

Antenne GRAVITAZIONALI

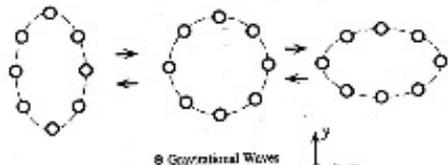


Figure 1: Effect of a gravitational wave (exaggerated) on a ring of test masses.

$$h = \frac{\Delta l}{l}$$

strain ratio

$$|FFT(h(t))|^2 \left[\text{Hz}^{-1/2} \right]$$

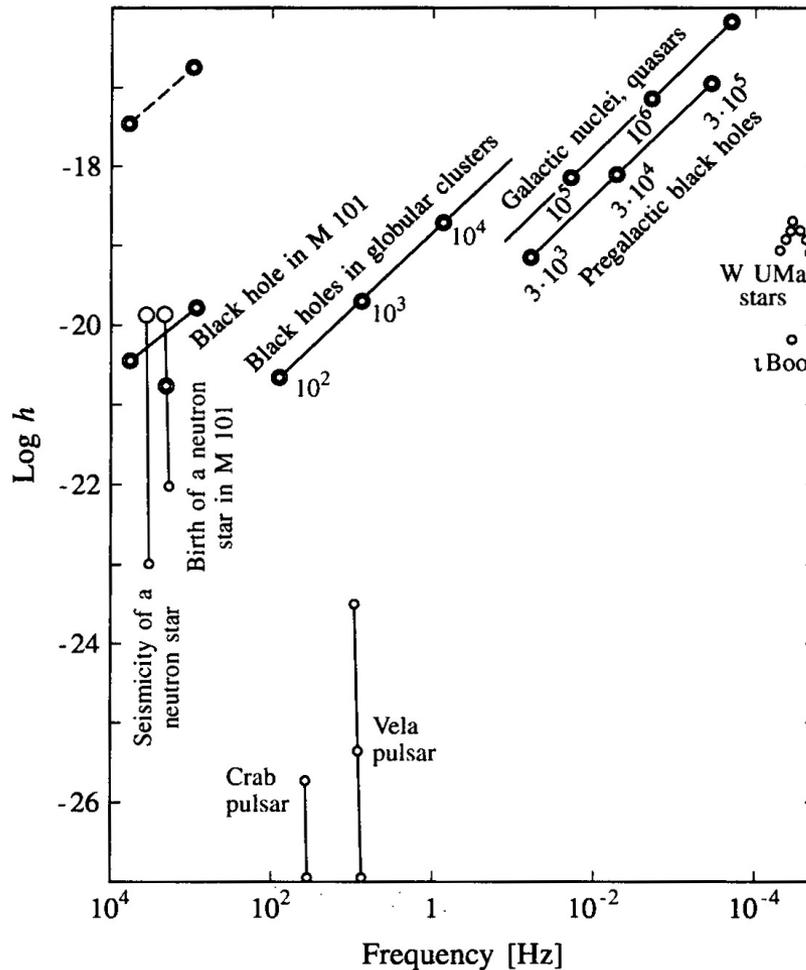
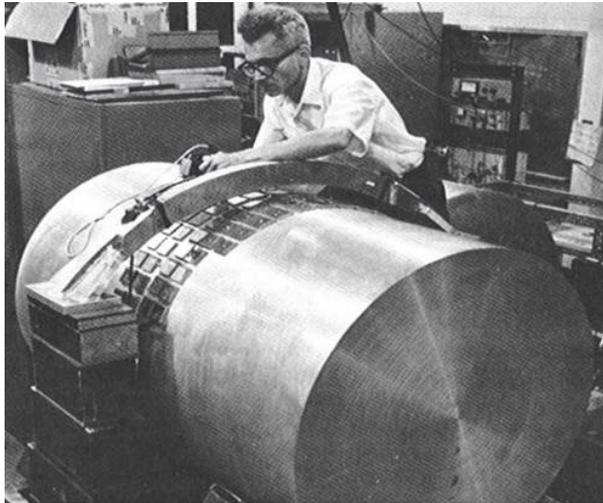


Fig. 1.3. Theoretical predictions of dimensionless amplitude h for various potential sources of gravitational waves, as a function of their frequency. Periodic sources are denoted by \circ and burst sources by \odot . [Brillet A., Damour T., Tourenc C., Ann. Phys. **10**, 201 (1985). With the kind permission of Editions de Physique]

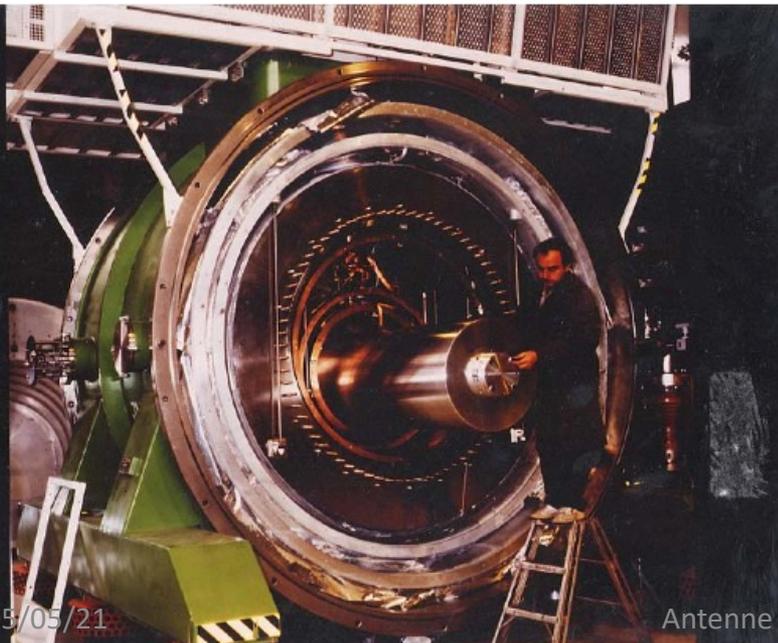
Weber Resonators



$h \sim 3 \cdot 10^{-16} \text{ Hz}^{-1/2}$ (prototipo di Weber a T ambiente)

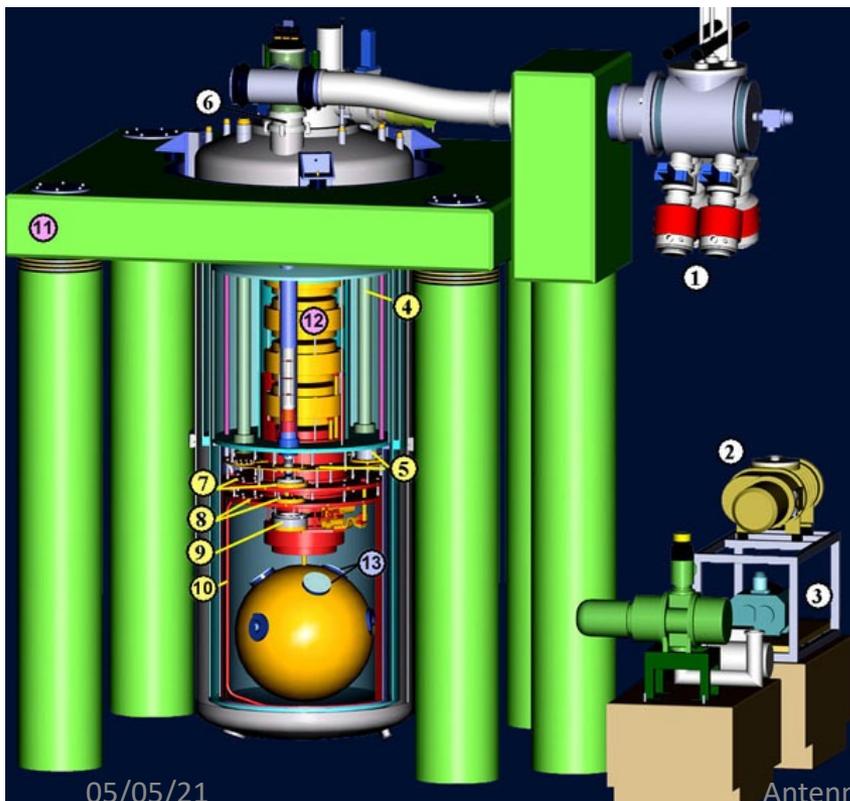
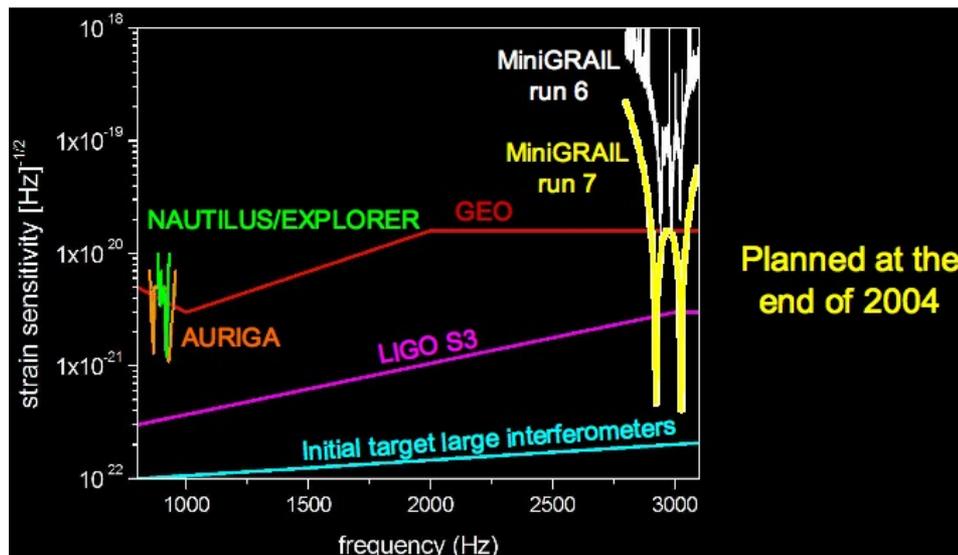
$h \approx 1.5 \cdot 10^{-22} \text{ Hz}^{-1/2}$ (evoluzione raffreddata a T criogeniche)

Nautilus ed Explorer a Frascati



MiniGrail

Material CuAl6%
 Density $\rho = 8000 \text{ kg/m}^3$
 Diameter $d = 0.65 \text{ m}$
 Mass $M = 1150 \text{ kg}$
 Sound velocity $v_s = 4100 \text{ m/s}$
 Resonant frequency $f = 3160 \text{ Hz}$
 Operating temperature * $T = 20 \text{ mK}$
 Strain sensitivity * $h \sim 10^{-20}$



Interferometri

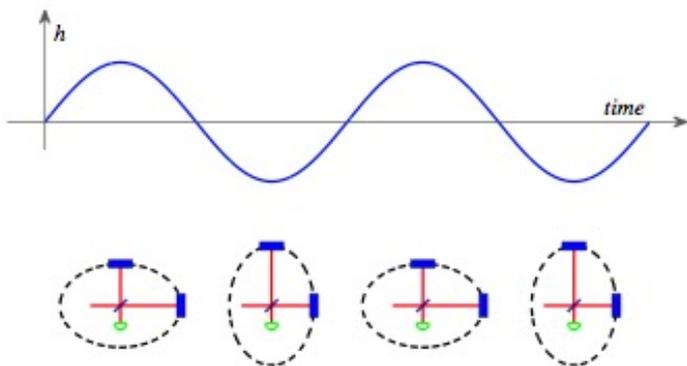
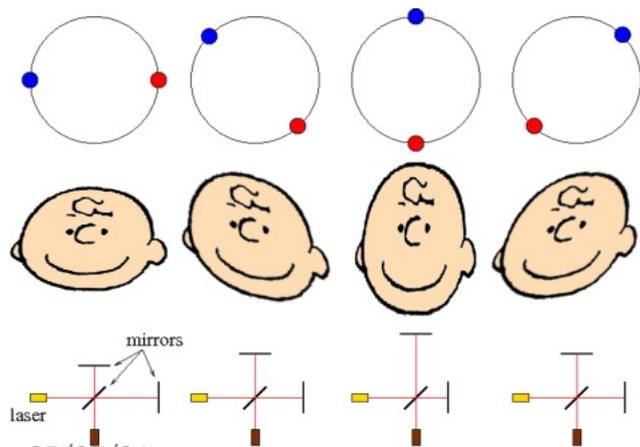
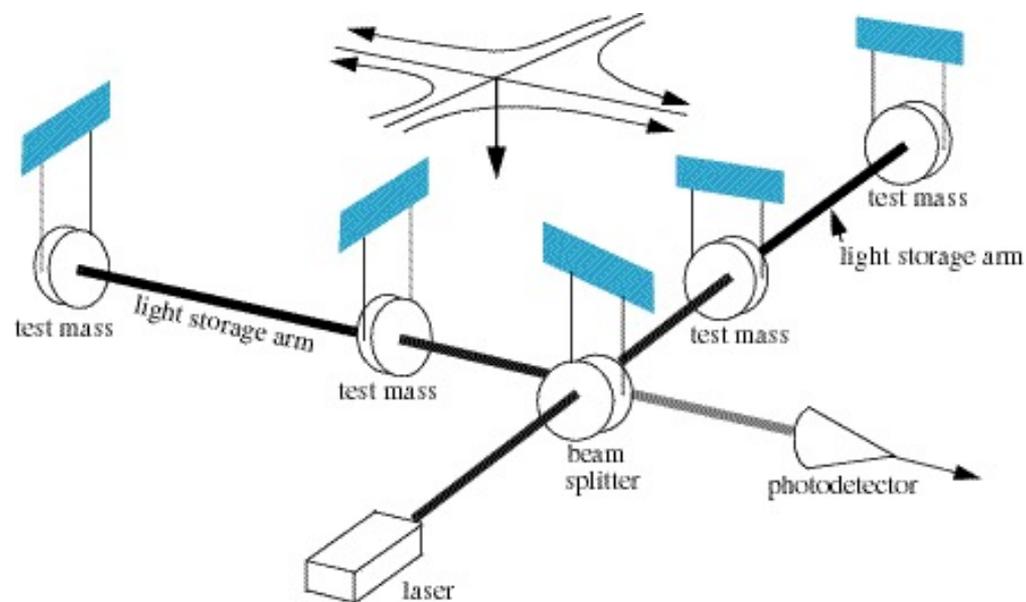


Figure 1. A gravitational wave traveling perpendicular to the plane of the diagram is characterized by a strain amplitude h . The wave distorts a ring of test particles into an ellipse, elongated in one direction in one half-cycle of the wave, and elongated in the orthogonal direction in the next half-cycle. This oscillating distortion can be measured with a Michelson interferometer oriented as shown. The length oscillations modulate the phase shifts accrued by the light in each arm, which are in turn observed as light intensity modulations at the photodetector (green semi-circle). This depicts one of the linear polarization modes of the GW.



Strumentazione Astronomica

LIGO

Laser Interferometer for Gravitational waves Observations



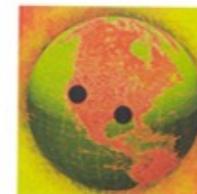
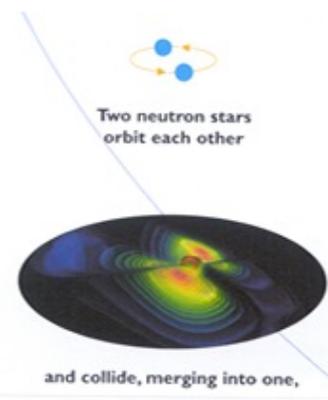
Hanford, Washington



Livingston, Lo

Bracci da 4km

Nelle cavità risonanti il fascio si riflette circa 280 volte per una lunghezza efficace equivalente a 1120 km



which reach Earth and will be detected simultaneously at two observatories.

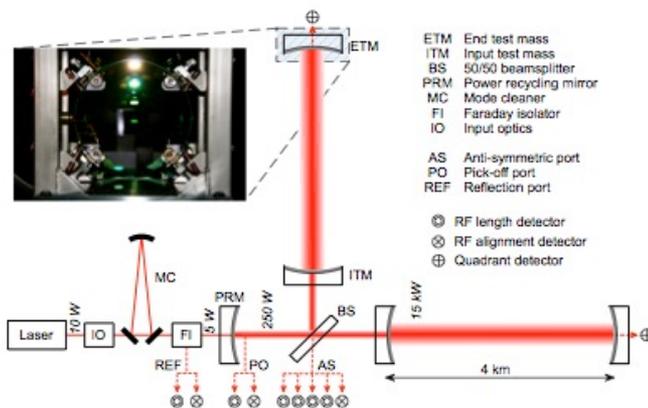
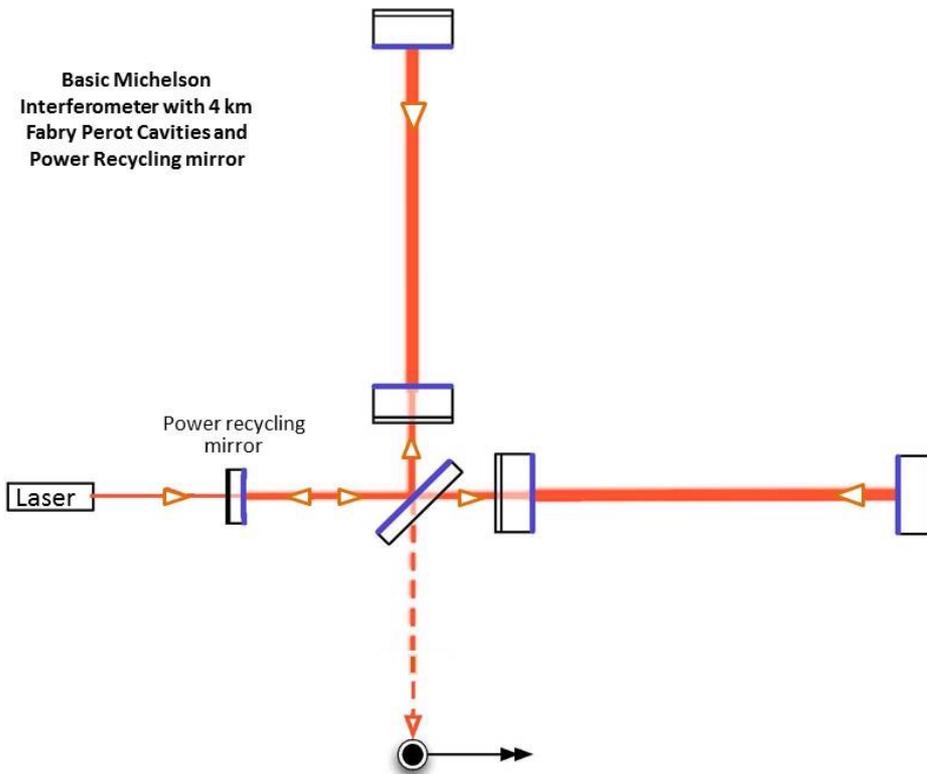


Figure 3. Optical and sensing configuration of the LIGO 4 km interferometers (the laser power numbers here are generic; specific power levels are given in Table 1). The IO block includes laser frequency and amplitude stabilization, and electro-optic phase modulators. The power recycling cavity is formed between the PRM and the two ITMs, and contains the BS. The inset photo shows an input test mass mirror in its pendulum suspension. The near face has a highly reflective coating for the infrared laser light, but transmits visible light. Through it one can see mirror actuators arranged in a square pattern near the mirror perimeter.

LIGO

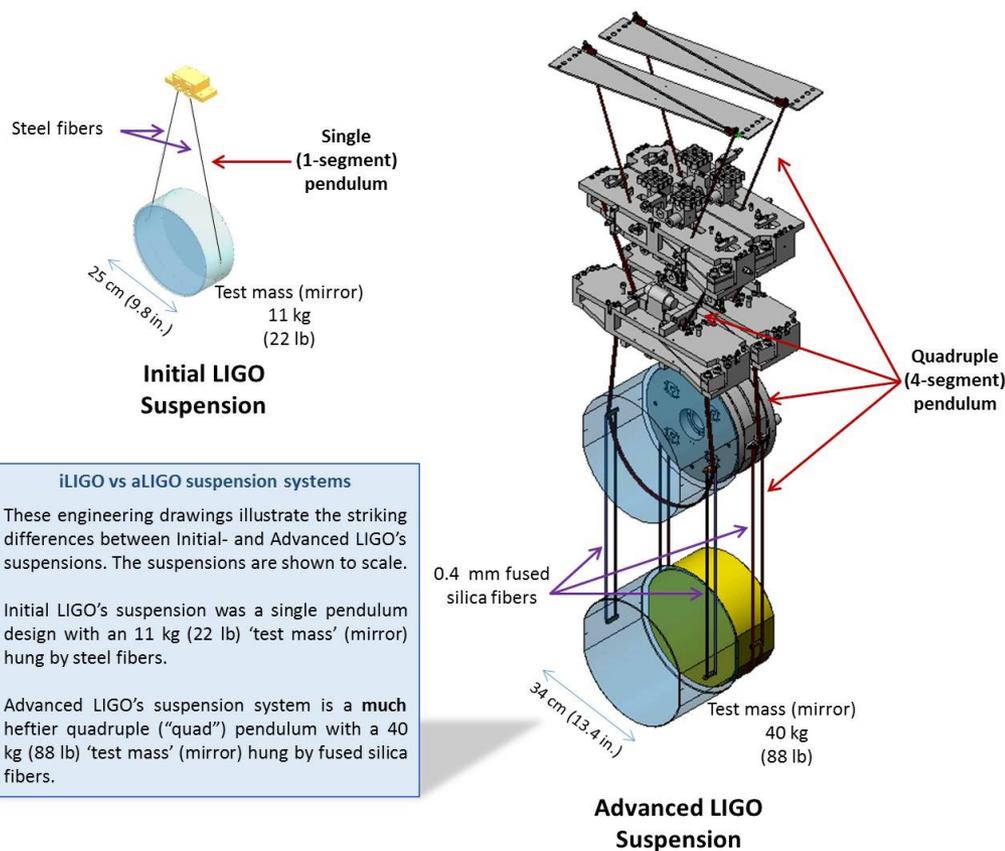
Laser Interferometer for Gravitational waves Observations



Per sostenere una tale moltiplicazione della lunghezza dei bracci senza diminuire in modo inaccettabile il rapporto S/N occorre utilizzare un sistema di power recycling che porta la potenza iniziale del laser (200W) a una equivalente di 750 kW

LIGO

Laser Interferometer for Gravitational waves Observations

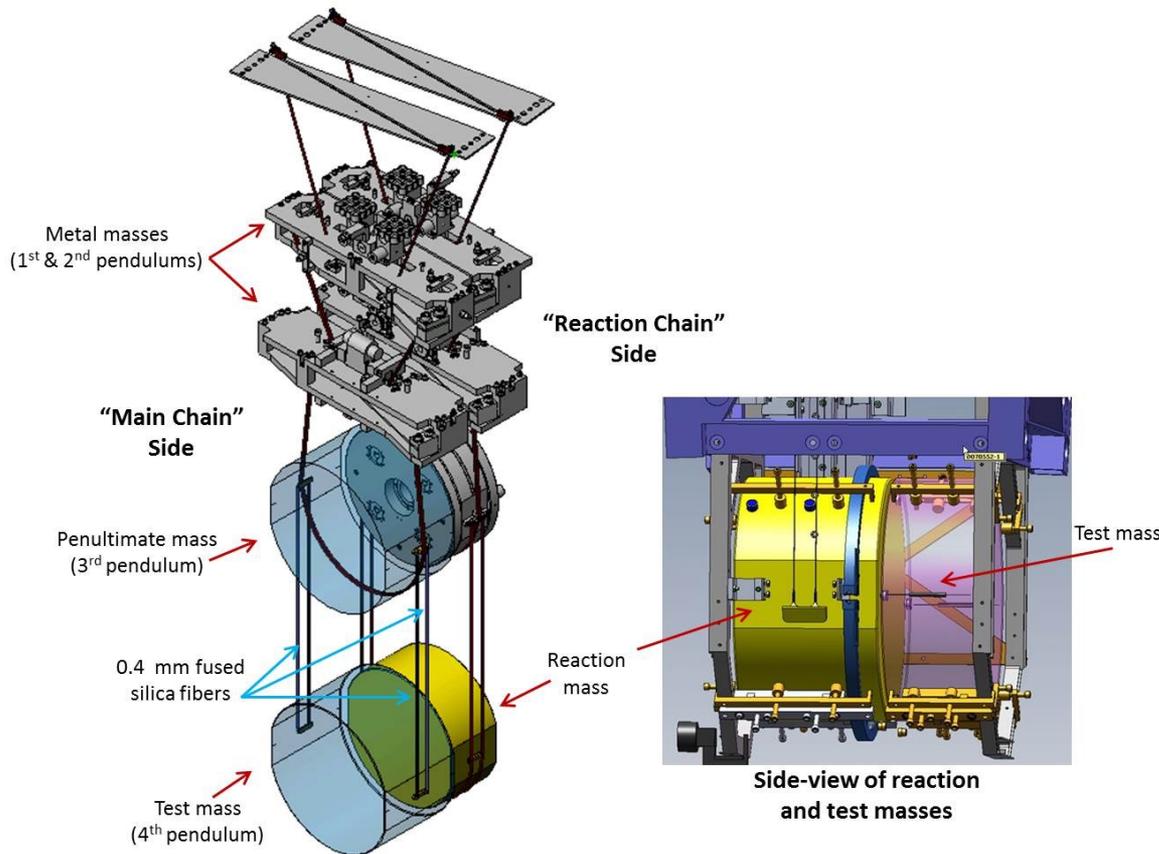


Il Sistema di sospensione delle test mass (specchi) serve ad isolarle dalle vibrazioni "sismiche".

Da LIGO ad Advanced LIGO il sistema ha migliorato lo smorzamento di un fattore 10^8 grazie ad una massa molto maggiore, un sistema di pedoli multipli con fibre di sospensione al silicio e un sistema di reazione attivo

LIGO

Laser Interferometer for Gravitational waves Observations

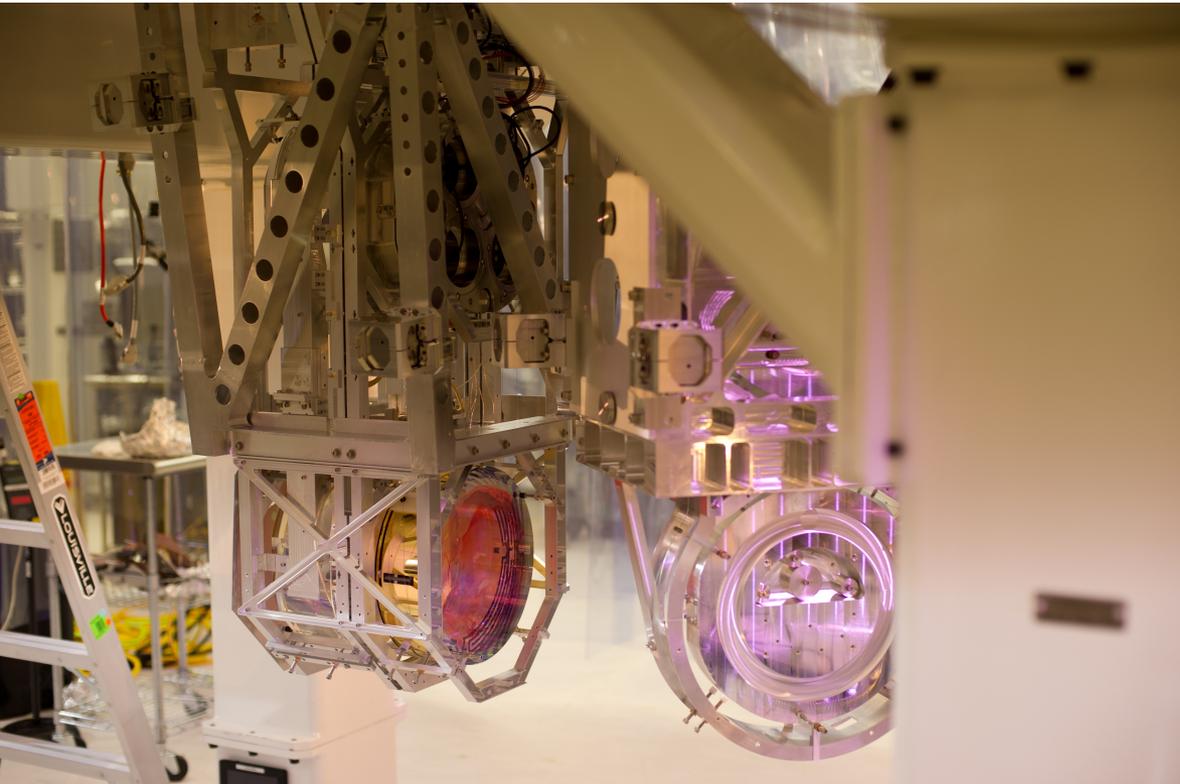


Gli specchi grandi, massivi e dall'ottima riflettività hanno il vantaggio di assorbire meno i fotoni del laser (meno deformazione) e di rinculare meno sotto l'effetto dell'impulso dei fotoni (maggiore massa inerziale)

La massa totale del pendolo quadruplo è di 360 kg. La posizione è mantenuta stabile grazie sistemi attivi magnetici ed elettrostatici che sono in grado di smorzare il rumore sismico a 10^{-19} m.

LIGO

Laser Interferometer for Gravitational waves Observations



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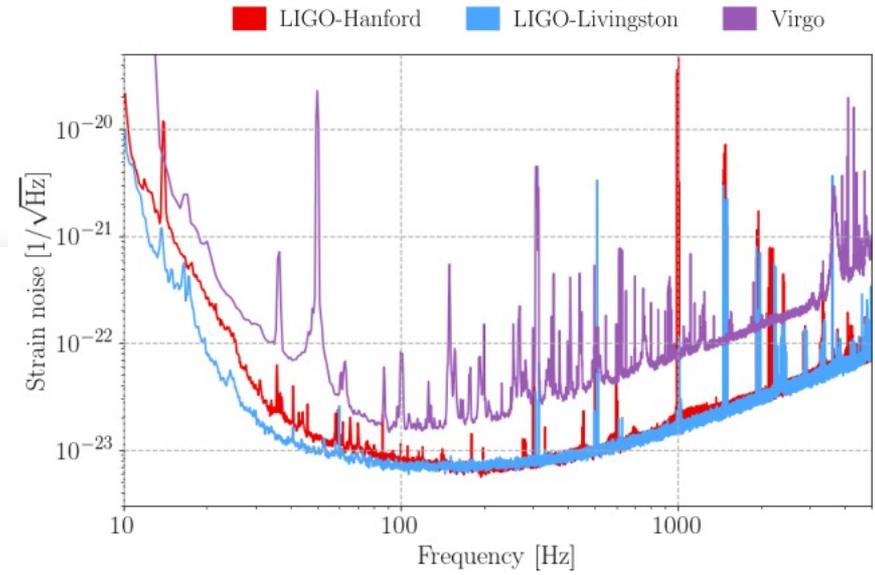
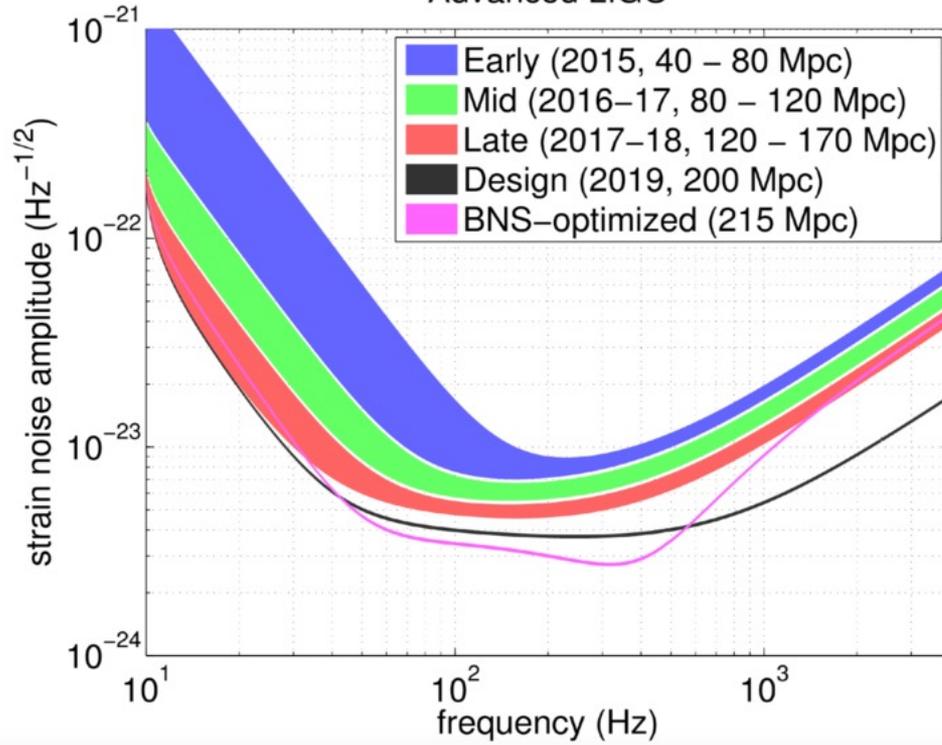
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Strumentazione Astronomica



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Advanced LIGO



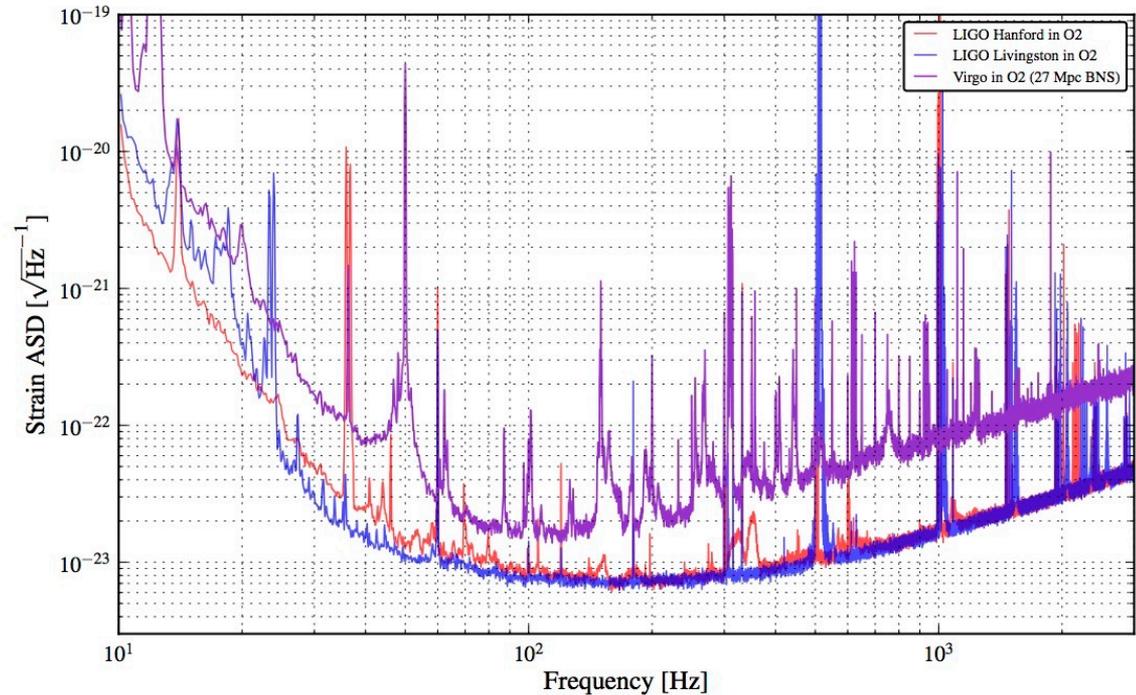
EGO – VIRGO

European Gravitational Observatory

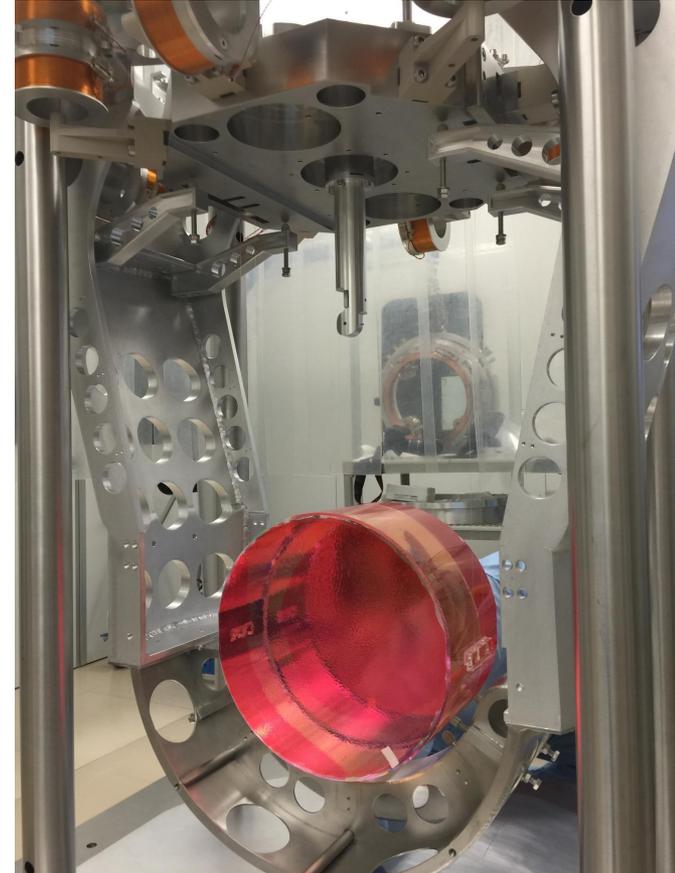
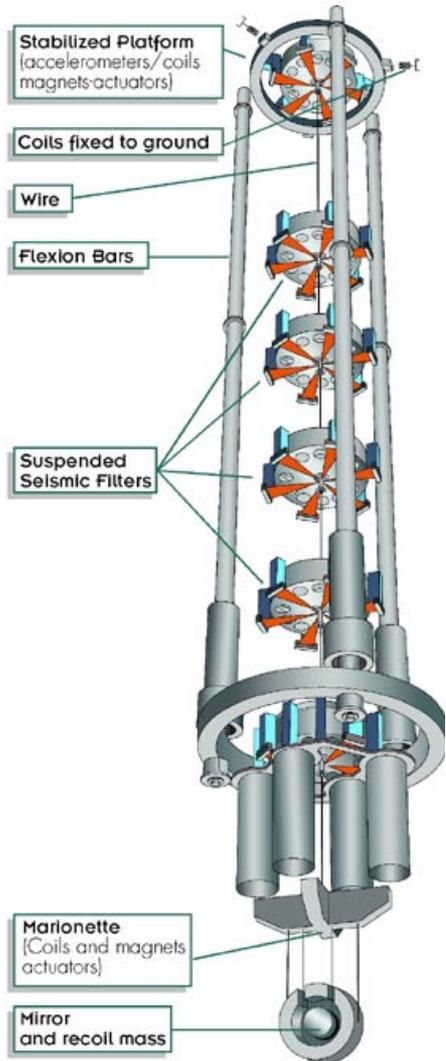
Vicino a Cascina (Pi)

Bracci di 3 Km che dopo
il ricircolo sono equivalenti
a 120 km

Lavora in coincidenza con aLIGO



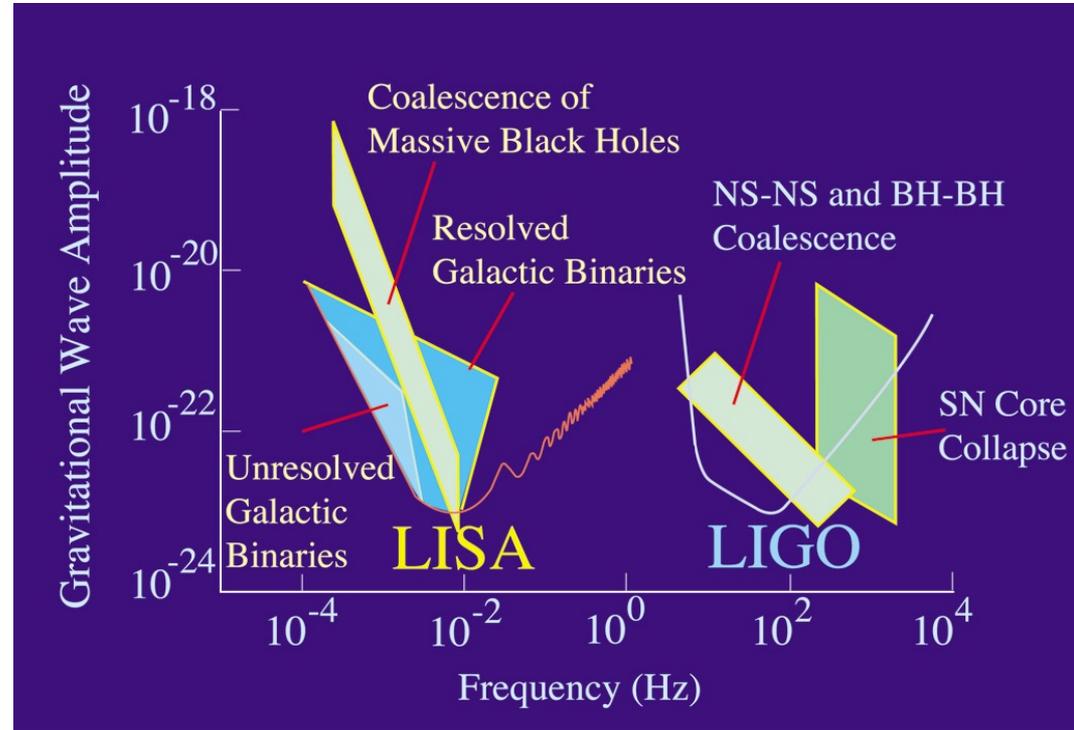
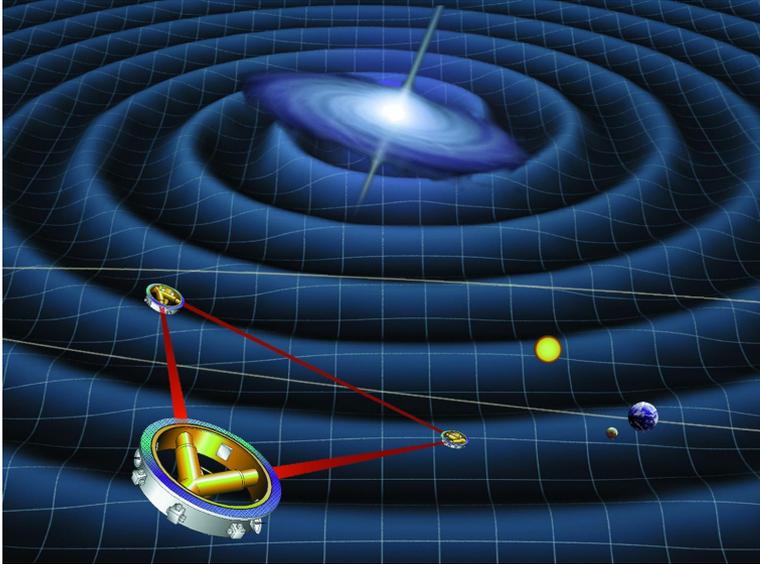
EGO - VIRGO



EGO - VIRGO

Principle: Michelson laser interferometer with two Fabry-Perot cavities in the arms and power recycling.	
Arms length:	3 kilometers
Vacuum tube:	120 cm diameter, fully welded (no seal)
Vacuum performance	
Pressure after baking at 150o C:	< 10 ⁻⁹ mbar
hydrocarbons partial pressure	10 ⁻¹³ mbar
Laser and injection system:	
Nd:YAG diode-pumped laser at 1064 nm	
Laser power:	20 W
Mode cleaner:	144 m long, 3 mirrors ring cavity
Finesse of mode cleaner cavity	1000
Frequency stability	< 10 ⁻⁴ Hz ^{1/2} at 1 kHz
Relative Intensity Noise (RIN)	< 10 ⁻⁷ at 1 kHz
Power Stored in Fabry-Perot cavity:	15 to 50 kW (depending of finesse)
Power Stored in recycling cavity:	1 kW
Optics	
Main mirror substrates	special "Virgo" grade fused silica absorption < 1 ppm/cm diameter 350mm
Reflective coatings	absorption < 1ppm
Anti reflection coatings	reflection < 0.1 %
Surface quality	λ/200 rms
Surface microroughness	< 1 Angstrom
Suspensions	
Inverted pendulum pre-isolator plus 6 passive stages.	
Active control on first and last stage and on mirror.	
Seismic attenuation	10 ⁻¹¹ at 10 Hz
rms mirror motion before locking:	<1 mm, < 0.1 mradian
Thermal stabilization	+/- 0.1 degree C
Frequency range	10 Hz to 10 kHz
Sensitivity	h ~ 3 10 ⁻²¹ Hz ^{-1/2} at 10 Hz h ~ 3 10 ⁻²³ Hz ^{-1/2} at 1 kHz
Provision for future implementation of signal recycling technique	

LISA (Laser Interferometer Space Antenna)



Bracci da 5 milioni di km

Strumentazione Astronomica

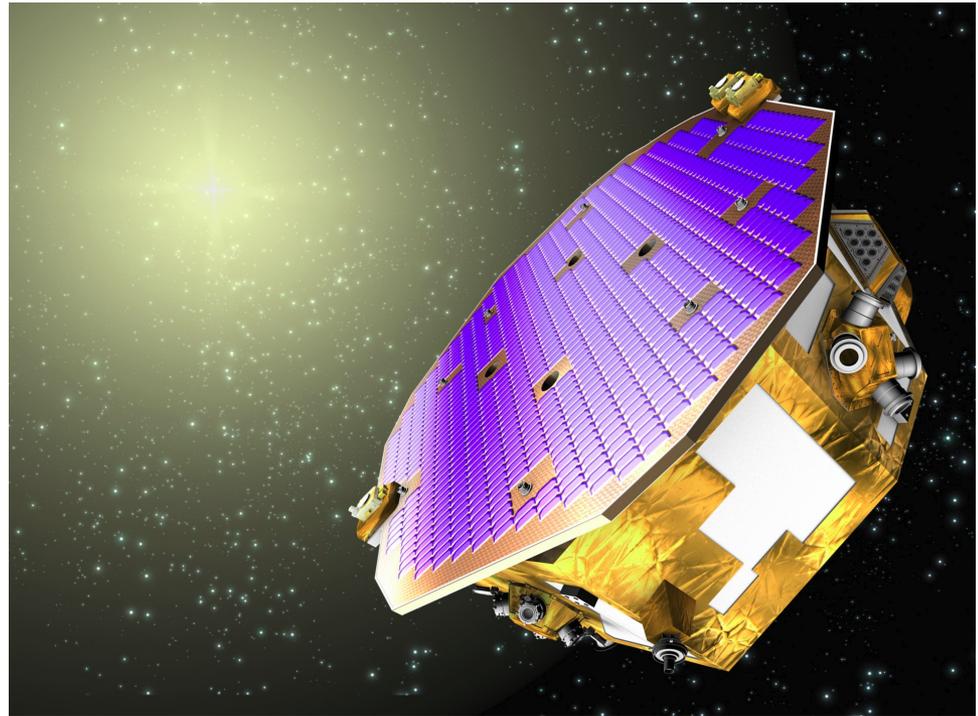
LISA PATHFINDER

- Missione spaziale dell'ESA
- Test per la tecnologia di eLISA
- Modelli fisici per sottrazione di effetti parassita

- Lancio: settembre 2015

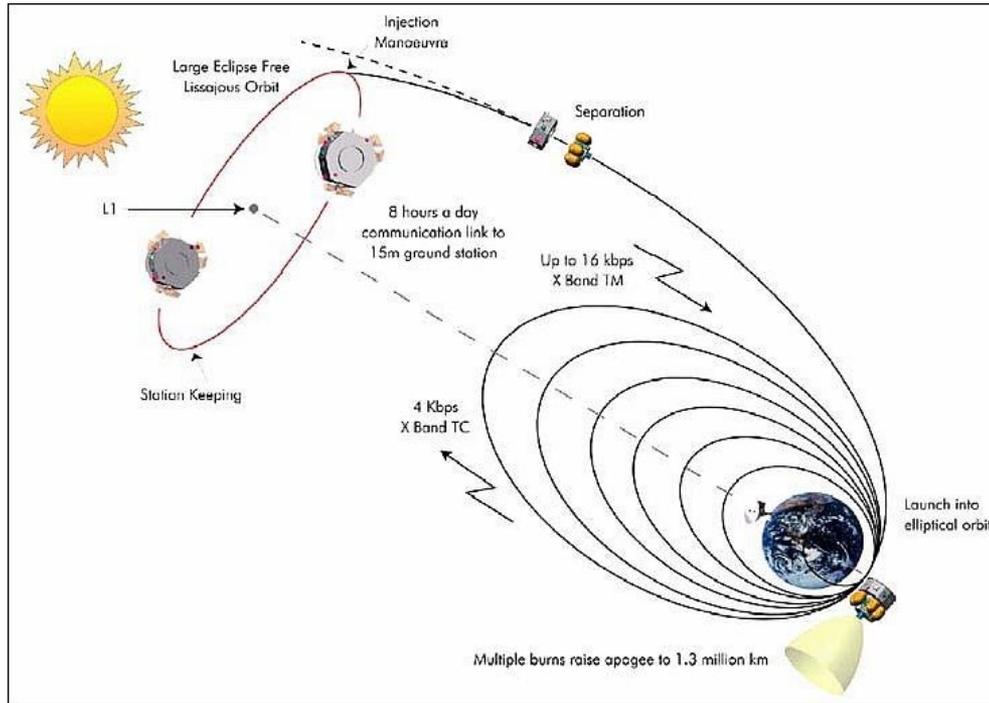
- Viaggio:
 - Orbita di parcheggio ellittica
 - Orbita di Lissajous attorno ad L1

- Durata missione: circa sei mesi (+ estensioni)



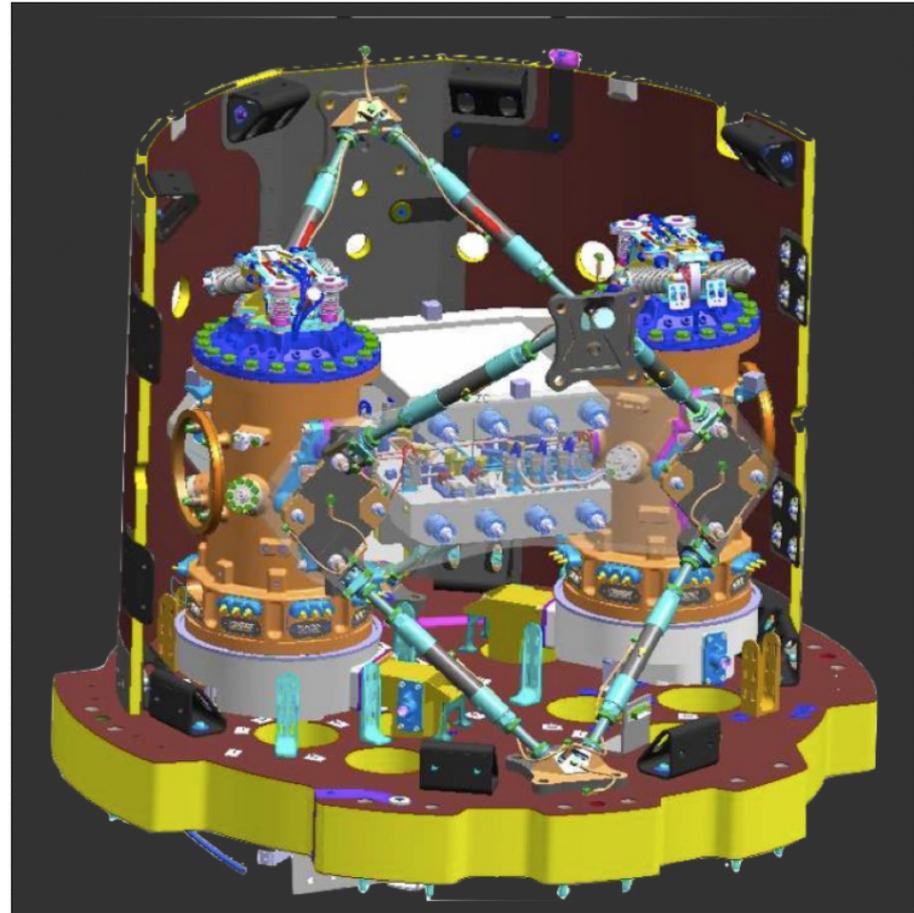
Partnership: Italia, Francia, Germania, Gran Bretagna, Paesi Bassi, Spagna, Svizzera

LISA PATHFINDER



LISA PATHFINDER

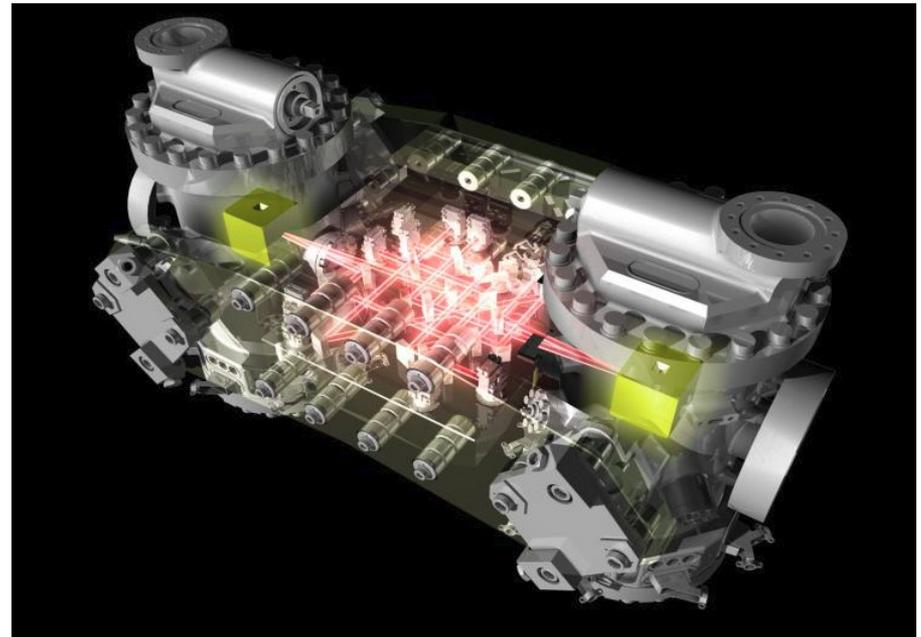
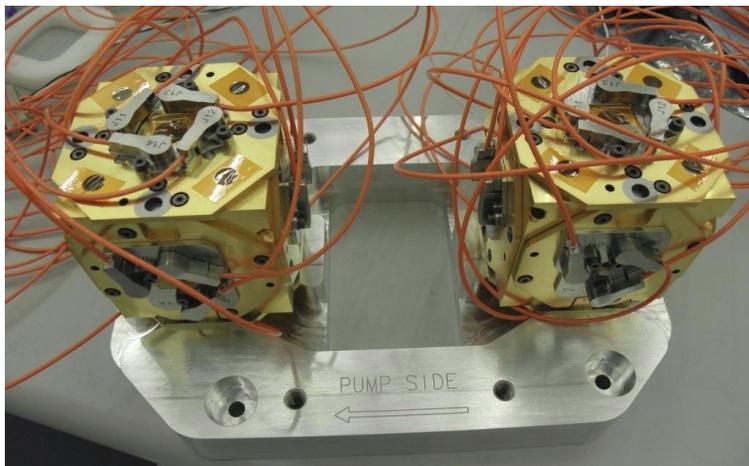
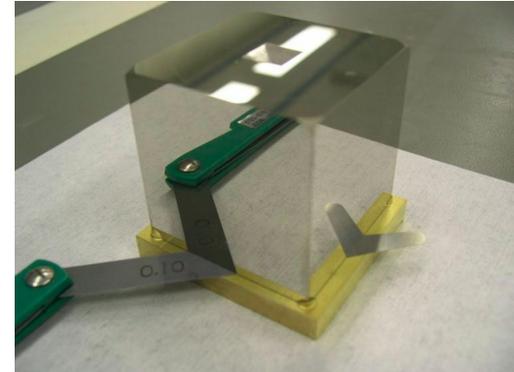
- Due masse sono poste all'interno di due camere a distanza di 38 cm
- Gli spostamenti relativi sono calcolati tramite interferometria laser su un banco ottico



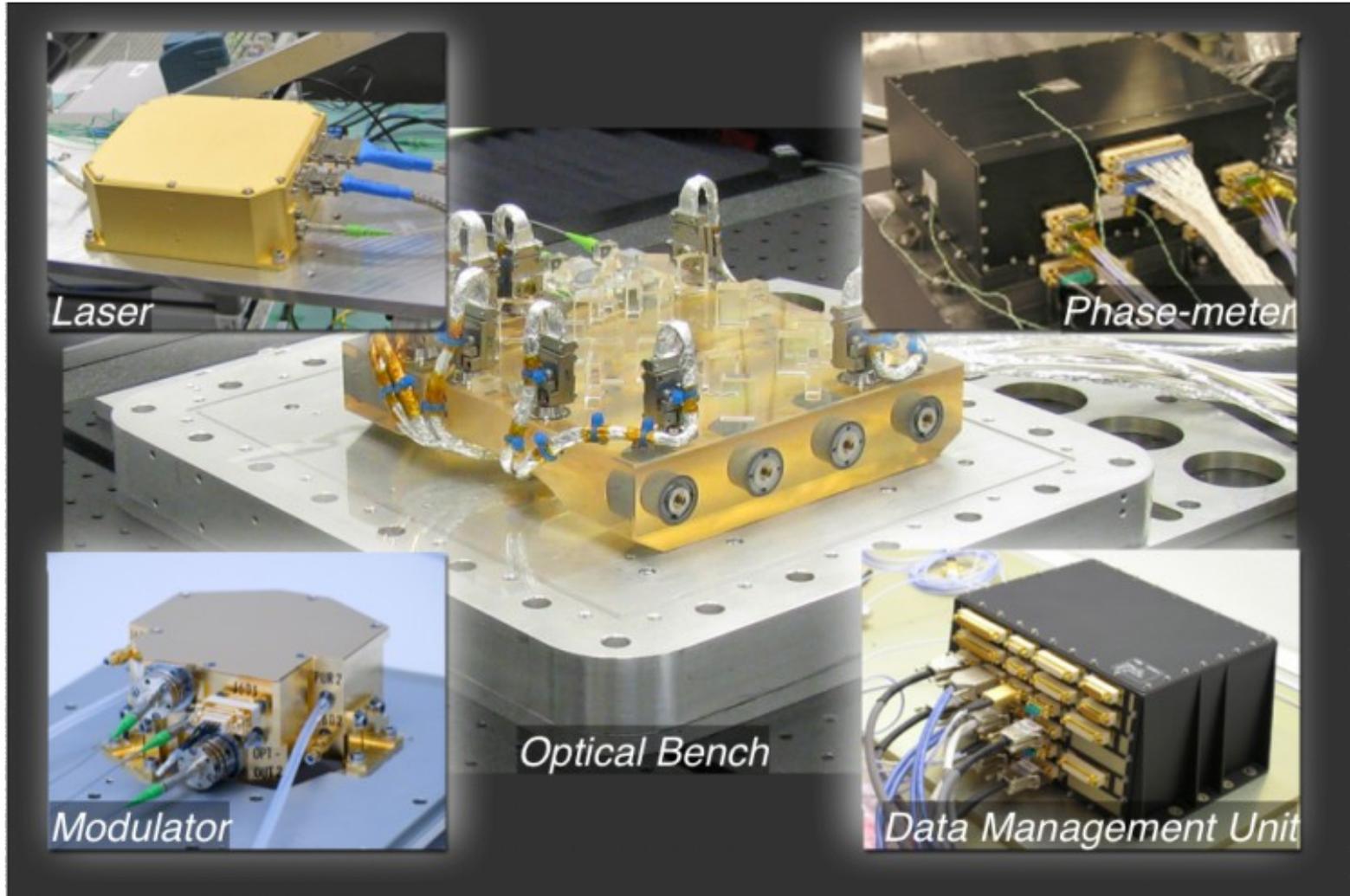
LISA Technology Package

E' il carico utile principale su LPF

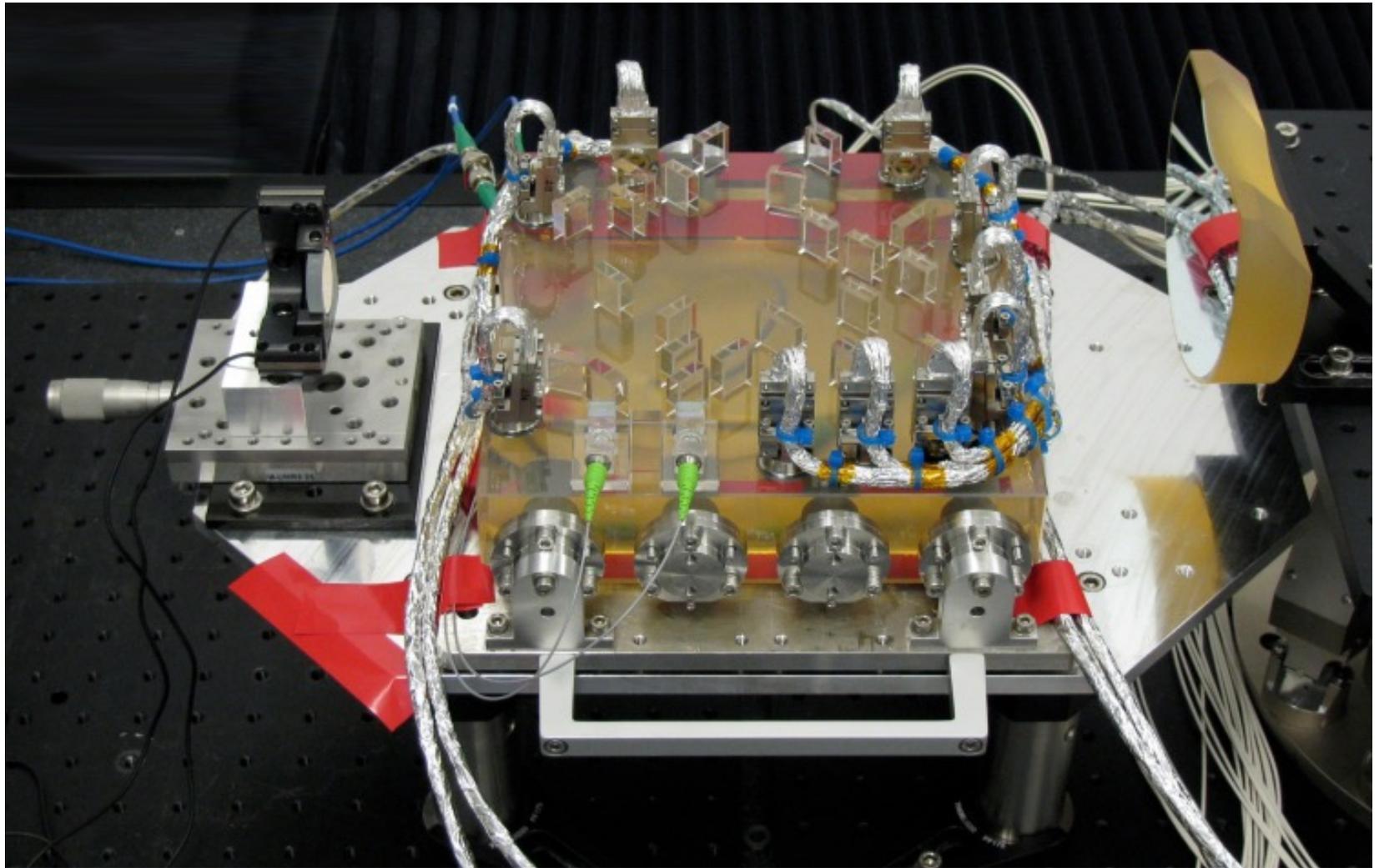
- Due test mass (TM) di 46 mm in Au-Pt in caduta libera
- Custodie elettrostatiche
- Camera a vuoto
- Sistema ottico di misura (OMS) per misure di posizione e assetto delle TM



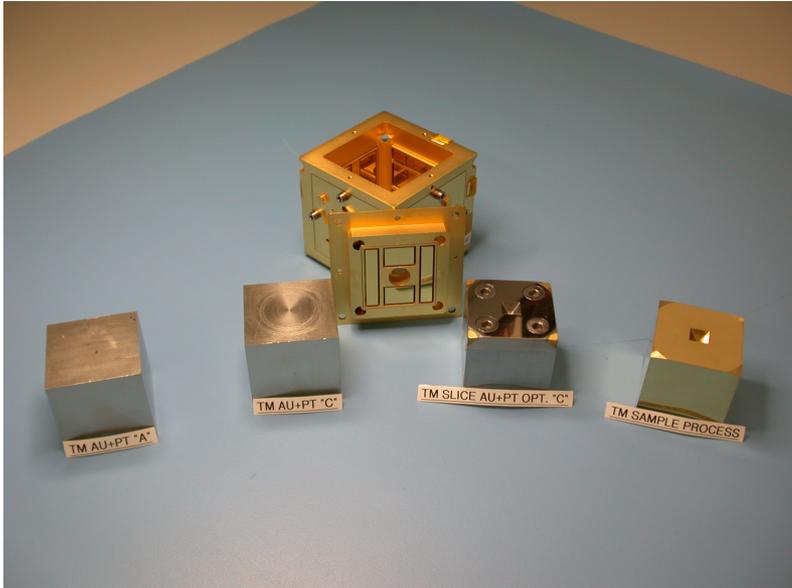
LTP's Optical Metrology System



Strumentazione Astronomica

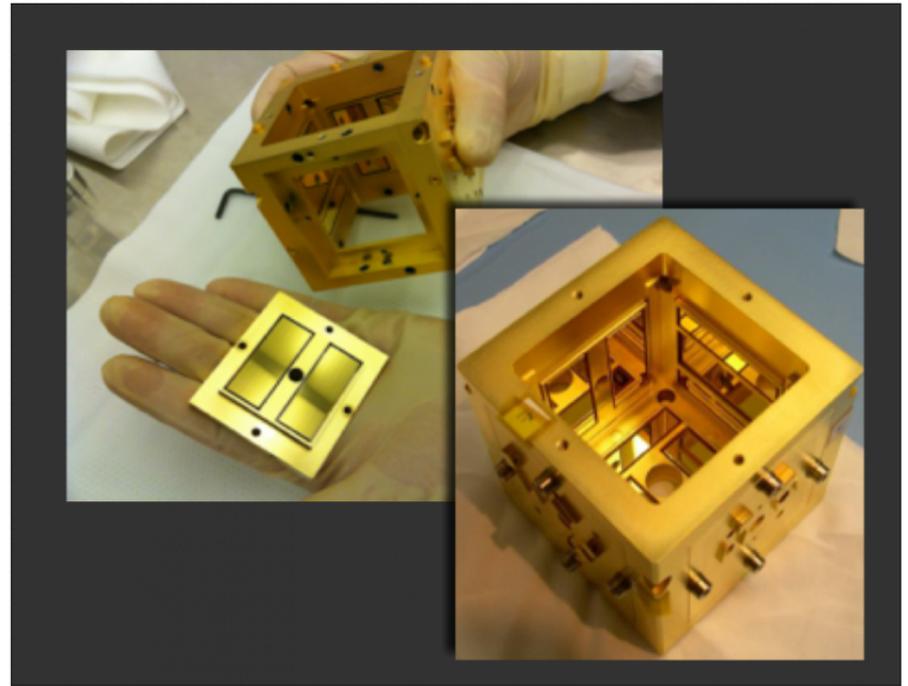
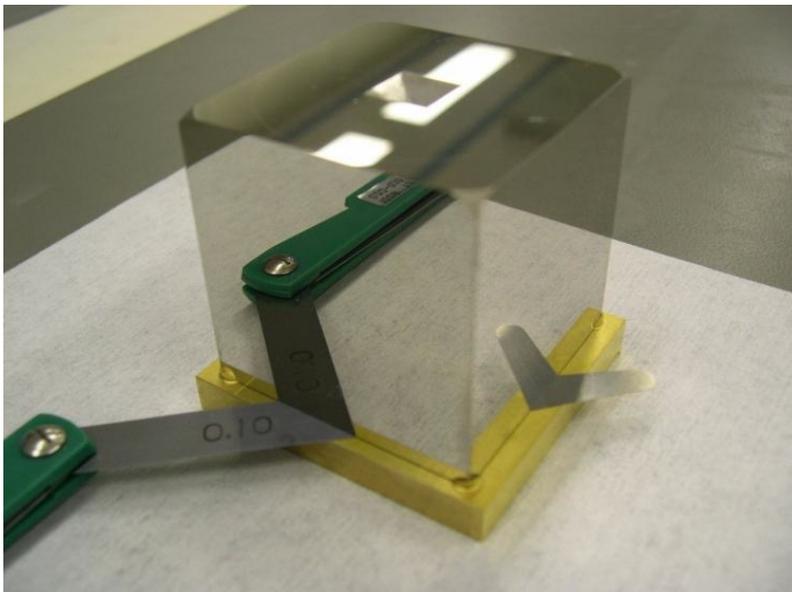


Strumentazione Astronomica

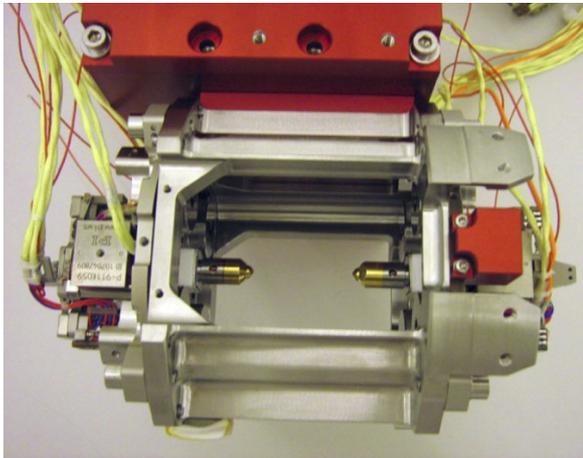
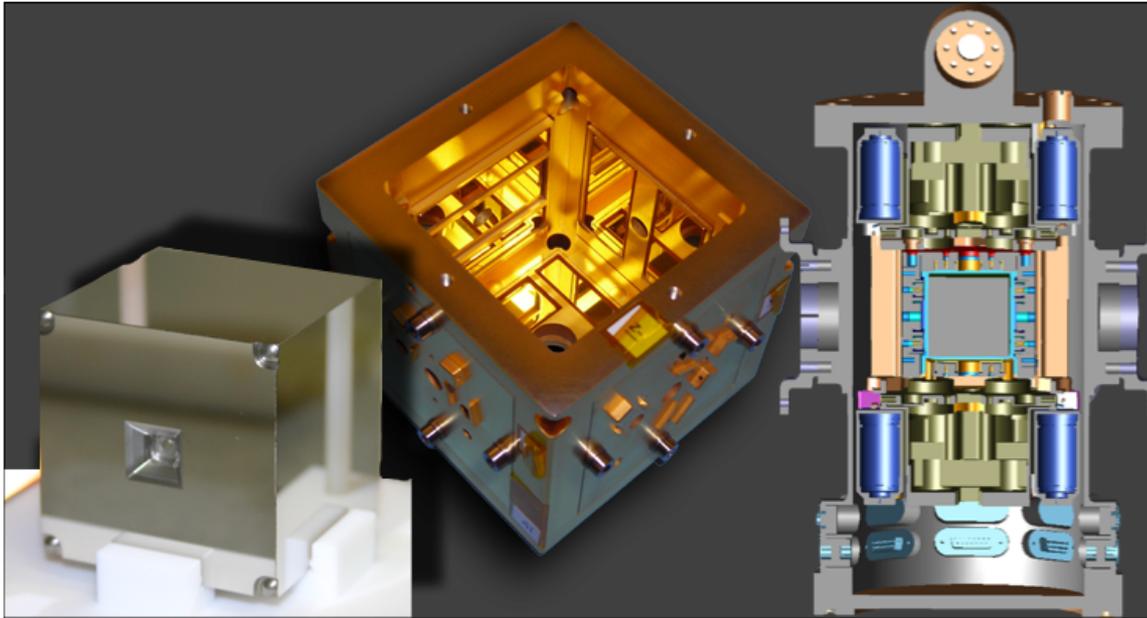


1.97 kg Pt-Au

Capacitive Sensors



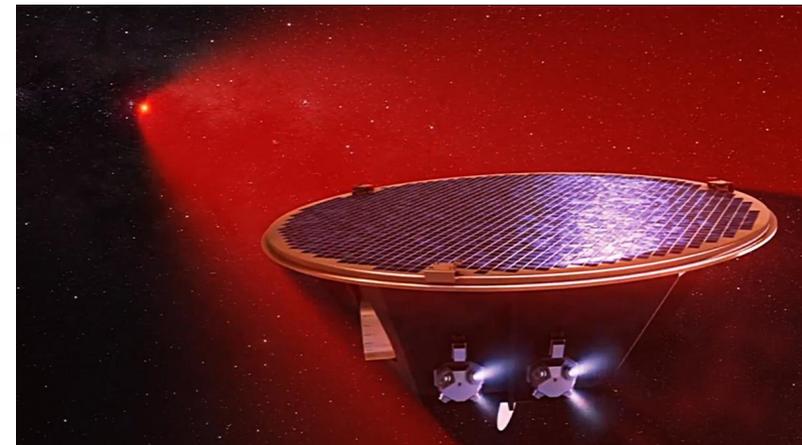
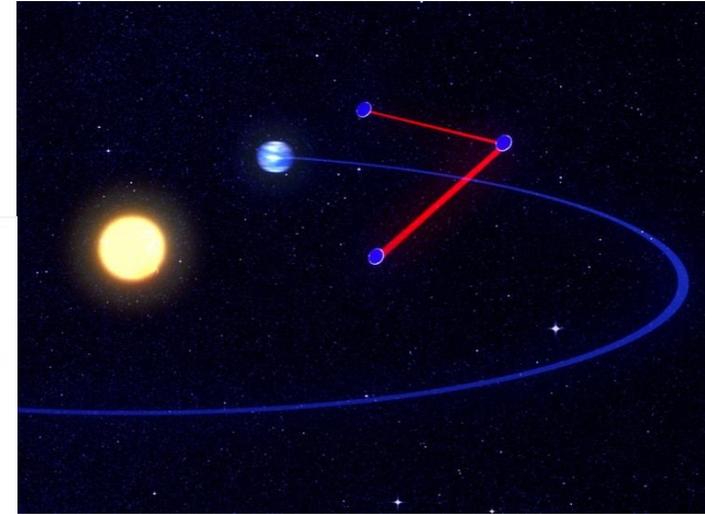
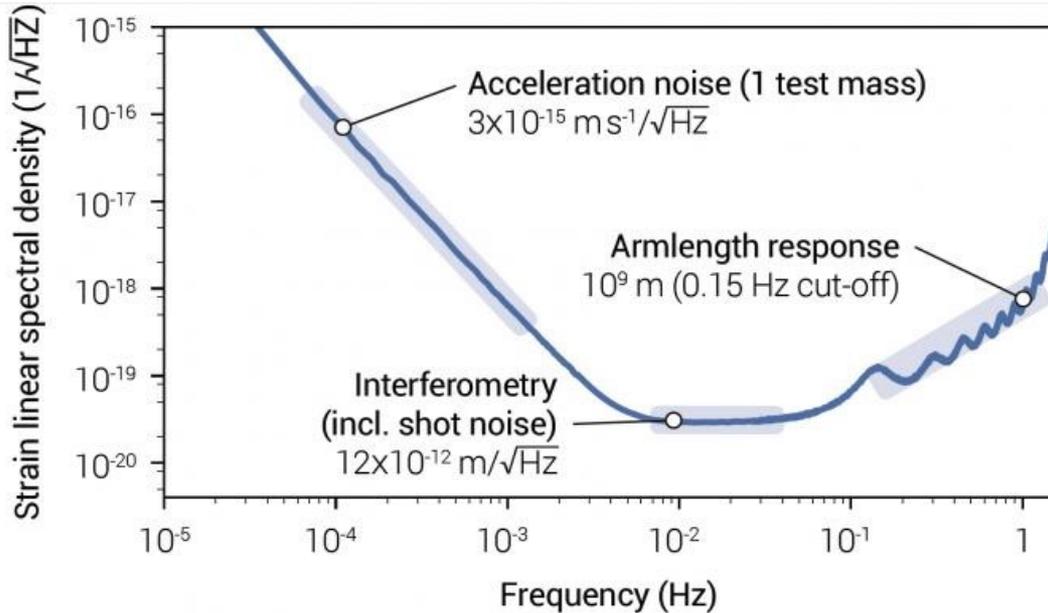
Gravitational Reference System



Sensibilità 1Fg

eLISA 2028...

<https://www.elisascience.org>



Data la distanza, l'attenuazione è 6.25×10^{-20} e una "visione" diretta è impossibile.

Si usa un laser in modalità "transponder"

Bisogna conoscere la distanza con un'accuratezza di 1m su 10^9