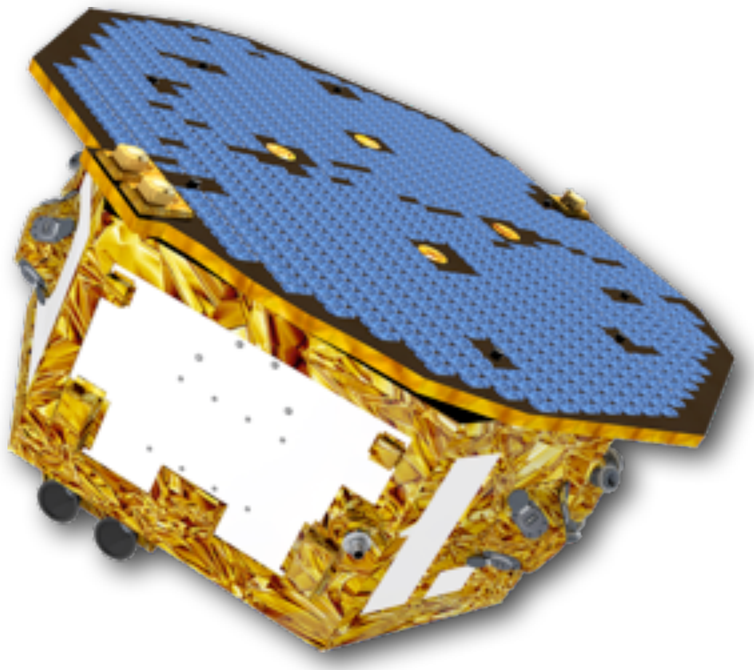

esa SCIENCE
LISA
Pathfinder
Paul McNamara on behalf
of the LPF Team
LISA Symposium X
University of Florida, May 2014
lisa pathfinder

Introduction

- LISA Pathfinder (LPF) is a technology verification mission for future spaceborne gravitational wave detectors
  - LPF was approved by ESA to demonstrate the concept of low frequency gravitational wave detection in space
- The LPF mission is a stepping stone in the development of a spaceborne GW mission
  - LISA Pathfinder provides us with:
    - A better understanding of the physics of the forces acting on a free-falling test mass
    - Industrial experience in the development, manufacture, and testing of technologies required for GW detection
    - Data analysis algorithms and tools dedicated to the analysis of the system as a whole
    - Essential experience in the commissioning of a LISA-like mission



LISA Pathfinder

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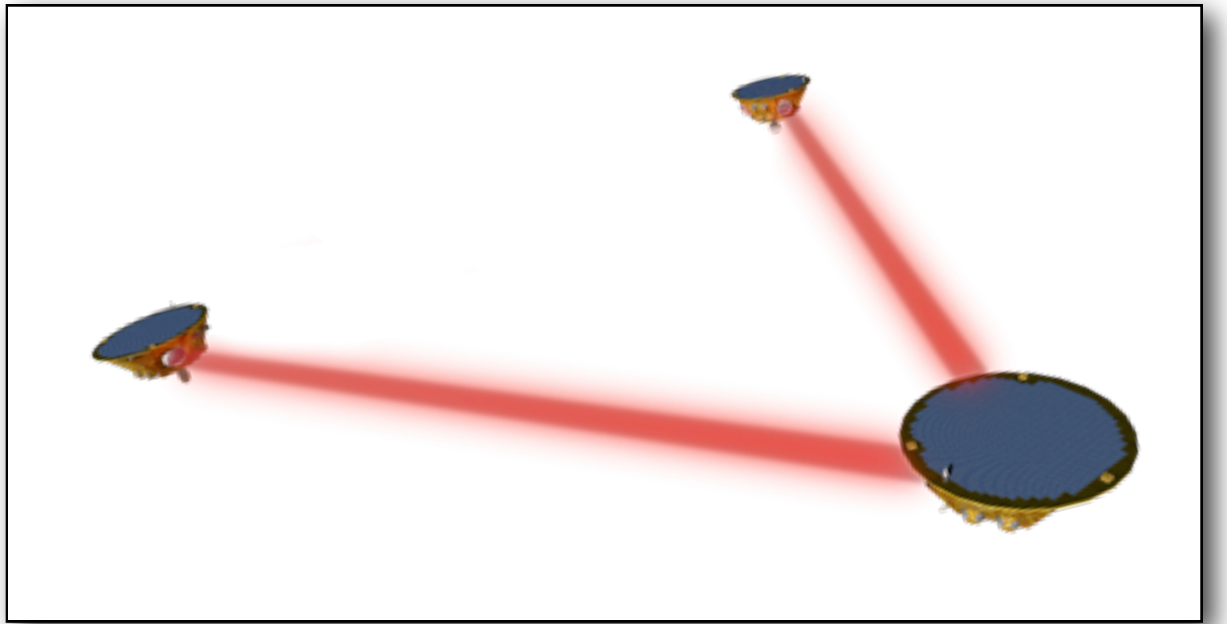
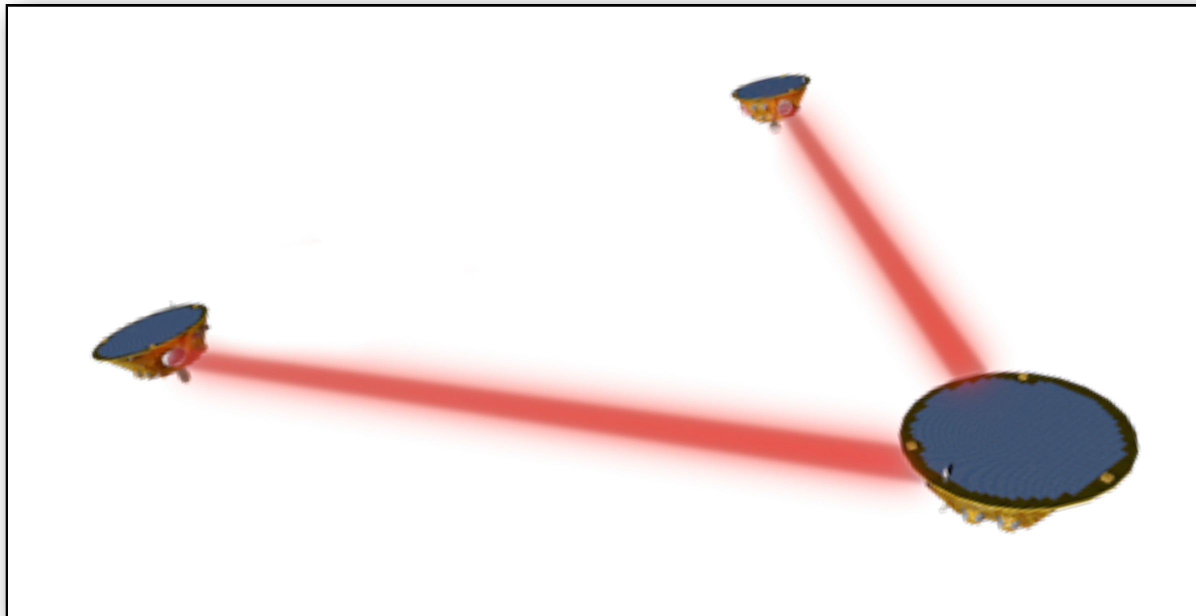
LISA Pathfinder Concept



(e)LISA:

- 3 spacecraft, separated by ~1million km
- Role of each spacecraft is to protect the fiducial test masses from external forces

LISA Pathfinder Concept



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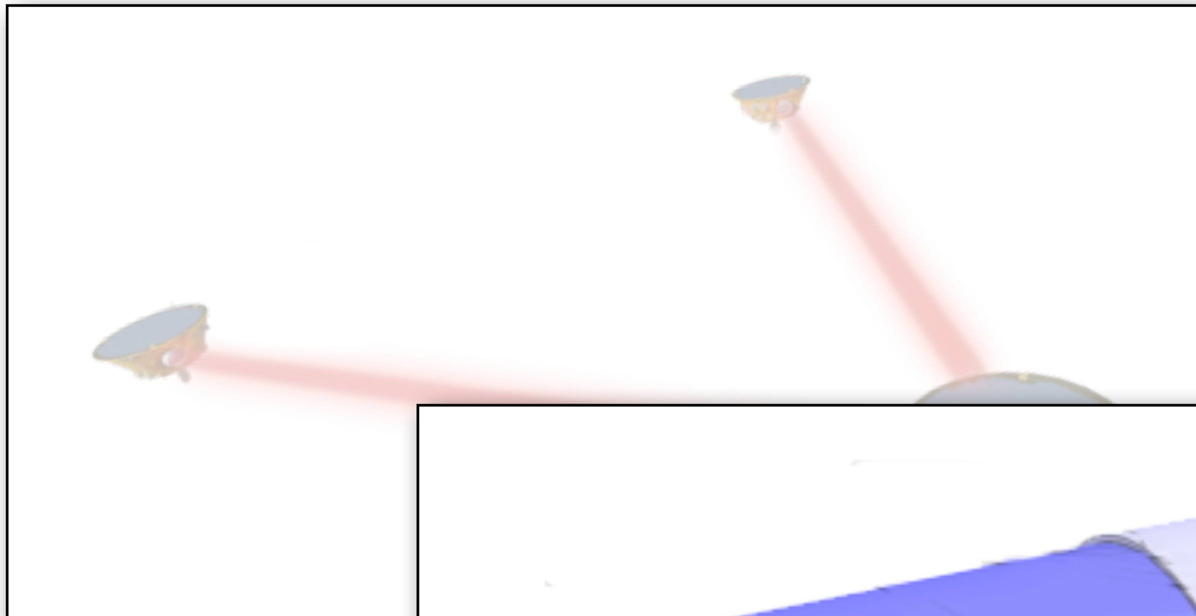
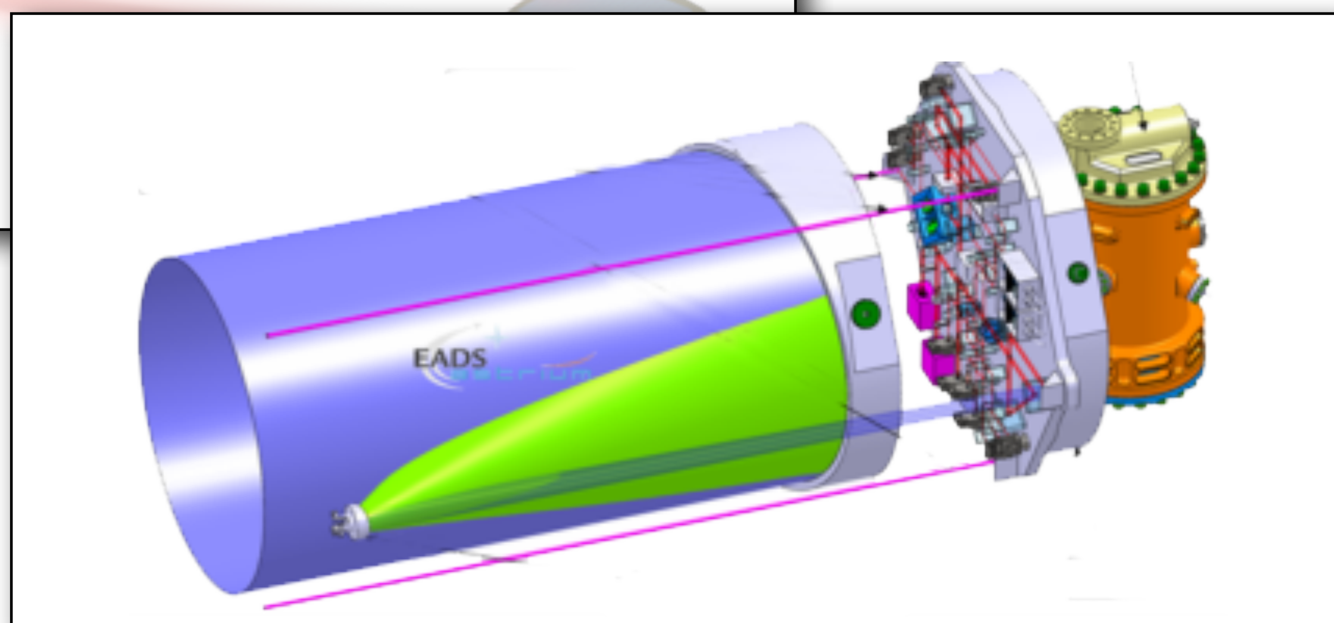
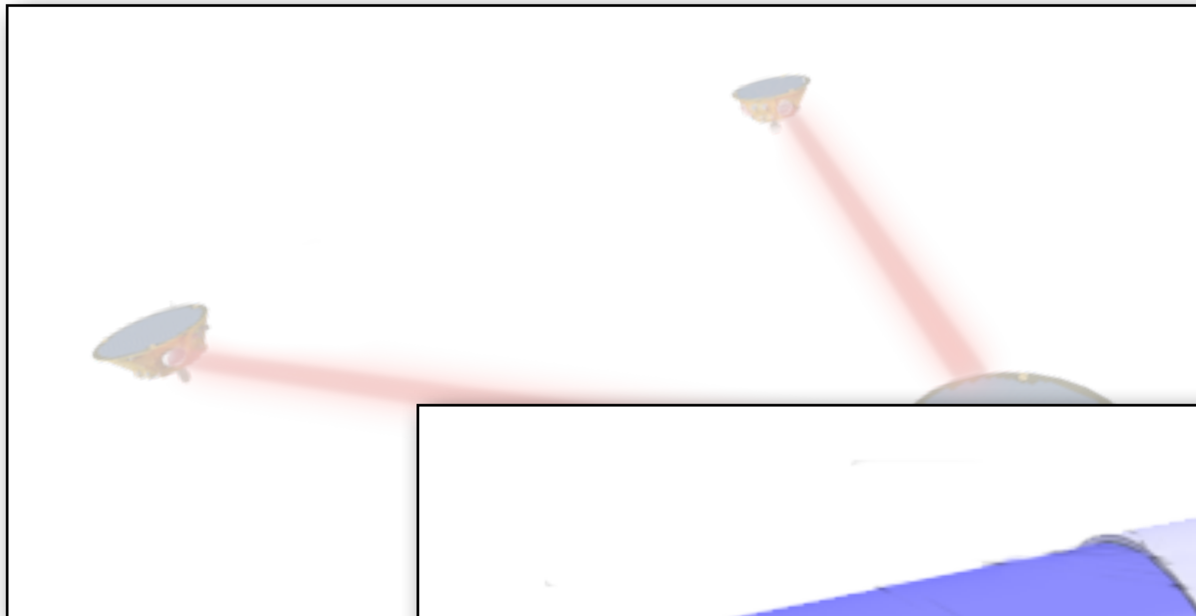


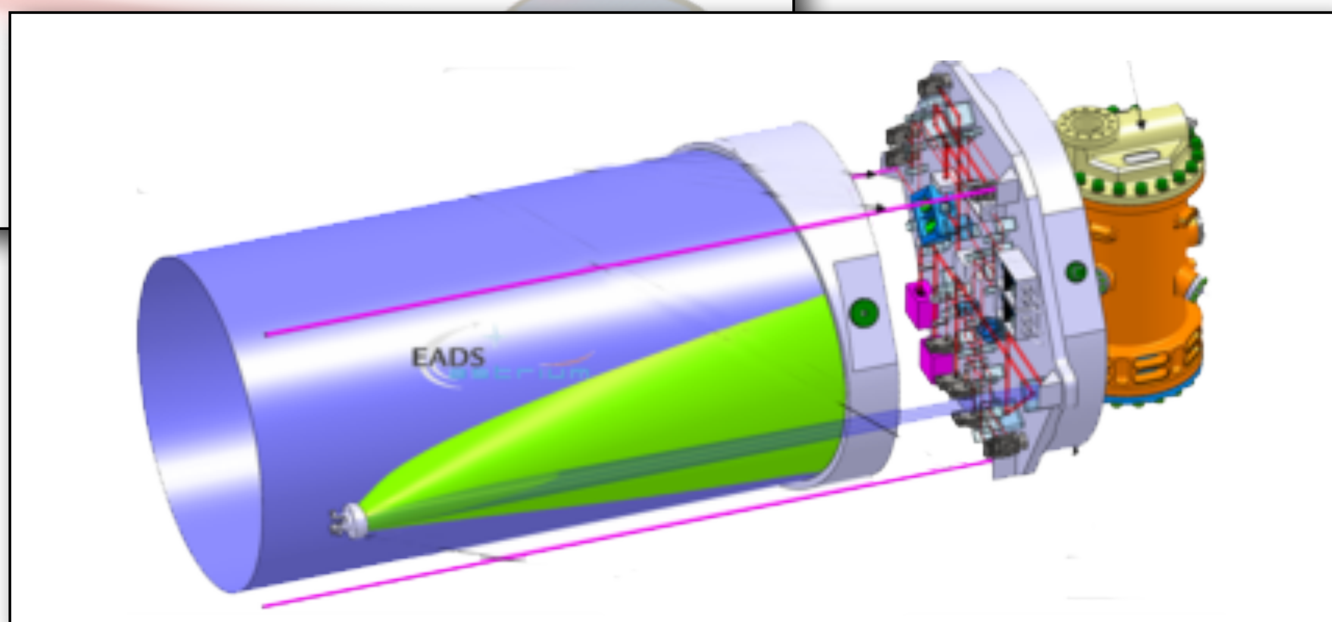


(e)LISA:

- Locally measure distance from TM to s/c using:
    - Laser interferometry along sensitive axis (between s/c)
    - Capacitive sensing on orthogonal axes
- TM displacement measurements are used as input to DFACS which controls position and attitude of s/c with respect to the TM

LISA Pathfinder Concept





LISA Pathfinder Concept

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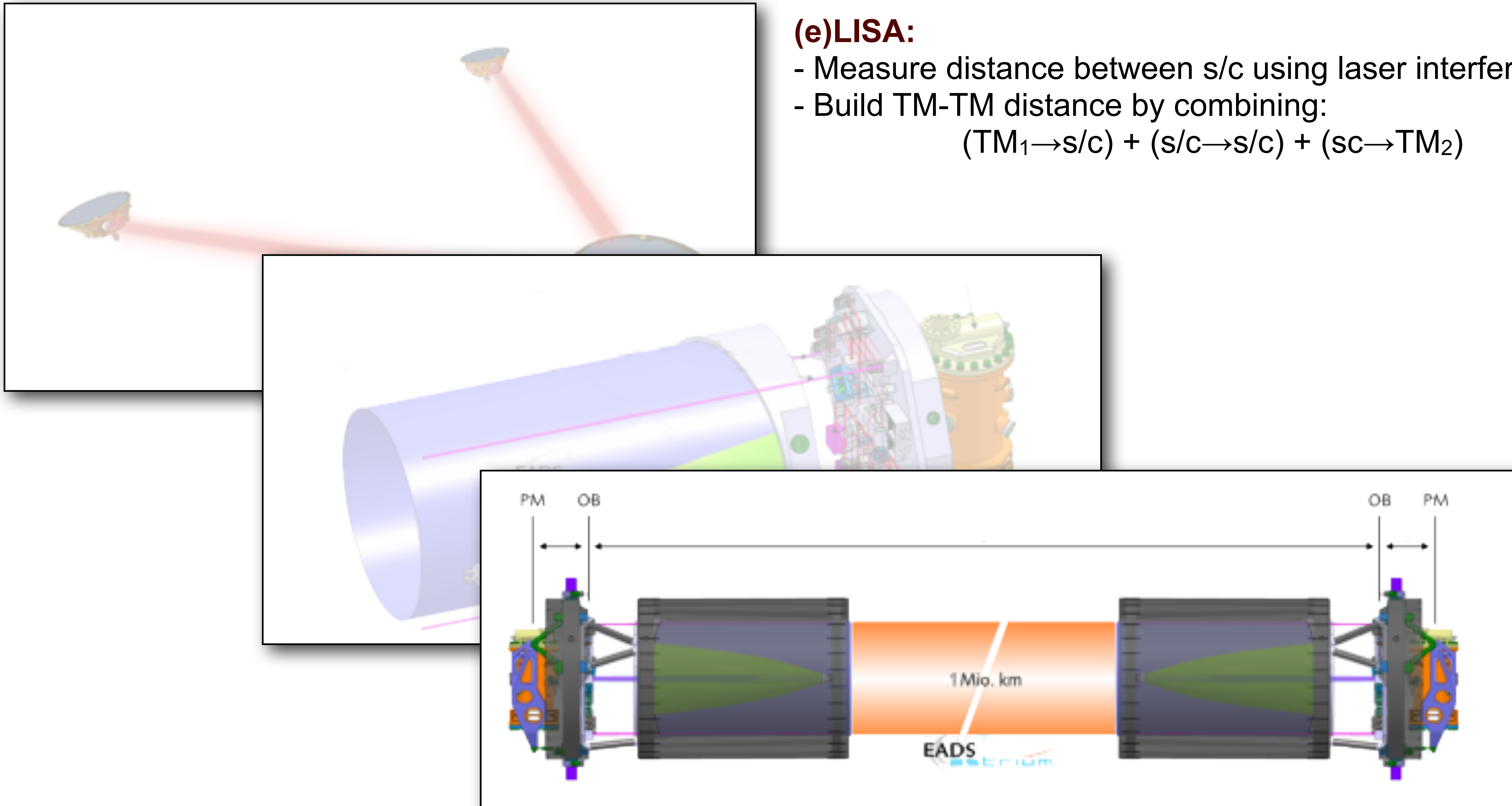
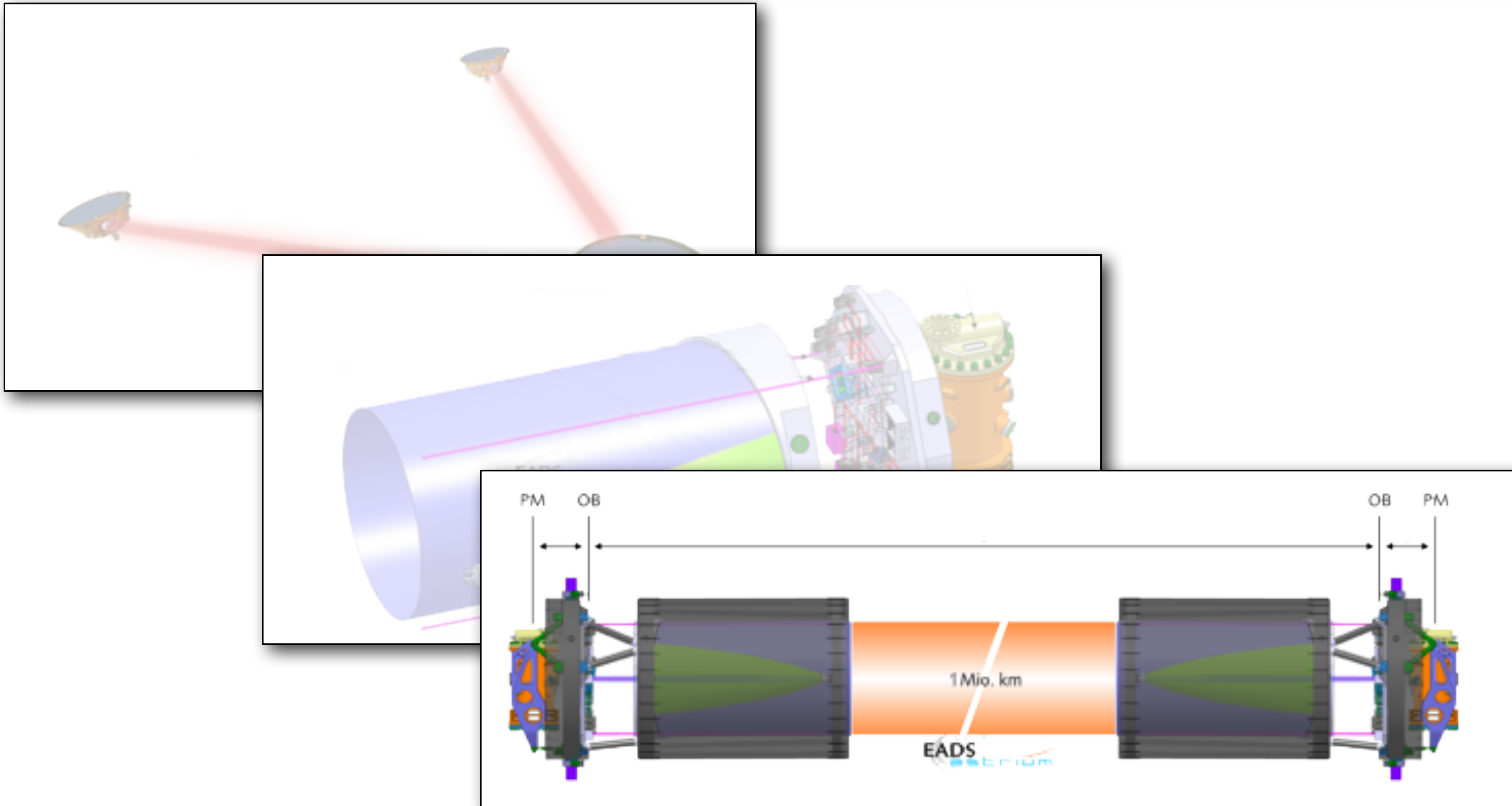


(e)LISA:

- Measure distance between s/c using laser interferometry
- Build TM-TM distance by combining:

$(TM_1 \rightarrow s/c) + (s/c \rightarrow s/c) + (sc \rightarrow TM_2)$

LISA Pathfinder Concept



LISA Pathfinder Concept

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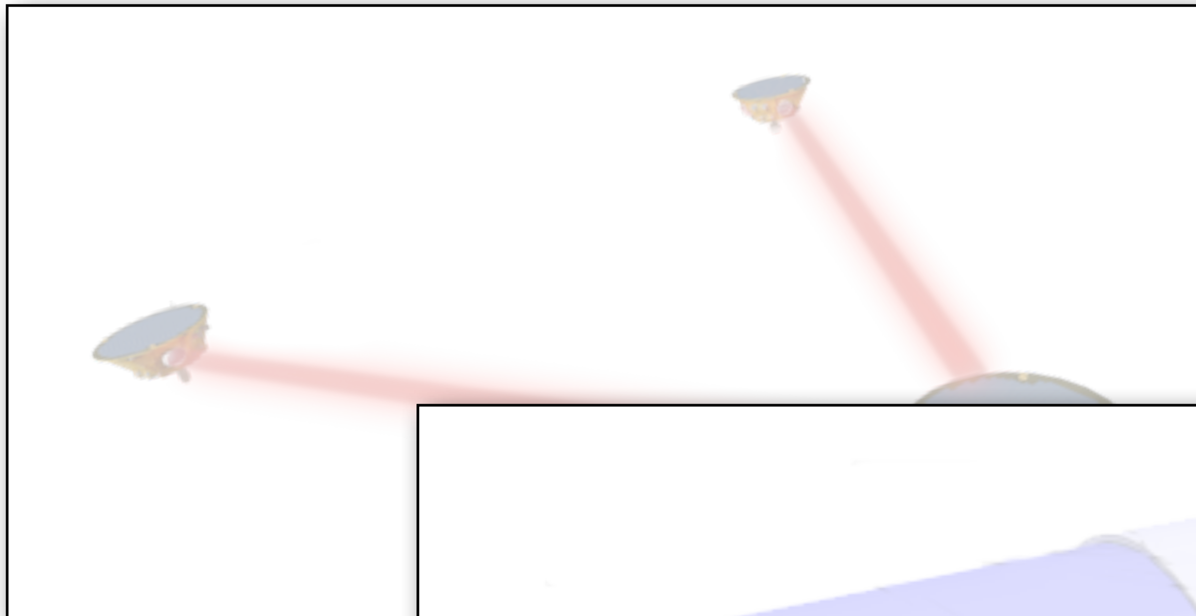
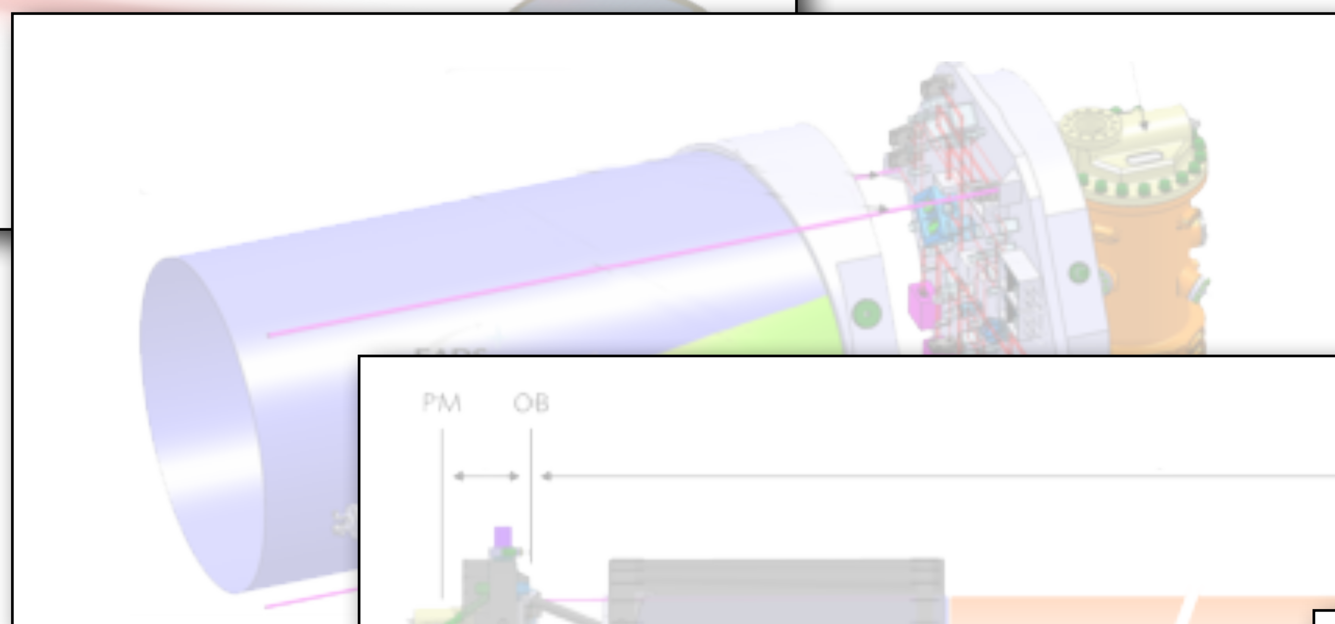
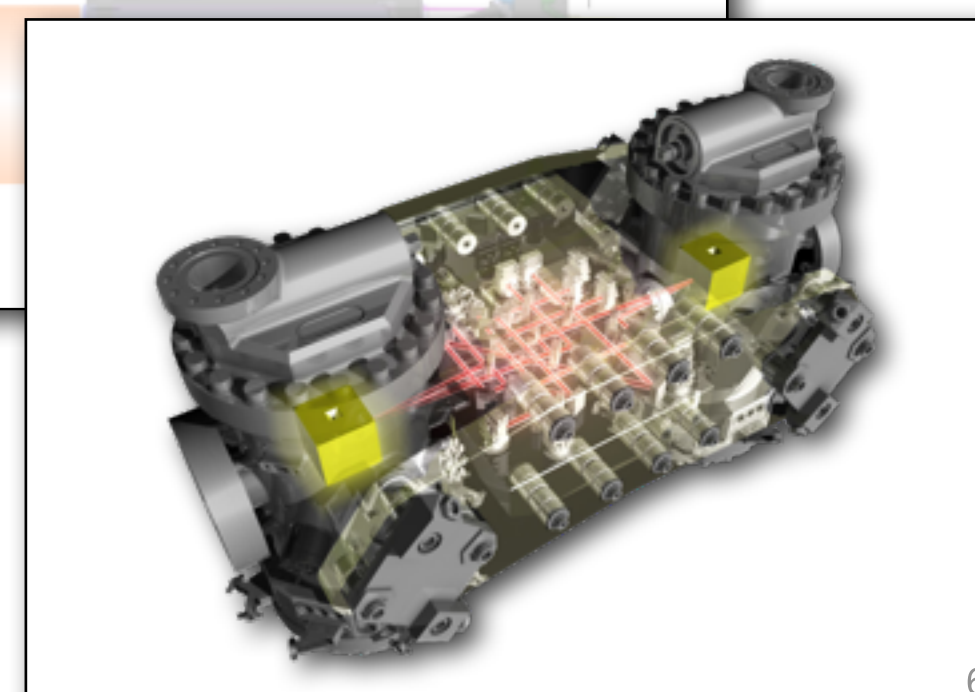


LISA Pathfinder
- Two test masses/two inertial sensors
- Laser interferometric readout of $TM_1 \rightarrow s/c$ & $TM_1 \rightarrow TM_2$
- Capacitive readout of all 6dof of test masses
- Drag-Free and Attitude Control System
- Micro-Newton Thrusters





Primary Performance Requirements

- LISA Pathfinder has two primary performance requirements:
  - Differential Acceleration Noise between free-floating test masses

$$S_a^{\frac{1}{2}}(f) \leq 3 \times 10^{-14} \left[1 + \left(\frac{f}{3\,\mathrm{mHz}}\right)^4\right]^{\frac{1}{2}} \mathrm{ms}^{-2}/\sqrt{\mathrm{Hz}}$$

  - Displacement sensing noise

$$S_{oms}^{\frac{1}{2}}(f) \leq 9.1 \times 10^{-12} \left[1 + \left(\frac{3\,\mathrm{mHz}}{f}\right)^4\right]^{\frac{1}{2}} \mathrm{m}/\sqrt{\mathrm{Hz}}$$

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  - Differential Acceleration Noise between free-floating test masses

Bill Weber: "LPF: achieving and measuring sub-femto-g free fall for gravitational wave astrophysics"

  - Displacement sensing noise

Harry Ward: "Optical Metrology: From LISA Pathfinder to eLISA"

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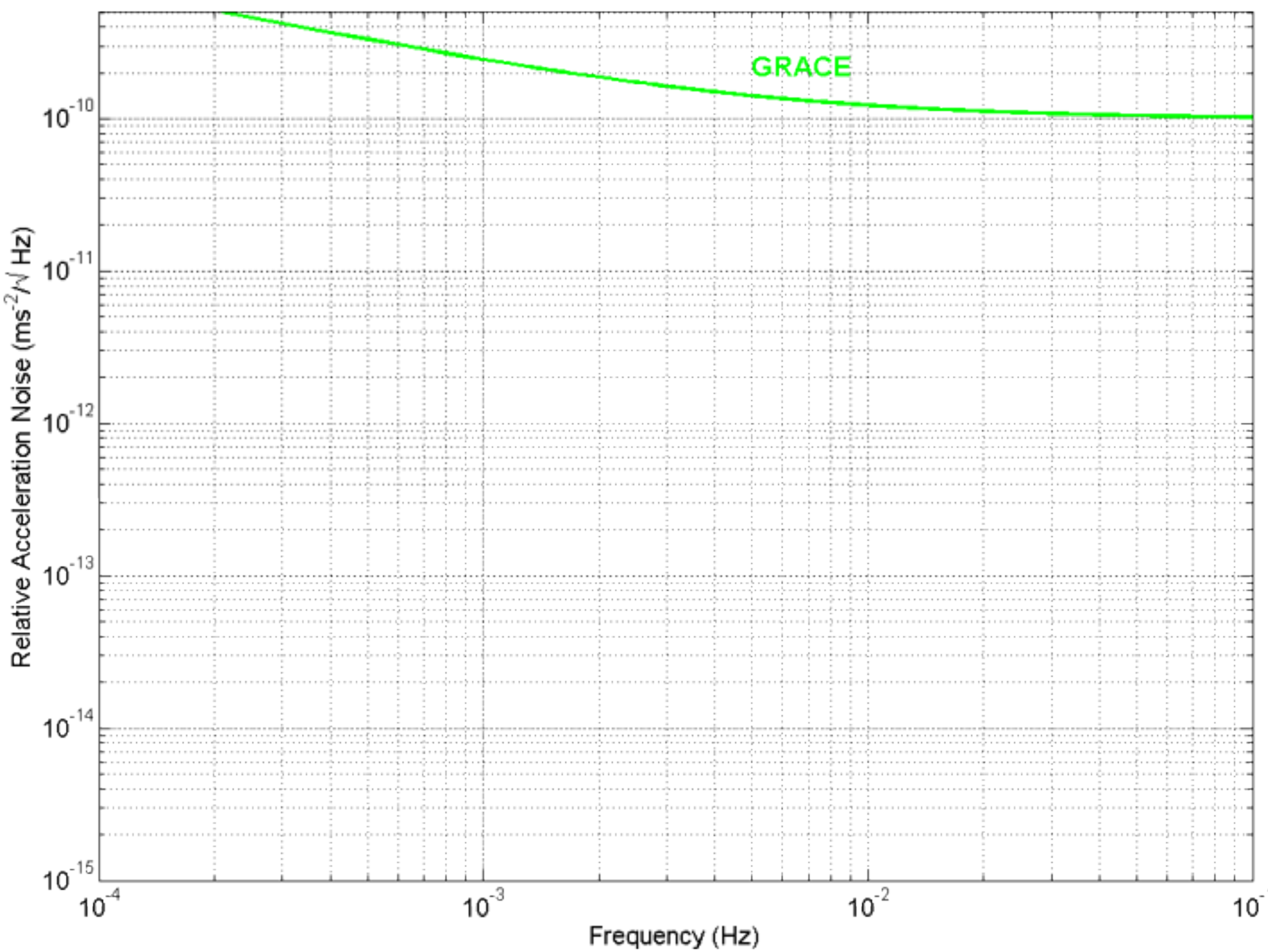
Performance Comparison



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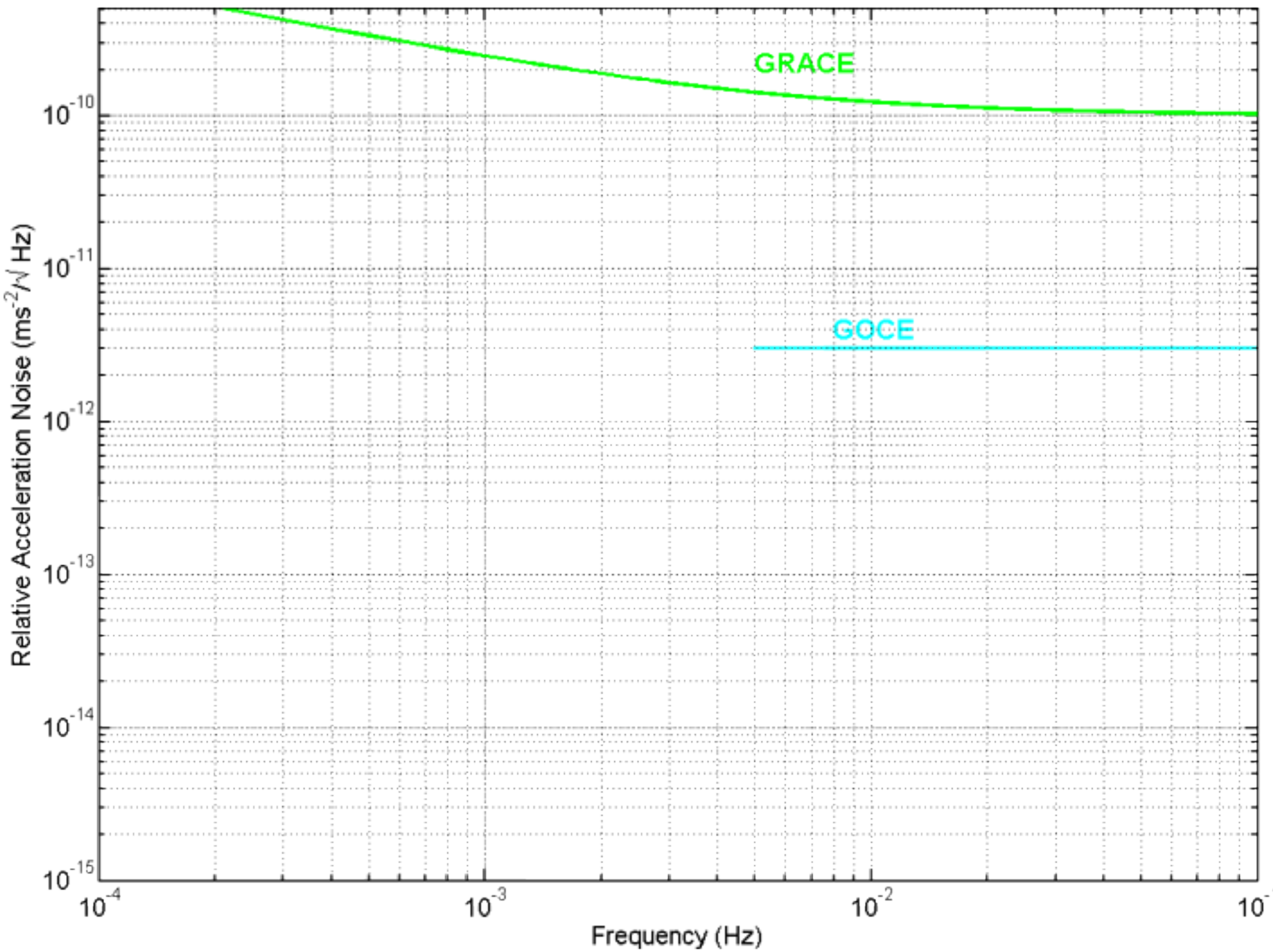
Performance Comparison



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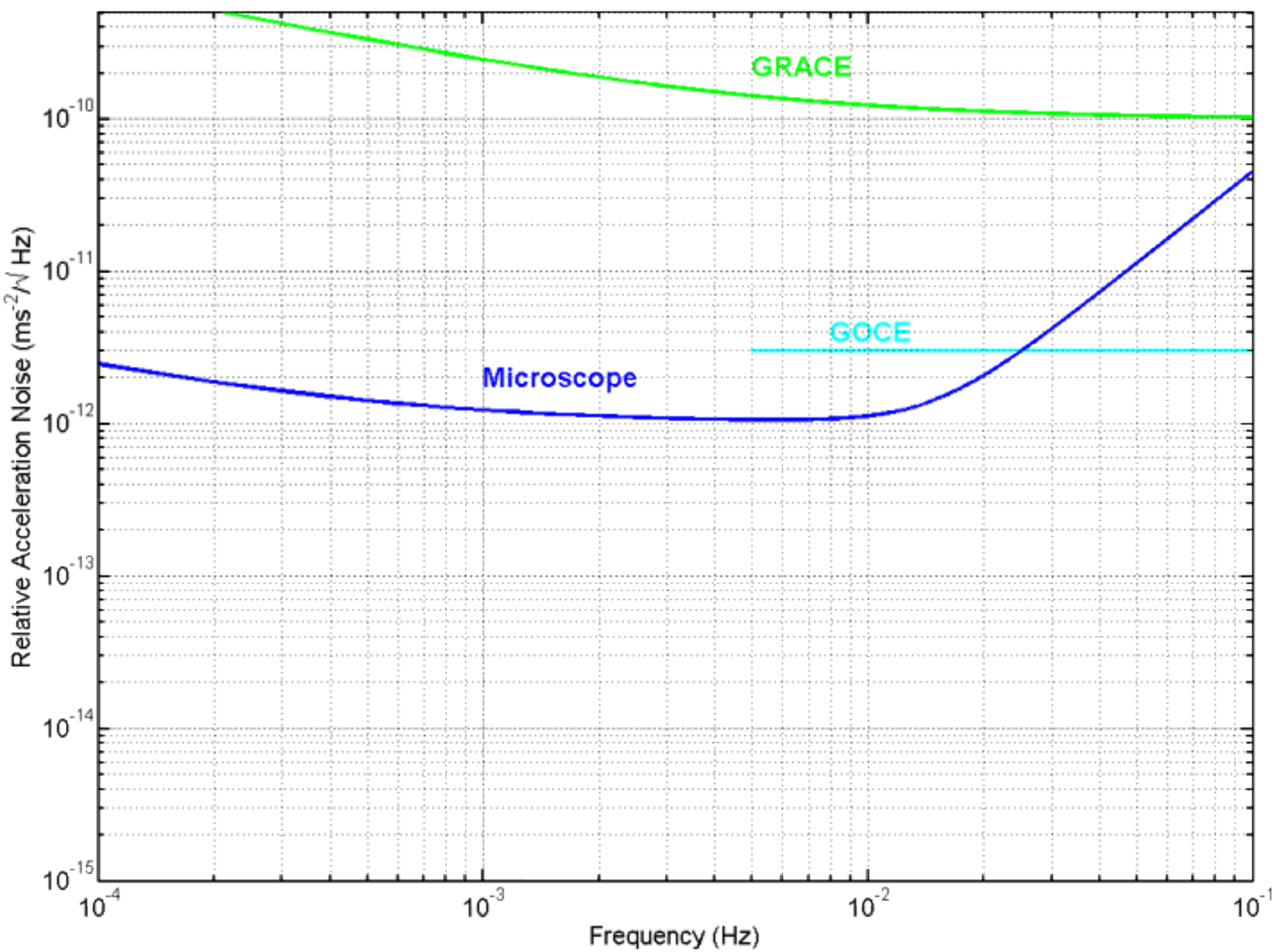

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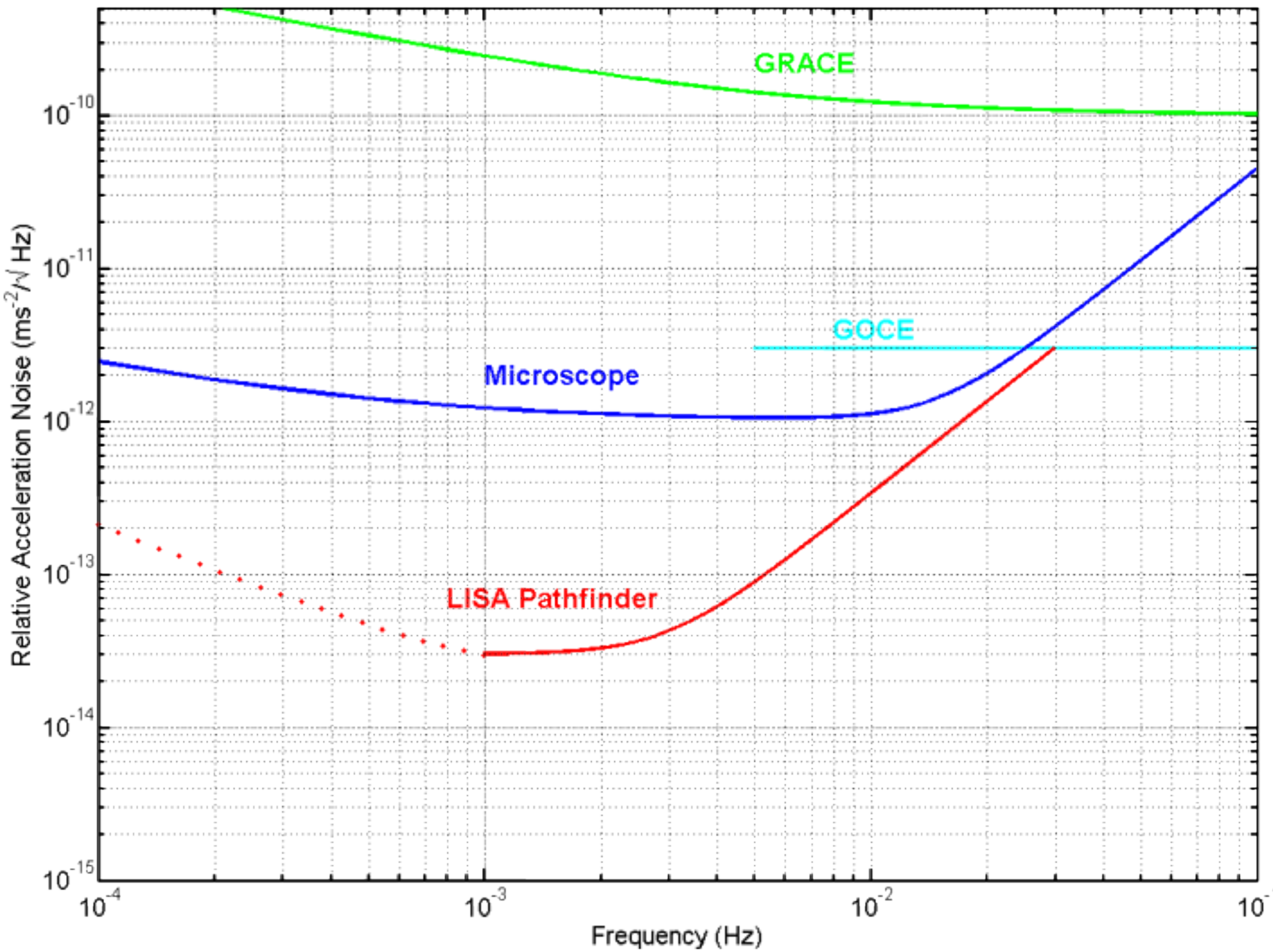

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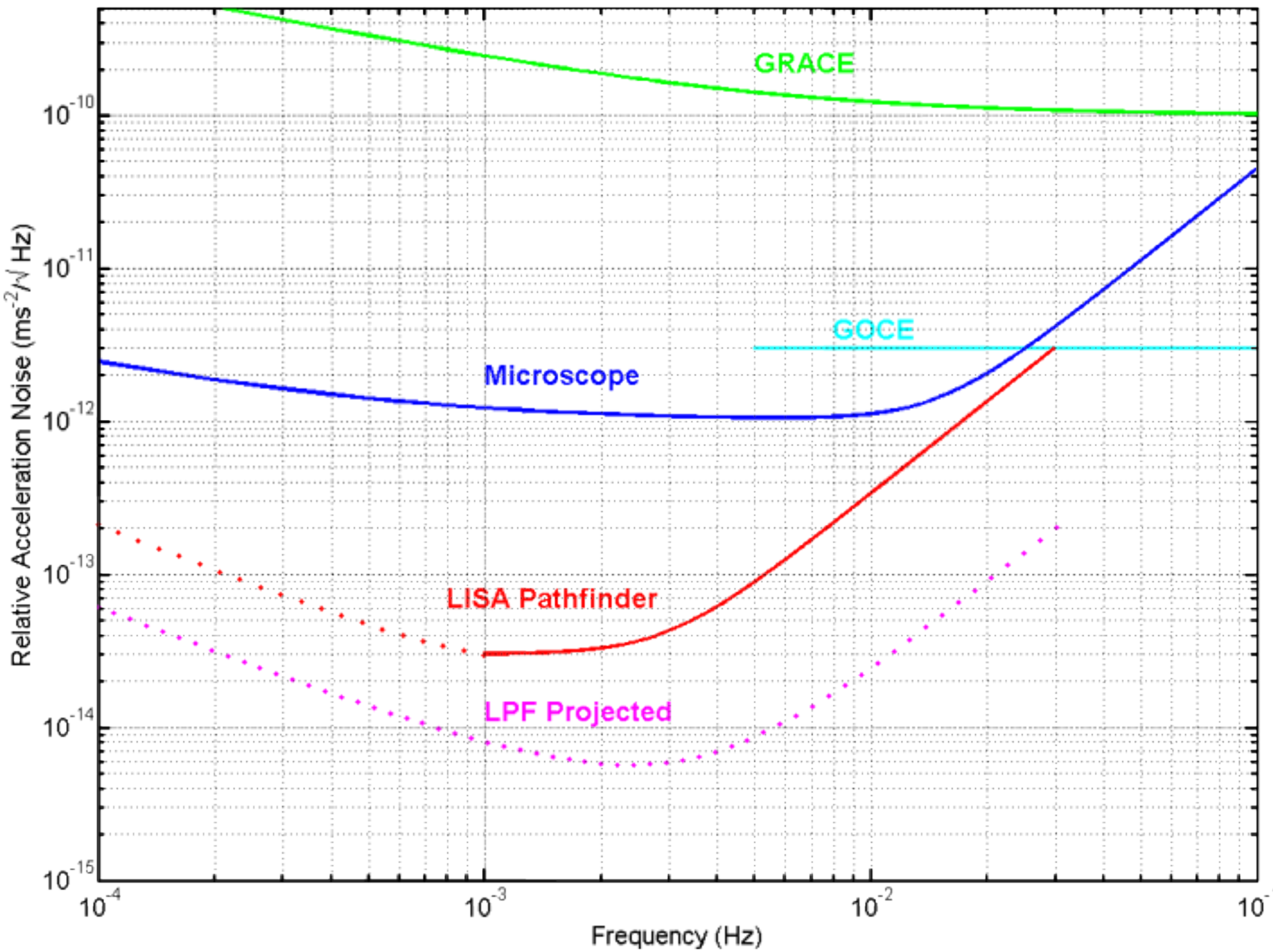

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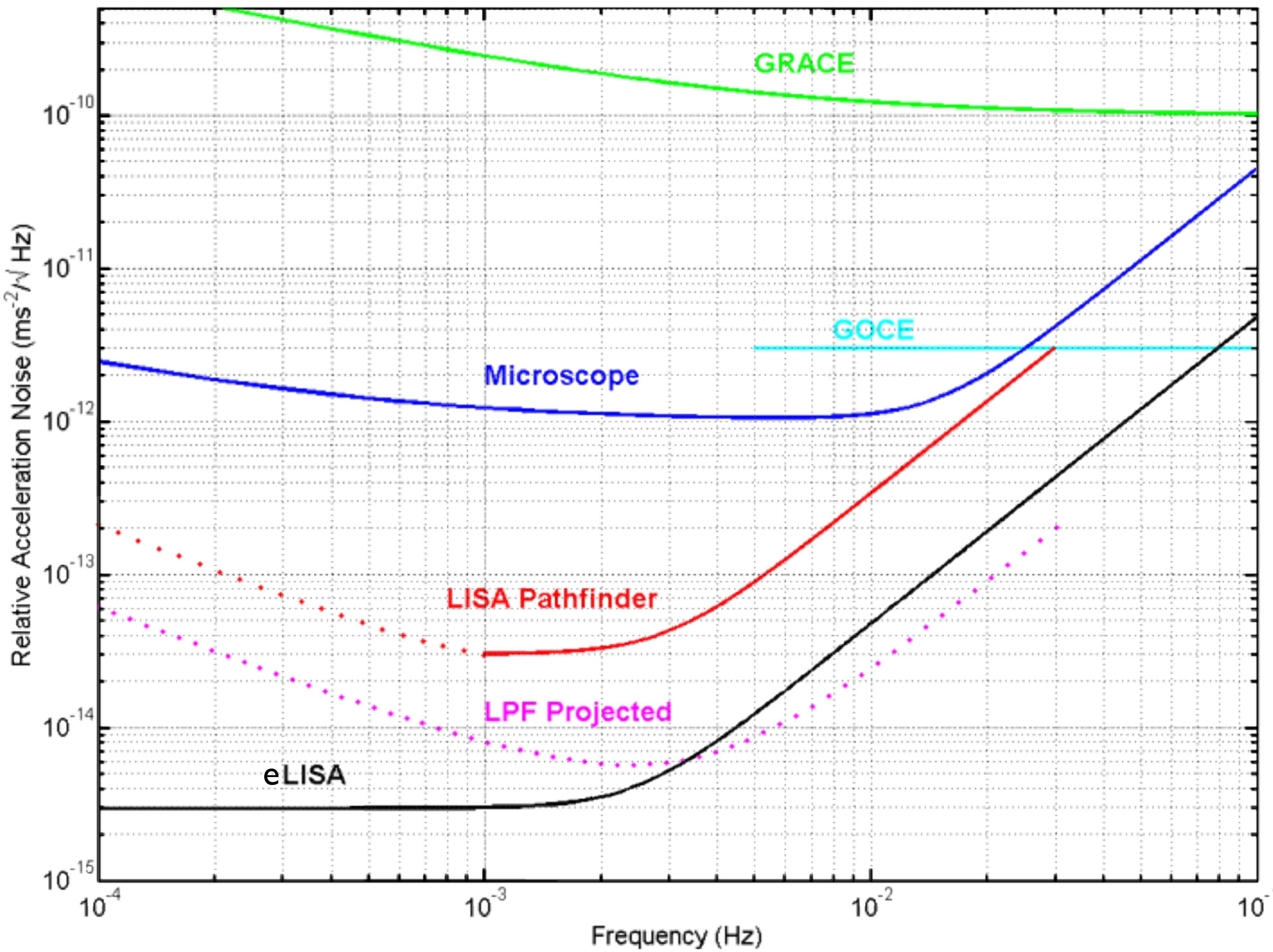

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Performance Comparison

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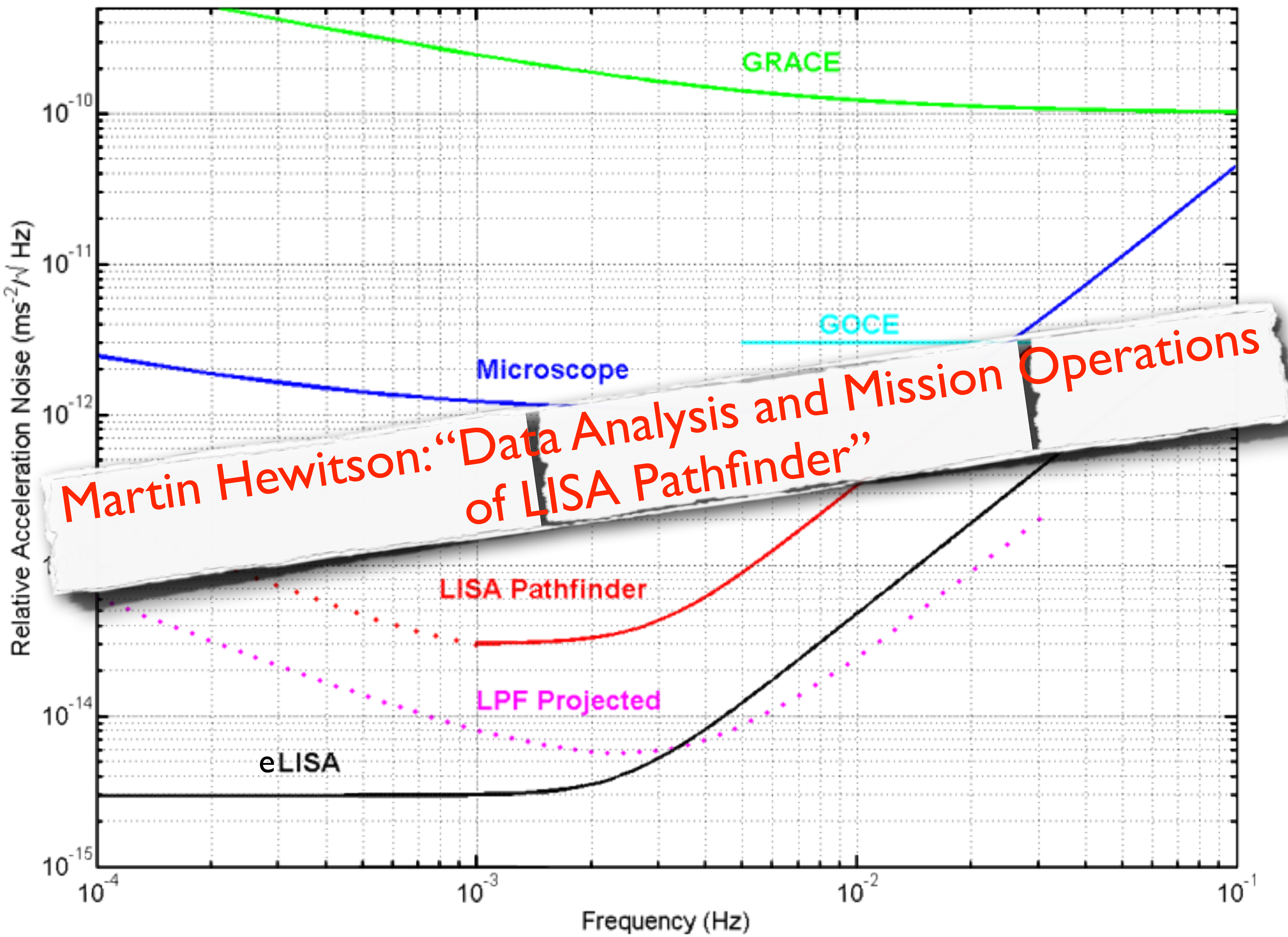

Martin Hewitson: "Data Analysis and Mission Operations of LISA Pathfinder"

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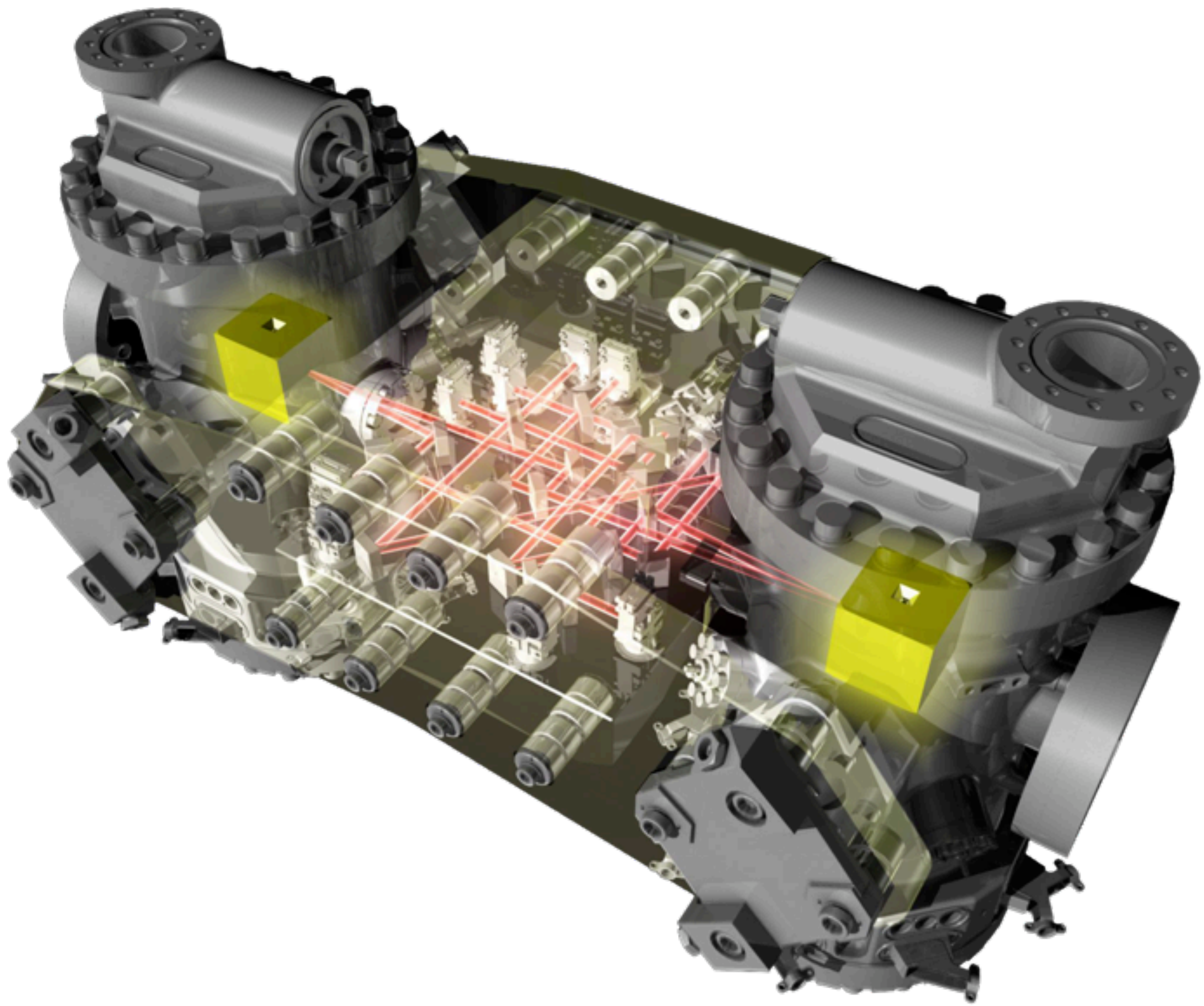
LISA Technology Package



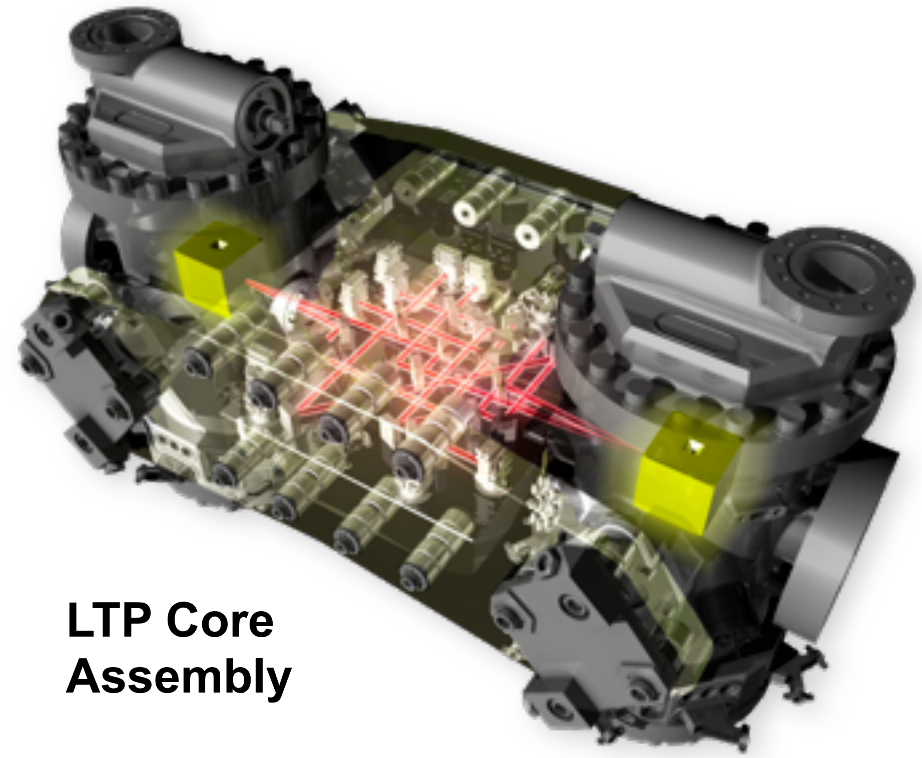
LISA Technology Package

- Procurement and manufacture of the LTP funded by European member states and ESA

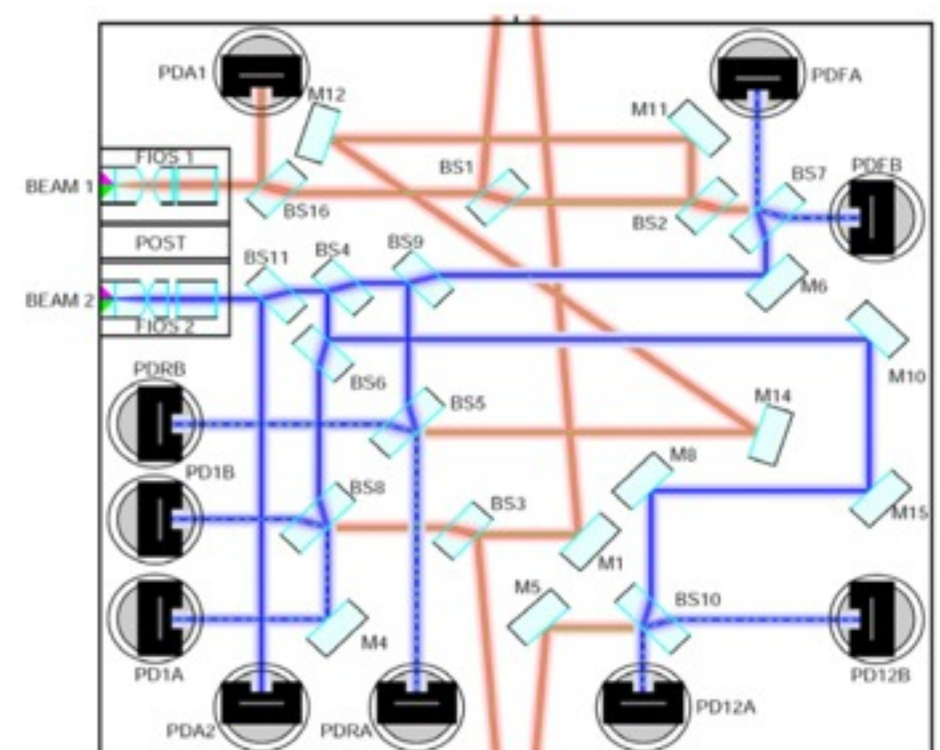
France:
Laser modulator
Germany:
PI, LTP Architect (Astrium), Laser
Italy:
PI, Inertial Sensor (ISS)
Netherlands:
ISS SCOE
Spain:
Data Diagnostics System, Data Management Unit
Switzerland:
ISS Front End Electronics
United Kingdom:
Optical Bench, Phase-meter, Charge Management

LISA Technology Package

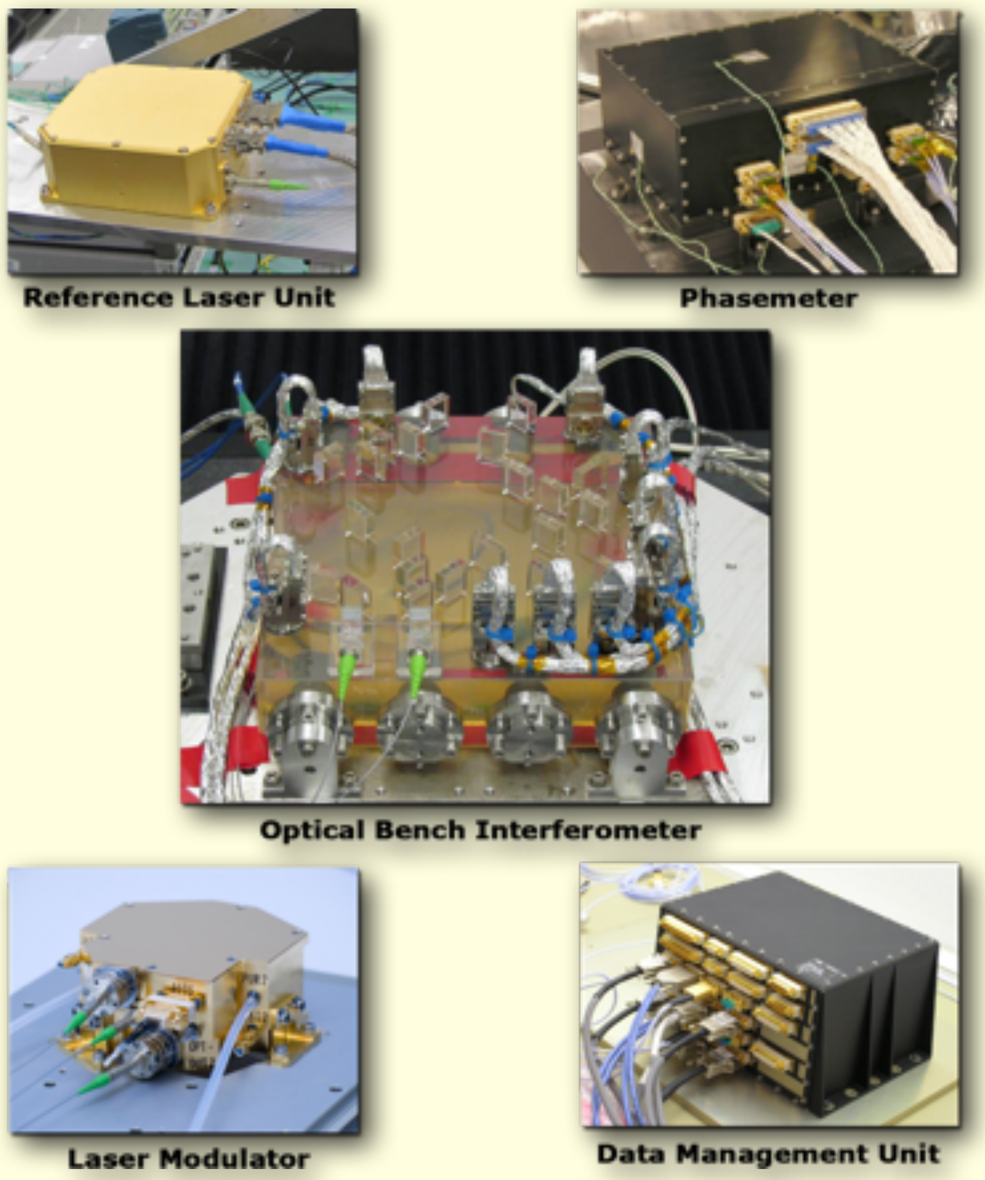
- The LISA Technology Package (LTP) is the European instrument payload on LPF
- Two Au:Pt test masses housed in separate vacuum enclosures
- Relative position of test masses read-out by
  - Heterodyne laser interferometry on sensitive axis
  - Capacitive sensing on all degrees of freedom
- Four interferometers on ultra-low expansion optical bench
  - x1, x2-x1, Frequency noise, Reference interferometer



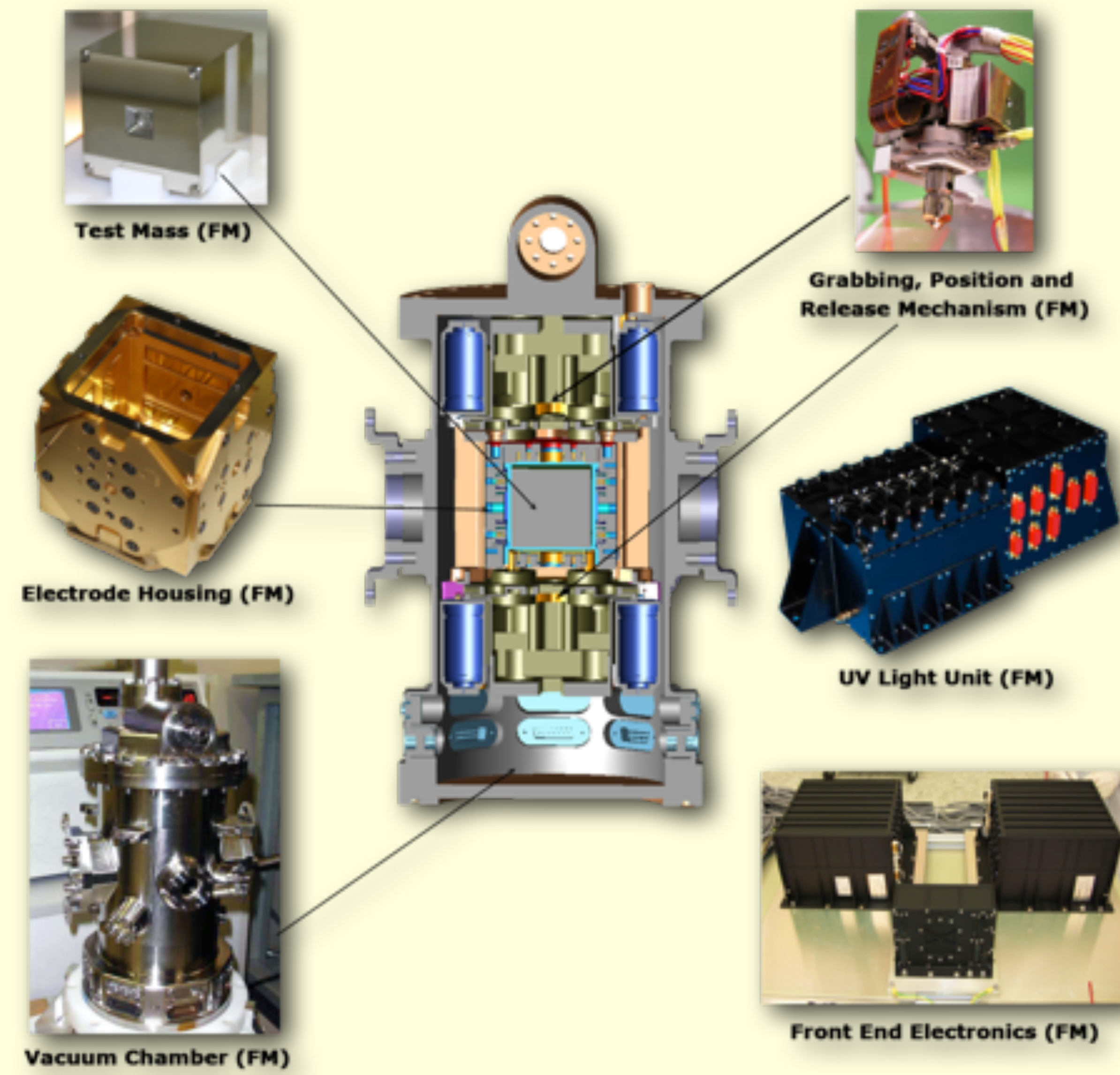
LTP Core Assembly



The LTP main subsystems



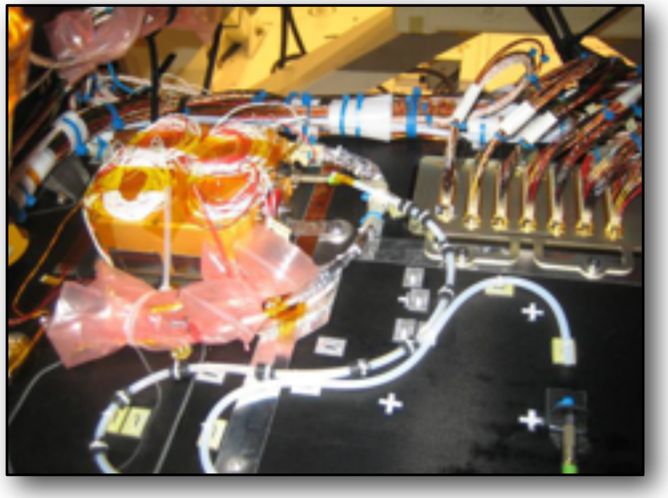
Optical Metrology Subsystem



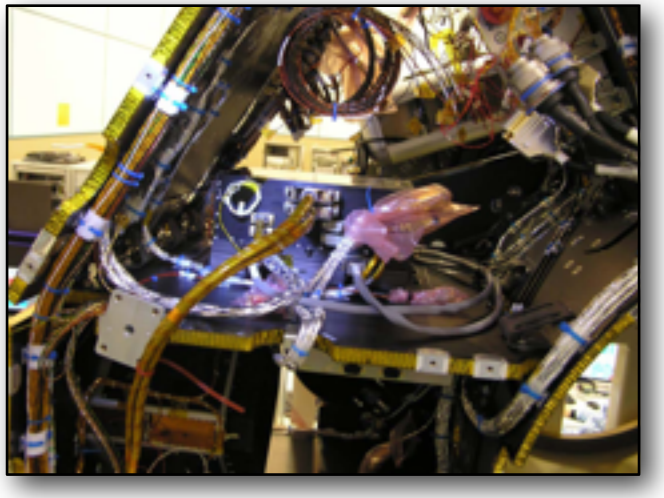
Inertial Sensor Subsystem

Mission Status [1]

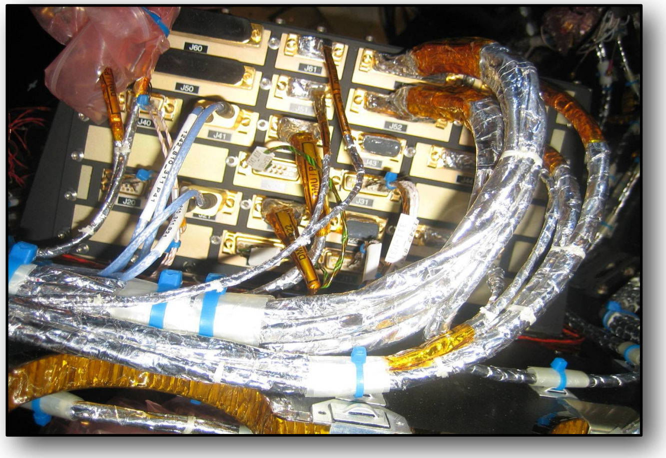
- All electronic boxes have been integrated to the spacecraft
  - Only the microthrusters and LTP Core Assembly (interferometer and inertial sensors) are not yet delivered



Reference Laser Unit

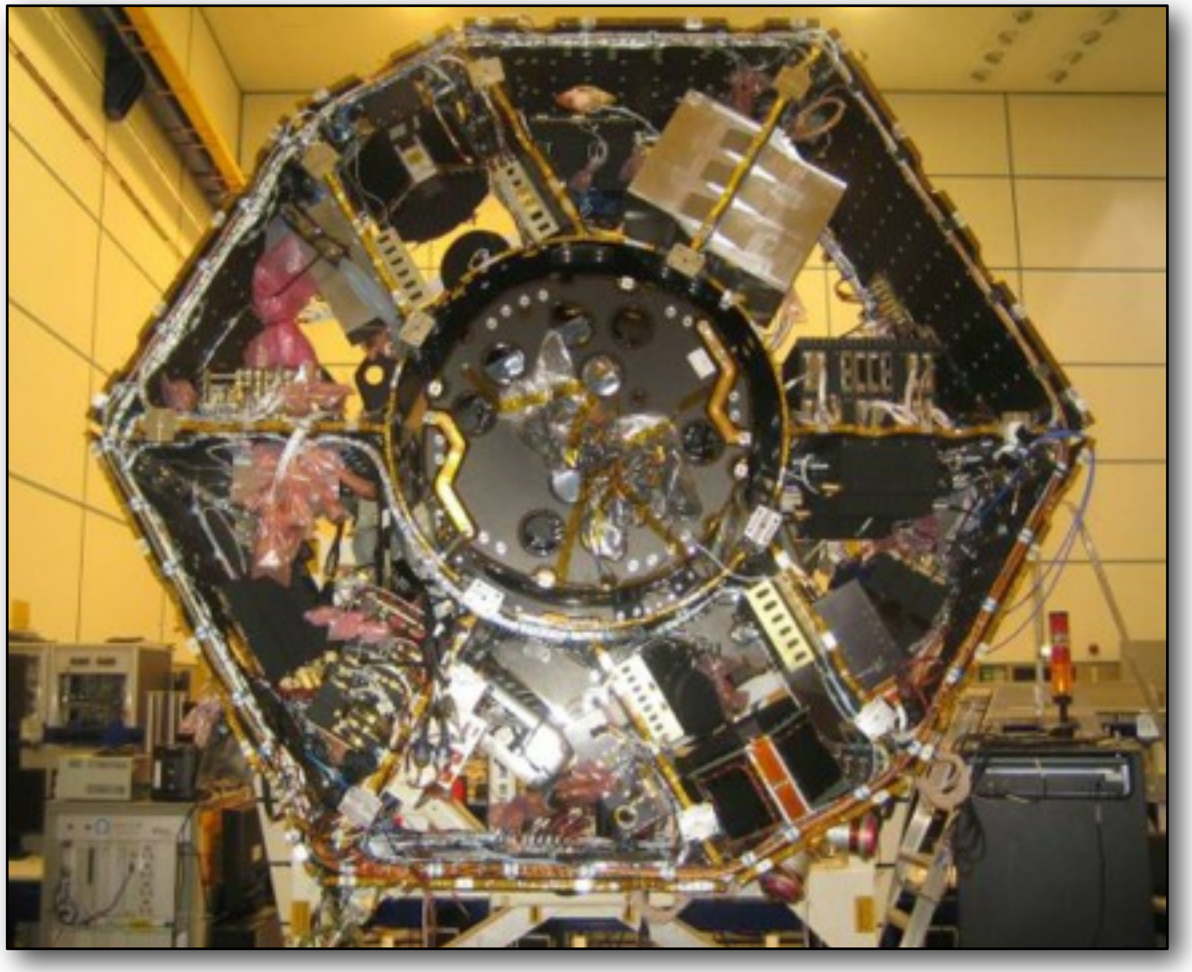


Phasemeter



Payload Computer

ISS Front-End Electronics



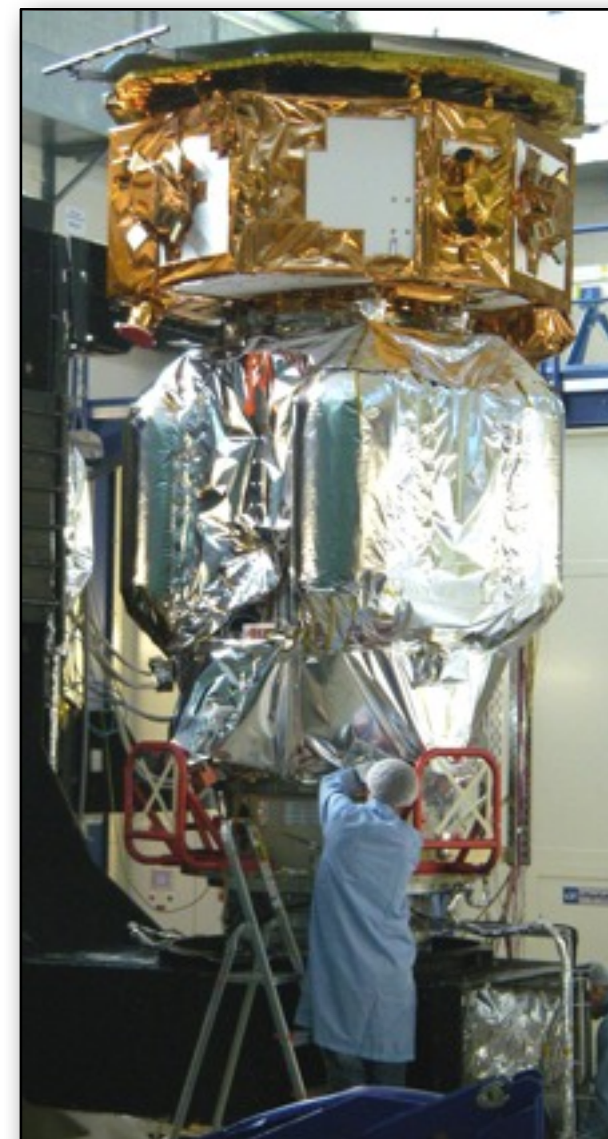
Integrated Sciencecraft.
All photos courtesy of Airbus Defence and Space

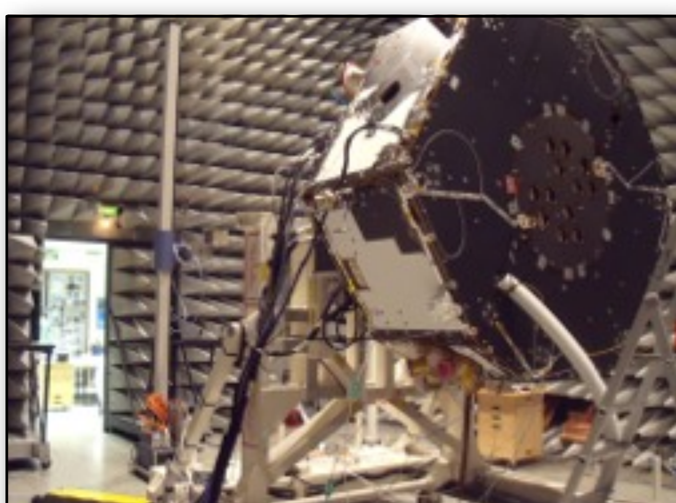
Mission Status [2]

- Several system environmental tests have already taken place
  - Further system tests are on hold pending the delivery of the LTP Core Assembly

Vibration/shock tests

Closed-loop tests





EMC

On-Station Thermal Test

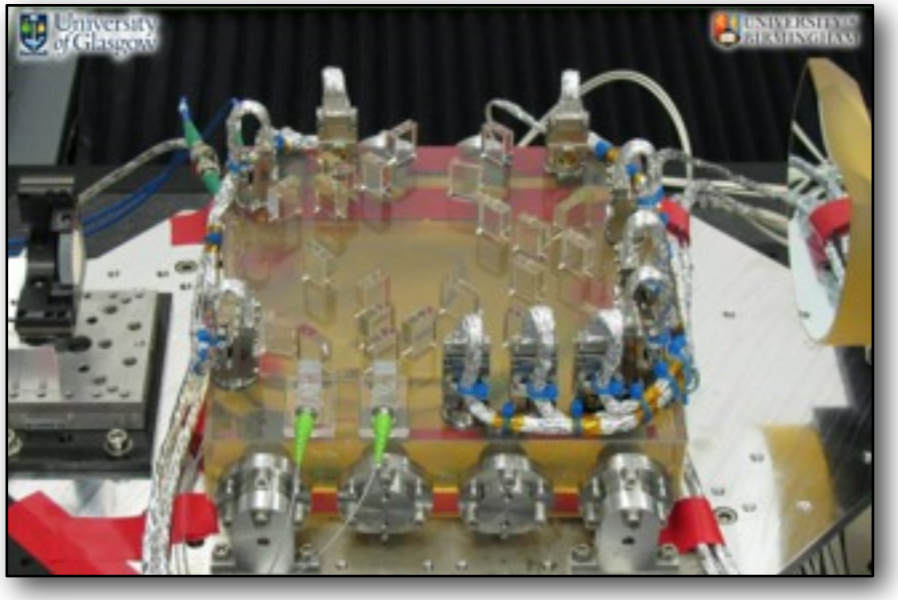
Transfer Orbit Thermal Test

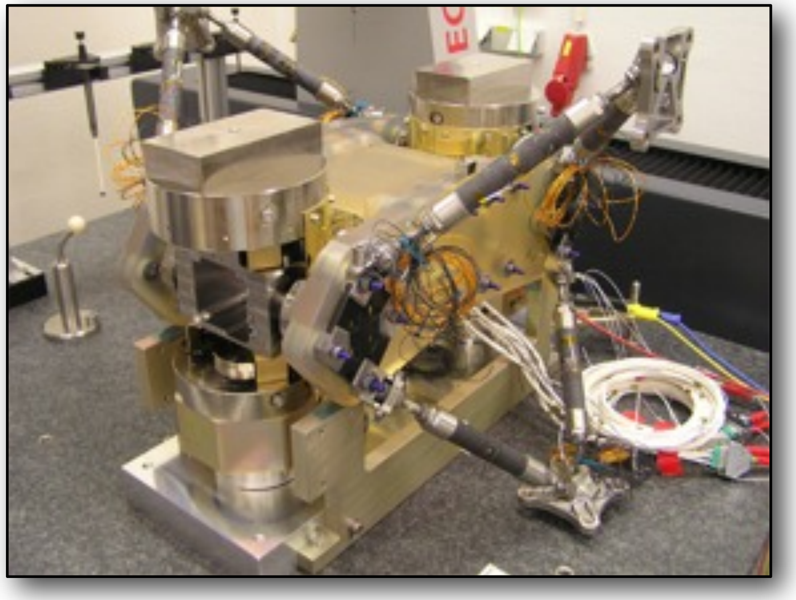
Mission Status [2]

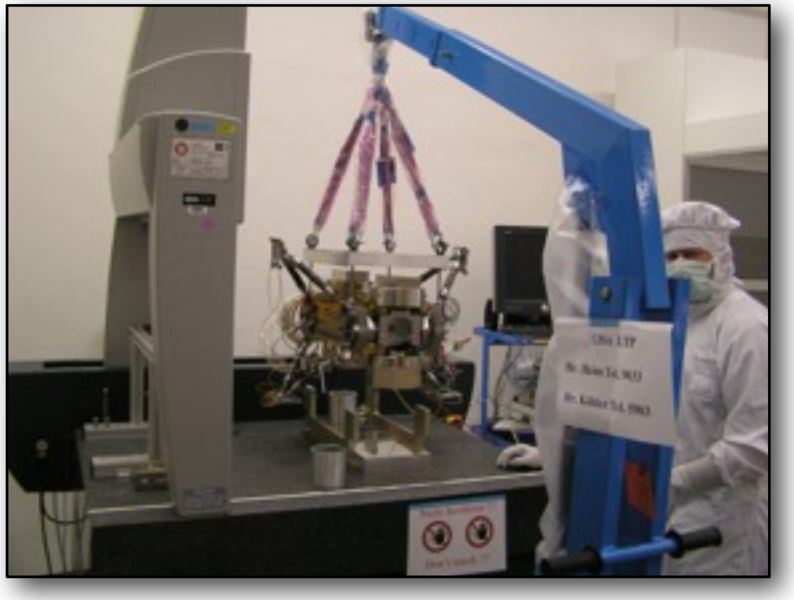
- Several system environmental tests have already taken place
  - Further system tests are on hold pending the delivery of the LTP Core Assembly

System Level Performance

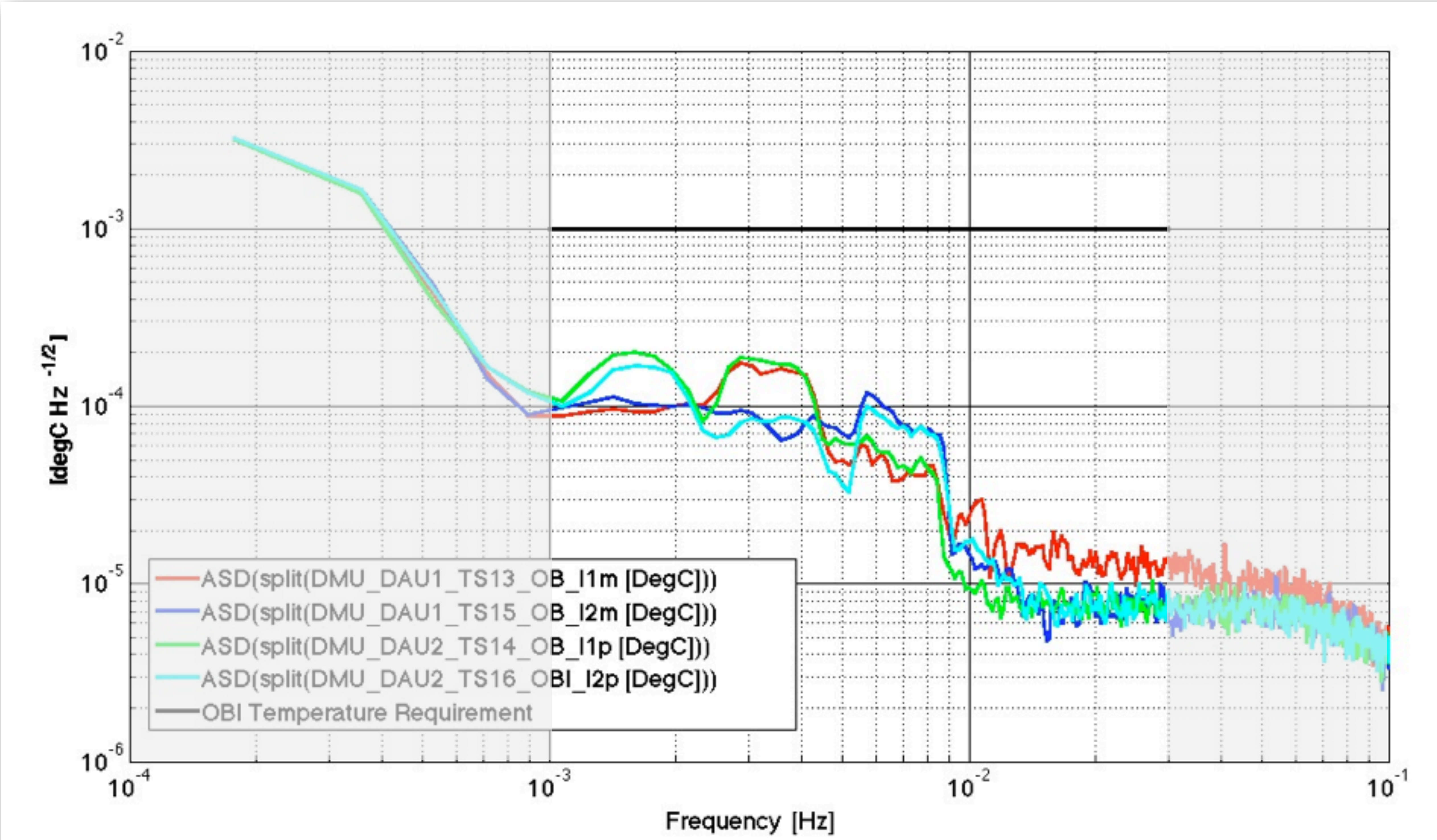
- During the On-Station Thermal Test, we integrated a Thermal Optical Qualification Model (TOQM) in lieu of the LTP core assembly
  - The TOQM consists of the flight optical bench with flight mounting hardware, and thermal dummies in place of the inertial sensors
- The measured thermal and interferometric performance meets (and significantly exceeds) all requirements.



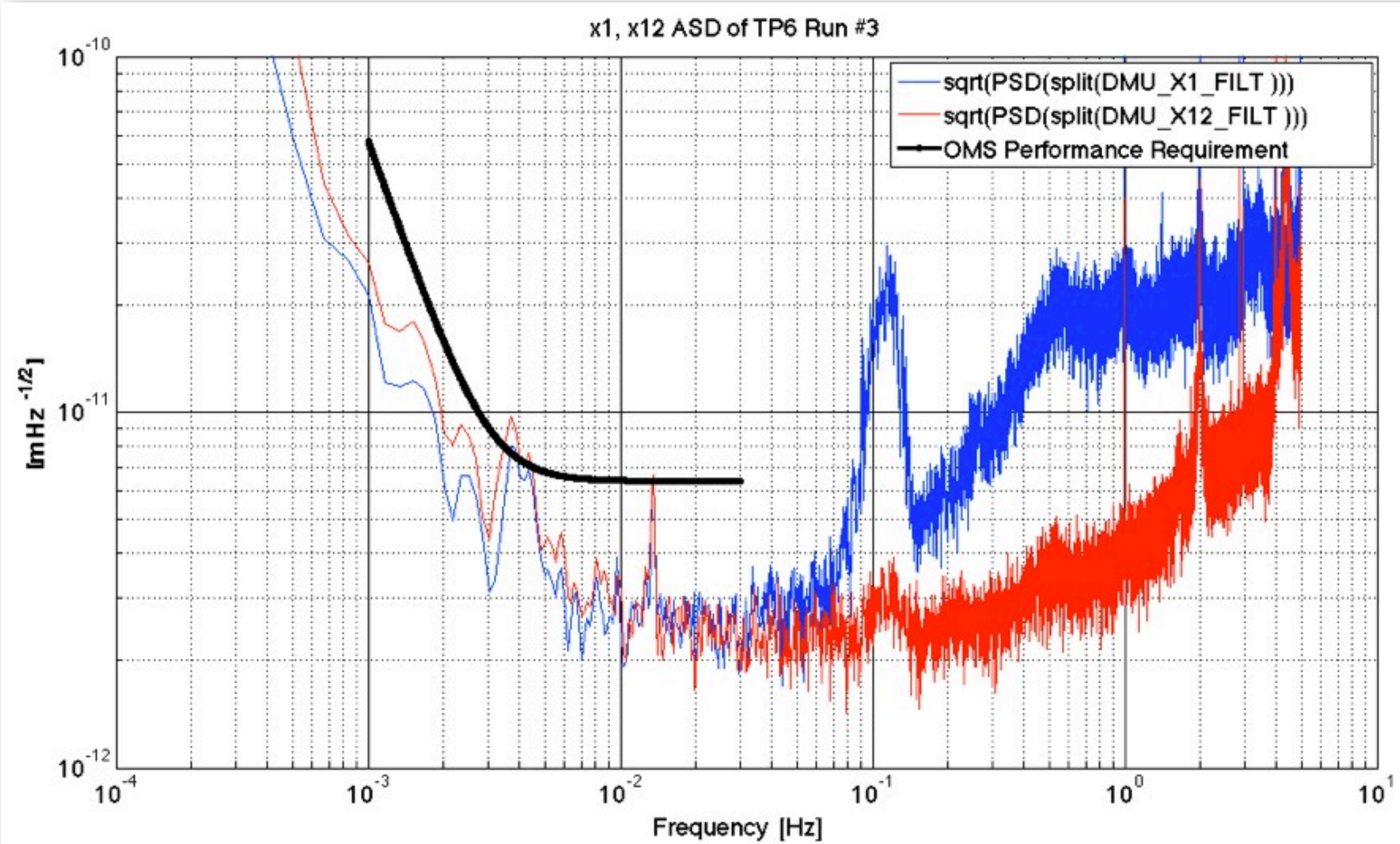




OSTT Thermal Performance

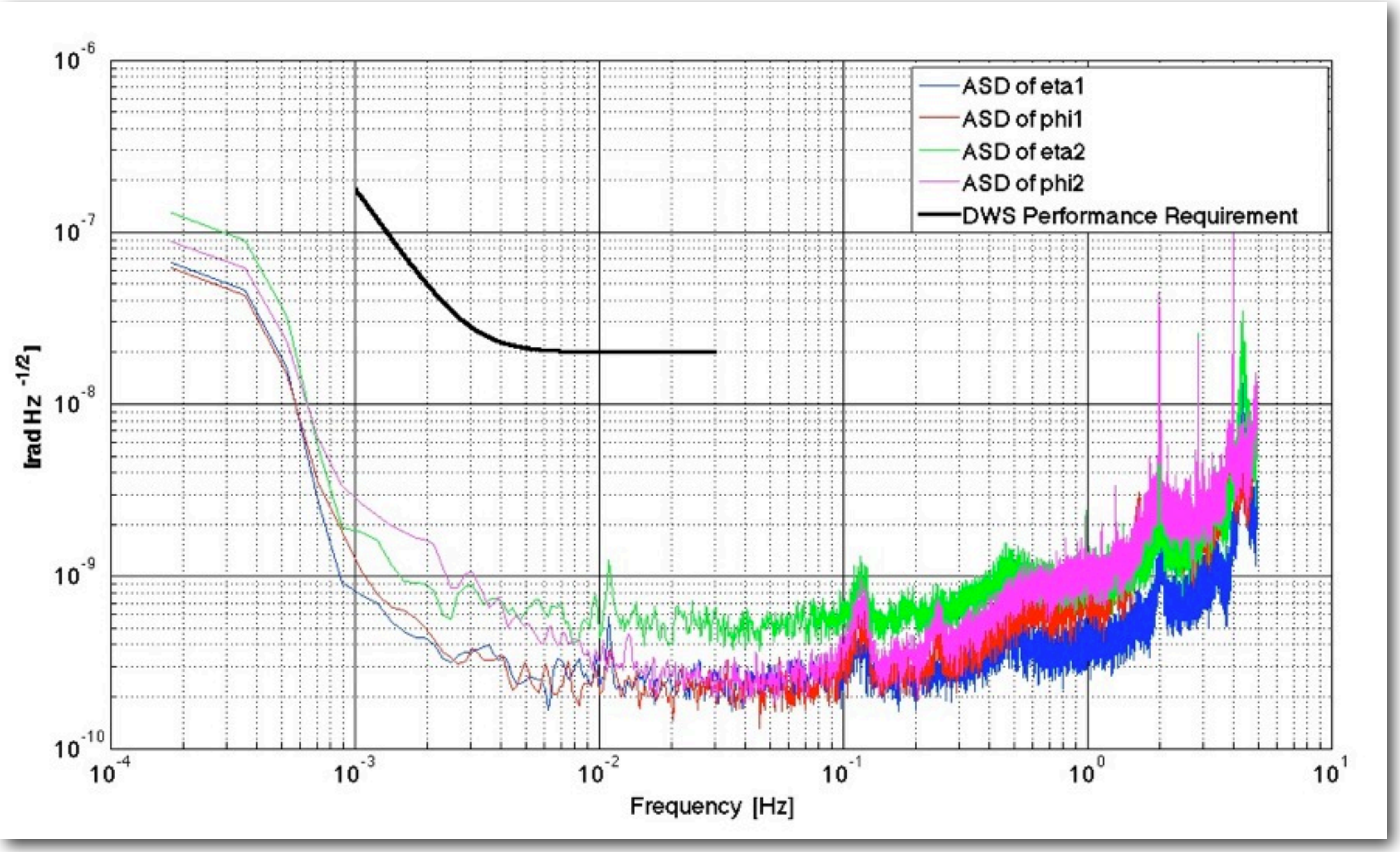


OSTT OMS performance



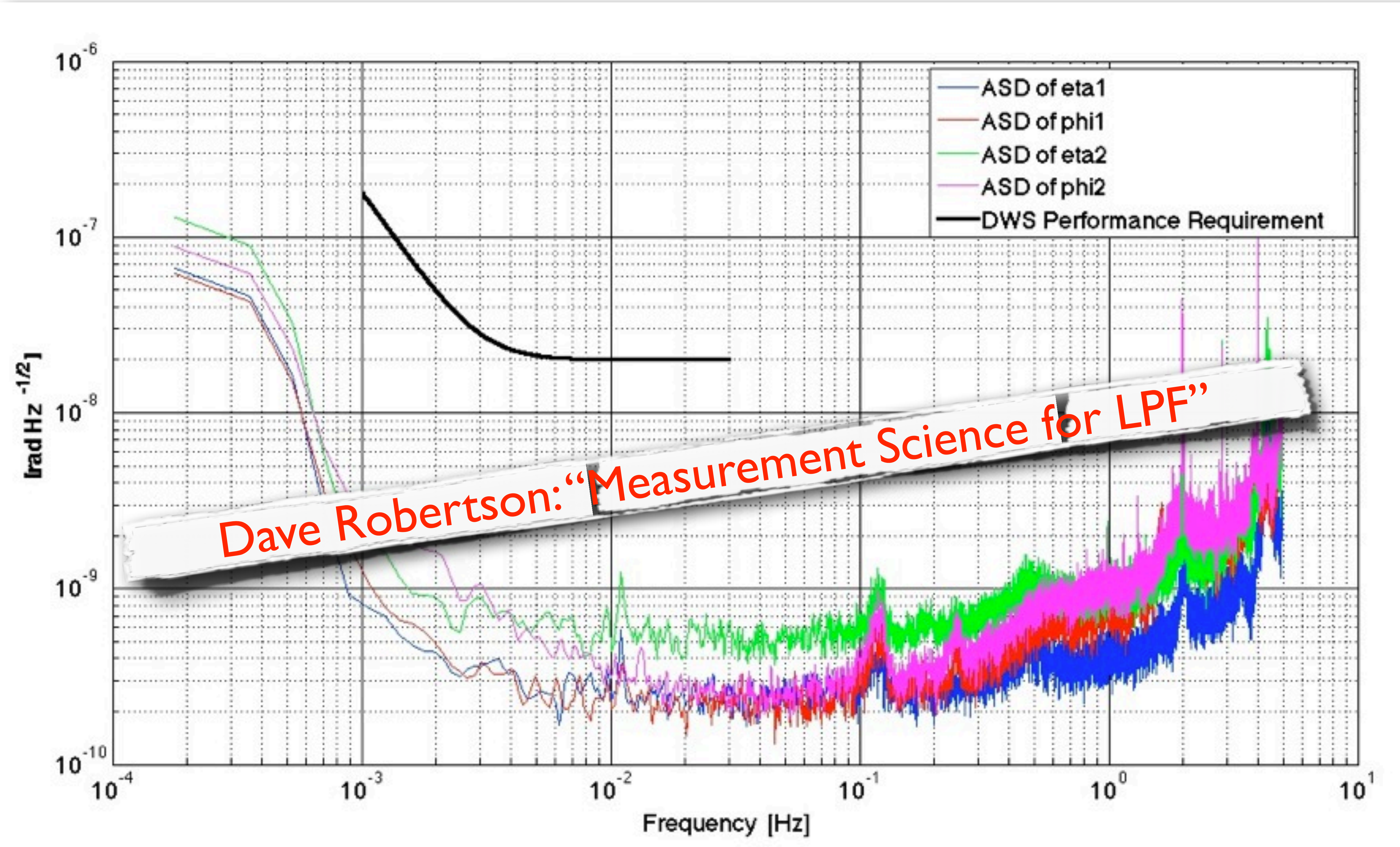
Interferometer displacement noise

OSTT OMS performance



Interferometer angle sensing noise (Differential Wavefront Sensing)

OSTT OMS performance

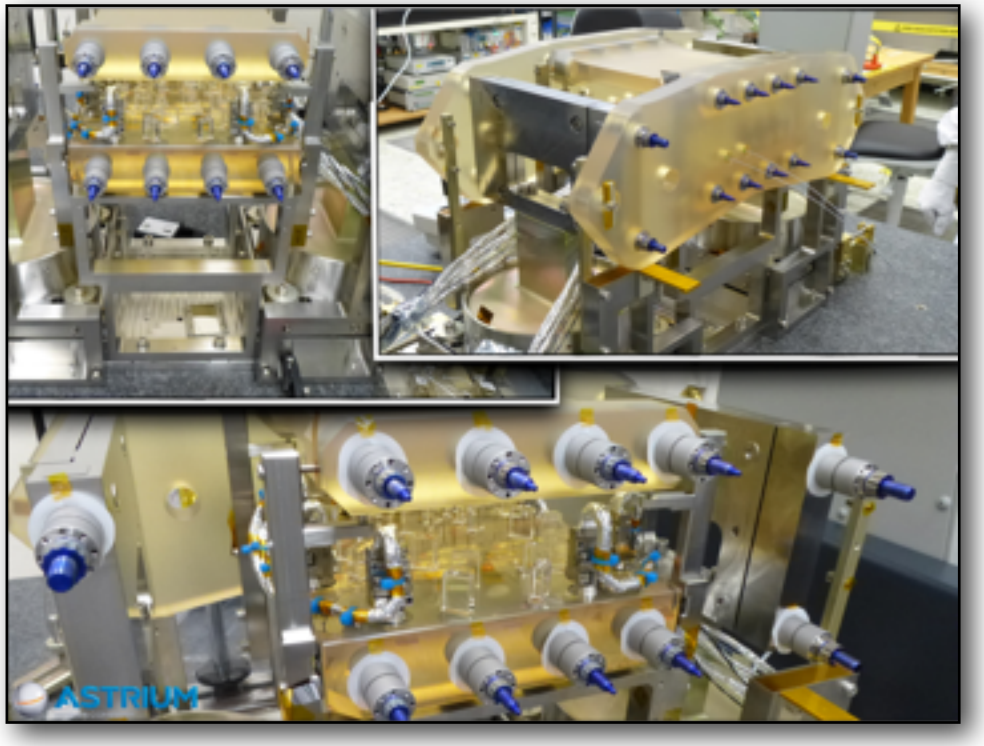


Interferometer angle sensing noise
(Differential Wavefront Sensing)

What's Missing? [1]

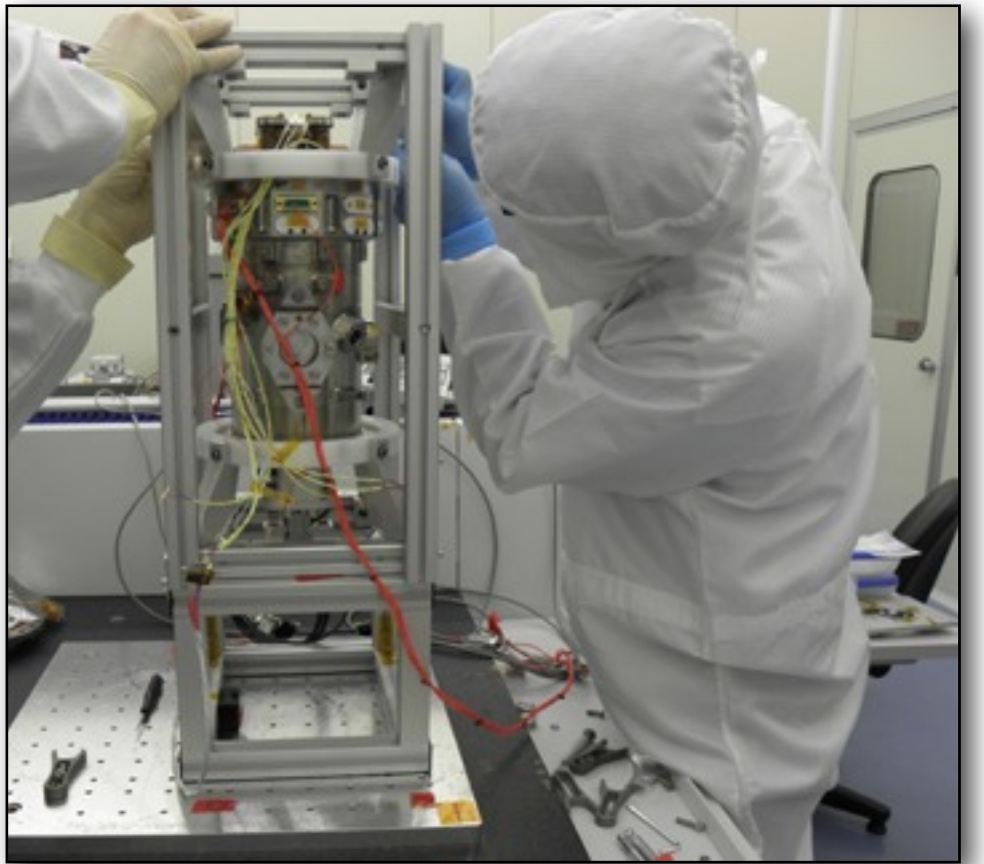
LTP Core Assembly

- All subsystems/components have been delivered
- The optical bench has been integrated to its support structure, and is now in storage awaiting delivery of the inertial sensors



Ongoing Activities:

- Integration of the inertial sensors
- Following integration, the inertial sensors will be tested separately (thermal & vibration), prior to being integrated to the optical bench
- Final testing of the LCA will then take place followed by integration of the payload to the spacecraft



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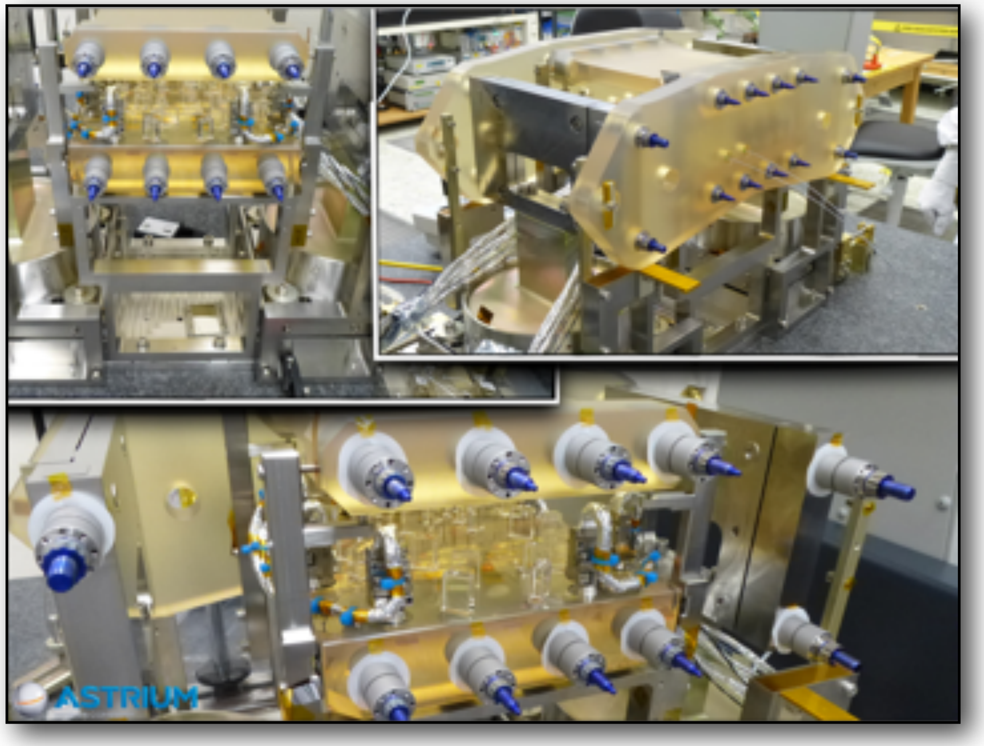

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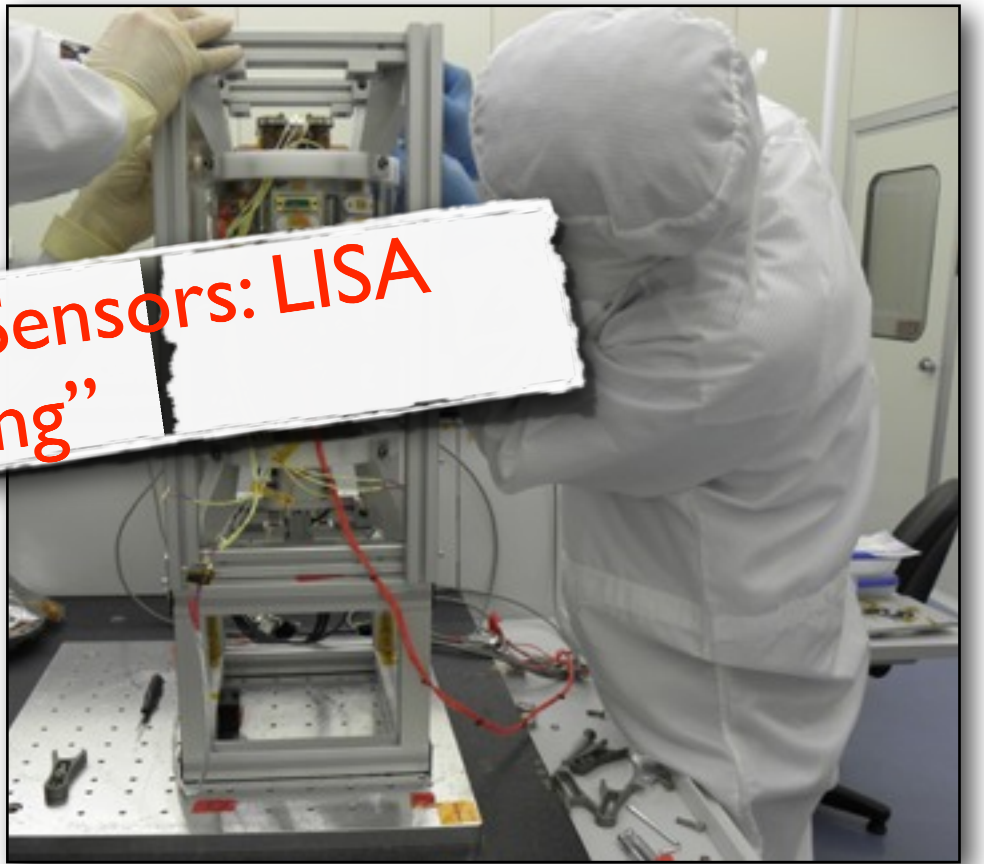
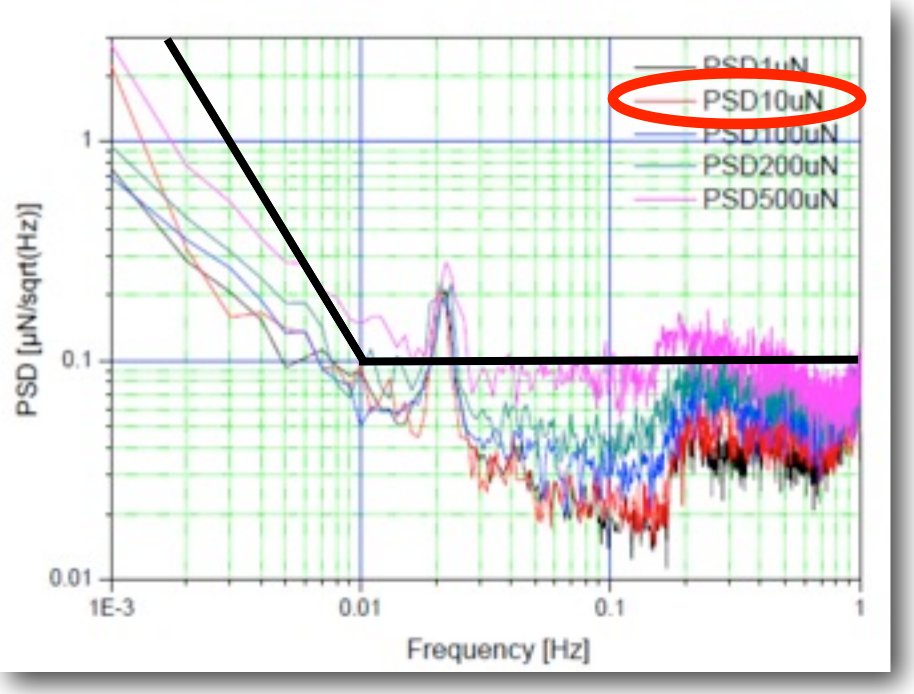
Rita Dolesi: "Gravitational Reference Sensors: LISA Pathfinder and ground testing"



What's Missing? [2]

Microthrusters

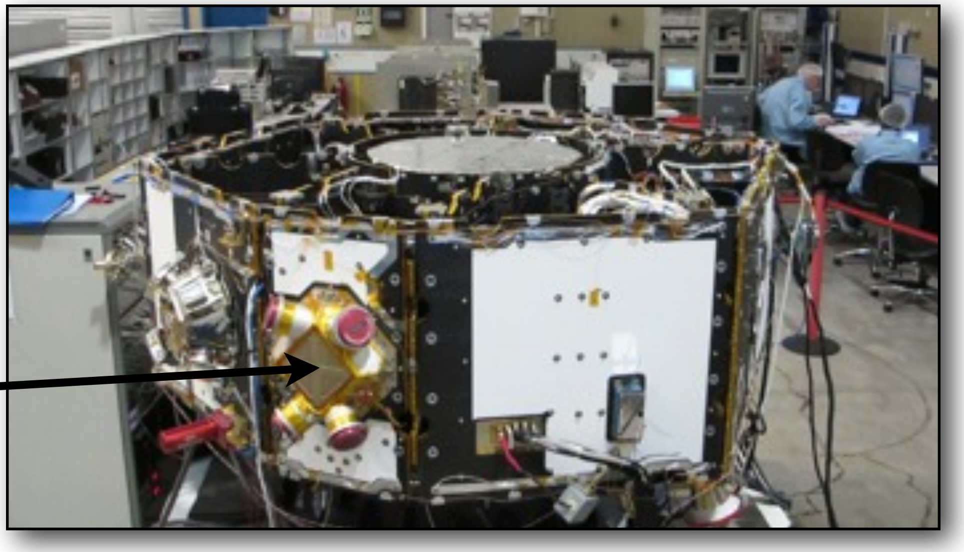
- After delays in the qualification schedule of the FEEP thrusters, we took the decision to change the thruster baseline to a Cold Gas micro-thruster
  - Recently developed for ESA's GAIA mission
- Performance of cold gas thrusters has improved several fold over the last few years
  - The GAIA cold gas thruster meets (and exceeds) the LPF requirements
  - Main issue is the low specific impulse of gas thrusters
    - Requires more kg of fuel per unit thrust



Measured thrust noise of GAIA thrusters

Colloid thrusters

- In addition to the Cold Gas Thrusters, LPF will also carry a set of Colloidal thrusters, as part of the NASA ST7 mission
- Colloids have been delivered and are integrated to the flight spacecraft



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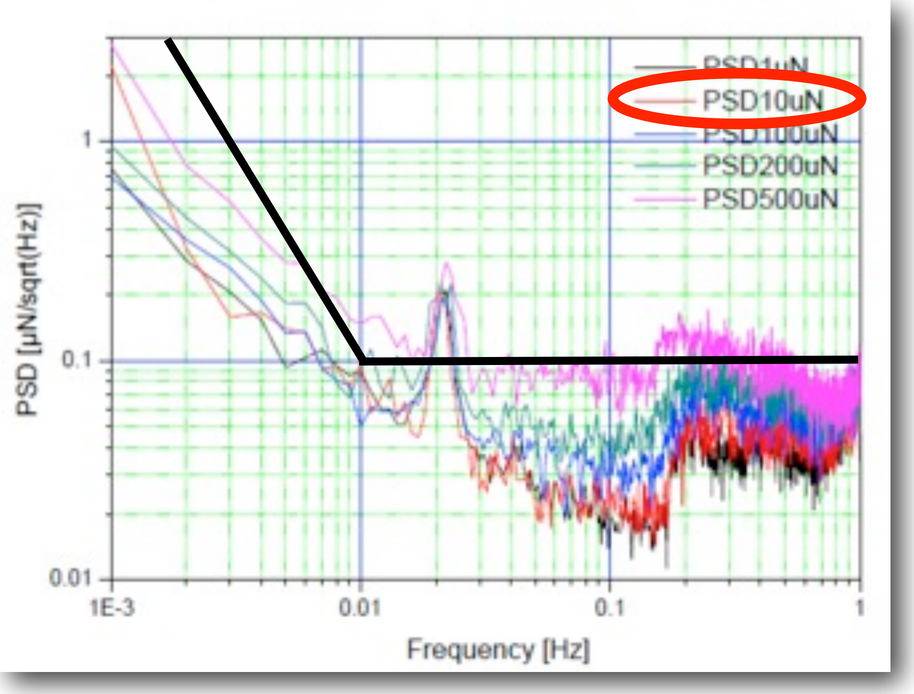

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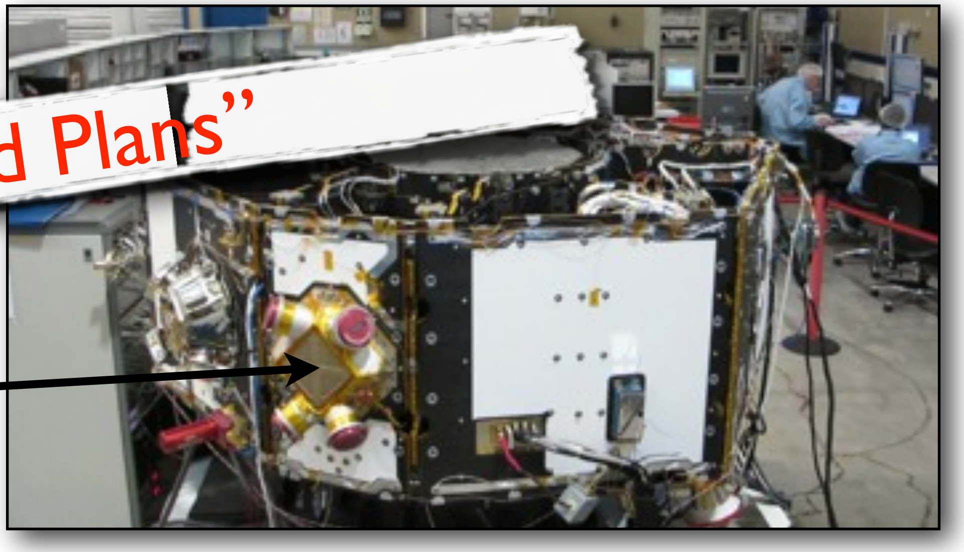
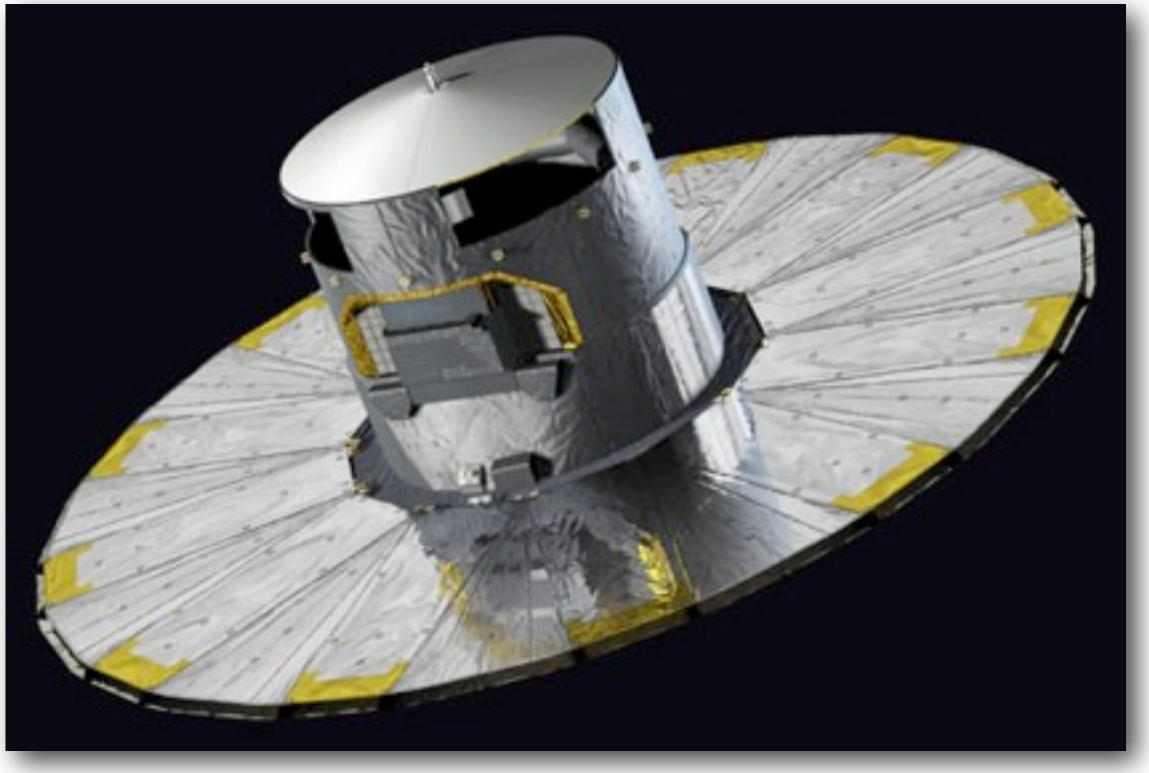


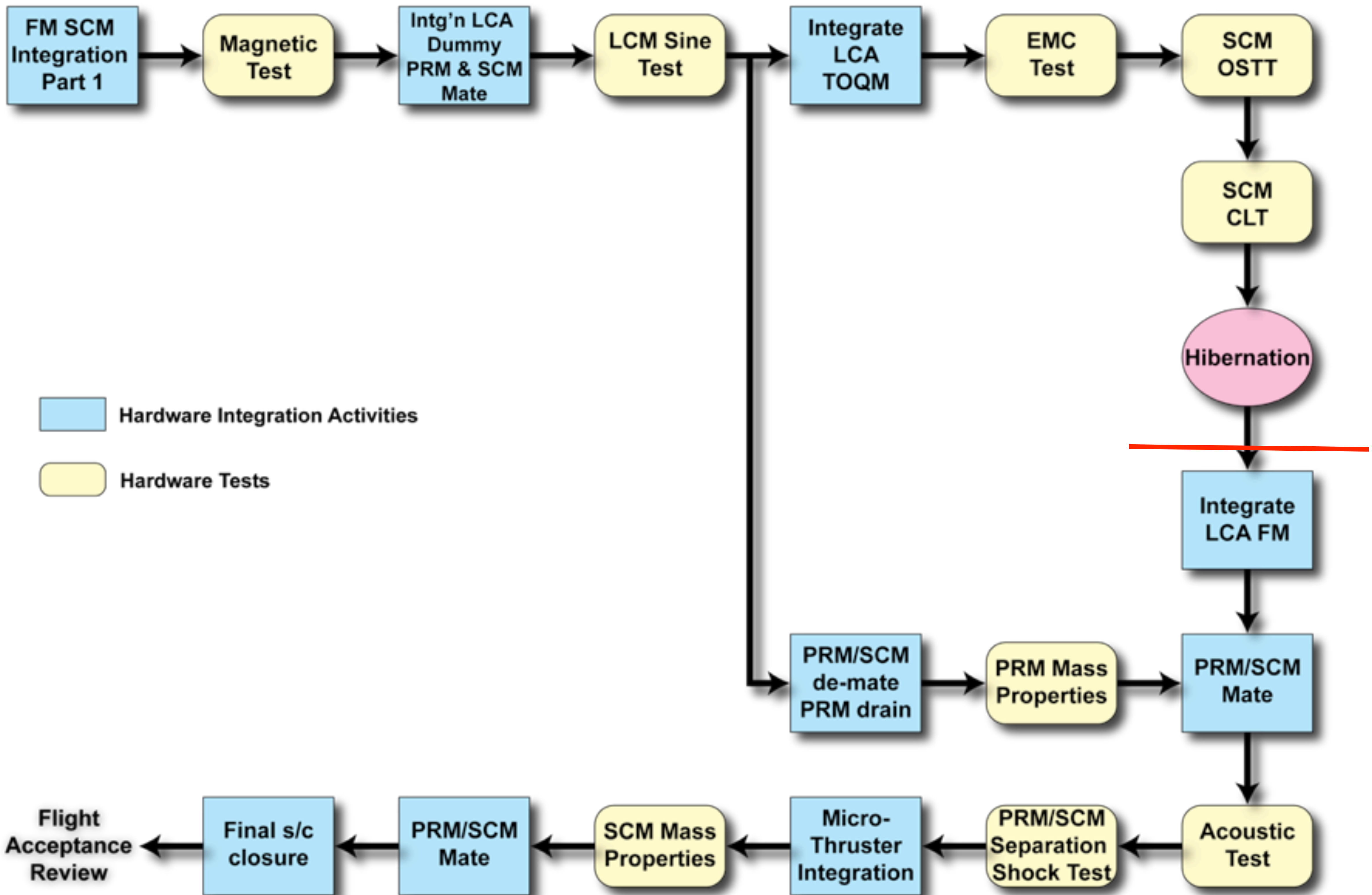
Ira Thorpe: "ST7 DRS Status and Plans"

Cold Gas Thrusters: Status

- Cold Gas Thrusters
  - Most flight hardware has been delivered to the industrial prime, and has gone through unit testing (e.g. magnetic testing)
  - *Final thruster head will be delivered at the end of this year*
- Cold gas thrusters are now flying on GAIA
  - First performance results expected at the end of commissioning



What's left? [1]


FM SCM Integration Part 1
Magnetic Test
Intg'n LCA Dummy PRM & SCM Mate
LCM Sine Test
Integrate LCA TOQM
EMC Test
SCM OSTT
SCM CLT
Hibernation
Integrate LCA FM
PRM/SCM de-mate PRM drain
PRM Mass Properties
PRM/SCM Mate
Acoustic Test
PRM/SCM Separation Shock Test
Micro-Thruster Integration
SCM Mass Properties
PRM/SCM Mate
Final s/c closure
Flight Acceptance Review
Hardware Integration Activities
Hardware Tests

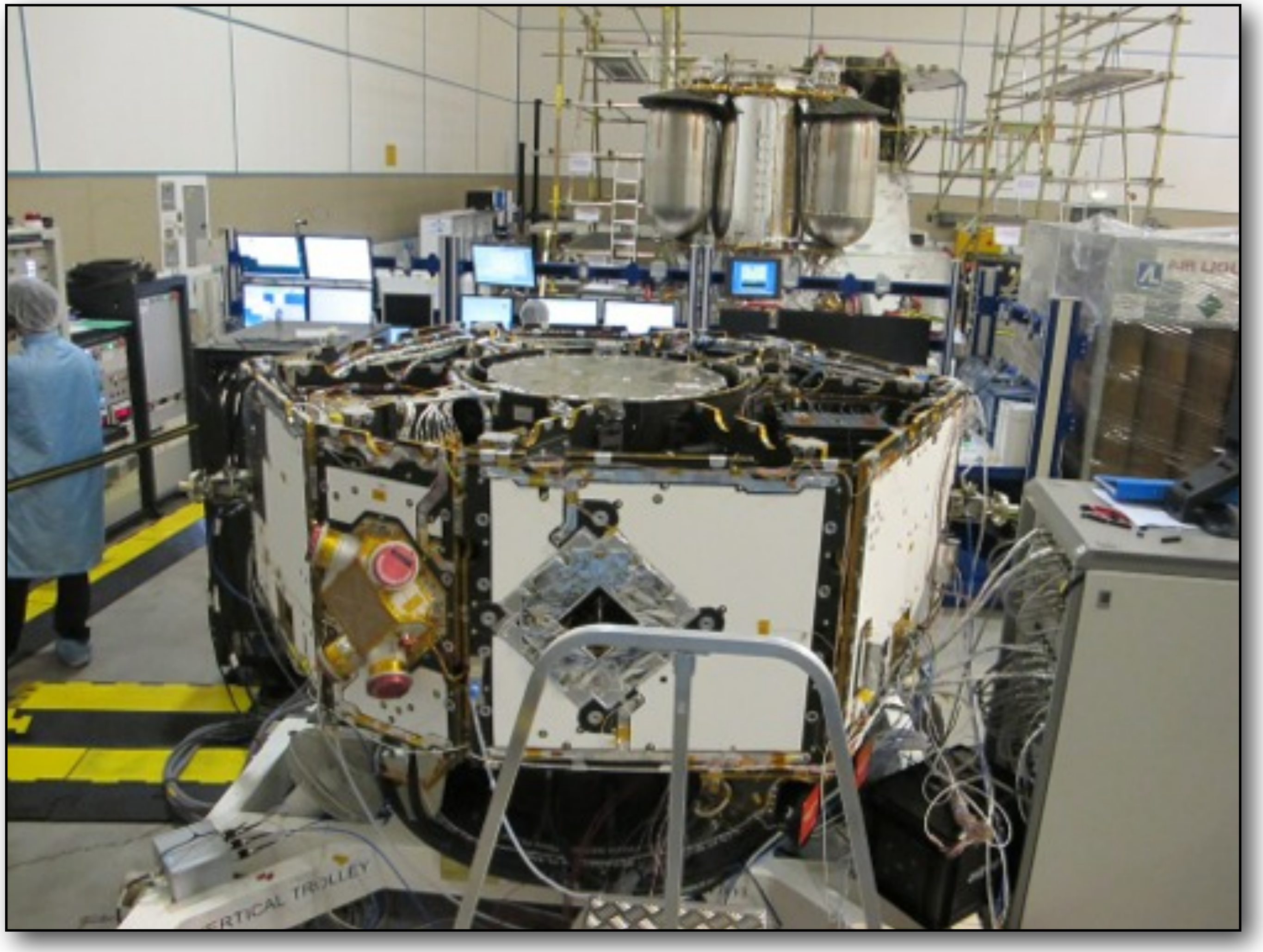
What's left? [2]

- In addition to the satellite system tests, several end-to-end tests will also be performed
- These tests will be performed on various platforms:
  - pre-SOVT test
    - These are a series of tests performed on a mission simulator
    - Tests are designed to prepare Payload Operation Requests (PORs) which can be used in subsequent tests (SOVT) and during operations
  - SOVT (System Operations Validation Test)
    - A test performed on the real-time testbed (RTB)
      - RTB is a *flat-sat* using the Engineering Models (EMs) of the hardware
    - The SOVT tests the end-to-end ground segment

What's left? [3]

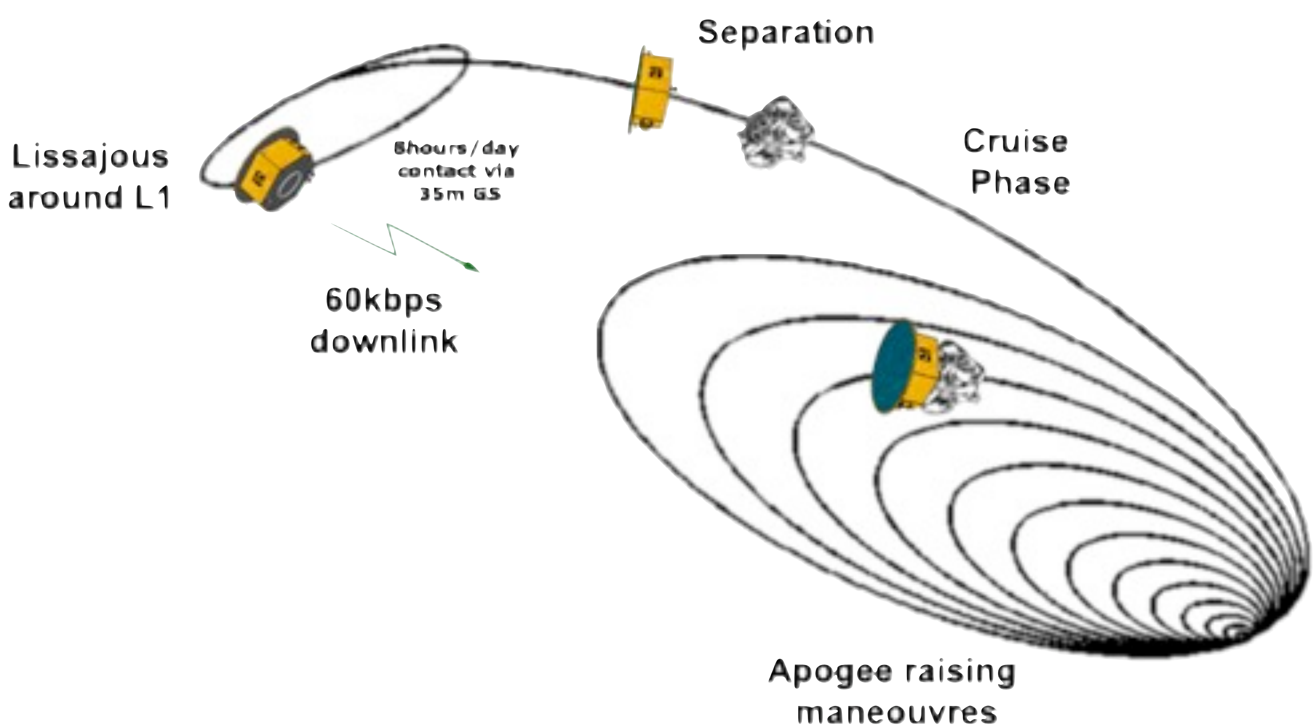
End-to-end closed loop test (e2e CLT)

- This is a functional/performance test on the spacecraft
  - Special Check-Out Equipment is used where necessary
    - Inertial Sensors, Interferometer, Power System, Dynamics
- Designed to test the closed-loop control of the s/c during science experiments



Launch and Operations

- LPF will be launched into a 200kmx1600km parking orbit by the new Arianespace launcher, VEGA
- 6 apogee raising manoeuvres required to deliver LPF to L1
- Prop module separates shortly before entering science orbit
- Final orbit is a ~500,000 x ~800,000km Lissajous orbit around L1



Operations

- Mission Operations are controlled from ESOC, Germany
- 8 hours ground station contact per day
  - 35m ESA Cebreros station
  - Downlink rate of 60kbps
- Science Operations controlled from ESAC, Spain
  - Operations run via Mission Timeline
- Real time commanding only during commissioning and contingency events

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Conclusion

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- LISA Pathfinder is well on its way to validate the technologies required by future spaceborne GW detectors
- Results from the OSTT demonstrate performance better than requirements
- The project is now out of hibernation, and preparing for the final environmental tests and the launch campaign
- Launch is scheduled for July 31st 2015
  - L - 438 days and counting.....

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- Results from the OSTT demonstrate performance better than requirements
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- Launch is scheduled for July 31st 2015
  - L - 438 days and counting.....
- The future is now....it's *LISA Pathfinder*

Thank you

- ESA ESTEC
- ESA ESAC
- ESA ESOC
- EADS Astrium UK
- EADS Astrium GmbH
- University of Trento
- Albert Einstein Institute
- University of Glasgow
- University of Birmingham
- Imperial College London
- ETH Zurich
- Institut d-Estudis Espacials de Catalunya
- Universidad Politecnica de Barcelona
- APC Paris
- IFR Stuttgart
- Laben
- Carlo Gavazzi Space
- ALTA
- ARCS
- Contraves
- Kaiser Threde
- NTE
- SCISYS
- Spacebel
- SRON
- Technologica
- TESAT
- ZARM
- JPL
- NASA Goddard
- BUSEK