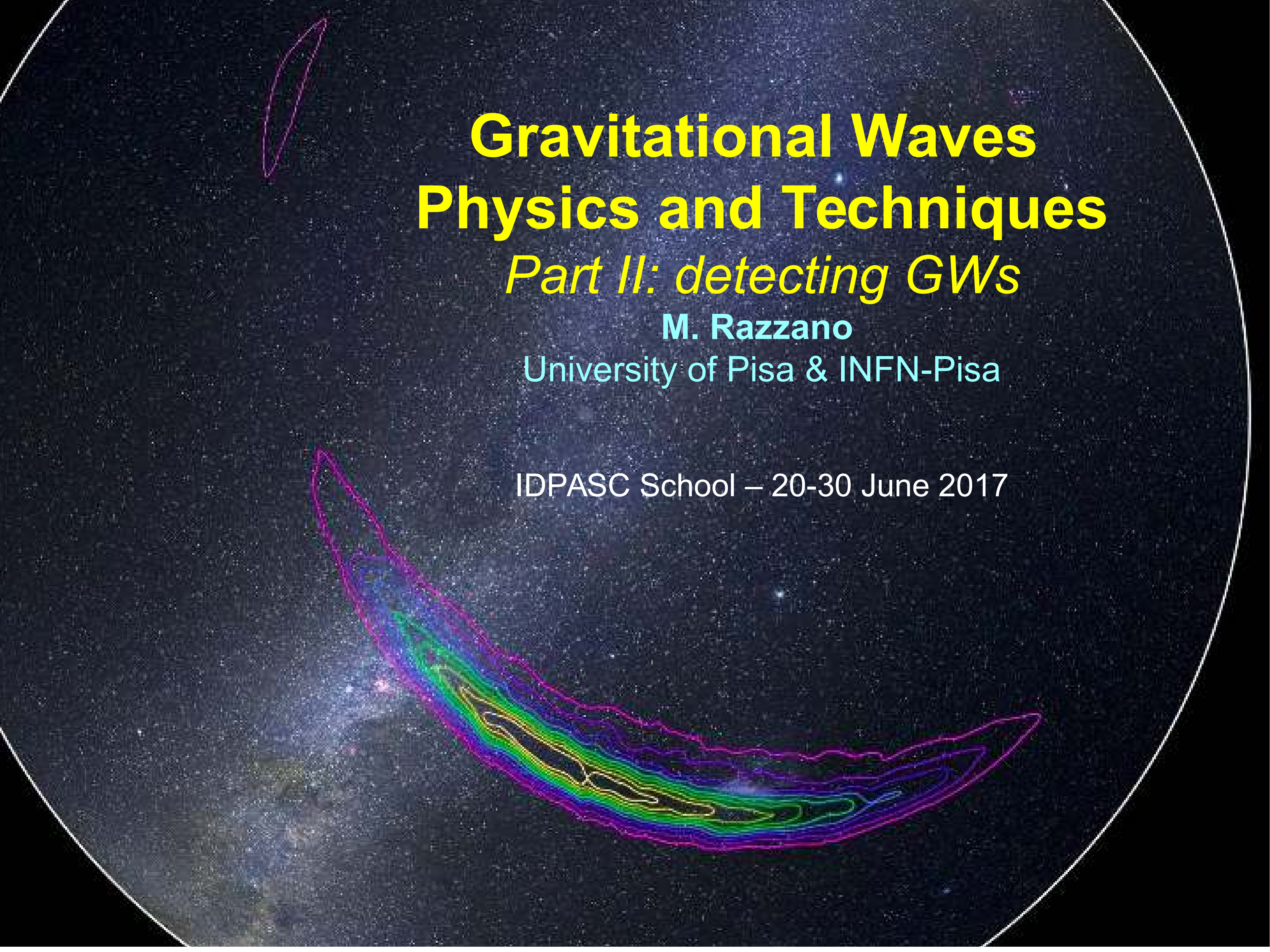

Gravitational Waves Physics and Techniques

Part II: detecting GWs

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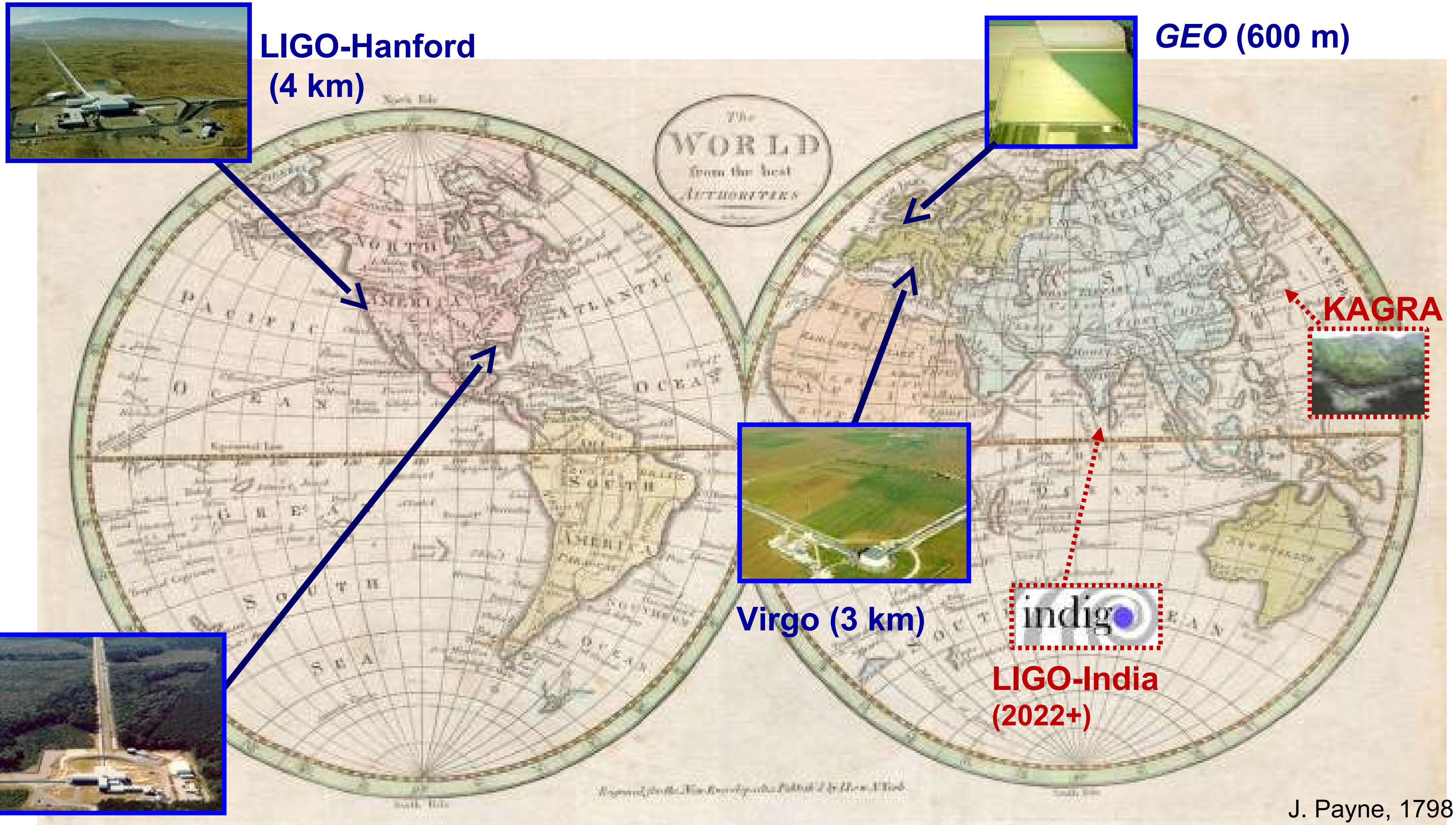
IDPASC School – 20-30 June 2017

The era of Advanced GW detectors

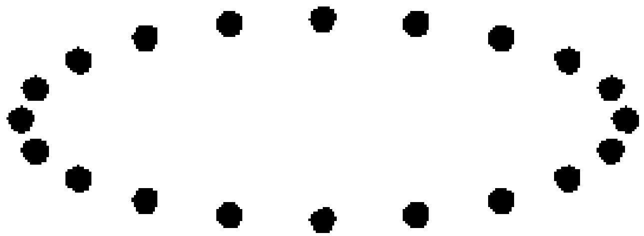


LIGO-Livingston
(4 km)

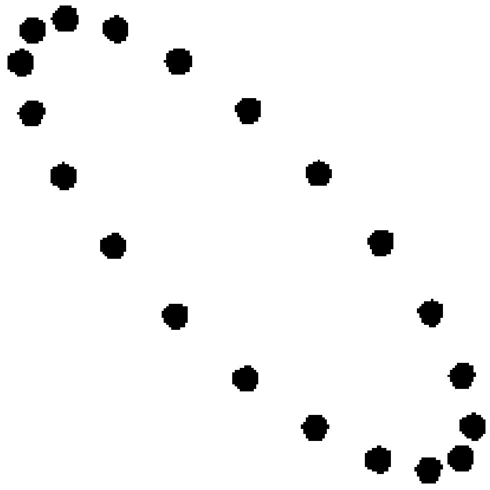
Advanced LIGO now in its second observing run (O2)
Virgo planned to join soon

M. Razzano

Effect of gravitational waves



Plus (+) polarization



Cross (x) polarization

Effect of gravitational waves

The GW strain h(t) is related to the relative change in length:

$$h \approx \Delta L / L$$

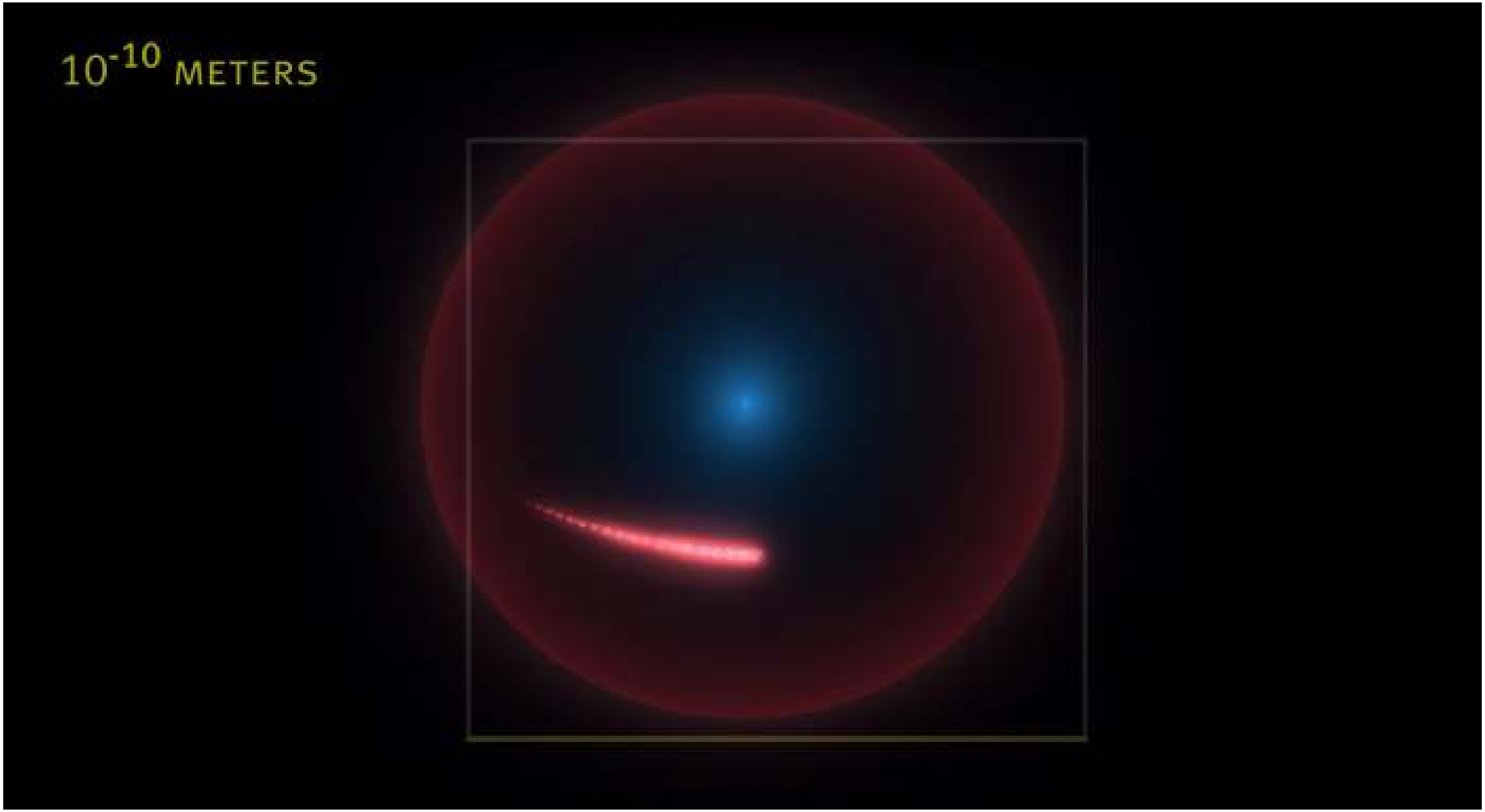
The problem is, h is very small (order of 10^{-21} !)

This means, on a length scale of 1 km:

$$\Delta L \approx 10^{-18} \text{ m !}$$

How small it is?

Effects of gravitational waves



Catching gravitational waves

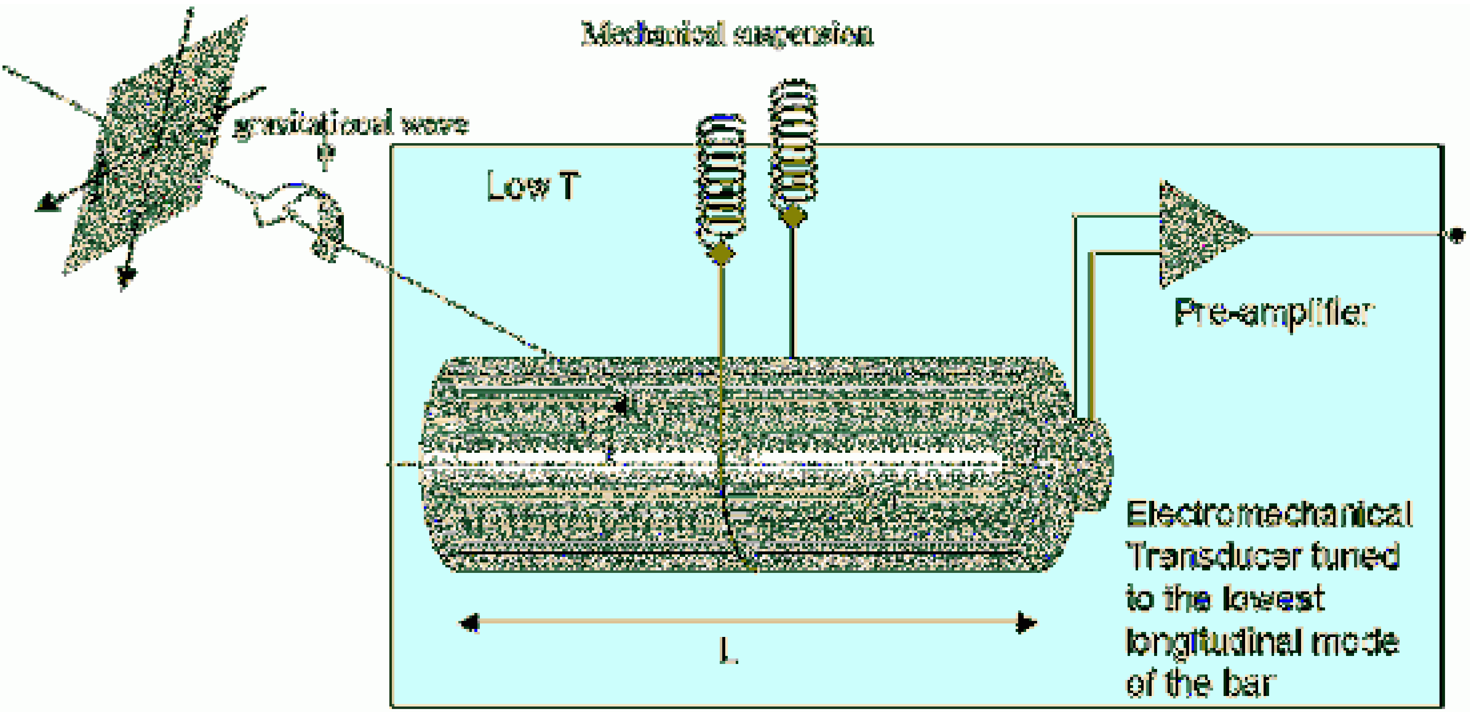
Special Collections and University Archives, University of Maryland Libraries

First experiments by Joseph Weber in 60’s

Resonant bars

First claim of detections in late 60’s, never confirmed by other experiments

Resonant detectors

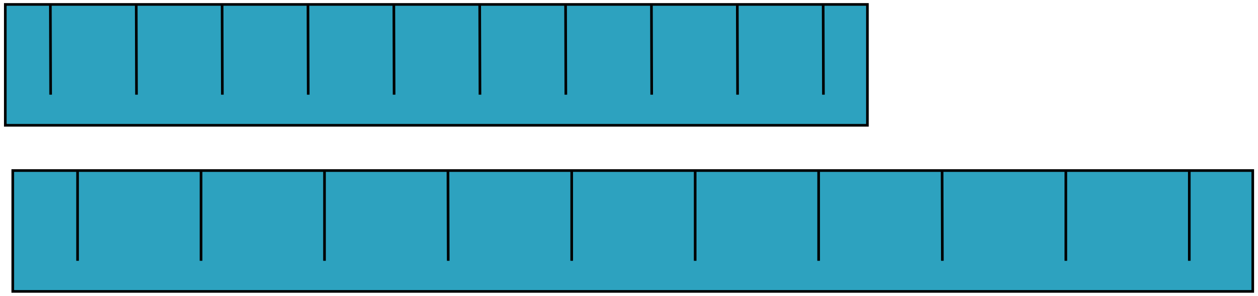


Auriga collaboration

- Resonant bars (but also other shapes, e.g. spheres)
- Freq ≈1 kHz, range ≈ 100 Hz
- Main detectors: AURIGA, Allegro, Explorer, Nautilus, Niobe

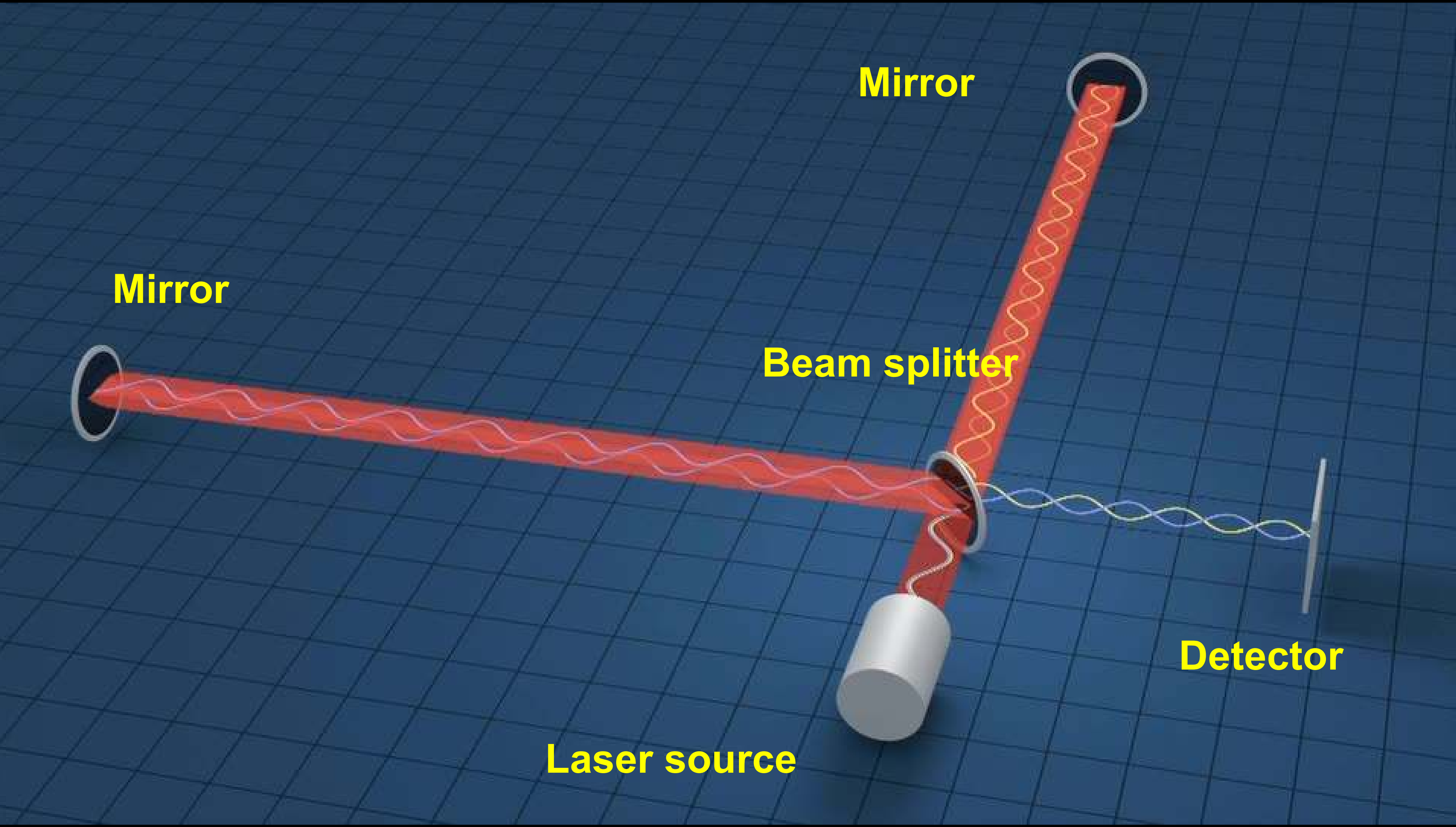
From resonant bars to the interferometers

- How do we sense spacetime deformations?
  - Our rule also is distorted



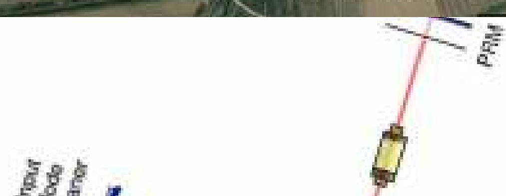
- But, we can use light as a "meter"
  - Speed constant and invariant
  - Measure back and forth time

Interferometer principle

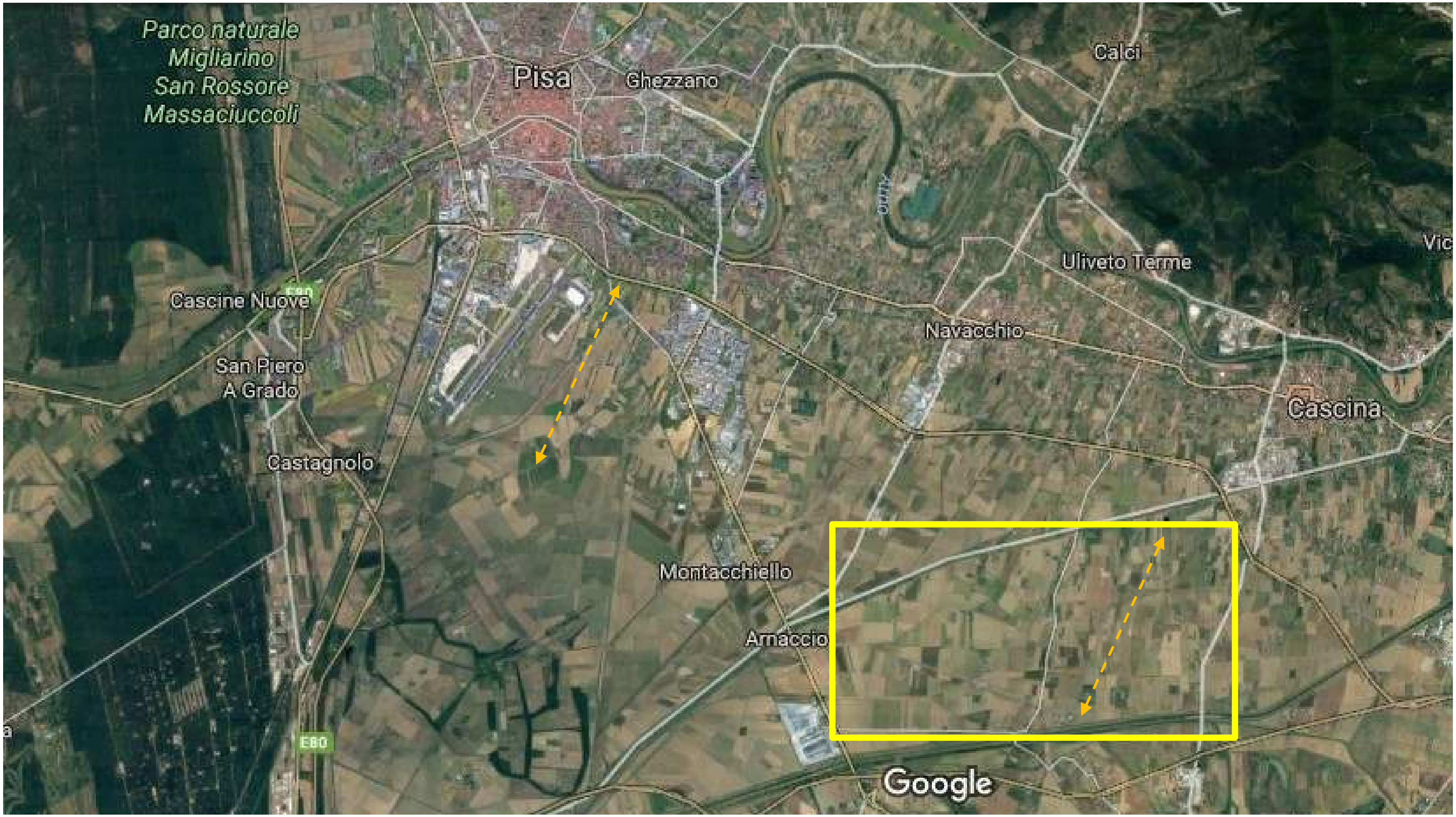


Virgo

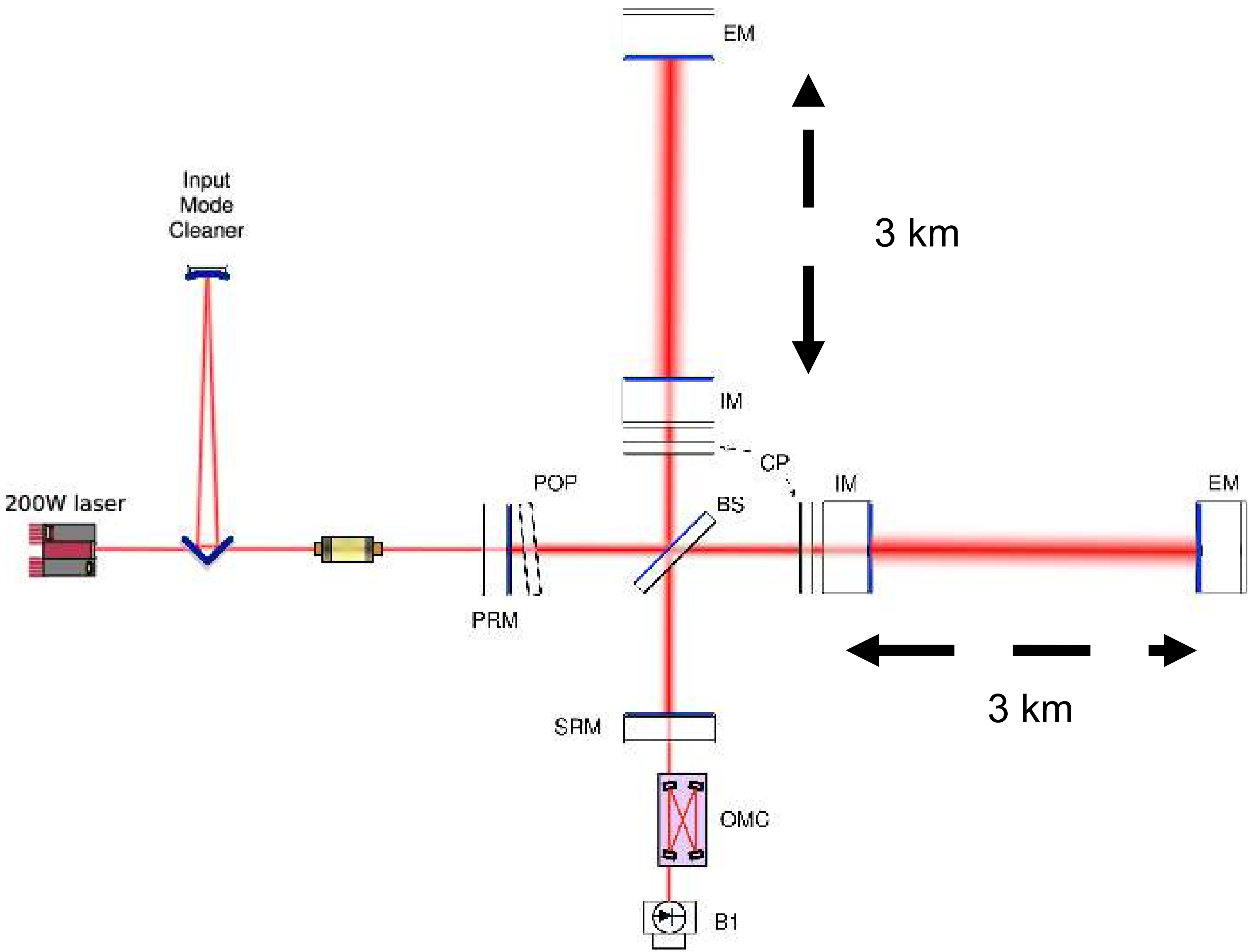
Advanced Virgo



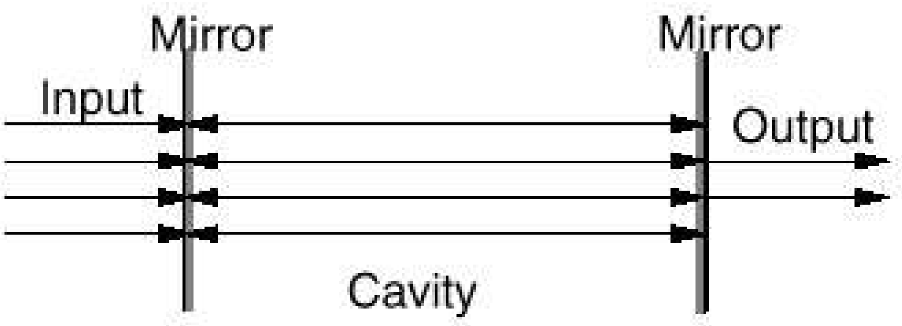
Advanced Virgo



Advanced Virgo



Fabry-Perot cavity

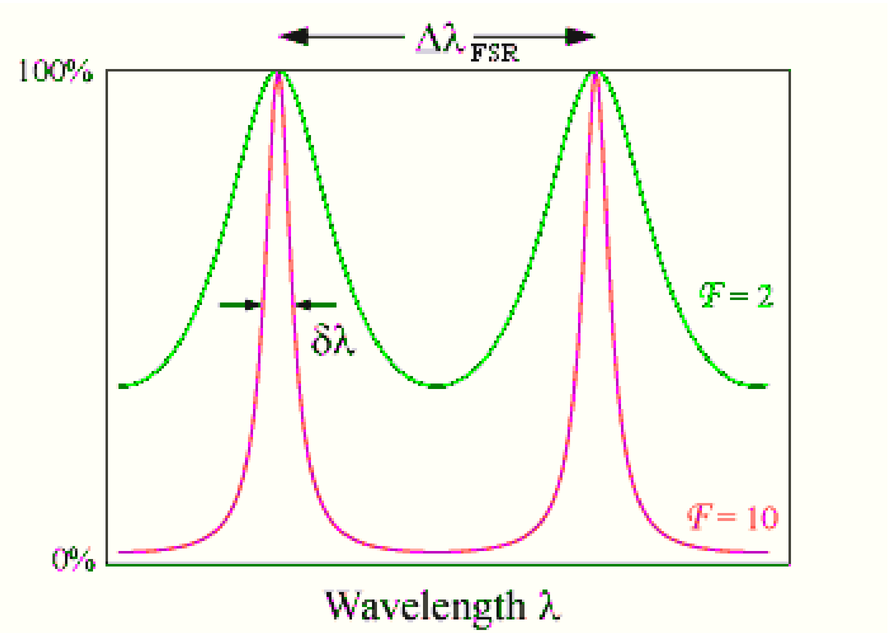


Optical cavity to make light bounce back and forth (larger L) and be more sensitive

Size and wavelength can be adjusted to increase gain

When gain is maximum, we say we are at resonance

The Finesse parameter describe the sharpness of the peaks (and the resolution) of the cavity



Describing the noise

- Given a random process, we can describe it in terms of statistics
- If noise is stationary, we can define some useful quantities (e.g. mean, variance)
- We define the power spectrum PS

$$\lim_{T\to\infty} \frac{1}{T} \int_{-T/2}^{T/2} (x_T(t))^2 dt$$

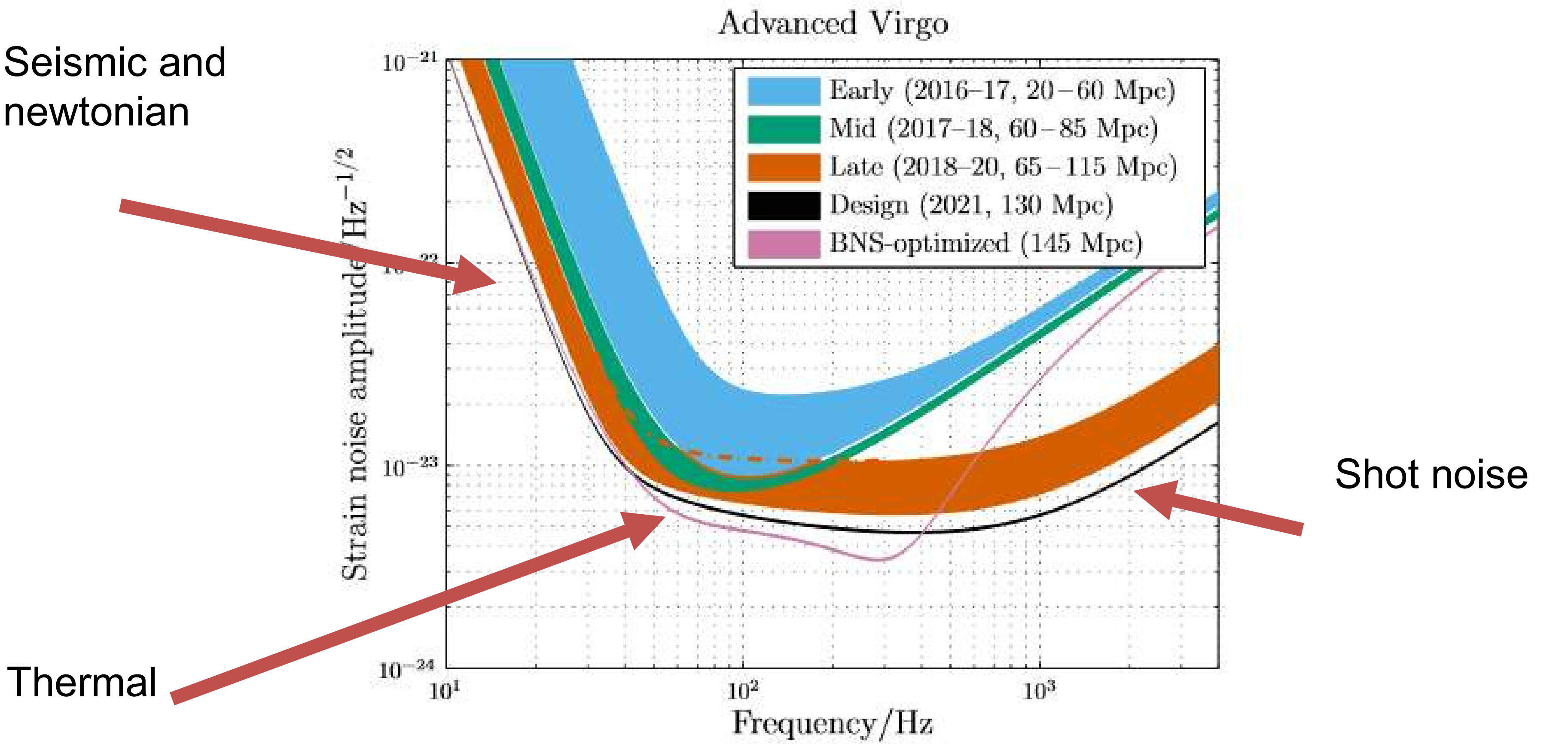
- Noise can be white (PS independent of frequency) or colored
- Given the power spectrum, we can derive the power spectral density:

$$S_x(f) = \lim_{T\to\infty} \frac{2}{T} \left(\int_{-T/2}^{T/2} x(t) e^{-2\pi i f t}\, dt \right)$$

$S_x(f)$

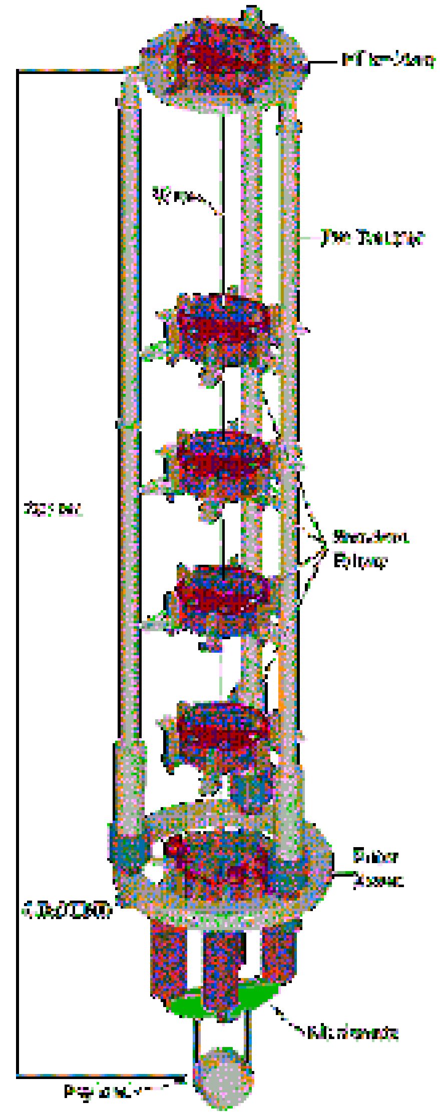
- The sqrt of S is called spectral amplitude or spectral strain sensitivity

Fighting the noise



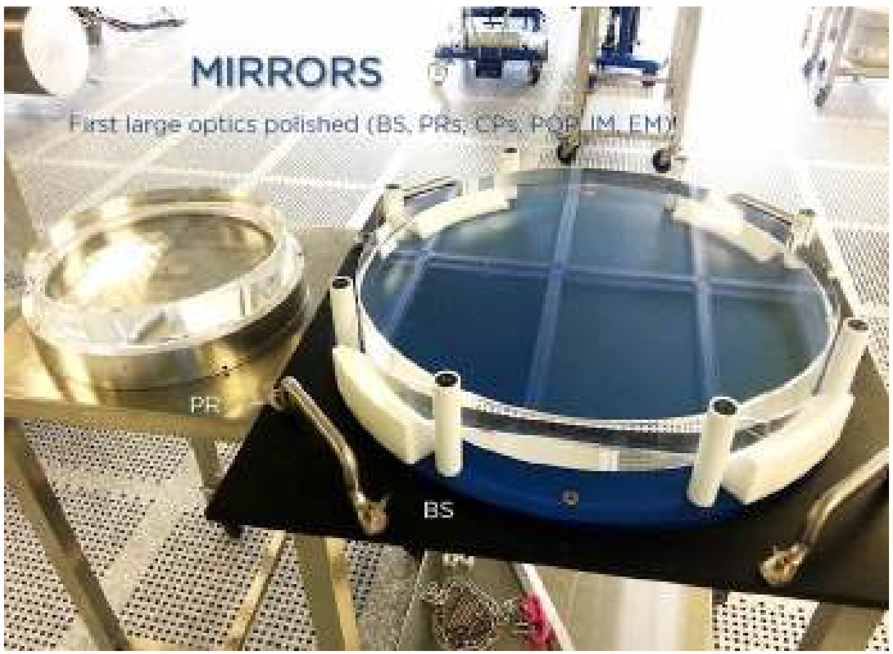
Seismic noise

- **Superattenuator**
  - **Inverted pendulum**
  - **Attenution of 10^{12} at 10 Hz**



Frontier technology

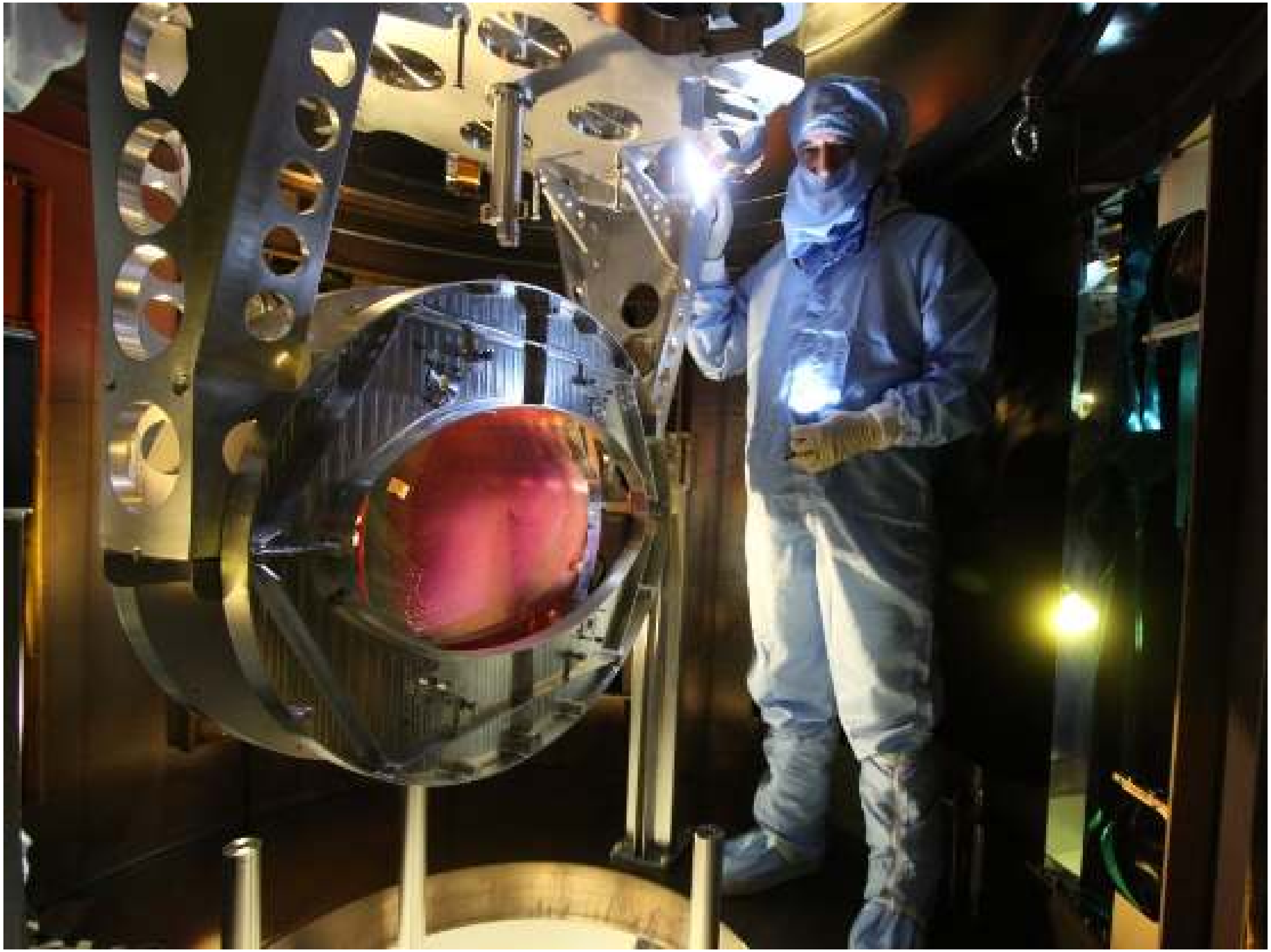
- **Mirrors**
  - **SiO2, 35 cm diameter, 20 cm thick, precision 10^{-8} m**
- **Monolithic suspensions**
  - **Fibers SiO2, 400 micron diameter, support 42 kg mirrors**



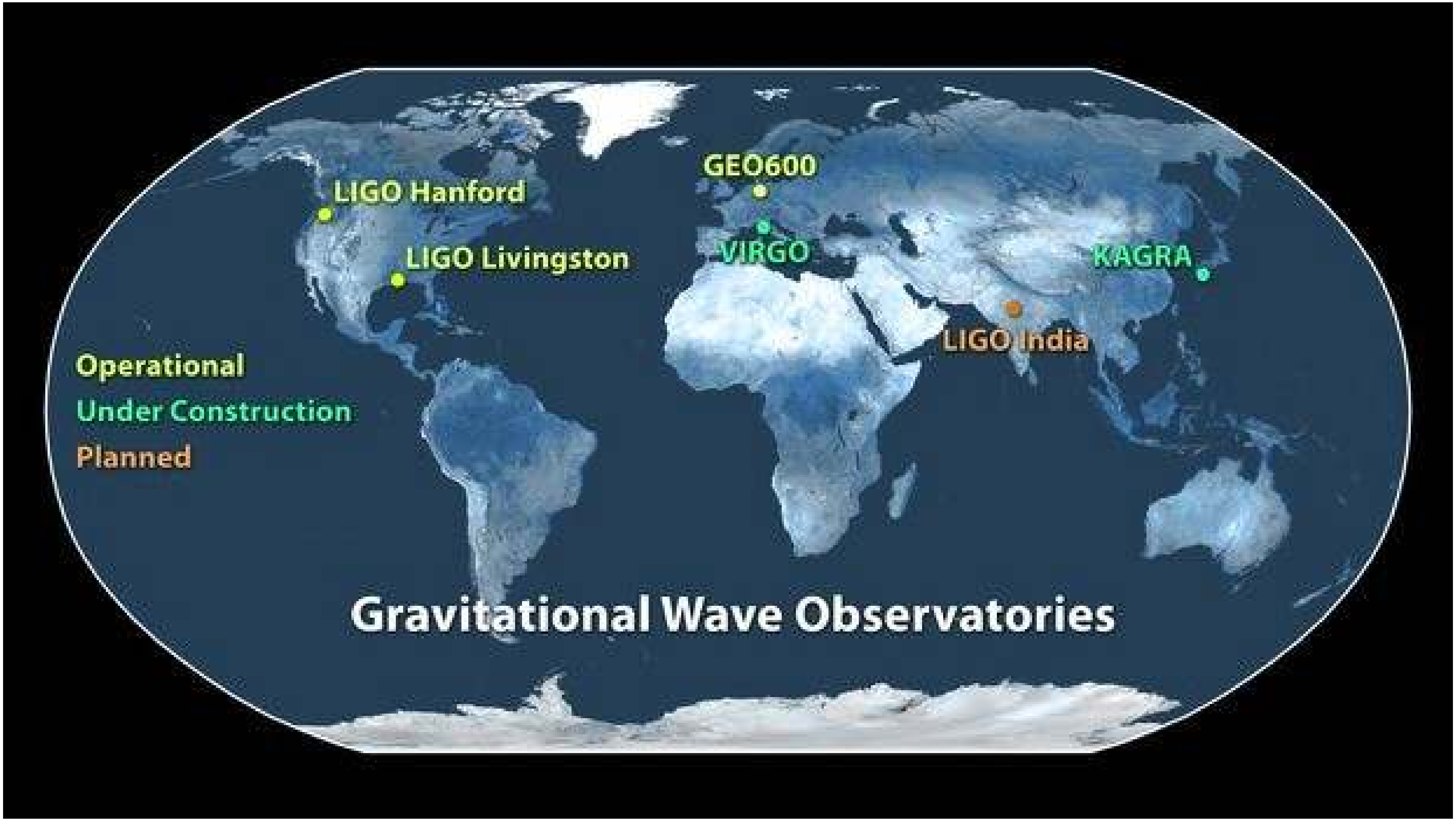
Ultra-high vacuum

- Largest vacuum chamber in Europe
  - 2 tubes + 10 towers = 7000 m^3
  - Constant vacuum 10^{-9} mbar

Beam splitter



International network



International network

GEO600
(600 m)

VIRGO
(3 km)

KAGRA
(3 km)

LIGO Hanford (4 km)

LIGO Livingston (4 km)

The era of Advanced GW detectors

Prospects for Observing and Localizing Gravitational-Wave Transients with Advanced LIGO and Advanced Virgo

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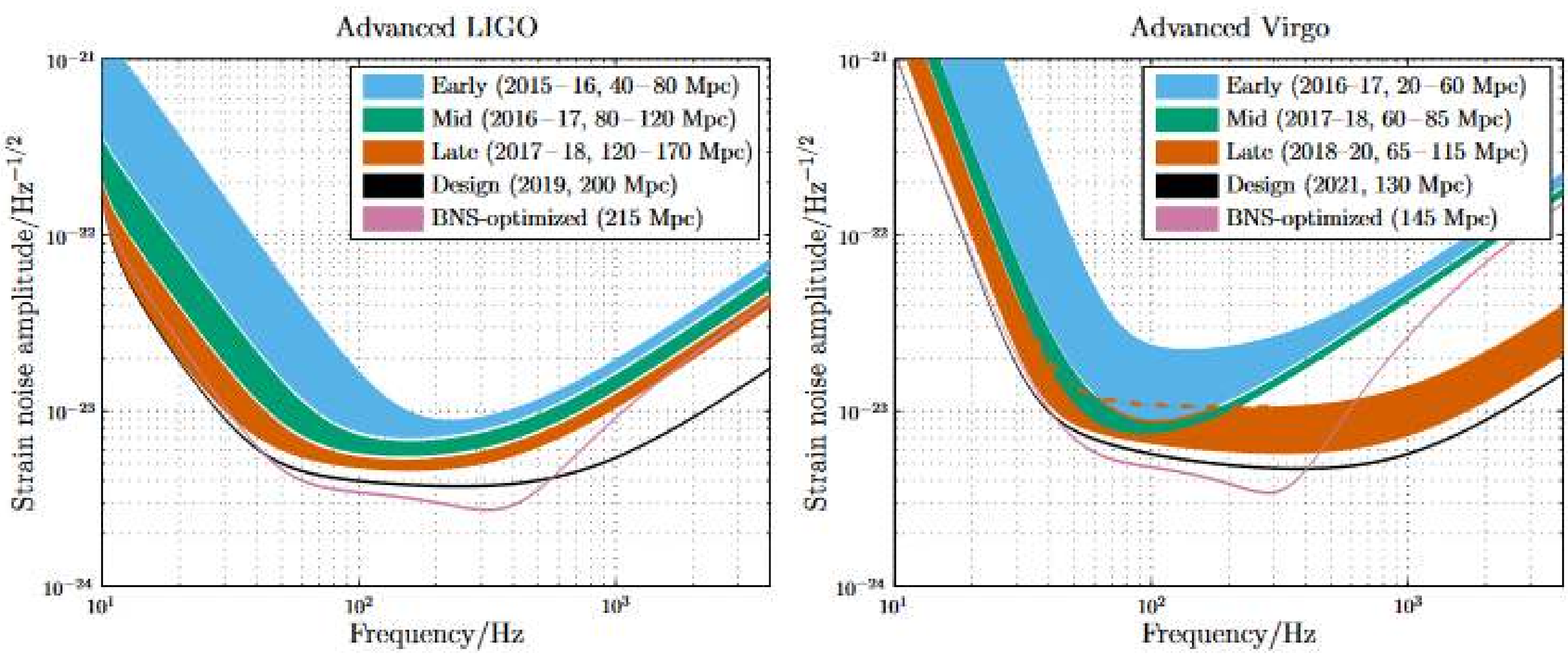
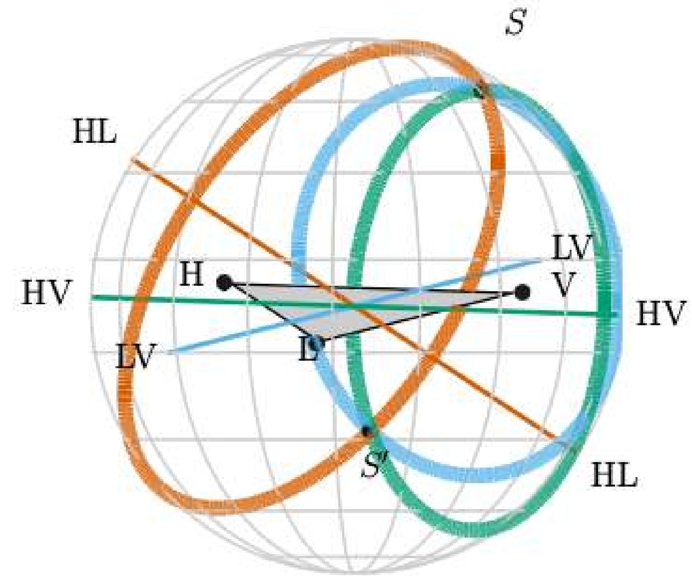


Abbott+16, LRR 19,1

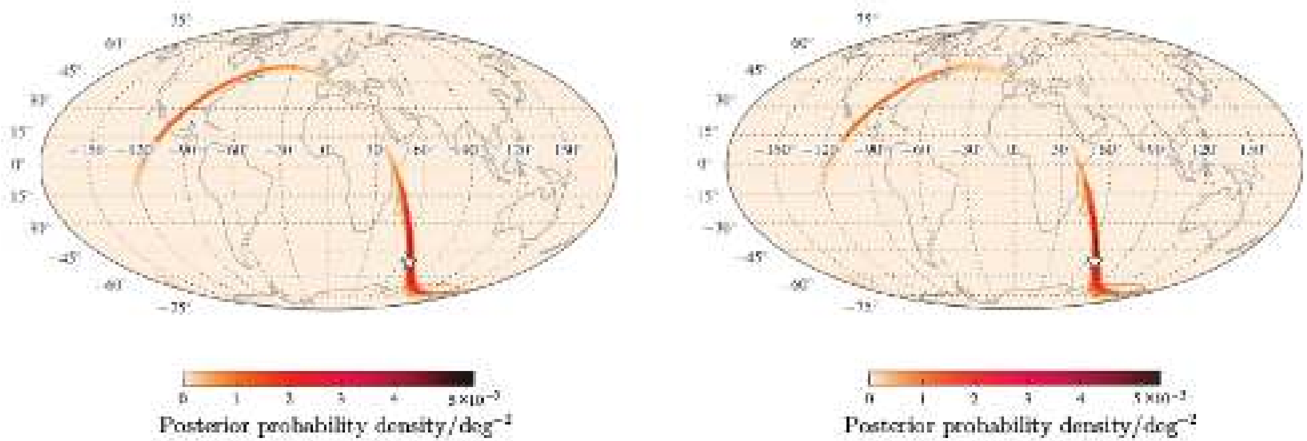
M. Razzano

Sky Localization of GW transients

- “Triangulation” using temporal delays
- Depends on the SNR
- Low SNR → large error box (tens – hundreds sq deg)
- Wide-fov telescopes are required!



Abbott+16, LRR 19,1



Abbott+16, LRR 19,1

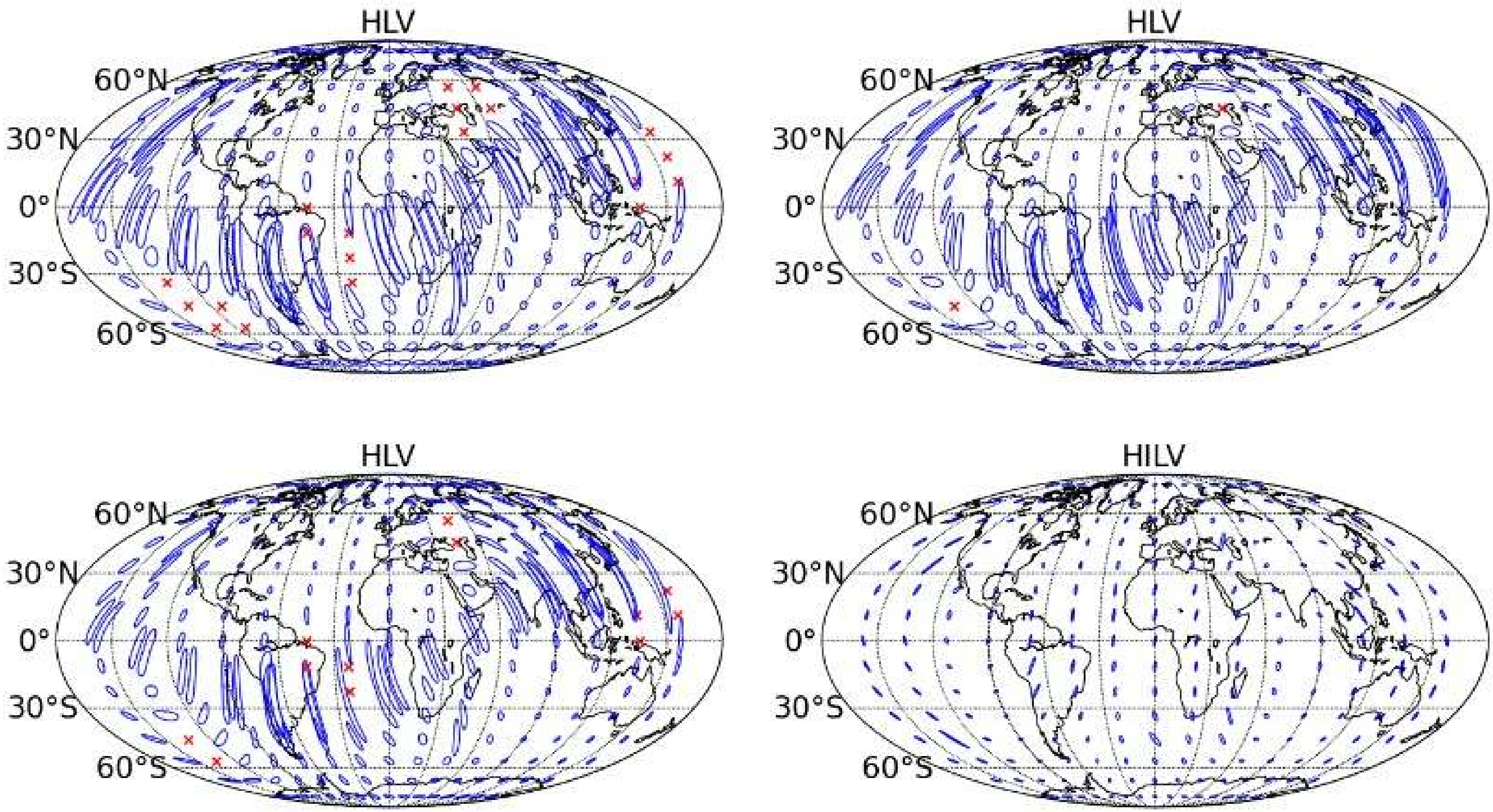
BNS system, SNR ~13.2
LALINFERENCE (left), BAYESTAR (right)

M. Razzano

Sky Localization

BNS, 80 Mpc

2016-17 | 2017-18



2019+ | 2022+

BNS, 160 Mpc

90% CL

X

No detection

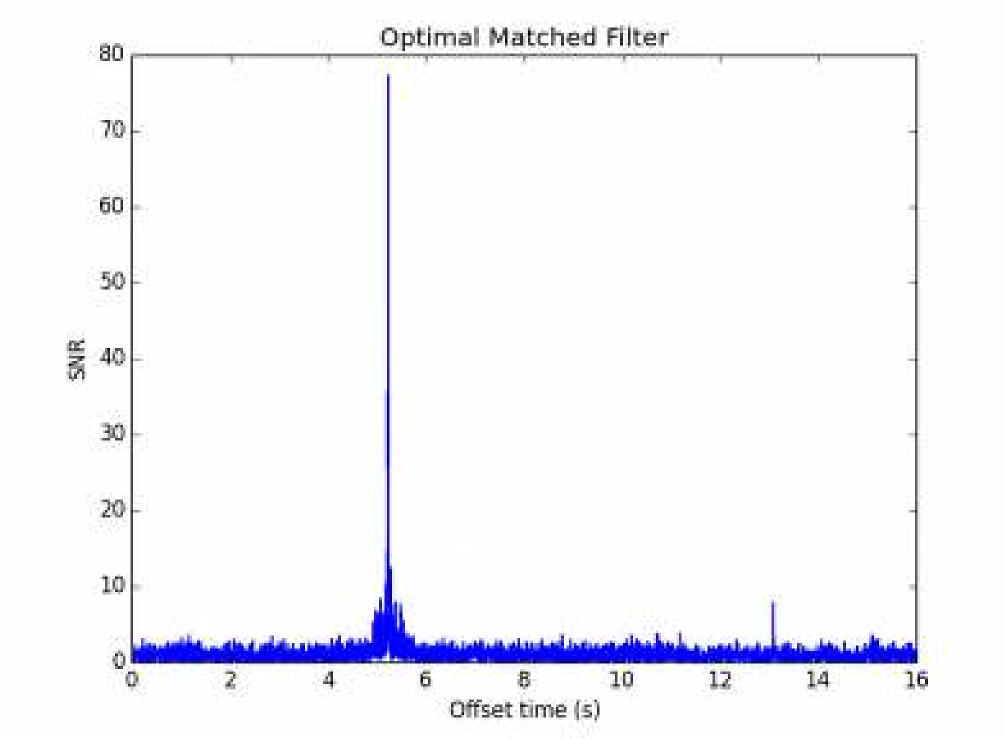
Abbott+16, LRR 19,1

Optimal detection statistics

- Often, the signal is buried in a large noise.
- In order to detect a signal, we use mainly the mathed filter technique, using a banks of templates (e.g. from chirp)

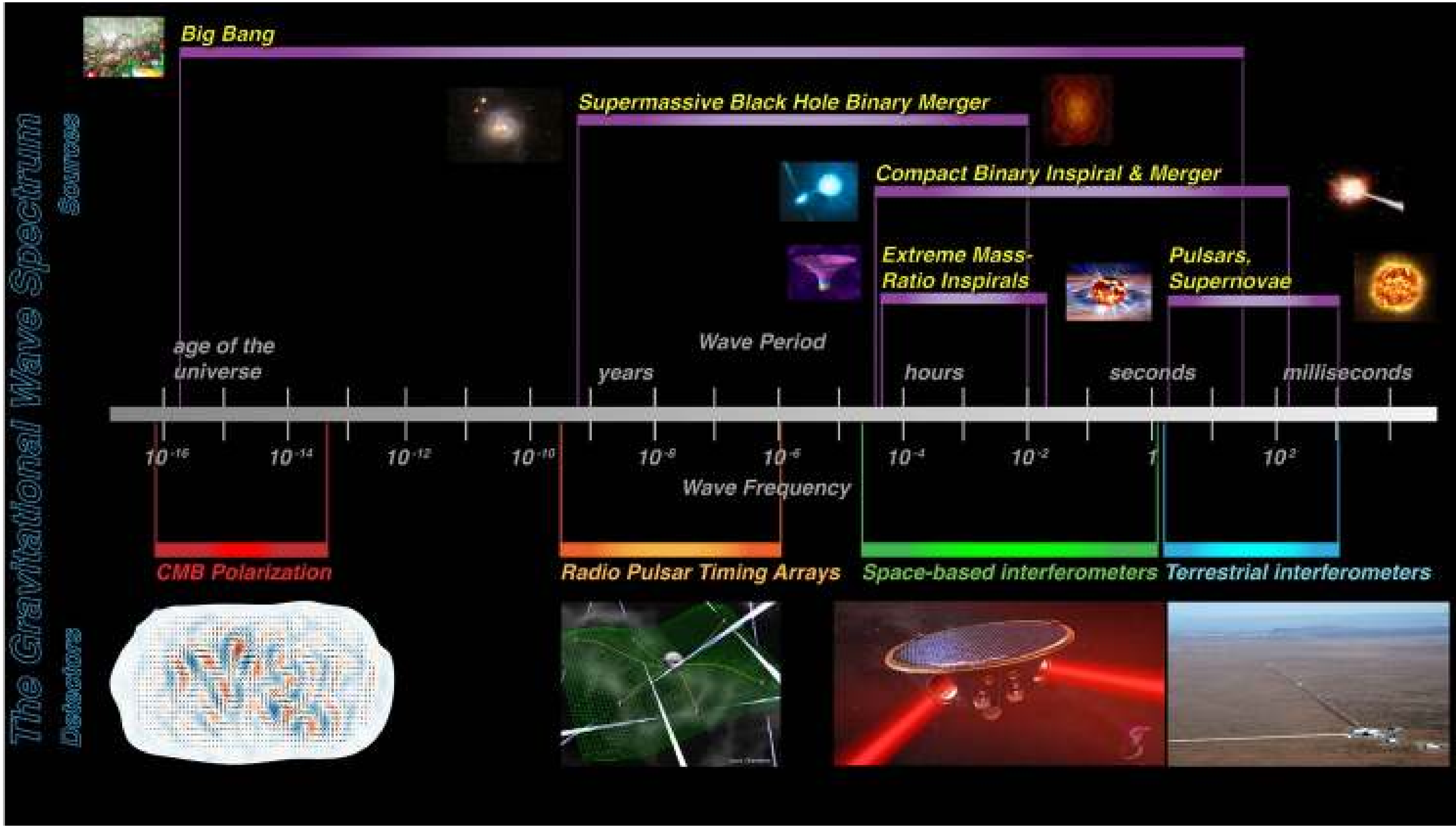
$$\left(\frac{S}{N}\right)^2 = 4\int_0^\infty \tilde{h}(f)\tilde{K}(f)\,df = \int_0^\infty |\tilde{h}(f)|^2/S(f)\,df$$

- In case the signal is not know, we use excess-power based methods



Credits: LIGO

Not just Virgo/LIGO...



Now, let's see some results!