LISA – Preventivi 2024

Carlo Zanoni

(on behalf of Rita Dolesi and the LISA team)

Questions addressed by GW (AdV+, ET/LISA)

- Fundamental questions in Gravity: — Fundamental interactions, Dark matter, dark energy
  - New/further tests of GR
  - Exploration of possible alternative theories of Gravity
- Fundamental questions in particle physics — Inflation, additional interactions, dark matter
- Probing the EOS of neutron stars — Nuclear physics, quark-gluon plasma
- Cosmology and Cosmography with GWs — Cosmology
- Accurate Modelling of GW waveforms
- GW models in alternative theory of gravitation — Cosmology
- What is the explosion mechanism in Supernovae? — Nuclear physics
- What is the history of SuperMassive black holes? — Cosmology
- GW Stochastic Background? Probing the big bang?
- Multimessenger Astronomy in 3G? — Astroparticle, GRB, Neutrino Physics

Credit: M. Punturo 2020

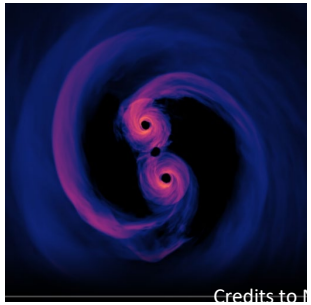
LISA science objectives

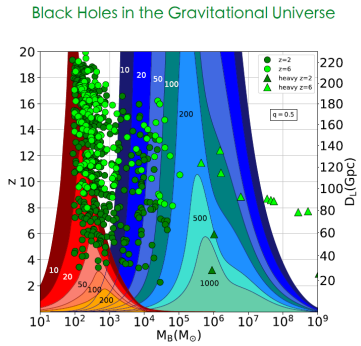
LISA Definition Study Report - ESA-SCI-DIR-RP-002
https://arxiv.org/ftp/arxiv/papers/2402/2402.07571.pdf

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**

Some of the uniqueness of LISA

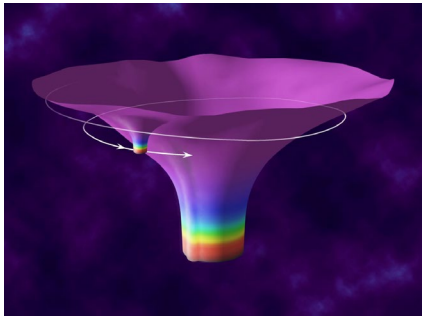




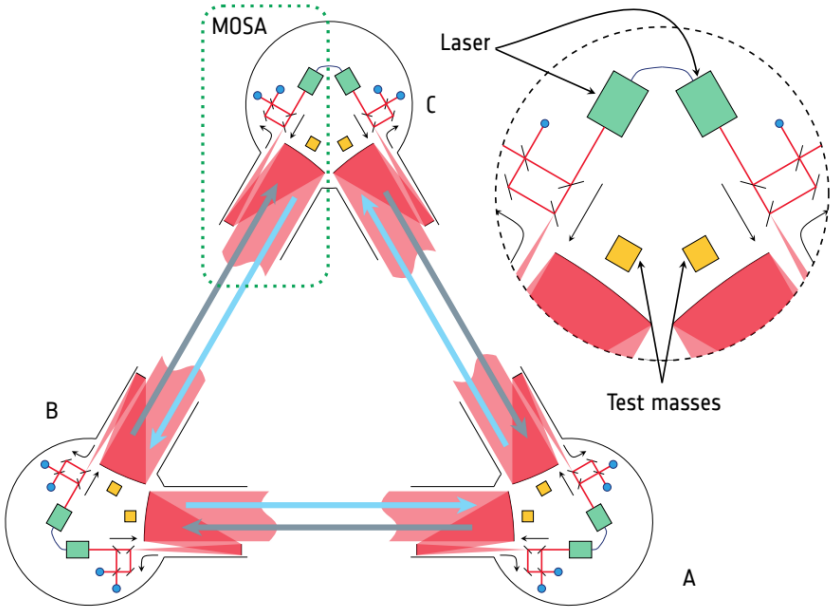
Supermassive Black Holes binaries with high signal to noise

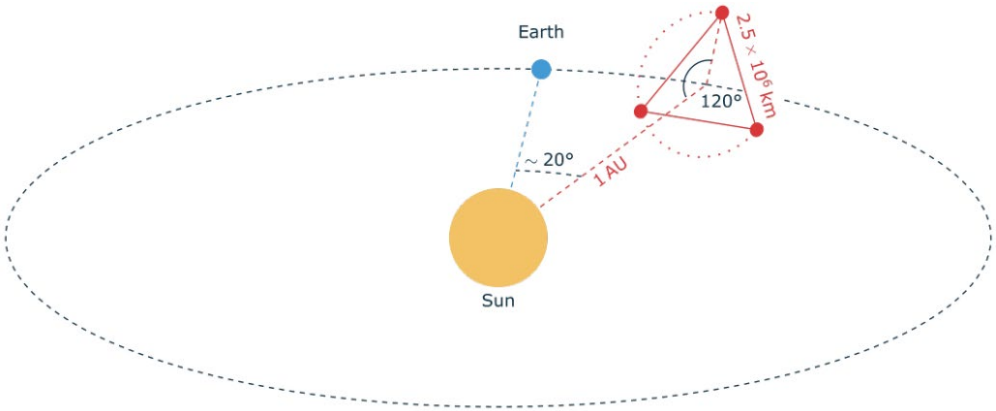
Extreme Mass Ratio Inspirals
Inspiral of stellar–mass compact object into massive black hole. If the compact object is a white dwarf, possible electromagnetic counterpart

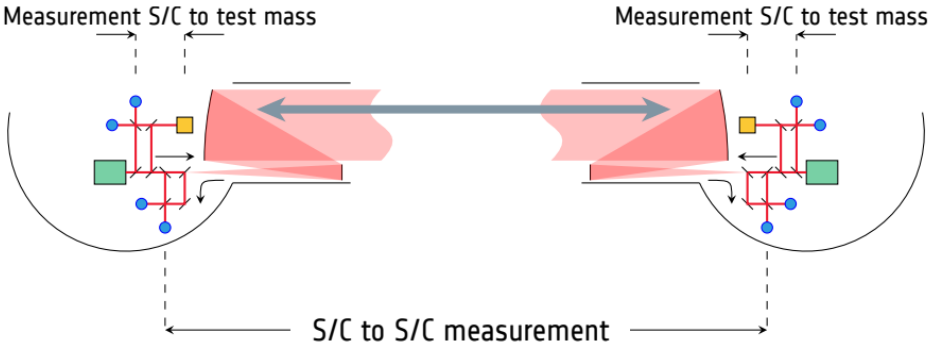
Test the properties of the space time around massive dark objects. the presence of dark matter which causes a different phase evolution.



LISA concept



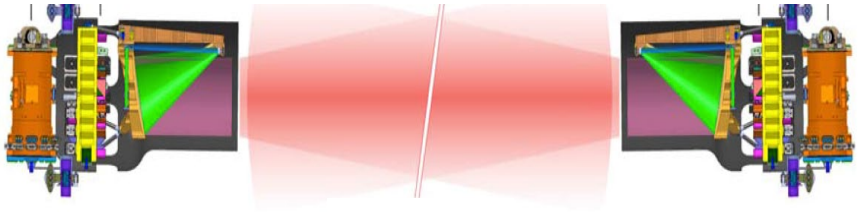




Measurement	
Gravitational waves (GWs) in the Frequency Band of 0.1 mHz - 1.0 Hz with a GW Strain Spectral Density: 10^{-21}–10^{-23}	
Payload	
Lasers	2 per spacecraft • 2 W output power • wavelength 1064 nm • frequency stability 300 Hz/$\sqrt{\text{Hz}}$
Optical Bench	2 per spacecraft • double-sided 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 fm/(s^2 $\sqrt{\text{Hz}}$) • 46 mm cubic AuPt test mass • Faraday cage housing • electrostatic actuation in 5 degree of freedom
Mission	
Duration	4.5 years science orbit • >82 % duty cycle • ~6.25 years including transfer and commissioning
Constellation	Three drag-free satellites forming an equilateral triangle • 2.5 × 10^6 km separation • trailing/leading Earth by ~20° • inclined by 60° with respect to the ecliptic
Orbits	Heliocentric orbits • semimajor axis ~1 AU • eccentricity $e \approx 0.0096$ • inclination $i \approx 0.96°$

LISA Definition Study Report - ESA-SCI-DIR-RP-002
https://arxiv.org/ftp/arxiv/papers/2402/2402.07571.pdf

LISA Sensitivity

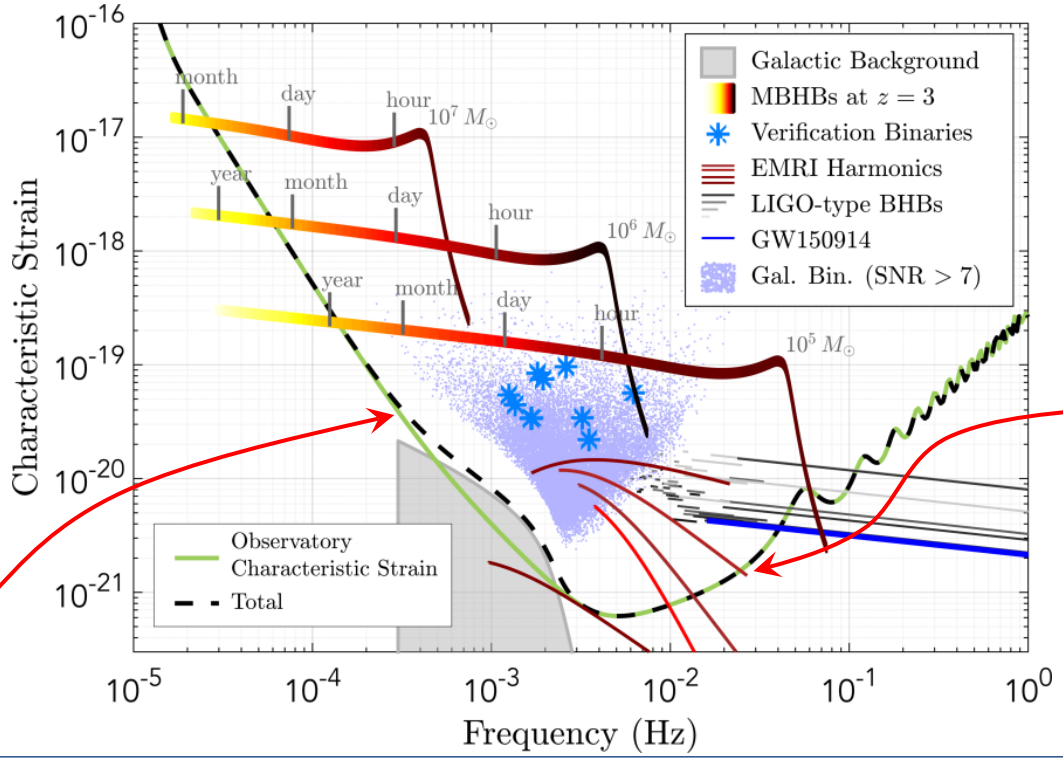


2.5 Million km

Measure acceleration between free-falling test masses (TM) 2.5 million km apart

- 3 parts: TM-SC, SC-SC, SC-TM

Spacecraft controlled to follow TM:
drag-free control (nm/Hz$^{1/2}$ level)



TM **acceleration noise**,
3 fm/s^2/Hz$^{1/2}$

(Low freq limit - crucial for SMBH)

Interferometer readout noise,
15 pm/Hz$^{1/2}$

(High freq limit)

LISA is an adopted mission (Jan-24)

On the trail of the:

- LPF success,
- GW observations on-ground and
- intense preparatory work since 2017

and recognizing:

- a robust scientific case and
- the technical feasibility (TRL > 5)

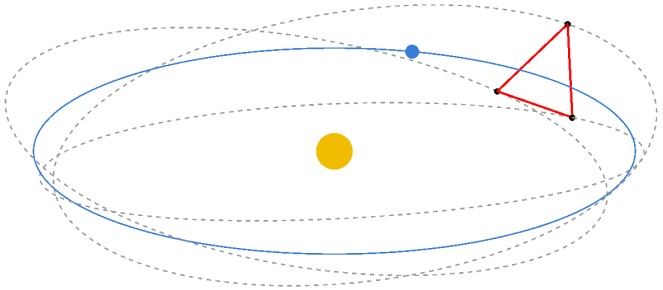
the LISA *study* becomes a project and starts its implementation.

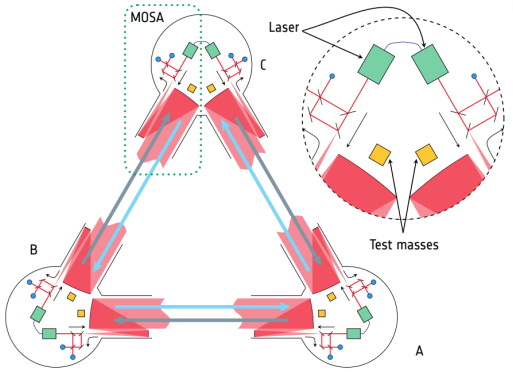
LISA Product Breakdown (notional)

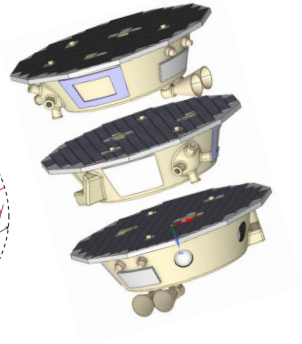
- LISA
  - Ground segment
  - Space segment
    - Spacecraft
    - Payload
      - Moving Optical Sub-Assembly
      - Interferometry Detection System
      - Gravitational Reference System
      - Telescope

ESA

Customer Furnished Items (CFIs)







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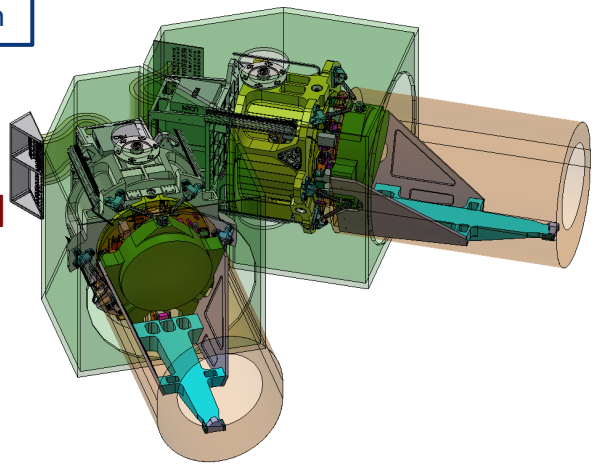
ESA

Customer Furnished Items (CFIs)

Equivalent to VIRGO end-station



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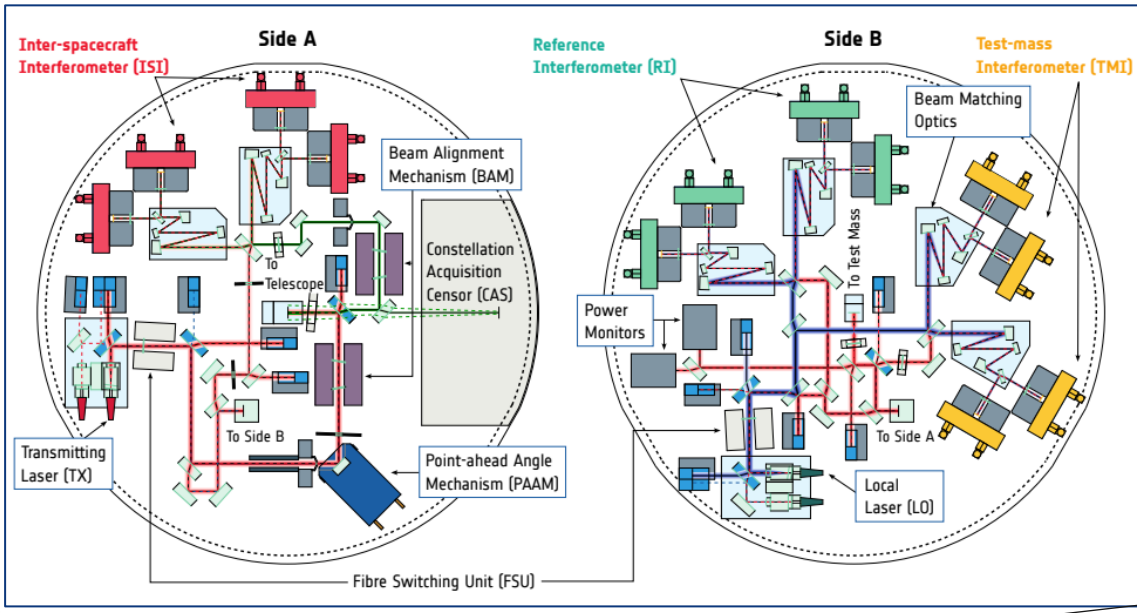

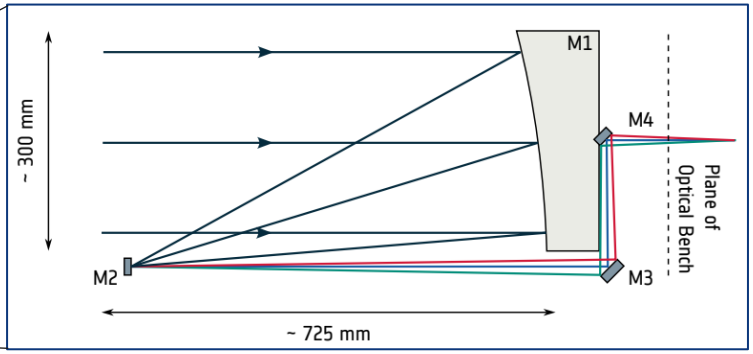

LISA Product Breakdown (notional)

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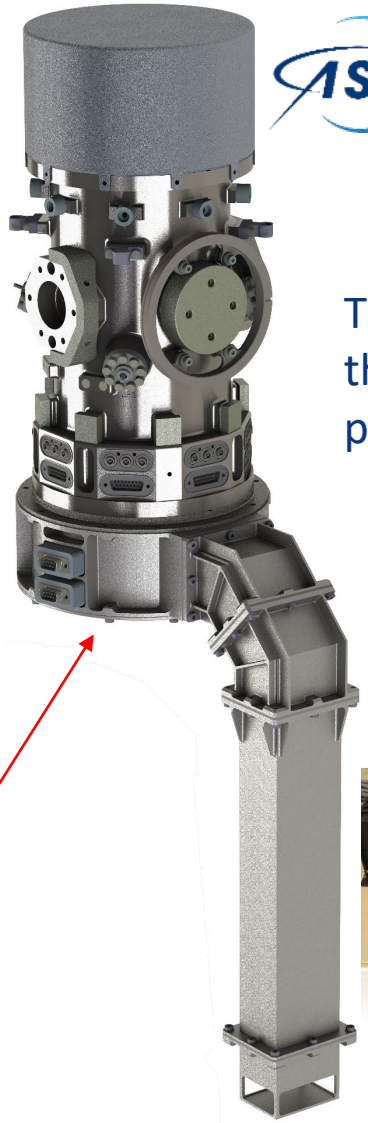
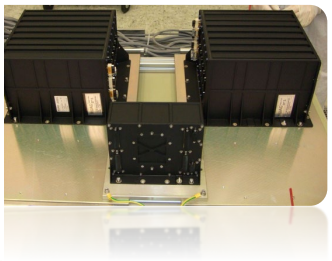
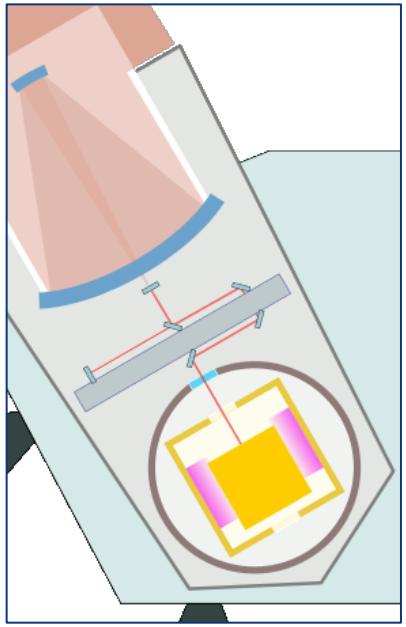
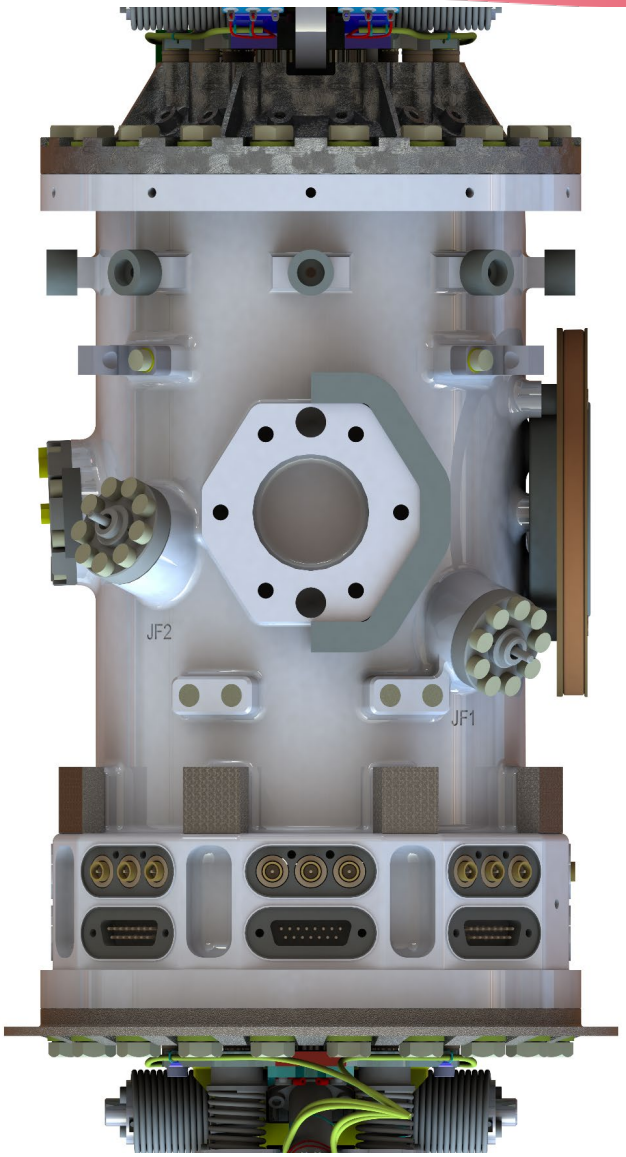






The GRS is the system that impacts the most the acceleration noise performance of the free-falling TM.

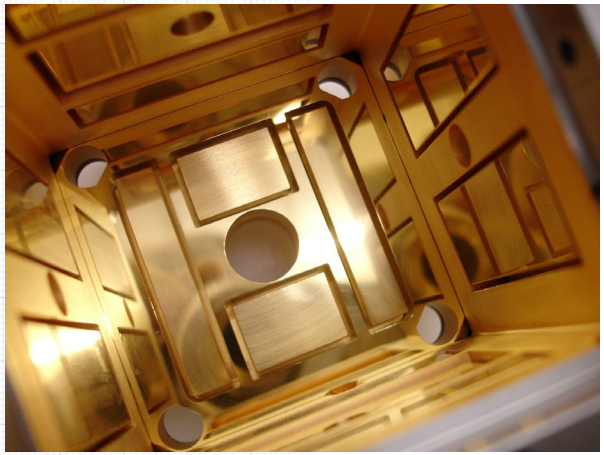
Gravitational Reference System

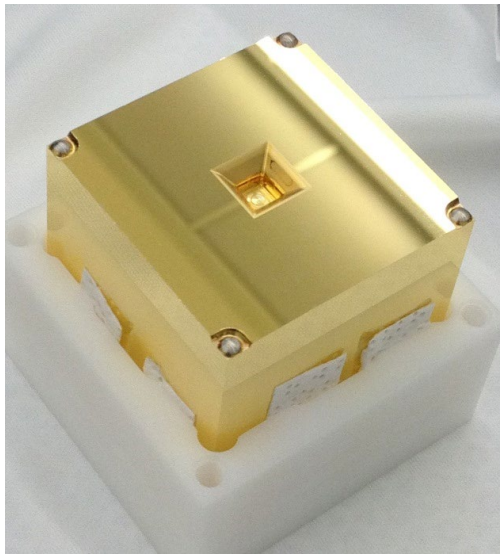


Design and testing done for LPF, with support from **INFN**.

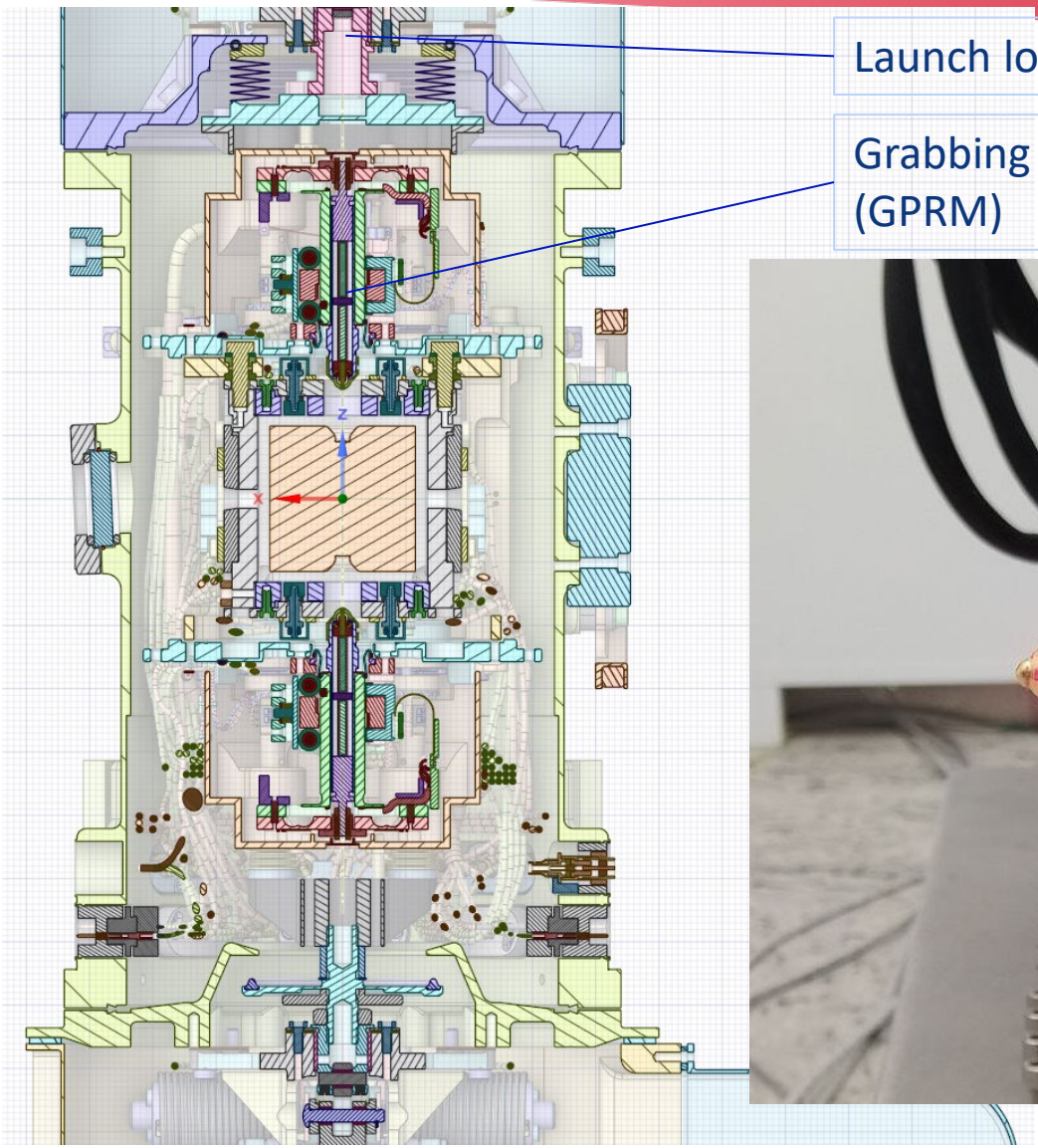
Electrode Housing (EH)
Mb electrodes coated in Au

Test Mass (TM)
1.96 kg in Au-Pt



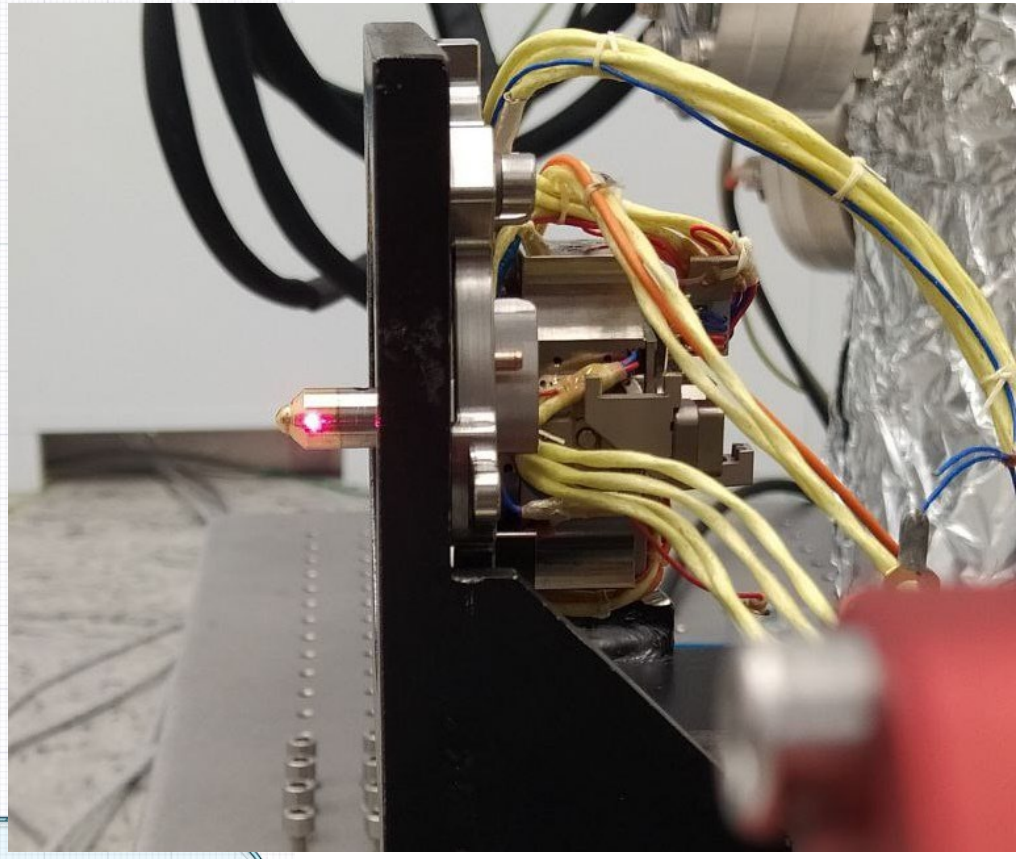


Gravitational Reference System

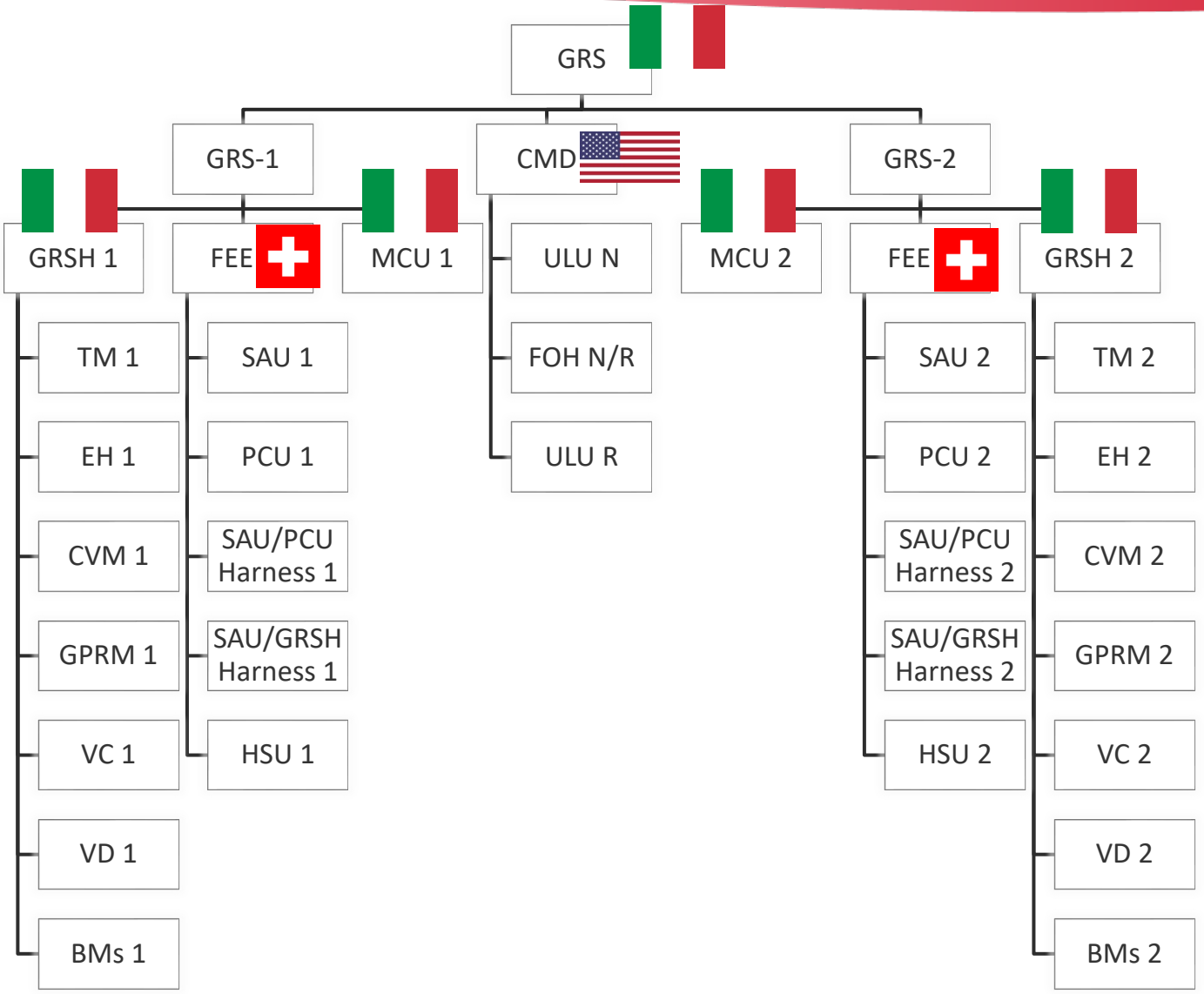


Launch lock (CVM)

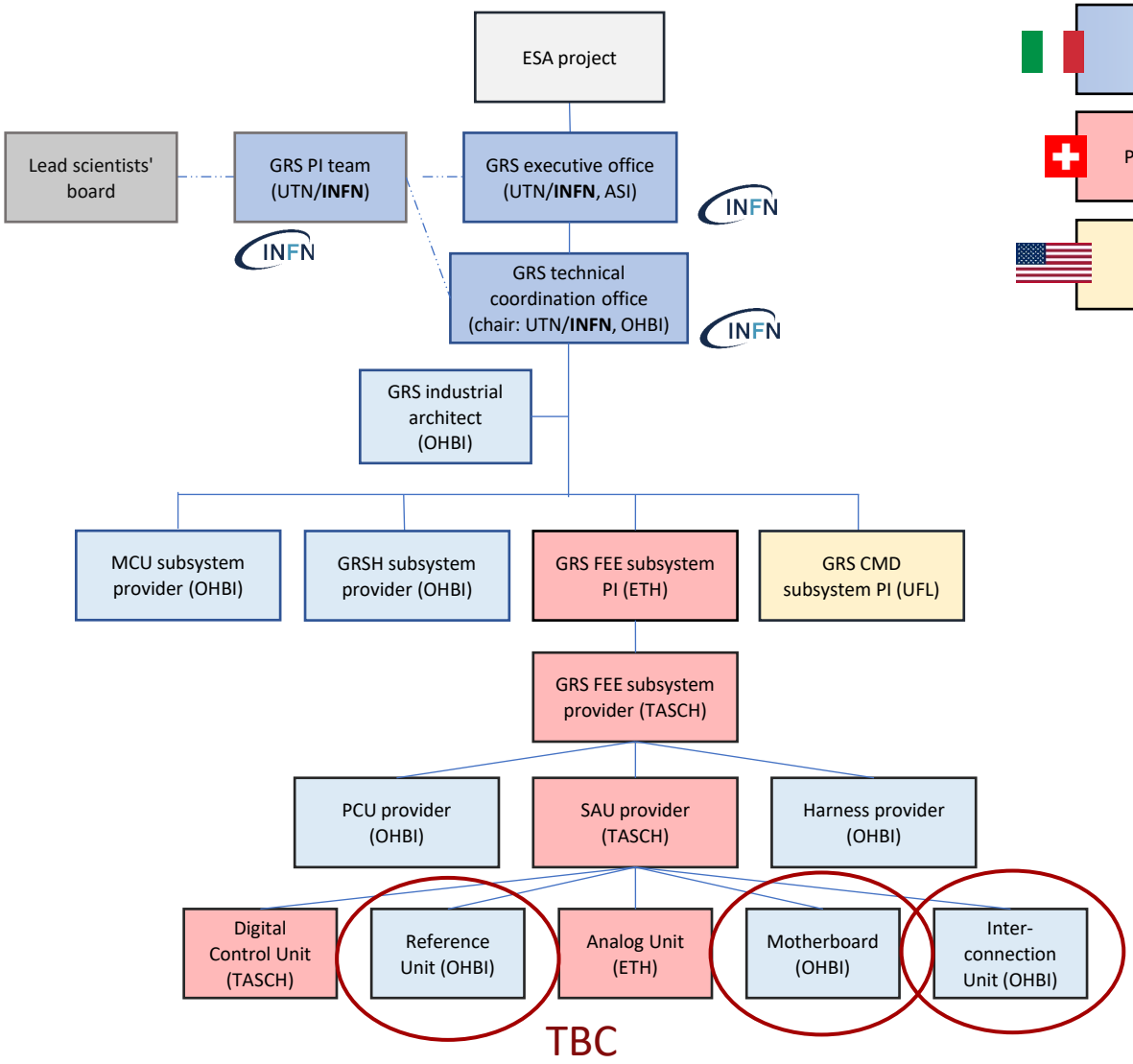
Grabbing positioning and release mechanism (GPRM)

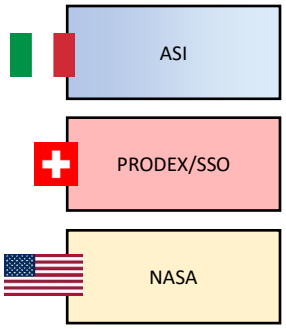


GRS Avionics and Architecture



GRS Procurement and Management Scheme





Ruolo INFN in LPF e LISA

- Al progetto di un osservatorio di onde gravitazionali dallo spazio, **INFN** ha partecipato con grande lungimiranza fin dalla proposta iniziale di **LISA Pathfinder**.

- Ha sostenuto i gruppi scientifici nella fase di **definizione e prototipazione del sensore inerziale** con masse in caduta libera indispensabile alla rivelazione delle onde gravitazionali, e **nello sviluppo dell'innovativa strumentazione di verifica a terra.**

- I test con pendoli di torsione supportati dalla CSN2 sono l'unica occasione per la verifica a terra di performance di caduta libera

- Tali contributi sono stati **cruciali** per il **successo della missione LISA Pathfinder e lo saranno per LISA**, **confermando e estendendo allo spazio il ruolo INFN** come istituto di ricerca di riferimento per la comunità scientifica italiana impegnata nella realizzazione di osservatori di onde gravitazionali.

- Analoga partecipazione è stata rilanciata per **LISA**, in stretta sinergia con ASI, rafforzata da un importante supporto al **Systems Engineering**

Accordi INFN-ASI

Accordo di programma INFN/ASI
Per LISA Pathfinder

Accordo ASI/UniTN/INFN/MiB
Per LISA fase A/B1
(fino ~~giugno~~ luglio 2024)

In progress:
Rinnovo Accordo ASI/UniTN/INFN/MiB….
Per LISA fase B2

Accordo di programma

Tra

Agenzia Spaziale Italiana (ASI)

E

Istituto Nazionale di Fisica Nucleare (INFN)

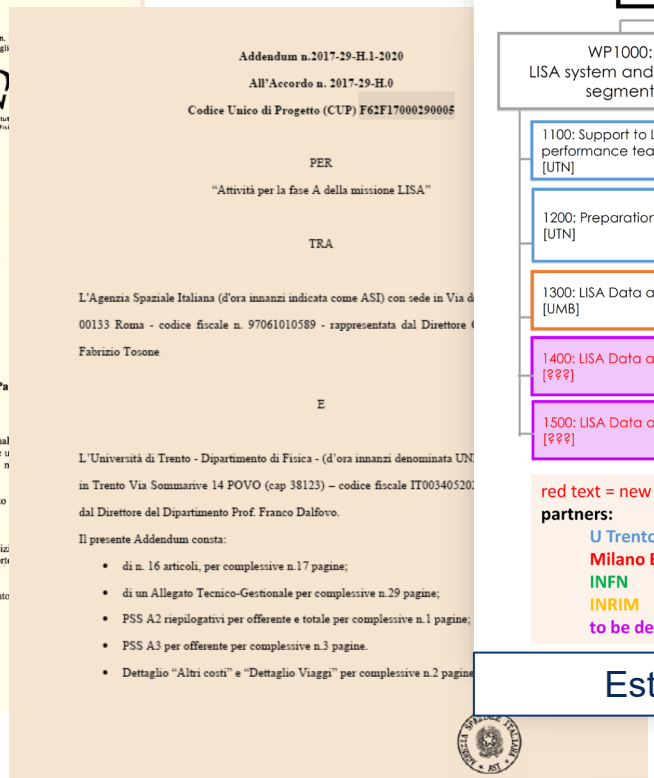
per la realizzazione del programma di ricerca scientifica LISA/LISA Pa

Vista la convenzione quadro fra l'Agenzia Spaziale Italiana e l'Istituto Nazional Nucleare del Giugno 1999 con la quale i due Enti (le Parti) si impegnano a mantenere u costante e continuativo per lo sviluppo di programmi di ricerca scientifica n dell'Osservazione dell'Universo di interesse congiunto;

Visto l'articolo 2 della suddetta convenzione che prevede, per lo svolgimento programma di ricerca comune, specifici Accordi di Programma volti a definire:

- Le forme di collaborazione;
- Le risorse umane, strumentali e finanziarie messe reciprocamente a disposizi svolgimento del programma, ivi compresa l'indicazione esplicita del rapport sussistente fra ogni addetto alla ricerca e al suo supporto e le Parti.

L'Agenzia Spaziale Italiana e l'Istituto Nazionale di Fisica Nucleare convengono quanto la realizzazione del programma di ricerca scientifica LISA Pathfinder.



Addendum n.2017-29-H.1-2020

All'Accordo n. 2017-29-H.0

Codice Unico di Progetto (CUP) F62F17000290005

PER

"Attività per la fase A della missione LISA"

TRA

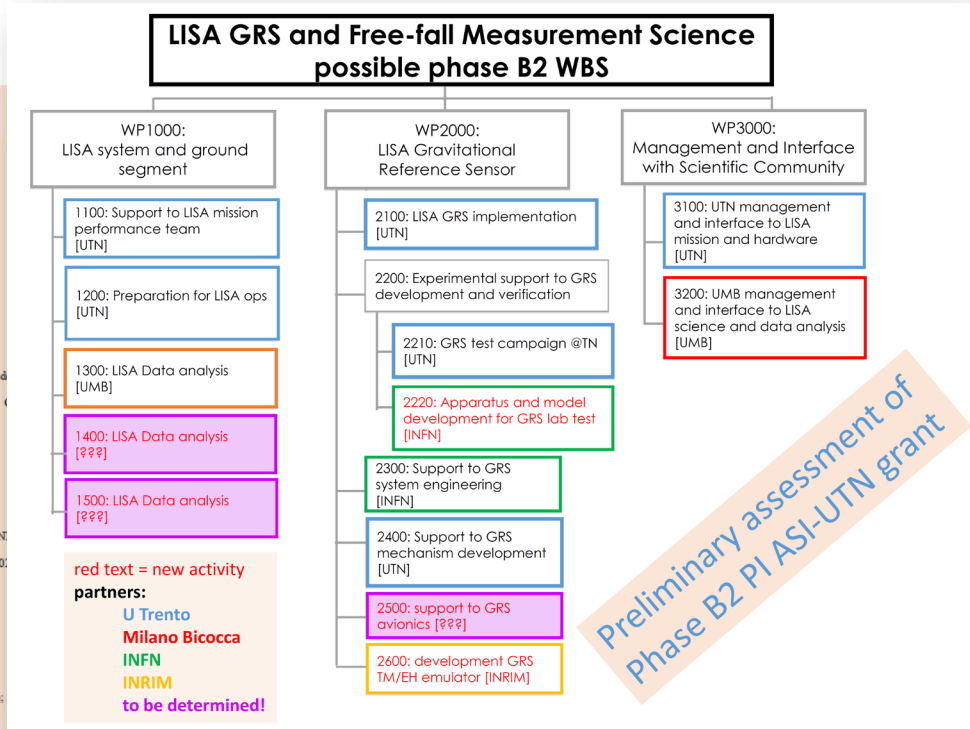
L'Agenzia Spaziale Italiana (d'ora innanzi indicata come ASI) con sede in Via d 00133 Roma - codice fiscale n. 97061010589 - rappresentata dal Direttore Fabrizio Tosone

E

L'Università di Trento - Dipartimento di Fisica - (d'ora innanzi denominata UN in Trento Via Sommarive 14 POVO (cap 38123) – codice fiscale IT003405202 dal Direttore del Dipartimento Prof. Franco Dalfovo.

Il presente Addendum consta:

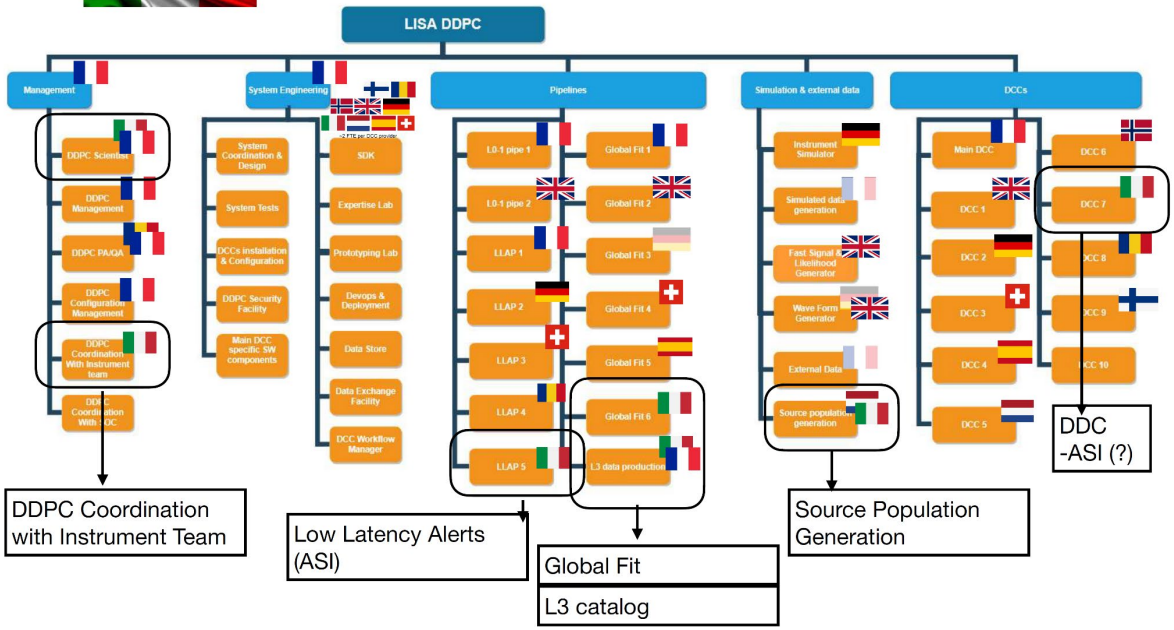
- di n. 16 articoli, per complessive n.17 pagine;
- di un Allegato Tecnico-Gestionale per complessive n.29 pagine;
- PSS A2 riepilogativi per offerente e totale per complessive n.1 pagine;
- PSS A3 per offerente per complessive n.3 pagine.
- Dettaglio "Altri costi" e "Dettaglio Viaggi" per complessive n.2 pagine



Estensione del coinvolgimento INFN in LISA

Tavolo negoziale 8 luglio 2024

LISA Distributed Data Processing Centre DDPC



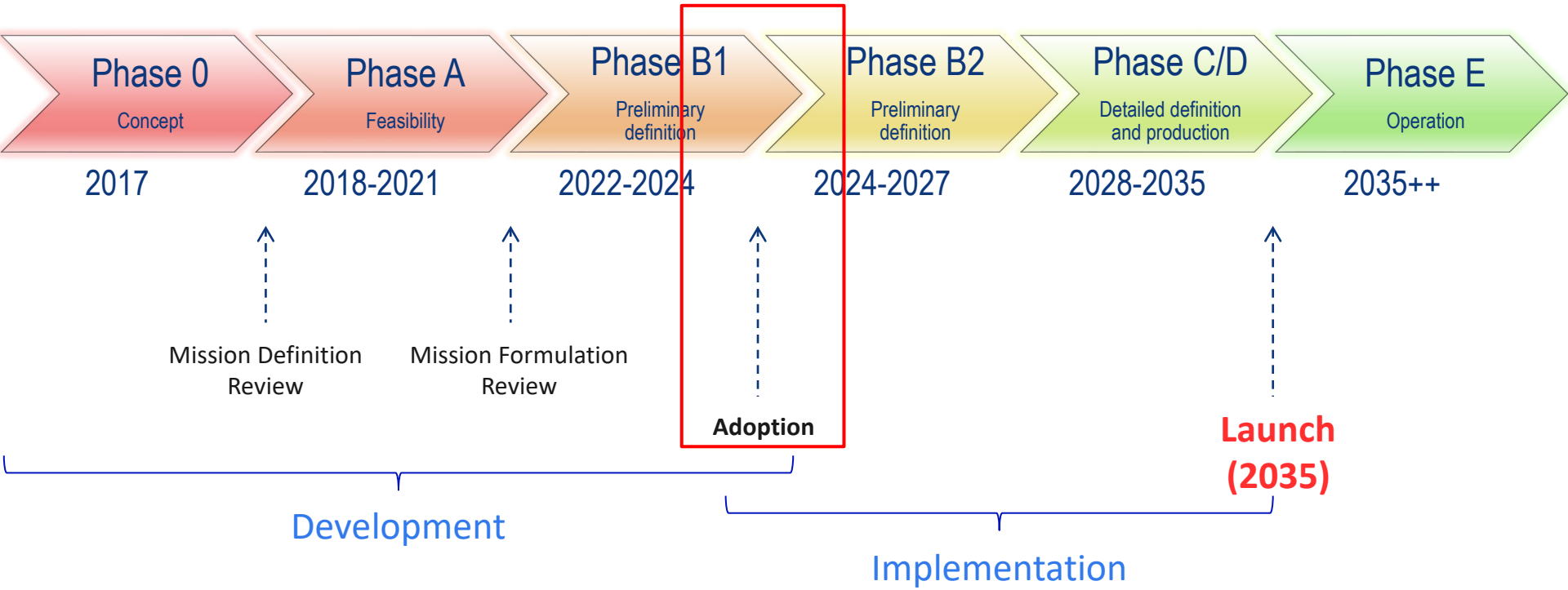
Nel MLA, ASI supporta il DDPC con attività specifiche → necessità di stabilire un piano e delle risorse e come saranno distribuite tra ASI, università e istituti (INFN, INAF…).
Gruppi teorici italiani sono già coinvolti, e.g. Milano Bicocca nell'accordo ASI e PI di un PRIN.

Kick off meeting del DDPC in giugno 2024

MUR PRIN LISA Phase A 2017 W88A22

https://sites.google.com/unimib.it/lisa-phase-a/home

LISA is an adopted mission

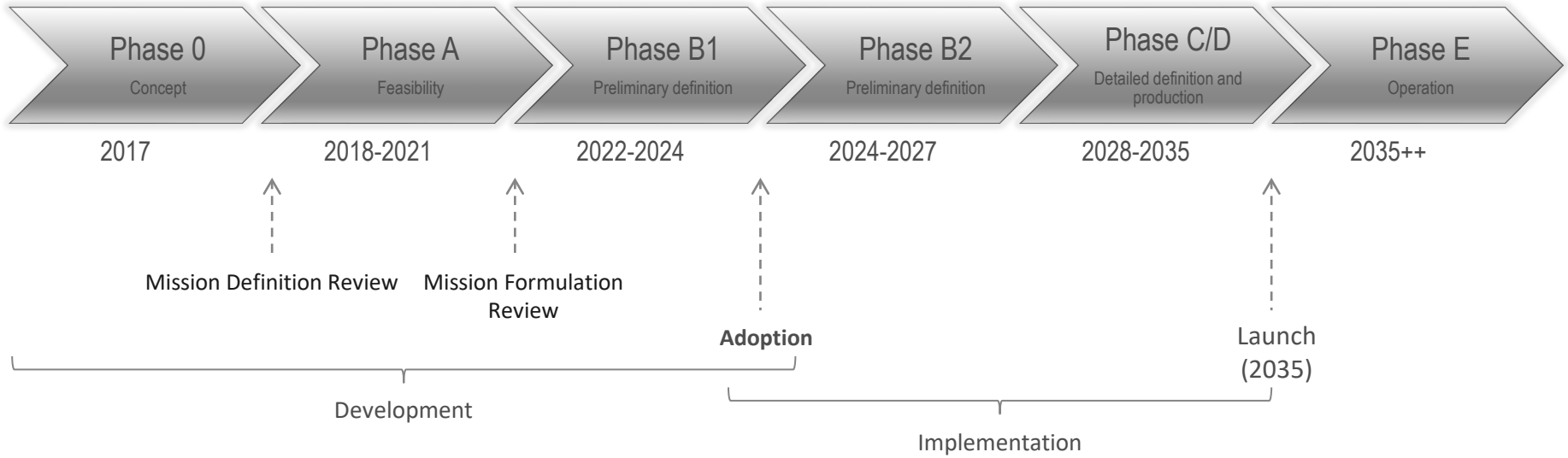


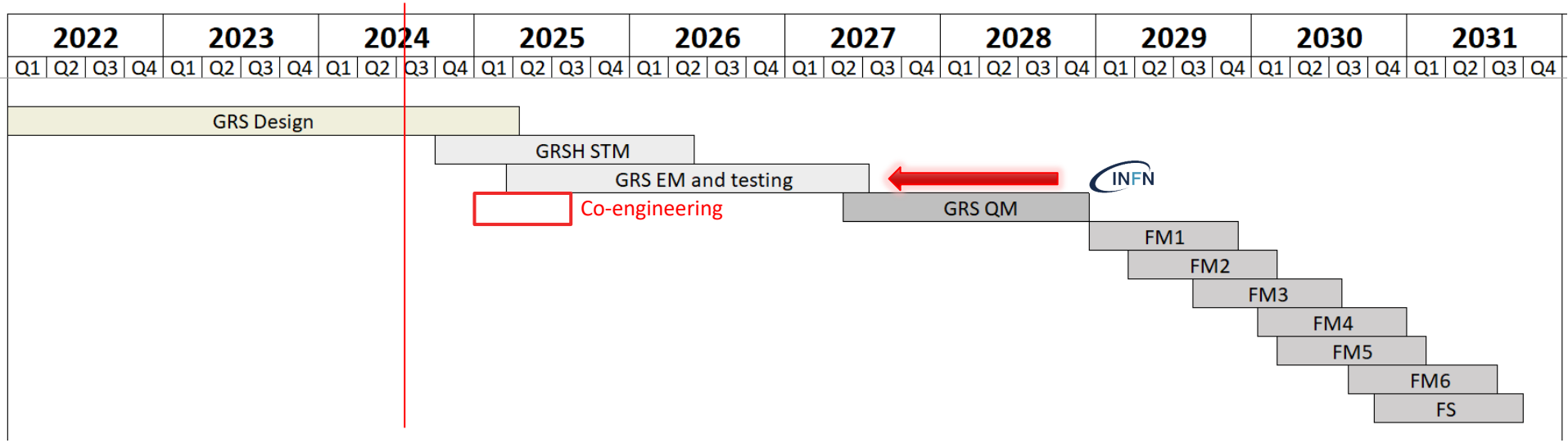
Next year is dedicated to:

- Finalization and release of technical specifications (systems engineering)

  → ITT for prime selection (ESA)
- Co-engineering with selected prime and ESA

GRS Schedule





GRS EM Test Plan @ UniTN/TIFPA

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

LISA-UTN-INST-TP-001
Issue/Rev. 1.0

	Name	Date	Signature
Prepared by	Rita Dolesi	10/05/2023	
Checked by	William J. Weber Rita Dolesi	10/05/2023 10/15/2023	
Approved by	William J. Weber	12/05/2023	

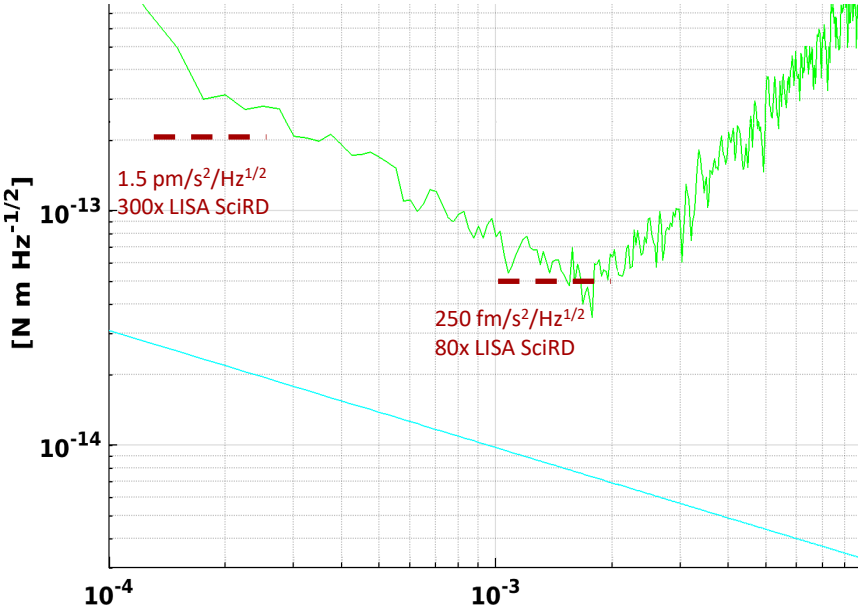
Summary

- Preliminary description of the individual test campaigns
- List of requirements whose compliance is demonstrated or supported by these tests
- Description of facilities
- Test configuration

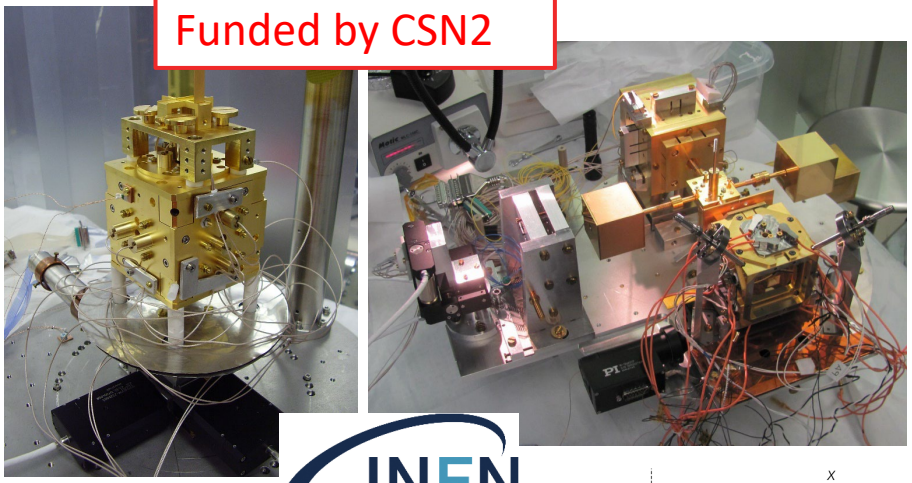
Torsion pendula

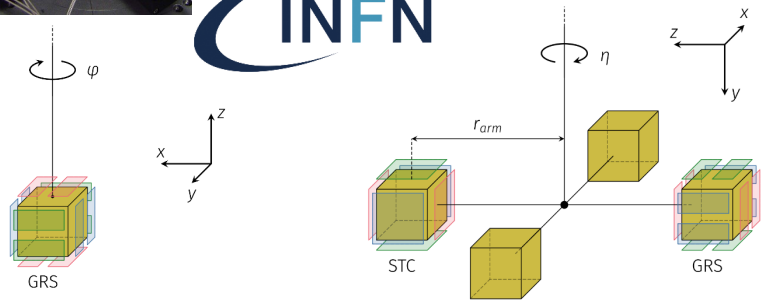
Torsion pendula can measure small forces and are the **only tools** to test the LISA **free-fall** on ground:

1. *1TM torsion pendulum*: more sensitive, but to torques only
2. *4TM torsion pendulum*: directly sensitive to forces as TM is mounted off-center (~10 cm arm)



Funded by CSN2

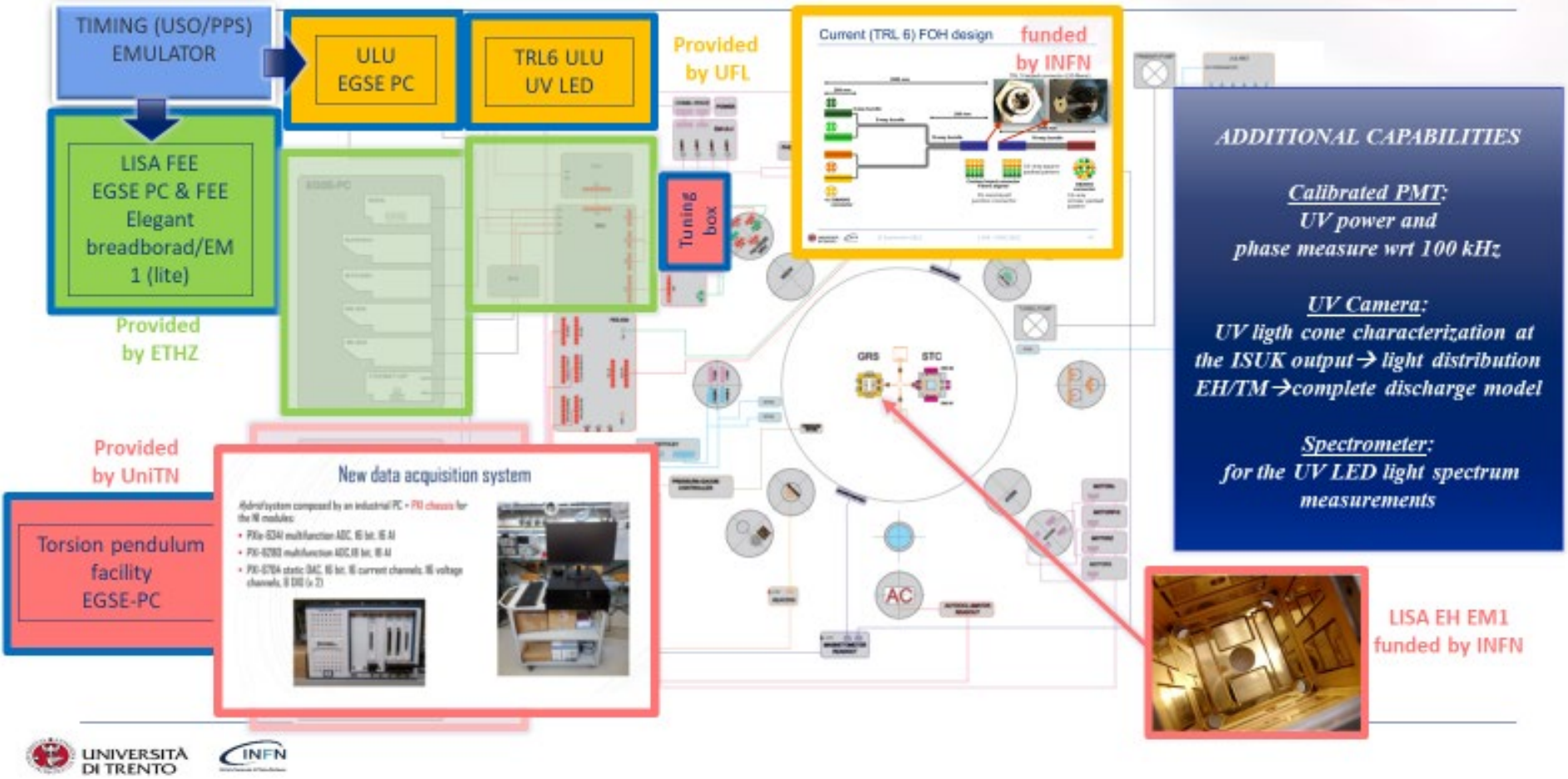




	Force @ 2 mHz
1 TM	7×10^{-16} N in 1 hour
4 TM	10^{-15} N in 1 hour

Torsion pendula

LISA 4TM pendulum facility schematic overview



Torsion pendula

Nano-Newton electrostatic force actuators for femto-Newton-sensitive measurements: System performance test in the LISA Pathfinder mission

M Armano, H Audley, J Baird, M Bassan, P Binetruy, M Born, D Bortoluzzi, ...

Physical Review D 109 (10), 102009

In-depth analysis of LISA Pathfinder performance results: time evolution, noise projection, physical models, and implications for LISA

M Armano, H Audley, J Baird, P Binetruy, M Born, D Bortoluzzi, E Castelli, ...

arXiv preprint arXiv:2405.05207

E2E Discharge Tests

Measure directly the charge on a TM, with a variety of discharge strategies.

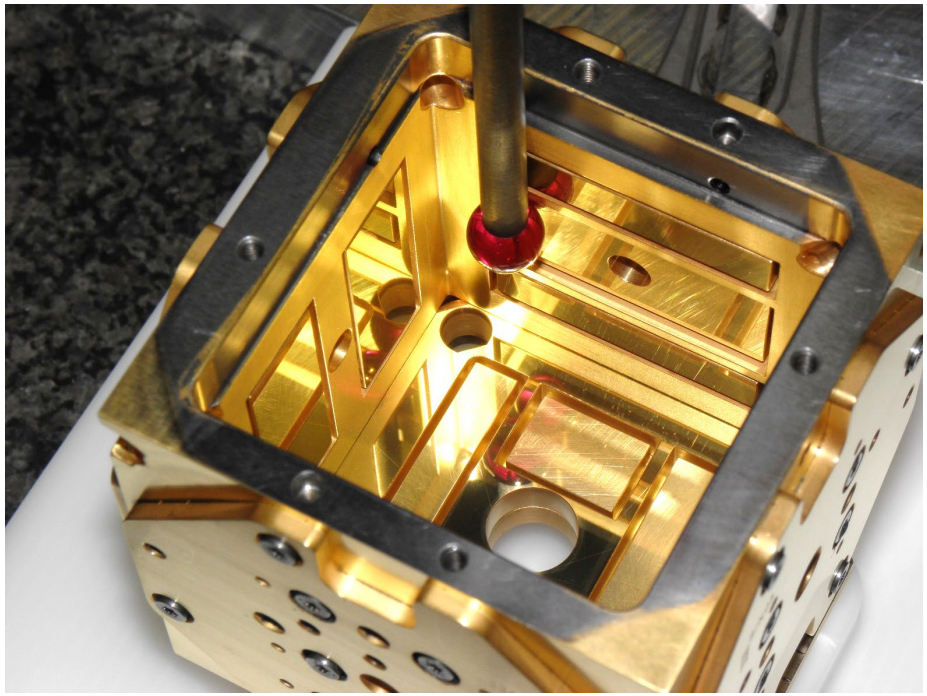
Tests started in late 2023.

Similar (or same) apparatus to be used at **proton-therapy** for a representative charging experiment.

Procurement Engineering Model Electrode Housing

Istituto Nazionale di Fisica Nucleare
AMMINISTRAZIONE CENTRALE
Direzione Amministrazione, Finanza e Controllo
Servizio Gare e Contratti
Ufficio Bandi e Contratti

Funded by CSN2



p. c.: ***Prof. Francesco PEDERIVA***
Direttore del TIFPA dell'INFN

Dr. Carlo ZANONI
Responsabile Unico del progetto

OGGETTO: ***Lettera di trasmissione del Contratto per la fornitura di modello EM (engineering model) dell'Electrode House per la missione spaziale LISA _ CIG n. 9892677F4D.***

Procurement Engineering Model Electrode Housing

- Kick-off: 04 March 2024

  58k EUR of pre-payment

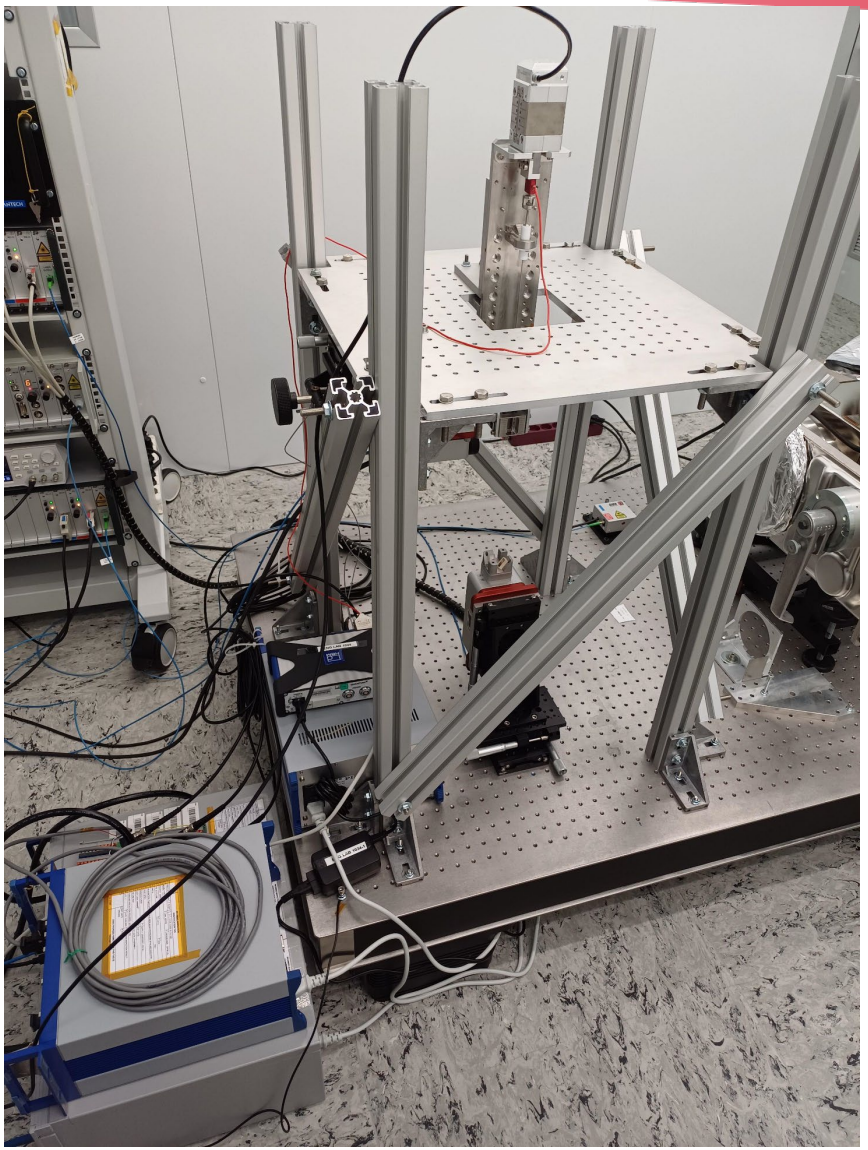
- 1st milestone: 08 May 2024

  58k EUR transfer

INFN	**MINUTA** *MINUTE*	**Programma-Contratto** / *Program-Contract*: Fascicolo n. 2024_XI/2.2.640 "fornitura di modello EM (engineering model) dell'Electrode Housing per la missione spaziale LISA" CIG n. 9892677F4D RUP: Carlo Zanoni
		Oggetto della riunione / *Meeting subject:* Milestone 1
Num. Documento / *Document #* :		**Pagina**/*Page* **1** **di**/*of* **4**

Luogo di riunione *Meeting Place*	Teleconferenza	**Data** *Date*	08/05/2024
Scritto da *Written by*	Carlo Zanoni		

GPRM testing



Funded by CSN2

- Tests concluded in March 2024
- Basis for the definition of the new GPRM baseline (Apr-24)
- Interesting R&D outputs on friction between titanium and Teflon
- Getting ready for comprehensive GPRM EM tests towards the end of 2024

NEW:

- Caging Mechanism Modeling

Stato Impegni 2024/richieste 2025

- Missioni
  - esaurita quota LISA su Dotazioni Gr 2, con luglio esauriti anche fondi LISA (chiederemo anche sblocco di 1K€ SJ)

- Acquisti:
  - 64 k€ +35 k€ SJ da spendere
  - Principalmente destinati a costruzione di masse di test rappresentative di quelle di volo per i pendoli di torsione; per contenere i costi siamo in attesa di definizione/accordi tra OHB e fornitori delle TM di volo.
  - Stiamo eleborando piano B alternativo di spesa da proporre se necessario alla CSN2 di settembre.

Richieste 2025 (preliminare)

- Richieste di missione per partecipazione a incontri CSN2/referee, congressi e workshop internazionali: 25k EUR

- Attività di laboratorio: aggiornamento delle facility con pendolo di torsione per aumentarne le performance e la rappresentatività: 30-60k EUR

- Richieste di strumenti software (già in uso con licenze INFN): ANSYS, MatLab, COMSOL, Solidworks

Personale

- 16 ricercatori/tecnologi, circa 13.5 FTE

Cognome	Nome
Bortoluzzi	Daniele
Cavalleri	Antonella
Ciani	Giacomo
Chiavegato	Vittorio
Dal Bosco	Davide
Dalla Ricca	Edoardo
Dimiccoli	Francesco
Dolesi	Rita
Ferroni	Valerio
Marzari	Francesco
Mezzena	Renato
Sala	Lorenzo
Vetrugno	Daniel
Venturelli	Francesco
Weber	William
Zanoni	Carlo

Support to ground-based GW

Charges for the external Virgo technical review

Stan Bentvelsen, Massimo Carpinelli, Gianluca Gemme,

Marco Pallavicini, Vincent Poireau, Alessio Rocchi

May 2024

PEOPLE

- Committee
  - Lisa Barsotti
  - GariLynn Billingsley
  - Peter Fritschel
  - Paul Fulda
  - Hartmut Grote
  - Brian Lantz
  - Joseph Martino
  - Peter Wolf
  - Carlo Zanoni

Role of the external committee

The role of the external committee is to perform a review on the technical choices proposed by the collaboration, including the strategy to address, identify, and solve known unknowns such as the mystery noise. This review committee should be a **permanent committee**, meeting typically twice a year, and ensuring a close monitoring of the technical choices made by the collaboration along the entire duration of the project (including the organizational and managerial aspects related to the technological proposal).