Status of the LISA Data and Diagnostics Subsystem

Miquel Nofrarias

Iberian Gravitational Wave Meeting, June 10th 2021
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)

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)

LISA Instrument Group (LIG)
Data and Diagnostics Subsystem (DDS) M. Nofrarias – Spanish lead

Management Team
Josep Colomé (IEEC-CSIC) – NPM
- National Project Management Board
Alberto García (IEEC)

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

INDUSTRIAL PARTNER(S)
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
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

Phase A2 Milestones

16-18/02
PM2
Unit Interface & Budget Consolidation
MOSA design & analysis
Performance model consolidation
Schedule & Risks
Operations & Calibration

20-22/04
PM3a

22-24/06
PM3b
Data pack

31/07
MFR Submission

28/9
MFR K/O

12/12
MFR Board

ESA Review Support
Preparation for B1

M. Hewitson, IEG Core Telecom, 2021-03-25
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: $1uK/\sqrt{\text{Hz}}$ 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

  - 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…)

![Graph 1](image1.png)

![Graph 2](image2.png)
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)

ADS1278 ADC Ev. board

AMR connectors

Sensor Head

Analog signal conditioning

EMF electronics

Flipping electronics

EMF Coil

Current Buffer

DAC

PID

0 Set Point

Flipping Controller
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
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
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

LISA - radiation monitor

- Define simple Geometry in PENELOPE
  - Test Mass 46x46x46 mm³ cube
  - Electrode Housing 70x70x70 mm³ 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 your attention.

Questions?