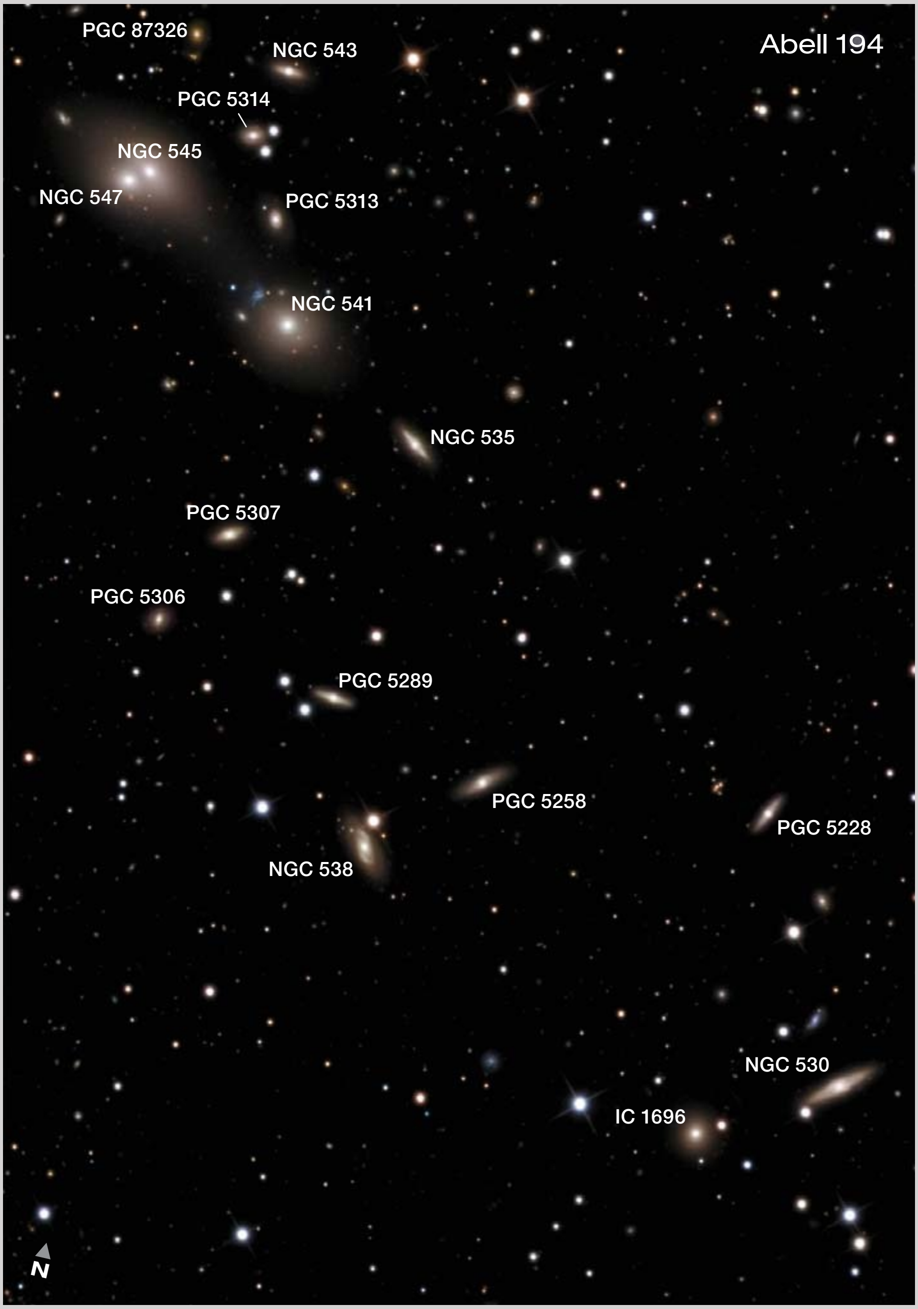
Arps at the Core

The more northerly object is actually two galaxies: **NGC 545** and **NGC 547**. This binary blob comprises Arp 308, one of 338 "peculiar" galaxies cataloged in 1966 by Palomar astronomer Halton C. Arp (**https://is.gd/ArpCatalog**). Both components of Arp 308 glow at magnitude 12.2, but NGC 545 is larger than NGC 547. According to my records, "the disc of NGC 545 is slightly elongated; the partner smaller and round. Their bright cores seem roughly equal in size and luminosity." Even at high magnification, the eye-catching pair struck me as "two barely separate masses enveloped in a single, broad halo."

Just 4½′ southwest of Arp 308 is 12.1-magnitude **NGC 541**. To my eye, this spherical puffball seemed "larger, more diffuse, a bit dimmer than either part of Arp 308." But wait, there's more: In their superb *Arp Atlas of Peculiar Galaxies*, Jeff Kanipe and Dennis Webb identify NGC 541 as Arp 133, an E0 (or S0) galaxy with three "fragments" dotting its eastern edge. Chief among them is **Minkowski's Object**, which they describe as "a distorted magnitude-16.1 galaxy, apparently pushed to starburst by a jet emerging from a black hole in NGC 541." This miniscule outlier escaped my scrutiny, but those with larger light-buckets might succeed.

CETI: HEVELIUS

▶ The brighter galaxies in Abell 194 gather in the northeast end of the cluster. NGC 545 and NGC 547 will likely appear as a single glow in your eyepiece, but you might be able to distinguish their cores with enough magnification and very transparent skies. The cluster stretches southwest to the lenticular galaxy NGC 530, and then on to PGC 5164, which lies outside the lower boundary of this image.



The area above the Arps is dotted with little lumps of light. Almost 7′ north of NGC 545 is 13.7-magnitude **NGC 548**, which I logged as "tiny but discernible," and a scant 2′ west of NGC 545 (northeast of NGC 541) is teensy **PGC 5313**. A line from NGC 541 through PGC 5313 arrives at **PGC 5314**, adjacent to a pair of 14th-magnitude stars. That star-pair aims farther north toward 13.1-magnitude **NGC 543**, an edge-on galaxy that to me was "tiny, round, not elongated." Alas, I missed two essentially starlike phantoms: **PGC 87326**, which lies directly east of the edge-on, and **PGC 73958**, northeast of the edge-on.

Deep in the Cluster

Let's reverse direction and head deeper into Abell 194. Less than 4′ southwest of NGC 541 is 13.8-magnitude **NGC 535**. My notes say this edge-on galaxy appeared "smaller and fainter than the anchor galaxies (NGC 545/547, 541), but clearly spindle-shaped, aiming at the anchors. Large in the middle, not a streak." At that point, I found myself staring at eight members of Abell 194 in a single, high-power field of view. The tally will be ten if I ever detect the phantoms mentioned above!

From NGC 535, a sharp turn south-southwestward swept up 13.7-magnitude **NGC 538** slightly more than 8½′ away. My log records this inclined spiral system as a "bit bigger and brighter than NGC 535 but not as slender. Strongly elongated, leans northeast, 12.4-mag star off northeast tip." Spanning the space north and west of NGC 538 is a gentle curve, 14′ long, of four teeny-weeny edge-on galaxies. **PGC 5307**, **PGC 5289**, **PGC 5258**, and **PGC 5228** were all visible — though the last one, PGC 5228, was difficult. (Need help? An imaginary line from NGC 545/NGC 547, through NGC 541 and NGC 535, extends directly to PGC 5228.)

Another 6¼′ southwest of PGC 5228, toward the southwest end of the Abell 194 "strip," is the best edge-on galaxy of the group: 13.0-magnitude **NGC 530**. My notes read: "Good contrast, distinctly edge-on, oriented northwest-southeast. Bigger, brighter toward the middle. Averted vision picks up tapered 'wings' — 13.6-magnitude star off southeast tip." That easy edge-on points southeastward in the direction of 13.6-magnitude **IC 1696**, a "biggish, roundish, pale fuzz accompanied by a 14.4-magnitude star northwest."

Southwest of NGC 530, I found three more 14th-magnitude galaxies in a 14′-long line stretching across the southwest terminus of Abell 194. **NGC 519** was "just a fuzzy dot" attended by a 13.5-magnitude star immediately south. However, upon closer inspection, "that star and four others, plus the galaxy, form a strikingly dipper-like asterism."

RUSSELL CROMAN

• **FURTHER READING:** For a comprehensive table of positions, surface brightnesses, position angles, and more, see **https://is.gd/Abell194**.

Only 6′ farther southwest is teensy **PGC 5164**, guarded by a 10.1-magnitude star directly north. Another 8′ onward, outside the cluster's official boundary, is **PGC 5145**. Both galaxies were mere mists in the high-power field.

If we return to the inclined spiral NGC 538 (roughly in the middle of the pack), then turn sharply southeast for almost 16′, we arrive at my final Abell cluster member: 13.5-magnitude **NGC 557**. Although its spiral form is similar to that of NGC 538, all I could glimpse of NGC 557 was its round core. A 9.0-magnitude star shines 4¾′ southeast.

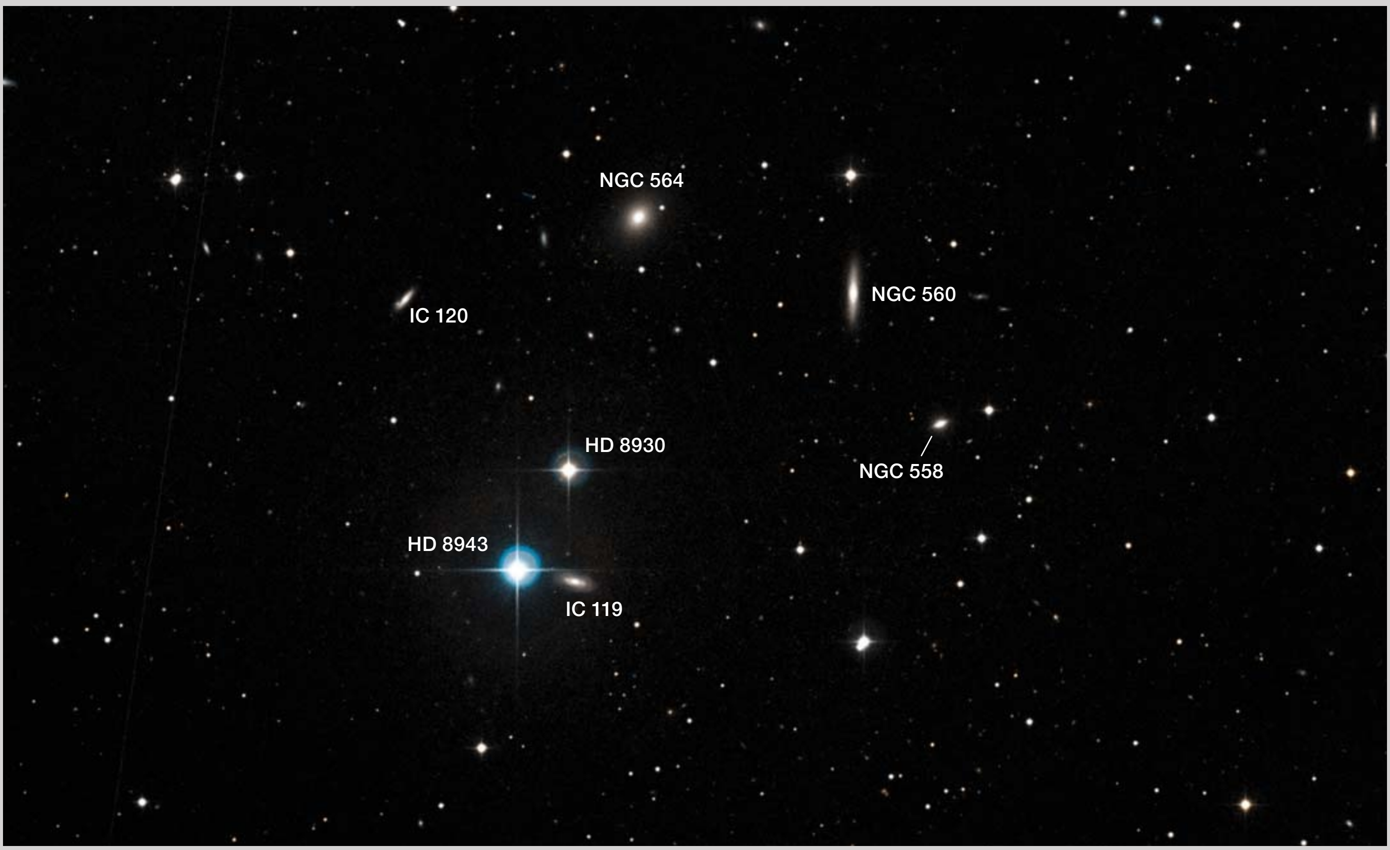
Bonus Blobs

I finished off the night by shifting ½° southeast of NGC 557 to the 7.0-magnitude star HD 8943, which sports an 8.6-magnitude companion 3′ to the north-northwest. My interest lay not in the star-pair, but in five small galaxies (none of them members of Abell 194) lurking nearby, mostly to the north and west of the stars.

Barely 1.5′ west of HD 8943 — almost swamped in the star's glare — is 13.7-magnitude **IC 119**. It took some patient staring on my part, but I detected the wee ghost with averted vision. Four other galaxies form a shallow crescent, concave toward the star-pair. The dominant object is 12.5-magnitude **NGC 564**, an elliptical galaxy I noted as "oval, brighter toward the middle." Not as big or bright as the elliptical, but marginally more interesting, is 13.0-magnitude **NGC 560**. In my observing log for this compact edge-on, I reported "a distinct, stubby streak aiming north toward 10.5-magnitude star." Contrasting that is 14.3-magnitude **NGC 558**, which appeared "terribly minute and faint." Finally, **IC 120** registered as "an amorphous patch," tough to hold even with averted vision.

My coverage of this entire region suggests that one can derive a lot of satisfaction from a single, careful observation. The keys are practice, patience, and keeping thorough notes. That said, I want to attack Abell 194 again — after all, it's been five years! Now, about that autumn overcast . . .

■ Contributing Editor **KEN HEWITT-WHITE** observes galaxies from a large ark he built during British Columbia's monsoon season.



POSS-II / CALTECH / STSCI / PALOMAR OBSERVATORY

▲ The galaxies gathered around 7th-magnitude HD 8943 are a bonus observation but may offer even more of a challenge than does Abell 194. IC 119 in particular may be difficult to spot as the star's glare masks its slender body. Move north past HD 8930 to find NGC 564, the brightest galaxy in the area.

Celestron's CGX Mount

This highly versatile German equatorial mount can fill the needs of many visual observers and astrophotographers.

▲ The main pieces of Celestron's CGX mount include a 44-pound equatorial head, 19-pound tripod, and a pair of 11-pound counterweights. It takes less than 5 minutes to assemble the CGX in the field.

Celestron CGX Equatorial Mount

U.S. Price: $2,199
Celestron.com

What We Like:

Excellent design and construction

Great performance

Capable of remote operation

What We Don't Like:

No through-the-mount wiring for telescope accessories

IT WASN'T THAT LONG AGO when you could count the major manufacturers of stand alone telescope mounts on the fingers of one hand, and "advanced-electronics" meant a clock drive powered by a synchronous AC motor. Not so now. Today there's a huge selection of mounts from dozens of manufacturers in North America, Europe, and Asia. They range from tiny trackers made for cameras to behemoths designed for observatory installations and the largest amateur telescopes. And even many of the "simplest" mounts feature motor drives with computerized Go To pointing. This is all good news, since a solid mount with Go To drives and smooth tracking goes a long way toward making a night under the stars a pleasant experience.

I suspect that the new CGX mount from Celestron has caught the eye of many amateurs. It's a mid-weight German equatorial rated for a 55-pound (25-kg) load, and on paper it looks to be ideal for compact telescopes and astrographs up to about 12-inch aperture. To see if this is indeed true, I spent several months last summer testing a CGX that we borrowed from Celestron for this review. I used it with 85- and 101-mm refractors, an 8-inch Schmidt-Cassegrain telescope (SCT), and a relatively heavy 11-inch astrograph.

ALL IMAGES BY DENNIS DI CICCO

Out of the Box

Even as I began unpacking the CGX from its shipping cartons, it was obvious the mount was designed by people experienced with German equatorial mounts in the field. I had a dozen entries in the "pros" column of my notes before finishing the initial assembly. They ranged from little things like extension marks on the tripod legs and a locking collar on the power-input plug, to significant features like ergonomically excellent lifting handles on the equatorial head and a tripod design that lets you easily set the head on the tripod (sans counterweights) and let go without fear of the head falling off before it's secured with three cap screws.

Other positive features apparent during the initial assembly included a solid tripod spreader that also serves as an eyepiece holder and small accessory tray. It can be loosened slightly and turned, allowing the tripod legs to be folded up without having to entirely remove the spreader — something I found particularly convenient. The mounting saddle accepts wide (Losmandy-style) and narrow (Vixen-style) dovetail bars. All the hand knobs are large, making it easy to tighten or loosen them. There's only one size cap screw involved with setting up the mount, and the corresponding hex wrench clips into a holder underneath the carrying handle on the base. But it's worth noting that the cap screws are metric, so you'll want to keep track of them and the hex wrench so they don't get mixed in with the odd assortment of English hardware that typically accompanies many observers into the field.

Apart from the various electrical connections on the fixed part of the polar-axis housing, wiring for the motor drives is internal; there are no loose wires hanging from the mount to snag as you slew the CGX around the sky.

That's good news, but on the downside the CGX lacks through-the-mount wiring for equipment on the mount. As such, power cables and computer connections for cameras and the like must be run externally, and that's always a concern, especially for setups run remotely. I've had good results using internal wiring on other mounts, but Mike Rice, who maintains dozens of remotely operated telescopes at his New Mexico Skies Observatory, avoids it. He says that internal wiring usually adds extra cables and connections to a setup, and when problems arise, cables are often the culprits.

The CGX requires a 12-volt DC power source capable of delivering 4 amps. It comes with a power cord having a cigarette-lighter plug but no AC adapter. An optional adapter ($70) is available, but I had no problems running the CGX with a power supply scavenged from an old laptop. Another optional accessory I found unnecessary is the polar-alignment scope ($140), which attaches to the mount's declination-axis housing. Setting the polar-axis elevation with the mount's built-in scale and eyeballing it north was sufficient for visual observing, since the Go To software in the NexStar+ hand control compensates for moderate offset from the celestial pole once the CGX is initialized with a star alignment.

The software also has an easy-to-use method for achieving good polar alignment. The process begins by centering a selected star in an eyepiece (preferably one with a reticle). The mount then automatically offsets a calculated amount from the star, and you manu-

▲ The CGX is rated for telescopes up to about 55 pounds. It worked well for astrophotography with this 40-pound setup (that required an additional 10-pound counterweight) in the author's backyard observatory. As explained in the text, the mount was typically run remotely from his house a few hundred feet away.

▶ This 88-minute exposure of the Crescent Nebula, NGC 6888, in Cygnus was made with the setup pictured above. It's a stack of 22 consecutive, 4-minute, autoguided exposures through a hydrogen-alpha filter. The CGX's smooth tracking and precise response to commands from the autoguider made every exposure in the sequence a keeper.

◀ Clearly marked keys and a straightforward menu system make it relatively easy to master the basic operation of the CGX with its NexStar+ hand control.

▲ The CGX saddle accepts both Losmandy- and Vixen-style dovetail bars.

ally shift the azimuth and altitude of the polar axis to re-center the star in the eyepiece. I used this method for all my astrophotography with the CGX and found it to be very good. But I have some advice that isn't in the manual or given in the alignment instructions that scroll across the hand control's display. Your alignment star should be near the meridian and celestial equator, and tightening the locks on the mount's altitude and azimuth adjustments should be done in small steps, since the mount is likely to move slightly in the process, requiring tweaks to the adjustments to keep the alignment star centered as the locks are fully tightened.

Visual Tests

Initially I set up the CGX in my driveway and used it on a handful of nights for visual observing with the 101-mm refractor and 8-inch SCT. There's no need to repeat instructions here for initializing the mount for Go To operation, since they are clearly spelled out in the manual, as well as (and perhaps more importantly) on the hand control as you work through the procedure. Suffice it to say the process is fast and easy, but the large selection of alignment stars available is only shown by name on the hand control. Even novices should be comfortable with Arcturus, Regulus, Vega, and the like, but other stars such as Alsciaukat, Rukbah, and Wasat might well leave veteran skygazers scratching their heads. I always managed to initialize the CGX with familiar stars even under the restricted view of the sky I have from my driveway. Nevertheless, having decent star charts handy, such as those in *Sky & Telescope's Pocket Sky Atlas,* is a good idea.

For visual observing the CGX proved first rate. The mount is solid and certainly capable of handling an 11- or 12-inch SCT. Slewing is smooth and very quiet, and the mount responded precisely and without backlash when I pressed the direction keys on the hand control. All the celestial-object databases we've come to expect with Go To telescopes are available from the hand control, and even the Sun is included in the solar system listing. The hand-control's illuminated and clearly labeled keys, combined with scrolling instructions for the mount's various functions and menus that are relatively straightforward, kept the learning curve for the CGX quite reasonable.

While I didn't control the CGX for visual observing with any external planetarium software, including the version of *Starry Night* supplied with the mount, I expect it would be virtually identical to the positive experience Rod Mollise had testing the Celestron NexStar Evolution telescope (*S&T:* May 2017, p. 60).

Astrophotography

For astrophotography tests, I cobbled together an adapter to attach the CGX to one of the piers in my backyard observatory. I used the software-assisted method mentioned earlier to polar align the mount. The result wasn't perfect alignment, but it was more than adequate for 10-minute exposures with an optical system working at an image scale of 1.4 arcseconds per pixel. Furthermore, the mount was plug-and-play compatible with an SBIG autoguider operating through *MaxIm DL* software. The system worked so flawlessly from the outset that I never bothered refining the polar alignment or training the CGX's periodic-error correction.

This bodes well for anyone considering the CGX for portable astrophotography, since it should take as little as 15 minutes or so in a twilight sky to get the mount sufficiently polar aligned and ready for long-exposure photography. I especially like the CGX's fine-adjustment control on the polar-axis elevation. It is precise and easy to operate even when the mount is fully loaded with a telescope and counterweights — something that's been a problem with other mounts I've used.

Remote Observing

I can't always keep up with the features of every Go To mount available today, but to the best of my knowledge

▲ This articulating mechanism on the CGX's polar-axis adjustment provides precise control of the mount's elevation even when it is loaded with a heavy telescope and counterweights.

▲ Cables for power, the hand control, a USB computer connection, and an autoguider all attach to this fixed module on the polar-axis housing. Thanks to internal wiring there are no dangling cables for the motor drives. But, as detailed in the accompanying text, there is no provision for internal wiring for equipment mounted on the CGX.

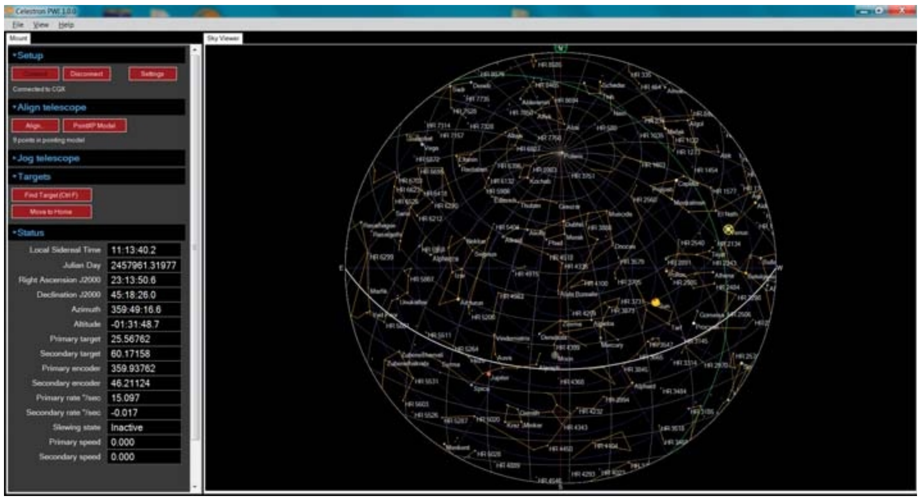
the CGX is the lowest-cost mount that is fully capable of remote operation. Almost since the dawn of Go To technology in amateur telescopes, mounts have included functions that let you park (or sleep or hibernate) them and resume observing at a later date without needing to initialize them to the sky again. On the surface this sounds like all that's necessary for a remote setup, but it is only if something doesn't go wrong such as a power failure, computer crash, or any of a multitude of other things that can bedevil a computer-controlled system. To fully qualify for remote observing, a mount needs the ability to recover from glitches and know where it's pointing a telescope without the need for a human to be present at the scope. Mounts that can do this either need a precise homing ability or absolute position encoders. The CGX has the former.

I spent a number of nights running the CGX from start to finish without setting foot outside the house. The mount was controlled by a laptop computer in the observatory running *Celestron PWI* software supplied with the mount. I connected to the laptop with convention remote-access software (*TeamViewer* from **teamviewer.com**) and controlled power to the mount and telescope cameras via internet-accessible power outlets. Even though I was only a few hundred feet from the observatory, I could easily have been any place on Earth with an internet connection.

The whole remote start-up process was fast and very straightforward. I'd power up the mount and cameras, launch the *Celestron PWI* program, and connect to the CGX mount. (The camera and autoguider were operated with *MaxIm DL* running simultaneously on the same laptop.) Once the mount was connected to *Celestron PWI,* I'd command it to move to its home position (with the scope pointed north on the meridian above the pole), after which I could begin observing. Everything worked beautifully.

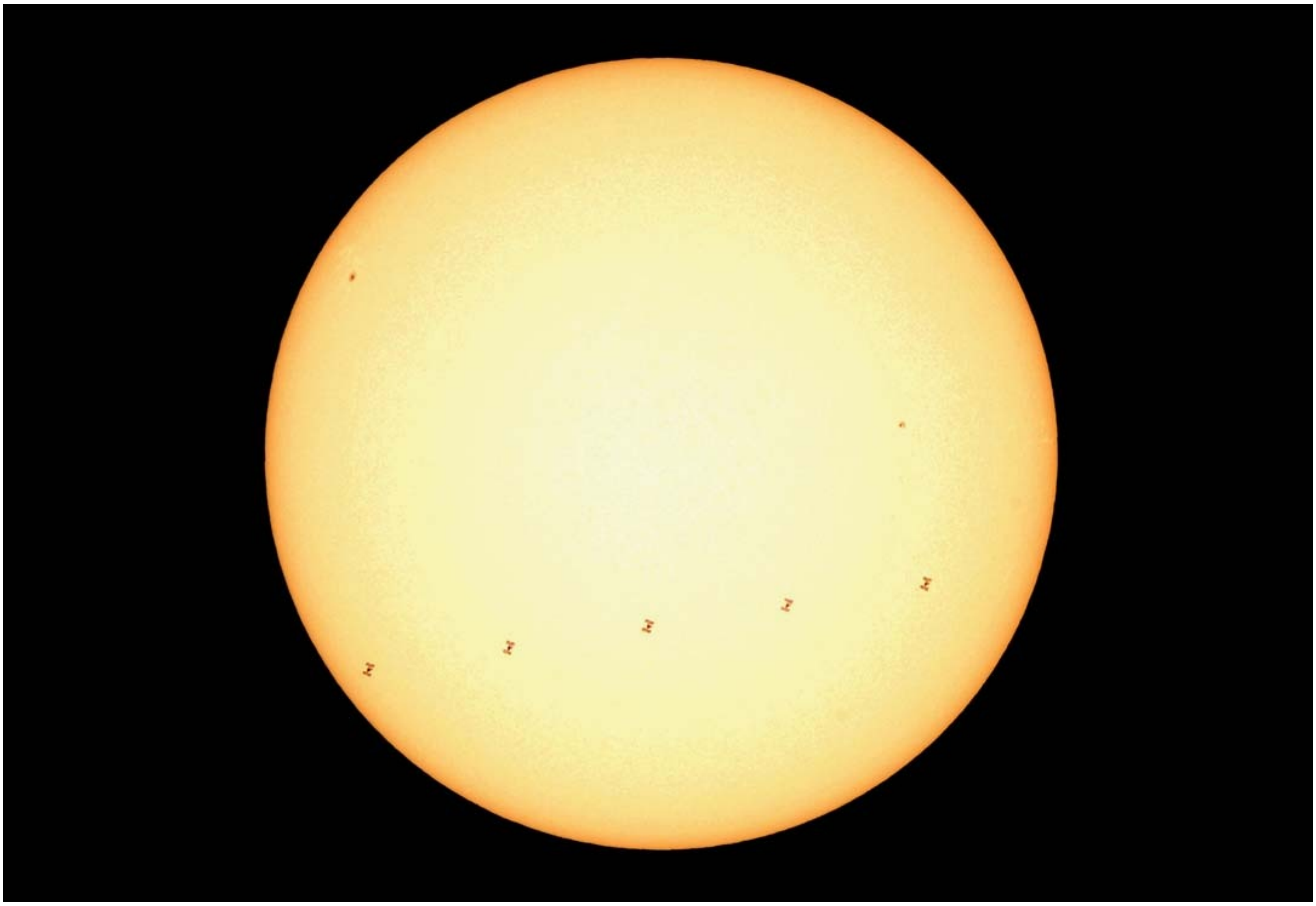
To test the robustness of the system, I purposely crashed the mount and/or laptop by killing the power. In every case I simply powered the equipment back up and repeated the start-up process. The CGX always moved to its home position regardless of where it was pointing when the system crashed.

I tested the initial version of *Celestron PWI,* but an update with additional features is in the works and should be available soon after this review is published. The version I tested is very basic mount-control software. It is not a planetarium program. The displayed star map is simply a snapshot of the sky over the mount showing relatively bright stars and solar system objects. You can't zoom in for more detail, but you can



▶ ▲ The author used the *Celestron PWI* software included with the mount for all of his remote observing. It is a robust but basic mount-control program and not planetarium software. The star chart is a "snapshot" of the current sky over the CGX, and you cannot zoom in for more detail than is seen here.

▶ The author especially liked *Celestron PWI*'s easy-to-use procedure for creating and saving a pointing model that improves the CGX's Go To accuracy for current and future observing.



▲ This composite image of the International Space Station crossing the Sun's disk last June 21st might not have happened were it not for the CGX's quick startup capability and the Sun being included in its list of solar system targets. A last-minute change in the weather gave the author barely 5 minutes to open his observatory and set up for a burst of five exposures with a Nikon D700 DSLR attached to an 85-mm refractor operating at f/14.

click on the objects shown to select them as Go To targets. There is, however, a good search function for deep-sky targets and the like. Objects selected from the search results are then shown on the star chart, and you can slew to them. As such, anyone who knows what they want to observe can use *Celestron PWI* to point the CGX at their objects of interest. You can also slew to any celestial coordinates that you input.

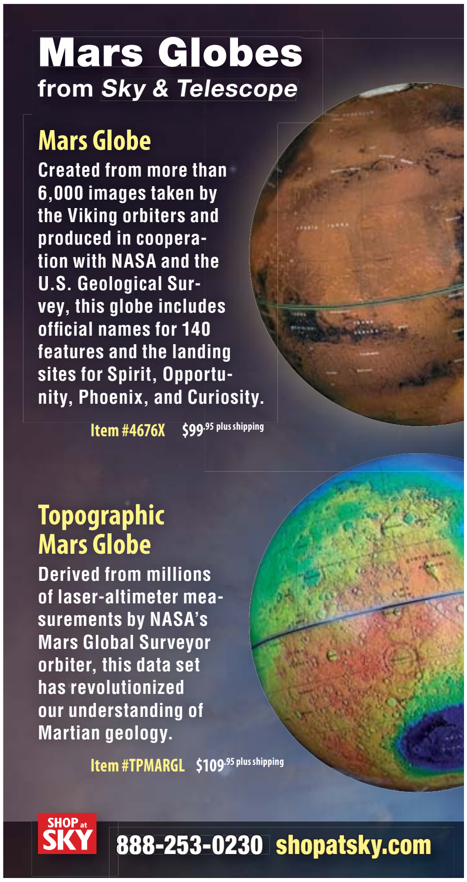
The software has an extremely nice and easy-to-use method for building a pointing model that improves the Go To accuracy. You simply select any star shown on the map, center it in the telescope's field of view, and click one button to add it to the model. Do this for half a dozen stars on both sides of the meridian, and you likely have a model with pointing accuracy much better than 1 arcminute over the whole sky. You can then save this model and reload it for future observing sessions.

Smooth Sailing?

I had very few problems while testing the CGX. One bump in the road occurred while loading the *Celestron PWI* software, but it very likely arose because of software previously installed on my laptop computer. The only mount issue worthy of mention occurred when I was running some tests by observing stars in a noontime sky on a very hot day (ambient temperature near 100°F) and after the mount had been baking in direct sunlight for more than an hour. A command to home the scope sent the mount to the correct position for the right-ascension axis, but not declination. A few more tries and the right-ascension homing failed as well. I shut the CGX down, only to find that everything was back to normal when I resumed testing that evening. The homing never failed after that day, leading me to suspect that extreme heat was the issue. Not surprising given that parts of the mount in direct sunlight were almost too hot to touch when the problem occurred.

Small issues aside, the CGX fully lived up to my expectations. Indeed, it proved to be the nicest Celestron mount I've yet tested. And it also delivered on its under-promoted potential for remote observing at an unprecedented low cost. It's a mid-weight German equatorial that I can strongly recommend.

■ **DENNIS DI CICCO** has covered astronomical equipment in the pages of *Sky & Telescope* for more than 40 years.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Bright-Sky Imaging

THERE ARE PLENTY OF THINGS TO SHOOT UNDER MOONLIT AND URBAN SKIES.

DON'T FEAR THE MOON A nearly full Moon or even light pollution shouldn't keep you from taking advantage of clear skies. Author Ron Brecher shares some tips on making the most out of less-than-ideal conditions. Unless otherwise noted, all images are courtesy of the author.

BIGSTOCKPHOTOS.COM / ORIONTRAIL2

The Moon is full about every four weeks; that's a given. Within about a week either side of full, the Moon floods the night sky with reflected sunlight. This can be, among other things, beautiful, romantic, eerie, tranquil, or even photogenic in its own right. But it creates real challenges for deep-sky astrophotography. Even when there's no Moon, skies near even small cities may be plagued by light pollution. High humidity or particles in the air can make matters worse, with light scattering making the sky even brighter.

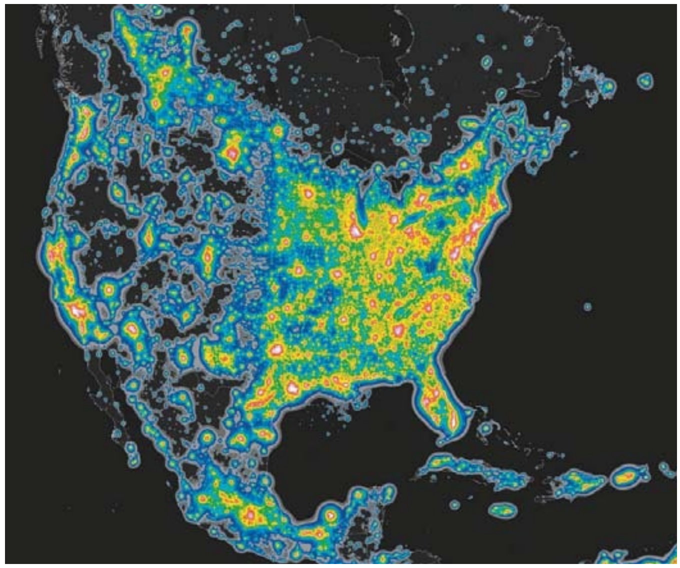
So what's a dedicated deep-sky imager to do? Take a deep breath. Think things through. Then work to make the best of the situation.

Much like man-made light pollution, the Moon's light washes out many faint objects, especially dim galaxies. Since I'm not willing to surrender two weeks of deep-sky imaging to the Moon every month, and light pollution is all around me, I've developed a few strategies to keep the shutter open even under less-than-ideal conditions.

Location, Location, Location

One effective strategy is to choose targets in the darkest part of the sky. When the Moon is near first quarter or last quarter, I can usually find some pretty dark areas of sky in the north, especially on very transparent nights when there are fewer particles in the air to scatter moonlight. The Moon follows a more southerly path through the ecliptic during the summer, so it's farther away from more northern target areas in summer than in winter (though the nights are so short!). By shooting on transparent nights and shooting objects only when they're near the meridian (say, 2 hours on either side), one can minimize the effects of light pollution and lunar glare.

If you have a portable imaging rig, try to pick a setup location in the shadow of trees or a building. This will help to keep direct, intense moonlight from entering your optic. Choosing a northern target when imaging in the Northern Hemisphere (or a southern target when imaging from south of the equator) will also help keep the Moon from shining on the inside of your optical tube or dew shield.



▲ **BRIGHTENING SKIES Top:** This map shows the intensity of light pollution in the United States, with white denoting the strongest concentrations. **Bottom:** Open clusters, including NGC 457 seen at middle, make great targets even in bright skies. Stacking many short exposures will keep the background from getting too blown out.

TOP: F. FALCHI ET AL. / *SCIENCE ADVANCES* 2016

Star Clusters and Nebulae

Another way to get the most from bright skies is by choosing targets that still show well through the glow. Open clusters and globular clusters are my objects of choice under a bright Moon, especially if I want to acquire an entire color image data set in one session using a monochrome camera with color filters. Compared to galaxies and nebulae, star clusters are often overlooked by imagers, yet they each have their own appearance and unique character while adding variety to your imaging portfolio. They also make great targets for checking the performance of your telescope across the entire field of your sensor.

Some choice clusters in the fall and winter months include NGC 7789, sometimes known as Caroline's Rose Cluster, located just east of Beta (β) Cassiopeia. It's quite large and colorful, and a fine open cluster to target. Another splashy open cluster is M35, and it contrasts well when framed in the same field with the more distant cluster NGC 2158.

Many globular clusters are well-placed targets during the summer and autumn months in the Northern Hemisphere. Choose a bright one high in the northern sky, far from the ecliptic, like M5, M13, or M92. Careful processing can bring out even the faint outer reaches of these objects and reveal beautifully colored stars.

Other Bright Targets

Small, bright planetary nebulae, as well as some emission nebulae, can be captured well in a bright sky and found on most any night of the year. Targets like M42 (the Orion Nebula), M57 (the Ring Nebula), and M27 (the Dumbbell Nebula) are bright enough to punch through moderate light pollution and moonlight, even without using narrowband filters. And don't be afraid to target nebulae that lie very close

▲ **FULL OF STARS Top:** Globular clusters, such as M10 seen here, also make fine targets under most any skies. **Middle:** Planetary nebulae can easily punch through moderate light pollution. The full Moon was up while recording most of the narrowband data used in this composite of M27. **Bottom:** Shooting nebulae through narrowband emission-line filters (including Hα, O III, S II, and N II) greatly reduces the impact of light pollution and moonlight in deep-sky images. This color composite of NGC 6960, the western side of the Veil Nebula, reveals plenty of reddish Hα and teal-colored O III.

to a bright star, such as IC 59 and IC 63, which are tucked up very close to Gamma (γ) Cassiopeia.

Comets are another class of targets to watch for in less-than-ideal conditions. If you get the chance to catch a nice bright comet against a field of background stars or a star cluster, take advantage of it. Comets come and go very quickly with very little warning, and they may be out of sight or in a less interesting field before conditions become ideal for a better shot. Many comets are at their best in twilight, when bright skies are unavoidable.

Galaxies may be the toughest objects to capture under bright skies. The majority are small, dim, and fuzzy. It's best if you can wait for (or go to) a darker sky to shoot them, but if that's not an option for you, then try to shoot plenty of images and process them carefully to tease out the faintest outer details. As in all astrophotography, excellent focus is critical. In bright skies, it's even more so, because good focus gives the maximum possible contrast both in stars and extended objects.

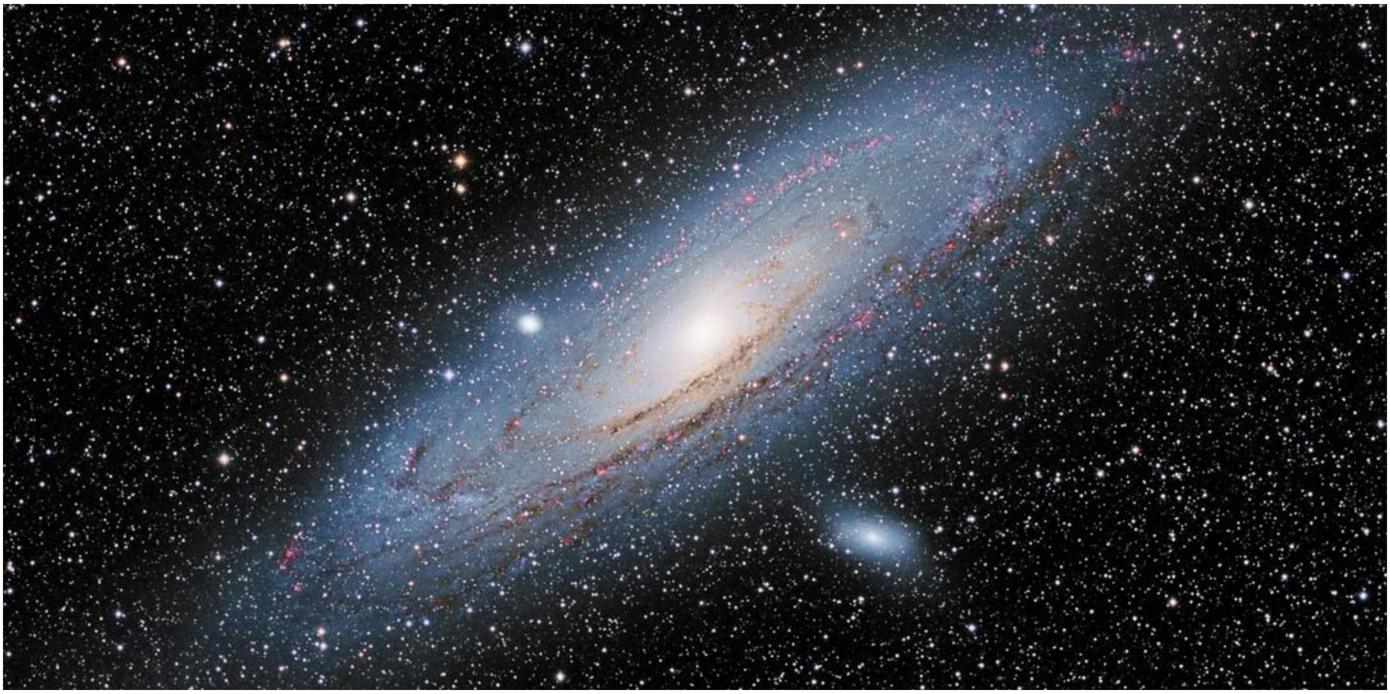
The Narrowband Solution

A popular deep-sky imaging solution to both moonlight and light pollution is to shoot with a monochrome camera through narrowband filters. These filters block all light except for a narrow range of wavelengths — roughly 3 to 10 nanometers wide — where specific elements emit visible light. These strips are known as emission lines. Narrowband filters (particularly hydrogen-alpha, or Hα) have the added benefit of blocking most sources of strong light pollution as well as moonlight, permitting users to image on practically any clear night of the year. Narrowband filters are most effective when shooting emission nebulae, including most of the bright nebulae on the Messier list, as well as planetary nebulae. They're ineffective on reflection nebulae, though. These filters can also be used with one-shot color cameras, including DSLRs.

I tend to shoot a mix of both natural color (RGB) and narrowband data to take advantage of most any clear skies I get. My color pictures are often made up of data recorded through five filters — typically red, green, blue, Hα, and doubly ionized oxygen (O III). I usually wait for a transparent and moonless night to shoot my broadband red, green, and blue images, and often shoot Hα and O III data when the Moon is up.

Notice I don't use a clear (luminance) filter. Rather, I synthesize a luminance channel by combining all my other filtered shots into a monochrome result that can be used as a luminance image. I've found that the luminance filter is more severely affected by light pollution and moonlight than the individual color filters, so I tend to get a better result this way.

This approach works particularly well for planetary nebulae and emission nebulae, since much of their light is emitted in the same narrow ranges of wavelengths passed by narrowband filters. In addition to the bright targets mentioned earlier, you can go after some fainter quarry off the beaten path using narrowband filters. The Sharpless catalog contains many emission nebulae perfect for scopes of all sizes. A good resource for choosing targets from this catalogue is Dean



▲ **GALACTIC ENHANCEMENT** Galaxies are perhaps the hardest target to shoot under bright skies. However, some nearby specimens, such as M31 seen here, contain many small H II regions that can be captured well through a Hα filter even in a light-polluted sky or when the Moon is nearly full.

Salman's gallery found online at **sharplesscatalog.com**. It lists objects by constellation and provides information on each object's size and brightness, with notes to suggest what filters might work best.

Short Exposures

When shooting under light pollution or moonlight, you'll need to record shorter exposures (and many of them) than you can in darker conditions. This is because the bright sky saturates your camera's detector quickly, washing out your target before you can capture enough photons in a single exposure. Stacking many short images also does a better job of removing artifacts and other unwanted signal in individual frames, including airplane and satellite trails.

In bright conditions, I often shoot exposures of about ⅓ to ½ of what I usually use in more ideal conditions. For example, I usually take 10-minute exposures with red, green, and blue filters on a dark night. With the Moon up, I typically shoot 5-minute exposures. These shorter exposures have a lower background brightness with more dynamic range between the darkest and brightest pixels in the image compared to a long exposure under the same conditions.

Banishing Gradients

Once you have your images recorded, one of the first processing hurdles you'll encounter is eliminating brightness gradients. Images recorded under brightly lit skies will inevitably capture unwanted brightness gradients along with the precious photons that we're really after. Fortunately, most image-processing software these days includes tools that can reduce the impact of unwanted light gradients in images. I use *PixInsight*'s DynamicBackgroundExtraction and AutomaticBackgroundExtraction tools to address these problems, which is one of the first steps in my deep-sky image processing workflow (*S&T:* August 2016, p. 66). Another option is the plug-in tool for *Adobe Photoshop* called *GradientXterminator* (**https://is.gd/zryU32**), which is an effective and easy-to-use solution after converting your image to TIF format. There are also many online tutorials describing gradient removal methods for other image-processing software.

Strategies for Success

Most amateur astrophotographers know that there's a sort of "Drake equation" for the probability of getting in a good night of imaging. And the news isn't good. For most of us, astrophotography is limited due to clouds, wind, work, family commitments, and pesky equipment malfunctions. But with a few carefully chosen strategies, you can stop the Moon from robbing half of your imaging time every month and mitigate the impact of light pollution on your results. Use the brightest nights — whether from moonlight or light pollution — to make sure your equipment is in top shape for those clear, transparent, and moonless nights that we all crave. Target objects that outshine your local light pollution, or simply take test shots to help you frame new targets. Taking these steps can greatly expand the number of nights you can be out collecting photons, rather than letting your equipment sit idle.

■ **RON BRECHER** shoots deep-sky targets from his backyard observatory in Guelph, Ontario. Visit his website at **astrodoc.ca**.

State of the Art – Today

Here's a look at the cutting edge of telescope technology now.

▲ Werner Schmidt with his telescope in its f/8 configuration on its angled pier mount. That's the f/4 secondary cage in his hands.

LAST MONTH I WROTE about amateur telescope making in the 1950s. This month let's look at what's possible in the hobby today.

I could scarcely believe it when Detlef Werner Schmidt wrote to me about his latest project. Some of you may already know Werner as the designer of the Feather Touch focuser and the founder of Starlight Instruments, so you might expect another fabulously well-machined gem, and you would be right. But would you expect an imaging Newtonian that can be switched from f/4 to f/8 in about 10 minutes? Without re-collimating?

No kidding. Werner has built just such a telescope. And he has built it with his typical attention to detail and exquisite machining.

Werner had several goals in mind when he started. He wanted a sharp imaging scope that would illuminate a large CCD with minimal field aberrations. He wanted both wide-field and high-magnification capability. He wanted to minimize diffraction spikes. He wanted to keep it light and manageable. And he wanted no need to perform in-field collimation.

Any of the above would be difficult enough on its own, but in combination

▲ The scope in its f/4 configuration. Note how it clears the pier even when pointing at Polaris.

ALL PHOTOS BY WERNER SCHMIDT

they're an engineering challenge to say the least. Then add to that the decision to make the system modular so the scope could be switched from f/4 to f/8 in the field — by completely swapping secondary cages. This clearly wasn't going to be a standard Dobsonian.

For the optical systems, friend and optical designer Roger Ceragioli started with a 12½-inch f/4 Zambuto mirror. To fix the field aberrations inherent in an f/4 paraboloid and flatten the focal plane, he came up with a modified Wynne corrector. Werner says, "I kept being a pain in the you-know-what to Roger, and he kept coming up with better and better designs." What they wound up with is a set of corrector lenses that fits partly in the focuser drawtube and partly in front of the secondary mirror. The f/8 configuration is similar, with an apochromatic Barlow in front of the secondary and additional lenses built into the drawtube, which results in a low 25% central obstruction.

Not surprisingly, the secondary spiders are non-traditional as well. Werner says, "I was never a fan of big fat diffraction spikes. It looks good on a Christmas card but not in astrophotos." So he went with a three-vane design using stainless steel sheet stock that's only .003 inch thick. That's thinner than a typical sheet of paper. Why three, which would generate six spikes, rather than the traditional four? Roger explains: "A 3-vane spider has 25% less diffracted light than a 4-vane spider, and since there are six spikes instead of four, those six end up being a lot dimmer." Werner adds, "The other reason is that I needed room for the side opening in the secondary can for the reflected light rays." The result speaks for itself: Almost no diffraction spikes are visible in photos taken through the scope.

The tube sections are made of machined aluminum, which provides excellent rigidity while keeping the weight down. The entire scope (in either configuration) weighs 55 pounds, including 7 cooling fans on the primary mirror.

Perhaps the most impressive feature of this entire system is the way one secondary cage can be removed and the other one attached, and the corrector lenses in the focuser drawtube can be swapped out — and when you're done you have a completely different system without even having to re-collimate. To accomplish that, the mating surfaces have to be extremely flat and precisely aligned.

Oh, and the secondary cages rotate to place the eyepiece in a convenient position in any part of the sky, also without affecting collimation.

Then there's the pier the scope mounts to. Werner didn't want to do a pier flip when the OTA reached the meridian, so he designed an angled pier for his Astro-Physics 1200GTO mount that stays out of the way. Werner reports, "With either system on the mount I can fully rotate while pointing to Polaris, so no more pier flip, and I can go nap during imaging."

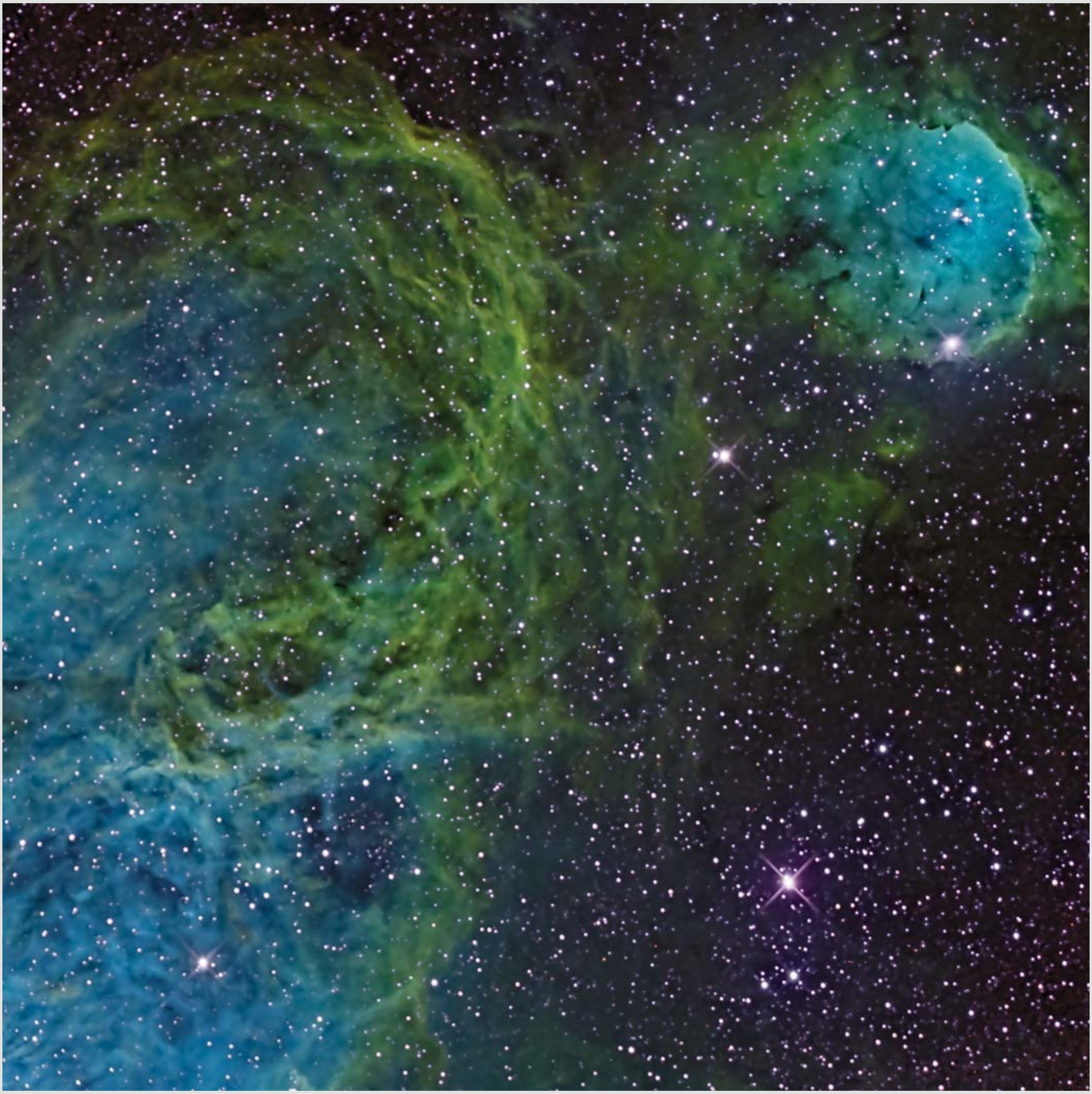
The dual focal-length scope was a great learning experience. Werner says "It was fun to push the boundaries with Roger, without whose design skills this project wouldn't have happened."

• **For more information on this innovative telescope design, contact Werner at dwsfx2@gmail.com.**

▲ Many of the machined parts for Werner's scope. Some assembly required.

▲ The Cone Nebula photographed at f/4. Note the round stars and absence of diffraction spikes on all but the brightest stars.

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



◁ BLUE BUBBLE

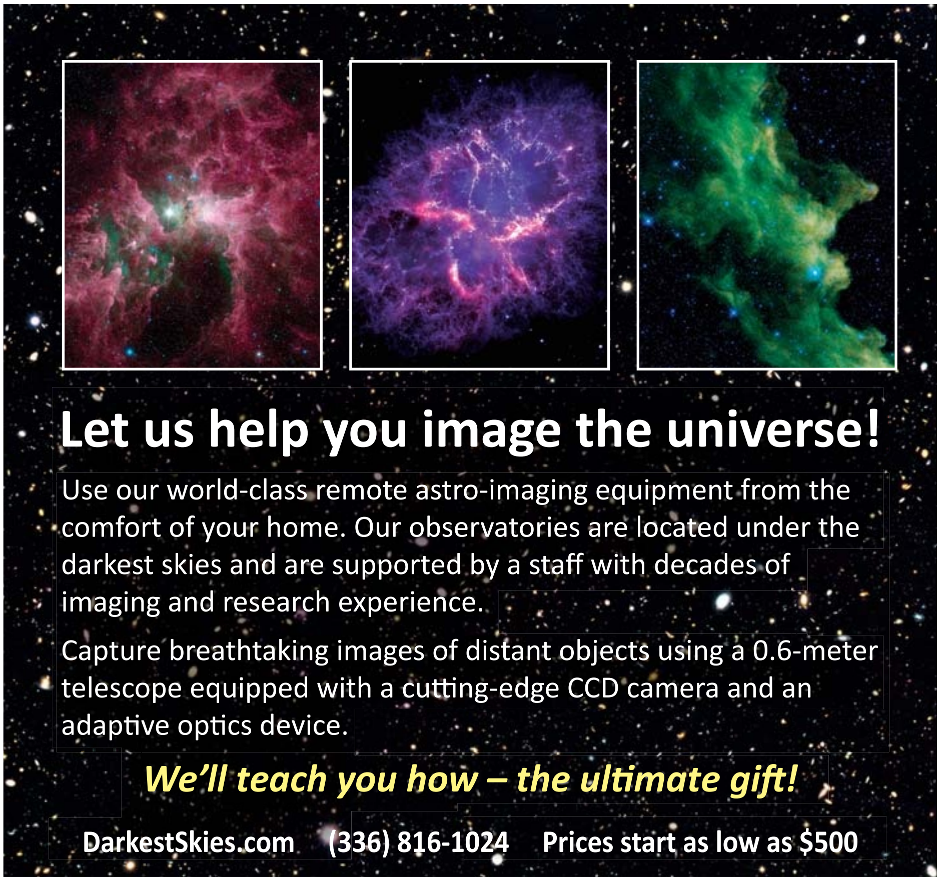
Derek Santiago

Abell 33, in Hydra, is nicknamed the Diamond Ring Nebula because of the 7th-magnitude star perched on this planetary nebula's outer rim at lower right.
DETAILS: *Celestron EdgeHD 9.25-inch Schmidt-Cassegrain telescope, QSI540 wsg CCD camera, and Astrodon O III and Hα filters. Total exposure: 7 hours.*

△ IN CARINA'S SHADOW

Darryn Lavery

The star-forming region NGC 3324, at upper right, lies just 2° northwest of the far grander Carina Nebula, whose extended outer wisps dominate this view.
DETAILS: *Astro Systeme Austria 16N Newtonian astrograph and Apogee Aspen CG16070 CCD camera with O III, S II, and Hα filters. Total exposure: 55 minutes.*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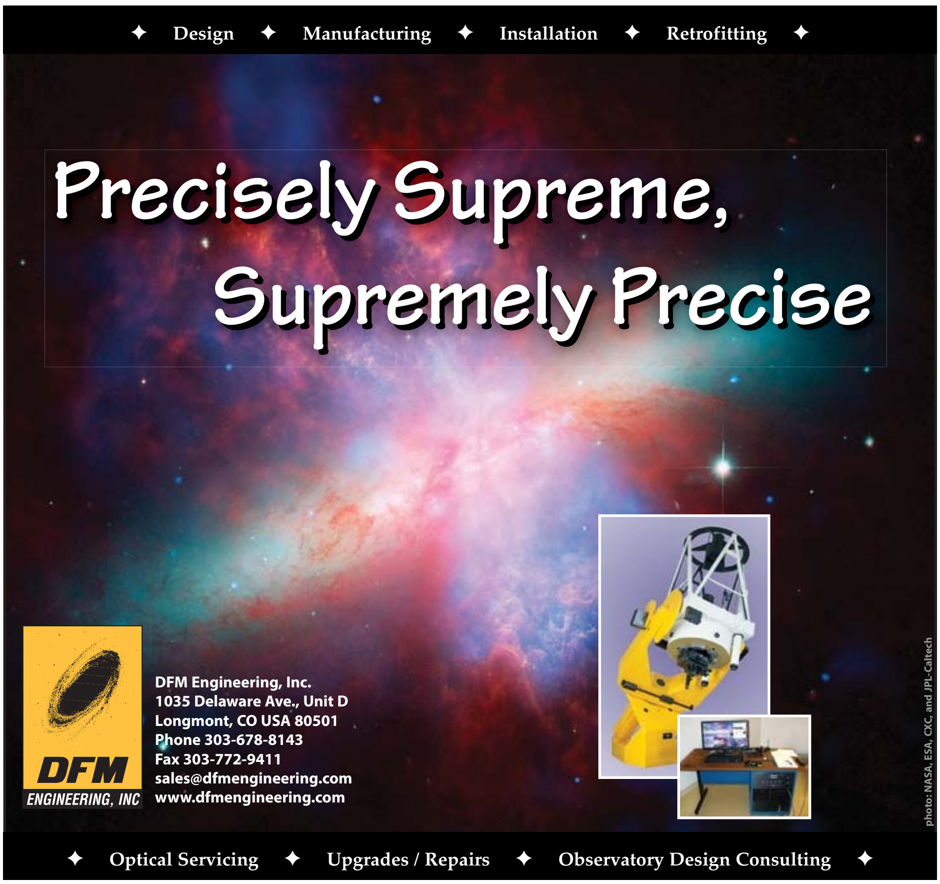
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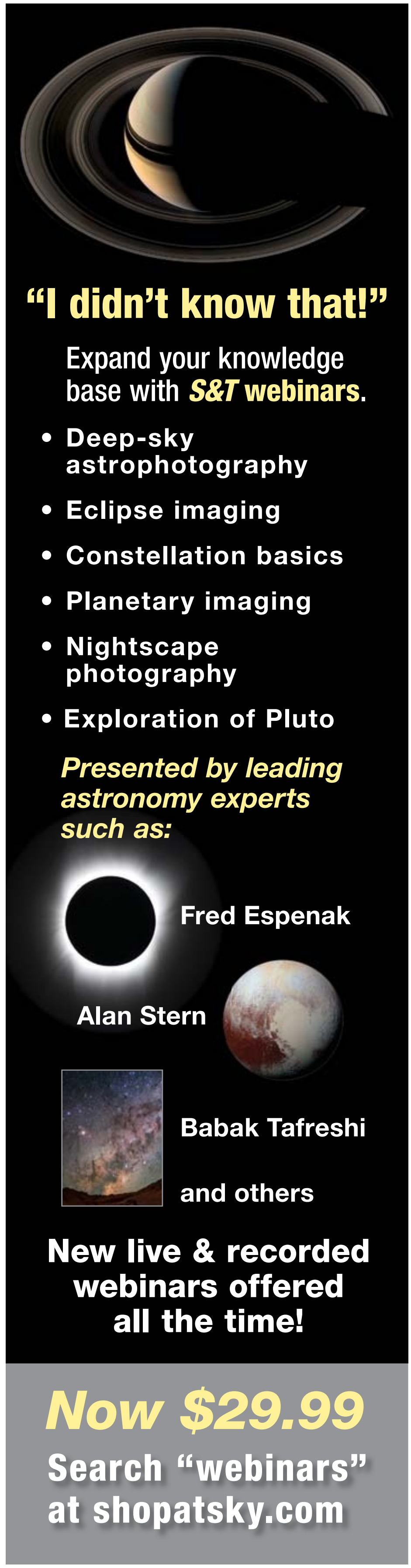
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▷ ENTER THE CAVE

Patrick Winkler

Also known as Sh2-155, the Cave Nebula is a dense interstellar cloud that's ablaze with star formation. It lies roughly 2,400 light-years away in Cepheus.

DETAILS: *TeleVue NP 127fli apochromatic refractor and FLI Microline MLx694 monochrome CCD camera with hydrogen-alpha filter. Total exposure: 120 minutes.*

▽ MANY SPLENDORS

Terry Robison

Located just 1¼° from the Lagoon Nebula in Sagittarius, IC 4685 is a complex mix of emission and reflection nebulae. For example, NGC 6559 is lower left of center.

DETAILS: *RC Optical Systems 10-inch astrograph and SBIG STL 11000m CCD camera with Astrodon LRGB filters. Total exposure: 10¼ hours.*

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AD INDEX

Event Calendar

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

GRAND CANYON NATIONAL PARK

September 16–24
OKIE-TEX STAR PARTY
Kenton, OK
okie-tex.com

September 21–23
ILLINOIS DARK SKIES STAR PARTY
Chandlerville, IL
sas-sky.org/2017-idssp

September 21–24
HIDDEN HOLLOW STAR PARTY
Mansfield, OH
wro.org/hidden-hollow-star-party

September 22–24
BLACK FOREST STAR PARTY
Cherry Springs State Park, PA
bfsp.org

September 22–24
CONNECTICUT STAR PARTY
Goshen, CT
asnh.org/slideshow/CSPpicIndex.php

September 29–30
ASTRONOMY AT THE BEACH
Island Lake State Recreation Area, MI
glaac.org/astronomy-at-the-beach

September 30
ASTRONOMY DAY
Everywhere!
astroleague.org/al/astroday/astroday.html

October 13–22
JASPER DARK SKY FESTIVAL
Jasper National Park, Alberta
jasperdarksky.travel

October 14–22
PENNYRILE STARGAZE
Hopkinsville, KY
facebook.com/southstarparty

October 15–22
CHIEFLAND ASTROFEST
Chiefland Astronomy Village, FL
chieflandastrofest.com

October 17–22
ENCHANTED SKIES STAR PARTY
Magdalena, NM
enchantedskies.org

October 17–22
DEEP SOUTH STAR GAZE
McComb, MS
stargazing.net/DSRSG

October 19–22
SJAC FALL STAR PARTY
Belleplain State Forest, NJ
sjac.us/starparty.html

October 21
NOVAC STAR GAZE
C.M. Crockett Park, VA
novac.com/wp/outreach/stargaze

October 28
INTERNATIONAL OBSERVE THE MOON NIGHT
Everywhere!
moon.nasa.gov/inomn.cfm

November 18
NIGHT UNDER THE STARS 2017
Alamo Lake State Park, AZ
azstateparks.com/alamo-lake/events

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

Reach Out & Touch

The Square Kilometre Array project in South Africa needs to involve locals — and fast.

The MeerKAT radio telescope, seen here in 2016, will eventually become integrated into South Africa's portion of the SKA.

WOULD YOU SELL your property to scientists who plan to build the world's largest array of radio telescopes? As a reader of *Sky & Telescope*, you possibly would. But farmers in the sparsely populated Great Karoo semi-arid region in South Africa are not so keen.

Most of them are very suspicious of the plans for the Square Kilometre Array (SKA; *S&T:* June 2017, p. 24). Radio galaxies, pulsars, and the epoch of reionization don't ring a bell with them. Instead, they believe that the SKA antennas will compromise their cell-phone reception. Or, worse, that the mysterious radio waves might cause cancer. Local opposition to the future observatory is fierce — and growing.

Gone are the days when an astronomer would do his research at the eyepiece of a telescope in his backyard, as William Herschel did in the late 18th century. Scientists are building ever-larger structures to study both the macro- and micro-cosmos. Just think of the ALMA Observatory in Chile, the LIGO gravitational-wave detectors, or the enormous, underground particle-physics experiments at CERN in Switzerland.

Sometimes, protest against such facilities has an environmental basis. Endangered species might suffer from building activities in remote areas, for example. In other cases, as the Thirty Meter Telescope consortium discovered on Mauna Kea, Hawai'i, strong religious objections exist. Quite often, people feel they're victims of some government-funded chain of events that is beyond their control.

In the Great Karoo, construction of the MeerKAT array — an SKA pathfinder observatory — is well underway. By the end of this year, project crews will have erected 64 radio dishes, each 13.5 meters in diameter. Eventually, MeerKAT will be incorporated into the much larger South African portion of the SKA.

> No one had thought about actively involving landowners from the very start.

That is, if enough land can be acquired, hopefully without expropriation procedures.

When I visited the site in November 2016, I discussed these issues with SKA media liaison officer Angus Flowers. To my astonishment, I learned that the SKA Organization had not yet invited local farmers to the facility. The nearby town of Carnarvon has held public hearings, but apparently no one had thought about actively involving landowners from the very start and trying to win their enthusiasm for the world's biggest astronomy facility ever.

In Western Australia, where SKA's low-frequency facilities will be built, things went better. For many years, astronomers have worked closely with the Yamatji people who originally owned the land. Likewise, when the Low-Frequency Array — or LOFAR, consisting of many thousands of small antennas — went up in the Netherlands, officials organized "kitchen-table conversations" with local farmers over many years, gradually winning their support.

Knowing how sensitive these issues can be, astronomers should always pay a lot of attention — and enough money — to communicating their plans to local communities. Explain the science. Be open and honest about your project's goals and scope. Make clear that an observatory passively studies the sky and can't cause diseases. Above all, convey your passion for learning about the wonderful world we all inhabit.

These days, public outreach and education have become more important than ever. I strongly believe that, in the end, they will always have the potential to succeed. After all, the urge to marvel at and understand the universe is truly universal. I just hope it's not too late for SKA South Africa.

■ *S&T* Contributing Editor **GOVERT SCHILLING** is an astronomy writer in the Netherlands. *Ripples in Spacetime*, his book on gravitational waves, was published in July.

SKA SOUTH AFRICA