SPACE TIMES

OzGrav Bi-monthly newsletter

December 2019

Welcome

Welcome to the December edition of *Space Times.*

In late November, OzGrav hosted the Early Career Researcher workshop and Annual Retreat in beautiful Lorne, Victoria. It was great to catch up with our members who attended and presented at the sessions. I'd like to thank our fantastic OzGrav HQ team and our node admins for all their hard work in successfully organising and running the show. The annual retreat is an opportunity to learn about the diverse range of research activities that make up OzGrav and develop a sense of community. I think this year's retreat was a success on both of these counts.

In this edition of Space Times, we report on the upcoming collaboration between Japan's Kamioka Gravitational-Wave Detector (KAGRA) with the USA's Laser Interferometer Gravitational-Wave Observatory (LIGO) and Europe's Virgo (page 3); OzGrav researchers Juan Calderon Bustillo (Monash University) and Meg Millhouse (University of Melbourne) investigate the first collision of black holes with unequal masses (page 4); and OzGrav goes on an expedition to South Africa to commission the MeerKAT radio telescope (page 12).

2019 has been another huge year for OzGrav, LIGO and the SKA pathfinder telescope, MeerKAT. I wish you a safe and relaxed holiday break and look forward to working with you all in 2020 when we have our mid-term review and fully digest the avalanche of discoveries our instruments are producing.

Regards,
Matthew Bailes - OzGrav Director

News in brief

- Congratulations to OzGrav Investigators Jeff Cooke and Adam Deller on their sucessful ARC Discovery Project 2020 funding!
- Congratulations to OzGrav alumni Lilli Sun on receiving the 2019 LIGO Laboratory Award for Excellence in Detector Characterization and Calibration!
- Congratulations to OzGrav Chief Investigator Susan Scott on receiving the Physics ANU Founders' Day award for 30 years of service at ANU
- OzGrav will be hosting the IPTA 2020 Annual conference 9-19 June, 2020 at Swinburne University & the University of Tasmania in Hobart.
- Welcome to our new postdoctoral researchers that have recently joined OzGrav including Ryosuke (Ryo) Hirai (Monash University), Jielai Zhang (Swinburne University) and Huy Tuong (University of Adelaide)

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Subscribe or submit your contributions to lspadafora@swin.edu.au

KAGRA to join LIGO and Virgo in *hunt for gravitational waves*

Japan's Kamioka Gravitational-Wave Detector (KAGRA) will soon team up with the USA's Laser Interferometer Gravitational-Wave Observatory (LIGO) and Europe's Virgo in the search for subtle shakings of space and time known as gravitational waves. Representatives for the three observatories signed a memorandum of agreement (MOA) about their collaborative efforts on October 4th 2019. The agreement includes plans for joint observations and data sharing.

'At present, KAGRA is in the commissioning phase, after the completion of its detector construction this spring. We are looking forward to joining the network of gravitational-wave observations later this year,' says Takaaki Kajita, principal investigator of the KAGRA project and member of OzGrav's Scientific Advisory Committee.

'This is a great example of international scientific cooperation,' said OzGrav Partner Investigator David Reitze. 'Having KAGRA join our network of gravitational-wave observatories will significantly enhance the science in the coming decade.'

Since the first detection of gravitational waves in 2015, LIGO and its partner Virgo have identified more than 30 likely detections of gravitational waves, mostly from colliding black holes.

'The more detectors we have in the global gravitational-wave network, the more accurately we can localize the gravitational-wave signals on the sky, and the better we can determine the underlying nature of cataclysmic events that produced the signals,' said Reitze.

With KAGRA joining the network, these gravitational-wave events will eventually be narrowed down to patches of sky that are only about 10 square degrees, greatly enhancing the ability of light-based telescopes to carry out follow-up observations. For its initial run, KAGRA will operate at sensitivities that are likely too low to detect gravitational waves; however, as the performance of the instrumentation improves over time, it will reach sensitivities high enough to hunt for gravitational waves. Having a fourth

An illustration of the underground KAGRA gravitational-wave detector in Japan. Image credit: ICRR, Univ. of Tokyo.

detector will also increase the overall detection rate, helping scientists to probe and understand some of the most energetic events in the Universe.

KAGRA is expected to come online for the first time in December 2019, joining the third observing run of LIGO and Virgo, which began on April 1, 2019. The Japanese detector will pioneer two new approaches to gravitational-wave searches. It will be the first kilometer-scale gravitational-wave observatory to operate underground, which will dampen unwanted noise from winds and seismic activity; and it will be the first to use cryogenically chilled mirrors—a technique that cuts down on thermal noise.

'These features could supply a very important direction for the future of gravitational-wave detectors with much higher sensitivities. Therefore, we should make every effort, for the global gravitational-wave community, to prove that the underground site and the cryogenic mirrors are useful,' said Kajita.

In addition, LIGO India is expected to join the network of observatories in 2025, signifying the beginning of a truly global effort to catch ripples in the fabric of space and time.

This article is an extract of the original media release published on LIGO news.

Scientists report the first collision of black holes with unequal masses

To date, the gravitational-wave detectors Advanced LIGO and Virgo have confirmed the detections of ten binary black hole collisions. Advanced LIGO is a network of two 4km long laser interferometers, capable of measuring distances a thousand times smaller than a nucleus.

'It is one of the most precise rulers ever created,' said OzGrav postdoc Calderon Bustillo. Detailed measurements had shown that all of the known black hole collisions were consistent with equal mass pairs of black holes.

Investigations recently accepted in the Physical Review D, involving two OzGrav researchers Meg Millhouse (University of Melbourne) and Juan Calderon Bustillo (Monash University) and their colleagues, have shown that one of these signals, known as GW170729, was produced by the collision of two black holes of different masses, making this binary the first of this kind.

To reach this conclusion, the team has compared this signal to models of binary black hole collisions more complete than those used originally by the LIGO Scientific Collaboration.

Bustillo explained: 'Just as orchestras play music through several instruments, gravitational waves are emitted through several modes.' However, normally one mode dominates the others, which are omitted in the analysis.

Among the events reported in the first gravitational-wave transient catalog, GW170729 stands out for a few different reasons. First, this event was found with the highest significance by a search that has loose constraints on what the gravitational-wave signal will look like. Second, with a mass 80 times that of the sun, GW170729 was the heaviest black hole observed so far. 'This made it the best candidate for subdominant modes to have an effect in the analysis,' said Bustillo.

For these reasons, GW170729 was the target of a follow-up investigation that used more enhanced models in the analysis. The research team has found that GW170729 has slightly different properties than those found initially. 'They were able to rule out, with 90% confidence, that this signal was produced by a pair of black holes with equal mass, making it the first conclusive observation of a collision of two black holes with different masses,' said Bustillo.

The research team also compared the reconstructed signal with and without the enhanced models to a method of signal reconstruction that makes no assumption about the source of the gravitational wave. This so-called 'unmodeled' reconstruction can capture features in the data that may be missed by incomplete models. Though the unmodeled analysis was broadly consistent with both the enhanced and basic models, it showed slightly better agreement with the models that include the effects of subdominant modes.

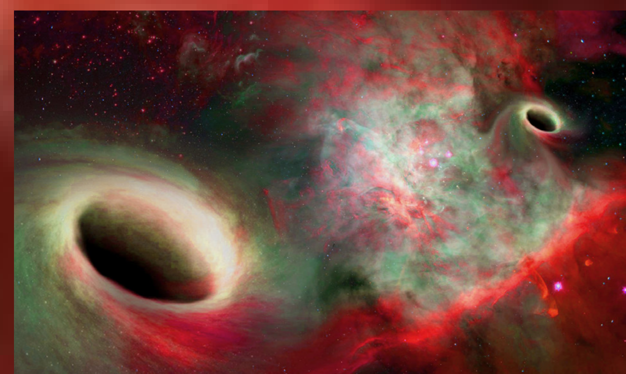

Image credit: Josh Valenzuela, University of New Mexico

Advanced LIGO has recently entered the second half of its third science run and is reporting weekly observations of black hole collisions.

'As more binary black hole systems are detected, we're more likely to find signals that may not be accurately represented by our current models. It's important to have lots of tools to analyze a wide variety of potential signals,' said Millhouse.

Importantly, these collisions can also assist in measuring new astrophysical phenomena such as the gravitational recoil, also known as 'black hole kick'. When an unequal mass binary collides, it emits gravitational waves in an uneven manner, with significant energy coming out in some directions and little in others. This causes the resulting black hole to recoil at velocities that can reach thousands of kilometres per second, enough to eject them from their host galaxies.

One year ago, Bustillo discovered how the information about this kick can be read in the emitted gravitational waves: 'This process is the same that causes a shotgun to hit your shoulder when you fire it: in one direction you get the bullet (in our case, the gravitational waves) and in the other you get the shotgun recoiling (in our case, the final black hole).'

Up to now, it was believed that this recoil velocity (also known as kick) would cause small 'Doppler' frequency shifts in the emitted signal, 'in the same way we can know whether an ambulance, or a Formula 1, is coming towards us or going away from us,' said Bustillo. However, this effect would be so subtle that to measure it, scientists would need to wait until the space-based gravitational wave detector LISA is launched, by 2034.

In a research article, published in Physical Review Letters, Bustillo and his colleagues at Georgia Tech in the US demonstrated that the black hole kick causes a more dramatic effect on the gravitational wave signals.

'We have found that, when the final black hole recoils toward or away from Earth, the signals observed do not differ in tiny frequency shifts, they are actually very different,' said Bustillo. In fact, the signals are so different that the recoil direction can be measured using the current Advanced LIGO detectors.

To obtain this result, the research team simulated hundreds of binary black hole collisions in supercomputers and studied the gravitational wave signals emitted.

'Each of these simulations can take weeks, but it is the only way to know exactly what happens when two black holes collide,' said Calderon Bustillo. Advanced LIGO is showing that these simulations faithfully represent real collisions, and 'one of these observations should allow us to measure a kick for the first time'.

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These two papers are available at https://arxiv.org/abs/1903.06742 and https://journals.aps.org/prl/abstract/10.1103/PhysRevLett.121.191102

OzGrav research highlights:
Is there a spectral turnover in spin noise of millisecond pulsars?

Millisecond pulsars—neutron stars spinning up to 1000 times per second—are exceptionally accurate "clocks" scattered around our Galaxy. By monitoring the pulse arrival times of millisecond pulsars, through a pulsar timing array, astronomers are searching for low-frequency gravitational waves from supermassive binary black holes at the centres of distant galaxies. However, on time scales of several years, the rate at which some millisecond pulsars spin begins to randomly drift. This phenomenon is called 'spin noise'. The origin of spin noise is still unknown but it poses a major challenge to gravitational-wave detection, as it can disguise the true gravitational wave signal.

A recent work, led by OzGrav PhD student Boris Goncharov at Monash University, attempted to better understand the spin noise of millisecond pulsars. The study looked for a specific feature in the spin noise spectrum called 'spectral turnover' which occurs when the spin noise becomes weaker over a longer timescale., Finding this effect would greatly assist in the search for gravitational waves with pulsar timing arrays. . By searching through observations of 49 pulsars spanning up to three decades—collected through the International Pulsar Timing Array, including the Parkes Pulsar Timing Array in Australia, the European Pulsar Timing Array and NANOGrav in North America—no evidence of spectral turnover was found. In the future, longer observations and a larger sample of pulsars will be able to find the definitive answer. The researchers also tested a physical model of spin noise, proposed by OzGrav Chief Investigator Andrew Melatos and Bennett Link in 2013, where the spin noise was due to superfluid turbulence in the cores of neutron stars. They found that the superfluid turbulence model might be accountable for spin noise in approximately half of the millisecond pulsars studied but this was strongly disfavoured for three pulsars.

Researchers involved: Boris Goncharov, Xingjiang Zhu, Eric Thrane

The research paper is now available on the preprint website at https://arxiv.org/abs/1910.05961

OzGrav student/postdoc travel awards: Deeksha visits Melbourne!

OzGrav PhD student Deeksha Beniwal, from the University of Adelaide, was recently awarded an OzGrav student/postdoc travel grant to spend three months in Melbourne, working with her OzGrav colleagues at University of Melbourne, Swinburne University and Monash University. Her trip fostered new collaborations between instrumentation and data analysis groups while supporting OzGrav's outreach goals. The following report summarises her trip and experiences.

With the support of postdocs and PhD students at the University of Melbourne, I was able to make significant progress on my research paper and the continuous gravitational wave (CW) search. I had the opportunity to ask questions, receive feedback and discuss results and issues with the group in our weekly meetings. This visit taught me a great deal about the data analysis techniques used in the CW community and how it applies to my research. It was also beneficial to learn more about the supercomputing resources within OzGrav.

OzGrav postdoc Hannah Middleton, from the University of Melbourne, and I visited Swinburne University to meet with the members of the Swinburne Physics club. We introduced the concepts of gravitational waves physics to these students by doing a short presentation and using the Melbourne laser interferometer as an example. We also revisited the group later to help them build their own interferometer.

Science outreach has been a passion of mine since the beginning of OzGrav, so I also took advantage of this trip to collaborate with Carl Knox—the digital media and marketing officer in OzGrav—on ideas for OzGrav's upcoming documentary.

During my visit, I arranged a collaboration between the University of Adelaide and Monash University: I discussed a potential astronomy-related project for one of our female masters student, from Adelaide, with OzGrav Associate Investigator Paul Lasky and organised a teleconference to facilitate face-to-face conversations. This project will improve our cross-institutional collaboration within the OzGrav and expand our expertise in the field of gravitational wave data analysis and astronomy. Getting a female postgraduate student will also help us overcome the gender imbalance within our group.

This trip has improved my understanding of the CW data analysis techniques— I am now able to work on my research independently and share my knowledge with my colleagues. I can also contribute to diversifying the expertise within the Adelaide OzGrav node and supervise students interested in working in this research area. In summary, my extended trip to Melbourne has been extremely useful in setting me on the right path and I'm grateful to OzGrav for supporting me in the process.

Squeeze leads to stellar-mass black hole collision precision

OzGrav scientists at The Australian National University (ANU) have found a way to better detect all collisions of stellar-mass black holes in the Universe. Stellar-mass black holes are formed by the gravitational collapse of a star. Their collisions are some of the most violent events in the universe, creating gravitational waves or ripples in space-time. These ripples are miniscule and detected using laser interferometers. Until now, many signals have been drowned out by so-called quantum noise on the laser light pushing the mirrors of the laser interferometer around, making the measurements fuzzy or imprecise.

The researchers' new method, called 'squeezing', dampens quantum noise making measurements more precise, with the findings published in Nature Photonics. The breakthrough will be critical for next-generation detectors, which are expected to come online within the next 20 years.

One of the researchers involved, OzGrav Associate Investigator Robert Ward, said further experiments were being prepared to confirm the team's proof of concept for a new device to dampen the effect of quantum noise.

'The detectors use particles of light called photons from a laser beam to sense the change in position of widely separate mirrors,' said Ward. 'However, the detectors are so sensitive that just the random quantum variability in the number of photons can disturb the mirrors enough to mask the wave-induced motion.'

The researchers have shown that squeezing reduces this variability, making detectors more sensitive. The Advanced Laser Interferometer Gravitational-wave Observatory (LIGO) detectors in the United States and the European Gravitational Observatory's detector in Italy called Virgo have detected the mergers of two black holes, the collision of two neutron stars and possibly also a black hole eating a neutron star. The OzGrav team at ANU plays a lead role in Australia's partnership with LIGO. Other members of the quantum squeezer team include OzGrav Director David McClelland, OzGrav Chief Investigator Bram Slagmolen and OzGrav student Min Jet Yap.

'The 'quantum squeezers' we designed at ANU along with other upgrades for the current LIGO detectors have greatly improved their sensing capabilities,' Slagmolen said.

Yap explained that the latest experiment proves that scientists can cancel out other quantum noise that can affect the sensing capabilities of detectors. 'The new-generation LIGO detectors will have the capability to detect every black-hole smash in the Universe at any given moment,' he said.

The LIGO team plans to design and build the upgraded quantum squeezers within the next few years. The new devices could be retrofitted to the current LIGO detectors, enabling scientists to detect many more violent events much further into the Universe.

The published work was undertaken in collaboration with researchers from Louisiana State University, Crystalline Mirror Solutions and the University of Vienna.

This article was originally featured on ANU's website.

OzGrav scientists in Perth help defend the Earth from dangerous asteroids

The University of Western Australia (UWA) has been awarded a contract by the European Space Agency to monitor potentially dangerous asteroids that come close to Earth.

The team includes scientists from UWA's Department of Physics and the University of Poznan in Poland who will use the powerful Zadko Telescope at the Gravity Precinct in Gingin, to survey the skies from a Perth vantage point—a pivotal location. The project includes the development of software that will allow scientists to share sightings of potential asteroid threats with urgency to observatories across the globe.

'There are thousands of rocks that orbit the Sun close to Earth and monitoring their activity is hugely important for the protection of our planet.' - David Coward

OzGrav Chief Investigator David Coward said the Zadko telescope has the capability to monitor asteroids as far away from Earth as Mars, including dangerous space rocks near Earth that may have been undetected.

'There are thousands of rocks that orbit the Sun close to Earth and monitoring their activity is hugely important for the protection of our planet,' Coward said.

'These rocks are often termed "city destroyers" and you need to have high precision telescopes, like the Zadko telescope, to monitor these threats.'

'It's the smaller space rocks between 10 and 100 metres in diameter where current surveillance is missing. These rocks are often termed 'city destroyers' and you need to have high precision telescopes, like the Zadko telescope, to monitor these threats.'

In 2019, a 100-metre-wide asteroid was detected just hours before it came within 70,000 kilometres of Earth; in 2013 a fireball entered Earth's atmosphere over Russia at 600,000 kilometres per second, resulting in sonic blasts that shattered countless windows and injured more than 1000 people.

OzGrav postdoctoral researcher Bruce Gendre explained that space objects had caused great devastation to the Earth in the past, including the asteroid impact that caused the extinction of dinosaurs.

'This is why the European Space Agency's affiliates approached UWA,' Gendre said. 'The Zadko Telescope responds instantly and automatically to European Space Agency alerts to track objects in space near Earth.'

According to Zadko Observatory Manager John Moore, the timing of this contract couldn't be more perfect: 'It comes after the telescope has just received significant upgrades including a new mirror coating which has improved its sensitivity ten times to what it was previously,' Moore said.

The Zadko Telescope is supported by the UWA Faculty of Engineering and Mathematical Sciences and the Australian Research Council Centre of Excellence for gravitational wave discovery (OzGrav).

This article was originally published on UWA's website and featured in The West Australian.

OzGrav 2019 ECR Workshop and Annual Retreat

Another year, another successful OzGrav Early Career Researcher (ECR) workshop and retreat! On 17-22 November, OzGrav hosted the much anticipated annual event in sunny Lorne. Over the week, a total of 128 delegates attended, as well as partners and families, from interstate and overseas. In addition to the panel and breakout sessions each day, members participated in a range of social and networking activities, including zip lining, trivia, hiking, fun thinking games (thanks Lisa Horsley!) and the conference dinner. We hope all OzGrav members enjoyed themselves and found the sessions useful. Huge thanks to the OzGrav HQ team for organising all the logistics and to our fantastic node admins who helped on the ground. We look forward to next year's retreat.

OzGrav Alumni: Where are they now?

Igor Andreoni

Postdoctoral Fellow at Caltech

Tell us about your time at OzGrav.

When OzGrav was established it was quite an exciting time for those who like gravitational wave science, so I applied for student membership as soon as it was possible to do so. OzGrav grew at an impressive rate. I was surprised to see how many people, who are working in many different fields, contribute to gravitational wave discovery. During my time at OzGrav I had the opportunity to be exposed to a broad range of topics, which was somewhat challenging but valuable. I particularly enjoyed the workshops where people can throw ideas and inter-node projects come to life.

What has been your journey since OzGrav?

At the end of my PhD, I wanted to continue doing research in astronomy. One of the hardest decisions I've ever made was to leave Australia (how could you not fall in love with it after living for a few years in Melbourne?) and start a new experience overseas. Now I work in a collaboration called GROWTH (Global Relay of Observatories Watching Transients Happen) and the focus of my research is even more gravitational-wave related—I spend most of my time chasing after LIGO and Virgo triggers with optical telescopes. The experience that I gained through my PhD with OzGrav is proving invaluable. Moreover, I am happy to witness (and continue encouraging) a productive collaboration between GROWTH and OzGrav.

How did you come to decide on this career choice?

I guess that becoming a researcher has always felt like a natural path to me. I like the creative aspect of being a researcher and a postdoctoral appointment is a great opportunity to better understand different potential professions. Far from tying you up too tightly, a postdoc position provides a good deal of freedom about future careers. For example, it is interesting to see how many opportunities some fellow postdocs found on their way, including several different types of roles within academia as well as exciting industry jobs.

What opportunities do you believe OzGrav has provided you as a person?

Most of all, the opportunity of networking and to further appreciate that several pieces of expertise must come together to produce results.

What are some of the proudest moments of your career?

Probably when people came to help out with our 'Deeper Wider Faster' program (DWF) in December 2015, when I had just started my PhD and coded a rough pipeline to discover optical transients in real time. I have never been a master programmer, so seeing the pipeline actually working and allowing other colleagues to assess the results felt like an unbelievable success. In general, I feel proud of how we encouraged the community to work together during DWF, gravitational wave follow-up and other projects. I can't thank Jeff Cooke, OzGrav Chief Investigator, enough, especially for guiding me towards this collaborative vision.

What have been the challenges in getting to where you are now?

PhD students face all sort of challenges! Probably the most difficult challenge is remaining balanced and motivated in stressful times, especially towards the end of the PhD program. When starting a postdoc, the challenges are different. For example, you may feel that you cannot afford to make any mistake as a postdoc, because you can longer say 'sorry, I'm just a student'. I guess that facing the fear of failing is a key challenge that we all should experience (and overcome) to work with greater peace of mind.

What inspires you to continue the work you do every day?

The chance of discovering something new at any time, especially when it is less expected.

Upcoming conferences

- 30th Texas Symposium on Relativistic Astrophysics 15-20 December 2019
- ANITA Summer School 3-7 February 2020, NSW
- KOZWaves 4th Australasian Conference on Wave Sciences, 17-19 February 2020, The University of Melbourne
- GWADW 2020 will be held 11-17 May 2020 in Hokkaido, Japan
- IPTA 2020 student workshop & science meeting 9-19 June, 2020 at Swinburne University & University of Tasmania
- 7th IUPAP International Conference on Women in Physics: 13-17 July, 2020 in Melbourne
- 13th International LISA Symposium will be held 19-24 July, 2020 in Glasgow, Scotland
- Network Gender and STEM Conference 2020: 30 July-1 August 2020, Sydney
- IAU Communicating Astronomy with the Public (CAP) Conference: 21-25 September, 2020 at Macquarie University

Upcoming prizes & awards

- The Bok Prize - closing 14 February 2020
- The Charlene Heisler Prize - closing 14 February 2020
- The Louise Webster Prize - closing 14 February 2020
- The Anne Green Prize - closing 14 February 2020
- Australian Institute of Physics awards and prizes - closing April 2020

‘MeerKAT’ radio telescope in South Africa

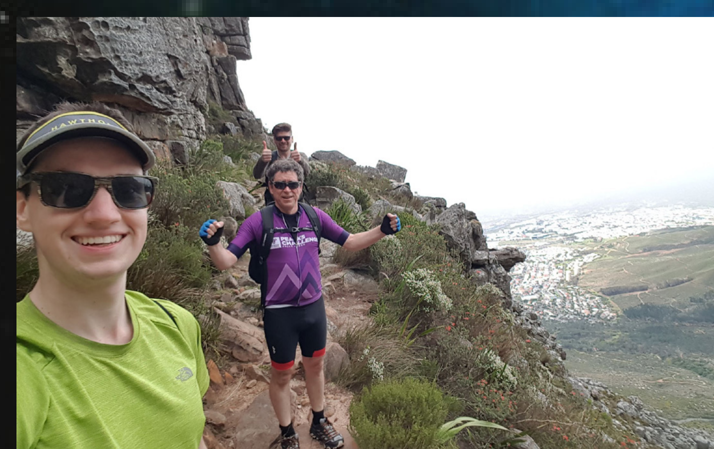
In September 2019, OzGrav sent a delegation of three fearless pulsar astronomers to Cape Town, South Africa to help commission the new Square Kilometre Array (SKA) pathfinder ‘MeerKAT’ telescope. The MeerKAT will ultimately represent about 1/3 of the SKA-mid frequency telescope in Karoo, South Africa. It currently comprises of 64 x 14 metre dishes, each with receivers that offer large bandwidths and operate in a radio quiet zone. OzGrav’s Swinburne University of Technology is responsible for providing the pulsar processor for the MeerKAT and is using it to prototype the pulsar processor for the SKA as part of the Federal government’s SKA R&D program.

OzGrav postdocs Daniel Reardon and Ryan Shannon, and Director Matthew Bailes went to the headquarters of the South African national radio observatory (SARAO) under the spectacular Table Mountain to work with the engineers and scientists there. Matthew heads the international ‘MeerTime’ project—an ambitious 5000+ hour project using radio pulsars to probe relativistic gravity and detect gravitational waves from supermassive black hole binaries—and Ryan is the project scientist.

There were many highlights on the trip including giving an update on the project to over 50 SARAO engineers and scientists using Mark Myers’ (OzGrav Education and Outreach Content Developer) fantastic interactive binary pulsar demonstrator. Daniel also demonstrated that the telescope is already breaking records in precision timing, with the lowest pulsar noise figures to date. The talk had a positive impact on the technical staff and reinforced the benefits of face-to-face meetings between scientists and engineers. While the OzGrav team was there, the telescope also performed its first UHF observations of the double pulsar and independent sub-arrays were implemented for the first time.

On a more sobering note, the team were reminded of the devastating circumstances in Cape Town with extreme variations in living standards, high levels of crime and unacceptable violence towards women. The city had just staged a large-scale protest demanding improvements in attitudes and safety for women after experiencing the worst year for violence against women in South Africa.

OzGrav hopes that the success of the MeerKAT and SKA telescopes will become something South Africans can be proud of as they try to heal the scars of apartheid.



Between the work weeks, the pulsar team scaled the spectacular Table Mountain

Mission Gravity: OzGrav’s education and VR program

In an effort to increase Australian students’ uptake of STEM subjects, OzGrav’s Education and Outreach Coordinator Jackie Bondell has developed a world-first program within the Australian curriculum called Mission Gravity. Jackie explains that Mission Gravity combines ‘scientific modeling with interactive digital and virtual reality (VR) environments.

The program requires students to collaborate in teams, creating models of stellar evolution by collecting and analysing data from virtual trips to stars. Jackie has been encouraging uptake of the program among Australian and international teachers, including unveiling Mission Gravity at the American Association of Physics Teachers Conference in Utah and the European Science Educators Research Association in Italy earlier this year.

Research has shown that young learners are often engaged by digital and virtual experiences using computer programs, VR headsets and animation to understand complex ideas like gravitational waves. Key to Mission Gravity is interactive software developed by OzGrav’s Mark Myers that allows one student in each group (who can then swap with others in the group) to travel to and observe stars in a VR headset.

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What the students ‘see’ and how they use virtual tools to measure things, like the temperature, size and composition of a star, is also projected onto a screen for the other students and teaching staff to witness. Each group studies a different star to determine properties of the star and understand its life-cycle from present day to death.

Mission Gravity facilitates students to work together in making observations, interpreting their results and creating a model for the life of their star, which is then shared with the class. Students use physics and VR to model how stars evolve using virtual scientific tools. ‘To develop this program, OzGrav focused on designing a science lesson that effectively incorporates VR into student-centred activities while aligning with curriculum standards,’ Jackie said.

‘We’ve created a web browser-based version for teachers to use in conjunction with the supplemental materials that have been developed to support the delivery of the content. This content will be freely available to teachers via an in-development OzGrav teacher’s portal. In 2020 we will be promoting virtual school visits to reach rural students and will be seeking funding to support face-to-face visits in rural areas’

If you’re interested in learning more or getting involved in the Mission Gravity program, please contact epo@ozgrav.org

OzGrav's summer outreach program: Upgrading AMIGO

The OzGrav summer outreach program was a successful three-week intensive research program initially trialled with the OzGrav team at the University of Adelaide in early 2019. The aim of the program was to introduce students to research and outreach, helping them develop their skills.

The scholarship involved: designing and developing upgrades for Adelaide's Mini Interferometer for Gravitational-wave Outreach (AMIGO); creating flyers or posters to link the summer research projects to gravitational wave technologies; learning about OzGrav's contributions to the general gravitational wave community; participating in outreach events; and showcasing AMIGO upgrades to the public.

The 2019 OzGrav outreach scholarships were awarded to Thomas Roocke, Georgia Bolingbroke and Harbans Kaur Mann. Each student worked on designing and developing a specific AMIGO upgrade including control systems (Fabry–Pérot), Hartmann Wavefront Sensors and Seismic Isolation systems.

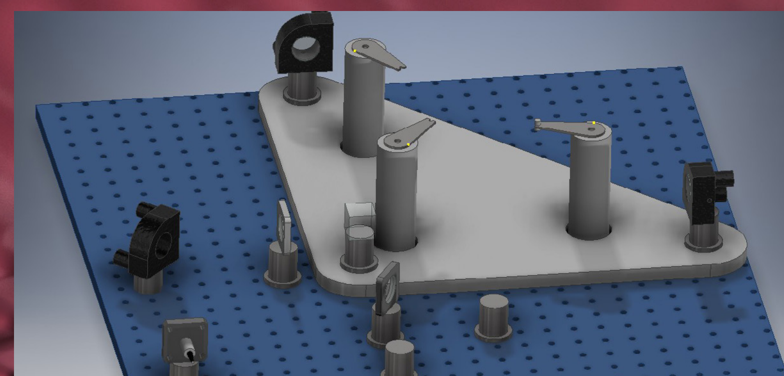
Georgia said: 'My research project with OzGrav has been an amazing opportunity and an excellent experience. I learnt so much over the 6 weeks and I believe what I learnt will help me not only with completing my undergraduate degree but also in undertaking research in the future. I am even more excited to continue my career in physics and am extremely grateful for the skills and knowledge I've attained throughout the project'.

Georgia has actively volunteered for countless outreach activities and is planning to conduct research within the OzGrav Adelaide team as a part of her honours degree. She also represented OzGrav at the recent IONS KOALA conference in Dunedin, New Zealand.

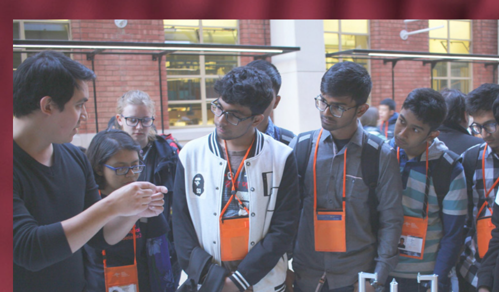
Thomas has continued to actively work and contribute research to OzGrav. He has participated in numerous outreach activities and visited the Virgo gravitational wave detector. Recently, Thomas also had the opportunity to meet Dr. Barry C. Barish and discussed OzGrav's contributions to the wider gravitational wave community.

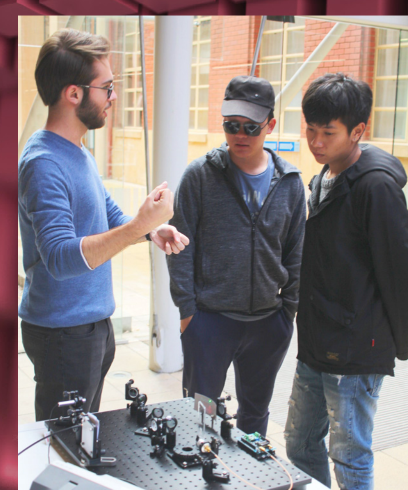
Harbans has moved back to Melbourne and continues to engage with OzGrav by participating in the Monash group.

increased 63m² viewing area.



Conceptual design of the AMIGO suspension plate.





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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