Data and Diagnostics Subsystem

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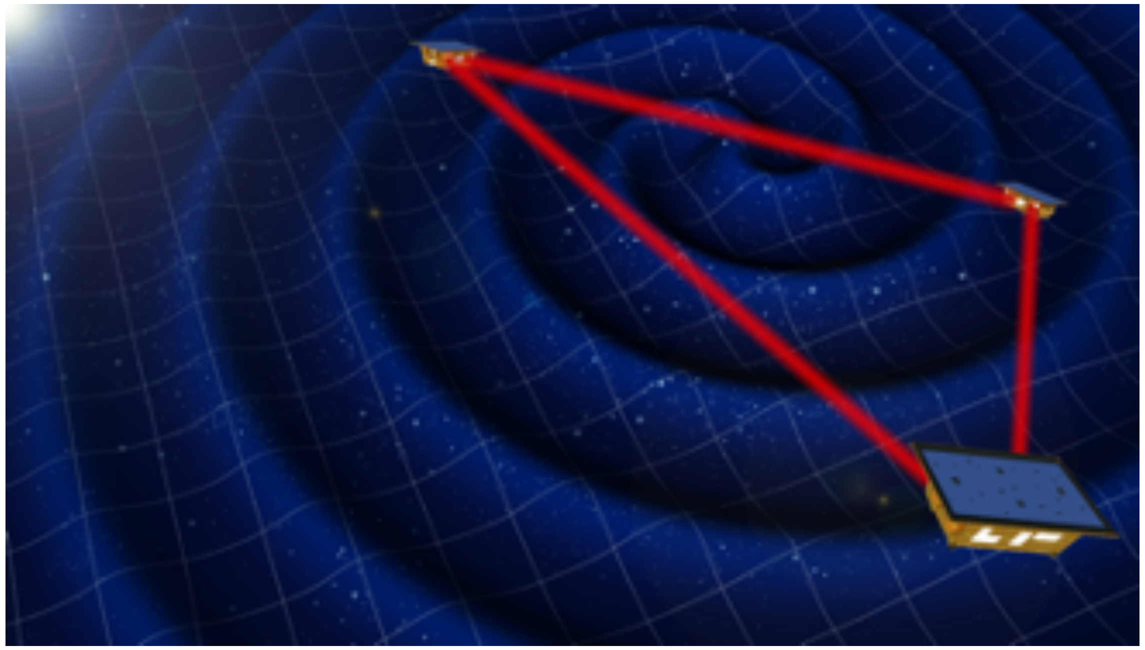
The Gravitational Astronomy group

- **Our research** focus on all aspects related to the field of Gravitational Astronomy
- **We lead** the Spanish contribution to ***LISA***. We also contribute to other GW projects as the *Einstein Telescope* or *ELGAR*.



- We contributed to the **mission operations and data analysis** of LISA Pathfinder (2015-17), the precursor of LISA.

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Overview

- Payload control and software

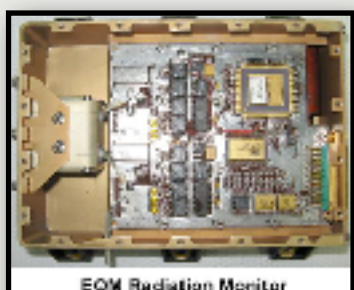
- Diagnostics
  - Temperature sensors
  - Magnetometers
  - Radiation monitor

LISA Pathfinder: Data & Diagnostics

Data Management Unit

Commanding and control of LTP subsystems.
Single command interface to S/C
Provides power supply and Processing to Diagnostics
Implements Optical Metrology control loops

Radiation Monitor



2 PIN diodes in telescope conf.

Measuring energy deposition for coincidence events

Thermal diagnostic subsystem

24 sensors (10^{-4} K/√Hz)

16 heaters

Monitor and charac. of thermal sensitive locations

Magnetic diagnostic subsystem

4 fluxgate magnetometers

2 coils

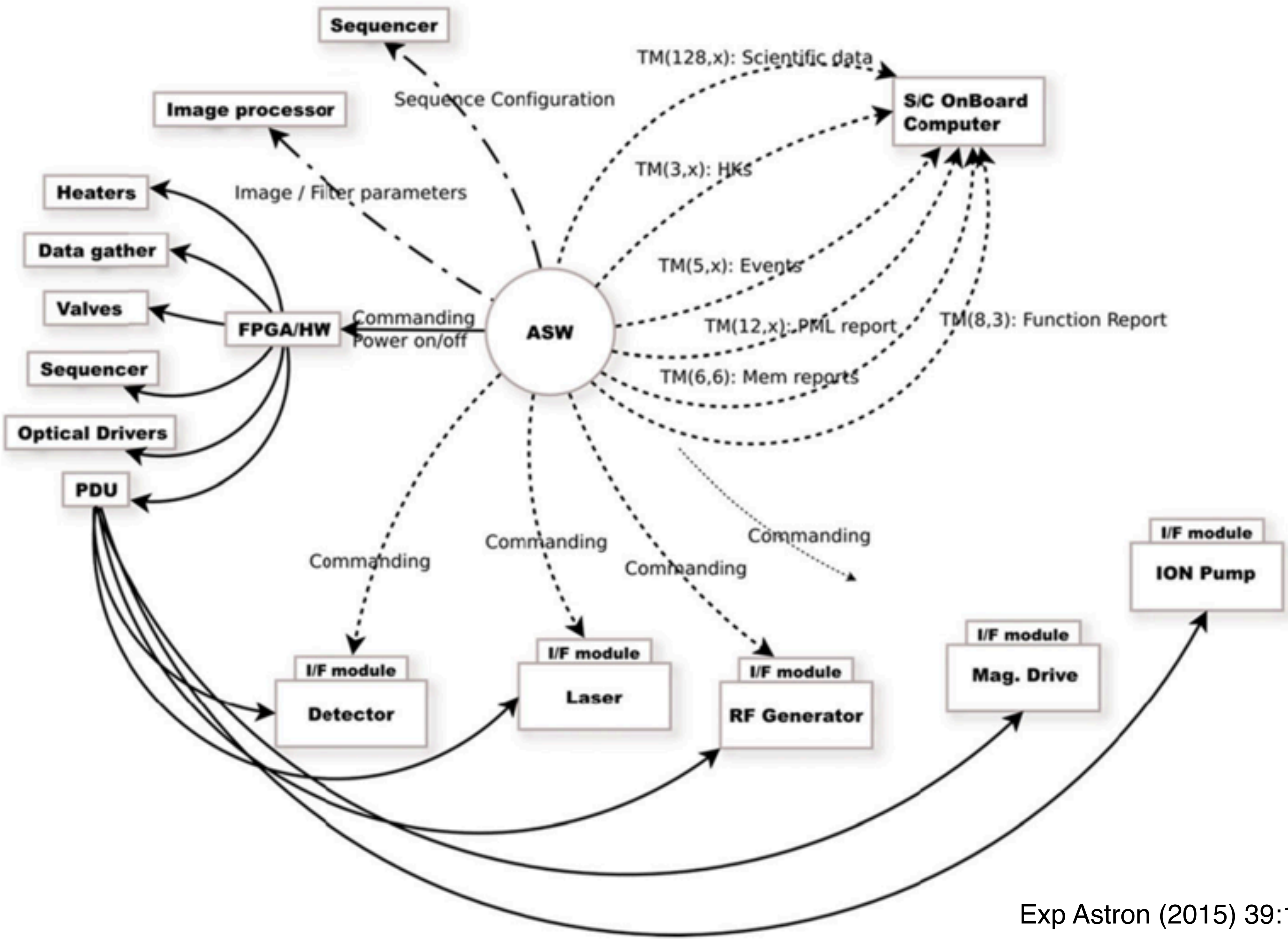
Monitor and charac. of test mass magnetic properties

Payload control and software

- Following the LPF heritage, the STE-QUEST proposal included a **DMU (Data Management Unit)**
  - Main digital control unit was based on the LEON processor developed under an ESA program – the **LEON 2** processor.
  - Also included data acquisition electronics and housekeeping systems. It includes e.g. interfaces to photodiodes monitoring the fiber harness, to thermistors and to the CCDs.

- In terms of software, the architecture was based on:
  - **Boot Software (BSW)**
    - assess and report on the overall DMU hardware health status,
    - establish a reliable communication link with the OBC,
    - check and provide access to RAM and EEPROM memory (where the ASW shall be stored),
    - allow remote patching of Application Software.
  - **Application Software (ASW)**
    - Handling of the AI subsystems
    - Computation of science data
    - System monitoring, including health status and Onboard Monitoring Function

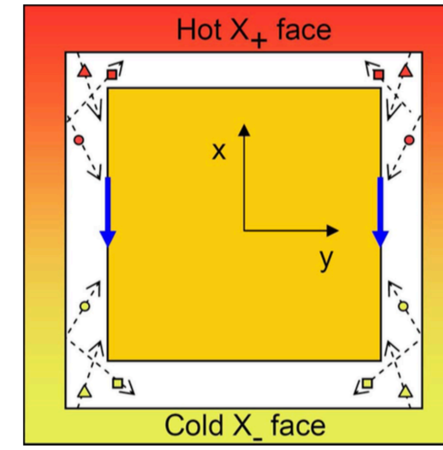
Payload control and software



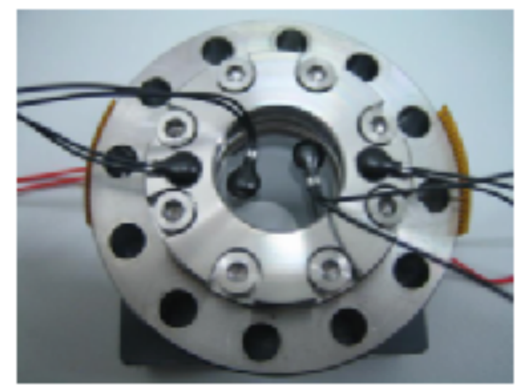
Exp Astron (2015) 39:167–206

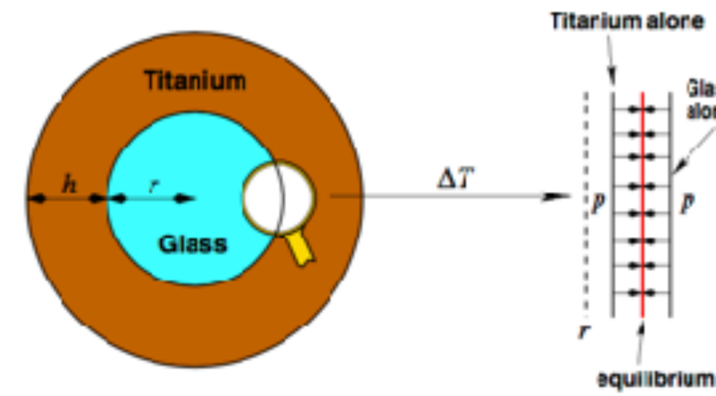
Temperature sensors (in LPF) — motivation

- Temperature variations are critical for space-based GW detectors, mostly because they are ubiquity in the **low frequency band**.
  - Notice: the following effects **should be minimised by design**.
  - Diagnostics should serve as **support to noise model** and/or **data quality**.
- In LPF, temperature gradients across the test mass induce
  - **Forces in the test mass.** Not directly applicable (in the same scale) to STE-QUEST.
  - **Temperature variations in optical elements** can lead to path-length changes**.** Could be relevant to STE-QUEST
  - **Path-length changes in the structure** holding the experiment inside the thermal shield. Relevant to STE-QUEST
    - “coils of the atom interferometer are allowed to change **260 nm** due to thermal expansion although they consume an average **power of 22 W**”. *Rev of Sci. Inst* ***85****, 083105 (2014)*

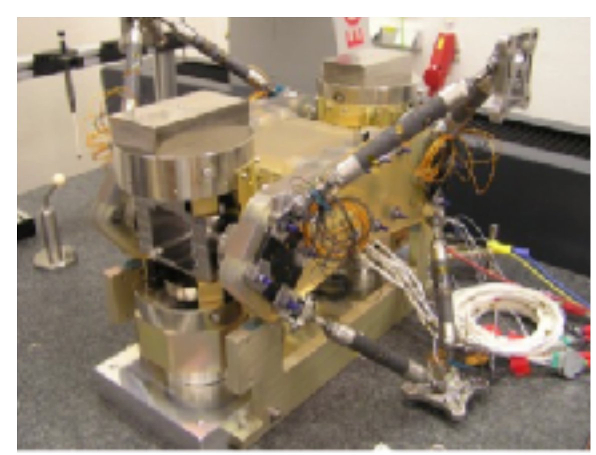


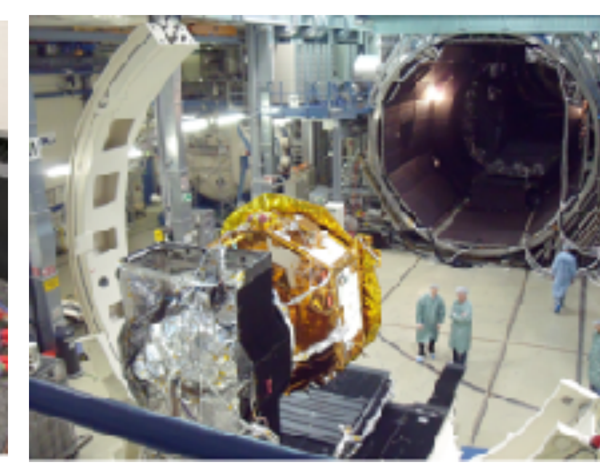
L *Carbone et al. Phys. Rev. D 76 (2007)*





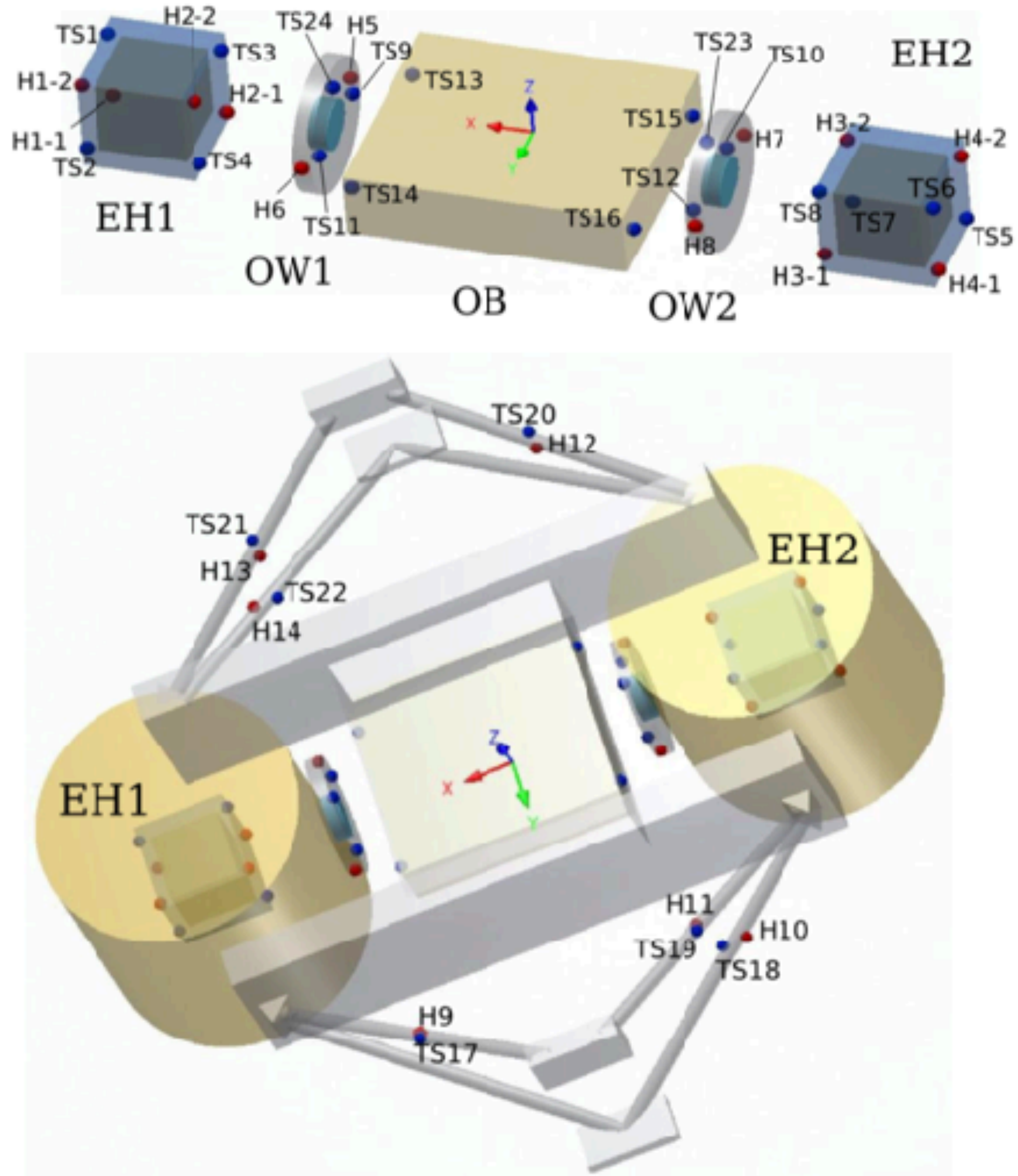
M Nofrarias et al. Class. Quantum Grav. 24 (2007)





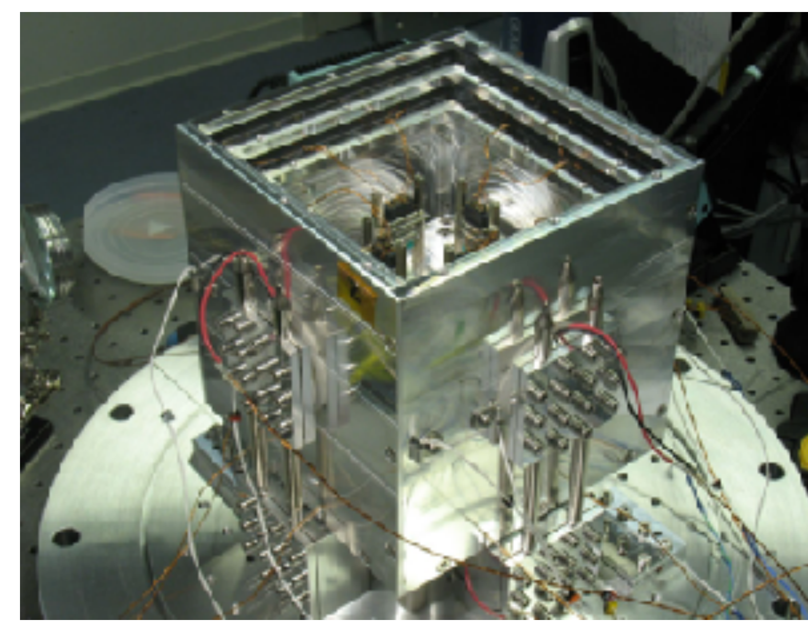
F Gibert et al. Class. Quantum Grav. 32 (2015)

Temperature sensors (in LPF) — motivation



Temperature read-out development

- Developing LISA temperature diagnostics subsystem under ‘Enhanced temperature measurement for LISA’ (LETS) **ESA contract**
  - Team: IEEC (ES), DLR (DE), SENER (ES)
- The objective is the design of a prototype temperature subsystem for LISA (**TRL4**)
  - Increasing 1 order of magnitude performance: **1uK/√Hz down to 1mHz**
- Two main components:
  - **Front-end electronics** composed by Analog Front-end Board (AFB), Power Distributing Board (PDB) and Digital Processing Board (DPB)
  - **Ultra-stable test bench** (DLR) composed by concentric Al thermal shield layers inside vacuum tank. Peltier elements for active control.
- Current status:
  - Achieved **sensitivity compatible with LISA in most of the band**. Studying low frequency excess noise.



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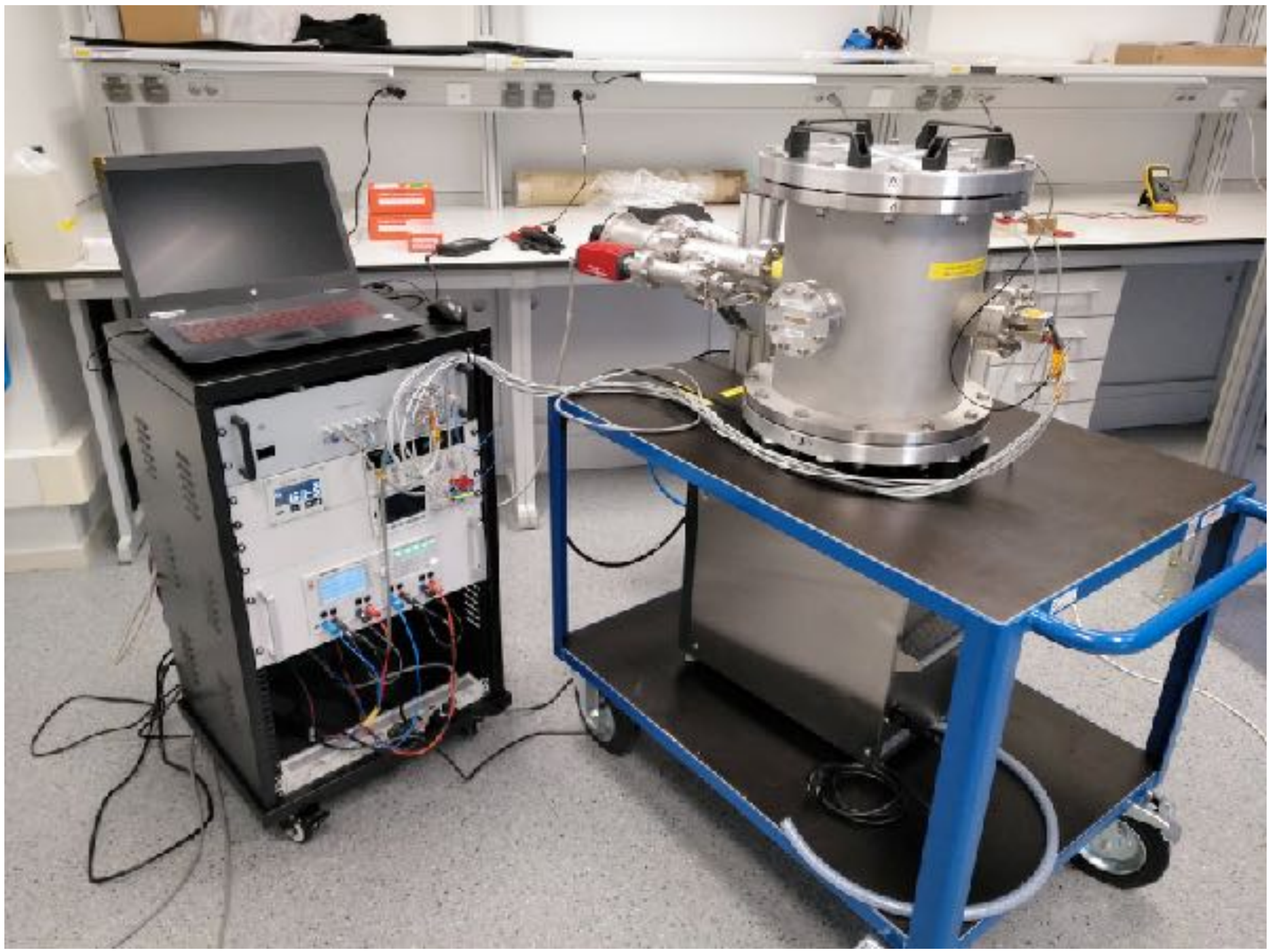
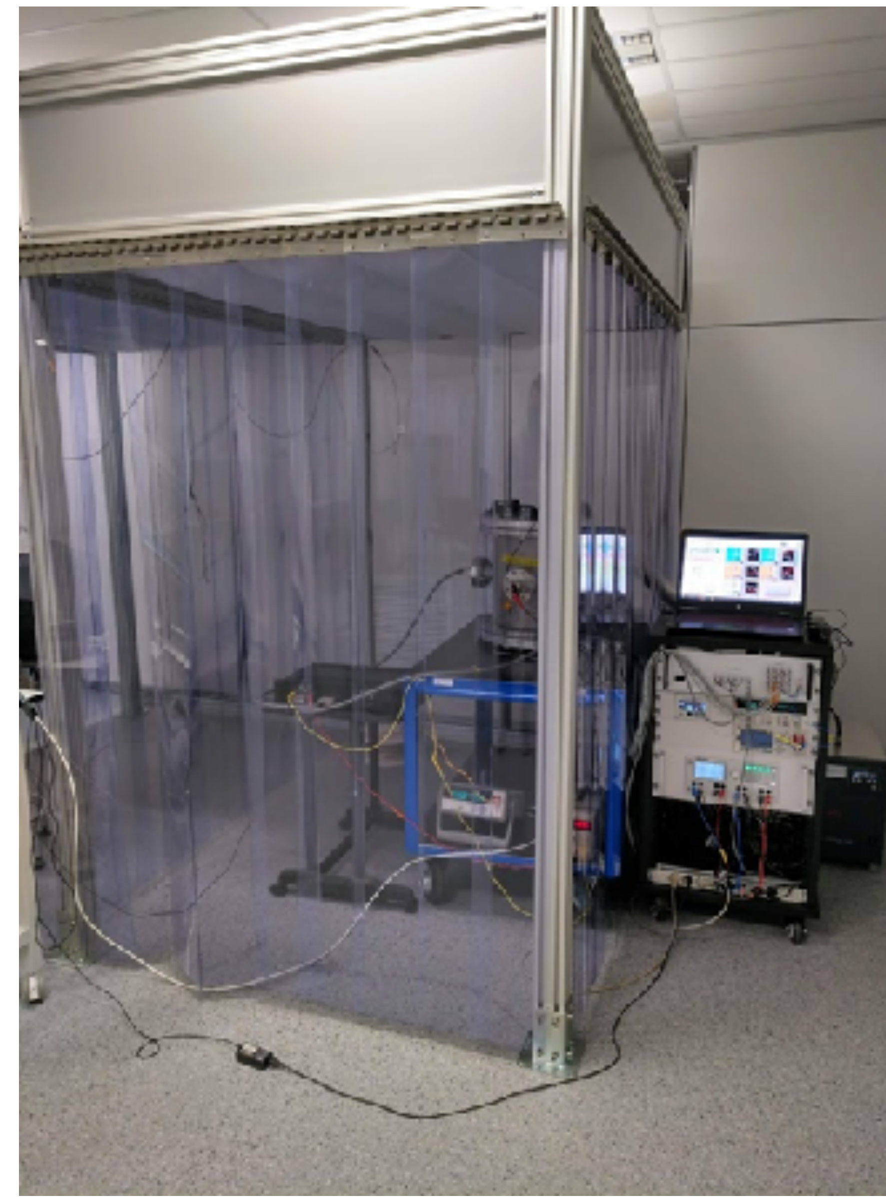
Temperature read-out development

- Setup running inside temperature control cabine (±5mK stability)





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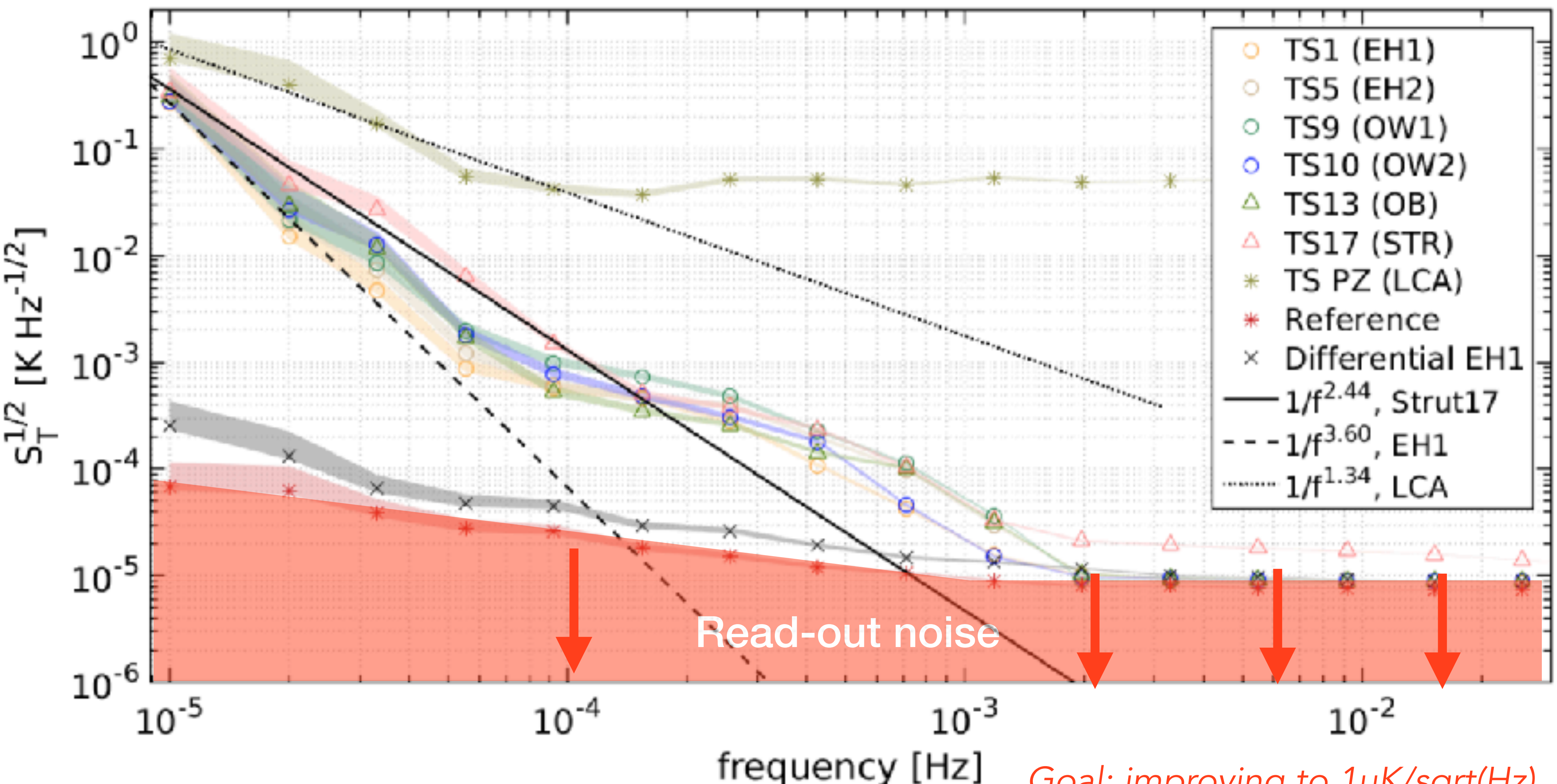
Temperature read-out development



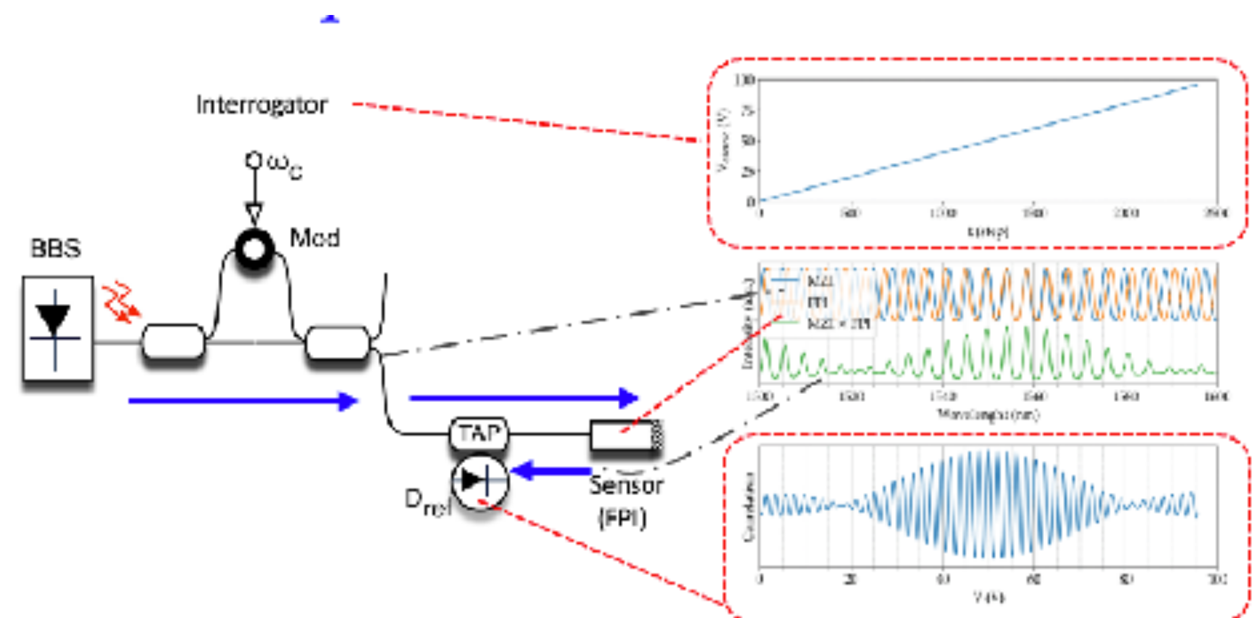
Goal: improving to 1uK/sqrt(Hz)

Armano, M et al. 486 MNRAS (2019)

Temperature read-out development

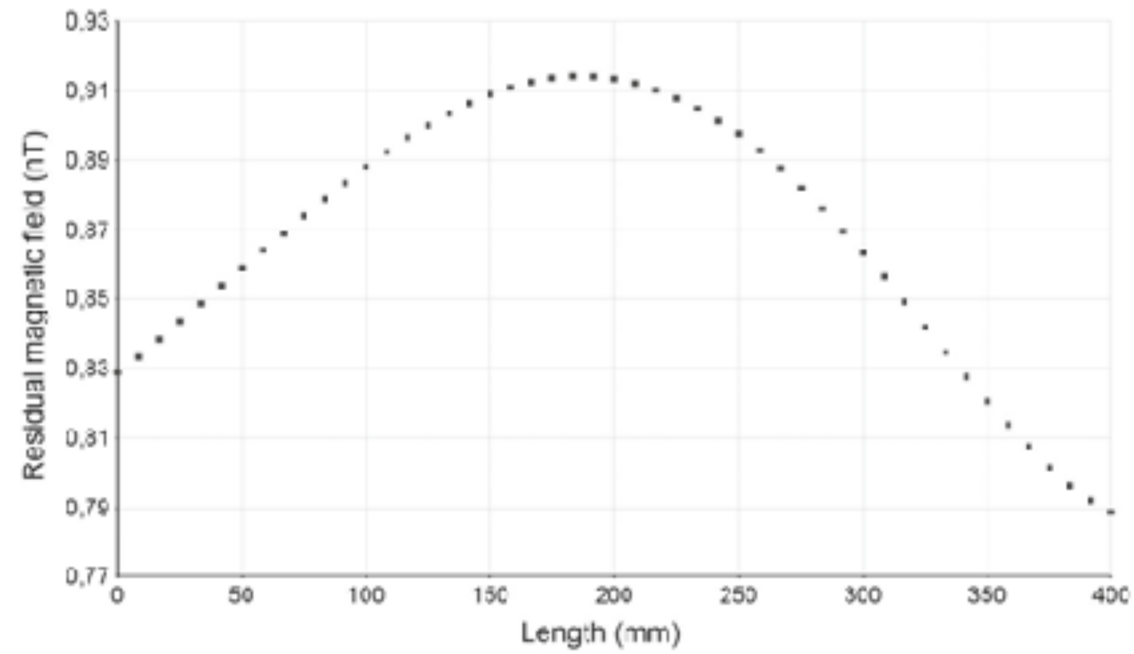
- Developing temperature diagnostics subsystem under '*Optical Fibre Micro-Kelvin Temperature Sensor Network for Sensitive Optical Payloads*' under **ESA contract**
  - Team: IEEC-ICE (ES), INESCTEC (PT)

- The objective is the design of a prototype temperature subsystem (**TRL4**) using optical fibers
  - Same requirement as before (1uK/√Hz down to 1mHz) but **using optical fibers**
  - **Avoiding, for instance, spurious magnetic fields close to the experiment**
- The current baseline is based on a **time-of-flight measurement** between FP-sensor and FP-stable reference.
- Current status:
  - Passed PDR, moving to DDR (Detailed Design Review)

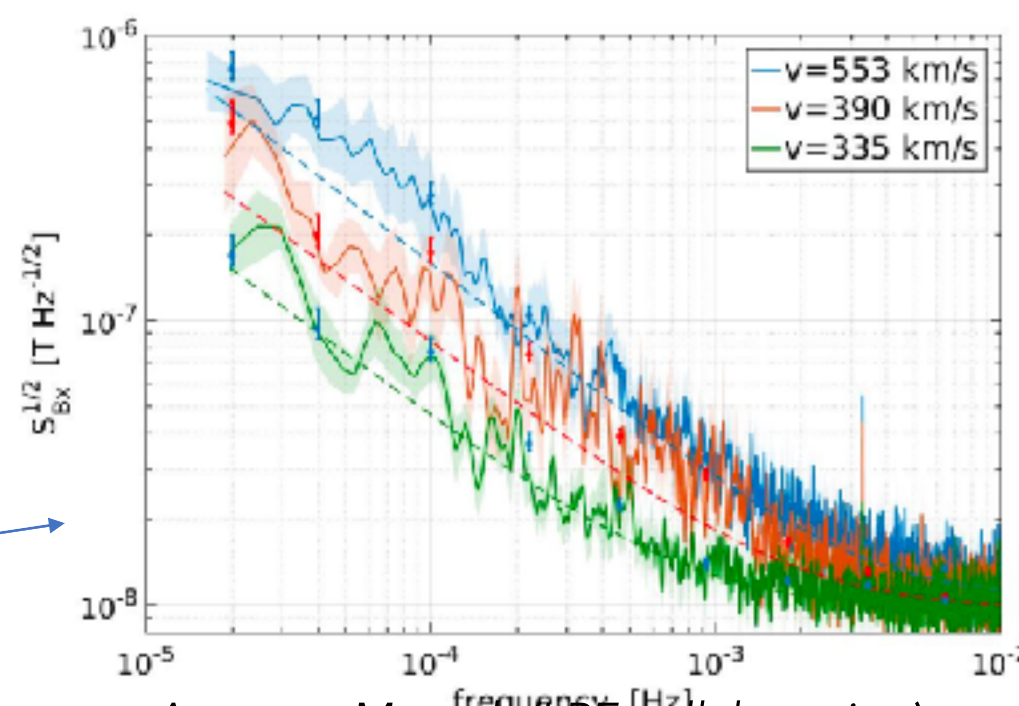


Magnetometers — motivation

- In STE-QUEST monitoring and control of the magnetic field is more prominent than, for instance, in LISA PAthfinder.
  - Still, in both cases stray magnetic fields are a source of **spurious acceleration**.
- In STE-QUEST, the baseline is
  - **4-layer mu-metal** configuration
  - Active (low frequency, >1s) **compensation coil**
  - **Magnetometers** (AMR-like)
  - **Degaussing coils** (~mT) to avoid residual magnetic field induced by the mu-metal
- In LISA PAthfinder, the test mass acts as a magnetic dipole. Magnetic field and magnetic field gradients can induce **forces in the test mass**
  - The dominant contribution couples **local gradients** with **interplanetary fluctuations** $\langle S_B \cdot \nabla B_{DC} \rangle$
- Notice that magnetometers on-board must monitor **two components**



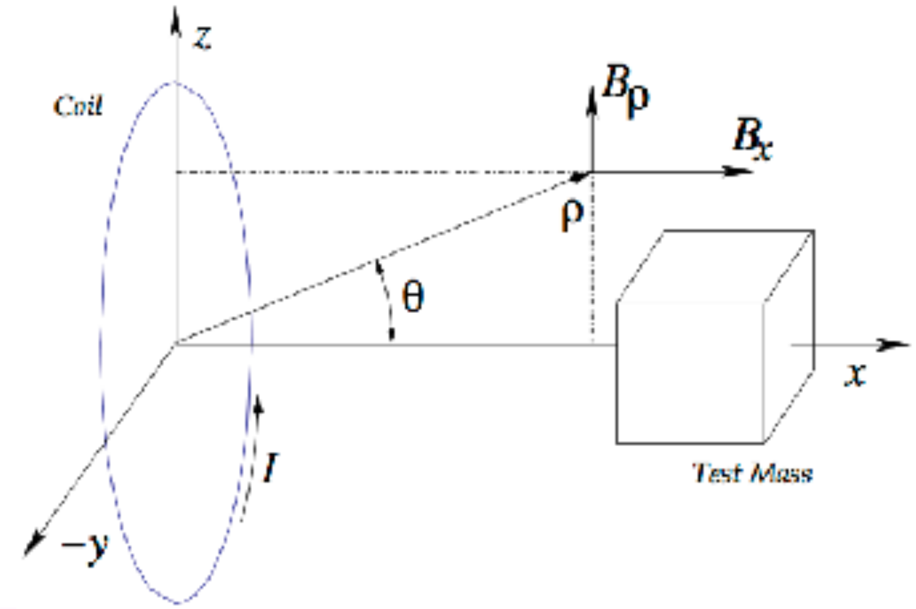
Milke, A., et al. Rev. Sci. Rev. Sci. Instrum. 85, 083105 (2014)

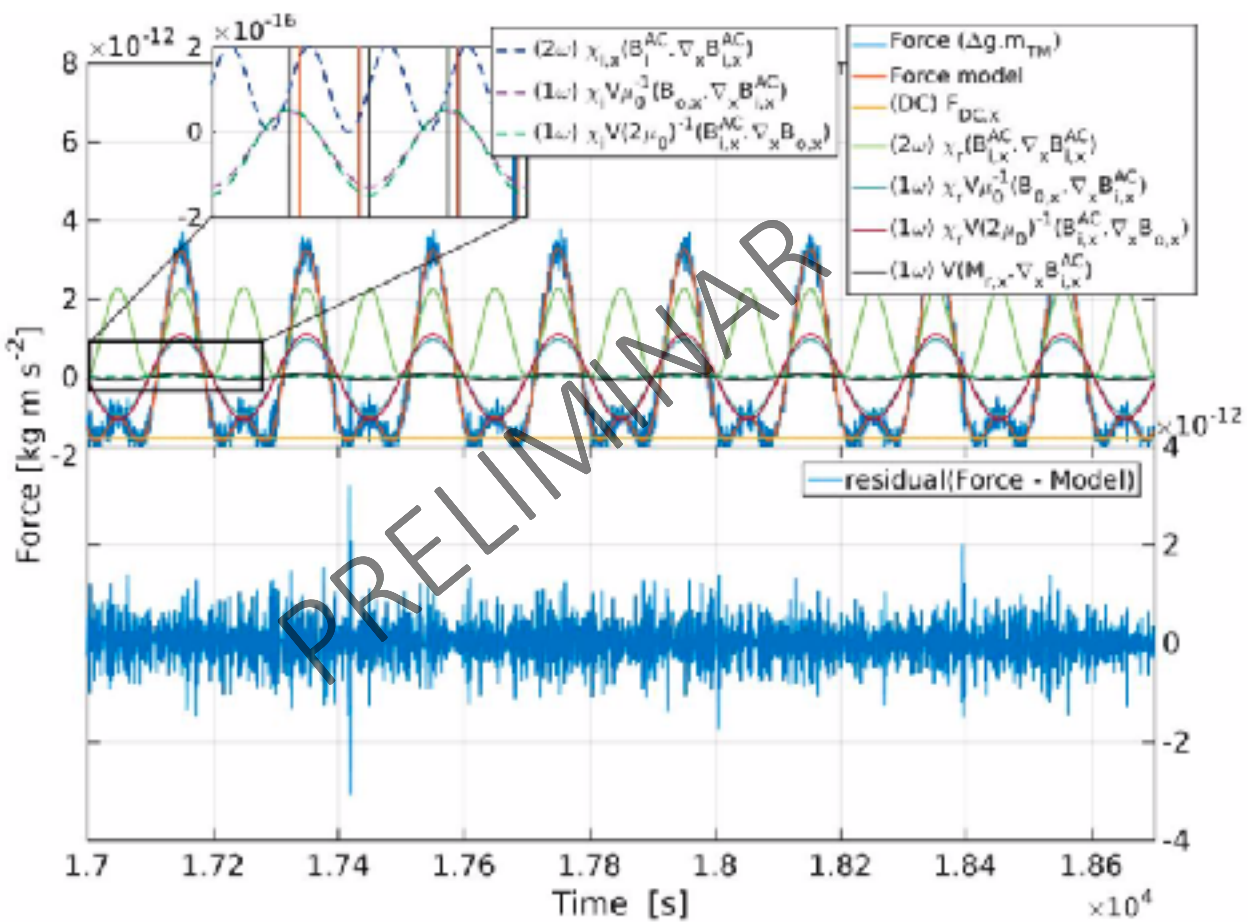


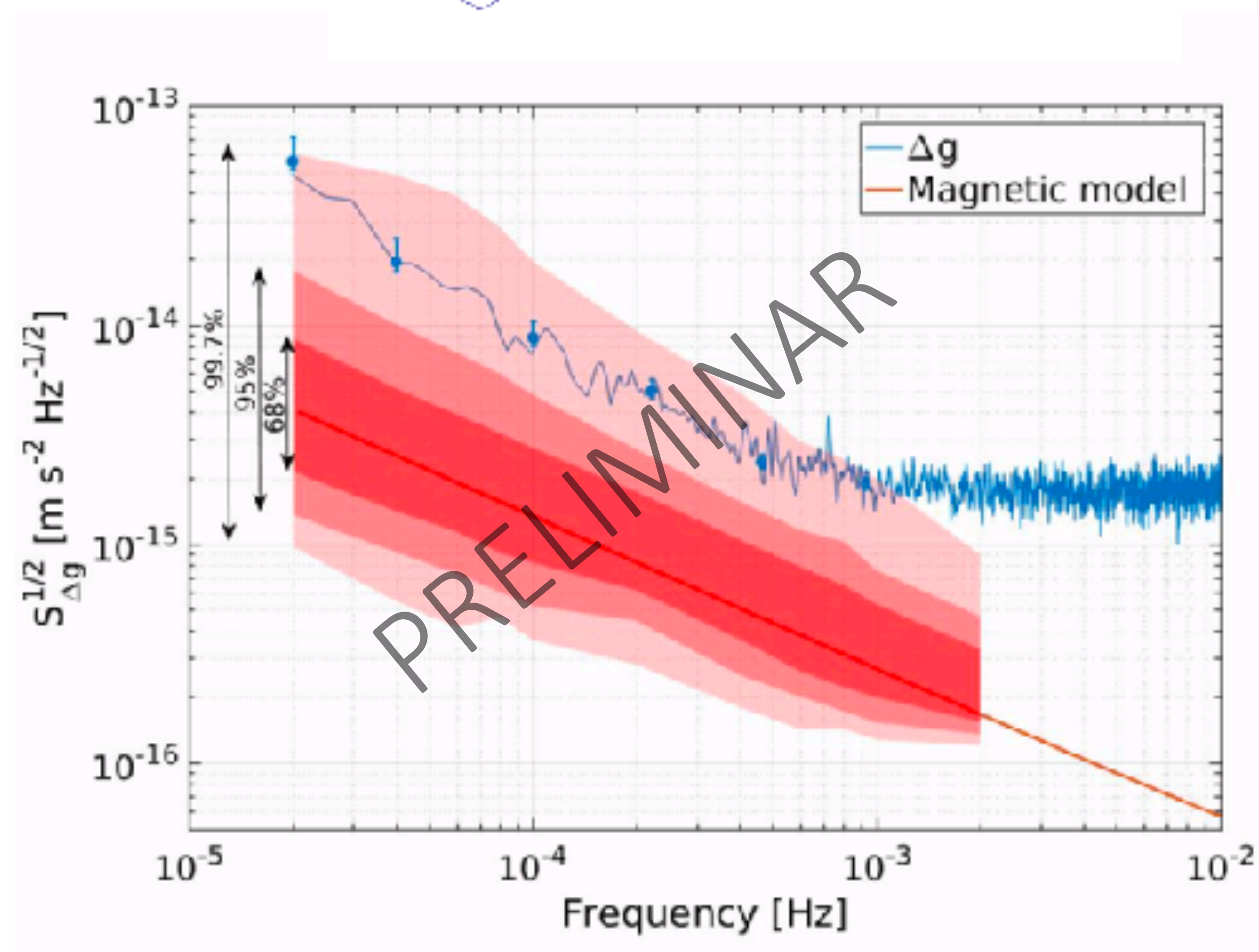
Armano, M et al. (LPF collaboration) 494 MNRAS (2020)

In-flight magnetic experiments in LPF

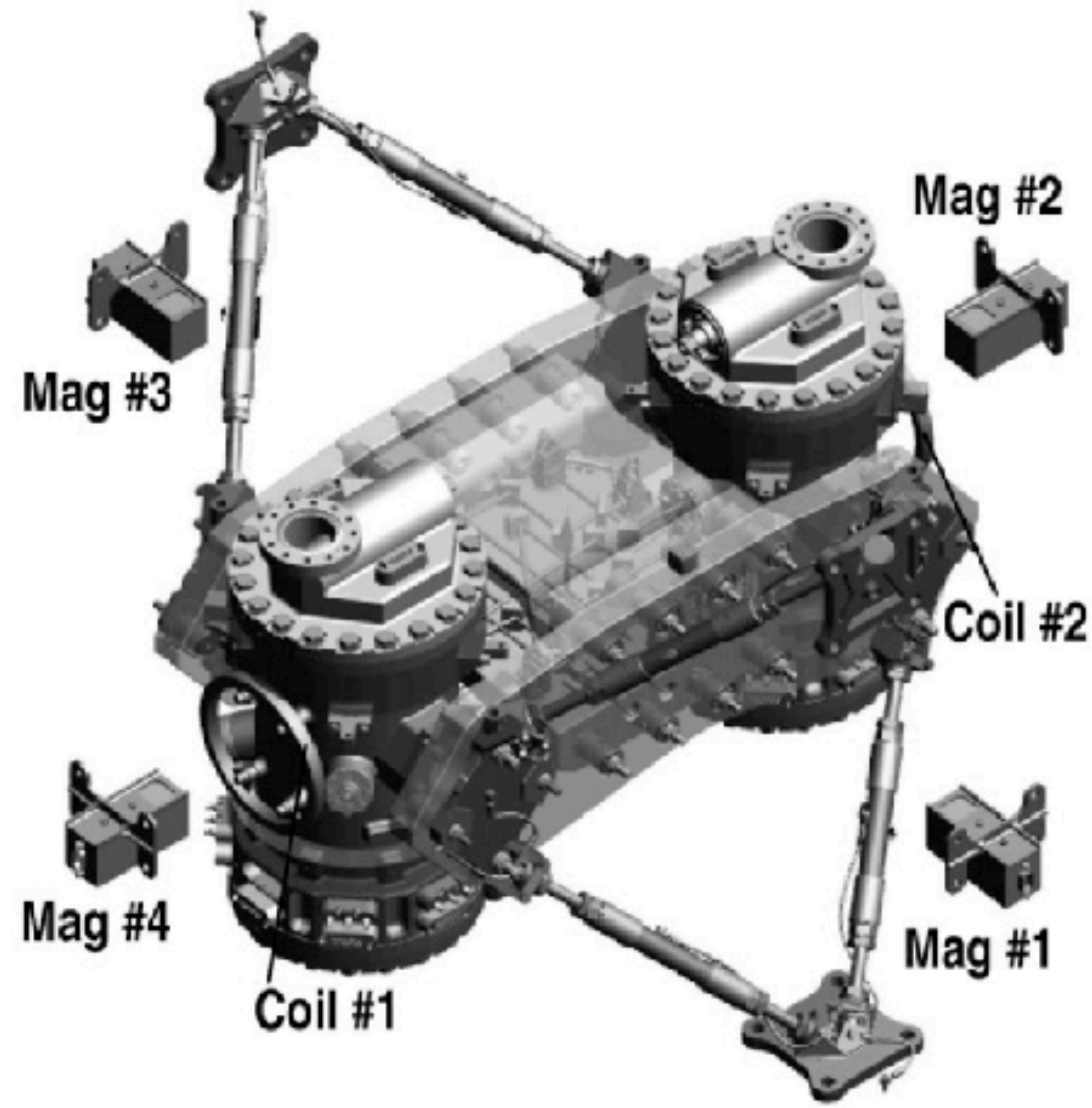
- In LISA Pathfinder, magnetic force noise contribution was characterised in-flight.
  - Scheduled experiments with coils to obtain magnetic relevant parameters and derive magnetic force noise projection





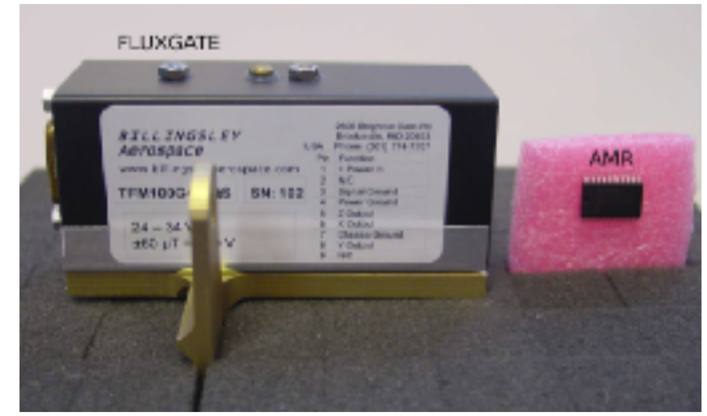


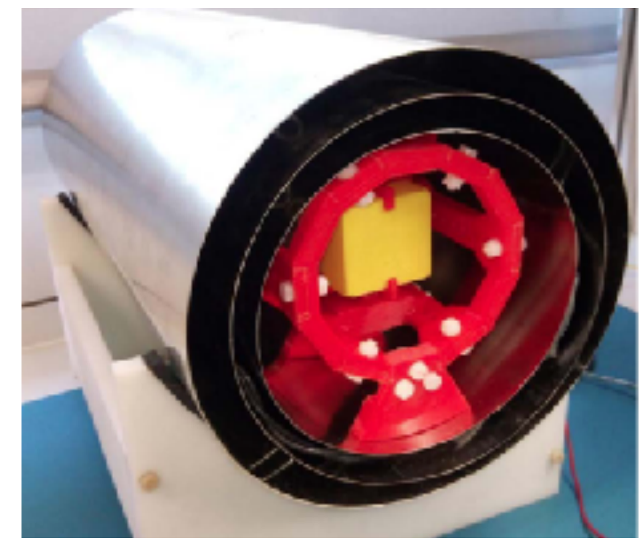
Magnetometers (in LPF) — motivation

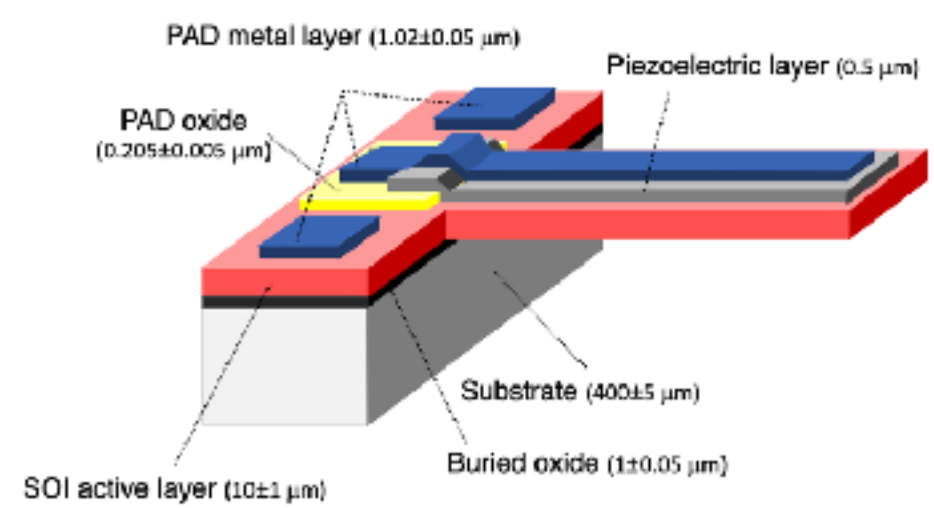


Magnetometer read-out development

- IEEC developed an improved magnetic diagnostic system more compact and avoiding back-action problems
  - based on **Anisotropic magneto-resistors (AMR),** solid-state, low noise magnetic sensors.
  - AMR is a compact, hence improves magnetic field **spatial resolution**
  - Reduction of power needed: AMR (20mW) vs. Fluxgate (1W)
- In order to achieve the required performance, some noise reduction techniques are applied
  - **Flipping**: applying set/reset pulses to keep magnetic moments aligned. Also removing bridge offset and drifts at low frequencies
  - **Electro-magnetic feedback**: aims to maintain bridge output near, to compensate bridge sensitivity gain due to thermal fluctuations.
- Current implementation **fulfils req. LISA performance**
- Developing an alternative compact magnetometer based on MEMs (reducing further sensor power dissipation)
  - Magnetic field modulation, using MEMs resonators and high permeability layers, to mitigate 1/f noise
  - TMR used as sensing device

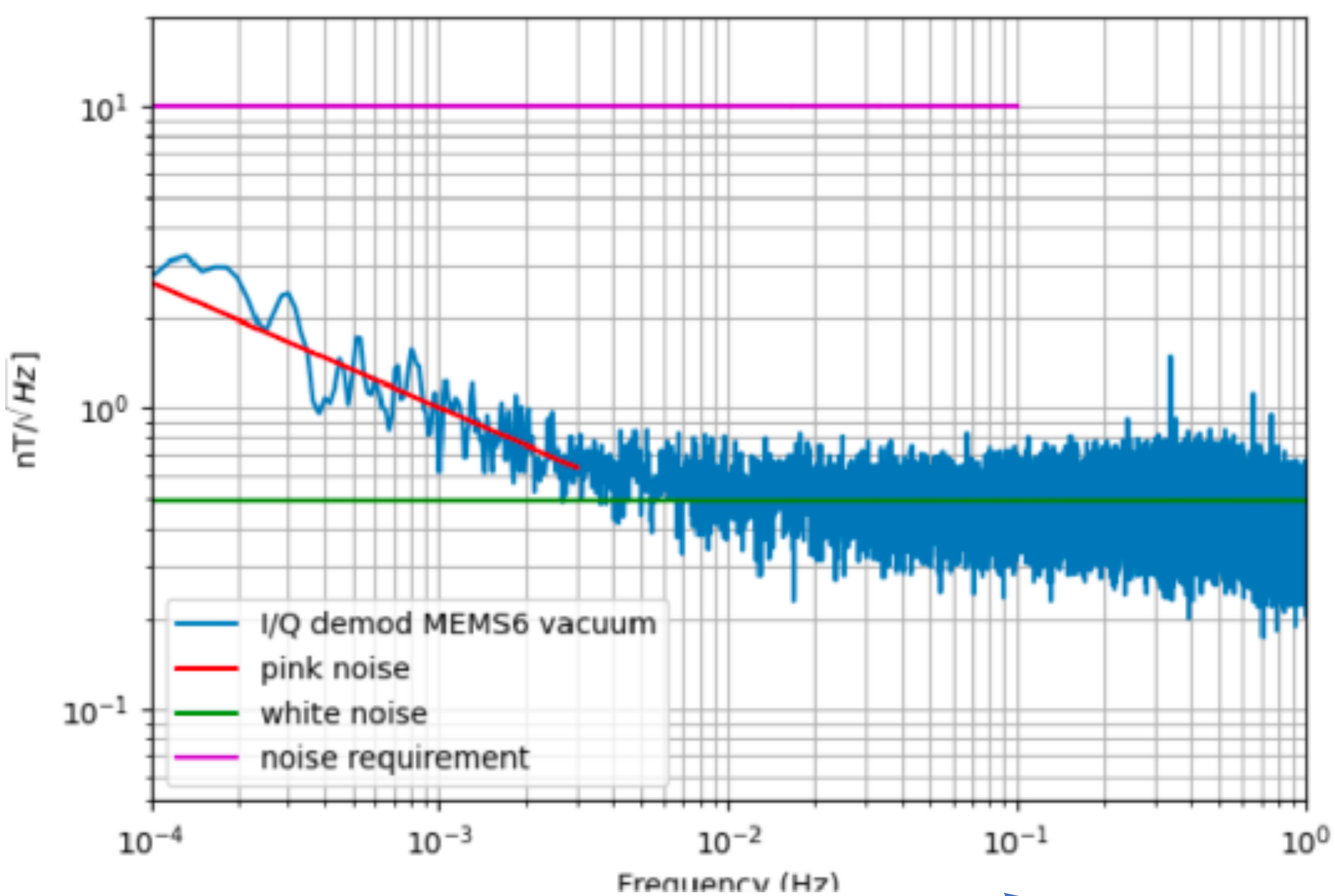


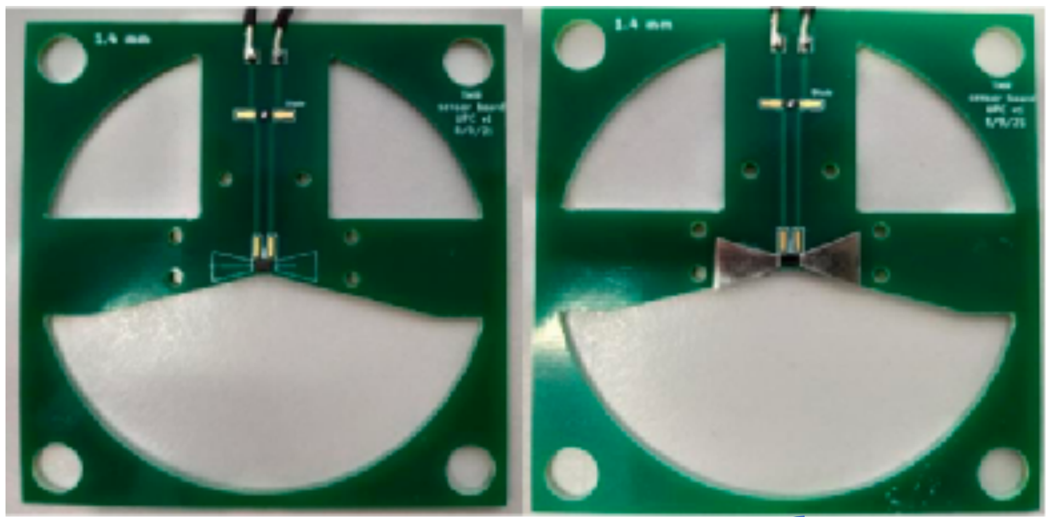




Magnetometer read-out development

- MEMs based solution tested in representative environment, achieving ≲ 1nT/√Hz @ 1mHz
  - interplanetary magnetic field fluctuations are typically above (10 nT/√Hz @ 1mHz)

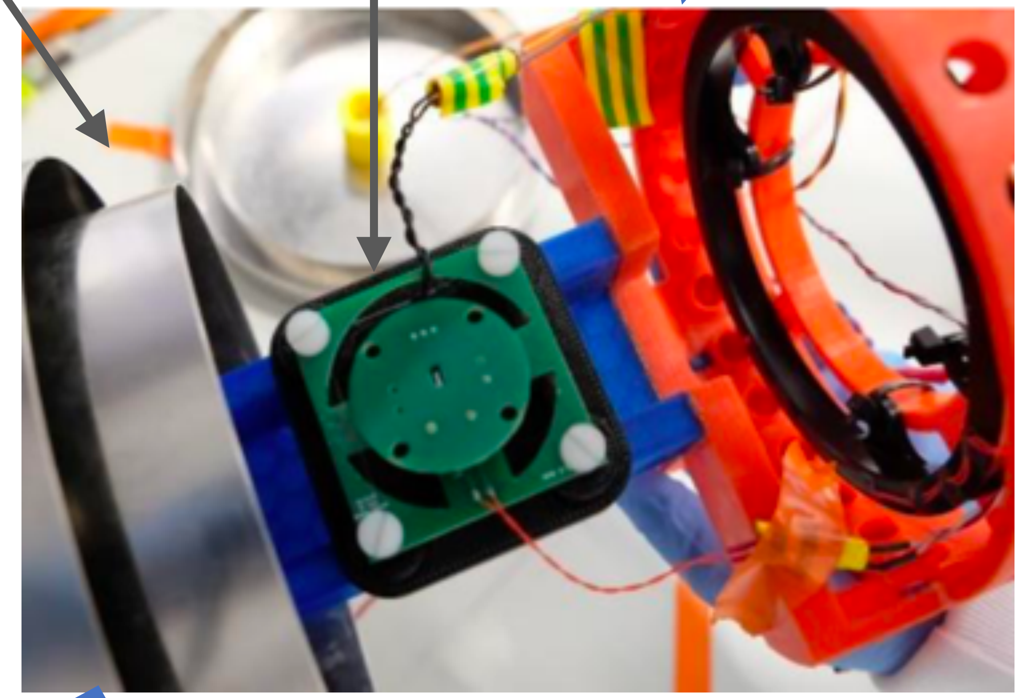




MU-METAL

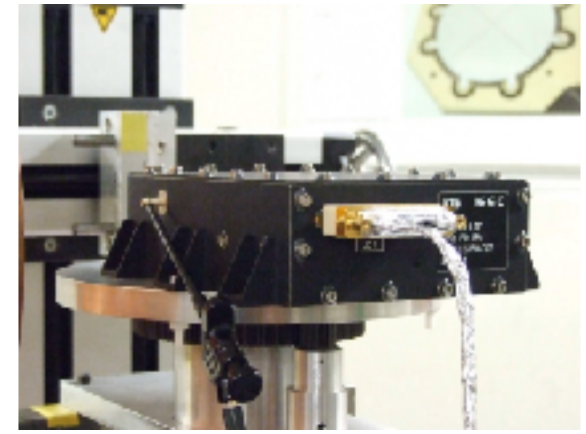
SENSOR

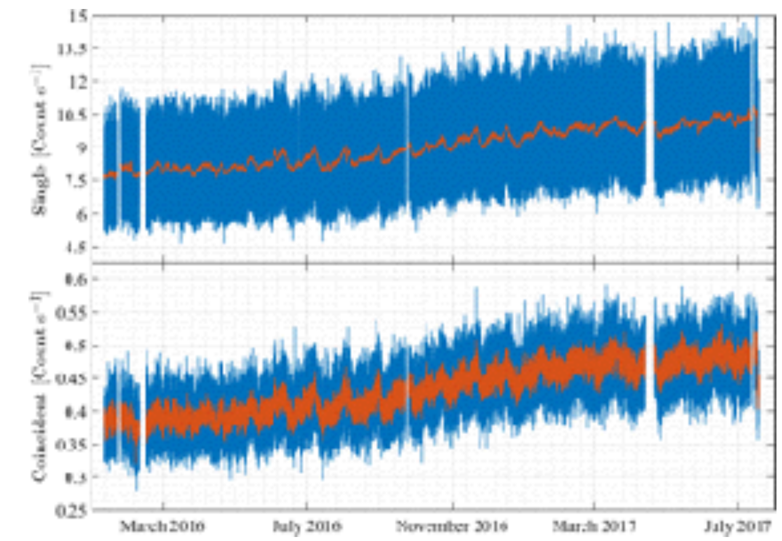
CALIBRATION COIL



Radiation monitor (in LPF) — motivation

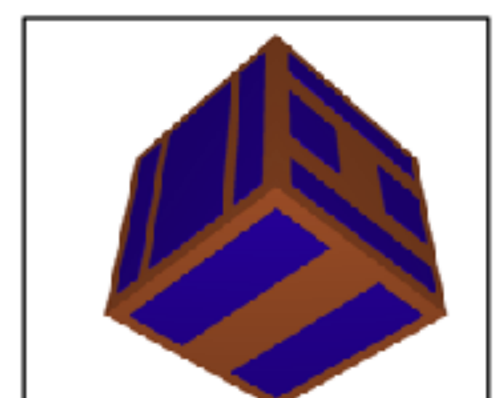
- In LPF, high energy environment responsible for **test-mass charging**
- **In LPF/LISA, two main mechanisms need monitoring**
  - **Galactic Cosmic Rays (GCR)**
    - nearly constant low-level charging rate
    - flux modulation: interaction isotropic flux at heliosphere boundary and solar wind (inducing 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.
- IEEC provided the radiation monitor for LPF
  - was a simple particle counter for particles with **E > 70 MeV** (no capabilities for particle discrimination).
- IEEC is currently running simulations with **PENELOPE** (able to resolve electrons down to 100 eV) to study/optimise the LISA radiation monitor





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

Geometry under study (PENELOPE)



Summary

- Following M3/M4 proposal, Data and Diagnostics Subsystem in STE-QUEST main aims are:
  - payload processing and control
  - provide precision diagnostics to support data analysis and/or provide data vetoes
- A lot of heritage already existing from LISA Pathfinder and also synergies from current developments towards LISA.
- Still, a lot of work ahead in optimising how this subsystem can be optimised to provide the essential diagnostic information to the mission.

Thanks for you attention