SPACE TIMES

OzGrav
September 2020

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Welcome

Dear colleagues,

Welcome to the September edition of OzGrav's newsletter.

A special note to our Victorian-based members who have now been in one form of lockdown or restriction for the past 6 months. Most of us are well fed, have a roof over our head, and plenty of work to do. This doesn't make it an easy time though, and it is hard not to miss the freedoms that we have given up in order to suppress the virus. Let's hope that the case numbers keep falling and that Australia is soon on top of the second wave.

This week I've been part of the International Pulsar Timing Array science meeting being held virtually via zoom. Despite the tyranny of distance and time zones, it has been fantastic to see our international collaborators and (friendly) competitors online, to hear their voices and interact with them, albeit from the confines of our homes. Indeed we've probably had more people engaged in the meeting online than we would normally manage to bring together in person, so there have definitely been some positives associated with holding meetings virtually.

This year's OzGrav annual retreat will also be held virtually and the Executive team are doing their best to bring our members together in an interactive way that isn't 'just another zoom meeting'.

I hope you enjoy this issue of Space Times, and that we see each other again soon.

Regards - Matthew Bailes

Regards,
Matthew Bailes - OzGrav Director

News in brief

- Congratulations to OzGrav PhD students Nutsinee Kijbunchoo (ANU) and Chayan Chatterjee (UWA) who won the 3-minute thesis finals at their respective universities and went on to the semi-finals of the Asia Pacific 3MT competition!
- Congratulations to OzGrav Associate Investigator Chris Fluke who has been appointed as a SmartSat CRC Professorial Chair for the priority research area: Space System real-time data fusion, integration and cognition.
- The OzGrav Retreat & Early Career Research Workshop will be going ahead as virtual events during the week of 23-27 November 2020, so mark the dates in your calendar and keep an eye out for the official announcement of the program soon.
- Astronomy Australia presentations and seminars: http://asa.astronomy.org.au/presentations.php. This includes both talks aimed at professional astronomers and those intended for a broader audience.

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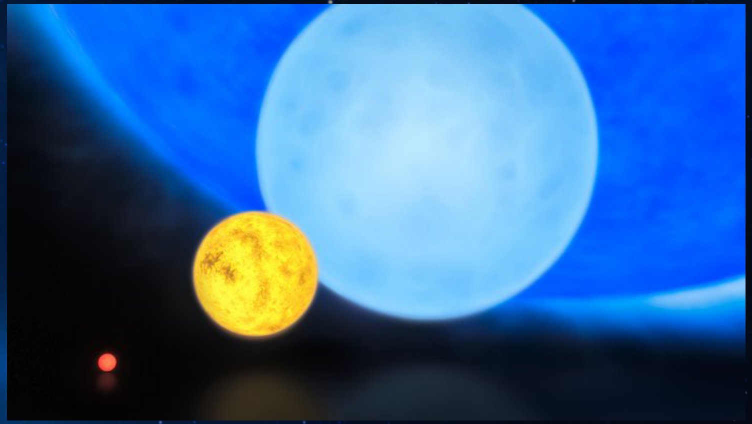
METISSE offers new insights into the lives of massive stars

Massive stars are larger than about 10 times the mass of the Sun and are born far less often than their low mass counterparts. Yet, they play an important role in the evolution of star clusters and galaxies. From enriching their surroundings in supernova explosions, to altering the dynamics of their systems, massive stars are the precursors of many vivid and energetic phenomena in the Universe.



This artist's impression of different mass stars; from the smallest 'red dwarfs' weighing in at about 0.1 solar masses, to massive 'blue' stars weighing around 10 to 100 solar masses. While red dwarfs are the most abundant stars in the Universe, it's the massive blue stars that contribute the most to the evolution of stars clusters and galaxies. Credit: ESO/M. Kornmesser

The best tools to study massive stars are detailed stellar evolution codes: computer programs which can calculate both the interior structure and the evolution of these stars. Unfortunately, detailed codes are computationally expensive and time-consuming—it can take several hours to compute the evolution of just a single star. For this reason, it's impractical to use these codes for modelling stars in complex systems, such as globular star clusters, which can contain millions of interacting stars.

To address this problem, a team of scientists led by the ARC Centre of Excellence for Gravitational Wave Discovery (OzGrav) developed a stellar evolution code called METhod of Interpolation for Single Star Evolution (METISSE). Interpolation is a method for estimating a quantity based on nearby values, such as estimating the size of a star based on the sizes of stars with similar masses. METISSE uses interpolation to quickly calculate the properties of a star at any instant by using selected stellar models computed with detailed stellar evolution codes.

Lightning fast, METISSE can evolve 10,000 stars in less than 3 minutes. Most importantly, it can use different sets of stellar models to predict the properties of stars—this is extremely important for massive stars. Massive stars are rare, and their complex and short lives make it difficult to accurately determine their properties. Consequently, detailed stellar evolution codes often have to make various assumptions while computing the evolution of these stars. The differences in the assumptions used by the different stellar evolution codes can significantly impact their predictions about the lives and properties of massive stars.

In their recently published study, the OzGrav researchers used METISSE with two different sets of state-of-the-art stellar models: one computed by the Modules for Experiments in Stellar Astrophysics (MESA), and the other by the Bonn Evolutionary Code (BEC).

Poojan Agrawal—OzGrav researcher and the study's lead author—explains: 'We interpolated stars that were between 9 and 100 times the mass of the Sun and compared the predictions for the final fates of these stars. For most massive stars in our set, we found that the masses of the stellar remnants (neutron stars or black holes) can vary by up to 20 times the mass of our Sun'.

When the stellar remnants merge, they create gravitational waves—ripples in space and time—that scientists can detect. Therefore, this study's results will have a huge impact on future predictions in gravitational-wave astronomy.

Agrawal adds: 'METISSE is just the first step in uncovering the part massive stars play in stellar systems such as star clusters, and already the results are very exciting.'

As featured in Phys.org and Tech Explorist.

Background image by James Josephides

First ever monster intermediate black hole directly observed

Black holes are massive, right? The first pair of black holes detected were each about 30 times more massive than the Sun. When they merged, the resulting 'remnant' was a black hole that was a whopping 60 times more massive than the Sun.

Astronomers from the LIGO and Virgo Scientific Collaboration (LVC) have recently reported the first ever direct observation of the most massive black hole merger to date. Two monster black holes collided to form an even more massive object—an intermediate-mass black hole, about 150 times as heavy as the Sun.

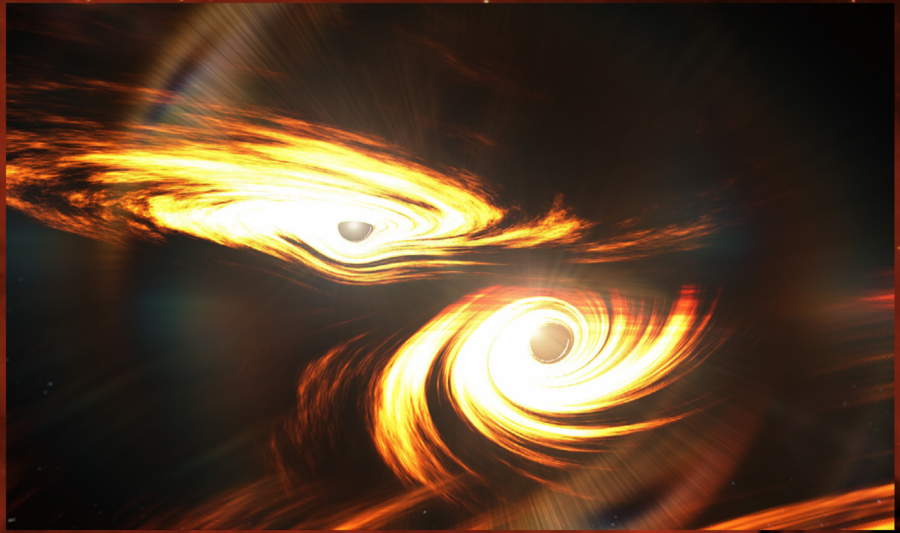
Researchers from the ARC Centre of Excellence for Gravitational Wave Discovery (OzGrav) contributed to the detection and used the computing resources of the new Gravitational-Wave Data Centre to infer the masses of the merging black holes.

Juan Calderón Bustillo—co-author and OzGrav postdoctoral researcher at Monash University—reports: 'This is the first time we've observed an intermediate-mass black hole, almost twice as heavy as any other black hole ever observed with gravitational-waves. For this reason, the detected signal is much shorter than those previously observed. In fact, it's so short that we can barely observe the black hole collision, we can only see its result'.

The online detection team at the University of Western Australia detected the event, GW190521, seconds after the gravitational-wave data were available, and helped generate public alerts for the LIGO Scientific Collaboration.

These 'impossible' black holes have 'forbidden' masses according to what we currently understand about the lives of massive stars.

The rare event has prompted researchers to question how the black hole formed, its origins and how the two black holes found each other in the first place. OzGrav PhD student and co-author Isobel Romero-Shaw, from Monash University, comments on the perplexing masses: 'Black holes form when massive stars die, both exploding in a supernova and imploding at the same time. But, when the star has a core mass in a specific range—between approximately 65 and 135 times the mass of the Sun—it usually just blows itself apart, so there's no leftover black hole. Because of this, we don't expect to see black holes in this solar mass range, unless some other mechanism is producing them.'



Artist's impression of binary black holes about to collide.
Image credit: Mark Myers, , OzGrav

Based on this current study's mass measurements, researchers found that this kind of black hole couldn't have formed from a collapsing star—instead, it may have formed from a previous black hole collision.

OzGrav postdoctoral researcher and LVC member Simon Stevenson, from Swinburne University of Technology, says: 'These 'impossibly' massive black holes may be made of two smaller black holes which previously merged. If true, we have a big black hole made of smaller black holes, with even smaller black holes inside them—like Russian Dolls.'

'We are witnessing the birth of an intermediate mass black hole: a black hole more than 100 times as heavy as the Sun, almost twice as heavy as any black hole previously observed with gravitational-waves,' adds Stevenson. 'These intermediate mass black holes could be the seeds that grow into the supermassive black holes that reside in the centres of galaxies.'

These gravitational waves came from over 15 billion light years away! But isn't the Universe only around 14 billion years old, you ask? It turns out that the Universe was actually around 7 billion years old when these two black holes collided. As the gravitational waves rippled out through the Universe, the Universe was expanding.

Consequently, the measured distance to this collision is now further than the product of the speed of light and the time travelled—mind (and space) bending stuff! This shows gravitational waves are able to probe the ancient history of the Universe, when galaxies were forming stars at a rate around 10 times higher than the present day.

Also featured in The ABC, 7 News, The Daily Telegraph, News.com.au and Space Australia

Faces of OzGrav: **Ya Zhang**

Growing up and studying in China, I got my first chance to go on exchange to Australia during my undergraduate years. The exchange was to the University of Queensland and it started the journey that brought me to Australian National University (ANU) for my PhD. By then I had already been introduced to the world of optics through undergraduate projects in optical coherence tomography, which brought together fibre optics and digital signal processing (DSP), the two key themes of my PhD.

My first exposure to gravitational waves (GW) and their detection was in my final undergraduate year when I did a project with the Centre for Gravitational Astrophysics at ANU. That work introduced me to coherent interferometry and how it can be applied more broadly outside of GW detection.

The research was challenging but ultimately rewarding and fun, so I decided to come back for more. I am now 2 years into my PhD, focussing on laser frequency metrology and developing stabilisation techniques using fibre optics and DSP algorithms. Over the past four years, I dived into the world of field-programmable gate array (FPGA) based programming, and I hope to extend my knowledge and experience further through the rest of my PhD and my future career.

Beyond the lab I enjoy spending my time outdoors. I've taken advantage of the many nice hikes in the Canberra area and beyond, and I hope to do more in the future. One of my favourite walks to date is the Grand Canyon track in the Blue Mountains. Alongside hiking, I enjoy landscape photography and occasionally portraits as well, but exclusively of cats, ducks and other wildlife.

Background image sourced from Pixabay

Rethinking the fireball medium:
Investigating gamma-ray bursts and stars

Artist's impression of a gamma-ray burst.
Credit: ESO/A. Roquette

Gamma-ray bursts (GRBs) are extremely energetic explosions that have been observed in distant galaxies; they are the most luminous explosions in the Universe.

A team of OzGrav scientists from the University of Western Australia recently studied a high redshift long GRB (a more common explosion lasting between 2 seconds to several minutes) called GRB160203A. After four hours, the afterglow of this specific GRB begins rebrightening, spiking in luminosity at different times. Using data from every telescope that observed the cosmic event with the 'fireball' simulation model, the OzGrav team concluded that these bright features are best explained by the jet of intense light, electrons, and swept-up debris (known as the fireball) crashing into irregularities of the environment, like a fast car hitting a speed bump.

The afterglow of GRB160203A has two main parts—the 'well-behaved' period, lasting four hours, and the 'unusual' period afterwards. The fireball model suggested that, in the well-behaved period, the fireball was in the interstellar medium—the space between the stars, which consists of gas with at least ten trillion times fewer particles than air in the same volume. In the unusual period, the fireball model failed to make any predictions about the environment of the burst due to the rebrightening events. This was our clue to investigate popular modifications to the model and explain the odd behaviour.

The two most popular modifications to the fireball model are the magnetar collapse model and the termination shock model. The magnetar collapse model predicts that a magnetic neutron star (a small celestial object densely packed with neutrons) collapses, injecting energy into the fireball with the quickly changing magnetic field which is then converted to light.

The termination shock model proposes that the fireball is passing through the boundary between the stellar wind and the interstellar medium. As the front of the fireball crashes into the boundary and slows down, the back of the fireball catches up and smashes into the front. This 'reverse shock' releases energy in the form of light; however, neither model can explain why there are at least two rebrightening events. The magnetar cannot collapse twice and the fireball cannot cross the stellar/interstellar medium more than once.

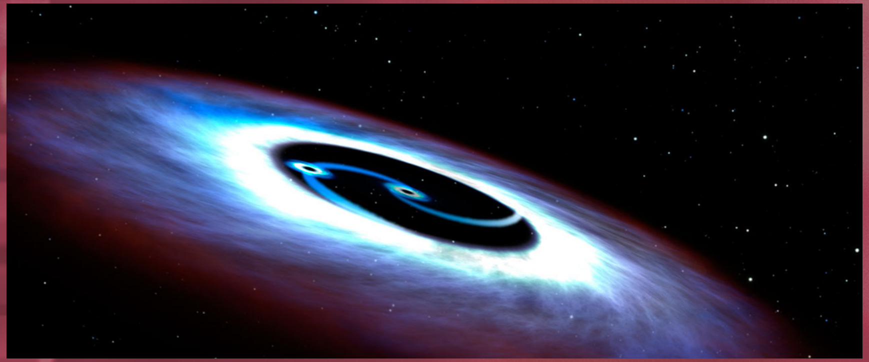
The other models considered involved a non-uniform medium for the fireball—a turbulence model. As the fireball enters a region of higher density, it causes a reverse shock and releases light. The source of this spike in density could come from the wind surrounding a rare Wolf-Rayet star, or the natural turbulence of the interstellar medium. Wolf-Rayet stars constantly shed material in shells around themselves due to their unstable nature. The interstellar medium, like all turbulent fluids, has pockets of high and low density scattered throughout, like the chips in a chocolate chip biscuit.

OzGrav researcher and lead of the study Hayden Crisp says: 'We created a model of the brightness of the GRB as if it was well-behaved throughout the observations. By comparing the modelled brightness to the actual brightness, the relationship between brightness and medium density showed the fireball medium's density over time. We saw that the rebrightening events correspond to a 5 to 50x increase in the density of the fireball medium'.

Crisp adds: 'Of the two plausible models, we prefer the turbulence model as the fireball model implies the well-behaved period is in the interstellar medium. Our main conclusion from this research is that the assumption of a uniform fireball medium is inappropriate in this case. A non-uniform environment may provide a new lens to examine the growing number of unusual bursts and provides a competitive model for explaining their features'.

The astrophysical odds of GW151216

Every ten seconds or so, a pair of black holes or neutron stars collide somewhere in the Universe. These collisions generate gravitational waves—ripples in the fabric of space and time—which are observed on Earth using hyper-sensitive laser interferometers, based in the US and Italy. However, the detectors are not sensitive enough to see every collision, only those that are sufficiently close by.



Artistic illustration of a binary black hole. Credit: NASA, ESA, and G. Bacon (STScI)

The data from the detectors is publicly available, allowing scientists from around the world to check the findings of the LIGO and Virgo collaborations who operate the detectors. Open data also allows outside groups to try new ways to find signals, providing healthy competition for LIGO and Virgo! Last year, a group from Princeton did just this—analysing the open data, they found a new binary black hole candidate called GW151216.

One way to ascertain if a candidate gravitational-wave event is real is to look for consistent signals in two or more observatories. Using this principle, a team of researchers from the ARC Centre of Excellence of Gravitational Wave Discovery (OzGrav), at Monash University, developed a new method to determine if candidate gravitational-wave events are real.

OzGrav researcher Dr Greg Ashton likens the detection of gravitational-wave signals to listening to sounds in the night: 'Imagine that you wake in the middle of the night to a strange noise. You turn to your partner to ask if they heard it too. If you both describe the same sound, then you are unlikely to have imagined it. We use the same idea. We compare the signal between the detectors and against known terrestrial noise'.

In their study, Ashton and his collaborator, OzGrav Chief Investigator Prof Eric Thrane, applied their method to the candidate GW151216 and found that there's only a 3% chance that it's real.

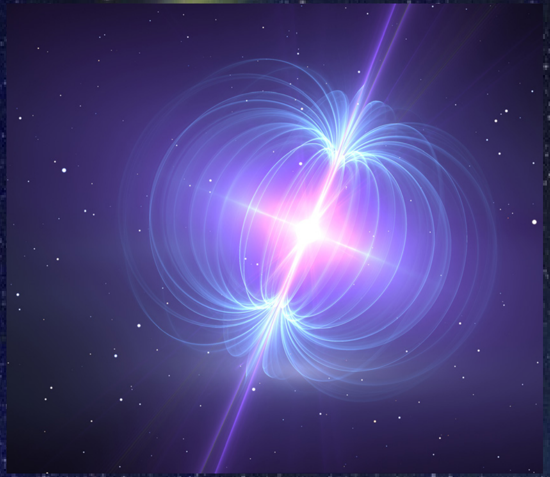
'We would've liked to conclude that it's a real event,' says Ashton. 'As the number of gravitational-wave detections grows, it will become increasingly important to assess the provenance of candidate events to ensure we draw conclusions from bona fide gravitational-wave signals.'

Ashton and Thrane are now looking to further develop their method and apply it the many other candidates in the data.

Background image by Carl Knox, OzGrav

A magnetar parallax

The distance to a nearby magnetar has been measured by observing the changes in its position over the course of a year relative to a pair of quasars.



An artist's impression of a magnetar.
Source: Pitris from Dreamstime

Astronomers have just made the most accurate distance measurements yet to the ultra-magnetised star XTE J1810-197 – and at a distance of about 8,000 light-years, the rare magnetar is one of the closest to us, and is quite a bit closer than we previously thought.

The research was led by OzGrav astronomers and made use of the OzSTAR supercomputer at Swinburne University of Technology.

In addition to getting perhaps the most precise distance to a magnetar to date, astronomers were also able to hypothesise about the magnetar's genesis. A supernova remnant, located rather too close by to be coincidental, may be the remains of a former companion star of XTE J1810-197.

Magnetars are a special and particularly terrifying variety of neutron star; stars composed nearly entirely of neutrons that spin at insane rates, up to hundreds of times per second. Their magnetic fields are stronger than anything else known.

The magnetar XTE J1810-197 was discovered in 2003 by the Rossi X-Ray Timing Explorer (RXTE) as it was observing another magnetar, a soft gamma repeater, known as SGR 1806-20. At the time it was discovered, XTE J1810-197 was furiously emitting X-rays, but gradually faded away until 2018 when it became active again.

Magnetars are rather rare, with less than 30 known examples in our galaxy. The magnetar XTE J1810-197 is rarer still, a special class of neutron star that has the properties of both magnetars and pulsars. Recent evidence suggests that neutron stars may go through different stages of evolution, first as a pulsar then as a magnetar (or maybe the other way around), but there is still a lot to learn about stars like XTE J1810-197. Knowing with some accuracy how far away they are is a good start.

Led by OzGrav PhD student Hao Ding from Swinburne University, a collaboration between researchers in Australia, the USA and South Africa have taken measurements of the parallax of XTE J1810-197 over a period of a little more than a year. Previously thought to be 10,000 light-years away, they found it to be substantially closer at about 8,000 light-years.

'In this work, we measure the positions of the magnetar with respect to two quasars that are quasi-linear to the magnetar. The technique we used can also be used to measure the parallaxes of radio-bright stars within about 10 kpc [kilo-parsecs, a commonly used unit of measurement amongst astronomers] distance. Beyond the distance limit, a parallax would be too small to detect.'

According to Hao Ding, having an accurate distance for XTE J1810-197, as well as an understanding of its motion across the sky (known as its proper motion), will benefit researchers trying to understand the properties of these fascinating stars. 'Precise proper motion and parallax measurements would benefit long-term pulsar timing of magnetars, and, in particular, lead to a more reliable characteristic age'.

Collaborator and OzGrav PhD student Marcus Lower is also from Swinburne and has an affiliation with the CSIRO. 'Having an accurate distance measurement to the magnetar is extremely useful. For instance, we can now accurately measure the temperature of its surface based on how bright it appears in X-rays. It also allows us to measure the distance to blobs of hot gas between us and the magnetar based on the twinkling of its radio pulses.'

There's also the question of whether there is any link between the nearby supernova remnant (SNR) – the remains of stars blown apart in supernovae explosions – and XTE J1810-197. While the two are separated by some distance, 'our precise proper motion points back to the central region of the SNR called G11.0-0.0 at about 70,000 years ago,' says Hao Ding.

The magnetar XTE J1810-197 was the first one observed emitting radio pulses, and over 15 years later it is still giving up its secrets in the biggest science lab there is – the universe.

Extracted from the feature article on Space Australia written by Dan Lambeth

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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