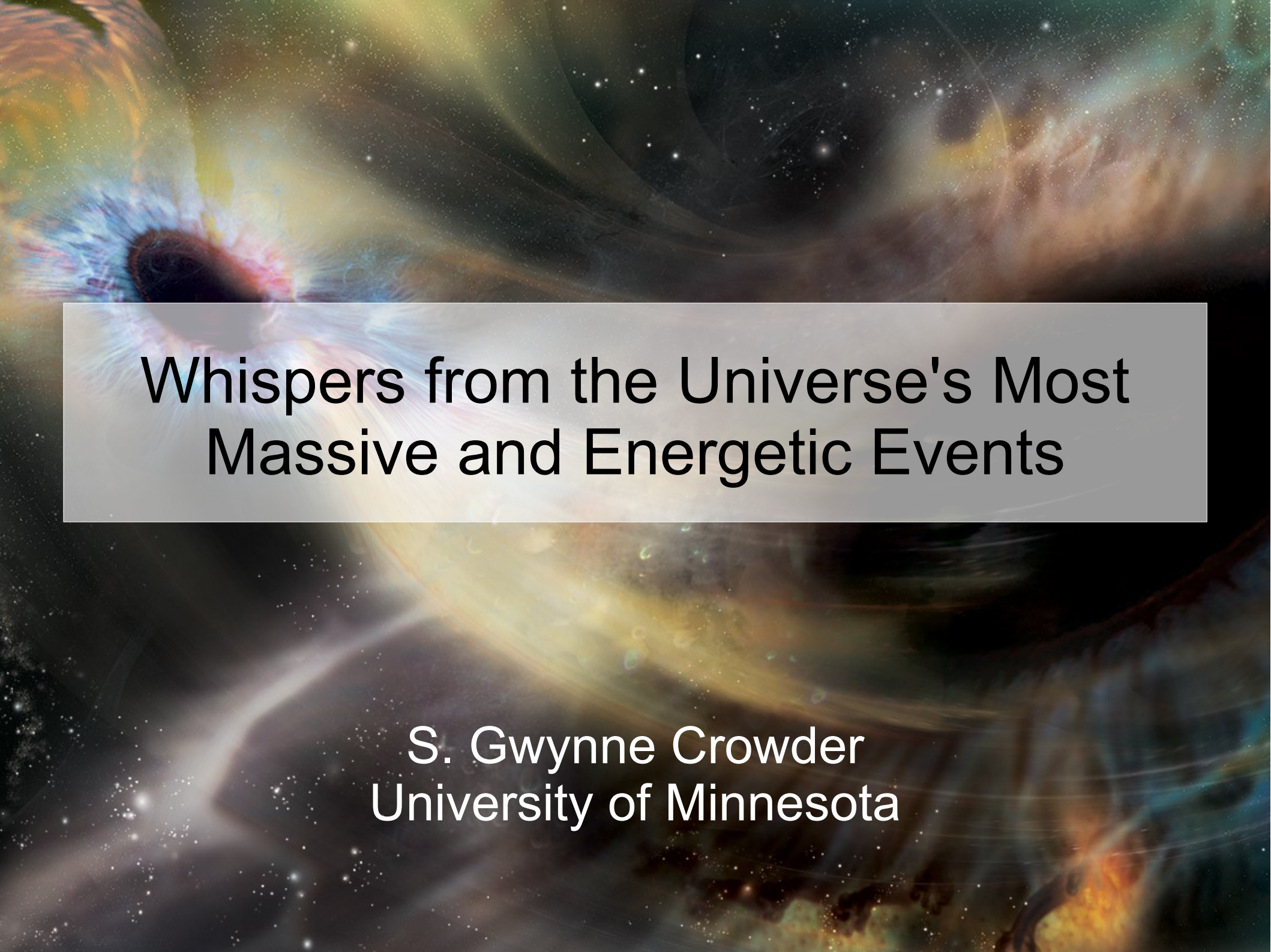
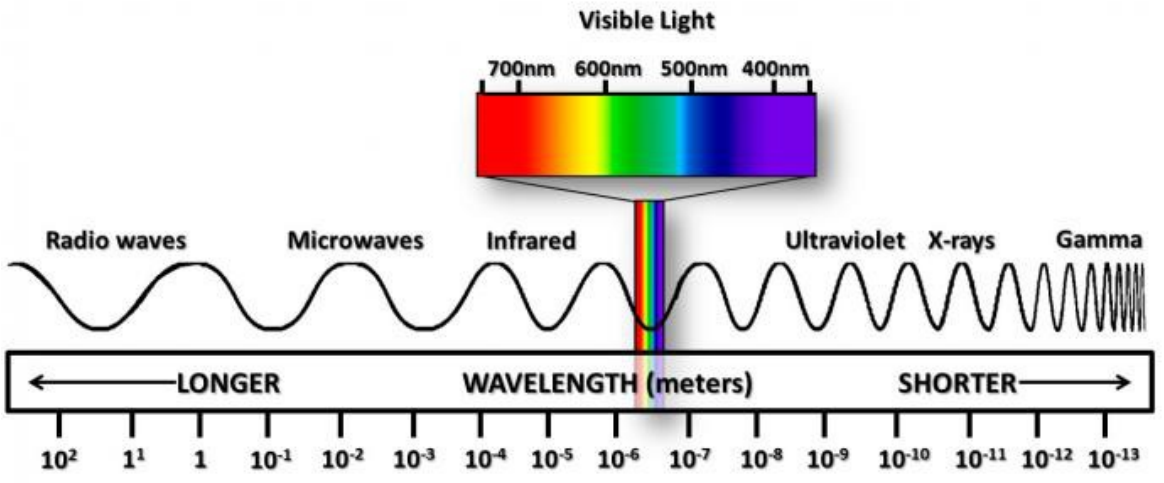


Whispers from the Universe's Most Massive and Energetic Events

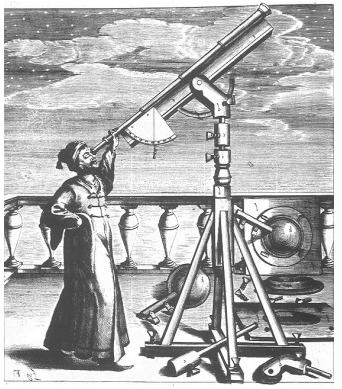
S. Gwynne Crowder
University of Minnesota

Until now...

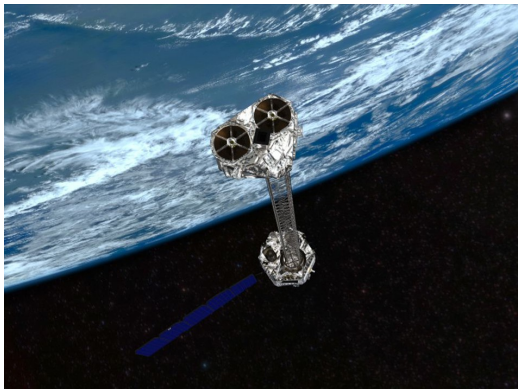


Ces.fau.edu

Steven Bundy

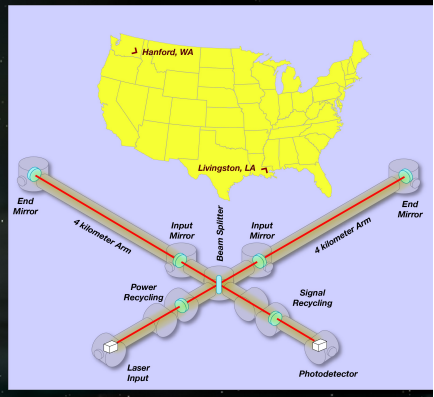


galileo.rice.edu



NASA

DISCOVERY OF GRAVITATIONAL WAVES



MERGER

INSPIRAL

RINGDOWN

0.20 0.25 0.30 0.35 0.40 0.45

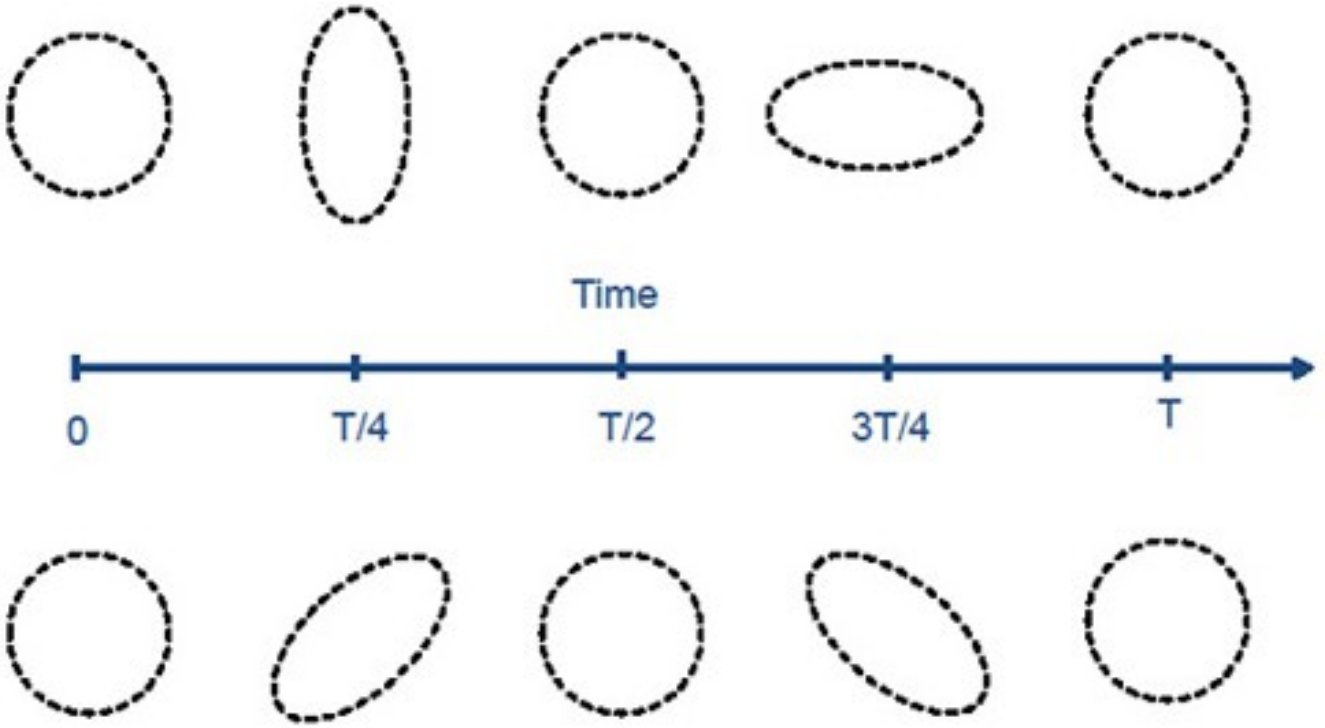
Overview

- What are gravitational waves? Why are they important?
- The LIGO search
- First direction detection!
- Looking for a stochastic background

GW = Gravitational wave

What are gravitational waves?

- Ripples in fabric of spacetime
- Caused by accelerating masses
- Amplitude ("strain"): $h = \Delta L/L$



How big an effect are they?

- Angry motorist shaking their fist: *h* ~ *7e-52*

RMI

How big an effect are they?

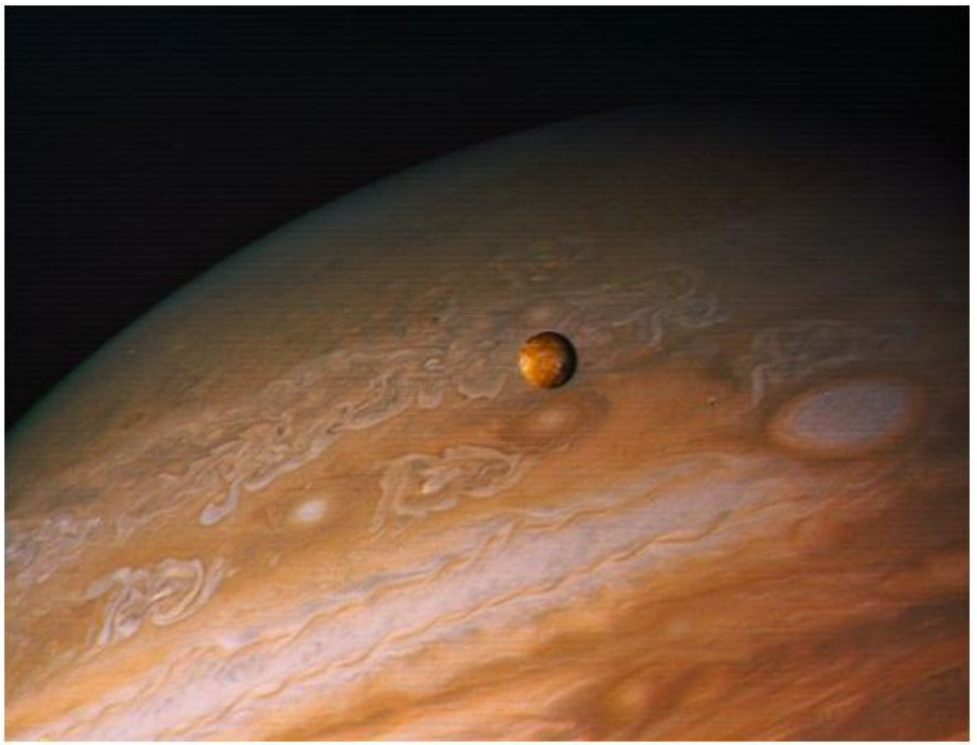
- Angry motorist shaking their fist: *h ~ 7e-52*
- Battleships colliding: *h ~ 5e-46*

Photo # NH 68352 USS Washington alongside USS Vestal after collision with USS Indiana, Feb. 1944

U.S. Naval Historical Center Photograph

How big an effect are they?

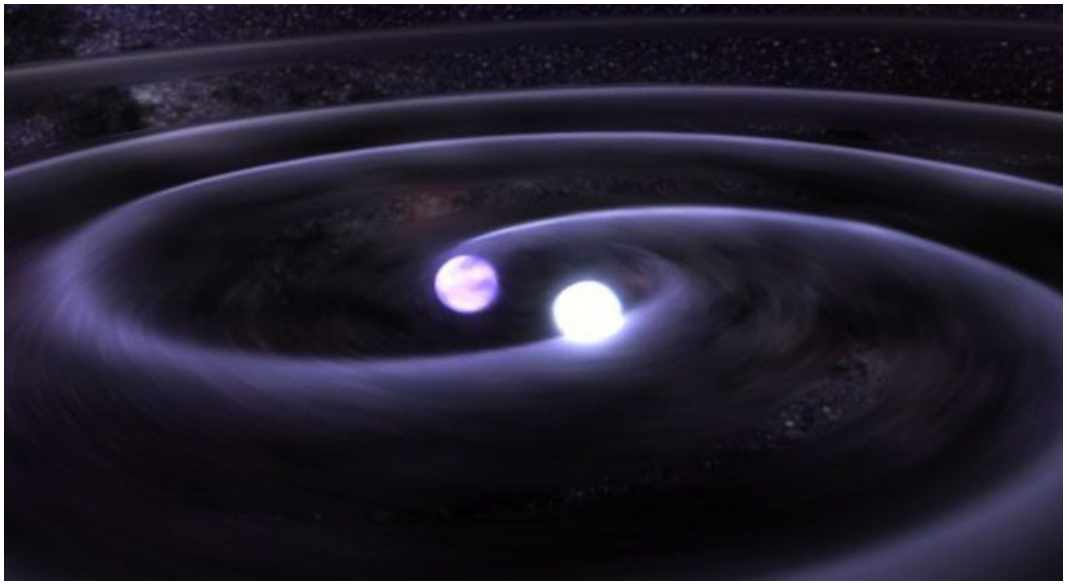
- Angry motorist shaking their fist: *h ~ 7e-52*
- Battleships colliding: *h ~ 5e-46*
- Io orbiting Jupiter: *h ~ 3e-25*



NASA

How big an effect are they?

- Angry motorist shaking their fist: *h ~ 7e-52*
- Battleships colliding: *h ~ 5e-46*
- Io orbiting Jupiter: *h ~ 3e-25*
- Neutron star binary @ Galactic Center: *h ~ 2e-19*



NASA

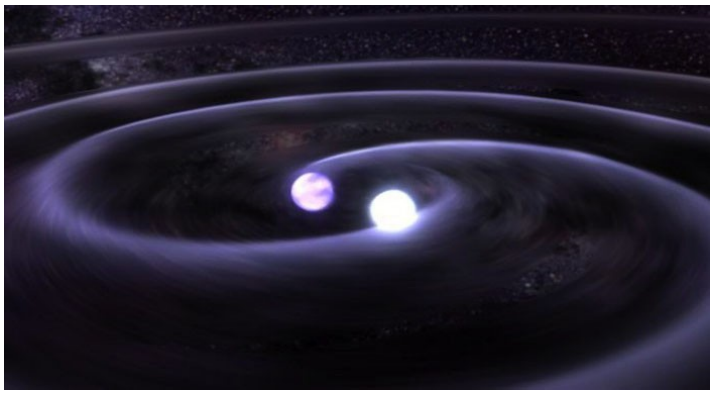
How big an effect are they?

- Angry motorist shaking their fist: $h \sim 7e\text{-}52$
- Battleships colliding: $h \sim 5e\text{-}46$
- Io orbiting Jupiter: $h \sim 3e\text{-}25$
- Neutron star binary @ Galactic Center: $h \sim 2e\text{-}19$

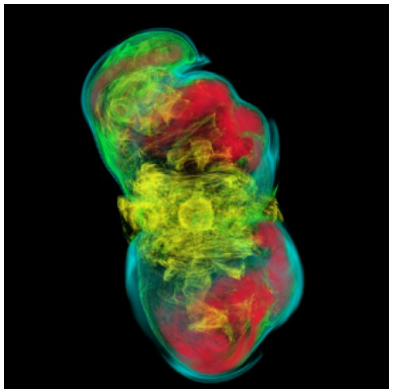
If neutron star binary observed over 1 km scale, motion of detector ~10^{-16} m!

Why are they important?

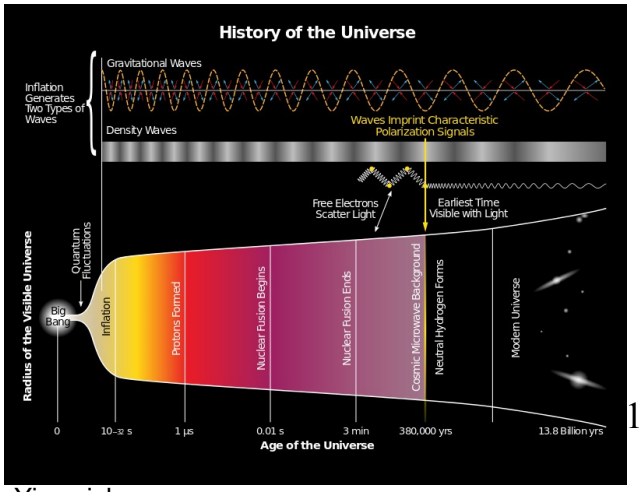
- Confirm general relativity
- Provide new tool for studying the Universe, particularly in regions of strongly curved spacetime
  - Inspirals of black hole and neutron star binaries
  - Spinning neutron stars
  - Stellar core collapse
  - Dynamics of early Universe



NASA



Philipp Mösta and Sherwood Richers

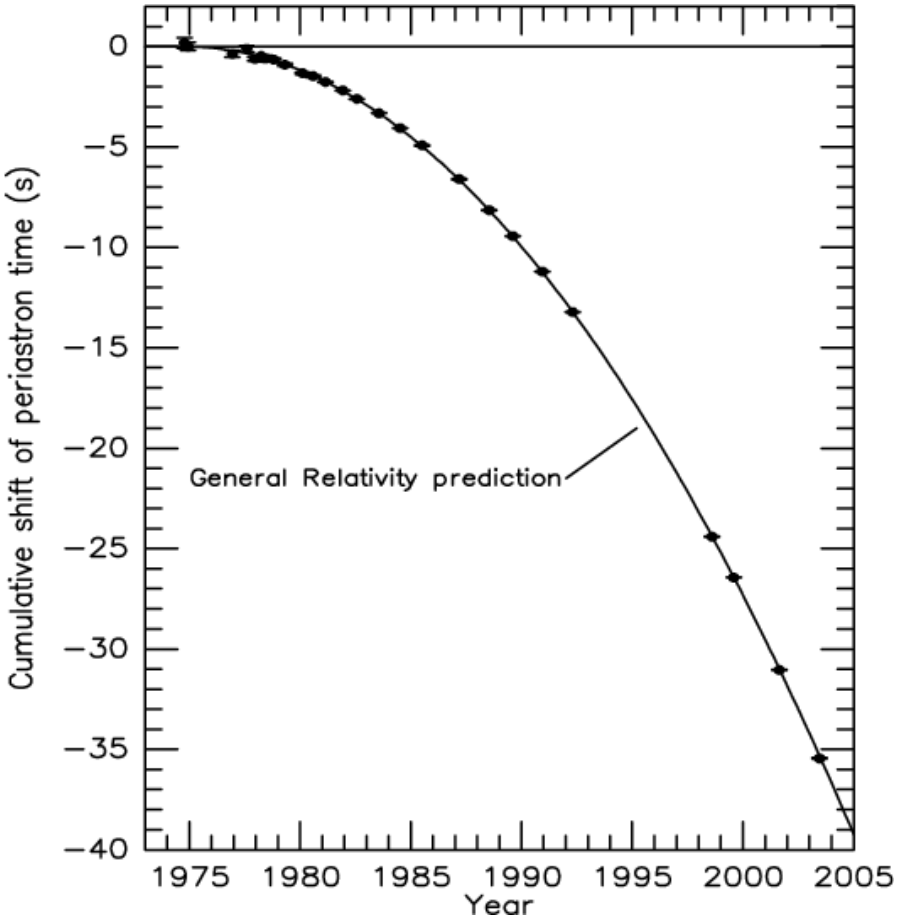


Yinweichen

Indirect evidence

- Orbital decay first observed by Hulse and Taylor

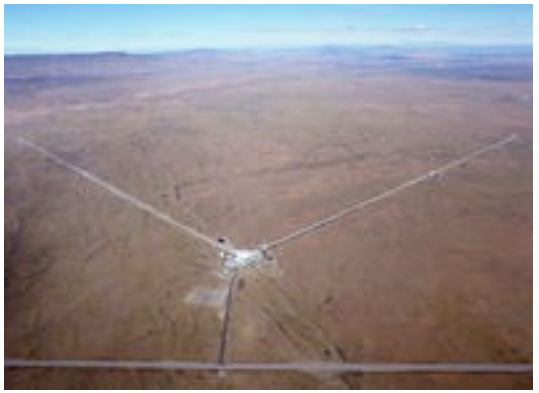
Nobel Media



Weisberg & Taylor (2005)

LIGO

- Search for direct evidence of GWs
- Look for astronomical sources of GW
- ~1000 scientists worldwide
- Largest project funded by NSF



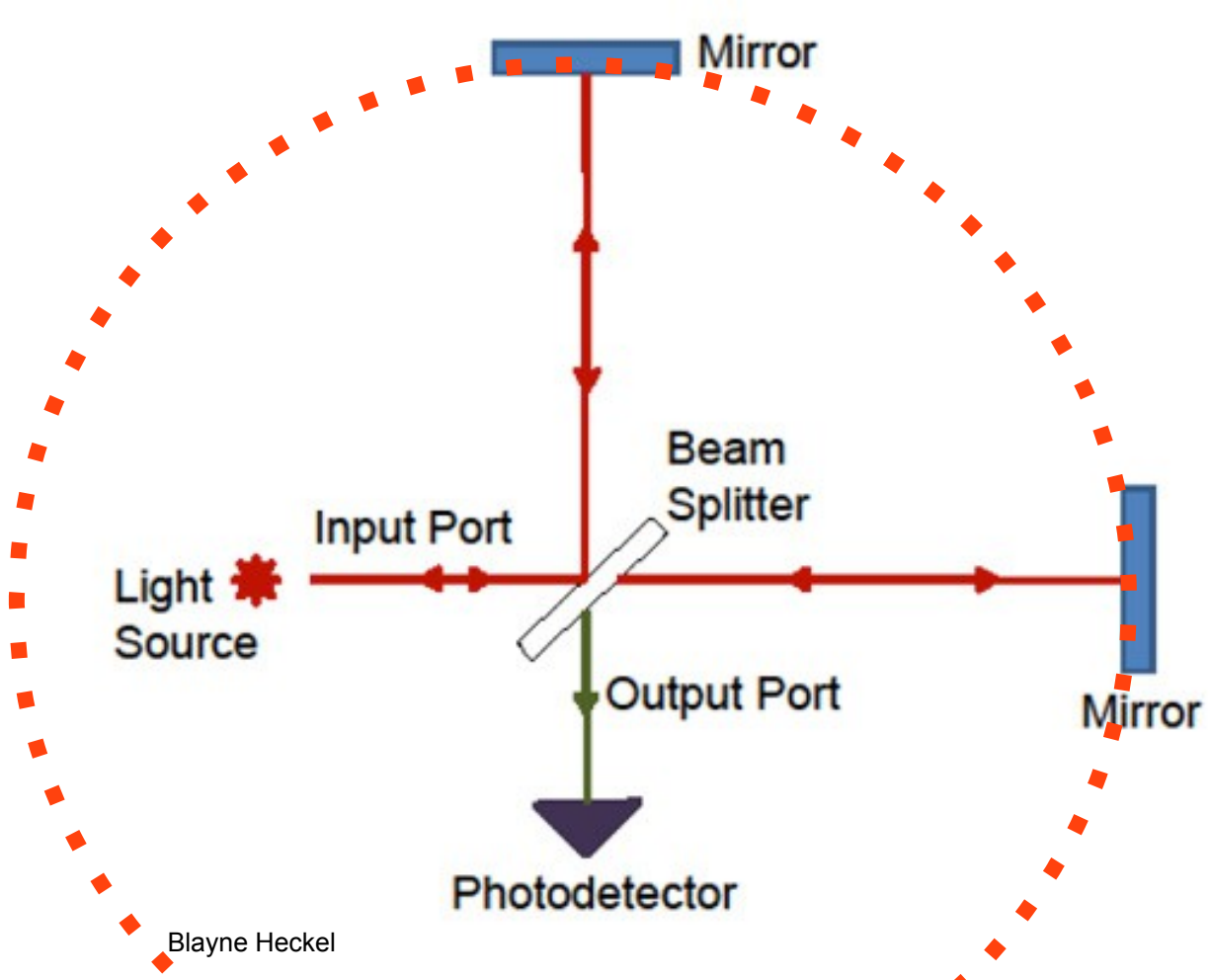
LIGO

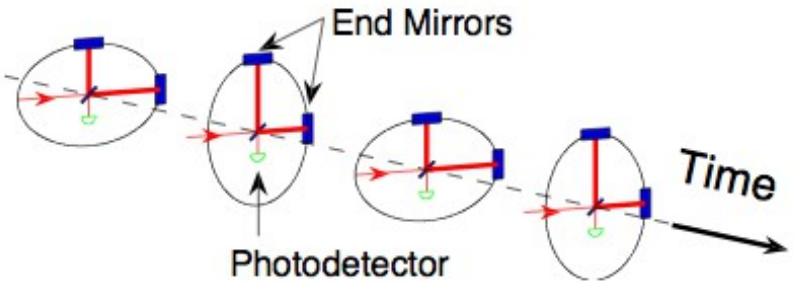
LIGO

VIRGO

LIGO

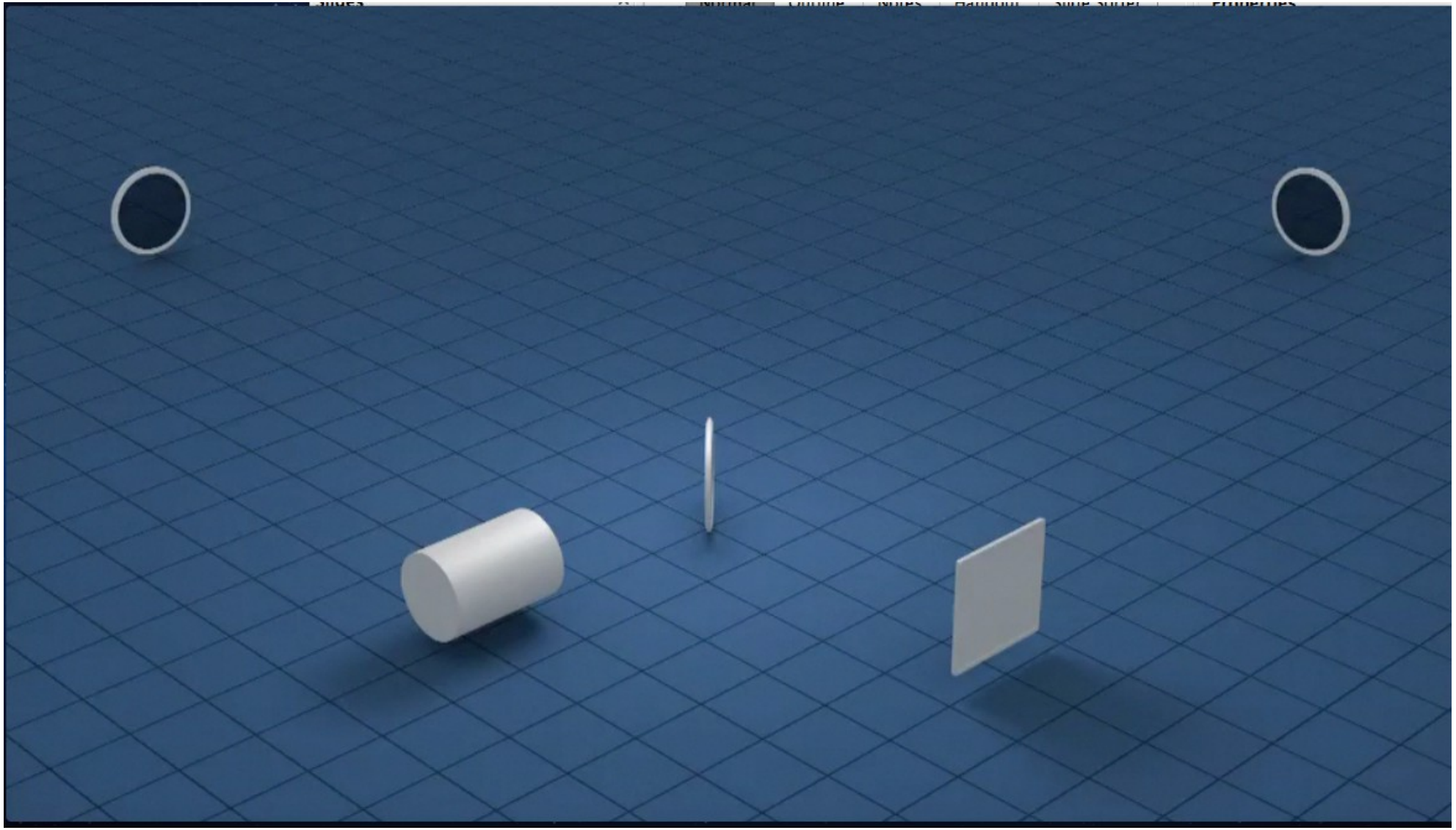
- Simplified: Michelson interferometer





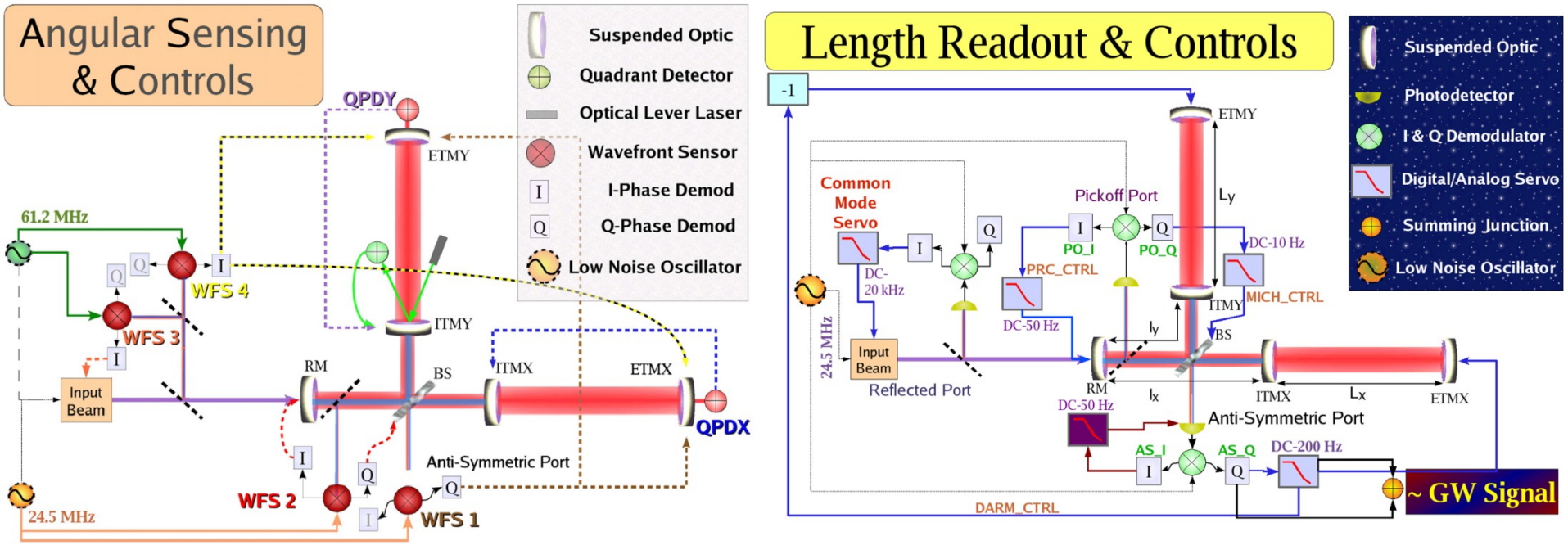
Abbott *et al*. (2009)

Interferometer visualization



LIGO

- 4 km arms + predicted strain ~10^{-22} → motion of mirror ~10^{-19} m



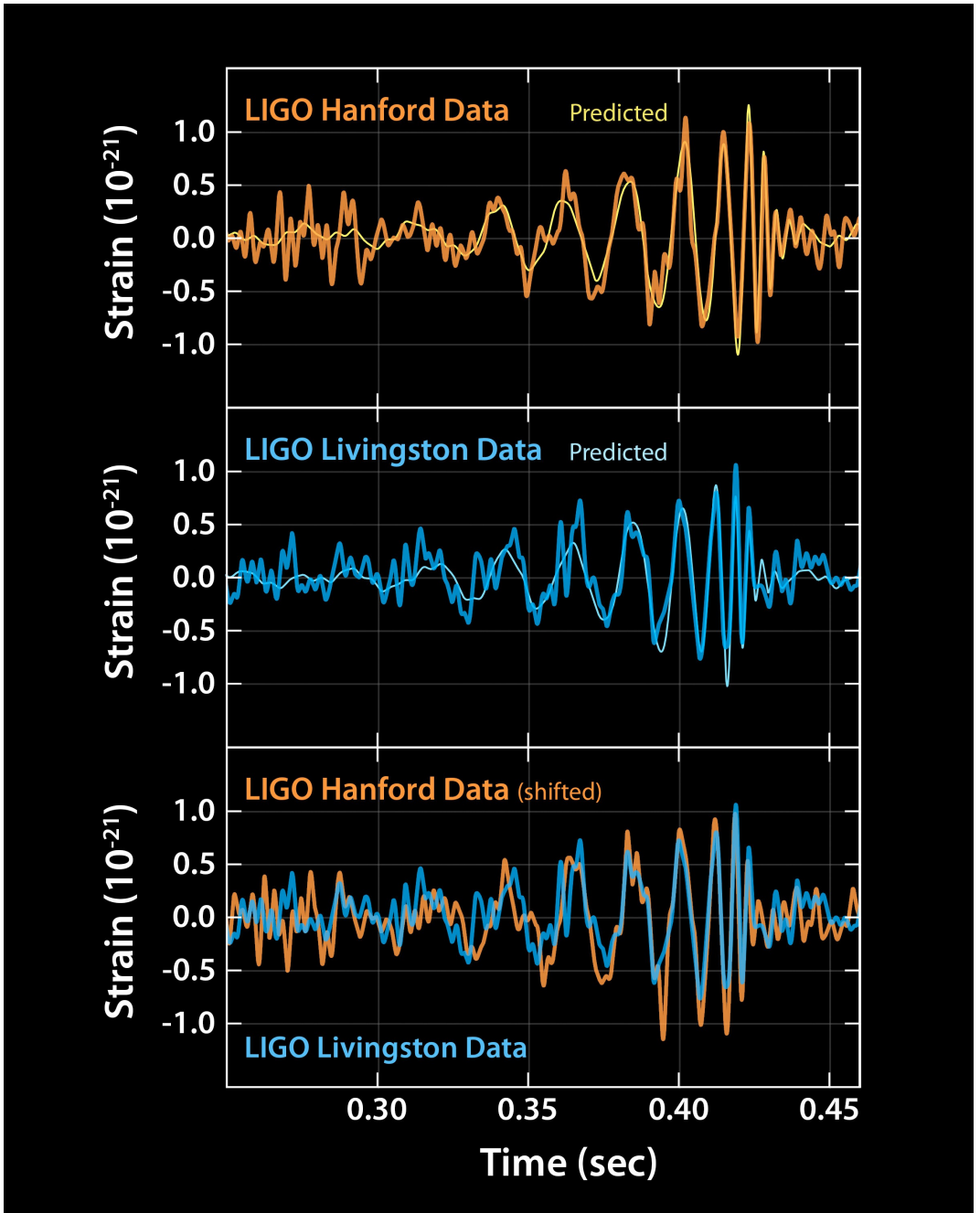
Aasi, *et al*., (2015)

Advanced LIGO[1]

- Over next several years, expect to achieve four orders of magnitude improvement in sensitivity to GW energy density at 100 Hz
- Expect to be sensitive to frequencies down to 10 Hz
- Initial observations began this fall

[1] Harry *et al.* (2010)

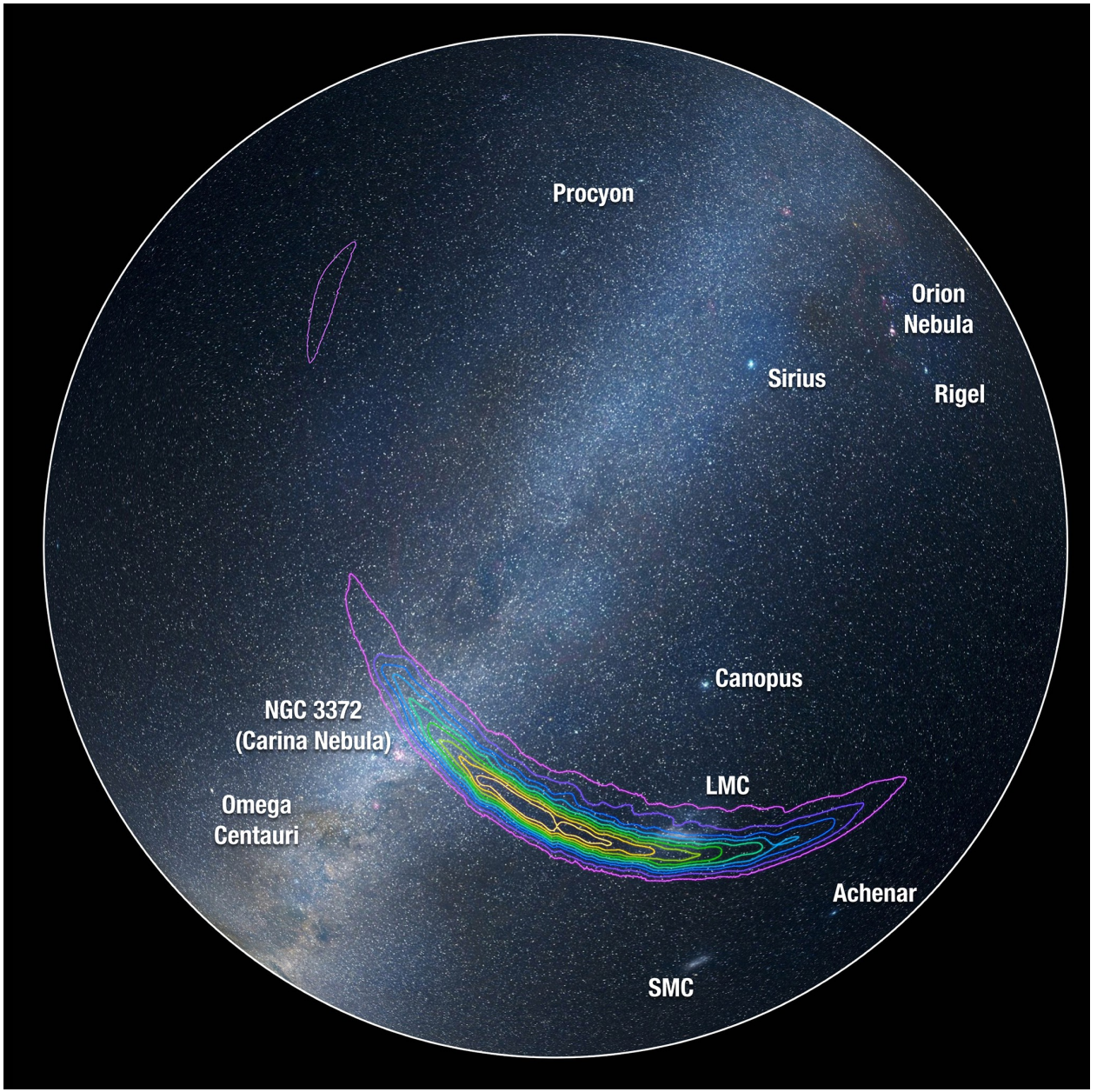
GW150914: First direct detection



- Entire detected signal ~0.5 s long
- Two black holes merging into one
- Black holes: 29 and 36 solar masses
- Event occurred over 1 billion years ago
- Merged black hole: 62 solar masses

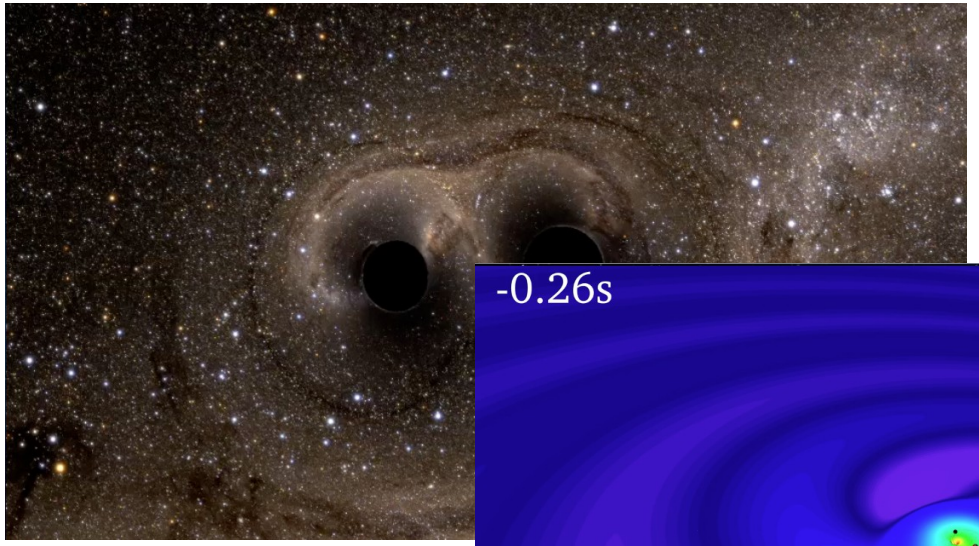
Abbott *et al.* , PRL 116, 061102 (2016)

GW150914

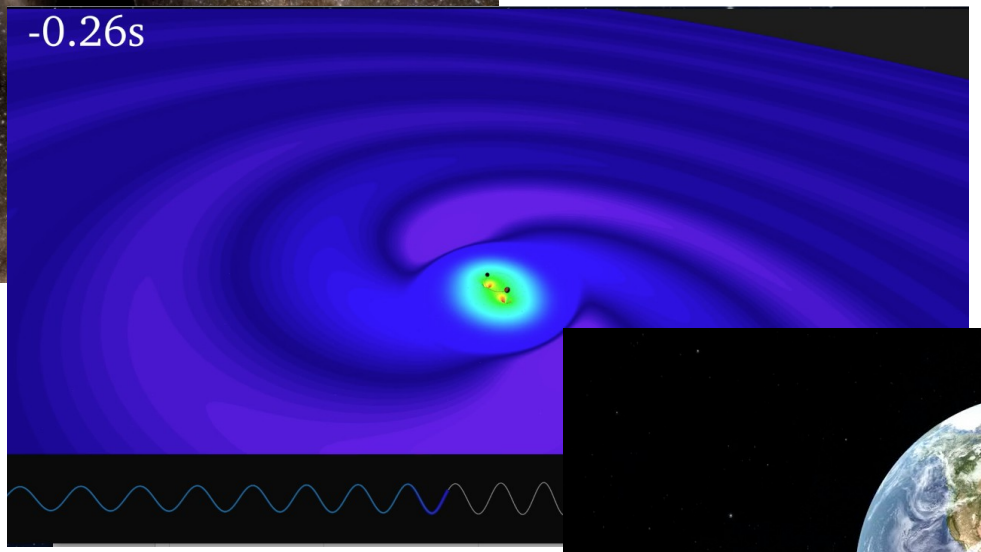


LIGO

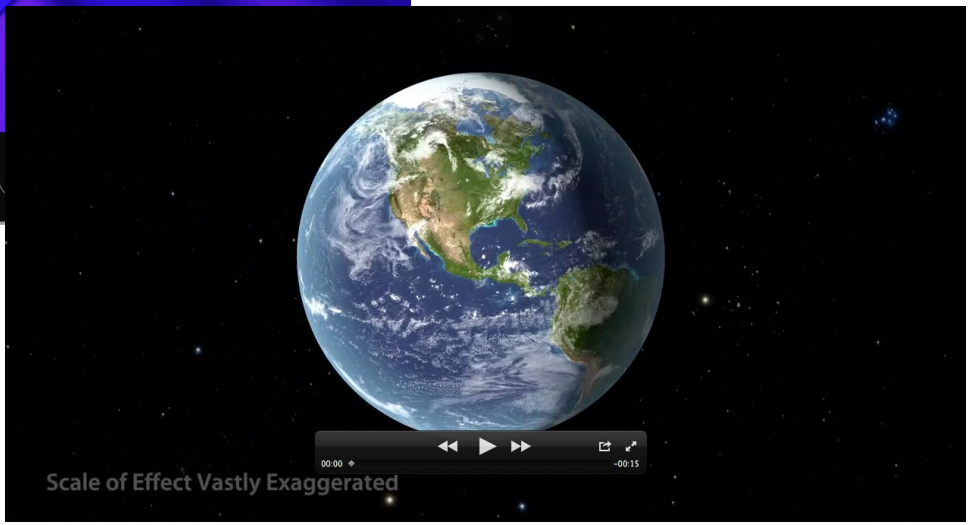
Visualizing GW150914



SXS



SXS

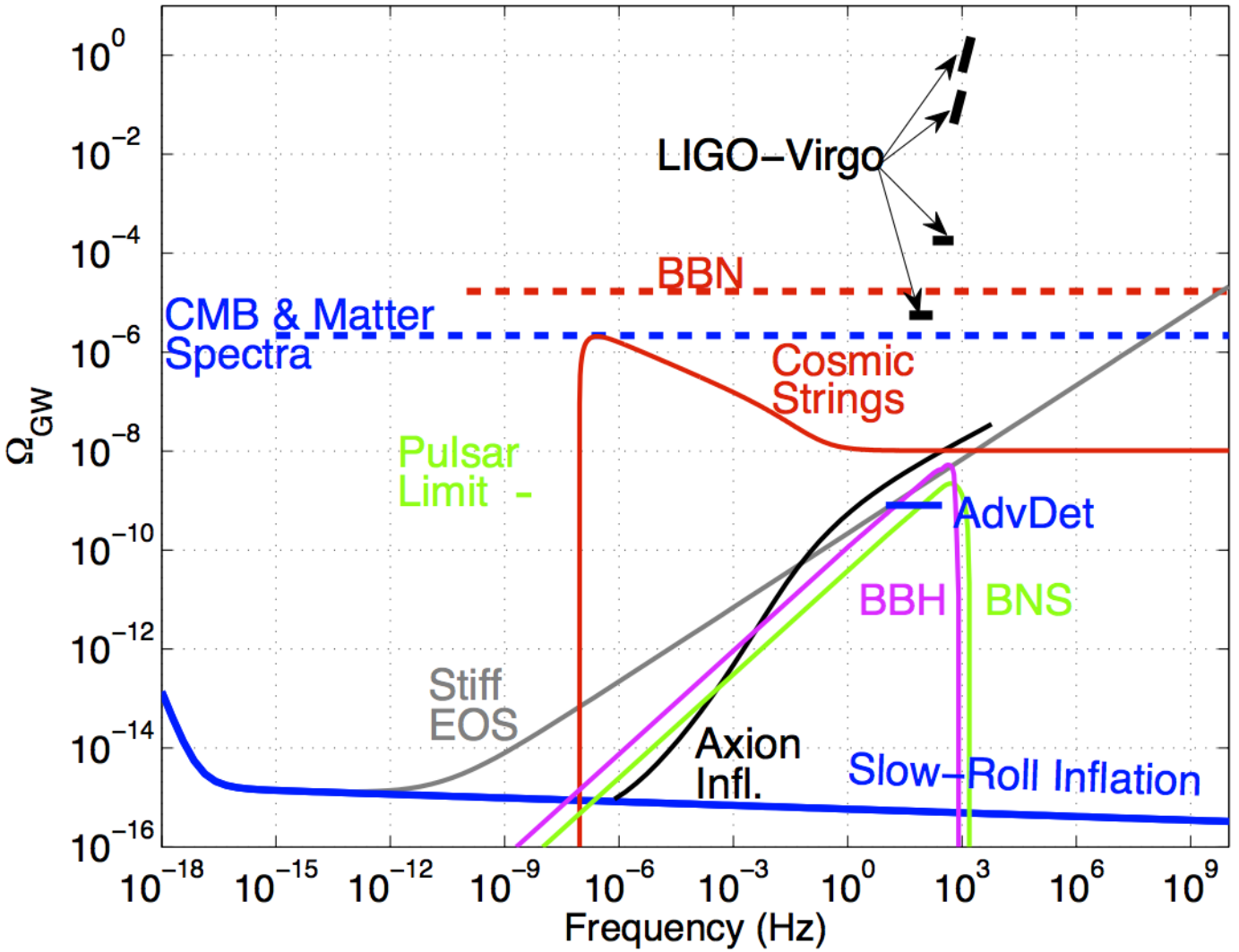


LIGO/R. Hurt

A background buzz of gravitational waves

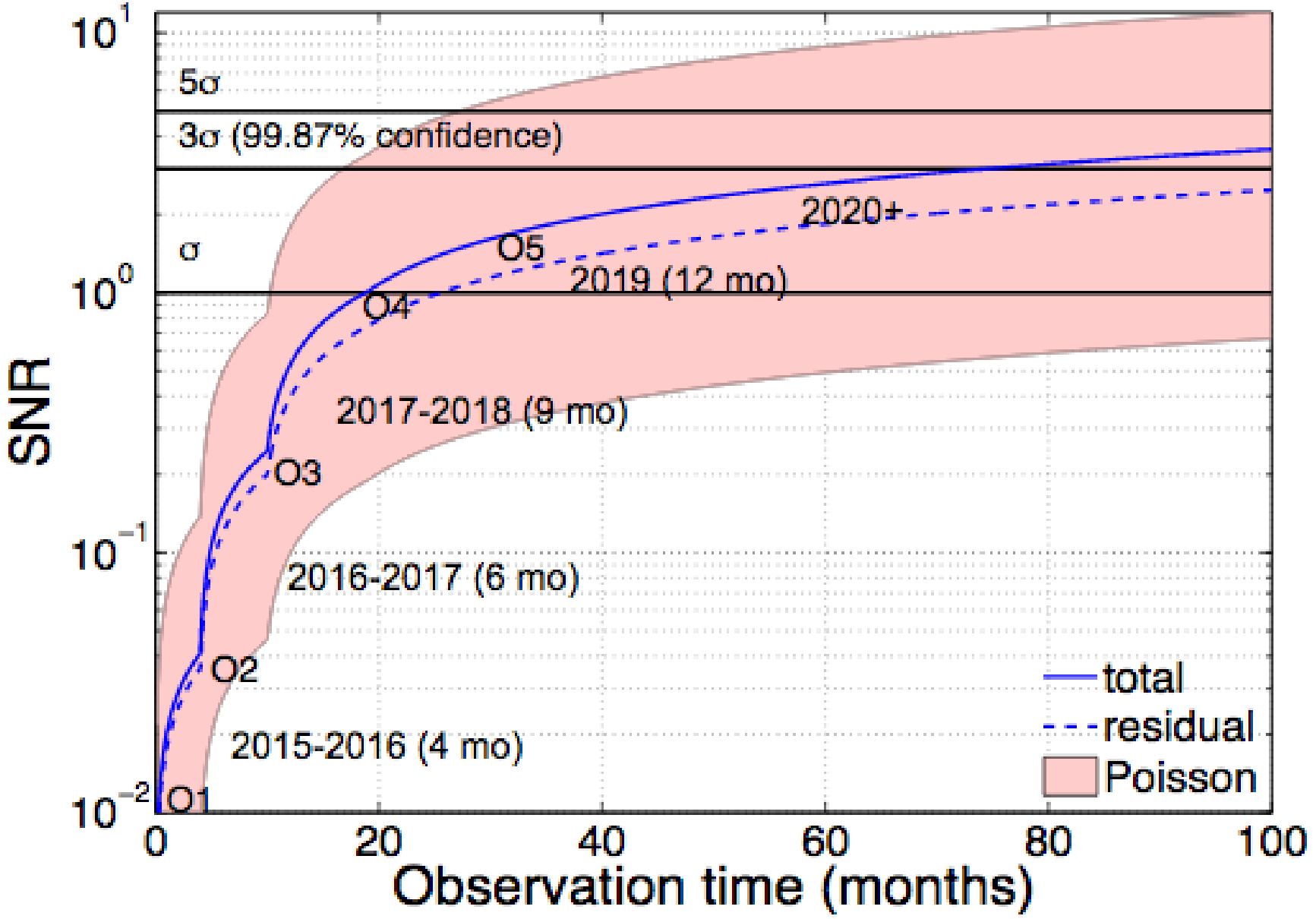
- Searching for the stochastic gravitational-wave background
- Like background sound level in crowded room
- Both cosmological and astrophysical sources could contribute
- Search for a correlated signal between separate detectors
- Not yet detected

Search for a stochastic background with initial LIGO and Virgo



Aasi *et al.*, PRL 113, 231101 (2014)

Prospects with Advanced LIGO



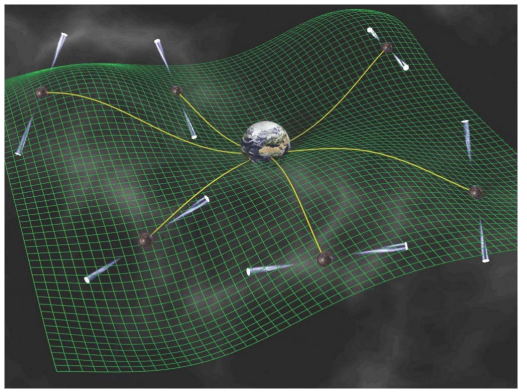
Abbott *et al.*, PRL 116, 131102 (2016)

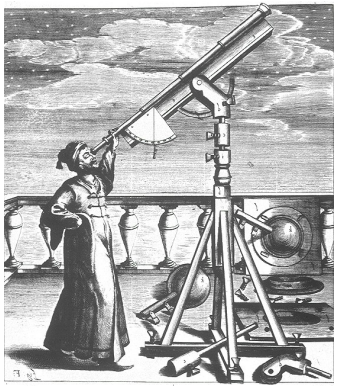
Final thoughts

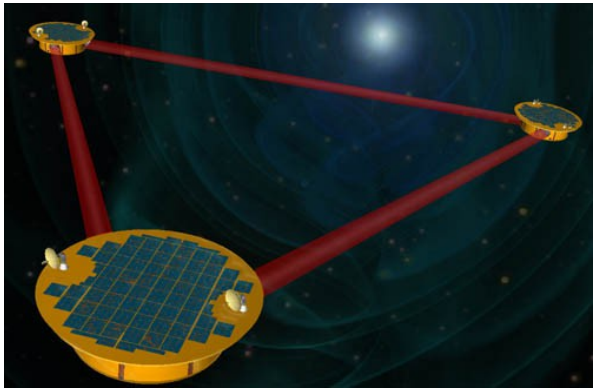
- Exciting time for gravitational-wave astronomy!
  - First direct detection of GWs
  - First evidence that stellar-mass black holes exist in binary systems
  - First evidence of black hole binaries merging
- With increases in LIGO sensitivity in coming years, expect further discoveries![1]

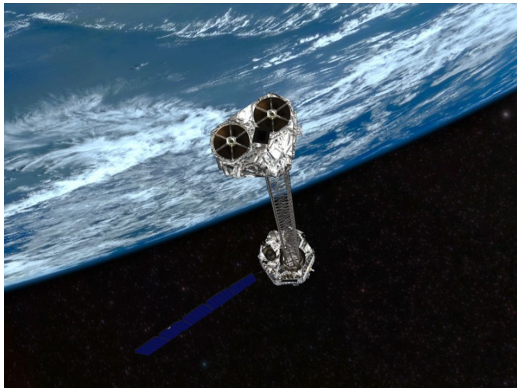
[1]Abbott *et al.*, LLR 19, (2016)

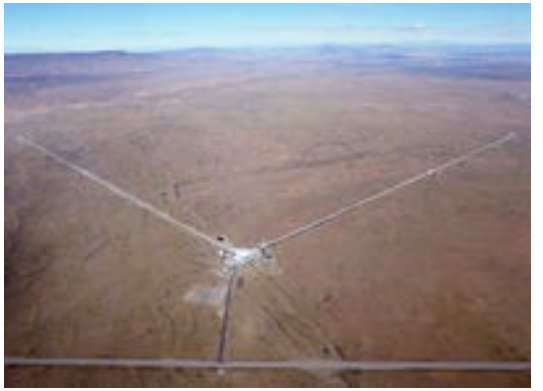
Just the beginning





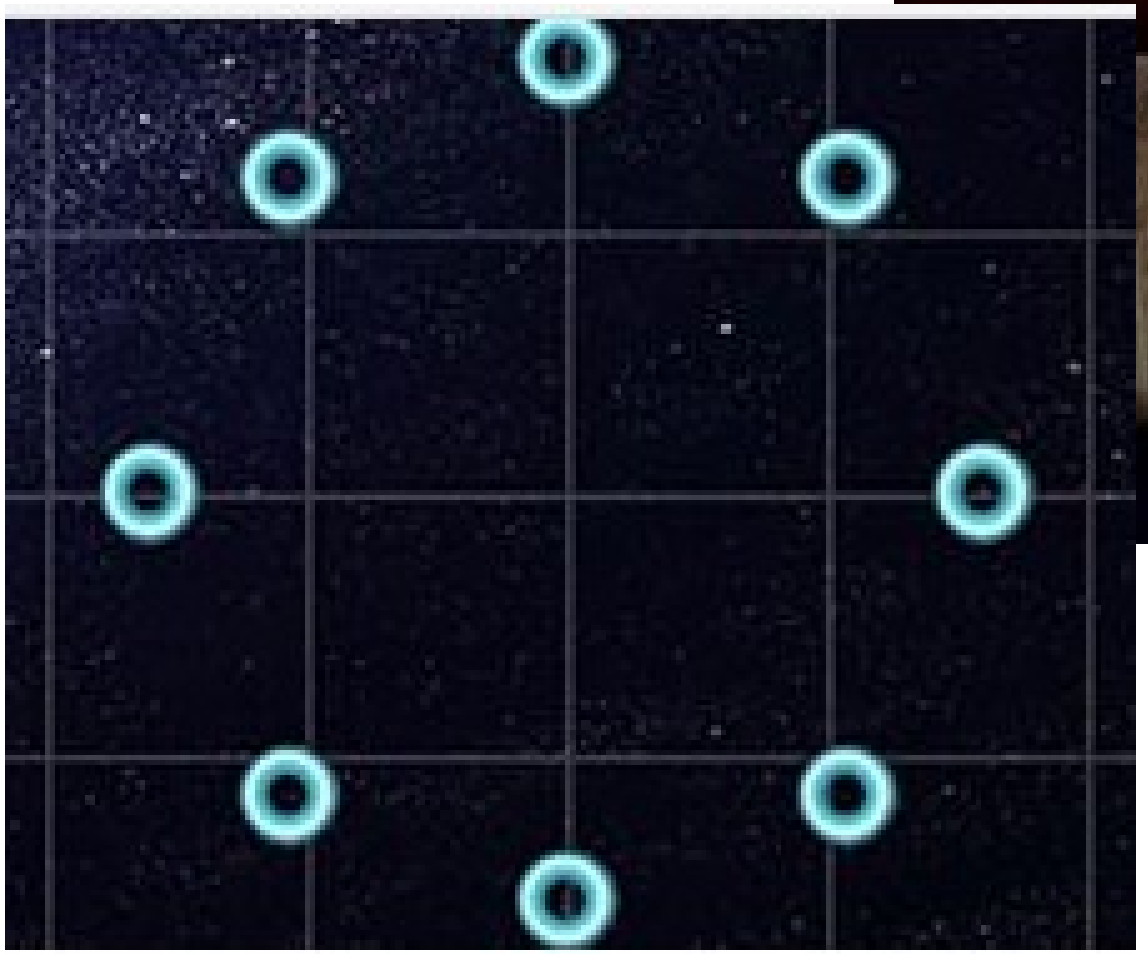




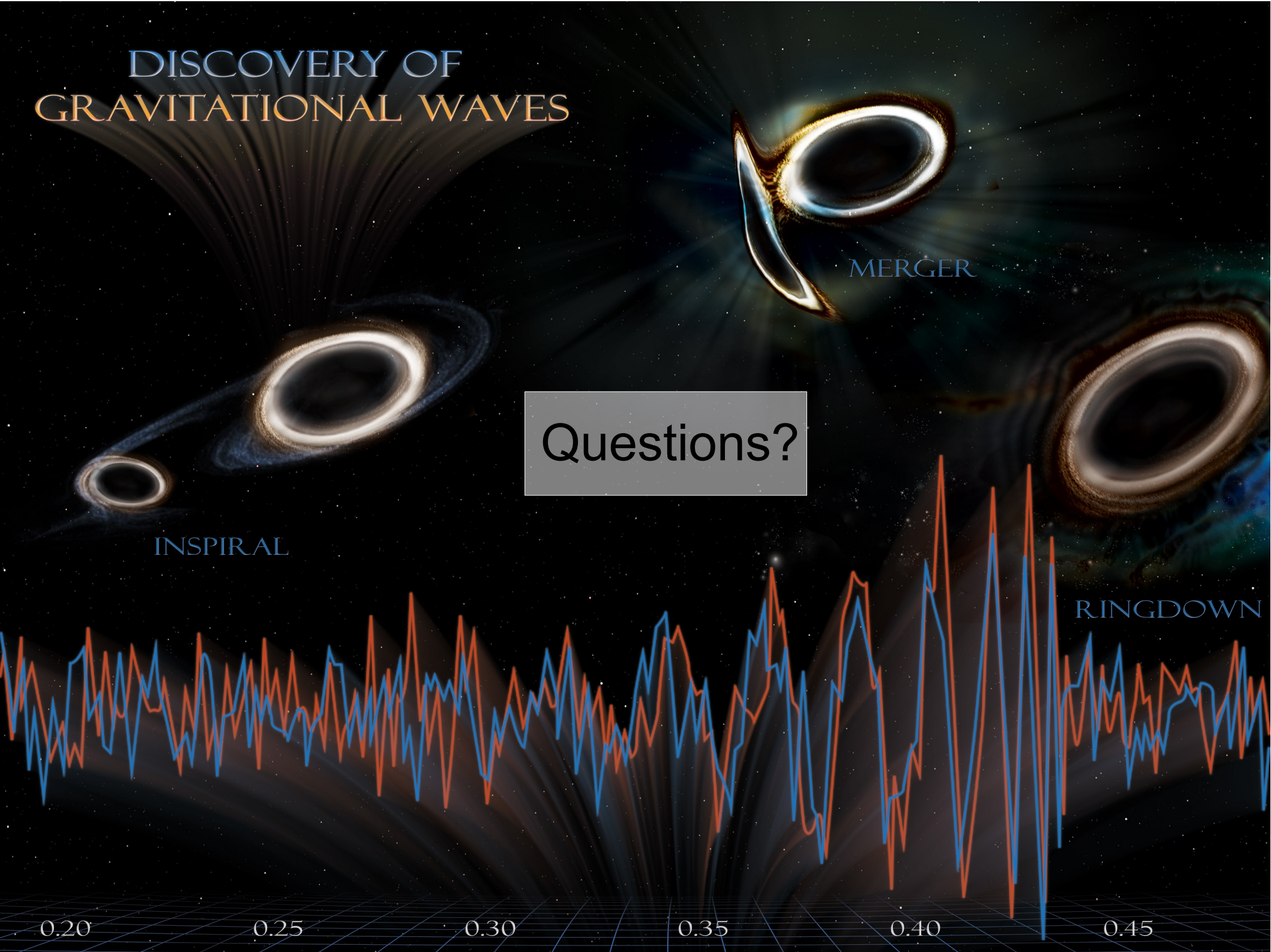


Free apps!
www.laserlabs.org

Pocket Black Hole



Stretch and Squash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