LLRF Presentation, Chicago, 30 Sept, 2019

Overview of Gravitational Waves and the Technologies Used in LIGO

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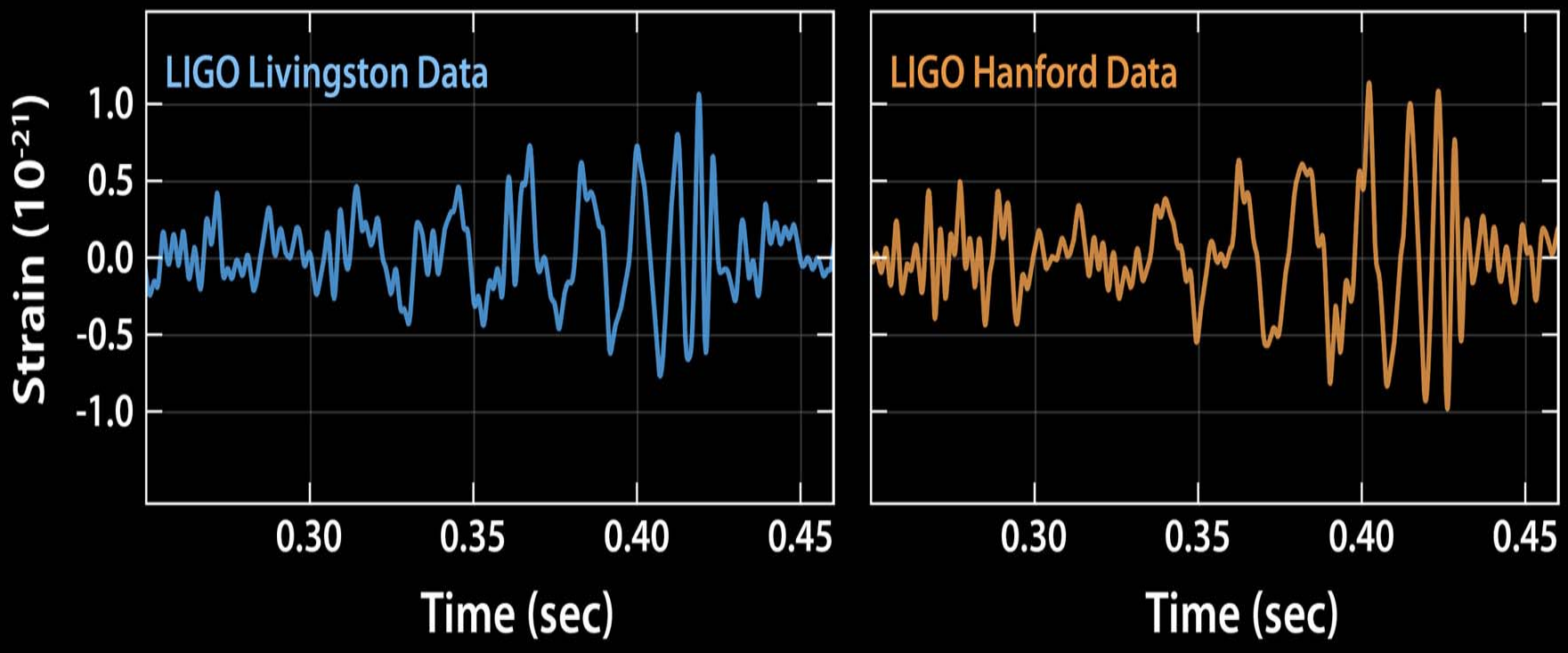
For the LSC

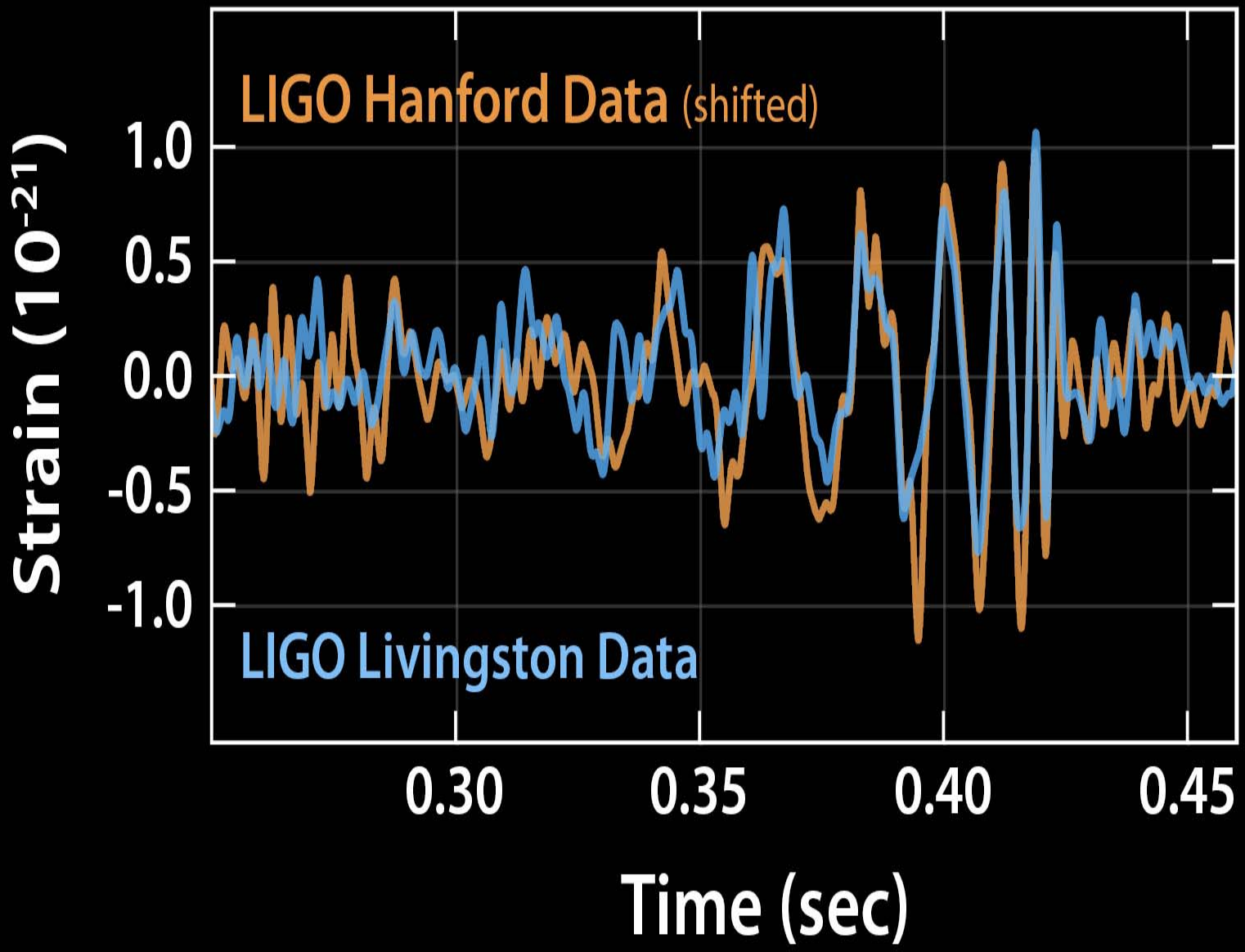
Image Credit: Aurore Simmonet/SSU

Outline

- *The Story of September 14th, 2015*
- *Some Neutron Stars*
- *What are Gravitational Waves?*
- *How does LIGO Work?*
- *How does LIGO deal with Noise?*

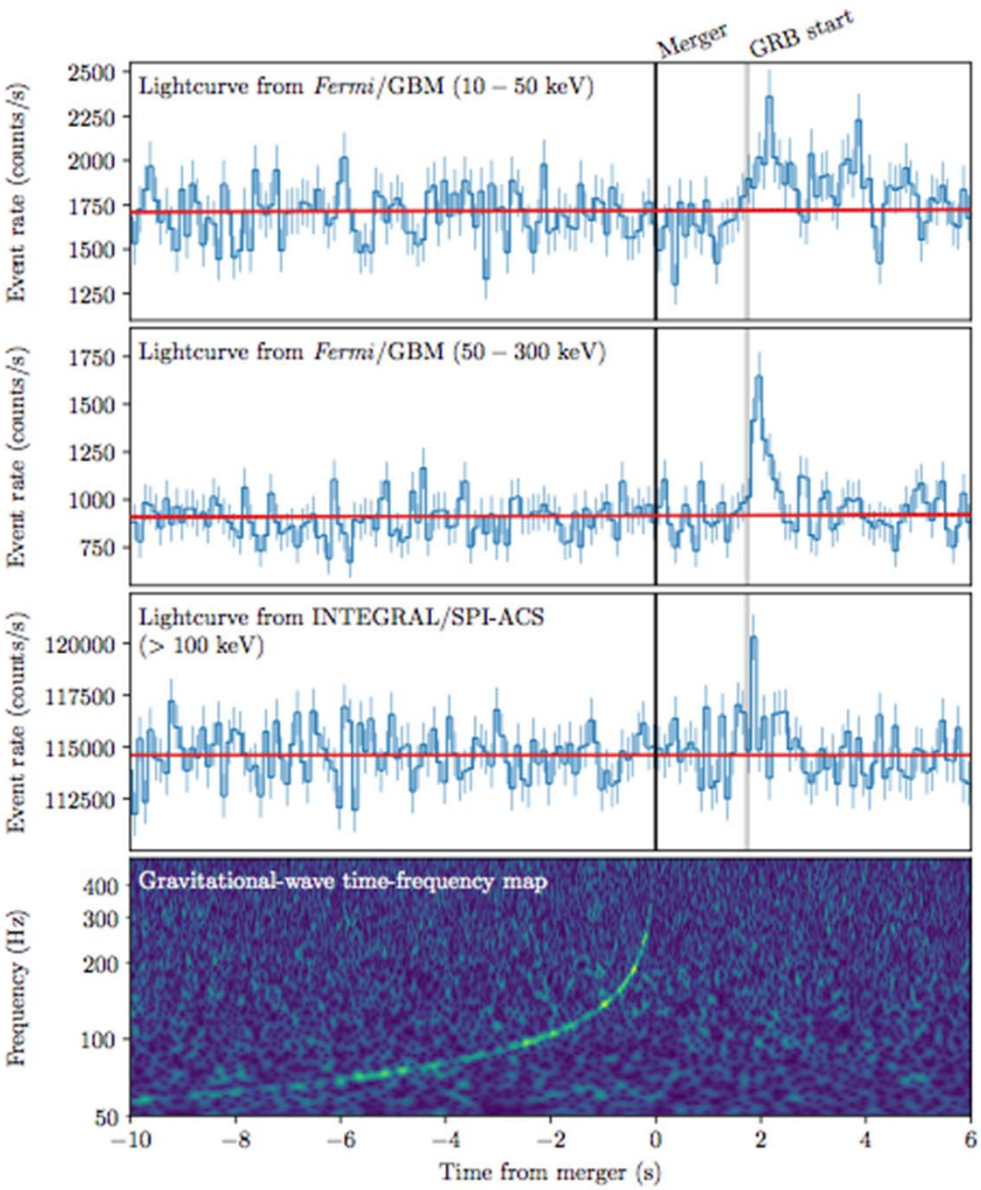
2:50 AM PST


LIGO Livingston Data
LIGO Hanford Data
Strain (10^{-21})
1.0
0.5
0.0
-0.5
-1.0
0.30
0.35
0.40
0.45
Time (sec)
Time (sec)


LIGO Hanford Data (shifted)
LIGO Livingston Data
Strain (10^{-21})
1.0
0.5
0.0
-0.5
-1.0
0.30
0.35
0.40
0.45
Time (sec)

Neutron Star Merger

Multi-messenger observations



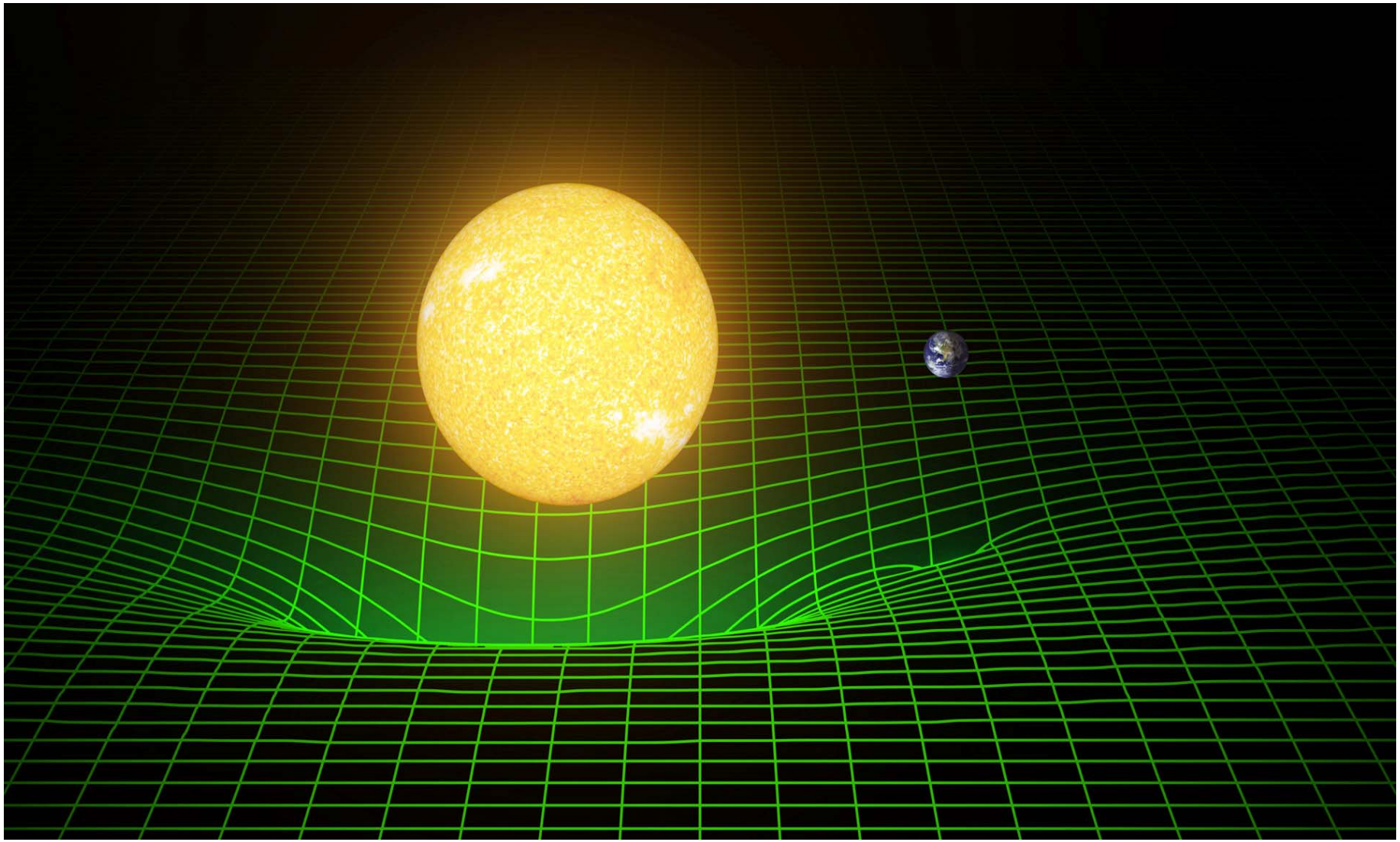
- The *Fermi* Gamma-ray Burst Monitor independently detected a **gamma-ray burst** (GRB170817A) with a time-delay of ~1.7 s with respect to the merger time.
- Confirmed by INTEGRAL

- Binary neutron star (BNS) mergers are progenitors of (at least some) SGRBs

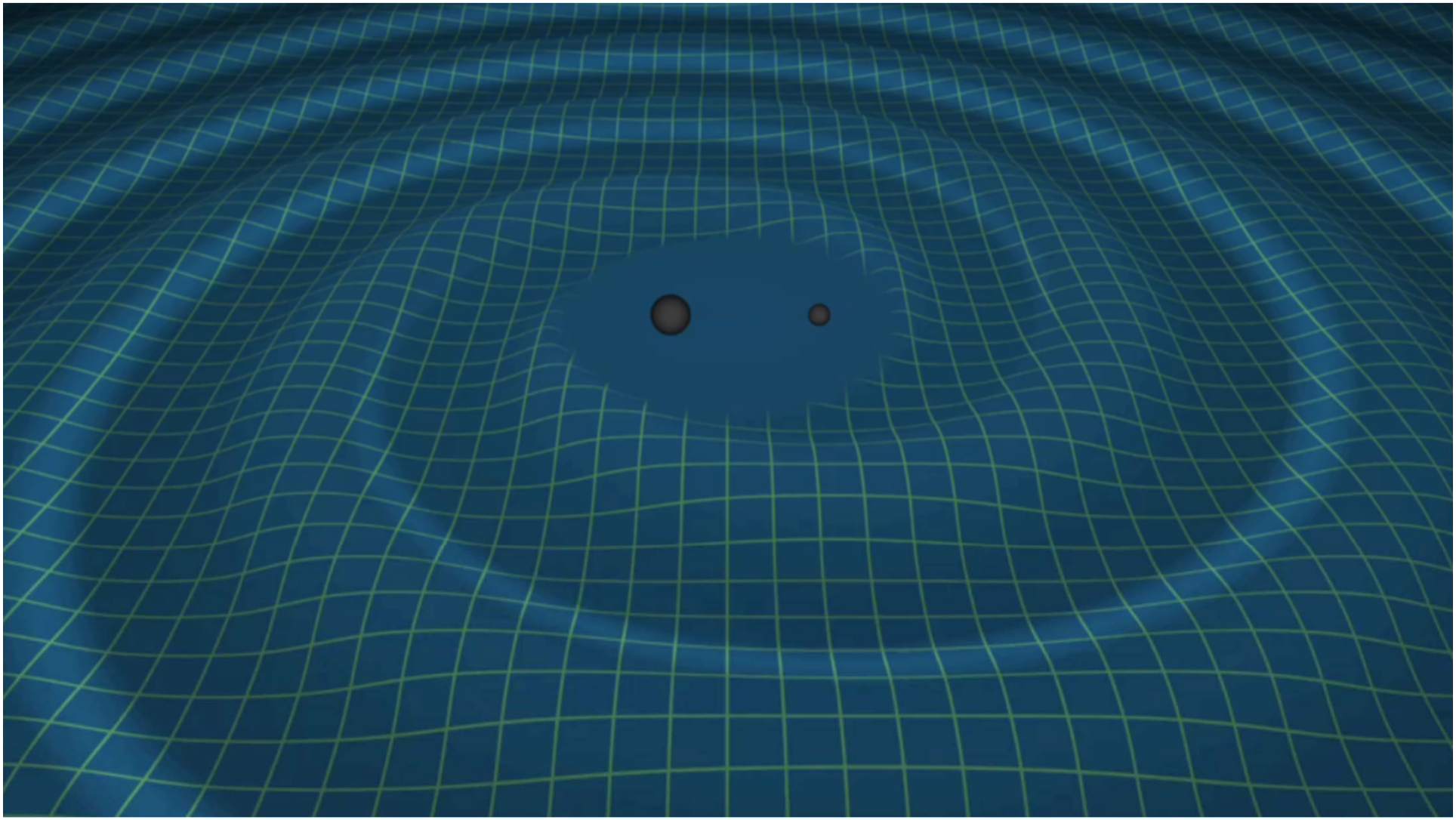
The Astrophysical Journal Letters, 848:L13 (27pp), 2017 October 20

LIGO-G1901784-v1

Gravity & Curved Space-time

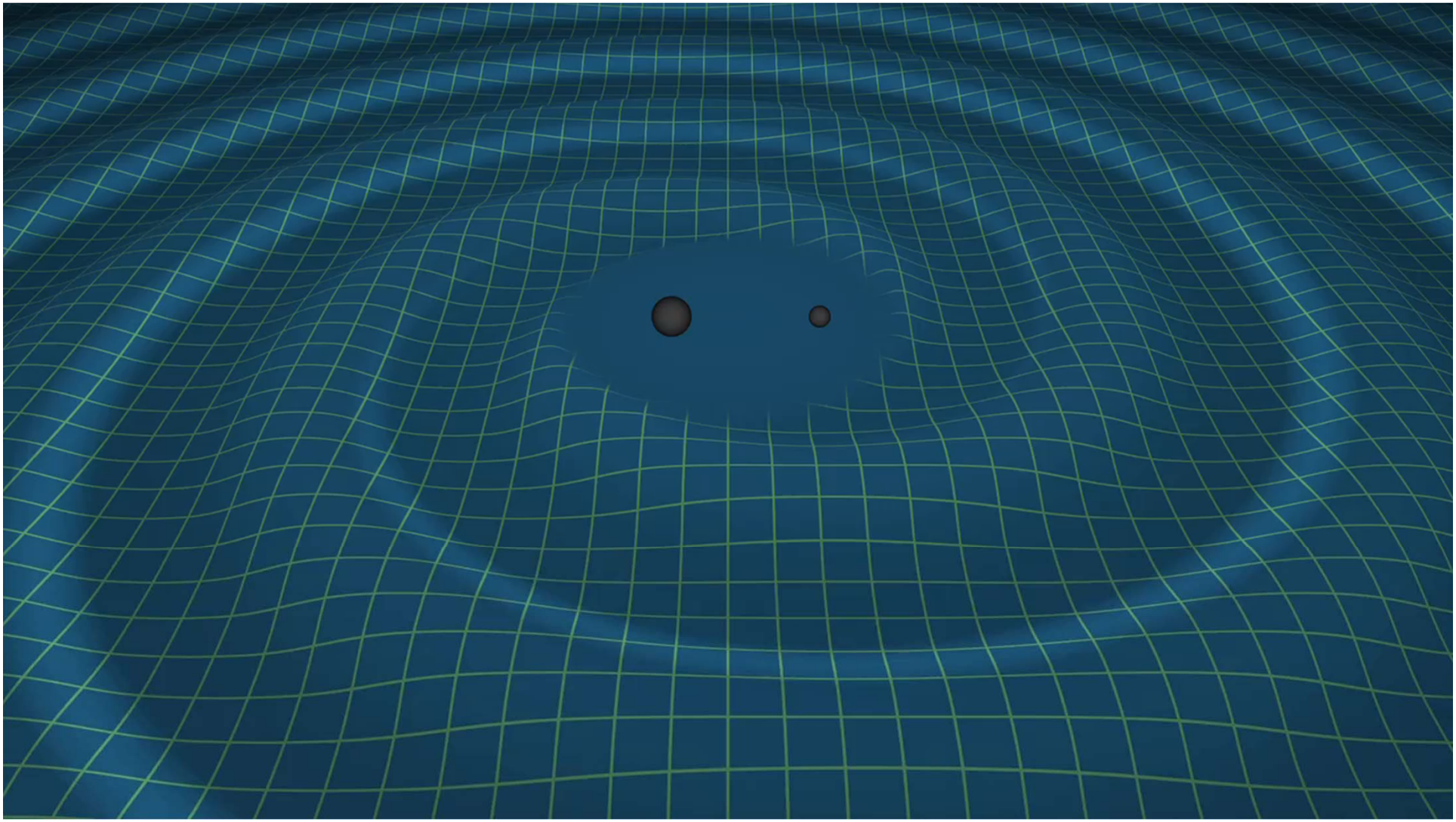


Gravitational Waves



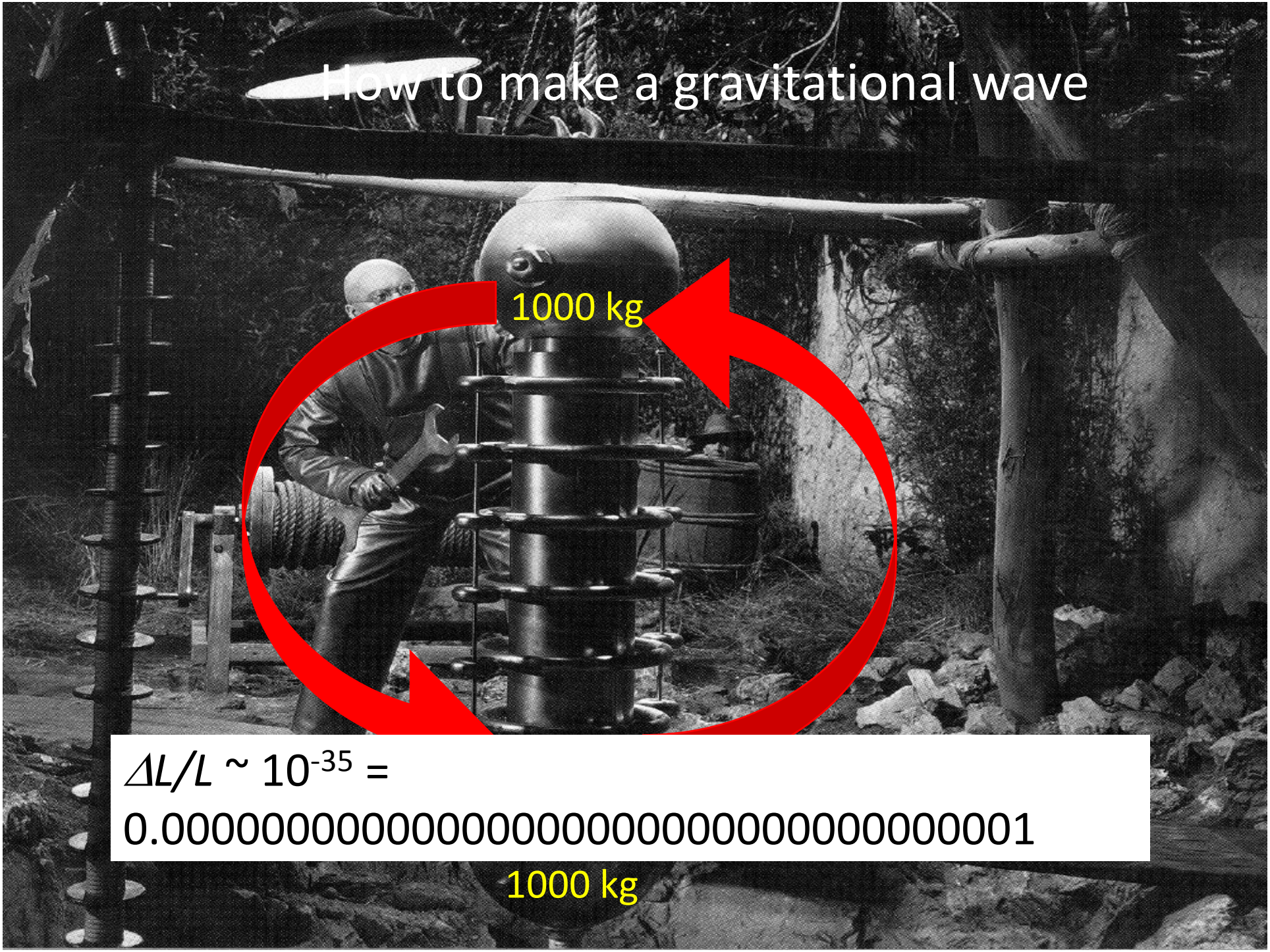
Credit: LIGO/Tim Pyle

Gravitational Waves



Credit: LIGO/Tim Pyle

How to make a gravitational wave



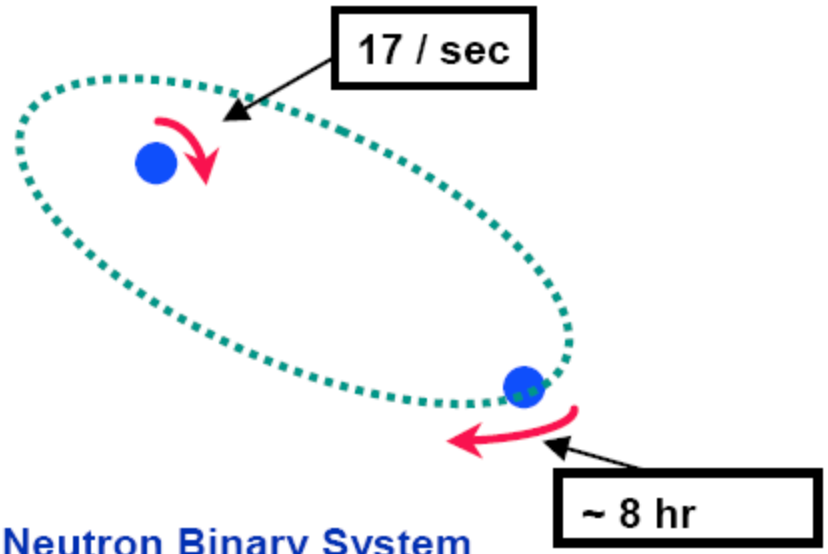
$\Delta L/L \sim 10^{-35} =$

0.00000000000000000000000000000000001

Gravitational Waves
the evidence

Neutron Binary System – Hulse & Taylor

PSR 1913 + 16 -- Timing of pulsars



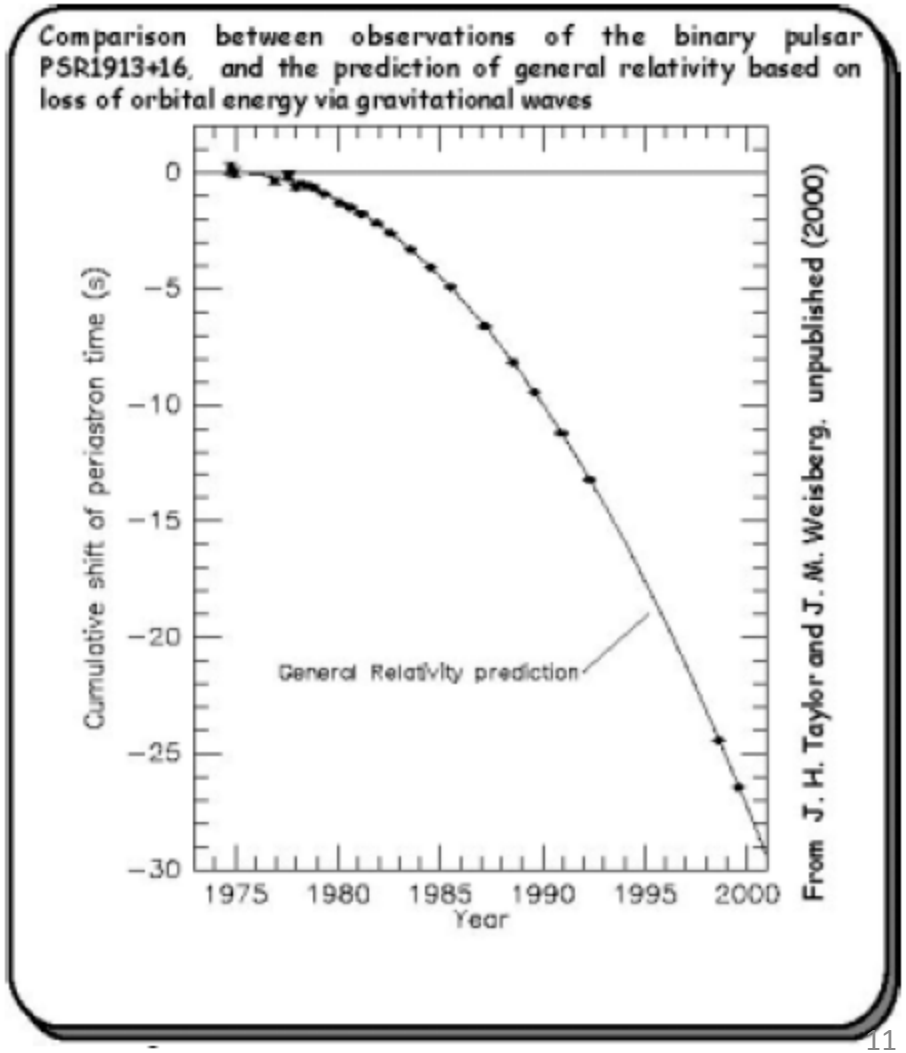
Neutron Binary System

- separated by 10^6 miles
- $m_1 = 1.4m_\odot$; $m_2 = 1.36m_\odot$; $\varepsilon = 0.617$

Prediction from general relativity

- spiral in by 3 mm/orbit
- rate of change orbital period

Emission of gravitational waves

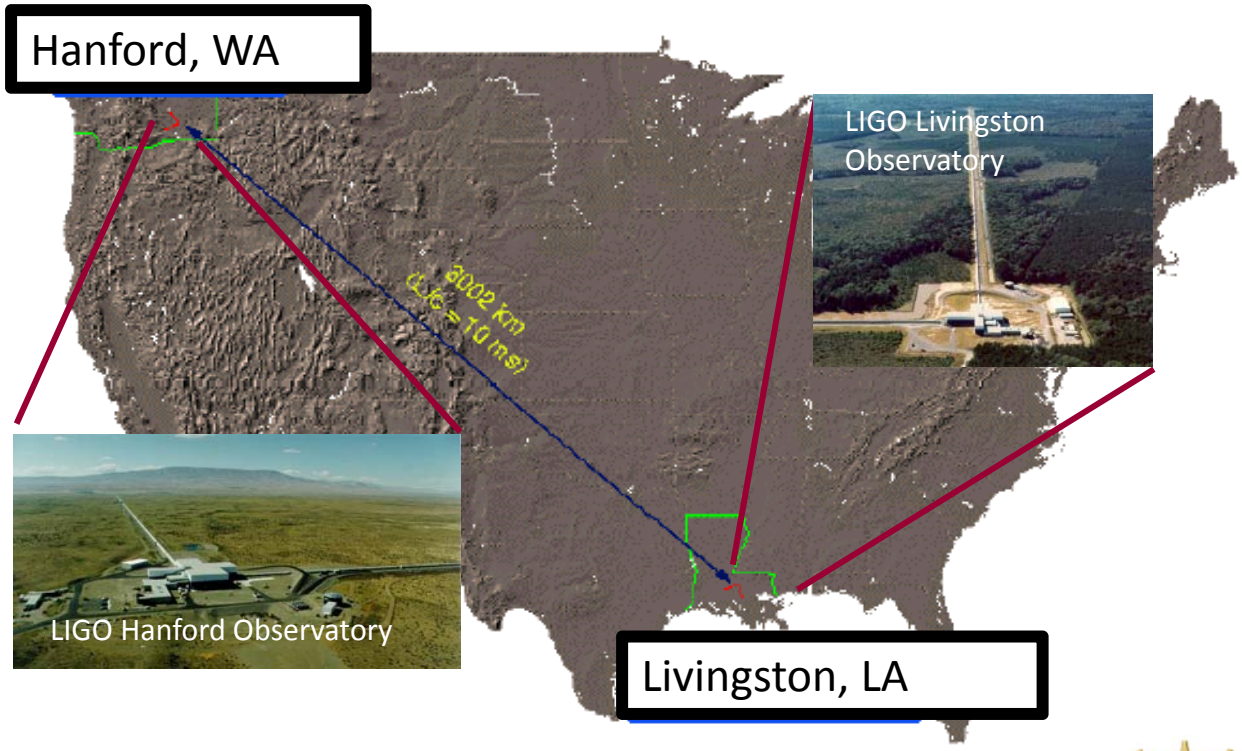


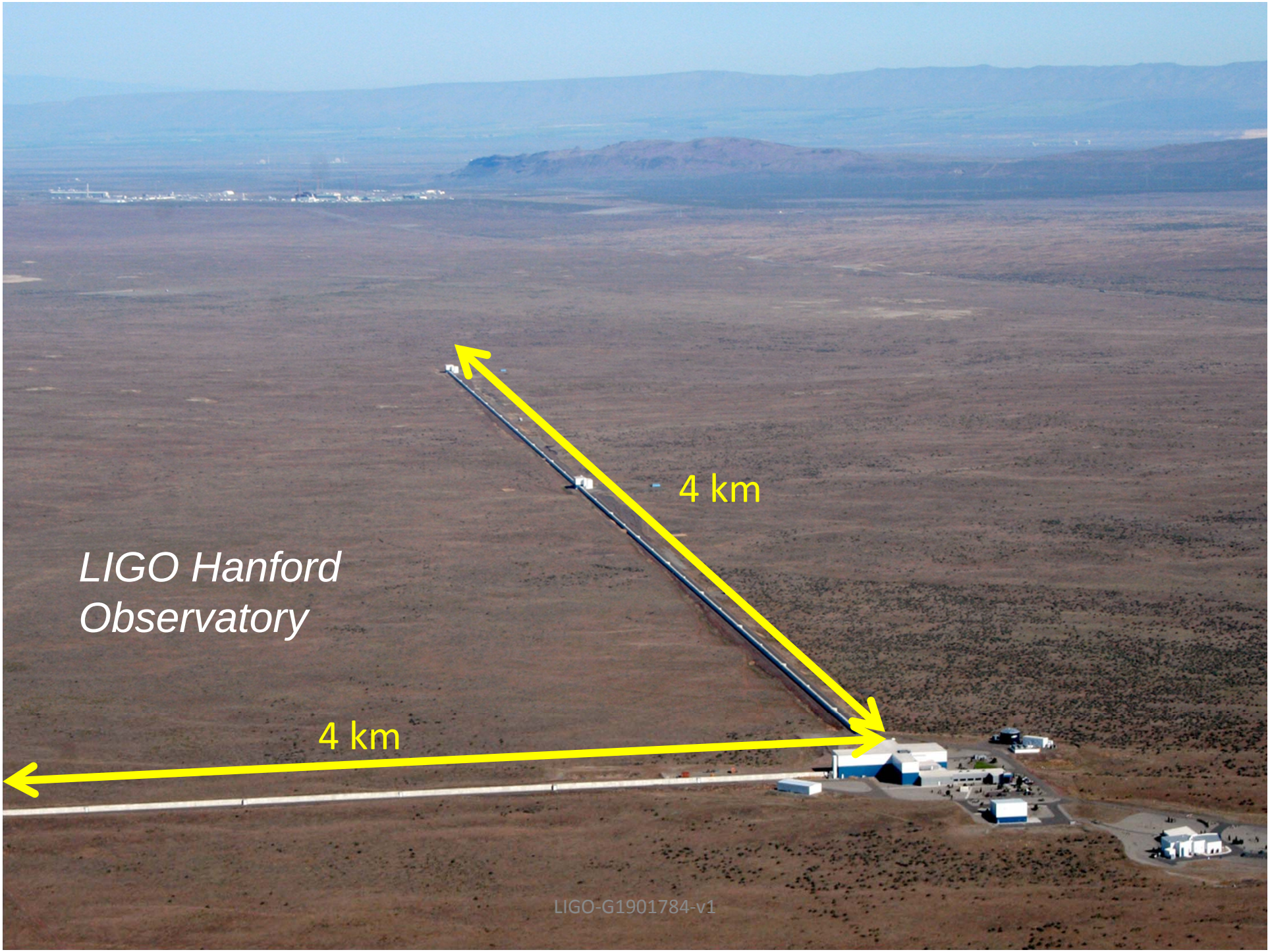
LIGO

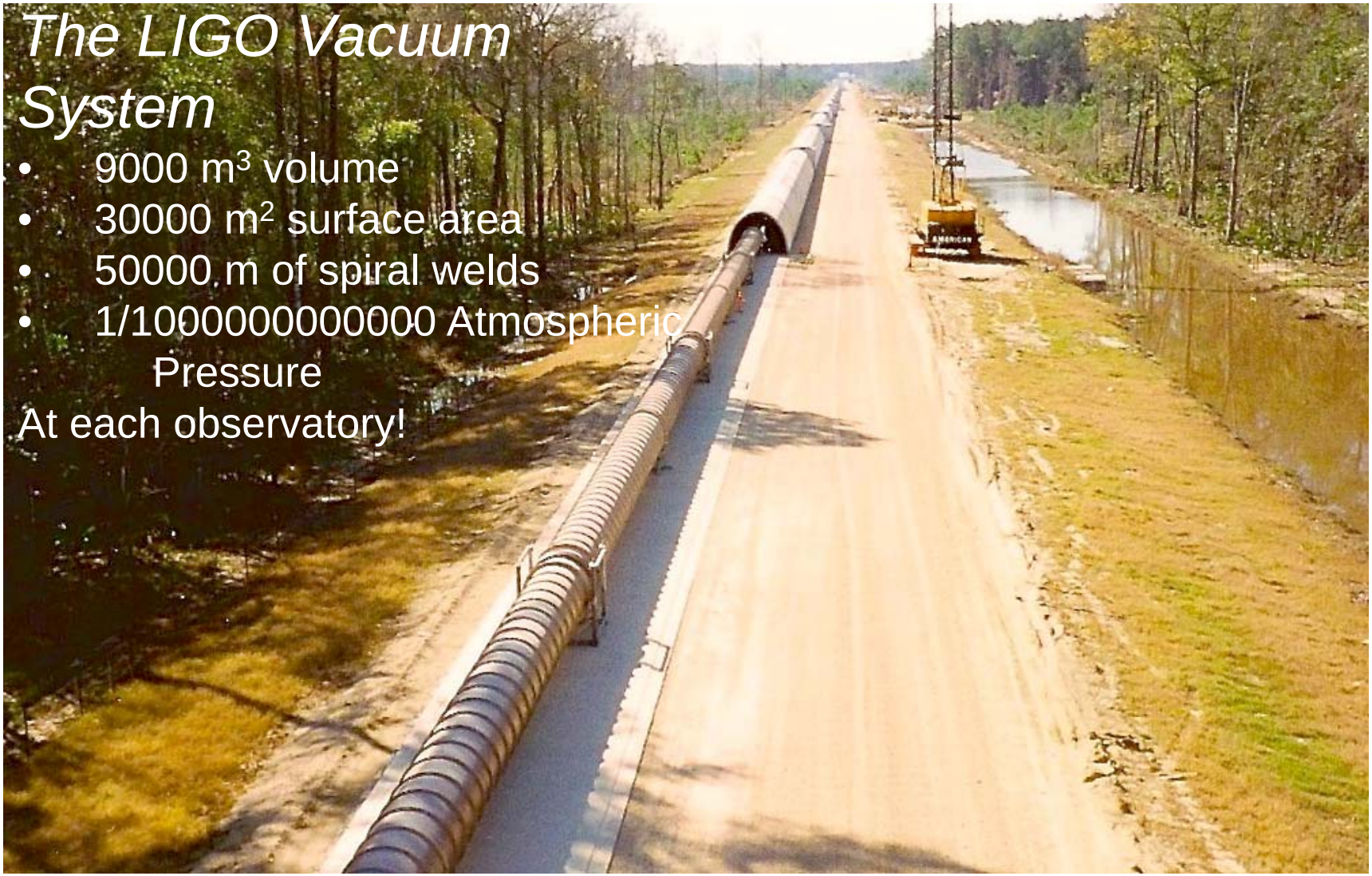
LIGO Laboratory is operated by Caltech and MIT

LIGO Laboratory:
190 staff located at Caltech, MIT, Hanford, Livingston

LIGO Scientific Collaboration:
~ 1100 **scientists, ~80 institutions, 15 countries**
that do the science of LIGO




4 km
LIGO Hanford
Observatory
4 km



The LIGO Vacuum System

- 9000 m^3 volume
- 30000 m^2 surface area
- 50000 m of spiral welds
- 1/1000000000000 Atmospheric Pressure

At each observatory!

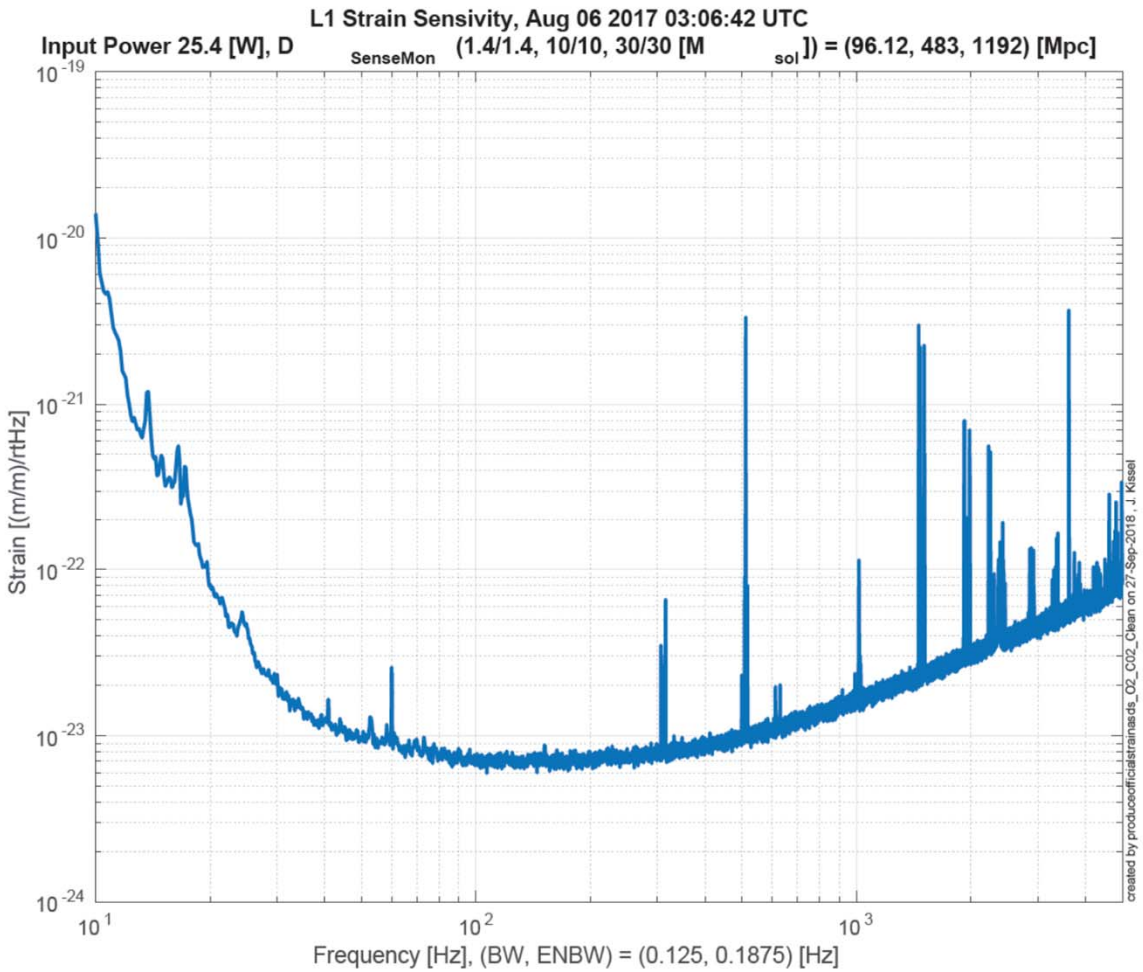
Criteria for GW detection

- The same waveform must be seen at the Louisiana and Washington sites within ± 10 mSec
- The waveform at a site cannot be coincident with signals from the environmental monitors at the site
    - 3 axis seismometers
    - 3 axis accelerometers on the chambers
    - Tilt meters
    - Microphones
    - Magnetometers
    - RF monitors
    - Line voltage monitors
    - Wind speed monitors
- The waveform at a site cannot be coincident with auxiliary signals in the interferometer not directly associated with the gravitational wave output
    - Alignment control signals
    - Laser frequency and amplitude control signals
    - Approximately 10^5 sensing signals within the instrument

Journey to 10^{-18} meters (Sensing)

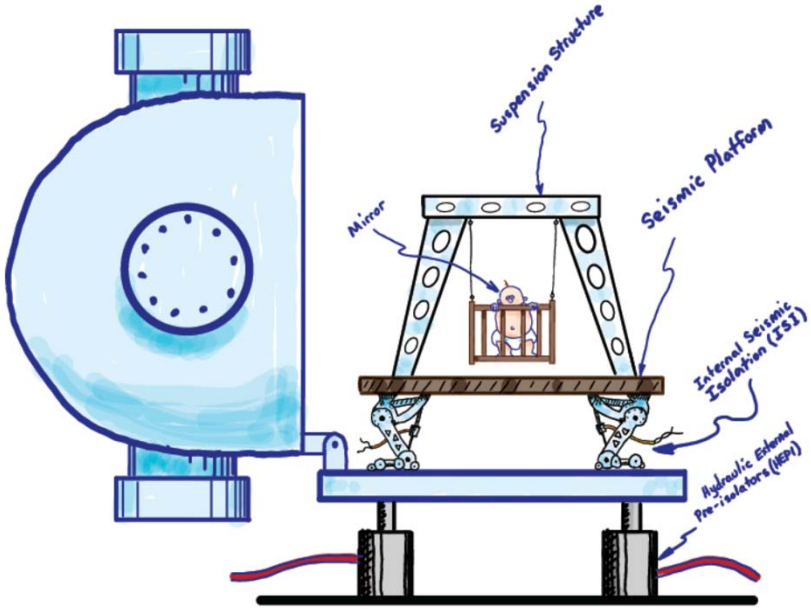
- 10^{-6} m – Wavelength of Light
  - 10^{-12} m – Split into 10^{6} slices
    - 10^{-17} m – Optical Resonance
      - 10^{-19} m – Laser Power (~100W)

Strain Sensitivity During O2

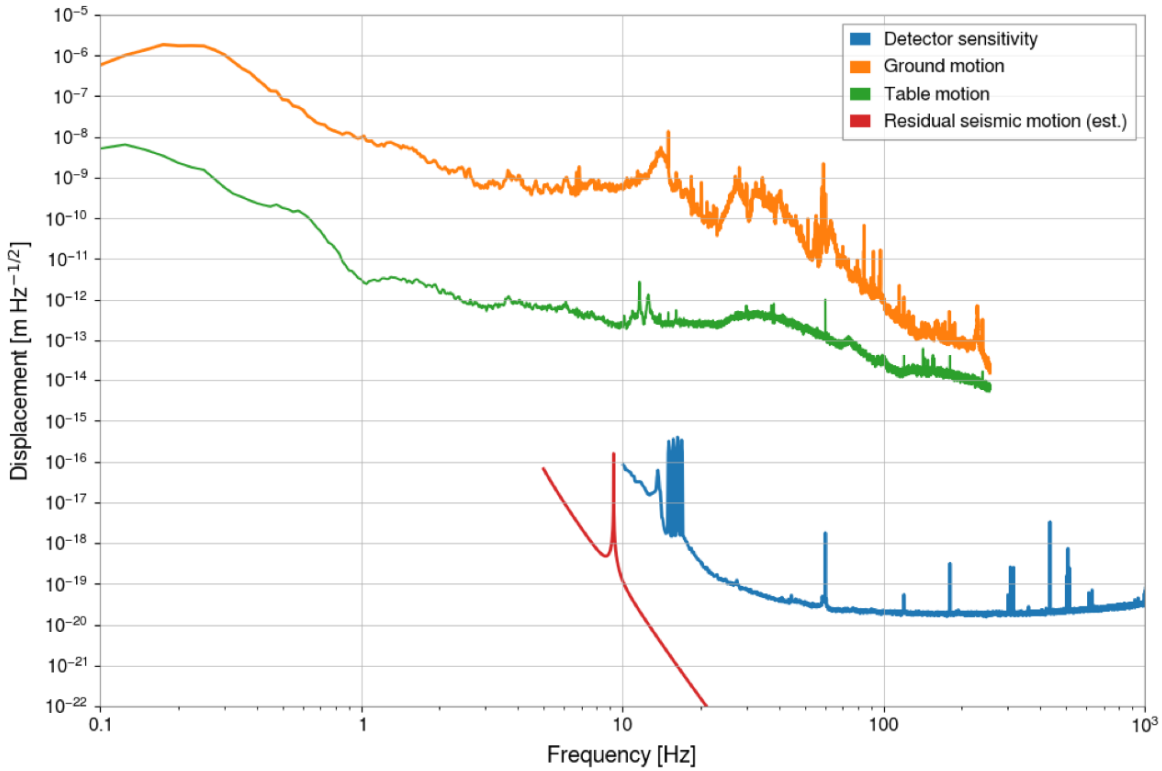


Journey to 10^{-18} meters (Isolation)

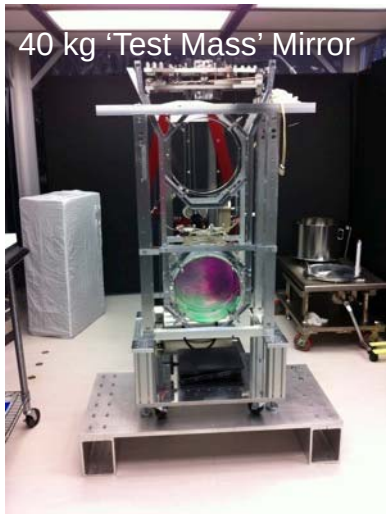
- 10^{-6} m/$\sqrt{\text{Hz}}$ – Ground Motion at ~0.15Hz
  - 10^{-9} m – Ground Motion at 10Hz
    - 10^{-12} m – Active Seismic Isolation
      - 10^{-20} m – Quadruple Pendulum

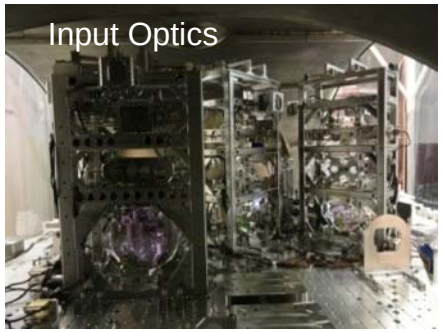


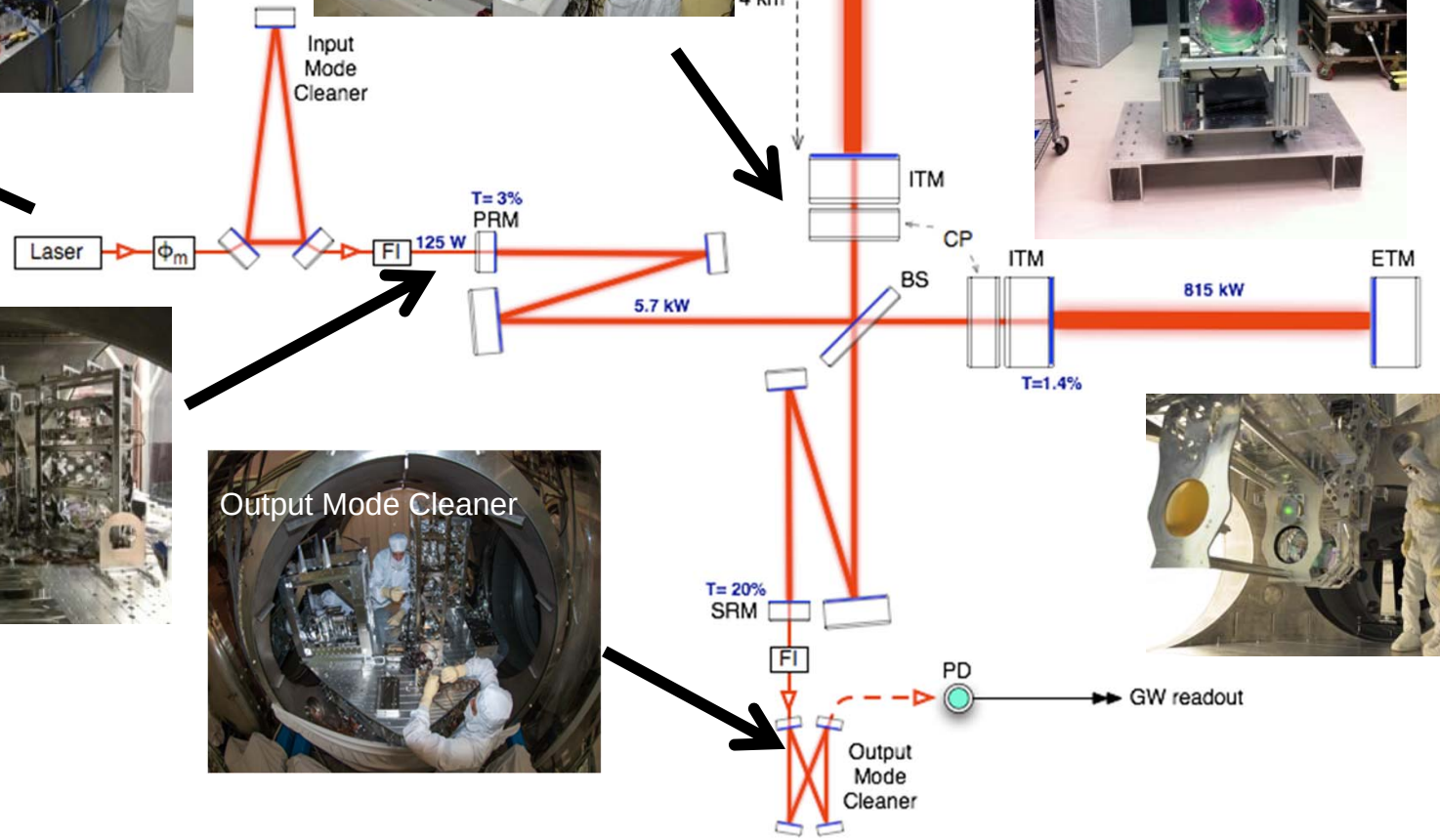
Isolation Performance



Advanced LIGO Interferometer





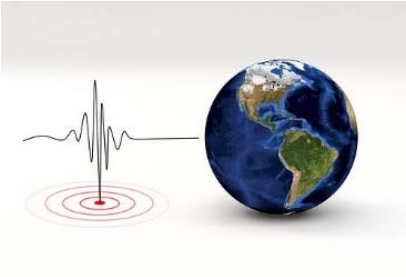


Noise Sources

Tidal Forces on Earth's Crust*

Ocean Wave Microseism*

Unanticipated Random Noise



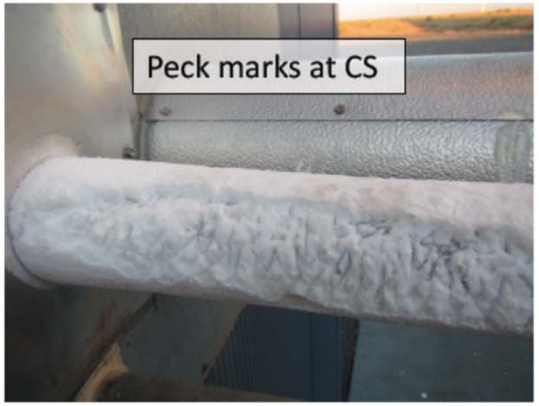
Earthquakes*

Freight Train *

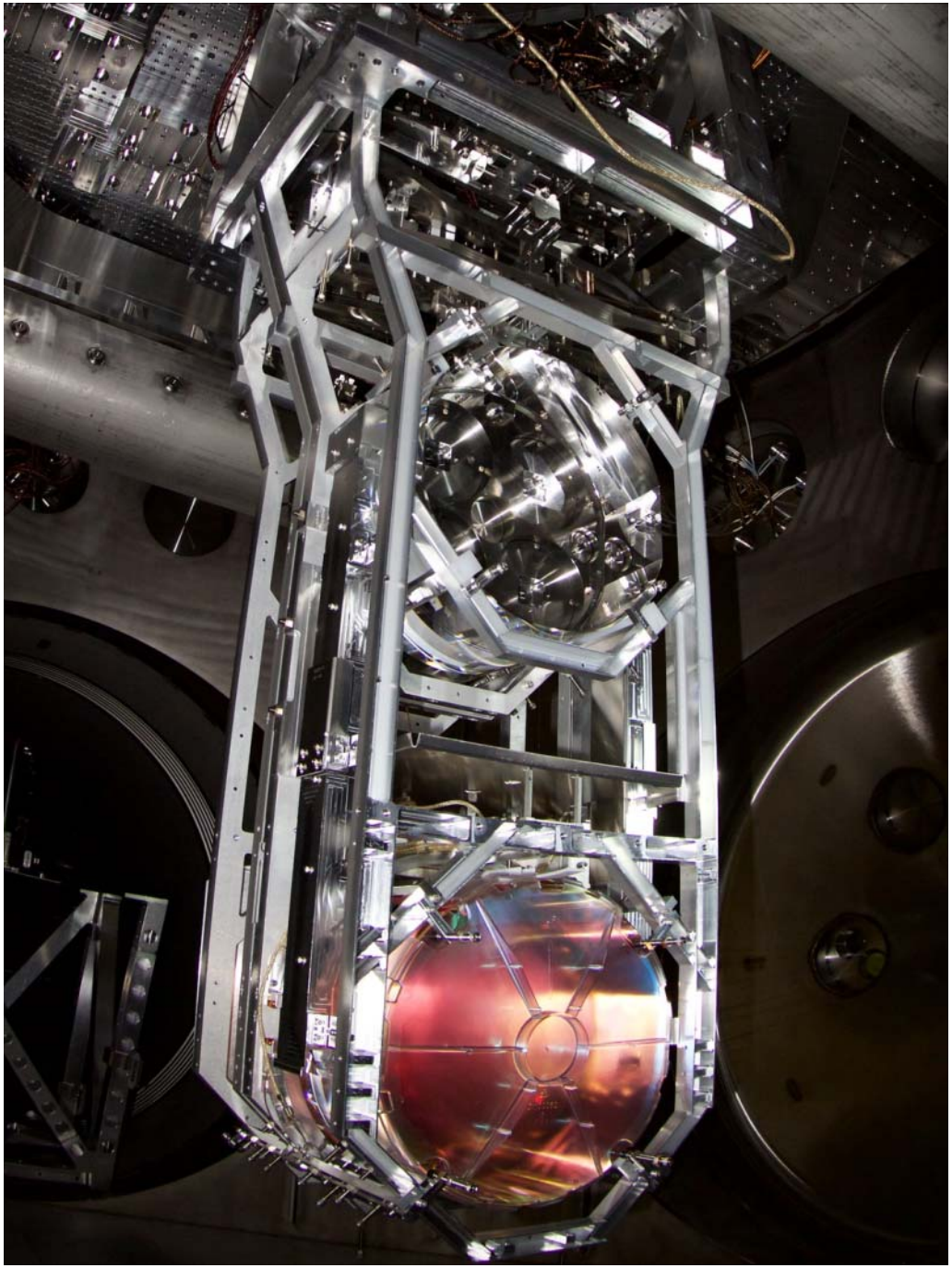
Anthropogenic Sources*

* Image Credit Pixabay

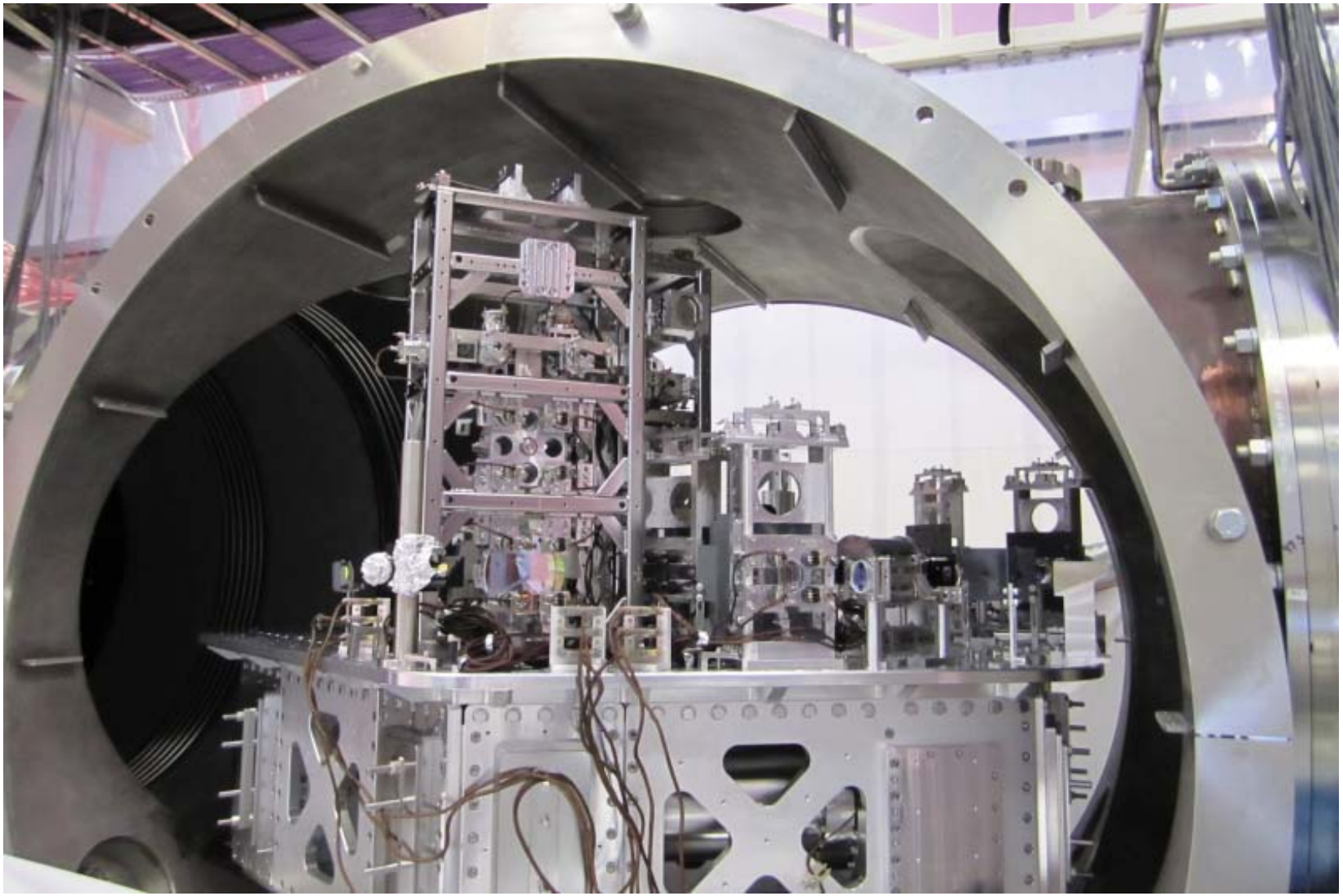
Noise Sources (Avian)



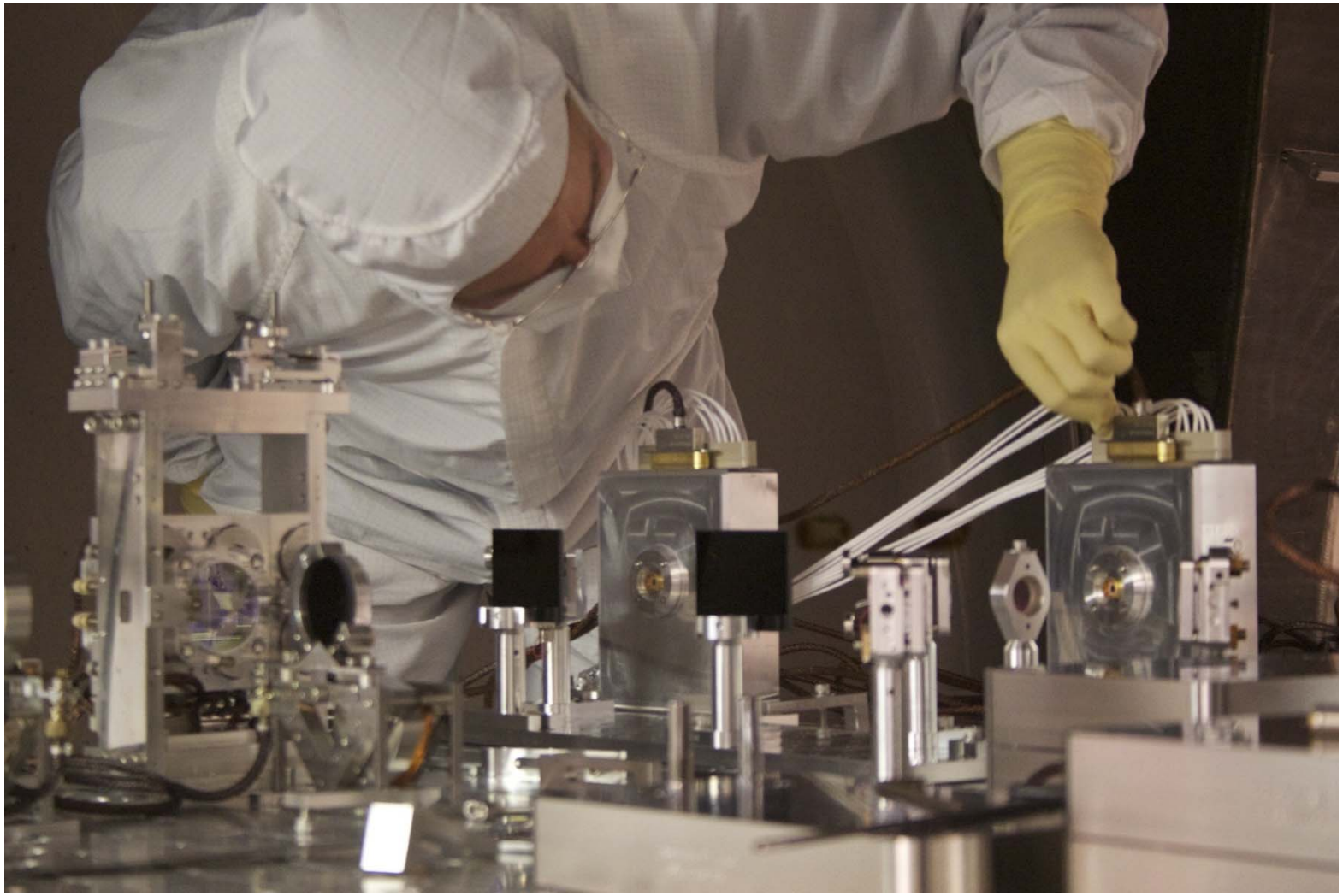
Advanced LIGO Quadruple Suspension
Credit Caltech/MIT/LIGO Lab



Inside a HAM Chamber



Opto-electronics Inside Vacuum Chamber



Thanks to LLRF Committee!

- *gracedb.ligo.org/superevents/public/O3*

Available at the App Store for iOS devices