LISA and LISA PATHFINDER

at the

5th International LISA Symposium

11-16 July 2004, ESTEC, Noordwijk, NL

Karsten Danzmann

Max Planck Institute for Gravitational Physics
(Albert Einstein Institute) and University Hannover

on behalf of the LISA Science Team

Opening talk 4th LISA Symposium 2002:

- LISA as we know it was proposed in 1993
- LISA launch is now consistently quoted as 2011
- Today, 2002, we are half-way there

$\Rightarrow$ Time for reflection

$\Rightarrow$ Time for visions into the future

Half-time between Proposal and Launch!

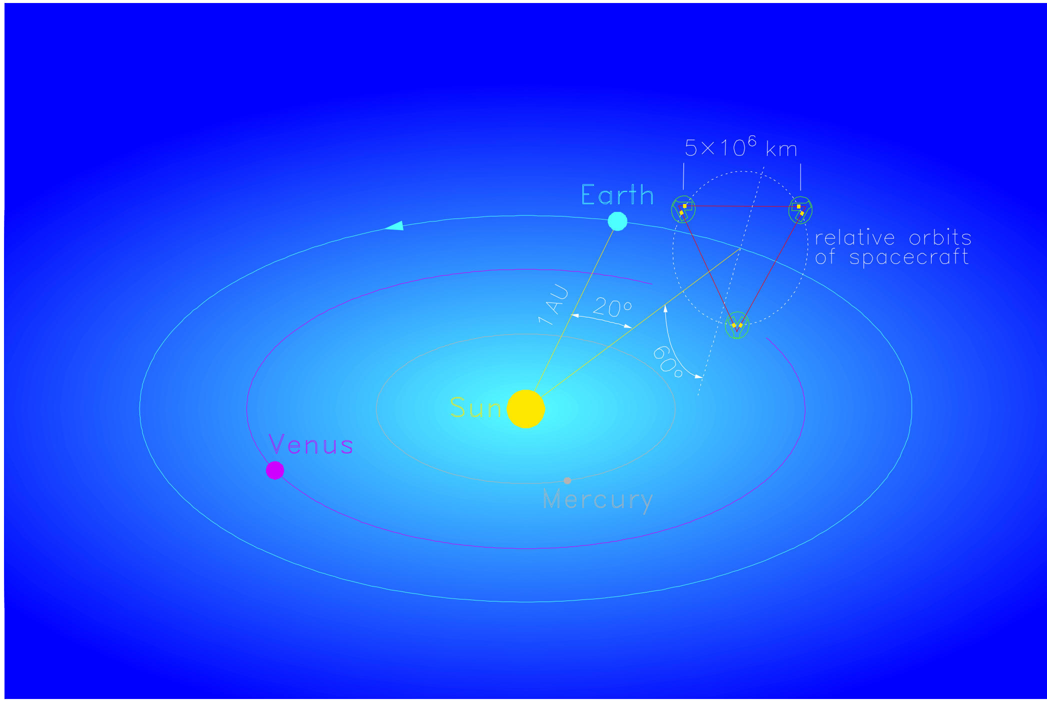
Halbzeit!

LISA in 2004: Getting Real!

- **LISA Mission Formulation Phase beginning Fall 2004**
- **ESA Contractor selected**
- **Joint NASA/ESA Management Structure in place**
- **Joint NASA/ESA Integrated Technical Teams (ITTs) in place**
  - Interferometry Measurement System (IMS)
  - Disturbance Reduction system (DRS)
  - Constellation
- **LISA Pathfinder (LPF) Technology Mission approved by ESA SPC in November 2003**
- **LPF Mission Industrial Contract in place**
- **NASA DRS and ESA LTP P/Ls on track for launch 2008**

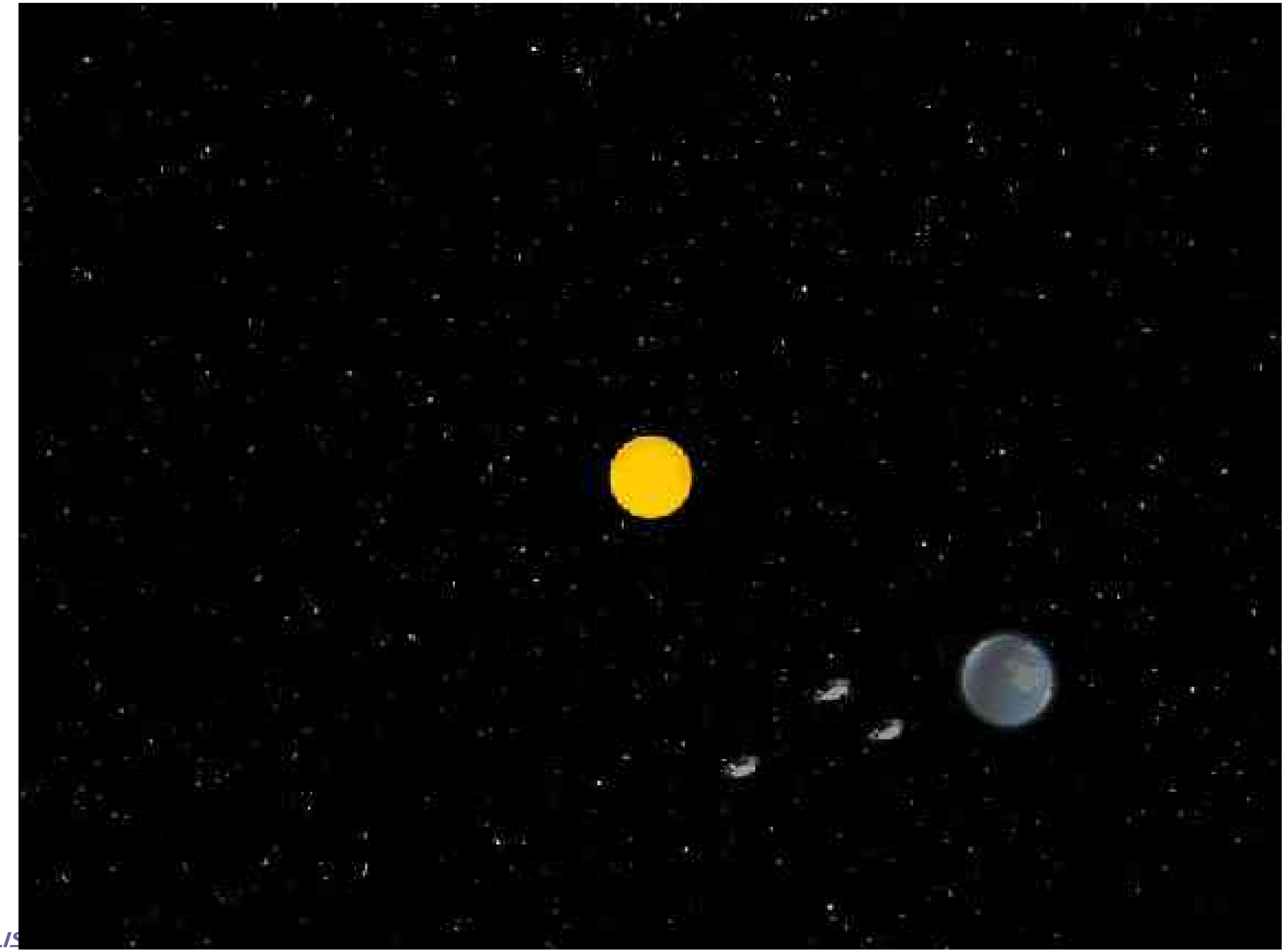
A Collaborative ESA/NASA Mission

- Cluster of 3 S/C in heliocentric orbit
- Free flying test masses shielded inside the S/C
- Trailing the earth by 20 ° (50 Mio km)

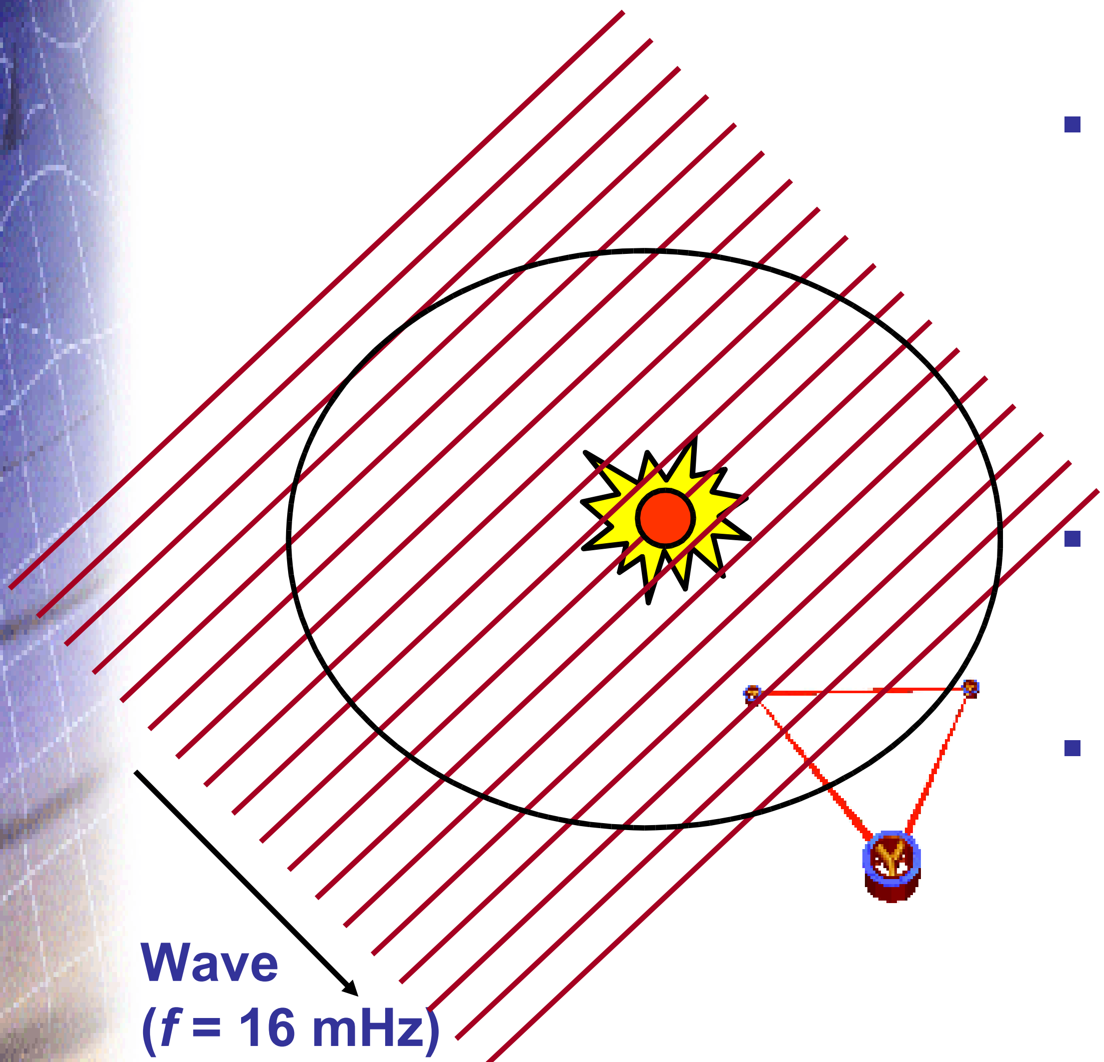


- Equilateral triangle with 5 Mio km arms
- Inclined against ecliptic by 60 °

LISA Orbital Motion



Angular Resolution with LISA



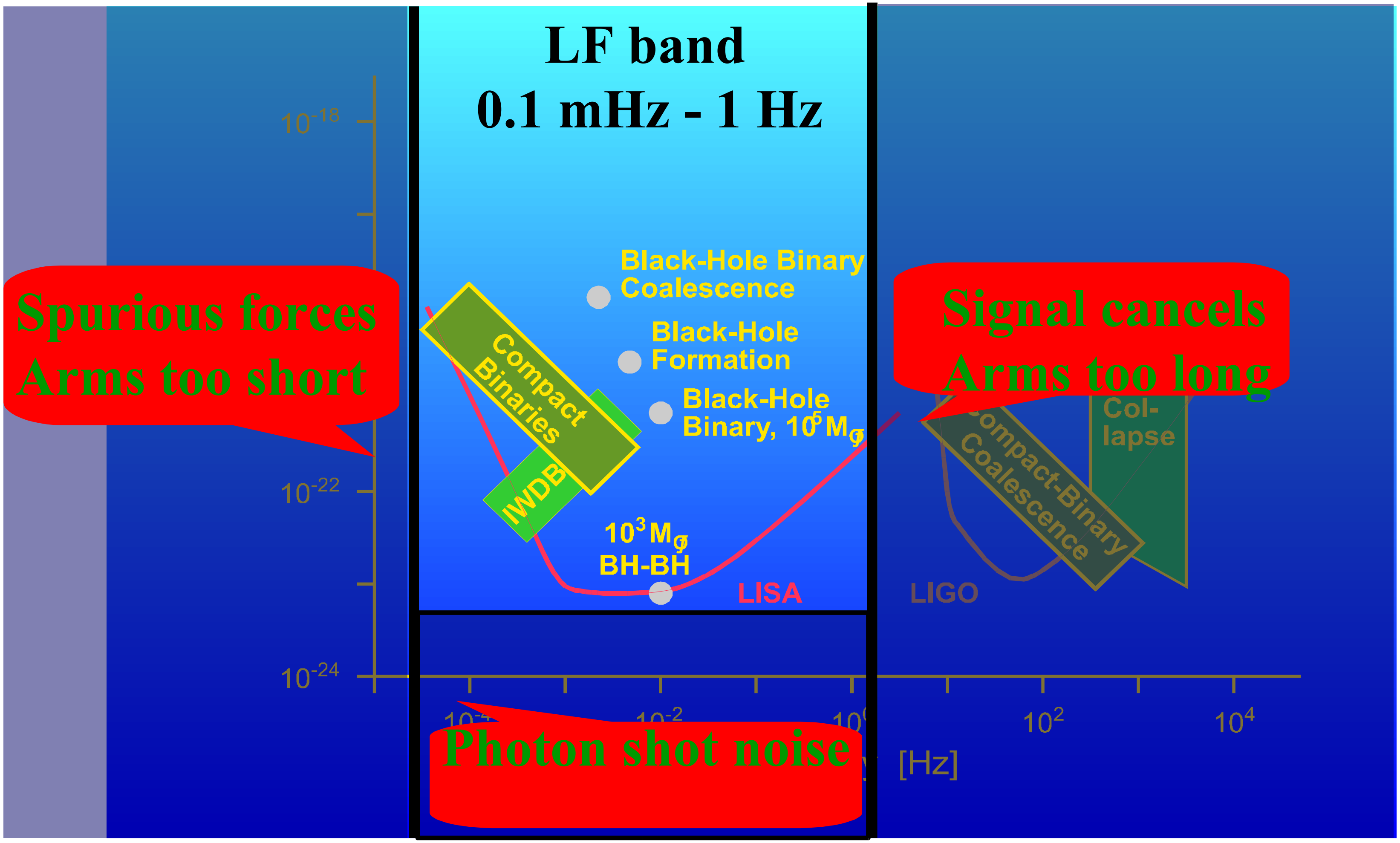
- Using phase modulation due to orbital motion is equivalent to ***Aperture Synthesis*** (like in Radio-Astronomy)
- Gives diffraction limit

  $\Delta\theta = \lambda / 1$ AU
- Measurements on detected sources:

  - $\Delta\theta \sim 1' - 1^{o}$

  - $\Delta(\text{mass,distance}) \leq 1\%$

Why are LISA's Arms 5 Mio km Long?



Why are LISA‘s Arms 5 Mio km long?

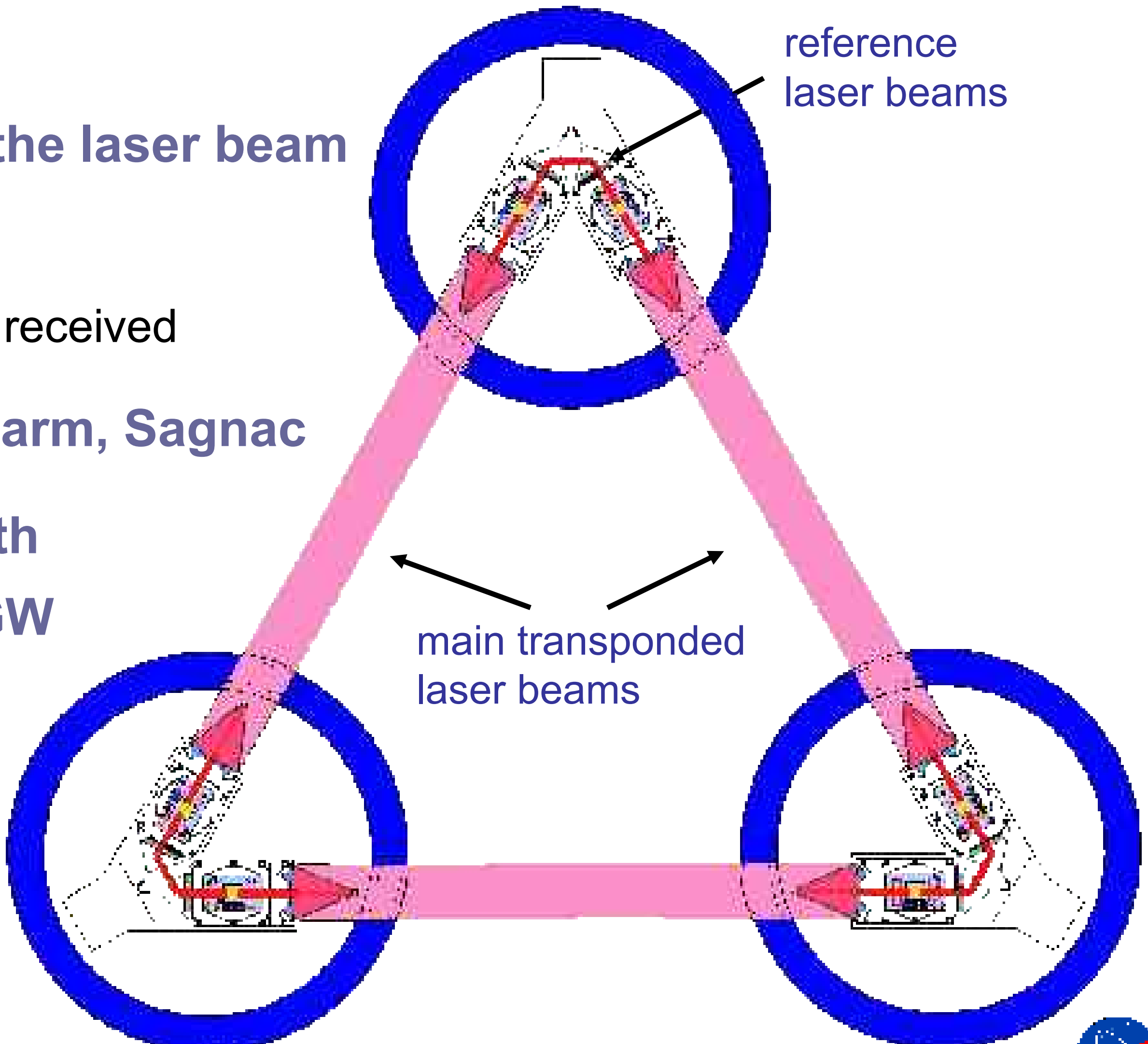
- **Bottom of sensitivity curve only depends on laser power and telescope diameter**
- **Shorter arms lose the low frequencies (>10^7 $M_\odot$ BHs)**
- **Longer arms lose the high frequencies (< 10^3 $M_\odot$ BHs)**
  - 5 Mio km is a compromise!

Draft LISA Science Requirements:

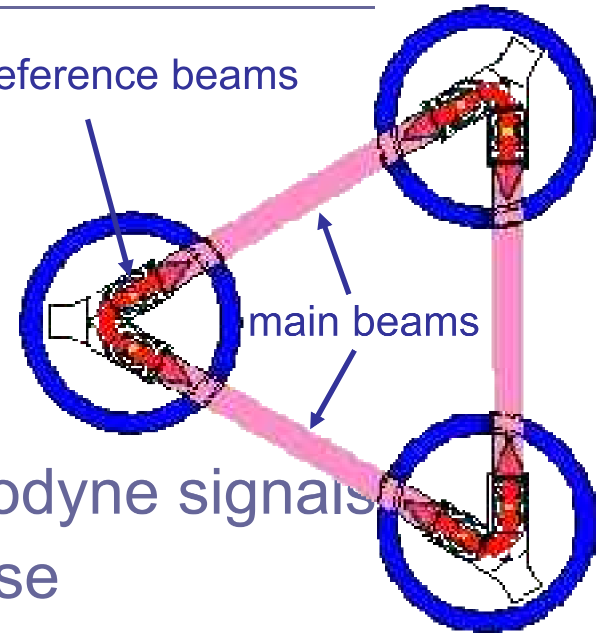
- **Gravitational capture of compact objects by supermassive BHs**
  - Most challenging requirement and goal
  - Also one of the highest-priority LISA science objectives
- **Merging supermassive BHs**
  - Typically high-signal to noise, but sets goal and requirement at 10^{-4} Hz (in order to get accurate distance and other parameters for 10^6 M_{sol} BHs)
- **High-Z intermediate mass seed BHs**
  - 10^3-10^5 M_{sol} BHs at z = 7 - 30
  - Somewhat speculative, but highly interesting for probing protogalaxies
- **Cosmic backgrounds/bursts**
  - Standard slow-roll inflation not detectable
  - Explore as much phase space as possible, but no firm requirement

LISA layout

- Laser beams reflected off free-flying test masses
- Diffraction widens the laser beam to many kilometers
  - 0.7 W sent, 70 pW received
- Michelson with 3rd arm, Sagnac
- Can distinguish both polarizations of a GW
- Orbital motion provides direction information



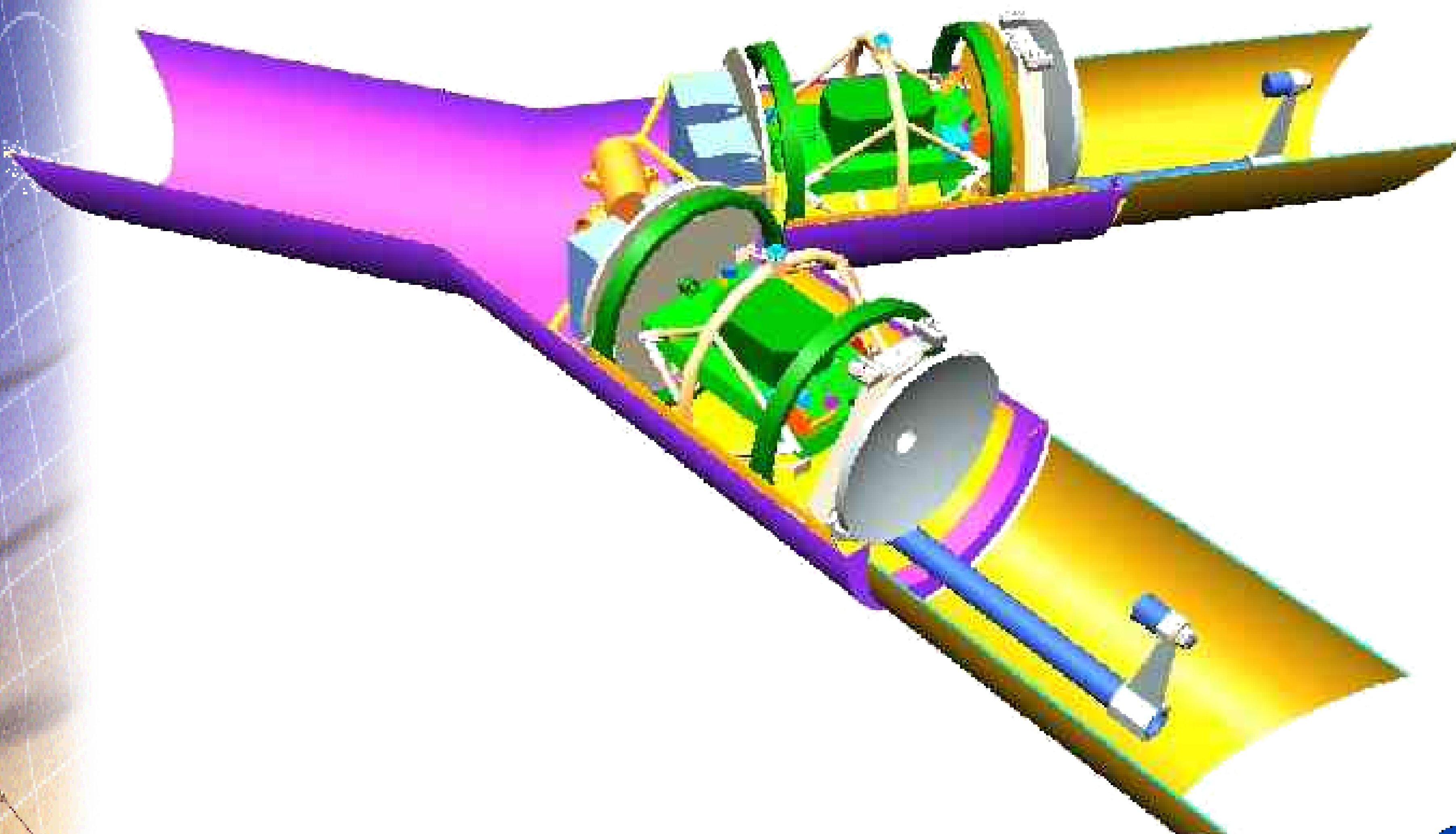
LISA Interferometry



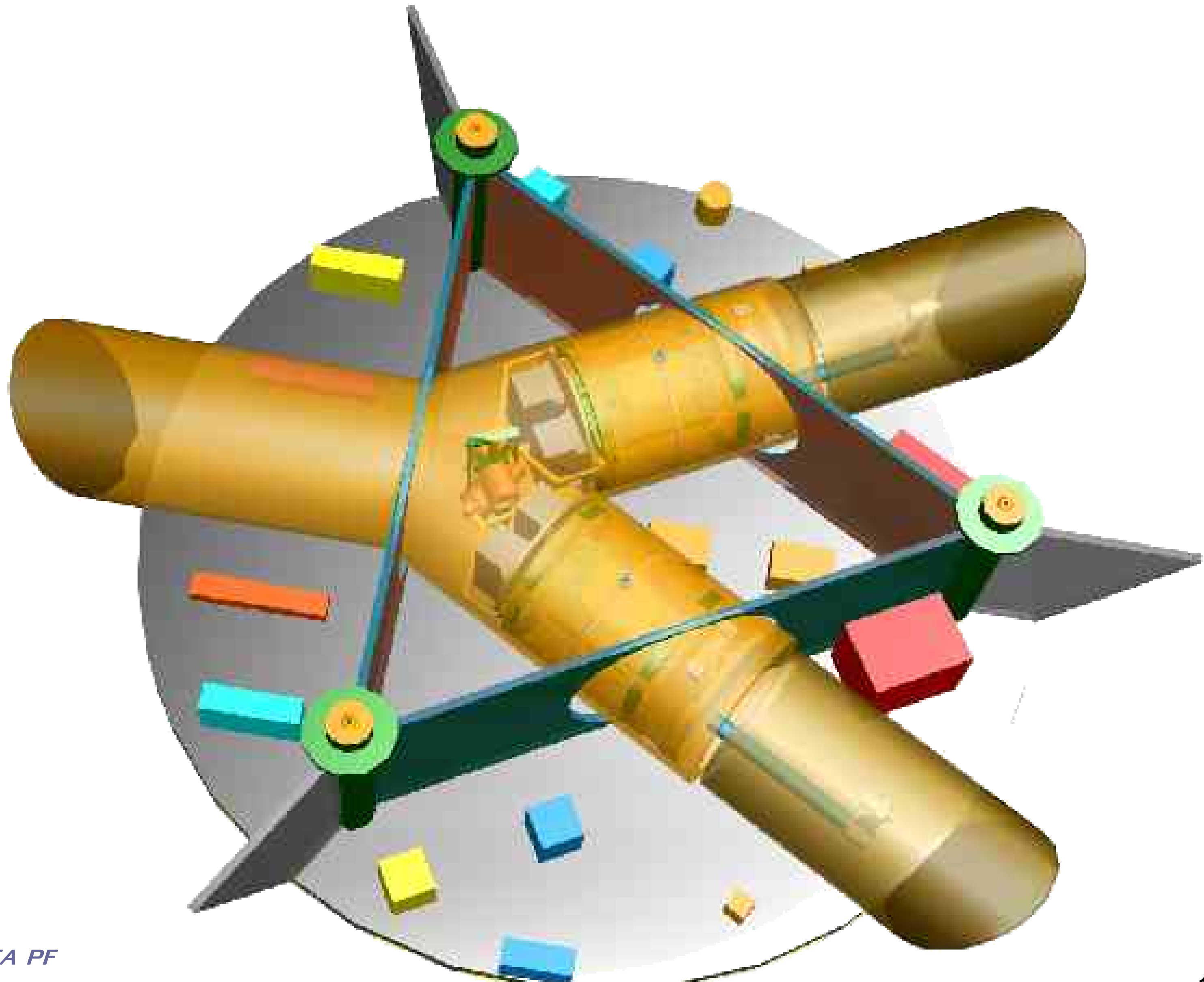
- Each beam (reference and main) is separately heterodyned with the local laser on a photodiode
- *Time-delay Interferometry:*
- Specific linear combinations of heterodyne signals in time domain cancel laser/USO noise and keep GW signal
- One linear combination cancels the GW signal and laser/USO noise

⇒ **LISA can distinguish a stochastic gravitational wave background from instrumental noise background!**

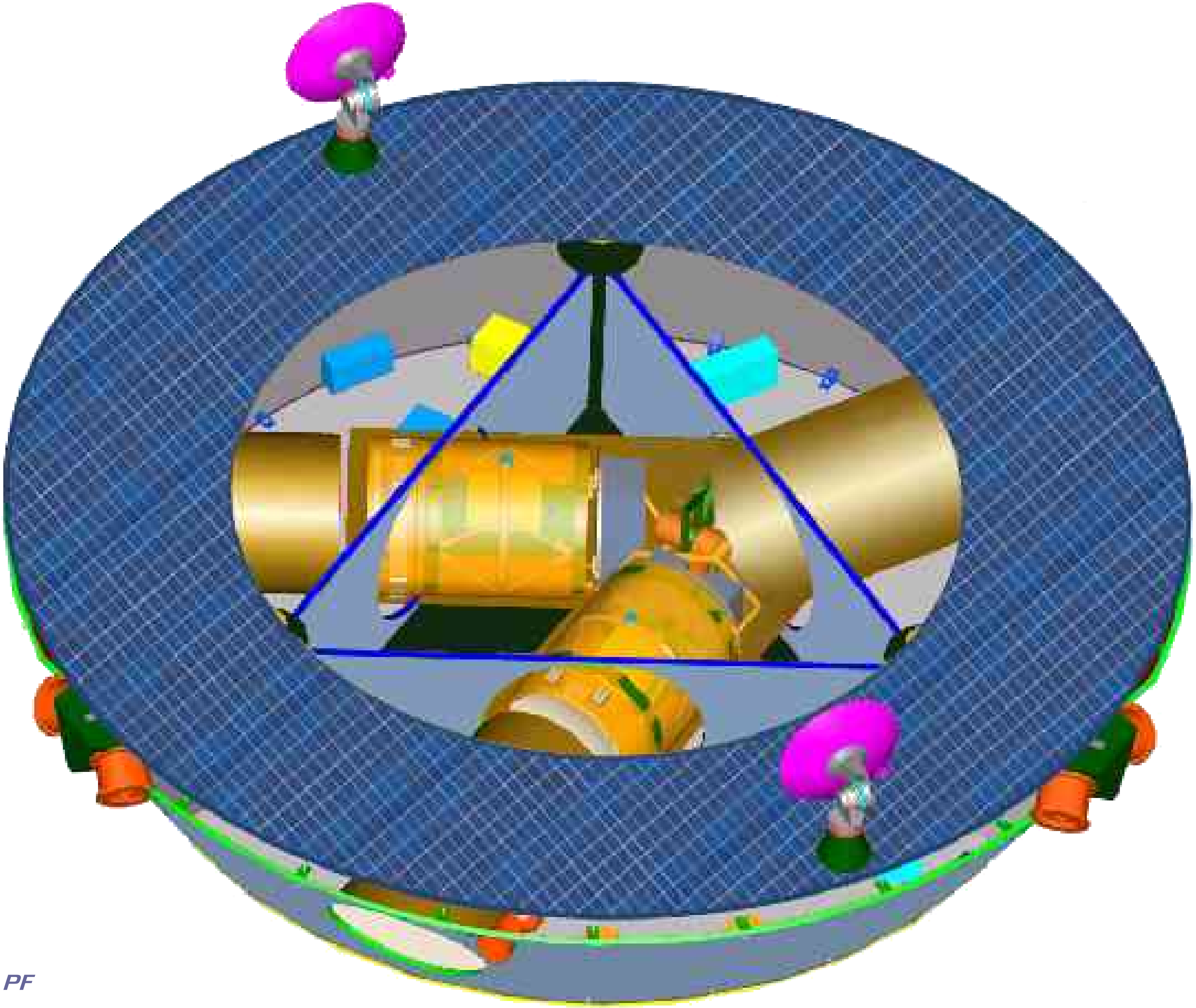
Spacecraft Layout



Spacecraft Layout

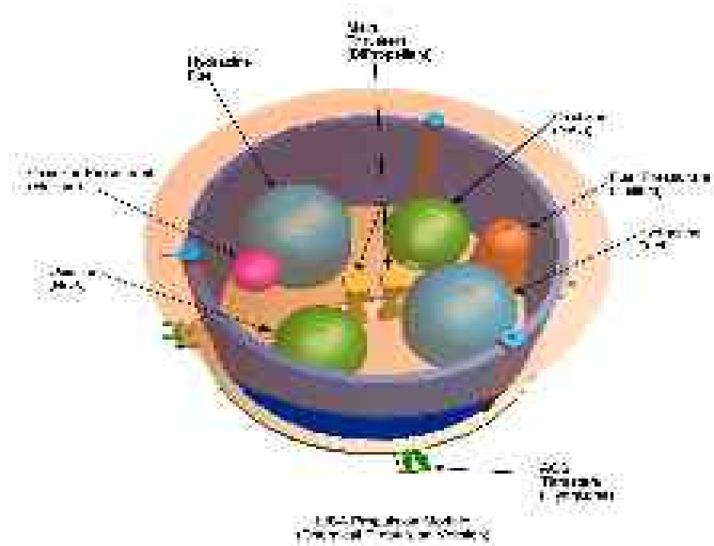


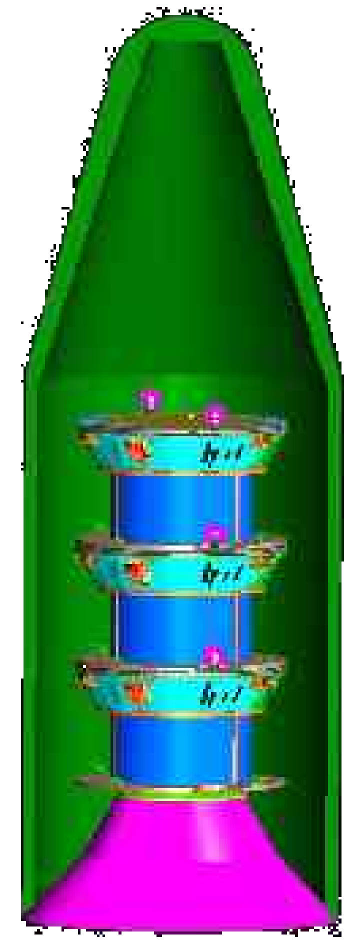
Spacecraft Layout



LISA Launch and Cruise

- **Delta IV medium launches all three spacecraft**
- **Each spacecraft is attached to its own propulsion module**
  - Propulsion Module ΔV = 1.22 km/sec
  - Propulsion module incorporates a bipropellent (N_2O_4 / hydrazine) system and a Reaction Control System for attitude control
- **13 month cruise phase**





LISA needs the perfect Free Fall

10^{-12}

$$\sqrt{S_F}\left(\frac{N}{\sqrt{Hz}}\right)$$

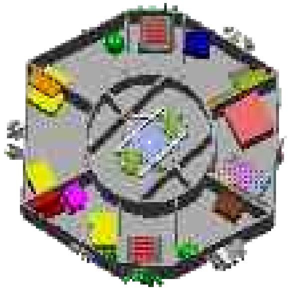
Spurious Force

10^{-13}

10^{-14}

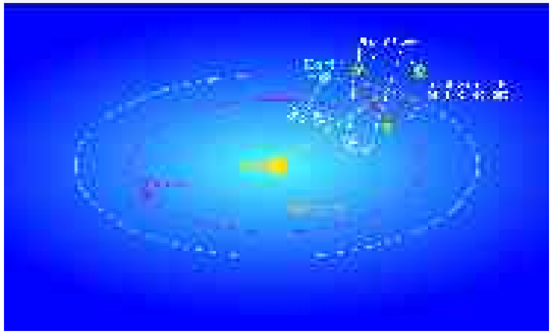
10^{-15}

Torsion pendulum



Flight test

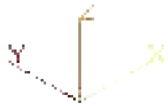
LISA



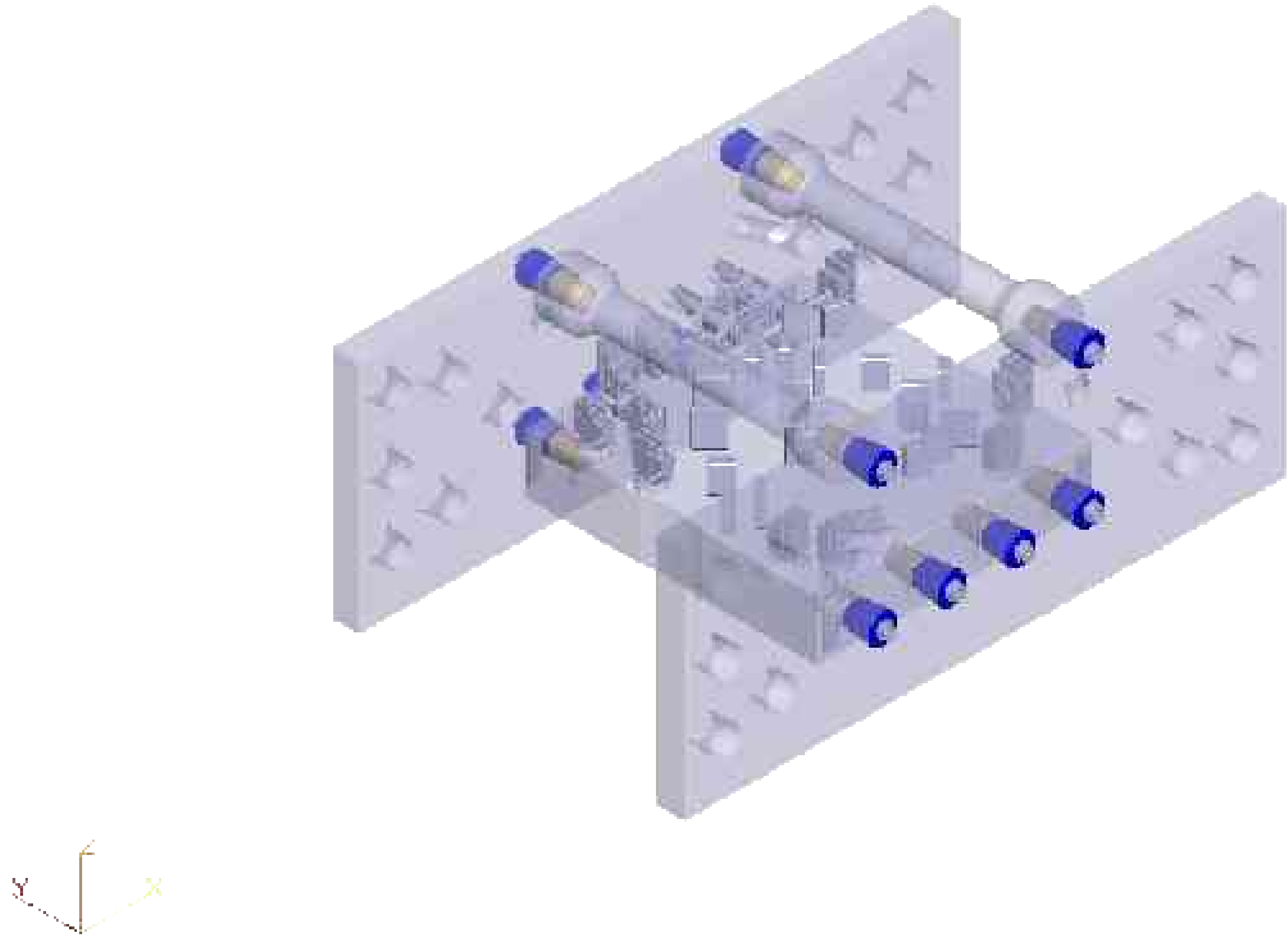
Testing Technology in Space: LISA Pathfinder (SMART-2) Mission

- Risk mitigation for LISA
- Technology demonstration for
  ESA LISA Technology Package (LTP)
- NASA contribution of Disturbance Reduction System (DRS)
- 1 S/C testing drag-free operation, perfect free fall of 2 test masses, interferometric readout,
- Cs-FEEPS, Colloid, Cold-Gas and Chemical propulsion
- Launch in 2008

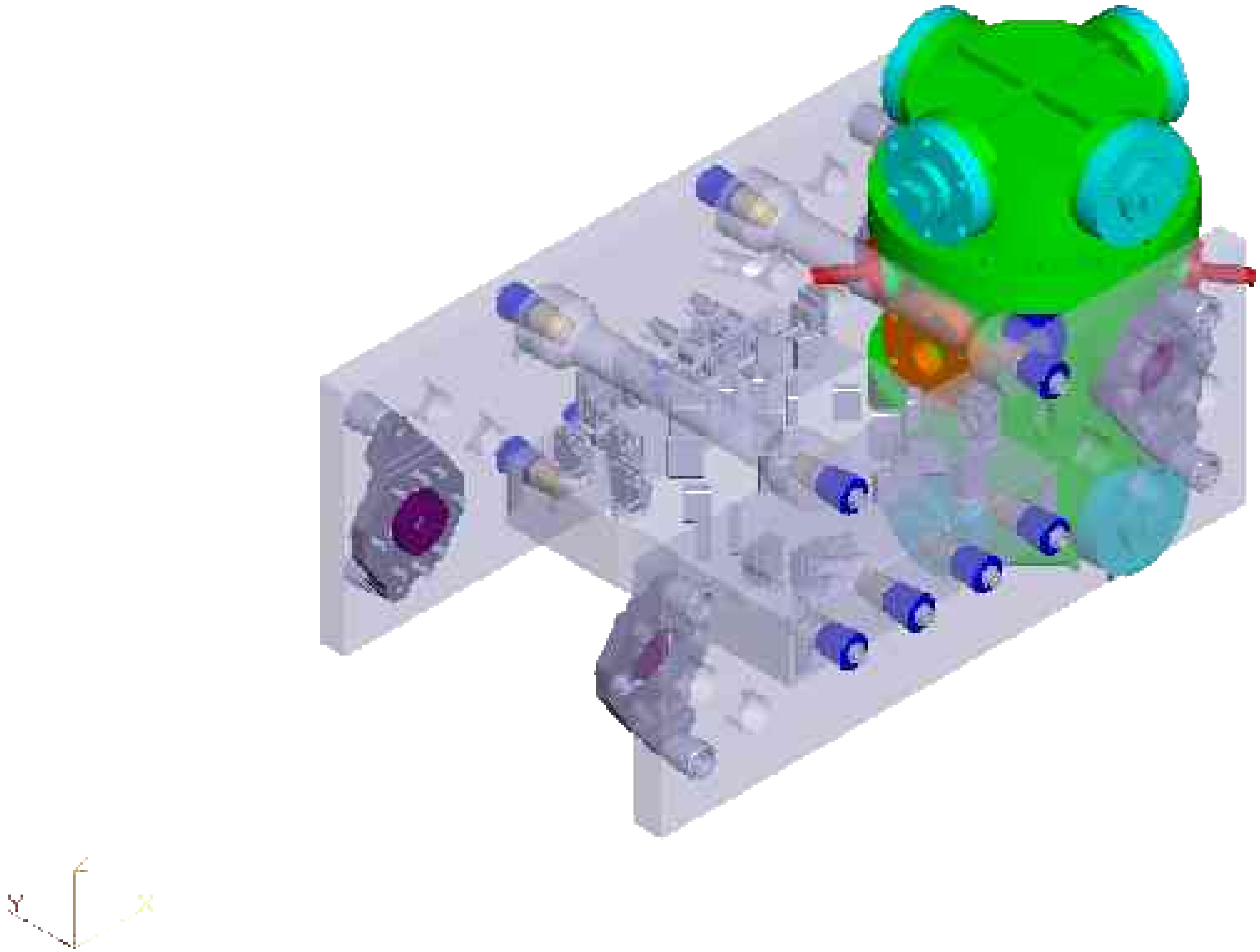
The LTP



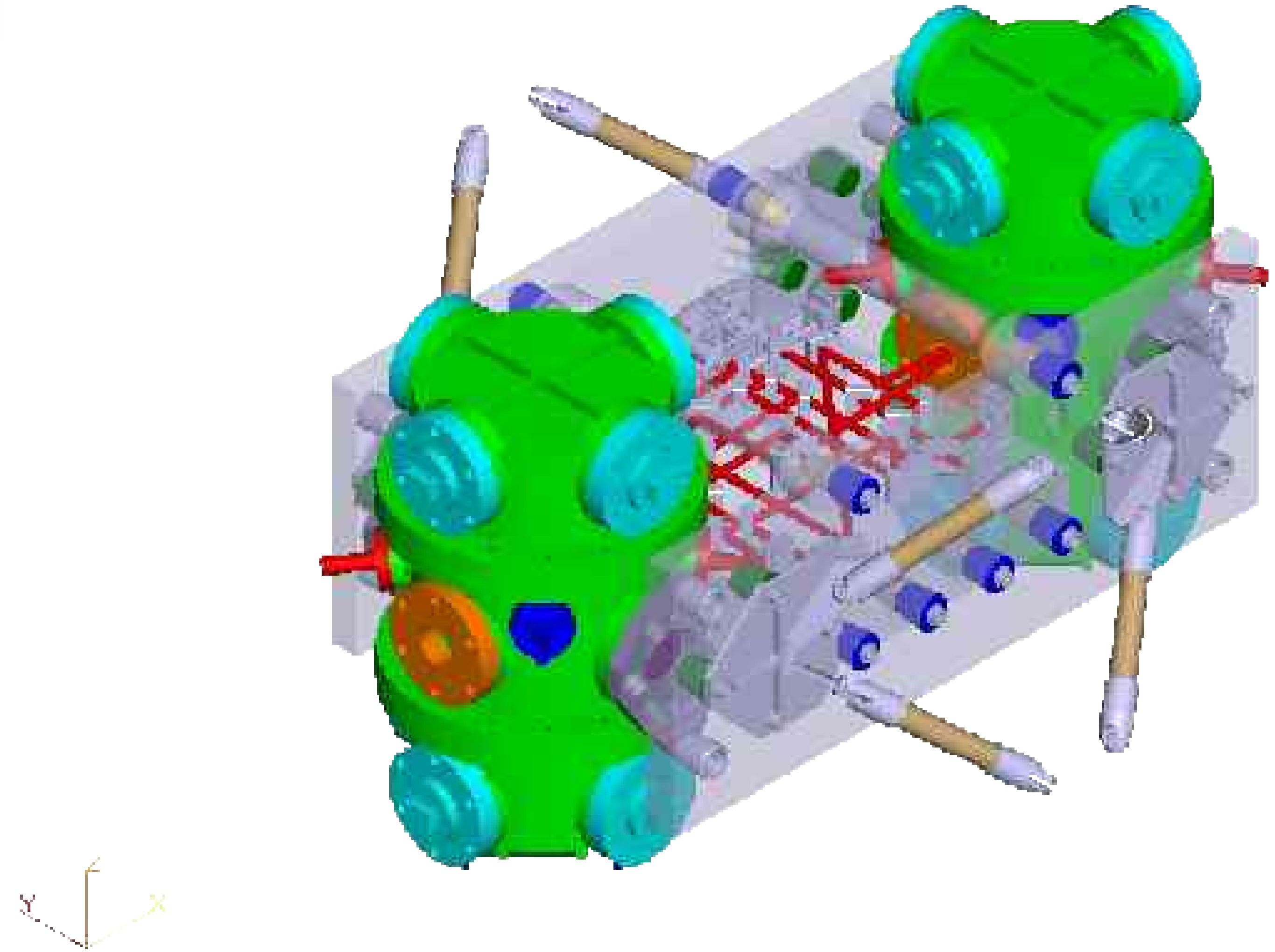
The LTP



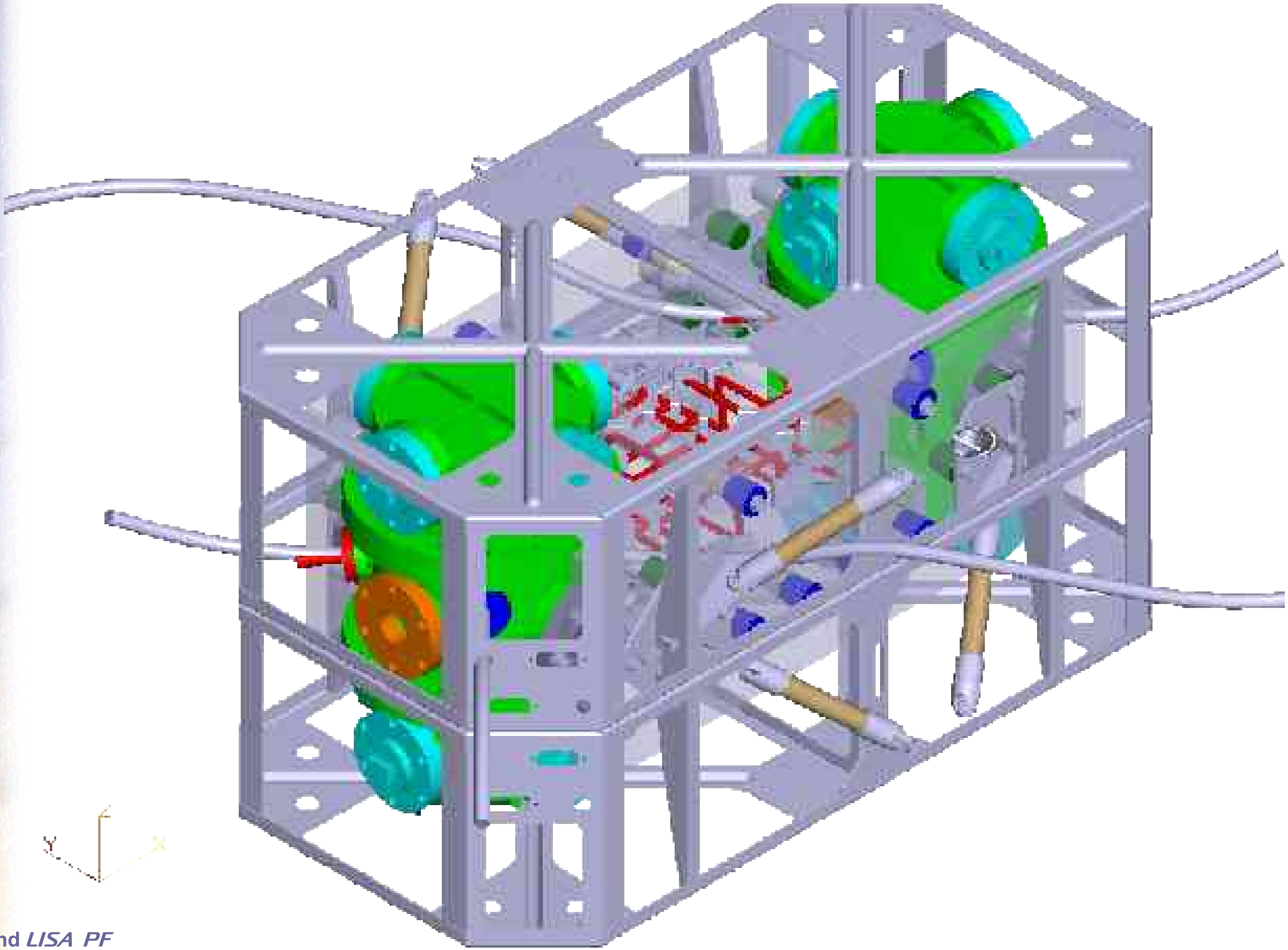
The LTP



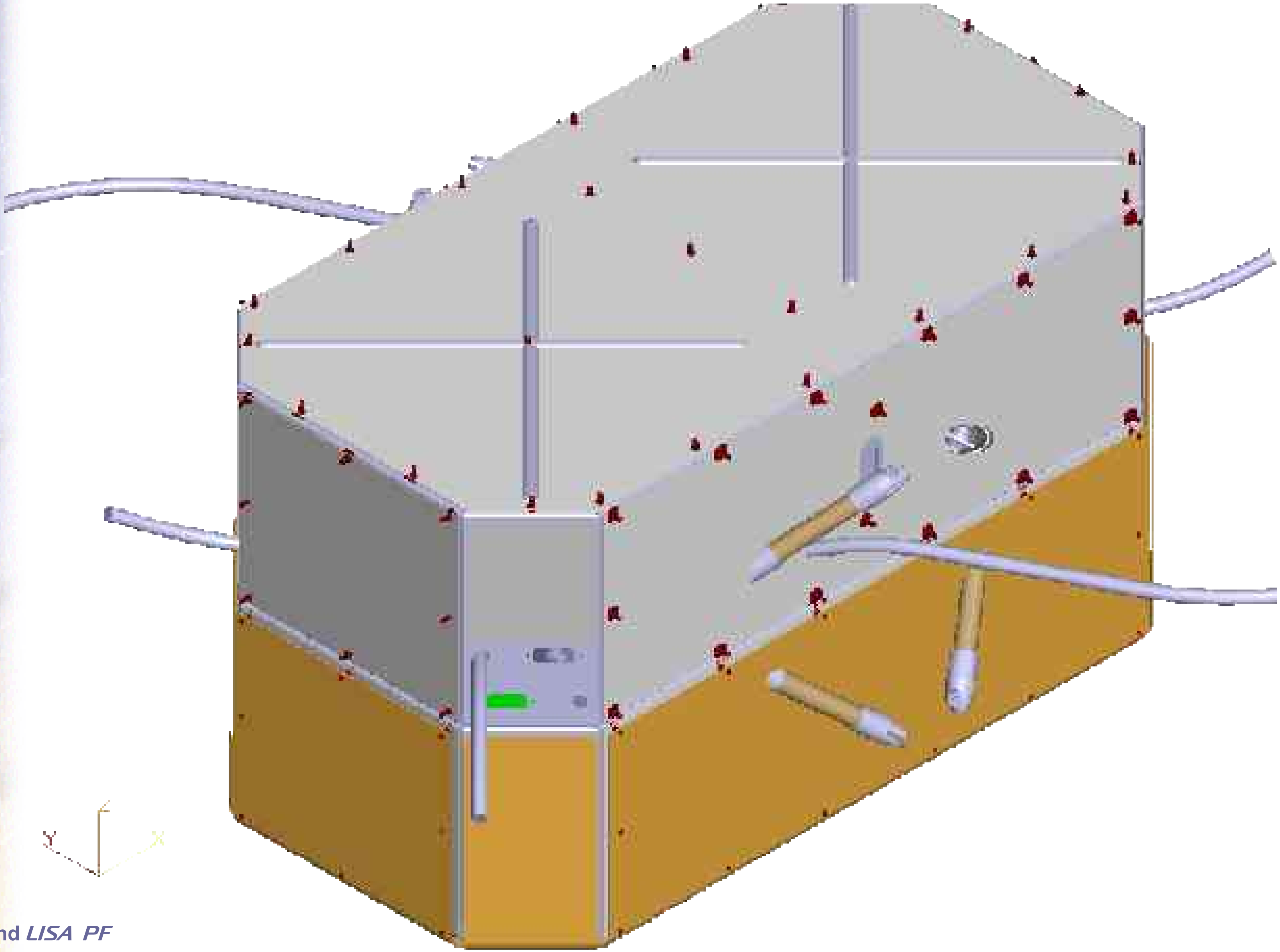
The LTP



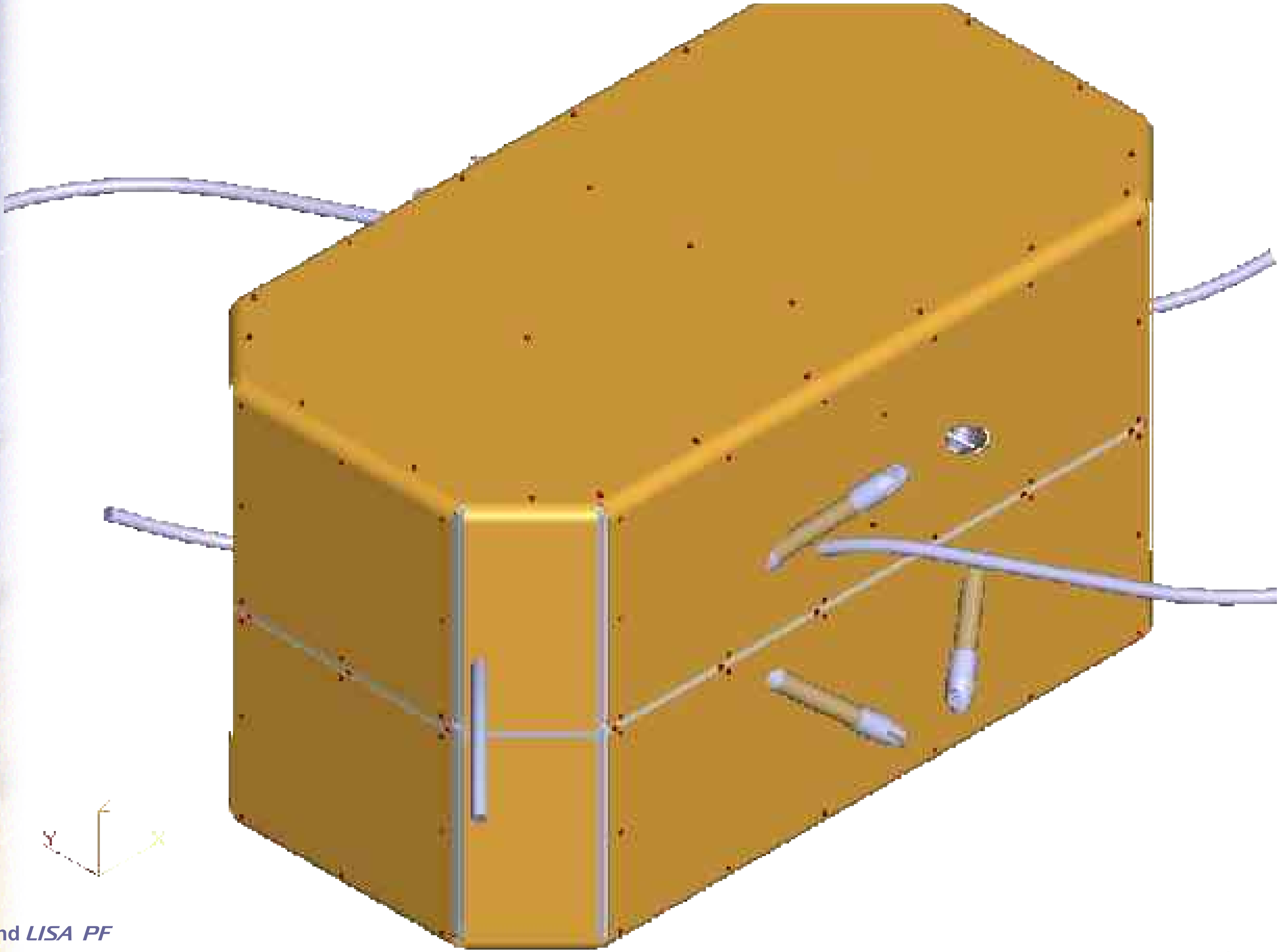
The LTP

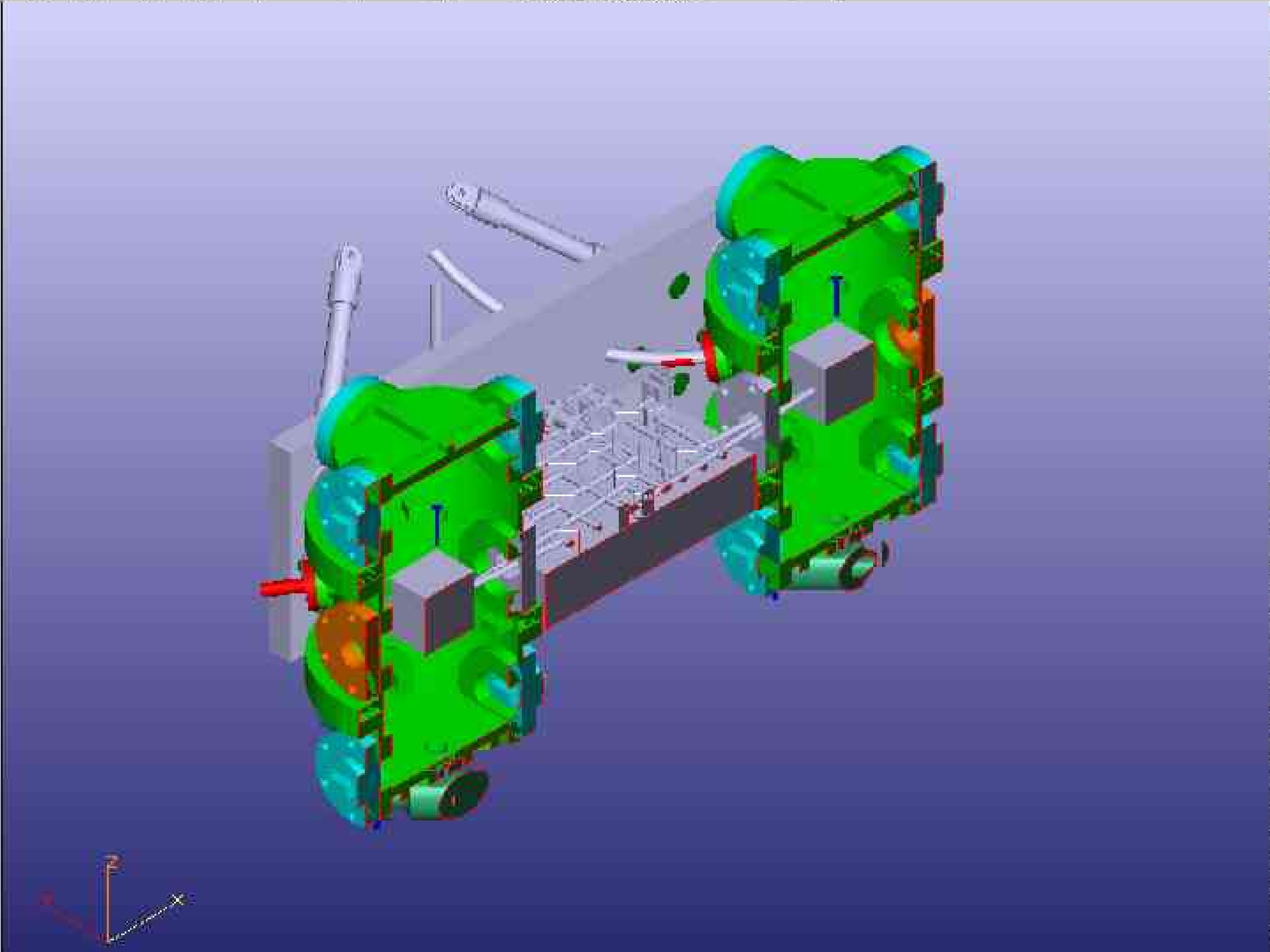


The LTP



The LTP



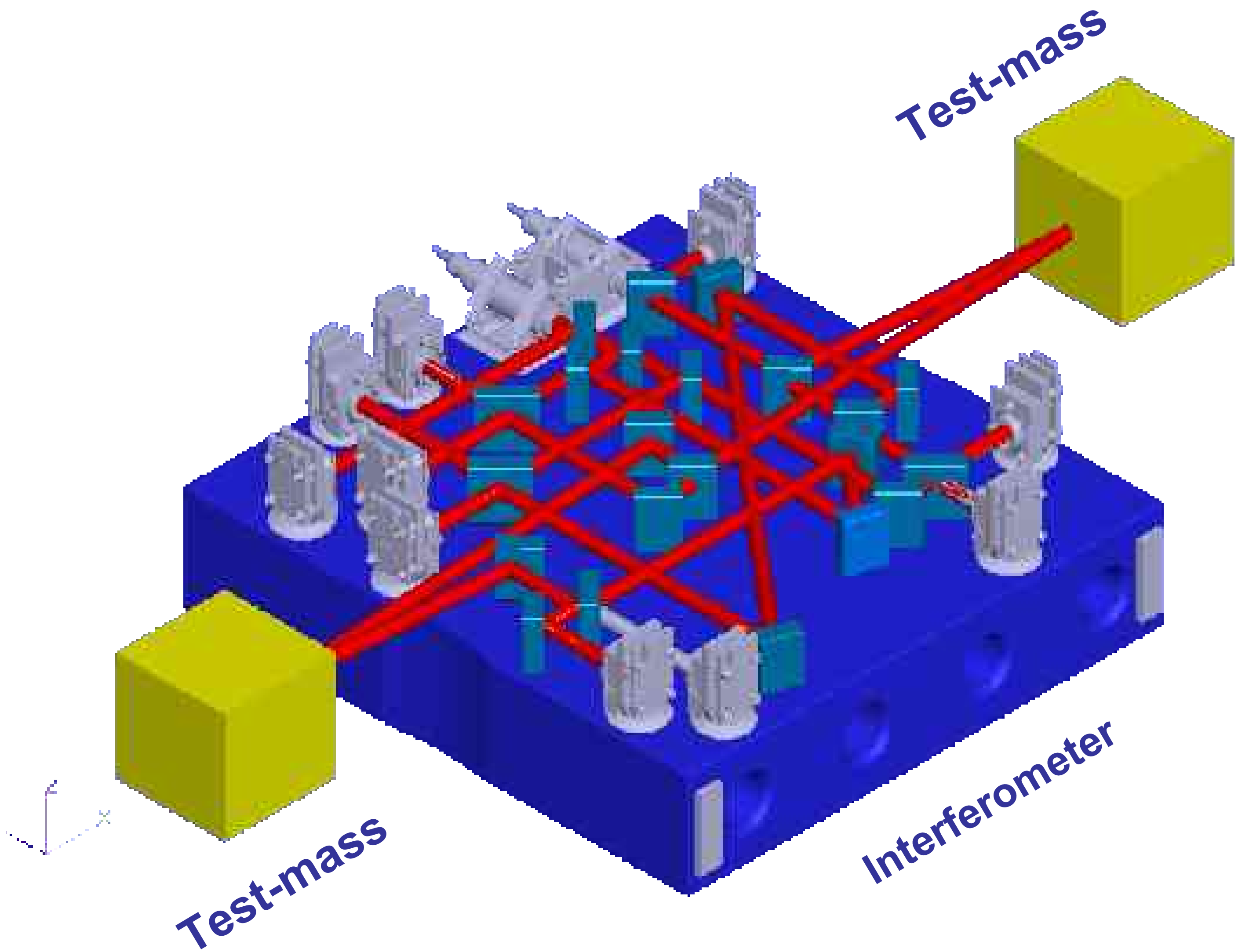


Z
X

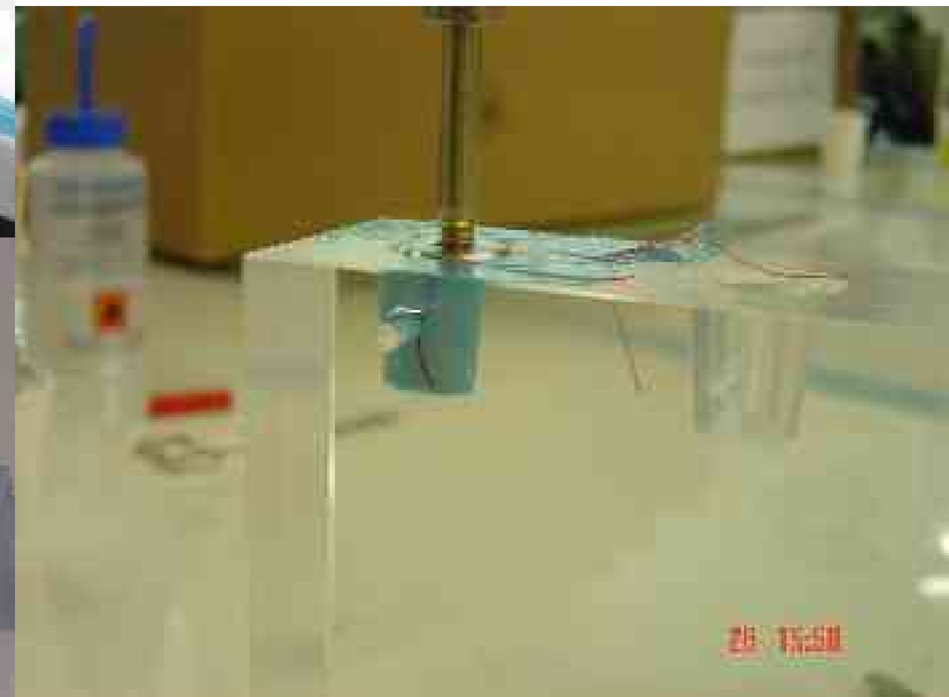
National Contributions to LPF

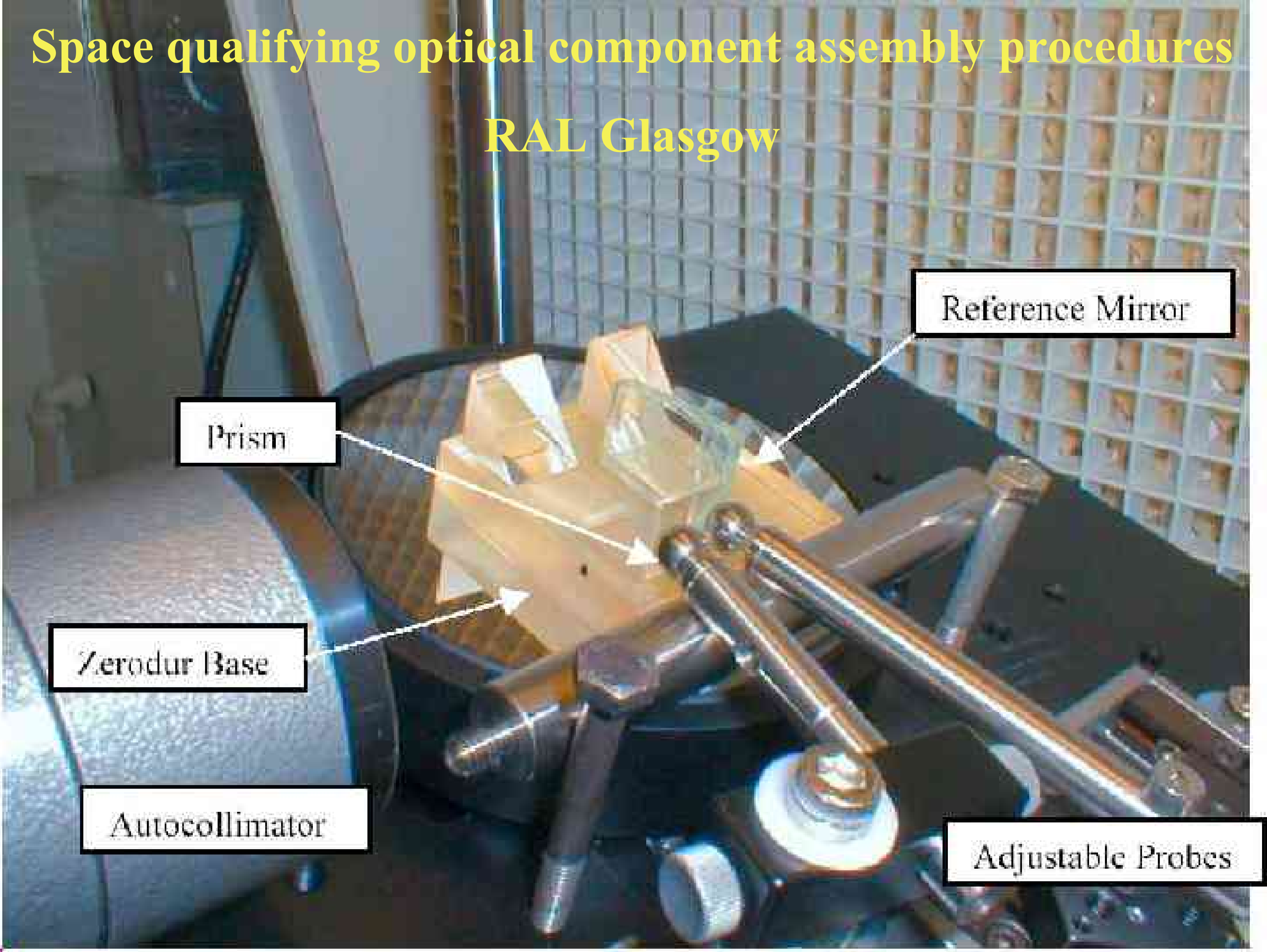
- **Industrial Architect and System Engineering**
  - Germany (Prime), Italy (Support)
- **Inertial Sensor**
  - Italy (Design, AIVT), Switzerland (Front End Electronics), UK (Charge Control), Open (Caging Mechanism)
- **Laser Assembly (Laser, AOM bench, stabilization algorithms)**
  - Germany (Design, Laser, AIVT), Open (F?) (AOMs)
- **Interferometry and Optical Bench**
  - Germany (Design and final AIVT), UK (Optics and OB pre-integration)
- **Phasemeter Front-End (Diodes, ADs, FPGAs, Algorithms)**
  - UK (FM and EM), Germany (Concept and Breadboard)
- **Data Management Unit (Processor, PM back end, environ monitor)**
  - Spain

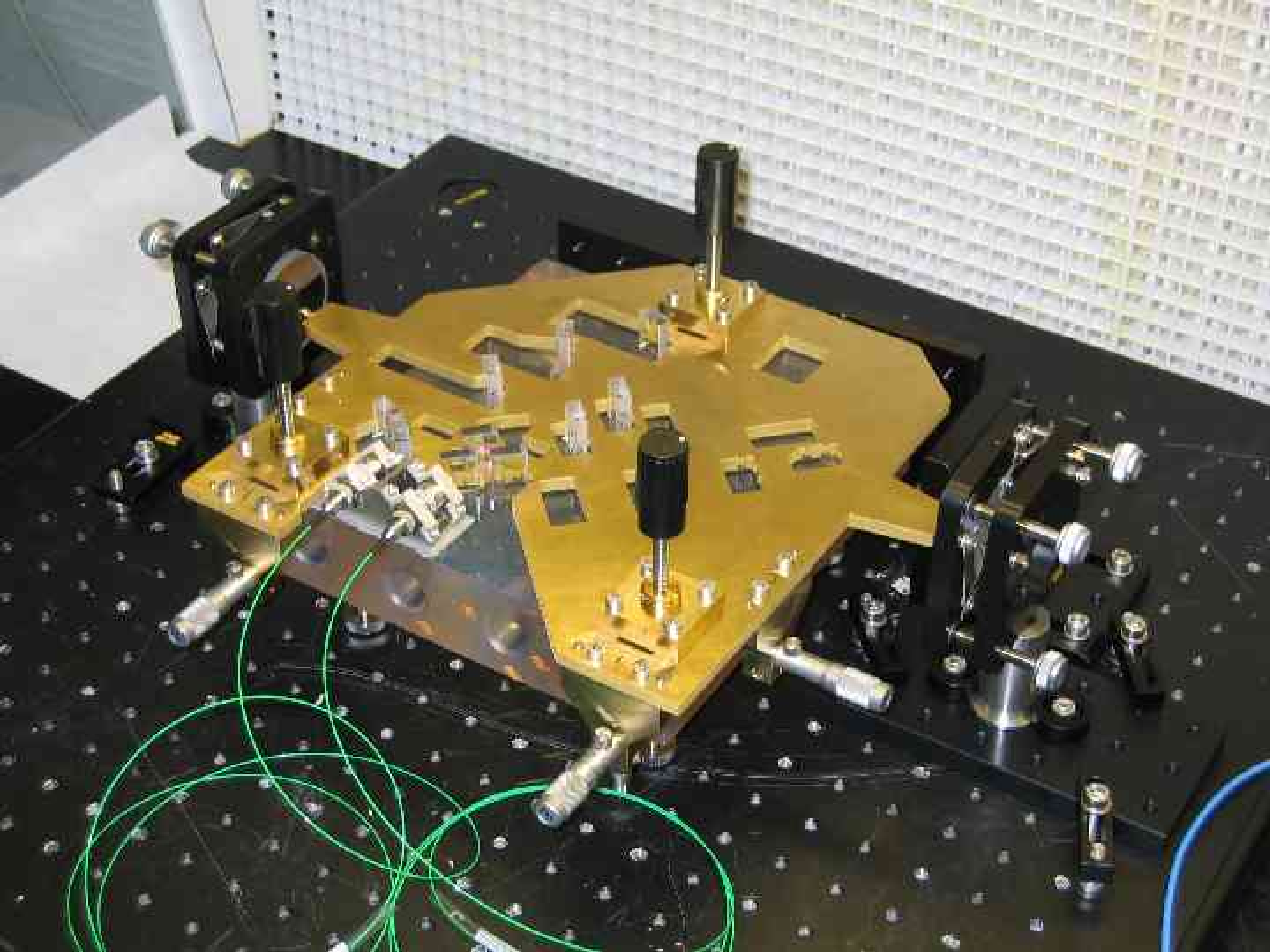
Optical Metrology



Assembly of Optical Bench at Astrium Friedrichshafen



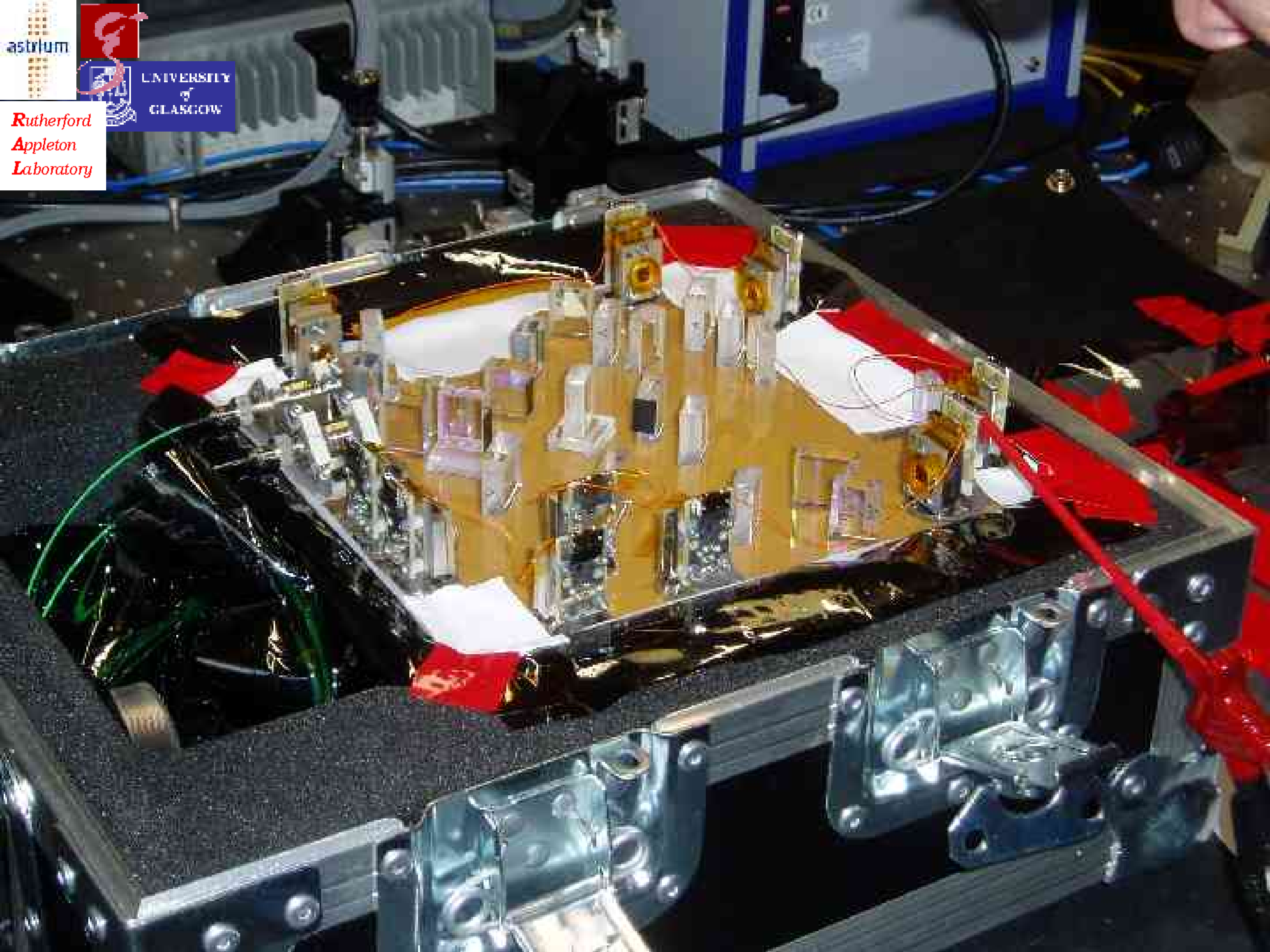

Space qualifying optical component assembly procedures
RAL Glasgow
Reference Mirror
Prism
Zerodur Base
Autocollimator
Adjustable Probes



astrium

UNIVERSITY of GLASGOW

Rutherford Appleton Laboratory

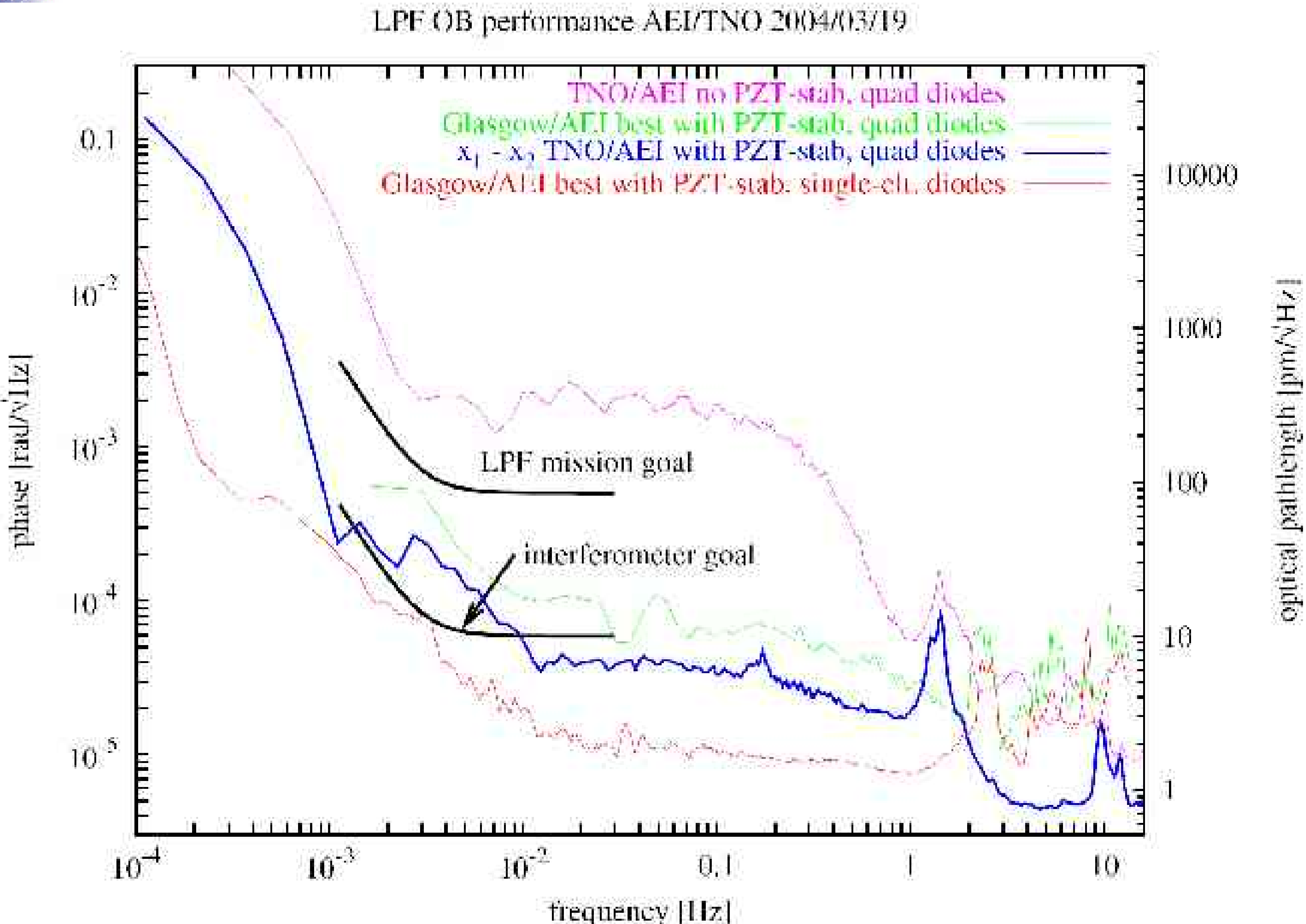


Assembly in Friedrichshafen

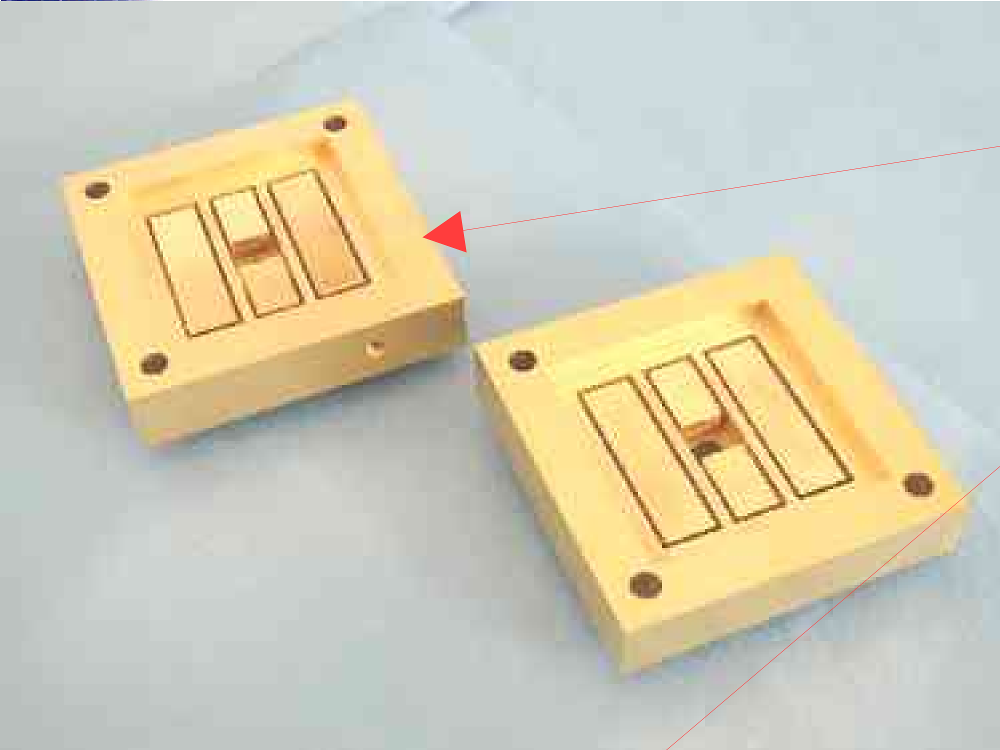
First tests in Friedrichshafen

Vibration test of Optical Bench

Optical Bench EM Performance



Test-Mass Capacitive Motion Sensor



Top and Bottom Lids

Central frame

Test Mass

Università degli Studi di Trento

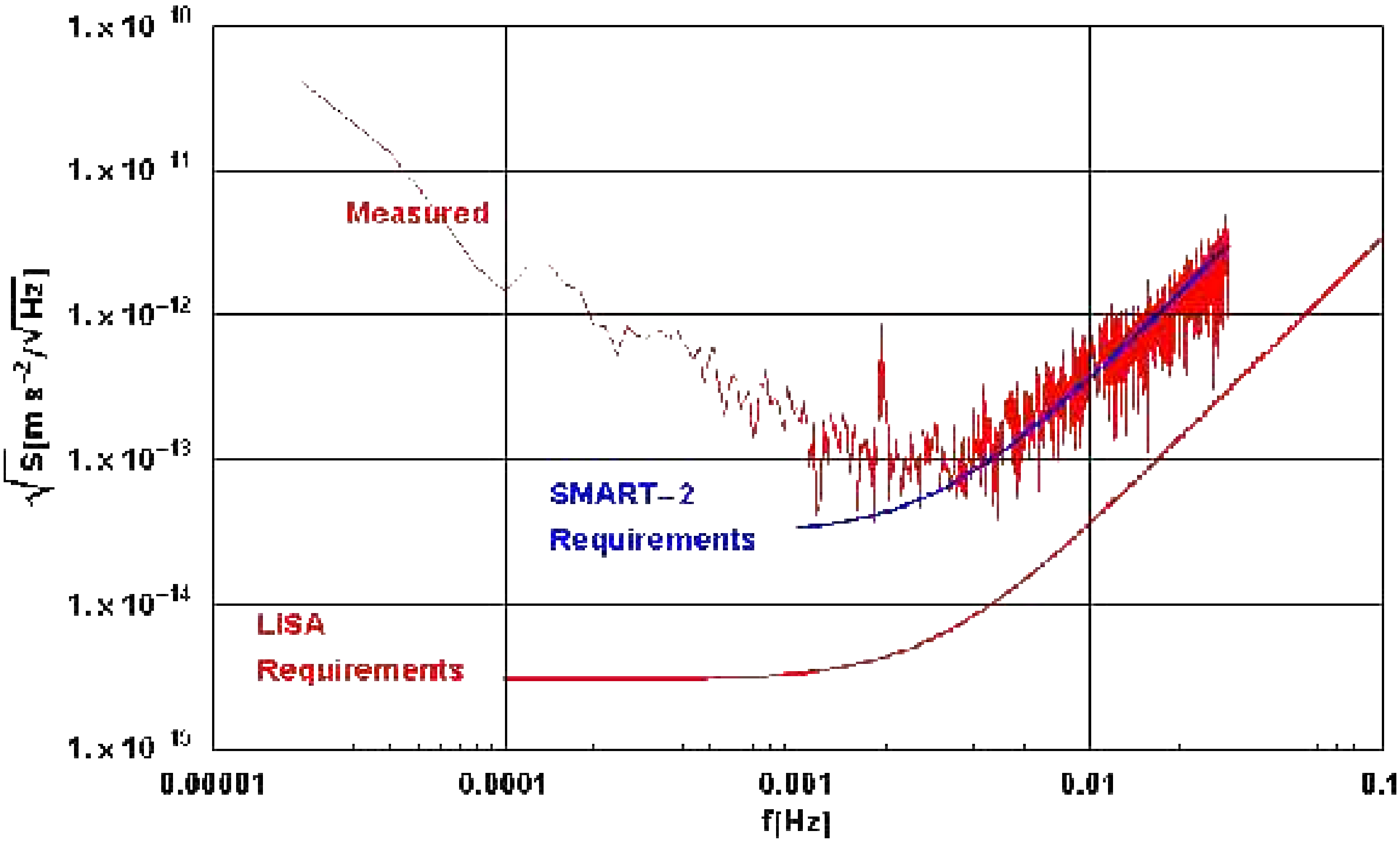
•**Major design features**

- ➢Large gaps because of patch fields
- ➢Minimize thermal gradients (metal instead of ULE)
- ➢Avoid DC actuation (AC used)

Ground testing of Inertial Sensor on Torsion Pendulum

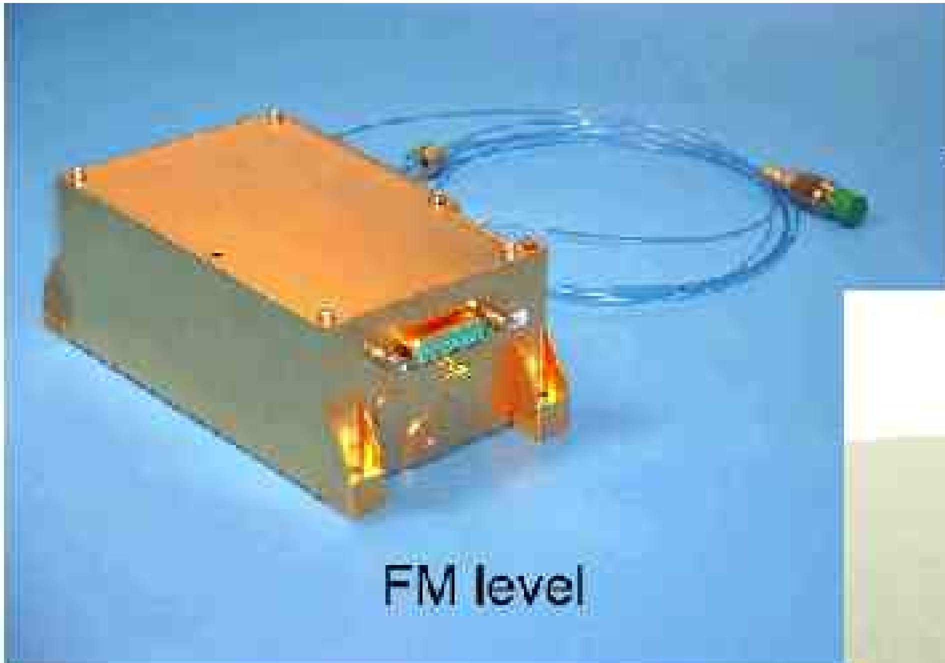
Ground Test of Inertial Sensor

only sensitive to most feared surface effects



http://xxx.lanl.gov/PS_cache/gr-qc/pdf/0307/0307008.pdf

Testing of LISA-PF Laser

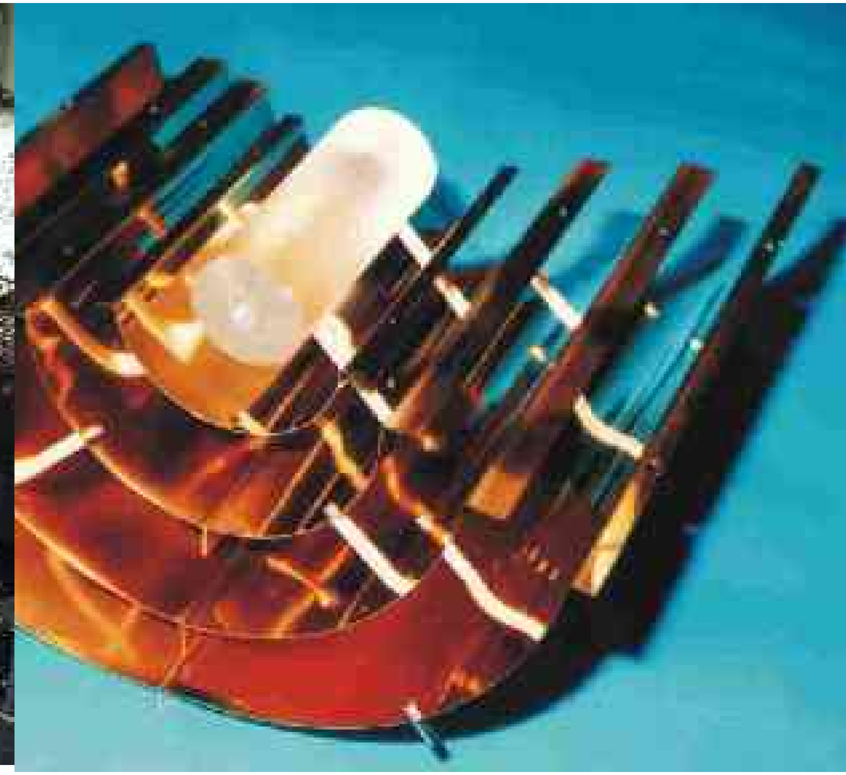


Laser assembly current status

Lab level with view to EM

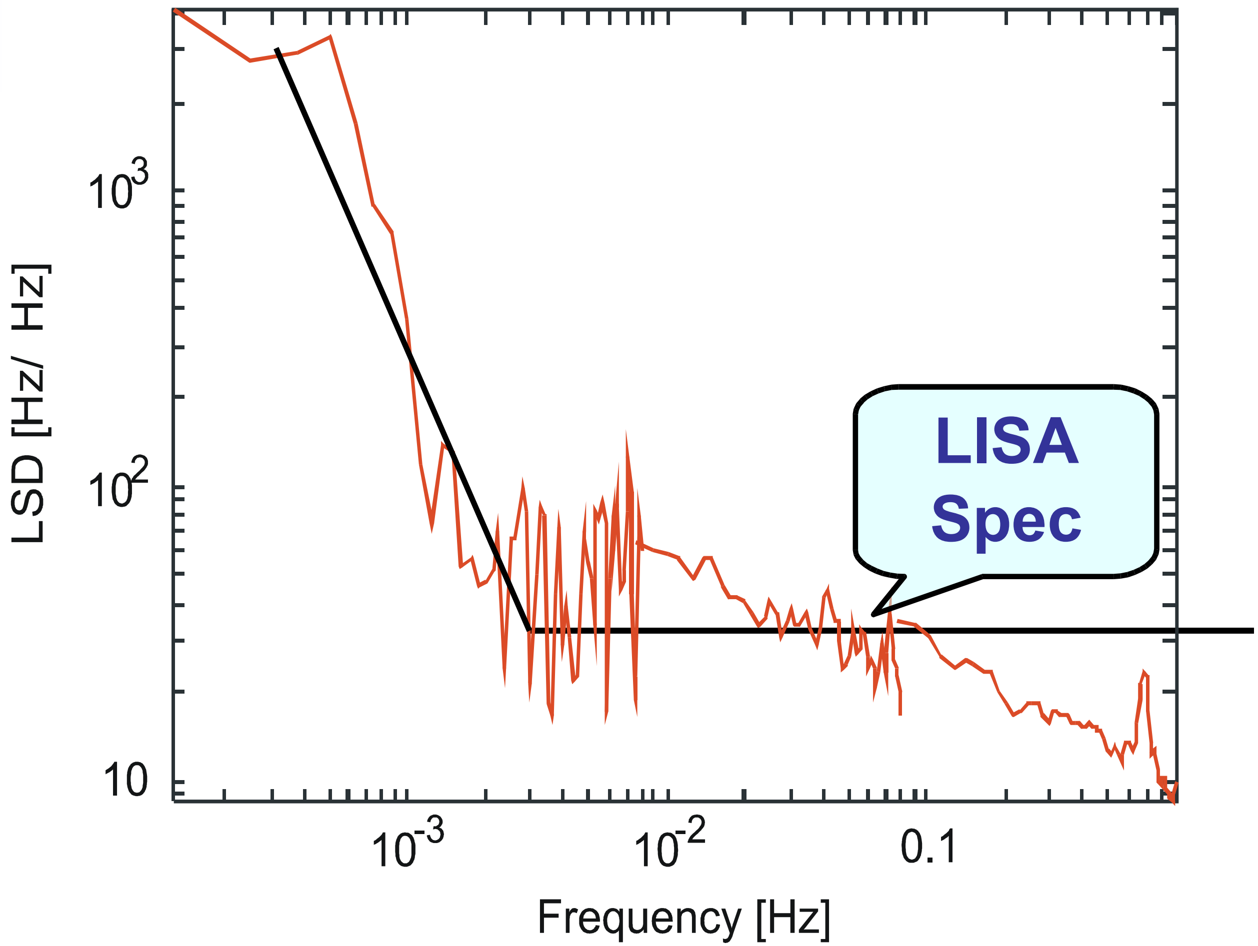
© Astrium

Thermal isolation of reference cavity



- Cavity length 20 cm, finesse 9000
- Vacuum 2x10-7 mbar
- Gold-coated thermal isolation layers
- Spacers from ceramics with low thermal conduction

Laser Frequency Stability



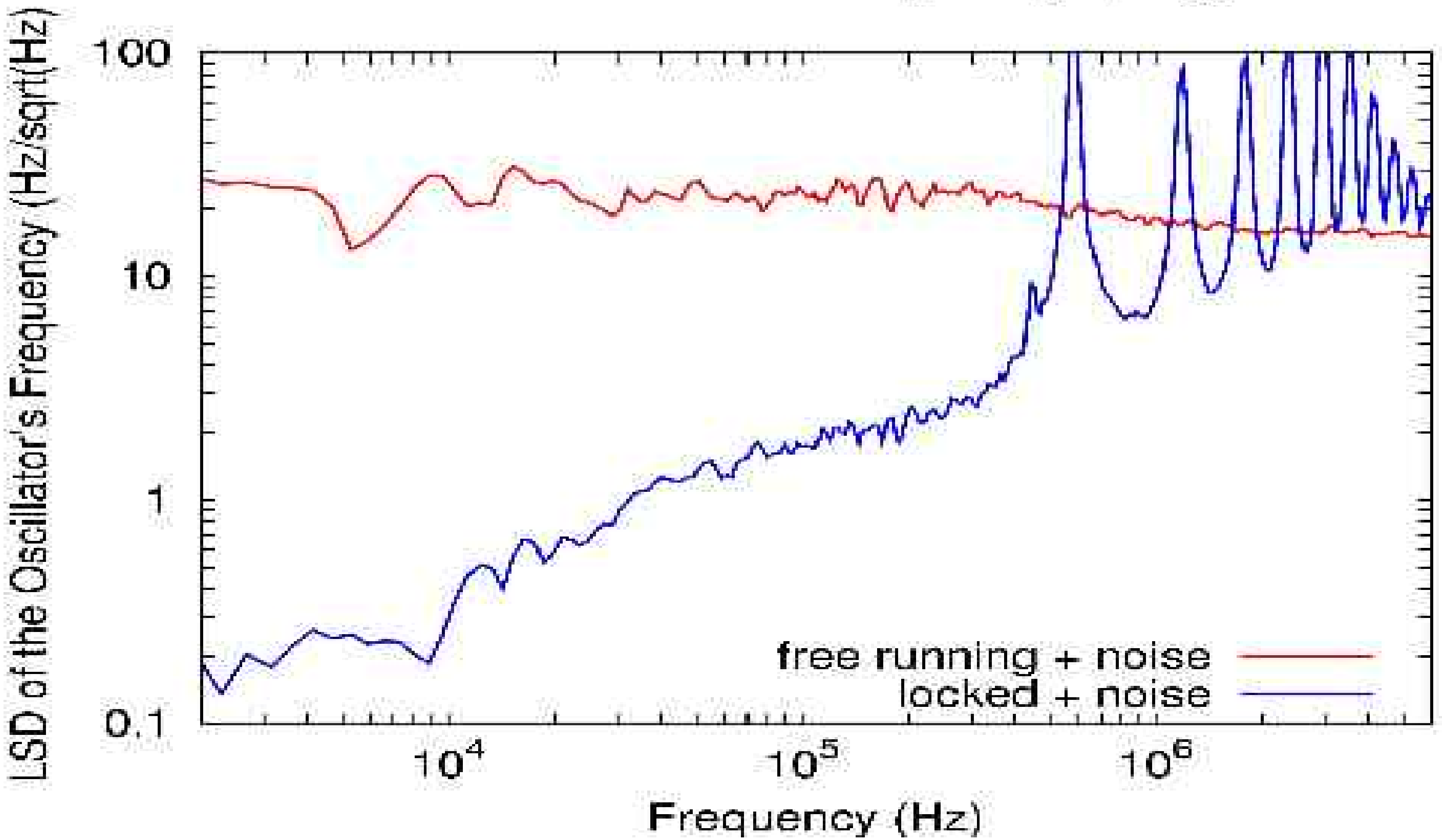
2 independent systems, out-of-loop comparison

LASER Locking to LISA Arms

- **Laser arm-locking standard on ground-based interferometers**
- **But in LISA: 30 sec round-trip light-time delay complicates servo design**
- **Several groups have come up with servo designs that would give enormous suppression of the laser noise by using the average of the LISA arms as stable reference**
- **All of these designs would greatly reduce the requirements on TDI, by up to several 10 000, and also on ranging**
- **Potentially almost no pre-processing on board required!**
  - All raw data to ground!
- **Recent progress in experiment and simulation!** ***(talks by Sheard, Thorpe, Heinzel)***

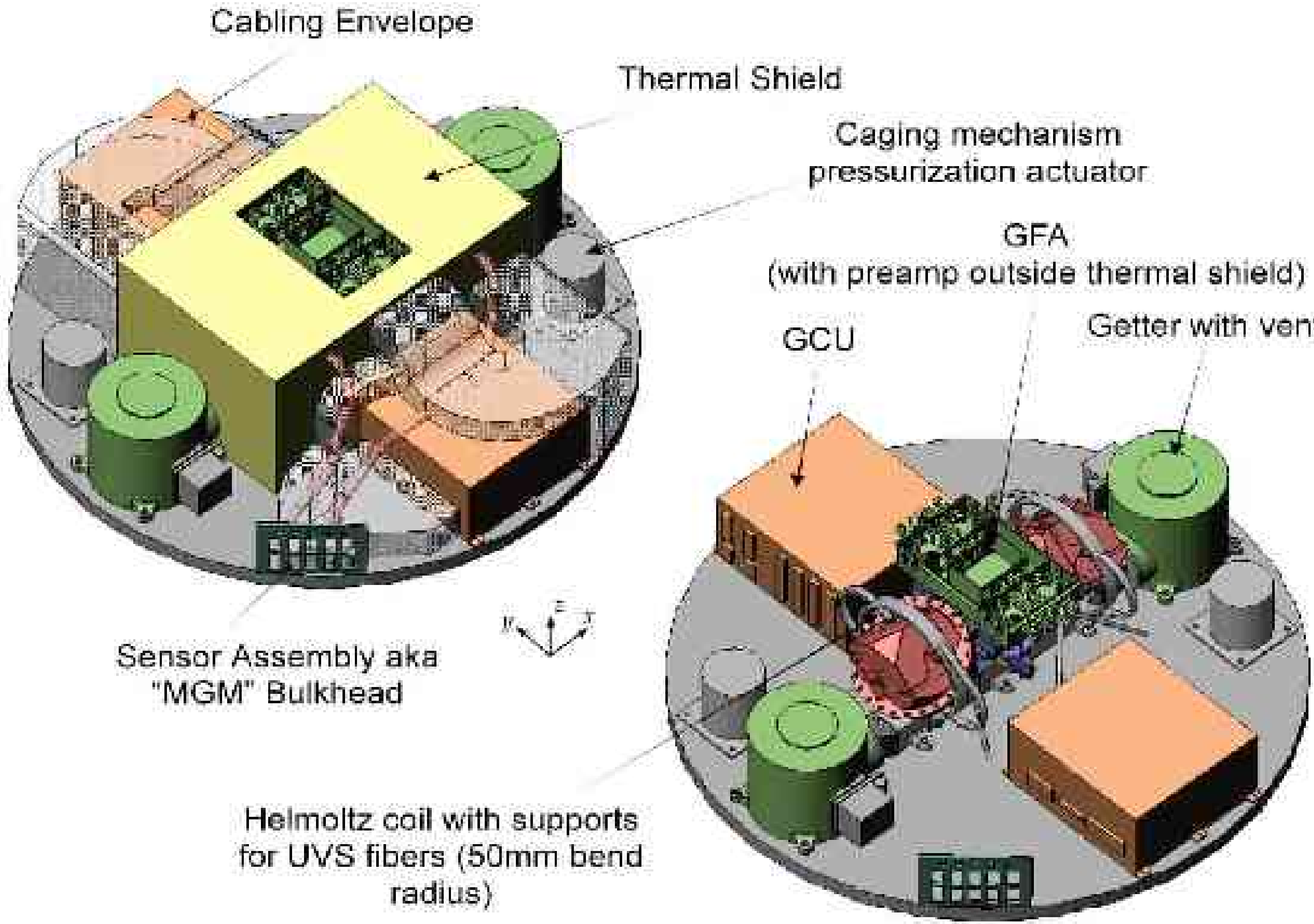
First Tests of Locking to Arms

- Laboratory tests with 70 MHz RF and drum of coaxial cable



- Locking nicely and stably with Unity Gain Frequency above frequency of fifth null!

NASA GRS Package



Housing alignment repeatability testin
underway

- BeO Stepped Walls
- Test jig
- Installation fixtures
- CMM and Vibration testing

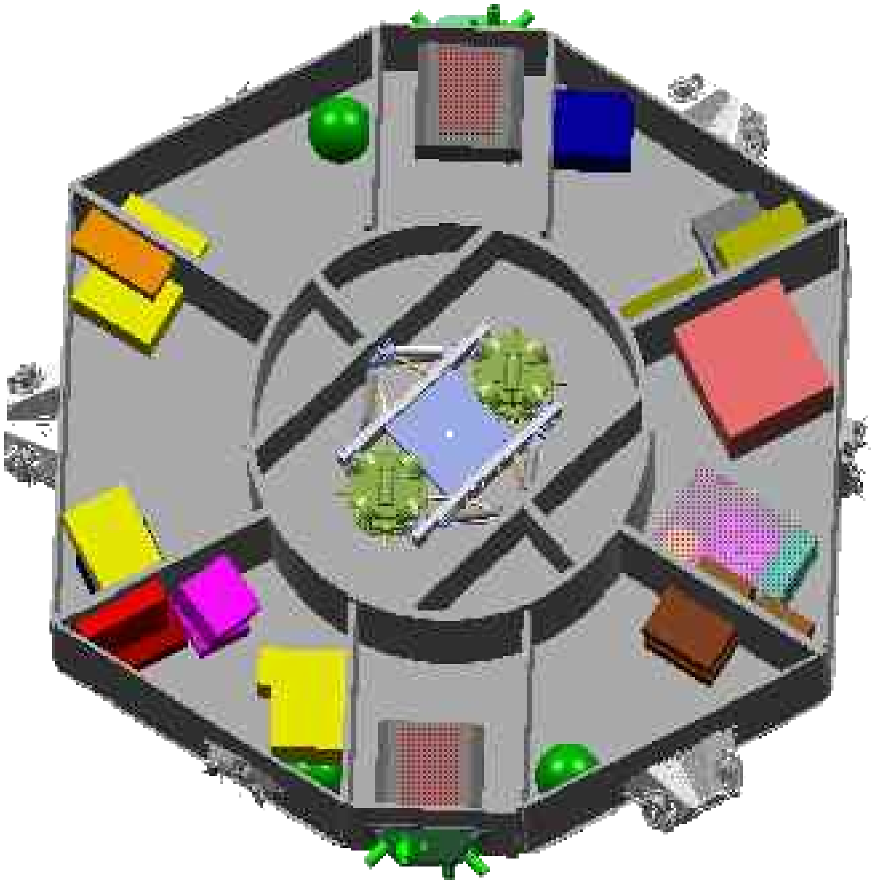
Interferometer Vibration Test

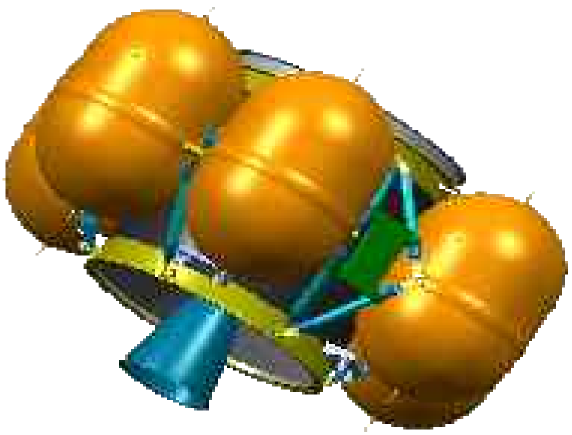
LISA Pathfinder

- **European LTP**
  - Inertial Sensor
  - Optical Metrology
  - Drag-free control
  - Phase-measurement

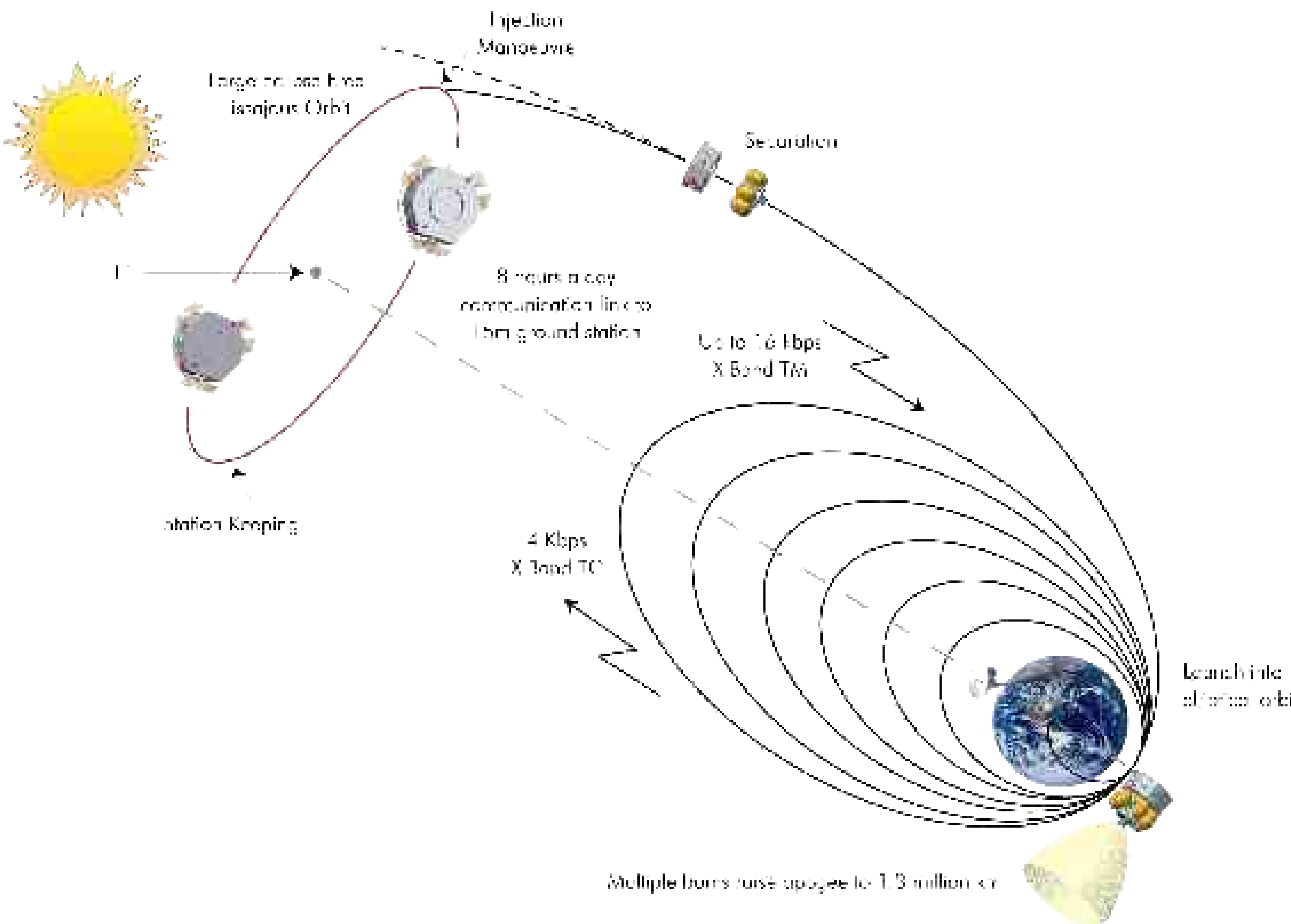
- **US DRS**
  - Similar to LTP with "coordinated differences" (materials, design, interferometry)
  - Oriented 45º to the LTP to allow for a "LISA simulation" during combined operation
- **Thruster systems**
  - FEEPS, colloidal thrusters, cold gas, hydrazine

Spacecraft and Propulsion Module





Operational Orbit: Lagrange Point 1



Critical decisions on Cosmic Vision

7 November 2003
ESA PR 75-2003. At its 105th meeting, on 5/6 November, ESA's Science Programme Committee (SPC) made important decisions concerning the Cosmic Vision programme. Due to the current financial exigencies and an outlook with no budget increase or other relief, the SPC was forced to cancel the Eddington mission and rescope the BepiColombo mission.

Eddington had two aims, both remarkable and very pertinent to front-line astronomical interests. The first was to look for Earth-like planets outside our solar system - one of the key goals in the search to understand how life came to be, how it is that we live where we do in the universe and whether there are other potential life-supporting environments 'out there'. At the same time it was going to follow the path that the ESA-NASA mission SOHO had taken with the Sun of using astroseismology to look 'inside' stars. In the longer term, the loss of this one mission will not stop ESA and the scientific community pursuing the grand quests to which it would have contributed.

The loss of the BepiColombo lander is also hard to take scientifically. ESA, in conjunction with the Japanese space agency, JAXA, will still put two orbiters around Mercury but the 'ground truth' provided by the lander is a big loss. However, to land on a planet so near the Sun is no small matter and was a bridge too far in present circumstances, and the chance for Europe to be first has probably been lost.

The origins of the problems were recognised at the ESA Council meeting held in June. Several sudden demands on finance occurred in the spring, the most obvious and public being the unforeseen Ariane 5 grounding in January, delaying the launches of Rosetta and Smart-1. A temporary loan of EUR 100 million was granted, but must be paid back out of present resources by the end of 2006

Related links
- ESA Science
- Eddington overview
- BepiColombo [illegible]
- LISA overview

ESA Portal - Critical decisions on Cosmic Vision - Microsoft Internet Explorer

File Modifica Visualizza Preferiti Strumenti ?

http://www.esa.int/esaCP/SEMPVUW_DMD_index_0.html

...environments 'out there'. At the same time it was going to follow the path that the ESA-NASA mission SOHO had taken with the Sun of using astroseismology to look 'inside' stars. In the longer term, the loss of this one mission will not stop ESA and the scientific community pursuing the grand quests to which it would have contributed.

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ESA's SPC was therefore caught in a vice. Immediate mission starts had to be severely limited and the overall envelope of the programme contained.

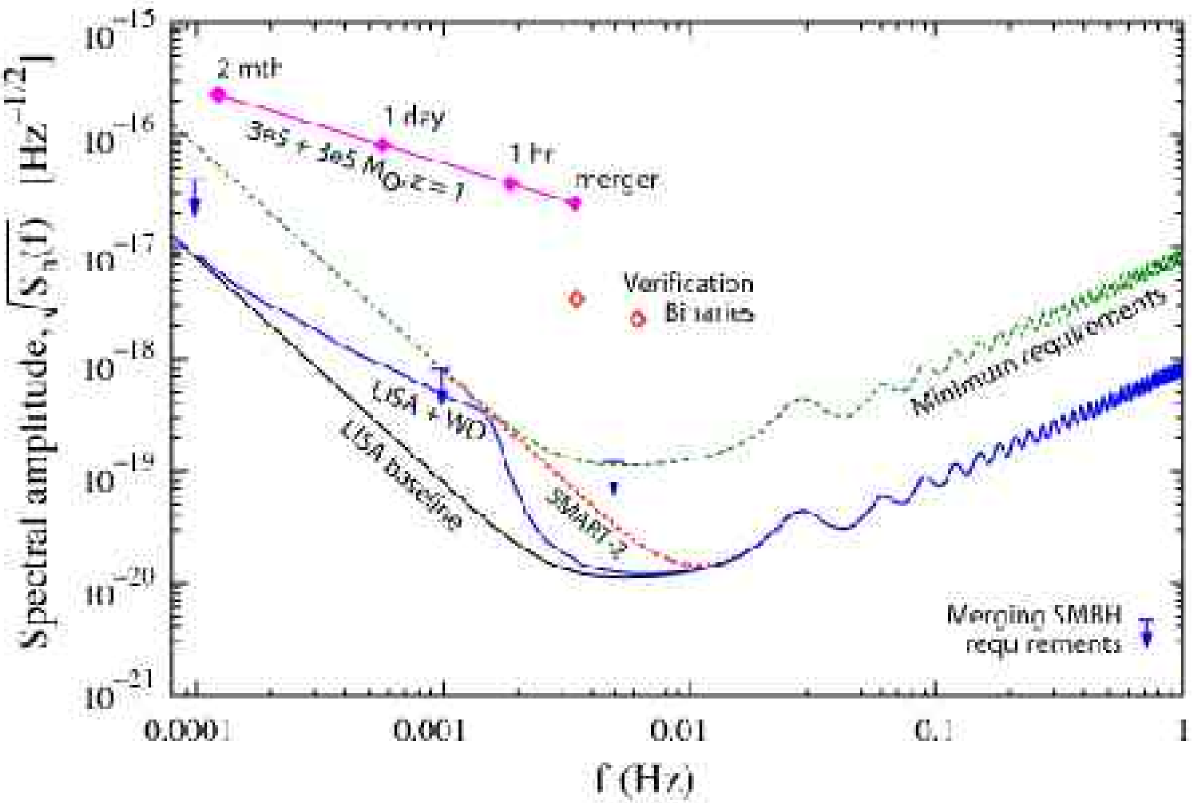
A long and painful discussion during the SPC meeting resulted in the conclusion that only one new mission can be started at this time, namely LISA Pathfinder, the technical precursor to the world's first gravitational wave astronomical observatory, LISA. The LISA mission itself (to be carried out in cooperation with the United States) is scheduled for launch in 2012.

...has to adapt constantly to the available funding as well as respond to the expectations of the scientific community, and to technological developments. Within these boundaries, the decisions made by the SPC try to maximise the outcome of Cosmic Vision across disciplines, keeping it challenging and at the same time affordable. Nonetheless, there are many European scientists with ambitions that exceed the programme's ability to respond.

Minimum Science Mission (2 of 2)

LISA TRIP Site Visit

Beyond Einstein: From the Big Bang to Black Holes



- High SNR even for Minimum Requirements
- SMART-2 demonstration goal results in performance better than Minimum Requirements

NASA GSFC - JPL

esa

LISA

Laser Interferometer Space Antenna

TRIP: Technology Readiness and Implementation Plan Review

SITE VISIT

Jet Propulsion Laboratory
Pasadena, California

April 1, 2003

Assessment of Risk

Achieving technology roadmap:

<u>Medium</u>

Formulation in addition to technology development:

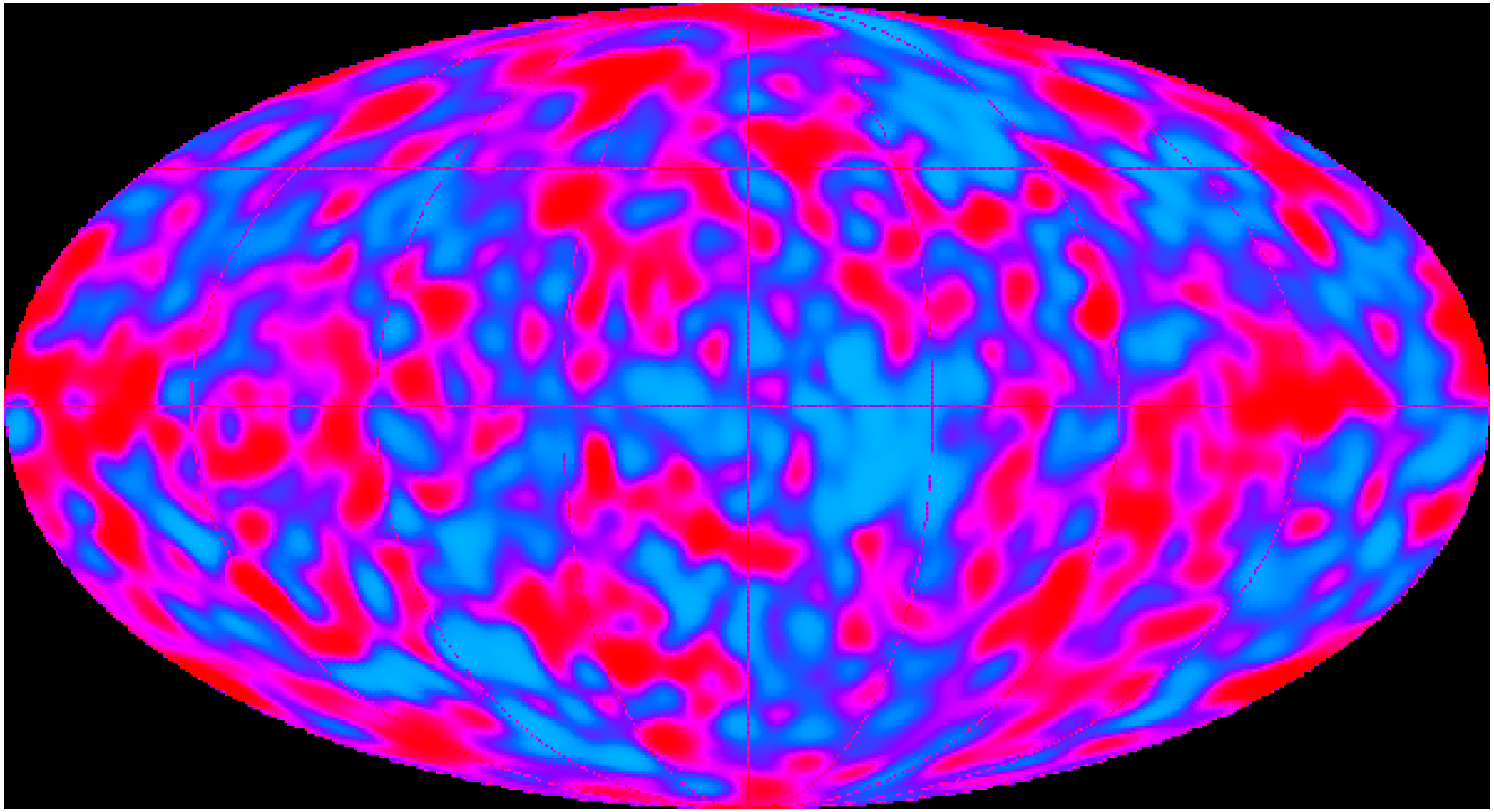
<u>Medium</u>

Implementation:

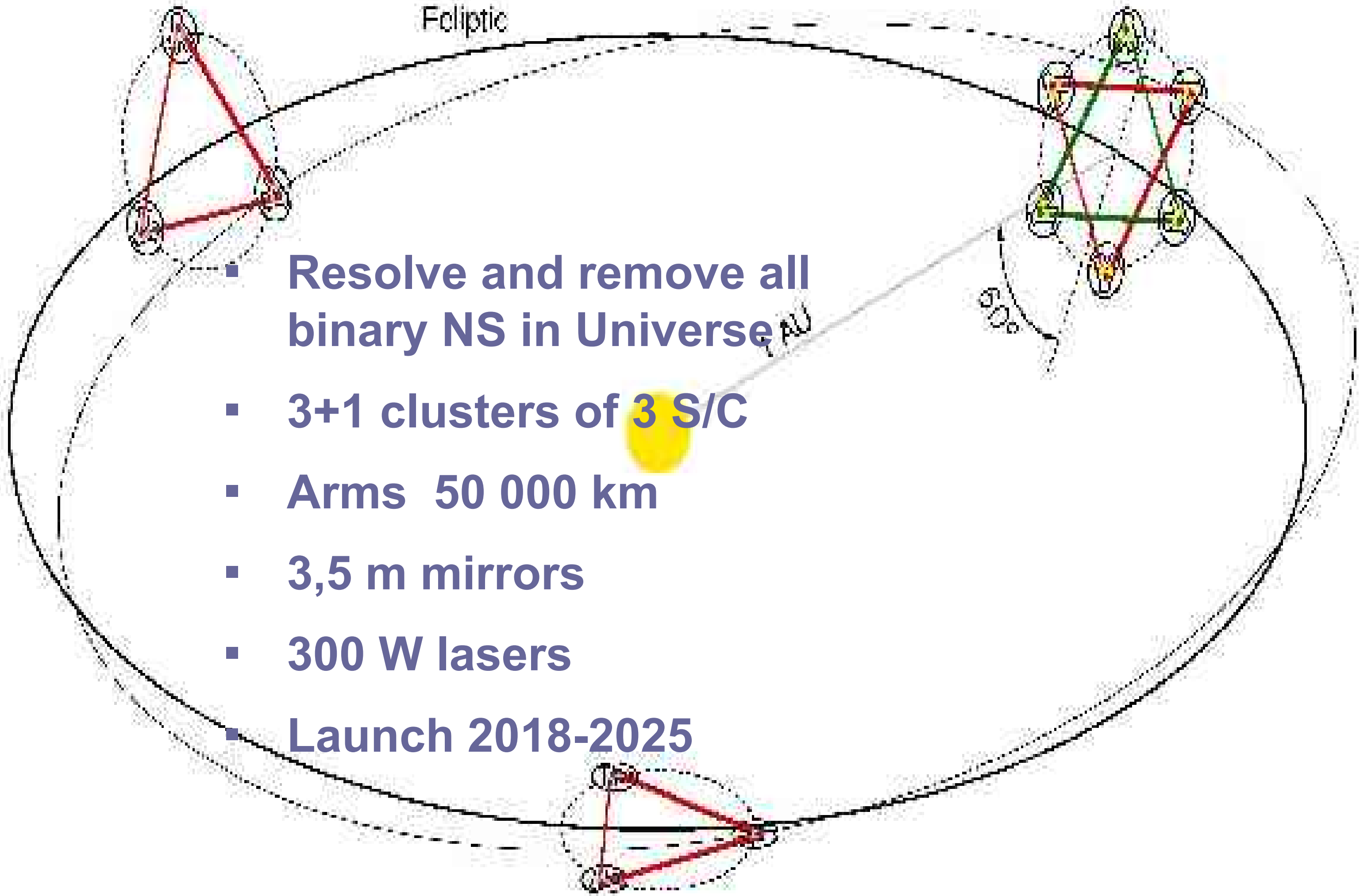
<u>Medium</u>

The LISA Follow-on Mission

- Searching for a stochastic background from the early universe?



Big Bang Observer (BBO)



- Resolve and remove all binary NS in Universe
- 3+1 clusters of 3 S/C
- Arms 50 000 km
- 3,5 m mirrors
- 300 W lasers
- Launch 2018-2025

- Proposal to NASA VM03-0021-0021
  - Approved for study Feb 20, 2004

Cosmic Vision 2015-2025
What are the themes for space science?

02 Apr 2004

A call to the European Science Community

Deadline 1 June 2004
Submission Period is Closed

Introduction

This announcement is to invite the community to participate in a *Call for Themes for Cosmic Vision 2015-2025* to assist in developing the future plans of the Cosmic Vision programme of the ESA Directorate of Science. The European Space Agency's Science Programme Committee (SPC), the body that oversees the Agency's mandatory science activities has indicated that it is time to look further into the future. In November 2003, the SPC agreed a plan for space science, Cosmic Vision, for the years 2004-2014. Now the community is asked to help in developing the Cosmic Vision plan for the ESA Science Programme for the decade 2015-2025.

Print this Email this

SEE ALSO
- Purpose and Conclusions of the Cross-disciplinary Perspective Groups (XPG)

DOCUMENTATION
- Original letter: Cosmic Vision 2015-2025
- Original letter: Purpose and Conclusions of the Cross disciplinary Perspective Groups (XPG)

ESA Cosmic Vision: 4 GW Proposals

Super-massive Black Holes in the early Universe

A proposal in Fundamental Physics
in response to ESA's *Call for Themes 2015–2025*
of 2 April 2004

Gravitational Wave Cosmology

A proposal in Fundamental Physics
in response to ESA's *Call for Themes 2015–2025*
of 2 April 2004

Submitted by K. Danzmann on behalf of the proposing team
(Names and affiliations can be found in the Appendix)

Exploring Dark Matter

A proposal in Fundamental Physics
in response to ESA's *Call for Themes 2015–2025*
of 2 April 2004

Submitted by B. Schutz on behalf of the proposing team
(Names and affiliations can be found in the Appendix)

Searching for the missing baryonic matter

A proposal in Fundamental Physics
in response to ESA's *Call for Themes 2015–2025*
of 2 April 2004

Submitted by S. Vitale on behalf of the proposing team
(Names and affiliations can be found in the Appendix)

Planning for LISA Data Analysis

- **Analysis of the LISA data should be recognized by the agencies (ESA and NASA) as an integral part of the project, and planning for it should be done as carefully as for the hardware.**
  - The success of the entire mission is put at risk if the analysis is done poorly.
  - Analysis task for LISA is likely to be significantly more complex and demanding than that required for data from ground-based detectors.
- **LIST should develop during the next year a detailed plan for data analysis**
- ***Working model:***
  Two cooperating LISA Science Centers, one in the USA and one in Europe.
  - Responsibility to specify the analysis design, plan its implementation, and supervise its execution.
  - Enlist participation of wider scientific community in developing algorithms, writing software, and interpreting the results.

The Future of Ground-Based Observatories

- 1st generation is going into operation this year *(GEO600, LIGO, TAMA in 2004, VIRGO in 2005)*
- 2nd generation will follow 2008, plans are well developed *(Advanced LIGO proposal evaluated positively)*
- 3rd generation 2013, concepts are being developed *(GEO upgrade in 2008, EGO, LIGO III)*
- *Sensitivity improves tenfold each time and by 2014 there will be a flourishing high-frequency GW astronomy*!

The Future of Space Observatories

- **LISA Pathfinder** (SMART-2) is technology demo
  30 cm armlength
  Launch 2008
- **LISA** will open low-frequency window with supermassive BHs and precision observations
  5 Million km armlength
  Launch 2013
- **Big Bang Observer** and **Cosmic Vision Missions** to look for the early universe, dark energy, missing mass and THE UNKNOWN!
  Many clusters of S/C
  Launch 2018/25

The End