OzGrav

ARC Centre of Excellence for Gravitational Wave Discovery

STRATEGIC PLAN 2021-2024

VISION

TO PURSUE EXCEPTIONAL RESEARCH & SCIENTIFIC DISCOVERY

OzGrav will cement Australia's position as an international leader in gravitational wave research.

TO PROVIDE WORLD–CLASS RESEARCH TRAINING & LEADERSHIP

Our postdoctoral fellows and students will be provided with high-quality supervision, and our career development programme will ensure researchers are equipped for successful careers in both academia and industry.

TO INSPIRE YOUNG PEOPLE TO TAKE UP CAREERS IN SCIENCE & TECHNOLOGY

OzGrav Education & Public Outreach programmes will inspire and educate the general population about the nature of our Universe and explain how the scientific method works and can be trusted.

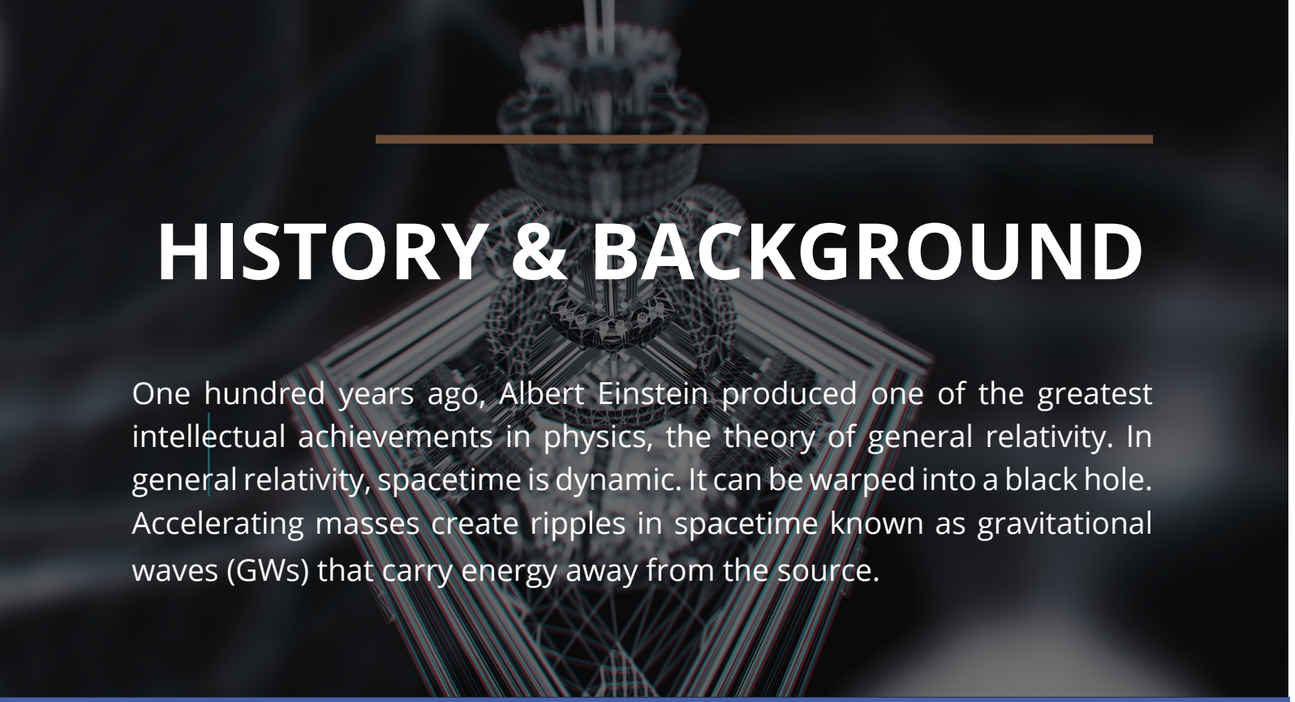
VALUES

OzGrav is strongly committed to the equitable and inclusive treatment of all its members and colleagues, and to the elimination of discrimination and barriers of disadvantage. OzGrav seeks to create a culture of acceptance, and respects the strength that diversity creates.

All background images by Carl Knox, OzGrav/Swinburne University

MISSION

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. The Centre brings together the Australian pulsar and gravitational-wave communities in a focused national program. Through this centre Australian scientists and students have the opportunity to fully participate in gravitational wave astronomy on an international stage.



HISTORY & BACKGROUND

One hundred years ago, Albert Einstein produced one of the greatest intellectual achievements in physics, the theory of general relativity. In general relativity, spacetime is dynamic. It can be warped into a black hole. Accelerating masses create ripples in spacetime known as gravitational waves (GWs) that carry energy away from the source.

Recent advances in detector sensitivity led to the first direct detection of gravitational waves in 2015. This was a landmark achievement in human discovery and heralded the birth of the new field of gravitational wave astronomy. It was followed in 2017 with the first detection of a neutron star merger that ushered in a new era of astronomy in which extreme events in the cosmos can be heard by gravitational wave detectors and seen by telescopes, giving us two senses with which to probe the Universe.

OzGrav is funded by the Australian Government through the Australian Research Council Centres of Excellence funding scheme, and is a partnership between Swinburne University (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. OzGrav commenced operations on 6th April 2017 with funding totalling approximately $40M for seven years.

GOVERNANCE & MANAGEMENT

The **OzGrav Executive Committee** oversees the management, operations, and performance of the Centre across the six collaborating research nodes. Led by the Centre Director, the Centre Executive Committee comprises representation from each node. The Executive receives advice from five OzGrav committees: **the Governance Advisory Committee, Scientific Advisory Committee, Research Translation Committee, Equity and Diversity Committee, and the Professional Development Committee.** The Executive Committee oversees and makes decisions about the Centre's research and non-research programs, finances, strategic funding allocations, policies, management and governance.

Day-to-day operational matters are managed by the **core administrative team**, led by the Chief Operating Officer, in consultation with the Centre Directorate (comprising the Centre Director, Deputy Director, and Chief Operating Officer).

The Centre's **Governance Advisory Committee** includes prominent representatives from the Australian education, research, engineering and business sectors. This committee is responsible for advising on OzGrav's strategic direction, governance and fiscal management, structure and operating principles, performance against Centre objectives, and intellectual property and commercialisation management.

The role of the **OzGrav Scientific Advisory Committee** is to provide the Centre with independent scientific expertise, advice, and experience from established national centres and leading international laboratories regarding the OzGrav research program.

The **Research Translation Committee** is responsible for overseeing the identification and management of commercialisable technologies developed under the Centre, and advising on strategies and initiatives to support industry engagement and technology transfer.

The **Equity and Diversity Committee** oversees the development and implementation of strategies to enable positive and supporting work environments for all our members, and to promote equity and diversity. The committee has developed an equity and diversity action plan, and regularly reviews and monitors the Centre's performance against the plan.

The Professional Development Committee identifies and advises on career development and training opportunities to equip our members with a broad range of translatable skills. The committee is also responsible for developing and overseeing the Centre mentoring program. The Professional Development Committee also receives and considers advice from our self-run Early Career Researcher Committee.

OzGrav research is structured into Themes and Programs. **The Instrumentation Theme** is managed by Deputy Director David McClelland. The **Data/Astrophysics Theme** is managed by Director Matthew Bailes and Chief Investigator Eric Thrane. Each Theme comprises Programs which are overseen by a Chair or Co-Chairs who help coordinate Program activities and report on progress and plans to the Theme leader.

PRIORITY 1

ACHIEVE EXCELLENCE IN RESEARCH & TECHNOLOGY DEVELOPMENT

The ARC Centre of Excellence for Gravitational Wave Discovery (OzGrav) builds on over 40 years of Australian contributions to instrumentation and data pipelines that led to the first detection of gravitational waves in 2015. With the commencement of OzGrav, the size of the Australian gravitational wave community has grown from approx 70 in 2016 to more than 250 in 2020, and with it our reputation for research excellence has grown too, both nationally and abroad.

To continue to maximise OzGrav's research outputs & impact, we use our annual retreats as a time for in-depth review and planning to ensure that our efforts are focussed on answering the key scientific and instrumentation challenges and that we are agile in responding to new opportunities. We strongly support our members to collaborate with other world-leading researchers both within the Centre and externally, and we have competitive travel awards and international distinguished visitor programs to facilitate this. We also support OzGrav science workshops and events with potential new collaborators and industry partners. The impacts of the global pandemic have curtailed many in-person events and visits involving travel, so where possible, we have pivoted to virtual replacements.

OzGrav coalesces many disparate research activities into a focussed national program, cross-fertilising across disciplines that extend from lasers and radio instrumentation to big data, theoretical modelling and astronomy. We use weekly Centre-wide videocons to ensure that our members are across each others' research and aware of the enormous breadth of in-house expertise that they can draw on through OzGrav.

To maximise OzGrav's reputation and visibility, we work closely with the global community, taking on leadership positions within the LIGO-Virgo collaboration and future detector planning groups. We also promote our members' achievements through media releases, social media, newsletters and nominating members for prestigious prizes.

To build on OzGrav's successes to date and to sustain our high level of research outputs, we are proactive in seeking and securing additional funding to support new avenues of research and research translation.

PRIORITY 1

ACHIEVE EXCELLENCE IN RESEARCH & TECHNOLOGY DEVELOPMENT

STRATEGIC OBJECTIVE	ACTIONS	PERFORMANCE MEASURES (*INDICATES AN OFFICIAL KPI)
1.1 Enhance Australia's international reputation for excellence in gravitational wave research	• Engage with and influence the global gravitational wave community • Provide travel awards to bring esteemed international visitors to visit the centre • Disseminate research results through high-impact publications • Present research results at scientific conferences and workshops • Provide training and mentoring to our researchers about communicating science to a professional audience • Publish and disseminate regular newsletters highlighting our achievements	• Number of leadership positions held within the relevant international bodies • Number of publications and citations, and quality of research journals * • Number of presentations at international conferences • Number of prizes awarded to our members
1.2 Establish a collaborative culture to maximise the centre outputs	• Provide travel awards to enable students and ECRs to work with collaborators, and present results at conferences • Hold weekly centre-wide videoconferences to share research results and plans • Use strategic funds to support national and international workshops • Support node placements and visits • Maximise networking and planning opportunities at annual retreats • Maintain effective communications channels including Slack, website, wiki, emails, newsletters	• Cross-nodal leadership of research programs • Number of cross-nodal publications • Attendance at centre-wide activities including weekly videoconferences and annual retreat • Number of workshop and conferences held by the Centre * • Usage/uptake of communications channels • Feedback via our climate and culture survey
1.3 Increase collaboration with strategic partners	• Attend and organise events and workshops with potential collaborators, industry and other external partners • Give presentations and briefings to external stakeholders • Support visits to and by external collaborators	• Number of leadership positions held within the relevant international bodies • Number of publications and citations, and quality of research journals * • Number of presentations at international conferences • Number of prizes awarded to our members
1.4 Secure Australia's role in the future of gravitational wave discovery	• Engage with the international future detector planning process • Communicate our accomplishments and future opportunities to ARC, government and other potential sponsors • Identify and secure funding to support our research during the Centre's lifetime and beyond	• Number of OzGrav members on 3G and space-borne detector planning working groups • Number of presentations/briefings to government and other potential sponsors * • Funding secured to support new avenues of research • Funding secured to undertake future detector pilot and/or design studies *

OzGrav has a Professional Development Committee that identifies and advises on career development and training opportunities to equip our members with a broad range of translatable skills. The PDC also receives and considers advice from our self-run Early Career Researcher Committee.

One of the main responsibilities of these two committees is to determine the training priorities and program for the annual 2-day ECR workshop along with webinars held throughout the year. Topics have ranged from science communication, to job applications & interview tips, leadership skills, and wellbeing and mental health. We also provided opportunities each year for our ECRs to hear about career paths outside of academic research, including through industry networking sessions and panel Q&A sessions.

Our students and ECRs have unique opportunities to develop their skills onsite through commissioning work at the LIGO observatories in the USA. OzGrav also has competitive grant schemes targeted for ECRs, including Travel Grants to visit other nodes and/or present research at international conferences, and a Research Translation Seed Funding Scheme.

OzGrav strives to create leadership and career development opportunities through the appointment of early-to-mid-career researchers to Program Chair or Co-Chair roles, where they receive mentorship from the Theme leaders. The Program Chair roles also provide leadership opportunities to female researchers, to assist with succession planning and improving gender balance at senior levels in the long-term.

We recognise that mentoring can be an important ingredient in career development and success. We therefore created a mentoring program open to all OzGrav members, including students, researchers and professional staff. Participation in this program has roughly doubled in the first half of OzGrav and we are putting in place more structure around the program to ensure it has continued growth in the second half of OzGrav.

PRIORITY 2

SUPPORT THE PROFESSIONAL DEVELOPMENT OF OUR MEMBERS AND STRENGTHEN AUSTRALIA'S CAPACITY IN STEM

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STRATEGIC OBJECTIVE	ACTIONS	PERFORMANCE MEASURES (*INDICATES AN OFFICIAL KPI)
2.1 Build Australian capacity in gravitational wave research	• Recruit talented students, researchers and staff, following inclusive and family-friendly practices • Provide relevant research skills and professional development training • Establish a mentoring program to provide career guidance to centre members • Provide leadership opportunities for our early and mid career researchers, with a path to transition to more senior roles • Establish a succession plan for key roles in the centre (see Appendix A.3)	• Number of Centre members * • Number of postgraduate completions * • Number of mentoring programs and events offered by the Centre * • Number of training and PD sessions provided * • Number of members participating in the mentoring program • Number of early and mid-career researchers with leadership roles in the centre (e.g. Program Chair)
2.2 Create a cohort of members with transferable skills into other sectors	• Provide training in transferable skills such as communications, leadership, software development, project management	• Number of training and personal development sessions provided * • Level of participation by members in training and PD sessions
2.3 Ensure our members' achievements are recognised and rewarded	• Keep members informed about award opportunities and encourage nominations from diverse and under-represented candidates • Provide merit-based OzGrav grants and awards • Publish and disseminate regular newsletters highlighting our achievements • Promote our ECR's achievements through media releases and social media	• Number of external awards and prizes received by our students and ECRs * • Diversity of recipients of OzGrav grants and awards • Number of media releases featuring our ECRs

PRIORITY 3

CREATE AN INCLUSIVE CULTURE THAT SUPPORTS EQUITY AND DIVERSITY

OzGrav is strongly committed to equitable and inclusive treatment of all its members and colleagues, and to the elimination of discrimination and barriers of disadvantage.

Equity and diversity issues are wide ranging and include characteristics such as age, diversity of sex, sexuality and gender, religion, indigenous status, non-English speaking background, race, disability, mental and physical health, pregnancy, parenting and other responsibilities related to care of dependents. It is important that the Centre's personnel reflect the diversity of the community, and that we implement strategies to help under-represented and disadvantaged groups overcome barriers and to promote equality of opportunity.

We recognise that gender equity is a particular issue facing the fields of physics and astrophysics, and science, technology, engineering and mathematics (STEM) more broadly. The Centre has an important role to play in helping to address this situation. We draw on the best practices endorsed by the Athena Swan Charter, the ASA IDEA Chapter, the Science in Australia Gender Equity (SAGE) Pilot, and Swinburne University's Gender Equality Strategic Action Plan. We have also drawn on the policies and plans of the ARC and other centres of excellence, in particular the Pleiades gold award winning CAASTRO. We are pleased that OzGrav's early efforts to support equity and diversity were recognised by our receipt of a Bronze Pleiades award in 2019 from the Astronomical Society of Australia.

Complementing the high-level strategic objectives listed in this document, OzGrav has a detailed **Equity & Diversity Action Plan**, which should be read in conjunction with this Strategic Plan. The Equity & Diversity Action Plan is managed by our Equity & Diversity Committee that comprises members from each of our Nodes with relevant training in equity & diversity matters. Performance against the plan is also monitored by our Executive Committee and Governance Committee.

In 2019, we contracted an independent expert to run a confidential anonymous climate survey to give us insight into the culture, attitudes, and experiences throughout the Centre. We were very heartened by the conclusions in the survey report, including: *"Overall, members expressed the belief that OzGrav is an inclusive and respectful working environment that is flexible and friendly and where their contributions are valued".*

Additionally, 94% of members rated their experience in the Centre as 'Good' or 'Excellent', which the survey report stated was *"a strong statement of the level of engagement of members so far – even where areas have been highlighted for improvement, members enjoy being part of the Centre".* We aim to build on these strengths in the second half of the Centre.

PRIORITY 3

CREATE AN INCLUSIVE CULTURE THAT SUPPORTS EQUITY AND DIVERSITY

STRATEGIC OBJECTIVE	ACTIONS	PERFORMANCE MEASURES (*INDICATES AN OFFICIAL KPI)
3.1 Improve diversity in the centre	• Adopt inclusive recruitment practices • Use strategic funding to recruit talented people from under-represented demographics	• Gender balance and diversity of new recruits/members
3.2 Create a culture that is family-friendly and supports work-life balance	• Offer carer grants to enable primary carers to participate in conference or travel for work • Offer flexible work arrangements & where possible keep core work meetings during the hours of 10am-4pm • Offer positions as part-time negotiable, where possible	• Uptake and awareness of OzGrav policies, practices and carer grants • Feedback via our climate/culture survey
3.3 Ensure OzGrav events & workplaces are respectful and inclusive	• Ensure diversity on conference organising committee, speakers, and chairs • Event organisers consider accessibility requirements in venue selection • Begin major meetings with Acknowledgement of Country • Ensure members and attendees are aware of the OzGrav Code of Conduct • Provide remote participation options for meetings • Provide childcare at OzGrav retreats • Provide equity & diversity training • Appoint independent ombudspeople to provide confidential dispute resolution advice	• Gender & other diversity statistics collected by event organisers • Feedback via our climate/culture and post-event surveys • Complaints/issues raised with ombudspeople and/or event organisers • Participation in E&D training

Background image: Artist illustration by Carl Knox, OzGrav/Swinburne University

PRIORITY 4

SUPPORT RESEARCH TRANSLATION AND INDUSTRY ENGAGEMENT IN ORDER TO MAXIMISE THE IMPACT OF OUR R&D

Gravitational-wave research has a rich, innovative history with substantial commercial impact. OzGrav is committed to collaborating with the industry sector through research partnerships and engagement, as well as building deep alliances between companies and universities.

We work with our partners to ensure new gravitational-wave technologies make it out of the lab and into the real world where they can make a lasting scientific, environmental and economic impact.

Contributing to major national science and research priorities (advanced manufacturing, soil and water, and environmental change), OzGrav members have already worked with industry partners on numerous technology spin-offs. (See our Industry Success Stories brochure for some highlights: www.ozgrav.org/industry-success-stories.html)

Our Research Translation Committee is responsible for implementing and advising on technology transfer and commercialisation strategies in partnership with university engagement offices. The RTC has representatives from each node, including from their commercialisation branches. Each Node representative engages with their members to identify research translation opportunities and outcomes. They review and advise on Centre IP and other promising research.

The Centre has encouraged our members to adopt a progressive IP utilisation strategy to support spin-out companies and work with commercial partners. We strive to empower our members to undertake translation activities, for example by including translation-specific selection criteria for accessing a portion of the Centre's strategic funds. We have also run industry engagement and commercialisation workshops, industry-meets-OzGrav workshops, and support industry internships for our PhDs and ECRs.

PRIORITY 4

SUPPORT RESEARCH TRANSLATION AND INDUSTRY ENGAGEMENT IN ORDER TO MAXIMISE THE IMPACT OF OUR R&D

STRATEGIC OBJECTIVE	ACTIONS	PERFORMANCE MEASURES (*INDICATES AN OFFICIAL KPI)
4.1 Identify and support research translation opportunities	• Research Translation Committee to identify and advise on RT opportunities and potentially commercialisable IP • Chair of Research Translation Committee to undertake tour of all Nodes to discuss RT opportunities with members individually • Use strategic funds to offer Research Translation seed grants, prioritising ECR-led applications • Organise workshops and training on commercialisation and entrepreneurship	• Number of Research Translation Seed grants awarded • Number of, and participation in, research translation workshops • Number of NDA/JA/RSA/MoU/SU/SO (Non-Disclosure Agreement, Joint Appointment, Research Service Agreement, MOU, Start-up company, Spin-out company) *
4.2 Establish networks with industry and end users	• Support industry internships & joint appointments • Engage with industry to explore opportunities for collaboration • Organise networking sessions & joint workshops with industry	• Number of Industry internships * • Number of Industry briefings * • Number of NDA/JA/RSA/MoU/SU/SO (Non-Disclosure Agreement, Joint Appointment, Research Service Agreement, MOU, Start-up company, Spin-out company) * • Number of industry interactions (e.g. via Linkage projects or co-location) *

PRIORITY 5

EDUCATE AND INSPIRE THE PUBLIC

OzGrav aspires to bring the excitement of contemporary science to the general public, school students and teachers, providing opportunities for our researchers to promote their gravitational wave research to diverse audiences.

We promote our work across a broad range of channels and audiences by producing and disseminating media releases and other written summaries with informative and visually appealing graphics. We work with media specialists to ensure OzGrav science stories are highlighted in both national as well as regional press via newspaper and online articles, television interviews and radio interviews. The Centre provides yearly science-communication training for its members using both in-house and with external science communication experts. OzGrav media specialists work in tandem with our scientists to communicate gravitational wave science in the most captivating ways, including via custom graphics and animations to support media releases.

The OzGrav Education and Outreach team travels to various places and schools around Australia to deliver interactive public engagement activities, developed in-house using both visualisation technology (such as virtual reality, mixed reality and apps) and hands-on activities (such as tabletop interferometers). The team also designs immersive museum exhibits and continues to partner with more science centres to expand OzGrav's reach.

The Centre utilises the researchers' science expertise and the professional staff's curriculum-development, teaching, and digital expertise to develop engaging educational experiences for students. We are committed to building on the success of our Mission Gravity education program and developing further innovative modules to keep inspiring future-ready learners in science and technology. We are designing new programs focused on gravitation, gravitational wave detection and data analysis across the secondary curriculum and in primary programs to share valuable content and increase enthusiasm for STEM.
To support educators, we deliver multiple in-person and remote teacher workshops about OzGrav science content and educational technology. Furthermore, we present our successful case studies to seek philanthropic funding towards engagement with low-socioeconomic and remote schools.

PRIORITY 5

EDUCATE AND INSPIRE THE PUBLIC

STRATEGIC OBJECTIVE	ACTIONS	PERFORMANCE MEASURES (*INDICATES AN OFFICIAL KPI)
5.1 Promote public awareness of our research	• Produce and disseminate media releases promoting our research and researchers • Initiate & participate in public outreach events, with a special focus on regional engagement • Collaborate with museums to offer OzGrav exhibits & displays	• Number of publicly available videos, apps, animations, graphics explaining our science * • Number of public presentations * • Number of media articles about OzGrav science and people *
5.2 Inspire children and under-represented groups to engage with STEM	• Build collaborations & train others to deliver OzGrav education programs to extend the reach of the program • Build programs to meet a broad range of student levels • Provide teacher workshops to enable educators to deliver OzGrav developed materials • Establish collaborations to engage with more regional and remote schools & communities • Pursue philanthropic and grant opportunities to fund engagement with low socio-economic schools	• Number of schools interacting with OzGrav * • Number of teachers engaging in OzGrav PD with survey feedback on efficacy • Number of new educational assets developed • Number of regional or remote schools engaged with
5.3 Upskill our members in communicating science to a range of audiences	• Provide science communication training & media engagement opportunities, especially for our students and ECRs • Develop multimedia materials to support our members in explaining our science	• Number of communication and engagement workshops/ opportunities provided to members • Number of OzGrav members engaging in science communication opportunities

APPENDICES

A.1 DATA/ASTROPHYSICS THEME RESEARCH PLAN 2021-2024

RESEARCH PROGRAM	MILESTONE	DUE DATE
Gravitational Wave Data Analysis Program The Gravitational Wave Data Analysis Program will lead and contribute to analysis of data from the LIGO, Virgo, and KAGRA gravitational wave observatories. The SPIIR pipeline will be a principal participant in the low-latency detection of gravitational waves from binary neutron stars and black holes. Searches for gravitational waves from supernovae, post-binary neutron star merger remnants, rapidly-rotating neutron stars, and an astrophysical/cosmological background will continue, with the aim of making first detections of these as-yet-unobserved sources. OzGrav members will continue to make invaluable contributions to vital service activities within the LIGO-Virgo-KAGRA Collaborations: from calibrating and characterising the detectors, developing and leading analyses, writing and managing Collaboration papers, and serving in leadership roles such as working group/subgroup chairs and internal reviewers.	• Lead and contribute to analysis of data from 3rd observing run of LIGO-Virgo-KAGRA	• 31/12/2021
	• Lead and contribute to analysis of data from 4th observing run of LIGO-Virgo-KAGRA	• 31/3/2024
Pulsar Detections Program The years 2021-2024 are poised to be pivotal in nanohertz-frequency gravitational wave astronomy. Existing pulsar-timing-array (PTA) projects are starting to see what could be the first hints of the expected signal: common signals in the arrival times from the ensemble of millisecond pulsars. The sensitivity to the signal increases rapidly with ensemble size and gradually with time; there is growing optimism that a detection of pulsar-band gravitational waves will be realised within the time frame of the second half of OzGrav (Oz1B). By providing high quality data, inferences, and astrophysical interpretations, OzGrav can be a leader in the area. Below we outline key activities and outcomes expected over the duration of Oz1B, positioning Australia to continue to be a leader into the era of the Square Kilometre Array (SKA).	• Deliver high precision pulsar data sets from MeerKAT and Parkes telescopes	• December 2021 (MPTA DR1)
	• Deliver a new sample of pulsars discovered through reprocessing of the Parkes-HTRU surveys	• December 2021 (PPTA DR3) June 2023 (MPTA DR2)
	• Detect or present stringent constraints on nanohertz-frequency gravitational waves using Parkes, MeerKAT and International data sets • Search for gravitational wave signals PPTA-DR2 and PPTA-DR3	• March 2021: Initial search of PPTA-DR2 • June 2022: PPTA-DR2. June 2024: GW Searches of IPTA
	• Constrain nuclear equations of state through J0437-4715 pulsar mass and NICER radius	• June 2021
Multi-Messenger Observations Program The central theme of the multi-messenger program within OzGrav is to provide insights on astrophysical phenomena by combining GW data with data from other observational domains, such as the electromagnetic spectrum, neutrinos or cosmic rays. It includes observational, theoretical and data driven themes and has significant crossover with other OzGrav programs. Efforts over the second half of OzGrav will include coordinating observing programs of individual facilities for electromagnetic follow-up of gravitational-wave events with a focus on Australian-led instruments. Current facilities include: Optical imaging (Skymapper, Zadko, GOTO-South, Huntsman, KMTNet, LSGT, LOCGT), optical spectroscopic (AAT AAOmega, ANU 2.3m WiFeS) , IR imaging (DREAMS), and radio (including VLBI, ATCA, ASKAP, Parkes, Molonglo), as well as facilities operating with the Deeper Wider Faster (DWF) program. There are also plans to roboticise the ANU 2.3m instrument, which will enhance the automated follow-up efforts during O4. The DWF program will be enhanced through an award toward progressing the design of Keck Wide Field Imager for GW EM counterpart searches. As part of the program's effort of EM follow-up monitoring, the low-latency detection pipeline SPIIR will develop infrastructure for early warning alerts working towards negative latency notices 10's of seconds before BNS mergers. Additionally, several data-driven searches will be conducted, including joint GW-GRB and GW-FRB observations, as well as multiwavelength surveys in the radio, optical and very high energy gamma-ray bands. Key outcomes for the program are to rapidly observe multiple binary neutron star mergers and report on the discoveries as a centre-wide activity; to build the necessary infrastructure for GW follow-up using untriggered GRB and FRB events in the absence of a GW alert as a template.	• Deeper Wider Faster will continue to coordinate global facilities for real-time fast transient discovery	• Runs: 2021A, 2022B
	• O4 Follow-up	• Start of O4 (mid 2021)
	• Data driven themes and FRB/GRB triggers: GOTO, CTA, Zadko, ASKAP	• Surveys: 2022-2023. O4: GW-FRB and GW-GRB GRB follow-up continues through 2024

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Relativistic Astrophysics Program Relativistic astrophysics is devoted to the study of high-energy astrophysics, particularly concerned with extreme energies, velocities and densities. This field has undergone significant change since the beginning of OzGrav, primarily due to revolutionising observational firsts. These include the multi-messenger binary neutron star observations GW170817, unprecedented x-ray timing and equation of state inferences by the NICER mission, significant new observations of fast radio bursts including repeaters and those coincident with a galactic magnetar, and the first pulse-to-pulse observations of a glitching pulsar. Many of the above have significant involvement from OzGrav scientists, both in the observation and astrophysical and fundamental physics interpretations of the events. The observations, and continued expectations throughout the remainder of the OzGrav COE drive the relativistic astrophysics programme to make progress in the theoretical understanding of all these phenomena, and also in utilising these theoretical models to understand and interpret potential new observations over the next three to four years.	• Develop end-to-end modeling and understanding of multi-messenger binary neutron star observations, including dynamics and cooling of post-merger remnants and the effect they have on electromagnetic and future gravitational-wave observations	• 2023
	• Develop falsifiable predictions for observables related to cold and hot nuclear equations of state, and begin to apply these to electromagnetic and gravitational-wave observations of neutron stars (including isolated neutron stars and binary mergers)	• Theoretical infrastructure 2022. Apply to pulsar data in 2023, and gravitational-wave data during O4.
	• Marry theoretical models of glitch dynamics with pulse-to-pulse observations of glitches (including nulls, quasi-nulls, ...) and improved long-term glitch statistics	• 2021-2024
Population Modelling Program There are 3 main elements to the OzGrav Population Modelling Program. Firstly, OzGrav members are developing phenomenological models for the population properties of gravitational-wave sources, and leading efforts within the LIGO/Virgo collaborations to apply these to the latest gravitational-wave observations. Efforts in this area in 2021-2024 will focus on developing models with higher fidelity, accounting for population outliers (or subpopulations, e.g. GW10814 and GW190521) and applying these models to gravitational-wave observations from the third and fourth observing runs. Secondly, OzGrav members are developing state-of-the-art population synthesis models including COMPAS and METISSE. The key goals for 2021-2024 for these models is i) continue to update these models with the latest understanding of massive stellar/binary evolution and ii) to use these models to perform inference on the physics of massive stellar/binary evolution by interpreting both gravitational-wave and other observations with a physical model. The final prong of the Population Modelling program involves detailed modelling of stellar dynamics in star clusters and other dense stellar environments, using tools such as the N-Body code. A key aim here will be to update these models to account for the latest understanding of massive stellar and binary evolution. With these updates in hand, the next step will be to perform a large number of simulations of star clusters across a broad parameter space. These simulations can then be compared against gravitational-wave observations.	• Develop phenomenological population models and apply to gravitational-wave observations from the third and fourth observing runs of LIGO/Virgo	• O3 modelling Q2 2021, O4 modelling Q1 2024
	• Use COMPAS population synthesis models to perform inference on physics of massive stellar and binary evolution using a physical model	• Proof of principle comparisons in Q2 2022, analyse O4 data in 2024
	• Update massive star physics in detailed NBODY models and perform a large number of simulations with different initial conditions to understand gravitational-wave sources coming from dense stellar environments	• NBODY modelling: March 2024

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RESEARCH PROGRAM	MILESTONE	DUE DATE
Inference Program One of the central aims of the inference program is to enable and facilitate core astrophysics with LIGO/Virgo data. We have developed the primary inference analysis tool of the LIGO-Virgo Collaboration which is deployed to infer the properties of binary black holes, binary neutron stars, and mixed binaries. In the second half of OzGrav, we will focus on maximizing the likelihood of finding electromagnetic counterparts to binary neutron star mergers by producing optimal and rapid skymaps for candidate events within a few minutes of detection. As the event rate of binary mergers increases throughout O4 and beyond, we will produce high-fidelity reduced order models of gravitational-wave signals which will mitigate large computational burdens of data analysis, whilst simultaneously enabling the most accurate possible measurements of gravitational-wave sources properties. A key outcome in this area will be the development of accurate numerical-relativity surrogate models which include the effects of orbital eccentricity and spin-precession. These will be used to enable accuracy measurements of eccentricity. Finally, we will aim to play a greater role in the next-generation detector community by developing inference methods which can scale to the challenges posed by these instruments. While next-generation detectors are several years to a decade away, inference methods allow accurate theoretical astrophysics studies which will strengthen the science case for future observatories.	• Develop rapid, fully Bayesian sky localization of binary neutron star merger candidates for fast EM follow-up	• Reviewed and deployed for beginning of O4 (early 2022)
	• Develop next generation of reduced order models for higher-order mode gravitational waveforms for core inference in O4 and beyond. These will include beyond GR effects	• Early 2022 (in time for O4) for next-gen reduced order models
	• Contribute to development of eccentric numerical relativity “surrogate” models	• Numerical relativity surrogates will appear around mid 2022 and development and refinement will continue through to 2024
	• Develop inference methods for next-generation gravitational-wave detectors (Cosmic Explorer, Einstein Telescope, LISA etc...) and use to study (astro)physics topics in the context of these instruments. We will contribute to ongoing detector R&D where inference studies are needed to assess science cases, trade studies etc.	• 2021-2024
Supercomputing Infrastructure The supercomputing program is dedicated to providing the data and computing resources required by OzGrav researchers to drive world-class outcomes. The infrastructure focus is the OzSTAR supercomputer at Swinburne which underpins efforts in the areas of low-latency detection, inference analysis and theoretical modelling, to name a few. OzSTAR was installed in 2018 and over the lifetime of OzGrav has increased in capacity by 20%, to comprise 6,000 central processing unit (CPU) cores and 300 graphics processing units (GPUs), and achieved 99% uptime. Over 24 million hours of data processing and simulations have been performed by OzGrav researchers each year, across 25 distinct research projects and over 120 users. Improvements to the infrastructure include the installation of a high-performance low-latency network between the OzSTAR storage and compute servers, implementation of an automated process for transferring LIGO data onto OzSTAR and connection of OzSTAR into the Open Science Grid (OSG). Next steps include completion of work to double the storage capacity of OzSTAR to 12 Petabytes so as to cater for the expected data volumes for the remainder of the OzGrav COE. Other priorities for the next 3-4 years are to continue working with OzGrav researchers to optimise their workflows and maximise efficient usage of the infrastructure, to ensure that the infrastructure is O4-ready and to coordinate the development of machine learning techniques across the data and astrophysics programs. We will work closely with the recently established NCRIS-funded Gravitational Wave Data Centre (GWDC) in these endeavours. Finally, the major supercomputing infrastructure goal is to design and install the successor to OzSTAR within the timeframe of the remainder of the OzGrav COE.	• Ensure that OzSTAR is O4-ready in terms of providing the hardware and software required for detection, inference, analysis and modelling	• Early 2022
	• In collaboration with the GWDC organise a week-long Machine Learning workshop that brings together existing efforts in this area across the data and astrophysics programs with a view to showcasing these efforts but also to provide industry-standard training to consolidate, coordinate and enhance these efforts	• End of 2022
	• Design, procure and install OzSTAR II to ensure ongoing data and computing capacity for the national gravitational wave research community	• End of 2023

APPENDICES

A.2 INSTRUMENTATION THEME RESEARCH PLAN 2021-2024

RESEARCH PROGRAM	MILESTONE	DUE DATE
Quantum Program Quantum noise limits the sensitivity of gravitational wave detectors over much of the detection band. The quantum program develops new methods and technologies to improve the quantum limited sensitivity of future detectors. The core research areas include the development of coherent light sources and associated technologies around the 2 micron wavelength, which is where future detectors will operate. Key areas are the development of high-power light sources and non-classical "squeezed" light sources.	• 5W ECDL MOPA 2um laser • 30W Tm:fiber MOPA 2um laser • Frequency stabilize 5W 2um laser • 2 um squeezed light source with 10dB of squeezing • Phase sensitive amplification of a squeezed light field • Demonstrate internal squeezing	• 31/12/2021 • 31/12/2023 • 31/12/2023 • 31/12/2023 • 31/12/2023 • 31/12/2023
Low Frequency Program The Low-Frequency Programme is making great progress with fully assembled prototypes of tilt-meters, Newtonian force sensor and isolation systems. The Torpedo and ALFRA prototype will be integrated with each other for characterisation with the aim for improvements on the Torpedo performance. The ALFRA will also be installed in the isolation systems at the Gingin facility. In addition to the ALFRA's the Gingin seismic array will be used to even further improve the isolation system at the Gingin facility, using advanced control implementation. In addition we will see to engage with international projects such as Einstein Telescope - Low-Frequency detector. The Program has two main goals • Measure Atmospheric NN using Torpedo • Seismic Imaging of Gingin environment	• Seismically isolated Torpedo results - fully characterised with NCAL, in vacuum. • ALFRA characterisation using multiple units • Deployment of seismic array at Gingin, WA • Use array to improve isolation system performance • Establish control scheme to mitigate Newtonian noise	• 31/12/2023 • 31/12/2023 • 31/12/2023 • 31/12/2023 • 31/12/2023
Commissioning Program The commissioning program works to directly improve the performance of existing detectors. We have been unable to conduct any onsite commissioning in 2020 and the first part of 2021 due the international travel ban for scientists based in Australia. With the award of the LEIF Project LE210100002 to the OzGrav institutions, commissioning on advanced LIGO will be funded under that grant. We look forward to engaging with the LIGO commissioning for the start of O4. We plan to focus and grow OzGrav-funded commissioning activities with other international collaborations, including Advanced Virgo+, KAGRA and LIGO-India, and pathfinder projects such as GEO600 in Hannover, Maastricht ET Pathfinder and the Mariner CE Pathfinder in Pasadena. We will investigate methods to participate remotely ahead of the resumption of physical trips to sites after which, remote commission will also continue.	• Engage with AdV+, KAGRA and LIGO-India commissioning • Build new activities with pathfinder projects	• Ongoing • Ongoing

APPENDICES

A.2 INSTRUMENTATION THEME RESEARCH PLAN 2021-2024

RESEARCH PROGRAM	MILESTONE	DUE DATE
Distortions and Instabilities Program The distortions and instabilities programme has made great progress in the first half of OzGrav. Flagship project developing active wavefront control for LIGO's A+ project has been selected for install in O4 (2021). The other flagship project building an 80m cryogenic suspended Silicon coupled cavity is progressing well with detailed analysis of the Silicon test masses and build of suspensions. Other major successes have been demonstrating novel mode matching error signal schemes, novel test mass temperature distribution monitoring scheme, modelling parametric instability in future detectors and improved simulation tool Finesse 3 to better understand gravitational wave detectors. These significant successes have allowed new research direction to be sought as indicated in the projected milestones. In addition to the pre-existing milestones around developing the silicon 80m cavity, parametric instability experiments and simulations and Hartmann sensor developments, new focus has been put on investigating Silicon Birefringence, Beam splitter thermal distortion and using machine learning to interpret phase camera images. These additional projects are motivated by critical need for investigation by international GW detector instrumentalists. Birefringence is a critical issue in the KAGRA detector, significantly reducing effective circulating power. KAGRAs dilemma highlights the needs for low birefringence and expert measurement techniques to verify optic specifications. The NEMO concept requires high optical power to achieve high frequency sensitivity. A beam splitters has an angled beams incident on it, thermal distortions from these beams result in higher order aberrations that are difficult to compensate. With NEMO circulating power these distortions limit circulating optical power. This motivated the investigation of these thermal distortions and compensation techniques. Finally an impediment to phase camera use in gravitational wave detectors has been the difficulty in interpreting the images. This motivates the new project where analytic and machine learning techniques are being employed and compared to decompose phase camera images into basis of Hermite Gaussian modes and interferometers degrees of freedom. These new projects will allow the distortions and instabilities theme to make significant contributions to the field in the second half of the OzGrav Center of Excellence.	• Interpreting phase camera images • Phase camera image of parametric instability • Beam splitter thermal distortion compensation (simulation) • Next Generation Parametric Instability Models	• 2021 • 2021 • 2021 • 2021
	• 80m coupled cavity mode matching control • Characterization of parametric instability in cryogenic suspended silicon cavity • Substrate absorption measurements • Improved Simulations Tools Finesse 3, LTC (ongoing, publication in 2022) • Silicon Birefringence	• 2022 • 2022 • 2022 • 2022 • 2022
	• Cryogenic silicon thermal control / compensation • Hartmann camera for 2um	• 2023 • 2023

APPENDICES

A.2 INSTRUMENTATION THEME RESEARCH PLAN 2021-2024

RESEARCH PROGRAM	MILESTONE	DUE DATE
Space Program The OzGrav space program will continue experimental research towards the first gravitational wave detector in space. The Space Programs' focus has been precision phase measurements and laser stabilization to enable contributions to inter-spacecraft laser interferometers: LISA and other international projects. There are three areas that this research will contribute through: 1. Enabling future missions (beyond LISA, for example); 2. Contributing directly to first generation detectors such as LISA; and 3. Contributing to other interspacecraft laser interferometers such as GRACE Follow-On, that use all the same hardware and techniques as LISA but are already operating (for different scientific purposes). The space program in the period 2021-2024 will have close interaction with international space missions. For example, the space program is adapting the LISA specific laser stabilization technique, called Arm-Locking, to the new mission requirements that were recently adopted (i.e. arm lengths now are half of the original plan, now at 2.5 million km)	• Contribute to international space missions: LISA and GRACE Follow-On	• Early 2021- onward
	• Demonstrate viability of new laser stabilisation techniques for space detectors: Tilt-Locking and Arm-locking	• Late 2021
	• Probe limits of low-power phase tracking. Compare inter-spacecraft laser ranging with dual one-way ranging to two-way ranging with a passive retro-reflector	• Late 2022
Pulsar Timing Program The Pulsar Timing Instrumentation program is moving from its demonstration phase with the successful deployment of four prototypes of the SKA pulsar processor to the South African SKA site and implementation into the 64-dish MeerKAT SKA precursor telescope. The Swinburne prototypes have led to the submission of 10 pulsar papers for publication, six of which have already been accepted for publication. The MeerTime consortium, of which OzGrav Director Matthew Bailes is the PI, is seen as a blueprint for future large-scale SKA pulsar projects with engagement of scientists from Australia, South Africa, Germany, the UK, France, Italy, the Netherlands engaged. The development of a spin-off company is under negotiation with Swinburne University of Technology, with OzGrav personnel among the founders. By the end of 2021 it should be possible for third parties to access data products from the MeerTime and UTMOST telescopes and by the end of 2022 higher-order terms required to study relativistic binary pulsars implemented in a self-consistent fashion.	• Establish company to pursue Pulsar Timing SKA Construction contract with Swinburne as a partner	• 30/6/2021
	• Enable access to public data from MeerTime/UTMOST data portal	• 31/12/2021
	• Remove dispersion-smearing for relativistic binary pulsars	• 31/12/2022
Planning for Future Detectors We will complete our contribution to the global GWIC3G Committee on Third Generation Ground-based Detectors charged with examining the path to the development of a network of future ground-based gravitational-wave (GW) observatories. The GWIC3G initial study will be released by mid-2022. We will aim to play a greater role in the next-generation detector community, in particular Cosmic Explorer, by: (1) developing broad data analysis methods which can scale to the challenges posed by these instruments. While next-generation detectors are around a decade away, inference methods allow accurate theoretical astrophysics studies which will strengthen the science case for future observatories. Concretely we will contribute to the study of binary black hole and neutron star mergers over cosmic time, star formation, extreme nuclear matter, and cosmology; and (2) we will complete our analysis in collaboration with Cosmic Explorer team of the optimal siting of detectors in global 3G array. We will continue to investigate the best sites for any Australian node in the 3G network. In addition, We will complete a preliminary design, and preliminary cost estimate (to within 50%) for the construction of, a 3G Pathfinder facility in Australia. We will continue to monitor planning for space-based detectors.	• Develop scalable inference frameworks which can handle long-duration, and multiple overlapping, signals in next-generation detectors	• Mid-2021
	• Release GWIC3G study • Study next-generation detector capabilities for understanding the population of binary black holes and neutron stars at high redshift	• Mid-2020
	• Publish global Array and Australian site studies	• Early 2023
	• Determine how next-generation detectors will constrain the neutron star equation of state, and implications for understanding dense nuclear matter	• Mid-2023
	• Release Pathfinder preliminary investigations	• Late 2023

APPENDICES

A.3 SUCCESSION PLANNING

OzGrav has a succession plan for filling the key roles in the Centre of: Director, Deputy Director, Chief Operating Officer, Node leaders, and Theme leaders. Some details of the plan are confidential and therefore it is not appropriate to publish them in this public document. Note that in most cases an internal candidate(s) has been identified who is ready to step immediately into the role if required. In the remaining cases, the position would be advertised externally, with an internal member identified to fill the role in an acting capacity in the interim.

In addition, OzGrav endeavours to give our Early and Mid-Career Researchers a wide range of leadership and professional development opportunities to equip them to be future leaders in this field, including:

- Chairing/co-Chairing of OzGrav's Research Programs, under the mentorship of the Theme leaders
- Key roles on OzGrav committees
- Key roles on international committees
- Lead roles on LIGO-Virgo paper writing teams
- On-site commissioning experience
- Extensive series of in-person and online ECR workshops and webinars covering a broad range of skills training, and personal and professional development
- Mentoring program that pairs successful senior members with more junior members in the Centre
- Promoting Associate Investigators to Chief Investigators, where appropriate
- Recruitment of new talent into the Centre as Affiliates, Associate Investigators, Chief Investigators, or Partner Investigators, as appropriate