SPACE TIMES

OzGrav

August 2020

Welcome

Dear colleagues,

Welcome to another edition of *Space Times* and once again I find myself composing this missive from my home in Melbourne under lockdown (Stage 4). It's been a tough last few weeks in Victoria in what has been a challenging year.

Despite this, I was very pleased to see that, once again, OzGrav research has featured on the cover of the Australian Research Council's annual magazine and that many of us remain scientifically productive during lockdown.

Just this morning I was putting the finishing touches on three papers and it occurred to me that no two of us find the lockdown and its challenges the same.

I wanted to spare a thought for those of you in Victoria with small children, who suddenly find themselves not only parents after hours but teachers during school hours, and for those of you separated from loved ones no matter where you are.

It's been great to see strong turnouts at the weekly OzGrav telecons, and even if you find zooms not to your taste, I'd encourage you to take the time to keep in contact with your supervisors, colleagues and friends if you can't meet up face to face.

It's become obvious that the OzGrav retreat will have to be virtual this year. The Executive Committee will be considering the format, family-friendliness and effectiveness of the program at its next meeting in early September.

Stay tuned and take care.

Regards,
Matthew Bailes - OzGrav Director

News in brief

- We're thrilled to make the cover of the ARC's annual *Making a Difference* magazine! The stunning artwork by Carl Knox describes Paul Lasky and Greg Ashton's investigation into the Vela pulsar glitch. Read the story on page 12
- Congratulations to the following OzGravvers on receiving awards and commendations in the 2020 Research Awards in the Faculty of Science Engineering and Technology (FSET) at Swinburne Uni:
  Postgraduate Student of the Year – Winner: Sara Webb; Commendations: Debatri Chattopadhyay
  Early Career Researcher Award – Winner: Simon Stevenson
  Higher Degree by Research Outstanding Article – Winner: Debatri Chattopadhyay
- OzGrav EPO Coordinator Jackie Bondell and our VR outreach/educational programs have been selected as a finalist for the Falling Walls Breakthrough of the Year in the category 'Science Engagement Initiatives'

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

Global GRANDMA collaboration connects telescopes worldwide

The results of a long-term observation campaign to detect the collision of compact objects in the Universe has been announced by a global collaboration, GRANDMA, including The University of Western Australia (UWA). The GRANDMA collaboration is a multi-national network of 25 robotic telescopes from 12 countries with the electromagnetic capability to follow up gravitational waves.

Hubble Telescope. Source: Pixabay

GRANDMA allowed researchers to perform a targeted search for the sources of gravitational waves detected by the world's largest gravitational-wave observatory, the Laser Interferometric Observatory (LIGO).

The search revealed that all of the sources targeted are most likely optically 'dark', suggesting most cosmic collisions between black holes remain hidden to conventional telescopes.

UWA and the University of Paris coordinated an approach to control multiple facilities and observatories around the world which allowed for the continuous scanning of the sky, and published the results in Monthly Notices of the Royal Astronomical Society.

The ability to detect sources of gravitational waves is relatively new and while several have now been detected, only one has been observed through an optical telescope.

The elusiveness of these objects is due to the uncertainty of their exact location which can have a difference of thousands of square degrees in space, similar to searching for a boat somewhere in the middle of the ocean.

OzGrav researcher Bruce Gendre from UWA said the initiative highlighted the importance of having a network of dedicated telescopes that could contribute to global knowledge.

"Australia, like several other countries, is focused on studying the sources of gravitational waves, however most communities are working solo," Gendre said. "The problem is that everyone is currently trying to find a needle in the same, incredibly large, haystack. GRANDMA is the first collaboration to split the haystack into small piles and focus resources on time-domain astronomy."

The researchers also established the program Amateur Kilonova Catcher that allowed anyone with a telescope to report their observations.

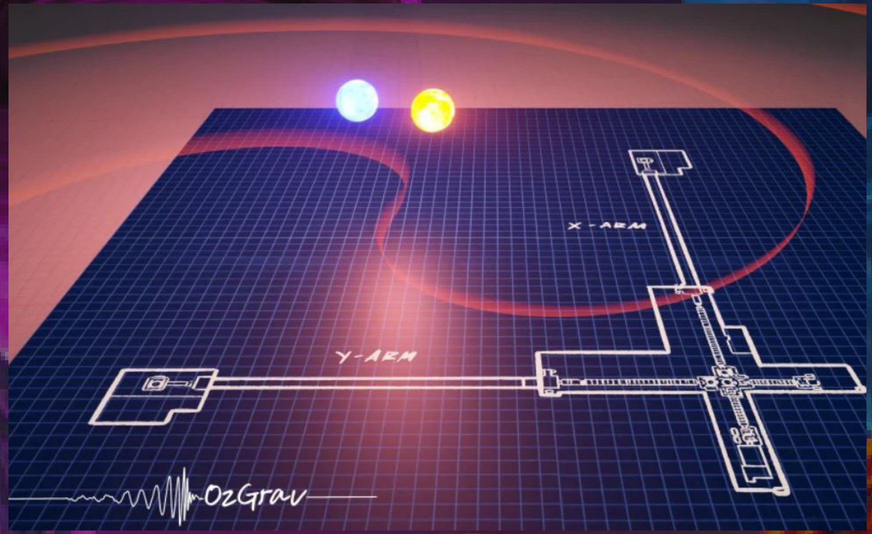
The next round of observations will commence in 2021.

As featured on Space Connect

Background image by James Josephides

Finding NEMO: The future of gravitational-wave astronomy

A new study makes a compelling case for the development of "NEMO"—a new observatory in Australia that could deliver on some of the most exciting gravitational-wave science next-generation detectors have to offer, but at a fraction of the cost.



Blueprint of a GW detector - Carl Knox, OzGrav

The study, co-authored by the ARC Center of Excellence for Gravitational Wave Discovery (OzGrav), coincides with an Astronomy Decadal Plan mid-term review by Australian Academy of Sciences where "NEMO" is identified as a priority goal.

"Gravitational-wave astronomy is reshaping our understanding of the Universe," said one of the study's lead authors OzGrav Chief Investigator Paul Lasky, from Monash University.

"Neutron stars are an end state of stellar evolution," he said. "They consist of the densest observable matter in the Universe, and are believed to consist of a superfluid, superconducting core of matter at supranuclear densities. Such conditions are impossible to produce in the laboratory, and theoretical modeling of the matter requires extrapolation by many orders of magnitude beyond the point where nuclear physics is well understood."

The study presents the design concept and science case for a Neutron Star Extreme Matter Observatory (NEMO): a gravitational-wave interferometer optimized to study nuclear physics with merging neutron stars.

The concept uses high circulating laser power, quantum squeezing and a detector topology specially designed to achieve the high frequency sensitivity necessary to probe nuclear matter using gravitational waves.

The study acknowledges that third-generation observatories require substantial, global financial investment and significant technological development over many years.

According to Monash Ph.D. candidate Francisco Hernandez Vivanco, who also worked on the study, the recent transformational discoveries were only the tip of the iceberg of what the new field of gravitational-wave astronomy could potentially achieve.

"To reach its full potential, new detectors with greater sensitivity are required," Francisco said. "The global community of gravitational-wave scientists is currently designing the so called 'third-generation gravitational-wave detectors (we are currently in the second generation of detectors; the first generation were the prototypes that got us where we are today)."

Third-generation detectors will increase the sensitivity achieved by a factor of 10, detecting every black hole merger throughout the Universe, and most of the neutron star collisions.

But they have a hefty price tag. At about $1B, they require truly global investment, and are not anticipated to start detecting ripples of gravity until 2035 at the earliest.

In contrast, NEMO would require a budget only under $100M, a considerably shorter timescale for development, and it would provide a test-bed facility for technology development for third-generation instruments.

The paper concludes that further design studies are required detailing specifics of the instrument, as well as a possible scoping study to find an appropriate location for the observatory, a project known as "Finding NEMO."

As featured in The Age, Phys.org, and Space Australia

Faces of OzGrav: **Manoj Kovalam**

At school, I was taught that cats understand Physics better than most humans do, particularly in adjusting their body postures to gravity. My obsession for both cats and physics started back then.

Like most other kids at that age, I was fascinated by stars and space, always stuck to the National Geographic channel on TV looking for new discoveries and space documentaries. This interest never faded away and it led me to study science for my undergrad, even though it's not a very popular option in India.

During my Master's, my supervisor introduced me to gravitational wave science (a very hot topic at that time) and I worked on analysing detector data, trying to identify gravitational-wave signals. After graduating, I started looking for potential PhD opportunities and found that the data analysis group at the University of Western Australia was the best place to continue my studies. I started off as an intern for 3 months and then became a full-time PhD student in the group.

Prior to this, I always liked working independently, but here I am, part of this huge collaboration that is OzGrav, with people from different streams working together towards a common goal. This is a new and an amazing experience for me. At OzGrav, I've had more than just an academic growth—I've achieved all-round development. The best part about OzGrav is the annual retreats, especially the fun activities involving teamwork.

Science aside, amidst my usual flow of work I also enjoy playing video games, watching anime (hail prince Vegeta!), going out on bike trips with a friend and petting random cats on the street (but getting beat up by them in the end).

I do not have any particular plans for my future yet, but that said, I am very excited to venture into the unknown.

Background image by Carl Knox, OzGrav

Continuous gravitational waves in X-ray star systems: *the search continues...*

Artist's impression of the exotic binary star system AR Scorpii. Credit: M. Garlick/University of Warwick/ESO

Gravitational waves are ripples in space-time that come in many forms. So far, short-duration gravitational-wave signals have been observed from colliding black holes and colliding neutron stars, but scientists expect to find other kinds of gravitational waves.

Recently published research led by OzGrav studied continuous waves: long-lasting gravitational waves, in this particular case, waves from neutron stars – old dead stars in specific star systems called low-mass X-ray binaries. Gravitational-wave detectors LIGO (Laser Interferometer Gravitational-wave Observatory) and Virgo provide excellent data to search for continuous waves as their signals are likely to be present in the detector data all the time (compared to gravitational waves from colliding black holes which last only a second or so).

Neutron stars, which are typically about one and half times the mass of our Sun, are very compact at only 20km across. Some neutron stars are alone, while others are in "binary systems" where the neutron star and a companion star orbit around each other. The OzGrav team focused on looking for continuous waves from spinning neutron stars in "low mass X-ray binaries" (LMXBs). Low mass describes the neutron star's companion which typically has a lower mass than our Sun; they are called X-ray binaries because scientists have observed X-rays from them using X-ray telescopes.

In the study, the team searched for continuous waves from spinning neutron stars by directly targeting five LMXBs, which is a first for these five LMXBs. All the targeted LMXBs have X-ray observations which indicate how fast the neutron star is spinning: its rotation frequency. This is extremely useful information when searching for continuous waves as it's expected that the frequency of the continuous wave is related to the rotation frequency of the neutron star. This allowed the team to search for each LMXB within a specific frequency range.

Lead author and OzGrav researcher from the University of Melbourne Hannah Middleton says: "We used a search method, developed by researchers at the University of Melbourne, which was previously used to search for another LMXB called Scorpius X-1. Scorpius X-1 is a promising continuous wave source because its X-rays are very bright, but the X-ray observations were unable to measure Scorpius X-1's rotation frequency. This means that a wide range of frequencies need to be looked at. By taking advantage of the X-ray measurements of rotation frequency for our five LMXBs, we can reduce the computational cost of the search, sometimes by as much as 99 per cent."

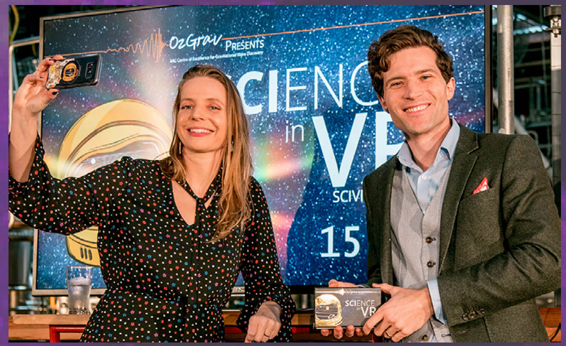
But knowing the rotation frequency is not quite enough: the continuous wave frequency may not equate to the rotation frequency, so the team searched for small frequency ranges around the measured values.

"The continuous wave frequency might even be slowly changing over time, so we need to be able to track it over many months of data," adds Middleton. "The search uses a technique called a hidden Markov model which is widely used in applications from speech recognition to communication technologies. The resulting search can keep track of a signal even if the frequency changes unpredictably during an observation."

So, what did the scientists find? After analysing data from the second observing run (over 200 days between November 2016 to August 2017), unfortunately they did not find strong evidence for continuous wave signals from these five LMXBs. But the search continues! LIGO and Virgo's third observation run (from April 2019 to March 2020) has just completed, so the OzGrav scientists have plenty of data analysis and star searching to sink their teeth into.

As featured on Phys.org

Virtual events



- National Science Week - 15-23 August. OzGrav will be hosting several Immersive Science in VR (SciVR) events across 58 hubs all over Australia. Download the free SciVR app any time and discover the changing Universe
- Adventures Abroad in Science: CBR Women discuss Experiences & Research with OzGrav Chief Investigator Susan Scott on the panel - 15 August at 9AM
- Flash of Discovery public lecture presented by OzGrav postdoc Jielai Zhang - 17 August at 2pm
- Online GROWTH astronomy school - 17-21 August
- The ASA has a centralised listing of Australian astronomy presentations and seminars.
- Tour a scale replica of the LIGO gravitational-wave detector in Minecraft! 22 August 2.30-3.30PM AEST

Get your OzGrav face masks!

Want to stay safe *and* stylish? Grab an exclusive OzGrav mask on our Red Bubble site here! There are four designs to choose from with regular adult, small adult (13 years +) and two children sizes (3-7 and 8-12 years). All masks have two layers of fabric with a sublimated print on the outer layer. The small adult masks feature shorter straps for a more snug fit on smaller faces (select 'small mask' in the 'Type' drop down menu). Once you've clicked one of the aforementioned links to the Red Bubble site (either the adult or kid size link), you can scroll down to the bottom and browse more designs available. Please note: the masks are for general public use only and are not intended for use in medical settings.

Classic blue OzGrav mask - buy here

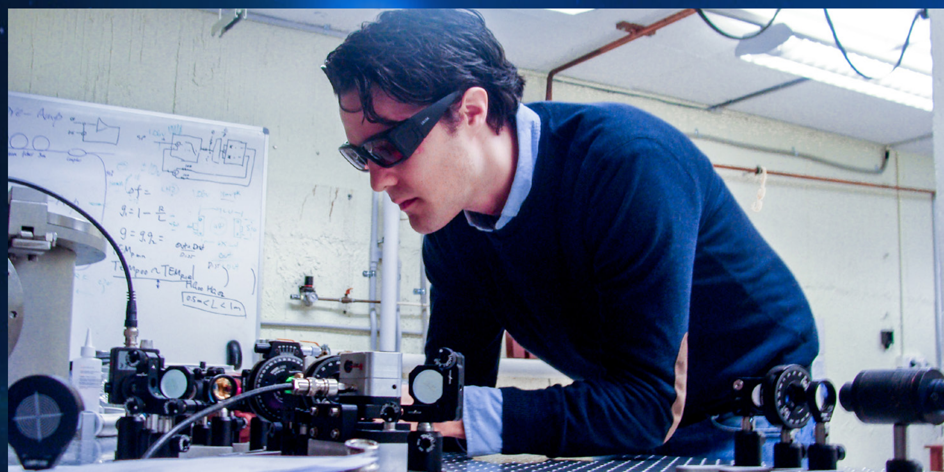
OzGrav OzSTAR mask - buy here

White OzGrav mask - buy here

Background image by James Josephides

Earth-shaking science in the freezer: Next-gen vibration sensors at cryogenic temperatures

A cutting-edge vibration sensor may improve the next generation of gravitational-wave detectors to find the tiniest cosmic waves from the background hum of Earth's motion.



OzGrav postdoc Joris van Heijningen - Credit Mateao van Niekerk

During his PhD, postdoctoral researcher Joris van Heijningen from the ARC Centre of Excellence for Gravitational Wave Discovery (OzGrav), developed the world's most sensitive inertial vibration sensor. Now, he proposes a similar design, but 50 times more sensitive, at frequencies below 10 Hz, using cryogenic temperatures.

This new sensor measures vibrations as small as a few femtometre (a millionth of a billionth of a meter) with a 10 to 100 millisecond period (10 Hz to 100 Hz). The paper recently published in IOP's Journal of Instrumentation reveals a prototype of the next generation of seismic isolation systems with sensitivity down to 1Hz, using cryogenic temperatures—lower than 9.2 degrees and above the absolute zero.

Even though we can't feel it, our planet is always vibrating a tiny bit due to many different events, both cosmic and earthly; for example, from gravitational waves (miniscule ripples in spacetime); ocean waves crashing on the shore; or human activity. According to Dr van Heijningen, some places vibrate more than others and, if you plot these vibrations, they lie between two lines called the Peterson Low and High Noise Models (LNM/HNM).

'The best commercial vibration sensors have been developed to have a sensitivity that lies below the LNM. They are sufficiently sensitive to measure all places on Earth with a decent signal-to-noise-ratio,' says van Heijningen.

To date, the Laser Interferometer Gravitational-Wave Observatory (LIGO), with its four-kilometre long arms, uses seismic isolation systems to prevent earthly vibrations affecting scientific measurements; however, future gravitational wave-detectors demand more advanced and precise vibration sensors.

Scientists are already working on a third generation of detectors that will have the power to detect hundreds of black-hole mergers each year, measuring their masses and spins—even more than LIGO, or its European equivalent, Virgo, can measure.

In the US, there will be the Cosmic Explorer: a 40-kilometre observatory that will be able to detect hundreds of thousands of black-hole mergers each year. Equally as impressive will be the Einstein Telescope in Europe, with its 10-kilometre armed, triangular configuration built underground.

Future detectors will be able to measure gravitational waves at frequencies lower than the current cut-off ~10 Hz, 'because that's where the signals from collisions of black holes are lurking,' van Heijningen explains. But one of the main issues of these huge detectors is that they need to be extremely stable—the smallest vibration can hamper detections.

'Essentially getting the system close to zero degrees Kelvin (which is 270 degrees below zero celsius) drastically reduces the so-called thermal noise, which is dominant at low frequencies. Temperature is a vibration of atoms in some sense, and this minuscule vibration causes noise in our sensors and detectors,' says van Heijningen.

Future detectors will need to cool down to cryogenic temperatures, but it is no easy feat. Once scientists achieve that, exploiting the cryogenic environment will improve sensor performance following this proposal design. At his new position as a research scientist at UCLouvain in Belgium, van Heijningen plans to prototype this sensor design and test its performance for The Einstein Telescope.

As featured on Phys.org

New optomechanical technology to enhance gravitational-wave detectors

Gravitational-wave detectors are extremely complex instruments of precision measurement. They use interference as the physical mechanism to measure passing gravitational waves (GWs)—ripples in space-time—from different astronomical sources and events, like two neutron stars merging. The passing wave signal gets encoded into a wave of light and is read-out after exiting the interferometer. The issue is that the signal is so weak that any movement from the optical components will degrade the signal strength. For example, the random motion of particles that make up the material called 'thermal noise'.

In the design of GW detectors, 'optomechanical' cavities are used to enhance the signal from GW detectors. These cavities, or 'resonators', typically have two, moving-end mirrors which trap and amplify light. There is one problem however: the mirrors can move too much due to thermal noise! If we can minimise the thermal noise of these resonators, it will improve the GW sensitivity.

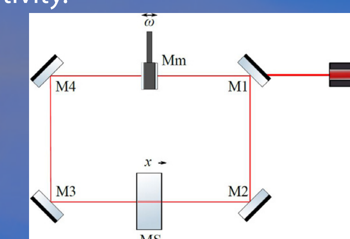


Figure 1

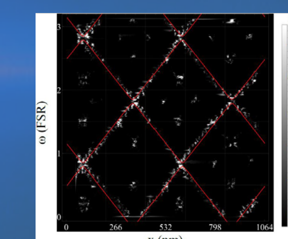


Figure 2

The Double-End-Mirror-Sloshing (DEMS) cavity—shown in Figure 1—is a special type of optomechanical cavity which consists of four mirrors, a transmitting sloshing mirror and a resonator which reflects light from both sides (double-end-mirror). Using the DEMS cavity, the resonator exhibits very low levels of thermal noise through a process called 'optical dilution', which works by trapping the resonator in a potential well using radiation pressure. This keeps the resonator tightly bound, so it's not easily disturbed from the random thermal fluctuations.

In a study led by the OzGrav, researchers explain that, although the optical spring is not unique to the DEMS cavity, the troublesome impact of radiation pressure noise and anti-damping effects are circumvented in the DEMS cavity, but are unavoidable in a two-mirror cavity.

First author and OzGrav research assistant Parris Trahanas explains: 'The key mechanism that allows the DEMS cavity these qualities is the transmissive sloshing mirror component—it turns the DEMS cavity into a coupled optical resonator, which is the optical equivalent of connecting two spring mass systems together with a third spring.'

The resultsin Figure 2 show the avoided crossing of the optical resonances which is characteristic of a coupled oscillator—this will be an extremely useful tool for GW detectors, but could be more broadly applied to any field requiring low thermal noise in mechanical resonators.

Background image by James Josephides

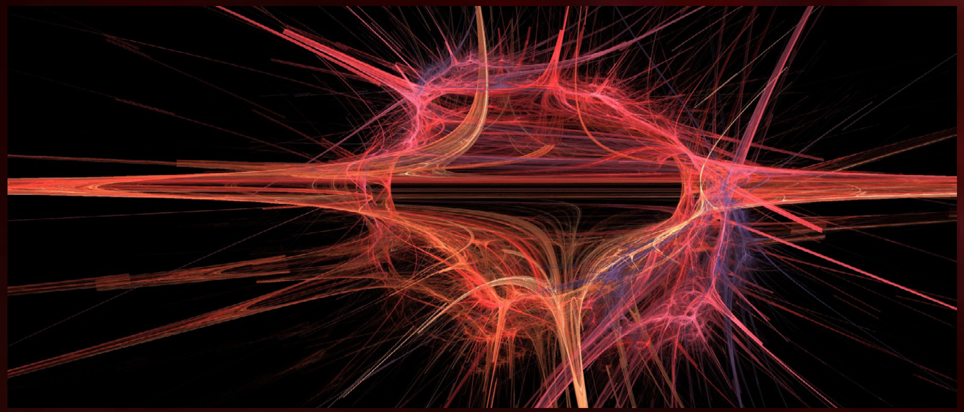
Scientists create a new method to detect never-before-seen cosmic events

The LIGO and Virgo detectors provided the first direct empirical evidence of the existence of gravitational waves—ripples in space time. All their signal detections came from pairs of compact objects, such as black holes or neutron stars, that spiralled in towards each other and merged to form a single remnant object, taking place in galaxies far, far away.

The gravitational-wave signal from one of these mergers oscillates and increases in pitch as the pair of objects spiral closer towards each other, commonly referred to as a "chirping" signal. However, physicists predict that there are many other sources for gravitational waves—not all gravitational waves come from a pair of merging objects or have a "chirp"-like sound.

For example, Einstein's theory of gravity predicts a peculiar type of gravitational-wave signal called "the memory effect", which does not oscillate nor chirp like the observed signals, rather it rises steadily over time and eventually levels off.

Alternatively, some theories of the early Universe predict the existence of cosmic strings: exotic leftover remnants from the very early Universe yet to be observed. These are predicted to emit sharp signals that rise quickly before decaying again just as fast.



Unfortunately, it's incredibly difficult to decipher the data and identify cosmic strings and gravitational-wave memory against the inherent noise from the detectors.

Researchers from the University of Florida and OzGrav, including Paul Lasky and Eric Thrane at Monash University, ventured to solve this problem.

In their recently published paper, they provided a complete framework for analysing gravitational-wave data to identify the various astrophysical signals. They also calculated the chance of each source producing gravitational-wave signals observed in their simulated data.

Gravitational-wave detectors will improve as technology advances, consequently increasing the rate of detections. Scientists predict the exciting possibility of detecting gravitational-wave signals from different sources other than an ordinary binary merger.

To mimic such an astrophysical scenario, the researchers simulated gravitational-wave detections and estimated probabilities of each signal model. This allowed them to accurately classify the astrophysical origin of each simulation, demonstrating that this method could successfully identify real gravitational-wave detections in the future.

Interestingly, they noticed that the cosmic string signal looks very similar to a massive binary black hole merger signal (something that physicists expect to detect very soon).

This put their method to the ultimate test: could they properly identify a simulated merger signal coming from a pair of massive spiralling black holes? The team answered with a resounding 'Yes!'

Lead author Atul Divakarla says: "Our method was able to rule out the cosmic string hypothesis in favour of the massive merger hypothesis. It may be the first approach that discovers a never-before-seen gravitational-wave signal by ruling out astrophysical signals we've already seen".

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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