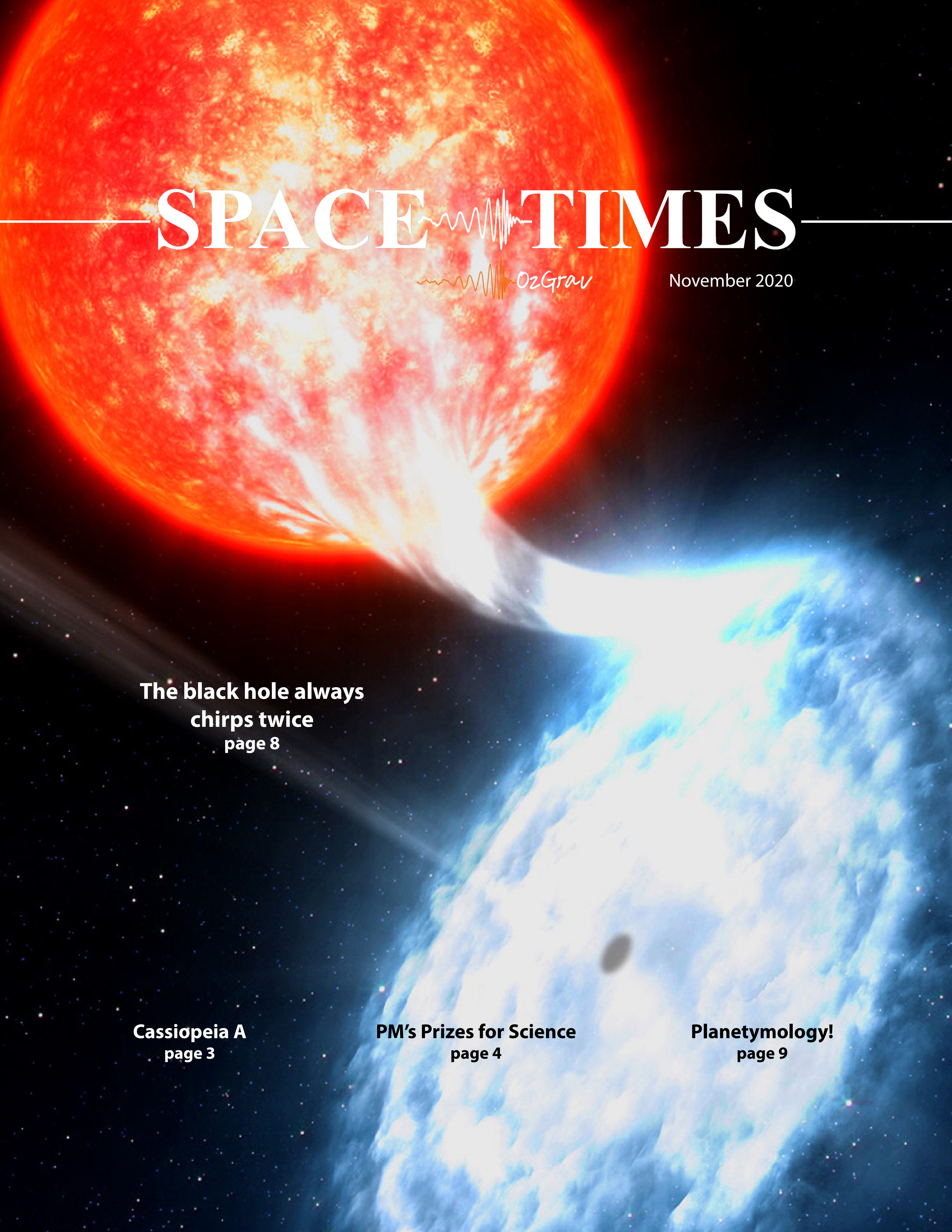
SPACE TIMES

OzGrav

November 2020

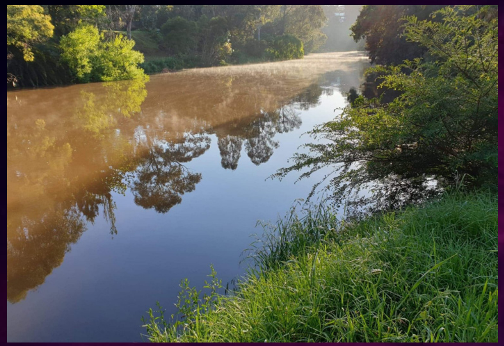


Welcome

Dear Colleagues,

No matter where you are in the world there's no doubt that 2020 has been a long year. For the three OzGrav nodes in Melbourne this has been especially so with two lockdowns in seven months, and little physical contact with our friends, colleagues and families.

It is hard to describe the joy that easing of restrictions brings after hanging on the daily case numbers for what seems like an eternity. Over the past three weeks, cafes and businesses have been reopening and Melburnians were allowed to venture more than 5 km from home for the first time in over 100 days. I celebrated by venturing down one of my favourite cycling paths by the Yarra river and swinging by Swinburne's campus and a favourite coffee shop. Later that day my daughter and grand-daughter rang the doorbell asking if we could go for a walk together. These simple things may not have sounded very significant last February, but I found them all quite moving experiences, as if the tension of the last year was being released.



Collectively our staff have been remarkably productive during lockdown, and as you'll see in this issue, pursuing some great science. But if my own emotions are anything to go by, it would be incredibly surprising if many of our staff and students haven't found the year very challenging, and we're constantly looking at how OzGrav can assist our members facing uncertain times in the academic sector. One of our recent initiatives is a scheme I recently announced to try and provide bridging funding to those stranded between jobs or their PhDs.

One of my personal favourite sections of Space Times is 'Faces of OzGrav'. This month we meet the remarkably effervescent Dr Lilli Sun from ANU, whose journey to an academic position at ANU was quite unique. Finally, we are celebrating the wonderful news that the four elder statespersons of OzGrav, Profes-sors David Blair, Susan Scott, David Mc-Clelland and Peter Veitch, were awarded the Prime Minister's Prizes for Science!!! This is a fantastic achievement for these Australian pioneers of this field and the future of gravitational wave astronomy in Australia and OzGrav.

I offer my heartiest congratulations to them.

Yours sincerely,
Matthew Bailes - OzGrav Director

News in brief

- Congratulations to OzGrav Chief Investigator Emeritus Prof David Blair (University of Western Australia); Deputy Director Prof David McClelland (Australian National University); Chief Investigator Prof Susan Scott (Australian National University); and Chief Investigator Prof Peter Veitch (University of Adelaide) on receiving the 2020 Prime Minister's Prizes for Science! More on page 4.
- Congratulations to OzGrav postdocs Jade Powell (Swinburne) and Johannes Eichholz (ANU) on receiving a DECRA Fellowship from the ARC.
- Congratulations to OzGrav Chief Investigator Prof Susan Scott (ANU) on being elected as a Fellow of the American Physics Society (APS).
- The 2020 Nobel Prize in Physics was awarded to Sir Roger Penrose, Reinhard Genzel and Andrea Ghez, for their significant discoveries about the nature of black holes—objects very close to OzGravvers' hearts.
- The OzGrav Retreat & Early Career Research Workshop will be going ahead as virtual events during the week of 23-27 November 2020.

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

Revealing the lonely origin of Cassiopeia A: one of the most famous supernova remnants

Massive stars end their lives with energetic explosions known as supernova explosions. 'Stripped-envelope supernovae' show weak or no traces of hydrogen in its ejecta, meaning that the star lost most or all of its hydrogen-rich outer layers before it exploded.

The stripped-envelope supernova remnant, Cassiopeia A - NASA/CXC/SAO CC BY)

Scientists hypothesise that these stars mostly originate in binary star systems, where one of the stars rips off the outer layers of the other star with its gravitational pull–many searches have been made to discover the remaining companion star following the stripped-envelope supernovae. In some searches, the companion star was successfully detected, but there are also numerous cases where the companion couldn't be found, posing a serious problem for the binary hypothesis. The most famous case is called Cassiopeia A (Cas A): a stripped-envelope supernova remnant that is predicted to have a stellar companion, but nothing could be found in its explosive aftermath.

In a recently published study led by the ARC Centre of Excellence for Gravitational Wave Discovery (OzGrav), researchers propose a new scenario for creating these 'lonely' stripped-envelope stars.

OzGrav researcher and lead author of the study Dr Ryosuke Hirai explains: 'In our scenario, the stripped-envelope star used to have a binary companion with a mass very similar to itself. Because the masses are similar, they have very similar lifetimes, meaning that the explosion of the first star will occur when the second star is close to death too'.

In the last million years of their lives, massive stars are known to become red supergiants where their outer layers are very puffed up and unstable. So, if the first supernova of the binary star system hits the other massive star—while it's this puffy red supergiant—it can easily strip off the outer layers, making it a stripped-envelope star. The stars disrupt after the supernova, so the secondary star becomes a lonely stellar widow and will appear to be single by the time it explodes itself, a million years later.

The OzGrav scientists performed hydrodynamical simulations of a supernova colliding with a red supergiant to investigate how much mass can be stripped off through this process. They found that if the two stars are close enough, the supernova can strip nearly 90% of the 'envelope'—the outer layer—off the companion star.

'This is enough for the second supernova of the binary system to become a stripped-envelope supernova, confirming that our proposed scenario is plausible,' says Hirai. 'Even if it's not sufficiently close, it can still remove a large fraction of the outer layers which makes the already unstable envelope even more unstable, which can lead to other interesting phenomena like pulsations or eruptions.'

If OzGrav's scenario occurs, the stripped-off envelope should be floating as a one-sided shell at about 30- 300 light years away from the second supernova site. Recent observations revealed that there is indeed a shell of material located at around 30-50 light years away from the famous Cas A.

Hirai adds: 'This may be indirect evidence that Cas A was originally created through our scenario, which explains why it does not have a binary companion star. Our simulations prove that our new scenario could be one of the most promising ways to explain the origin of one of the most famous supernova remnants, Cas A'.

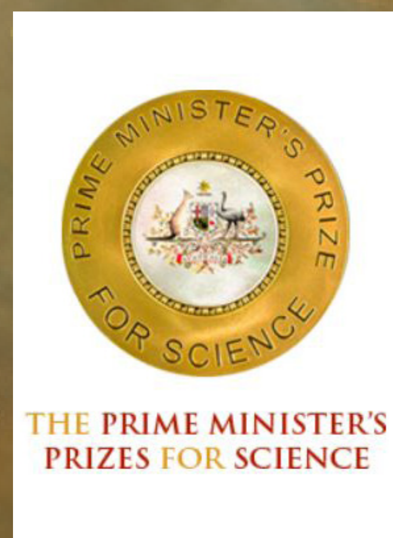
The OzGrav scientists also predict that this scenario has a much wider range of possible outcomes—for example, it can produce a similar number of 'partially-stripped' stars. In the future, it will be interesting to explore what happens to these partially-stripped stars and how they could be observed.

As featured in Phys.org

Background image: Pixabay

OzGrav scientists win Australia's most prestigious science awards: the 2020 Prime Minister's Prizes for Science

Four OzGrav scientists have been awarded the 2020 Prime Minister's Prizes for Science for their critical contributions to the first direct detection of gravitational waves–a landmark achievement in human discovery: Chief Investigator Emeritus Professor David Blair (University of Western Australia); Deputy Director Professor David McClelland (Australian National University); Chief Investigator Professor Susan Scott (Australian National University); and Chief Investigator Professor Peter Veitch (University of Adelaide).



The Prime Minister's Prizes for Science are Australia's most prestigious awards for outstanding achievements in scientific research, research-based innovation and excellence in science teaching. This year's recipients are four pioneering Australian physicists from OzGrav that contributed to the groundbreaking discovery of gravitational-wave signals from the collision of two black holes 1.3 billion years ago. This was made possible by decades of research and innovation of the team as part of the Laser Interferometer Gravitational-wave Observatory Scientific Collaboration (LSC).

Emeritus Prof. David Blair says: "It is wonderful to receive the Prime Minister's Prize for Science. It's a fitting tribute to all of the students and scientists who participated in this amazing quest that was finally rewarded with the detection of gravitational waves. This is a prize for physics in Australia."

Emer. Prof. Blair created a large-scale high-optical power research facility in Gingin, Western Australia, to mimic Advanced LIGO interferometers and investigate the subtle interactions between light, sound and heat that would occur in full-scale detectors. His pioneering work predicted that laser light would scatter from sound in the mirrors, causing parametric instability at power levels far below that needed to obtain detector sensitivity. When this theory was validated during LIGO commissioning, Emeritus Professor Blair sent team members to help implement stabilisation methods that allowed the detectors to achieve sufficient power levels to make the first detection of gravitational waves.

In 1916, Albert Einstein first predicted the existence of gravitational waves—minute distortions in the fabric of space-time that are non-electromagnetic in nature and spread from their source at the speed of light; however, he believed they would never be detectable.

Prof. Peter Veitch says: "Einstein developed his theory of relativity in 1915, but people questioned whether gravitational waves really existed or whether they were just some sort of mathematical nonsense predicted by the theory. Since then there has been a large advance in our understanding of the Universe, and our research has focused on developing the technologies required to detect Einstein's theorised gravitational waves."

Prof. Veitch's University of Adelaide team invented and installed critical instrumentation for the Advanced LIGO detectors, namely their Hartman sensors. These sensors provide a solution to a major technological problem – the distortion of the laser beam within the detector – by measuring them simply and with a sensitivity that is 30-times better than any other sensor. The Hartman sensors are used at all stages of the detection process: commissioning, measurement and adaptive correction of the distortions, and optimising the detector sensitivity and stability.

"Over the last few decades, there were many scientists who either didn't believe that gravitational waves existed, or felt that they were simply too small to ever be detected," explains Prof. Susan Scott. "We had enormous technological difficulties to overcome – everything had to be about a thousand times better, including the shapes of the mirrors, the frequency of the lasers, the acoustic wringing of the mirrors and the vibration isolation."

In September 2015, recent advances in detector sensitivity led to the first direct detection of gravitational waves; two Advanced Laser Interferometer Gravitational-Wave Observatory (aLIGO) laser interferometers simultaneously detected a signal characteristic of a pair of black holes – 29 and 36 times the mass of the sun – merging into one. This was followed by a further detection in 2017, from the collision of two neutron stars. The first detection of its kind, this event solved a 50-year-old mystery confirming that these mergers are the source of previously observed high-energy gamma ray bursts, and of heavy metals such as gold, platinum and uranium in the Universe.

Prof. Scott initiated the Australian effort in gravitational wave data analysis in 1998, and led Australian research in digging gravitational wave signals out of detector noise. Her Australian National University team contributed key components to the LIGO Data Analysis System through which the detection signal was processed in 2015, designing and conducting the first gravitational wave search to be carried out under Australian leadership.

Prof. David McClelland says: "This achievement (gravitational wave detection) came about only through long term investment in basic R&D by the Australian Research Council, our universities and many similar organisations around the world. This investment has led to impactful science, impactful technologies and inspired a generation of scientists and engineers."

The impact of the first 2015 detection, the acclaimed 'discovery of the century', has been immense, opening up previously unknown parts of the Universe, such as hidden black holes; understanding the origin of gamma ray bursts (and with the potential to discover how supernovae explode); and to even peer back to the beginning of time at the Big Bang.

Prof. McClelland led the Australian National University team that played a crucial role in designing, installing and commissioning Advanced LIGO's lock acquisition system, and in the construction and installation of Australian hardware for precision routing of the laser beam. His pioneering quantum 'squeezing' technology (now installed in all detectors) is essential for boosting interferometer sensitivity to the current level where signals are detected weekly when in operation.

The legacy of the team's combined research ensures that Australia is now 'front-and-centre' in exploring this brand-new window into the Universe. "The pioneering work of our team over the last quarter of a century has ensured that Australia played a leading role in the first direct detection of gravitational waves," says Prof. Susan Scott. "Australia is now in a position to be a powerhouse in the emergent field of gravitational wave astronomy."

For OzGrav Director Professor Matthew Bailes (Swinburne University of Technology), the result is especially pleasing. "This is fantastic recognition of the role Australia has played in opening this new window on Einstein's Universe. I'm thrilled for not only these four pioneers of the field in Australia, but for the future generations of scientists and engineers that will follow in their footsteps."

Background image: JOSH VALENZUELA/UNM

RESEARCH HIGHLIGHT

Triaxially-deformed, freely-precessing neutron stars: continous electromagnetic and gravitational radiation

Rapidly rotating, asymmetric neutron stars that undergo free precession can produce both modulated pulse signals and continuous gravitational radiation with characteristic features, and thus are potential interesting multi-messenger astrophysical sources.

Studies have been carried out to characterise the electromagnetic and gravitational-wave signals from freely-precessing neutron stars, mostly focused on biaxial stars; however, in the most generic cases, triaxially-deformed neutron stars demonstrate more complex features as a result of free precession. In this study, co-authored by OzGrav Associate Investigator Lilli Sun from Australian National University (who was working with Caltech at the time of this research), scientists extend previous work and derive the dynamical evolution of a generic, triaxially-deformed, freely-precessing neutron star with both analytical and numerical approaches.

If the neutron star is observed as a pulsar via radio and/or X-ray telescopes, the free precession could introduce observable characteristic modulations in both the timing and width of the pulse signals, depending on the wobble angle and other source properties. Moreover, free precession of a triaxially-deformed neutron star could manifest as additional lines in the spectra of continuous gravitational waves, detectable by the ground-based gravitational-wave detectors like Advanced LIGO, Virgo, and KAGRA.

The researchers introduce a numerical method to integrate the equations of motion in generic cases where analytical solutions are difficult to derive. The timing residuals, pulse-width modulations, as well as the gravitational-wave spectra of a precessing triaxial star, are presented with concrete examples. The results in this work provide guidance for future multi-messenger studies of triaxially-deformed, freely-precessing neutron stars.

Multi-messenger observation of precessing neutron stars will become promising with future high-precision electromagnetic observations (e.g., NICER X-ray timing) and next-generation gravitational-wave detectors (e.g., Einstein Telescope and Cosmic Explorer). Combining characteristic features in radio/X-ray signals and continuous gravitational waves of precessing neutron stars allows scientists to obtain valuable information about the source properties, e.g., the wobble angle, the non-axisymmetry and oblateness of the star. These measurements could shed light on the long-standing questions about the neutron star internal structure and the supranuclear matter equation of state.

Written by OzGrav Associate Investigator Lilli Sun (ANU)

OZGRAV IN THE MEDIA

New research suggests innovative method to analyse the densest star systems in the Universe

Artist's impression of supernova remnant, Pixabay

In a recently published study, a team of researchers led by the ARC Centre of Excellence for Gravitational Wave Discovery (OzGrav) at Monash suggests an innovative method to analyse gravitational waves from neutron star mergers, where two stars are distinguished by type (rather than mass), depending on how fast they're spinning.

Neutron stars are extremely dense stellar objects that form when giant stars explode and die—in the explosion, their cores collapse, and the protons and electrons melt into each other to form a remnant neutron star.

In 2017, the merging of two neutron stars, called GW170817, was first observed by the LIGO and Virgo gravitational-wave detectors. This merger is well-known because scientists were also able to see light produced from it: high-energy gamma rays, visible light, and microwaves. Since then, an average of three scientific studies on GW170817 have been published every day.

In January this year, the LIGO and Virgo collaborations announced a second neutron star merger event called GW190425. Although no light was detected, this event is particularly intriguing because the two merging neutron stars are significantly heavier than GW170817, as well as previously known double neutron stars in the Milky Way.

Scientists use gravitational-wave signals—ripples in the fabric of space and time—to detect pairs of neutron stars and measure their masses. The heavier neutron star of the pair is called the 'primary'; the lighter one is 'secondary'.

A binary neutron star system usually starts with two ordinary stars, each around ten to twenty times more massive than the Sun. When these massive stars age and run out of 'fuel', their lives end in supernova explosions that leave behind compact remnants, or neutron stars. Each remnant neutron star weighs around 1.4 times the mass of the Sun, but has a diameter of only 25 kilometres.

The first-born neutron star usually goes through a 'recycling' process: it accumulates matter from its paired star and begins spinning faster. The second-born neutron star doesn't accumulate matter; its spin speed also slows down rapidly. By the time the two neutron stars merge—millions to billions of years later—it's predicted that the recycled neutron star may still be spinning rapidly, whereas the other non-recycled neutron star will probably be spinning slowly.

Another way a binary neutron star system might form is through continuously changing interactions in dense stellar clusters. In this scenario, two unrelated neutron stars, on their own or in other separate star systems, meet each other, pair up and eventually merge like a happy couple due to their gravitational waves. However, current modelling of stellar clusters suggests that this scenario is ineffective in merging the neutron stars.

OzGrav postdoctoral researcher and lead author of the study Xingjiang Zhu says: 'The motivation for proposing the recycled-slow labelling scheme of a binary neutron star system is two-fold. First, it's a generic feature expected for neutron star mergers. Second, it might be inadequate to label two neutron stars as primary and secondary because they're most likely to be of similar masses and it's hard to tell which one is heavier.'

The recent OzGrav study takes a new look at both GW170817 and GW190425 by adopting the recycled-slow scheme. It was found that the recycled neutron star in GW170817 is only mildly or even slowly spinning, whereas that of GW190425 is spinning rapidly, possibly once every 15 milliseconds. It was also found that both merger events are likely to contain two nearly equal-mass neutron stars. Since there is little or no evidence of spin in GW170817, and neutron stars spin down over time, the researchers deduced that the binary probably took billions of years to merge. This agrees well with observations of its host galaxy, called NGC 4993, where little star formation activities are found in the past billions of years.

OzGrav associate investigator and collaborator Gregory Ashton says: 'Our proposed astrophysical framework will allow us to answer important questions about the Universe, such as are there different supernova explosion mechanisms in the formation of binary neutron stars? And to what degree do interactions inside dense star clusters contribute to forming neutron star mergers?'

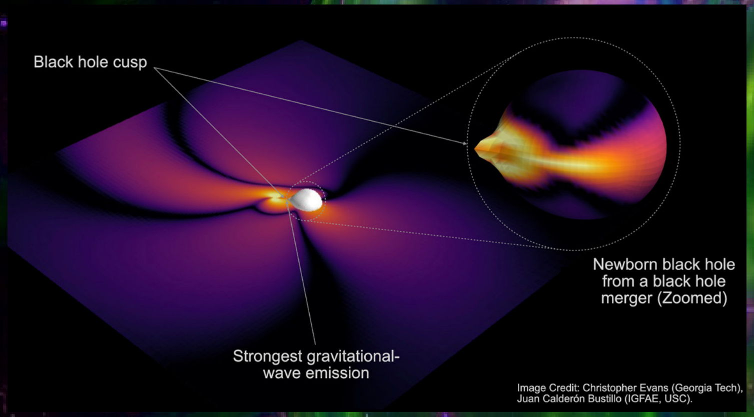
The LIGO/Virgo detectors finished their joint third observing run (O3) earlier this year and are currently conducting scheduled maintenance and upgrades. When the fourth run (O4) starts in 2021, scientists will be readily anticipating more discoveries of neutron star mergers. The prospect will be even brighter when the Japanese underground detector KAGRA and the LIGO-India detector join the global network over the coming years.

As featured in Phys.org

Background image: Pixabay

The black hole always chirps twice: Scientists find clues to decipher the shape of black holes

A team of gravitational-wave scientists led by the ARC Centre of Excellence for Gravitational Wave Discovery (OzGrav) reveal that when two black holes collide and merge, the remnant black hole 'chirps' not once, but multiple times, emitting gravitational waves—intense ripples in the fabric space and time—that inform us about its shape. The study was recently published in *Communications Physics* (from the prestigious *Nature* journal).



Black holes are one the most fascinating objects in the Universe. At their surface, known as the 'event horizon', gravity is so strong that not even light can escape from them. Usually, black holes are quiet, silent creatures that swallow anything getting too close to them; however, when two black holes collide and merge together, they produce one of the most catastrophic events in Universe: in a fraction of a second, a highly-deformed black hole is born and releases tremendous amounts of energy as it settles to its final form. This phenomenon gives astronomers a unique chance to observe rapidly changing black holes and explore gravity in its most extreme form.

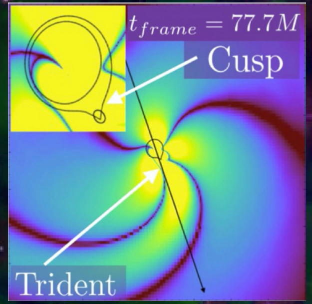
Although colliding black holes do not produce light, astronomers can observe the detected gravitational waves—ripples in the fabric of space and time—that bounce off them. Scientists speculate that, after a collision, the behaviour of the remnant black hole is key to understanding gravity and should be encoded in the emitted gravitational waves.

In the article published in Communications Physics (Nature), a team of scientists led by OzGrav alumnus Prof. Juan Calderón Bustillo—now 'La Caixa Junior Leader - Marie Curie Fellow' at the Galician Institute for High Energy Physics (Santiago de Compostela, Spain)—has revealed how gravitational waves encode the shape of merging black holes as they settle to their final form.

Graduate student and co-author Christopher Evans from the Georgia Institute of Technology (USA) says: 'We performed simulations of black-hole collisions using supercomputers and then compared the rapidly changing shape of the remnant black hole to the gravitational waves it emits. We discovered that these signals are far more rich and complex than commonly thought, allowing us to learn more about the vastly changing shape of the final black hole'.

The gravitational waves from colliding black holes are very simple signals known as 'chirps'. As the two black holes approach each other, they emit a signal of increasing frequency and amplitude that indicates the speed and radius of the orbit. According to Prof. Calderón Bustillo, 'the pitch and amplitude of the signal increases as the two black holes approach faster and faster. After the collision, the final remnant black hole emits a signal with a constant pitch and decaying amplitude—like the sound of a bell being struck'. This principle is consistent with all gravitational-wave observations so far, when studying the collision from the top.

However, the study found something completely different happens if the collision is observed from the 'equator' of the final black hole.



Detail of the shape of the remnant black hole after a black hole collision, with a 'chestnut shape'. Regions of strong gravitational-wave emission (in yellow) cluster near its cusp. This black hole spins making the cusp point to all observers around it.

CREDIT: C. Evans, J. Calderón Bustillo

'When we observed black holes from their equator, we found that the final black hole emits a more complex signal, with a pitch that goes up and down a few times before it dies,' explains Prof. Calderón Bustillo. 'In other words, the black hole actually chirps several times.'

The team discovered that this is related to the shape of the final black hole, which acts like a kind of gravitational-wave lighthouse: 'When the two original, 'parent' black holes are of different sizes, the final black hole initially looks like a chestnut, with a cusp on one side and a wider, smoother back on the other,' says Bustillo. 'It turns out that the black hole emits more intense gravitational waves through its most curved regions, which are those surrounding its cusp. This is because the remnant black hole is also spinning and its cusp and back repeatedly point to all observers, producing multiple chirps.'

Co-author Prof. Pablo Laguna, former chair of the School of Physics at Georgia Tech and now Professor at University of Texas at Austin, pointed out 'while a relation between the gravitational waves and the behaviour of the final black hole has been long conjectured, our study provides the first explicit example of this kind of relation'.

Also featured in Phys.org, Science Times and News Break.

Background image: Pixabay

PLANETYMOLOGY!

We're thrilled to announce the launch of *Planetymology* by OzGrav PhD student Isobel Romero-Shaw, from Monash University. Following her well-received OzGrav public lecture on the topic of The Etymology of the Universe, Isobel continued to pursue her interests in the etymology of the Universe and published this charming children's book! Isobel tells us more about the inspiration behind the project...

'The inspiration for this book was an amalgamation of various influences,' says Isobel. 'I'd been reading The Incredible Human Journey by Dr. Alice Roberts and The Art Instinct by Denis Dutton, which both got me interested in tracing human migration across the planet and the evolution of different cultures. I then heard on a podcast that the word galaxy comes from the Greek term for the Milky Way, galaxias kyklos, meaning milky circle, and I thought that was just lovely. So I started getting interested in etymology, and when I was given the opportunity to give one of OzGrav's public lectures, I thought I could make use of my new obsession by turning it into a public talk.'

'A few weeks later, I gave the OzGrav public lecture on the topic of The Etymology of the Universe, or Star Words. This was well received, and a few weeks after that I gave the same talk to Mount Burnett Observatory. I'd already discussed with OzGrav folks about making the cute planet characters into stickers or something for outreach, and I had in my head the beginnings of an idea for a kid's book based on those characters. When one of the Mount Burnett members asked me what I was planning on doing with the talk next, I realised that I really did want to make it into a book!'

'Making the book was such a fun project, and I really learnt a lot. In a lot of cases I felt like a kid myself, with a new wonder for the history hidden in everyday words. I think science, history and the arts are way too often split into these seperate boxes. Kids are told that they're a 'maths person' or a 'bookish person' or an 'arty person', and I don't see why that should be the case when everything is so interesting and interlinked. I am an astrophysicist, and that's often just as much about creativity as it is about logic—most problems need both in order to solve them!'

Faces of OzGrav: **Lilli Sun**

Former OzGrav PhD student Lilli Sun has returned to the OzGrav's welcoming arms (virtual—social distancing, right!) as our new Associate Investigator. Lilli tells us about her career journey over the last seven years…

Seven years ago, I was a project manager in IBM China System and Technology Lab, leading software development for IBM Storage products. I started working in that group as a software engineer right after getting my Master's degree in Engineering in Shanghai Jiao Tong University. I liked the job, but couldn't stop thinking about the things I loved better: physics, general relativity, black holes, etc… That year, I wrote an email to Prof. Andrew Melatos at the University of Melbourne (UoM), asking about the possibility of doing a PhD program on gravitational waves, which completely changed the direction of my life.

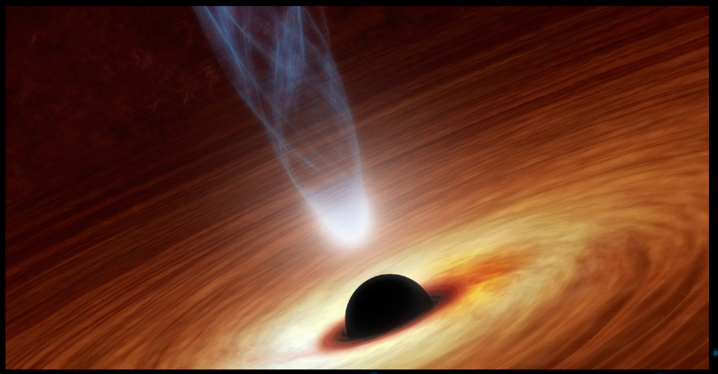
Six years ago, I started my PhD candidature in Andrew's group, mainly working on continuous-wave data analyses. Lacking background knowledge, I spent a lot effort catching up on maths and physics. It was great fun going back to classes, doing homework, and sitting in exams. Meanwhile, I started working on a novel method introduced and developed by the UoM group — the Viterbi tracking. I remembered calculating the Viterbi paths in exams when I was an undergrad in Engineering school. That felt like, déjà vu.

Five years ago, GW150914 happened, followed by all kinds of excitement including a golden multi-messenger event. I could not conceive of a more exciting PhD life! In those years, I implemented the first Viterbi search pipeline; analysed the first set of Advanced LIGO data, targeting Sco X-1; and then, extended my work to many other types of fascinating sources: young neutron stars, remnants of binary neutron star mergers, and ultralight bosons.

Two years ago, I left Australia and started a postdoc position in the LIGO Lab at Caltech, after getting my degree. I continued looking for waves from neutron stars and conjectured boson clouds, and I spent a lot time at the two LIGO sites, calibrating the detectors. Getting to know the complicated instruments made me feel much better than treating the data purely as output of a giant black box. I miss the time in the desert and swamp, which was quiet, special, and accompanied by many friends.
This has been a difficult year for everyone, starting with bush fires throughout Australia, followed by COVID-19. Setting all of those aside, I couldn't feel more excited to come back to Australia as a research fellow at the Australian National University and as an OzGrav Associate Investigator, starting a new journey in gravitational astrophysics research. A few years after I got into this field, detecting transient events has become a daily routine. I cannot wait to see what lies ahead. But first of all, I hope the global pandemic will come to an end soon, and that we can meet each other in person again!

Detecting colliding supermassive black holes: the search continues

A new study has developed an innovative method to detect colliding supermassive black holes in our Universe. The study has just been published in the *Astrophysical Journal* and was led by postdoctoral researcher Xingjiang Zhu from the ARC Centre of Excellence for Gravitational Wave Discovery (OzGrav), at Monash University.



Artist's impression of a supermassive black hole – NASA/JPL/CALTECH

At the centre of every galaxy in our Universe lives a supermassive black hole—a black hole that's millions to billions times the mass of our Sun. Big galaxies are assembled from smaller galaxies merging together, so collisions of supermassive black holes are expected to be common in the cosmos. But merging supermassive black holes remain elusive: no conclusive evidence of their existence has been found so far.

One way to look for these mergers is through their emission of gravitational waves—ripples in the fabric of space and time. A distant merging pair of supermassive black holes emit gravitational waves as they spiral in around each other. Since the black holes are so large, each wave takes many years to pass by Earth. Astronomers use a technique known as pulsar timing array to catch gravitational waves from supermassive binary black holes—so far to no avail.

In parallel, astronomers have been looking for the collision of supermassive black holes with light. A number of candidate sources have been identified by looking for regular fluctuations in the brightness of distant galaxies called "quasars". Quasars are extremely bright, believed to be powered by the accumulation of gas clouds onto supermassive black holes.

If the centre of a quasar contains two black holes orbiting around each other (instead of a single black hole), the orbital motion might change the gas cloud accumulatio and lead to periodic variation in its brightness. Hundreds of candidates have been identified through such searches, but astronomers are yet to find the smoking-gun signal.

'If we can find a pair of merging supermassive black holes, it will not only tell us how galaxies evolved, but also reveal the expected gravitational-wave signal strength for pulsar watchers,' says Zhu.

The OzGrav study seeks to settle the debate, determining if any of the identified quasars are likely to be powered by colliding black holes. The verdict? Probably not.

"We've developed a new method allowing us to search for a periodic signal and measure quasar noise properties at the same time," says Zhu. "Therefore, it should produce a reliable estimate of the detected signal's statistical significance."

Applying this method to one of the most prominent candidate sources, called PG1302-102, the researchers found strong evidence for periodic variability; however, they argued that the signal is likely to be more complicated than current models.

"The commonly assumed model for quasar noise is wrong," adds Zhu. "The data reveal additional features in the random fluctuations of gas accumulation onto supermassive black holes."

"Our results are showing that quasars are complicated," says collaborator and OzGrav Chief Investigator Eric Thrane. "We'll need to improve our models if we are going to use them to identify supermassive binary black holes."

As featured in Phys.org

Background image: Pixabay

Massively parallel Bayesian inference for transient gravitational-wave astronomy

The past year has seen a remarkable number of extraordinary gravitational-wave events including merging black holes and neutron stars: GW190814 contains the lightest black hole or heaviest neutron star ever observed; GW190412 and GW190814 provided strong evidence for higher-order multipoles predicted by General Relativity; and GW190521 was the heaviest binary black hole merger ever observed—and is a clear observation of an intermediate-mass black hole.

Learning about these events involves inferring the rich information contained in our gravitational-wave data. We infer information from gravitational waves by comparing experimental data to detailed astrophysical models of the signals. This turns out to be an extremely computationally challenging process. Using 'out of the box' inference algorithms would take many months, years or even decades to infer the properties of gravitational-wave signals. In the past, we've relied on various approximate methods to mitigate the large analysis times; however, these approximations break down when faced with the unique events of the past year.
Unlike codes previously used in LIGO/Virgo, ours can scale to many hundreds to thousands of computers (like on the OZSTAR supercomputer cluster) which reduces the end-to-end run time (or 'wall time') of inference analyses by many orders of magnitude.

> "We increasingly require more sophisticated (and expensive) models of gravitational waves to learn about the full properties of the systems which produced them. Not being able to use these models can present a roadblock to doing the best possible science. Because of this, we developed a massively parallel Bayesian inference framework which is both accurate, flexible and scalable."

This solved an important problem in astrophysical data analysis and made it feasible to perform the most precise measurements on the events of the past year. Many of the measurements which appeared in the recent LIGO publications were produced by our new method. The method itself is implemented in a software library called parallel bilby (pBilby).

The cost of inference is still extremely high: in terms of computer hours, a single analysis can take around 10 CPU years to complete. However, when deployed on a supercomputer cluster, the wall time can be brought down to about a week. Going forward, this greatly enhances our ability to extract the most information possible from our data. When LIGO/Virgo resumes observing, pBilby will be crucial for learning about the properties of new and exciting events.

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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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