

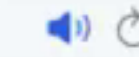
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GW150914 Chirp



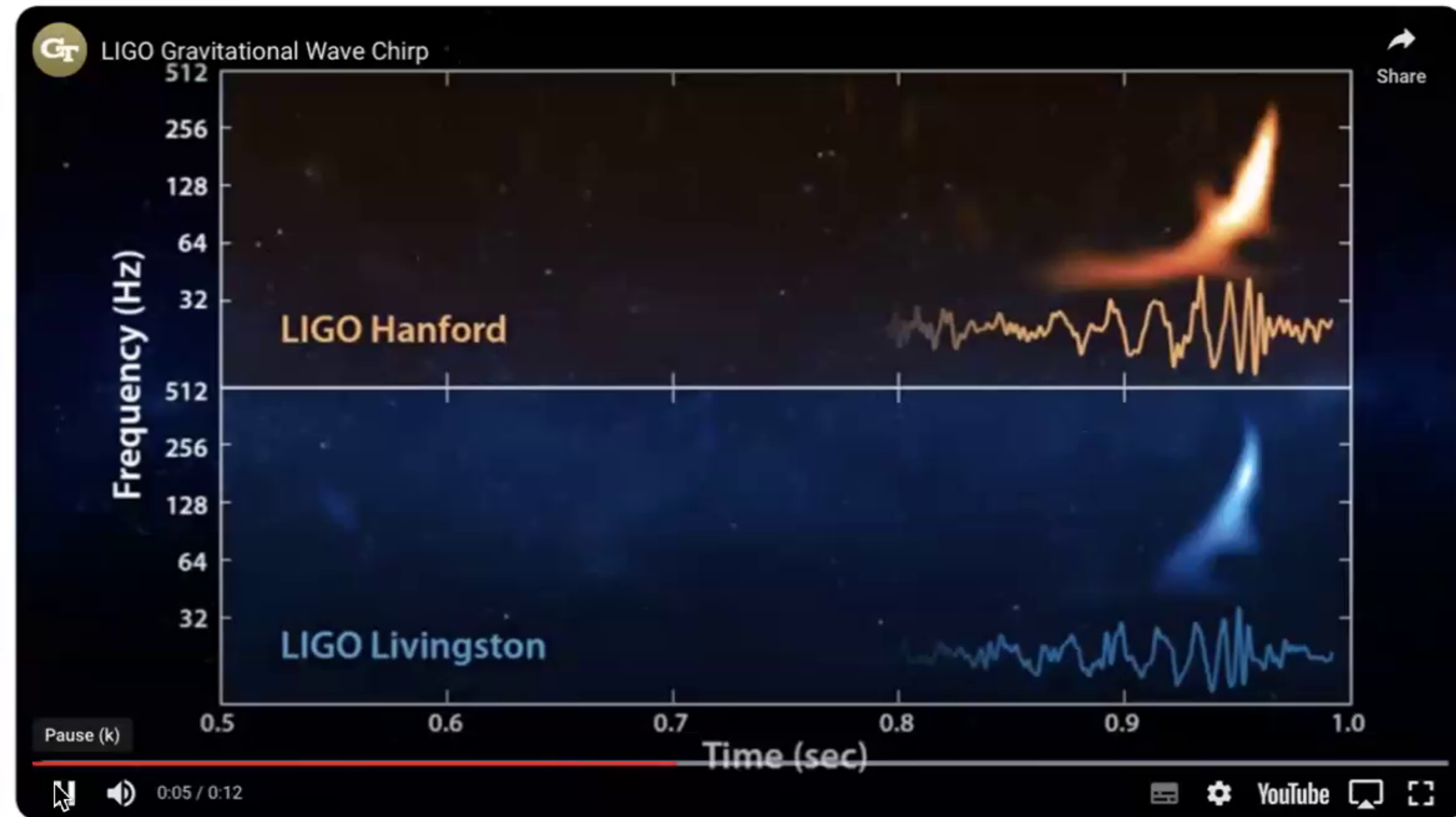
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LIGO Gravitational Wave Chirp

YouTube · Georgia Tech · 11 Feb 2016

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9:31 AM

Next animation



OzGrav

1



Slide 1 of 29

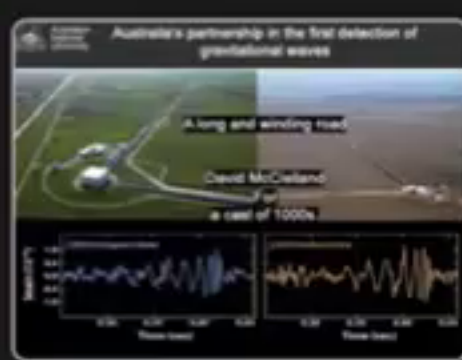


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2



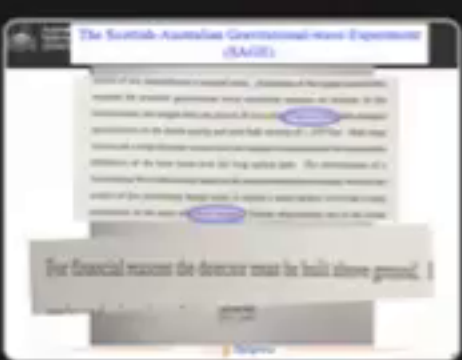
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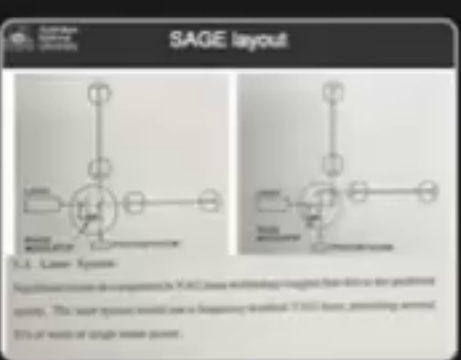
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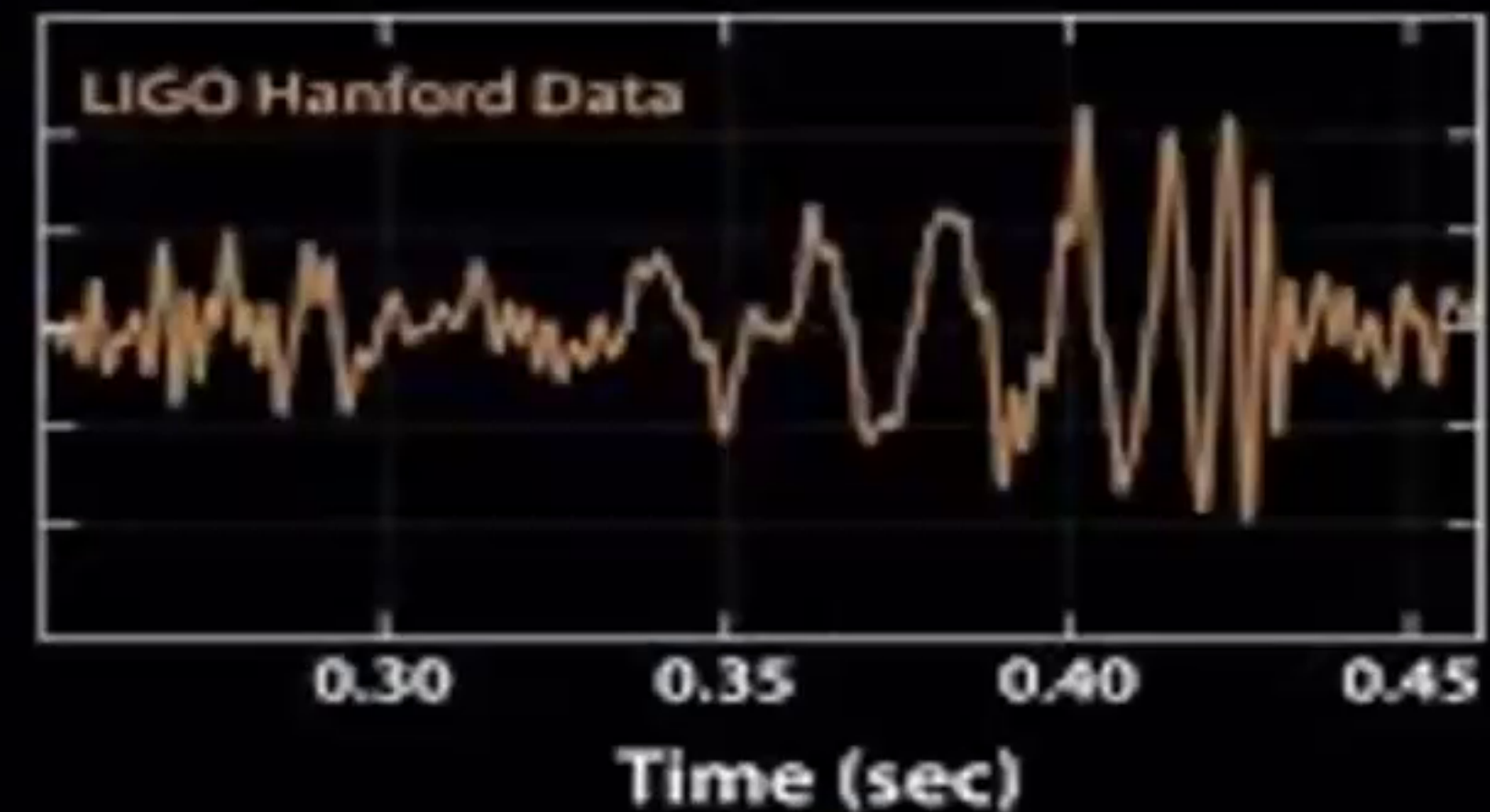
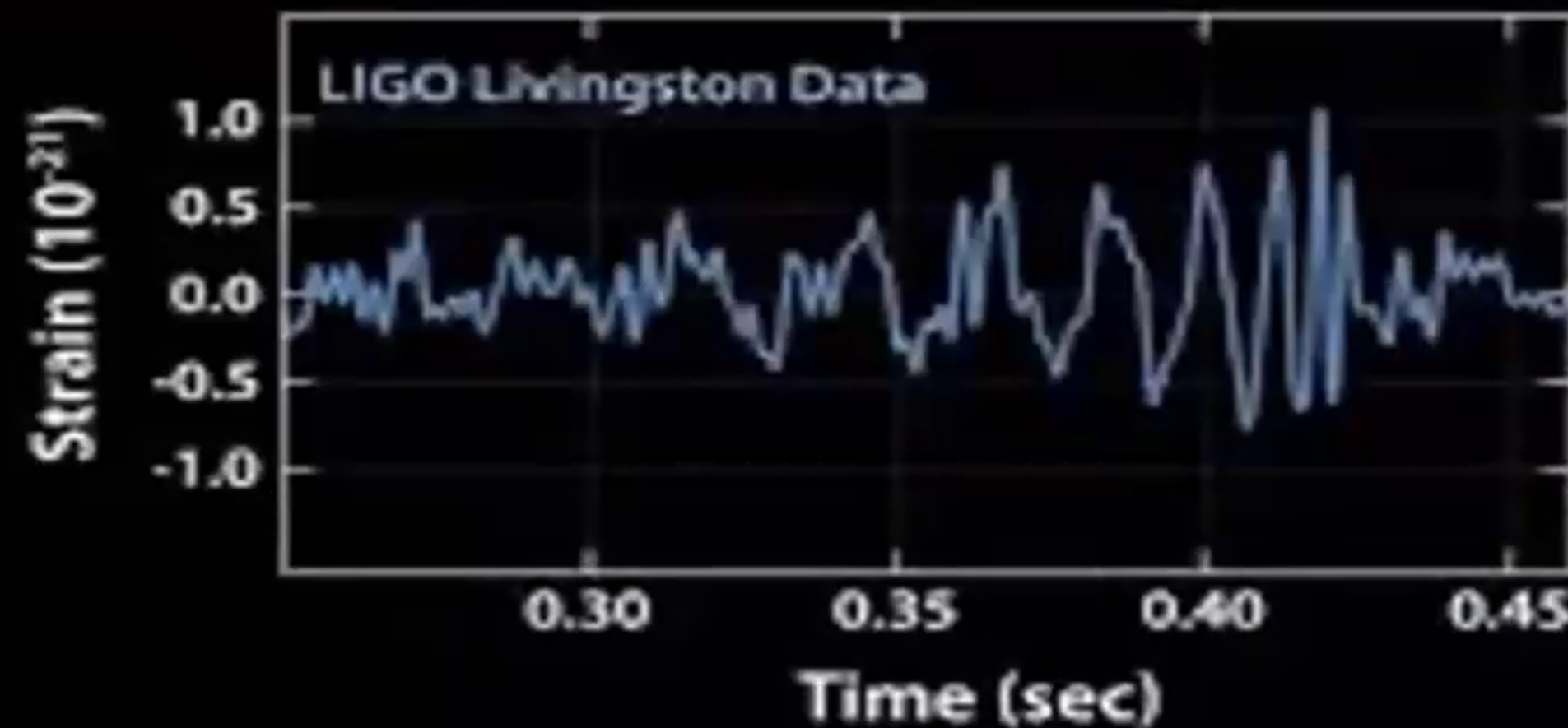


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Australia's partnership in the first detection of gravitational waves





Late 1980s

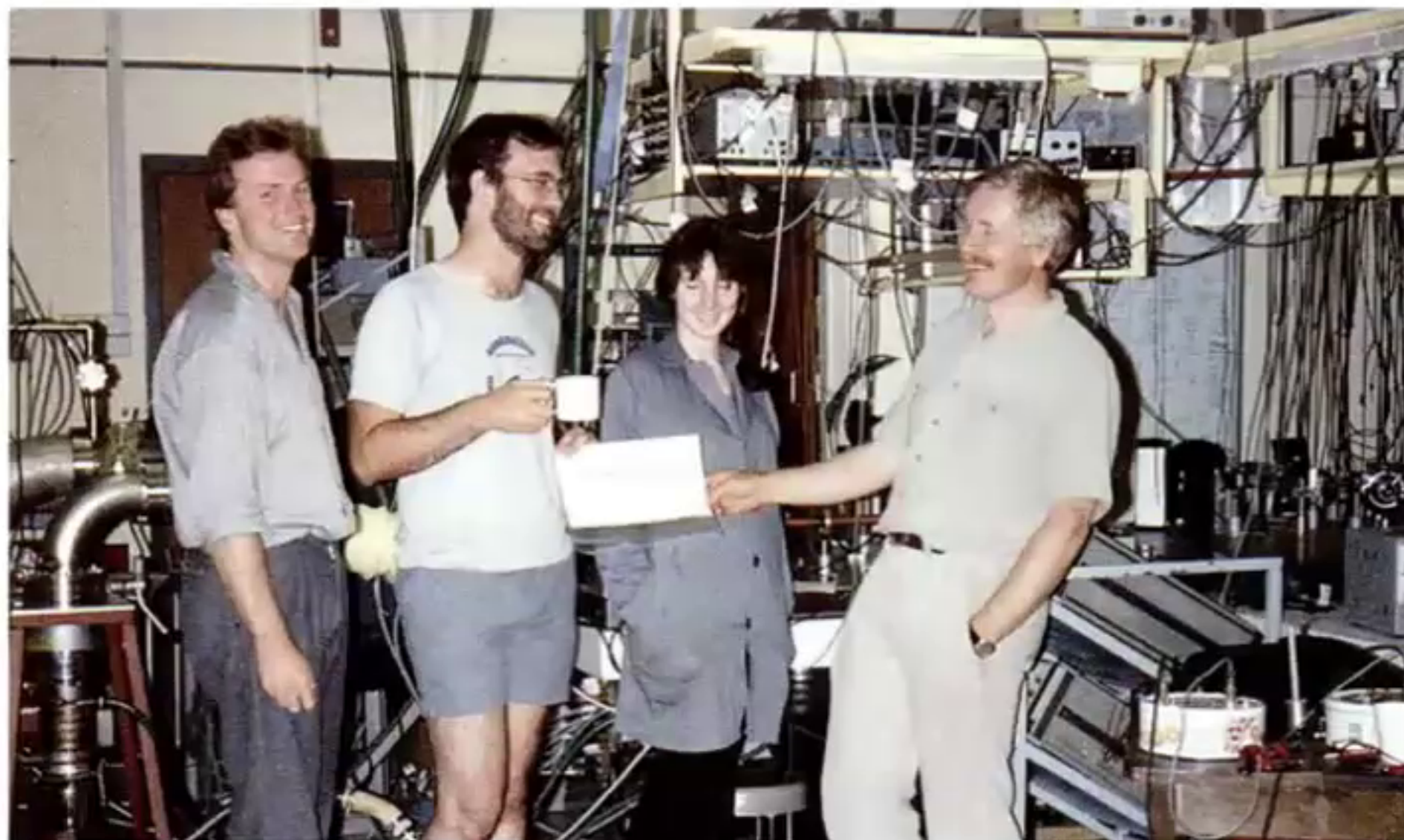
1980: Caves proposes ‘squeezing’ light to enhance LIGWD



Late 1980s

1980: Caves proposes ‘squeezing’ light to enhance LIGWD

**Late 1980’s ANU squeezes light
- SO lets get into the GWD business!**



McClelland, Manson, Hope, Bachor





Late 1980s

Disclaimer: DEM and UWA



Pre 1988:

- Blair, Veitch (UWA) and resonant bars
- McClelland, Bachor, Sandeman (ANU) Quantum optics
- Hough (Glasgow): 10m Glasgow prototype interferometer and the **US\$60M** Glasgow 3km detector proposal.





Late 1980s

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1988:

- MG8 Perth: Hough converts Blair
- Independently, McClelland contacts Blair/Veitch with proposal to collaborate on LIGWD



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1988:

- MG8 Perth: Hough converts Blair
- Independently, McClelland contacts Blair/Veitch with proposal to collaborate on LIGWD

1988: why not a Scottish Australian LIGWD!

UK has the heritage; Australia has the land

Preliminary Design Study for a Laser
Interferometer Gravitational Wave Observatory
in Western Australia

A proposed collaboration between
University of Glasgow
University of Western Australia
and
Australian National University

Prepared on behalf of the University of Western Australia and
the State Government of Western Australia

(28/10/88)
(14/11/88)



The Scottish-Australian Gravitational-wave Experiment (SAGE)

Preliminary Design Study for a Laser
Interferometer Gravitational Wave Observatory
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University of Glasgow
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(14/11/88)



The Scottish-Australian Gravitational-wave Experiment (SAGE)

consist of two perpendicular evacuated tubes. Attainment of the higher sensitivities required for practical gravitational wave astronomy requires an increase in the interferometer arm lengths from the present 30 m to about 3 km to 5 km, with stringent specifications on the mirror quality and ultra high vacuum of $\sim 10^{-8}$ Torr. Both large mirrors and a large diameter vacuum tube are required to accommodate the unavoidable diffraction of the laser beam over the long optical path. The development of a Gravitational Wave Observatory based on the laser interferometer technique, which is the subject of this preliminary design study, is clearly a major project involving a large expenditure of the order of \$20-25 million. Similar observatories are in the initial

Australian National University

Prepared on behalf of the University of Western Australia and
the State Government of Western Australia

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OZGrav



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Australian National University

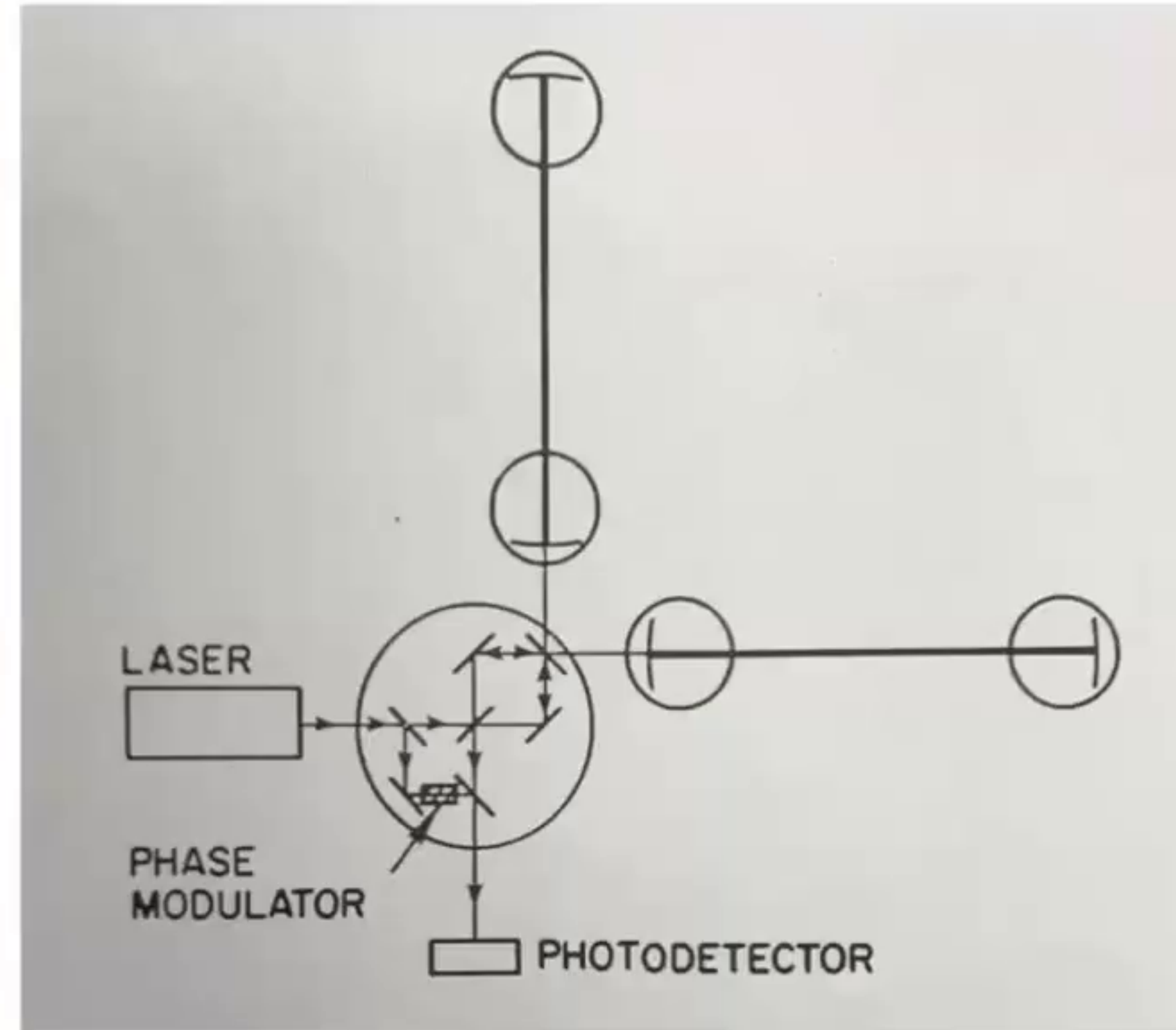
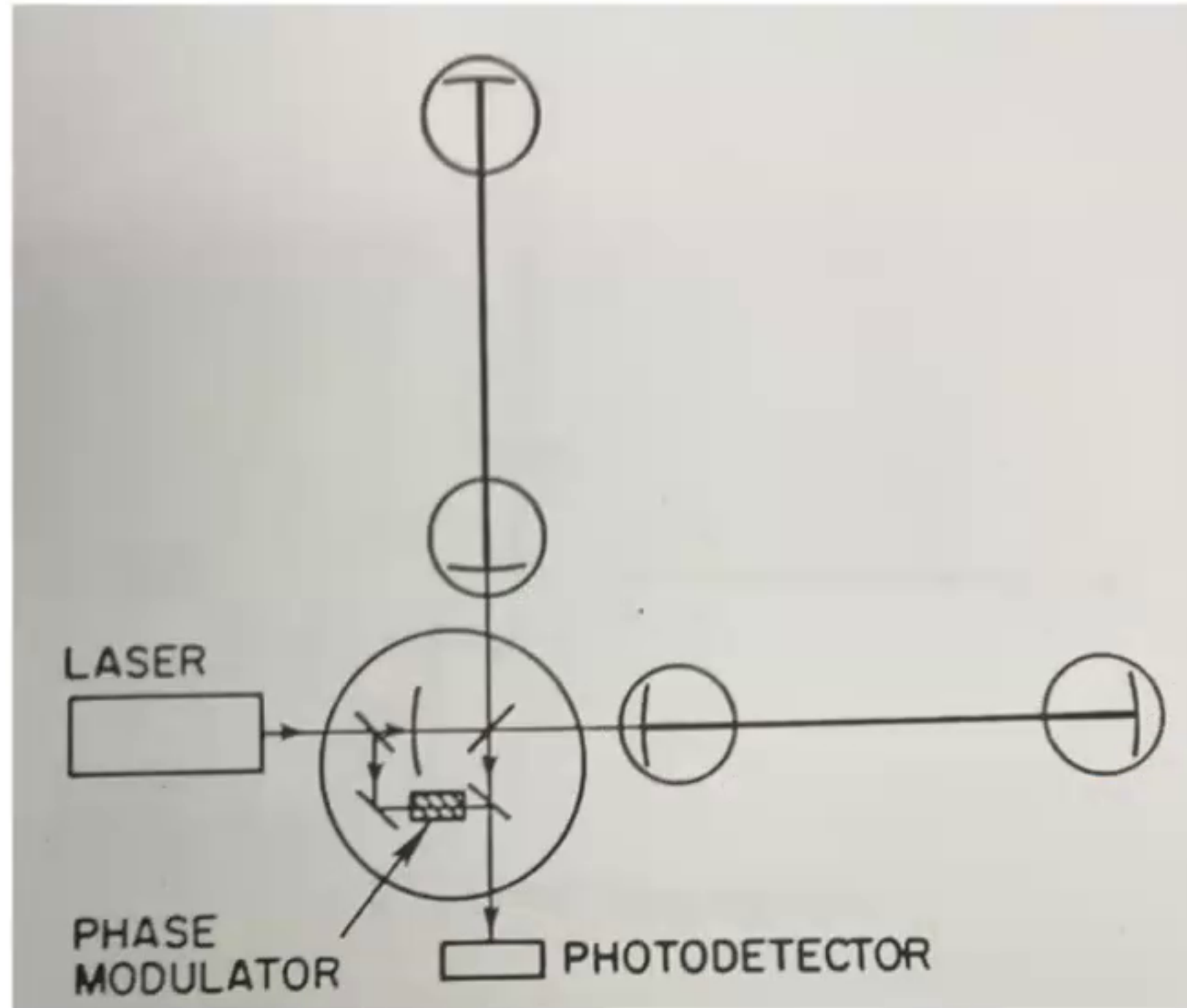
For financial reasons the detector must be built above ground. I

(28/10/88)
(14/11/88)

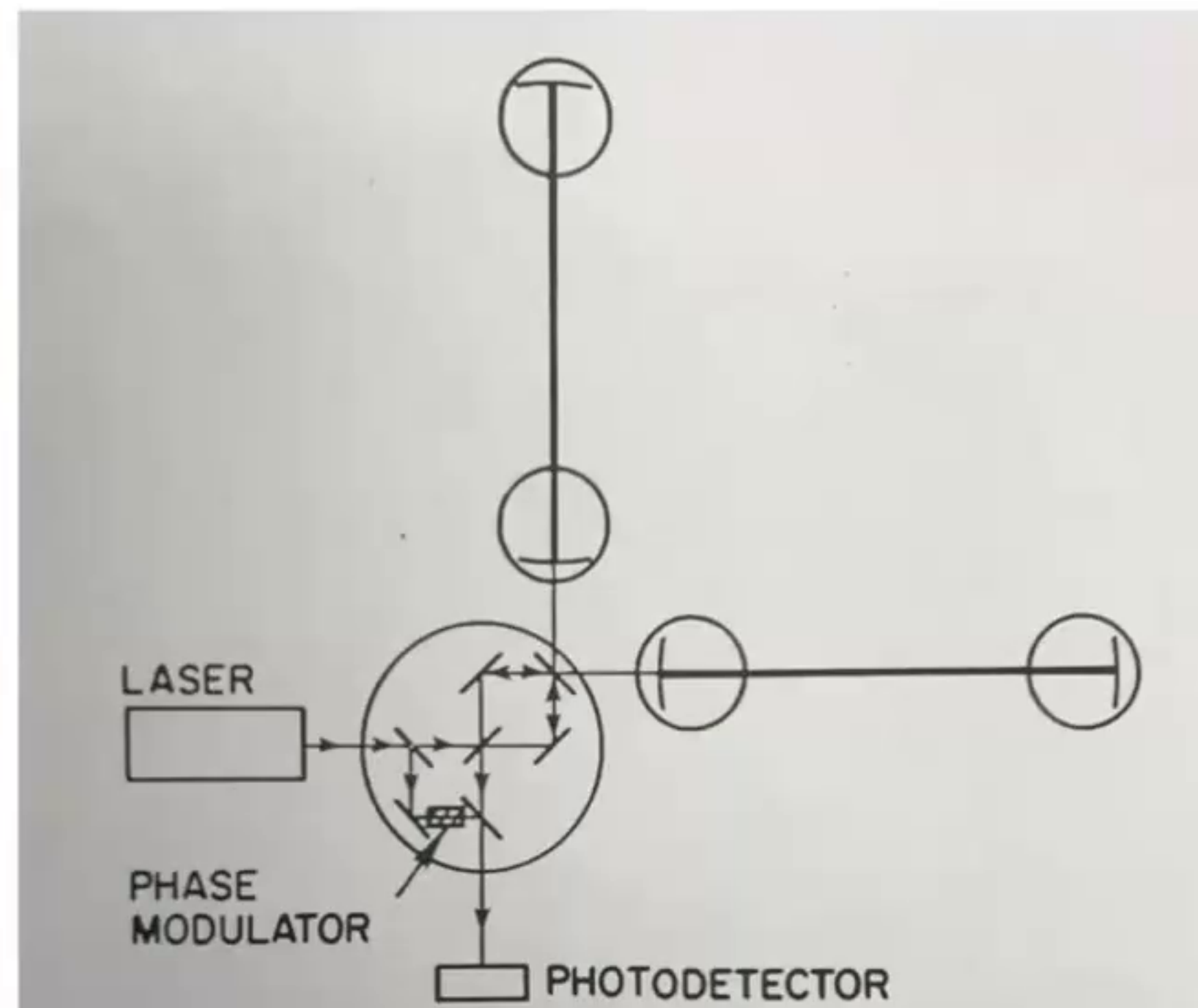
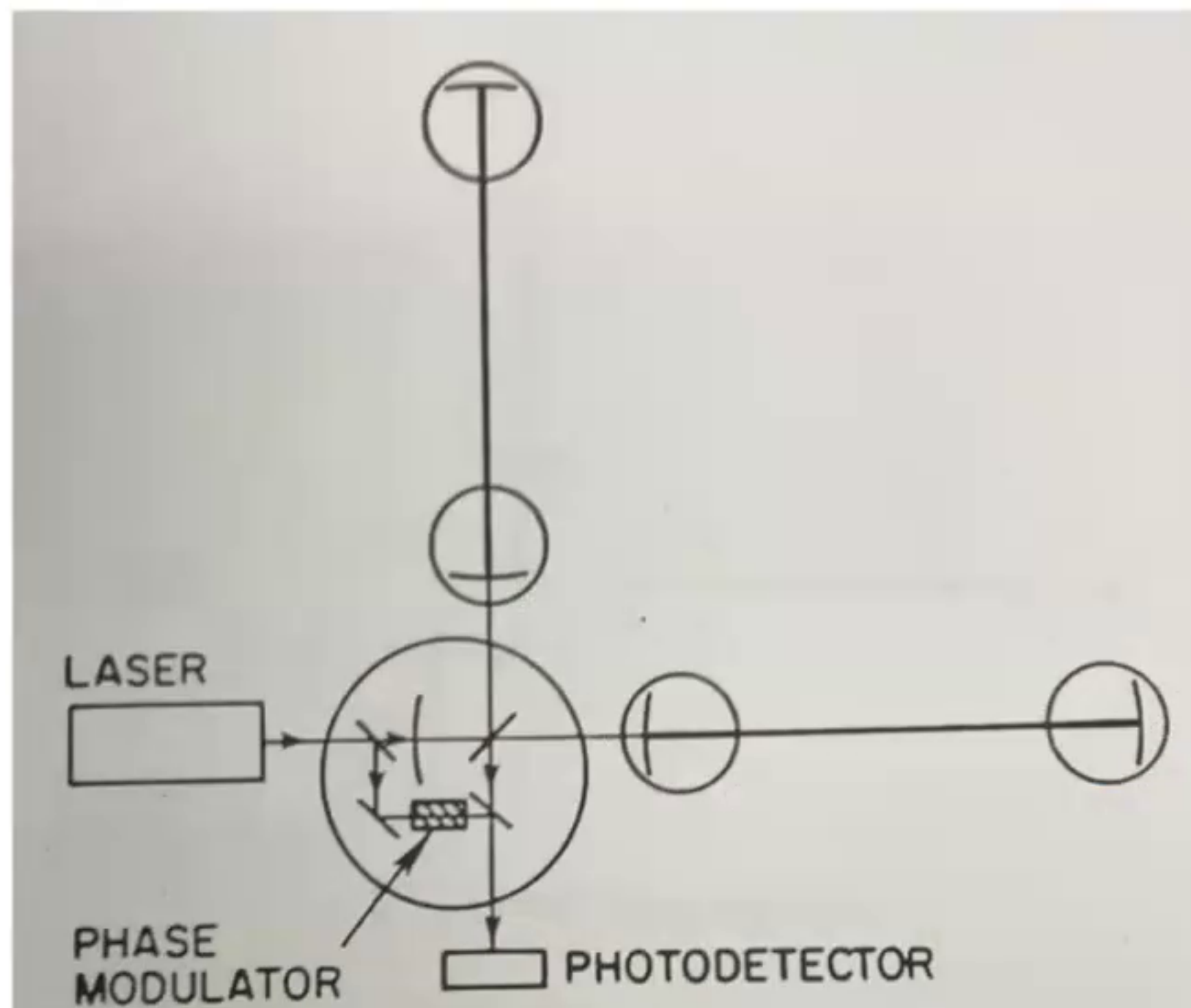
OZGrav



SAGE layout



SAGE layout

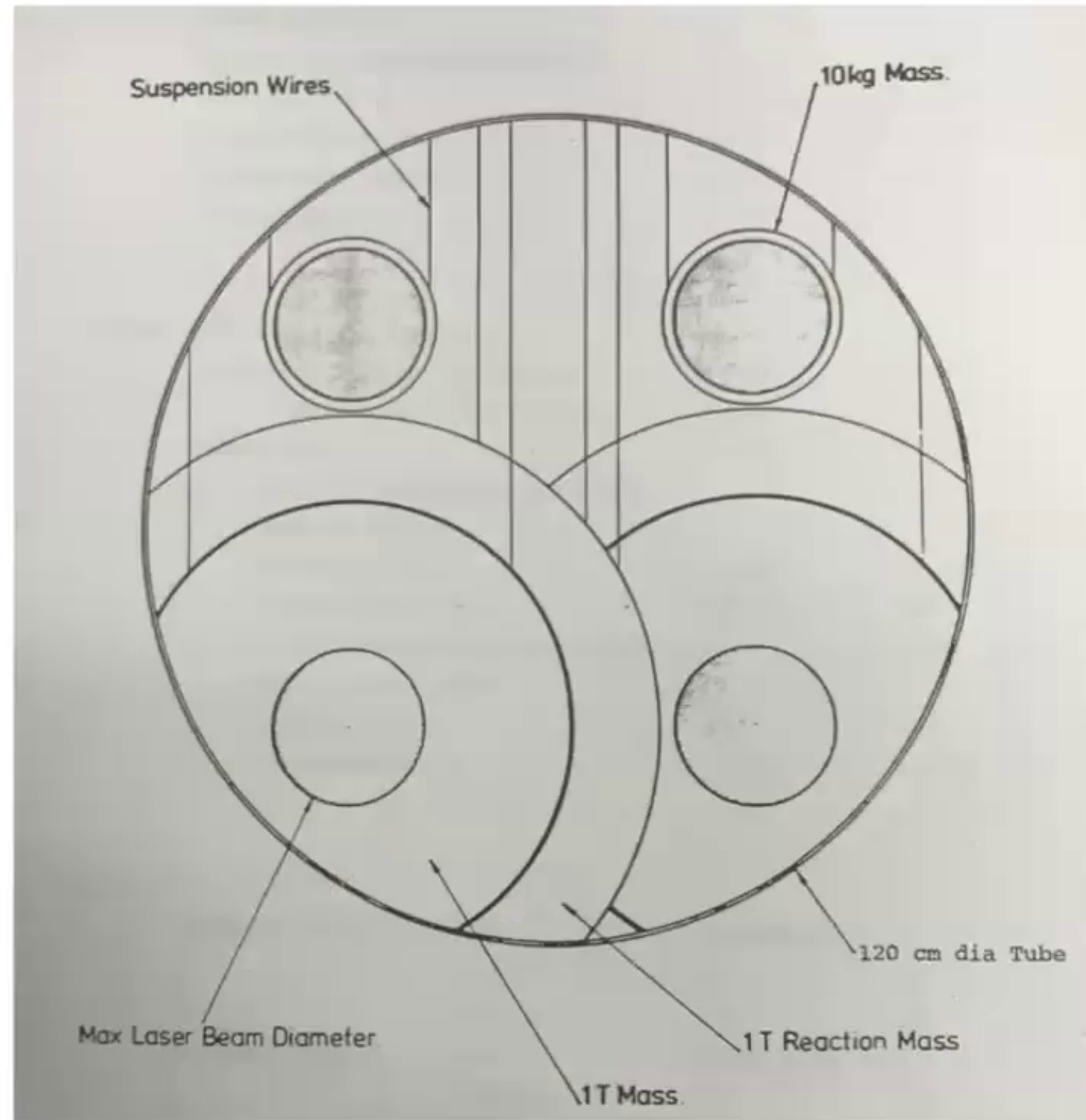


5.1 Laser System

Significant recent developments in YAG laser technology suggest that this is the preferred option. The laser system would use a frequency doubled YAG laser, providing several 10's of watts of single mode power.



SAGE – 2 interferometers



Then the world changed....

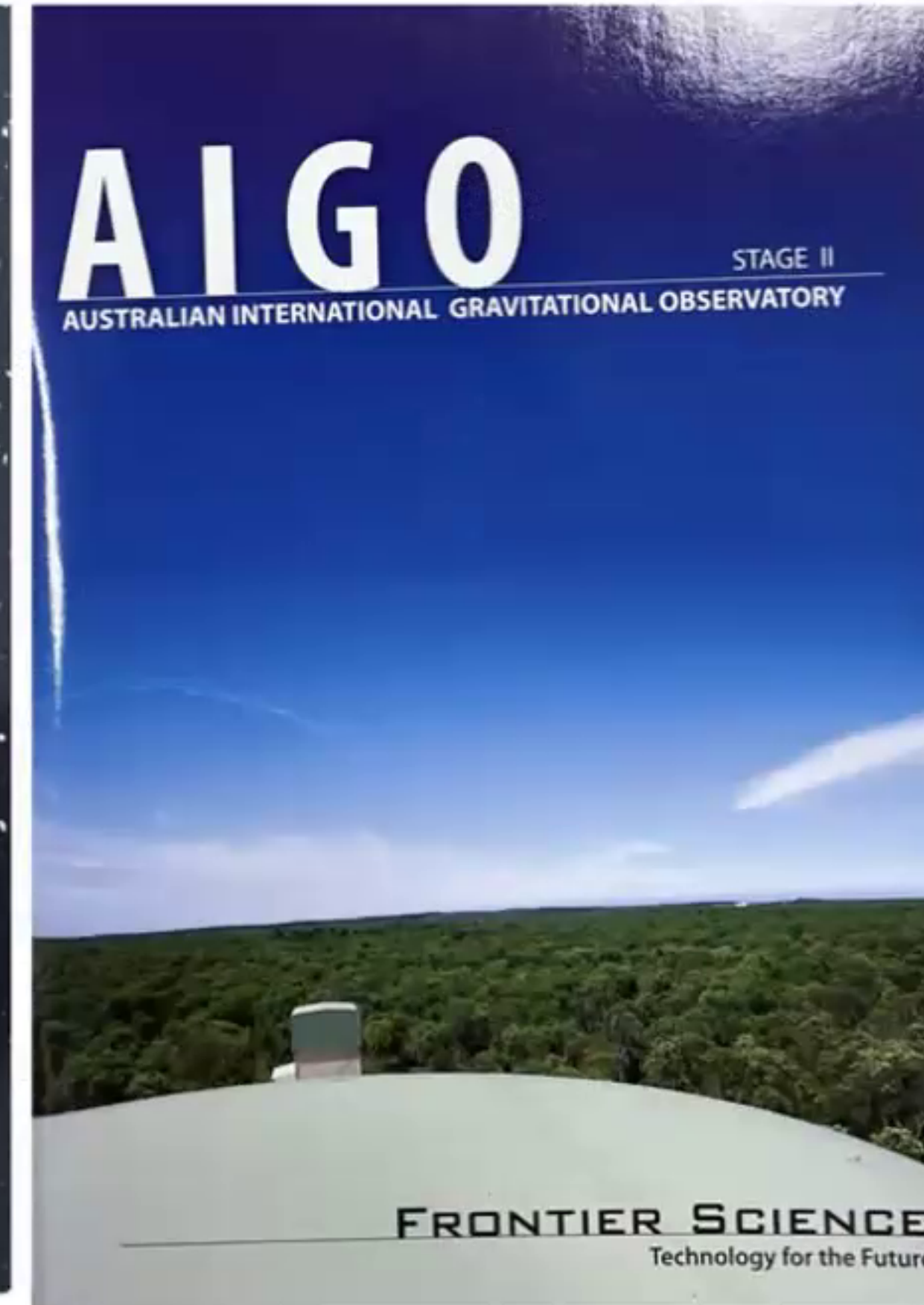
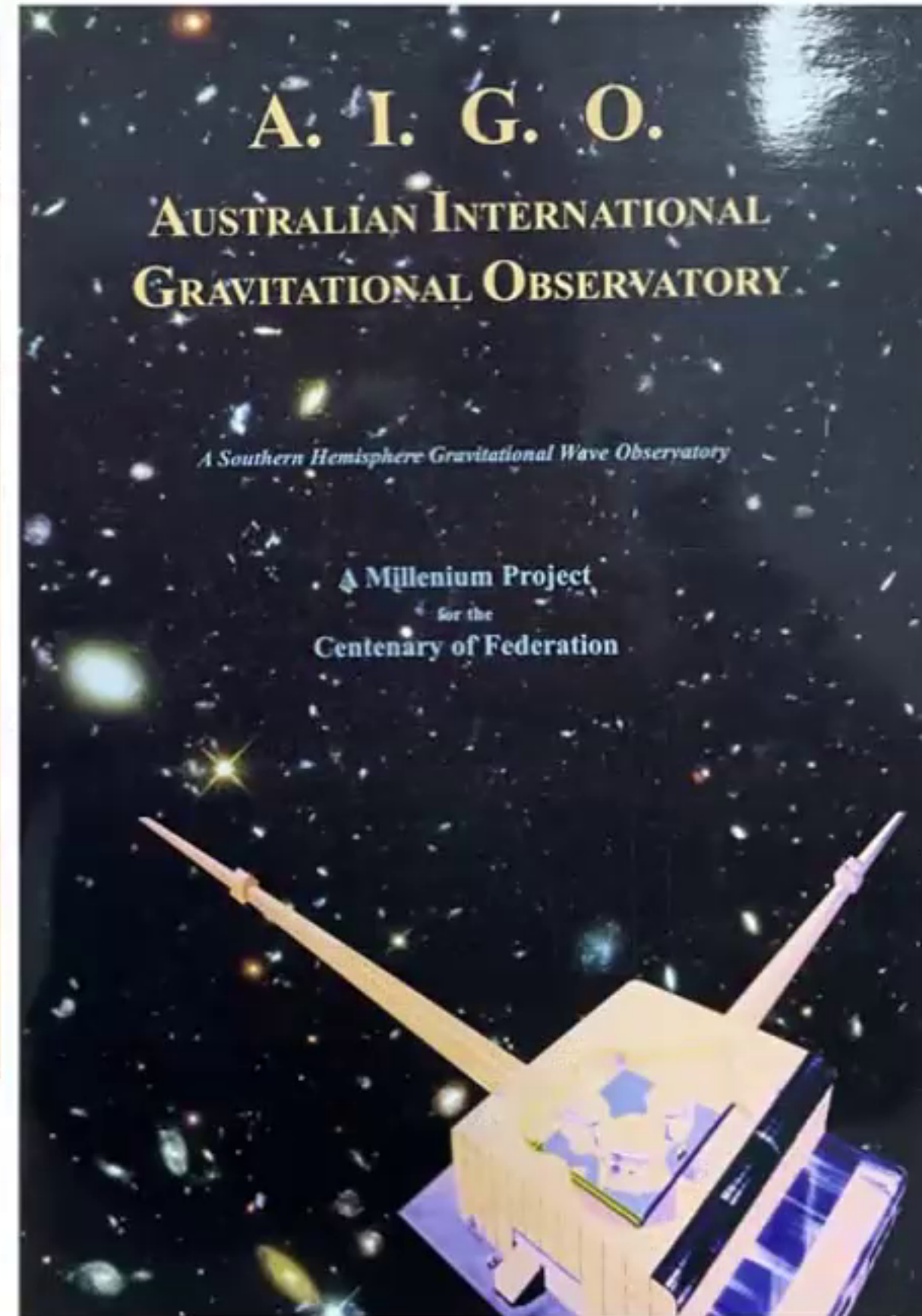
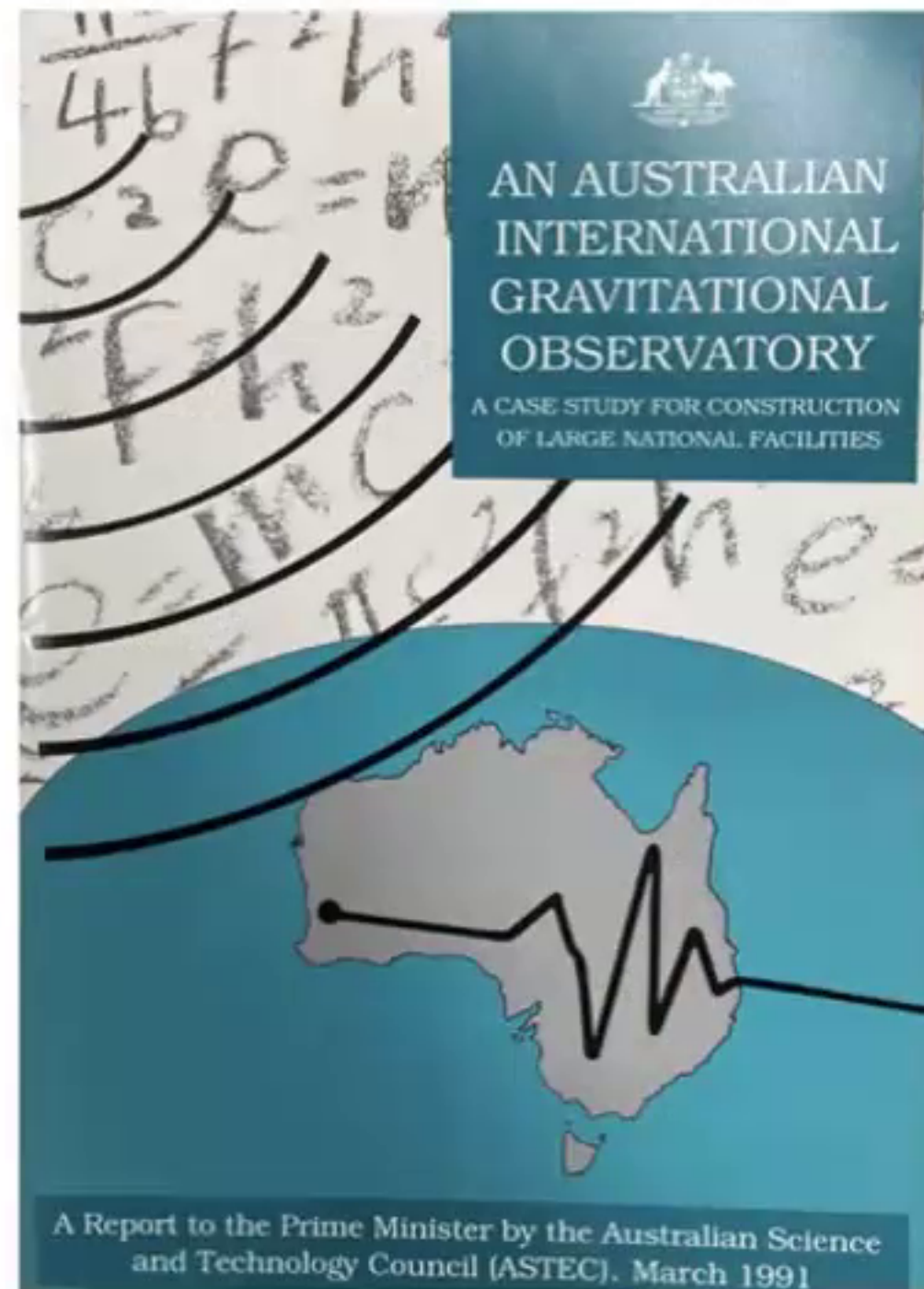
1989: Berlin wall came down

UK dumps Australia in favour of Europe!

So we go it alone:

The Australian International Gravitational-wave
Observatory (AIGO) is borne

We increase the price and descope throughout
the 1990s, \$30M ... \$40M



Numerous AIGO bids throughout the 1990s
AIGO-400 put up as a Millenium Project
Deaf ears and empty pockets

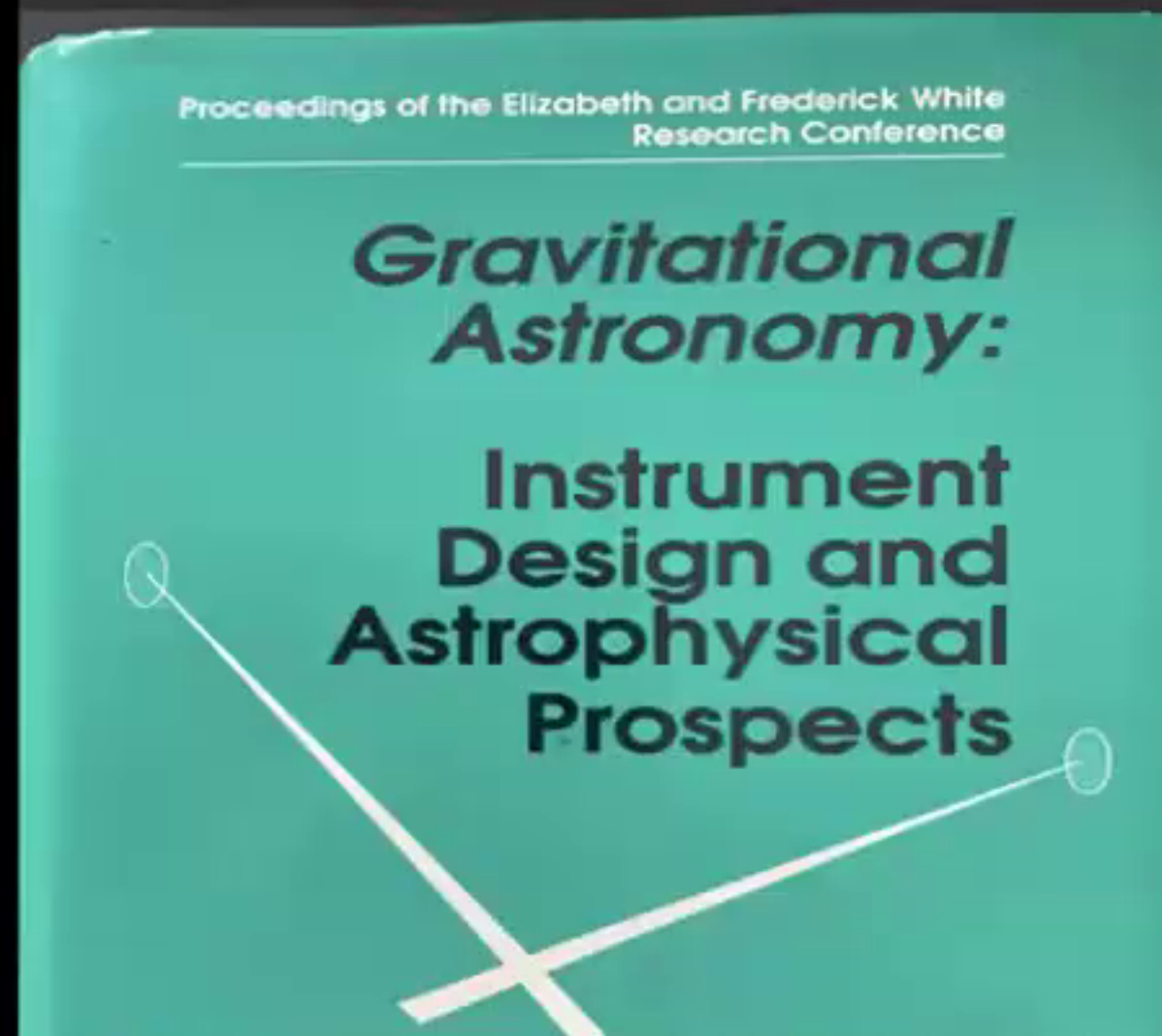
OzGrav



Australian
National
University

1990

E&F White International Conference on GWA; Canberra



Of note:

Bob Byer, Ginzton Lab, Stanford

Thibault Damour* Institute Des Hautes Etudes Scientifiques

Karsten Danzmann Max-Planck-Institute Für Quantenoptik,

Paul Davies, U Adelaide

M Fujimoto, NAOJ

Alberto Giazotto, INFN, Pisa

Patrice Hello, Laboratoire d'Optique Appliquee, Palaiseau,

Ju Li, University of Western Australia

Dick Manchester, CSIRO

Brian Meers, University of Glasgow

Gerard Milburn, U Queensland

Peter Michelson, Dept of Physics, Stanford University,
Stanford,

Guido Pizzella, European Centre for Nuclear Physics,
Geneva,

Valentin Rudenko, Sternberg Astronomical Institute, Moscow

Peter Saulson, JILA, Boulder, Colorado,

Dan Walls, Dept of Physics, University of Auckland, Auckland,
New Zealand

12 (of 65) from Industry/CSIRO

Following year, Robbie Vogt and Fred Raab visited Australia



1992: Susan Scott (ANU) brings the theory dimension

1993: Jesper Munch joins UA; recruits Peter Veitch



1994: ASGRG formed

1992: Susan Scott (ANU) brings the theory dimension

1993: Jesper Munch joins UA; recruits Peter Veitch



1994: ASGRG formed

1995: Formation of Australian Consortium for Interferometric Gravitational-wave Astronomy (ACIGA) *Inaugural Chair: John Sandeman*

- ANU control systems and quantum noise
- UA lasers, stabilization, distortions
- UWA isolation & suspension systems; instabilities
- joint (successful) bid to ARC for coordinated Large (ie DP) Grants successful *

ACIGA grows to include UoM, Monash and CSU

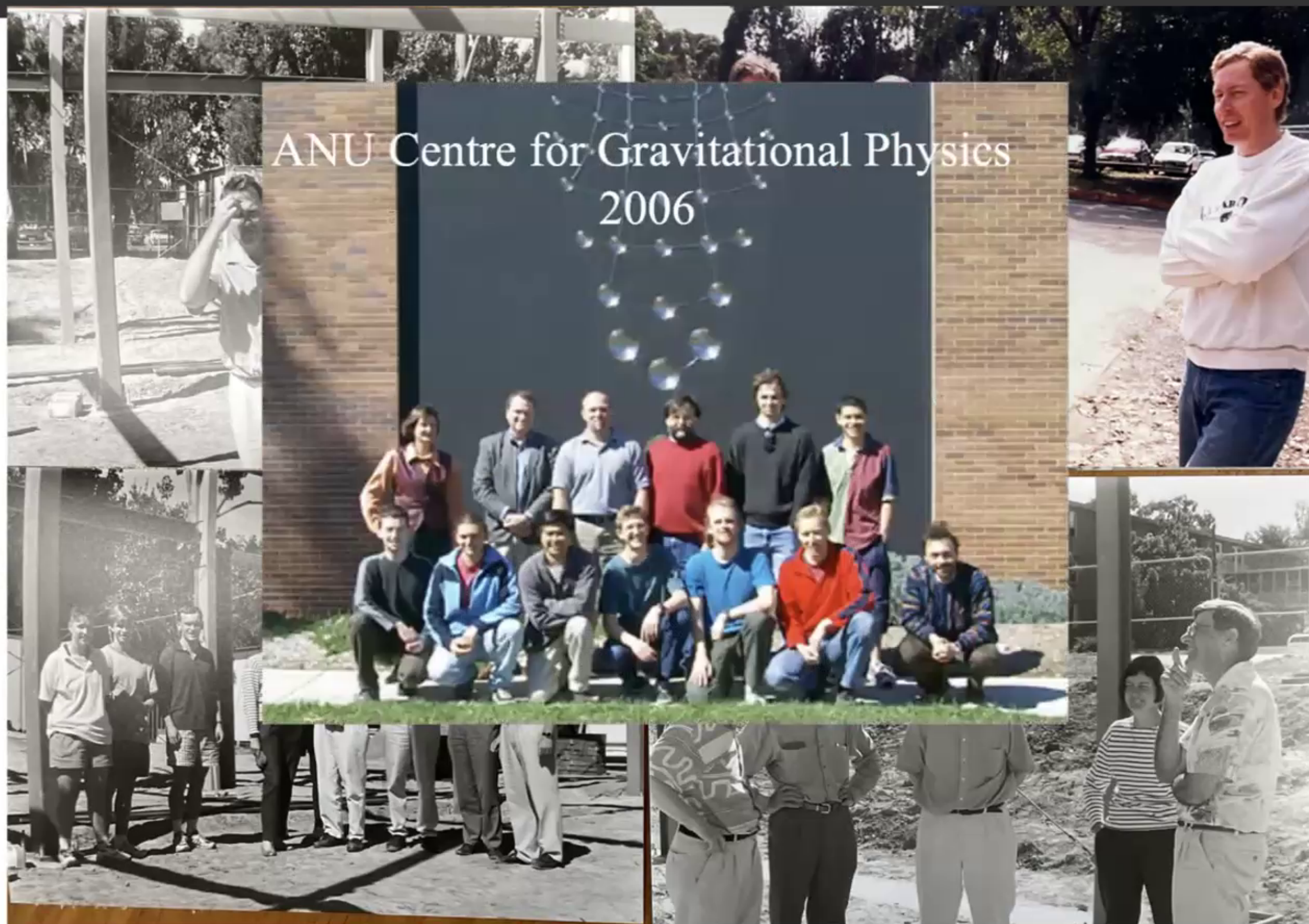


ANU high-bay GW lab completed 2000





ANU high-bay GW lab completed 2000



1998: LIGO Scientific Collaboration formed

ACIGA founding member

2003: Gingin High Power, suspended mass, test facility commences

2004: Initial LIGO

scientific and technical contributions from ACIGA

2004: McKenzie et al reports squeezing in the LIGO band

2008: Advanced LIGO project (aLIGO)

partnership USA, UK, Germany and Australia

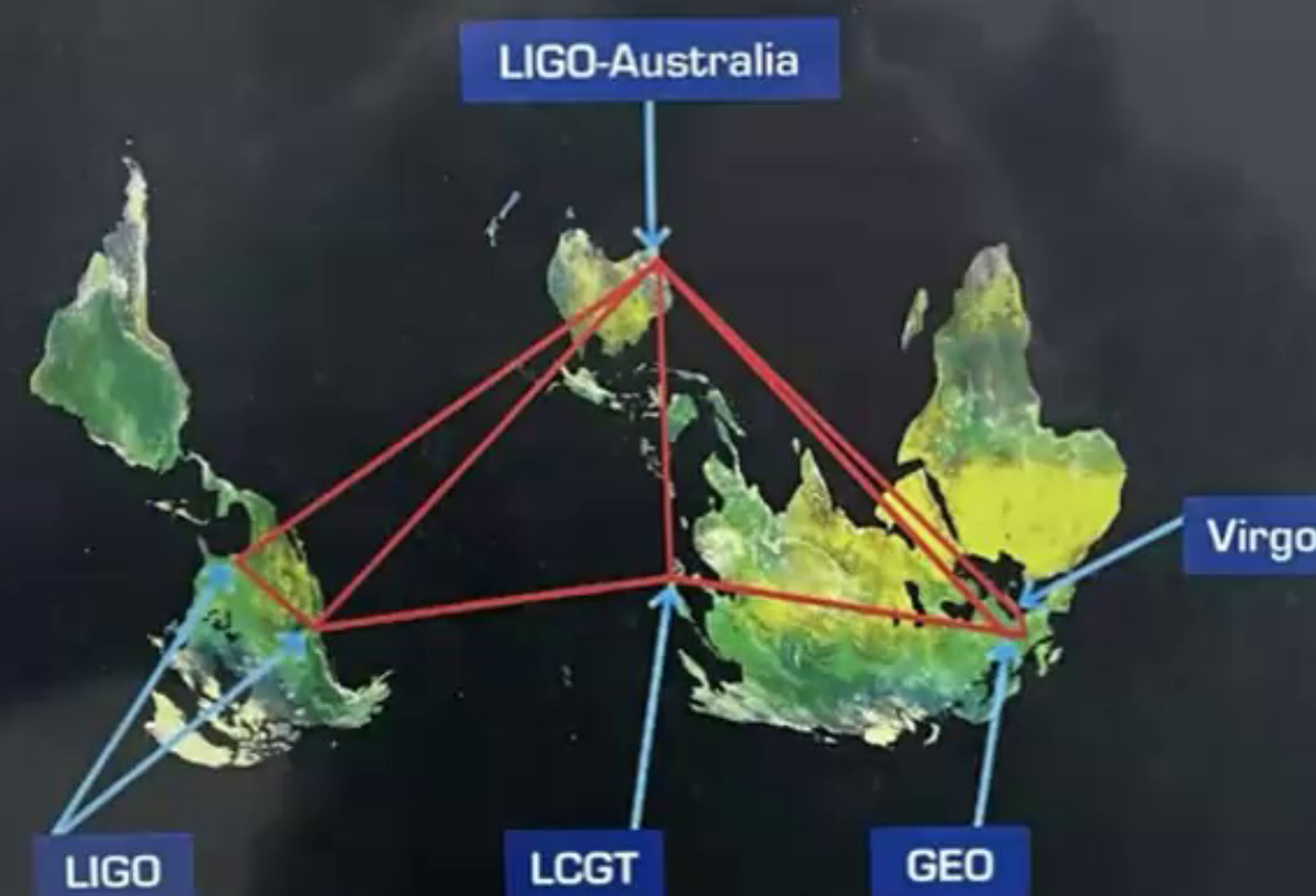
2009: LE09/13/17/21: Australian Partnership in Advanced LIGO





Interlude:2010- 2012 * LIGO- Australia: An opportunity lost but lessons learned

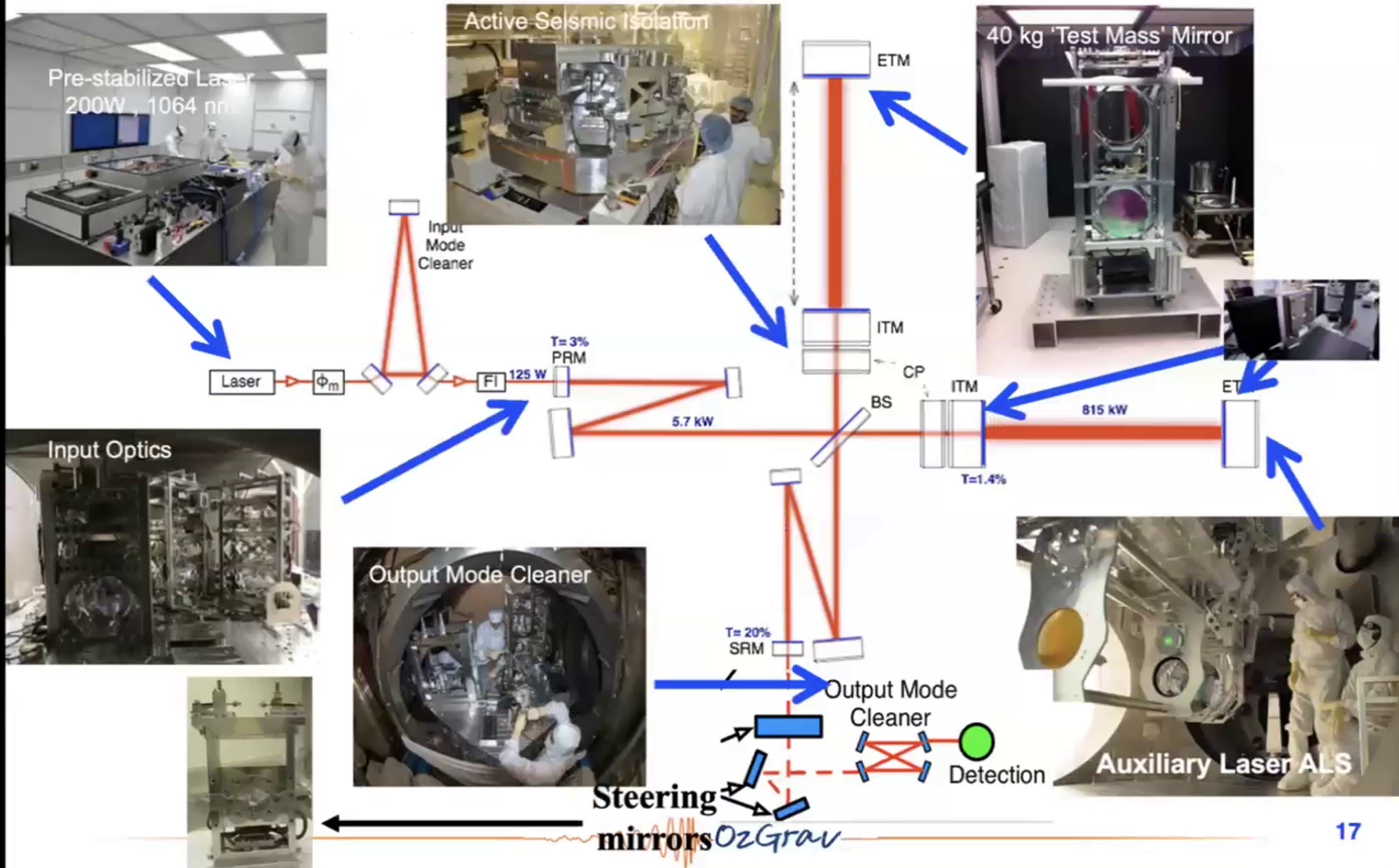
LIGO-AUSTRALIA - ON THE CREST OF THE WAVE



OPPORTUNITY AND CHALLENGE

The next decades will see a revolution in physics and astrophysics as a global network of ultra-sensitive gravitational wave detectors begin to harness the new spectrum of gravitational waves to probe the dark side of the universe. Australia can become a pivotal partner in this most challenging quest. The US LIGO Laboratory will transfer to Australia an advanced gravitational wave detector, valued at \$140M, provided Australia funds the construction of a national facility to house the detector (estimated to cost \$140M) and commits to funding operations for at least 10 years (operating costs estimated at \$6M p.a.). This offer has the approval and support of the National Science Foundation, the primary funding agency for Advanced LIGO, and the approval of the President's National Science Board, provided Australia makes a commitment by October 1, 2011.

Advanced LIGO Interferometer





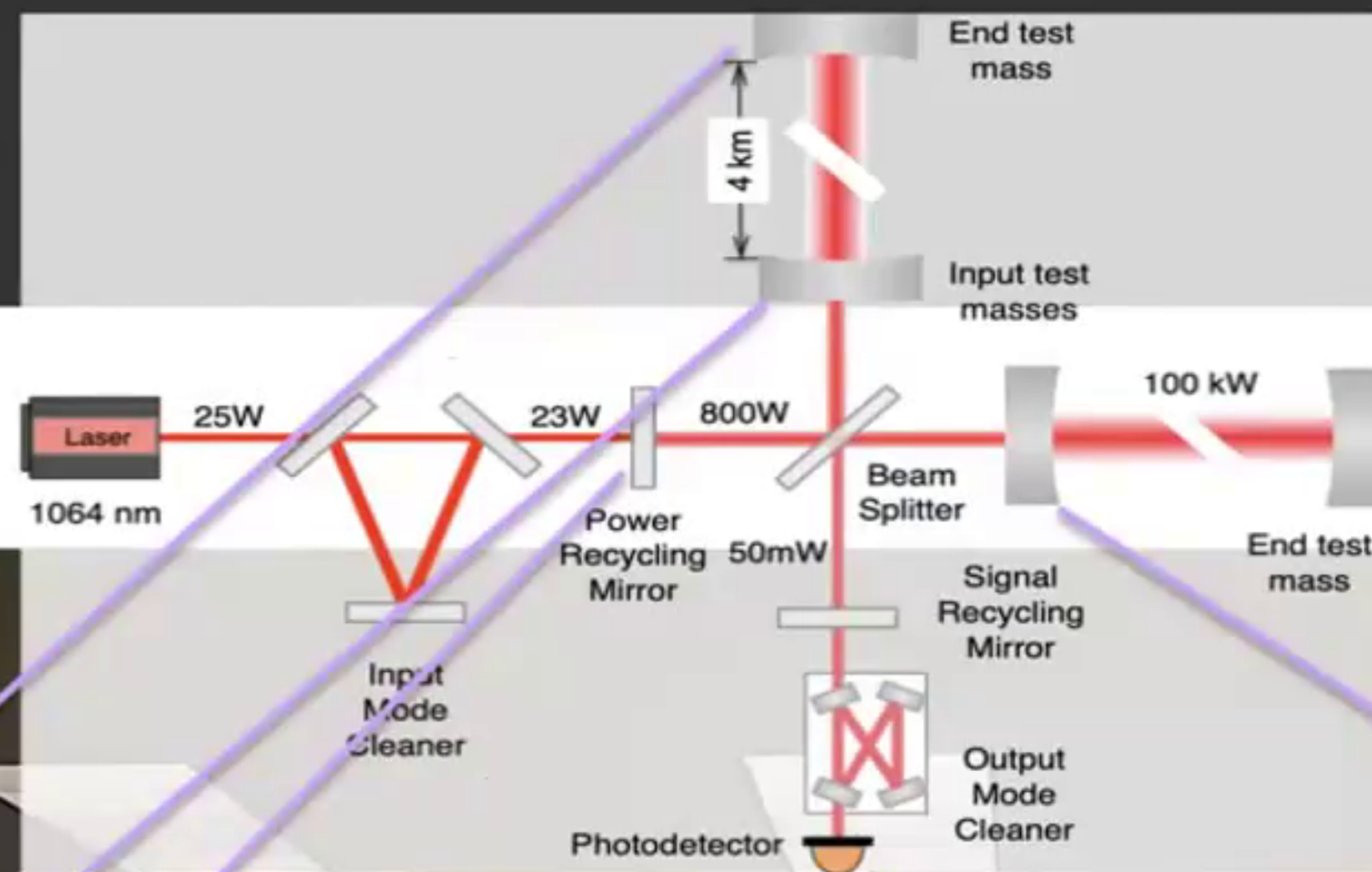
Australian Partnership in aLIGO

funded by ARC LIEF

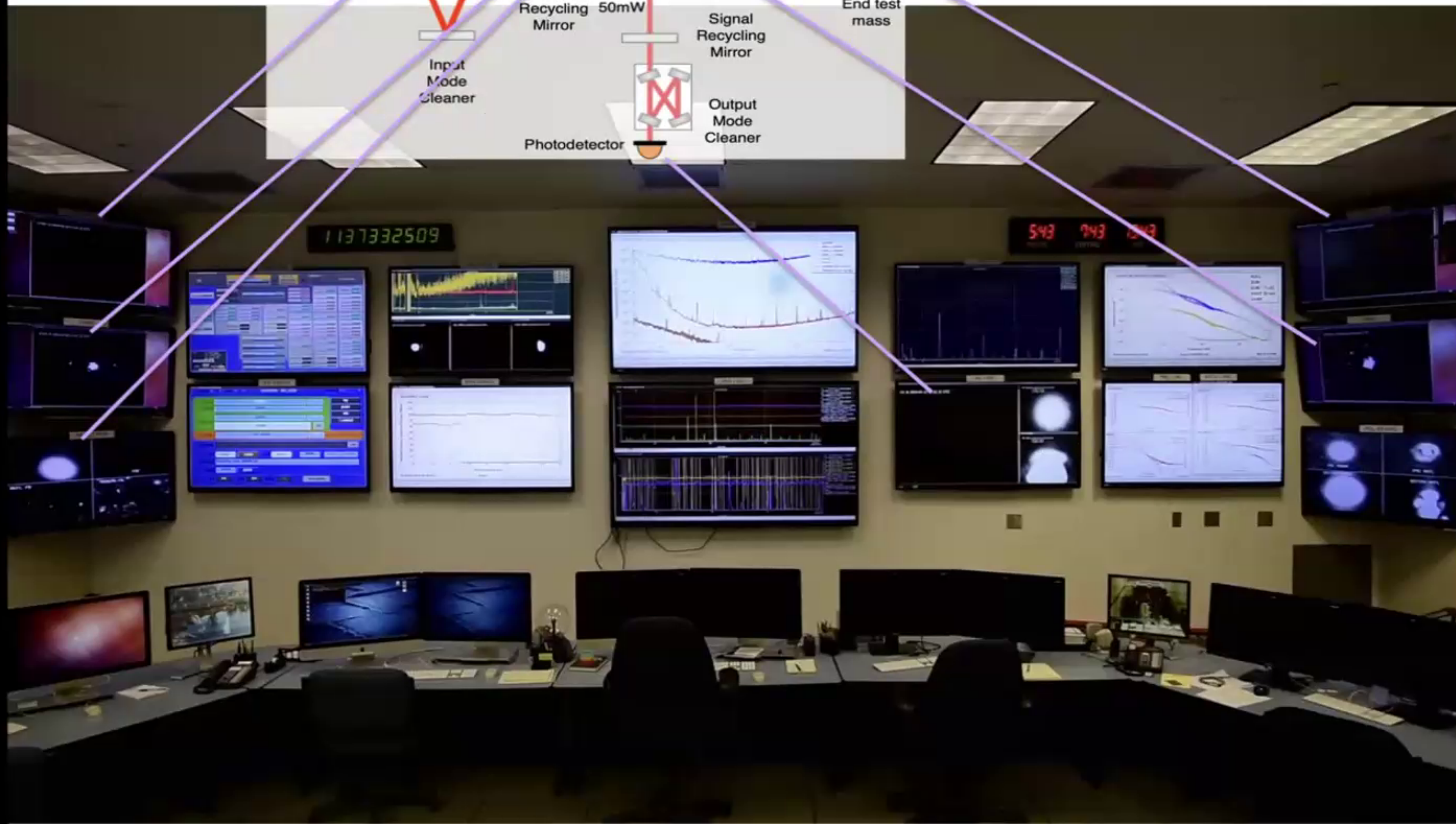
- Suspended Steering Mirror (ANU)
 - » Directing interferometer sensing beam.
- Lock Acquisition System (ANU)
 - » Arm Length Stabilisation
 - » Guiding the interferometer gently into science mode.
- Hartmann Cameras (UA)
 - » Monitoring the shape of the test masses under thermal load.
- Optical and Gold coatings (CSIRO)
 - » Providing high quality coatings on the input optics and beamsplitter.
- Parametric Instability Control (UWA)
 - » Mitigation techniques to avoid interferometer instabilities with high optical powers.
- Hardware injection (Monash)
- Data Quality and detector characterization (All)
- Coalescing binary and CW searches (UWA, ANU, U Melbourne)
- EM Follow-up (Swinburne, ANU, UWA, CSIRO)



Australian
National
University

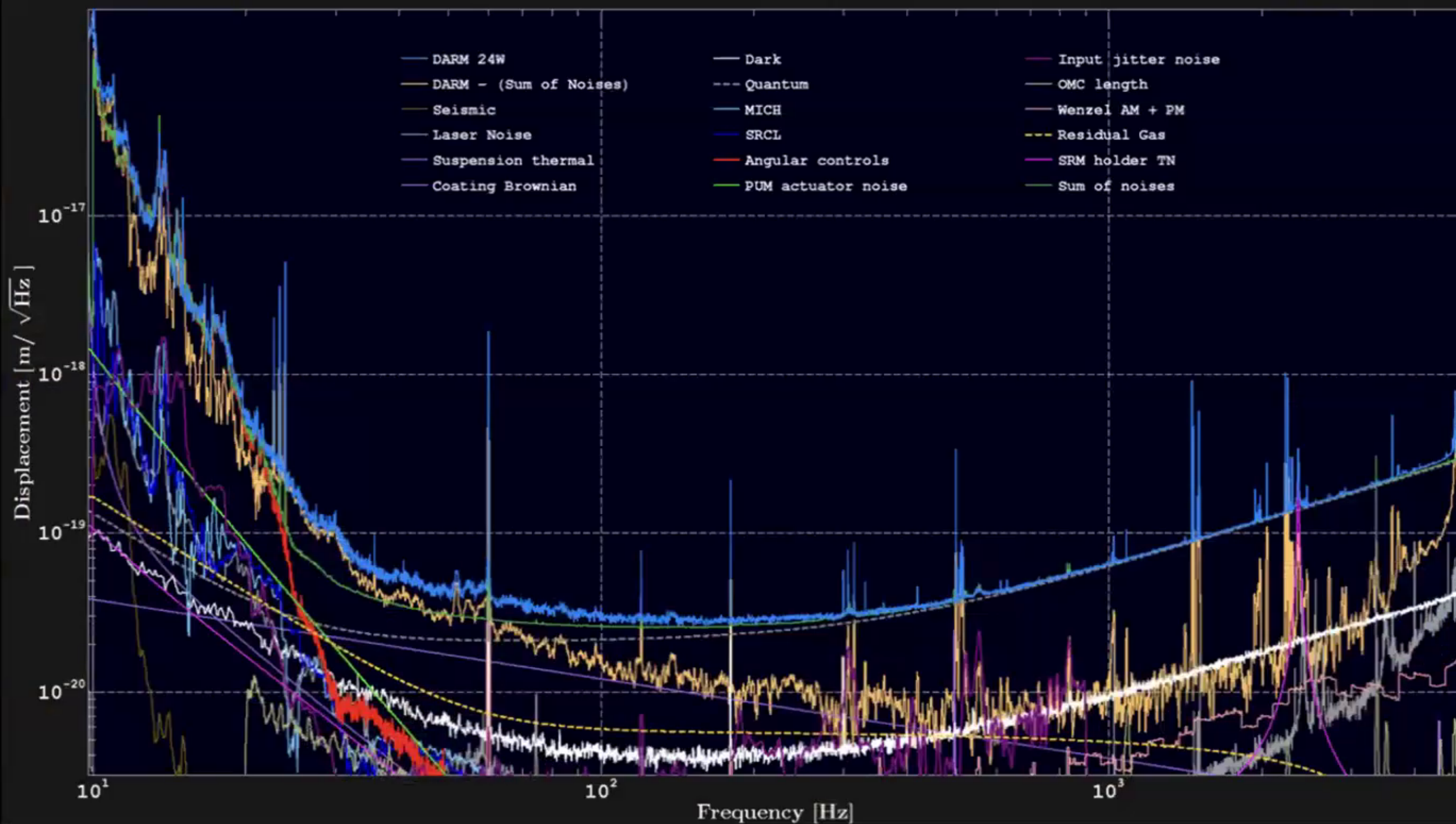


M. Fyffe





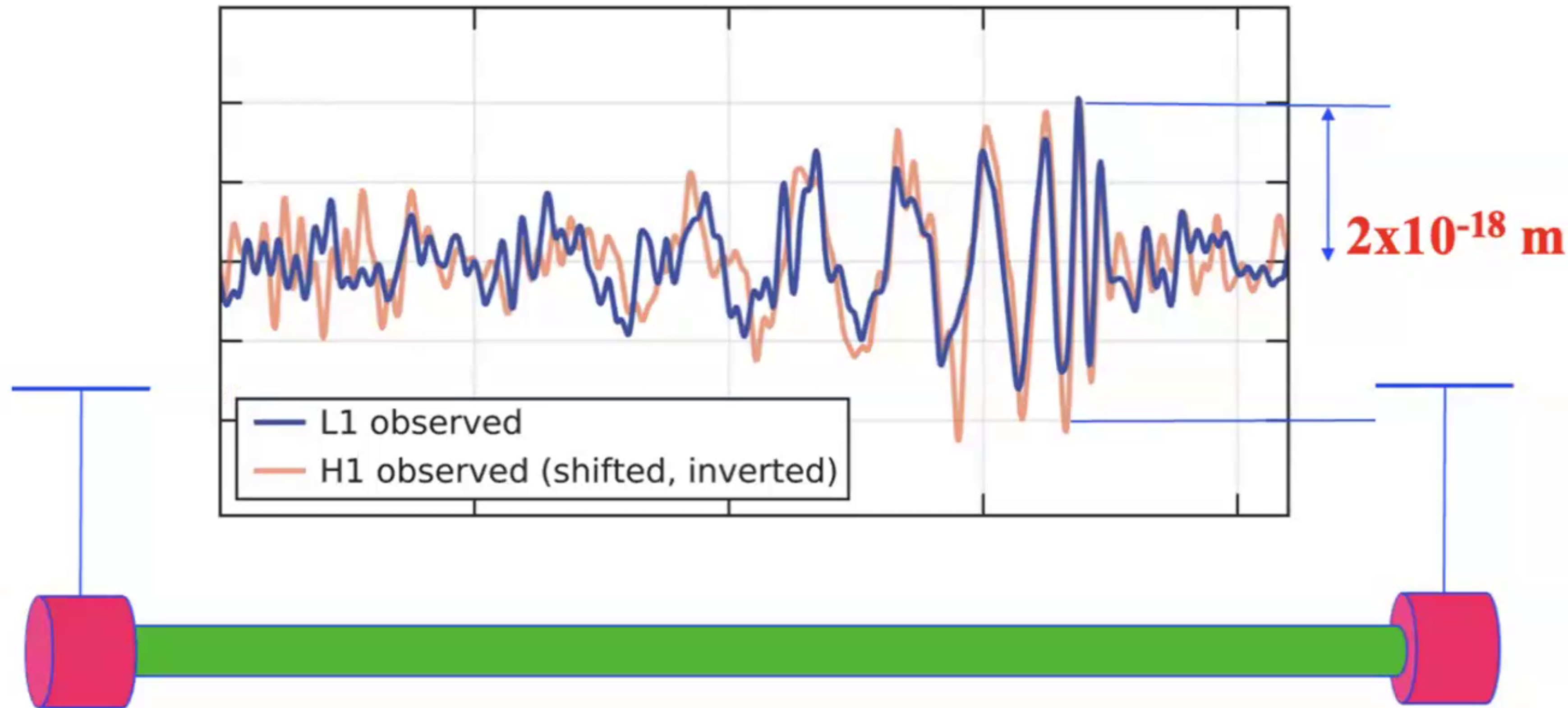
aLIGO in Observing run 2





The signal GW150914 **LIGO**

Pinup for precision measurement and engineering!



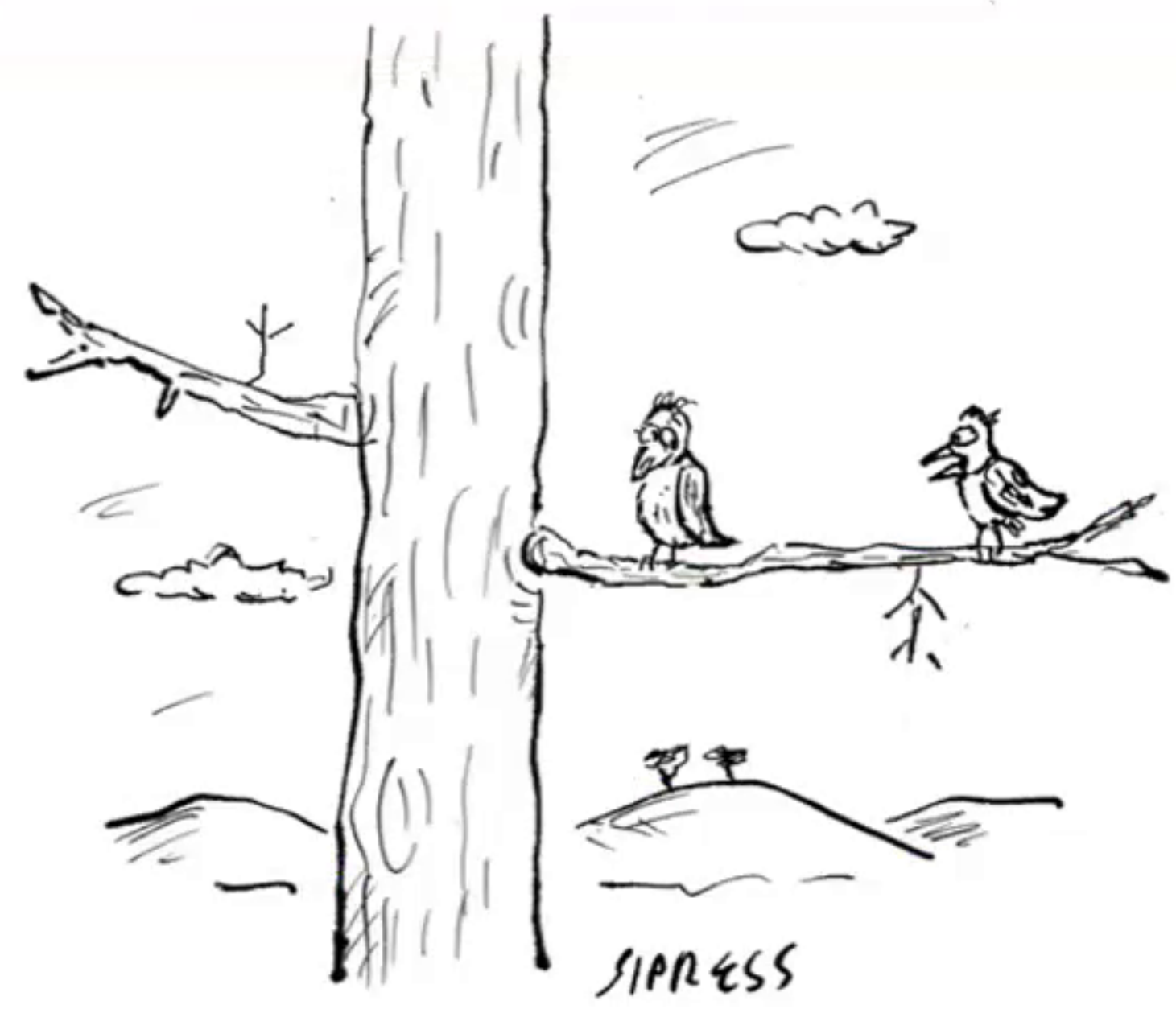
Effectively we have observed the separation between the centres of mass of 40kg objects oscillate from 30Hz up to 240Hz with a peak amplitude of $\sim 2 \times 10^{-18} \text{ m!}$





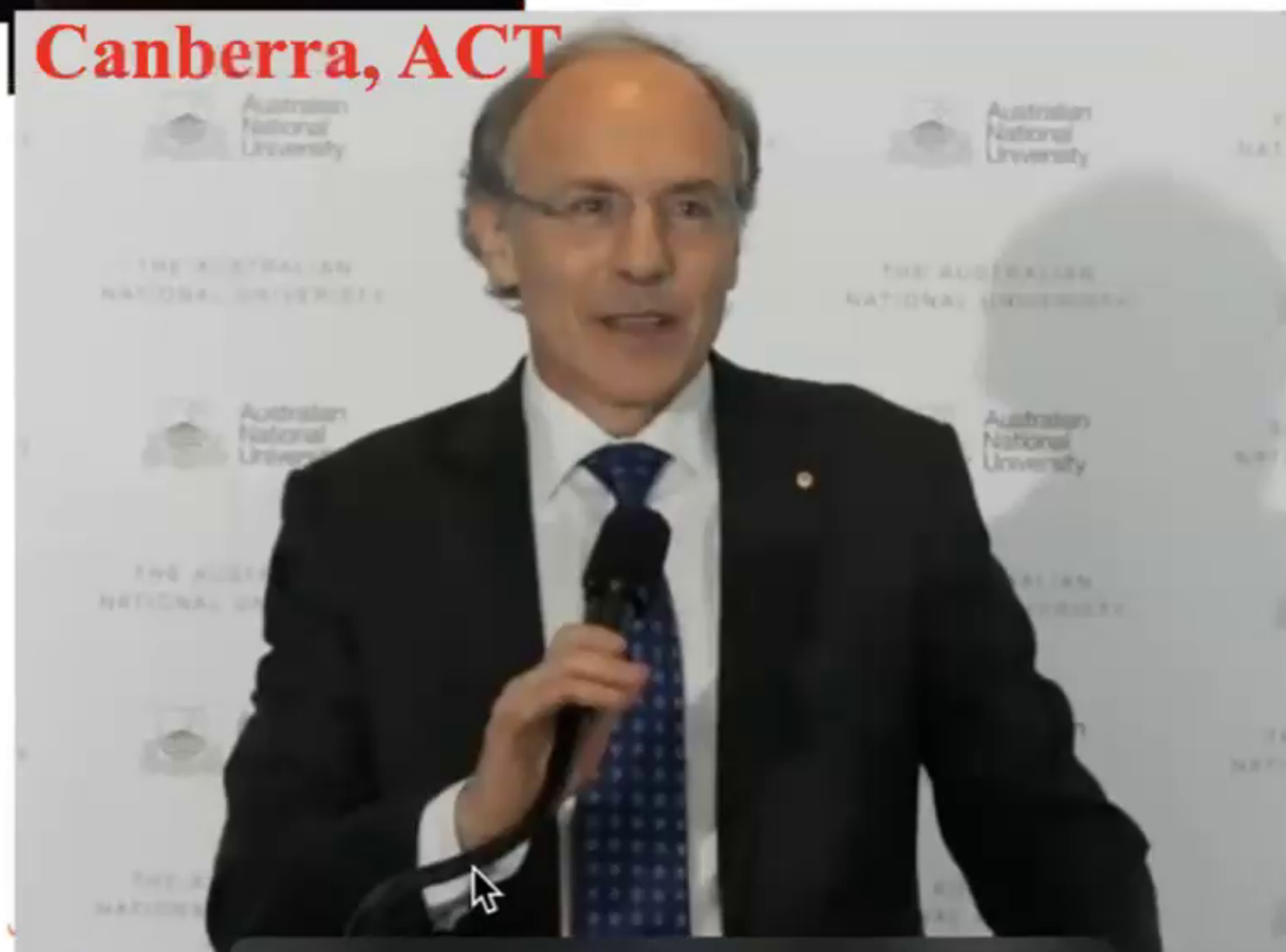
February 11, 2016

Washington DC



"Was that you I heard just now, or was it two black holes colliding?"

Canberra, ACT



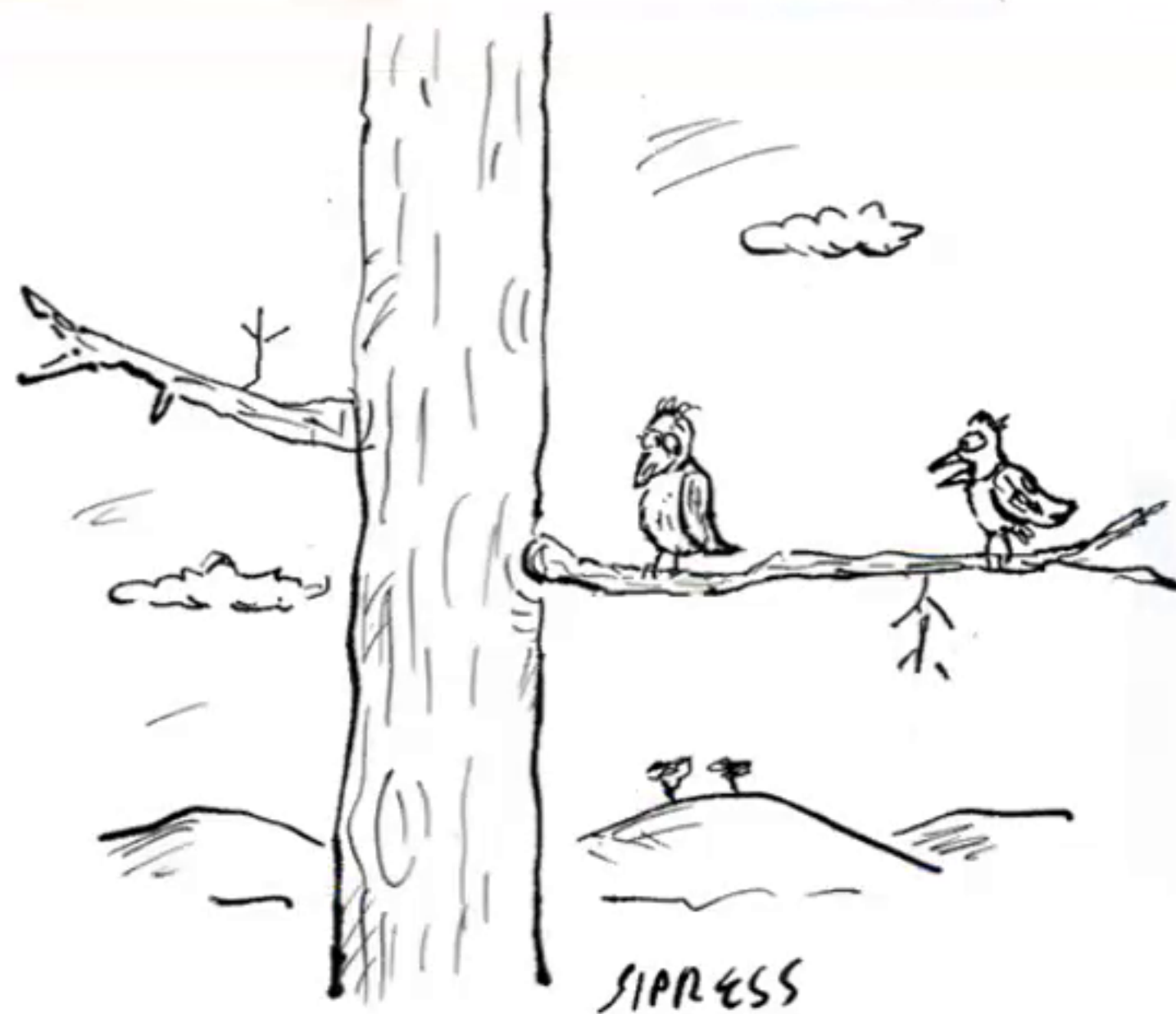


Australian
National University



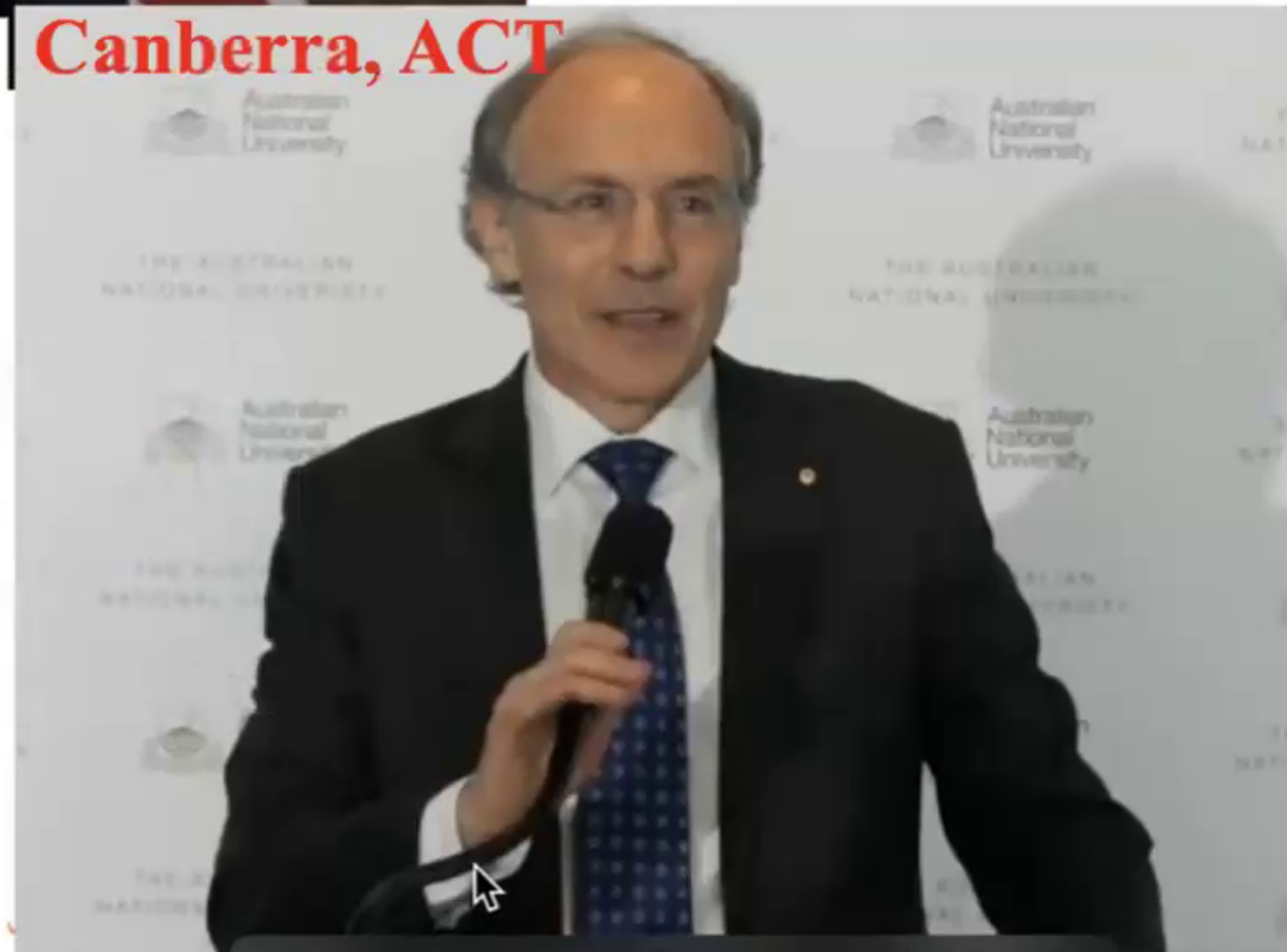
Washington DC

February 11, 2016



*"Was that you I heard just now, or was it two black holes
colliding?"*

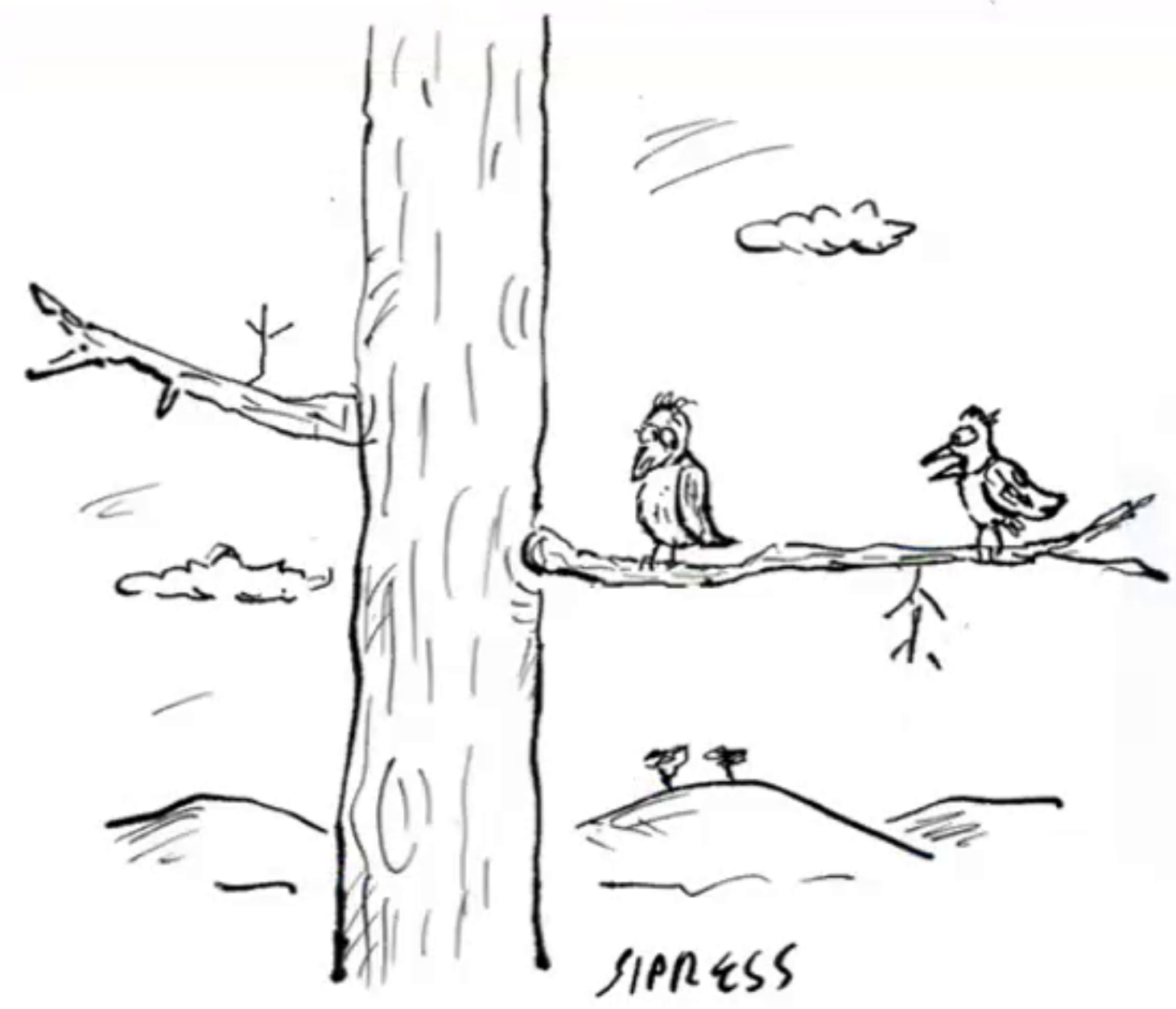
Canberra, ACT





February 11, 2016

Washington DC



"Was that you I heard just now, or was it two black holes colliding?"

Canberra, ACT





Nobel Prize 2017 – Barish, Thorne, Weiss



**And 4 recipients of the
PM Prize for Science 2020**

But on the order of 50
Australian authors on the
detection paper.

Nobel Prize 2017 – Barish, Thorne, Weiss



**And 4 recipients of the
PM Prize for Science 2020**

But on the order of 50
Australian authors on the
detection paper.

I am a particularly indebted to
Dan Shaddock, **Bram
Slagmolen**, Rob Ward

And

non authors

Mal Gray, Terry McRae, Kirk
McKenzie.



Nobel Prize 2017 – Barish, Thorne, Weiss



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I am particularly indebted to
Dan Shaddock, **Bram
Slagmolen**, Rob Ward

And

non authors

Mal Gray, Terry McRae, Kirk
McKenzie.

And of course

UWA: Blair, Ju, Zhao +

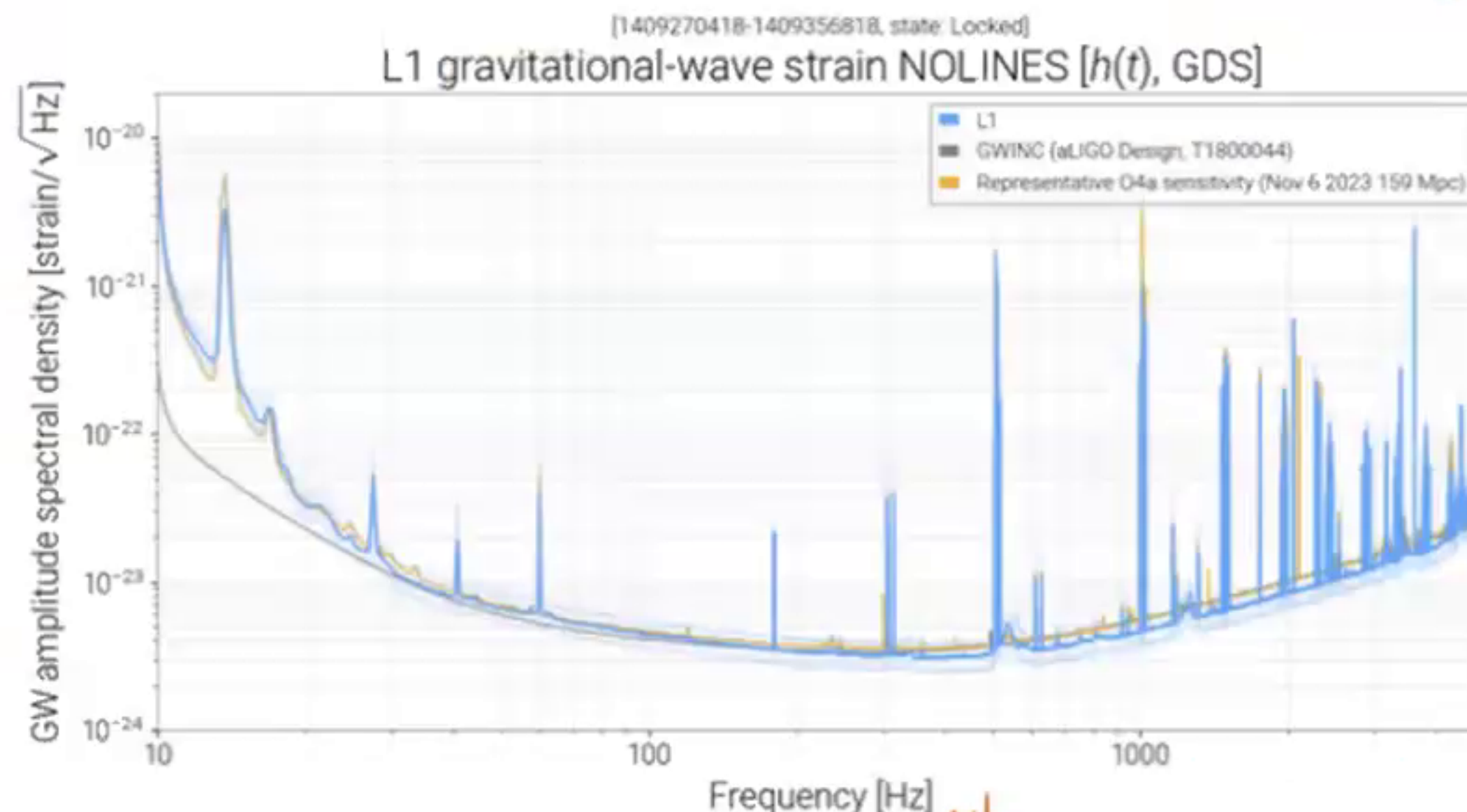
UA: Munch, Veitch, Ottaway +

Gray

Since 2015

- Final subsystem was installed on LIGO from 2019
 - *a frequency dependent squeezer to reduce quantum noise*
 - key contributions from Australia
 - 30 years after the possibility drew me in

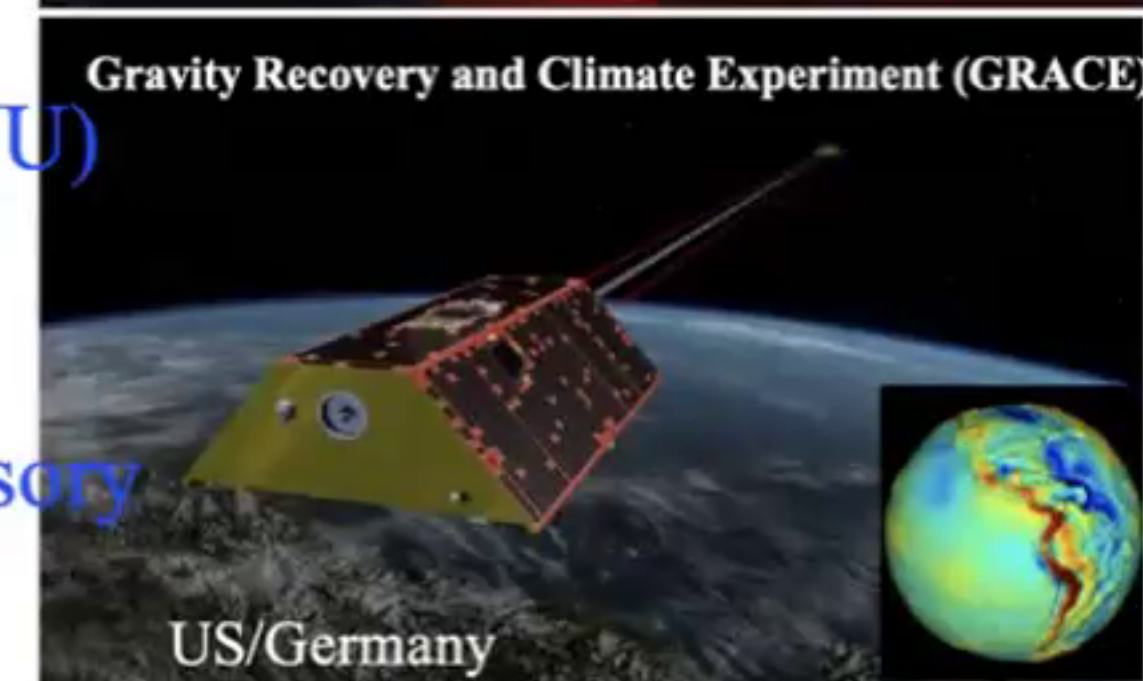
For the next few years the design will not change in any significant way.....



OzGrav

Contributions to LISA + GRACE FO+

- Australia and Australian scientists have contributed to development of LISA and GRACE Follow-On (Earth Science) over the last 25 years.
- **Scientific input since 2003**
 - Invention laser stabilization technique “arm locking” (ANU/NASA-JPL)
 - Advancement of LISA’s measurement scheme: time delay interferometry (Shaddock + JPL coauthors)
 - LRI technology architecture design (JPL, ANU, Germany)
 - Contribution to digital locking system of LRI Cavity
 - Prototype Triple Mirror Assembly (ANU, CSIRO)
 - Flight units were developed and delivered by Germany.
 - Laser-Link Acquisition joint development (JPL, Germany, ANU)
 - Low Power Limits of Phasemeter
- **Implementation Team on GRACE FO (2018 launch)**
 - McKenzie – US LRI Manager (‘16-’19), Shaddock - Advisory
 - Team members: Sheard, de Vine, Wuchenich, Sutton, Francis
- **Technology development for GRACE C (2028 launch)**
 - Long term laser stabilization, system engineering



<http://cga.anu.edu.au> <http://ozgrav.org> <http://ligo.org>

- The Centre for Gravitational Physics (now Astrophysics), ANU
- The Australian Consortium for Interferometric Gravitational wave Astronomy (ACIGA)
- Centre of Excellence for Gravitational wave Discovery (OzGrav)
- The LIGO Scientific Collaboration
- **The Australian Research Council**





And we bid you adieu.... well perhaps not quite yet!!

