OzGrav

# SPACE TIMES

July 2023

## AUSTRALIAN ASTRONOMERS FIND POSSIBLE 'FINGERPRINTS' OF GRAVITATIONAL WAVES

page 6

### ANU & UWA LAUNCH A REVOLUTION IN AUSTRALIAN SCIENCE EDUCATION

page 6

### OZGRAV DIRECTOR WINS PRESTIGIOUS SHAW PRIZE

page 5

### ANU TO BOOST THE GLOBAL HUNT FOR GRAVITATIONAL WAVES

page 8

# Welcome to the July issue of Space Times!

Dear Colleagues,

One of the best things about the Australian Research Council's Centres of Excellence is how they bring Australia's most talented scientists together, provide them with the funding security and resources to recruit world-leading teams of critical mass, and enable them to focus more on doing science rather than on grant preparation.

As OzGrav's first 7 years of funding are ending, we've had some remarkable successes in recent weeks that I'm confident would not be taking place without funding for the Centre. Firstly, OzGrav staff, students and technicians helped prepare the Advanced LIGO interferometers for the long-awaited 4th observing run "O4". Just last week I had an excited postdoc appear at my door wanting to show me one of LIGO's highest significance black hole mergers which was a joy to behold. It was a great thrill to be able to show my two work-experience Y10 students the clear signature of the black hole merger and explain the physics behind it to them.

Last week also saw the worldwide release of the pulsar timing array searches for gravitational waves from supermassive black hole binaries in the distant universe. Many OzGrav staff are members of the Parkes Pulsar Timing Array collaboration, and

it was one of four groups seeing hints of the gravitational wave background that you can read about in this newsletter.

I'd describe the results as tantalising!

Two weeks ago, OzGrav organised the 2023 in-person meeting of the International Pulsar Timing Array at Port Douglas. Not only was it a great (and warm) venue, but there was also lots of great science being discussed.

Swinburne also hosted the O4 data workshop with over 50 in-person participants and much more online organised by Jade Powell and colleagues. It was great to see so many people back together, and we had a bonus table tennis and social event in the city to celebrate OzGrav's 6th anniversary.

Earlier in a jam-packed month, we saw the national launch of the "Einstein First" and "Quantum Girls" educational programmes led by David Blair and Susan Scott at the Shine Dome in Canberra, which gained a lot of press and the presence of many dignitaries.

Finally, whilst sitting at my desk about a month ago I received the unexpected but very happy news that I'd shared the Shaw Prize for Astronomy in 2023 with my former student Duncan Lorimer and his partner Maura McLaughlin for our team's discovery paper on the first Fast Radio Burst.

I've had a very fortunate life in science with many great mentors and colleagues,

and was thrilled to receive this recognition.

I hope it will enable us to open even more opportunities for our many OzGrav staff and students. The Shaw Prize is awarded at a fancy ceremony in Hong Kong in early November, and I'll be relying on my OzGrav colleagues to not let it go to my head.

A special farewell to OzGrav's Lisa Horsley whose passion and enthusiasm for science outreach has found a new home at Swinburne's Wantirna campus.

Yours sincerely - **Matthew Bailes**

## NEWS IN BRIEF

– Congratulations to Chief Investigator Kirk McKenzie (ANU) on winning a Moon to Mars Initiative Demonstrator Mission Grant for the "Laser Technology for the next GRACE mission" project.

– OzGrav recently obtained a Pleiades Silver level award, a very positive testament to our commitment to promoting and achieving equity and inclusion.

– OzGrav has won the bid to host the 2024 GWADW! More information to come.

– Congratulations to former OzGrav PhD student Isobel Romero-Shaw who won the 2022 Robert Street Doctoral Prize in Physics for the best PhD in Physics and Astronomy at Monash University.

– The audio visual musical *Continuum* which is Part II of the "Binary Coalescence Project" by Aiv Puglielli was selected as a finalist at the Quantum Shorts Film Festival! Congratulations to Linqing Wen and Carl Knox who contributed to the project.

## UPCOMING EVENTS

– **Amaldi 15 Virtual Conference:** 17-21 July. More here

– **OzGrav Winter School:** 19-21 July, Perth. More here

– **InSTEM Conference:** 19-21 Sept, Melbourne. More here

– **LVK Meeting**: 11-14 Sept, Tomaya Japan.

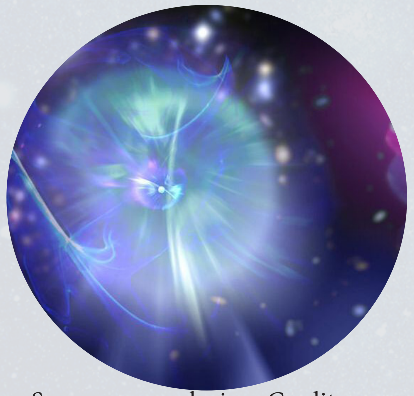
– **OzGrav ECR workshop & Annual Retreat:** 13-17 Nov, Adelaide. More here

Background picture: Artist's view of a supernova explosion, which drives turbulence in the interstellar medium. Credit: Carl Knox, OzGrav-Swinburne University

## The hunt for interstellar tornadoes with twinkling pulsars

Space is mostly empty because of the vast distances between the stars that make up our Galaxy. Although it is often thought of as a vacuum, there is a diffuse medium that fills the void, made up of of gas, dust, and plasma (ionised particles). The plasma of this interstellar medium interacts with the radio waves that astronomers observe to study some of the most extreme objects in the universe, such as black holes and neutron stars (pulsars). In particular, the interstellar plasma slows down and scatters radio waves.

The observed result of this scattering is that radio waves from pulsars "twinkle" because of turbulence in the interstellar plasma, just as stars in the night sky twinkle because of turbulence in our atmosphere. Remarkably, astronomers can leverage this twinkling, also known as "scintillation," to study the interstellar plasma and the pulsars themselves.



Supernova explosion. Credit: Carl Knox, OzGrav-Swinburne.

One mysterious feature of the interstellar plasma is the presence of dense, compact, and intensely-turbulent regions, akin to an interstellar tornado. These so-called "extreme scattering events," or ESEs, are poorly understood because they are difficult to study. Our current understanding is so poor that scientists would expect such extreme objects to quickly destroy themselves. How they form and how they sustain themselves is the mystery. The solution to this puzzle likely involves the magnetic fields in our Galaxy but further study of ESEs is critical. Unfortunately, ESEs are so small by astronomical standards, that they are completely invisible to other areas of astronomy.

A new research paper led by Dr Daniel Reardon of Swinburne University of Technology, offers a novel technique for finding changes in interstellar plasma density, caused for example by the passing of these interstellar storms through the radio waves from a pulsar. The technique involves identifying changes to the characteristics of the twinkling of pulsars as the plasma density varies. It can be used to measure the density and strength of such storms, which will provide valuable insights into their nature. Understanding ESEs and the magnetic fields that should support them, plays a role in our understanding of how galaxies themselves form, evolve, and birth stars.

The technique was proved through a practical demonstration on one pulsar, J1603-7202, which was known to have been affected by an ESE. The density of this ESE was previously estimated through the method of pulsar timing, which relies on detecting the time delay induced by the plasma, rather than the twinkling. The new method is complementary and broadens our window on these interstellar tornadoes. In this new study, a smaller structure in the interstellar plasma, similar to the known ESE, was also identified even though it was invisible to the pulsar timing method

As we can now identify changes to the density of interstellar plasma using the twinkling of radio sources, many more pulsars can be used as tools to detect compact structures, such as ESEs. Pulsars are incredibly useful objects for studying the weather of interstellar space, and the weather in turn can be used to study the pulsars themselves. Pulsar timing and twinkling will be used together to solve fundamental problems in physics, such as the nature of gravity and the behaviour of matter at extreme density.

Daniel Reardon and William A. Coles, "Determining electron column density fluctuations in a dominant scattering region using pulsar scintillation", 28 March 23.
https://arxiv.org/





## PROFESSOR MATTHEW BAILES WINS PRESTIGIOUS SHAW PRIZE

**Congratulations to OzGrav Director Prof Matthew Bailes who was awarded the extremely prestigious Shaw Prize in Astronomy, along with collaborators Duncan Lorimer and Maura McLaughlin, for the discovery of Fast Radio Bursts!**

**Matthew Bailes,** Director of the ARC Centre of Excellence for Gravitational Wave Discovery, alongside **Duncan Lorimer,** Professor and Interim Chair of Physics and Astronomy at West Virginia University, USA and **Maura McLaughlin,** Distinguished Professor and Director of the Center for Gravitational Waves and Cosmology at West Virginia University has been awarded the prestigious **Shaw Prize in Astronomy** for their role in the discovery of fast radio bursts.


The scientists were working at Parkes radio telescope in 2006 when, as they reviewed archived data, they discovered an extraordinary pulse of energy a trillion times brighter than anything seen in our galaxy, from a billion light-years away, but that lasted for just a fraction of a second.

Their discovery was extremely controversial among astronomers, as many new discoveries are, and some even suspected the detection was just an anomaly caused by a nearby thunderstorm. But soon other telescopes managed to detect them – and now they are detected routinely.

This award highlights Matthew's dedication in the field of astronomy. His contributions not only enhance scientific knowledge but also inspire future astronomers. This also emphasizes the significant role of Australian scientists in astronomy, cementing the country's position as a leading hub for cutting-edge research. As we celebrate this achievement, we eagerly anticipate Matthew's ongoing discoveries and the valuable insights they will provide into the mysteries of the universe.

Congratulations Matthew!





Editor-in-chief: Ariadna Hernandez Subscribe here.

# AUSTRALIAN ASTRONOMERS FIND POSSIBLE 'FINGERPRINTS' OF GRAVITATIONAL WAVES

**Astronomers using data collected by CSIRO's Parkes radio telescope, Murriyang, have found their strongest evidence yet for low-frequency gravitational waves.**

Parkes Radio Telecope. Credit: CSIRO/ Alex Cherney

For nearly 20 years the Parkes Pulsar Timing Array collaboration has monitored a set of rapidly spinning stars that pulse like a lighthouse, called pulsars.

They are looking for nanosecond pulse delays caused by gravitational waves to provide further evidence for Einstein's general theory of relativity and build on our understanding of the Universe.

By compiling and analysing this large data set, the team has taken another step towards detecting gravitational waves through the study of pulsars.

Their latest results have been published today in The Astrophysical Journal Letters and Publications of the Astronomical Society of Australia.

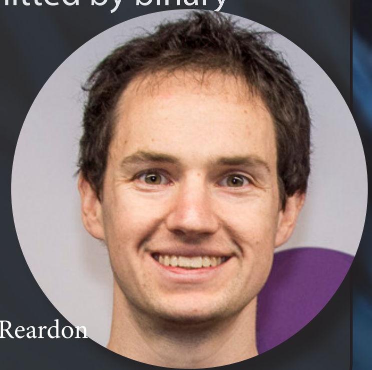

PTA. Credits: Carl Knox, OzGrav

In 1916 Albert Einstein proposed space-time as a four-dimensional fabric, and that events such as exploding stars and merging black holes create ripples – or gravitational waves – in this fabric.

Almost a century later, in 2015, researchers from the LIGO and Virgo collaborations made the first direct observation of gravitational waves caused by the collision of two stellar-mass black holes.

In contrast to these gravitational waves, which oscillate multiple times per second, the Parkes Pulsar Timing Array collaboration is searching for gravitational waves emitted by binary supermassive black holes at the centres of galaxies. These gravitational waves oscillate over timescales of many years.

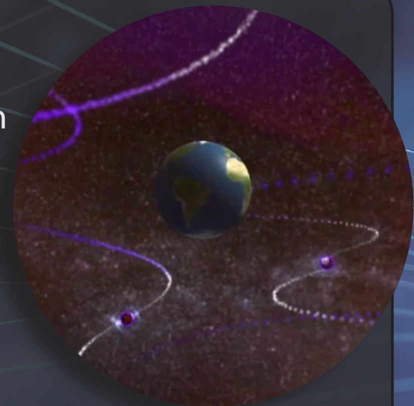
OzGrav and Swinburne University of Technology researcher Dr Daniel Reardon, who led the searches, said that as these gravitational waves pass through our galaxy and wash over the Earth, they will change the apparent rotation frequency of fast-spinning pulsars.



Daniel Reardon







Representation Pulsars reaching earth. Credit: OzGrav

"We can detect gravitational waves by searching for pulses that arrive earlier or later than we expect. Previous studies have shown an intriguing signal in pulsar timing array observations, but its origin was unknown," Dr Reardon said.

"Our latest research has found a similar signal among the set of pulsars we've been studying, and we now see a hint of the fingerprint that identifies this signal as gravitational waves.

"Unlike stellar-mass bursts of gravitational waves, supermassive black holes take years or decades to complete their orbits, and so their signature takes a decade or more to emerge," he said.

Astronomers around the globe have been busy chasing this gravitational-wave signal by studying pulsars.

Other collaborations in China (CPTA), Europe (EPTA), India (InPTA) and North America (NANOGrav) see a similar signal in their data; their results are also published today in several journal papers.

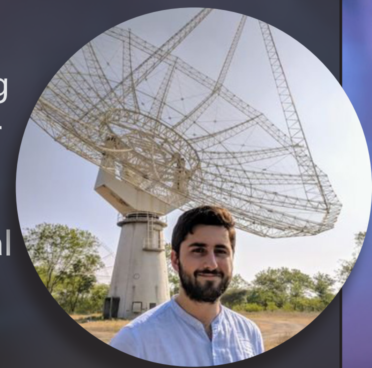
CSIRO astronomer Dr Andrew Zic, who co-led the analysis, said that while it is exciting all the major collaborations are seeing hints of the waves the true test will come in the near future, when all of the data is combined into a global dataset..

"This signal could still be caused by things like variations in a pulsar's rotation over a long period of time, or may simply be a statistical fluke," Dr Zic said.

"Our Parkes radio telescope, Murriyang, has an advanced receiver and an excellent view of the best pulsars in the southern sky, which are essential for this work.

"The next step is to combine pulsar data sets collected by telescopes in both the northern and southern hemispheres to improve the sensitivity of our observations," he said.

Through the International Pulsar Timing Array consortium, the individual groups around the globe – including the Parkes Pulsar Timing Array collaboration in Australia – are working together to combine their data to better characterise the signal and confirm its origin.



Andrew Zic

"The next stage of our research will combine the full power of the global array, and rule out any anomalies," said Dr Zic.

Using pulsars to confirm the detection of low-frequency gravitational waves will expand this emerging area of science, to be explored further by new instruments including the SKA telescopes currently being built in Australia and South Africa.

This article is as published in Australian astronomers find possible 'fingerprints' of gravitational waves, CSIRO News, 29 June 2023.





Editor-in-chief: Ariadna Hernandez Subscribe here.

Background picture: Artist's Impression of a Pulsar Timing Array. Credit: Carl Knox, OzGrav-Swinburne University

# ANU & UWA LAUNCH A REVOLUTION IN AUSTRALIAN SCIENCE EDUCATION

**Two national teaching programs aiming to revolutionise science education in Australian schools have been launched by ANU and UWA, to generate the next generation of Aussie Einsteins, quantum gurus, and our future science and technology workforce.**

The national launch of the Quantum Girls and Einstein-First programs is being led by two Prime Minister's Prize for Science winners and OzGrav members, Distinguished Professor Susan Scott from ANU Research School of Physics/Centre for Gravitational Astrophysics and Emeritus Professor David Blair from The University of Western Australia (UWA).

The two programs will bring primary and high school science education into the 21st century and help reverse Australia's critical skills shortage in science, technology, engineering and maths (STEM), especially among young girls.

In Einstein-First, kids are introduced to a STEM education curriculum through interactive group activities, including concepts such as black holes, quantum computers and climate science.

"In Australia, we face a big problem of not enough school-leavers choosing to pursue a career in STEM fields, and this is especially true for girls. The Einstein-First and Quantum Girls programs are designed to ignite the interest and passion in science among primary and secondary school children.

**The Quantum Girls program expands on Einstein-First and will aim to train 200 female teachers, who will then teach quantum science and quantum computing to girls aged 11 to 15.**

Prof David Blair, researcher at UWA and OzGrav's Chief Investigator, began testing Einstein-First in Western Australian schools more than a decade ago. He was frustrated that school curriculums relied upon 19th century physics and that modern concepts such as relativity often weren't taught until university.

Blair says the success of the program has led to it being offered to schools across the country, having already been replicated by teachers at schools in the US and parts of Europe.

"The theories of Albert Einstein, who revolutionised science in the early 1900s, aren't too hard for school kids," Blair says. "Our kids are curious and excited by science.

"This is why we must modernise the curriculum … and teach everyone the language of modern physics, the language of Einstein, starting in primary school."

Additionally, UWA has received federal funding for a new course named Einsteinian Physics for Schoolteachers, which will upskill teachers as part of the Einstein-First program.

Scott hopes the programs will help reverse Australia's critical skills shortage in Stem, especially among women.

The most recent Australian government data shows girls' confidence in STEM subjects is generally lower than boys, and falls as they get older. At the same time, women make up only 36% of enrolments in university Stem courses, and just 16% of vocational Stem courses.

And at a managerial level, only 8% of CEOs in STEM-qualified industries are women.

"At the moment our school system is failing us in what we need for the future. We can't afford to let that happen," Scott says. "We do have a Stem crisis and our future depends on the Stem workforce.

"Climate science, renewable energy – we will need a lot of people in science and engineering to solve these problems [that are] so important for this generation."

Learn more about Einstein-First and Quantum Girls at www.einsteinianphysics.com.

All photo credits Jesse Grunch.

ANU and UWA launch a revolution in science education, June 12, 2023. Click here.
Cassidy, Caitlin. Nerf guns, marbles and einstein: Schools taking Quantum Leap to halt Australia's stem crisis, June 13, 2023. Click here






Background picture: Midjourney

# ANU TO BOOST THE GLOBAL HUNT FOR GRAVITATIONAL WAVES

**A new facility at The Australian National University (ANU) will help scientists detect some of the most extreme events in the universe and put Australia "front and centre" of the exciting field of gravitational wave science.**

Associate Professor Chris Lidman and Dr Lili Sun in the LIGO control room at the ANU Centre for Gravitational Astrophysics.

Gravitational waves are elusive ripples in space-time, difficult to detect due to their weak nature. They require dramatic events like the collapse of massive stars or the merging of black holes or neutron stars to be observable on Earth. When detected, these waves allow scientists to study some of the most hidden secrets of our universe, such as the moment the cores of massive stars collapse and the permanent distortion of space-time.

The new ANU facility will act as a remote control room for Laser Interferometer Gravitational wave Observatory (LIGO) in the United States (US) – one of the leading gravitational wave observatories on the planet -- and play a major role in the latest global observing run, commencing today.

The LIGO remote control room is based at the Centre for Gravitational Astrophysics (CGA), the ANU node of the Australian Research Council Centre of Excellence for Gravitational Wave Discovery (OzGrav). Similar remote control rooms will be launched at the other OzGrav nodes in coming months.

OzGrav's Chief Investigator Dr Bram Slagmolen said the new ANU facility gives our scientists the ability to directly engage with the operation of the US-based gravitational wave detectors.

"This facility provides real-time information on the performance of the detectors, as well as notifications on detected events," he said.

Dr Lilli Sun, OzGrav's CI said: "The detectors are extremely sensitive and have to be precisely calibrated before we can correctly extract the gravitational wave signals and decode the astrophysical information.

"The ANU LIGO remote control room creates a virtual environment for us to 'sit at the detector,' monitoring and understanding the response of the detectors in real-time, which is essential to accurate and precise calibration."

The latest global observing run will also be boosted by the rejuvenated ANU 2.3-metre telescope, based at Siding Spring Observatory, which will join the ANU SkyMapper telescope in the global follow-up campaign.

The newly automated ANU 2.3-metre telescope can now respond to gravitational wave detections in minutes rather than hours, greatly helping our understanding of these extraordinary events.

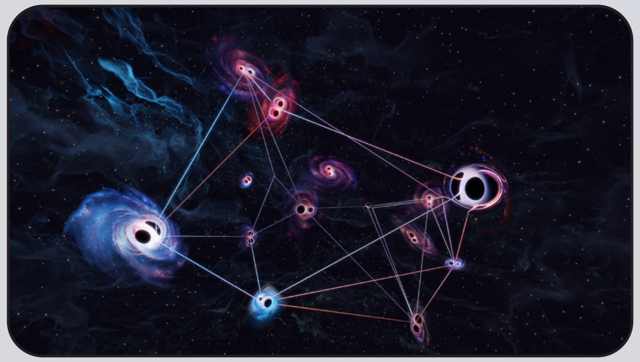
Research School of Physics, ANU. "Anu to Boost the Global Hunt for Gravitational Waves." ANU to boost the global hunt for gravitational waves, May 30, 2023. Click here to read full article.







## Gravitational-wave astronomy with the maximum population likelihood



Convex Hull. Credit: Carl Knox. Check animation here

The LIGO-Virgo-KAGRA Scientific Collaboration has now observed many dozens of collisions of black holes. From these observations, gravitational-wave astronomers have been probing the astrophysical distribution of the properties of these sources; how heavy they are, if they're spinning, and where they are located in the Universe. From these studies, scientists have learnt about structure in the mass distribution of binary black hole mergers, and the increase in the number of collisions as they look further back into the Universe.

However, these observations rely on strongly parameterized models, where scientists rely on simple mathematical expressions for these distributions. By using these "strongly" parameterized models, scientists are susceptible to both missing features in the observed population of sources and confusing more complex features for these simpler effects. This bias is known as "model misspecification" and requires careful consideration to overcome.

To help diagnose model misspecification and explore the space of possible models that fit the observed astrophysical distribution, novel work from researchers at the California Institute of Technology and Monash University have explored the use of the "maximum population likelihood" and its associated population distribution to understand these issues in the current set of observations.

In their recent paper, published in Physical Review Research, OzGrav members Ethan Payne and Eric Thrane demonstrate the utility of this formalism for diagnosing these concerns of model misspecification. Using the current observations of gravitational-wave signals from coalescing binary black holes, they show that the distribution associated with the maximum population likelihood broadly recovers the necessary astrophysical distribution to describe the observed binary black holes, without requiring strong parametric models. Then, they show that while there is no strong evidence for model misspecification at present, future analyses will be able to determine whether current model choices are appropriate.

As gravitational-wave observatories hear the signals from hundreds more binary black hole collisions, these non-parametric approaches to studying the astrophysical population will become invaluable.

Ethan Payne, and Eric Thrane. "Model Exploration in Gravitational-Wave Astronomy with the Maximum Population Likelihood." Physical Review Research 5, no. 2 (2023). https://doi.org/10.1103/physrevresearch.5.023013.

OzGrav says:

**Hey! have you... been keeping up with our socials?**

OzGrav says:

You've probably already heard about the amazing video series created by our very own Dr. Sara Webb, the astrophysics wizard behind the popular TikTok account **@sarawebbscience.** If you haven't checked it out yet, you're missing out on some mind-blowing content!

Sara Webb's reels have taken the internet by storm, captivating audiences far and wide. These videos are a refreshing take on astrophysics, as they feature our brilliant students and postdocs explaining complex concepts in a way that everyone can understand. It's like having your own personal astrophysics tutor, but way more fun!

From mind-boggling black holes to mind-expanding theories about the universe, Sara Webb's video series covers a wide range of topics. Whether you're a space enthusiast or just curious about the wonders of the cosmos, these reels will leave you both educated and entertained.

But the fun doesn't stop there! We've shared these incredible reels across all our social media platforms, including YouTube, Instagram, Facebook, and LinkedIn. So, no matter where you prefer to get your daily dose of cosmic knowledge, we've got you covered.

So, what are you waiting for? Grab your popcorn, sit back, and get ready to embark on a cosmic adventure with Dr. Sara Webb and our talented members. Head over to the TikTok account **@sarawebbscience** and let the astrophysics excitement begin!

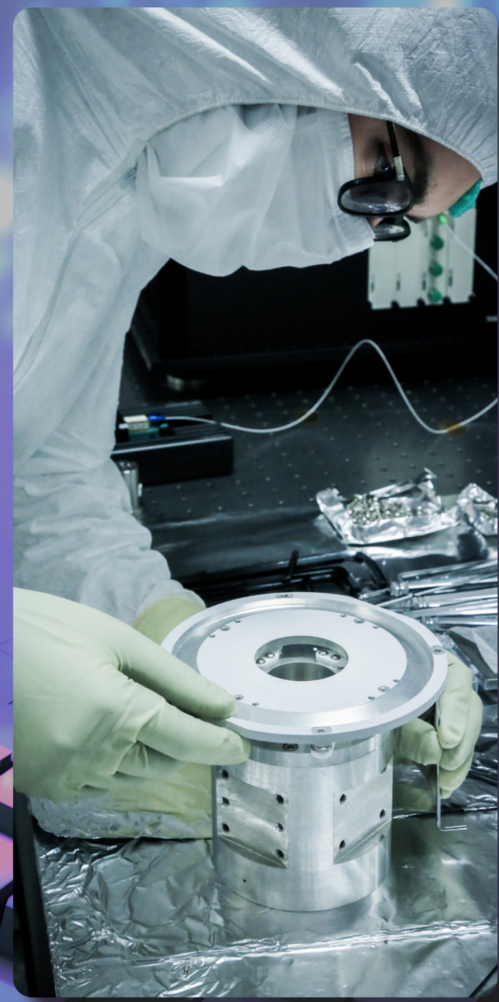
## The Future of Thermal Compensation'

The Adelaide node is preparing for the future of thermal compensation in ground-based gravitational wave detectors with an international workshop in July. A team of international researchers from MIT, Syracuse University, and UC Riverside will converge on the University of Adelaide with our fellow OzGrav researchers to identify solutions for a myriad of thermal compensation problems detrimental to current and planned future detectors like Cosmic Explorer (CE) and the Neutron Extreme Matter Observatory (NEMO). Design concepts for these future detectors require several MW of circulating power, significantly higher than the current generation. Existing and expected thermal problems must be addressed to improve detection prospects before we can be justified in moving ahead with the third generation.

Thermal issues have recently consumed months of commissioning time in preparation for O4, which is a great impetus for the development of OzGrav's very own Thermal Compensation System (TCS) testing facility, to be hosted at the University of Adelaide.

Anticipated for delivery in 2024, the TCS test facility is a 1.2 m x 6 m vacuum chamber to be installed in our existing labs, complete with our very own test mass. The test facility will permit the verification of thermal models and the testing of state-of-the-art thermal actuators and sensors before installation in the detectors. Delivering fully functional and thoroughly tested technologies to the detectors is no easy feat - something we are familiar with in Adelaide with the recent delivery of our Thermal Suspended Active Matching Stage (TSAMS) to the LIGO detectors!

Written by Zachary Holmes, OzGrav- University of Adelaide



TSAMS Assembly at the University of Adelaide. Photo credit: Huy Tuong Cao

Background picture by Carl Knox, Swinburne University-OzGrav.

# 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:** Ariadna Hernandez, ahernandez@swin.edu.au
**Image credit:** as stated on each page.
Front cover by Carl Knox, OzGrav-Swinburne University