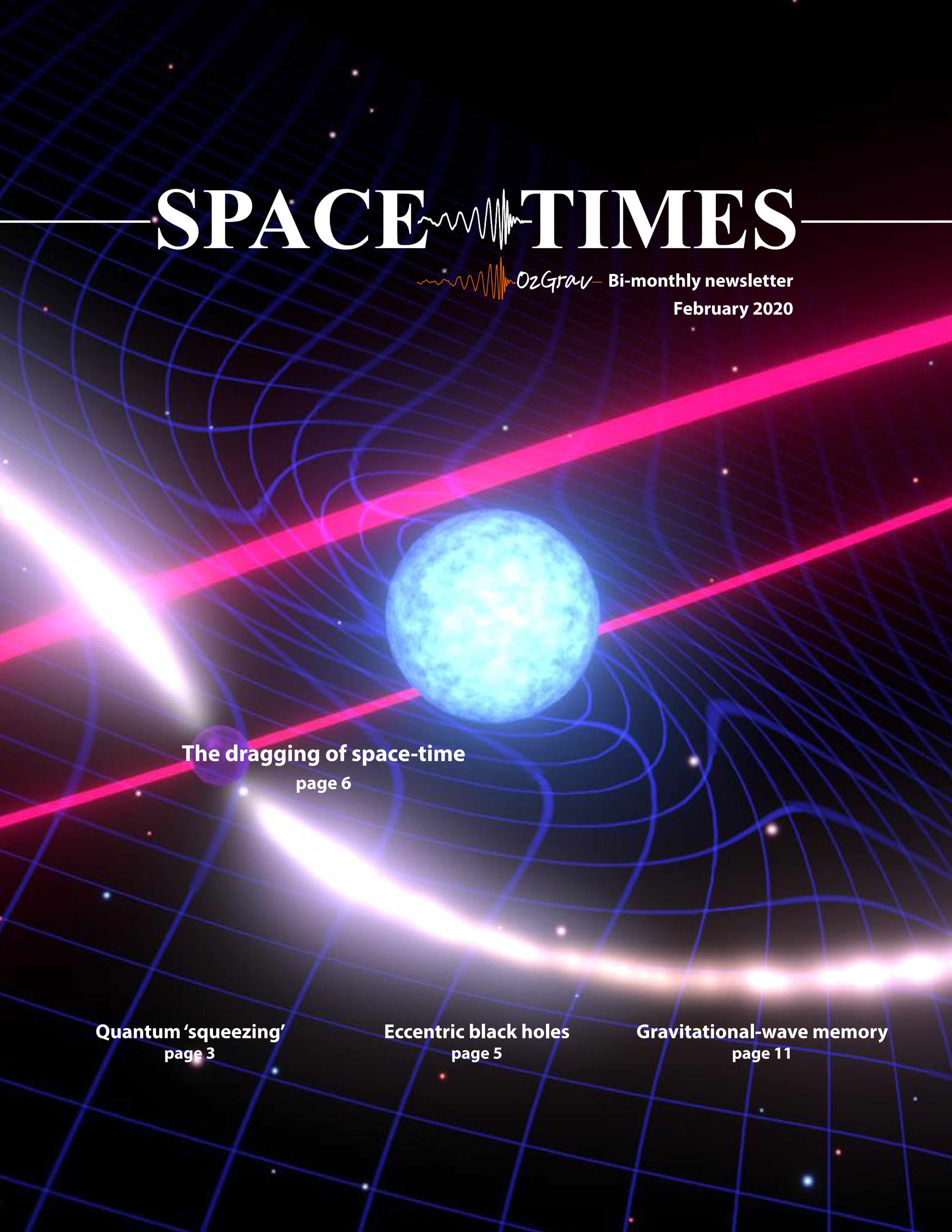
SPACE TIMES

OzGrav Bi-monthly newsletter
February 2020



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Welcome

Welcome to the February edition of *Space Times.*

I've just got back from visiting the Flatiron Institute in New York City for a workshop on Fast Radio Bursts (FRBs). The meeting was organised by a small team including our Governance Advisory Board member and timing array expert Dr Chiara Mingarelli and Dr Brian 'kilonova' Metzger. One of the things I love about astronomy is meeting up with new and old friends from different cultures and seeing how our expertise in one area (gravitational waves) is relevant to others—like FRBs. But travelling half-way around the world contributes a hefty carbon footprint. The devastating effects of the recent Australian bushfires was acutely felt by our colleagues in Canberra, among others, serving as a painful reminder that our planet is facing a climate emergency.

It is clear that in academia, as in many other areas of our life, we must urgently confront a harsh reality: the detrimental impact our occupation and travel has on the environment. Rather than impose directives from on high, I will be looking to the membership of OzGrav for ideas about how we should collectively balance the needs for conference attendance and networking in the future.

I hope you enjoy reading this edition of the newsletter that introduces some of our science, access schemes and personnel. I had the great pleasure of being invited out to lunch in New York at Columbia University by one of our LIGO colleagues who was very excited about the developments in gravitational wave instrumentation, astrophysics and outreach at OzGrav. I'm very fortunate to have a team of which I can be proud. Keep up the good work!

Cheers,
Matthew - OzGrav Director

News in brief

- Congratulations to OzGrav Chief Investigator (and head of our Space Instrumentation program) Kirk McKenzie and Associate Investigator Alan Duffy for being nominated as finalists for the inaugural Space Connect Australian Space Awards!
- In January, OzGrav headquarters hosted a team of financial modellers from ANZ bank to showcase OzGrav's software and numerical techniques, as well as the new Australian Gravitational Wave Data Centre. The workshop explored opportunities for future collaboration in financial data modelling and analysis.
- OzGrav's *Virtual Universe* will be launching 21 February 2020, in conjunction with the inaugural Einstein-First International workshop (18-21 February), at the Gravity Discovery Centre in Gingin, Western Australia. More on page 12.
- The first confirmed detection of gravitational waves featured in National Geographic's top 20 scientific discoveries of the decade.
- New Scientist ranked the detection at #3 in their top 10 discoveries.

Editor-in-chief: Luana Spadafora
Subscribe or submit your contributions to lspadafora@swin.edu.au

A quantum leap that's been **decades** in the making

Science enthusiasts and the general public have become accustomed to finding out about cataclysmic events in space such as black holes colliding, as though spotting them was as easy as riding a bike.

In fact, scientists only detected ripples from such an event for the first time about four years ago. Forty years of tireless work from a collaboration of thousands of people around the globe went into that breakthrough.

Since then, the Advanced Laser Interferometer Gravitational-wave Observatory (LIGO) detectors in the United States (US) and Virgo, the European Gravitational Observatory's detector in Italy, have detected the mergers of two black holes, the collision of two neutron stars and possibly also a black hole eating a neutron star.

OzGrav Deputy Director Professor David McClelland at Australian National University (ANU) is leader of the Australian partnership in Advanced LIGO. He and his team of instrument scientists had a big role to play in the discoveries, but their work stands to make an even bigger impact in the future.

A paper recently published in the prestigious journal *Physical Review Letters* outlines exciting results from the team's work to help improve the sensitivity of laser interferometers in the US that can detect ripples in space and time from these violent smashes in the Universe.

These ripples, known as gravitational waves, are minuscule and many of them can be easily drowned out by so-called quantum noise in the laser's surrounding vacuum that is pushing the interferometer's mirrors around and making measurements fuzzy. The ANU researchers' method, called 'squeezing', dampens quantum noise to help make measurements more precise.

The LIGO detectors were recently taken offline for upgrades to improve their range and precision, including with the enhanced squeezing capability.

Members of Professor McClelland's Centre for Gravitational Astrophysics, Ms Nutsinee Kijbunchoo and Dr Terry McRae, spent a year at the Hanford Observatory as lead members of the LIGO installation and commissioning team. That team includes Dr Georgia Mansell, who did her PhD on quantum squeezing at ANU and is now at LIGO, as well as collaborators from MIT and Caltech.

Ms Kijbunchoo was one of the three female graduate students who led the quantum squeezing improvement of the advanced LIGO gravitational wave observatory reported in Physical Review Letters.

> 'The ANU researchers' method, called "squeezing"', dampens quantum noise to help make measurements more precise.'

Ms Kijbunchoo, along with MIT's Maggie Tse and Haocun Yu, used technology pioneered at ANU and refined at MIT to improve the detector's performance by more than 15 per cent.

'Not long after, I was really excited when the first gravitational-wave signals were observed with these 'quantum enhanced' detectors I had helped build,' Ms Kijbunchoo said.

'When we injected squeezing into the Hanford detector for the first time, the range improvement even before the optimisation was jaw dropping. That was really the moment I realised how important squeezer was and how much I have contributed. I can graduate happy.'

Dr Lisa Barsotti from the MIT LIGO Lab, the leader of the overall installation project, said that the ANU and MIT collaboration in this area has been pivotal to LIGO reaching much, much further out into space.

Professor McClelland recalls the day 15 years ago when, his then graduate student, OzGrav Chief Investigator Kirk McKenzie burst into his office to announce that they had made, for the first time anywhere, the type of squeezing needed for gravitational-wave detectors.

He said while there was still much work to be done at that point in time, the team realised how they could achieve their goal.

'The achievement this year is the fulfilment of a dream we had 17 years ago, but it is also just the beginning,' Professor McClelland said.

Watch the interview with Nutsinee Kijbunchoo on ABC News here.

This is an extract from the media release published on ANU news.

New study reveals a huge neutron star collision 3.4 times heavier than the Sun

A new collaborative study with the ARC Centre of Excellence for Gravitational Wave Discovery (OzGrav) reveals a possible collision of two neutron stars earlier in 2019—only the second time this type of cosmic event had ever been detected.

The gravitational-wave observatory network, that includes the National Science Foundation's LIGO and the European Virgo detectors, picked up what appeared to be gravitational ripples from a collision of two neutron stars back on 25 April 2019.

Gravitational waves and light were first witnessed in the same event in 2017. This second event in 2019, called GW190425, did not result in any light being detected; however, researchers have learned that the collision resulted in a merged object with an unusually high mass.

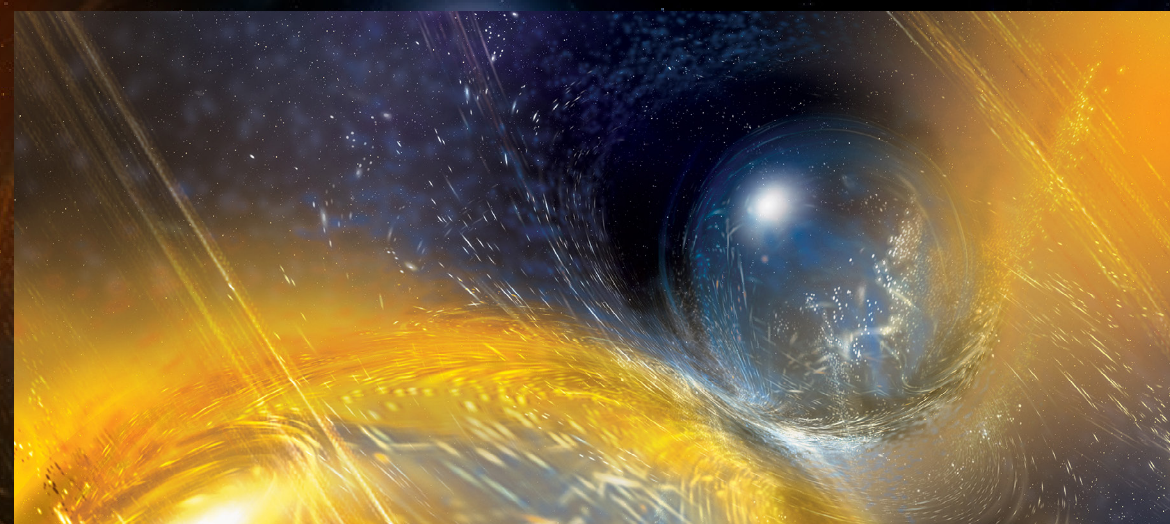
OzGrav postdoctoral researcher Simon Stevenson says: 'This event is a perfect example of how gravitational-wave astronomy is a completely new and unique way of looking at the Universe. Binaries with similar masses to this event may not exist in the Milky Way or may be completely invisible to conventional radio telescopes'.

Neutron stars are the remnants of dead stars that exploded. When two neutron stars spiral together, they undergo a violent merger that sends gravitational waves shuddering through the fabric of space and time.

The gravitational waves first detected in 2015 were generated by the fierce collision of two black holes. Since then, scientists have registered dozens of new candidate black hole mergers. The first detection of a neutron star merger took place two years later, in 2017.

OzGrav Postdoctoral Researcher Vaishali Adya says: 'This detection manifests the importance of continued improvement of the already amazingly sensitive gravitational wave detectors, as this event would not have been observable prior to the latest upgrades. OzGrav played a vital role in these upgrades, one of which involved reducing the quantum noise in the detectors'.

OzGrav Postdoctoral Researcher Xingjiang Zhu says: 'The combined mass of the merging objects is surprisingly high, much greater than any previously known double neutron star binaries including the one detected in 2017. This provokes us to think about the nature of this event and how the source might have been formed'.



Artist's impression of the binary neutron star merger producing GW190425. Credit: National Science Foundation/ LIGO/Sonoma State University/A. Simonnet.

The combined mass of the merged bodies in this event is about 3.4 times that of the mass of the Sun. Typically, neutron star collisions are only known to happen between pairs of neutrons stars with a total mass up to 2.9 times that of the Sun. One possibility for the unusually high mass is that the collision took place not between two neutron stars, but a neutron star and a black hole, since black holes are heavier than neutron stars. But if this were the case, the black hole would have to be exceptionally small for its class. Instead, the scientists believe it is more likely that the event was a shattering of two neutron stars and that their merger resulted in a newly formed black hole.

Neutron star pairs are thought to form either early in life—when companion massive stars successively die one by one—or when they come together later in life within dense, busy environments. The data from the 2019 event do not indicate which of these scenarios is more likely—more data and new models are needed to explain the unexpectedly high mass. The discovery suggests that we may have detected an entirely new population of binary neutron star systems.

OzGrav Associate Investigator Greg Ashton says: 'This event was really interesting. The chirp-like signal was seen by two of the three detectors for about 128 seconds before the final merger. Unfortunately, one of the detectors was not observing at the time, which meant that the sky localization was poor. Perhaps because of this, and because it was so far away, no electromagnetic light was observed from this event. Nevertheless, we saw it very clearly in the gravitational wave data and could use that to calculate the masses, spins, and orientations of the objects'.

'Additional exciting and unexpected discoveries can be expected as the sensitivity of the LIGO detectors improves. OzGrav is working closely with LIGO to improve their sensitivity, developing new instrumentation and analysis techniques', says Professor Peter Veitch, University of Adelaide OzGrav Node Leader.

As featured in Sky and Telescope, Space Australia, Mirage News

OzGrav research highlights:
New insights into eccentric black holes

OzGrav scientists reveal the eccentricity of binary black holes: the shape of the orbit formed when two black holes fall into a dance as they spiral towards each other and eventually collide. While the most common orbit is thought to be circular, about one in 20 are in egg-shaped eccentric orbits, which can indicate completely different binary life histories.

Since the first detection of gravitational waves (GW) in September 2015, LIGO and its European counterpart Virgo have published the discovery of ten merging black-hole binaries. The latest run has already uncovered more than 30 new detections, with more forecast by April 2020.

OzGrav PhD student (and first author) Isobel Romero-Shaw recently published a study on the origins of GW 190425—an event which was only announced in January 2020 by the LIGO/Virgo collaboration.

The GW signals provide a wealth of information about the pre-merger binaries; however, no one has yet deciphered how these black holes pair up in the first place.

New research, published in the journal Monthly Notices of the Royal Astronomical Society, reveals an important clue to how these black hole binaries are formed, how long they've been 'together' and what happens when they finally collide.

The study, led by Romero-Shaw, OzGrav Chief Investigator Eric Thrane and Associate Investigator Paul Lasky—all from Monash University—looked at data from the first and second rounds of observation of LIGO and Virgo, in particular, the ten black hole collisions that these two observation runs confirmed. They found that the orbits of all ten of these systems were remarkably circular, which is consistent with the expectation that about one in 20 orbits are not.

The current LIGO/Virgo run has already detected more than 30 additional collision signals. According to Romero-Shaw, the large amount of data coming from the third observing run 'will mean we are much more likely to see eccentric collisions of black holes, which will give us real insight into how these systems form'.

According to Thrane, the more common circular orbits come from black holes who have been together from when they were garden-variety stars before they exploded and became black holes. Thrane explains: 'These binaries are like siblings if you like. They grew up together and their orbit is circular'.

Eccentric orbits occur when black holes fall under each other's gravitational influence by chance as they are zipping around galaxies. 'These are more like adults who meet later in life and pair up. Their orbital relationship is more interesting—much like in life,' he says.

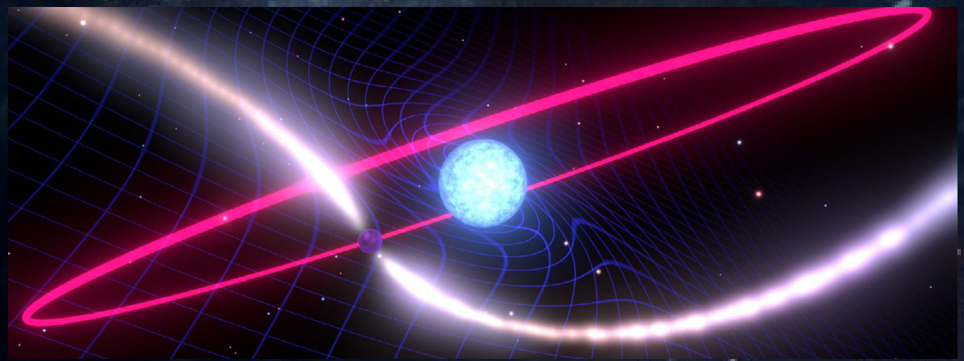
Importantly, when these two objects collide, the shape of their orbit means their gravitational-wave signal looks different. These detected explosions can now be used to retrospectively study the objects that collided.

Lasky adds that the current LIGO and Virgo observing run is detecting 'large numbers of these binaries and by April 2020—when the run finishes—we will have a far greater insight into what these events mean'.

As featured in Space Australia

Astronomers witness the **dragging** of space-time in stellar cosmic dance

An international team of astrophysicists led by OzGrav Director Matthew Bailes, has found exciting new evidence for 'frame-dragging'—how the spinning of a celestial body twists space and time—after tracking the orbit of an exotic stellar pair for almost two decades. The data, which is further evidence for Einstein's theory of General Relativity, was published in the prestigious journal, *Science*.



Artist's depiction of a rapidly spinning neutron star and a white dwarf dragging the fabric of space-time around its orbit. Credit: Mark Myers

More than a century ago, Albert Einstein published his iconic theory of General Relativity – that the force of gravity arises from the curvature of space and time and that objects, such as the Sun and the Earth, change this geometry. Advances in instrumentation have led to a flood of recent (Nobel prize-winning) science from phenomena further afield linked to General Relativity. The discovery of gravitational waves was announced in 2016; the first image of a black hole shadow and stars orbiting the supermassive black hole at the centre of our own galaxy was published just last year.

Almost twenty years ago, a team led by Swinburne University of Technology's Professor Bailes—director of the ARC Centre of Excellence in Gravitational Wave Discovery (OzGrav)—started observing two stars rotating around each other at astonishing speeds with the CSIRO Parkes 64-metre radio telescope. One is a white dwarf, the size of the Earth but 300,000 times its density; the other is a neutron star which, while only 20 kilometres in diameter, is about 100 billion times the density of the Earth. The system, which was discovered at Parkes, is a relativistic-wonder system that goes by the name 'PSR J1141-6545'.

Before the star blew up (becoming a neutron star), a million or so years ago, it began to swell up discarding its outer core which fell onto the white dwarf nearby. This falling debris made the white dwarf spin faster and faster, until its day was only measured in terms of minutes.

In 1918 (three years after Einstein published his Theory), Austrian mathematicians Josef Lense and Hans Thirring realised that if Einstein was right all rotating bodies should 'drag' the very fabric of space time around with them. In everyday life, the effect is miniscule and almost undetectable. Earlier this century, the first experimental evidence for this effect was seen in gyroscopes orbiting the Earth, whose orientation was dragged in the direction of the Earth's spin. A rapidly spinning white dwarf, like the one in PSR J1141-6545, drags space-time 100 million times as strongly!

A pulsar in orbit around such a white dwarf presents a unique opportunity to explore Einstein's theory in a new ultra-relativistic regime.

Lead author of the current study, Dr Vivek Venkatraman Krishnan (from Max Planck Institute for Radio Astronomy - MPIfR) was given the unenviable task of untangling all of the competing relativistic effects at play in the system as part of his PhD at Swinburne University of Technology. He noticed that unless he allowed for a gradual change in the orientation of the plane of the orbit, General Relativity made no sense.

MPIfR's Dr Paulo Friere realised that frame-dragging of the entire orbit could explain their tilting orbit and the team presents compelling evidence in support of this in today's journal article—it shows that General Relativity is alive and well, exhibiting yet another of its many predictions.

The result is especially pleasing for team members Bailes, Willem van Straten (Auckland University of Tech) and Ramesh Bhat (ICRAR-Curtin) who have been trekking out to the Parkes 64m telescope since the early 2000s, patiently mapping the orbit with the ultimate aim of studying Einstein's Universe. 'This makes all the late nights and early mornings worthwhile', said Bhat.

As featured in The ABC, The Conversation and Scientific American

Watch the video explainer here.

OzGrav's Carer Grant Scheme: An interview with Eric Howell

OzGrav is strongly committed to the equitable and inclusive treatment of all its members and colleagues, and to the elimination of discrimination and barriers of disadvantage. Striving to create a culture of acceptance, OzGrav actively promotes a culture that is inclusive for everyone, regardless of their background or individual characteristics, such as race, religion, sexuality, gender, disability, carer responsibilities, and mental or physical health.

Eric with his wife, Shirley, and son Brian.

To impart these values, OzGrav offer a carer grant scheme that allows people with primary carer responsibilities to participate in conferences or travel to work with collaborators. This is designed to be flexible and may be used to cover, for example, childcare costs and travel of dependent children to accompany the primary carer.

We interviewed Associate Investigator (AI) Eric Howell, based at the University of Western Australia (UWA), on how the scheme has helped him in his work and family life.

1. Can you tell us about your work with OzGrav and how you came to join as an AI?

I had been working in both gravitational wave and gamma ray burst (GRB) astrophysics as part of and since my PhD. I had obtained an ARC DECRA Fellowship around the time OzGrav was set up, so it was natural to join as an AI.

2. How has OzGrav's carer grant scheme assisted you and your family?

My wife Shirley became disabled after she suffered a brain haemorrhage in 2007—we also have a five-year-old boy, Brian. My wife made a remarkable recovery, learning to speak and move again, during a year spent at a rehabilitation centre. Although she is reasonably independent, at home she still needs a lot of help, especially with our young son. She also requires transportation to several appointments. Travelling and collaborating is important in my research but organising overseas and domestic trips has always been highly challenging. As we have no family in WA this involved juggling trips around Shirley's mother, who lives in Brisbane, or my sister, in Melbourne. The OzGrav carer grant has been really helpful, allowing me to take my family to domestic research trips and bring my mother-in-law down to assist in Melbourne when I go on international trips. It's still quite challenging to juggle everything, but the carer grant has been a fantastic help for me.

3. What opportunities have you been able to take thanks to the scheme?

It's really helped with existing and new collaborations: spending time at the Monash node working with Kendall Ackley, and at the University of Amsterdam; and attending LIGO-Virgo-KAGRA meetings, which was never possible before. The latter meetings have been of paramount importance in meeting and presenting to members of the GRB/Fast Radio Bursts (FRB) group, resulting in involvement in GRB search papers and setting up a future gravitational wave search for FRBs as part of the Canadian Hydrogen Intensity Mapping Experiment (CHIME). Such activities would have been very difficult without face-to-face interactions.

4. What do you think of OzGrav's overall culture and approach to diversity and inclusion?

OzGrav's overall culture and approach to diversity and inclusion is a real breath of fresh air. The carer grant is only one of OzGrav's many fantastic initiatives. When I talk to researchers from other organisations they're always really impressed with the level or diversity and support within OzGrav. In addition to these initiatives, OzGrav are always seeking new levels of support for their members—this is to be highly commended.

Deep learning medical imaging methods and the Universe

Risk-taking means different things to different people. When a scientist takes a risk with their work, what are they putting on the line? It could be months of effort, their reputation, or the next career step. But with risk, comes reward. When scientists pursue ambitious science there's no guarantee of success, but they're still prepared to push the boundaries to advance frontiers more quickly.

Jielai Zhang—one of OzGrav new postdocs working with Chief Investigator Jeff Cooke in the Deeper, Wider, Faster program—has all the traits of a born scientific risk-taker. This is no surprise if you dig into her background and her upbringing: born in Shanghai, China, Jielai moved to Sydney when she was 8-years-old. She completed an undergraduate degree in engineering and science, majoring in maths and physics at the University of Sydney before crossing continents to take a PhD in astrophysics and astronomy at the University of Toronto. Jielai then seized the opportunity to become one of the first Schmidt Science Fellows in 2018, shifting her focus to work on biomedical imaging at IBME at the University of Oxford. Her combination of curiosity and an appetite for taking risks has now taken her to the cusp of her next leap: starting a new role with OzGrav to study how astronomical phenomena changes on timescales of seconds.

Jielai Zhang - OzGrav Postdoc

Jielai's academic journey so far… I started taking significant risks in my work when I travelled to Canada for my PhD at the University of Toronto in astrophysics and astronomy. During my PhD, I built a new telescope in a small team of 4, the Dragonfly Telephoto Array, using an unproven novel design. The unknown factor was worth the risk and I did not shy away. I wanted to explore faint galaxies that nobody had looked at before and we had to build a new telescope to see it.

At the end of my PhD, I become interested in a new field of astronomy called 'Time Domain Astronomy'. This looks at how the Universe changes on a very fast time scale. The constellation in the sky used for sailing 1,600 years ago is the same today but the sky is also changing on very fast time scales – we just didn't know about it before. We're talking days, minutes, seconds or less.

The new field of astronomy I now work with requires very fast exposure times which acquire a lot of data, so I had been looking into new techniques, methods and tools from other fields that I could apply to this huge data volume in astronomy that we haven't had to deal with before. That's when I came across medical imaging, deep learning and machine learning. I zeroed in on medical imaging as I started to investigate it because of the way it applied a method called 'Deep Learning' which I felt was useful to astronomy. I was intrigued to learn more and then I came across the Schmidt Science Fellows program which would allow me to pivot for a whole year into another field rather than learning slowly on the side which is what I thought I may have had to do. The program would allow me to get face-to-face exposure to people in the field that I wish to learn more about and that's why I applied.

Now, as I enter my new role as an OzGrav postdoctoral research fellow, I am confident knowing that can I approach and get advice from a network of people outside of my field. This is particularly useful when I want to apply deep learning and machine learning to new types of data.

This article is an extract of the original feature published on Schmidt Science Fellows.

Upcoming conferences

- KOZWaves 4th Australasian Conference on Wave Sciences, 17-19 February 2020, The University of Melbourne
- 9th Australian Space Forum, 19 February 2020, Adelaide Convention Centre
- Catalysing Gender Equity 2020, 20 - 21 February 2020, Adelaide Convention Centre
- 4th Women in STEM Leadership Summit, 23 - 26 March 2020, Sydney
- IPTA 2020 student workshop & science meeting 9-19 June, 2020 at Swinburne University & University of Tasmania
- IAU Symposium 363: Neutron Star Astrophysics at the Crossroads: Magnetars and the Multimessenger Revolution, 22-26 June 2020, L'Aquila, Italy
- 7th IUPAP International Conference on Women in Physics: 13-17 July, 2020 in Melbourne

Upcoming prizes & awards

- L'Oreal ANZ For Women in Science Fellowship - closing 2 March 2020
- The Prime Minister's Prizes for Science - closing 12 March 2020
- Australian Institute of Physics awards and prizes - closing 1 April 2020
- The National Measnurement Institute (NMI) prize - closing 14 April 2020
- The Barry Inglis Medal - closing 14 April 2020
- Australian Institute of Policy and Science Tall Poppy Awards - closing mid-April 2020
- The Australian Optical Society Awards - closing 30 April
- Nancy Millis Medal for Women in Science - closing 1 May 2020
- Australian Museum Eureka Prizes - closing 1 May 2020

Using deep learning to pinpoint gravitational waves

Following the recent overwhelming success of deep learning and artificial intelligence in research, industry and medicine, OzGrav researchers from the University of Western Australia (UWA), have built a deep learning model to pinpoint where in the sky gravitational wave signals have come from.

The model can localise the source of gravitational waves produced by colliding pairs of black holes potentially as much as a thousand times faster than any other technique.

Gravitational waves are small ripples in the space-time continuum caused by colossal stellar events such as colliding black holes. In September 2015, following recent advances in detector sensitivity, the LIGO Scientific Collaboration detected gravitational waves for the first time. This was a landmark achievement in human discovery and heralded the birth of the new field of gravitational wave astronomy.

The need for speed and accuracy is particularly important in the context of gravitational wave localisation—scientists need to tell a global network of telescopes where to point on the sky as quickly as possible, so they can see any electromagnetic light that may also have come from the gravitational wave event. The current algorithm used to locate gravitational wave sources in real time takes a few seconds to process. More accurate methods usually take several hours to compute. The light generated by gravitational wave events can be very short-lived at certain wavelengths, like short gamma ray bursts, which last a mere 2-3 seconds, so scientists need methods that can rapidly process huge data as fast and accurately as possible.

The idea behind deep learning is simple: it's an algorithm designed to mimic the functioning of neurons in our brain to carry out tasks, like categorising observed stimuli. This is done by making the network learn the correlations between a labelled input dataset and the output it is trying to predict. Just like electric signals or synapses flow through neurons in our brain, the input information provided to an Artificial Neural Network travel through layers of nodes (usually several layers deep), with each layer introducing some non-linearity to the input.

'The idea behind deep learning is simple: it's an algorithm designed to mimic the functioning of neurons in our brain to carry out tasks, like categorising observed stimuli.'

This non-linearity helps the network learn complex features of the data. The 'learning' happens through a rigorous 'training' of the network. During the training, the predictions of the network are compared with the true values, and the parameters of the network are adjusted to minimise any erroneous gaps.

Chatterjee and the team successfully trained the Artificial Neural Network to learn the input data for source localisation. The data was pre-processed to extract the important physical Physics parameters from simulated gravitational wave signals, injected into 'random noise'. The network classified these signals into several classes and accurately identified the source direction of the gravitational waves. The model localised the test samples much faster than other methods and at a low computational cost. The researchers plan to extend this work for pairs of merging neutron stars and neutron star-black hole systems.

Chatterjee says: 'Hopefully the methods we introduce can also be translated to other areas of research and industry and help further untap the seemingly limitless potential of deep learning and artificial intelligence'.

OzGrav's Chief Investigator Professor Linqing Wen who led the study says: 'The future is wide open for gravitational wave discovery using the machine learning technique'.

Also featured in Space Australia.

Astronomers search for *gravitational-wave memory*

Astronomers regularly observe gravitational waves (GW)—ripples in space and time—that are caused by pairs of black holes merging into one. Einstein's theory of gravity predicts that GW, which squeeze and stretch space as they pass, will permanently distort space, leaving a 'memory' of the wave behind. However, this memory effect has not yet been detected as it's extremely small, leaving the faintest traces.

OzGrav researchers at Monash University have finally developed a method to search and detect GW memory. Led by OzGrav PhD student Moritz Huebner, the recently published paper explains the tricky conquest of searching for memory by analysing data from numerous different observations. Huebner presented these results at the Australian National Institute for Theoretical Astrophysics (ANITA) in Canberra on 6 February 2020.

The scientific models expect memory to leave an extremely faint trace on the detectors which is far smaller than the waves from the black hole collision itself. Therefore, data needs to be combined from many different gravitational wave events. To do this, the team used some of the most precise GW and memory models developed from the study of black hole mergers.

'Our algorithms carefully comb through the data and measure the exact evidence for the existence of GW memory,' said Huebner.

For each individual observation, this painstaking method can take hundreds of hours on a normal computer chip to explore all the possibilities of how a GW signal came about—this prompted the researchers to focus on fine-tuning the setting to reduce the amount of computing hours without compromising the search. So far, the results of the search applied to the first ten black-hole collisions—detected by LIGO and Virgo between 2015 and 2017—have proven inconclusive. LIGO and Virgo are not yet sensitive enough to make any statements about GW memory.

'For each individual observation, this painstaking method can take hundreds of hours on a normal computer chip to explore all the possibilities of how a GW signal came about—this prompted the researchers to focus on fine-tuning the setting to reduce the amount of computing hours without compromising the search.'

So, will we ever be able to detect memory?

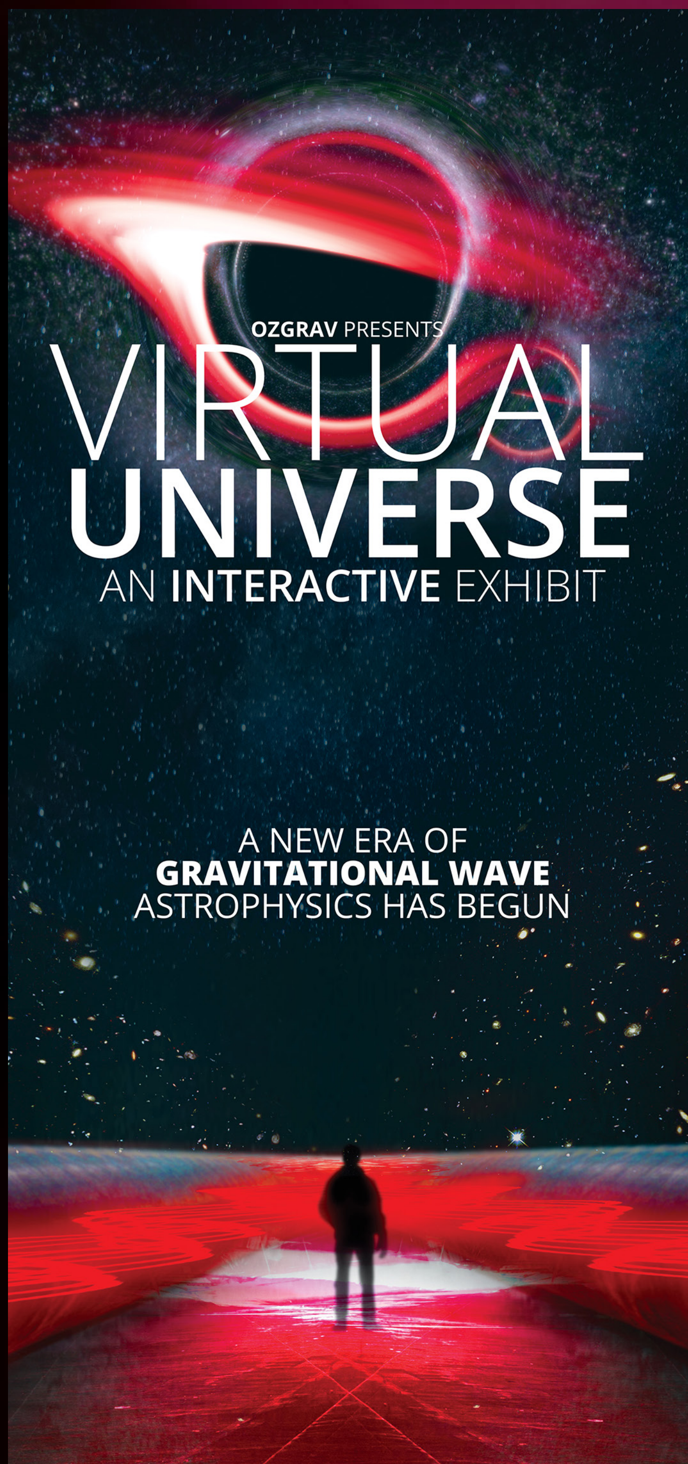
'Thankfully, we can now use data from the first ten black-hole collisions and have a decent idea of how many observable GW events there will be in the future. We can also calculate how much evidence of memory can be detected in each event,' said Huebner.

Throughout the study, the researchers also discovered that their new search method must take data from approximately 2000 black hole mergers to detect memory. While this might sound implausible, the team expects to hit this number by the mid-2020s.

Plus, LIGO and Virgo are continuously being upgraded and have seen more than 40 mergers since April 2019, when the third observation run started. With further technological advances and the Japanese KAGRA observatory soon coming online, the team is confident that they'll detect multiple binaries every day which will finally lead to revealing GW memory.

As featured on Phys.org.

OzGrav's **Virtual Universe** at the Gravity Discovery Centre



OzGrav will be showcasing a new interactive exhibit *Virtual Universe* on 21 February at the Gravity Discovery Centre (GDC) gallery in Gingin, Western Australia. The launch will be in conjunction with the inaugural Einstein-First International Workshop (18-21 February) hosted by OzGrav node University of Western Australia.

As part of the Gingin Science Precinct, the Gravity Discovery Centre (GDC) is a place of learning and wonder. The not-for-profit centre showcases hands-on science exhibits, sharing the latest discoveries in physics and astronomy with a focus on gravity and cosmology. The GDC is the public education interface of the Australian International Gravitational Observatory (AIGO), as well as the Zadko Telescope located on-site. It's also home to the Leaning Tower of Gingin—an impressive engineering feat inspired by the Leaning Tower of Pisa: a 45-metre tall steel structure, leaning at an angle of 15 degrees and held in place by 180 tons of concrete.

Virtual Universe will include multiple interactive screens and artistic projections, weaving the story of gravitational waves and allowing visitors to manipulate the fabric of space-time. Mark Myers and Carl Knox from the Education and Outreach team at OzGrav HQ have created a multi-sensory experience that's both stunning and informative: users can visualise gravitational waves and engage with the wall art and content to grasp a deeper understanding of the science. The exhibit aims to inspire people from all walks of life and look at gravitational wave science from a fresh, new angle.

About OzGrav

The ARC Centre of Excellence for Gravitational Wave Discovery (OzGrav) is funded by the Australian Government through the Australian Research Council Centres of Excellence funding scheme. OzGrav is a partnership between Swinburne University of Technology (host of OzGrav headquarters), the 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.

The mission of OzGrav is to capitalise on the historic first detections of gravitational waves to understand the extreme physics of black holes and warped spacetime, and to inspire the next generation of Australian scientists and engineers through this new window on the Universe.

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The Kamioka Gravitational Wave Detector (KAGRA), formerly the Large Scale Cryogenic Gravitational Wave Telescope (LCGT), is a project of the gravitational wave studies group at the Institute for Cosmic Ray Research (ICRR) of the University of Tokyo. It will be the world's first gravitational wave observatory in Asia, built underground, and whose detector uses cryogenic mirrors. The design calls for an operational sensitivity equal to, or greater, than LIGO. The project is led by Nobelist Takaaki Kajita who had a major role in getting the project funded and constructed.

Website: www.ozgrav.org
Email: info@ozgrav.org
Editor-in-chief: Luana Spadafora, lspadafora@swin.edu.au

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