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ON THE COVER

We haven't seen Mars this well for 15 years. Turn to page 36 for our full Red Planet 2018 observing guide.

Australia's space future assured

ALTHOUGH THE AUSTRALIAN GOVERNMENT'S intention to establish a national space agency had been announced a few months ago, it was nonetheless heartening to see the initiative formalised in the 2018 federal budget in May (see page 12). With a fairly sizeable initial allocation of funds (although not as much as many had hoped), the new agency will have the resources it needs to help set a national direction for Australia's space industry and support innovative nascent enterprises and research teams. Australia already has lots of expertise in space science and technology, and a number of very successful small space enterprises. The new agency will help stimulate even more activity and put the nation on the road to assuming its rightful place amongst spacefaring nations.

At the same time, there are big changes happening in professional optical astronomy in Australia (see page 14). The famous Australian Astronomical Observatory (AAO) will see a split between operational activities one the one hand, and headquarters, R&D and other activities on the other. The AAO has been a world leader from the time it opened in 1974, with the 3.9-m AAT and 1.2-m UK Schmidt Telescope punching well above their weight for longer than many would have thought in an era of telescopes twice their size. It's great to see that their future is assured, so that a new generation of astronomers can capitalise on more than 40 years of successful operations.

Jonathan Nally, Editor
editor@skyandtelescope.com.au

AUSTRALIAN SKY & TELESCOPE

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EDITORIAL
EDITOR Jonathan Nally
ART DIRECTOR Lee McLachlan
CONTRIBUTING EDITORS
John Drummond, David Ellyard, Ross Gould, Steve Kerr, Alan Plummer, David Seargent, Con Stoitsis
EMAIL info@skyandtelescope.com.au

ADVERTISING
ADVERTISING MANAGER Jonathan Nally
EMAIL jonathan@skyandtelescope.com.au

SUBSCRIPTION SERVICES
TEL 02 9439 1955
EMAIL subs@paragonmedia.com.au

PARAGON MEDIA PTY LIMITED
ABN 49 097 087 860
TEL 02 9439 1955 FAX 02 9439 1977
Suite 14, Level 2/174 Willoughby Rd, Crows Nest NSW 2065
PO Box 81, St Leonards, NSW 1590

PUBLISHER
Ian Brooks

paragon MEDIA

SKY & TELESCOPE INTERNATIONAL
EDITOR IN CHIEF Peter Tyson
SENIOR EDITORS
Alan M. MacRobert, J. Kelly Beatty
EQUIPMENT EDITOR Sean Walker
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Susan N. Johnson-Roehr
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ILLUSTRATOR Leah Tiscione
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DIGITAL CONTENT STRATEGIST
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This Hubble Space Telescope image of NGC 1052-DF2 shows the blob-shaped galaxy's diffuse nature — it has so few stars and is so sparse that background galaxies are visible through it.

A galaxy without dark matter?

ASTRONOMERS HAVE LONG thought you couldn't have galaxies without dark matter, just as you can't have a cup of coffee without the cup. But the fluffy galaxy NGC 1052-DF2 contradicts this picture. Combining ground- and space-based observations, Pieter van Dokkum (Yale University) and colleagues have found that this diffuse galaxy has 400 times less dark matter compared to other systems of similar mass. In fact, it might not have any dark matter at all.

The peculiar object is part of a group of galaxies 65 million light-years away that's dominated by the beefy elliptical NGC 1052. Astronomers already knew NGC 1052-DF2 existed, but its appearance in images from the team's Dragonfly Telephoto Array puzzled the researchers. Follow-up revealed the galaxy is so sparse that it's see-through.

Ten strangely big and bright globular clusters surround the galaxy. By measuring how quickly they orbit DF2, the astronomers estimated the galaxy's mass, which they found to be surprisingly low — roughly equal to the mass visible as stars, with essentially no dark matter. No other objects in DF2's class of so-called *ultra-diffuse galaxies* show this paucity of dark matter.

It's unclear how the galaxy came to exist. One possibility is that the elliptical had stripped DF2 of its dark matter when it passed too close, causing the remaining stars to 'puff up'. But the Dragonfly team doesn't see signs of disturbance around the galaxy, which it thinks disfavours this scenario. The researchers suggest a few other possible origins for DF2, but nothing fits perfectly.

That the coffee can exist without the cup indicates that the cup and coffee are both real entities, the team concludes. If the presence of dark matter were only an illusion, arising because we're using the wrong theory of gravity, then we'd always see signs of it in galaxies. But if the dark matter can be sometimes there and sometimes absent, then dark matter must exist. This result therefore undermines alternative approaches, including *modified Newtonian dynamics* (MOND), a theory of gravity that does without dark matter by suggesting gravity works slightly differently than in Einstein's framework, the team says.

MOND expert Stacy McGaugh (Case Western Reserve University) isn't so sure. He agrees that MOND predicts that DF2's globulars should move faster than they do. But he's squeamish about tweaking the fraction of dark matter in any given galaxy just to make sense of its stars' motions — that's an inference, not a prediction that can be proved or disproved, he says.

The Dragonfly team continues to look for more galaxies like DF2, and they've found three potentially similar objects for further study. With more than one such galaxy in hand, astronomers might be able to say more about how these galaxies form and what they mean for dark matter.

■ CAMILLE M. CARLISLE

NGC 1052-DF2: P. VAN DOKKUM / R. ABRAHAM / STSCI; 'OUMUAMUA: © WILLIAM K. HARTMANN

Is 'Oumuamua pancake-shaped?

A new, pancake-shaped artist's concept of 'Oumuamua.

A NEW ANALYSIS of 818 telescopic observations suggests that our first known interstellar visitor could have the shape of a flattened disk.

Small-body specialist Michael Belton (Belton Space Exploration Initiatives) and colleagues pooled brightness estimates from nearly a dozen major instruments — including the Hubble Space Telescope — in order to unravel the details of 1I/'Oumuamua's shape and spin.

Belton and co-author Karen Meech (University of Hawai'i) say that 'Oumuamua is tumbling, spinning every 54.48 hours with a pronounced wobble that takes 8.67 hours to complete. However, it's unclear if the object is rotating mainly end-over-end or if the primary spin axis is close to its long axis, like a wobbling, badly thrown football. How it spins determines our understanding of its shape, which Bel-

James Webb Space Telescope delayed until 2020

NASA OFFICIALS HAVE announced that the launch of the James Webb Space Telescope will be delayed until approximately May 2020, slipping more than a year from its previous goal between March and June 2019.

To date, the agency has spent $7.3 billion on Webb's development. If the mission's development costs go over the $8 billion maximum that Congress set in 2011, Congress will need to reauthorise the project. An independent review will nail down the changes in cost and schedule, and NASA will report its assessment to Congress in late June.

NORTHROP GRUMMAN CORPORATION

▲ This 2017 image shows all five tennis-court-size, membranous layers of Webb's sunshield, displayed in Northrop Grumman's clean room in Redondo Beach, California. These will have to fold into the Ariane 5 rocket fairing.

The pieces of Webb are all complete; what's costing time and money is the often unpredictable "integration and testing" phase. NASA officials admit that the initial schedule for this phase was optimistic.

Some of the technical challenges faced were instructive. For example, the complex sunshield was torn during testing, so engineers made changes to its storage and deployment. Preventing damage is crucial, as the shield protects the telescope's sensitivity at near-infrared wavelengths.

There were also avoidable errors: A transducer was incorrectly powered and had to be replaced, resulting in a three-month delay, and an incorrect solvent was run through the propulsion system, damaging valves and seals and necessitating their replacement. To avoid future mistakes, NASA officials outlined plans to monitor contractor Northrop Grumman more closely.

Webb is a top priority within the astronomical community and represents NASA's largest international space science project. Once it launches, the 6.5-metre near-infrared telescope will orbit the Sun at the Lagrangian point L_2, 1.5 million km farther out than Earth. The telescope will peer farther back in cosmic time than Hubble to see the universe's first stars and galaxies. Astronomers will also use Webb to characterise nearby exoplanets.

The delay will have a broad impact on the astronomical community, notes associate administrator Thomas Zurbuchen, both in terms of perception and actual cost. Nevertheless, he insists, he doesn't want the agency to shy away from large, complex projects: "I want us to have ambition." ■ MONICA YOUNG

ton's team concludes could be anything from a cigar to a fat pancake. For the moment, either shape is equally likely.

'Oumuamua's overall spectrum and apparent lack of outgassing imply that it's rocky, which could mean that it was ejected from the inner region of its host solar system. Yet Sean Raymond (University of Bordeaux, France) and others argue that too few asteroidal fragments would be ejected to make it statistically likely for one to reach us, unless it was ejected from a two-star system.

'Oumuamua may keep its secrets, but chances are we'll find another interloper soon: Calculations by Aaron Do (University of Hawai'i) and colleagues suggest that there are likely several of these objects in the inner Solar System at any given time.

■ J. KELLY BEATTY

IN BRIEF

Update on the aurora named STEVE

For years amateur astronomers have seen and photographed a thin, faintly pink- or purple-coloured ribbon that runs east-to-west southward of the northern lights. (To read about the discovery, visit **https://is.gd/aurorasteve**.) Eventually dubbed 'Steve,' neither amateurs nor researchers knew what the phenomenon was. Analysing data from the European Space Agency's Swarm A satellite, which flew directly through a Steve ribbon in 2016, Elizabeth MacDonald (NASA Goddard) and colleagues suggest that the amateurs had spotted the *subauroral ion drift* (SAID), a rapid flow of charged particles through Earth's atmosphere that's associated with brightening aurora. However, scientists had never known of visible emission from SAIDs, and the radiation mechanism remains unclear. In the meantime, the visual phenomenon gets to keep its name: STEVE, short for Strong Thermal Emission Velocity Enhancement.

■ MONICA YOUNG

Tiangong 1's remote re-entry

China's first space station, Tiangong 1 (Chinese for "celestial palace"), re-entered Earth's atmosphere over the South Pacific on April 2 after almost seven years in space. No humans reported witnessing the re-entry, but NASA and the European Space Agency mounted a campaign to remotely monitor the space station in an effort to better model future reentries. The re-entry location was largely unknown beforehand, complicated by the vehicle's uncertain mass: While the media often cited it as 8.5 metric tonnes, that number assumed a tonne of fuel still onboard. Tracking the re-entry impressed upon scientists the sensitivity of predictions to solar activity, the state of Earth's thermosphere and atmospheric drag.

■ DAVID DICKINSON

Milky Way's core is home to lots of black holes

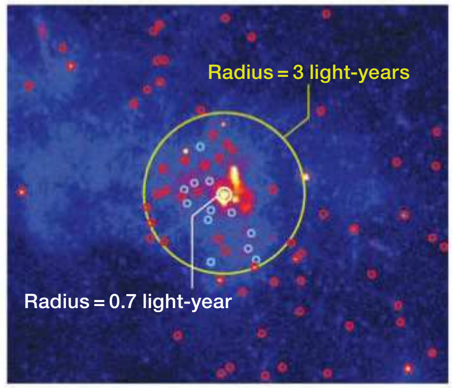
A NEW X-RAY STUDY has uncovered a dozen potential stellar-mass black holes within 3 light-years of the supermassive black hole lurking in our galaxy's core — and these might be just the tip of the proverbial iceberg.

We've long known that a supermassive black hole lurks in the Milky Way's centre. Now, a new study makes the case that up to 10,000 or so stellar-mass black holes could be keeping it company.

Beginning with 16 days' worth of observations that the Chandra X-ray Observatory had collected over the past 12 years, Charles Hailey (Columbia University) and colleagues analysed 26 sources that remain unresolved at X-ray wavelengths and lie within 3 light-years of the supermassive black hole. Typically, most X-ray emitters found near our galaxy's centre are white dwarfs in binary systems, which siphon gas off of their ordinary stellar companions and radiate more of their energy at *lower* X-ray energies. But 12 of the 26 sources the team found are relatively brighter at *higher* X-ray energies. They also appear to be binaries, but with more massive neutron stars or black holes instead of white dwarfs. Hailey and colleagues argue that the sources are more likely to be black holes, as long-term monitoring of the galactic centre should have found all neutron star binaries by now via their outbursts.

If there are a dozen stellar-mass black hole binaries that we can see, then many more isolated (and therefore invisible) black holes might exist in the galactic centre. Exactly how many depends on the binaries' origin. If they formed when the stellar remnants captured old, low-mass stars — instead of beginning life as a pair of stars — then there could be as many as 10,000 black holes in the galaxy's core.

But whether all 12 sources are black holes and how they got there remains uncertain. Hailey and his team acknowledge that as many as half of their X-ray sources could be *rotation-powered millisecond pulsars*: fast-spinning neutrons stars that exhibit



▲ A Chandra X-ray image of the Milky Way's centre is overlaid with circles around unresolved X-ray sources. Red circles indicate white dwarf binaries, while blue circles denote likely black hole binaries.

fewer outbursts. Then there might be several hundred instead of thousands of black holes in the galactic centre. Daryl Haggard (McGill University, Canada), who wasn't involved in this research, notes that future radio studies could distinguish between black holes and neutron stars, which would help pin down the number and origin of massive objects in our galaxy's core.
■ MONICA YOUNG

X-RAY: C. HAILEY ET AL. / *NATURE*; SUPERNOVAE: M. PURSIAINEN / UNIVERSITY OF SOUTHAMPTON AND DES COLLABORATION

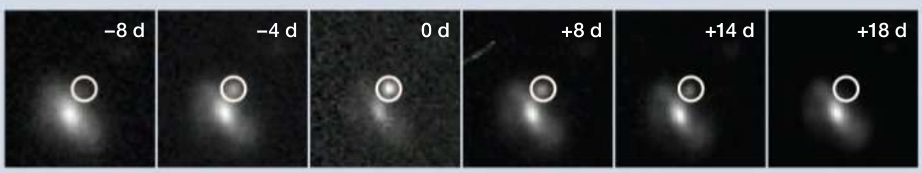
Astronomers catch cache of 'fast supernovae'

THE DARK ENERGY SURVEY'S SUPERNOVA (DES-SN) Program has detected 72 fast and furious explosions, Miika Pursiainen (University of Southampton) announced at the European Week of Astronomy and Space Science 2018 in Liverpool, UK. These *fast-evolving luminous transients* (FELTs) have the energy of a regular supernova explosion, but they brighten and fade within days or weeks rather than months or years.

A few dozen of these 'fast supernovae' were already known, but their origin remained unclear. With DES data in hand, Pursiainen and colleagues conclude that the emission from a typical FELT comes from a hot, expanding shell of material — possibly a dense cocoon around an exploding star. The shell may span anywhere between a few and 100 astronomical units (the average distance between Earth and the Sun), with a temperature between 10,000°C and 30,000°C.

These findings agree with another recent result from NASA's Kepler mission. In 2015 Kepler spotted a FELT known as KSN 2015K, measuring its brightness every 30 minutes over a three-week period. Armin Rest (Space Telescope Science Institute) and colleagues report that KSN 2015K's rise to peak brightness occurred in just 2.2 days, before it faded by a factor of two over 5 days. The richly sampled light curve enabled the team to exclude all but one viable scenario: A giant star had shed a huge amount of gas and dust less than a year before it went supernova. When it ultimately exploded, the star's outer layers slammed into the thick cocoon, turning most of the kinetic energy into heat and light.

Pursiainen and Rest agree that it's unclear whether this cocoon model would apply to all 72 DES-SN supernovae. Future DES observations will doubtless reveal more FELTs, and studying larger numbers will help elucidate their true nature. ■ GOVERT SCHILLING



▲ One of the 72 fast-evolving luminous transients (FELTs) observed by the Dark Energy Survey

Supergiant runaway star

ASTRONOMERS HAVE SPOTTED a rare supergiant star speeding through the Milky Way's neighbouring galaxy, the Small Magellanic Cloud, at 300 km/s. Kathryn Neugent (University of Washington) and colleagues will present the results in an upcoming issue of the *Astronomical Journal*.

The sighting is unique not only because of the star's high speed but also its advanced phase of evolution. The star, J01020100-7122208, appears to be a yellow supergiant, a phase that lasts only 10,000 to 100,000 years before the star balloons into a red supergiant.

"It's unexpected to find a very rare object in a very rare phase," says Warren Brown (Harvard-Smithsonian Center for Astrophysics), who wasn't involved in this study. "The joint probability is unlikely, so the implication is that runaways are quite common."

A runaway star moves significantly faster than other stars from its birthplace. Most known runaway stars are in the Milky Way; this yellow supergiant is only the second known evolved runaway in another galaxy. Neugent and colleagues suggest the star became a runaway when its stellar companion exploded in a supernova, ejecting mass from the system and enabling the star to fly away at high speed.

■ ELIZABETH HOWELL

Integral Shape Filament in Orion Nebula

Star-forming braids in the Orion Nebula

New ALMA observations reveal fibre-like structures within a longer, well-studied filament of dense gas within the Orion Nebula. These fibres will eventually form massive stars.

Back in 2015, Mario Tafalla (National Astronomical Observatory, Spain) and Alvaro Hacar (now at Leiden University, The Netherlands) studied a 30-light-year-long gaseous filament in a region forming low-mass stars. They found that the filament was like a rope made of smaller bundles of 'fibres'. The denser fibres were each typically 1½ light-years long. The seeds of future stars — compact areas that will eventually collapse into stars but haven't yet — can be seen as knots in these braids.

Hacar thought fibres might act as the fundamental building blocks of star formation, with more massive stars requiring more fibres. But it was unclear whether the bundle-of-fibres scenario would apply in denser environments, like the Orion Nebula, where high-mass stars come together. Other teams had suggested that the fibres in such regions would be more massive rather than more numerous.

High-mass stars are rare and typically far away, making their birthplaces difficult to observe. So Hacar and colleagues used the Atacama Large Millimeter/submillimeter Array to zoom in on the 20-light-year-long Integral Shape Filament, which crosses massive star-forming regions in the Orion Nebula. The team found a network of 55 fibres that braid into the single, larger filament, a result that fits into the pattern of more fibres in more massive star-forming regions. The only difference is that Orion's fibres are typically only ½ light-year long, on average three times shorter than the ones the researchers spotted in the low-mass star-forming region.

■ MONICA YOUNG

IN BRIEF

Hubble images most distant star

It's difficult to resolve stars in galaxies outside our own, but with the help of some cosmic lensing, the Hubble Space Telescope has imaged a star that existed when the universe was less than a third of its current age, at a redshift of 1.49. Hubble's optics were aided by two of the universe's own lenses: The first was the presence of a foreground galaxy cluster known as MACS J1149-2223, whose immense gravity bent and magnified the light from the background star. The second was something closer to the star, with three times the Sun's mass — perhaps another star, a neutron star or a stellar-mass black hole — that gravitationally tweaked the starlight in what's known as a *microlensing event*. The combination of the two gravitational lenses magnified the star's light more than 2,000 times, making it visible to Hubble. The star itself is a blue supergiant much bigger, brighter, and hotter than the Sun.

■ MONICA YOUNG

Nearby galactic relic of the ancient universe

NGC 1277 is a stunted galaxy, largely ungrown since the universe's early years, observations by Michael Beasley (Canary Islands Institute of Astrophysics, Spain) and colleagues confirm. The galaxy, which lies 240 million light-years away in the centre of the Perseus Cluster, is a dense 'red nugget' — although it has twice as many stars as the Milky Way, it's about a quarter of our galaxy's size and filled with old stars that formed early on. Astronomers already suspected that NGC 1277 was frozen in time, but Beasley's team decided to test the idea. They hypothesised that, if NGC 1277 were really a relic, all its globular star clusters would be rich in heavy elements because they had formed when the galaxy first coalesced. The team's Hubble Space Telescope observations confirm NGC 1277 has almost no young globular clusters, so NGC 1277 hasn't grown much by accreting other galaxies. The relic offers astronomers access to a relatively nearby example of early systems that are much more difficult to study.

■ CAMILLE M. CARLISLE

ESO / H. DRASS / ALMA (ESO / NAOJ / NRAO) / A. HACAR

Parkes gets new 'bionic ear'

A $2.5 MILLION instrument developed by CSIRO and a consortium of Australian universities will give the Parkes radio telescope the ability to cover more frequencies as it listens for faint radio waves from space.

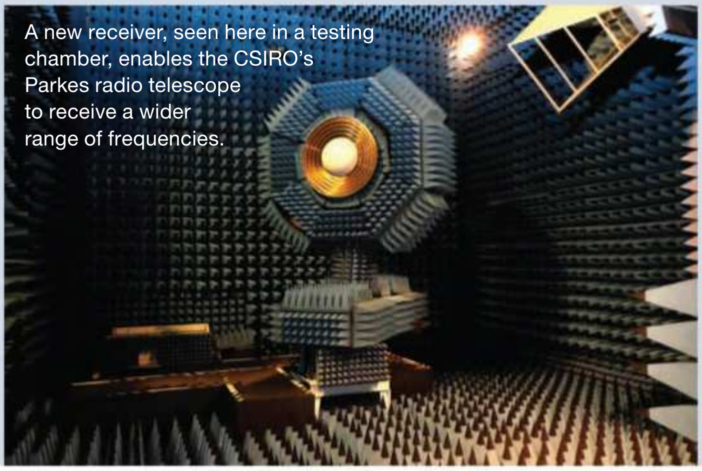
The new receiver covers the spectrum from 700 MHz to 4 GHz and does the work of several extant receivers, as well as covering extra frequencies.

"Stars and galaxies 'sing' with different voices, some high, some low," said CSIRO astronomer Dr George Hobbs said. "Until now we've had receivers that heard just one part of the choir at a time. This new one lets us listen to the whole choir at once."

Continuous upgrades have given Parkes 10,000 times more sensitivity that it had when it was commissioned in 1961. And the beauty of the new receiver is that it will enable several observation campaigns to be conducted simultaneously.

"While some of us are timing a pulsar, other astronomers could be looking for the signs of newborn stars," Dr Hobbs said.

"The expertise built up in these technologies will enable Australia to compete effectively into the era of the Square Kilometre Array, the world's largest radio telescope."



A new receiver, seen here in a testing chamber, enables the CSIRO's Parkes radio telescope to receive a wider range of frequencies.

"Most of the projects the new system will be used for are forefront astronomical science," added Swinburne's Professor Matthew Bailes, leader of the university consortium. Some of those projects include looking for evidence of gravitational waves from black holes in the infant Universe, researching the interior of neutron stars and mapping Galactic magnetic fields.

The university development consortium is led by Swinburne University of Technology, with funding from the Australian Research Council, Germany's Max Planck Institute for Radioastronomy and the Chinese Academy of Sciences. Both CSIRO and Swinburne designed and built elements of the receiver.

■ JONATHAN NALLY

◀ KiwiStar Optics' 1.1-metre-diameter lens will be used on a spectrograph at the William Herschel Telescope in the Canary Islands.

Large lenses for large surveys

One of the world's largest astronomical lenses has been made in New Zealand, destined for the William Herschel Telescope in the Canary Islands. The 1.1-metre-diameter lens is one of six being fabricated for the 6-element prime focus corrector for the telescope's new WEAVE multi-object survey spectrograph.

WEAVE will be used to conduct a large-scale survey over five years of 10 million objects, such as galactic stars and distant extragalactic sources.

The lenses are the work of Wellington-based KiwiStar Optics, a unit of Callaghan Innovation, New Zealand's innovation agency, which specialises in precision astronomical optics.

"We bring the glass over from the USA, Japan or Germany and then it is milled into shape using our 5-axis CNC mill. Once in shape the lens goes through a series of shaping and polishing processes to get it within 1 micron of accuracy (a human hair is about 75 microns)," said Dave Cochrane, Team Leader of Optical Manufacturing at KiwiStar Optics and the manager of the lens project.

"The final polishing process is done using powders as small as 1 micron, and an accuracy down to 0.05 microns (less than 1000 times smaller than a human hair).

"When both sides of the lens are polished, it is packed and shipped to one of several specialist vacuum coaters in the USA for anti-reflective coating. The lens is then returned to KiwiStar Optics for final testing and inspection before being shipped to the client."

According to KiwiStar Optics' manager, Sandra Ramsay, "It's not widely known outside of astronomy circles that New Zealand has this level of technical expertise and state-of-the-art equipment to create these lenses".

"KiwiStar Optics has a significant reputation globally for its highly-specialised lenses and we are now working our way through a substantial list of large contracts."

Those contracts include three high-resolution cameras for the VISTA telescope in Chile, as well as more lenses and spectrographs.

■ JONATHAN NALLY

KIWISTAR OPTICS; CSIRO

Australia's new space race

No longer lost in space, Australia is finally to get its own space agency.

At long last, after decades of inaction, years of lobbying and countless missed opportunities, an Australian federal government has finally seen sense and has committed to establishing an Australian national space agency.

Foreshadowed earlier in the year, the development comes after months of study by an Expert Reference Group, charged with advising the Government on Australia's potential as a player in the global space market. That market is currently estimated at $460 billion and growing at about 10% per year.

On May 14 the Minister for Jobs and Innovation, Michaelia Cash, made the announcement everyone had been waiting for.

"We have an extraordinary opportunity to increase our share of the growing global space economy," she said. "Space technologies are not just about taking people to the Moon, they open up opportunities for many industries, including communications, agriculture, mining, oil and gas.

"An Australian space agency will support the long-term development of space technologies, grow our domestic space industry and secure our place in the global space economy," the Minister added.

A sense of relief

The announcement earlier this year, and May's confirmation, was met with a feeling of relief by those in Australia's space sector, many of whom had feared that this would be another false alarm. After all, over the past 30-plus years there had been several reports presented

▲ The only satellite launched from Australian soil, WRESAT, lifted off in November 1967.

The European Space Agency's deep space tracking station at New Norcia, Western Australia. The government has allocated $15 million in the latest budget for local enterprises to partner with international agencies.

to government (some even initiated by government) outlining the benefits to the nation of the establishment of such an agency.

The Space Industry Association of Australia (SIAA) is one body that has welcomed the announcement.

"The benefits of a national space agency... have been the subject of detailed research and lobbying by the SIAA and other key players in the Australian space sector over the last 18 months," said the SIAA's chair, Michael Davis.

"It is vitally important that the recommendations of the Expert Reference Group be accepted and implemented," said Davis. "This will ensure that the new agency has the necessary support from both government and industry to achieve the long term goals of industry engagement and economic development by promoting collaboration and investment nationally and internationally."

According to the SIAA, Australia has the chance to increase its share of the global space market from 0.8% to 4% within 20 years, reaching a dollar value of more than $3.5 trillion within the next three decades.

"We can't afford to get stuck on Earth when everyone else is going to the stars. Australia can finally step up and participate as an equal with other nations," added Flinders University space specialist, Dr Alice Gorman.

"The European Space Agency has 9 centres and NASA runs 11 which support spaceflight programs. Large chunks of the private sector rely on them but our model has to be different."

"This is an investment which allows us to compete in the global space race," she said.

"We are talking about an industry that will need engineers, scientists, researchers, archaeologists, and even writers and artists," she added. "Some skin in the game also gives our voice credibility on issues like space junk and space treaties."

Great opportunities

Professor Brian Schmidt, Vice-Chancellor of The Australian National University (ANU) and a Nobel Prize winner, said that the move will invigorate Australia's space industry.

"The Government's new investment in a space agency is a solid down payment in the development of Australia's space story. We look forward to bringing our extensive cross-disciplinary capability to support the agency, its initiatives and activities," Professor Schmidt said.

"ANU is home to key national space resources and has vast capacity and capability to support a new space agency with broad expertise from science through to law and policy.

"Our staff at the Research School of Astronomy and Astrophysics are deeply engaged with industry, government and academia along with other national space agencies around the world.

"Through our national facilities, which include the Advanced Instrumental Technology Centre (AITC) at Mount Stromlo and the Siding Spring Observatory, ANU already plays a leading role in the national space industry."

So, more than 50 years after the launch of WRESAT — the only satellite ever launched from Australian soil — the nation's government has finally decided to offer serious guidance and encouragement to Australia's space sector. Overdue, but not too late. As the saying goes, *per ardua ad astra* — 'through struggle to the stars'.

AUSTRALIA'S SPACE FUNDING AT A GLANCE

The new national space agency will start work on July 1, 2018, led by Dr Megan Clark, former head of the CSIRO.

$26.0 MILLION over four years to establish the Agency and coordinate domestic space activities.

$15.0 MILLION over three years 20 to establish an International Space Investment project.

$260 MILLION for research into better GPS-like location systems and satellite imagery.

More details at industry.gov.au/Space

A new era for Australian astronomy

Australian optical astronomy is rapidly evolving, as existing telescopes change hands and an international alliance brings access to major new facilities.

It's hard to think of a time when the landscape of astronomical research in Australia was changing as rapidly as it is at present. While radio astronomy maintains a steady-as-she-goes approach, with innovative new facilities paving the way for the Square Kilometre Array, the optical community is undergoing epochal transformation — bringing both opportunities and challenges.

At the heart of the changes is infrastructure — which, for astronomers, of course, means telescopes and instrumentation. Every ten years, Australian astronomers present to government their aspirations for the future in a Decadal Plan. All recent Plans — including the current one (*Australia in the Era of Global Astronomy, 2016-2025*) — have highlighted the need for significant amounts of time on optical telescopes in the 8-metre class. And it is no secret that Australian astronomers have long coveted the idea of the nation being affiliated with ESO, the European Southern Observatory.

European vistas

ESO membership involves significant cost, and requires high-level government support. And last year, there was a shift in the fortunes of the astronomers' ambitions. Rumours of behind-the-scenes negotiations gave way to a blaze of publicity at the Astronomical Society of Australia's 2017 annual meeting in Canberra. There, on July 11, a $129-million, ten-year strategic partnership was inaugurated by Senator the Hon Arthur Sinodinos, then Commonwealth

ANU

◀ **VERDANT SKIES** Siding Spring Observatory in New South Wales is dominated by the dome of the 3.9-m Anglo-Australian Telescope (centre). On the extreme left is the 1.3-m ANU SkyMapper Telescope, while the 1.2-m UK Schmidt Telescope and Las Cumbres Observatory 2.0-m Telescope are on the right.

▲ **QUIET ACHIEVER** The world-famous 3.9-m Anglo-Australian Telescope, on its giant horseshoe mount, was opened by Prince Charles in 1974.

ÁNGEL LÓPEZ-SÁNCHEZ

Minister for Industry, Innovation and Science, and Professor Tim de Zeeuw, then ESO Director-General.

The Strategic Partnership provides Australian astronomers with long-term access to the world's most comprehensive suite of optical astronomy facilities, at La Silla and Cerro Paranal in northern Chile. The ability to use the four 8.2-m telescopes of ESO's Very Large Telescope (VLT) at Paranal is an important prize for Australian astronomers, fulfilling the critical requirement for access to this class of instrument.

The new deal also explicitly aims to capitalise on Australian know-how in instrumentation, with promised benefits for domestic universities and industry. Australia-based astronomers can now access a range of professional and research opportunities, such as fellowships, scholarships and employment; Australian companies can tender for work at the La Silla and Paranal facilities; and Australian optical instrumentation groups can bid for the construction of any hardware required at those facilities.

Excluded from the new partnership are ESO's Atacama Large Millimetre Array (ALMA) and the 39.3-metre European Extremely Large Telescope (E-ELT), currently under construction at Cerro Armazones (near Paranal). At the conclusion of the strategic partnership in 2028, Australia will have the opportunity to enter into full membership of ESO, with access to both ALMA and E-ELT.

Embracing the new era

The Australian Government has a long tradition of partnering with the astronomy community and making strategic investments at the right time for the benefit of research excellence and industry innovation. The next generation of astronomy infrastructure is financially beyond the reach of any single nation, which is why partnering with organisations such as ESO is critical to our global competitiveness.

The government's initiative in forging the partnership with ESO has been widely praised within the Australian astronomical community. The concomitant change, however — which, at the time of writing, is in the final stages of formulation — heralds the biggest makeover in the 44-year

▲ **NEW VISTAS** The deal with the European Southern Observatory gives Australian astronomers access to world-leading facilities in Chile, including the four, 8.2-metre telescopes of ESO's Very Large Telescope.

▲ **RIGHT PLACE, RIGHT TIME** The Anglo-Australian Observatory (as it was known in 1987) was perfectly placed to study supernova 1987A. This was the brightest supernova seen in almost 400 years, and was best observed from the Southern Hemisphere.

DAVID MALIN/AAO

history of the Australian Astronomical Observatory (AAO).

Until 2010, AAO was the Anglo-Australian Observatory, a UK-Australian institution with joint funding that was frequently held up as an exemplary international collaboration. Following the UK's withdrawal from the agreement in 2010, the Observatory became a division of the Australian Government's science department, which today is the Department of Industry, Innovation and Science (DIIS). That metamorphosis left the key functions of the old AAO intact; namely, the operation of the 3.9-m Anglo-Australian Telescope (AAT) and 1.2-m UK Schmidt Telescope (UKST) at Siding Spring Observatory near Coonabarabran, and the Observatory's headquarters and technology and facilities base in Sydney.

The advent of Australia's partnership with ESO draws a line under this chapter in the AAO's history, and the DIIS operating model will come to an end on June 30, 2018. What will replace it is a move from the government to the research sector, with the Coonabarabran and Sydney operations moving into two different

university consortia. This will extend the operational life of the AAT beyond 2020 and will allow the AAO's instrumentation function to be strengthened into a genuinely national capability, developing new industry and commercial connections over the long term. The extension of AAT operations into the mid-2020s accords with the outlook presented in the Decadal Plan.

The new model for the AAO's facilities places the operation of the AAT under the management of Astronomy Australia Limited (AAL), a not-for-profit company whose members are Australian universities and research organisations. From July 1, 2018, the Commonwealth will lease the AAT premises exclusively to the Australian National University (ANU), acting on behalf of a consortium of 13 fee-paying Australian universities. The ANU already owns and operates Siding Spring Observatory where the AAT is located, and the AAT Consortium agreement will cover the operation of the telescope for seven years, of which funds for the first four are already committed. The majority of the AAT's staff will become ANU personnel.

The situation for the UKST is rather different. Despite being operated by the AAO since 1988, it has been owned by the ANU since 2010. As described later in this article, two new large-scale surveys (Taipan and FunnelWeb) will take up all available time on the telescope.

> "The government's initiative in forging the partnership with ESO has been widely praised within the Australian astronomical community."

So much for the telescopes — what of the AAO's facilities in Sydney? Once again, the importance of the Observatory's world-class instrumentation programme is highlighted in the Decadal Plan, and it will continue into the new era. From July 1, 2018, the AAO's science and technology group will be taken over by a consortium led by Macquarie University and including the ANU and the University of Sydney, with funding primarily through AAL in partnership with the universities. It is expected that the unity of the group will be retained within Macquarie University in order to preserve the internationally-known AAO brand-name.

The transition of a government-funded institution like AAO is a complex and often emotional process. However, what is certain is that the ESO Strategic Partnership will give our astronomers access to the world's best tools, infrastructure and collaborations in optical astronomy and, through this, the key to new ground-breaking discoveries over the coming decades. At the same time, both university consortia responsible for the AAT and the AAO instrumentation capability from July 1, 2018 are committed to returning things to 'business as usual' as soon as possible after the transition. Indeed, with the instrumentation group becoming part of a truly national capability, 'business as usual' could soon be bigger and better than ever.

AAO yesterday and today

When the British and Australian governments looked jointly at possible

ESO/B. TAFRESHI (TWANIGHT.ORG)

▲ **HISTORIC DAY** The then Minister for Industry, innovation and Science, Arthur Sinodinos, and the then Director General of ESO, Tim de Zeeuw, signed a Partnership Agreement between Australia and ESO in July 2017.

sites for a new 150-inch (or, in today's parlance, 4-metre) class telescope in the Southern Hemisphere during the late 1960s, Siding Spring was considered to be the best place in Australia. Work on the telescope began in earnest in 1969, and from the moment HRH Prince Charles arrived at Siding Spring Observatory to 'declare this aperture open' on October 16, 1974, the AAT's early history was unashamedly triumphal. It was by far the biggest telescope available to British and Australian astronomers. Moreover, the pioneering colour imagery of David Malin took it firmly into the popular media, and early electronic detectors such as the Image Photon Counting System reaped an enviable harvest of scientific discovery. Alongside it, the wide-angle UK Schmidt Telescope (opened on August 17, 1973) was producing the most significant photographic atlas of the southern sky.

From the beginning, the AAO's Sydney-based scientists and engineers showed themselves to be adept at building novel instruments for use with the AAT. It was the early use of optical fibres, however, that set the Observatory on its current course. The idea of using fibres to pipe the light of stars and galaxies into auxiliary instruments was not actually invented at AAO. However, it was transformed from an interesting novelty into a highly productive technique at both the AAT and the UKST during the early 1980s.

The technique is known as 'multi-fibre spectroscopy', and it enables detailed measurement of the vital statistics of target stars or galaxies, hundreds at a time, in large-scale 'population census'-type studies. Pilot spectroscopic surveys on both telescopes demonstrated its potential and, in the mid-1990s, the AAO unveiled 2dF (for 2-degree Field) on the AAT. This ground-breaking instrument enabled the spectra of 400 objects to be obtained simultaneously using fibres positioned robotically in a 2-degree field of view — an unprecedented field of view for a 4-metre class telescope.

2dF's first task was a three-dimensional survey of the distribution of galaxies within 2.5 billion light years to provide a detailed cross-section of the Universe. The project measured 221,000 galaxies and was completed in 2002, quickly becoming one of the richest sources of AAO scientific papers to date. In 2005, it was used to find the 'missing link' between the temperature fluctuations in the Cosmic Microwave Background Radiation — the 'flash' of the Big Bang — and today's distribution of galaxies.

Building on this achievement, the AAO built a succession of room-sized instruments to be fed remotely by 2dF, culminating in 2014 with HERMES, a high-resolution spectrograph that was especially designed to investigate the history of our Galaxy using detailed observations of large numbers of individual stars. The 'Galactic Archaeology with HERMES' (GALAH) project has already netted the spectra of half a million stars. Another recent innovative instrument is the Sydney-AAO Multi-Object Integral field spectrograph, or SAMI, which deploys multiple fibres for the detailed study of nearby galaxies.

▼ **AUSSIE INGENUITY** The OzPoz fibre positioner was built by the Australian Astronomical Observatory for the FLAMES multi-object spectrograph used by ESO's Very Large Telescope. A robotic arm accurately places optical fibres into position to pick up the light of selected galaxies or stars. This example of Australian know-how going overseas is likely to be repeated under the new strategic partnership with ESO.

DIIS; ESO

▲ **PORTRAIT VIEW** The definitive image of the 1.2-metre UK Schmidt Telescope (essentially a large astronomical camera) in the 6dF era, with the robot room on the left and the spectrograph enclosure on the right.

BEN WRIGLEY

And tomorrow

The AAO's instrumentation program will continue unabated under its new management. Instruments currently in development for the AAT include HECTOR (a considerably more powerful version of SAMI) and Veloce, a highly-stable spectrograph for precision velocity measurements of stars, facilitating studies of planets circling other stars — among other things.

Projects for other observatories include AESOP, a 2,400-fibre tilting-spine positioner for ESO's 4-m VISTA telescope, and the Gemini High-Resolution Optical SpecTrograph (GHOST), which has been developed for the 8-m Gemini South telescope in a collaboration between AAO, the Herzberg Institute for Astrophysics in Canada, and the ANU.

More fundamental instrumentation research is also being carried out, particularly in the field of astrophotonics. Over the next few years, novel waveguide devices are expected to radically change the way in which astronomical instruments are built, and add wholly new capabilities.

Meanwhile, not to be outdone by its larger sibling, the UKST began a new role as a dedicated spectroscopic survey telescope in 2001 using a robotic fibre instrument called 6dF — for 6-degree Field. Its first major project was the 6dF Galaxy Survey (6dFGS), measuring the redshifts of 150,000 galaxies, completed in 2005. The telescope went on to carry out the RAVE survey (for RAdial Velocity Experiment), a multi-national project to measure the velocities and physical parameters of half a million stars. RAVE was completed in 2013, and its scientific legacy is still being exploited.

But after a major refurbishment, the UKST is now embarking on two new surveys. They are Taipan (two million galaxies for cosmological and extragalactic studies, which will complement a major project on the ASKAP radio telescope array) and FunnelWeb (three million stars to generate an entirely new spectroscopic catalogue).

Both use a novel fibre-positioner recently commissioned on the UKST. Each of the 150 fibres is now positioned by its own micro-robot, rather than with a pick-place machine such as that used by 2dF or 6dF. All the fibres can be moved simultaneously, reducing reconfiguration time to a few minutes.

DECADES OF DISCOVERY

Over the years, the AAO's telescopes and scientists have been involved in many major astronomical breakthroughs:

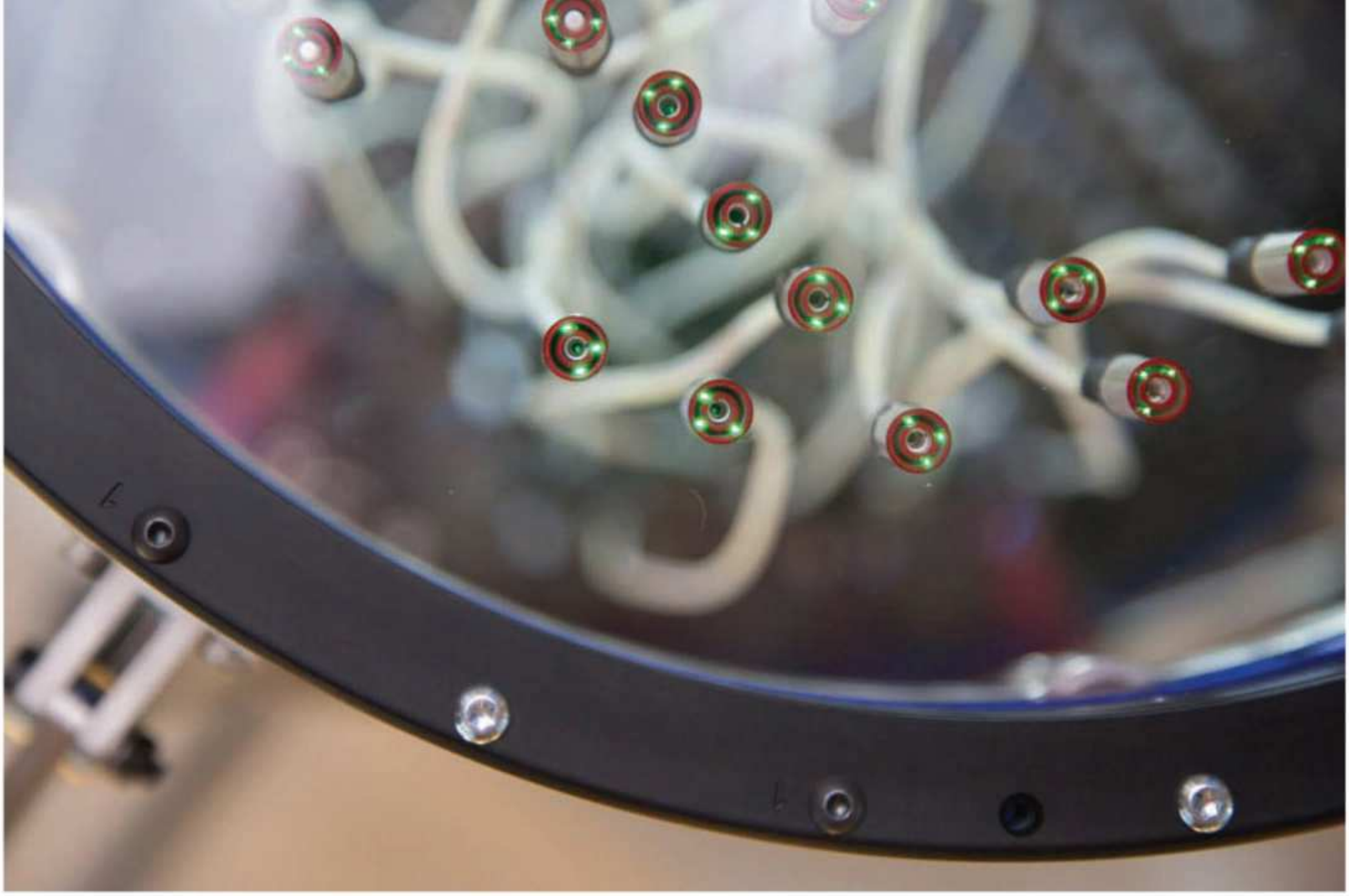
- detected clouds near the surface of the planet Venus through its very dense atmosphere
- detected the first optical counterpart of a supernova remnant in the Southern Hemisphere
- observed the spectacular explosion of the Supernova 1987A, the brightest supernova since the invention of the telescope four centuries earlier
- discovered extremely small, 'ultra-compact' dwarf galaxies
- weighed the Milky Way galaxy
- made the first detection of an isolated brown dwarf star in our Galaxy
- measured the Hubble Constant (the rate of expansion of the Universe) with unprecedented accuracy
- carried out the highest-precision search for exoplanets in the Southern Hemisphere, identifying more than 40 planets around other stars
- discovered streams of stars in our Galaxy that are the remnants of dwarf galaxies absorbed into our own
- confirmed the link between the Cosmic Microwave Background Radiation (the 'flash' of the Big Bang) and today's distribution of galaxies.

This 'Starbugs' technology has been developed by AAO as a demonstrator for MANIFEST, the proposed 'Many Instrument Fibre System' for the 24.5-m Giant Magellan Telescope.

Not quite an instrumentation project, but vitally important for archiving and disseminating survey data, is AAO's Data Central. This new venture, designed specifically to meet the needs of the Australian astronomical community, was funded by DIIS to provide a large-scale data archive. Data Central is rapidly

BLACKEST DAY With 50-metre-high flames leaping up the southern flank of the mountain, the AAT disappeared into a pall of smoke during the devastating bushfires of January 13, 2013. Fortunately, all the site's telescopes survived.

ROB PATERSON



▲ **FIBRE OPTICS** 'Starbugs' on the glass focal plate of the UK Schmidt Telescope. Each 8-mm diameter, vacuum-adhered 'bug' contains an autonomous positioning robot, three fibres (glowing green) for precise positioning, and an optical fibre (seen disappearing in the background) that picks up and transports the light of target galaxies or stars to a waiting spectrograph.

ANDY GREEN

growing, and can be accessed at https://datacentral.aao.gov.au.

Beside its staff, its instrumentation programme and the efficiency with which its telescopes are operated, there has been one other major ingredient to AAO's success — its environment. While Siding Spring can't compare for atmospheric stability with the high mountain sites of northern Chile, it does offer a night sky as dark today as it was when its first inhabitants looked skywards tens of thousands of years ago, thanks — in part, at least — to the efforts of the Siding Spring Dark Sky Committee. In parallel with its legislative work, the Committee also spearheaded a proposal to have the adjacent Warrumbungle National Park recognised as Australia's first Dark Sky Park, which was achieved in 2016.

A bright future

It is now more than a decade since the AAT was feted as the top-ranked 4-metre telescope in the world for productivity (by number of scientific papers) and impact (number of citations). Moreover, at the time, the AAT was ranked fifth in productivity and impact among optical telescopes of any size, on the ground or in space.

What is remarkable about those figures is that they were achieved not when the telescope was in its first flush of youth, but relatively late in its life. They demonstrated the efficacy of the large-scale survey strategies set in place in the mid-1990s, when 2dF was being commissioned. While the international landscape today is somewhat different, with a number of telescopes poised to carry out similar work, those performance figures hold out the promise that the AAT will remain productive for a much longer period than is currently guaranteed. With the continuing commitment and loyalty of astronomers past and present to the AAO, that promise is bound to be fulfilled.

A great many people have contributed to the work reported in this article. A number of key individuals in the Australian Government, DIIS, AAL and the universities have put in an enormous amount of effort in brokering the partnership with ESO and the AAO transition. Also noteworthy is the work of the AAO Transition Team and the DIIS Optical Astronomy Group. Perhaps the biggest thank you should go to the staff of the AAO, for their extraordinary achievements in the day-to-day running of the facility, and their forbearance in what is unquestionably a difficult period.

■ **FRED WATSON AM** is Head of Light and Environment at AAO, and holds adjunct appointments at Sydney University, UNSW, USQ, WSU, QUT and Macquarie University. **JANE URQUHART** is Director of AAO, and Head of the Science and Commercialisation Policy Division of the Department of Industry, Innovation and Science.

Space Invaders

How real is the threat that a giant asteroid or comet could strike Earth and wipe us out?

In July 1994, Comet Shoemaker-Levy 9 spectacularly riddled Jupiter with immense chunks of its erstwhile self — a never-before-seen pummeling that grabbed the attention of astronomers and the public worldwide. By that time, most scientists had bought into the notion, first advanced in 1980, that an impact from another huge space object had wiped out the dinosaurs 65 million years ago. But the 1994 comet crash was a stark reminder that massive collisions still happen in our Solar System today.

After first asking NASA to assess the threat, in 1996 Congress tasked the space agency with finding, within a decade, 90% of the estimated 1,000 near-Earth asteroids at least 1 kilometre in diameter. NEAs are those asteroids with a perihelion of less than 1.3 astronomical units... that is, an orbit whose closest point to the Sun is under about 195 million km. And 1 km across is the minimum size that, if the object struck us, could potentially trigger a global catastrophe — unleashing a years-long winter, causing

major crop failures, and conceivably ending civilisation as we know it. (By comparison, the 'dino killer' at the end of the Cretaceous was an estimated 10 km across.)

By 2011 asteroid-hunting surveys had met the legislative mandate, and today the census is closer to 95% complete. NASA's official catalogue of NEAs 1 km or larger stands at 887 of an expected 934 (plus or minus 10 or so). Fortunately, not a single one is on a collision course with our planet.

In fact, the risk of civilisation-ending catastrophe "has been largely put aside by discovery," says retired senior research scientist Alan Harris (formerly Jet Propulsion Laboratory), one of the leaders in this field. It's one of the great scientific achievements of our era.

The missing 5%

Why does NASA feel confident that the total population of 1 km and larger NEAs is likely less than 950? Harris likens estimating their total numbers to keeping track of ducks in wildlife management. "You tag 'em and turn 'em loose, then you come back next year and you grab a bunch of them and see what fraction of them has tags," he says. "You know how many you tagged, so you just multiply back up to what you now estimate to be the whole population."

Within the past year, three separate population estimates of NEAs, one of them by Harris, all wound up with roughly similar numbers at all size ranges. "The three of us all agree within a factor of two or so all the way up and down the line," Harris says, including within a few percent at the 1-km-diameter size. "That gives me confidence that we're on the right track, because three different groups with three different sets of data all come up with about the same answer."

The 'missing' 5%, the roughly 50 objects still lurking in the shadows, are thought to lie in resonant orbits with Earth. Imagine one on the far side of the Sun in an orbit that takes just as long as we do to go around our star — a 1:1 resonance. We'd never see it. "It simply would never get close enough to Earth to get into our detection window," says Paul Chodas (Center for Near Earth Object Studies, Jet Propulsion Laboratory). "But that's a narrow niche, and over time, if even just slightly outside that niche, it will eventually come by our planet and we will see it."

Outstanding questions

We might know the size of the enemy's army, but uncertainties remain in understanding the combatants themselves. One is how to translate between the inherent brightness of an NEA (which usually is a mere speck in survey images) and the object's actual diameter and density. Planetary scientists start with the absolute magnitude *H*, the brightness a fully illuminated body would have if it were 1 astronomical unit from both the Sun and Earth. Then they assume a particular surface reflectivity (typically 14%) in order to convert *H* to a physical size. But not all asteroids are equally reflective.

Another ambiguity is the degree of impact damage by girth. As noted, scientists use 1 km as the lower size limit on what could provoke global climatic damage. "But we don't really know that for sure — maybe it's 2 km," says Harris. If that's the case, our chances are even better: There's maybe a tenth as many 2-km NEAs as 1-km ones, with a corresponding drop in the frequency that one might collide with us. Moreover, almost all of the remaining undiscovered NEAs lie in that 1-to-2-km size range. "That means our risk of global catastrophe is uncertain mostly by not knowing where that lower threshold is," Harris says.

EARTH: NASA; ASTEROIDS: THECRIMSONMONKEY / GETTY IMAGES

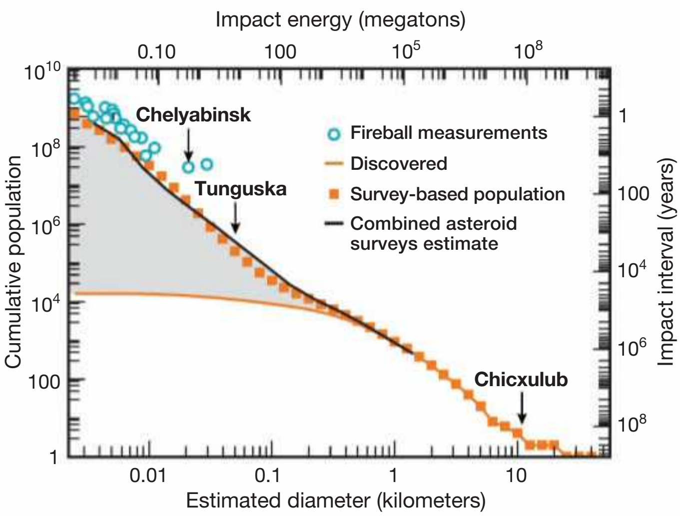
Where a monster space rock comes down also is critical. The Chicxulub impactor, which triggered the extinction of the dinosaurs (and much else) after smacking into the Caribbean off what is today the Yucatán Peninsula, struck thick sedimentary deposits rich in hydrocarbons and sulfur. Spewed into the atmosphere, the resulting soot and aerosols likely had a much more devastating environmental effect than if the intruder had hit, say, a mountain of granite in northern Canada.

Size matters

They say no good deed goes unpunished, and in 2002, when it became clear that observing teams were well on the way to finding 90% of kilometre-size NEAs, NASA chartered a Science Definition Team (SDT) to look at what it would take to bring that 1-km threshold down even lower. Should we also ferret out those NEAs that, while not global threats, might still cause significant *regional* devastation and thus still pose a substantial risk to Earth's population?

The team's report, released in 2003, recommended discovering 90% of all NEAs larger than 140 metres in diameter — the size at which widespread regional damage could result. Last year, a reconvened SDT recommitted to that same size threshold (see the full report at **https://is.gd/2017NASA_SDT**).

As it had in the 1990s, Congress went with the recommendation, setting the end of 2020 for the survey's completion. The decree did not come, however, with a substantial boost in funding, which the NASA community would have needed to meet that time constraint. Astronomers already know they won't reach the Congressional deadline.



▲ **WHAT'S MISSING?** After decades of searching, astronomers have found nearly all of the largest objects with diameters of 1 km or greater — and they're relatively rare. Supergiants like the Chicxulub impactor that struck 65 million years ago are rarer still. But a large gap (grey region) remains between what we've detected and what we expect exists for the smaller but still potentially hazardous bodies.

For one thing, pinpointing the smaller objects is a significantly harder task. Not only is it easier to find the bigger ones, but as you go down in size the number of asteroids also increases exponentially. (It's different with comet nuclei, which, once they approach the Sun, don't seem to hold together for long if they're smaller than about 1 km.) Experts put the number of NEAs with a size of 140 m or greater at more than 24,000.

"It's one thing to suspect that size population, and it's another thing to actually go find them," says Lindley Johnson, who heads NASA's Planetary Defense Coordination Office. "We've got a ways to go."

Currently, we've found about 8,100 objects with an *H* of 22 or brighter, which corresponds to scientists' best estimate

> **"You will only know if an impact is going to happen a matter of months in advance, and the best you can do is evacuate and things like that. You know, Bruce Willis just can't save us."**

of the absolute magnitude of objects 140 m and larger. So they're about one-third complete. New wide-field surveys soon to come online, including the Large Synoptic Survey Telescope in Chile, will help locate many of the NEAs in this expanded census. But all ground-based systems, both professional and amateur, have limitations. First, objects this small can only be spotted during the week or so when they pass closest to Earth. Yet a given telescope on Earth's surface can only search the half of the sky roughly opposite from the Sun. The time it can be online is bounded, and weather and Moon interference can also affect survey performance.

A telescope flown in space wouldn't have such constraints. "It is clear that if we want to get this catalogue of NEAs completed in anything under several decades, we need to go to space-based capabilities," Johnson says.

Seeing in the dark

One of the most promising proposals is NEOCam. (NEO stands for *near-Earth objects*, a term that also encompasses comets.) This space telescope would be 'parked' at *Lagrangian point* L_1, a point of equilibrium between the respective gravitational tugs of the Sun and Earth that sits between the two bodies. "At L_1, we have a wide view of the volume of space surrounding the Earth's orbit, which is where NEOs that are the most likely to be hazardous spend much of their time," says Amy Mainzer (Jet Propulsion Laboratory). Mainzer is principal investigator both of NEOWISE, a highly successful asteroid-hunting mission now winding down, and of the proposed NEOCam.

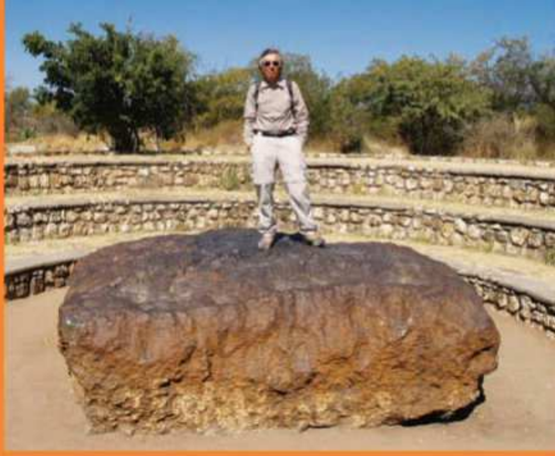
DEFENDING AGAINST A SPACE ROCK

"The foundational principle of planetary defense is FIND THEM EARLY," says Lindley Johnson, NASA's Planetary Defense Officer. Depending on the scenario and warning time, we have at least three methods we could consider to redirect or destroy a hazardous object heading our way.

With significant lead time, we might use a *gravity tractor*. This is a spacecraft that would use the gravitational force created by its own mass to nudge an object off its Earth-targeting path. This method has not been tested, however, and we would need decades to build, launch and undertake this type of mitigation.

A *kinetic impactor* would smash into the interloper at a high speed, transferring its momentum to the object. Ideally, this would change the object's velocity, causing its course to deviate enough for it to miss us. This one would require enough time for the craft to be built, launched and travel to its target — a few years at minimum.

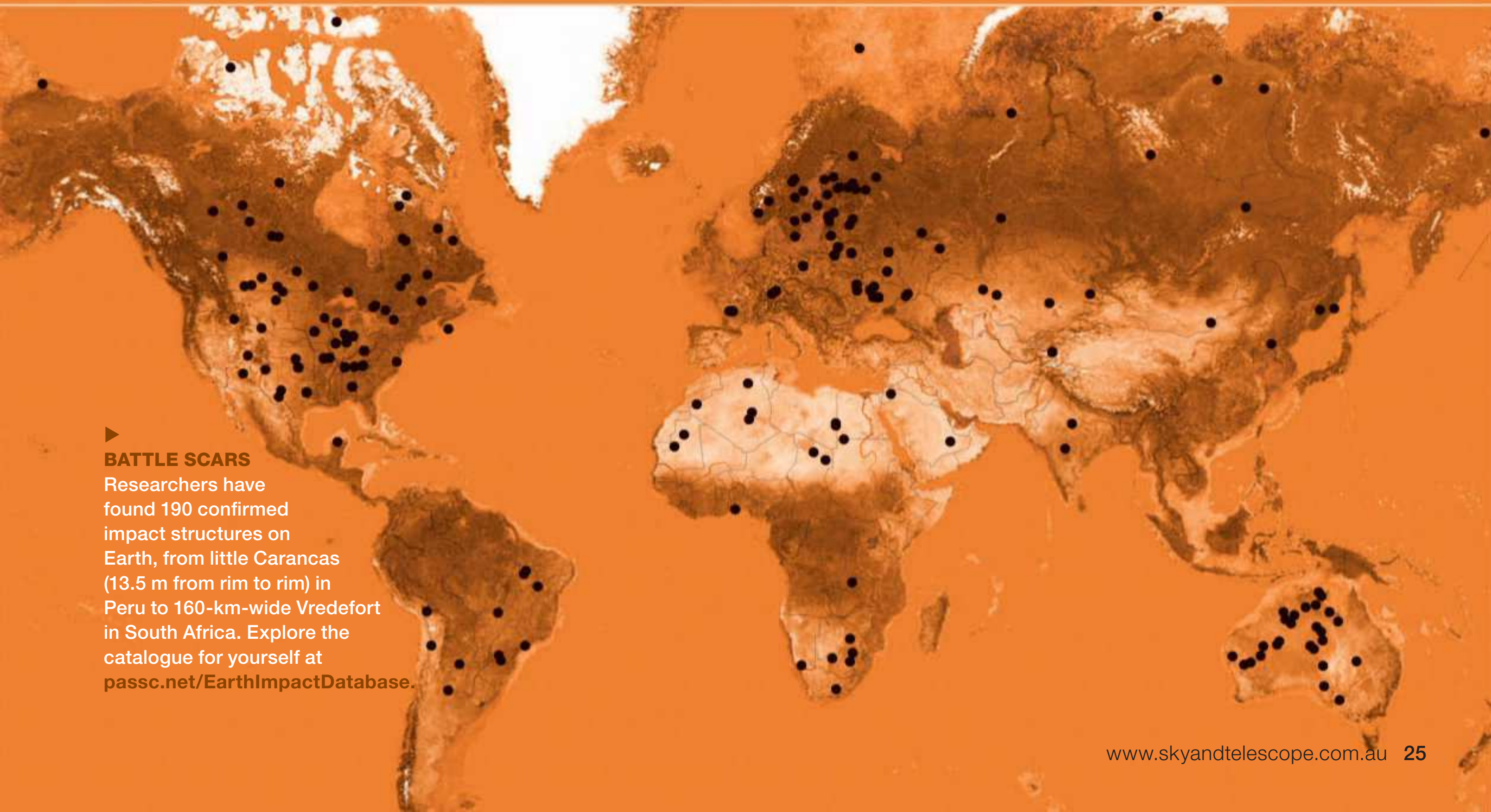
If the threat of impact was imminent or the rock was too large for these two methods to be viable, a *nuclear explosive device* might be the only option. We might have to deal with the fragments, but they'd have more localised effects.



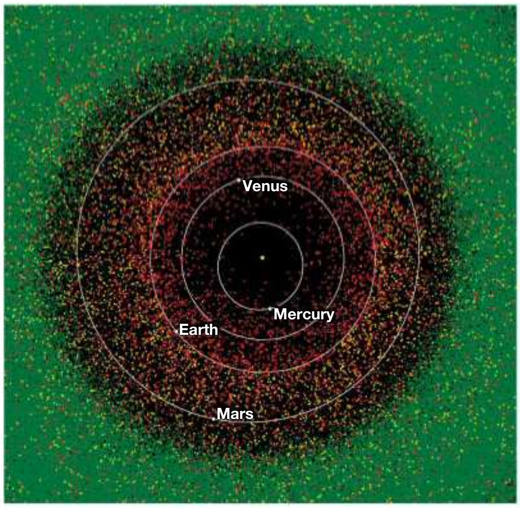
▲ **HOBA METEORITE** Due to its enormous mass (about 60 tonnes), the largest meteorite found on Earth, the Hoba iron meteorite in Namibia, still sits where a farmer discovered it in 1920. Scientists think it fell to Earth about 80,000 years ago.

SHORT- VS. LONG-PERIOD COMETS

Short-period comets originate in the Kuiper Belt out beyond Neptune's orbit and usually take 200 years or less to orbit the Sun. Long-period comets lie in the Oort Cloud, an extremely distant region hosting billions of comets. A single trip around our star could take a long-period comet 30 million years.



▶ **BATTLE SCARS** Researchers have found 190 confirmed impact structures on Earth, from little Carancas (13.5 m from rim to rim) in Peru to 160-km-wide Vredefort in South Africa. Explore the catalogue for yourself at passc.net/EarthImpactDatabase.



◀ **DON'T PANIC** The positions of known asteroids in the inner Solar System are plotted for May 1, 2018. The green dots are all numbered asteroids that do not approach Earth. The yellow ones represent those that approach our planet but don't cross its orbit. The red dots mark asteroids that cross Earth's orbit but don't necessarily closely approach our planet itself. Although the plot makes our neighbourhood look claustrophobically crowded, remember that the space represented by this diagram is predominantly empty.

Equipped with a 0.5-m telescope, NEOCam would scan the celestial sphere in the infrared, specifically the mid-infrared wavelengths around 10 microns. While we humans can't perceive such wavelengths, asteroids — especially dark ones — are naturally brightest in this part of the spectrum, re-radiating most of the sunlight they absorb in the mid-infrared, Mainzer says. NEOCam would detect NEAs at greater distances than ground-based telescopes can and at sizes smaller than 140 m. It would also help astronomers get a better handle on each NEA's size, orbit, spin rate and other factors. This is useful not just for hazard management but also for more generally understanding asteroids, which serve as time capsules of Solar System history and, someday, could be spacefaring resources.

NASA is currently assessing NEOCam's viability, but in the highly competitive environment of federally funded space missions, there's no guarantee it will fly. (NEOCam would cost the American taxpayer about $600 million to build and launch, Johnson told me.) "We are waiting to see what the future holds," Mainzer says.

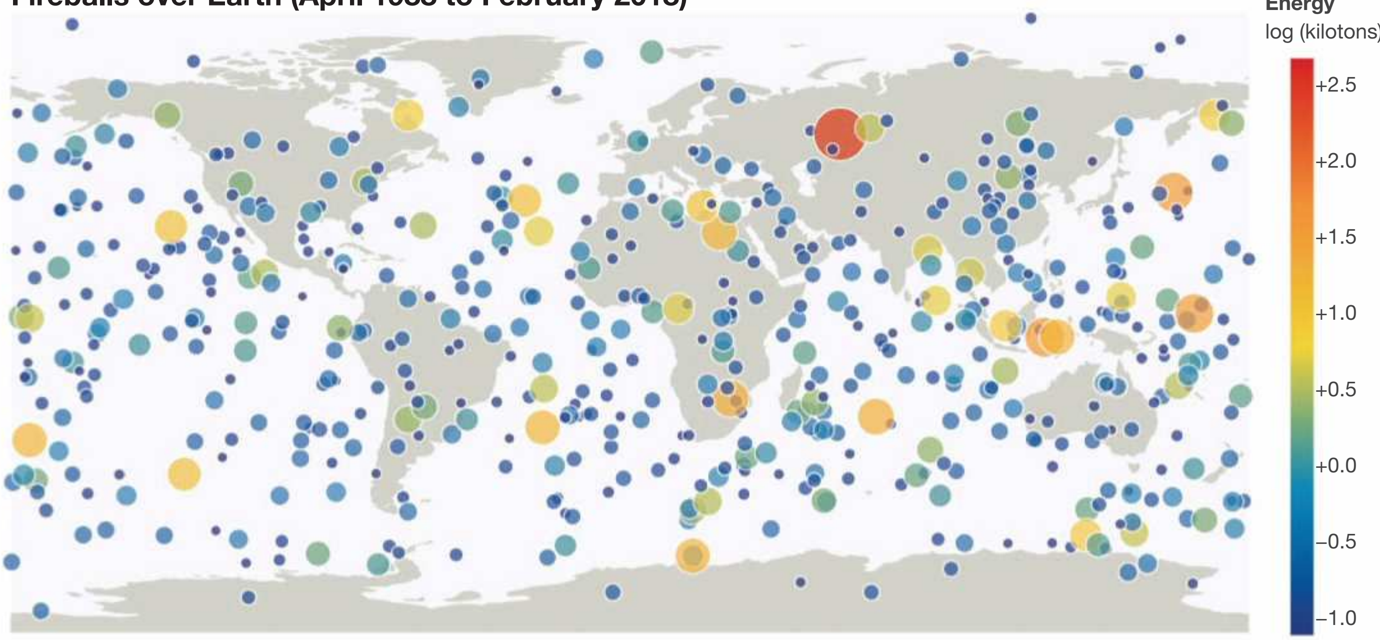
Getting even smaller

Earth's close encounters in the last century or so are a reminder that even modest-size objects can be dangerous. Thought to have been roughly 20 m in diameter, the meteoroid that exploded over Chelyabinsk, Russia, in 2013 injured more than 1,600 people and caused at least $30 million in damage. The so-called Tunguska event in 1908 involved an object more than twice as large, at around 50 m. Fortunately it exploded in the lower atmosphere over a sparsely populated area of Siberia, but the multi-megaton blast still flattened 2,000 square km of forest.

Both incidents are symptomatic of a small impact: While a large asteroid would punch right through the atmosphere and hit the ground intact, smaller rocks detonate high up. When they do so, they unleash damaging shock waves that can reach the surface. (Large asteroids would also generate shock waves.) If a Tunguska-size event happened over a big city, millions could die.

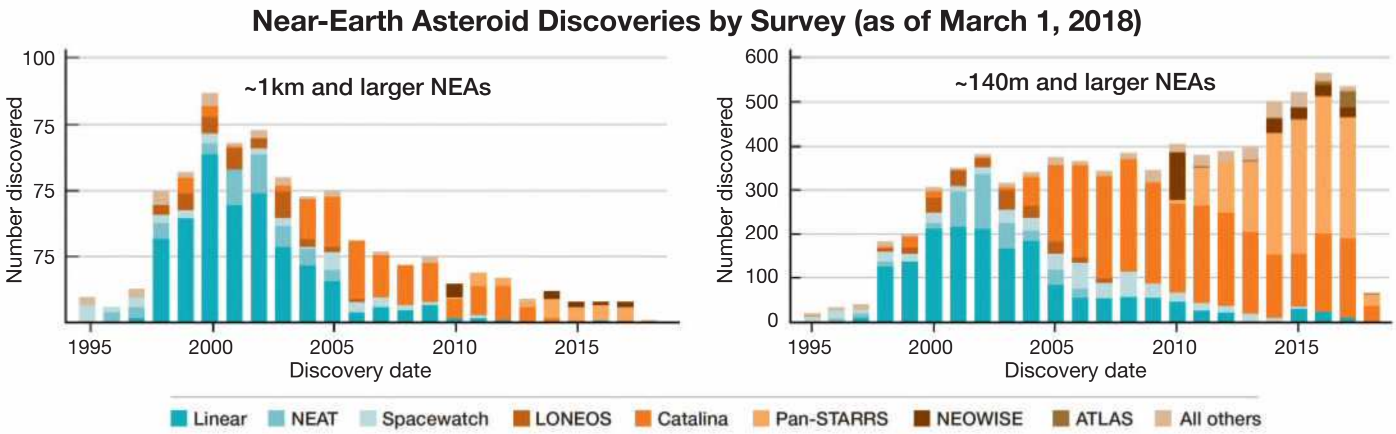
Fortunately, the chance of something like a Tunguska fireball exploding over a major city is slim, Harris says. "They only hit the Earth about once in a thousand years, and only

Fireballs over Earth (April 1988 to February 2018)



▲ **BOMB-GRADE FIREBALLS** Between 1988 and 2018, US government sensors have picked up 735 bright fireballs, a subset for which we have geographic coordinates pinned down (shown). The large red dot marks the 2013 Chelyabinsk event.

ASTEROID POSITIONS: CNEOS; FIREBALL MAP: ALAN CHAMBERLIN (CNEOS / JPL-CALTECH / NASA)



▲ **TALLY UP** Observers have found roughly 95% of near-Earth asteroids that are 1 km or larger, with most of the discoveries made in the early 2000s (*left*). Now their focus is on finding objects 140 metres wide and larger (*right*). Note the different *y*-axis scales.

GREGG DINDERMAN / S&T; SOURCE: ALAN CHAMBERLIN (CNEOS / JPL-CALTECH / NASA)

one in 10 will hit a populated area, or maybe one in 20 or 30." Our homegrown severe earthquakes, hurricanes, floods and tsunamis are all more likely hazards, he says. "It comes down to just a very minor threat. How much of society's resources do you want to pile into that?"

Don't forget the comets

Researchers' focus to date has been on the risk from asteroids (and to a lesser extent from short-period comets, those that come from the Kuiper Belt). This is wise: Asteroids that might pose an impact threat far outnumber comets.

But long-period comets, those that originate in the Oort Cloud, are typically huge — a kilometre or more across — and arrive at much greater speeds relative to Earth than asteroids do. They also appear in our environs with little advance notice. "They're simply undetectable until they approach within the orbit of Jupiter or Saturn, so it's really not possible to see them with decades of warning," says Chodas.

It doesn't leave time, as we might have with known asteroids whose orbits we can calculate decades ahead, of using deflective or destructive methods to remove or lessen the impact. "You will only know if an impact is going to happen a matter of months in advance, and the best you can do is evacuate and things like that," Harris says. "You know, Bruce Willis just can't save us."

The good news, again, is such icy rogues are very few and far between. Long-period comets pass close to Earth only 1% as often as NEAs do. "There are a lot fewer of them coming into the inner Solar System, and, frankly, space is a big place," says Johnson. "I'm not saying that's not a hazard we have to deal with, but let's take care of the asteroids first, then hopefully future technologies will provide us better capability against the less-probable threat."

Don't panic

Beyond finding, cataloguing, and even visiting comets and asteroids, there's one more important piece: improving general awareness.

It's not inconceivable, for example, that an out-of-the-blue explosion in the sky like that over Chelyabinsk could spur acts of aggression or even war by governments that mistake them for attacks. For that reason, Johnson's office works closely with the US Department of Defense to get details about atmospheric impacts out quickly.

The NASA community also strives to keep the public informed of the actual nature of the threat. This can backfire, particularly when talking about 'run-of-the-mill' asteroids of the 1- to 10-m variety that regularly pass between Earth and the Moon. "Most of the close approaches we report on our website are astronomically close, but in human terms still very far away," Chodas says (see **https://cneos.jpl.nasa.gov**). "Yet the images that [news editors] post on their web stories often depict giant asteroids passing *extremely* close."

These mini ones, including the thousands of tiny objects that burn up harmlessly in the atmosphere every day, are just not the focus of the big NASA search efforts. "It's not that we don't need to pay attention to these impacts," says Linda Billings (National Institute of Aerospace), who is a consultant to Johnson's Planetary Defense Coordination Office. "We *are* paying attention. But these events, and NEO close approaches to Earth, are happening all the time." We just didn't know about them before we had robust systems in place to pick them up, as we do now.

Johnson concurs. "I do worry a little bit that we will have cried wolf one too many times, so to speak, and we will lose the ear of the public when one comes around that we really need to tell them about." It's true that we don't have to worry about these smaller objects, he says. "But we do need to keep an eye out and find what's out there, because one of these days there will be a bigger one that's going to impact us, and we just don't know when that is."

■ Among space rocks that strike Earth, **PETER TYSON** favours those he can hold in his hand, such as the Campo del Cielo meteorite he recently acquired.

We've been to asteroids before. Several of them, in fact — flybys, orbital rendezvous . . . we've even touched down on two asteroids and brought back samples from one of them. But this winter, two robotic emissaries will usher in a new era of exploration when it comes to these small Solar System bodies.

That's because these spacecraft, the Japanese space agency's Hayabusa 2 and NASA's Osiris-REX, will study two dark, primitive, near-Earth asteroids unlike any we've explored before. Many of the asteroids we've examined close up have been of just one type — the so-called S-type asteroids (S stands for *silicaceous*). These dominate the inner asteroid belt and may be the source of the most common stony meteorites we have in our museum collections, known as ordinary chondrites. But they only make up one-sixth of all the asteroids we know of. The majority belong to another, very important class: the carbonaceous C-type asteroids.

C-type asteroids (and the alphabet soup of other, closely related 'dark' spectral types) have, for the most part, escaped our exploratory escapades. But these carbon-rich bodies are some of the most pristine survivors we have from the Solar System's early days. What little we know about their composition suggests that it's similar to the Sun, albeit without most of the hydrogen, helium and other easily vaporised compounds. As such, we think they've changed very little since the planets formed some 4½ billion years ago.

We're pretty sure we have plenty of meteorites from these types of primitive asteroids — the carbonaceous chondrites. But meteorites we collect here on Earth have complicated pasts and don't usually come with 'Made in X' labels on them. Trying to decipher their origins is a little like trying to understand the detailed geologic history of eroded pebbles gathered from the bed of a stream flowing from a distant mountain range. Samples hand-picked directly from these asteroids, on the other hand, would give us a rare look at the very material from which our own planet accreted, without ambiguity about its provenance and context. Planetary scientists thus hope that the small caches Hayabusa 2 and Osiris-REX bring back to

DARK ASTEROIDS Ryugu and Bennu's surfaces are about as black as toner cartridge powder.

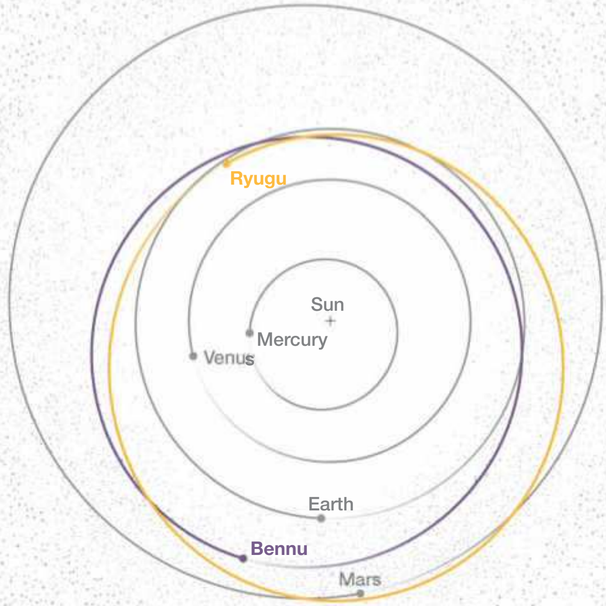
TOUCHDOWN A brief touch is all NASA's Osiris-REX needs to gather priceless info on the Solar System's building blocks. Japan's Hayabusa 2 will use a similar strategy.

Earth will reveal precious new information that even our vast collection of fallen meteorites cannot provide.

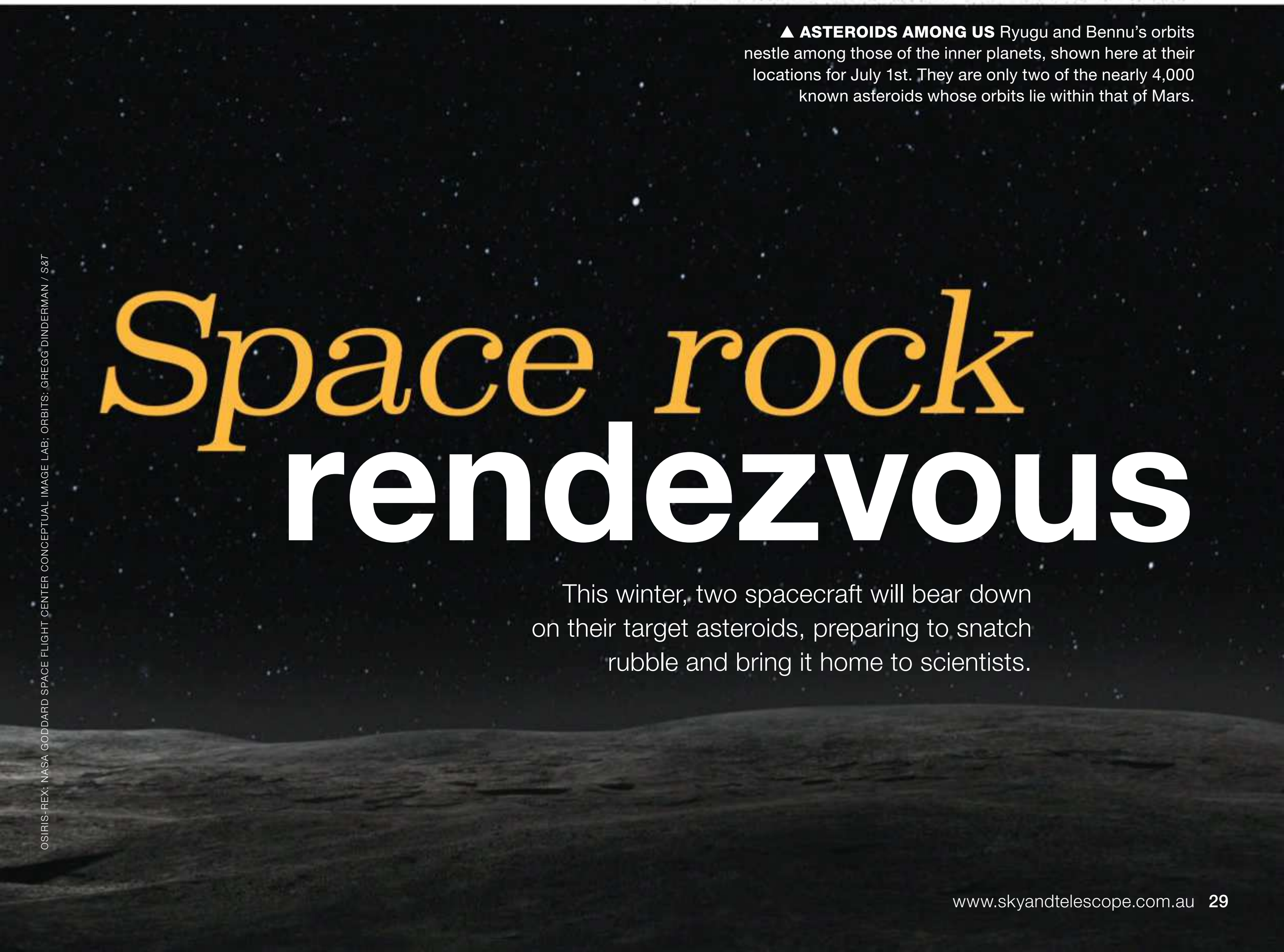
Petite and primitive

The diminutive destinations of the Hayabusa 2 and Osiris-REX missions are, respectively, the near-Earth asteroids 162173 Ryugu (formerly designated 1999 JU_3) and 101955 Bennu (provisionally tagged as 1999 RQ_{36} when it was discovered). Scientists chose these targets not only for their compositions, but also because both are comparatively easy to reach from an orbital mechanics perspective. Both follow moderately eccentric orbits that carry them away from the Sun to the distance of Mars and bring them just interior to Earth's orbit, crossing our planet's path in the process.

Ryugu is the larger of the two at just shy of a kilometre across. We don't know much about it, but ground-based observations reveal a 7.6-hour rotation period and a spectral marker in reflected sunlight that's characteristic of iron-bearing clay minerals. Since clays form in the presence of



▲ **ASTEROIDS AMONG US** Ryugu and Bennu's orbits nestle among those of the inner planets, shown here at their locations for July 1st. They are only two of the nearly 4,000 known asteroids whose orbits lie within that of Mars.



Space rock rendezvous

This winter, two spacecraft will bear down on their target asteroids, preparing to snatch rubble and bring it home to scientists.

OSIRIS-REX: NASA GODDARD SPACE FLIGHT CENTER CONCEPTUAL IMAGE LAB; ORBITS: GREGG DINDERMAN / S&T

water, and Ryugu is a small, airless world without weather, the possible presence of clays suggests that Ryugu's larger parent body was heated just enough to melt at least some of the water ice it accreted along with rocky minerals as it formed. Hayabusa 2 may thus bring us a sample of early Solar System materials that have been altered by ancient water.

With a mean diameter of 492 metres, Bennu is about half the size of Ryugu. The asteroid passes close to Earth every six years, making Bennu simultaneously one of the most potentially hazardous near-Earth objects and the most accessible carbonaceous asteroid.

These close approaches have provided numerous opportunities for ground-based optical and radar observations, meaning Bennu is also one of the best-characterised near-Earth asteroids, with detailed assessments of its size, shape and spin state. Its rapid, 4.3-hour rotation and top-like shape suggest that it's been spun up by solar thermal effects and possibly by tidal effects due to close encounters with Earth, both of which would cause loose surface material to migrate toward the equator. The radar observations also show evidence for at least one house-size boulder on the surface. Based on what the first Hayabusa spacecraft found at the near-Earth asteroid 25143 Itokawa, scientists expect to find plenty of rocks strewn across the landscape.

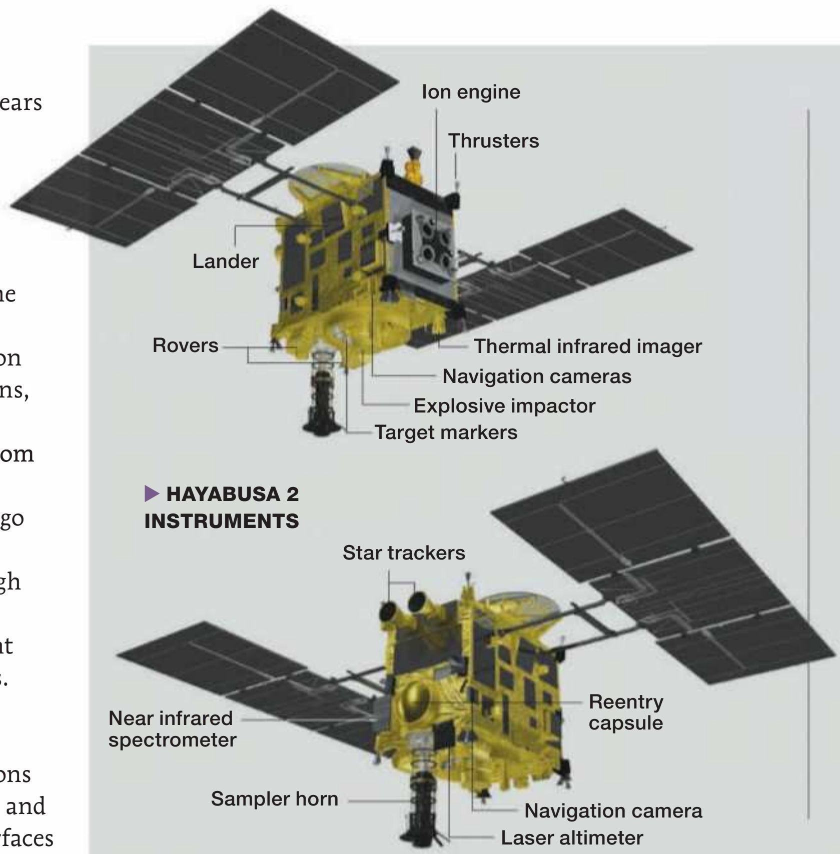
Long before Bennu evolved into its present orbit, it likely began life as part of a larger, 100-km-scale parent asteroid somewhere in the inner main belt 4.6 billion years ago. The mineralogy implied by its spectral properties suggests it has survived largely unchanged by geochemical processes since its initial assembly during the first several million years of Solar System history. Based on detailed computer simulations, the fragment that became Bennu was likely knocked from its parent body between 700 million and 2 billion years ago and gradually found its way into near-Earth space through a combination of rotation-fed orbital drift and the giant planets' gravitational effects.

Grab and Go

The challenge for both missions is to rendezvous with, touch, and acquire samples from the surfaces of very small Solar System bodies, bodies for which we have very little 'hands on' intuition. How do you design a sample-collection strategy when you don't know the surface's makeup or the size of its fragments, and in a microgravity environment that can turn even the simplest of everyday field geology activities into a quagmire of unexpected outcomes? Will you be sampling fine dust, pea-size gravel, or the solid surface of exposed bedrock? Do you plan to scoop up a loose aggregate, drill into hardened rock, or blast the asteroid with a projectile and fly through the cloud of lofted debris? And how do you do any of these without endangering the spacecraft itself?

Fortunately, decades of observational and theoretical studies of asteroids and the findings from the pioneering missions that preceded Hayabusa 2 and Osiris-REX have taught us at least a little of what to expect when we arrive at Ryugu and Bennu. Every asteroid we've explored so far has had some sort of fragmented regolith on its surface, a layer of pulverised rock built up by millennia, even eons, of impacts by smaller asteroids. So we expect the surfaces of Ryugu and Bennu to be similarly littered with rocky samples just waiting to be nabbed.

Furthermore, because the asteroids are so small, their surface gravities will be very weak, making operations there more akin to zero-*g* docking at the International Space Station than a hike across a lunar plain. These considerations rapidly funneled mission planners toward sampling concepts that involved a form of a 'touch-and-grab-some-gravel' approach.



▶ **HAYABUSA 2 INSTRUMENTS**

▶ **EXPLOSIVE ARRIVAL** On its final sampling run, Hayabusa 2 will drop an explosive impactor toward Ryugu (1) then dash to hide behind the asteroid's limb before the impactor detonates. As it flees, the mother ship will drop a camera satellite to watch the explosion (2). Once the explosion-sped projectile carves a crater in the asteroid (3), Hayabusa 2 will return to the site and briefly touch down (4-5). A projectile shot from its collecting horn will spray debris up into the spacecraft, where it will be caught and cached. A second later, Hayabusa 2 will take off (6).

While the overall design philosophy for both missions may be roughly similar (fly out to a primitive near-Earth asteroid, rendezvous with the target and study it for a while, select a good sampling site, collect the sample, and return it to Earth), the specific sampling strategies for each are different in their details.

Hayabusa 2 is the successor to Japan's plucky Hayabusa mission, which returned to Earth in June 2010 with tiny samples of Itokawa. Launched from the Tanegashima Launch Center on December 3, 2014, the Hayabusa 2 spacecraft employs essentially the same configuration as its predecessor, but with some novel technologies. The main body of the spacecraft itself is about the size of a refrigerator, adorned with two wing-like solar panel arrays that provide power for the spacecraft's instruments and ion engine.

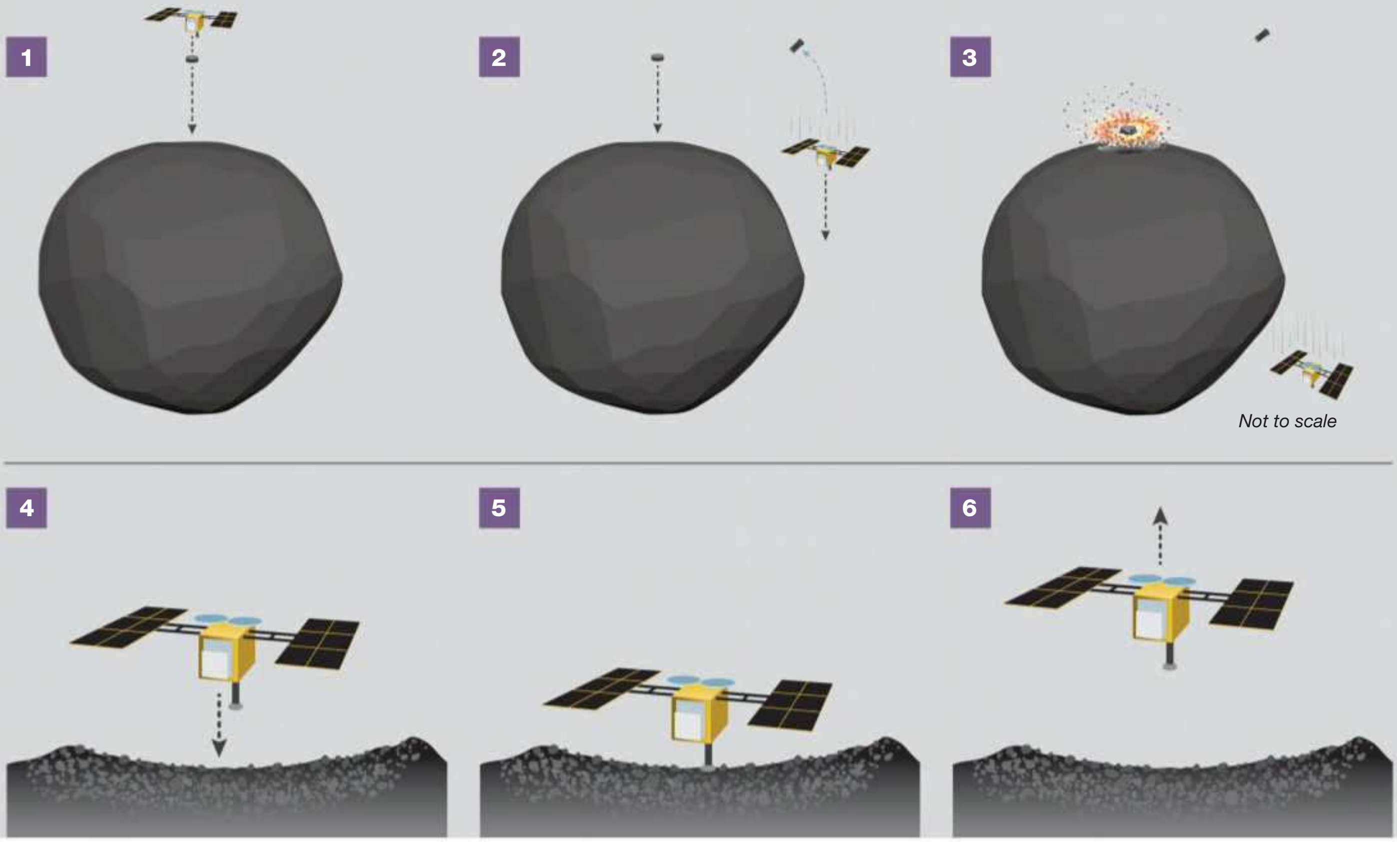
After Hayabusa 2 arrives at Ryugu in June 2018, the spacecraft will gradually approach the asteroid over 18 months or so as the mission team studies its mineral composition, measures the temperature and thermal properties of its surface, and searches for the best location to sample. During this time the mother ship will deploy a small lander called the Mobile Asteroid Surface Scout, or Mascot, as well as three small, hopping rovers named Minerva-II.

The shoebox-size Mascot probe has its own camera, a multi-colour microscope to closely examine the asteroid's surface materials, a radiometer to take Ryugu's temperature, and a magnetometer. Its battery should power a 16-hour or so investigation of the surface.

The Minerva-II rovers are direct descendants of the Minerva deployed toward Itokawa from the original Hayabusa but which unfortunately failed to actually reach the asteroid's surface. There are two types of hopper: one larger, eight-sided rover that's roughly 20 cm tall, and a second, hexadecagonal pair, each just 10 cm tall, or roughly the size of the palm of your hand. They contain their own cameras and other instruments similar to those on Mascot. Each probe has two DC motors inside that work together to 'hop' the probes across the surface. Combined with Mascot, the rovers will reveal what the surface is like on a scale similar to what a human explorer would experience poking around as a field geologist, nicely complementing the global-scale observations the main spacecraft gathers.

Finally, the mother ship will descend toward the surface to collect its prize. A metre-long, metal sampling horn extends down from the spacecraft's underbelly. An aluminium contact sensor and collapsible metal skirt will sense the touchdown on Ryugu, setting off a sample collection process that will shoot a 1-cm-size tantalum projectile into the bit of surface inside the end of the sampling horn at a speed of 300 metres per second (1000 kph). The ejecta from the little

HAYABUSA 2: JAXA; SAMPLING: GREGG DINDERMAN / *S&T*



impact will travel up the horn and into one of three separate sample containers inside the return capsule. The edge of the sampling horn is also folded back under to create an inner rim designed to trap material that gets stuck in there when the horn touches the asteroid, as a backup in case the projectile sampling mechanism fails to fire (as happened on the original Hayabusa mission). There's no time to linger: Just one second after this sequence, the spacecraft will boost itself away from the asteroid to avoid tipping over.

The entire descent, sample and ascent sequence will be repeated, up to a total of three times, filling all three sample containers with about 100 milligrams of regolith particles.

The final grab-and-go will be special, though. To uncover material unaltered by space-weathering effects, Hayabusa 2 will first shoot an explosive impactor toward the asteroid, accelerating a copper projectile fast enough to excavate a crater a few metres wide. The freshly exposed subsurface material will serve as the sample site. A small camera subsatellite will watch the cratering process unfold from about a kilometre way in space, taking an image every second for later downlink to Earth while the mother ship hides behind Ryugu. Once things are safe, the mother ship will again descend, sample, and dart away.

Once all three samples have been acquired, the sample container will be shut tight inside the return capsule with an aluminium seal that will protect any volatiles in the material from being vaporised by exposure to space's vacuum.

In December 2019, Hayabusa 2 will depart Ryugu for its year-long journey back to Earth. Just a few hours from home in December 2020, the return capsule will separate from the main spacecraft before beginning its 12-km/s reentry through the atmosphere, ending with a parachute-assisted landing at the Woomera Test Range in Australia.

Not a carbon copy

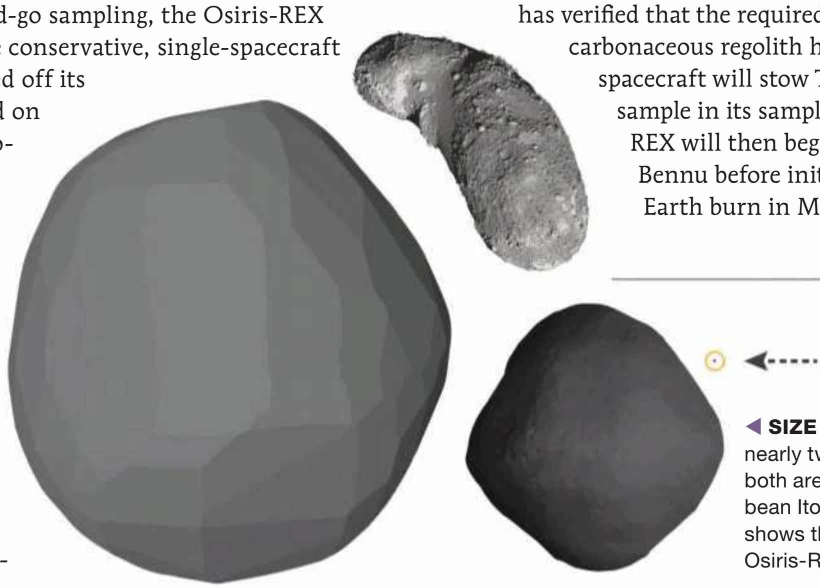
In contrast to Hayabusa 2's adventurous multi-vehicle choreography and blast-and-go sampling, the Osiris-REX mission team chose a more conservative, single-spacecraft methodology. Having roared off its Cape Canaveral launch pad on September 8, 2016, the two-tonne spacecraft begins its approach phase to Bennu in August 2018, during which time the operations and science teams will begin a search for small moons and any damaging dust that might orbit the asteroid, examine the surface, and refine their model of Bennu's shape.

After a few tentative low-speed passes several kilometres from the asteroid and a couple months in an initial 1.5-km-high 'practice' orbit, Osiris-REX will begin the detailed survey and reconnaissance phase of its mission in late February 2019. Its three-camera suite will map the asteroid, provide detailed context for the sample site, and monitor the progress of the sample acquisition itself. Meanwhile, a laser altimeter will produce a finely detailed topographic map, while three different spectrometers map the mineral, organic and thermal lay of the land.

The Touch-And-Go (TAG) sample acquisition strategy is designed with both spacecraft safety and preservation of the sample's pristineness in mind. The microgravity environment makes extended spacecraft contact with the surface a risky venture, especially given that Osiris-REX is about the size of a walk-in closet and could easily tip over. So, much like their Japanese colleagues, the Osiris-REX team has opted for a slow descent, brief touchdown, and get-out-of-there plan of action.

This plan centres on the Touch-And-Go Sample Acquisition Mechanism (TAGSAM), an articulated arm that extends a few metres below the main structure of the spacecraft. At the business end of the arm is a large-dinner-plate-size annulus of fine metal mesh, which makes the instrument look like the combination of a metal detector and a vacuum. Osiris-REX will edge up to Bennu and plant TAGSAM on the surface. As soon as the spacecraft senses proper contact, the instrument will spew out a stream of pure nitrogen gas, kicking up loose material and blowing it up into the TAGSAM head, thereby trapping small pebbles up to 2 cm in size. As a backup, engineers designed the TAGSAM contact pads to allow some regolith particles to stick there as well. Although this strategy will pick up regolith that's been exposed to space weathering, it does avoid the complicated multi-impact approach Hayabusa 2 will use.

Within seconds of collecting its sample, planned for July 2020, Osiris-REX will beat a comparatively hasty 0.7-metre-per-second retreat from the asteroid. Once the mission team has verified that the required 60 grams or more of carbonaceous regolith has been collected, the spacecraft will stow TAGSAM and its regolith sample in its sample return capsule. Osiris-REX will then begin a slow drift away from Bennu before initiating its return-to-Earth burn in March 2021. The sample



SIZE AT A GLANCE Ryugu is nearly twice as large as Bennu, and both are more rotund than kidney-bean Itokawa. The spacecraft icon shows the approximate size of Osiris-REX and Hayabusa 2.

RYUGU AND ITOKAWA: JAXA, BENNU: OSIRIS-REX TEAM / NASA / GSFC

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capsule will enter the atmosphere over the Utah Test and Training Range west of Salt Lake City, Utah, on September 24, 2023, marking the end of Osiris-REX's primary mission but the start of a journey of discovery for the global community of planetary scientists who will dig in to the gritty treasure.

Pushing back the frontiers

The samples returned from both of these groundbreaking missions and the new knowledge gained about their parent asteroids will not only finally tell us how the different flavours of carbonaceous chondrite meteorites are related to various types of dark asteroids. They'll also provide crucial steps forward in planetary science and exploration.

One of the most fundamental questions we have about the formation of our own home world is: Where did Earth's water and organic materials come from? Were they present in the material Earth itself formed from, or were they delivered to Earth after the planet was assembled?

For many years, scientists' favored answer was that Earth's water came from comets that had hit the planet early on, but as we've studied comets' compositions we've realised that the isotopes in their water don't match Earth's. Instead, our planet's water might be 'native,' carried in the rocks that stuck together to build our world up — the same rocks that endure today as asteroids. Finally getting our hands on samples plucked from the types of asteroids long suspected to be the most primitive building blocks of the terrestrial planets will go a long way to answering these questions.

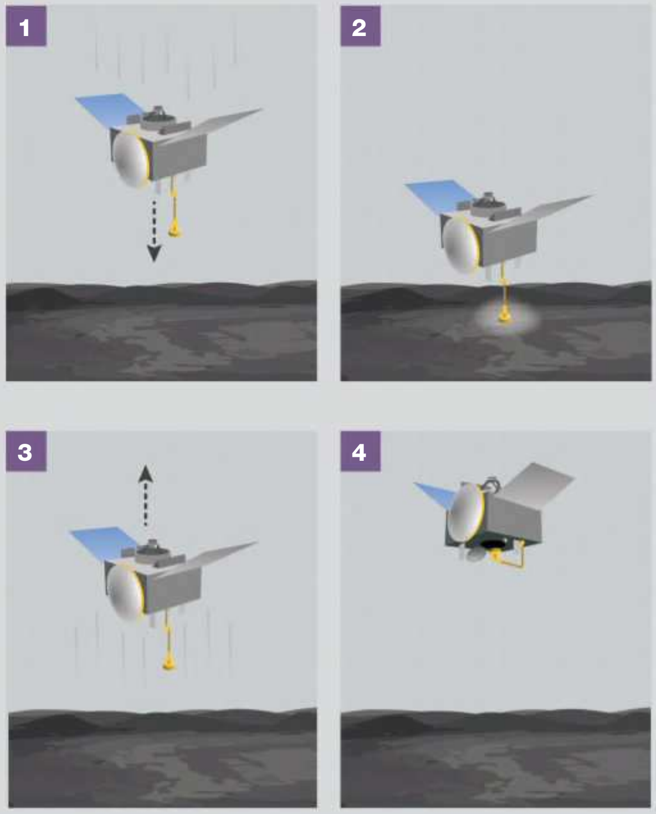
In addition to their compelling scientific value, the near-Earth asteroids are literally gold mines in the sky: Not only do we think they contain precious metals, they also should have water that we can convert into spacecraft fuel, providing important in situ resources once we're routinely exploring and navigating the inner Solar System.

Just operating in close proximity to Ryugu and Bennu is going to provide crucial knowledge that will come in handy as we expand our experience working in space beyond Earth. Hayabusa 2 and Osiris-REX are pioneers in helping us wrap our heads around the sometimes counterintuitive working environments we're going to encounter on the surfaces of these lumpy little worlds.

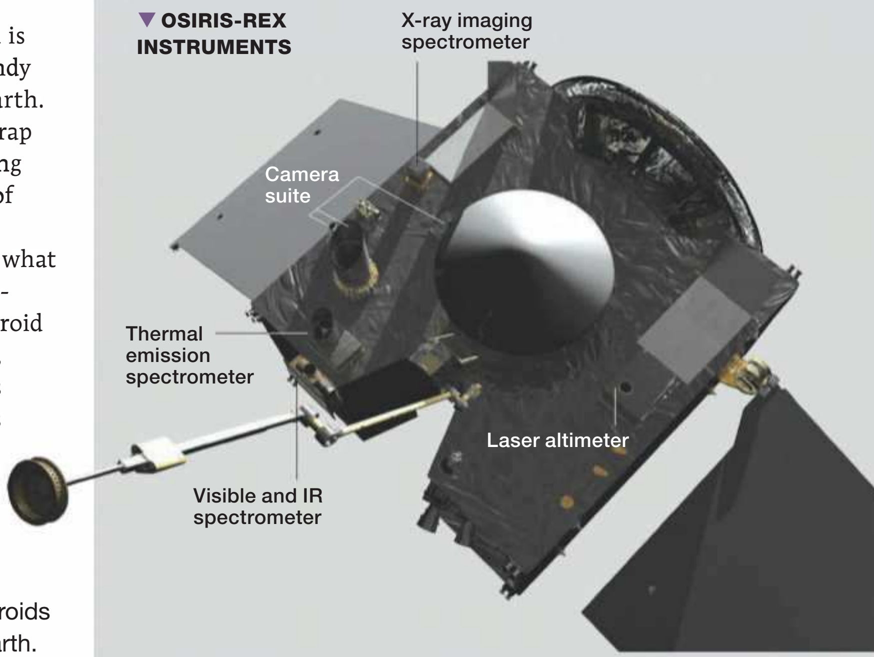
And of course, there's always the looming problem of what to do if an asteroid targets Earth. Although a civilisation-ending hit is unlikely, smaller rocks could come. An asteroid impact is a natural disaster that we can actually prevent, but only if we know more about the asteroids themselves and how they respond to our poking and prodding. So as exaggerated as it sounds, these missions might not only tell us about Earth's past — they could also help us preserve its future.

■ **DAN DURDA** is a principal scientist at the Southwest Research Institute, where he studies the evolution of asteroids and the effects of their impacts on one another and on Earth.

▼ **NASA'S STRATEGY** Expecting a rubble-strewn surface, Osiris-REX will forego projectiles when it touches down on Bennu (1). Once its sampling head is securely planted on the asteroid's surface, it will release a burst of nitrogen gas (2), kicking up dust and small pebbles into the instrument. A few seconds after touchdown, the spacecraft will lift off (3), stowing the sample in its return capsule on the craft's underbelly (4).



▼ **OSIRIS-REX INSTRUMENTS**



OSIRIS-REX: NASA; SAMPLING: GREGG DINDERMAN / *S&T*

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Mars the MIGHTY returns

The Red Planet is at its biggest and brightest. Read on for the best tips on what to see.

We've waited 15 long years and now it's time to party. Mars reaches perihelic opposition — an opposition when a planet is at its closest point to the Sun — on July 27. This is the first perihelic opposition of Mars since August 2003, meaning that it's bigger and bolder in the night sky than it's been in more than a decade. Are you as eager as I am to roam its deserts and poles with a telescope? Maybe even track a dust storm or catch sight of clouds capping mighty Olympus Mons?

Mars, a planet that requires the patience of marble, has a more eccentric orbit than most denizens of our Solar System. At approximately two-year intervals, Earth lines up with Mars at opposition, but a majority of those alignments occur at the same time Mars is relatively far from the Sun. Not this year. Mars is almost at perihelion at the same time as opposition, so it will be a snug .38 a.u. (57.6 million kilometers) away from Earth, close enough for telescopic observers to have a field day ferreting out dark surface markings and changeable weather.

On the night of opposition, in the company of the waxing gibbous Moon, the Red Planet will burn an intense magnitude –2.8, equaling Jupiter at peak brightness. That's a lot of light to muster for a tiny planet only twice the size of our Moon. It just goes to show how distance trumps size when it comes to things celestial.

At the same time, the planet's disk will balloon to 24.3″ (arcseconds), only 0.8″ smaller than during the 2003 opposition when Mars came its closest to Earth in 59,635 years. Because Mars won't arrive at perihelion until September, its closest approach to Earth is slightly delayed, occurring on July 31. After that date, the two planets begin to part ways.

June opens with Mars already 15.5″ across and shining at magnitude –1.2, nearly the equal of Sirius. Even users of small telescopes should have no problem seeing the south polar ice cap and numerous dark albedo markings. By July 1, it fills out to 21.1″ and reaches its greatest size at month's end as the polar cap continues to shrink.

As well as its glorious girth, southern observers will be in the box seat during this juicy Mars apparition. At most perihelic oppositions, including this one, the planet moves into the belly of the ecliptic low in the southern sky. On July 27, Mars gleams from southwestern Capricornus at declination –25° and at culmination stands 81° above the horizon from the latitude of Sydney. This high altitude means fewer air layers to peer through, resulting in decreased turbulence, better seeing and sharper images.

▲ **BURNING BEACON** Mars glows above the Swiss 1.2-metre Leonhard Euler Telescope at ESO's La Silla Observatory in Chile in this photo from 2014. The Red Planet will reach an almost-blistering magnitude –2.8 at opposition on July 27.

MARS: NASA / JPL-CALTECH; INSET: Y. BELETSKY (LCO)/ESO

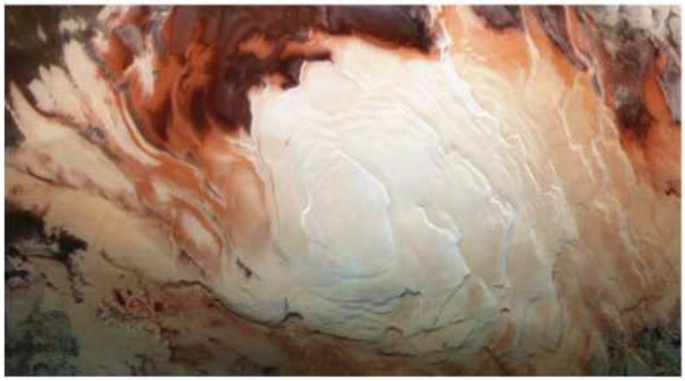
As always, your best strategy is to observe the planet as often as possible to maximise the chance of getting a sharp look during infrequent spells of excellent seeing, when all dross falls away and the planet looks as real as being there. Remember to allow your telescope's optics to cool to the outside temperature, so they don't become their own source of 'boiling' air. Mars won't be this close to Earth again until September 2035, a simple fact that motivates many a Mars-watcher to put eye to eyepiece every clear night around opposition.

The Red Planet will remain in Capricornus for the next few months, making a brief foray west into neighbouring Sagittarius near the end of its retrograde loop in late August. Minimum declination of –26° 33′ will occur on August 15 and by the end of October still be a respectable –17°.

What to see

The south polar cap (SPC) will highlight the first half of the apparition. Tipped in our direction, this frozen CO_2 button will appear big and bright as it emerges from its winter hood of clouds in late April and May. Watch it gradually shrink and rift as opposition approaches. We'll also see part of the north polar hood (NPH), a dull, diffuse cap of clouds shrouding the north polar cap (NPC). Look for it along the planet's northern limb throughout the winter and early spring. The NPH is often confused with the much brighter, more distinct true cap, but that won't be visible until mid-winter 2019.

Spring in Mars' southern hemisphere occured on May 22 with the cap at maximum extent. North of the SPC, keep a wary eye out for another polar cap look-alike, the

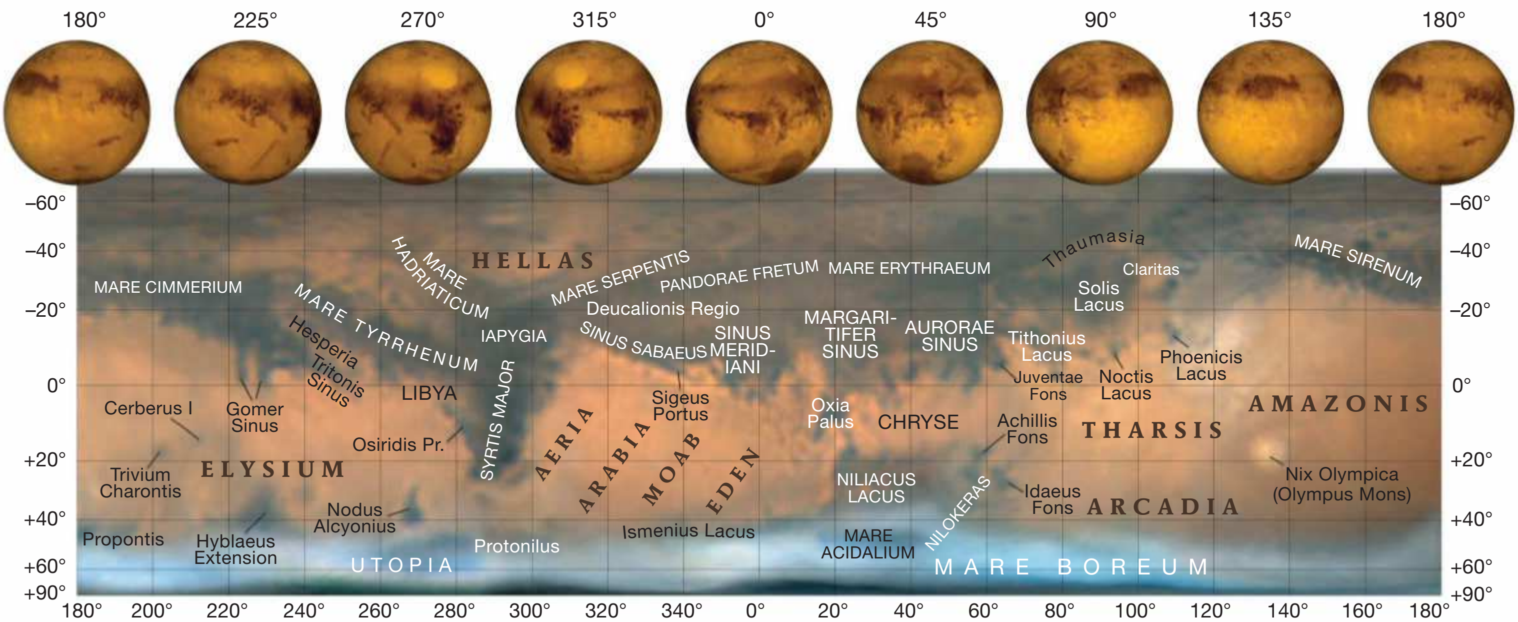


▲ **SOUTHERN ICE** The south polar cap, which reaches 3 km deep in places, is made up of frozen water and carbon dioxide.

2,300-kilometre-wide impact basin Hellas. In June, Hellas might be still be coated with frost or hidden under a blanket of clouds, mimicking the appearance of a polar cap, but you can tell the two apart — Hellas is distinctly north of the SPC and appears duller. Even small scopes should provide great views of these polar features.

Albedo markings

Like the Moon, Mars readily reveals surface features called *albedo markings* across its orange globe. Some change shape with the seasons or from apparition to apparition depending on how the Martian winds move bright surface dust around. The most obvious southern hemisphere features include Syrtis Major, an ancient shield volcano shaped like the subcontinent India; the 'chicken drumstick' combination of Sinus Sabaeus



▲ **PRACTICE MAKES PERFECT** The more often you observe Mars, the easier you'll find it to detect albedo markings. Use this map to identify them. Damian Peach assembled this map from images he took during 2009–10. The globes, tipped correctly for the current apparition, are from the software program WinJupos. Each globe displays the central meridian longitude that is directly below it on the map. Moderate-aperture telescopes will show only the darkest, largest regions. South is up.

COME CLOSER As it approaches Earth, Mars will swell from a small apparent disk to a maximum diameter of 24.3″ on July 31, the date of closest approach. Opposition occurs on July 27. The images show Mars at 0^h UT, with the planet's declination and distance from the Sun noted in astronomical units (au). South is up.

Date	Feb. 12	Mar. 25	Apr. 20	May 9	July 31	Oct. 31	Nov. 21	Dec. 21	Feb. 6
Diam	6″	8″	10″	12″	24.3″	12″	10″	8″	6″
Dec	–23.4	–23.5	–23.4	–22.4	–25.8	–16.8	–11.7	–3.5	9.8
AU	1.566	1.173	0.938	0.781	0.385	0.781	0.932	1.169	1.570

MARS CALENDAR

May 22
Equinox on Mars. The planet shines at magnitude –1.0, with a diameter of 13.9″.

June 28
Retrograde (westward) motion begins. Mars shines at magnitude –2.0, with a diameter of 20.2″.

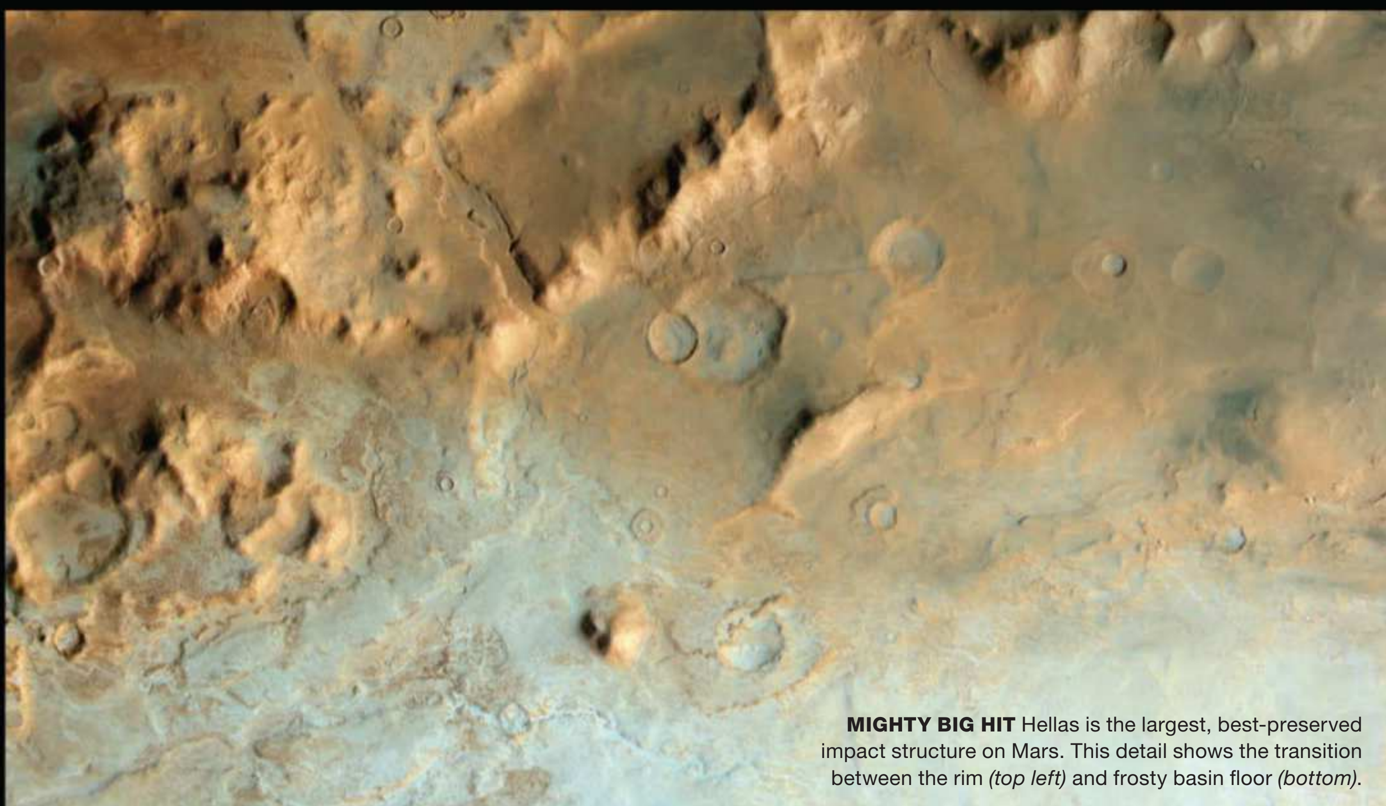
July 27
Mars reaches opposition. Mars shines at magnitude –2.8, with a diameter of 24.3″.

July 31
Mars makes its closest approach to Earth.

Aug. 28
Retrograde motion ends, direct (eastward) motion resumes. Mars shines at magnitude –2.2, with a diameter of 21.6″.

Sept. 16
Mars is at perihelion. The planet shines at magnitude –1.7, with a diameter of 18.3″.

Oct. 16
Solstice on Mars. The planet shines at magnitude –0.9, with a diameter of 13.6″.



MIGHTY BIG HIT Hellas is the largest, best-preserved impact structure on Mars. This detail shows the transition between the rim *(top left)* and frosty basin floor *(bottom)*.

SOUTH POLE: ESA / DLR / FU BERLIN / BILL DUNFORD; ALBEDO MARKINGS: DAMIAN PEACH / GREGG DINDERMAN (S&T); APPARITION: ALPO; HELLAS: ESA / DLR / FU BERLIN / CC BY-SA 3.0 IGO and Sinus Meridiani (east of Syrtis Major); the great bands of Mare Tyrrhenum and Mare Cimmerium that stretch west of Syrtis Major; the vast and amoebic Mare Erythraeum-Aurorae Sinus complex; and the dark eye of Solis Lacus. In the northern hemisphere you can't miss the dark thumb of Mare Acidalium and Niliacus Lacus located at the same longitudes as Mare Erythraeum.

But identifying albedo markings can take time. Most are subtle and difficult to pick out against the glaring orange landscape; but with practice, they become easier to see until you recognise them like continents on a globe. To make the task easier, observe the planet with as much magnification allowed by the seeing conditions. I've always found a red #23A filter a big help in boosting their contrast.

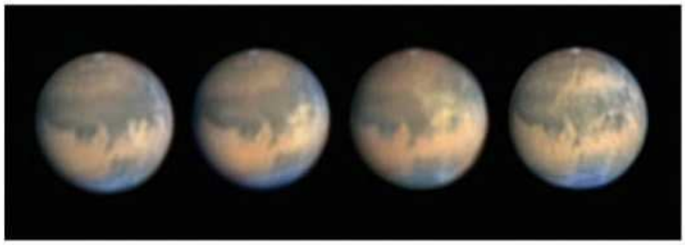
This is especially true when viewing Mars' 'boring' hemisphere, located between about longitudes 110° and 240°, which includes the narrow polar-hugging stripe of Mare Sirenum and the low-contrast volcanoes of the Tharsis Plateau. Orographic clouds often cover Olympus Mons, the planet's largest extinct volcano, making it look like a pale, white pustule in the ochre desert.

Clouds, hazes and dust storms

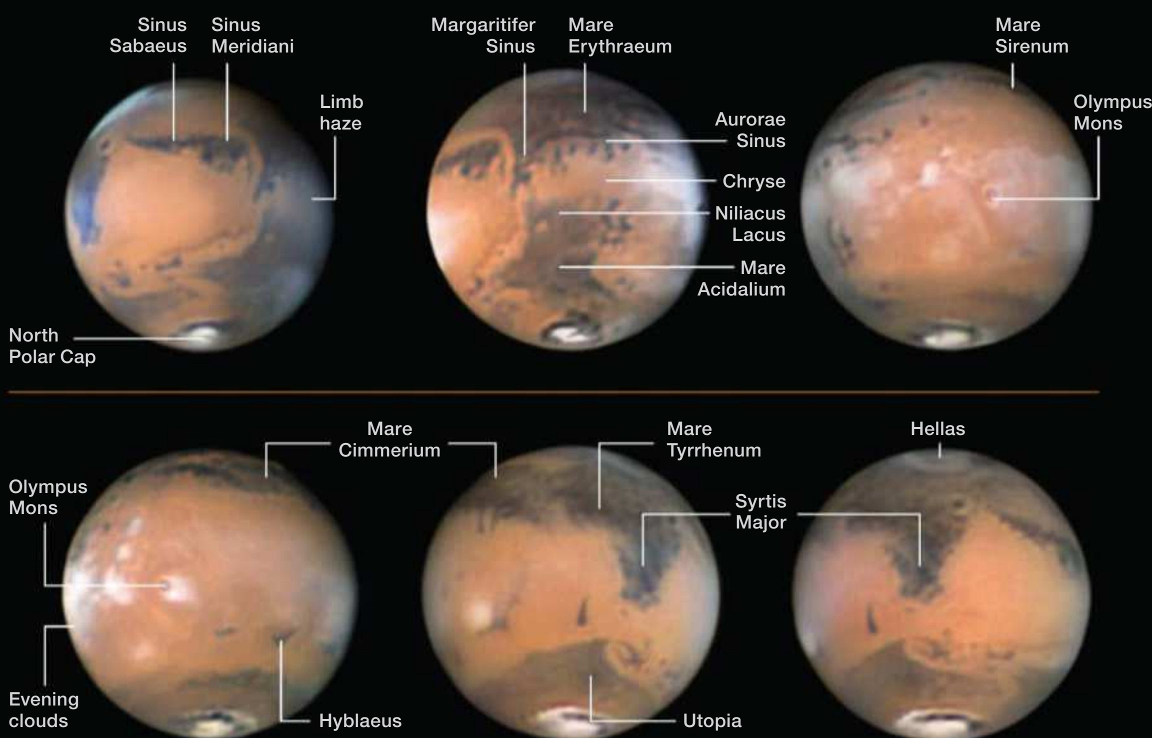
One of the most exciting aspects of observing Mars is discovering its similarities to Earth. Both planets have their share of clouds, fog and mist. On Mars, these often appear as narrow bands of white haze along either the morning or evening limb where the Sun is just rising or setting. In my experience, these are the most common clouds visible through amateur telescopes, but watch for isolated puffs and high-altitude clouds that hug Martian volcanoes. A blue #80A filter will enhance their visibility.

In the opposite hemisphere, autumn will be underway during Earth's winter and spring, with clouds forming over the north polar cap (NPC) and beyond to create the NPH. By October, the NPH may extend as far south as latitude 50° north, giving the 'top' of Mars a diffuse, off-white cast as if it had been dipped in milk. Isolated clouds can appear anytime, especially as the SPC shrinks through the summer and fall.

One of the most dramatic events to witness is a dust storm — as long as it doesn't expand to become a planet-encircling event! This last occurred in June 2007, when, within a few



▲ **YELLOW STORM RISING** With frequent observing, you can detect changes in the day-to-day appearance of Mars. For example, a dust storm erupted on the planet in October 2005. By recording images each night, Sean Walker was able to track the progress of the yellowish clouds as they travelled across the planet's dark surface. South is up.

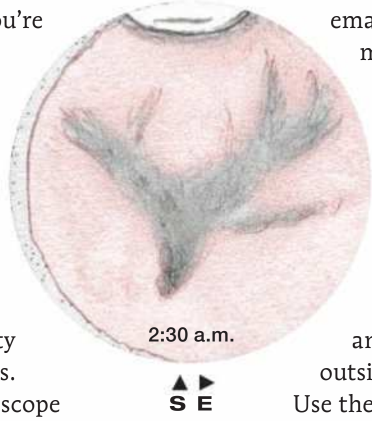


SHARPEST VIEW
These images captured during the planet's 2012 apparition show many of Mars' dark albedo markings. The planet rotates every 24 hours, 38 minutes. Since that's very similar to Earth's rotation, we view nearly the same hemisphere from night to night. If you observe Mars at 11 p.m. from the same place night after night, the planet will appear to rotate in retrograde (backward) over a period of about six weeks. If you see Syrtis Major front and centre at 11 p.m. the first night, you will see it in that same spot about six weeks later. To see a different side of the planet, you need to observe Mars at a different time of night or from a different longitude. South is up.

weeks, dust had blanketed nearly every feature from view. Fortunately, such planet-wide events are uncommon, with just 10 recorded over the past 130 years.

The more often you observe Mars, the more familiar you'll be with any changes in the appearance of albedo features that mark the onset of a dust storm. Watch for a familiar feature to disappear or a light area to appear. Visually, dust storms appear as bright, yellow patches. A #23A red filter will brighten and enhance the view and serve to confirm that you're seeing dust and not water vapour clouds.

Dust storms are common during the Martian southern summer, which begins in mid-October. Good spots to keep an eye on include the Chryse region and Hellas-Noachis from late August through November.



◀ **NIGHT WATCH** The author drew two sketches of Mars, two hours apart, as viewed with a 25-cm telescope at 256× on August 4, 2003 UT. The sketches show the planet's rotation as well as several of its most prominent features, including the dark 'finger' of Syrtis Major and the south polar cap. In the bottom view, a dark rift shows in the cap. Such rifts appear as the cap shrinks.

Phobos and Deimos

Close oppositions provide a perfect opportunity to see the Martian moons, Deimos and Phobos. Without the planet nearby, even a 75-mm telescope would be up to the task: their 2018 opposition magnitudes are 11.5 and 10.5, respectively. But Deimos strays just 1.2′ (arcminutes) and Phobos only 21″ from the planet at best, so you'll need at least a 25-cm instrument and careful planning. First and foremost, make your attempt around opposition when the moons are brightest and their angular distance from Mars is at maximum.

I saw both moons during the 2003 perihelic opposition of Mars through a 28-cm Schmidt-Cassegrain telescope by hiding the brilliant planet behind an occulting strip made of aluminium foil taped across the field stop of an ancient orthoscopic eyepiece. With Mars safely hidden and a magnification of 233× applied, Deimos was an obvious pinpoint of light in the glare. Phobos, though brighter, orbits much closer to the planet and proved much more challenging.

Go for it and surprise yourself. Several planetarium-style software programs including the free Stellarium (**stellarium.org**) display the moons, allowing you to plan your observing session when either is at maximum elongation from the planet.

Be a planetary ambassador

Finally, don't forget to get the public involved. Who could forget the internet rumor started in 2003 about Mars appearing as big as the full Moon at opposition? I won't quote the full e-mail that bounded from inbox to inbox, but surprisingly, its content was mostly true, as it claimed Mars through a 75× eyepiece would look as large as the full Moon to the naked eye. Since the post referred to its apparent diameter, it was correct. Multiply 25″ × 75 and you get 31′, the full Moon's apparent diameter.

Then an unfortunate thing happened. As the email made the rounds, the reference to "at a modest 75-power magnification" was left out, leading neophyte skywatchers to expect a frighteningly large, Moon-sized Mars casting a rusty spectre over the landscape. Like a mosquito you hear but forever fail to swat, the description has popped up at every subsequent opposition. Watch for it to reappear on schedule this apparition, and when friends ask what's up, patiently explain and then direct them to the real thing right outside their window.

Use the hype that will inevitably spin out of social media to your advantage to share Mars and the joys of looking up with those new to the hobby. And it won't hurt one bit if you mention how important minimising light pollution is for a great dark sky experience.

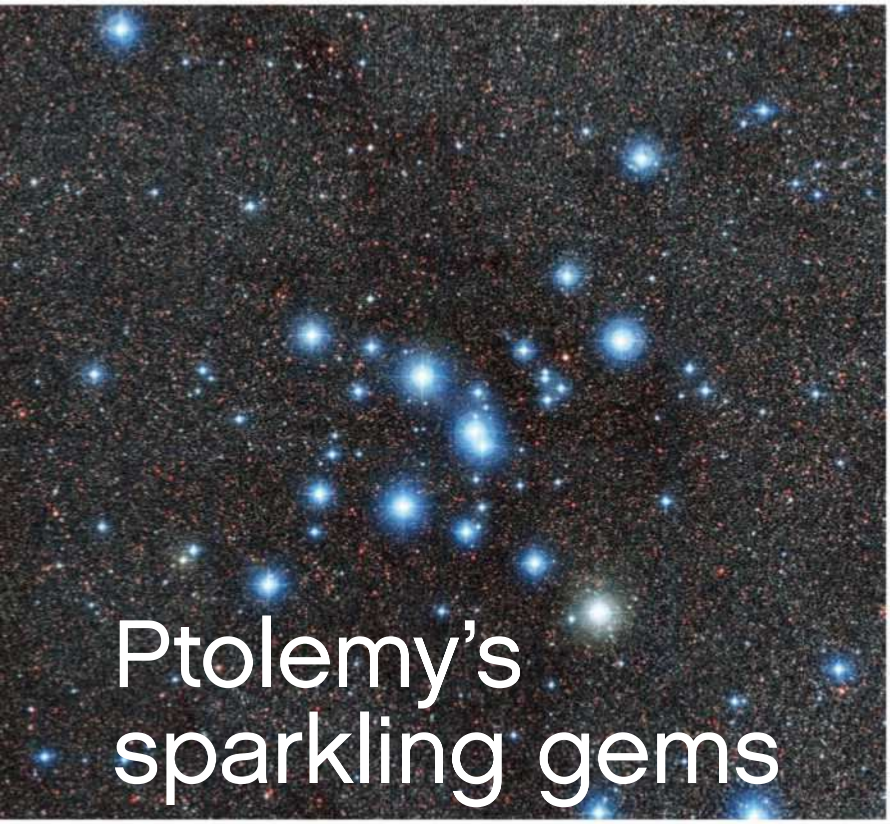
■ **BOB KING** has been an avid observer since childhood. He's a long-time member of the American Association of Variable Star Observers (AAVSO) and author of multiple observing guides, including *Wonders of the Night Sky You Must See Before You Die*. Visit his blog at **astrobob.areavoices.com**.

ALBEDO MARKINGS: DAMIAN PEACH; SKETCHES: BOB KING

USEFUL RESOURCES

Though the internet is often a tool for rumour-mongering, it can also provide good information for planetary observers. Here are a few sites to visit during this opposition of Mars.

- *Sky & Telescope* Mars Profiler (**https://is.gd/marsprofiler**)
- Association of Lunar and Planetary Observers (ALPO) Mars Section (**alpo-astronomy.org/marsblog**)
- The Red Planet (**https://mars.nasa.gov/#red_planet/**)
- The 2018 Perihelic Opposition of Mars (**alpo-astronomy.org/jbeish/2018_MARS.htm**)
- How to Make An Occulting Bar (**https://is.gd/OccultingBar**)
- Mars Observers Yahoo Group (**groups.yahoo.com/group/marsobservers)**



Ptolemy's sparkling gems

There is such a wealth of celestial richness in Scorpius for the binocular user that it's sometimes hard to know where to begin. The constellation's star clusters, nebulae (bright and dark) and overall background star-field hold the promise of many hours of enjoyable viewing. One of the standout objects in Scorpius is number 7 on Charles Messier's famous list of deep sky objects. (It is, in fact, the southernmost object on his list.) Messier 7 is also catalogued as NGC 6475, but its common name is the Ptolemy Cluster, named after the 2nd century CE astronomer Claudius Ptolemy.

Every astronomer worth their salt has remarked upon the sparkling gems that make up M7. Ptolemy himself in CE 130 mentioned the "nebula following the sting of Scorpius," while John Herschel described "a brilliant coarse cluster" and Ernst Hartung noted that it is "a remarkable sight". Messier called it a "cluster considerably larger than the preceding" item on his list, M6.

Easily spotted with the naked eye, your binoculars (depending upon their size) will reveal a scattering of around a dozen stars, while a telescope will reveal up to about 80. Take the time to gaze into the cluster's depths, noting how its component stars seem to float in front of the Milky Way's background.

The combined magnitude of M7's stars is listed at 3.3, which is why it's so easy to spot with the naked eye, particularly as it is nice and high for us southern observers. Astronomers estimate it lies about 800 light-years from Earth, and is heading toward us at a leisurely 14 kilometres per second.

■ **JONATHAN NALLY** loves sweeping up and down the Milky Way with his 10×50s.

USING THE STAR CHART

WHEN

Early June	10 p.m.
Late June	9 p.m.
Early July	8 p.m.
Late July	7 p.m.

These are standard times.

HOW

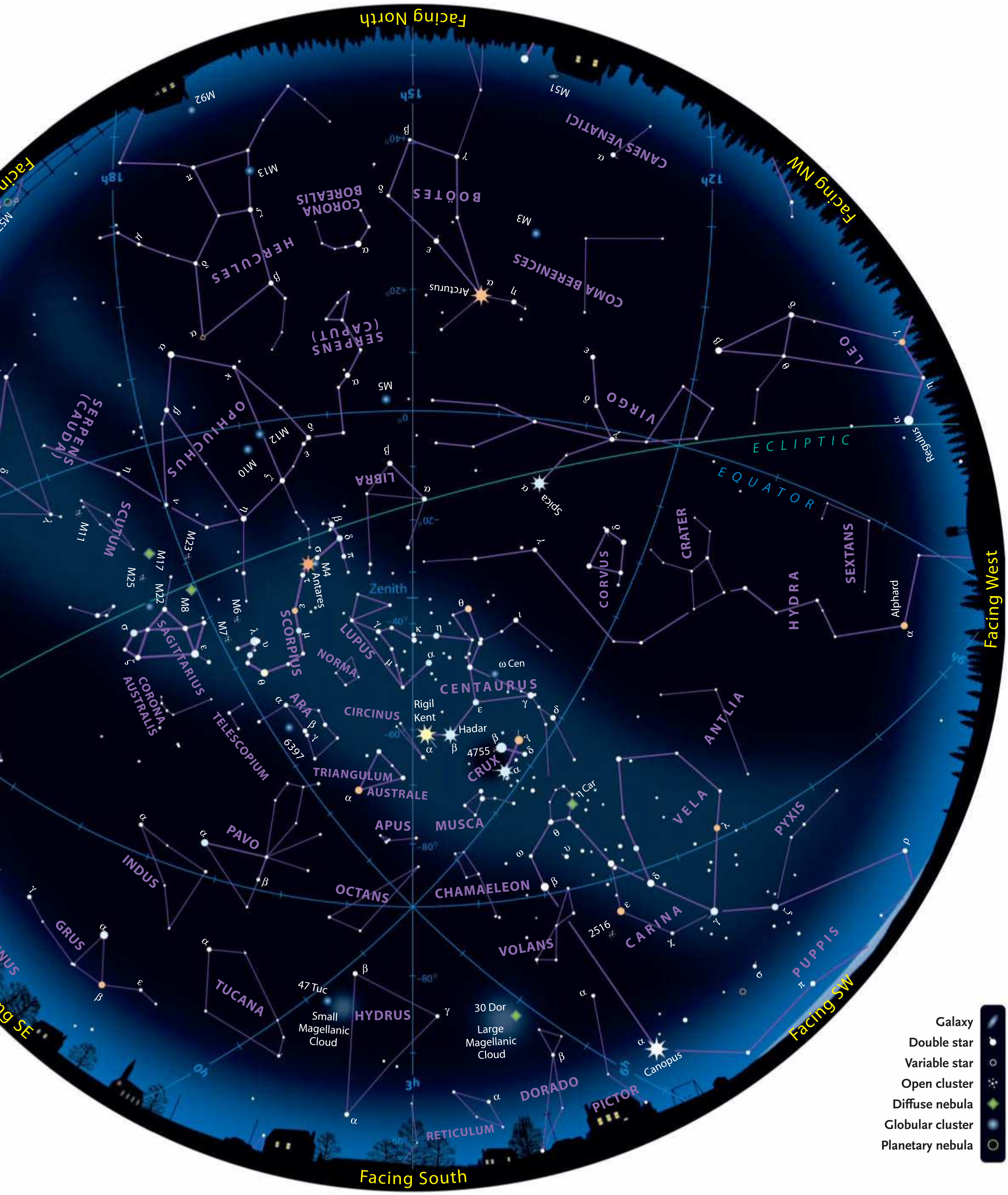
Go outside within an hour or so of a time listed above. Hold the map out in front of you and turn it around so the label for the direction you're facing (such as west or northeast) is right-side up. The curved edge represents the horizon, and the stars above it on the map now match the stars in front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

FOR EXAMPLE: Turn the map so the label 'Facing North' is right-side up. About halfway from there to the map's centre is the bright star Arcturus. Go out and look north nearly half-way from horizontal to straight up. There's Arcturus!

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

ONLINE

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



Facing North
Facing NW
Facing West
Facing SW
Facing South
Facing SE
15h
12h
18h
9h
6h
3h
0h
M92
M51
M13
M3
M5
M12
M10
M11
M17
M25
M22
M23
M8
M6
M7
M4
CANES VENATICI
CORONA BOREALIS
BOÖTES
HERCULES
COMA BERENICES
Arcturus
SERPENS (CAPUT)
LEO
Regulus
OPHIUCHUS
SERPENS (CAUDA)
VIRGO
ECLIPTIC
EQUATOR
LIBRA
Spica
SCUTUM
CRATER
SEXTANS
CORVUS
HYDRA
Alphard
Antares
Zenith
SCORPIUS
LUPUS
NORMA
SAGITTARIUS
ω Cen
CENTAURUS
CORONA AUSTRALIS
ARA
CIRCINUS
Rigil Kent
Hadar
ANTLIA
TELESCOPIUM
6397
4755
CRUX
TRIANGULUM AUSTRALE
η Car
VELA
PYXIS
PAVO
APUS
MUSCA
INDUS
OCTANS
CHAMAELEON
CARINA
2516
GRUS
VOLANS
PUPPIS
TUCANA
47 Tuc
Small Magellanic Cloud
HYDRUS
30 Dor
Large Magellanic Cloud
Canopus
DORADO
PICTOR
RETICULUM
Galaxy
Double star
Variable star
Open cluster
Diffuse nebula
Globular cluster
Planetary nebula

All my Mars at once

The author shares a lifetime of encounters with the Red Planet.

When I was young the title of a science fiction story that I hadn't even read caught my attention: 'All the Last Wars at Once'. Now, with Mars closer to us than at any other time in the 32 years between 2003 and 2035, I'd like to share a concentrated account of memorable Mars moments — mostly observational — from my lifetime. Like mine, your sights of mighty Mars this winter will be grounded in whatever past experiences you've had with this most fascinating of our Solar System's planets, the world most like Earth.

My earliest Mars. I can't recall the very first time I knowingly saw Mars, but it was probably before I was 8 years old. Carl Sagan said he was 8 when he stared imploringly at what he thought (but wasn't sure) was Mars. "Imploringly" because he was hoping to be mystically transported to Mars by wishing for it like John Carter did in Edgar Rice Burroughs's early 20th-century tales of adventures on the Red Planet. I probably didn't read the John Carter books until I was a few years older. But actually my earliest encounter with Mars happened when I was about minus-5 or minus-6 months old. My mother always told me she remembered how often and intensely she found herself watching Mars in that season of a near-perihelic opposition of the planet when she was pregnant with me.

Mars and stars. This column is called 'Under the Stars,' so it seems appropriate to mention a few connections of Mars and stars that make the stars involved all the more wonderful.

Mars spends most of its time far enough from Earth for it to be outshone by close to 30 of the brightest stars. But then it remarkably kindles, doubling in brightness in mere months, until, in a month such as July 2018, it burns almost five magnitudes brighter, greatly outshining even Sirius.


Mars and the Moon shine in evening twilight.

The star most famously connected with Mars is, of course, the red giant Antares, whose name means 'rival of Mars' — rival in colour. Back in February, Mars passed fairly near Antares at similar brightness. But the perihelic oppositions of Mars typically occur when Mars has moved on to glow like a burning coal in the largely dim zodiac constellations of Capricornus or Aquarius.

Mars, Mebsuta and me. Mars has a special connection with a much dimmer star: The planet periodically has very close conjunctions with magnitude-3.1 Epsilon (ε) Geminorum, the star also known as Mebsuta. But back in April 1976 the transparency was excellent and seeing good enough for something much better: Mars' spectacular occultation of Mebsuta. A friend of mine who was (and still is) a gifted telescopic observer saw the star briefly twinkle through the thin Martian atmosphere.

Another person who observed the Mebsuta occultation was a 14-year-old. He had read about the upcoming event in the weekly newspaper column I had started with the coming of Comet West the previous month. (To this day I am still writing that column, though now every other week.) This bright young person contacted me about his observation, and we eventually met, observed together, and went on to become very close friends. Sadly, he died last summer after a long fight with cancer.

In the next issue I'll take an inside look at Martian lore, Viking at Mars, very special daytime observations of Mars, and the greatest meetings of Mars with other planets — including the conjunction of Jupiter and Mars at their best that happens only once every 143 years.

■ Contributing Editor **FRED SCHAAF** is the author of 13 books, including *The Brightest Stars*.

Mars assumes control

The Red Planet rules the night as it reaches perihelion and closest approach.

You're going to hear a lot about Mars this month, but actually the whole of July is superb as far as planet observing goes, as all five naked-eye planets will be visible in the evening sky for the entire period. So keep your fingers crossed for some good weather!

Let's begin with **Mercury** (mag. –0.1 and diameter 6.7″ at the start of the month; 1.5 and 10.0″ by month's end). Reaching greatest elongation on the 12th, the innermost planet will be on display in the western evening sky, setting almost two hours after the Sun on July 1 and 75 minutes post-sunset by the end of the month. The tiny world will be seen skirting the Beehive Cluster (Messier 44) on the 4th, having a close encounter with the Moon on the 15th, and appearing close to 1st-magnitude Regulus on the 25th.

Venus (–4.2, 17.5″) is a western evening object, too, setting just after 8:00pm at the start of July and just before 9:00pm by month's end. Slowly moving through Leo, the bright planet will appear close to Regulus on the 10th, with the thin crescent Moon coming close on the 16th.

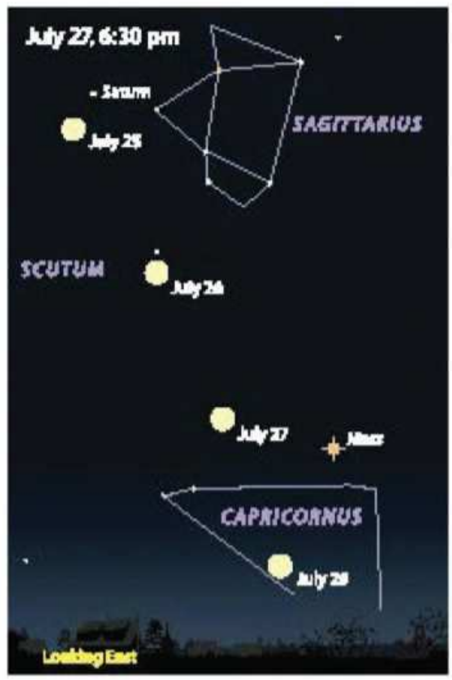
Jupiter reached opposition in May and Saturn in June, but now it's **Mars**' turn, with the Red Planet coming to opposition on the 27th. This will be its best apparition since 2003, with the planet reaching an apparent diameter of 24″ by the last week of July and magnitude –2.8 on the night of opposition. Mars will be closest to Earth a few nights later, on July 31, at a distance of 57,589,196 kilometres.

Being at opposition, the Red Planet will of course rise in the east around the time of sunset and will therefore be visible all night long. Grab your telescope and see if you can spot any features, such as the south polar cap or Syrtis Major. And if you're feeling adventurous, why not try for one or both of its moons, Phobos and Deimos? Turn to pages 36-41 for a full rundown on when, where and how to see the Red Planet.

Jupiter (–2.2, 39.8″), now two months past opposition, is a still a fine sight high in the northern evening sky, setting around 2:30am at the start of the month and by about 1:00am at month's end. The planet has been undergoing retrograde motion for the past few months but will reach its stationary point on the 11th, whereupon it will start heading east again. Take a look on the 21st, and you'll see the nine-day-old Moon nearby.

▲ Venus and Mercury shine together in the west after sunset.

▲ Jupiter, now two months past opposition, is still a fine sight.



▲ Mars reaches its best opposition for 15 years on July 27.

Saturn (0.1, 18.3″) is now just one month past opposition, and can be seen in the eastern sky as evening twilight ends. The ringed world is still a fine sight through the telescope, with its rings tilted nicely and its major moons conducting their dance around the planet. Take a look on the 25th and you'll see the Moon just below Saturn, with the star cluster Messier 22 a few degrees off to its right.

Pluto (14.2, 0.1″), too, reaches opposition this month, on the 12th. The tiny, dim world is obviously not a naked-eye sight, but if you have the right kind of gear with which to spot it, I recommend you give it a go... for conditions will become more difficult each year now as the dwarf planet recedes further from the Sun. See pages 56-57 for our guide to finding and observing Pluto.

There'll be **two eclipses** this month — a partial solar eclipse on the afternoon of the 13th, and a total lunar eclipse on the morning of the 28th. The former will be seen only by those in the extreme south of Australia; the latter will be seen across the country to varying degrees depending upon where you live. Don't forget to use safe observing techniques if you intend to witness the solar eclipse. See pages 60 for full details.

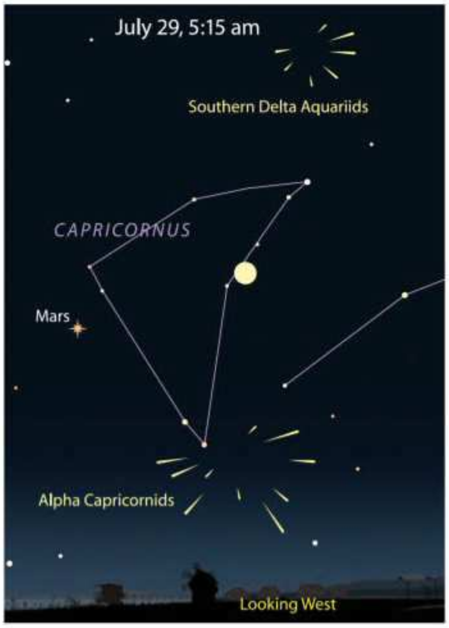
Finally, our own planet will reach its **farthest point from the Sun** (aphelion) on July 7, when we'll be 152,095,566 kilometres from our parent star. Many non-astronomers think that the Earth's farthest and closest (perihelion) points from the Sun are responsible for our seasons. They're not, of course; rather, the seasons are caused by Earth's axial tilt. This is a good topic on which to engage with your friends and family, using the opportunity to impart a little astronomical knowledge.

Two peaks in two days

Twin meteors showers will compete for attention at the end of July.

Mid-winter is a great time for meteor observing in the Southern Hemisphere, with two fine meteors showers to see in a similar region of the sky (see diagram).

The Southern Delta Aquariids are active from July through to August, peaking on the morning of July 30. The near full Moon will greatly affect rates this year; however, from dark skies, you might be able to see anywhere from 5 to 7 meteors every hour. Start your observing session after 3:00am for the best views.



The Alpha Capricornids are active from July to August too, peaking one day earlier on the morning of July 29. This shower is well-known for producing bright fireballs, and so will be somewhat less affected by the near full Moon because of this. I recall once witnessing a magnitude –6.0 green bolide when observing from rural Victoria in 2012.

The predicted zenithal hourly rate, or ZHR — the theoretical number of meteors that would be seen if the shower were directly overhead, and you were therefore looking through the minimum amount of atmospheric extinction — for 2018 is 2 to 3 meteors per hour. And just like with the Southern Delta Aquariids, it is best to start observing after 3:00am.

■ **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)

JULY

- **1** Mars 5° south of Moon
- **7** Earth at aphelion
- **10** Venus 1.1° north of Regulus
- **10** Aldebaran 1.1° south of Moon
- **12** Mercury greatest elong. east (26°)
- **13** Partial solar eclipse
- **15** Mercury 2° south of Moon
- **16** Venus 1.6° south of Moon
- **21** Jupiter 4° south of Moon
- **25** Saturn 2° south of Moon
- **27** Mars at opposition
- **28** Total lunar eclipse
- **31** Mars closest approach

LUNAR PHENOMENA

JULY

Last Quarter ...... 6th, 07:51 UT
New Moon ...... 13th, 02:48 UT
First Quarter ...... 19th, 19:52 UT
Full Moon ...... 27th, 20:20 UT
Perigee ...... 13th, 08h UT, 357,431 km
Apogee ...... 27th, 06h UT, 406,223 km

Hercules' time to shine

Heroic efforts are not needed to see these double stars.

Last year we visited part of Hercules, with some doubles from Lyra thrown in. This time our selection is from southwest Hercules, not as far above the Celestial Equator. First up is the easy, bright **Kappa Herculis**, a 5th- and 6th-magnitude pair of yellow stars that shows well through 8-cm scopes. An optical pair with no gravitational connection, it's nevertheless an attractive object, although merely a result of our line of sight.

About 3.5 degrees south-southeast from Kappa is **STF 2021** (Σ 2021 on star charts), sometimes labelled 49 Ser. A gravitational binary in a very large orbit, its uncertain orbital period is estimated as 1350 years. With my 14-cm refractor at 80× it was a neat orange and yellowish pair, in a scattering of moderate and faint stars. Using an 8-cm f/5 refractor, 53x showed the stars just separated and 110× gave an easy split. The brighter images of 14-cm showed the colours better.

Another binary, with a much shorter orbital period of 230 years, **STF 2052** is 5 degrees east and just north from Kappa Her. It's 64 light-years from us, and the present separation of the stars in line of sight is 47 a.u., similar to Pluto when widest from the Sun. Presently near maximum separation, STF 2052 was closest a century ago. With my 14-cm refractor at 80× it showed as a moderately bright, equal orange pair, just apart.

Well south from this area, in the field of 5.6 magnitude 28 Her, is **STF 2056**, a quite unequal double, with 1.5 magnitudes difference between the stars. The 14-cm refractor at 80× showed a rather nice, yellowish-white, unequal pair. At an easy 6.7″ separation, similar proper motions suggest it is a binary, though it has changed very little in nearly 200 years. It's not a nearby object, perhaps 400 light-years away.

The brightest of our doubles this month is 3rd-magnitude **Zeta Her**, a quite unequal (2.5 mag. difference) and fairly close pair in an orbit of only 34.45 years. Merely 35 light-years from us, the fairly eccentric orbit has a maximum separation around 17 a.u., similar to the distance of Uranus from the Sun.

Hartung describes Zeta's colour contrast as "almost orange" and "greenish," but most observers see shades of yellow for both stars. With my 14-cm refractor, in recent times at 160× I saw the companion as a spot disrupting the first diffraction ring, becoming more obvious at 230×.

Zeta is a good object for steadier nights, but can be difficult. Reflecting telescopes make unequal pairs more difficult than with a refractor, because the secondary mirror increases the brightness of the first diffraction ring. Various observers commented on attempting Zeta in 2015, when it was at 1.2″ separation, and found it visible with as little as a 12-cm refractor; but it was sometimes difficult with larger reflectors.

Some 3 degrees south from Zeta is **46 Her** (STF 2095), of 7th and 9th magnitudes at 5″ separation. Again I observed it with 14 cm and the short 8-cm, the latter hinting at the companion with 53× and making it clear at 110×. It is, however, somewhat dim for 8 cm. With 14 cm at 80× it was a fairly bright yellow star with an easy, lesser companion; a good effect.

About 1.5 degrees east and slightly north from 46 Her is **STF 2107**, an unequal, fairly close yellow pair, mag. 6.9 and 8.5. Due to only 1.4″ separation and the brightness difference I'd suggest using at least 10 cm. The 14-cm refractor at low power showed a bright yellow star making a triangle with two lesser stars. It was just apart at 230×, with an attractive brightness contrast.

The last of our doubles this time is **STF 2094**, 8 degrees south of Zeta and slightly east, a near equal pair of yellowish stars with a dim, fairly wide third star. The 8th-mag. stars are quite close at 1.1″, so this one is for medium apertures, say 12 cm and more. The 14-cm refractor showed it well at 160×, just double, with the 12th-mag. star 25″ northwest also seen.

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

Double stars of Hercules

Star Name	R. A.	Dec.	Mag.	Sep.	Position angle	Date of measure	Spectrum
Kappa (STF 2010)	16h 08.1m	+17° 03′	5.1, 6.2	27.3″	015°	2016	G7III
STF 2021	16h 13.3m	+13° 32′	7.4, 7.5	4.1″	358°	2015	G9V+G9V
STF 2052	16h 28.9m	+18° 25′	7.7, 7.9	2.4″	121°	2016	K1V
STF 2056	16h 31.6m	+05° 26′	7.8, 9.2	6.7″	313°	2015	A3
Zeta (STF 2084)	16h 41.3m	+31° 36′	3.0, 5.4	1.2″	139°	2014	G0IV+K0V
STF 2094	16h 44.2m	+23° 31′	AB 7.5, 7.9	1.1″	074°	2015	F5III
"	"	"	AC 7.5, 11.7	24.7″	310°	2013	"
46 Her (STF 2095)	16h 45.1m	+28° 21′	7.4, 9.2	5.2″	163°	2013	F7III
STF 2107	16h 51.8m	+28° 40′	6.9, 8.5	1.4″	104°	2015	F5IV

Data from the *Washington Double Star Catalog*.

Long-period luminaries

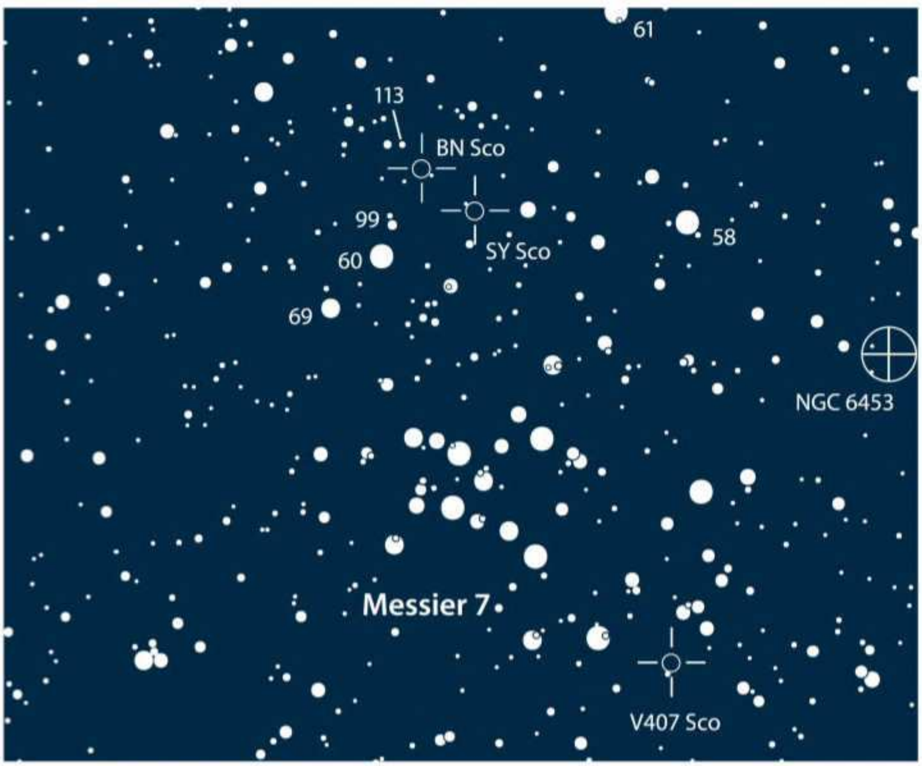
Three stellar targets in the heart of an open cluster.

Messier 7 in Scorpius is also known as Ptolemy's Cluster, named for the 2nd century European astronomer. This cluster is found in a rich field — in addition to the globular cluster NGC 6453 far in the background, there are also a couple of Barnard's dark nebulae and many double stars. And there are hundreds of variable stars within the 1.3 degree field of M7, although most of them are not suitable for visual observers. But let's look at three very different long-period variables that most certainly are suitable.

BN Sco is a rare example of a Mira-type variable with a double maxima. It is very red, and has a period of 620 days with a magnitude range from 9.8 to less than 14.5. Nearby is **SY Sco**, a Mira-type with a period of 230 days, ranging from magnitude 8.5 to 14.5. And to the south of the cluster is **V407 Sco**, a star for whose understanding we owe thanks to Australian observer Peter Williams. Because of his work we can now say that V407 Sco has a period of 401.5 days with a magnitude range of 10.2 to less than 14.5.

All three of these stars are in need of visual observations, but nothing more strenuous than once per week or two. To begin, don't look for the targets themselves, but rather find their fields. The stars themselves may or may not be visible. The magnitudes on the chart on this page only give a rough idea of what you're looking at; it's recommended that you generate your own charts through the AAVSO website (**aavso.org**).

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



◀ SY Sco is located at 17h 53m 48.82s, –34° 24' 02.9"; BN Sco at 17h 54m 10.57s, –34° 20' 27.3"; and V407 Sco at 17h 52m 25.52s, –35° 03' 17.4" (epoch J2000). This chart (courtesy of the AAVSO) shows stars to about magnitude 12.5. Visual magnitudes shown with decimal points omitted to avoid confusion with faint stars — so 60 denotes a magnitude 6.0 star.

SPOT ON

JUPITER IS STILL worth your attention, even though it is now a couple of months past opposition. Here are the times, in Universal Time, when the Great Red Spot should cross the planet's central meridian. The dates, also in UT, are in bold.

July 1, 0:10, 10:06, 20:01; **2,** 5:57, 15:53; **3,** 1:48, 11:44, 21:40; **4,** 7:36, 17:31; **5,** 3:27, 13:23, 23:18; **6,** 9:14, 19:10; **7,** 5:06, 15:01; **8,** 0:57, 10:53, 20:48; **9,** 6:44, 16:40; **10,** 2:36, 12:31, 22:27; **11,** 8:23, 18:19; **12,** 4:14, 14:10; **13,** 0:06, 10:01, 19:57; **14,** 5:53, 15:49; **15,** 1:44, 11:40, 21:36; **16,** 7:32, 17:27; **17,** 3:23, 13:19, 23:15; **18,** 9:10, 19:06; **19,** 5:02, 14:58; **20,** 0:53, 10:49, 20:45; **21,** 6:41, 16:36; **22,** 2:32, 12:28, 22:24; **23,** 8:19, 18:15; **24,** 4:11, 14:07; **25,** 0:02, 9:58, 19:54; **26,** 5:50, 15:45; **27,** 1:41, 11:37, 21:33; **28,** 7:28, 17:24; **29,** 3:20, 13:16, 23:11; **30,** 9:07, 19:03; **31,** 4:59, 14:55.

These times assume that the spot will be centred at System II longitude 290°. If the Red Spot has moved elsewhere, it will transit 1 2/3 minutes earlier for each degree less than 290° and 1 2/3 minutes later for each degree more than 290°.

Three comets for consideration

Cometary comings and goings for mid-year.

Comet **C/2016 M1 (PANSTARRS)** continues its path through the far southern skies during July, as it approaches its August 10 perihelion (closest point to the Sun) at a relatively remote 2.21 a.u.

As mentioned in the previous issue, this is a relatively bright comet intrinsically; it should remain at about magnitude 9 throughout the month as its decreasing distance from the Sun is partially offset by its increasing distance from Earth. Trekking from Ara into Norma mid-month, the comet will be well-placed for observers at mid-southern latitudes.

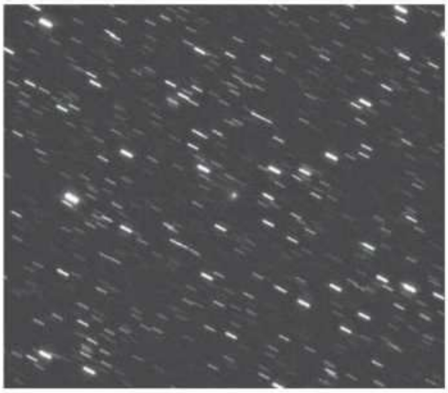
The previous issue also made mention of **C/2017 T3 (ATLAS)**, which is due to arrive at its perihelion passage, at a distance of 0.82 a.u. from the Sun, on July 19. Throughout this month, the comet treks from Orion, into Monoceros during the middle of July, clipping Canis Major by the end of the third week and reaching Puppis as the month's final week begins. This will make it a pre-dawn object, low on the eastern horizon. The comet will probably glow at around magnitude 9.5 as July opens, but as it is approaching both Earth and Sun through the first half of July, it is expected to brighten by about half a magnitude near the date of perihelion and fade only slightly through the latter half of the month as it approaches to 1.35 a.u. from Earth on August 1.

July will also see the relatively close approach of a periodic comet making only its second observed return to perihelion. This object was discovered by Pan-STARRS 1 on February 13, 2013 and initially given the asteroid designation of 2013 CU 129 because of its stellar appearance. Subsequent observations in June of that year did, however, detect clear signs of cometary activity and CCD images showed quite a strong tail. Having a period of just 4.9 years, the comet was recovered last January 12 by D. C. Fuls at Mt Lemmon and, on the 16th by E. Schwab at Egelsbach in Germany, in images obtained remotely with the 0.8-m Schmidt telescope at Calar Alto in Spain. Given the designation P/2018 A2 (PANSTARRS), the comet's magnitude was estimated as 20.6 on the 12th and 20.0 on the 16th. It has now been given the permanent designation of **364P/PANSTARRS**.

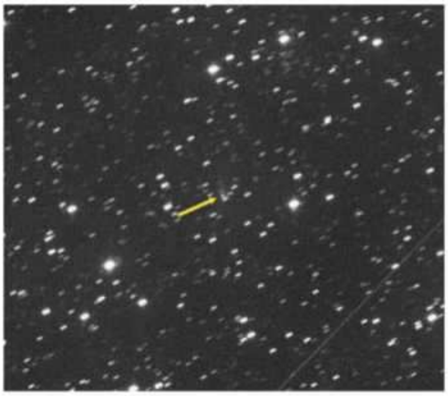
An interesting visitor

An intrinsically faint object, 364P/PANSTARRS passed perihelion at 0.798 a.u. from the Sun on June 24, but will make a relatively close approach of just 0.23 a.u. to our planet on July 18. At the beginning of July it will be located low in the head of Hydra before clipping Monoceros and passing into Puppis during the first week and into Canis Major during the second week of the month. It will become better placed in the morning skies from the middle of July, reaching Columba late in the third week before crossing Caelum and into Eridanus during July's final days. Despite its close approach to Earth, it will likely not become brighter than about magnitude 11 to 11.5, although some more optimistic forecasts suggest that it could be about one magnitude brighter than this around the time of its closest passage. In any case, this year provides a good opportunity to obtain visual observations of this dim but interesting object.

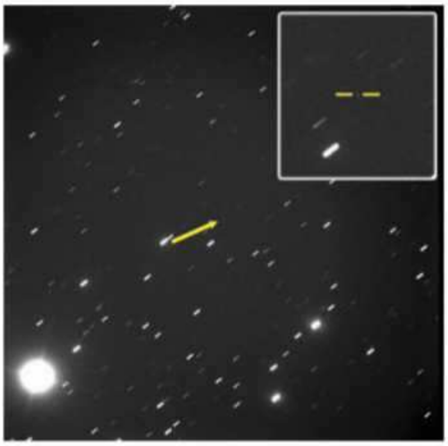
■ **DAVID SEARGENT** is a long-time comet observer and author of several books on the subject, including the recent *Weird Comets and Asteroids* and *Visually Observing Comets*.



▲ Comet C/2016 M1 (PANSTARRS) is well placed for viewing in the southern sky during July.



▲ 364P/PANSTARRS will come to a closest approach of 0.23 a.u. from Earth on July 18.



▲ Look for C/2017 T3 (ATLAS) low on the eastern horizon before dawn.

Winter deep sky delights

Warm nights and dark skies are ideal for enjoying these classic beauties.

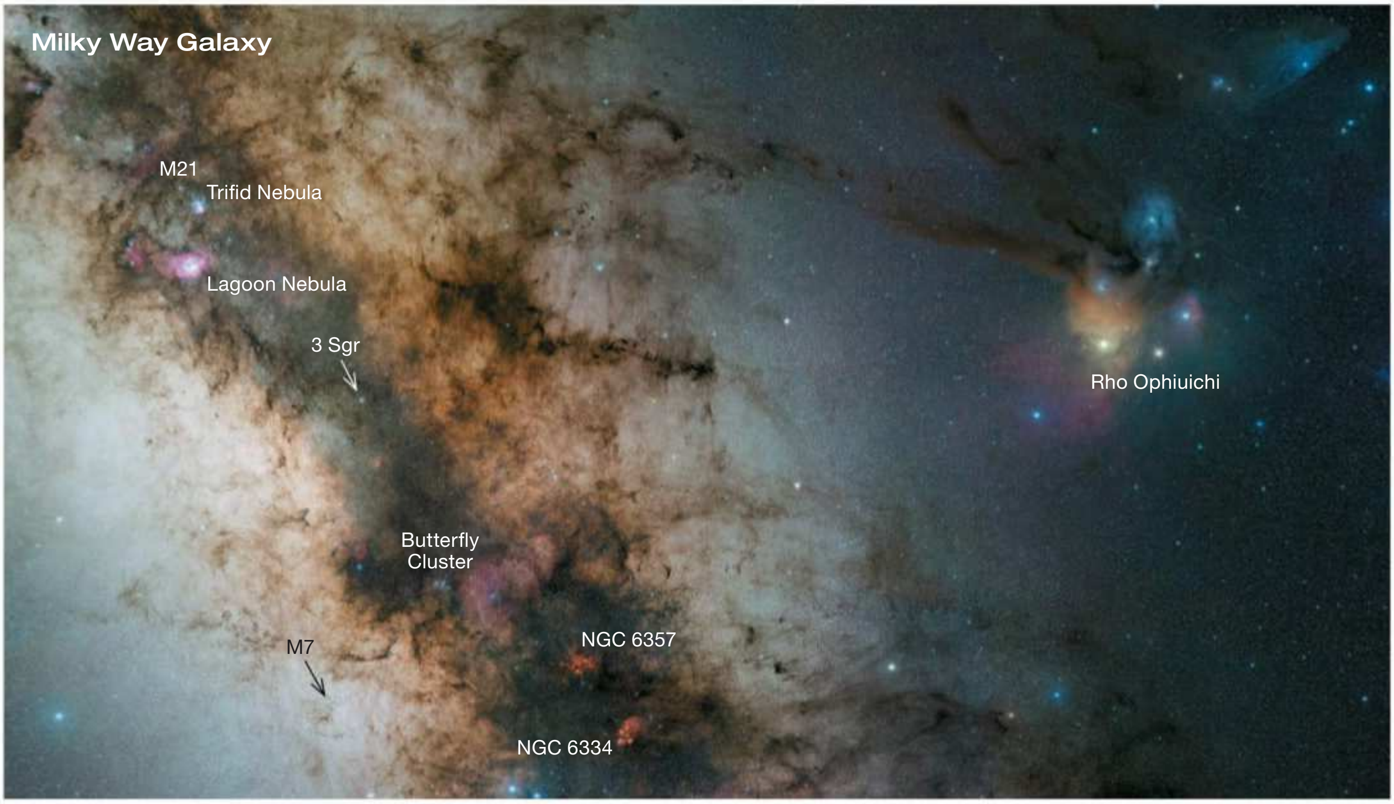
Atop our grassy hill, green fields turn obsidian as night sweeps her cloak across the world. A telescope is waiting, the stars appear, and I'm where I belong. Winter nights are an ideal time for those of us who feel at home among the stars to lose ourselves in some of the most beautiful wonders of the deep sky.

Planetary nebulae are shining baubles on the dome of the sky that come in an amazing wealth of guises. One of the most famous is the **Ring Nebula** (M57) in Lyra, which Antoine Darquier independently discovered with a small refractor while observing the Comet of 1779. He claimed it resembles a planet that's fading away. Although Darquier may have been the first to compare this type of nebula to a planet, it was William Herschel who coined the term 'planetary nebula' several years later.

M57 is low in the north for most Australasian observers, but it's worth giving it a try to see this well-known bauble. My 130-mm refractor at 23× clearly shows M57 as a very small nebula bracketed by the stars Beta (β) and Gamma (γ) Lyrae. Its ring-like structure reveals itself at just 37×. At 117× the annulus becomes distinctly oval, with ends that are dimmer than its sides. The ring's interior isn't as dark as the sky, creating an overall effect that John Herschel likened to "gauze stretched over a hoop". M57 bears magnification well and appears quite stunning at 234×. Variations in brightness along the rim are accented at this higher power, and the ring's interior appears rounder than its outer periphery, as shown in my sketch on the next page.

Those who hunt more difficult game can stalk M57's 15th-magnitude central star. Although folks have snared it through scopes as small as 20 cm in aperture, I've never nabbed it with anything smaller than my 36.8-cm. The key to a successful sighting lies in having exceptionally good seeing

▼ Bright nebulae and brilliant star clusters sparkle along the dark dust lanes of the Milky Way Galaxy. Taken from Cerro Paranal, Chile, the image below, which shows the winter Milky Way between Sagittarius and Scorpius, was assembled from 52 different sky fields composed from about 1,200 individual images taken through B, V, and R filters with a 100-mm refractor. The final mosaic represents a total of 200 hours exposure time.

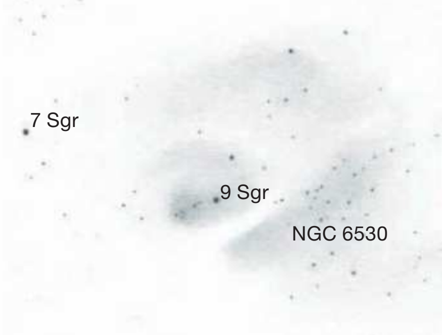


ESO / S. GUISARD

Ring Nebula

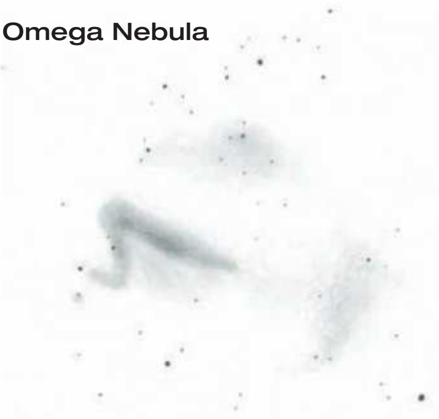
▲The author's sketch of M57, the Ring Nebula, as seen through her 130-mm refractor at 234×, shows the nebula's gauzy, circular interior.

Lagoon Nebula



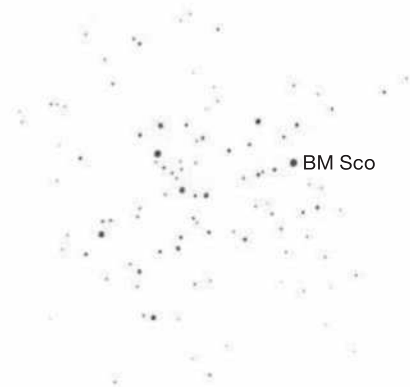
▲The author sketched the Lagoon Nebula as viewed through her 130-mm refractor at 48×.

Omega Nebula



▲Sometimes called the Swan Nebula due to its evocative shape, the Omega Nebula improves when viewed through an O III or narrowband filter. The sketch shows the view through a 130-mm refractor at 63×.

Butterfly Cluster



▲The Butterfly Cluster really sparkles with binoculars or a small scope. The sketch shows the individual lights as viewed through a 130-mm refractor at just 48×.

SUE FRENCH (4)

(atmospheric steadiness) and very high magnification.

Although M57 looks like a simple ring, its structure is actually much more complicated. You could think of it as a bright doughnut wrapped around the middle of a faint AFL football, all embedded in a complex, tenuous halo. The ring structure dominates largely because we're gazing down the pole of the planetary nebula. If we could see the Ring Nebula from the plane of its equator, it might look much like our next object, the **Dumbbell Nebula** (M27) in Vulpecula, the Little Fox.

Swept up by Charles Messier in 1764, M27 was the first planetary nebula ever discovered. It rests 24′ south-southeast of 14 Vulpeculae and can be recognised through my 9×50 finder. When seen through my 130-mm scope at 23×, the Dumbbell Nebula looks substantially larger than the Ring Nebula. Its bright region is shaped like an apple with the sides munched away. Protruding from the sides of this apple core is a dimmer region that turns the nebula into a football. At 48× the apple core's rims shine brightest, and its pinched-in sides are more obvious. There's also a fairly bright bar diagonally connecting the caps from east-northeast to west-southwest. The football extensions stand out best at 63×, but it's a rather plump football. Upping the power to 164× the apple core displays brighter wedges hugging the narrower angles where the bar meets each cap. At 234×, the southwestern wedge seems brighter than its counterpart in the northeast.

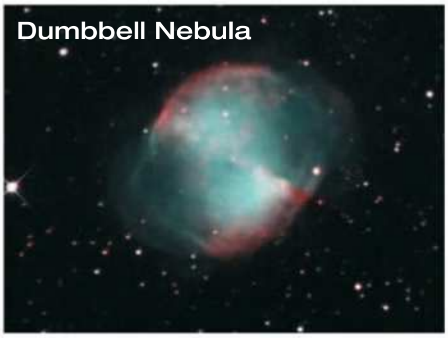
The Dumbbell's central star is easier to spot than the Ring's, but it's still not easy. The smallest scope I've seen it through was my husband's erstwhile 140-mm refactor, employing a magnification of 300×.

Next we'll visit the gorgeous **Lagoon Nebula** (M8), named for the darkling

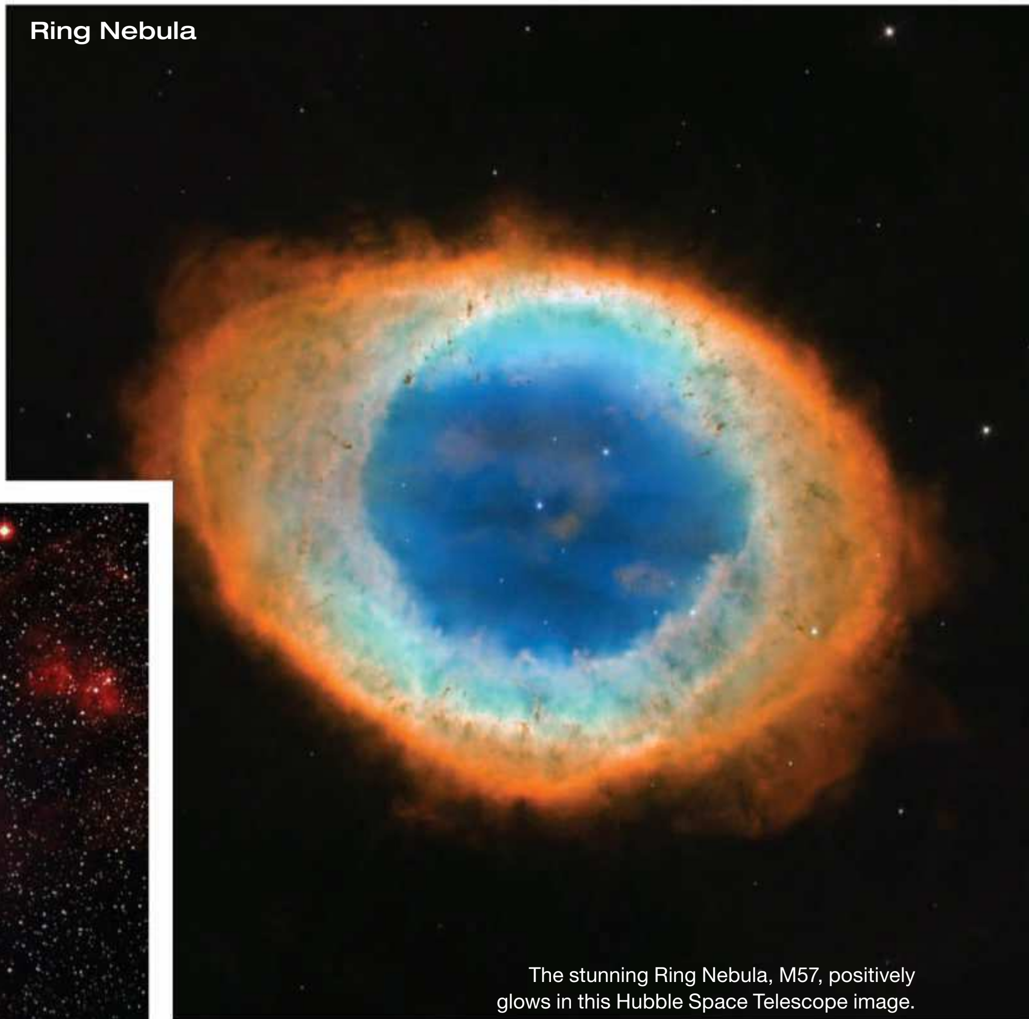
Sue's winter favourites

Object	Type	Mag(v)	Size/Sep	RA	Dec.
Ring Nebula (M57)	Planetary nebula	8.8	1.6′ × 1.1′	$18^h\ 53.6^m$	+33° 02′
Dumbbell Nebula (M27)	Planetary nebula	7.4	8.0′ × 5.5′	$19^h\ 59.6^m$	+22° 43′
Lagoon Nebula (M8)	Emission nebula	3.0	45′ × 30′	$18^h\ 04.1^m$	–24° 18′
Omega Nebula (M17)	Emission nebula	5.5	20′ × 15′	$18^h\ 20.8^m$	–16° 10′
Butterfly Cluster (M6)	Open cluster	4.2	33′	$17^h\ 40.3^m$	–32° 16′

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



▲The Dumbbell Nebula looks like a well-gnawed apple core through the eyepiece. Upping the magnification may reveal extensions more evocative of an AFL football.



The stunning Ring Nebula, M57, positively glows in this Hubble Space Telescope image.

◀ The Omega, or Swan, Nebula (M57) is a winter deep sky delight in Sagittarius.

channel within, like a shadowy bay lapping on a silver shore. In a fairly dark sky, this emission nebula is readily visible to the unaided eye as a misty patch hovering above the brightest stars of Sagittarius. My sketch shows the view through my 130-mm refractor at 48×. No filter was used when placing the stars, but a narrowband filter was added to help define the nebula. The ebony lagoon divides the nebulosity enveloping the open cluster NGC 6530 from the section harboring the brilliant but tiny double-knot of nebulosity called the Hourglass. The two sections are crowned by fainter bands of mist to their north. The brightest star within the nebula is blue-white 9 Sagittarii, and just off M8's western side, the star 7 Sagittarii shines pale yellow.

Another captivating nebula in Sagittarius that begs for a sketch is the **Omega Nebula** (M17), though I've always preferred its alternate nickname, the Swan Nebula. One look at its most prominent feature brings to mind a celestial swan floating on the dark waters of the night. Beyond the figure of the swan, large swaths of diaphanous haze wrap around the swan's body. An O III or a narrowband filter makes the nebula stand out better, and each was used to refine the nebulosity on my sketch. Surrounded by its full retinue of stars, the swan is also enchanting without a filter.

We'll wind up this issue's tour with a drawing of the **Butterfly Cluster** (M6) in Scorpius. It was a faint daub of light to the unaided eye when I sketched this lovely pile of jewels with my 130-mm refractor at 48×. Its brightest star is the irregular variable BM Sco, which looks yellow-orange through the telescope. Its magnitude range is about 5.3 to 6.5. While a sketch can't compare to a nice personal view or photo, it gives a good idea of the relative brightness of the stars. The Butterfly Cluster is so named because many of its stars seem to outline four wings, with perhaps even a head and antennae to the northwest. Can you picture the lepidopteran?

■ Contributing Editor **SUE FRENCH** welcomes your comments at **scfrench@nycap.rr.com**.

Spotting hidden craters

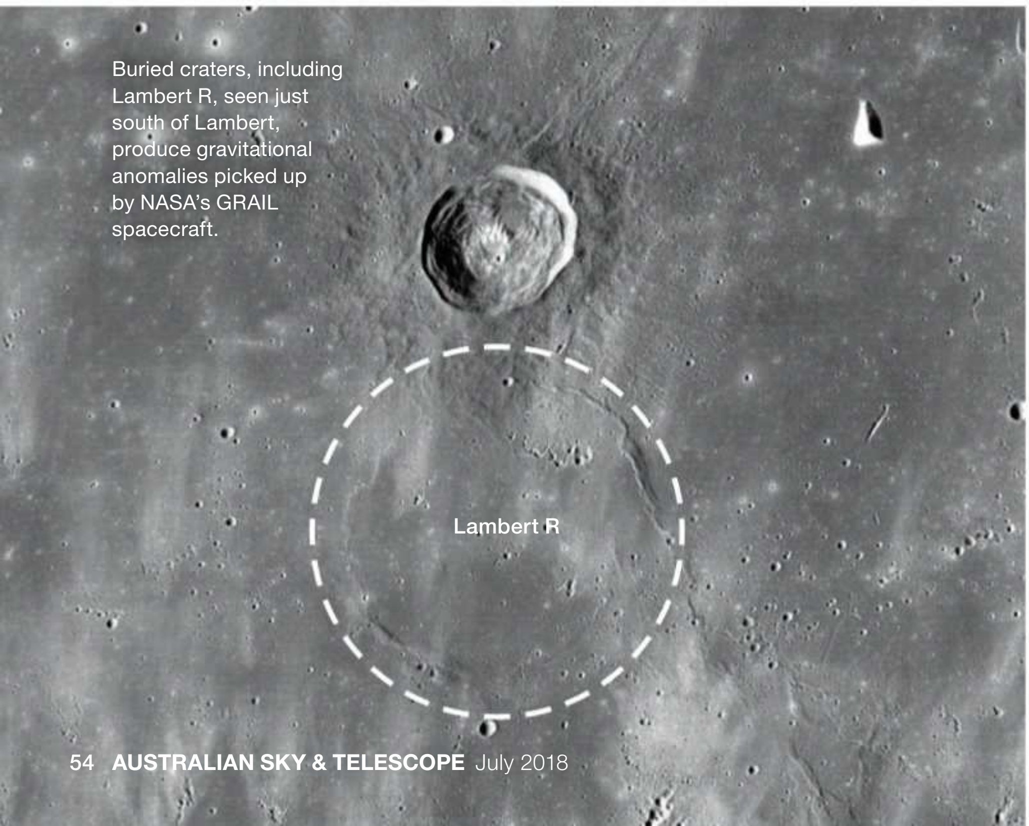
Gravitational hints shed light on buried lunar craters.

Maria are the most conspicuous large features on the Moon. They have smooth surfaces, dark hues and a general paucity of superposed impact craters. Most maria lavas erupted between about 3.8 and 2.5 billion years ago, lying within large impact basins whose rims are best seen at the curved **Apennine** and **Altai** mountain ranges. The ages of formation of the basins themselves are poorly known, but all are from earlier than about 3.8 billion years ago. The interval between basin excavation and the last lava flows in them is as much as 1.5 billion years. During that time, numerous impact craters must have formed on the basin floors and on the various individual flows of lavas that accumulated to form the maria we see today. Craters on top of the last flows are easy to spot, as their rays and other ejecta cross the maria; **Copernicus**, **Aristillus** and **Kepler** are prominent examples. Other mare craters, such as **Lansberg**, **Eratosthenes** and **Archimedes**, formed earlier than the last lava flows that covered their ejecta.

Additional craters have been almost completely buried by lavas, leaving just traces of their circular rims. A well-known example is 56-km-wide **Lambert R** (R for ruin) just south of Lambert in southern Mare Imbrium. Other such ghost craters occur in southern Oceanus Procellarum and elsewhere, and one just south of Plato has its own informal name: Ancient Newton. Some craters must have also formed on basin floors and early mare lavas but since then were completely submerged by lavas and are no longer detectable. That is, until now.

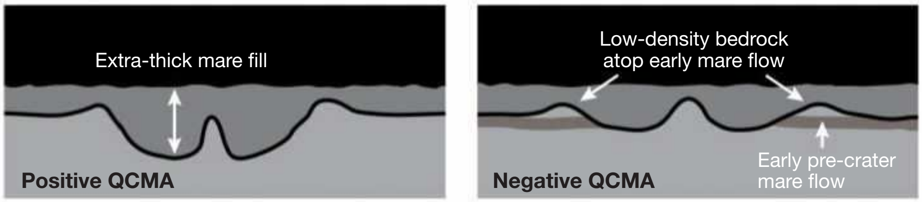
Alexander Evans (formerly at the Massachusetts Institute of Technology) and colleagues have processed the extraordinary high-resolution measurements of lunar gravity obtained by NASA's Gravity Recovery and Interior Laboratory spacecraft (GRAIL) and discovered 104 circular gravity anomalies with no surface expressions. These features, which Evans and colleagues call Quasi-Circular Mass Anomalies (QCMA), occur within and near maria, and are interpreted as being due to craters that formed on an earlier surface of an impact basin that mare lavas later completely inundated. Their map shows locations of QCMAs in yellow and visible craters in pink.

Surprisingly, QCMAs have both mass excesses and deficiencies. The explanation of these differences relies upon the fact that the highlands crust excavated by basins has a relatively low density of 2.4 grams per cubic centimetre, whereas the density of lava flows that erupt onto basin floors is 3.2 g/cc. If a buried crater is filled by a lot of lava, it's likely to have a mass excess, and if it has more highlands material, a mass deficiency. Consider a large, complex impact crater with terraced walls and an uplifted central peak that formed on the original floor of a basin. It would have excavated relatively low-density highlands material. Assume that late mare lavas surround a crater, overflow its rim and flood the floor, and continue to rise until completely submerging the crater rim. The thickness of the lava is greater inside the crater than outside because craters excavate material from below their surroundings. For example, the floor of a typical 100 km-wide crater extends about 3 km below the surrounding terrain. GRAIL measurements over the centre of such a crater will show a positive gravity anomaly (more mass) compared to outside the crater due to a 3-km-thicker pile of high-density mare lavas inside. So QCMAs with positive anomalies are mostly large and probably formed on the

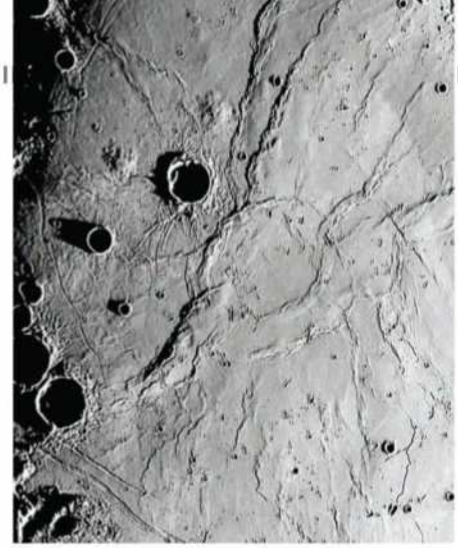


Buried craters, including Lambert R, seen just south of Lambert, produce gravitational anomalies picked up by NASA's GRAIL spacecraft.

LAMBERT R: NASA / GSFC / ARIZONA STATE UNIVERSITY; ANOMALIES: NASA / GRAIL / EVANS



▲ Quasi-Circular Mass Anomalies (QCMAs) are categorised into two groups. Positive QCMAs (left) contain higher mass than their surroundings, which is thought to be due to mare lava flooding a crater that excavated deep into the underlying terrain. Negative QCMAs have a mass deficiency compared to their surroundings, implying a buried crater that formed in the low-mass early lunar highlands material.



▲ The crater Lamont is a completely buried impact basin that appears as a shallow system of circular ridges.

ANOMALIES: GREGG DINDERMAN / *S&T*; LAMONT: ROBERT REEVES

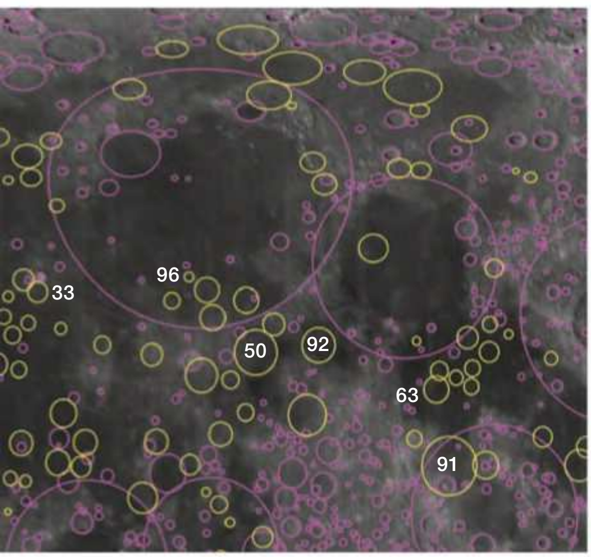
original basin highlands floor.

Evans's group explains QCMAs with negative gravity anomalies as marking craters that formed into early mare lava flows, excavating through the lavas into the underlying lower-density highlands material. During the modification stage of crater formation, the uplift of the central peak and surrounding floor would create a crater infill of low-density highlands rocks fractured by the impact event. If this low-density floor material rose to the level of the surrounding pre-lava terrain, the thickness of subsequent lava fill inside the crater would be the same as outside and there would be no gravity anomaly or, if the highlands material rose higher, a negative one. Projectiles that impacted into thick mare deposits may not intersect the low-density highlands deposits at all and therefore not generate any gravity anomaly — these stealth-buried craters would be totally undetectable.

We can identify a few of the yellow circles on the QCMA map with known features. Number 63, in western Mare Tranquillitatis, is **Lamont**, a small dual-ring impact basin. Immediately to the south is the larger QCMA #91 that underlies **Sinus Asperitatis**, a previously recognised buried crater or basin. And south of the Imbrium Basin rim are two other named features: #50 is **Sinus Aestuum** and #92 is **Mare Vaporum**, both thought to be small impact basins. All of these small basins have positive gravity anomalies, implying that they formed before lavas erupted in their areas. One final identified small feature is the aforementioned Lambert R (#96), which has a negative anomaly, meaning that it formed after lavas had erupted in its vicinity. That is quite likely considering that bits of its rim emerge above the surrounding Mare Imbrium lavas.

Notice that there is only one QCMA within each of the impact basins Crisium, Nectaris, Humorum, Serenitatis and the inner part of Imbrium. For all of these except Nectaris, the lavas are possibly so thick that submerged craters are totally encased in mare lavas and generate no anomalies.

It's surprising that large QCMAs occur in Mare Frigoris and Oceanus Procellarum where no underlying impact basins are thought to exist, and thus the mare thickness might be less than needed to completely cover crater rims. These are mostly negative gravity anomalies, but I would have thought that their large diameters and shallow Procellarum lavas would have caused most of the impacting projectiles to excavate into the underlying highlands materials. Perhaps Procellarum lavas are thicker than I imagine.



◀ This map of circular gravitational anomalies highlights visible craters in pink, while those with no visible surface features appear in yellow. The numbered regions are known buried craters that can be observed when sunlight strikes the area at a low angle.

The detection of QCMAs is exactly what would be expected, and like most good discoveries raises more questions for investigation. Let me encourage you to observe a sequence of craters formed on and at different depths below the present mare surface. Start with **Copernicus**, which sits atop the latest lavas, then look at nearby **Eratosthenes** and **Archimedes**, whose ejecta are covered by lava flows. Next, search out Lambert R when the Sun illumination is low to see peaks of a rim that barely rise above the mare surface. And then look for a few of the submarine craters shown on the map. Number 33, which is just south of Aristarchus, is hinted at by low mare ridges. Further north, look for the big QCMAs in Mare Frigoris that seem to have no correlation with mare ridges at all.

■ Contributing Editor **CHARLES WOOD** chairs the Lunar Nomenclature Task Group of the IAU's Working Group for Planetary System Nomenclature.

Pluto in 2018

This intriguing little world is at opposition this month. Catch it while you can.

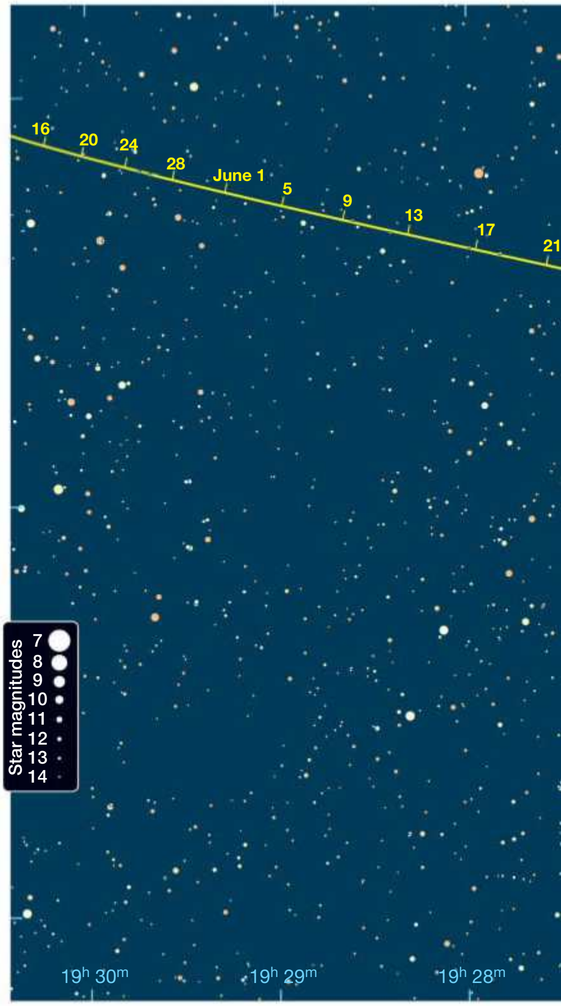
By the time this issue hits the newsstands, the third anniversary of NASA's New Horizons flyby of Pluto will be upon us. What have we learned about our tiny, distant neighbour in the past 36 months? Before New Horizons, scientists didn't know much about Pluto's surface, but data and images sent back by the spacecraft have helped transform Pluto from an astronomical object into a geological world. What appeared as a mottled orb through the eyes of the Hubble Space Telescope has resolved into a dynamic planet with faulted terrains, immense and active surface flows of nitrogen ice, glacially eroded highlands, jumbled mountains of water ice blocks, and possibly even a cryovolcano or two. The jury's still out as to the source of internal heat driving Pluto's geological activity, but data give every indication that it's there. Pluto may still be distant (about 32.6 a.u. from us right now), and it may still be tiny (its radius is only 1,187 km), but we can no longer think of it as cold.

These are the kind of fun facts that compel amateur astronomers to track down this diminutive dwarf planet even if it doesn't look like much through the eyepiece. Because let's face it: Pluto is a challenging target. Not only is it dim, shining about magnitude 14.8 this season, it's travelling through a crowded region of the sky. You'll find it in northern Sagittarius, as shown in the small charts opposite. The large chart is 1.2° tall and shows stars to magnitude 14.5, which gives some idea of how deep your search will go. The most obvious light in the field is 50 Sagittarii. On July 11–12, the night of opposition, Pluto will be just 12′ from this *K*-class star, making 50 Sgr an obvious jumping-off point for the star-hop. The date ticks on the large chart are for 0^h Universal Time.

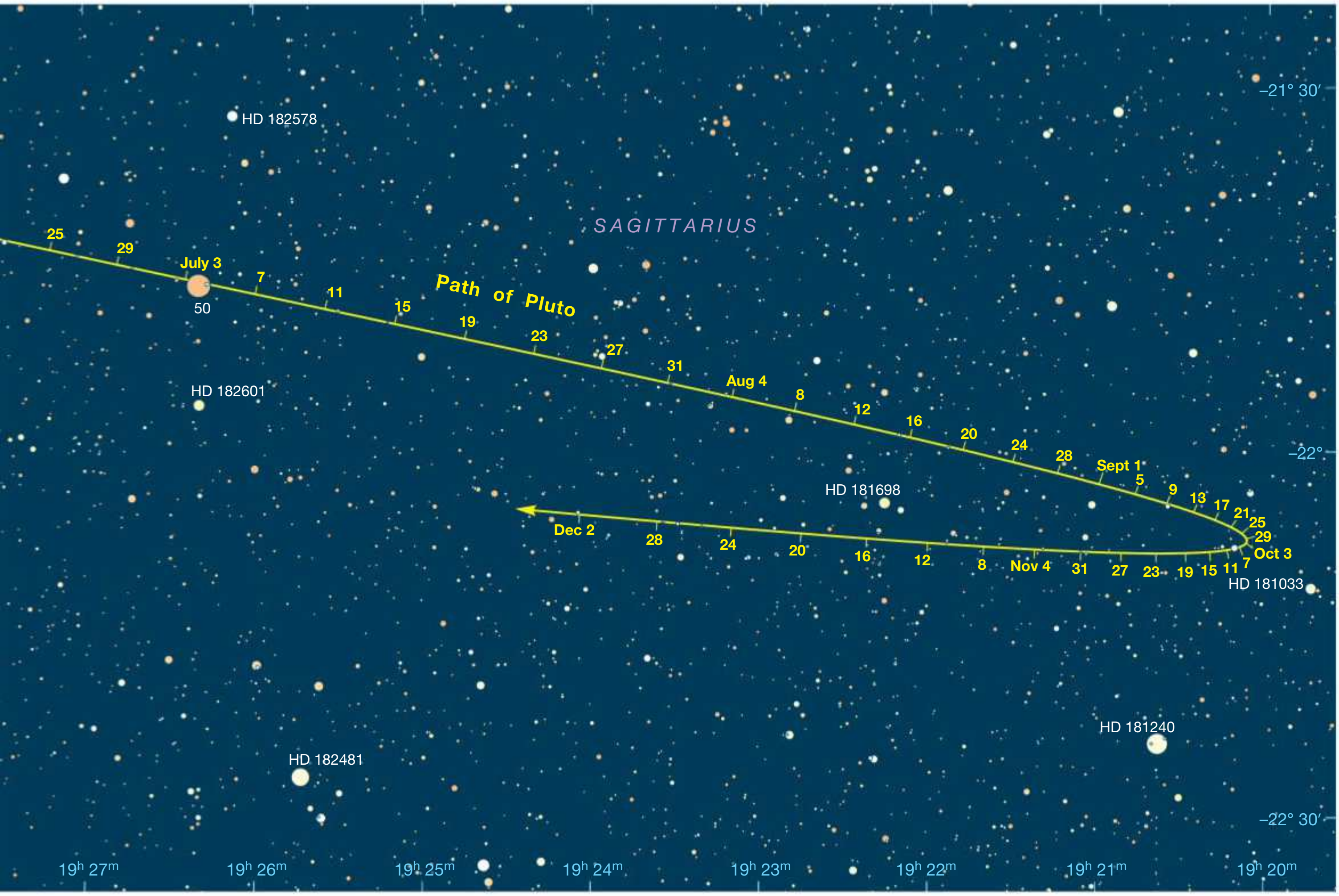
An advantage, though, is Pluto's southerly position. It's at a declination of almost –22° right now, high enough (77° altitude at culmination as seen from Sydney) to give the best possible seeing. The hunt is easier under dark, transparent skies. You may have some luck with smaller apertures, but using a 25- or 30-cm scope will make the night go more easily, especially if there's any hint of light pollution. Draw a sketch so you can return to the eyepiece on the next clear evening to confirm your observation.

Pluto will continue to slowly move southward each year until 2030, when it will be near declination –24°. That's the good news. The bad news is that it will dim by about a tenth of a magnitude each year as it moves away from perihelion. And it won't stop fading until it reaches magnitude 16 at aphelion in 2114.

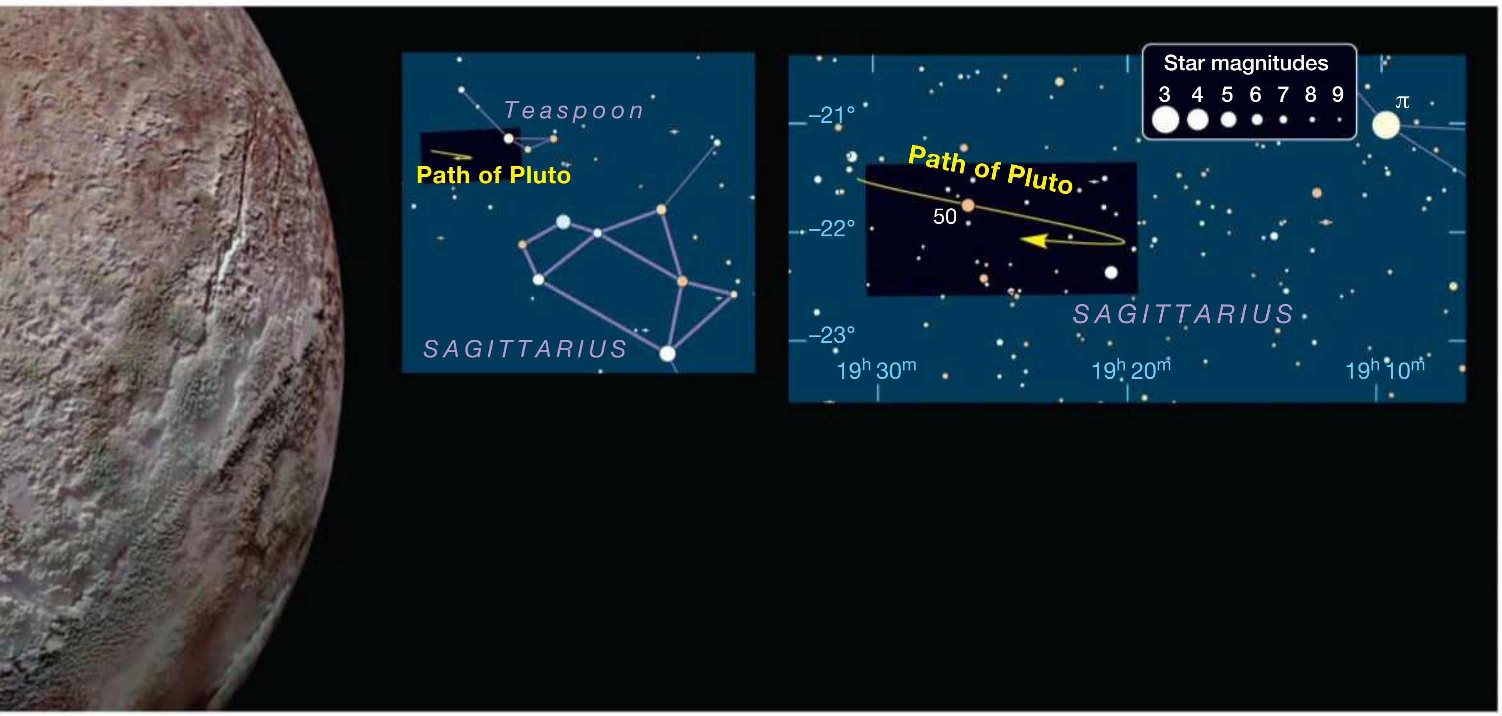
All of this is to say that your best shot at getting to know this distant world is right here, right now.



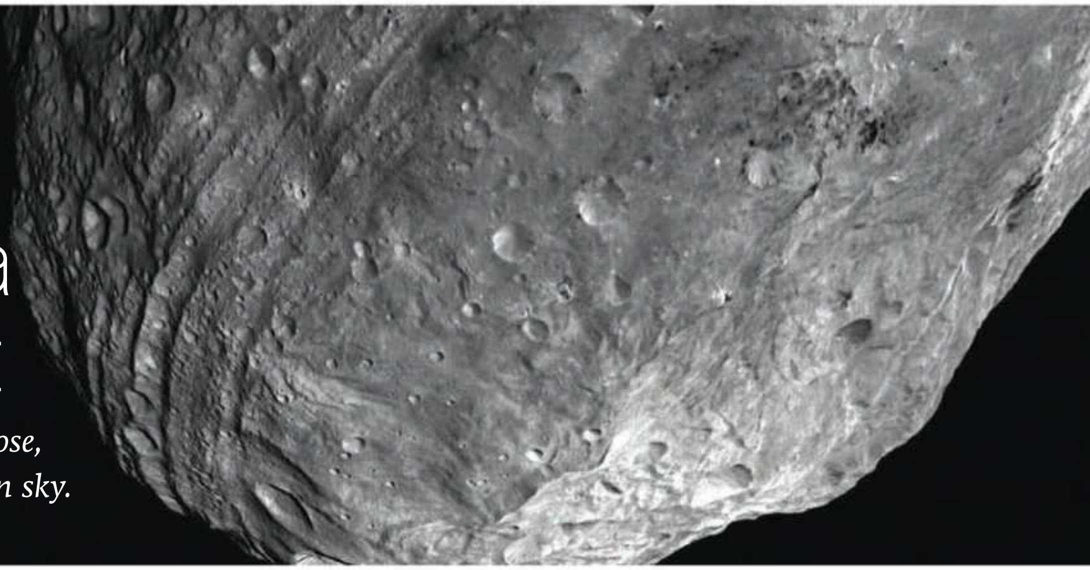
▶ Methane ice dominates the high-altitude landforms of Pluto's equatorial region. The knife-like ridges, or 'bladed' terrain, may have been formed by a sublimation cycle. In the extreme cold, methane freezes out of the atmosphere to form deposits hundreds of metres deep. Later, during warming periods, the methane ice evaporates to leave behind spectacularly sharp cliffs and crags.



SAGITTARIUS
Path of Pluto
HD 182578
HD 182601
HD 181698
HD 181033
HD 181240
HD 182481
July 3
50
25
29
7
11
15
19
23
27
31
Aug 4
8
12
16
20
24
28
Sept 1
5
9
13
17
21
25
29
Oct 3
7
11
15
19
23
27
31
Nov 4
8
12
16
20
24
28
Dec 2
−21° 30′
−22°
−22° 30′
19h 27m
19h 26m
19h 25m
19h 24m
19h 23m
19h 22m
19h 21m
19h 20m



Teaspoon
Path of Pluto
SAGITTARIUS
Star magnitudes
3 4 5 6 7 8 9
π
Path of Pluto
50
SAGITTARIUS
−21°
−22°
−23°
19h 30m
19h 20m
19h 10m



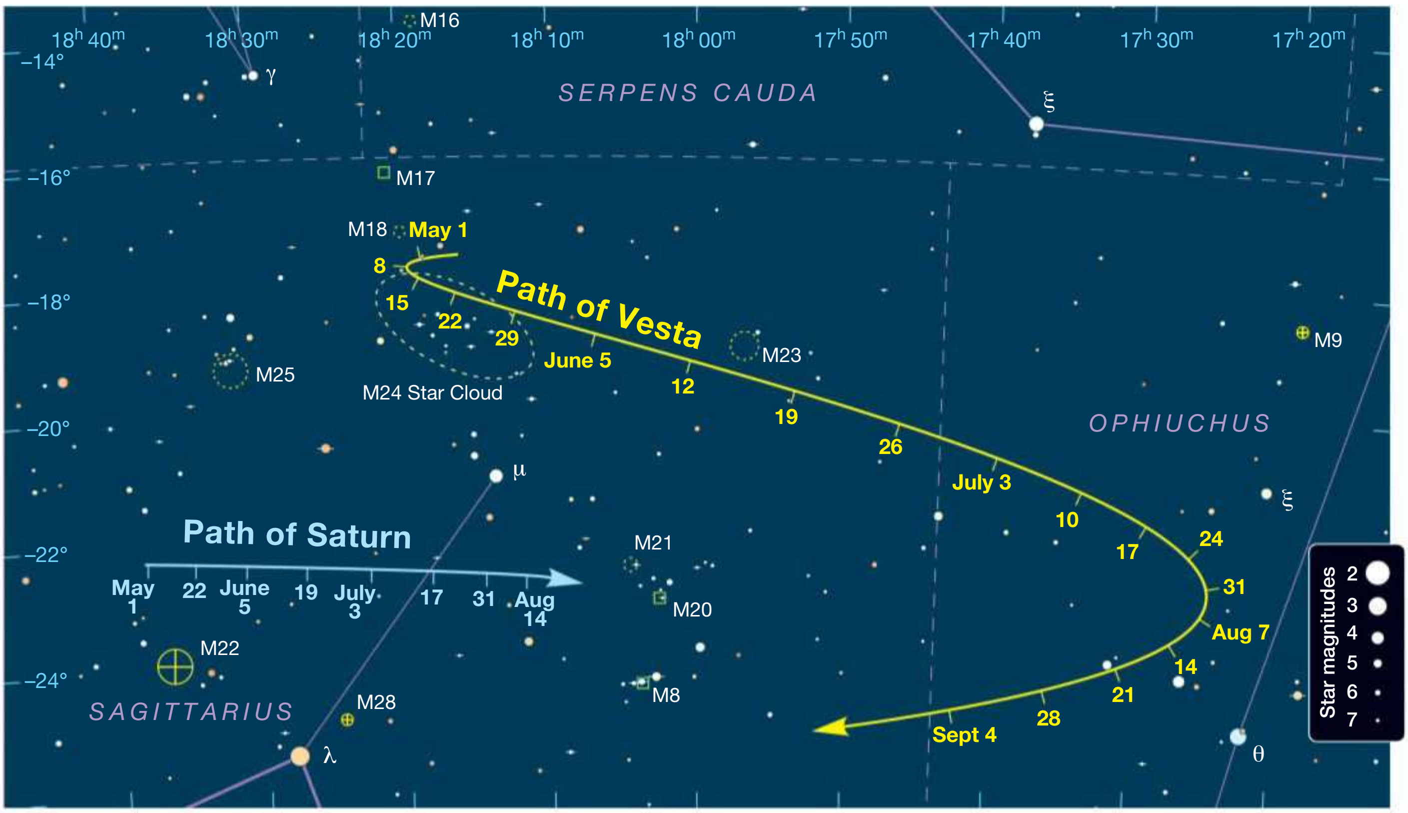
See Vesta at its best

Asteroid 4 Vesta is nice and close, a lustrous light in the southern sky.

Vesta, the fourth-discovered asteroid, reaches opposition (opposite the Sun in the sky when viewed from Earth) on June 19. Though neither the largest nor the most massive of the main belt asteroids, Vesta is the brightest of them all when it is at opposition. This year it shines in Sagittarius at magnitude 5.3 and will be visible without optical aid under reasonably dark skies. It'll be a bit dimmer for the rest of June and into July, ranging from magnitude 5.6 to 5.9, but still within reach of the naked eye under good skies.

There's something intrinsically interesting about observing asteroids — they're giant space rocks, after all — but the success of NASA's Dawn mission turned Vesta into a particularly compelling target. While the Hubble Space Telescope had resolved some of its largest surface features in the 1990s, it wasn't until the Dawn spacecraft dropped in on Vesta in 2011 that scientists were able to study the asteroid in detail. Vesta is almost, but not quite,

▼ Vesta's position is marked with a tick at 0^h UT every seven days.



VESTA: NASA / JPL-CALTECH / UCLA / MPS / DLR / IDA spherical; it's missing a good chunk out of its south pole. It's also differentiated, meaning it has a crust, a mantle and a core, like Earth. This layering was predicted by spectral analyses pre-dating the Dawn mission, as well as by studies of meteorites thought to have originated on Vesta (see sidebar on the next page), but spacecraft data helped confirm these theories. Vesta, mostly intact, fully differentiated, is unique among asteroids. That we can see it by simply looking up at the right part of the sky is great, to say the least.

Where to find Vesta

Vesta's in a busy part of the sky, travelling through northwest Sagittarius, not too far north and then northwest of Mu (μ) Sgr, and then into Ophiuchus. Zero-magnitude Saturn hangs out a few degrees below Mu in mid-June, serving as a clear directional beacon. By the end of July, Vesta will be found roughly halfway between Saturn and the star Antares.

The good thing for us is that Vesta's declination is around –20°, making it ideally positioned for observers at almost all southern latitudes.

Given that it is at opposition in mid-June, Vesta clears the horizon around 6:00pm local time and culminates around midnight, reaching an altitude of around 70°. By mid-July the distant, miniature world will be well above the horizon (about 37° altitude) after sunset and culminating at around 10:00pm.

When observing, sorting Vesta from its celestial neighbours might take some time and will certainly be easier with optical aid, even when it's at its brightest. It will appear stellar in nature through binoculars and small telescopes; very large apertures, say 20-30 centimetres or more, may show hints of the irregular disk.

Vesta sports an angular diameter of around 0.69″ for most of June and July, but seeing and transparency can affect the view. Even if you can't resolve the disk, high-aperture observing can offer its rewards: Many observers report seeing colour in Vesta through large scopes at high power. Descriptions range from pale yellow to pinkish rose.

Meet the neighbours

In the week before opposition, look for Vesta in the vicinity of the broad open cluster Messier 23. By June 19, the minor world will be roughly halfway between M23 and the globular cluster NGC 6440 (it will right next to the latter on June 23). By the end of June and the next full Moon, Vesta will have crossed into the southern reaches of Ophiuchus. On June 30 it will about 1° from the 4.9-magnitude star 58 Oph.

Spending the next couple of weeks crossing a barer patch of sky, Vesta will find itself within 1° of the magnitude 5.8 double star, HD 157527 on July 22. By the end of July, it will located roughly halfway between that star and Beta Oph.

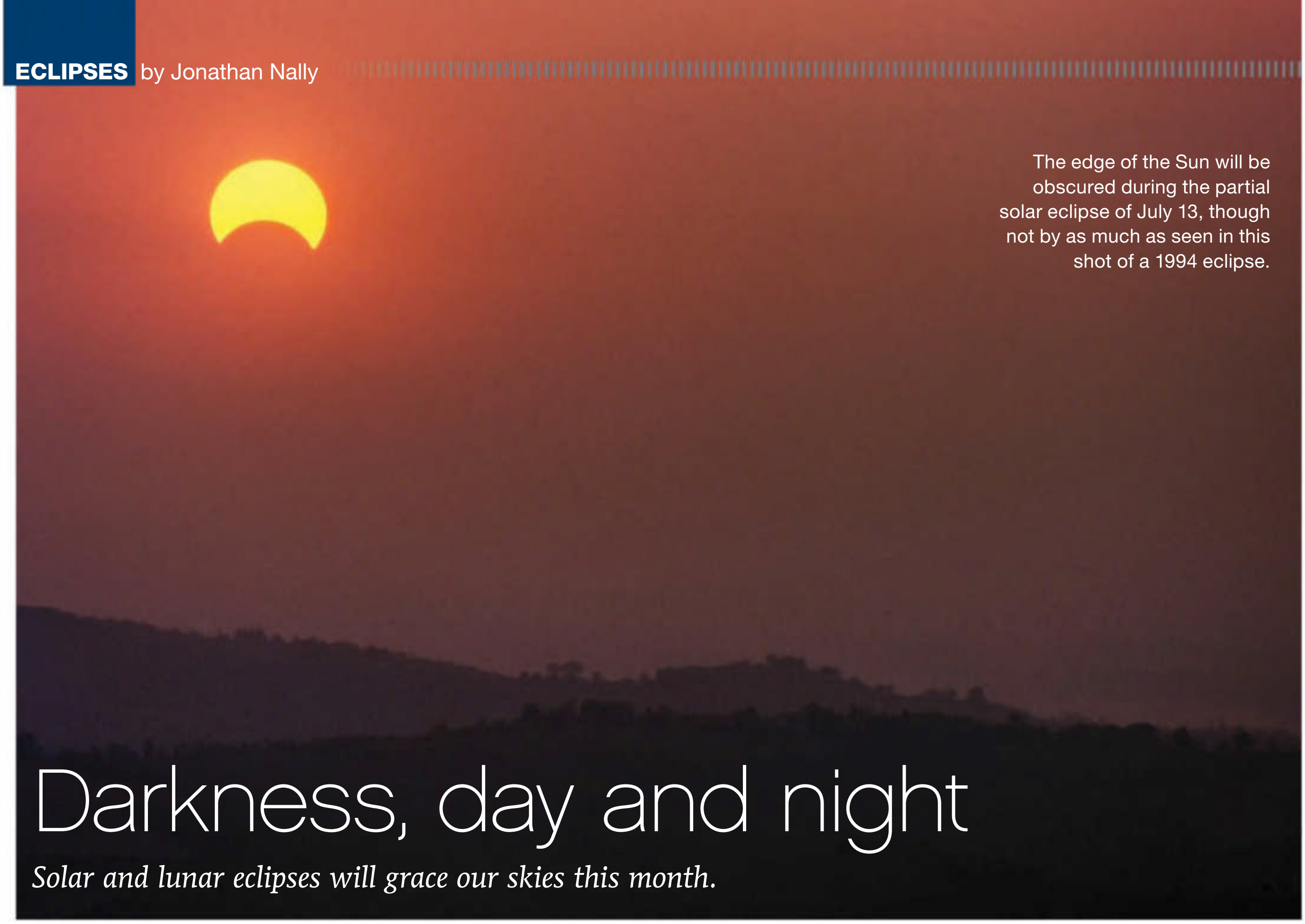
Ancient asteroid bits

The arrival of NASA's Dawn spacecraft at Vesta revealed intensive scarring on the asteroid's surface. Vesta's not-quite-spheroid shape is the result of a massive impact event about 1 billion years ago. The collision produced an approximately 500-km-wide crater, now named Rheasilvia, at Vesta's south pole. About 1% of Vesta's volume was displaced, with ejecta deposited in a 100-km ring around the impact basin and 2 million cubic kilometres of material sent into space.

About 5% of all meteorites we find on Earth come from the Rheasilvian impact. The mineralogy of Howardite-Eucrite-Diogenite (HED) meteorites, which resemble terrestrial igneous rocks, places them in this group. HED meteorites were first connected with Vesta in the 1970s, when scientists noted that their infrared and visible spectra were similar to the asteroid's.

The image above shows three slices of HED meteorites as viewed through a polarising microscope. The slices share a common mineralogy, but their dissimilar textures indicate that they originated in different parts of Vesta's crust and surface and crystallised at different rates. The slice on the left comes from a meteorite named QUE 97053, which was recovered from the Queen Alexandra Range of Antarctica. QUE 97053 is basaltic eucrite that formed in volcanic flows on the surface of Vesta some 4.4–4.5 billion years ago. The centre slice comes from a cumulate eucrite that fell in Moore County, North Carolina, in 1913. Cumulate eucrites are similar to basaltic eucrites, but have orientated crystals. They're thought to have formed in the upper parts of Vesta's crust rather than in surface flows. The slice on the right comes from a diogenite meteorite named GRA 98108, recovered from Graves Nunatak, Antarctica. Diogenites, which formed in magma chambers deep in Vesta's crust, are composed mostly of orthopyroxene and hypersthene, with smaller amounts of olivine, plagioclase, troilite and chromite.

NASA / UNIVERSITY OF TENNESSEE



The edge of the Sun will be obscured during the partial solar eclipse of July 13, though not by as much as seen in this shot of a 1994 eclipse.

Darkness, day and night

Solar and lunar eclipses will grace our skies this month.

This month we'll witness a partial solar eclipse and a total lunar eclipse, although how much you get to see will depend strongly on where you live or observe from. Only those in or near Perth will see the lunar eclipse in its entirety; everywhere else will see only portions of each eclipse or nothing at all.

If you live in Tasmania or the southern coastal regions of Victoria, you'll get a chance to see the partial solar eclipse on the afternoon of July 13. It will also be visible if you happen to be in Bass Strait or the Southern Ocean, but it won't be visible anywhere else, nor will it be the best eclipse ever seen even if you are in the right place at the right time.

At maximum, from Hobart only 3.5% of the Sun's diameter will be obscured (at 1:25pm local time). From Melbourne it will be an even slimmer 0.4% (1:22pm), while from Adelaide the eclipse will be barely noticeable at maximum at 12:40 pm. The duration of the eclipse from Hobart will be 1 hour 4 minutes and 12 seconds; from Melbourne it will be 33 minutes and 6 seconds.

Nonetheless, it's certainly worth trying for if you have clear skies. Just remember to use sensible solar observing precautions to protect your eyesight.

The lunar eclipse of July 28 will be far better behaved, although it too will elude some observers as it will occur in

Total eclipse of the Moon, July 28, 2018

City	Partial begins	Totality begins	Totality ends	Partial ends
Adelaide	3:54 am	5:00 am	6:44 am	7:20 am^
Auckland	6:24 am	7:25 am^		
Brisbane	4:24 am	5:30 am	6:36 am^	
Christchurch	6:24 am	7:30 am	7:51 am^	
Darwin	3:54 am	5:00 am	6:44 am	7:13 am^
Hobart	4:24 am	5:30 am	7:14 am	7:33 am^
Melbourne	4:24 am	5:30 am	7:14 am	7:30 am^
Perth	2:24 am	3:30 am	5:14 am	6:19 am
Sydney	4:24 am	5:30 am	6:55 am^	
Wellington	6:24 am	7:30 am	7:36 am^	

All times are in local time for the relevant time zone. ^ Moon sets at this time, prior to the end of the eclipse.

the morning hours and the Moon will have set at some locations before the event has concluded. The table gives the times for the beginning and end of the partial and total phases for major cities around Australia and Zealand.

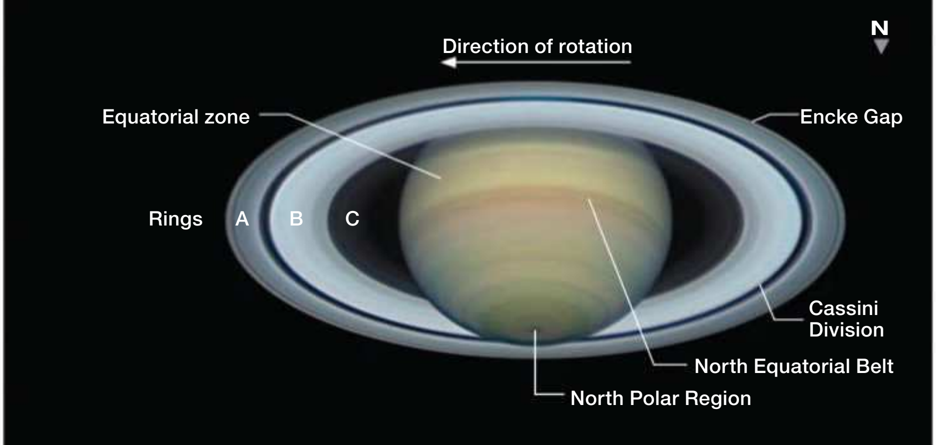
Despite the (for many) unfavourable time of day of the event, it will nevertheless be a great eclipse to see, as the Moon will travel right through the middle of the Earth's umbral shadow. This means the Moon will go a dark red colour and the event will be quite long — 104 minutes duration, to be precise.

Next eclipses

Next year we'll be treated to a lunar eclipse on July 17, and a partial solar eclipse on December 26. The next total solar eclipse visible from Australia will be on April 20, 2023, when the path of totality will briefly touch the Western Australia coast near Exmouth. After that, we have to wait until July 22, 2028 for a really good total solar eclipse. And indeed it will be a beauty — cutting right across the country from the far north-west of WA, through the Red Centre and then right overhead Sydney before crossing the Tasman Sea and cutting across the bottom of New Zealand's South Island. Start planning for it now!

▼ A total lunar eclipse will grace our skies on the morning of July 28.

DAMIAN PEACH / E. KRAAIKAMP / F. COLAS / M. DELCROIX / R. HUESO / G. THERIN / S. SPRINAU / S2P / IMCCE / OMP



Precious views of the ringbearer

Saturn arrives at opposition on June 27, very close to the time of full Moon. On the night of June 27–28, the Moon and Saturn will only be about 1° apart. It's a pleasant scene, but to get the best binocular or telescopic view of the ringed planet, make plans to observe on the nights (weeks!) before and after opposition.

Last quarter Moon falls on June 7 (and again on July 6), when Saturn rises at 6:30pm, about 1¼ hours after the Sun sets. Saturn's –22° declination means it is very well placed for observers at southerly latitudes. This present declination is about ½° farther south than it was when the planet was at opposition last year. This southerly crawl will continue until 2021, so we have plenty of good viewing to look forward to in the coming years.

Saturn's declination means it is presently climbing to a superb 78° altitude at culmination from the latitude of Sydney, transiting around 12:30am local time in the middle of June and 10:30pm by the middle of July.

Saturn's brightness won't change a whole lot during June and July. It begins June at magnitude +0.2, rising to 0.0 by the 1st of July. By the end of July it will be back to +0.2 again.

Saturn's equatorial diameter shrinks ever so slightly during the same period, but we're talking a change of around one quarter of an arcsecond — it's essentially 18″ for all of June and July.

▲ Saturn's rings were tilted 26.5° from our line of sight when Damian Peach captured this image with the 106-cm f/17 Cassegrain at Pic du Midi Observatory on June 11, 2017. Notice that Saturn's south pole was entirely occluded by the nearly wide-open rings. South is up.

Radiant rings

You won't notice much of a change in the tilt of Saturn's rings, either. They'll be open to 25.7° for June and 26.1° for July. That's not quite the maximum 27°, but still an almost ideal view. Small telescopes will show the rings and in steady seeing can reveal the Cassini Division, the dark gap between the A and the brighter B ring. The ghostly C ring can be difficult to see even in images. Start searching at the points where the ring crosses the globe, then follow it across the face of the planet (if you can).

If you observe for several days in a row, you might notice that the rings appear brighter around the date of opposition. This phenomenon is attributed to the *Seeliger effect* (sometimes called an *opposition surge*). Because the Sun is behind us, the shadows of the ice and dust particles that make up the rings are hidden. Sunlight hits the rings straight on, and the back-scattered light pumps up the brightness from our vantage point in the Solar System.

Is that star blue or green?

The *eXcalibrator* freeware program helps to take the guesswork out of colour-balancing your deep sky images.

As a child on car trips with my family, I often heard my parents ask this question about car colours: Is that blue or green? While driving my parents to a restaurant nearly 40 years later, from the back seat came the same question, "Is that blue or green?" I turned to my wife and said, "I can't believe they're still doing that." Today I engage in discussions about colour as it relates to stars, galaxies and nebulae instead of cars.

Several years ago, I shared an image of the open cluster M67 on an online imaging forum. A more experienced astrophotographer commented that the stars in the photo were too yellow, as open clusters usually have younger bluish stars. As the discussion continued, another imager, Wolfgang Renz, noted that M67 is a very old cluster, no longer dominated by blue stars. Using data from the Naval Observatory Merged Astrometric Dataset (NOMAD) catalogue, he showed that the stars are mostly white or yellowish white.

This started my quest for a repeatable process to obtain consistent and reasonably accurate colour balance in my deep sky astrophotos. The journey eventually culminated in the development of the freeware program *eXcalibrator* for Windows (**https://is.gd/eXcalibrator**).

Colour Is complicated

When imaging the night sky, several factors affect the colour of your results. First, the spectral sensitivity of different CCD and CMOS detectors varies greatly. Some are more sensitive to blue light, while others respond better to red or green light. This is true with both a monochrome camera (used with individual colour filters) or a one-shot colour camera (which incorporates tiny red, green and blue filters over individual pixels).

▲ **TOO BLUE** There are many ways to achieve a natural colour balance in deep sky photography, though most are subjective. This image of M31 in Andromeda was captured by the author and processed two different ways. The right side is balanced based on comparison to other images found online, while the left side uses *eXcalibrator* to establish colour balance based on known star colours in the image.

Another variable is the combination of red, green and blue filters used in all digital cameras to make the colour result. Whether you're using a monochrome or one-shot colour camera, these filters vary in their transmission curves and cutoffs. In some cases, the red, green and blue passbands overlap. Other filter sets have distinct transmission gaps intended to reduce the effects of light pollution.

Additionally, several variables beyond your equipment can affect the colour of your images. These include *atmospheric extinction* and transparency. The lower your target is in the sky, the more atmosphere its light travels through, which blocks an increasing amount of blue light. Hazy skies also block bluer wavelengths more than red, skewing the colour in your result. Other effects are due to extraterrestrial factors such as dust in our galaxy, and even intergalactic gas and dust between your target and your camera. Finally, inconsistent image processing choices, such as the normalisation (the equalisation of individual exposures) before stacking, can skew the result.

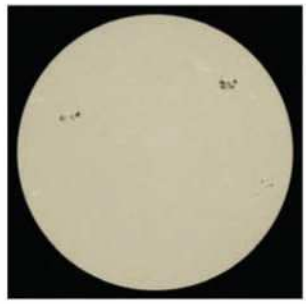
Colour correcting

Astrophotographers often rely on several methods to correct the colour balance. Some are better than others. Often, an imager will look online to compare their image with those of others. This is perhaps the *least* reliable way of achieving accurate deep sky colour! Do a web search for M31, and you'll be presented with dozens of images of this galaxy, some bluer, others reddish. 'Eyeballing' the colour in your images this way might produce a pretty result, but it isn't very accurate.

One reasonable way to colour balance a galaxy image is to assume that the integrated light of a face-on spiral galaxy is white. This approach shows a galaxy with its intrinsic colour. However, many galaxies, for example, IC 342, are seen through intervening dust within the Milky Way, which reddens its overall appearance. So using this intrinsic colour assumption for IC 342 makes the foreground stars too blue.

Another common technique is to set the background colour in your image to a neutral grey. This works well for some images, though not if the field is filled with emission nebulosity or dust.

Some imagers even use the cumulative light of all the stars in a picture as a white-point average. This does work with some objects, if there is no intervening galactic extinction. For instance, the core of a globular cluster often makes a good white-point reference.



▲ **WHITE STAR** While our Sun is informally referred to as a yellow dwarf, it is really a white *G*-type main-sequence star (*G*2V). Amateur astronomers use other solar analogue *G*2V stars as reliable white-point calibration targets.

Of all the techniques mentioned, using the colour of stars in your images is a step in the right direction to achieve reasonably good colour balance. But star colours vary greatly, depending on which direction you look. Stars in the arms of our Milky Way tend to be young and therefore blue. Looking to the galaxy's halo and bulge, you see more reddish stars. In fact, the general stellar population is mostly comprised of red dwarfs, so the true average colour of stars skews toward the red end of the spectrum.

Solar analogue

Many amateurs, in their pursuit of an accurate colour calibration method, rely on a technique that uses *G*2V spectral-class stars as a white-balance reference. Our Sun is a *G*2V star, and its light appears white to our eyes. Using this approach, you adjust the red, green and blue exposures so that the *G*2V stars in an image appear white — if there are

▼ **DUSTY VEIL** One common technique used to colour-balance galaxy photos is to assume their integrated light should be white. But some galaxies, such as the face-on spiral galaxy IC 342 seen below, are viewed through dust within the Milky Way. The integrated light balance technique *(left)* produces a nicely coloured galaxy image. Using *G*2V-like stars as calibration sources in eXcalibrator results in an image of the galaxy reddened by dust, which blocks bluer wavelengths *(right)*.

SUN: SOLAR DYNAMICS OBSERVATORY / NASA

any G2V stars in the field.

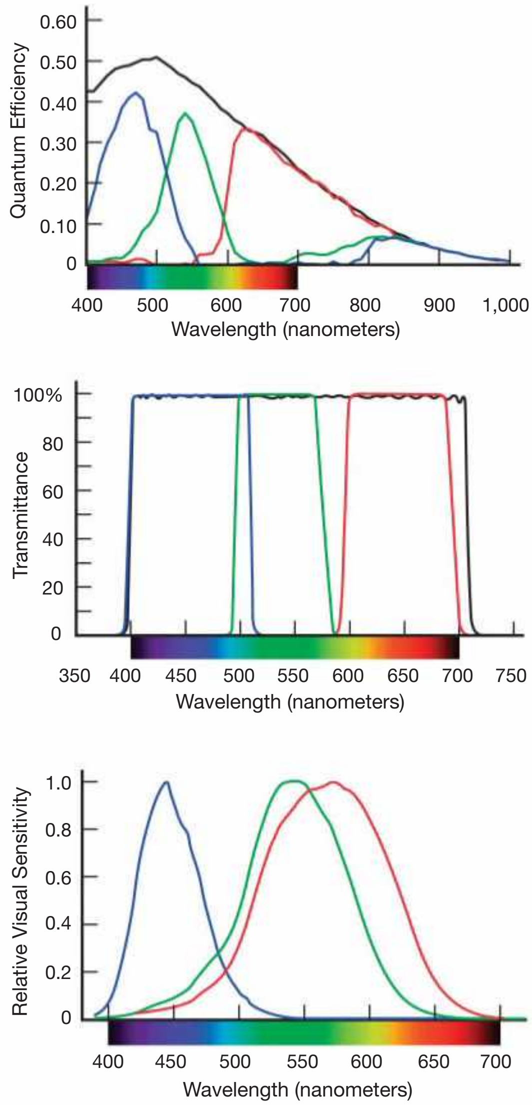
Using this singular calibration method still has problems. First, as mentioned earlier, there is no correction for the altitude of the target as it is imaged throughout a night or over several nights. It's particularly problematic when the target falls below about 40° above the horizon. Atmospheric dust scatters green light more than red, and blue more than green.

Secondly, G2V calibration doesn't account for the sky's variable transparency. As the night progresses, thin clouds might come and go. This can compromise the data for just one of the three colour filters, throwing a meticulous G2V calibration scheme out the window. Still, this technique at least heads you in the right direction.

Continued research led to the work of amateur Bernhard Hubl and Mishca Schirmer of the Max Planck Institute for Astronomy. They use stars from the Sloan Digital Sky Survey (SDSS) database as white-balance reference points. They identified white (Sun-like) stars in their images to determine colour correction.

This seemed like a reasonable solution. I liked combining a G2V-like calibration method with information from the image itself to colour-balance. Additionally, this technique uses catalogue data acquired by a professional survey. And so, with help from Hubl and Schirmer, *eXcalibrator* was born.

With the help of amateur Bruce Waddington, the program incorporates a linear regression (LR) routine to allow the use of stars of any colour as calibration sources that reference the SDSS data. By obtaining nearly identical results, the LR routine reinforces the white-star colour-balancing concept. The program also incorporates the AAVSO Photometric All-Sky Survey (APASS) data, fully automating colour calibration in deep sky images recorded with monochrome cameras and colour filters.



▲ **SPECTRAL VARIABLES** While many outside factors can contribute to the colour of your deep sky astrophotos, none is as influential as the camera and filter you use to shoot through. The spectra above show the red, green and blue spectral response curve of a KAI 11002 CCD detector *(top)* and the passbands of AstroDon Gen2 colour filters. The bottom graph displays the spectral response of the human eye. Each camera and filter combination will produce different exposure times to achieve a natural colour balance.

Putting *eXcalibrator* to work

Contrary to Superman legend, the Sun is not a yellow star. When viewed near the zenith or from space, the Sun looks and photographs white. Measuring the colour balance of the Sun with SDSS's u- (ultraviolet through blue), g- and r-filter values yields (u–g) = 1.43 and (g–r) = 0.44. So *eXcalibrator* searches an image for stars with SDSS (u–g) and (g–r) values similar to the Sun's. The program uses the average values of the identified stars to determine the proper red, green and blue scaling ratios for colour correction.

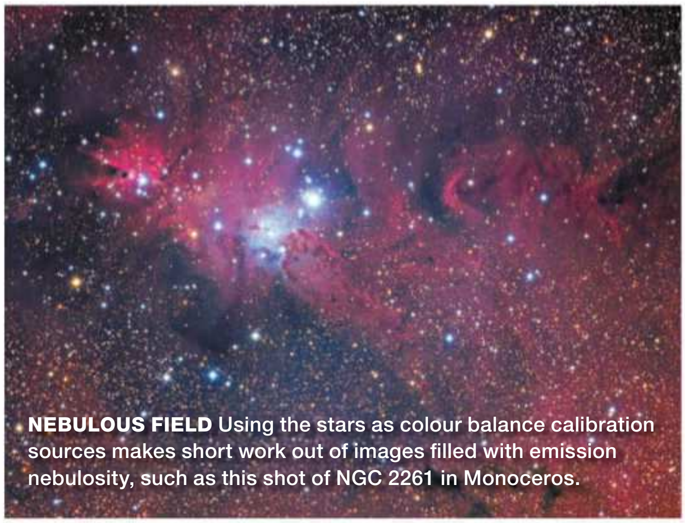
With the LR routine, *eXcalibrator* only incorporates the green and red values from the SDSS or APASS data (most filters for amateur cameras block ultraviolet light). The program then computes a colour correction by comparing the stars' colours in the image with their known colour values from these databases.

There are two ways to use *eXcalibrator*. The first is to colour-balance your data. To start, you first need to plate-solve one of your calibrated and stacked monochrome FITS images shot through a red, green or blue filter, which can be accomplished with the Image Link function in *TheSkyX* (**bisque.com**) or online at **nova.astrometry.net**. This adds World Coordinate System (WCS) information to the FITS header that the program will then use to find suitable calibration stars in the image. The program also works on one-shot colour images that have been split into their respective colour channels and saved as FITS files.

Once one of the images has been plate-solved, load the red, green and blue images into their respective boxes and also select the plate-solved image in the WCS File box. The program then employs the FITS WCS data to determine the centre of the field of view, image size, scale and rotation. Click Calibrate Image, and the program downloads SDSS or APASS data from the VizieR Catalogue Service. *EXcalibrator* then identifies stars that should be white and calculates the colour adjustment. To obtain a larger sample, the LR routine also selects stars that are yellow and cyan in hue. When completed, the program presents you with the average weight

GREGG DINDERMAN / *S&T* (3)

▲ **EXCALIBRATING** Using *eXcalibrator* is easy. Plate-solve one of your colour images and enter it into the WCS File section at upper right. Next, select each of your red, green and blue frames in their respective lines at top left. Then simply click the Calibrate Image button at the bottom right, and in a few moments the scaled weight of each channel will be presented next to Avg at the bottom left of the screen.



NEBULOUS FIELD Using the stars as colour balance calibration sources makes short work out of images filled with emission nebulosity, such as this shot of NGC 2261 in Monoceros.

of each colour, which you then use when combining them in your preferred image processing program.

Calibrating an imaging system

The other way *eXcalibrator* can be used is to determine the exposure times for each filter taken with your particular equipment under near-ideal conditions. This is accomplished by taking two or three 5-minute exposures with each colour filter with your scope pointed near the zenith. You calibrate, register and stack those results, and then run the resulting images through the *eXcalibrator* process. The correction factors to adjust the red, green and blue exposure times should be used when shooting future images. For example, calibrating one of my imaging systems produced RGB colour ratios of 1.0, 1.12, and 1.20, respectively. So I shoot my individual R, G and B exposures at 10, 11 and 12 minutes. Using these calibrated system values, my images should have a well-balanced natural colour appearance.

By imaging under good transparency and taking care to avoid atmospheric extinction due to the altitude of your target, the final *eXcalibrator* R, G and B correction factors should usually be close to 1:1:1.

Once you've calibrated your system, it's easy to integrate *eXcalibrator* into your own imaging routine. Here's my typical astrophotography workflow:

» Acquire the data for my imaging target.
» Calibrate, register and combine the R, G and B exposures.
» Plate-solve one of the stacked results.
» Run the R, G and B images through the *eXcalibrator* process to determine the final colour adjustment.
» Use the adjustment weights to assemble the colour image.
» Continue with stretching and other processes to produce the final colour image.

Even with a calibrated system, *eXcalibrator* will produce slightly varying channel weights in different data sets, because it takes into account atmospheric extinction, transparency and other variables from when the images were acquired.

▶ **GOLDEN CLUSTER** Globular clusters are another target that is thought to be a good white-point calibration object. But many of these star clusters are dominated by older, redder stars and are also seen through intervening dust in the Milky Way. The image of M10 at upper right presents a colour image calibrated by assuming the core of the cluster is white, while the version at right used *eXcalibrator* to determine the cluster's colour based on the spectral properties of known stars in the field.

Using different camera and filter pairings, it's possible to adjust the colour with *eXcalibrator* so that white stars appear white — an excellent way to consistently obtain good colour in the initial tri-colour assembly. By following through with consistent image processing, you can accurately compare different images and say, for example, 'Galaxy A is bluer than Galaxy B'.

If you agree that making white stars white will produce reasonable colour in your astro-images, then hitch your wagon to *eXcalibrator* and take it for a ride. Colour balance in astrophotography is ultimately a matter of personal taste. But being reasonably accurate from the start will add consistency to your results and make your later processing decisions easier.

■ **BOB FRANKE** is a retired software developer and avid astrophotographer. See more of his images at **bf-astro.com/index.htm**.

The Meade 115mm Series 6000 ED Triplet APO ready for a night's activity, shown with an optional 2-inch mirror diagonal. The scope also accepts finderscopes that attach using a standardised dovetail system commonly found on small refractors.

Meade's 115-millimetre ED triplet

This 115-mm apochromat packs a lot of bang for the buck.

115mm Series 6000 ED Triplet APO

US price: $1,899

tasco.com.au

What We Like

Sharp, well-corrected optics

Colour-free views

Attractive finish

What We Don't Like

Visual back locking system can be awkward

Focuser backlash

THIS IS A GREAT TIME to be in the market for a premium refracting telescope. The price for high-quality refractors has fallen dramatically in recent years, and you can now purchase a 100- to-115-mm extra-low dispersion (ED) apochromatic (APO) telescope that's almost entirely free of the false colour that plagues achromats for a fraction of the cost commonly seen a decade ago.

I've had a ball with my own recently purchased apochromat after using almost nothing but Schmidt-Cassegrain telescopes for many years. However, I still consider myself a refractor novice and was eager to see how others performed. So when I was approached about evaluating Meade's 115mm Series 6000 ED Triplet APO, I was certainly up for the task.

First impressions are important, and when I unboxed the scope on the day it arrived, I lit up when I saw it. This is a pretty refractor. Although similar in appearance to many current APOs, it has the distinctive Meade blue lens cap and trim. The build quality is very good for the price; not quite the same as units costing twice as much or more, but solidly built. The multi-coated objective coatings were visibly effective;

incident light falling on the lens seemed to practically disappear.

The scope includes a 3-inch Crayford-style focuser with a 10-to-1 fine-focus knob that incorporates a non-marring compression-style system to secure your star-diagonal, camera or eyepiece. The focuser itself can be rotated independently of the tube, a big help for astrophotographers when composing shots. Up front is a sliding dew shield that can be retracted when installing solar filters, or to save space when storing or transporting the scope.

Accessories included with the 115 ED are few. A nice set of tube rings are bolted to a robust Vixen-style dovetail bracket. The rings are drilled on top to accommodate an optional bracket for a guide telescope or other accessories.

Finally, there's an attractive light-weight carrying case for the telescope. While this aluminium-framed plastic case holds the scope snugly in place with die-cut foam and is sufficient for storing and transporting the scope, it's not meant to take much abuse.

Meade provided several optional accessories with the telescope, including a 2-inch mirror star diagonal, though no finderscope, which is an extra-cost option. Luckily, the scope is fitted with the industry-standard finder base,

▲ The telescope's triplet objective showed reflections only under bright sunlight.

which permitted me to use the 50-mm finderscope from my own refractor.

The 115 ED is an f/7 triplet refractor with one ED element to improve colour correction. This is a sizeable aperture telescope as APO refractors go, yet it weighs in at a mere 5.5 kg.

I was curious to see how well this reasonably priced 115mm APO performed, and was expecting good things. How much detail can this modest aperture produce on some of my favourite targets? As you'll see, this refractor novice now concedes that some of the stories about the telescopes' performance I used to dismiss as myths are true.

First light

When you take the false colour of simple achromatic objective lenses out of the refractor equation, you are left with an instrument featuring superior sharpness and contrast thanks to the lack of an obstructing secondary mirror, which reduces contrast in the views through reflectors and compound telescopes.

While the 115mm would not have stressed out my lightweight Go To German equatorial mount (GEM), I chose to place the Meade on my 22-kg-payload-capable GEM to give the scope its best chance to shine. The triplet is noticeably front-heavy, thanks to its 3-element objective lens. Fortunately, the tube rings provide plenty of room to find balance even with heavy eyepieces, binoviewers or cameras attached.

First light in my backyard was spent soaking in views of bright stars and the first quarter Moon. Nothing tests the mettle of a refractor like our nearest celestial neighbour. But first I turned to brilliant Vega. While it's not uncommon for an ED refractor to display a little colour fringing on a bright star that's slightly out of focus, this wasn't the case with the Series 6000. Vega was an icy blue, both in perfect focus and just barely either side of focus.

And views of the Moon? If I tried, I could see an unobtrusive yellow-green

ROD MOLLISE (4)

▲ *Left:* The beefy 3-inch focuser included with the 115 ED includes a blue anodised 10-to-1 fine-focus knob. *Right:* The unit's drawtube is marked in centimetres to help quickly repeat focus with your favourite eyepieces and other accessories. The 2½- to 2-inch visual back can be independently rotated by holding the large knurled ring and turning the 'captain's wheel' with aluminium pegs.

rim on the lunar limb, but that was it. The terminator was awash with sharp craters, and the shadows within were inky black, without a hint of the purple tinge often seen with a lesser instrument. My main impression, however, was the sharpness of the lunar landscape.

One other thing I appreciated was the Meade's f/7 focal ratio. While f/6 APOs are popular, I found the scope's slightly longer-than-average focal length enabled me to use somewhat longer (and more comfortable) eyepieces to reach high powers. The telescope took all the magnification I could throw at it under good seeing.

Star tests on the 115 were as I had hoped. Diffraction ring patterns of a slightly out-of-focus star on both sides of focus looked nearly identical, a sign that its objective is well-corrected.

While I observed a few deep sky objects from my backyard, I did most of my deep space cruising on a visit to a dark site. It was amazing what this scope could do for globular star clusters.

Looking at M15 in Pegasus, I had to keep telling myself this was a 'small' telescope. The relatively tight globular

can be a test for instruments in this aperture range, but not for the 115. I was easily able to resolve its outer halo of stars, both because they were tiny in the telescope's sharp images and because its excellent optical quality allowed me to really push the magnification, making resolution easier.

Although the 115 did a nice job on medium-sized deep sky targets, it was with the big objects that it really shone. With a 35-mm wide-field eyepiece in the focuser, I had stunning views of the huge North America Nebula (NGC 7000) and both bright sections of the Veil Nebula. While the scope doesn't provide a lot of aperture horsepower, I was still amazed at what this modest refractor could reveal. Not only were the east and west loops of the Veil visible, but with the aid of a light-pollution reduction filter I was also able to detect Pickering's Triangle, the dim patch of nebulosity lying between the two halves of the Veil. Of the big galaxies, M31 was particularly marvelous, easily showing off one dust lane. Andromeda's normally subdued satellite galaxy, M110, was bright and obvious.

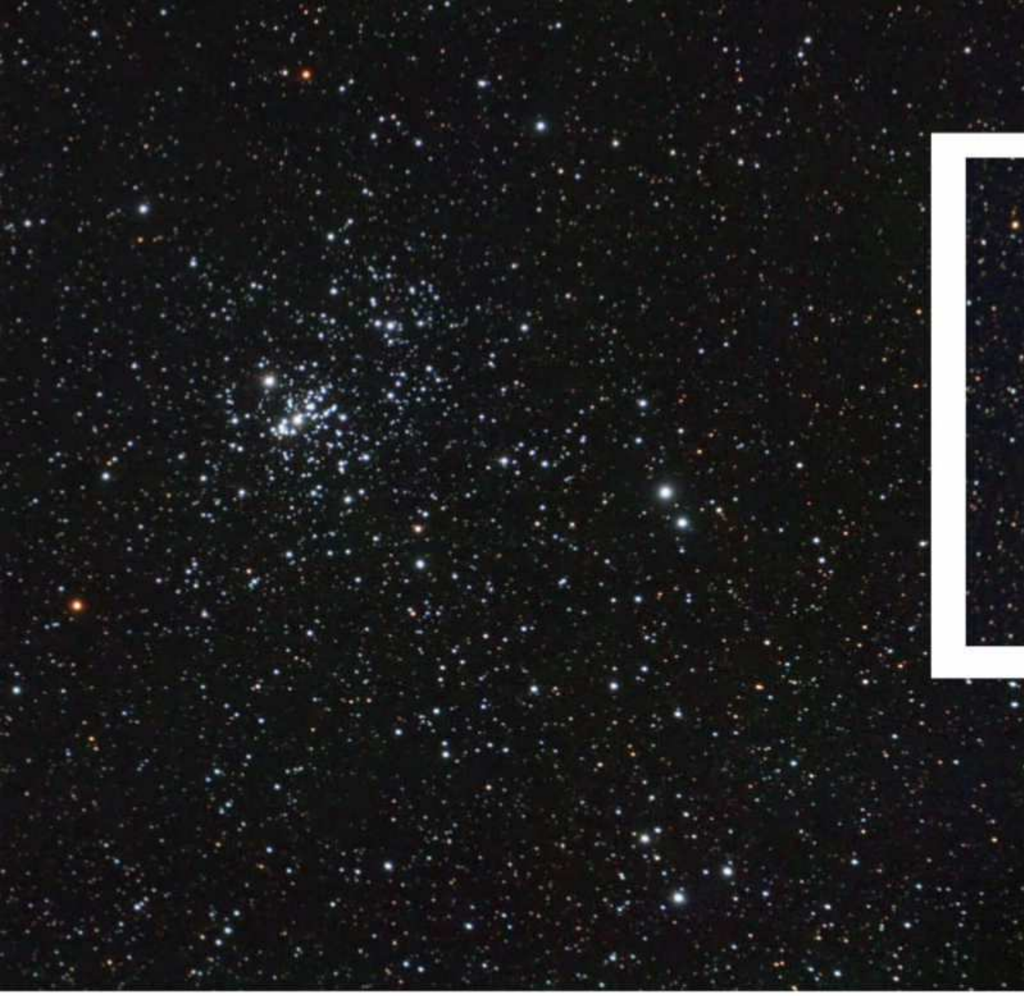
▼ The Meade 115mm Series 6000 ED Triplet is shipped in a hard-sided plastic case with metal trim and form-fitting foam.

Imaging performance

The Meade 115 ED functioned well visually, but that's only part of the power of these instruments. The critical question was whether this reasonably priced telescope would be up to the rigours of deep sky astrophotography. In imaging, mechanical soundness is at least as important as optical quality. I'd been impressed with the focuser and other mechanical qualities of the 115mm during my visual run, but astrophotography will stress any telescope.

The typical weak link with refractors

ROD MOLLISE (4)



◀◀ Views of the Moon were colour-free, with inky-black shadows within the craters along the limb at first quarter.

◀ The star field around NGC 869 and NGC 884, the Double Cluster, was tack-sharp when using field-flatteners. The author used an off-brand flattener for this photo that doesn't reduce the telescope's focal length, to take full advantage of the scope's resolving power.

▲ Although a relatively small target for a 115-mm instrument, M27, the Dumbbell Nebula, displays a wealth of detail in this image captured with the 115 ED and a Canon 400D DSLR operating at f/7.

is the focuser. The Meade's 2½-inch Crayford-style focuser acquitted itself well in the most crucial test. I inserted my heaviest DSLR camera and field flattener into the focuser and pointed the scope near the zenith. Would it slip without the focuser being locked down? Nope. Despite its easy focusing action, it never even threatened to slip. I can forgive many focuser *faux pas* if this requirement is met. The unit also had plenty of range; I had no problem bringing any camera or eyepiece combination into focus, though I secured the draw tube lock knob when imaging.

There were, however, a few minor deficiencies with the scope's focuser. While the 10-to-1 fine-focus knob is a boon for achieving sharp images, this particular telescope's fine focus action exhibited some backlash. I'd focus inward, let go of the knob, and it would spring back slightly. Although this never prevented me from achieving proper focus, it was nevertheless something I always needed to be aware of.

The other thing I had concerns with was the focuser's visual back. This is a ring with three 'captain's wheel'-style pegs. In typical operation, you insert a star diagonal or camera and rotate the ring clockwise using the pegs for added grip on the collar to secure the chosen accessory. While my heavy DSLR was held securely, rotating the visual back counterclockwise to remove the diagonal or camera would sometimes loosen the whole visual back, which screws onto the scope's focuser. Not a fatal flaw, but annoying nevertheless.

As for the telescope's imaging performance on deep sky objects, I gave that a high grade. Without a field flattener like Meade's optional Series 6000 model, stars near the field edge are radially elongated, as is typically seen with an uncorrected refractor. But inserting the flattener completely removed the distortion, producing sharp, round stars right to the edge of my camera's APS-C format detector. Stars looked remarkably clean and fringe-free across the entire field.

In my backyard, the f/7 focal ratio of the Meade proved as much of a plus for imaging as for visual observing. While it doesn't provide quite the wide field of faster focal ratios, the 115mm f/7 still delivers plenty to work with, particularly by offering a larger image scale. The reward for shooting at f/7 was that it allowed me to expose longer in my light-polluted yard before the sky background became overwhelmingly bright.

What's the best compliment I can give the Meade Series 6000 115mm ED Triplet APO refractor? I was sorry to see it go when the time came to return it. My biggest surprise was how much I enjoyed using this small scope visually. While there's no such thing as an all-purpose telescope, this excellent instrument was as close to that as any telescope I've used in a long time.

■ After decades of using SCT's, Contributing Editor **ROD MOLLISE** has recently embraced the joys of refractors.

Advancing the SETI quest

Hope, perseverance, and the courage of their convictions sustain those seeking hints of alien civilisations.

Seven days per week, the SETI Institute uses the Allen Telescope Array in California to search for alien signals.

SETH SHOSTAK / SETI INSTITUTE

IN MARCH I ATTENDED a SETI Institute workshop, where a multidisciplinary group of astronomers, neuroscientists, anthropologists, philosophers and historians pondered new approaches to expanding the search for extraterrestrial intelligence. Discussions ranged from the physics of planet formation, through the origin and evolution of life and the prospects for complex life and intelligence, to forthcoming hunts for both biosignatures and 'technosignatures' on exoplanets.

To me, the way these topics flowed together at the meeting served as a reminder that the distinction between astrobiology and SETI is completely artificial. It might exist in terms of bureaucracies and funding streams, but intellectually the quest to know how we — and living things in general — fit into the universe is all part of the same nested series of questions.

How does matter turn into living cells? Is this unlikely or inevitable? What is required of a planet to support this and the subsequent transitions to differentiated cells, multicellular life, cognition, curiosity and technology? What planetary transitions accompanied, enabled or were caused by these biological leaps? Could these have occurred on other types of planets that we know or suspect exist, and how would we recognise them?

For the future of SETI, the practical questions are, regrettably, as vexing as the intellectual ones. Few would deny how far-reaching success would be, but how do you maintain funding and scientific interest in a field where the payoff in any given year (or even decade) is so uncertain?

Not long ago, many deemed exobiology, along with SETI, as a fringe field, which 'serious' researchers must keep at arm's length. In the 1990s, anti-intellectual budget cutters in the US Congress discontinued all US federal government support for SETI. In 1998, attitudes changed. This came about largely due to the discovery of possible microfossils in a meteorite from Mars and the subsequent flurry of scientific and public excitement. It turned out to be a false alarm, but exobiology was rechristened as 'astrobiology' and suddenly became acceptable, well-funded, and even thought central to NASA's mission.

In terms of government backing, however, SETI remains out in the cold. Maybe it needs its own highly credible false alarm! In the meantime, how do SETI researchers, year in and year out, remain engaged and positive?

At the workshop, you couldn't help but notice that among the most engaged and positive participants were the now 'retired' SETI pioneers Frank Drake and Jill Tarter. Their enthusiasm doesn't depend upon immediate gratification. Both clearly believe, as do I, that we are not alone, that these efforts will ultimately pay off, and that whether we live to see it or not, we're contributing to something extremely important and larger than ourselves.

With new technologies and search strategies coming into play, with all the exoplanets that astronomers will soon bring into focus, and with people like Tarter and Drake willing to spend their entire careers on the quest — the odds be damned — I believe we have many reasons to be hopeful.

■ **DAVID GRINSPOON** gave a paper at the SETI workshop entitled, "Cognitive Planetary Transitions: An Astrobiological Perspective on the 'Sapiezoic Eon'". He coined the term to denote a theoretical time when cognitive processes become integrated into a planet's functioning.

Image courtesy Dr. John Carver (50 megapixel MicroLine ML50100 camera)

Kepler CMOS: Paradigm Shift

It is no surprise that the CCD's best performance is with a single long exposure. What may be surprising is the Kepler KL4040 CMOS camera has a better signal-to-noise ratio than the PL16803 even with a single long exposure. The signal-to-noise ratio of the KL4040 is better than the PL16803 even when using short exposures that are stacked!

The benefit of taking multiple short exposures is the option to discard a bad exposure ruined by satellite trails, tracking errors, or bad seeing (etc.). Incredible low-noise images are now possible with a single long exposure or many stacked short exposures. The KL4040's superior performance allows it to be used for a wide range of applications and requirements.

At Finger Lakes Instrumentation, we design and build unrivaled CMOS and CCD cameras, filter wheels, and focusers to pave your way to success—whichever path you choose. Designed and manufactured in New York, USA.

FLI™
Finger Lakes Instrumentation

Visit us at flicamera.com for more information about our cooled CMOS and CCD cameras, focusers, and color filter wheels.

G-Tracker is a work of Art

Simple. Elegant. Good Enough.

WHEN I WAS INTO astrophotography, I used to spend half an hour or longer polar-aligning my telescope. Nowadays all I do is visual observing with a trackball scope, and polar alignment is a matter of figuring out more or less where the pole is and plopping the mount down sort of aligned with it.

It would be nice if there were a simple, elegant way to make alt-azimuth mounts track with equal facility. Not necessarily perfect, but good enough. Art Gamble has figured out just such a device, and it's as simple as you can get.

It looks a little like a barn-door tracker: two slabs of wood, a hinge, and a screw that slowly tilts one of the wooden slabs upward. In order to put the hand-knob close at hand while he's observing, Art added a flexible shaft made from two grease gun hoses. Since Art is a retired machinist, he also made a tracker out of metal. That one comes in two pieces and works more or less the same, using the back feet of the moving part as the hinge. A third design uses a strap hinge and might be the simplest of the lot.

To use the G-Tracker, as Art has dubbed it, you simply put it under the east leg of your tripod or under the east foot of your Dobsonian, and turn the knob attached to the screw. That side of your tripod or ground board rises upward, and your scope moves westward. If you're aimed anywhere near the meridian (the north-south line that runs directly overhead), your tracking is pretty much spot-on. The farther you stray to the east or west, the more your target takes a diagonal path through the field of view.

When that happens, place your object a little off-centre and let it drift through centre toward the other side of the field while you're tracking. Even near the horizon, that motion is much slower than having no tracking at all.

No, it's not perfect, but it greatly increases the amount of time your target stays in the field of view. As Art says, "This device is meant to be an aid to give you more time at the eyepiece; astrophotographers need not apply".

There are ways to improve its accuracy, though. If you're going to spend much time in a particular part of the sky, you can always adjust the mount so the east leg becomes the northeast leg, which corrects its aim for objects in the northeast or southwest; or make it a southeast leg, which helps in the northwest or southeast.

At some point you have to stop and reset the screw or you risk tipping over your telescope. You can double your tracking time by raising the west side of your mount by that same height, starting out low on the east side and tracking through level to high.

If you start 2.5 cm low and go until you're 2.5 cm high, that's ten minutes — plenty of time for most observations. It's a great improvement over no tracking at all. And that's the name of the game when it comes to ATM projects: *improvement*.

■ Contributing Editor **JERRY OLTION** aims for 'good enough' when tracking.

▲ The plywood version uses a piano hinge on one end and a metal plate on the other for the adjustment screw to rest on.

▲ The G-Tracker design lends itself to many different forms; three variations are shown here.

ART GAMBLE (3)

Stellar road trip

Take a journey along New Zealand's Starlight Highway.

New Zealand is home to the world's first official 'Starlight Highway,' or Te Ara O Rehua, a stretch of road that includes all of State Highway 80 to Mt Cook village and part of State Highway 8 between Twizel and Fairlie; about 150 kilometres in total.

The Starlight Highway passes through the Mackenzie Basin, which has spectacular views that have drawn tourists and visitors for decades. Until recently, however, most people just passed through rather than stopping and staying for a few nights. But that has all changed due to the huge growth in astro-tourism in the region.

This new industry has been fuelled by three factors: the presence of the University of Canterbury's Mt John Observatory, the formation of the Aoraki Mackenzie International Dark Sky Reserve, and the spread of light pollution that is blotting out the stars across the developed world.

Mt John Observatory is perched high above dazzling Lake Tekapo. The observatory has four optical telescopes, including the 1.8m MOA telescope. The latter was installed in 2004 in partnership with Nagoya University and is used for research on dark matter, exoplanets and stellar atmospheres using gravitational microlensing.

The pristine dark skies have long been protected from light pollution, thanks to the foresight of the Mackenzie District Council. Back in the 1980s, the council introduced lighting ordinances to enable international astronomical research to continue at the Observatory. These ordinances, coupled with the low population level, have successfully protected its magnificent night skies.

The value of the night sky here was recognised by the founding in 2012 of the Aoraki Mackenzie International Dark Sky Reserve, the world's largest, covering an immense 4,367 square kilometres. It's no wonder it has been granted coveted Gold Tier status, the highest level, by the International Dark-Sky Association. Today, the spectacular starry skies found within the AMIDSR differentiate this area from other parts of New Zealand that have equally stunning day-time scenery.

The newly-designated Starlight Highway reflects the importance of this local asset, which has fuelled the growth in astro-tourism. This began in 2004 when the University allowed a local company to deliver astronomical public outreach through day-time and night-time tours of Mt John Observatory. Since then, astro-tourism has become a multi-million dollar industry (*AS&T* May/June 2018, p74); proof that natural dark skies are valuable from an economic viewpoint, and not just the environmental and aesthetic perspectives.

Official recognition of the Starlight Highway by the New Zealand Transport Agency would not have been forthcoming without tremendous support from former and present Mackenzie District Council mayors Claire Barlow and Graham Smith, the local community boards at Twizel, Tekapo and Fairlie, and many other individuals, businesses and organisations. It took a lot of time and effort to work through the bureaucracy, but the Starlight Highway was formalised late in 2017 and the signage is now in place.

You can't miss the Starlight Highway sign in Fairlie.

REBECCA GREATREX is a member of the Aoraki Mackenzie International Dark Sky Reserve Board and initiator of the Starlight Highway.

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

Sydney Astrofest
July 7
Free family telescope viewing, planetarium shows and more.
sydney.edu.au/science/outreach/

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

CWAS AstroFest
14–15 July
Annual astronomy conference and David Malin Awards ceremony.
www.cwas.orga.au/Astrofest/

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

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

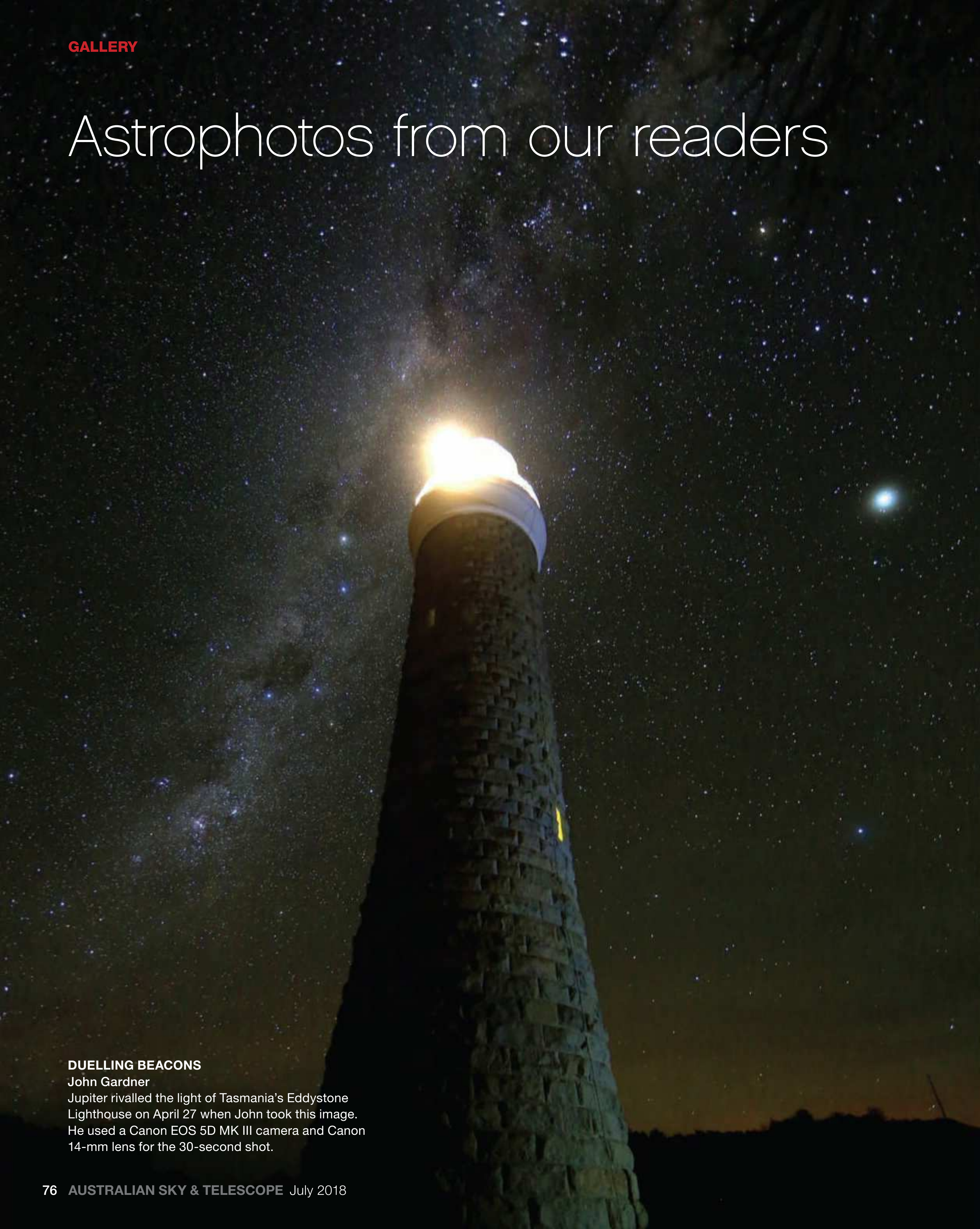
Siding Spring StarFest
September 28–30
Public lectures, telescope tours and family activities at Coonabarabran, NSW.
starfest.org.au

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

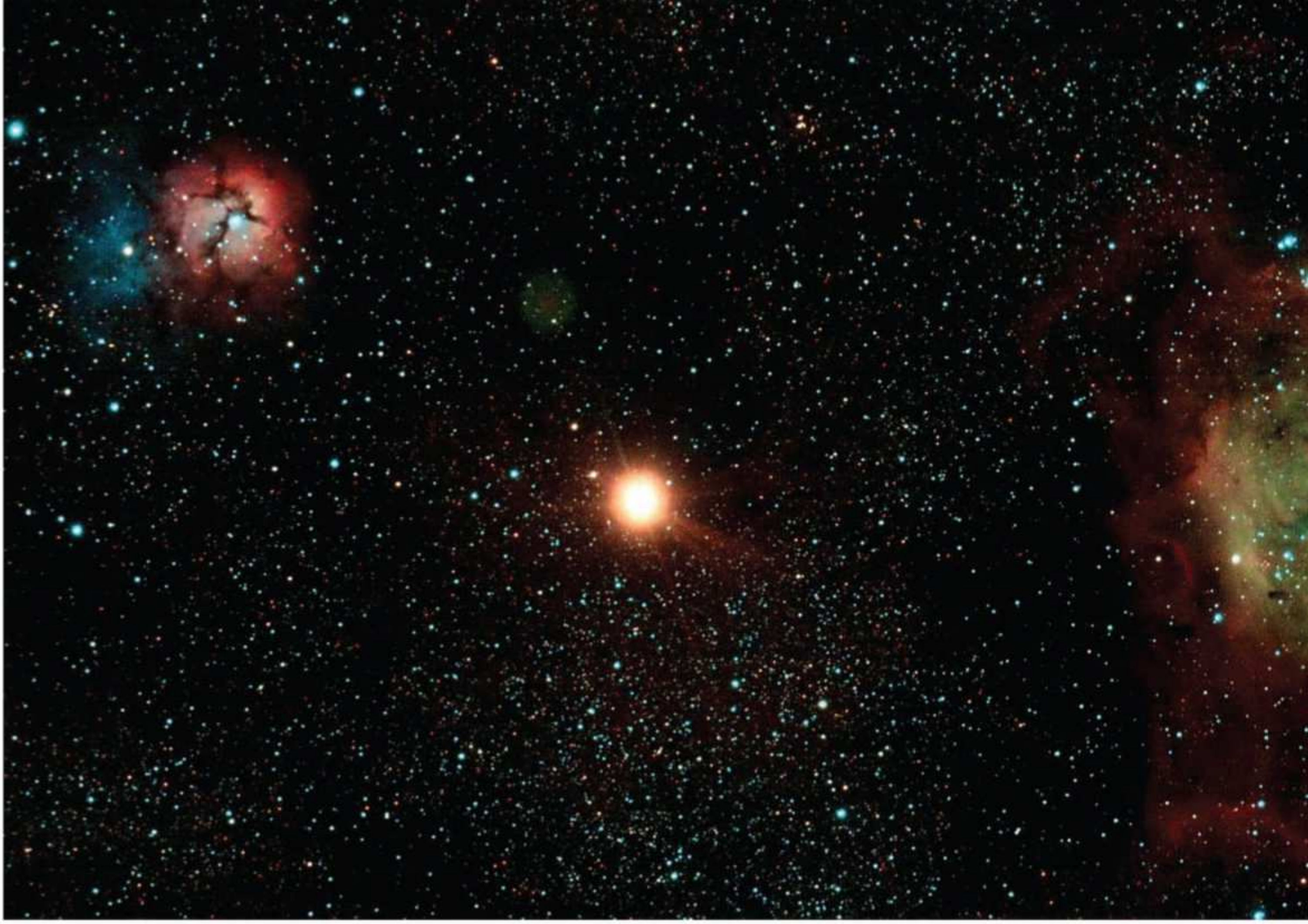
VicSouth 2018
November 2–6
Annual week of astronomy under very dark rural Victorian skies.
vicsouth.info/vicsouth.htm

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

Astrophotos from our readers

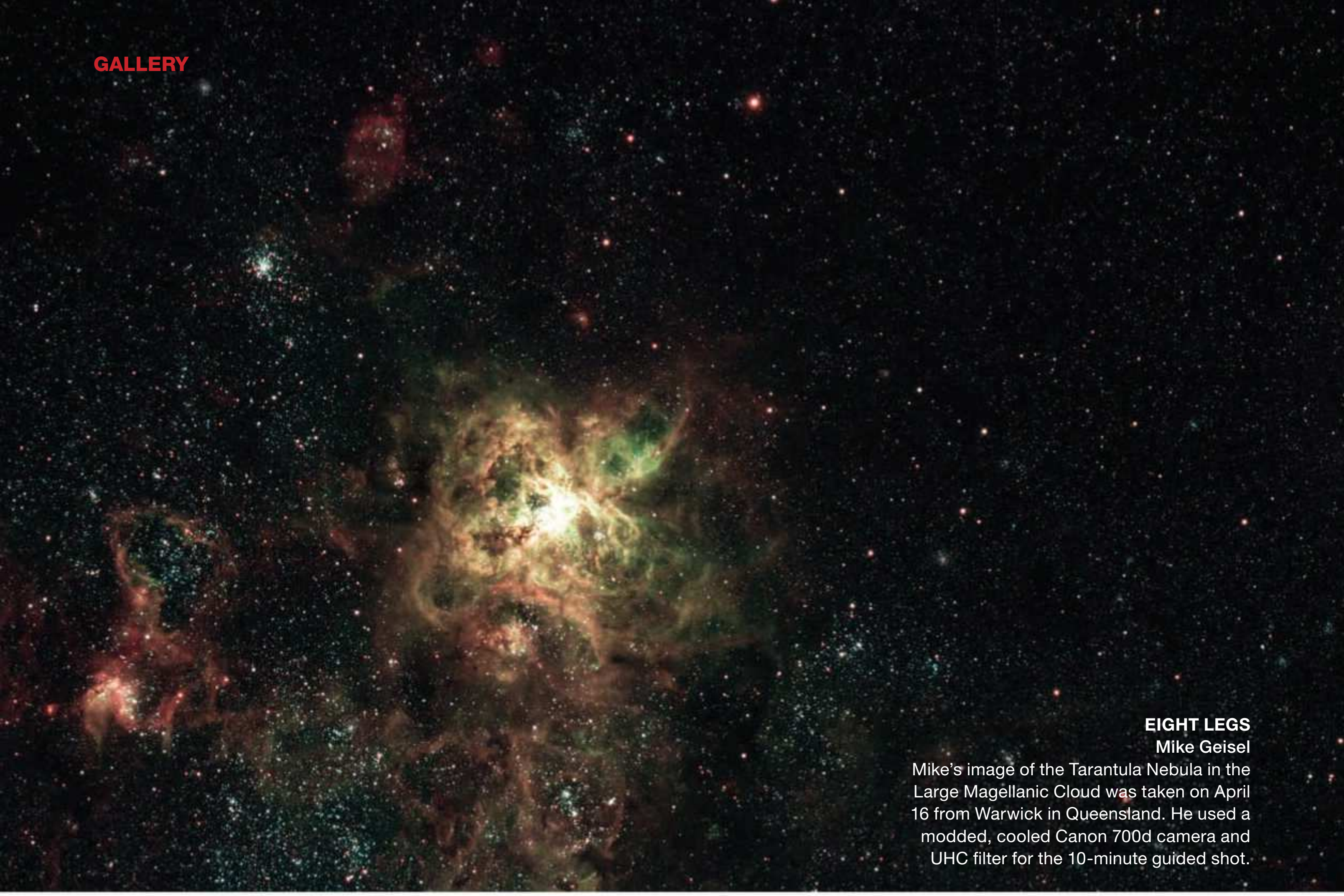


DUELLING BEACONS
John Gardner
Jupiter rivalled the light of Tasmania's Eddystone Lighthouse on April 27 when John took this image. He used a Canon EOS 5D MK III camera and Canon 14-mm lens for the 30-second shot.



▲ **HELLO MARS**
Ben Curcio
The Red Planet snuck between the Trifid and Lagoon nebulae on March 20. Ben used a Canon EOS 40D camera for the 40× 60-second image.

◀ **PLANET WARS**
Niall MacNeill
Looking every bit like the Death Star, Ganymede poked its head out from behind Jupiter on March 29 as Niall was imaging from near Bathurst in NSW. He used a ZWO ASI 174MM camera with RGB filter set and 2.5× Tele Vue Powermate to capture 1.4 million (!) frames, 600,000 of which he stacked and processed to produce this startling image.



EIGHT LEGS
Mike Geisel
Mike's image of the Tarantula Nebula in the Large Magellanic Cloud was taken on April 16 from Warwick in Queensland. He used a modded, cooled Canon 700d camera and UHC filter for the 10-minute guided shot.

VELA VIEW Mike Keith
Oddly-shaped planetary nebula VBRC 1 (or RCW 21) and open cluster Pismis 3 are close together on the sky in the constellation Vela. This image was remotely captured with the 0.5-metre astrograph of the ChileScope observatory near Cerro Pachon, Chile. Total exposure time was 5 hours using a FLI ProLine 16803 camera.

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.

FIRE BELOW
Aidan Jaros-Grilli
In May, authorities conducted hazard reduction burning on Mount Solitary near Katoomba in NSW. This was the first time since 1955 that the mountain had been set alight. Aidan captured the view with the Milky Way overhead using a Sony a7S camera and Sigma 15-mm f/2.8 fisheye lens. Exposure time was 30 seconds.

AUSTRALIAN SKY & TELESCOPE Market Place

Moon Chart & Phase Maps set

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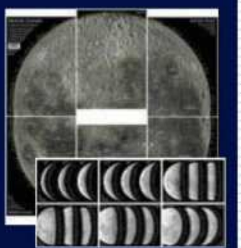

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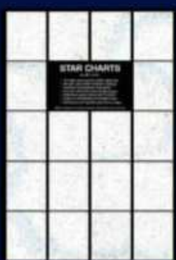

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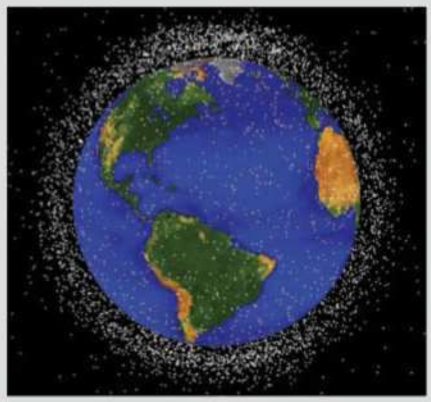

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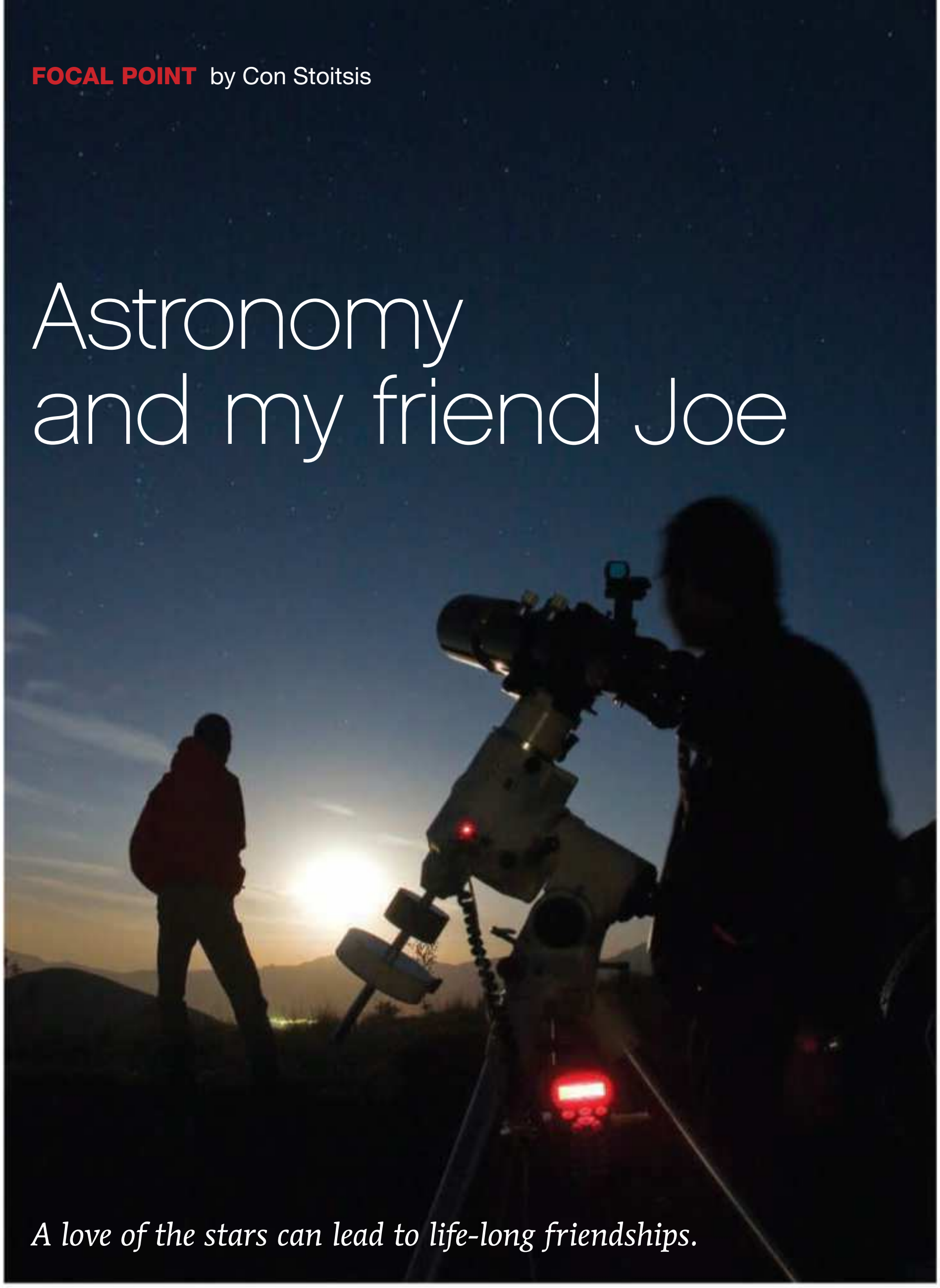

A love of the stars can lead to life-long friendships.

TWAN/BABAK TAFRESHI

Some months ago, while fishing the Goulburn River in Nagambie in country Victoria, my good friend Joe and I began to reminisce about our early teens and how astronomy has been the cornerstone of our 35-year friendship. Joe and I grew up in Footscray in Melbourne, doing the usually things kids did back then — we played footy and cricket with my brothers, Greg and Angelo, and the other kids in the street. These were the days before the Internet and computers.

My early interest in astronomy came after a visit to the old Melbourne Planetarium in 1978. I'm not sure how Joe caught the bug, but it may have stemmed from my own interest. After my initial visit, he and I began to visit the place regularly. It got to the point that the staff knew us by name and would give us free reading material. I remember one of the planetarium demonstrators at the time, probably sick to death of seeing us so often, gave us the 1979 Astronomical Society of Victoria (ASV) yearbook, and told us we should contact the society's section directors with our questions. We took this advice, and over the next four years we got to know the ASV directors very well. We would call them with all sorts of questions. I'm sure they sensed our enthusiasm, and they were always keen to answer our questions. In 1984 we became members.

Our early observing sessions were magical experiences. Joe and I would pick target objects during the day, look them up in our books and planispheres and then set-up our telescopes in my backyard in the afternoon. We'd prepare a hot drink and some snacks, and wait in anticipation for the Sun to set. Once it got dark we were in our element. A glimpse of a meteor would keep us talking for hours, as would any new bright comets. Our sessions were usually ended by our parents, but I remember on many occasions we would lose track of time and observe until very late.

This arrangement went on for years. As we got older, our equipment became more elaborate and our knowledge improved, and our appreciation of the sky grew. When we turned 18 we had our first real dark sky experience, after organising what was a very disorganised camping trip with friends. We stumbled across an area we later found out to be the original dark sky site of the ASV. We camped there that night with some friends, and have used this 'secret spot' many times since. Over the years we have had many observing highlights together — too many to mention — but I'd say Comet Halley in 1986 and the Leonids meteor shower of 2001 really stand out.

Although Joe and I have shared many hours under the stars, we both have families now, and do not get together as much as we once did. Astronomy has become more of a lifestyle for me; I observe whenever I can. Joe's enthusiasm for astronomy may not be what it once was, but it's astronomy that still brings us together. We get together two or three times a year to do some observing, and camping, from our secret spot.

Astronomy is about more than just observing and imaging — it's all about the friendships we make, and keep, for a lifetime.

CON STOITSIS writes the meteor column in this magazine, and is the director of the ASV's comet and meteor sections.

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