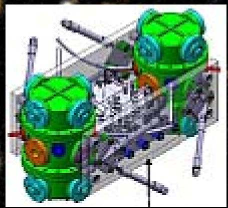

LISA TECHNOLOGY PACKAGE

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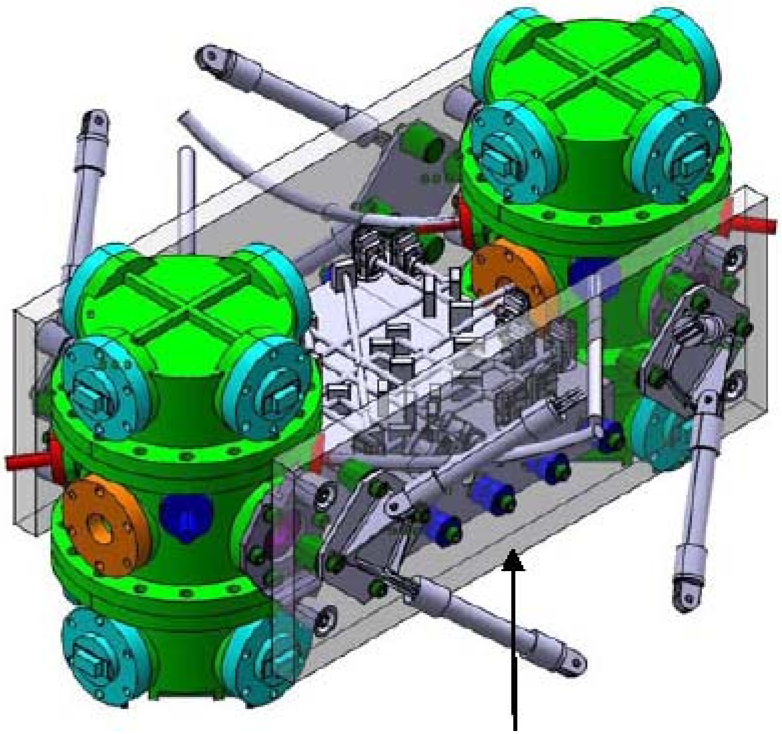

Università degli Studi di Trento

LISA Technology Package Architect

EADS ASTRIUM

CARLO GAVAZZI
CARLO GAVAZZI SPACE

Max-Planck-Institut
für Gravitationsphysik
Albert-Einstein-Institut

Rutherford Appleton Laboratory
Daresbury Laboratory
CLRC Council for the Central Laboratory of the Research Councils

UNIVERSITY of GLASGOW

TNO

Contraves Space

MAURICE TE PLATE
EUROPEAN SPACE AGENCY
ESA-ESTEC

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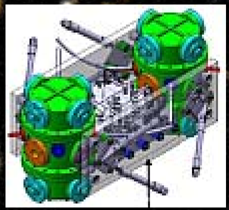
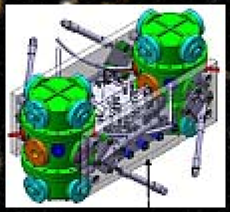


LISA TECHNOLOGY PACKAGE

LISA Pathfinder

- ESA’s SMART-2 now renamed LISA Pathfinder
- Technology demonstrator mission in preparation for LISA.
- Payload:
    - ESA supplied LISA Technology Package
    - NASA supplied ST-7
- Launch in 2007

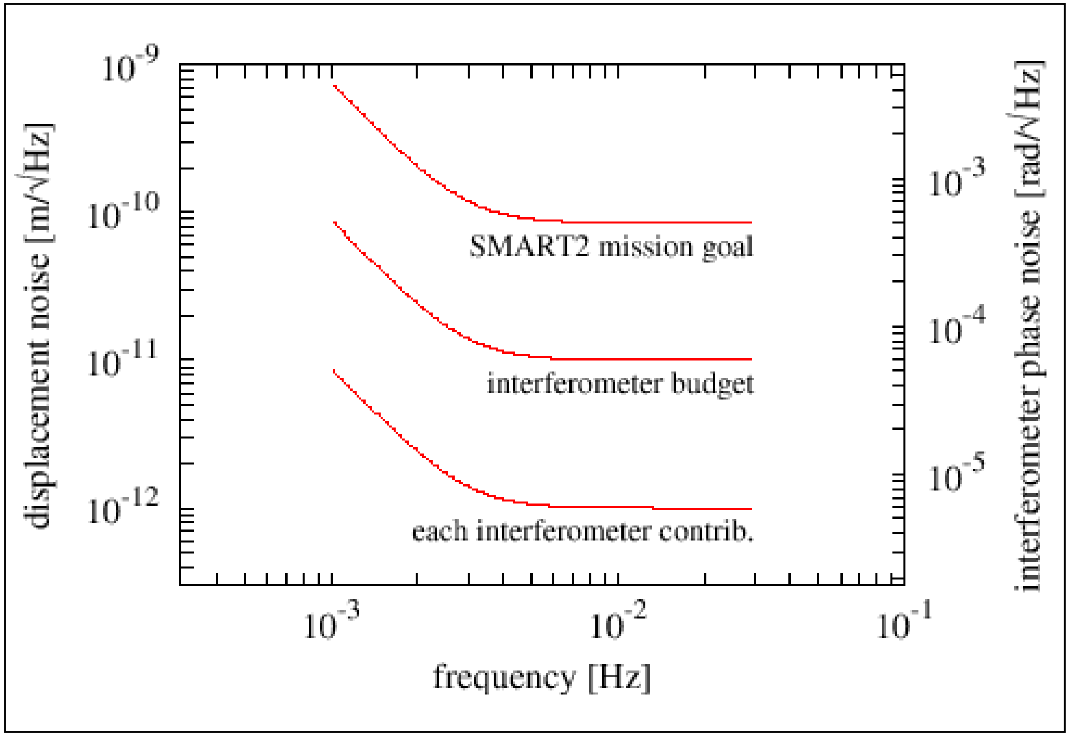


LISA TECHNOLOGY PACKAGE

Purpose LISA pathfinder

Demonstrate drag-free flying:

- Verify the performance of the gravitational reference sensors by optically monitoring the distance between two free floating test masses



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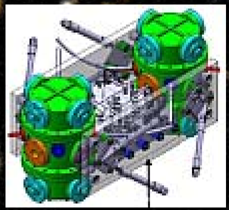


LISA critical Technologies to be demonstrated by LPF

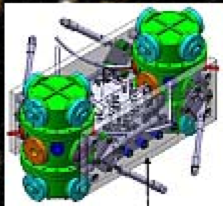
- **Gravitational reference sensors**:

  Test mass in a cage with capacitive sensors / actuators. The test mass is freely floating, subject only to gravitational forces, and the spacecraft shields and follows it (drag-free control).

- **Low-noise μN thrusters:**

  These compensate all non-gravitational forces acting on the spacecraft.

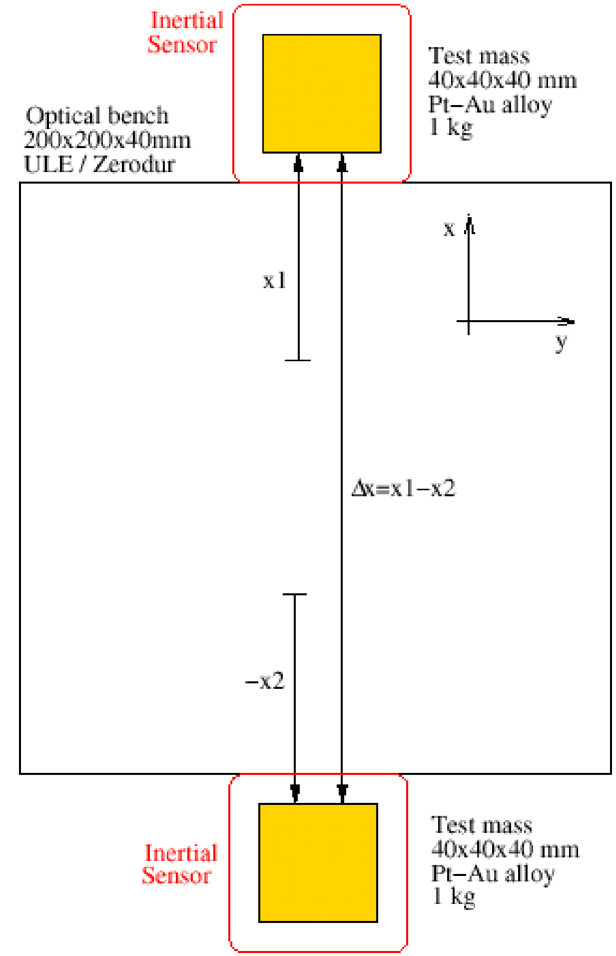
- **Ultra-stable optical interferometry**

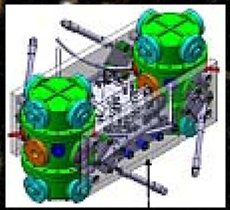


Optical interferometer system

LTP interferometer is the diagnostic tool to continuously monitor the test masses in all operating modes by measuring:

1)	**X1-X2**:	Distance between T/M's
2)	**X1**:	Position T/M 1 w.r.t. OB
3)	**Tilt (X1):**	Tilt T/M 1 (Y and Z-axes)
4)	**Tilt (X1-X2):**	Differential Tilt T/M 1 and T/M 2





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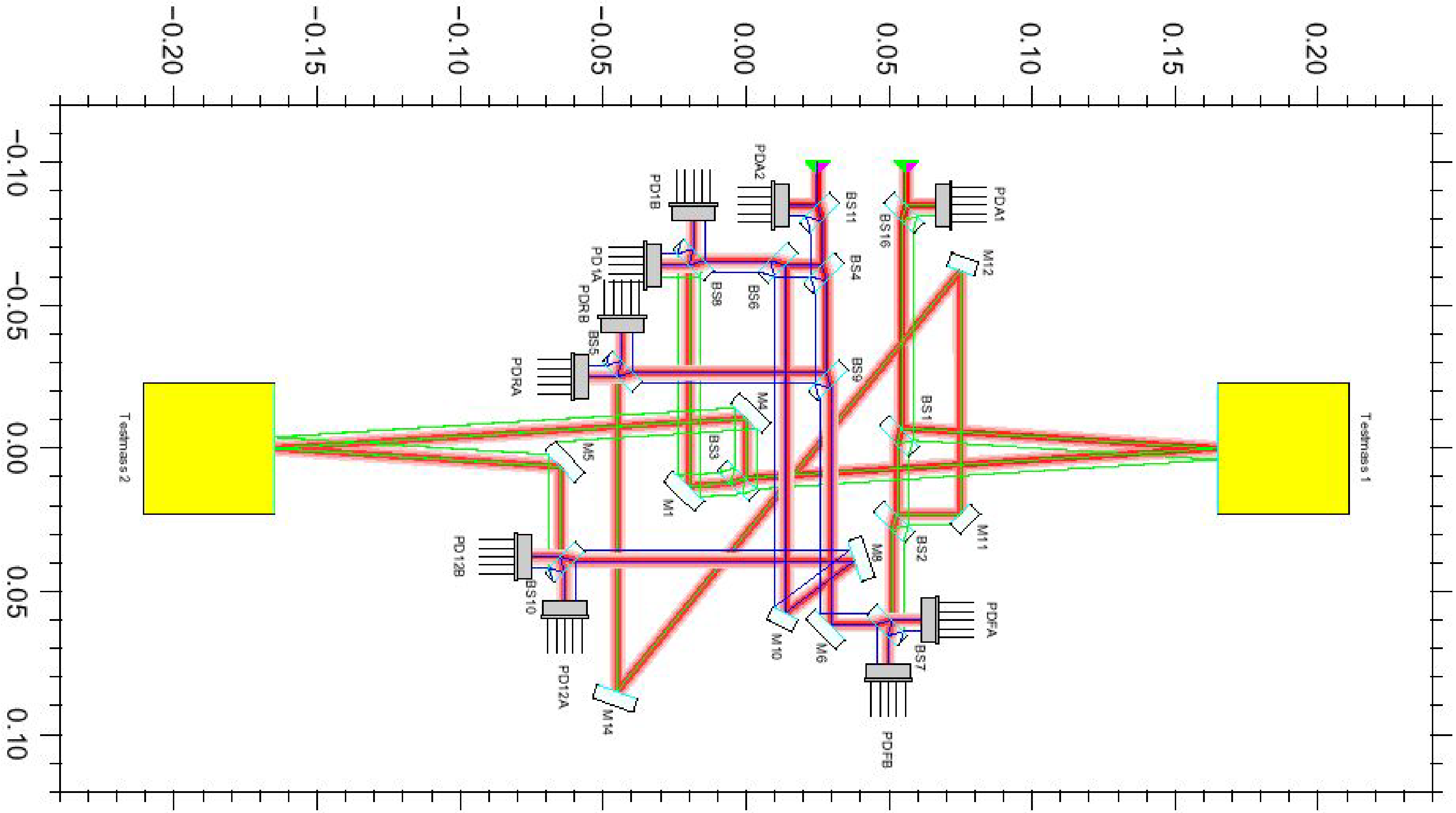
Interferometer Design

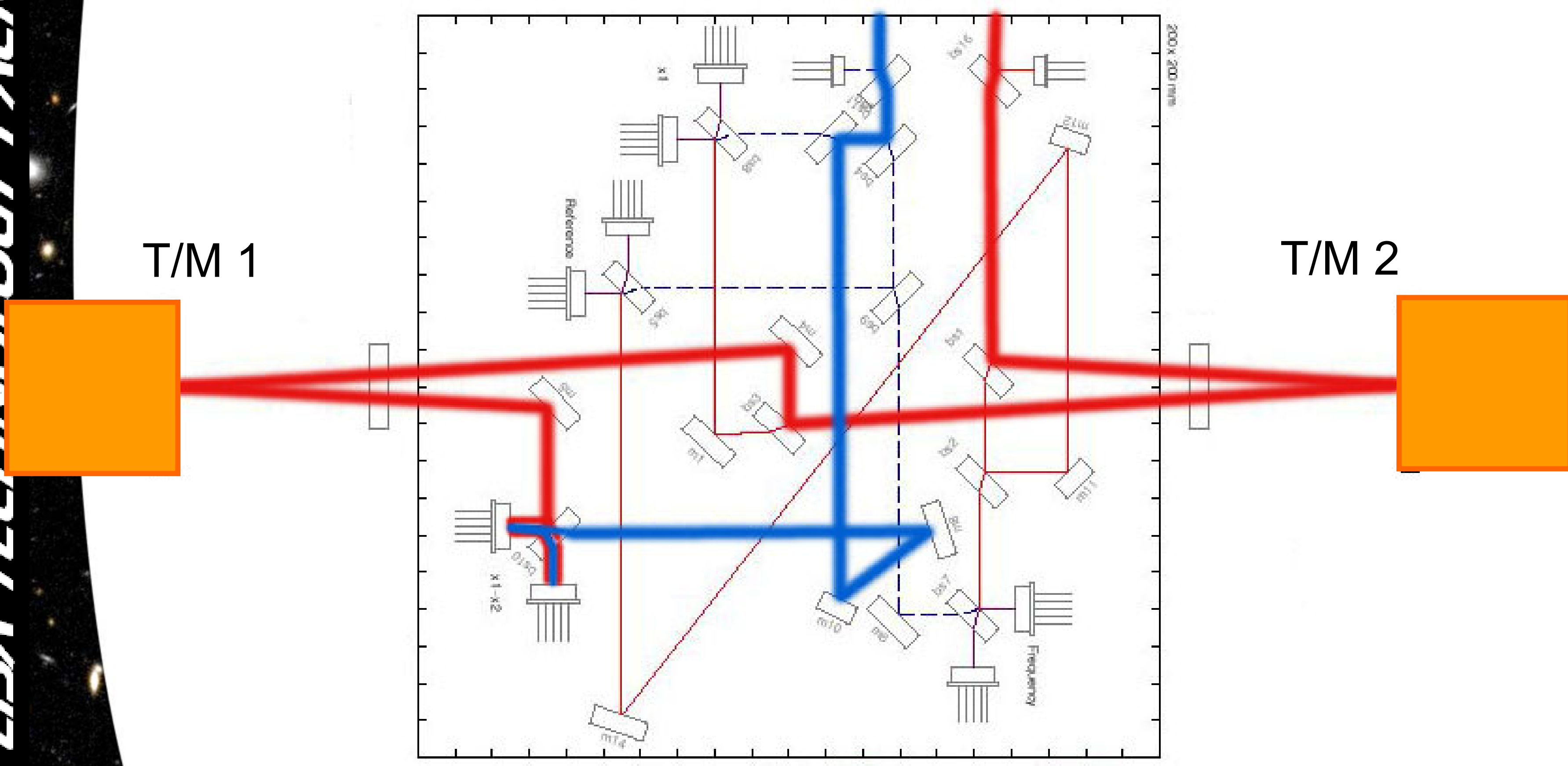


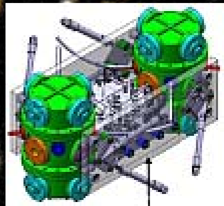
4 non-polarizing heterodyne Mach Zehnder interferometer systems on Zerodur slab of 200 X 200 mm^2

X1-X2 path

Time dependence heterodyne signal:

$$\cos\varphi = \cos\left(2\pi f_{\mathrm{het}}\, t - \frac{2\pi\, x}{\lambda}\right)$$





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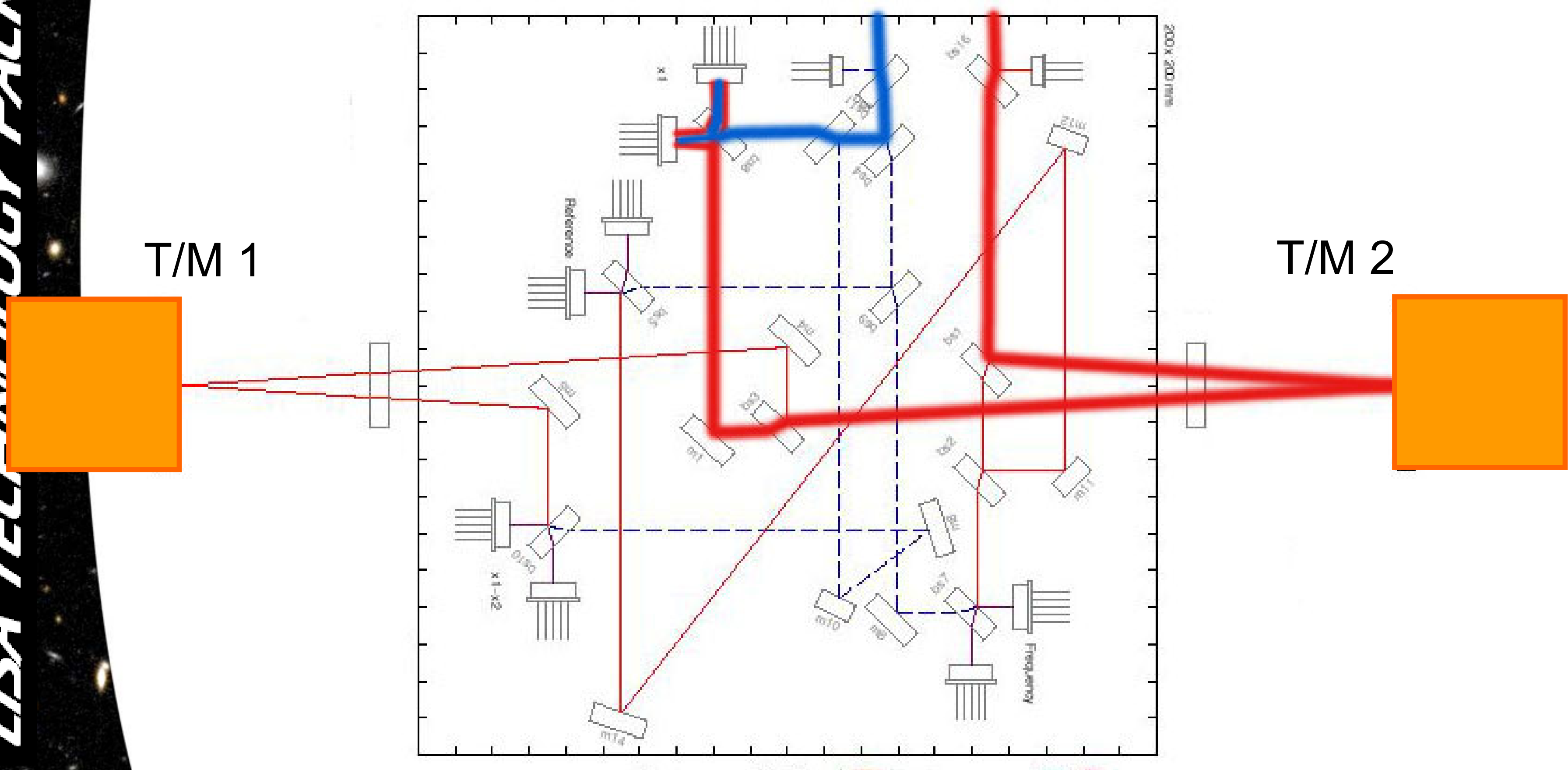
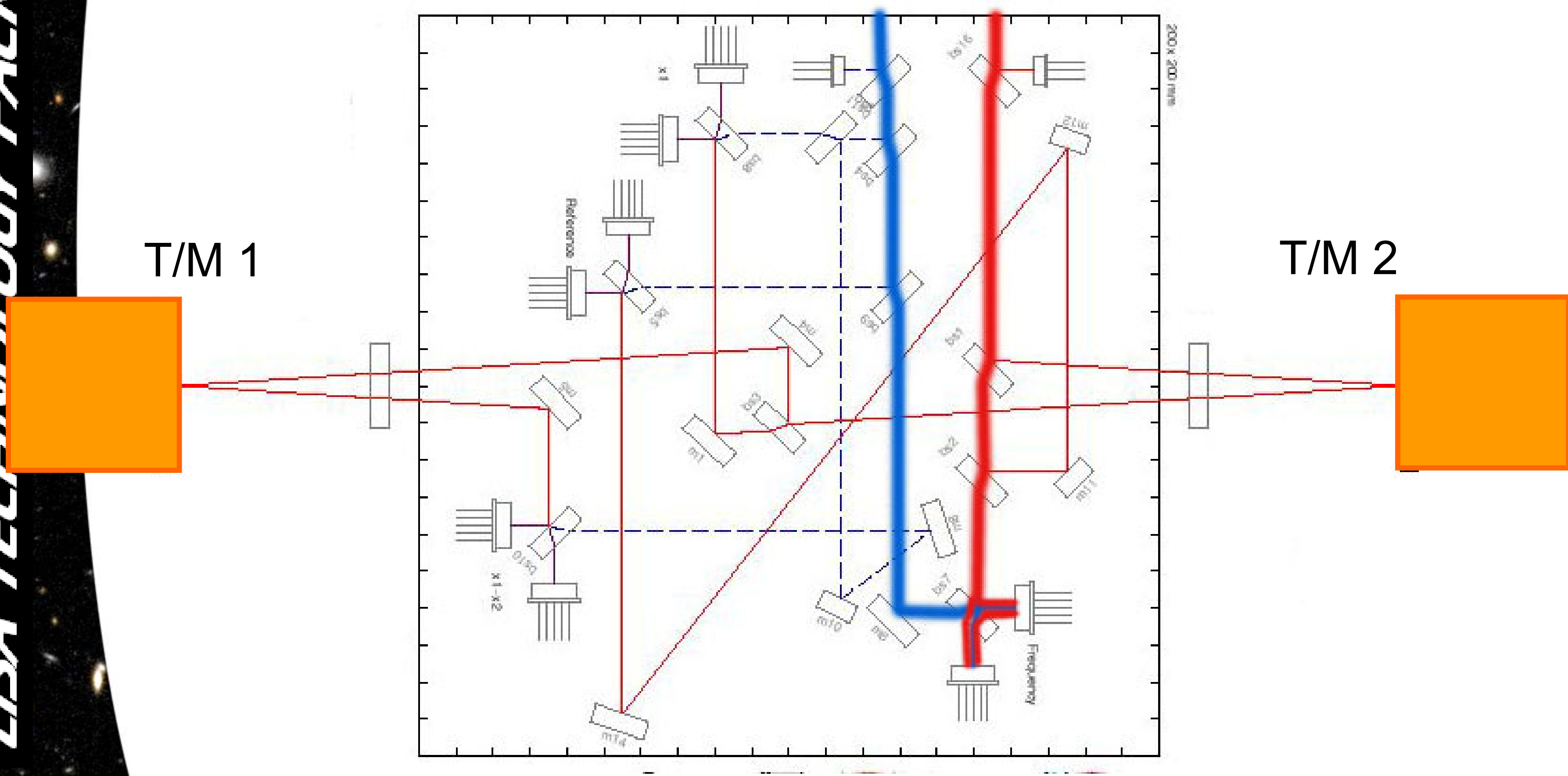
X1 path

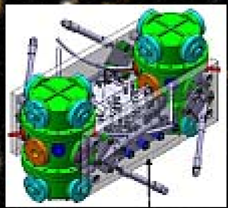
Distance between one test mass and the optical bench



Reference ifo

Provides the reference phase for the (X1-X2) and X1 measurements





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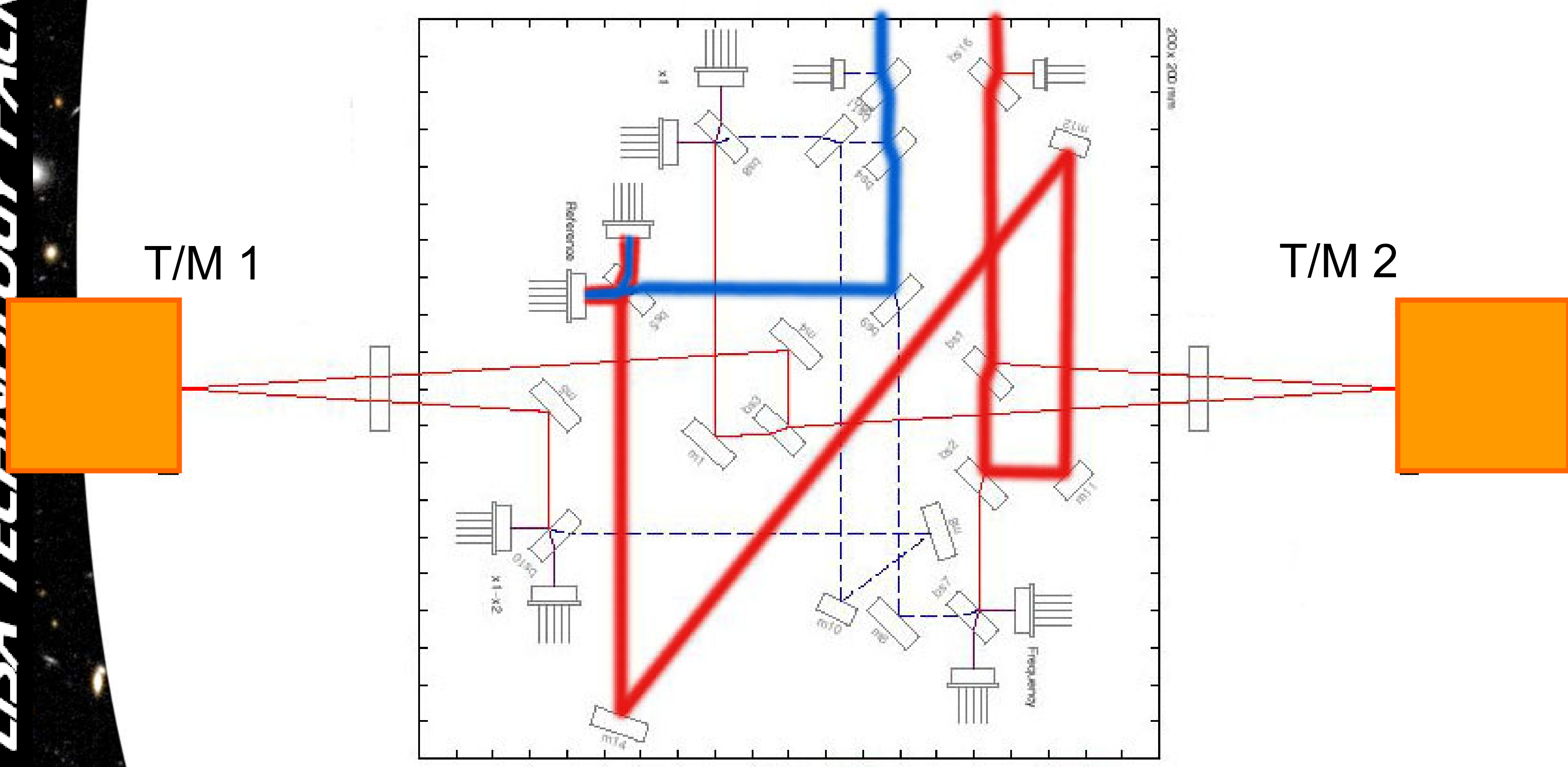
Unequal Arm length ifo

Intentionally unequal path lengths →
Measure laser frequency fluctuations



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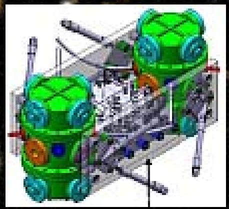

Monitoring detectors

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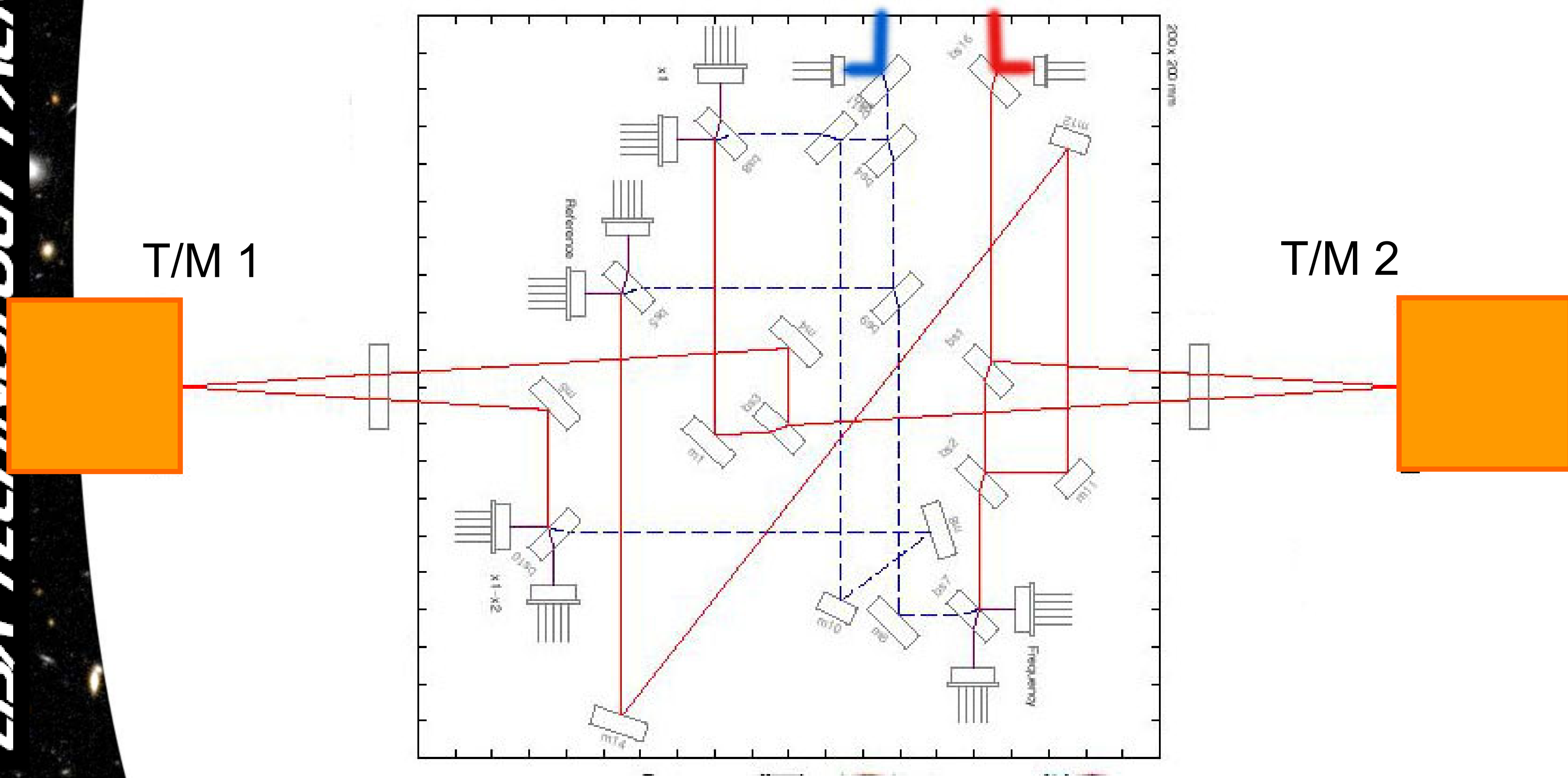

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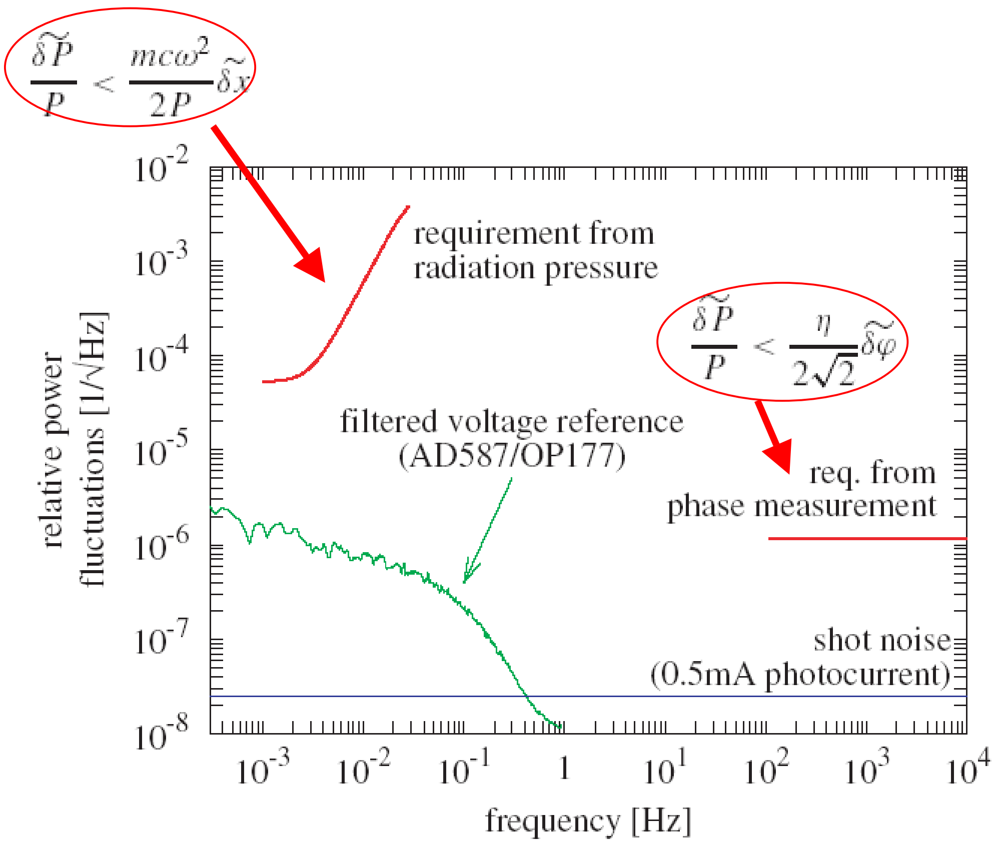
Laser Power Stabilization

Requirement for laser power stability driven by:

- Radiation pressure on test mass
- Direct coupling into phase measurement @ f_{het}



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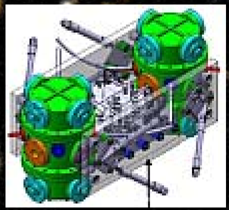


Radiation pressure

- Noise budget allocated to each interferometer noise source: $\delta x < 1\text{pm}/\ /\sqrt{\text{Hz}}$ between 1 mHz and 3 mHz
- Displacement fluctuation given $\delta x = \dfrac{2\delta P}{mc\omega^2}$
- Required power stability : $5 \times 10^{-5} / \sqrt{\text{Hz}}$ between 1 mHz and 3 mHz, relaxing as f^2 up to 30 mHz

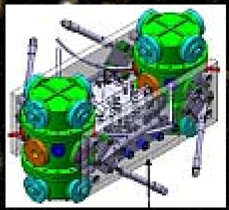
Coupling into phase measurement

- At the heterodyne frequency (a few KHz) the requirement is:

$$\frac{\widetilde{\delta P}}{P} < \frac{\eta}{2\sqrt{2}}\widetilde{\delta\varphi}$$

- Required power stability: $1.8 \times 10^{-6} / \sqrt{\text{Hz}}$

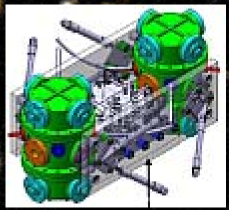
Conclusion: Power stabilization no major obstacle



Frequency stabilization

- Laser frequency fluctuations cause spurious phase fluctuations
- Between 3 mHz and 30 mHz, the requirement for frequency stability is:

$$\widetilde{\delta\nu_{\mathrm{L}}} < \frac{c}{2\pi\,\Delta l}\widetilde{\delta\varphi} = 28\,\frac{\mathrm{kHz}}{\sqrt{\mathrm{Hz}}}\Big/\left[\frac{\Delta l}{1\,\mathrm{cm}}\right]$$



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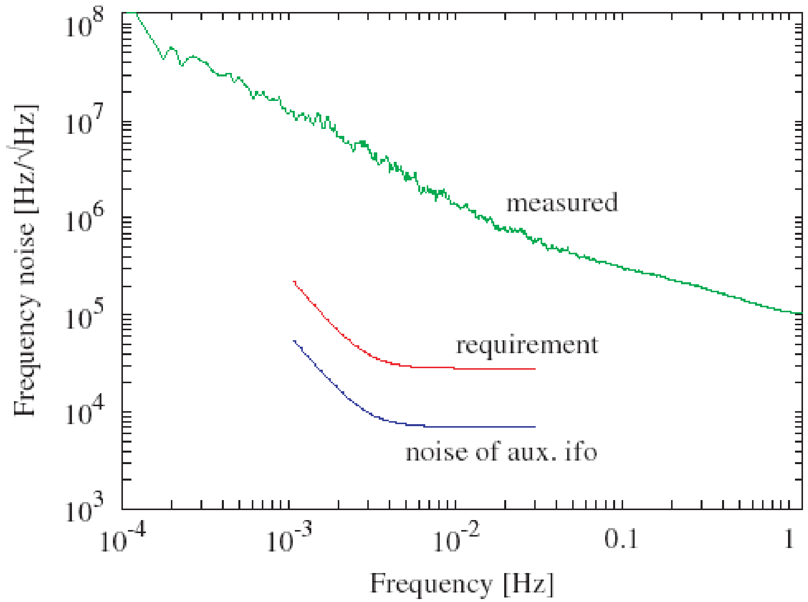
Frequency stabilization



- Factor 100 is needed for frequency stabilization
- Reference cavities or molecular references too complicated
- In stead unequal armlength auxilliary ifo (ΔL = 40 cm) is used
- Two possible stabilization schemes:
  - Use **feedback loop to actively stabilize** the laser
  - Apply a **post-measurement correction**
- Selected B/L → Active stabilization

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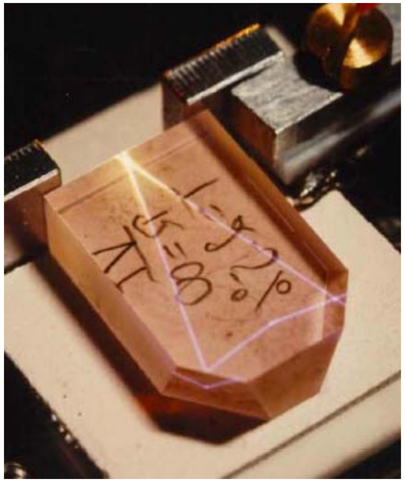
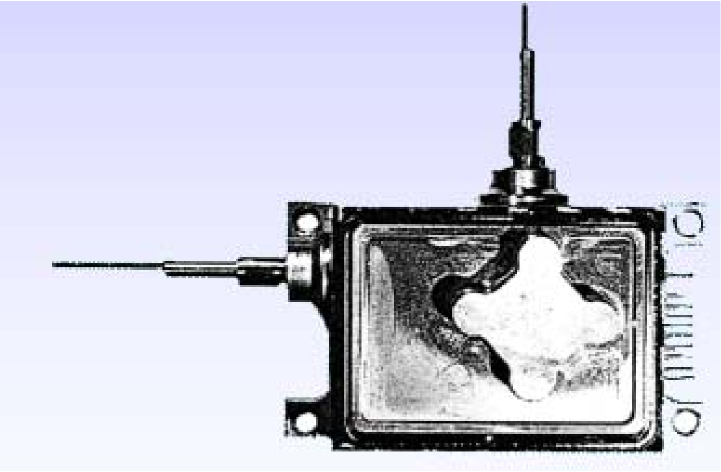
Laser

- TESAT Laser:
  - •NPRO Nd:YAG
  - •Laser Head (Nd:YAG crystal) space qualified
  - •Output power : 1 W





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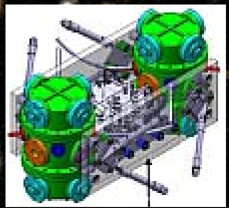

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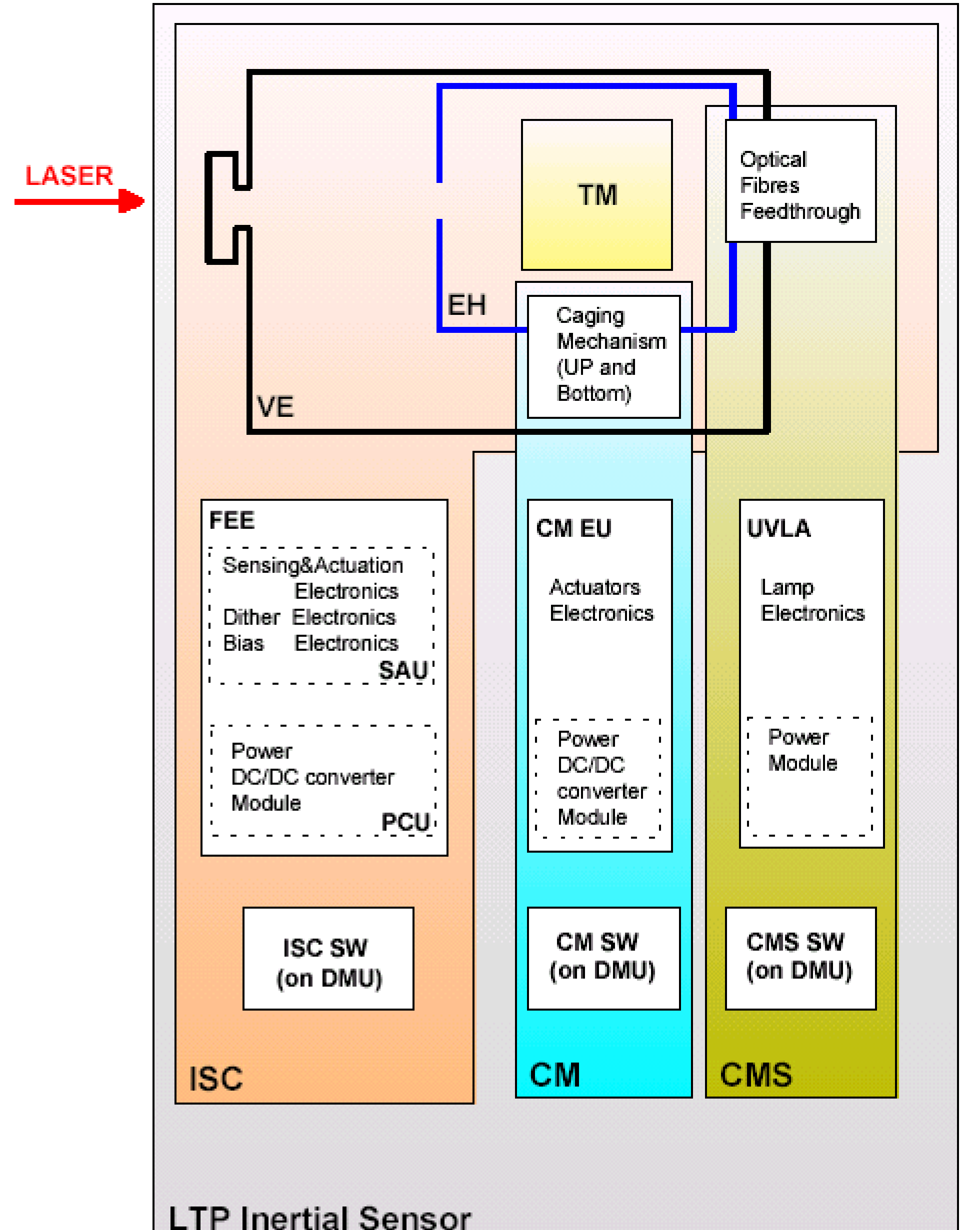
Inertial sensor System

- FEE shall drive the electrode’s voltages to produce electrostatic sensing and force
- CM (Caging mechanism) shall safely hold the test mass during launch and afterwards shall position it at the centre of the housing
- CMS (charge management system): shall make sure the charge on the test mass is lower than the required level



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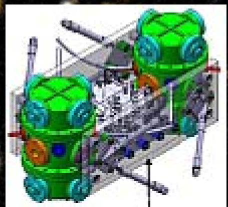
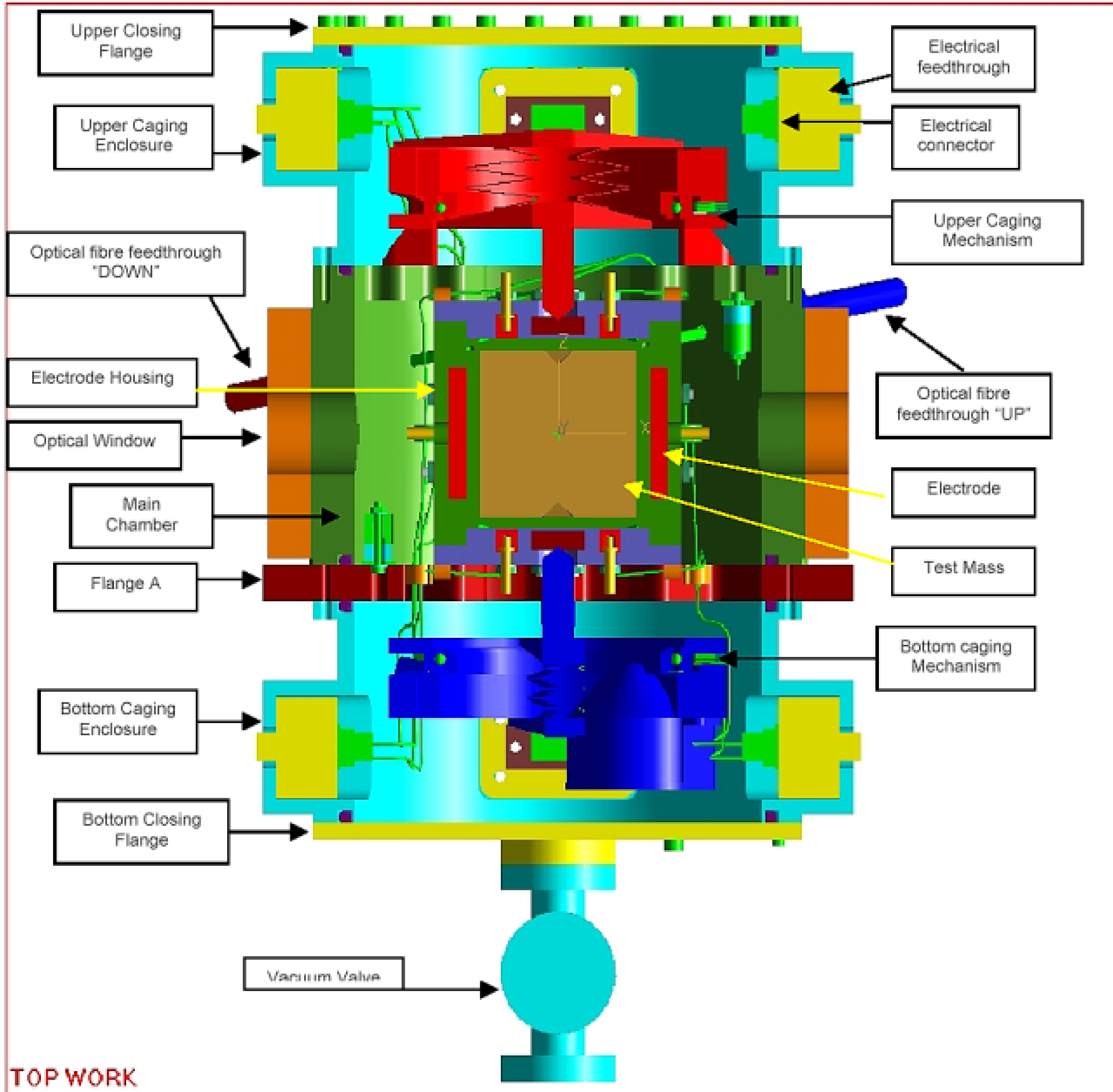


Inertial Sensor Overview



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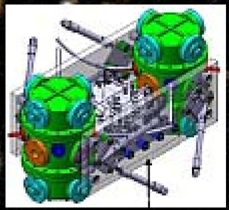

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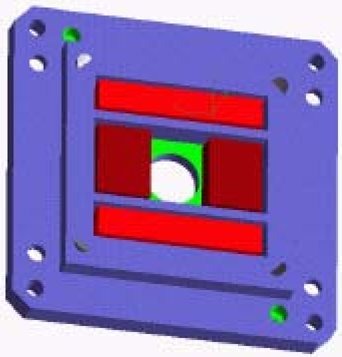
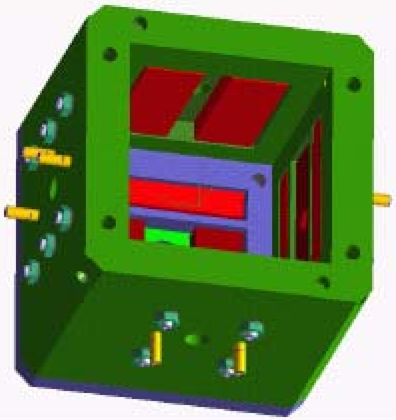
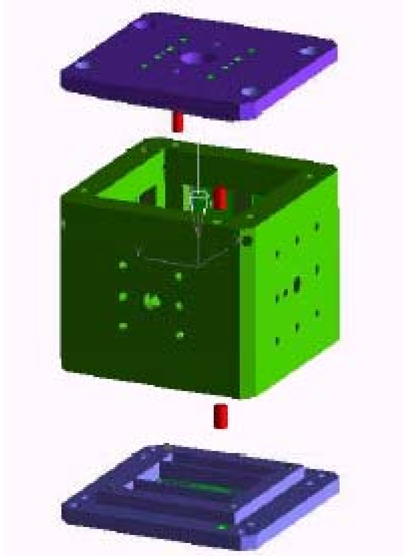
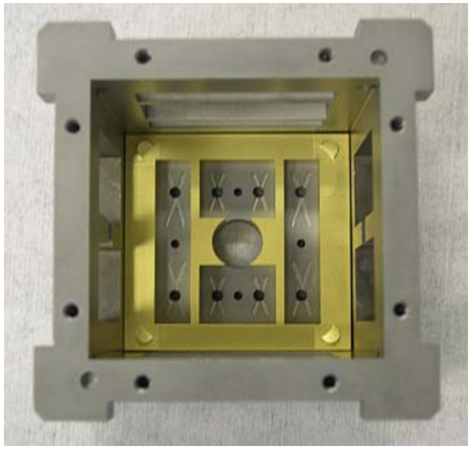
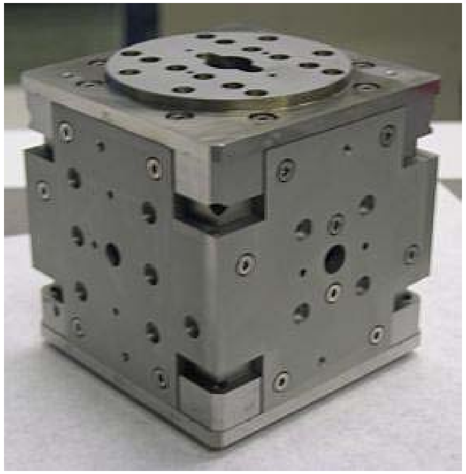
Electrode Housing

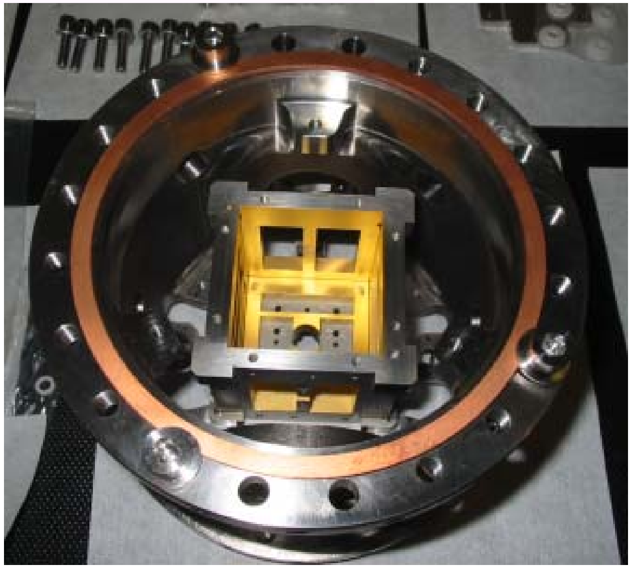












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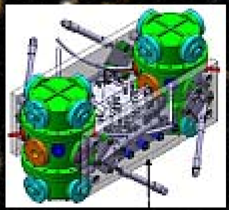
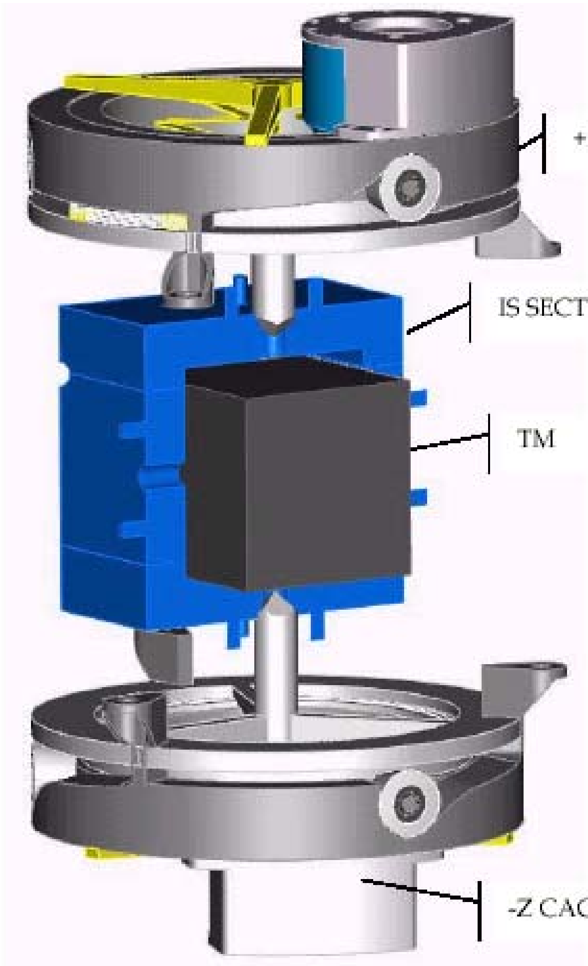
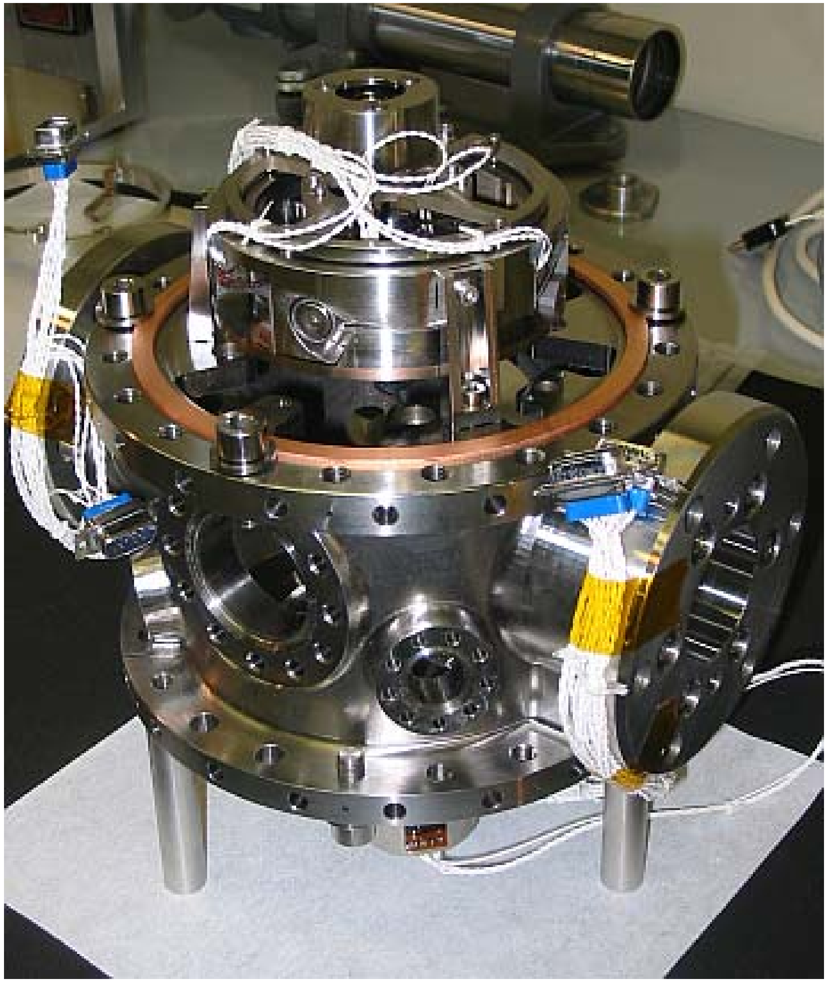


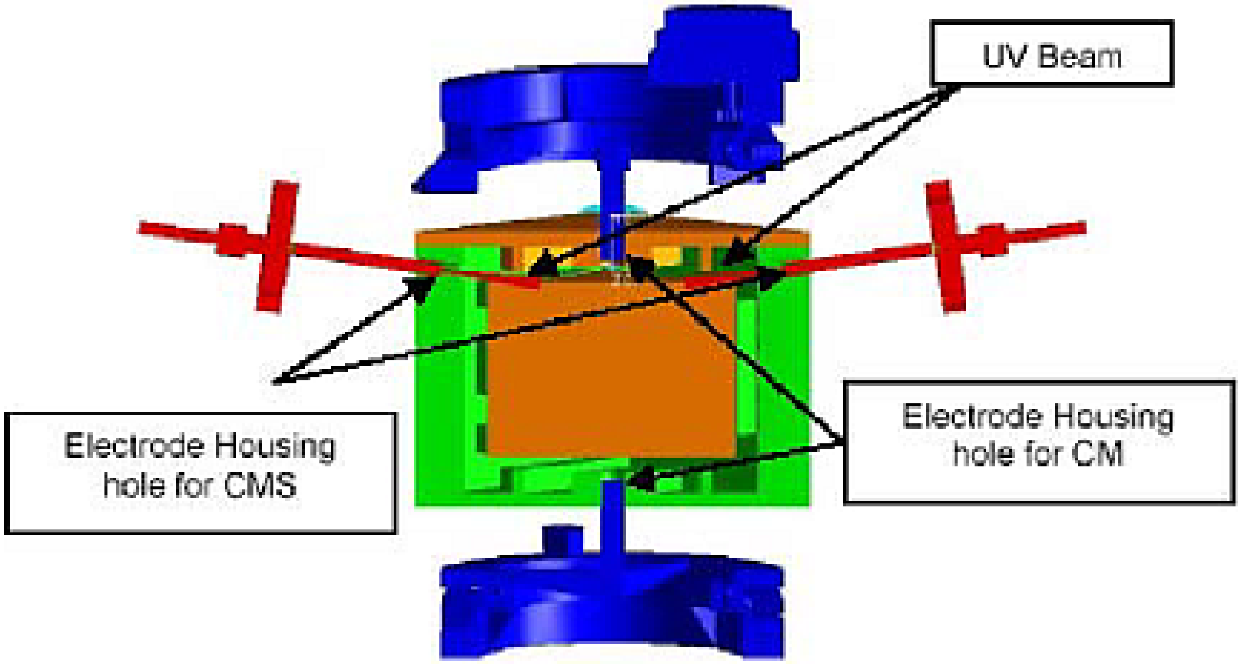
Caging Mechanism

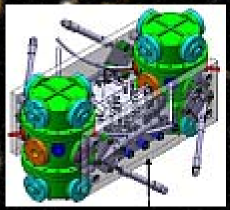




Charge Management System

- Needed for discharging the testmasses

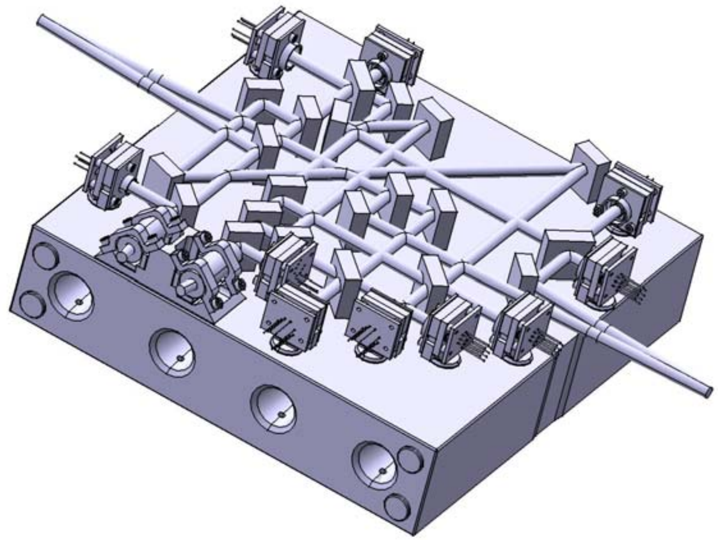




Status Inertial Sensor

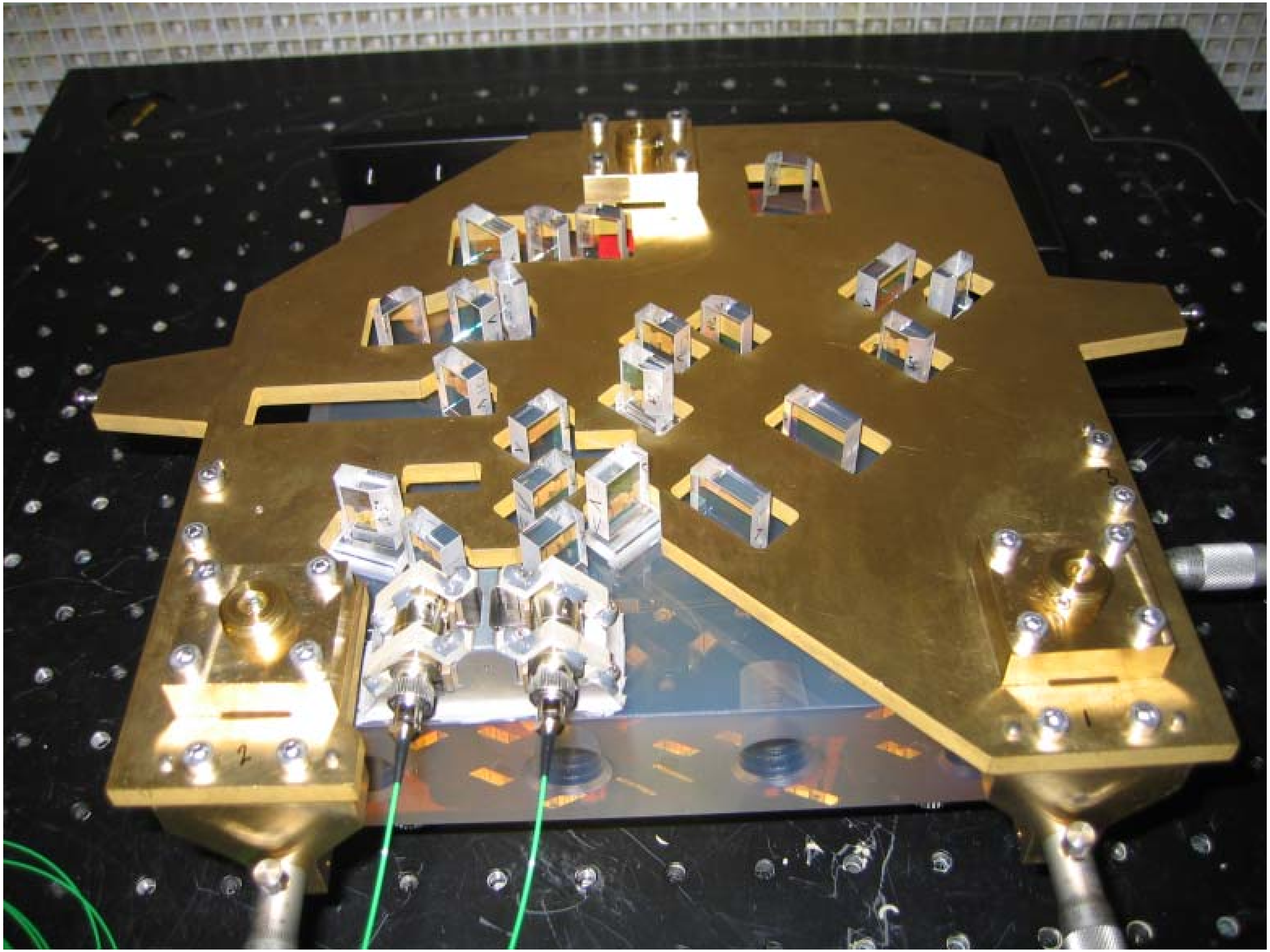
- Engineering Model level for the mechanical part and the FEE is being finalized.
- BB electronics for non critical electronical parts
- Manufacturing of all the mechanical inertial sensor H/W is finished.
- Intermediate vibration testing will be performed shortly to check the structural performances of the caging mechanism

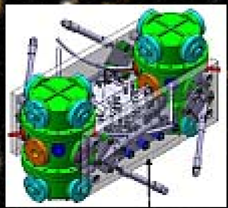
Status Interferometer H/W



- Optical interferometer integration completed February 7th 2004
- Interferometer successfully shipped from RAL (UK) to ASG (Germany) February 8th 2004
- ASG currently finalizing the assembly of the complete LTP OB system.
- Completely assembled LTP OB system will be shipped to TNO-TPD (Netherlands) shortly
- Performance test campaign (including environmental testing) will be finalized end March
- Technical Readiness Demonstration

Optical Bench system during Alignment at RAL, UK





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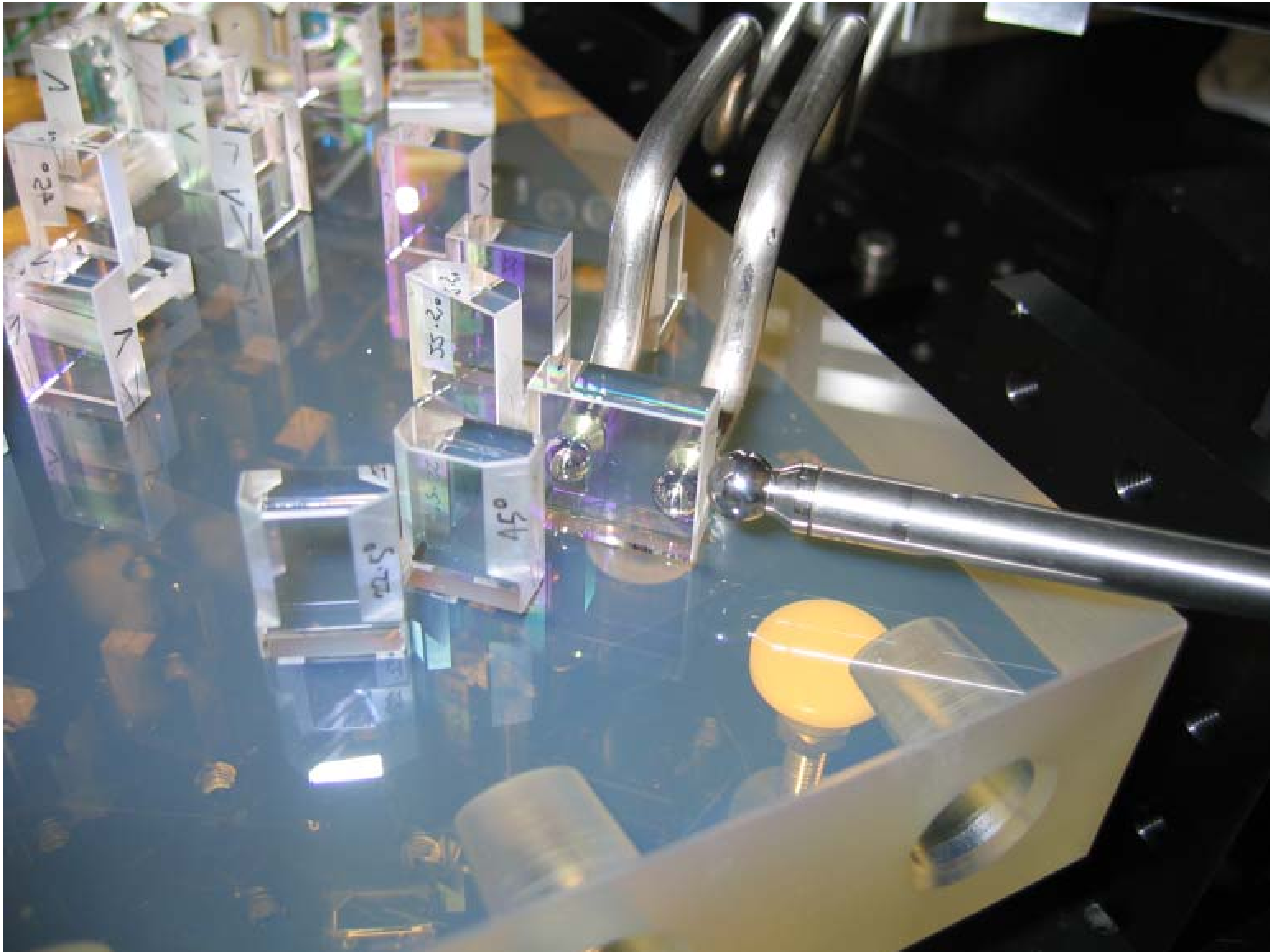
Final step of each interferometer alignment



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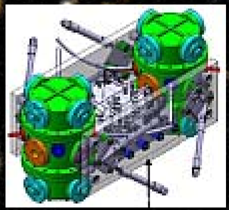

Completed interferometer including photodiodes

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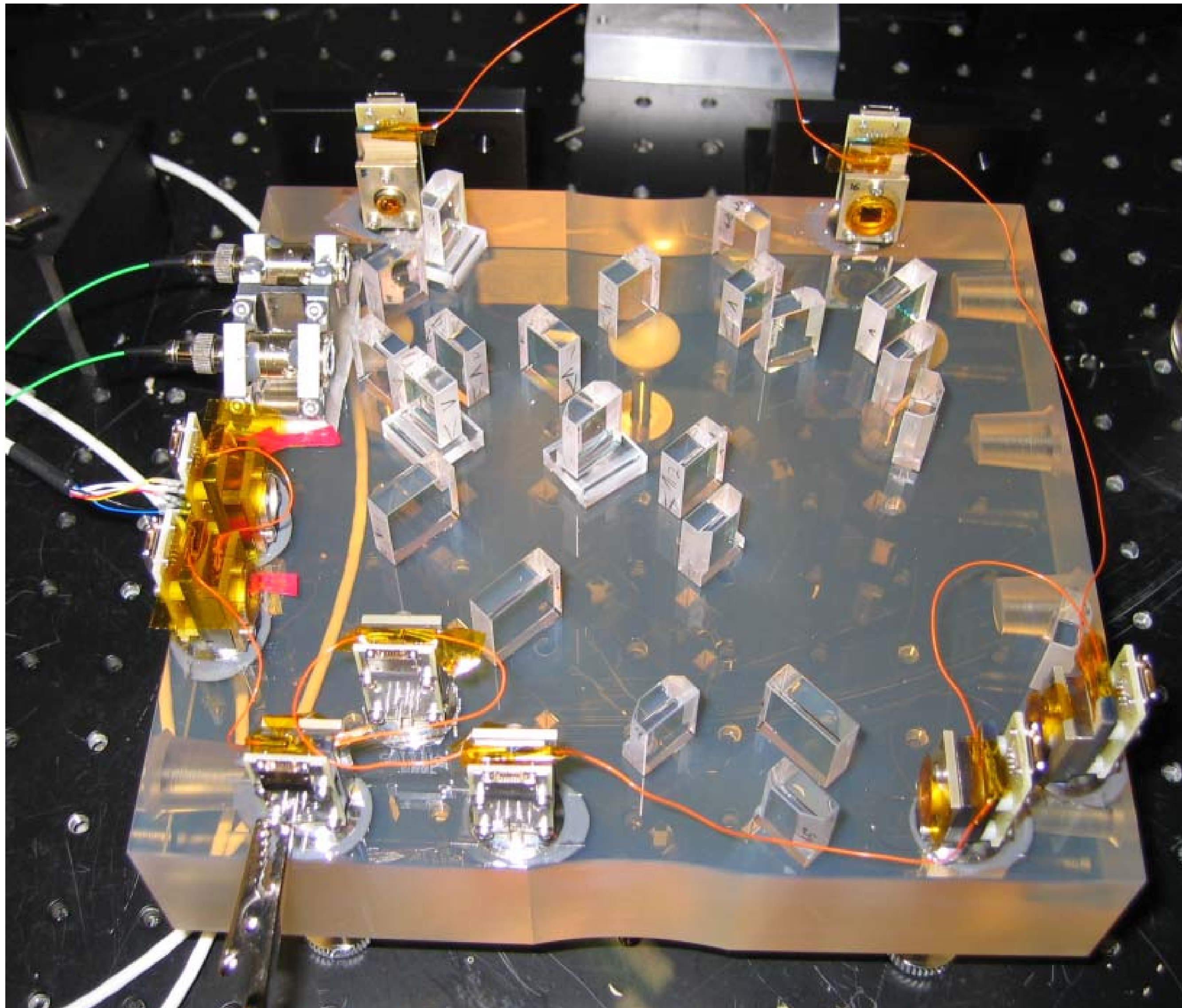

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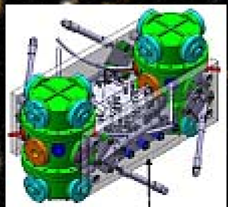

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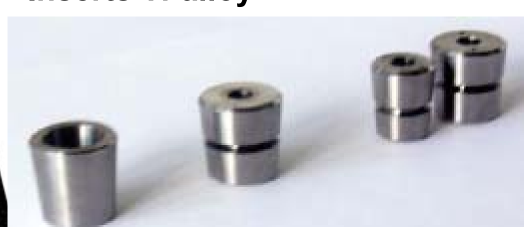
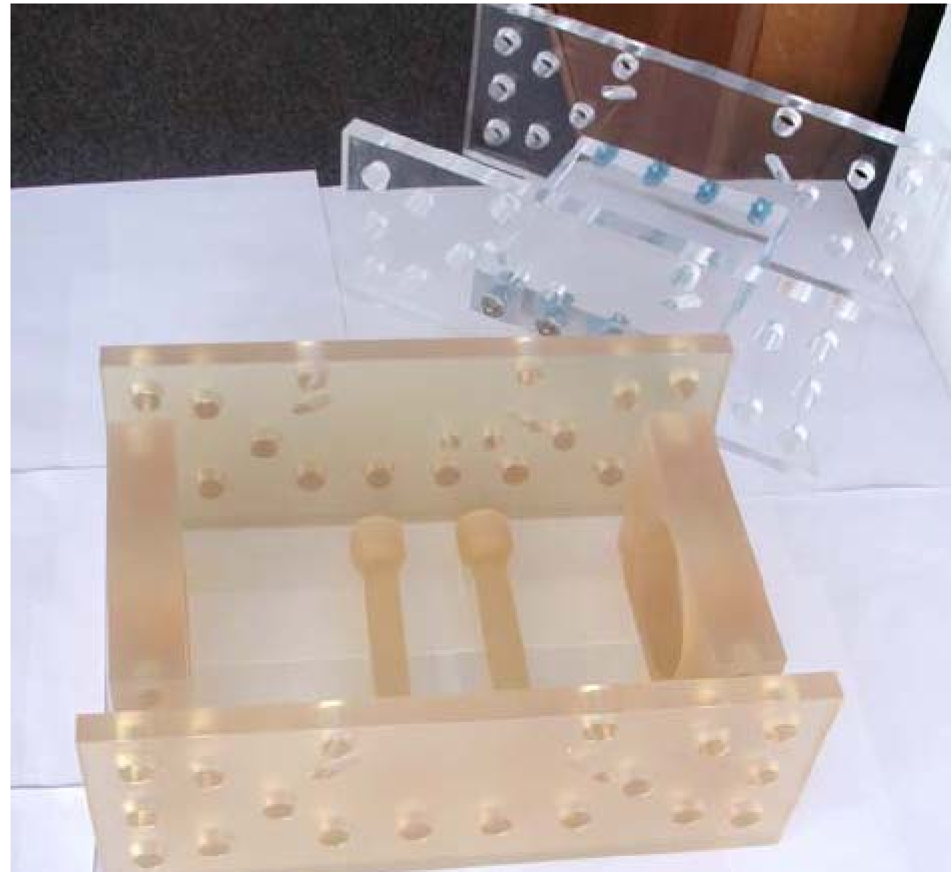
Hardware added by ASG

Ti Brackets for struts…

Ti Interface OB – IS

Inserts Ti-alloy





Zerodur Side slabs, dummy end mirrors and stiffening rods

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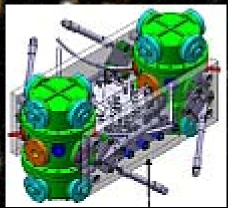

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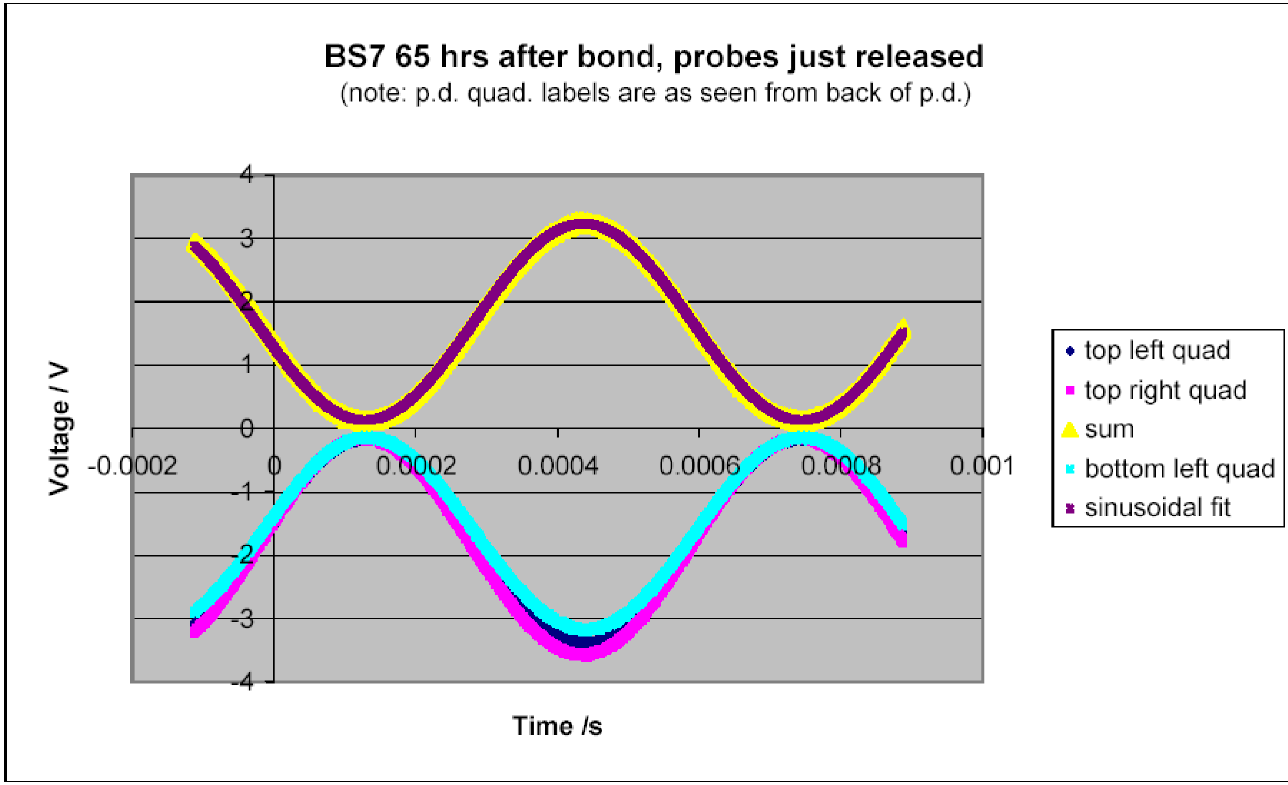
First results
LTP EM OB system



Oscilloscope Readings		
max sum signal		3.23
min sum signal		0.13
contrast	**(max-min)/(max+min)**	**92%**

Contrast excitingly high

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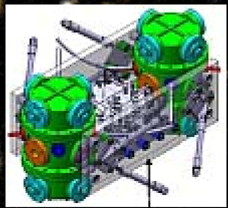

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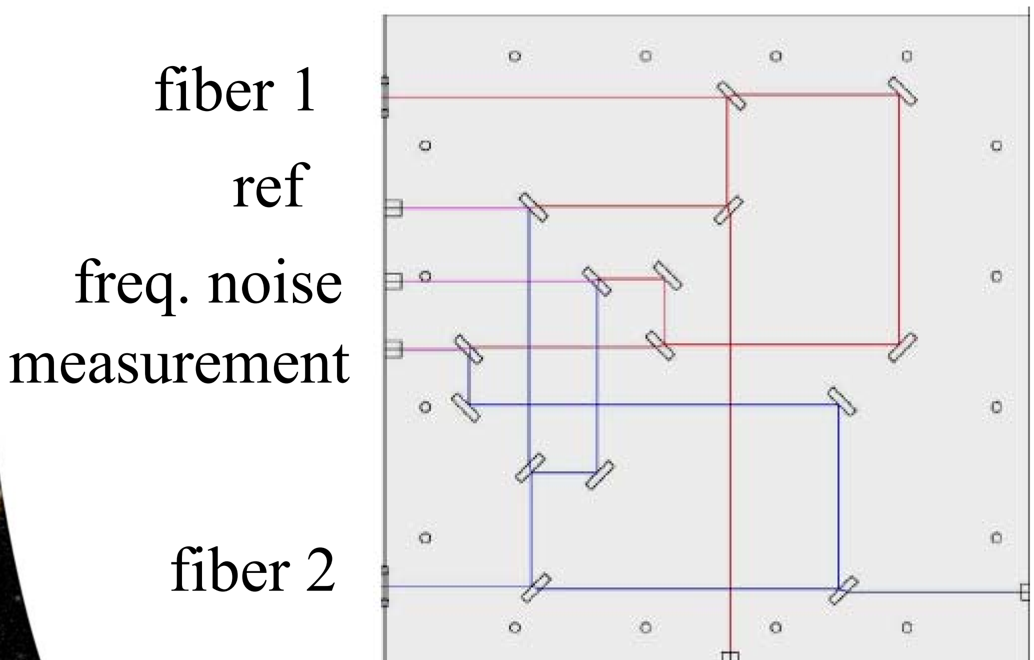
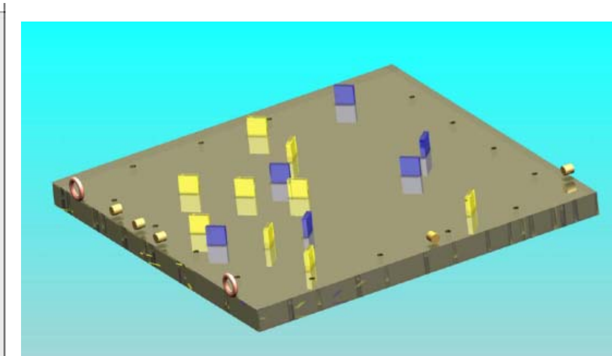
Glasgow pre-investigations

- During pre-investigations phase of the OB activity, UoG developed a simple rigid interferometer system, phasemeter and laser beam preparation bench
- Goal: Demonstrate the suitability of hydroxide catalysis bonding for the construction of the SMART2 and LISA optical benches – precursor to LTP optical bench (RAL)





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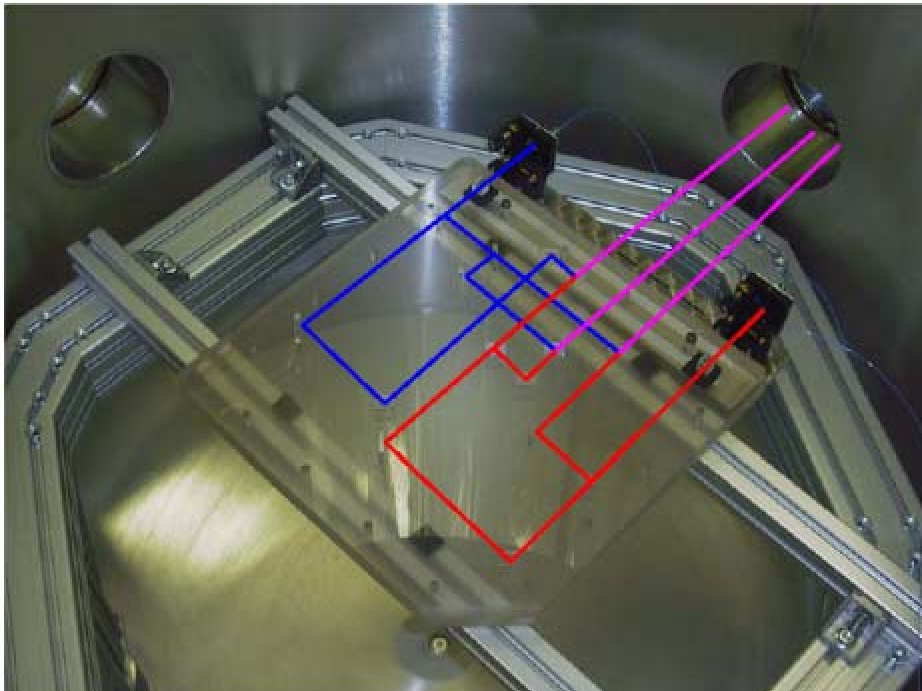
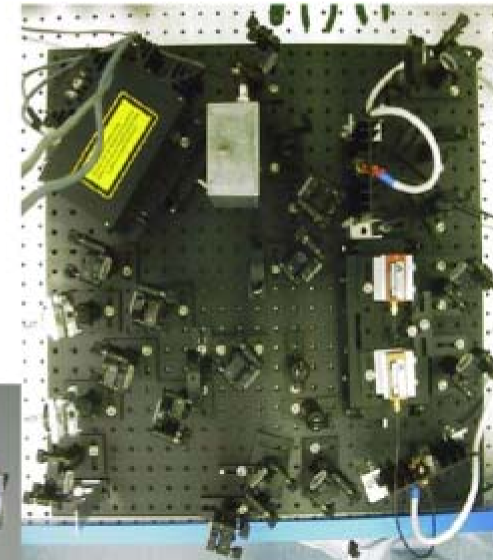
Glasgow pre-investigations



Optical bench in vacuum tank

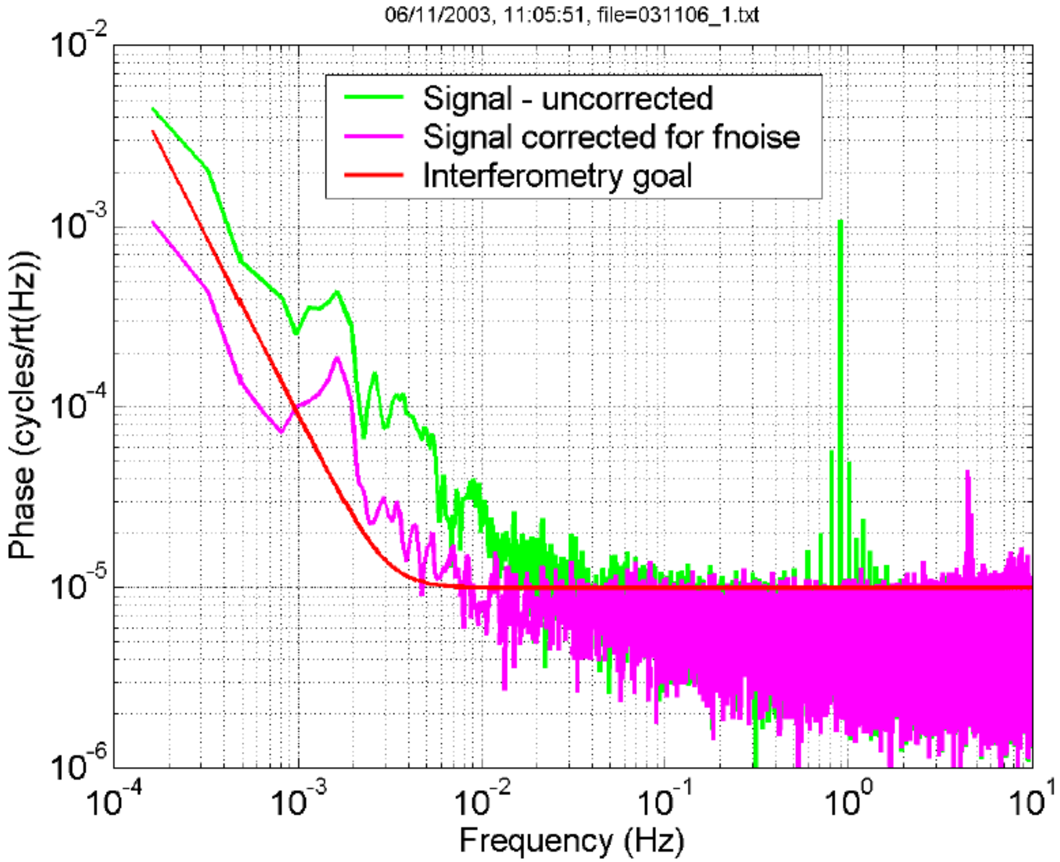
Phasemeter



Laser beam preparation bench

Results pre-investigation tests UoG

- After extensive investigations, UoG demonstrated that the displacement stability of their simplified, but still very representative, OB system meets the LPF goal for almost the complete frequency range



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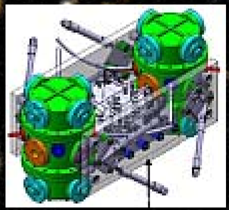
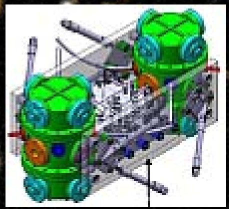


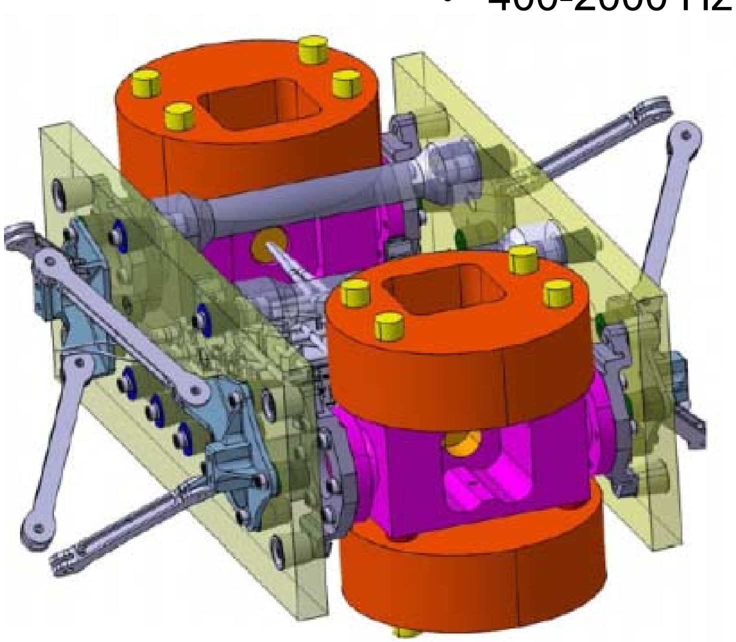
Performance Tests planned on LTP OB system

- **Displacement noise test**:
  Requirement 10 pm/√Hz
  for frequencies between 3 mHz and 30 mHz
- **Full stroke test** (± 100 μm)
- **Tilt Test**: Misalignments that are introduced shall be: 5-10-20-50-100-200-500-1000 μrad.

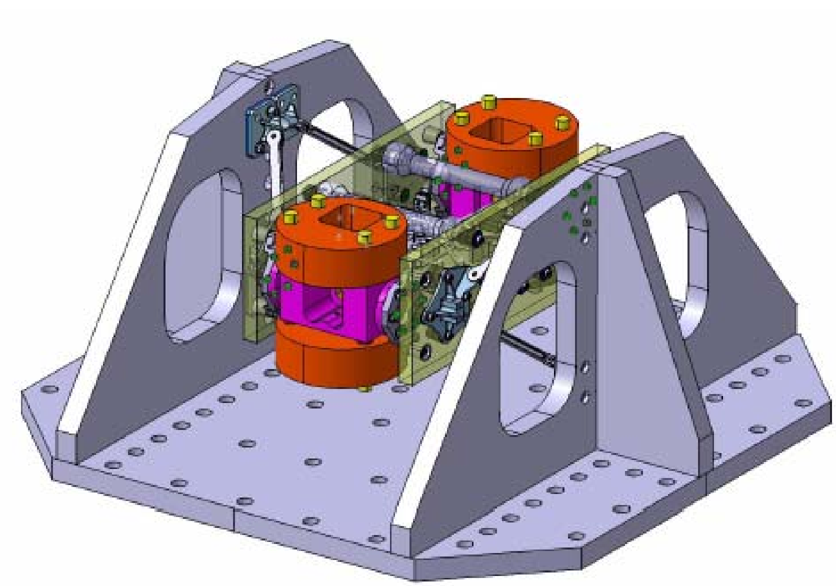


Vibration testing

- Qualification level Sine vibration test → 25 g
- Qualification level Random vibr. Test →
  - 20-100 Hz → +3 dB/oct
  - 100 Hz - 400 Hz →0.1 g^2/Hz between
  - 400-2000 Hz → -6 dB/oct



OB system with integrated dummy tests masses



Test adaptor for vibration tests

Thermal Cycling

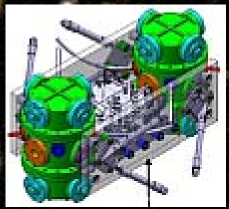
- 5 thermal cycles from 0 °C and +40 °C
- Equilibrium time > 1hr
- Temp change rate < 1 °C/min
- Vacuum → 1e-5 mbar

TNO test facility for thermal cycling

Performance Test Facilities

- TVC for performance testing completely qualified and commissioned
- Facility already successfully used for ESA's GAIA project

TNO TVC for performance test campaign



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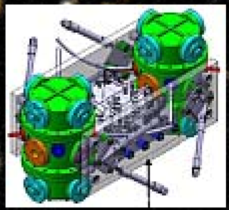
Time Schedule

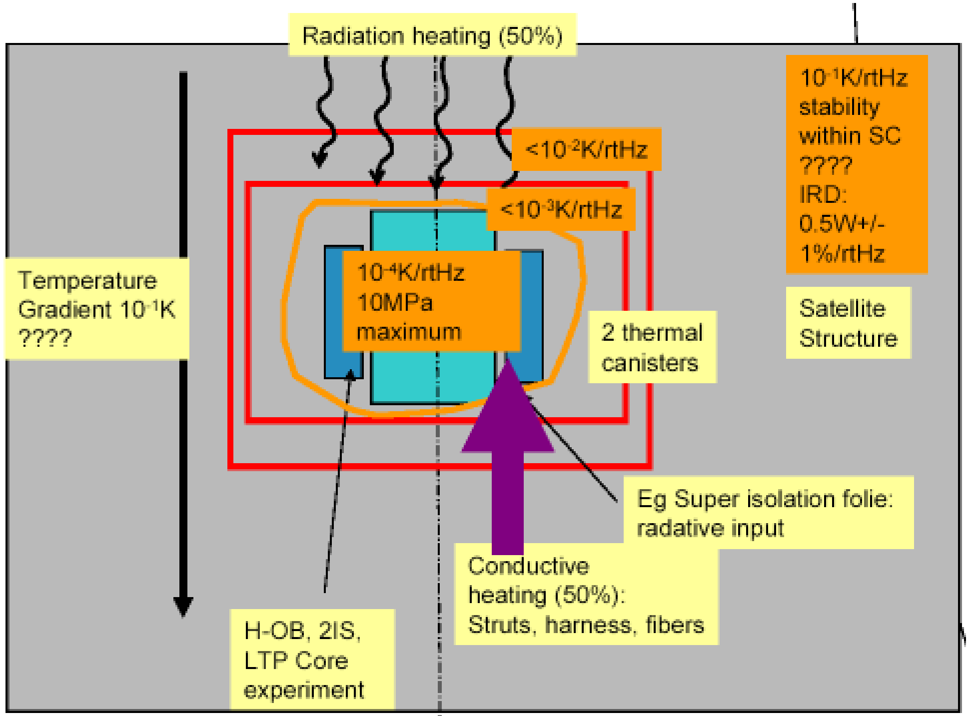
- **Optical bench activity:**
  - Delivery integrated EM OB to TNO February 18th
  - Finish Performance test campaign March 31st
  - Finish of OB activity April 26nd

- **LTP implementation Phase**
  - **Kick off → Beginning 2004**
  - **PDR → August 2004**
  - **CDR → August 2005**
  - **TRR → January 2006**
  - **FAR → June 2006**



End of presentation

Thermal I/F to S/C



LISA TECHNOLOGY PACKAGE

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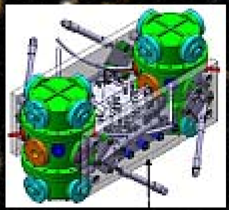
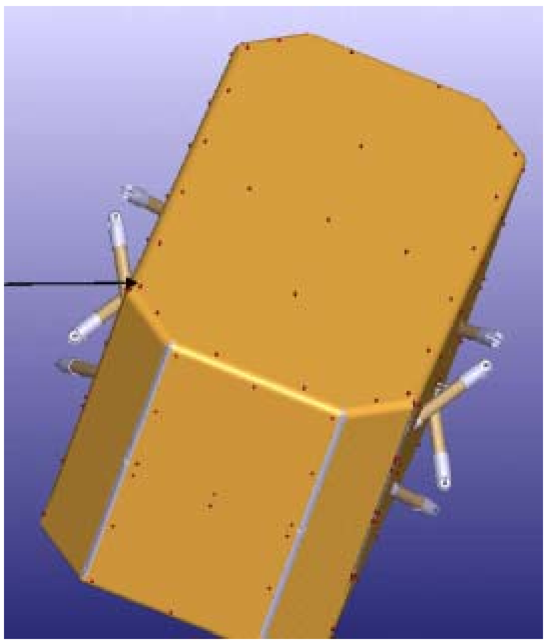
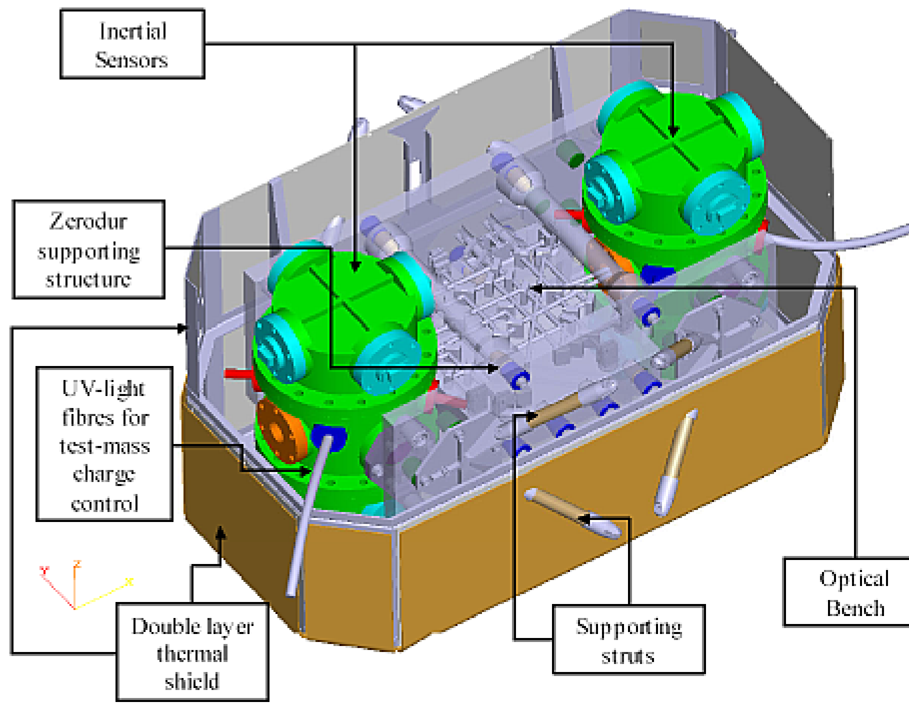


LISA TECHNOLOGY PACKAGE

Thermal shield FM

- Needed thermal stability $< 10^{-4}$ K/$\sqrt{\text{Hz}}$





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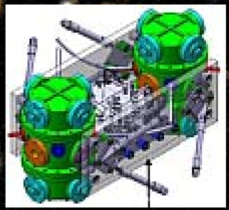

Modes of inertial sensor operation

- S/C follows one of the test masses. The other one is left freely floating
- Second test mass is controlled in only a few of its DOF
- S/C folows a linear combination of both test mass positions.