SPACE TIMES

OzGrav Bi-monthly newsletter
October 2019

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Welcome

Welcome to the October edition of *Space Times.*

It's amazing how quickly gravitational wave astrophysics is evolving. As we celebrated the fourth anniversary of the first gravitational wave detection last month, LIGO/Virgo accelerated their discovery rate and are providing a treasure trove of cosmic events for analysis. This is particularly rewarding for many of our staff who have been working towards this for decades, and the younger members who have trekked to the sites to enhance and debug the detectors.

We are also extremely proud of Dr Ryan Shannon (Swinburne University of Technology) and Professor Ilya Mandel (Monash University) who were recently awarded ARC Future Fellowships. Ilya's project is on *Shining Gravitational Waves on Binary Astrophysics.* Ryan's project is on *Transforming Fast Radio Bursts Into An Astrophysical Tool.* This is a wonderful testament to the quality and impact of their research, and a great result for OzGrav.

In this edition of Space Times, we explore the value of OzGrav's gravitational wave science and how it's improving self-driving cars and learn about the innovative methods of OzGrav's Jeff Cooke and Garry Foran to *hear* the stars: using sound to study distant galaxies and explosions in the Universe. We also cover stories about OzGrav Chief Investigator Ilya Mandel's Tibetan trip teaching astrophysics to monks; the Zadko Observatory in Gingin, Western Australia; and the possible collision between a black hole and neutron star. Plus, we meet some of the faces of OzGrav, past and present, and get a snapshot of the recent Education and Public Outreach events.

We are fortunate to have a talented team at OzGrav to help showcase our science through our newsletters, annual reports, and graphics like our striking cover image. I hope you enjoy reading this edition.

I'm just about to board a plane to visit the Hanford LIGO detector and am excited to see one of the seven wonders of the scientific world!

Regards
Matthew Bailes (OzGrav Director)

News in brief

- Congratulations to the new ARC Centre of Excellence for Dark Matter Particle Physics, which has been awarded $35M to investigate the nature of Dark Matter. OzGrav looks forward to opportunities to collaborate with the new Centre, due to commence in 2020 led by Professor Elisabetta Barberio at the University of Melbourne.
- Congratulations to Dr Ryan Shannon (Swinburne University of Technology) and Professor Ilya Mandel (Monash University) who were recently awarded ARC Future Fellowships.
- Postdoc Joris van Heijningen (UWA) participated in a podcast on The Naked Scientists —*Black Hole collides with a neutron star.*
- OzGrav has won the bid to host the 14th Edoardo Amaldi Conference on Gravitational Waves in Melbourne in 2021. The tentative dates are 19-23 July 2021. This will be a great opportunity to showcase the Australian gravitational wave community to our international colleagues

OzGrav

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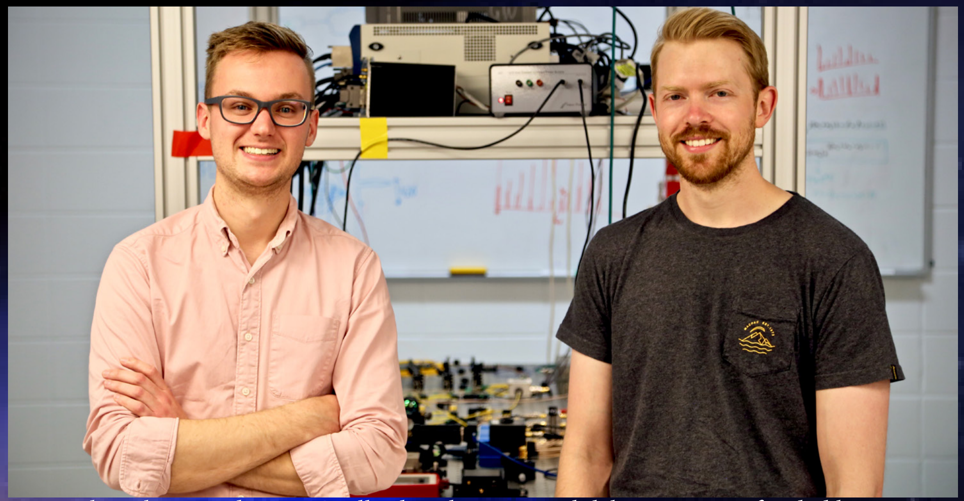
Making safer self-driving cars using *Gravitational Wave Detection Technology*

Two scientists from the ARC Centre of Excellence for Gravitational Wave Discovery (OzGrav) and the ARC Centre of Excellence for Engineered Quantum Systems (EQUS), at the Australian National University, are using technology originally developed to detect gravitational waves—the small ripples in the space-time continuum caused by colossal stellar events such as colliding black holes—to make self-driving cars safer.

Postdoctoral Research Fellow Dr Lyle Roberts and PhD Researcher James Spollard are developing a light detection and ranging (LiDAR) sensor that measures not only how far away objects are, but also how fast they are moving. This work is being supported through the OzGrav Research Translation Seed Funding scheme that is open to OzGrav members (see further details here)



Dr Lyle Roberts and James Spollard in their research lab at ANU co-funded by ARC Centres of Excellence OzGrav and EQUS.

LiDAR is considered to be a crucial technology for self-driving vehicles as it provides highly detailed three-dimensional maps of the surrounding environment. LiDAR works by scanning a laser beam around the vehicle and analysing the light that reflects off the surrounding objects.

Conventional LiDAR sensors typically only map the distance to surrounding objects. However, the LiDAR sensor developed by the researchers measures many attributes of the light simultaneously, including frequency, which gives it the ability to measure distance as well as velocity.

By measuring velocity, Roberts and Spollard aim to help self-driving cars achieve super-human perception. This is important because road networks have been designed for over a hundred years to be navigated by humans, not robots. According to Spollard, 'in order for self-driving cars to be safer than human drivers, they require better-than-human perception. Autonomous vehicles are about 99% of the way there, but it's that last 1% that really matters.'

The human brain's visual cortex—which processes information produced by the eyes—is highly efficient at prioritising object based on movement, Roberts explains. 'Objects that move within our field-of-view are more difficult to anticipate and therefore considered a higher priority than stationary objects. When driving, we tend to pay more attention to things that move because they are more likely to be hazardous.' By giving autonomous vehicles the ability to measure velocity, they intend to improve the safety of self-driving by enabling them to prioritise objects based on movement.

This LiDAR technology makes clever use of a technique that is being used in the Nobel-Prize winning detection of gravitational waves. Director of OzGrav Professor Matthew Bailes says: 'At OzGrav, we're really excited to support real-world applications of gravitational wave technology. Lyle and James's LiDAR technology is just one of many examples of cutting-edge gravitational wave research having spin-off benefits to society and industry.'

'This is a great example of an application inspired by quantum technology research, where the control techniques and precision needed at the quantum level can be rolled out into industrial and consumer technologies,' says EQUS Director Professor Andrew White.

As featured in the Herald Sun; Adelaide Advertiser and Courier Mail.

Hearing the stars: sonification in astronomy

OzGrav student Garry Foran isn't the first blind astrophysicist but his work, with his supervisor—OzGrav Chief Investigator Jeff Cooke—is truly unique: developing novel tools that use sound to study distant galaxies and detect the fastest explosions in the Universe.

As part of OzGrav's research program called *Deeper Wider Faster*, these tools have not only made astronomy more inclusive for visually-impaired scientists, they've also opened the door to more efficient ways of processing data and even helped sighted astronomers make new discoveries. While the technology has been developed for all scientists, 'it just also happens that it serves visually impaired and blind people, allowing them to participate in real science in the community, from anywhere in the world,' says Cooke.

Back in 2015, when Foran knew he would need to retrain in a different scientific area to compensate for his increasing blindness, he approached Cooke. Initially, Cooke wasn't sure that the idea could work: 'When Garry came to me with his story and his desire to study astrophysics, I did think of astronomy as quite a visual science. But his project was designed to study complex relationships between galaxy properties in a mathematical sense, free from visual bias of possible trends. We started to work with data sonification to help Garry hear the spectra of data that the rest of us see on our computers and hear the complex sounds of multiple parameters at once.'

Cooke and Foran are currently working on using sonification in the Deeper Wider Faster program which uses over 60 telescopes globally and in space to look for the fastest bursts in the Universe. According to Cooke, when this massive program is being coordinated and run, it generates simultaneous data from many of these telescopes. Sonification is the use of human sound recognition to perceptualise data—a very new field in astronomy. Cooke and Foran, together with Jeff Hannam from RMIT University and Dr. Wanda Diaz Merced (another blind astrophysicist from South Africa), recently published a paper on sonification as a way to tackle the vast amounts of data being generated in astronomy. Data sources include facilities like the Square Kilometre Array which is expected to produce data faster than the global traffic on the internet.

Cooke says: 'You need to understand the data within seconds, before the fast bursts fade. You need to get through a lot of data fast. There's this urgency there. When Garry came, we were looking for ways to try to analyse the data faster and better, and sound came up as an option. We started learning that there are many areas of sound that haven't been exploited, and that you can hear certain information faster than you can see it.'

One of the tools the researchers developed is called *StarSound*, which turns data points into different sounds and uses higher order harmonics to look for previously unseen (by sighted scientists at least) connections and relationships. Higher-order harmonics are the same thing that help us discern if we hear a note by a flute or a trumpet. The note, frequency, duration and volume are all the same. But the human ear can instantly distinguish if the sound is a flute or a trumpet because different higher-order harmonics come off each instrument.

StarSound incorporates stereo sound to enable blind and visually-impaired people to hear and visualise the data plot—it integrates software that's been used in the music industry since the early 1970s to generate, manipulate and synthesise sound. The team aims to exploit the human brain to isolate and filter out desired sounds, otherwise known as the 'cocktail party effect': whereby someone can hear their name spoken softly in a noisy room because they are sensitised to certain sounds.

'When Garry came, we were looking for ways to try to analyse the data faster and better, and sound came up as an option. We started learning that there are many areas of sound that haven't been exploited, and that you can hear certain information faster than you can see it.' - OzGrav Chief Investigator Jeff Cooke

Garry Foran with his guide dog, Trooper.

Image credit: NASA/JPL-Caltech

The art of inexplicable Eddies

Many of us as kids have played Poohsticks—throwing a twig into flowing water from a bridge or riverbank and watching it race downstream, but then losing the competition because your stick gets caught in the endless spin of an eddy on the edge of a creek. On a larger scale, these same eddies or whirlpools have reportedly dragged ships down into a watery grave. But eddies don't only exist in water.

Image by Mark Ashkanasy

Picture the video of a plastic bag caught in a swirling gust of wind in the film *American Beauty*, or the cow being dragged through the air in a monster tornado in the film *Twister*. Imagine the condensed water spiralling off the tips of a fighter jet, or the terrifying jolt as a jumbo jet gets caught in unexpected turbulence. Eddies are the physical outcome of the movement of fluids (both liquid and gas) and they exist on many scales. Now, a team of scientists, engineers and artists, led by OzGrav Chief Investigator Andrew Melatos and artist Briony Barr of Scale Free Network, have come together to produce an art-science experiment, called *A Hierarchy of Eddies*, showing audiences the complexity of these turbulent systems.

Eddies can be described mathematically using what is called the Navier-Stokes Equation, but the creators of this work say there's something about their evolving shapes that transcends physics or maths and enters the realms of philosophy, psychology and performance. A Hierarchy of Eddies is currently touring as part of an exhibition, *Experimenta Makes Sense: International Triennial of Art*, by Melbourne-based arts organisation *Experimenta.*

The exhibit was created with technical advice from computation fluid dynamics researcher Professor Andrew Ooi and masters student Tony Zahtila, both from University of Melbourne.

A Hierarchy of Eddies is, in part, inspired by a quote from English mathematician, physicist, meteorologist, psychologist and poet Lewis Fry Richardson who lived between 1881 and 1953. Reinterpreting mathematician Augustus De Morgan's rhyme about the biological order of fleas ('Big fleas have little fleas upon their backs to bite 'em / And little fleas have lesser fleas, and so, ad infinitum…'), Richardson wrote:

Big whorls have little whorls
which feed on their velocity,
And little whorls have lesser whorls
And so on to viscosity.

Melatos is a theoretical astrophysicist who was part of the Laser Interferometer Gravitational-Wave Observatory (LIGO) collaboration that in 2015 confirmed the existence of gravitational waves.

But he is also fascinated by what he calls the emergent properties of scientific phenomena – the complex patterns in space and time that arise when simple, fundamental rules are repeated over and over. The experiment explores the turbulence of eddies using two large fans and ten litres of polystyrene balls enclosed in a glass chamber. Standing on the outside, the audience can watch as the balls are swept into air currents, creating chaotic patterns and shapes in ever-changing whorls.

'Through viscosity and nonlinear forces, the air translates the pressure produced by the fans into complex, turbulent eddies at all length-scales, from the small to the large. In this respect, the particle chamber is both theatrical performance and archetypal out-of-equilibrium system.' But the work is also about the relationship between the viewer and the artwork. According to Melatos, each viewer's experience of the tableau is unique. In this way, the collaboration blurs the line between artistic representation and scientific emulation. 'It provokes the viewer to do their own experiment into the mysteries of far-from-equilibrium pattern formation. It opens the door between studio and laboratory and encourages free passage.'

By Dr Daryl Holland from University of Melbourne and Briony Barr from Scale Free Network

A full version of this abridged article can be found on Pursuit.

OzGrav Alumni: Where are they now?

Letizia Sammut

I was interested in astronomy from a young age. Some of my earliest memories are from going for walks in the evening with my father, who was an avid amateur astronomer. He would point out planets and constellations and explain how the Earth's rotation and orbit are the result of gravity.

Like many, when I decided to take on a PhD, I was unsure where it could or where I wanted it to take me. I just knew I was interested in gravitational waves so studying them sounded good to me (for a few years at least). My first exposure to the concept of gravitational waves came in 2006, when it was listed on the topic list for the research component of my third-year undergraduate physics course. I was intrigued and spent the next semester teaching myself general relativity (which was not formerly taughtat my university until honours level) to unpack Einstein's field equations. I learnt about the types of various detectors around the world and found out about LIGO. Although the prospect of detecting gravitational waves seemed onerous and still a long way off, the idea of an entirely new observational window on the Universe really inspired me and I wanted to be a part of it.

During my PhD, I developed a data analysis pipeline to search for a continuous signal from neutron stars in Low Mass X-Ray Binary systems. I continued to write and run search pipelines as a postdoc at Monash University, searching for the stochastic gravitational wave background. Developing and testing analysis code and scripts in different computer languages, as well as installing and maintaining software packages on various operating systems, provided me with a desirable skill set in the field of Scientific Computing.

It was a busy and exciting time with many new detections coming in and OzGrav coming together and gaining momentum. I enjoyed my involvement with LIGO and was excited by the prospects of OzGrav, however I was also feeling ready to try something new. There was an opportunity for a Senior Scientific Software Engineer at the Australian Nuclear Science and Technology Organisation (ANSTO), which runs the Australian synchrotron facility. This job would allow me to combine my passion for science and my experience in computer programming and software development to facilitate leading edge science for the benefit of the broader community.

As part of the Scientific Computing team at the Australian Synchrotron, I am responsible for designing and developing the software solutions for the operational and scientific outcomes of the facility. A synchrotron is a light-source that generates extremely bright light by accelerating electrons to almost the speed of light and deflecting using magnetic fields. At each deflection, very intense light is emitted which is a million times brighter than the sun.

The scientific research and innovation output of the Synchrotron span hugely diverse fields—from medicine to cultural heritage—and the many specialised 'beamlines' or experiments make my work interesting and varied. The systems developed and maintained within Scientific Computing range from communicating and moving technical hardware (motor, mirrors, cameras, etc.), to enabling facility users to access and analyse their data.

And for the multitude of problems, there are usually a multitude of possible solutions. My job involves staying up-to-date with and on top of the ever- changing and advancing programming tools and software engineering. This means I am constantly learning and applying new tools and technologies, often working on multiple projects at once.

Being part of a team also means there is lots of collaboration, usually involving multidisciplinary groups. This teamwork and collaboration is something I really enjoy, and am happy to be able to continue after the collaborative experience of being part of both LIGO and OzGrav.

Originally featured in LIGO magazine.

Scientists marvel at possible collision between a black hole and neutron star

For the first time scientists may have witnessed the end of a neutron star as it was engulfed by a black hole. On August 14 2019, Australian and international researchers from the LIGO (US) and Virgo (Italy) gravitational wave observatories detected tickles in the cosmos triggered by this event, which was immediately reported on a public database available to the world's astronomers.

Gravitational waves are small vibrations in the space-time continuum caused by accelerating objects. Earlier this year, researchers got fleetingly excited when they measured a possible collision between a black hole and neutron star, but the signal was weak and may have been a false alarm.

However, this latest signal is very loud! It was observed by both LIGO detectors and the Virgo detector, with a total false alarm rate estimated to be one-in-ten septillion years.

We would have to wait for a quadrillion times longer than the age of the Universe to get an event like this by accident from noise alone.

Based on preliminary publicly available results, this event named S190814bv appeared to be a promising Neutron Star-Black Hole merger candidate. It is estimated that the collision between the two objects occurred around 900 million light-years away, and within an area about 23 square degrees across the sky. (For comparison, the moon is about half a degree across).

The detection is considered important not just because it would be the first time a neutron star has been seen being eaten by a black hole (which to date has only been hypothesised), but it would confirm that these sorts of mergers exist and help us understand how such systems were formed.

OzGrav researchers, who were part of the international LIGO-Virgo Collaboration that made the discovery, spent the following days and nights busily scouring the sky with a network of telescopes to confirm whether this collision also produced visible light.

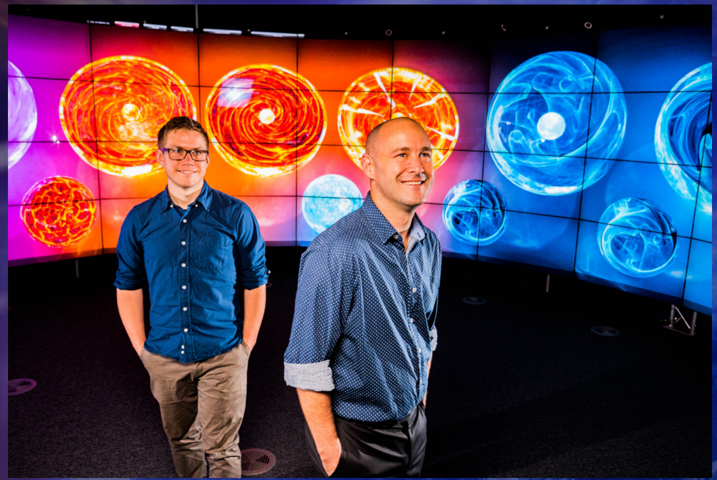
'We would have to wait for a quadrillion times longer than the age of the Universe to get an event like this by accident from noise alone.'

They were expecting to either observe a cosmic fireball associated with a neutron star being ripped apart by a black hole, or see nothing If telescopes see nothing, it's possible that the neutron star was swallowed entirely by the black hole without being ripped apart. There is also the intriguing possibility that the swallowed object was not in fact a neutron star, but was a very light black hole, lighter than any other black hole we know about in the Universe—a truly awesome consolation prize for the scientists.

As featured in ABC News, CBS News and Science Alert

Glitch in neutron star reveals hidden secrets

Neutron stars are among the densest objects in the Universe, and they rotate extremely fast and regularly. Until they don't. Occasionally, these neutron stars start to spin even faster, caused by portions of the inside of the star moving outwards. It's called a 'glitch', and it's a rare glimpse into what lies within these mysterious objects. In a recent paper published in Nature Astronomy, a team from OzGrav, at Monash University; McGill University, in Canada; and the University of Tasmania, studied the Vela Pulsar: a neutron star in the southern sky, 1,000 light years away from Earth.



Greg Ashton and Paul Lasky

According to the paper's first author OzGrav Associate Investigator Greg Ashton, only 5% of pulsars are known to glitch—Vela 'glitches' approximately once every three years. This makes Vela a prized jewel among the 'glitch hunters' like Ashton and his colleague, OzGrav Associate Investigator Paul Lasky. By re-analysing data from observations of the Vela glitch in 2016—taken by co-author Jim Palfreyman from the University of Tasmania—Ashton and his team found that during the glitch, the star started spinning even faster before relaxing down to a final state.

According to Lasky, this observation (done at the Mount Pleasant Observatory in Tasmania) is particularly important because, for the first time, scientists got invaluable insights into the interior of the star, revealing that the inside of the star actually has three different components. 'One of these components, a soup of superfluid neutrons in the core, moves outwards first and hits the rigid crust of the star causing it to spin up. But then, a second soup of superfluid that moves in the crust catches up to the first causing the spin of the star to slow back down. This

'...for the first time, scientists got invaluable insights into the interior of the star, revealing that the inside of the star actually has three different components.'

overshoot has been predicted a couple of times in the literature, but this is the first real time it's been identified in observations,' says Lasky.

Another observation defies explanation: 'Immediately before the glitch, we noticed that the star seems to slow down its rotation rate before spinning back up. We have no idea why this is, and it's the first time it's ever been seen! We speculate it's related to the cause of the glitch, but we're honestly not sure,' says Ashton. He suspects this paper will spur some new theories on neutron stars and glitches. '

As featured in The Age

Faces of OzGrav

Sofia Suvorova

I studied Mathematics at Moscow State University before I came to Australia in 1993, at which time I started a PhD in Applied Mathematics under the expert tutelage of Bill Moran at Flinders University in South Australia. I have worked on a variety of signal processing projects, such as Wavelets; Statistical Signal Processing and Optimisation; and Radar and Sonar Sensor Management. My own special skill is finding elegant practical applications of mathematical knowledge to unsolved problems.

OzGrav Chief Investigator Andrew Melatos recently introduced me to the astrophysical problems associated with gravitational waves recorded by LIGO. These recordings may contain 'messages from the Universe'. I believe that the way to understand these message-waves is by using the methods of signal processing.

I work on developing cutting-edge, radical and efficient algorithms in this exciting area—my team were the first people to introduce the Viterbi Algorithm to detect continuous gravitational waves. Our implementation is now recognised by LIGO as the standard for this. I'm also currently working on pulsar timing analysis.

I continue to raise my two boys who also have mathematical interests (one is already a Humboldt Research Fellow) and keep a menagerie of four-legged (two dogs) and no-legged creatures (two fish) as companions. Unfortunately, only the two-legged creatures in my family have mathematical interests.

Joris Vincent van Heijningen

My first University experience was not physics, but aerospace engineering. Material science seemed most interesting to me so after one year I switched to the stuff we do and love. My first long project was in nuclear physics, specifically in perturbed angular correlation of radioactive isotopes in the reactor institute at Delft University of Technology, in the Netherlands. We used the effect of the environment (e.g. acidity level) on the timing of cascade gamma emission of those isotopes to probe said environment.

Next was particle physics and I was lucky enough to do a project on optical alignment of future linear accelerators at the European Organization for Nuclear Research (CERN). I then completed a short project on silicon microstrip detectors for X-ray free electron diffraction experiments at the Stanford Linear Accelerator Center (SLAC). Following this, I started a PhD at Nikhef in Amsterdam and worked for Virgo and the Kamioka Gravitational Wave Detector (KAGRA), while developing an interferometric readout of a Watt linkage type accelerometer. This was a great experience and, as we all know, 'well timed' (or, I was lucky once again). It gave me ample opportunities for outreach that led to many public seminars and a national TV appearance in the Netherlands!

In June 2016, a few months after the first gravitational wave detection was announced, a Dutch TV crew flew to Pisa, Italy, to shoot an episode for *Klokhuis*—a Dutch children's TV show. Explaining the story of gravitational waves to children was challenging, but I like to think we did a good job. Our script was presented to perfection and I even got a few seconds of fame as the 'physics expert'. Growing up watching Klokhuis every day, this meant a lot to me. The show was aired in February 2017, and a few months later I was pointed to a tweet by a Belgian professor. He praised the 'excellent' show, but the biggest compliment of all was the drawing by his 10-year-old child depicting the concepts we had explained in the episode!

My next goal is to help design, fund and build the 3rd generation of gravitational wave detectors. In addition to the opportunity to study OzHF, where we push a 2.5 G high frequency detector to a good position, I would love to work on the Einstein Telescope or Cosmic Explorer. The future is bright for our field; I hope to benefit from the momentum and hope that we'll 'never stop listening!'.

Upcoming conferences

- Yokohama-GRB meeting 28 October - 1 November 2019, Yokohama
- OzGrav ECR workshop 18 - 19 November 2019, Lorne, (Mantra resort)
- OzGrav Annual Retreat 20 - 22 November 2019, Lorne, (Mantra resort)
- The 29th Workshop on General Relativity and Gravitation 25-29 November, Japan
- 30th Texas Symposium on Relativistic Astrophysics 15-20 December 2019
- ANITA Summer School February 2020, NSW
- KOZWaves 4th Australasian Conference on Wave Sciences, 17 - 19 February 2020, The University of Melbourne
- GWADW 2020 will be held 11-17 May 2020 in Hokkaido, Japan
- 13th International LISA Symposium will be held 19-24 July 2020 in Glasgow, Scotland

Upcoming prizes & awards

- Australian Institute of Physics awards and prizes - nominations now open until April 2020

From Flat Earth Theory to gravitational waves: Teaching Tibetan monks astrophysics

OzGrav Chief Investigator Ilya Mandel, from Monash University, recently travelled to the Gaden monastery outside of Hubli in the southern region of India, where he spent a fortnight training current and future geshe—monks with the equivalent of a Ph.D.—in their studies. Started in 2006 by Emory University in the US and the Dalai Lama, the aim of the Emory-Tibet Science Initiative is designed to give Tibetan monks university-level science training across a variety of disciplines. The program is part of the Dalai Lama's push to modernise the six-year curriculum of the monastic universities.

The first-year curriculum includes basic introductory material in physics, biology, neuroscience and the philosophy of science and the teaching is undertaken by visiting academics from around the world. By year four, the monks receive an introduction to quantum physics, 'and by their final year the curriculum extends to astrophysics and cosmology,' says Mandel. The training isn't all one way, as scientists can observe Tibetan Buddhist approaches to study, meditation, and debate.

Their traditional methods of learning and teaching are far removed from a western lecture theatre—Mandel explains: 'The monks can debate an issue for literally hours. It will at times get quite heated with lots of gesturing, but at the end of the debate there are no hard feelings between the combatants. They are not very good mathematicians, but are expert logicians, able to quickly find flaws in any argument, so the sorts of approximations and over-simplifications we typically provide in introductory lectures in the Western curriculum don't fly: the monks are guaranteed to spot the logical inconsistencies.'

As one of the class projects, the monks were asked to debate, in the traditional Tibetan style, over a physics question: whether everyone in the class has at least one particle in their body from the apple that fell on Newton's head. After 45 minutes, the lively debate had to be stopped, otherwise they would have continued until nightfall. (By the way, the answer is yes, in case you haven't done the calculation yet.)

According to Mandel, observing the monks' relationship to physics is a way to understand the history of the subject. In their drive to understand the world from first principles and philosophical contemplation, rather than reliance on empirical evidence or experiments, the Tibetan monks would be natural allies of the Aristotelean school of thought. In fact, the parallels run to details—for example, just like Aristotle, the monks are convinced that the natural state of matter is rest, and in the absence of forces all bodies in motion must come to rest.

The monks are generally keen to learn about the modern Western approach to science and many support that a new way of thinking must be embraced when dealing with scientific questions. One monk quoted the Dalai Lama in this respect, who argued against flat Earth traditionalists within the Tibetan community by querying if they had ever seen the obvious by looking out of an airplane. However, there is a limit to this willingness to shift the viewpoint. When discussing various forms of energy—the energy of motion, gravitational energy, the energy of a spring, electrical energy etc.—the monks were appalled by the absence of the energy of ideas and compassion energy from the list. On being told that these are not concepts that physics deals with, they were rather disappointed by the focus on the body rather than the mind. Perhaps it is a good reminder that, as exciting as gravitational waves are, there are other things that are not dreamt of in modern physics.

Tibetan monks debating

Education and Public Outreach

National Science Week - Science in the Park

Suspension AMIGO and alpacas at Adelaide University Open Day

Science Alive & AMIGO at Adelaide University

ANU visit to Amaroo Primary School

SciVR Live Stream Event

The Zadko Observatory

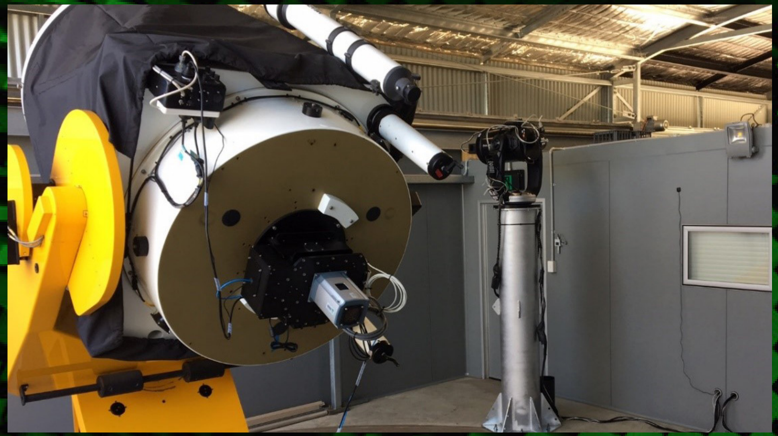
As the quest for space exploration continues to grow, many of Australia's remote locations are proving ideal sites for future development. The Zadko Telescope, located approximately 70 kilometres north of Perth in the Shire of Gingin (Western Australia), is the only metre-class optical research facility at this southern latitude between the east coast of Australia and South Africa. It can also rapidly image optical transients* at a longitude not monitored by other similar facilities.

The Zadko Telescope performs an important role in tracking and mapping space debris, which is the millions of pieces of "junk" orbiting Earth, mostly made up of fragments of spacecraft and satellites. Space junk is a significant and growing problem, because it travels faster than the speed of a bullet and can cause major damage to functioning satellites if it collides.

Since its operation in June 2008, Zadko has also detected numerous Gamma Ray Burst afterglows, two of these being the most distant optical transients imaged by an Australian telescope. With OzGrav's support, Zadko has been involved in significant international research projects with partners including the University of Western Australia; LIGO; NASA (Gamma Ray Burst and solar system science); the European Space Agency (Fast Radio Bursts); and many more agencies. Recently, the French Space Agency (CNES) has also requested Zadko telescope time to track the launch of Europe's Galileo GPS satellites.

Zadko is also a useful tool for education, training and public outreach, as the global awareness and importance of astronomy continues to increase. For example, in 2017, there was national media coverage of Zadko's contribution to the discovery of colliding neutron stars, capturing the imagination of the public.

Over the past two years, six other remotely-operated, equatorially-mounted telescopes have now been added to the Zadko Observatory. Two belong to a French company (Ariane Group) and are used for space surveillance and space traffic management; another belongs to a US company (Numerica Corporation) and is used for space surveillance and exploration of the GEO belt.



There's also a low-surface brightness refractor used for probing the faint Universe that is managed by the International Centre for Radio Astronomy (ICRAR), as well as SPIRIT III & IV research-grade instruments used by schools across Australia.

The original 6.7 metre fibreglass dome which housed the Zadko Telescope was replaced in 2011 with a state-of-the-art robotic rolling roof facility—it includes a 21m² climate-controlled operation room and telescope service room. This additional service room allowed for a potential future conversion into a second control room as other telescopes are added to the increased 63m² viewing area.

Author: John Moore

*Definition - * Optical transients are objects in space that change brightness on timescales ranging from minutes to years.*

The Zadko Observatory team consists of Associate Professor David Coward, Research Associate Bruce Gendre, Research Fellow Eric J Howell, Honorary Research Fellow John Kennewell, Senior Technical Officer / Observatory Manager John Moore and Electronic Engineer Andrew Burrell.

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.

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