Submission Template

2016 National Research Infrastructure Roadmap

Capability Issues Paper

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Would you like your submission to remain confidential, i.e. not published on the website?	NO

This submission contains three components A) Answers to questions posed in the Capability Issues Paper, B) a submission about the Australian International Gravitational Observatory and potential China partnership, which provides the context for this submission, and C) Answers to specific questions posed to the proponents by the Chief Scientists Office.

A) Answers to Questions 1-32.

Question 1:

Question 2: Are these governance characteristics appropriate and are there other factors that should be considered for optimal governance for national research infrastructure.

Answer: *Various international partnership models as discussed in questions below.*

Question 3: Should national research infrastructure investment assist with access to international facilities?

Answer: An economic benefit criterion should be used. Funding of infrastructure is a method that countries use to provide economic benefits through support of manufacturing, employment and economic multipliers as discussed in other questions below. The payment of large subscription fees cannot be justified unless it comes with the economic benefits discussed above.

Question 4: What are the conditions or scenarios where access to international facilities should be prioritised over developing national facilities?

Answer: *Access to international facilities is a relevant option when Australian science and industry and the economy are equally benefitted if the facilities are international as opposed to national. If the national facility meets the economic benefit criterion, and* *the international one does not, then the national facility should have priority*

Question 5: Should research workforce skills be considered a research infrastructure issue?

Answer: *Not in general, but research infrastructure requires a sufficiently trained workforce. For LIGO a tiny team proposed the project but funding led to a massive, rapid skills growth. See below.*

Question 6: How can national research infrastructure assist in training and skills development?

Answer: *As long as research infrastructure is accompanied by funding to utilise the facility, it can be a vital component of skills development through traineeships, apprenticeships, research training and higher degrees.*

Question 7: What responsibility should research institutions have in supporting the development of infrastructure ready researchers and technical specialists?

Answer: *It would be beneficial and natural for research institutions to offer traineeships. Funding for such programs should be made available.*

Question 8: What principles should be applied for access to national research infrastructure, and are there situations when these should not apply?

Answer: *There are a variety of models based on the research area. The user- pays model is relevant to service infrastructure designed to support for-profit research such as gene sequencing. This model is inappropriate for state funded basic research that relates to discoveries that may be decades away from commercialisation, such as astronomy.*

Question 9:

Question 10: What financing models should the Government consider to support investment in national research infrastructure?

Answer: *For expensive infrastructure such as a gravitational wave observatory the best financing model could be a Seed funding + Co-funding model. Government investment of Seed funding of ~ 1% of project cost could enable proponents to complete an international co- funding proposal. Funds are needed to support planning meetings, meetings with government representatives on issues including international governance, the creation of business plans and funding.*

Note that worldwide private investment in basic physics research, such as CERN is rare, except in the cases of a few prominent foundations and individual philanthropists such as Keck or Kavli. It would be very risky to base government funding policy of philanthropy.

Question 11:

Question 12: Are there international or global models that represent best practice for national research infrastructure that could be considered?

Answer: *International physics research has developed very successful funding models. At the highest level, CERN and ESA are funded based on agreed national subscriptions. (some subscriptions are given in-kind such as Indian participation in CERN.) Another* *successful model involves in-kind contributions from national partners. Advanced LIGO was funded in this way. The host country pays a significant fraction of the costs. However, economic multiplier benefits should be considered as part of the funding assessment process.*

Economic multipliers: It is important to note that the economic multiplier benefits of large infrastructure projects can be very high. (documented for CERN and ITER), especially for projects located in economically vulnerable regions. A preliminary economic multiplier analysis for a gravitational wave detector at Gingin showed significant economic benefit for the Wheatbelt region of WA which is currently in economic decline due to climate change. A gravitational wave observatory offers strong benefits to the declining metal manufacturing industries, and provides a way of assisting local industries to become internationally cmpetitive.

Question 13: In considering whole of life investment including decommissioning or defunding for national research infrastructure are there examples domestic or international that should be examined?

Answer: Observatories are long lived facilities for which it is rarely necessary to consider decommisioning costs (unlike nuclear reactors forwhich this issue is very significant)

Question 14: Are there alternative financing options, including international models that the Government could consider to support investment in national research infrastructure?

Answer: We recommend consideration of an annual budget model (similar to CERN) which puts the onus on the proponents to use their funds with maximum efficiency to achieve timely completion. A full capital cost budget estimate can lead to over-budgetting (to mitigate risks) or cost blow-outs (due to incomplete risk analysis). The former wastes funds while the latter leads to funding crises. Under the annual budget model the LHC was completed successfully but behind schedule without major financial problems.

Advanced Physics, Chemistry, Mathematics and Materials

Question 21: Are the identified emerging directions and research infrastructure capabilities for Advanced Physics, Chemistry, Mathematics and Materials right? Are there any missing or additional needed?

Answer: One of the emerging directions in the current document is the precision measurement. We emphasise that gravitational wave detection represents the ultimate in precision measurement. Most quantum measurement technologies originated from gravitational wave detection. Technologies just emerging such as quantum non- demolition, back action evasion, and optical spring techniques and optical squeezing will continue to be driven by the demands of gravitational wave detection, but have broadened into a large community working on engineered quantum systems.

Question 22: Are there any international research infrastructure collaborations or emerging projects that Australia should engage in over the next ten years and beyond?

Answer: Next generation gravitational wave detector technology development. Australia should *participate in worldwide community efforts in developing next generation detector technologies as well as working to create the infrastructure in Australia to support future detectors.*

Question 23: Is there anything else that needs to be included or considered in the 2016 Roadmap for the Advanced Physics, Chemistry, Mathematics and Materials capability area?

Answer: The southern hemisphere international gravitational wave observatory. At this time an observatory in Australia offers enormous scientific benefits using proven technologies. The low current cost of stainless steel makes this an extremely opportune time for such a project.

Underpinning Research Infrastructure

Question 30: Are the identified emerging directions and research infrastructure capabilities for Underpinning Research Infrastructure right? Are there any missing or additional needed?

Answer: CSIRO's closing of its precision optics facility represents the loss of an important capability that underpinned the development of LIGO. While it will be replaced by international facilities there would still be a strong case for reversing this loss before the key equipment and personnel are lost.

Question 31: Are there any international research infrastructure collaborations or emerging projects that Australia should engage in over the next ten years and beyond?

Answer: Australia should engage with the developing gravitational wave observatories in the northern hemisphere while developing the southern hemisphere observatory.

Question 32:

B) Towards an Australian International Gravitational Wave Observatory

Background

In 2016 the LIGO Scientific Consortium announced the discovery of gravitational waves verifying Einstein's predictions dating back to 1915. This has been universally acknowledged as one of the greatest discoveries of modern physics. Australia needs to carefully consider how to maximize its economic, scientific and cultural benefit in light of this discovery. Worldwide there is recognition that the discoveries mark the tip of the iceberg, and that rich scientific rewards can be expected as the field develops. In Asia, and China in particular, there is a very strong push for the development of gravitational wave astronomy.

There are two obvious strengths Australia brings to this arena:

- Personnel: First of foremost, many of our scientists played important roles in this achievement; Australia was one of four countries officially part of the LIGO scientific consortium responsible for the discovery. Elements of the critical expertise at the forefront of this field are uniquely present in the Australian University sector. Australian gravitational wave astronomers have recently joined forces under the new banner of OzGRav, a consortium aimed at pursuing fundamental research and development to capitalize on the historic first detections of gravitational waves to understand the extreme physics of black holes and warped space-time and to inspire the next generation of Australian scientists through this new window on the Universe.

- Australia: Secondly, now that gravitational waves have been discovered, the race is on to localize their sources, and it makes sense to ultimately maximize the distance between detectors, leading to an international consensus that a Southern hemisphere detector, and hence one situated in Australia is highly desirable.

The timescale for detector design, construction and commissioning is decadal and realistic budgets for competitive detectors are measured in 100s of million dollars. For a country like Australia this necessitates international collaboration and long- term planning to realize the dream of a detector featuring Australian technology as part of the global gravitational wave research effort.

Current gravitational wave detectors are referred to as “second-generation” facilities and there is a broad consensus that the technology to build detectors with an order of magnitude improvement will require extensive R&D before any realistic designs for “third-generation” detectors can be seriously costed.

A realistic option for Australia is to continue to research the technologies that may feature in third-generation detectors, and perform the necessary site tests to ultimately host the Southern-hemisphere detector on a 10-15 year timescale.

The China connection

The discovery of gravitational waves has sparked tremendous interest from China in this nascent field. China is impatient to become a player and is exploring options.

In 2015 an international workshop was funded by the Chinese Academy of Sciences in Beijing to discuss next-generation detectors for Gravitational Wave Astronomy. During that meeting many designs for future detectors were discussed ranging from the relatively conservative (modest extensions of the highly-successful Advanced LIGO (aLIGO) interferometer) to more radical “third-generation” detectors that would pioneer fundamentally new technologies.

Scientists from UWA have been discussing with members of the Chinese Academy of Sciences, Tsinghua University and Beijing Normal University about whether there is an option for Australia and China to partner on what one might consider a generation “2+” detector that would be located at the Australian Gingin site just north of Perth. The strawman design would extend the aLIGO concept by lengthening the arms, increasing the mass of the mirrors and increasing the laser power. If these advances all achieved their sensitivity goals, they could increase the range of the Advanced LIGO detector by a factor of 4, resulting in a 64-fold increase in volume – a massive advance for the field.

At present the European and US gravitational wave communities are completely focused on developing and optimizing their own detectors, and there are no realistic sources of cash funding to contribute to an Australian detector in this decade, so China is one of the few options available for Australia to partner with in the near future.

China’s Belt and Road Initiative is an official Chinese government policy for overseas engagement through investment. An Australia-China gravitational wave collaboration proposal may be well matched to this initiative.

A Chinese-Australian detector is therefore a possible avenue to accelerating our involvement in this field to more quickly engage Australian industry than third- generation detector R&D permits.

1. An Australian Observatory Concept

Gravitational wave detector sensitivity increases with detector arm length. The Australia-China observatory would be designed as an enduring facility (lifetime circa 50 years) capable of supporting detectors of up to 8km arm length – twice that of Advanced LIGO. The initial detector would be based on the proven, current, second generation detector technology while retaining the capability to allow an upgrade to some third generation detector technologies (such as cryogenically-cooled silicon test masses) if the technology is proven.

2. Detector Concept

The initial detector design concept was developed at the Next Detectors workshop in Beijing last year (published in Science-China in December 2015). The concept is for a detector twice the length, combined with test masses of twice the mass and twice the suspension length that gives four times the sensitivity of Advanced LIGO. This is achieved using the detector parameters given in the table below:

Test masses	80kg fused silica, 50cm diameter
Suspensions	1.5m Glasgow suspension fibres
Isolation	UWA-type advanced vibration isolation
Quantum Engineering	ANU frequency dependent squeezing with filter cavity
Newtonian noise suppression	Currently under development at ANU
Optics and lasers	LMA mirrors, and commercial 1064nm fibre laser
Thermal compensation	University of Adelaide Hartmann sensors
Configuration	Dual recycling Fabry-Perot Michelson interferometer

The new technologies of optical squeezing and Newtonian noise suppression are not in the critical path, but are significant for upgrading all detectors and are already being developed at ANU who are world leaders in this domain.

Because the detector is based largely on Advanced LIGO but with UWA-developed Advanced Virgo type isolation systems, it is comparatively low risk and has the opportunity to be improved based on learning from the current detectors during their first few years of operation.

3. Science case

There are two scientific reasons to construct a gravitational wave detector of this design. Firstly its geographical location enables more precise localization of events than can be achieved by Northern hemisphere detectors alone. Secondly, if it performs to specification, the event rate should be much higher than other detectors because of the increased volume it will probe. How the event rate will scale with sensitivity is very secure, the overall event rate requires extrapolation from just two events and will become more certain in the near future when LIGO’s O2 run is completed early next year. A full science case documenting the benefits and complementarity with Australia’s existing strengths in the Optical, Radio and other bands will be the subject of a future white paper. In an optimistic scenario, the detector may ultimately detect 104 binary black hole coalescence events per year up from just 2 in 2015.

4. International concept

- An international southern hemisphere detector could be developed under a CERN-like or SKA-like model. The project should be part of the LIGO Scientific Collaboration (LSC) from the outset to benefit from their experience and our existing collaborative links. One of the leading Chinese groups is already a member of the LSC. It would be important that the project be supported by LIGO and other international projects. The LIGO Director Professor David Reitze and past Director Professor Barry Barish have participated in meetings with Chinese groups interested in gravitational waves. Their support would be crucial.

- Vice-President Pan of the University of Science and Technology of China expressed interests in collaborating on the project by exploring gravitational physics and macroscopic quantum mechanics, such as the the quantum entanglement of macroscopic objects and at planetary distance.
- We are currently ascertaining whether there is sufficient land available at
- Gingin to house the detector. WA Chief Scientist Peter Klinken is aiding in this endeavour in cooperation with the WA government. Experience with the SKA suggests that site selection is not a trivial undertaking and can take some years to complete, especially when taking into account native title issues etc. An alternative “brown field” site selection process could extend the timescale for any project by some years.
- Science Infrastructure: We would be aiming to maximize the amount of infrastructure that could be manufactured in Australia by Australian companies. For instance indicative quotes suggest that the 16 km of stainless steel pipe would cost circa $25M AUD plus welding costs.
- • European participation: The Virgo project’s LMA laboratory operated by
- CNRS in Lyon has capability to create the 80kg 50cm diameter mirrors. The University of Glasgow could supply fused silica suspension technology. This could form part of an international partnership with the best laboratories in Europe.
- The US LIGO Laboratory would support the project in many ways, including aspects of detector optical design, scattered light control, control architecture and control system design concepts.

5. Costing

It is too early to give a definitive costing for the project but the overseas detectors that are in operation or soon to be in operation are circa 250M AUD.

We estimate that the largest cost item would be personnel and of order 600 EFT years but this would have to be properly costed. The vacuum tubes with field welds, testing and bellows are of order $50M. Other major components such as tanks and isolators can easily come to ~$15M, lasers and optics ~$20M, computing and control, buildings, airconditioning and clean rooms and other items ~$50M.

Annual operating costs of similar infrastructure are often 7-10% of capital, so circa $20-25M/annum.

It would be inappropriate for the University sector to own and operate the facility, and this would best be done by organisations like the CSIRO that have experience with facilities like the Parkes and Narrabri observatories, and are engaged in the SKA process.

6. Provisos/Difficulties

There could be difficulties in developing a China-Australia collaboration because of the Defense Trade Controls Act (DTCA). It will be important to determine whether an Australia-China collaboration is allowable under the DTCA, when the project includes laser technology and other restricted technologies. It would also be important to determine whether US trade restrictions would prevent US partnership in a project that included China. In addition there are potentially significant difficulties for Chinese institutions to contribute significant funds or equipment to international projects.

The Gingin site has extensive infrastructure and has been used extensively for studying high optical power techniques for Advanced LIGO using 80m suspended optical cavities. Careful studies of the full 8km x 8km site would be required before committing to build a large scale detector.

7. Benefits

Despite potential difficulties, the proposed project to build an Australia-China gravitational wave observatory has many benefits for Australia:

- It will involve a significant amount of advanced manufacturing,
- It will engage Australia closely with the country that will soon be dominating world international science,
- It will drive an innovative culture and lead to many practical spin-offs,
- It will boost education and training.

Because the detector has long baselines to all other detectors in the world, it becomes the key vertex in the array, dramatically boosting the ability of the array to pinpoint the location of signals in the sky. The combination of enhanced sensitivity and triangulation enables signals like those recently discovered to be observed many times per day. By exposing the dynamic and evolving universe, Australia will become a leading player as we learn to interpret revolutionary new discoveries. The discoveries will keep science in the news and motivate our young people to follow careers in STEM.

8. Conclusions

We are conscious that such large scale investments (circa $100M) from government require the most rigorous processes and costings, from preliminary design reviews to critical design reviews as well as the necessary geo-political considerations and negotiations. We look forward to working with government to ensure that the infrastructure roadmap can support ambitious international landmark facilities such as an Australian gravitational wave detector, whether in the short- or medium-terms to drive high-tech industry and inspire our youth into careers in STEM.

C) Answers to specific questions regarding the Australian International Gravitational Wave Observatory posed by the Chief Scientists Office

1) *What will be the national benefit?*

The national benefit of an Australian International gravitational wave detector goes far beyond the enormous scientific benefits as we begin to explore the new spectrum of gravitational waves. It includes a) the international relations benefit of a major international scientific collaboration, b) boosting and supporting Australian manufacturing industry in the area of precision manufacturing, c) reviving Australia's world leading expertise in precision optics, d) the regional economic benefits of hosting large teams of international scientists, e) the scientific benefits of scientific interaction between Australian and international scientists.

2) *Where does Australia excel? Where will Australia excel?*

Australia is the one of four countries to formally participate in Advanced LIGO that made the first direct detection of gravitational waves. Australian physicists have world-recognised skills in high power optics, low noise measurement, vibration isolation, optical squeezing, wavefront sensing and three-mode opto-acoustic interactions. We also have outstanding expertise in the theory of general relativity and analysis of big data sets.

If we build a large observatory, we will command the longest baselines in the array and optimum performance will be demanded by the international community. Our data will determine the angular resolution and will enable telescopes such as ASKAP, the SKA, MWA and optical transient search telescopes (such as Skymapper and Zadko in Australia) and 8m class telescopes in Hawaii and Chile to study the host galaxies.

3) *Can we ensure that our research will be internationally significant?*

Australia's unique position in commanding the longest possible baselines to northern hemisphere sources, enables an Australian detector to optimize the angular resolution of the world wide array, the key requirement for source localization. The proposed initial Australian detector would be the most sensitive detector in the world until third generation detectors come on line. At this stage the Australian detector would be upgraded to match third generation technology.

4) *How do we leverage the rest of the world?*

See question 14 above. First provide seed funding to allow the international collaboration to be developed. Then through international collaboration following the CERN or SKA model, supported by a commitment of partial Australian funding.

5) *What kinds of new capabilities would particularly attract industry partnerships?*

High precision high performance vacuum pipe manufacturing, vibration isolator for mineral exploration and precision instruments, precision measurement technologies, optical spectroscopy for material characterisation, laser technologies for space applications, GPU data science, geophysical investigations, precision geothermal cooling systems.

6) Are there emerging areas of research that require international engagement with research infrastructure outside Australia?

The Australian detector would be a key part of a worldwide detector network requiring close engagement with other observatories currently in USA, Japan and Europe, a developing observatory in India and a likely observatory in China.