GRAVITATIONAL WAVES

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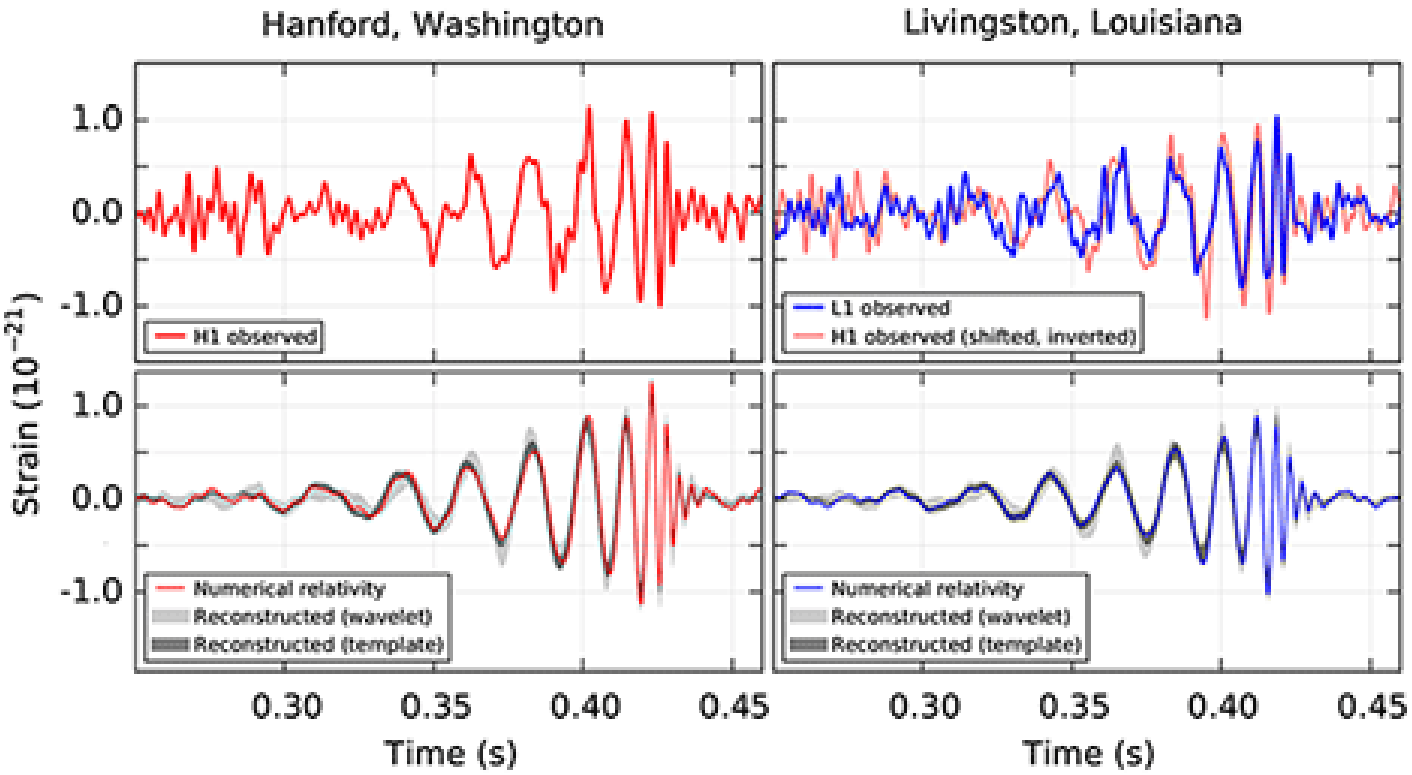
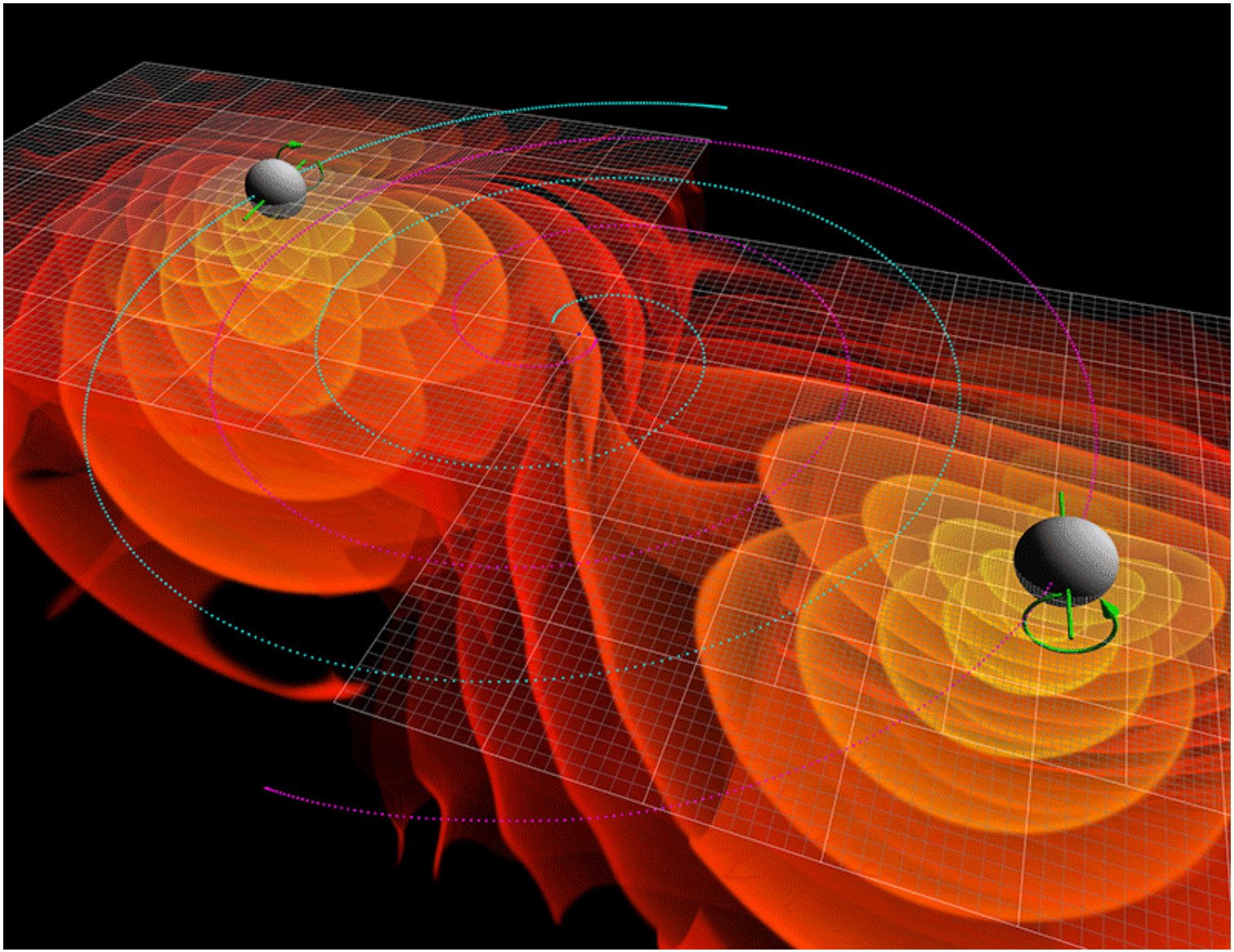
The signal

- The signal was detected on September 14, 2014 at 9:50:45 UTC by the observatories Livingston and Hanford (USA):



Gravitational Waves



Gravitational Waves: Emission of Energy

Consider a binary system with masses m_1 and m_2 (reduced mass $\mu = m_1 m_2/M$ and total mass $M = m_1 + m_2$) following a circular orbit of radius R and frequency ω. This system emits the following power in the form of gravitational waves:

$$P = \frac{32}{5} G (\mu R^2)^2 c^{-5} \omega^6 \,.$$

Using the 3rd Kepler's law: $\omega^2 R^3 = GM$

$$P = \frac{32}{5} \frac{c^5}{G} \left(\frac{\mu}{M}\right)^2 \left(\frac{GM}{c^2 R}\right)^5$$

The planet Earth emits about 200 W.
And the whole solar system: 5000 W!
But, it is possible to show that $P_{\max} = 10^{52}$ W!

Gravitational Waves: Amplitude

- Suppose again a binary system composed by to equal masses following a circular orbit of radius R and period P.
- The amplitude, h, of the gravitational wave can be estimated as:

$$h \sim 10^{-21} \left(\frac{M}{M_\odot}\right)^2 \left(\frac{1\ \mathrm{h}}{P}\right)^{2/3} \left(\frac{100\ \mathrm{pc}}{r}\right)$$

- Pitágoras (mod): $(\Delta s)^2 = (1 + h_{xx})(\Delta x)^2 + (1 + h_{yy})(\Delta y)^2$
- Then :

$$\frac{\Delta L}{L} \sim h$$

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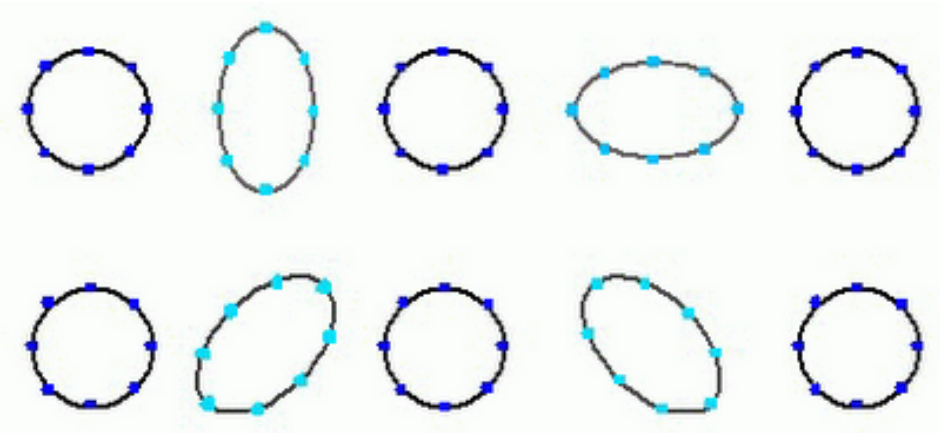
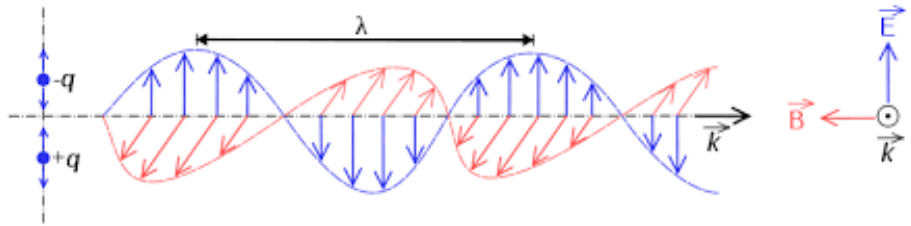
Gravitational Waves: Polarization

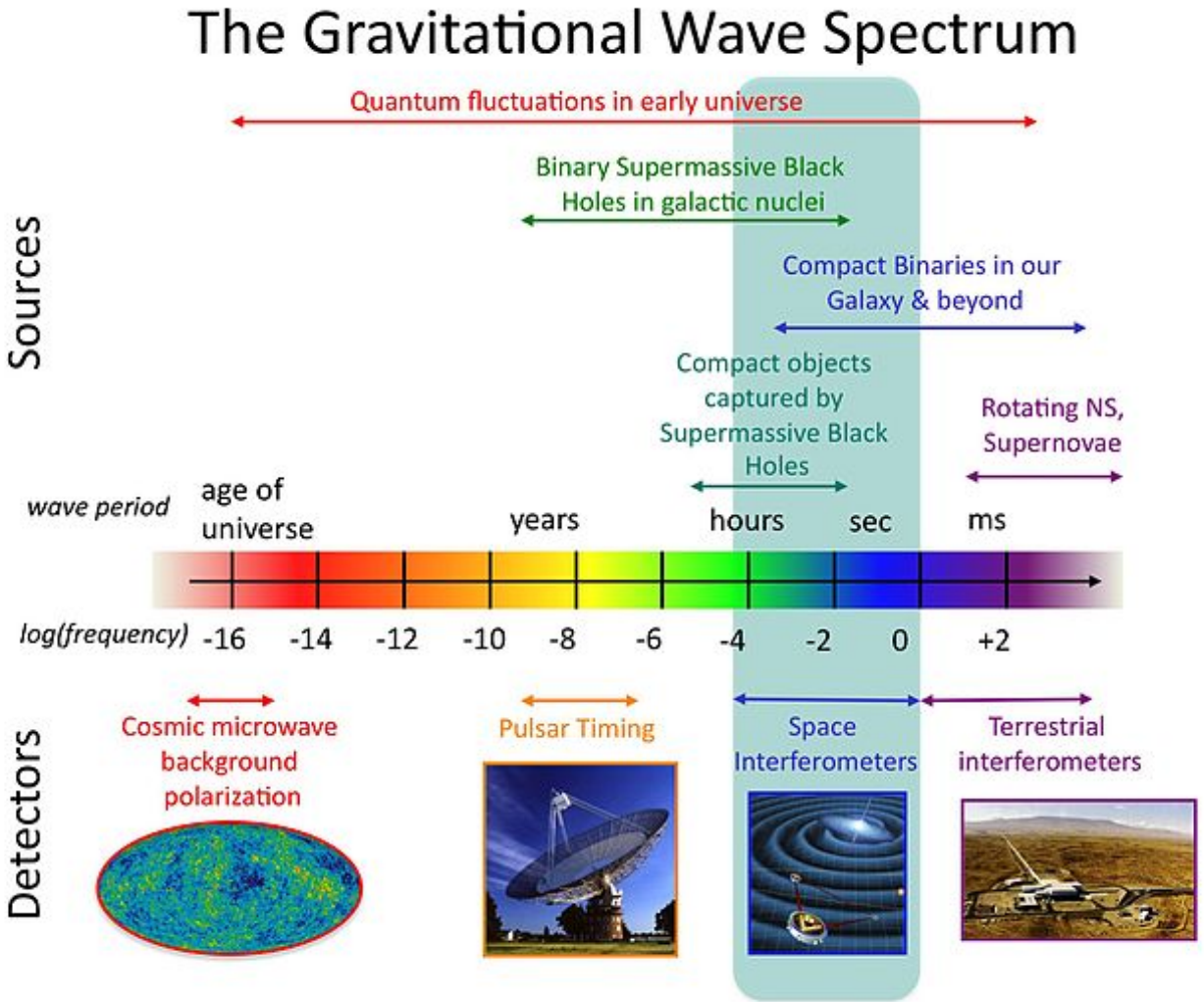
Gravitational



Electromagnetic

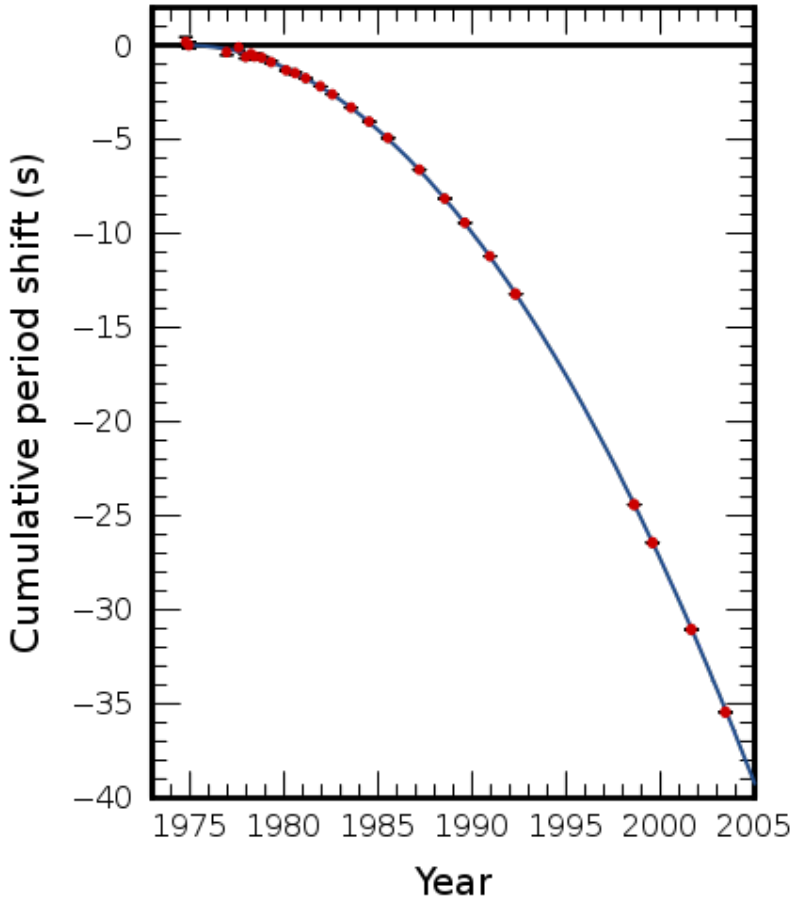


Gravitational Waves: Astrophysical Phenomena



Gravitational Waves (indirect detection)

- Study of the orbital parameters of the binary pulsar PSR B1913+16.
- R. A. Hulse and J. H. Taylor (Nobel Prize, 1993)

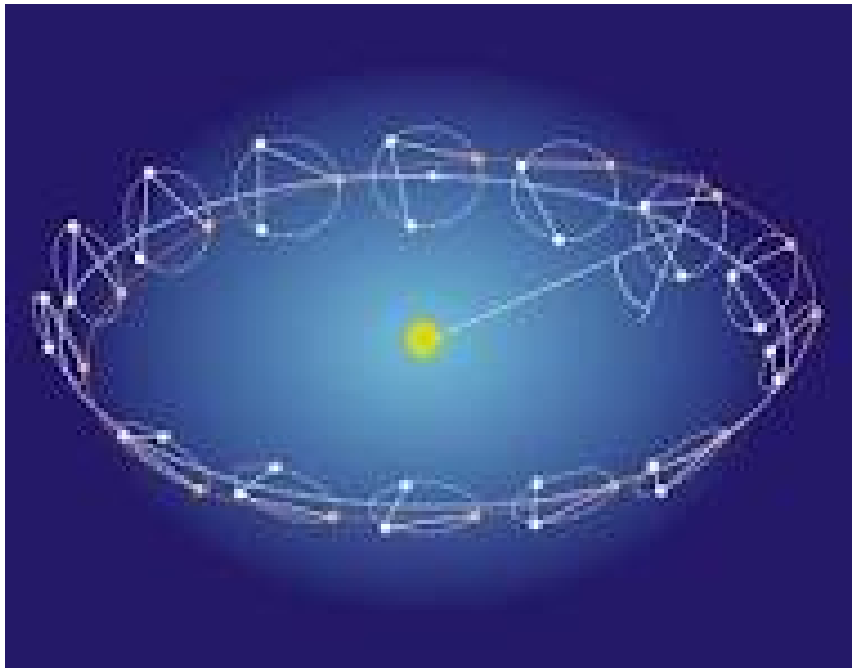


Laser Interferometer Gravitational-Wave Observatory (LIGO)

Europe+Future

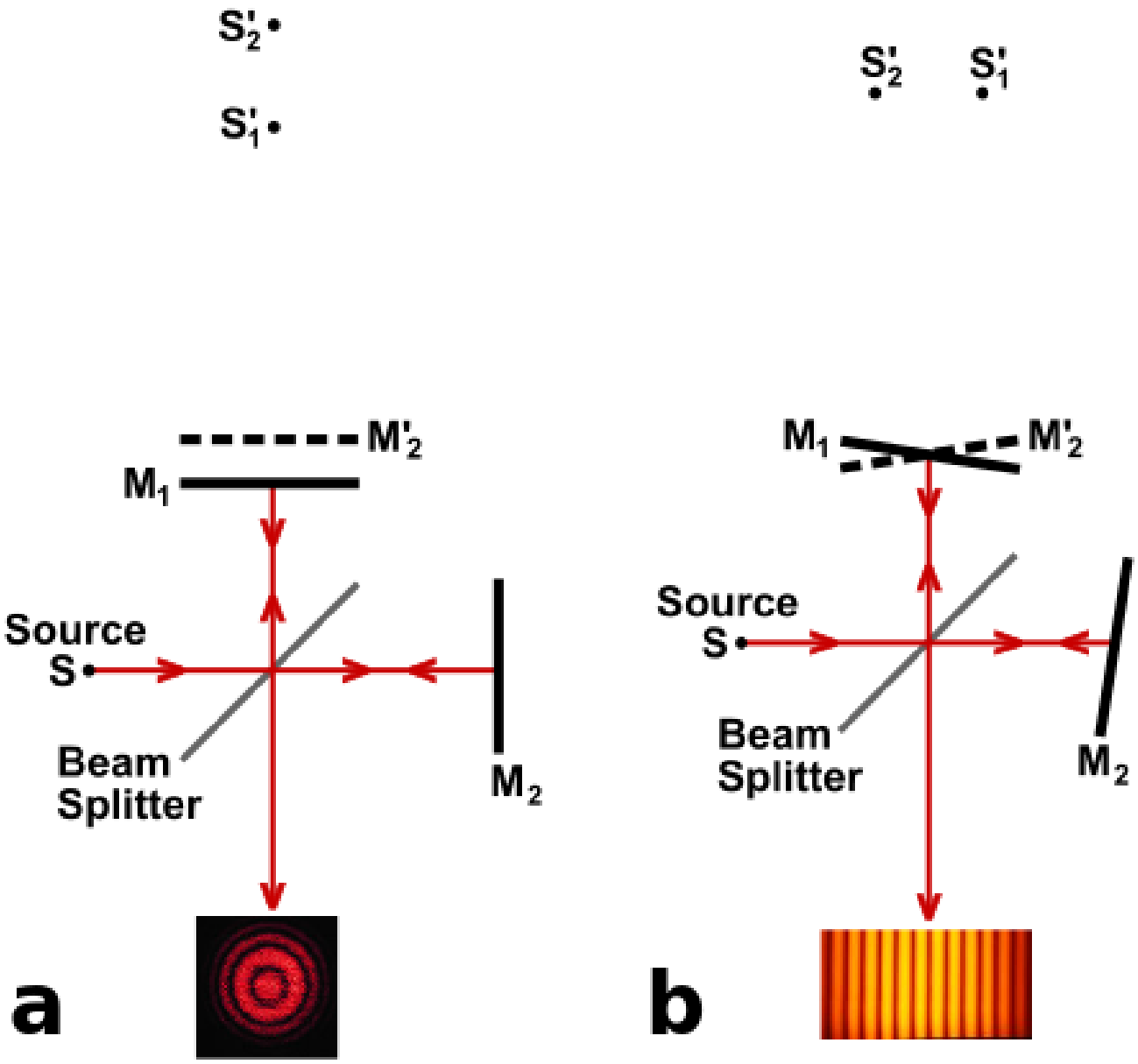
VIRGO:

LISA:

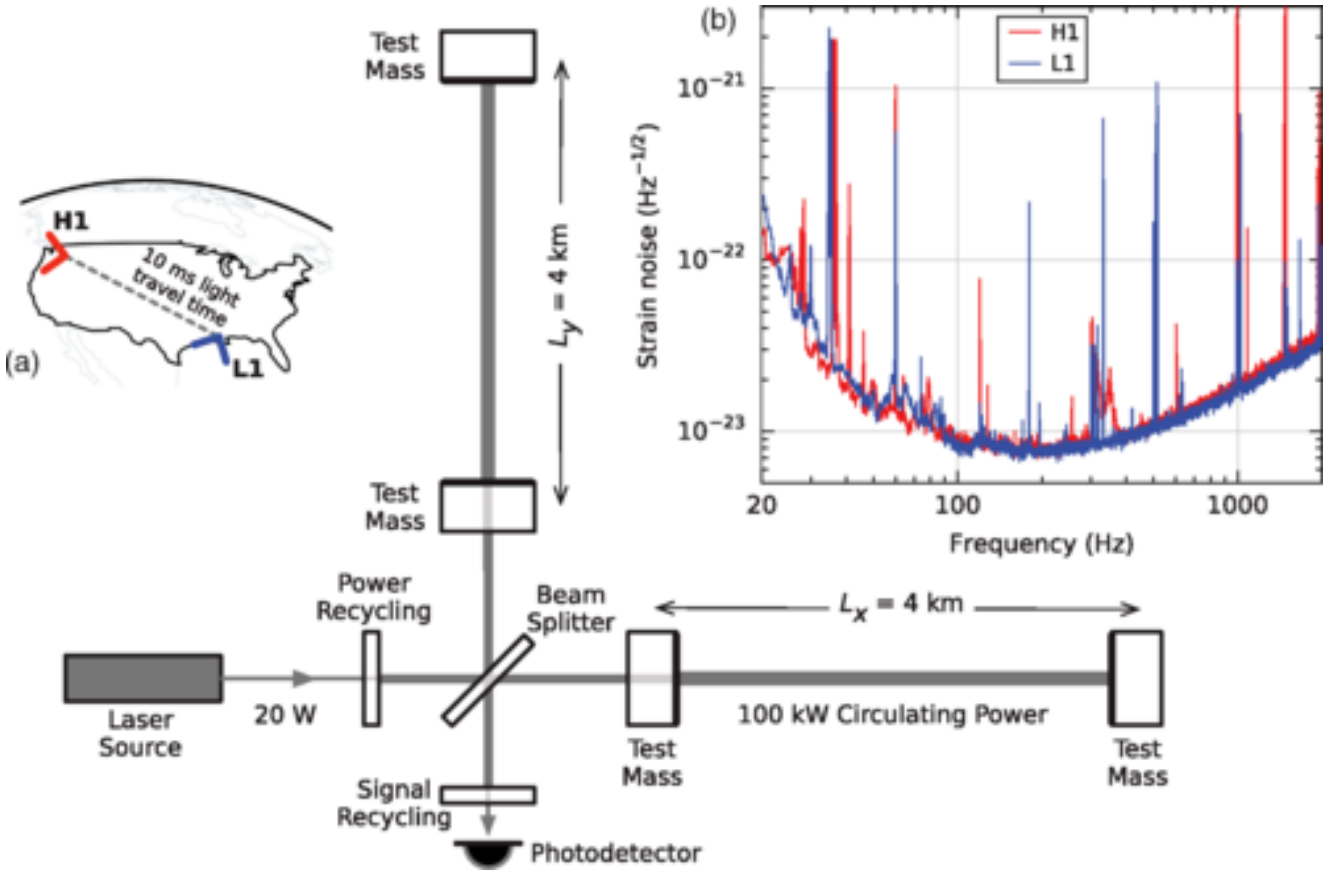


Other observatories: TAMA 300 (Japan) and GEO 600 (Germany)

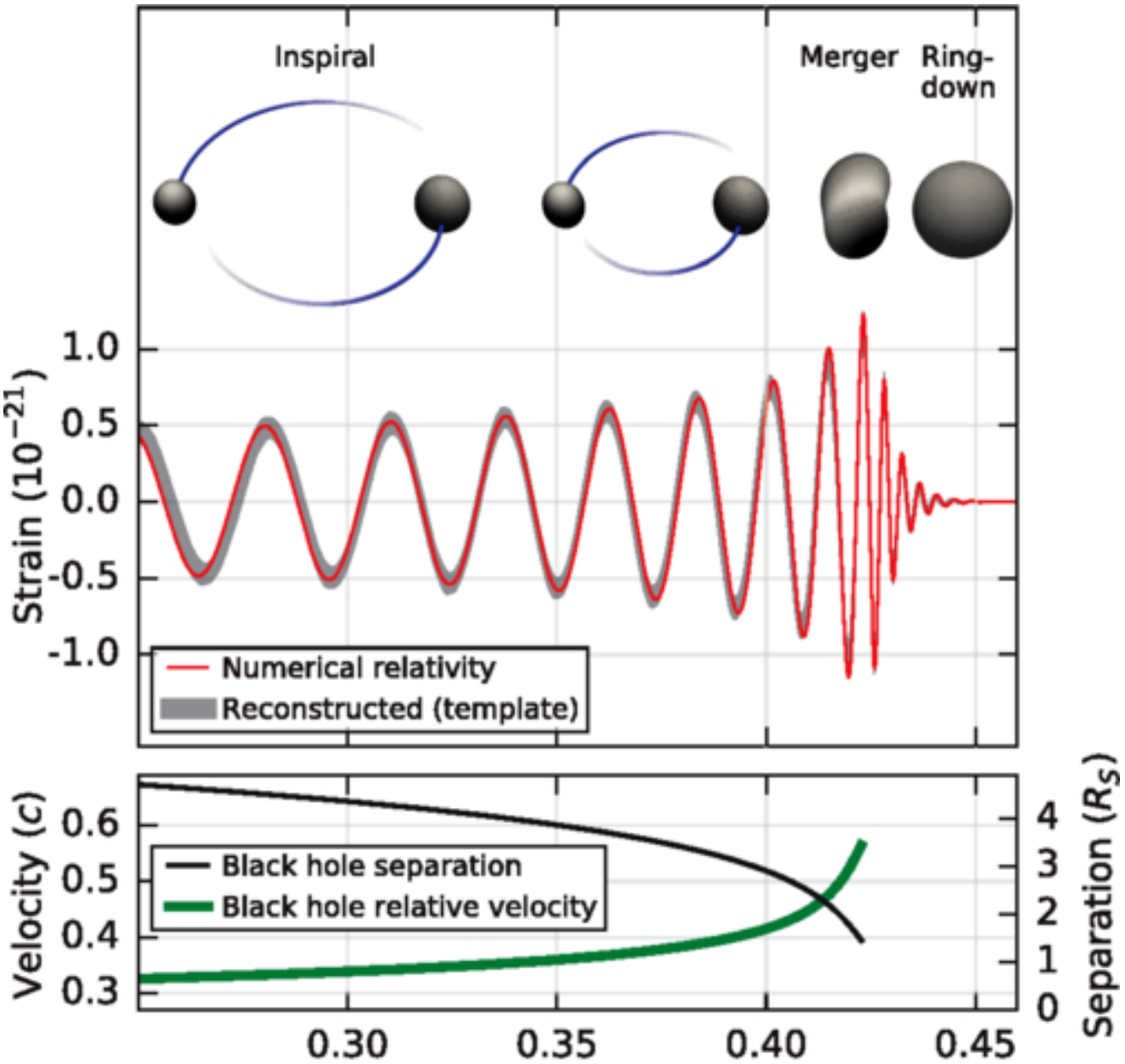
Interferometers



Interferometers (LIGO)



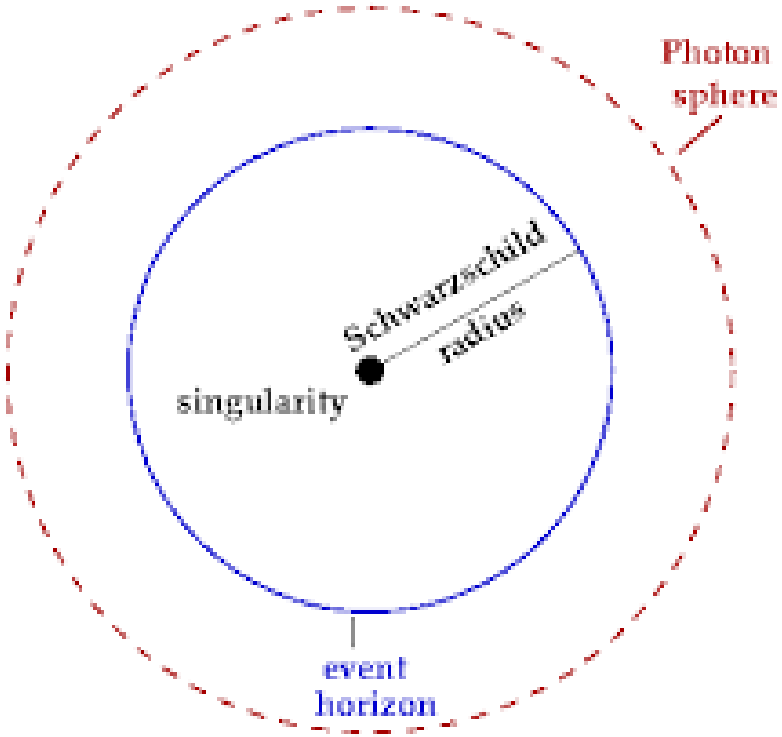
Signal of the coalescence of two black holes

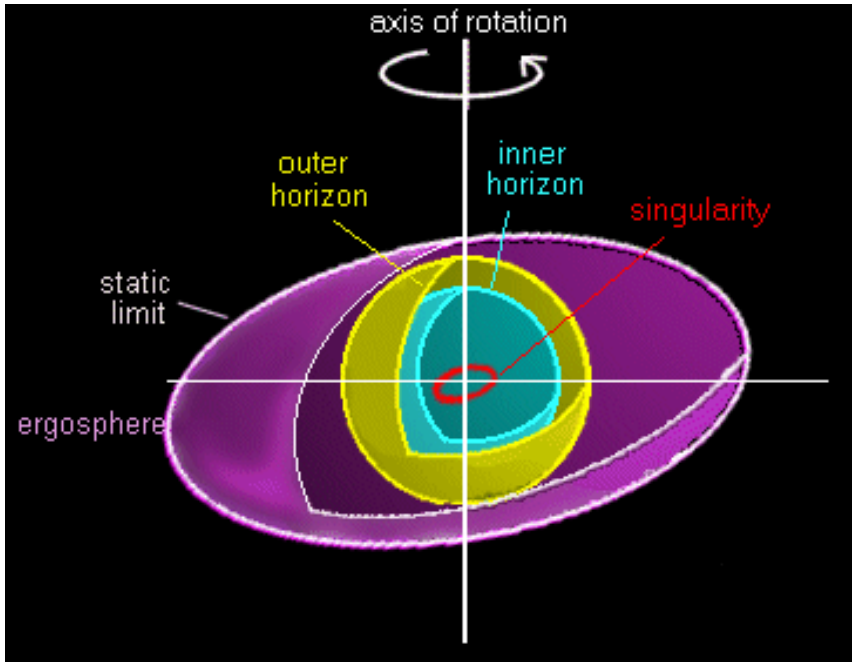


Physical parameters of both black holes

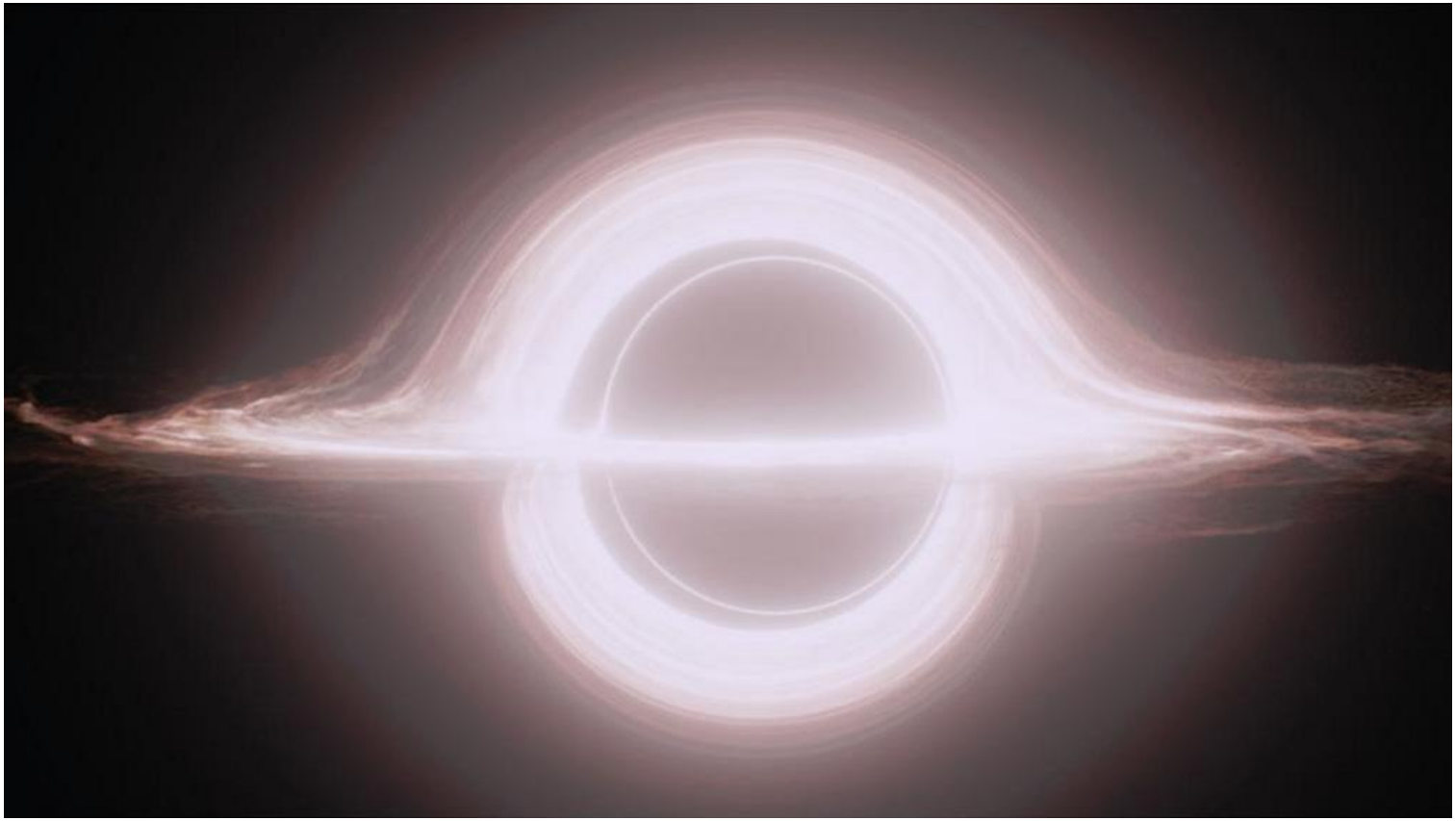
- Primary: $36 \pm 5 M_\odot$
- Secondary: $29 \pm 4 M_\odot$
- Final mass: $62 \pm 4 M_\odot$
- Final angular momentum: 0.67 ± 0.07
- Luminosity distance: 410 ± 180 Mpc
- Redshift (Cosmological): 0.09 ± 0.04
- Total radiated energy: $3 \pm 0.5 M_\odot c^2$

Black Holes


Photon sphere
Schwarzschild radius
singularity
event horizon


axis of rotation
outer horizon
inner horizon
singularity
static limit
ergosphere

Kerr Black Hole (Gargantua)



Where?