LISA and LISA Pathfinder

gravitational wave observation in space

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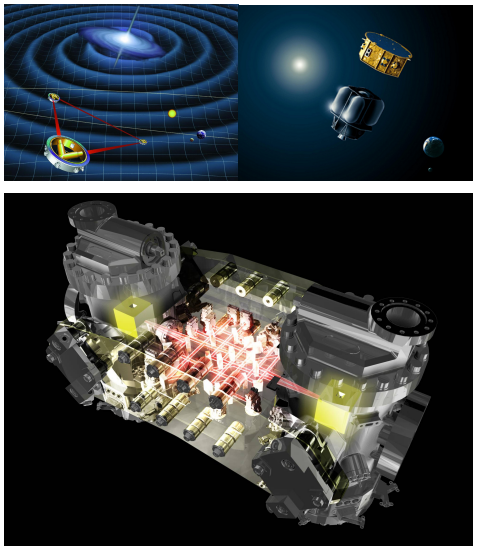
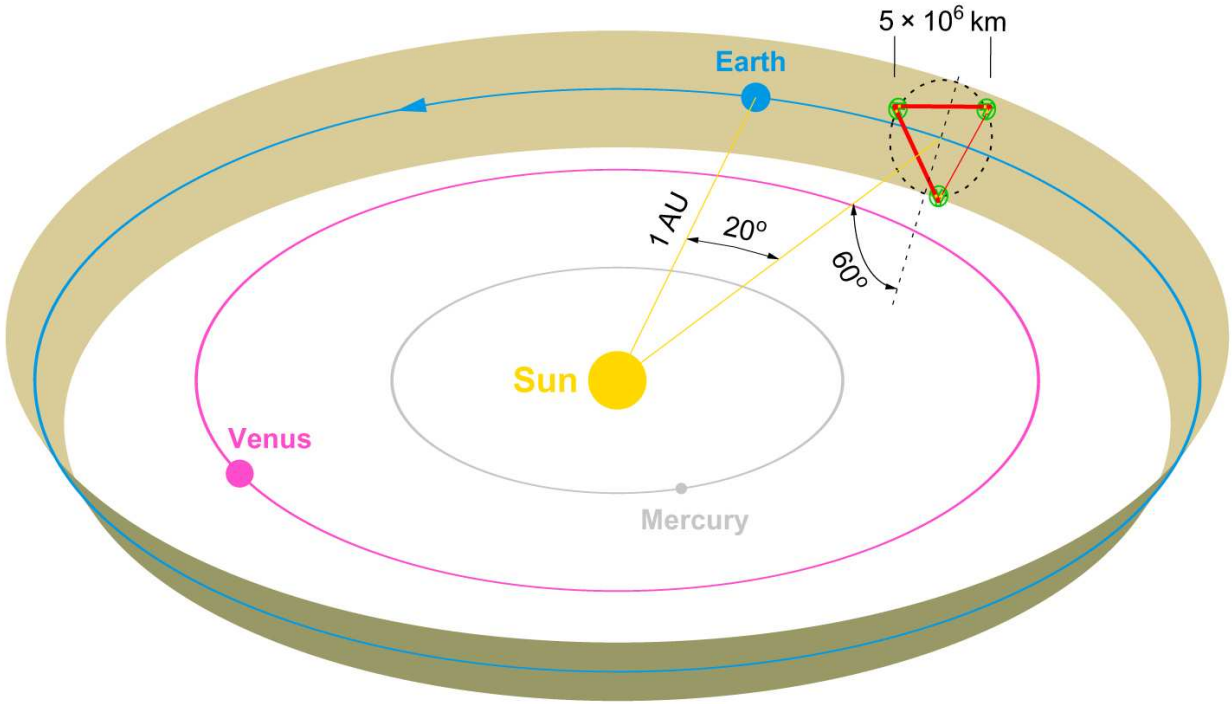


ERE 2010
Granada, 09/09/2010

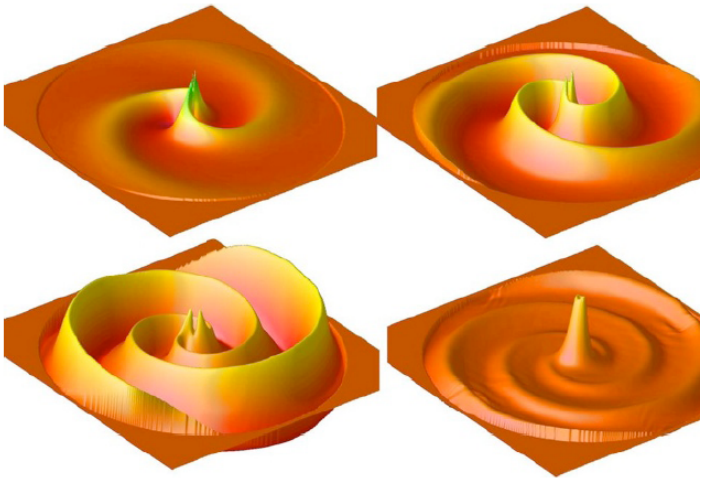
LISA: Laser Interferometer Space Antenna

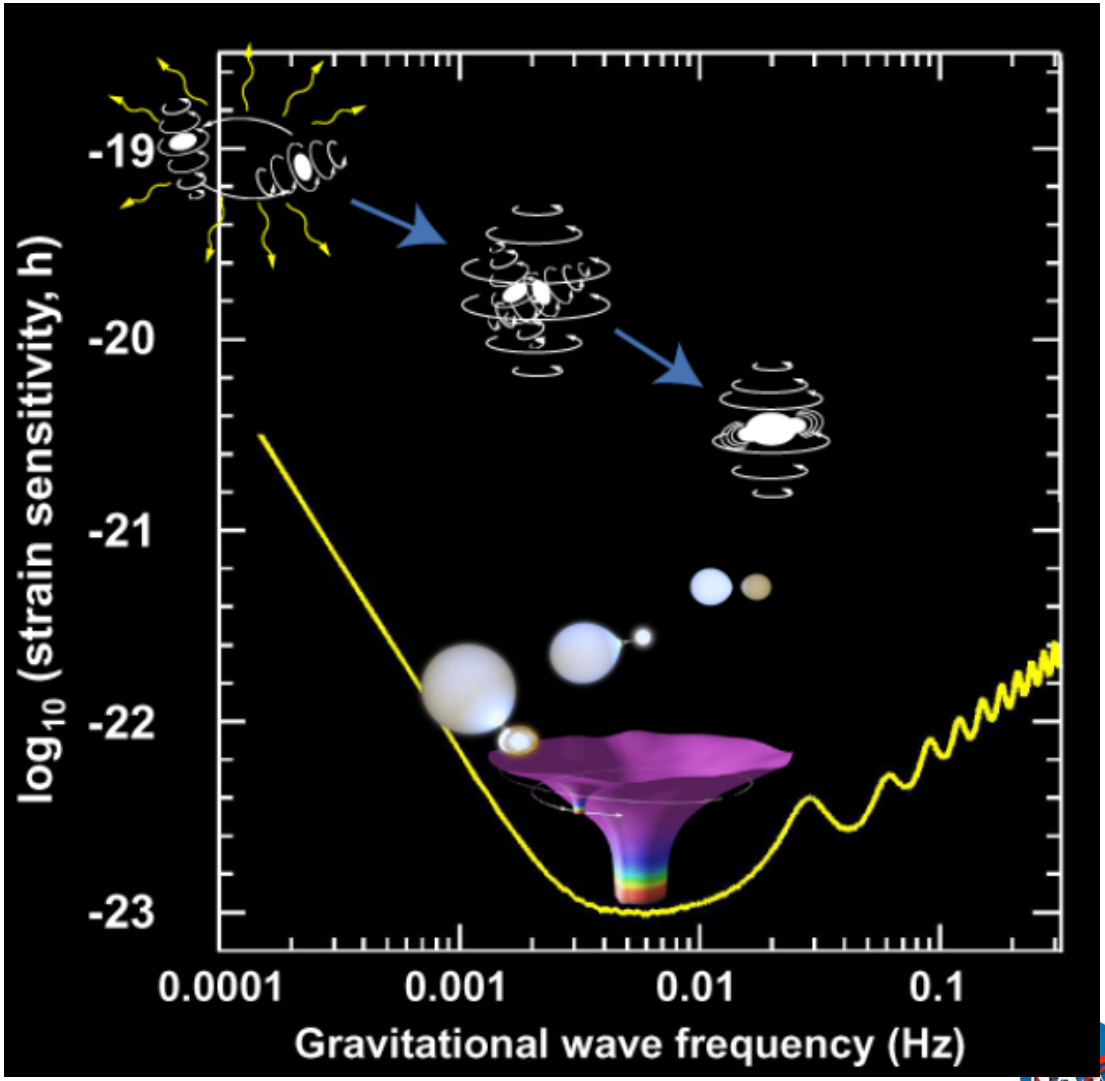
- Gravitational wave detector in space (NASA-ESA collaboration)
- Sensitivity at low frequencies: $10^{-4}\,\text{Hz} \cdots 0.1\,\text{Hz}$
  - Inaccessible for ground-based detectors (seismic noise predominance)
- Interferometer arm: 5 Million km $\pm\ 1\ \% \quad \rightarrow \quad h = 2\dfrac{\delta L}{L}$
- Guaranteed sources of gravitational waves



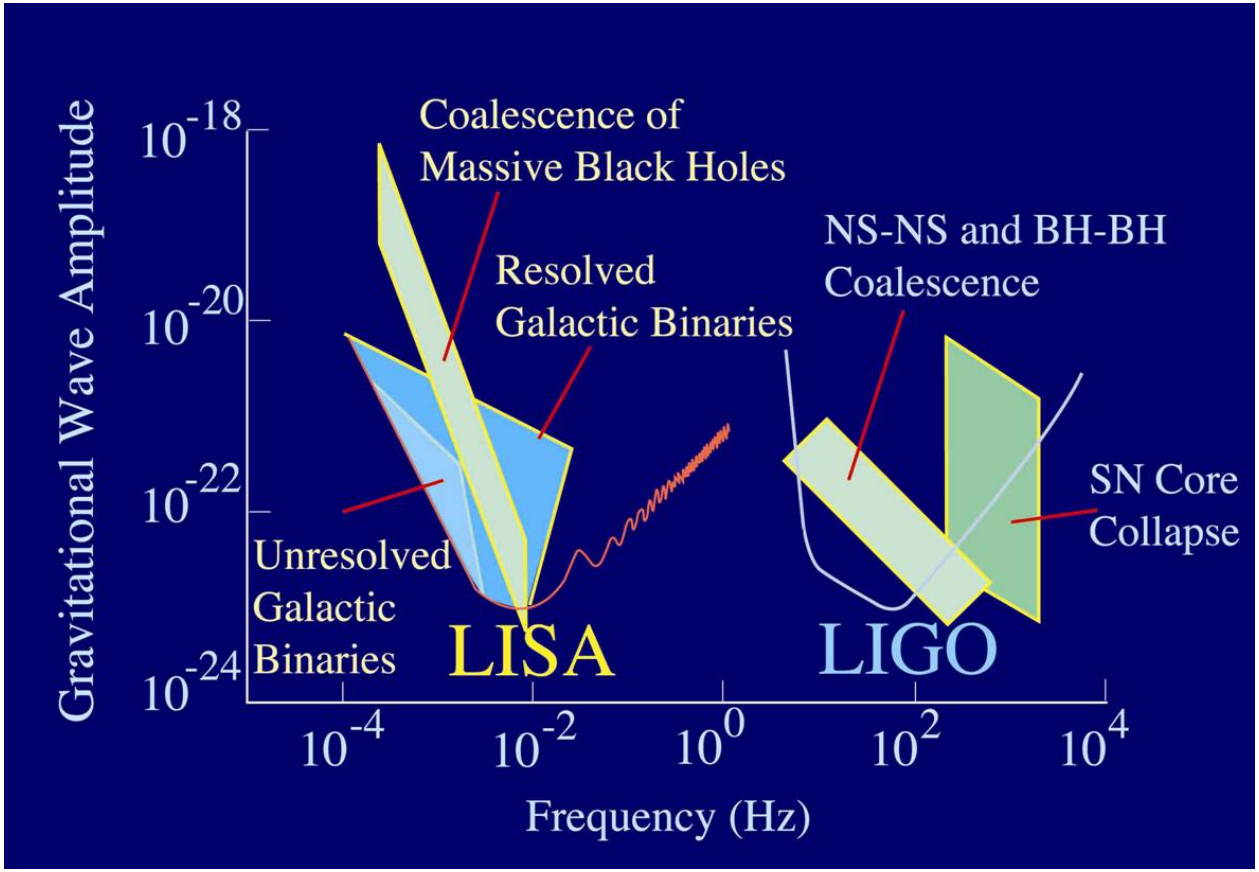
LISA main sources

- Binary systems (from SMBH to white dwarfs)
- Coalescence and mergers
- EMRI extreme mass ratio inspirals
- Backgrounds



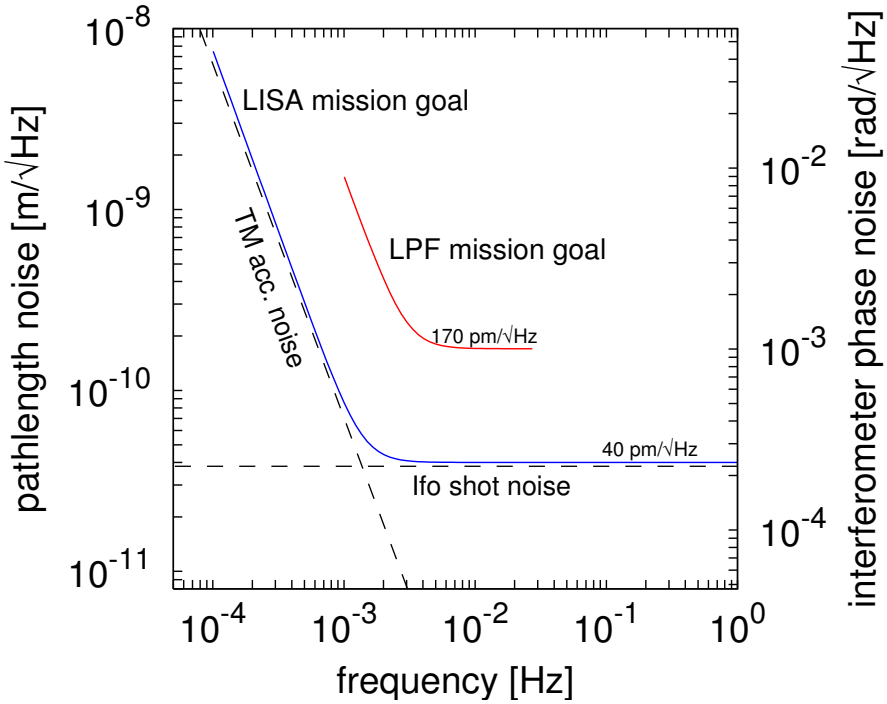


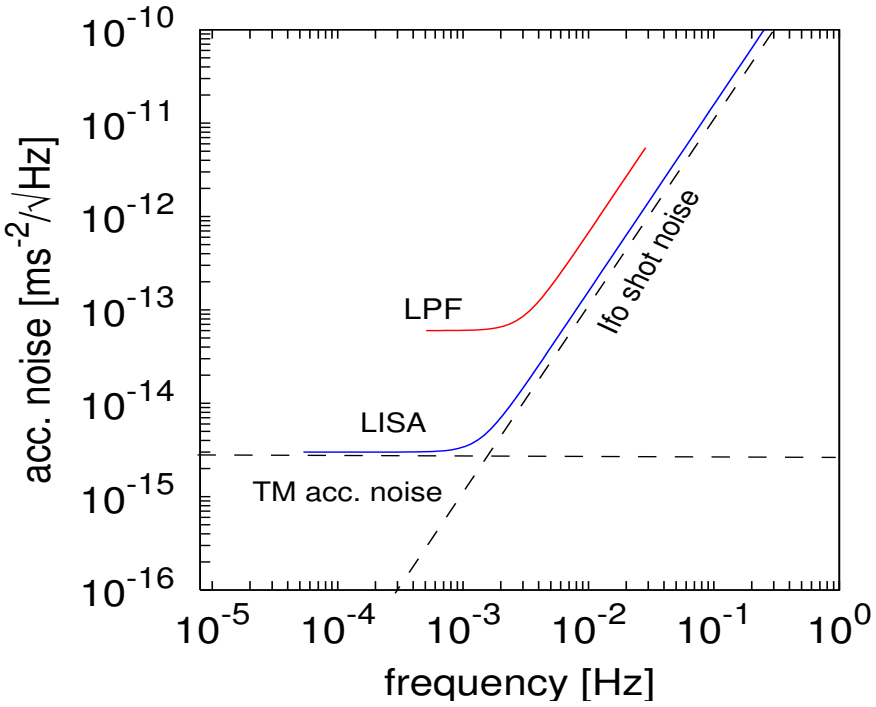
LISA strain sensitivity $\mathbf{h} = 10^{-21}$ at 1 mHz



- One year integration time and SNR $= 5 \Rightarrow$ h $= 10^{-23}$
- Comparable to ground based detectors at high frequencies

LISA main technologies





Interferometry

Optical pathlength sensitivity:

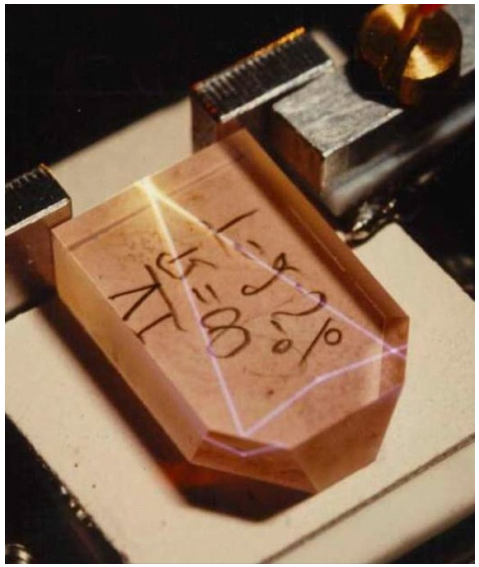
$\widetilde{\delta s}$ =40 pm/$\sqrt{\text{Hz}}$ at 1 mHz.

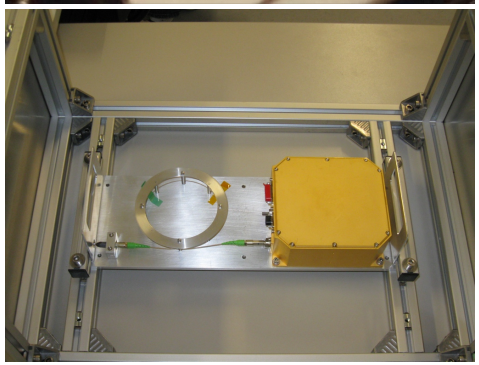
Acceleration noise

Test masses drag-free level:

$\widetilde{\delta a}$ =3×10^{-15} m · s^{-2}/$\sqrt{\text{Hz}}$ at 1 mHz.

Laser





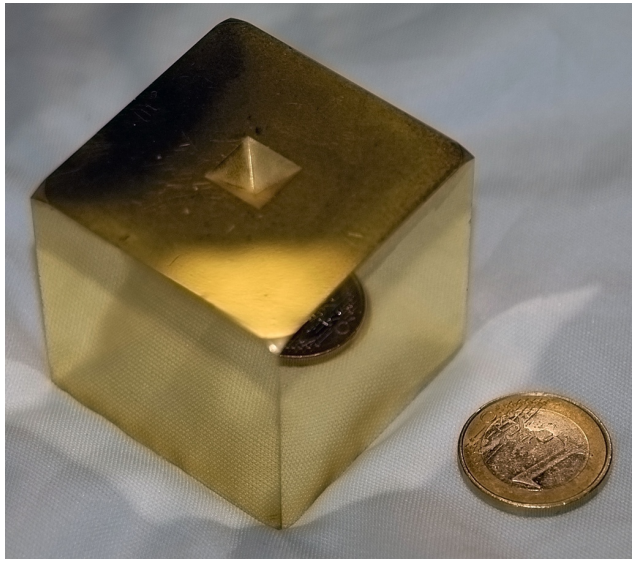
Nd:YAG-NPRO (LISA)

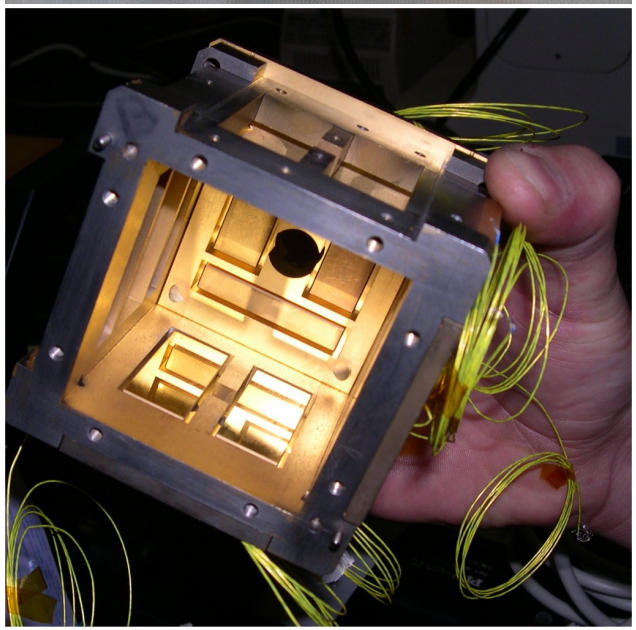
- Wavelength: $\lambda = 1064\,\mathrm{nm}$
- Output power: $\mathrm{P} = 1\text{–}2\,\mathrm{W}$
- Required laser unit frequency stability: $\tilde{\delta f} \leqslant 30\,\mathrm{Hz}/\sqrt{\mathrm{Hz}}$ @ $1\,\mathrm{mHz}$ (total required stability: $10^{-6}\,\mathrm{Hz}/\sqrt{\mathrm{Hz}} \Rightarrow$ **TDI**)

TESAT flight model (LISA Pathfinder)

- Output power: P=25 mW
- Fiber coupled
- Space qualified

Interferometer end mirror: Drag-Free Testmasses





Test Mass

- Pt-Au alloy
- $4 \times 4 \times 4\,\mathrm{cm}^3$
- Ideally free falling

Inertial Reference Sensor

- Capacitive sensor
- Position readout of the TM
- Correction of the TM position

Caging Mechanism

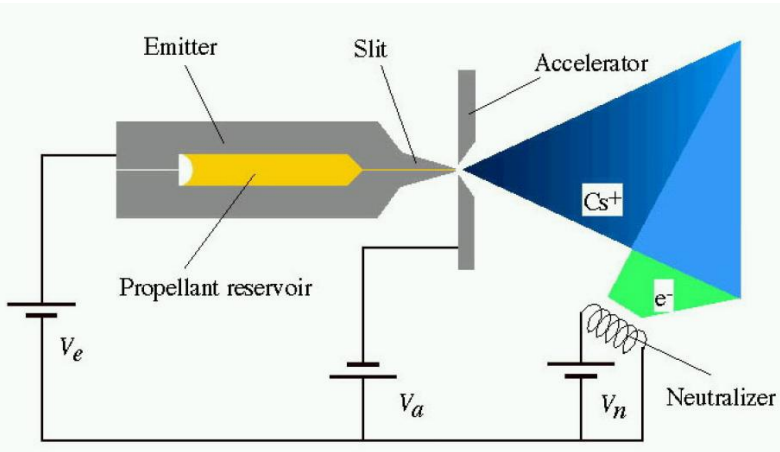
2000 N vs. 3 μN

Launch phase

The TM has to be hold in a stable position. The technical challenge is to

- ensure stability without destroying the electrical & mechanical properties
- separate the TM from the Caging-system in the dynamic range of the IRS

Micro-Newton Thrusters



μN-thrusters

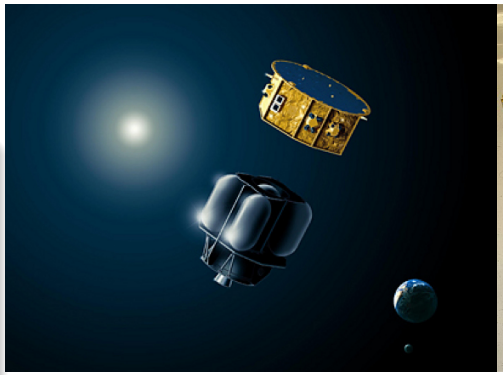
- Used in other missions with different specifications
- Developed by industry
- Dynamic range: $0.1\,\mu\mathrm{N}$–$100\,\mu\mathrm{N}$
- Resolution: $0.1\,\mu\mathrm{N}$

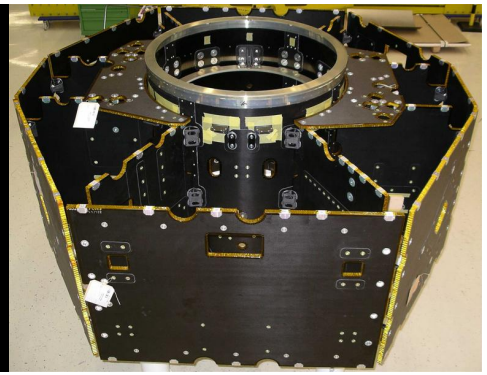
The MTs correct the position of the spacecraft with respect to the TM $\Rightarrow$ Drag-Free!

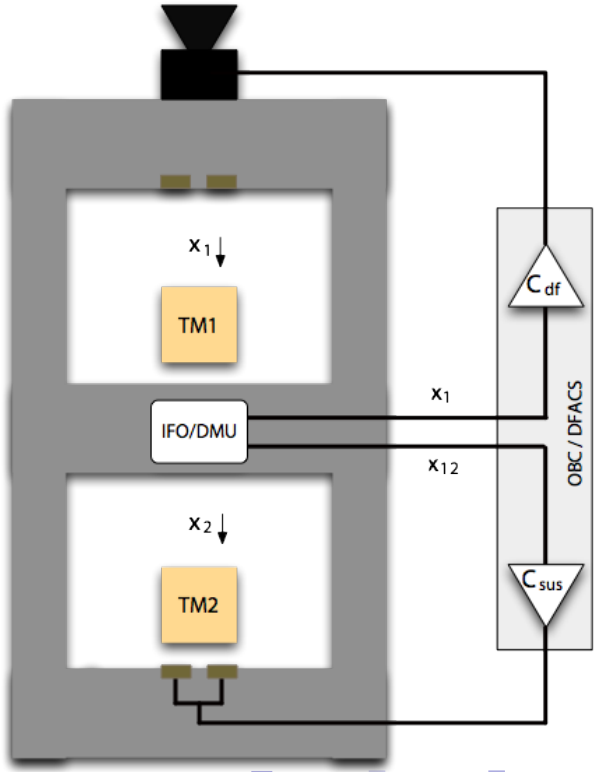
LISA Pathfinder (LPF)

Demonstration of LISA technologies in space

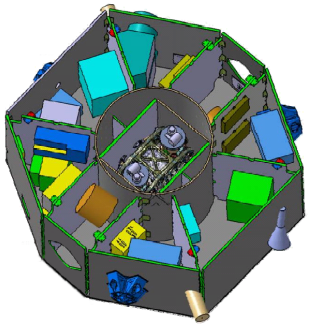
- Two LISA-like TMs inside one satellite $\Rightarrow$ one small "LISA-arm".
- **Interferometry** between Test-Masses with **picometer** precision.
- **Drag Free** System for Test Masses with **femtonewton** stability.
- Micronewton thrusters for drag free control of the satellite.
- LISA Technology Package (LTP): European experiment (this talk).

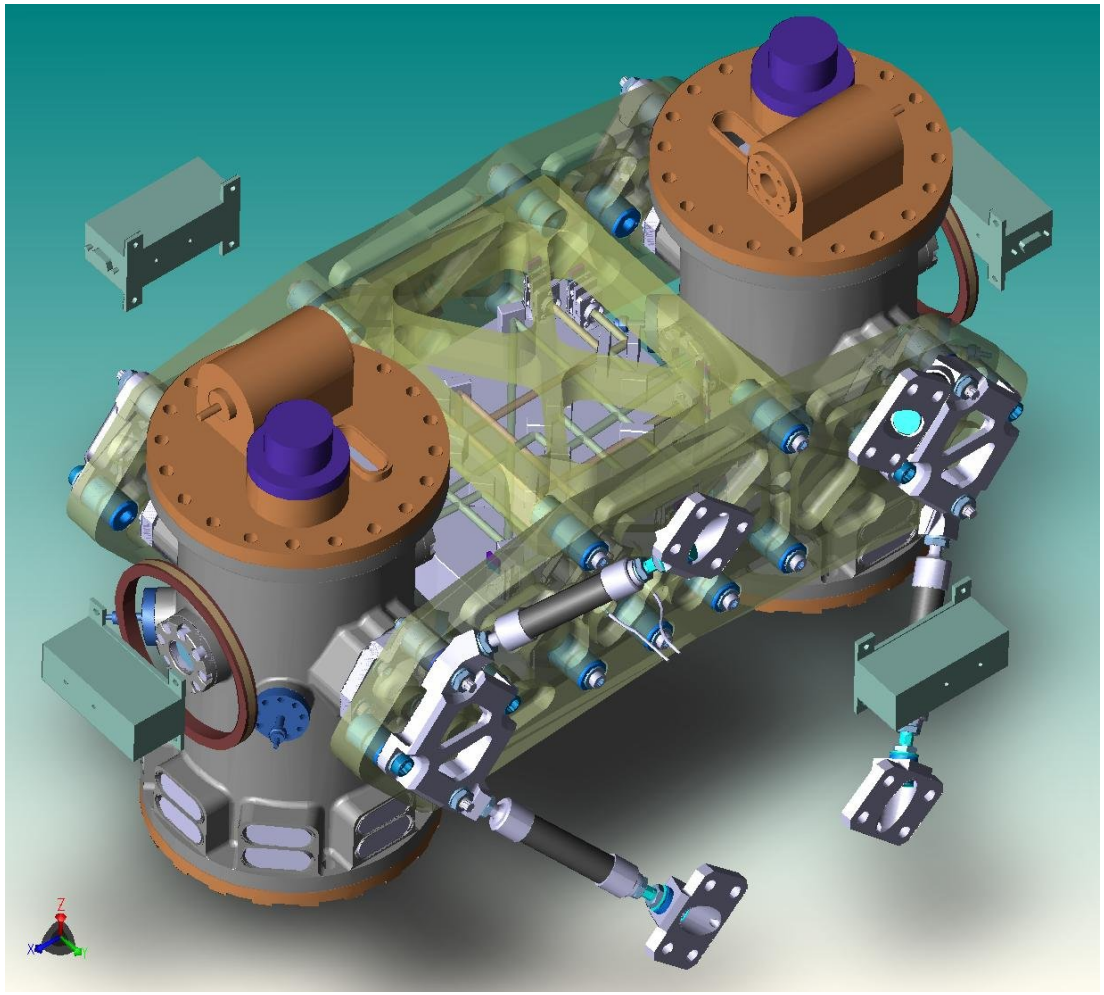


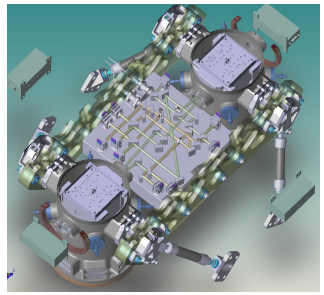




The LISA technology package (LTP) core assembly

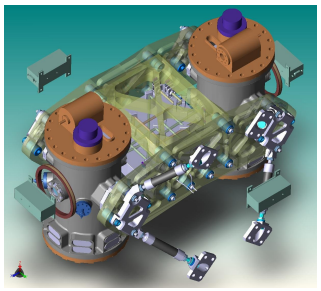


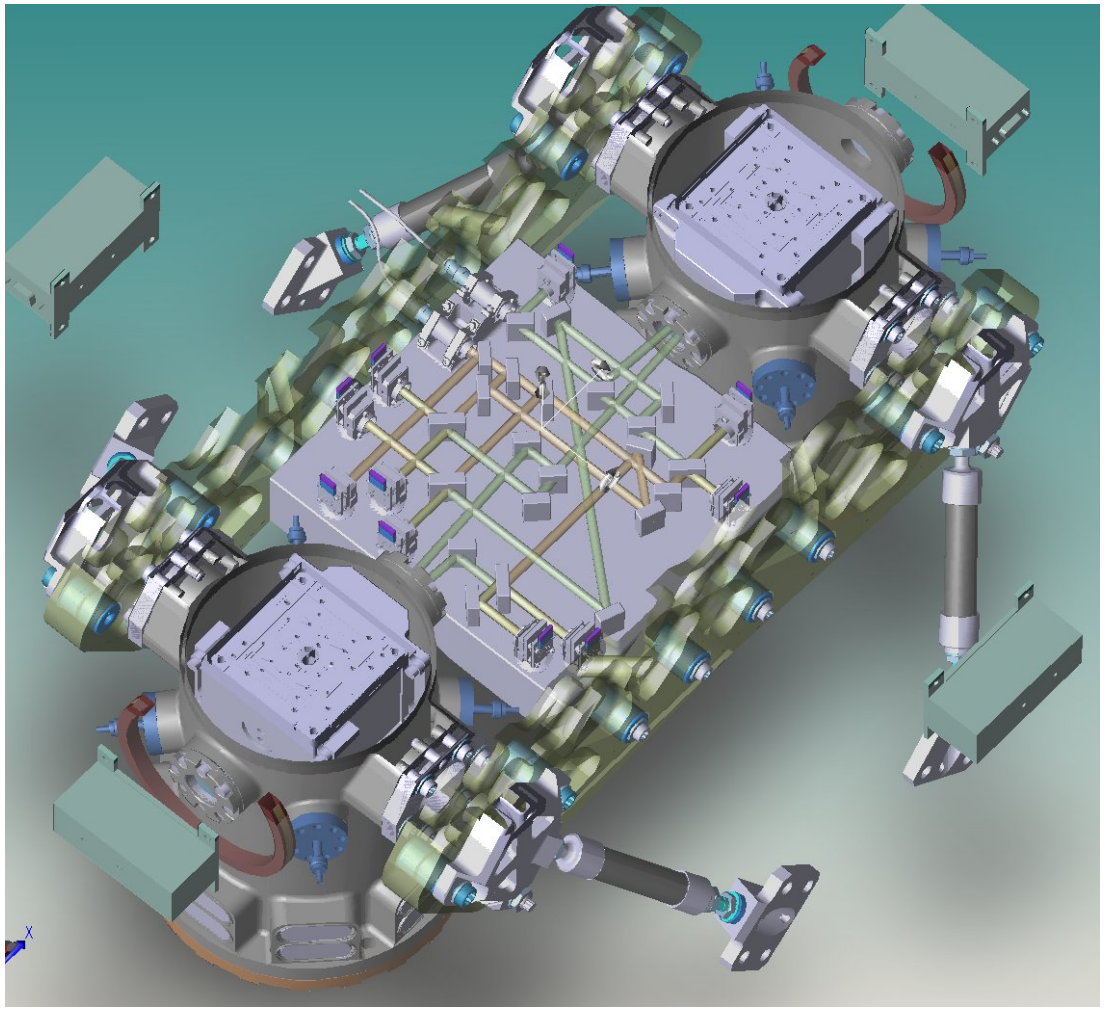


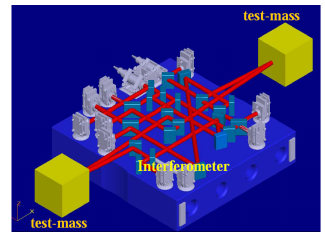


Two test masses inside their vacuum enclosures and interferometer between them.

The LTP core assembly

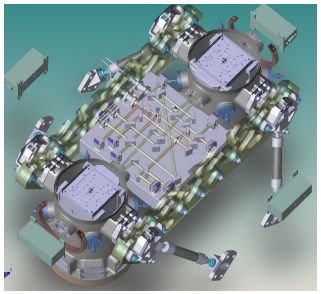


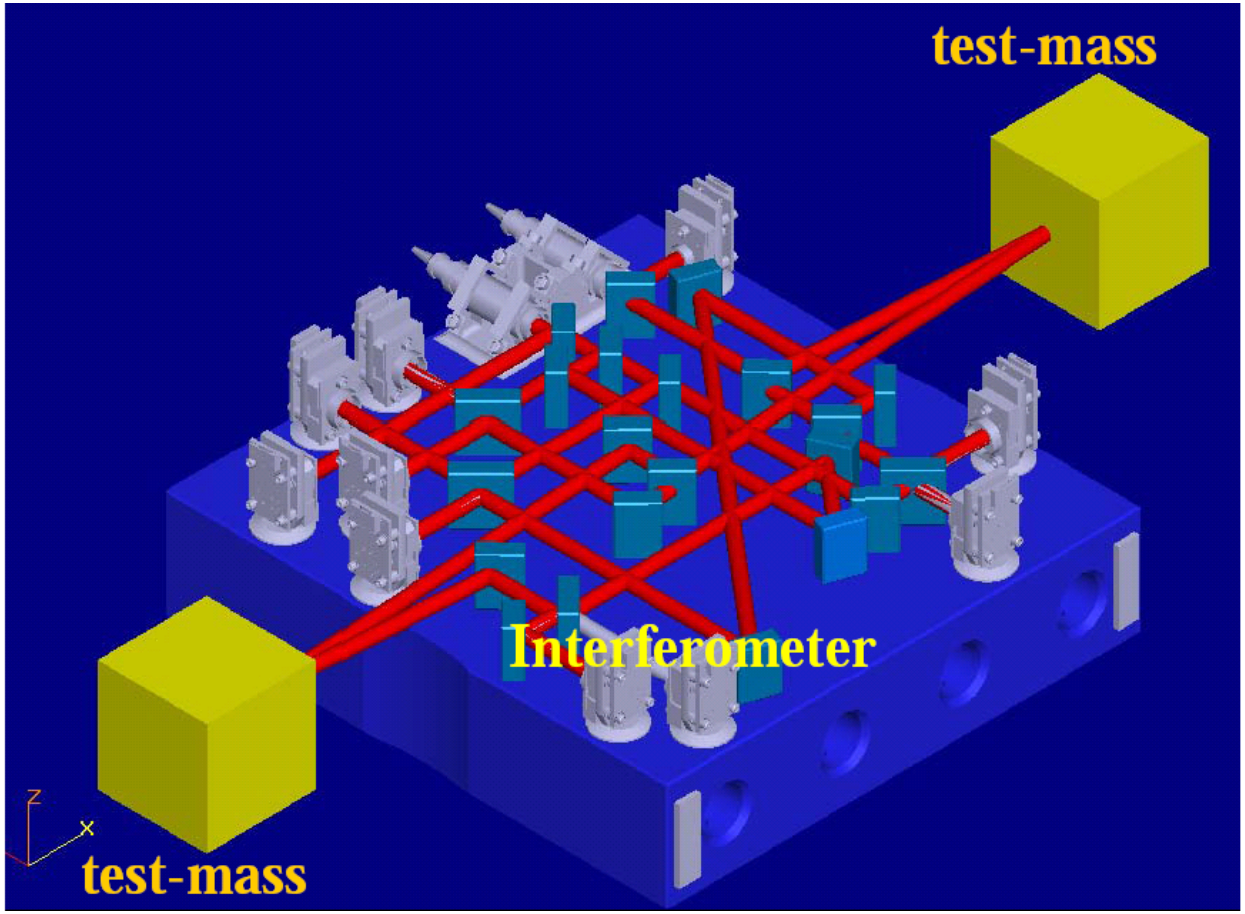


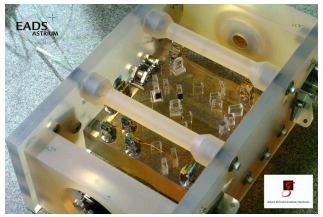


Two test masses inside their vacuum enclosures and interferometer between them.

LTP interferometric concept

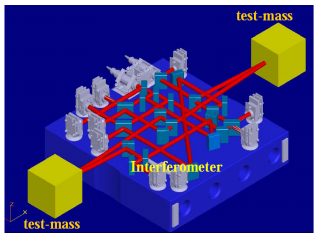


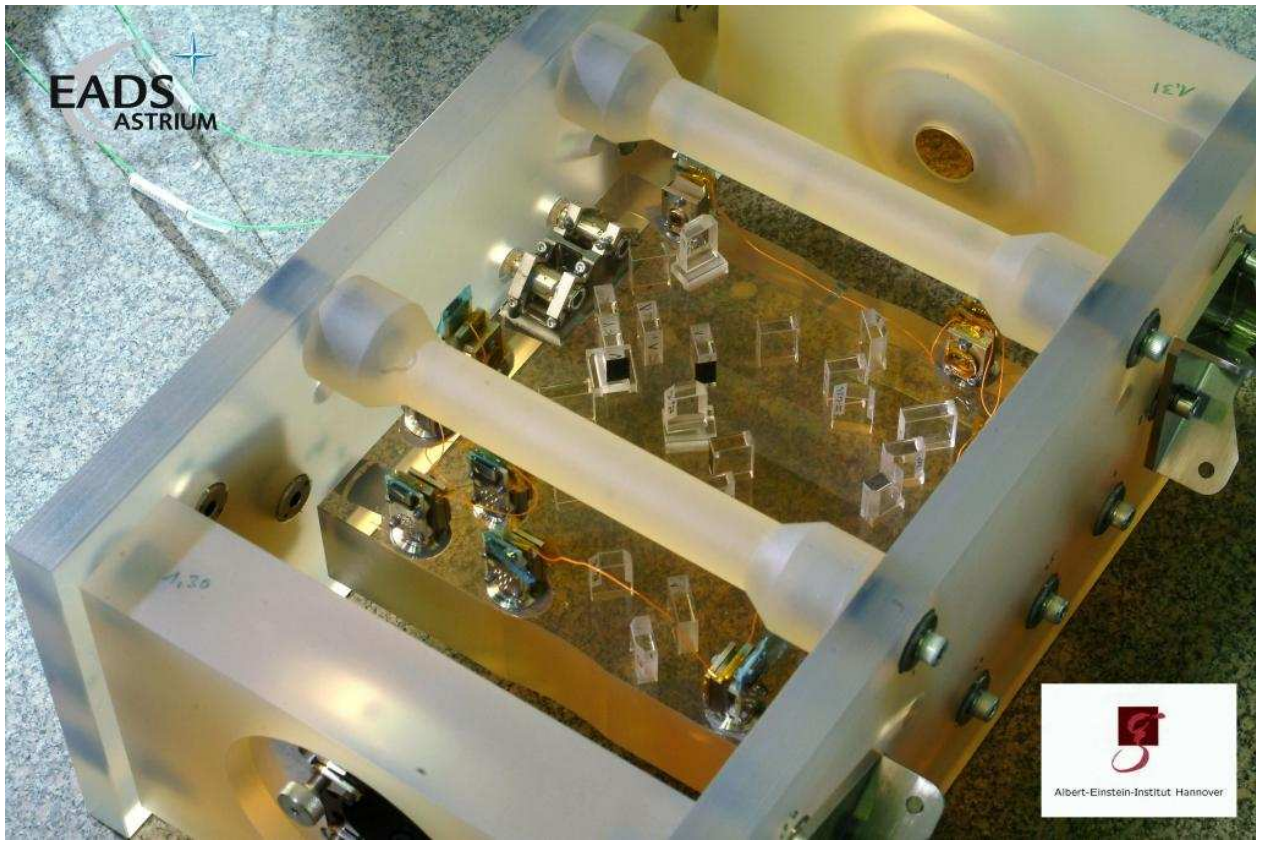




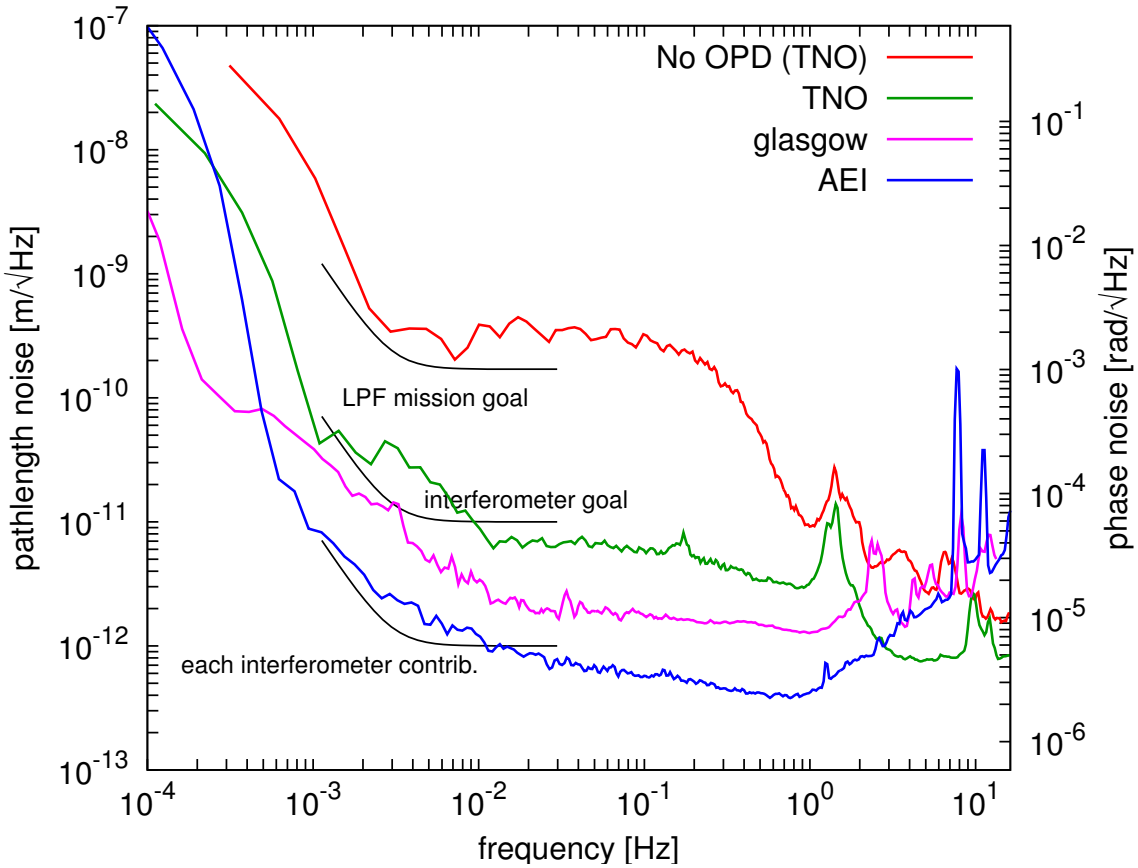
The LTP interferometer monitors test masses position fluctuations and alignment.

LTP optical bench engineering model (EM)



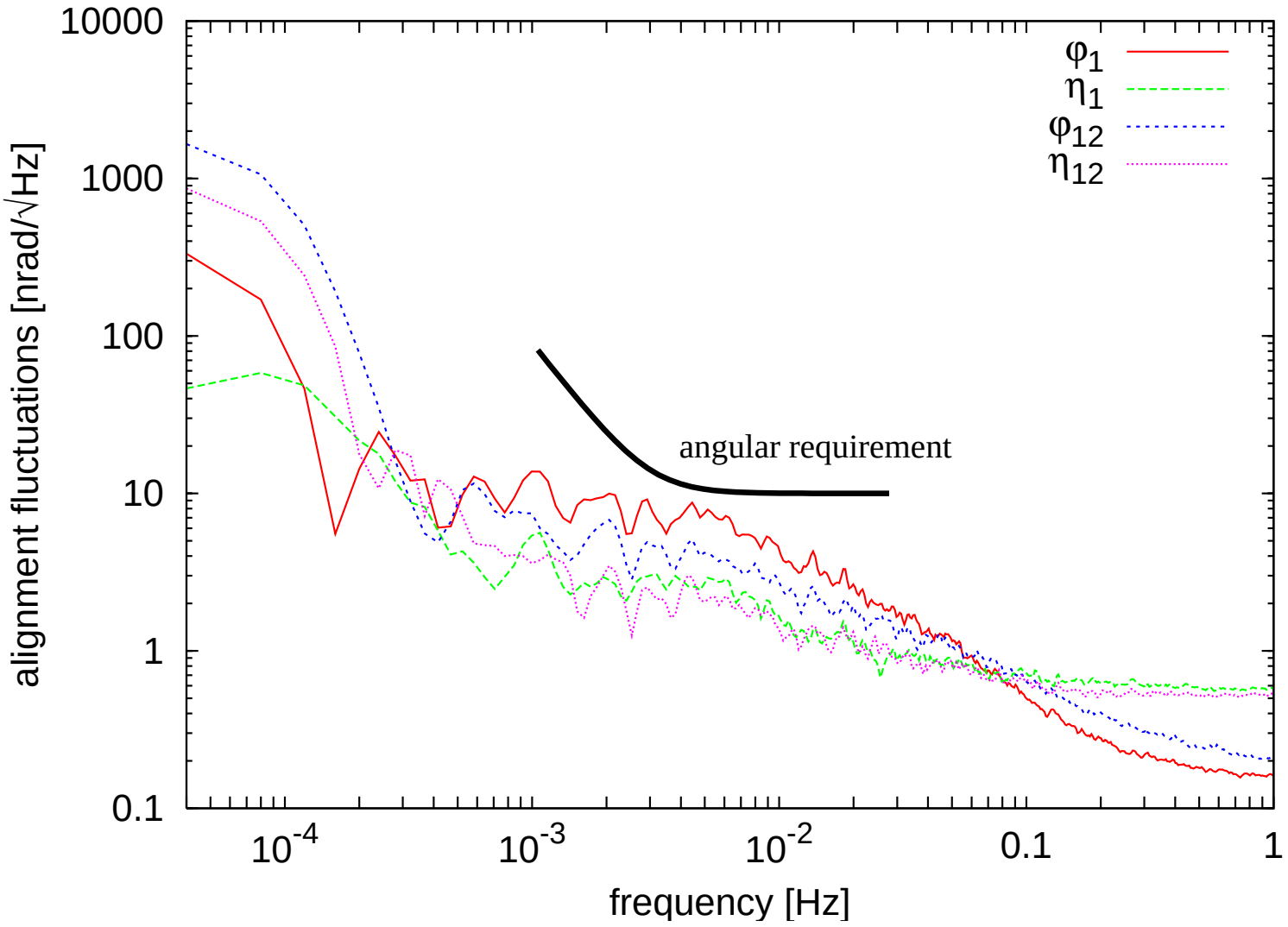


LTP interferometry test-bed: performance milestones

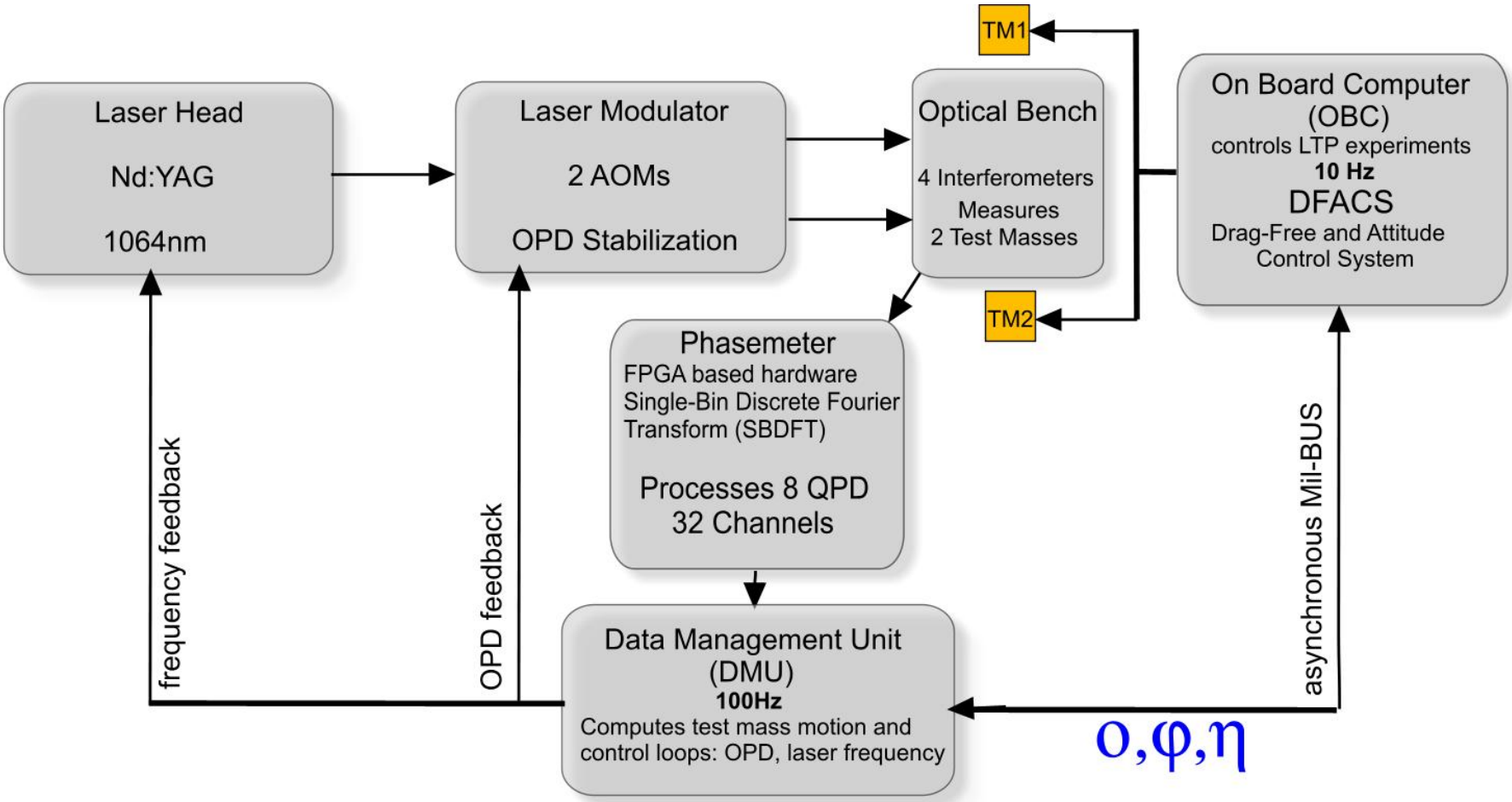


Current performance with AEI phasemeter and EM optical bench.

DWS alignment sensitivity



Ground testing of LPF flight hardware



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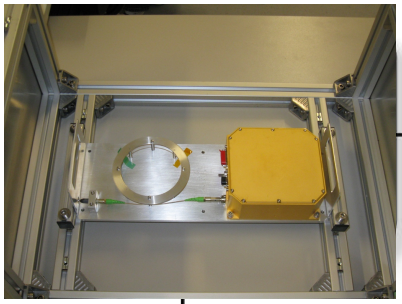

Laser Modulator

2 AOMs

OPD Stabilization

Optical Bench

4 Interferometers
Measures
2 Test Masses

TM1

TM2

On Board Computer (OBC)
controls LTP experiments
10 Hz
DFACS
Drag-Free and Attitude Control System

Phasemeter
FPGA based hardware
Single-Bin Discrete Fourier Transform (SBDFT)

Processes 8 QPD
32 Channels

Data Management Unit (DMU)
100Hz
Computes test mass motion and control loops: OPD, laser frequency

frequency feedback

OPD feedback

asynchronous Mil-BUS

o, φ, η

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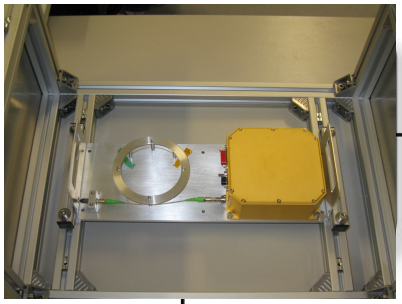

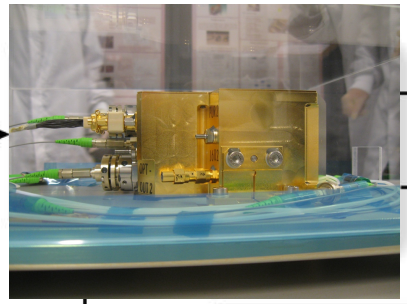

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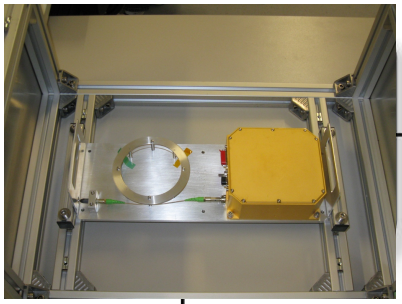

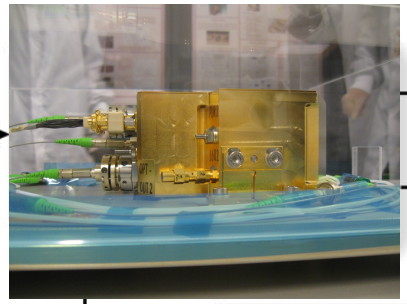

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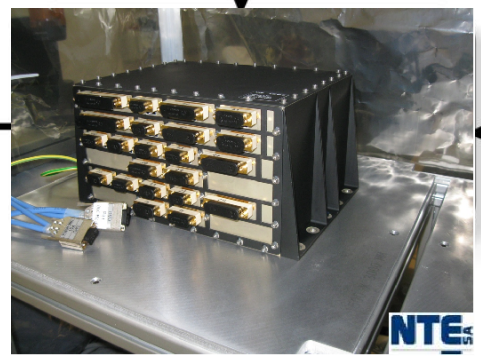

o, φ, η

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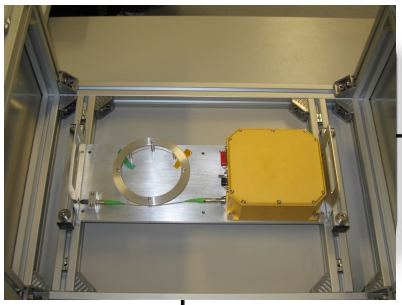

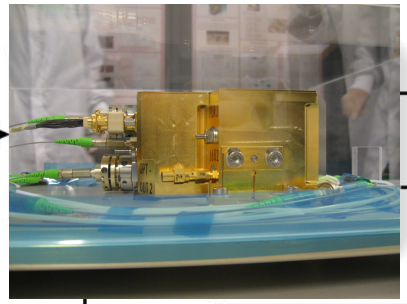

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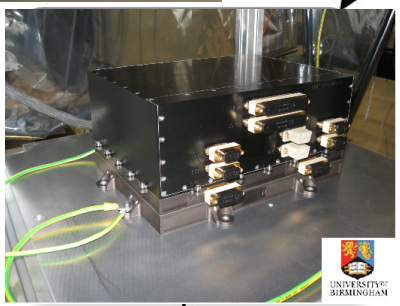

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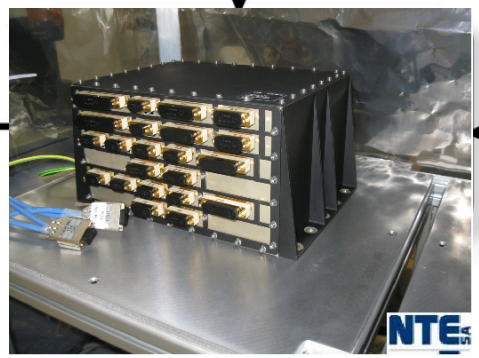

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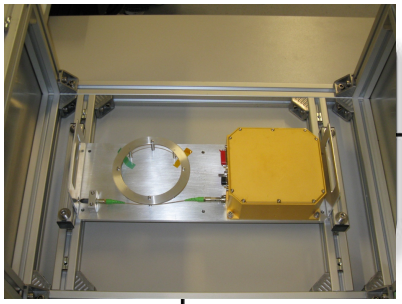

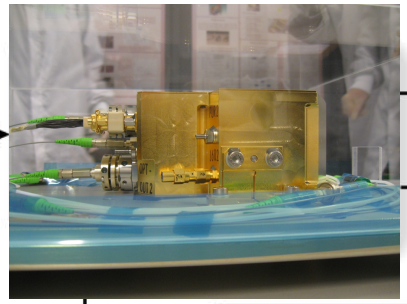

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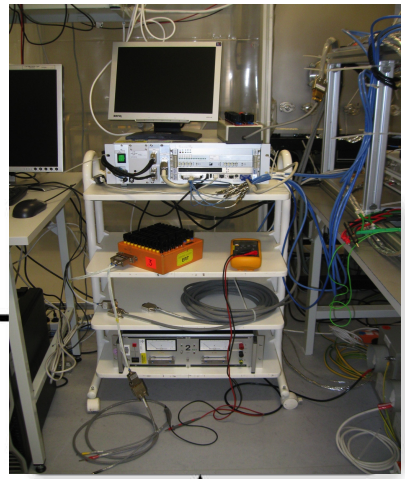

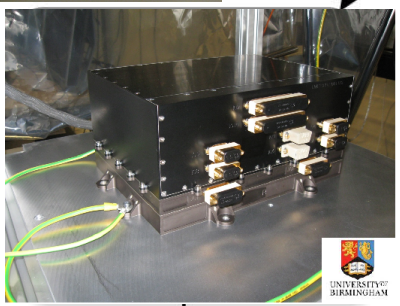

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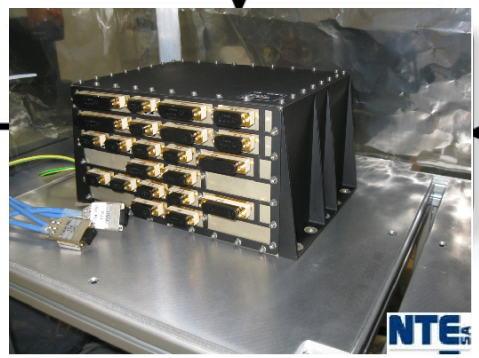

o,φ,η

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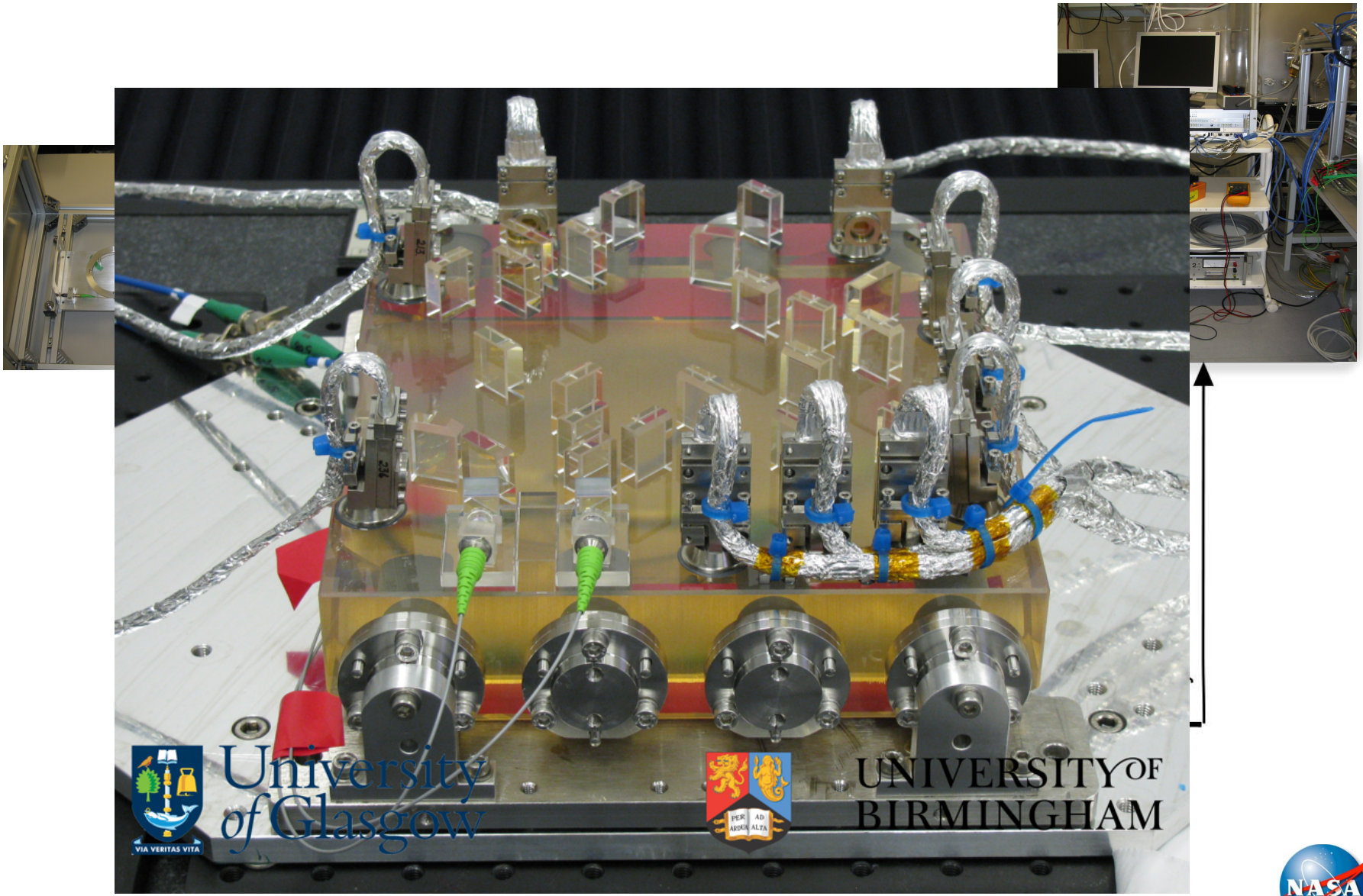

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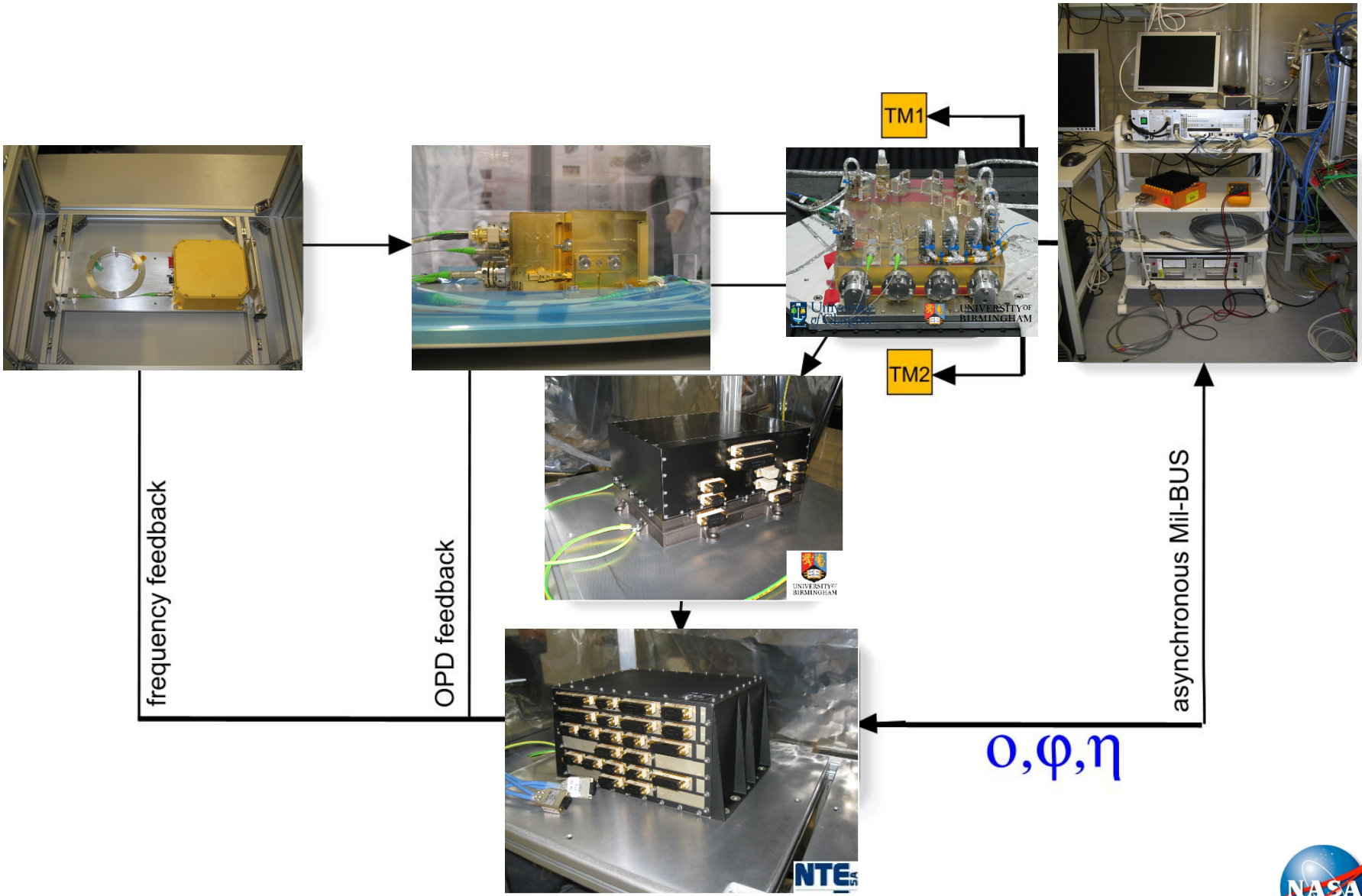

Summary

- We have a mature concept for the LISA instrument.
- LISA Pathfinder is a great test facility for LISA technology.
- Flight models of LISA Pathfinder units have been delivered and are being tested (as we speak!) prior to integration.
- Still a long way to go but we're getting there...