Spanish contribution to LISA

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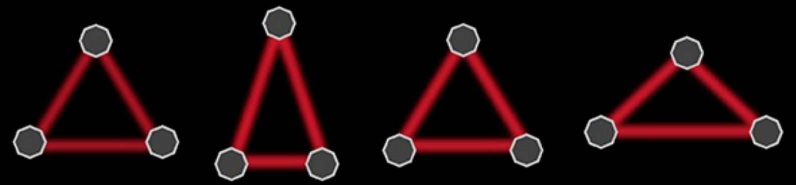
Ministerio de Ciencia, Innovación y Universidades
Financiado por la Unión Europea NextGenerationEU
Plan de Recuperación, Transformación y Resiliencia
Agencia Estatal de Investigación

LISA

LISA - LASER INTERFEROMETER SPACE ANTENNA

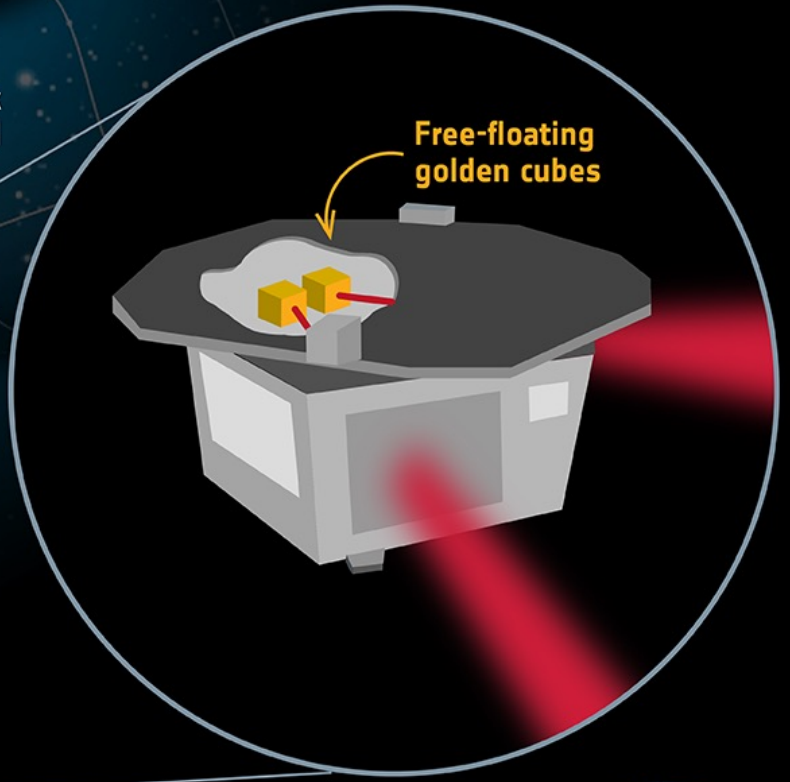
Gravitational waves are ripples in spacetime that alter the distances between objects. LISA will detect them by measuring subtle changes in the distances between **free-floating cubes** nestled within its three spacecraft.

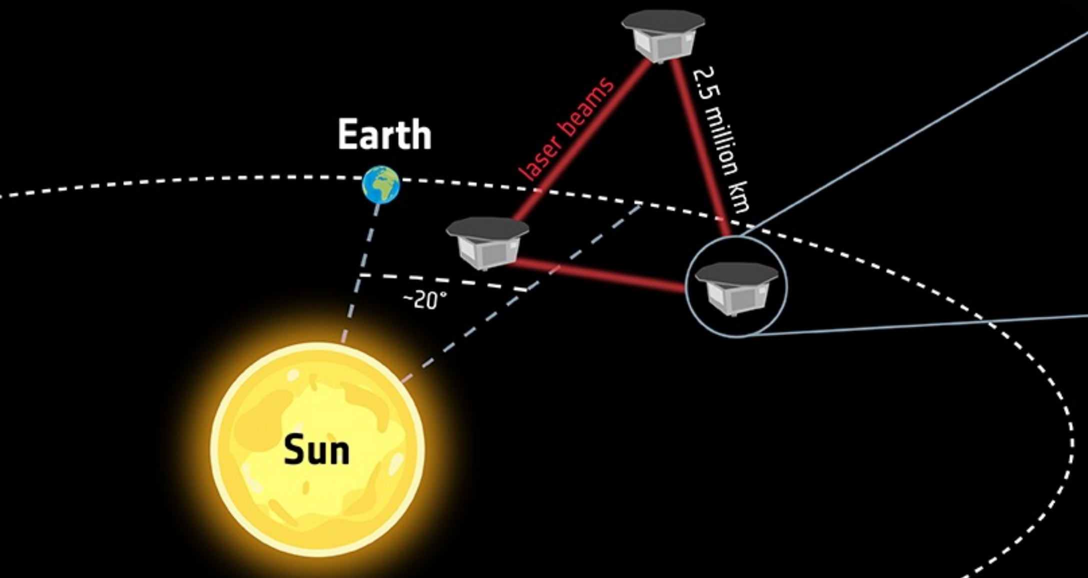
3 identical spacecraft exchange **laser beams**. Gravitational waves change the distance between the **free-floating cubes** in the different spacecraft. This tiny change will be measured by the laser beams.



* *Changes in distances travelled by the laser beams are not to scale and extremely exaggerated*

Powerful events such as **colliding black holes** shake the fabric of spacetime and cause gravitational waves





LISA

Scientific Payload

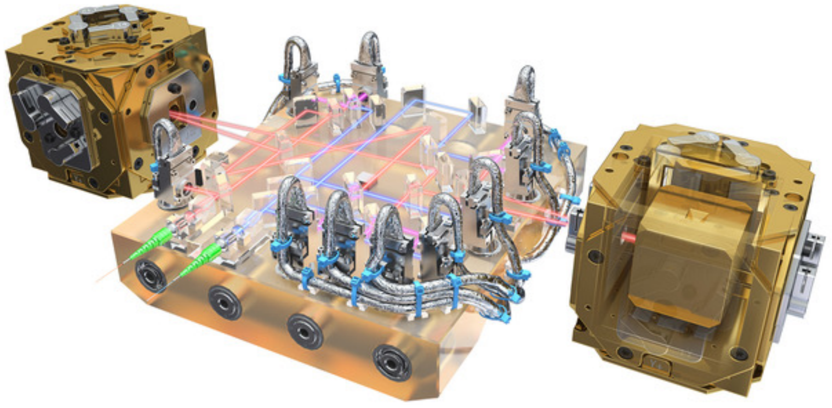
AEI (DE), UTN (IT), CNES (FR), **IEEC (ES)**

Mission Specific Hardware needed to meet the Scientific Objectives.

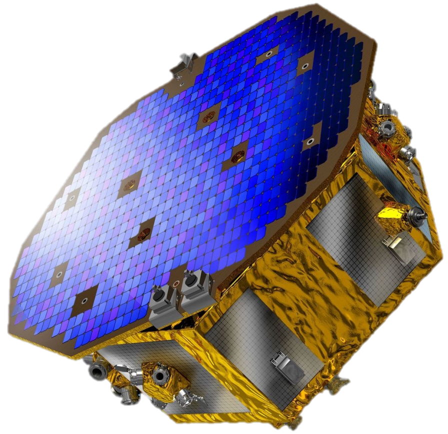
Platform/ Spacecraft

Prime

All the other elements needed to support the mission as the platform, solar panels, OBC, etc.



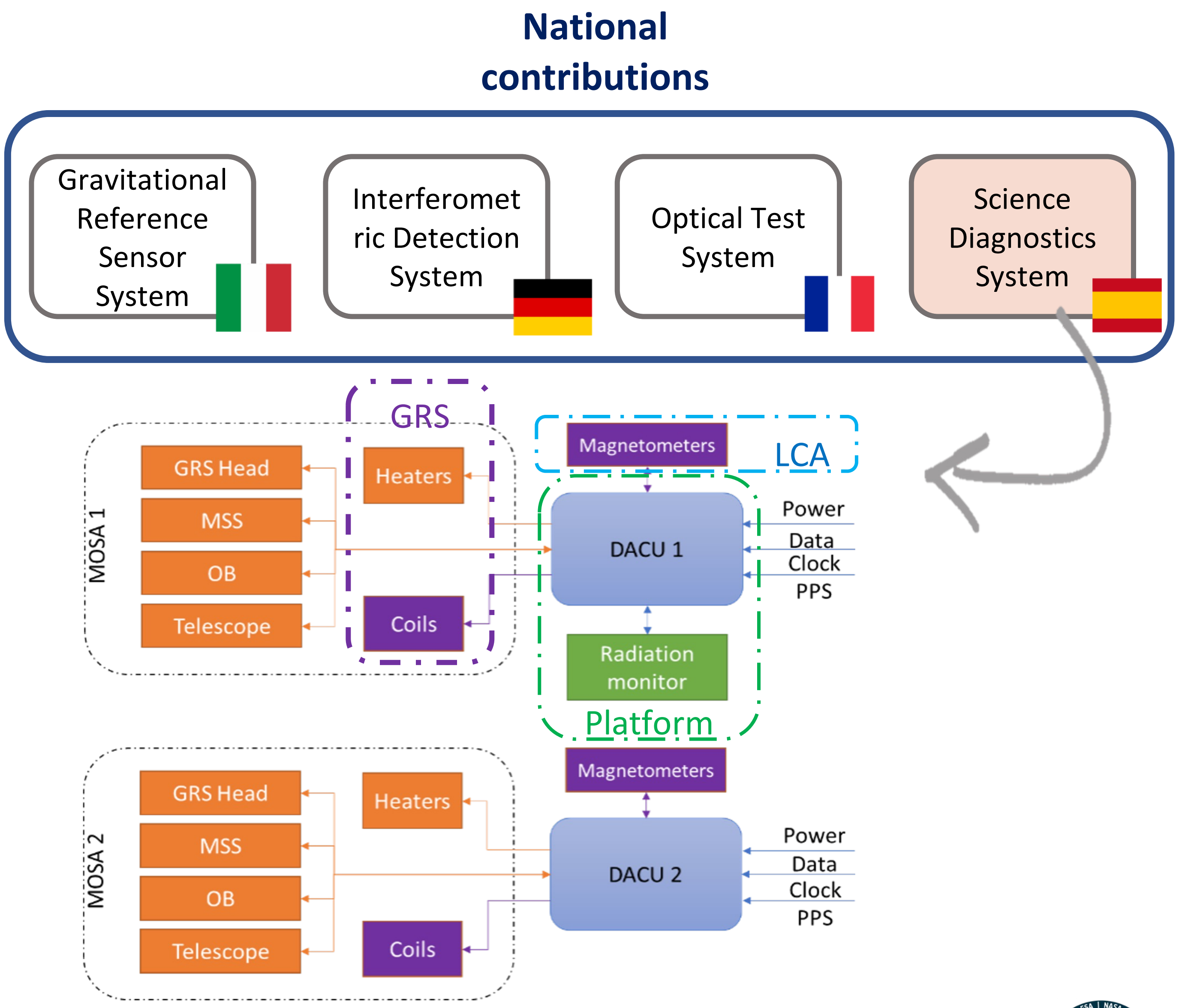
Payload Mounted Within the Platform



Images from LISA Pathfinder.

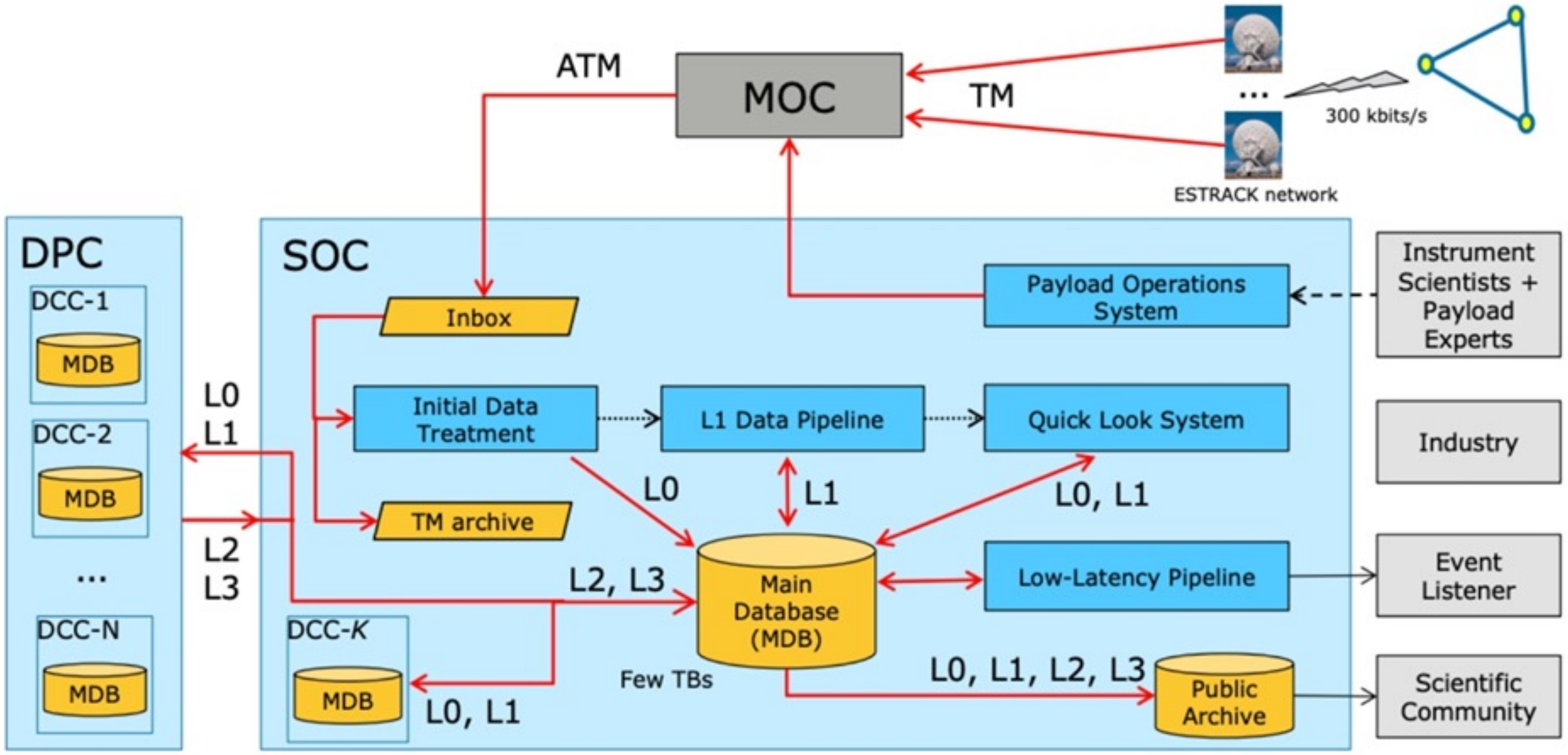
SDS Overview

1. Characterize and monitor:
   a. MOSA thermal environment [DDS.FUN.00040]
   b. TM magnetic environment in low frequency and audio frequency [DDS.FUN.00060, DDS.FUN.00070]
   c. TM radiation environment [DDS.FUN.00100]
2. Generate science data information during science mode (time series for the temperatures and magnetometers and histograms for coils and RM) [DDS.FUN.00140]

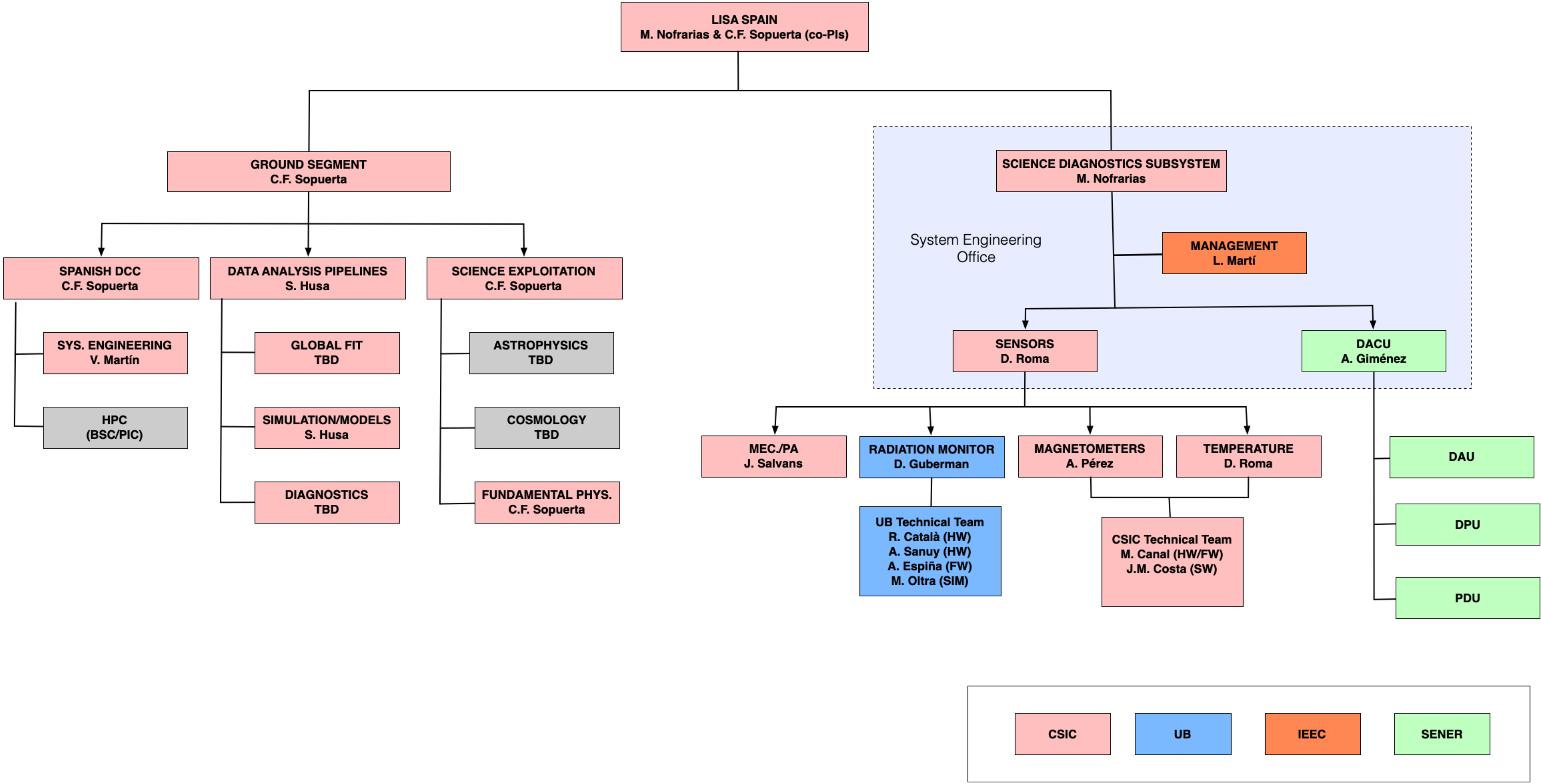


Ground Segment

- Each member state that participates in the mission is expected to develop a DCC where the scientific process to produce L2 data from L1 data will take place.
- It is also expected that each DCC will participate in the system engineering of the design and implementation of the LDPG (under French responsibility).
- LISA Data Challenges (LDC) working group where training exercises with synthetic LISA data is developing the algorithms that will become part of the LISA data analysis pipelines.

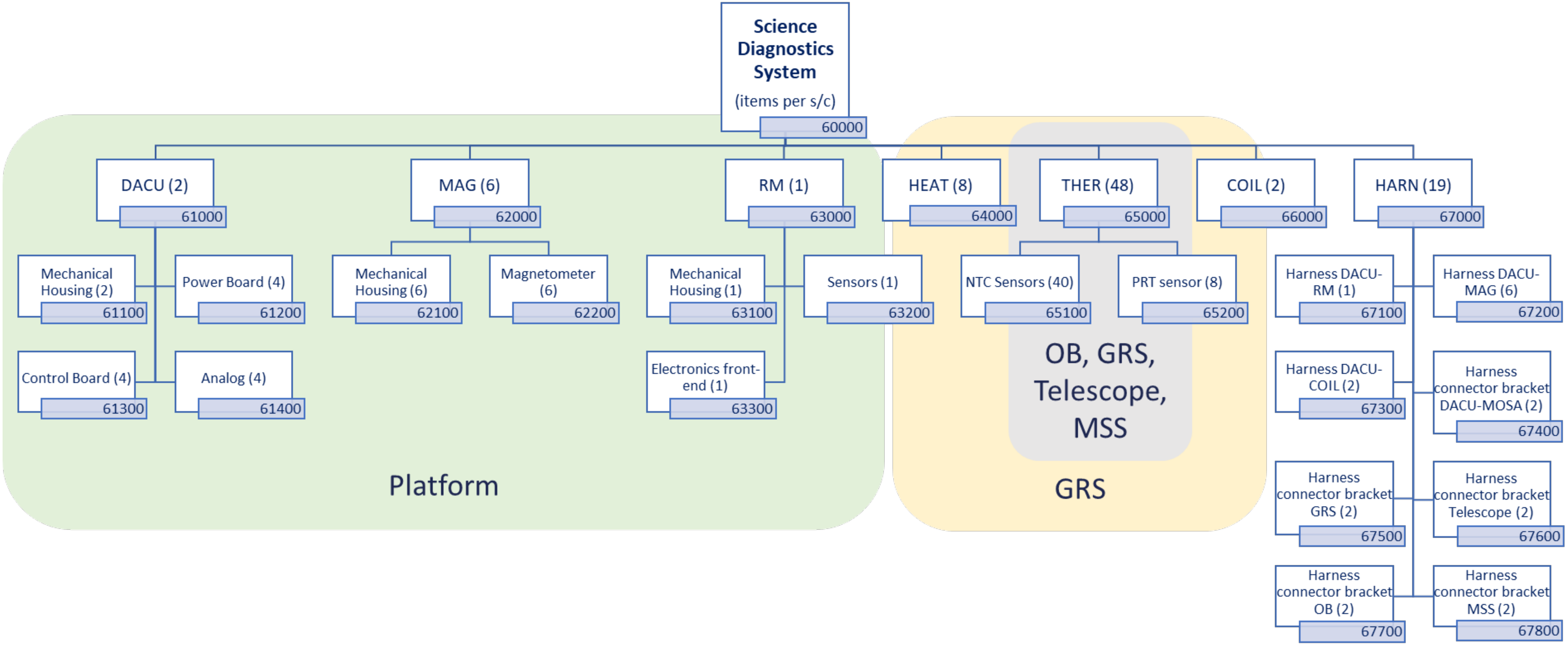


Organization

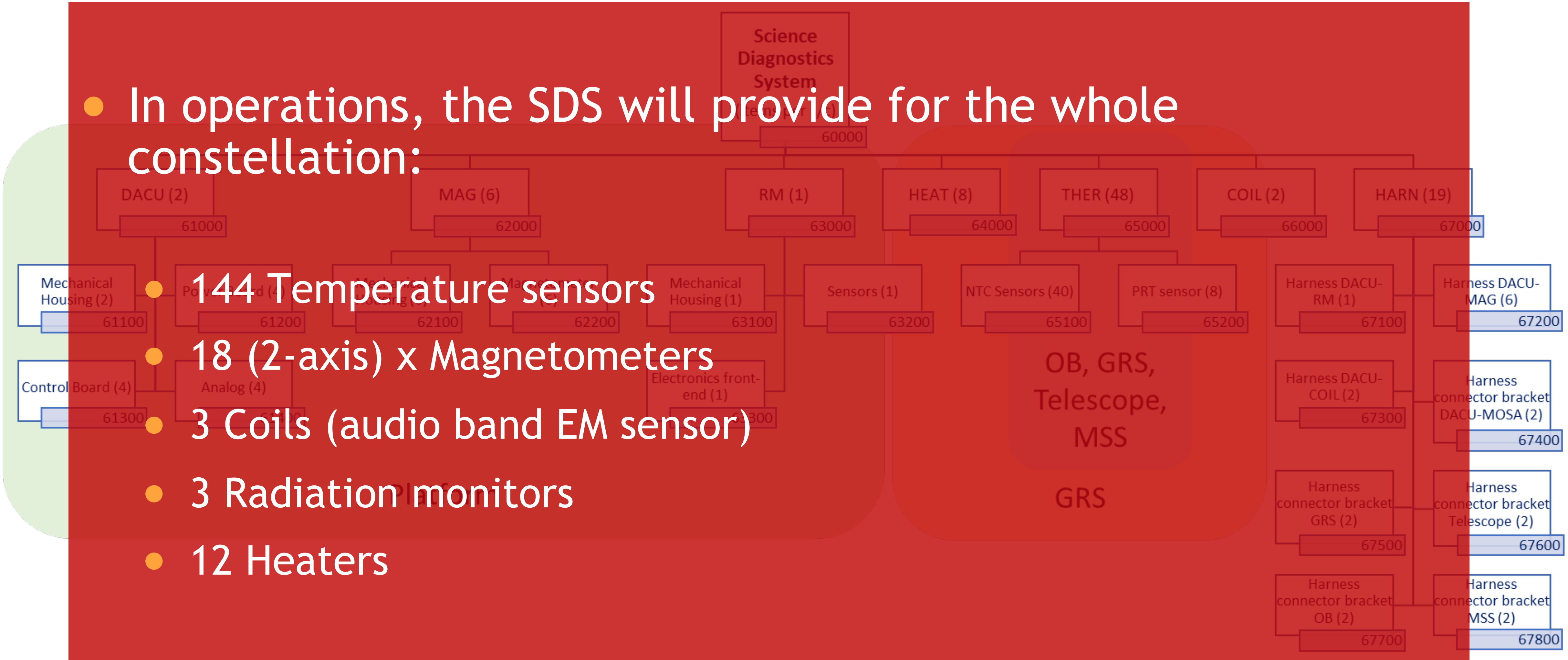


First LISA Spain meeting held Oct. 2023.
Forthcoming planned for **Oct. 2024.**
Please join if interested in contributing to LISA

Product Tree



Product Tree



- In operations, the SDS will provide for the whole constellation:
  - 144 Temperature sensors
  - 18 (2-axis) x Magnetometers
  - 3 Coils (audio band EM sensor)
  - 3 Radiation monitors
  - 12 Heaters

ESA Timeline

To be ready for the **Co-Engineering** Phase with the Prime
the following milestones are being set:

Q1 2024	Q2 2024	Q3 2024	Q4 2024	Q1 2025	Q2 2025
Mission Adoption *IRD Definition* *DIL Definition* *ITT Released*	*LISA Payload Meeting #2*	*CPPA Kick-Off* *Prime Selection* IRD V2 Definition DIL Approval ***IDS PDR***	IRD V2 Definition Negotiation with Prime *LISA Payload Meeting #3 (TBC)* ***GRS PDR***	*Co-Engineering Phase*	*Co-Engineering Phase* ***SDS PDR***

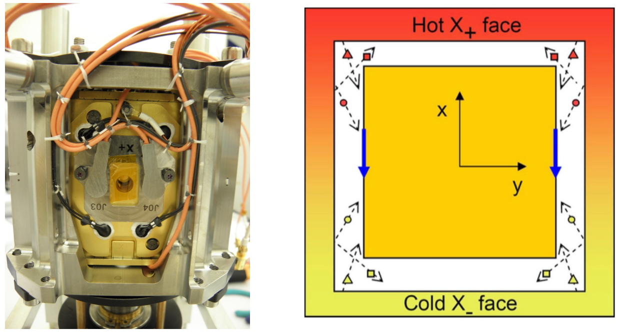
PDR pf the SDS will be in June 2025, and all systems must meet the design requirements to successfully pass the review.

SDS Timeline

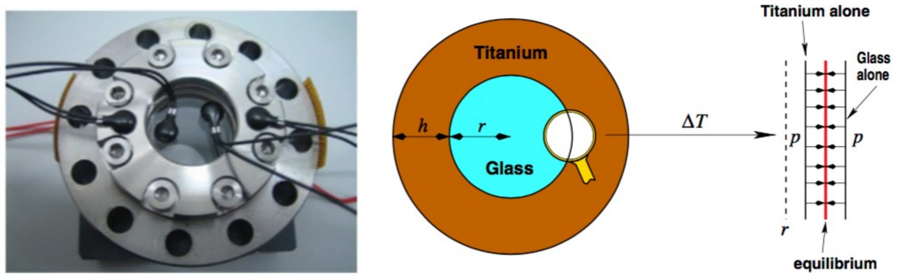
Q1 2024	Q2 2024	Q3 2024	Q4 2024	Q1 2025	Q2 2025
IRD Definition *DIL Definition* *ITT Released*	*LISA Payload Meeting #2*	*CPPA Kick-Off* *Prime Selection* IRD V2 Definition *DIL Approval* ***IDS PDR***	IRD V2 Definition Negotiation with Prime *LISA Payload Meeting #3 (TBC)* ***GRS PDR***	*Co-Engineering Phase*	*Co-Engineering Phase* ***SDS PDR***
IRD Definition *DIL Definition* *ITT Released*	*LISA Payload Meeting #2* **Schedule Update** **Model Philosophy** **Verification Strategy** **Procurement of EBBM Components**	*Updated DCLs* IRD V2 Definition In detail definition of Interfaces ***MTM EBBM Model*** ***RM EBBM Model***	Definition of Interfaces: - EICD, MICD, Mass Budgets, data budgets, etc. - Qualification of not qualified components.	*Co-Engineering Phase* Integration Procedures Documentation for PDR **EM/QM Thermal Sensors 1st delivery**	*DACU PDR* *SDS PDR* **DACU EBBM Testing**

Temperature sensors — motivation

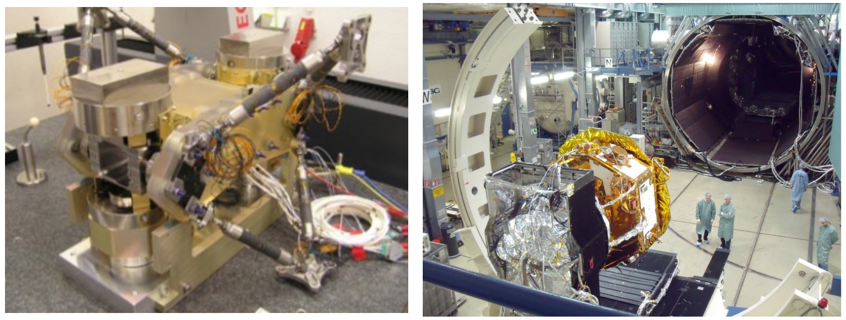
- Temperature gradients across the test mass induce **forces in the test mass**
  - Effects: radiation pressure, radiometer, outgassing
  - Dominant contribution (gradient) tends to ~20 pm/s^2/K (LPF)
- Temperature variations in **optical elements** can lead to pathlength (eg. **optical window**, the only non-bonded optical element)
  - Thermal gradients can induce stress on the glass or changes in the refr. index
  - Modeling and experiment on-ground characterised the **opto-thermo-elastic coupling** ~5nm/K
- The **MSS** (struts in LPF) holds the experiment inside the thermal shield. Hence, are natural **thermal links** to the MOSA.
  - Effects: Thermal gradients can induce mechanical stress in the structure.
  - Experiment on-ground (LPF) characterised the **thermo-elastic** contribution to ~1nm/K



L *Carbone et al. Phys. Rev. D 76 (2007)*



M Nofrarias et al. Class. Quantum Grav. 24 (2007)



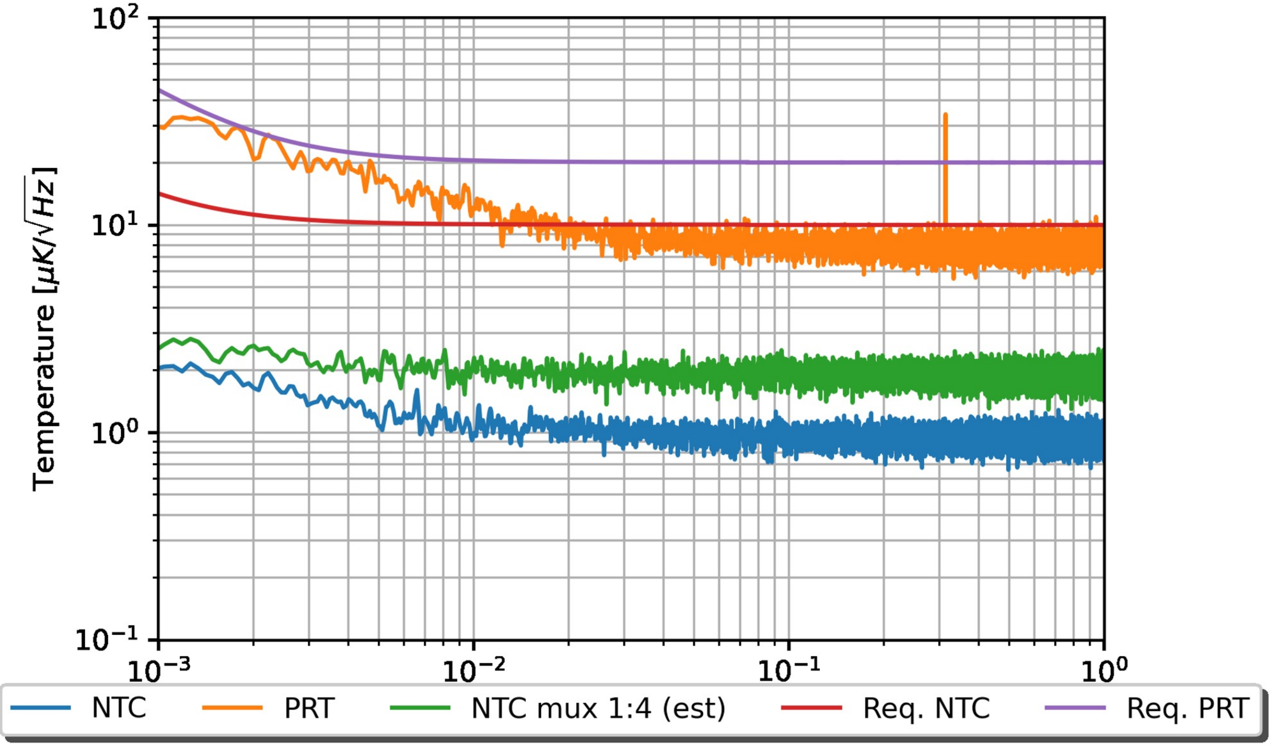
F Gibert et al. Class. Quantum Grav. 32 (2015)

Temperature sensors/Heaters

Usage of **NTCs on most locations** (most sensitive sensors) and **Platinum RTDs on magnetic sensitive locations** (GRSH-EH).

Heater equivalent to the LPF design:

- 2 two logical (4 physical) heaters for each GRSH-EH (i.e. each DACU), connected to two different DACU boards.
- Heaters are resistors with a nominal resistance of 100 Ω and without magnetic material, where each physical heater shall be able to dissipated up to 45 mW.



Roma-Dollase, D., Gualani, V., et al. & Nofrarias, M. (2023). Resistive-Based Micro-Kelvin Temperature Resolution for Ultra-Stable Space Experiments. Sensors, 23(1), 145.

Magnetometers — motivation

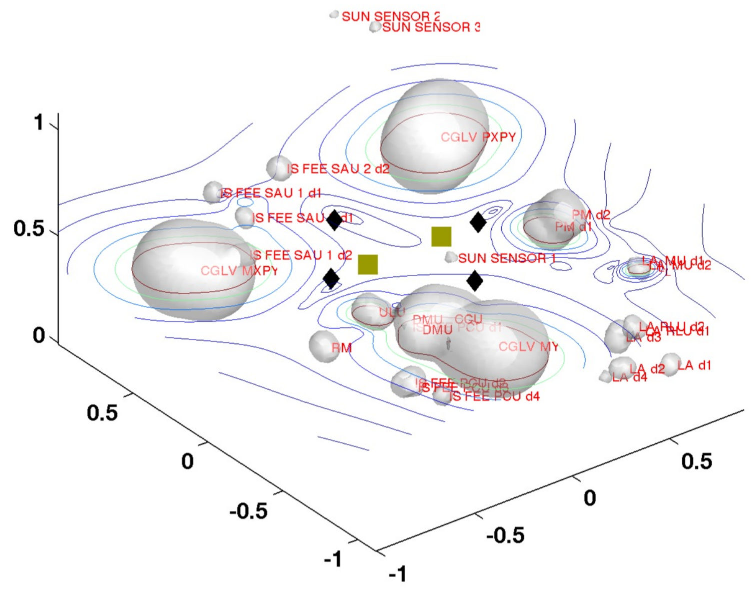
- The test mass acts as a magnetic dipole. Magnetic field and magnetic field gradients can induce **forces in the test mass**

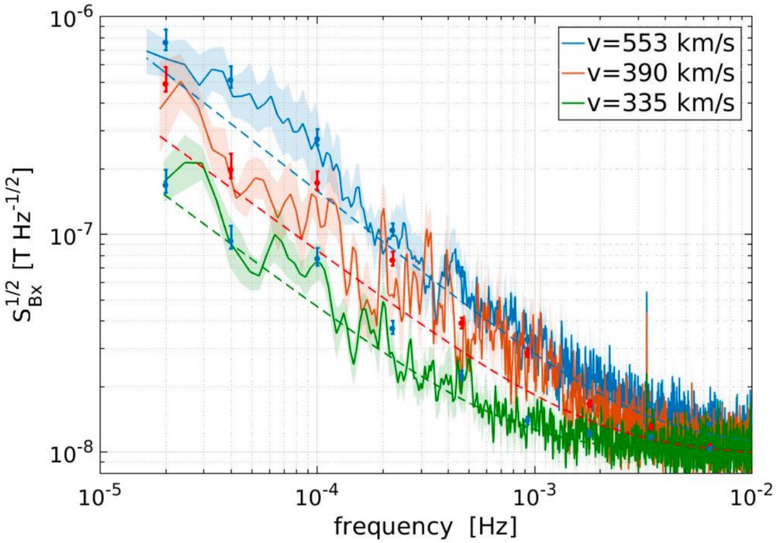
$$\mathbf{F} = \left\langle \left[\left(\mathbf{M} + \frac{\chi}{\mu_0} \mathbf{B} \right) \cdot \nabla \right] \mathbf{B} \right\rangle V$$

  - The dominant contribution couples **local gradients** with **interplanetary fluctuations**

$$\langle S_B \cdot \nabla B_{DC} \rangle$$

- Magnetometers on-board must monitor **two components:**
  - S_B**: low frequency fluctuations** are dominated by the interplanetary contribution
    - strong variability with solar wind! (LPF)
    - 150-750 nT/Hz$^{1/2}$ at 20 uHz
  - ∇B_{DC}: **magnetic field gradient** in the TM position is unknown
    - the TMs surrounded by sources, magnetometers are far away
    - our best estimate of $\nabla B_{DC,x}$ was during the coils experiments (derived parameter): **-3700 nT/m (other dof are unknown)**



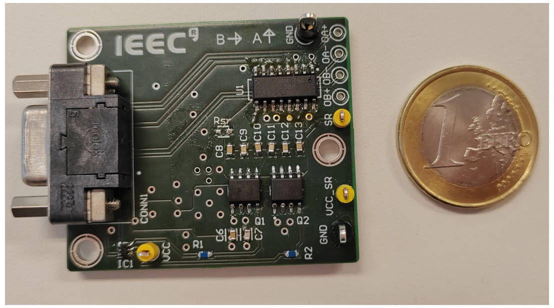


Armano et al. MNRAS 494 3014-3027 (2020)

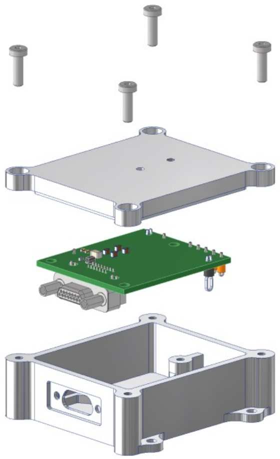
Magnetometers

Developed some AMR and we are working to upgrade all designs to flight quality and do representative EBBM for the PDR.

Commercial components that meet the performance and help us characterize the MTM.

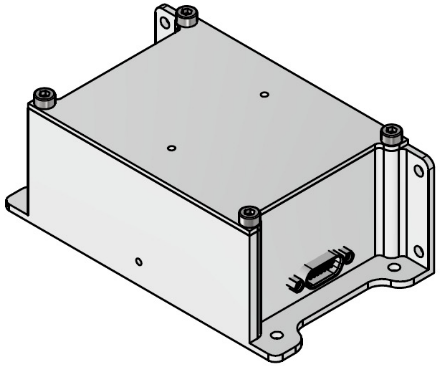


Commercial MTM



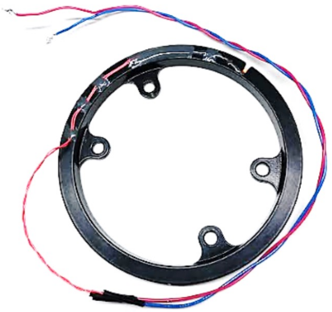
Flight MTM

Preliminary Design.



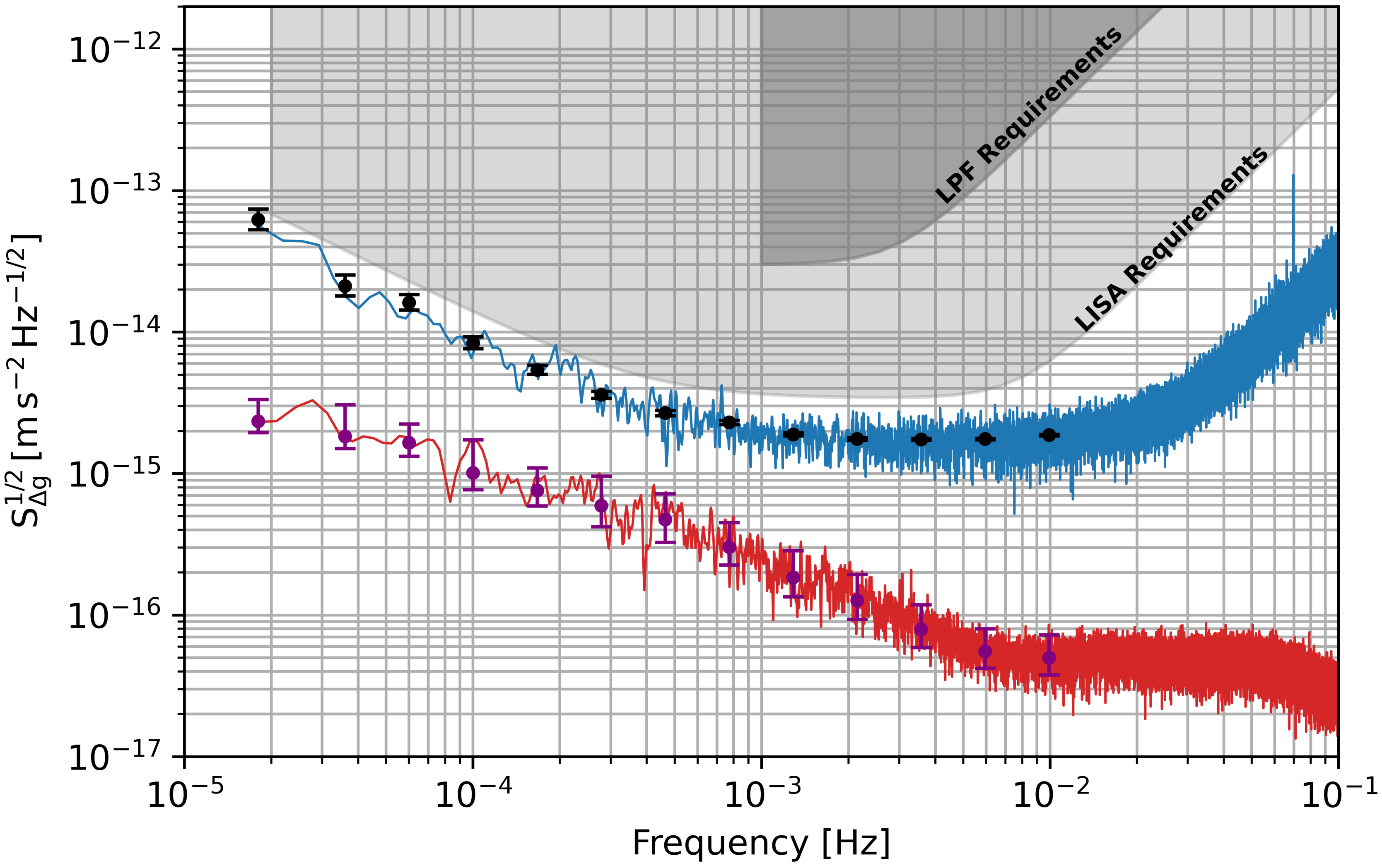
Flight components that withstand the radiation, thermal and mechanical environment of launch.

Flight Coil



The Coils are the same as form the LPF, need to find a supplier that will manufacture them and perform the transfer of the know-how.

Magnetometers



Continued analysis of magnetic contribution to force noise in LISA Pathfinder.

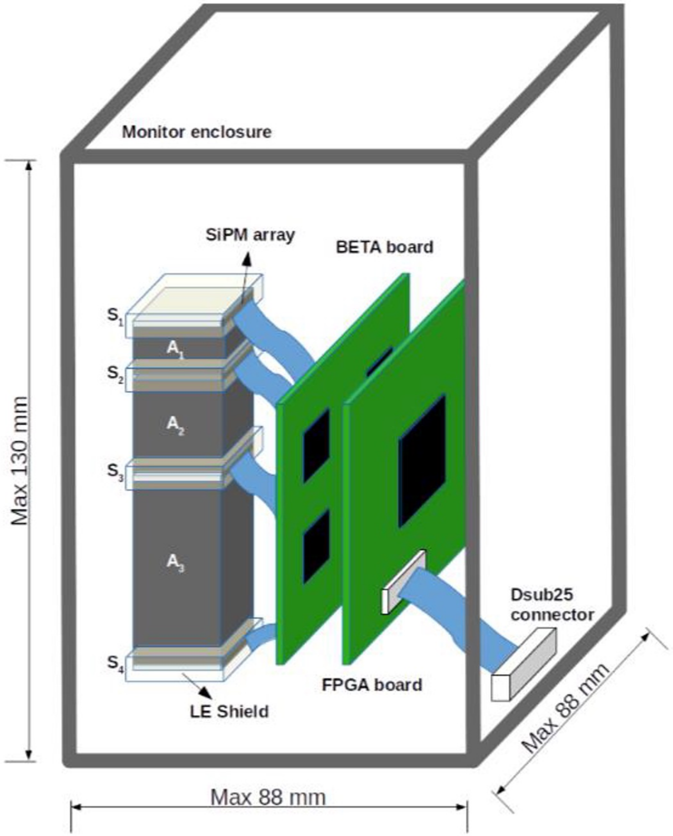
Armano et al. Submitted for publication

Radiation Monitor

Preliminary concept of radiation monitor, studies and discussion still open regarding the final structure.

- Current baseline is based on **four plastic scintillators and silicon photomultipliers** separated by three absorbers of different size
- The **BETA ASIC**, designed for the HERD mission, can **amplify, shape and digitize** up to 64 photodiodes output.
- An **FPGA** will interface with the BETA ASIC to provide coincidence event and/or individual trigger rates in form of histograms.

Low-energy (LE) shield prevents particles with energies below 70 MeV from reaching them, similar to the expected effect of the GRSH-EH.

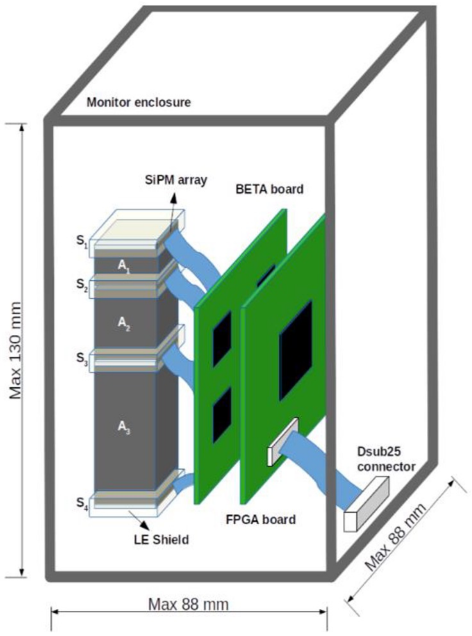


Radiation Monitor

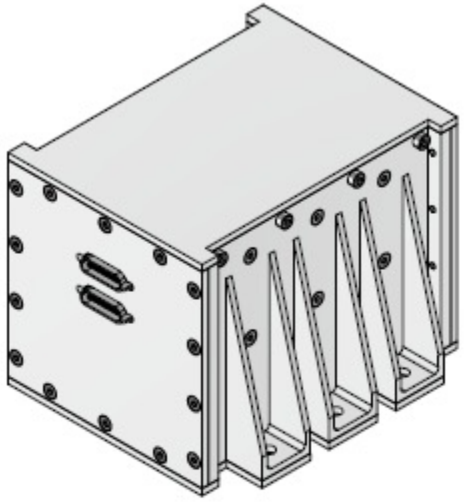
The Radiation monitor first EBBM needs to be upgraded to flight quality and do representative EBBM for the PDR.

Commercial components that meet the performance and help us characterize the MTM.

Concept RM



Flight RM

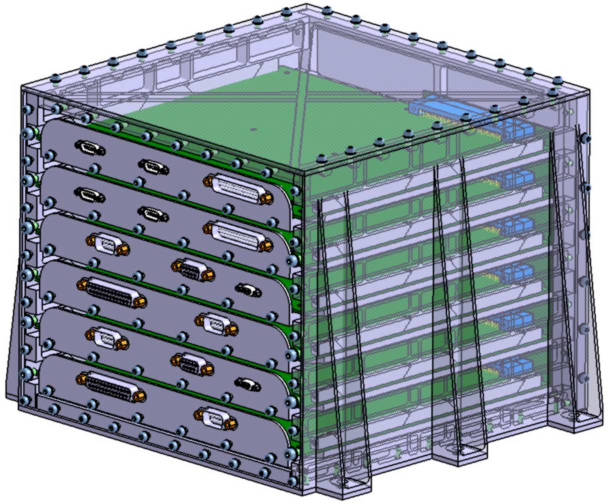
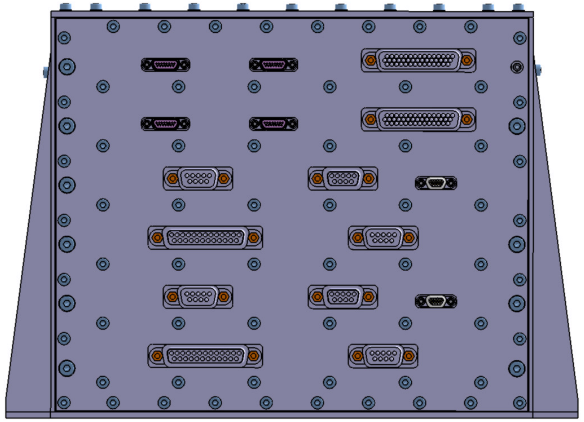
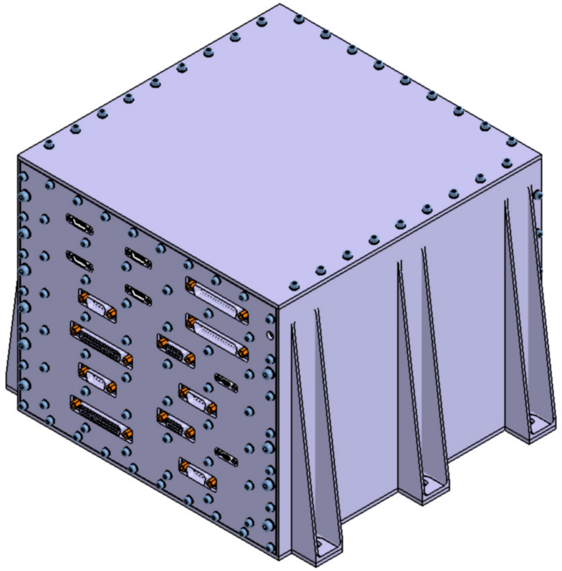
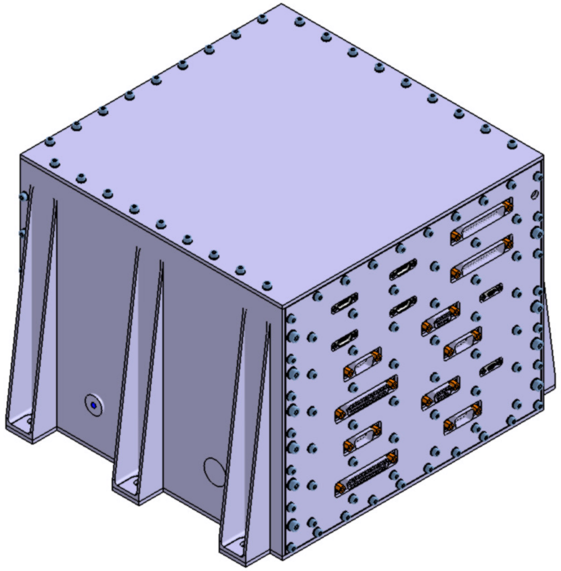


Preliminary Design.

Flight components that withstand the radiation, thermal and mechanical environment of launch.

DACU

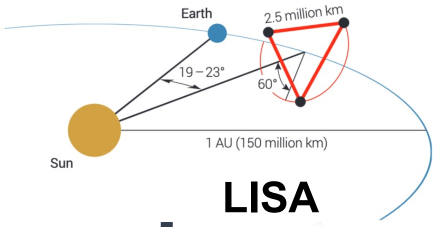
DACU Design will be consolidated and an EBBM of the DACU will be developed within the PRODEX contract 2024-25 (SENER Aerospacial/IEEC) in the framework of the SDS PRD.

Item	Total Mass (Kg)	Maturity Margin (%)	Maturity Margin (kg)	Mass with margin (kg)
DACU Structure (225 (h) x 280 (w) x 250 (l) mm) Thickness [3mm]	4,505	20	0,901	5,406
Screwing	0,296	20	0,0592	0,355
PCBs + Connectors + Internal Screwing	2,165	20	0,433	2,598
EEE Parts (w/o Connectors)	0,635	20	0,127	0,762
Total DACU Mass	7,601	-	-	9,121

ILIADA: In-Flight LISA Diagnostics Demonstrator

2034



LISA

2026

ILIADA

2015

LISA PATHFINDER

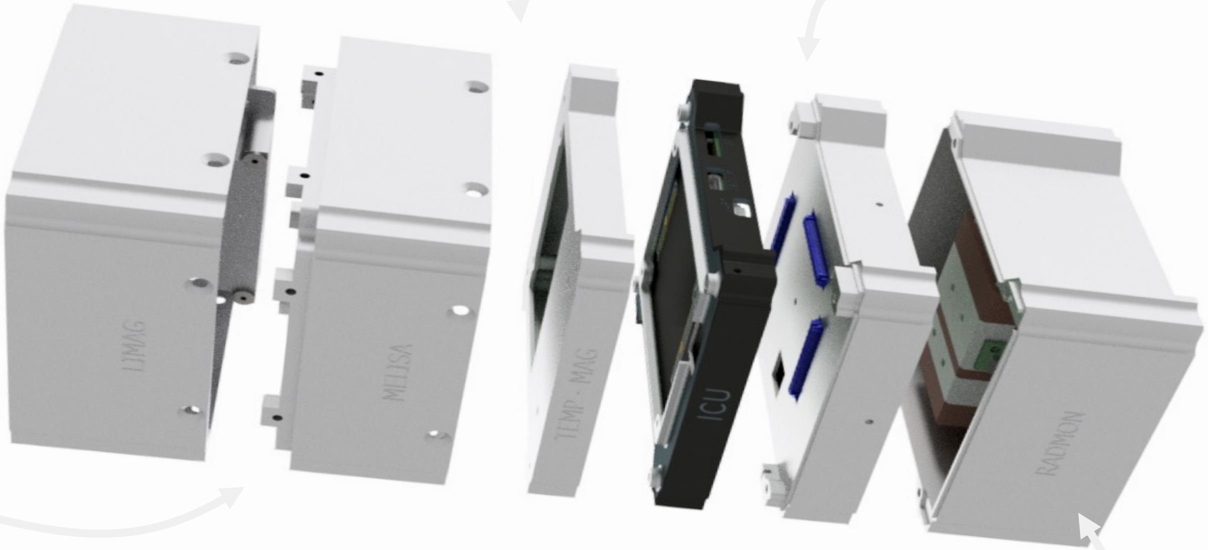
ILIADA is an in-orbit demonstrator (2U) for the LISA Science Diagnostics Subsystem (SDS), the Spanish contribution to the mission. In the framework of the Generalitat de Catalunya NewSpace Strategy.

LIMAG: magnetometer based on **Anisotropic Magnetoresistive sensors** (AMR). Reaching 50 nT/$\sqrt{Hz}$@ 0.1 mHz.

TEMP: NTC temperature sensors reaching . Reaching 1 uK/$\sqrt{Hz}$ @ 1 mHz.

ICU: IEEC heritage from GENEO mission. Based in the C3SatP computer.

MELISA: magnetometer based **on Tunnel Magnetoresistive sensors (TMR)** modulated by a **MEMS cantilever**. Reaching 20 nT/$\sqrt{Hz}$@ 0.1 mHz.



RADIATION MONITOR: four plastic scintillators and silicon photomultipliers. separated by three absorbers of different size. BETA ASIC amplifies, shapes and digitizes.

CSIC: D.Roma, V. Martín, J. Salvans. S. Farràs, M. Canal, A. Pérez, J.M. Costa, J.L. Gálvez, M. Nofrarias. **UB**: R. Català, A. Sanuy, A. Espiña, M. Orta, D. Guberman. **UPC**: X. Manyosa, J. Ramos, M. Domínguez, **UAB**: M. Montón.
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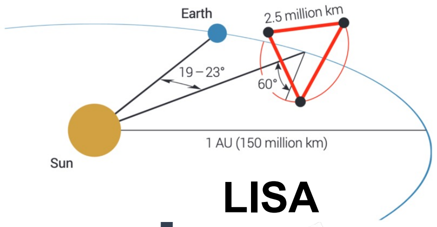
2034



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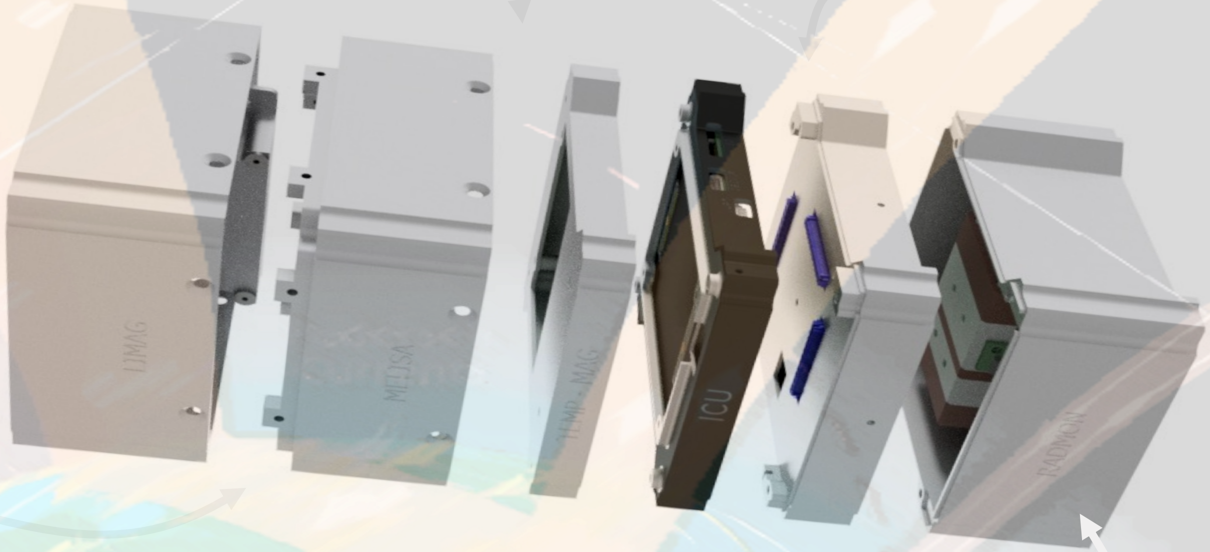

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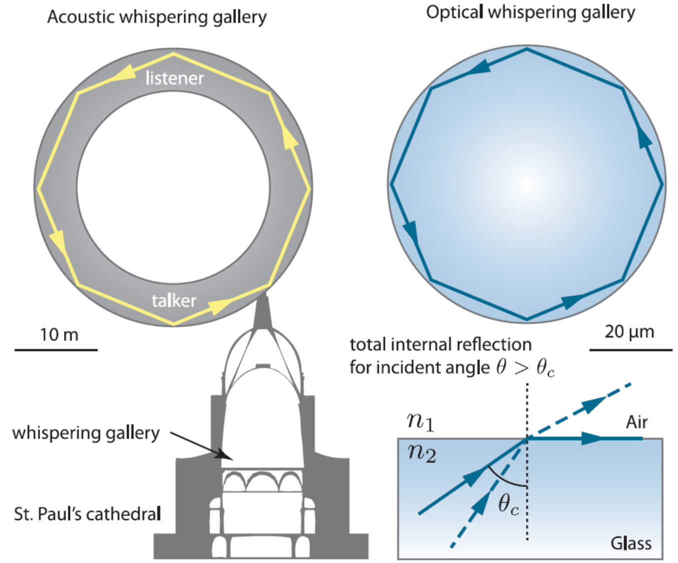
Research on opto-mechanics based sensors

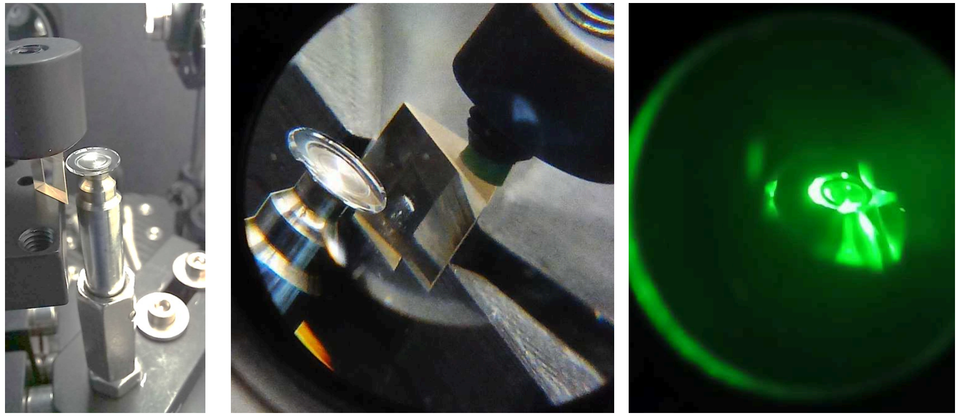
WGMRs are widely used in the field of optics fulfilling different purposes, the most common being:

- Ultra stable frequency reference sources: "**Optical clocks**"
- Non linear crystal: Second Harmonics Generator (SHG), third… and **frequency combs**.
- **High sensitivity sensors**.



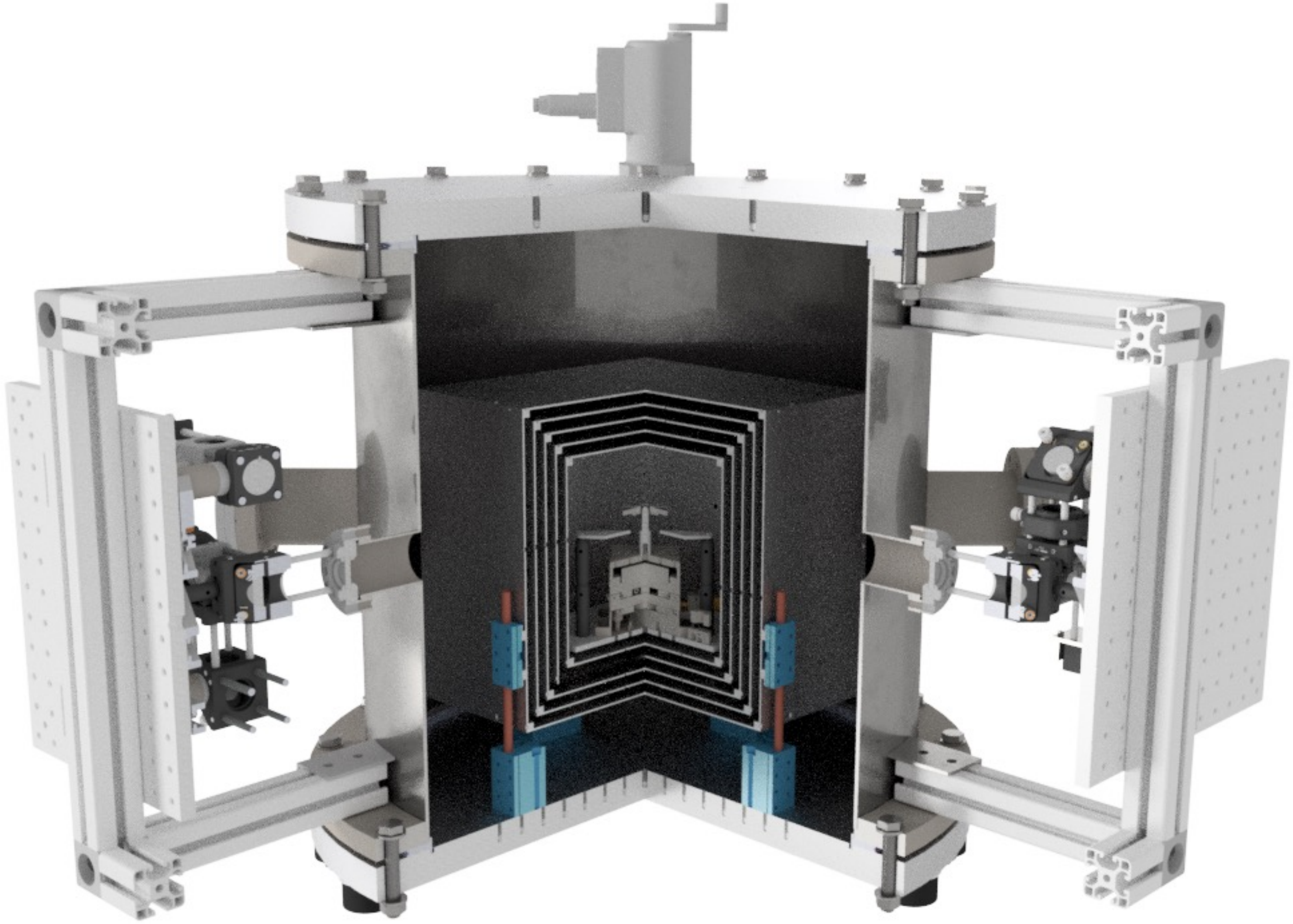
Uses of optical clocks/combs in space involve:

- Navigation
- Interferometry
- Spectroscopy
- Fundamental physics experimentation
- Astronomical scanning
- Others…



Our primary goal is to in-house know-how on optomechanical resonators and optoelectronic systems, with potential application in different fields of precision measurement, both from ground and in space.

Research on opto-mechanics based sensors



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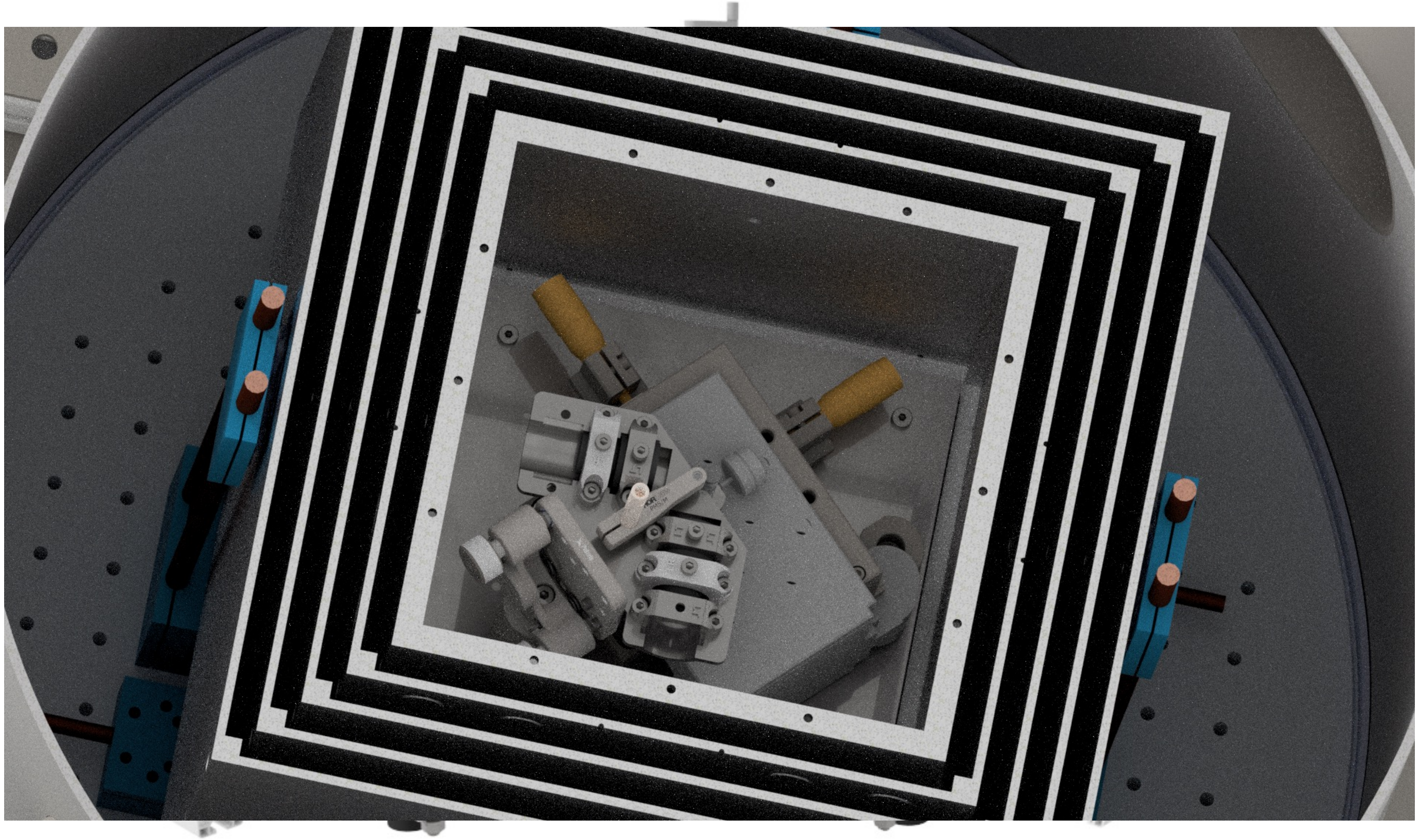

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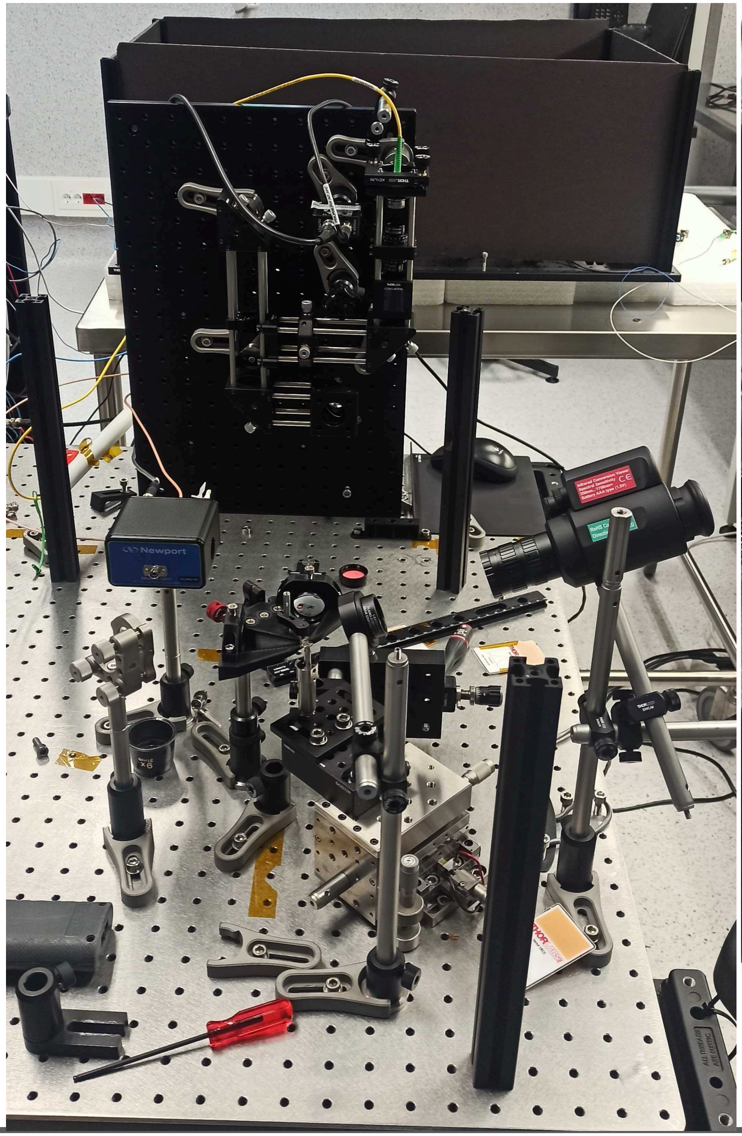
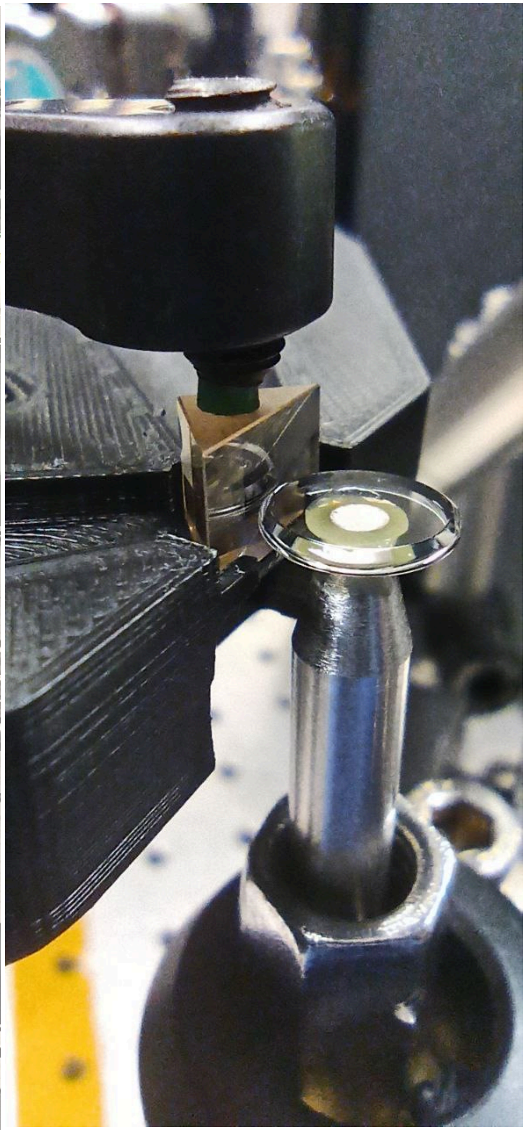
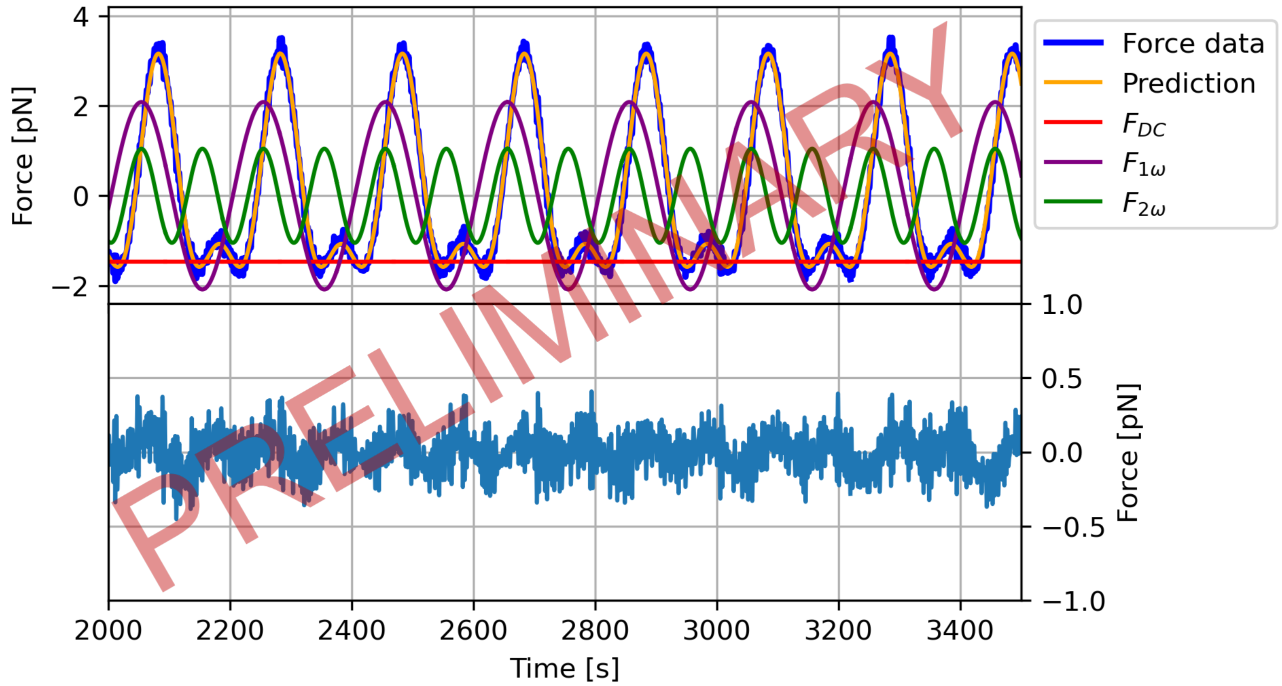


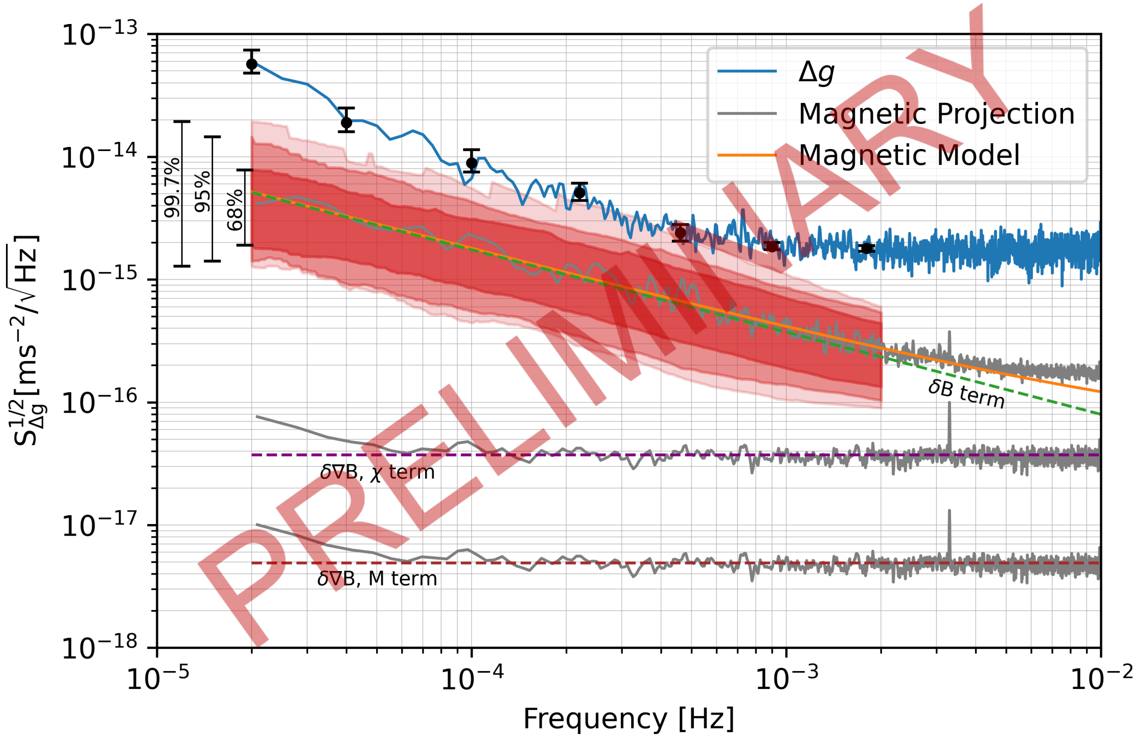


Thank you!

Magnetometers — motivation

- In LISA Pathfinder, we used coils to estimate this contribution. This experiments are not foreseen in LISA.
- Acceleration noise estimate is ~ **3.7 fm/s/Hz$^{1/2}$ at 0.1 mHz** (LISA performance model assumes 4 fm/s/Hz$^{1/2}$ at 0.1 mHz)





Submitted to LPF collaboration.

Diagnostics – Low-frequency magnetometer

Requirement:

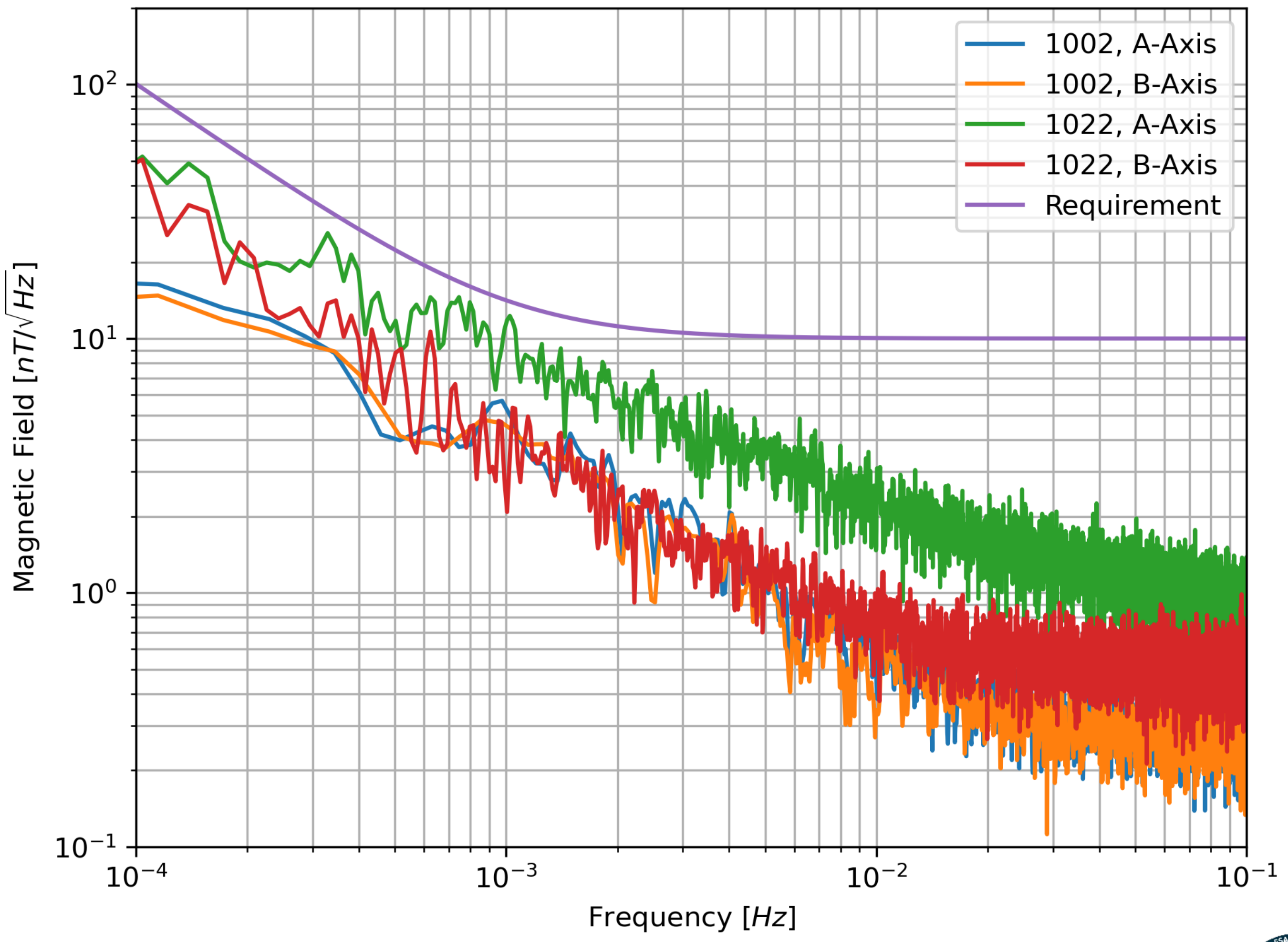
100 nT/√Hz @ 0.1 mHz

Noise performance:

< 50 nT/√Hz @ 0.1 mHz

Conditions:

- 3 layers of mu-metal
- Inside the ATCU
- WB fed at 2 V
- Power consumption below 20 mW



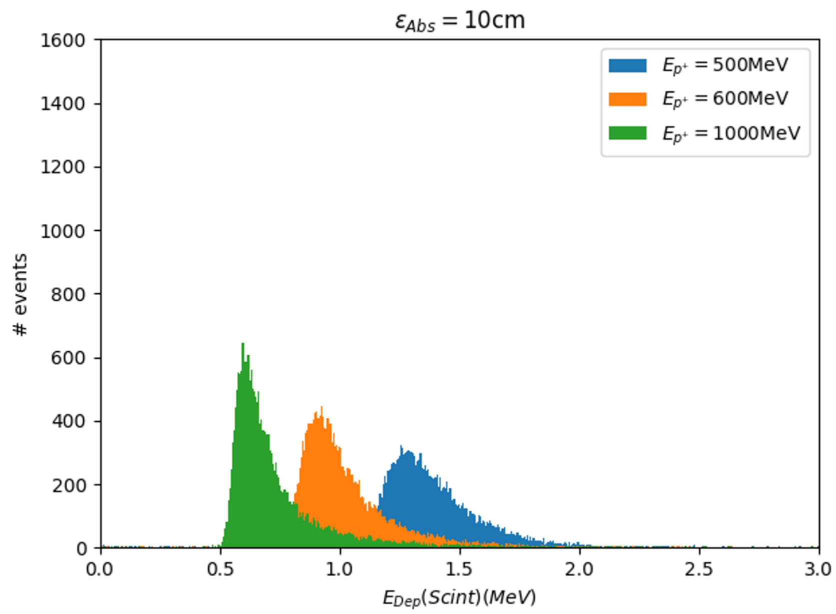
Diagnostics – Radiation Monitor

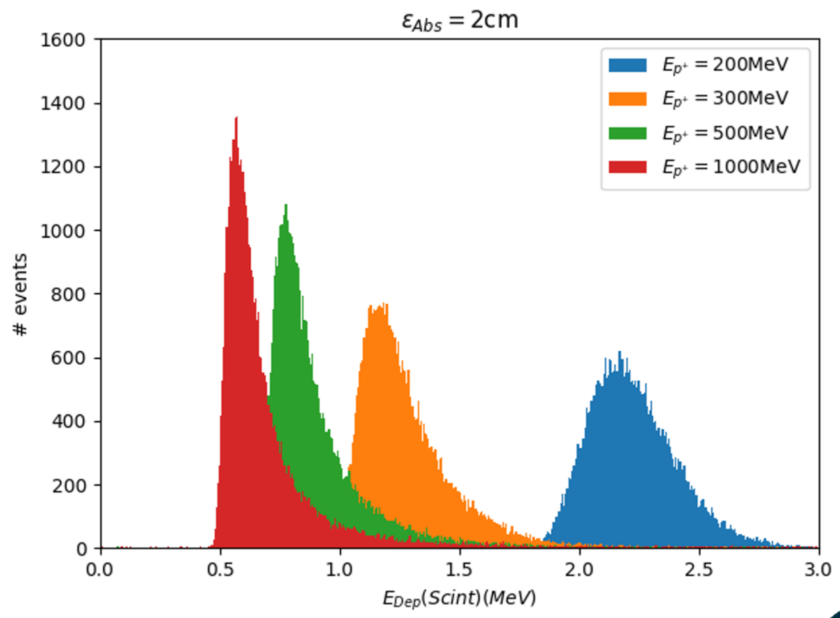
Main objectives:

- To have ~1% statistical uncertainties on the integral cosmic ray flux in ~ 1 hour
- To achieve some energy resolution at a few hundred MeVs

Simulations (with Geant4) have been performed to establish which may be the necessary sizes of absorbers to provide useful data for LISA test mass charging.

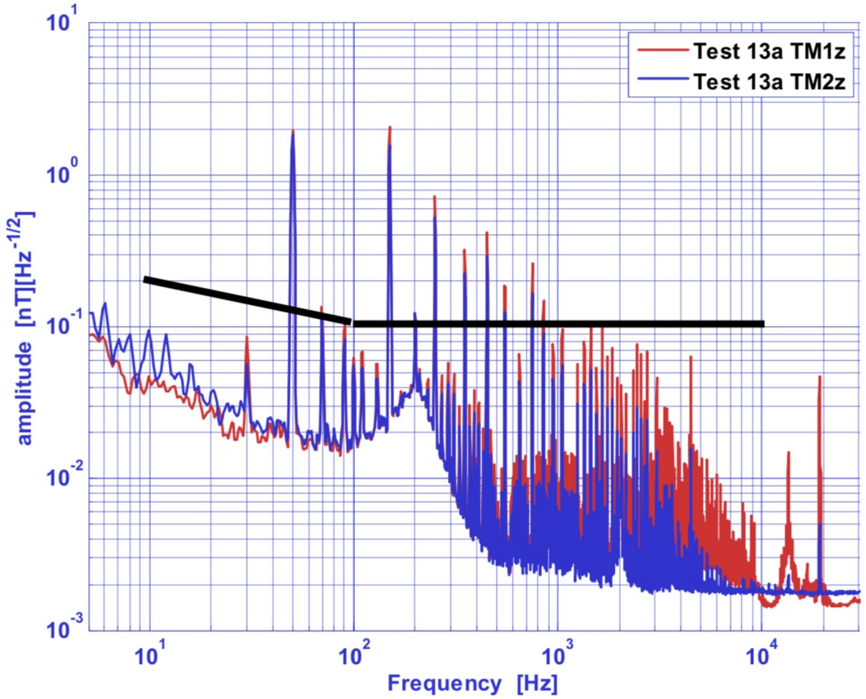
Mass budget is the main limiting factor for the RM and directly impacts the event rate (larger scintillator area increases event rate) and energy resolution (larger absorbers allows energy resolutions of higher energies): *LISA-IEEC-MAG-TN-002 BETA Radiation Monitor: notes on the mass budget*

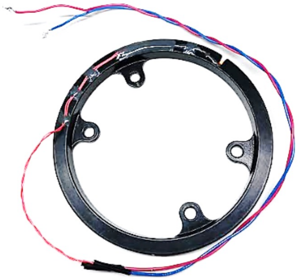




Audio band magnetic sensor — motivation

- LPF found excess noise in the low frequency band. A potential source was identified as coming from:
  - *" high-frequency (> 10 Hz) magnetic fields "down-converting" into the LPF band by the ∇(B^2) dependence of the magnetic force. These could be tested in the future by audio-range magnetometers, which were not available on board LPF "*. **From Armano *et al.* a Phys Rev, Lett. 120, 061101 (2018**)
- High frequency magnetic fields were characterized during on-ground integration. Notice they are highly dependent on S/C operations/configuration
  - LPF S/C magnetic test report (S2-ASU-TR-2028)
  - Studied by Fertin & Trougnou (2009), established a req. on amplitude peaks assuming 20% amp. modulation.
- Current baseline in LISA is to use the coil as high frequency magnetic sensor.
  - Use the coil as it is. No impact in GRS design, only in the front-end, which need to add a read-out.



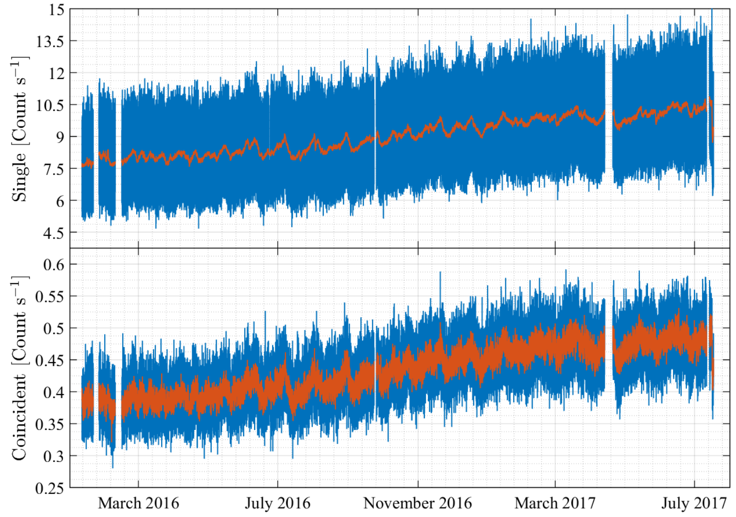


Radiation monitor — motivation

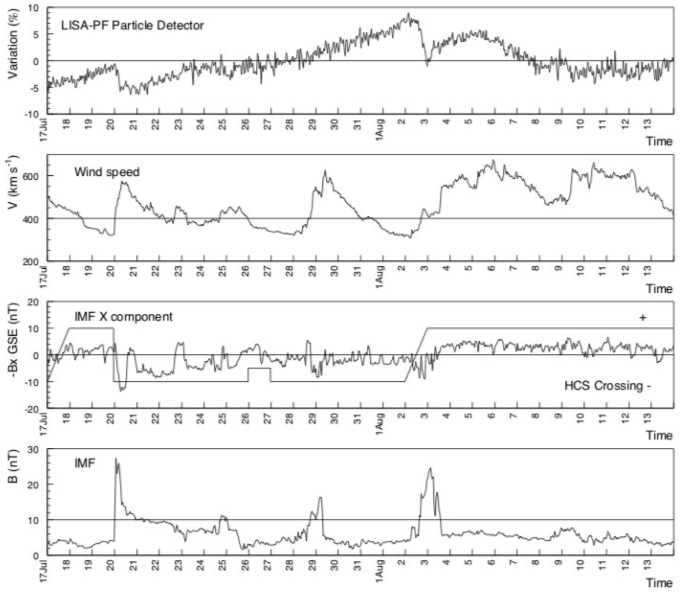
- High energy environment responsible for **test-mass charging** a potential source of acceleration noise

$$F_x(q) = -\frac{q}{C_T}\left|\frac{\partial C_x}{\partial x}\right|\Delta_x,$$

- Two main mechanics that needs monitoring
  - **Galactic Cosmic Rays (GCR)**
    - nearly constant low-level charging rate
    - flux modulation: interaction isotropic flux at heliosphere boundary and solar wind (inducing 27d, 13.5d, 9d periodicities)
  - **Solar Event Particles (SEP)**
    - can last for days, increasing TM charging orders of magnitude. Not measured and unavoidable in LISA.

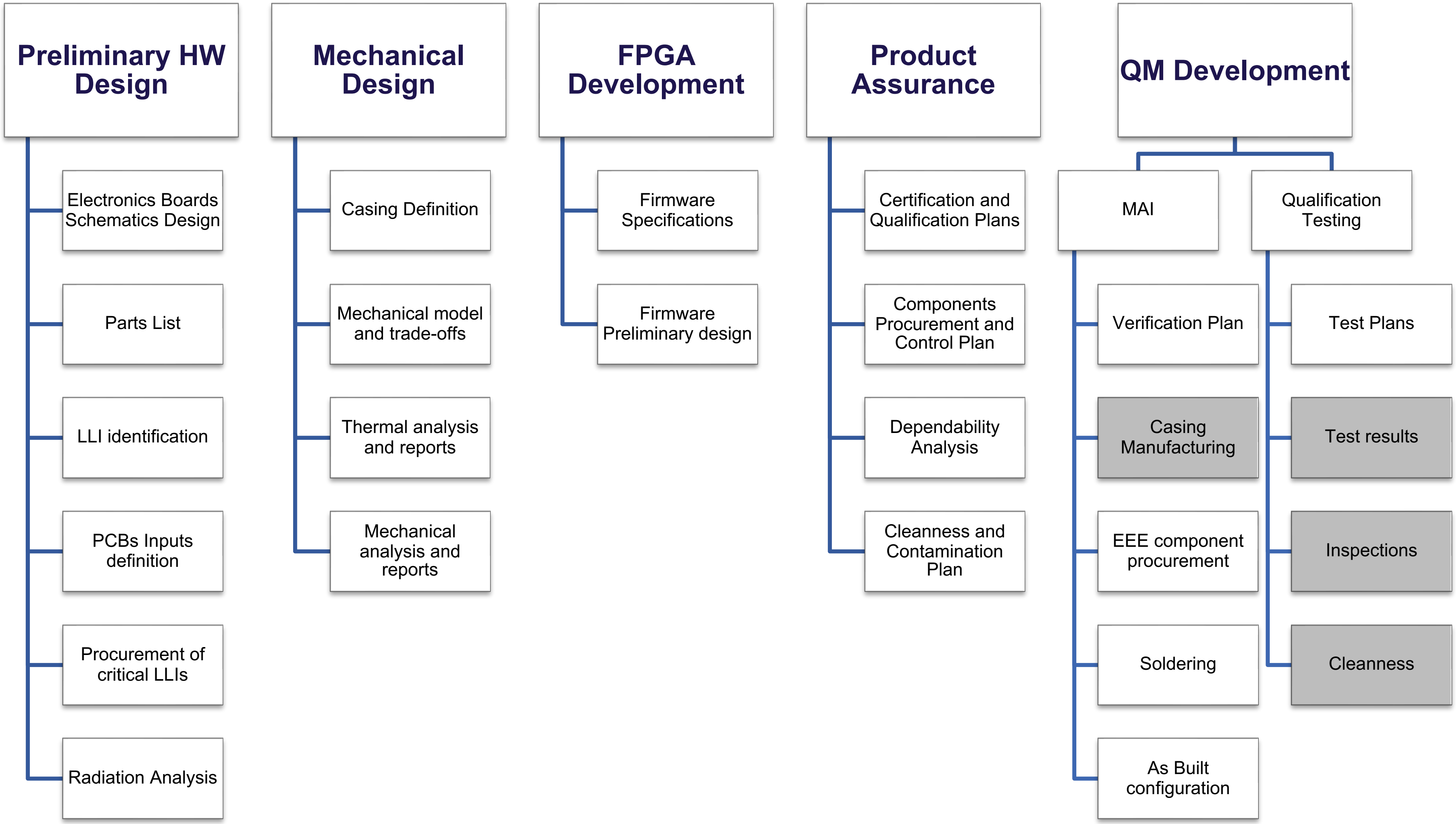


Armano et al. (LPF collaboration) *Astroparticle Physics* 98 (2018)



Armano et al. (LPF collaboration) *The Astrophysical Journal*, 854 (2018)

RM Work Breakdown



MTM Work Breakdown

- **Preliminary HW Design**
  - Electronics Boards Schematics Design
  - Parts List
  - LLI identification
  - PCBs Inputs definition
  - Procurement of critical LLIs
  - Radiation Analysis
- **Mechanical Design**
  - Casing Definition
  - Mechanical model and trade-offs
  - Thermal analysis and reports
  - Mechanical analysis and reports
- **Product Assurance**
  - Certification and Qualification Plans
  - Components Procurement and Control Plan
  - Dependability Analysis
  - Cleanness and Contamination Plan
- **QM Development**
  - MAI
    - Verification Plan
    - Casing Manufacturing
    - EEE component procurement
    - Soldering
    - As Built configuration
  - Qualification Testing
    - Test Plans
    - Test results
    - Inspections
    - Cleanness