SPACE TIMES

OzGrav

July 2020

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Welcome

Welcome to the July edition of *Space Times*.

Dear Friends,

For those of us in Melbourne, July has been a difficult month because going back into lockdown feels like a step backwards after Australia's initial excellent handling of the pandemic. Wherever you are, I'd encourage you to take advantage of your virtual networks to engage in regular professional and social activities, not demand too much of yourselves, and not be afraid to take some time off. Oh and get some exercise!

This month the Centre was scheduled to have its mid-term review, and it's very reassuring to see so many of the OzGrav scientists and admin staff producing excellent work as featured in this newsletter. I'm also delighted that gravitational waves are now a bona fide part of Australia's astronomical research as featured in the Decadal plan's mid-term review.

The discovery of gravitational waves was listed as the highlight of the last five years; the review also encourages the government to think about the research and development necessary for the construction of a high-frequency gravitational-wave detector to explore the interiors of neutron stars.

This is an excellent outcome for the field and a testament to the degree of cohesion and collaboration of OzGrav's team.

Stay safe!

Regards,
Matthew Bailes - OzGrav Director

News in brief

- On 8th July the Mid-Term Review of the Australian Astronomy Decadal Plan was launched, which included strong endorsement for the field of gravitational wave astronomy, as well as exploration of future Australian-based detector. On the same day, OzGrav's paper outlining a Neutron Extreme Matter Observatory (NEMO) went public, garnering great publicity in the media. Well done to all who contributed to the NEMO paper!
- The ARC officially accepted our 2019 annual report, providing very positive feedback about the achievements of our centre. Many thanks to all who contributed, and to Lisa and Carl for putting the report together.
- Congratulations to our Research Translation Chair Jong Chow (ANU) and his research and industry collaborators on being awarded a $2.8M CRC-P grant to develop, design and manufacture the next-generation of optical gyroscopes for high-precision autonomous navigation. Read more about this exciting project on page 10.
- Congratulations to Nutsinee Kijbunchoo who won the Jury's Choice Award of the Wiki Science Competition with her image of Baffled LIGO Scientists.

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

What happens before a star dies? New research on 'pre-supernova' neutrinos

A recent study on 'pre-supernova' neutrinos—tiny cosmic particles that are extremely hard to detect—has brought scientists one step closer to understanding what happens to stars before they explode and die. The study, co-authored by postdoctoral researcher Ryosuke Hirai, from the ARC Centre of Excellence for Gravitational Wave Discovery (OzGrav) at Monash University, investigated stellar evolution models to test uncertain predictions.

Exploded star blooms like a cosmic flower. Source: NASA/CXC/U.Texas

When a star dies, a huge number of neutrinos are emitted which are thought to drive the resulting supernova explosion. The neutrinos flow freely through and out of the star before the explosion reaches the surface of the star. Scientists can then detect neutrinos before the supernova occurs, in fact, a few dozen neutrinos were detected from a supernova that exploded in 1987, several hours before the explosion was seen in light.

The next generation of neutrino detectors are expected to detect about 50,000 neutrinos from a similar kind of supernova. The technology has become so powerful that scientists predict they will detect the weak neutrino signals that come out days before the explosion; just like a supernova forecast, it will give astronomers a heads up to catch the first light of a supernova. It's also one of the only ways to directly extract information from a star's core—similar to an X-ray image of your body, except it's for stars. But an X-ray image is meaningless unless you know what you're looking at.

'...just like a supernova forecast, it will give astronomers a heads up to catch the first light of a supernova.'

Although there is a general understanding of how a massive star evolves and explodes, scientists are still uncertain about the lead up to the supernova explosion. Many physicists have attempted to model these final phases, but the outcomes appear random no can confirm if they're correct. Since pre-supernova neutrino detections allow scientists to better assess these models. a team of OzGrav scientists investigated the late stages of stellar evolution models and how that might affect pre-supernova neutrino estimates.

OzGrav researcher and co-author Ryosuke Hirai says: 'This will help us make the most of the information from future pre-supernova neutrino detections'. In this first study, we explored the uncertainty on a single star that is 15 times the mass of the Sun. The neutrino emission calculated from these stellar models differed greatly in the neutrino luminosity. This means that pre-supernova neutrino estimates are very sensitive to these small details of the stellar model.'

The study revealed the significant uncertainty of pre-supernova neutrino predictions, as well as the relationship between the neutrino features and the star's properties.

'The next supernova in our galaxy can happen any day, and scientists are looking forward to detecting pre-supernova neutrinos, but we still don't know what we can learn from it. This study lays out the first steps of how to interpret the data. Eventually, we'll be able to use pre-supernova neutrinos to understand crucial parts of massive star evolution and the supernova explosion mechanism.'

As featured on Phys.org.

Background image from Pixabay

Scientists find mysterious astrophysical object in black hole collision

The LIGO and Virgo observatories recently announced the detection of gravitational waves caused by the collision of a black hole, weighing up to 25 times the mass of the Sun, accompanied by a mysterious astrophysical object—around 2.5 times the mass of the Sun. Researchers predict the object is likely to be either a dense star, or another black hole; however, its mass contradicts this theory: it's heavier than expected for a neutron star and lighter than a black hole.

Understanding what caused the gravitational waves is a classic 'big data' challenge for scientists. Rory Smith, an astronomer from the ARC Centre of Excellence for Gravitational Wave Discovery (OzGrav) at Monash University, who contributed to the study explains: "Figuring out the origin of these gravitational waves required using thousands of computers for several months to churn through all the data. Gravitational-wave astronomy is at the bleeding edge of supercomputing, and Australia is a world leader in our field."

But this discovery is much more unusual and exciting than scientists had ever expected. The cosmic event called GW190814, observed on 14 August 2019, was accompanied by a mysterious astrophysical object—around 2.5 times the mass of the Sun. Researchers predict it's likely to be either a dense star, known as a neutron star, or another black hole; however, its mass contradicts this theory—it is heavier than expected for a neutron star and lighter than a black hole.

Black holes and neutron stars are two of the most extreme objects ever observed in the Universe—they are born from exploding massive stars at the end of their lives. Typical neutron stars have a mass of one and a half times the mass of the Sun, but all of that mass is contained in an extremely dense star, about the size of a city. Imagine scooping up a whole mountain from the Earth—it would equate to a mere teaspoon of the total mass of a neutron star.

Black holes are even more extreme objects than neutron stars: they have a lot of mass, normally at least 3 times the mass of our Sun, in a tiny amount of space. Their gravitational pull is so strong that not even light can escape if it passes too close to a black hole. Calculations reveal the black hole collision happened between 700 million and one billion years ago, but it has taken that long for the gravitational waves to travel to the Earth.

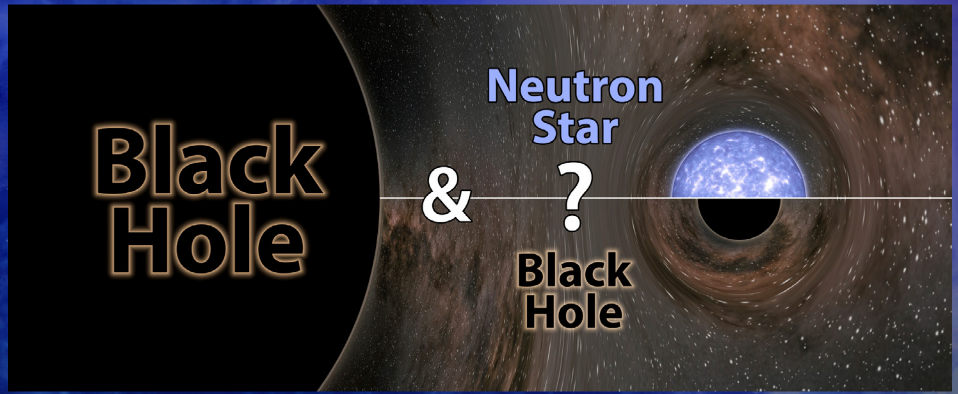


Image by Robert Hurt

"We may have discovered either the heaviest neutron star or the lightest black hole ever observed. If it really is a heavy neutron star, then this will radically alter our understanding of nuclear matter in the densest, most extreme environments in the Universe," says Smith.

The GW190814 event poses some interesting questions as to how the strange object formed. The evolution of a binary system—two orbiting stars that are gravitationally bound to each other—describes the history of its formation and life. Gravitational-wave observations of pair mergers provide a window into the past lives of the binary companions.

Binary systems may live in isolation—far away from neighbouring stars. Or they may live within dense communities of stars which influence and interact with each other over their lives; however, as Chattopadhyay explains: "The difference in masses between the companions makes it less probable that the system formed in isolation".

So, it seems likely that GW190814 formed in a different way. One theory is that it was formed inside a star cluster, where there is a higher density of stars living together in the same neighbourhood. It's possible that each object was the result of a chain of collisions between many stars and black holes.

This theory could explain the uneven masses in GW190814: "In these dense environments, like star clusters, stars interact with each other more often. They form and break star pairs throughout their lives. This can create mergers between objects with very different masses," says Chattopadhyay.

Alternatively, one of the companions of GW190814 could have been in several collisions with other objects in the star cluster, before this observation.

Scientists hope to soon unravel the mystery with more gravitational-wave observations in the future.

Also featured on SBS, CNet and ARC News

Mysterious spinning neutron star turns out to be a rare discovery

On March 12th 2020 a space telescope called Swift, detected a burst of radiation from halfway across the Milky Way. Within a week, the newly discovered X-ray source, named Swift J1818.0–1607, was found to be a magnetar: a rare type of slowly rotating neutron star with one of the most powerful magnetic fields in the Universe.

Spinning once every 1.4 seconds, it's the fastest spinning magnetar known, and possibly one of the youngest neutron stars in the Milky Way. It also emits radio pulses like those seen from pulsars--another type of rotating neutron star in our galaxy. At the time of this detection, only four other radio-pulse-emitting magnetars were known, making Swift J1818.0–1607 an extremely rare discovery.

In a recently published study led by a team of OzGrav scientists, it was found that the pulses from the magnetar become significantly fainter when going from low to high radio frequencies: it has a 'steep' radio spectrum. Its radio emission is not only steeper than the four other radio magnetars, but also steeper than ~90% of all pulsars! Additionally, they found the magnetar had become over ten times brighter in only two weeks.

After further analysis, the OzGrav team found interesting similarities to a highly energetic radio pulsar called PSR J1119–6127. This pulsar underwent a magnetar-like outburst back in 2016, where it too experienced a rapid increase in brightness and developed a steep radio spectrum. If the outburst of this pulsar and Swift J1818.0–1607 share the same power source, then slowly over time, the magnetar's spectrum should begin to look like other observed radio magnetars.

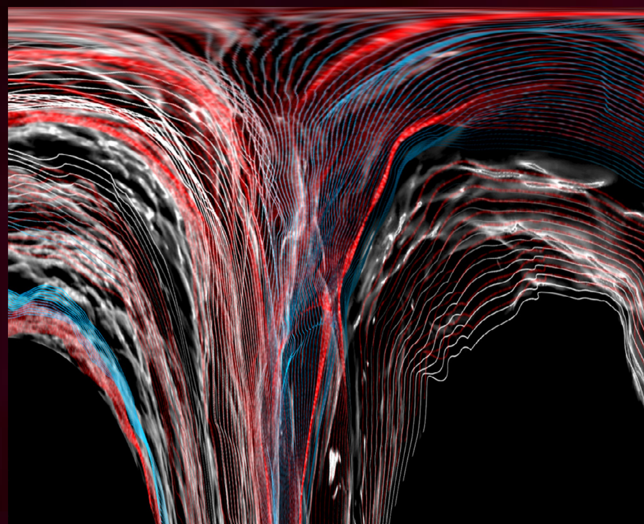
The age of the young magnetar (between 240-320 years), was measured from both its rotation period and how quickly it slows down over time; however, this is unlikely to be accurate. The spin-down rates of magnetars are highly variable on year-long timescales, particularly after outbursts, and can lead to incorrect age estimates. This is also backed up by the lack of any supernova remnant—remnants of luminous stellar explosions—at the magnetars position.

Lead author of the study Marcus Lower proposed a theory to explain of the magnetar's mysterious properties: 'Swift J1818.0–1607 may have started out life as a more ordinary radio pulsar that obtained the rotational properties of a magnetar over time. This can happen if the magnetic and rotational poles of a neutron star rapidly become aligned, or if supernova material fell back onto the neutron star and buried its magnetic field'.
The buried magnetic field would then slowly emerge back to the surface over thousands of years. Continued observations of Swift J1818.0–1607, over many months to years, are needed to test these theories.
As featured in Phys.org

Background image by Carl Knox, OzGrav

Scientists reveal a lost eight billion light years of **Universe evolution**

Every year, two million black hole mergers are missed. OzGrav scientists work out how to detect them, revealing a lost eight billion light years of Universe evolution.



Artist impression of gravitational waves- Carl Knox, OzGrav

Last year, the Advanced LIGO-VIRGO gravitational-wave detector network recorded data from 35 merging black holes and neutron stars. A great result – but what did they miss? According to Dr Rory Smith from the ARC Centre of Excellence in Gravitational Wave Discovery at Monash University, it's likely there are another two million gravitational wave events from merging black holes, "a pair of merging black holes every 200 seconds and a pair of merging neutron stars every 15 seconds" that scientists are not picking up.

Dr Smith and his colleagues, also at Monash University, have developed a method to detect the presence of these weak or "background" events that to date have gone unnoticed, without having to detect each one individually.

The method – which is currently being test driven by the LIGO community – "means that we may be able to look more than 8 billion light years further than we are currently observing," Dr Smith said.

"This will give us a snapshot of what the early universe looked like while providing insights into the evolution of the universe." The paper, recently published in the Royal Astronomical Society journal, details how researchers will measure the properties of a background of gravitational waves from the millions of unresolved black hole mergers.

Binary black hole mergers release huge amounts of energy in the form of gravitational waves and are now routinely being detected by the Advanced LIGO-Virgo detector network. According to co-author, Eric Thrane from OzGrav-Monash, these gravitational waves generated by individual binary mergers "carry information about spacetime and nuclear matter in the most extreme environments in the Universe. Individual observations of gravitational waves trace the evolution of stars, star clusters, and galaxies," he said.

"By piecing together information from many merger events, we can begin to understand the environments in which stars live and evolve, and what causes their eventual fate as black holes. The further away we see the gravitational waves from these mergers, the younger the Universe was when they formed. We can trace the evolution of stars and galaxies throughout cosmic time, back to when the Universe was a fraction of its current age."

The researchers measure population properties of binary black hole mergers, such as the distribution of black hole masses. The vast majority of compact binary mergers produce gravitational waves that are too weak to yield unambiguous detections – so vast amounts of information is currently missed by our observatories.

"Moreover, inferences made about the black hole population may be susceptible to a 'selection bias' due to the fact that we only see a handful of the loudest, most nearby systems. Selection bias means we might only be getting a snapshot of black holes, rather than the full picture," Dr Smith warned.

The analysis developed by Smith and Thrane is being tested using real world observations from the LIGO-VIRGO detectors with the program expected to be fully operational within a few years, according to Dr Smith.

As featured on Phys.org, Nano Werk, Media Net and Interesting Engineering.

Awards and prizes

- The RSV Medal for Excellence in Scientific Research - close 31 July
- The AIP Women in Physics Lecturer - close 1 August
- The Edgeworth David Medal - close 30 September

Virtual events

- OzGrav online lectures continue with new talks every fortnight. Keep updated on our social media channels and watch live on our YouTube channel.
- National Science Week - 15-23 August. OzGrav will be hosting several Immersive Science in VR (SciVR) events
- Online GROWTH astronomy school - 17-21 August
- The ASA has a centralised listing of Australian astronomy presentations and seminars.

OzGrav Alumni: **Craig Ingram**

I was very lucky to start my life in research with OzGrav. I went back to study as a mature age student (insert groans from all teaching staff here) with plans of teaching but when an opportunity to undertake post-grad studies with OzGrav arose, I grabbed at the chance and never looked back. It is with a heavy heart that I am now leaving the cult otherwise known as OzGrav. It has been a great experience to work in such a group surrounded with experience, enthusiasm, and an amazing willingness to share.

My new role is as an optical satellite engineer in a joint venture between the University of Adelaide (UofA) and CSIRO developing hyperspectral imaging CubeSats.

We are first looking at using hyperspectral imaging to characterise various water properties for coastal and inland water ecosystems. This is important as these waterways are vital for human consumption, irrigation, sanitation etc., and are under increased stress from various direct human impact as well as climate change. UofA and CSIRO are hoping to develop a presence in the monitor of these waterways to support national and international directives, as well as build a stronger position in the space research sector.

The basis of the hyperspectral imager.

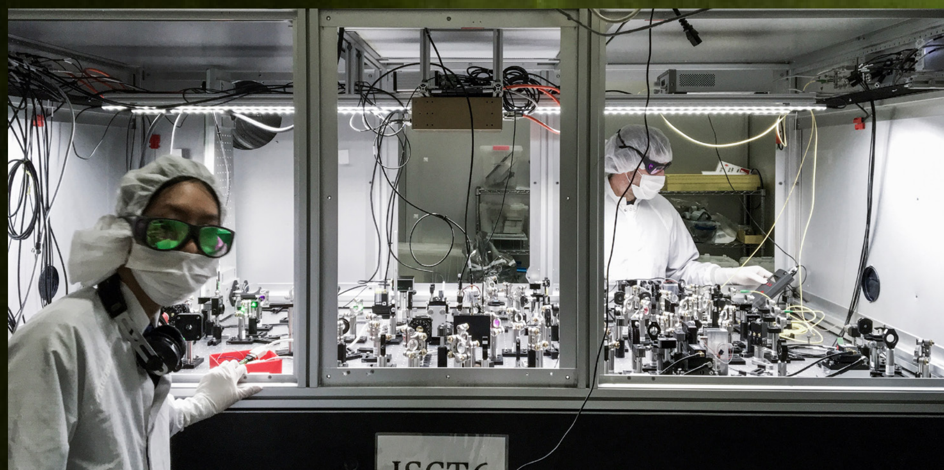
So, I have gone from helping develop a detector down here on Earth to look out into space, only to develop a space-based detector looking back down on Earth. I quit a job as a photographer only to end up again taking photos again. Strange how these things work.

I want to thank everyone in OzGrav. There aren't many groups that are as all round tight and friendly. Thanks to Matty B for steering this crazy ship – how many Directors of such a massive project would take the time to go for a ride with some punter student? A big shout out to all the HQ team: it has been fun and thanks for all your support of our stupid ideas such as AMIGO. Cheers to all the people that I met at retreats, conferences and telecons. Everyone has always been kind and fun. And finally, thanks go out to the Adelaide crew. You are all amazing and helped me through the last few years like a boss. Cannot wait to see what the future holds for all of you. Great things for sure.

Background image by James Josephides, Swinburne University of Tech.

Gravitational-wave scientists smash quantum noise limits

A global team of scientists, including researchers from the ARC Centre of Excellence for Gravitational Wave Discovery (OzGrav) have made a surprising discovery: working out how to break quantum limits. The quantum limit comes from the interaction between light and a test mass, and breaking this limit, just like breaking the sound barrier, once seemed impossible.



ANU PhD student Nutsinee Kijbunchoo (left) and postdoc Terry McRae (right) building one of the squeezer tables at LIGO Hanford. Credit: Nutsinee Kijbunchoo, ANU

The results, published in the prestigious journal *Nature*, show the standard quantum limit has been breached using squeezed light technology pioneered at the Australian National University (ANU) and refined at Massachusetts Institute of Technology (MIT) on the 40kg test masses in the LIGO gravitational-wave detectors.

These gravitational-wave detectors are the most precise measurement devices ever built, and this result shows that they are now poised to see the effects of quantum physics, which governs the smallest objects in the universe, on human sized objects. ANU PhD student Nutsinee Kijbunchoo and postdoctoral fellow Dr Terry McRae spent more than a year at the LIGO sites building and commissioning the squeezed light system that lead to this quantum physics breakthrough.

Dr Carl Blair, from the University of Western Australia (UWA) who was part of the team, said discovering how to break quantum limits was significant for physics and science.

"It's amazing to think that sitting in the control room at LIGO, manipulating some controls on a computer you can manipulate the quantum noise of a 40 kg mirror," he said. "We were able to break the limit doing something very mysterious: squeezing the quantum vacuum."

"This result definitively shows that Quantum mechanics applies to the large scale world of multi kilogram objects and not just to atoms molecules and small microgram scale objects. This ability to make more precise measurements of natural phenomenon has historically been one of the driving forces for technological innovation," said Dr Terry McRae, an OzGrav researcher at ANU.

This leaves many open questions. For example, "will we see quantum quirkiness in the human scale world some time soon? Like tunnelling through impossible barriers or entanglement where two objects separated by vast distances act like one object?" said Dr Carl Blair, physicist from UWA.

Furthermore the use of these techniques have extended the detectors' range by 15 percent and when observing, LIGO and Virgo now see events almost every week. Combined with an increase in the main laser power that carries the gravitational wave signal, that is separate from the squeezed light source, the LIGO detectors can measure a gravitational-wave signal, generated by a source such as a binary neutron star inspiral, from about 400 million light years away.

Also featured in Cosmos

Cartoon by Nutsinee Kijbunchoo (ANU)

Faces of OzGrav:
Nutsinee Kijbunchoo

After spending 2.5 years as an operator at LIGO Hanford I thought it was about time to move on. Well, my visa extension was expiring but that wasn't a surprise. I planned for grad school from the very beginning (and I couldn't be more thankful to the higher-ups at the site who hired me knowing that I'd be gone in a couple years). I never planned to move to Australia though. I had to drop off my two cats halfway in Bangkok with my parents before I continued my trip to Canberra. I was playing it by ear. This was June 2017.

After having spent less than half a year at ANU I heard of the LIGO commissioning break and saw the opportunity to be involved in something fun. I asked (almost begged) my advisor David McClelland to send me back. He kindly did, a couple of times, to install and commission the ANU designed squeezer (as David would emphasis, it's true though). The very first time I was sent back I barely knew what squeezing was. I spent about a month reviving the 2um squeezing experiment to its old glorious self and then I was off to Hanford alongside with a postdoc Terry McRae.

After having to follow someone else's schedule for most of my PhD I thought I couldn't be happier to be back at ANU lab where I have control over my own. Unfortunately, the Covid-19 lockdown and now after-hour lab access restriction means I couldn't get things done whenever I want (I'm naturally a night owl). But looking on the bright side it is easier to set aside time to enjoy my hobbies such as drawing comics, taking photos, and making videos (which I haven't done recently). I take commissions and participate in small contests for small coffee money when I can!

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Background image by Pixabay

Next-gen navigation technology in a new $8.7 million project

Australian researchers and industry partners are joining forces to develop, design and manufacture the next-generation of optical gyroscopes for high-precision autonomous navigation in a new $8.7 million project.

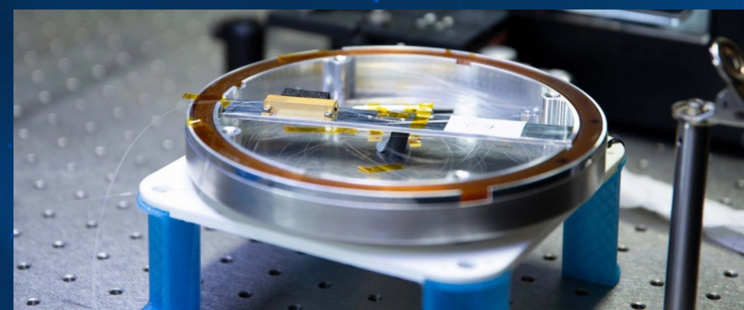

Image provided - ANU

The rapid and transformative development of autonomous vehicles in recent years has seen numerous technological breakthroughs. The deployment of ultra high-performance gyroscopes can enhance their performance in terms of safety and guidance.

The use of ultra high-performance gyroscopes can already be found in a wide range of industries including infrastructure management, mining, space sciences, agriculture, and defence. The new project is led by navigation systems manufacturer Advanced Navigation, with research partners The Australian National University (ANU), RMIT University, and commercial partner Corridor Insights. It will develop a new standard for optical gyroscopes, improving precision while reducing cost and size.

OzGrav Associate Investigator Jong Chow from ANU stated that the collaboration is a chance to bring together expertise from around the country: "We have such a broad range of photonics expertise in Australia. This project brings it together, creating a nexus between universities, research and education, industry and government."

The project has been supported through a $2.8 million Cooperative Research Centre Projects (CRC-P) grant to Advanced Navigation. Chris Shaw, CEO of Advanced Navigation, said the project would translate ground-breaking foundational research at universities to commercialisation, demonstrating Australia's capability across the advanced manufacturing pipeline. "This project will establish Australia as a leading manufacturer of high-performance, cost-effective navigation solutions," Mr Shaw said.

At the core of this endeavour is technology developed at the ANU Centre for Gravitational Astrophysics, OzGrav and Department of Quantum Science. The technique, 'digital interferometry', combines advanced signal processing with precision optics to create ultra-high-resolution measurements using light.

ANU researcher Chathura Bandutunga said: "We use digital signal processing to encode the lightwaves we use for our measurement. This encoding allows us to enhance the sensitivity of our instruments to rotation."

While initially developed for measuring gravitational waves in spaceborne gravitational-wave detectors, the ANU team has adapted the technology to find a second home in optical gyroscopes.

In parallel, researchers at RMIT's Integrated Photonics and Applications Centre (InPAC) are undertaking leading research in creating photonic chips - miniaturised optical components, enabling large experiments to be put into a much smaller package.

"The clever signal processing developed at ANU allows us to tell apart tiny signals from noise, and our photonic chip technology enables all that functionality to fit on a chip the size of a fingernail," Distinguished Professor Arnan Mitchell from RMIT said.

"By compressing the light detection technology onto a photonic chip we can shrink ultra high-performance gyroscopes from the size of a bread box to the size of a coffee cup."

Taking these research ideas through to the field, commercial partner Corridor Insights will pilot the next-generation of optical gyroscope in autonomous infrastructure management, looking for early detection of defects and faults in Australia's rail network.

Also featured on Space Connect.

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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Background image by James Josephides, Swinburne University