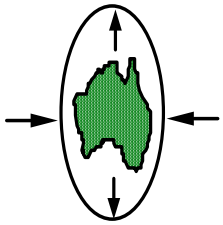
AUSTRALIAN INTERNATIONAL GRAVITATIONAL RESEARCH CENTRE

The University of Western Australia

Achieve International Excellence



Australian International Gravitational Research Centre (AIGRC)

School of Physics
University of WA

Research Expertise

The AIGRC is affiliated with international networks including the LIGO Scientific Collaboration led by MIT and Caltech, which gives us close contact with leading edge technology developments. Our work is advised by the Gingin Advisory Committee of the LIGO Scientific Collaboration. Our research is priorities are documented through collaboration white papers and work is monitored through a process of annual MOU research plans and outcomes. Our industry related work is undertaken through contracts and agreements with industry partners and affiliated companies.

The AIGRC has a large research facility at its remote low noise Gingin site. The site uniquely combines multiple sensitive research projects with a public education facility designed to encourage young people to take up science and engineering careers. The education centre consists of the Gravity Discovery Centre and the Gingin Observatory which is the largest public astronomy centre in the southern hemisphere. More than 20,000 visitors per year visit the site. One of the highlights of the school visits is the visit to the research centre and the opportunity to meet real scientists in their work environment.

The AIGRC has an exceptional record of bringing outstanding international students to join its research programmes, including many from China and others from Chile, India, France, Poland, and Taiwan. We have access to the best of the best students in China at universities such as USTC, Nanjing, and Tsinghua and Beijing Normal Universities. We have close links with the best gravitational research institute in China.

The AIGRC is led by a team of senior researchers, including Professors, Adjunct Professors and ARC Future Fellows. The Director is winner of the WA Scientist of the Year Award, the Clunies Ross Science and Technology Medal and the Prime Minister's Eureka Prize for Promoting Science.

This document summarises the exceptional research expertise in the AIGRC across six technological areas:

1) optics, lasers and optical sensors,
2) vibration isolation,
3) exploration instrumentation,
4) GPU supercomputing,
5) geothermal cooling and
6) high vacuum technology.

1) Optics, Lasers and Optical Sensors

Gravitational wave detectors are the most sensitive instruments ever created, able to detect energy ~ 10^{-30} Joules per Hz of bandwidth, and motions of ~10^{-20} meters. This sensitivity is achieved through major advances in optics, high optical power laser metrology, and the use of control systems to maintain the alignment and positions of multiple optical elements in highly vibration isolated vacuum environments. Many of the technologies have applications in a variety of industrial situations.

- High Power Lasers
  - Expertise with diode pumped YAG lasers and YAG Fibre lasers in power range 1-50W
  - Laser stabilisation to suppress frequency and amplitude noise for ultimate measurement sensitivity
- High power laser cavities
  - Up to 50kW CW laser power for measurement of very small displacements, light scattering in highly transparent materials, vibration measurements down to 10^{-17}m
- Non-contact optical sensors
  - Displacement sensors down to about 10^{-11} – 10^{-12} m/Hz$^{1/2}$
  - Angular motion sensing down to 10^{-11} radians
- Thermal compensation for very high power laser applications
  - Techniques for correction of thermal distortions due to residual power absorption in high power optical systems.
- Opto-acoustic parametric amplifiers
  - This new general class of amplifier uses light to directly amplify mechanical vibration.
  - Amplifiers have application in quantum memory, magnetometers, and fundamental studies in quantum measurement.

2) Vibration Isolation

The extreme challenges of vibration isolation for gravitational wave detection have led to numerous technical innovations and quite revolutionary approaches. Multi-stage isolation systems achieve 240dB of isolation, while isolation frequencies are as low as 20mHz. Many of these isolation systems can be adapted to industrial applications where the requirements are usually much less demanding.

- Vertical vibration isolation with minimum elastic stored energy.
  - Euler springs invented at the AIGRC allow up to 2 order of magnitude reduction in spring mass for vertical vibration isolation in vibration situations with constant mass load.
- Ultralow frequency vertical vibration isolation
  - Lacoste Linkage vibration isolators that reduce vertical resonant frequencies to 20mHz (about 1 cycle per minute).
  - Euler-Lacoste Linkages that combine the low elastic stored energy of the Euler spring with the very low frequency of the Lacoste linkage.
- Ultralow frequency horizontal vibration isolation
  - Roberts Linkage vibration isolators capable of vibration attenuation down to 20mHz.
  - Inverted pendulum vibration isolation down to 50mHz.
  - Watts Linkage isolators for one-dimensional vibration suppression down to 20mHz.

- Rotational Vibration Isolation
  - Rotational isolation down to 20mHz with very low translation to rotation coupling.
  - Multistage rotational/translational isolation for high isolation at audio frequencies.
- High sensitivity tilt sensors
  - 2D Tilt sensors based on novel walk-off laser readout.
  - Tilt control using ultrasensitive tilt readout.
- Self-damping systems
  - Systems that passively extract vibrational energy internally to the vibrating system
  - Pendulums that lose energy internally to allow critical damping without application of external forces.

3) Exploration Instrumentation

The AIGRC is affiliated with the companies Gravitec and Trinity Research Laboratories, and has collaborative research with Fugro. Our expertise includes the following:

- Very low frequency airborne EM sensors designed to double the exploration depth of EM sensors
- Vibrating String Magnetic and Gravity Gradiometers for borehole applications
- Vehicle-borne Active EM gradiometer sensors for detection of conductors, and magnetic materials
- Portable magnetic gradiometer for gold exploration, UXO detection and buried pipe detection.
- Vibrating silicon optical magnetometer.
- Suppression of rotational vibration in airborne systems

4) GPU Supercomputing

Gravitational wave data analysis is computationally intensive. The AIGRC group has led the implementation of massively parallel GPU based systems using iVEC facilities in WA. We have highly skilled computer scientists working on real time data analysis. We have access to numerous clusters across the LSC collaboration including one of the largest cloud computing platforms Einstein@Home.

5) Geothermal Cooling

- The AIGRC pioneered direct geothermal cooling technology in WA. Two major systems have been installed at Gingin. Both systems use about 10% of the energy that would be required for conventional airconditioning.
- The AIGRC is working with the WA Centre of Excellence for Geothermal Energy to design advanced geothermal temperature control systems for the planned large scale gravitational observatory.

6) High Vacuum technology

- The AIGRC systems at Gingin include 160m of high vacuum stainless steel pipe, large scale vacuum chambers, huge vacuum compatible vibration isolation and optical systems.

- We worked with major suppliers to develop efficient fabrication methods for our proposed long baseline observatory that recquires 8km of high vacuum pipe.
- We have great expertise in high vacuum pre-treatment and high vacuum compatibility.
- We have expertise with all types of pumps, especially oil free high vacuum pumps, leak detection and vacuum performance evaluation.

7) **Robotic Astronomy**

The Gingin site includes the Zadko telescope, an advanced robotic telescope operated in collaboration with the France-led TAROT network of telescopes. The telescope is used in conjunction with major space observatories operated by NASA and ESA, gravitational wave observatories, neutrino observatories and radio telescopes. Major research projects include the monitoring of gamma ray bursts, supernova explosions, asteroids and space junk.

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