

# SPACE TIMES

OzGrav

December 2021

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# Welcome

Dear Colleagues,

The pandemic has delivered very different experiences for our members depending upon their geographical location. I myself have been pleasantly surprised by how much my mood has improved by Melbourne's November return to our offices. It's wonderful to interact with my staff in person and sit in the sun to enjoy a barista-made coffee at one of the local cafes. I've also been able to properly separate my home and work lives, which I think is helping my focus and stress levels. As clever as Zoom is, there's a real benefit to informal catch-ups with students and staff that I've really missed in 2020/21.

Last week, OzGrav had its second virtual annual retreat, followed by local social events in our four node cities. I'm grateful to our ECRs who helped devise the combination of Gathertown and Zoom interactions, and our admin staff who always ensure everything runs smoothly. Overall our staff have remained very productive despite the lockdowns and, for most of us, the elimination of international travel.

Since the first gravitational wave detection in 2015, the growth in gravitational wave astrophysics has been remarkable with the

number of detections now at 90, all thanks to the hard work of a large international team including many of our OzGrav team. O4 (the fourth observing run starting late 2022) promises to yield the most detections yet and should help OzGrav complete its seven-year mission with new exciting science.

Two of our ECRs, Drs Jade Powell and Lilli Sun, have also been recently promoted to OzGrav Chief Investigators – congratulations Jade and Lilli!

Finally, I'd like to wish you all a refreshing break in the Christmas/New year holiday period and I look forward to seeing as many of you as possible in person as soon as practicable.

Yours sincerely - Matthew Bailes (OzGrav Director)



## NEWS IN BRIEF

- OzGrav PhD students Isobel Romero-Shaw and Debatri Chattopadhyay have collaborated together on a [colouring book about women in physics!](#) It's now available on Amazon as a paperback (hardback coming soon)!
- Congratulations to Isobel Romero-Shaw for winning Monash's Norris Family Award for Outstanding Author Contribution by a Graduate Research Student to a published 'Quality' Scholarly Research Output for the paper "GW190521: Orbital eccentricity and signatures of dynamical formation in a binary black hole merger"
- Congratulations to OzGrav Assoc. Investigator Colm Talbot for winning Monash's Vice-Chancellor's Commendation for thesis excellence for his thesis: "Astrophysics of Binary Black Holes at the Dawn of Gravitational-Wave Astronomy"
- Recent OzGrav Alumnus Ethan Payne (was from Monash and now at Caltech) received the [2021 LIGO Laboratory Award for Excellence in Detector Characterization and Calibration](#) for his outstanding work improving the incorporation of LIGO detector calibration errors into gravitational-wave parameter estimation analyses.
- Congratulations to OzGrav Chief Investigator Jeff Cooke, OzGrav Assoc. Investigator Adam Deller and OzGrav Postdoc Daniel Reardon who have received promotions at Swinburne.
- Congratulations to OzGrav PhD student Disha Kapasi who has been selected to represent ANU students in the 10th Anniversary edition of the [Global Young Scientists Summit \(GYSS\)](#) where she will interact with Nobel Laureates and world-renowned scientists.
- Congratulations to OzGrav Postdoc Simon Stevenson (Swinburne) for being awarded a DECRA!
- [The Capstone Editing Grant for Mid-Career Researchers applications are currently open and close on 24 February 2022](#)

## RESEARCH HIGHLIGHT

### Probing mysterious X-Ray remnants from extreme cosmic bursts of light

Short gamma-ray bursts are extremely bright bursts of high-energy light that last for a couple of seconds. In many of these bursts, there is a mysterious material left behind: a prolonged 'afterglow' of radiation, including X-rays. Despite the efforts of many scientists over many years, we still don't know where this afterglow comes from.

[In our recently accepted paper](#), we investigated a simple model that proposes a rotating neutron star—an extremely dense collapsed core of a massive supergiant star—as the engine behind a type of lengthy X-ray afterglows, known as X-ray plateaux. Using a sample of six short gamma-ray bursts with an X-ray plateau, we worked out the properties of the central neutron star and the mysterious remnant surrounding it.

The model we used was inspired by remnants from young supernova. While remnants from short gamma-ray bursts and supernovae have many differences, the energy driving from a rotating neutron star has the same underlying physics. So, if the remnant of a short gamma-ray burst is a neutron star, it must have a similar energy outflow as a supernova remnant.

In our study, we borrowed the basic physics from previous short gamma-ray burst models to predict the luminosity and duration of the X-ray plateau. For each short gamma-ray burst, the results suggested that the remnant neutron star is a millisecond magnetar: a neutron star with an extraordinarily powerful magnetic field. All known magnetars have a very slow rotation frequency; similarly, all observed neutron stars with millisecond spins have weak magnetic fields. This gap in observations isn't surprising because the magnetic field of the star converts the rotational energy into electromagnetic energy. For a magnetar-strength field, this process happens on a scale from seconds to days – exactly the duration of most X-ray plateaux.

This paper is the first attempt at estimating the source of X-ray afterglows using this kind of model. As the model matures and further data is collected, we'll be able to make stronger conclusions about the source of X-ray plateaux and, if we're lucky, discover what these mysterious remnants are.

Written by OzGrav researcher Lucy Strang, University of Melbourne.

**Editor-in-chief:** Luana Spadafora  
Subscribe or submit your contributions to [lspadafora@swin.edu.au](mailto:lspadafora@swin.edu.au)

Background image by the International Centre for Radio Astronomy Research



**Limits on weak supernova explosions from isolated stars**

Many of the heaviest stars in the Universe will end their lives in a bright explosion, known as a supernova, which briefly outshines the rest of its host galaxy, allowing us to view these rare events out to great distances. At the lower end of this mass range, the supernova explosion will squeeze the core of the star into a dense ball of neutrons that is much denser than what can be reproduced in laboratories. So, scientists must rely on theoretical models and astronomical observations to study these objects, known as neutron stars.

At the very low end of this range, the supernova explosions are thought to be weaker and dimmer, but even for state-of-the-art supernova simulations, it's challenging to test this hypothesis. [In our recently published study](#), we found a new way to test these weaker supernovae: by associating weaker supernova explosions with slowly moving neutron star remnants, neutron star speeds could accurately estimate the weaker supernovae, without the need for expensive simulations.

Neutron stars don't shine bright like other stars, but instead produce a very narrow beam of radio waves which may (if we're lucky) point toward the Earth. As the neutron star rotates, the beam of light appears to flash on and off, creating a lighthouse effect. When this effect is observed, we refer to it as a pulsating star, or pulsar. Recent advances in radio telescopes allow for precise measurements of pulsar velocities. We combined our measurements with simulations of millions of stars and found that the typically high pulsar speeds did not allow for many weak supernovae.

However, there is a caveat: many of the massive stars that produce neutron stars are born in stellar binaries. If a normal supernova occurs in a stellar binary, the neutron star remnant will experience a large recoil kick—like a cannonball rushing away from the exploding gunpowder—and it will likely eject away from its companion star where it may later be observed as a single pulsar. But if the supernova is weak, the neutron star may not have enough energy to escape the gravitational tug of its companion star, and the stellar binary system will remain intact. This is a necessary step in the formation of neutron star binaries, so the existence of these binaries proves that some supernova explosions must be weak.

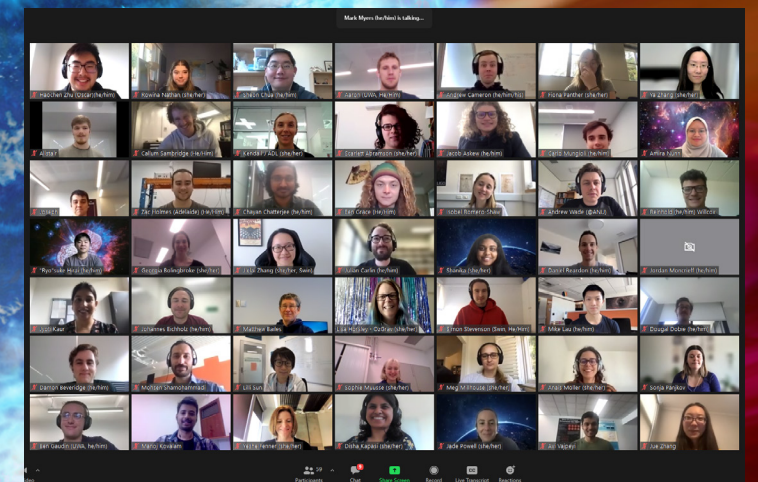
We found that to explain both the existence of neutron star binaries and the absence of slow-moving pulsars, weak supernovae can only occur in very close stellar binaries, not in single, isolated stars. This is useful for modelling supernova simulations and adds to a growing body of research suggesting that weak supernovae may only happen in stellar binaries which have previously interacted with each other. Studies like this, which simulate many stars in relatively low detail, are key to understanding the effects of uncertain physics on stellar populations, which is unfeasible with highly-detailed simulations.

Written by PhD student Reinhold Wilcox, Monash University

Background image by Carl Knox, OzGrav-Swinburne University

**OzGrav virtual ECR workshop and retreat 2021**

Another year, another successful OzGrav ECR workshop and retreat! This year, OzGrav nodes collaborated virtually via Zoom, Slack and Gathertown to share ideas and lessons, and enjoy many interactive games (thanks to Lisa Horsley!). As restrictions eased throughout Australia, many members were able to finally catch up in person at each node after another challenging year working from home. A big thanks to all the organisers and node admin staff who coordinated the scheduling and behind-the-scenes tech, including Erin O'Grady for all her excellent work. Below are some photos from the virtual meetings, games and social events from different nodes. (All photos supplied).





## Scientists present largest number of gravitational wave detections to date from black holes & neutron stars

The gravitational-wave Universe is teeming with signals produced by merging black holes and neutron stars. In a new paper released today, an international team of scientists, including Australian OzGrav researchers, present 35 new gravitational wave observations, bringing the total number of detections to 90!

All of these new observations come from the second part of observing run three, called “O3b”, which was an observing period that lasted from November 2019 to March 2020. There were 35 new gravitational wave detections in this period. Of these, 32 are most likely to come from pairs of merging black holes, 2 are likely to come from a neutron star merging with a black hole, and the final event could be either a pair of merging black holes or a neutron star and a black hole. The mass of the lighter object in this final event crosses the divide between the expected masses of black holes and neutron stars and remains a mystery.

Dr Hannah Middleton, postdoctoral researcher at OzGrav, University of Melbourne, and co-author on the study says “Each new observing run brings new discoveries and surprises. The third observing run saw gravitational wave detection becoming an everyday thing, but I still think each detection is exciting!”

### Highlights

Of these 35 new events, here are some notable discoveries (the numbers in the names are the date and time of the observation):

- Two mergers between possible neutron star - black hole pairs. These are called GW191219\_163120 and GW200115\_042309, the latter of which was previously reported in its own publication. The neutron star in GW191219\_163120 is one of the least massive ever observed.
- A merger between a black hole and an object which could either be a light black hole or a heavy neutron star called GW200210\_092254
- A massive pair of black holes orbiting each other, with a combined mass 145 times heavier than the Sun (called GW200220\_061928)
- A pair of black holes orbiting each other, in which at least one of the pair is spinning upright (called GW191204\_171526)
- A pair of black holes orbiting each other which have a combined mass 112 times heavier than the Sun, which seems to be spinning upside-down (called GW191109\_010717)
- A ‘light’ pair of black holes that together weigh only 18 times the mass of the Sun (called GW191129\_134029)

The different properties of the detected black holes and neutron stars are important clues as to how massive stars live and then die in supernova explosions.

“It’s fascinating that there is such a wide range of properties within this growing collection of black hole and neutron star pairs”, says study co-author and OzGrav PhD student Isobel Romero-Shaw (Monash University). “Properties like the masses and spins of these pairs can tell us how they’re forming, so seeing such a diverse mix raises interesting questions about where they came from.”

Not only can scientists look at individual properties of these binary pairs, they can also study these cosmic events as a large collection - or population. “By studying these populations of black holes and neutron stars we can start to understand the overall trends and properties of these extreme objects and uncover how these pairs came to be” says OzGrav PhD student Shanika Galaudage (Monash University) who was a co-author on a companion publication released today: ‘The population of merging compact binaries inferred using gravitational waves through GWTC-3 P2100239’. In this work, scientists analysed the distributions of mass and spin and looked for features which relate to how and where these extreme object pairs form. Shanika adds, “There are features we are seeing in these distributions which we cannot explain yet, opening up exciting research questions to be explored in the future”.

Detecting and analysing gravitational-wave signals is a complicated task requiring global efforts. Initial public alerts for possible detections are typically released within a few minutes of the observation. Rapid public alerts are an important way of sharing information with the wider astronomy community, so that telescopes and electromagnetic observatories can be used to search for light from merging events - for example, merging neutron stars can produce detectable light.

Says Dr Aaron Jones, co-author and postdoctoral researcher from The University of Western Australia, “It’s exciting to see 18 of those initial public alerts upgraded to confident gravitational wave events, along with 17 new events”.

All of these detections were made possible by the global coordinated efforts from the LIGO (USA), Virgo (Italy) and KAGRA (Japan) gravitational-wave observatories.

Between the previous observing runs, the detectors have been continually enhanced in small bursts which improves their overall sensitivity. Says Disha Kapasi, OzGrav student (Australian National University), “Upgrades to the detectors, in particular squeezing and the laser power, have allowed us to detect more binary merger events per year, including the first ever neutron star-black hole binary recorded in the GWTC-3 catalogue. This aids in understanding the dynamics and physics of the immediate universe, and in this

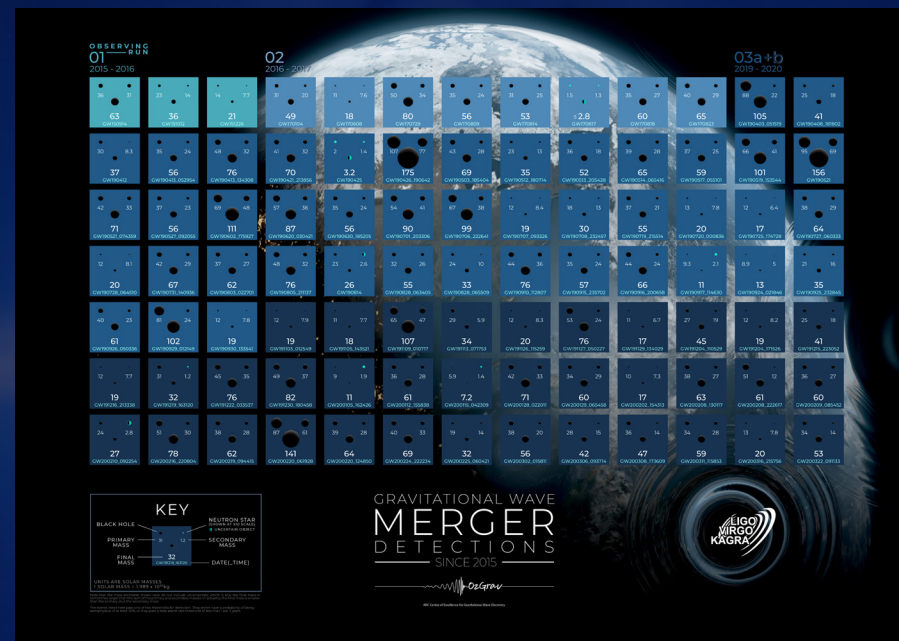
exciting era of gravitational wave astronomy, we are constantly testing and prototyping technologies that will help us make the instruments more sensitive.”

The LIGO and Virgo observatories are currently offline for improvements before the upcoming fourth observing run (O4), due to begin in August 2022 or later. The KAGRA observatory will also join O4 for the full run. More detectors in the network help scientists to better localise the origin or potential sources of the gravitational waves.

“As we continue to observe more gravitational-wave signals, we will learn more and more about the objects that produce them, their properties as a population, and continue to put Einstein’s theory of General Relativity to the test,” says Dr Middleton.

Also featured in [The Guardian](#), [Space Australia](#), [Canberra Times](#) and [Perth Now](#).

Feature image by Carl Knox, OzGrav-Swinburne University





## Pratyasha Gitika



During my Master's thesis, I got introduced to modelling compact objects such as neutron stars and then extended my work to estimate gravitational wave amplitudes from isolated spinning neutron stars and millisecond pulsars. For this project, I worked on pulsar data from the Australia Telescope National Facility database. The idea of such dense exotic stars was quite fascinating, and I wanted to explore the subject further. After a quick chat with my current supervisors, I was convinced that if I want to continue studying pulsars and gravitational waves, then Ozgrav is the place to be.

Currently, I'm a newly appointed PhD student with Ozgrav at the Centre for Astrophysics and supercomputing, Swinburne University. For my PhD, I'll observe and analyse pulsar data from one of the most powerful and sensitive radio telescopes in the southern hemisphere i.e. MeerKAT. We will explore the galaxy's pulsars for studies of relativistic gravity, binary evolution and probe the millisecond pulsars that inhabit the globular clusters.

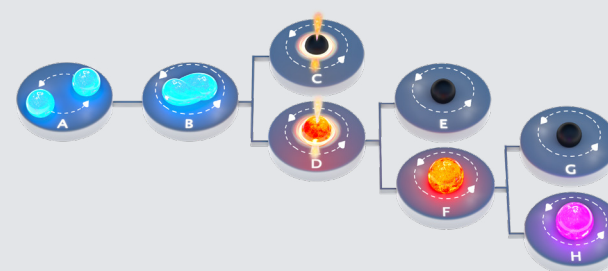
Travelling from India to Australia to commence my PhD has been a big challenge. Even though I got my offer letter in 2019, the international travel ban put a halt to the process all along. I am fortunate to be one of the few people who could travel to Australia during the pandemic and grateful to everyone who helped me along the way. In the little amount of time I have spent here, I have met and interacted with some amazing people who have made moving to a whole new hemisphere and continent much easier. The beautiful city of Melbourne is the icing on the cake and the weather here never fails to surprise me.

In my spare time, I enjoy acrylic painting and teaching myself a chord or two on the keyboard. The flora and fauna in Australia is quite different from my home country and I love walking around and exploring those.

Background image by James Josephides, Swinburne University

### The aftermath of binary neutron star mergers

On 17th August 2017, LIGO detected gravitational waves from the merger of two neutron stars. This merger radiated energy across the electromagnetic spectrum, light that we can still observe today. Neutron stars are incredibly dense objects with masses larger than our Sun confined to the size of a small city. These extreme conditions make some consider neutron stars the caviar of astrophysical objects, enabling researchers to study gravity and matter in conditions unlike any other in the Universe.



*Schematic representation of binary neutron star merger outcomes. Panels A and B: Two neutron stars merge as the emission of gravitational waves drives them towards one another. C: If the remnant mass is above a certain mass, it immediately forms a black hole. D: Alternatively, it forms a quasispherical hypermassive neutron star. E: As the hypermassive star spins down and cools it can not support itself against gravitational collapse and collapses into a black hole. F, G: If the remnant's mass is sufficiently low, it will survive for longer, as a 'supramassive' neutron star, supported against collapse through additional support against gravity through rotation, collapsing into a black hole once it loses this support. H: If the remnant is born with small enough mass, it will survive indefinitely as a neutron star. Schematic from Sarin & Lasky 2021. Image credit: Carl Knox (Swinburne University).*

The momentous 2017 discovery connected several pieces of the puzzle on what happens during and after the merger. However, one piece remains elusive: What remains behind after the merger? [In a recent article published in General Relativity and Gravitation](#), Nikhil Sarin and Paul Lasky, two OzGrav researchers from Monash University, review our understanding of the aftermath of binary neutron star mergers. In particular, they examine the different outcomes and their observational signatures.

The fate of a remnant is dictated by the mass of the two merging neutron stars and the maximum mass a neutron star can support before it collapses to form a black hole. This mass threshold is currently unknown and depends on how nuclear matter behaves in these extreme conditions. If the remnant's mass is smaller than this mass threshold, then the remnant is a neutron star that will live indefinitely, producing electromagnetic and gravitational-wave radiation. However, if the remnant is more massive than the maximum mass threshold, there are two possibilities: if the

remnant mass is up to 20% more than the maximum mass threshold, it survives as a neutron star for hundreds to thousands of seconds before collapsing into a black hole. Heavier remnants will survive less than a second before collapsing to form black holes.

Observations of other neutron stars in our Galaxy and several constraints on the behaviour of nuclear matter suggest that the maximum mass threshold for a neutron star to avoid collapsing into a black hole is likely around 2.3 times the mass of our Sun. If correct, this threshold implies that many binary neutron star mergers go on to form more massive neutron star remnants which survive for at least some time. Understanding how these objects behave and evolve will provide a myriad of insights into the behaviour of nuclear matter and the afterlives of stars more massive than our Sun.

Written by OzGrav researcher Nikhil Sarin, Monash University.



# New funding opportunities for OzGrav members

**OzGrav is pleased to announce the following new funding opportunities available to our OzGrav members. We encourage our OzGrav members to familiarise themselves with the Grants available to them and all submissions are welcome:**

## **Research and Innovation Grant**

OzGrav is pleased to offer Research & Innovation Grants to provide funding to enable our students and postdocs to undertake new and innovative projects. The funds are aimed at empowering early career researchers to pursue novel ideas. These projects may be pure research or innovative projects to apply technology or skills to other real-world applications. Applications from teams of students/postdocs are welcomed, with cross-nodal teams especially encouraged.

## **Professional Development Grant**

The OzGrav Professional Development Grant aims to enable OzGrav Early Career Researchers to participate in activities and training to improve their professional development skills.

## **Hardship Grant**

The Hardship grants scheme is intended to support OzGrav students and postdocs facing financial difficulty or loss of income/employment as a result of extraordinary circumstances (e.g. impacts of the pandemic leading to unforeseen financial difficulties, gaps in employment, etc). The funds are intended to allow the recipient to work effectively on OzGrav research.

## **Other existing OzGrav funding opportunities include:**

### **Carer Grant**

The Carers Grant is open to OzGrav CIs, AIs, Postdocs, Staff & Students whose professional opportunities are impacted by their primary care giver role\*.

The maximum amount that can be awarded to a recipient is \$2,000 and the funds can be used for, but not limited to, the following:

- Childcare, nanny or carer services
- Travel expenses for dependent child/children )
- Expenses associated with providing in-home care for the dependent, e.g. in-home care services, or travel for a family member to provide in-home care
- Travel expenses associated with bringing a collaborator to visit the primary care giver

### **International visitor funding**

The OzGrav International Visitor Program has been established to support travel by leading international scientists to collaborate on OzGrav projects with OzGrav CIs and other members within Australia. This is a competitive funding program, with potential visitors to be nominated by OzGrav CIs. Visitors will be encouraged to visit multiple nodes, participate in node and theme meetings, and give seminars or public talks during their visit. At least one third of the budget should come from the hosting or sponsoring node(s).

### **Sponsorship request**

OzGrav accepts requests to sponsor events or projects that are relevant and beneficial to our members. Please submit the below application for and the Executive Committee will review your application for sponsorship.

### **Vacation scholarship contribution**

OzGrav is pleased to offer a financial contribution towards vacations scholarships for 8-12 weeks per student for a suitable Project. OzGrav central will provide 2/3 of the stipend support (up to a maximum of \$400 per student from OzGrav central) and nodes will fund the remaining portion of the stipend. We assume that the level of the stipend will be in accordance with the node's usual vacation scholar rates.

### **Travel award scheme**

This scheme is intended to support travel and placements that would not be possible without supplemental funding. We note that each node already has a budget that includes a base level of travel support for students and postdocs. Under this scheme, priority is given to extended placements/visits to work on OzGrav research. Only in exceptional circumstances will we support travel to attend a conference, as this would usually be expected to be covered by the node.

### **GWIC 3G Funding**

OzGrav has been awarded additional ARC funds to support Australian participation in the GWIC Third Generation Ground-based Detectors Study. These funds may be used to enable OzGrav members to work with the GWIC 3G working groups and subcommittees to develop plans and reports articulating:

- The science case for the next generation of observatories which drive the designs of future detectors
- Recommendations for the coordination of key research and development themes and programs that will lead to technological breakthroughs needed to achieve design goals
- Recommendations for governance frameworks to efficiently manage and operate the next generation GW network

Further information and details about how to apply for these grants, as well as existing funding opportunities and initiatives, can be found on the [OzGrav website](#). If you have any questions regarding any of our funding opportunities, please contact OzGrav's Chief Operating Officer Yeshe Fenner [yeshefenner@swin.edu.au](mailto:yeshefenner@swin.edu.au)



## RESEARCH HIGHLIGHT

### Exploring common envelope outcomes with responses of stripped stars

**B**inary neutron stars have been detected in the Milky Way as millisecond pulsars and twice outside the galaxy via gravitational-wave emission. Most of them have orbital periods of less than a day—a contrasting difference to their progenitors: massive stellar binaries that have hundreds or thousands of days orbital periods. In the last several decades, there has been much debate about explaining how massive binaries transition to double compact objects. To date, one of the strong contenders to explain this transition is the highly-complex stage of binary stellar evolution known as the common-envelope phase.

The common-envelope phase is a particular outcome of a mass transfer episode. It begins with the Roche-lobe overflow of (at least) one of the stars, and it's prompted by a dynamical instability. In a simple version, the stellar envelope of the mass-transferring star—the donor—bloats and engulfs the whole binary, creating a new system comprised of an inner compact binary, and a shared “common” envelope. The interaction of the inner binary with the common envelope results in drag, and the dissipated gravitational energy is transferred onto the common envelope, which can lead to its ejection. A successful ejection suggests that a compact binary can form. But what does a “successful ejection” mean?

To explore the common-envelope phase with three-dimensional hydrodynamical models, we attempted to address the likely outcomes of common-envelope evolution by considering the response of a one-dimensional stellar model to envelope removal. [In a recent study](#), we focussed on the common-envelope phase scenario of a donor star with a neutron star companion. We emulated the common-envelope phase by removing the envelope of the donor star, either partially or completely. After the star was stripped, we followed its radial evolution. The most extreme scenarios resulted as expected: If you remove all the envelope, the stripped star remains compact. Alternatively, if you leave most of the envelope, the stripped star subsequently expands a lot. The question is: what happens in between the extreme cases?

Our research shows that when most of the envelope, but not all of it, is removed, the star experiences a short phase of marginal contraction (<100 years), but overall, the star remains compact during the next 1000 years. This suggests that a star doesn't need to be stripped all the way to the core to avoid an imminent stellar merger. Moreover, the amount of energy needed to partially strip the envelope is less than the one needed to fully remove it. Finally, it's reassuring that our results show a strong correlation to variations in donor mass and composition.

This research is a step forward in the understanding of the common envelope phase and the formation of double neutron star binaries. Our results imply that a star can be stripped without experiencing Roche lobe overflow immediately after the common envelope, a likely condition for a successful envelope ejection. It also suggests that stripped stars retain a few solar masses of peculiar, hydrogen-poor material in their surface. While this amount of hydrogen is not excessive, it might be observable in the spectra of a star and can play a role at the end of its life when it explodes into a supernova. While the full understanding of the common-envelope phase remains elusive, we are connecting the dots of the evolution and fate of systems that have experienced a common-envelope event.

Written by OzGrav research Alejandro Vigna-Gómez from the Niels Bohr Institute (University of Copenhagen)

Background image from Pixabay

## RESEARCH HIGHLIGHT

### Investigating the spins of binary black hole mergers

**W**ith the growing catalogue of binary black hole mergers, researchers can study the overall spin properties of these systems to uncover how they formed and evolved. Recent work paints a conflicting picture of our understanding of the spin magnitudes and orientations of merging binary black holes, pointing to different formation scenarios. Our recent study, published in the *Astrophysical Journal Letters*, resolved these conflicts and allowed us to understand the spin distribution of binary black holes.

#### Forming black hole binaries

There are two main pathways to form a binary black hole: the first is via ‘isolated’ evolution, a process which involves the black hole binary being formed from the core collapse of two stars in a binary; the second is ‘dynamical’ evolution where interactions between black holes in dense stellar clusters can lead to a pair of black holes capturing each other to form a binary. These pathways show distinct features in the spin distribution of binary black hole mergers.

Binaries formed via isolated evolution tend to have spins that are closely aligned with the orbital angular momentum, whereas dynamically formed systems have spins that are randomly orientated and have a distribution of spin tilts that is isotropic. In the latest population study from LIGO-Virgo, we saw evidence for both of these channels, however a more recent study by Roulet et. al 2021, showed that the population was consistent with the isolated channel alone.

This inconsistency raises the question: how can we obtain different conclusions from the same population? The answer is model misspecification: The previous spin models were not designed to capture possible sharp features or sub-populations of spin in the model.

#### The emerging picture of the spins of black hole binaries

Using a catalogue of 44 binary black hole mergers, this new study finds evidence for two populations within the spin distribution of black hole binaries: one with negligible spins and the other moderately spinning with preferential alignment with the orbital angular momentum.

This result can be fully explained via the isolated formation scenario. The progenitors of most black holes lose their angular momentum when the stellar envelope is removed by the binary companion, forming black hole binaries with negligible spin, while a small fraction of binaries have the second-born black hole spun up via tidal interactions. This study opens a number of interesting avenues to explore, for example, an investigation of the relationship between the mass and spin of these different subpopulations. Investigating such correlations can help improve the accuracy of our models and enable us to better distinguish between different evolution pathways of binary black holes.

Written by OzGrav PhD student Shanika Galaudage, Monash University



## Exploring the mysterious origins of the most extreme light flashes in the Universe

Our Universe shines bright with light across the electromagnetic spectrum. While most of this light comes from stars like our Sun in galaxies like our own, we are often treated with brief and bright flashes that outshine entire galaxies themselves. Some of these brightest flashes are believed to be produced in cataclysmic events, such as the death of massive stars or the collision of two stellar corpses known as neutron stars. Researchers have long studied these bright flashes or ‘transients’ to gain insight into the deaths and afterlives of stars and the evolution of our Universe.

Astronomers are sometimes greeted with transients that defy expectations and puzzle theorists who have long predicted how various transients should look. In October 2014, a long-term monitoring programme of the southern sky with the Chandra telescope—NASA’s flagship X-Ray telescope—detected one such enigmatic transient called CDF-S XT1: a bright transient lasting a few thousands of seconds. The amount of energy CDF-S XT1 released in X-rays was comparable to the amount of energy the Sun emits over a billion years. Ever since the original discovery, astrophysicists have come up with many hypotheses to explain this transient; however, none have been conclusive.

In a recent study, a team of astrophysicists led by OzGrav postdoctoral fellow Dr Nikhil Sarin (Monash University) found that the observations of CDF-S XT1 match predictions of radiation expected from a high-speed jet travelling close to the speed of light. Such “outflows” can only be produced in extreme astrophysical conditions, such as the disruption of a star as it gets torn apart by a massive black hole, the collapse of a massive star, or the collision of two neutron stars.

Sarin et al’s study found that the outflow from CDF-S XT1 was likely produced by two neutron stars merging together. This insight makes CDF-S XT1 similar to the momentous 2017 discovery called GW170817—the first observation of gravitational-waves, cosmic ripples in the fabric of space and time—although CDF-S XT1 is 450 times further away from Earth. This huge distance means that this merger happened very early in the history of the Universe; it may also be one of the furthest neutron star mergers ever

observed.

Neutron star collisions are the main places in the Universe where heavy elements such as gold, silver, and plutonium are created. Since CDF-S XT1 occurred early on in the history of the Universe, this discovery advances our understanding of Earth’s chemical abundance and elements.

Recent observations of another transient AT2020blt in January 2020—primarily with the Zwicky Transient Facility—have puzzled astronomers. This transient’s light is like the radiation from high-speed outflows launched during the collapse of a massive star. Such outflows typically produce higher energy gamma-rays; however, they were missing from the data—they were not observed. These gamma rays can only be missing due to one of three possible reasons: 1) The gamma-rays were not produced. 2) The gamma rays were directed away from Earth. 3) The gamma-rays were too weak to be seen.

In a separate study, led again by OzGrav researcher Dr Sarin, the Monash University astrophysicists teamed up with researchers in Alabama, Louisiana, Portsmouth and Leicester to show that AT2020blt probably did produce gamma-rays pointed towards Earth, they were just really weak and missed by our current instruments.

Dr Sarin says: “Together with other similar transient observations, this interpretation means that we are now starting to understand the enigmatic problem of how gamma-rays are produced in cataclysmic explosions throughout the Universe”.

The class of bright transients collectively known as gamma-ray bursts, including CDF-S XT1, AT2020blt, and AT2021any, produce enough energy to outshine entire galaxies in just one second.

“Despite this, the precise mechanism that produces the high-energy radiation we detect from the other side of the Universe is not known,” explains Dr Sarin. “These two studies have explored some of the most extreme gamma-ray bursts ever detected. With further research, we’ll finally be able to answer the question we’ve pondered for decades: How do gamma ray bursts work?”

As featured in [Phys.org](#)

## 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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