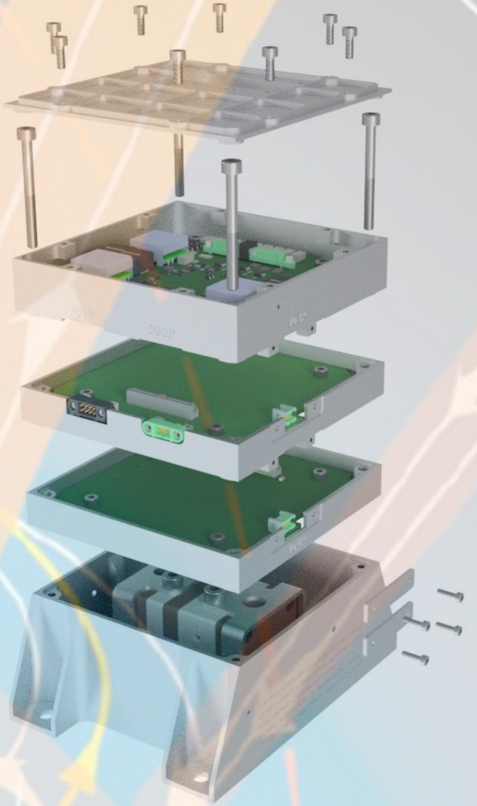
ILIADA: In-orbit LISA Diagnostics Demonstrator



M. Nofrarias

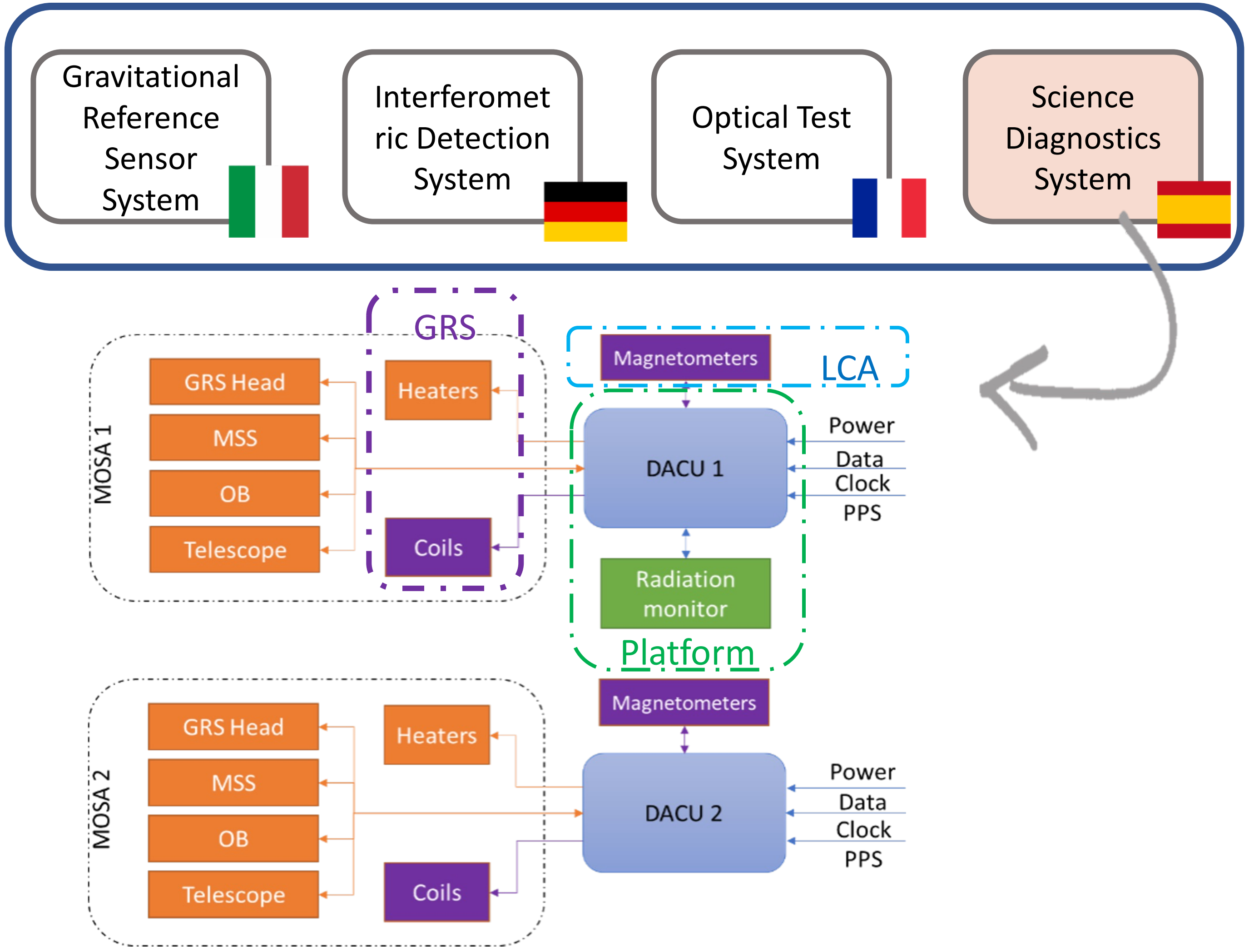
Instituto de Ciencias del Espacio (ICE, CSIC) & Institut d’Estudis Espacials de Catalunya (IEEC)

On behalf of the *ILIADA Consortium* (David Roma-Dollase, Victor Martín, Josep Salvans-Tort, José Luis Gálvez, Juan Ramos-Castro, Marius Montón, Xavier Manyosa, Manuel Domínguez-Pumar, Ana Pérez-Ortega, Miquel Canal, Daniel Guberman, Andreu Sanuy, Roger Català, Albert Espiña, Marina Orta, Laura Martí)

SDS Overview

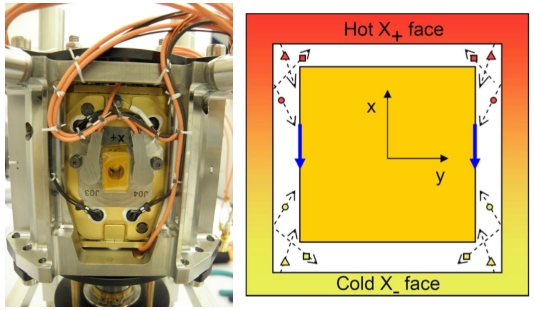
1. Characterize and monitor:
   a. MOSA thermal environment [DDS.FUN.00040]
   b. TM magnetic environment in low frequency and audio frequency [DDS.FUN.00060, DDS.FUN.00070]
   c. TM radiation environment [DDS.FUN.00100]
2. Generate science data information during science mode (time series for the temperatures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

National contributions

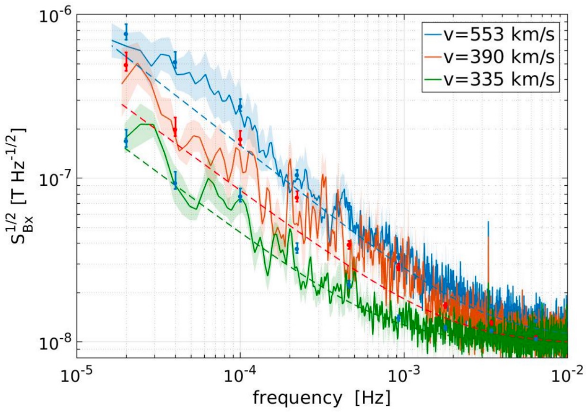


Diagnostics motivation in LISA

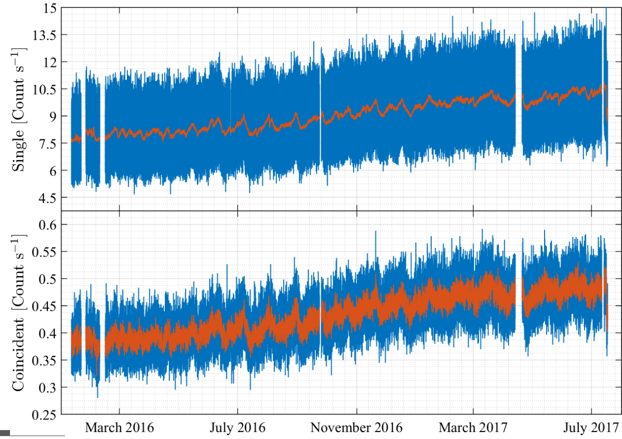
- **Temperature variations** induce forces and path length variations
  - **Forces applied to the TM**: radiation pressure, radiometer, outgassing
  - Temperature variations in **optical elements** can lead to pathlength changes
  - Thermal gradients can induce **mechanical stress** in the structure.
- **Magnetic field and magnetic field gradients** can induce forces in the test mass, the test mass acts as a magnetic dipole.
  - The dominant contribution couples **local gradients** with **interplanetary fluctuations** $\langle S_B \cdot \nabla B_{DC} \rangle$
- **High energy particles environment** responsible for test-mass charging. Two main mechanics that needs monitoring
  - **Galactic Cosmic Rays (GCR)**: nearly constant low-level charging rate
  - **Solar Event Particles (SEP)**: can last for days, increasing TM charging orders of magnitude.



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

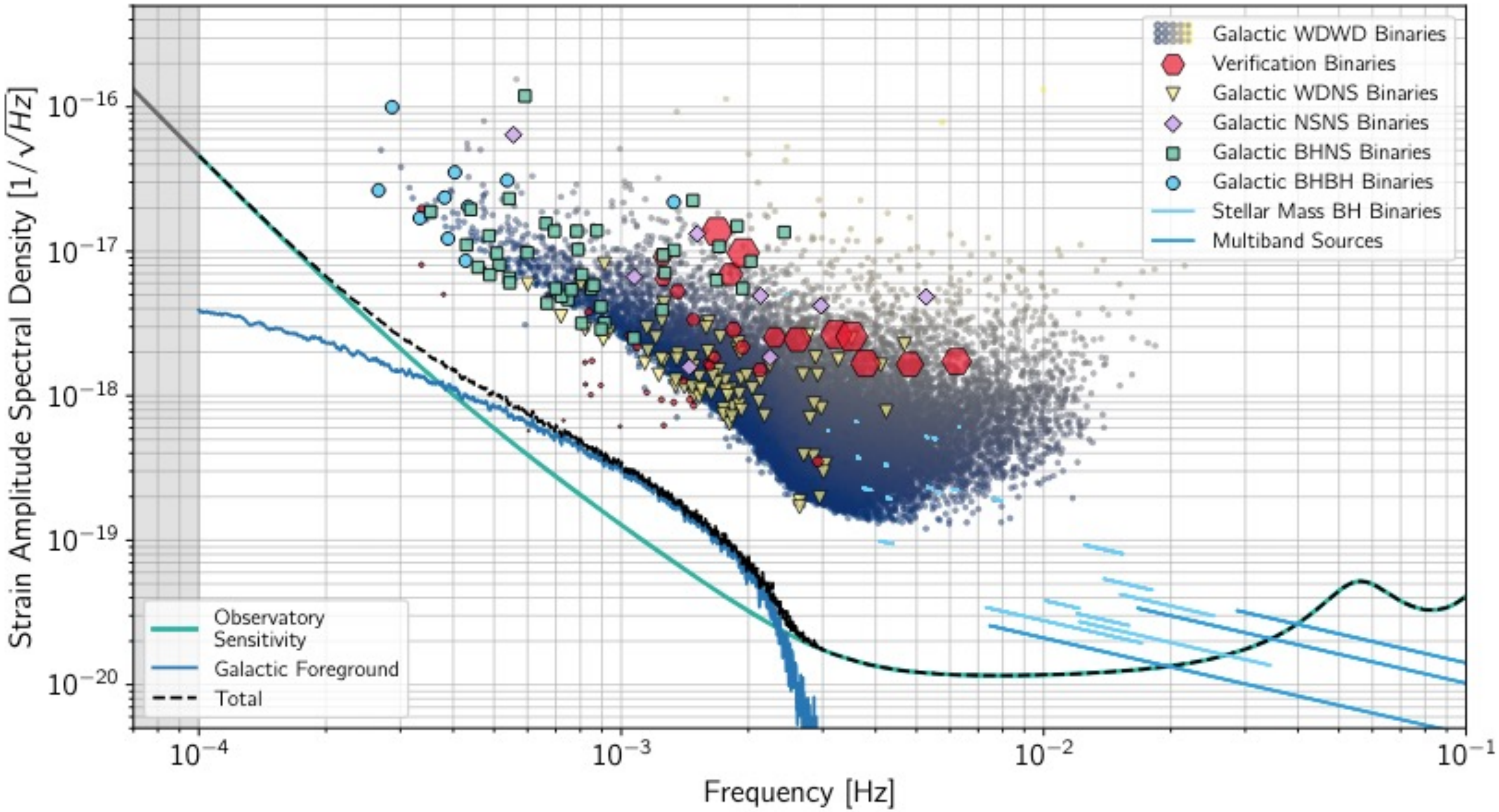


Armano, M et al. (LPF collaboration) 494 MNRAS (2020)

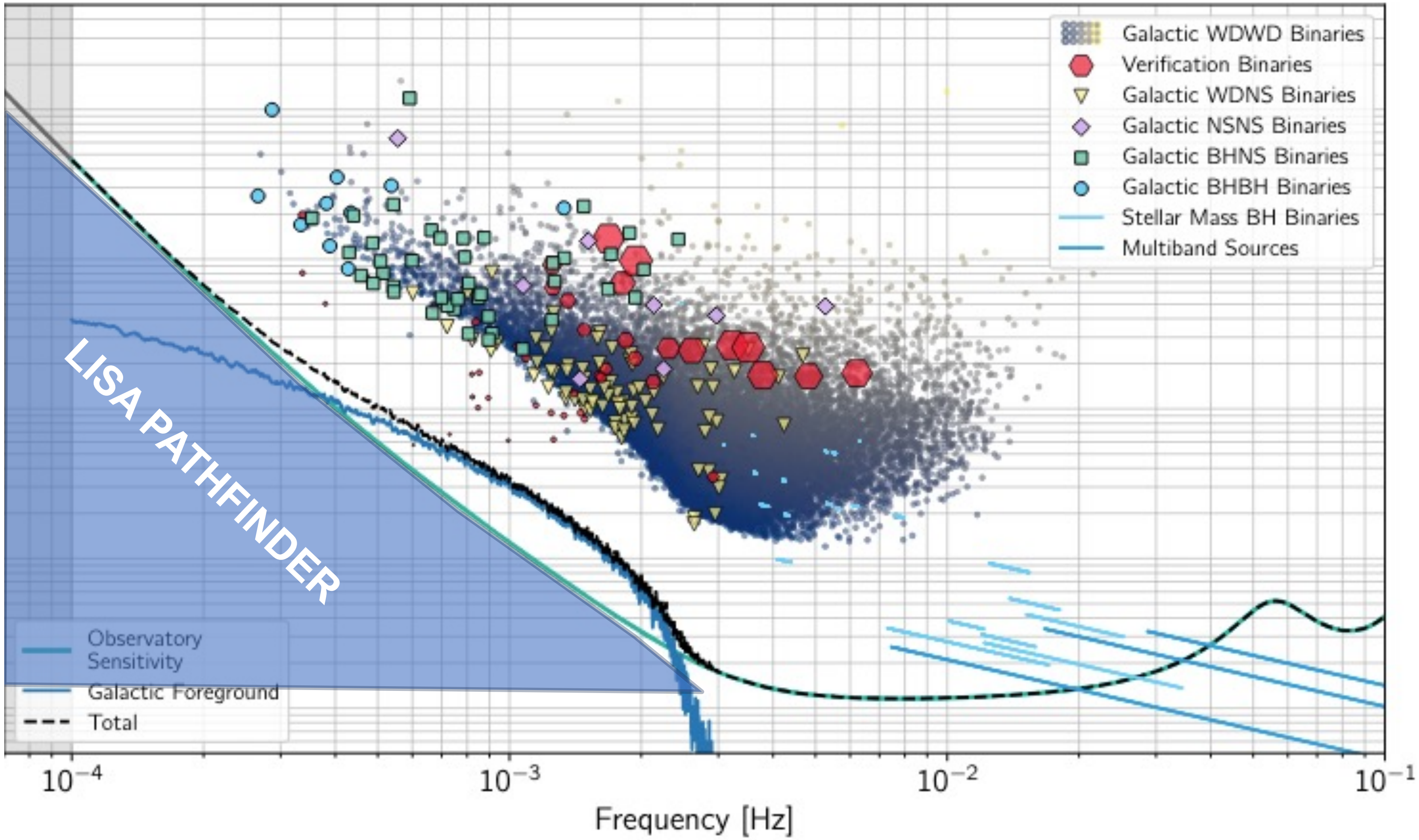


Armano et al. (LPF collaboration) *The Astrophysical Journal*, 854 (2018)

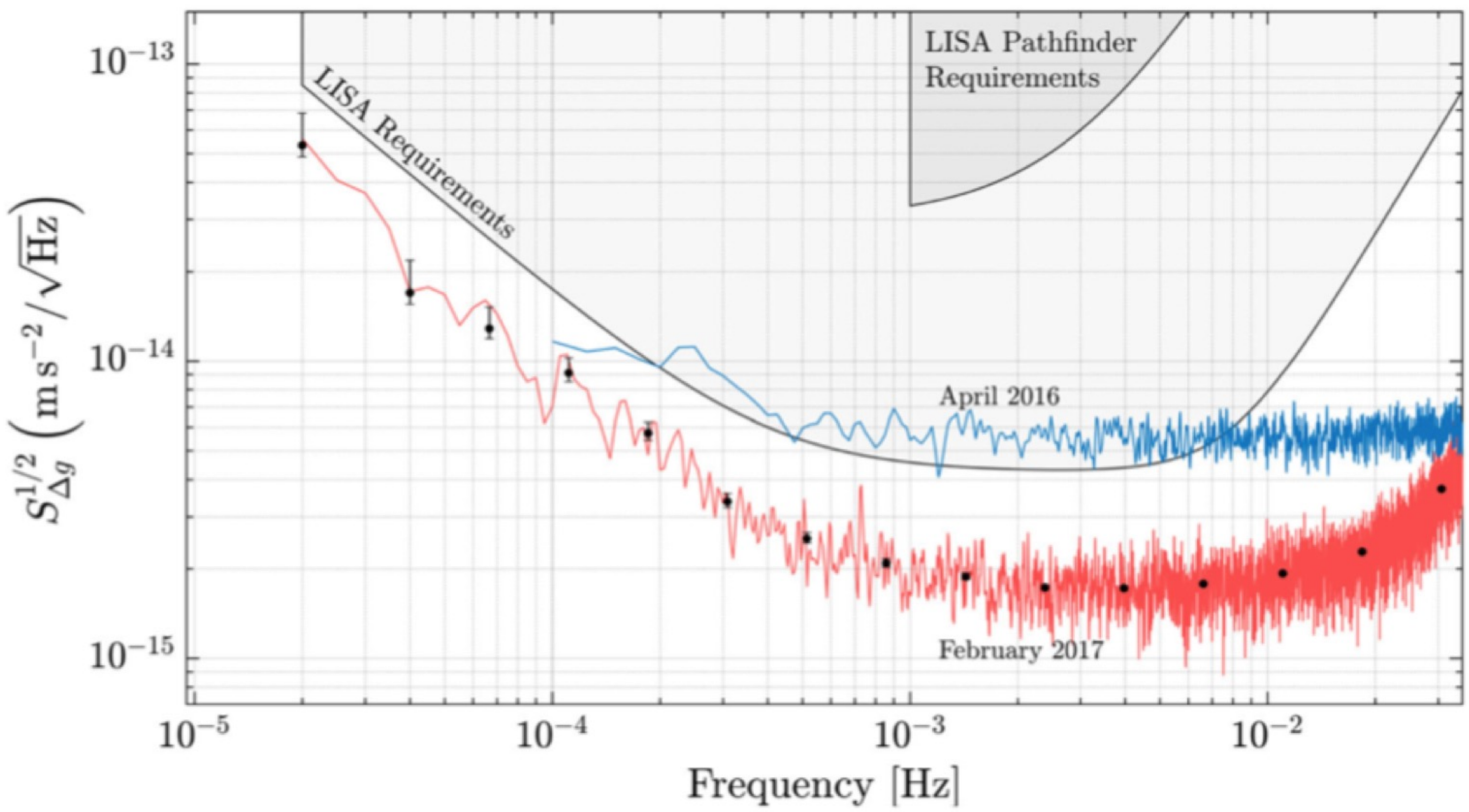
Diagnostics motivation in LISA – LISA Pathfinder



Diagnostics motivation in LISA – LISA Pathfinder

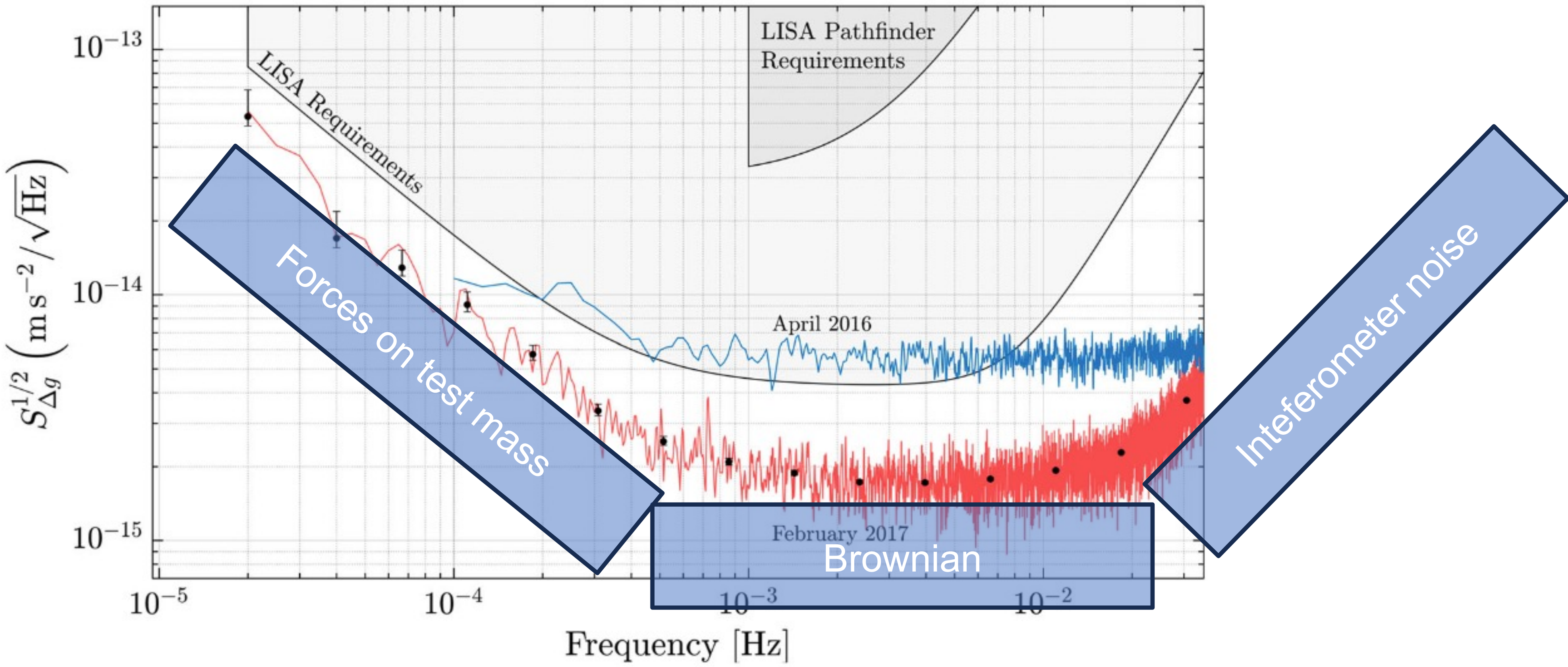


LISA Pathfinder



Armano et al. (LPF collaboration) Beyond required LISA free-fall performance: new LISA Pathfinder results down to 20 μHz Phys. Rev. Lett. 120 (2018)

LISA Pathfinder



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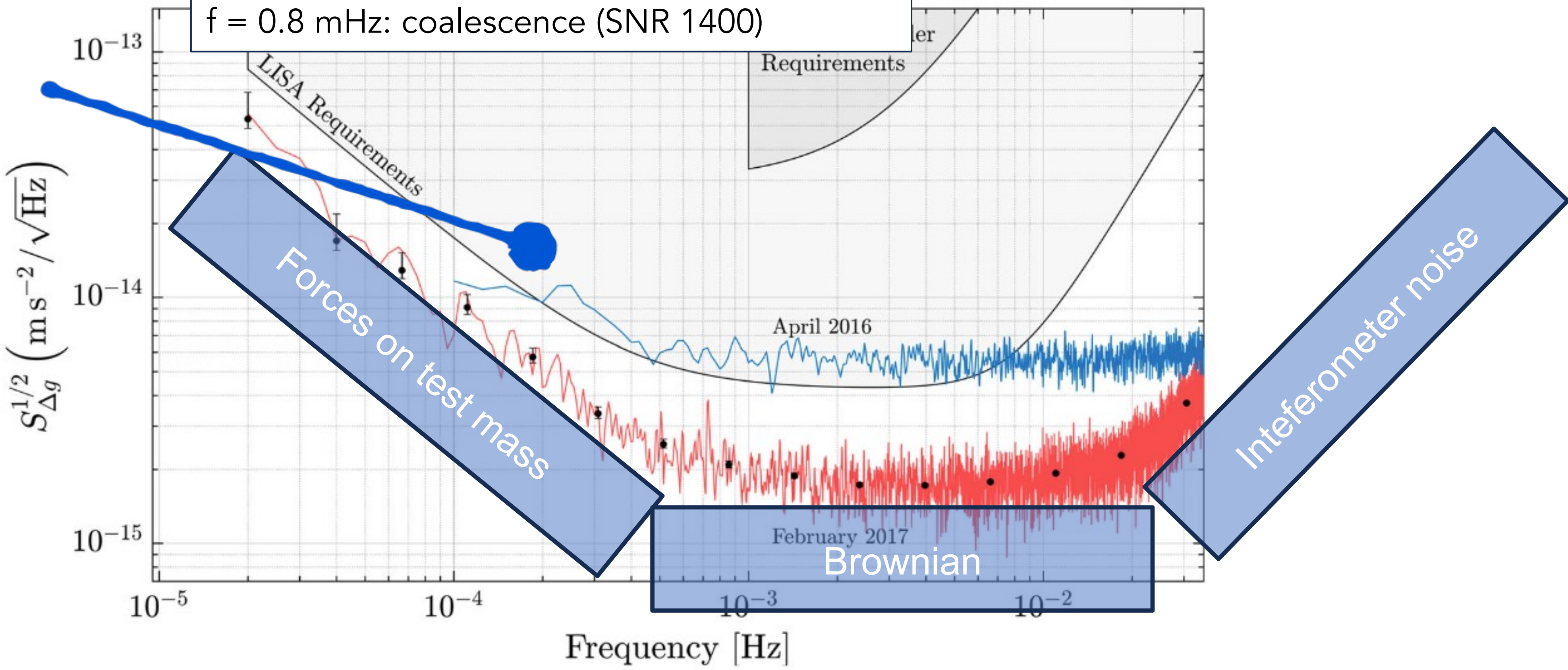
LISA Pathfinder

SMBH merge (M = 5 x 106, z=2)
f = 0.02 mHz: 35d before coalesce (SNR 50)
f = 0.8 mHz: coalescence (SNR 1400)



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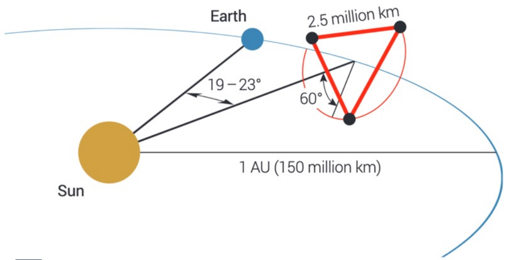
ILIADA

2035



LISA Pathfinder Diagnostics Subsystem (DDS)

- 24 NTC temperature sensors
- 4 Fluxgate magnetometers
- 1 Radiation monitor (Si PIN)
- 16 Heaters
- 2 Coils

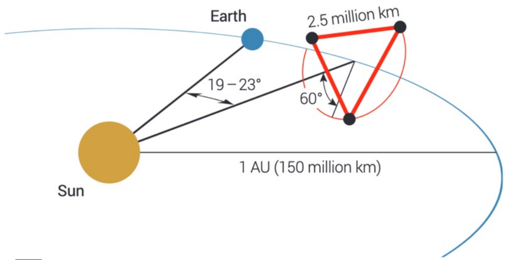
LISA Scientific Diagnostics Subsytem (SDS)

- 144 NTC/Pt temperature sensors
- 18 AMRs magnetometers
- 3 Radiation monitor (Si PM)
- 12 Heaters
- 3 Coils (audio band EM sensors)

2015

ILIADA

2035



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2026

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2015

ILIADA is an in-orbit demonstrator (2U) for the LISA Science Diagnostics Subsystem (SDS).

In the framework of the Generalitat de Catalunya NewSpace Strategy.

New Space strategy

The *Generalitat de Catalunya* (Catalan government) started in 2020 the Catalan *New Space* strategy to boost the local ecosystem related to space missions and services with two missions:

- **2021** – Launch of GENIOT (*Enxaneta*). 3U telecommunications satellite to provide IoT service. Included an IOD.
- **2022** – Launch of GENEO (*Menut*): 6U Earth observation satellite to provide high-frequency multispectral images (Sentinel, Copernicus)
- **2023** - published a tender for an Earth Observation mission (GENEO-02).
  Includes an In-Orbit Demonstrator

GENEO-02 will be a Sun-Synchronous Orbit with a high above 540 km and have communications both at S (TT&C and IOD data) and X (EO data) band. IOD requirements:

- Maximum **volume of 2U**, maximum **mass of 2.66 kg**
- Nominal power consumption **below 6 W**, 8 W peak.
- CubeSat Space Protocol interface with OBC over CAN or serial port.
- IOD shall not interfere with the main payload.
- **FM IOD delivery Q1 2025**.

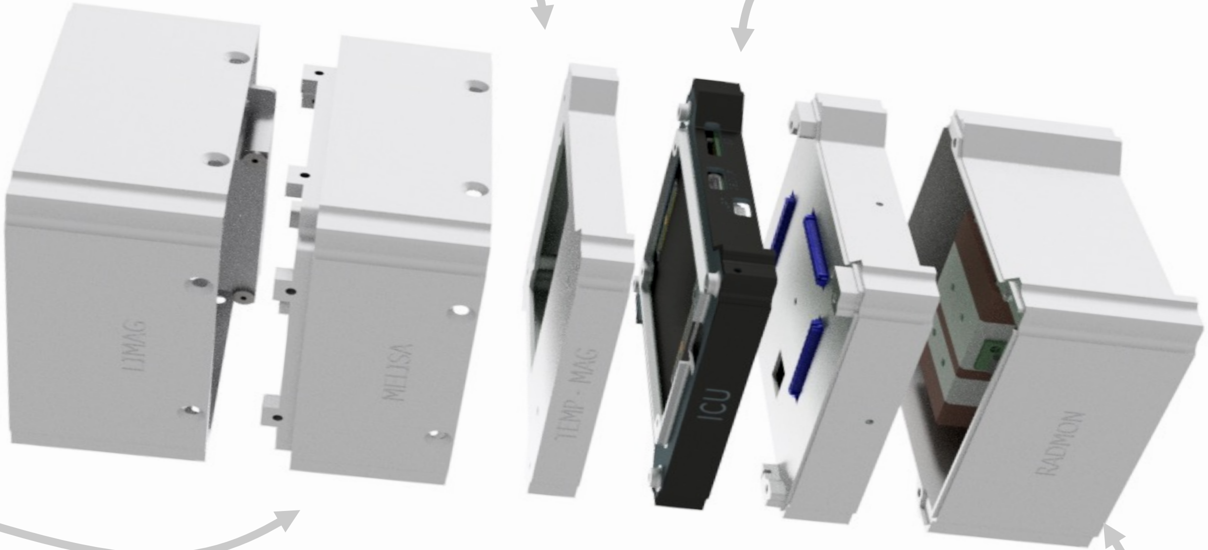
ILIADA (proposal) concept

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

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

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

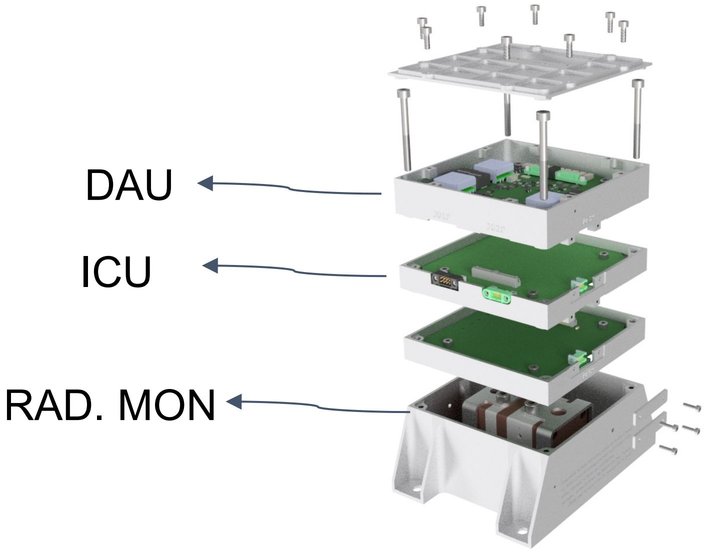
MELISA: magnetometer based **on Tunnel Magnetoresistive sensors (TMR)** modulated by a **MEMS cantilever**. Reaching 20 nT/$\sqrt{Hz}$@ 0.1 mHz.

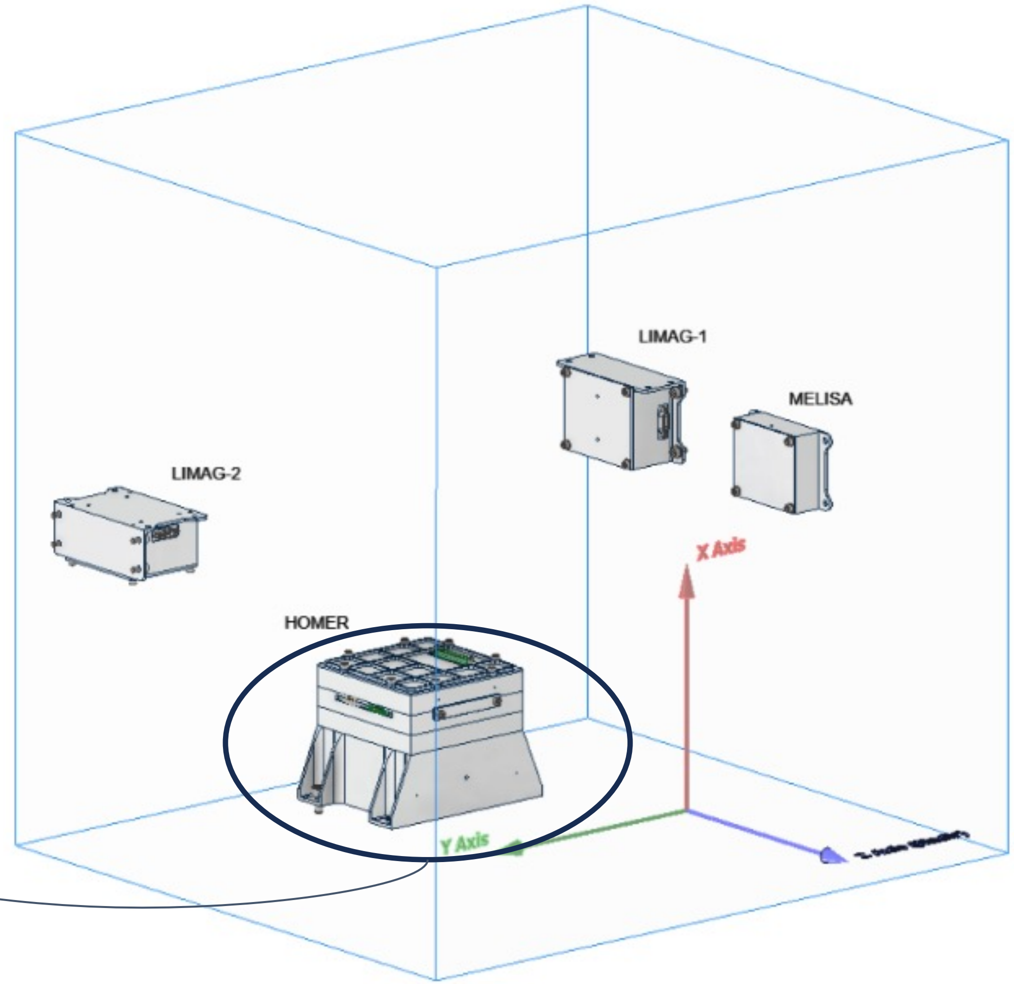


RADIATION MONITOR: four plastic **scintillators** and **silicon photomultipliers**. separated by three absorbers of different size. **BETA ASIC** amplifies, shapes and digitizes.

ILIADA current concept

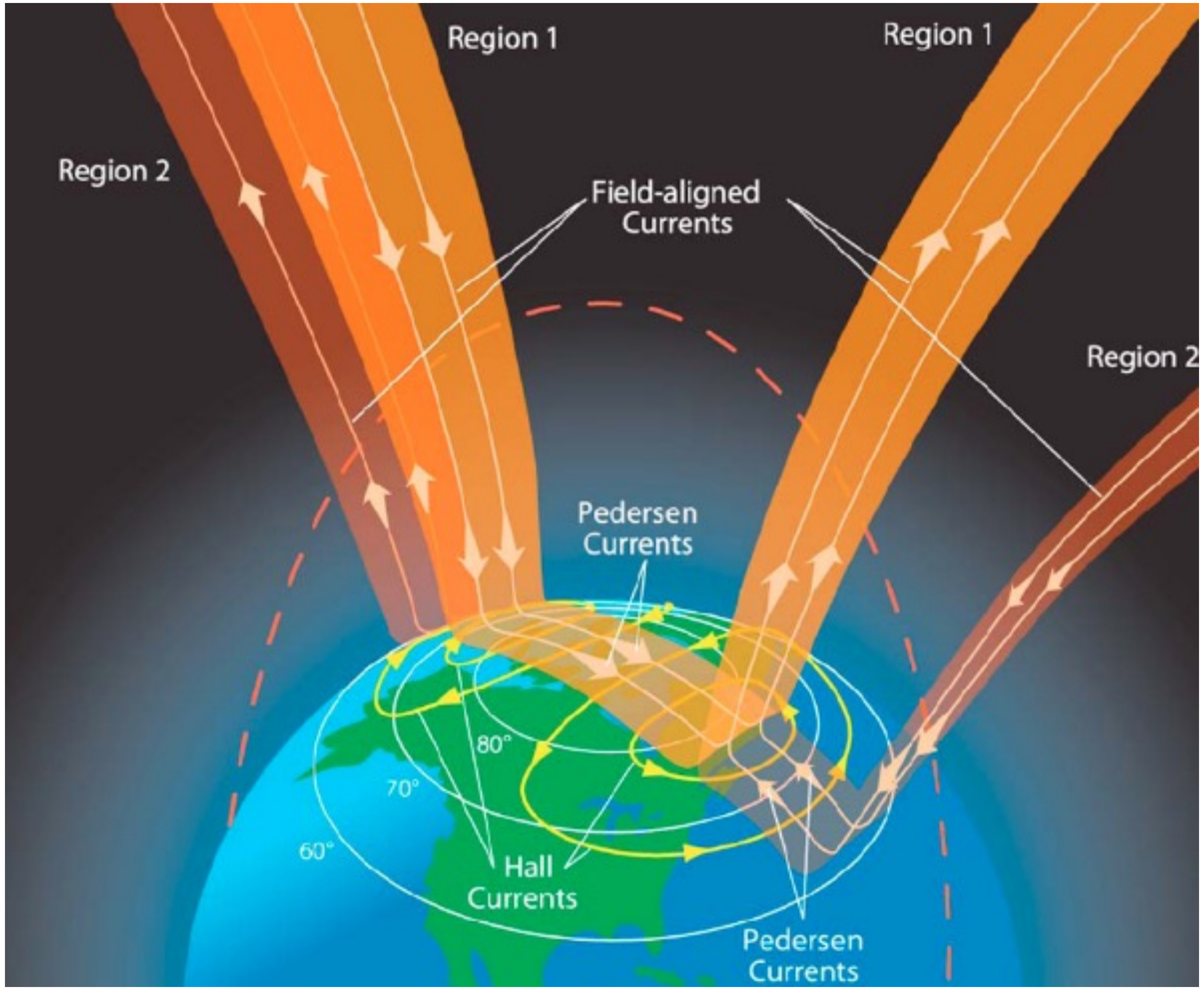
- GENEO-02 platform expected to be a **micro-sat**. Adapted the ILIADA mechanical interface.
  - Splitted the 2U volume into a main unit (HOMER) and three unit hosting magnetometers (AMRs and MEMs)





ILIADA motivation

- **Primary goal: rise LISA diagnostics related TRL** that is, temperature, magnetic and charged particles sensing.
- **Secondary goal**: measurement of *Birkeland currents (Field Aligned Currents)*, a set of electrical currents flowing along the geomagnetic field lines.
  - Expected **transient signals** in **magnetic field** and **particle flux** when crossing the poles.
- Note: detecting those currents implies subtraction of the S/C magnetic field based on platform telemetry.
  - Valuable methods/strategies for LISA since LISA will use platform integrated magnetometers



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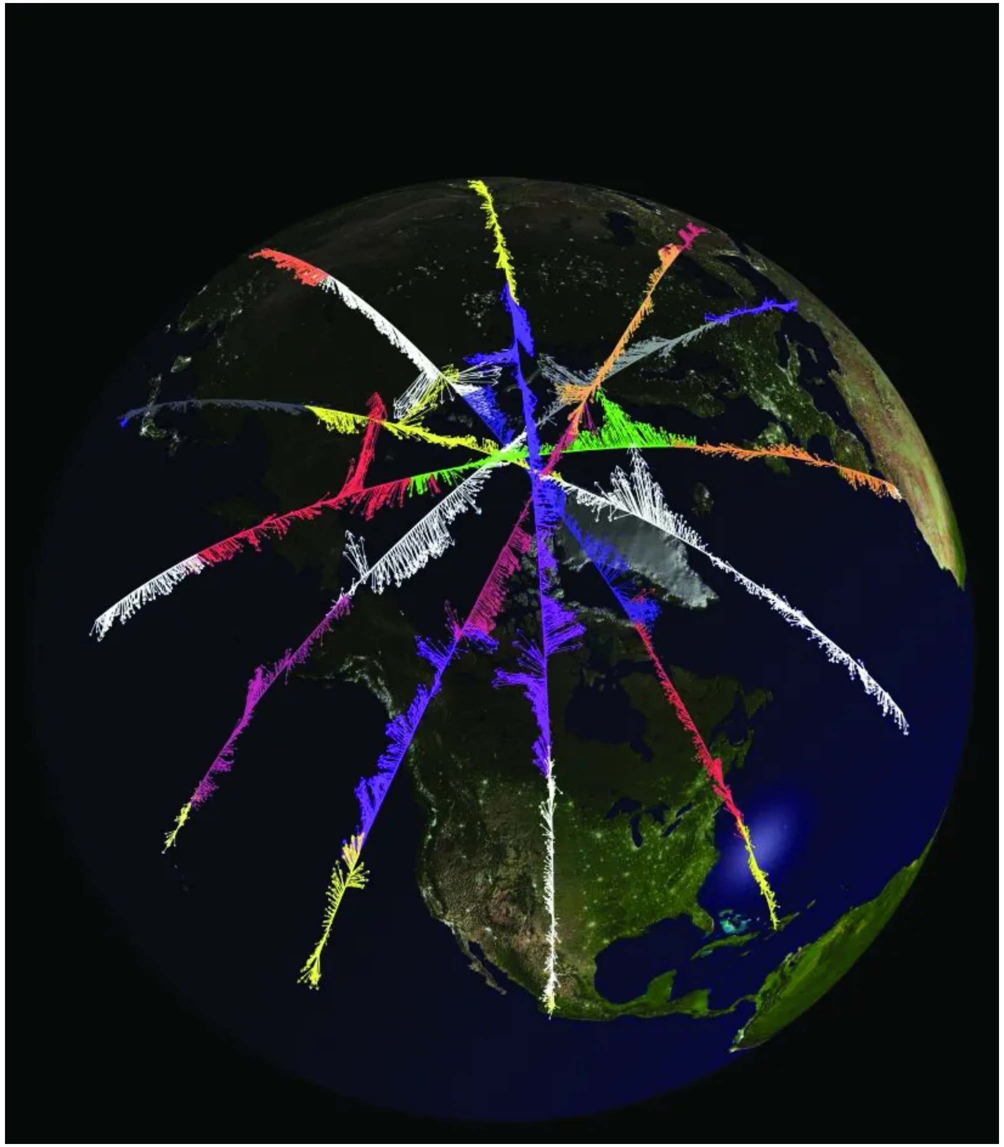
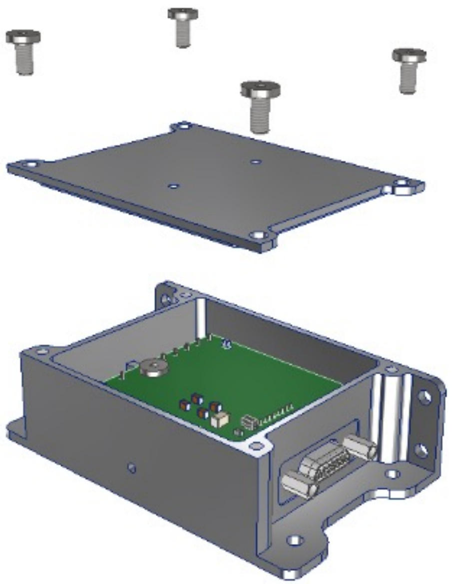


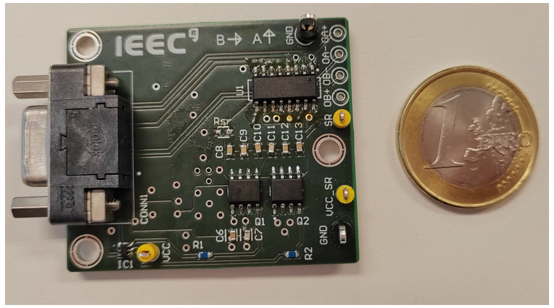
Anderson, B. J., et al. (2014), Development of large-scale Birkeland currents determined from the Active Magnetosphere and Planetary Electrodynamics Response Experiment, Geophys. Res. Lett., 41,3017–3025

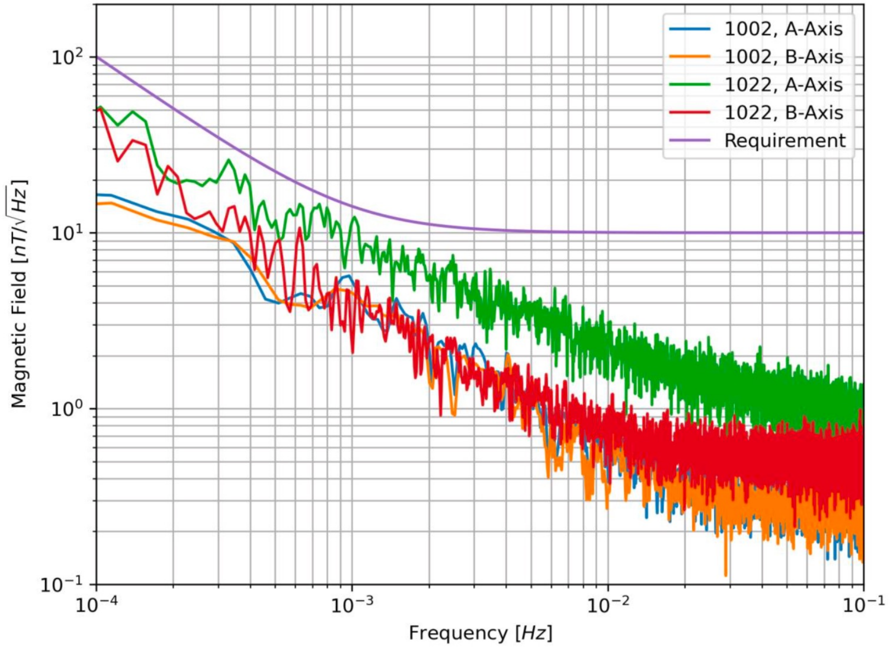
LIMAG (LISA Magnetometers)

2-axis magnetometer based on **Anisotropic Magnetoresistive sensors** (AMR) in a full Wheatstone bridge disposition with a high-sensitivity (~60-20 V/T).

- Includes *flipping electronics* to modulate the output signals and overcome 1/f noise.
- Low power consumption (~100 mW).
- Mass below 140 g.
- Noise below 50 nT/$\sqrt{Hz}$ @ 0.1 mHz



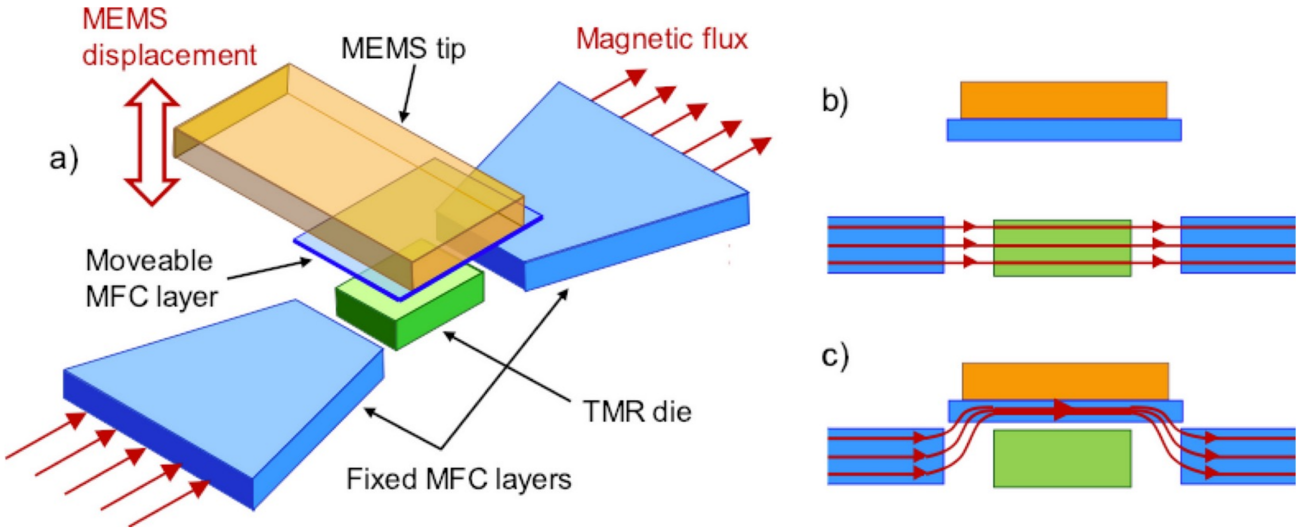


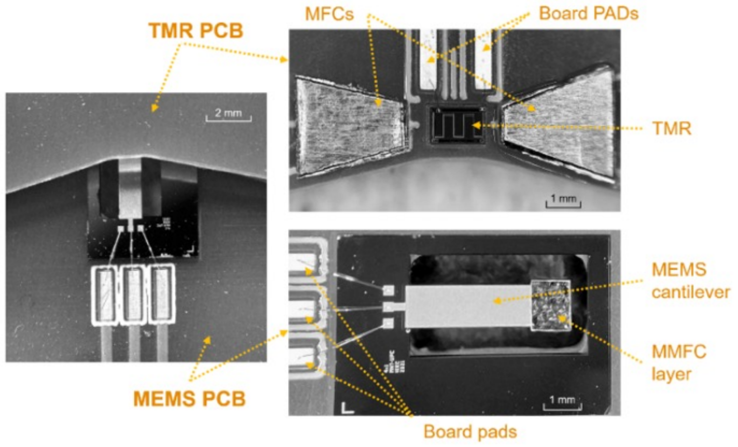


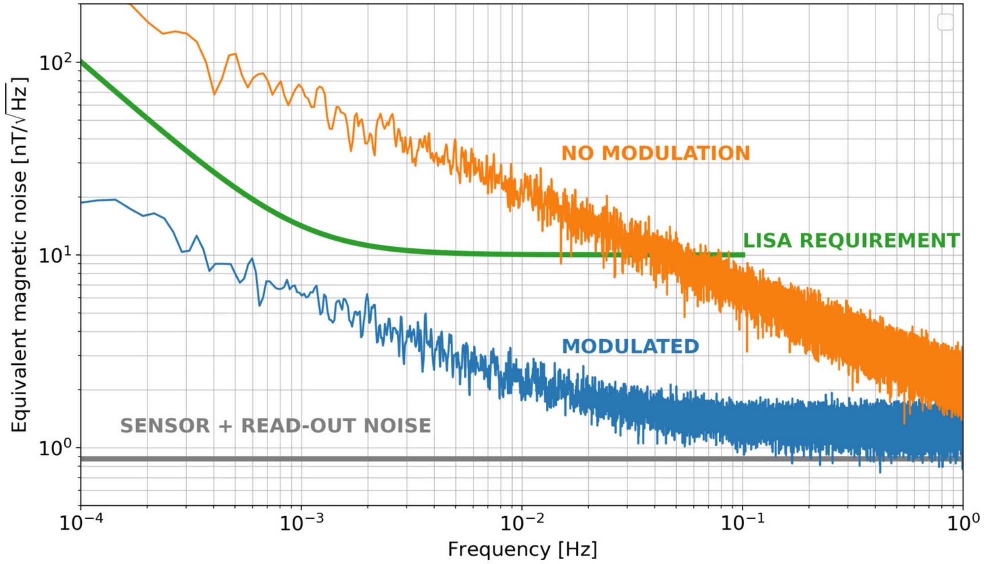
MELISA

1-axis magnetometer based on **Tunnel Magnetoresistive sensors** (TMR) modulated by a **MEMS cantilever** with a flux concentrator material at the tip. Placed in a Wheatstone bridge disposition with a high-sensitivity (~70 V/T).

- Low power consumption (~1 mW).
- Mass below 140 g.
- Noise below 20 nT/$\sqrt{Hz}$ @ 0.1 mHz
- High temperature coefficient







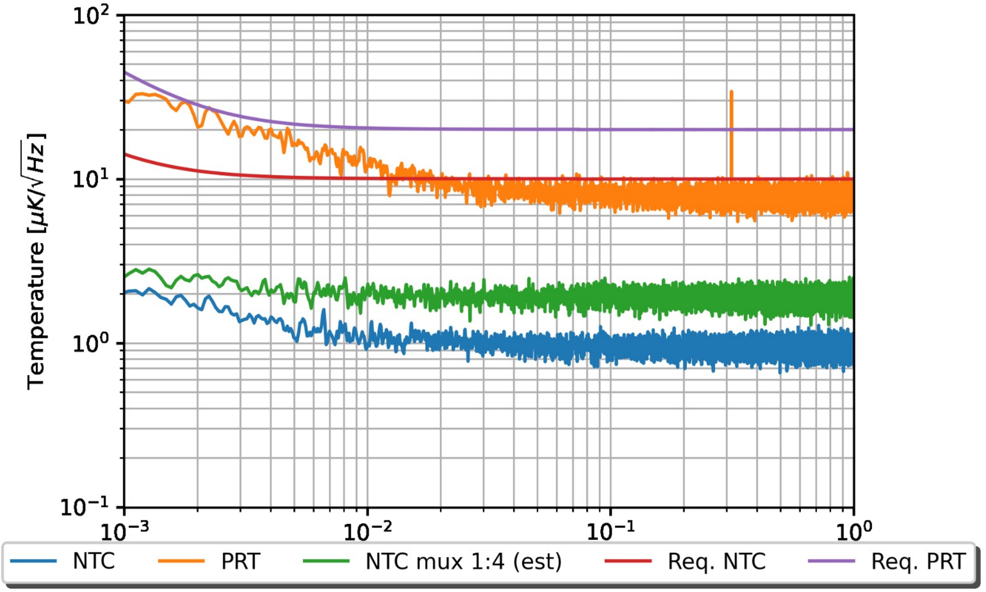
Manyosa, X. et al. MEMS miniaturized low-noise magnetic field sensor for the observation of sub-millihertz magnetic fluctuations in space exploration. Measurement 230, 114489 (2024)

LETS (LISA Enhanced Temperature System)

ILIADA temperature subsystem implements the **LISA temperature subsystem baseline**, able to reach a stability of ~1 μK/$\sqrt{Hz}$ at the mHz. Read-out based on an AC powered Wheatstone bridge.

NTCs sensors together with **Platinum (non-magnetic)** sensors, latter provides better accuracy.

An adapted version of the **LISA SDS read-out** for temperature and magnetics will be used for all of them.



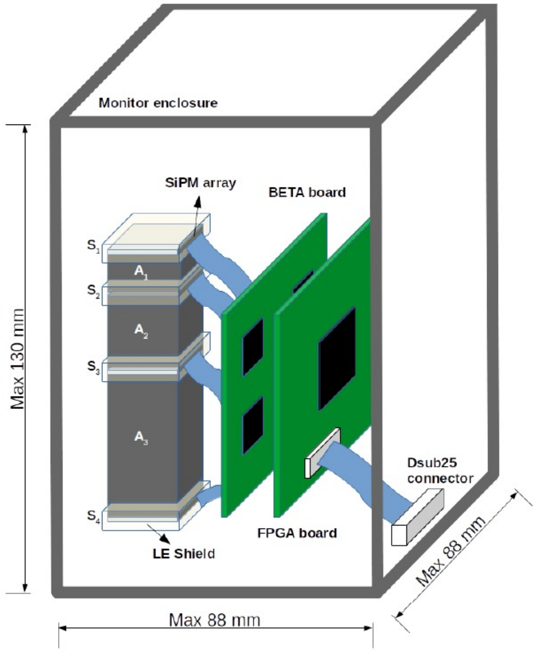
Roma-Dollase, D. et al. Resistive-Based Micro-Kelvin Temperature Resolution for Ultra-Stable Space Experiments. Sensors, 23(1), 145. (2023

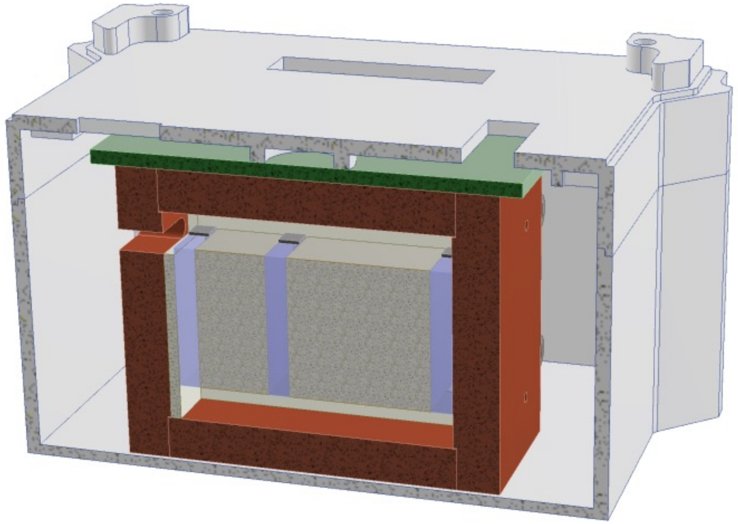
Radiation Monitor

Radiation monitor will be a reduced version of the LISA baseline, based on

- **Four plastic scintillators and Silicon photomultipliers** separated by three absorbers of different size
- The **BETA ASIC**, originally 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.

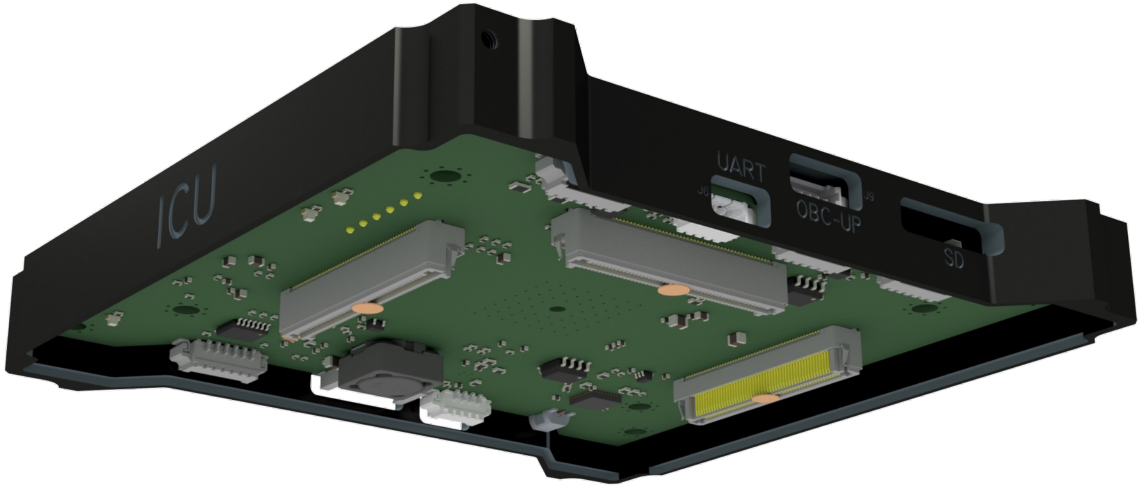




ICU

Flight heritage from the previous GENEO mission (IEEC heritage).

- Based on a **SAMv71 microcontroller**.
- Includes Flash memory card.
- External interfaces like CAN, UART, SPI, …
- Running a FreeRTOS with CSP libraries.
- Will be communicating with the OBC, packing the RM data and modulating/demodulating temperature/magnetic sensors.



ILIADA status

- KOM March 2024
- Platform changed from cubesat to micro-sat. Redefined interfaces.
- Mechanical structure fixed and procurement started. PCB detailed designed undergoing.
- PDR currently scheduled for November. Expected delivery to Prime Q2 2025. Launch Q1 2026.

Thank you!