SPACE TIMES

OzGrav

May 2021

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Welcome

Dear colleagues,

Welcome to another edition of Space Times! OzGrav has now had its fourth birthday and many of us were interviewed as a part of the ARC's mid-term review process. I was really proud to get the positive verbal feedback from the review panel and look forward to their official recommendations.

The Gravitational Waves discipline is very young in terms of detections but has a 100-year history in many respects. With the help of Professor Tamara Davis, OzGrav has been running a series of national workshops and seeking white papers for projects that could form part of a second Centre of Excellence, with gravitational waves as a focus. A steering committee has been formed and we've been meeting every week or so to distil the white papers into a coherent argument for more investment in this exciting area of science. I will be leading the bid as Director, and the expression of interest must be submitted by the end of July.

In the meantime, I hope you enjoy hearing about our current science and meeting some of our personnel.

Regards - Matthew
Director, OzGrav

NEWS IN BRIEF

- Congratulations to OzGrav Associate Investigator Dr Bernhard Müller (Monash), on receiving the 2021 Australasian Leadership Computing Grants from National Computational Infrastructure (NCI) Australia. The grant will fund research on 'High-resolution Core-Collapse Supernova Simulations', with both OzGrav Associate Investigators Dr Jade Powell (Swinburne) and Prof Alexander Heger (Monash) working on the project.

- OzGrav Diversity Day Lunch will be happening on Friday 21st May in celebration of *World Day for Cultural Diversity for Dialgoue and Development*. There will be a Centre-wide video conference and all nodes will be organising their own special lunch. Members are also encouraged to bring along a dish that reflects their cultural background!

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

Deep space listening: 6000 hours of research to hear continuous gravitational waves

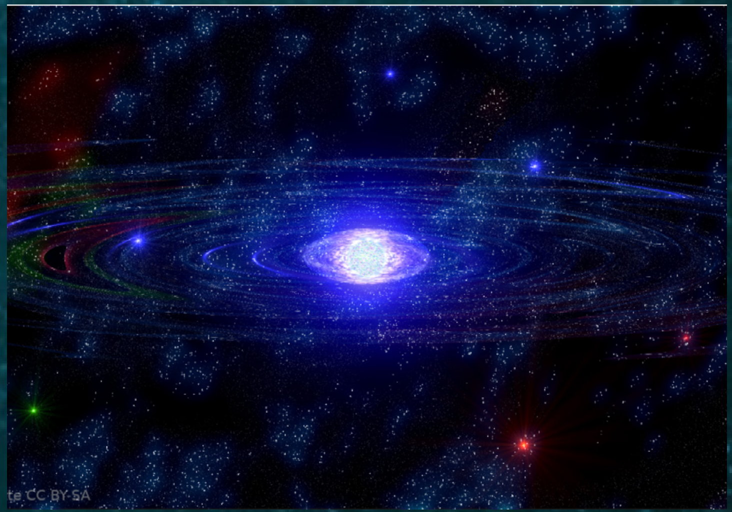
When searching for lost keys, there are a number of possible strategies. You might try moving from room to room, casting your eye over every flat surface, in the hope of spotting the missing keys. Of course, this assumes that they are somewhere in plain sight; if they're hidden under a newspaper or have fallen behind the sofa, you'll never spot them. So which is the best strategy?

Scientists face a similar conundrum in the hunt for gravitational waves—ripples in the fabric of space and time—from rapidly spinning neutron stars. These stars are the densest objects in the Universe and, provided they're not perfectly spherical, emit a very faint "hum" of continuous gravitational waves. Hearing this "hum" would allow scientists to peer deep inside a neutron star and discover its secrets, yielding new insights into the most extreme states of matter. However, our very sensitive "ears"—4-kilometre-sized detectors using powerful lasers—haven't heard anything yet.

Part of the challenge is that, like the missing keys, scientists aren't sure of the best search strategy. Most previous studies have taken the "room-to-room" approach, trying to find continuous gravitational waves in as many different places as possible. But this means you can only spend a limited amount of time listening for the tell-tale "hum" in any one location—in the same way that you can only spend so long staring at your coffee table, trying to discern a key-shaped object. And since the "hum" is very quiet, there's a good chance you won't even hear it.

In a recently published study, a team of scientists, led by postdoctoral researcher Karl Wette from the ARC Centre of Excellence for Gravitational Wave Discovery (OzGrav) at the Australian National U niversity, tried the "where else could they be but the kitchen?" approach.

Wette explains: "We took an educated guess at a specific location where continuous gravitational waves might be, based in part on what we already know about pulsars—they're like neutron stars but send out radio waves instead of continuous gravitational waves.



Rapidly rotating neutron stars may be "humming" continuous gravitational waves. Credit: K. Wette.

We hypothesised that there would be continuous gravitational waves detected near pulsar radio waves." Just like guessing that your missing keys will probably be close to your handbag or wallet.

Using existing observational data, the team spent a lot of time searching in this location (nearly 6000 days of computer time!) listening carefully for that faint "hum". They also used graphic processing units—specialist electronics normally used for computer games—making their algorithms run super-fast.

"Our search was significantly more sensitive than any previous search for this location," says Wette. "Unfortunately, we didn't hear anything, so our guess was wrong this time. It's back to the drawing board for now, but we'll keep listening."

As featured on *Phys.org.*

Background image: Mark Myers, OzGrav-Swinburne

FACES OF OZGRAV

Katie Auchettl

OzGrav Affiliate from the University of Melbourne

If you had told me as a kid that I could work with people from all around the world, using telescopes located in some of the most amazing locations on Earth--and even more amazingly, in space--to understand the most extreme events in the Universe, I'm not sure I would have believed you. In fact, it wasn't until the end of the first six months of my PhD at Monash University that I focused on studying the nature of extreme astrophysical phenomena that we all know and love in OzGrav (originally I focused on indirect detection of dark matter).

With the support of my PhD advisors, this decision to change fields mid-PhD provided me with the unique opportunity to work directly with experts in high-energy astrophysics at the Harvard-Smithsonian Centre for Astrophysics. After graduating from my PhD in 2015, I was a postdoctoral fellow at the Center for Cosmology and Astroparticle Physics (CCAPP), at the Ohio State University, and an Assistant Professor at the Niels Bohr Institute, at the University of Copenhagen (KU). In 2019, I also became an Assistant Adjunct Professor at the University of California, Santa Cruz (UCSC).

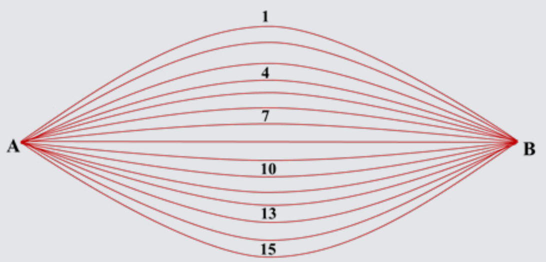
My time at CCAPP, KU and UCSC was incredibly rich and rewarding. With the support and opportunities provided to me during my time at these institutes, I was able to significantly broaden and expand my research. Now, I focus on multi-wavelength and time-domain observations to better understand the physical processes and observational signatures related to the extreme death of stars and their compact objects.

In 2020, I joined the School of Physics at the University of Melbourne as a Senior Lecturer, ASTRO-3D fellow and OzGrav Affiliate. Although my start back in Melbourne was delayed by Covid-19, I have been warmly welcomed by everyone in OzGrav. I'm looking forward to learning from and connecting with Centre members, as well as supporting them with their goals; I want to provide the same supportive and welcoming environment that I experienced during my career at OzGrav (and ASTRO-3D) so far. So, please feel free to reach out at any time, as I would love to hear from you!

RESEARCH HIGHLIGHT

Teaching quantum physics to high school students

There is a growing interest in introducing quantum physics at an early age in schools because of its applications in emerging technologies, such as quantum computers. To make it accessible to school students, our recently published study presents a novel way of exploring basic quantum mechanical phenomena, such as matter-wave interference, diffraction, and reflection.



Possible photon paths

Our graphical approach, based on Feynman path integrals, offers insights into the quantum world in which observations represent quantum probability density.

Close up view of phasor wheel. Image supplied.

We combine tactile tools called phasor-wheels with real-life analogies and videos of single-quanta interference and employ elementary mathematics to teach these concepts.

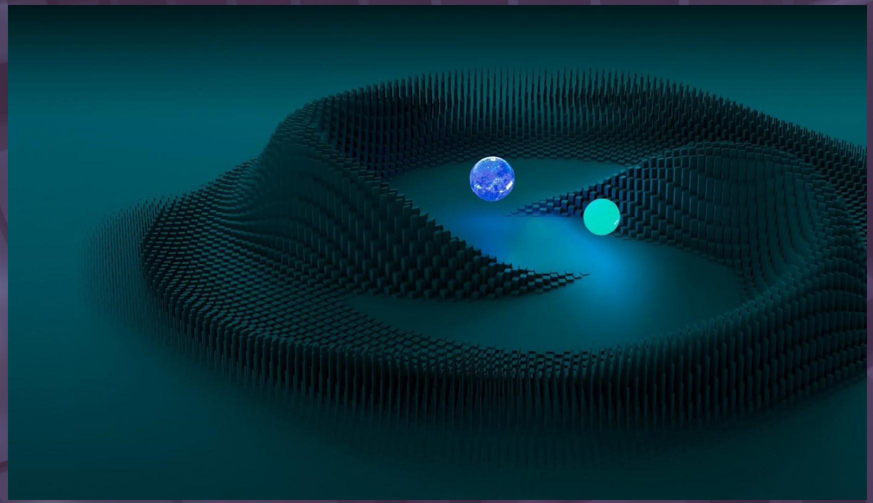
Our approach uses practical, hands-on tools for teaching, making it appealing to students from high school (years 9 and 10) and above. The engaging material encouraged active participation and students found it easy to understand these abstract scientific concepts.

Written by OzGrav PhD student Rahul Choudhardy, University of Western Australia

Background image: Pixabay

Gravitational-wave scientists propose new method to refine the Hubble Constant—the expansion and age of the Universe

A team of international scientists, led by the Galician Institute of High Energy Physics (IGFAE) and the ARC Centre of Excellence for Gravitational Wave Discovery (OzGrav), has proposed a simple and novel method to bring the accuracy of the Hubble constant measurements down to 2%, using a single observation of a pair of merging neutron stars.



Artist's illustration of a pair of merging neutron stars. Credit: Carl Knox, OzGrav-Swinburne University

The Universe is in continuous expansion. Because of this, distant objects such as galaxies move away from us. In fact, the further away they are, the faster they move. Scientists describe this expansion through a famous number known as the Hubble constant, which tells us how fast objects in the Universe recede from us depending on their distance to us. By measuring the Hubble constant in a precise way, we can also determine some of the most fundamental properties of the Universe, including its age.

For decades, scientists have measured Hubble's constant with increasing accuracy, collecting electromagnetic signals emitted throughout the Universe but arriving at a challenging result: the two current best measurements give inconsistent results. Since 2015, scientists have tried to tackle this challenge with the science of gravitational waves: ripples in the fabric of space-time that travel at the speed of light. Gravitational waves are generated in the most violent cosmic events and provide a new channel of information about the Universe. They're emitted during the collision of two neutron stars—the dense cores of collapsed stars–and can help scientists dig deeper into the Hubble constant mystery.

Unlike black holes, merging neutron stars produce both gravitational and electromagnetic waves, such as x-rays, radio waves and visible light. While gravitational waves can measure the distance between the neutron-star merger and Earth, electromagnetic waves can measure how fast its whole galaxy is moving away from Earth. This creates a new way to measure the Hubble constant. However, even with the help of gravitational waves, it's still tricky to measure the distance to neutron-star mergers--that's, in part, why current gravitational-wave based measurements of the Hubble constant have an uncertainty of ~16%, much larger than existing measurements using other traditional techniques.

In a recently published article in the prestigious journal The Astrophysical Journal Letters, a team of scientists led by ARC Centre of Excellence for Gravitational Wave Discovery (OzGrav) and Monash University alumni Prof Juan Calderón Bustillo (now La Caixa Junior Leader and Marie Curie Fellow at the Galician institute of High Energy Physics of the University of Santiago de Compostela, Spain), has proposed a simple and novel method to bring the accuracy of these measurements down to 2% using a single observation of a pair of merging neutron stars.

According to Prof Calderón Bustillo, it's difficult to interpret how far away these mergers occur because 'currently, we can't say if the binary is very far away and facing Earth, or if it's much closer, with the Earth in its orbital plane'. To decide between these two scenarios, the team proposed to study secondary, much weaker components of the gravitational-wave signals emitted by neutron-star mergers, known as higher modes. 'Just like an orchestra plays different instruments, neutron-star mergers emit gravitational waves through different modes,' explains Prof Calderón Bustillo. 'When the merging neutron stars are facing you, you will only hear the loudest instrument. However, if you are close to the merger's orbital plane, you should also hear the secondary ones. This allows us to determine the inclination of the neutron-star merger, and better measure the distance'.

However, the method is not completely new: 'We know this works well for the case of very massive black hole mergers because our current detectors can record the merger instant when the higher modes are most prominent. But in the case of neutron stars, the pitch of the merger signal is so high that our detectors can't record it. We can only record the earlier orbits,' says Prof Calderón Bustillo.

Future gravitational-wave detectors, like the proposed Australian project NEMO, will be able to access the actual merger stage of neutron stars. 'When two neutron stars merge, the nuclear physics governing their matter can cause very rich signals that, if detected, could allow us to know exactly where the Earth sits with respect to the orbital plane of the merger,' says co-author and OzGrav Chief Investigator Dr Paul Lasky, from Monash University. Dr Lasky is also one of the leads on the NEMO project. 'A detector like NEMO could detect these rich signals,' he adds.

In their study, the team performed computer simulations of neutron-star mergers that can reveal the effect of the nuclear physics of the stars on the gravitational waves. Studying these simulations, the team determined that a detector like NEMO could measure Hubble's constant with a precision of 2%.

Co-author of the study Prof Tim Dietrich, from the University of Potsdam, says: 'We found that fine details describing the way neutrons behave inside the star produce subtle signatures in the gravitational waves that can greatly help to determine the expansion rate of the Universe. It is fascinating to see how effects at the tiniest nuclear scale can infer what happens at the largest possible cosmological one'.

Samson Leong, undergraduate student at The Chinese University of Hong Kong and co-author of the study points out "one of the most exciting things about our result is that we obtained such a great improvement while considering a rather conservative scenario. While NEMO will indeed be sensitive to the emission of neutron-star mergers, more evolved detectors like Einstein Telescope or Cosmic Explorer will be even more sensitive, therefore allowing us to measure the expansion of the Universe with even better accuracy!".

One of the most outstanding implications of this study is that it could determine if the Universe is expanding uniformly in space as currently hypothesised. 'Previous methods to achieve this level of accuracy rely on combining many observations, assuming that the Hubble constant is the same in all directions and throughout the history of the Universe,' says Calderón Bustillo. 'In our case, each individual event would yield a very accurate estimate of "its own Hubble constant", allowing us to test if this is actually a constant or if it varies throughout space and time.'

Written by Prof Juan Calderón Bustillo. As featured on Phys.org.

Background image: Carl Knox, OzGrav-Swinburne University

OZGRAV IN THE MEDIA

Deciphering the lives of double neutron stars in radio and gravitational wave astronomy

Scientists from the ARC Centre of Excellence for Gravitational Wave Discovery (OzGrav) have described a way to determine the birth population of double neutron stars—some of the densest objects in the Universe formed in collapsing massive stars. The recently published study observed different life stages of these neutron star systems.

Scientists can observe the merging of double neutron star systems using gravitational waves—ripples in the fabric of space and time. By studying neutron star populations, scientists can learn more about how they formed and evolved. So far, there have been only two double neutron star systems detected by gravitational-wave detectors; however, many of them have been observed in radio astronomy.

One of the double neutron stars observed in gravitational wave signals, called GW190425, is far more massive than the ones in typical Galactic populations observed in radio astronomy, with a combined mass of 3.4 times that of our Sun. This raises the question: why is there a lack of these massive double neutron stars in radio astronomy? To find an answer, OzGrav PhD student Shanika Galaudage, from Monash University, investigated how to combine radio and gravitational-wave observations.

The birth, mid-life and death of double neutron stars

Radio and gravitational-wave astronomy enables scientists to study double neutron stars at different stages of their evolution. Radio observations probe the lives of double neutron stars, while gravitational waves study their final moments of life. To achieve a better understanding of these systems, from formation to merger, scientists need to study the connection between radio and gravitational wave populations: their birth populations.

Shanika and her team determined the birth mass distribution of double neutron stars using radio and gravitational-wave observations. "Both populations evolve from the birth populations of these systems, so if we look back in time when considering the radio and gravitational-wave populations we see today, we should be able to extract the birth distribution," says Shanika Galaudage.

The key is to understand the delay-time distribution of double neutron stars: the time between the formation and merger of these systems. The researchers hypothesised that heavier double neutron star systems may be fast-merging systems, meaning that they're merging too fast to be visible in radio observations and could only be seen in gravitational-waves.

GW190425 and the fast-merging channel

The study found mild support for a fast-merging channel, indicating that heavy double neutron star systems may not need a fast-merging scenario to explain the lack of observations in radio populations. "We find that GW190425 is not an outlier when compared to the broader population of double neutron stars," says study co-author Christian Adamcewicz, from Monash University. "So, these systems may be rare, but they're not necessarily indicative of a separate fast-merging population."

In future gravitational wave detections, researchers can expect to observe more double neutron star mergers. "If future detections reveal a stronger discrepancy between the radio and gravitational-wave populations, our model provides a natural explanation for why such massive double neutron stars are not common in radio populations," adds co-author Dr Simon Stevenson, an OzGrav postdoctoral researcher at Swinburne University of Technology.

As featured on Phys.org.

Background image by Pixabay.

UPCOMING PRIZES & AWARDS

- 2021 Australian Museum Eureka Prizes - nominations close 28 May 2021
- The AIP Walter Boas Medal - nominations close 1 June 2021
- Fresh Science 2021 - nominations close 1 June 2021
- The AIPS TH Laby Medal for Excellence in Physics - nominations close 1 July 2021

UPCOMING EVENTS AND WEBINARS

- 2021 Gravitational Wave Advanced Detector Workshop 17-21 May 2021, online
- Communicating Astronomy with the Public (CAP) 24-27 May 2021, online
- Harley Wood School of Astronomy 9-11 July 2021
- Astronomical Society of Australia Annual Scientific Meeting 12-16 July 2021
- Amaldi14 meeting 19-23 July 2021, which will be an online event hosted by OzGrav.
- Network Gender & STEM Conference 29-31 July 2021
- Gravitational Wave Physics and Astronomy Workshop (GWPAW) 14-17 December 2021, Hannover

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.

Image credit: as stated on each page. Front cover by A. Simonnet, LIGO, Sonoma State University.