LISA related research at IEEC

Miquel Nofrarias

Iberian Gravitational Wave Meeting, 19-20 Oct. 2020

IEEC
Institut d'Estudis Espacials de Catalunya

Organization

Industrial & R+D ecosystem with strong space heritage

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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)

LISA Science Group (LSG)

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

C. Giardini (IEEC-UB)

PhD Student(s):

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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

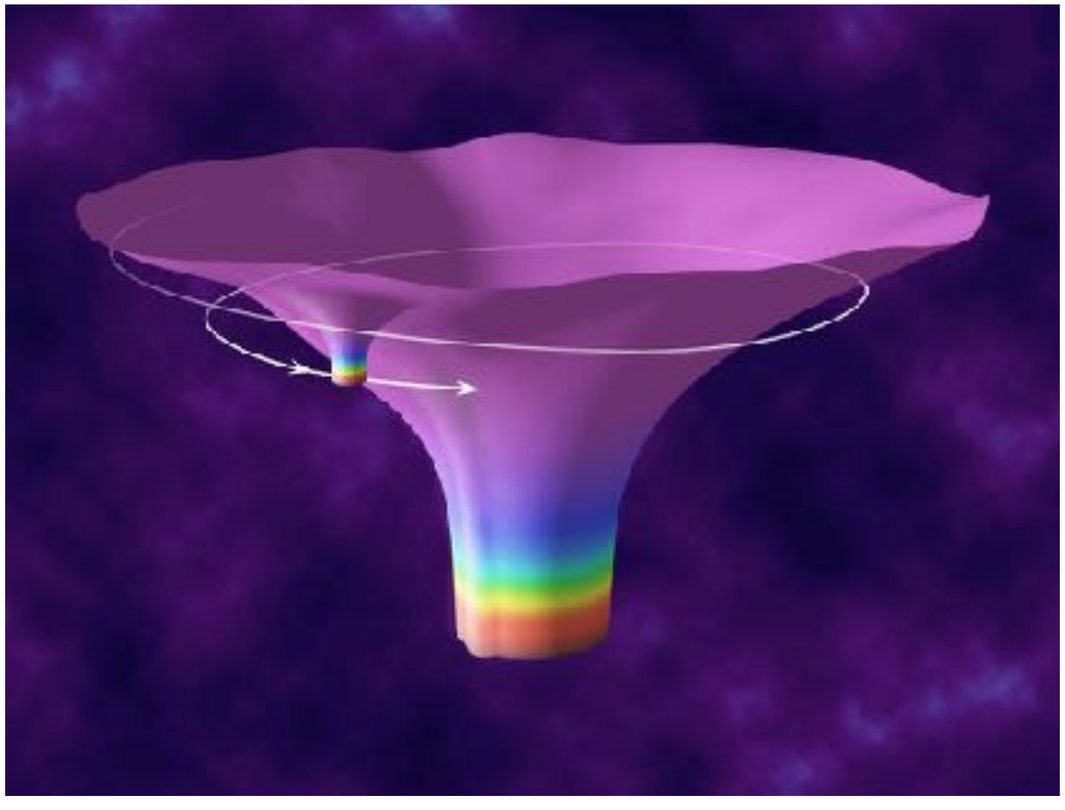
IEEC-UB
A. Herms
D. Gascón
F. Salvat
E. Graugés
A. Arán
D. Sánchez

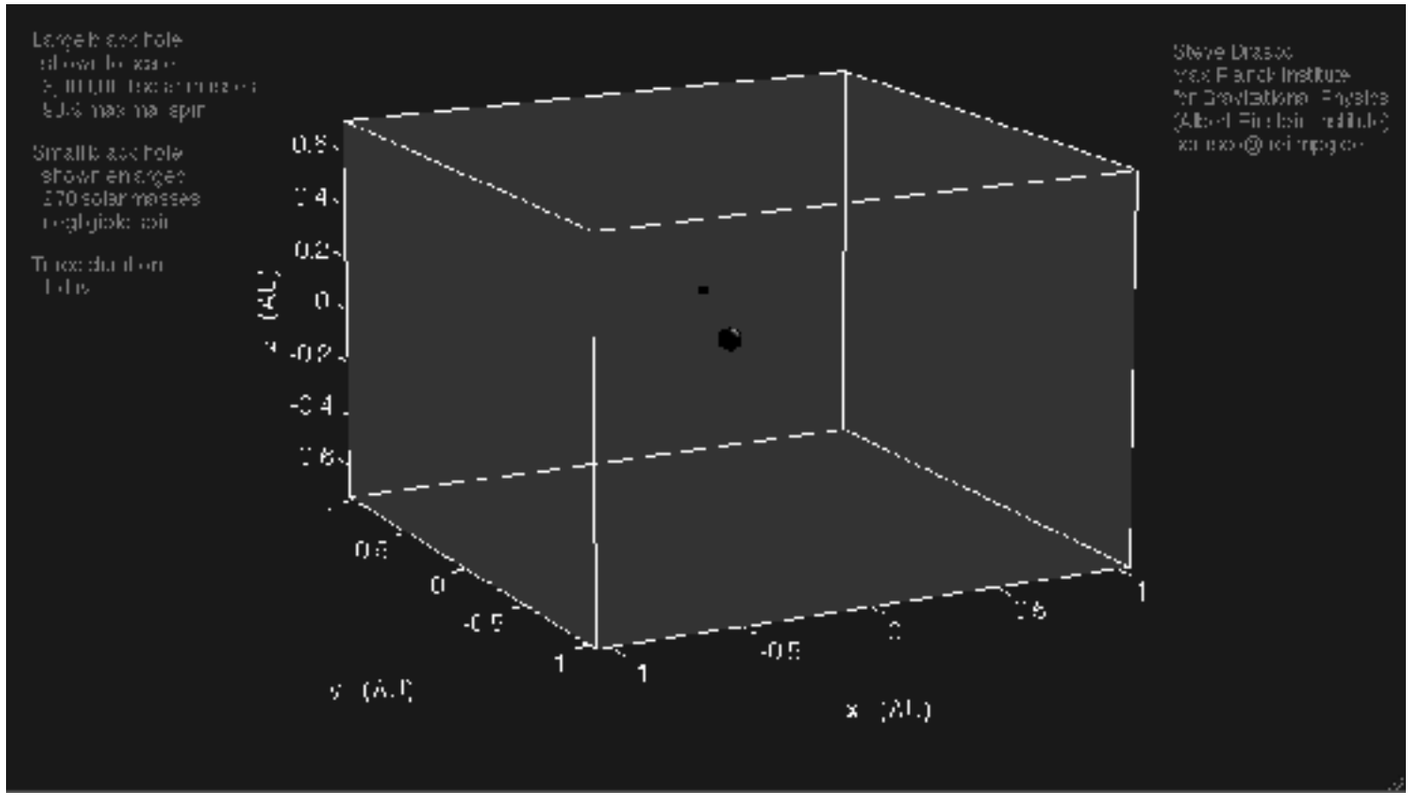
Instrument Control Computer Team

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

Modelling of sources of Gravitational Waves

- We are using techniques of Numerical Relativity and Relativistic Perturbation Theory (post-Newtonian, post-Minkowskian, Black Hole perturbations,…) to build the future template banks for LISA Data Analysis.
- We are also building approximate template banks to be used in the LISA Data Challenges. The focus at the moment is in **Extreme-Mass-Ratio Inspirals**





Astrophysics, Cosmology and Fundamental Physics with GWs

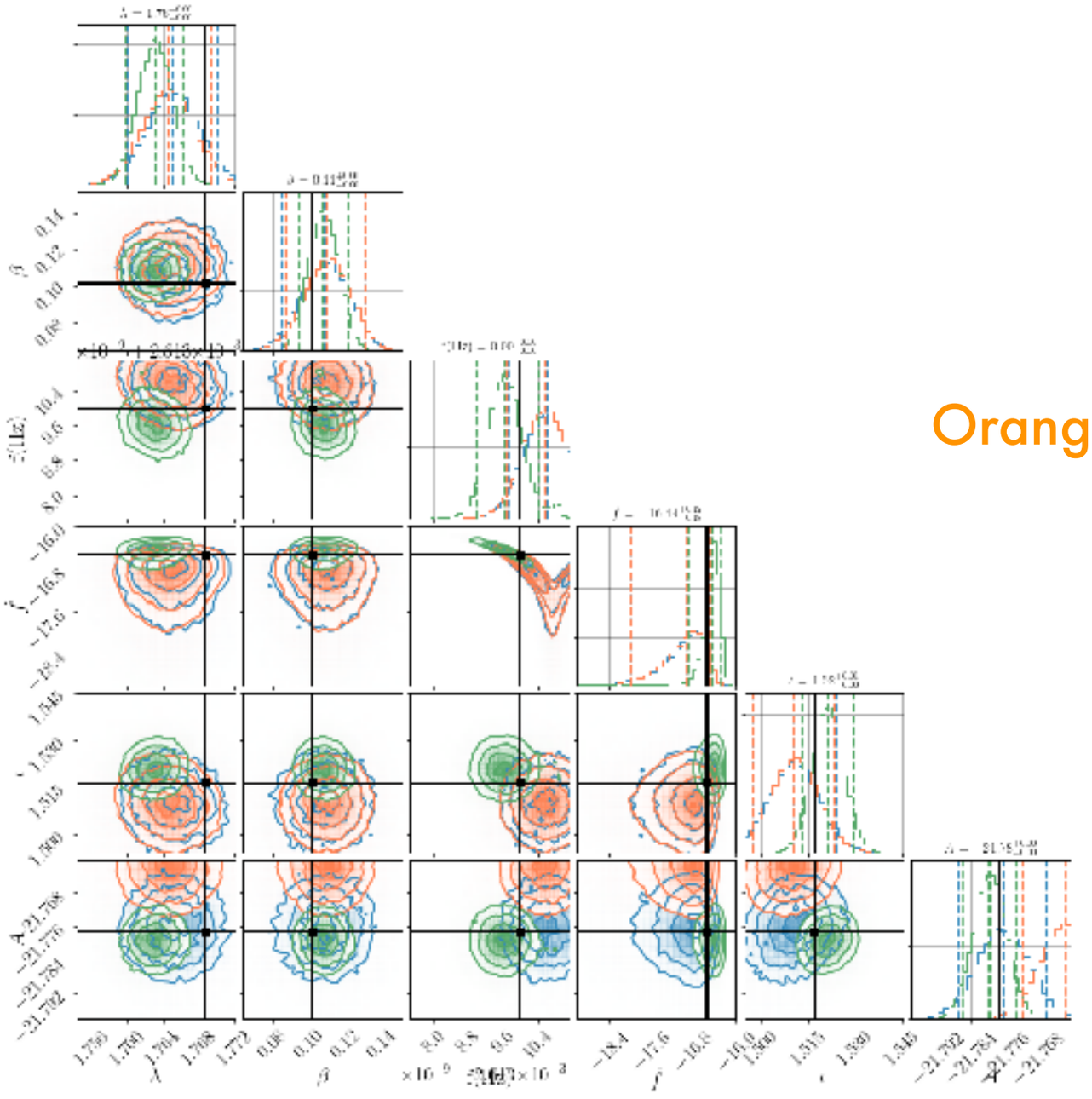
- Study of the possible **channels for the formation** of gravitational wave sources, with particular focus on Extreme-Mass-Ratio Inspirals for LISA. We are
  - interested in the **event rates** as well as in the distribution of **physical parameters** of the sources.
- Development of methods to test the geometry of Black Holes (no-hair conjecture) and also to **test General Relativity and alternative theories of gravity** by using GW observations of coalescing Black Hole Binaries and Extreme-Mass-Ratio Inspirals.
- Impact of the possible existence of **Primordial Black Holes** and their imprints in Gravitational Wave signals (from single sources to stochastic backgrounds).

Data Analysis for LISA

- We participate in the development of the **Ground Segment of the Mission** with the aim of developing a future LISA Data Center at IEEC facilities.
  - This includes: LISA Data Processing Working Group, LISA Data Challenges, LISA Simulator WG, etc.
- **Software Development** to build the infrastructure of the future LISA Data Analysis and the Data Centers.
- Development of Data Analysis Algorithms for **LISA Data Analysis**. We are currently working in two different lines:
  - Markov-Chain Monte-Carlo methods.
  - Deep Learning Methods.

Data Analysis for LISA

- Results for the first Round (*Radler*) of the LISA Data Challenges (LDCs).



Blue: University of Birmingham

Orange: NASA Marshall Space Flight Center

Green: ICE-IEEC

Instrument contribution

- The LISA Data and Diagnostics Subsystems (DDS) is composed by two units that fulfils two different functionalities:
  - The **Diagnostics Subsystems** monitor several environment sources of noise that can disturb either the interferometric measurement or the test mass dynamics on-board LISA.
    - *Thermometers/heaters: thermal disturbance can induce forces on the test mass*
    - *Magnetometers/coils: magnetic fields (IMF or SC) induce forces on the test mass*
    - *Radiation monitor: particles induce charge in the free falling test mass*
  - The **Instrument Control Computer** acts as the instrument computer. Interfaces with the on-board computer and is the responsible for managing and controlling different subsystems
    - *Hardware: processor, memory, communications*
    - *Software: Boot SW, Application SW*

SPACECRAFT

INSTRUMENT

PHASEMETER

LASER

INSTRUMENT CONTROL COMPUTER

GRAVITATIONAL REFERENCE SENSOR

OPTICAL METROLOGY

TELESCOPE

DIAGNOSTICS

NB: Platform representation is limited to functions which directly interfere to the payload

Change .og

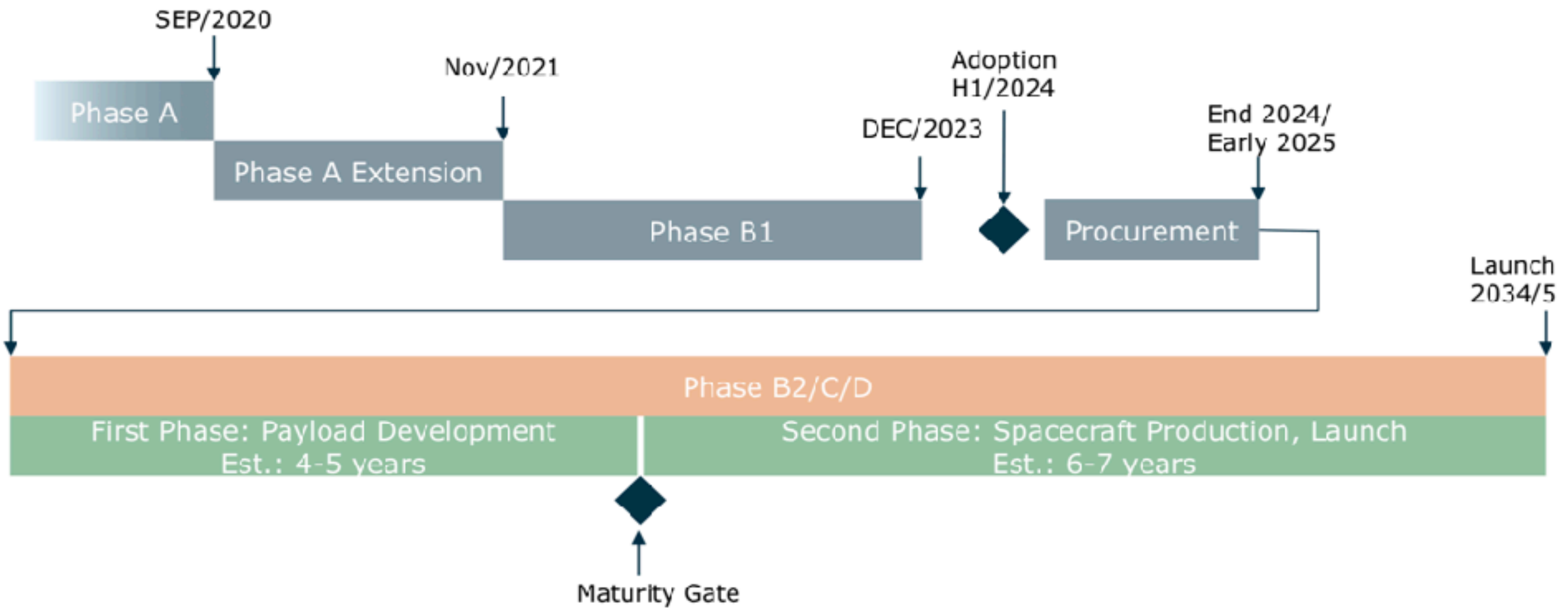
Key

LISA Metrology System
Functional Block Diagram

Ewan Fitzsimons, UKATC V0.4 Rev 1 - 06/09/2017

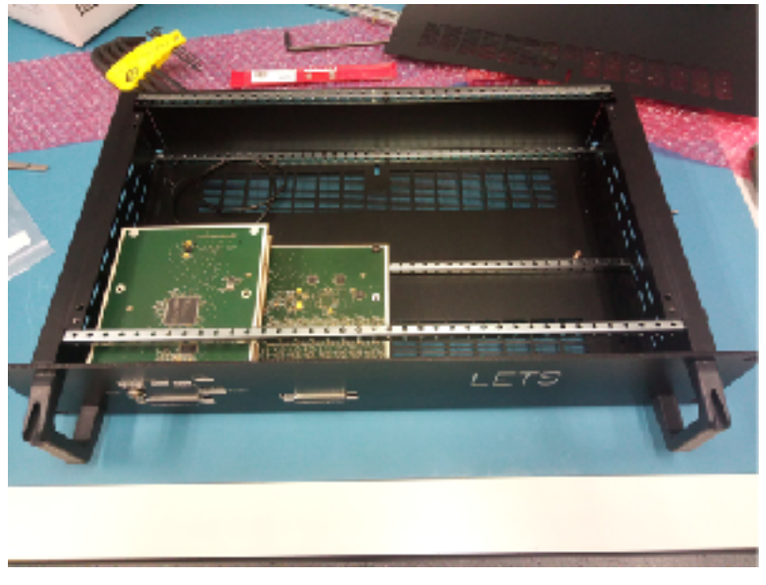
LISA schedule (from ESA)

Implementation Strategy (all dates TBC)

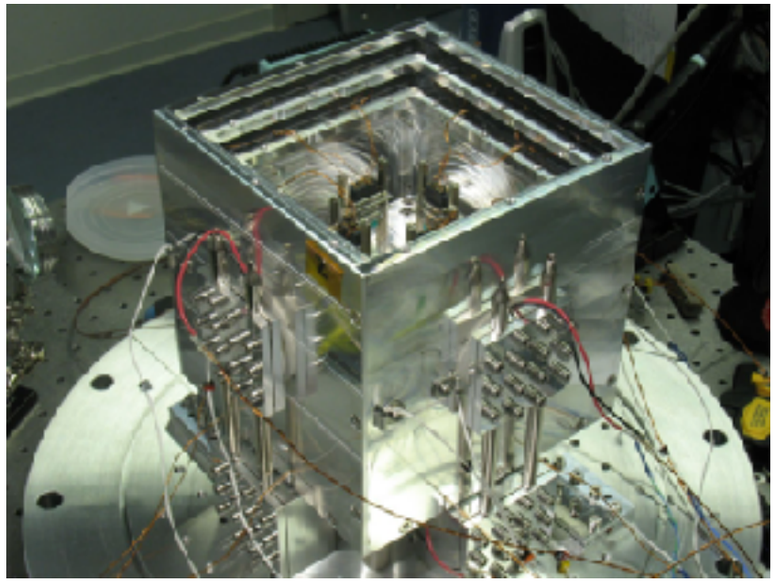


LISA — temperature diagnostics subsystem

- Developing LISA temperature diagnostics subsystem under **'Enhanced temperature measurement for LISA' (LETS)** ESA contract
  - Team: IEEC (ES), DLR (DE), SENER (ES)
  - Duration 18 months (ending Feb. 2021, 3m COVID delay)
- 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:
  - All equipment manufactured. DLR delivered test bench to IEEC for integration and test
  - Passed TRR (Sep. 2020). Moving forward for test phase.



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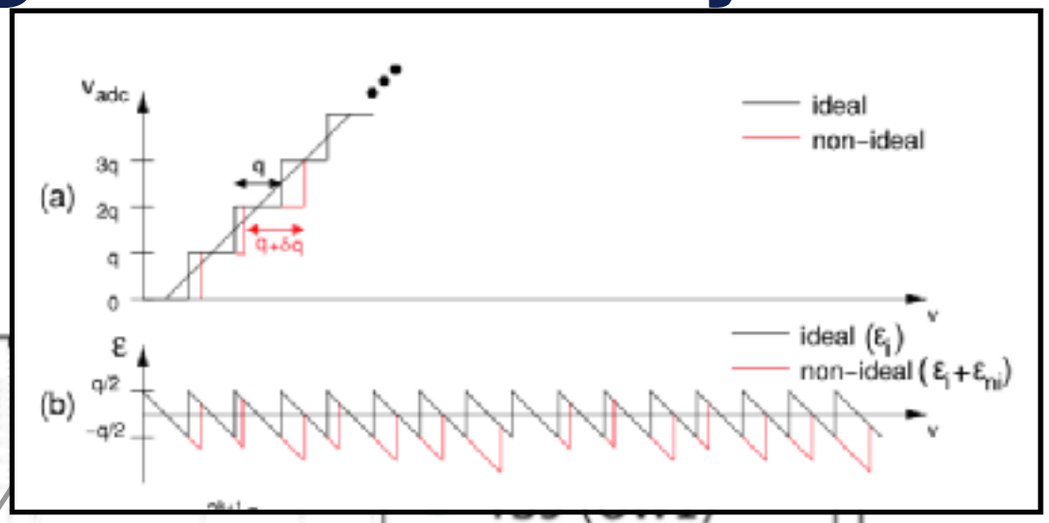
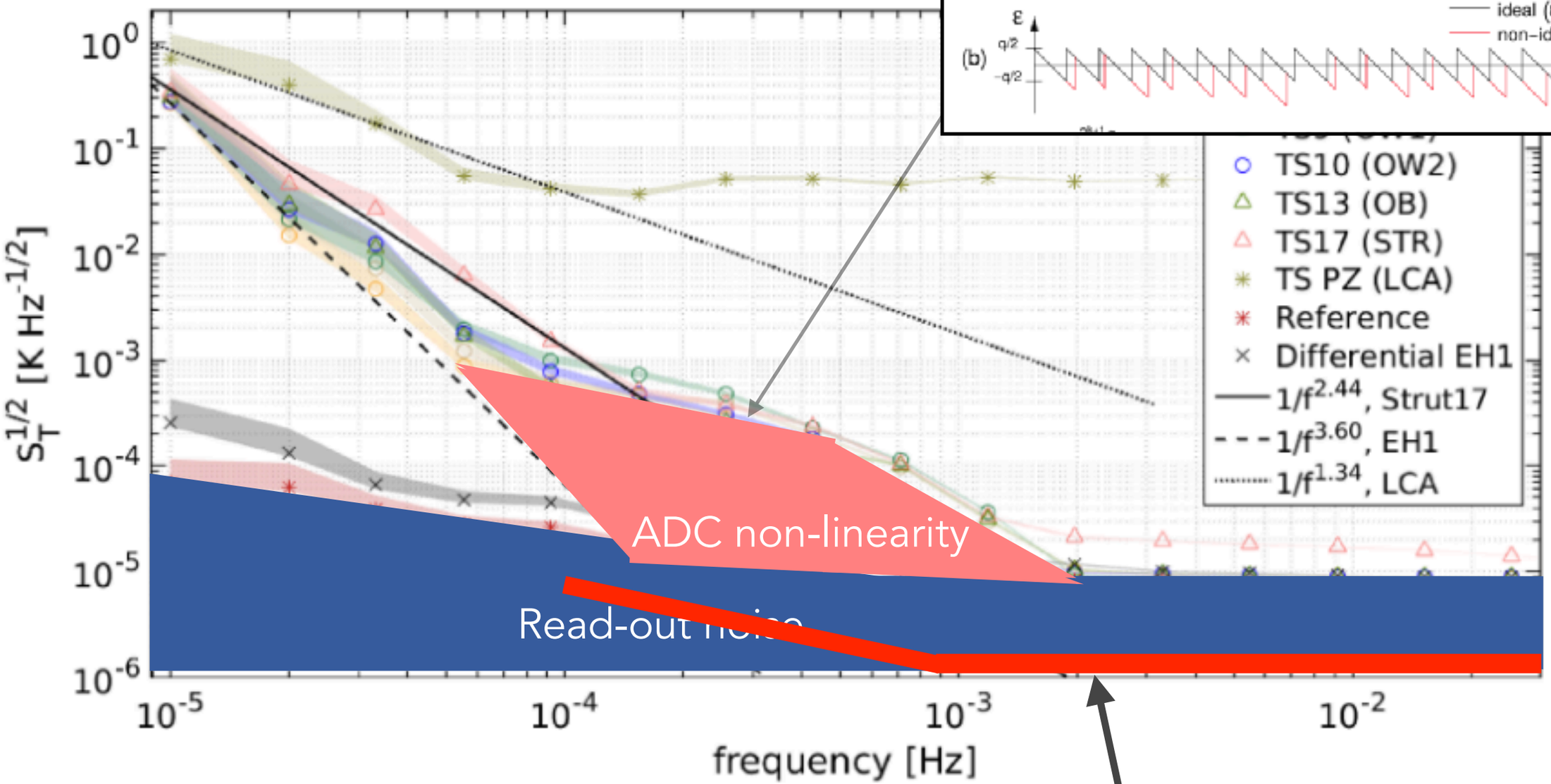
LISA — temperature diagnostics subsystem

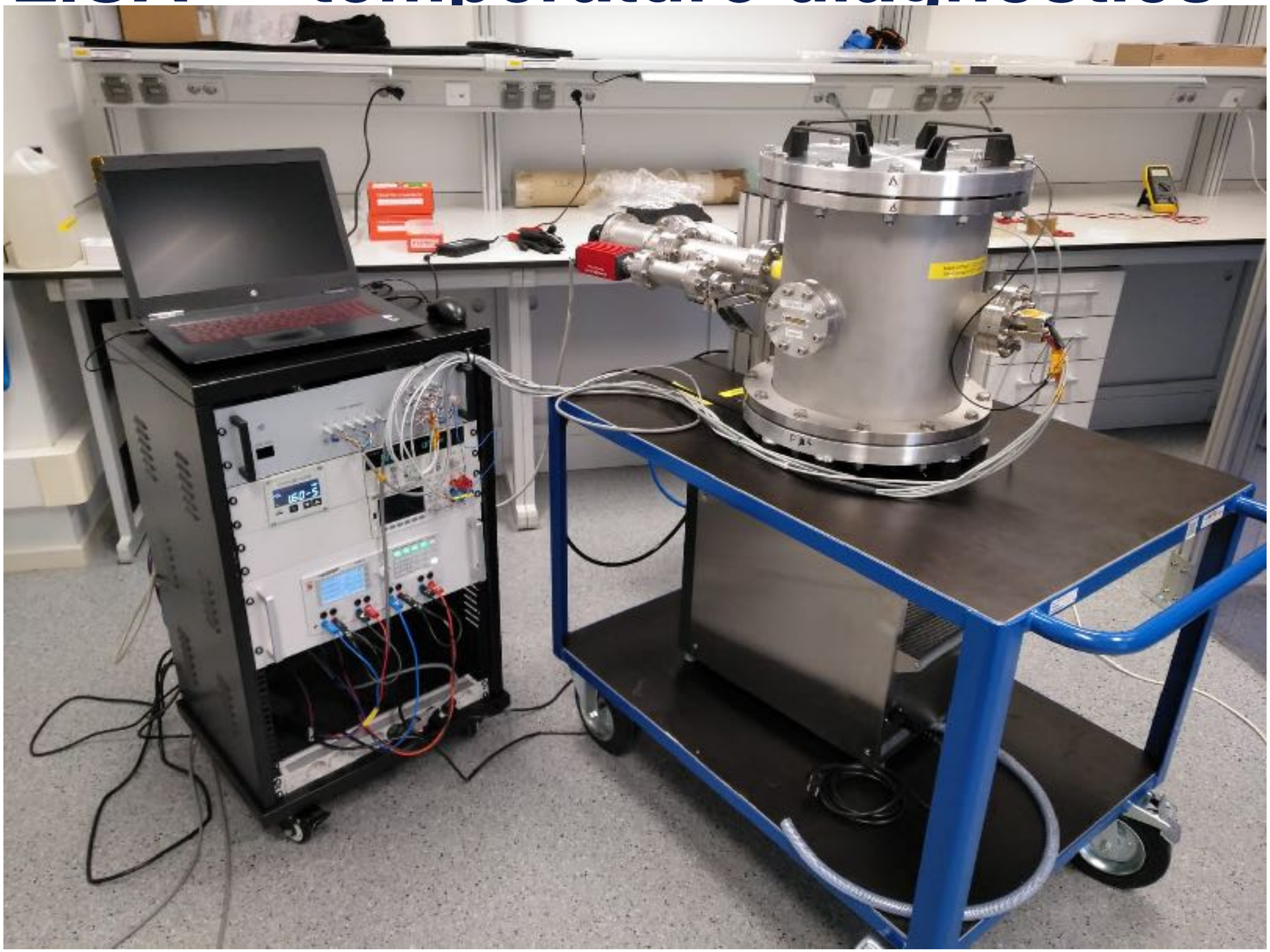
J Sanjuán, M Nofrarias
Rev. Sci. Inst. 78 (2018)





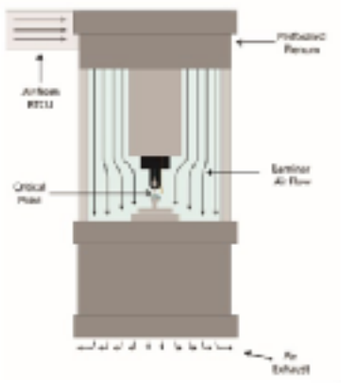
Armano et al. (LPF collaboration) Temperature stability in the sub-millihertz band with LISA Pathfinder, MNRAS 486 (2019)

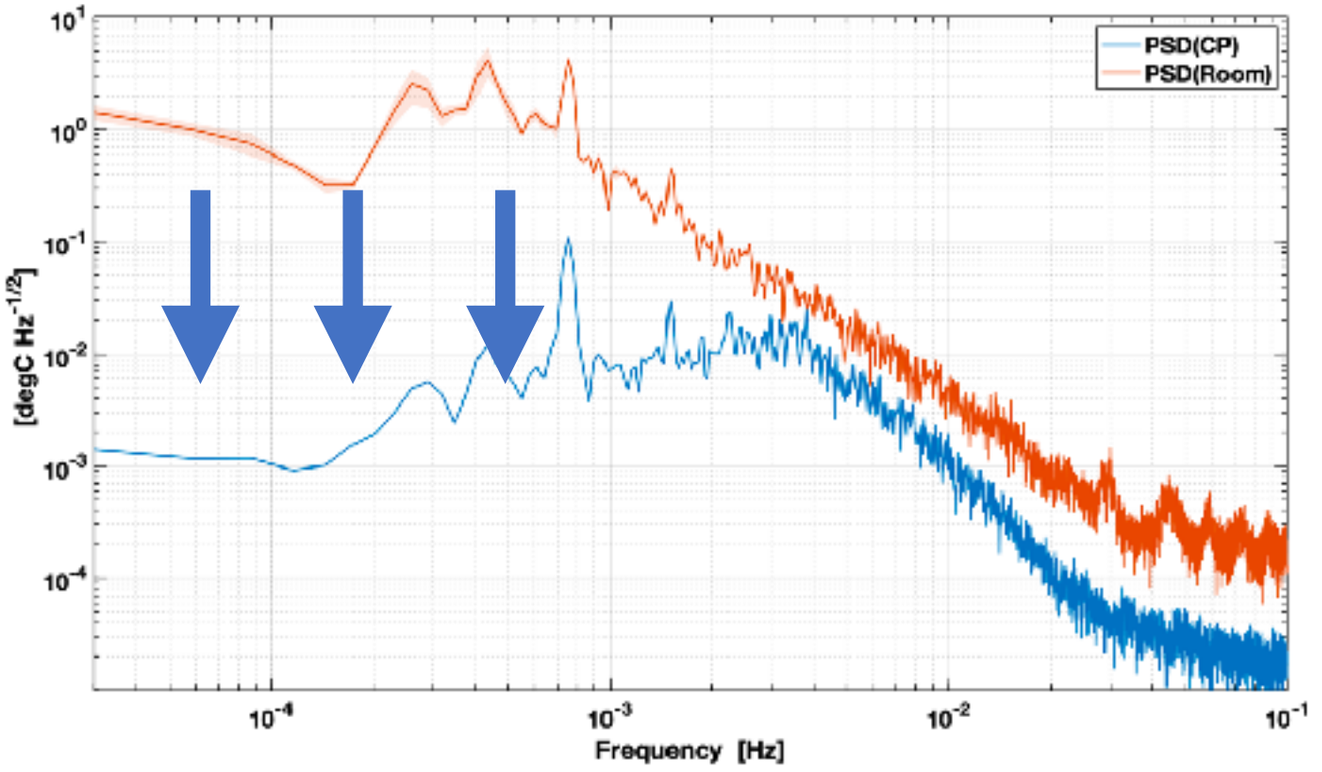
LISA — temperature diagnostics



LISA — temperature diagnostics

- High stability temperature control facility at IEEC-CSIC labs
  - *Facility with controlled laminar flow with ±1mK stability.*
  - *General purpose facility for AIVT, particularly for LISA*
  - *Facility is installed and operative*

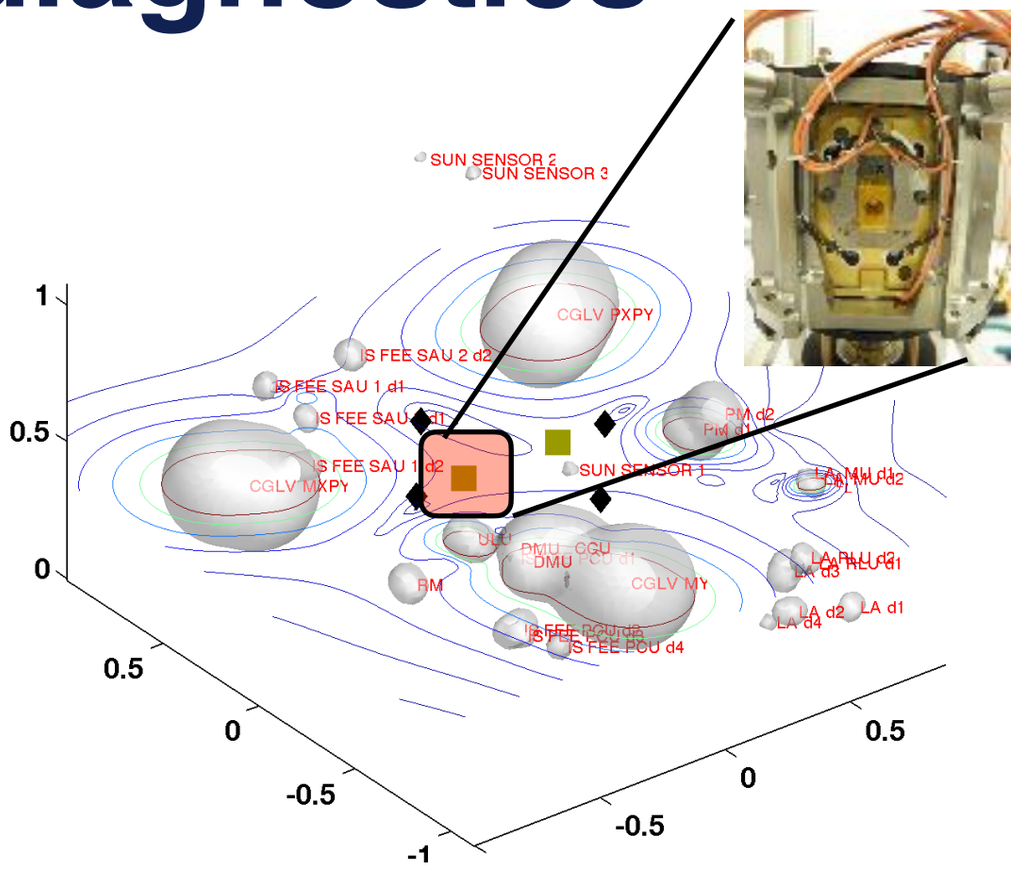




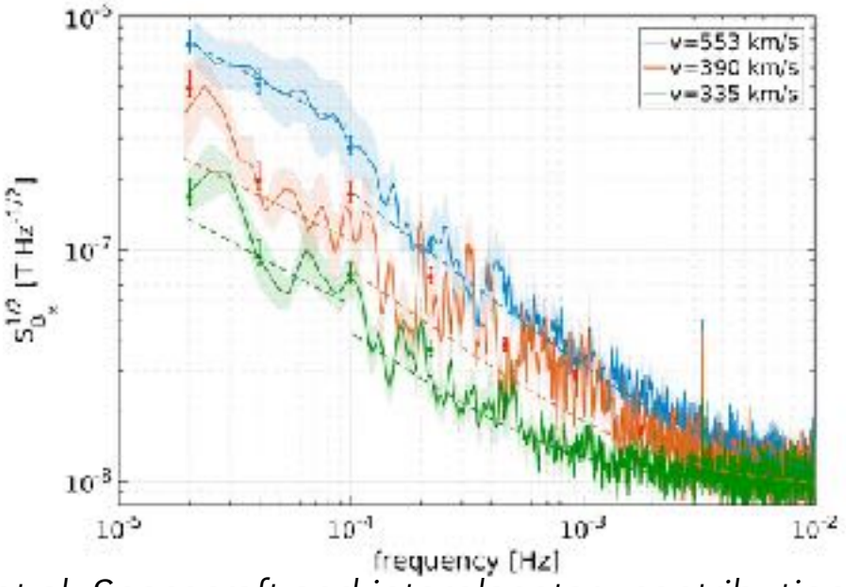
LISA — magnetic diagnostics

- Our main goal is understanding magnetic contribution to force noise in the TM position.
  - TM acting as a magnetic dipole in free fall

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



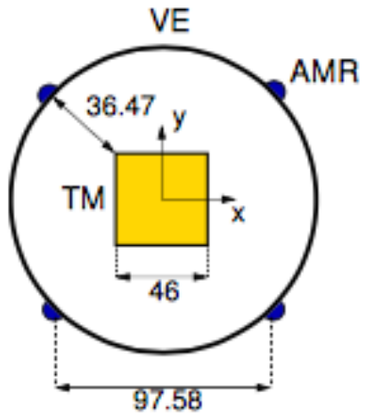
- Many contributions to consider. The dominant one is (∇B_{SC} x δB_{IMF}) :
  - **∇B_{SC}:** ~100 magnetic sources coming from the on-ground characterisation of SC units
  - **δB_{IMF}**: low frequency fluctuacitions of interplanetary mag. field. Associated with the dynamics and structure of the solar wind. **Intrinsic non-stationarities.**

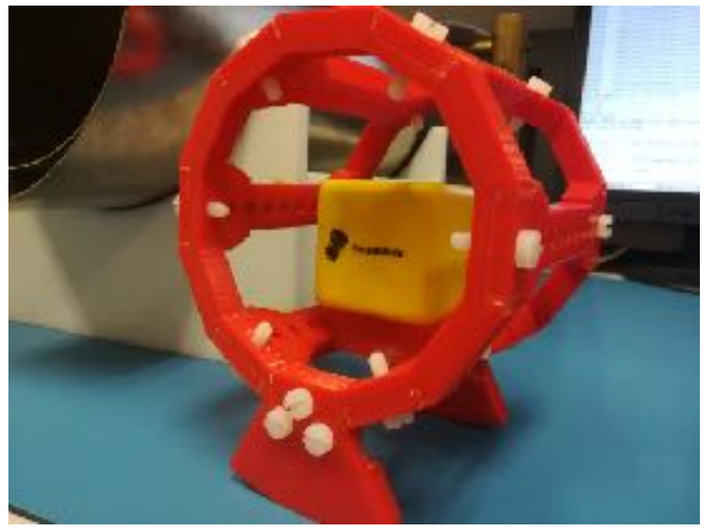


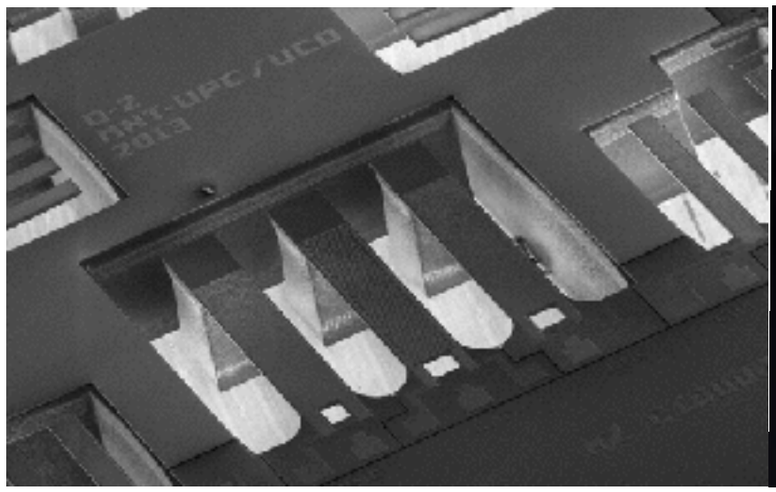
Armano, M et al. Spacecraft and interplanetary contributions to the magnetic environment on-board LISA Pathfinder, MNRAS (2020)

LISA – magnetic diagnostics

- We have developed an improved magnetic diagnostic system more compact and avoiding back-action problems
  - based on **Anisotropic magneto-resistors (AMR)**
  - AMR is a compact, low-noise with no magnetic back-action
  - A solution with 8 AMRs would reduce error to 1%
- Currently design of a LISA magnetic diagnostics test bench to test
  - Test new magnetic sensors technologies in a LISA-like geometry
  - Next steps are integrating in mu-metal shielding and design acquisition
  - Need further development to reach TRL6
- Adding expertise from the Micro and Nano technology group (IEEC-UPC)
  - The group was in charge of the MEDA wind sensor (Mars2020)
  - Magnetic field modulation, using MEMS resonators and high permeability layers, to mitigate 1/f noise
  - Currently working on a **MEMS design based on a Tunneling Magnetic Resistors (TMR)**

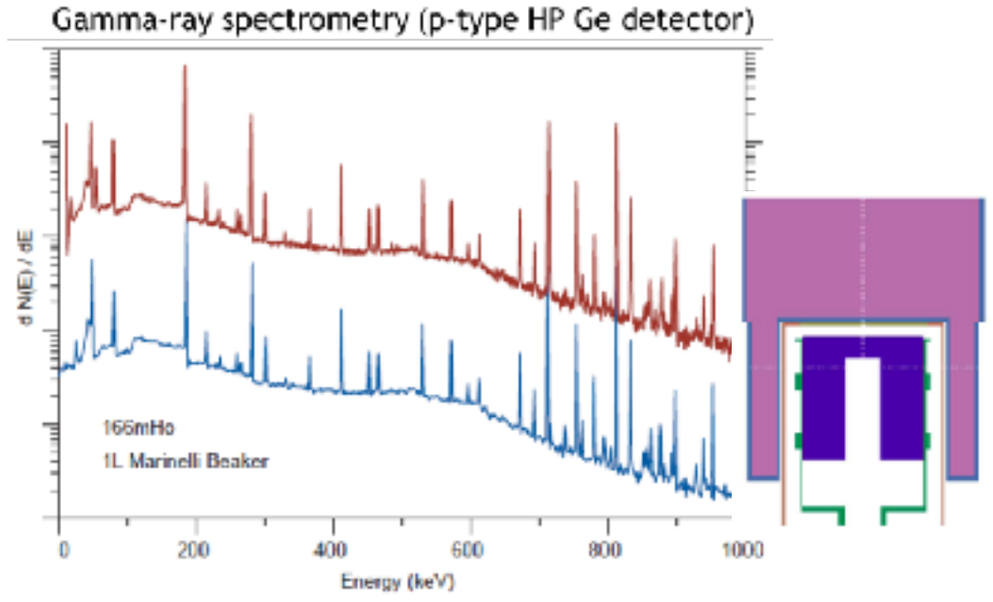


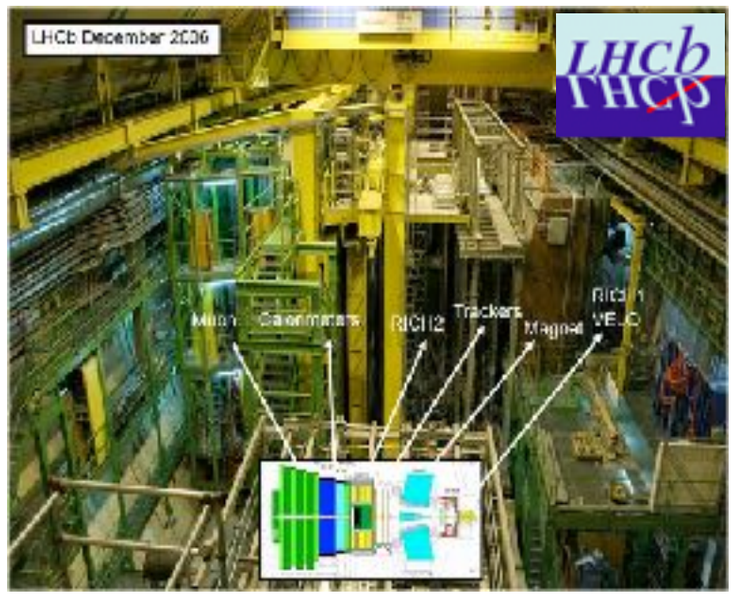




LISA — radiation monitor

- Working in collaboration with the ICC (IEEC-UB) team. Several knowledge areas involved
  - Heliospheric Physics and Solar Weather group.
    - Developed the SOLPENCO (Solar Particle Engineering Code)
    - Knowledge on space radiation environment
  - Radiation simulation group. Developed PENELOPE (Penetration and ENErgy LOss of Positrons and Electrons) code.
    - World experts in Monte Carlo simulation at low energies
  - Instrumentation experience on radiation detectors and space projects:
    - Since 1999 several detectors developed (LHCb at CERN, Babar, HERA-B among others).
    - Participation in different ESA missions: Solar Orbiter, Ariel among others

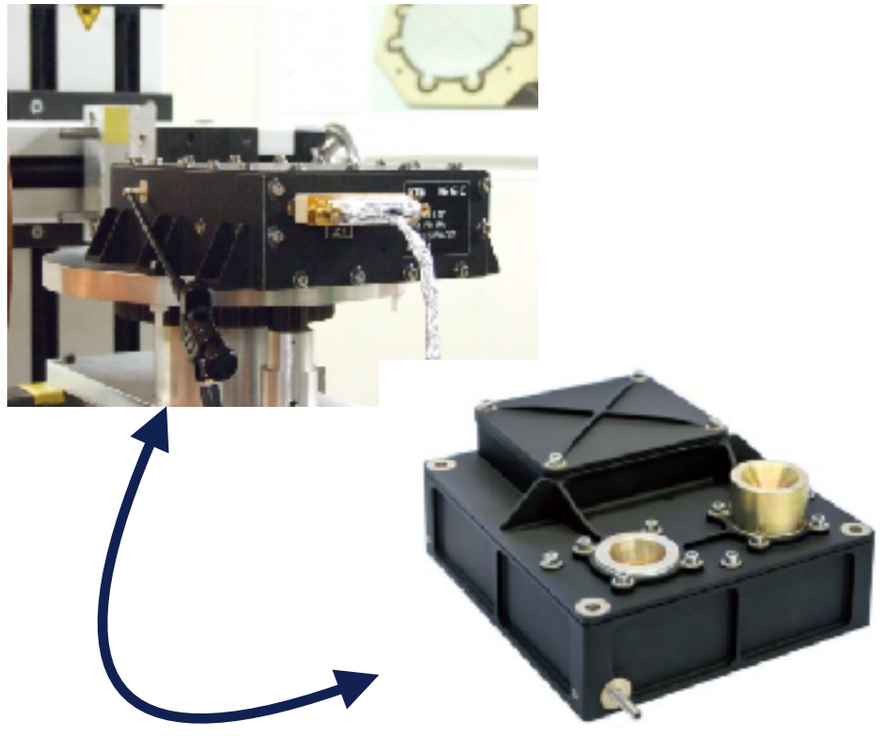




LISA - radiation monitor

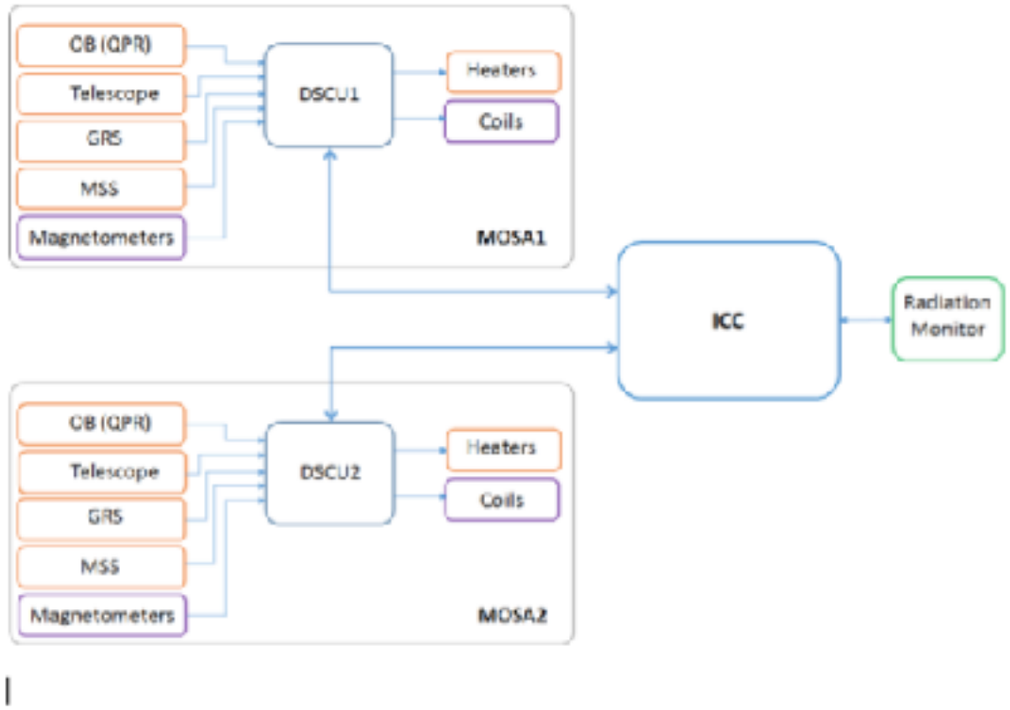
- High energy environment responsible for test-mass charging
  - Affects the capacitive control of the test masses: acceleration noise
  - Two sources: **Solar Event Particles (SEPs) and Galactic Cosmic Rays (GRCs)**
- Radiation monitor to track test mass charging in the LISA test masses
  - Study the 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 by experts in this domain: unique expertise - Francesc Salvat as main advisor.
  - 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 phase A extension

- Co-leading the **'LISA Phase-A Instrument Study for a Gravitational Wave Observatory'** ESA contract
  - Team: AEI (DE), UTN (IT), CNES (FR), IEEC (ES), SFTC (UK)
  - Contributing to the LISA design at system level during phase A
- LISA Phase A extension study will be running 2020-21. Instrument leads to interact with two instrument primes (Thales, Airbus) to agree on baseline design
- IEEC provided several key **definition documents** to be iterated with primes during phase A
  - LISA Diagnostics Requirements
  - LISA Diagnostics Interface Definition Document
  - LISA ICC Functional Definition
  - LISA Diagnostics Interface Definition Document
- Interaction with primes to continue until Mission Formulation Review (MFR), expected end 2021.



Thanks for you attention.

Questions?