Gravitational wave cosmology

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Wave physics and imaging applications workshop, 2022

This talk: saoghal.net/slides/waves

Hello

- Academy Research fellow and Associate Professor [tenure track] in gravitational wave cosmology
- From Scotland, Finnish citizen since 2019
- Our Computational Field Theory group has approximately 3 faculty, 2 postdocs, 5 graduate students and 5 research assistants
- Member of the LISA gravitational wave mission consortium; holds Finland's seat on Executive Board

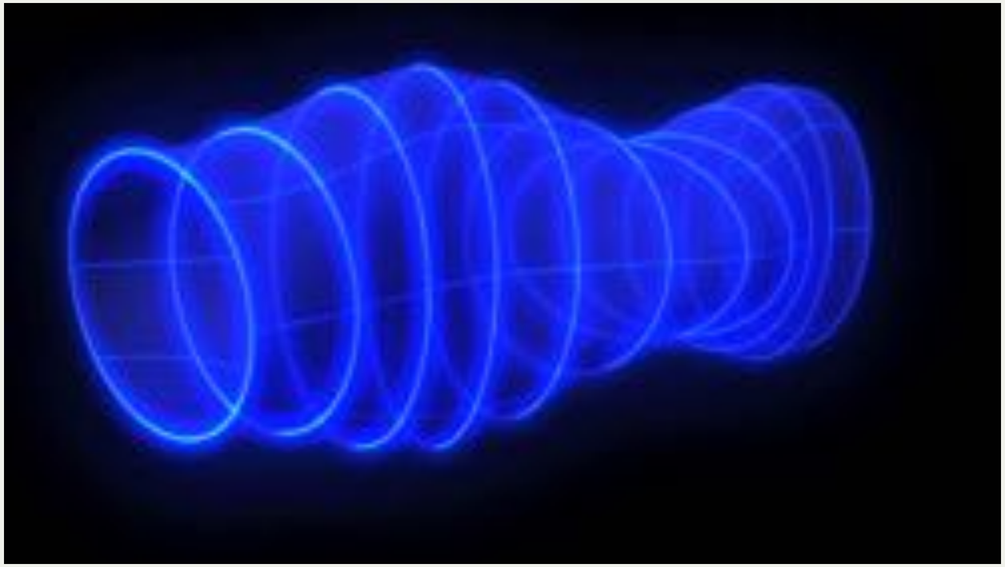
History of gravitational waves

- 1915: General relativity
- 1916: Prediction of gravitational waves
- 1936: 'Proof' they don't exist [wrong!]
- 1957: Persuasive "Sticky bead argument"
- 1960s: Searches start
- 1975: Inferred from Hulse-Taylor pulsar [1993 Nobel Prize]
- 2015: Directly detected by LIGO [2017 Nobel Prize]

What is a gravitational wave?

- Stretches and squeezes a ring of matter

$\Leftrightarrow$

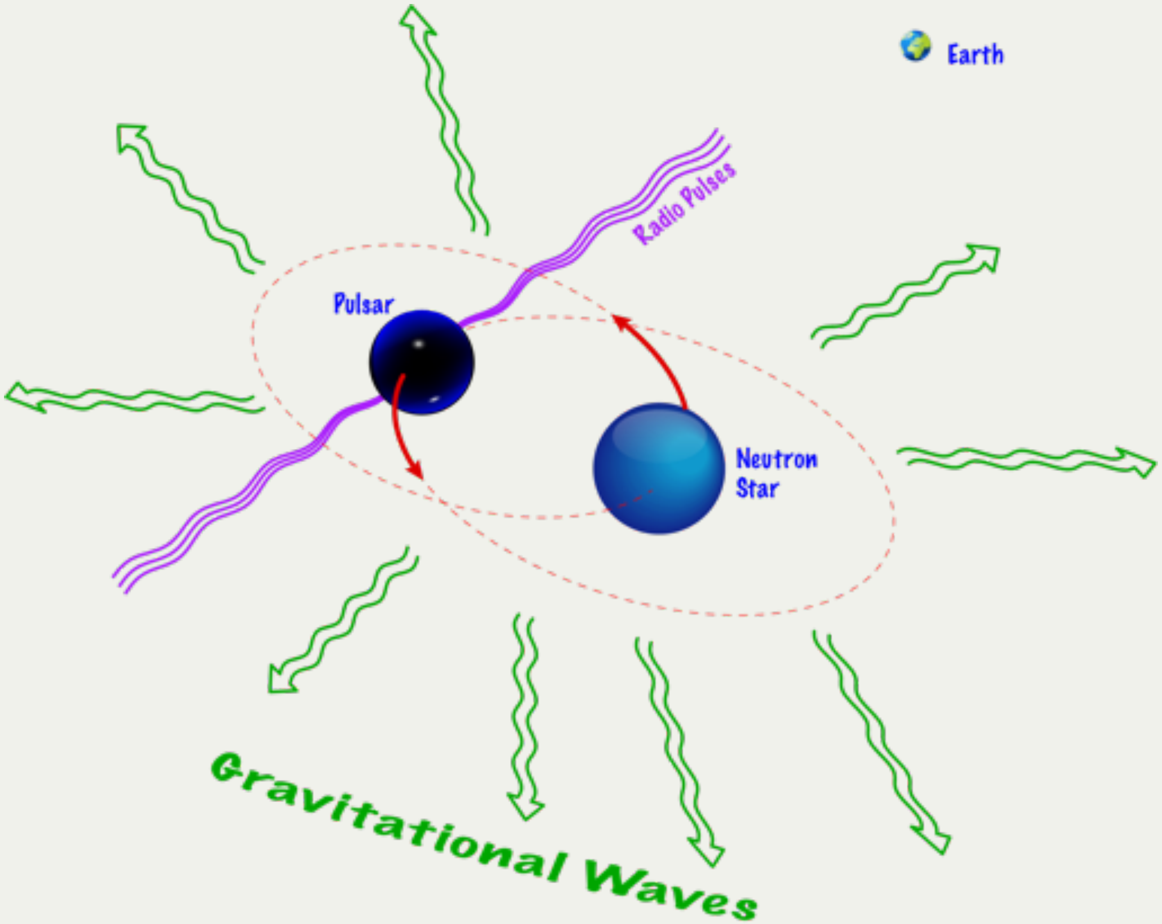


Sources: Wikimedia; ESA

Two polarisations

- just like light

First evidence: Hulse-Taylor pulsar

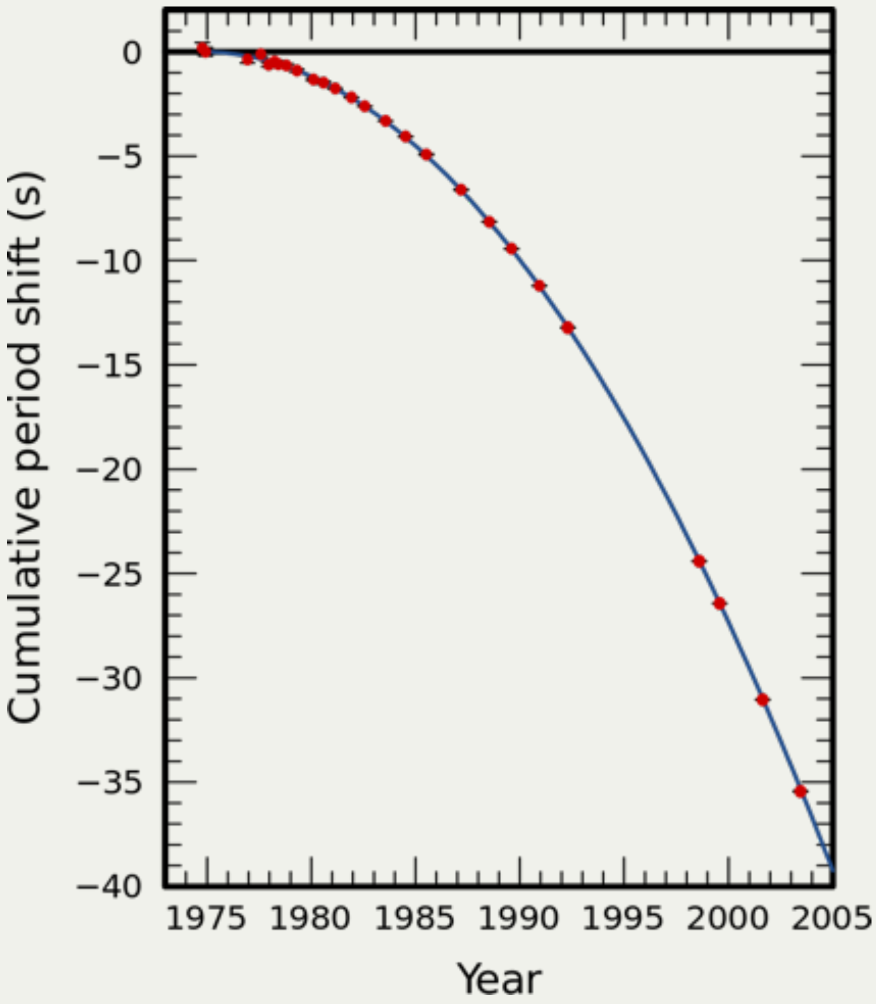


Source: Shane L. Larson

Hulse-Taylor pulsar

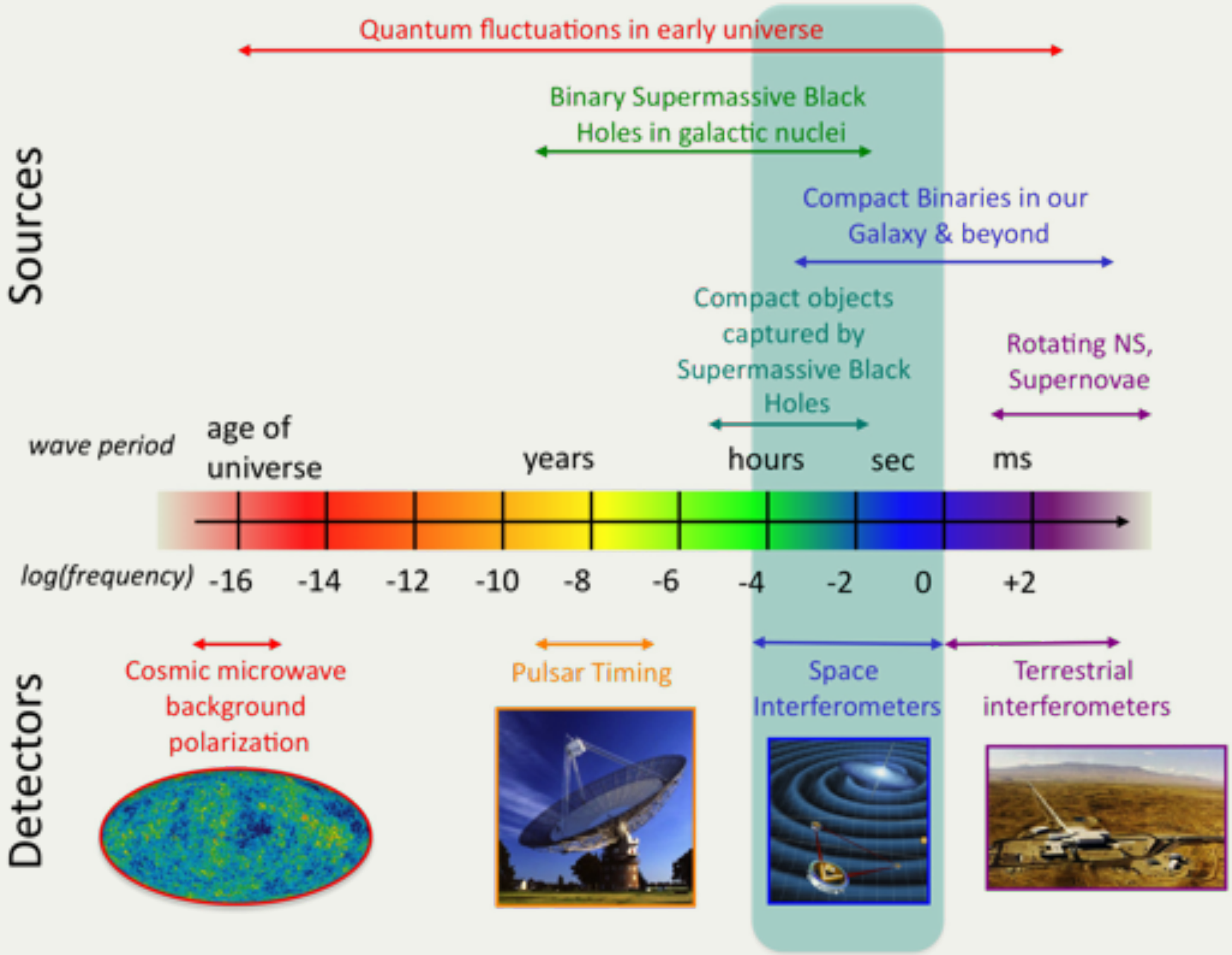
- Two neutron stars, of which at least one pulsar
- Orbital diameter: 3 light seconds
- Orbital period: 7.75 hours
- Orbit slowly contracting (3.5 metres per year)
- Energy must be going somewhere… gravitational waves
- Gravitational wave power output: 7×10^{24} W (about 2% of the Sun's EM radiation).

Orbital decay of Hulse-Taylor pulsar



Solid line - GR prediction; red dots - measurements

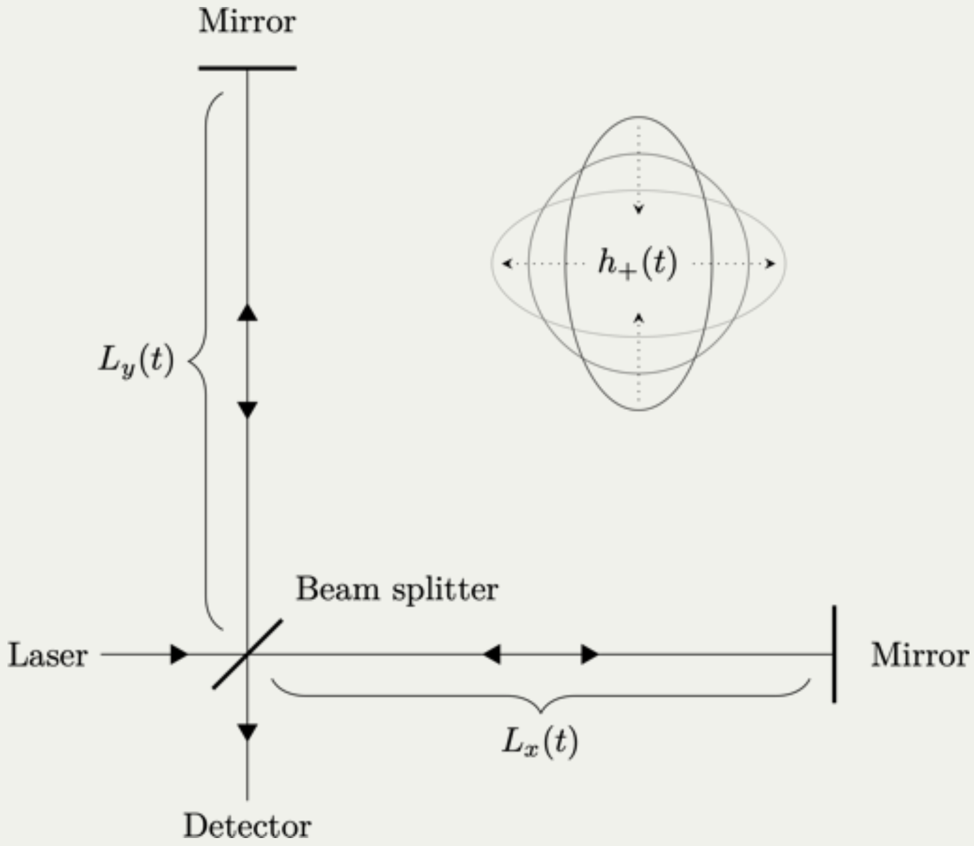
The Gravitational Wave Spectrum



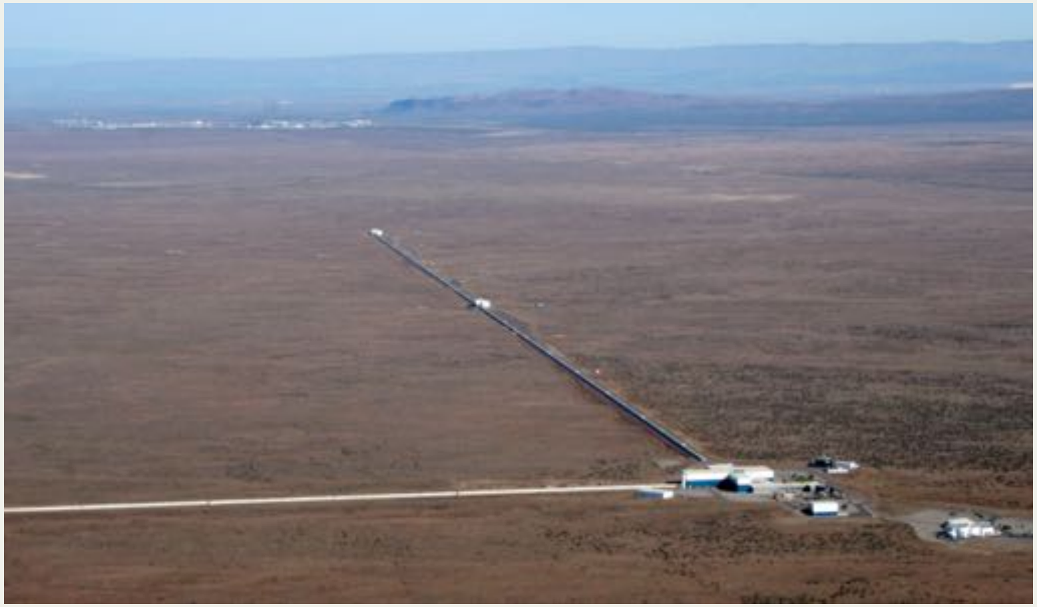
Source: NASA

Direct detection of GWs

Measure time-dependent strain with an interferometer:

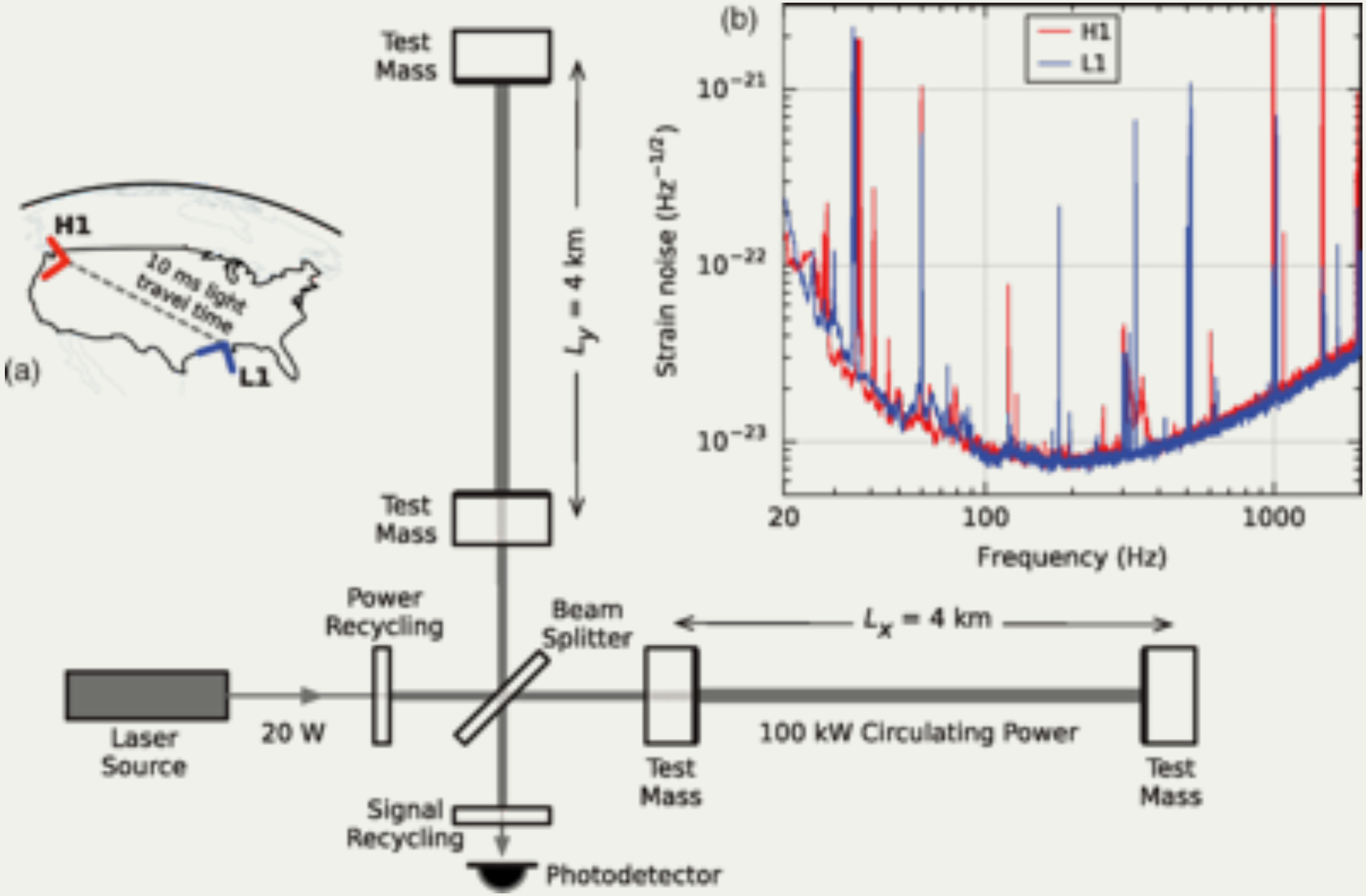


LIGO at the Hanford Site



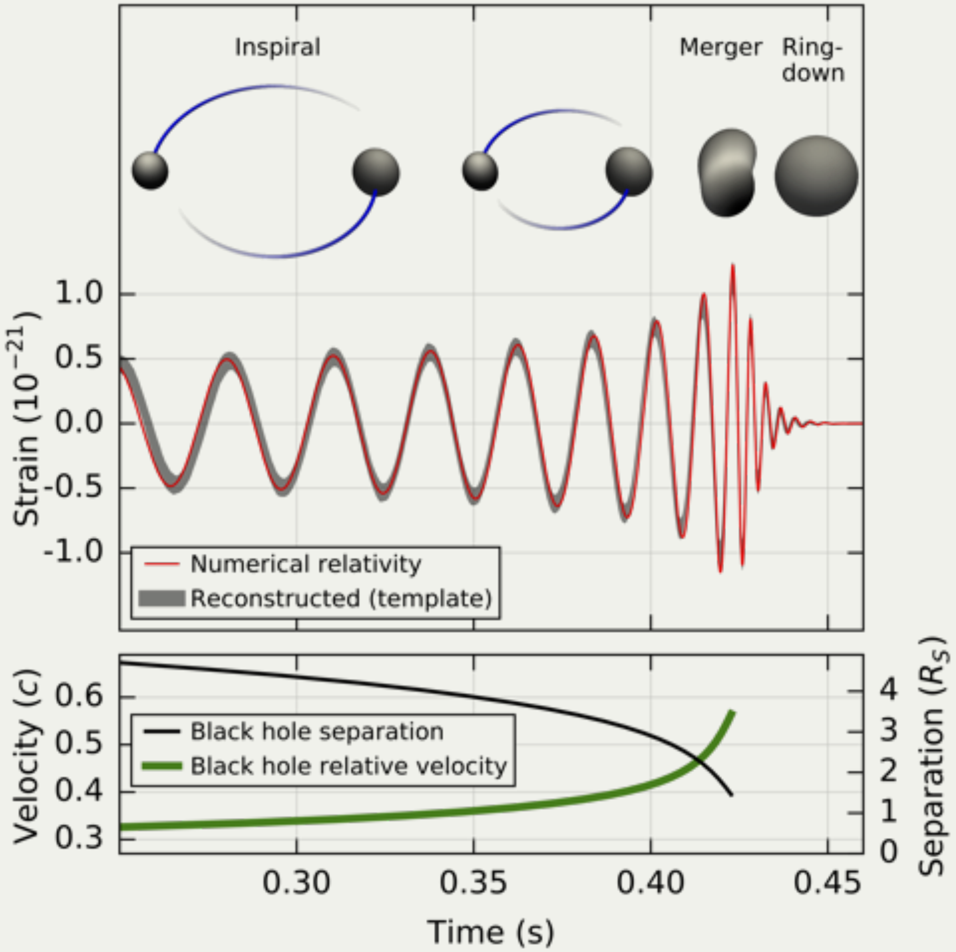
Source: [CC-BY-NC-ND] Prachatai

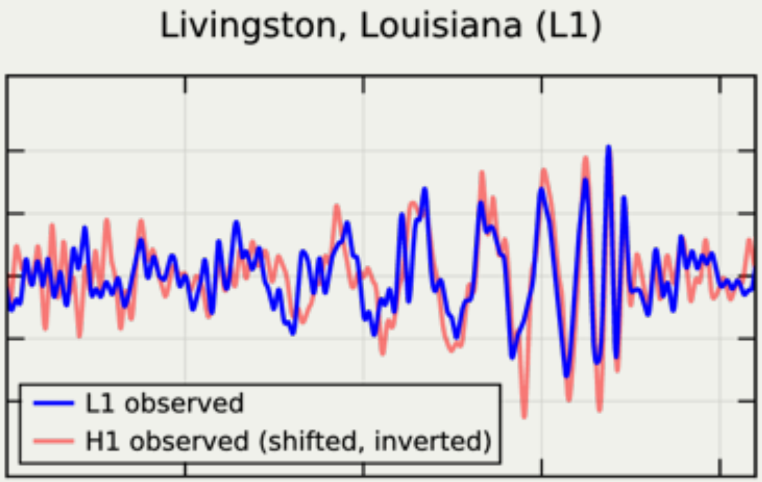
LIGO design



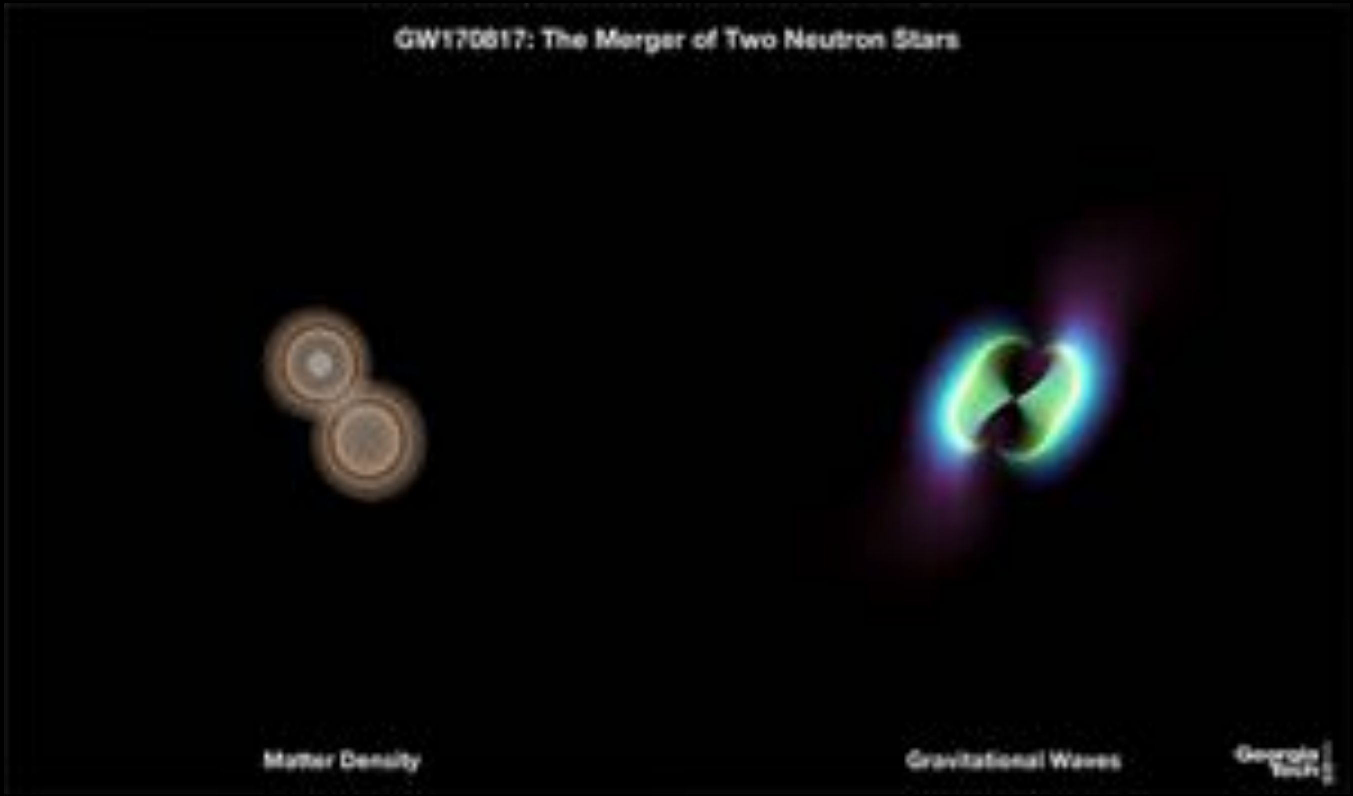
Source: [CC-BY] Phys. Rev. Lett. 116, 061102

Two black holes merging



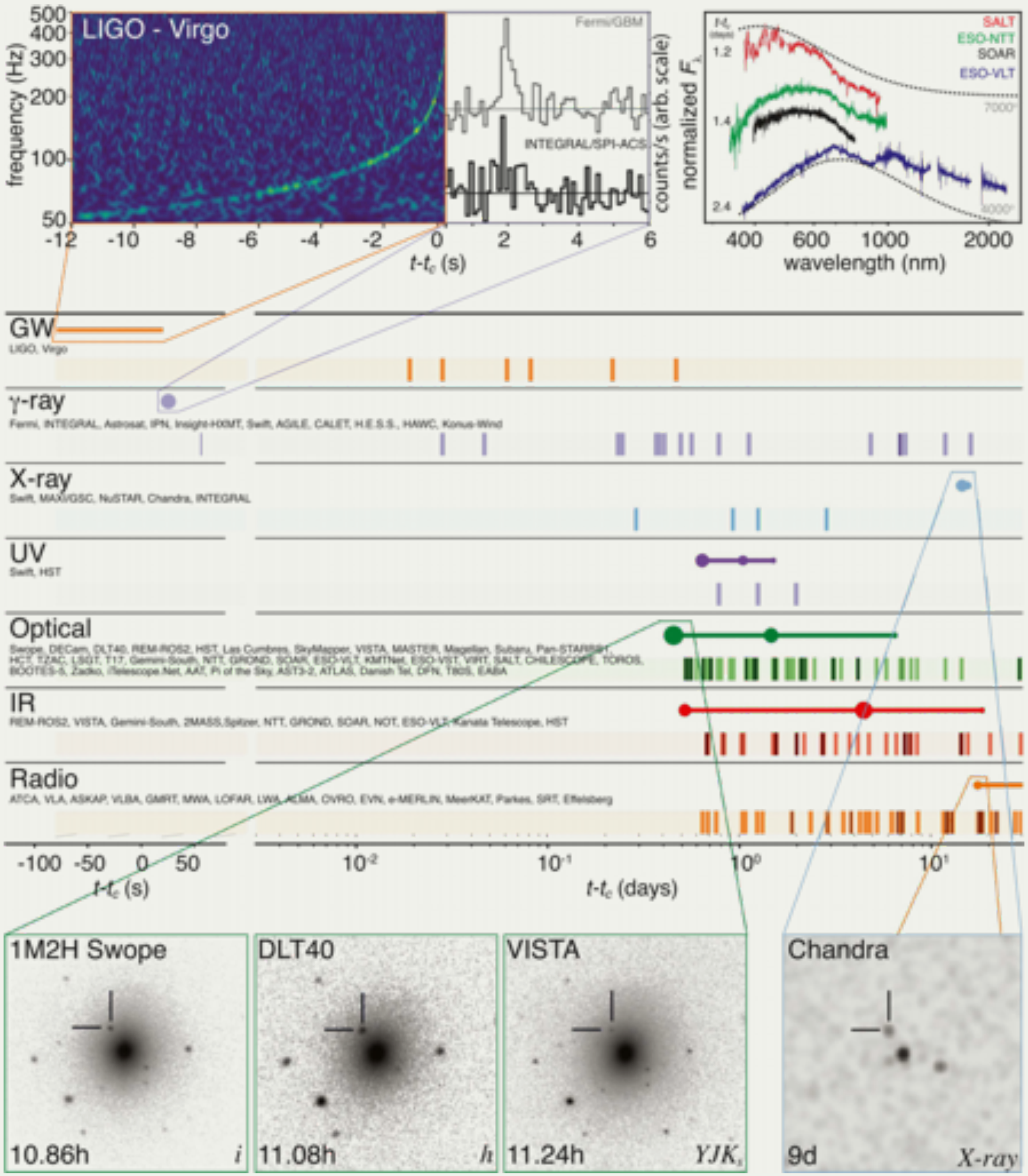


Two neutron stars merging



Light and gravitational waves from neutron stars

Source:
[CC-BY] ApJ 848 L12 (2017)

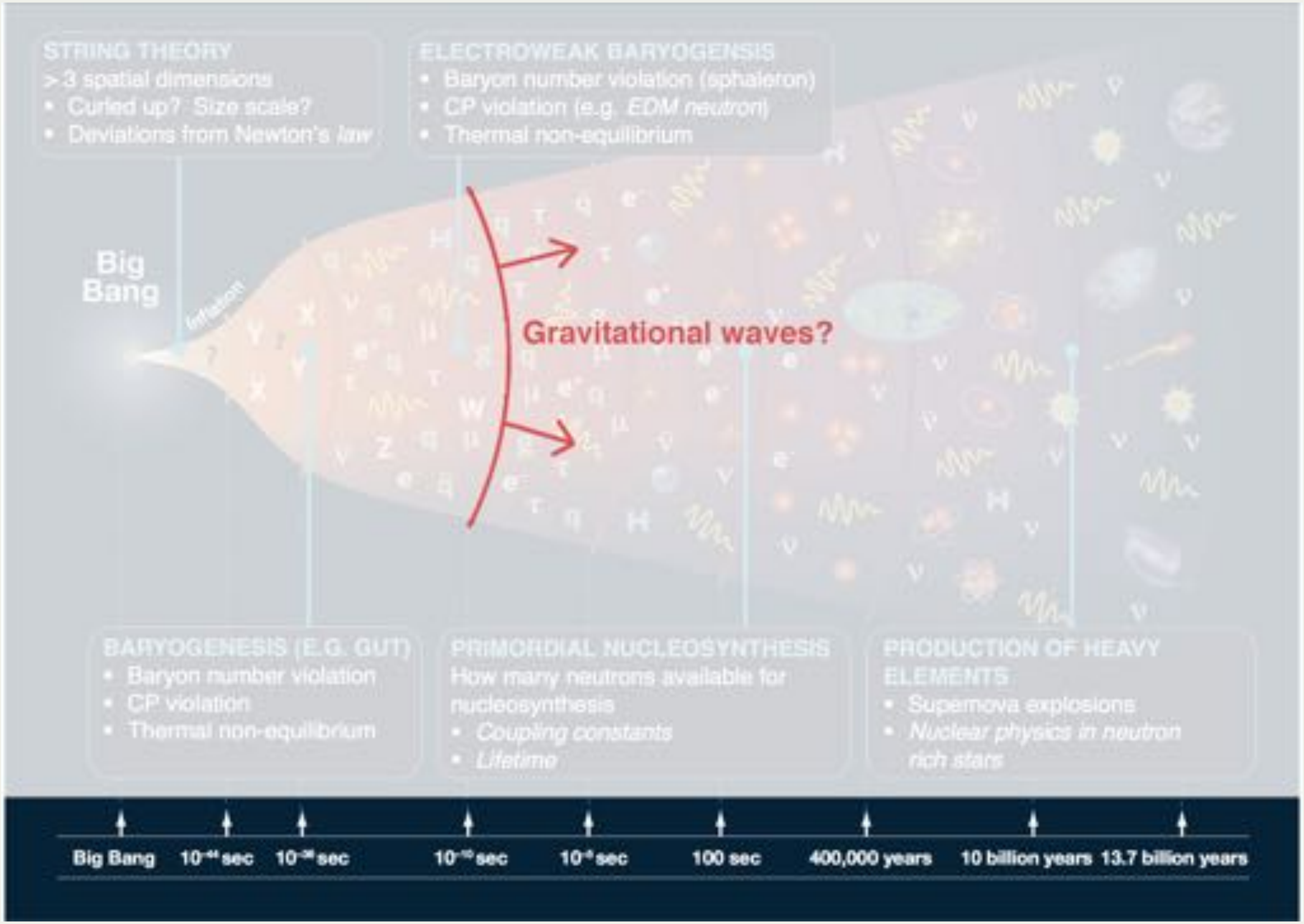


Neutron star merger and cosmology

1. Photons arrived 1.7s later, after travelling 100 M ly
   ⇒ gravitational waves travel at the speed of light
2. Independent measurement of universe's expansion:
   - Luminosity of gravitational waves → distance
   - Telescopes observe host galaxy → velocity

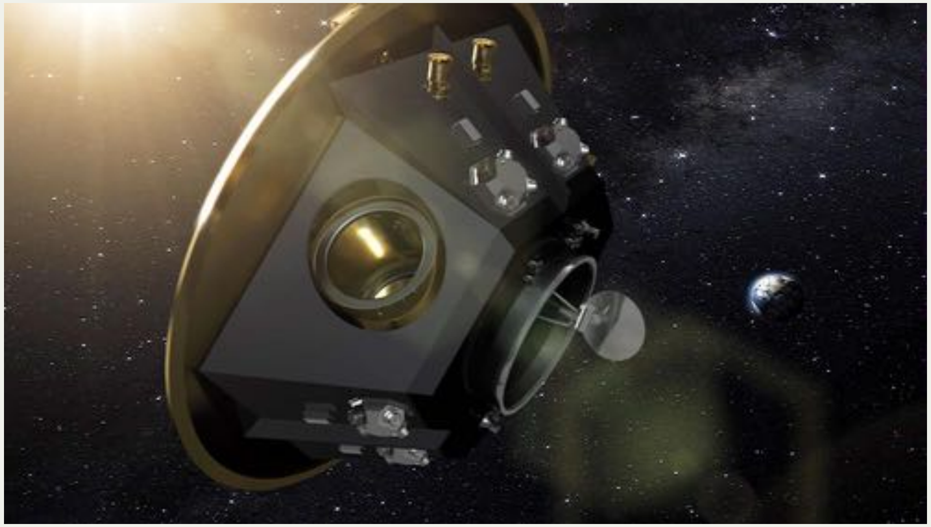
What happened in the early universe? when the universe was optically opaque? to dark matter?

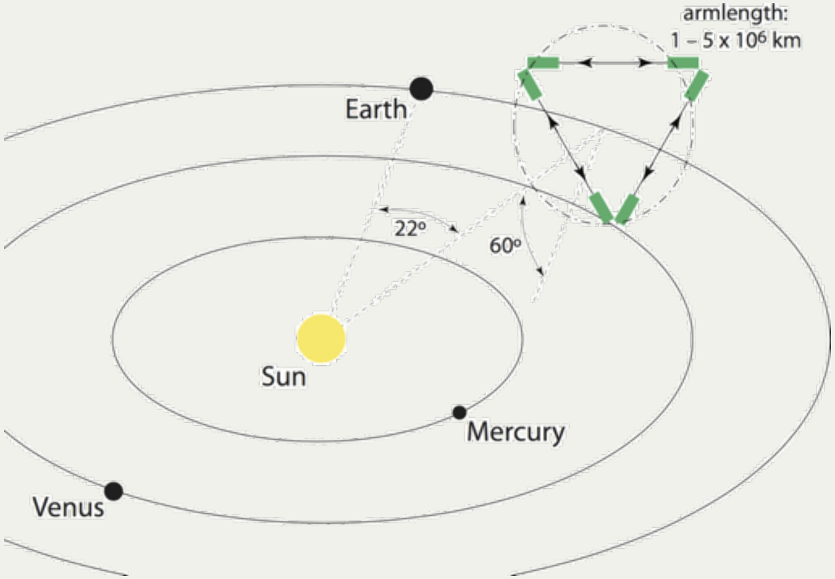
Source: arXiv:1205.2451



LISA mission

Need to study longer wavelengths, need to go to space!

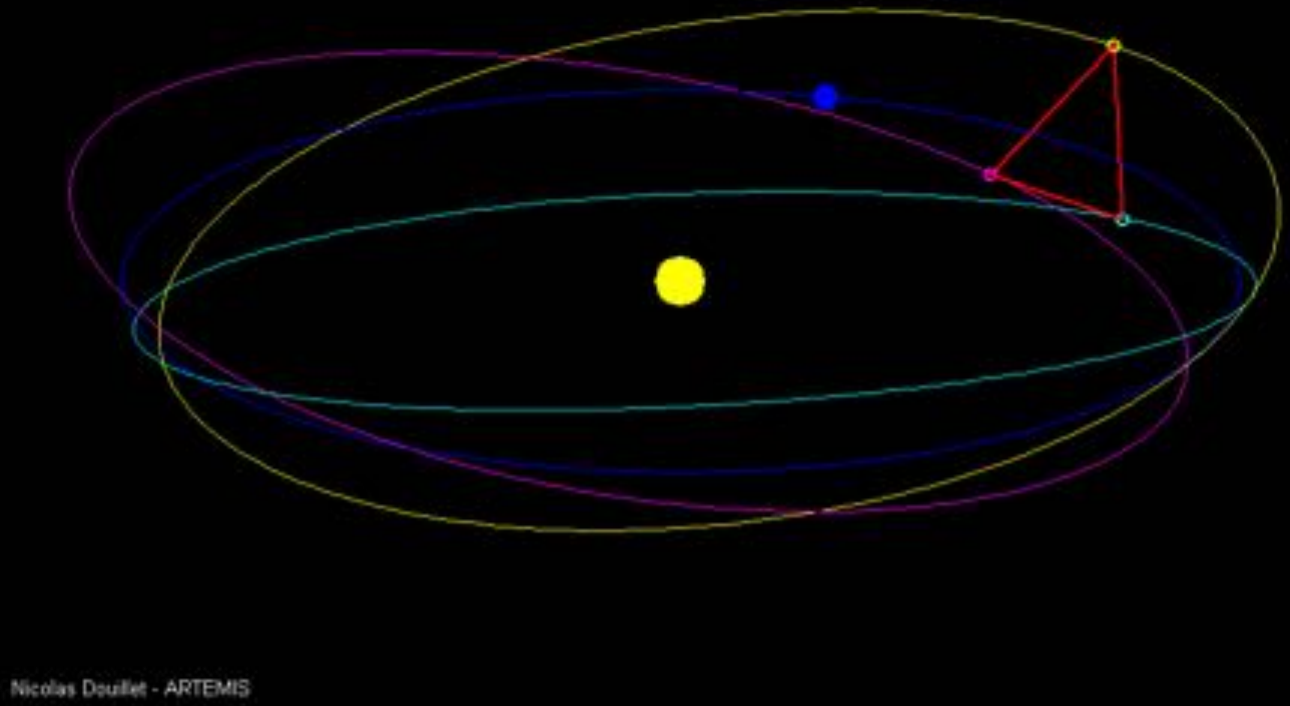




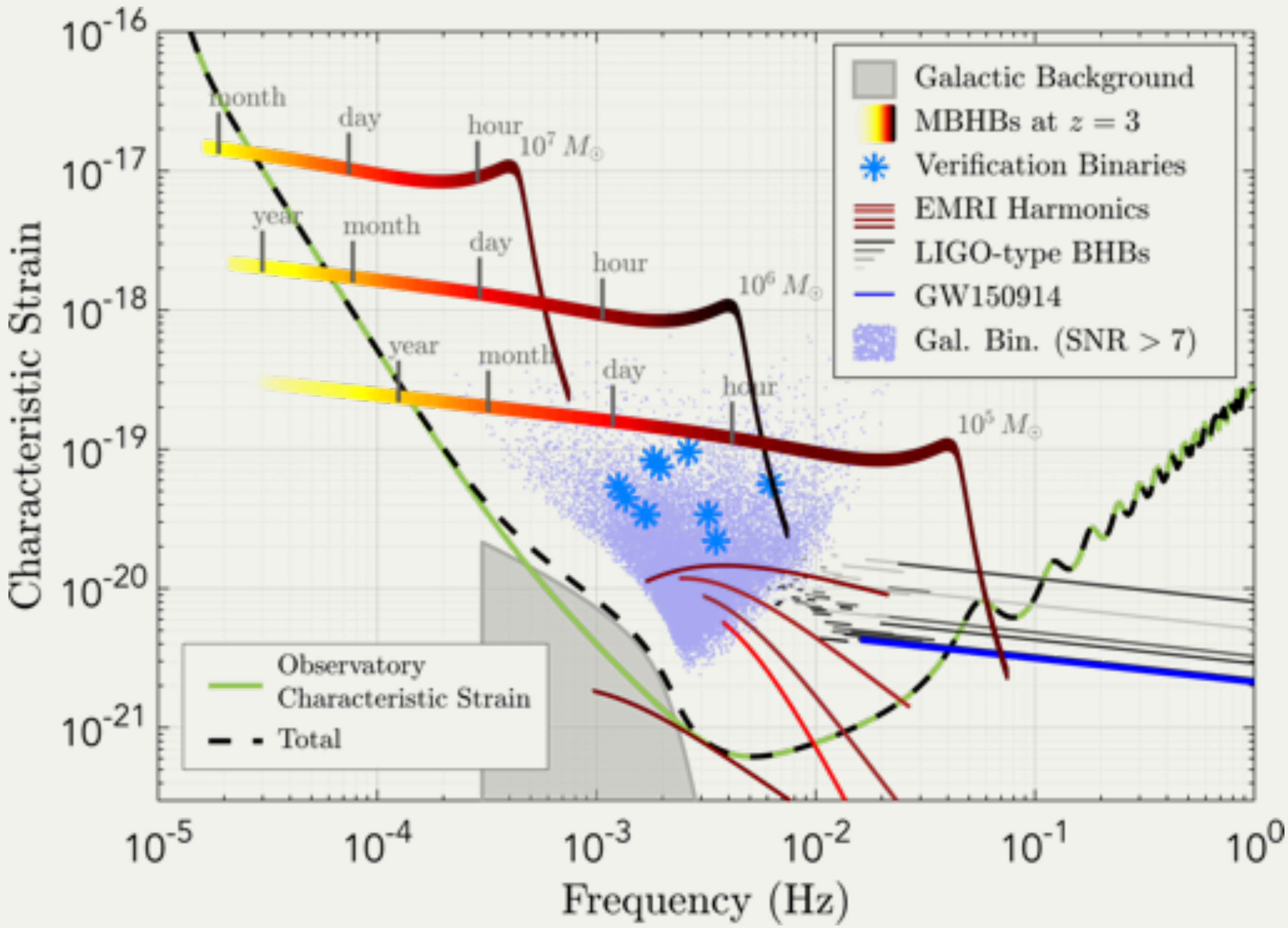
- Three arms (six lasers), 2.5 M km separation
- Launch mid-2030s as ESA L-class mission

Source: LISA Consortium.

LISA's orbit

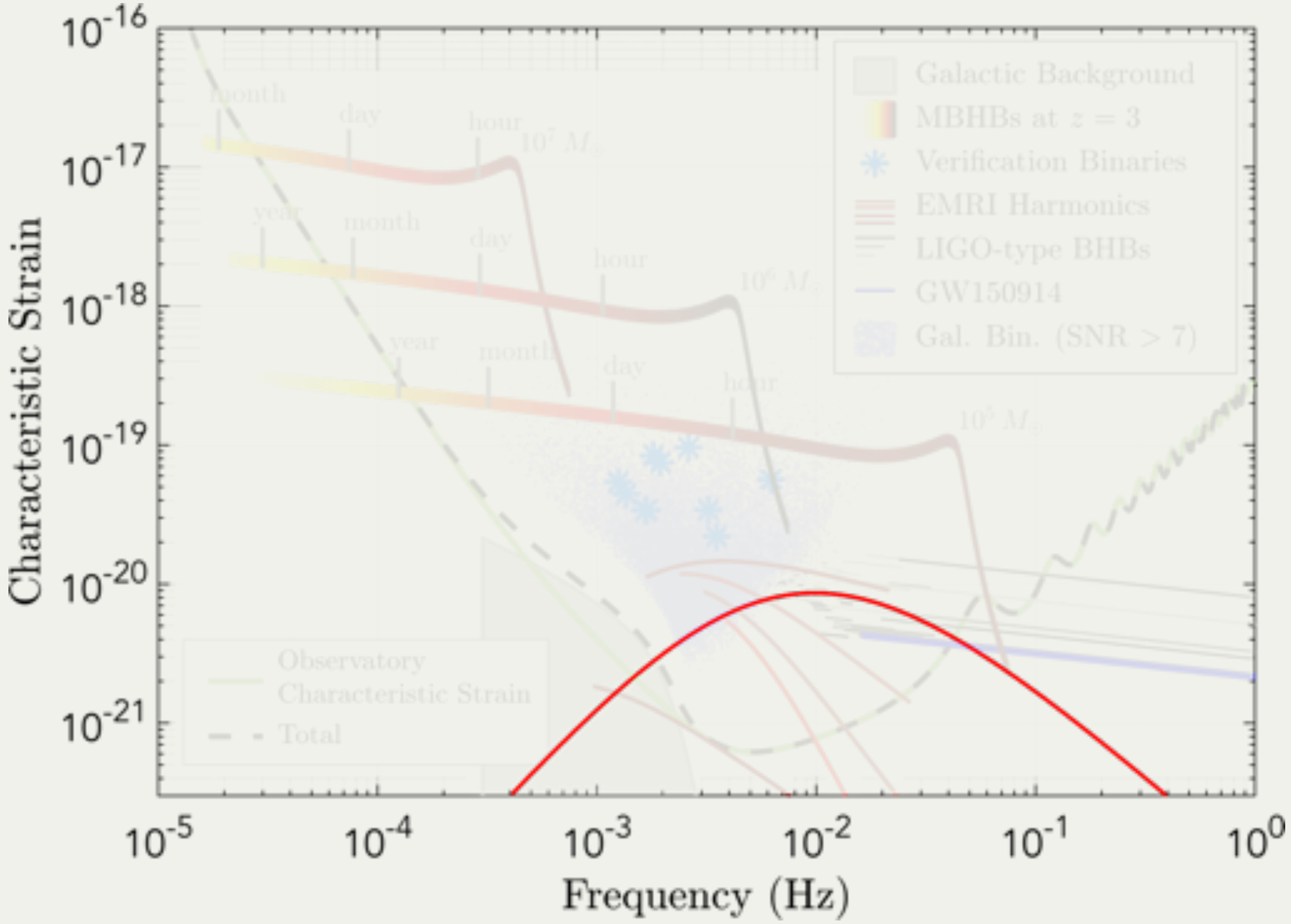


LISA: "Astrophysics" signals



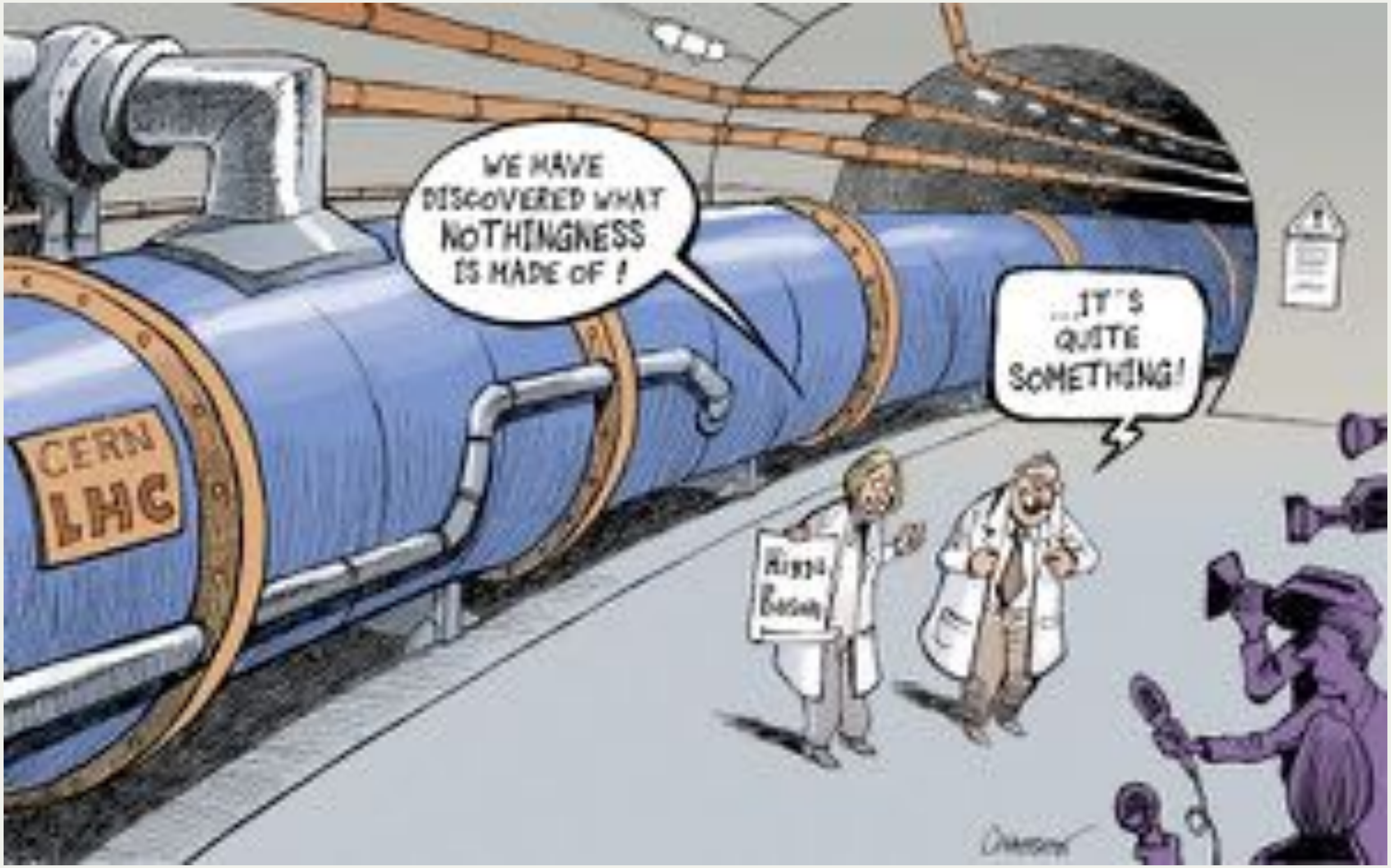
Source: arXiv:1702.00786

LISA: Stochastic background?

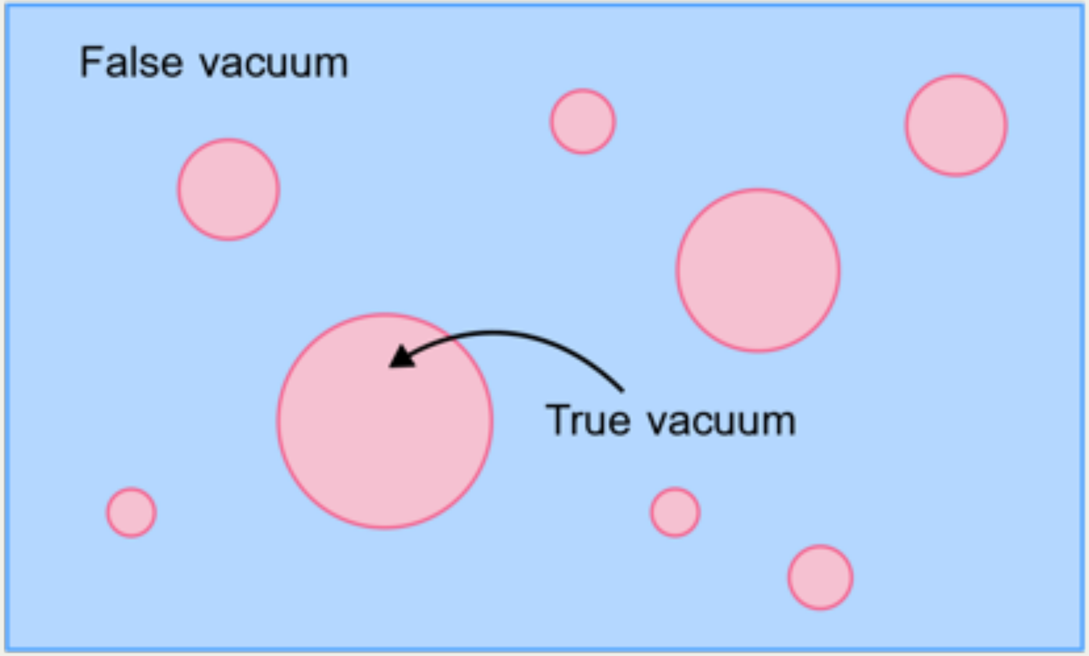


[qualitative curve, sketched on]

Higgs boson

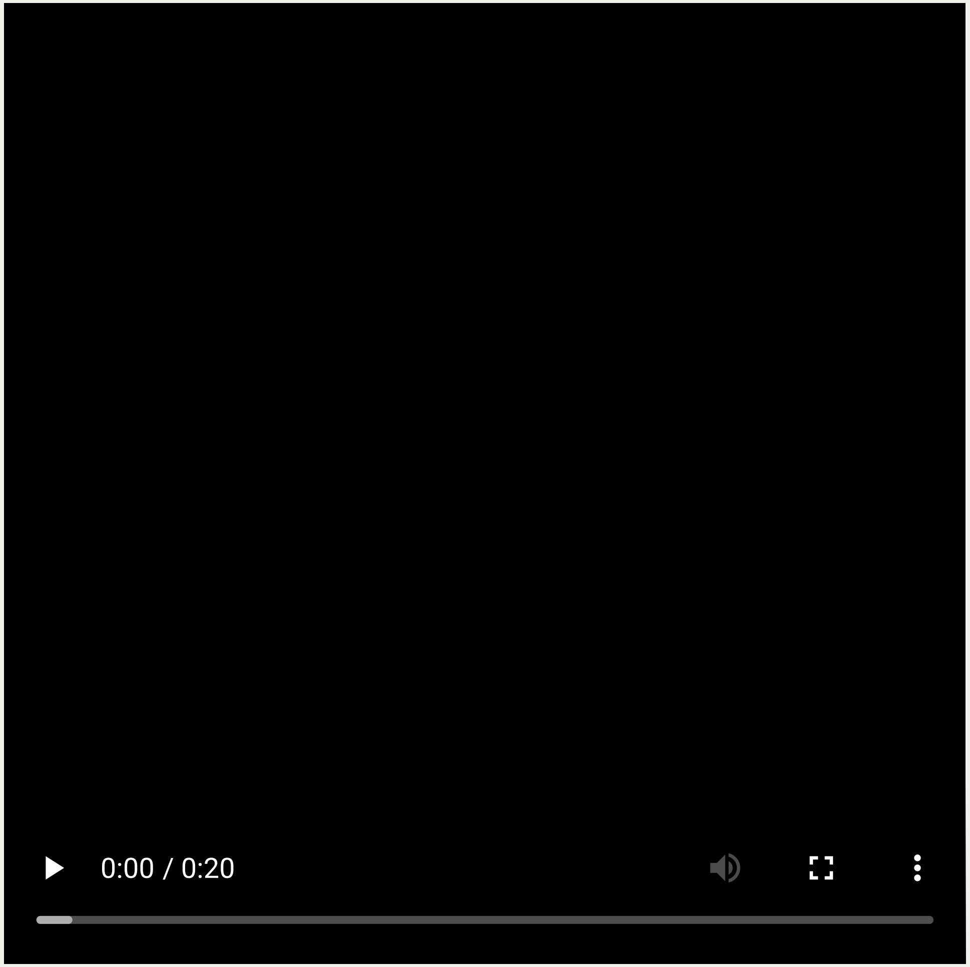

CERN
LHC
WE HAVE DISCOVERED WHAT NOTHINGNESS IS MADE OF !
...IT'S QUITE SOMETHING!
Higgs Boson

How did the Higgs get that way?



Source: Anna Kormu

How did the Higgs get that way?



To conclude: key points

- **Scale of the problem?**
  - Strains around 10^{-21}
  - Frequencies around 100 Hz [LIGO], 1 mHz [LISA]
- **Measurement devices?**
  - Michelson interferometers [LIGO etc.]
  - Time delay interferometers [LISA etc.]
- **Unresolved questions**
  - Existence and amplitude of stochastic background
  - Whether it can be detected, given foregrounds