A visualization of gravitational waves, showing concentric ripples of light and dark blue and purple, emanating from a central dark region. The ripples are more pronounced on the left side, fading towards the right.

LIGO's Detection of Gravitational Waves from Two Black Holes

Gregory Harry

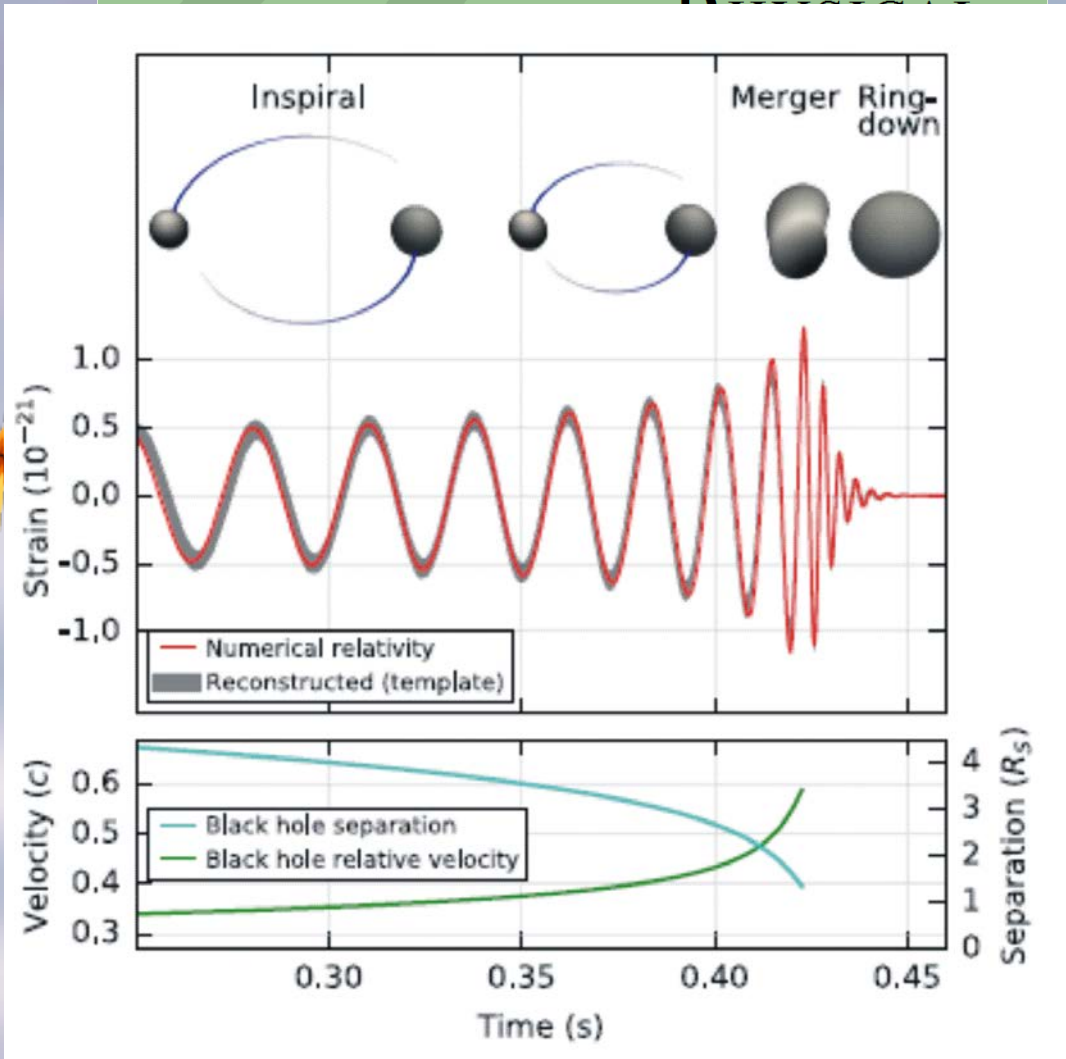
Department of Physics, American University

February 17, 2016



LIGO

GW150914



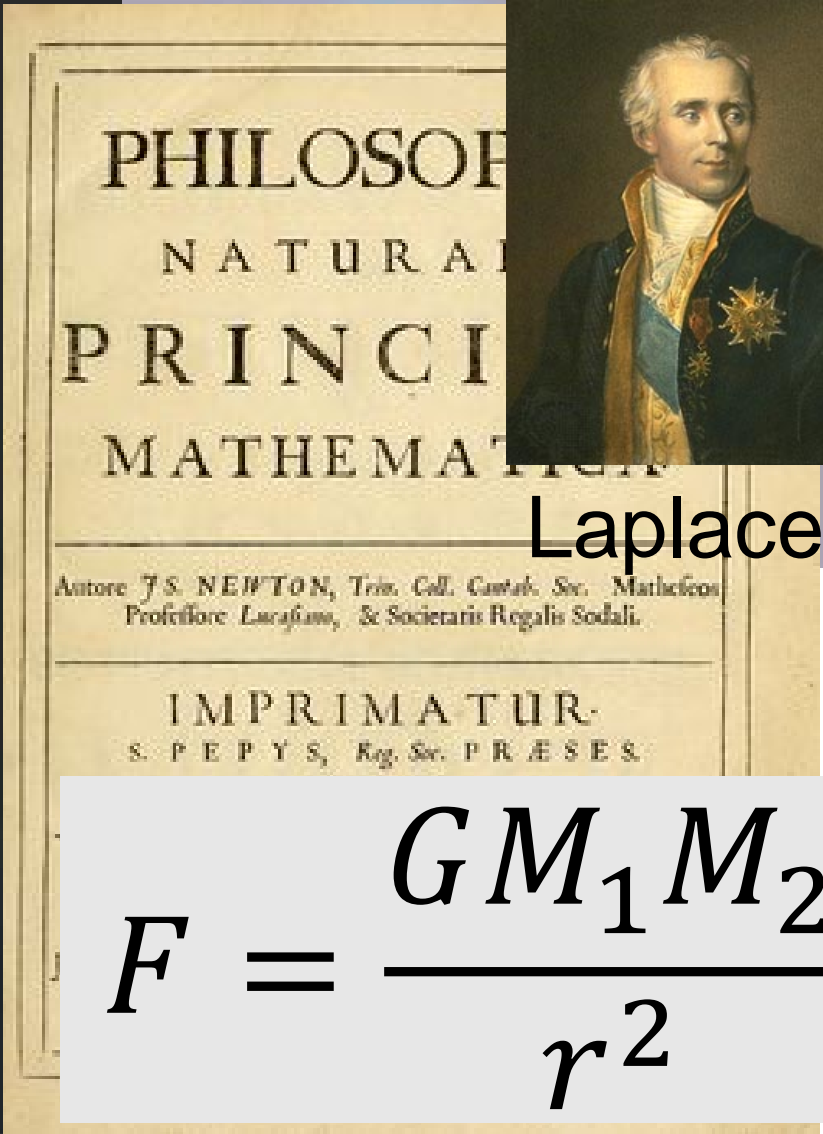


LIGO

Early History of Gravity



Isaac Newton



PHILOSOPHIAE
NATURALIS
PRINCIPIA
MATHEMATICAE

Autore JS. NEWTON, Trin. Coll. Cantab. Soc. Mathematicos
Professore Lucasiano, & Societatis Regalis Sodali.

IMPRIMATUR.
S. PEPYS, Reg. Soc. PRÆSES.



Laplace

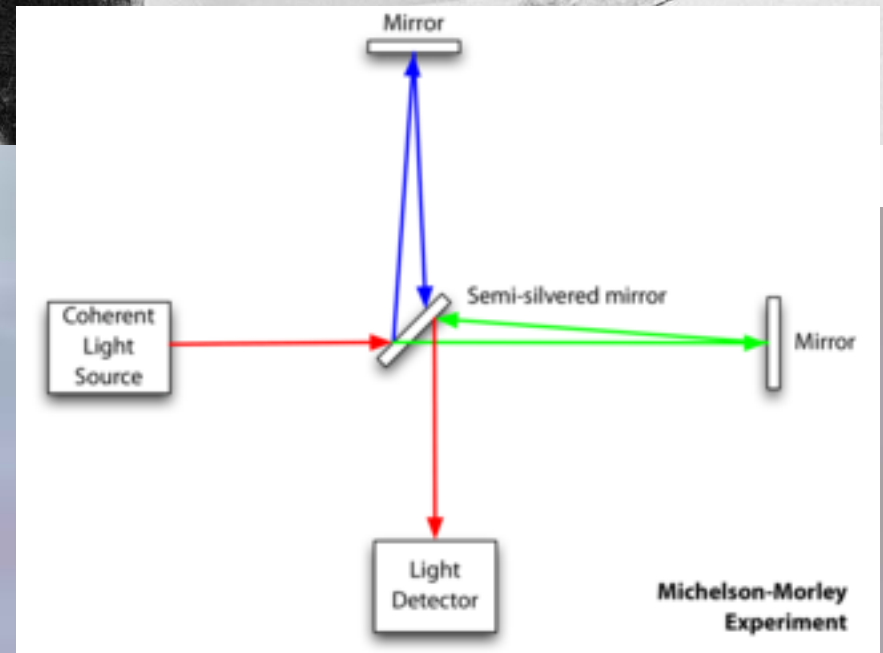
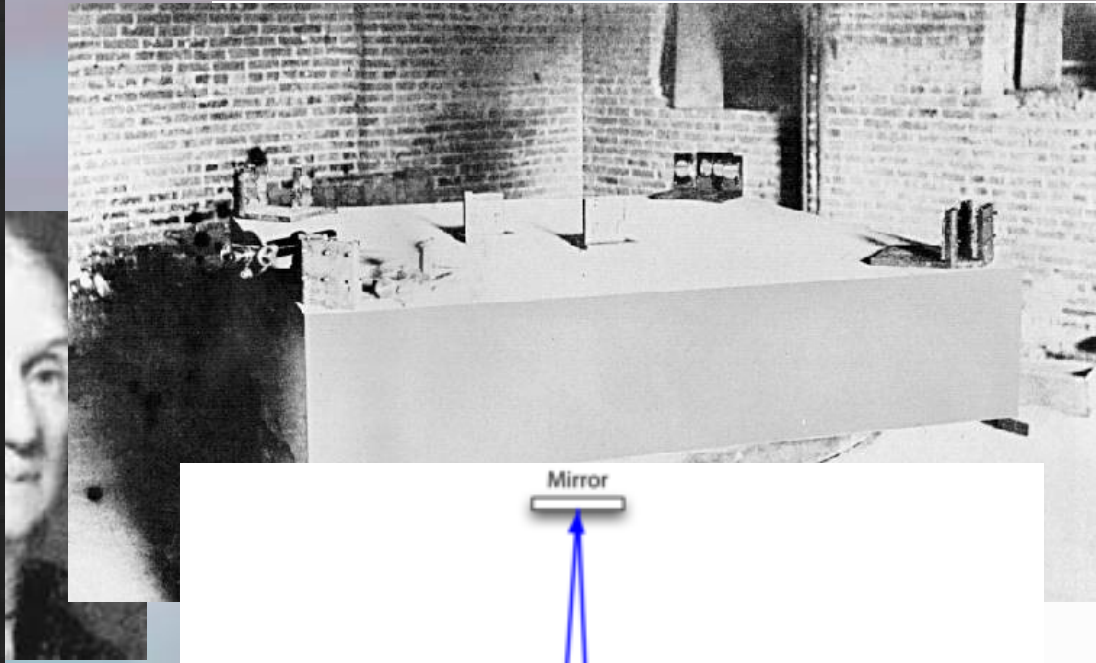
$$F = \frac{GM_1M_2}{r^2}$$



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19th Century History of Gravity

Albert Michelson





20th Century History of Gravity (General)

Albert Einstein



844 Sitzung der physikalisch-mathematischen Klasse vom 25. November 1915

1915

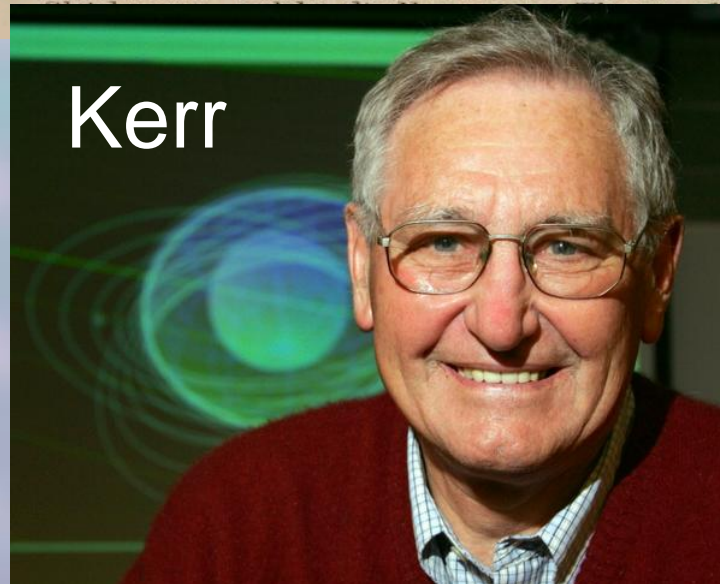
Die Feldgleichungen der Gravitation.

VON A. EINSTEIN.

In zwei vor kurzem erschienenen Mitteilungen¹ habe ich gezeigt, wie man zu Feldgleichungen der Gravitation gelangen kann, die dem Postulat allgemeiner Relativität entsprechen, d. h. die in ihrer allgemeinen Fassung beliebigen Substitutionen der Raumzeitvariablen gegenüber kovariant sind.

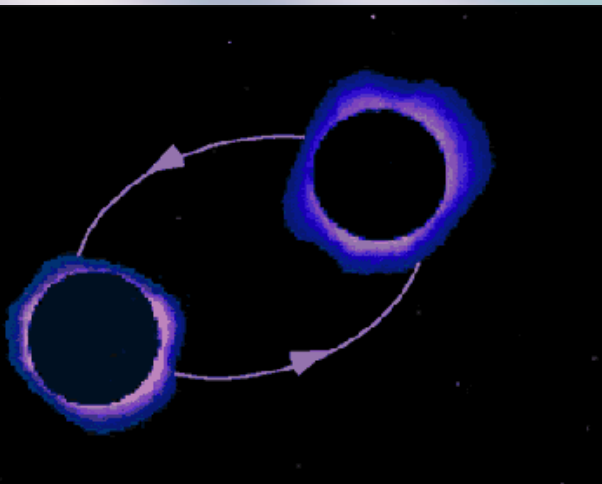
Der Entwicklungsgang war dabei folgender. Zunächst fand ich Näherung enthalten

Kerr



Black Holes

- Stars with escape velocity $> c$ can form
- Called **Black Holes**
- High mass, high density
- Two black holes are a good source of gravitational waves



- Know black holes exist
- Unknown whether black holes form in pairs ???
- Unknown what mass range black holes can have ???



20th Century History of Gravitational Waves



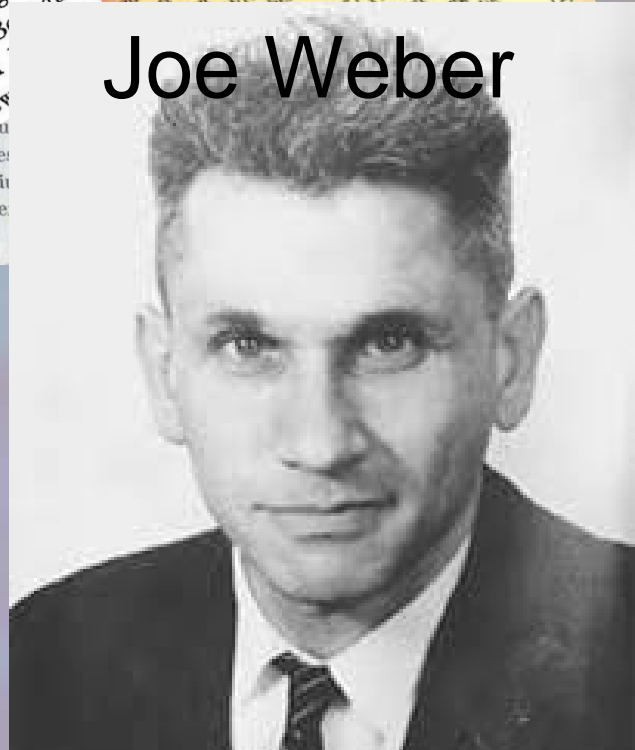
Noise
...er molekularkinetischen Theorie
...derte Bewegung von in ruhenden
...iten suspendierten Teilchen;
... von A. Einstein.

...er Arbeit soll gezeigt werden, daß nach der molekular-
... Theorie der Wärme in Flüssigkeiten suspendierte Grö-
... on mikroskopisch sichtbarer Größen
... wegung der Wärme Bewegungen
... wesen müssen, daß diese Be-
... oskop nachgewiesen werden
... hier zu behandelnden Be-
... atete zeiträu-
... ar wenig unte-

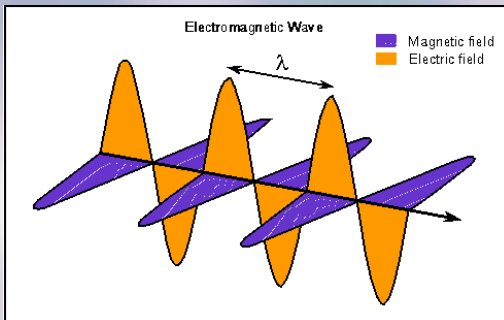
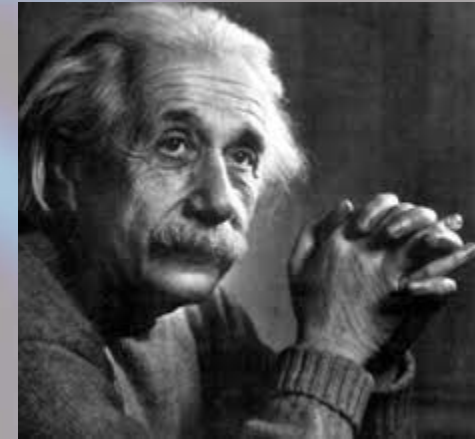
Mitteilung vom 31. Januar

Zur Quantentheorie der Strahlung.
Von A. Einstein¹⁾.
Die formale Ähnlichkeit der Kurve der chroma-
tischen Verteilung der Temperaturstrahlung
mit Maxwell'schen Geschwindigkeits-Verteilungsa-
bleiben können. In der Tat wurde
in der wichtigen theoretischen
er sein Verschiebungsgrenz
(1)
(2)

Joe Weber

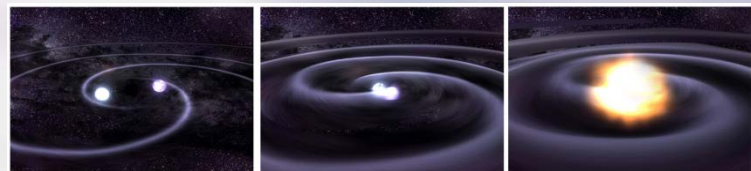


- Einstein's theory of gravity is called the General Theory of Relativity
- Gravity can not travel faster than the speed of light



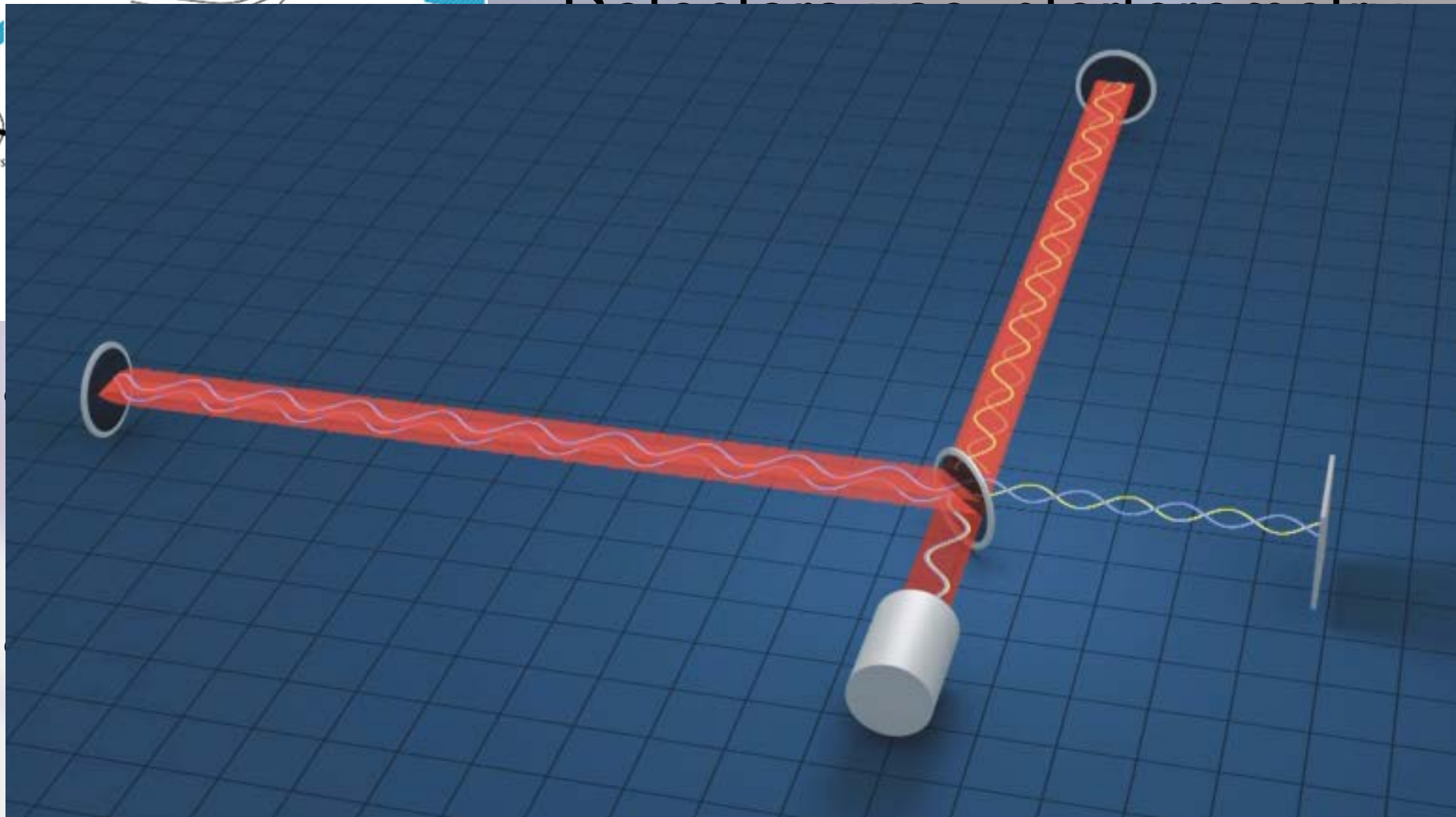
- Predicts waves of gravity
- Similar to waves in electric and magnetic fields
- Much smaller amplitude

– Strain $\frac{\Delta L}{L} \cong 10^{-22}$



LIGO

LIGO Interferometers

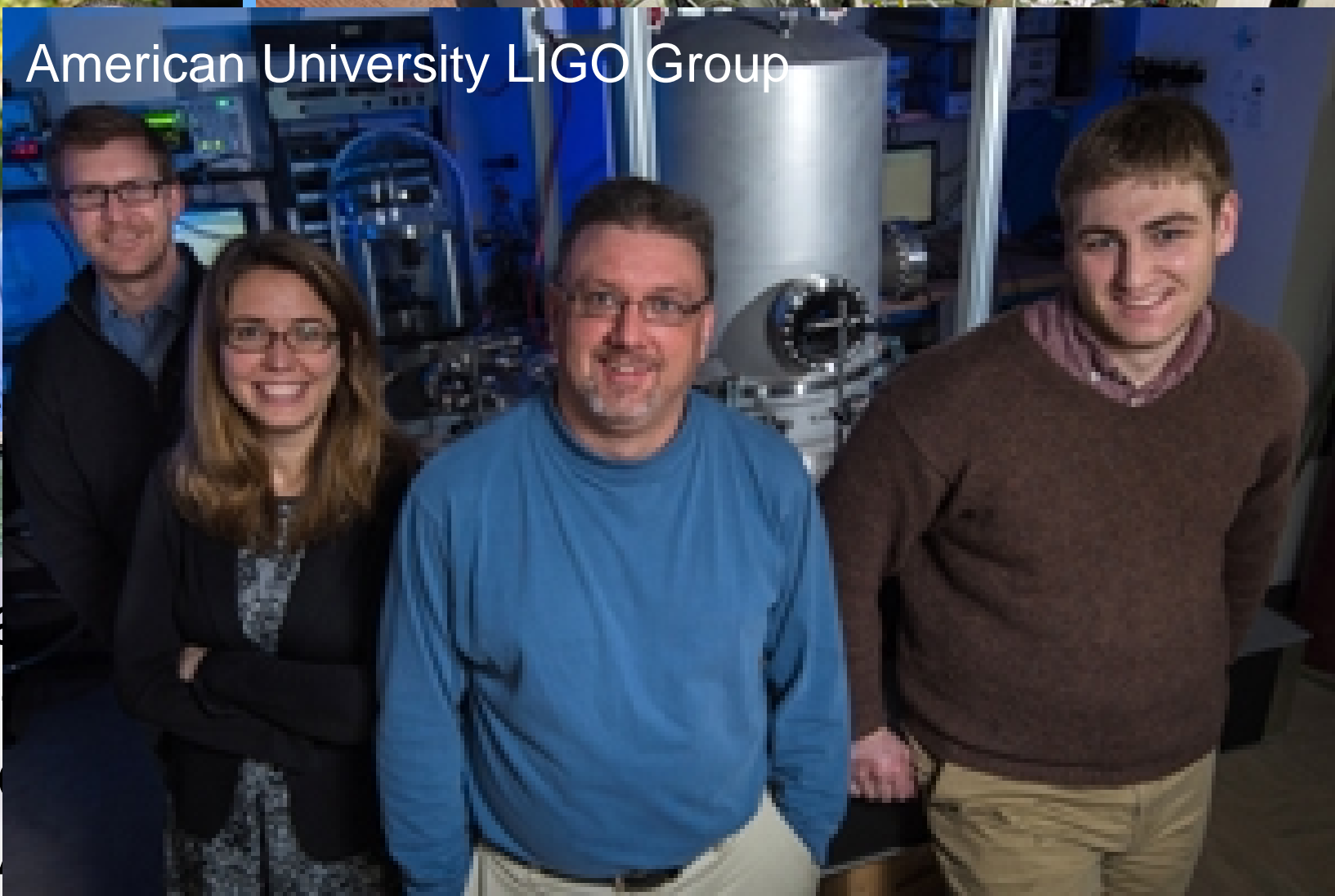


- Low seismic noise environment



My History with Gravitational Waves

American University LIGO Group



roup



Ho Sang Paik

Pe

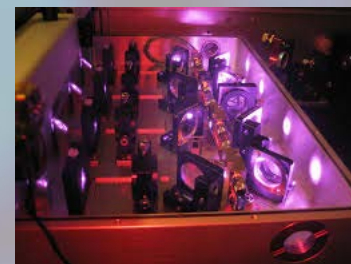
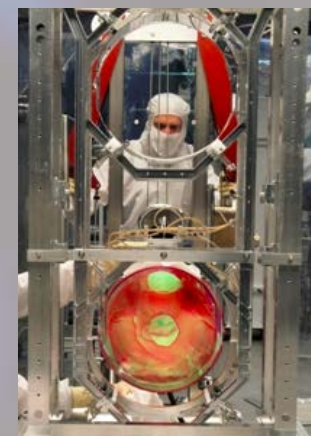
Ca

-
-
-

Advanced LIGO

- Improved Detectors

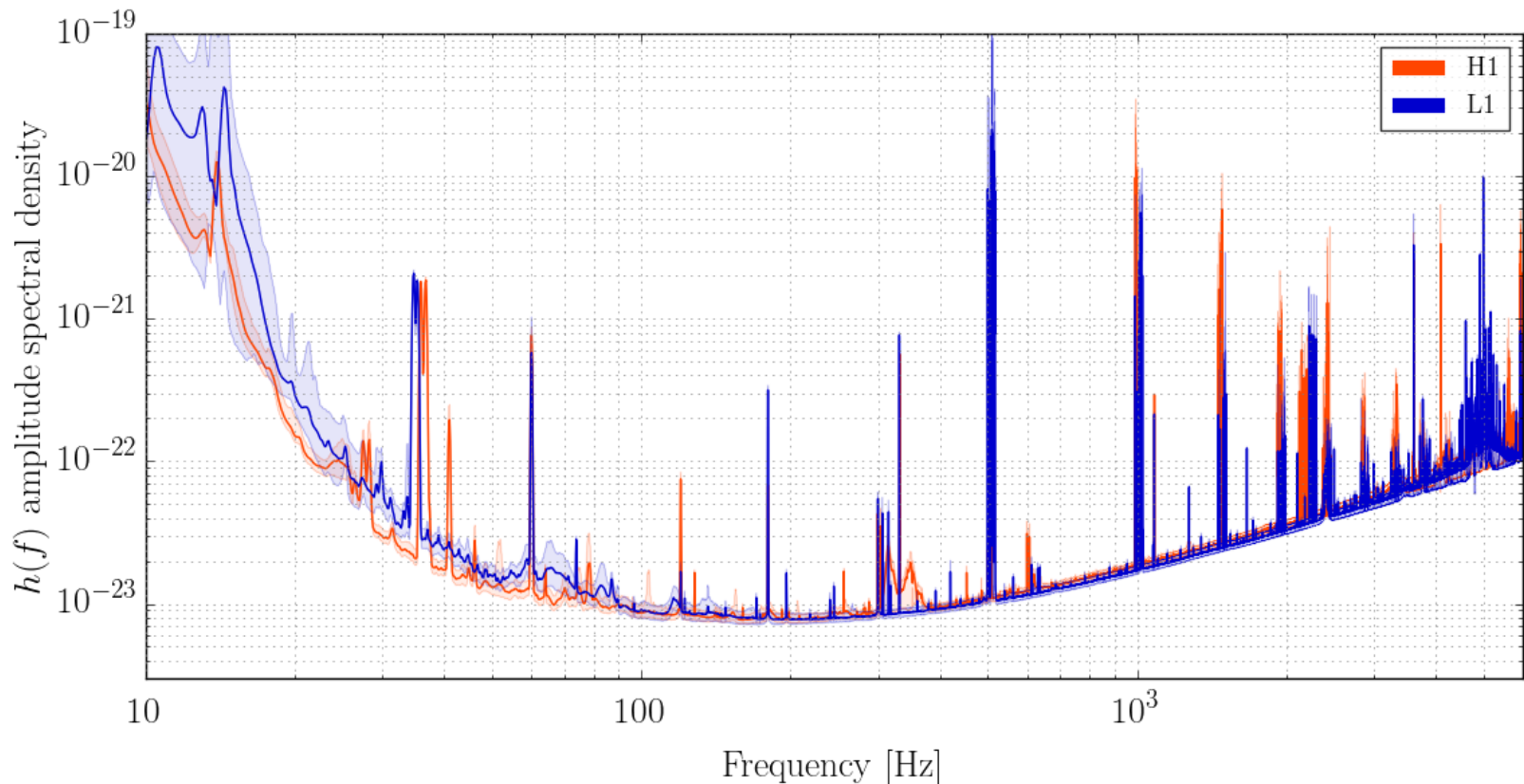
- Active seismic isolation
- Wider frequency range (10 Hz)
- Higher power laser (180 W)
- Larger mirrors (40 kg)
- Additional mirror to enhance signal



- Data taking at intermediate sensitivity from Aug 2015 – Jan 2016
- First detection September 2015
- Currently improving sensitivity for further observations late 2015

Advanced LIGO Sensitivity

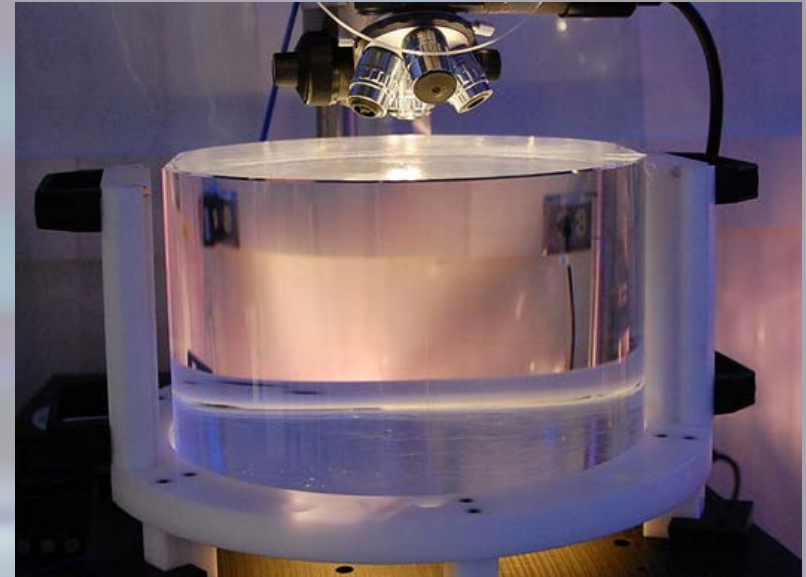
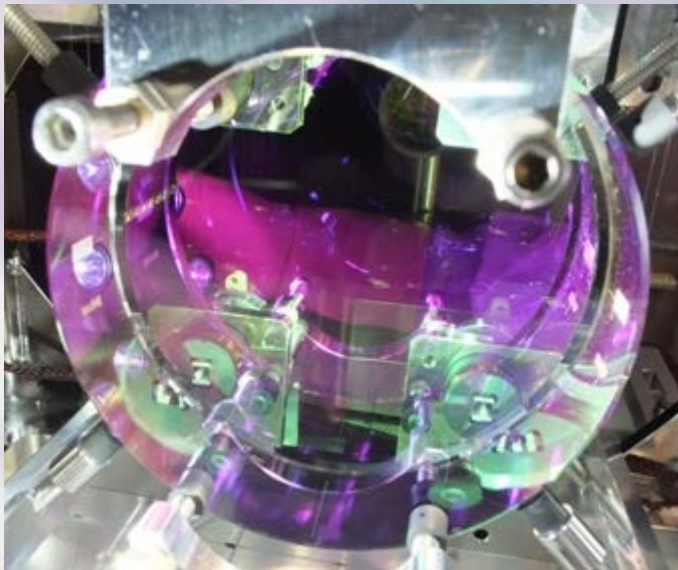
Limited by Earth motion, thermal motion, and quantum mechanics





Advanced LIGO Mirrors and Coatings

- Fused silica optics
 - 40 kilograms
 - Very low absorption
 - Continuous connection to suspension

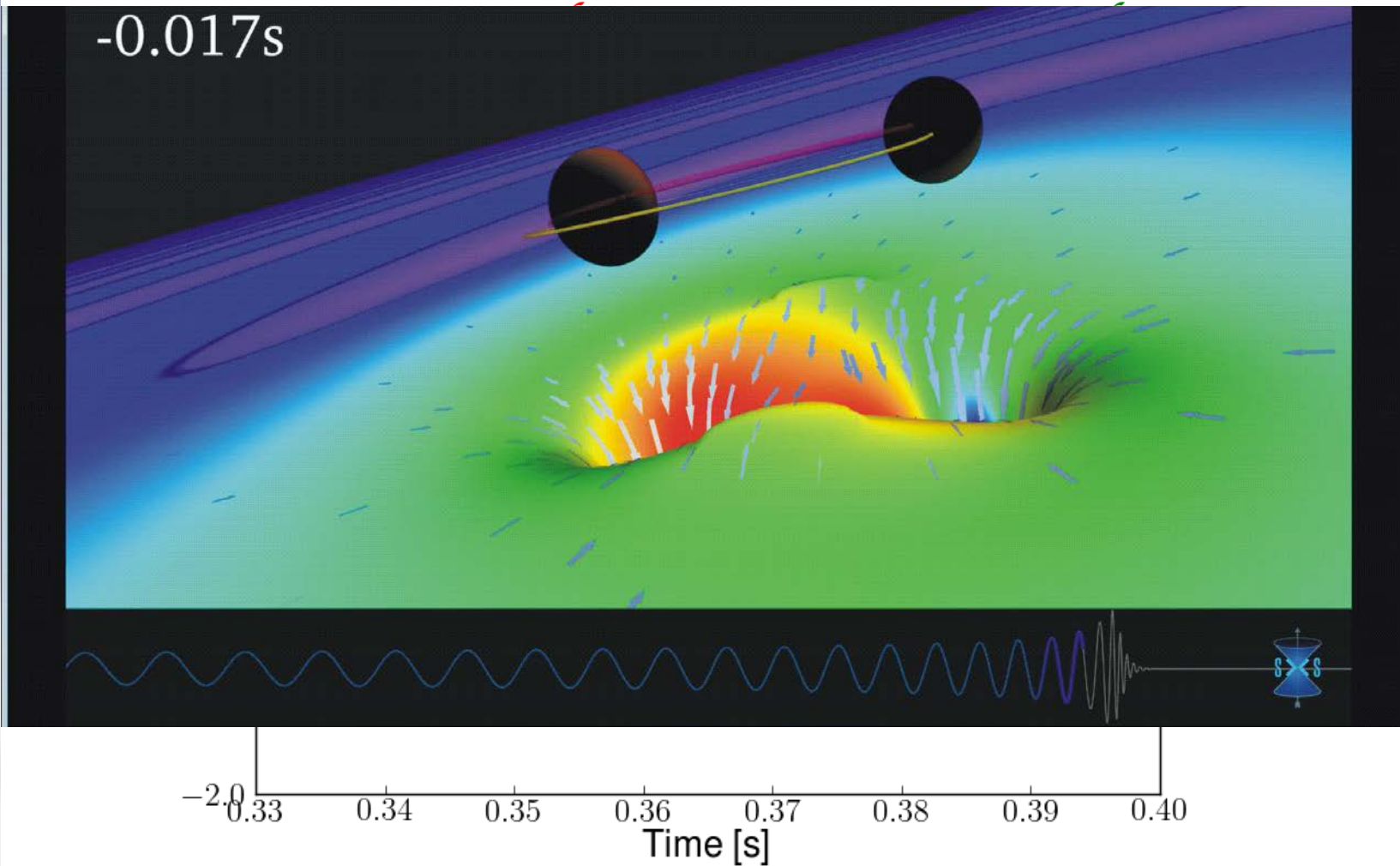


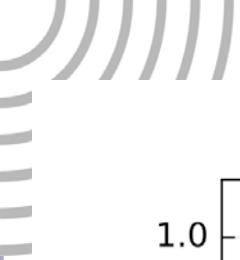
- Optical coatings
 - Reflect light
 - Form resonance cavity
 - Very low absorption
 - Low thermal noise



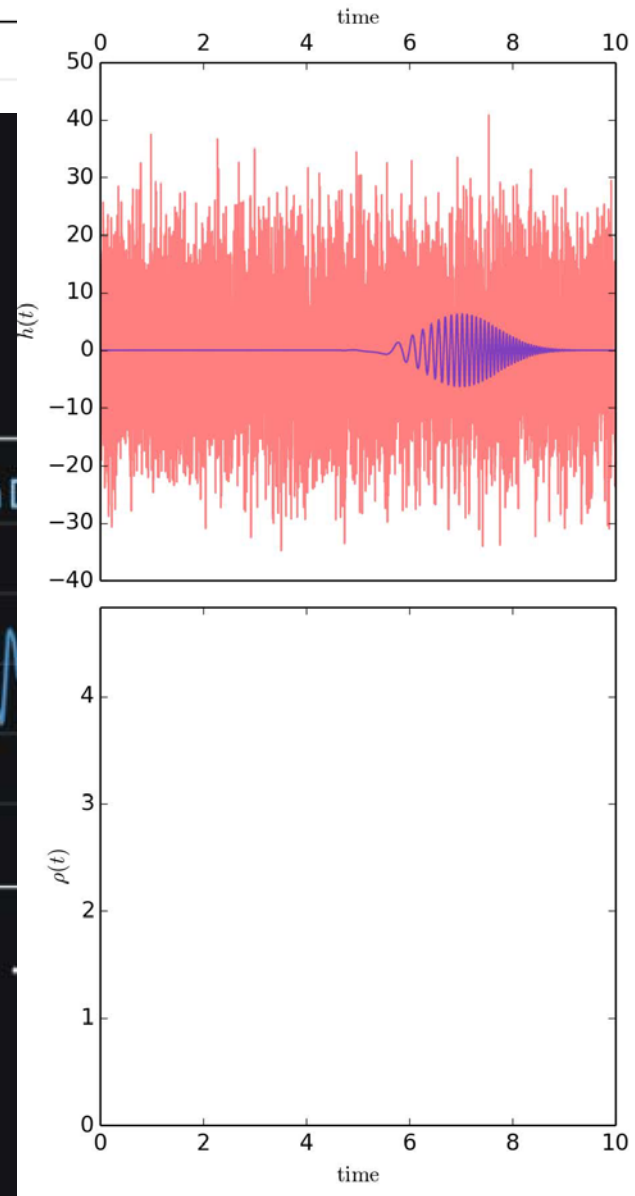
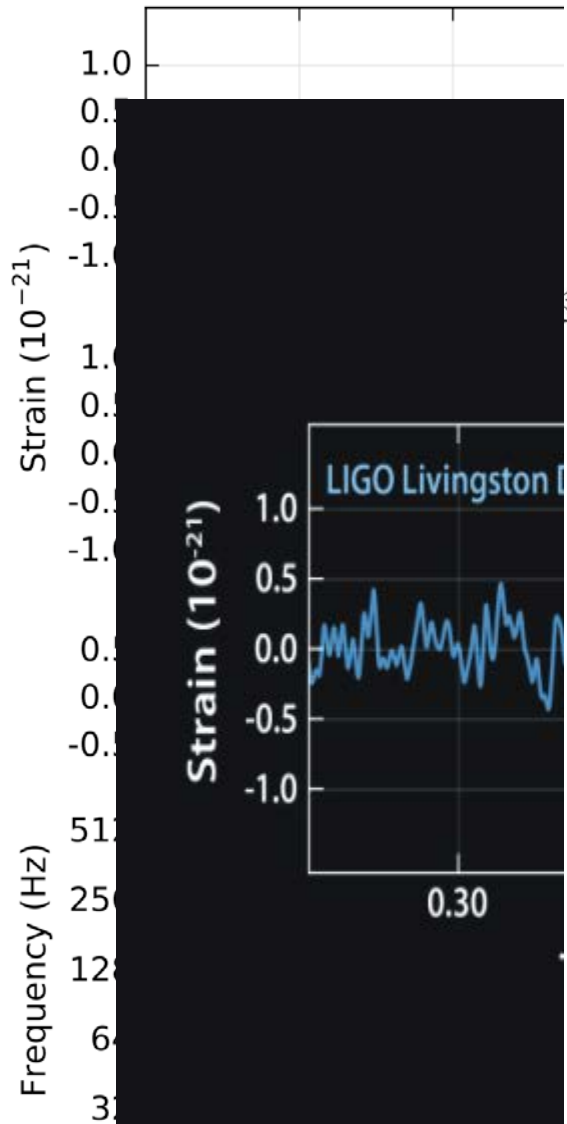
LIGO

Gravitational Waveform from Binary Black Hole Inspiral

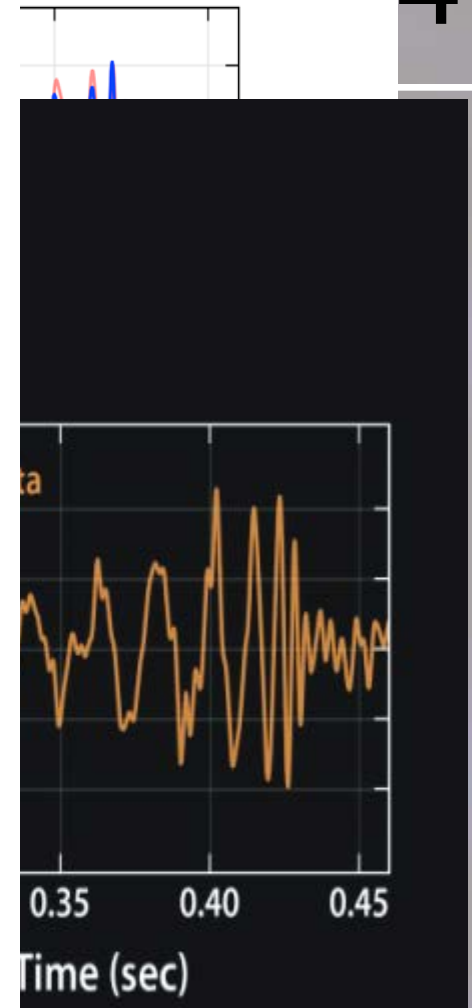




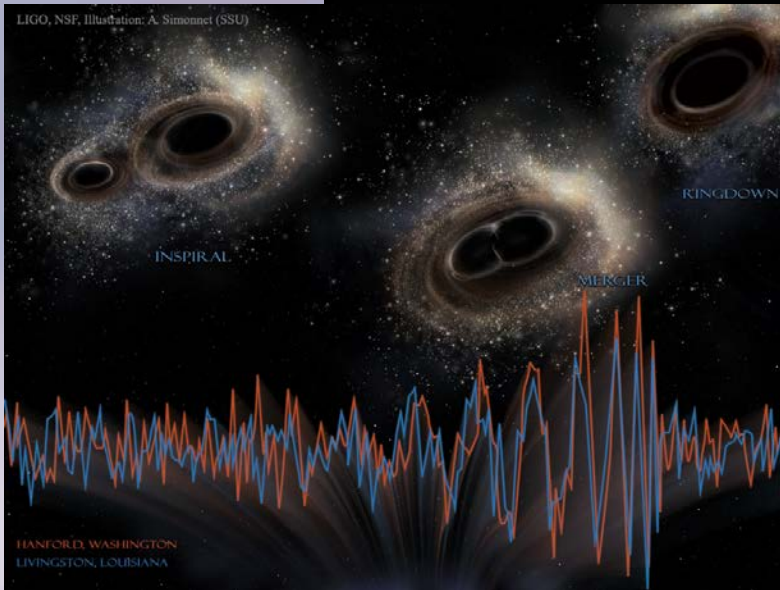
Hanford, Washingt



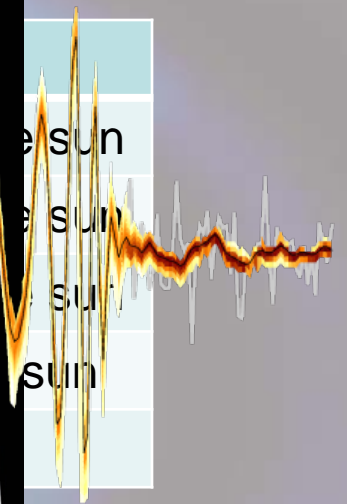
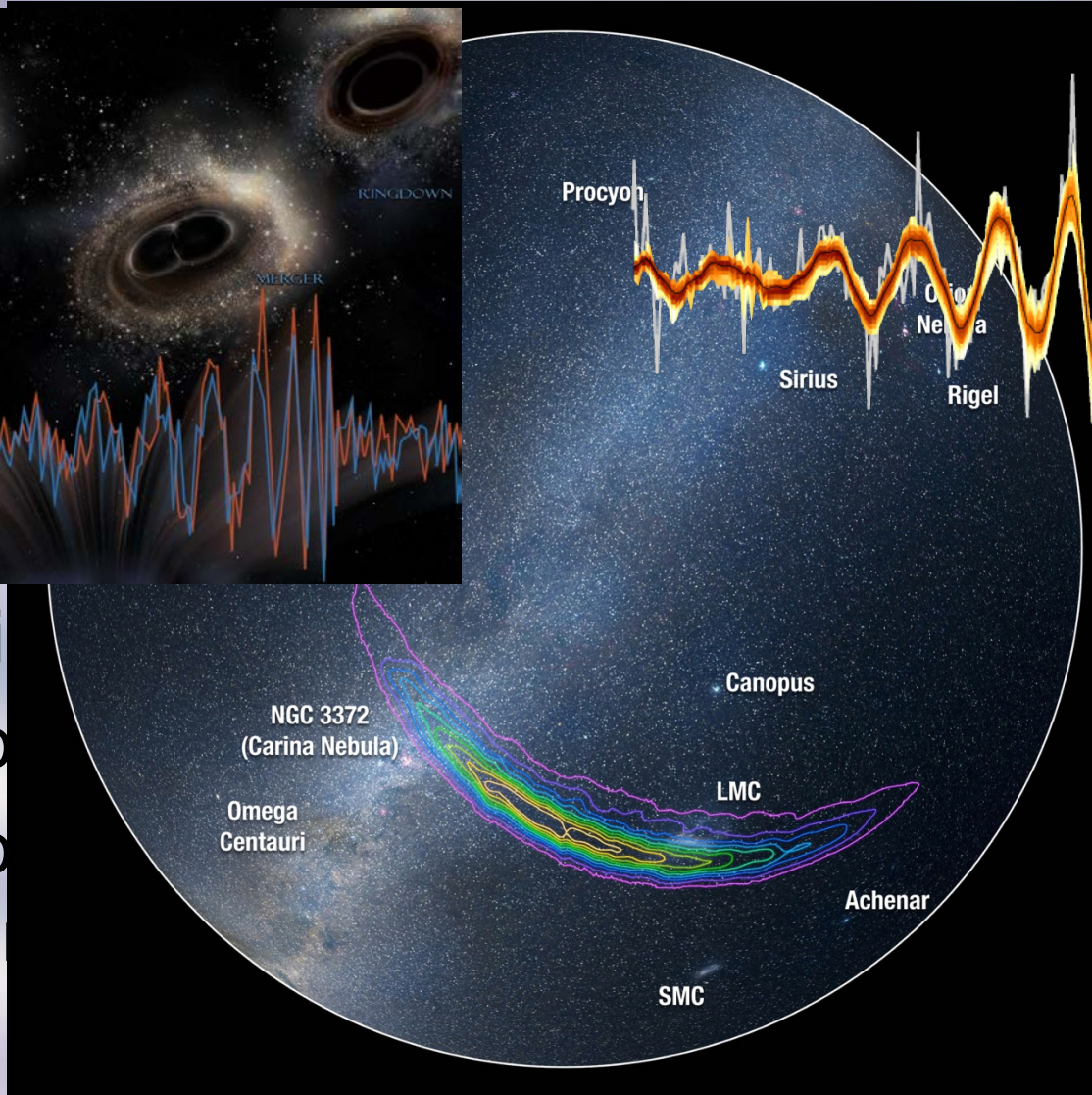
ra (L1)



Three Discoveries



- Gravitational waves
- Black holes
- Black holes collide and merge



Einstein

10 solar mass

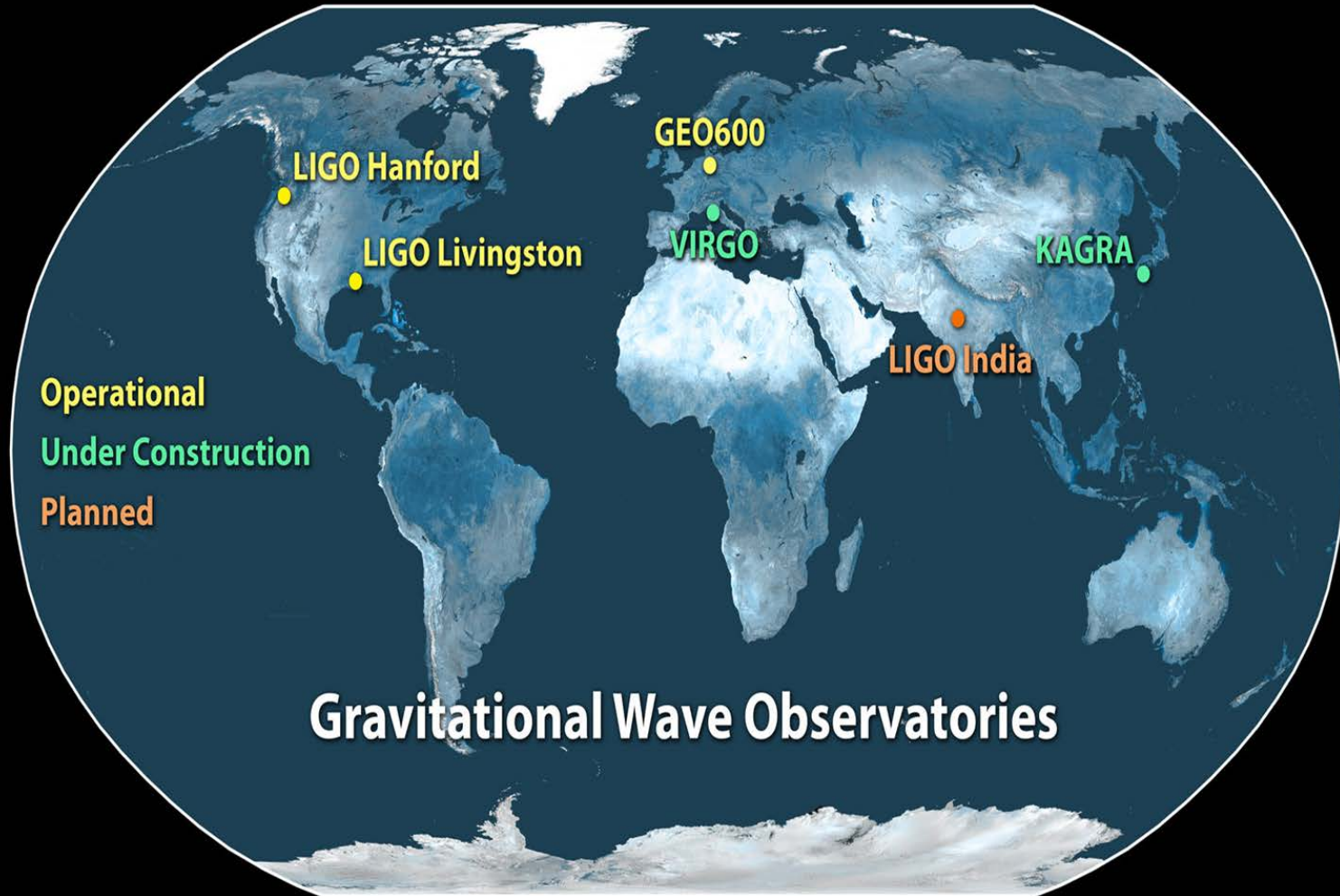
eventually

black hole



LIGO

International Network



Future Hopes and Plans

- Form International Network

- Virgo in Europe
- KAGRA in Japan

- LIGO India

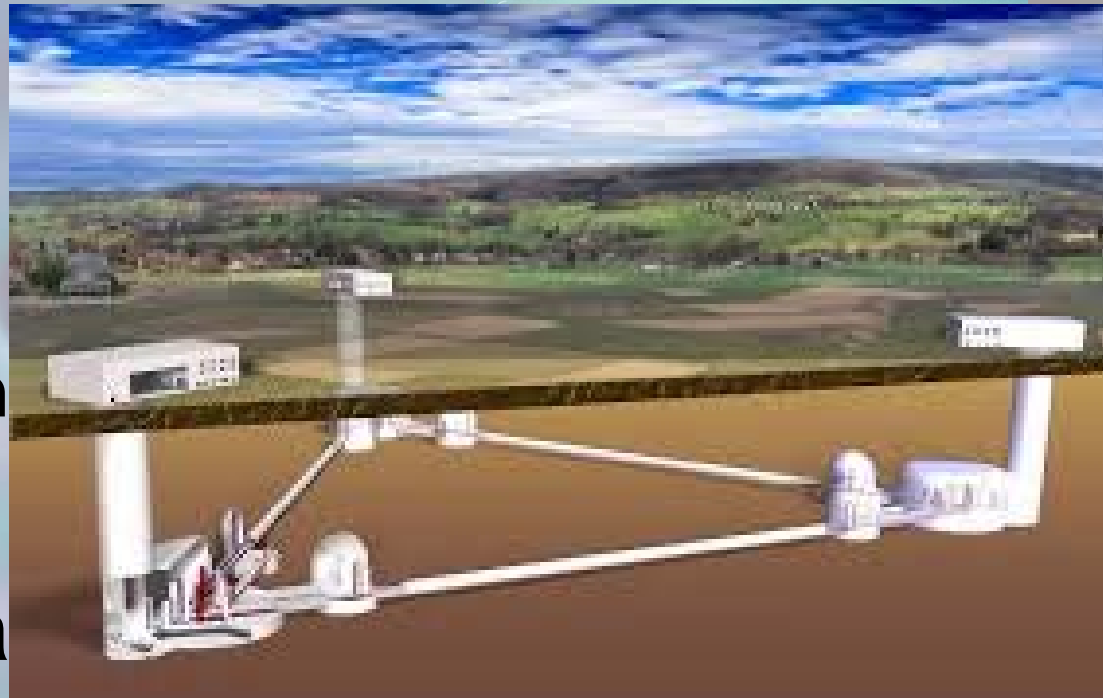
- Tweet from Indian

- LISA - Space

- Upgrades to Advanced

- Squeezing, optics, seismic noise cancellation

- Einstein Telescope



LIGO

LIGO at AU



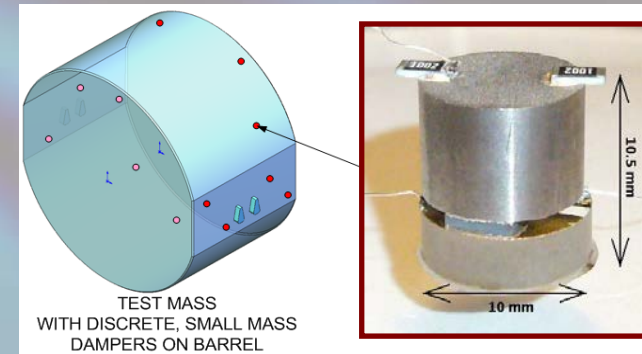
AU LIGO Lab Summer 2013

- Next generation of scientists
- Train students to enter field

AU LIGO Contributions

Advanced LIGO

- Titania/tantala coatings
- Epoxies to minimize noise for optics retrofit
- Addressed optics storage concern for LIGO/India
- Continual optics monitor



Organizational

- Optics chair, Coating cognizant scientist
- Academic affairs, political outreach

Future detectors

- Crystalline AlGaAs coatings
- Thermal noise in different directions

