THE ASTRONOMY AND SCIENCE MAGAZINE FOR THE SOUTHERN HEMISPHERE

WINTER EDITION, 2024

SOUTHERN ASTRONOMER

HOW TO OBSERVE A ONCE-IN-A-LIFETIME COMET IN OUR SOUTHERN SKIES

DARK MATTER DOWN UNDER

THREE OUTSTANDING AUSTRALIAN SCIENTISTS ON THE SEARCH FOR DARK MATTER.

THE LUCKY HEMISPHERE

SOUTHERN ASTRONOMERS ARE THE LUCKY ONES. FIND OUT WHY INSIDE.

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Front Cover Photo: Geoff Healey took this stunning photo of P2 Pons-Brooks at a dark sky site near Heathcote, Victoria, in May 2024.

Above Left Photo: Gerald Grech took this brilliant photo of NGC 3576, the Statue of Liberty Nebula can only be seen in the Southern Hemisphere.

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RYAN EDWARD FRITZ

Ryan Fritz is the editor of *The Southern Astronomer*. Since 2021, he has been the editor of *Crux*, a bi-monthly magazine for members of the Astronomical Society of Victoria. Since 2014, he has also been the editor of The Advocate, an online magazine for not-for-profits and charities in Australia. For 10 years, he has worked in media, marketing, and communications for some very well-known charities. He fell in love with astronomy at a young age when he first saw the rings of Saturn through a telescope. Since then, he has been trying to learn the fine art of astrophotography.

READ MORE ABOUT OUR TEAM HERE.

MEET OUR TEAM

KEVIN ORRMAN-ROSSITER

Like most of us, Kevin grew up wanting to be an astronaut. He studied physics at university, and then discovered he was very good at experimental physics. He earned a Masters of Applied Science and also earned a PhD and a prestigious Queen Elizabeth II Fellowship. He worked as an R&D scientist After spending sometime as a consultant. He has rediscovered his love of science, and communicating science. He owns a solar telescope and loves solar astronomy.

MICHAEL MATTIAZZO

Michael became hooked on comets after observing the first and most famous periodic comet, 1P Halley, in 1986. Since then, he has visually observed and photographed well over 250 comets. He was mentored by one of the most significant visual comet hunters of all time, Bill Bradfield. Michael is now credited with the discovery of nine SWAN comets. He is currently a member of both ASSA and ASV and resides in Swan Hill, regional Victoria.

STEVE DE LISLE

Steve de Lisle is a passionate amateur astronomer with over 50 years of experience observing the night sky. Steve is married with three grown children and has four grandchildren. His main interest is astrophotography and cosmology. He is a retired clinical psychologist and enjoys writing.

TONY NEILSON

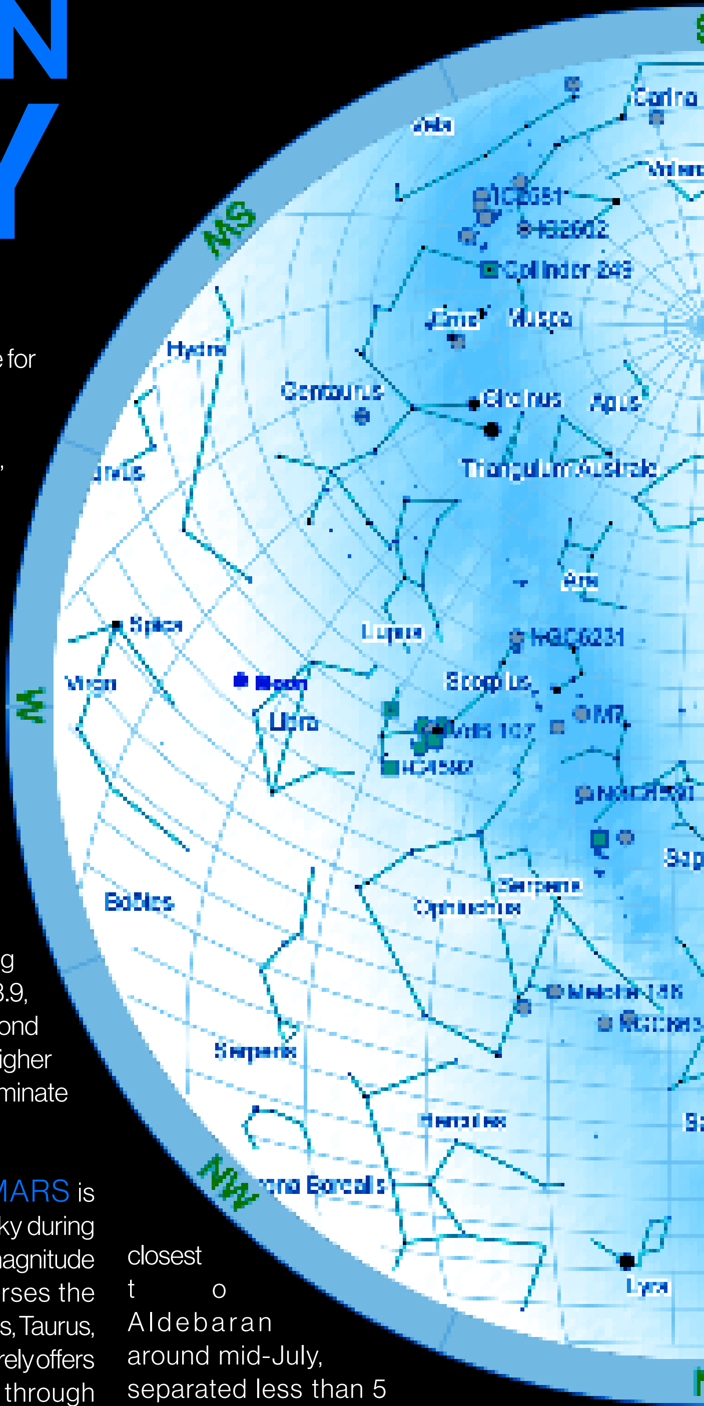
Tony developed an early love of science fiction and science, which stayed with him through a professional career that diverged wildly from where he thought it might take him. He designed and constructed RF detectors to observe pulsars during his physics honours year at the University of Tasmania before completing a PhD in laser physics at the University of Southampton. In Melbourne, Tony worked in telecommunications regulation. Now retired, he hopes to spend more time writing science fiction and astrophotography.

TIM DAVIS

Tim obtained a Bachelor of Science with Honours in physics and then a PhD in experimental gravitation from the University of Melbourne. He worked at CSIRO for 29 years doing pure and applied research in many fields, running a microfabrication laboratory, and leading science research groups. During this time, he was actively involved in science outreach, giving public talks on science, contributing to The Conversation, He has published over 130 papers in scientific journals, including in *Nature* and *Science*.

JULY

WHAT'S UP IN THE SKY



HIGHLIGHTS

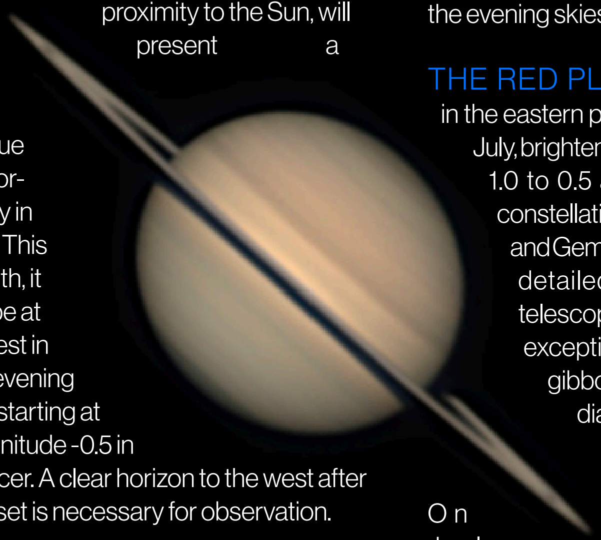
- Friday, 5 July: Earth at aphelion (furthest point from the Sun)
- Monday, 8 July (5am): Mercury 3 degrees south of Moon
- Friday, 12 July: Moon at apogee (furthest point from the Earth)
- Tuesday, 23 July: Pluto at Opposition (7.5 billion kilometres from Earth)
- Friday, 24 July: Moon at perigee (closest point to the Earth)

MOON PHASES

- Saturday, 6 July: New Moon
- Sunday, 14 July: First Quarter
- Sunday, 21 July: Full Moon
- Sunday, 28 July: Last Quarter

THE PLANETS

MERCURY often a challenging planet to observe due to its proximity to the Sun, will present a unique opportunity in July. This month, it will be at its best in the evening sky, starting at magnitude -0.5 in Cancer. A clear horizon to the west after Sunset is necessary for observation.



On the evening of 7 July, it will transit across the Beehive star cluster M44. On 8 July, the crescent Moon will appear several degrees to the east of it. On July 25, it will be 2° SW of Regulus (Alpha Leonis). Despite fading to magnitude 0.5, it will still be more conspicuous than Regulus (mag 1.4). This is a rare occurrence where Mercury will be visible in a dark sky, so it's a prime time for observation.

VENUS Telescopically, the small half-crescent-shaped disk will be 7" across. The planet will be the brightest object in the night sky after the Moon, will start to appear in the early evenings just above the western horizon in late July.

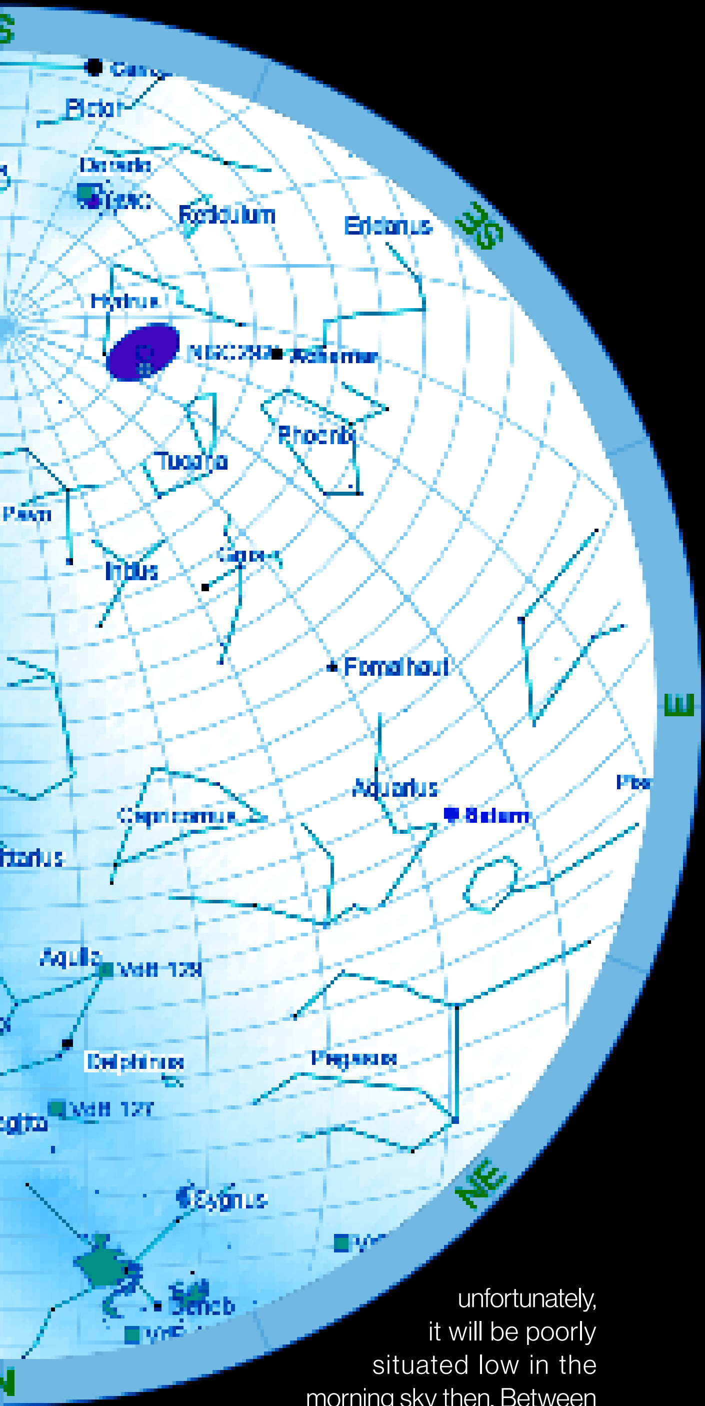
On 31 July, it will sit 10 degrees above the western horizon half an hour after sunset, shining brightly as a magnitude -3.9, almost entirely lit 10-arcsecond disc. It will gradually climb higher in the coming months to dominate the evening skies

THE RED PLANET MARS is in the eastern pre-dawn sky during July, brightening from magnitude 1.0 to 0.5 as it traverses the constellations of Aries, Taurus, and Gemini. Mars rarely offers detailed viewing through telescopes; this period is no exception. In July, its small gibbous disk will be 5" in diameter.

On the morning of July 16, it will be 33' southeast of Uranus

THE GIANT PLANET JUPITER having recently passed through solar conjunction, reappears in the north-eastern pre-dawn sky in Taurus, to the North of Aldebaran. Shining at magnitude -2.0 with a visual diameter of 34", Jupiter will be closest to Aldebaran around mid-July, separated less than 5 degrees away. Any telescope will reveal it latitudinal bands, red spot and Galilean moons.

THE MAJESTIC RINGED PLANET SATURN captivating sight visible through a telescope, will be one of the highlights of this period. On 1 July, the magnitude 1.1 planet will be situated in Aquarius near the border with Pisces. It has a visual diameter of 16" and a narrow ring system spanning 42". Every 15 years or so, the Earth passes through the orbital plane of the rings, resulting in their "disappearance". This intriguing event will next occur in March 2025, but



unfortunately, it will be poorly situated low in the morning sky then. Between July and September 2024, the rings will be a scant 2 to 3 degrees inclined, resulting in a needle-like appendage.

URANUS s visible in the morning sky in Taurus, near the Aries border. It shines at magnitude 5.8 with a tiny blue disk of 3.5" diameter.
Technically visible to the unaided eye from a dark site, binoculars or a telescope will be more helpful for observing it. On 15 July, it will be 33 arcminutes northwest of Mars.

NEPTUNE is visible in the late-night north-eastern sky in Pisces and is best situated in the pre-dawn hours. It is a planet only visible through telescopes or binoculars, shining at magnitude 7.8 with a diameter of 2.3".

Sky Map Above: The night sky from Melbourne, Australia at 16 July 2024 at midnight.

THE CONSTELLATIONS

Scorpius is high in the eastern sky. Below Scorpius is the constellation Sagittarius.
The Southern Cross, Crux, is high in the south and almost vertically surrounded by the Alpha and Beta Centauri pointer stars. These two stars are part of the large constellation Centaurus, which surrounds Crux on three sides.

METEOR SHOWERS

Meteor showers between July and September include Southern Delta Aquariids, active between 12 July and 23 August, with a maximum occurring on 31 July.
The Zenith hourly rate is usually around 25, with a meteor velocity of 41 km/s. The Capricornids are active between July 3 and August 15, with a maximum occurring on July 31. The zenith hourly rate is lower (ZHR = 5), and a slower velocity of 23 km/s makes them distinguishable from the faster SDAs. Frequent fireballs are a feature of this meteor shower.

DEEP SKY TARGETS IN JULY

- IC 4603: Rho Ophiuchi Cloud Complex
- M20: Trifid Nebula
- NGC 6188: The Fighting Dragons of Ara
- NGC 5236: Southern Pinwheel Galaxy

Rho Ophiuchi Cloud Complex. Credit: Anne-Maree McComb. See the full image: https://rb.gy/3bt4et

PHASES OF THE MOON JULY

This calendar was designed by Allexxandar of Freepix.com.

Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
28	29	30	31	1	2	3
4	5	6	7	8	9	10
11	12	13	14	15	16	17
18	19	20	21	22	23	24
25	26	27	28	29	30	31

RIPPLES IN **SPACE-TIME**

The merger of two black holes in the far distant past heralds a new era of gravitational wave astronomy in which Australian scientists are taking key roles.

Words by TIM DAVIS

At 7:50 pm Eastern Standard Time on 14 September 2015, the telltale sign of a cataclysmic event was racing towards Earth at the speed of light. Forty-five seconds later, it struck the Earth from a point in the southern sky, roughly from the direction of the Magellanic clouds. But even if you had been outside at the time, gazing up at the stars, you would not have noticed a thing. The ripple in space-time was like a quiet whisper, the faintest echo of a catastrophe that occurred long, long ago.

It happened over a billion years ago, when two massive stars had come to the end of their lives. The nuclear fuel needed to maintain their fiery glory had all but burnt out, causing almighty explosions – supernovae – that spewed matter and radiation far into space and leaving dense cores of atoms with little radiation pressure to fight the never-ending pull of gravity. The remnants of these stars began to condense until the atoms were squeezed unnaturally tight. For both stars, the pull of gravity was so strong that the repulsion of the atomic electrons and nuclear protons was overcome and they were crushed together to form neutrons.

Had these stars been less massive or had they blasted more material into space, this would have been the end of the episode; a cold, dense ball of neutrons with a one-millimetre-thick atmosphere of normal matter is all that would have remained. But not in this case. These stars had

Figure 1: An artist's impression of the two orbiting black holes with a nebula in the background. The apparent position of the stars near the each blackhole is distorted by the intense gravitational fields. Credit: Astronomical Society of Victoria.

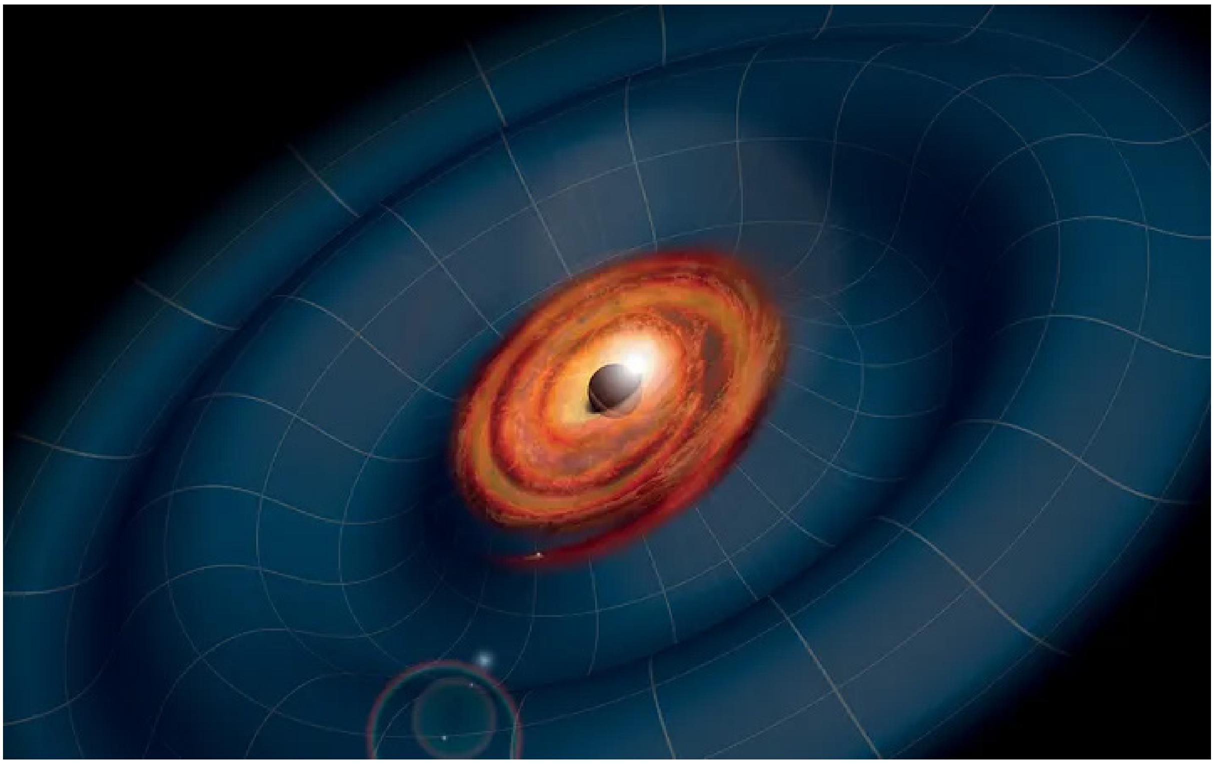


Figure 2: An artist's impression of a black hole generating gravitational. Credit waves. Image: Ben Gilliland/STFC.

been too greedy at birth, grabbing too much primordial hydrogen during their incubation and burning hot all their lives. Now their burnt remains were too dense, and the force of gravity had become too strong. They had warped space-time, crushing down on themselves and creating space-time singularities from which nothing can escape: black holes.

And yet, this is not the end of the story. Fate had a final twist for these two former stars. Black holes should have a long lifetime. They do not radiate like stars; instead, they drag in matter from the surrounding space. But not for these two – they were on a collision course. Slowly but surely, their intense gravitational fields began to take hold, drawing them closer and closer together. But such a collision is rarely perfectly head on; the chances of that are astronomically small. Like dancers on ice, skating towards one another to finally grasp hands and end up spinning in a pirouette, the gravitational pull drew the two black holes together leaving them slowly orbiting one another. They were now trapped in a bizarre cosmic dance. The distortion of space-time around them was intense and as they orbited one another, their gravitational field formed waves, carrying away energy, like ripples in the water spiralling down a plug hole.

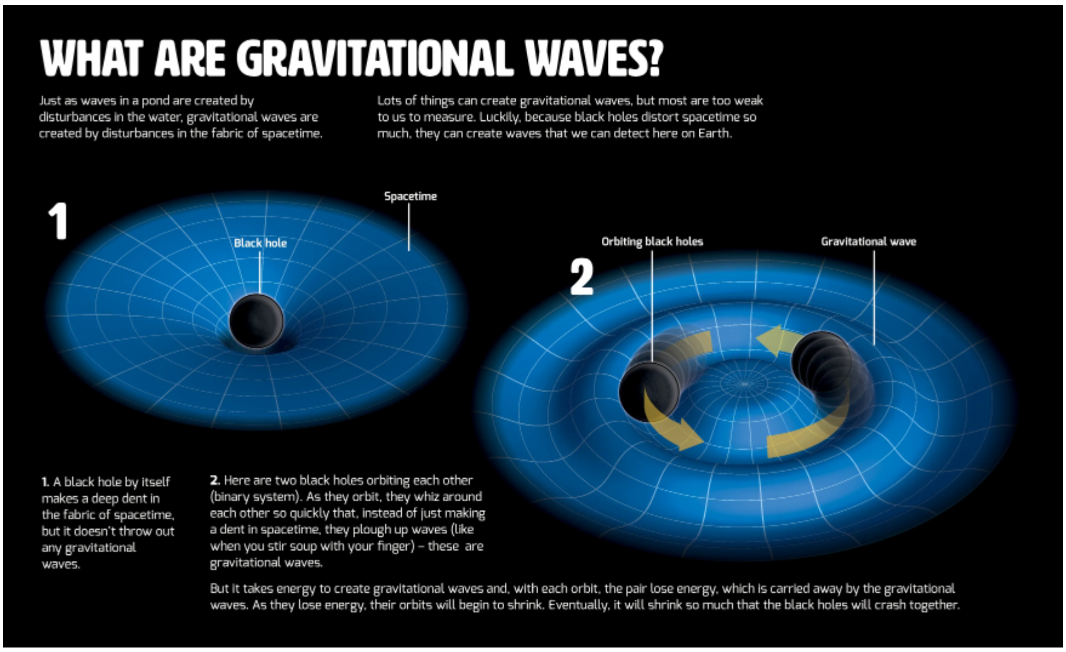


Figure 3: What are gravitational waves? Ben Gilliland/STFC

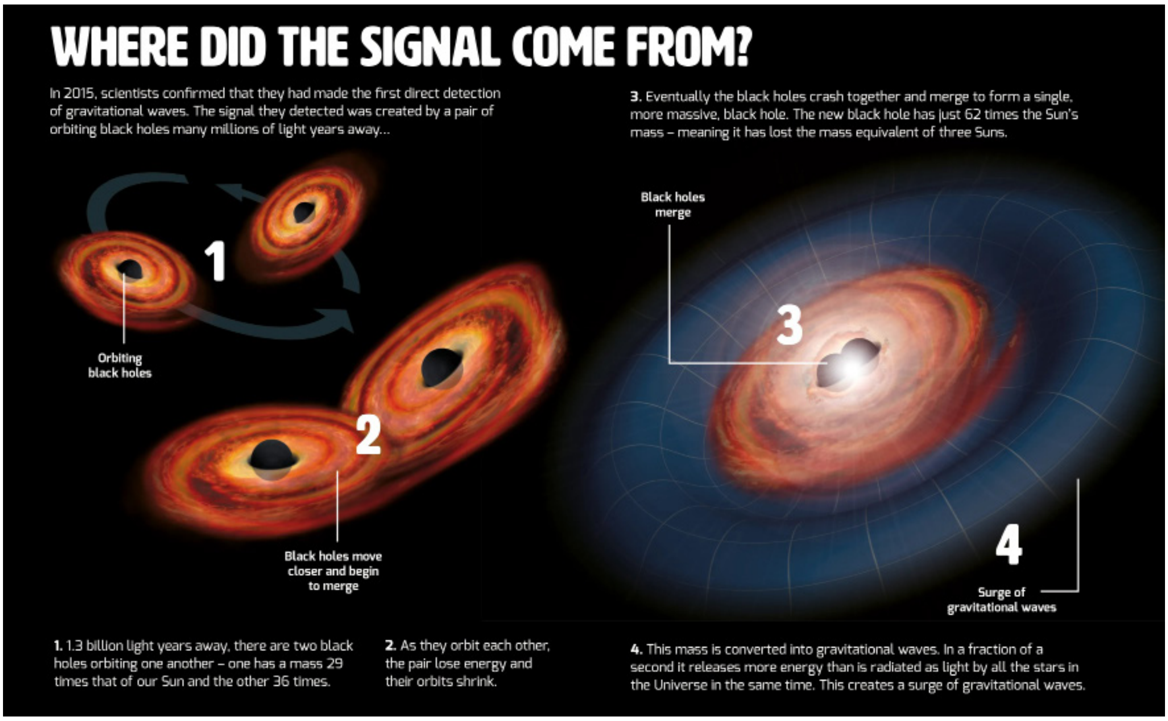


Figure 4: Where did the signal come from? Ben Gilliland/STFC .

The energy keeping them in their orbit was being lost, causing them to slowly move towards one another. Just like ice dancers in their pirouettes, they began to orbit faster and faster as the distance between them became smaller and smaller. And as they orbited faster and faster, more and more energy was lost as gravitational radiation. There was only one outcome possible: eventually they would collide.

Just before the collision, their orbital speed increased dramatically. In the last fraction of a second of their separate existence, they were orbiting roughly 350 kilometres apart, barely the distance between Melbourne and Albury. The gravitational force was so strong that the two black holes were orbiting 75 times a second, travelling almost at one-third of the speed of light, and this increased rapidly just as they collided. The distortion in space-time was so strong that in the last 20 milliseconds before the collision, the power they emitted in the form of gravitational waves was 50 times greater than the combined power of all the light emitted by all the stars in the known universe. During this event, the mass equivalent of three of our suns was turned directly into distortions in space-time and was radiated away at the speed of light.

The collision of the two black holes is believed to have occurred 1.4 billion years ago at a distance from Earth of 1.4 billion light years. If indeed you had been standing outside at 7:50 pm on 14 September 2015, looking south in the direction of the Magellanic clouds, you would not have noticed anything untoward. The distortions in space-time that had been rippling out across the universe for the past 1.4 billion years had become incredibly weak, requiring specialised equipment to detect. That they were indeed detected is a testament to generations of scientists, including some Australians, working at the forefront of gravitational wave detector technology.

Gravitational waves are weak compared with electromagnetic waves and become very feeble after travelling vast distances between galaxies. As such, extremely sensitive equipment is required to detect them. Albert Einstein first predicted the possibility of gravitational waves in 1916, a year after he presented his final version of the general theory of relativity to the Royal Prussian Academy of Sciences. This was an extension of his special theory of relativity, in which he showed that time and space are intertwined, a consequence of the measurement of the speed of light.

Following Michelson and Morley's experiments in 1887, it was discovered that light always propagates at the same speed, irrespective of the motion of the observer. This bizarre physical property is at odds with our usual experience. For example, think of measuring the speed of a wave in water. This depends on our state of motion and on the flow of the water. The speed of a wave propagating with the flow of water appears faster than a wave propagating against the flow. This does not happen with light. No matter what our state of motion, we will always measure the same speed of light. The consequence is that our measurements of time and space change depending on our relative speed in such a way that our measurements of the speed of light always yield the same answer. This is a result of Einstein's special theory of relativity.

In his general theory of relativity, Einstein extends the argument to inertial and gravitational accelerations. An inertial acceleration is one we apply to ourselves such as when an elevator starts to rise or when we press the accelerator pedal in our car. A gravitational acceleration arises due to the gravitational force. Einstein noted that an inertial acceleration is indistinguishable from the acceleration due to gravity. The

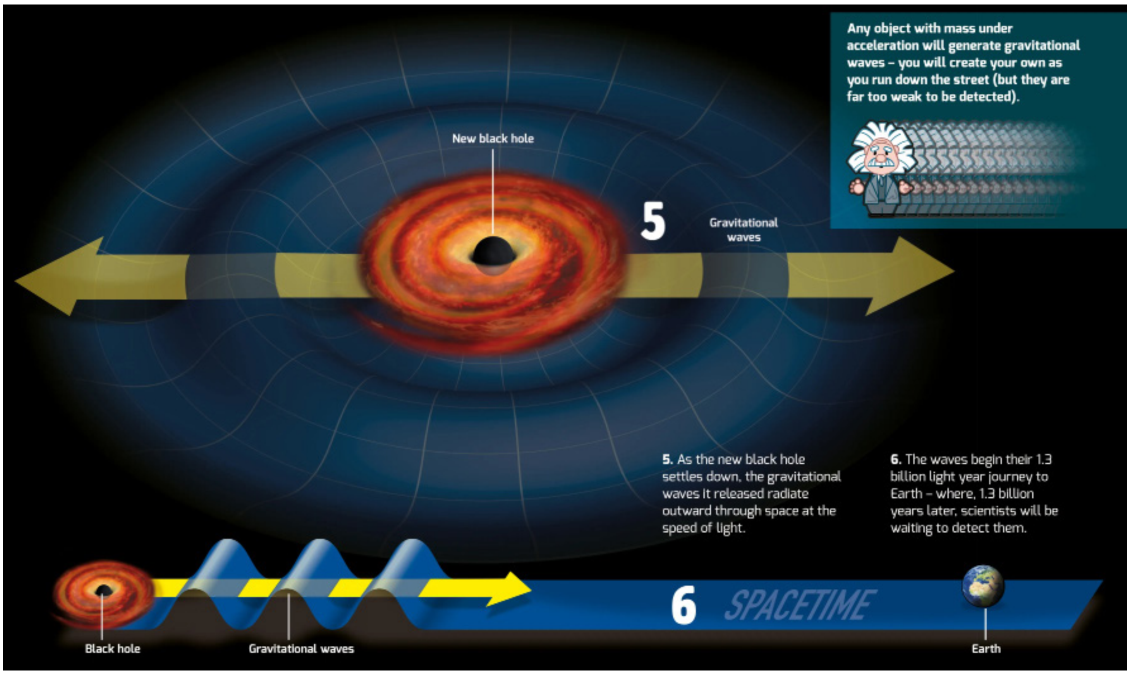


Figure 5: A new black hole Ben Gilliland/STFC.

classic example of this is to imagine you are in a closed box floating in space.

All of a sudden you feel yourself standing on the floor of the box. You cannot tell whether this is due to the box being placed on the surface of the Earth and you are being pulled down by gravity or whether the box is accelerating away into space. This is known as the principle of equivalence of gravitational and inertial mass. This idea gave Einstein a way of linking the principles of relativity, which involve distortions in time and space arising from accelerations, to the force of gravity. Einstein showed that these distortions can propagate as waves: ripples in space-time.

Einstein's calculations led him to believe that the power emitted by orbiting bodies was so small that it would be impossible to detect the gravitational waves. But this did not stop people from trying. A gravitational wave causes a periodic expansion and compression of space as it passes by. An object hit by such a wave experiences this periodic strain and resonates in sympathy, which forms the basis of a gravitational wave antenna.

The first antennae were designed in the 1960s by Joseph Weber from the University of Maryland. These were large aluminium bars that were expected to resonate when a gravitational wave struck them, not unlike a bell struck with a hammer. Although Weber claimed to have detected such waves, no-one was able to reproduce his results and some of his methods were discredited.

At the same time, David Blair from the University of Western Australia was on the lookout for difficult problems in physics and there was a need for a gravitational wave antenna in the Southern Hemisphere. The problem with gravitational wave antennas is making them sensitive enough to detect the minuscule strains induced by the gravitational wave. This requires eliminating all sources of noise that swamp the signal, many of which are simply caused by heat.

Blair reasoned that greater sensitivity could be obtained using a superconducting resonator, such as a metal bar made from niobium. When cooled below 9 Kelvin (or minus 264 °C), the electrons in niobium form a unique quantum state whereby the metal resistance becomes zero – it becomes superconducting – and in this state, its thermal noise becomes dramatically lower. Blair managed to convince the University of Western Australia to purchase 1.5 tonnes of niobium that was fashioned into a bar 3 metres long and 30 centimetres in diameter, kept safe in a cryostat at liquid helium temperatures.At the time theorists believed that supernovae could

Figure 6: Professor David Blair of the University of Western Australia (UWA). Credit: researchimpact.uwa.edu.au

emit a few per cent of a star's rest mass as gravitational waves, which meant that Blair's niobium bar experiment had a good chance of detecting them. The scientific process follows a typical path of first building a system followed by a seemingly never-ending cycle of chasing and eliminating sources of noise to improve sensitivity. But as the sensitivity of the system improved over time, the theorists continued to revise their predictions of the strength of gravitational waves downwards by orders of magnitude.

It is now thought that gravitational waves from supernovae will require even more sensitive detectors than we have today.

However, during the decades of gravitational wave antenna development, Blair and his group encountered an unusual effect, now known as parametric instability. In their system, the vibrations of the niobium bar are detected using a sensitive microwave transducer. The vibrations of the metal bar modulate the microwave frequency, which is then detected using an extremely accurate sapphire clock invented by Blair especially for this purpose. With this system, the noise had been reduced to such small levels that the gentle touch' of the microwaves on the surface of the niobium was enough to cause it to vibrate. And because the vibration of the bar modulated the microwave field, it created a positive feedback effect, not unlike the squeal from a microphone too close to a loudspeaker. This is known as parametric amplification. For the gravitational wave antenna this was an unwanted instability that swamps any signal to be measured.

Through a careful scientific analysis of this problem, Blair and his group managed to find ways of damping and circumventing these instabilities.

Along with the Australian detector, four others were constructed (two in the United States, and one each in Switzerland and Italy) to provide a worldwide network listening for gravitational wave events in the Milky Way. All of these detectors were many orders of magnitude more sensitive than Weber's. But despite the incredible efforts of Blair and his group, their system never detected any gravitational waves. At 3 metres long it was just too small and it was not possible to fashion a larger niobium bar, even though they proved it was possible to detect motions of their antenna as small as 10^{-20} metres. Blair noted in retrospect that their antenna did not have enough bandwidth. It could only detect gravitational waves with frequencies between about 700 and 800 Hertz instead of gathering signals across the broad range of frequencies necessary for detecting events such as the collision of black holes.

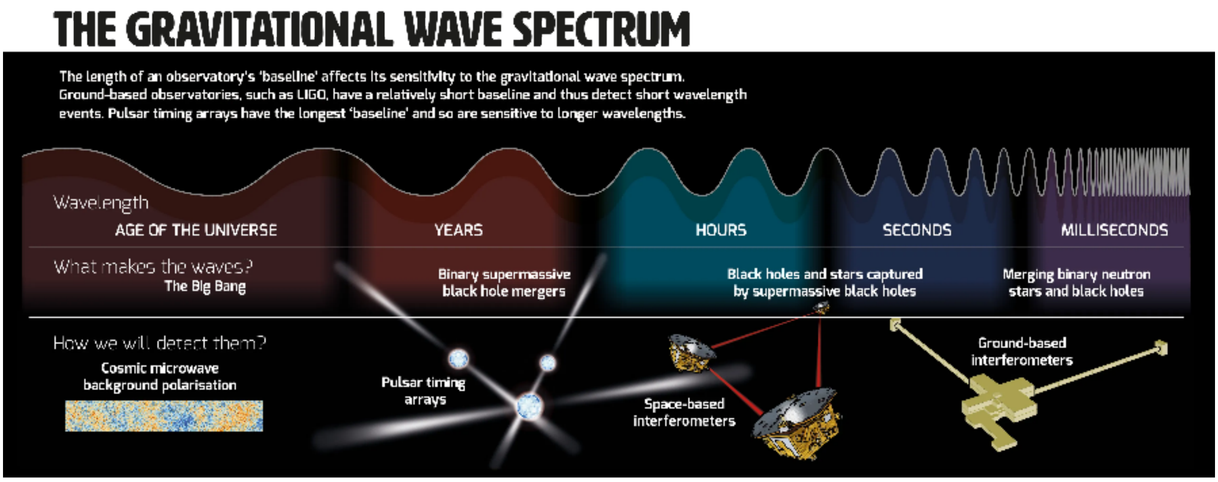
The amount of expansion and compression of space due to the passage of low frequency gravitational waves increases with distance, on account of their huge wavelengths. This means that larger antennas are more sensitive and this is where LIGO comes in. The Advanced LIGO system (Laser Interferometer Gravitational-wave Observatory) detects the expansion and compression of space using a laser beam reflecting off two pairs of mirrors, with each pair placed 4 kilometres apart and the two optical beam paths at right angles.

This configuration is known as a Michelson interferometer. A gravitational wave passing through the interferometer causes the mirror positions to oscillate. When the separation of one pair of mirrors increases, the separation of the pair at right angles decreases. The mirror oscillations are detected by a modulation in time of the interference pattern of the light beams. The pattern change forms a key signature of a gravitational wave. The system is incredibly sensitive, as needed to detect strains induced by the gravitational wave of one part in 10^{20}. This is equivalent to measuring 0.1 per cent of the diameter of a proton for the 4 kilometre separation of the mirrors in the LIGO system.

The first gravitational wave detected had a characteristic chirped signal, an oscillation beginning at 35 Hertz and increasing rapidly to 250 Hertz, a result of the in-spiralling of the two black holes as they collided.

From his experience with the niobium bar, it was obvious to Blair that the LIGO system would also suffer from parametric instability. The photon pressure of the laser beam on the mirrors could induce small oscillations that, in turn, would modulate the laser beam, feeding back on the motion of the mirrors. Despite numerous warnings of the possibility of parametric instability, the scientific community was sceptical that the LIGO system would suffer from such an effect until 2014 when Blair received an urgent message seeking his expertise on controlling parametric instability. By this time, the University of Western Australia gravitational wave researchers had built a LIGO test system at Gingin in Western Australia where they recreated the intense laser light necessary to make the LIGO detectors sufficiently sensitive.

They had demonstrated the existence of parametric instability in their system and had tested various schemes for controlling it. Blair's son, Carl Blair, who was a PhD student at the time, went to the LIGO facility in the United States and in collaboration with LIGO scientists gradually brought the instabilities under control. By September 2015,



their efforts enabled the detectors to run with the 20 kilowatts of laser power necessary to achieve the required level of sensitivity. A few days later the LIGO system detected its first gravitational wave. In recognition of his efforts, Blair shared the 2020 Prime Minister's Prize for Science. (For a history of gravitation research in Australia, read Blair's recently published book Uncovering Einstein's New Universe).

The cost of a system like LIGO is enormous: estimated to be over 1 billion US dollars. The size and complexity of the facility requires a huge number of scientists and engineers for maintenance and operation along with a commensurate budget. With such an expense, these facilities are usually run as an international consortium involving scientists from around the world, including Australia.

Some years prior to 2015, scientists from Australian universities had been seeking substantial research funding to help contribute to the search for gravitational waves. In 2014, they formed a proposal for a Centre of Excellence in Gravitational Wave Discovery, which they named Ozgrav. Matthew Bailes, a highly respected astronomer from Swinburne University of Technology in Melbourne, agreed to lead a proposal for funding from the Australian Research Council. Although it was short-listed for funding, Bailes was not confident that their proposal would get through.

After all, this was unproven science: no one knew whether gravitational waves could be detected at all. Then came the 2015 announcement from the Advanced LIGO team that they had detected a gravitational wave event that appeared to originate from two black holes colliding. The Ozgrav proposal shot to pole position and was funded.

Ozgrav is a partnership between Swinburne University, Australian National University, Monash University, University of Adelaide, University of Melbourne and University of Western Australia, along with other collaborating organisations in Australia and overseas. They are members of the LIGO scientific collaboration working on techniques to minimise the effects of parametric instability as well as providing technical expertise on monitoring the state of the LIGO mirrors, reducing the effects of seismic vibrations, developing algofrithms for data analysis and improving sensitivity.

Figure 7: Virgo Observatory in Santo Stefano a Macerat near the city of Pisa, Italy.
Credit: The Virgo Collaboration/CCO 1.0.

But the real questions is whether or not Australia will have its own gravitational wave observatory. Bailes is cautiously optimistic. The cost of such a system would be in the hundreds of millions of dollars but there is a need in the astronomy community to have at least one system in the Southern Hemisphere.

To date there are only three working gravitational wave antennas: two LIGO antennas are in the United States and the third, the VIRGO system, is near Pisa in Italy. A system based in the Southern Hemisphere would provide important information, allowing much more precise location of the sources of gravitational waves using a simple triangulation technique. This alone may provide stimulus for the international community to help fund such an observatory.

Since 2015, hundreds of gravitational wave events have been detected but there is uncertainty as to the physics behind their generation. Questions still arise as to what remains after black holes collide. Is it a black hole or a remnant neutron star? As a part of the Ozgrav partnership, a new detector concept has been developed. Named NEMO (Neutron Star Extreme Matter Observatory), it is a gravitational wave detector similar to the LIGO system but aimed at detecting neutron star mergers with frequencies in the kilohertz region.

Bailes and his colleagues have developed a white paper outlining the scientific value of building such a detector, not to mention the benefits from such a project, like the building of local technical expertise in advance technologies that have potential spin offs in more commercial fields.

As Bailes notes, Australia already has world-class facilities in optical and radio astronomy. A gravitational wave observing facility would be the perfect complement.

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