SPACE TIMES

OzGrav October 2022

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Welcome

Dear Colleagues,

Welcome to another issue of Space Times!

This week received the wonderful news that our OzGrav International Partner Investigator (PI) Prof Dr Michael Kramer (Germany) was part of a successful team that was awarded 170 million Euros per year to establish a new research centre (The DZA) that will help ensure Germany remains a powerhouse in gravitational wave and radio astronomy for decades. The Centre will be constructed over the next few years and employ over 1000 people in the Saxony region. The level of investment is staggering and an indicator of the growth of the research disciplines in which OzGrav is engaged.

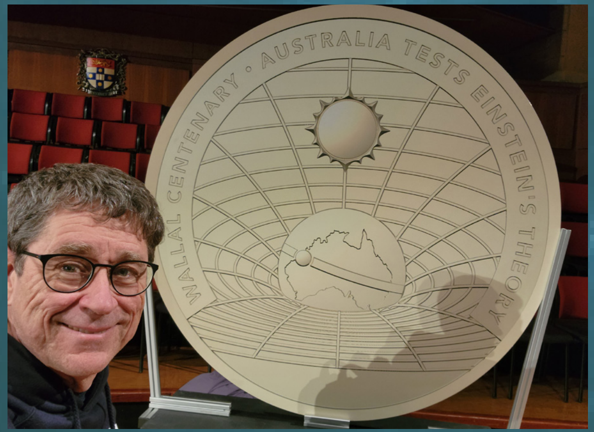
Closer to home OzGrav concluded the competitive processes for a second 7-year investment in gravitational wave science, the results of which should be known in early November. We nervously wait for the outcomes and hope that Australia can maintain its strong position in GW astrophysics.

In this issue, you can read about OzGrav's ARC bid, twinkling pulsars, black holes, the Gingin GW precinct, outreach and meet ANU's Professor Susan Scott, an OzGrav Chief Investigator.

Finally, many of OzGrav's staff and students come from many places in the world which are currently the subject of political unrest or affected by the war in Ukraine. You are in our thoughts.

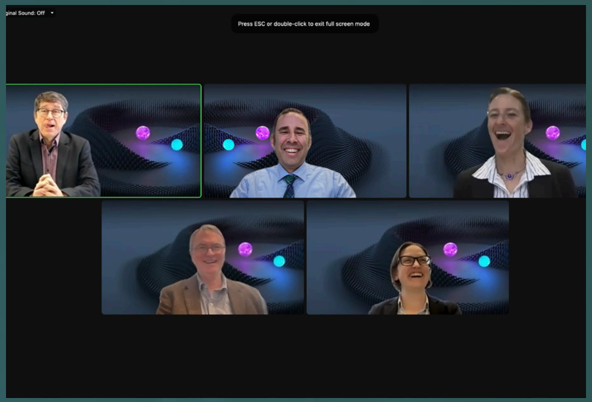
Regards,

Matthew Bailes.



Display of the Royal Australian Mint's Wallal Centenary commemorative coin

OzGrav2 reaches its final hurdle



On 2nd of August, OzGrav reached the final hurdle in our bid for a second Centre of Excellence (OzgGrav 2): a one-hour interview with an expert review panel from the Australian Research Council.

Our interview team comprised proposed Director Matthew Bailes; Deputy Directors, Tamara Davis and David McClelland; Chief Investigators Tara Murphy and Eric Thrane; and Swinburne DVC-R Karen Hapgood. Our team was co-located in Matthew's office with the panel members on Zoom.

So now we wait!!

We expect to be advised of the outcome in early November 2022 - just before our Annual Retreat in Canberra.

Says Matthew: "Regardless of the outcome, I believe we put our best foot forward. Thank you to the interview team and all the OzGrav2 CIs whose ideas resulted in a bid which I am extremely proud of".

NEWS IN BRIEF

- Congratulations Kirk Mckenzie who has been appointed as the SmartSat CRC Professorial Chair in Precision Measurement in Space!
- Dougal Dobie (Swinburne) is taking on the role of co-chair of the multi-messenger program, joining co-chair Katie Auchettl (Uni Melb). Dougal is taking over from Jielai Zhang who is leaving OzGrav to take up a new role in Defence. Good luck Jielai!
- David Coward (UWA) and collaborators were awarded with the ARC Linkage Grant "Characterising satellites using un-resolved optical observations".
- Congratulations to Ethan Payne (Caltech/Monash/ANU) and Dr Lilli Sun (Caltech/ANU) for the LIGO Laboratory Award for Excellence in Detector Characterization and Calibration!
- We also celebrate Katie Auchettl, Anais Möller and Daniel Brown on being awarded ARC DECRAs! Well done!
- There are new PhD opportunities and OzGrav vacancies! For more information head to https://jobs.anu.edu.au/ and https://www.ozgrav.org/swin-2022-phd.html

Editor-in-chief: Ariadna Hernandez Subscribe here.
Background image by Carl Knox, OzGrav-Swinburne University

OBSERVING TWINKLING PULSARS TO UNDERSTAND MYSTERIOUS INTERSTELLAR PLASMA

Pulsars—rapidly-spinning remnants of stars that flash like a lighthouse—occasionally show extreme variations in brightness. Scientists predict that these short bursts of brightness happen because dense regions of interstellar plasma (the hot gas between stars) scatter the radio waves emitted by the pulsar. However, we still don't know where the energy sources required to form and sustain these dense plasma regions come from. To better understand these interstellar formations, we require more detailed observations of their small-scale structure, and a promising avenue for this is in the scintillation, or "twinkling," of pulsars.

When a pulsar's radio waves are scattered by the interstellar plasma, the separate waves interfere and create an interference pattern on the Earth. As the Earth, pulsar, and plasma move relative to each other, this pattern is observed as brightness variations in time and in frequency: the dynamic spectrum. This is scintillation, or "twinkling". Thanks to the point-like nature of pulsar signals, the scattering and twinkling occurs in small regions of the plasma. Following specialised signal processing of the dynamic spectrum, we can observe striking parabolic features known as scintillation arcs that are related to the image of the pulsar's scattered radiation on the sky.

One particular pulsar, called J1603-7202, underwent extreme scattering in 2006, making it an exciting target for examining these dense plasma regions. However, the pulsar's trajectory still hasn't been determined as it orbits another compact star called a white dwarf in a face-on orbit, and scientists don't have alternative methods to measure it in this situation. Fortunately, scintillation arcs serve a double purpose: their curvatures are related to the pulsar's velocity, as well as the distance to the pulsar and the plasma. How the pulsar's velocity changes as it orbits depends on the orbit's orientation in space. Therefore, in the case of pulsar J1603-7202, in our recent study we calculated the changes in the curvature of the arcs over time to determine the orientation.

The measurements we obtained for the orbit of J1603-7202 are a significant improvement compared to previous analyses. This demonstrates the viability of scintillation in supplementing alternative methods.

Artist illustration of a pulsar. Credit: Carl Knox, OzGrav-Swinburne University

We measured the distance to the plasma and showed that it was about three-quarters of the distance to the pulsar, from Earth. This does not seem to coincide with the positions of any known stars or interstellar gas clouds. Pulsar scintillation studies often explore structures such as this, which are otherwise invisible. The question therefore remains open: what is the source of the plasma that scatters the pulsar's radiation?

Finally, using our orbit measurement, we are able to estimate the mass of J1603-7202's orbital companion, which is about half the mass of the Sun. When considered alongside the highly circular orbit of J160-7202, this implies the companion is likely a stellar remnant composed of carbon and oxygen - a rarer find around a pulsar than the more common helium-based remnants.

As we now possess a near-complete model of the orbit, it's now possible to transform scintillation observations of J1603-7202 into on-sky scattered images and map the interstellar plasma at Solar System scales. Creating images of the physical structures that cause extreme scattering of radio waves may give us a better understanding of how such dense regions form and of the role the interstellar plasma plays in the evolution of galaxies.

Written by PhD Student Kris Walker (ICRAR-UWA) & Dr Daniel Reardon (OzGrav-Swinburne University)
As featured in scitechdaily.com

What's happening at the Gingin Gravity Precinct?

If you head north 80km from Perth to Gingin, you'll find olive groves, wineries and sheep – and an observatory that is detecting everything from space junk to ripples in space-time.

UWA's five-hectare Gingin Gravity Precinct includes the fully robotic Zadko Observatory, and the Gravity Discovery Centre and Observatory for public education.

Inside the Zadko Observatory, the Zadko Telescope (one metre f/4 fast-slewoptical telescope) is used for deep space astronomical research and space situational awareness activity. Zadko is so powerful that it is being used in partnership with the European Space Agency.

International industry partners have also set up bases within the Zadko Observatory – these include the French-based Ariane Group (a subsidiary of Airbus), USA Defence contractor Numerica Inc., the Polish Space Agency and the Japanese Aerospace Exploration Agency. Additionally, next door you'll find the US Air Force Academy's Falcon Telescope.

The Zadko Telescope has been used in partnership with the Laser Interferometer Gravitational-Wave Observatory (jointly operated by Caltech and MIT and supported by the US National Science Foundation) for the detection of gravitational wave candidate events and discovery. It has also assisted NASA with Gamma RayBurst and solar system science, and the European Space Agency with Fast RadioBursts.

With millions of pieces of space junk orbiting the Earth, the Zadko Telescope is constantly tracking and mapping space debris, helping prevent collisions with satellites.

Zadko Observatory lead astronomer Dr Bruce Gendre says the telescope's location (as the only instrument of its class between the east coast of Australia and South Africa) makes it particularly important.

"The Zadko Telescope is actively used for the study of exotic transients and is triggered by space satellites. It plays a niche role in space surveillance, as it is located at a longitude not covered by many other metre class facilities," Dr Gendre said.

Also within the Gingin Gravity Precinct is the High Optical Power Test Facility (HOPTF) – two 80-metre suspended optical cavities in a vacuum with high-power lasers.

Famously, HOPTF contributed to the first ever detection of gravitational waves (ripples in the curvature of space-time) in 2015. The discovery confirmed a major prediction of Albert Einstein's 1915 general theory of relativity.

UWA researchers are continuing to develop techniques for improving the sensitivity of the current detectors, as well as for the next generation of gravitational wave detectors, including the proposed Australia gravitational wave detector NEMO (Neutron star Extreme Matter Observatory).

More widely, future research initiatives at the Gingin Gravity Precinct include renewable electric micro-grid technology, site seismic data analysis and biological studies of the surrounding natural woodland with high species diversity.

The Gingin Gravity Precinct is one of six Research Infrastructure Centres managed by UWA's Office of Research, with gravitational wave research supported by the ARC Centre of Excellence for Gravitational Wave Discovery (OzGrav). The Zadko Observatory forms one of twelve nodes of UWA's International Space Centre.

This article was first published in the UWA Forward on the 21st of July 2022.

Background picture: Gingin Gravity Precint, from the GGP Official Facebook

Chaotic dance of wide triple stars

Our Sun is unique; most stars are born as binaries, or even higher multiple systems. Randomly placed three gravitating bodies are most likely to be unstable and lead to ejection of one of the bodies on a short timescale. Only for hierarchical configurations, where the inner orbit is much smaller than the outer orbit, is the system long-term stable. But even then, for certain configurations, the two closest stars could experience periodic eccentric oscillations, which had been widely used in a variety of topics, from Solar-system to Galactic scales.

Star orbits in a three-body system. Credits: European Southern Observatory (ESO).

It turns out that the equations that govern hierarchical triples and the Sun-grazing comets are very similar and can be essentially unified. In a paper published by MNRAS led by Dr. Grishin, the authors combined the long-term dynamics of three stars with the galactic field that perturbs the two most distant stars. The resulting outcome is an enchanting chaotic dance. "Inevitably, the two innermost stars could pass by each other very closely", adds Grishin. "Direct collision occurs if the distance is smaller than the stars' size. Larger close approaches avoid collisions, but the close passage may cause a tidal capture, and the two stars end up in a close orbit." Finally, some systems become unstable and disintegrate.

In order to infer how often and under what conditions each outcome occurs, the authors ran a population of thousands of initial triple systems, varying the orbital parameters, mass ranges and stellar types. A whopping 9% undergone a close encounter. "This is significant because it is in contrast with the standard picture, where only a tiny fraction of the systems are able to get so close", concluded Grishin.

The outcome of these encounters depends mainly on the stellar properties. Low mass stars collide more frequently, rather than tidally captured. When red giants are included, the collision and tidal capture probabilities are roughly equal, mainly due to the strong tidal forces raised on the red giant. Finally, a small fraction of systems even end up as double white-dwarf collisions that produce a Supernova explosion.

The authors also estimated the expected encounter rates. After accounting for typical stellar populations in the galaxy, between 1 and 10 stars undergoes tidal capture or a collision, depending on its type. "We find collisions on the main-sequence the most abundant" added Grishin.

"Their product could resemble a blue straggler star, normally identified as a young star in an older cluster." The collision rates are comparable to dense stellar cluster environments. Other types of transient events are also frequent. "A white dwarf spiralling inside a giant's envelope is a critical, poorly understood, stage of stellar evolution - the common envelope stage. In this particular channel, the initial orbit is eccentric, which is almost unexplored." Overall, the total merger and capture rates are remarkably high for widely separated field stars. "It is remarkable, because the stellar field environment is thought to be collisionless due to the low stellar density. Here we show that it is not the case and the collision rates could be comparable to dense clusters."

Written by OzGrav Associate Investigator, Evgeni Grishin, Monash University.
Publication: https://ui.adsabs.harvard.edu/abs/2022MNRAS.512.4993G/abstract

How a dark matter embrace could slow a spinning black hole

A new study led by Dr Lilli Sun and her colleagues from the Centre for Gravitational Astrophysics have found that counting large black holes could help us find elusive dark matter particles.

Large black holes are formed when smaller ones collide – in dense regions of the universe this could happen multiple times. But if the colliding black holes are spinning fast then the new black hole could be kicked out of the dense area, preventing any further mergers.

But Dr Lilli Sun and her colleagues from CGA and the ARC Centre of Excellence for Gravitational Wave Discovery (OzGrav) realised in some scenarios dark matter clouds can form around fast spinning black holes. In the process the black holes lose their rotational energy and avoid ejection from the dense area.

"If certain ultralight particles exist, then a huge number of them could appear and get trapped in the black hole's powerful gravity field, forming a cloud co-rotating with the black hole," said Dr Sun, from CGA and OzGrav. The formation of the cloud could spin down a black hole very quickly, because the rotational energy of the black hole is extracted into the boson cloud."

Since the first detection of gravitational waves in 2015 many black hole mergers have been found, some involving black holes larger than could be formed by stars collapsing at the end of their life – such behemoths must have come from smaller black holes merging into larger ones, perhaps multiple times.

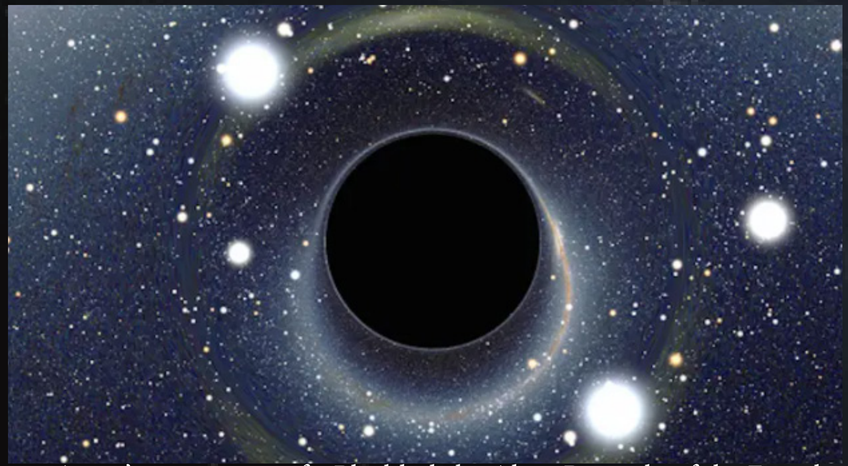

Dr Lilli Sun

However, Dr Sun and her collaborators realised that dark matter could play a significant role in the cosmic game of dodgem cars that black holes play in regions packed with stars.

But that depends on what dark matter actually is – which to date is not known. Its existence is known from large scale gravitational effects, such as the rotation of galaxies, but the nature of it has remained elusive.One theory proposes clouds of small particles, and it is this proposition that Dr Sun and her colleagues has explored, in a paper in the Astrophysical Journal.

"These hypothetical particles have been proposed as solutions to a number of astrophysics and particle physics problems," said first author, Ethan Payne, formerly from CGA and OzGrav, now a PhD student at Caltech in the United States.

"The intricate physics of black-hole superradiance provides a bridge between novel observations of binary black-hole mergers and the possible impacts of ultralight bosons."


Artist's impression of a Blackhole by Alain Riazuelo of the French National Research Agency, via Wikipedia

If dark matter were made up of such small particles, it is possible they could interact with a black hole through a process called superradiance, that would sap the rotation of the black hole.

The superradiance effect is maximized if the Compton wavelength of the particles is comparable to the size of the black hole, which would create a resonance that would allow the energy to be efficiently coupled out of the black hole.

Such a multistep link – small particles slowing black holes, leading to more mergers and therefore on average larger black holes – is difficult to prove. It's a conceptual proposition that might apply to populations of black holes in dense clusters, but it's not straightforward – there are many subtleties, Dr Sun said.

This article was first published on the Research School of Physics from ANU College of Science Newsletter, on July 20, 2022.
As featured in physics.anu.edu.au

Background picture: Aurore Simonnet/LIGO-Caltech-MIT-Sonoma State

Nondegenerate internal squeezing: An all-optical, loss-resistant quantum technique for gravitational-wave detection

The detection of gravitational waves over the past decade motivates looking to the future of using gravitational waves to explore the universe. Detecting kilohertz-band frequency gravitational waves - tiny ripples in spacetime oscillating at 1000 to 4000 cycles per second - could illuminate the otherwise inaccessible cores of neutron stars. These hottest, densest places in the universe (outside of black holes) could teach us much about nuclear physics. Future gravitational-wave detectors, however, will not be able to probe them because of quantum noise. This is, unless advancements are made.

Quantum noise

The laser light inside of a gravitational-wave detector can be described as a wave with amplitude and phase. Fundamental fluctuations in the amplitude and phase arise from the quantum nature of reality. The detectors are so sensitive that these fluctuations are measured as quantum noise obscuring the gravitational-wave signal! Although detectors presently use devices called “squeezers” to tackle the quantum noise, if future detectors are to measure kilohertz-band signals, then they need new techniques to avoid the quantum noise.

A new quantum technique

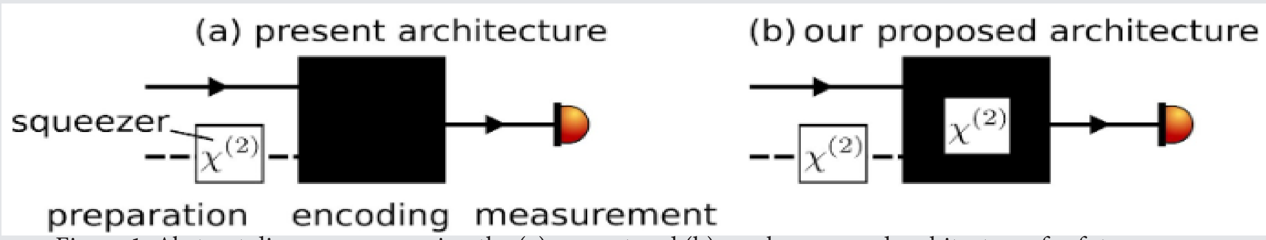


Figure 1: Abstract diagrams comparing the (a) present and (b) newly proposed architectures for future gravitational-wave detectors. Into the “black box” enters light or vacuum prepared using a squeezer. The gravitational-wave signal is then encoded onto the light and finally exits to be measured. In the new technique, an additional squeezer is used inside the encoding stage to improve the sensitivity.

A group of OzGrav researchers from the Australian National University have recently published a Letter in Physical Review D describing how future gravitational-wave detectors might overcome quantum noise. As shown in Figure 1, this technique changes the encoding stage of the detector using a squeezer. The improvement in sensitivity (signal-to-noise ratio) comes from amplifying the measured gravitational-wave signal more than the quantum noise.

The next research steps are to show that this technique is feasible using advanced modelling and a table-top experiment.

This article was written by James W. Gardner, Min Jet Yap , Vaishali Adya ,† Sheon Chua , Bram J. J. Slagmolen , and David E. McClelland Centre for Gravitational Astrophysics, Australia and OzGrav-ANU.

OzGrav researcher Susan Scott

“I remember watching the first lunar landing on TV as a child, in 1969 – we’d been sent home from school for the day, and it went on for hours. Eventually my friends got bored and took off outside to play, but I sat there mesmerised watching those guys leaping about on the surface, as if in slow motion. I was fascinated in that aspect of the gravity of the Moon compared to Earth. I probably didn’t tell myself then that I was going to become a gravitational scientist, but I think that event really sparked my interest.”

Distinguished Professor Susan Scott. Credit: ANU

Distinguished Professor Susan Scott was featured in Cosmos Magazine in the article titled “The weight of the Worlds”. In this piece, she talks about her trajectory as a scientist and discusses the developments in research and technology for the detection of gravitational waves in Australia and abroad.

Susan Scott recalls being involved with gravitational wave detection in the 1990s, pointing out that although a few groups of scientists were working on interferometer aspects, there was little involvement in the science that was going to come out of the ‘big gravitational wave detectors that were planned” back in the day.

Questions like “how to process the data?” coming from gravitational wave detectors marked the next step of her career and research while being an active contributor to LIGO.

At LIGO she recalls experiencing the real “sciencey side” of gravitational wave detection by making use of theories of general relativity and having to “calculate the exact signals that might come out of a system to make the first detection”. Scott esteems the next big thing in gravitational waves discoverty will be detecting those coming from neutron stars, a research that she as been involved in for some years now.

Today, gravitational wave discovery aims to detect the continuous wave stream from a single neutron star as it spins. Professor Scott points out that although there is not much knowledge of neutron stars, they are vital for our fundamental understanding of the universe at large.

This piece was a summary of the original article titled “The weight of the worlds”, written by Susan Scott, Chief Investigator at OzGrav-ANU, and published in Cosmos Magazine, July 29, 2022.
To read the full article head to: cosmosmagazine.com

National Science Quiz

As part of National Science Week 2022, OzGrav was a sponsor for the National Science Quiz. This night of science and fun was hosted on 7 August in front of a live audience of over 200 people in Fed Square in Melbourne and live streamed on YouTube for remote participation to over 400 at-home teams.

The event was hosted by Charlie Pickering from ABC-TV and featured two teams. Each team consisted of two scientists and a comedian, merging scientist content with humorous banter in the quest to be crowned the National Science Quiz Champion!

Kirsten Banks (Astrophysics and Science Communication), A/P Bradley Moggridge (Environmental and Indigenous Water Science), A/P Jacqui Romero (Experimental Quantum Physics), and Prof. Barbara Holland (Mathematical Biology) were joined by ABC presenters Lawrence Leung and Nate Byrne.

Remote teams and the in-person audience participated in the Quiz via Sildo and two audience champions were crowned!

After a suspenseful tie-breaker question, the team of Jacqui Romero, Lawrence Leung and Bradley Moggridge was declared the winner and the team of Kirsten Banks, Barbara Hooland and Nate Byrne was subsequently slimed!

The National Science Quiz was left by FLEET, the ARC Centre in Future Low-Energy Electronics technologies, and sponsored by additional CoEs including OzGrav, EQUS, Plant Success, Exciton Science, TMOS, as well as Matrix, Monash Engineering and the Department of Defence.

The success of the Quiz, as noted by its Steering Committee, comes from building science capital with public engagement. This event shows that there are

many ways to engage with science, encouraging people to feel that STEM is an important and useful part of people's lives.

OzGrav's main role in the Quiz was communicating with schools and teachers to engage them in the event and will continue to work with the steering committee to utilise the NSQ material as educational resources for schools.

You can read more about the Quiz at: https://www.nationalsciencequiz.com.au/

Background image by Carl Knox, OzGrav-Swinburne University

Next generation STEM Leaders

Since its inception, the main goal of OzGrav's Education and Outreach programs is to "capitalise on the historic first detections of gravitational waves to... inspire the next generation of Australian scientists and engineers through this new window on the Universe". In conjunction with Hume Central Secondary College in Broadmeadows, VIC, the OzGrav outreach team piloted a new program to mentor early secondary students to serve as science ambassadors to help host science activities for local primary school students.

Education and Outreach Coordinator Jackie Bondell connected with Hume Secondary Central College Principal Vivienne Caravas to discuss ways in which OzGrav could collaborate with the school to provide a unique science opportunity for her students. Principal Caravas enthusiastically entered this conversation as she is a tireless advocate for providing STEM enrichment for the students from Hume Central, a cohort from a diverse range of backgrounds that have been traditionally underserved in STEM opportunities.

From these early conversations, we designed a program in which OzGrav would train two cohorts of Year 7 students across two campuses of Hume Central Secondary College to deliver OzGrav outreach activities such as the VR Guided Tour, the Gravity Well, app-based games, and the ever-popular badge machine! Led by OzGrav Outreach Officer Lisa Horsley, these training sessions not only taught the 40 Year 7 STEM Ambassadors the basics of OzGrav science but also prepared the students for confident science communication.

Over two days, the STEM Ambassadors (with oversight from Lisa and Jackie) ran activities with over 200 primary school students in Years 5-6 from five local primary government schools. The STEM Ambassadors refined their communication throughout the days and overcame the challenges associated with engaging with students from a

variety of backgrounds.

Principal Cavaras wrote, 'On behalf of everyone here at HCSC, I just wanted to thank you both once again for providing our students with such a great opportunity. Both our Year 7 ambassadors and primary school students loved the applied learning experiences. We look forward to working with you in 2023 and beyond!'

OzGrav plans to continue this model of 'training the trainers' as a way to broaden the impact of its Education and Outreach programs.

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.

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