SPACE TIMES

OzGrav

December 2020

Welcome

Dear Colleagues,

Finally 2020 draws to a close and it has been a year unlike any other! We started the year with horrific bushfires significantly impacting our colleagues in NSW and the ACT before the world was hit by COVID-19.

Despite the lockdowns, many determined OzGravvers have continued to be very scientifically productive and you can read about some of their achievements, prizes and dreams in this issue.

Today, although there are no cases of community transmission in any state or territory in Australia, we feel for many of the OzGrav team who have relatives in countries that remain badly affected by the virus.

Have a great holiday break over the Christmas period, you all deserve it! I know I am personally really looking forward to a break, and hope that with the rollout of vaccines we'll soon return to our pre-COVID lives.

Regards - Matthew Bailes - OzGrav Director

News in brief

- Congratulations to OzGrav Director Matthew Bailes on receiving the Vice Chancellor's Lifetime Achievement Award at Swinburne University.
- Congratulations to OzGrav Chief Investigator Prof Susan Scott (Australian National University) on receiving the the Dirac Medal in Theoretical Physics.
- Congratulations to OzGrav Affiliate Prof Alan Duffy who was named Academic of the Year at the Space Connect Awards
- Congratulations to OzGrav Affiliate Rebecca Allen winning their accelerator program challenge in the Deloitte Aus-UK GRAVITY Challenge.
- The New Scientist 'Biggest mysteries of the cosmos' course features OzGrav postdoc Fiona Panther as an expert guide! If you're fascinated by the biggest questions of the cosmos, this introductory online course is for you. Sign up here.

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

OZGRAV IN THE MEDIA

OzGrav researchers reveal the origins of merging black holes

Over the past five years, astronomy has been revolutionised as scientists have used ripples in the fabric of spacetime, called gravitational waves, to reveal the secrets of the previously hidden world of black holes. Gravitational waves are created when two black holes merge in a cataclysmic release of energy, but until now, there were few clues as to how and why black holes merge.

Researchers from the LIGO and Virgo Collaborations recently announced a series of discoveries providing some of the first hints as to the origin of black hole mergers. OzGrav researchers from Monash University helped lead the effort.

> **"We are announcing the discovery of 44 confirmed black hole mergers, which is a more than a four-fold increase in the number of previously known gravitational-wave signals," explains OzGrav PhD student Shanika Galaudage, who helped write one of the new LIGO papers.**

"With so many black holes to study, we can start to answer deep questions about how these systems came to merge," Ms Galaudage says.

A key clue comes from the fact that black holes spin. The orientation of the black hole spins affects the gravitational-wave signal.

OzGrav Affiliate and study author Dr Colm Talbot says: "There are two theories for how two black holes can get together. Sometimes, pairs of stars called binaries make pairs of black holes that merge, creating ripples in space-time called gravitational waves. Alternatively, two black holes can stumble into each other."

Artist's impression of a binary black hole merger - Mark Myers, OzGrav

The verdict? "It seems there are multiple ways for two black holes to get together," says OzGrav Chief Investigator Eric Thrane.

> **"Some binary black holes are born from pairs of stars. Others wander the cosmos before finding a partner to merge with. Either way, a tremendous amount of energy is released in gravitational waves."**

This article is extracted from the original media release produced by Silvia Dropulich at Monash University. Also featured on CNet.

Background image: NASA

RESEARCH HIGHLIGHT

Massive overcontact binary stars open a new window to stellar evolution

In 2015, the first direct observation of gravitational waves was made by the Advanced Laser Interferometer Gravitational-wave Observatory (aLIGO) (Abbott et al. 2016). The detected signal, known as GW150914, not only provided the most rigorous test of General Relativity—Einstein's theory of gravity—it was also the first observation of two black holes merging. This confirmed the existence of black holes, binary stellar-mass black hole systems, and proved that they can merge within the current age of the Universe.

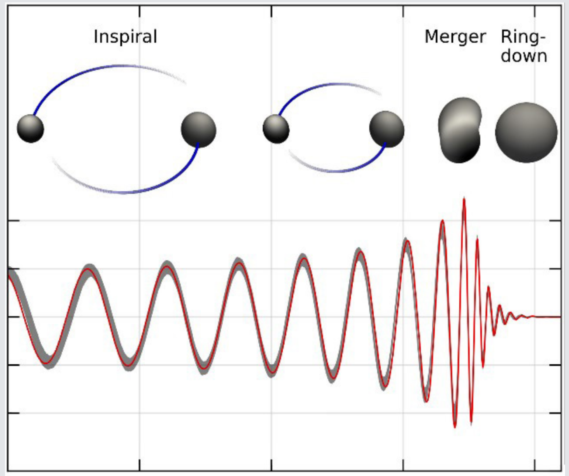


Figure 1 - sourced from Physics from Planet Earth

Since that first detection, aLIGO has detected many more black hole mergers but scientists are still puzzled: many of the black hole mergers that aLIGO has detected so far, including GW150914, involve systems with the component black holes weighing-in at more than 20 solar masses each—some much more. These are massive black holes—heavier than any previously known black holes from X-ray binary observations—which raises the question: how did they form? Our recent study seeks to answer that question.

aLIGO records (part of) the inspiral, merger, and ring-down of the orbiting black holes—as shown in figure 1 . aLIGO can only record these events if they occur within its operating lifetime—that means that the progenitor stars must collapse to black holes before they merge, and the subsequent orbiting black holes must spiral in towards each other and merge within the age of the Universe. For that to happen, the black holes must be big and close together; however, progenitor stars big enough and close enough to produce a binary black hole (BBH) system that would spiral in and eventually merge within the age of the universe, and that could generate gravitational waves detectable by aLIGO, would be too big and too close; so these progenitor stars merge first and then collapse into black holes.

Thus, the aLIGO detections raise the intriguing questions: how did the black holes get so massive? And how did they get so close together? Chemically Homogeneous Evolution (CHE) has been proposed as a possible solution. Rapid spinning stirs a star leading to its interior becoming homogeneous, and possibly fusing entirely rather than just the core. A hot, rapidly spinning, chemically homogeneous star doesn't expand as it ages in the way a conventionally evolving star does. The chemically homogeneous model begins with a pair of close, massive stars rotating around each other extremely rapidly—so close that they become tidally locked, causing the stars to spin rapidly on their own axes. The component stars of this massive, overcontact binary eventually collapse into massive black holes, which are now close enough to spiral in and merge within the age of the Universe.

For the first time, we simultaneously explore conventional isolated binary star evolution and chemically homogeneous evolution under the same set of assumptions. This approach allows us to constrain population properties and make simultaneous predictions about the gravitational-wave detection rates of BBH mergers for the CHE and conventional formation channels. This joint model for the classical and CHE isolated binary evolution channels will enable simultaneous inference on binary evolution model parameters and the metallicity-specific star formation history once the full trove of observations from the aLIGO third gravitational-wave observing run is available. Ultimately, the relatively short delay times of CHE BBHs make them ideal probes of high-redshift star formation history; their high masses make them perfect targets for third-generation gravitational-wave detectors with good low-frequency sensitivity, such as the Einstein Telescope or the Cosmic Explorer.

Written by OzGrav PhD student Jeff Riley - Monash University

Get us to Antarctica!

OzGrav PhD students Debatri Chattopadhyay and Isobel Romero-Shaw have been selected, out of over 400 applicants, to join 98 other women on the Homeward Bound program: a year-long educational journey culminating in a three-week-long physical journey to Antarctica.

Debatri and Isobel focus on different aspects of gravitational-wave science, with Debatri simulating the mergers that create gravitational waves, and Isobel analysing the signals themselves to work out the histories of the binaries. They both have Master's degrees in Physics from their previous institutions, with Debatri hailing from the University of Calcutta and Indian Institute of Technology Kharagpur, and Isobel from the University of Birmingham in the UK.

The program trains women in the traditionally male-dominated fields of science and technology to be the leaders of tomorrow, ready to address the biggest problem facing our planet and our species: climate change. To fund this program, Debatri and Isobel need to raise $6000 each through their crowd funding campaign.

If you can, please donate to this important cause – you can even receive unique gifts for your contributions, like a postcard from Antarctica and a mini plush penguin! **Read more and donate here.**

Background image: Pixabay

Stellar flares with a chance of radio bursts: the weather *from Proxima Centauri*

A discovery that links stellar flares with radio-burst signatures will make it easier for astronomers to detect space weather around nearby stars outside the Solar System. Unfortunately, the first weather reports from our nearest neighbour, Proxima Centauri, are not promising for finding life as we know it.

"Astronomers have recently found there are two 'Earth-like' rocky planets around Proxima Centauri, one within the 'habitable zone' where any water could be in liquid form," said Andrew Zic from the University of Sydney. Proxima Centauri is just 4.2 light years from Earth.

"But given Proxima Centauri is a cool, small red-dwarf star, it means this habitable zone is very close to the star; much closer in than Mercury is to our Sun," he said. "What our research shows is that this makes the planets very vulnerable to dangerous ionising radiation that could effectively sterilise the planets."

Led by Mr Zic, under the supervision of OzGrav Associate Investigator Professor Tara Murphy, astronomers have for the first time shown a definitive link between optical flares and radio bursts on a star that is not the Sun. The finding, published in The Astrophysical Journal, is an important step to using radio signals from distant stars to effectively produce space weather reports.

"Our own Sun regularly emits hot clouds of ionised particles during what we call 'coronal mass ejections'. But given the Sun is much hotter than Proxima Centauri and other red-dwarf stars, our 'habitable zone' is far from the Sun's surface, meaning the Earth is a relatively long way from these events," Mr Zic said. "Further, the Earth has a very powerful planetary magnetic field that shields us from these intense blasts of solar plasma."

The research was done in collaboration with CSIRO, the University of Western Australia, University of Wisconsin-Milwaukee, University of Colorado and Curtin University, with contributions from the ARC Centre for Gravitational Wave Discovery (OzGrav) and University of California Berkeley.

Zic said: "M-dwarf radio bursts might happen for different reasons than on the Sun, where they are usually associated with coronal mass ejections. But it's highly likely that there are similar events associated with the stellar flares and radio bursts we have seen in this study."

Coronal mass ejections are hugely energetic expulsions of ionised plasma and radiation leaving the stellar atmosphere. "This is probably bad news on the space weather front. It seems likely that the galaxy's most common stars – red dwarfs – won't be great places to find life as we know it," Mr Zic said.

In the past decade, there has been a renaissance in the discovery of planets orbiting stars outside our Solar System. There are now more than 4000 known exoplanets. This has boosted hopes of finding 'Earth-like' conditions on exoplanets. Recent research says that about half the Sun-like stars in the Milky Way could be home to such planets. However, Sun-like stars only make up 7 percent of the galaxy's stellar objects. By contrast, M-type red dwarfs like Proxima Centauri make up about 70 percent of stars in the Milky Way. The findings strongly suggest planets around these stars are likely to be showered with stellar flares and plasma ejections.

Artist's impression of stellar flare from Proxima Centauri ejecting material onto nearby planet. Credit: Mark Myers/OzGrav

METHODOLOGY

The Proxima Centauri observations were taken with the CSIRO's Australian Square Kilometre Array Pathfinder (ASKAP) telescope in Western Australia, the Zadko Telescope at the University of Western Australia and a suite of other instruments.

OzGrav Researcher Dr Bruce Gendre, from the University of Western Australia , said the research helps understand the dramatic effects of space weather on solar systems beyond our own.

"Understanding space weather is critical for understanding how our own planet biosphere evolved – but also for what the future is," Dr Gendre said.

Professor Murphy said: "This is an exciting result from ASKAP. The incredible data quality allowed us to view the stellar flare from Proxima Centauri over its full evolution in amazing detail.

"Most importantly, we can see polarised light, which is a signature of these events. It's a bit like looking at the star with sunglasses on. Once ASKAP is operating in full survey mode we should be able to observe many more events on nearby stars."

This will give us much greater insights to the space weather around nearby stars.

Other facilities, including NASA's planet-hunting Transiting Exoplanet Survey Satellite and the Zadko Telescope observed simultaneously with ASKAP providing the crucial link between the radio bursts and powerful optical flares observed.

Mr Zic said: "The probability that the observed solar flare and received radio signal from our neighbour were not connected is much less than one chance in 128,000."

The research shows that planets around Proxima Centauri may suffer strong atmospheric erosion, leaving them exposed to very intense X-rays and ultraviolet radiation.

But could there be magnetic fields protecting these planets? So far there have been no observations of magnetic fields around exoplanets and finding these could prove tricky. Mr Zic said one potential way to identify distant magnetic fields would be to look for aurorae, like those around Earth and also witnessed on Jupiter.

"But even if there were magnetic fields, given the stellar proximity of habitable zone planets around M-dwarf stars, this might not be enough to protect them," Mr Zic said.

This is an extract of a media release originally written by the Media Office at the University of Sydney.

Background image: Pixabay

First internationally-recognised gravitational-wave data centre awarded additional NCRIS grant

The Gravitational Wave Data Centre (GWDC) has recently received a $1M grant from the Australian Government, via its National Collaborative Research Infrastructure Strategy (NCRIS) program, allowing it to extend operations into 2022.

Based at Swinburne University of Technology, the GWDC is the first internationally-recognised gravitational wave data centre in Australia. Established in July 2019, the centre was created to provide infrastructure, training and support to gravitational wave researchers across the country. This support enables Australian researchers to lead the discovery of events from the latest data on an international scale and to maximise the scientific impact of their discoveries.

This recent grant of $1M awarded to the GWDC will allow operations to continue into 2022, giving Australian astronomers the chance to receive data from the Advanced Laser Interferometer Gravitational-wave Observatory (aLIGO) and Virgo detectors as well as pulsar timing data from the Square Kilometre Array (SKA) and precursor facilities. These facilities currently capture gravitational waves from the collisions of stellar-mass black holes and neutron stars, and hope to capture the final death throes of supermassive black holes in the near future. Data from these events is then able to be live-streamed to optimised supercomputing facilities in Australia to enable real-time detections.

> **“The Gravitational Wave Data Centre is transforming the way the Australian community acquires, processes and presents its data and is a model for how projects like the SKA will work in the future. It’s fantastic to see how efficiently the data moves from our detectors and telescopes into the analysis pipelines and publications.” – Director of the ARC Centre of Excellence for Gravitational Wave Discovery (OzGrav), Professor Matthew Bailies.**

Astronomy Australia Limited (AAL) has previously supported the GWDC with funding from the NCRIS program and was delighted to secure these additional funds for the GWDC.

“We are very pleased to be able to keep supporting Australian researchers engaged in the award-winning field of gravitational-wave astrophysics through the continuation of the GWDC. AAL is grateful to The Hon Dan Tehan, Minister for Education, and the Department of Education, Skills and Employment for its financial support in realising the GWDC as an excellent model for the curation of data-intensive science” – Chair of the AAL Board, Professor Naomi McClure-Griffiths.

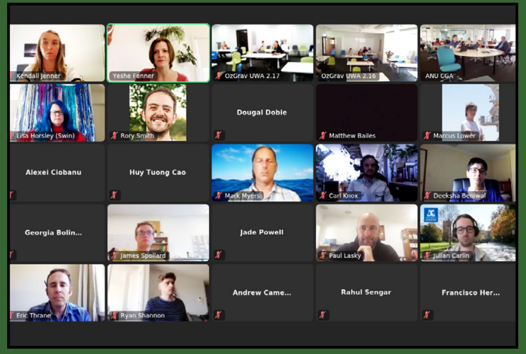
The GWDC currently supports research from six major Australian institutions – The Australian National University, Monash University, Swinburne University of Technology (host institution for the GWDC), The University of Melbourne, The University of Western Australia and The University of Adelaide. The GWDC operates alongside the existing Astronomy Data and Computing Services (ADACS) team at Swinburne, which has been providing a generalised data and computing service to the national astronomy community from early 2017.

The NCRIS program is an initiative of the Australian Government managed by the Department of Education, Skills and Employment. AAL manages the astronomy component of the NCRIS program, which supports Australian involvement in a range of national and international facilities.

This article is a media release originally published by Astronomy Australia Limited.

OzGrav 2020 ECR Workshop and Retreat!

OzGrav successfully ran its first VIRTUAL ECR workshop and retreat in November and, despite the lack of real-life gathering as a whole centre, members still had valuable opportunities to connect and collaborate with each other. There were over 170 registrants and some universities were lucky to get together for social activities, including kayaking in sunny Perth!



All photos supplied.

Background image: Pixabay

RESEARCH HIGHLIGHT

Characterization of systematic error in Advanced LIGO calibration

The Advanced Laser Interferometer Gravitational-Wave Observatory (Advanced LIGO) detectors and the Virgo detector have directly observed transient gravitational waves (GWs) from compact binary coalescences. After a series of instrument upgrades to further improve the sensitivity—like replacing test masses and optics, increasing laser power, and adding squeezed light—the two LIGO detectors started the third observing run (O3), together with Virgo, on April 1st, 2019 and finished the year-long observation on Mar 27th, 2020.

The time series of dimensionless strain, defined by the differential changes in the length of the two orthogonal arms divided by the averaged full arm length (~4 km in the two LIGO detectors), is used to determine the detection of a GW signal and infer the properties of the astrophysical source. (The figure shows a conceptual diagram of the optical configuration of the Advanced LIGO interferometers.)

Due to the presence of noise and the desire to maintain the resonance condition of the optical cavities, the detectors do not directly measure the strain. The differential arm displacement is suppressed by the control force allocated to the test masses. The residual differential arm displacement in the control loop is converted into digitized photodetector output signals. Therefore, the strain is reconstructed from the raw digitized electrical output of each detector, with an accurate and precise model of the detector response to the strain. This reconstruction process is referred to as detector 'calibration.' The accuracy and precision of the estimated detector response, and hence the reconstructed strain data, are important for detecting GW signals and crucial for estimating their astrophysical parameters.

Understanding, accounting, and/or compensating for the complex-valued response of each part of the upgraded detectors improves the overall accuracy of the estimated detector response to GWs. Calibration systematic error is the frequency-dependent and time-dependent deviation of the estimated detector response from the true detector response. We describe our improved understanding and methods used to quantify the response of each detector, with a dedicated effort to define all places where systematic error plays a role. We use the two LIGO detectors as they stand in the first half (six months) of O3 to demonstrate how each identified systematic error impacts the reconstructed strain and constrain the statistical uncertainty therein. We report the accuracy and precision of the strain data by estimating the 68% confidence interval bounds on the systematic error and uncertainty for the response of each detector (in magnitude and phase).

In the first half of O3, the overall systematic error and uncertainty of the best calibrated data is within 7% in magnitude and 4 degrees(?) in phase in the most sensitive frequency band 20–2000 Hz. The systematic error alone, in the same band, is estimated to be below 2% in magnitude and 2 degrees in phase. Current detection of GW events and estimation of their astrophysical parameters are not yet limited by such levels of systematic error and uncertainty. However, as the global GW detector network sensitivity increases, detector calibration systematic error and uncertainty plays an increasingly important role. Limitations caused by calibration systematics on estimated GW source parameters, precision astrophysics, population studies, cosmology, and tests of general relativity are possible. Efforts are being carried out to better integrate the work presented in this paper into future GW data analyses. Research and development of new techniques are underway to further reduce calibration systematic error and uncertainty below the 1% level, a key milestone towards minimizing impacts of calibration systematics on astrophysical and cosmological results.

Written by OzGrav Associate Investigator Lilli Sun (ANU) | Link to study here.

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 space-time, 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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