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AUSTRALIAN SKY & TELESCOPE

THE ESSENTIAL MAGAZINE OF ASTRONOMY

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Earth's space junkyard

Can we stop it before it's too late? P18

SPACE RACE

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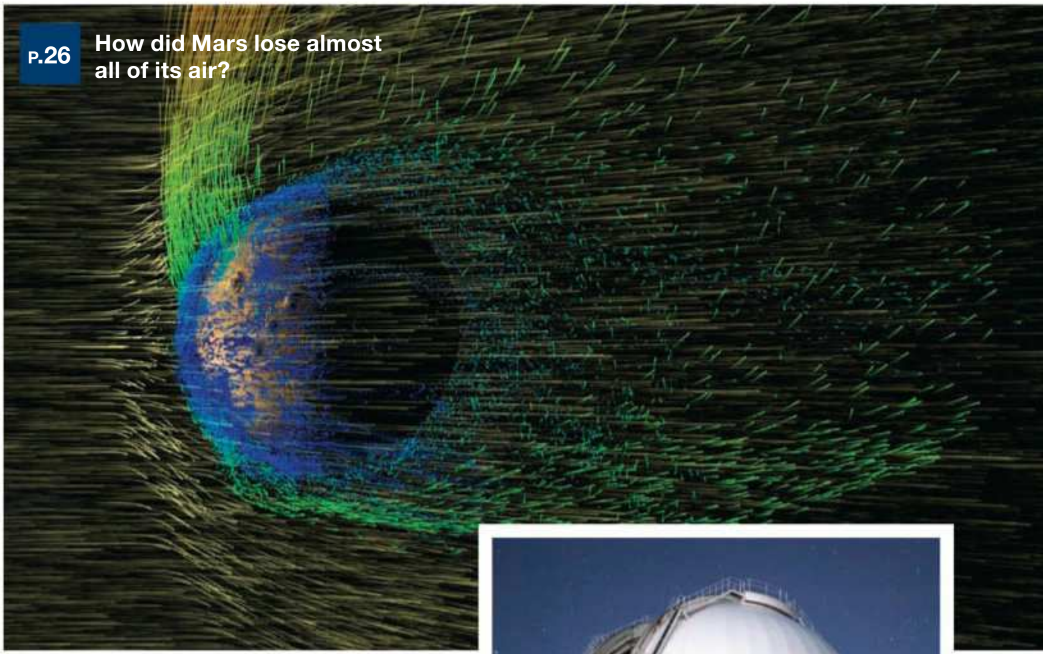
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THE ASTRONOMY SCENE

ON THE COVER

Earth orbit is turning into a spacecraft junkyard. Is there anything that can be done? Turn to page 18.

Remembering your first scope

DO YOU REMEMBER when you first looked through a telescope? Was it when you were young or much later as an adult? And do you remember the feeling you had when seeing real objects floating in space for the first time? Not pictures on a page or a screen, and not science fiction, but the real thing. It's a fabulous feeling to suddenly realise that there really is a whole universe out there, just waiting for you to explore it by proxy through some clever optical wizardry.

Most astronomy enthusiasts, although not all, go on to buy (or in the old days, build) a telescope of their own. What was your first scope? Was it the archetypal department store 60-mm refractor that boasted 500 million times magnification? Perhaps it was a birthday gift, or a hand-me-down from a relative. Or maybe your school had one. (My high school had one, allegedly, but we never saw it — it was in pieces in a cupboard somewhere.)

In this issue (page 34) we present our guide to the basic telescope types, and take you through how to determine which one is best for you... or for someone else if you're thinking of giving a budding astronomer a gift for Christmas. If it's the latter, don't forget to give a gift subscription to *Australian Sky & Telescope* as well, to help inspire and amaze them.

Jonathan Nally, Editor
editor@skyandtelescope.com.au

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Insight lander heads to Mars

NASA'S INSIGHT MARS LANDER launched aboard an Atlas V rocket on May 5, rising through the predawn fog from the Vandenberg Air Force Base in California. The spacecraft's name stands for Interior Exploration Using Seismic Investigations, Geodesy, and Heat Transport. Prime contractor Lockheed Martin Space based the spacecraft design on the Phoenix lander, which touched down near the Martian north pole in 2008.

Insight should arrive at Mars on November 26 after an interplanetary cruise of nearly 500 million km. The spacecraft will make a direct descent to the planet's surface. About 6 minutes after entering the Martian atmosphere, Insight will use — as Phoenix did — a combination of aerodynamic drag, parachutes and radar-triggered thrusters. However, compared to Phoenix, Insight is more massive (358 kg), arrives at higher velocity (22,680 kph), and has a higher-elevation landing site (which means there's less atmosphere to slow its speed).

Planetary scientists have longed for a chance to probe the deep interior of Mars. Understanding the circumstances of the Red Planet's formation — its bulk composition and the size of the eventual core, mantle, and crust — requires the kind of dedicated geophysical investigation that principal investigator Bruce Banerdt (Jet Propulsion Laboratory) first conceived in the late 1980s. Insight will soon conduct those experiments with a trio of key instruments. The Seismic Experiment for Interior Structure (SEIS) will detect marsquakes with exquisite sensitivity. The Heat Flow and Physical Properties Probe (HP^3) will drive a bullet-shaped 'mole' up to 5 metres deep into the Martian soil to calculate the rate at which heat is escaping from the planet's deep interior. And the Rotation and Interior Structure Experiment (RISE) will use two transponders to precisely track the planet's rotation and, over time, help determine the orientation of the Martian polar axis. "To me that's as close as you can get to magic and yet still be science," says Banerdt.

The selected landing location, centred at 4.5°N, 135.9°E in western Elysium Planitia, is near the equator to ensure strong sunlight for the solar cell panels. The location was also selected for its flat, relatively rock-free terrain and loose soil. Insight does have a couple of cameras, but any panoramas will probably show a boring landscape. Yet the Red Planet's geological beauty isn't just skin deep — the interior is what will tell us the true character of our neighbouring world. ■ J. KELLY BEATTY

● Learn more about Insight's mission at https://is.gd/marsinsightlaunch.

◀ NASA's Insight Mars lander awaits launch in the foggy predawn hours at the Vandenberg Air Force Base in California.

IN BRIEF

Helicopter to fly with Mars 2020 rover

NASA has announced that a small, autonomous helicopter, named Mars Helicopter Scout, will make the journey to the Red Planet with the Mars 2020 rover. It may become the first mission to fly on another planet. Tucked away under the rover during descent, the helicopter will be deposited on the Martian surface shortly after landing. Weighing in at 1.8 kg, the baseball-size helicopter will whip its rotor blades at 3,000 rpm (10 times the rate of a helicopter on Earth) to create lift in the tenuous Martian atmosphere. As a technology demonstrator, the helicopter won't carry science instruments, but it will have two cameras that could prove valuable in mapping terrain. Funded for US$23 million early this year, the helicopter is expected to last 30 days, during which NASA plans at least five short flights. The first flight will make an initial vertical climb of 3 metres. Subsequent sorties will feature journeys up to 90 seconds in duration that range over several hundred metres.

■ DAVID DICKINSON

PAULINE ACALIN

TESS mission launches successfully

This graphical representation of Gaia's all-sky data is based on measurements of 1.7 billion stars.

Gaia maps 1.7 billion stars, widens cosmic census

EUROPEAN ASTRONOMERS have published the second release of data (DR2) from the European Space Agency's Gaia satellite. The resulting catalogue is the most extensive and precise yet, containing data on 1.7 billion stars.

Based on 22 months of data collection, Gaia's DR2 consists of precise parallaxes, and thus geometric distances, to more than 1.3 billion stars, as well as positions and brightnesses of almost 1.7 billion stars. That's a huge leap compared to the mission's first data release in 2016, which contained 2 million stellar distances. Moreover, the newly published distances rely solely on Gaia's own measurements — in DR1 Gaia's measurements had to be augmented by data from the 1990s-era Hipparcos satellite observations.

The satellite spins continuously around its axis as it orbits the Sun, enabling its two telescopes to scan great circles on the sky, observing about 100,000 stars every minute. The optics feed three instruments: one for astrometry (to determine stars' positions and *proper motions* across the sky), one for photometry (to measure the stars' colours and effective temperatures), and one for spectroscopy (to measure bright stars' *radial velocity* toward or away from Earth and to assess their composition). At Gaia's heart is a CCD with 848 million pixels, the largest digital camera ever used in space.

Thanks to spectrometry, Gaia's DR2 contains estimates of the effective temperature, radius and luminosity of 76 million stars, as well as time-dependent measurements for more than 550,000 variable stars. Closer to Earth, Gaia also observed about 14,000 known Solar System objects, most of them asteroids. On the other end of the distance scale, the database contains positions and brightnesses for more than half a million quasars. Their near-zero parallax means they serve as useful references for Gaia's celestial coordinate system.

More data releases will follow DR2, with the final Gaia catalogue — the definitive stellar catalogue for the foreseeable future — scheduled to be published in late 2022.

■ JAN HATTENBACH

● **For additional images and an animated view of the Hyades star cluster, visit https://is.gd/gaiaDR2.**

GAIA: GAIA DATA PROCESSING AND ANALYSIS CONSORTIUM (DPAC) / A. MOITINHO / A. F. SILVA / M. BARROS / C. BARATA (UNIV. OF LISBON, PORTUGAL) / H. SAVIETTO (FORK RESEARCH, PORTUGAL); TESS LAUNCH: SPACEX

A NEW PLANET-HUNTER is on its way to search for new worlds: The Transiting Exoplanet Survey Satellite (TESS) launched successfully on April 18 aboard a SpaceX Falcon 9 rocket. The mission will survey nearly the whole sky for exoplanets.

TESS launched just in time, as NASA's Kepler will run out fuel within several months. Like Kepler, TESS will be looking for the brief dips in starlight produced when exoplanets transit their stars. But unlike Kepler, which aimed toward a small field containing more than 150,000 mostly faraway stars, TESS will examine 200,000 stars near Earth. The planets TESS finds around these stars will be more easily studied through follow-up observations on the ground and in space.

The spacecraft will be the first to operate in a lunar-resonant orbit dubbed P/2, circuiting Earth every 13.7 days — half the Moon's period. This orbit is extremely stable, requiring a minimum of fuel, and maximises TESS's ability to view the entire sky. It also enables TESS to send full-frame images back to Earth on every close pass. Following initial testing, TESS will begin surveying the sky with a series of 27-day exposures.

TESS has funding approved for two years of operations, but principal investigator George Ricker (MIT) says the spacecraft is built to last for 10 to 20 years. The mission cost less than US$200 million to develop, excluding launch expenses.

During its first year, TESS will observe the Southern Hemisphere sky; each 24° × 24° field of view will overlap on the ecliptic pole. TESS will then switch to the Northern Hemisphere sky for its second year. While going around the north celestial pole, some of TESS's observations will come full circle, following up on the region of Kepler's first four years of data collection. ■ ELIZABETH HOWELL

TESS launched on April 18 aboard a SpaceX Falcon 9 rocket.

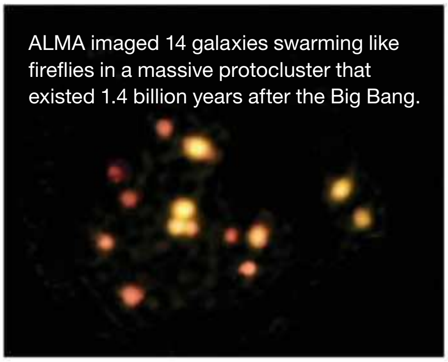
14 galaxies might have become the largest cluster in the Universe

AT LEAST 14 GALAXIES congregating just 1.4 billion years after the Big Bang might have become one of the most massive structures in the universe — if we could observe it to the present day.

Each galaxy in this *protocluster* is alight with stars forming 50 to 1,000 times more quickly than the Milky Way; the complex as a whole has the mass of 10 trillion Suns. The fact that these galaxies came together in such a massive structure so early on challenges our ideas of how clusters form.

Clusters, the largest gravitationally bound structures in the universe, contain hundreds or thousands of galaxies tethered together by their massive halos of dark matter. As galaxies are coming together, such a group is called a protocluster, and its future isn't guaranteed — depending on its environment, it might yet fall apart. But in the case of protocluster SPT 2349–56, the team reports in the journal *Nature*, the 14 galaxies are close enough together that the still-growing structure would probably have survived to the present day.

The protocluster was first seen as a bright, millimetre-wavelength smudge by the South Pole Telescope. Follow-up observations by the Atacama Large Millimeter/submillimeter Array (ALMA), combined with Spitzer observations at infrared wavelengths, resolved the smudge into at least 14 galaxies forming stars out of huge gas reservoirs.



ALMA imaged 14 galaxies swarming like fireflies in a massive protocluster that existed 1.4 billion years after the Big Bang.

While most protoclusters discovered so far are about as bright as theoretical models predict, SPT 2349–56 is 10 times brighter. Computer simulations haven't been able to make protoclusters produce as many stars as SPT 2349–56 does.

That said, the authors acknowledge theory's limited scope. Allison Noble (MIT), who wasn't involved in the study, agrees that current models haven't yet probed large enough scales to predict such an extreme case. Nevertheless, this protocluster, and any others like it, will help astronomers better understand how the universe grew its largest structures.

■ MONICA YOUNG

Do supermassive black holes wander the Milky Way?

NEW SIMULATIONS SUGGEST that galaxies like the Milky Way could be home to a dozen big black holes.

A gigantic black hole sits at the centre of the Milky Way and most other large galaxies. But when galaxies merge, their central black holes can find themselves with an eviction notice.

Astronomers have increasingly realised that evicted black holes only migrate to the new galaxy's core in a small fraction of mergers. The problem is especially acute when one of the galaxies is much smaller than the other. By implication, then, the outskirts of big galaxies should play host to a large number of supermassive black holes.

To understand wha this means for galaxies like the Milky Way, Michael Tremmel (Yale University) and colleagues used the Romulus set of simulations, which follows the growth of cosmic structure in a cube of computerised space some 80 million light-years on a side. The team watched the development of Milky Way–mass galaxies and their interaction with their fellow stellar metropolises from soon after the universe's birth (when galaxy mergers were far more common) to today.

The team reports that, of 26 Milky Way–mass galaxies, each plays host to on average 4 to 20 supermassive black holes; roughly five of the black holes (again, on average) lie within 30,000 light-years of the galaxy's centre.

When a merger in the simulation deposited a black hole near the plane of the galaxy's disk, the black hole gravitationally interacted with stars and gas and quickly sank to the core. Black holes following orbits that kept them far from the galaxies' disks, where they encountered few stars or gas, never migrated inward.

But if the Milky Way does host giant black holes in its outskirts, they're likely well outside the disk. Furthermore, the team estimates that our Solar System would come across one of these wanderers every 100 billion years or so — nearly 10 times the age of the universe.

■ CAMILLE M. CARLISLE

IN BRIEF

CubeSats launch with Insight

Along for the ride with the Mars-bound Insight spacecraft are twin microsatellites called Mars Cube One (MARCO) A and B, the first CubeSats to visit interplanetary space. Each spacecraft comes equipped with solar panels, cold-gas thrusters, an X-band antenna and an ultra high-frequency receiver. Both spacecraft also have star trackers and wide- and narrow-field cameras. The satellites deployed successfully from spring-loaded launchers located on the Centaur upper stage and phoned home shortly after their release, indicating that their solar panels and communications antennae were functioning. The duo will fly past the Red Planet in November and attempt to relay data from the lander's descent to the Martian surface, transmitting data from Insight to Earth at 8 kilobits per second. While the success of the Insight mission isn't dependent on MARCO, the CubeSats will test key technologies for communication relays, which could act like 'black box' data recorders for future landings. ■ DAVID DICKINSON

ALMA (ESO / NAOJ / NRAO), B. SAXTON (NRAO / AUI / NSF)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Hawking takes on the multiverse

STEPHEN HAWKING'S LAST cosmology paper, published posthumously with Thomas Hertog (KU Leuven, Belgium) in the *Journal of High Energy Physics*, might solve the cosmological problem of *eternal inflation*.

A lot of evidence suggests that, just a tiny fraction of a second after the Big Bang, the infant universe experienced inflation, a brief, fantastic growth spurt. Our pocket of space — what we call the observable universe — experienced a quantum fluctuation and spontaneously exited inflation. But according to most theories, inflation wouldn't have stopped everywhere at once. Beyond what we can observe, most of space will keep stretching at an exponential rate forever.

Eternal inflation implies that our cosmos is one of an infinite variety of pocket universes, known as the multiverse. Each one follows an infinite variety of physical laws. But an infinite multiverse hypothesis may pose a problem: Hawking argued it isn't testable.

The problem, Hawking and Hertog write, could stem from the fact that previous theories have treated quantum effects as fluctuations in a universe dominated by relativity. Instead, the scientists argue, relativity should break down in the early universe.

To show this, they first simplified the maths, formulating a universe without matter or energy and with an overall saddle-shaped geometry. We don't live in such a universe, but it's a common starting point for new cosmological theories. As is often done in string theory, they then treat this universe as a hologram: 3D equations reduce to 2D quantities on a surface. (This doesn't mean our universe *is* a hologram, just that we can mathematically treat it like one.) Rather than reducing a spatial dimension, though, Hawking and Hertog removed time. Relativity is no longer necessary in a timeless universe; quantum theory reigns.

When Hawking and Hertog solved the equations that govern this universe, they came to an astounding conclusion: The universe that emerges from inflation is finite. We still live in a multiverse, but now it's one with limited possibilities, which makes it more easily testable.

However, Alexander Vilenkin (Tufts University) urges caution in interpreting these results, noting that the simplified mathematical treatment, and the conclusions Hawking and Hertog derive from it, might not apply to our real, more complicated universe. "I am sure Thomas Hertog will try to go beyond this model," Vilenkin adds, "but it is hard to tell how successful this is going to be."
■ **MONICA YOUNG**

This view of the rock slab dubbed Old Soaker spans 1.2 metres.

NASA / JPL-CALTECH / MSSS

Mud cracks on Mars reveal a lake's history

NASA'S CURIOSITY ROVER spotted polygonal shapes on the surface of rocks on Mars in January 2017. Now, analysis confirms that these are cracks in dried mud, which shed light on the history of the lake that once filled Gale Crater.

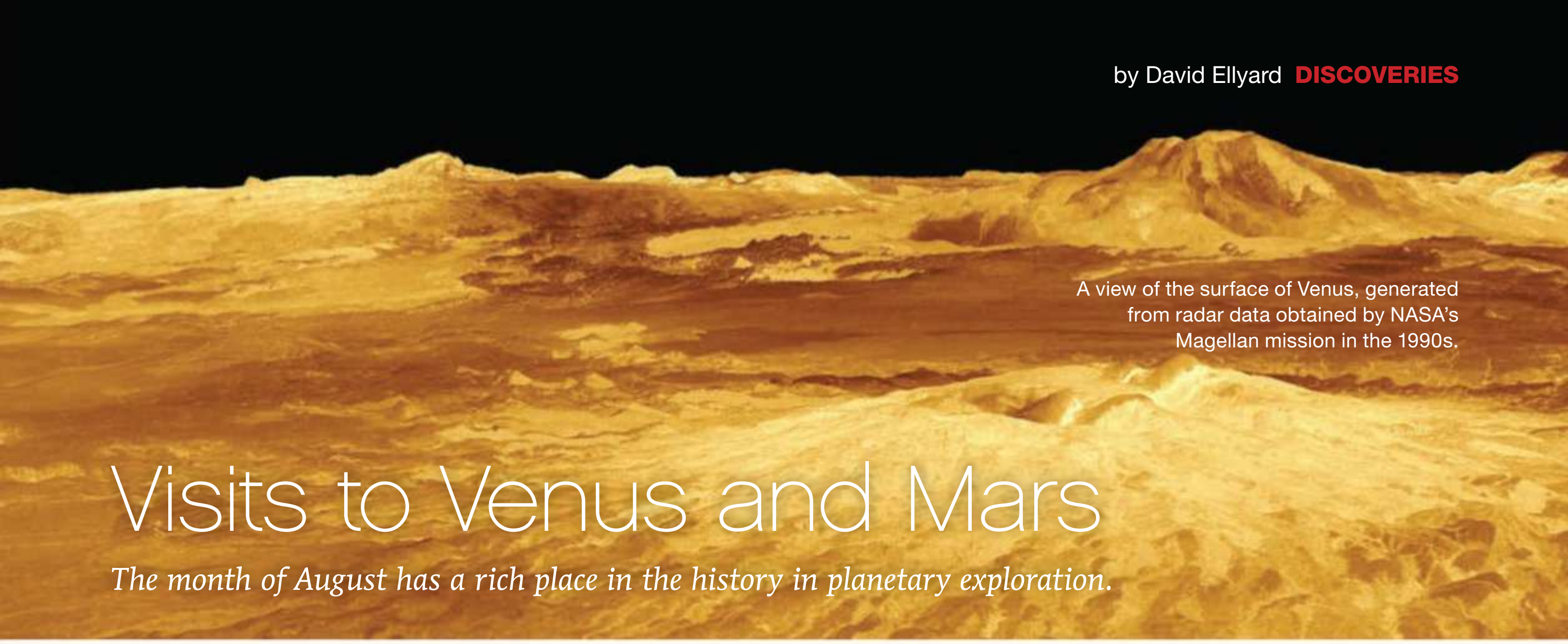
Nathaniel Stein (Caltech) and colleagues found that the cracks formed during fluctuations in the water level of a lake that existed there about 3.5 billion years ago. The results appear in the journal, *Geology*.

Curiosity landed on the northern side of the crater in 2012 and has slowly been making its way south. Close to the crater's centre, it took pictures of a rock slab nicknamed Old Soaker, as well as a similar nearby slab dubbed Squid Cove. A polygonal network of cracks in the red mudstone on these slabs' surfaces looks like what you'd expect from wet sediment that contracted as it dried.

The cracks are filled with sediment that has a chemical composition matching the underlying rock. Most likely, the cracks were filled in shortly after they formed as the lake level rose again. Sediment suspended in the water would have slowly settled into the cracks.

"These cycles of rise and fall likely happened many times before the region finally dried out for good," Stein says.

The history of Martian water will continue to unfold as the rover encounters ever-younger material on its way up the Murray Formation, the mountainous region in the crater's centre. ■ **JULIE FREYDLIN**



A view of the surface of Venus, generated from radar data obtained by NASA's Magellan mission in the 1990s.

NASA/JPL

Visits to Venus and Mars

The month of August has a rich place in the history in planetary exploration.

Our nearest planetary neighbours, Mars and Venus, are currently very easy to spot. Venus is in the west after sunset, rising steadily higher and growing brighter. Mars is shining brightly in the northern half of the sky.

The early history of the exploration of these planets has an association with this time of year. For example, on August 10, 1990, the US space probe Magellan reached Venus, having been launched from the cargo bay of a Space Shuttle in Earth orbit (the first interplanetary probe to be so carried) in May, 1989.

Venus is such a brilliant sight in the night sky because of its thick layers of reflective clouds, which however totally obscure the surface from view. Magellan carried radar to penetrate the clouds and image the surface as it orbited the planet every three hours. Once computer-processed back on Earth, the radar readings generated stunning views of a tormented landscape so long hidden from sight, with evidence of past intense volcanic activity. Very few impact craters were sighted, indicating that the surface is relatively young geologically speaking.

After four years of service that included measuring the gravitational field of Venus with great accuracy, Magellan was directed to de-orbit into the planet's atmosphere, gathering information on the Venusian air even as it headed for oblivion.

The exploration of Mars has dates associated with August, too. On August 5, 1969, Mariner 7 completed a flyby of the Red Planet. From an altitude of about 3,000 kilometres it snapped 22 images covering about 20% of the surface. These showed that Mars is very different to the Moon, with which it had been compared following images taken years earlier during the Mariner 4 fly by. The south polar icecap was visible, with Mariner 7's instruments indicating that it was made up of frozen carbon dioxide rather than water ice. Radio tracking of the trajectory of the spacecraft provided new and more accurate data of the planet's size, shape and mass.

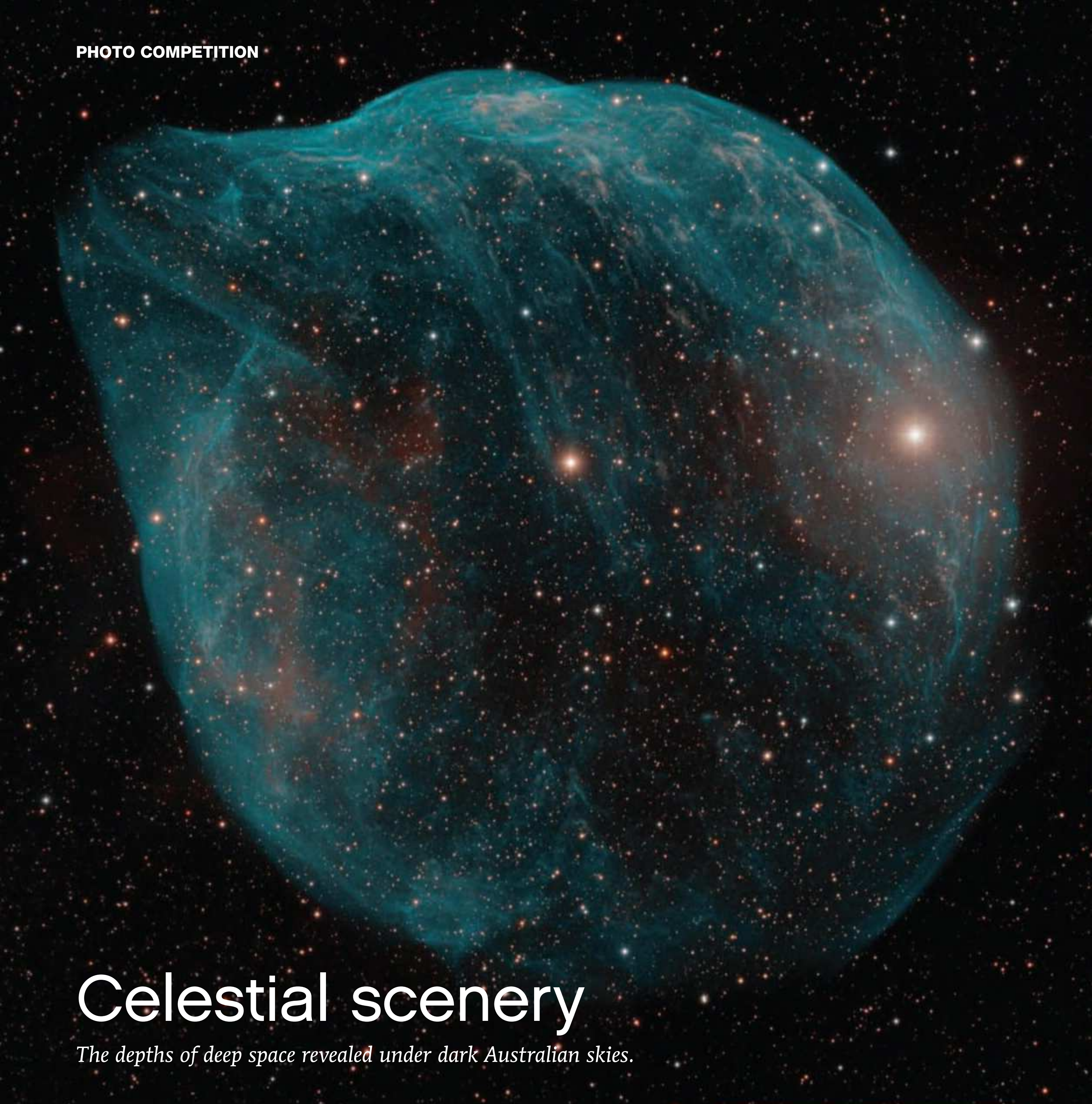
The space program most active in the exploration of Mars in the 1960s and 1970s was that of the Soviet Union. The Soviet's had launched many more missions toward Mars than the US had done, but without a great deal of success. Having 'lost' the race to the Moon in the '60s, the Soviets were keen to show they were still a power in space enterprise. Perhaps for ideological reasons they were particularly interested in the 'red' planet.

In July and August 1973, the Soviets launched a series of Mars-bound probes. The objectives of the missions were ambitious. Mars 4 and 5 were intended to go into orbit around the planet, while Mars 6 and 7 were to fly past and drop landers to the surface. The first objective had been first achieved by Mars 2 and 3 two years earlier, though efforts to map the planet from orbit were thwarted by global dust storms. At much the same time the US had similar success with Mariner 9. But neither country had managed to get a package of instruments onto the surface.

The Soviet success rate did not improve, perhaps indicating how close to the edge the technology of the day was being pushed. Mars 4 did not enter Mars orbit, while Mars 5 failed after 9 days in orbit having returned only 180 frames. As for the landers, the Mars 7 lander separated four hours too early from the flyby craft and missed Mars altogether. The Mars 6 lander did better, sending several minutes of data back to the mother ship as it descended. This was the first data ever collected from the Martian atmosphere, but contact was lost before the planned time of touch down. Some of the data relayed was unreadable due to faulty computer chips.

The first real success in getting a lander onto the Martian surface was achieved by the US two years later. Viking 1 was launched on August 20, 1975. For reasons of political symbolism, the probe's controllers had hoped to set the craft down on Mars on July 4, 1976, 200 years after the Declaration of Independence. That did not quite work out. But the date it landed, July 20, was still significant, being six years to the day after Apollo 11 had touched down on the Moon.

DAVID ELLYARD presented SkyWatch on ABC TV. He is the author of *Who Discovered What When* and *Who Invented What When*.



Celestial scenery

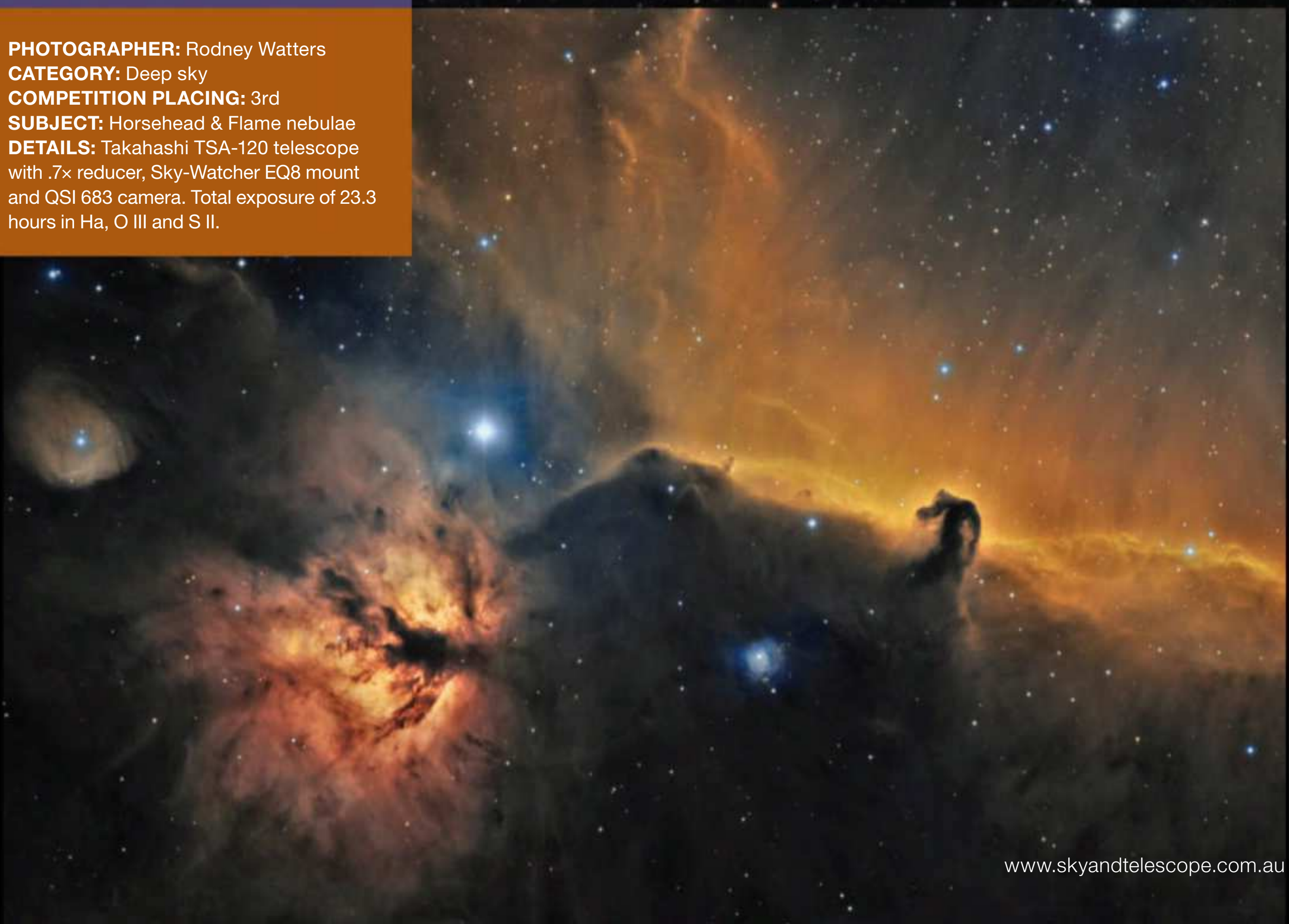
The depths of deep space revealed under dark Australian skies.

THE WINNERS OF THE ASTRONOMICAL SOCIETY of NSW's annual Astroimaging Competition are announced each year during the South Pacific Star Party at the Society's rural dark sky property, Wiruna. And this year, once again, the work produced by some of Australia's best astrophotographers is nothing short of spectacular.

As a supporter of the Competition and Star Party, *Australian Sky & Telescope* is proud to publish the winning images from this year's deep sky and open categories, and we extend our congratulations to the photographers.

PHOTOGRAPHER: Dean Carr
CATEGORY: Deep sky
COMPETITION PLACING: 1st
SUBJECT: The Gourd Nebula
DETAILS: Orion EON 130-mm ED Triplet APO refractor, Sky-Watcher EQ8 mount and QSI 683WSG-8 camera.
EXPOSURES: Ha, 13.5 hours; O III, 13.5 hours. Processed with PixInsight.

PHOTOGRAPHER: Fred Vanderhaven
CATEGORY: Deep sky
COMPETITION PLACING: 2nd
SUBJECT: Messier 83
DETAILS: RCOS 25-cm Ritchey-Chrétien telescope, SBIG STXL 6303E camera and 24 hours exposure of 20-minute LRGB subs.



PHOTOGRAPHER: Rodney Watters
CATEGORY: Deep sky
COMPETITION PLACING: 3rd
SUBJECT: Horsehead & Flame nebulae
DETAILS: Takahashi TSA-120 telescope with .7× reducer, Sky-Watcher EQ8 mount and QSI 683 camera. Total exposure of 23.3 hours in Ha, O III and S II.

▲ **PHOTOGRAPHER:** Peter Patonai
CATEGORY: Open
COMPETITION PLACING: 1st
SUBJECT: Solar eclipse
DETAILS: AstroTech EDQ 65mm telescope, Pentax K5 camera. Composition of 14 exposures ranging from 1/1000th to 4 seconds, for a total of 10 seconds.

▼ **PHOTOGRAPHER:** Niall MacNeill
CATEGORY: Open
COMPETITION PLACING: 2nd
SUBJECT: Jupiter & Ganymede
DETAILS: Celestron C14 EdgeHD telescope and ZWI ASI 174MM camera. Best frames selected and stacked from a 30-minute run (10 RGB runs, 1 minute per colour channel).

▶ **PHOTOGRAPHER:** Greg Priestley
CATEGORY: Open
COMPETITION PLACING: 3rd
SUBJECT: Radio telescope & star trail
DETAILS: Sony A7 camera with Rokinon 14-mm f/2.8 IF ED UMC aspheric lens. Sixty exposures of 30 seconds, ISO 2500.

LITTERBUGS This artist's representation of space debris in low-Earth orbit is based on real data but exaggerates the size of individual objects so that they are visible at this scale.

LITTER IN ORBIT:

How to Clean Up Space Junk

Millions of pieces of debris orbit Earth, and it's going to take a coordinated effort to solve the problem.

Sixty-some years ago, Sputnik became Earth's first artificial satellite. But it wasn't the only thing launched that day — the main rocket stage of the launch vehicle also ended up in orbit. There are now more than 9,000 tonnes in orbit around Earth, and 80% of that is orbital debris — 'space junk'.

Space is famously big, so you might think that even tens of thousands of orbiting objects would have plenty of room to themselves. Indeed, the average distance between debris at any moment is hundreds of kilometres. But each of those objects is flying around Earth at swift speeds: 28,000 km/hr in the lowest, fastest orbits. They sweep through so much space in the course of a short time that the occasional cosmic collision is not only likely but inevitable.

In the Kessler syndrome, collisions become so frequent that a chain reaction gradually reduces the near-Earth satellite population to aluminium confetti and makes space travel impractical.

On February 10, 2009, a half-tonne communications satellite, Iridium 33, smashed into a dead Russian satellite at a relative speed of 41,940 km/hr and an energy of 54,000 megajoules. (A single megajoule is the energy of a one-tonne truck hitting you at 160 kph.) In a fraction of a second, both satellites were reduced to thousands of pieces of shrapnel, many of which remain in orbit today and pose a threat to other space traffic.

As the amount of space junk increases, we risk what's called the *Kessler syndrome*, in which collisions become so frequent that a chain reaction gradually reduces the near-Earth satellite population to aluminium confetti and makes space travel impractical.

Debris demographics

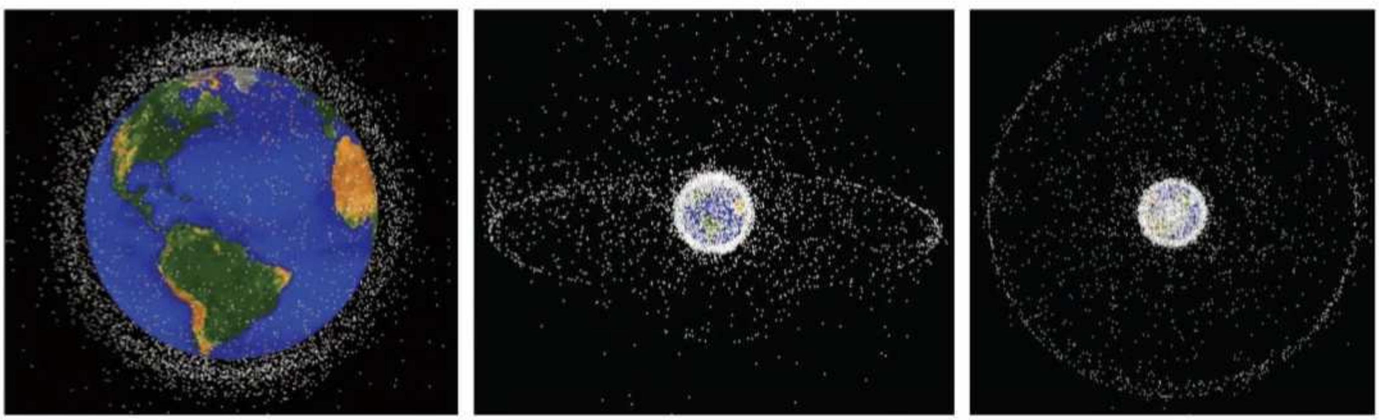
We can distinguish two main kinds of junk: Deliberate littering includes dead satellites, expended rocket stages and discarded parts such as covers and lens caps. Debris can also result from destructive events, such as rocket explosions, satellite collisions and antisatellite tests. As the number of satellites has gone up, the number of different types of space junk has also increased over time. In the classic Space Race years of the 1960s, only a few dozen satellites were operating at any one time, but today there are almost 2,000 — and the amount of orbital garbage has ballooned accordingly. The junk increased dramatically in 2007, when China tested an antisatellite missile and destroyed one of its weather satellites, and again in 2009, thanks to the Iridium collision. A handful of incidents have undone decades of efforts to reduce the amount of space junk.

Any piece of debris orbits Earth in a path similar to that of the satellite that made it. Most satellites are either in *low-Earth orbit* (LEO), between 200 and 1,700 km above the surface, or in the 35,800-km-high *geostationary orbit* (GEO), where satellites take 24 hours to circle the planet in order to stay in the same location on the sky as seen from Earth. GEO is mostly used for communications and television-broadcasting satellites, although low-power communications payloads used for cellphone and email traffic can be found in LEO, too.

A special set of near-polar orbits within LEO are known as *Sun-synchronous orbits* (SSO), where satellites pass over the same part of Earth at roughly the same local time every day. Here you can find the satellites that image Earth, both for civilian mapping and government surveillance purposes.

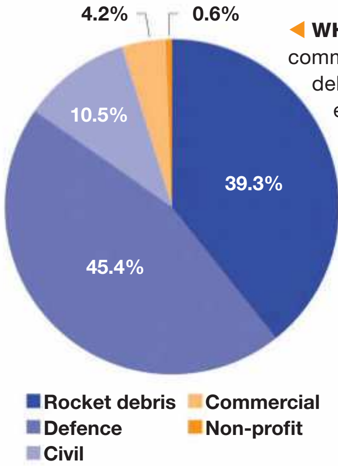
At intermediate heights (*medium Earth orbit*; MEO) between LEO and GEO, the intense Van Allen radiation belts make it harder for satellites to operate. Nevertheless, GPS navigation satellites are among those that operate here in 12-hour orbits.

▼**JUNK NEAR EARTH** The vast majority of debris exists in low-Earth orbit (*left*), but a significant number of objects are in or near geostationary orbit *(centre)*, which, aligned with Earth's equator, lets satellites to match our planet's spin. A polar perspective *(right)* provides a different view of the density of objects in LEO and GEO orbits. View the debris in motion at **https://is.gd/spacedebrismovie**.



LITTERBUGS: ESA; JUNK NEAR EARTH: NASA (3)

GEO 35,800
MEO
1,700
LEO
200 km



◀ **WHO'S LITTERING?** The littering by civilian and commercial satellites is relatively minor compared to the debris generated by military satellites (medium purple) and exploded rocket stages (dark purple).

All of these orbits are roughly circular — relatively few satellites operate in *highly elliptical orbits* (HEO), where the low and high points (perigee and apogee) are very different from each other. But a lot of junk lies in HEO, mostly from rocket stages, which were left there while delivering a satellite to GEO.

Still, most of the known junk is in LEO, and thanks to the 2007 Chinese military weapons test, the majority of that is in SSO.

That distribution may be an illusion, though, as it's much harder to detect small debris in the higher orbits farther from Earth. The same object in a 10 times higher orbit is 1/100th as bright to optical telescopes and appears 1/10,000th as bright to radar reflection. We'll know better what the high-orbit debris situation is in a few years, when new satellites dedicated to mapping high-altitude space debris give us the true picture. It's likely to be depressing news.

Litter prevention

The major spacefaring nations are now taking steps to lower the risk of a Kessler cascade. Although no international law controls space littering, informal agreements exist between the world's major space agencies. The Inter-Agency Space Debris Coordination Committee provides a forum for these agencies to set recommendations — for example, how high above GEO you should boost your dying satellite so it won't bump into operational ones. The leading centres for research on debris are the Orbital Debris Program Office at NASA's Johnson Space Center in Houston, Texas, and the European Space Agency's Space Debris Office in Darmstadt, Germany, which also hosts regular international conferences on the problem.

These groups have found that there's no one-size-fits-all solution when it comes to space junk. Different kinds of junk need different approaches.

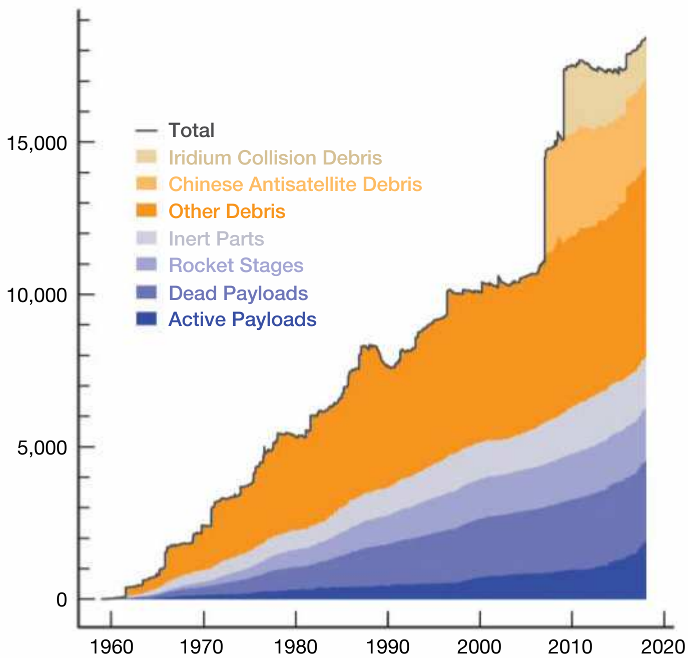
Active satellites are 'passivated' at the end of their missions. This neologism indicates that the owners try to get rid of all energy sources that might cause the satellite to blow up at a later date — usually, by venting all rocket propellant and all the fluid from any batteries. In the past, battery explosions had been another significant contributor to space junk.

If the satellite is in a low orbit, it will be lowered toward Earth as much as possible before getting rid of its rocket fuel. The idea is to make it vulnerable to atmospheric burn-up. Getting the satellite to re-enter immediately is best, since you can then control where it burns up, but there may not be enough fuel to do this. Even reducing the perigee a bit will help, since the atmosphere gets much denser the lower you go, and atmospheric drag will become more effective in bringing the satellite down, perhaps in months instead of decades.

For satellites in GEO, it wouldn't be practical to bring the satellite down from that high. Instead, they go into a so-called 'graveyard orbit, a few hundred kilometres above the geostationary belt. Satellites placed here will stay out of the belt for hundreds of years, even with the perturbing gravity of the Moon and Sun.

Such actions mark a drastic change from 30 years ago, when most low-orbit satellites didn't have the ability to change their orbits at all. A rocket put them in space, and they orbited solely under the influence of gravity and air drag. Nowadays, most satellites with a mass of more than a few hundred kilograms have their own rocket-propulsion systems to alter the orbit at mission's end.

But recent years have brought us a new problem: Since 2003 nanosatellites (less than 10 kg) have become common, most using a standard design known as a CubeSat. More than 500 CubeSats are now in orbit, and almost none of them have their own rocket engines, posing a challenge for other satellites. Even if a CubeSat is still operating, if it can't



▲ **A GROWING PROBLEM** The amount of space junk has increased dramatically over a few decades. Most debris comes from accidental rocket explosions or deliberate military tests. Single collision events, such as the deliberate Chinese test or the accidental Iridium/Cosmos crash, can worsen the situation significantly. Littering of inert parts, rocket stages and dead satellites makes up most of the rest. Active satellites (dark purple) are only a small fraction of the orbital traffic.

GREGG DINDERMAN / S&T; SOURCE: J. MCDOWELL (2) get out of the way it might as well be space debris as far as an approaching satellite is concerned. Until recently many CubeSats were launched to low orbits with short lifetimes to perform technology demonstrations. But as CubeSat systems mature, operational constellations are being designed to stay up longer.

In the past couple of years, a wave of new experimental CubeSats have been built to test various ways to get out of LEO cheaply once they're done working. One company is advocating tiny solid rocket motors, but an early test fired in the wrong direction. Most of the current experiments use some variation of *drag brakes*: Either a balloon or parachute pops out of the tiny satellite at the end of its mission and inflates to a much larger size. Friction with the upper atmosphere then decelerates the satellite, ensuring re-entry within a few weeks or months.

A bunch of older rocket stages are still in orbit as ticking time bombs.

To address the longevity of both CubeSats and larger items, Japan has shown an interest in electrodynamic space tethers, launched coiled up and then unreeled. Earlier US experiments demonstrated tethers many kilometres long. As the tether passes through Earth's magnetic field, currents run along the wire, converting the satellite's orbital motion into heat. As a result, the satellite slowly drops out of orbit. Unfortunately, space tethers have seen a variety of problems in deployment and implementation, which makes it unlikely that they will ever see wide use.

Rocket stages present a slightly different challenge, since they usually run on batteries that last only a few hours. But disposing of them uses the same general idea as for large satellites. When the rocket completes its mission of delivering a satellite, its tanks won't be entirely empty — technicians always leave a little extra in reserve. And since there's no air in space, the rocket also carries an extra tank of oxidiser to help it burn the fuel. As long as the leftover fuel and oxidiser are kept separate, there's no problem. But if the gaskets in the plumbing erode, perhaps months or years after the mission, the two can mix and you can get a large explosion.

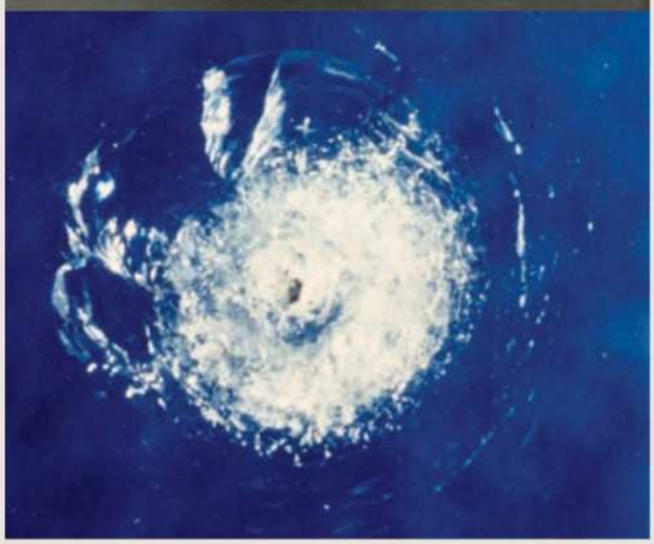
Most modern rockets are designed so that the engine can restart at the end of the mission and use up all the leftovers, preferably making the rocket stage re-enter, too, so that it spends only hours instead of years in space. But a bunch of older rocket stages are still in orbit as ticking time bombs: One type of Russian rocket motor, called SOZ, was responsible for four explosions over the past two years. In each case, the motor had been orbiting for about a decade.

Satellite operators have also learned to do less littering. In the early days of the space age, satellites would often jettison instrument covers that were no longer needed using springs or explosive bolts. Now such covers are often mounted on

NASA (2)

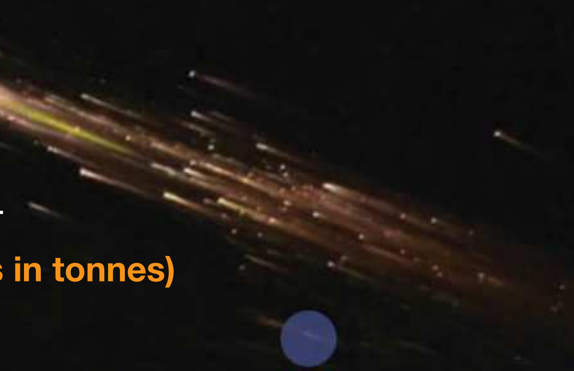
DEBRIS STATISTICS
(through December 25, 2017)

* Includes 43,086 catalogued objects and 1,339 objects that are known but not tracked.



▲▲ **'SHOTGUN' BLAST** This view shows a small hole that orbital debris created in a panel of the Solar Maximum Mission.

▲ **WINDOW CRACK** Orbital debris the size of a paint chip made this small pit in the window of the *Challenger* during NASA's 7th space shuttle mission.



▶ SPECTACULAR BREAKUP A European Space Agency's unmanned cargo resupply spacecraft, dubbed Jules Verne, burned up over the Pacific Ocean in 2008 after delivering supplies to the International Space Station. An observing campaign monitored the re-entry to compare against computer modelling. Watch the breakup at **https://is.gd/julesvernebreakup.**

BIGGEST UNCONTROLLED RE-ENTRIES (re-entry mass in tonnes)

12.2	Zenit-2 rocket 11S772/ EPN 03.694	**June 21, 1985**	*Pacific Ocean*
13.2	UR-500 No. 207 (Proton-1 rocket)	**September 18, 1965**	*Unknown*
13.2	UR-500 No. 212 (Proton-3 rocket)	**January 4, 1966**	*Unknown*
13.2	UR-500 No. 209 (Proton-2 rocket)	**August 21, 1966**	*Unknown*
13.6	Saturn S-IVB-205 (Apollo 7 rocket)	**October 18, 1968**	*Indian Ocean*
14.5	Saturn S-IVB-204 (Apollo 5 rocket)	**January 23, 1968**	*Off Australian Coast*
14.6	Tselina-2 No. 3L/Zenit-2 11S772 rocket (Kosmos-1714)	**February 27, 1986**	*Pacific Ocean*
16.2	Apollo BP-13/ Saturn SA-6	**June 1, 1964**	*Pacific Ocean*
16.3	Almaz-1 space station (Salyut-2)	**May 28, 1973**	*Pacific Ocean (near Fiji)*
16.4	Apollo BP-15/ Saturn SA-7	**September 22, 1964**	*Indian Ocean*
17.0	N-6 No. 1 satellite (Proton-4)	**July 24, 1969**	*Unknown*
17.2	Saturn SA-5 rocket/ Jupiter nosecone	**April 30, 1966**	*Brazil*
18.5	DOS 3 space station (Kosmos-557)	**May 22, 1973**	*Indian Ocean*
39.0	DOS 6 space station/TKS-M module (Salyut-7/Kosmos-1686)	**Feb 7, 1991**	*Argentina*
45.1	Saturn S-II-13 (Skylab rocket)	**January 11, 1975**	*Atlantic Ocean (west of Madeira)*
75.7	Skylab space station	**July 11, 1979**	*Australia*

RE-ENTRY HEADLINES

One aspect of the space junk problem that tends to get media attention is what happens when larger chunks re-enter Earth's atmosphere.

While a lot of the debris pieces are made of aluminium, which melts during re-entry, some denser and hardier parts survive the fiery descent and reach Earth's surface. In the 60-some years since Sputnik, though, no one has been hurt, and there has been no serious damage from things falling from the sky. In 1962 the service module of Sputnik 4, the prototype Vostok spaceship, re-entered over the US — a piece of it was found in the middle of a street in Manitowoc, Wisconsin, but there wasn't even a crater.

The most notorious re-entry was also the biggest ever — the 77-tonne Skylab space station, which broke up over Western Australia in 1979. Since then, most large spacecraft have been brought down under control using rocket motors, usually in the so-called 'spacecraft cemetery' in the central southern Pacific Ocean.

Nowadays, when even a moderate-size spacecraft does make an uncontrolled re-entry, such as the 7.5-tonne Chinese Tiangong 1 space lab on April 2, it makes headlines.

▲ LONE STAR The main propellant tank of the second stage of a Delta 2 launch vehicle landed near Georgetown, Texas, on January 22, 1997. The approximately 250-kg tank is primarily made of stainless steel and survived re-entry relatively intact.

hinges so that they remain attached. It's more expensive and potentially less reliable, but avoids extra debris.

Bad behaviour in orbit

All of these techniques are working to keep space junk at a lower level, but they can't prevent deliberate explosions and collisions. These have been another big source of debris historically, one that is completely avoidable. Soviet satellites often carried self-destruct packages to prevent them falling into American hands if they re-entered. Unfortunately, sometimes these packages would go off by accident. The Soviet missile early warning system used one-tonne infrared observatories called Oko (old Russian for 'eye') to watch for American missile launches from orbit. These satellites only lasted a few years at best, remaining in highly elliptical orbits as space junk, and their self-destruct systems had a regrettable habit of activating months or years after the satellite's demise, strewing debris on a path ranging all the way from LEO to GEO altitudes.

The US, USSR, and China have also all played with weapons designed to destroy an enemy's space systems. Fortunately, none of these weapons have been used against an opponent, but they've been tested against the country's own satellites. The weapons have usually been aimed at a dedicated target. But a US Air Force test in September 1985 did use an F-15 to take out a still-operational US Navy solar physics observatory, causing some bitterness from the Navy scientists whose data suddenly stopped coming in. (Wags at the time suggested the traditional Air Force/Navy rivalry had escalated to confusion about who their real enemy was.)

Deliberate collisions are simple to avoid: Let's just not do that sort of thing. But that still leaves the accidental ones. At the moment, the debris from accidental collisions is still a small fraction of all the space junk (only about 3%), so do we really need to worry about it? The problem is that if you have ten times the number of satellites, you typically make ten times the amount of all the other kinds of debris. But you get a hundred times as many collisions; the probability of an orbital crash goes up as the square of how much traffic there is. So if we keep increasing our use of space, in a few decades the collisions are likely to surpass everything else and become the main space debris problem. Then we'll be in trouble — Kessler's prediction may come true.

So far, our efforts to reduce how much debris we generate have met with mixed success. Attention is now shifting to more active measures.

Space garbage trucks

With tens of thousands of small debris objects floating in near space, some fairly imaginative, and indeed desperate, ideas have been suggested. Powerful Earth-based lasers could melt small debris pieces. Or, a satellite could deploy a huge sticky net, perhaps covered in the aerogel used to collect solar wind samples, and act as a sort of space vacuum cleaner. (Of course, an actual vacuum cleaner wouldn't work in the vacuum of space!) Such devices go under the heading of *active debris removal*, the term of art for space garbage collection.

Perhaps these removal mechanisms aren't really needed, though, because it turns out the smallest objects aren't the worst problem. Most of them have a fairly large area-to-mass ratio: They're more like feathers than cannonballs, so they're strongly affected by atmospheric drag. In orbits below 500 kilometres, objects will usually re-enter over the course of the solar cycle. Every 11 years, as our star reaches solar maximum, its wind stretches out Earth's atmosphere. As high-density air reaches higher altitudes, it clears out much

▶ **RE-ENTRIES AROUND THE WORLD** Debris fragments have been recovered on the ground worldwide. Even so, the hazards posed by re-entering spacecraft and debris are extremely small. Space agencies and nation states typically aim for a casualty risk of less than 1 in 10,000 probability for a single uncontrolled re-entry.

JULES VERNE: ESA / NASA; LONE STAR: NASA; MAP: GREGG DINDERMAN / S&T; SOURCE: ESA of the LEO debris.

Further, simulations show that the biggest contributors to a Kessler cascade would be the largest satellites. The Iridium-Cosmos collision is a case in point — it's this sort of crash that makes the most debris. So maybe we should focus on getting rid of the monster space junk first; there's less of it, so that's an easier problem.

We will soon have the technology to do just that. Building on the collective experience in sending robotic cargo ships to the International Space Station (ISS), companies may soon build satellites to grab onto and repair or refuel communications payloads, even those that — unlike the ISS — weren't designed for visitors. Such space tugs could also move their prey to a different orbit, perhaps sending them down to controlled re-entry over the ocean.

▲ **INVENTION OF NECESSITY** The Cleanspace One concept, which features a Pac-Man-like mechanism for capturing space junk, is one of many inventive ideas on the drawing board for dealing with orbital debris.

But whose stuff can you deorbit? NASA, for example, would be allowed to deorbit its own space junk, but the legality of grabbing onto someone else's dead satellite is questionable, even if it belongs to a country that no longer has a space program. Space lawyers are already talking about this issue!

Space tugs wouldn't come cheap, either. Different satellites fly at various orbital inclinations to the equator. Changing from one orbit to another would require too much fuel to be practical, so tugs would have to stay at a narrow range of inclinations.

Nevertheless, in the long run I expect we'll see a fleet of space garbage trucks sidling up to long-dead spacecraft and nudging them to their doom. Or, perhaps, sending them to very high orbits, where the low orbital velocities make it cheaper to change inclination. You could potentially collect billions of dollars of defunct high-tech material in an orbital scrapyard, where materials could be recycled.

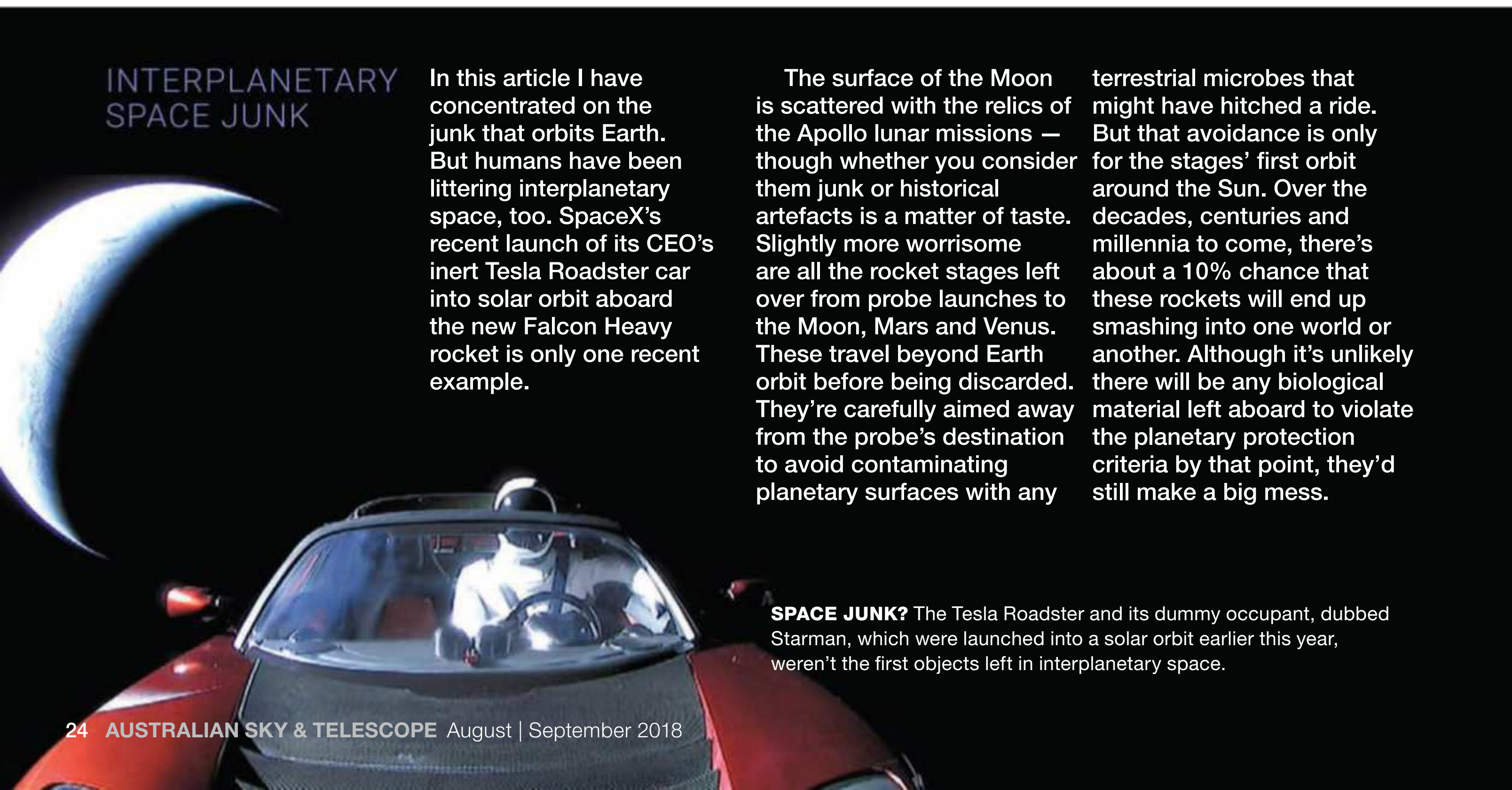
At this point, the challenge has become more political and economical than technical. I believe that some kind of international tax on satellite operators will be needed to fund the orbital cleanup system. As usual with environmental problems, it's one thing to realise we have a disaster on our hands — it's quite another to agree to do something about it. Let's hope we still have space exploration a century from now!

■ In addition to studying black holes and devising data-analysis software, astrophysicist **JONATHAN MCDOWELL** (Harvard-Smithsonian Center for Astrophysics) is an avid investigator of space history. His free online newsletter, *Jonathan's Space Report*, has provided technical details of satellite launches since 1989. Find out more at **planet4589.org**.

INTERPLANETARY SPACE JUNK

In this article I have concentrated on the junk that orbits Earth. But humans have been littering interplanetary space, too. SpaceX's recent launch of its CEO's inert Tesla Roadster car into solar orbit aboard the new Falcon Heavy rocket is only one recent example.

The surface of the Moon is scattered with the relics of the Apollo lunar missions — though whether you consider them junk or historical artefacts is a matter of taste. Slightly more worrisome are all the rocket stages left over from probe launches to the Moon, Mars and Venus. These travel beyond Earth orbit before being discarded. They're carefully aimed away from the probe's destination to avoid contaminating planetary surfaces with any terrestrial microbes that might have hitched a ride. But that avoidance is only for the stages' first orbit around the Sun. Over the decades, centuries and millennia to come, there's about a 10% chance that these rockets will end up smashing into one world or another. Although it's unlikely there will be any biological material left aboard to violate the planetary protection criteria by that point, they'd still make a big mess.



SPACE JUNK? The Tesla Roadster and its dummy occupant, dubbed Starman, which were launched into a solar orbit earlier this year, weren't the first objects left in interplanetary space.

Dr Alice Gorman, space archaeologist

ASHTON CLARIDGE/FLINDERS UNIVERSITY

SPACE JUNK HAS A TALE TO TELL

Space heritage is the evidence of human exploration of space in the 20th and 21st centuries. It comprises objects and places on the surface of the Earth, such as launch sites and tracking stations; satellites and space junk in Earth orbit; planetary landing sites; and deep space probes throughout the Solar System. It represents a distinct social and technological phase of human cultural evolution.

By far the largest off-earth component of this heritage is located in Earth orbit. Since the launch of Sputnik 1 in 1957, Earth orbit has become filled with debris — more than 23,000 pieces larger than 10 cm, and millions of fragments below this size. Due to the damaging effects of high-speed collisions between bits of space junk, the increasing amount of debris is starting to become a threat to the satellite services that the people of Earth rely on to deliver telecommunications, Earth observation, navigation, timing and more. It is widely recognised that some form of active debris removal is needed to secure access to space for the future.

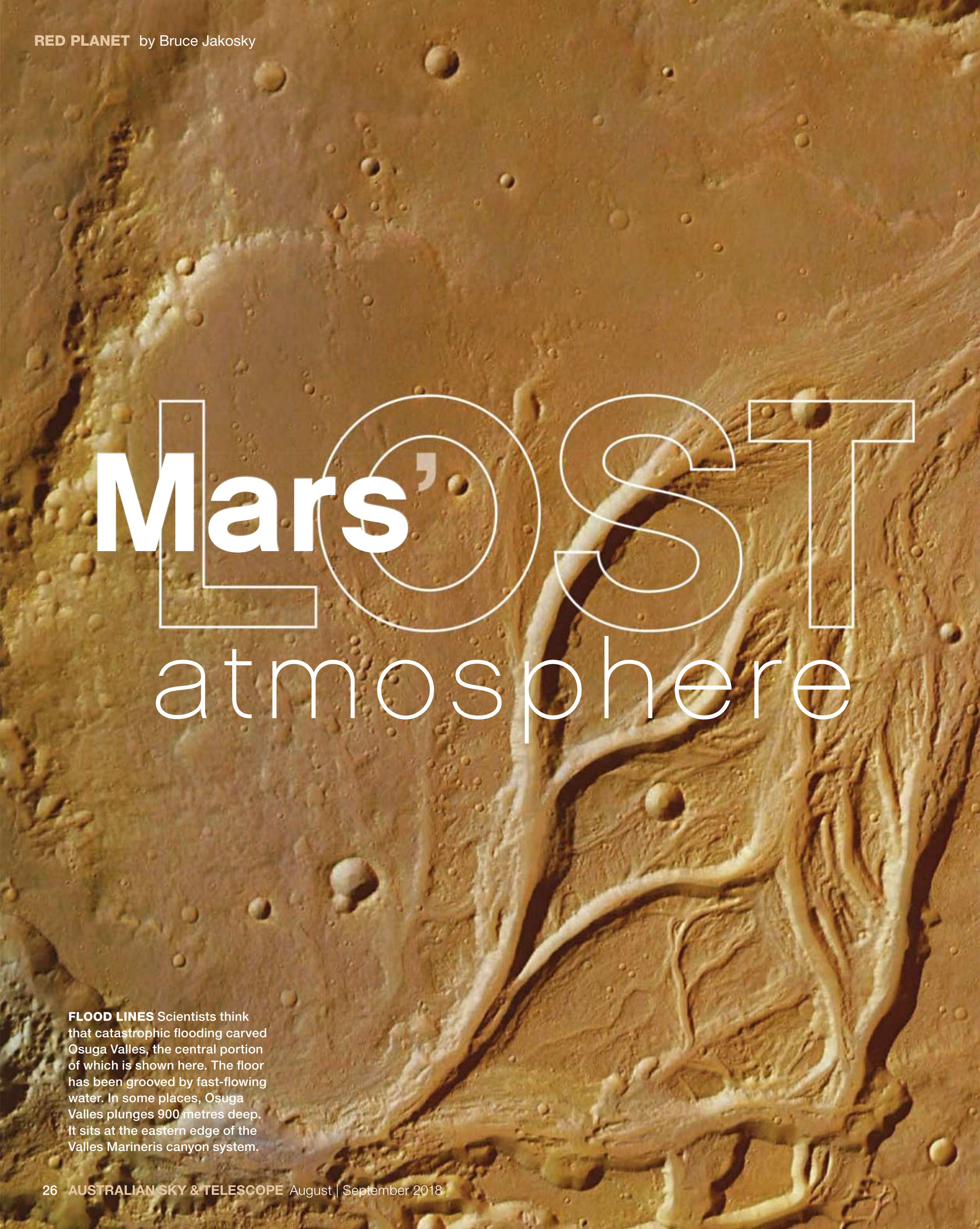
However, some of this debris has heritage value for communities on Earth. Numerous defunct satellites have been shown to have historic, aesthetic, scientific and social significance as defined by the internationally recognised guidelines of Australia's Burra Charter (2013). Such satellites include Vanguard 1, the oldest human object in space; Telstar 1, the first active telecommunications satellite; and Australis Oscar V, an Australian amateur radio satellite launched in 1970. Australis Oscar V is one of only a handful of Australian satellites in orbit that attest to our independent participation in the Space Age.

For items such as Australis Oscar V, leaving them in their original orbital context is the most appropriate and cost-effective management strategy, if the collision risk is low. Collision analyses are performed every day, so we know when the risks become more critical. But it would help if there was a more co-ordinated process to identify and protect space junk with high cultural significance. This could include establishing formal and informal heritage lists, and creating a technical committee of the International Council on Monuments and Sites (ICOMOS), which advises UNESCO on heritage matters.

While heritage on Earth is often (wrongly) perceived as a constraint to development, in Earth orbit it can be an opportunity with which to test the principles needed for space environmental management. Recognising space heritage beyond the Cold War superpowers is also a tool to promote inclusiveness in space as recommended by the United Nations Vienna Declaration (1999). Culturally significant space artefacts enable communities on Earth to feel connected to space as part of the common heritage of humanity. Recognising our heritage in space is especially important now, with the formation of the first Australian Space Agency — we should be using our stories and these objects to forge a new space identity.

Dr Alice Gorman is a space archaeologist at Flinders University.

Dr Gorman and other technology experts, including NASA's Dr Christyl Johnson, will be presenting at Hybrid World Adelaide at the Adelaide Convention Centre, July 20–24, 2018. Hybrid World Adelaide is a digital entertainment and technology event that explores a future where the real and digital worlds collide and ultimately evolve. Full details at hybridworldadelaide.org



Mars' LOST atmosphere

FLOOD LINES Scientists think that catastrophic flooding carved Osuga Valles, the central portion of which is shown here. The floor has been grooved by fast-flowing water. In some places, Osuga Valles plunges 900 metres deep. It sits at the eastern edge of the Valles Marineris canyon system.

NASA's MAVEN mission has confirmed how our planetary neighbour lost its protective gas envelope.

Mention anything about the potential for life on Mars, and you'll get people's attention. The conversation often centres on water. Life as we know it requires liquid water, and the evidence that Mars has had liquid water in various forms throughout its history means that it could have supported life.

But Mars is a frozen, desert planet today, with a thin atmosphere and temperatures typically well below the melting point of water ice. So why do we think Mars had abundant liquid water in the past? And what caused the climate to change to one unfriendly to life as we know it?

The evidence that Mars once had liquid water came initially from orbiter images. Thanks to them, we've known for decades that Mars has systems of valleys that look like they formed via water runoff. We've seen what appear to be deposits of sediments carried by water as it flowed into the enclosed basins of impact craters. We've also observed that the oldest surfaces look worn down, and that few impact craters smaller than about 10–15 km wide mar the landscape, which combined tell us that significant erosion has occurred — with erosion by water runoff being the favoured explanation.

Starting with the Mars Pathfinder landing in 1997, we also began observing small-scale surface features that suggested water once flowed. We've identified sediment deposits that bear all the hallmarks of having been laid down in liquid water. And we've seen small, round deposits formed by the buildup of waterborne material, called *concretions*, and even specific minerals that require liquid water in order to form.

By estimating dates for these various features, planetary scientists have put together a rough timeline for water on Mars. It reveals that the strongest signs of liquid water tend to be very old. In fact, all of the geological and geochemical evidence points toward Mars having had a climate that allowed liquid water to be widespread on the surface up until about 3.5 to 3.7 billion years ago. Conditions then changed rapidly (geologically speaking), and whatever allowed water to be present disappeared over a period of only a few hundred million years, leaving behind a colder and drier planet.

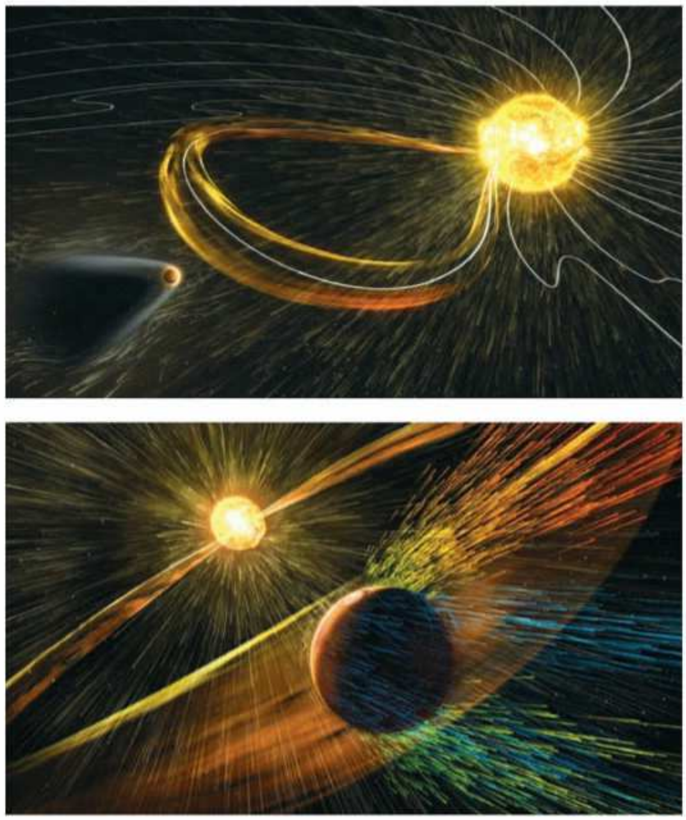
There is some evidence for water in later epochs — large flood channels that appear to have been formed by the catastrophic release of water from the subsurface, very recent (within the last couple million years) gullies that may involve water — but not as an abundant, stable liquid. These later features would all involve subsurface sources and do not require a different climate than what we see today.

What would the climate on early Mars have looked like? We expect that the average temperature likely was near 0°C or higher in order to support extensive liquid water. This compares to today's average temperature of around −60°C. The simplest explanation for the higher earlier temperatures is the presence of an abundant greenhouse gas that would trap the heat from the Sun and raise the global temperature. Carbon dioxide is the best greenhouse gas candidate, and it's the primary component of Mars's current, thin atmosphere. Scientists have not worked out the details of this ancient warming — whether CO_2 alone could raise the temperatures or whether another greenhouse gas such as hydrogen or methane would have been required — but most expect that a thicker atmosphere early in Mars's history will turn out to be the right explanation.

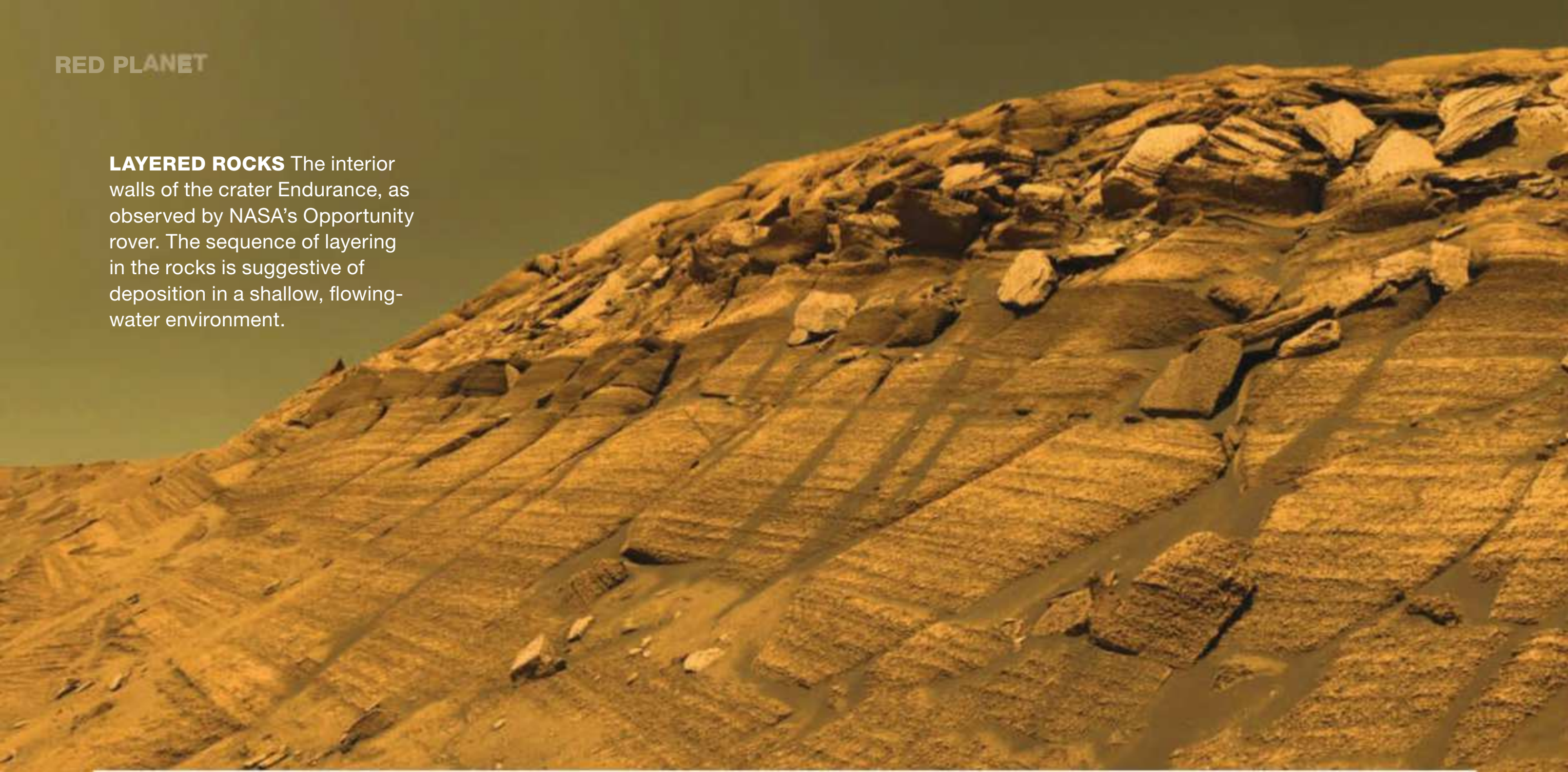
This is the picture we had prior to the Mars Atmosphere and Volatile Evolution (MAVEN) mission, which launched in 2013: that there must have once been a thicker atmosphere and that CO_2 played a role. How did that atmosphere disappear? That is the mystery we sent MAVEN to solve.

Chemistry clues

My fellow planetary scientists and I had already spent many years thinking about where the CO_2 could have gone. Observations had revealed CO_2-derived minerals (such as carbonates) in small amounts on the surface. In theory,



▲ **POOR MARS** *Top:* The Sun strips Mars of its atmosphere, via its ever-present wind of charged particles (streaks) and occasional violent eruptions (brownish band). *Above:* Close-up, with atmospheric escape.



LAYERED ROCKS The interior walls of the crater Endurance, as observed by NASA's Opportunity rover. The sequence of layering in the rocks is suggestive of deposition in a shallow, flowing-water environment.

these minerals could contain CO_2 that had come from the atmosphere. However, scientists had spent the previous two decades looking for a carbonate reservoir on the surface or in the crust that was large enough to hold all the gas from a thick atmosphere, and they hadn't found it.

If atmospheric CO_2 had not gone into the surface or subsurface, then it might have escaped to space. We knew that at least some atmospheric gas had been lost to space: Measurements from the European Mars Express spacecraft, launched in 2003, showed ions from the planet's ionosphere being carried away by the solar wind. Although these measurements ultimately gave us a pretty good estimate of how much gas is being lost today, we didn't have enough information on the physical processes involved to estimate with any certainty how much atmosphere Mars had lost over time. We knew that the Sun's ultraviolet light and the solar wind, which together drive escape, both had been more intense in the past, but without details on the role that each of the potential mechanisms contributed to gas's removal, we couldn't extrapolate the loss rates back through time.

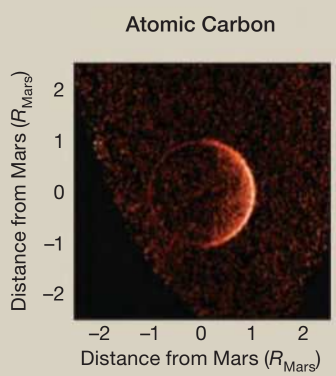
Also, we had chemical measurements from the Viking mission, from Earth-based telescopes, and from Martian meteorites collected on Earth that all strongly suggested that atmospheric loss to space had occurred. This evidence comes from isotopes, the different forms of an element that are distinguished by the number of neutrons in their atomic nuclei. The ways that gas is removed from the atmosphere into space preferentially take the lighter isotope of a pair — normal hydrogen is removed more efficiently than the heavier deuterium, nitrogen-14 over nitrogen-15, and argon-36 over argon-38 — leaving the gas that is left behind enriched in the heavier isotope. Measurements of each of these isotopic pairs in the atmosphere showed just such an enrichment. This meant that loss to space probably was an important process for changing the atmosphere. However, without detailed knowledge of the composition and structure of the upper atmosphere, going from that enrichment to an estimate of the total amount of gas lost involves a lot of guesswork.

And that's where MAVEN came in. We wanted to make measurements that would tell us how much gas is escaping to space today, what the specific processes are that are removing it, and how we could extrapolate back in time to get the total amount lost throughout Martian history. Then we could determine whether atmospheric loss to space had been the dominant process in changing the Martian climate, only one important process among several, or instead a relatively unimportant process.

Making these measurements was no easy task. The many ways that the upper atmosphere and the solar wind could interact, not to mention the ways *these* ways could interact, make the work similar to unraveling the proverbial Gordian knot. Mars is a complex planet. Goings-on in its deep interior, surface, atmosphere, upper atmosphere, and solar wind all link together, sometimes strongly, and we have to

▶ **HALOS** MAVEN has detected coronae of atomic oxygen and carbon around Mars that are *en route* to escaping. More dramatically, an extended cloud of hydrogen atoms (blue image) extends at least 10 Mars radii beyond the surface. The red circle marks Mars's location.

▶▶ **SEASONAL CHANGES** Mars loses the most atomic hydrogen to space during the northern hemisphere's late autumn and winter.



understand the interactions between each of the components in order to understand the system as a whole.

Missing suspects

First, we needed to measure the solar properties that drive escape of gas from the Martian atmosphere and the specific ways the upper atmosphere's composition and structure respond. With its nine science instruments, MAVEN measures the amount of solar ultraviolet light hitting the planet; the solar wind speed, density, and magnetic field; and the solar energetic particles that are emitted from the Sun by solar storms. On the receiving end of the physical system, MAVEN also measures the basic state of the upper atmosphere's temperature, neutral-gas composition, and ion composition, as well as the electron properties in the ionosphere. Recently, we've been able to add measurements of the neutral and ionic winds in the upper atmosphere, too.

We're also determining how much gas Mars is losing today, following the clues in the upper atmosphere most likely to be important:

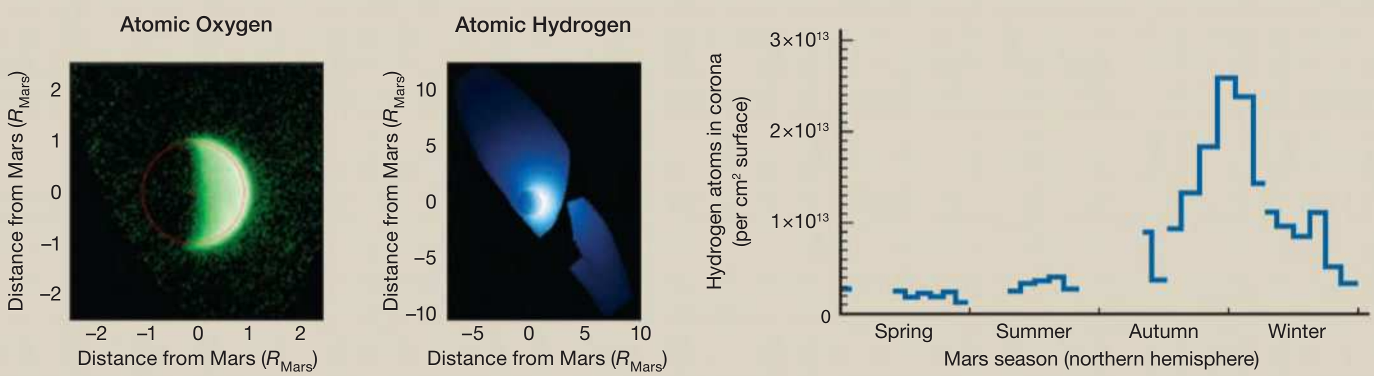
- The ions in the atmosphere that are being picked up and stripped away by the solar wind;
- The ions that are swept up and then flung back into the atmosphere, knocking other atoms into space in a process called *sputtering*;
- The properties of the ionosphere that tell us how much gas is being removed by photochemical processes; and
- The hydrogen distribution in an extended 'corona' surrounding Mars that tells us how much hydrogen is escaping to space.

Together, these measurements enable us to follow the chain of evidence to determine the importance of each of the likely loss processes.

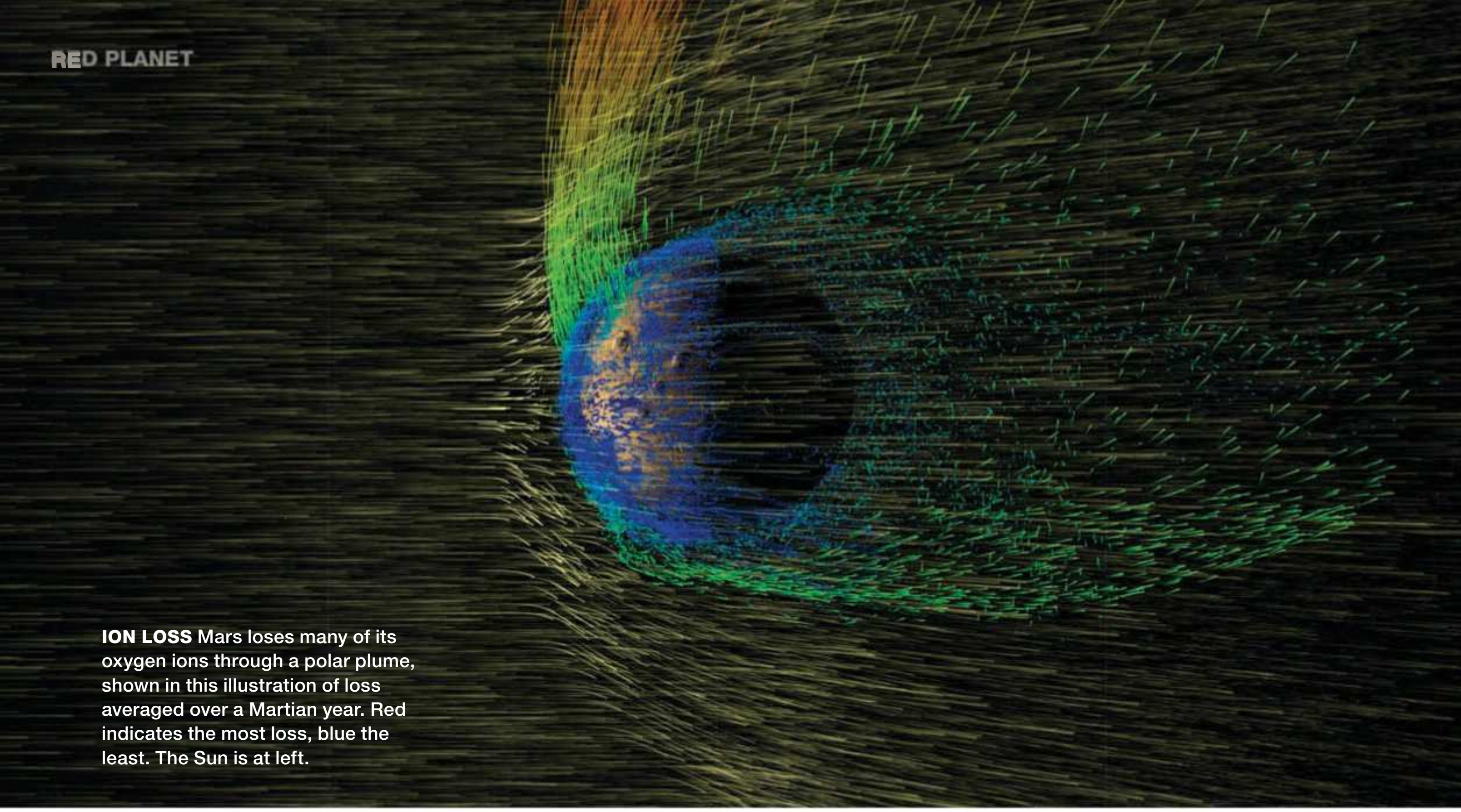
MAVEN entered orbit in September 2014. With it, we've collected measurements for longer than a full Martian year, and we've seen Mars at all seasons. During this time, we've seen several tens of solar storms hit Mars, including a couple of big ones, and we've also seen the intensity of the solar ultraviolet light change significantly as the Sun has gone through part of its 11-year cycle. We've made observations at essentially all solar zenith angles (the angle between the Sun and the spacecraft as measured from the centre of Mars), at all local solar times and at most latitudes. We've observed at a wide range of locations on the planet, including over the regions of strong crustal magnetic fields and over regions with no magnetic field, and including all geological provinces.

▶ **CONCENTRIC RINGS** Layered sediments fill this 2-km-wide crater, which lies inside the larger, equatorial crater Schiaparelli. It's unclear if the layers formed from dust or volcanic ash settling from the atmosphere, or as water-borne deposits built up over time.

The major atoms that we've observed being lost to space today are hydrogen and oxygen. (Other elements are being lost as well, but they're harder to observe than hydrogen and oxygen are.) These come from H_2O and CO_2, broken apart by the Sun's ultraviolet light. Hydrogen is leaving by *thermal escape*, which means that the gas is hot enough that some of the hydrogen atoms naturally move fast enough to escape Martian gravity. The hydrogen isn't being lost at a constant rate, however — we see a factor-of-ten variation in the escape rate throughout the Martian year, with the greatest loss rates occurring during the seasons when the atmosphere is the dustiest. We think that the dust increases the atmospheric temperature, allowing the water molecules that are the source of hydrogen to rise to higher altitudes, where they can be broken apart more easily and where escape is possible. Recent work with data from the



LAYERED ROCKS: NASA / JPL / CORNELL; CONCENTRIC RINGS: NASA / JPL / UNIV. OF ARIZONA; HALOS: MAVEN TEAM / UNIVERSITY OF COLORADO / NASA; SEASONS GRAPH: GREGG DINDERMAN / *S&T*, SOURCE: AUTHOR



ION LOSS Mars loses many of its oxygen ions through a polar plume, shown in this illustration of loss averaged over a Martian year. Red indicates the most loss, blue the least. The Sun is at left.

Mars Reconnaissance Orbiter supports this picture.

The major way Mars loses oxygen today is by what's called *photochemical loss*. In this process, an ionised oxygen molecule (O_2^+) collides with an electron and recombines to form a neutral molecule. This recombination releases enough energy to break the molecule into two separate oxygen atoms and give them enough energy that, if one is moving upwards, it will escape into space (if it doesn't hit anything else first).

Adding these losses up, we've discovered that Mars is losing gas to space at a rate of about 2 to 3 kg/second. That's 10 million billionths (10^{-16}) of the total atmosphere lost each second. That may not sound like much, but it's enough of a trickle that, over the more than 4 billion years of Martian history, it could have removed enough oxygen and hydrogen to create a global layer of water a few metres thick. Equivalently, the oxygen that has been lost would have made enough CO_2 to produce an atmosphere ten times thicker than the present one of 6 millibars atmospheric pressure.

We don't think that the loss rate has been constant in time, however. The Sun's ultraviolet radiation and its wind of energetic particles were both more intense early in the Solar System's history and would have driven greater gas loss. Now that we know the specific processes involved, though, we can calculate how much loss would have occurred earlier in Martian history if these same processes were at work.

Using these extrapolations, it appears that more than a half bar of CO_2 could have been lost to space. This is roughly 100 times the amount of CO_2 that is in today's atmosphere, and it is enough to have produced significant greenhouse warming. Given that the young Sun might have unleashed solar storms more often than it does today, even more CO_2 could have been stripped away.

ALL BUT GONE

Mars has lost about 98% of its original atmosphere — it's both been lost to space and locked up in surface minerals and ice.

This result might sound a bit hand-wavy, but we can determine the total loss more directly, too, thanks to argon. Argon's heavier isotope naturally settles lower in the Martian air than the lighter one, creating a predictable ratio of argon-36 to argon-38 in the upper atmosphere. This ratio will be different at the surface, where things are well mixed. The argon ratio at the ground has been measured most accurately by the SAM instrument on the Mars Curiosity rover. Combining Curiosity and MAVEN measurements with the argon ratio seen on other Solar System bodies tells us that Mars has lost to space about two-thirds of the argon that had ever been in its atmosphere.

Argon also reveals *how* it was lost. Because argon is a noble gas, it can't be removed by chemical processes such as interacting with the surface and forming mineral deposits there, as carbon dioxide forms carbonates. Only the physical sputtering mechanism will work. If Mars lost a lot of argon via sputtering, it probably lost similar amounts of carbon dioxide that way, too. Other processes, such as photochemical loss, would have removed even more of the CO_2, giving us confidence that our extrapolations from current oxygen and hydrogen loss aren't totally off the mark.

IONS: NASA'S SCIENTIFIC VISUALIZATION STUDIO / MAVEN SCIENCE TEAM

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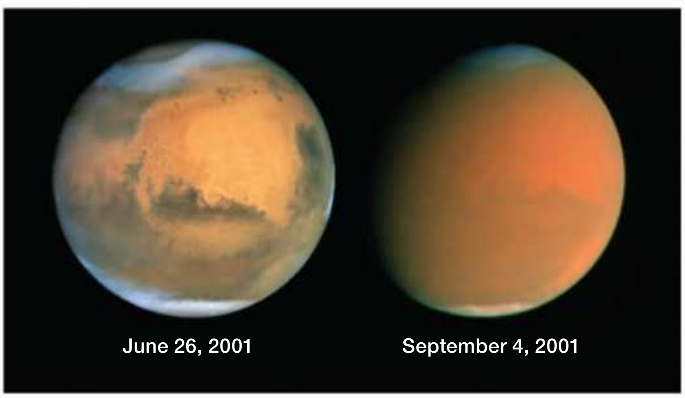
Following the trail of evidence from MAVEN and what we know about the Sun, the majority of this loss would have occurred early in the planet's history, when the Sun's ultraviolet light and the solar wind were most intense. In the very earliest epochs, Mars's global magnetic field likely protected the atmosphere from stripping — the field would have kept the solar wind standing off at a greater distance, as happens on Earth today. Based on magnetic records in the planet's surface, we think the global magnetic field turned off roughly 4 billion years ago. That switch would have allowed the solar wind to hit the upper atmosphere directly, triggering significant atmospheric loss to space. The bulk of Mars' atmosphere then would have been lost within a few hundred million years. As the solar radiation and wind calmed down later in history, the loss would have slowed to a gradual leak, but the damage would have been done. The loss we see occurring today would be the tail end of that slow leak.

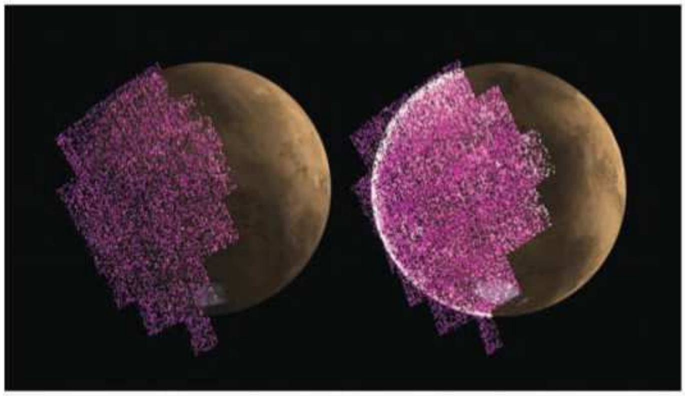
This timing of the Sun's stripping of the atmosphere will sound familiar: It matches the timing of the climate change inferred from the geologic features left by water. That's not by our design; it's the result of totally different lines of evidence converging on the same picture. Scientists suspected that the bulk of the Martian atmosphere has been lost to space, but MAVEN has confirmed it. This means that escape to space was the major process responsible for changing the Martian climate from its early, potentially warm and wet environment to the cold, dry planet that we see today.

Not quite a closed case

Where do we go from here? Our results are based on one Mars year so far. But not every year is the same on Mars. The lower atmosphere's water cycle and the behaviour of dust there can vary significantly from one year to another and can affect the supply of gas to the upper atmosphere. MAVEN hasn't observed the effects of a global dust storm yet. The planet's dust storm season begins this summer, though, so perhaps we'll get lucky.

▼ **GLOBAL STORM** A dust storm enveloped the Red Planet with the onset of southern hemisphere spring in 2001, shown here just before (left) and two months after the storm began. Airborne dust absorbs sunlight and warms the atmosphere, enabling water vapour to rise to higher altitudes and escape to space.





▲ **GLOBAL AURORA** Unlike on Earth, Mars has planet-wide auroral events, and the one in September 2017 was 25 times brighter than any aurora previously seen on Mars. An image before the event (left) shows just noise; the right-hand image shows the event at its peak.

In addition, the Sun goes through an 11-year cycle of behaviour, which changes the properties of the solar wind and our star's ultraviolet output. MAVEN arrived just after solar maximum in the current cycle and was able to see how a moderately active Sun affects Mars's atmosphere, but it was a very weak solar maximum, with only a few strong solar storms hitting the planet. We aren't entirely sure yet what the 'most common' behaviour of the modern atmosphere is. This means that the extrapolation of present-day loss rates into the past carries some uncertainty.

The spacecraft and all of its science instruments continue to operate nominally (a wonderful word to hear for anybody involved in the spacecraft world!). We plan to continue observations in coordination with the European Mars Express mission, which has been in orbit for more than a decade. And we'll coordinate with future observations from other spacecraft: The European/Russian Trace Gas Orbiter has finally settled into its circular, near-polar orbit at Mars and is beginning science observations, and the United Arab Emirates Hope orbiter will launch in 2020 to study how the lower and upper atmosphere connect.

MAVEN's current extended mission runs through September 2018, but it has enough fuel that we think it can survive until 2030. We plan to continue our science observations as long as possible, along with serving as a communications relay between Earth and rovers and landers on the Martian surface. It's our hope that, in addition to what we've already learned from MAVEN, teaming it up with current and future spacecraft will teach us even more about Mars's atmosphere and the history of habitability on this small, frozen world.

■ Planetary scientist and MAVEN Principal Investigator **BRUCE JAKOSKY** is Associate Director of the Laboratory for Atmospheric and Space Physics at the University of Colorado, Boulder. He has been exploring Mars since the Viking missions in the 1970s.

ADUST STORM: NASA / J. BELL (CORNELL UNIV.) / M. WOLFF (SSI) / HUBBLE HERITAGE TEAM (STSCI / AURA); AURORAS: NASA GSFC / UNIVERSITY OF COLORADO; TIMELINE: TERRI DUBÉ / *S&T*

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Your First Scope

Consider this expert advice before making your first big purchase as an amateur astronomer.

You're ready to buy your first telescope — Woohoo! You probably have lots and lots of questions. How much money should you spend? What model should you get? Reflector, refractor or catadioptric? Equatorial or alt-az mount? Do you need a computerised telescope? And what about astrophotography and imaging?

Hold on — one step at a time! Hopefully you've already done some basic homework. In addition to reading reviews, both in print and on the internet, it helps to have some good reference books, including a star atlas. And you'll want to try a few scopes before committing to one. Local astronomy clubs often hold public 'star parties' where visitors can look through a variety of telescopes, often for free. Buying a telescope isn't that different from buying a computer or camera — there are likely several models that will satisfy you. The trick is to narrow your list of potential candidates to a few models based on your needs. Spending a few minutes with this article will help you find what's right for you.

What is a telescope?

The most basic function of a telescope is to *gather light*. Many beginners are surprised to learn how large some of the objects are in the night sky. The Andromeda Galaxy, for instance, is almost eight times the diameter of the full Moon. But because the fully-adapted human eye can only open to about 7 mm, it appears as a light grey smudge against the black sky. Even a modest telescope of 75 mm to 15 cm of *aperture* (the diameter of a scope's main mirror or lens) helps the view tremendously. The smudge starts to take on definition, size and detail. Unlike camera lenses, which are rated by their focal length and f/ratio, telescopes are rated on their aperture, followed by their *focal ratio* (a telescope's focal length divided by its aperture). Common examples include 100-mm f/10, 15-cm f/8, 20-cm f/10 and so on.

What about magnification?

To calculate your setup's *magnification*, divide the focal length of the telescope by the focal length of the eyepiece. A typical 20-cm f/10 Schmidt-Cassegrain, which has a focal length of 2000 mm, will yield 80× with a 25-mm eyepiece. Want to increase the power? Put in a different eyepiece. A 10-mm eyepiece in the same telescope will yield 200×.

A modest amount of magnification usually gives the best results. Many beginners are too aggressive with their magnifications. They wind up amplifying not only the object, but their problems as well. These include atmospheric turbulence, shakiness in the telescope's mount, and any flaws or misalignment in the optics. For the Andromeda Galaxy, for instance, 80× is usually plenty. If anything, such a large object often benefits from less power. If you're trying to frame the Pleiades star cluster with a long focal length telescope, for example, you may have trouble lowering the power enough to see all the stars!

On the other hand, observers interested in viewing the planets, Moon or double stars tend to use higher magnifications. Even here, it pays not to go too high. Many observers find that powers in the 150× to 175× range are easily high enough to see what they want.

Based on the above, potential telescope purchasers should steer clear of department store-grade telescopes with absurd '575×' magnification claims. Using such high powers is a rare event even with high-quality equipment, let alone with cheap $100 toys.

Using binoculars

Many beginners find their ideal first telescope is actually a pair of binoculars. If you only have $100 or so to spend, a pair of binoculars is better than any $100 telescope. Even experienced astronomers often keep binoculars handy for quick peeks, or as a supplement to their telescopes. You may have a pair lying around already. If so, use them! On the next clear night, go outside and sweep the sky. You'll be amazed at what you see with them.

Binoculars are rated by their magnification and aperture. Thus, a 7×35 pair of binoculars has 35-mm objective lenses and operates at 7×. As with telescopes, the more aperture, the better. By the time you get to the 50-mm range, you'll be able to see a lot. The main disadvantages of binoculars are the difficulty to hold them still for long periods of time, neck/back fatigue when looking straight up, and the inability to share the views.

Telescopes — which kind?

Telescopes come in many shapes, sizes and designs. Each has its advantages and disadvantages. Let's go through the three major types.

The *refractor* is what most people think of when they hear the word 'telescope'. It consists of a long, skinny tube with an objective lens at one end and an eyepiece at the other end. Refractors have the reputation for producing sharp, clear images. The tubes are sealed and the optics generally don't require adjustment. Purists love refractors, as do astrophotographers. On the downside, they're the most expensive of the three designs, become large and unwieldy over 15 cm, and less expensive models suffer from chromatic aberration, a purple fringing around bright objects. The problem with chromatic aberration is even if you don't know what it is, once you're taught to see it, you can't unsee it, causing you to lust after fancier and more expensive refractors.

The Newtonian *reflector* gathers light with a mirror at the bottom of the tube and sends the image up to a diagonal mirror near the top of the tube. The diagonal diverts the image out the side of the tube to the eyepiece. In many ways, the reflector is the opposite of the refractor. With a refractor, the viewer looks through the back of the telescope. In a reflector, the viewer stands by the side and looks through an eyepiece near the front end of the telescope. This arrangement sometimes looks odd to a beginner, but it's actually quite comfortable once you get used to it.

Reflectors have the advantage of being the least expensive of the three designs, which accounts for their popularity. People who make their own telescopes almost always choose to make a reflector. Reflectors are also inherently free of the chromatic aberration that plagues cheap refractors. On the downside, reflectors become very large once you get past 25 cm of aperture. In addition, they require periodic adjustment of their optics to make sure everything is aligned. Finally, the diagonal mirror sits directly in the light path, resulting in some degradation of the image, although this effect isn't nearly as large as you may think.

The *compound* (or catadioptric) telescope uses a combination of lenses and mirrors. There are many forms of compounds, but the most common is the Schmidt-Cassegrain (sometimes abbreviated as 'SCT') followed by the Maksutov-Cassegrain. Since

REFRACTOR

GREGG DINDERMAN / SKYWATCH

ADVANTAGES:

- Best performance per cm of aperture
- Rugged construction and sealed tube increase portability
- Usually no need for user adjustment
- Relatively fast cool-down time

DISADVANTAGES:

- Highest cost per cm of aperture
- Short tubes require extra-expensive lens designs to suppress false-colour fringing
- Requires a tall mount
- Usually gives a mirror-image view

REFLECTOR

ADVANTAGES:
- Most aperture for the money
- Simple design
- Viewing at top of tube allows low mount (such as the Dobsonian mount shown here)
- No mirror-imaging
- Reasonably portable

DISADVANTAGES:
- Requires occasional collimation (alignment of mirrors)
- May be unsuitable for photography
- Often the bulkiest tube

COMPOUND

ADVANTAGES:
- Most compact tube per inch of aperture
- Short tube is easiest to mount
- Eyepiece height varies least
- Sealed tube
- Smaller models very portable

DISADVANTAGES:
- Fairly high cost per cm of aperture
- Requires occasional collimation
- Longest cool-down time of any design
- Usually gives a mirror-image view
- Equatorial mount can be bulky

GREGG DINDERMAN / *SKYWATCH* (2); ED TING; INSET: JEREMY PEREZ

compound telescopes use both lenses and mirrors, their list of advantages and disadvantages reads like a combination of the ones from the refractor and the reflector. Like a refractor, the viewer looks through the back of the telescope. Like a reflector, it gathers light using a mirror. Compounds are easily recognised by their signature short, stubby bodies. They can pack a great deal of aperture into a relatively compact size. Compounds are often seen on fancy, computerised tracking mounts with all sorts of amazing features.

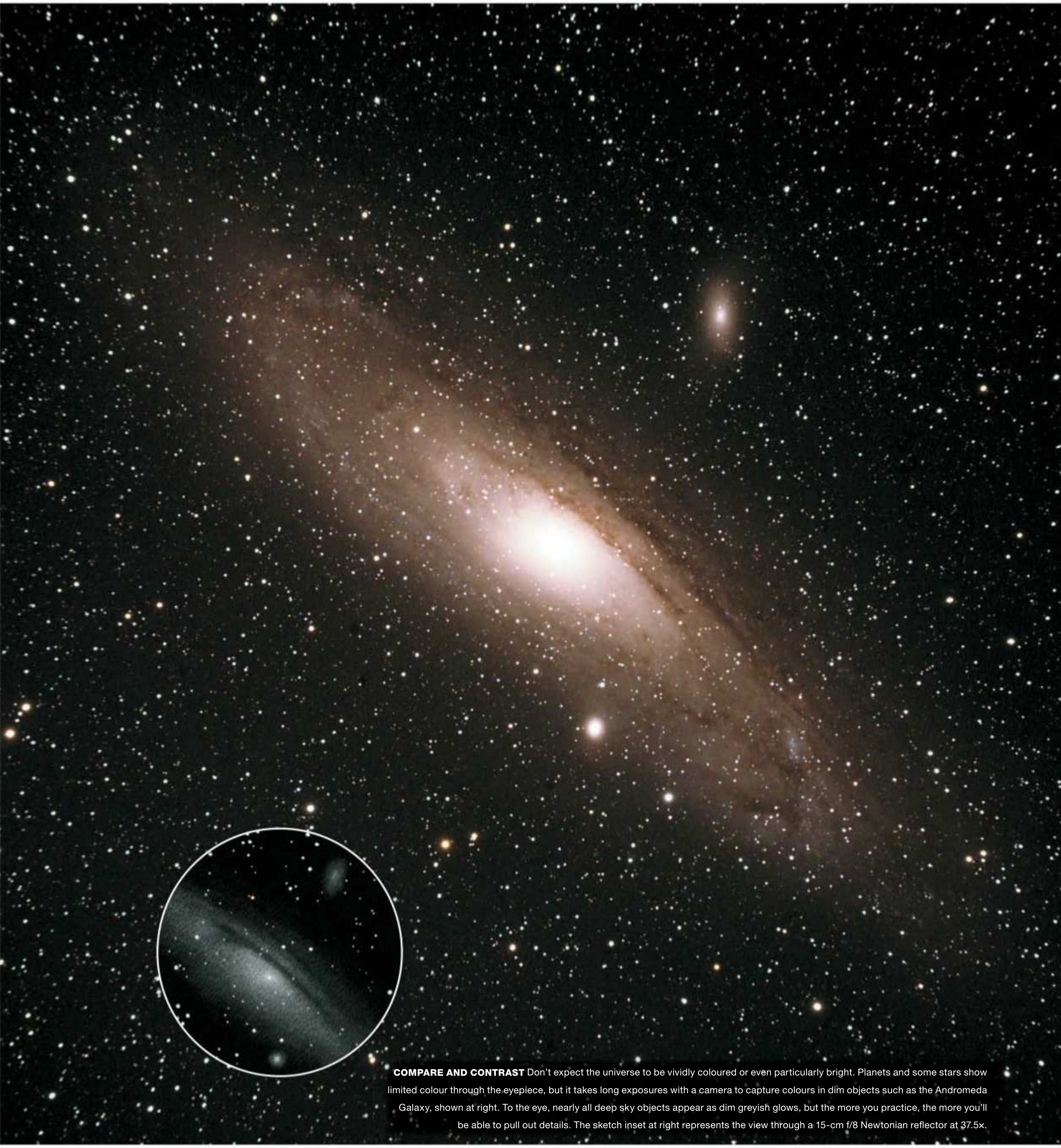
There's no one perfect telescope, so there's no use looking for it. Good telescopes can be found in any design. The old adage was that planetary, lunar and double star fans gravitated towards refractors, deep sky hunters used reflectors, and general purpose observers used compounds. Although there's still some truth to these generalisations, these days almost any well-made telescope should be able to show you what you want to see.

Mountings

Don't overlook the importance of the mount. It must be steady enough to hold the optical tube so that the image does not shake, but light enough that the owner will not be discouraged from moving it outside.

There are two major types of mounts. The *alt-azimuth* ('alt-az' for short) mount consists of a basic up-down, left-right motion system. It's cheap and light, and there are (usually) no computers or motors to break down. You move the telescope by hand, pointing it to where you want it to go.

The *equatorial* mount is mounted on a tilted axis pointed toward the south celestial pole; it tracks the stars as the



COMPARE AND CONTRAST Don't expect the universe to be vividly coloured or even particularly bright. Planets and some stars show limited colour through the eyepiece, but it takes long exposures with a camera to capture colours in dim objects such as the Andromeda Galaxy, shown at right. To the eye, nearly all deep sky objects appear as dim greyish glows, but the more you practice, the more you'll be able to pull out details. The sketch inset at right represents the view through a 15-cm f/8 Newtonian reflector at 37.5x.

Earth turns. Some equatorial mounts also come equipped with fancy 'Go To' computers and motors, and will slew to selected targets on their own. Such computers often have amazing features, including object libraries of 60,000-plus objects, a sky tour mode, and readouts to convey information to the user.

In the past, alt-az mounts usually lay at the low-tech end of the spectrum, while equatorial mounts got all the fancy new features. But recently manufacturers have started adding fancy electronics to alt-az mounts; these days, it's not unusual to find an alt-az mount with just as much sophistication as a typical equatorial mount.

Upon hearing the difference, many beginners declare they want the tracking and computer abilities. There's nothing wrong with this, but you should be aware that there's usually an initialisation or setup procedure associated with these fancy mounts. This can cut into your precious observing time, and as with any computerised device, there are sometimes bugs and crashes that can be hard to diagnose in the dark. On the other hand, with the simpler alt-az mount, you can be up and observing within minutes.

Avoiding aperture fever

Not long ago, someone on the verge of buying a certain highly-regarded 35-cm (14-inch) SCT contacted me. He'd never looked through a telescope before. Using the internet, I hooked him up with an astronomy club in his area. It turned out they were holding a skywatch that weekend and not only was there someone in the club who owned the same SCT, he was willing to let the beginner help set it up and break it down. Some weeks later, the buyer wrote back thanking me. He wound up purchasing a 15-cm SCT.

If you already have a 15-cm telescope, you'll eventually meet someone who has a 20-cm. The images will be brighter through the 20-cm, and you'll start wondering if you need to increase your aperture. The problem is, there's always a bigger scope. That same owner of the 20-cm telescope wonders if a 25-cm will be better. Eventually it reaches the point where the scope gets so big it never gets used. This affliction is known as aperture fever and it strikes almost every astronomer at some point. The trick is to find the sweet spot — large enough to show you what you need, but not too big. For most people, this sweet spot lies somewhere in the range of a 100-mm refractor, a 15- or 20-cm reflector or a 20-cm SCT.

What about astro-photography?

Seeing images through the eyepiece seems to spur an innate desire to capture it with a camera. At our club's skywatches, the most excited members of the public are often the ones who catch a quick snap of the Moon with their phones. Beyond this simple activity, however, astrophotography is complicated, expensive and time consuming. I usually advise people to wait at least a year before attempting photography. Other than buying cheap department store telescopes, astrophotography is one of the main reasons I see people dropping out of the hobby, and that's a shame. So please, heed this advice. Wait. There's plenty to keep you busy in the beginning, between learning the night sky and learning to use your telescope. When the call of photography finally beckons, you'll know when you're ready to tackle it.

Having realistic expectations

A generation ago we wouldn't need to address this, but these days, with HDTV, video games, and — yes— amazing astrophotos on the internet, I've sometimes found it necessary to temper people's expectations. Most objects will look like smudges through the eyepiece. Jupiter and Saturn will

'Kicking the Tires'

Things to check when selecting a telescope

GREGG DINDERMAN / SKYWATCH

rarely be larger than the size of a small coin on a dinner plate. Astronomical observing isn't necessarily about what you are actually seeing, it's about the idea of what you're seeing. Photons of light from impossibly large objects have travelled millions, if not billions, of years to reach the eyepiece.

Ready to buy?

Astronomy is like a lot of other hobbies. You often wind up spending a lot of money, only to find out you didn't have to spend a lot of money in the first place.

In over 20 years of writing and speaking about telescopes, my recommendation for a first scope has never changed — I recommend a 15- or 20-cm Dobsonian alt-az reflector. These are available from a number of manufacturers. A 15-cm reflector is cheap, simple and relatively portable. If you're ambitious, get the 20-cm. Resist the urge to start with a 25-cm or 30-cm. The fancier variants come equipped with motors and/or computers. Either will teach you a lot and keep you busy for a long time, possibly forever. Expect to spend $400 to $600.

If you're pretty sure lunar, planetary and/or double star observing are going to be your primary targets, you may wish to consider a good quality 100-mm refractor on an equatorial mount. Expect to spend $600–$1,200 for basic models. If you're computer savvy and want a jack-of-all-trades telescope, think about getting a 15- or 20-cm SCT. These will set you back $1,000–$2,000.

Whatever you buy, be sure to use it regularly. A telescope is your gateway to the cosmos — from the craters on the Moon, to the rings of Saturn and the cloud bands on Jupiter, to open and globular clusters, to emission, reflection, and planetary nebulae, and even to distant galaxies. I envy you — the joy of now discovery is still before you.

Now, let's get out there and observe!

■ **ED TING**'s first telescope was a 15-cm reflector that he saved for by working at a burger chain. Find more of his advice and opinions at **scopereviews.com**.

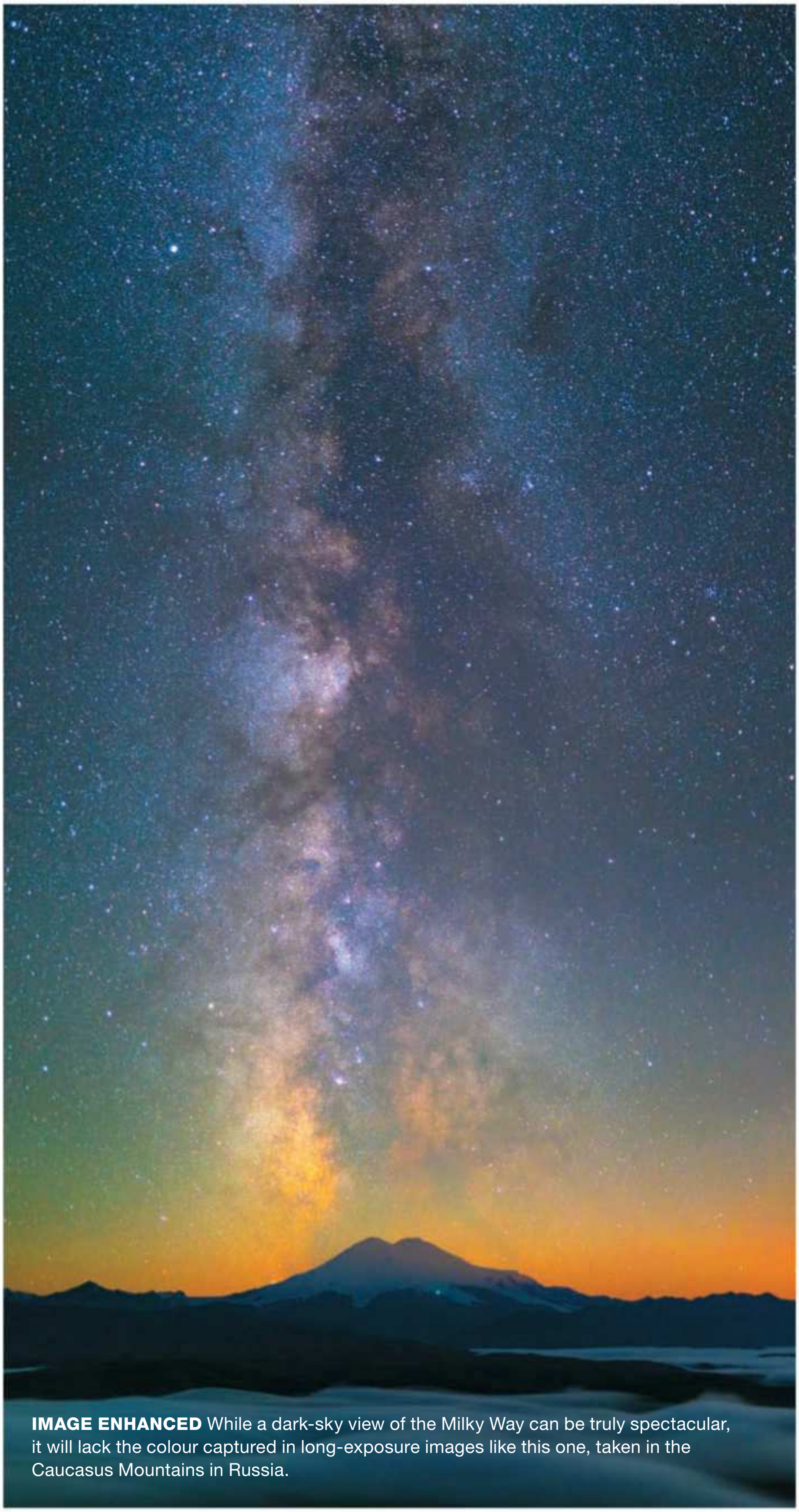


IMAGE ENHANCED While a dark-sky view of the Milky Way can be truly spectacular, it will lack the colour captured in long-exposure images like this one, taken in the Caucasus Mountains in Russia.

VIKTAR / ISTOCK

First into orbit

Australia's states are lining up to host to the nation's new Space Agency.

In scenes reminiscent of the early years of the Space Race, when various cities in the USA lobbied the US government to base space facilities in their locales — leading to the country's main launch site being situated in Florida but the astronaut headquarters in Texas, and with research institutes spread all around the country — Australia's states have begun a bidding and publicity war in the quest to have our country's new Space Agency hosted in their state.

New South Wales

The NSW Government has enlisted the backing of the first Australian-born person to fly in space, Dr Paul Scully-Power, in its bid to host the Agency. Scully-Power, an oceanographer, flew aboard Space Shuttle Challenger in 1984 and spent eight days in space. "Since then he has led a highly distinguished career in sectors such as defence, national security, aviation, marine science, communications, systems analysis and education," said the Premier, Gladys Berejiklian.

"We are home to the nation's busiest and biggest space industry sector, bringing high-tech research and advanced manufacturing together to support the nation's future space ventures," the Premier added. "The Commonwealth is looking for a home for its new national space agency — there's no question that NSW is best placed to host it and there's no-one better suited than our nation's first astronaut to lead our bid."

NSW Minister for Trade and Industry, Niall Blair, added that "One in every three space industry jobs in Australia are already based in NSW — we are the natural home for the Australian Space Agency".

Western Australia

The Western Australia government disagrees, saying that WA is the logical home for the Space Agency. And it has a consultant's report to back it up. The report concludes that WA has geographic advantages and the expertise needed to build a thriving space industry, especially in the priority areas of communications technologies, satellite data, debris monitoring, artificial intelligence, robotics and big data analytics. The state already has 74 international and Australian

NASA (2)

◀ The first Australian to fly in space, Dr Paul Scully-Power (top left), has been enlisted by the NSW Government to aid its bid to host Australia's new Space Agency.

Nanosatellites similar to this one will soon be launched by Adelaide-based company, Fleet Technologies.

companies involved in space and space-related services.

"The report shows WA has the geography, capability and local expertise to have a thriving space industry," said WA Science and Innovation and ICT Minister, Dave Kelly. "The Federal Government has the perfect opportunity to launch the Australian Space Agency right here right now in WA, by partnering with the European Space Agency who want to build a second deep-space antenna in New Norcia."

Victoria

Meanwhile, the Victorian Government is hard on the case, insisting that its state should be the frontrunner for the Agency. It claims that more than one-in-five Australian space-related science and technology companies are based there, including some of the biggest names in aerospace —Lockheed Martin, Thales, Boeing and BAE Systems. La Trobe University already has a $20 million partnership with the German Space Agency to develop a camera to fly aboard the International Space Station.

"Global companies like Lockheed Martin and Boeing have already seen Victoria's economic and jobs growth potential in this industry," said Minister for Industry and Employment, Ben Carroll. "Victoria has generations of manufacturing experience and major companies willing to invest. This makes us the perfect home for the Australian Space Agency."

"Victoria is at the forefront of research, engineering and advanced manufacturing in the areas of aerospace, satellite communications, cybersecurity and spatial information for both the civil and defence industries," added Victoria's Lead Scientist, Dr Amanda Caples.

South Australia

South Australia already has a burgeoning space technology sector, but to give it a kick along the state government has launched a Space Incubator Program, part of a $4 million Space Innovation Fund that was set up in September 2017. "Capturing the opportunities of the space industry to grow our economy and create high-value jobs of the future is a key priority for the State Liberal Government," said the Premier, Stephen Marshall.

"We want to make South Australia a key player in the space industry nationally and internationally. We are committed to building a culture of entrepreneurship in South Australia to grow the local space industry and create new business opportunities."

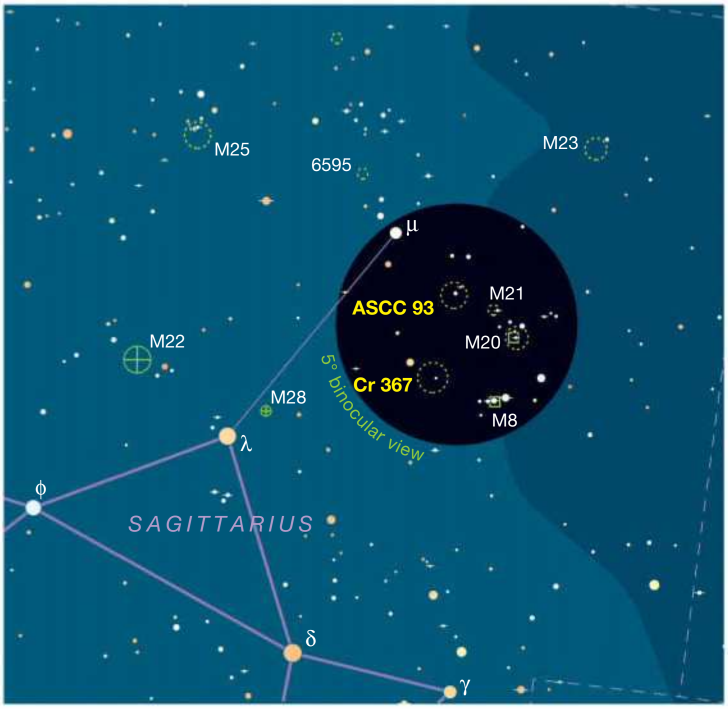
> "A short-lived Australian Space Office in the 1990s was under-resourced and not able to accomplish much."

Those opportunities is being pursued by several local companies. One of them is Fleet Technologies, which will launch its first two nanosatellites into orbit at the end of 2018. Another is Myriota, a spin-off from the University of South Australia, which this year raised $15 million to build a network of satellite-linked Internet of Things sensors.

Meanwhile, an Italian company, SITAEL, is setting up a headquarters in Adelaide and will become the first company in Australia with the ability to design and manufacture satellites and payloads of up to 300 kilograms. "SITAEL's move into Adelaide will create high-tech jobs for South Australians, open up new collaboration opportunities with local companies and strengthen our state's reputation as a leader in space innovation and technology development," said Premier Marshall.

Wherever the Space Agency ends up being based, the main hope is that the Federal Government gives it sufficient funding to enable it do worthwhile work and stimulate innovation. A short-lived Australian Space Office in the 1990s was under-resourced and not able to accomplish much.

Having missed the main boat through the early decades of the space age, here's hoping the establishment of a national Space Agency will not be just another false start, but rather a stepping stone to finding Australia's true place in space.



Surprises come in twos

Perhaps the best argument for slowing down and really looking at celestial objects is that you often see something surprising, either in the object itself or in the same field. So it was last weekend, when I was checking on M8, the Lagoon Nebula, and M20, the Trifid Nebula, for the first time this season. I noticed what looked like a pair of open clusters in the same field, each about 1.3° east-northeast of the respective nebulae. They were so bright and obvious that my first thoughts were, "How have I not noticed these before?" and, "What the heck are they?"

The more southerly and brighter of the two was easy to identify: It was **Collinder 367**. With a diameter of 40′ and a magnitude of 6.4, it's big and bright enough to be plotted in most atlases these days. The northern cluster wasn't listed in any of my magnitude-6 or -7 atlases, but I found it in one of the deeper, more comprehensive sources back home. It's **ASCC 93**, one of 109 new open clusters identified by Kharchenko and colleagues in 2005, based on the All-Sky Compiled Catalogue of 2.5 million stars that was published online in 2001. It's smaller and dimmer than Cr 367 but still an easy catch through 7×50 binos under reasonably dark skies.

Whatever we call them, I can't help but see four objects in a parallelogram now. In the northwest corner, M20, M21 and a group of bright stars between them all merge together into a bright glow that rivals M8, which occupies the southwest corner. To the east, Cr 367 and ASCC 93 seem like smaller, fainter echoes of their nebular neighbours. Have a look and see if they don't jump out at you as well.

■ **MATT WEDEL** thought he'd know the sky pretty well after a decade of observing. He's never been happier to be wrong.

USING THE STAR CHART

WHEN

Early August 10pm
Late August 9pm
Early September 8pm
Late September Dusk
These are standard times.

HOW

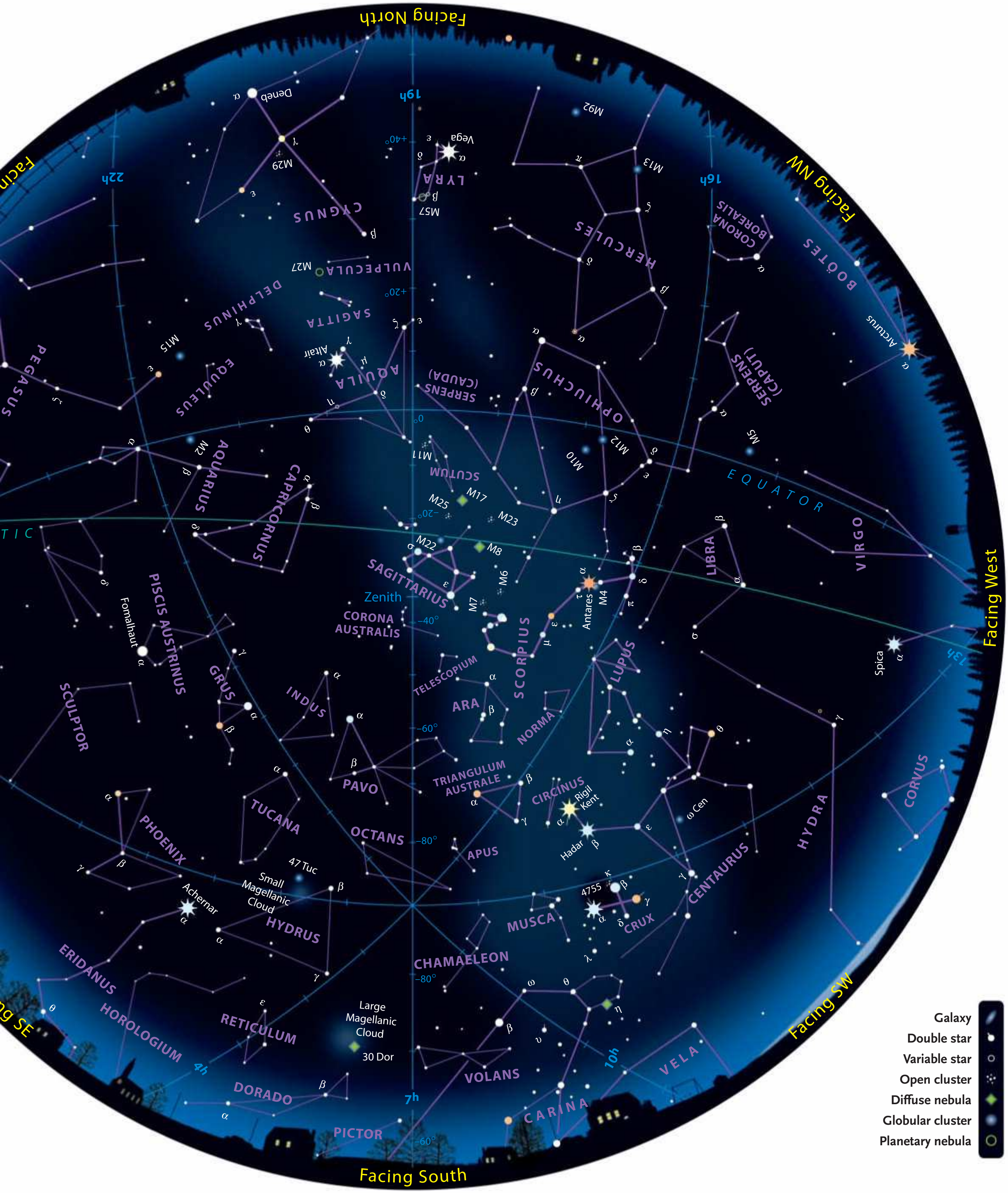
Go outside within an hour or so of a time listed above. Hold the map above your head with the bottom of the page facing south. The chart now matches the stars in your sky, with the curved edge representing the horizon and the centre of the chart being the point directly over your head (known as the zenith).

FOR EXAMPLE: Look at the chart, and you'll see that the bright star Altair in the constellation Aquila is about halfway between the northern horizon and the middle of the chart. So if you look into the northern sky, you'll find Altair about halfway between the horizon and the zenith.

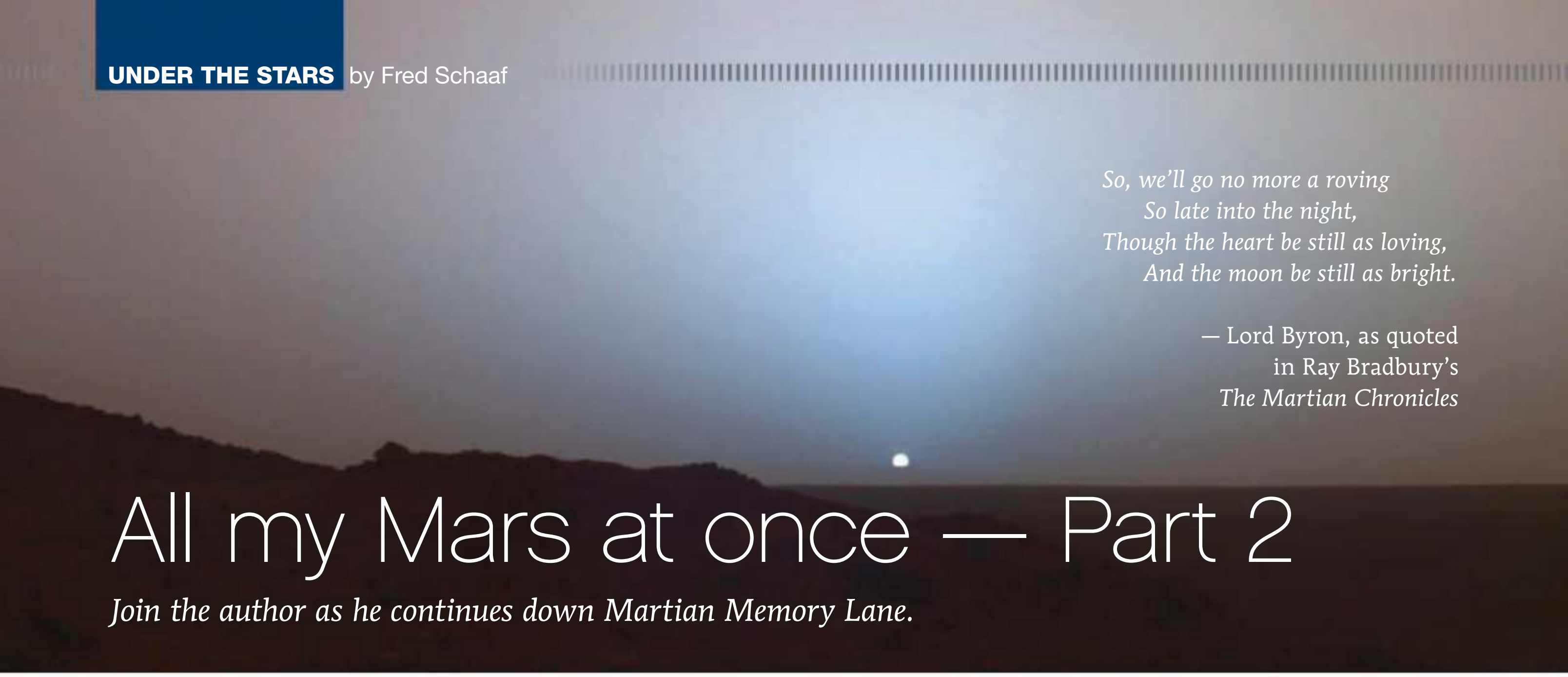
NOTE: The chart is plotted for latitude 35°S (for example, Sydney, Buenos Aires, Cape Town). If you're much further north of there, stars in the northern part of the sky will be higher and those in the south lower. If you're further south, the reverse is true.

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
19h
16h
22h
13h
10h
7h
4h
Deneb
Vega
LYRA
M57
CYGNUS
M29
M92
M13
HERCULES
CORONA BOREALIS
BOÖTES
Arcturus
VULPECULA
M27
SAGITTA
DELPHINUS
M15
EQUULEUS
PEGASUS
Altair
AQUILA
SERPENS (CAUDA)
OPHIUCHUS
SERPENS (CAPUT)
M5
M12
M10
M11
SCUTUM
EQUATOR
M17
M25
M23
M2
AQUARIUS
CAPRICORNUS
M22
M8
SAGITTARIUS
M6
M7
M4
Antares
LIBRA
VIRGO
Zenith
CORONA AUSTRALIS
SCORPIUS
LUPUS
Spica
Fomalhaut
PISCIS AUSTRINUS
GRUS
INDUS
TELESCOPIUM
ARA
NORMA
SCULPTOR
PAVO
TRIANGULUM AUSTRALE
CIRCINUS
Rigil Kent
Hadar
ω Cen
CORVUS
HYDRA
TUCANA
OCTANS
APUS
CENTAURUS
PHOENIX
47 Tuc
Small Magellanic Cloud
Achernar
HYDRUS
4755
MUSCA
CRUX
ERIDANUS
CHAMAELEON
HOROLOGIUM
RETICULUM
Large Magellanic Cloud
30 Dor
VOLANS
VELA
CARINA
DORADO
PICTOR
Galaxy
Double star
Variable star
Open cluster
Diffuse nebula
Globular cluster
Planetary nebula



So, we'll go no more a roving
So late into the night,
Though the heart be still as loving,
And the moon be still as bright.

— Lord Byron, as quoted
in Ray Bradbury's
The Martian Chronicles

All my Mars at once — Part 2

Join the author as he continues down Martian Memory Lane.

▲ NASA's Mars Exploration Rover Spirit captured this panorama of Mars' western sky as the Sun set behind the rim of Gusev Crater.

Because of the ideal Mars opposition this year, I wanted to cram into a two-part column as many of my marvelous Mars memories as possible. Here's part two. What most wonderful memories of Mars do *you* have?

From John Carter to the Viking Project. How delightful are the invented names and words in Edgar Rice Burroughs's books about John Carter of Mars: thoats, calots, banths, Barsoom, and especially Tars Tarkas — a name I've always thought would be great for a very large planetary telescope. Who hasn't read, heard or seen 'The War of the Worlds as presented by H. G. Wells, Orson Welles or George Pal? And potent parts of Ray Bradbury's *The Martian Chronicles* include 'Rocket Summer,' and two poignant quotes from the poet Byron.

Speaking of fantasies, I vicariously lived a real-life one through the Viking Project internship of my uni roommate, Steve Albers. He sent me everything, from insider Viking images to JPL employees' recreation club flying disks, and shared with me by far the longest phone calls of my life.

When Mars and Saturn touched. On June 4, 1978, Mars and Saturn were high in darkness and a little more than 0.1° apart, a proximity that greatly enhanced Saturn's gold and Mars' orange. The sharp area of our vision is only within a few degrees of its centre, so when I gazed slightly away to take in the whole scene, the reduced sharpness made the rays of the two planets appear to touch each other. Also wonderful was the crisp, detailed view through a 20-cm telescope at 200× — Mars with its polar icecap and dark markings together in the same field as Saturn with its rings and brighter moons.

When Mars and Jupiter conquered the full Moon. Conjunctions of Mars and Jupiter occur at intervals of slightly longer than two years, when Mars is relatively dim and small, because the planets are never more than about 90° from the Sun. Never? No, once every 143 years the two planets meet when they are near opposition, at their brightest and biggest. This last happened on the night of February 29–March 1 in 1980. That night brightest Jupiter and brightest Mars stood together right beside the precisely full Moon — and the two planets formed the only night-sky sight I've ever witnessed that exceeded even the impact and power of a full Moon.

The loveliest trio: yellow Jupiter, orange Mars and blue-white Regulus. That once-in-143 years there was actually a special series of three Mars-Jupiter conjunctions. On May 3, 1980, the last of the conjunctions occurred in the evening with magnitude –2.2 Jupiter, magnitude +0.2 Mars, and magnitude 1.3 Regulus within a circle little more than 1.5° in diameter. The heart of Leo overflowed with the radiance of a triple 'star' of proximity-enhanced gold, orange and blue-white.

Two wonders of a daytime Mars. From my home, the Moon just missed the Red Planet the winter Mars was nearing its famed perihelic opposition of 2003, the closest in over 59,000 years. Up the ladder with my 25-cm f/7 Newtonian, seemingly levitating over the lunar surface, I was astonished by the colour contrast of Martian orange with lunar yellow-white — but even more by the latter's contrast with the *chillingly* white polar icecap of Mars. As the Sun rose and the sky turned blue, the icecap remained intense and contrasted beautifully with that blue.

Many years earlier, not too many minutes after sunrise, I observed Mars with the unaided eye, and its orange was prominent against the deep blue sky. But even more special was the fact that I was observing Venus and Jupiter with the unaided eye in daylight at the same time. A repeat of this feat, but this time before sunset, might be tried again late in August 2018.

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

Venus & Jupiter are 'western stars'

These two bright worlds are unmistakable in the evening sky.

The innermost planet, **Mercury** (11″ diameter and mag. 2.9 on Aug 1; 4.8″ and –1.0 by Sep 30), is essentially out of view during August and September, reaching inferior conjunction (between the Earth and the Sun) on August 9, after which it hugs the eastern dawn horizon for the rest of the month, only 5 or 6 degrees in altitude. September is no better, with the planet swinging around to the other side of the Sun (superior conjunction) on the 21st and pretty much lost to view on the western twilight horizon. The tiny world will be easier to find in the western twilight in October.

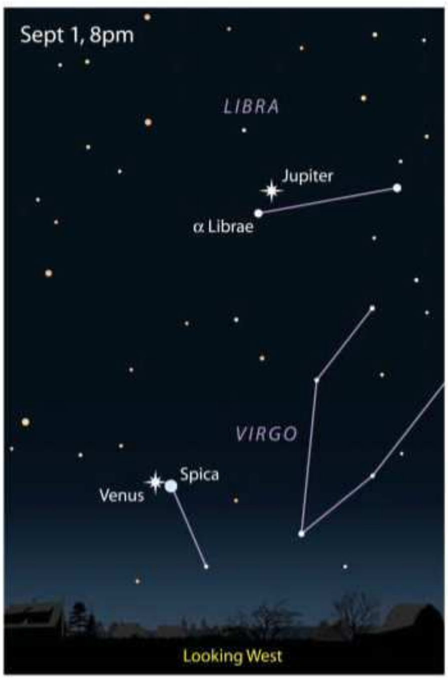
Venus (30″, –4.6 on Sep 1) is a better bet, shining brightly in the western sky from early twilight until about 9:00pm. Currently in Virgo, the planet will slowly slide closer and closer to 1st magnitude Spica (Alpha Virginis) during August, reaching a separation with the star of only 1.2° on September 1 and 2. Watch for the Moon nearby on August 14 and 15, and the triangle made by Venus, the Moon and Jupiter on September 13.

Mars (23.4″, –2.5 on Aug 15) was at opposition on July 27 and at its closest point to Earth (they're not always the same) on July 31. Easily visible in the east from twilight onwards, the Red Planet will now begin shrinking in apparent size as the distance between Earth and Mars starts to increase, so now's the time to make the most of the view with your telescope. Can you see any signs of the dust storm that arose in June? Mars' perihelion (closest point to the Sun) will come on September 16. Watch for the Moon near the planet on August 23 and September 20.

Jupiter (37.9″, –2.1 on Aug 1), which reached opposition in May, is still a fine sight in the northwestern evening sky from twilight onwards (setting at 1:00am on August 1, and at 10:00pm by September 30). The giant planet will make a fine pairing with the star Alpha Librae from August 15 to 19, when they'll be only slightly more than 0.5° apart. Look for the crescent Moon nearby on August 17 and September 14. Jupiter is slowly drawing down toward the horizon, heading for conjunction in November.

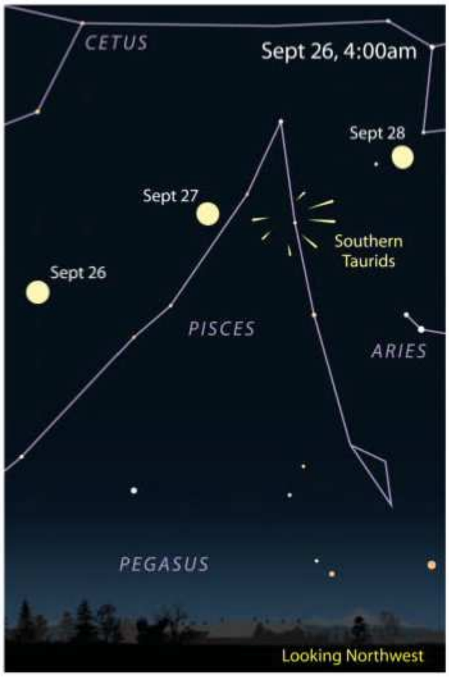
Saturn (42″, 0.2 on Aug 1) is called the ringed planet, even though we know that Jupiter, Uranus and Neptune also have rings. But some names just stick. This particular ringed planet spends August and September in Sagittarius, nice and high around mid-evening, having reached opposition in June. Saturn has been in retrograde motion but that will end as it comes to its stationary point on September 6. Look for the Moon nearby on August 21 and September 17, and also watch as the planet creeps close to the Trifid and Lagoon nebulae at the end of August.

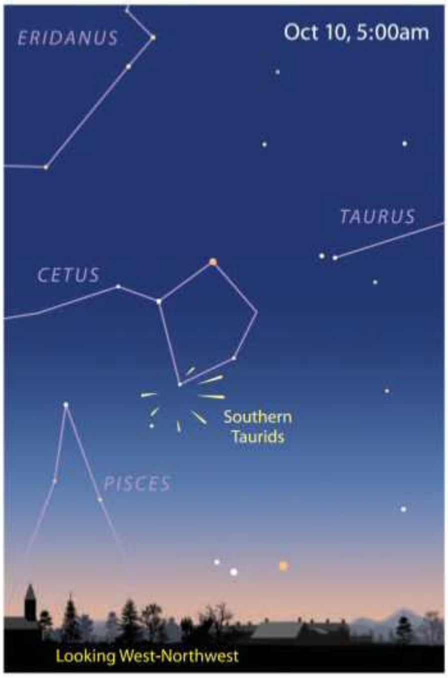
▲ Mars and Saturn shine in the morning sky.



▲ Venus vs Spica, Jupiter vs Alpha Librae.

▲ The two gas giants together in the west.





◀ The Southern Taurids are active from mid-September through to late November. Note how the radiant position moves.

Meteors, with a chance of fireballs

Tackle the Southern Taurids and maybe spot a fireball or two.

This time of year is a relatively quiet period for meteor showers in the Southern Hemisphere. Our northern friends are getting ready to be thrilled by the Perseids, but unfortunately we barely get to see them from our latitudes as the radiant is at declination +58°. Not to worry — beginning in September we will have the **Southern Taurids** to look forward to, which, although always low in numbers, do put on a good show in September and October. This year the shower will be active from September 10 to November 20, peaking on the morning of October 10.

The Southern Taurids are groups of meteoroids originating from comet 2P/Encke. The meteors can be any colour, with many of them leaving trains that last for minutes. The shower is well known for its bright meteors and fireball activity, and bolide events are quite common too. In fact, when it comes to fireballs and bolides, only the Alpha Capricornids are superior.

The best time to view the Southern Taurids is from 2:00am until dawn. You should be able to see 5 to 7 meteors per hour during the peak, and closer to 2 to 3 per hour a few weeks either side. This year the Moon will set early on the morning of October 10, so conditions will be favourable.

Whist watching for Southern Taurids, keep an eye out for sporadic meteor activity too. Sporadics can appear from any direction in the sky, with rates in August and September expected to be around 7 to 9 meteors per hour in the hours before sunrise.

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

SKY PHENOMENA (dates in AEST)

AUGUST

4 Uranus 5° north of Moon
7 Aldebaran 1.1° south of Moon
9 Mercury in inferior conjunction
11 Lunar eclipse
15 Venus 6° south of Moon
16 Moon 8° north of Spica
17 Jupiter 5° south of Moon
18 Venus greatest elong. east (46°)
18 Mercury stationary
19 Moon 9° north of Antares
21 Saturn 2° south of Moon
24 Mars 7° south of Moon
27 Mercury greatest elong. west (18°)
28 Mars stationary

SEPTEMBER

2 Venus 1.4° south of Spica
3 Aldebaran 1.2° south of Moon
6 Mercury 1.0° north of Regulus
6 Saturn stationary
8 Moon 1.8° north of Regulus
13 Venus 10° south of Moon
18 Saturn 2° south of Moon
20 Mars 5° south of Moon
21 Mercury in superior conjunction
21 Venus greatest illuminated extent
23 Equinox
27 Uranus 5° north of Moon
30 Moon 1.4° north of Aldebaran

LUNAR PHENOMENA

AUGUST

Last Quarter ...... 4th, 18:18 UT
New Moon ...... 11th, 09:58 UT
First Quarter ...... 18th, 07:49 UT
Full Moon ...... 26th, 11:56 UT
Perigee ...... 10th, 18h UT, 358,078 km
Apogee ...... 23rd, 11h UT, 405,746 km

SEPTEMBER

Last Quarter ...... 3rd, 02:37 UT
New Moon ...... 9th, 18:01 UT
First Quarter ...... 16th, 23:15 UT
Full Moon ...... 25th, 02:52 UT
Perigee ...... 8th, 01h UT, 361,351 km
Apogee ...... 20th, 01h UT, 404,876 km

Sagittarius rises again

Take aim at these targets within the Archer-Centaur constellation.

This is the third time this column has visited part of Sagittarius. Back in 2014, I wrote about **Zeta Sagittarii (HDO 150)**, located 90 light-years from us, a binary of only 21 years orbital period. In recent years Zeta has been in the wider part of its orbit, which makes it possible to see as a notched pair with 15-cm scopes, or split with 25 cm and larger. The pair has been known since 1867, so the orbit is now well measured. When closest, which will be the case around 2022–23, the stars are 0.17″ apart and unsuitable for almost all backyard observers.

Zeta Sgr's present separation is 0.5″, not much less than at widest separation. One orbital period ago in 1997, I saw this near-equal pair as a figure-8 with an 18-cm refractor. A 35-cm aperture gave a neat split. For those with larger telescopes, it could be interesting to observe Zeta Sgr each year to see the separation closing down to the telescope's limit of detectability — about 0.35″ for 20 cm aperture, and 0.20″ for 35 cm.

About 7 degrees north from Zeta is **H N 129**, a William Herschel discovery. Smaller telescopes deal with the 7th and 9th magnitude stars well; at 8″ separation, an 80-mm shows them nicely. The effect is better with more aperture, and 18 cm makes the pair fairly bright.

Our next double, **HJ 5082** (h 5082), is 11 degrees north of Zeta, and another easy pair for 80-mm scopes at nearly 8″ separation and stars of 6th and 9th magnitude. It was discovered in the 1830s and has changed very little. With 18 cm at 100x, the deep yellow star had an easy, fairly close companion east, and a fainter star further out to the southeast.

S 710, first recorded by James South with a small telescope, is 3 degrees north-northeast from HJ 5082. The 6th- and 8th-magnitude stars are 6.4″ apart, so it shows well with 80 mm and with 18 cm was an attractive pairing in a moderately starry field.

Another William Herschel discovery, **H N 126**, is located 0.25 degree north-northwest of magnitude 3.8 Omicron Sgr. A near equal pair of white magnitude-8 stars, the 1.4″ separation will be a test for 80-mm refractors, though it's easy with larger scopes — 18 cm at 100x showed a tiny pair, the stars just apart; with 180x it was a neatly separated attractive pair. A true binary with period estimated near 500 years, it's some 168 light-years from us according to the new Gaia parallax measure.

S 715 and **S 716** are in the same field, 2.5 degrees east from S 710 and slightly north. The stars are 7th and 8th magnitude, with easy separations, so 80 mm shows them. With 18 cm at 100x the brighter and wider S 715 is not far west from S 716, which is aligned at nearly the same angle, though reverse in brightness; a very nice combination in a fairly starry field.

54 Sgr (S 722) is 5 degrees east-northeast from Rho-1 Sgr (mag. 3.9), a 7th-magnitude duo at 10″ separation, the near-equal white stars a neat pairing through any telescope.

Another close binary is **HU 75**, 5.5 degrees north-northeast from Rho-1 Sgr. Discovered in 1899 by the notable double star specialist W.J. Hussey from Lick Observatory in California, this binary has an orbital period of 130 years. It widened after discovery to a maximum near 0.7″ around the 1940s, then closed down to a minimum of 0.16″ some 10 years ago. Now widening again, the present separation is 0.32″, which is very tight territory. To make it harder still, there's a brightness difference of 2 magnitudes between the stars. Currently, scopes around 40 to 45 cm might show the pair just apart, given a very steady atmosphere and magnifications of, say, 700x and above. Optimists with 30- to 35-cm scopes could try for an elongated image fading at one end.

Finally, further south again, **H N 119** is 6.5 degrees northeast of Zeta Sgr. There's a marked brightness difference here, plus a colour difference of orange and white, at an easy 7.5″ separation. Good with small telescopes, it's bright and striking with 18 cm.

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

Double stars of Sagittarius

Star Name	R. A.	Dec.	Mag.	Sep.	Position angle	Date of measure	Spectrum
HDO 150 (Zeta)	19h 02.6m	–29° 53′	3.3, 3.5	0.50″ eph	241° eph	2018.7	A2III+A4IV
HJ 5082	19h 03.1m	–19° 15′	AB 6.2, 9.0	7.7″	089°	2016	G5II-III
"	"	"	AC 6.2, 10.8	20.2″	112°	2016	"
H N 129	19h 04.2m	–22° 54′	8.9, 9.2	8.3″	309°	2016	A0V
H N 126	19h 04.3m	–21° 32′	7.9, 8.1	1.4″	186°	2016	F8V
S 710	19h 06.9m	–16° 14′	6.1, 8.4	6.4″	000°	2016	B8IV
S 715	19h 17.7m	–15° 58′	7.1, 7.9	8.4″	017°	2016	A3V
S 716	19h 18.1m	–15° 57′	8.4, 8.6	5.0″	194°	2010	B9.5V
HU 75	19h 29.6m	–12° 39′	7.1, 9.2	0.32″ eph	170° eph	2018.7	F5IV-V

Data from the *Washington Double Star Catalog*. eph signifies an ephemeris number.

When amateur astronomers gather

This year's National Convention held something for everyone.

This column is usually concerned with the visual observation variable stars, and the contribution amateur observers can make to science. But this month let's go further afield. Every two years on the Easter weekend, the National Australian Convention of Amateur Astronomers, or NACAA (pronounced 'Nakka') is held, hosted by a different astronomical association each time. The idea is for amateurs to meet and share ideas and techniques (and gossip) with other amateurs over coffee, a beer and good food. It's a unique opportunity to make new acquaintances and meet people we otherwise would only get to know online. Of course, more formal presentations and functions are scheduled over the weekend, and some professional astronomers participate also.

This year it was the turn of the Ballaarat Astronomical Association in collaboration with the Ballarat Municipal Observatory and Museum. And a rattling good time it was, too! Presentations covered aspects of the history of astronomy in Australia, photometric variable star and planetary work, travelogues and much more. Professor Virginia Kilborn gave the opening address, titled 'A Golden Age for Astronomy in Australia'. She discussed many things already familiar to readers of this magazine, not least being Australia's new partnership with the European Southern Observatory, and the forthcoming Square Kilometre Array. Steve Fleming and Tex Moon (both remarkably well dressed for amateur astronomers) spoke of how much original research one can do simply with the Internet, or using relatively cheap CMOS cameras and small telescopes.

The highlight for me (and for my endlessly tolerant wife) was Associate Professor Emma Ryan-Weber. She gave a truly remarkable talk on naked-eye observing, ranging from estimating distances within the Solar System right out to cosmology and the most profound naked eye observation of all… that the night sky is dark. Why? This question is known as Olber's Paradox, and it invites conclusions about the finite speed of light and an expanding universe.

NACAA 2020 will be held in Parkes, NSW, hosted by the Central West Astronomical Society (CWAS), and it already looks like it will be a spectacular weekend. It's possible that the Convention will coincide with the David Malin Awards for astrophotography, and — phase of the Moon allowing — the CWAS Astrofest. I hope to see you there.

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

Action at Jupiter

JUPITER, STILL IN LIBRA, appears high in the west all month. Near the middle of August, about 6½ hours separates sunset and Jupiter-set, with the gap slowly growing smaller as the evenings pass.

Jupiter reaches east quadrature (90° east of the Sun) on August 6. This is a good time to shadow watch as Jupiter's moons dance around the planet. Any telescope shows the four Galilean moons, and binoculars usually show at least two or three.

Here are the times, in Universal Time, when the Great Red Spot should cross Jupiter's central meridian. The dates, also in UT, are in bold.

Aug. 1, 0:54, 10:49, 20:45; **2,** 6:41, 16:37; **3,** 2:33, 12:28, 22:24; **4,** 8:20, 18:16; **5,** 4:11, 14:07; **6,** 0:03, 9:59, 19:54; **7,** 5:50, 15:46; **8,** 1:42, 11:38, 21:33; **9,** 7:29, 17:25; **10,** 3:21, 13:17, 23:12; **11,** 9:08, 19:04; **12,** 5:00, 14:56; **13,** 0:51, 10:47, 20:43; **14,** 6:39, 16:35; **15,** 2:30, 12:26, 22:22; **16,** 8:18, 18:14; **17,** 4:09, 14:05; **18,** 0:01, 9:57, 19:53; **19,** 5:48, 15:44; **20,** 1:40, 11:36, 21:32; **21,** 7:27, 17:23; **22,** 3:19, 13:15, 23:11; **23,** 9:06, 19:02; **24,** 4:58, 14:54; **25,** 0:50, 10:45, 20:41; **26,** 6:37, 16:33; **27,** 2:29, 12:25, 22:20; **28,** 8:16, 18:12; **29,** 4:08, 14:04, 23:59; **30,** 9:55, 19:51; **31,** 5:47, 15:43.

These times assume that the spot will be centred at System II longitude 292°. If the Red Spot has moved, it will transit 1⅔ minutes earlier for each degree less than 292° and 1⅔ minutes later for each degree more than 292°.

Features on Jupiter appear closer to the central meridian than to the limb for 50 minutes before and after transiting. A light blue or green filter slightly increases the visibility of the planet's reddish and brownish markings.

The 'meteor storm' comet returns

Set your sights on 21P/Giacobini-Zinner during September.

August and September will be pretty good for time southern comet observers, with three comets of note to keep us occupied. First up is **C/2016 M1 (PANSTARRS)**, which will reach its rather large perihelion distance of 2.21 a.u. from the Sun on August 10. Beginning the month close to the boundary of the far southern constellations Norma, Circinus and Lupus, the comet will continue to slowly drift southward during the late winter and early spring. It will reach Centaurus during the final quarter of August and, throughout September, will linger close to Alpha Centauri as it slowly moves away from the inner Solar System.

On present indications, C/2016 M1 is expected to be about magnitude 9.5 to 10 during early August, fading by approximately half a magnitude by the end of September.

Early August will find another comet, **C/2017 T3 (ATLAS)**, sinking into both the morning and evening twilight, although suitably placed observers should have a better chance of following it in the early evening skies. Having passed perihelion (at 0.82 a.u.) on July 19 and making its closest approach to Earth (1.35 a.u.) on August 1, the comet will be fading as it moves away from both Earth and Sun. Trekking from Puppis into Pyxis during the first week of the month, C/2017 T3 is unlikely to be brighter than magnitude 10. The waning Moon will not make observing any easier for morning viewing, but the comet may still be worth a try if you have a clear eastern horizon, and before it is completely overtaken by the morning twilight.

The real cometary 'star' of the period, however, will be the short-period (6.55 years) **21P/Giacobini-Zinner**, which this year is making a very favourable return. Trekking southward from high northerly declinations, the comet will be visible in the early morning sky from mid-southern latitudes. Beginning early September in the constellation Auriga, 21P will cross into Gemini on September 13 and into Monoceros some ten days later. Perihelion and closest passage of Earth (1.014 a.u. and 0.39 a.u. respectively) will occur on the same day — September 10. Around this time the comet is expected to be about magnitude 7.5, fading to 8 or a little fainter by the end of the month.

21P is famous for having produced the spectacular Draconid meteor storms of October 1933 and 1946, when at least 6,000 meteors per hour were recorded. The comet also made history by becoming the first to be visited by a spacecraft, albeit rather distantly. On September 11, 1985, the International Comet Explorer (ICE) flew through 21P's ion tail, making the very first in situ measurements of a comet's magnetic and plasma environment.

▲ **FREQUENT FLYER** Comet 21P/Giacobini-Zinner was captured by the Kitt Peak 0.9-metre telescope on October 31, 1998. North is up with east to the left.

N. A. SHARP/NOAO/AURA/NSF

According to comet expert Z. Sekanina, 21P's nucleus — thought to be about two kilometres in diameter — is a rapidly-rotating body shaped somewhat like a pancake. Maybe we should call it a cometary 'flying saucer'?

■ **DAVID SEARGENT** is the discoverer of comet 1978 XV. His most recent book, *Snowballs in the Furnace*, is available from Amazon.com

M17: The nebula with too many names

Follow this guide to find one of the best H II regions in the night sky.

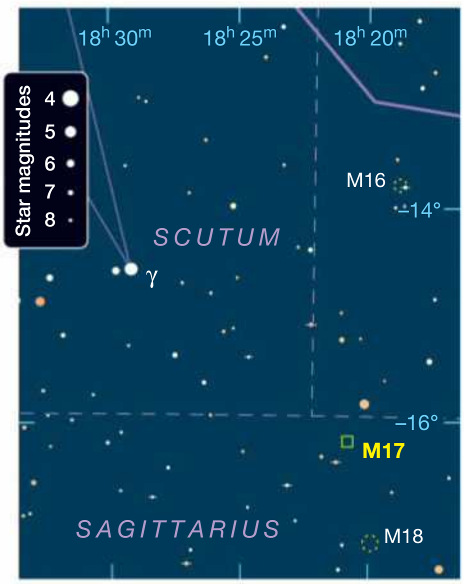
Messier 17 has at least five proper names — the Omega Nebula, Horseshoe Nebula, Checkmark Nebula, Swan Nebula and the Lobster Nebula. Why so many?

Sir John Herschel started off the story by comparing M17 to the capital Greek letter Omega. His 1833 sketch shows something like an Ω with a long tail, and given his immense intellect, I can see why he chose the name. But he used the names Omega and Horseshoe interchangeably, and his sketches from the first half of the 19th century accentuate the horseshoe part of the nebula. Although the shape of M17 doesn't conjure up an Omega or a horseshoe for most 21st-century observers, both names are still widely used.

I totally get the Checkmark name — that's what M17 looks like through my 20-cm scope. And I could see it as the Swan with my old 31.5-cm Dobsonian. From a Southern Hemisphere perspective, many observers call it the Lobster Nebula. Pareidolia — the phenomenon of seeing a familiar pattern where there is none — really depends on your orientation.

▲This image of the star-forming region of M17 was captured by the Wide Field Imager on the MPG/ESO 2.2-metre telescope at the ESO's La Silla Observatory in Chile. The pink-to-red colour comes from hydrogen gas clouds that are being excited by extremely hot newborn stars. North is down, west is to the left.

M17 IMAGE: ESO



So even though M17 has too many names, at least they're a good selection from which to choose.

What is it?

M17 is a bright H II region in the Milky Way with a colossal but hidden star cluster catalogued as **NGC 6618**. It's also the brightest portion of a giant molecular cloud (GMC) located approximately 6,000 light-years away in the Sagittarius spiral arm. That makes the optically visible portion of M17 roughly 15 light-years in length.

M17 has nourished three waves of star formation. The first formed roughly 2,000 stars between 2 and 5 million years ago, followed by the rapid compression of gas and dust. That increase in density, nearly 2 million years ago, kick-started the formation of approximately 12,000 more stars and continues today, making up the huge NGC 6618 star cluster. Unfortunately, these stars lie mostly hidden within the H II gas of M17 and are best seen in infrared.

A third phase of star formation is ongoing in the outer regions of M17's GMC, involving about 1,000 stars.

The massive O-class stars in NGC 6618 blast out intense ultraviolet radiation that excites the hydrogen gas in the M17 molecular cloud to emit visible light, producing the emission nebula/H II region we're so fond of naming.

◀ John Herschel, who sketched this representation of the nebula in 1833, alternated between the names Omega and Horseshoe. What do you see? North is down, west is to the left.

FURTHER READING: To learn more about Messier 17 and view the author's earliest sketch of the region, see https://is.gd/BanichM17.

The Swan's neck and head

All but one of M17's names implies a loop somewhere in the nebula, which represents the head and neck of my favourite shape, the Swan.

Although visually smaller and fainter than the body, what we see as the gracefully curved head and neck of the swan is actually the most massive part of the nebula. The brightest portions look like a vaporous numeral 2 to me, and yet this is the area that inspired the Omega and Horseshoe names.

The most dramatic part is actually the black area inside the curve of the 2 — on the best nights it looks almost impossibly black. This dense portion of M17's molecular cloud creates a memorably high contrast region with the bright head and neck curving around it.

On close inspection I was able to see two faint stars in the foreground of the darkness — close to its south and northwest edges. I also noticed a rather sharp corner on the inside edge near the top of the 2.

Farther along the neck, and almost on the border with the black molecular cloud, shine three rather prominent stars, which are opposite a star of comparable brightness right near the southern end, or top, of the 2. These are some of the visible stars of the NGC 6618 cluster. Just east of the centre of the three stars is a small, bright knot of nebulosity that I see only on the most transparent nights.

Continuing the curve past the top of the 2 are two subtle, not quite parallel streaks that flow into a faint haze that circles back to the base of the 2. This faint nebulosity completely encloses the dark area inside the curve of the 2 and reinforces its utter blackness. Also note the two, equally faint, feathery streaks pointing south from the head.

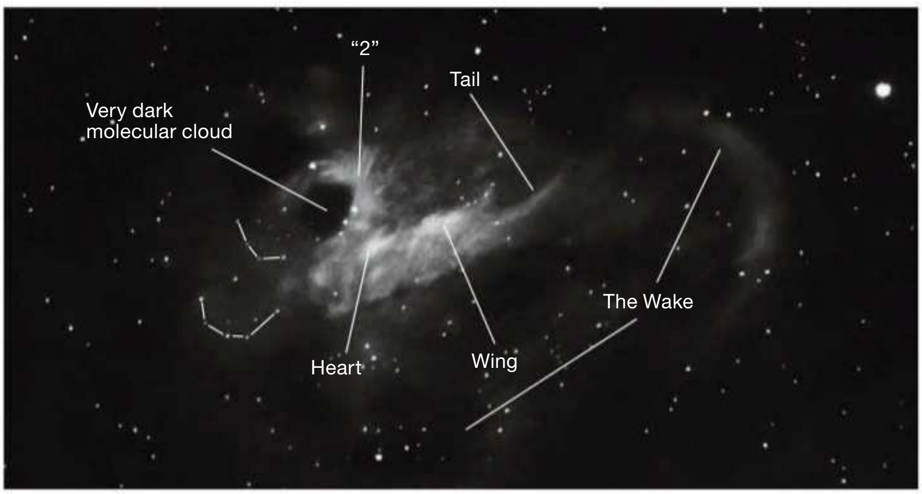
Above the 2 is a small puff of nebulosity with a fairly prominent star that crowns the head of the swan. There are other puffs of fainter nebulosity surrounding the head, but this is the most obvious and picturesque.

The Swan's heart, wing and tail

Extending mostly east-west, the swan's body is the brightest and most detailed portion of M17. It's also the most fun area to observe at various magnifications, especially around the two brightest areas along the southern edge of the body. The one closest to the swan's neck and head is shaped much like an elongated heart.

The next brightest area lies closer to the tail end of the body and, with pareidolia now in full force, I can even conjure up a wing. Boosting magnification brings out its undulations and ragged outline, and a thin extension — the wing tip — curving toward the southeast. Its shape is reinforced by an arc of stars along its southern border.

There's a longer, beautifully curved extension off the eastern end that gracefully arcs toward the southeast to make an excellent tail. It shows up best with averted vision.



▲ In this sketch by the author, the components of M17 have been labelled to match the descriptions in the text. Note how dark the molecular cloud inside the curve of the head and neck appears, as well as the sharp corner it makes. Can you spot the two arcs of relatively faint stars highlighted by the dashed lines? These stars reinforce the appearance of the faint haze in this area, looking as if they've collected the last bit of nebulosity that drained from the darkness inside the 2. North is down, west is to the left.

▲This infrared image shows the massive NGC 6618 star cluster that's still forming deep inside the gas clouds of M17. Notice how the head of the Swan disappears at near-infrared wavelengths. North is down, west is to the left.

Although we can't see much of the NGC 6618 cluster, its main concentration of stars is located in the crook between the swan's neck and body. If human vision were sensitive to near-infrared wavelengths, this might be the most spectacular part of M17.

The wake

North and east of the body ranges a complex of much fainter loops and patches of nebulosity. There's a lot of subtle detail here, especially under ideal skies. Look for small, subtle dark patches as well as bright ones. The most prominent are off the northern edge of the swan's body — use higher powers to see them best. A nebula filter will give the fainter wisps and dark areas greater contrast and will, for that matter, boost the contrast of the entire nebula.

East of the tail is a large, faint loop that arcs south to north at about 90 degrees to the body of the swan. It can be surprisingly prominent on a good night but doesn't quite connect to the tail. The northern end of the arc leads to the patches of nebulae just north of the swan's body, which in turn connects to the base of the neck — and suggests a wake through water, completing the illusion of a swimming swan.

However you see M17, it's a marvellous H II region with exceptionally contrasting dark nebulae. Even the Orion Nebula doesn't have an area with such contrast. Unfortunately, M17 and M42 are never visible at the same time for a direct comparison, so take good notes, make a sketch or two, and see for yourself. It's possible M17 will become your second favourite H II region of the Milky Way, regardless of what it looks like.

▲This sketch of M17 was done by the author over 4½ hours of drawing at the eyepiece over three nights. Although the article discusses observations made with the author's 0.7-metre telescope, most of what he sketched can be seen through considerably smaller scopes under a dark sky. He mostly used 253×, but didn't use nebula filters. The entire 'body' of the nebula can appear twisted like a barber pole because the orientations of the brighter areas are similar. North is down, west is to the left.

SKETCH: HOWARD BANICH; COLOUR IMAGE: 2MASS / UMASS / IPAC / CALTECH / NASA / NSF

■ **HOWARD BANICH** loves a good H II region whether it looks like something else or not. He can be reached at **howard.banich@nike.com**.

Hunting Phobos and Deimos

Spotting these diminutive moons is a daunting challenge for dedicated observers.

This year, a three-month-long window to mid-September will present an opportunity to glimpse the tiny moons of Mars, which rank among the most difficult targets for amateur telescopes. Your chances of success will increase the closer you observe to July 31, the date of the closest approach of Mars to Earth this apparition. Deimos will then be a 12.0-magnitude object, while Phobos will shine at magnitude 10.9.

Both satellites would be easy prey for a 15-cm telescope if they weren't so close to their parent planet, which is hundreds of thousands of times brighter. They were only detected in 1877 by American astronomer Asaph Hall using the recently commissioned 0.65-metre (26-inch) Clark refractor at the US Naval Observatory, decades after considerably fainter satellites of Saturn, Uranus and Neptune were discovered. In 1971, NASA's Mariner 9 spacecraft revealed both Phobos and Deimos as irregularly shaped, heavily cratered shards of cosmic debris that are among the least reflective objects in the entire Solar System.

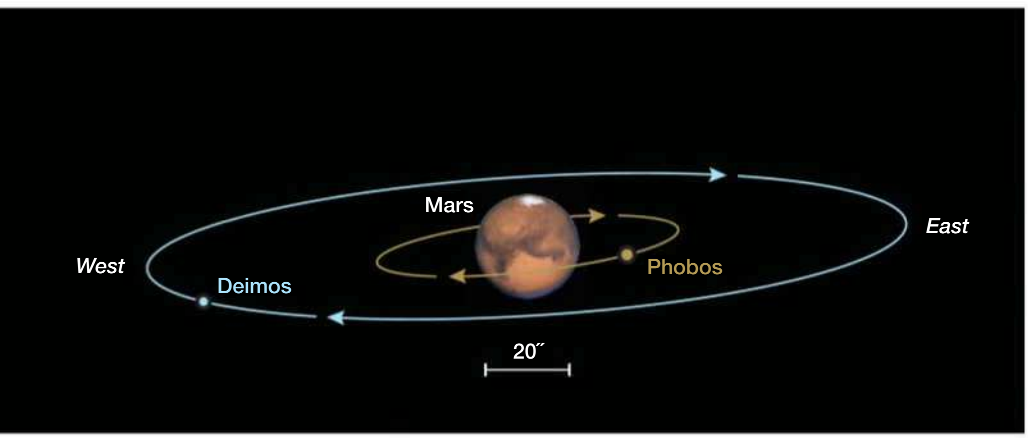
In 1939, astronomers Harry Edward Burton and Bevan Sharpless of the US Naval Observatory began to systematically study the orbital behaviour of the Martian satellites. Drawing on observations made between 1879 and 1941, Sharpless published a paper in 1945 in the *Astronomical Journal* entitled 'Secular Accelerations in the Longitudes of the Satellites of Mars' that presented the first evidence that the orbit of Phobos was decaying and would ultimately result in the satellite's destruction.

Sharpless' work attracted little interest until the late 1950s, when Soviet astrophysicist Iosif Shklovsky alleged that tidal forces and the frictional drag imparted by the tenuous Martian atmosphere were causing Phobos to spiral toward the surface of the Red Planet at a much faster rate than was possible for a solid body. Shklovsky speculated that Phobos and Deimos might be hollow artificial satellites. This suggestion was taken seriously by several luminaries, including Raymond Wilson, Chief of Applied Mathematics at NASA, and Carl Sagan, a rising star among American planetary scientists. However, President Eisenhower's national science adviser Fred Singer cautioned:

> *The big 'if' lies in the astronomical observations; they may well be in error. Since they are based on several independent sets of measurements taken decades apart by different observers with different instruments, systematic errors may have influenced them.*

Singer was prudent — Shklovsky's calculations were based on flawed data. Phobos is indeed spiraling inward but at a rate of only 1.8 metres per century. The doomed satellite will not collide with Mars or be torn to pieces and scattered as a ring around the planet for another 40 million years.

While Shklovsky regarded the moons as the relics of a long-dead race of Martians, to Felix Zigel, of the USSR Academy of Sciences, they were evidence of an existing civilisation on Mars. In 1960 Zigel wrote that he was puzzled by the fact that during the favourable Mars opposition in 1862, Phobos and Deimos had eluded experienced observers equipped with much larger telescopes than the 0.65-metre refractor employed by Hall in 1877, namely William Lassell's 1.2-metre (48-inch) reflector on the island of Malta and Lord Rosse's 1.8-metre (72-inch) 'Leviathan of Parsontown' at Birr Castle in Ireland, the largest telescope in the world at the time. Despite the mediocre reflectivity of their metal speculum mirrors, these reflectors were vastly superior in light-gathering power. Zigel reasoned that the failure to detect the presence of Phobos and Deimos was because they had been lofted into orbit around Mars sometime between 1862 and 1877.



◀ The tiny moons of Mars do not stray far from the Red Planet. Phobos at its farthest extends less than one Mars diameter from the planet's limb, while Deimos reaches about three. See **https://is.gd/marsmoonstable** for a list of elongation times of both moons in the months closest to opposition.

NASA / ESA / HUBBLE HERITAGE TEAM

Zigel failed to take into account that Hall succeeded where his predecessors failed because he was an unusually astute observer who carefully scrutinised the sky surrounding Mars using a novel technique. Hall recounted:

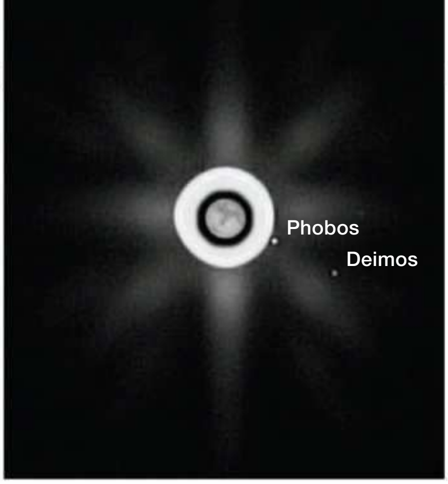
> *I began to examine the region close to the planet and within the glare of light surrounding it. This was done by keeping the planet just outside the field of view and turning the eyepiece so as to pass completely around the planet.*

Several weeks after its discovery, Hall and two of his colleagues glimpsed Deimos through the Naval Observatory's smaller 24.4-cm (9.6-inch) refractor using this "right way of looking".

In 2001, renowned planetary observer Stephen James O'Meara devised an elegant method of heeding Hall's advice to "get rid of the dazzling light of the planet". Instead of positioning Mars just outside the field of view, he cut a semicircle from a Wratten gelatin filter and mounted it against the field stop at the focal plane of his eyepiece, where it bisected the field of view.

Rather than affixing the filter to the field stop with a dollop of glue or a sliver of tape, a rubber O-ring from the local hardware store makes an ideal temporary retainer on some oculars that is easy to install and remove. Short-focal-length eyepieces that provide high powers generally have small lenses that make the installation of a filter mask more challenging. The combination of a low- or medium-power eyepiece and a Barlow lens to boost the magnification is recommended.

Although a neutral-density filter will give excellent results, O'Meara prefers to use a blue (Wratten #47) filter that selectively attenuates the planet's ruddy glow. "Since Mars will shine dimly through this mask," he advises, "you can more easily judge the distance and direction from the planet where you should look for each moon". It's always best to attempt to detect these tiny wisps of light near the time of their eastern or western elongations, when their apparent distance from Mars is greatest; rotate the eyepiece so that the edge of the filter mask is aligned on the planet's north-south line.



◀ Because the moonlets are vastly fainter than Mars, amateur John Boudreau overexposed the planet to capture both Phobos and Deimos as they were best positioned on the night of December 26, 2007 using a 14-cm Astro-Physics refractor and Imaging Source video camera. He then composited a properly exposed image of the planet into the final image.

Deimos, the fainter and more distant satellite, circles Mars once every 30 hours 18 minutes, appearing about two-and-a half Mars diameters from the planet's brilliant limb at greatest elongation. Roger Venable of ALPO notes that for 2½ hours before and after each time of maximum apparent elongation, its separation is still greater than 85% of maximum. Outside that interval it is quite hard to see.

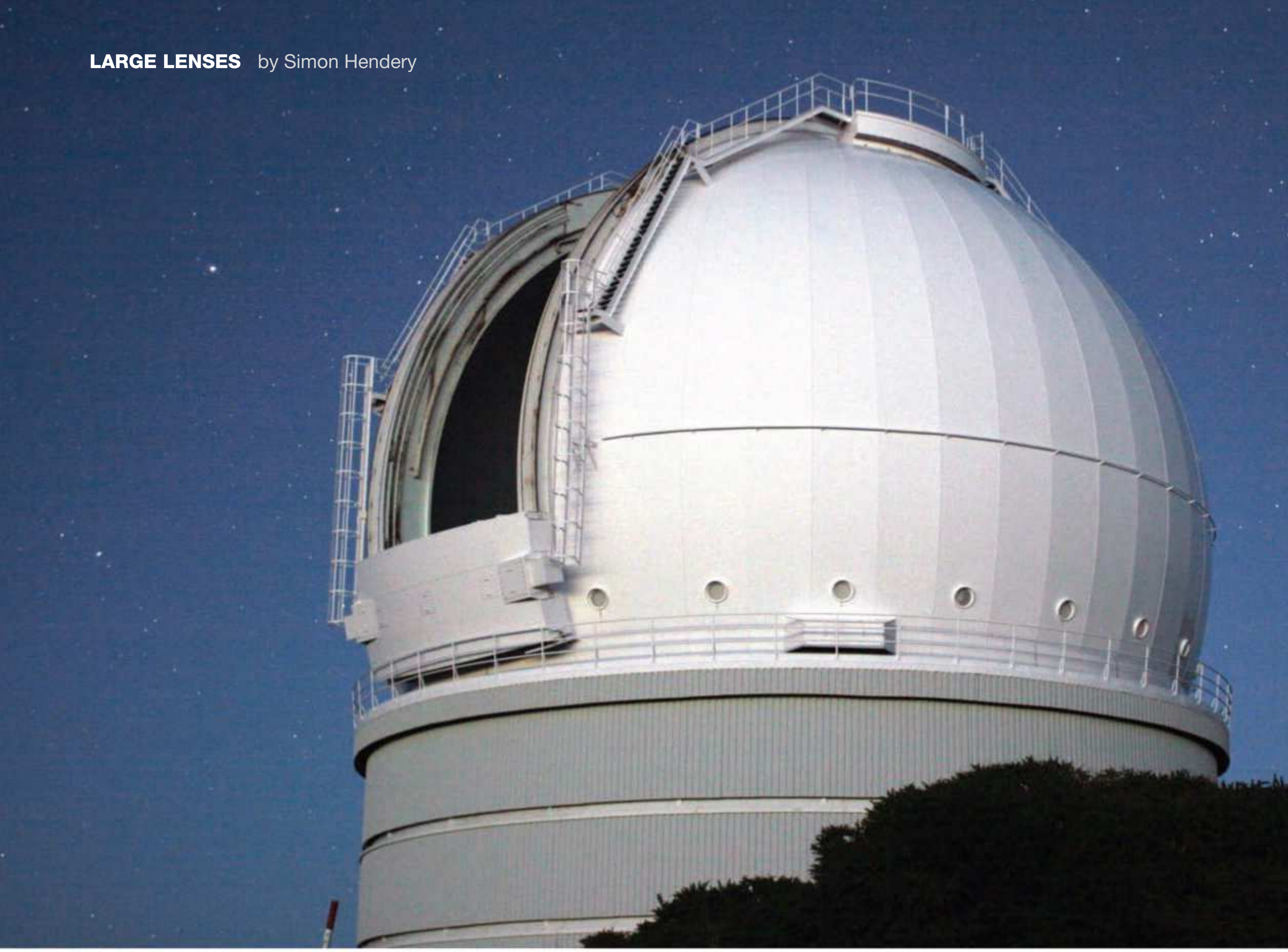
Although Phobos is considerably larger and brighter, its closer proximity to Mars makes it a far more challenging quarry. Orbiting a scant 6,000 kilometres above the Martian surface and circling Mars in only 7 hours 39 minutes, Phobos never appears more than 16 arcseconds from the planet's limb (only ⅔ the apparent diameter of the Martian disk at the end of July), and it moves fast. For 30 minutes before and after the time of maximum apparent separation, it's still greater than 86% of maximum.

Using the highest magnification the seeing will bear and clean, well-collimated optics are essential ingredients for success. Diffraction from the vanes of a Newtonian reflector's secondary mirror support can be a troublesome source of scattered light, so refractors and catadioptrics are the preferred weapons of choice. Experienced observers with superior visual acuity have bagged Phobos using 20-cm telescopes, while Deimos has been glimpsed with just 15-cm of aperture. Good luck and good hunting!

Instead of making an occulting bar to help him see the moons of Mars, long-time observer Stephen James O'Meara fashioned a semi-circular filter using a Wratten #47 gelatin filter affixed in front of the field stop on a medium-power eyepiece using a 28.6-mm outer-diameter O-ring.

FILTER: SEAN WALKER / S&T

■ **THOMAS A. DOBBINS** has been observing Mars since 1965, the year that NASA's Mariner 4 spacecraft flew by the enigmatic world.



NIK SZYMANEK

Precision optics

A New Zealand company that specialises in high-tech optics is taking on the world.

From an unassuming industrial park on the outskirts of a Wellington suburb, a New Zealand company is delivering world-leading solutions for some of the planet's most important astronomy projects, including several in Australia.

Earlier this year KiwiStar Optics produced one of the world's largest astronomical lenses — at 1.1 metre in diameter — for the William Herschel Telescope project in Spain's Canary Islands. Its most recent project has been building and installing a spectrograph as part of the MINERVA-Australis telescope array at Queensland's Mount Kent Observatory.

Despite a history dating back decades, and an industry reputation for producing state-of-the-art equipment needed to produce some of the world's best lenses, KiwiStar Optics manager Sandra Ramsay admits the company has a low profile outside astronomy circles.

"We design, manufacture and install everything from one-off components to complete optical systems. Our work includes building large precision lenses for some of the world's best telescopes, astronomical spectrographs, and optical components and instruments," she said.

Ramsay says the business is primarily based around two products: large, customised and highly-specialised telescope lenses up to more than 1 metre in diameter, and astronomical spectrographs.

From humble beginnings

KiwiStar Optics is a business unit of Callaghan Innovation, New Zealand's Innovation Agency, and is based at the Gracefield Innovation Quarter, home to a cluster of high-tech businesses and Callaghan Innovation's Research

"We're one of only a handful of companies in the world making 500 mm to 1 metre lenses," said Cochrane.

WIDE EYES A multi-object spectroscope attached to the William Herschel Telescope (in the Canary Islands) will use giant lenses made by New Zealand firm, KiwiStar Optics.

▲ **REFLECTIONS** A view looking into the primary and secondary mirrors of the William Herschel Telescope.

MAX ALEXANDER

and Development division, about 15 kilometres from Wellington's CBD.

"At Gracefield, we have access to state-of-the-art equipment and onsite experts, including from New Zealand's national metrology institute and Callaghan Innovation's specialist machine shop," said Ramsay.

"KiwiStar Optics has a core team of 14 staff but we also tap into numerous skill sets and expertise from across Callaghan Innovation's much larger pool of scientists, engineers and technicians who work with us. We also have a strong supply chain of New Zealand businesses who complement our skills and expertise."

Dave Cochrane, KiwiStar Optics' team leader of optical manufacturing, says that while the company's genesis was the formation of a government optics workshop after World War II, the KiwiStar Optics name — and its current business focus — date back to 2004 when a strategic decision was made to focus on large optics.

"With global spending on large telescopes growing, and increasing competition around the manufacture of smaller lenses — up to 300 mm diameter — we decided to focus on making large optics for astronomy, essentially starting at 400 mm diameter. We're one of only a handful of companies in the world making 500 mm to 1 metre lenses," said Cochrane.

One of the world's largest lenses

An example of the world-leading work being done by KiwiStar Optics is its contribution to the William Herschel Telescope (WHT), Europe's second-largest telescope, based on the island of La Palma in the Canary Islands, Spain.

As reported in the June 2018 issue of *Australian Sky & Telescope*, KiwiStar Optics manufactured six lenses for the telescope's Prime Focus Corrector, with the largest being 1.1 metre in diameter. The lenses will form a crucial part of a new multi-object spectroscopy facility being constructed for the telescope, called WEAVE (WHT Enhanced Area Velocity Explorer).

WEAVE will enable simultaneous observations of up to a thousand targets over a 2-degree field of view, and is designed to complement information produced by other European astronomical projects. It will operate for a minimum of five years and conduct large-scale surveys of over 10 million objects, including stars in the Milky Way.

Spectrograph for Mt Kent

KiwiStar Optics' most recent major contract, and the latest in a growing number of Australian projects, is the delivery of one of its 'KiwiSpec' spectrographs for the University of Southern Queensland's Mt Kent Observatory.

Scheduled for completion mid-2018, the KiwiSpec R4-100 spectrograph is part of Mt Kent's expansion to include the MINERVA-Australis telescope array.

The multi-telescope MINERVA-Australis project complements the four-telescope MINERVA (MINiature Exoplanet Radial Velocity Array) array in Arizona, USA, with both facilities dedicated to the observation of exoplanets found by NASA's Transiting Exoplanet Survey Satellite (TESS) space mission.

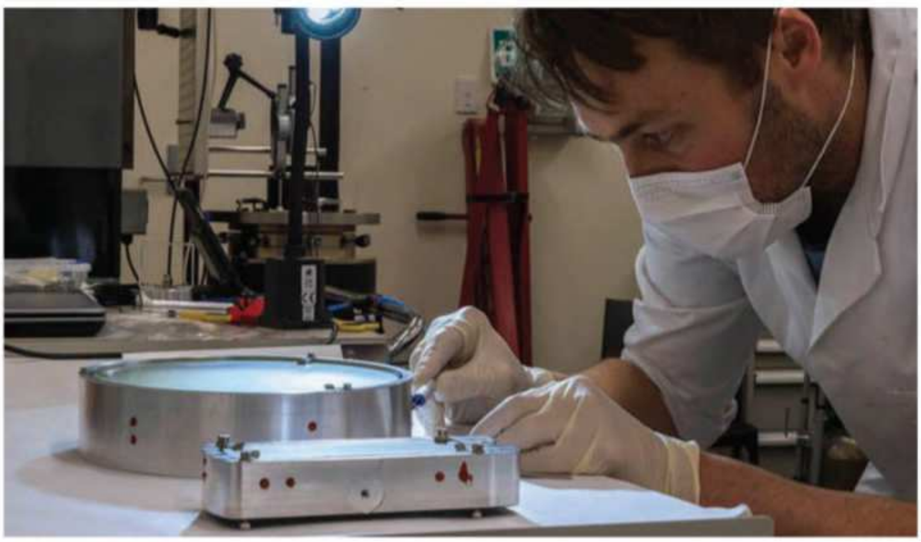
The spectrograph is compact, bench-mounted, in vacuum, optical fibre-fed and enables six optical fibres to be sampled at a time. It will enable precise radial velocity measurements (whether an object is moving towards or away from Earth) of less than 1 metre per second, as well as transit studies (where one celestial object briefly eclipses another).

Close Australian connections

Ramsay says KiwiStar Optics is active in Australia through its relationship with Electro Optic Systems (EOS), a Canberra-based company with a significant space systems division.

"We've sub-contracted to EOS for several large pieces of work for Australian observatories and we've also partnered with them to deliver some large international projects. It's a very constructive and mutually beneficial relationship, and one we are keen to continue and grow," she said.

▲ **LARGE LENS** KiwiStar Optics' team leader of optical manufacturing, Dave Cochrane, cleans one of the six 1.1-metre lenses made for the William Herschel Telescope.



▲ **ENGINEERING** KiwiStar Optics has produced a number of specialised spectrographs, such as this KiwiSpec, for observatories around the world.

The relationship began when KiwiStar Optics sub-contracted EOS to build the Prime Focus Corrector (PFC) for FMOS, a fibre-fed, wide-field spectroscopy system for the Subaru Telescope in Hawaii, which enables near-infrared spectroscopy of more than 100 objects at a time. This was installed in 2007.

KiwiStar Optics later partnered with EOS to build the PFC for the SkyMapper telescope at Siding Spring Observatory, Coonabarabran, which is undertaking the five-year Southern Sky Survey.

Other Australian projects KiwiStar Optics has been involved with include building a prototype image slicer for Australia National University's Wide-Field Spectrograph (WiFeS), installed on the 2.3-metre telescope at Siding Spring Observatory.

The company has worked on projects for Australia's largest optical telescope, the 3.9-metre Australian Astronomical Telescope, also at Siding Spring. This has included producing precision optical components and, most recently, carrying out the optical fabrication, mechanical design and manufacture, assembly and testing of the collimator optics and four large aperture cameras for the HERMES spectrograph.

KiwiStar Optics also manufactured a set of three-element corrector optics for the Harlingten Telescope at Tasmania's Greenhill Observatory.

Future looks bright

Ramsay says work is not letting up and KiwiStar Optics has a substantial list of large contracts on its order book. Projects in the pipeline include the manufacture of more large lenses, building three high-resolution cameras for the VISTA telescope in Chile, and constructing more spectrographs.

With international demand for its expertise continuing to grow, the future looks bright for this New Zealand company with its sights set on helping those with their eyes set on the stars.

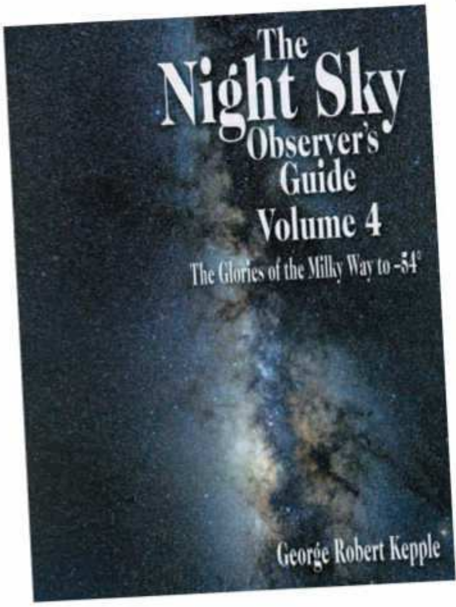
■ **SIMON HENDERY**, is a New Zealand-based technology and innovation writer.

KIWISTAR OPTICS

▼ OBSERVING GUIDE

Willmann-Bell has released *The Night Sky Observer's Guide Volume 4: The Glories of the Milky Way to -54°* by George Robert Kepple (US$34.95). This fourth volume of the series describes the appearance of more than 1,800 deep sky objects in the Milky Way as seen through 15- to 47-cm telescopes, including more than 1,000 targets not included in previous volumes. The book begins with a primer on the types of objects to be observed, as well as equipment and observing strategies. The following 23 chapters focus on each individual constellation of interest within the plane of the Milky Way. Nearly 1,000 black-and-white photographs and sketches complement the author's detailed descriptions. Hardbound, 21.5 by 28 cm with 500 pages, ISBN 978-1-942675-06-8.

willbell.com



▶ ULTIMATE ASTROGRAPH

Celestron has announced its flagship astrograph, the 36-cm Rowe-Ackermann Schmidt Astrograph (US$12,995). This f/2.2 optical system is designed to record pinpoint stars across a 60-mm image circle. The telescope incorporates a new moving mirror focuser design that minimises focus shift and includes ventilation fans to allow the scope to rapidly reach ambient temperature. Its 108-cm-long, 40-cm-diameter optical tube assembly includes two Losmandy-style mounting bars and weighs 34 kg. Additional accessories include a 48-mm camera adapter and a battery pack for the cooling fans.

celestron.com

▲ SATELLITE SPOTTER

Southern Stars now offers an updated app for satellite observers using Apple devices. Formerly known as *Satellite Safari*, *Orbitrack* (US$4.99) includes a host of new features to track the orbital path of more than 3,500 satellites, enabling users to quickly identify these moving spacecraft in real time, including many military satellites. Its voice-controlled Virtual Reality (VR) mode provides an immersive 3D spaceflight experience that works with any iPhone-compatible VR headset. The app displays a chosen satellite's path across the sky as well as a simulated view from the Earth below the satellite itself. Its orbital elements are updated daily to ensure accurate predictions. *Orbitrack* is compatible with iPhone models 5s and up, or iPads running iOS 10 or higher. An Android version is expected soon.

southernstars.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.

Messier 27: The first planetary nebula

Explore this complex deep sky object through your telescope with the help of an experienced observer's ever-so-elaborate sketches.

M27 has everything going for it. It's a large, bright planetary nebula with a striking and subtly detailed shape. It's well placed in the northern sky (about altitude 33° from Sydney) during the middle months of the year. It has a famous nickname that captures the essence of its shape. It's even easy to find, especially if you triangulate its position using Gamma (γ) and Delta (δ) Sagittae.

Almost universally referred to as the Dumbbell Nebula, the brightest parts of M27 really do look like a handheld workout weight. But it often looks even more like an apple core or an hourglass. John Herschel coined the dumbbell name and suggested the hourglass comparison in 1827. The resemblance to an apple core, which is a more modern nickname, is just as strong.

However, I think Herschel's best description of M27 is "A most extraordinary object," and anyone who's seen it through a telescope will probably agree that that describes its impact through the eyepiece better than any of its nicknames.

Charles Messier was able to discover the Dumbbell the night before the full Moon of July 1764 because it has the highest surface brightness of any large planetary nebula. His description reads, in part, "nebula without a star" and "it appears of oval shape". That general appearance fit many of his discoveries, so it became just the 27th object on his list of enigmatic nebulae that didn't move relative to the stars. Today we know that M27 was the first planetary nebula ever to be discovered.

Messier was using a 15-cm speculum mirror Gregorian telescope at 104× when he first found M27. His discovery not only shows that searching for comets didn't wait for the Moon to get out of the way but is also a dramatic illustration of M27's conspicuousness.

Its size and brightness — 8 × 5 arcminutes in diameter, magnitude 7.5 — make it an easy target even through binoculars and finder scopes. Its apparent shape can range from a dumbbell, to a rounded rectangle, to a slightly squashed oval depending on your observing conditions, scope and experience. You may even see all three shapes blended together.

M27, the planetary nebula

Stars with 1 to 8 masses of our Sun — which make up a good proportion of stars in the universe — will probably produce a planetary nebula when they lose the ability to sustain fusion during their final red giant phase and evolve into white dwarf stars.

But as common as this phenomenon is, it's also short-lived. It lasts only a few tens of thousands of years, a mere flicker compared to the billions of years that stars in this mass range live on the main sequence.

As it turns out, M27 is a young planetary nebula with an estimated age between 9,800 and 14,600 years. That's just two to three times longer than recorded human history. The nebulosity has a diameter of about 3.1 light-years (around two-thirds the distance to Alpha Centauri, the closest star system to ours) and is approximately 1,360 light-years away.

At the centre of the nebula lies the largest white dwarf thus far measured, with a radius approximately 0.055 times that of the Sun's. A temperature of 108,600 K, about 18 times solar, makes it hot and bluish. At magnitude 12.9, it can be seen through a modest-size amateur telescope.

This white dwarf star has an unseen stellar companion, which is believed to have played a major role in sculpting the nebulous shape of M27.

ESO / I. APPENZELLER / W. SEIFERT / O. STAHL

▲ **A MOST EXTRAORDINARY OBJECT** Messier 27, also known as the Dumbbell Nebula, the Hourglass Nebula, and more recently, the Apple Core Nebula, was first discovered by Charles Messier in 1764 and subsequently observed by William Herschel, who bestowed upon it the “dumbbell” moniker. In this glorious composite image obtained with Antu, one of ESO’s four Very Large Telescope 8.2-metre unit telescopes in Chile, the structure of the nebula is clearly seen. The red colour in the outer parts of the nebula traces hydrogen expelled during the first phase of mass loss from the red giant, while the green represents oxygen ejected during a second phase. North is up in all images.

And get this: The densest parts of M27's nebulosity contains up to 100,000 particles per cubic centimetre. That sounds like a lot, but astonishingly, is less dense than most laboratory vcacuums.

M27's shape

Ionised hydrogen (H II, coloured red in the image on the previous page) dominates the brightest portions of M27. It's been ejected outward to form the brightest segments of the northern and southern arcs and a diagonal line of nebulosity that seems to run through its centre. Doubly ionised oxygen (O III, green in the image) dominates in the interior and helps complete the familiar dumbbell. The faint extensions that close M27's oval also consist mostly of O III. Thanks to the central white dwarf star blasting out intense ultraviolet light, all this glowing molecular gas is about 10 times hotter than normal diffuse interstellar gas.

The hydrogen is from the first phase of the red giant's mass loss, while the oxygen is from a second episode. The oxygen was dredged from the inner layers of the quickly contracting star by the final bursts of nuclear fusion, along with other elements like sulphur and nitrogen.

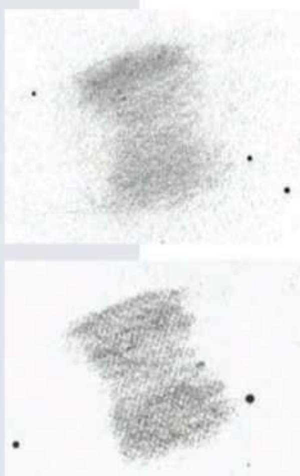
A delightful surprise is the fundamental nature of the Dumbbell's three-dimensional shape. Studies have shown that M27 and M57, the Ring Nebula, probably have much the same intrinsic structure, and we see them as so dissimilar because our viewing angle of the two objects is different by roughly 90 degrees. The Dumbbell is presented essentially broadside from our perspective, while the Ring Nebula is orientated so we're looking straight down one end. If the viewing angles were reversed, we may well have given M57 the Dumbbell nickname and M27 would be called the Ring Nebula.

Dumbbell or rounded rectangle?

My earliest recorded observation of M27 is from June 1974 with my homemade 20-cm f/4 Newtonian. I'd observed it several times before with the 20-cm and my first telescope, a beautiful Tasco 75-mm f/15 achromatic refractor, but I had just begun recording my deep sky observations that June.

My first sketch (here at left) shows the familiar dumbbell, but three nights later my second sketch shows a more rectangular shape, with an ever so slightly pinched waist and rounded ends.

That got me wondering if sky transparency and darkness were responsible for the



◀ **EARLY SKETCHES** My first sketch of M27 is at top, and my second sketch, made three nights later, is on the bottom. In June 1974 I used my 20-cm f/4 Newtonian to make these sketches that inadvertently showed how the apparent dumbbell shape changes depending on sky conditions.

HOWARD BANICH (4)

PLANETARY NEBULA:
A misleading and unfortunate name

These subtle shells have nothing to do with planets and everything to do with the death throes of Sun-like stars. The misnomer originated with Charles Messier's description of M57 and was later reinforced by both William and John Herschel. Some of these nebulae really did look like ghostly versions of Jupiter or Uranus through their telescopes — small, round and evenly illuminated. So the term 'planetary nebula' made sense from that standpoint. Even so, many of them, like M27, don't resemble planets at all.

We now know planetary nebulae are the glowing remains of a red giant star that were expelled by instabilities created inside the star as its fusion reactions sputtered to a halt. During this process, the red giant contracts into a tiny white dwarf star.

Once the white dwarf hits a temperature of 25,000 K, which is hot enough to generate copious amounts of intense ultraviolet light, the nebulous remains from the end of the red giant phase are photoionised, causing them to glow. Until this temperature is reached, the central star merely illuminates this material, and the nebula is considered a protoplanetary nebula.

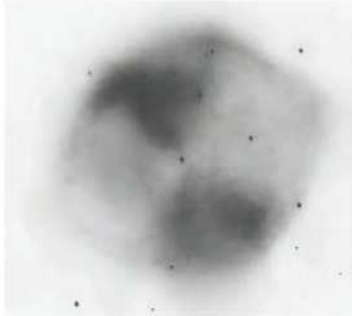
Once the star shrinks down to a white dwarf, it can no longer sustain nuclear fusion and instead shines by the residual, but nevertheless considerable, heat generated by its intense contraction.

Based on this knowledge, a more accurate name for this class of nebulous object might be along the lines of 'white dwarf nebula'. On the other hand, 'planetary nebula' isn't the only archaic and misleading name still in common use, so it seems destined to remain part of astronomy's vocabulary.

difference, so I next compared my deep M27 sketch made at a star party to a recent sketch made from my light-polluted driveway, both using my 0.7-metre scope. Sure enough, the pinched waist is more pronounced in the sketch from home.

Of course, the apparent shapes of all deep sky objects are greatly influenced by the darkness and transparency of the night sky, but what's notable in M27's case is that the trademark dumbbell shape is more obvious under a moderately light-polluted sky.

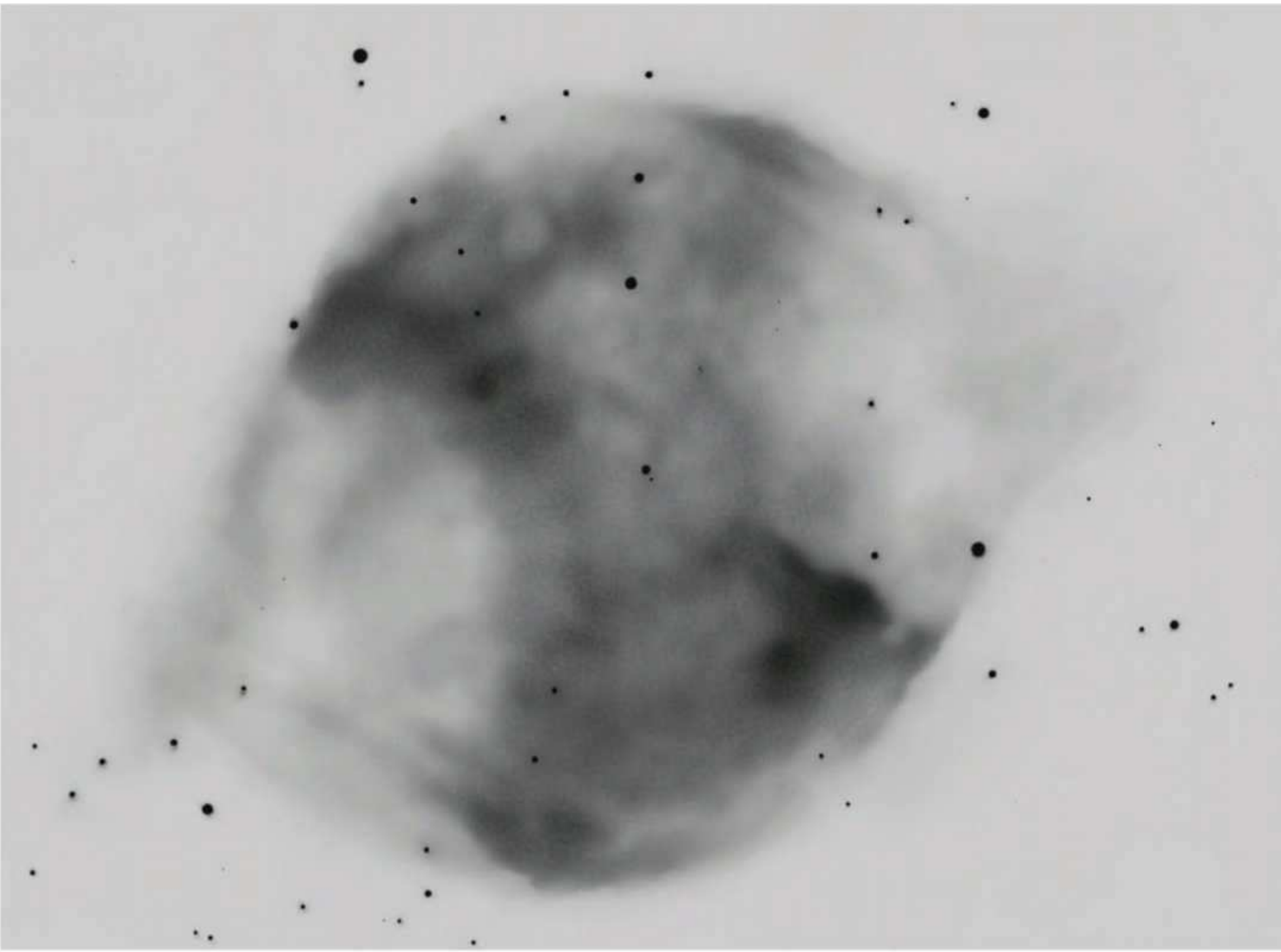
Then again, under a dark sky with my 0.7-metre scope I see more than just the dumbbell shape. The rounded rectangle becomes just as obvious as does the complete oval noted by Messier, and together they give M27 its robust and distinctive character. Each of these main shapes includes details of varying subtlety and is worthwhile exploring one by one.



◀ **PINCHED WAIST** A 0.7-metre sketch of M27 as seen from my driveway — note how pinched the waist area appears compared to my larger, deeper sketch (below).

Bright arcs

The brightest and most sharply defined parts of the Dumbbell are the two opposing arcs that make up the north and south ends of the dumbbell shape. These H II arcs are unevenly bright and are two of the most detailed areas to study at higher magnification, particularly where they meet a lumpy line of uneven nebulosity that runs diagonally through the centre of the Dumbbell. Especially interesting are the subtle striations in both arcs.



▲ **DETAILS EMERGE** My deep sketch (enhanced contrast) of the Dumbbell Nebula made with my 0.7-metre f/4 Newtonian shows the features described in the article. Note how the eastern and western extensions of the faint wings that complete the oval shape of M27 push out into the outer halo. The striations in the northern and southern arcs are prominent. I used magnifications from 155× to 408× under the dark, transparent skies of the Oregon Star Party over three nights. Nearly five hours of observing time went into this sketch.

Line of lumpy nebulosity

A softly glowing, uneven line of nebulous lumps runs northeast to southwest across M27, seemingly through its centre. This defines one side of the internal dumbbell shape. My deep sketch (previous page) shows this feature well, and on the best nights it forms one of the more obvious and detailed internal portions of the Dumbbell. It's also composed of H II and appears red in colour images. The brightest area makes up the southwest end, but the slightly less detailed northeast end is nearly as bright. Although my brain wants to make a connection right through the central star, I only see these brighter ends.

The opposing sides of the central dumbbell shape are less obvious and are made up of the brightest areas of the central O III nebulosity, which appears as green in the European Southern Observatory (ESO) image on the opening pages, or various shades of turquoise in other images of M27. Depending on observing conditions, this somewhat fainter and softly contoured interior nebulosity contributes to the apparent dumbbell/rectangle shape ambiguity.

Nebula filters help boost the contrast of these features. An Ultra High Contrast or O III filter brings out the fainter parts of the Dumbbell, especially in my moderately light-polluted home sky. But filters block the fainter field stars, so I find the unfiltered view more aesthetically pleasing under a dark sky. Your preference may be different, though, so try all your nebula filters and see for yourself.

The oval

Although faint, the O III wings that complete M27's oval shape have about the same visibility as the interior nebulosity and are bright enough that they're visible on a good night under suburban skies. That's because they have more contrast with the background sky than the interior nebulosity has with itself.

Considering that Messier saw the Dumbbell's overall oval shape through his 15-cm Gregorian telescope from a rooftop in smoky 1764 Paris, one night before a full Moon no less, your chances of seeing the entire oval are quite good. Try different magnifications and filters to see which gives the best view. And as a tribute to monsieur Messier, have a look the next time the nearly full Moon is in the sky, too.

Outer halo

The exceedingly faint outer halo of M27 is made of singly ionised hydrogen. It was expelled from the central star while it was ending its life as a red giant, representing the first stage of M27's planetary nebula formation. The H II halo is difficult to see not only because it's faint, but because M27 is so bright. Your best chance of detecting it is to keep the Dumbbell just outside your eyepiece field of view while looking for a nearly imperceptible glow. I've seen only the brightest, inner parts of the halo.

Central star

The white dwarf central star was an easy catch with my old 31.7-cm, and on nights with steady seeing a faint star (which is not the physical companion) can be seen just to its southwest. The white dwarf glows at magnitude 12.9 and is much easier to see than the central star of the Ring Nebula, so it's worth the small effort to observe simply because of its current status as the largest-diameter white dwarf.

Even though it's the largest white dwarf found so far, it's still rather tiny as stars go, at only 5.5% the radius of our Sun. On the other hand, its mass is a little over half that of our Sun, which is right in the middle of the typical mass range for white dwarfs. This combination of small radius and relatively high mass explains its extreme density. Quite a contrast to the thinner-than-an-Earthly-laboratory-vacuum of M27's nebula.

BONUS OBJECT: NSV 24959, the Goldilocks Variable star

Amateur astronomer Leos Ondra discovered a variable star, NSV 24959, within the nebulous borders of M27 in 1991. Because it's located farther away than M27, we view the Goldilocks Variable through the nebulosity.

NSV 24959 has a magnitude range of 15.2 to 17.1 and is apparently a Mira-type variable with a period of approximately 213 days. And much like the variable stars of Messier 5, the NSV 24959 variable is another reason to check in on the Dumbbell Nebula more often.

I haven't looked for this star yet, and it doesn't show up in any of my sketches by accident. A bit unlucky perhaps, but I'll certainly be keeping a careful eye out for it from now on.

For more information, see: **messier.seds.org/xtra/leos/gl.html**

▲ **DUMBBELL, HOURGLASS, APPLE CORE** And finally we get to the inverted version of my original sketch, giving a better sense of the eyepiece view through my 0.7-metre scope from a dark site. There are too many field stars to plot, but imagine about five times more than you see here and you'll get the idea of what a beautiful scene this is through a large telescope, and how they contribute to the 3D effect. Next time you observe this "most extraordinary object" decide for yourself what shape you see.

▶ **NESTED NEBULOSITIES** In addition to the brighter, inner nebulosity, M27 also displays a fainter, more extended nebula. Can you see it?

SKETCH: HOWARD BANICH; NEBULOSITY: MASIL IMAGING TEAM

Colour?

I've only seen the Dumbbell as various shades of grey through the eyepiece. But a few people have reported a greenish hue at very low magnifications, so give it a shot with your lowest-power eyepiece. Look directly at M27 to give yourself the best chance of seeing colour.

A 3D illusion

Wonderfully, the Dumbbell Nebula can sometimes seem to float in 3-dimensional space. This is an illusion, of course, but it can be a compelling sight through the eyepiece nonetheless. I see this effect best without a nebula filter, because the more field stars are visible, the more pronounced the false 3D. Sometimes boosting the magnification helps enhance this impression. And when the illusory 3D effect is strong, it's fun to spin M27 in my imagination and visualise its head-on ring shape.

Taking all this together, on a good night at a dark site the Dumbbell is stunning in my 28-inch scope, and it barely matters what magnification is used. I like it best when it fills about half the field of view, though — a bright, subtly lumpy, and softly glowing dumbbell-rectangle-oval, with its parent white dwarf star at its centre, all floating within a beautiful star field. A most extraordinary object indeed.

■ Contributing Editor **HOWARD BANICH** recently moved to much darker (but still light-polluted) skies. Reach him at **hbanich@gmail.com**.

◀ *Observatory* is an astronomical-image management program for Mac computers running OS X 10.11 or later, with a 64-bit processor.

Observatory 1.1.1
By Code Obsession

US price: $79.99

codeobsession.com

What We Like:
Finder Previews

Online database searches

Overlays for plate-solved images

What We Don't Like:
Interface not always intuitive

Plate solving was tricky

Extraneous features

Managing images with *Observatory*

This program for Mac computers helps you to organise your image data, and more.

FOR SOME, astrophotography is a hobby, a pastime that keeps us busy and out of trouble. For others, it's a passion, maybe even an all-consuming passion. The latter, among whom I include myself, tend to accumulate a lot of data. Years of imaging every clear night will generate a lot of FITS files (the standard image file format for astronomical images). Hard-drive storage is cheap these days, so it's not unreasonable that some seasoned astrophotographers may have hundreds of gigabytes or even terabytes of astronomical data amassed over the years.

How on earth do you keep track of it all, or find anything? For those who think hierarchically, there are folders upon folders based on objects or regions of the sky. Or perhaps you organise by camera/optic, or maybe just by date-based folders. For 'normal' photographers there are myriad tools for organising photo shoots or projects. My smartphone can show me all the photos I've ever taken with dogs in them, and I never even tagged any of them with 'dog'. We live in the future. None of these tools, however, would know what to do with FITS files, much less try and create a system whereby they can be searched easily. But now there is finally such a tool, and it's called *Observatory*.

With so much astronomical software being only available for Windows, it's nice to see a high-quality tool available for the Mac. Since I prefer to use a Mac on a day-to-day basis myself, I was especially keen to see what *Observatory* had to offer.

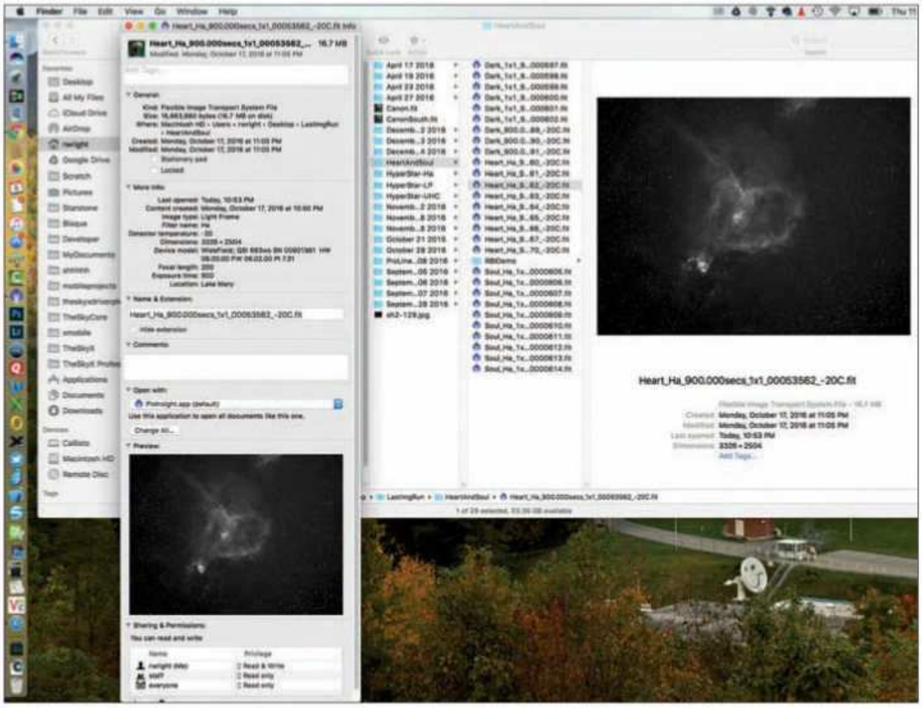
Shell extensions

The most exciting two features of the software to me actually aren't part of the main application at all. Simply installing the program extends the Mac user environment by adding image preview support in *Finder*, and *Spotlight* support for FITS headers.

Preview support is fantastic. When navigating your files with the Mac's *Finder*, a nice auto-stretch is applied to your images, and they can be previewed just like you'd expect any image format to be, such as JPEG or TIFF. When you install *Observatory*, this support includes both the FITS format, which is standard with most astro-imaging software, and the *PixInsight* native format XSIF, as well as the SBIG native formats for *CCDOPS* users. It's also amazingly fast, even for large image files.

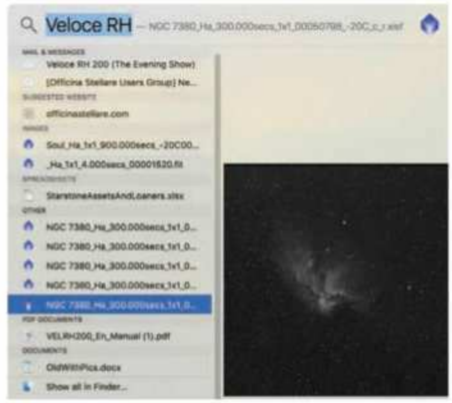
In addition to an image preview, 'Get Info' will display some of the most pertinent information from the FITS header, such as image type, filter name, exposure, etc. How many times have you had to open a FITS file just to inspect

ALL PHOTOS BY THE AUTHOR

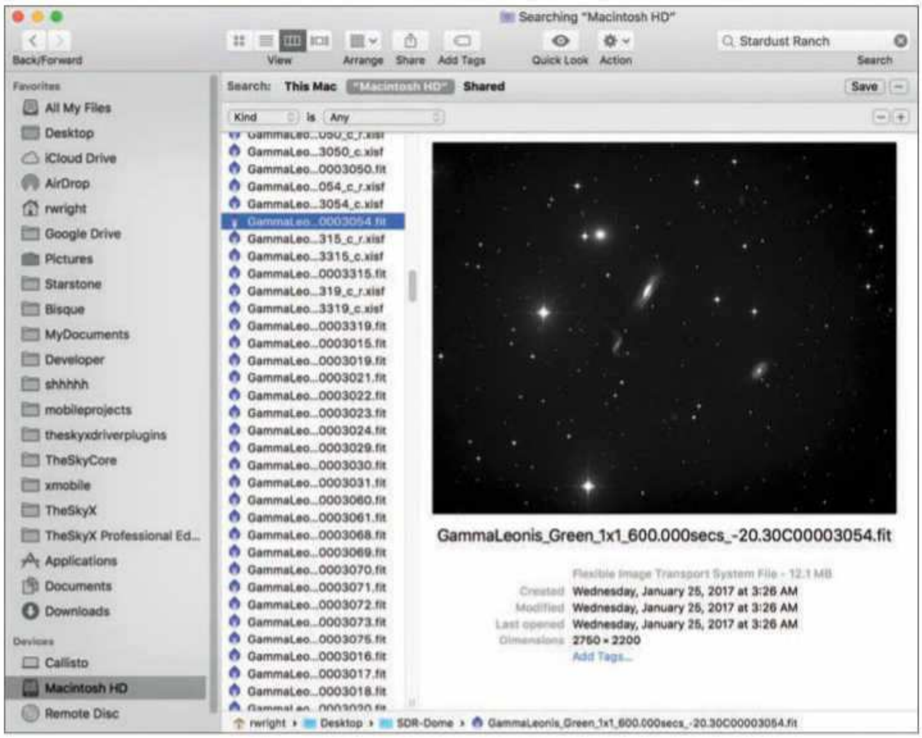


◀ *Observatory* adds functionality to your Mac. After installation, your desktop's Finder will display a preview of FITS images as it does for any other common image type. You can also access useful FITS metadata via 'Get Info'.

▼ The program also enables the MacOS *Spotlight* feature to locate FITS files based on keywords in the FITS header. For example, you can search for all images taken with a specific telescope or camera.



▶ Searching your hard drive for a specific location will now not only turn up documents with that keyword, but also FITS files with that keyword in the header.



the header for some of these items?

While this is quite useful, even more amazing is that *Spotlight* can now extend its search to the FITS headers in the images on your hard drive. This includes all the FITS files on your system, not just the ones managed by *Observatory*! Be advised this doesn't happen instantly; it takes some time (potentially days) for *Spotlight* to catalogue all your images in the background.

Spotlight is one of my favorite features of the Mac to begin with. If I can remember just a scrap of information about some document or email, *Spotlight* can find it for me. It will locate almost instantly Word documents, emails, and even a website I've visited from my browser history. It's my habit to set up the *TheSkyX*'s camera control so that my FITS images are tagged in the header with not just the essential camera and filter settings, but also my location and the optic and camera I used. Do I want to find all the images I shot with an Officina Stellare RH-200 using a Finger lakes Instrumentation ML16200 camera, or maybe just images taken at a specific star party? It's no problem!

All FITS keywords aren't stored, but many of the more useful ones are. For example, ORIGIN is indexed, so I can almost instantly locate all files taken at my observatory.

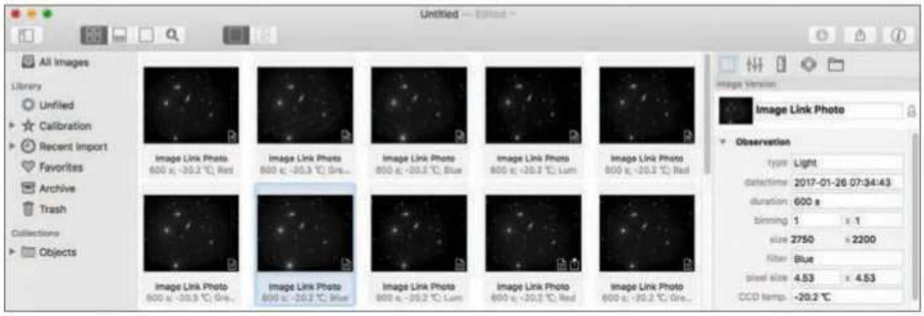
The library

The core purpose of *Observatory* is to serve as an organised library of your FITS archives. Somewhat like the application *Photos* on the Mac, you can preview all the images in your collection and organise them by albums based on object types. When you first start *Observatory* it will ask you if you want to start importing images or add a source folder.

To get started, you have to add a source folder and then import the images into it. The rationale for this two-step process at first eluded me.

The library file you can save here does not contain all the images, but only the metadata for where the images are. I could, for example, add other images to this collection, say from other imaging runs or of the same object using different telescopes and cameras. I could also add reference images here from one of a number of online image archives.

Once you've set up a folder full of FITS files, *Observatory* will apply a screen stretch (which does not alter the actual files) and display them as thumbnails. Double-clicking an image or changing the view mode will display an 'editor' for more detailed image inspection. Moving the mouse around over the image displays information such as the background counts, as well as the centroid and FWHM values for stars in the field.



▲ Much like other photo organisers, *Observatory* presents all your astronomical images as thumbnails. Because FIT files are linear and dark before post-processing, an auto-stretch is automatically applied to the preview, allowing you enough information to recognise the field.

Observatory also features 'Smart Folders' and will use object names and metadata to try to categorise your images to things like dark or emission nebula, or galaxies. I found this feature to be mostly hit or miss (not quite as accurate as my iPhone's 'dog' filter, but give it time), so I prefer to assign objects to the smart folders myself.

The Virtual Observatory

Another major feature of *Observatory* lets users add images from a number of online sources. Searching with the Virtual Observatory feature will teach you a great deal about the professional community and the kinds of data being produced by the world's astronomical institutions for research. Some of it, I should stress, is very useful for imagers looking for interesting source data. All of it is of course useful or interesting for analysis if your imaging goals are more science-related, though a fast internet connection is recommended. Searching is easy enough — type in the name (common or astronomical) or the coordinates of your desired target and off it goes to search any of the 11 available repositories you have selected.

A browser window lists the images found and other useful information, including the date the image was acquired, instruments used, coordinates, and image scale. You can scroll down through the list, and many of the images will have previews available that are displayed in the lower left of the window. Clicking the small preview will bring up a larger version of the image, and you can also transfer the image to *Preview* (the Mac default image viewing program), and of course import it into your own library.

Wait, are you serious? Is that a 14,400 × 10,800 pixel Hubble image at a scale of 0.05 arcseconds per pixel?! A little Curves in *Photoshop* and look Ma, I can process Hubble data too! In fact, this is probably the easiest way I've

▲ Double-clicking any thumbnail in *Observatory* opens a larger preview and displays additional image details from the file's metadata, such as FITS headers when selecting FITS files.

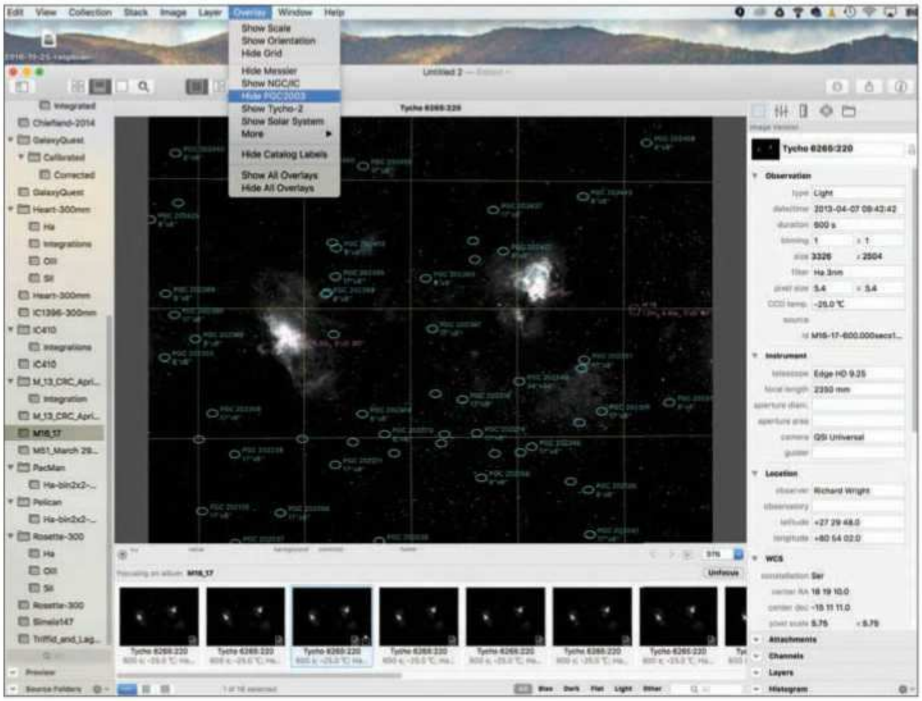
come across to find raw Hubble data in a usable form for us mere mortals.

Matching images

Observatory calls plate solving (providing an astrometric solution) 'Matching' the image. Honestly, I was only able to make this work once, even after adding the optional 9-gigabyte USNO UCAC4 dataset. There are a number of hints, and one of the prerequisites is knowing the RA/Dec of the field for a starting point (which can automatically be extracted from the FITS header). Fortunately, whether you use *Image Link*, *PinPoint* or Astrometry.net to plate solve, the embedded WCS (World Coordinate System) stored in the FITS headers is recognised by *Observatory*, so there are a number of other readily available ways to achieve this goal.

Having an image 'matched' enables another of my favourite features: overlays. There are a number of nice overlays available — Messier objects, PGC galaxies, Tycho-2 star designations, solar system objects, and RA/Dec Grid, an orientation arrow, and image scale.

The overlays, along with some information about the image including your own added notes, are displayed when you export the image to a PDF, which I thought was another nice and time-saving feature.



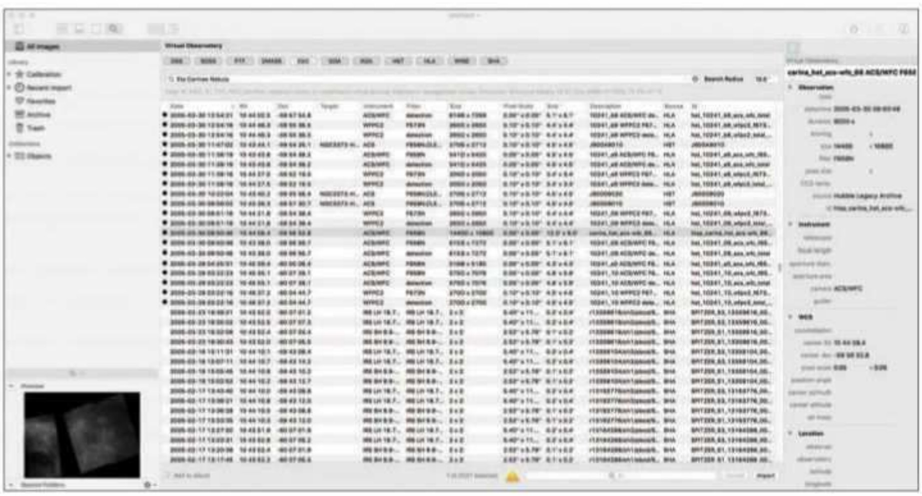
▲ Another of the program's excellent features is its ability to create custom overlays with labels and coordinate information. This works once an image has been plate-solved, or 'matched'.

Conclusion

This is a tremendous set of features, and I would recommend *Observatory* to any Mac-loving astrophotographer based on these alone. *Observatory* also offers the ability to calibrate and stack images in the library. I haven't focused on these features because I honestly question their presence, as I feel they distract from the core strengths of the application. There is so much more to preprocessing than simply calibration and stacking, and I wonder where the author is headed. Better in my opinion to keep *Observatory* focused on managing my collection, and offer another product if the desire is to begin competing in the image-processing market. On the other hand, I must admit getting your subs calibrated, stacked, and ready for additional work is also a compelling factor, and for the price of *Observatory* you do get a decent native calibration and stacking program for MacOS.

While the user interface seemed a bit counter-intuitive to me at times, it is a fantastic image management tool and great for online data mining. My only critique is I'd rather see the author focus more on the core strengths and utilities of the program, and leave processing to other packages, or break this function out into a complementary product.

■ **RICHARD S. WRIGHT, JR.** is a software developer for Software Bisque. He writes a monthly blog on astrophotography at **https://is.gd/3yZO2K**.



▲ Browsing online data sources with Virtual Observatory could not be made much easier than this. You can easily get lost in the treasure trove of online images available from many professional observatories, including raw data from the Hubble Space Telescope.

Idiosyncratic but authoritative

Binoculars: Fallacy & Fact

Binoculars: Fallacy & Fact isn't like other binocular books. It seems to have been directly downloaded from the brain of the author, William J. 'Bill' Cook, Chief Opticalman, US Navy (retired). It's idiosyncratic and informal, but also authoritative on many technical aspects of binoculars, and indispensable in describing techniques that aren't otherwise in print.

The book is self-published, and it shows. Physically it's fine, with an attractive soft cover, good paper and print quality, and over 100 black-and-white photos and diagrams. The self-publication becomes more evident in the organisation and writing.

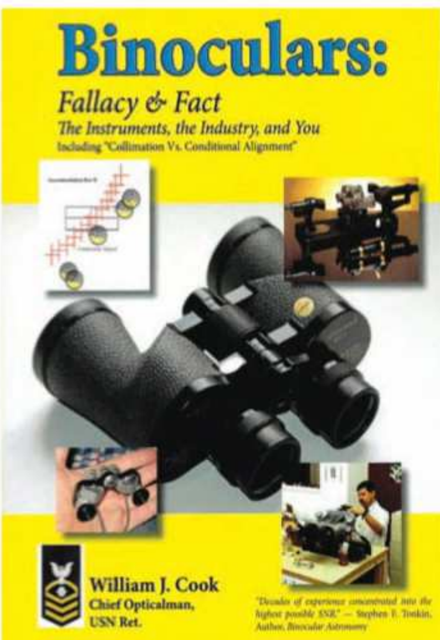
The book is structured as a series of 47 short chapters or 'vignettes'. The first 23 vignettes are a broad and deep treatment of how binoculars are designed, built, sold and serviced. The vignettes on prism types, optical coatings, waterproofing and cleaning optics are particularly good. Vignettes 24–26 relate the history and mythology of optics made in the United States, Germany and Japan, and vignettes 27–29 address magazines, the internet and advertising as sources of (mis) information about binoculars. The heart of the book is Vignette 30, on collimation versus conditional alignment. The final 17 vignettes cover a broad spectrum of topics, from Japanese optical manufacturers' codes to handholding large binoculars. The glossary at the end of the book is compact and helpful.

In addition to the technical content, which is clearly presented, interesting and useful, the book is full of digressions. Some of these illustrate common misunderstandings, but others are essentially a catalogue of slights the author has endured from publishers, people on internet forums and recalcitrant customers. At points the book doesn't seem clearly thought through. For example, the assessment and cleaning of anti-reflection coatings are extensively discussed on pages 33–38, but the different types of coatings aren't defined until page 145. One figure caption directs the reader to trace red and green light paths in a black-and-white diagram. The table of contents includes no page numbers, and the last two listings don't align with their topics. Finally, the book has quite a few typos.

In fairness, the author tells you about most of these problems directly, explaining in the foreword and epilogue why he made the choices he did here. Bill Cook has, for better or worse, produced precisely the book he set out to write.

Should you get this book? If you're interested in the real guts of binoculars, how prisms, focusers, coatings and the rest work together, don't hesitate. Even if you're a more casual binocular user, you'll find much of value here. I found myself flagging pages that described the most handy techniques, such as the step-by-step procedures for testing off-axis sharpness or quickly assessing anti-reflection coatings, and a couple of lines from the book made it into my file of favourite quotes. The conversational tone worked for me, despite the quirks.

The book is at its best when Cook is at his most technical, delving into the inner workings of binoculars with clarity, and at its worst when he's at his most self-indulgent, polishing old grudges. I wish the book had been more tightly edited, in part because I think it would reach a wider audience, and in part because it is so useful that I can't afford to not have a copy. That probably tells you all you need to know.



William J. Cook
CreateSpace Independent Publishing Platform, 2017
196 pages, ISBN 978-1548932190
US$24.95, paperback.

> If you're interested in the real guts of binoculars, how prisms, focusers, coatings, and the rest work together, don't hesitate to get this book. Even if you're a more casual binocular user, you'll find much of value here.

■ Contributing Editor **MATT WEDEL** wonders why there are so many books about telescopes but so few about binoculars.

An optimised Dob

Wringing the last gram of performance out of a scope.

IN HIS YOUTH, Steve Hosein spent many evenings looking up at the stars. In later years, he saw the sky from a Moroccan desert, the Peruvian Andes and at sea near Tasmania. He was used to crisp stars even before he began using a telescope, so it's no surprise that high contrast and quality were important when he began to build his own scope.

But other than using excellent optics, what can a person do to improve the view through a standard Dobsonian? Turns out, there's quite a bit.

Cooling the primary mirror is the first thing. A mirror that's warmer than the air around it will warp, and air currents will form in the light path, leading to even more distortion. In an enclosed tube, primary mirrors spend most of the night cooling down, seldom achieving ambient temperature until early morning. Some use fans to blow air against the back of the mirror, and sometimes fans in front to sweep away the boundary layer, but there's still no place for the warm air to go except up the tube, causing turbulence the entire way.

So Steve drilled a bunch of 45-mm-diameter holes in the tube, two in front of the primary, one aligned with the front face and one behind. The holes enable air to circulate around the primary and exit the tube without moving forward. To prevent light from shining in, he added a lightweight shield made from thin plastic that wraps around the holes after the mirror has cooled.

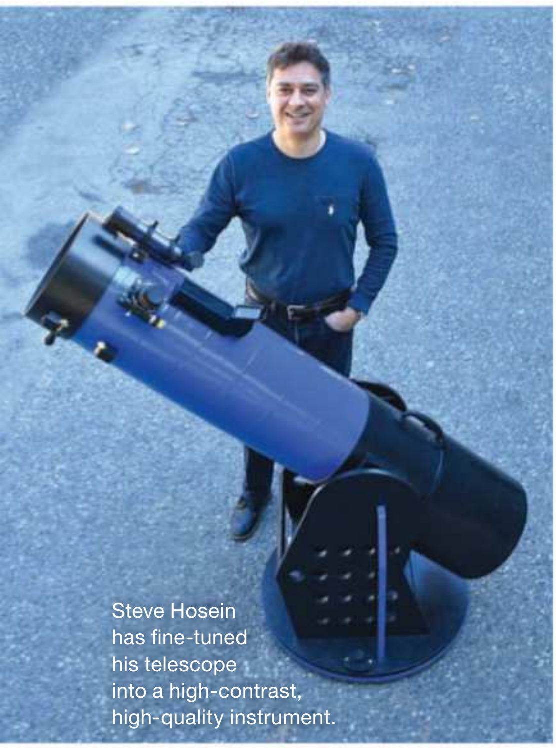
There's still plenty of light entering the front of the tube, though. Refractors use baffles along the length of the tube to minimise this, but reflectors can't do that because any baffles below the secondary can reflect light back up into the eyepiece. However, Steve realised that the portion of the tube from the secondary upward could still be baffled, so he built a set of closely spaced baffles that do just that. He used sheet aluminium cut with a Dremel tool and epoxied 10 rings together into a framework he could slide into the tube. Then he painted the baffles and the inside of the tube with an ultra-flat black paint called 'scenic black' formulated for the film industry.

The traditional four-vaned secondary spider is another source of stray light, in the form of diffraction. Reasoning that fewer, thinner vanes would help, Steve made a three-vane spider using 0.2-mm-diameter guitar strings. The attachment points are carefully placed one right over the other so their cross section from the primary mirror's perspective is minimal. They're held with guitar tuning pegs on the outside of the tube, which enables Steve to collimate the secondary by tightening and loosening the wires.

After all this, how does the scope behave? Steve reports that when observing from a 6-story rooftop in a highly light-polluted city location, with the scope aimed at Jupiter over a bright skylight only metres away, "I was amazed at how well the scope performed."

For more information, visit Steve's website at **https://is.gd/dobsonian**.

■ **JERRY OLTION** has drilled countless holes in telescope tubes, most of them being improvements.



Steve Hosein has fine-tuned his telescope into a high-contrast, high-quality instrument.

▲ Ventilation holes allow air to flow around the primary mirror, cooling it quickly. A shroud covers the holes to reduce stray light.

▲ Baffles at the front reduce stray light, while the wire secondary vanes minimise diffraction.

GARTH TAYLOR (3)

◀ David J. W. Moriarty has been awarded the 2018 Berenice and Arthur Page Medal.

A worthy winner

Queensland's David Moriarty receives prestigious scientific recognition.

The recipient of the 2018 Berenice and Arthur Page Medal was announced at the recent National Australian Convention of Amateur Astronomers. David J. W. Moriarty is an Honorary Senior Fellow with the Astrophysics Group at The University of Queensland, and member of the Astronomical Association of Queensland and Variable Stars South.

Presenting the award, professional astronomer Michael Brown said that "Tonight we recognise an impressive body of work by an Australian amateur astronomer, a long-time member of your community. He has specialised in measuring the light curves, spectra and periods of close binary stars. This has resulted in four publications in the *Journal of the American Association of Variable Star Observers*."

"I've had the pleasure of looking at these papers," Brown said. "The light curves are extremely impressive, with residuals often in the milli-magnitude range. I personally have measured exoplanet transits with amateur equipment, and I know how hard it is to achieve such exquisite photometry."

Using photometry, Moriarty measured the orbital periods of binary stars with new precision, in some instances resulting in major revisions of the published periods. The photometry data has also been used to measure oscillations in these stars.

Via collaborations with University of Queensland astronomers, he has obtained spectroscopy with the Siding Spring 2.3-metre telescope, enabling improved spectral classifications and measurements of the velocity curves for these stars. And his work has formed the basis for several university undergraduate projects.

The Astronomical Society of Australia's Berenice and Arthur Page Medal is awarded usually every two years to the amateur astronomer who has made the most outstanding contribution to science.

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

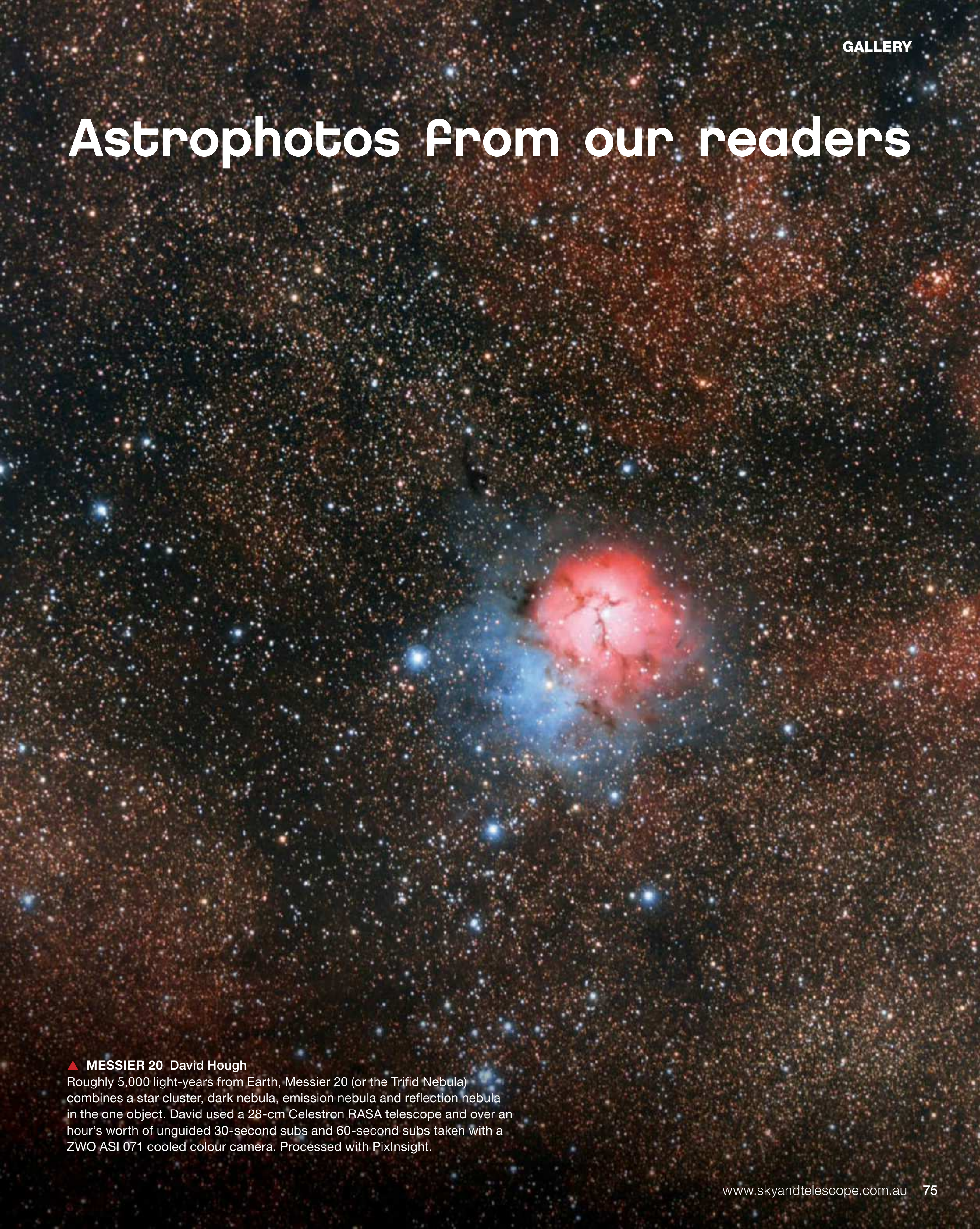
World Space Week
October 4–10
Celebrating the contributions of space science and technology to the betterment of the world.
worldspaceweek.org

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/

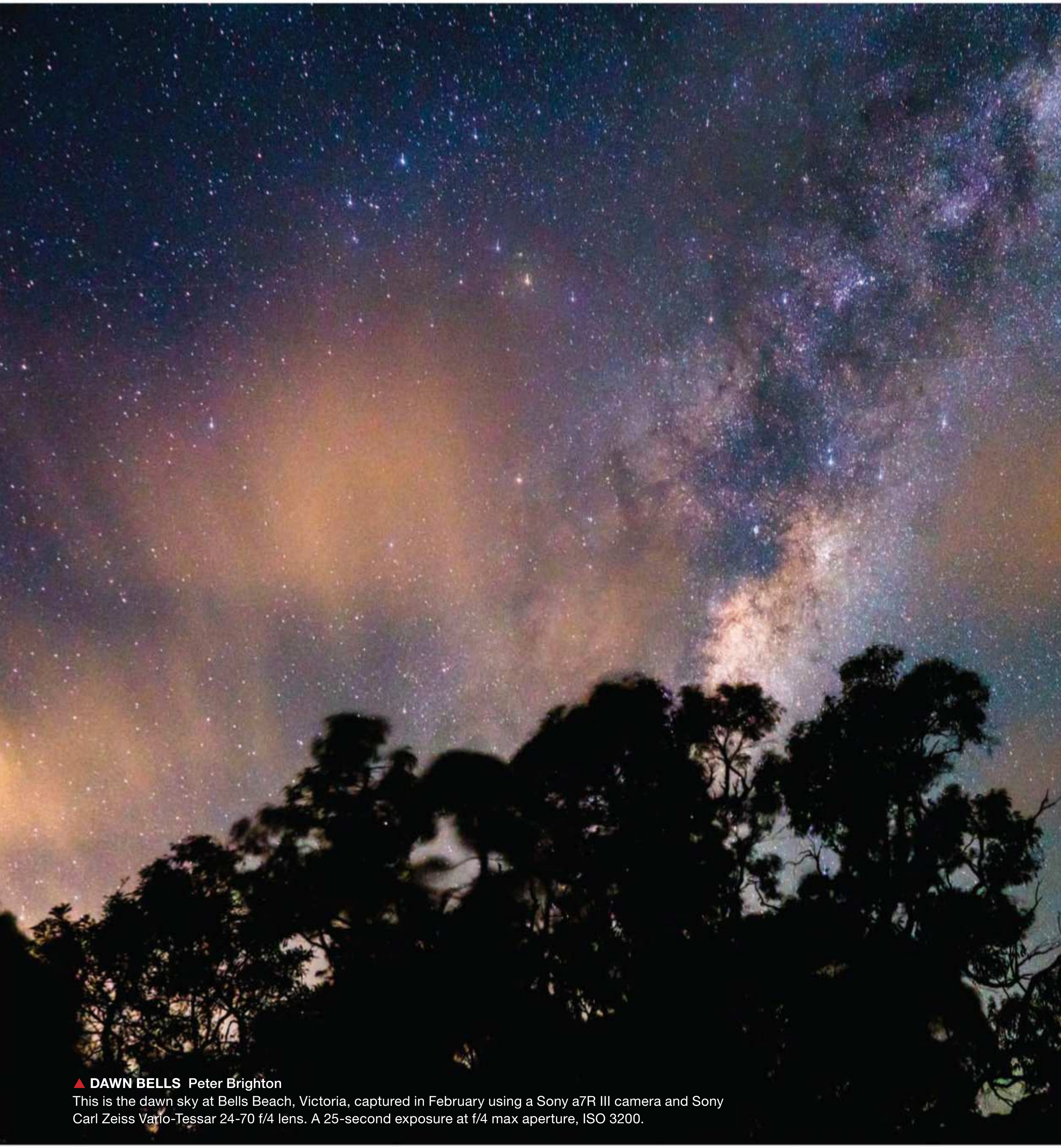
VicSouth 2018
November 2–6
Annual week of astronomy under very dark rural Victorian skies.
vicsouth.info/vicsouth.htm

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

Astrophotos from our readers



▲ **MESSIER 20 David Hough**
Roughly 5,000 light-years from Earth, Messier 20 (or the Trifid Nebula) combines a star cluster, dark nebula, emission nebula and reflection nebula in the one object. David used a 28-cm Celestron RASA telescope and over an hour's worth of unguided 30-second subs and 60-second subs taken with a ZWO ASI 071 cooled colour camera. Processed with PixInsight.



▲ **DAWN BELLS** **Peter Brighton**
This is the dawn sky at Bells Beach, Victoria, captured in February using a Sony a7R III camera and Sony Carl Zeiss Vario-Tessar 24-70 f/4 lens. A 25-second exposure at f/4 max aperture, ISO 3200.

▲ **SCULPTOR SPIRAL** Rodney Watters
NGC 300 is about 600 million light-years away, but that distance was no match for Rodney with his Takahashi TSA-120 OTA at f/5.6 (.75x focal reducer), QSI 683 WS8 camera and Astronomik LRGB (10-minute subs) and Ha (30-minute subs) filters. Total exposure time 26.5 hours.

▼ **PISMIS 4** Graham Meyer
Pismis 4 is an open star cluster in Vela, captured here by Graham using a William Optics FLT 132 scope, cooled QHY9 mono camera and LRGB filters. Total exposure time was 306 minutes.

▲ **STROMLO STARS** **Keat Teoh**
This is the view from the road leading up to Mt Stromlo Observatory outside Canberra. Keat used a Nikon D610 camera with AF-S Nikon 20mm f/1.8 lens. He stacked 57, 20-second exposures taken at f/1.8 and ISO 320.

▲ **CAT'S PAW** Matt Hughes
The Cat's Paw Nebula (or NGC 6334 or Gum 64), is about 5,500 light-years away in Scorpius. Matt used a Takahashi FSQ-106EDX III telescope, Atik 490EX mono camera and OIII, SII and Ha filters. Total exposure was 14 hours.

◀ **CLOUDY ISLAND**
Zac Veron
The Magellanic Clouds float high above Lord Howe Island in this photo by Zac, for which he used a Canon EOS 1D X Mark II camera and 20 seconds exposure at ISO 8000.

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 digital subscription or renewal to the magazine.

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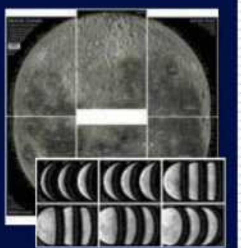

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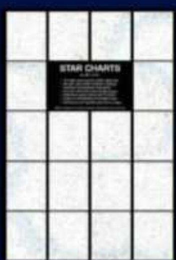
Star charts



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Next Issue ON SALE September 6

The Moon mystery

A planet-scale smash created Earth's satellite. But how did it manage to make a moon so like Earth?

The astronomer's astronomer

John Bolton is largely forgotten, yet he founded a new type of astronomy and probably should have won a Nobel Prize.

Shadow science

As the Moon's shadow sped over Earth last year, researchers intensely studied every aspect of the dramatic event.

Square galaxies

Grab your scope and spend some time hunting a bunch of faint fuzzies in the Great Square of Pegasus.

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Armchair astronaut

Always wanted to see Earth from space? Now you can, anytime, with a little help from NASA TV.

THE GREATEST SHOW on Earth is . . . the Earth.

It rolls by from about 400 km up, 24/7/365, thanks to four cameras NASA added to the International Space Station in 2014. Here is the vast Pacific Ocean, deep blue beneath scattered, puffy clouds. There are the Himalayas — which one is Everest? — and, 45 minutes later, the tangled coils of the Amazon.

You can soar over snow-white Canada in January, then return in June to see it brown and green with countless sparkling lakes. The continents and seas loom up at a steady pace as the ISS hurtles along at about 28,000 km/hour. Every 90 minutes there's a sunset, with the horizon dimming and the clouds turning purple, then black. In another 45 there's a sunrise, the illuminated cloudtops gleaming impossibly bright.

Thanks to the ISS's orbit, the cameras eventually give us views of virtually every part of our planet between the poles. Log on and guess where you are: Is that the Indian Ocean down there? Look, here comes China! There's desolation: Is it the Sahara — or perhaps the Aussie outback? Surely that broad river is the Mississippi?

NASA claims it mounted those cameras on the station's Columbus module to test how well they'd stand up to the harsh conditions of space. Maybe so, but the real grip of this free spectacle, accessible on computers and smartphones anywhere anytime, arises from the romance of spaceflight that has enthralled us for 57 years now, ever since those first puny rockets lifted men named Gagarin and Shepard toward the stars. For baby boomers in particular, the romance never quite died, even as we matured and began to see spaceflight as routine.

I could never have imagined as I sat in my classroom on May 5, 1961, for Alan Shepard's brief lob shot, that today approaching retirement I can effectively hop aboard the ISS and cruise around the globe, admiring it in living colour. It was unimaginable even in the days of Mercury and Gemini and Apollo. The film from Ed White's Gemini spacewalk gave us a glimpse, as did video from later Shuttle missions. But the really dramatic images came back to us from the Voyagers and Cassinis and Junos dispatched without humans to the outer planets, and from the rovers scurrying about on Mars.

As the show unreels we can also silently remember those who died trying to further our exploration of space — the Apollo 1 and Soyuz 11 crews, and those who didn't make it up on *Challenger* or down on *Columbia*. Some of them had already seen that prospect from space, and they were willing to risk all to savor it again.

The ISS turns 20 this year. Some evenings as I read a book I log onto the live camera shot and glance up now and then to see where we are, and in those moments I am a passenger in spirit if not reality, sharing the latest step in our species' grandest adventure.

Check it out on NASA TV at **https://is.gd/ISSnasatv**. It truly is the greatest show on Earth.

■ **MIKE BRAKE** is a journalist who got his first telescope at the age of 10 in 1957.

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