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AUSTRALIAN SKY & TELESCOPE

THE ESSENTIAL MAGAZINE OF ASTRONOMY

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ON THE COVER

Astronomers are looking back through time to the era when the first stars and galaxies began to shine. Turn to page 18.

A person to be admired

SHORLTY BEFORE this issue went to press, all hell broke loose in the media in the wake of cricket's latest ball-tampering scandal. Apart from all the other implications, some people expressed concern about the effect the loss of confidence in Australia's cricketing 'heroes' would have on the many kids who are mad about the sport. I happen to think they'll be smart enough to process it and carry on. For me, though, it raises the question of what constitutes a 'hero'. Personally, I couldn't care less about cricket, so I don't consider any members of the Australian team (nor any other team) to be my heroes. A hero, surely, is someone who saves lives or property, or fights oppression for some ideal, selflessly and with little regard to their own safety. So for me at least, heroes generally are not to be found on the sporting field.

But there are many people who aren't heroes yet who certainly deserve our admiration, whether that's for their skill, perseverance, courage, achievements and so on. By that definition, Stephen Hawking was certainly a person to be greatly admired and respected, not only for his contributions to science, but also for his never-say-die attitude, as well as his wit and his ability to connect with the public. Dubbed the most famous scientist since Einstein, his contributions will long remain in our consciousness, and generations to come will learn of the great man with the electric voice.

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Stephen Hawking, 1942–2018

STEPHEN HAWKING, renowned and inspirational physicist, died on March 14 at the age of 76. He spent decades defying expectations and living a remarkably full life, and is survived by three children and three grandchildren.

Hawking was born on January 8, 1942, in Oxford, England. Though clearly gifted, he didn't apply himself in school until he reached college, where he studied physics and graduated with honours. He went on to graduate school at the University of Cambridge. It was then, at age 21, that Hawking was diagnosed with amyotrophic lateral sclerosis (ALS), a disorder that affects nerves in the brain and spinal cord, leaving muscles to weaken and waste away. Hawking was told at the time that he would have one, maybe two years to live.

Yet two years later, Hawking was feeling relatively well, engaged to be married to Jane Wilde, and casting about for a thesis idea. That's when he came across Roger Penrose's work on singularities. While his thesis focused on the Big Bang singularity, this interest naturally led him to black holes, which would occupy most of his career.

Even as ALS confined him to a wheelchair by the 1970s, Hawking began to contemplate the ideas behind the concept he's most famous for: *Hawking radiation*. In this process, black holes lose energy (and therefore mass) by interacting with virtual particles. The vacuum of space is not totally empty; virtual particles pop into and out of existence. These short-lived particles come in pairs that quickly recombine and annihilate, resetting the energy scorecard to zero. But near a black hole's horizon, tidal gravity pulls apart the particles, boosting their energy such that they survive and become 'real'. One is lost into the black hole and the other flies away, carrying the energy it has taken from the black hole's gravity — thus reducing the black hole's mass.

Hawking radiation is difficult, if not impossible, to observe but has huge implications for physics. If black holes radiate their mass away, that would destroy the information the mass once held — something quantum mechanics forbids. Even now physicists are struggling to understand the implications in their quest for a true unification of general relativity and quantum mechanics.

Hawking completely lost his ability to speak in 1985 and relied solely on a computerised voice system. It slowed his communication, but in 1988 he nevertheless published the best-selling and foundational *A Brief History of Time*, which walks through the origin and structure of the universe, space, and time with clarity and a good dose of wit.

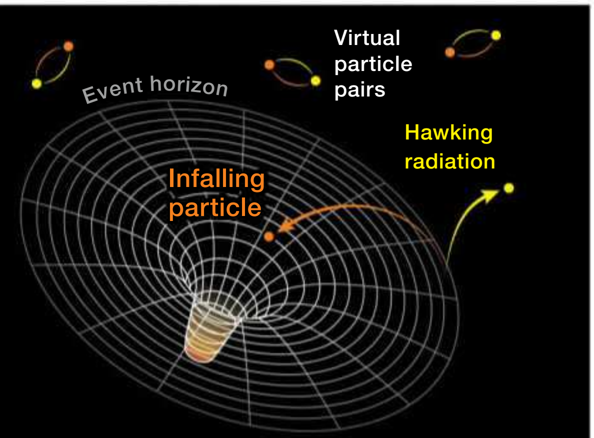
▲ Stephen Hawking addresses a crowd at Northeastern University in 1991.

Hawking divorced Jane, his wife of 30 years, in 1995 and married his one-time nurse, Elaine Mason. He and Mason divorced in 2006. However, Jane and Hawking maintained a good working relationship, and Jane's autobiography, titled *Travelling to Infinity: My Life with Stephen*, resulted in the 2014 movie that celebrated Hawking's life, *The Theory of Everything*.

Although he continued his research on black holes, recent years saw Hawking turn his gaze toward humankind's future, motivated by concerns over our planet's long-term habitability. He advocated a push for the stars and helped launch Breakthrough Starshot. At his 75th birthday celebration, he reminded attendees, "Remember to look up at the stars and not down at your feet. Try to make sense of what you see and wonder about what makes the universe exist. Be curious, and however difficult life may seem, there is always something you can do, and succeed at. It matters that you don't just give up."

■ MONICA YOUNG

In Hawking's concept of black hole radiation, the lucky one of a virtual pair of particles produced near the event horizon (a black hole's 'point of no return') may escape, appearing to radiate from the black hole itself.



HAWKING: KELLY BEATTY / S&T; ILLUSTRATION: GREGG DINDERMAN / S&T

Amateur captures supernova's first light

AN AMATEUR ASTRONOMER serendipitously has captured the first flash of a supernova, providing the earliest glimpse of a stellar explosion.

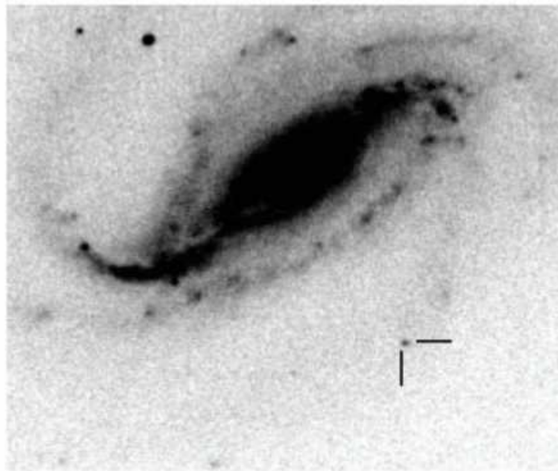
On September 20, 2016, Víctor Buso was testing his new CCD camera in the observatory he had built on the top of his home in Rosario, Argentina. He pointed his 40-cm Newtonian toward the galaxy NGC 613, taking a series of 20-second exposures over the course of 1½ hours. While the first images didn't show anything unusual, Buso soon noticed that a pixel near the end of one of the galaxy's spiral arms had brightened — and was becoming brighter with every shot.

Buso contacted another amateur astronomer, Sebastián Otero, a member of the American Association of Variable Star Observers, who helped Buso send out an international call for follow-up. The February 22 issue of *Nature* details the observations and their significance.

What Buso had captured was the *shock breakout*, the moment when the shock wave travelling outward from the collapsing core of the star breaks through the surface. The star's outer layers of gas heat up as they're ejected, brightening rapidly — in this case, at a rate of 40 magnitudes per day.

The shock-breakout phase had been largely theoretical because, although astronomers had seen hints of the phenomenon, it had never been definitively detected at visible wavelengths. The shock wave takes only a few hours to break out of the star, and much of its immediate emission is at higher-energy wavelengths.

The Neil Gehrels Swift Observatory subsequently monitored the supernova's X-ray, ultraviolet, and visible-light emissions. Based on the discovery and follow-up observations, Melina Bersten (National University of La Plata, Argentina) and her team determined that the exploding object had been a star in a binary system, which had lost its outer layers of gas to its companion star, leaving behind a helium-dominated core. The progenitor, once about 20 times as massive as our Sun, had shrunk to 5 solar masses by the time it exploded.



▲This is one of a series of negative images showing the supernova at the moment of discovery: an initially faint object (marked by crosshairs) in the southern, outer regions of the spiral galaxy NGC 613.

VÍCTOR BUSO & GASTÓN FOLATELLI

Buso, who works as a locksmith, says the discovery brought him great joy. "Sometimes I wonder why I do this, why I put so many hours and so much passion into this... Now, I have found the answer."

■ JAVIER BARBUZANO

IN BRIEF

Most distant super-supernova

Astronomers have detected the most distant superluminous supernova, flashing from more than 10 billion years in the past. Mathew Smith (University of Southampton, UK) and colleagues found the exploding star as part of the Dark Energy Survey Supernova Program. The event, called DES16C2nm, has a redshift of 1.998 and, like others in its class, appears to be poor in hydrogen. When combined with 10 other superluminous events, DES16C2nm turns out to be part of a fairly uniform group. There's no sign that the supernovae's properties differ across cosmic time. The team expects that DES will be able to detect such supernovae from the last 12 billion years; upcoming facilities may push even further back in time. The results appear in the February 10 issue of the *Astrophysical Journal*.

■ CAMILLE M. CARLISLE

NASA 2019 budget proposal cancels WFIRST

The White House's NASA budget proposal for fiscal year 2019 calls for the cancellation of the Wide Field Infrared Survey Telescope. The National Academies' 2010 decadal survey placed a top priority on the development of WFIRST to study dark energy and exoplanets. It moved from design study to formal development just last year, and the American Astronomical Society has released a statement rejecting the project's cancellation. However, the program was recently under external review to ensure it could deliver science at a reasonable cost, and findings upped the mission budget by US$300 million. The FY19 budget request also cuts all funding for NASA's Office of Education, as well as for several Earth-observing missions, and shifts exploration focus to the Moon. It's worth noting, though, that many of these cuts were also requested in the 2018 budget proposal and ultimately weren't approved.

■ DAVID DICKINSON

Arecibo's fate decided

Beginning April 1, the University of Central Florida (UCF) is taking over the operations and management of the Arecibo Observatory in Puerto Rico from the National Science Foundation (NSF), although NSF retains ownership. Arecibo had been threatened by funding shortfalls for more than a decade, as the NSF weighed its ability to both maintain existing facilities and invest in new ones. Late last year NSF solidified its plans to reduce its funding for Arecibo from the current US$8 million per year to US$2 million per year in 2022 while simultaneously seeking alternative sources of funding. Now, UCF leads a consortium that will provide support and technical personnel to manage the observatory, its research — including NASA's near-Earth asteroid observations — and associated educational and outreach activities. UCF astronomers will receive some dedicated time on the radio dish, and time will also still be awarded to the larger astronomical community.

■ MONICA YOUNG

Amazing storms, jet streams on Jupiter

NEW RESULTS PUBLISHED in the March 8 issue of *Nature* show us the latest looks at Jupiter from NASA's Juno spacecraft, revealing details of the giant planet's atmosphere.

In a visually stunning result, Alberto Adriani (INAF Institute for Astrophysics and Space Planetology, Italy) and colleagues report the discovery of two sets of cyclones at the planet's poles.

The complex at Jupiter's north pole has a central, 4,000-km-wide cyclone, with a ring of eight, regularly spaced storms of similar size around it. At the south pole, a central cyclone sits in the middle of an imperfect pentagon of five others, each between 5,600 to 7,000 km wide, or about half of Earth's diameter.

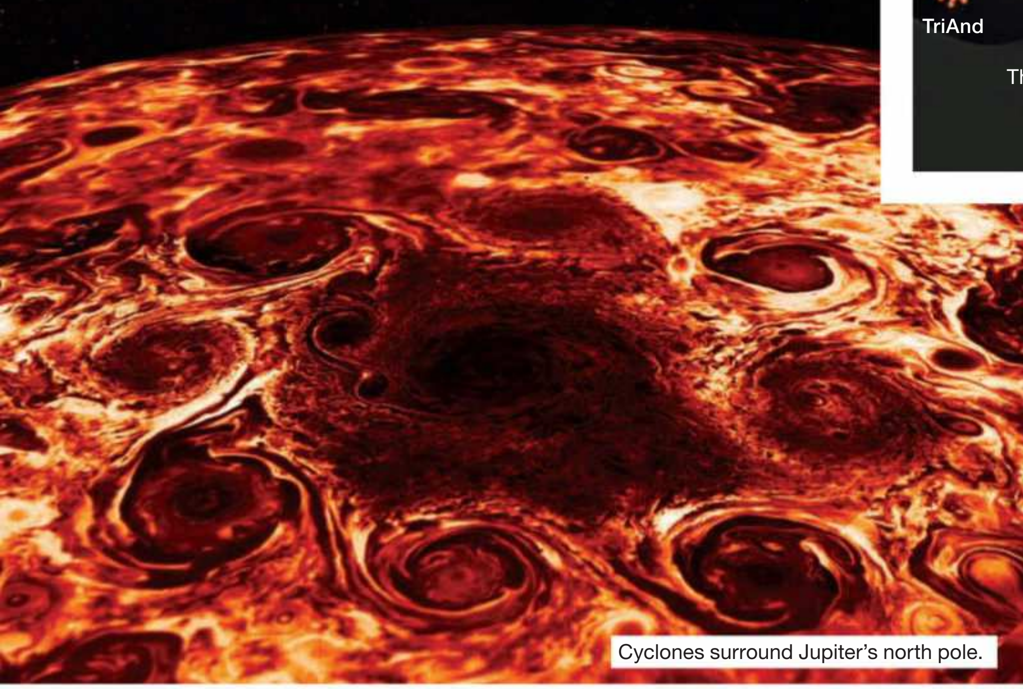
The individual storms rotate every 27 to 60 hours at hundreds of kilometres per hour. It's possible they drift around the central cyclones, but Juno observed little change over 7 months. The team doesn't know why the patterns remain stationary. It's also still unclear whether the cyclones formed at the poles or migrated there from elsewhere.

Additional work shows that the planet's jet streams reach some 3,000 km down, far deeper than many scientists expected. For comparison, Jupiter's weather layer — the part where sunlight is absorbed and clouds form — is only about 100 km deep. Deep jet streams favour a long-standing theory for Jupiter's atmosphere, in which the jet streams form a series of nested cylinders, like a roll of toilet paper that's been carved into a sphere (but fewer layers). Each latitude band corresponds to a different layer in the nest, with higher latitudes corresponding to deeper cylinders.

In the region dominated by the jet streams, the planet rotates differentially, turning more quickly at its equator than at its poles. But below the deep jet-stream layer, the planet appears to rotate more like a solid ball, which means the cylinder scenario may need some modification.

More results are forthcoming, including about widespread lightning, predominantly in the northern hemisphere. Still, questions linger — such as how deep the Great Red Spot goes — and await additional data.
■ CAMILLE M. CARLISLE

● For more results and images, visit https://is.gd/junosjupiter

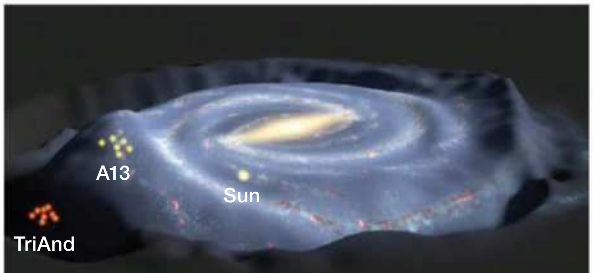


Cyclones surround Jupiter's north pole.

Dwarf galaxy evicted Milky Way stars

MOST STELLAR STREAMS in the Milky Way's halo are ghosts of dwarf galaxies past, long ago torn into shreds after encounters with our more massive galaxy. Now, new research that appeared online February 26 in the journal *Nature* shows that some of these stars might not be dwarf remnants at all — they might have come from the Milky Way's own disk.

Maria Bergemann (Max Planck Institute for Astronomy, Germany) and colleagues studied 14 stars in two halo populations, known as A13 and Triangulum-Andromeda (TriAnd), using the Keck I telescope in Hawai'i and the Very Large Telescope in Chile. After collecting the stellar spectra, the astronomers measured the abundances of elements heavier than hydrogen and helium. Unlike most of the stellar halo, these stars are rich in heavy elements, more akin to stars in the galaxy's disk.



The A13 and TriAnd clouds are in the outer galaxy, roughly 15,000 light-years above and below the galactic plane, respectively.

Moreover, TriAnd and A13 have similar abundances to each other, implying a common birthplace — even though they're separated by 30,000 light-years.

Bergemann and colleagues simulated a possible origin scenario. The Sagittarius dwarf galaxy, now stretched into a thin stream that wraps around the Milky Way, careened into our galaxy several billion years ago. Such an interaction would have disrupted the Milky Way's disk and sent swirls of stars above and below the galactic plane. ■ MONICA YOUNG

NASA / JPL-CALTECH / SWRI / ASI / INAF / JIRAM A13 AND TRIAND: © T. MUELLER / NASA / JPL-CALTECH

Akatsuki's views of Venus

Japan's Venus-bound orbiter Akatsuki survived great odds to reach its objective and is now wowing scientists with results. Akatsuki has been at Venus since December 2015, and in its final science orbital configuration since April 4, 2016. The very elliptical orbit has a period of 10.5 days, travelling from a closest approach of around 10,000 km to its farthest point 360,000 km from the planet. Akatsuki carries five cameras to view Venus in different wavelengths, each one penetrating into the planet's atmosphere to a different depth. Unfortunately, its two infrared cameras suffered an electrical fault in December 2016, but three cameras capturing ultraviolet, visible and long-infrared wavelengths still work. The ultraviolet imager (UVI) records high-altitude clouds illuminated by sunlight, as pictured here. Drifting along at elevations of 65 to 75 km, these clouds consist mostly of sulfuric acid. Amateur image processor Damia Bouic combined UVI images taken from different distances to create this composite. Read more and see additional stunning images at https://is.gd/Akatsukiviews.

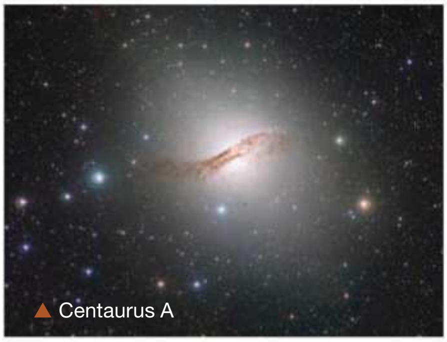
■ EMILY LAKDAWALLA

Orderly dwarf galaxies challenge cosmological wisdom

IN THE JOURNAL *Science*, Oliver Müller (University of Basel, Switzerland) and colleagues report that satellite galaxies are moving around the huge elliptical Centaurus A (NGC 5128) in an orderly fashion. The finding may challenge our understanding of galaxy evolution.

Current cosmological theory predicts that large galaxies should surround themselves with a chaotic swarm of dwarf galaxies. Instead, out of the 16 Centaurus A satellites with known line-of-sight velocities, 14 orbit in the same direction along a broad plane that crosses perpendicular to the galaxy's famous dust band. The result echoes similar findings for our own Milky Way Galaxy, as well as for the Andromeda Galaxy (M31).

Some theorists have proposed that such order might come from gravitational interactions within our Local Group of galaxies. But according to Müller and his coauthors, the likelihood of finding just one example of coordinated motion among dwarf satellites is smaller than 0.5% in current cosmological simulations. "Finding three such systems in the nearby universe seems extremely unlikely," they write.



▲ Centaurus A

However, as Eline Tolstoy (University of Groningen, The Netherlands) points out, "It's still small number statistics." Müller's team could only measure the velocities of the brightest satellite galaxies, which could skew the results. Moreover, previous observations have shown that Centaurus A has experienced a major merger in its past, which might have organised its satellites' orbits.

More complete observations of galaxies and their satellite systems can help settle the issue, but the measurements are difficult to make. New data from the European Space Agency's Gaia mission should at least clarify the motions of dwarf galaxies around the Milky Way.

■ GOVERT SCHILLING

CENTAURUS A: ESO; VENUS: JAXA / ISAS / DARTS / DAMIA BOUIC

IN BRIEF

New dividing line between giant planets and brown dwarf stars

Scientists have long set the dividing line between giant planets and brown dwarf stars at 13 times Jupiter's mass, the minimum required to ignite deuterium fusion in an object's core. However, writing in the *Astrophysical Journal*, Kevin Schlaufman (Johns Hopkins University) sets a different upper boundary: between 4 and 10 times Jupiter's mass. The new definition is based on how the objects form: Giant planets grow from the bottom up in a process called *core accretion*, so they should form more easily in protoplanetary disks enriched with heavy elements. Brown dwarfs grow from the top down, collapsing directly from a cloud of gas, which doesn't depend so much on heavy elements. Indeed, Schlaufman found that, in 146 carefully selected planetary systems, objects with masses less than 4 to 10 Jupiters tend to form around stars rich with heavy elements, while objects with more than 10 Jupiter masses form around all kinds of stars. These results won't reclassify any planets within our own Solar System, but they do have implications for where we draw the line between giant exoplanets and brown dwarfs. Read more at **https://is.gd/planetdefinition**.

■ SHANNON HALL

IN BRIEF

Some planets are bigger than they seem

Nearby stars can make some exoplanet candidates look smaller than they really are, says Carl Ziegler (University of North Carolina, Chapel Hill. The conclusion come from data obtained with the Robo-AO system, which is following up on some 4,000 candidate exoplanets from NASA's Kepler mission. The automated laser-guided adaptive optics system took rapid-fire images of each target star, looking for stellar companions that might mess up the data. Of 3,857 stars observed with Robo-AO, almost 600 had stellar companions. The extra stars' light contaminated exoplanet transits, making their dips appear smaller and thus giving the impression that the planets themselves are smaller. Generally, having another star in the system makes planets twice as wide as they first appear. Because of this contamination, 8 of the 26 potentially rocky, habitable-zone worlds studied might actually be gaseous. Among them are the confirmed planets Kepler-438b and Kepler-437b, which could be 2 to 3 times larger than estimated if they orbit their system's secondary star.

■ CAMILLE M. CARLISLE

NASA's new nuclear power source

NASA has announced the development of a new nuclear generator, one that may become a permanent fixture on lunar outposts or deep space missions in the coming decades. The Kilopower fission reactor will generate 10 kilowatts of electricity for a minimum of 10 years — more than enough to run several typical Australian househoulds. The new technology offers a more efficient, portable power source that opens new areas for space exploration, such as high latitudes on Mars. Launching nuclear generators into space isn't without its issues, of course, but tests show that if a Kilopower reactor were lost and the core breached during a launch, the peak dose from exposure to unfissioned uranium for people on the ground would be less than a millirem, and would more likely be in the microrem range, according to Pat McClure (Los Alamos National Laboratory). The average Australian receives about 620 millirems per year from background radiation.

■ DAVID DICKINSON

There's water beneath those Martian cliffs

THICK SHEETS OF water ice, some barely buried beneath the surface and more than 100 metres thick, have been spotted on several Martian cliff faces.

The widely scattered outcrops — seven in the southern hemisphere and one in the north — lie far from the planet's icy polar caps.

Colin Dundas (U.S. Geological Survey, Flagstaff) led the team that made the discovery using two instruments aboard NASA's Mars Reconnaissance Orbiter. First, detailed enhanced-colour images from the spacecraft's HIRISE camera revealed bluish layers in the scarps' steep faces. Then near-infrared maps from the CRISM spectrometer confirmed that the layers are enriched with water ice. The layers appear to persist year-round.

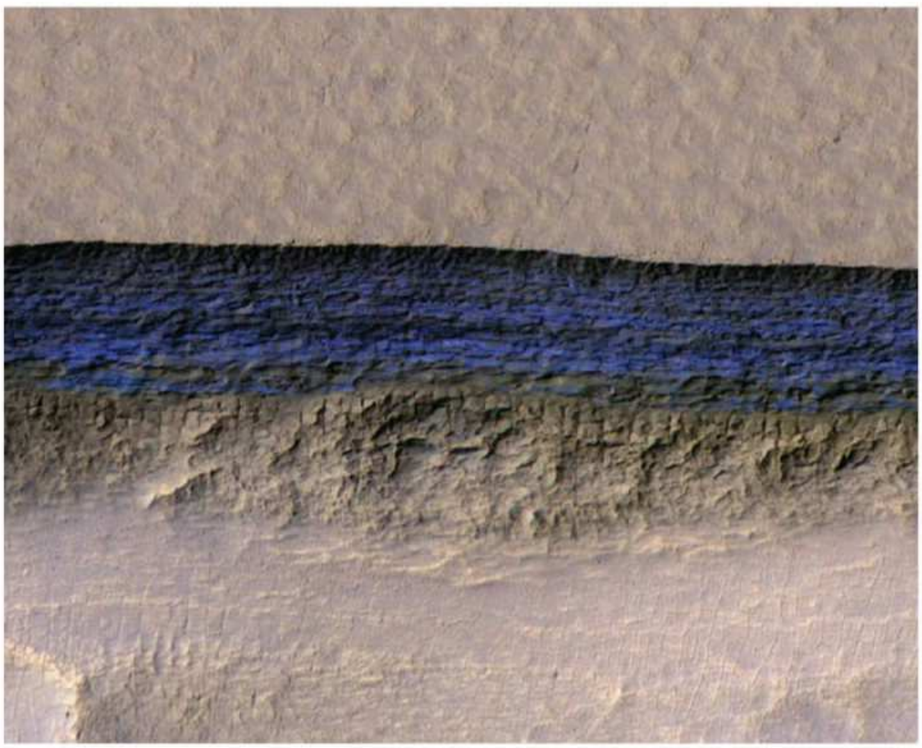
Planetary scientists have realised for more than a decade that vast deposits of water ice must lie just below the planet's dusty surface. Radar scans from orbit have revealed huge glaciers of ice within 20 metres of the surface over roughly a third of the Martian surface. But these newfound outcrops, reported in the January 12 issue of *Science*, open an unprecedented window into Martian climatic and geologic history.

The team surmises that the icy layers started out as dusty snow or frost laid down over time. The deposits eventually compacted and recrystallised. As exposed ice gradually sublimates, the rocky cliff face crumbles and erodes, revealing fresh exposures of previously buried ice.

The water ice begins within a few metres of the surface and can extend down to more than 100 metres. Given the planet's thin atmosphere and temperature swings, geophysicists calculate that water ice on Mars at the scarps' locations should be stable at depths of as little as 10 cm. Being able to access water so easily would be a huge boon to future human exploration of the planet.

■ J. KELLY BEATTY

▼ A thick sheet of underground water ice (blue in this enhanced-colour image) lies exposed along a steep slope at latitude 57°S. The ground at the top of the image is about 130 metres higher than the ground at the bottom.



NASA / JPL / UNIV. OF ARIZONA / USGS

Donati and his discovery

Remembering the most-observed comet of the 19th century.

Over the centuries, numerous celestial objects have been given names, and through those names we remember many people and places, some famous and some not so famous. We all know of Edmund Halley mostly because of the comet named after him (though he did not discover it) and despite his other achievements.

Many objects are named for lesser-known astronomers. So it is with the 19th century Italian, Giovanni Donati. A map of the Moon will show a crater called Donati, and further out we can find an asteroid bearing his name... even though, like Halley, he did not actually discover either of them. Yet he certainly did find Comet Donati. In fact, he found six comets over a 10-year period. But the one that came into his view in 1858 is *the* Comet Donati and one of the great celestial sights of all time.

On June 2 of that year, from his observatory in Florence, Donati glimpsed a small patch of light near the head of Leo. At magnitude 7 it was just out of naked-eye reach, but it soon brightened and moved, proving that it was indeed a comet.

By September it had moved into Ursa Major and had become a stunning sight for northern viewers. Lying across the stars of the Great Bear, its scimitar-shaped tail with three spikes stretched halfway from the zenith to the horizon at the time of its closest approach to Earth on October 9. In linear terms that span was more than 75 million kilometres. Only the Great Comet of 1811 was of equal or surpassing spectacle. Later, Comet Donati passed into the southern sky as it began to fade and was finally lost to view around March, 1859.

In the view of many, Comet Donati was the most beautiful comet ever seen. This was a big call. Certainly it was so spectacular that it attracted the attention of artists of the calibre of William Turner and others across Europe. The comet's passage was also recorded with the still-embryonic technology of photography, barely 20 years old but already taken up with enthusiasm by astronomers. Comet Donati was in fact the first comet to be photographed, initially by a portrait photographer in England and later through a telescope at Harvard University Observatory, though photographers struggled to achieve anything like the detail the painters could capture.

▲ William Turner's watercolour of Comet Donati's 1858 visit to Earth's skies.

PAUL MELLON COLLECTION

The comet was also the most observed by 19th century astronomers, as the skies were dark and the weather clear across northern Europe at the time. Its appearance also sparked an upsurge of interest in astronomy amongst the wider public, many of whom might have looked up with interest at the night sky for the first time. An erroneous calculation by one astronomer a year or so earlier, indicating that a comet would strike the Earth in 1857, had caused some hysteria — but in the event Comet Donati missed us by half the distance between the Earth and the Sun.

Perhaps the most famous lay observer of Comet Donati was Abraham Lincoln. He reported seeing it from his porch in Illinois on the eve of one of his famous debates about slavery with political rival Stephen Douglas— debates that influenced his election as a US senator, and ultimately as President and all that followed from that.

For Donati and others, of course, there was science to be done, as the true nature of comets was then still unknown. Donati was a leading exponent of the still-new technology of spectroscopy, which extracts information from light by breaking it up into its constituent colours. He had noted that as a comet approaches the Sun and heats up, its spectrum of colours changes, indicating that it has begun to shine by its own light rather than merely reflecting sunlight. So at least some part of a comet must be composed of gas that can be heated till it glows.

It will be a long time before Comet Donati returns to our skies. Calculations of its orbit as it rounded the Sun suggested it was headed out into deep space and will not be back for about 2000 years. It will reach its most distant point around the year 3047, before obeying the tug of the Sun and starting its return journey.

■ **DAVID ELLYARD** presented SkyWatch on ABC TV. His StarWatch StarWheel sold over 100,000 copies.

FINDING OUR PLACE By Dave Dickinson

Mapping the cosmos

How do astronomers know how big the universe is? The answer is in the stars.

ESO / P. HORÁLEK

IT'S ONE OF THE TOP QUESTIONS I get at public star parties. I'll line up the Andromeda Galaxy through the eyepiece, then start the pitch.

"That's the Great Andromeda Galaxy, 2.5 million light-years distant. Our galaxy, the Milky Way, is heading toward it at 110 kilometres per second, for a merger about four billion years from now."

"How do we know that?" comes the inevitable refrain.

It's a good question. Most lay people have heard of the Big Bang, if only because of the popular television sitcom, and maybe a few have heard of such cryptic terms as 'supercluster' and 'the Great Attractor'. But how do we know where all these things are and how they're moving?

To the stars

To measure the distance to the nearest stars, astronomers use a method straight out of trigonometry class known as *parallax*. This is simply the apparent 'jump' an object makes against the background when viewed from two different observation points. If we know both the distance between the two points and how much the target object's position seems to shift, it's easy to calculate the distance to the object. You can see a parallax shift by observing your outstretched thumb through one eye and then the other. In the 18th and 19th centuries, astronomers used parallax during rare transits of Venus to measure the distance between the Sun and Earth, called the *astronomical unit* (a.u.), and to unlock the scale size of the Solar System.

To measure the distance to the nearest stars, astronomers must use the 2-astronomical-unit-wide baseline of Earth's orbit. Even with such a tremendously large baseline, however, an object 3.26 light-years (one parsec) away only shifts one arcsecond, or about 1/1800th the diameter of a full Moon. No star is located that close to our Solar System; the nearest, Proxima Centauri, is 4.25 light-years, or more than 260,000 a.u., away.

The first good stellar parallax measurement was made by German astronomer and mathematician Friedrich Bessel in 1838, who calculated that 61 Cygni was 10.3 light-years distant. (The current measured value is 11.4 light-years.)

Stars can also help us determine the location of our place in the galaxy. German-English astronomer William Herschel made the first serious attempt at modelling the shape of our galaxy in 1785, based on the apparent distribution of stars in the sky. His sketch looked like a Christmas tree with two trunks, fallen on its side. Since then, measurements of stellar motions and the position of gas clouds,

◀ **AWE INSPIRING** The Milky Way Galaxy arches across the Chilean sky above the rugged landscape of the Atacama Desert, site of ESO's Paranal Observatory.

in addition to many other observations, have revealed that we live in a spiral galaxy with a disk more than 100,000 light-years across. We now know that Earth is located more than 25,000 light-years from our galaxy's core and completes an orbit around it once every quarter billion years.

But astronomers are still working to map our local region of the galaxy. The mission of making a precise stellar measurement catalogue (a science known as *astrometry*) moved into space with the European Space Agency (ESA) Hipparcos spacecraft, which operated from 1989 until 1993. ESA's ongoing Gaia mission (see box below) has since taken up the effort to measure precise parallaxes for more than one billion stars in the Milky Way Galaxy, about 1% of the total galactic population.

Beyond the Milky Way

The next rung of the cosmic distance ladder, the measurement of *Cepheid variable stars*, takes us farther out still. Cepheids brighten and fade in a methodical pattern. The period with which a Cepheid varies in brightness has a direct relationship to its intrinsic (not perceived) luminosity, making these stars great *standard candles*: Find a Cepheid in a cluster or galaxy, measure how bright it appears to be, and you can determine how far away it is, because brightness drops off by the inverse square of the source's distance. Henrietta Swan Leavitt first noticed this crucial relationship in 1908 while examining variable stars in the Large Magellanic Cloud.

Edwin Hubble's discovery of a Cepheid in the Andromeda Galaxy in 1925 allowed him to calculate the galaxy's distance — 1.5 million light-years. Not a bad first estimate, though short of today's value of 2.54 million light-years. Hubble's work settled a debate in astronomy by showing that many of the objects we observe lie far beyond the Milky Way Galaxy.

Think about it: Less than one century ago, many astronomy texts stated that the Milky Way constituted the entire breadth of the universe, with star charts labelling enigmatic fuzzy patches with names like the Andromeda "Nebula". We now think there are more than a trillion galaxies out there, many of which are much larger than ours.

Going with the flow

The discovery of cosmic *redshift*, our next stop on the cosmic distance ladder, gave us another yardstick to measure even larger distances on extra-galactic scales. Redshift is the shift in a source's spectral lines to longer, redder wavelengths, similar to the change in pitch due to the Doppler effect as a train's whistle recedes from the listener. Redshift exists because the source of light is moving with respect to our location. Conversely, an object moving towards us exhibits blueshift in its spectral lines.

Vesto Slipher made the first measurements of blueshift in 1912, of the Andromeda Galaxy. Thanks to the shift in its spectral lines, he discovered that the galaxy was moving toward us at an astounding velocity and probably wasn't in the Milky Way at all. Since then, we've been able to use the Doppler shift, standard candles, and other methods to determine the distances to nearby galaxies and how they move. This work reveals that the Milky Way, Andromeda and more than 50 known galaxies compose a small cluster we call the Local Group. In turn, the Local Group belongs to the Virgo Supercluster, which contains over 100 galaxy groups in a 100-million-light-year span. Virgo itself belongs to the great Laniakea Supercluster of galaxy clusters, which holds over 100,000 galaxies.

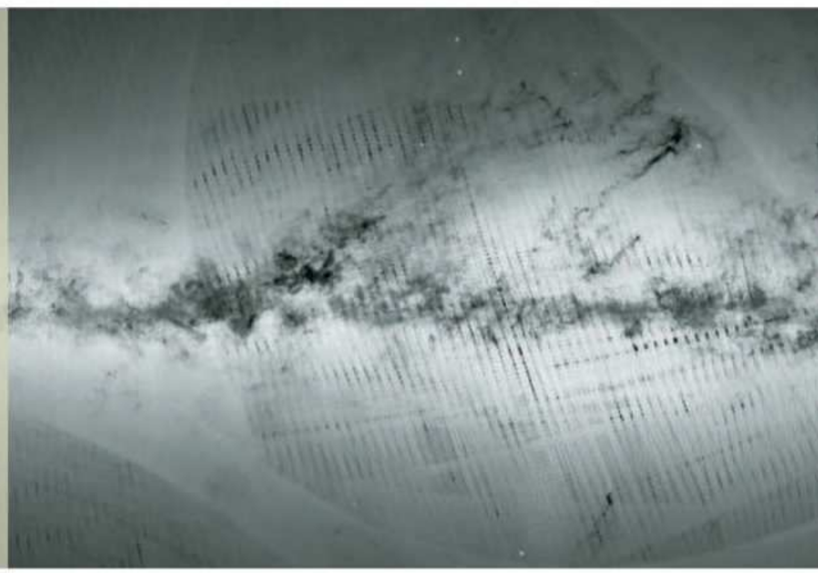
Census studies of galaxies begun in the 1970s point towards an additional flow of galaxy clusters through the

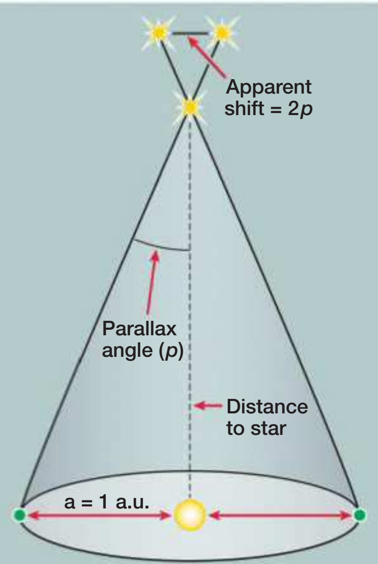
Gaia: The biggest map of all

The European Space Agency launched the Gaia astrometry spacecraft on December 18, 2013; the spacecraft became operational in July 2014. The Gaia mission's objective is to measure the positions of about 1 billion stars (that's about 1 percent of our galaxy's stellar population), both in our galaxy and other members of the Local Group, with an accuracy down to 24 microarcseconds. Astronomers have been performing spectral and photometric measurements of all the objects documented by the spacecraft and using them to derive the space velocities of the Milky Way's stars. The enormous dataset will help Gaia scientists build a three-dimensional structural map of our galaxy.

ESA released the map shown here in September 2016. It shows an all-sky view of the Milky Way and neighbouring galaxies based on Gaia's first year of observations (July 2014 to September 2015). Brighter regions indicate a denser concentration of stars. The dark regions across the galactic plane correspond to light-obscuring clouds of interstellar gas and dust.

ESA / GAIA / DPAC





Expanding at speed

FROM HERE TO THERE Using a method called *parallax*, astronomers can measure the distance to a nearby star using trigonometry. First, they measure the position of the star in relation to more distant background stars. When Earth is at the opposite point in its orbit around the Sun (six months later), they again measure the stars' positions. If the target star is close enough to us, its position will have shifted just a bit — less than an arcsecond — against the background stars. (There are 60 arcminutes per degree and 60 arcseconds per arcminute, so one arcsecond = 1/3600 of one degree.)

universe due to gravity. We're part of this flow. As it turns out, galaxies are like drops of water trickling through streams in a vast cosmic watershed. Besides revealing the existence of Laniakea, our local river in this watershed, this work (again using shifts in spectral lines) showed that the Local Group is moving toward two cluster structures called the Great Attractor and the Shapley Supercluster; the latter is some 650 million light-years away.

Where are these superclusters located in the sky? As bad luck would have it, both lie right along the disk plane of the Milky Way, in the direction of the southern constellation Norma. This poses an observational problem similar to the one encountered by earlier astronomers when they attempted to model the structure of the galaxy, the classic 'you can't see the forest (of galaxies) for the trees'. In this case, the trees are stars and dusty gas in the plane of our own galaxy, blocking our earthbound view of the many galaxies beyond.

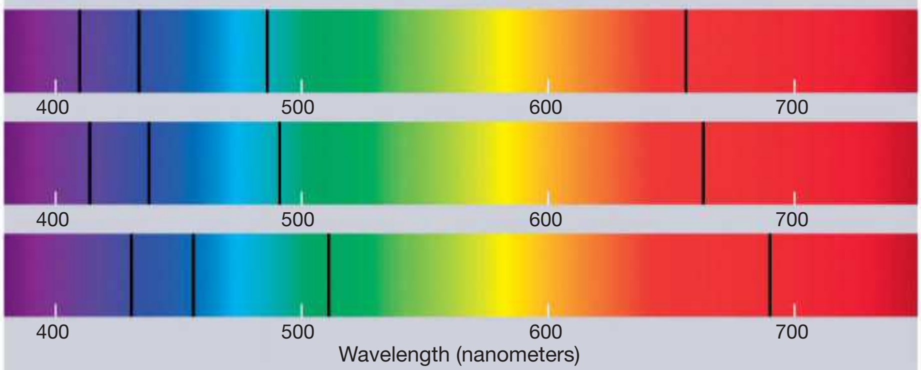
Avoiding our home galaxy

The Milky Way's band on the sky is sometimes called *the zone of avoidance*, because galaxies and ancient star clusters seem to avoid that region on the sky. Today we know that's not because the objects aren't there but because our galaxy's disk blocks our view of anything that's beyond it. But though opaque in optical light, the plane of the Milky Way is largely transparent at radio wavelengths. Because of this, projects such as the Parkes HI Zone of Avoidance (HIZOA) survey observe at the classic 21-cm radio wavelength for neutral hydrogen (the 'HI' in 'HIZOA'), looking through the dust and gas along the plane of the Milky Way to find 'missing' objects beyond.

HIZOA and other surveys have turned up 957 galaxies, mapping out the suburbs of the Norma Supercluster, a massive collection of galaxy clusters that forms a 'wall' 250 million light-years across, covering about 50° of sky. But beyond even this, the local cosmic watershed seems to be moving towards the massive Shapley Supercluster. Future surveys will peer through the veil and tell us more about where we're headed. Maybe future discoveries will add to our star party repertoire of how we know what we know about our place and motion through the cosmos.

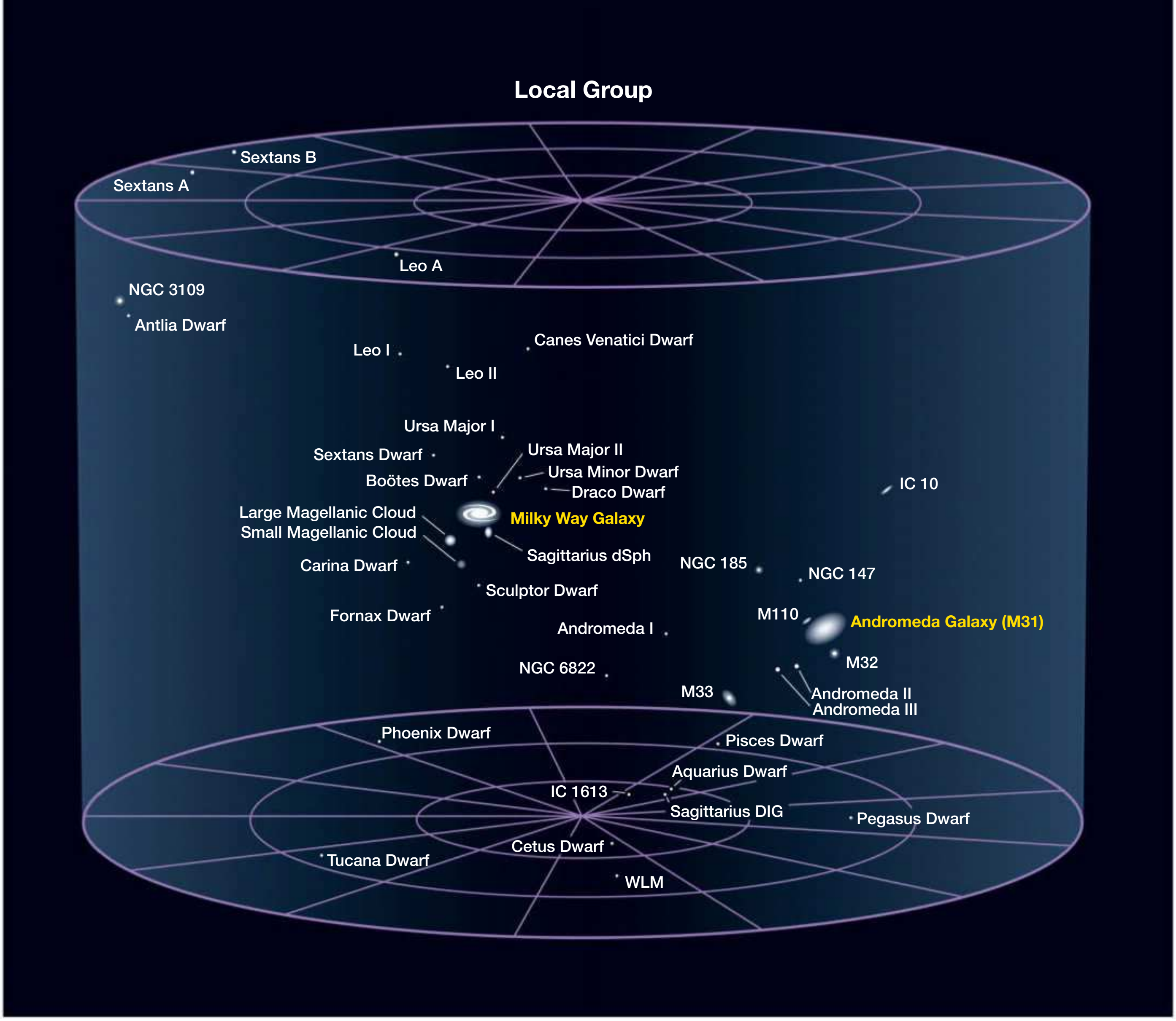
To infinity, and beyond

The redshift of galaxies' spectra already tells us something else important about the universe: On the largest scales, everything is rushing away from everything else. An observer at any given point in the universe sees all other points receding away from them, and this recession speed gets greater the



The spectra of galaxies show that everything is speeding away from everything else at the largest scale of the universe. In these example spectra, the dark absorption lines show where light has been absorbed by hydrogen (the absorbing hydrogen could belong to the outer layers of the star producing the light or to interstellar clouds of gas and dust). If a light-producing body is moving away from us, the absorption lines shift toward the red end of the spectrum. If the body is approaching, the lines shift toward the blue end. The top example shows the hydrogen absorption lines for a body at rest. The middle spectrum shows a radiating body moving away from us at 3,000 km/s. The bottom spectrum shows the same body moving away from us at 30,000 km/s.

LEAH TISCIONE / *SKYWATCH*



HOW TO FIND US The Milky Way and the Andromeda Galaxy dominate the Local Group, shown here with its brightest members. At least 54 galaxies belong to the Local Group, which stretches across 10 million light-years. Our galaxy and Andromeda, both of which are large enough to sport their own satellite galaxies, combine to contain the large majority of the Local Group's total stellar mass. The Local Group is part of the larger Virgo Supercluster, which in turn is a small part of the Laniakea Supercluster that spans some 510 million light-years and includes some 100,000 galaxies.

farther away objects are.

Think of a balloon with points drawn on its surface. All the points expand away from each other as the balloon inflates. Likewise, the universe itself — the very fabric of space — is expanding. As the universe expands, the galaxies (the points on the 'surface' of the expanding space) all move away from one another. There's no true 'centre' for the universe, just as there's no stationary point on the surface of the balloon.

How big is the universe? Based on the history of its expansion and its age, we think the observable universe is 93 billion light-years across, or 6,000 trillion times the distance between the Sun and Earth. But our observations of the residual radiation from the Big Bang indicate that the universe is only 13.8 billion years old. So, how can we see parts of the cosmos whose light should take longer to reach us than the actual age of the universe?

Well, although Einstein decreed that nothing in the universe can travel faster than the speed of light, this prohibition actually only applies to objects within the universe, not the universe itself. Based on the incredible homogeneity and uniform pattern of cosmic structure, astronomers think that the fabric of space itself exceeded that limit during a brief moment right after the Big Bang, called inflation.

Try explaining that one at a late-night star party.

■ DAVID DICKINSON is a freelance science writer, high-school science teacher, science fiction author, retired enlisted air force veteran, and avid stargazer. He shares the universe and more on his website astroguyz.com and @astroguyz on Twitter.

The FIRST Galaxies

Astronomers are travelling backwards in time to observe our universe's early history.

There's a certain exhilaration in hunting for the most distant galaxies in the universe. It's that feeling of pushing back the boundaries. Seeing a bit farther than anyone before you.

But I bet if you ask most astrophysicists who study the formation and evolution of galaxies, it's not the distance in space that excites them, but the distance in time. Electromagnetic radiation travels at a finite speed, and the light emitted by distant galaxies can take billions of years — large fractions of the age of the universe — to reach us. We see those distant galaxies as they were in the past, at the moment the light left them. Our ultimate goal is to detect the light emitted by the first galaxies: the cosmic dawn.

Remarkably, we're getting close. Any long-exposure image will reveal a universe teeming with galaxies; current estimates put the total number of galaxies around the trillion mark. As the sensitivity of CCD cameras improves and the size of telescopes increases, it has become routine for deep astronomical surveys to detect galaxies seen at a time when the universe was a small fraction of its current age.

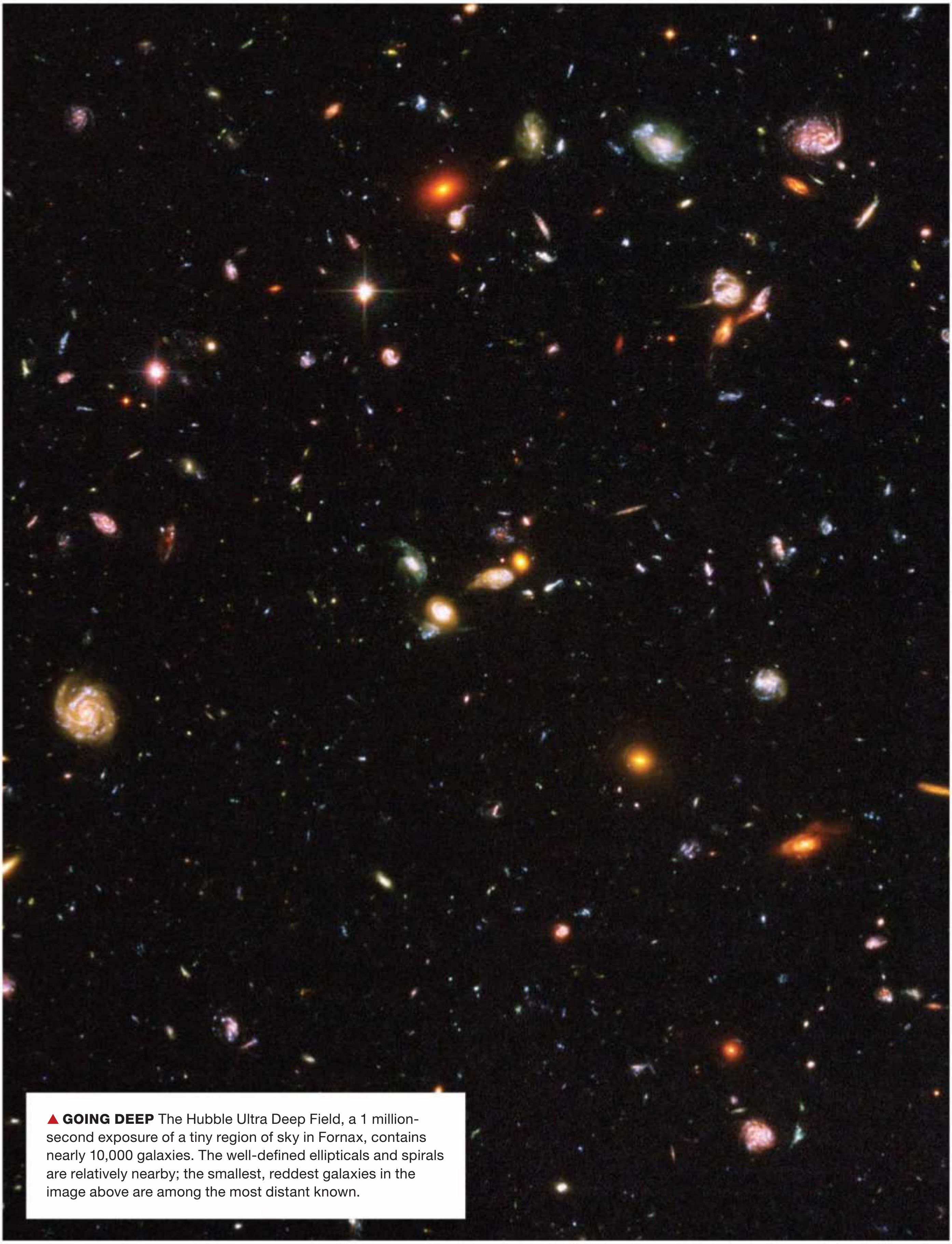
These infant galaxies are much too far away for light-years to be a useful measure. Rather, we use the galaxies' *cosmological redshift* as a proxy for their distance.

The universe — space itself — has been expanding ever since it came into existence in the Big Bang. The wavelength of an electromagnetic wave travelling through the expanding universe will stretch so that blue light emitted by a distant galaxy will have become red light by the time we detect it. The amount the wavelength has stretched tells us how much the universe has expanded since the photon began its journey. If we know the history of the expansion (since space hasn't grown at a steady rate), then we can use redshift to say something about how far away that galaxy is and how far back in time we are seeing it.

Although we have observed galaxy formation over most of the history of the universe, we still don't know how galaxies first formed. We have models and simulations, but not the observations to test them. This is why we need to see the earliest galaxies. In fact, what we'd really like to know is when we *stop* seeing galaxies.

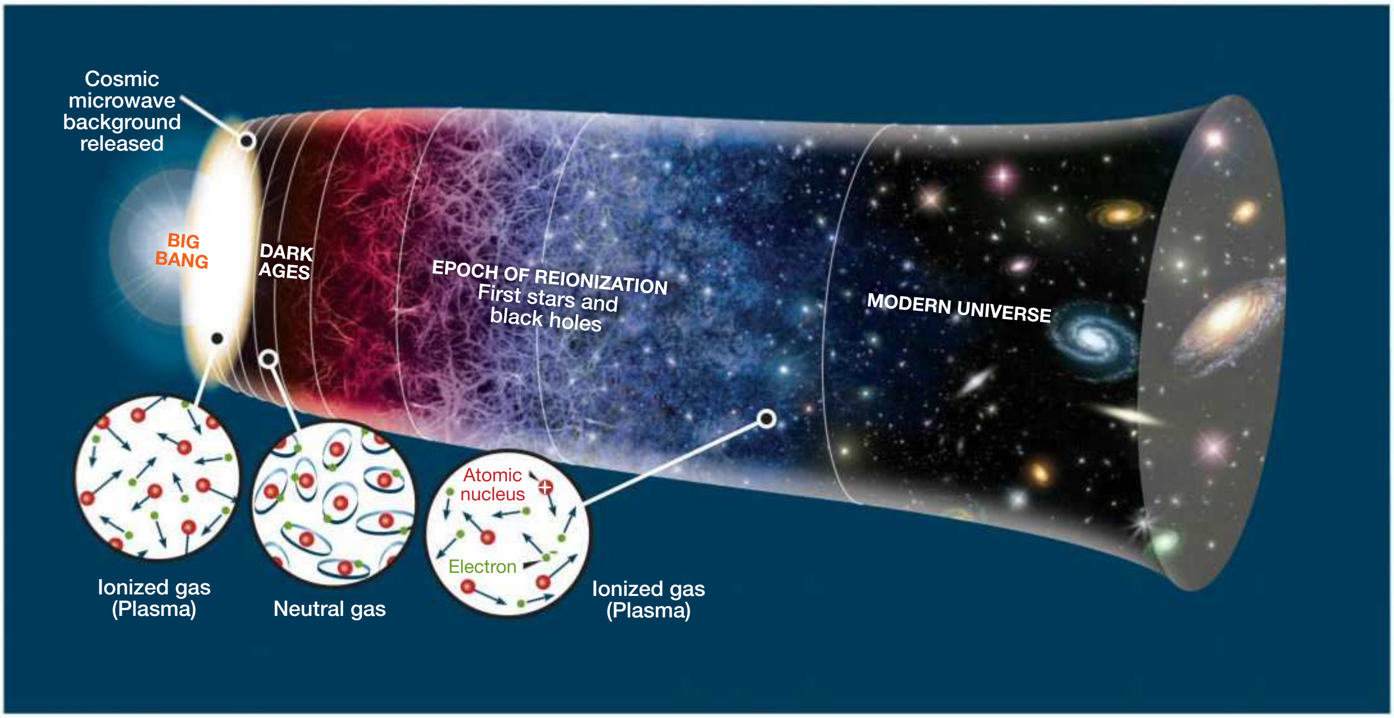
Cosmic dropouts

Measuring the redshift of very distant galaxies isn't easy. They're faint, and typically we need to disperse the small amount of light we do detect into a spectrum, thinning it out like butter spread over hot toast, in order to see how much light we receive at each wavelength. The spectrum allows us to identify key features, such as the spike-like emission lines of excited hydrogen gas, to determine precisely how much those lines have redshifted.



▲ **GOING DEEP** The Hubble Ultra Deep Field, a 1 million-second exposure of a tiny region of sky in Fornax, contains nearly 10,000 galaxies. The well-defined ellipticals and spirals are relatively nearby; the smallest, reddest galaxies in the image above are among the most distant known.

ULTRA DEEP FIELD: NASA / ESA / S. BECKWITH (STSCI) / HUDF TEAM



▲ **HISTORY OF THE UNIVERSE** The period after the Big Bang, when charged particles trapped photons, gave way to the the Epoch of Recombination, when particles combined into atoms and released the photons we now know as the cosmic microwave background. Soon after that, in the Epoch of Reionisation, higher-energy emissions from the first stars began once again stripping electrons off hydrogen atoms.

LEAH TISCIONE / S&T

If we want to hunt for the first galaxies, we need a lot of light-collecting area — that is, a big telescope — and a sensitive spectrograph. Still, there are far too many galaxies to measure the spectrum of each one. Technological advances are helping to solve that problem), but astronomers still commonly save time by narrowing down the search, preselecting those few galaxies in an image of thousands that are likely to be the most distant ones.

In the 1990s astronomers developed a deceptively simple and economic method to do just that, identifying galaxies at very high redshift using images alone. The trick works because galaxies, and the wider intergalactic medium, contain a lot of neutral hydrogen gas. This gas is very efficient at absorbing photons with wavelengths below 91.2 nanometres. This means that the spectrum of a typical galaxy in the distant universe has a pronounced dip, or 'break,' at that wavelength. At wavelengths below this so-called *Lyman break*, neutral hydrogen gas, either in the galaxy itself or in the intervening medium, absorbs most of the photons.

In practice this means that we can use a filter that only lets through wavelengths of light *below* the Lyman break and compare it to an image of the same patch of sky filtered to only allow wavelengths *above* the Lyman break. Some galaxies appear to 'drop out' of the shorter-wavelength filter — they are simply too faint to detect in the bluest band.

Now, the clever bit is when cosmological redshift comes into the picture. In more distant sources, the observed position of the Lyman break redshifts to longer wavelengths. That means that a more distant galaxy will disappear at a longer wavelength than a closer galaxy will. So, as we try to chase the galaxies to higher and higher redshifts, we can turn to different combinations of filters. The filter in which a galaxy vanishes from view gives a pretty strong clue as to the galaxy's *photometric redshift*, even without a spectrum; spectroscopy can later provide unambiguous confirmation.

But this method for determining redshift, now more generally referred to as the *dropout technique*, has a catch: Distant sources of light are also faint. So, although the technique is efficient, astronomers still need an exceptionally sensitive instrument and very deep observations to find the earliest galaxies. Without question, the instrument that has allowed us to best exploit the dropout technique — and given us the clearest glimpse of the earliest galaxies — is the Hubble Space Telescope. Hubble's Deep Fields are tiny 'windows' onto the distant universe, keyholes that the telescope has spent millions of seconds staring through to reveal thousands of galaxies in small patches of sky no larger than 1% of the angular area of the full Moon. Some of those galaxies appear merely as clumps of a few pixels, nearly lost amid the noise. Nevertheless, those pixels represent light from some of the earliest galaxies we know about, and they have allowed us to start piecing together the picture of galaxy formation within half a billion years of the Big Bang.

Cosmological Redshift

Redshift compares the observed wavelength of light with its wavelength when it was emitted. Hydrogen, for example, can emit light at 121.6 nm, but in a faraway galaxy we observe that line at redder wavelengths due to *Doppler shift*.

By comparing the two wavelengths — emitted and observed — *cosmological redshift* tells us the size of the universe today relative to the size of the universe then.

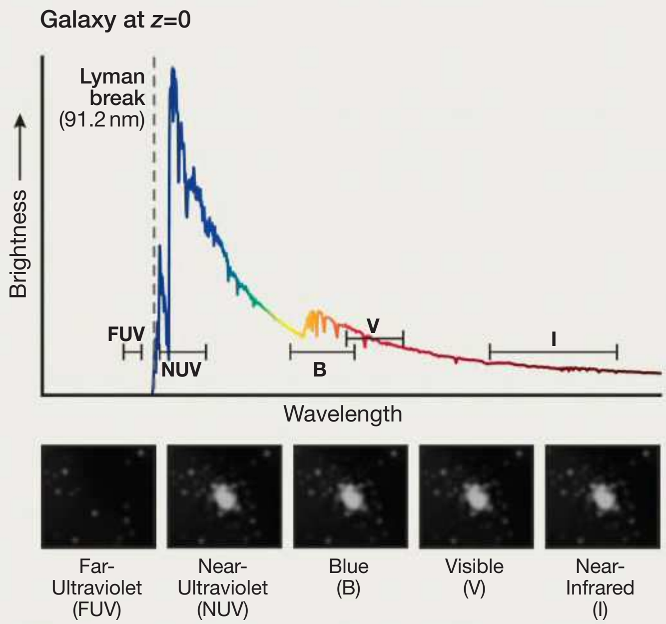
Here's the equation that describes this:

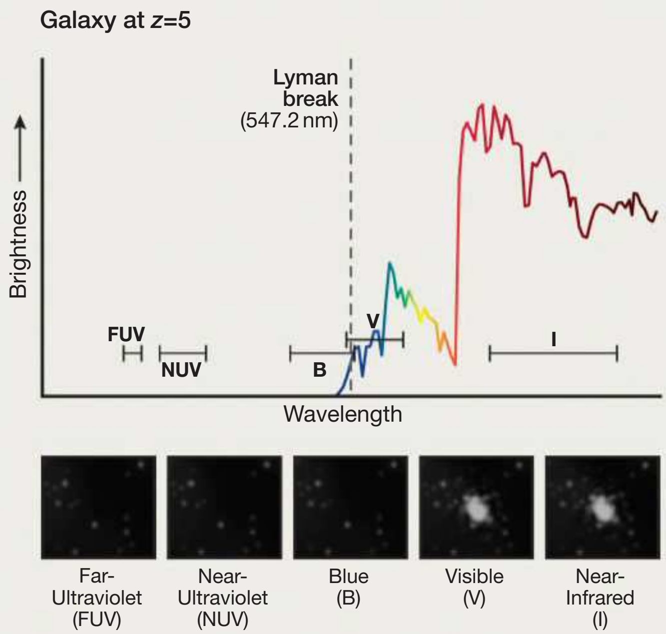
$$z = \frac{\lambda_{observed}}{\lambda_{emitted}} - 1$$

where λ is the wavelength.

Galaxies very near the Milky Way have a redshift of nearly 0, which means that the wavelengths we observe are about the same as those originally emitted. (Gravitational attraction also drives relative motions between galaxies, but any resulting shifts in wavelength are unrelated to the universe's expansion and hence to the galaxies' distances.)

The wavelengths of light from a galaxy with a redshift of 1 (that is, emitted in a universe roughly half its current age) will double by the time they reach us. A galaxy in the early universe, at a redshift of 10, will have had its light stretched by a factor of 11, pushing ultraviolet wavelengths to much longer (redder) wavelengths, near the infrared part of the spectrum.





COSMIC DROPOUTS Splitting light from a typical galaxy into its component colours results in a spectrum like the one shown at top, spanning far-ultraviolet to near-infrared wavelengths. Neutral hydrogen gas absorbs light emitted below the so-called Lyman break at 91.2 nanometres. Thanks to the break, examining the light at different filters reveals the distance to faint, faraway galaxies without actually having to measure their spectra. Because the expansion of the universe stretches the wavelengths of light travelling through it, the wavelength at which the Lyman break is observed shifts redward, so that the galaxy becomes unobservable at shorter wavelengths.

RED SHIFT: LEAH TISCIONE / S&T / J. GEACH; RED GRADIENT: HARDIK PETHANI / GETTY IMAGES

Cosmic dawn

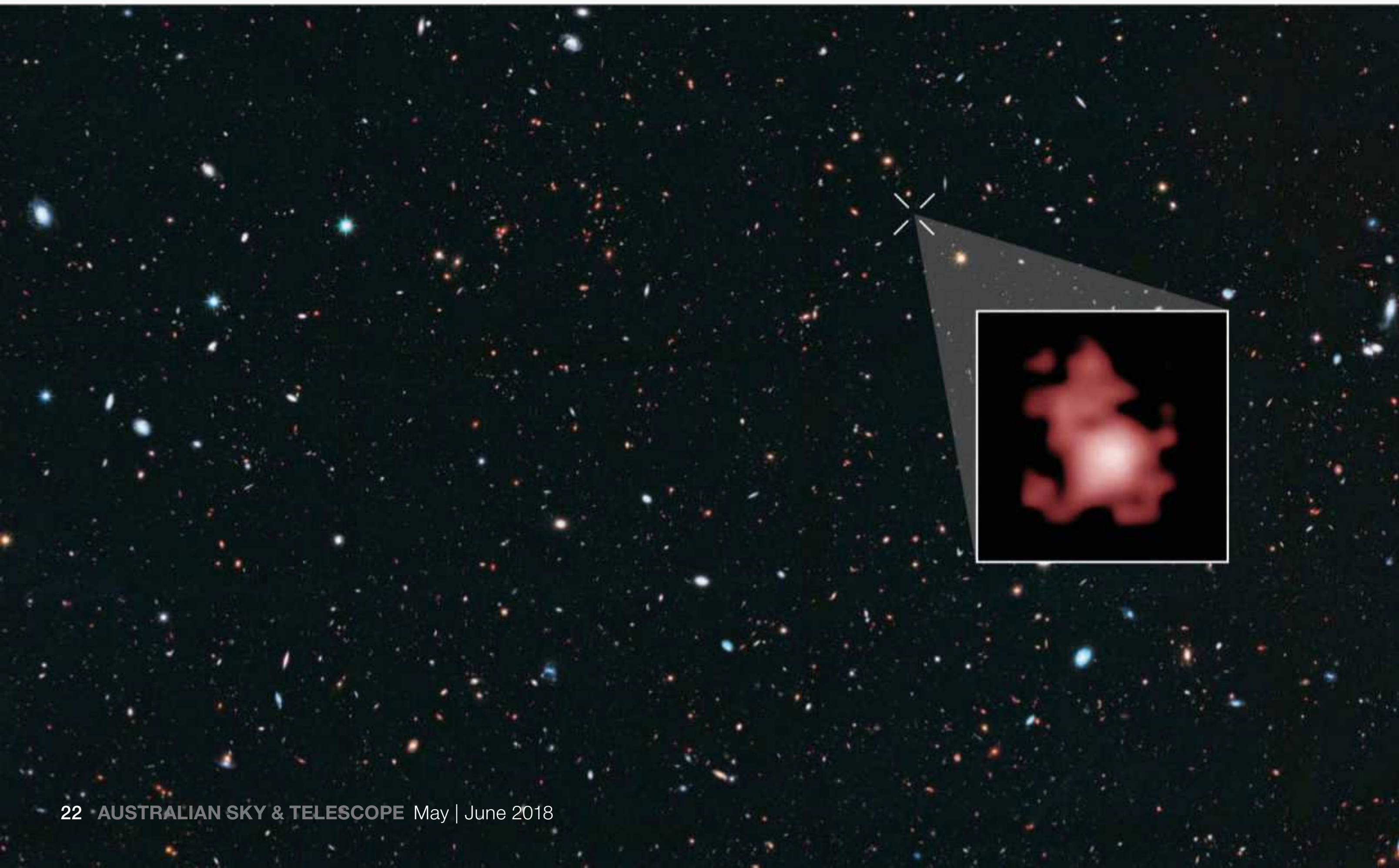
Besides the obvious prize of discovering the most distant object, why do we really care about finding the first galaxies? Because they are the missing piece of our picture of galaxy formation. We don't know how or exactly when the first galaxies ignited, or what their properties were, and that's frustrating. To rectify the situation, we must explore the earliest frontier of galaxy formation.

For the first few hundred thousand years of cosmic history, there were no atoms in the universe, just a hot broth of particles and photons. But about 370,000 years after the Big Bang, in what is known as the *Epoch of Recombination*, the universe cooled sufficiently for free electrons to bind to protons, transitioning the cosmos from a totally ionised phase to one that was electrically neutral. At this point most of the normal matter in the universe was in the form of neutral hydrogen atoms.

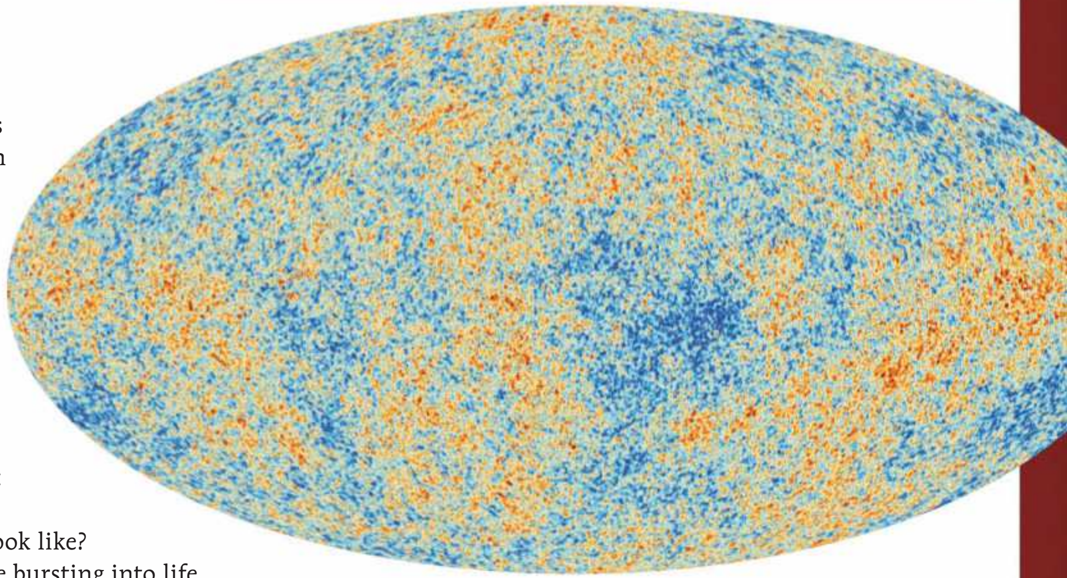
This vast medium wasn't smooth. Gravity had teased the subtle density fluctuations present at the start of the universe into thicker filaments and clumps, where dark matter and gas had gradually pooled and coagulated to form the seeds of the first galaxies.

At some point, a few hundred million years after the Epoch of Recombination, the first stars in these proto-galaxies flashed into life and streamed ionising starlight into

What did these reionising galaxies look like? Observations show that when they were bursting into life, the majority of these galaxies were small, just a few hundred light-years across. These young galaxies also had quite low masses, perhaps less than 1% of the Milky Way's mass.



the universe around them. Some of this radiation was energetic enough to again start stripping electrons from the hydrogen atoms in the surrounding intergalactic medium. As galaxy formation took hold, bubbles of ionised gas grew around new galaxies, spreading outward like some sort of disease. After another 500 million years or so, a time period known as the *Epoch of Reionisation*, the universe's neutral hydrogen was almost totally turned into plasma.



▲ **EPOCH OF RECOMBINATION** As the universe cooled enough to allow electrons and positively charged nuclei to come together into neutral atoms, the space between stars was freed of the ionised plasma that trapped light. Photons escaped, free to roam the universe as what is known as the cosmic microwave background. The Planck telescope's view of this radiation shows us the universe at 370,000 years of age.

What did these reionising galaxies look like? Observations show that when they were bursting into life, the majority of these galaxies were small, just a few hundred light-years across — comparable to the size of individual star-forming regions in the Milky Way and its companions, such as 30 Doradus. These young galaxies also had quite low masses, perhaps less than 1% of the Milky Way's mass. Simply not enough time had yet passed for large numbers of stars to form out of the gas reservoirs, or for lots of galaxy mergers to take place. Nevertheless, observations of dropout galaxies show that the average rate of star formation ramped up quickly in these small, low-mass galaxies, starting half a billion years after the Big Bang, if not earlier.

We also have some evidence that galaxies were settling into rotating disks at quite early times. But rather than sedately spinning, Milky Way–like pinwheels, which became prevalent more than a billion years later, early disk galaxies were probably quite clumpy and turbulent.

One of the most important differences between very high-redshift galaxies and those we see in today's universe is in the chemistry of their interstellar medium. Our Sun formed from a gas cloud composed mostly of hydrogen and a bit of helium but 'polluted' with heavier elements, known to astronomers as *metals*, that formed in previous generations of stars. Without metal enrichment of the interstellar medium, neither our planet nor the people on it could have formed. But these metals take time to build up: They are made inside stars during nuclear fusion, in supernova explosions, and in other extreme cosmic events. So we expect the first galaxies to be 'metal poor' compared to the Milky Way.

A lack of metals would mean that these galaxies should also contain relatively small amounts of interstellar dust, which tends to absorb starlight. The ionising radiation from massive stars would escape the galaxies more easily, making the reionisation process quite efficient.

◀ **FARTHEST GALAXY** In 2016 Hubble revealed the infant galaxy GN-z11, a galaxy that existed just 400 million years after the Big Bang and is the most distant galaxy known to date. The background image shows the GOODS-N project, which combines images of a small square of sky in Ursa Major from the Hubble, Spitzer and Chandra space telescopes, along with data from ground-based telescopes.

FARTHEST GALAXY: NASA, ESA, AND G. BACON (STSCI); PLANCK MAP: ESA / PLANCK COLLABORATION

Moreover, the stars that formed from the metal-poor gas would be metal-poor themselves. Metals absorb ultraviolet photons, which is one reason why metal-poor stars tend to emit lots more of this high-energy light compared to stars today. Observations of some of the earliest star-forming galaxies reveal gas containing oxygen and carbon atoms that are missing more than one electron. Ultraviolet light must have stripped these electrons, which means that much of the starlight escaping from early galaxies was in the form of high-energy photons. These observations again point to an efficient reionisation process and a quick cosmic dawn.

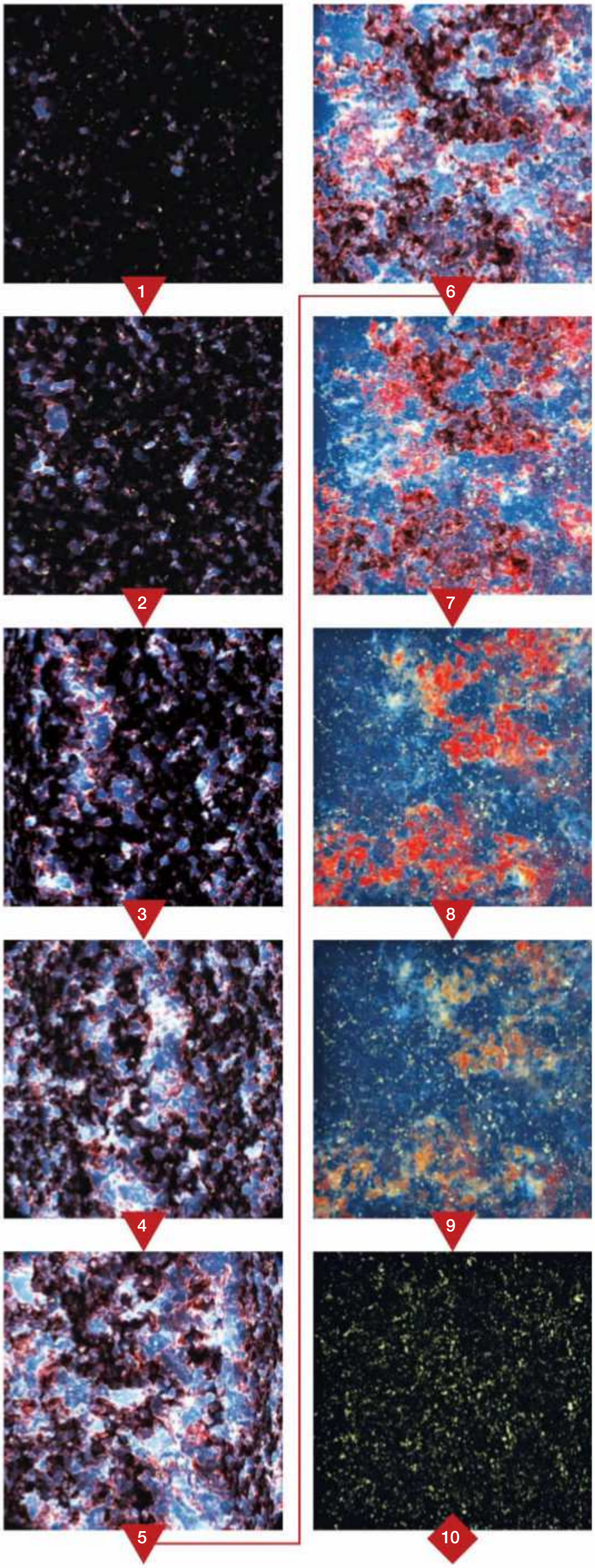
Pulling back the veil

Hubble's observations have taken us far, but astronomers are gearing up for two new telescopes that will help us see back even further in time. One is the James Webb Space Telescope (JWST), due to be launched in 2019.

"We have squeezed out every last drop of what the Hubble Space Telescope has to offer," explains Renske Smit (University of Cambridge, UK), a hunter of distant galaxies. "But the fact is, Hubble is limited in how far it can look back in time due to the wavelength range that it can see. The light from the very first stars is redshifted too far into the infrared, out of Hubble's view."

"JWST's uniquely designed infrared capabilities will allow us to look back beyond where Hubble has seen," Smit says.

On the ground, we can look forward to the next generation of 30- to 40-metre megatelescopes. One of these — the European Extremely Large Telescope (ELT) — is now being built some 3,000 metres up in the Atacama Desert in Chile. The ELT's huge segmented primary mirror will provide



◀**SLICES OF REIONISATION** The first galaxies and their stars lit up the early universe, kicking electrons away from hydrogen nuclei in what is known as the Epoch of Reionisation, between 400 million and 900 million years after the Big Bang. What was once a neutral medium between the stars gave way once more to ionised plasma. (The universe remains ionised today, but its lower density enables photons to still travel freely.) These slices come from a Swiss cheese-like simulation of the process.

the collecting area that will enable astronomers to detect starlight and ionised gas in galaxies at cosmic dawn.

JWST and ELT will provide an important next step, but there is a facility online that is already revolutionising our view of the early universe: the Atacama Large Millimeter/submillimeter Array (ALMA). Sited two kilometres higher than ELT, on the Chajnantor Plateau in the Atacama Desert, ALMA is a collection of 66 radio dishes that act as one telescope to deliver unprecedented sensitivity and exquisite resolution at wavelengths between about 300 microns and nearly 4 millimetres. ALMA can detect the thermal glow of interstellar dust heated by starlight, as well as emission from cooler gas clouds, even in the most distant galaxies.

One of ALMA's breakthroughs has been to show that the first generation of stars quickly enriched the universe with heavy elements, a development that surprised some astronomers. ALMA has detected light emitted by ionised oxygen and interstellar dust granules in galaxies as far back as a redshift of 8.4, just 600 million years after the Big Bang. These elements can only have been produced in and dispersed by stars, yet this was a time when reionisation was still in progress — the lights hadn't all been turned on yet. ALMA has also observed the telltale glow of a unusually massive amount of starlight-heated dust — 2.5 billion Suns' worth — in a galaxy at redshift 7, just 200 million years later.

How heavy-element enrichment happened so quickly is one of the key questions for studies of the first galaxies. The answer underpins much of our understanding of the subsequent 13 billion years of galaxy evolution.

Forget starlight

There's a new way of studying the Epoch of Reionisation that's exciting astronomers. Instead of looking at the galaxies, we're trying to detect the signature of the first stars' ignition in the stuff between the stars: the intergalactic medium.

A gas of neutral atomic hydrogen will emit radio waves due to a quantum effect called *hyperfine splitting*. According to the laws of quantum mechanics, the electron and proton in a hydrogen atom can either have the same spins or opposing ones. Atoms with electrons in aligned spins will occupy a state with marginally higher energy than atoms in the opposite, anti-aligned state. Occasionally, an electron's spin can flip, and the atom will release the energy as a photon. Because the energy transition is so small, the photon has a very low energy: We detect it at a frequency of 1.4 gigahertz, corresponding to a wavelength of 21 centimetres.

REIONISATION: M. ALVAREZ (HTTP://WWW.CITA.UTORONTO.CA/~MALVAREZ), R. KAEHLER & T. ABEL; RED GRADIENT: HARDIK PETHANI / GETTY IMAGES

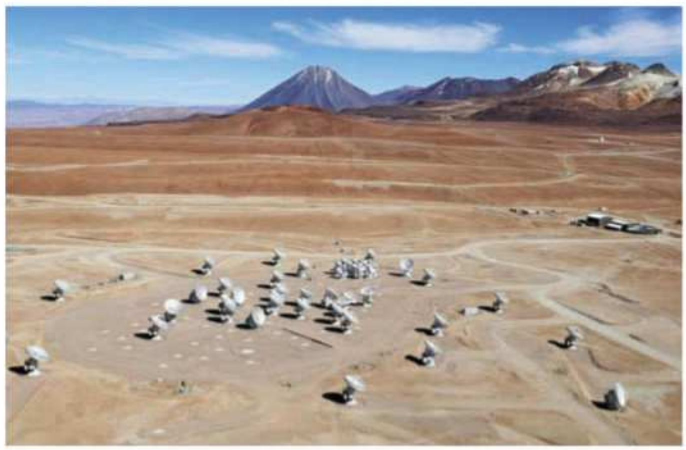
OBSERVING EXTREMES This visualisation shows the European Extremely Large Telescope, currently being built in the Atacama Desert in Chile. Its segmented primary mirror will span 39 metres, making the ELT the largest visible/infrared telescope on Earth. Its large collecting area will enable it to image aspects of galaxies at cosmic dawn.

The gas surrounding galaxies at cosmic dawn is essentially a huge sea of neutral atomic hydrogen, so it releases these radio waves. But like all distant sources of light, the 1.4 GHz signal is redshifted by cosmic expansion. By the time the radio waves reach us, they are at much lower frequencies, around 100 MHz or so for gas at the Epoch of Reionisation. The signal is also extremely faint, drowned out by radio emission from sources both within our own Milky Way (such as the Crab Nebula) and in other galaxies. The combination of low radio frequency and weak signal has made detecting neutral hydrogen in the early universe challenging with previous generations of radio telescopes.

But experiments are now under way to record this primordial radio signal and use it to map out reionisation. Telescopes such as the Low-Frequency Array (LOFAR), a network of radio receivers spread across Europe, and the new Canadian Hydrogen Intensity Mapping Experiment (CHIME) in British Columbia, are not only trying to detect the radio signal from distant neutral hydrogen, but they're also measuring its fluctuations in brightness, which tell us how reionisation actually happened.

As the first galaxies radiate out bubbles of ionised hydrogen, the radio signal from neutral hydrogen should weaken and ultimately vanish. The various sizes and distribution of these bubbles will imprint themselves on the radio signal, enabling us to compare different scenarios for how reionisation might have proceeded — without having to detect starlight at all.

It's been less than 100 years since we realised there were galaxies outside the Milky Way. The century after that discovery has seen a journey backward in time as we attempt to understand the origin of galaxies, including our own. Technological advances have allowed us to read this story in the increasingly faint and long-wavelength light coming from the edge of the observable universe. The search for the first galaxies and the Epoch of Reionisation is the final (or is it the first?) chapter of that story. What will the next century bring? Well, we've only skimmed the book; now, it's time to appreciate it in detail.

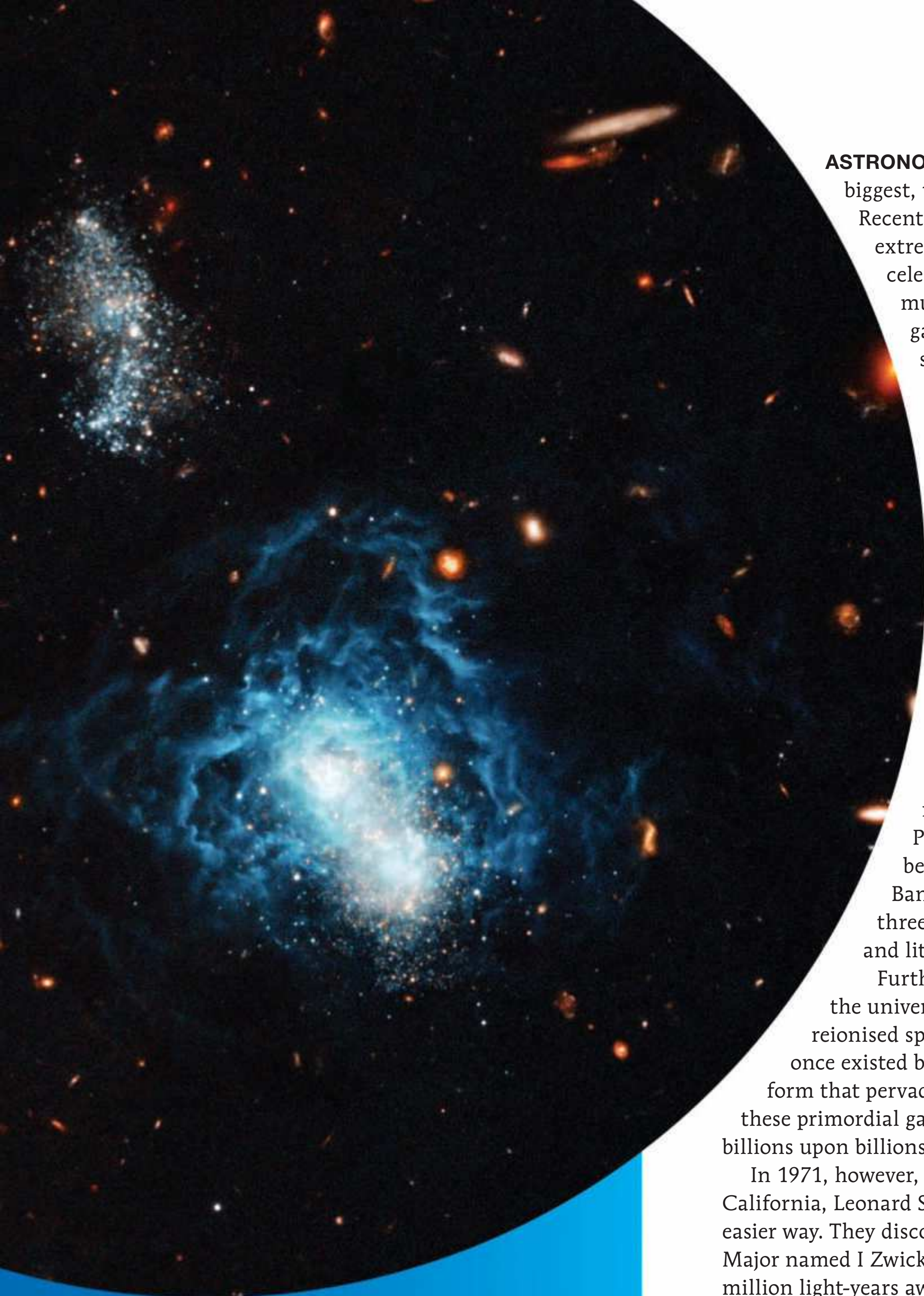


▲ **CAPTURING GALAXIES' SOULS** The Atacama Large Millimeter/submillimeter Array (ALMA) records ionised gas and dust in galaxies in a universe as young as 600 million years old. Its observations have revealed that the first galaxies' stars rapidly enriched the universe with 'metals'.

■ **JAMES GEACH** is an astronomer and Royal Society University Research Fellow at the University of Hertfordshire in the United Kingdom.

Star-making dwarf galaxies with just a trace of oxygen provide insight into the nature of the first galaxies, how they spawned their stars, and even the Big Bang itself.

The LITTLE Galaxies That Can



ASTRONOMERS OFTEN PURSUE EXTREMES: the biggest, the brightest, the farthest, the oldest. Recently observers have discovered the most extreme members of an already extreme celestial class that promises to teach us much about the cosmos: small blue galaxies that spawn new stars yet possess scarcely any oxygen.

A galaxy without oxygen is like a forest without fallen leaves. Massive stars create lots of oxygen during their bright but brief lives, then hurl the element into space when they explode. So it's no surprise that within a billion light-years of Earth, astronomers have spotted fewer than ten extremely oxygen-poor star-forming galaxies.

These galaxies have somehow survived for eons without acquiring much oxygen. Such oddballs are telling us some fundamental things about the early universe, because these galaxies resemble the first ones that ever arose. Primordial galaxies were also small, and because they formed soon after the Big Bang, they should have consisted of the three elements it created: hydrogen, helium and lithium — with little if any oxygen.

Furthermore, the first galaxies changed the universe. Radiation from their hottest stars reionised space, transforming the neutral gas that once existed between the galaxies into the ionised form that pervades space today. Alas, no one can see these primordial galaxies in detail yet, because they're billions upon billions of light-years distant.

In 1971, however, two British-born astronomers in California, Leonard Searle and Wallace Sargent, found an easier way. They discovered that a much closer galaxy in Ursa Major named I Zwicky 18 has almost no oxygen. A mere 60 million light-years away, the galaxy is a lot easier to study than its distant cousins. Indeed, we now have beautiful Hubble images that show it to be a splotchy blue dwarf galaxy brimming with gas and rambunctious young stars. Yet its abundance of 'metals' — elements heavier than hydrogen and helium — is just a few percent of the Sun's.

"We realised that these galaxies are very, very, very metal-deficient and hence probably the closest proxies to primordial galaxies," says Trinh Thuan (University of Virginia), who

▲**PRIMORDIAL PRETENDER** Despite hosting a collection of newly formed stars, the dwarf galaxy I Zwicky 18 (larger blue object) has an anaemic level of star-produced oxygen. It appears here with a companion called Component C (upper left), which might be a separate galaxy.

I ZWICKY 18: NASA / ESA / A. ALOISI (ESA / STSCI) has spent decades hunting for more in the hopes of finding a galaxy so extreme it has no oxygen at all. The search is worth it, because these curious systems also carry news from the very first minutes of the universe's life.

Fresh air

Oxygen is an excellent element to study in star-forming galaxies. Of all the 'metals' in the universe, oxygen is the most abundant. Oxygen is also the second most common element in Earth's air (after nitrogen) and its interior (after iron). In most stars, however, oxygen produces few spectral lines, making its abundance difficult to gauge. But when hot stars ionise interstellar gas, oxygen atoms in the gas glow at visible and near-ultraviolet wavelengths that astronomers can detect. Comparing the strengths of these emission lines with those of hydrogen reveals oxygen's abundance relative to hydrogen, the most common element in the universe.

Astronomers often express abundances using a scale on which the hydrogen level is always 12. This scale is logarithmic, so 11 means an element is one-tenth as abundant as hydrogen, 10 means the element is one-hundredth as abundant as hydrogen, and so on. The Milky Way is far bigger and brighter than most other galaxies, and its many stars have blessed it with lots of oxygen — good news for those of us who like to breathe it. Surprisingly, the Sun's exact oxygen abundance is controversial, but it is probably around 8.76. If so, the Sun has 1 oxygen nucleus for every 1,740 hydrogen nuclei.

Because stars create oxygen, galaxies with fewer stars have lower oxygen levels. For example, the Milky Way's two brightest satellite galaxies — the Large and Small Magellanic Clouds — have oxygen abundances around 8.35 and 7.95, respectively, giving them levels that are 39% and 15% solar. I Zwicky 18, the long-time champ among oxygen-deprived star-making galaxies, has an oxygen level of only 7.17. That's just 2.6% of the solar value.

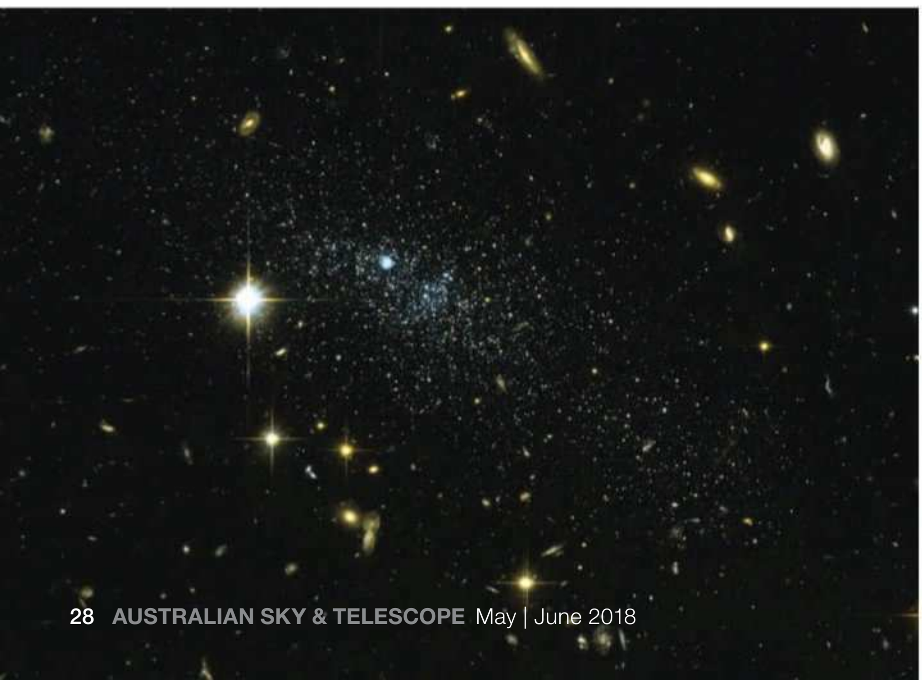
> In the Milky Way's disk, gas makes up 99% of interstellar matter and dust 1%. In I Zwicky 18, however, dust accounts for a mere 0.001% of interstellar matter.

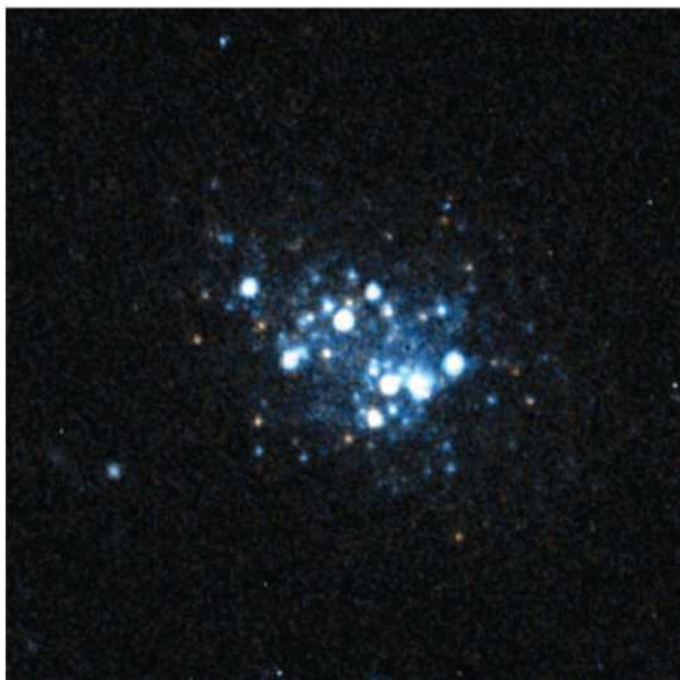
These galaxies have proved to be so rare that I Zwicky 18 remained the most oxygen-poor star-forming galaxy known for three decades. Eventually, however, it lost its crown to a blue galaxy three times farther away in Eridanus. The galaxy, named SBS 0335-052W, is part of a larger, oxygen-poor system and is creating new stars. In 2005, Yuri Izotov, Natalia Guseva (Main Astronomical Observatory, Kiev, Ukraine), and Thuan proclaimed this upstart galaxy the new champion. It has an oxygen level of 7.13.

Blue but not new

Astronomers once suspected that I Zwicky 18 might be a galactic infant, having formed all of its stars recently. Indeed, the galaxy derives its blue hue from bright, massive newborn stars, which wouldn't have had time to enrich their surroundings with oxygen.

Deeper observations, however, have revealed much older stars. Now astronomers think that the galaxy stands out





from the pack because nearly metal-free gas is falling onto it from beyond. This incoming gas diluted the galaxy's own, lowering the oxygen level and triggering the rash of starbirth that lights it up today. This idea also explains why the galaxy, though only somewhat less luminous than the Small Magellanic Cloud, has a sharply lower oxygen level.

In 2012, Riccardo Giovanelli (Cornell University) and colleagues used a new technique to find a new type of oxygen-poor star-forming galaxy: a dwarf in Leo much dimmer than I Zwicky 18 that likely owes its paucity of oxygen simply to a dearth of stars that create the element. The astronomers found the little galaxy's hydrogen gas before they saw its stars, picking up its 21-centimetre radiation with the Arecibo radio telescope. The galaxy has the same low level of oxygen as I Zwicky 18, so the astronomers christened the dwarf Leo P, the 'P' standing for 'pristine'.

Leo P is a mere 5 million light-years away. That puts it just beyond the edge of the Local Group, the collection of more than a hundred nearby galaxies — most of them dwarfs much dimmer than the Magellanic Clouds — which two giant galaxies, the Andromeda Galaxy and the Milky Way, govern. In fact, Leo P is the nearest oxygen-poor star-forming galaxy ever found. Emitting less than 1% as much light as I Zwicky 18, Leo P is also one of the least luminous galaxies ever seen engaged in starbirth; most galaxies this dim have run out of gas and lost their ability to make stars. Yet the little galaxy has certainly been around a long time, because Hubble has detected in it RR Lyrae stars, metal-poor pulsators that are more than 10 billion years old. The galaxy's secret? It has wisely avoided giants like our own Milky Way, which steal gas from smaller galaxies.

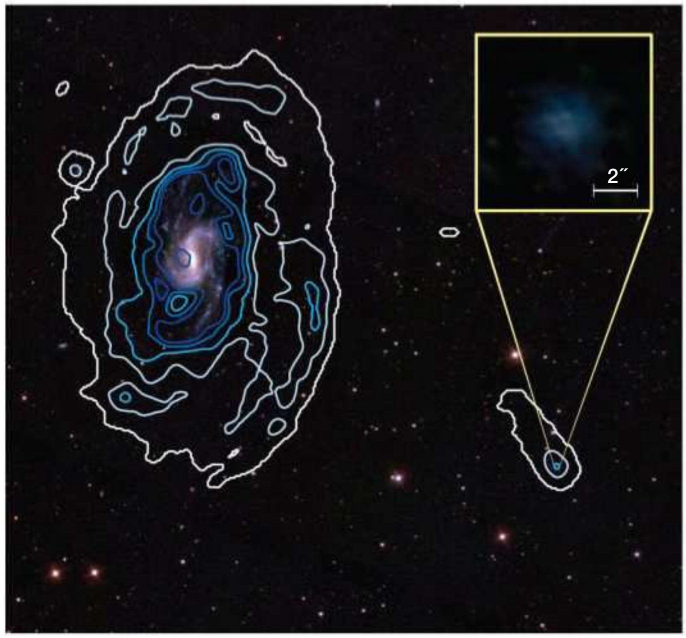
Leo P faces two challenges in trying to raise its oxygen level: It has few stars to forge the element and lacks the gravitational clout to hold on to it when they do. "It's tough being a little galaxy," says Kristen McQuinn (University of Texas, Austin). She estimates that Leo P has lost 95% of the oxygen that its stars created, because when they blew up, they shot the element away so fast the galaxy couldn't retain it.

In 2015, another galaxy first came to attention via its radio-emitting gas. When Alec Hirschauer, John Salzer (Indiana University), and colleagues examined an optical spectrum, they discovered the galaxy was a record-breaker. "It was obvious that it was very metal-poor," Salzer says. "My first reaction was: Well, we'd better be really sure of this." A second spectrum confirmed the first, yielding an oxygen level of only 7.02. Because this galaxy lies in Leo Minor, the Lesser

◀◀ **IS THAT A GALAXY?** In 2012, astronomers discovered the closest oxygen-poor star-forming galaxy, Leo P (the P is for 'pristine'). It lies just beyond the fringe of the Local Group of galaxies and has the same oxygen abundance as I Zwicky 18 but is much smaller and fainter.

◀ **LITTLE LION** The galaxy AGC 198691, nicknamed Leoncino, has an oxygen abundance of only 7.02 and abounds with gas. It's one of the most oxygen-poor star-forming galaxies known.

LEO P: NASA / ESA / KRISTEN MCQUINN (UNIV. OF TEXAS, AUSTIN); LEONCINO: NASA / A. HIRSCHAUER & J. SALZER (INDIANA UNIV.) / J. CANNON (MACALESTER COLLEGE) / K. MCQUINN (UNIV. OF TEXAS, AUSTIN); LITTLE CUB: IMAGE: SDSS COLLABORATION, CONTOURS: T. HSYU ET AL. / *ASTROPHYSICAL JOURNAL LETTERS* 2017



▲ **BARELY THERE** The Little Cub satellite galaxy (zoomed-in image inset) of NGC 3359 isn't much to look at in optical and infrared wavelengths. It has 100 times more gas than stars, though, and shows up in radio observations of neutral hydrogen (contours).

Lion, the discoverers dubbed the dwarf Leoncino, which is Italian for 'little lion'.

In 2016, Tiffany Hsyu (University of California, Santa Cruz) and her colleagues spotted a small blue galaxy in Ursa Major they named the Little Cub for its location in the constellation representing the Great Bear. This galaxy might orbit the beautiful barred spiral NGC 3359, and the interaction between the two galaxies might have sparked the birth of stars in the smaller galaxy. Its oxygen level is 7.13.

"These oxygen-poor galaxies give us a good idea of what star formation might have been like in the early universe, because the early universe was much more metal-poor than the universe we live in today," Hsyu says. The smallest star-forming galaxies, such as Leo P, lack oxygen for the same reason the first galaxies after the Big Bang did: They haven't made many stars. Even in larger dwarf galaxies like I Zwicky 18, where infalling gas has diluted native gas, star-forming conditions should mimic those in the primordial galaxies.

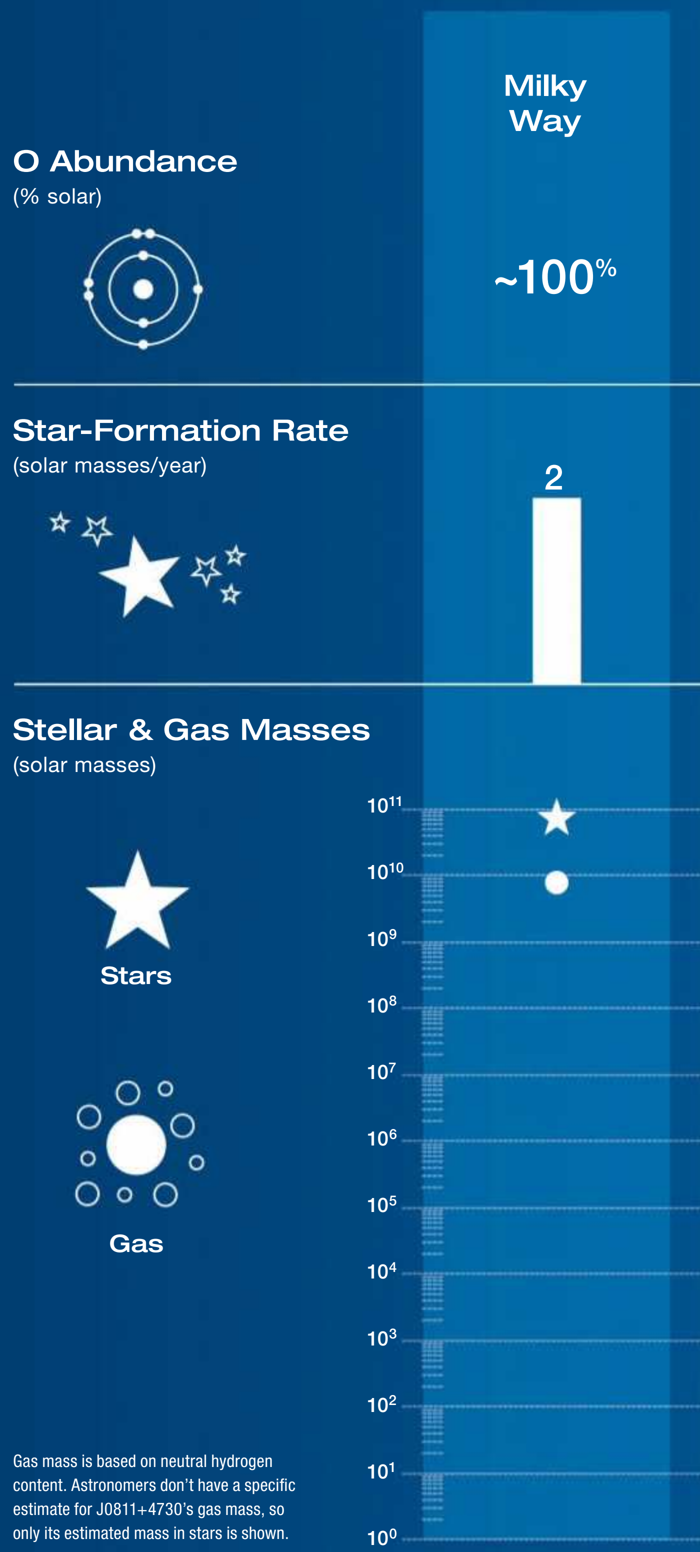
The galaxies certainly abound with the chief requirement for star formation: gas. In the Milky Way's disk and bulge, stars outweigh the gas, but in Leo P it's the other way around. In Leoncino, the gas is 50 times more massive than the stars, and the Little Cub has 100 times more gas than stars. These galaxies possess so little oxygen in part because they've converted so little of their gas to stars.

Despite all their gas, oxygen-poor galaxies have precious little of another ingredient important in the Milky Way's star formation: dust. That's not surprising, *(continued on page 32)*

▲ **STELLAR NURSERY** Massive stars make oxygen, littering their natal neighborhoods and stars born there. This false-colour Hubble image of the Carina Nebula shows oxygen in blue, hydrogen and nitrogen in green, and sulfur in red. Oxygen glows primarily where young stars have carved out the clouds.

CARINA: NASA / ESA / M. LIVIO / HUBBLE 20TH ANNIVERSARY TEAM (STSCI); BLUE BACKGROUND: HARDIK PETHANI / GETTY IMAGES

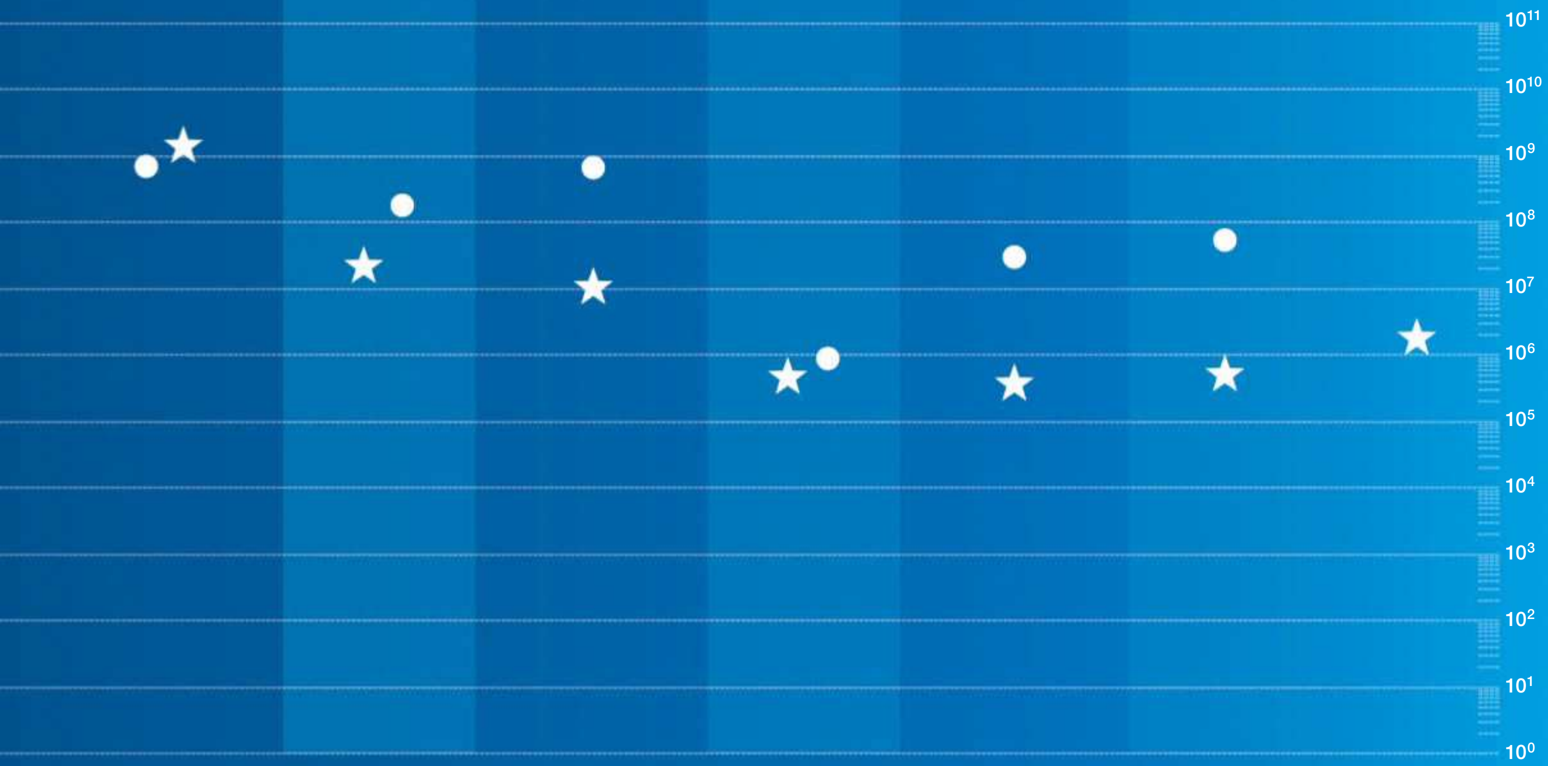
Galaxy scorecard



Gas mass is based on neutral hydrogen content. Astronomers don't have a specific estimate for J0811+4730's gas mass, so only its estimated mass in stars is shown.

Shown below are parameters for our home galaxy, one of its small neighbours (the Small Magellanic Cloud), and the oxygen-poor galaxies discussed in the article. Solar values serve as the benchmark for the oxygen abundances, and masses are approximate to within a factor of 10. Although the dwarfs churn out fewer stars per year than the Milky Way (second row), they also have a lot less mass to work with (bottom). The Milky Way's gas mass here includes the disk and bulge.

Small Magellanic Cloud	I Zwicky 18	SBS 0335-052W	Leo P	Leoncino	Little Cub	J0811+4730
15%	2.6%	2.3%	2.6%	1.8%	2.3%	1.7%
0.04	0.2	0.01	0.00004	0.001	0.0008	0.5



(continued from page 29) because dust grains consist mostly of carbon, oxygen, magnesium, silicon and iron, all of which are products of stars and are therefore scarce in these galaxies. In the Milky Way's disk, gas makes up 99% of interstellar matter and dust 1%. In I Zwicky 18, however, dust accounts for a mere 0.001% of interstellar matter.

When it exists, dust affects star formation. Dust grains darken star-forming clouds, shielding them from harsh radiation, and also promote star formation by emitting far-infrared radiation, which carries heat away from gas clouds. So do carbon and oxygen atoms. Cooler clouds have less thermal pressure, a force that counteracts gravity and can prevent a cloud from collapsing and becoming a star. Thus, with a shortage of dust and carbon and oxygen atoms to cool them, gas clouds in oxygen-poor galaxies may have to be more massive in order for gravity to take over and force collapse, giving rise to a greater proportion of massive stars. The same thing presumably happened in the universe's first galaxies.

Dust grains also serve as platforms on which atoms can meet one another and make molecules, such as molecular hydrogen, the most abundant molecule in the Milky Way's gas. Big clouds of molecular hydrogen fuel many of our galaxy's star-forming regions. No one has ever detected any molecular gas in a galaxy as oxygen-poor as I Zwicky 18.

What Is Dust?

Cosmic dust grains are small particles that range in size from about 10 to 100 nm. They're mostly silicate- or carbon-based and form in the atmospheres of aging red giant stars and in supernovae. Dust absorbs light with wavelengths similar to or smaller than its grain size, then re-emits it at infrared wavelengths. Its presence shields interstellar molecules from high-energy radiation and enables protostars to radiate away excess energy.

NOAO / AURA / NSF / N. SMITH (UNIVERSITY OF ARIZONA)

A new record-breaker

In 2017, Izotov and Thuan's team discovered the current champion: a starburst galaxy in Lynx that's 620 million light-years distant — 10 times farther than I Zwicky 18 — bearing the prosaic name J0811+4730. The blue galaxy spawned 80% of its stars during the past few million years, and its oxygen abundance is a mere 6.98, the lowest ever seen. That's just 1.7% the level of oxygen in the Sun.

Still, the galaxy emerged only after the astronomers searched a million spectra from the Sloan Digital Sky Survey. Thuan once hoped to find truly primordial galaxies containing no oxygen at all, but he now wonders whether he'll ever succeed. "It's very, very difficult," he says. "I've spent nearly 40 years of my professional life trying to find these things, but so far to no avail."

Perhaps, he adds, an ancient generation of massive stars showered the whole universe with metals, setting a minimum oxygen level in any galaxy that arose. As a result, galaxies with much less oxygen than the current record-breaker simply might not exist.

Little galaxies, little particles

With all the new discoveries, the field is blossoming. That may be good news not just for astronomers but also for particle physicists, because these galaxies could reveal how many types, or 'flavours,' of neutrinos there are.

Neutrinos are tiny neutral particles that whiz through space — and our bodies — at nearly the speed of light. Hence their name: *Neutrino* means 'little neutral one' in Italian. Physicists recognise three flavours: electron, muon and tau. If a fourth flavour exists, however, it would have affected the nuclear reactions during the universe's first three minutes and raised the amount of helium the Big Bang produced.

But how much helium did the Big Bang actually make? We can't look to Earth for the answer, because the scant helium we have here has nothing to do with the Big Bang. Instead, the lighter-than-air gas that lifts blimps and balloons stems from the radioactive decay of heavy elements such as thorium and uranium.

In contrast, most of the helium on the Sun's surface did come from the Big Bang. Unfortunately, countless stars that lived and died before the Sun's birth also contributed.

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▲ **ONE MORE FOR LEO** The dwarf galaxy DDO 68 (also known as UGC 5340) is a ragged collection of stars and gas clouds. At 40 million light-years away, it's one of the closer oxygen-poor star-forming galaxies. This image combines visible and infrared observations.

Astronomers could try and subtract the stellar contribution from the amount of helium the Sun was born with — about 27% by weight — and thereby extrapolate all the way back to the Big Bang abundance.

"*Extrapolate*: We hate that word," says Evan Skillman (University of Minnesota). Far better to measure the helium level in star-making galaxies so pristine their chemical composition almost reflects that of the early universe. "It's really the only way we have to estimate the primordial helium abundance," he says. In these galaxies, new stars emit ultraviolet light that strips electrons from helium atoms in the interstellar gas; electrons that rejoin the helium atoms create spectral lines revealing the element's abundance. In contrast, the many dim dwarf galaxies that orbit the Milky Way, some of which have still less oxygen, provide no such information because they lack both gas and hot young stars.

Past measurements of I Zwicky 18 and its kin have found that helium made up a quarter of the chemical elements emerging from the Big Bang, but different astronomers derive slightly different numbers. In 2014, Izotov and Thuan's team obtained a primordial helium abundance of 25.5%, which is so high it suggests the number of neutrino types is more likely to be four than three. But Skillman's team favors a lower primordial helium level, around 24.5%, which implies three neutrino flavours, in accordance with standard physics.

Now, having spotted three new oxygen-poor star makers in just the past three years, astronomers have three more chances to derive the primordial helium abundance. If that number comes in on the high side, physicists should be seeking a fourth type of neutrino. Thus these odd little galaxies might tell us not only what the first galaxies looked like but also how many flavours of 'little neutral particles' there are zipping through the cosmos.

■ **KEN CROSWELL** earned his PhD for studying a decidedly oxygen-rich galaxy, the Milky Way. His book about our galaxy, *The Alchemy of the Heavens*, was a *Los Angeles Times* Book Prize finalist. He has also written for *National Geographic*, *New Scientist* and *Scientific American*.

Star-Forming Galaxies with the Lowest Oxygen Levels

Galaxy	Constellation	Oxygen Abundance (hydrogen = 12)*	Approx. Distance (light-years)
J0811+4730	Lynx	6.98	620 million
Leoncino	Leo Minor	7.02	40 million?
SBS 0335-052W	Eridanus	7.13	190 million
Little Cub	Ursa Major	7.13	60 million?
I Zwicky 18	Ursa Major	7.17	60 million
Leo P	Leo	7.17	5 million
DDO 68	Leo	7.20	40 million

*Oxygen abundances are generally the average of the values for multiple regions within a single galaxy. Question marks indicate a notably high uncertainty in distance.

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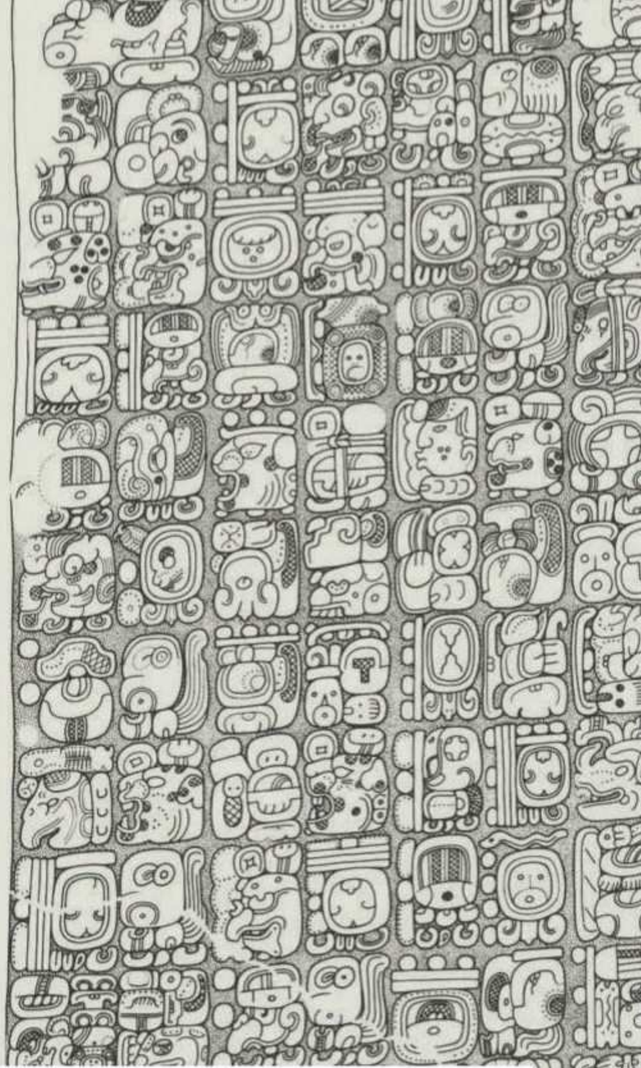
THE OBSERVATORY Evidence of Mayan interest in the heavens can be seen in monumental architecture like El Caracol at Chichen Itza. Scholars of archaeoastronomy believe that this snail-like building was designed to facilitate viewing astronomical phenomena such as the rising of the Sun and the setting of Venus.

HALLEY'S COMET & MAYA KINGS

Did a spectacular, once-in-a-millennium meteor shower prompt the crowning of a king?



It's the evening of April 10, CE 531, in the city of Caracol, a regional political centre located within the foothills of the Maya Mountains. The Moon set a few hours earlier, and a blanket of stars, concentrated overhead into a wispy Milky Way, is prominent in the pre-morning twilight. Suddenly, a brilliant shooting star streaks across the sky. Almost immediately, another falls from the heavens, and then another.

What follows is one of the most impressive celestial displays in living memory. Unbeknownst to those witnessing the meteor shower from Caracol, the Earth is passing through a giant cloud of interplanetary detritus left behind by Comet 1P/Halley — our most famous recurring icy visitor — from a series of near passes in the preceding centuries. For two hours, bright streaks of light rain down from the heavens above the Maya Mountains, producing one of the most intense meteor showers of the first millennium.

For the residents of Caracol, this shower wasn't just a once-in-a-lifetime spectacle. The heavens had spoken and political change was in the air. Four days after the shower, the people recognised K'an I, known as Lord Jaguar, as the new king, succeeding his father, Yajaw Te' K'inich I. The royal ascension was accompanied by familiar ceremonies during which the new king's blood was sacrificed to the gods as the sacred Maya beverage *saka*, made of maize and wild honey, was passed around.

We know about this series of events not from an ancient scripture, but thanks to a recent paper published in *Planetary and Space Science* by astronomer David Asher (Armagh Observatory) and Maya scholar J. Hutch Kinsman, who claim to have found the first evidence of meteor shower observation and recording anywhere in the Western Hemisphere.

The Maya Classic period ran from around CE 250–900. During this time, an empire encompassing some 50–75 city-states spanned the modern Central American countries of eastern Mexico, Guatemala, Belize, El Salvador, and Western Honduras. However, despite the range and longevity of this New World civilisation, piecing together its story has proven tricky. All but four of the Maya's ancient books, known as *codices*, were destroyed by the Spanish after their arrival in the 16th century. Adding together the content of the surviving codices, plus all hieroglyphic inscriptions recovered from stone monuments (*stelae*), panels, painted murals, and portable objects (such as bones, shells and ceramic vases), provides just a couple of thousand date entries across the

▲ **DECIPHERING THE PAST** Scholars have carefully transcribed the glyphs on ancient Maya monuments, many of which have been lost to looters and developers. This drawing records what remains of Monument 6, which was found in Tortuguero (present-day Tabasco, Mexico).

entire seven centuries of the Classic period. Events recorded on these dates mark not just the accession of kings, but also the births and deaths of important people and conquests of one city-state over another. We can also find astronomical information relating to Venus, and both solar and lunar eclipses, in these records. However, scholars have found no evidence of any meteor showers among the historical remnants.

Asher, a Solar System researcher with an interest in the history of astronomical observations, considers this lacuna a bit strange, as records of meteor showers have been recovered from ancient Chinese, Korean, Japanese and various European civilisations. In addition, based on their records of lunar and planetary movements, the Maya certainly had the capability to predict such celestial phenomena. “Did the records just disappear with much of the Maya book records,” Asher wondered, “or are there still clues we are missing?”

Asher has experience with meteor showers, having used the spectacular 1966 Leonid outburst, the biggest and most impressive of the 20th century, to predict the arrival time of subsequent displays in 1999, 2001 and 2002. Together with Robert H. McNaught, he achieved this with a computer program developed to model the trails of material shed by a comet and calculate when Earth’s travels around the Sun would cross them in the future. When they input the data for Comet Tempel-Tuttle, the parent comet for the Leonids, the shower predictions were accurate to a few minutes.

Asher’s interest in the Maya and their historical records came about only relatively recently following a chance encounter with Kinsman, a man who spends his time looking to the past rather than upwards. (Kinsman originally studied physics but has focused on the Maya for the last 20 years.) At their first meeting, Kinsman brought up the mysterious absence of shooting star records in the Western Hemisphere. (“It was a fascinating lecture,” recalls Asher.) By 2015 the two scholars had begun working together to address the missing Maya meteors.

Asher’s experience with the Leonids proved that with sufficient knowledge of a comet’s past location one could predict when the Earth would pass through its remnant trails later on. And if they knew the exact dates of meteor outbursts visible to the ancient Maya, perhaps they could spot indirect evidence of their impact in the recovered Maya events calendar. In terms of which comet to choose, the

EXPANSIVE CULTURE The Mayan civilisation spread across a large piece of Mesoamerica, including the Yucatán Peninsula and the mountains of the Sierra Madre region (present-day Mexico, Guatemala, and Belize). The city-states of the Maya Classic period (c. CE 250–900), which boasted populations as large as 120,000, produced most of the stone monuments and historical records that we have today.

MAP: LEAH TISCIONE / S&T

close proximity of Halley to Earth's orbit during the Maya mid-Classic period made a strong argument for looking for evidence related to its Eta Aquariid showers, which were recorded by ancient Chinese astronomers as far back as 74 BCE.

Asher and Kinsman applied the Leonid model to simulate meteoroid-sized particles attributed to Comet Halley's passages from as early as 1404 BCE in order to identify years when meteor outbursts might have been seen on Earth. After validating their approach by post-predicting observations in the ancient Chinese texts, they compared the same outburst dates to the surviving Maya record of notable dates.

They got 30 hits.

"Whilst some of them will be coincidences," Asher admits, "there are many more matches in or just after key meteor outbursts than you would expect to see by chance alone."

The recorded events that most commonly corresponded to Eta Aquariid displays were royal accessions, events that could easily be planned to coincide with or occur near the date of a meteor shower. For the shower in CE 531, Kinsman and Asher showed that the intensity of this burst resulted from Earth encountering particles released by Comet Halley during three previous passages (CE 295, 374 and 451). The relatively recent deposition of detritus by the comet meant there had been little time for dispersion, ensuring densely packed trails that could cause an intense outburst. The result was a shower Asher believes would have been spectacular, perhaps even to the extent of the incredible Leonid meteor storm of 1833, during which estimates have suggested 24,000 meteors were observable during an astounding nine-hour display. This celestial show was described at the time by Yale College Professor Denison Olmsted as "a constant succession of fire balls, resembling sky rockets, radiating in all directions from a point in the heavens," and if a similar shower had occurred in clear skies above the Maya city-states, it would have been impossible to ignore.

The calendar entry for CE 531 might itself provide additional evidence for a meteor-shower-inspired coronation,

The Venus Table

A large part of the Dresden Codex, the oldest and the best preserved Maya manuscript, is dedicated to astronomical and calendrical data. These data include solar and lunar eclipse predictions based on observable lunar phases, as well as tables for tracking the cycles of Venus, Mars and Mercury.

Six pages of the Dresden Codex are dedicated to the observable phases of Venus, beginning with the folio shown here. Credit for deciphering the so-called Venus Table goes to Ernst Förstermann, director of the Royal Library (now the Saxon State Library), who in 1901 worked out that the numbers inked in red across several pages of the codex were identical, and that they added up to 584. Recognising that this number was almost identical to the synodic period of Venus (583.92 days, the time it takes for Venus to return to the same position as seen from Earth), Förstermann determined that the red numbers — 236, 90, 250 and 8 — marked four significant points in the planet's cycle: its morning heliacal rising; its disappearance at superior conjunction; its first evening rise; and its disappearance at inferior conjunction. ■ S. N. JOHNSON-ROEHR

▲▼ **SKY TRACKERS** Despite a paucity of records related to meteor showers that might indicate otherwise, the Maya were keen observers of the night sky. Some of their astronomical knowledge was recorded in the Dresden Codex, a Maya history and astronomy treatise inked on paper made from the inner bark of a species of fig.

◀ **STONE METEORS** Tortuguero's Monument 6 includes a glyph depicting the CE 562 star war between the cities Tikal and Caracol. The droplets streaming from the glyph for 'star,' which resembles a pair of cartoon eyes, may represent the Eta Aquariid meteor shower.

as it includes not just the ascension event, but also the number of days that had passed since new Moon. This lunar tracking isn't uncommon in the Maya records, but in the case of this entry, the age of the phase was inscribed incorrectly. Kinsman and Asher interpret this error to mean that the inscribed age of the Moon referred to the date of the intense Eta Aquariid event, not the ascension itself. That is, the calendar noted a lunar age of 8 days (the age of the Moon during the meteor outburst on April 10th), not 12 days (the date the king was crowned).

"It appears that the Maya were back-calculating mythological events using calculations of the sidereal year that appear to have accurately targeted the Eta Aquariid meteor shower," says Dr. Michael Grofe, an archaeoastronomy specialist from the Maya Exploration Centre who wasn't involved in the project. "Kinsman and Asher make a compelling argument that the Maya both observed and predicted the Eta Aquariid meteor shower, and that the dates of the accession of Maya kings and queens, among other notable events, were timed to coincide with this astronomical phenomenon."

While CE 531 provides the most convincing match, Asher and Kinsman's date matches provide other tantalising possibilities. A modest outburst in CE 511 was followed nine days later by the ascension to the throne of a six-year-old queen, known as the Lady of Tikal. However, not all matches led to scenes of celebration. In CE 562 a major battle between rival cities Tikal and Caracol followed an Eta Aquariid outburst by slightly less than three weeks. The battle, which resulted in Tikal's conquest and subsequent disappearance from the historical record for the next 120 years,

> "There are many more matches in or just after key meteor outbursts than you would expect to see by chance alone."

is depicted in the record with a hieroglyph that looks a lot like a star showering Earth with liquid droplets. This evocative glyph led archaeologists to refer to this and similar devastating battles as *star wars*. Losing a star war often signalled the end, or at least the near erasure, of the defeated city-state. Archaeologists have noted that star wars tended to occur in the dry season (November to January) and typically began near the date of the appearance or disappearance of Venus. But could a star war also be prompted by a meteor shower?

An additional interesting match concerned not dust-induced meteors but Halley's Comet itself, which made its second-closest known approach to Earth on April 1, CE 374. About one month after the comet's passage, the Maya record shows the royal ascension of Teotihuacan ruler Spearthrower Owl (Atlatl-Cauac), whose hieroglyph and iconic representations clearly depict an owl holding an *atlatl*, a spear-throwing tool with stars, or 'celestial darts,' attached. It may be that Spearthrower Owl, who was responsible for the establishment of non-Maya rule over Tikal and other Maya city-states in CE 378, based his ascension on the passage of Halley's Comet in CE 374.

"The scale of some of these events organised close to major showers supports the idea the Maya were able to calculate the length of the sidereal year, and in all probability kept track of and observed Eta Aquariid meteor showers and outbursts," says Kinsman.

While some of the connections seem speculative, we are gaining more knowledge of the Maya daily through the study of their hieroglyphs, monuments, and codices. "We hope this collaboration can run and run," adds Asher, who now wants to apply the same technique to other comets and meteor showers that could have commanded the ancient Maya from the heavens. Short of revealing clear textual or archaeological evidence, this type of collaboration represents the best chance of understanding observations of meteor showers by the Maya.

■ **JAMES ROMERO** is a planetary and solar system science writer who has written for *Science News* and *New Scientist* magazines. He's also a geology graduate and amateur himself. You can follow him on twitter **@mrjamesromero**.

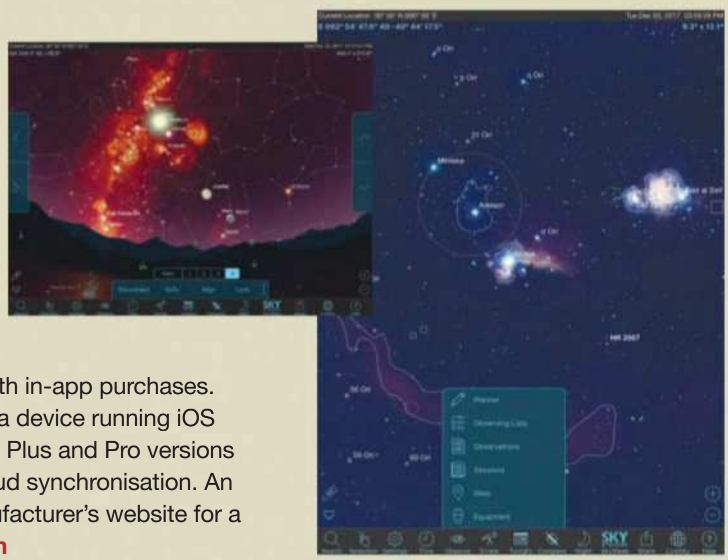
▲ BIG CAMERA

Finger Lakes Instrumentation has released the Kepler KL400 cooled sCMOS camera, suitable for astrophotography plus scientific research fields such as quantum imaging, hyper-spectral imaging, orbital debris detection and super-resolution microscopy. The 2k × 2k sensor has 11 × 11 micron pixels. The back-illuminated version (US$16,995) offers 95% quantum efficiency, 1.6e- read noise, deep sensor cooling and fast (48 fps) frame rates, producing a camera capable of capturing high-dynamic-range images in a single shot. A less-expensive front-illuminated version is also available, while a 16.8-megapixel large format camera is soon to follow.
flicamera.com

▲ BIG PIERS

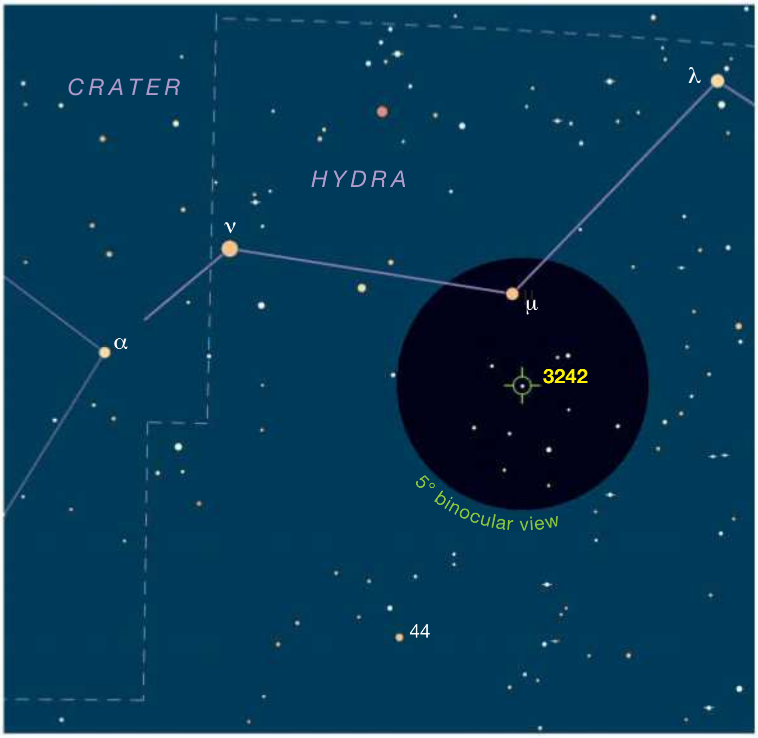
iOptron now offers piers for observatories. The Permanent Pier is a 7⅛-inch diameter, ¼-inch-walled aluminum pier with an 8¼-inch-square top plate. Four side struts are welded between the pier tube and the base plate to eliminate side flexure of the tube assembly under heavy or off-centre loads. Each Permanent Pier is capable of supporting loads of up to 163 kg and is available in three heights: 600-mm (23½-inches) for US$448, 800-mm for US$478, and 900-mm costing US$498. Custom heights and adapters are available by special order at additional cost.
ioptron.com

BIG SKY VIEWS ▶



One of the most popular planetarium apps for Apple devices gets a big update. *SkySafari 6* (starting at US$2.99) once again expands the usefulness of this popular app. Among its many new functions are a 'Say It' feature that incorporates basic voice control to find and centre objects, and 'Tilt It' that uses your device's accelerometers to slew your Go To telescope. *SkySafari 6* includes 29 million stars down to 15th magnitude and the PGC catalogue including 784,000 galaxies to 18th magnitude. Each of the stellar and deep sky object catalogues is expandable with in-app purchases. Available in Basic, Plus and Pro versions, each requires a device running iOS 8 or later and includes support for the Apple Watch. The Plus and Pro versions also incorporate Wi-Fi Go To telescope control and iCloud synchronisation. An Android version is expected by mid-2018. See the manufacturer's website for a complete listing of features. **simulationcurriculum.com**

New Product Showcase is a reader service featuring innovative equipment and software of interest to amateur astronomers. The descriptions are based largely on information supplied by the manufacturers or distributors. *Australian Sky & Telescope* assumes no responsibility for the accuracy of vendors' statements. For further information contact the manufacturer or distributor.



Small but fierce

NGC 3242, the Ghost of Jupiter (Caldwell 59), is a planetary nebula — concentric shells of gas blown off by a dying star, which reminded early observers of planets in size, shape and, in this case, even colour. Planetary nebulae are mostly small and dim as seen from Earth, and few of them are within reach of binoculars.

NGC 3242 is small, about 0.7′ across, but it's not dim. Most sources give a visual magnitude of 7.7 for it. In his book *The Caldwell Objects*, Stephen James O'Meara reported that at 23× through a 100-mm scope, NGC 3242 still looked basically stellar. However, specifically because its light is condensed into such a small area, O'Meara reckoned that it ought to be naked-eye visible under sufficiently dark skies. A handful of observers have since confirmed that possibility.

Here's your mission (should you choose to accept it). First, go have a look at NGC 3242 with binoculars. I mean, you will see it. And even if it just looks like a point of light, we shouldn't get too blasé about witnessing the death throes of a *star* across a gulf of thousands of light-years with handheld instruments. Second, see if you can detect the nebula with your naked eyes. Others have done it — can you? If not, what's the smallest instrument or least magnification you need to pick it up? Third, if you're rolling with big binos or a small telescope, determine the least magnification required to see the nebula as an extended, non-stellar object. Finally, assuming you're up late enough, swing east and have a look at M27, the Dumbbell Nebula, and see how they compare.

■ **MATT WEDEL** and NGC 3242 are, in the words of Leslie Peltier, making mutual estimates of each other's brightness.

USING THE STAR CHART

WHEN

Late April	11pm
Early May	10pm
Late May	9pm
Early June	8pm
Late June	7pm

These are standard times.

HOW

Go outside within an hour or so of a time listed above. Hold the map out in front of you and turn it around so the label for the direction you're facing (such as west or northeast) is right-side up. The curved edge represents the horizon, and the stars above it on the map now match the stars in front of you in the sky. The centre of the map is the zenith, the point in the sky directly overhead.

FOR EXAMPLE

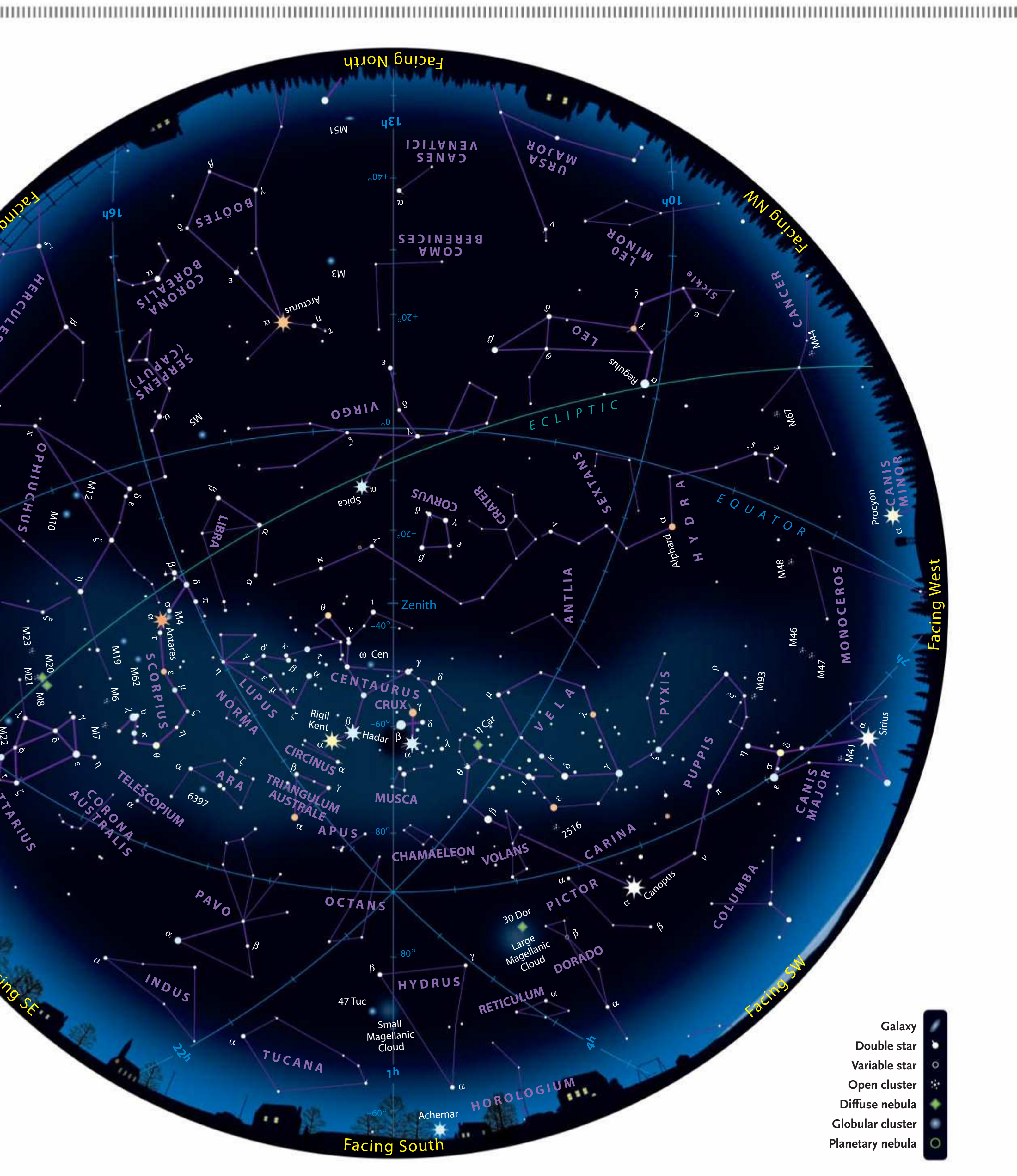
Turn the map so the label "Facing SW" is right-side up. About a third of the way from there to the map's centre is the brilliant star Canopus. Go out and look southwest nearly a third of the way from horizontal to straight up. There's Canopus!

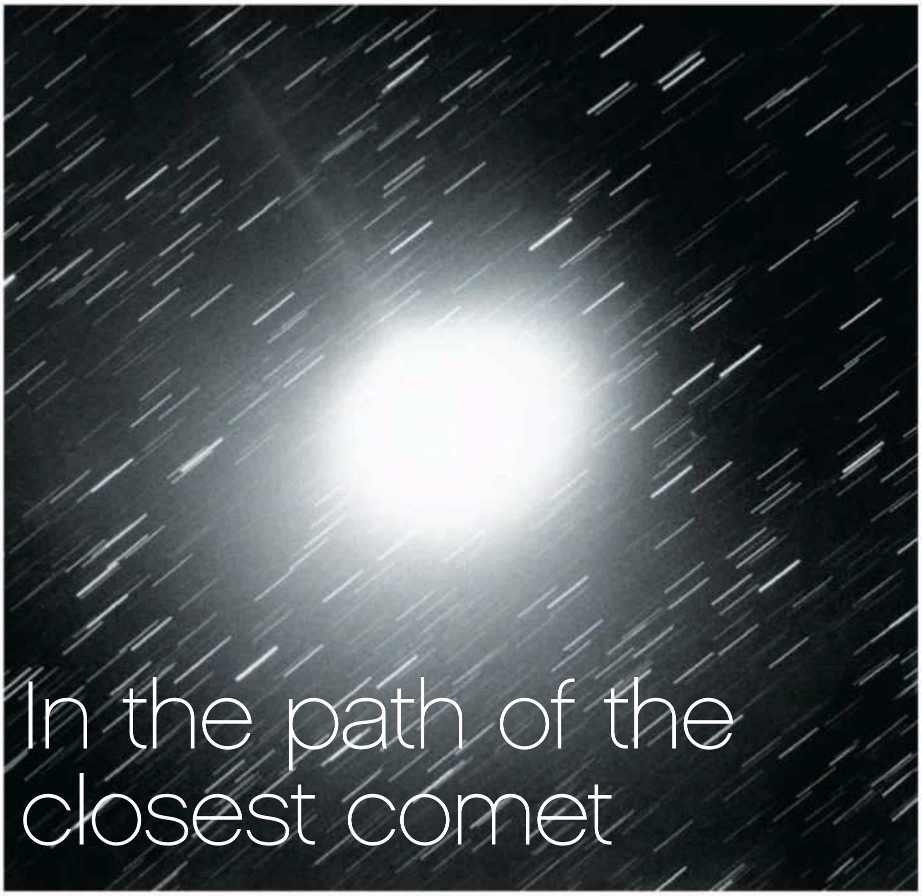
NOTE

The map is plotted for 35° south latitude (for example, Sydney, Buenos Aires, Cape Town). If you're far north of there, stars in the northern part of the sky will be higher and stars in the south lower. Far south of 35° the reverse is true.

ONLINE

You can get a real-time sky chart for your location at skychart.skyandtelescope.com/skychart.php


Facing North
Facing NW
Facing West
Facing SW
Facing South
Facing SE
URSA MAJOR
CANES VENATICI
BOÖTES
COMA BERENICES
LEO MINOR
CORONA BOREALIS
HERCULES
SERPENS (CAPUT)
VIRGO
LEO
Sickle
CANCER
Arcturus
Regulus
ECLIPTIC
EQUATOR
OPHIUCHUS
LIBRA
CORVUS
CRATER
SEXTANS
HYDRA
Alphard
Spica
CANIS MINOR
Procyon
MONOCEROS
ANTLIA
Zenith
ω Cen
CENTAURUS
CRUX
Rigil Kent
Hadar
η Car
VELA
PYXIS
PUPPIS
CANIS MAJOR
Sirius
SCORPIUS
Antares
LUPUS
NORMA
CIRCINUS
ARA
TRIANGULUM AUSTRALE
MUSCA
APUS
TELESCOPIUM
CORONA AUSTRALIS
SAGITTARIUS
CHAMAELEON
VOLANS
CARINA
Canopus
PICTOR
COLUMBA
PAVO
OCTANS
30 Dor
Large Magellanic Cloud
DORADO
INDUS
HYDRUS
RETICULUM
47 Tuc
Small Magellanic Cloud
TUCANA
HOROLOGIUM
Achernar
Galaxy
Double star
Variable star
Open cluster
Diffuse nebula
Globular cluster
Planetary nebula



In the path of the closest comet

From Draco to Cancer a comet hurtled.

Thirty-five years ago, some of the best weather in the world helped me to experience a prodigious wonder that most skygazers missed. It was the nearest pass to Earth of a comet in over 200 years. The marvel was Comet IRAS-Araki-Alcock (Comet I-A-A), discovered first by the Infrared Astronomical Satellite and then independently by amateur astronomers Genichi Araki in Japan and George Alcock (with binoculars, looking out a window) in England.

I spent six nights in the Northern Hemisphere following this intrinsically dim comet through ever brighter and bigger forms as it hurtled less than 4.8 million kilometres from Earth. Its path across the stars on those nights is one I'll never forget — and one which I'd like to explore in its own right here in this column.

First night: Naked eye past Draco's head. "My search with binocs immediately produced a prominent ball of fuzzy light in its still imperceptibly slow roll past the head of the celestial dragon," I wrote in my book *Comet of the Century* (Copernicus Books, 1996). When I first spotted Comet I-A-A, it was a roughly magnitude-4.9 object detectable with the naked eye, with a 15′ patch of coma visible through a 15-cm telescope.

The circumpolar head of Draco doesn't get highest in the north until the middle of the night in May, but was already prominent in the northeast in the evening. The Dragon's head points toward ascending Vega and the Keystone of Hercules. It consists of stars of 2nd, 3rd, 4th and 5th magnitude: Gamma (γ) Draconis (Eltanin), Beta (β) Draconis (Rastaban), Xi (ξ) Draconis (Grumium), and Nu (ν) Draconis (Kuma). Eltanin, at 2nd magnitude, is the orange eye of Draco. And 5th-magnitude Kuma is formed by equally bright white components a generous 62″ apart.

Third night: A Great Orion Nebula in the body of Draco. "Last torn cloud curtain edge was withdrawn to reveal a sky clean and sheer to about mag. 7.0 at its summit... and a handful of strong phosphorescence hung in mid-flight on that sky's north shoulder." The comet was in the long, twisting body of Draco, which wraps around the North Ecliptic Pole, near which glows NGC 6543, the wonderful 9th-magnitude Cat's Eye Nebula. But that night Comet I-A-A appeared larger and much brighter than M8, the Lagoon Nebula, like a detached piece of Milky Way, "... or at least for me in that magic clear dark — like another Orion Nebula in size, brightness and even shape!"

Fourth night: Flung from the Little Dipper's bowl. At nightfall the comet's coma was already surrounding Kochab, Beta (β) Ursae Majoris. "It was fascinating viewing the rather bright star cloaked in that slight veil, and the conjunction of the comet's centre with the star was surprisingly close." The comet was going so fast it only took minutes for it to move off this underappreciated orange 'Guardian of the Pole' that's very nearly as bright as Polaris. It was seemingly being flung, in one day, from the Little Dipper's bowl to just past the Big Dipper's bowl. I judged the comet to be magnitude 2.8 or 2.9 and 1° to 1¼° wide to the naked eye that night.

Sixth night: A huge, near-1st-magnitude comet passes M44. The head of the comet was very close to the smaller, much dimmer patch of Messier 44 (the magnitude-3.1 and 1½°-wide Beehive Cluster). Comet authority John Bortle rated the comet's head as magnitude 1.7 and at least 2° wide that evening. Walter Scott Houston estimated the comet's head as an astounding 6° across! And, in a sky so dark and clear I could trace the zodiacal light bridge across it, I saw the two edges of the previously tailless comet's tail extending up to 15° long.

■ **FRED SCHAAF** saw his first naked-eye comet, Tago-Sato-Kosaka, in 1970.

AURA / KPNO

A NEW HORIZON

You might have seen some of the stunning deep sky images astrophotographers produce with our CCD cameras. You might also know about our revolutionary Infinity software that brings the deep sky to your screen in just seconds. What you might not know is that we've taken all that experience, and turned it towards a new Horizon...

The Atik Horizon is our first camera to use a CMOS sensor. These sensors are known for their low read noise and high read speeds, and the Horizon's no exception - when used at high gain settings, it's our lowest read noise yet. This ability to turn up the volume makes it incredibly well suited to narrowband imaging, providing stunning clarity on faint and difficult targets. Its 3.8µm pixels also make it an excellent match for shorter focal length telescopes, a combination that rewards you with a wonderfully wide field of view.

We've packed it full of features like an in-built DDR3 image buffer, a 40°C cooling delta, quartz-fused cover glass and advanced protection against condensation to name just a few. All this adds up to a camera that blends form and function to create a seamless imaging experience and beautiful images of the deep sky.

If that's not enough, we've taken advantage of those fast read speeds and suitability for short exposures to build in compatibility with our Infinity live-stacking software. This means you can explore the night sky through high resolution images in a near real time environment, during the night, at the scope (or from the comfort of a nice, warm living room). It also removes some of the steep learning curve that can come with getting started in astrophotography, making the night sky accessible whatever your skill level.

But if you do find you'd like a little extra help, you can take advantage of our UK-based support and servicing, or join any one of our active online communities. And all of this comes with the biggest CMOS benefit of all - an absolutely irresistible price point.

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ATIK CAMERAS

Giant worlds rule the night

The next few months will be a planet watcher's paradise.

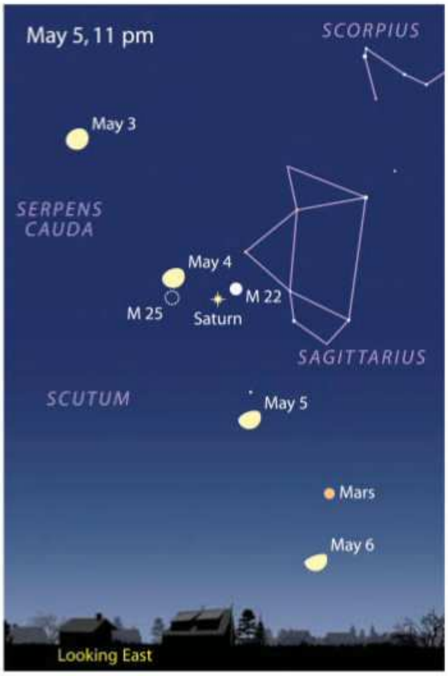
It's a pretty good time for planet watching at the moment, with Jupiter to reach opposition in May, Saturn the same in June, and Mars in July, with all five naked-eye planets being evening objects in June.

Mercury (magnitude 0.1 and diameter 7.3″ on May 1, mag. –0.2 and 6.5″ by June 30) begins May still in the eastern, morning sky. Rising about two hours prior to sunrise at the start of the month, the innermost planet will make a nice sight on the 14th with the very thin crescent Moon nearby. But by this stage it will have drawn much closer to the horizon and the Sun's glare, heading for superior conjunction (ie. on the other side of the Sun) on June 6. Returning to our western, evening sky at magnitude –0.8 in the second half of June, Mercury will be seen amongst the stars of Gemini. Take a look on the nights of June 24 to 26; the tiny planet will appear close to the star Pollux. Mercury will be brighter of the two, and they'll make a nice contrast.

Venus (–3.9, 12″ to 14″) will begin May in the evening sky in Taurus before spending the last week of the month and all of June in Gemini. Along the way it will pose for astrophotographers as it passes a couple of nice star clusters — the open cluster Messier 35 on May 21, and Messier 44 (also an open cluster, and known variously as Praesepe or the Beehive Cluster) on June 20. Other picturesque encounters will include the Moon (May 17 and June 16), Aldebaran (May 2) and Pollux (June 10). The planet will set around 7:00pm at the beginning of May, and 8:00pm by the end of June.

Mars (–0.7 to –1.6, 12.5″ to 18″), heading for opposition in July, rises around 10:00pm at the beginning of May but by just after 7:00pm at the end of June. The Red Planet moves from Sagittarius to Capricornus during this period, before starting two months of retrograde motion at the end of June. Watch for the Moon nearby on May 6, and June 3 and 30. If you have a telescope, have a look for the South Polar Cap from the last week of May onwards. May 23 marks the equinox on Mars, when the southern hemisphere begins the move from winter to spring... bringing with it more solar illumination for the southern half of the planet.

Jupiter (–2.5, 44.8″) is, of course, the leader of the pack at the moment, reaching opposition on May 9. Visible all night, the gas giant will make a fine sight whether you're using a telescope, binoculars or just the naked eye. Refer



▲ Saturn spends May and June close to Messier 22.

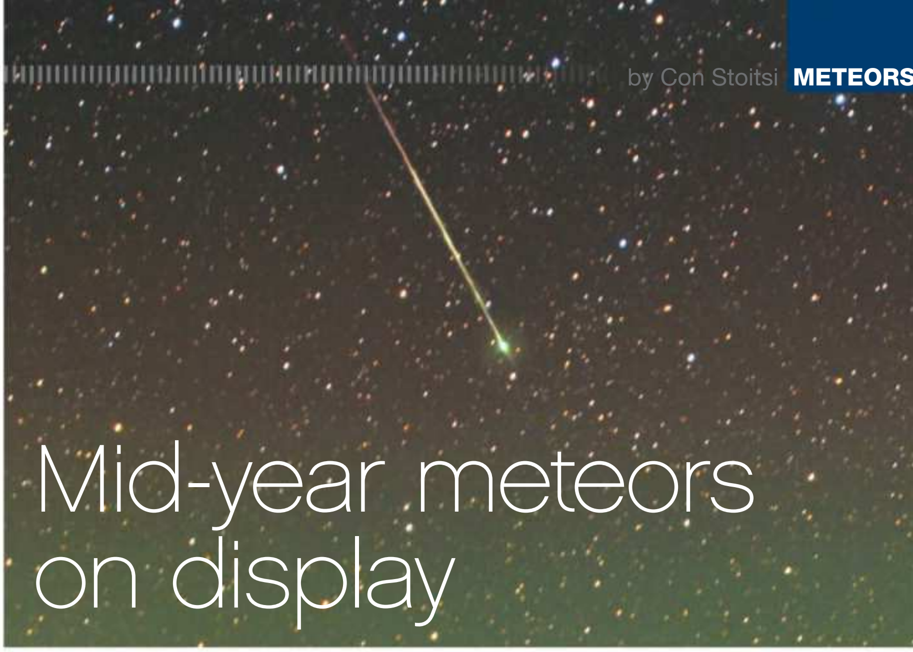
▲ Jupiter, at opposition on May 9, rules the sky.

▲ Venus will appear close to Messier 44 on June 20.

to pages 56-59 for a full run-down of what to expect and how to study the planet's cloud belts, Great Red Spot and moons. And look for our Moon nearby on May 27/28 and June 23/24.

Not to be outdone by its larger sibling, **Saturn** (mag. 0.3 and 18″ in mid-May, 0.0 and 18.4″ at June's end) will reach opposition on June 27. Like Jupiter, it will be visible all night around this time, and will make an ideal target for observation through even the smallest of telescopes. The planet's rings, with their Cassini Division, will be prominent and easy to spot. Saturn will stay close to the globular star cluster, Messier 22, during May and June, and will have close encounters with the Moon on May 4 and June 1.

Finally, our planet will reach the **southern winter solstice** (where has the year gone?) on June 21. The winter solstice for us is when the Sun is at its most northerly declination (+23.5°) and the hours of daylight are shortest. In the Northern Hemisphere the opposite holds true at this time of year, of course, with the Sun being nice an dhigh in the sky and with the hours of daylight longest at this solstice.



Mid-year meteors on display

Despite adverse lunar lighting, it's still a great time for meteors.

Meteor activity in general is highest in May and June from the Southern Hemisphere, with many minor meteor showers active. Unfortunately, this year the Moon will greatly affect these showers, and their zenithal hourly rate (ZHR) — the theoretical maximum number of meteor that can be seen at the zenith (ie. looking through the least amount of sky) — will be reduced.

The Eta Aquariids are active from mid-April to May, peaking on the morning of the May 6 this year, with a modest ZHR of 5 to 10 meteors forecast. This shower generally produces swift meteors of yellow colour and persistent trains are often recorded. Start your observations after 3:00am.

Peak sporadic meteor rates occur during May and June. Sporadics are random meteors not associated with any particular shower, and are best been at 4:00am local time, when our part of the Earth is facing the same direction as its travelling in its orbit around the Sun. Thus, not only are meteors swept up which are heading toward the Earth, but the movement of the Earth around the Sun enables it to catch up with some of the slower meteors and pull them in. The corollary is that rates are usually lowest in the evening when we're facing away from the direction of the Earth's travel.

CON STOITSIS is director of the Astronomical Society of Victoria's comet and meteor sections. You can follow him on Twitter **@vivstoitsis**

SKY PHENOMENA (dates in AEST)

MAY

1	Jupiter 4° south of Moon
4	Venus 7° north of Aldebaran
5	Saturn 1.7° south of Moon
6	Mars 3° south of Moon
9	Jupiter at opposition
10	Neptune 2° north of Moon
13	Mercury 2° south of Uranus
14	Uranus 5° north of Moon
14	Mercury 2° north of Moon
16	Aldebaran 1.2° south of Moon
18	Venus 5° north of Moon
20	Moon 8° south of Pollux
28	Jupiter 4° south of Moon

JUNE

1	Saturn 1.6° south of Moon
3	Mars 3° south of Moon
5	Jupiter 0.9° north of Alpha Librae
6	Mercury in superior conjunction
9	Venus 5° south of Pollux
10	Uranus 5° north of Moon
16	Venus 2° north of Moon
21	Solstice
24	Jupiter 4° south of Moon
26	Mercury 5° south of Pollux
27	Saturn at opposition
28	Saturn 1.8° south of Moon
29	Mars stationary

LUNAR PHENOMENA

MAY

Last Quarter ...... 8th, 02:09 UT
New Moon ...... 15th, 11:48 UT
First Quarter ...... 22nd, 03:49 UT
Full Moon ...... 29th, 14:20 UT
Apogee ...... 6th, 01h UT, 404,457 km
Perigee ...... 17th, 21h UT, 363,776 km

JUNE

Last Quarter ...... 6th, 18:42 UT
New Moon ...... 13th, 19:43 UT
First Quarter ...... 20th, 10:51 UT
Full Moon ...... 28th, 04:53 UT
Apogee ...... 2nd, 17h UT, 405,317 km
Perigee ...... 15th, 00h UT, 359,503 km
Apogee ...... 30th, 03h UT, 406,061 km

P. HORÁLEK/ESO

Return to the Wolf's den

Sink your teeth into the double stars of Lupus.

It's been eight years since this column last visited Lupus, the Wolf, and — as always — the doubles I mention here are a short selection from many in the region. If you have a mid-size scope, there are a lot more within your reach.

Near the Lupus/Centaurus border, **HJ 4672** is 3 degrees west-southwest from 2nd-magnitude Eta Centauri. Little changed since John Herschel's discovery in 1837, this is a bright yellow star with small companion when seen at 100× with 18 cm; an attractive pairing in a sparse field. Hartung saw it with 7.5 cm.

Some 5½ degrees south-southeast of HJ 4672 is **R 244**, discovered in 1881 by H.C. Russell, director of Sydney Observatory. There has been no definite change since, and 18 cm at 100× showed a bright white star with a tiny companion southeast in a rich field.

Northwest 1½ degrees from Alpha Lupi, **HJ 4690** is one of two bright orange stars dominating the field. It's wide and easy, with contrasting brightness and colours, orange and blue-white. More than 100 years after John Herschel's discovery, in 1951 W.S. Finsen in South Africa with a 26.5-inch (69-cm) refractor found that the primary star consists of near-equal 6th-magnitude stars. These are very close at all times, in an orbit currently estimated at 140 years. The 1950s measures were around 0.14"; the most recent, 2014, is 0.19".

HJ 4706 is found 1½ degrees east of 2nd-magnitude Alpha Lupi, an easy 7" separation though not a bright pair. My 18-cm scope at 100× showed a dull, deep yellow primary, the lesser companion making a nice combination, in a field with a little arc of three magnitude 10 stars some 8' southwest. It's a nice double for middle apertures, though visible with 80 mm.

HJ 4715 is 1 degree southeast from HJ 4706, and is a much brighter pair of slightly unequal white stars, in a faint star field. It has closed somewhat since the 1830s, but 80 mm will show it.

Kappa Lupi, **DUN 177**, is wide and bright. It appears to be a gravitationally bound pair of long period. The unequally bright stars look pale yellow to me, as they did to Hartung, who remarked on this "fine object for small apertures". Distant about 180 light-years, the orbit is huge, some 1400-plus a.u.

COO 179 was discovered in the 1870s at Cordoba Observatory, an easy but not bright white pair that was nicely seen with 18 cm at 100×. The field is middling starry; altogether a good effect.

Nearly midway between Beta and Epsilon Lupi is **I 228**, a discovery by Robert Innes with a 7-inch refractor. Not bright, and fairly close, I found it showed well with 18 cm at 180×, an equal, pale yellow, close pair in a quite starry (though mostly faint) field.

Half a degree or so northeast of I 228 is **DUN 179**, another easy unequal white pair in a starry field; 80 mm will show it, and it's attractive with 18 cm.

I discussed **Gamma Lupi** on these pages in 2010 and it's worth re-visiting. My first observation of Gamma in 1996 with an 18-cm refractor showed two discs in contact at 330×, bright and equal. In 2016, with my 21-cm Dall-Kirkham, 300× showed bare separation. A very fine double for those with not-too-small scopes; the separation currently is just over 0.8".

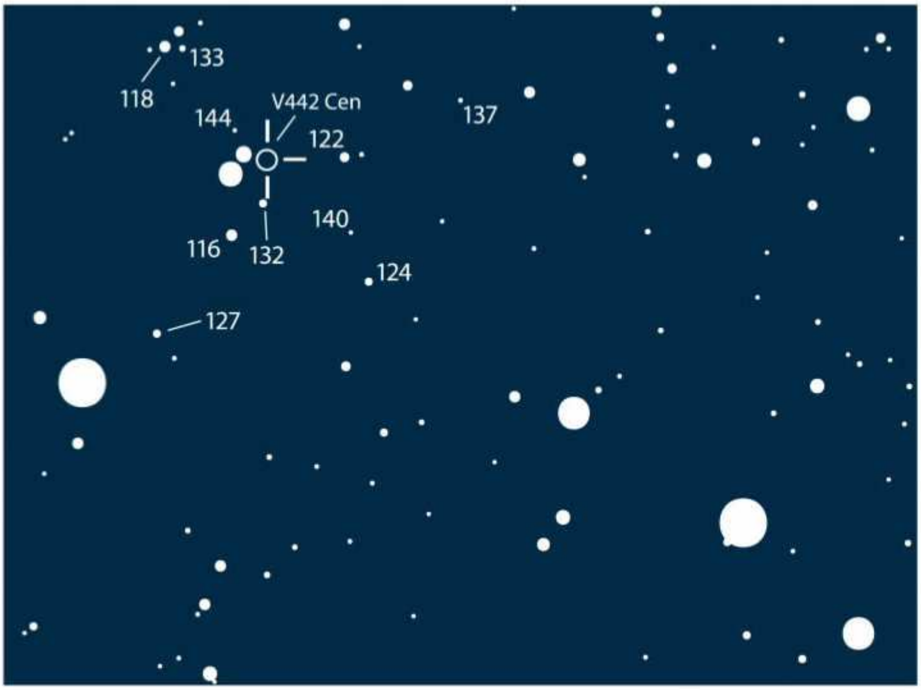
Gamma Lupi's orbital period was a puzzle for many years, but now seems well established at around 190 years. The only controversy these days is about photometry. All the earlier visual observers gave the brightness difference of the stars as 0.3 magnitude or less. Hipparcos in 1991 gave a ~0.1 magnitude difference with three different filters. This matches my own observations. Only Tycho gives the brightness difference of 1.5 magnitudes that is listed in the *WDS*. This appears to be another Tycho aberration. The Tycho magnitude for star A is similar to the combined brightness of the two stars as measured by others, which may suggest where the error originated. I have used the Hipparcos magnitudes in the accompanying table.

Double stars of Lupus

Star Name	R. A.	Dec.	Mag.	Sep.	Position angle	Date of measure	Spectrum
HJ 4672	$14^h\ 20.2^m$	-43° 04′	5.8, 7.9	3.5″	301°	2016	G8III
R 244	$14^h\ 22.6^m$	-48° 19′	6.1, 9.5	4.0″	121°	2010	B1III
HJ 4690	$14^h\ 37.3^m$	-46° 08′	AB 5.6, 7.7	19.6″	024°	2016	G8III+A1V
HJ 4706	$14^h\ 51.3^m$	-47° 24′	7.7, 9.0	7.0″	220°	2016	K2III+K
HJ 4715	$14^h\ 56.5^m$	-47° 15′	6.0, 6.8	2.1″	281°	2016	B9V
Kappa (DUN 177)	$15^h\ 11.9^m$	-48° 44′	3.8, 5.5	26.5″	143°	2010	B9.5V+A5V
COO 179	$15^h\ 13.0^m$	-37° 15′	8.0, 8.1	6.3″	227°	2010	A3/4V
I 228	$15^h\ 14.0^m$	-43° 48′	8.0, 8.2	1.2″	013°	2016	A4/5IV/V
DUN 179	$15^h\ 14.5^m$	-43° 23′	7.3, 8.5	10.5″	045°	2016	A1V
Gamma (HJ 4786)	$15^h\ 35.1^m$	-41° 10′	3.4, 3.5	0.83″	276°	2014	B2IV

Data from the *Washington Double Star Catalog*, with additions.

ROSS GOULD observes the sky from the nation's capital. He can be reached at **rgould1792@optusnet.com.au**



◀ V442 Cen is located at 11h 24m 51.91s, –35° 54' 36.7" (epoch J2000). This chart (courtesy of the AAVSO) has visual magnitudes shown with decimal points omitted to avoid confusion with faint stars — so 124 denotes a magnitude 12.4 star. The two bright stars are half a degree apart.

Outburst on the way

Make sure you're watching when V442 Centauri blows its top.

Most of the targets I've written about in this column have been long-period variables. Often bright, easy to find, and slow changing with large amplitudes, these are the 'bread and butter' of visual variable star observers. Yet there is another class at which visual observers excel — cataclysmic variables. Meet one of them, the dwarf nova V442 Centauri.

Dwarf novae are binary star systems that comprise a white dwarf drawing mass from its lower-mass, less-evolved companion star via an accretion disk. Think of water circling down a plughole, moving though a spinning disc-like structure. Dwarf novae outbursts originate in the disk, and are entirely different to classical novae and supernovae (although the same systems can produce these different events). In a classical nova the accreted shell on the white dwarf explodes, while a supernova is the explosion of the entire white dwarf.

The February 1978 issue of the US edition of this magazine published an early (misinterpreted) light curve of V442 Cen, from the work of the Royal Astronomical Society of New Zealand. This star has outbursts of short duration every few weeks, and interpreting the data is very difficult. I've studied the extensive data set, and it's easier to see the scheduling habits of the observers than to tell much about the long term nature of the star itself. So we need more observers please!

V442 Cen is reasonably easy to find and observe. You'll need an atlas to find the two 5th-magnitude stars shown on the chart above — half a degree apart, they'll be easily visible through a finder. The rest is easy. If you can see 12th magnitude, you won't have to wait too long before glimpsing V442 Cen in outburst.

■ **ALAN PLUMMER** observes from the Blue Mountains west of Sydney, and can be contacted at **alan.plummer@variablestarssouth.org**

SPOTTED IN CARINA

A bright (magnitude 5.7 at red wavelengths) transient object — possibly a classical nova — was spotted near the galactic plane in Carina on March 23. The discovery was made by the All Sky Automated Survey for SuperNovae (ASAS-SN).

The before image (top) is from a POSS2/UK Schmidt Telescope Unit red photographic plate taken in 1991; the after image was taken by Ernesto Guido using the 43-cm f/6.8 astrograph plus CCD camera at the iTelescope Observatory at Siding Spring.

At the time of writing, there was still some doubt as to whether this was a classical nova or some other kind of exotic outburst, with more spectrographic studies needed.

■ **JONATHAN NALLY**

Comet spotting in Sagittarius

A good comet for the winter months, and another one on the way.

The best prospect for amateurs with small telescopes during May and June will be **C/2016 M1 (PANSTARRS)**. Discovered on June 22, 2016, with the Pan-STARRS 1 telescope at Haleakala in Hawaii, this object was estimated at magnitude 19.7 at the time, but subsequent observations revealed that it was still well in advance of perihelion, which would not occur until August 10, 2018 at a distance of 2.21 astronomical units (a.u.) from the Sun.

C/2016 M1 is relatively bright intrinsically and is also dynamically evolved, implying that its relative brightness indicates a fairly large and/or active nucleus rather than a surface accumulation of very volatile substances likely to boil away as it nears perihelion.

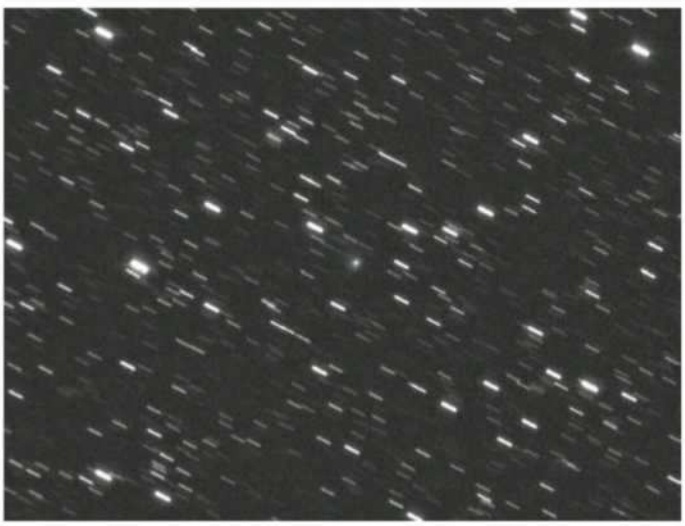
Fortunately for southern observers, C/2016 M1 is also travelling southward through the skies. Progressing from Aquila into Sagittarius during the opening week of May, the comet will traverse the latter constellation throughout the rest of May and the first half of June, before crossing Corona Australis and entering Ara by the end of that month. On June 24, it will make its closest approach to Earth at a distance of 1.29 a.u.

Visual magnitude estimates by northern observers early in the year indicate C/2016 M1 to be brightening steadily (even if not especially rapidly) and, if this early trend persists, it should increase in lustre from about magnitude 10.5 to near 9 through the May and June period. It is likely to stay around this maximum magnitude for an extended period, all the while remaining well placed for southern observers. On present indications, it is likely to still be around 10th magnitude at the end of August and brighter than 11th until the close of October.

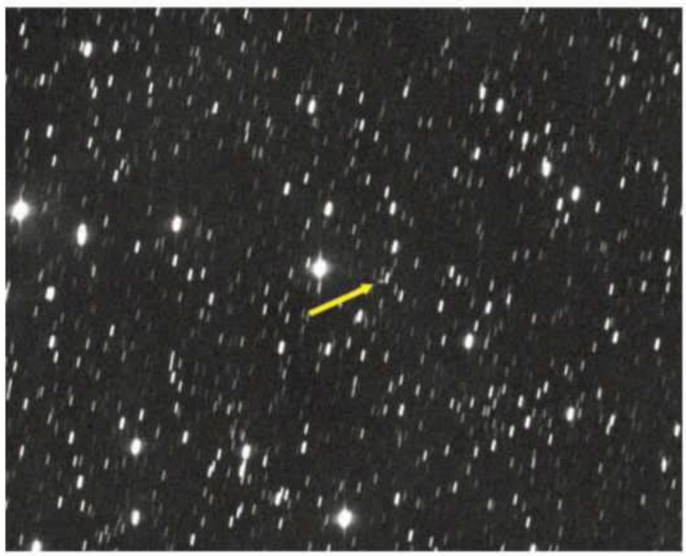
Keen-eyed observers with a clear eastern horizon may also be rewarded with a glimpse of another dynamically evolved, long-period comet during the closing days of June. Designated **C/2017 T3 (ATLAS)**, this object was discovered by the Asteroid Terrestrial-impact Last Alert System (ATLAS; see **fallingstar.com**) of the University of Hawaii on October 14, 2017. At the time of discovery, the comet was estimated at magnitude 18.3. Perihelion will occur on July 19 this year at a distance of 0.82 a.u. from the Sun.

The orbit of this comet passes quite close to Earth. Unfortunately, the comet itself does not! Indeed, C/2017 T3 will not be at all well placed for observing, but it may be possible to find it low in the dawn during the last few days of June, when it will be located in Orion and probably no brighter than about magnitude 10. Prospects do, however, look a little better following perihelion, but I'll have more to say about that in our next issue.

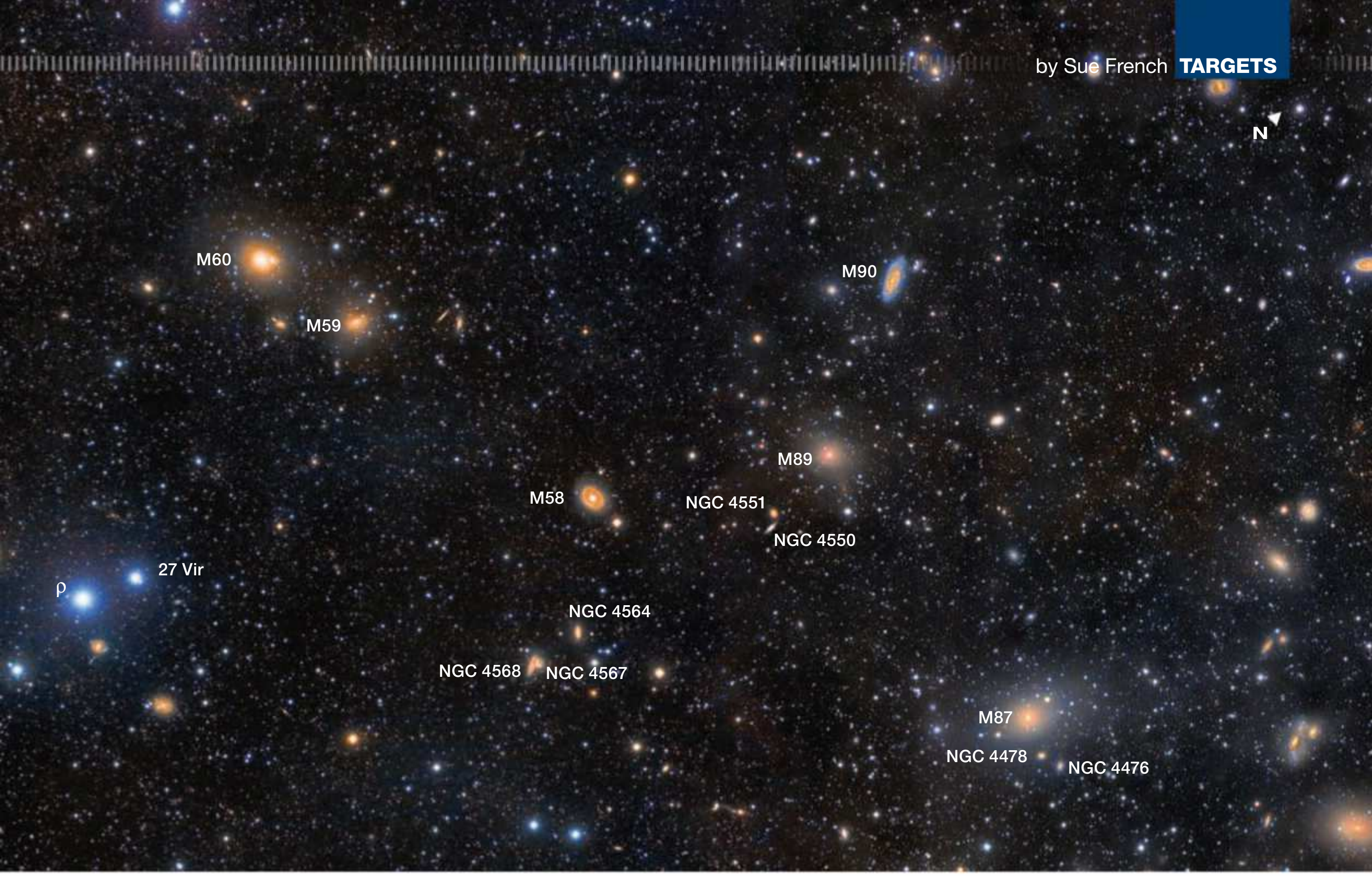
■ David Seargent is a long-time comet observer and author of several books on the subject, including the recent *Weird Comets and Asteroids* and *Visually Observing Comets*.



▲ C/2016 M1 (PANSTARRS) showed as a condensed fuzzball in July, 2017, when Michael Jager took this image. It's expected to reach about magnitude 9 to 10.5 during May as it moves through Sagittarius.



▲ Comet C/2017 T3 (ATLAS) appeared as a tiny dot when this image, also by Michael Jager, was taken on November 14, 2017.



The star-clad maiden

Visit Virgo to find these exemplary galaxies of autumn.

Would you the star of Bacchus find,
on noble Virgo's wing,
A lengthy ray from Hydra's heart
unto Arcturus bring;
Two-thirds along that fancied line,
direct th' inquiring eye,
And there the jewel will be seen,
south of Cor Caroli.

— William Henry Smyth,
The Bedford Catalogue, 1844

This charming quatrain describes how to find the star Vindemiatrix in Virgo using the Alpha stars of Hydra, Boötes and Canes Venatici as guides. The tie between Virgo and the Roman god Bacchus (Greek Dionysus) has many versions, but a woeful tale is told by Julius D. W. Staal in his wonderful book *The New Patterns in the Sky*. Bacchus taught Icarius, a mortal man, the art of winemaking. Icarius shared his newly created libation with friends and local shepherds, who mistook their intoxication for attempted poisoning and slew poor Icarius. His body, tossed aside in a ditch, was found by his faithful dogs and his daughter Erigone. In their grief, they followed him into death. Icarius was then placed in our sky as Boötes, his dogs as Canes Venatici, and Erigone as Virgo.

The area of the sky we'll be visiting lies west of Vindemiatrix and within the Virgo Cluster, which hosts about 1,500 galaxies. The cluster's main body is centred on the hefty galaxy **Messier 87**, sitting 54 million light-years away from us. Including dark matter, M87 weighs in at roughly 10 trillion solar masses or around 10 Milky Way galaxies.

Through my 130-mm refractor at 23×, M87 is an obvious glow just south of a deep-yellow, 8.6-magnitude star. It appears slightly oval at 63× and brightens considerably toward the centre. Examined at 117×, M87's brightness contours become rounder as you approach the centre, and they enfold a small, brilliant core. The halo has indefinite boundaries, but I'd put the size at about 4½′. Nearby **NGC 4478** also is visible, looking fainter and more obviously oval than M87. Its plump profile tilts northwest and is roughly

▲ This deep image of the Virgo cluster represents more than 36 hours of exposure. One easy route to the galaxy cluster hops from Epsilon (ε) Virginis (Vindemiatrix) to Rho and 27 Virginis. From those stars, it takes just a nudge to bring the galaxies into the field of view.

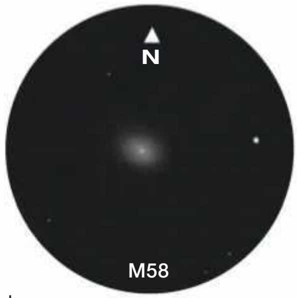
ROGELIO BERNAL ANDREO

1′ long. While gazing at NGC 4478, I noticed **NGC 4476** with averted vision. It's a bit smaller but more elongated than NGC 4478, leaning north-northeast, and too faint to disclose any details. NGC 4478 and NGC 4476 delineate the top of an 8.2′–tall trapezoid that they form with two 11th-magnitude stars to their south-southwest.

My 25-cm reflector at 187× shows M87's 5′-long face cocked north-northwest. The interior is bright to a diameter of approximately 2½′, and it grows much brighter toward the centre. NGC 4478 is easy to spot, covering about 1¼′. Its fairly bright core intensifies inward to a tiny nucleus. NGC 4476 shows well now, brightening slightly toward an elusive nucleus.

M87 is famous for its narrow plasma jet, which is powered by the accretion disk around the galaxy's central, supermassive black hole. It's not surprising that amateur astronomers would love to see this beast, but it's quite astonishing that many have succeeded. This isn't an undertaking for the faint of heart. Those who have succeeded are accomplished observers working under excellent skies and using magnifications of about 400×. Most used 50-cm and larger telescopes, but some triumphed with scopes as small as 31.8 cm in aperture. From the heart of the galaxy, the jet strikes out west-northwest for about 21″, but the part that is most likely to be visible is the stretch from 12″ to 18″. If you decide to attempt this feat, be careful not to mistake the extremely faint galaxy pair (UGC 7652) 2′ southwest of M87 for the jet.

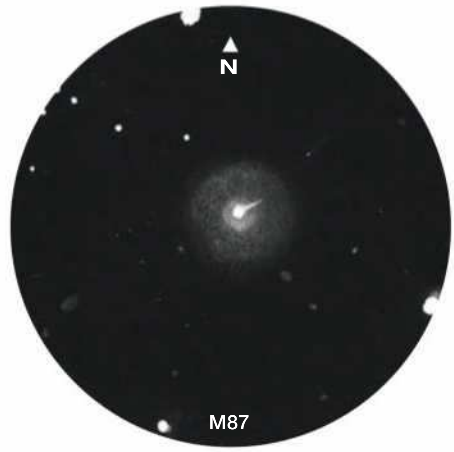
Placing M87 in the western side of the 130-mm scope's 23× field of view brings **Messier 89** into view, looking smaller than M87 and round with a bright centre. At 63× M89 displays a moderately faint halo, a brighter interior and a small, intense core — all round. Boosting the magnification to 117×, the scope teases out a starlike nucleus. The galaxy's halo fades into the background sky at a diameter of about 2′. My 25-cm scope at 166× reveals a 13th-magnitude star watching over the halo's east-northeastern edge.



▶ Under very high power, the irregular structure of the barred spiral M58 may be revealed. The typical view through an 20-cm reflector is shown here. The galaxy is tipped slightly toward the east-northeast and appears brighter at its core.

On deep images, M89 sports what appears to be a jet that extends a whopping 10′ from the galaxy's centre. However, this 'jet' is composed of stars and may be the product of an encounter with a smaller galaxy.

Only 20′ south of M89, we find the galaxy pair **NGC 4550** and **NGC 4551**. In a 1992 *Astrophysical Journal* paper, Vera Rubin and colleagues published an amazing find. Rubin later commented, "I discovered from observations of NGC 4550 that in the single disk of this galaxy, half the stars orbit clockwise, and half the stars orbit counterclockwise, both systems intermingled. This observation required that many astronomers modify the manner in which they measured velocities, for computer programs were not then equipped to handle such complexity. A nice discovery to make at age 63!" Few galaxies are known to have such a large dichotomy, a feature that might be due to the merger of two galaxies with misaligned spins.



▲ With the right equipment, you may be able to detect the high-energy jet of particles emanating from M87's supermassive black hole. This sketch represents the plasma stream as viewed with a 50-cm Newtonian reflector and deep sky video camera.

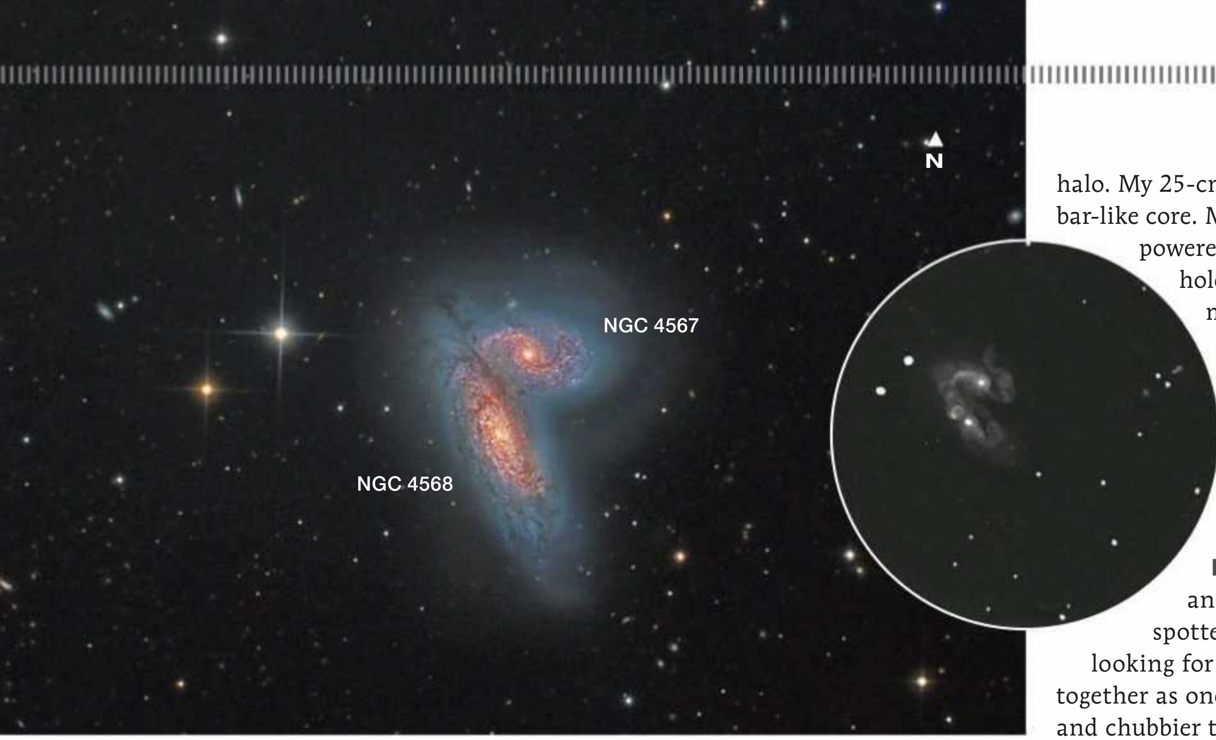
With a wide-angle eyepiece that gives 117× through the 130-mm scope, NGC 4550 and NGC 4551 share the field of view with M89. The very faint, 1½′-long, north-south spindle of NGC 4550 is enclosed in a trapezoidal box of four stars, magnitudes 12 and 13. The box is 5½′ tall, with the galaxy just beneath (west of) its lid. Dimmer and

Galaxies in Virgo

Object	Type	Mag(v)	Surface Brightness	Size/Sep	RA	Dec.
M87	Giant elliptical	8.6	13.0	8.3′ × 6.6′	$12^h\ 30.8^m$	+12° 23′
NGC 4478	Elliptical	11.5	12.6	1.9′ × 1.6′	$12^h\ 30.3^m$	+12° 20′
NGC 4476	Lenticular	12.2	12.8	1.7′ × 1.1′	$12^h\ 30.0^m$	+12° 21′
M89	Elliptical	9.8	12.5	5.1′ × 4.7′	$12^h\ 35.7^m$	+12° 33′
NGC 4550	Barred lenticular	11.7	12.7	2.9′ × 0.8′	$12^h\ 35.5^m$	+12° 13′
NGC 4551	Elliptical	12.0	13.0	1.8′ × 1.4′	$12^h\ 35.6^m$	+12° 16′
M58	Barred spiral	9.7	13.1	5.9′ × 4.7′	$12^h\ 37.7^m$	+11° 49′
NGC 4564	Elliptical	11.1	12.9	3.5′ × 1.5′	$12^h\ 36.5^m$	+11° 26′
NGC 4567	Spiral	11.3	13.1	3.0′ × 1.4′	$12^h\ 36.5^m$	+11° 15′
NGC 4568	Spiral	10.8	13.1	4.3′ × 1.0′	$12^h\ 36.6^m$	+11° 14′

Angular sizes and separations are from recent catalogues. 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.

M58: JEREMY PEREZ; M87: DALE HOLT



▲ *Above:* Because NGC 4567 and NGC 4568 are in the early stages of their merger, the structure of their spirals is still obvious. This LRGB image shows what can be captured of the interaction with a 43-cm astrograph (total exposure time = 18 hours). *Inset:* Dale Holt's video setup also revealed the distended halos of the two galaxies.

vaguely oval, NGC 4551 rests atop the lid and covers a petite ¾′. Both galaxies are easily seen through the 25-cm scope at 115×. NGC 4550 presents a large, brighter, elongated interior, while NGC 4551 bears a broadly but only slightly brighter interior. At 187× NGC 4550 stretches across 2′. NGC 4551 is a fat oval tipped east-northeast, bridging 1′ and holding an elusive stellar nucleus.

Messier 58 shares the field of view with M89 through the 130-mm refractor at 23×. Compared to its field mate, M58 is larger with lower surface brightness, but it grows more luminous toward the centre. An 8th-magnitude star sits 7.6′ due west. At 63× its oval form tips east-northeast, and at 117× the oval enfolds a tiny, vivid nucleus and is swathed in a rounder, dim, 3½′ halo. My 25-cm reflector highlights a bar-like core. M58's blazing nucleus is powered by a supermassive black hole (weighing in at 50 to 70 million solar masses) fed by an accretion disk of infalling matter.

Three additional galaxies are visible in the refractor's low-power field. Although they are fairly faint, **NGC 4564**, **NGC 4567** and **NGC 4568** were spotted without specifically looking for them. The last two blend together as one glow that's brighter and chubbier than NGC 4564. At 117× NGC 4564 displays a brighter, elongated interior and a small, radiant core. The faint halo is about 2′ long and less than half as wide. Even at 164× the dual nature of NGC 4567/4568 isn't clear, but the combo's subtly wider north end and two fugitive, marginally brighter patches hint at the possibility.

The NGC 4567/4568 galaxies are well distinguished through the 25-cm scope at 115×, each galaxy holding a somewhat brighter, elongated interior. NGC 4568 is about 3′ × 1′, tipped north-northeast, and harbours a tiny nucleus. NGC 4567's oval spans 2¼′, tilts a bit north of east, and embraces a small, brighter core. The halos of the galaxies merge at the eastern end of NGC 4567, which earns this pair its nickname, the Siamese Twins.

Because they look relatively undisturbed through the eyepiece and in deep sky images, the Siamese Twins were once thought to be a coincidental superposition of two unrelated galaxies. However, recent studies of their molecular gasses have found telltale signs indicating the galaxies are in the early stages of gravitational and tidal interaction.

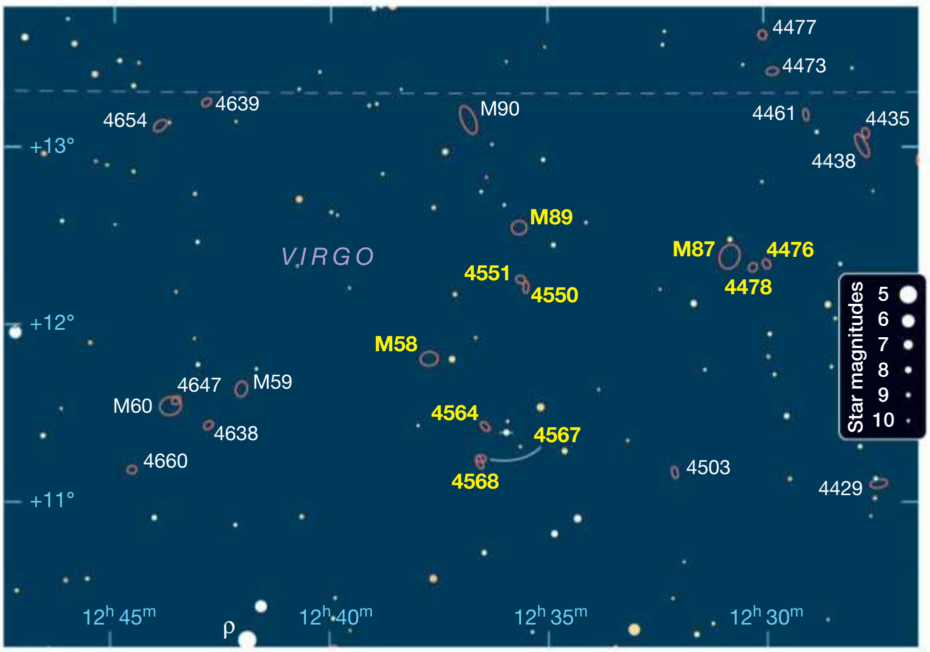


PHOTO: BILL SNYDER; SKETCH: DALE HOLT

■ Contributing Editor **SUE FRENCH** welcomes your comments and observing stories. She can be reached at **scfrench@nycap.rr.com**.

Living in the lunar shadows

Challenging to spot, some lunar rilles might someday shelter astronauts from harm.

Lunar craters have undeniable appeal when seen through a telescope, but eventually you'll want to explore the subtle details found splayed across the Moon's vast lava plains. High on my list are *sinuous rilles,* snakelike 'riverbeds' that sometimes meander across the maria for hundreds of kilometres. They're worth studying because one of them might someday serve as a habitat for visiting astronauts.

This is an old idea, dating back to the 1960s and early 1970s, when geologists realised that these winding features weren't formed by flowing water but by flowing lava. Dale Cruikshank (now at NASA Ames Research Center) and I were among those who proposed this explanation. We'd noted how fluid eruptions from Hawai'ian volcanoes tend to develop channels that efficiently transport lava downslope.

Splashes of lava solidify along the edges of these channels and gradually build levees that in some cases grow to span the flow's entire width. This insulating cap keeps the lava underneath from radiating heat away quickly, allowing it to flow further. Pieces of the roofs of some tubes collapse, creating 'skylights' that expose torrents of hot lava flowing below.

Future astronauts might descend into a hollow, long-frozen lava tube on the Moon to gain shelter from cosmic rays and small impact events, and to moderate the extreme temperature swings (300°C) that the surface endures over a 29½-day-long lunar diurnal cycle.

More common than thought

Among a comprehensive census of 195 sinuous rilles compiled by Debra Hurwitz while a graduate student at Brown University (see **lpi.usra.edu/lunar/rilles**), only six are known to have skylights. It seems that most channels were too wide for roofs to form and be supported.

Unfortunately, these six skylights are relatively tiny. The largest are only about 100 m wide, far too small for even the best telescopes to spot. Areas between lines of skylights should be uncollapsed lava tubes — in theory, at least.

Two teams have recently used different geophysical measurements to provide more direct evidence that such tubes exist. Loïc Chappaz (Purdue University) and six colleagues analysed the very precise measurements obtained by NASA's twin Gravity Recovery and Interior Laboratory spacecraft. Since a lava tube is empty space, it's detectable as a tiny deficit of mass. The Chappaz team delicately tweaked GRAIL's data to find indications of 11 lunar tubes — some extending beyond sinuous rilles, some between skylights, and some with no surface expression at all.

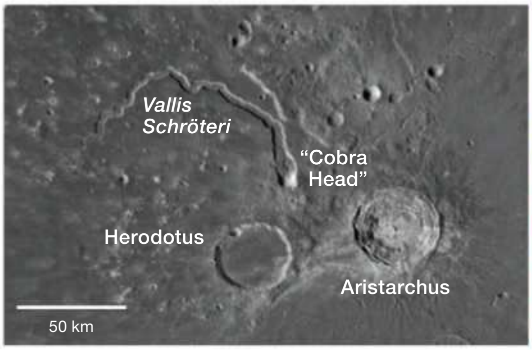
Among the most conspicuous is an extension beyond the end of the 'mega-rille' **Vallis Schröteri** (Schröter's Valley). The researchers model this tube as being 60 km long, 3.75 km wide, and an amazing 600 m tall. It apparently starts near the end of Schröter's Valley and extends out to the southwest under younger lavas that overlap the edges of the Aristarchus Plateau.

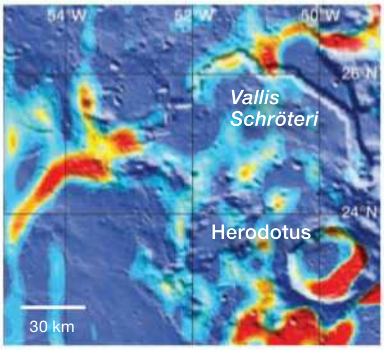
They identified another lava tube near two large rilles in the western Marius Hills. That's where spacecraft imagery revealed a 65-m-wide skylight, evidence for a relatively recent collapse. The tube continues 60 km past the end of the surface rille and apparently is much broader than the 400-m-wide channel seen on the surface.

The final large gravity anomaly

▲ An opening or 'skylight' on Mauna Ulu in Hawai'i reveals molten rock flowing through a lava tube just below the surface. Lunar rilles likely have hidden, but no-longer-active lava tubes as well.

DALE CRUIKSHANK





▲ *Left:* The 'mega-rille' Vallis Schröteri (Schröter's Valley) snakes across the lunar surface for hundreds of kilometres. *Right:* New results from GRAIL spacecraft data suggest that a hollow tube (red band left of centre) extends below the surface beyond the rille's southwestern end.

found by Chappaz's group appears to connect the southern ends of **Rima Sharp** and **Rima Mairan** in Sinus Roris. Then it continues to the north end of a bizarre 'braided rille' (likely a complex lava tube) due south of the 40-km-wide crater **Mairan**.

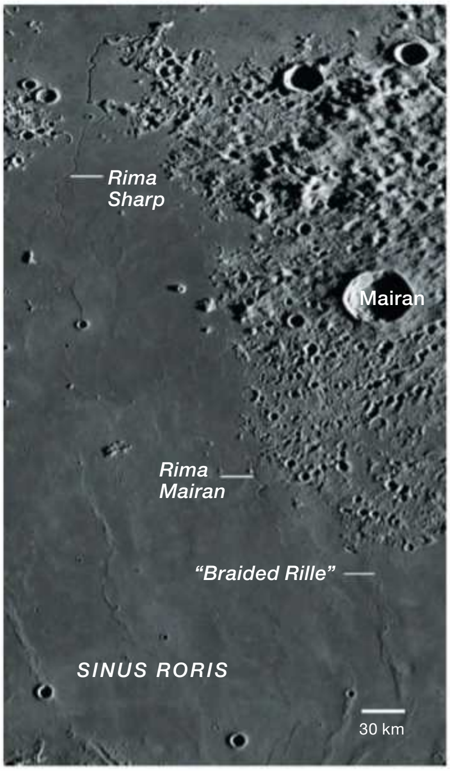
It seems strange that one tube would connect all of these lava channels around Sinus Roris, for this kind of linking doesn't happen on Earth. It's also perplexing to find tubes so much wider than the surface rille. In terrestrial cases, the tube is just a roofed channel — so they're the same width.

The Japanese lunar orbiter Kaguya has provided confirmation of tubes in the Marius Hills. Kaguya's Lunar Radar Sounder generates radio-wave pulses that penetrate tens to hundreds of metres into mare lavas, and then records echoes reflected from subsurface layers. Tesuya Kaku (Japan Aerospace Exploration Agency) and colleagues have detected numerous linear voids near the Marius Hills rilles that they believe come from the floors and ceilings of lava tubes.

Would these make suitable habitats for astronauts? Perhaps not. All of the lava tubes that I've entered had floors littered with collapsed roof blocks and stalactites hanging from their ceilings. Such sharp rocks and surfaces could make walking difficult or easily puncture an inflatable habitat or spacesuit. And access through a partially collapsed skylight could be tricky. It might be necessary to use a winch to get astronauts and their equipment into and out of an underlying tube.

Elusive quarry

Usually less than 1 km wide, lunar rilles are challenging to observe. Those with roofs (lava tubes) are even more difficult to detect, unless they have skylights — but even then it will be a struggle to glimpse them.



▲ The lunar rilles Rima Sharp and Rima Mairan snake along the eastern shore of Sinus Roris and might be part of an interconnected regional network of ancient lava tubes.

Still, the areas where they occur are readily observable. Easiest is the western end of Schröter's Valley, the widest lunar rille. You'll need a telescope with at least 75 mm of aperture; look 12 or 13 days after new Moon.

The nearby Mairan and Sharp rilles are both narrower than 1 km and would be nearly impossible to visually observe — except that parts of their lengths run nearly north to south. This means that, after local sunrise (likewise 13 days after new Moon), their eastern walls cast shadows onto their floors that appear like narrow black lines in the maria. Use 150× to 200× and a scope with a 15-cm or larger aperture to explore the area.

On the same night that you search for Schröter's Valley and the rilles in Sinus Roris, slide farther south along the terminator to the **Marius Hills**, a collection of nearly 200 volcanic cones, domes and rilles. Although too narrow to resolve visually, the rille and its associated skylight and lava tubes occur near the middle of this mass of mounds.

Not all rilles are in the maria. Using Lunar Reconnaissance Orbiter images, Pascal Lee (SETI Institute, Mars Institute) found that **Philolaus**, a young, 70-km-wide crater poleward of the western end of Mare Frigoris, has many small rilles and some skylights on its floor. These formed in impact melt that must have flowed after being ejected upward and then falling back to the surface. The rilles are too small to be observed, but the nearly 20-km-long patch of smooth impact melt can be glimpsed on the eastern floor of the crater.

As you observe the Marius Hills and the Sharp and Mairan rilles, imagine what it would be like to live in one of their tubes — with a skylight providing night views of an inky-black sky littered with stars.

■ **CHUCK WOOD** singed his eyebrows in 1971 while photographing a lava-tube skylight in an active flow on Kilauea in Hawai'i.

PHOTOS: NASA / LUNAR RECONNAISSANCE ORBITER; COLOUR PLOT: CHAPPAZ *ET AL* / *GEOPHYSICAL RESEARCH LETTERS*

Jupiter's time to shine

The Solar System's greatest gas giant will put on a bold appearance as it reaches opposition in May.

▲ This colour-enhanced image, taken as the spacecraft Juno flew by Jupiter on December 16, 2017, shows the intense storm patterns in the cloud bands of Jupiter's northern hemisphere.

NASA / JPL-CALTECH / SWRI / MSSS / BJÖRN JÓNSSON

Jupiter spent autumn creeping through the night. Just a few months ago, an audience with the Solar System's 'monarch' was an early morning pleasure, best taken care of before beginning the work day. Now, Jupiter appears with the dark, its rise coinciding with the setting of the Sun on May 9, the date of opposition. Jupiter rises about 30 minutes after sunset on the first evening of May and sets about two hours before the first sunrise of June, which means Jove is up the entire night during May, for all practical purposes. Even more important for visual observers: Jupiter is highest, and thus in the steadiest part of the sky, in the middle of the night. It transits about 45 minutes after midnight on May 1 and 70 minutes before midnight on the 31st. Altitude is essential for the best view of this gas giant; when Jupiter is up high, out of the haze above the horizon, you'll have the best shot at steady seeing (i.e. looking through less atmospheric turbulence).

Observing the giant

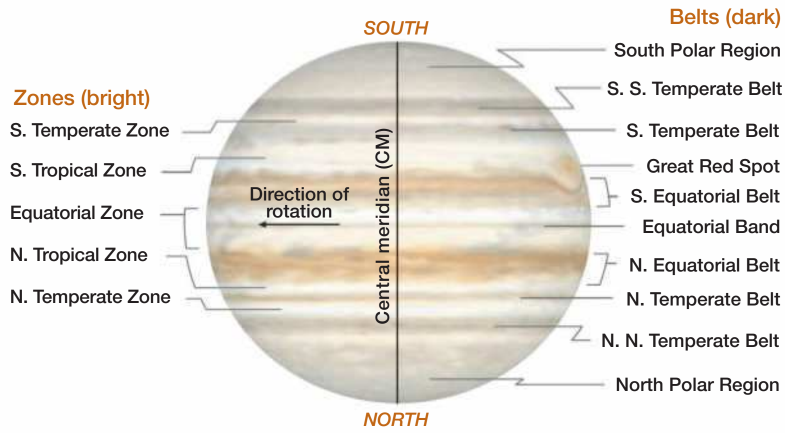
Even in the steadiest part of the sky, good observations of planets happen a millisecond at a time. Improve your views by setting up your optics early in the evening to let them adjust to the ambient temperature. Then, when Jupiter rides high in the sky, focus on the planet's edge and settle in for a good, long study session. The moments of absolute clarity are fleeting, and you'll find yourself instinctively testing your focus every now and again. It's good to check every once in a while, but patience is really your best tool here.

Once you've found the planet and tested your focusing skills, increase the magnification. You'll find Jupiter goes a bit blurry pretty quickly. With my 12.5-cm, f/5 reflector, I stop trying for more by the time I hit 150×. The 25-cm f/4.5 reflector shows Jupiter at its best around 250× or so, though occasionally a bit more power is better. It's tricky to find the perfect balance of magnification and sharpness, but that's part of the observing fun.

If you're having difficulty distinguishing Jupiter's atmospheric features, add a filter to your setup. Over the years, I've found a #80A (blue) filter to be the most useful for 'bumping' the contrast of the cloud bands, but #38A (dark blue) and #82A (light blue) may be better for you — try them all if you have them. Many observers find #8, #11, and #12 (yellow and yellow-green) filters help draw out details in the belts and polar regions. I sometimes screw on a #25 (red) filter for kicks and contrast, but usually return to a blue filter after a few minutes.

One of the great things about Jupiter is that our view of it changes relatively quickly. One Jovian revolution takes just under 10 Earth hours, so if you observe early, then return to the planet later that night, you'll see a decidedly different picture. The diagram at the right shows Jupiter's main markings. Through a small scope, you should be able to see the two major cloud bands, the South and North Equatorial Belts. From there, it's a matter of spotting subtleties. Jupiter's *belts*, both equatorial and temperate, are slightly ruddy or beige through the eyepiece. They're separated by brighter, whiter bands called *zones*. Distinguishing white-ish zones from wheat-ish belts is a full night's work.

Within the zones and belts rage storms. Look for these *ovals*, tight gatherings of clouds that dot Jupiter's bands. White ovals, which often develop in the South Temperate Belt, can really 'pop' through the eyepiece. Ovals can also be red, as in the Great Red Spot, or grey. *Barges* resemble compressed ovals; they're dark and red, but somewhat linear or blocky. Study the belts for variations in colour caused by *rifts*, long, bright streaks that stretch along the darker bands. Readily apparent in images but more elusive to the eye are *festoons*, tendril-like blue-grey features that angle into zones from a belt.



▲The features of Jupiter change in intensity, size and position over time; this basic schema should help you identify what you see through your eyepiece. South is up to match the view in many telescopes. Features rotate from celestial east to west.

The Great Red Spot

If you time your observing to coincide with the transit of the Great Red Spot (GRS), the changes on the planet's face become even more obvious. The GRS, which sits in a pocket between the South Equatorial Belt and the South Tropical Zone called 'Red Spot Hollow,' can be a challenge for observers with small scopes. Your best chance at seeing it is within an hour of the time it crosses the planet's central meridian. Here are those crossing times, in Universal Time, as predicted for late April and May. The dates, also in UT, are in bold.

April 15, 1:41, 11:37, 21:32; **16,** 7:28, 17:24; **17,** 3:19, 13:15, 23:10; **18,** 9:06, 19:01; **19,** 4:57, 14:53; **20,** 0:48, 10:44, 20:39; **21,** 6:35, 16:31; **22,** 2:26, 12:22, 22:17; **23,** 8:13, 18:08; **24,** 4:04, 14:00, 23:55; **25,** 9:51, 19:46; **26,** 5:42, 15:37; **27,** 1:33, 11:29, 21:24; **28,** 7:20, 17:15; **29,** 3:11, 13:07, 23:02; **30,** 8:58, 18:53.

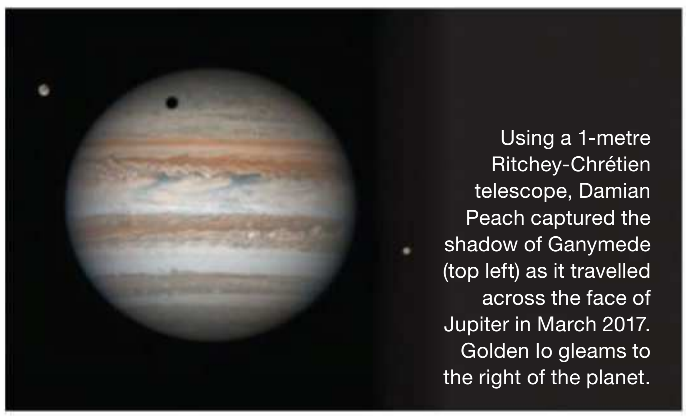
May 1, 4:49, 14:44; **2,** 0:40, 10:36, 20:31; **3,** 6:27, 16:22; **4,** 2:18, 12:14, 22:09; **5,** 8:05, 8:00; **6,** 3:56, 13:51, 23:47; **7,** 9:43, 19:38; **8,** 5:34, 15:29; **9,** 1:25, 11:21, 21:16; **10,** 7:12, 17:07; **11,** 3:03, 12:59, 22:54; **12,** 8:50, 18:45; **13,** 4:41, 14:37; **14,** 0:32, 10:28, 20:23; **15,** 6:19, 16:14; **16,** 2:10, 12:06, 22:01; **17,** 7:57, 17:52; **18,** 3:48, 13:44, 23:39; **19,** 9:35, 19:30; **20,** 5:26, 15:22; **21,** 1:17, 11:13, 21:08; **22,** 7:04, 17:00; **23,** 2:55, 12:51, 22:47; **24,** 8:42, 18:38; **25,** 4:33, 14:29; **26,** 0:25, 10:20, 20:16; **27,** 6:11, 16:07; **28,** 2:03, 11:58, 21:54; **29,** 7:50, 17:45; **30,** 3:41, 13:36, 23:32; **31,** 9:28, 19:23.

These times assume that the spot will be centred at System II longitude 288°. If the Red Spot has moved, it will transit 1⅔ minutes earlier for each degree less than 288° and 1⅔ minutes later for each degree more than 288°.

Jupiter's moons

With Jupiter at opposition the planet is at its boldest and brightest for the year, and so too are its Galilean moons. With close observing and the right equipment, you can detect differences in their sizes and colours (Io gives itself away with its orange-yellow appearance, Ganymede is the largest of the four). At opposition, Europa will appear the smallest, with a diameter of 1.0″. Io will show at 1.1″, Callisto at 1.5″, and Ganymede will boast a whopping 1.7″ diameter. Yes, these are tiny differences, but after enough repeat visits to the quartet, you'll be able to distinguish them from one another with ease.

Take the time to make a sketch, keeping in mind that a polished drawing isn't necessarily the goal. Rather, it's the process of looking while you're recording the view that will help you learn the planet. Don't worry about your cramped handwriting or inability to replicate the subtle bands of Jupiter's globe on the page. Even a 'sketch in prose' can be useful: What colour are the belts? Can you see any texture in them? Did you see the Great Red Spot? How were the planet's satellites positioned? Anything that helps you remember those brilliant moments of perfect seeing is good enough to put on paper. My best advice: If you think it, write it down, because you're unlikely to remember that thought or impression after a short night's sleep.



Using a 1-metre Ritchey-Chrétien telescope, Damian Peach captured the shadow of Ganymede (top left) as it travelled across the face of Jupiter in March 2017. Golden Io gleams to the right of the planet.

GANYMEDE: DAMIAN PEACH / CHILESCOPE TEAM; JUPITER DIAGRAM: GREGG DINDERMAN / S&T

Spotting Jupiter's famous spot

Timing is everything when it comes to glimpsing the iconic Great Red Spot. Steady seeing helps too.

▲The seeing was nearly perfect on May 19, 2017, when veteran planetary photographer Christopher Go captured the Great Red Spot marching across Jupiter's disk. The date was six weeks after the planet's opposition, and he recorded the images with a 35.6-cm telescope over a span of 52 minutes. South is up.

Ask your astronomically curious friends to name a famous feature on another planet, and the top choice will almost certainly be Saturn's rings. A strong runner-up will likely be Jupiter's Great Red Spot. Yet while most casual telescope users have gazed upon those glorious rings many times, far fewer have ever spied Jupiter's iconic GRS. So for those of you longing for your first glimpse of it — or just wanting another look — read on!

This year Jupiter comes to opposition on May 9. That's when this giant planet will appear its biggest (45 arcseconds across) and brightest (magnitude –2.5), and it'll be nearly as big and bright for several weeks before or after this date.

Even though it's not an entirely favourable opposition — in September 2010, Jupiter swelled to 50 arcseconds and magnitude –2.9 (nearly 50% brighter) — on the plus side, the planet's southern declination (–16°) this year means the planet will be nice and high in the sky for southern observers.

The GRS itself — an enormous, high-pressure (anticyclonic) 'storm' rotating every 6 days — has undergone a modest metamorphosis of late. If you haven't looked for the spot in the past decade, you'll be surprised by how much it's changed in the intervening years.

Shrinking and shifting

The GRS has gradually become smaller since telescopic observers made the first reliable measurements of its size in the 1880s. A century ago, for example, the Great Red Spot was 2½ times longer than it is now.

However, as Amy Simon (NASA Goddard Space Flight Center) and her colleagues detail in a forthcoming *Astronomical Journal* article, the rate of that shrinking accelerated by about 50% beginning about 1979, the year that Voyagers 1 and 2 made their historic flybys of Jupiter.

Today the GRS's longitudinal length is just 13.7°, or about 15,500 km. The width has shrunk too, down to just under 10° in latitude (12,000 km). It's still bigger than Earth — but not by much.

Meanwhile, the spot doesn't stay put. It's sandwiched at latitude 22½° south between a strong, westward-flowing jet stream to its north and an equally strong eastward jet to its south. The GRS spins counterclockwise like a giant ball bearing rolling between them, creating an oversize obstacle that deflects the jets as they flow past.

A little background: Jupiter rotates *differentially.* Its deep interior spins once every 9.925 hours ($9^h\ 55^m\ 30^s$), at what's called its System III rotation period. But the cloudtops within 10° of the equator zip around 5 minutes *faster* (System I) — while at the GRS's latitude, the mean rotation period (System II) is about 11 seconds *slower.*

Observers had long thought that the GRS spun around Jupiter at the System II rate, but it's actually lagging behind and gradually drifting westward with respect to all the cloud features around it. Simon and her team find that the GRS's westward drift has also accelerated in recent years, and they're struggling to understand the steering forces that could be causing it to move faster.

"The biggest factor is the surrounding winds," she explains, perhaps due to very slight changes in the latitudes of the adjacent zonal jets. But the effect is hard to measure since the GRS deflects those same winds. And the spot can be buffeted by disturbances that churn up the jets and other effects. "We have hints," Simon says, "but nothing has been conclusive."

The good news in all of this morphing is that the Red Spot has gotten redder and darker over the past decade. (Historically, the spot's colour seems to intensify when its westward drift accelerates.) The cause of the darkening isn't clear, but Simon suspects it has to do with conservation of angular momentum. As the spot shrinks, its internal circulation should speed up — but it hasn't. Instead, the swirling gas might be forced to go to higher altitudes (and there's evidence this is occurring), where lower pressures and temperatures might be driving 'colourful' chemical reactions.

The actual chemical compound responsible for the spot's ruddy hue is still unknown. Some candidates, like red phosphorous derived from phosphine (PH_3), aren't wholly consistent with the chemical makeup of the Jovian atmosphere. In 2016 Robert Carlson (Jet Propulsion Laboratory) and others suggested that the colour results from the reaction of ammonia (NH_3) and acetylene (C_2H_2). Recently a team led by Lawrence Sromovsky (University of Wisconsin at Madison) argued that this same compound could explain the hues of many other Jovian cloud features.

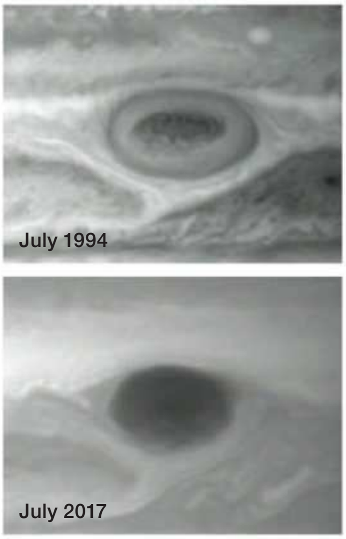
Timing Is everything

Chemistry aside, the Red Spot's now-deeper colour makes this a great time to try to spot it. But don't just dash outside with your scope — a little preparation is called for.

Most critically, you'll need to know when the GRS is front and centred on Jupiter's rapidly spinning globe. Look at the list of times on page 57 to find when the spot crosses the planet's *central meridian* (the north-south line through its poles). Don't forget to convert those values from Universal Time to your local time zone. Plan to look within an hour of a listed time — otherwise the spot will be close to the planet's limb and difficult to identify.

Ideally, chose a meridian-crossing time that occurs when Jupiter is high in your sky. You'll always see less detail when the planet is close to the horizon, both because of atmospheric turbulence along your line of sight and also due to the thick air's prism-like dispersion of colour in Jupiter's disk.

Next, use the Red Spot's colour to your advantage. A blue or green filter will make it stand out more readily from the surrounding clouds.



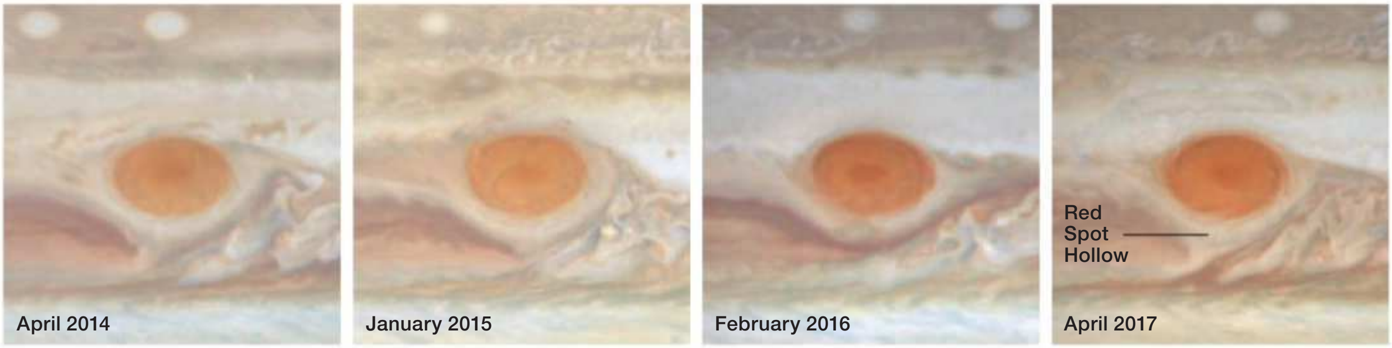
▲ These violet-filtered Hubble images accentuate the dramatic change in the GRS's size and interior structure over a 23-year period.

> "Use the Red Spot's colour to your advantage. A blue or green filter will make it stand out."

Finally, make sure your telescope is big enough. *AS&T*'s Sean Walker suggests that you'll need at least 100 mm of aperture to spot the GRS reliably. David Arditti (British Astronomical Association) adds, "For more experienced observers I have little doubt that a 75-mm refractor would be enough, under typical conditions, with a magnification of 80×."

Tony Flanders notes that the task will be much easier if the atmosphere is stable. "I find the variation in visibility from night to night due to seeing swamps the variations depending on the GRS's appearance," he cautions. "On a half-decent night, it should be prominent through a good 100-mm refractor or 15-cm reflector."

In fact, if you have two scopes, try setting them up side by side at comparable magnifications to see which one most easily coaxes the GRS into view. And if the spot itself isn't apparent, look for the 'Red Spot Hollow,' a bright indentation that the spot makes in the broad, dark South Equatorial Belt to its immediate north.



NASA / AMY SIMON (6)

▲ Natural-colour Hubble Space Telescope images show how the Great Red Spot's hue has darkened and deepened since 2014. The spot creates pronounced turbulence in the westward flow of the South Equatorial Belt (lower right in each image).

What makes a Great astrophoto?

BEST OF THE BEST The most memorable astrophotos are much like the best of other types of photography. They contain wonderful colour, contrast and elegant composition, like this famous Hubble Space Telescope image of M16, popularly known as the 'Pillars of Creation'.

NASA / ESA / HUBBLE HERITAGE TEAM (STSCI / AURA)

Recognising what goes into an outstanding image can help to improve your own work.

We've all marvelled at the amazing celestial images produced by both amateurs and professionals. From dazzling pictures of the Milky Way arching over an equally majestic landscape, to glittering portraits of spiral galaxies exploding with starbirth, we all know a great image when we see one.

So what actually makes for a supurb astrophoto? This question is surprisingly difficult, if not impossible, to answer. One reason is that our personal tastes are often as unique as individual snowflakes — beauty is in the eye of the beholder. What one person finds attractive might not make the grade in someone else's eyes. Another reason is that often it is a combination of things that takes an image to a higher level. Still another consideration is the subject — what makes for an outstanding nightscape image will be completely different than, say, what makes an outstanding planetary picture. So let's look closely at elements found in images that most can agree are top-notch, and incorporate those into our own photographs.

Focus

One of the first things we notice in any astrophoto is whether it's in focus. To be fair, it can be quite tricky to nail down focus with most astrophotographs. With the exception of images recorded from space-based observatories and planetary exploration missions, every astro-image you see is shot through Earth's usually churning atmosphere, bad 'seeing' that often results in fuzzy, blurry photos. And while some detail can be rescued using sharpening filters or complex astronomical deconvolution filters, nothing can completely make up for a poorly focused image.

Fortunately, we can mitigate the effects of seeing in our images in several ways. Monitoring the weather and seeing conditions is easy using websites or smartphone apps that give detailed predictions to let you know when the air is steady or not.

You can still take sharp astro-images in poor seeing if you switch your pixel scale to better match the conditions you're shooting in. For instance, if the seeing produces bloated stars measuring about 3 or 4 arcseconds across, you can switch to a short-focal-length instrument with your camera that produces an image scale of around 4 arcseconds per pixel. Also, if you're using an astronomical CCD or CMOS camera, you can bin the pixels, which groups four adjacent pixels together to function as a single pixel, reducing the resolution of your camera and masking the ill effects of poor seeing. If the seeing is really bad, you can simply switch to low-resolution, wide-field imaging, targeting entire constellations, or even photographing nightscapes. The trick is to match your equipment to the conditions you're shooting under.

Tracking

One aspect unique to astrophotography, compared to other types of photography, is tracking. Because our planet rotates, objects in the sky outside of the atmosphere are perpetually moving with respect to your camera and telescope. This requires a way to cancel out that movement using a motor-driven mount aligned to Earth's rotational axis. Good tracking is most important in telescopic close-ups of galaxies, nebulae and star-clusters — faint targets that require long exposures to reveal them properly. Perfect tracking also ensures you're able resolve the smallest details possible for your equipment. Otherwise, small-scale features become smeared, mimicking poor focus.

Few mounts track perfectly — most have small, repetitive errors known as *periodic error* that require corrections during an exposure. You can deal with this by attaching an additional camera (called an autoguider) to a guide scope or off-axis guider that monitors a single star during the main exposure, and automatically makes small corrections to ensure a perfectly guided image.

Fortunately, perfect tracking isn't necessary for every astrophoto. Because the Sun, Moon and planets are relatively nearby and bright, they can be adequately recorded in exposures of a fraction of a second and thus only require enough guiding to keep the target on your camera's detector.

One type of astrophotography that doesn't require tracking at all in most cases is nightscape photography. Shooting the night sky over a picturesque landscape with a simple camera-on-tripod setup and wide-angle lens produces such low resolution that you can get away with exposures of, say, 10 seconds without any noticeable trailing.

There is a simple formula known as the '500 rule' that calculates how long an exposure can be with a particular lens: $500 / fl = T$, where fl is the focal length of your lens, and T is how long you can expose before stars noticeably trail. This works especially well with today's low-noise DSLR and mirrorless cameras operating at high ISO settings, enabling you to capture subjects like the Milky Way over a picturesque landscape, plus meteor showers and aurorae. In fact, some trailing in a nightscape image doesn't detract from the overall scene, so you can shoot up to 30 seconds with fisheye and other extremely wide-angle lenses.

Colour, contrast and saturation

Unless you're shooting the Moon or concentrating on a specific monochromatic wavelength of light such as hydrogen-alpha, pleasing colour is an extremely important aspect in the best astrophotos. Note that I say *pleasing* rather than *accurate* — colour perception is somewhat subjective, and most people experience colour slightly differently. False-colour narrowband imaging has become quite popular as well.

That said, a natural-colour image of the night sky taken from a dark site should generally have a neutral sky background. The reddish-brown cast recorded in nightscape

▲ **SLIGHT TRAILS** While deep sky pictures require perfectly tracked images that produce round stars, nightscape photos aren't as stringent. This wide-angle, 30-second photo looks quite nice even with slightly trailed stars.

▲ **NOT BLACK** Establishing good contrast in a deep sky photo doesn't simply mean making the sky black and the stars white. Setting the background sky to black would have lost all of the beautiful dust in this exquisite image of NGC 7497.

photos should be corrected, with the exception of reddish or greenish natural airglow. Likewise, a high-resolution image of a spiral galaxy should still allow your eye to determine where the galaxy ends and the sky background begins. Determining this boundary in a sprawling nebulous field can be tricky but still manageable.

Even tri-colour narrowband images of deep sky objects, which rely on various false-colour palettes or combinations, still require a pleasing colour balance in order to present the varied hues that occur when ionised elements interact. If we were to be truly accurate, most tri-colour narrowband images would be dominated by the colour that hydrogen-alpha is assigned to in an image (often green), because it is the most pervasive element in the universe, compared to sulfur II or oxygen III. But to best display the colourful interactions of these elements, imagers equalise the exposures in an image.

Planetary photography also benefits from a pleasing colour balance. For instance, while Mars is a tawny-orange colour (though not saturated), blue and white are often seen in its thin clouds near the planets limb, and its occasional dust storms have a distinctive yellow hue. A related aspect of colour is *contrast*. Astrophotos are tricky to establish proper contrast in, because most targets are seen against a dark sky. You'd think that simply making the background black would be the easiest step, but actually that's not the case. For one thing, there is no truly 'black' sky as seen from Earth's surface. There are very few places where some artificial light pollution isn't visible somewhere in the sky. But our planet's atmosphere itself emits a small amount of light called *airglow*. This is commonly seen in nightscape photos taken from dark sites, though airglow can sometimes be very noticeable even from rural locations. I've recorded skyglow in backyard nightscape images taken just a few kilometres from my nearest large city.

Given these caveats, deep sky and nightscape imagers should strive to establish a dark, neutral background sky, but it shouldn't be completely black, so that faint nebulosity or the outer extent of spiral galaxies will still be visible in your image. Setting the background to pure black during image processing (known as clipping) often erases these subtle features from an otherwise excellent image.

The only exceptions to this 'dark but not black sky' rule in astronomical photography would be lunar and planetary images. Shadows in lunar craters really will be black, particularly since the Moon lacks any appreciable atmosphere to scatter light. Planet images generally appear to be surrounded by inky black skies because of the high focal lengths required to magnify the target enough to resolve details; planetary imagers often shoot at focal ratios of f/20 or more, which translates into highly magnified views, reducing the background sky brightness.

This brings us to saturation. While we all marvel at the colourful images of galaxies, nebulae, and star clusters in the pages of this magazine and elsewhere, the colours of most of these objects are not the blazing magentas or electric blues that are often depicted. The colours of deep sky objects are actually more pastel and subdued (watch for an article on this subject in an upcoming issue). The most colourful things we can see through a typical telescope are the stars, planets and the brightest planetary nebulae.

We are all guilty of pumping up the saturation for dramatic effect. That doesn't make it wrong, but there's a

SLIGHT TRAILS: SEAN WALKER / *S&T*; ADAM BLOCK / MOUNT LEMMON SKYCENTER / UNIVERSITY OF ARIZONA

SOLAR ANGLE Composing interesting images of the Sun, Moon and planets can be challenging, since all are simply round objects surrounded by a blank sky. But special events can offer unique opportunities. When photographing last August's total solar eclipse, the author planned everything long in advance, though in the excitement of the moment, camera orientation was left to chance. Fortunately, the error produced a better result than originally planned.

▼ **RICH COLOUR** When increasing the saturation in your pictures, take care to monitor each colour channel and avoid over-saturating the result, which presents problems when printing your results. This detailed image of the Horsehead Nebula, Barnard 33, displays richly saturated colour without going overboard. Here north is to the left.

limit to how far we can push the colour saturation before it becomes garish and detracts from the final image. One way to avoid over-saturating your images is to monitor the individual colour channels in your favourite image-processing program. For instance, when increasing the saturation of an emission nebula, pay close attention to the red channel. Make sure that detail is still apparent in the brightest areas and doesn't appear overexposed after your adjustments.

Composition

Although composing an astronomical subject in an image can be tricky, it's still an important aspect of the best astrophotos. Composition in astrophotography is tough because most things in the night sky are so far away they are essentially motionless, at least on a human timescale. You can't simply move two star clusters closer together for that family portrait!

So take care when composing deep sky astrophotos. A perfectly tracked, well-processed image of a galaxy still looks odd if the subject is placed too close to one side of the picture frame. And a tiny planetary nebula in the middle of an image surrounded by a nondescript star field might have a better impact if it were shot at an adequate image scale that resolves lots of small-scale detail.

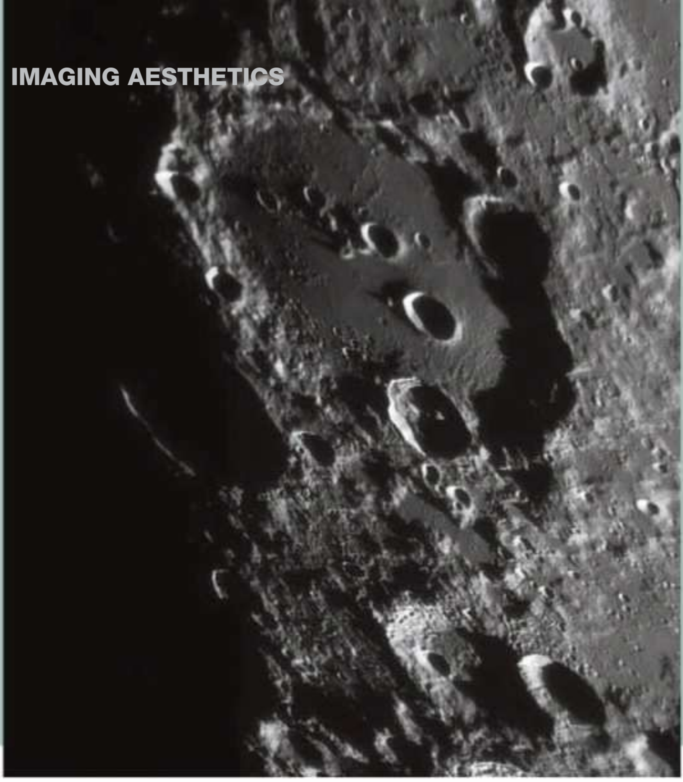
Spend time matching your target to your chosen equipment. There isn't much point spending an entire evening shooting a secluded, distant galaxy just 30 arcseconds across if your telescope and camera can only resolve 5-arcsecond objects or larger. That galaxy will only be about 6 pixels across in the final image!

Another aspect of composition is how your target is placed in the picture plane. A spiral galaxy like M104, the Sombrero Galaxy, might present a more dynamic composition if you rotated your camera slightly so that the long-axis of the target cuts across the frame diagonally rather than straight across.

These considerations also apply when imaging the bright planets. In particular, Jupiter offers more compositional choices than the other planets due to its size, extremely dynamic atmosphere, and retinue of Galilean moons, which can add up to four additional smaller detailed objects to a single composition.

Composing multiple adjacent targets in the same field presents its own challenges. Just because two objects can fit in the opposite corners of your camera's field doesn't mean it makes for a good composition. Each object in your image should have a comfortable space between it and the edge of the frame whenever possible.

ECLIPSE: SEAN WALKER / S&T; HORSEHEAD: KEN CRAWFORD



▲ **BLACK CRATERS** One of the few places that will be truly black in a good astrophoto is the shadowed region within lunar craters, like this image of sunrise in the crater Clavius demonstrates.

▲ **NIGHTSCAPE COMPOSITION** Nightscapes benefit greatly from good composition. Babak Tafreshi balanced this extremely bright aurora with its distorted reflection in the waters of a stream in Iceland.

The same rules apply to nightscape photography. Balancing your terrestrial and celestial targets in your picture frame is how you unify the scene. If you're planning to shoot a young crescent Moon alongside the Eiffel Tower, the photo might look better if you don't cut off the tower's base. Aurora photography is the same way: Balance your subject with elements in the foreground to make your photo attractive.

Composition is one aspect of astrophotography that you can modify *after* the image is taken. Today's digital cameras offer dozens of megapixels that make cropping easy and relatively painless. You can crop and rotate images of galaxies, nebulae, and most any subject — as long as you have enough pixels to work with. Cropping an image to better compose your subject is relatively easy, particularly if your picture has lots of extra space around the subjects. This is especially helpful when shooting faint moving targets such as comets with tails that are too faint to see through a camera's viewfinder.

Processing

Perhaps the most talked-about subject in astrophotography is image processing. While everyone's goal is surely to produce the best image possible, it's often tempting to add a little bit more sharpening or to boost the colour saturation. Knowing where to draw the line with the impressive tools available in astro-imaging software is definitely a learning curve. It takes time and experience to learn the difference between 'just enough' and 'going too far'.

In the best astrophotos, the viewer shouldn't look at the image and be able to identify which version of deconvolution was used or how much noise-reduction was applied. Good image processing is essentially invisible; it should allow the viewer to enjoy the picture without encountering processing artifacts. Stars aren't surrounded by dark rings, nor do they have dark cores. Likewise, the limbs of planets shouldn't appear like a melon rind, with a bright arc along the edge. These are all telltale signs of too much sharpening.

While I've listed some common attributes found in the best astrophotos, there's often much more to a stunning image than a list to check off when shooting the night sky. Some things you can't put a finger on beforehand, but you'll often recognise what works in the final composition. Keeping these elements in mind when planning and executing your next image can help improve your imaging skills — and even enable you to pull off your own masterpiece.

■ **SEAN WALKER** has several imaging projects in the works, though the biggest is an all-sky survey partnership that can be seen at **mdwskysurvey.org**.

SEAN WALKER / *S&T* (2)

Getting to know our exoplanet neighbours

Astronomers are slowly unlocking the secrets of unimaginably distant worlds.

IT WASN'T LONG AGO that it was astonishing simply to know that planets beyond our own Solar System really do exist. Now we know they're everywhere, orbiting nearly every star.

Yet, in a way, exoplanets seem like a cosmic tease. Given their enormous distance and dimness beside the blindingly radiant stars they hug so tightly, it will be hard to learn enough about them to satisfy the profound questions they raise. It's like coming upon a palace full of doorways we can't open, though we know behind them lie clues to the mystery of our existence.

One of the most extraordinary systems we've discovered so far is Trappist-1. There, seven roughly Earth-size planets orbit close enough to a dim red star that several may be in the *habitable zone*, with liquid water stable on the surface. Or not. It's awfully hard to say, because what we know is so rudimentary.

We've had only a rough idea of the worlds' masses and diameters. This enabled us to estimate what mix of metal, rock and ice they're made of. And we know their orbital periods and distances from the star, along with constraints on the ellipticities of their orbits. From this, simple calculations of surface temperature showed that three orbit within the habitable zone. Further modelling hinted that two of these might have lost all water to a 'runaway greenhouse,' and the outermost may be frozen over.

> It's like coming upon a palace full of doorways we can't open, though we know behind them lie clues to the mystery of our existence.

Given the little data we have, can we ever determine conditions on these worlds? Recently, planetary geophysicist Amy Barr Mlinar (Planetary Science Institute) and colleagues published some clever modelling they did that factors in the effects of tidal heating. Tidal heating is insignificant among our Solar System's inner planets. But it's potent among Jupiter's big moons, which repetitively pull on one another and yank their orbits into very slight ellipses. This non-circular motion leads to enough tidal forcing from Jupiter to melt their insides, creating volcanism on Io and a water ocean inside Europa.

In some ways the Trappist-1 system resembles more a system of Jovian moons than our Solar System. These planets torque one another's orbits and tug at each other's insides, depositing heat. Barr Mlinar's results suggested that, because of this heating, two of these Trappist-1 worlds — including one of those previously ruled uninhabitable due to a runaway greenhouse — might indeed support surface liquid-water oceans. Who knows? Maybe something is swimming in those waters.

This study is far from the last word. Barr Mlinar *et al.* described how the great uncertainties in these planets' masses and densities made it hard to reach definitive conclusions.

Yet, amazingly, just as this column was going to press, a group

NASA / JPL-CALTECH

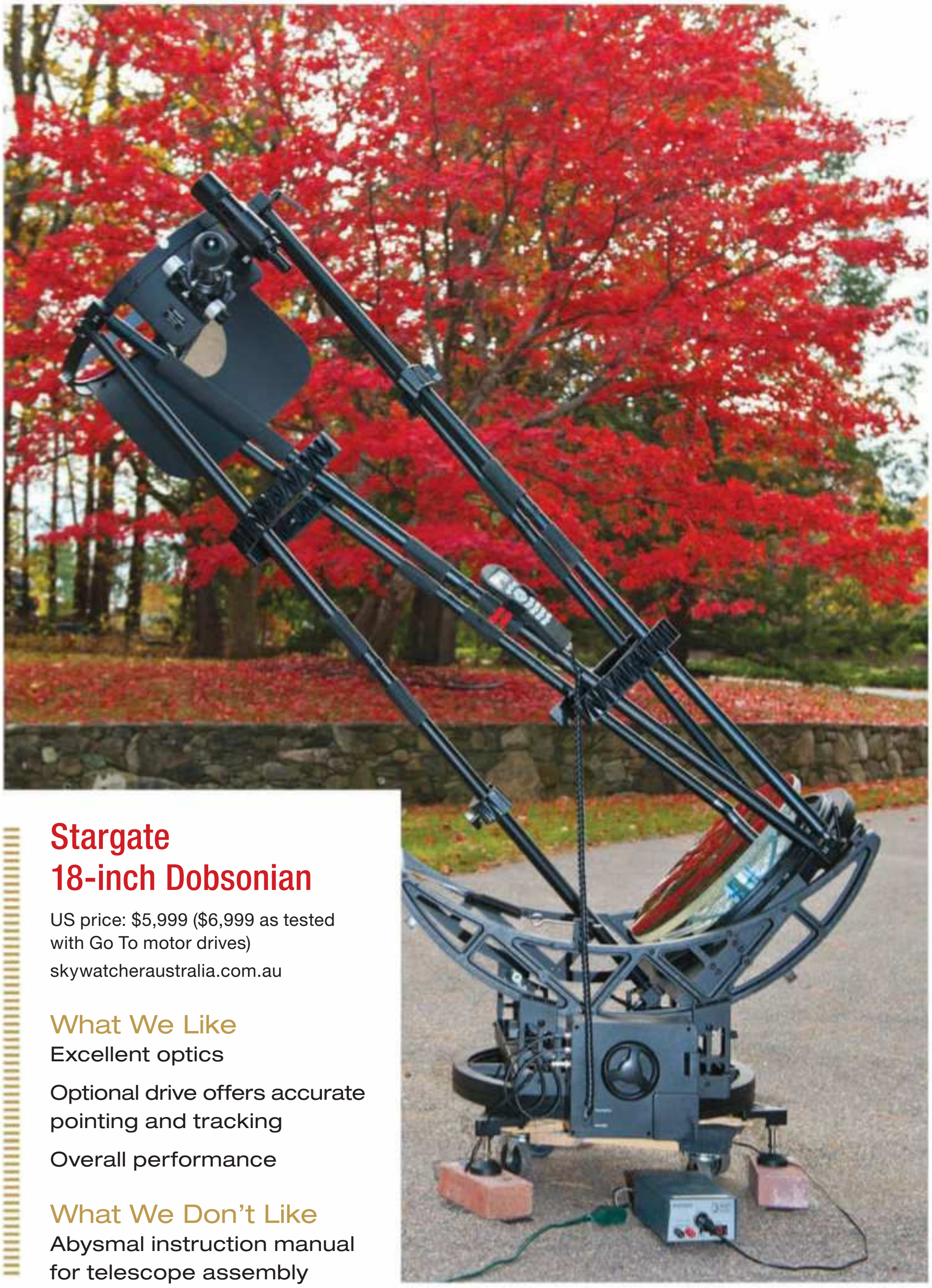
of astronomers led by Simon Grimm (University of Bern, Switzerland) reported much more precise masses for these planets, derived by analysing tiny changes in the timing of transits induced as the planets tweak one another's orbits. Now, geophysicists can apply these improved constraints to their interior models, and we'll get closer to understanding what these planets are really like.

The dance between observers and theorists gives me hope that in the coming decades, even without going there, we'll make huge strides toward finding out what lies behind all those enticing exoplanet doorways.

■ Astrobiologist **DAVID GRINSPOON** is coauthor with Alan Stern of *Chasing New Horizons*. Follow him on Twitter **@DrFunkySpoon**.

Sky-Watcher's Stargate 18-inch Dobsonian

The Stargate truss-tube Dobsonians are billed as the largest mass-market telescopes available. Is the 18-inch model worthy of the hype?



Stargate 18-inch Dobsonian

US price: $5,999 ($6,999 as tested with Go To motor drives)

skywatcheraustralia.com.au

What We Like

Excellent optics

Optional drive offers accurate pointing and tracking

Overall performance

What We Don't Like

Abysmal instruction manual for telescope assembly

AFTER TESTING SKY-WATCHER'S 18-inch (45.8-cm) Stargate truss-tube Dobsonian for several months late last year, it's easy to understand why deep sky observers proclaim that aperture is king. Objects that appear faint and ill-defined through smaller scopes take on a whole new dimension in an 18-inch. Many globular clusters are transformed from small, fuzzy glows into brilliant spheres of sparkling stars. Lots of planetary nebulae appear large and bright enough to show structure not seen with smaller apertures. And the fields surrounding many familiar deep sky objects are filled with a multitude of faint background stars lending 3D-like perspectives.

It was apparent how much I liked the Stargate when I quickly found myself looking forward to each clear night as an opportunity to observe rather just one to work on a product review. While the telescope ended up being one I truly enjoyed, and one I can strongly recommend, the review process didn't start out that way. But let's save that part of the story for later in this review and begin with the good stuff.

Although I'm no stranger to using large telescopes, especially at star parties, my own recreational deep sky observing is usually done with a 30-cm f/5 Dobsonian. As such, the 18-inch Stargate was a significant step up. In

◀ The Sky-Watcher Stargate 18-inch with SynScan motor drives for Go To pointing and tracking is a big telescope, standing more than 2.1 metres tall when pointed at the zenith. While the author set up the telescope by himself, the process would be far easier with two people.

ALL PHOTOS PROVIDED BY THE AUTHOR

addition to having 2¼ times more light grasp than the 30-cm, the Stargate's longer focal length (1,900 mm versus 1,524 mm) offered noticeably more magnification for a given set of eyepieces. By itself, this longer focal length would have yielded 25% more magnification. But because the Stargate is an f/4.1 Newtonian and suffers more from coma than the 30-cm f/5, I did most of my Stargate observing with a Tele Vue Paracorr coma corrector that increased the Stargate's effective focal length by a factor of 1.15×. And this meant a 43% increase in magnification for the same eyepiece used with the Stargate compared to my 30-cm Dob.

The Stargate ships with 2-inch 28-mm and 1¼-inch 10-mm eyepieces of decent quality. They yield 68× with a 49-arcminute field of view and 190× with a 15-arcminute field, respectively.

There is also a Cheshire eyepiece collimation tool, which is very good for checking the scope's optical alignment. Due to the length of the instrument, however, collimating the optics with the included tool is best done with two people — one looking through the Cheshire eyepiece while the other adjusts the collimation screws on the primary-mirror cell. I aligned the optics with a laser collimator that allowed me to tweak everything without additional help. And the good news is that once collimated, the scope held its alignment well.

I also used my own Tele Vue eyepieces that I keep handy with my 30-cm scope. These ranged from a 35-mm Panoptic that yielded (with the Paracorr) 62× and a field slightly more than 1° across, to a 7-mm DeLite giving 308× and an 11-arcminute field. I also had some exceptionally memorable views with a 21-mm Ethos, which gave almost the same field of view as the Panoptic, but at an impressive 103×.

▲ The Stargate comes with a 9×50 straight-through finder and a 2-inch, two-speed focuser with extension tubes/adapters for 2- and 1¼-inch eyepieces. As explained in the accompanying text, the author typically observed with the Tele Vue Paracorr coma corrector pictured here.

First night out

My first night under the stars with any telescope is usually reserved for just getting a feel for what it's like to set up and use the equipment — serious observing isn't typically on the agenda. As such I picked a spot on the walkway outside my garage where the sky is, unfortunately, heavily obscured by the house and surrounding trees.

While I set up the scope by myself, it would be far easier with two people. The base with its optional motor drives

▶ The Stargate Dobs have noteworthy primary mirrors made from fused glass. The 18-inch has a front plate (about 20 mm thick) and back plate separated by a dozen ribs surrounding a central hollow core. As such the 8.9-cm-thick mirror weighs only about 13.5 kg and acclimates to ambient temperatures much faster than a solid disk of glass would.

▶▶ In the workshop, the author's Foucault test of the primary mirror shows no sign of 'print through' from the supporting rib structure. There is a slight hint of a central depression due to the hollow core, but it falls completely within the shadow of the secondary mirror and is of no consequence. The mirror is an overall well-corrected paraboloid with subtle artifacts typical of machine-polished optics. It delivered excellent performance at the eyepiece.

weighs about 30 kg. But it's the optical assembly (a.k.a. 'the tube') that presents the biggest challenge. Complete with the side cradles attached to the primary-mirror assembly, the tube weighs almost 45 kg, and it's quite awkward for one person to lift and position on the base. But I still found this easier to do than to assemble the tube beginning with the primary-mirror assembly (by itself a 27+ kg unit) placed on the base. The problem here for one person is trying to get the secondary-mirror cage attached to the top of the six truss poles while they are pointing 2.1 metres above the ground and flailing around.

As twilight receded down the western sky, I pointed the Stargate to brilliant Vega. Although I'm well over 1.8 metres tall, I could just reach the eyepiece when standing on a 22-cm-high step stool. At 196× Vega appeared dazzlingly bright with four razor-sharp diffraction spikes extending across my 18-arcminute-wide field of view. Boosting the magnification to 308× and racking the eyepiece from one side of focus to the other revealed diffraction patterns suggesting that the optics in this scope were very good, but Vega was really too bright for a good star test, so I nudged the scope to the northeast to look at Epsilon Lyrae, the famous Double-Double.

Moving my eye from the Stargate's 9×50 finder to the 308× eyepiece provided me with a dramatic, in-your-face example of the advantages that a big aperture brings to many types of observing. The tightly spaced components of this pair of double stars were cleanly resolved with a wide gap of dark sky between the tight pairs. And all four stars were surrounded with neat sets of diffraction rings. I've seen this kind of clearly resolved separation at similar magnifications with smaller, high-quality telescopes, but there were added dimensions to the view in the Stargate. Each of the four stars vividly displayed its own delicate hue — something that is far more subtle with smaller apertures. And there was a multitude of faint background stars that

go mostly unnoticed through smaller scopes, giving a truly three-dimensional feel to the scene. It was now obvious that the optics were indeed very good.

With my appetite whetted for more, I decided to engage the motor drives and attempt the necessary star alignment for Go To pointing and tracking even though I hadn't yet gone through the manual for Sky-Watcher's SynScan drive system. Following instructions that scroll across the hand control, and after a few false starts (mainly because of accidentally pushing the wrong buttons on the hand control), I got the drive working, and I grabbed a star chart to see what interesting objects were within my limited view of the sky. Despite my less-than-ideal alignment, the Go To pointing was very good and tracking was likewise good. Thus began a very enjoyable evening of observing.

And it gets better

If I considered that first night good, then the second night was nothing short of spectacular. By then I'd made a trip to the local hardware store and picked up a small, cheap furniture dolly and a two-tier step ladder. With a couple of pieces of scrap wood I supported the assembled Stargate on the dolly and could easily roll it in and out of my garage. Furthermore, as the image on the next page shows, it was an easy matter to lift each leg on the base about 12 mm and slide a brick under it, putting the scope on a solid footing free of the dolly. After levelling the base and marking which leg belonged on which brick, I marked the location of the

With the threat of rain in the forecast, the author spread out the parts of the Stargate on his garage floor before beginning the assembly process.

◀ *Far left:* The two sections forming each of the scope's six truss poles have solid, screw-together connections at their centres. This keeps the length of the individual pieces very manageable for transport and storage. *Left:* The truss poles fit into numbered connections on the primary- (seen here) and secondary-mirror assemblies, and lock in place with a captive clamp and hand lever. As such, no tools are needed to assemble the optical tube.

bricks with a few pieces of tape on the driveway. On subsequent nights it took only a few minutes to roll the scope out of the garage and have it ready for observing. This may sound stupid, but because I didn't have to disassemble the scope to transport and store it, it was as easy to use on my driveway as any grab-and-go scope I've tested.

By the second night I'd also gone through the SynScan manual and had a better handle on the best way to do star alignments and, in general, use the drive's features. The hand control has the typical catalogues of objects that are available with modern Go To systems, including the Caldwell catalogue. There is, however, no listing of named deep sky objects, so if you're looking for the Ring Nebula, you'll have to find it by either its Messier number (M57) or its designation in the *New General Catalogue* (NGC 6720).

From an operational standpoint, the drive worked very well. When slewing the telescope at the higher speeds, there's a somewhat annoying lag in the response to pressing the slew buttons, but this goes away at slower speeds, making it easy to centre objects through the finder and telescope eyepiece. Since the power jack for the motors moves as the scope turns in azimuth, you have to be mindful of having enough slack in the power cord for the scope to turn. There is a cord-wrap feature that helps by preventing the scope from continuously slewing in one direction, but I never figured out exactly when it would activate. This is no big deal, but it can be a bit surprising when you expect to have the scope slew only a short distance from one object to the next but then find the azimuth motion reverse direction and turn nearly 360° to get back to the general area where you were just looking.

There a few subtle differences between the SynScan system and other Go To scopes I've used, but overall I was very pleased with its operation and features. I've not used a lot of Dobsonian scopes with Go To pointing, but I found this one to be very accurate, and the tracking excellent. Furthermore, you can disengage the motor clutches on both axes and move the scope manually to any part of the sky and reengage the clutches and resume observing without having to re-initialise the drives. A very nice feature.

Why the rocky start?

With so many positive things going for the Stargate, you're probably wondering why I said earlier that this review didn't start off well. The answer can be summed up in three words — the instruction manual. Regardless of what I might intuitively know about setting up telescopes, for the sake of a review I always follow the step-by-step instructions in the manual. I can't recall assembly instructions worse than those for the Stargate. In addition to easily recognised mistakes such as referring to the secondary-mirror assembly as the primary-mirror

▲ *Left:* The Stargate's ribbed secondary mirror is made of molded glass to help reduce weight and speed temperature acclimation. *Right:* Lightweight plastic covers for the primary and secondary mirrors help keep the optics protected and dust-free when the scope is not in use.

assembly, there are misidentified parts mentioned in the text that make the assembly procedure confusing. But even worse are the diagrams, many of which are riddled with errors. There are mislabelled diagrams; diagrams with missing labels; and diagrams mentioned in the text that simply don't exist. The worst of these errors involved the novel cable system used for the altitude drive, so the manual will be less of a problem for people who don't purchase a Stargate model with drives. But I found the Go To pointing and tracking to be so valuable that I would strongly recommend people consider getting the scopes with motor drives.

After working through the scope's frustrating assembly procedure, I worried that things were going to get even worse. When I initially unpacked the telescope from its four large shipping boxes there was a prominent slip of paper with the bold headline 'Attention'. It directed me to the Sky-Watcher website to download the latest version of the SynScan firmware and install it *using instructions in the manual*.

▲ The SynScan hand control has illuminated buttons and is typical of many of today's Go To systems. The author found it easy to master.

This is rather common for today's computerised scopes, but I was dismayed to see that the latest version of the firmware was dated more than six months before the Stargate was shipped to me for review, and the version of firmware in my hand control was even older. An update was clearly needed to keep the review accurate, but I certainly wasn't looking forward to another round of step-by-step instructions in the manual.

But here's the punchline: The whole procedure went precisely as described in the SynScan manual and took about 10 minutes! The only hurdle was the required serial connection between the computer and hand control to do the update. Since the hand control needs to be plugged into the scope and powered on for the update, that meant bringing a computer to the scope, and it's been years since any of my laptop computers has included a serial connection. I had to use a USB-to-serial adapter, which was no big deal.

Memories of the bumpy road travelled to get from opening the telescope's shipping boxes to first light with the Stargate 18-inch SynScan instantly faded into the background when I had that first look at the Double Double mentioned earlier. And were it not for writing this review, it would have probably stayed that way. The Stargate turned out to be a wonderful instrument to use. As with any big telescope, there are special considerations that go with storing, moving, setting up and taking down the Stargate. But if you're prepared for them, then I can strongly recommend this telescope. It really is that good.

■ **DENNIS DI CICCO** has been writing about astronomical equipment for more than 40 years.

▲ *Left:* The altitude drive for the Stargate SynScan models uses a wire-cable system visible in this view of the telescope base. It worked very well but had to be disconnected from the telescope tube in order for the tube assembly to be removed from the base. *Right:* Electrical connections for the SynScan drives are straightforward and well-marked. Furthermore, the cable connectors for the azimuth motor and encoder are slightly different, making it impossible to attach them incorrectly, even in the dark.

Hunter's zoom finder

This innovative design solves several problems at once.

HUNTER DAVIDSON LIVES NEAR a large, light-polluted city. He also enjoys manually aiming his telescope, which offers little success when the magnitude-4 sky reveals maybe a dozen stars. He has tried different types of finders, but found few that worked well.

Hunter needed an optical finder that would offer some gain. The trouble is, this would lead to a narrower field of view, which would reduce the number of useful field stars. He began asking himself, "So what provides both wide-angle at about naked-eye field of view as well as some magnification when needed?" The answer — a zoom finder.

With the words 'zoom finder' in his head, he went into his workshop and mated a Sony 20- to 80-mm f/2.5 TV zoom lens to an inexpensive Amici roof prism and the lenses from a 20-mm Plössl eyepiece. He couldn't use the entire eyepiece because the focal point of the zoom lens lies inside the prism, so he had to mount the eyepiece lenses so their focal point reached the same plane.

The result is a finder that zooms outward to give him a 50° field of view, which allows easy orientation even with only a few reference stars. Zooming to the narrowest field of view, 12.5°, adds about 3 magnitudes of gain, bringing out more stars as the field narrows. Designed for TV cameras, the lens has a smooth-acting lever for zooming, so Hunter can shift back and forth easily without jiggling the scope.

At its widest, the finder's field of view includes the front of the telescope, making it difficult to judge where the centre is. Even at full zoom, its 12.5° field is still a lot wider than the 1° field of a typical low-power eyepiece, and Hunter soon realised the biggest hiccup in his design: With the focal plane inside the Amici prism, he couldn't add cross-hairs to indicate the centre of his finder's field. So he augmented his zoom finder with a second, conventional 5° optical finder. Together they let him zero in on just about any target visible in his sky.

Then one night he had an epiphany: The zoom could function like cross-hairs. An object that's not centred will drift to the side when zoomed, but an object in the centre of the field will stay put. Hunter reports, "The long hand lever of the lens makes adjustment very easy, so I just zoom in and out, tweaking the scope position until the target star doesn't move. This is quicker than one might imagine and became second nature."

Now he says the most serious downside is that "this optics combination provides, to be kind, not the sharpest star images. But I find the images good enough, and 'good enough' seems okay for this application."

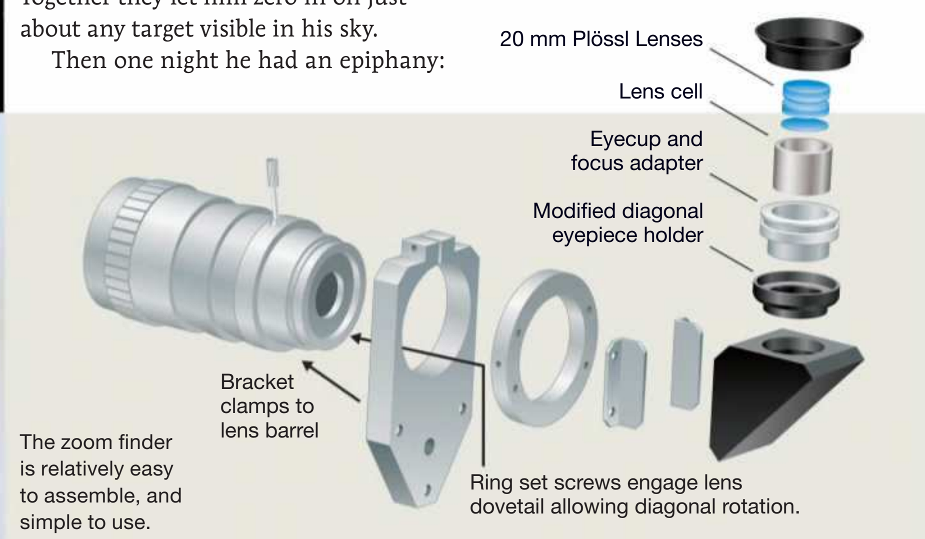
These zoom lenses are available on eBay fairly frequently. Others might work as well, but make sure they come to focus far enough from the rear element to allow room for a prism and eyepiece.

For more information, you can contact Hunter at **hunterdavidsonjr@gmail.com**.

■ **JERRY OLTION** uses all kinds of finders. A zoom may soon join them.

Hunter Davidson uses his zoom finder to locate guide stars in his light-polluted sky.

The zoom lever is easy to reach and operate in the dark.



The zoom finder is relatively easy to assemble, and simple to use.

HUNTER DAVIDSON (2); EXPLODED DIAGRAM: GREGG DINDERMAN / S&T

Artist's impressions of the new NZ$10m Astronomy Centre for Lake Tekapo.

Astronomy tourism is looking up

A new astronomy centre will help share the wonder of the night sky.

New Zealand is to get a new, NZ$10 million, 1,300-square-metre Astronomy Centre, near Takapō/Lake Tekapo on the South Island. A joint venture between the highly successful Earth & Sky astronomy tourism operation and Ngāi Tahu Tourism, the Centre will house a restored, 125-year-old, 46-cm telescope (known as the Brashear Telescope), plus interactive displays, a restaurant, bar and retail outlet.

At a traditional blessing ceremony near the site in March, Ngāi Tahu Tourism chief executive Quinton Hall said "We want our visitors to walk away in awe of the universe, enthralled about scientific discoveries and astonished by the seamless connection between science and our local Ngāi Tahu traditions".

"The nature of this facility, with its working telescopes and the exciting scientific research being undertaken by the University of Canterbury and Nagoya University, combined with the depth of Ngāi Tahu star lore traditions means the proposed experience offers a really unique educational opportunity for all visitors," he added.

Earth & Sky was established in 2004 by Graeme Murray and Hide Ozawa, and conducts astronomy tours at nearby Mt John Observatory. The Ministry of Business, Innovation and Employment has provided NZ$3m for the Centre, with the other NZ$7m to be contributed by the joint venture.

"The dome will clearly identify the building and highlight the importance of dark sky reserve tourism to the town," said Murray. "It's a clear visual signal that Takapō is one of the premier locations on the planet to view the night sky."

RASNZ Conference
May 4–6
New Zealand's annual astro gathering, this year to be held in Dunedin.
rasnz.org.nz/groups-news-events/conf-next

South Pacific Star Party
May 10–13
Annual star party of the Astronomical Society of NSW.
asnsw.com/spsp

Asteroid Day
June 30
A global day of education to help protect Earth from asteroids.
asteroidday.org

Star Stuff II
July 7–8
A weekend of astronomy fun on NSW's north coast.
starstuff.com.au

National Science Week
August 11–19
Lots of astro events around the nation. Keep visiting the website for the latest info.
scienceweek.net.au

Public viewing nights
August 17–18
Presented by the Sutherland Astronomical Society at its Green Point Observatory in Sydney's southern suburbs.
sasi.net.au

Siding Spring StarFest
September 28–30
Public lectures, telescope tours and family activities at Coonabarabran, NSW.
starfest.org.au

International Observe the Moon Night
October 28
An annual worldwide event that encourages observation and understanding of our Moon.
lpi.usra.edu/observe_the_moon_night/

VicSouth 2018
November 2–6
Annual week of astronomy under very dark rural Victorian skies.
vicsouth.info/vicsouth.htm

WHAT'S UP?
Do you have an event or activity coming up? Email us at editor@skyandtelescope.com.au

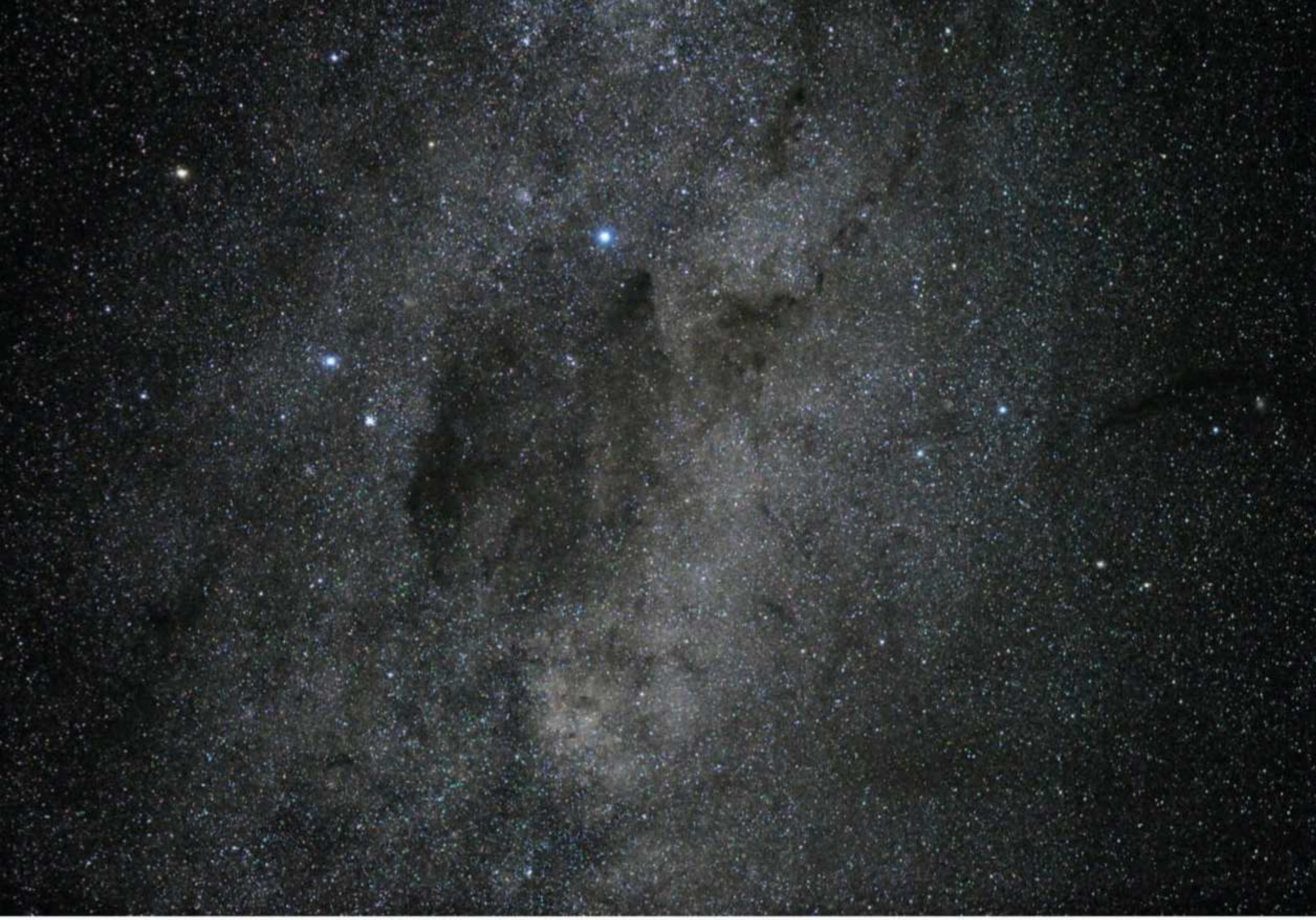
Astrophotos from our readers

▲ **BLOOD MOON**
Therese Albers
Stargazers on Victoria's Mornington Peninsula had a good view of January 31st's lunar eclipse. For this shot, Therese used a Pentax K-x camera, ED80 telescope and a 2.5-second exposure at ISO 400.

HOW TO SUBMIT YOUR IMAGES Images should be sent electronically and in high-resolution (up to 10MB per email) to contributions@skyandtelescope.com.au. Please provide full details for each image, eg. date and time taken; telescope and/or lens; mount; imaging equipment type and model; filter (if used); exposure or integration time; and any software processing employed. If your image is published in this Gallery, you'll receive a 3-issue subscription or renewal to the magazine.

◀ RED SKY AT NIGHT
Julianna Rotondi
Another eclipse shot from Victoria. Julianna used a Canon EOS 80D and 150-600 mm lens at f/6.3.

▼ SKY PIRATE
Rodney Watters
Known by some as the Skull and Crossbones Nebula, NGC 2467 comprises a couple of small star clusters and a region of nebulosity, all at different distances but in the same line of sight. Rodney used a QSI 683WS8 camera and H-alpha O-III and S-II filters. Total exposure time was 30 hours.



▲ **DARK DEPTHS**
Kevin Fox
Kevin's photo shows the Southern Cross, the adjacent Coal Sack Nebula and, centre right, the long, slender Dark Doodad Nebula. He used a Nikon D3 camera and Nikkor 105-mm lens for the 25-second exposure.

◀ **BALL OF STARS**
Bob Cornect
The globular star cluster Omega Centauri is one of the showpieces our of our southern skies. Bob used a Meade 40-cm SCT and an infrared-modified Canon EOS 6D camera for this IR (shown as red), G (green) and B (blue) false-colour shot.

▲ **SOUTHERN VISTA** **Tim Bruton** The Astronomical Society of Victoria's recent annual Messier Star Party attracted more than 200 people, and it's easy to see why with skies like this. Tim's 20-second shot was taken with a Canon EOS 6D and Samyang 14-mm lens.

▲ **THE HUNTER**
Ray Prior
Nothing beats the sight of majestic Orion, the Hunter, dominating summer's equatorial sky. Ray captured the scene using a Canon EOS 1100D camera, 50-mm lens and six, 90-second exposures.

▲ **SPACE GULL**
Mervyn Millward
The Seagull Nebula, IC 2177, is a large region of atomic hydrogen located about 3,600 light-years from Earth. For this image, Mervyn took 25 frames, 5 minutes each, through LRGB and H-alpha filters using a QSI 583WS camera and 85-mm refractor.

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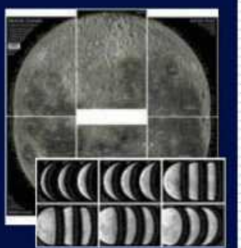

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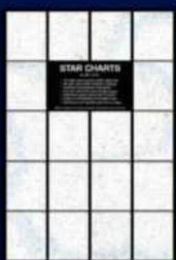
Star charts



18 star charts by world-renowned celestial cartographer, Wil Tirion. Covering the entire night sky and orientated for the Southern Hemisphere (with a index to constellation and bright stars), these charts are A4 size with a water-resistant coating, making them perfect for use at the telescope. Made in Australia. $14.95 + P&H

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ÁNGEL R. LÓPEZ-SÁNCHEZ (AAO/MQU)

Where next for the AAO?

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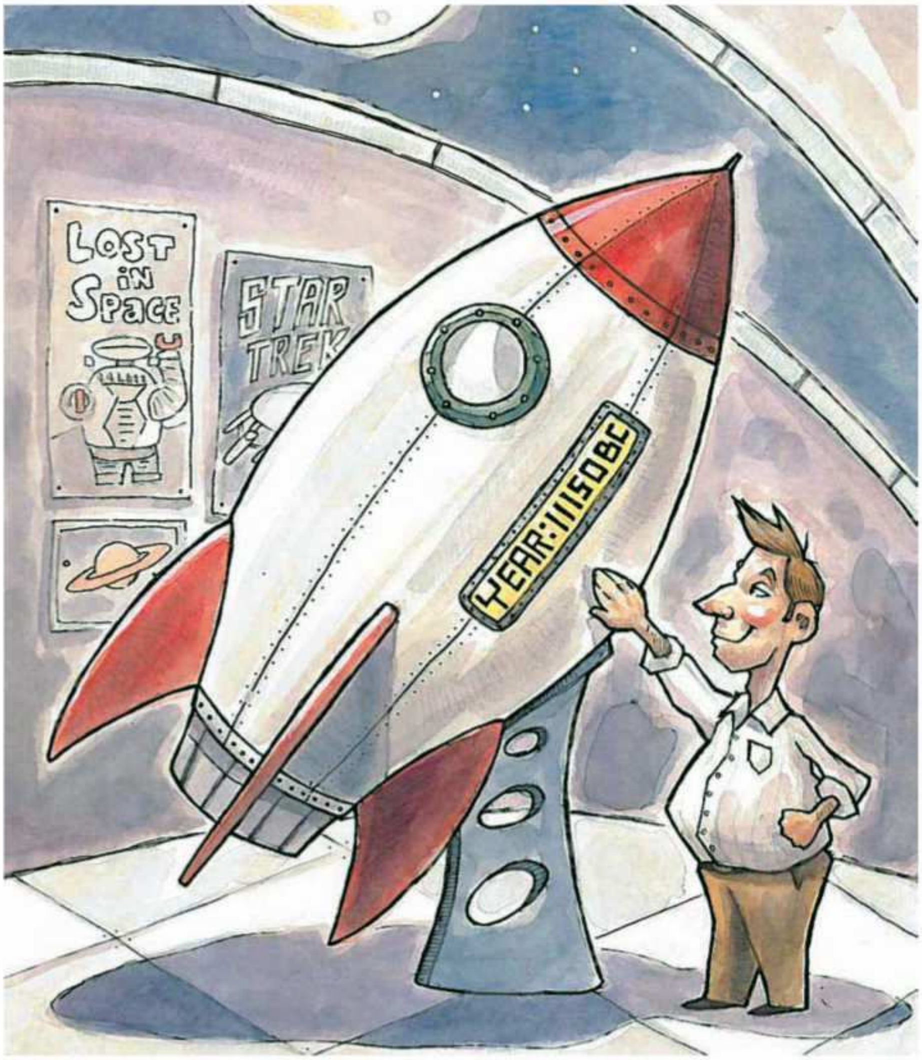
My plastic spaceship

A child's lofty dreams are realised, though not quite as he'd imagined.



AS A YOUNGSTER in the late 1960s and early '70s, one of my grandest dreams about being a grown-up was living in the Space Age. I fantasised about flying cars and vacations on the Moon while devouring endless episodes of *Space 1999*, *Star Trek* and *Lost in Space*. Astronauts were still being sent to the Moon when a trip I took to a planetarium in primary school sealed the deal and left me with a hunger that I'd never satisfy.

Today, alas, there is virtually no chance I will ever drive a flying car or vacation on the Moon. But I have my own spaceship, an enormously capable one. It can carry me on voyages through the Solar System, across the galaxy and even into intergalactic space. It's also a time machine. With it I can travel to the distant past, to an age when dinosaurs walked the Earth or, with some effort and care, to a shadowy period before our planet even existed.

You see, at some point in my adult life I became an astrophotographer. Like many who are serious about such a passion, I've built my own observatory under the dark skies of a remote location. My observatory is my spaceship. It's one of those domes that folds over and slides to the side, and the whole thing consists of the same plastic material that comprised my children's backyard playhouses.

Many a night I have laid down on the floor beneath my dome and stared up through the opening, as if through a portal into outer space. At such times, the equipment in the centre of my ship warbles and clicks in the faint glow of red lights pulsating with the implied power of my mighty craft. Our galaxy arches overhead, and occasionally a fellow traveller flies by, be it a streaking meteor, a comparatively slow-moving satellite, or an aircraft with other travellers heading to a more terrestrial destination. My course is celestial, though, and to the music of Enya or some sci-fi soundtrack I sail off across an ocean so vast few can comprehend it.

I am made of stardust, I think as I marvel at how my craft's machinery collects and records photons a million years old or more. I ponder the duality that to me they are ancient in years beyond counting, while from their perspective they were created a moment ago by some star many light-years away and only just spanned this immense distance.

Is it this crisscross of time streams that gives rise to the fabric of the universe? Am I the universe too, the dust or ashes of dead stars assembled here on Earth in such a way that I can reflect upon the universe, and myself, in such a fashion?

Yes, I have a spaceship, and it's more powerful than I ever imagined as a boy.

RICHARD S. WRIGHT, JR., is a software developer at Software Bisque.

JASON ABBOTT