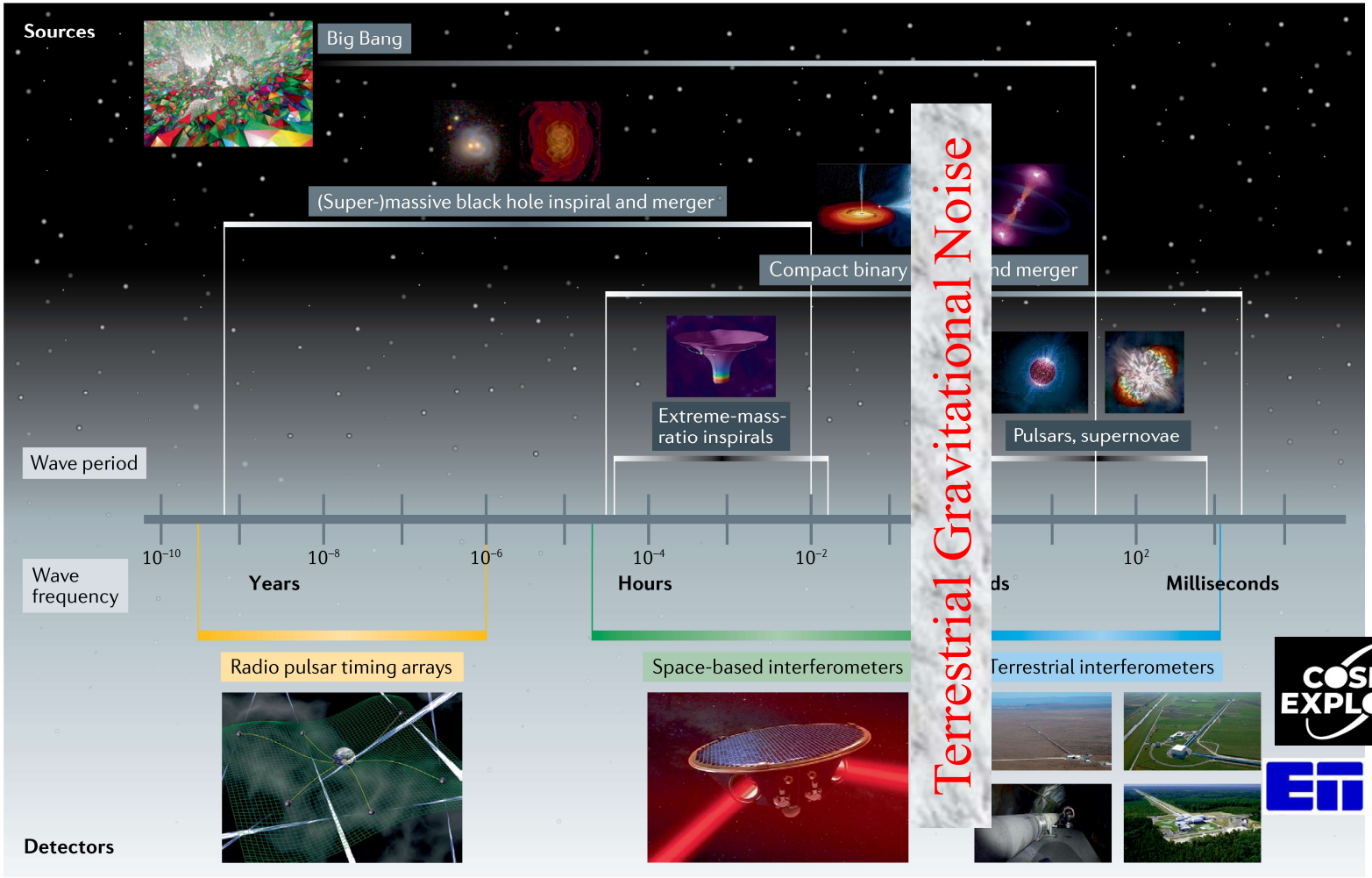
The LISA Mission

Rita Dolesi
On behalf of the LISA GRS PI Team
Università di Trento/TIFPA
Workshop Space@TIFPA
TIFPA, 11 maggio 2026

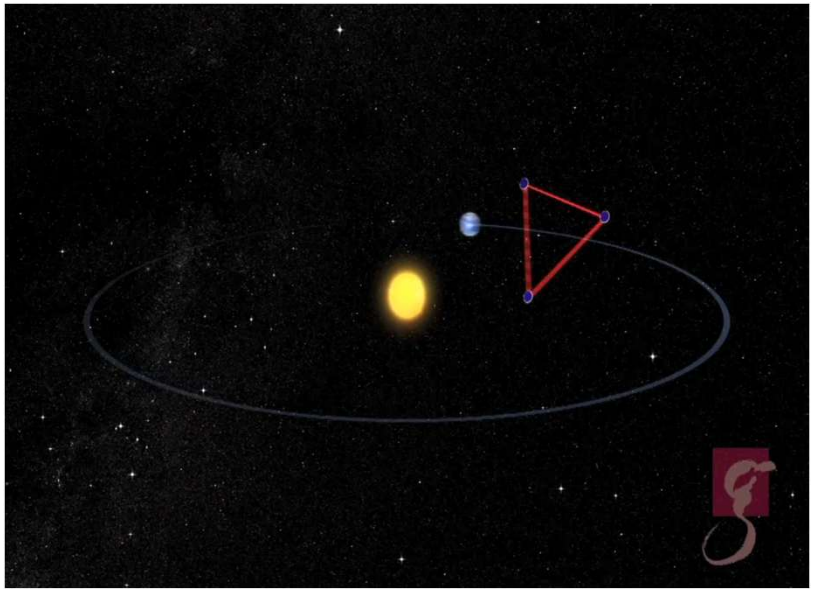
Gravitational Wave Astronomy

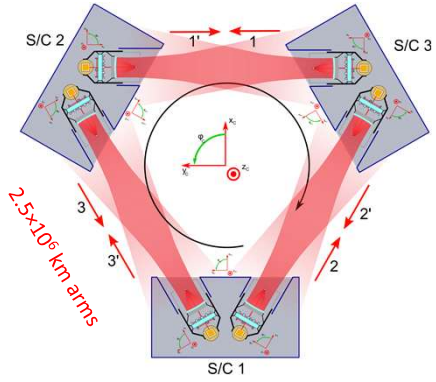
Gravitational- wave spectrum probed by strain- sensitive gravitational- wave detectors, ranging from 10^{-9} Hz to more than 1,000 Hz.



www.344 | May 2021 | volume 3 nature.com/natrevphys

La configurazione, la sensibilità e le sfide di LISA





CONFIGURAZIONE DI LISA

3 satelliti identici
3 bracci of 2.5 milioni di km
Costellazione LISA:
configurazione quasi equilatera in rotazione,
orbita eliocentrica a 1 UA, in trailing della Terra di 20°.

REQUISITI PRINCIPALI PER L'IMPLEMENTAZIONE DI LISA

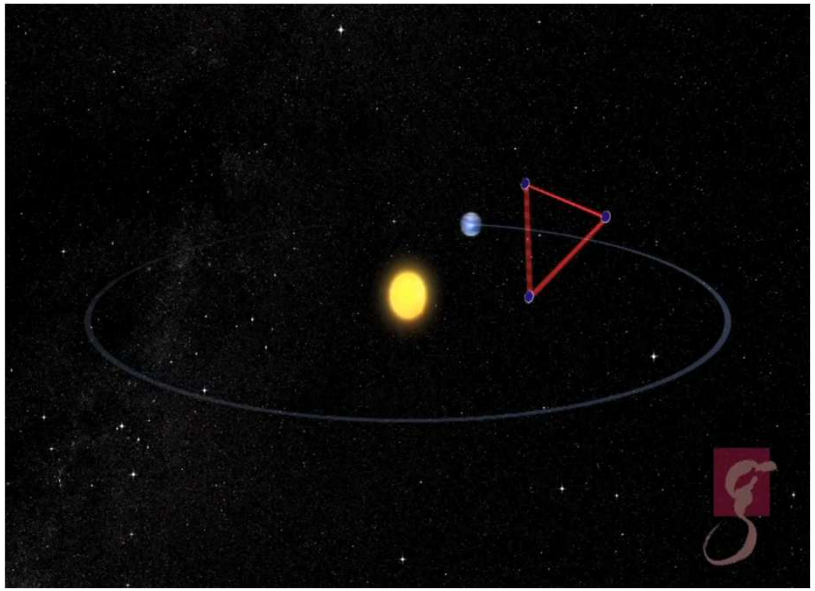
Masse in caduta libera a livello sub-femto-g

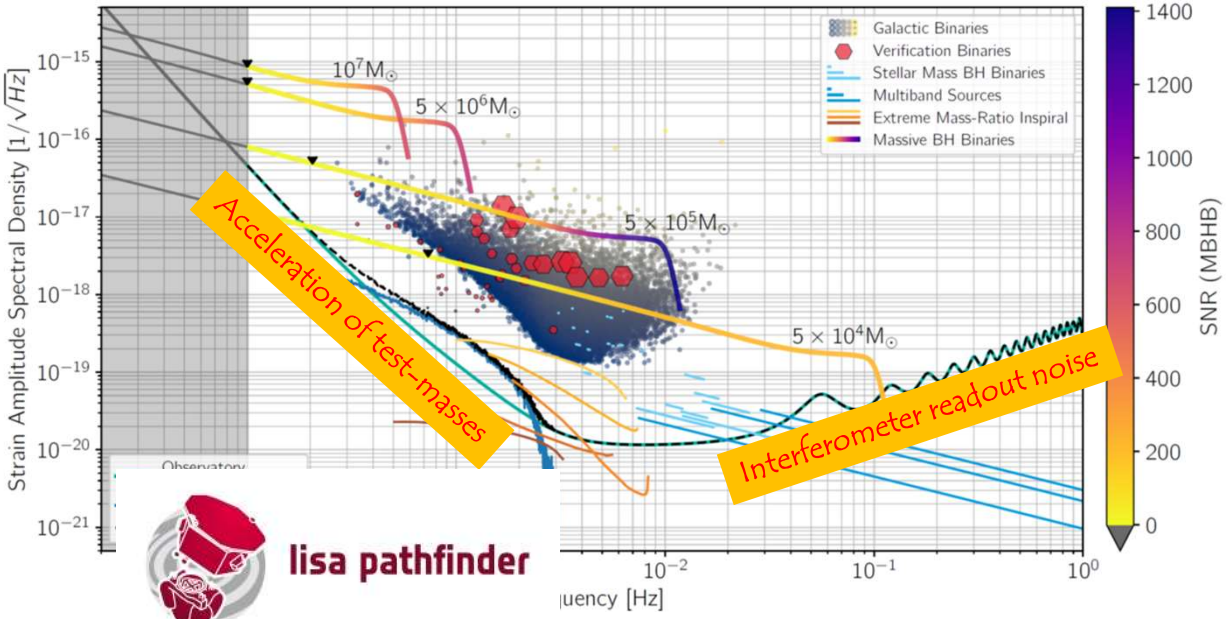
$$3 \ \frac{fm}{s^2} \ \frac{1}{\sqrt{Hz}}$$

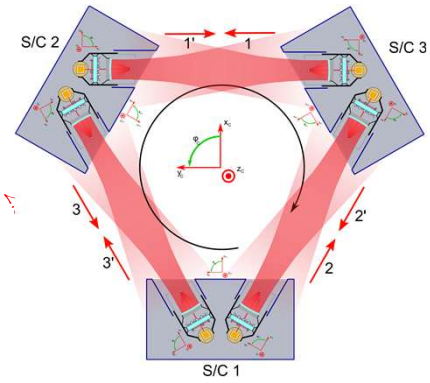
Interferometria laser inter-satellite in modalità transponder

$$10 \ \frac{pm}{\sqrt{Hz}}$$

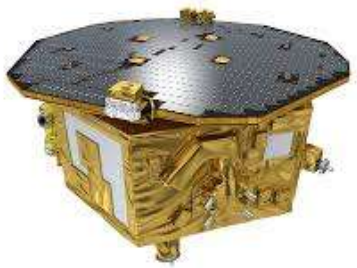
La configurazione, la sensibilità e le sfide di LISA







lisa pathfinder

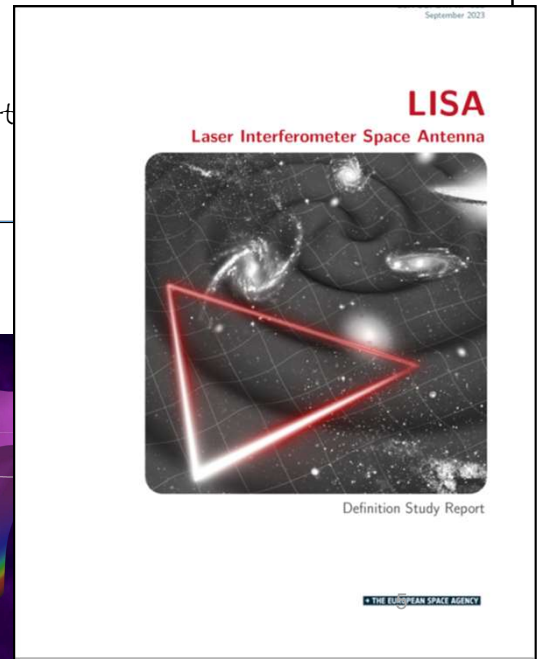


Credit: ESA/ATG medialab

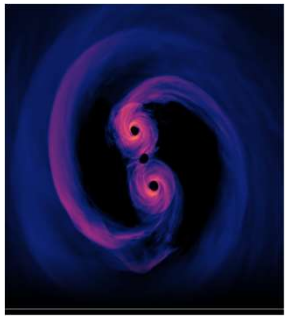
LISA Science Objectives

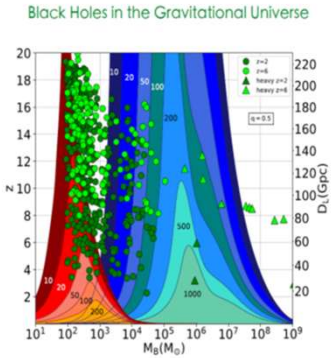
- Study the formation and evolution of **compact binary stars** and the structure of the Milky Way Galaxy
- Trace the origins, growth and merger histories of **massive Black Holes** across cosmic epochs
- Probe the properties and immediate environments of Black Holes in the local Universe **using extreme 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 part
- Search for gravitational wave bursts and **unforeseen sources**

https://www.cosmos.esa.int/web/lisa/lisa-redbook



Some of the uniqueness of LISA

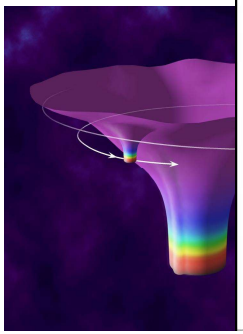




Supermassive Black Holes binaries with high signal to noise

Extreme Mass Ratio Inspirals
Inspiral of stellar-mass compact object into massive black hole. If the compact object is a white dwarf, possible electromagnetic counterpart

Test the properties of the space time around massive dark objects. the presence of dark matter which causes a different phase evolution.



The path to LISA

Courtesy of Oliver Jennrich, Amaldi Conf 2025

esa

FIRST IDEAS TO MEASURE GW IN SPACE
BENDER

1974

LISA PROPOSED TO ESA AS M3 MISSION TO DETECT GWs AND OBSERVE THE UNIVERSE
DANZMANN ET AL.

1993

LISA PROPOSED TO ESA AS FLAGSHIP L3 MISSION
LISA CONSORTIUM

2017

You are here

LISA

LAUNCH in 2035

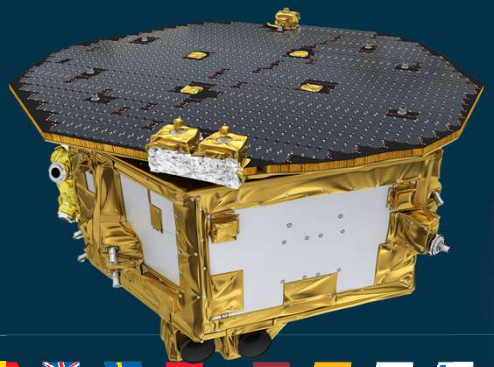
1989

ANTENNA FOR LASER GRAVITATIONAL WAVE OBSERVATIONS IN SPACE

FALLER, BENDER, HALL, HILS, STEBBINS, VINCENT
...millions of km sized antenna

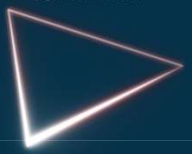
2015

LAUNCH OF LISA PATHFINDER
VITALE ET AL.



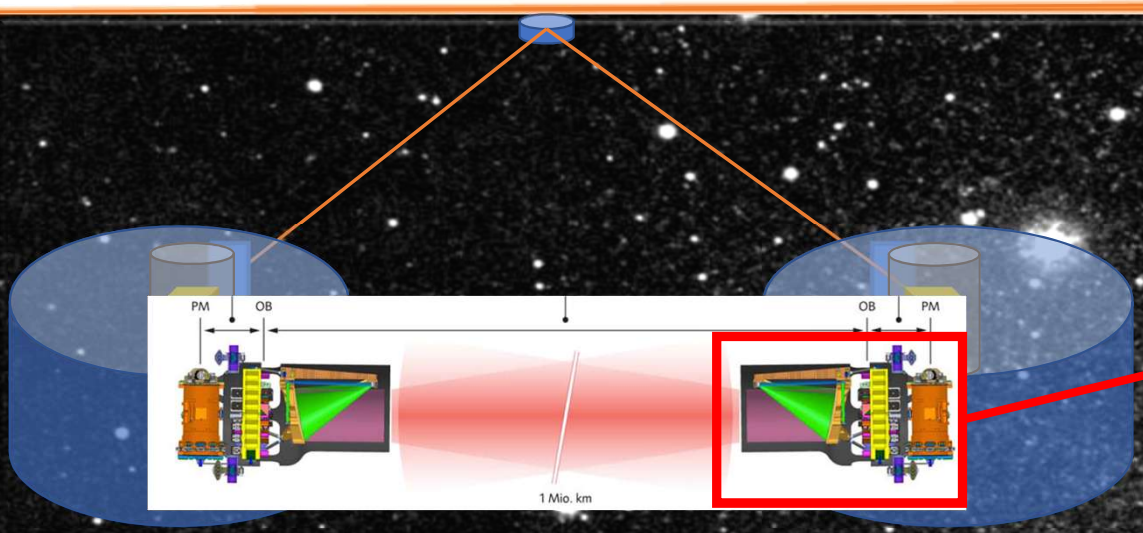
2024

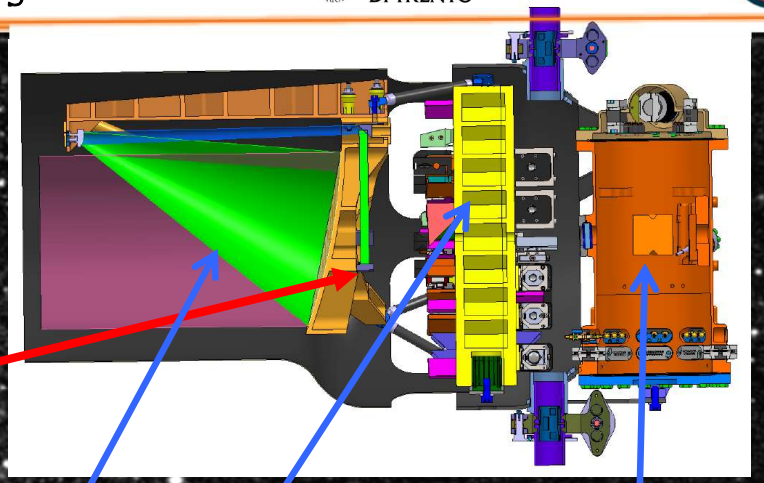
LISA ADOPTION
COLPI ET AL.

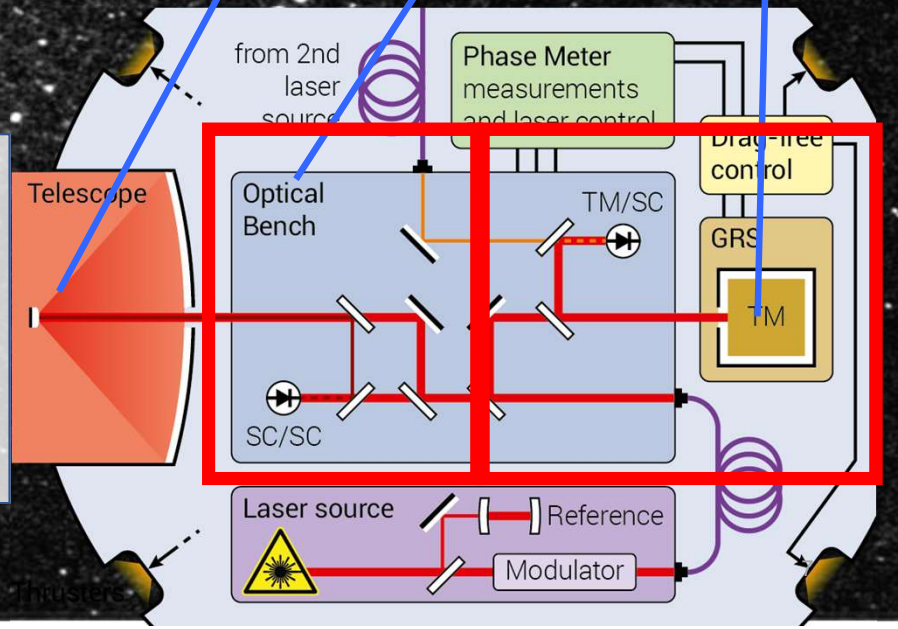


LISA: lo strumento

(Le immagini non riflettono disegni attuali)







The Gravitational Reference System with the test-mass

The Optical Bench with:

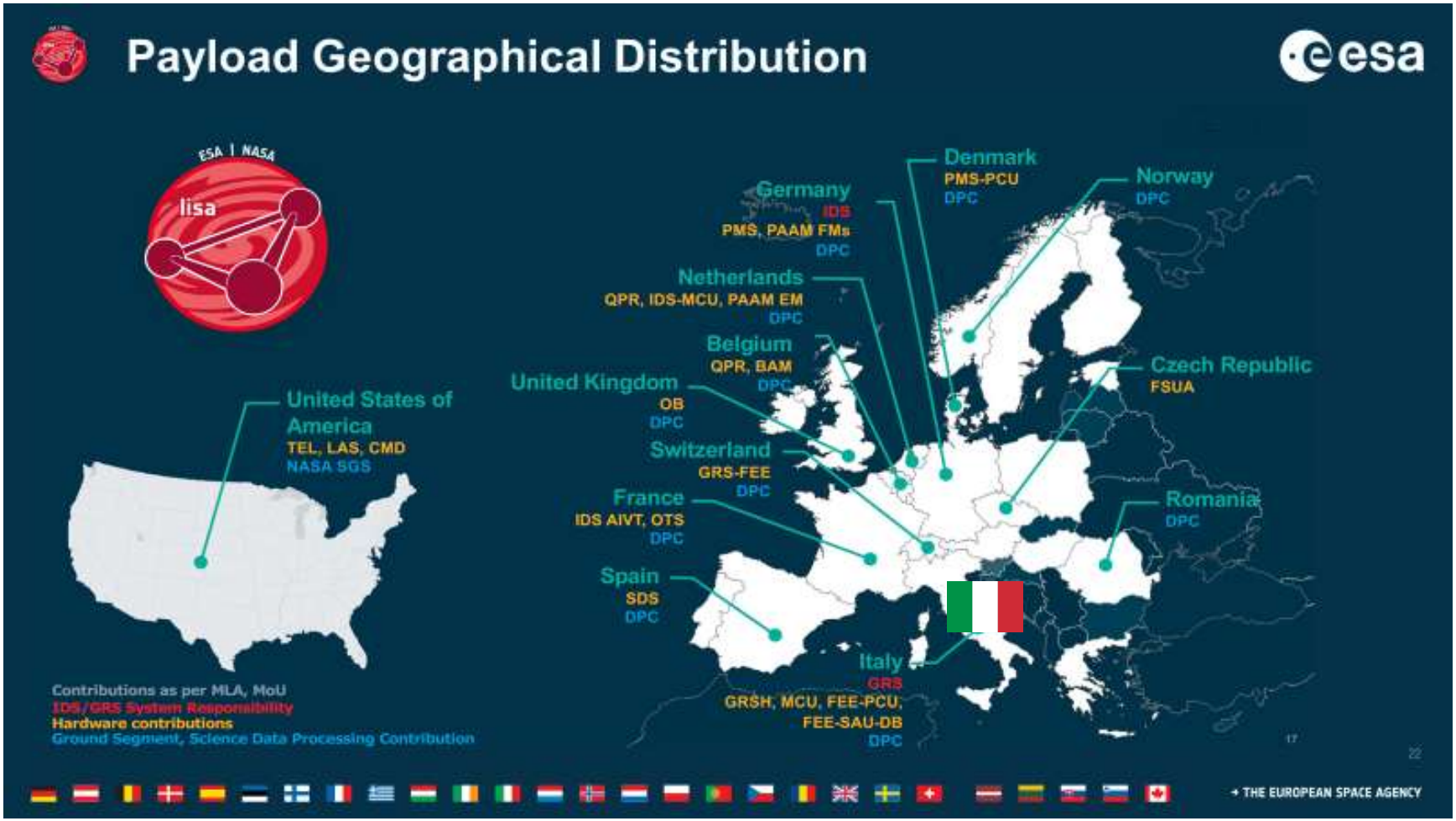
Local interferometer

Spacecraft to spacecraft interferometer

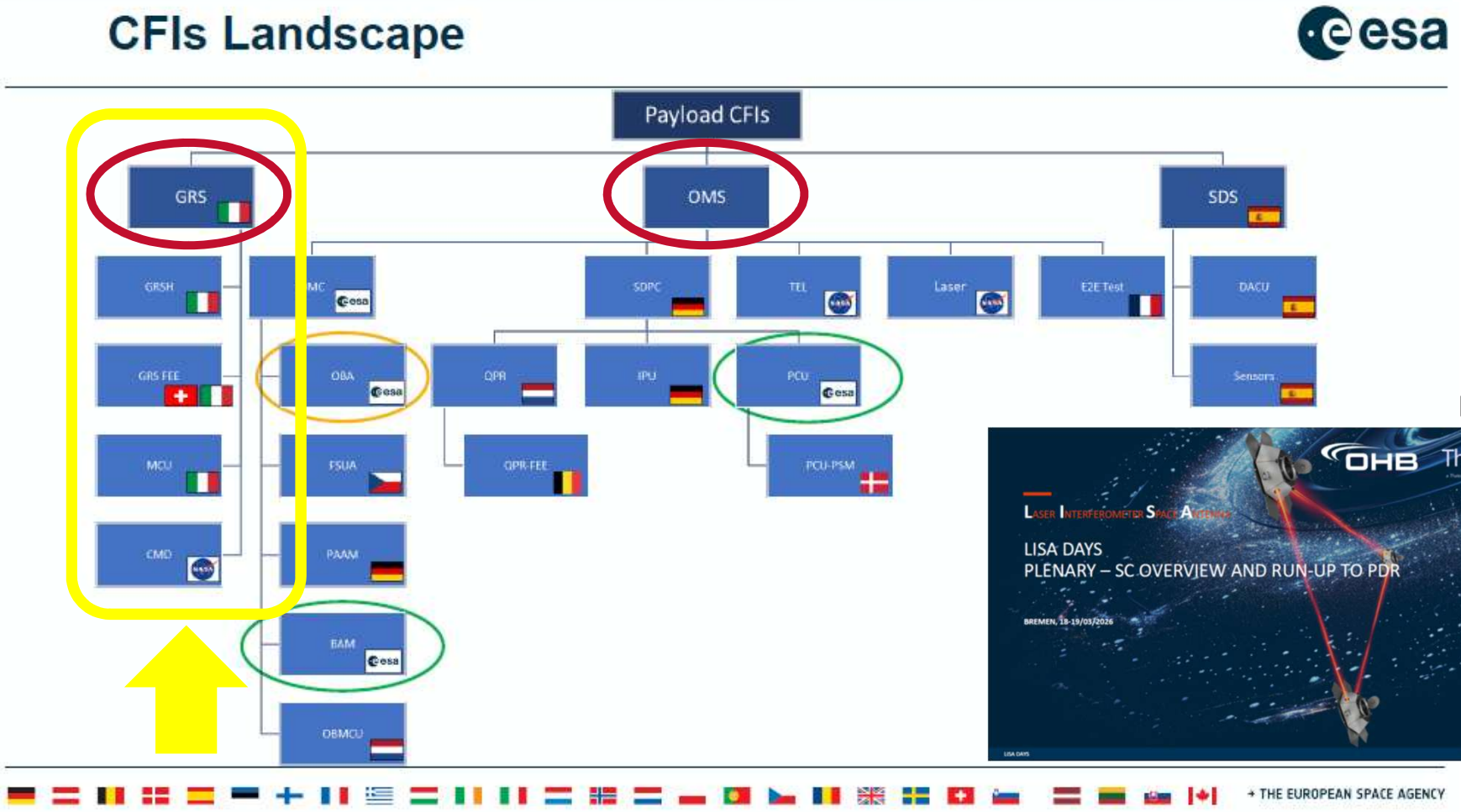
Telescope for the spacecraft to spacecraft interferometer

LISA Payload Implementation

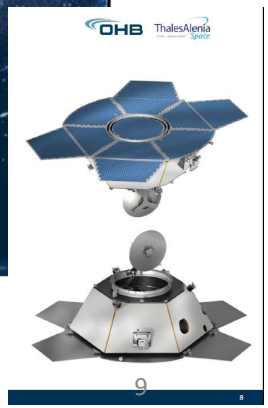
Courtesy of Oliver Jennrich



LISA: lo strumento

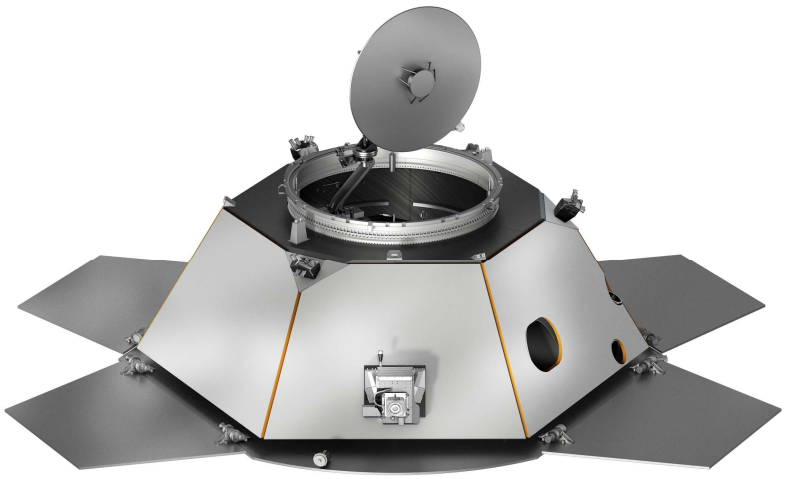


Industrial Prime

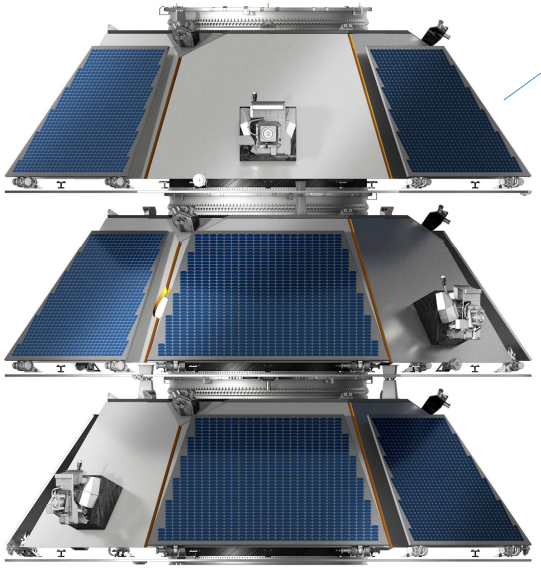


System Prime selection in Dec 2024

System Prime Contractor: **OHB-DE, with a partnership of TAS-I**
Contract signed with ESA for the supply of LISA spacecraft



Proposed LISA Spacecraft



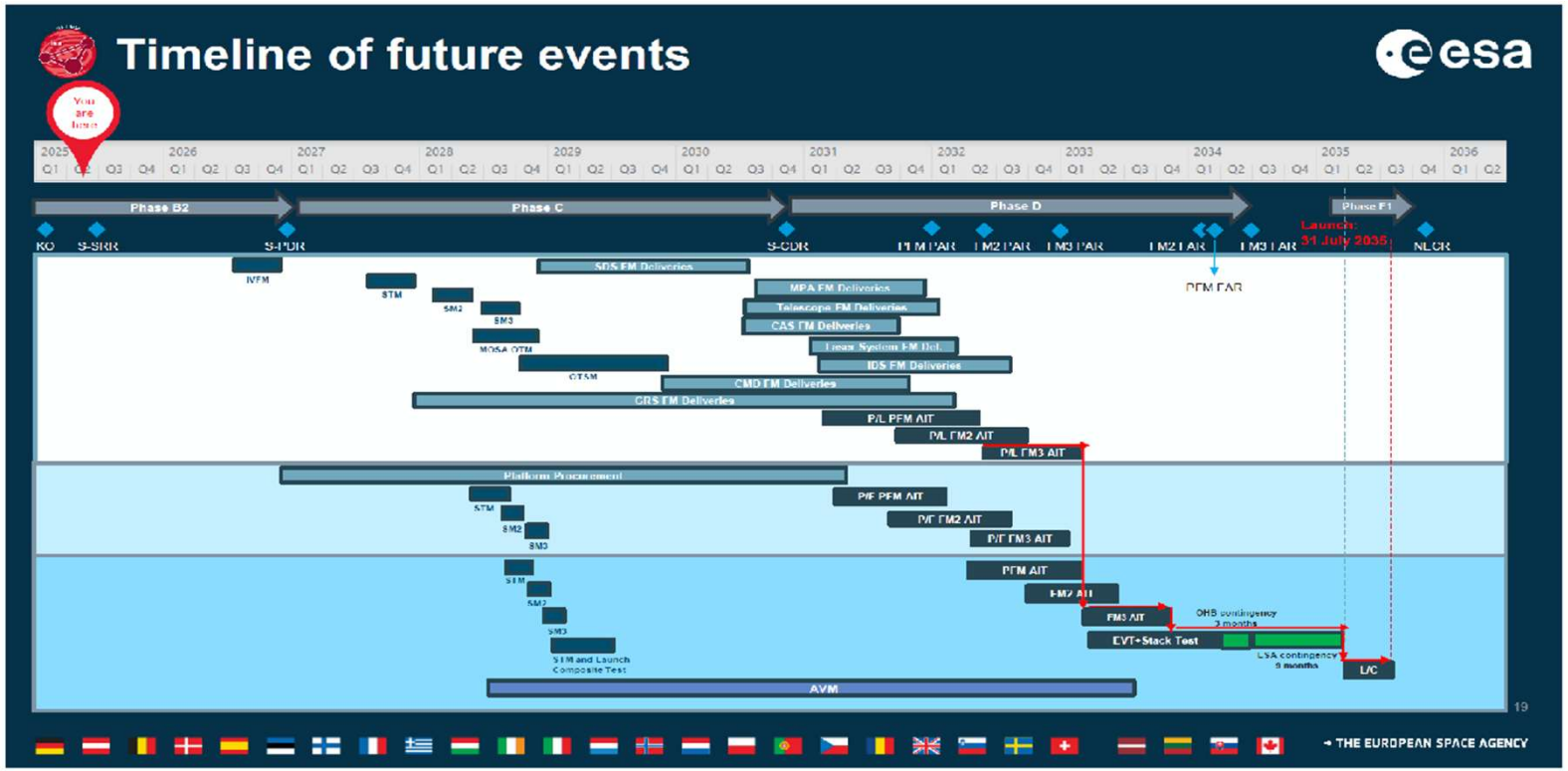
Proposed launch configuration

LISA LAUNCH in 2035

Schedula di alto livello di ESA per LISA

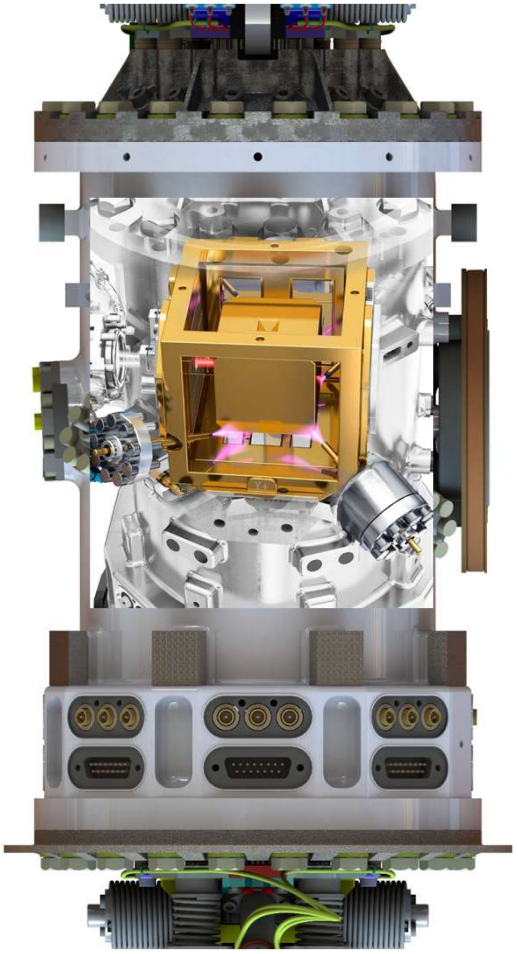
ESA main dates at the moment are confirmed

- System PDR close out Q1 2027,
- System CDR close out Q4 2030,
- and launch 2035.



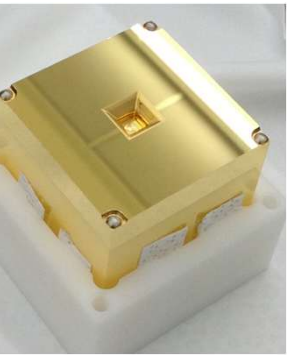
LISA: Gravitational Reference System

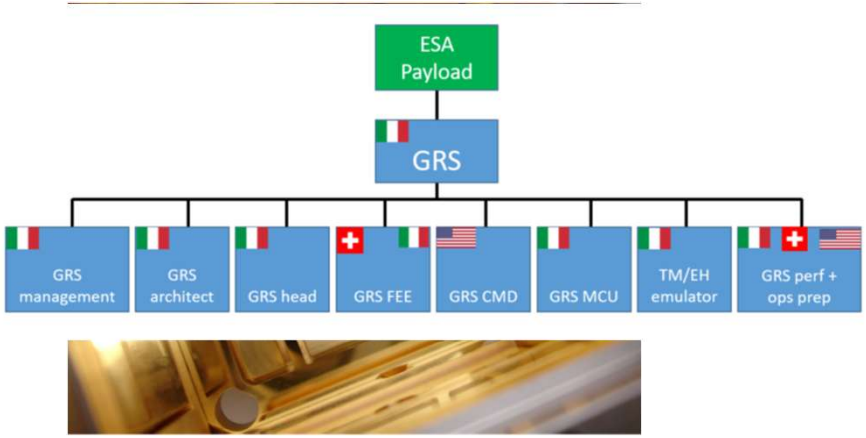
Il GRS è il sistema che influisce maggiormente sul rumore di accelerazione della TM in caduta libera.



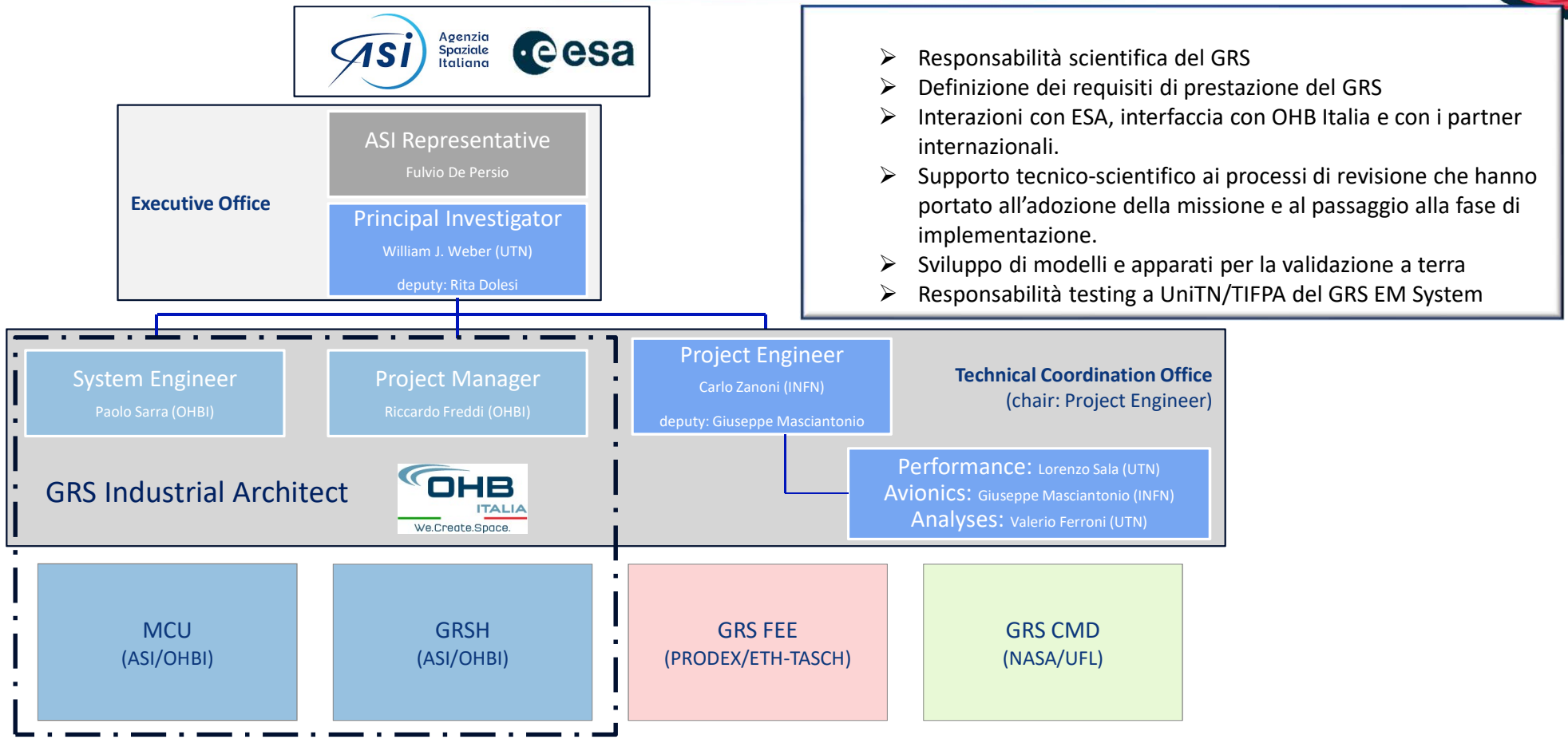
Electrode Housing (EH
Mb electrodes coated in Au

Test Mass (TM)
1.96 kg in Au-Pt



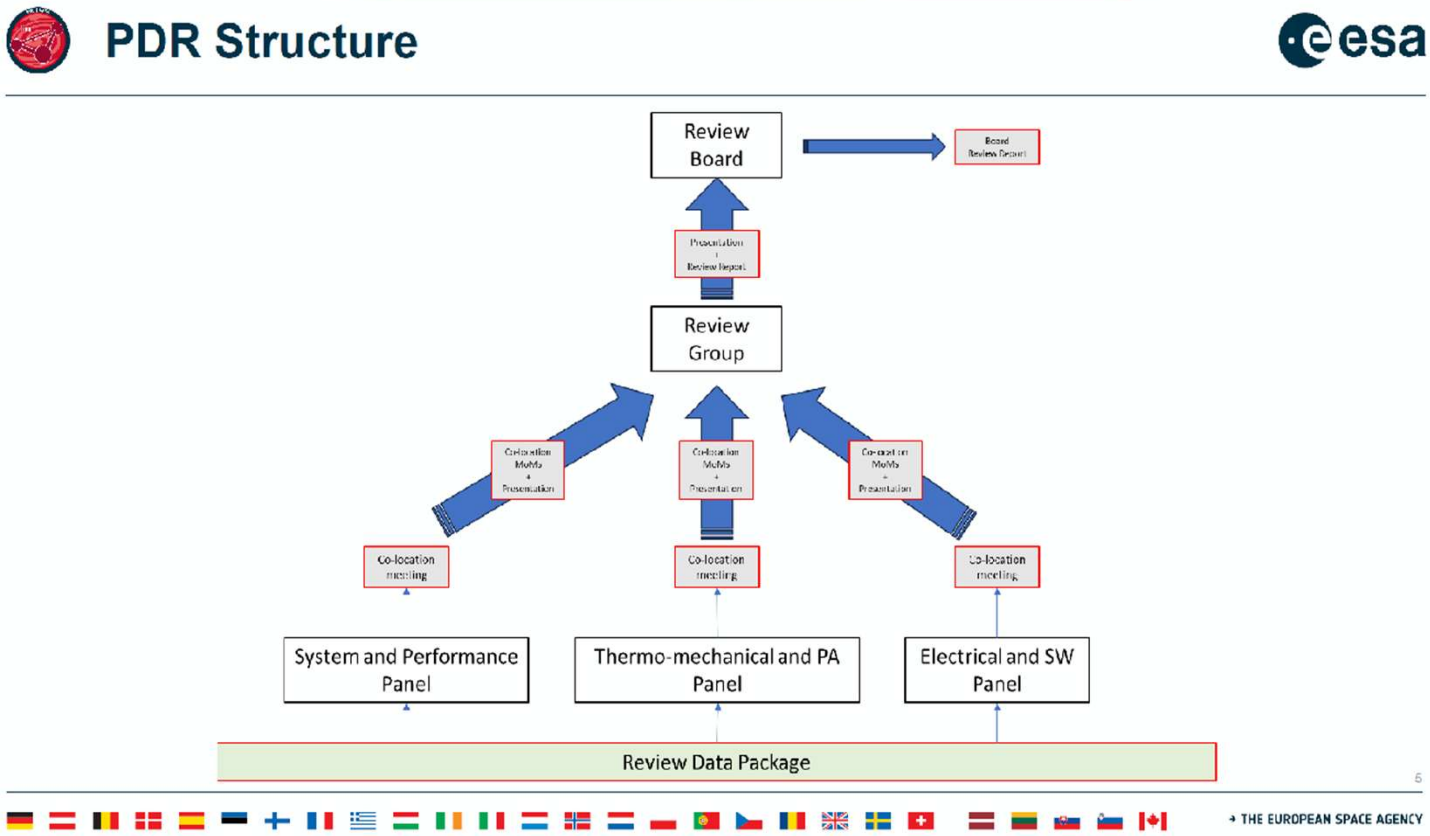


GRS PI Team @TIFPA: ruoli e attività



- Responsabilità scientifica del GRS
- Definizione dei requisiti di prestazione del GRS
- Interazioni con ESA, interfaccia con OHB Italia e con i partner internazionali.
- Supporto tecnico-scientifico ai processi di revisione che hanno portato all'adozione della missione e al passaggio alla fase di implementazione.
- Sviluppo di modelli e apparati per la validazione a terra
- Responsabilità testing a UniTN/TIFPA del GRS EM System

PDR actions



3 Panels (System and Performance; Thermal mechanical and product assurance; Avionics), ognuno con un “point of contact” – Lorenzo Sala, Valerio Ferroni e Giuseppe Masciantonio, coordinati da Carlo Zanoni

Attività in supporto alla missione e al GRS

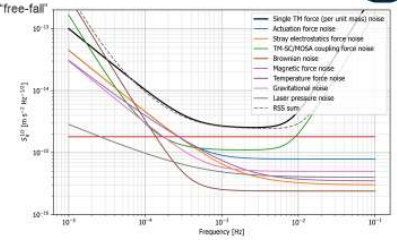
GRS performance budget - update

The GRS System is directly responsible (IRD2 requirements) for three entries under "free-fall" **performance budget** entry, i.e.,
the disturbing force per unit mass acting on the Test Masses:

- Actuation noise
- Stray Electrostatic Noise
- Brownian noise

In addition to these ones, the GRS System is responsible for:

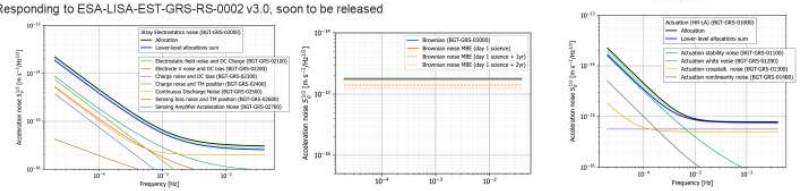
- Actuation/Intrinsic noise along all non-x DOFs
- Thermal, magnetic, and optical properties
- Self-g and electrostatic stiffnesses which couple to SC/TM-MOSAjitter



Models and budgets are reported in

- **LISA-UTN-INST-RP-0019** v2.1, December 2025
- **LISA-UTN-INST-TN-0037** v1.0, October 2025

Responding to ESA-LISA-EST-GRS-RS-0002 v3.0, soon to be released



Molecular simulations for GRS performance

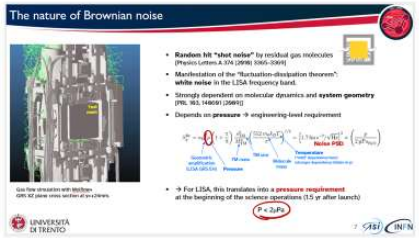
The GRS System is responsible for Brownian noise, generated by molecule collisions with the TM surfaces. This ultimately depends on **pressure within the GRS Vacuum Chamber.**
We are tackling this problem via two parallel strategies:

- Development of strategies for outgassing rate reduction and force noise mitigation (see next slide)
- Understanding of outgas-to-force relations, "conductivities", using molecular simulations

The software Molflow+ (developed at CERN) allows to efficiently simulate particle emission, and their momentum transfer to the TM surfaces.

These activities are relevant for multiple aspects:

- Analysis of the effect of gas bursts, and understanding of LPF glitches
- Analysis of the effect of quasi-stationary outgassing on quasi-static non-gravitational force, and dg/dT temperature-to-force coefficient
- Analysis of Brownian noise, and dependence of its PSD on geometrical properties.



LISA P&O support activities

- The LISA Trento team is involved in the activities of the **LISA P&O (Performance and Operations)** team, working on the mission performance budget and concept of operations.
- The P&O main activities involve the **full model of the LISA performance** during science operations (up to constellation level), monitoring all the relevant system budget entries.
- The Trento team participates supporting:
  - Modeling of force-inducing effects (not just those under GRS system responsibility)
    - Definition of parameters and noise entries relevant for performance
    - Development of the ESA LISA performance software package, including all models.
    - Development of the ESA LISA Performance Description ESA-LISA-EST-MIS-DD-0002
  - Data processing,
  - Data analysis tools and activities

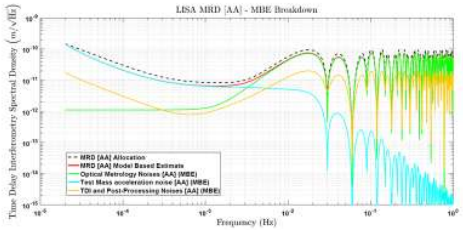


Figure 7.3 – MBE Breakdown for the LISA TDI MRD [AA] noise performance

LISA PSD verification algorithm and strategy

The Trento team has actively participated in the development of the ESA LISA PSD verification strategy, applicable for **verification of in-band PSD** (power spectral density) requirements.

The output of this activity has been a **TN released by ESA** in December 2025, which will be supported with a software package.

→ The TN describes a "PSD recipe" to be used to calculate dense, quasi-independent, and unbiased PSD estimation points in the relevant band, with a novel frequency scheme, and defines **a figure of merit** for joint requirement verification.

→ The TN provides a tool for detection of narrow-band processes, "spectral lines", and possible strategies.

References:

- **ESA-LISA-EST-MIS-TN-0004 v2.0**, ESA, 11/12/2025
- LISA-UTN-INST-TN-0035, v1.0, UTN, 2025
- L.Sala, S.Vitale, https://doi.org/10.48550/arXiv.2507.20846

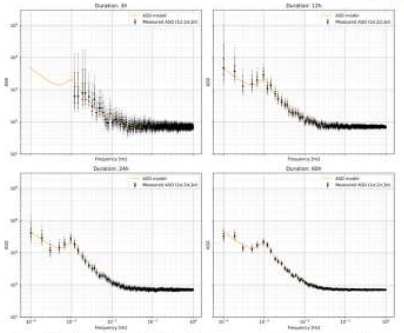


Figure 2.1 – Application of the described method to a measurement, after 3 hours (for monitoring purposes), 0.5 days, 1 day, and 2.5 days ('weekend run'). The orange line is the theoretical ASD. The black points represent the central ASD value (50% quantile), and the faded black error bars represent equally-tailed uncertainties at 1σ, 2σ, 3σ levels.

$$\lambda_k = P\left(S_k \le \tilde{S}_k \middle| \mathrm{PSD}_k\right) = Q_{M_k}\left(\frac{M_k \mathrm{PSD}_k}{\tilde{S}_k}\right)$$

La collaborazione INFN LISA

UNIVERSITÀ DI TRENTO

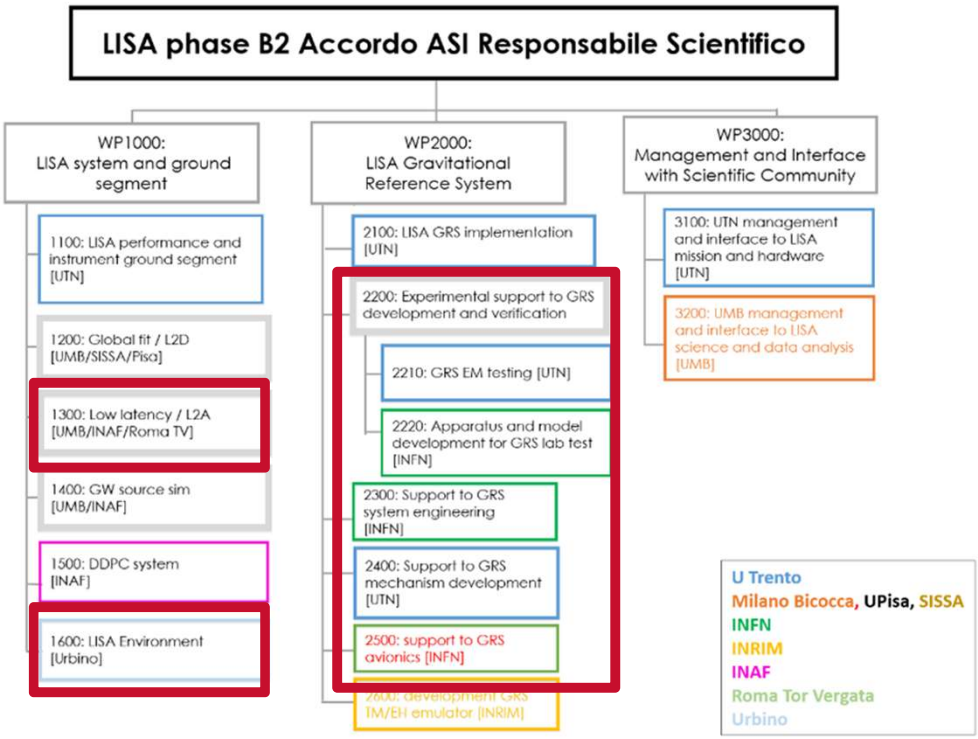
TIFPA Coordinatore Nazionale del progetto INFN LISA dal 2018

rilanciata partecipazione INFN in sinergia con l'ASI

- **Sviluppi della collaborazione LISA INFN**: (TIFPA, ROMA II, Firenze Urbino: **31 ric+Tecn, 22 FTE**)
- Reclutamento: un primo tecnologo e un ricercatore al TIFPA
- INFN Roma 2 (G. Masciantonio) nel GRS PI Team
- INFN Roma 2 (F. Tombesi) in data analisi LISA L2A group for low-latency activities
- Catia Grimani nel LISA Science Team

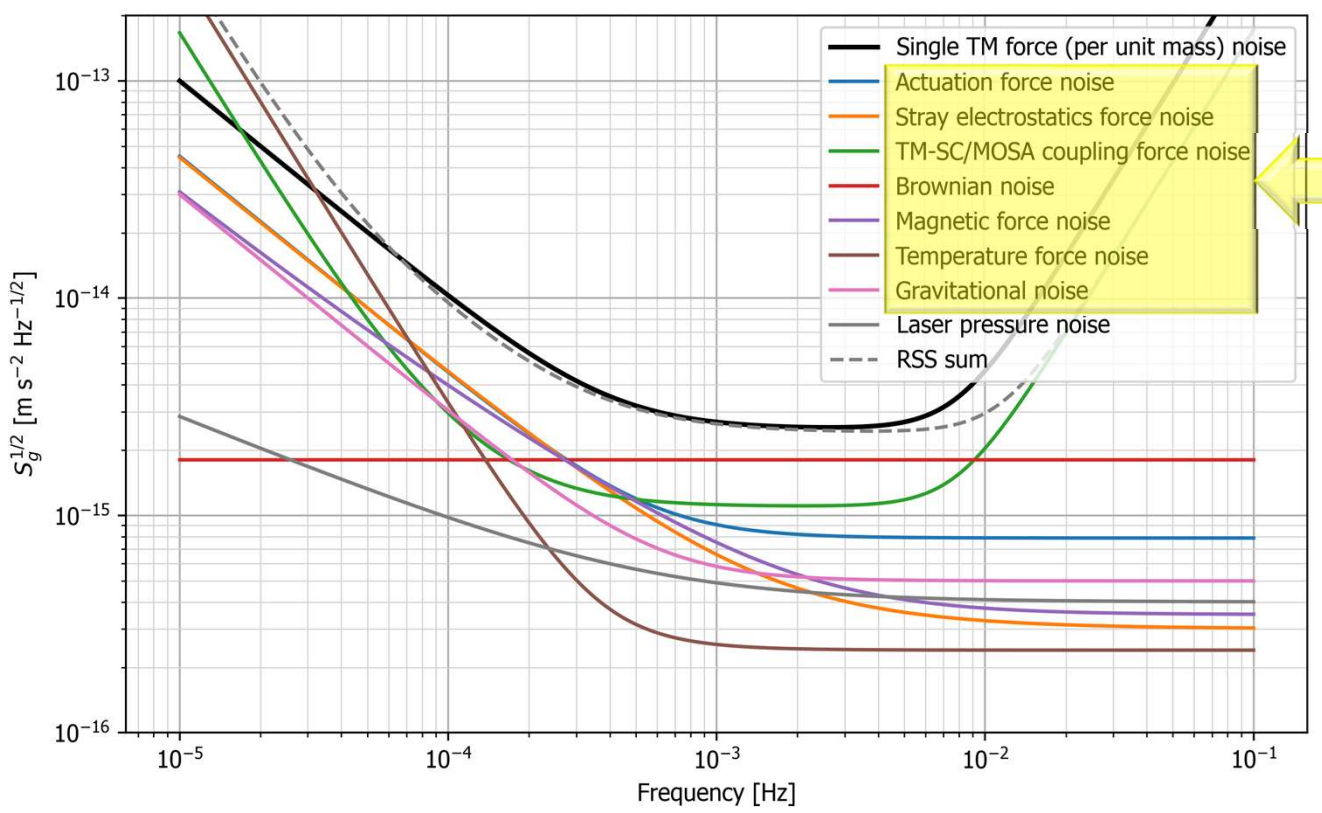
Crescita di una comunita scientifica nazionale

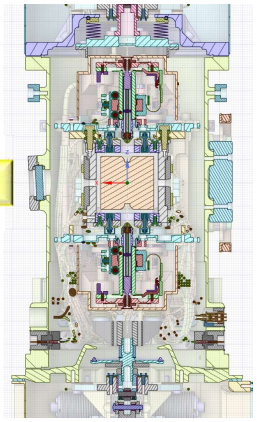
Coinvolgimento di **gruppi INFN e non**,
sia nell'implementazione dello strumento LISA sia nelle attività di Ground Segment in operazione,
stimolando sinergie con ET e VIRGO.



LISA GRS Performance Budget

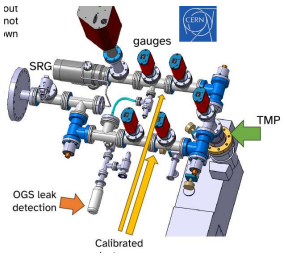
Include tutti gli effetti che generano forze spurie sulle masse di prova e che, di conseguenza, producono rumore di accelerazione





Dobbiamo verificarli per analisi e/o test !!

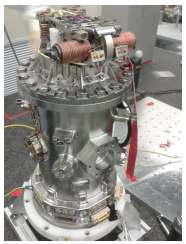
LISA GRS: campagna di test a terra



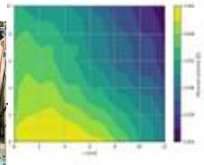
Ougassing measurement facility in collaboration with **CERN**

Tests on the improved Grabbing Positioning and rekease Mechanism **@ OHB-I/TUniTN/TIFPA**

Test mass capacitive sensor emulator for LISA system testing and TM metrology @ **INRIM**

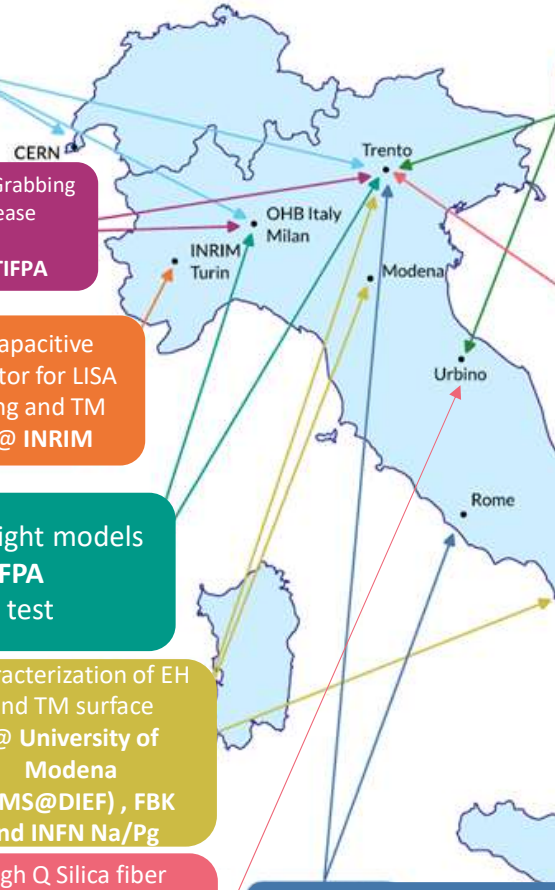


Tests on the EM, QM and flight models **@ OHB-I /Unitn/TIFPA** including End-2-End test

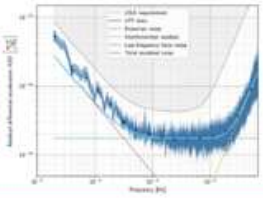


Characterization of EH and TM surface **@ University of Modena (LFMS@DIEF) , FBK and INFN Na/Pg**

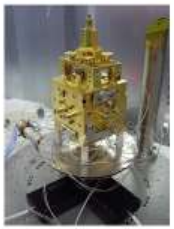
High Q Silica fiber from VIRGO as torsional member for pendulum **@ INFN UniUrb**

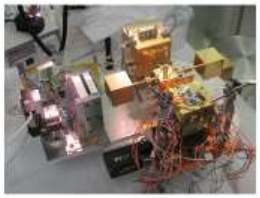


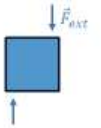
Improved **numerical modeling** (e.g. *understanding LPF glitches* and *excess noise, enviromental TM charging*)

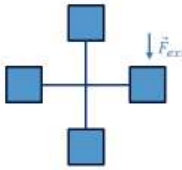


Torsion pendulum tests for force disturbances on hollow TMs:
- Capacitive sensor performance (sensing/actuation)
- Overall **force noise** upper limit
- **Stiffness** from injection, actuation, and DC voltages, TM charge
- Thermal effects (*dg/dT*) and outgassing
- Full **discharge test** (including *continuous discharge*)
- **Stray voltages** (Δ_v)
- Surface properties (*emission yield, patch potentials*)

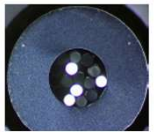


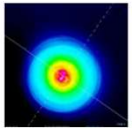






Beam profiling measurement of the UV light at OFT **@ INFN Roma 2**



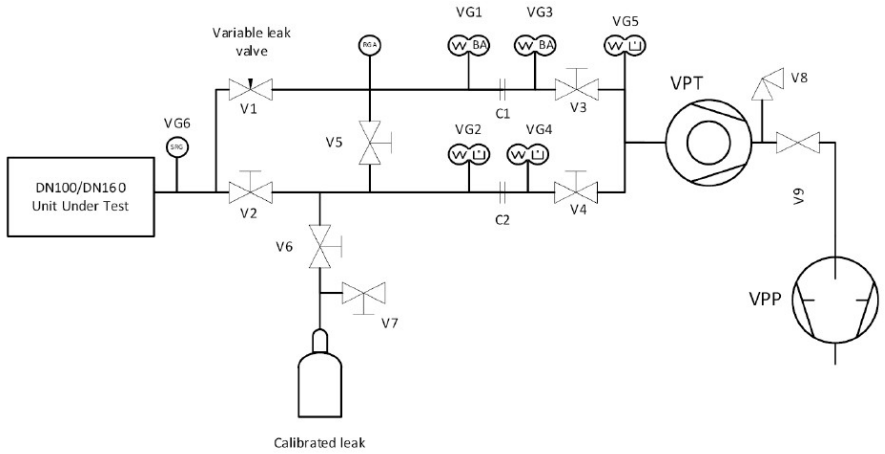


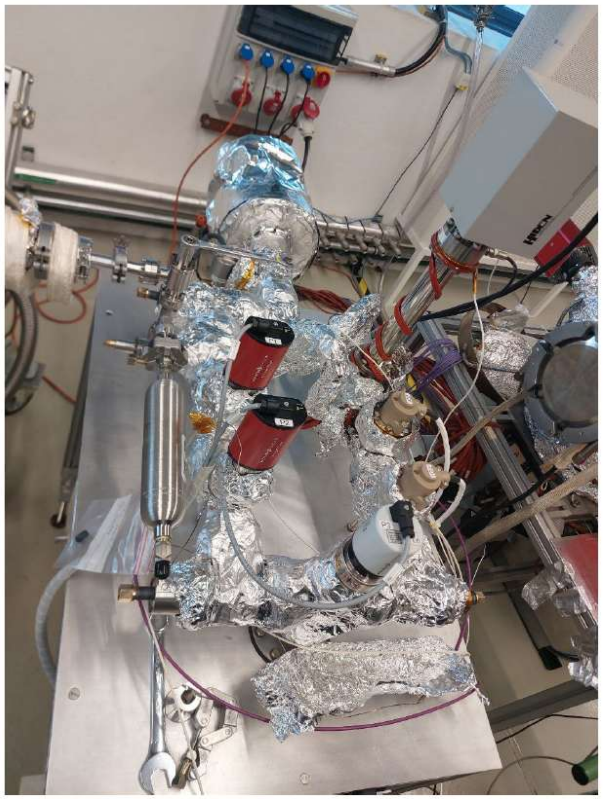
Preparing for GRS EM testing: End2End discharge and outgassing testing

The GRS Team (UniTN/INFN +OHB-I) have developed the strategy for vacuum management (LISA-UTN-INST-TN-0030 Issue/Rev. 2.0, June 2025)

With OHB-I and CERN we have developed the OGS

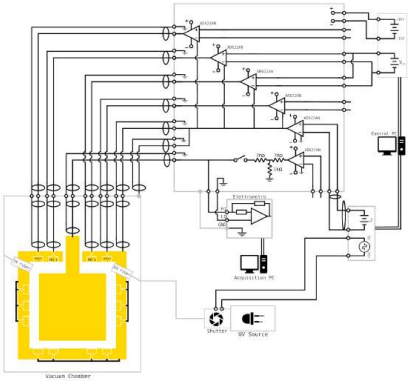
with LPF FM EH→ LISA EM EH →LISA QM EH → LISA FMs EH





Preparing for GRS EM testing: End2End discharge and outgassing testing

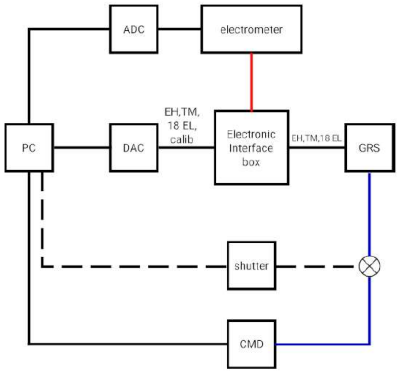
The facility prototype developed in UniTN enables direct measurement of the photocurrent generated by the discharge system under different conditions, and testing the effect of the bakeout



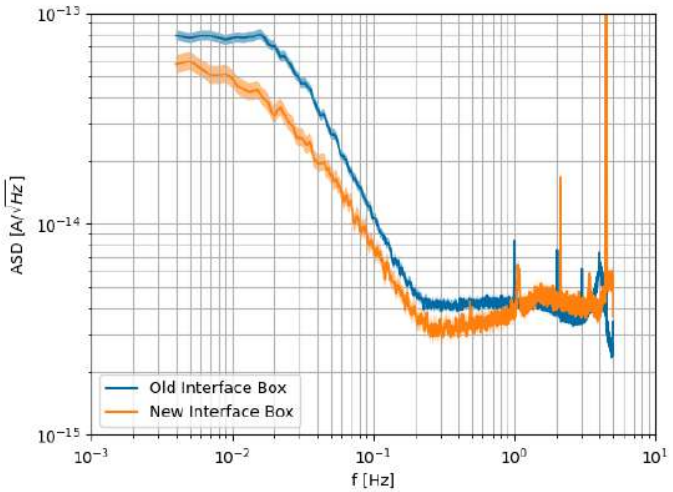
Electronics designed, tested, and will be delivered by UniTN to OHB-I bye the end of May 2026.

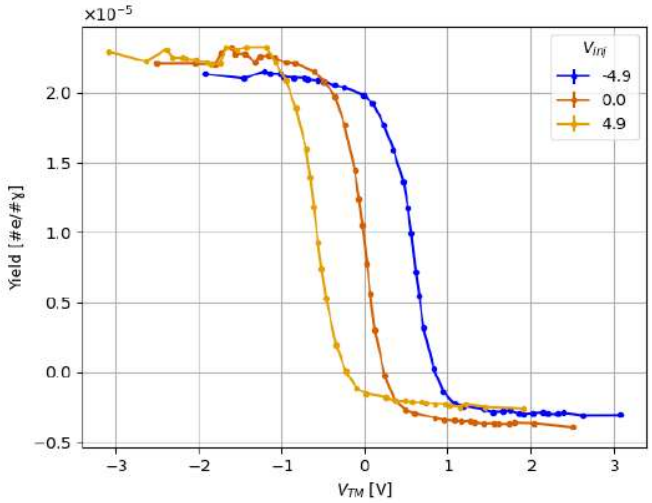
Based on the UniTN prototype, UniTN and OHB-I designed the End2End discharge facility to be integrated with the Outgassing Station @ OHB-I (see OHB-I presentation)

with LPF FM EH→ LISA EM EH →LISA QM EH → LISA FMs EH)



Francesco Venturelli

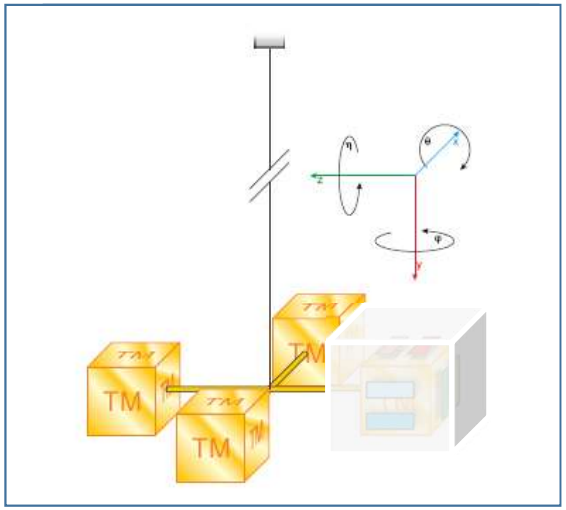




UNIVERSITÀ DI TRENTO INFN OHB ITALIA

Pendoli di torsione per simulare la caduta libera

Il membro inerziale comprende la test mass racchiusa nel sensore capacitivo



La capacità di eseguire **test mirati e rappresentativi** si è **dimostrata essenziale**.
Il potenziale dei pendoli torsionali in questo ruolo li ha resi lo **strumento di riferimento** per la comunità scientifica nello studio e nello **sviluppo di sensori per il moto geodetico nello spazio**.

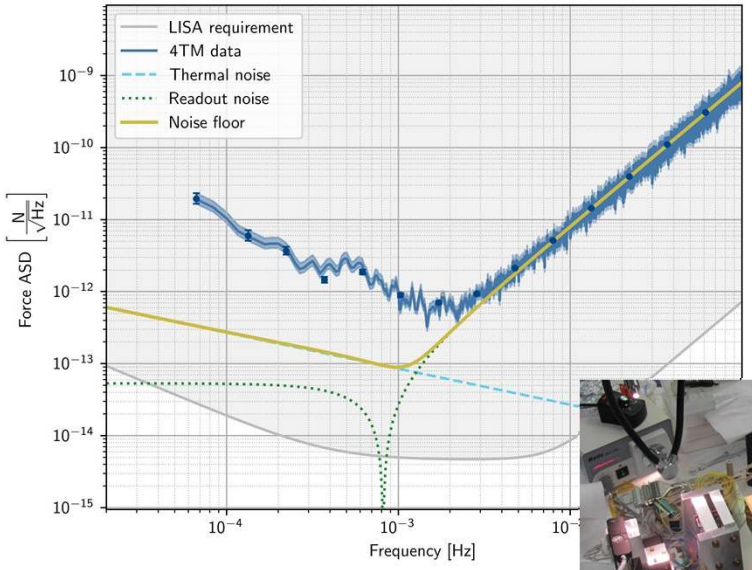
Pendoli di torsione per simulare la caduta libera

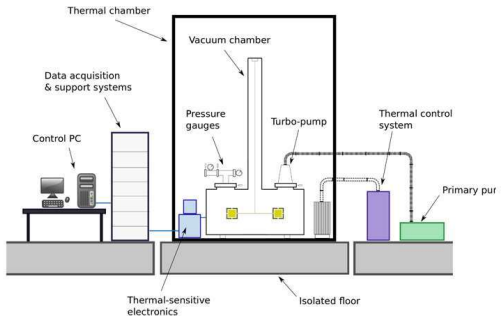
4TM:più rappresentativo

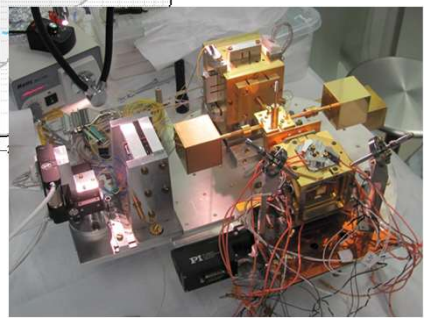
1TM: più sensibile

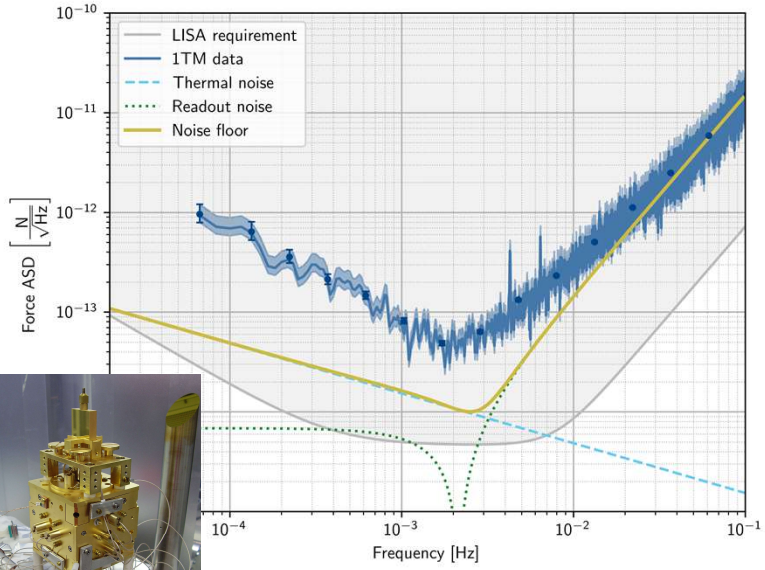
Consente di testare numerosi effetti al livello dei requisiti di LISA: a 2 mHz è possibile risolvere una forza di 10 fN in un'ora.

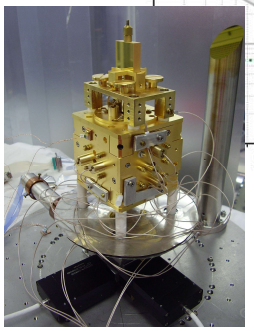
Il rumore è circa un fattore 6 superiore ai requisiti di LISA intorno ai mHz.











GRS EM System Testing: Documents and TRR

Work in progress


INFN UNIVERSITÀ DI TRENTO

LISA GRS

GRS EM Test Plan
at the University of Trento/INFN TIFPA

LISA-UTN-INST-TP-001
Issue/Rev. 2.1

Delivered in June 2025

Description of facilities and of test configuration

Preliminary description of
the individual test campaigns

List of requirements whose compliance
is demonstrated or supported by these tests

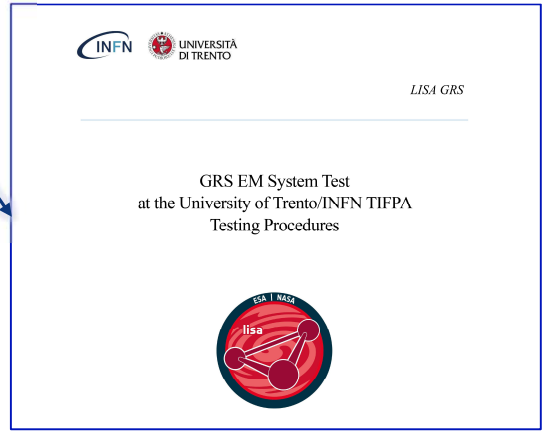

INFN UNIVERSITÀ DI TRENTO

LISA GRS

GRS EM System Test
at the University of Trento/INFN TIFPA
Testing Facilities and Integration Procedures

- Description of the testing facilities
- integration procedures,
- cleanliness contamination control plan,
- status and management of the facilities
- ….

Delivery for TRR @ Q3-Q4 2026 (TBC)
Delta-TRR for the facility commissioning
@ Q1/Q2 2027(TBC)


INFN UNIVERSITÀ DI TRENTO

LISA GRS

GRS EM System Test
at the University of Trento/INFN TIFPA
Testing Procedures

For each test:

- Item Under Test
- Aims of the test
- Test Set-up
- Description of the test
- Measurement outputs
- Success Criteria

Appendix: Step-by-step Procedure

Primo modello dell'EH di LISA !!

Finanziato da CSN2

NEWS

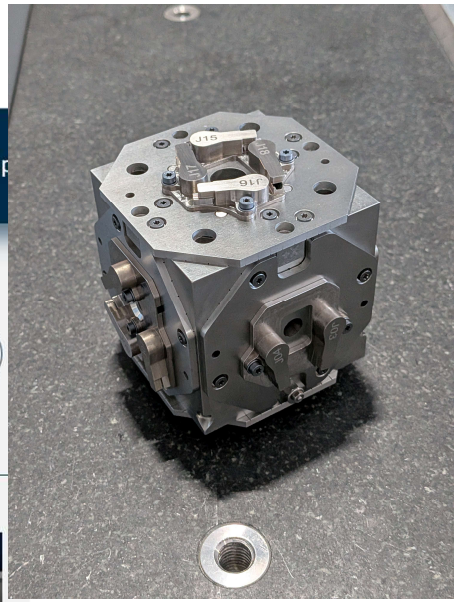
RIVELARE LE ONDE GRAVITAZIONALI DALLO SPAZIO: PRIMI PASSI PER LA MISSIONE LISA

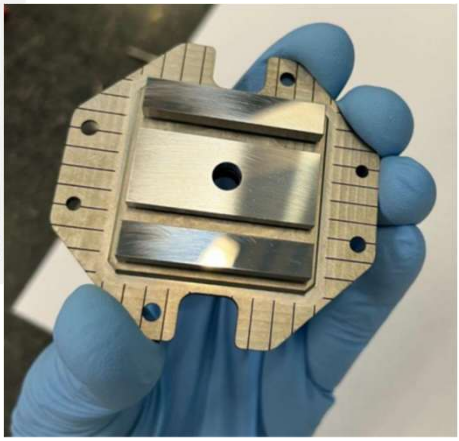
17 Ottobre 2025

Si è appena conclusa un'importante tappa verso la realizzazione della missione LISA dell'Agenzia Spaziale Europea (ESA), che avrà l'obiettivo di rivelare le onde gravitazionali dallo spazio. È stata infatti completata la costruzione del primo modello di un elemento centrale della missione, l'*electrode housing*, realizzato grazie alla supervisione e al finanziamento di 300 mila euro da parte dell'INFN Istituto Nazionale di Fisica Nucleare, che ne ha affidato la costruzione all'azienda OHB Italia SpA.

LISA sarà il primo rivelatore spaziale di onde gravitazionali, e seguirà la Terra nella sua orbita intorno al Sole. Sarà costituito da un triangolo equilatero ai cui vertici ci saranno tre satelliti, a 2,5 milioni di chilometri di distanza l'uno dall'altro, che si "scambieranno" fasci laser, funzionando come un

Il modello ingegneristico dell'electrode housing sviluppato per la missione spaziale dell'ESA LISA con Riccardo Freddi e Andrea Moroni (OHB Italia) e Carlo Zanoni (INFN-TIFPA), da sinistra a destra.





Prospettive di sviluppo area gravitazione sperimentale

Consolidare a Trento un polo di riferimento internazionale per la gravità sperimentale dallo spazio, capace di integrare strumentazione di frontiera, modellizzazione, analisi dati e formazione avanzata.

- Portare a compimento la nelle prossime fasi di **verifica sperimentale del GRS** missione fino al lancio, e durante **l'operazione di LISA**
- Promuovere Integrazione tra hardware, modellizzazione del rumore e data analysis nel quadro del **LISA Science Ground Segment**
- Promuovere **sinergie con VIRGO e Einstein Telescope per far crescere la comunità italiana** come riferimento nel campo delle onde gravitazionali e in generale promuovere la crescita della comunità italiana nelle missioni spaziali di gravitazione nella prospettiva di future iniziative oltre LISA.
- **Ampliare le sinergie** con INFN, ASI, CERN, CNRS e **altri enti per nuovi progetti** in cui metter a frutto le nostre **experties in sistemi di riferimento geodetici e strumentazione di misura innovativa.**
- **Espandere la measurement science** su vuoto, superfici, carica, outgassing e piccole forze con tecniche di misura innovative e di frontiera.
- **Formare nuova leadership scientifica**: dottorato, post-doc, corsi avanzati e coinvolgimento di studenti in attività sperimentali di frontiera.

Una piattaforma di ricerca che collega **fisica fondamentale, tecnologie spaziali e attrazione di collaborazioni competitive nazionali e internazionali**, con **percorsi formativi** che aprono prospettive di **inserimento in ambito accademico, istituti di ricerca, in agenzie spaziali e industria aerospaziale**.