SPACE TIMES

OzGrav

September 2021

Welcome

Dear Colleagues,

Welcome to another issue of Space Times! Last week we said goodbye to Swinburne and OzGrav PhD student Debatri Chattopadhyay (Swinburne University) in a virtual farewell as she heads off to her postdoctoral position in Cardiff after a successful PhD viva. Congratulations Debatri!

In this issue we feature OzGrav Alumni Qi Chu and Joshua McCann as they begin their careers in industry after successful postdoctoral and PhD positions at UWA, and highlight some of our innovative outreach underway.

As I type this message, my 2-year-old grand-daughter (who now lives with us) is singing downstairs, the sun is shining on a cool Melbourne Spring day, and I'm preparing for another day of Zoom meetings after a morning ride and coffee at the local Italian-run shop that has been doing a roaring trade since the lockdowns began. Despite the lockdown restrictions, many of our staff and students continue to make good progress, find jobs and enjoy little things that give us cause for celebration. Please take care wherever you are, and I hope to see you soon, either online or in person.

The Yarra River on a sunny Melbourne morning ride.

Regards,
Matthew Bailes - Director

NEWS IN BRIEF

- It was a very busy National Science Week for OzGrav members with our events running from coast-to-coast and online. The official book launch of 'Teaching Einsteinian Physics in Schools' took place during the week too. Well done to all who participated! Read all about it on pages 8 & 9.
- An Expression of Interest for a subsequent ARC Centre of Excellence for Gravitational Wave Discovery was submitted in July, led by Mathew Bailes as Director-elect and a strong team of proposed Chief Investigators and Partner Investigators. We will find out later this year whether the EOI will progress to the full proposal stage.
- OzGrav researchers Dr Meg Millhouse and Lucy Strang (both University of Melbourne), and Dr Karl Wette (ANU) were interviewed for the IOP Physics World podcast The physics of Olympic sports, searching for continuous gravitational waves
- Congratulations to OzGrav researcher Shanika Galaudage (Monash University) on winning the September 2021 LVK meeting poster prize for Data Analysis / Theory
- Congratulations to OzGrav Chief Investigator Dr Bram Slagmolen (ANU) for being elected to the position of Technical Advisor to the LSC Oversight Committee
- Congratulations to OzGrav Affiliate Dr Rebecca Allen (Swinburne University) who has been selected by the Australian Institute of Policy and Science to receive a prestigious Young Tall Poppy Science award. The awards honour up-and-coming scientists who combine world-class research with a passionate commitment to communicating science.

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

RESEARCH HIGHLIGHT

Bayesian inference for gravitational waves from binary neutron star mergers in third-generation observatories

In the 2030's, gravitational-wave detectors will be thousands of times more sensitive than Advanced LIGO, Virgo, and KAGRA. The network of "third generation" (3G) observatories will almost certainly include Cosmic Explorer (US), Einstein Telescope (EU), and may include a Southern-hemisphere Cosmic-Explorer like observatory. These amazing instruments will see every binary neutron star merger in the Universe, and most binary black holes out to redshifts beyond 10: hundreds of thousands, possibly millions, of resolvable signals per year. Many of these signals will be extremely loud, with signal to noise ratios in the thousands, facilitating breakthroughs in fundamental physics and cosmology. And herein lies a challenge! How do we extract all the information from these signals? On the surface it seems like a straightforward task: just keep on running parameter estimation like we're already doing! But it turns out that our current parameter estimation methods don't scale so well when signals are really loud, and very long in band.

To see why, we imagined a binary neutron star merger signal "GW370817", which originated about 40 Mpc from Earth — roughly the distance of GW170817 (assuming 3G detectors are online in 2037, we're guaranteed to observe a thousand or so binary neutron star mergers on August 17th, 2037!). A network of 3G detectors would observe GW370817 for 90 minutes, with a staggering signal to noise ratio of 2500. Analysing this signal is around a thousand times more computationally expensive than analysing a signal in today's detectors — by our back of the envelope estimates, it would take around 1000 years! This prohibitive analysis time is a hurdle to astrophysics with 3G data, and it's the problem we solve in our paper. To drive down the computation time, we developed "reduced order models" of gravitational-wave signals which allow us to infer binary neutron star properties using heavily compressed data, with almost no loss in accuracy. We reduced the computational cost of inference on 3G data by a factor of 13'000. Together with a pinch of parallel computing, we're able to perform data analysis in a few hours. This is good news for astrophysics in the 3G era.

While the 2030's and 3G detectors are a few years away, our results and methods are useful for a wide range of theoretical and design studies, which are ramping up in lockstep with the development of the detector technology. For those old enough to remember, the first LISA mock-data challenges began in 2005, which gives a sense of how much exploratory work takes place before a detector is operational. For the time being, there are plenty of interesting astrophysics questions we can start to think about in the context of 3G detectors: how well will we be able to measure the neutron star equation of state and the maximum mass of neutron stars? And what will this tell us about extreme matter? How well can neutron star spins be measured and can this tell us anything about supernova mechanisms? etc. Our results and method will facilitate this kind of theoretical work by enabling us to perform robust inferences on binary neutron star properties in mock 3G data.

Link to research paper: https://arxiv.org/abs/2103.12274

Written by OzGrav researcher Rory Smith, Monash University.

Background image by Carl Knox, OzGrav-Swinburne University

OZGRAV IN THE MEDIA

Making waves at the museum: The interactive science exhibit based on a real-life gravitational-wave detector

Gravitational wave scientists have designed and built an interactive science exhibit modeled of a real-life gravitational-wave detector to explain gravitational-wave science. It was developed by an international team, which includes researchers now at the OzGrav ARC Centre of Excellence for Gravitational Wave Discovery (OzGrav).

The recently published research paper is now featured in the American Journal of Physics and the exhibit, which is called a Michelson interferometer, is on long-term display at the Thinktank Birmingham Science Museum in the UK. The project has a lasting international impact with online instructions and parts lists available for others to construct their own versions of the exhibit.

Observations of gravitational waves -- ripples in the fabric of space and time -- have sparked increased public interest in this area of research. The effect of gravitational waves is a stretching and squashing of distances between objects. Real-life observatories are large complex devices based on the Michelson interferometer that use laser light to search for passing gravitational waves.

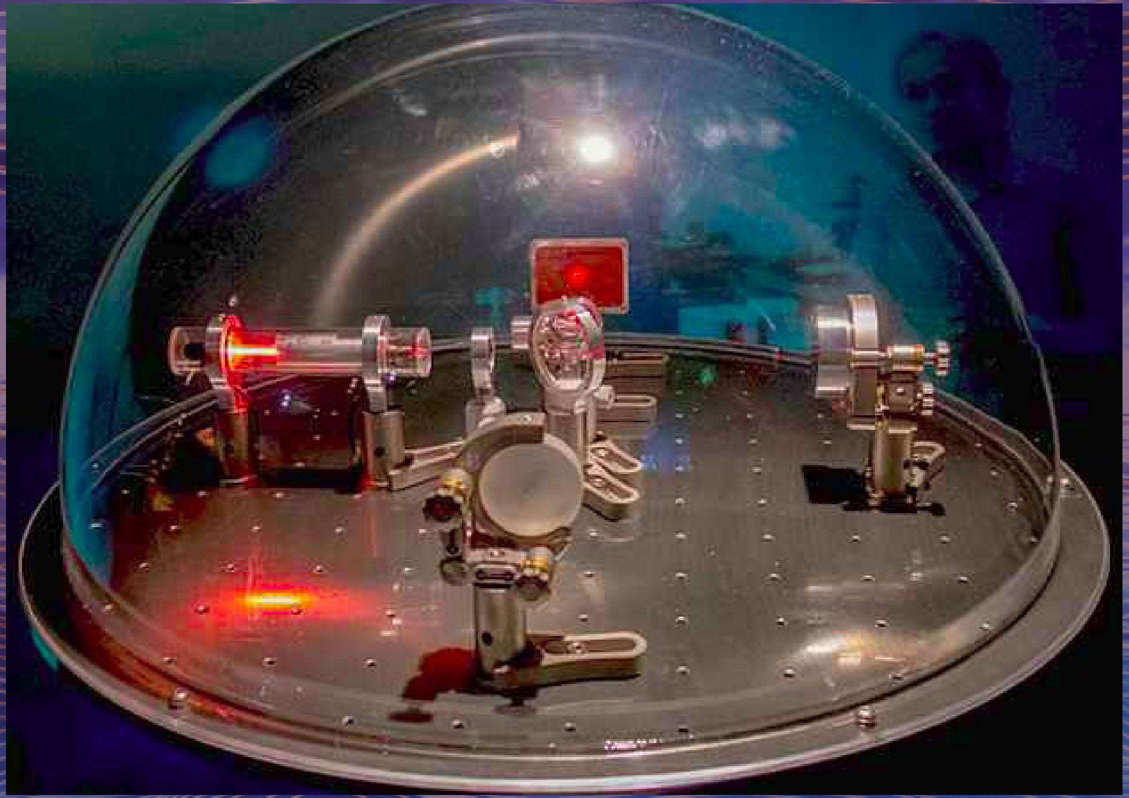
In a Michelson interferometer, laser light is split into two perpendicular beams by a beam-splitter; the beams of laser light travelling down the detector arms reflect off mirrors back to the beam-splitter where they recombine and produce an interference pattern. If the relative length of the arms changes, the interference pattern will change. The exhibit model cannot detect gravitational waves, but it's extremely sensitive to vibrations in the room!

The Michelson interferometer exhibit has an attractive high-shine design, using lab-grade optics and custom-made components, drawing people in to take a closer look. A list of all the parts used in the intricate design is available on the official website - the creators are continuing to investigate low-cost designs using laser pointers and building blocks.

At science fairs, experts are normally present to explain the items on display; however, this is not the case in a museum. 'Exhibits need to be easily accessible with self-guided learning,' explains OzGrav postdoc Dr Hannah Middleton, one of the project leads from the University of Melbourne.

'We've developed custom interactive software for the exhibit through which a user can access explanatory videos, animations, images, text, and a quiz. Users can also directly interact with the interferometer by pressing buttons to input a simulated gravitational wave, and produce a visible change in the interference pattern.'

The gravitational-wave exhibit provides a lasting engagement in the city of Birmingham's family science museum and was exhibited in London at the 2017 Royal Society



The Michelson interferometer installed at the Thinktank Birmingham Science Museum [image supplied from the paper]

Summer Science Exhibition. The project led to further engagement opportunities including Gravity Synth, a musical instrument based on a Michelson interferometer. The Gravity Synth was developed through a collaboration between Birmingham-based audio-visual artist Leon Trimble and gravitational-wave researchers, including OzGrav researchers Dr Aaron Jones (University of Western Australia) and Dr Hannah Middleton (University of Melbourne).

Dr Jones explains: 'After this project, I was inspired to break down traditional barriers between arts and science and develop an art-science experience for our mutual benefit'. The Gravity Synth EP is available here and the project was included as part of the LIGO Magazine's special feature on art, music and gravitational waves.

As featured in Phys.org.

UPCOMING AWARDS & PRIZES

- The Capstone Editing Grant for Mid-Career Researchers -Applications are currently open and close on 24 February 2022.

Background image by Carl Knox, OzGrav-Swinburne University

Dr Qi Chu

Qi began her education by studying telecommunication engineering and computer science. After visiting Prof. Linqing Wen and Prof. David Blair's groups at the University of Western Australia (UWA), she became extremely interested in physics, particularly gravitational waves. She took on a PhD project in UWA and later became an OzGrav and UWA postdoc.

For the last ten years, Qi worked on low latency searches of gravitational wave signals and participated in many exciting new discoveries with LIGO and Virgo. During this time she worked with talented people from LIGO and OzGrav and gained many transferrable skills for both industry and academia. These skills include reasoning and deduction skills, data analysis and reporting skills, and interpersonal skills.

Now, Dr Qi Chu just started her new role as a data scientist at Australia's largest natural gas provider, Woodside, in Perth. She's currently onboarding a data science team to work on various data rendering and optimisation projects from Woodside's natural gas production process.

Industry has been adapting to the new era of big data technology and artificial intelligence, including traditional resource companies like Woodside or BHP. There's more investment in new data infrastructures and technologies to transform data-driven organizations. Researchers from academia are particularly welcome to bring in new perspectives and skills to this transformation.

Joshua McCann

I've been interested in space and astronomy since I was a child. I would get as many space and planet books out from the library as I could. This extended to watching shows like Star Streak (my first introduction to a gravitational wave :P). Despite my interest in space, I was more interested in using my hands when I was a teenager. This led me to leave school in year 11 and pursue an electrical apprenticeship. I completed this and grew more and more interested in engineering, which spurred me onto undertaking an Electrical Engineering Degree.

Upon completing my Honours in Electrical Engineering, I returned to work as an electrical engineer. During my 2nd year of this position, I came across an advertisement for PhD students at the University of Western Australia (UWA) in gravitational wave (GW) science. They were looking for instrumentation engineers. This was my chance to finally combine my interest in space with my profession as an engineer. So, in February of 2017, I started my PhD in the UWA GW group and by April I was a member of OzGrav. While in Ozgrav, I focused on the design, build and testing of a ground rotation sensor, specifically designed to help measure and in turn reduce tilt and translation coupling in GW seismic isolation systems. The sensor we developed, called the ALFRA, was successful in receiving further funding beyond my PhD, with aims to provide the sensors to LIGO.

My new role as lead/senior design engineer came about through industry contacts and word of mouth. Previous work colleagues had heard that I was about to complete my PhD and, before I knew it, I was called to come down and meet with the engineering manager at a company that develops gyroscopic stabilisers for ships. Now, I lead an electrical engineering team in the electrical design and construction of our product. My role involves a large portion of research and development, specifically around new products the company plans to provide. Essentially, my role is to problem solve—this is where my skills learnt during my PhD and with OzGrav really come into play. Most of my PhD felt like problem-solving and teaching myself skills to overcome technical challenges. So now, I can do this type of thinking intuitively and apply it to an industry setting.

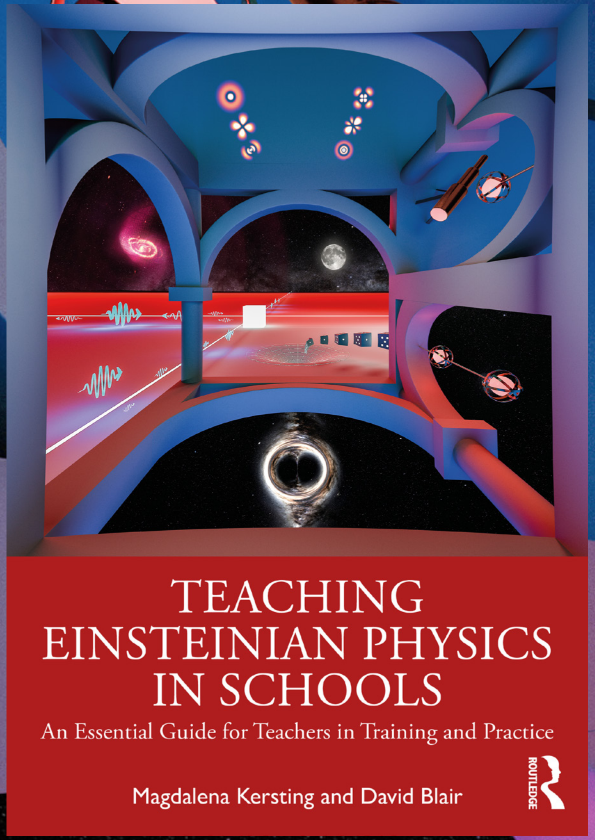
Background image by Carl Knox, OzGrav-Swinburne University

And that's a wrap: National Science Week events!

SciVR Live Talk - attendees explored the virtual universe with Prof Alan Duffy and Dr Rebecca Allen.

SciVR events around Australia - Attendees went on a virtual hunt out to Mars and then into the universe, tracking explosive events as they occur with Alan Duffy and Rebecca Allen with live Q&A.

The 2021 live streamed **National Science Quiz** was hosted by Charlie Pickering (previous host of The Project) and included an all-star panel of science communicators and scientists.



As part of the Einstein-First Project at the University of Western Australia, the book Teaching Einsteinian Physics in Schools was launched in National Science Week to revolutionise school science. Science luminaries - including OzGrav Chief Investigator Susan Scott (Australian National University) and one of the 2020 winners of the Prime Minister's Prize for Science - announced this campaign to take school science from the 19th century and place it firmly in the 21st century. The new book introduces Einsteinian science to teachers at the level needed for both primary and middle school. It advocates complete replacement of obsolete concepts with the Einsteinian concepts that underpin all modern technology.

As part of the Binary Coalescence Project, 'Space+Time' was launched online - an audio-visual track in response to the research outcomes of OzGrav astrophysicist Dr Linqing Wen (UWA). Facilitated by creatives in Mandarin and English, the virtual interviews which took place between Dr Wen (Perth) and Aiv (Melbourne) explored the first principle understanding of the idea of 'binary coalescence' in astronomy, as observed in the research of gravitational waves and the origins of the universe. Watch the launch here on YouTube

All images supplied.

Background image by Carl Knox, OzGrav-Swinburne University

OZGRAV IN THE MEDIA

New research takes us closer to figuring out supermassive black holes

Galaxies host supermassive black holes, which weigh millions to billions times more than our Sun. When galaxies collide, pairs of supermassive black holes at their centres also lie on the collision course. It may take millions of years before two black holes slam into each other. When the distance between them is small enough, the black hole binary starts to produce ripples in space-time, which are called gravitational waves.

A simulation of colliding supermassive binary black holes. Image credit: NASA.

Gravitational waves were first observed in 2015, but they were detected from much smaller black holes, which weigh like tens times our Sun. Gravitational waves from supermassive black holes are still a mystery to scientists. Their discovery would be invaluable to figuring out how galaxies and stars form and evolve, and finding the origin of dark matter.

A recent study led by Dr Boris Goncharov and Prof Ryan Shannon—both researchers from the ARC Centre of Excellence for Gravitational Wave Discovery (OzGrav)—has tried to solve this puzzle. Using the most recent data from the Australian experiment known as the Parkes Pulsar Timing Array, the team of scientists searched for these mystery gravitational waves from supermassive black holes.

The experiment observed radio pulsars: extremely dense collapsed cores of massive supergiant stars (called neutron stars) that pulse out radio waves, like a lighthouse beam. The timing of these pulses is extremely precise, whereas the background of gravitational waves advances and delays pulse arrival times in a predicted pattern across the sky, by around the same amount in all pulsars. The researchers now found that arrival times of these radio waves do show deviations with similar properties as we expect from gravitational waves However, more data is needed to conclude whether radio wave arrival times are correlated in all pulsars across the sky, which is considered the "smoking gun". Similar results have also been obtained by collaborations based in North America and Europe. These collaborations, along with groups based in India, China, and South Africa, are actively combining datasets under the International Pulsar Timing Array, to improve the sky coverage.

This discovery is considered a precursor to the detection of gravitational waves from supermassive blackholes. However, Dr Goncharov and colleagues pointed out that the observed variations in the radio wave arrival times might also be due to ipulsar-intrinsic noise. Dr Goncharov said: "To find out if the observed "common" drift has a gravitational wave origin, or if the gravitational-wave signal is deeper in the noise, we must continue working with new data from a growing number of pulsar timing arrays across the world".

As featured in Phys.org

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
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