



ARC Centre of Excellence for Gravitational Wave Discovery

# OzGrav

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*ARC Laureate Fellow*



Australian  
National  
University



THE UNIVERSITY OF  
WESTERN AUSTRALIA



# Our Mission

*OzGrav's mission is to capitalise on the historic first detections of gravitational waves to understand the extreme physics of black holes and warped spacetime, and to inspire the next generation of Australian scientists and engineers through this new window on the Universe.*

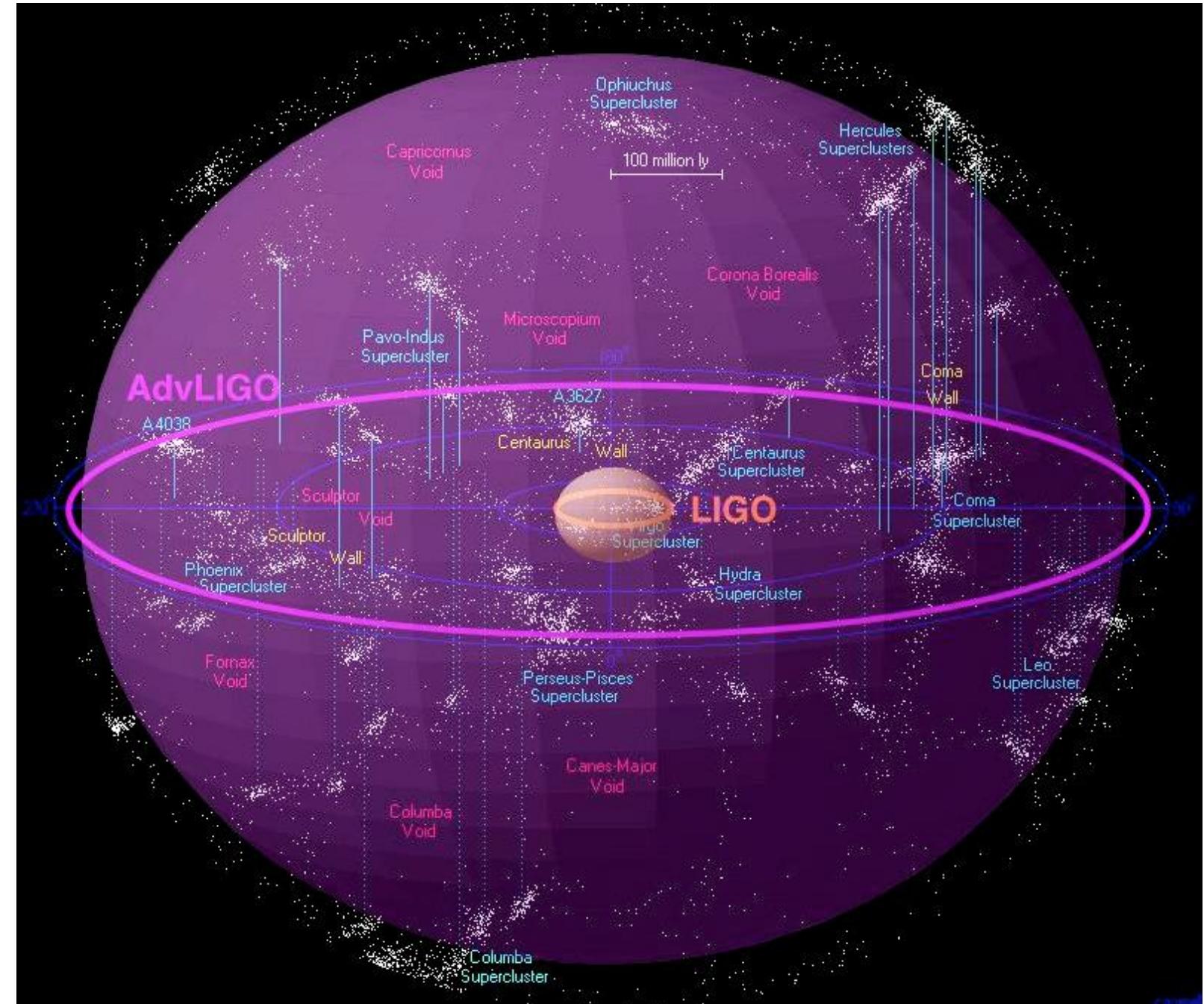


# Advanced LIGO:

Design  
sensitivity 10x  
LIGO.

1000x merger  
rate.

ns+ns target  
rate uncertain



# The Gravity Wave Discovery

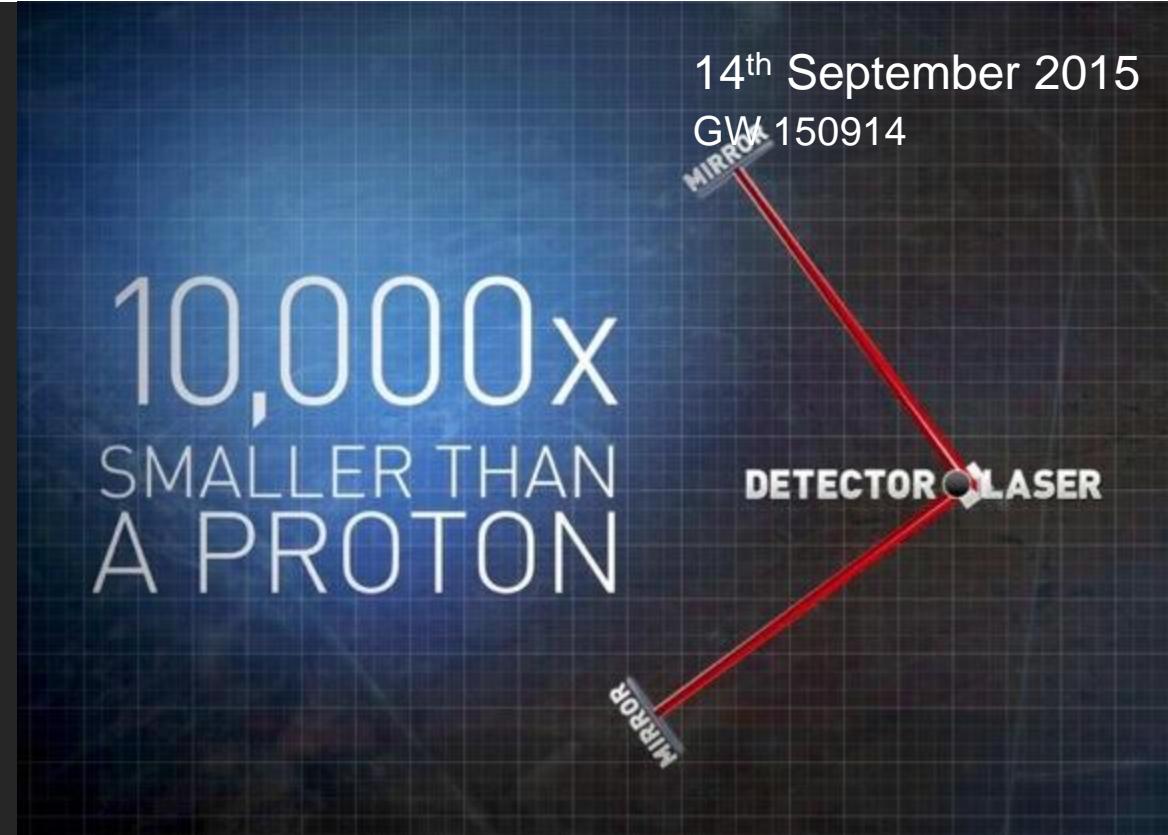
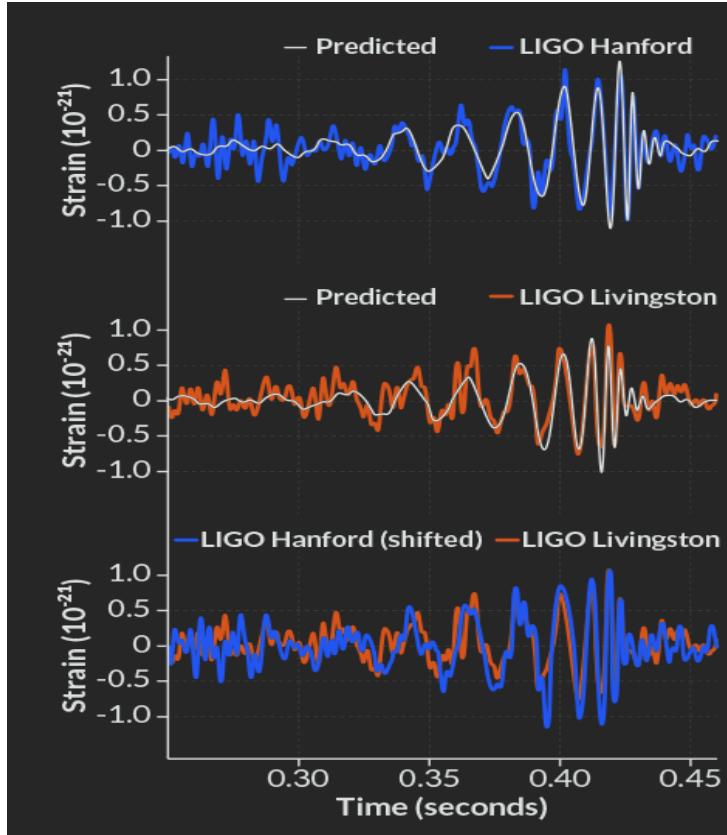
## Ripples in Space-time detected by LIGO\*



\*Laser Interferometer Gravitational-wave Observatory

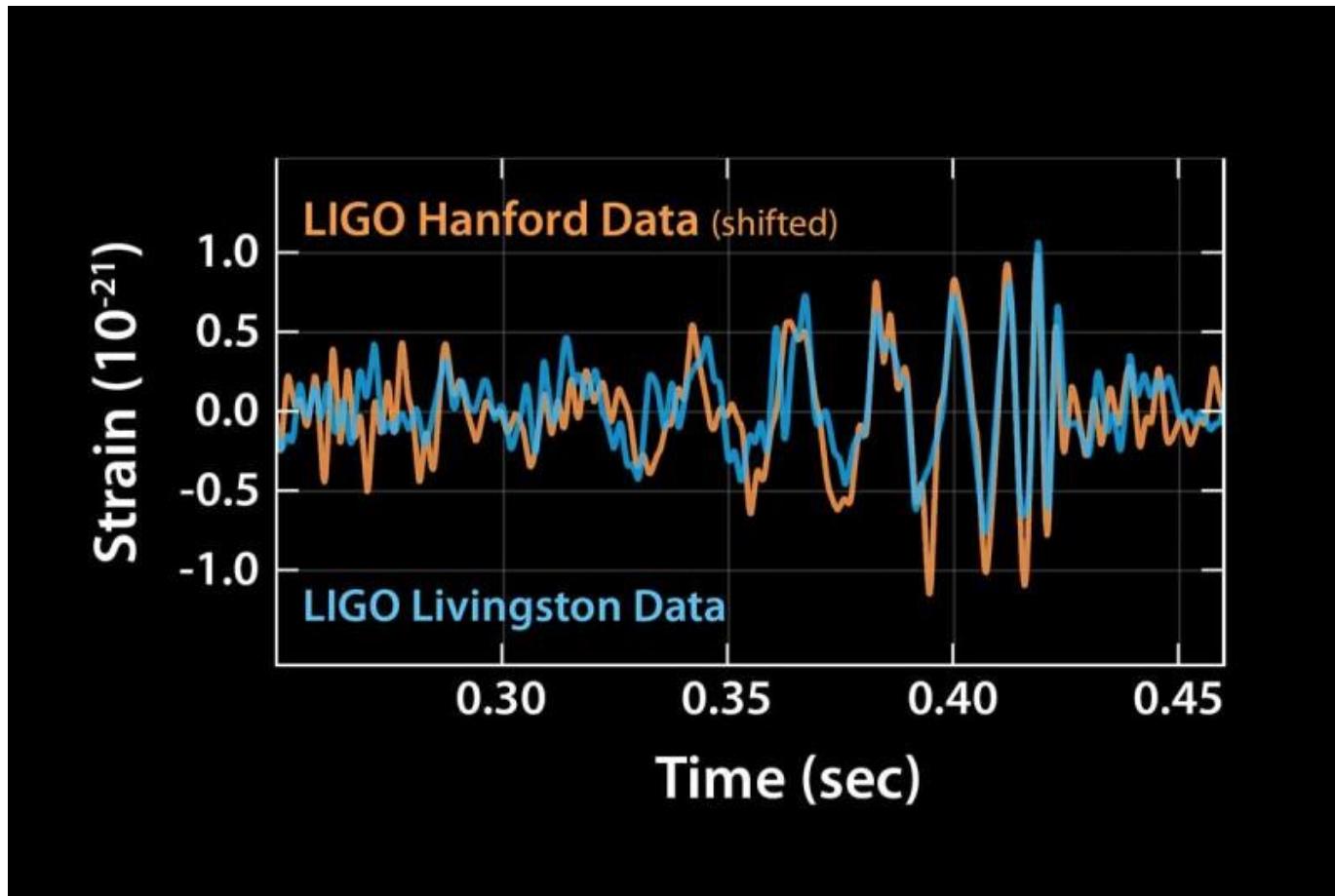
# The Gravity Wave Discovery

## Most extreme event since the Big Bang

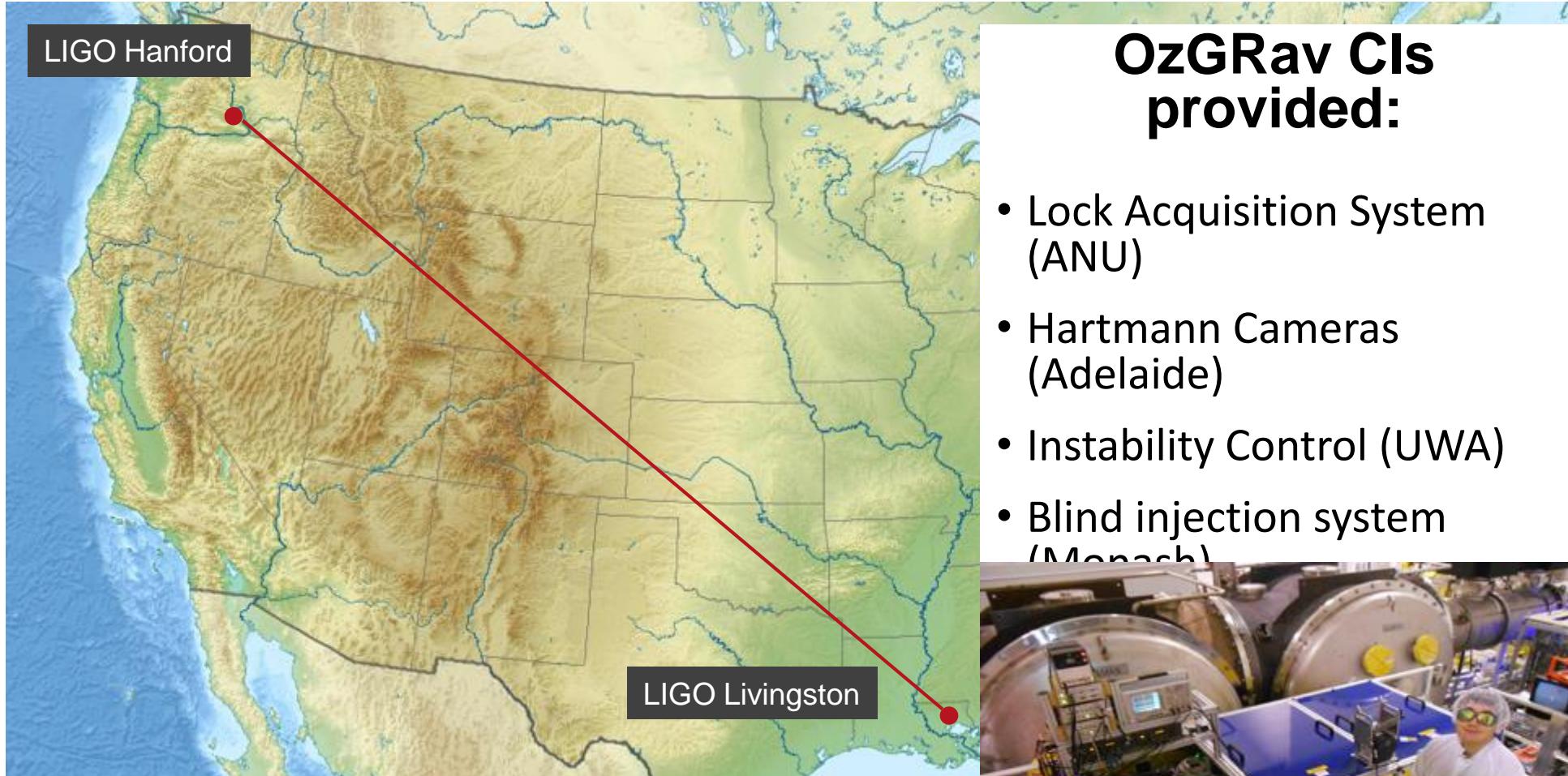


Width of a human hair at alpha centauri!

# Real data!



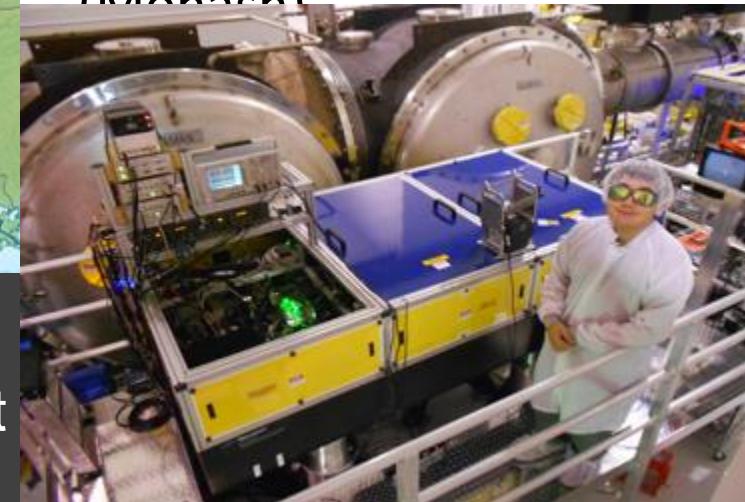
# Advanced LIGO interferometer



Breakthrough instrumentation = A\$900 M  
4km-long, L-shaped detectors. 3000km apart

## OzGrav CIs provided:

- Lock Acquisition System (ANU)
- Hartmann Cameras (Adelaide)
- Instability Control (UWA)
- Blind injection system (Monash)



# Black hole merger (SXS lab)



# GW150914

- 230-570 Mpc ( $z=0.054-0.136$ )
- SNR = 24
- Total Mass 60-70 Mo, 36(4)+29(4) Mo
- Time delay 7 ms
- Likely Sky Position “Southern Hemisphere”!!!
- Strain  $10^{-21}$  !!!
- GW Energy 3Mo –  $3.6 \times 10^{56}$  ergs/s
- 250 Hz at coalescence
- Rate  $1/(2-400)$  Gpc $^{-3}$  yr $^{-1}$



# Announcement & Impact

LIGO Press Release: 11<sup>th</sup> Feb 2016

- Six significant news days
- Social media and news frenzy



#EinsteinWasRight



- Paper downloaded 10,000 times per minute! (166 Hz!)
- Special US\$3M Breakthrough Prize
- 2016 Gruber Cosmology Prize

*"the most significant discovery in my lifetime."*

– Dr. Alan Finkel (AO), Australia's Chief Scientist

The New York Times  
Late Edition  
Today, some sunshine giving way to times of clouds, cold, high 28. Tonight, a flurry or heavier squall late, low 15. Tomorrow, windy, high 21. Weather map, Page A19.  
NEW YORK, FRIDAY, FEBRUARY 12, 2016 \$2.50

WITH FAINT CHIRP, SCIENTISTS PROVE EINSTEIN CORRECT

A Ripple in Space-Time  
An Echo of Black Holes Colliding a Billion Light-Years Away

By DENNIS OVERBYE  
A team of scientists announced on Thursday that they had heard and recorded the sound of two black holes colliding a billion light-years away, a fleeting chirp that fulfilled the last prediction of Einstein's general theory of relativity.

That faint rising tone, physicists say, is the first direct evidence of gravitational waves, the ripples in the fabric of space-time that Einstein predicted a century ago. It completes his vision of a universe in which space and time are interwoven and dynamic, able to stretch, shrink and jiggle. And it is a ringing confirmation of the nature of black holes, those bottomless gravitational pits from which not even light can escape, which were the most foreboding (and unwelcome) part of his theory.

Credit: CALTECH/MIT/LIGO LABORATORY

A worker installed a baffle in 2010 to control light in the Laser Interferometer Gravitational-Wave Observatory in Hanford, Wash.

Long in Clinton's Corner, Blacks Notice Sanders  
By RICHARD FAULSETT  
ORANGEBURG, S.C. — When Helen Doty was asked whom she would vote for in the South Carolina primary, she answered as if the very question were al-

Courted Hard in South Carolina, Loyalists Listen Closely  
candidate she barely knew. "It makes me feel good," she said, choking. "that young people are listening to the elderly people." She now said she was an undecided voter and planned to do some homework on Mr. Sanders. Mrs. Doty has four children.

Last Occupier In Rural Oregon Is Coaxed Out  
By DAVE SEMI

This article is by Dave Semi.



# Why OzGrav and Why Now?

- **Instrumentation**

- Advanced LIGO about to get even better
- Square Kilometre Array pathfinders imminent



- **Future instrumental advances require large international teams**

- OzGrav + (MIT, Glasgow, Caltech, Max Planck Institute, Chinese Academy of Sciences)

- **New Sources of Gravitational Waves**

- Unique combination of pulsar and GW communities
- Continuous wave sources, backgrounds
- Triggers: supernovae, starquakes, bursts

- **Astrophysics**

- Revealing Warped Space Time
- Understanding black holes
- Expecting the unexpected

Observational Astronomers

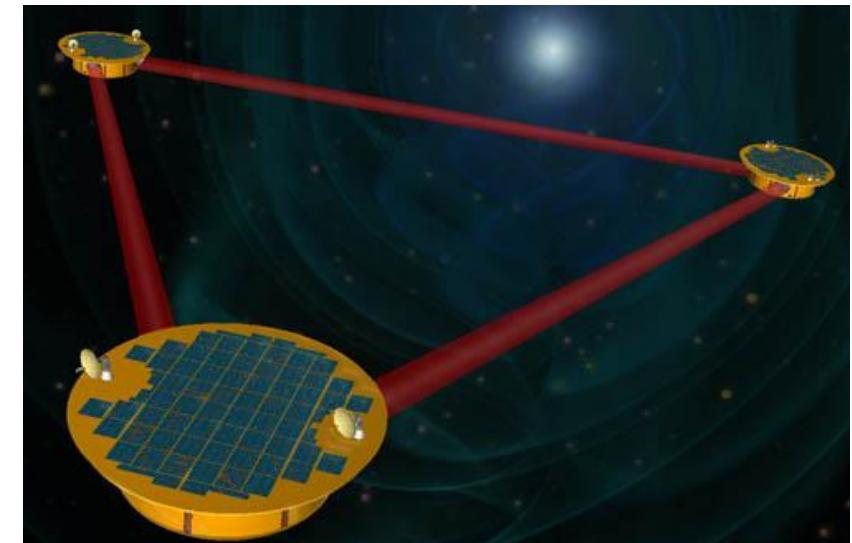


# OzGrav's Instrumentation Program

## - Making aLIGO better, and beyond

- Instrumentation Theme (Leader David McClelland)

- Quantum
  - Quantum Squeezing (sacrifice knowledge of amplitude for phase)
- Low Frequency
  - Noise elimination
- Instabilities and Distortions
  - Higher fidelity
- Space
  - LISA resurrected
- Radio
  - Pulsar Timing Instrumentation



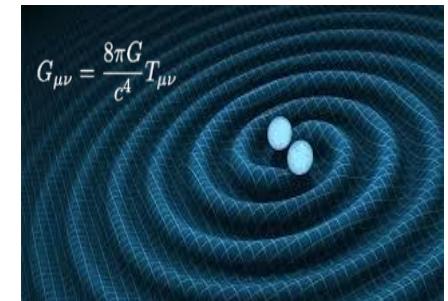
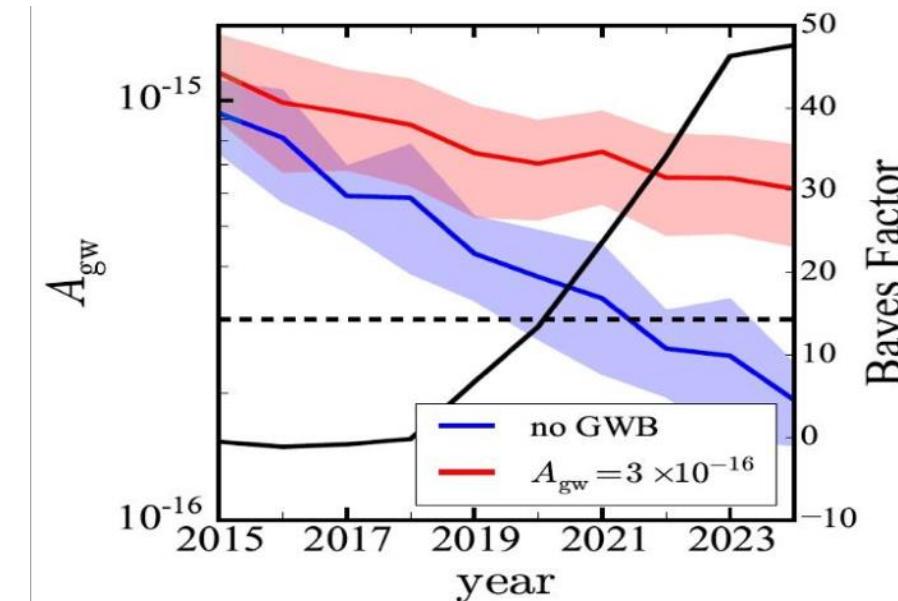
# OzGrav's Data Program

- Data Theme (Leader Matthew Bailes)
  - LIGO Pipelines (Melatos/Wen/Thrane/Scott)
    - Rapid Detection
    - CW sources
    - Parameter Estimation
    - Stochastic Background
  - Supercomputing (Hurley)
    - New [Supercomputer@Swin.edu.au](mailto:Supercomputer@Swin.edu.au)
    - ~3 Petaflops
  - Pulsar Timing Arrays
    - GW background
  - The merger progenitor population
    - Pulsar surveys for binaries
  - Tests of GR
    - SKA vital

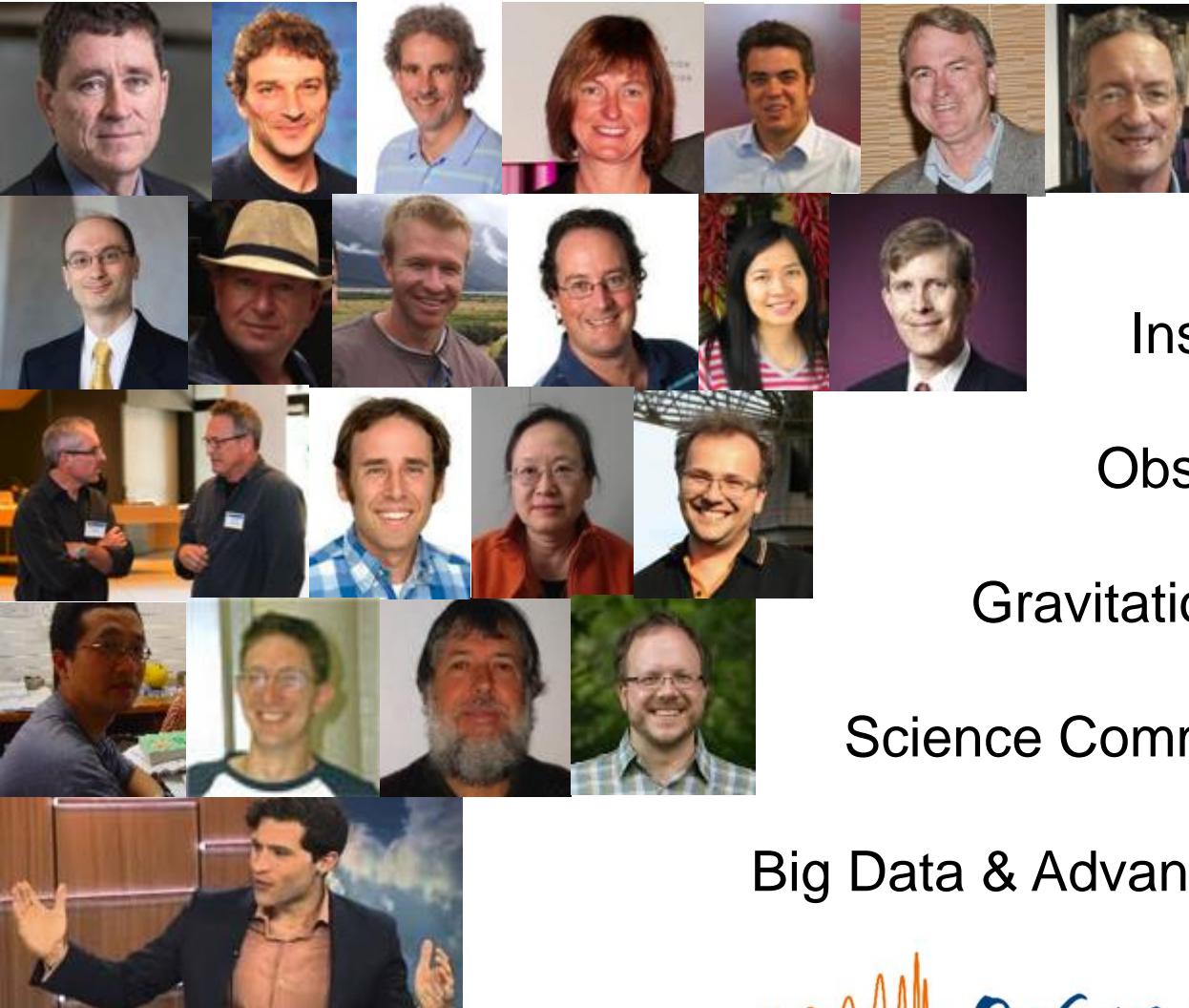


# OzGrav Astrophysics

- Observations
  - Multi-wavelength Follow-up (Cooke/Scott)
  - Skymapper
  - ASKAP, MWA?
  - PKS+UWB, MeerKAT, SKAs
  - Zadko Telescope (Coward), etc
  - Inverse Searching
    - Local SNe, FRBs, etc
- Sources (Levin)
  - Understanding the events
  - Continuous wave sources
- Gravity (Bailes/Kramer)
  - Pulsar timing arrays
  - Tests of GR using pulsars



# Our Science Team



Theorists

Pulsar Astronomers

Instrumentation Scientists

Observational Astronomers

Gravitational Wave Astronomers

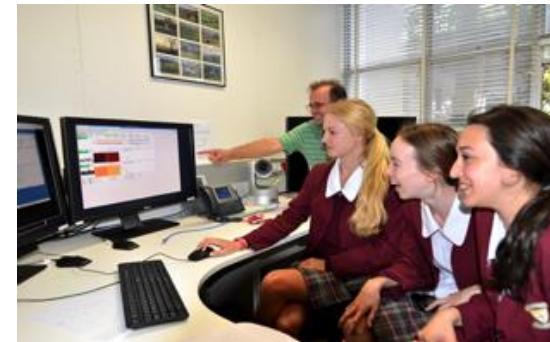
Science Communicators & Educators

Big Data & Advanced Computing Experts



# Education & Outreach (Blair)

- Face to face:
  - Gingin Gravity Discovery Centre
  - Pulse@Parkes
  - Public lectures
- Mass media
  - The Conversation
  - Press releases
  - Social Media
- Ambassadors
  - Cameron McEvoy
  - Alan Duffy
- Target under-represented STEM groups



# IP & Commercialisation

- Prof Dan Shaddock to lead OzGrav's research translation program
- Parallel commercialisation entity "OzGrav.com"
  - Consultancy



# OzGrav Timeline (7 years)

2016	2017	2018	2019	2020	2021	2022
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Executive planning session

Budget, draft policies

Recruit admin personnel

All-CIs retreat (policy refinement)

Theme Workshops

Supercomputer design

Supercomputer Operations

Recruitment of Science staff

LIGO O2  
Run

LIGO O3 Run

Future LIGO Runs

Parkes UWB Operations

MeerKAT 16

MeerKAT 64

SKA Phase 1 (2020+)



# Gravitational Wave Astronomy Future

- Add VIRGO (soon), KAGRA (3y), LIGO-India (6y)
  - Positions “better”
- Beyond 2G Detectors
  - 3G = 10x more sensitive (to  $h$ ) 1000x volume
    - GWIC working group forming
  - 1 event/month - 10,000 events/year! (1/year)
    - Star formation rate of BH+BH tracer
- SKA-mid
  - G/T  $\sim$  15x PKS – 225x as many pulsars/hour at same SNR as PKS
- LISA
  - Space-based GW detectors