LIGO's Detection of Gravitational Waves from Two Black Holes

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LIGO

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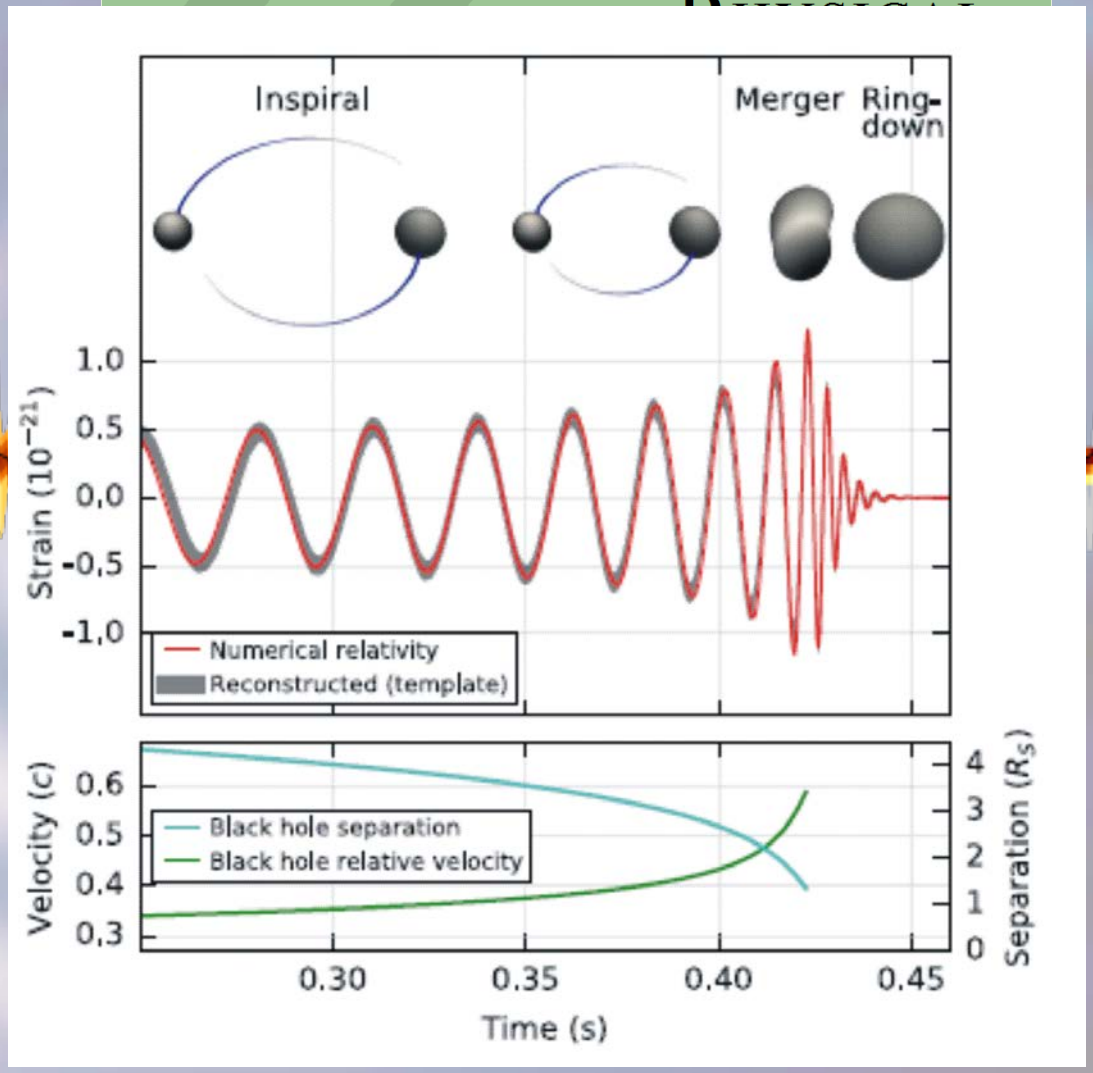
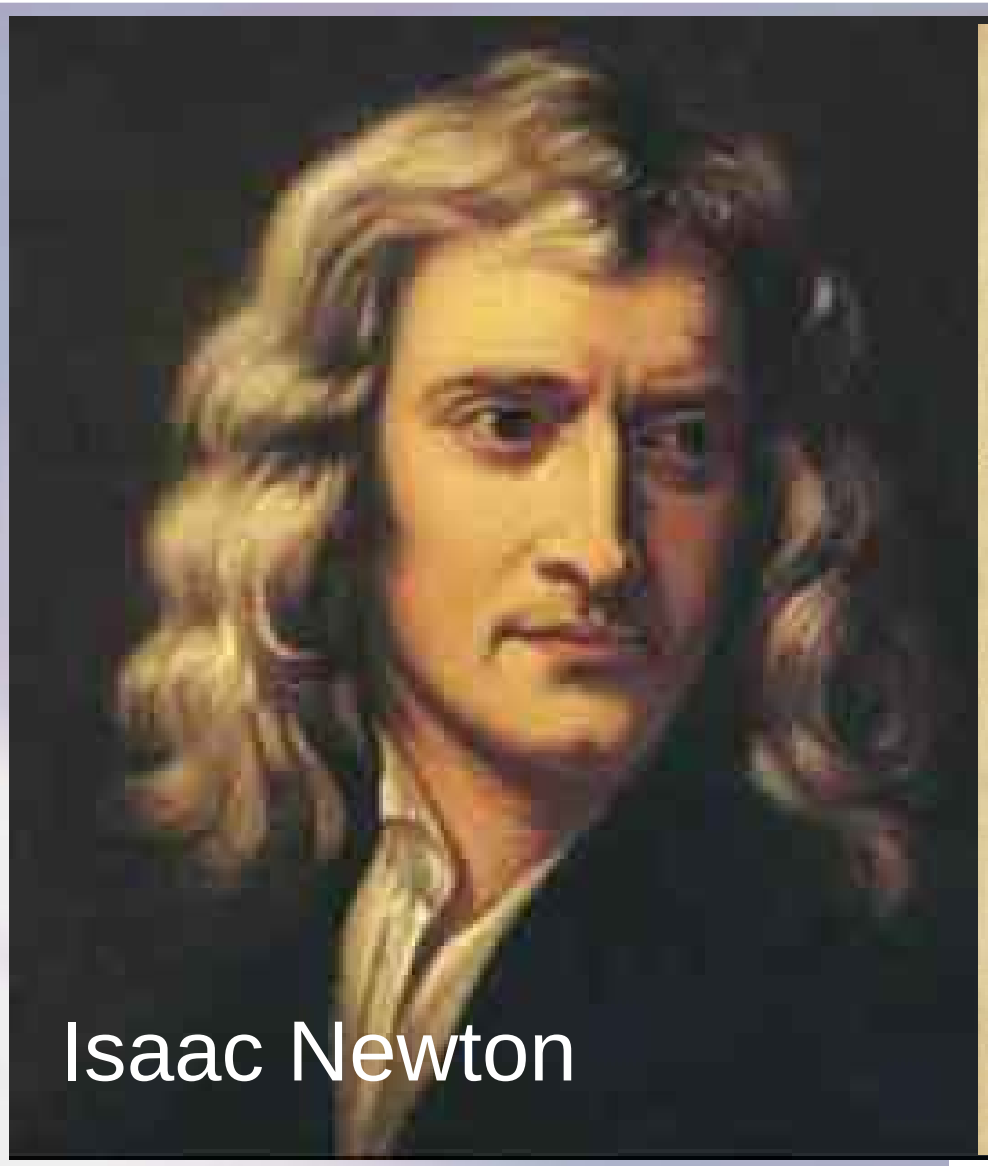
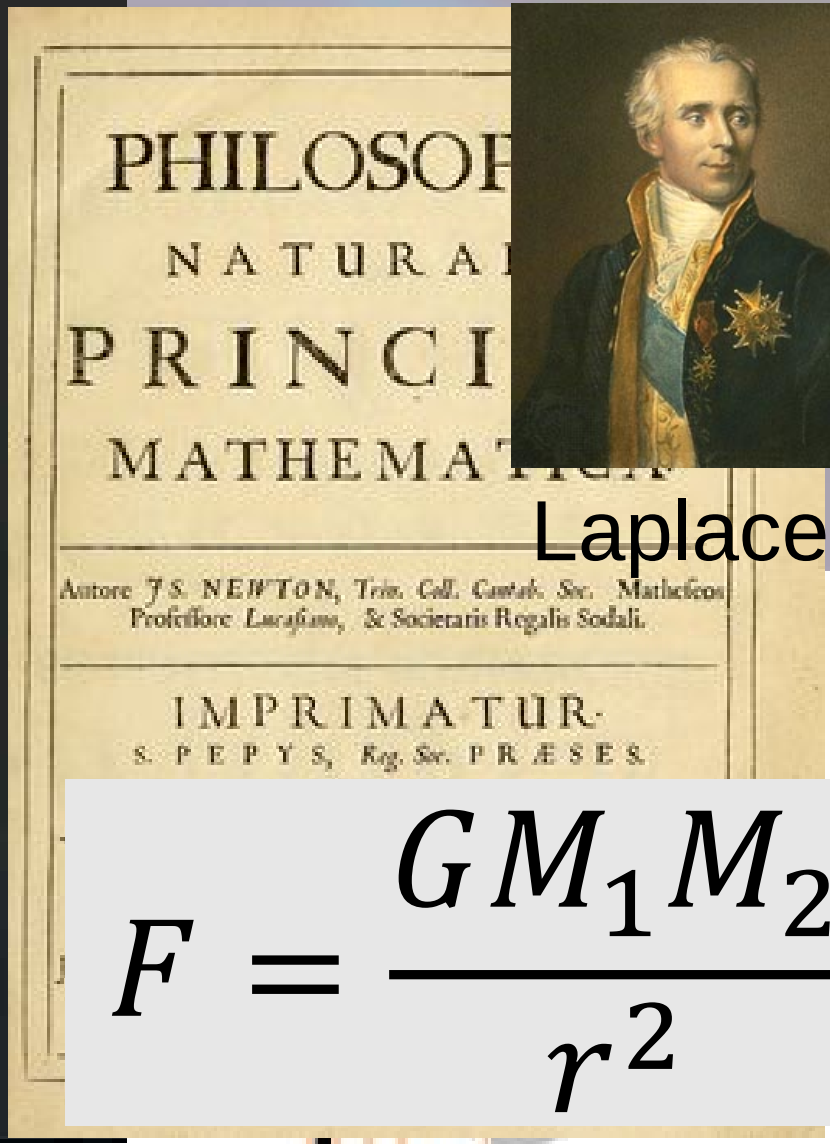


LIGO

Early History of Gravity



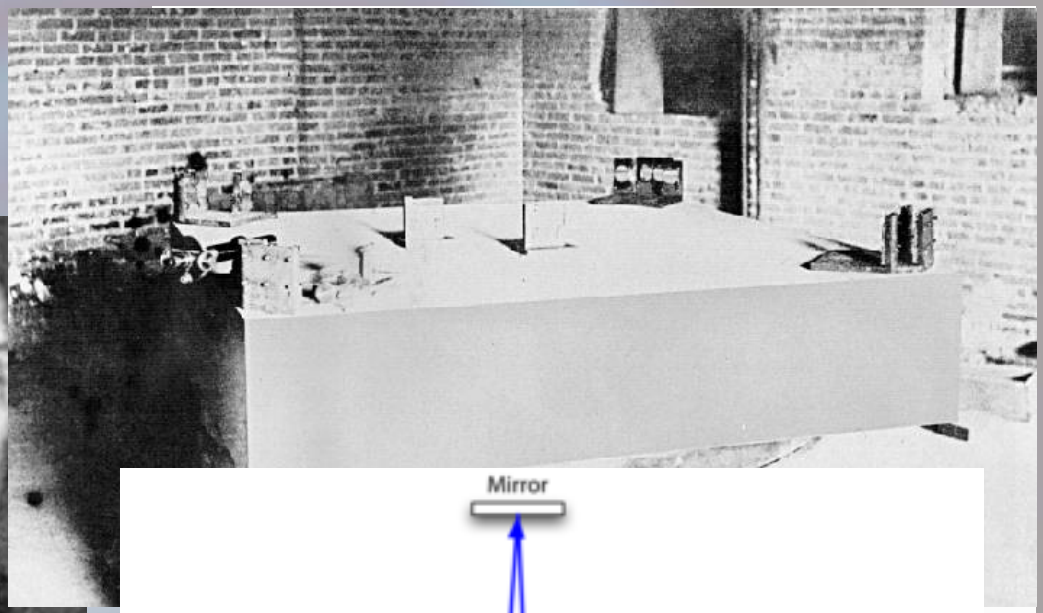
Isaac Newton

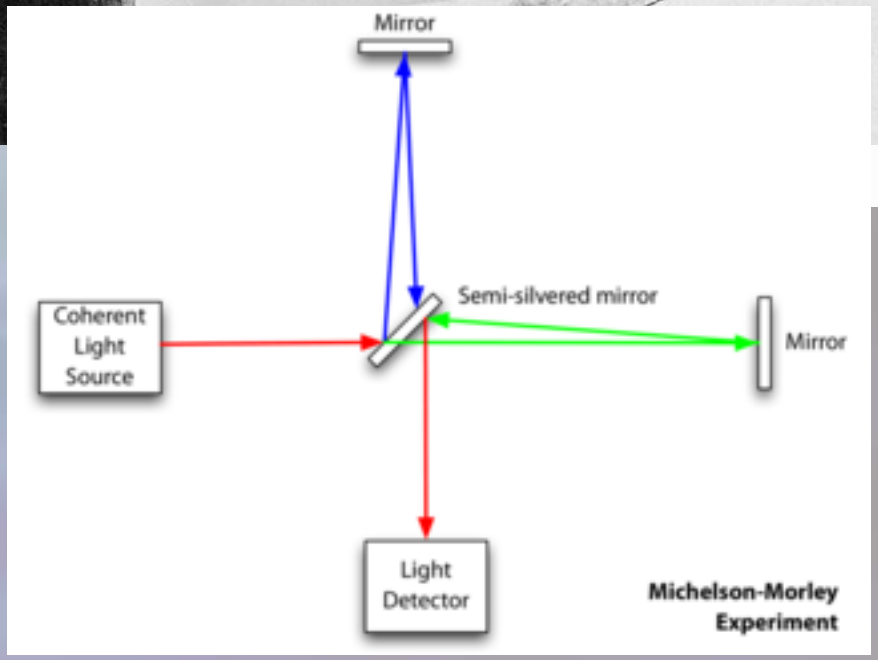


Laplace

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

19th Century History of Gravity





20th Century History of Gravity (General)

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

1915

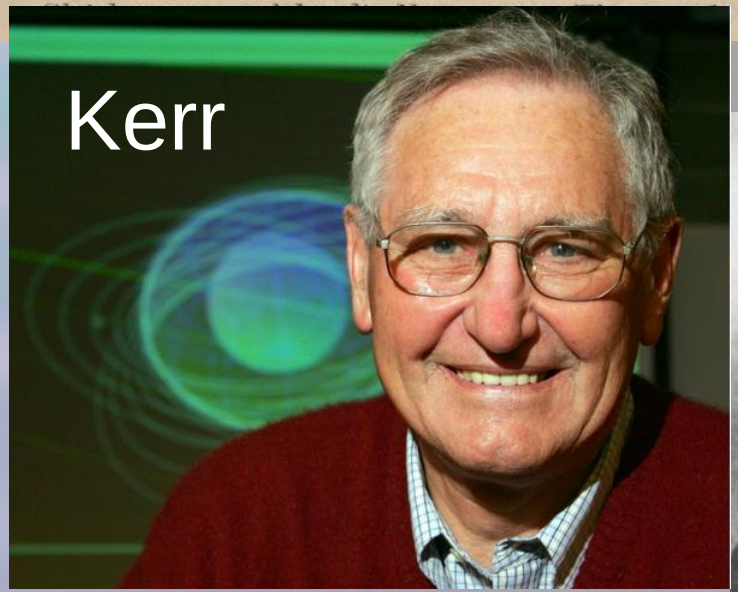
Die Feldgleichungen der Gravitation.

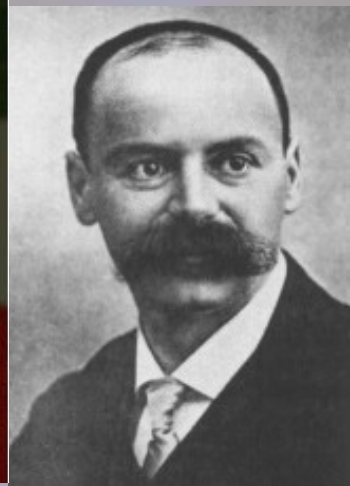
Von A. Einstein.

In zwei vor kurzem erschienenen Mitteilungen[1] 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 Raumzeitvariabeln gegenüber kovariant sind.

Der Entwicklungsgang war dabei folgender. Zunächst fand ich

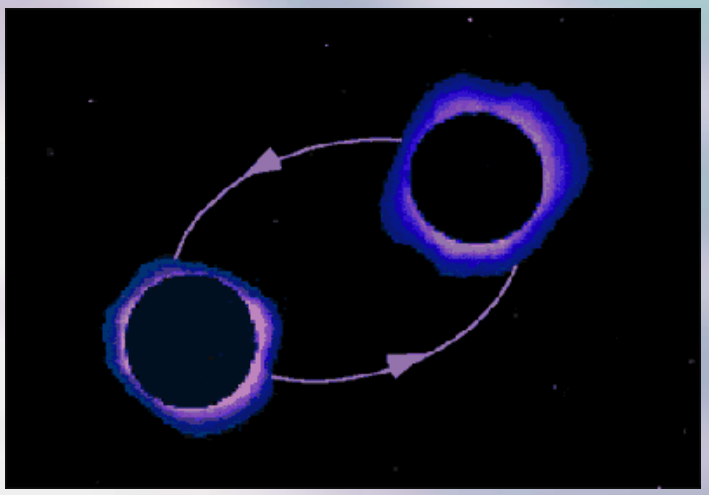
Näherung enthalten





Black Holes

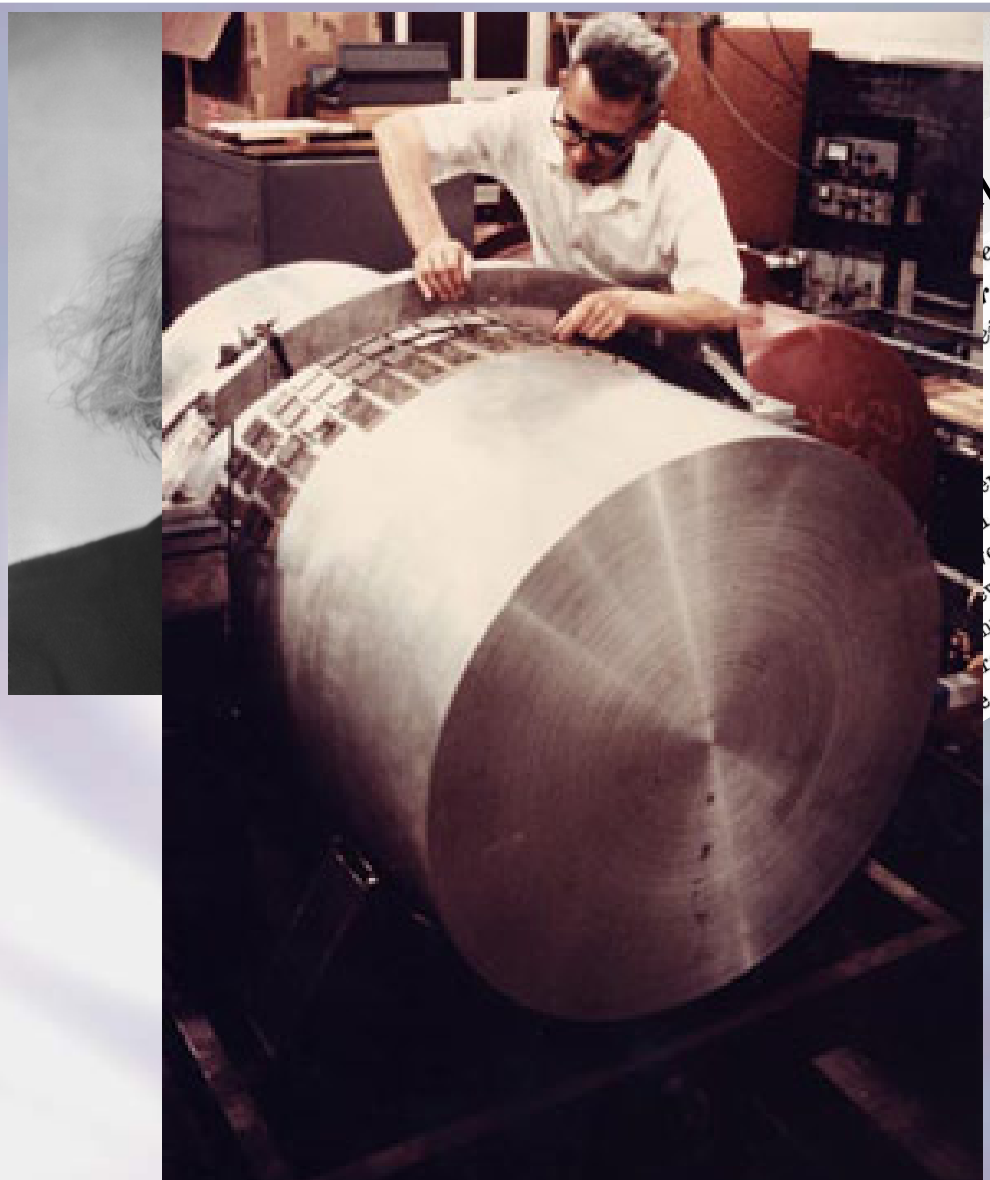
- Stars with escape velocity $> c$ can form
- Called **Black Holes**
- High mass, high density
- Two black holes are a good source of gravitational waves

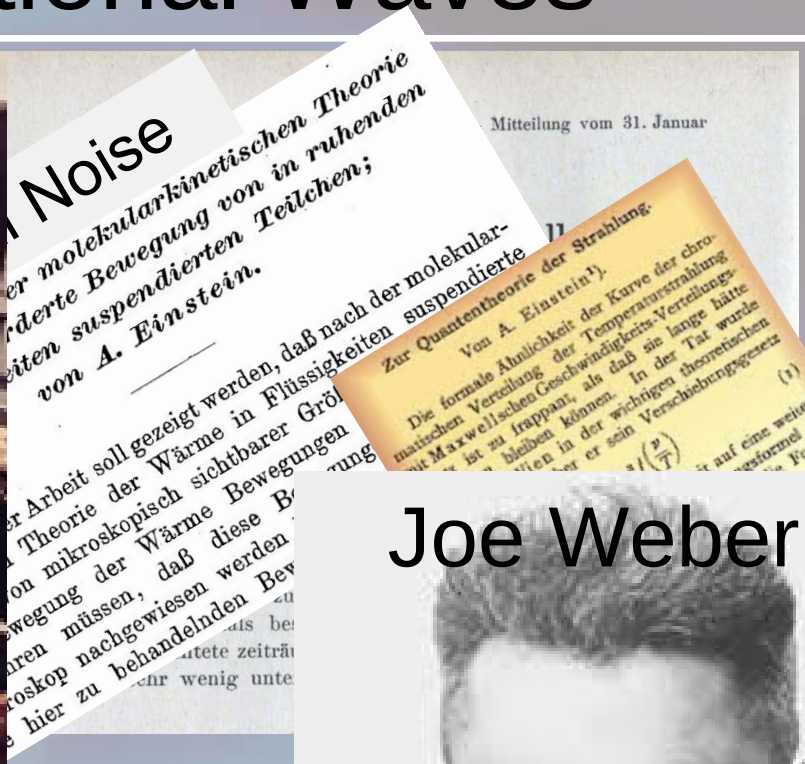


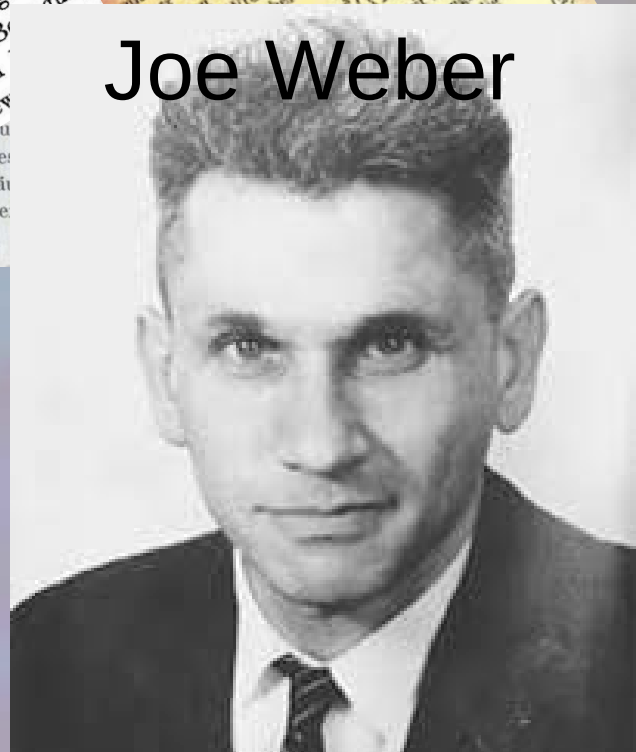
- Know black holes exist
- Unknown whether black holes form in pairs ???
- Unknown what mass range black holes can have ???

LIGO

20th Century History of Gravitational Waves



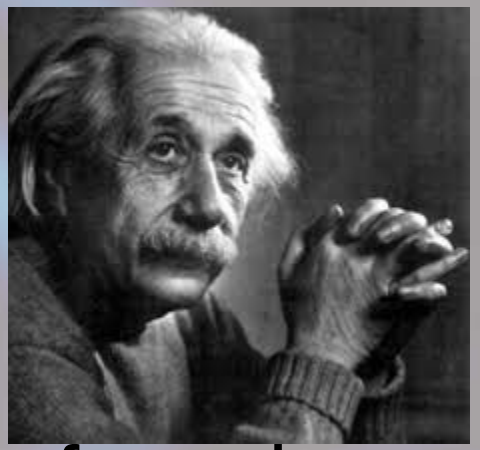


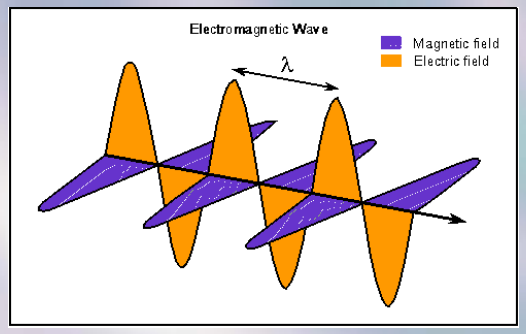


Joe Weber

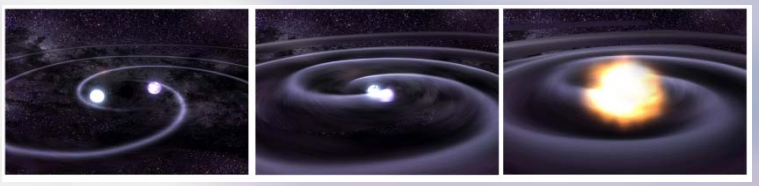
Gravitational Waves

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



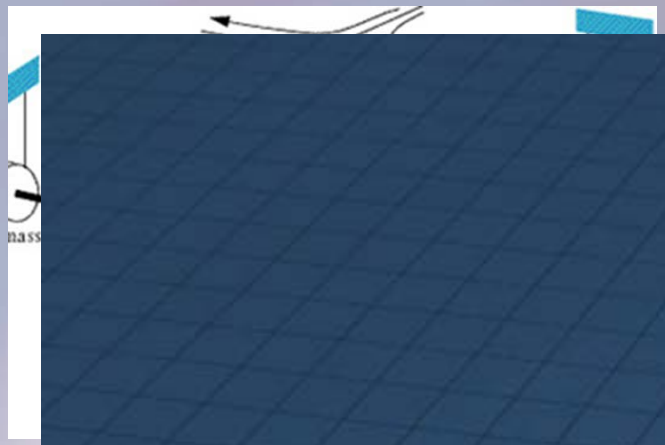


- Predicts waves of gravity
- Similar to waves in electric and magnetic fields
- Much smaller amplitude
  - Strain $\frac{\Delta L}{L} \cong 10^{-22}$



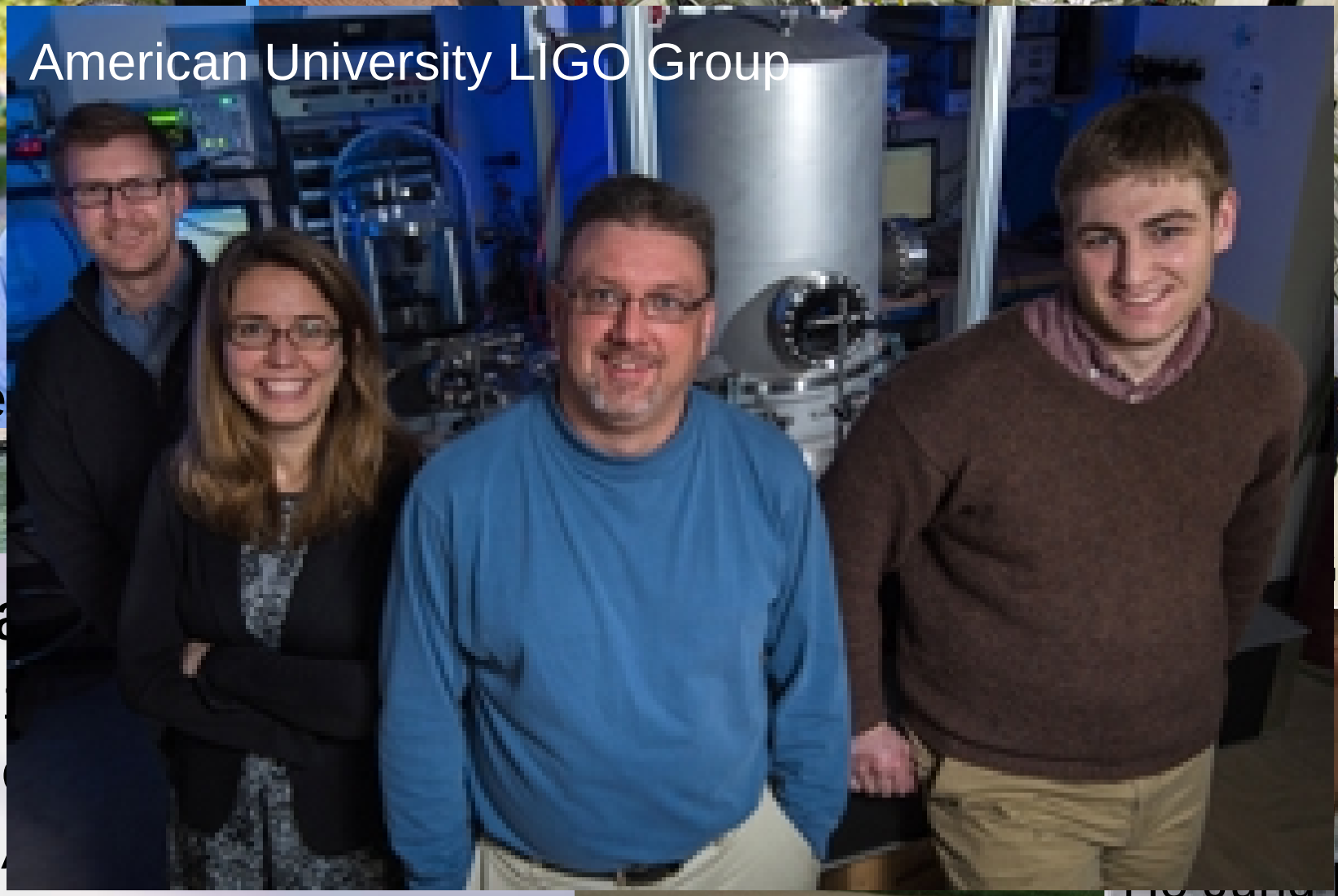
LIGO Scientific Collaboration

LIGO Interferometers



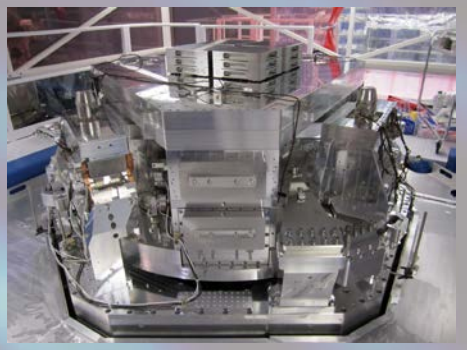
– Low seismic noise environment

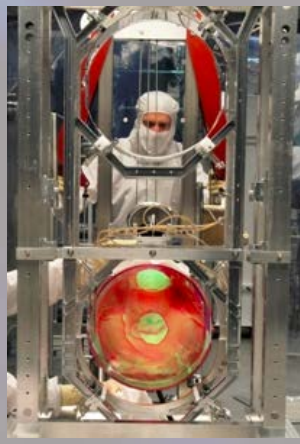
My History with Gravitational Waves



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

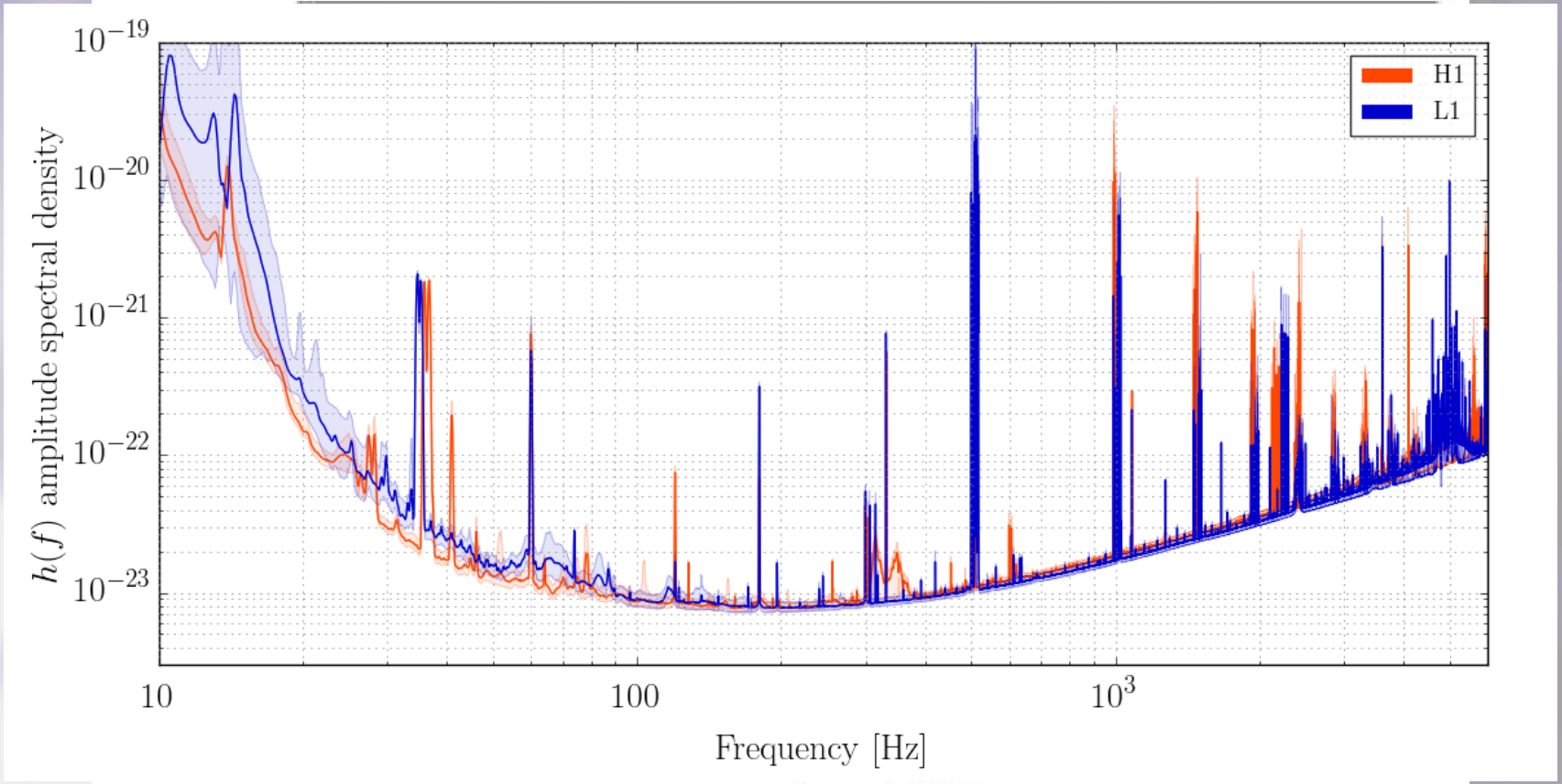




- Data taking at intermediate sensitivity from Aug 2015 – Jan 2016
- First detection September 2015
- Currently improving sensitivity for further observations late 2015

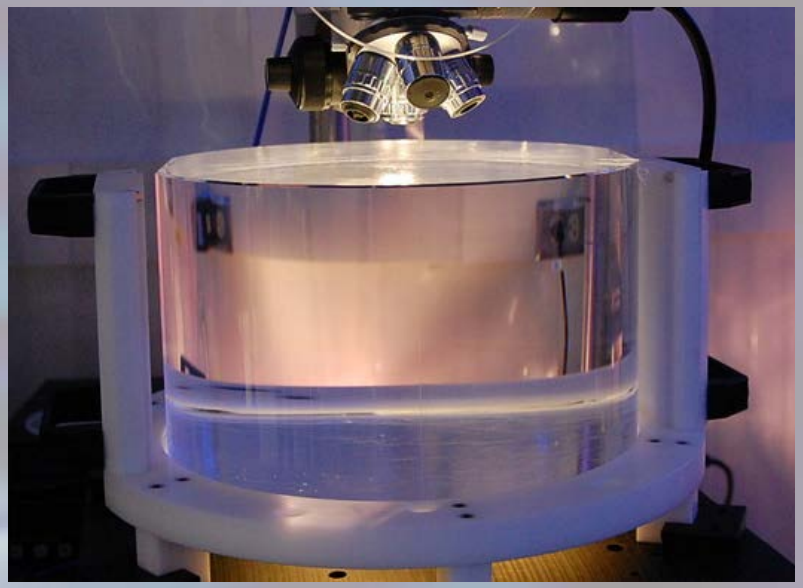
Advanced LIGO Sensitivity

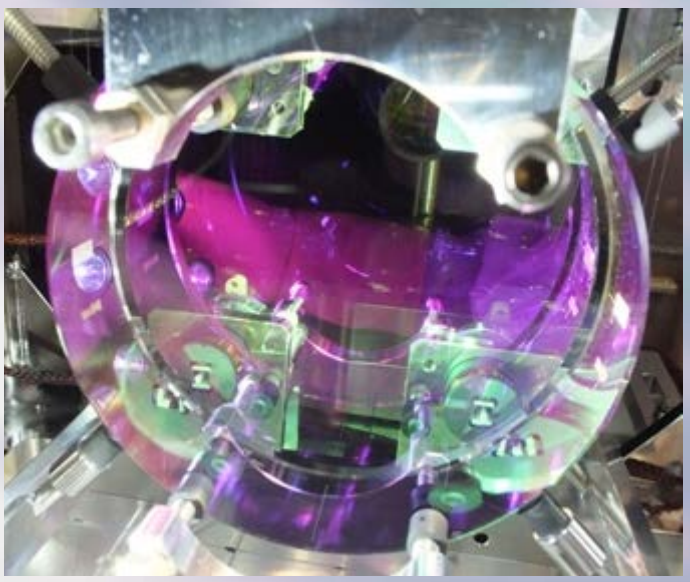
Limited by Earth motion, thermal motion, and quantum mechanics



Advanced LIGO Mirrors and Coatings

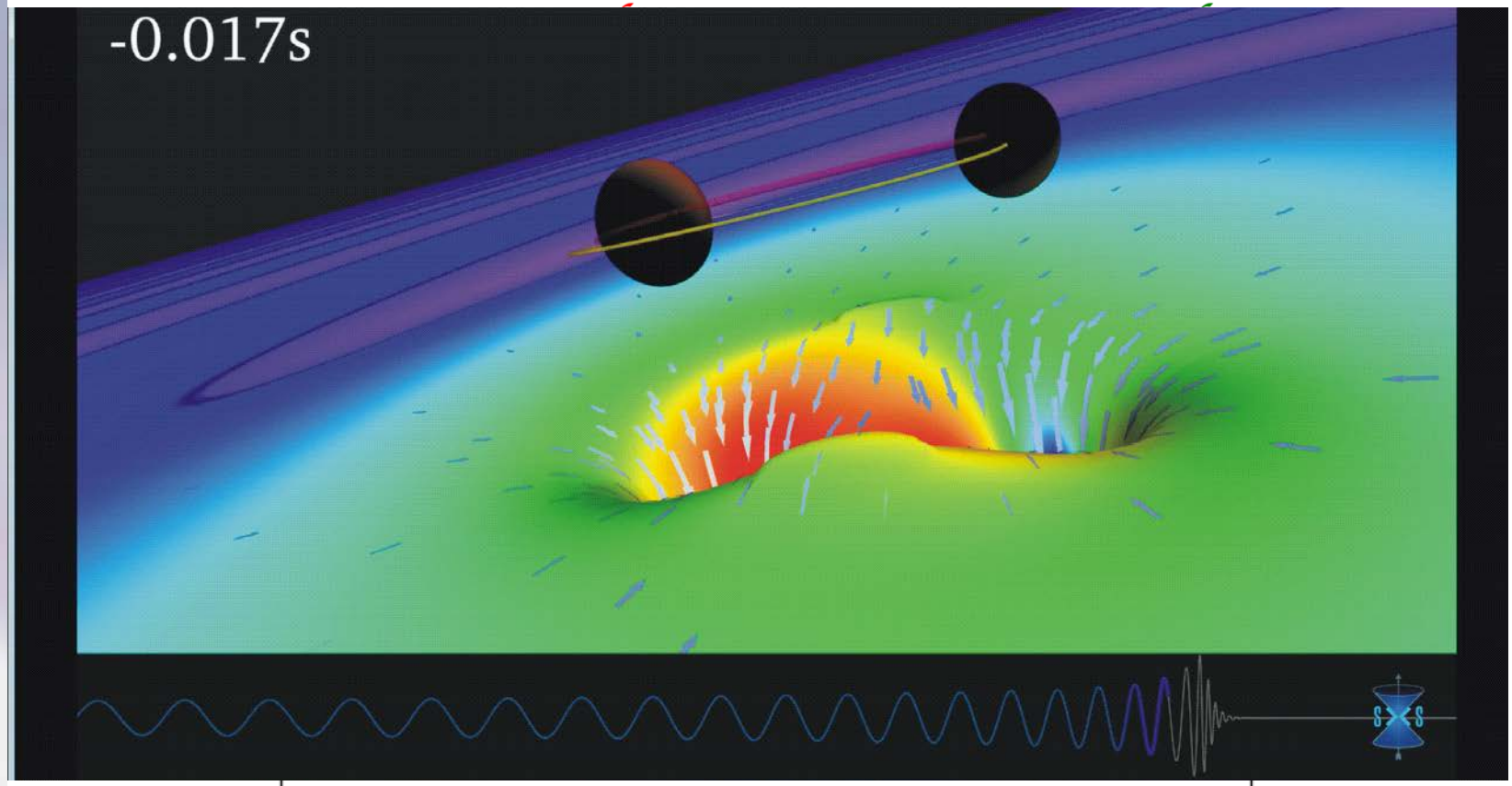
- Fused silica optics
  - 40 kilograms
  - Very low absorption
  - Continuous connection to suspension

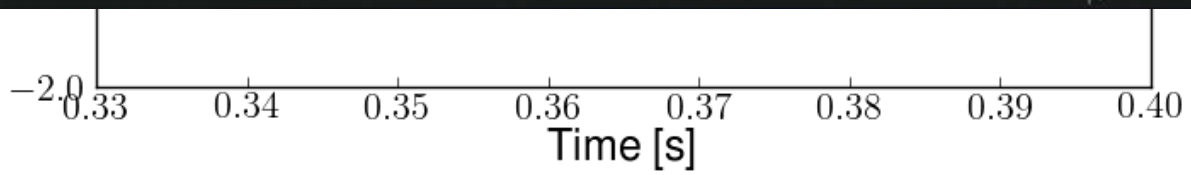


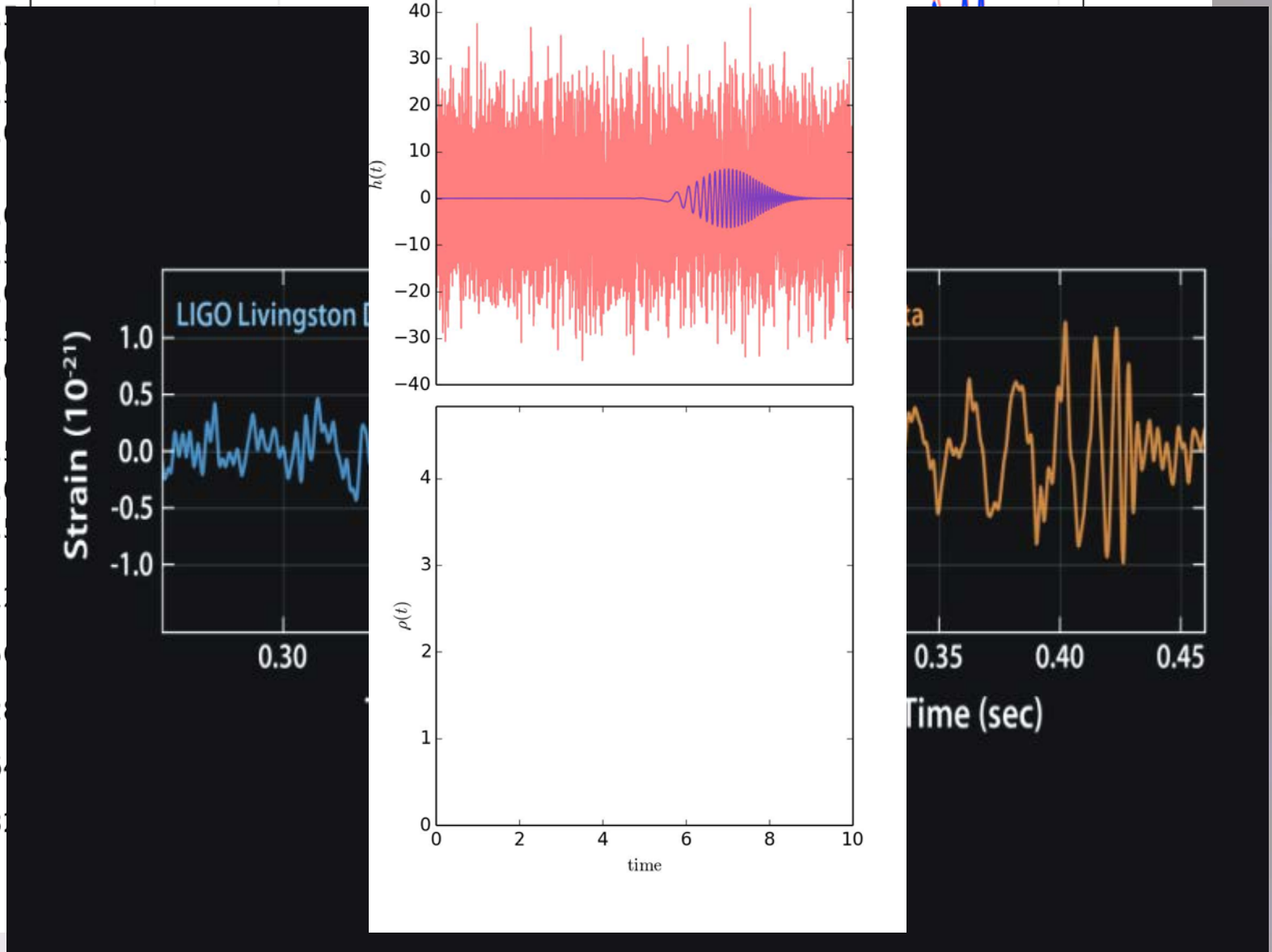


- Optical coatings
  - Reflect light
  - Form resonance cavity
  - Very low absorption
  - Low thermal noise

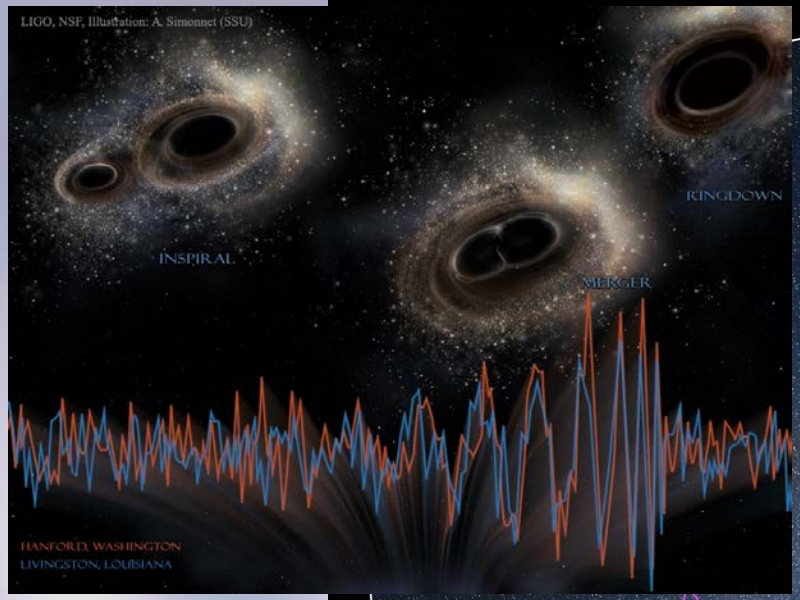
Gravitational Waveform from Binary Black Hole Inspiral






Hanford, Washingt
na (L1)
Strain (10^{-21})
Frequency (Hz)
LIGO Livingston
Strain (10^{-21})
0.30
0.35
0.40
0.45
Time (sec)
time
$h(t)$
$\rho(t)$
time

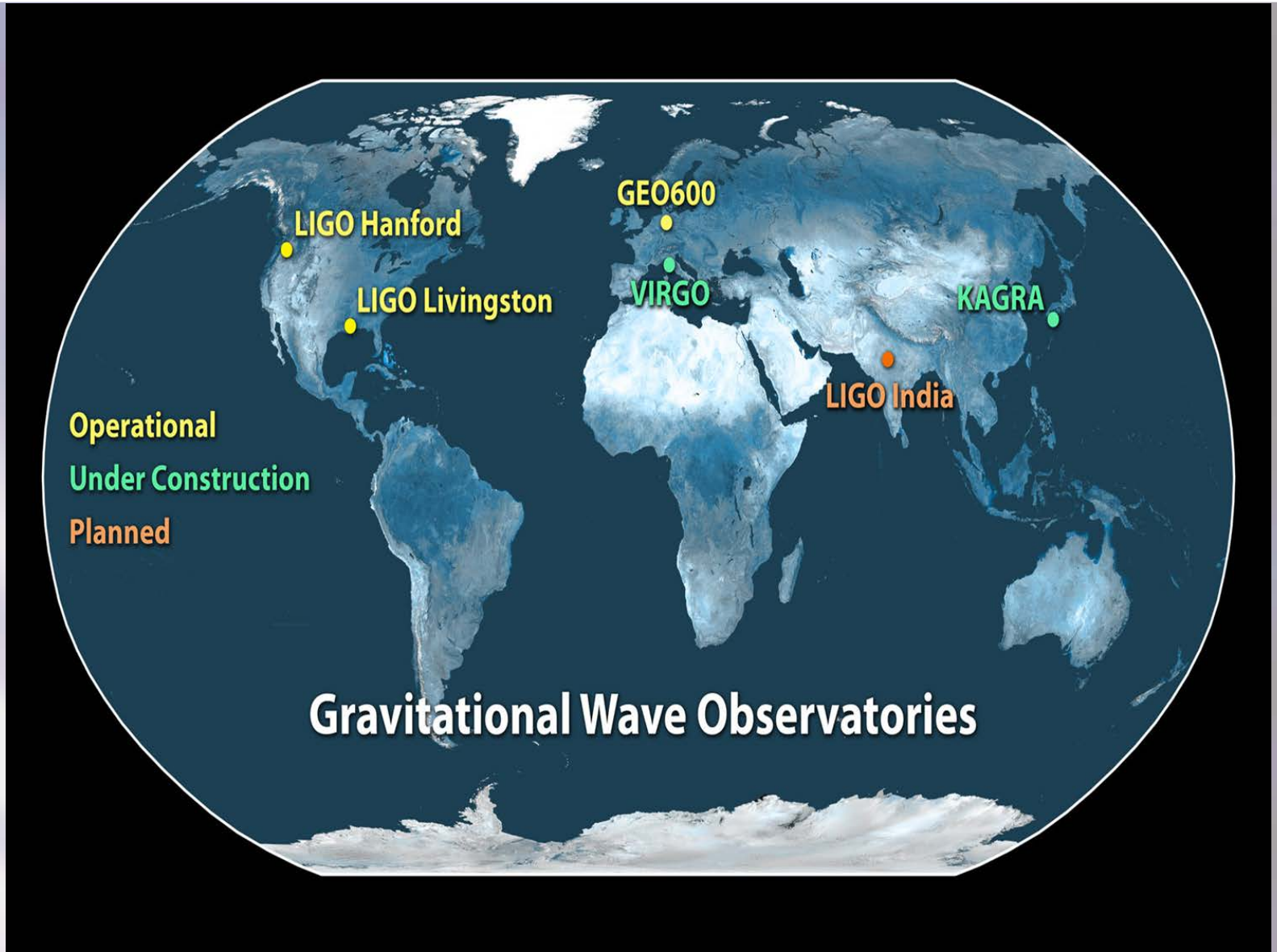
Three Discoveries



- Gravitati nstein
- Black ho solar mass
- Black ho ntually collide a hole

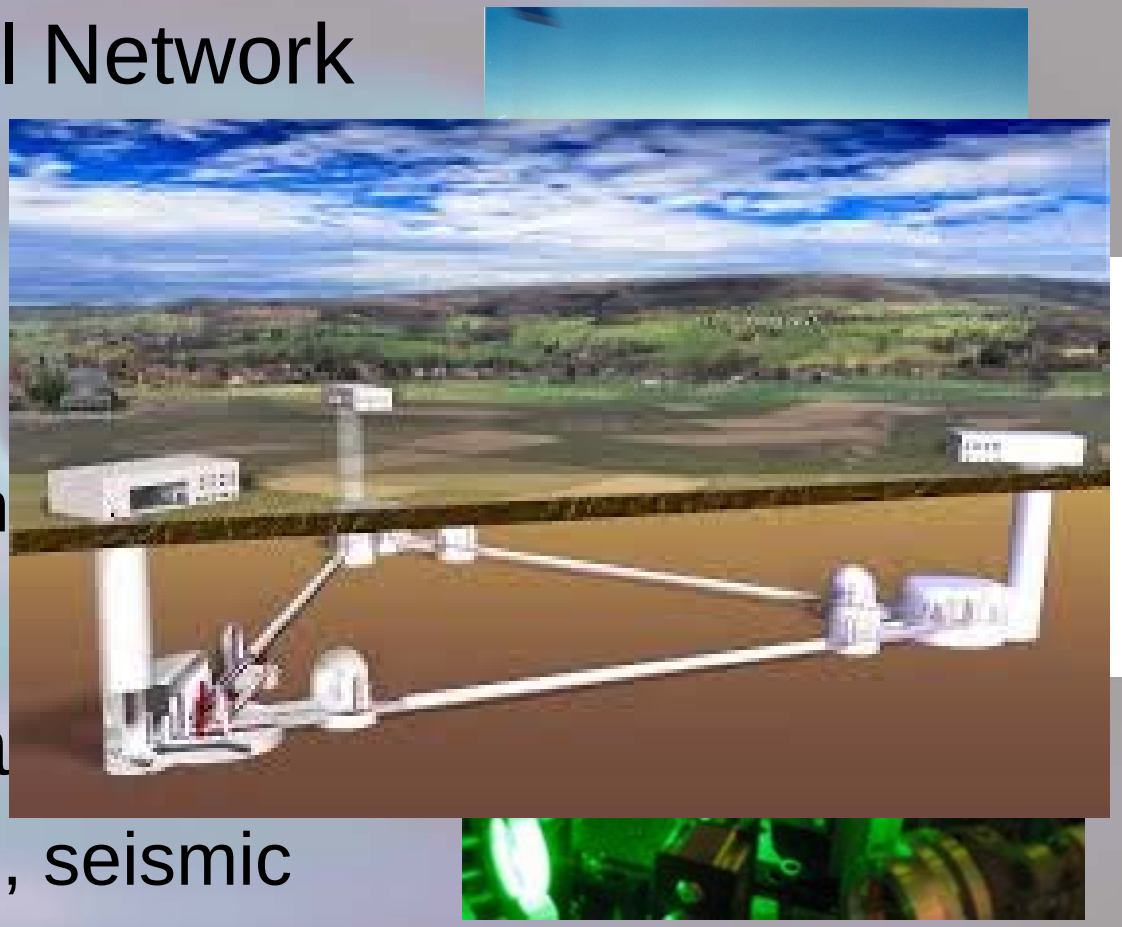
LIGO

International Network



Future Hopes and Plans

- Form International Network
  - Virgo in Europe
  - KAGRA in Japan
- LIGO India
  - Tweet from Indian
- LISA - Space
- Upgrades to Adva
  - Squeezing, optics, seismic noise cancellation
- Einstein Telescope



LIGO at AU

- AU is a member of the LIG
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- 500-
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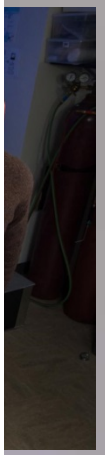
- Imp
- Next g s
- Train students to enter field

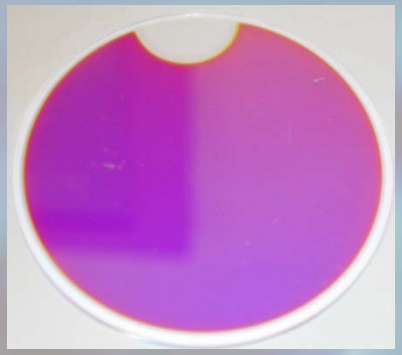


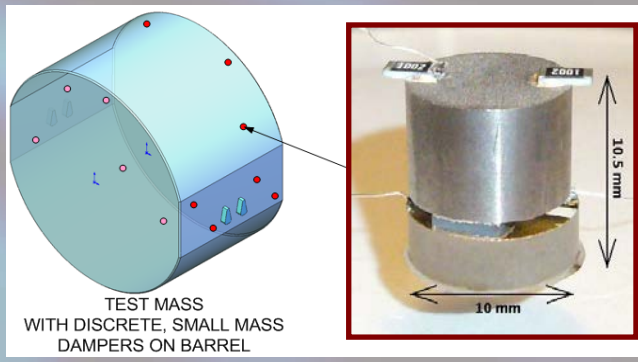
AU LIGO Lab Summer 2013

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