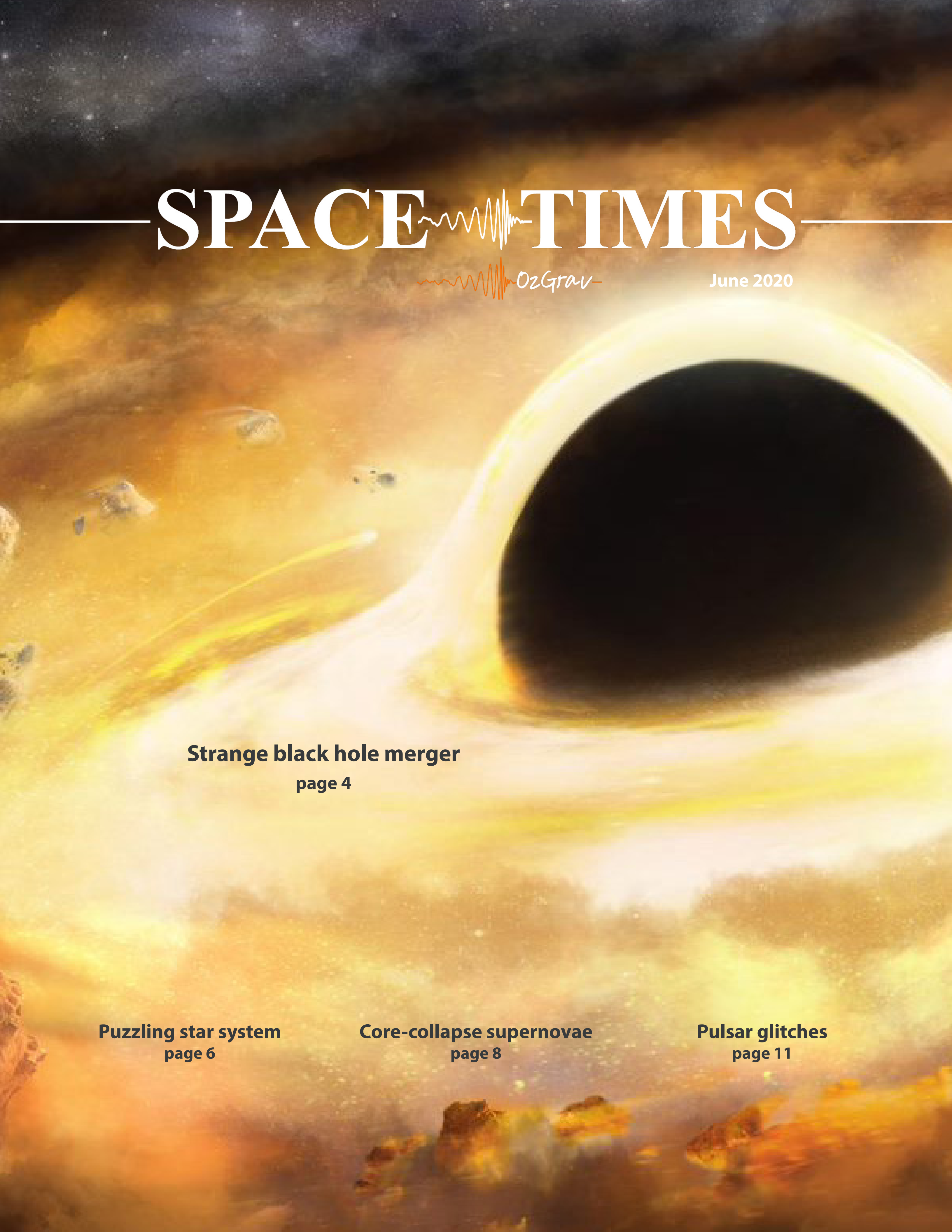


SPACE TIMES

OzGrav

June 2020

Welcome

Welcome to the June edition of *Space Times*.

It has been incredibly heartening to see the easing of restrictions in Australia and the number of community transmissions of COVID-19 becoming tantalisingly small. Our friends in New Zealand appear to have potentially eliminated the virus from its shores, and let's hope that many more countries will join them in achieving this milestone. Our thoughts are with all of our colleagues and their families that reside in countries that are not so fortunate.

I find myself compelled to comment on the events in the US that have led to widespread protests and a growing movement to address racial inequality in the US and around the world. In 1992, I landed in Los Angeles just after the delivery of the Rodney King trial had been announced and was struck by the fires burning throughout the city as we were landing. It is very disheartening to see the lack of progress on racial inequality in the intervening 28 years in the US. But racial inequality also persists here in Australia, and in the field of STEM, and it would be ignorant to think that we shouldn't constantly reflect on our own efforts to strive for racial equality.

To end on a happier note, I was thrilled to see Tamara Davis (now AM!!!) made a member of the Queen's Birthday Honours list, and Carolyn Maxwell win the Educator's prize at UWA.

I hope you enjoy reading this issue, full of new research highlights and stories from our OzGrav community.

Regards,
Matthew Bailes - OzGrav Director

News in brief

Professor Tamara Davis

- OzGrav heartily congratulates our Governance Advisory Committee member Professor Tamara Davis (UQ) who was awarded a Member (AM) in the General Division of the Queen's Birthday Honours List 2020 for her service to astrophysics and leading young astronomers
- Congratulations to OzGrav PhD student Carolyn Maxwell on receiving the Australian College of Educators Prize at UWA for achieving the highest mark in her Master's dissertation
- OzGrav EPO Coordinator Jackie Bondell has rolled out a new series of live-streamed, virtual incrusions, as well as the Mission Gravity immersive VR program, across more than 90 high schools in Victoria, NSW and the ACT
- A consultation draft of the Australian Astronomy Decadal Plan Mid-Term Review was released on 18th May; OzGrav was delighted to see that it acknowledged the significance of gravitational-wave science and recommended continued support for our infrastructure requirements

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

Future detectors to detect millions of black holes and trace the evolution of the Universe

On 17 August 2017, the LIGO and Virgo collaborations detected gravitational waves from a pair of neutron stars merging. This world-first, multi-messenger discovery was accompanied by a range of counterparts identified with electromagnetic telescopes. The observations allowed astronomers to directly measure the Hubble constant—a unit that describes how fast the Universe is expanding

A recent study by the ARC Centre of Excellence for Gravitational Wave Discovery (OzGrav), led by researchers Zhiqiang You and Xingjiang Zhu, studied an alternative way to do cosmology with gravitational-wave observations.

Two black holes about to collide - Mark Myers, OzGrav

In comparison to neutron star mergers, black hole mergers are much more abundant sources of gravitational waves. LIGO and Virgo collaborations have published 10 binary black hole merger events and dozens more candidates have been reported; whereas there have been only two neutron star mergers detected so far.

Unfortunately, no electromagnetic emission is expected from black hole mergers. Theoretical modeling of supernovae—powerful and luminous stellar explosions—suggests that there is a gap in the masses of black holes around 45-60 times the mass of our Sun. Some inconclusive evidence that supports this mass gap was found in observations made in the first two observing runs of LIGO and Virgo. The new OzGrav research shows that this unique feature in the black hole mass spectrum can help determine the expansion history of our Universe using gravitational-wave data alone.

OzGrav PhD student and first author Zhiqiang You says: 'Our work studied the prospect with third-generation gravitational-wave detectors, which will allow us to see every binary black hole merger in the Universe'.

Apart from the Hubble constant, there are other factors that can affect how black hole masses are distributed. For example, scientists are still uncertain about the exact location of the black hole mass gap and how the number of black hole mergers evolves over the cosmic history.

The new study demonstrates that it is possible to simultaneously measure black hole masses along with the Hubble constant.

It was found that a third-generation detector, like the Einstein Telescope or the Cosmic Explorer, should measure the Hubble constant to better than one percent within one year's operation. Moreover, within a mere one week observation, the study revealed it's possible to distinguish the standard dark energy-dark matter cosmology with its simple alternatives.

As featured on Phys.org and Space Australia.

Background image from Pixabay

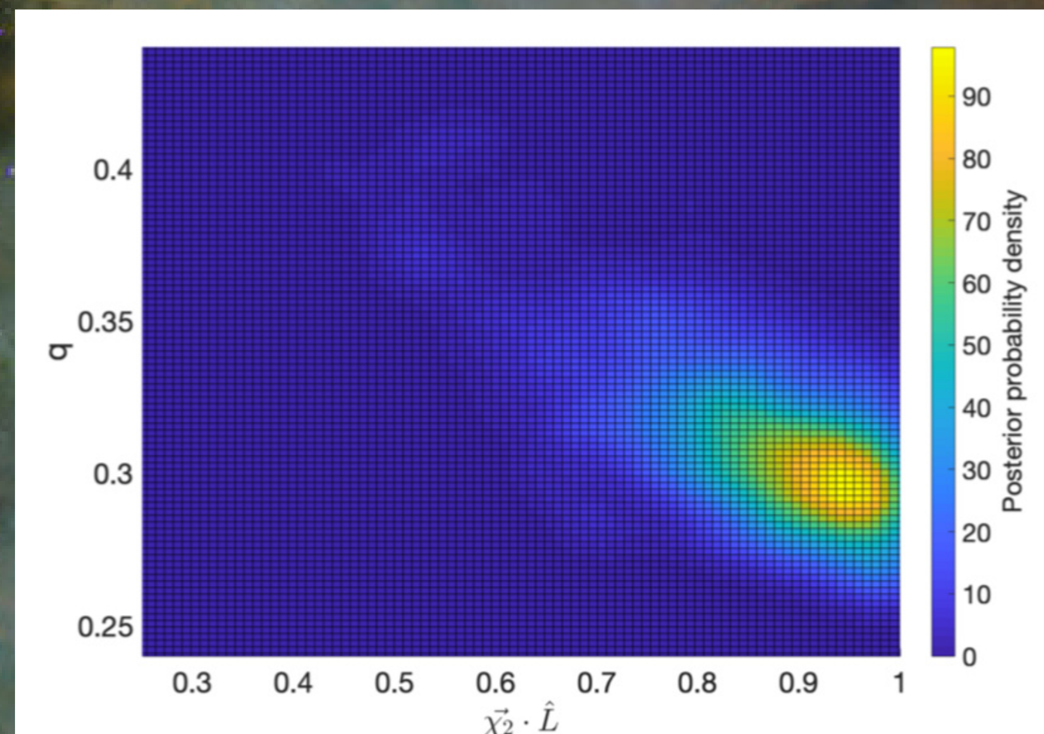
A new possible explanation of strange black hole merger GW190412

Scientists from the ARC Centre of Excellence for Gravitational Wave Discovery (OzGrav) reveal an alternative explanation of the recently announced black hole merger, GW190412. The paper was just accepted by Astrophysical Journal Letters.

On the 12th of April 2019, the LIGO and Virgo observatories detected gravitational waves—ripples in space and time—from an unusual cosmic event of two black holes merging. Unlike the ten previously reported black hole mergers, in which the two black holes may have had equal or nearly-equal masses, this event, called GW190412, definitely had two very unequal black holes, with the heavier one possibly three or four times more massive than the lighter one.

In addition, the discovery paper (released in Australia on 19 April 2020) reported that at least one of the merging black holes had to be spinning: rotating around its axis. However, gravitational waves do not allow accurate measurement of individual spins. Only a specific spin combination can be measured. Therefore, to infer individual spins, assumptions must be made based on scientific models. The LIGO and Virgo collaborations assumed that the heavier, first-born black hole could be spinning, and reported that it had a moderate spin in the gravitational-wave discovery paper.

Within 24 hours of the discovery's announcement, OzGrav Chief Investigator Ilya Mandel, from Monash University, and collaborator Tassos Fragos, from the University of Geneva, wrote a follow-up paper which has just been accepted by Astrophysical Journal Letters. Motivated by the best current models of the evolution of massive stars in binaries, Mandel and Fragos argued that the more massive, or 'heavier', black hole in the event is very slowly spinning; whereas the 'lighter' black hole is spinning very fast, in the same direction as the orbital motion.



The figure shows the probability distribution for the dimensionless spin of the lighter black hole along the orbital direction (horizontal axis) and the mass ratio (vertical axis) found by Mandel and Fragos.

Mandel and Fragos state that if isolated pairs of stars orbiting around each other give birth to merging black holes, they naturally make first-born, heavier black holes that spin very slowly. Before a star forms a black hole, it evolves into a giant with a gaseous envelope. When it does so, it slows down, like a spinning figure skater extending her arms. When this envelope is stripped off by extreme tidal forces exerted by the other star in the binary, a slowly rotating central core is left behind, which ultimately collapses into a slowly spinning black hole.

The same process should typically apply to the second-born, lighter star, which eventually collapses into the lighter black hole. However, when the second star loses its gaseous envelope, the binary separation can be sufficiently small enough to allow the naked star core to spin up through 'tidal locking'.

Mandel explains: 'Tidal locking occurs when tides from an orbiting companion forces an object's period of rotation—the time it takes it to spin around its axis—to equal the time it takes for a full orbit of the binary system. For example, tidal locking of the Moon to the Earth sets the Moon to rotate the same 28 days equal to its orbital period around the Earth. This explains why we never get to see the dark side of the Moon—except when listening to Pink Floyd.'

So, sometimes the second black hole can spin up and rapidly rotate. Mandel and Fragos find this to be the case in the GW190412 event. Such systems should also merge soon after their formation, since tidal locking will only happen in very tight binaries.

Although it's difficult to confirm this interpretation, future detections of black hole mergers will allow for more accurate testing of this model.

'We're all very excited about the upcoming data release from the first half of LIGO/Virgo's third observing run. This will be a fantastic treasure trove, mining for new insights into how stars and binaries evolve,' says Mandel.

Also featured in The Herald Sun

Faces of OzGrav:
Debatri Chattopadhyay

I was around ten when I found 'A Journey to the Centre of the Earth' by Jules Verne from my parents' collection. It was in a translation by a famous Bengali author, Adrish Bardhan. Classroom science teaching was quite bland, so I thought 'science fiction' will be an extension of that. To my surprise, it wasn't!

Within the first few pages, the book sucked me inside a rabbit hole. I was rooting for an eccentric scientist, for characters in a completely different geographic location, culture, and time-period from my own. It presented fantasy with a tinge of established science, a mix of outrageously improbable and possibly impossible situations; enchanting enough to hold my attention.
I wanted to know how magnets behave, how earth's gravity worked and found the characters to be as intrepid as David Livingstone.
I kept reading more Verne. The sheer fluidity with which he introduced key science concepts—from the electromagnetic spectrum to fluid dynamics; through ingenious and adventurous plot points—was intensely captivating. Essentially, it was the ultimate 'scientific romance'.

And then we started doing levers, fulcrums and Archimedes' principle as a part of the school science curriculum. To my surprise, it became easily my favourite. By the time Physics, as a subject, was introduced in Grade VII, I knew I wanted to do it. It was the only school subject that captured my passion and curiosity completely. Popular science books that my parents introduced me to kept fuelling my love. George Gamow's 'One Two Three... Infinity' was one of my favourites.
I went on to get an Honours and Masters in physics. Looking back, I think Verne, in Bardhan's amazing translation, influenced my early enthusiasm. While Verne died more than a century before, Bardhan passed away last year. There are many examples of how literature has popularised science; this is from my own experience.

Background image by Josh Valenzuela, University of New Mexico

Scientists puzzle over massive, never-before-seen star system in a galaxy far away...

Earlier this year, an international team of scientists announced the second detection of a gravitational-wave signal from the collision of two neutron stars. The event, called GW190425, is puzzling: the combined mass of the two neutron stars is greater than any other observed binary neutron star system. The combined mass is 3.4 times the mass of our Sun.

Artist impression of galaxy - Pixabay

A neutron star binary this massive has never been seen in our Galaxy, and scientists have been mystified by how it could have formed—until now. A team of astrophysicists from the ARC Centre of Excellence for Gravitational Wave Discovery (OzGrav) think they might have the answer.

Binary neutron stars emit gravitational waves—ripples in space-time— as they orbit each other, and scientists can detect these waves when the neutron stars merge. The gravitational waves contain information about the neutron stars, including their masses.

The gravitational waves from cosmic event GW190425 tell of a neutron star binary more massive than any neutron star binary previously observed, either through radio-wave or gravitational-wave astronomy. A recent study led by OzGrav PhD student Isobel Romero-Shaw from Monash University proposes a formation channel that explains both the high mass of this binary and the fact that similar systems aren't observed with traditional radio astronomy techniques.

Romero-Shaw explains: 'We propose that GW190425 formed through a process called 'unstable case BB mass transfer', a procedure that was originally defined in 1981. It starts with a neutron star which has a stellar partner: a helium (He) star with a carbon-oxygen (CO) core. If the helium part of the star expands far enough to engulf the neutron star, this helium cloud ends up pushing the binary closer together before it dissipates. The carbon-oxygen core of the star then explodes in a supernova and collapses to a neutron star'.

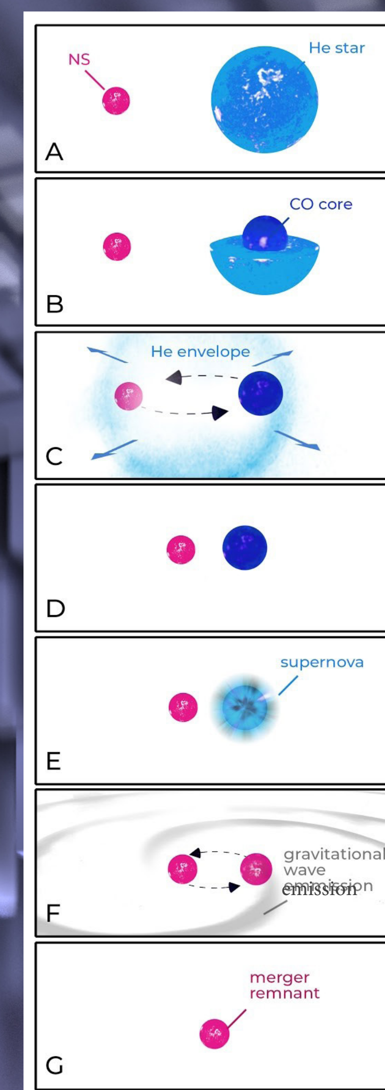
Binary neutron stars that form in this way can be significantly more massive than those observed through radio waves. They also merge very fast following the supernova explosion, making them unlikely to be captured in radio astronomy surveys.

'Our study points out that the process of unstable case BB mass transfer could be how the massive star system formed,' says Romero-Shaw.

The OzGrav researchers also used a recently-developed technique to measure the eccentricity of the binary—how much the star system's orbital shape deviates from a circle. Their findings are consistent with unstable case BB mass transfer.

Current ground-based gravitational-wave detectors aren't sensitive enough to precisely measure the eccentricity; however, future detectors—like space-based detector LISA, due for launch in 2034—will allow scientists to make more accurate conclusions.

As featured on Phys.org



Credit: Carl Knox, OzGrav

Awards and prizes

- Victoria Prize for Science and Innovation - close 15 June
- The Bragg Gold Medal - close 1 July
- The TH Laby Medal - close 1 July
- The AIP Women in Physics Lecturer - close 1 August

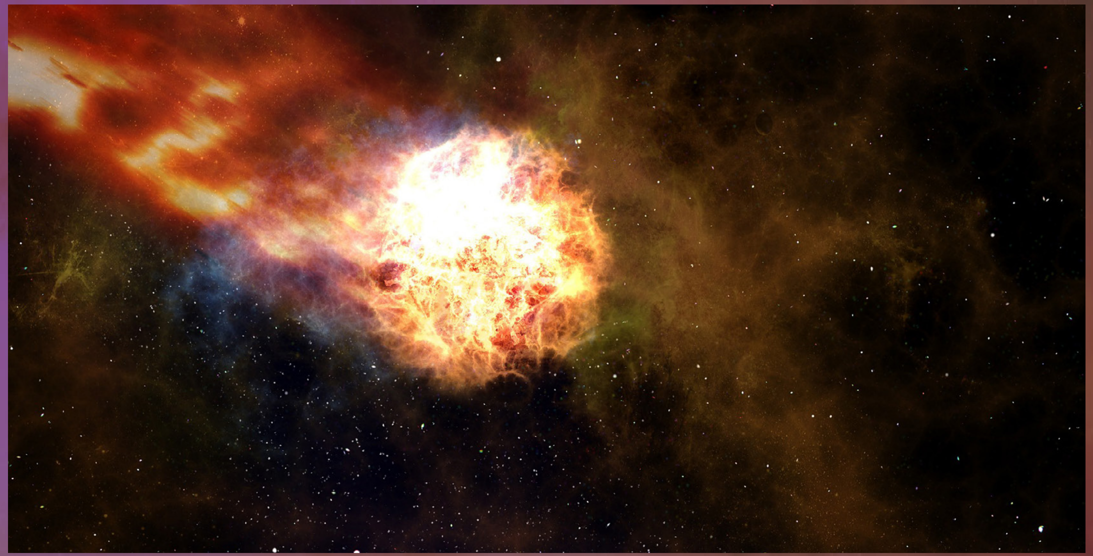
Virtual events

- OzGrav online lectures continue with new talks every fortnight. Keep updated on our social media channels and watch live on our YouTube channel.
- AIP live lectures: 10AM AEST 2 July OzGrav's own Paul Lasky will present: 'OzHF: What can Australia's proposed high-frequency gravitational-wave detector teach us about neutron stars?'
- National Science Week - 15-23 August. OzGrav will be hosting several Immersive Science in VR (SciVR) events
- Online GROWTH astronomy school - 17-21 August
- OzGrav online lecture series continuing with Isobel Romero-Shaw at 12pm AEST on Tues 12th May, and Ilya Mandel in the following week. Watch live on the OzGrav YouTube channel.
- The ASA has a centralised listing of Australian astronomy presentations and seminars.

Background image by Carl Knox, OzGrav

New insights into the physics of exploding massive stars and future detectors

In a recent study, published in the Monthly Notices of the Royal Astronomical Society, researchers Dr Jade Powell and Dr Bernhard Mueller from the ARC Centre of Excellence for Gravitational Wave Discovery (OzGrav) simulated three core-collapse supernovae using supercomputers from across Australia, including the OzSTAR supercomputer at Swinburne University of Technology.



Artist's impression of a supernova. Source: Pixabay

The simulation models—which are 39 times, 20 times and 18 times more massive than our Sun— revealed new insights into exploding massive stars and the next generation of gravitational-wave detectors.

Core-collapse supernovae are the explosive deaths of massive stars at the end of their lifetime. They are some of the most luminous objects in the Universe and are the birthplace of black holes and neutron stars. The gravitational waves—ripples in space and time—detected from these supernovae, help scientists better understand the astrophysics of black holes and neutron stars.

Future advanced gravitational-wave detectors, engineered to be more sensitive, could possibly detect a supernova—a core-collapse supernova could be the first object to be observed simultaneously in electromagnetic light, neutrinos and gravitational waves.

To detect a core-collapse supernova in gravitational waves, scientists need to predict what the gravitational wave signal will look like. Supercomputers are used to simulate these cosmic explosions to understand their complicated physics. This allows scientists to predict what the detectors will see when a star explodes and its observable properties.

In the study, the simulations of three exploding massive stars follow the operation of the supernova engine over a long duration—this is important for accurate predictions of the neutron star masses and observable explosion energy.

OzGrav postdoctoral researcher Jade Powell says: 'Our models are 39 times, 20 times and 18 times more massive than our Sun. The 39-solar mass model is important because it's rotating very rapidly, and most previous long duration core-collapse supernova simulations do not include the effects of rotation'.

The two most massive models produce energetic explosions powered by the neutrinos, but the smallest model did not explode. Stars that do not explode emit lower amplitude gravitational waves, but the frequency of their gravitational waves lies in the most sensitive range of gravitational wave detectors.

'For the first time, we showed that rotation changes the relationship between the gravitational-wave frequency and the properties of the newly-forming neutron star,' explains Powell.

The rapidly rotating model showed large gravitational-wave amplitudes that would make the exploding star detectable almost 6.5 million light years away by the next generation of gravitational-wave detectors, like the Einstein Telescope.

As featured in Phys.org and Space Australia

OzGrav Mentoring Program

Joshua McCann

Throughout my working and studying career, I have been fortunate enough to have had many mentors with various backgrounds and skills. In life we aim to learn from our experiences. In these experiences come many mistakes which we do our best to learn from and avoid in the future. Having a mentor along the way can help us avoid some of those mistakes or, if not avoid, at least bounce back and learn from them. My first experience with a mentor was during my undergraduate degree. I was a first year and was picking my timetable. My mentor at the time helped me see that trying to cram 4 lectures and 2 tutorials into one day would not result in the best retention of knowledge and that by staggering the content I would achieve better results with less stress. While this seems like a small piece of assistance, it altered my thinking around learning and helped me through all of my undergrad.

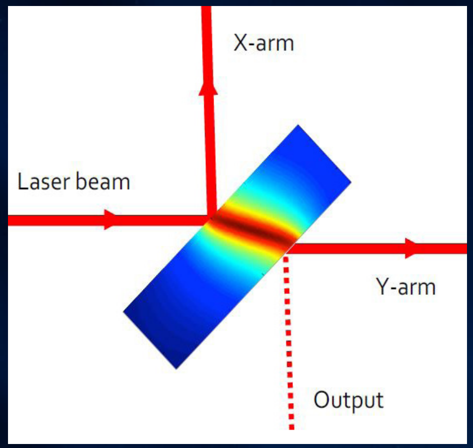
At the commencement of my PhD I felt hugely overwhelmed. Surrounded by academics and students who had been studying gravitational waves for years, I felt behind and out of practice. When OzGrav sent out offers for a mentee/mentor program I signed up straight away. While I had supportive PhD colleagues and supervisors, none of them quite knew what it was like to come from industry back to academia. I was lucky enough to be assigned a mentor who was a final year PhD candidate with years of experience in industry before pursuing his academic career. With such similar backgrounds, I found he was able to listen and empathise with challenges, while giving advice that suited me.

Although my mentor was in Canberra, and I'm in little old Perth, we still managed to video chat several times a year and met in person for coffee at least 4 times. In the final year of my PhD, I was able to connect with a mentor currently working in industry here in Perth. While I haven't decided if I will continue in academia or head back to industry, I learnt so much from my mentor about where my skills fit and how research and industry can benefit each other. Mentoring programs are usually voluntary and because of that I would always encourage others to sign up. Sometimes you'll find you have little need for the extra guidance but, in my experience, it's reassuring and worthwhile to know that someone's there for you when you need them.

Background image by James Josephides, Swinburne University

OzGrav-Adelaide Summer Research and Outreach program

The OzGrav summer program is a six-week intensive research program initially trialled at the University of Adelaide in early 2019. The aim of the program was to engage students in research early on and help them develop their skills, getting them to work on various projects and events associated with the University of Adelaide's portable interferometer (AMIGO). Following the program's huge success, the students share their impressive achievements.



COSMOL system model

Just Another Mode Matching Tool (JAMMT) is software written in Java to simulate the changes in the laser beam profile as it travels through an optical system. It is useful for modelling systems with multiple components, especially where manual analytics would be impossibly long and tedious. However, JAMMT has developmental limitations due to the dwindling use of Java in modern programming by OzGrav in particular.

Kenn Goh, a second-year undergraduate student, created a beam modelling software and interface based on JAMMT called YAMMT (Yet Another Mode Matching Tool). Kenn developed this code in Python and html such that it can be run locally in a browser without the user having to download any software. The interface displays a gaussian beam profile and allows the user to add different lenses and edit their properties. The program then automatically updates the beam profile.

The current cameras used for wavefront sensing in the LIGO interferometers have recently been discontinued. A proposed alternative is the Ximea camera which is a charge coupled detector (CCD) that detects photons as they hit the sensor in the CCD. However, it is important to characterise the performance of the camera to determine whether such small and cheap cameras could serve as valid alternatives to the current sensors.

Sophie Muusse, a third-year undergraduate student, worked on testing out the Ximea. She achieved this by taking multiple images with the camera and averaging them to increase the perceived sensitivity. Sophie also tested the camera's consistency over time and worked on identifying and minimising factors that affect the measurement.

The beam splitter in the LIGO detector is a critical component of interferometer as it uses the interference of light to detect gravitational waves. However, the large amount of laser power can cause it to heat up and expand over time, changing the distance light has to the travel in LIGO's two arms.

Muskan Pathak, a third-year undergraduate student, worked on addressing this issue by simulating the beam splitter in a finite element model package called COMSOL. She tested out different orientations of the beam splitter to see how it affects the heating profile inside the beam splitter.

The Hartman wavefront camera is a sensor developed by the University of Adelaide to analyse and control the distortions of the wavefront of a laser beam. This is important when considering the high-quality optics and high optical power required in LIGO. These optics and mirrors can absorb some of this power, causing heating and distorting the wavefront of the beam.

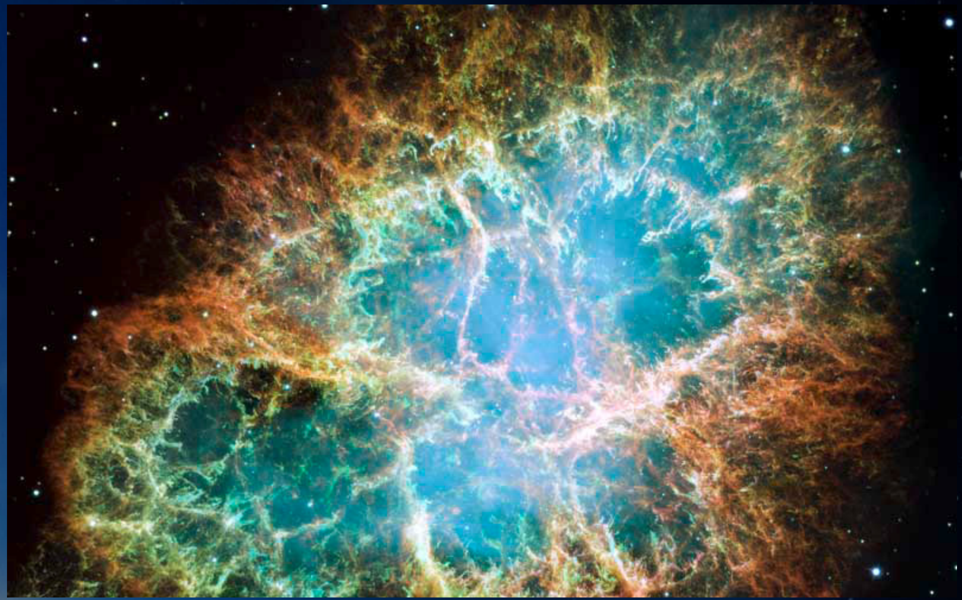
Jack Murrell, a second-year undergraduate student, worked on developing a tool to demonstrate the operation and use of a Hartmann wavefront camera. Jack created a simple optical setup which included a deformable mirror and stepper motor to bend the mirror. In this project, the wavefront of a laser beam and the change in the shape of the mirror is tracked by measuring the changes in the position of some reference spots on a camera.

Unveiling the truth inside ***pulsar glitches***

Pulsars are dead stars that spin remarkably steadily – they are some of the most regularly ticking clocks in the Universe! However, every few years some pulsars 'glitch', and speed up a tiny amount almost instantaneously. Understanding what causes these glitches may unveil what's really happening inside these super-dense dead stars.

Detailed theoretical and computer models are hard to connect to real observations, so instead PhD student Julian Carlin and Chief Investigator Andrew Melatos, from the ARC Centre of Excellence for Gravitational Wave Discovery (OzGrav), built a 'meta-model' in a paper recently published in the Monthly Notices of the Royal Astronomical Society.

The meta-model relies on the idea that 'stress' builds up inside the pulsar until it reaches a threshold, and then some of this stress is released as a glitch.



Multi-wavelength image of the Crab nebula, which hosts a glitching pulsar at its heart. Credit: NASA, ESA, J. Hester and A. Loll (Arizona State University)

The interesting thing about this meta-model is that the stress increases by taking a 'random walk' upwards: like an intoxicated person returning home from the pub who might take two steps forward, one step back, then three steps forward. The randomness in how the stress builds is supported by some theoretical models, as well as a recent study of a glitch-in-action led by OzGrav researchers Greg Ashton, Paul Lasky, and others.

Meta-models make predictions about what we should see in the long term from glitching pulsars.

'This model predicts that there should always be a correlation between big glitches and the time until the next glitch: if a lot of stress is released, it takes longer on average for the pulsar to build enough stress for another glitch,' explains Carlin.

Using this prediction, Carlin and Melatos tried to falsify the meta-model, asking the question: 'Are there long-term observations that can't be explained?'. The answer depends on the pulsar. Some are well-explained by the meta-model, while others don't quite match the predictions.

'We need to see more glitches before this question can be answered for certain, but this work shows a way to answer it for many theoretical models, all at the same time,' says Carlin.

Also featured in Space Australia

Background image by James Josephides, Swinburne University

What we do in isolation

Here's what some of our OzGrav members have been getting up to in isolation

'My partner and I bought a whole bunch of rock climbing equipment just before the lockdown happened, so we had to find some way of using it...' - Paul Altin, Postdoc

COO Yeshe Fenner and her partner have been working on some home reno projects, including paving and grooming their beautiful garden.

Communications Officer Luana Spadafora fawns over her co-worker/Tabby kitten, Stella, all day long. She's not sure how she'll cope when OzGrav HQ eventually moves back to campus.

OzGravvers at UWA had a virtual BBQ and farewell for postdoc Joris van Heijiningen. The zoom session featured a prized marron—the third largest freshwater crayfish in the world, unique to WA's south-west region!

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.

OzGrav is part of the international LIGO-Virgo collaboration. LIGO is funded by NSF and operated by Caltech and MIT, which conceived of LIGO and led the Initial and Advanced LIGO projects. Financial support for the Advanced LIGO project was led by the NSF with Germany (Max Planck Society), the U.K. (Science and Technology Facilities Council) and Australia (Australian Research Council-OzGrav) making significant commitments and contributions to the project. Nearly 1300 scientists from around the world participate in the effort through the LIGO Scientific Collaboration. The Virgo Collaboration is composed of approximately 350 scientists from across Europe. The European Gravitational Observatory (EGO) hosts the Virgo detector near Pisa in Italy, and is funded by Centre National de la Recherche Scientifique (CNRS) in France, the Istituto Nazionale di Fisica Nucleare (INFN) in Italy, and Nikhef in the Netherlands.

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

Image credit: as stated on each page. Front cover by James Josephides, Swinburne University

Background image by James Josephides, Swinburne University