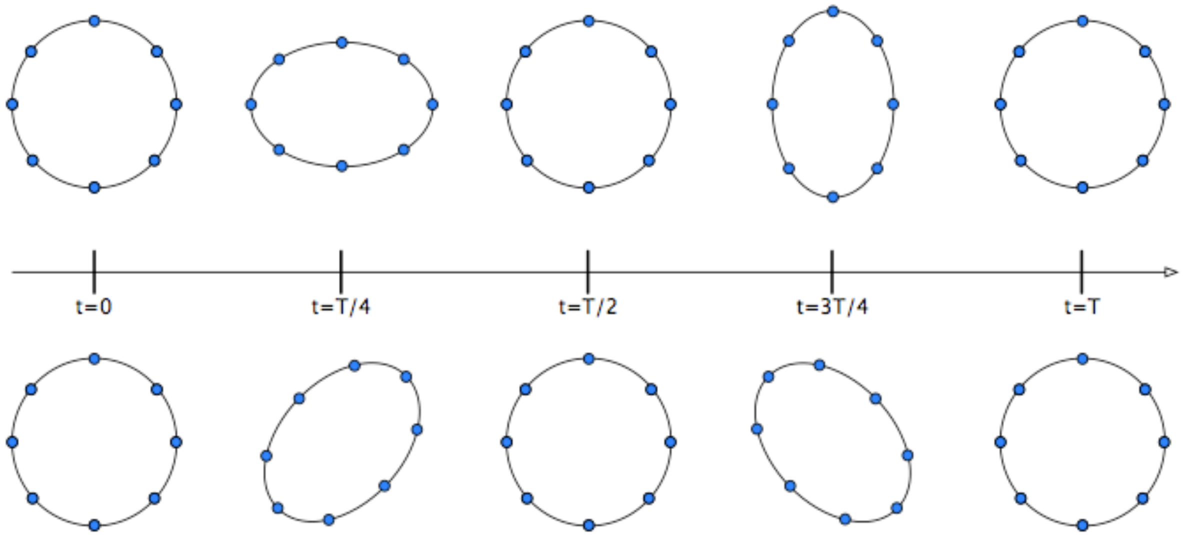
Searching for gravitational waves

Matteo Barsuglia
(barsuglia@apc.univ-paris7.fr)

CNRS - Laboratoire Astroparticule et Cosmologie

The gravitational waves (GW)

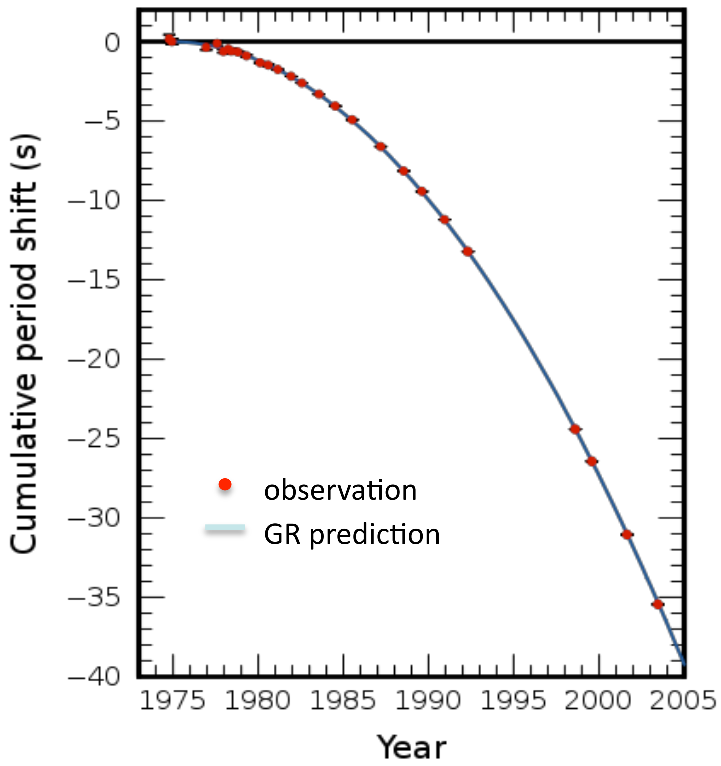
Perturbations of the space-time metrics



Coalescence of neutron stars of 1.4 solar masses at 15 Mpc

$$h \approx \delta L / L = 10^{-21}$$

Indirect evidence: The Hulse-Taylor pulsar



Nobel prize in 1993

Weinsberg and Taylor, *Relativistic Binary Pulsar B1913+16: Thirty Years of Observations and Analysis, astro-ph/0407149 (2004)*

Why searching for gravitational waves

- Fundamental physics
  - ex:Tests of the General Relativity
- Astrophysics
  - ex: GRB
- Cosmology
  - ex: new type of standard candles
  - ex: cosmological background of GW

Physics, Astrophysics and Cosmology
With Gravitational Waves, Satyaprakash and Shultz
Living review in Relativity

A new messenger

- GW are produced by coherent relativistic motion of large masses
- GW travel through opaque matter
- Gravity dominate the dynamics of several interesting astrophysical systems

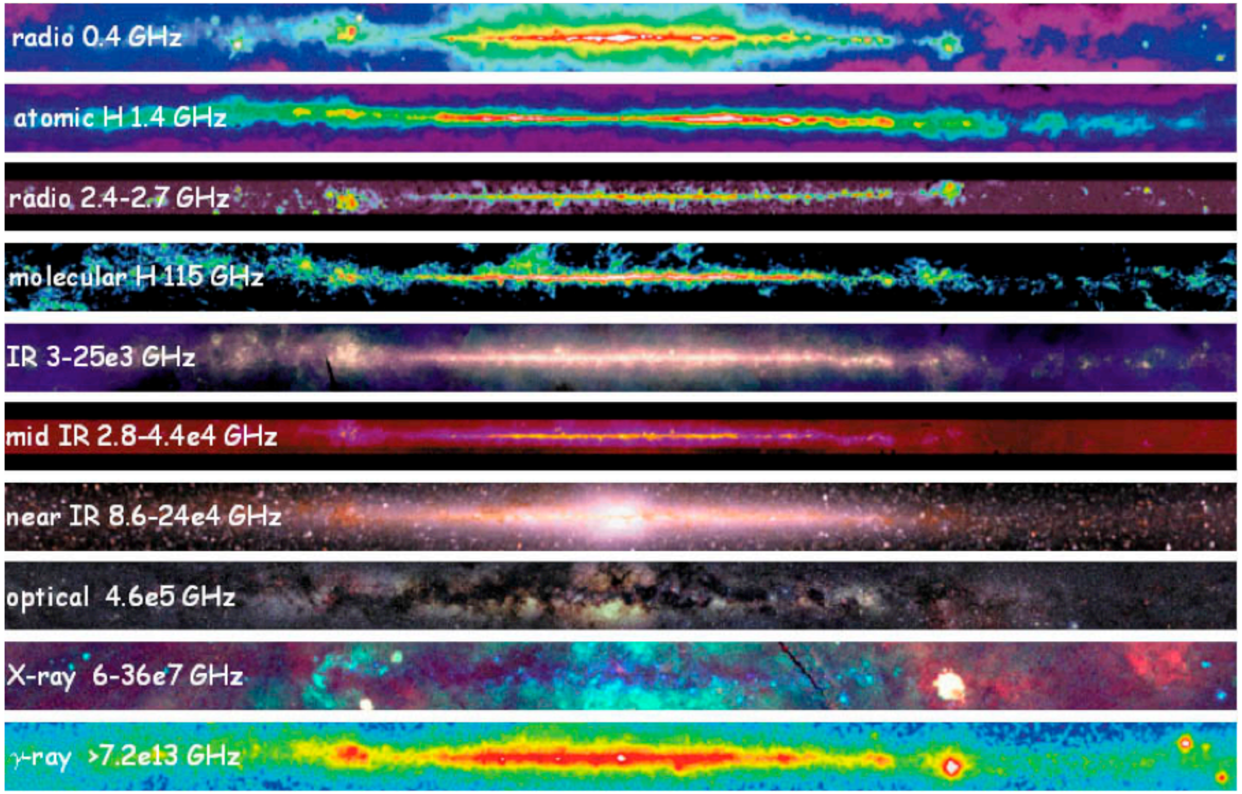
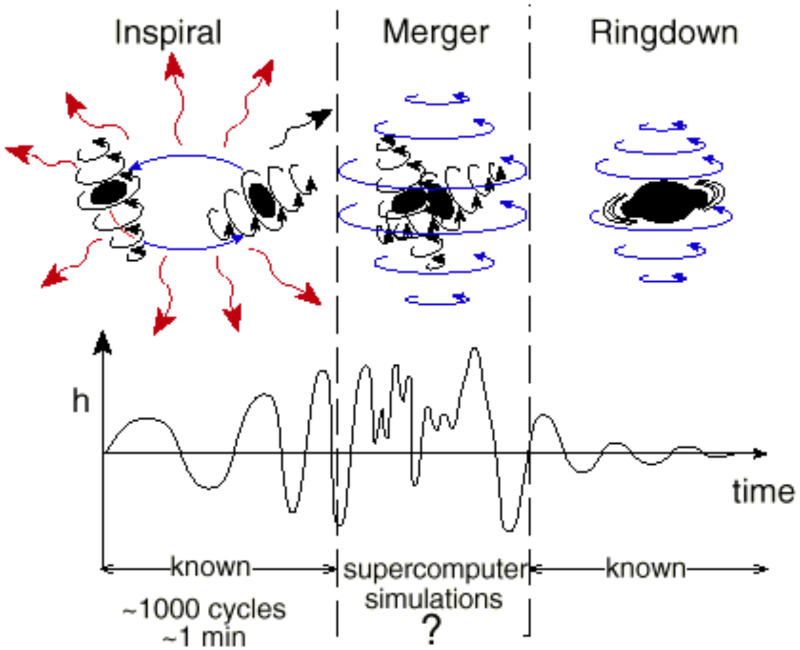
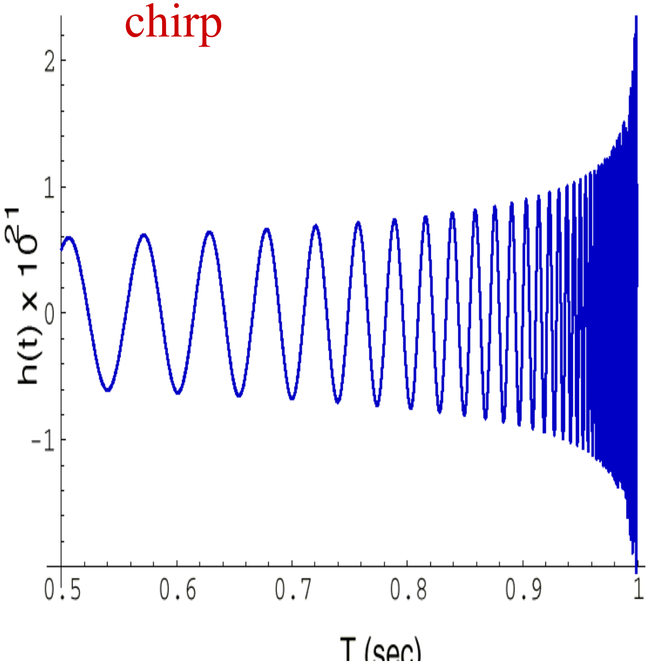


Image: NASA

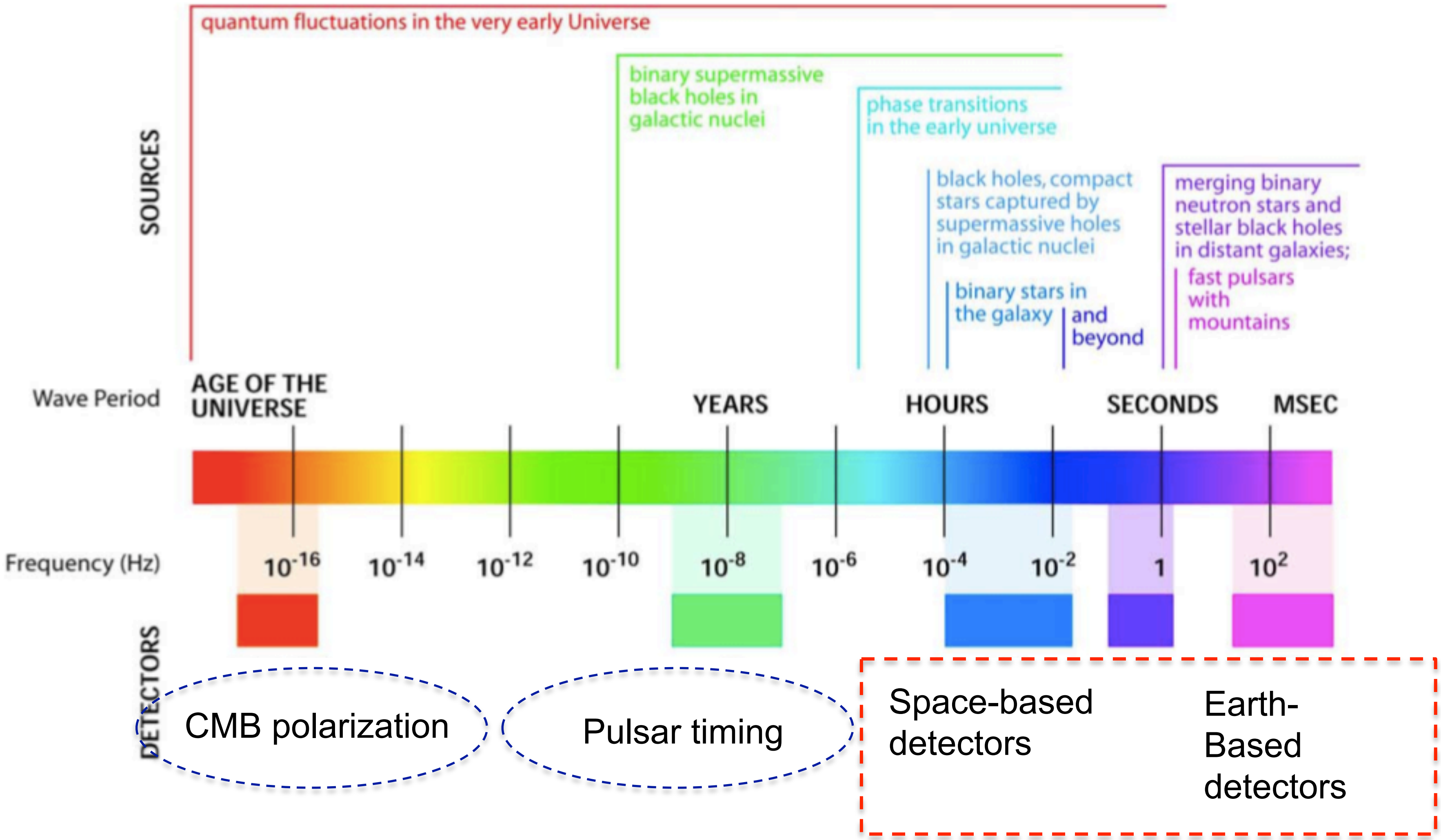
Gravitational-wave sky ?

Compact objects binary mergers



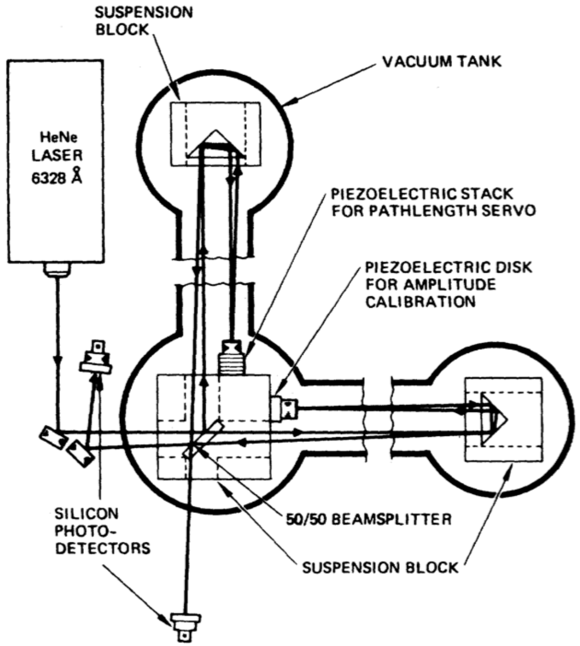


The gravitational-wave spectrum



In this talk

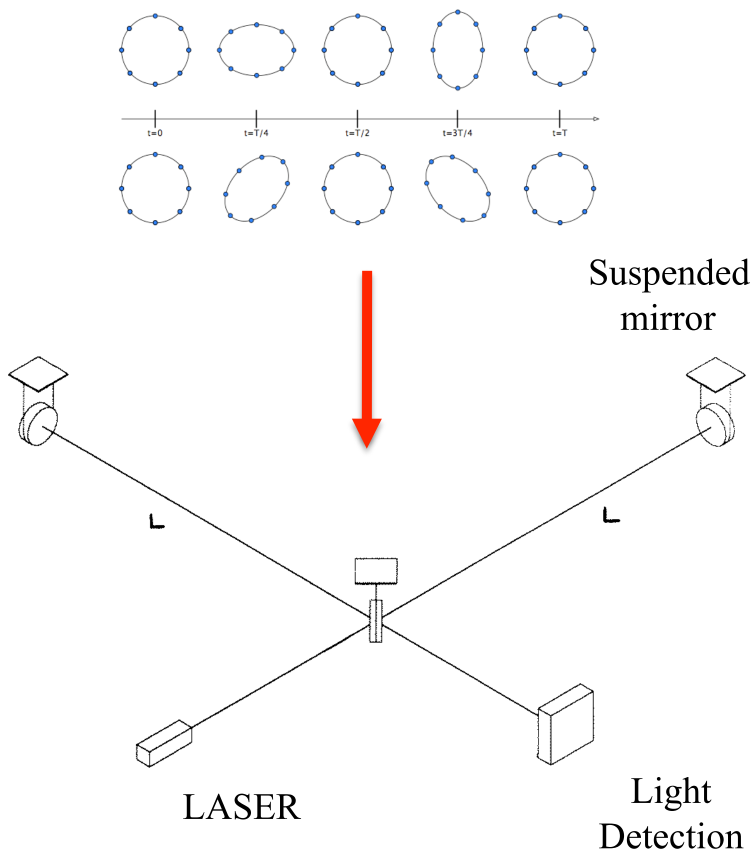
First experiments



Weber 1960

Forward 1978

Interferometric detectors



If target $h \sim 10^{-21}$

(NS/NS in the Virgo Cluster)

and $L \sim 10^{3}$ m

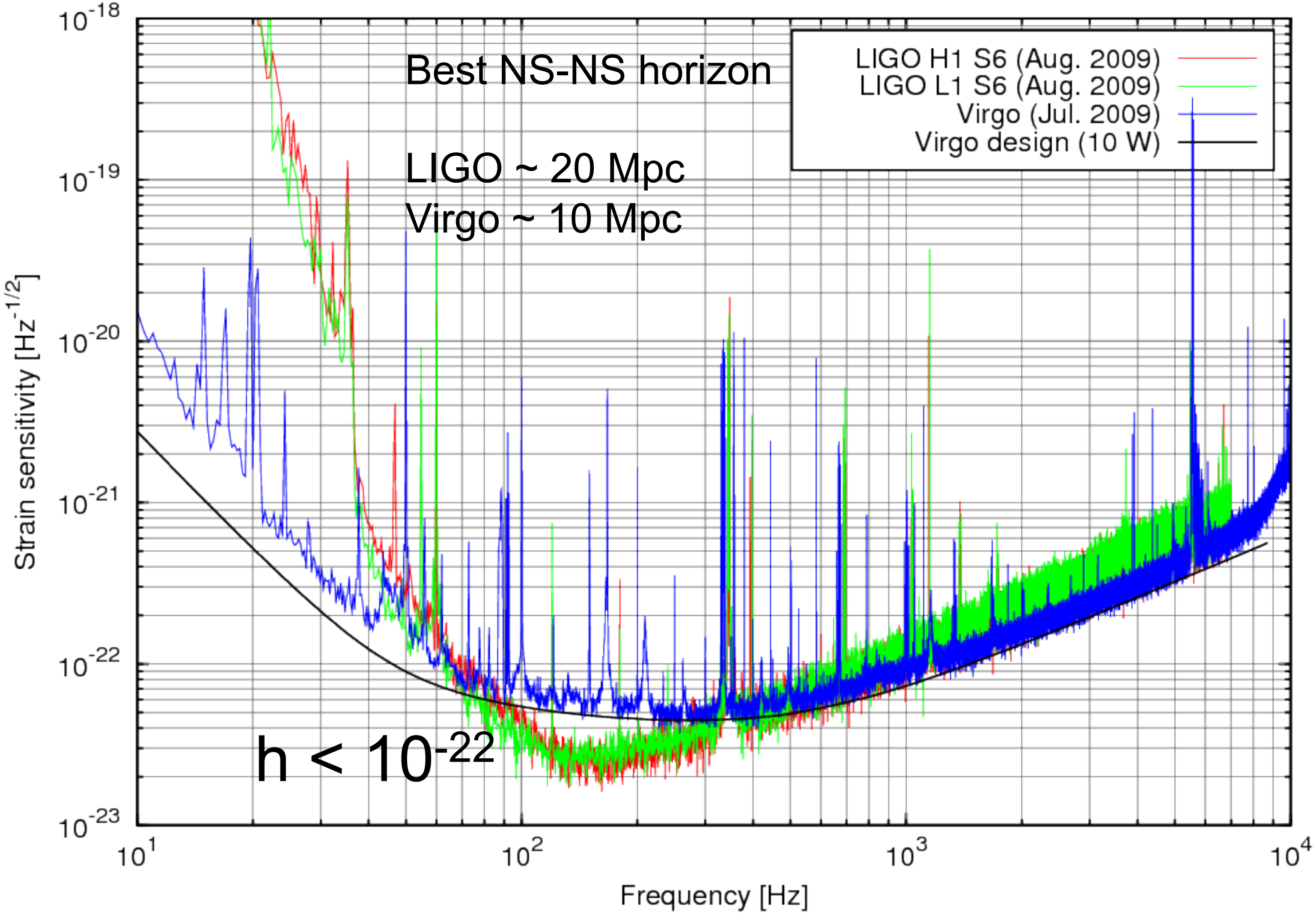
$\Delta L \sim 10^{-18}$ m

4 km

2003: Virgo

An international network

Sensitivities obtained



LIGO/Virgo results

~ 2 years integrated data, but… no detection

- Several upper limits established (rate of coalescences, ellipticity of spinning neutron stars, stochastic background)
- ~ 20 astrophysics papers published

Data analysis challenges in gravitational-wave astronomy, E.Chassande-Mottin for the LIGO and Virgo Collaborations, arXiv 1210.7173v1 (2012)

LIGO/Virgo results/2

nature Vol 460|20 August 2009|doi:10.1038/nature08278

LETTERS

An upper limit on the stochastic gravitational-wave background of cosmological origin

The LIGO Scientific Collaboration* & The Virgo Collaboration*

THE ASTROPHYSICAL JOURNAL, 737:93 (16pp), 2011 August 20 doi:10.1088/0004-637X/737/2/93

BEATING THE SPIN-DOWN LIMIT ON GRAVITATIONAL WAVE EMISSION FROM THE VELA PULSAR

Compact binary coalescences: rates estimates

TABLE II: Compact binary coalescence rates per Milky Way Equivalent Galaxy per Myr.

Source	R_{low}	R_{re}	R_{high}	R_{max}
NS-NS ($MWEG^{-1}$ Myr^{-1})	1 [1][a]	100 [1][b]	1000 [1][c]	4000 [16][d]
NS-BH ($MWEG^{-1}$ Myr^{-1})	0.05 [18][e]	3 [18][f]	100 [18][g]	
BH-BH ($MWEG^{-1}$ Myr^{-1})	0.01 [14][h]	0.4 [14][i]	30 [14][j]	

Table 5. Detection rates for compact binary coalescence sources.

IFO	Source[a]	$\dot{N}_{low}$ yr^{-1}	$\dot{N}_{re}$ yr^{-1}	$\dot{N}_{high}$ yr^{-1}	$\dot{N}_{max}$ yr^{-1}
	NS–NS	2×10^{-4}	0.02	0.2	0.6
	NS–BH	7×10^{-5}	0.004	0.1	
Initial	BH–BH	2×10^{-4}	0.007	0.5	

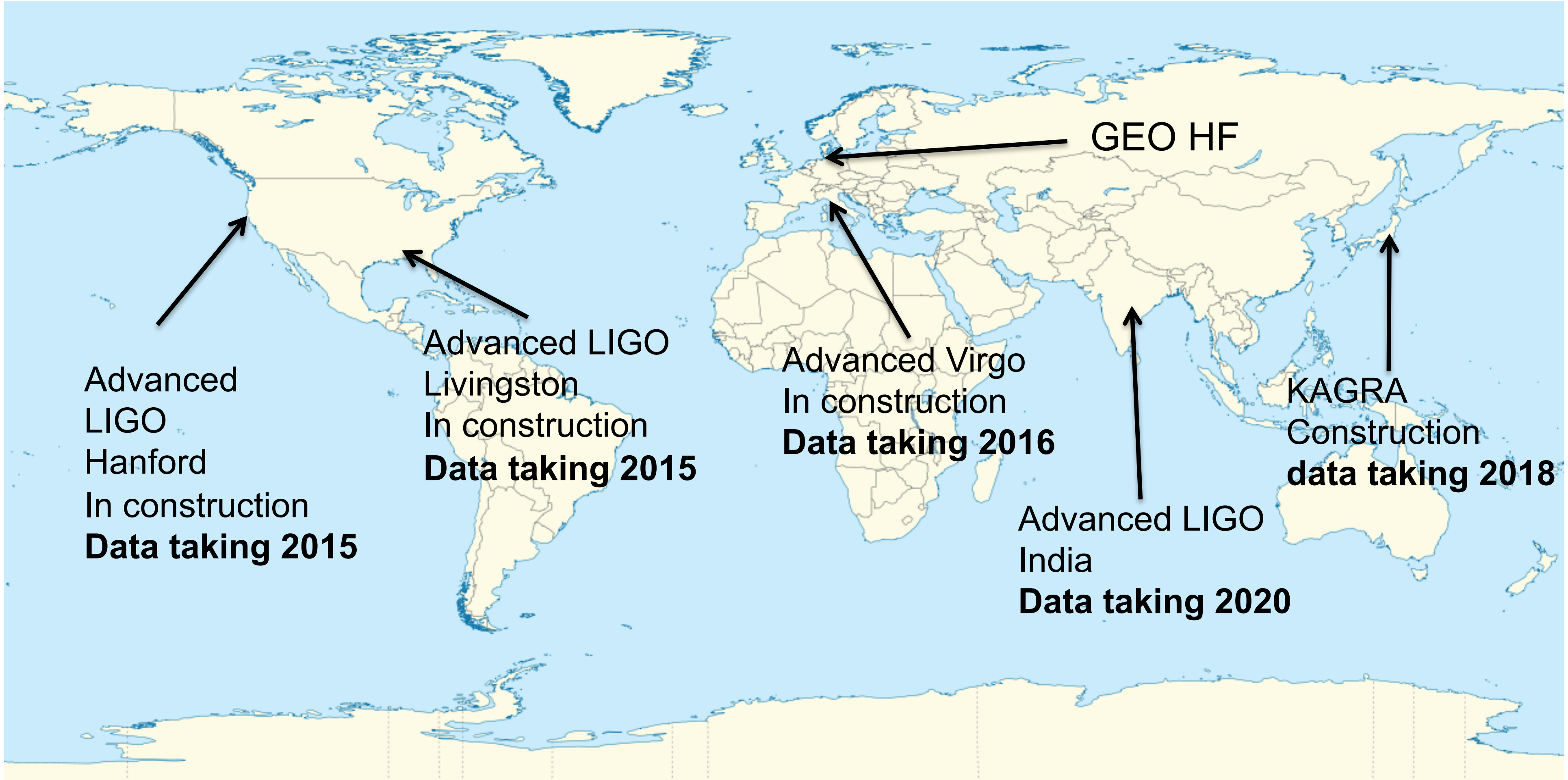
J.Abadie et al, “Predictions for the rates of compact binary coalescences observable by ground-based gravitational-wave detectors", Class Quantum Grav. 27 173001(2010)

Advanced detectors

X 10 sensitivity increase → x1000 rate increase

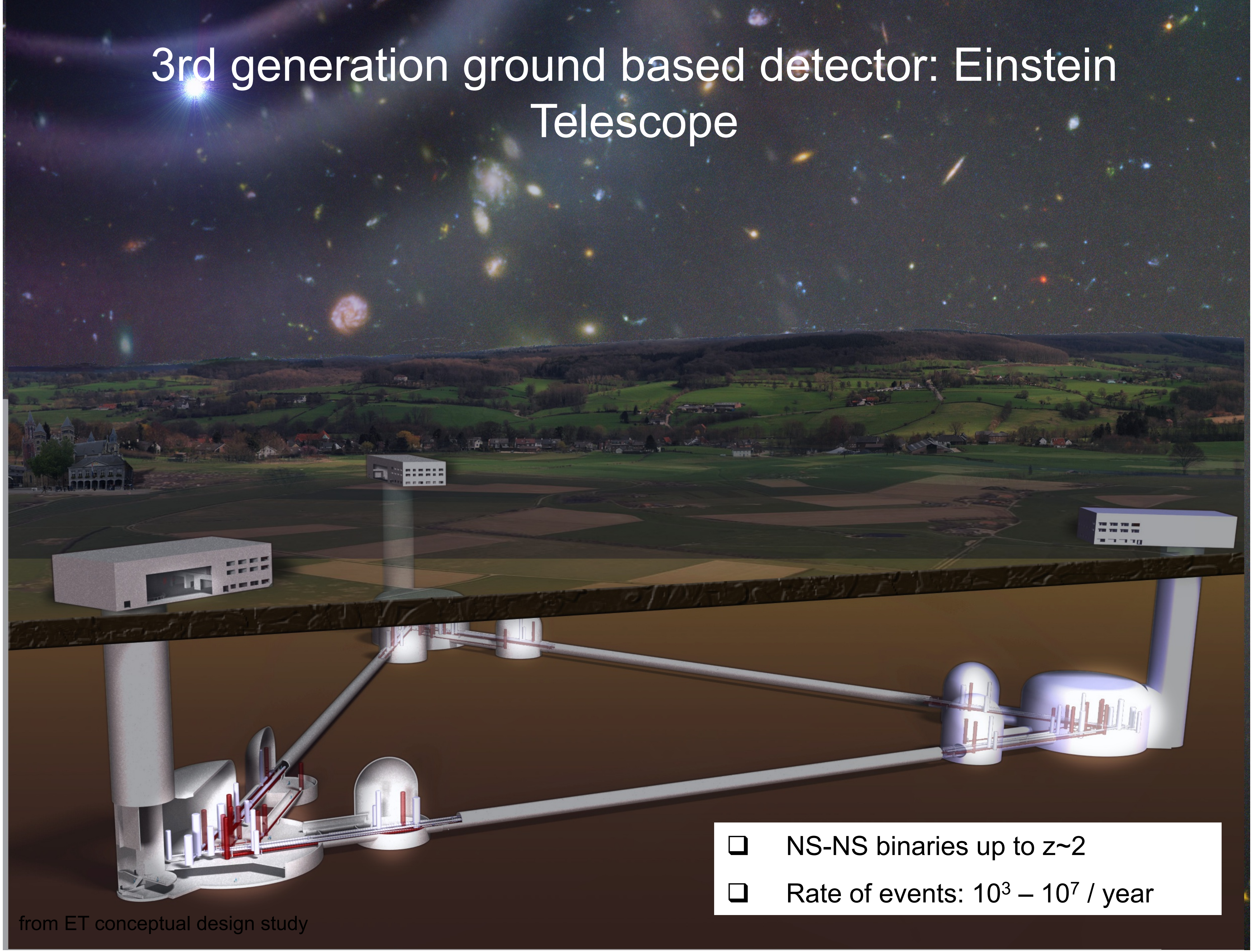
realistic rate for NS-NS mergers ~ 40 NS/NS /year

Second generation detectors



Likely detection in the period 2016-2018

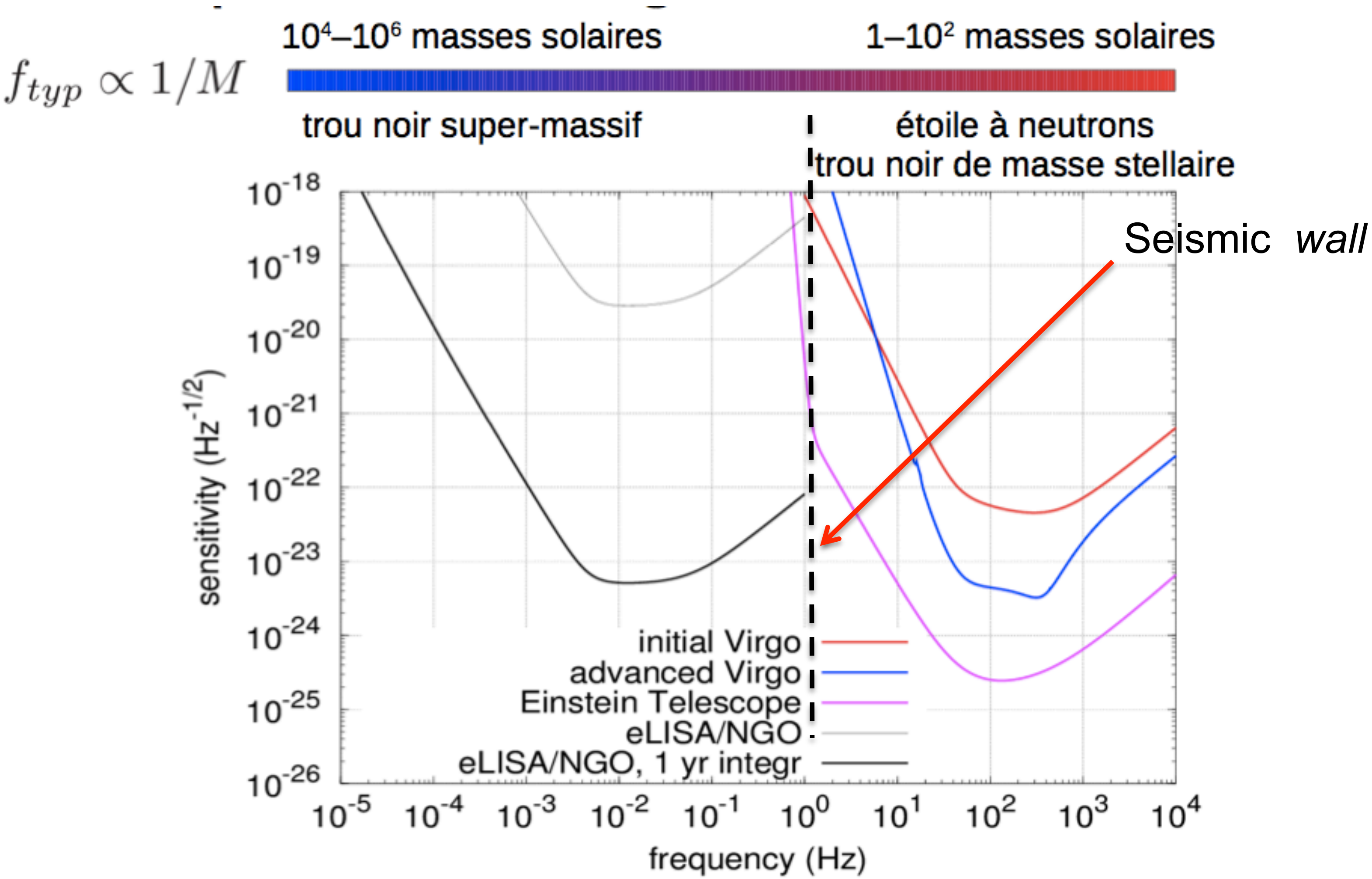
3rd generation ground based detector: Einstein Telescope



- NS-NS binaries up to z~2
- Rate of events: $10^3 - 10^7$ / year

from ET conceptual design study

Space-based detectors



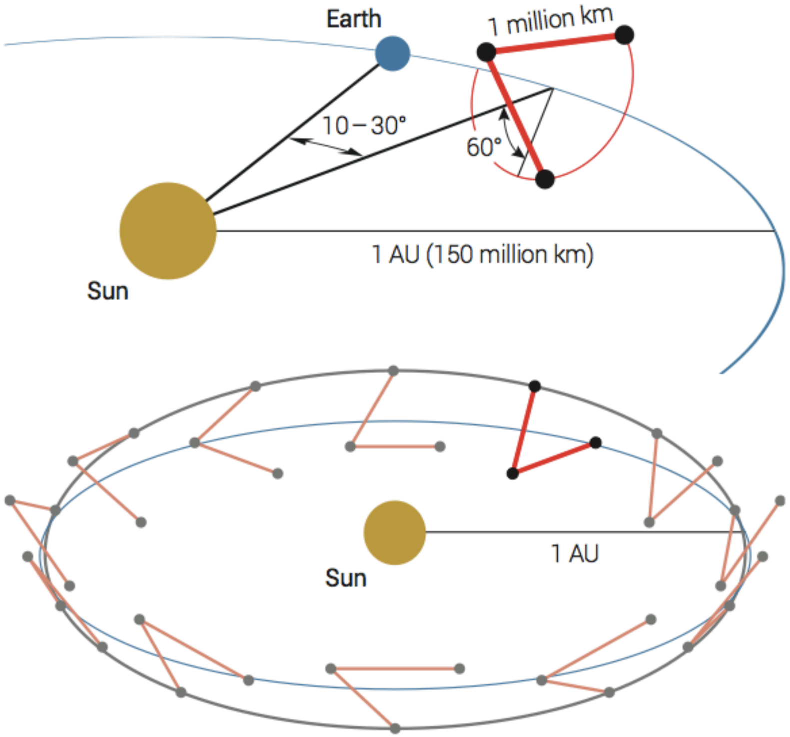
LISA →NGO → eLISA

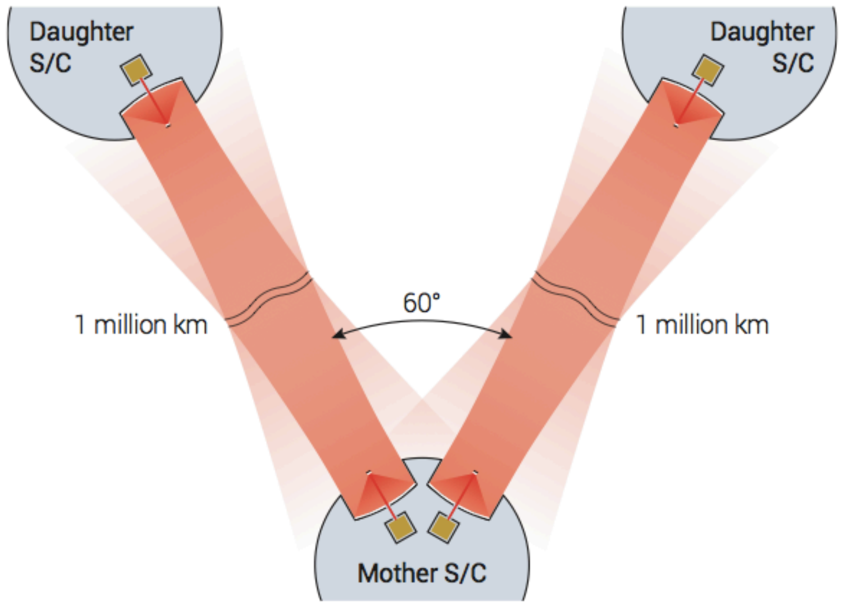
- LISA ~ 15 years of developments

- Withdrawal of NASA in 2011
- NGO (next gravitational-wave observatory) candidate for L1 mission in 2012 - not selected by ESA
- Scientific theme for the next L mission - end of 2013
- Selection of L mission in 2014
- If eLISA selected, launch in 2028

The gravitational Universe,
http://elisascience.org/whitepaper

eLISA mission concept

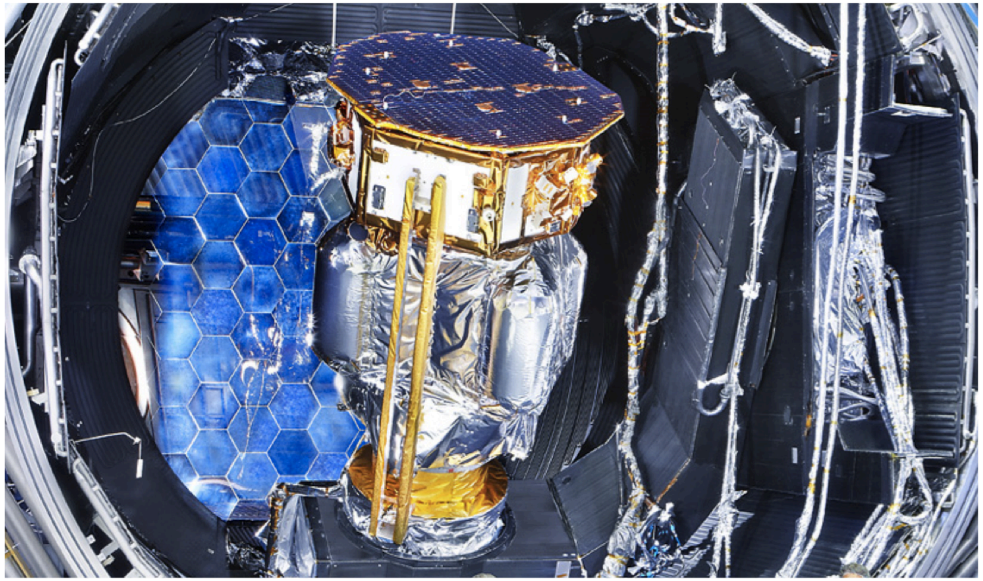




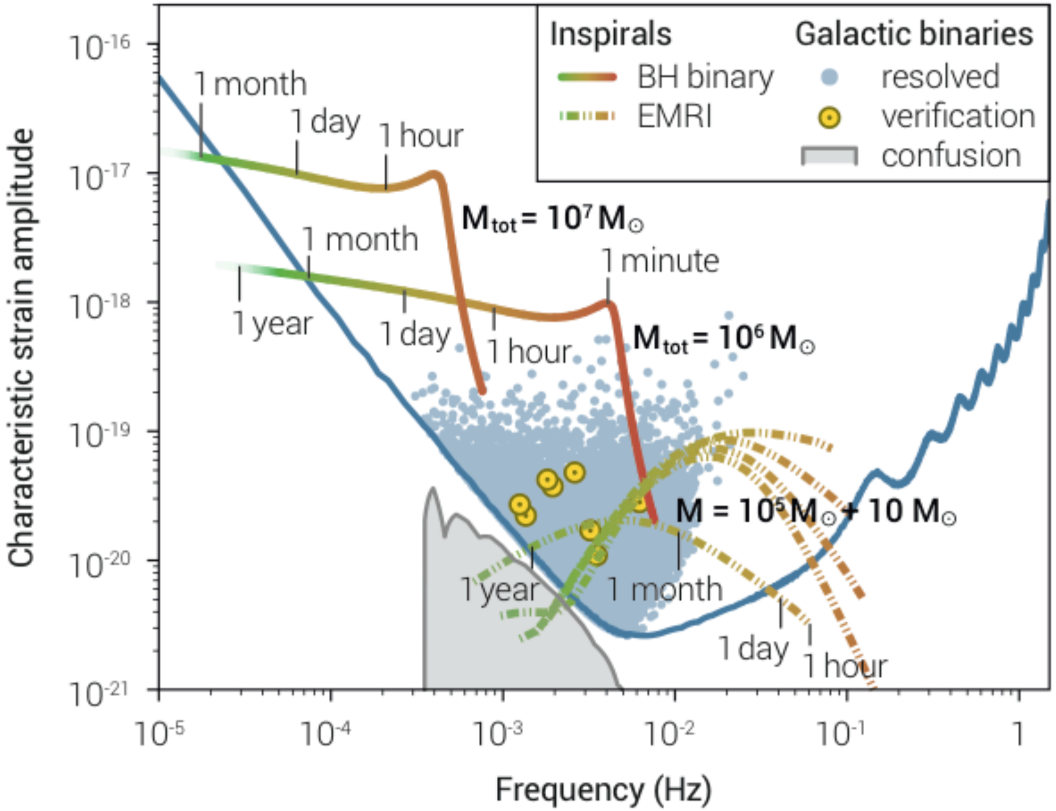
LISA pathfinder

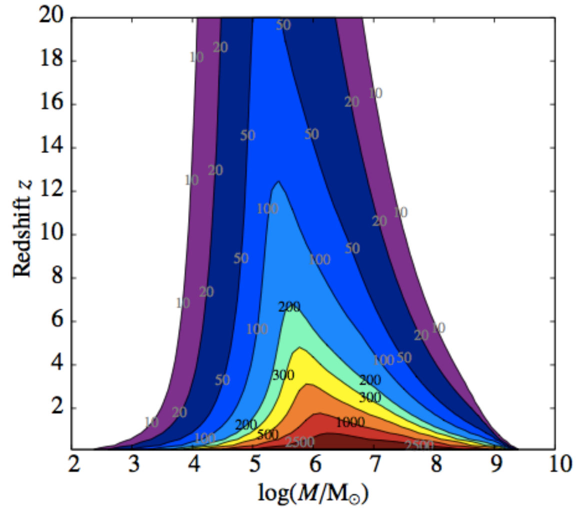
- Technological demonstrator of eLISA
  - Demonstration of drag-free masses
  - Interferometry
  - Thrusters, phase meters,…

- Launch 2015, duration 3 months



eLISA sources and science potential





Summary

- Gravitational-wave: test GR and a have a **new messenger** for astrophysics and cosmology
- 1st generation earth-based gravitational-wave interferometers work
  - Technologies demonstrated – Data - Upper limits published
- 2nd generation detectors earth-based under construction (aLIGO, AdVirgo, KAGRA, aLIGO India) – first data in 2015
  - Tens of NS-NS coalescences expected at the full sensitivity - **likely first detection**
- Space mission eLISA
  - **Very rich science in the mHz regime**
  - Selection of L mission in 2014, LISA pathfinder in 2015
  - If selected, LISA launch in 2028