Status of the LISA Data and Diagnostics Subsystem

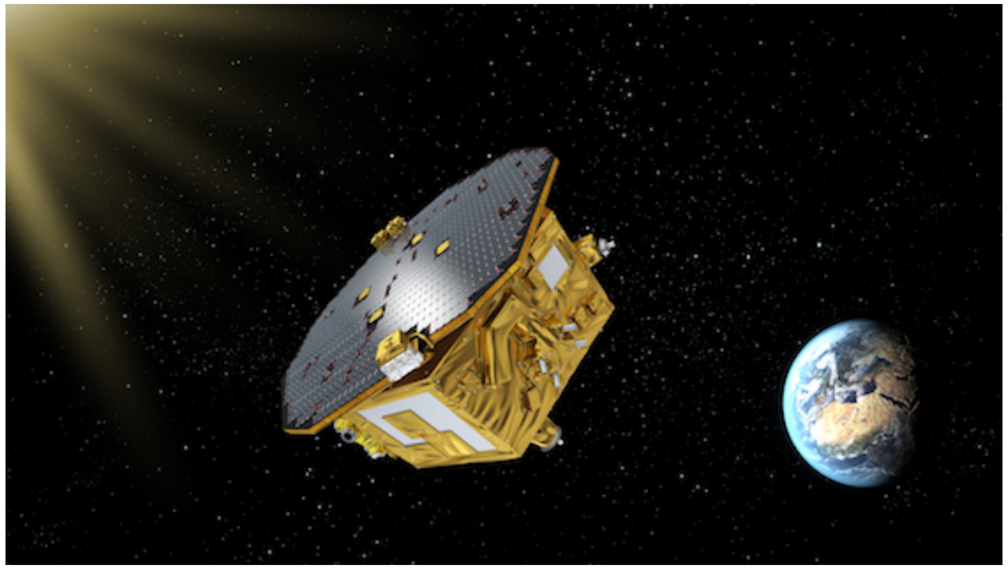
Miquel Nofrarias

Iberian Gravitational Wave Meeting, June 10th 2021

IEEC
Institut d'Estudis
Espacials de Catalunya

Organisation

- Funding **approved** for the period 2020-23
- Focused on academic activities
  - *Industrial contribution derived to PRODEX call*
- More groups involved at the IEEC institute, both in experimental and theoretical fronts
  - *Team: 12 staff researchers (2 Science +10 Instrument), 2 staff managers, 5 senior engineers, 4 post-docs, 3 PhD students*
  - *Extensive experience in space instrumentation*



Spanish Mission Lead

Carlos Sopuerta (IEEC-CSIC) – PI

- LISA Science Study Team
- Consortium Board (Spanish representative)

Miquel Nofrarias (IEEC-CSIC) – co-PI

- LISA System Engineering Office (SEO)
- LISA Instrument Group (Spanish representative)

MINISTERIO DE CIENCIA E INNOVACIÓN

CDTI

LISA Science Group (LSG)

C. F. Sopuerta (IEEC-CSIC) - Spanish lead

C. Giardini (IEEC-UB)

PhD Student(s):

D. Cruces (IEEC-UB)

I. Martin (IEEC-CSIC)

Management Team

Josep Colomé (IEEC-CSIC) – NPM

- National Project Management Board

Alberto García (IEEC)

INDUSTRIAL PARTNER(S)

LISA Instrument Group (LIG)

Data and Diagnostics Subsystem (DDS) M. Nofrarias – Spanish lead

Diagnostics Team

IEEC-CSIC
C. Sierra
D. Roma
JP. López

IEEC-UPC
J. Ramos
M. Domínguez
V. Jiménez
A. Orpella
J. Pons

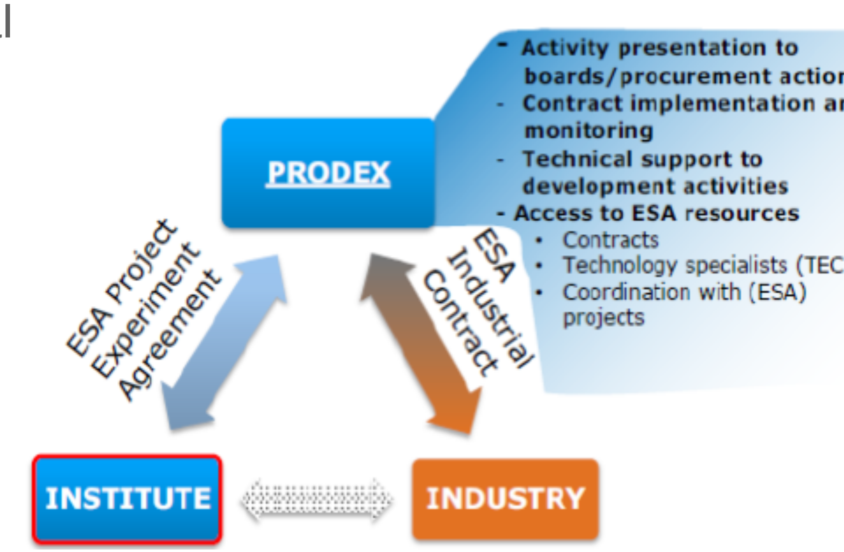
IEEC-UB
A. Herms
D. Gascón
F. Salvat
E. Graugés
A. Arán
D. Sánchez

Instrument Control Computer Team

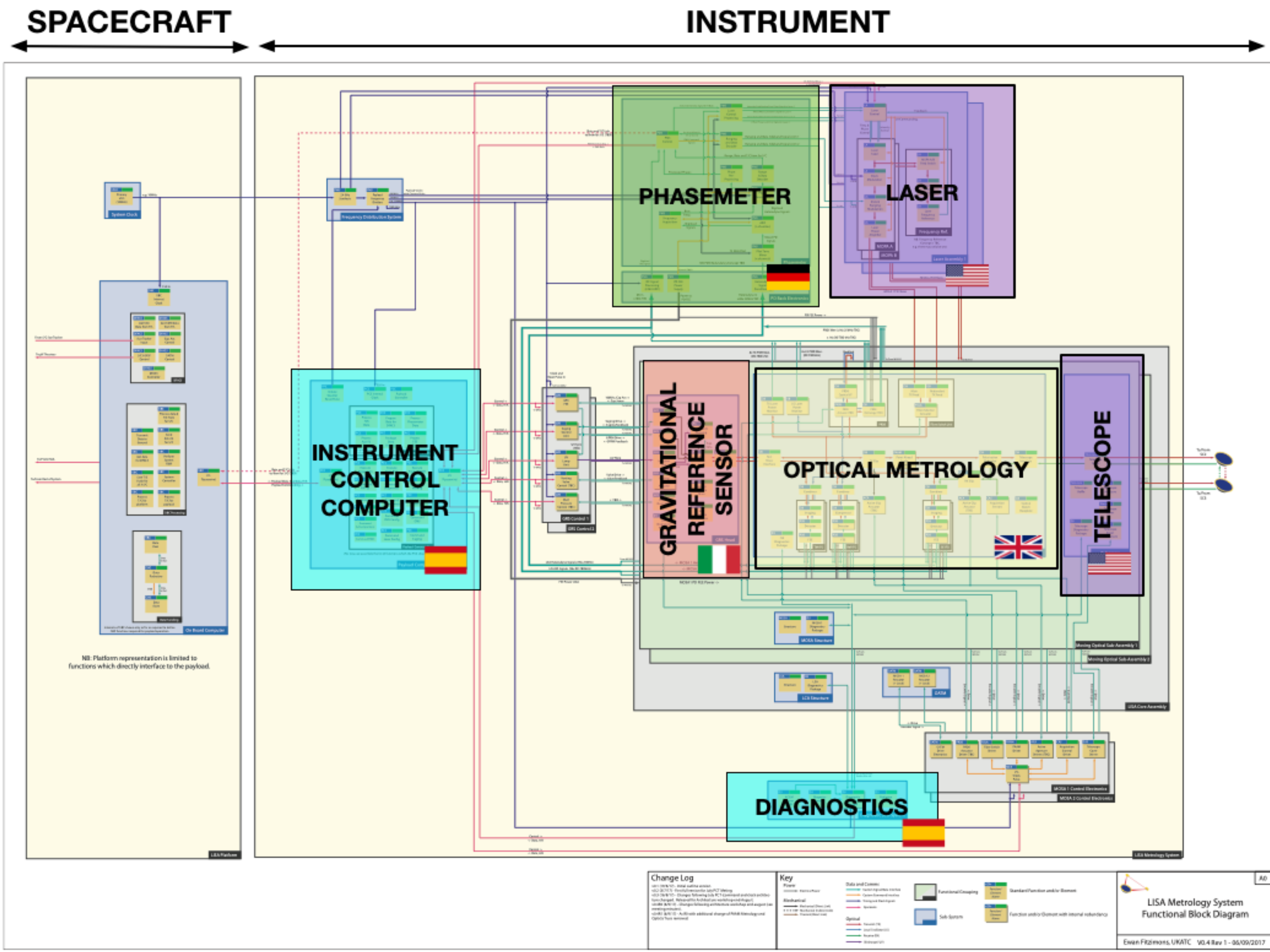
IEEC-CSIC
C. Sierra
D. Roma
V. Martin

Organisation - PRODEX

- New instrument for space missions: PRODEX
  - Approved in the last CM19: 30 M€
  - Complement the research program and coordinate the academic and industrial activities
  - **Focused on the industrial contributions**
  - Increase the stability of the Spanish contribution to the scientific missions
- Presented LISA phase A study in the first call (2021)
  - Proposal lead by Sener Aerospacial.
    - *IEEC key partner*
  - Type A: phase A
  - Duration: 12 months
  - Financial proposal: 299 k
- Scope
  - Boost Spanish contribution to the Diagnostics Subsystem, as the core element of the LISA Payload lead by Sener Aerospacial.
  - Key technologies
    - A feasible concept for the **sensors front-end electronics** to achieve the needed low-noise performance while minimizing the thermal impact on the MOSA
    - An architecture definition for the Payload **Data Processing Function** (SW, HW, FW) fulfilling the overall payload needs, and the data processing requirements towards the formation flying management (3 satellites constellation)
  - Intended to consolidate the **Spanish Industry contribution** to an L-Mission as LISA technologies
- Letter of support from LISA Consortium



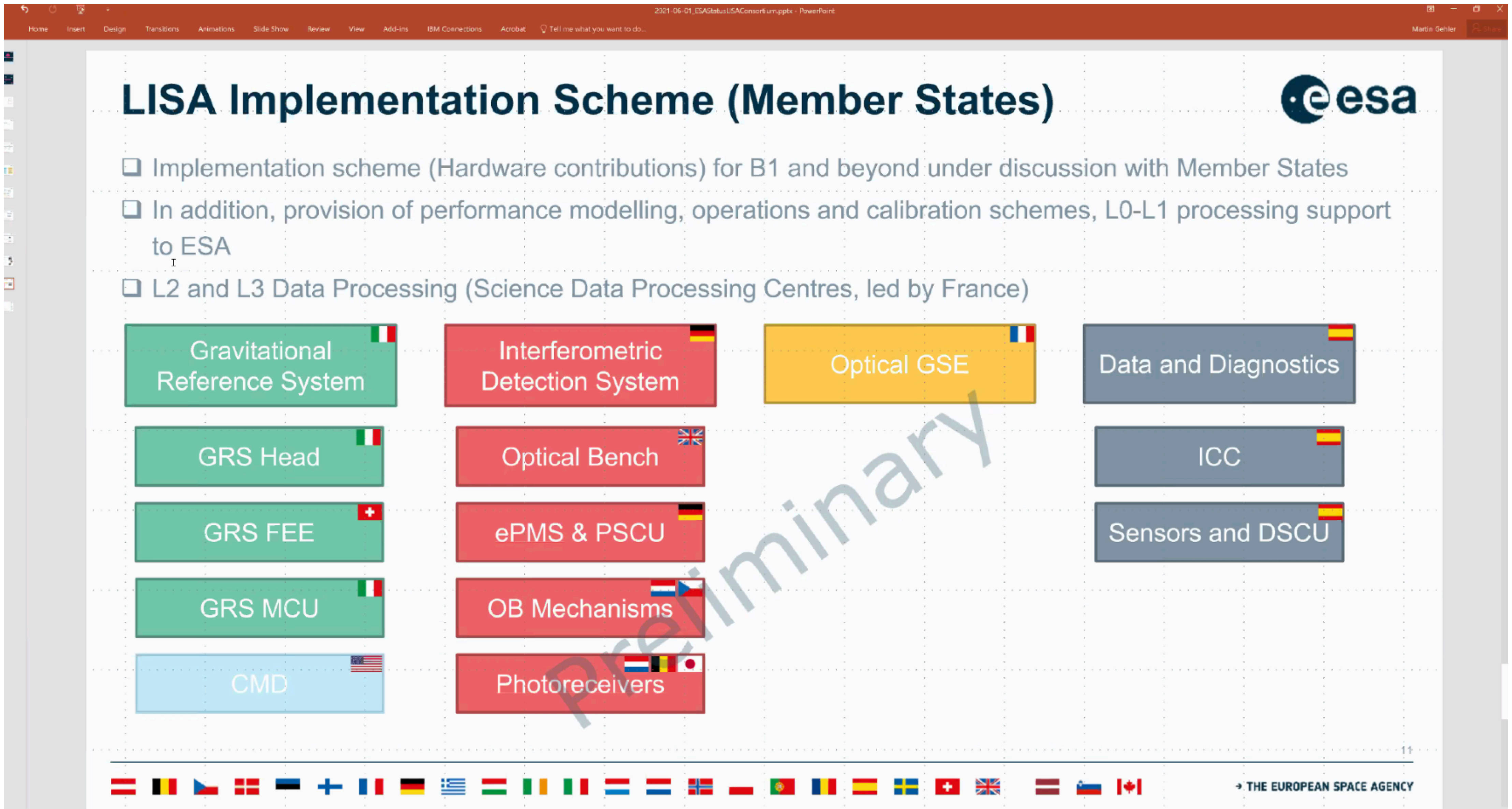
Aeroespacial



SPACECRAFT
INSTRUMENT
PHASEMETER
LASER
INSTRUMENT CONTROL COMPUTER
GRAVITATIONAL REFERENCE SENSOR
OPTICAL METROLOGY
TELESCOPE
DIAGNOSTICS
NB: Platform representation is limited to functions which directly interface to the payload.
Change Log
Key
LISA Metrology System
Functional Block Diagram
Ewan Fitzsimons, UKATC V0.4 Rev 1 - 06/09/2017

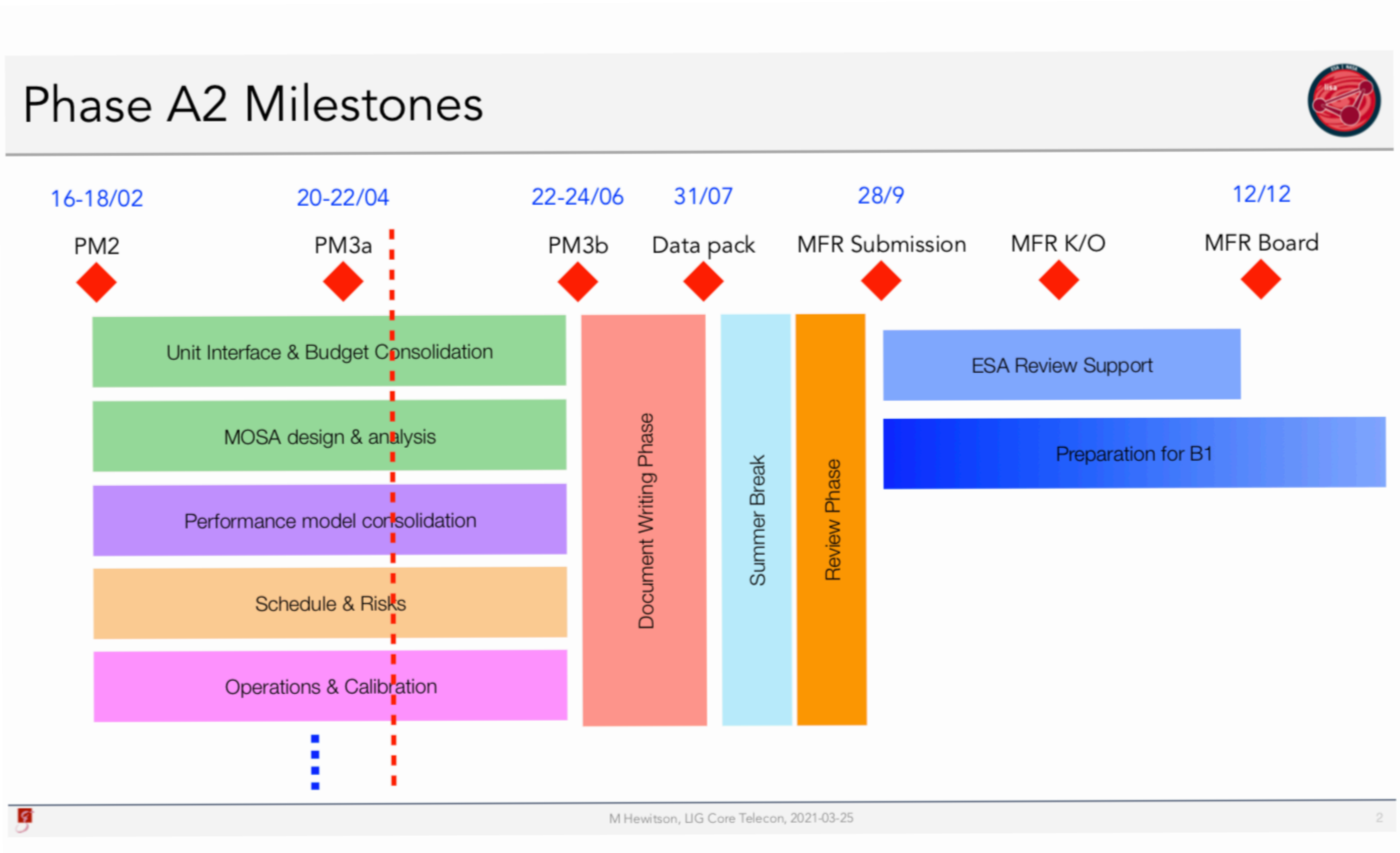
Hardware implementation scheme

- Consolidation of the Spanish role (at the current stage)



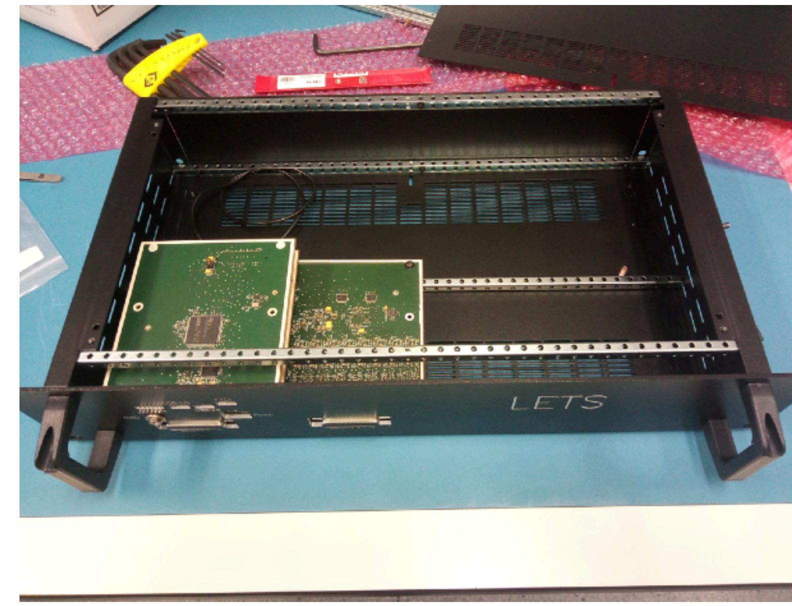
M. Gehler (LISA Study Project Manager) slide, LISA Consortium, June 2021.

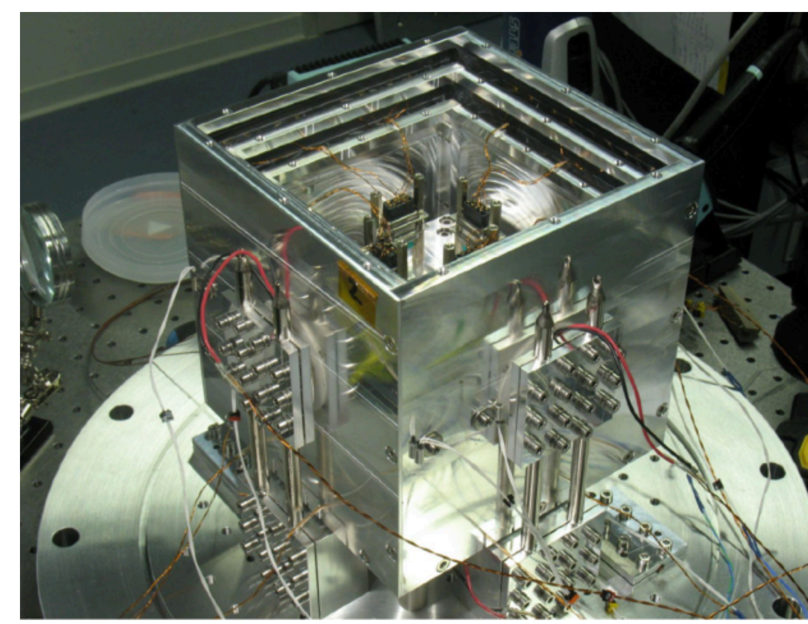
LISA Phase A schedule



LISA — temperature diagnostics subsystem

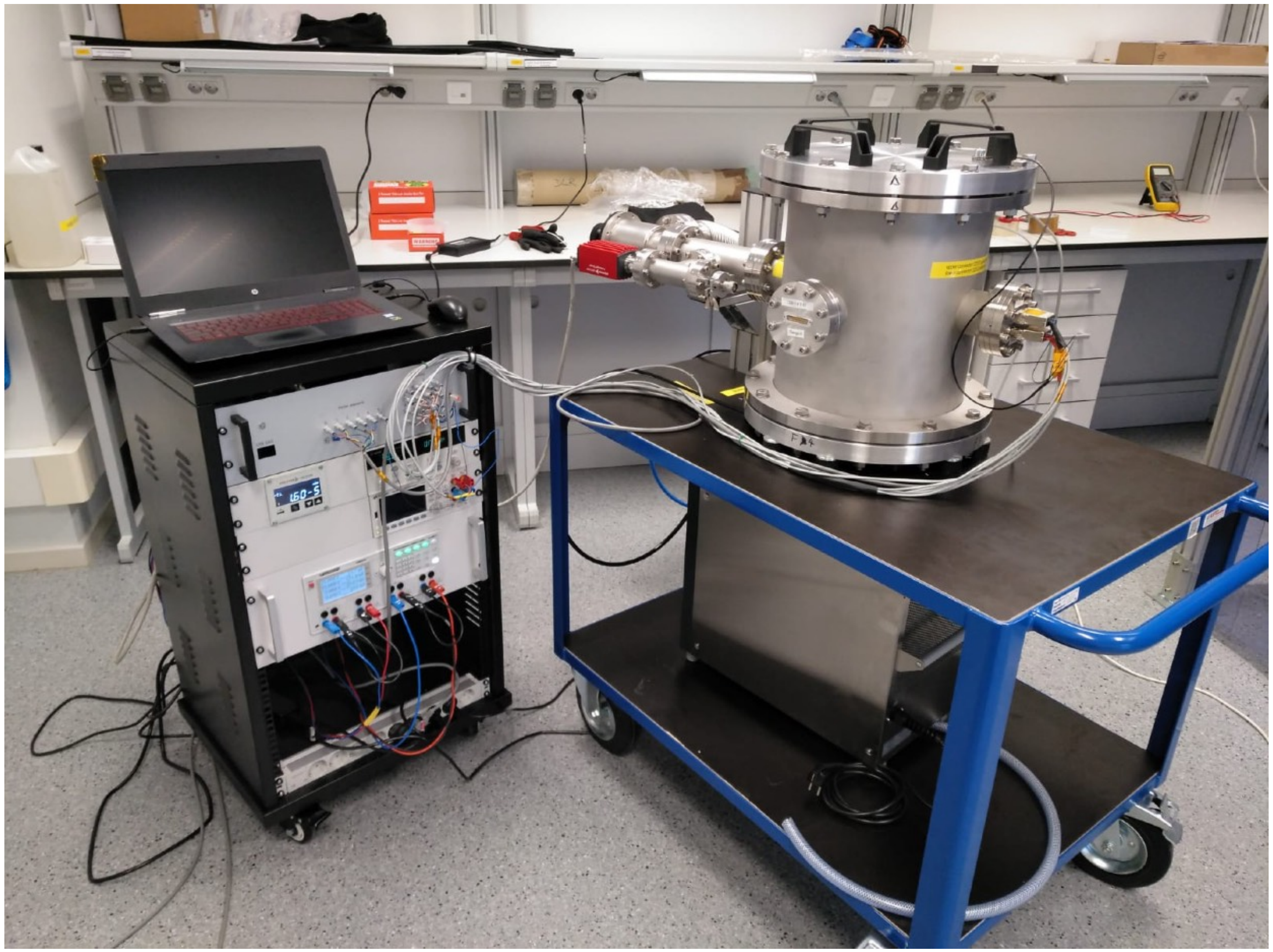
- Developing LISA temperature diagnostics subsystem under **‘Enhanced temperature measurement for LISA’ (LETS)** ESA contract
  - Team: IEEC (ES), DLR (DE), SENER (ES)
  - Duration 18 months (delayed due to COVID)
- The objective is the design of a prototype temperature subsystem for LISA (TRL4)
  - 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:
  - Aiming for Final Presentation on June 30th

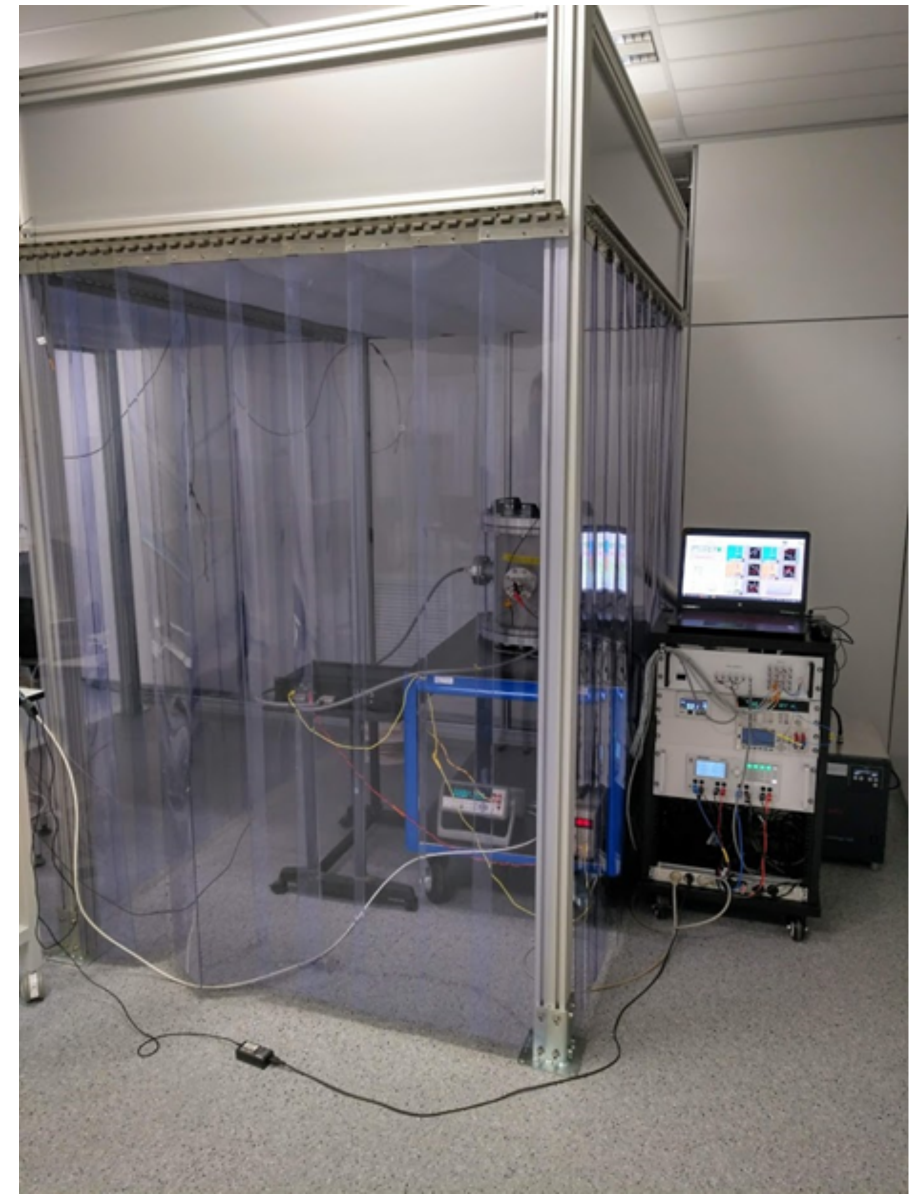




LISA — temperature diagnostics

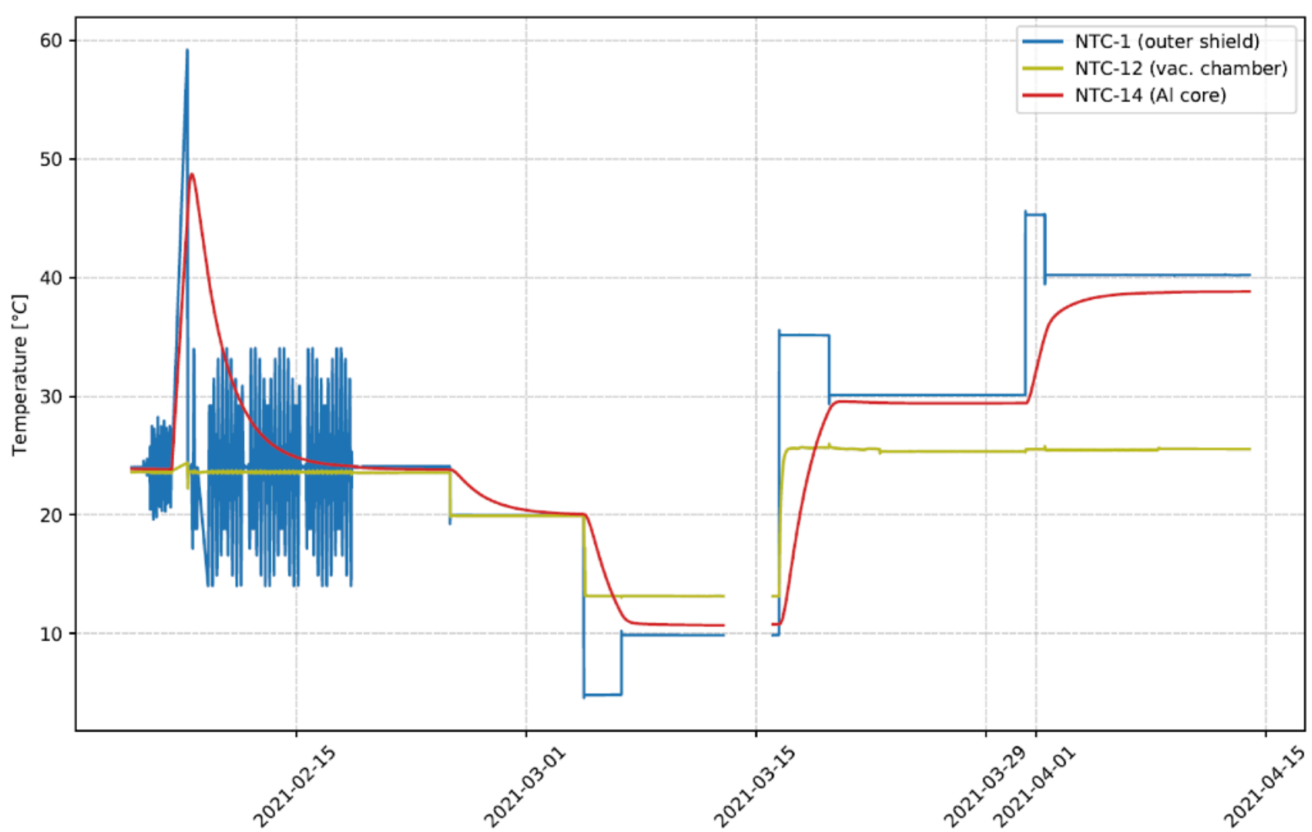
- Setup running at ICE, inside temperature control cabine (±5mK stability)

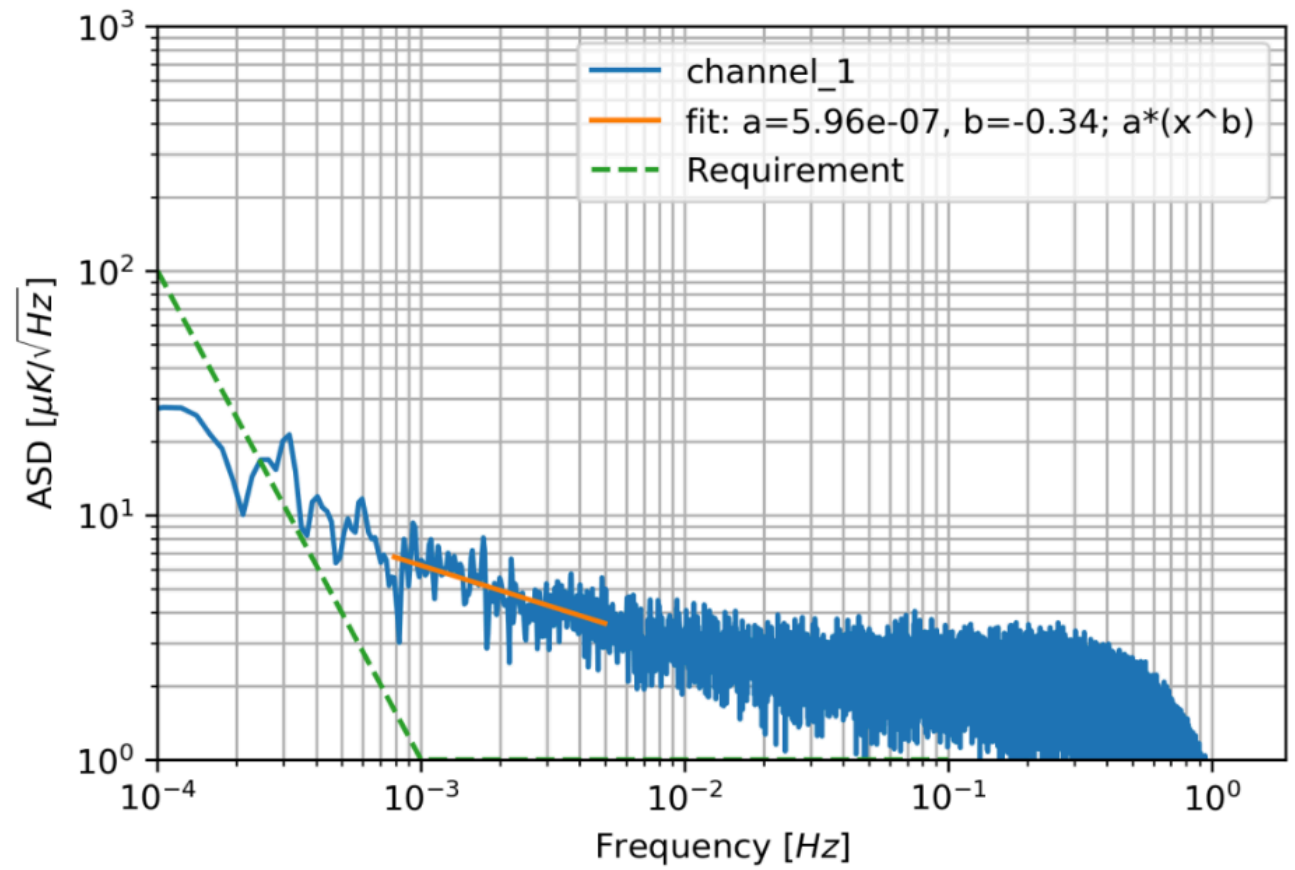




LISA — temperature diagnostics

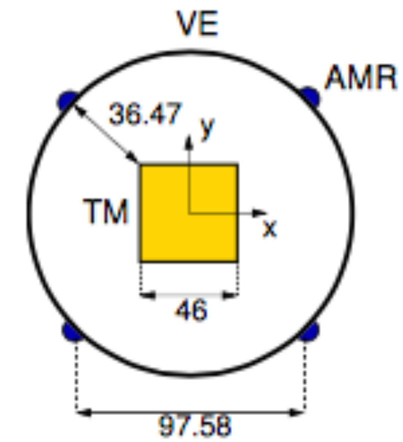
- Noise runs running since Feb. '21.
  - Long runs required to reach 0.1mHz regime
- After extensive testing, we've been able to track down several noise contributions. Close to the requirement. Floor noise 2-3 uK/√Hz, still some excess noise at 1mHz
- Remaining excess noise being investigated (harness, grounding, interferences…)

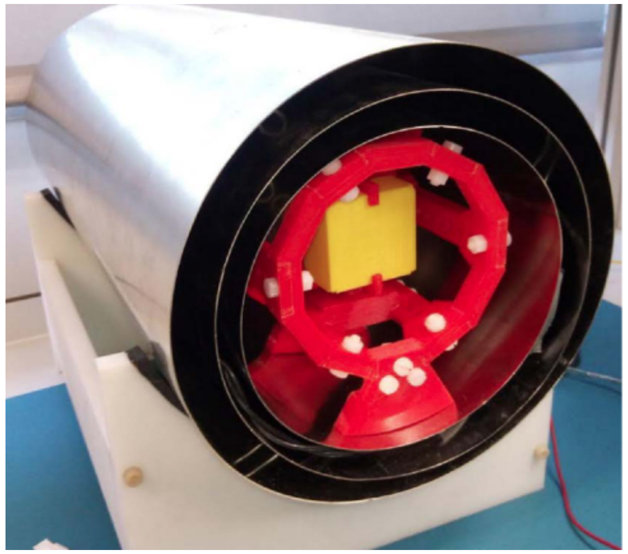


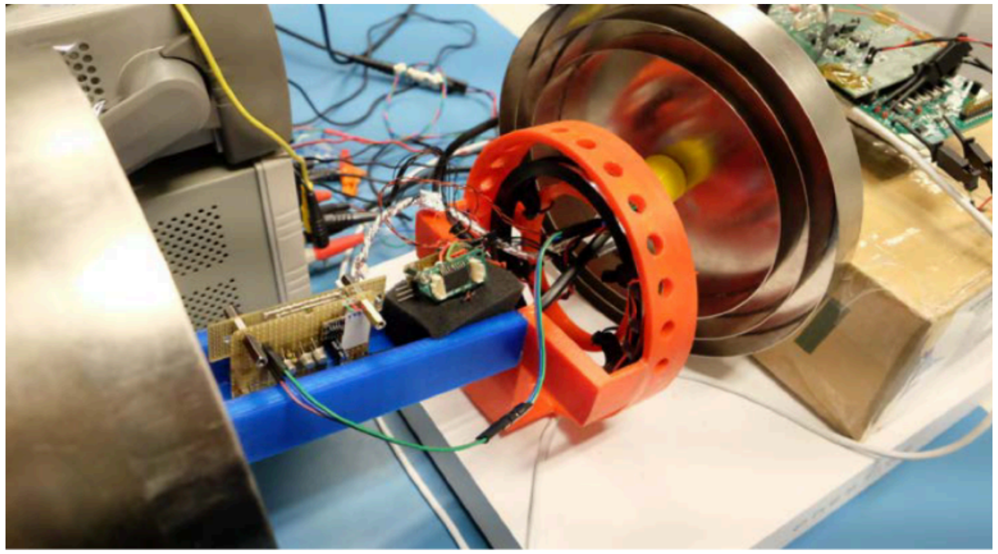


LISA — magnetic diagnostics (AMRs)

- We have 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, low-noise with no magnetic back-action
  - A solution with 8 AMRs would reduce error to 1%
- Setup for testing is composed by
  - three concentric **mu-metal** layers to isolate from Earth magnetic field
  - a **coil** inside to generate controlled inputs
  - a **3D printed structure** to located sensors and allow gradient estimates
- In order to achieve the required performance for LISA, 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.



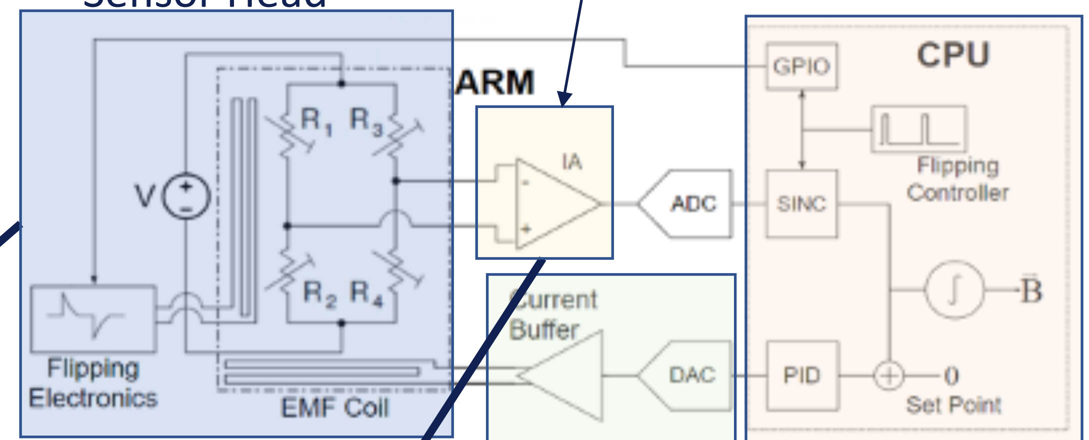




LISA — magnetic diagnostics (AMRs)

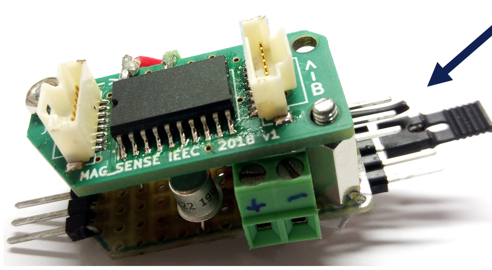
Analog signal conditioning

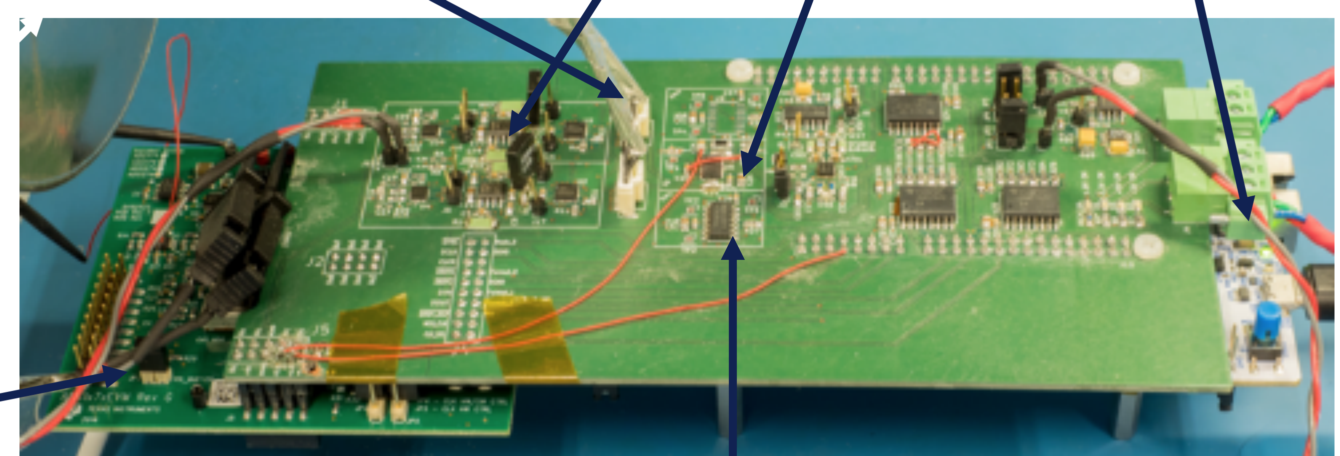
Sensor Head



EMF electronics

AMR connectors



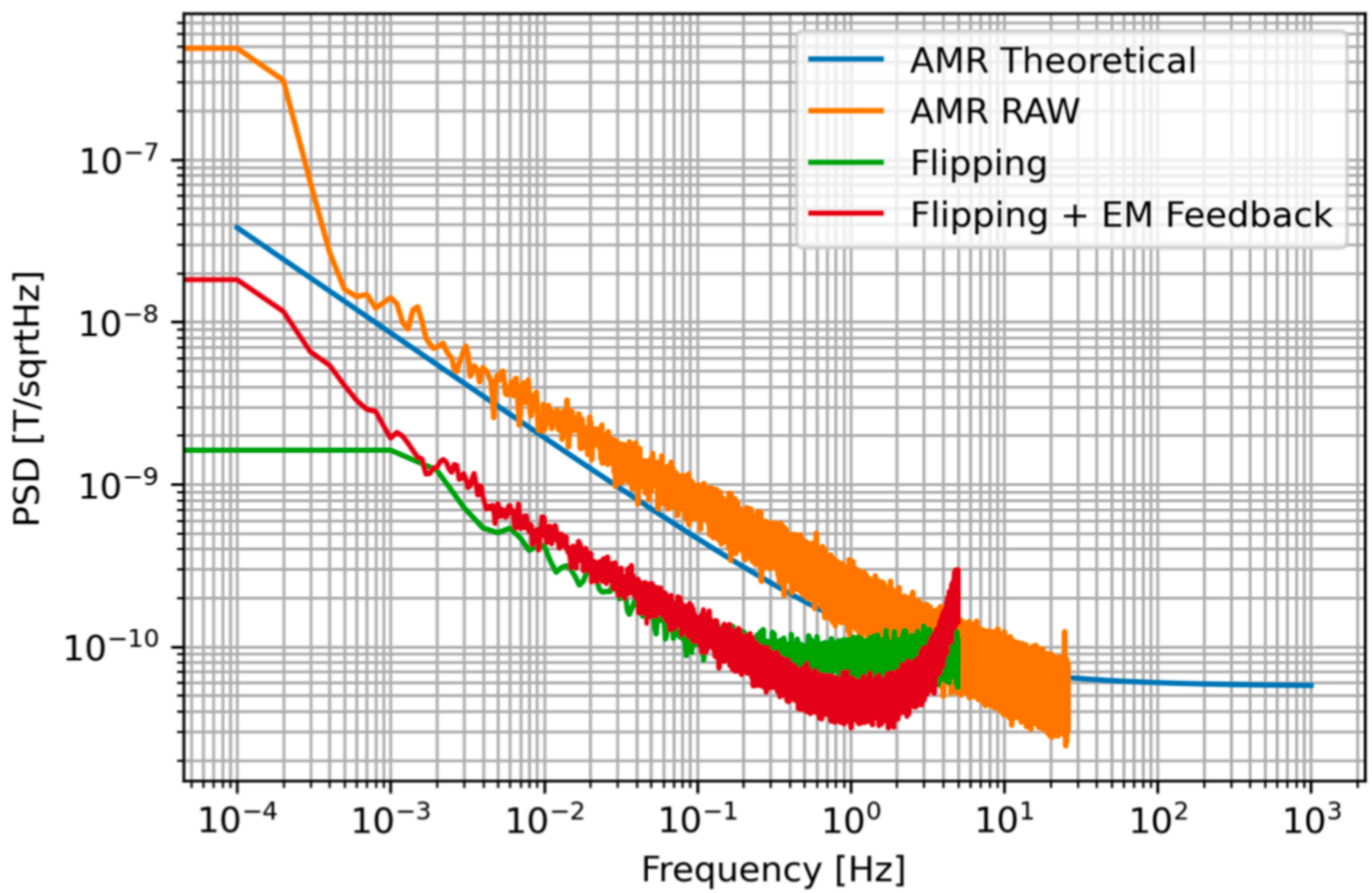


ADS1278 ADC Ev. board

Flipping electronics

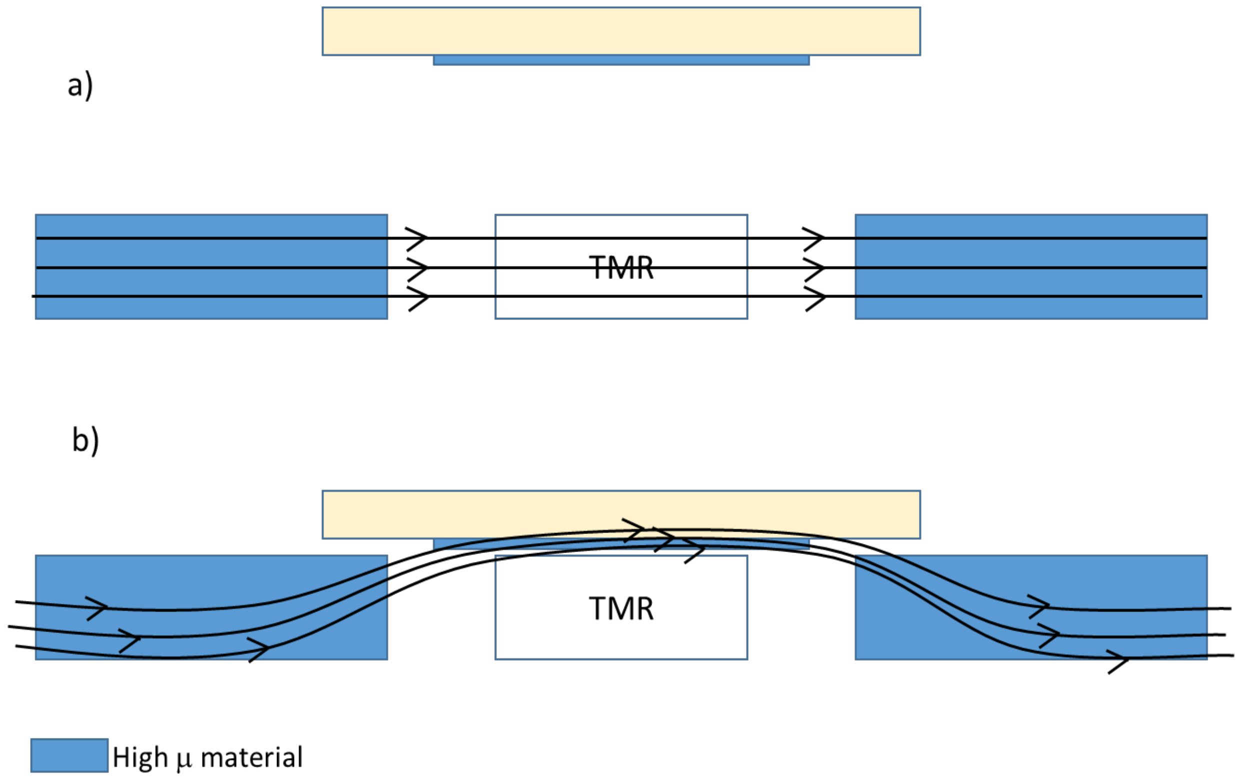
LISA — magnetic diagnostics (AMRs)

- Results show that flipping technique improves performance in the LISA band
- Similar results are obtained when applying flipping + EMF
- Currently evaluating back-action effects, i.e. magnetic field signal of a sensor as measured by another sensor



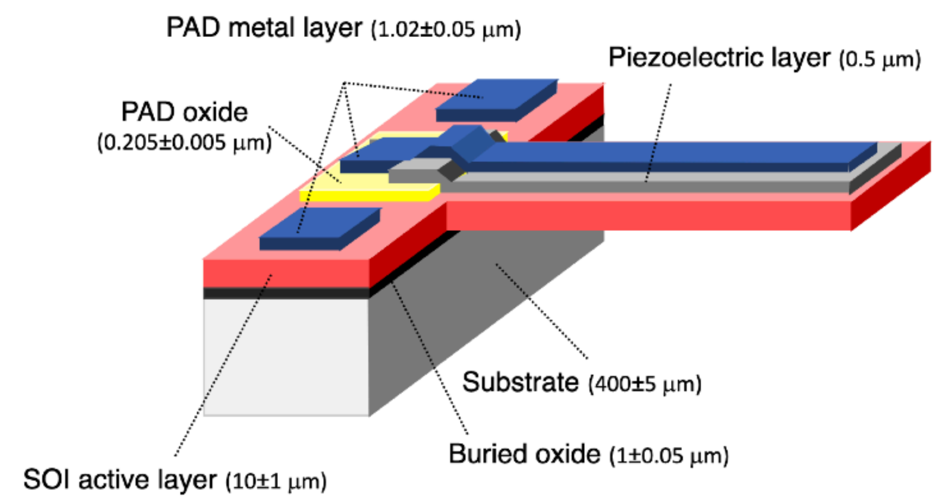
LISA – magnetic diagnostics (MEMs)

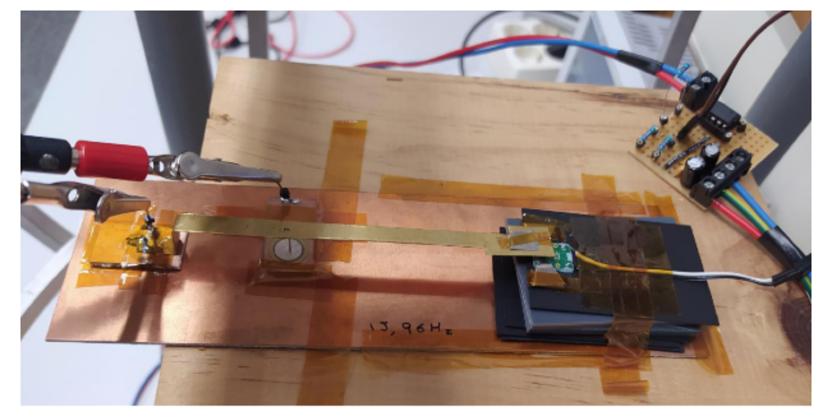
- A MEMS-based magnetometer for LISA
  - Magnetic flux is sensed using **TMR** (Tunnel Magnetoresistance)
  - Flux is enhanced using a **MFC** (Magnetic Flux Concentrator)
  - By **mechanically oscillating** the MFC near the TMRs, the Magnetic Flux is modulated at a high frequency avoiding 1/f noise

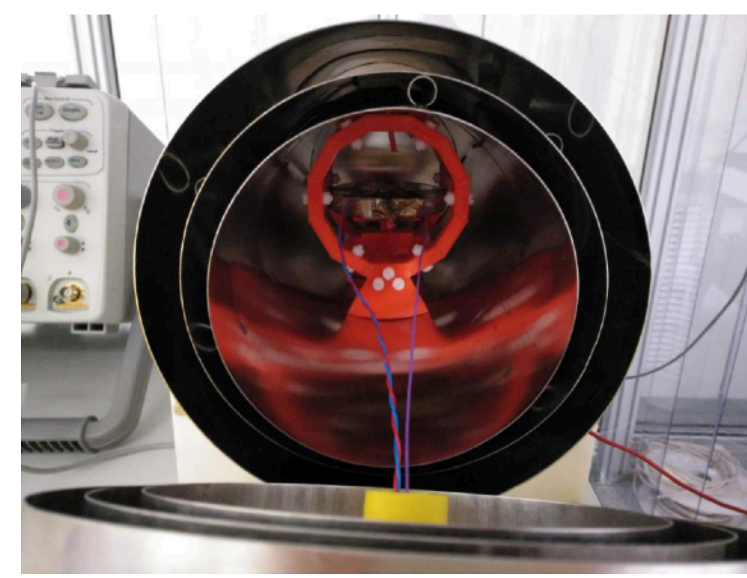


LISA — magnetic diagnostics (MEMs)

- Developing a compact magnetometer based on MEMs
  - Magnetic field modulation, using MEMs resonators and high permeability layers, to mitigate 1/f noise
  - TMR used as sensing device
- **MELISA** (*MEMS miniaturized low-noise magnetic field sensor for LISA*) got selected in an **internal IEEC call** for seed funding for innovative projects across different IEEC units (UPC, CSIC, UB)
- Studying resonator parameters through FEM simulations for different designs.
  - in particular resonance frequency (100-900 Hz), displacement (10-100 um) and magnetic modulation (< 60%)
- First proof-of-principle breadboard (**macrocantilever**) implemented to characterise modulation depth and read-out.
  - 10 cm long brass cantilever, reaching 1.5mm displacement at 15.7 Hz
- Characterised the noise floor of the TMR device inside mu-metal at ICE temperature control canine



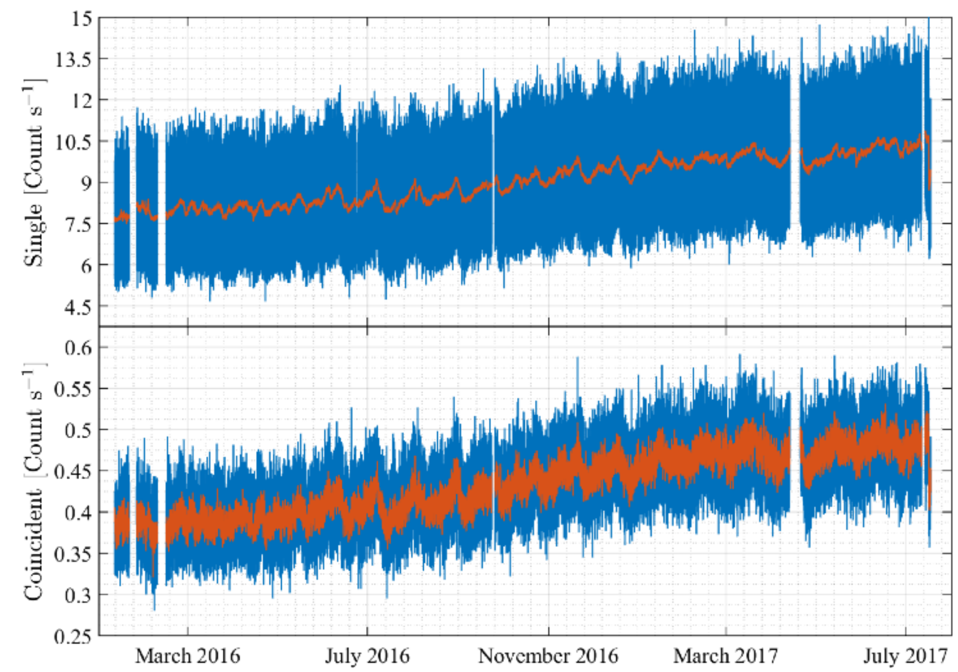




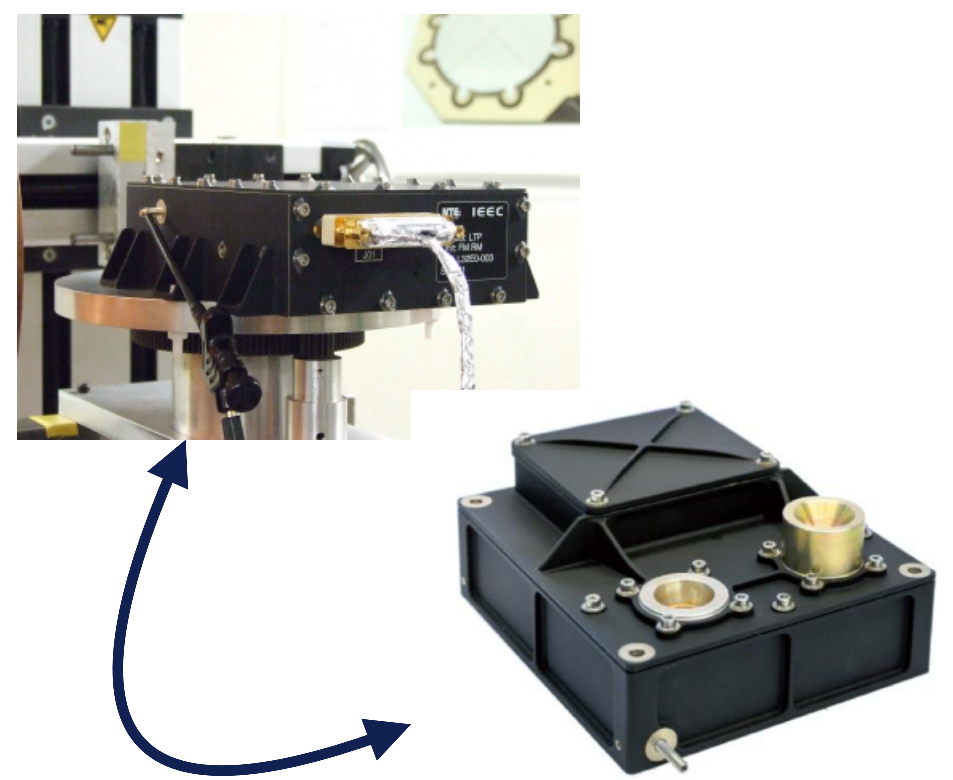
IEEC
Institut d'Estudis Espacials de Catalunya

LISA - radiation monitor

- Radiation monitor to track test mass charging in the LISA test masses
  - Study the high energy radiation environment responsible for test-mass charging
  - Analyze the charge generation in test masses
    - A complete simulation **Monte Carlo model to predict direct and indirect energy deposition** will be developed.
      - Low energy particles are dominant in test mass charging
      - Adequate tools as **Penelope or new Geant-4** version will be used.
  - Study of radiation monitor requirements
    - ESA proposes using the standard **NGRM** in each spacecraft: is it enough?
    - Is a customized monitor needed ?
- Validation of model in test beam campaigns

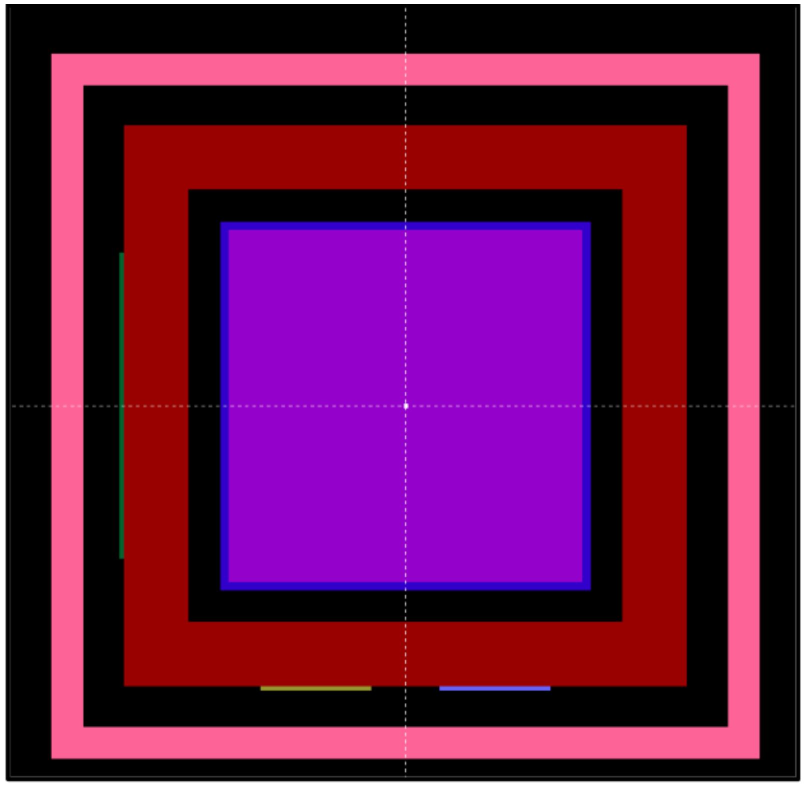


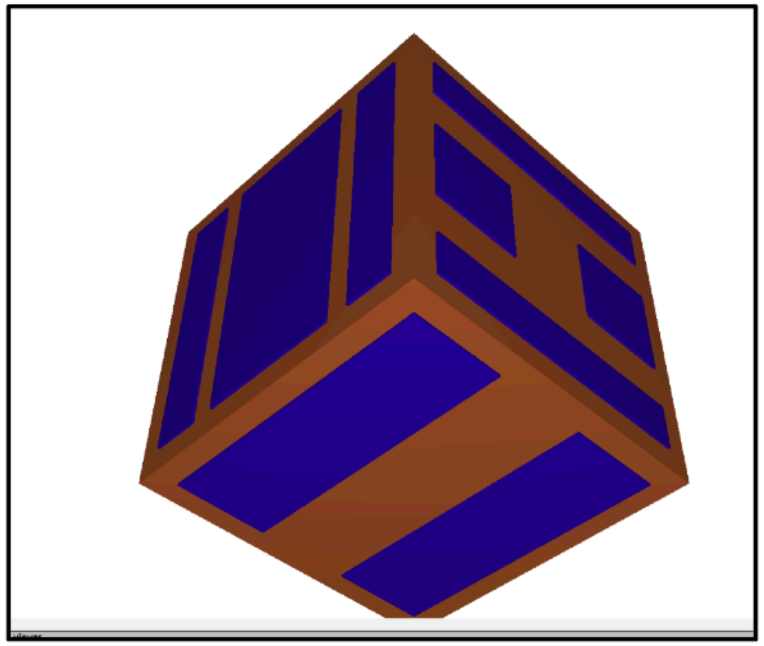
Armano et al. *Astroparticle Physics* 98 (2018)



LISA - radiation monitor

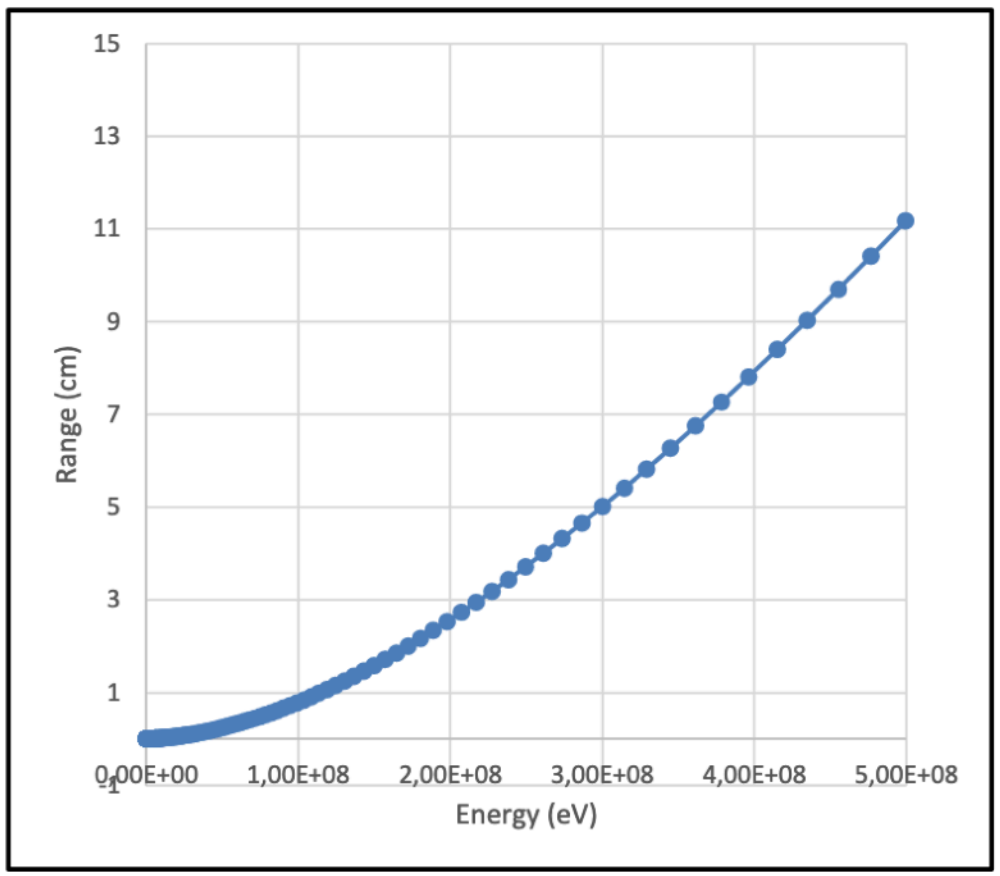
- Define simple Geometry in PENELOPE
  - Test Mass 46x46x46 mm^3 cube
  - Electrode Housing 70x70x70 mm^3 cube foil
  - Aluminum shielding
- Material definition:
  - Al –Shielding (spacecraft)
  - Pt (27%) + Au (73%) Test Mass
  - Mo -Electrode Housing
  - Sapphire (Al_2O_3) Electrodes
- First studies using protons
  - Proton energy from 10 to 450 MeV
  - Energy of absorption for the electron particle = 50 eV

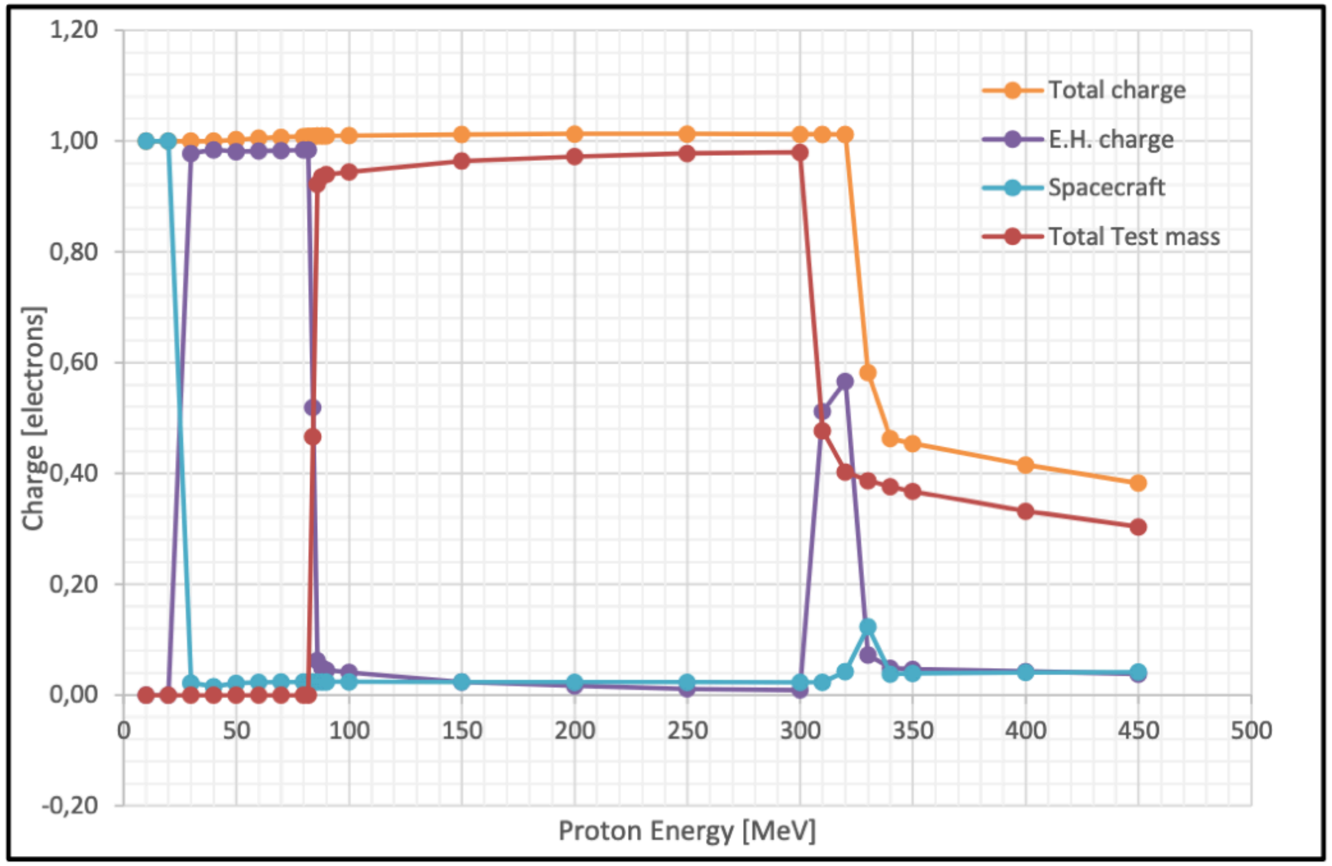




LISA - radiation monitor

- First results with proton beam providing some insight
  - Around 300 MeV, proton range > test mass length
  - Test mass charge below 84 MeV is practically 0.
- Currently working in collaboration with ESA NGRM team to study in more detail the characteristics of the NGRM detector
  - ESA NGRM team providing detector response up to 1 GeV
- Next steps to consider cosmic ray spectrum and study NGRM counts to TM charge





Thanks for you attention.

Questions?