



Missione LISA: frontiere sperimentali per un osservatorio spaziale di onde gravitazionali



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UNIVERSITÀ
DI TRENTO



Agenzia
Spaziale
Italiana



TIFPA
Trento
Institute for
Fundamental
Physics and
Applications

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- Osservazione astrofisica con onde gravitazionali:
Potenzialità delle basse frequenze e **obiettivi**
- Il **concetto** di LISA e **requisiti** di performance
- Panoramica: **strumentazione** e **stato attuale** della missione
- Il contributo di **LISA Pathfinder**

25/01/2024

ASI

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COMUNICATI STAMPA •

SEMAFORO VERDE DALL'AGENZIA SPAZIALE EUROPEA ALLE MISSIONI LISA E ENVISION

Si tratta del più importante osservatorio spaziale per le onde gravitazionali e di una sonda che studierà i tanti misteri ancora nascosti del pianeta Venere. I due progetti vedono una forte partecipazione italiana con l'Agenzia Spaziale Italiana, l'Istituto Nazionale di Fisica Nucleare e l'Università di Trento

25 Gennaio 2024

esa

SCIENCE & EXPLORATION

Capturing the ripples of spacetime: LISA gets go-ahead

25/01/2024 38093 VIEWS 188 LIKES

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comunicati stampa

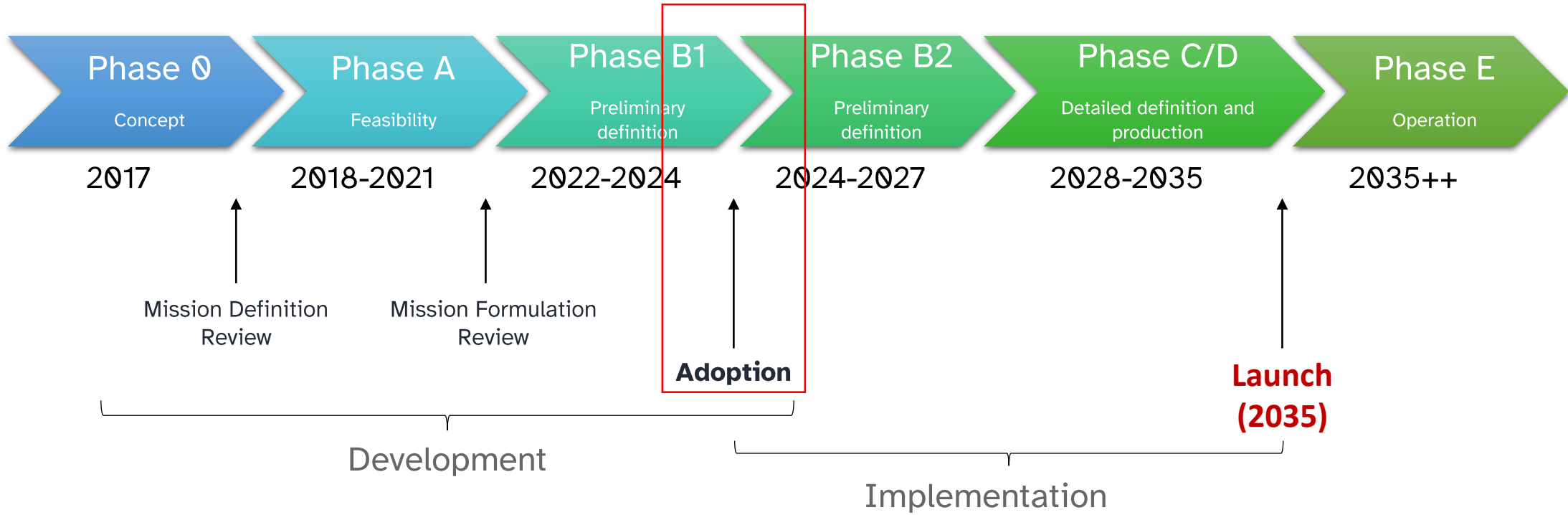
25 GENNAIO 2024

SEMAFORO VERDE DALL'AGENZIA SPAZIALE EUROPEA ALLE MISSIONI LISA E ENVISION

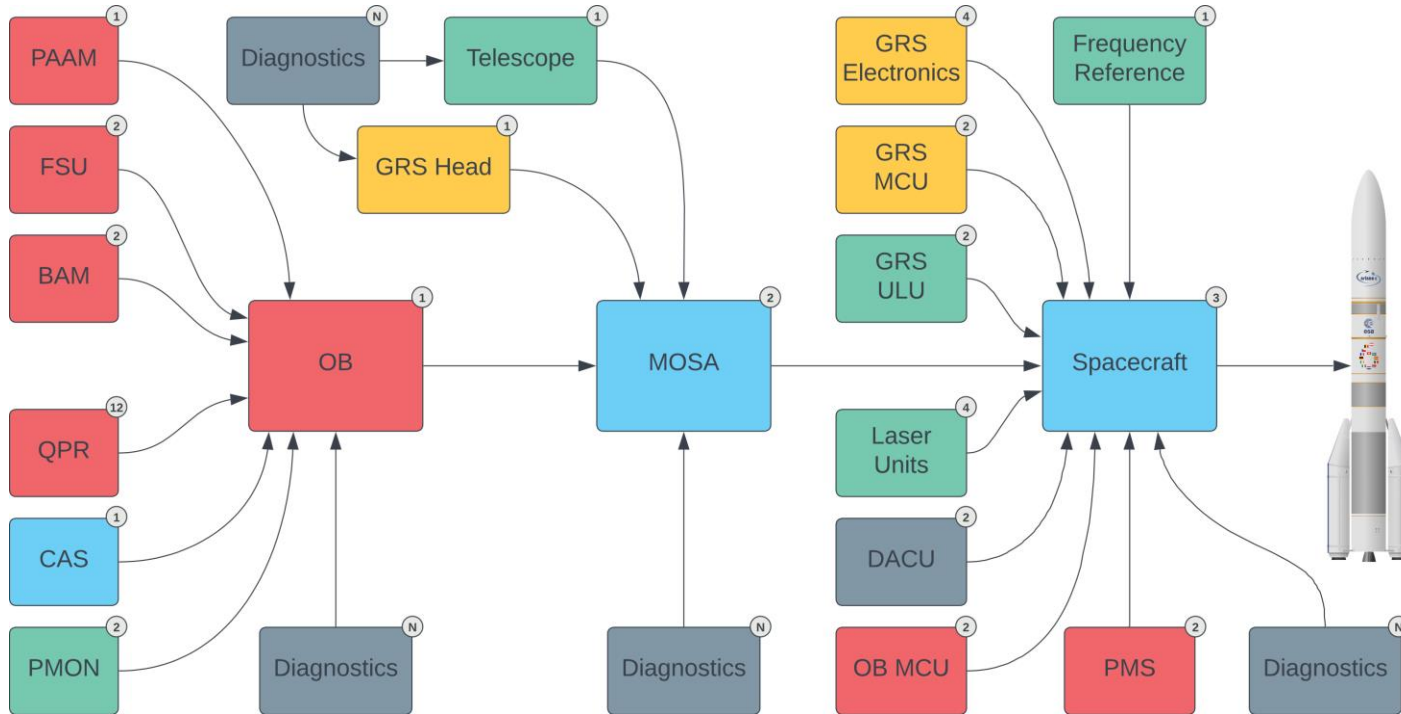
Il Comitato del Programma Scientifico (SPC) dell'Agenzia Spaziale Europea (ESA) ha adottato oggi le missioni LISA e EnVision. Essere adottati significa che la fase di studio è completata e l'ESA si impegna ora ad attuare le missioni. Si tratta del più importante osservatorio spaziale per le onde gravitazionali e di una sonda che studierà i tanti misteri ancora nascosti del pianeta Venere. I due progetti vedono una forte partecipazione italiana con l'Agenzia Spaziale Italiana, l'Istituto Nazionale di Fisica Nucleare e l'Università di Trento. LISA verrà lanciata a metà degli anni '30 mentre la partenza verso Venere di EnVision è al momento prevista per il 2031.

MISSIONE LISA

LISA: stato della missione

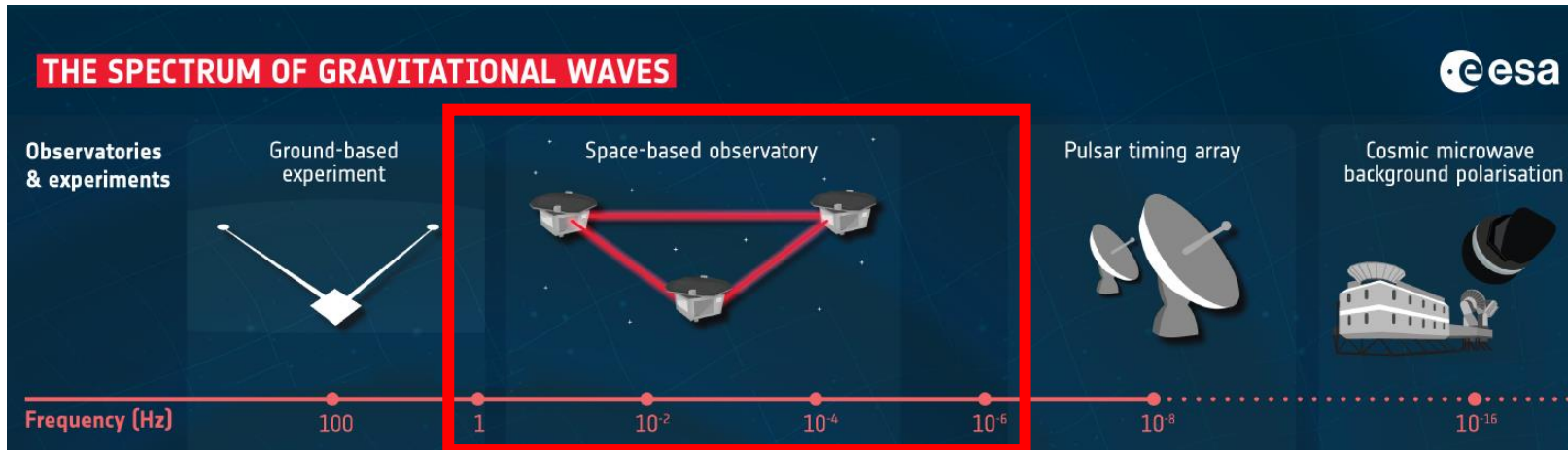


LISA: componenti e integrazione



| | | |
|------|------|--|
| IDS | IDS | Interferometric Detection Subsystem |
| GRS | GRS | Gravitational Reference Sensor |
| SDS | SDS | Science Diagnostics Subsystem |
| PAAM | PAAM | Point Ahead Alignment Mechanism |
| FSU | FSU | Fibre Switching Unit |
| BAM | BAM | Beam Alignment Mechanism |
| QPR | QPR | Quadrant Photoreceiver |
| CAS | CAS | Constellation Acquisition Sensor |
| PMON | PMON | Power Monitor |
| OB | OB | Optical Bench |
| MOSA | MOSA | Moving Optical Sub-Assembly |
| MCU | MCU | Mechanism Control Unit |
| ULU | ULU | Ultra-violet Light Unit |
| DACU | DACU | Diagnostics Acquisition and Control Unit |
| PMS | PMS | Phasemeter Measurement System |

Potenzialità delle basse frequenze

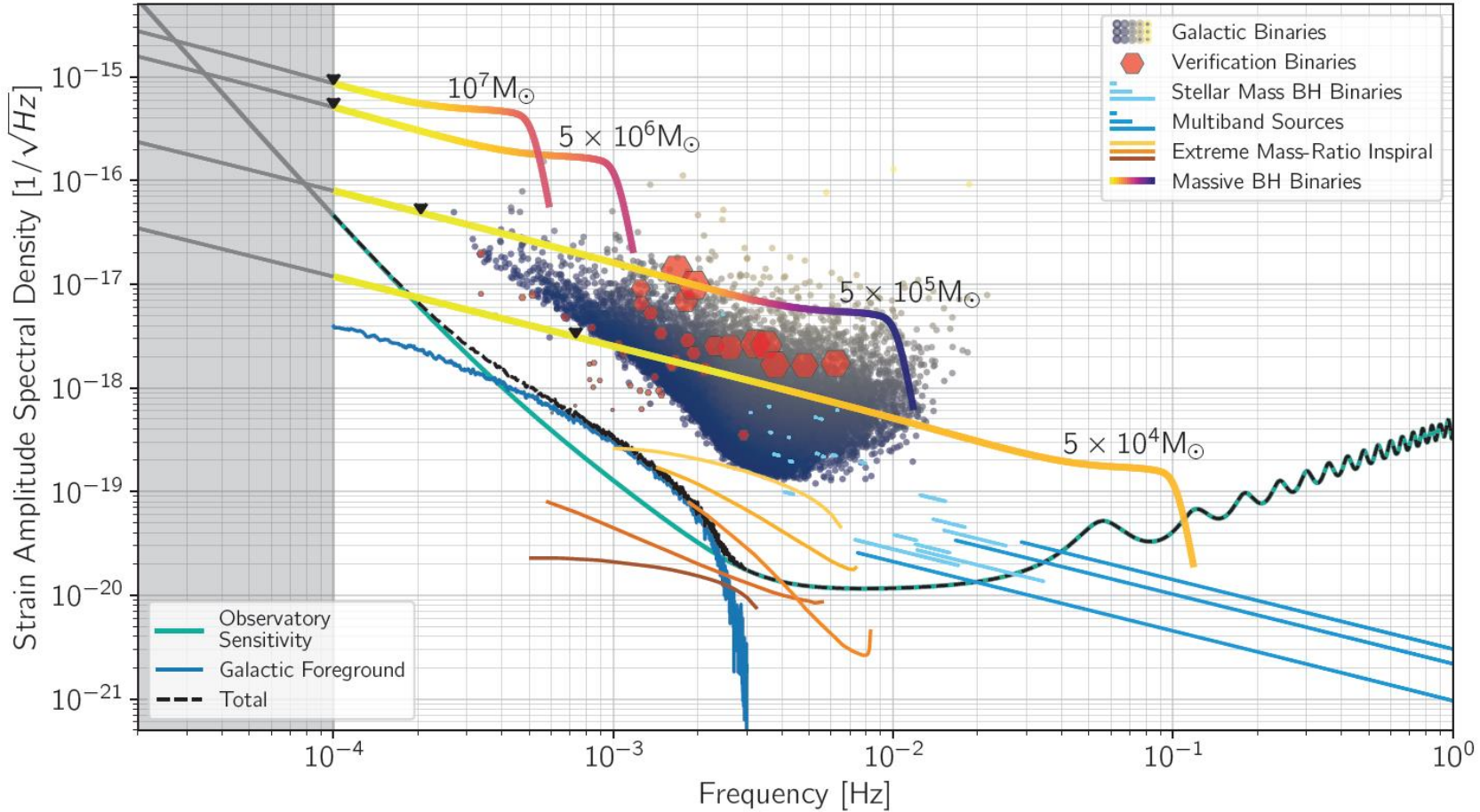


Science Objectives

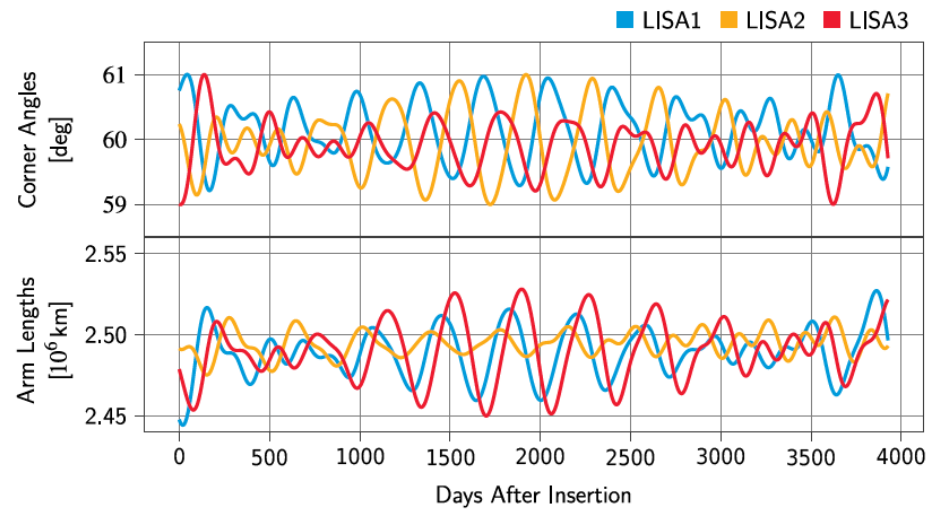
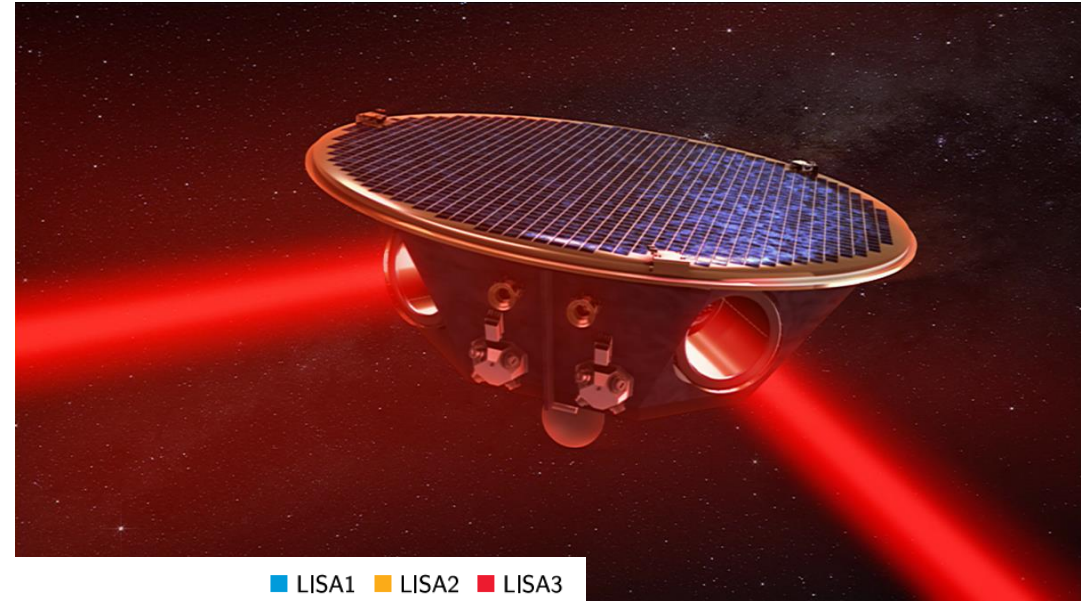
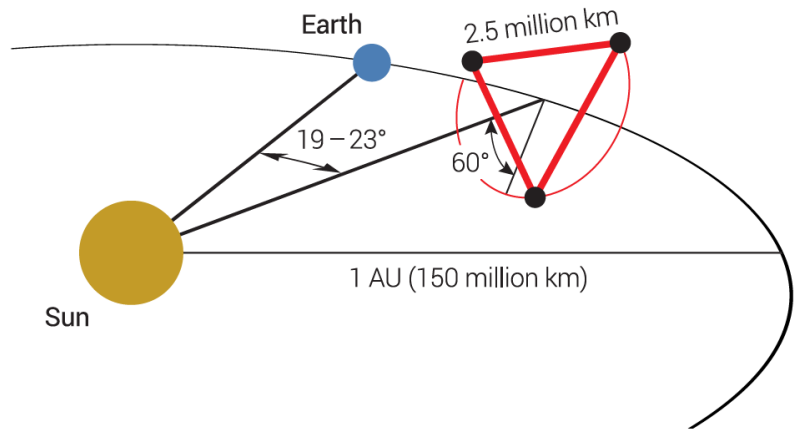
- Study the formation and evolution of **compact binary stars** and the structure of the Milky Way Galaxy
- Trace the origins, growth and merger histories of **massive Black Holes** across cosmic epochs
- Probe the properties and immediate environments of Black Holes in the local Universe using **extreme mass-ratio inspirals** and **intermediate mass-ratio inspirals**
- Understand the astrophysics of **stellar-mass Black Holes**
- Explore the **fundamental nature of gravity** and Black Holes
- Probe the rate of **expansion of the Universe** with standard sirens
- Understand **stochastic gravitational wave backgrounds** and their implications for the early Universe and TeV-scale particle physics
- Search for gravitational wave bursts and **unforeseen sources**



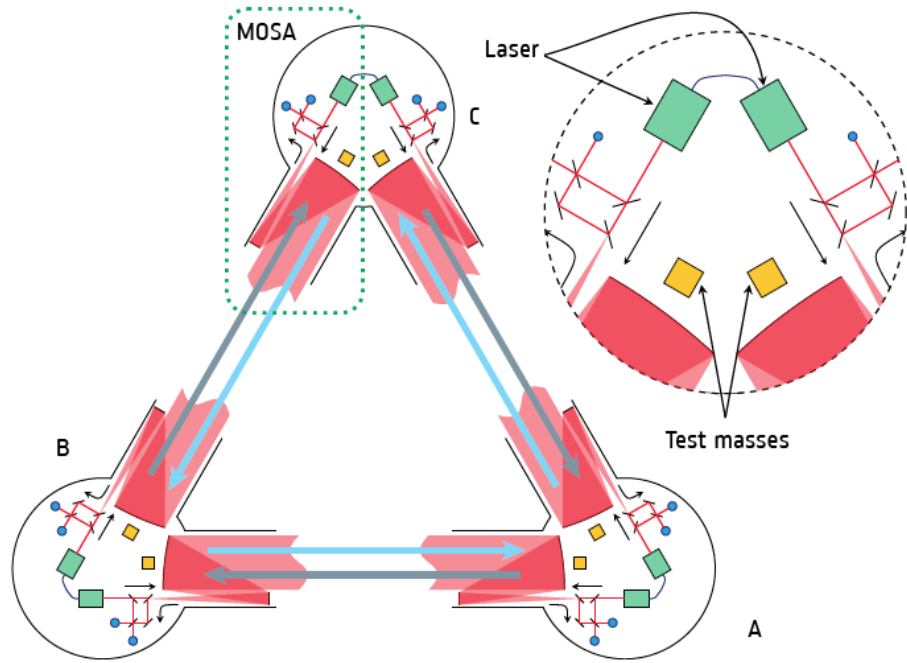
Potenzialità delle basse frequenze



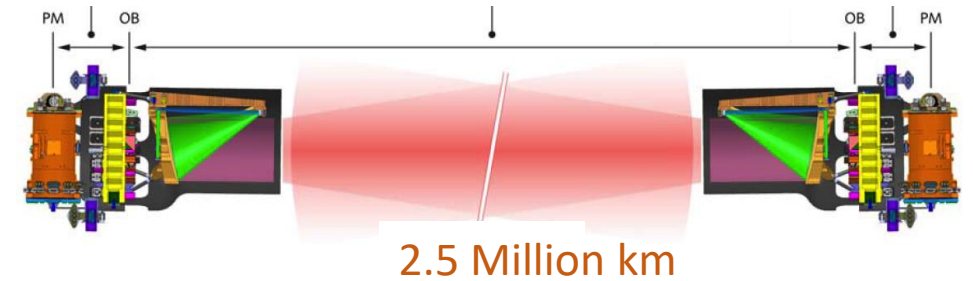
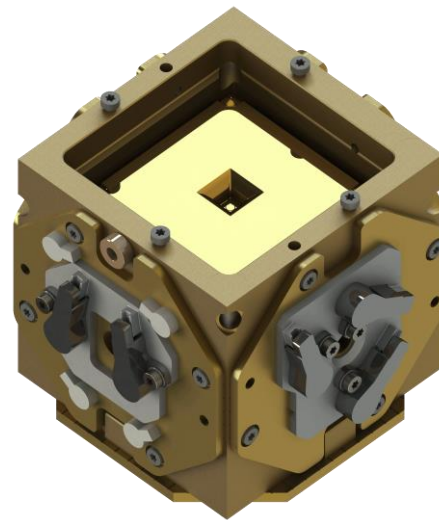
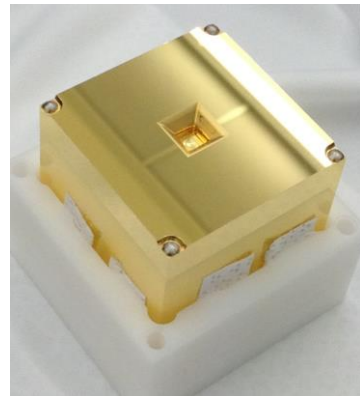
Il concetto di LISA



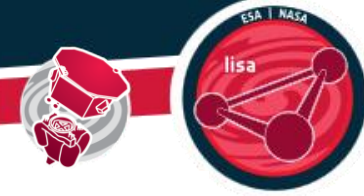
Il concetto di LISA



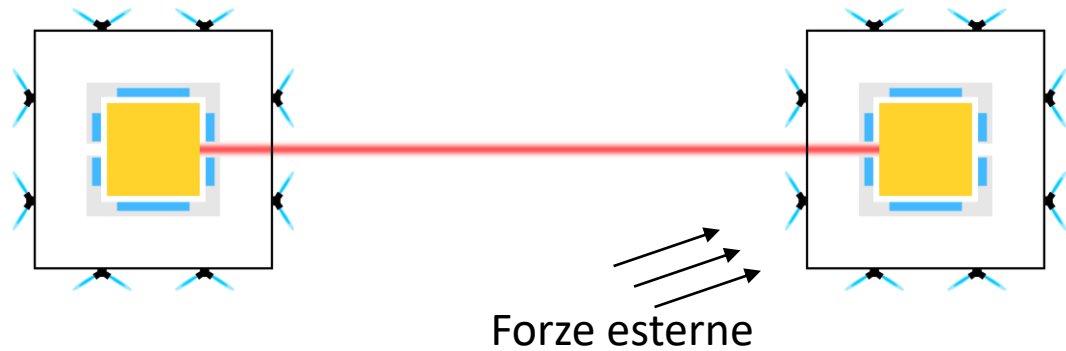
| Payload | |
|--------------------------------|--|
| Lasers | 2 per spacecraft • 2 W output power • wavelength 1064 nm • frequency stability 300 Hz/ $\sqrt{\text{Hz}}$ |
| Optical Bench | 2 per spacecraft • double-sided use • high thermal stability (Zerodur) |
| Interferometry | heterodyne interferometry • 15 pm/ $\sqrt{\text{Hz}}$ precision • Inter-spacecraft ranging to ~1 m |
| Telescope | 2 per spacecraft • 30 cm off-axis telescope • high thermal stability |
| Gravitational Reference System | 2 per spacecraft • acceleration noise $3 \text{ fm}/(\text{s}^2 \sqrt{\text{Hz}})$ • 46 mm cubic AuPt test mass • Faraday cage housing • electrostatic actuation in 5 degree of freedom |



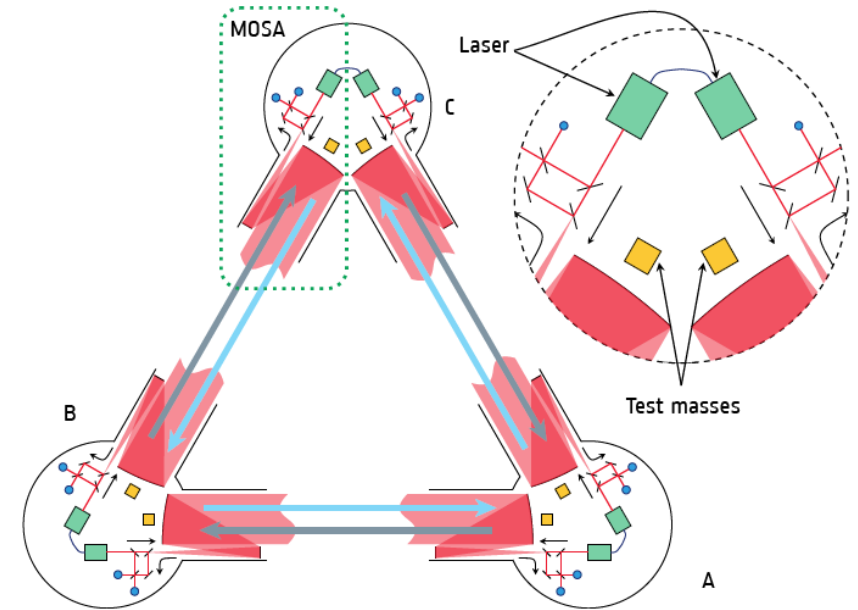
Concetto di misura e requisiti



- Misura di variazioni **“Doppler shift”** di frequenza tra fascio laser emesso e ricevuto.
- Misura **interferometrica** end-to-end, “heterodyne detection” laser 1064nm, 2W, braccio 2.5 Mkm
- **Test mass** Au-Pt da 2 kg, in caduta libera nominale lungo asse laser. Controllo feedback loop lungo altri gradi di libertà.
- Micro-Newton thrusters → circuito di controllo **drag-free**

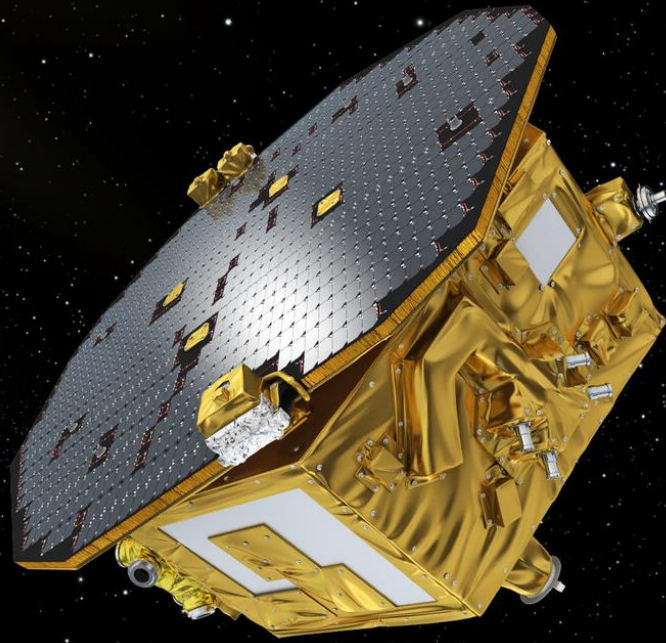


$$\frac{\Delta \dot{v}}{v_0} = \frac{1}{2} \left(\dot{h}(t_r - L/c) - \dot{h}(t_r) \right) \approx -\ddot{h}(t_r) \frac{L}{2c} + \frac{a_e(t_r - L/c) - a_r(t_r)}{c}$$

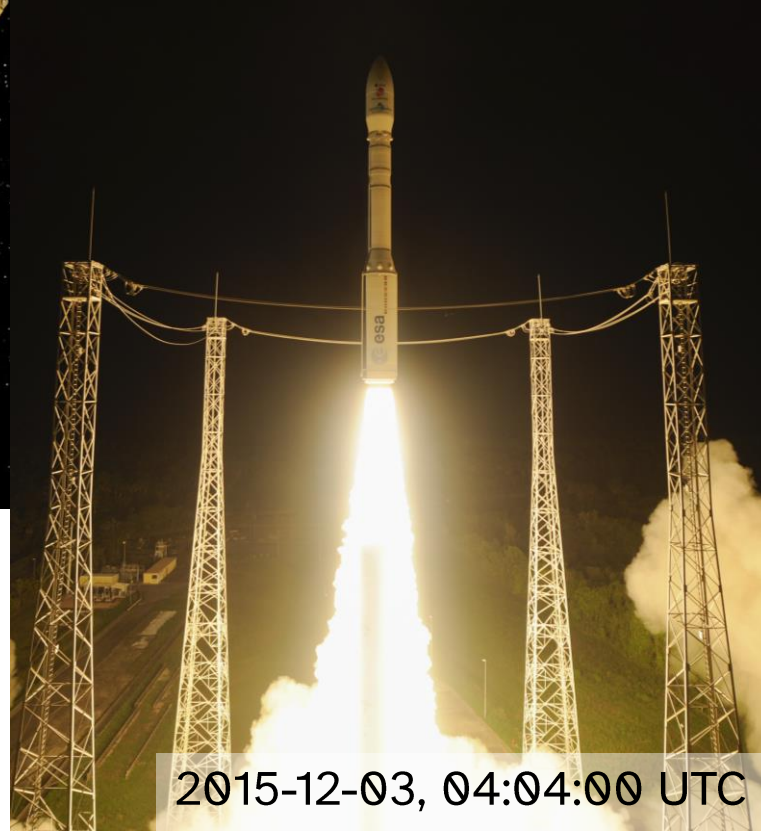


| Characteristic | Requirement |
|--------------------------|--|
| Free-fall purity | $\delta_a(1 \text{ mHz}) \lesssim 3 \times 10^{-15} \text{ m s}^{-2}/\sqrt{\text{Hz}}$ |
| Displacement sensitivity | $\delta_x(1 \text{ mHz}) \lesssim 15 \times 10^{-12} \text{ m}/\sqrt{\text{Hz}}$ |
| GW measurement band | $100 \mu\text{Hz} \leq f_{\text{GW}} \leq 1 \text{ Hz}$ $L_{\text{arm}} \approx 2.5 \times 10^6 \text{ km}$ |

LISA Pathfinder



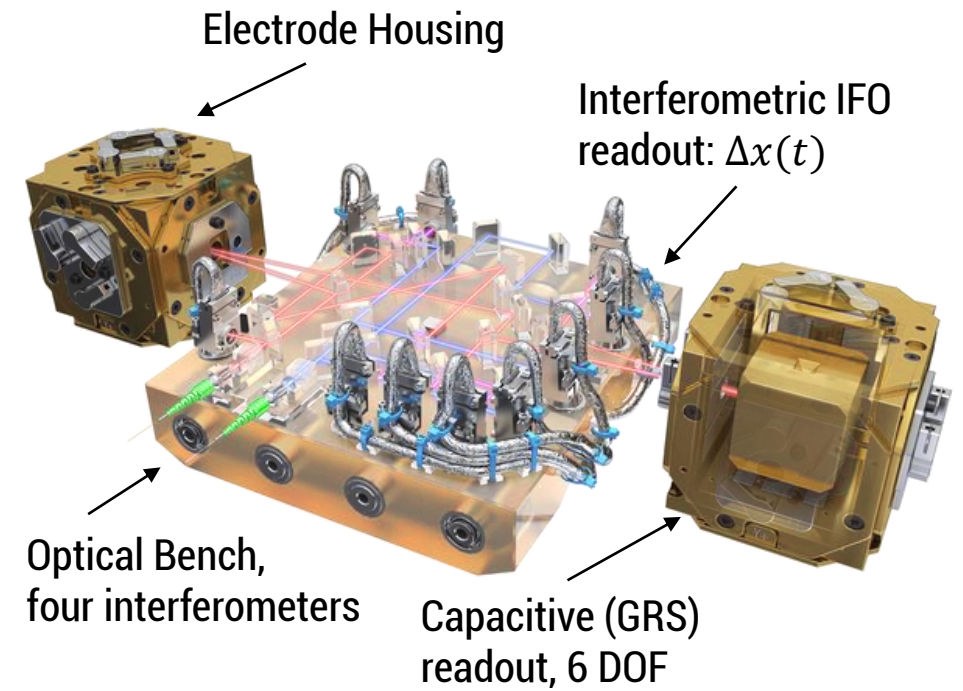
Lancio verso L1: Dicembre 2015
Termine operazioni: Luglio 2017



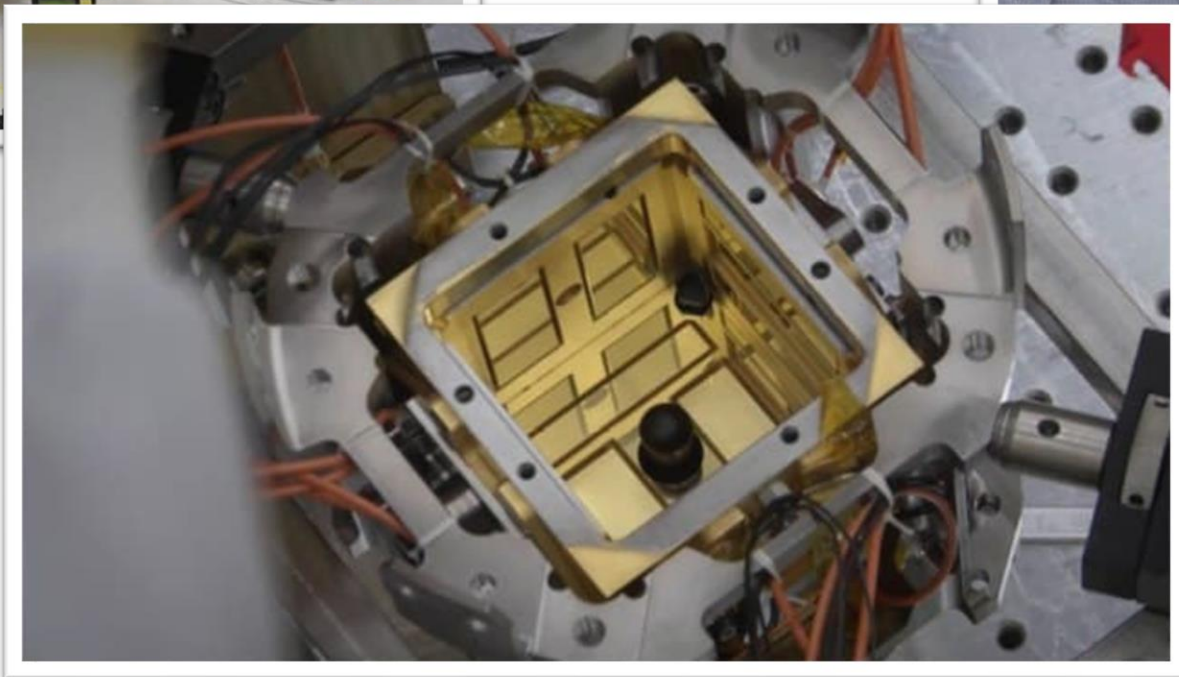
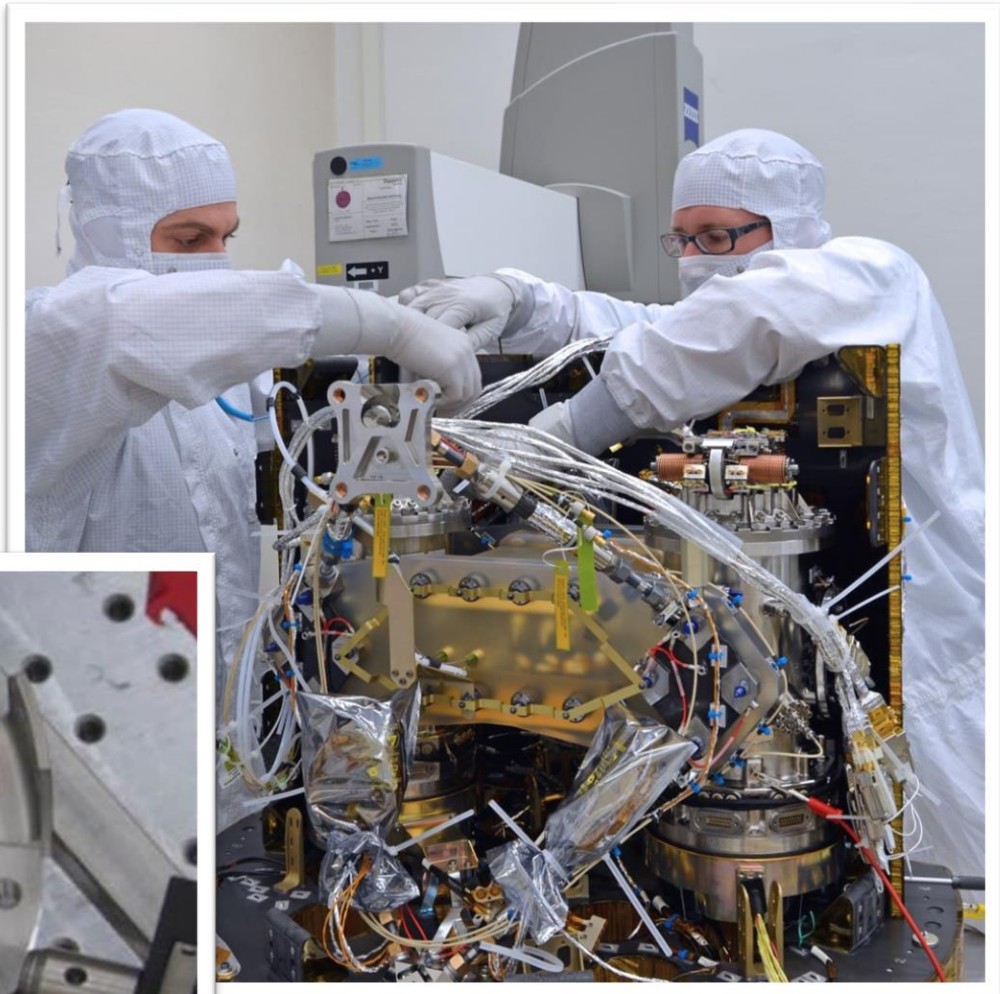
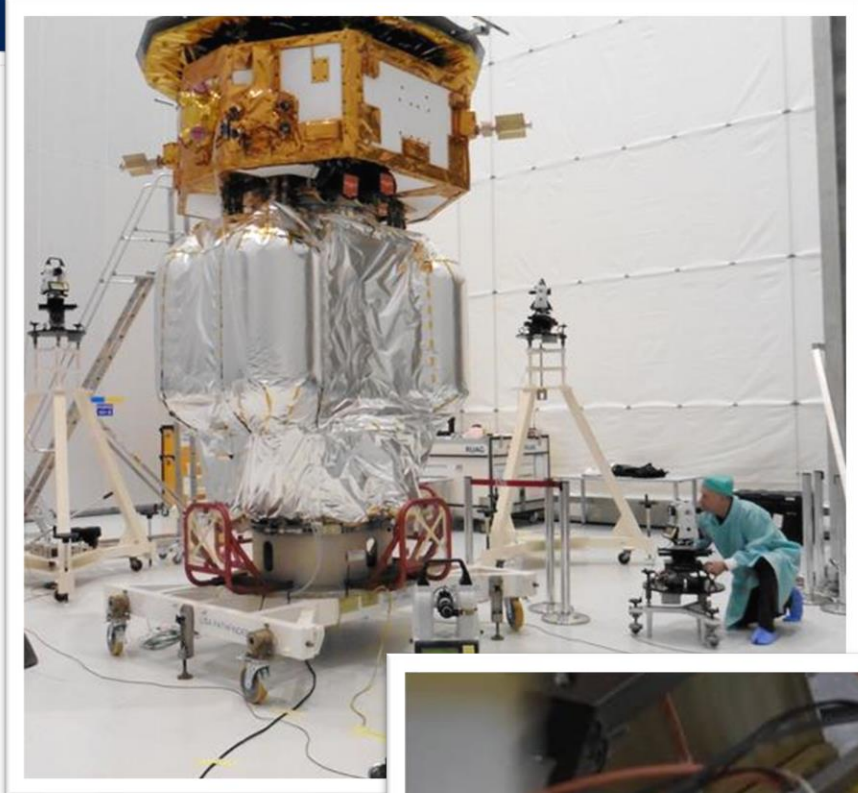
2015-12-03, 04:04:00 UTC



lisa pathfinder



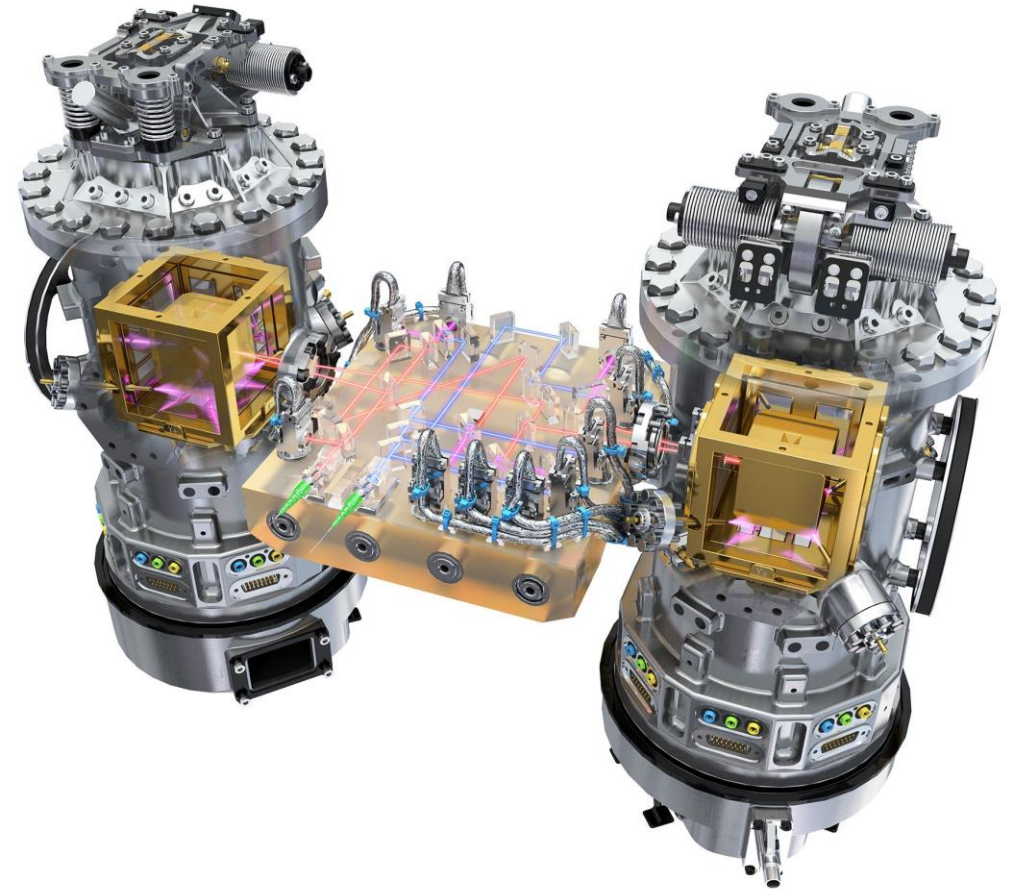
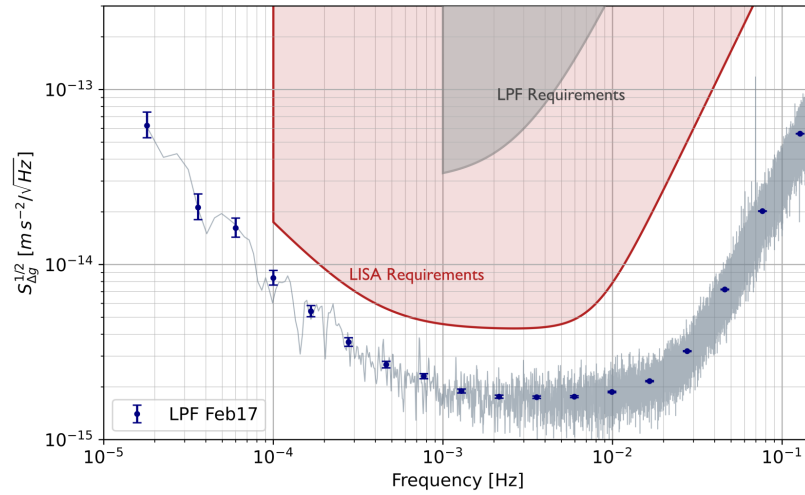
Credits: ESA – C.Carreau, ESA/ATG medialab



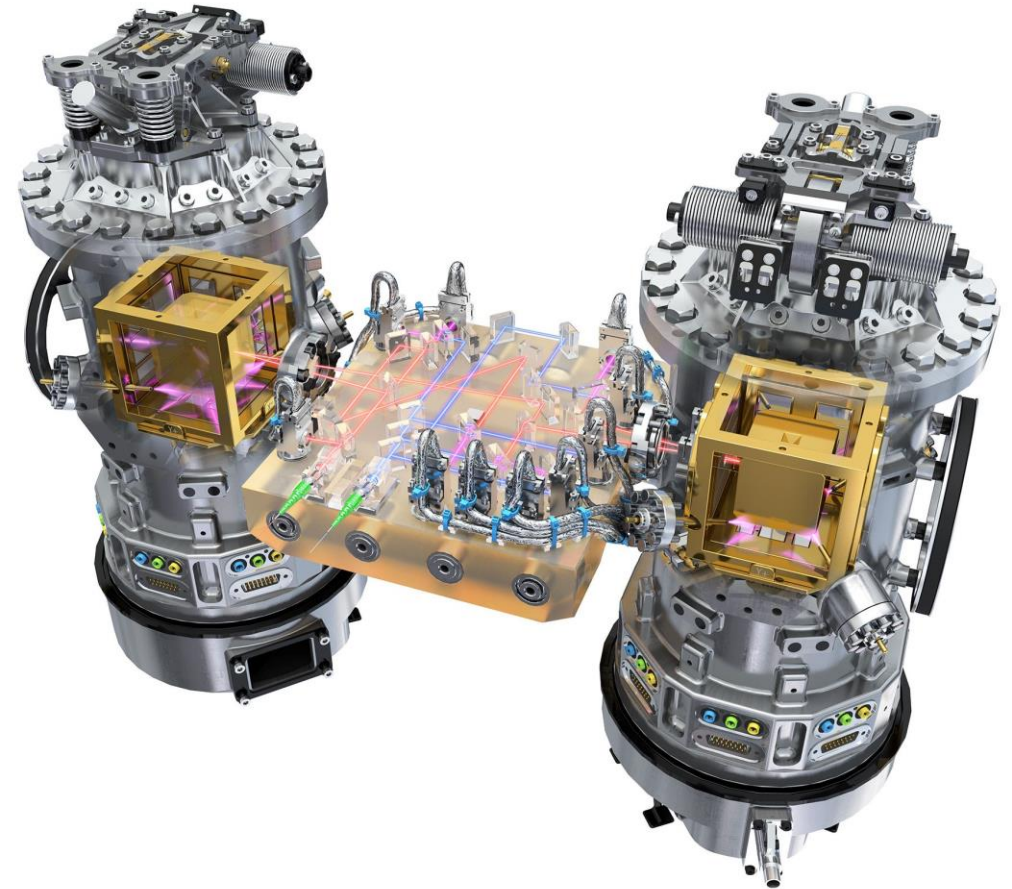
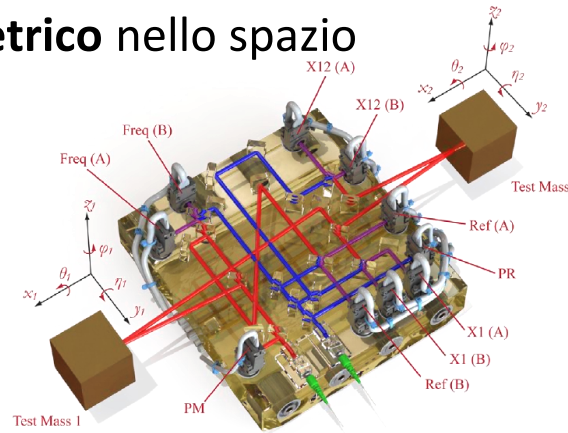
LISA Pathfinder: risultati



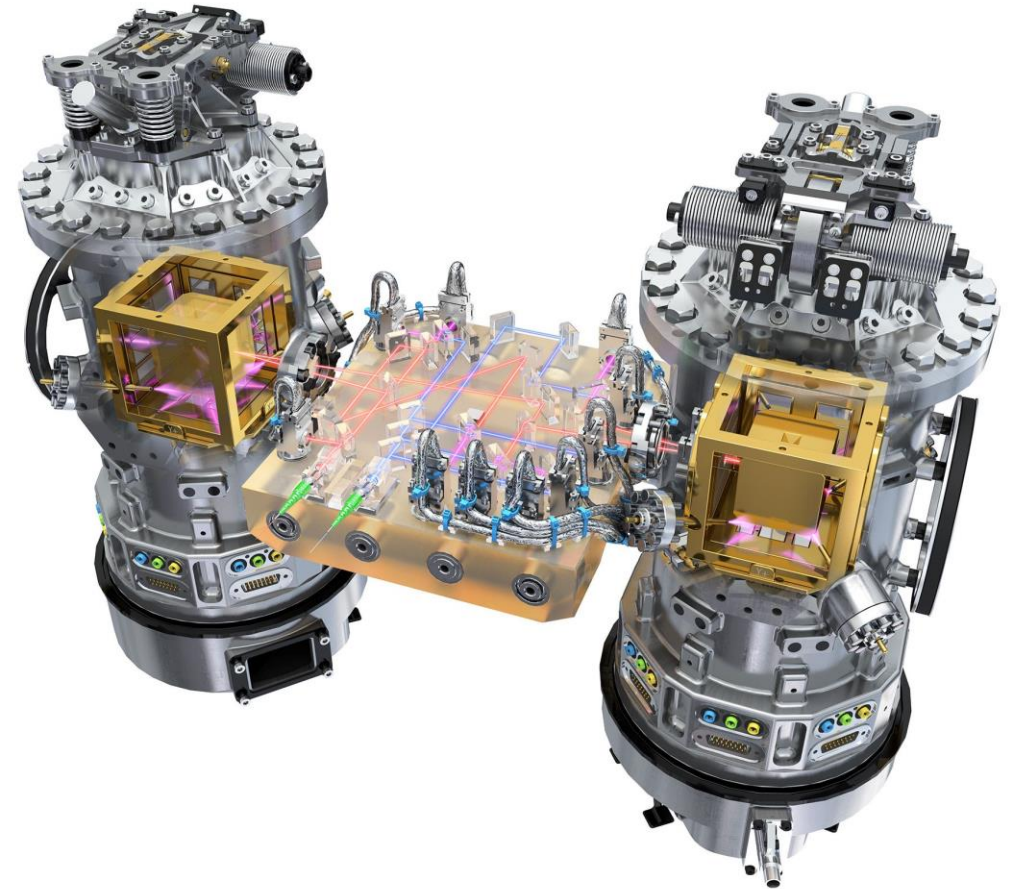
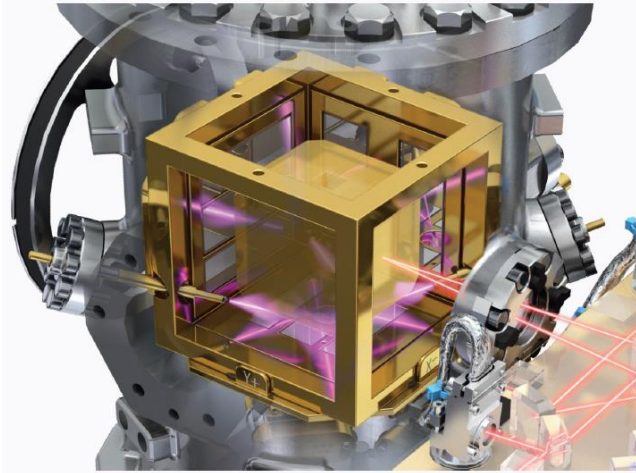
- Rumore in **accelerazione** residuo (@ 1mHz): **fm s⁻² Hz^{-1/2}**
PRL **120**,061101 (2018), PRL **116**,231101 (2016)



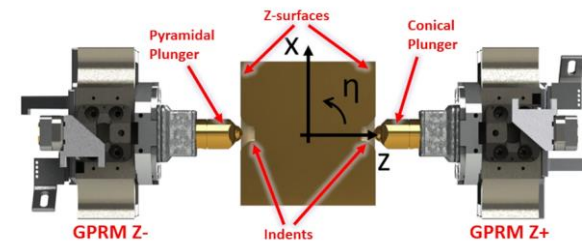
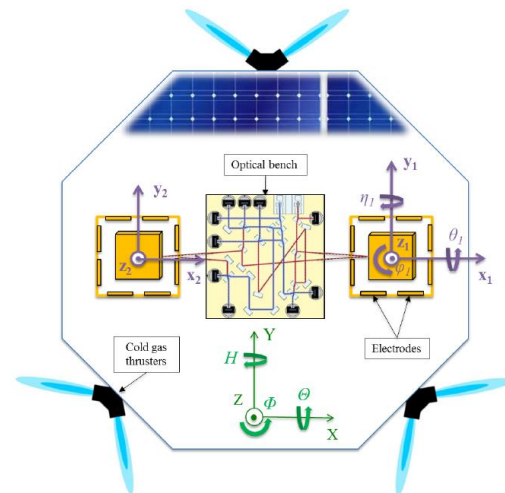
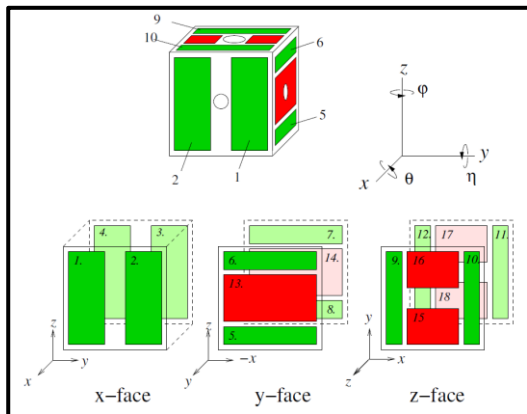
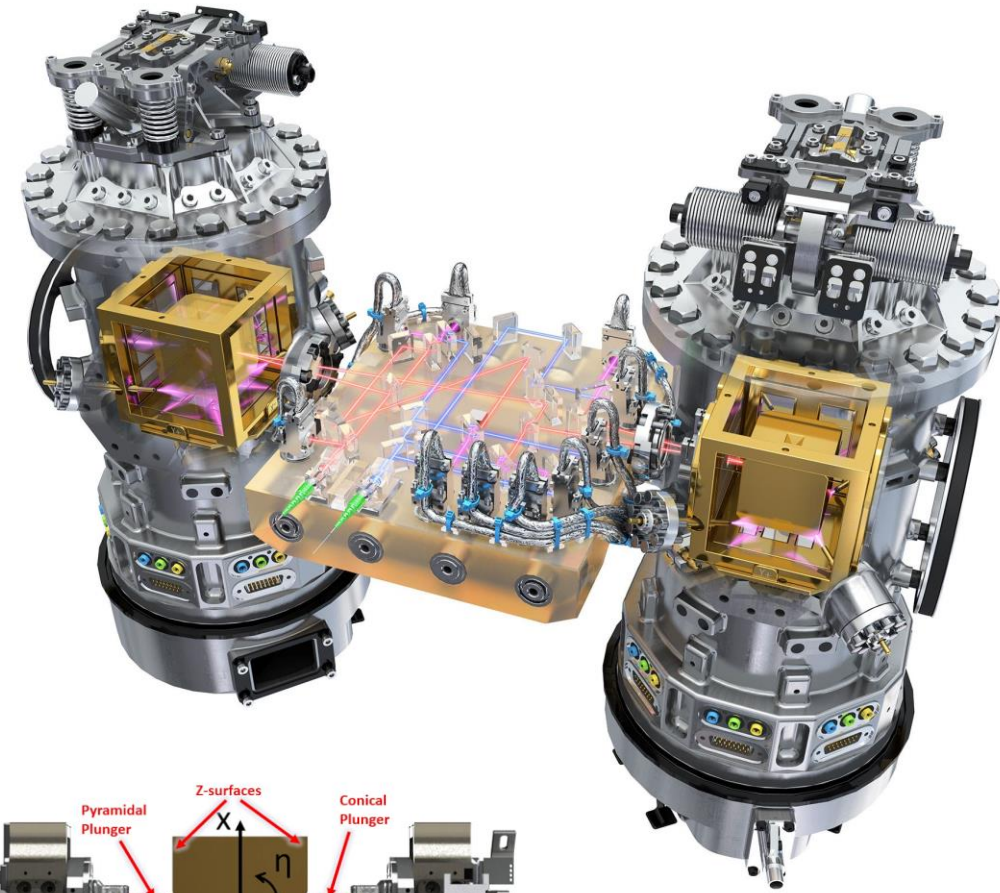
- Rumore in **accelerazione** residuo (@ 1mHz): **fm s⁻² Hz^{-1/2}**
PRL **120,061101** (2018), PRL **116,231101** (2016)
- Il primo **interferometro sub-picometrico** nello spazio
PRL **126,131103** (2021)



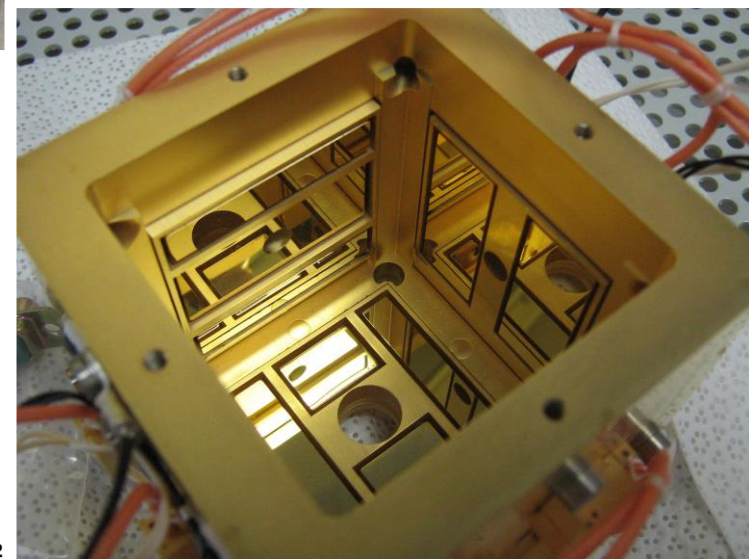
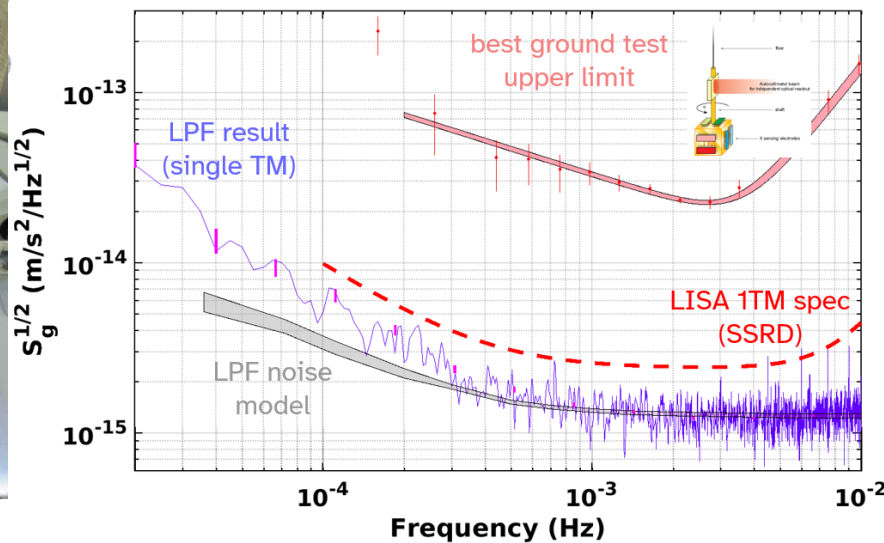
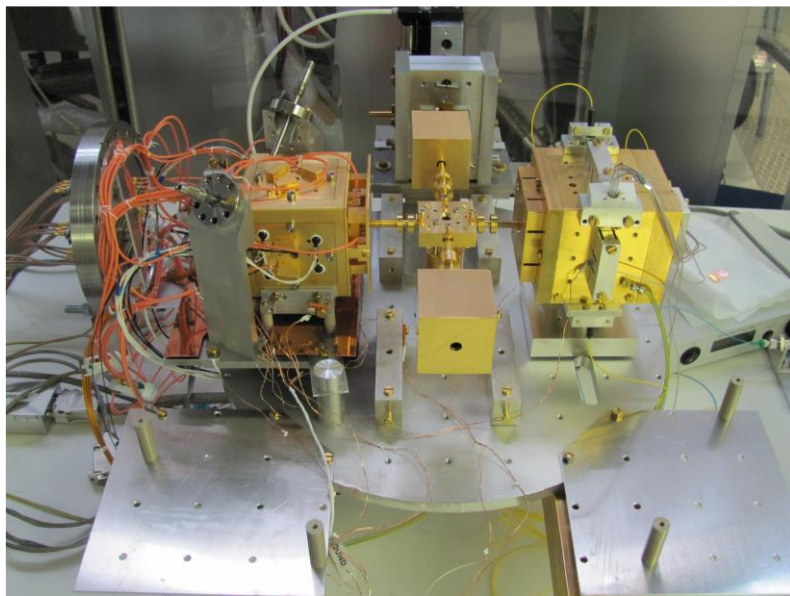
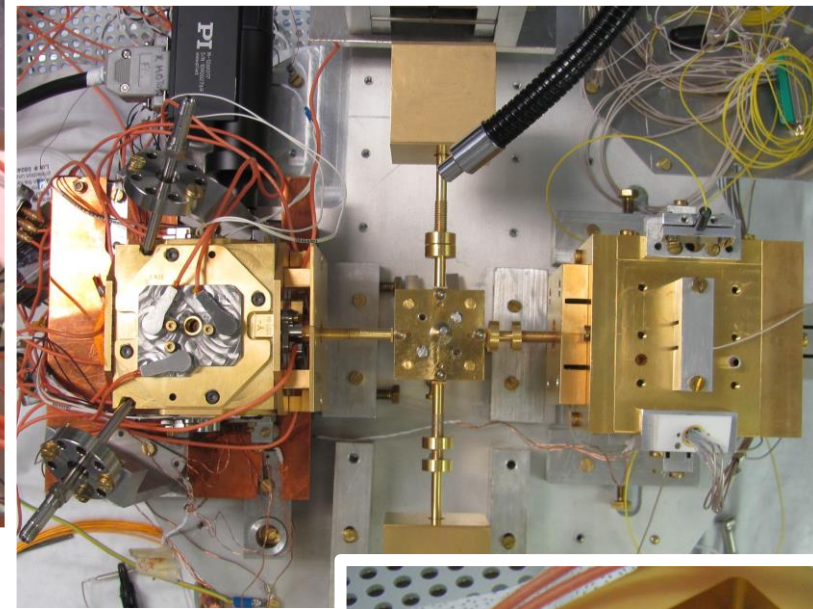
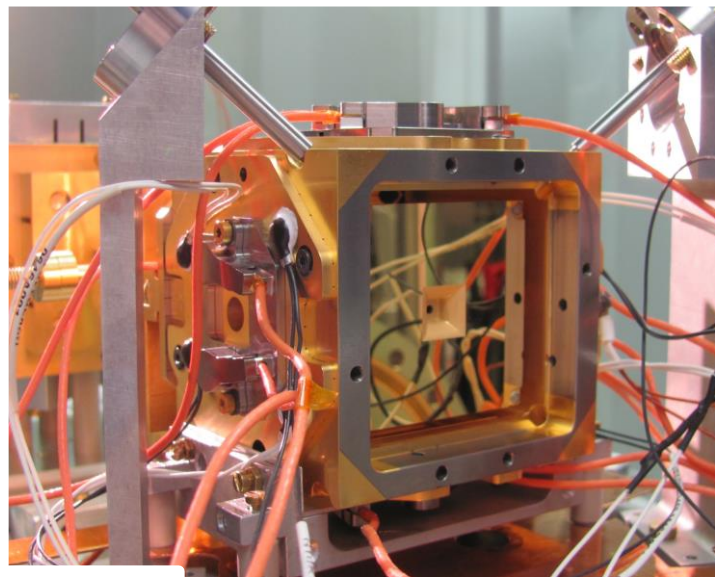
- Rumore in **accelerazione** residuo (@ 1mHz): $\text{fm s}^{-2} \text{ Hz}^{-1/2}$
PRL **120**,061101 (2018), PRL **116**,231101 (2016)
- Il primo **interferometro sub-picometrico** nello spazio
PRL **126**,131103 (2021)
- Sistema di **scarica UV contact-free** (interazione raggi cosmici),
PRL **118**,171101 (2017)



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PRL **120**,061101 (2018), PRL **116**,231101 (2016)
- Il primo **interferometro sub-picometrico** nello spazio
PRL **126**,131103 (2021)
- Sistema di **scarica UV contact-free** (interazione raggi cosmici),
PRL **118**,171101 (2017)
- **Attuazione** elettrostatica con sensibilità sub-femtoNewton.
- Controllo **drag-free** per LISA.
- Grabbing-Positioning-Release Mechanism

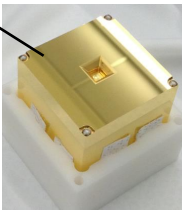
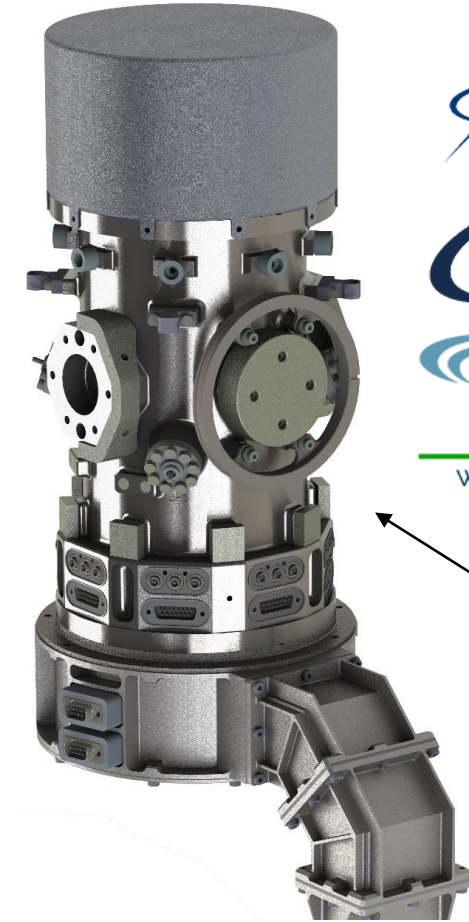
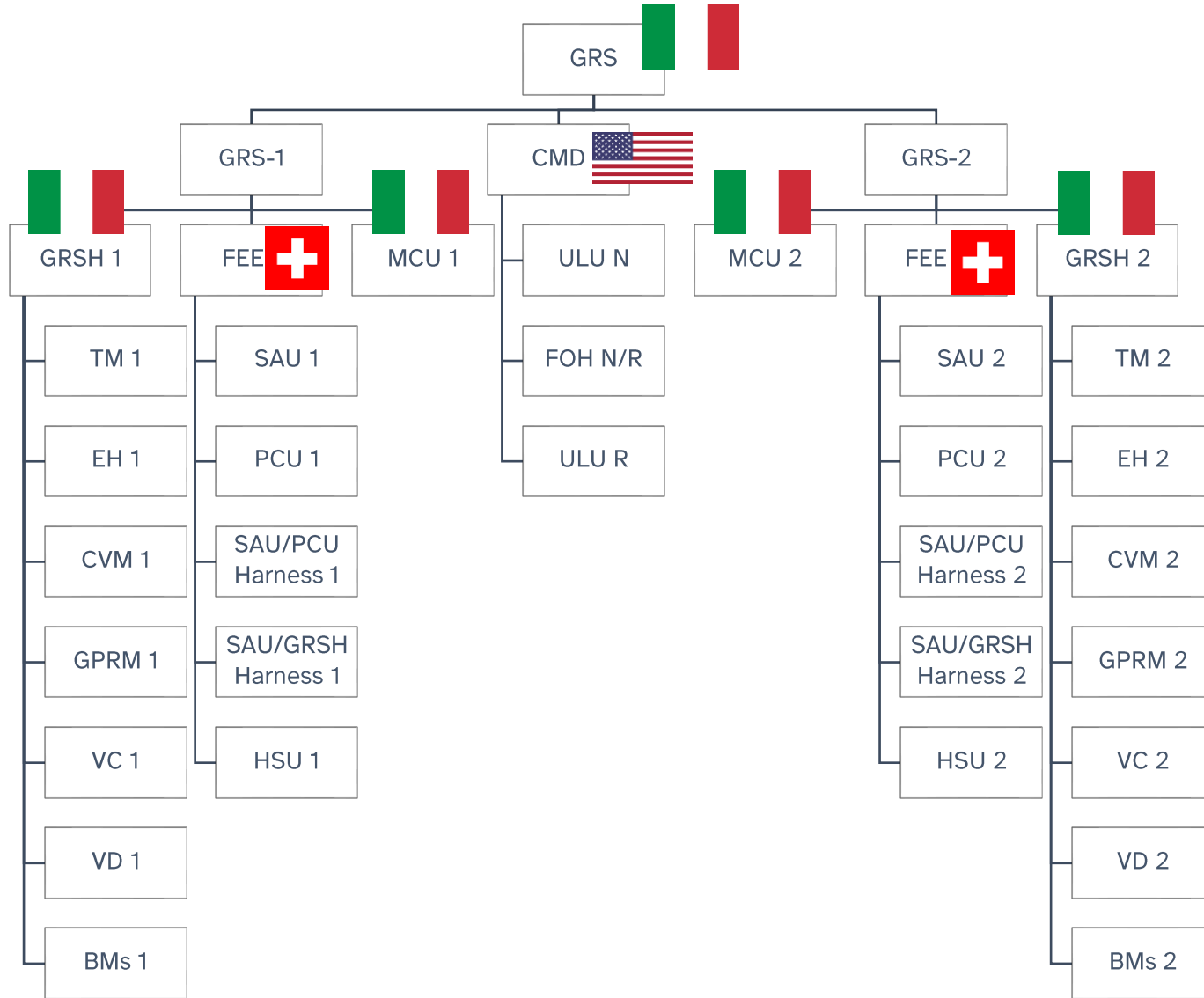
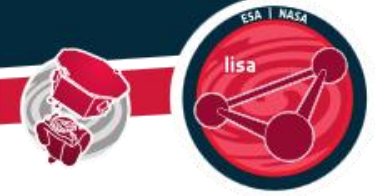


Testing facility @ UniTrento / INFN

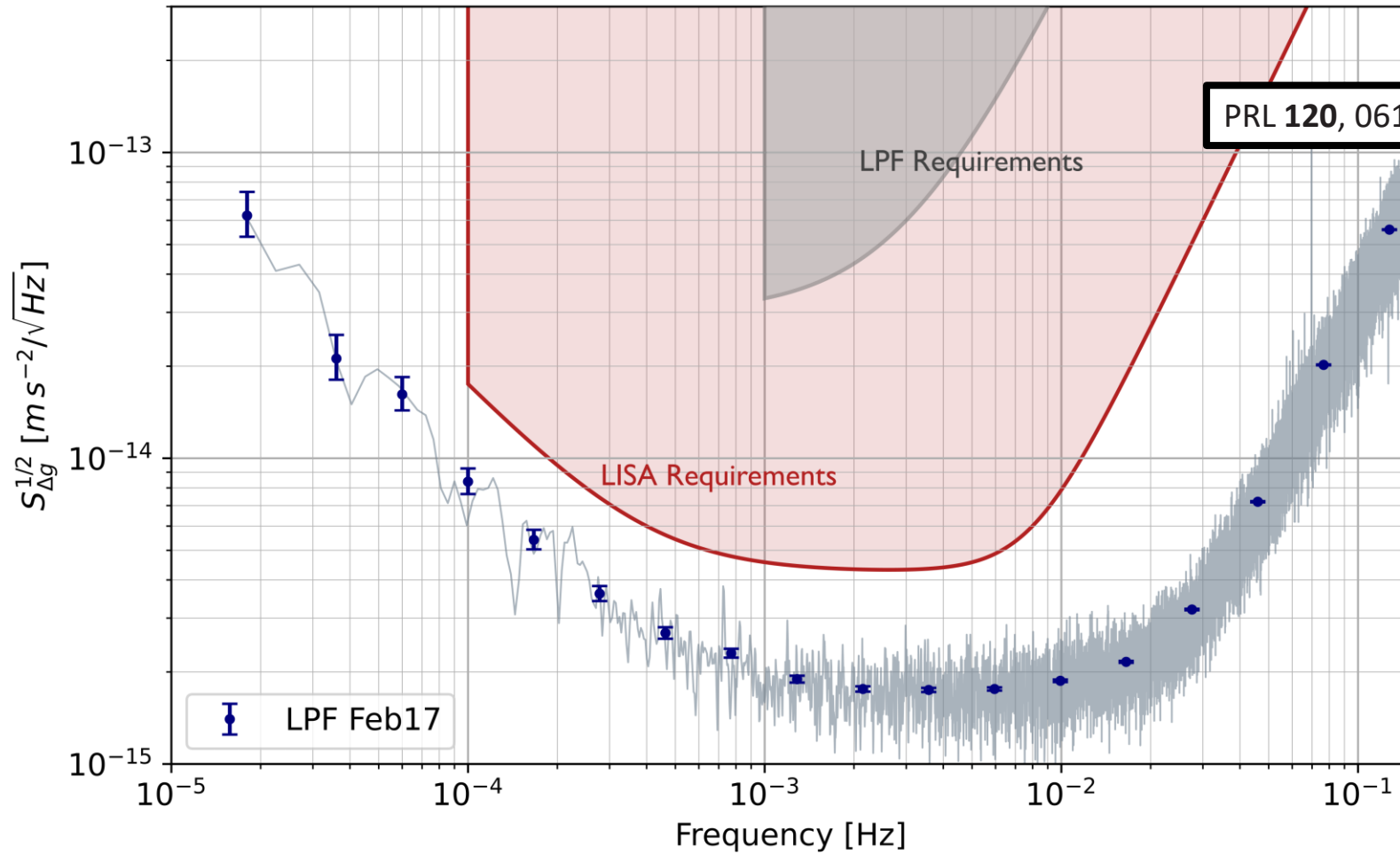




GRS (Gravitational Reference System)



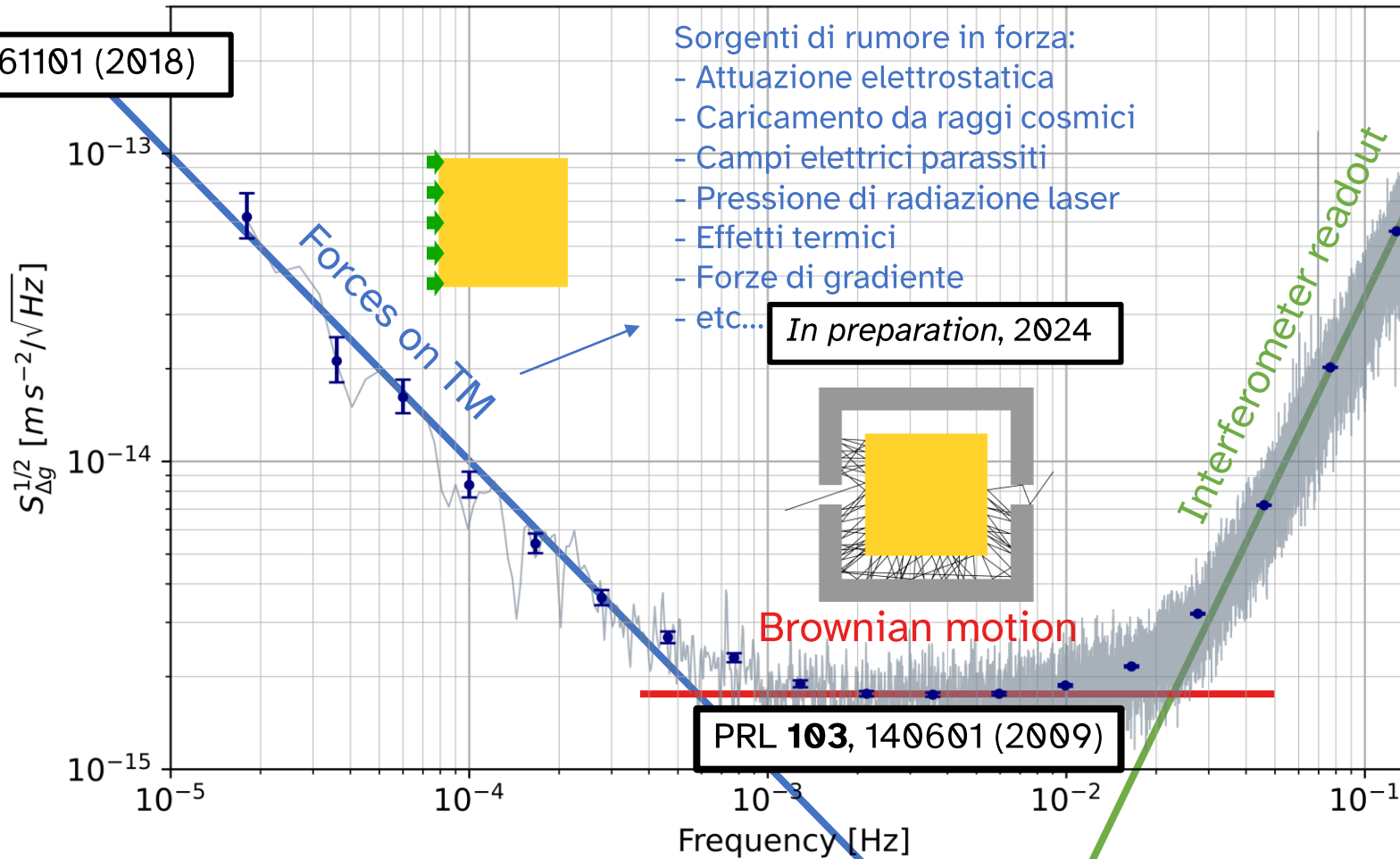
Una caduta libera quasi-geodetica



Sorgenti di rumore



PRL 120, 061101 (2018)



PRL 103, 140601 (2009)

$$32.0_{-1.7}^{+2.4} \text{ fm}/\sqrt{\text{Hz}}$$

PRL 126, 131103 (2021)