

# Observation of gravitational waves

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 Louisiana State University, LIGO Livingston

For the LIGO Scientific Collaboration and  
 the Virgo Collaboration  
 March 11, 2016



LIGO Livingston Observatory,  
 Louisiana, USA

LIGO-G1600503-v1



Virgo detector, Cascina, Italy



LIGO Hanford Observatory  
 Washington, USA

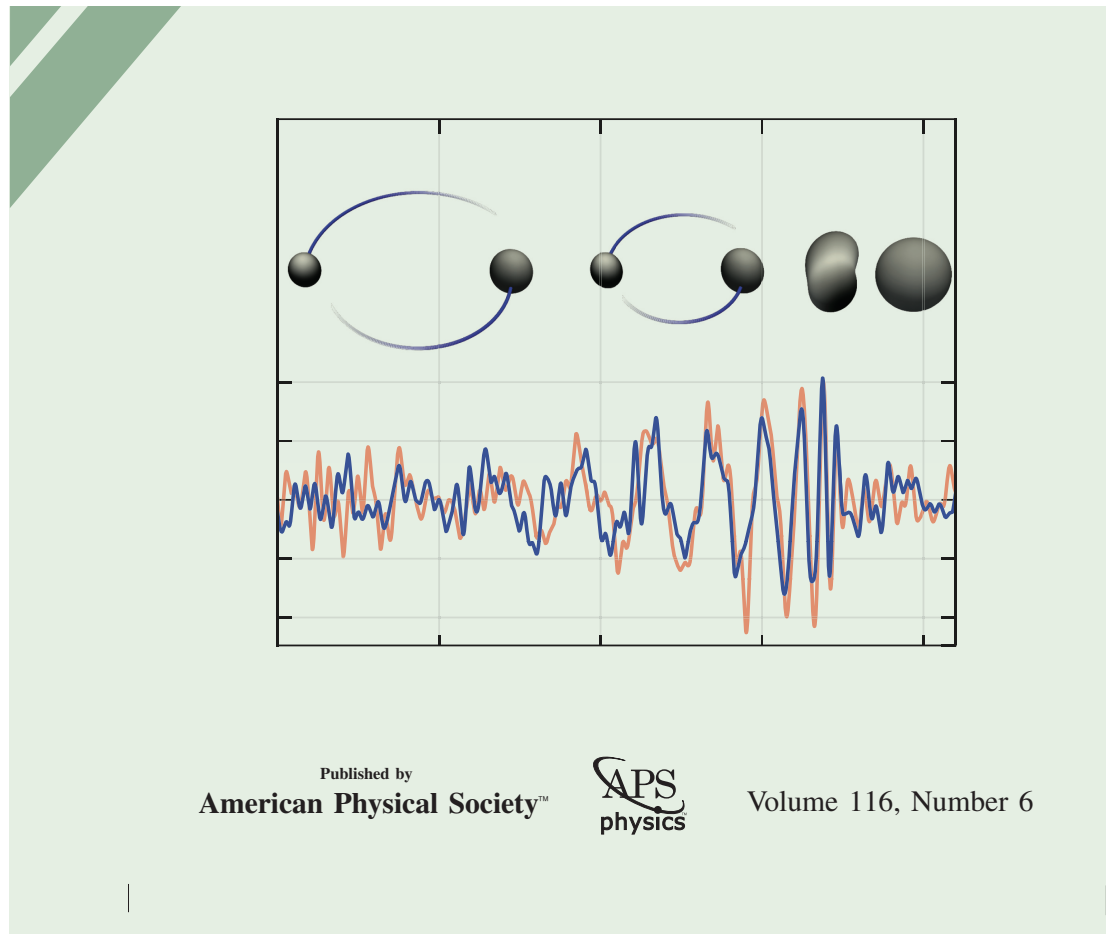


# Observation of Gravitational Waves from a Binary Black Hole Merger

B. P. Abbott *et al.*\*

(LIGO Scientific Collaboration and Virgo Collaboration)

(Received 21 January 2016; published 11 February 2016)

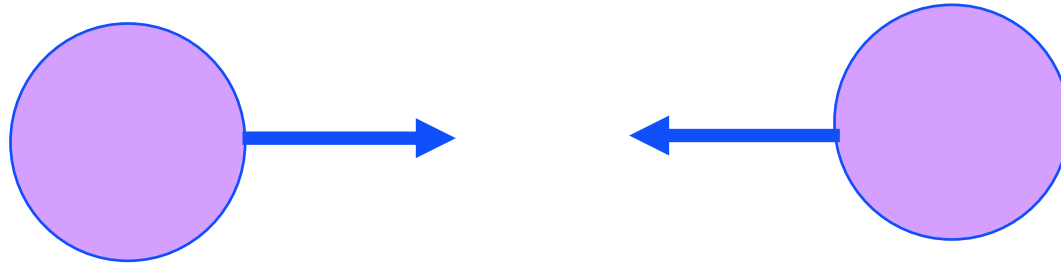


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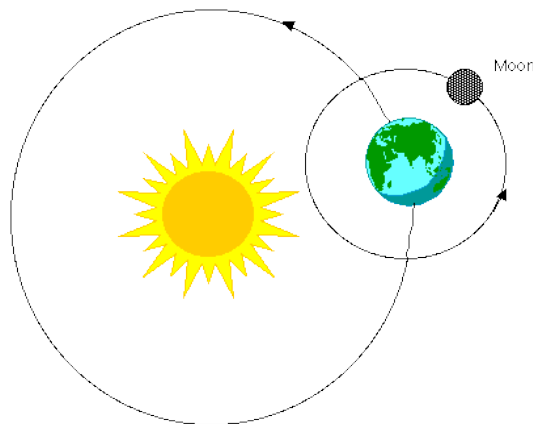
# Newton's gravity



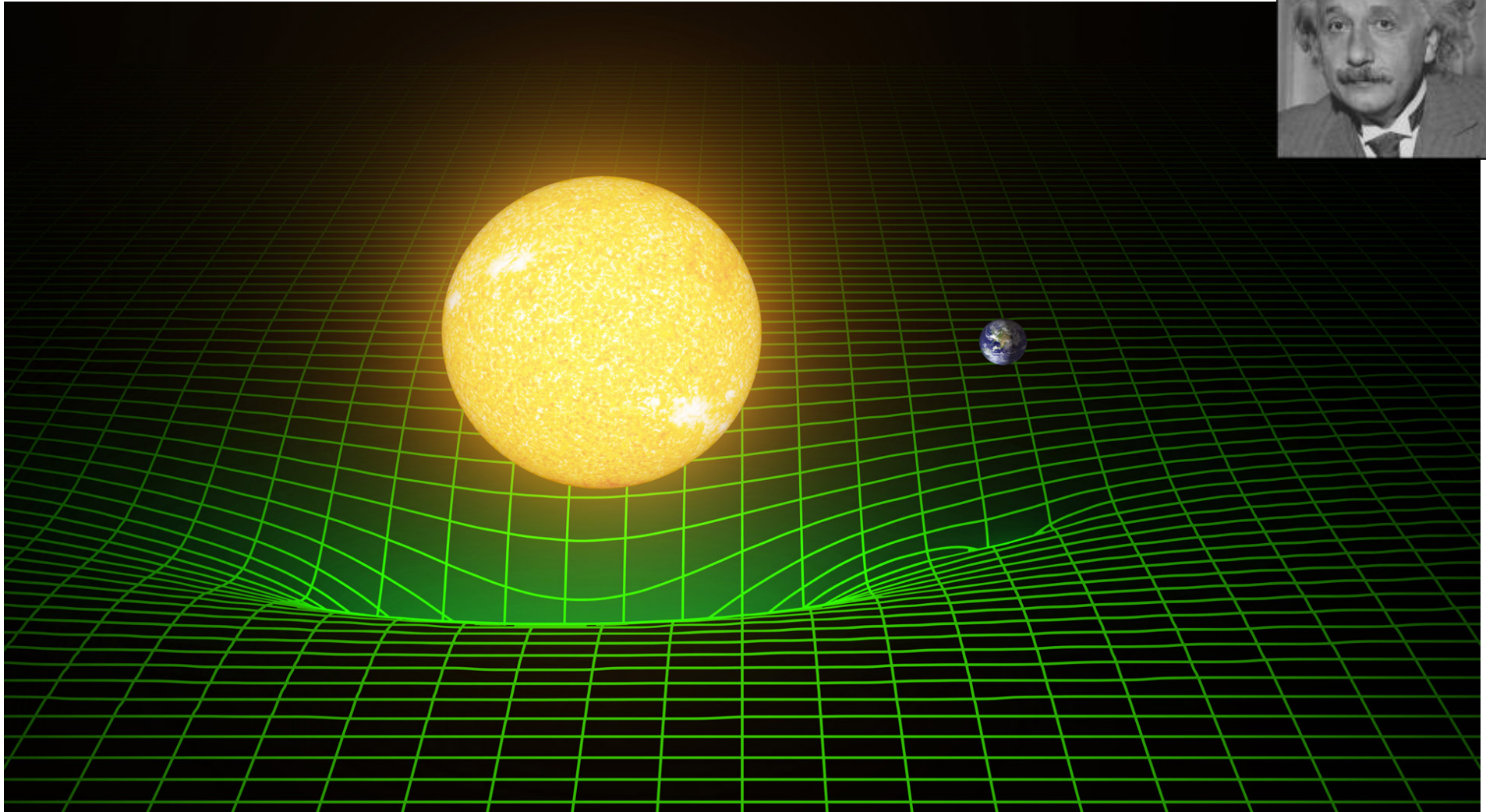
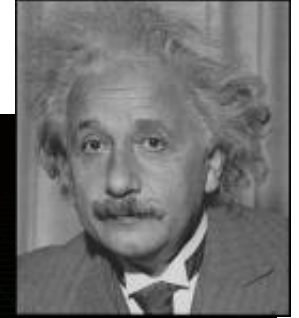
“Newton’s law”:  $F = Gm_1m_2/r^2$



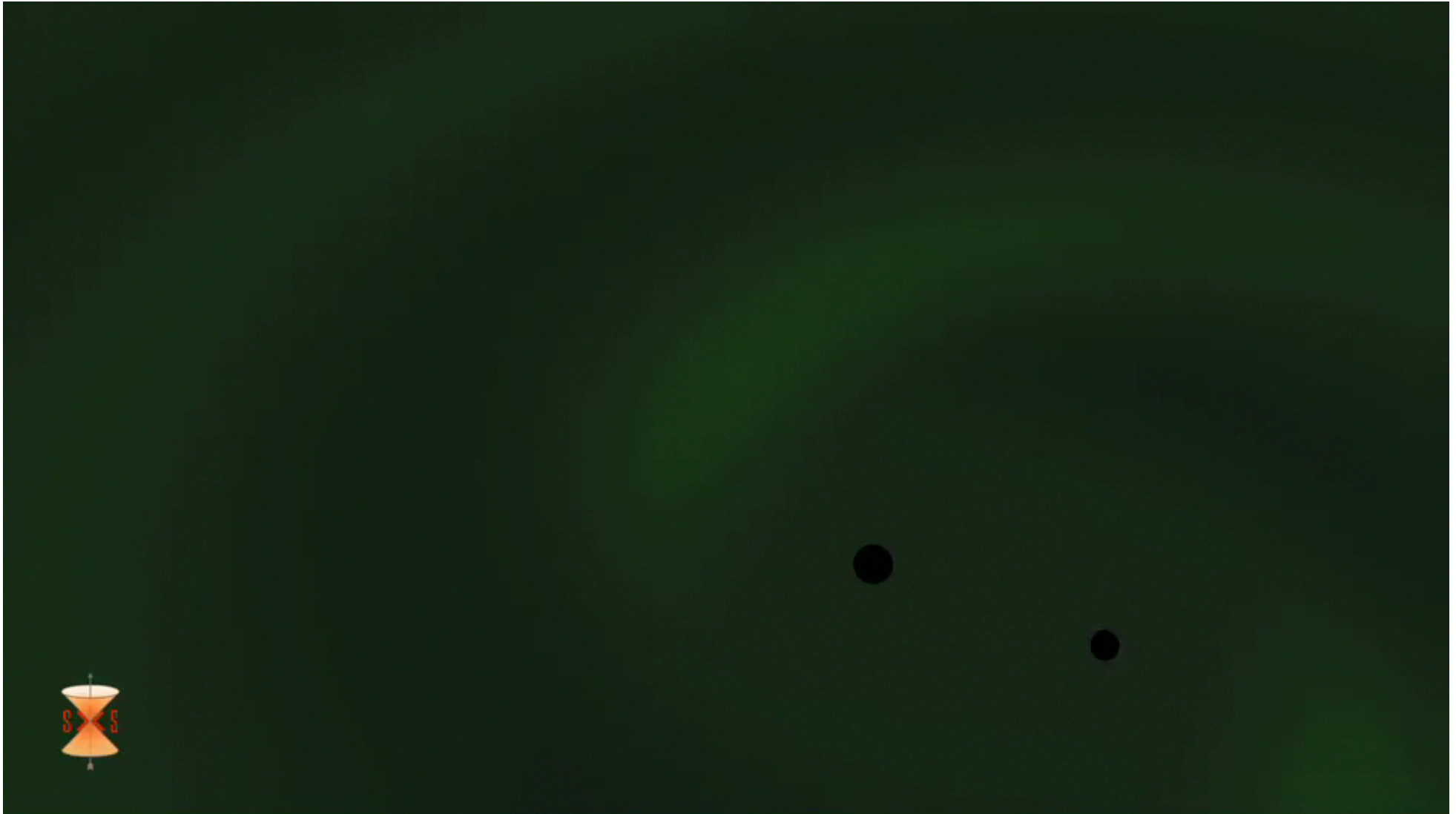
Explains why apples fall, why the planets move around the Sun,...



# Einstein's gravity



# Einstein's gravity





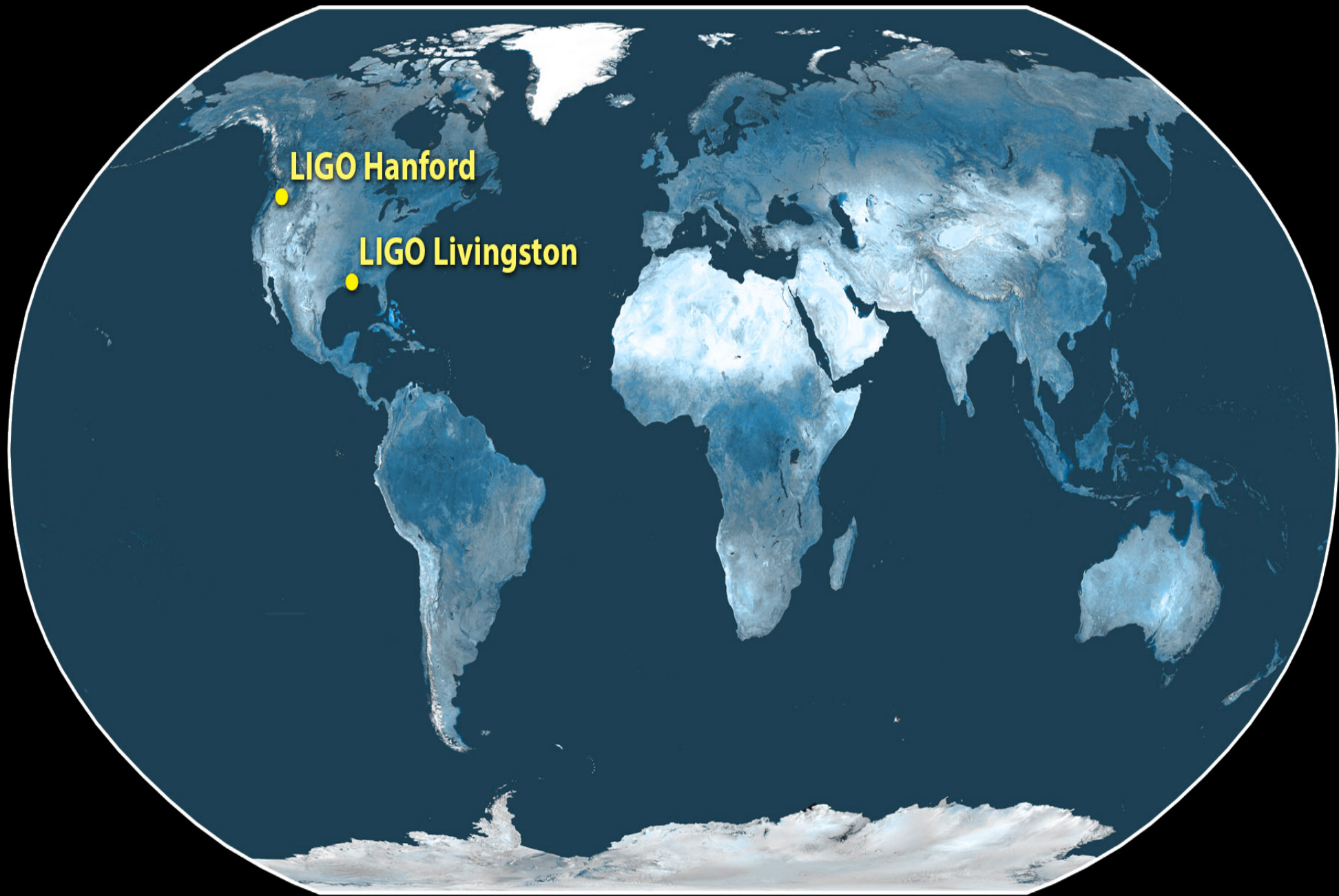
# How LIGO works



# LIGO Livingston: drone view



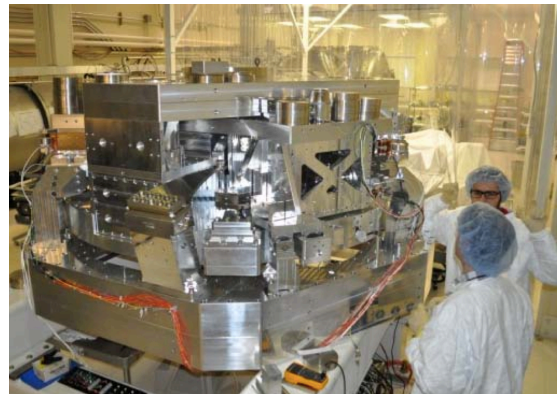
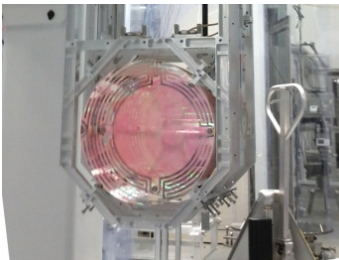
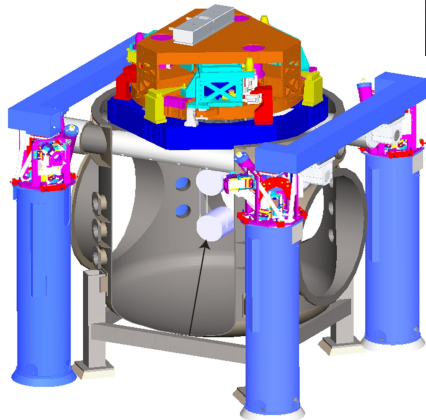
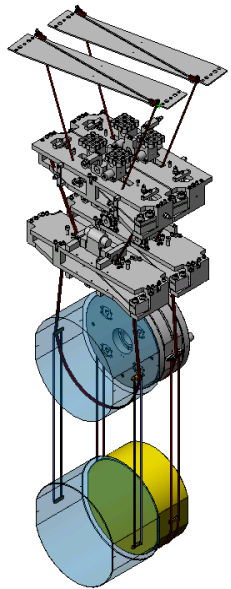
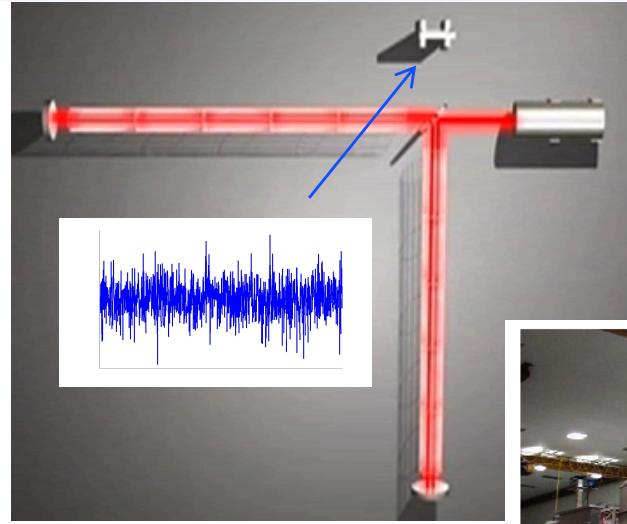


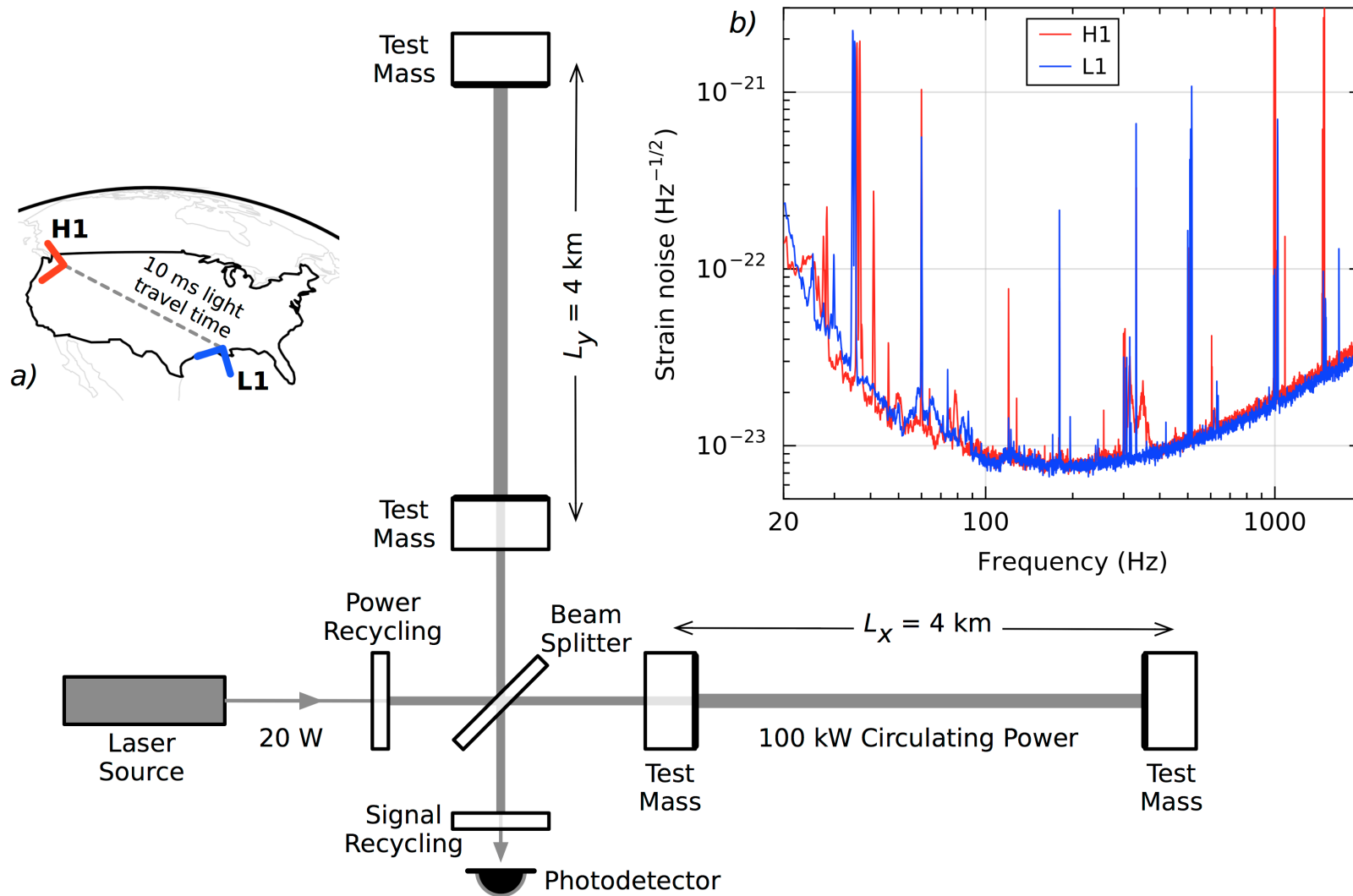


LIGO Hanford

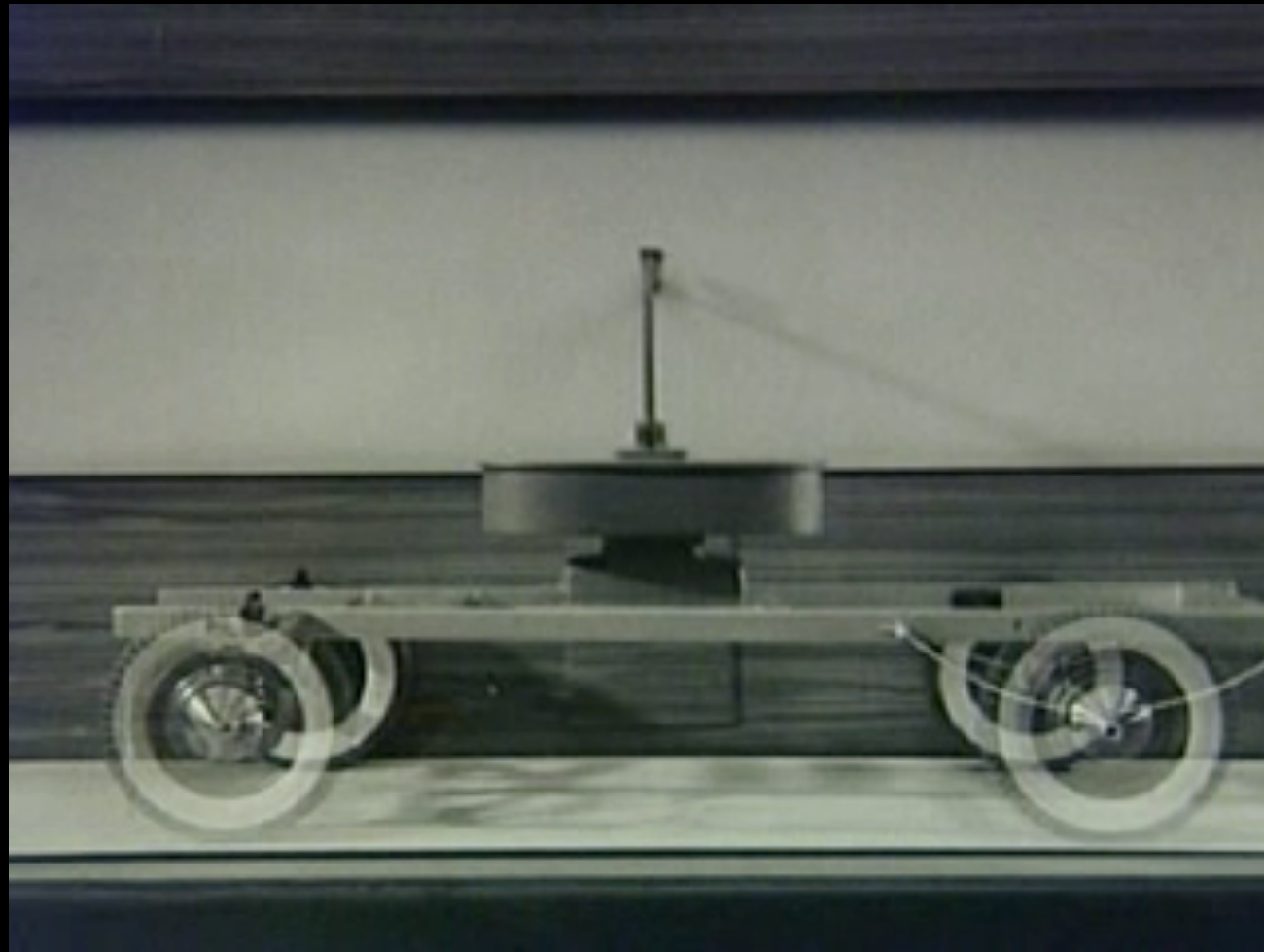
LIGO Livingston

# Advanced LIGO detectors



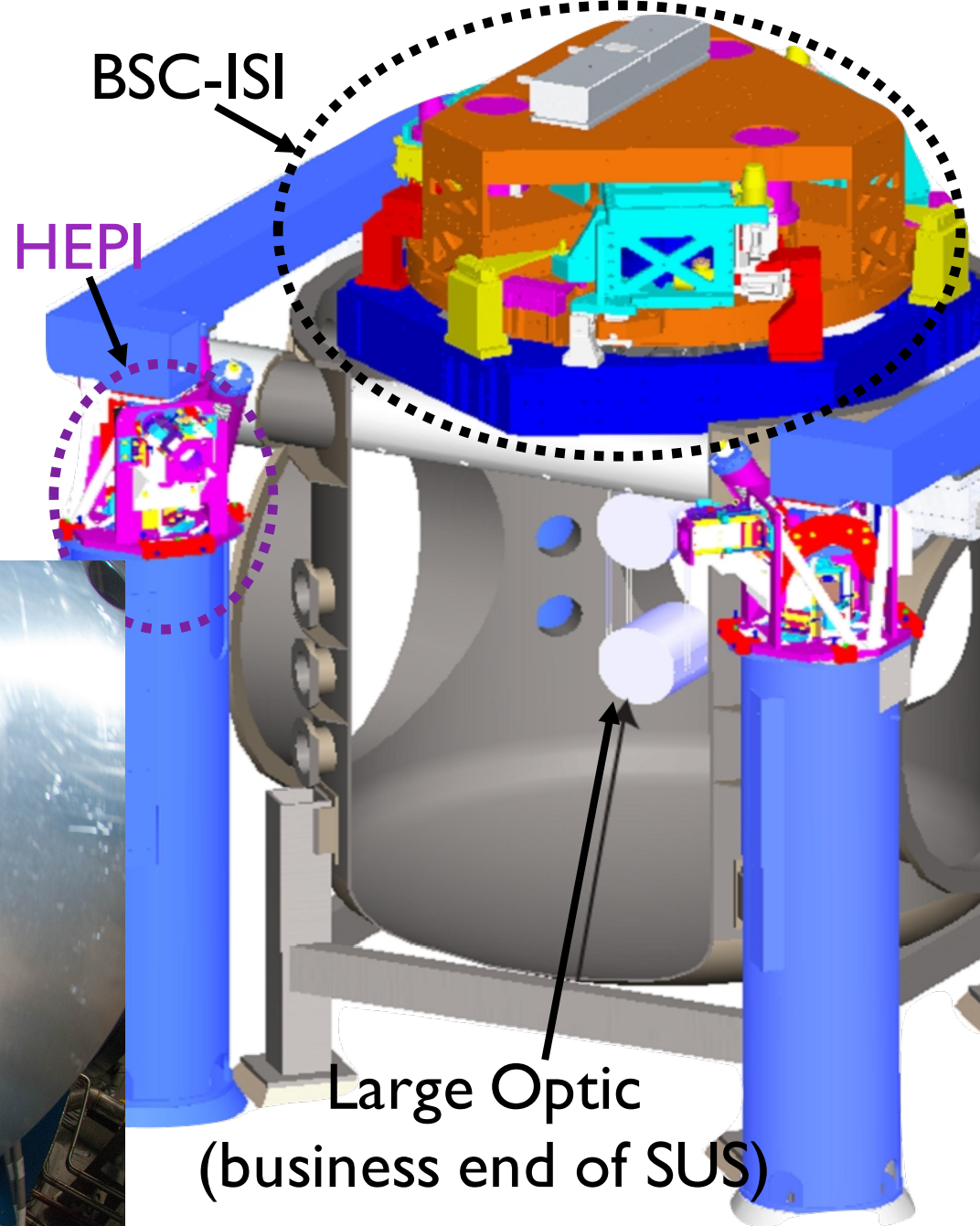


# 1938 seismic isolation technology

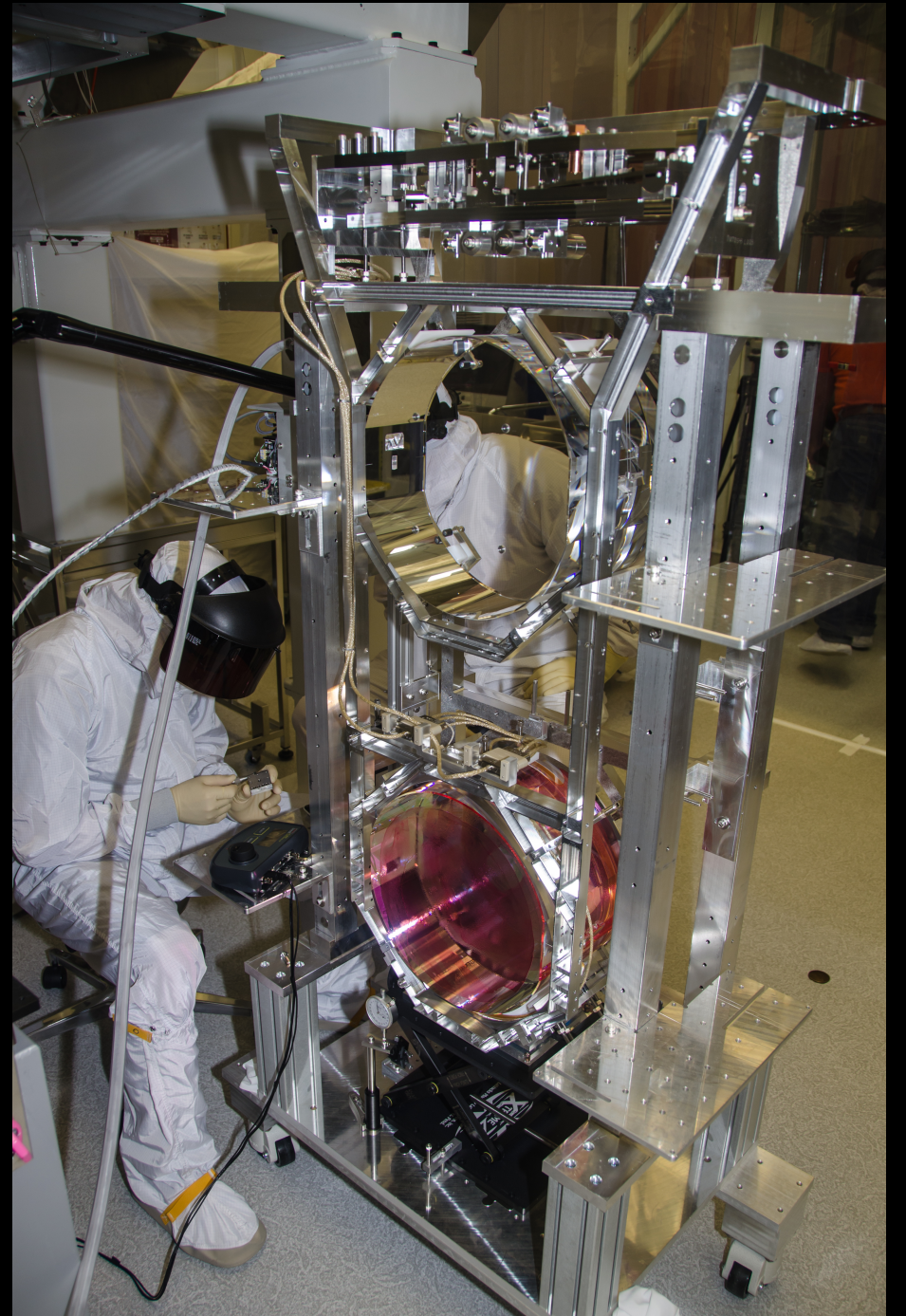


# 21<sup>st</sup> Century Seismic Isolation

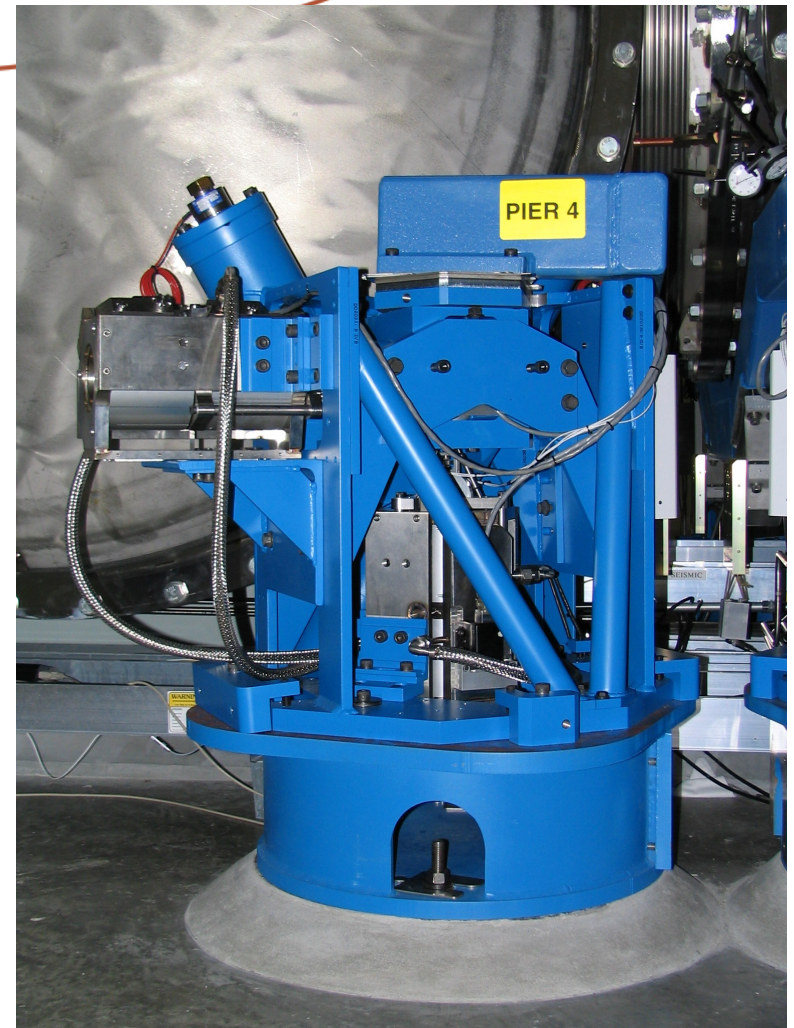
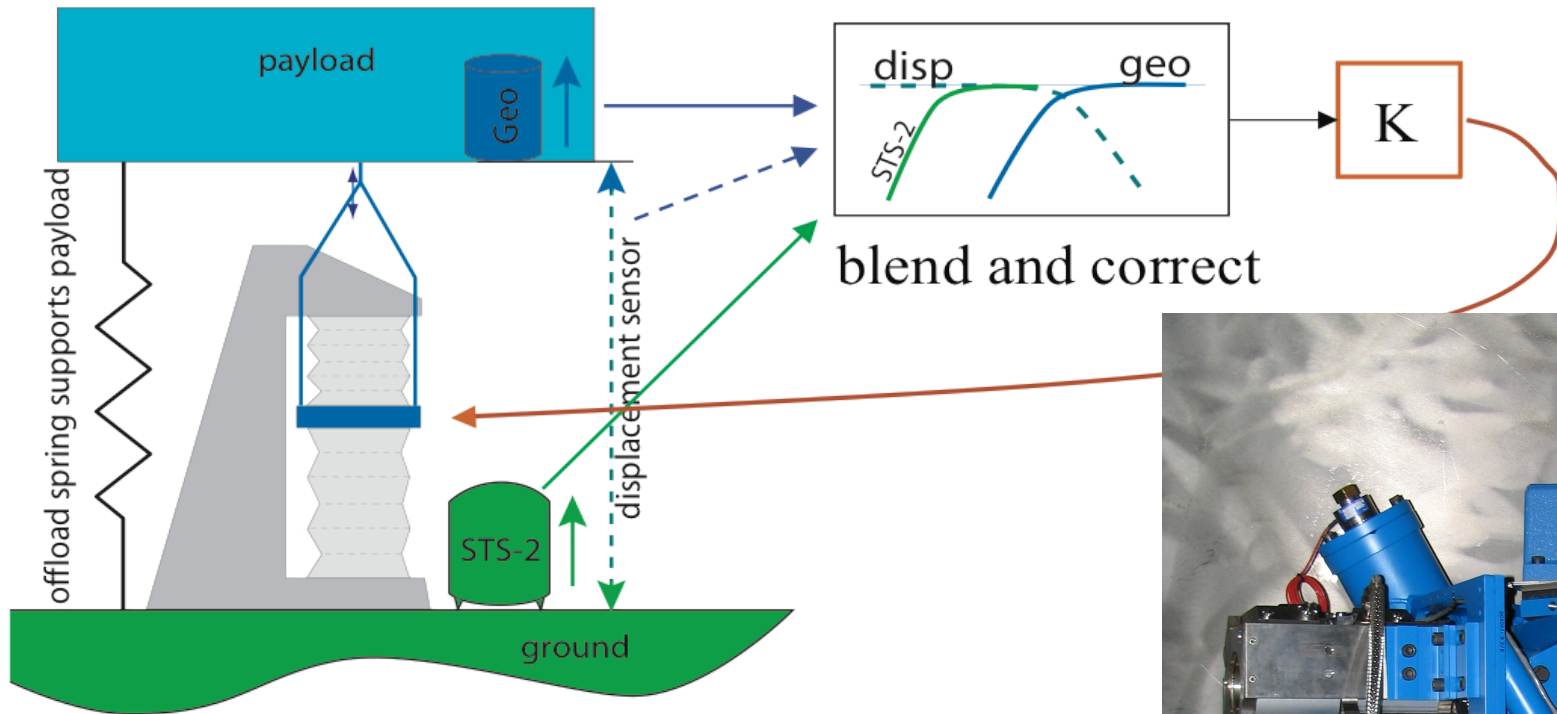
- HEPI: Hydraulic External Pre-Isolator  
large throw, isolation below  $\sim 5$  Hz
- ISI: Internal Seismic Isolation  
Isolates above  $\sim 0.2$  Hz  
Quiet, well controlled table
- Quad pendulum: superior performance  
at 10 Hz and above



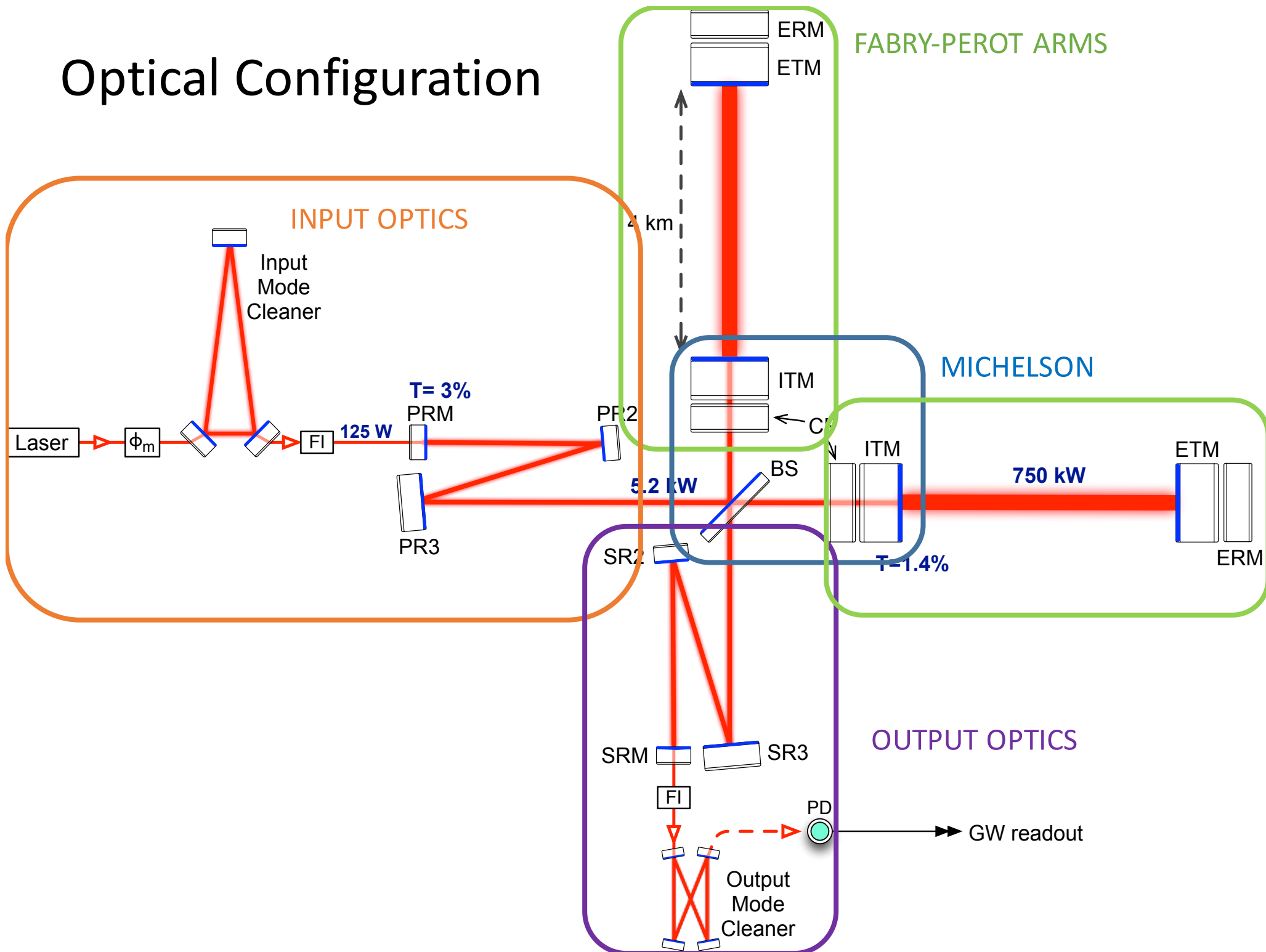
# Quadruple Pendulum test mass suspension



# Active Seismic Isolation

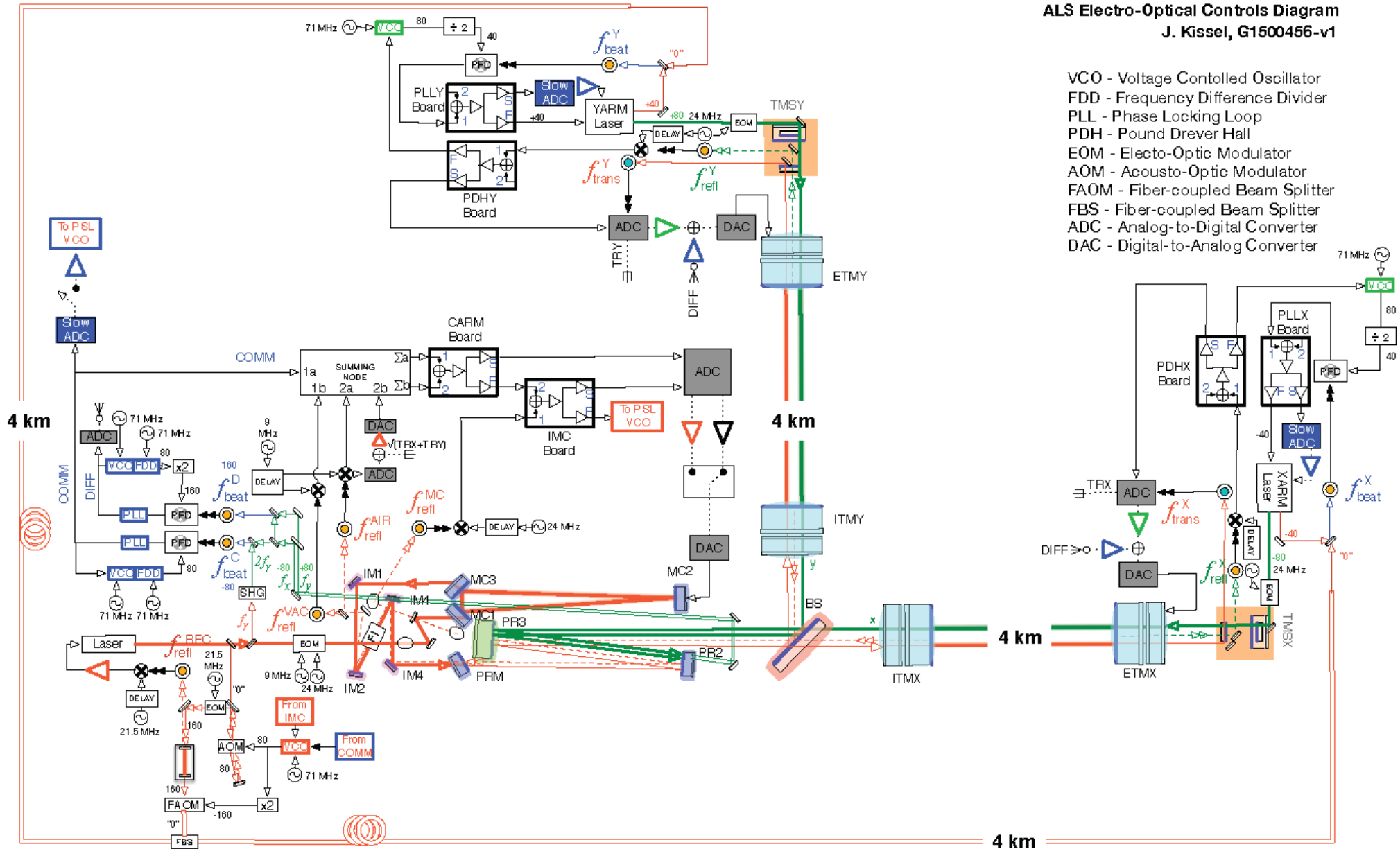


# Optical Configuration



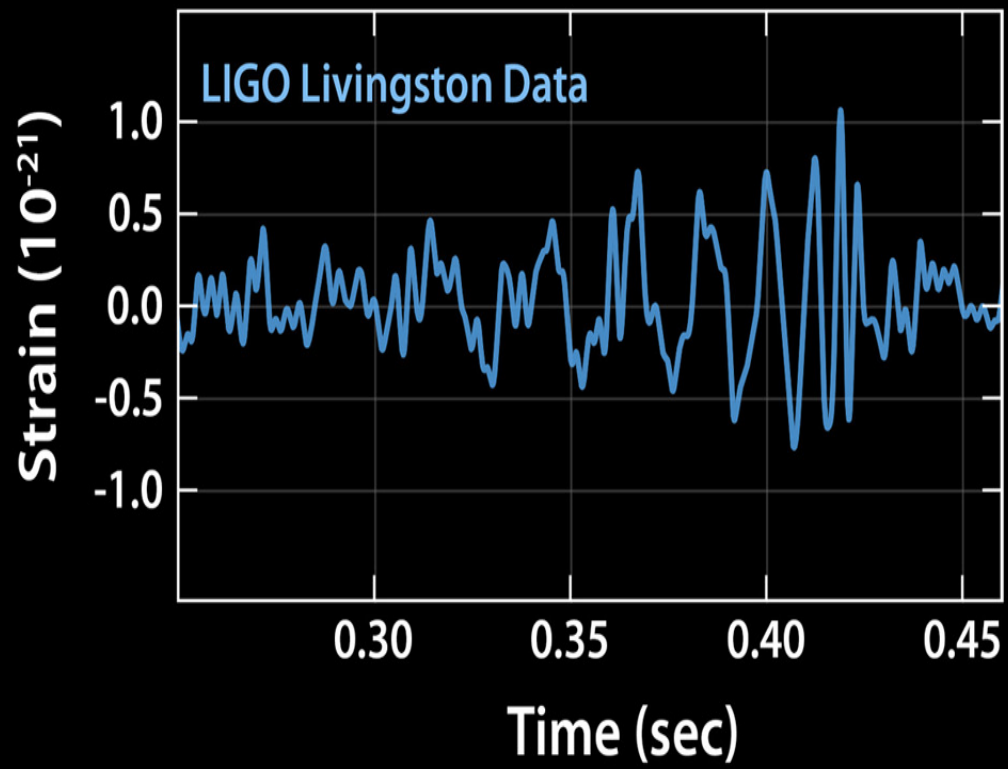


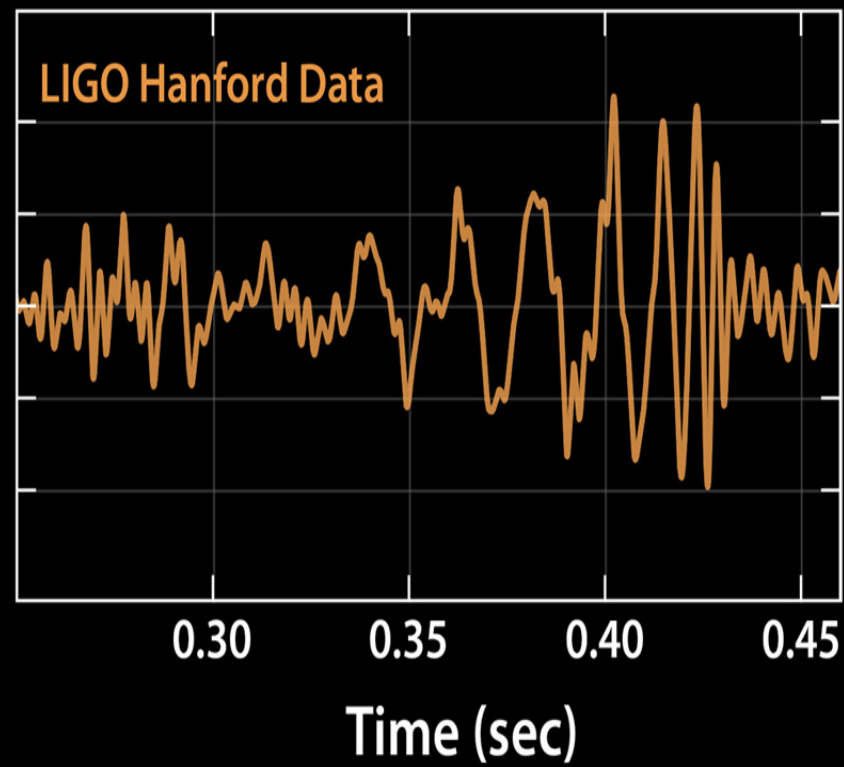
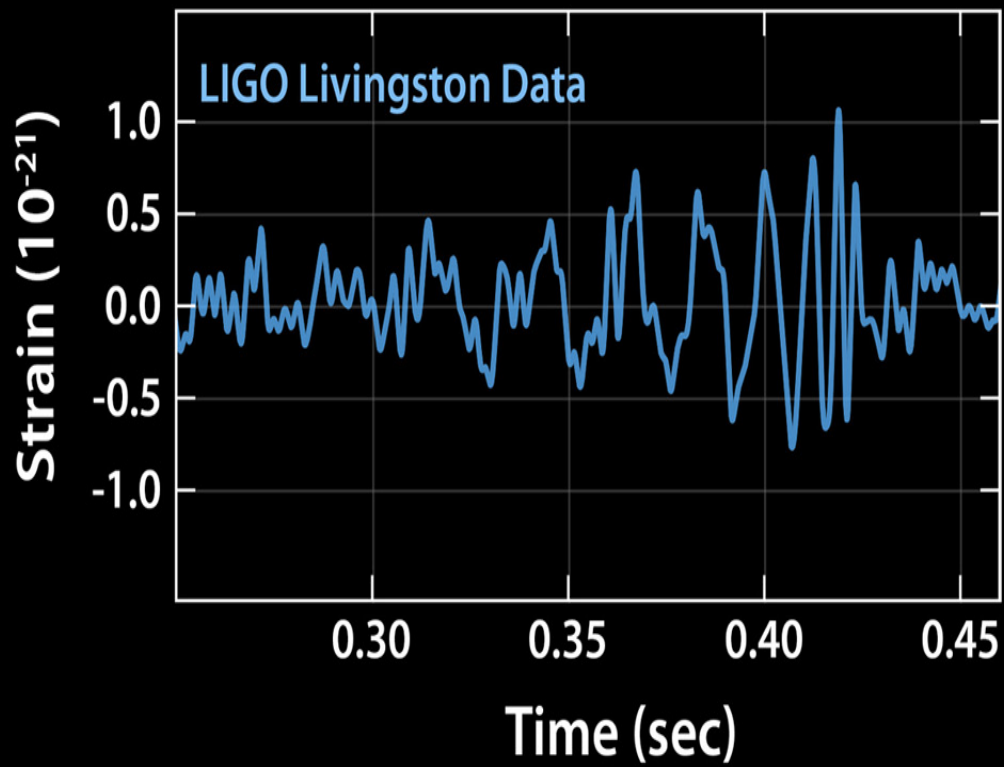
# Optical alignment and control... just one part:

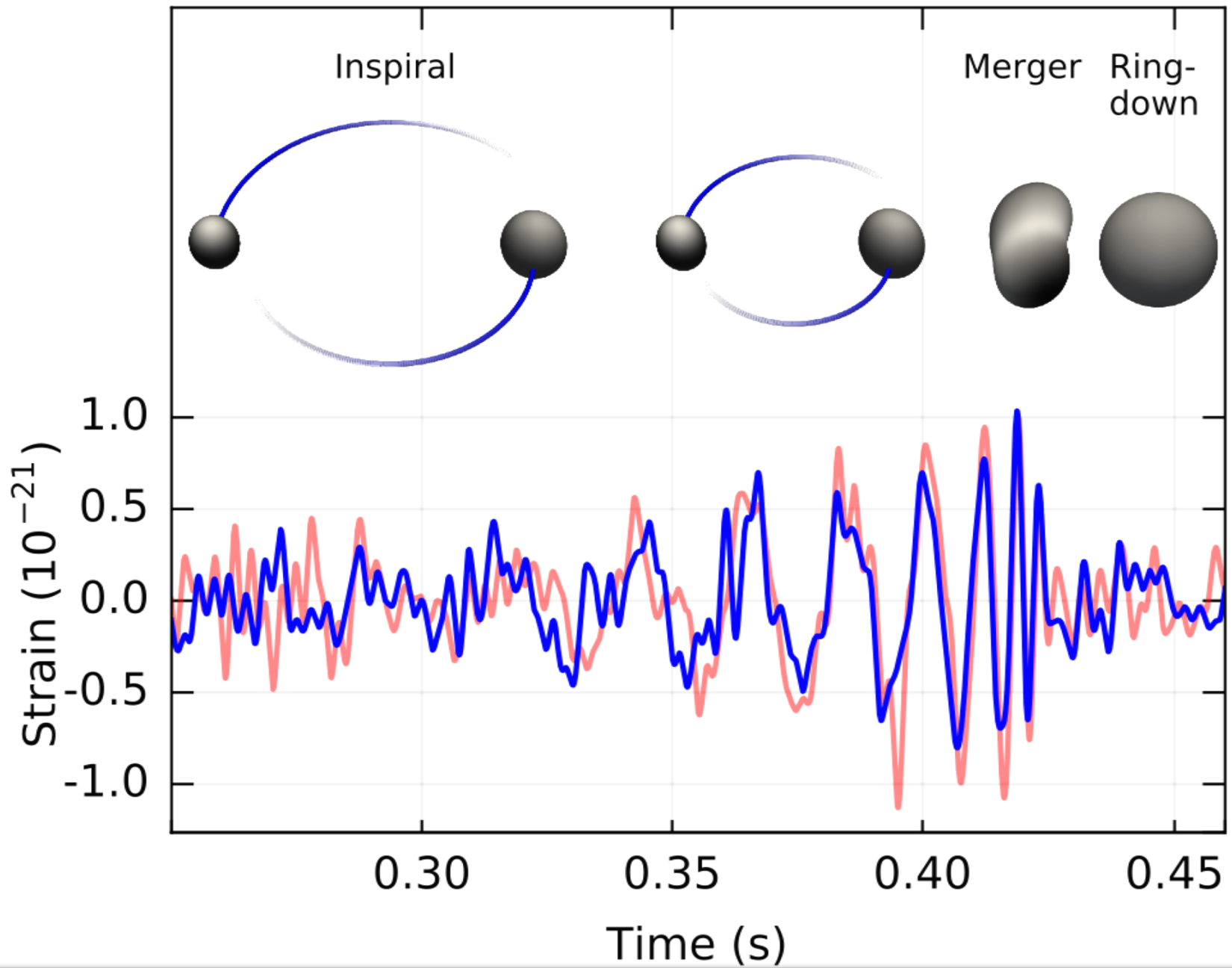


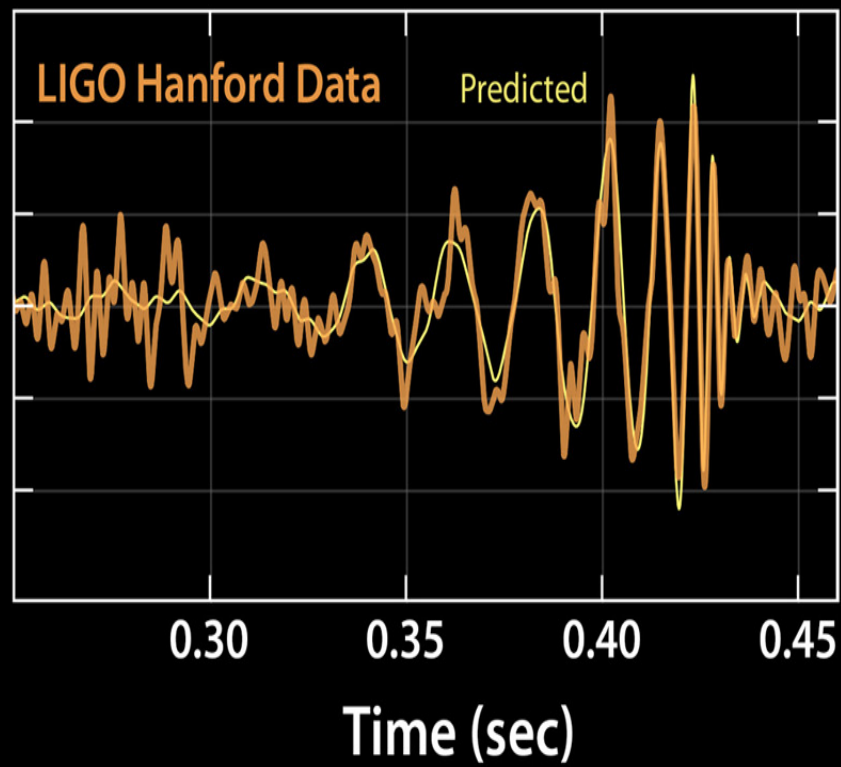
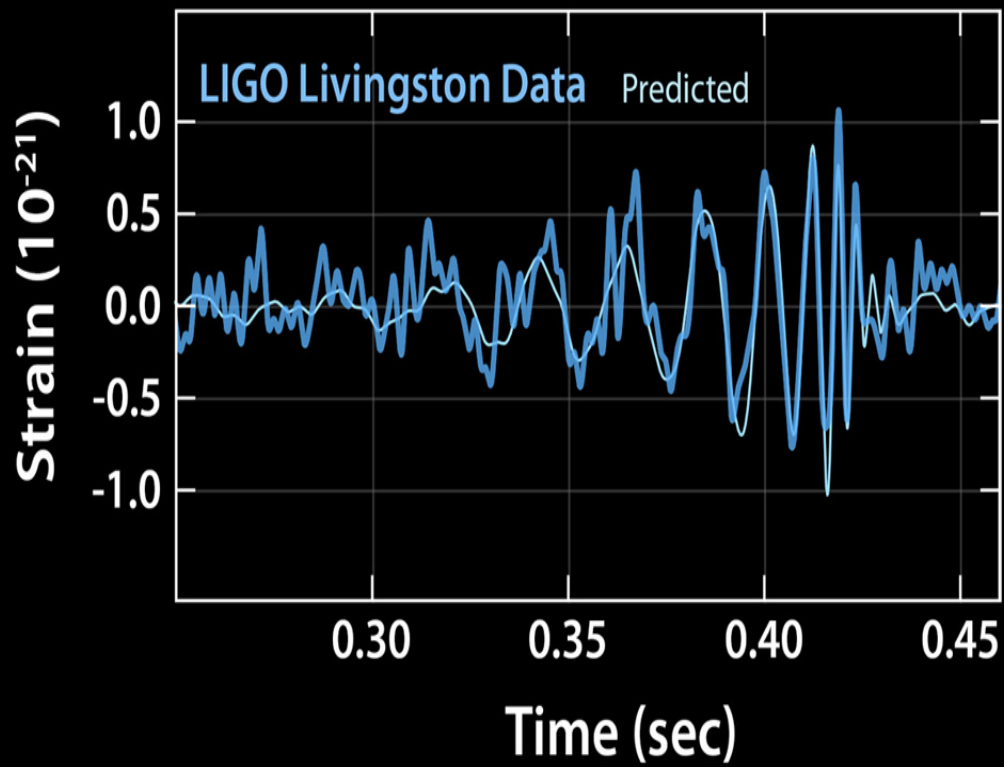
# LIGO control room: lock acquisition

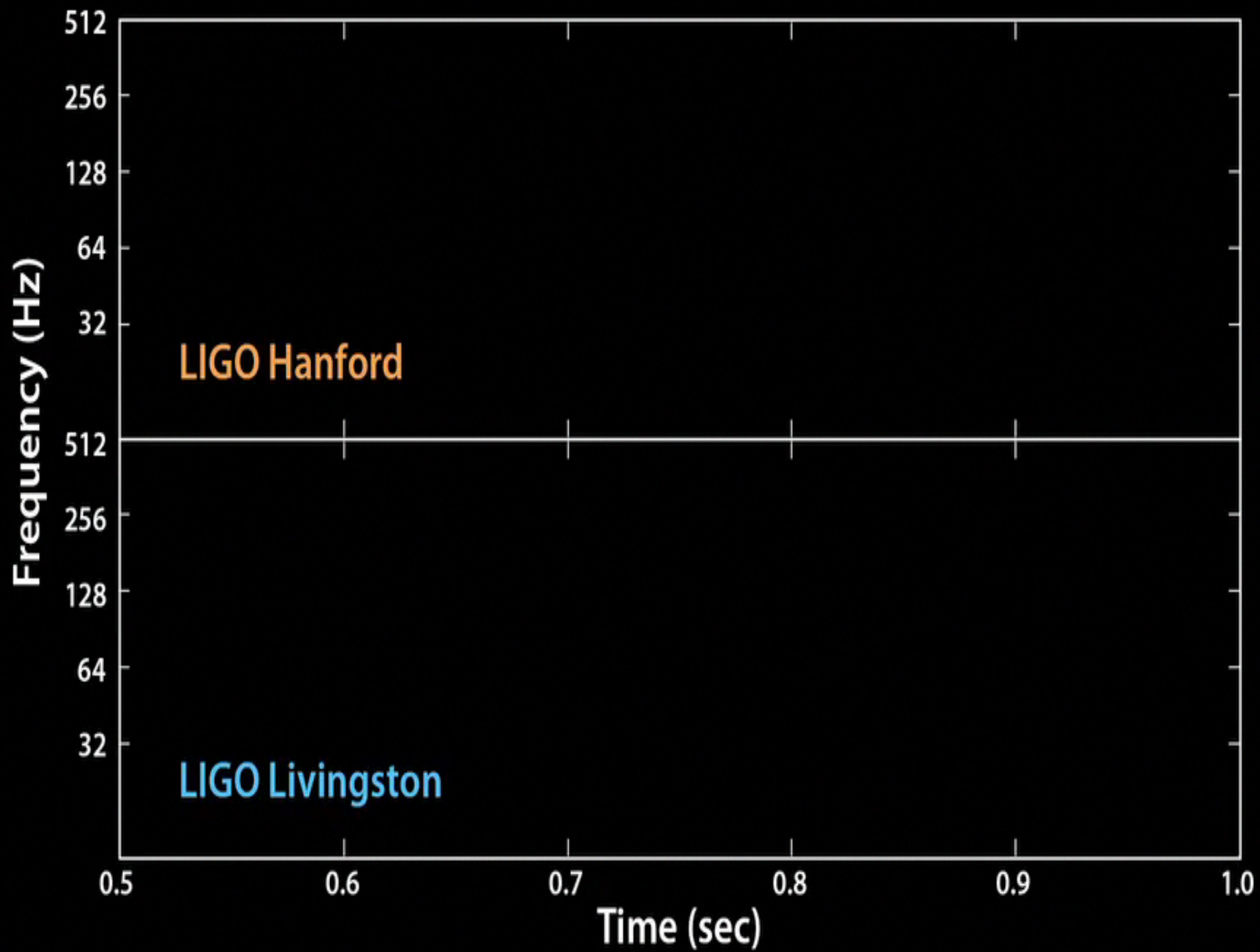


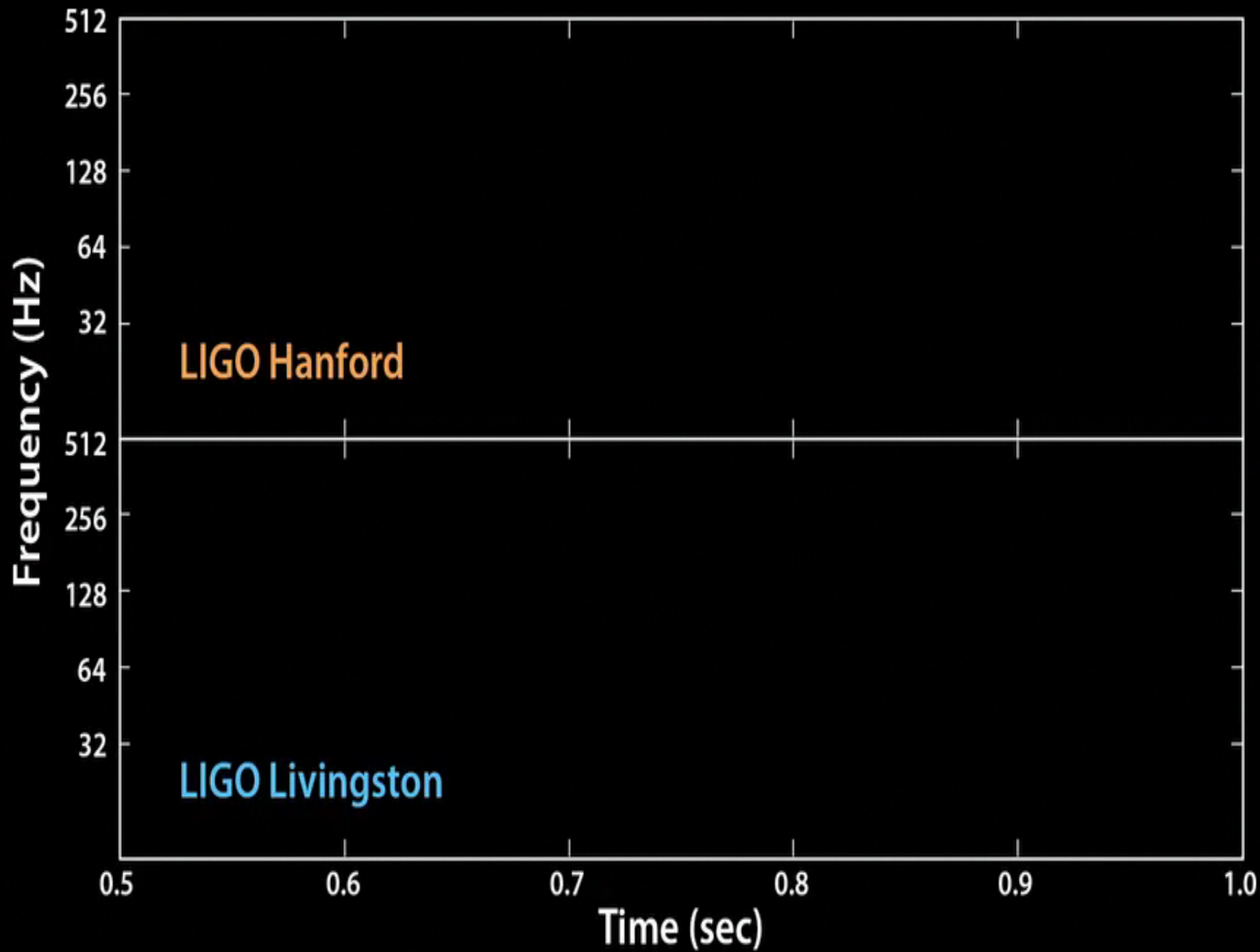




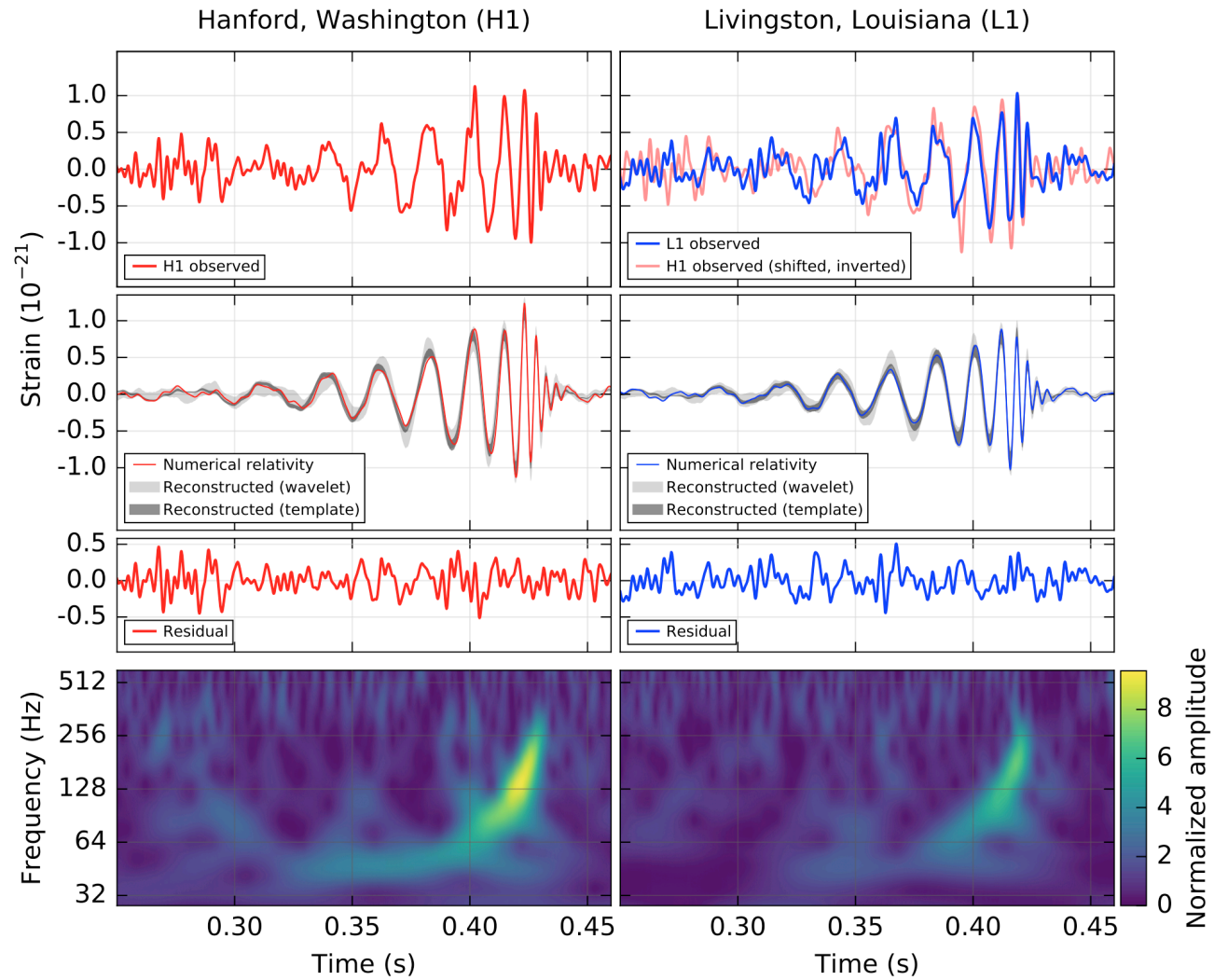


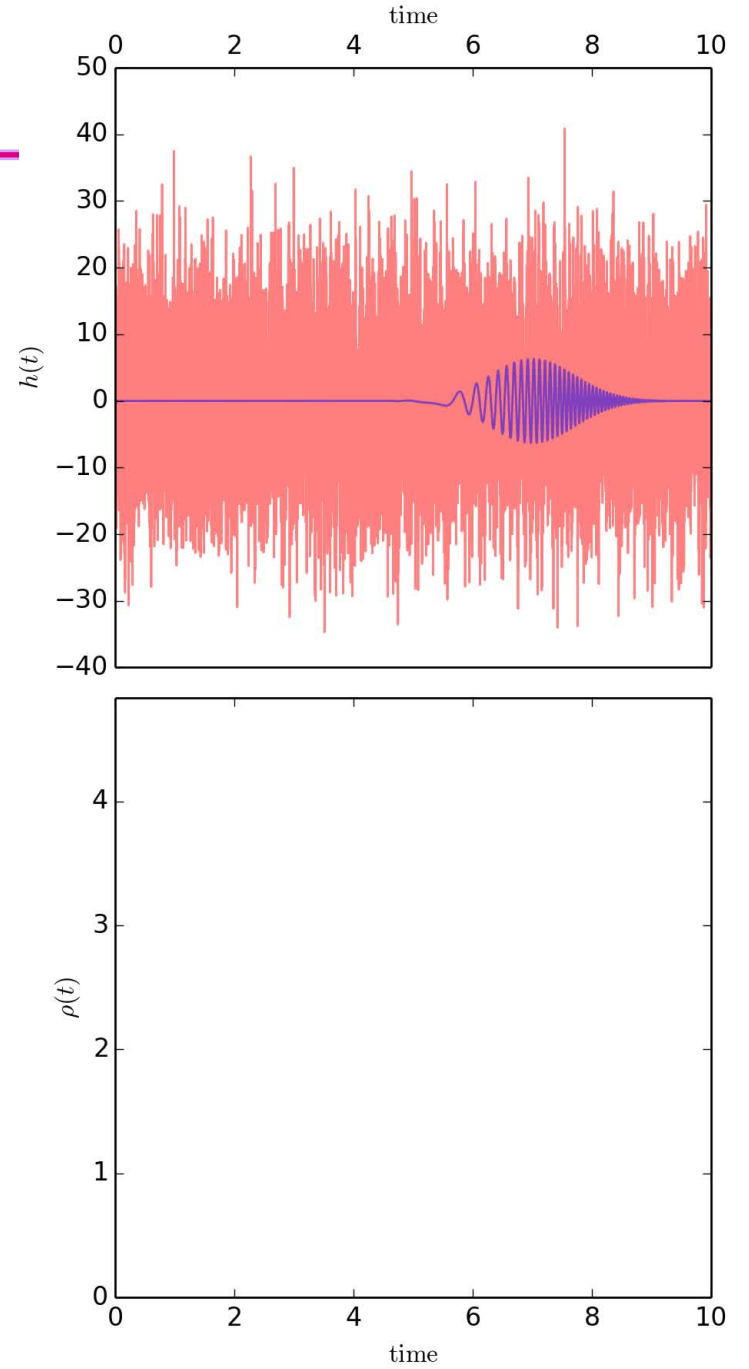
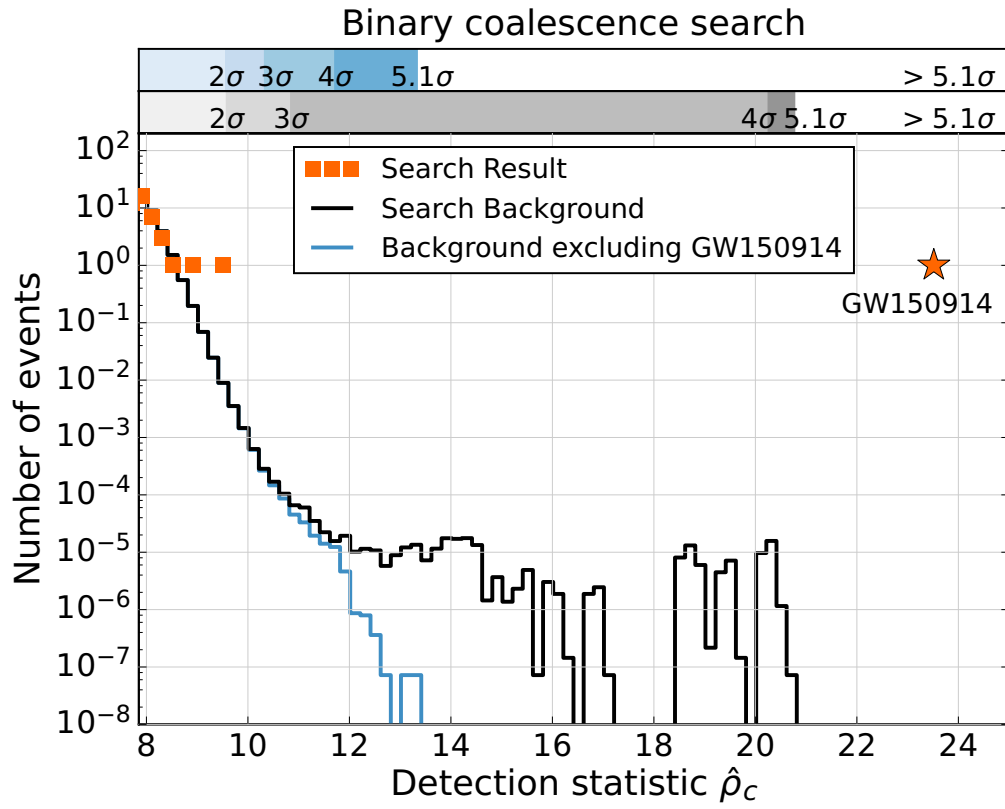


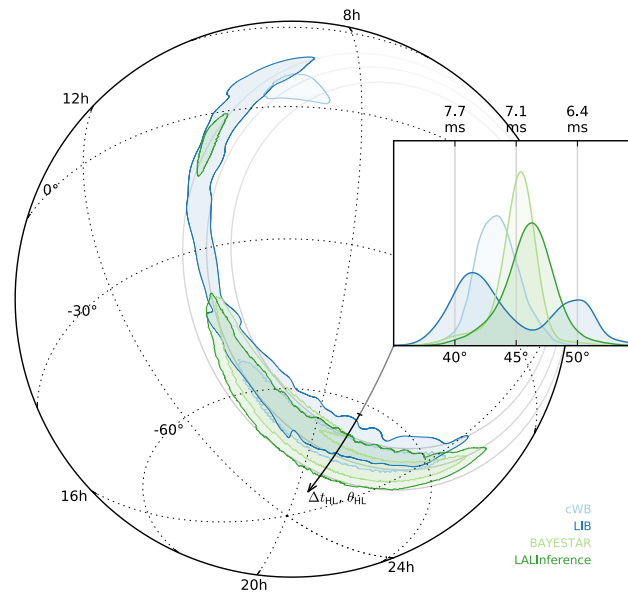
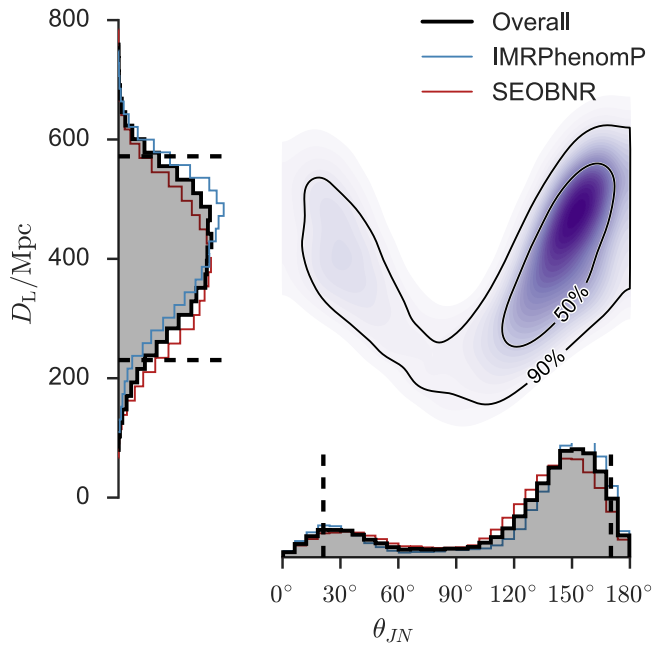
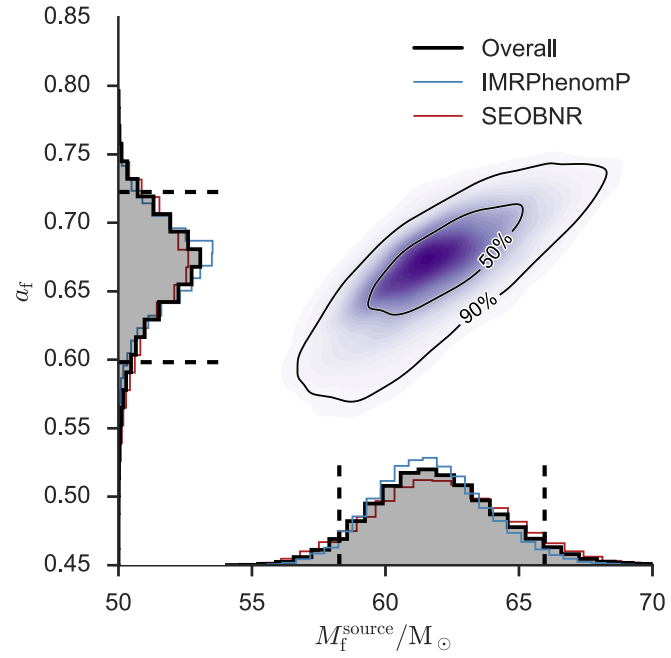
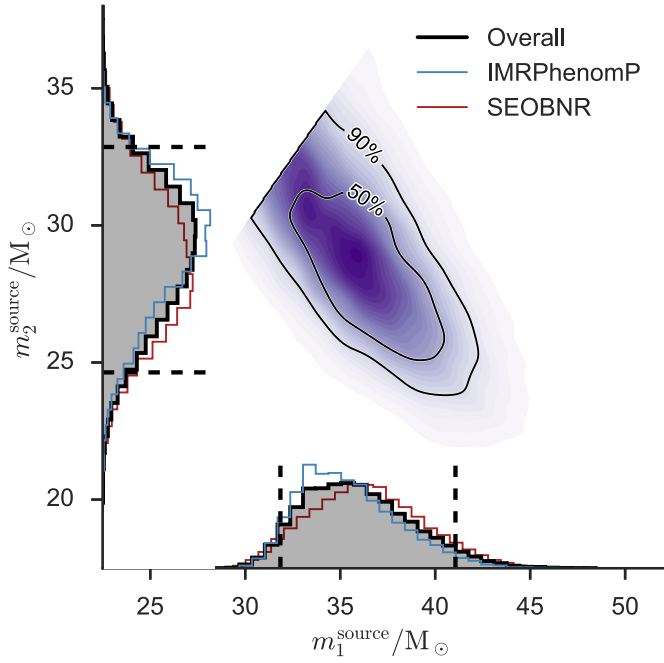




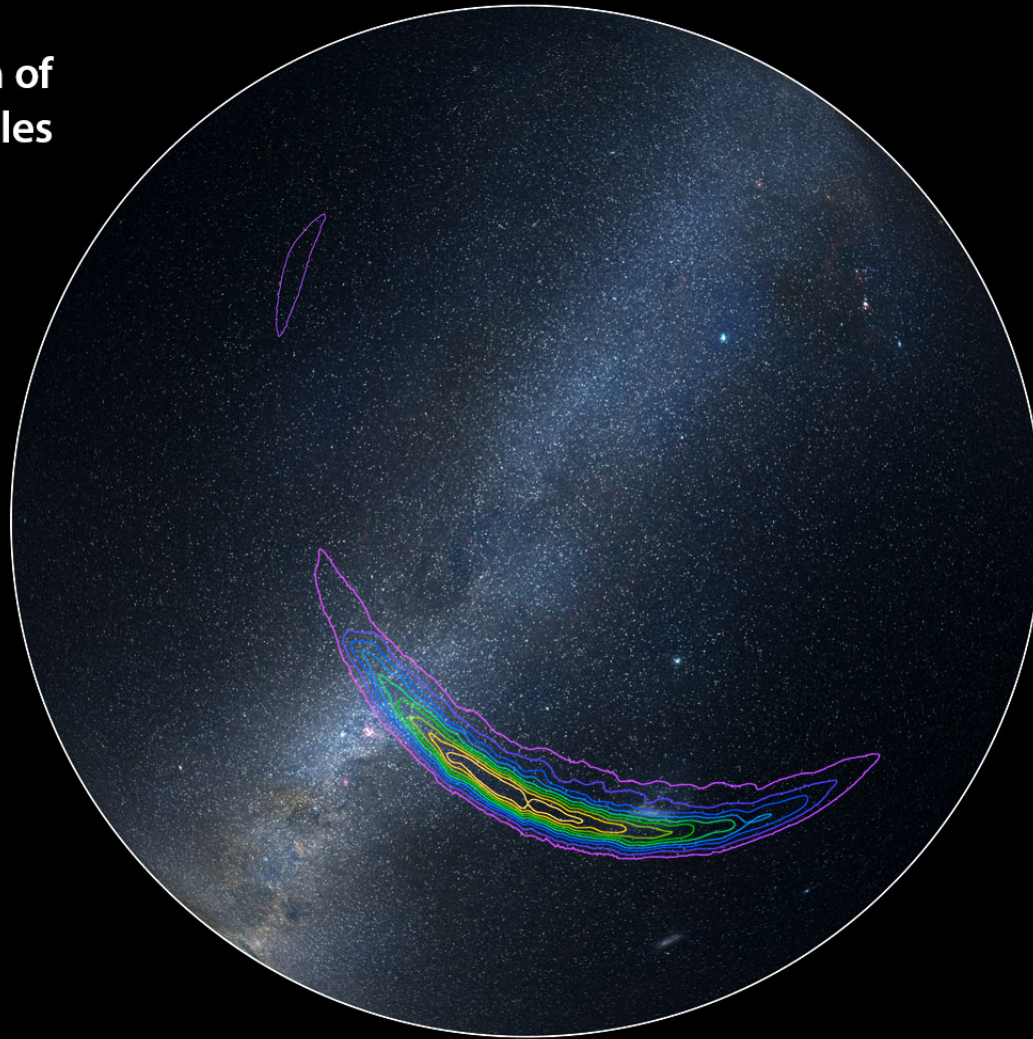


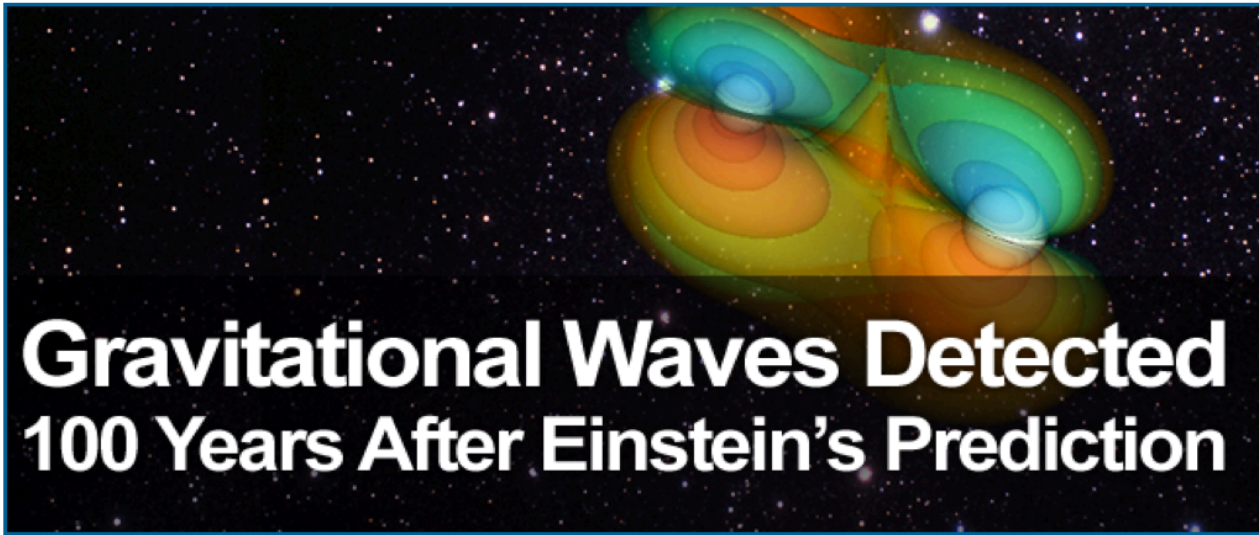






Probable location of  
merging black holes





## Gravitational Waves Detected 100 Years After Einstein's Prediction



**“LIGO Detection”:** The path to discovery. Watch a new documentary about LIGO

### NEWS

- Feb 11, 2016** [LIGO announces the detection of gravitational waves](#)
- Feb 8, 2016** [Media Advisory: Scientists to provide update on the search for gravitational waves](#)
- Jan 16, 2016** [LSC Statement on Harassment](#)
- Jan 12, 2016** [First Observing Run \(O1\) ends](#)
- Dec 23, 2015** [Planning for a bright tomorrow: prospects for gravitational-wave astronomy with Advanced LIGO and Advanced Virgo](#)
- Nov 24, 2015** [Stuck in the middle: an all-sky search for gravitational waves of intermediate duration](#)

### PRESS RELEASE

- Feb 11, 2016** [Gravitational Waves Detected 100 Years After Einstein's Prediction](#)  
[More at the LIGO Lab website](#)

### ABOUT LSC

LIGO Scientific Collaboration is a group of **more than 1000 scientists worldwide** who have joined together in the search for gravitational waves.

[Learn more now](#)
[Get involved! Find out how](#)



**“LIGO: A Passion for Understanding”**  
 Watch a documentary about science and people of LIGO



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 Watch a documentary about science and people of LIGO

# Patience and stewardship over generations:

~100 years ago: Albert Einstein published his theory of General Relativity, including prediction of gravitational waves.

~50 years ago: Weber builds bar antennas to attempt detection of the waves.

~45 years ago: Key ideas for interferometric antennas developed by Weiss and others.

~40 years ago: NSF funding of pre-LIGO R&D.

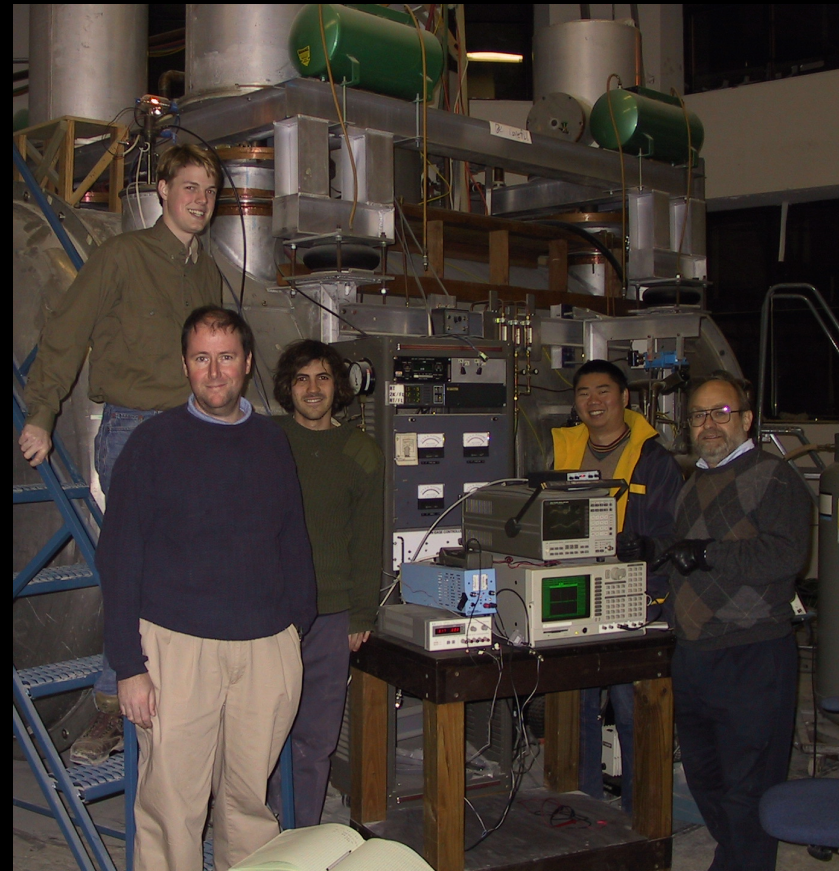
~25 years ago: LIGO proposed to the NSF.

~20 years ago: LIGO site construction began.

~5 years ago: Advanced LIGO installation began.

# 45 years of gravity in Louisiana: worth the work and patience

- LSU Physics and Astronomy hired William Hamilton 1970 to design and construct two “cryogenic bar” detectors, for LSU and Stanford. Warren Johnson joined in the '80s, and the bar was operated until LIGO had better performance.
- NSF-funded LIGO Livingston broke ground in '95 and reached design sensitivity 10 years later.
  - No detections!
- An Advanced LIGO upgrade was installed starting in 2010, and had its first run in fall 2015.
  - Discovery!



# Why Livingston, Louisiana (and Hanford, WA)?

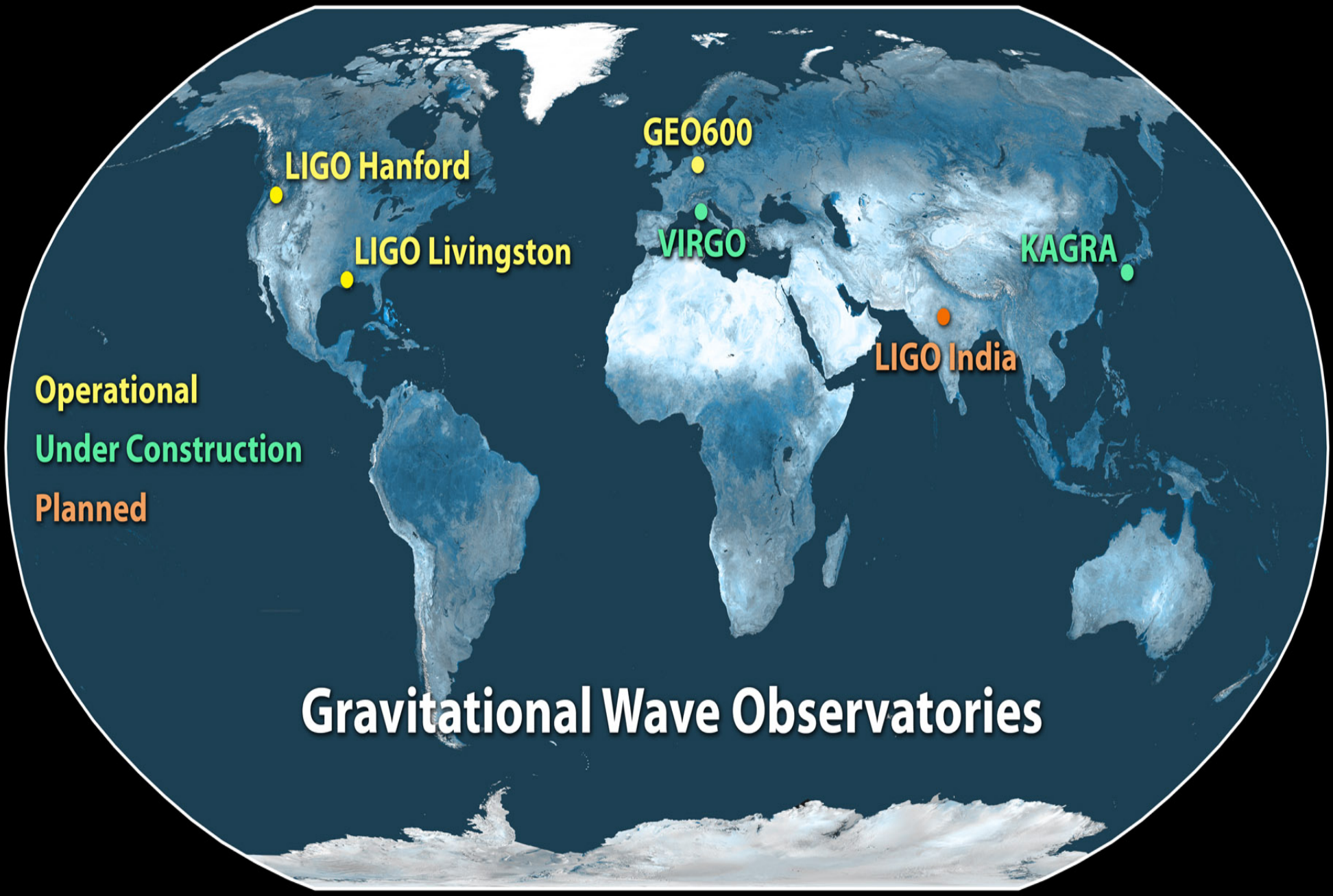
- Observatory sites must have room for a 4 km “L,” be affordable, and have low ground vibration. So cities are out, and rural areas in.
- The two sites must be far apart so that environmental noise would not affect the two the same way, and so that a source’s position on the sky could be estimated.
- The NSF asked for proposed sites, grouped them in pairs, and asked the LIGO Project, Caltech and MIT, to evaluate them.
- Together with other local partners, such as the State and Livingston Economic Development Council, LSU faculty and chancellor emeritus Wharton proposed this location for consideration as a LIGO observatory.
- Livingston and Hanford were selected in 1992, with the additional advantage that a southeast and northwest site make a large triangle with a then-hoped-for site in Europe.



# Science Education Center exhibit hall

50 hands-on stations, ages pre-K through post-retirement.  
Open to public 3<sup>rd</sup> Saturday of each month





LIGO Hanford

LIGO Livingston

GEO600

VIRGO

LIGO India

KAGRA

Operational

Under Construction

Planned

# Gravitational Wave Observatories

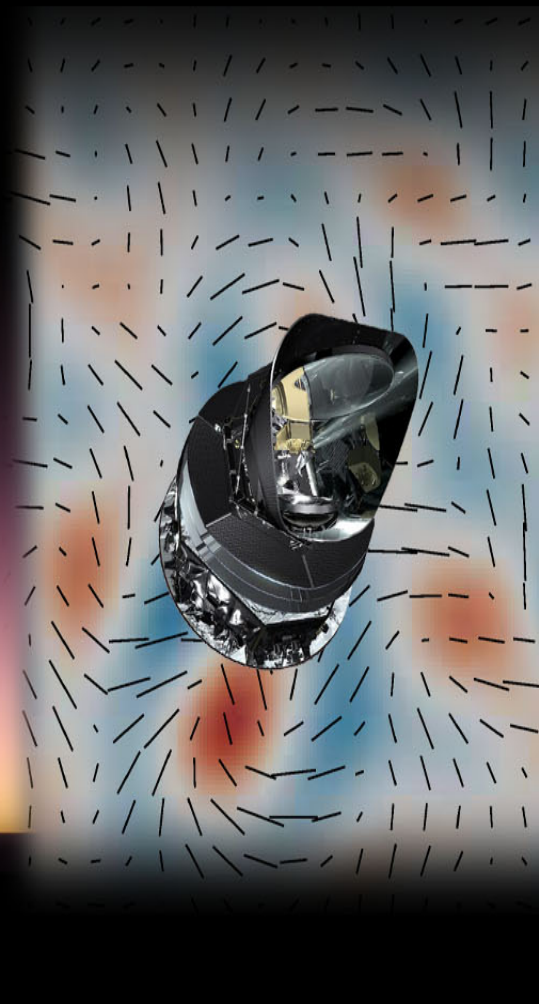
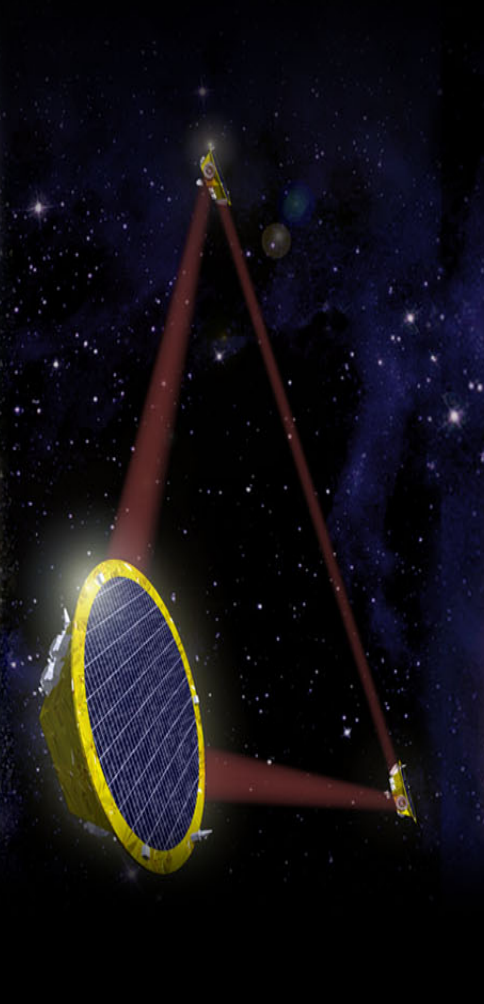
# Gravitational Wave Periods

Milliseconds

Minutes  
to Hours

Years  
to Decades

Billions  
of Years





Thank you!