LISA Pathfinder: Mission Status

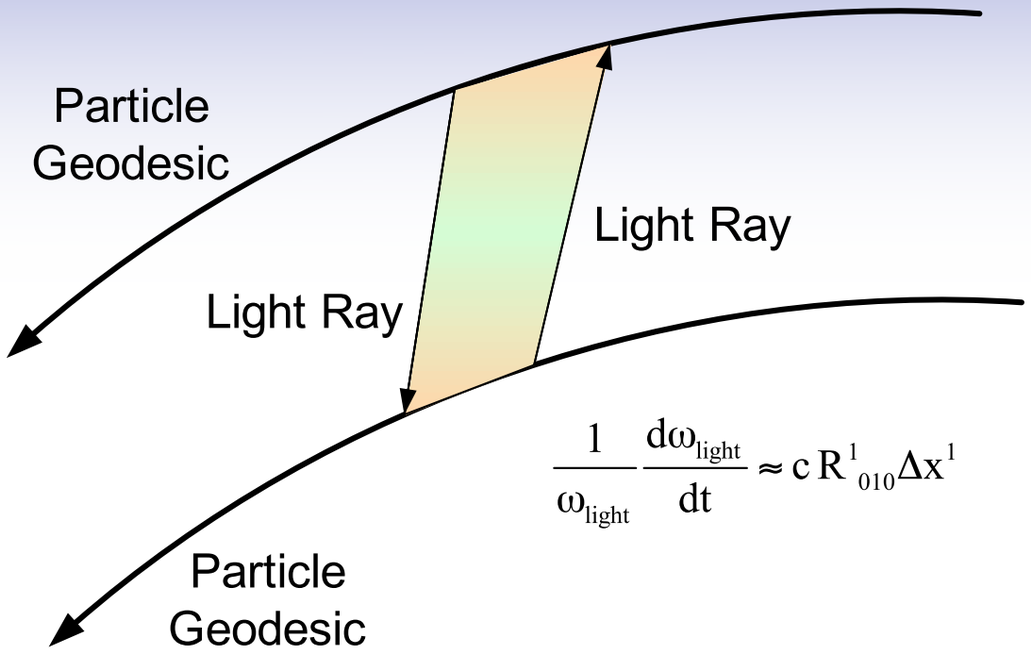
Paul McNamara
LISA Pathfinder Project Scientist

Introduction

- LISA Pathfinder (LPF) is a technology validation mission for NGO[1]
  - LPF was approved by ESA to demonstrate the concept of low frequency gravitational wave detection in space
- LISA Pathfinder will test in flight:
  - Inertial sensors (a.k.a. Gravitational Reference Sensor)
  - Interferometry between free floating test masses
  - Drag Free and Attitude Control System (DFACS)
  - Micro-Newton propulsion technology
- The basic idea of LISA Pathfinder is to squeeze one arm of the NGO constellation from 1 million km to a few tens of cm!
  - Fully tests NGO local interferometry

[1] When approved by the Science Programme Committee, LISA Pathfinder was a dedicated technology validation mission for the LISA mission. In the mean time, LISA has been reformulated and renamed NGO

Mission Concept



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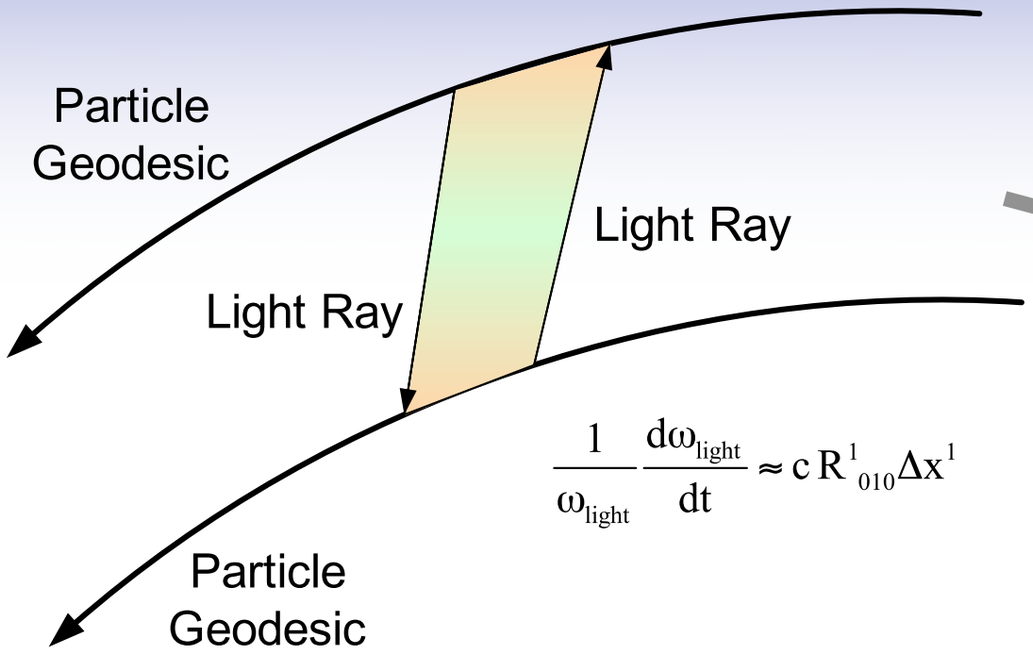
Mission Concept



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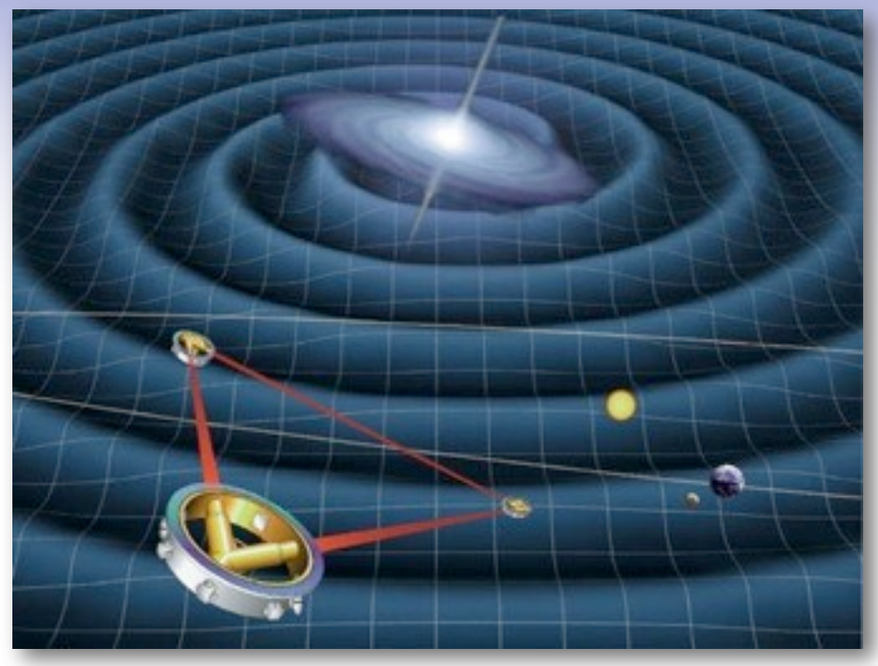

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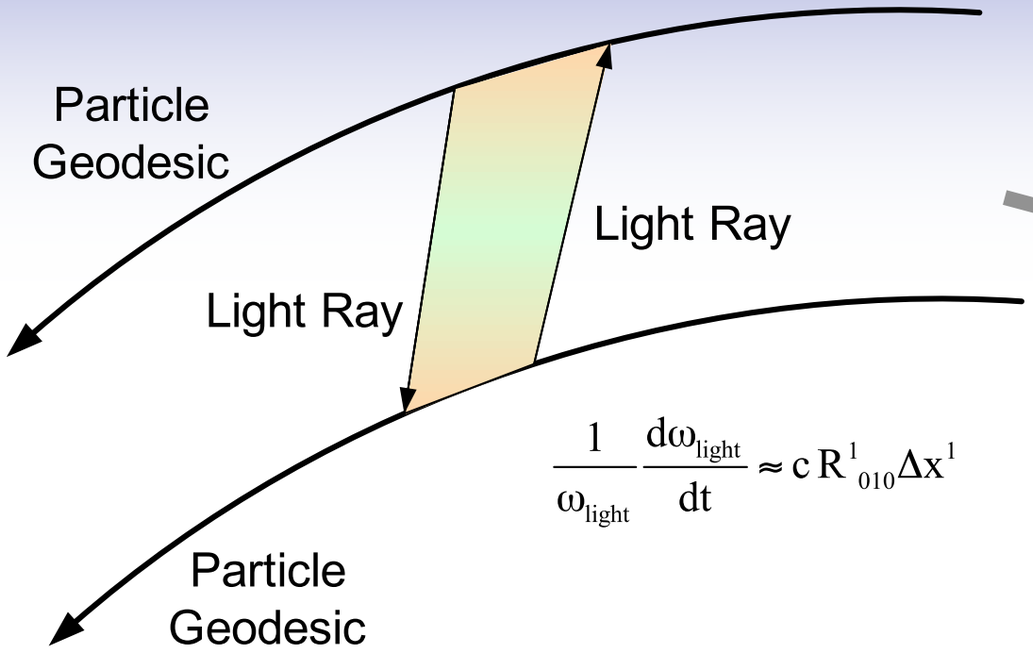
Mission Concept



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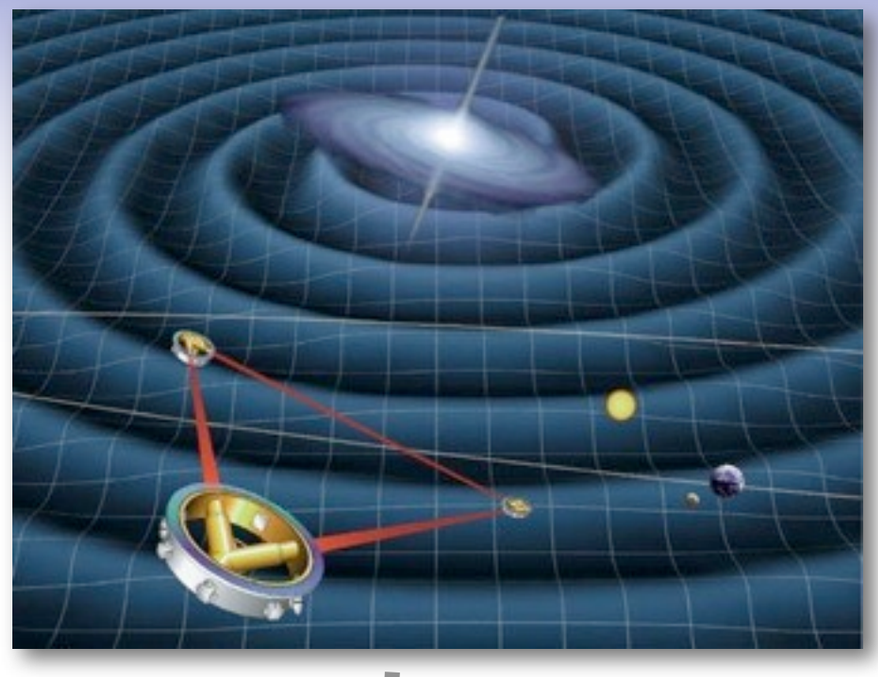

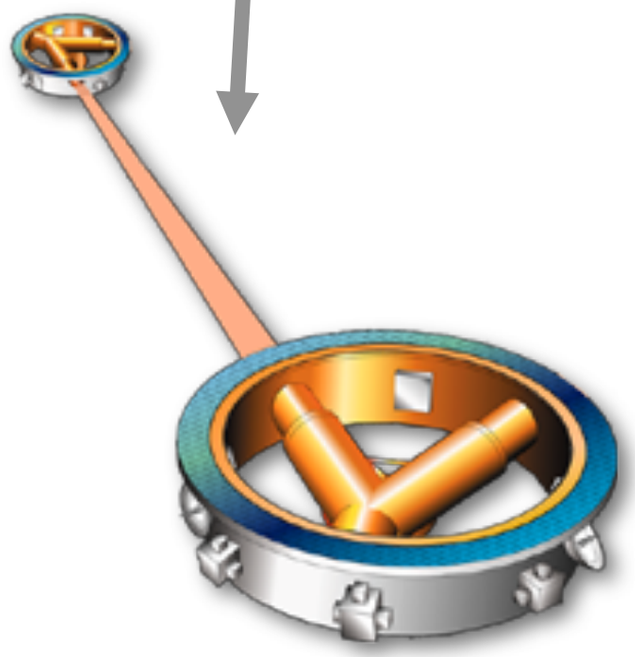

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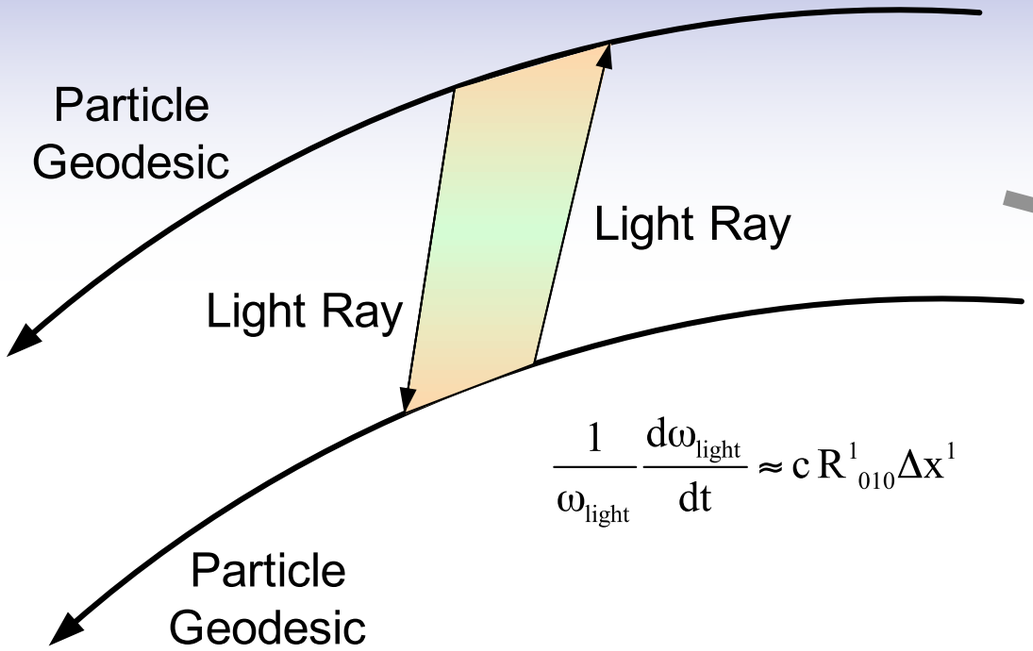
Mission Concept



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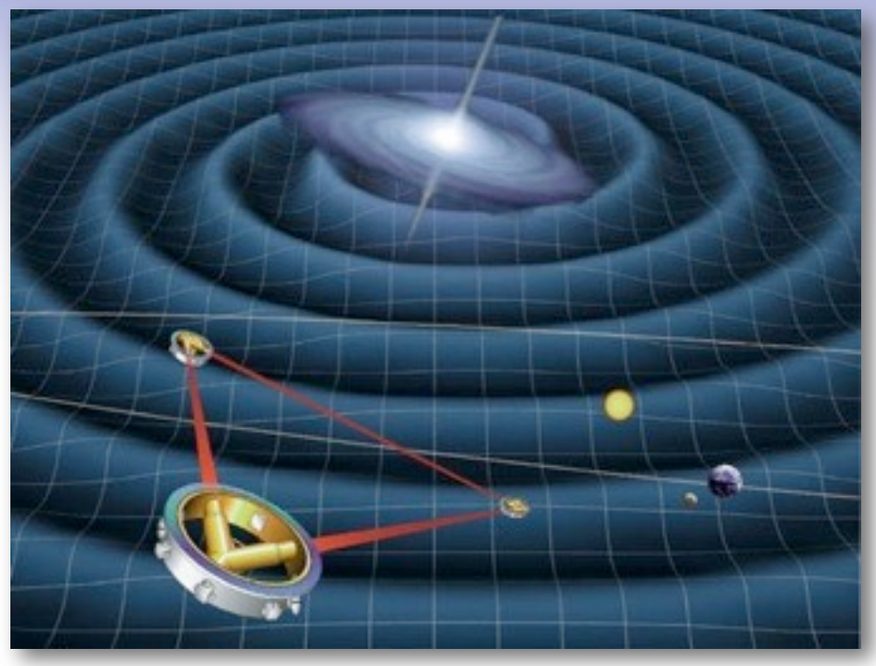

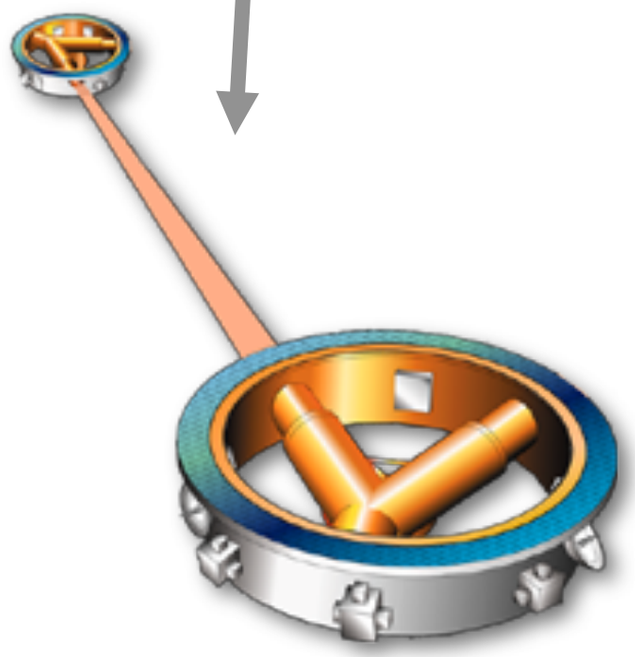

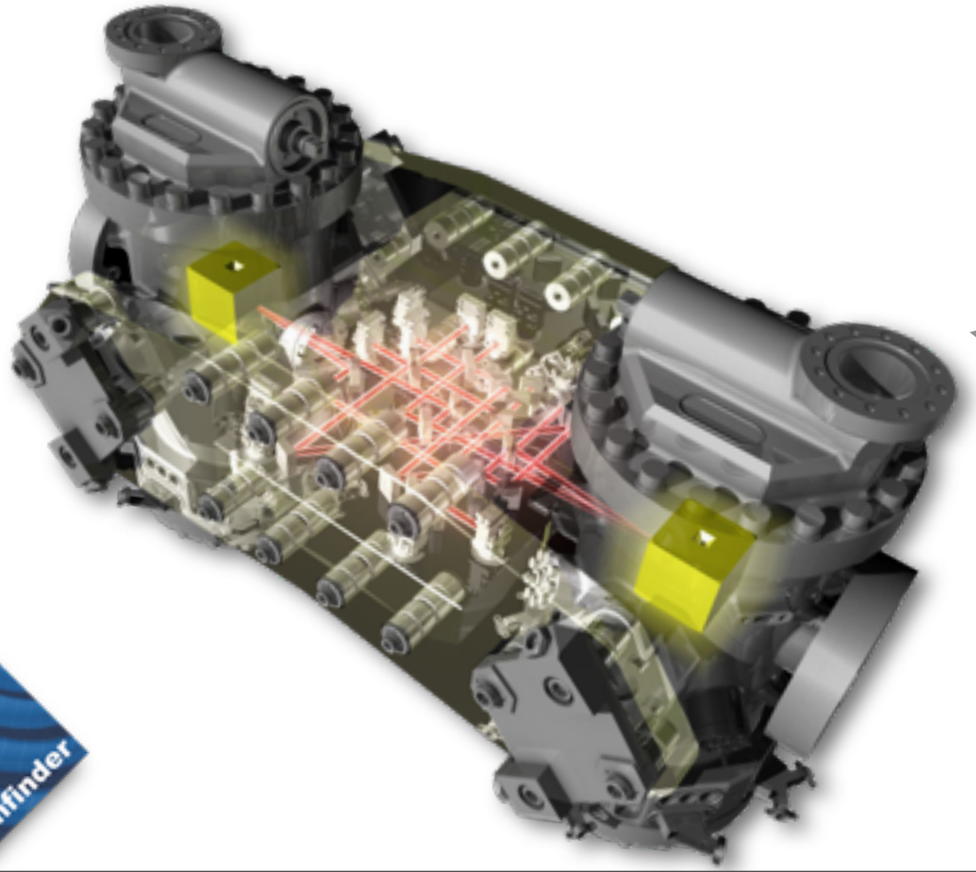

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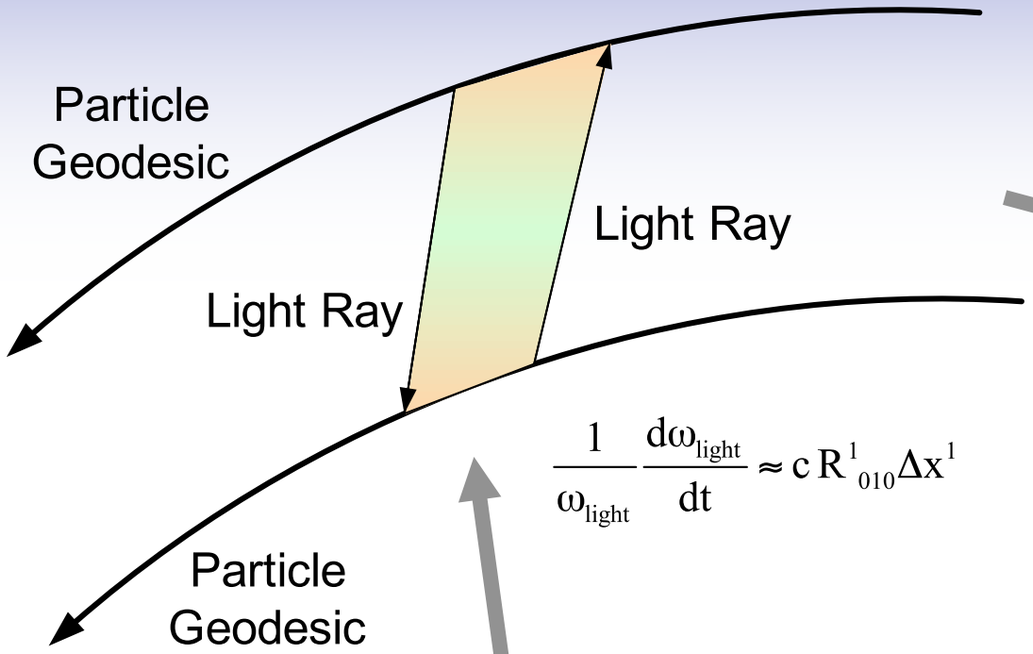

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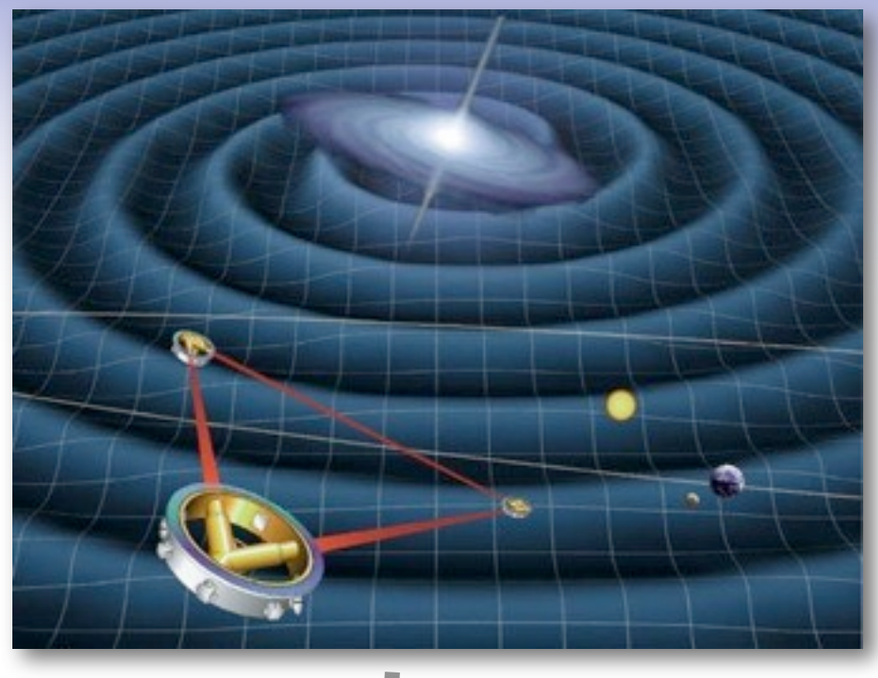
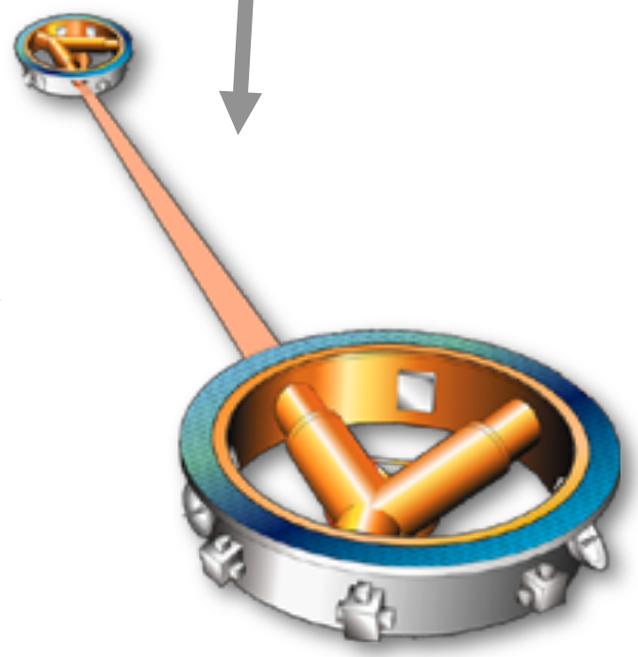
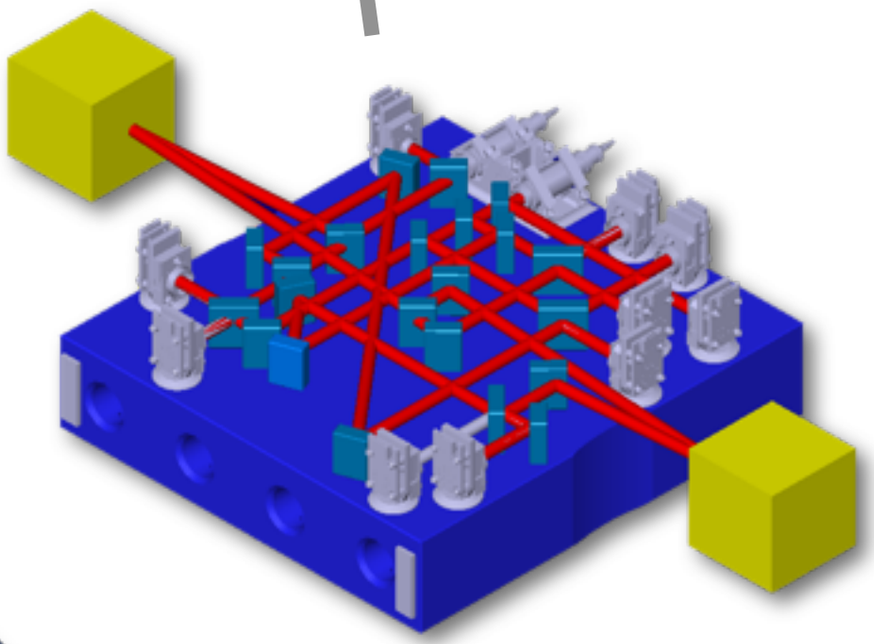
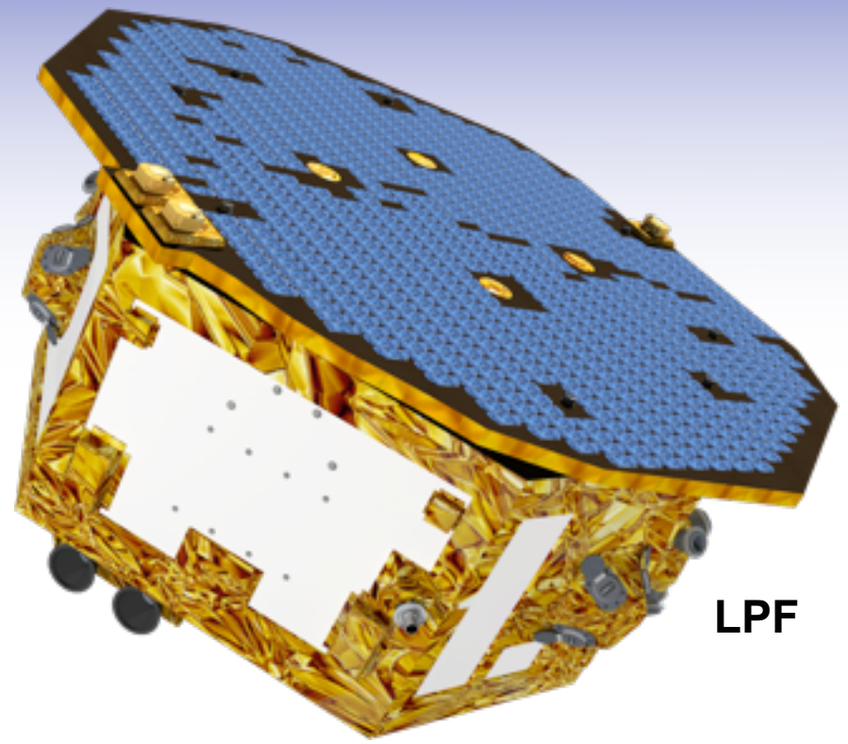




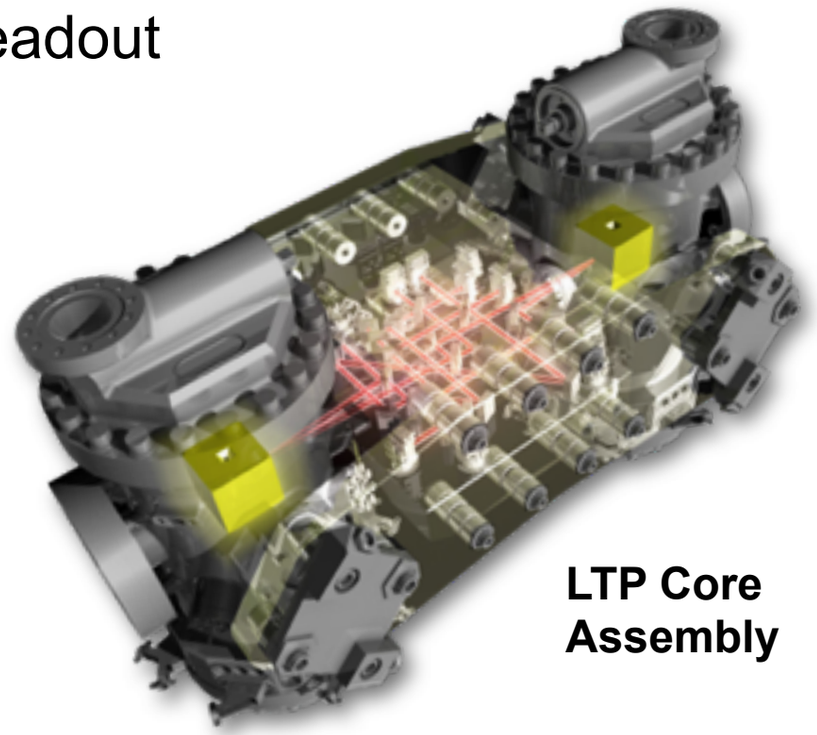


LISA Pathfinder

- LISA Pathfinder consists of:
  - **Spacecraft**
    - Provided by ESA
      - Industrial Prime Contractor: Astrium UK
    - s/c also includes the drag free control software (DFACS) and micro-Newton thrusters
  - **Payloads**
    - **The LISA Technology Package (LTP)**
      - Provided by European member states and ESA
      - Consists of inertial sensors, and interferometric readout
    - **The Disturbance Reduction System (DRS)**
      - Provided by NASA
      - Consists of processor running drag-free control software and micro-Newton thrusters

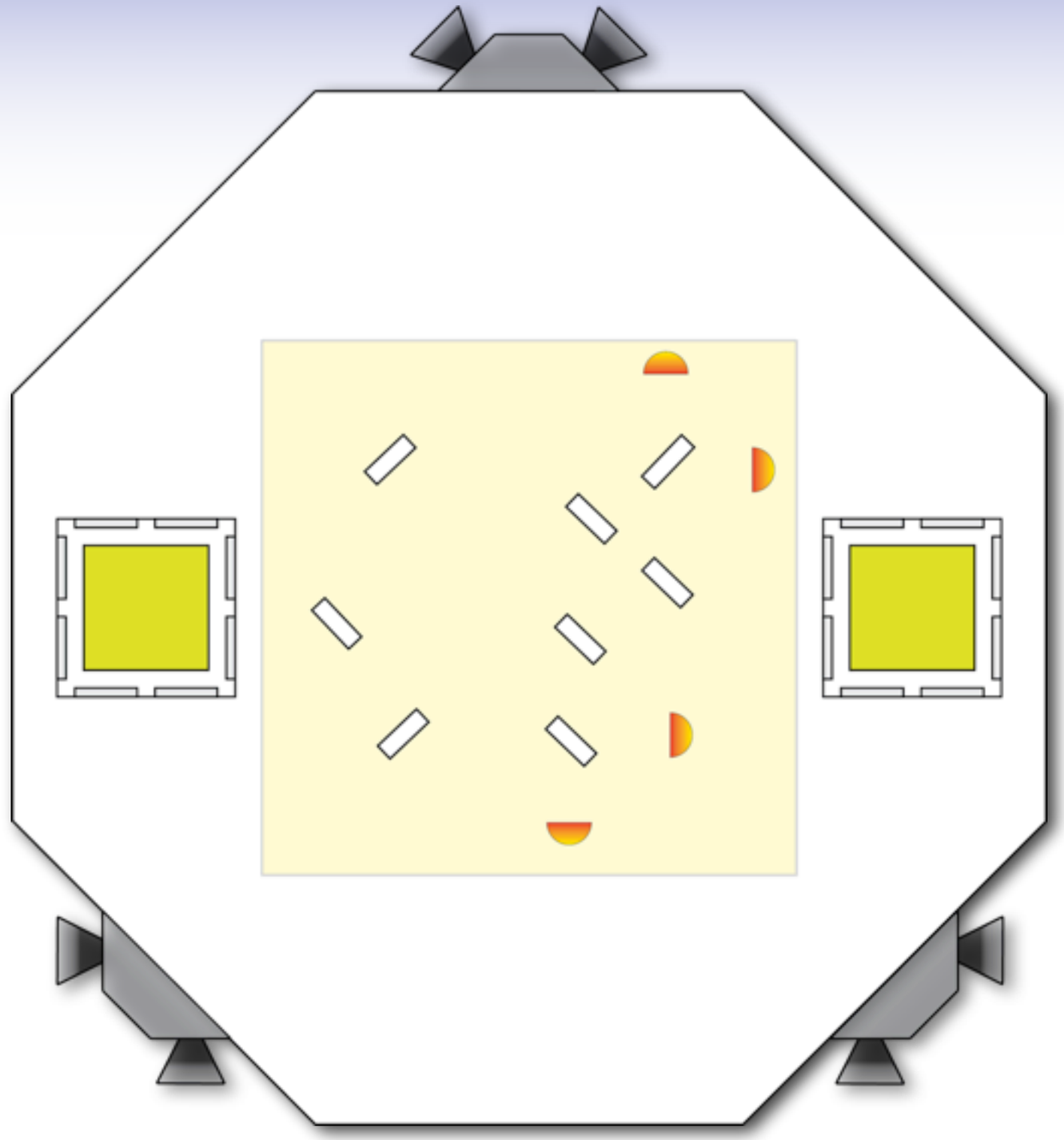


LPF



LTP Core Assembly

DFACS Principle



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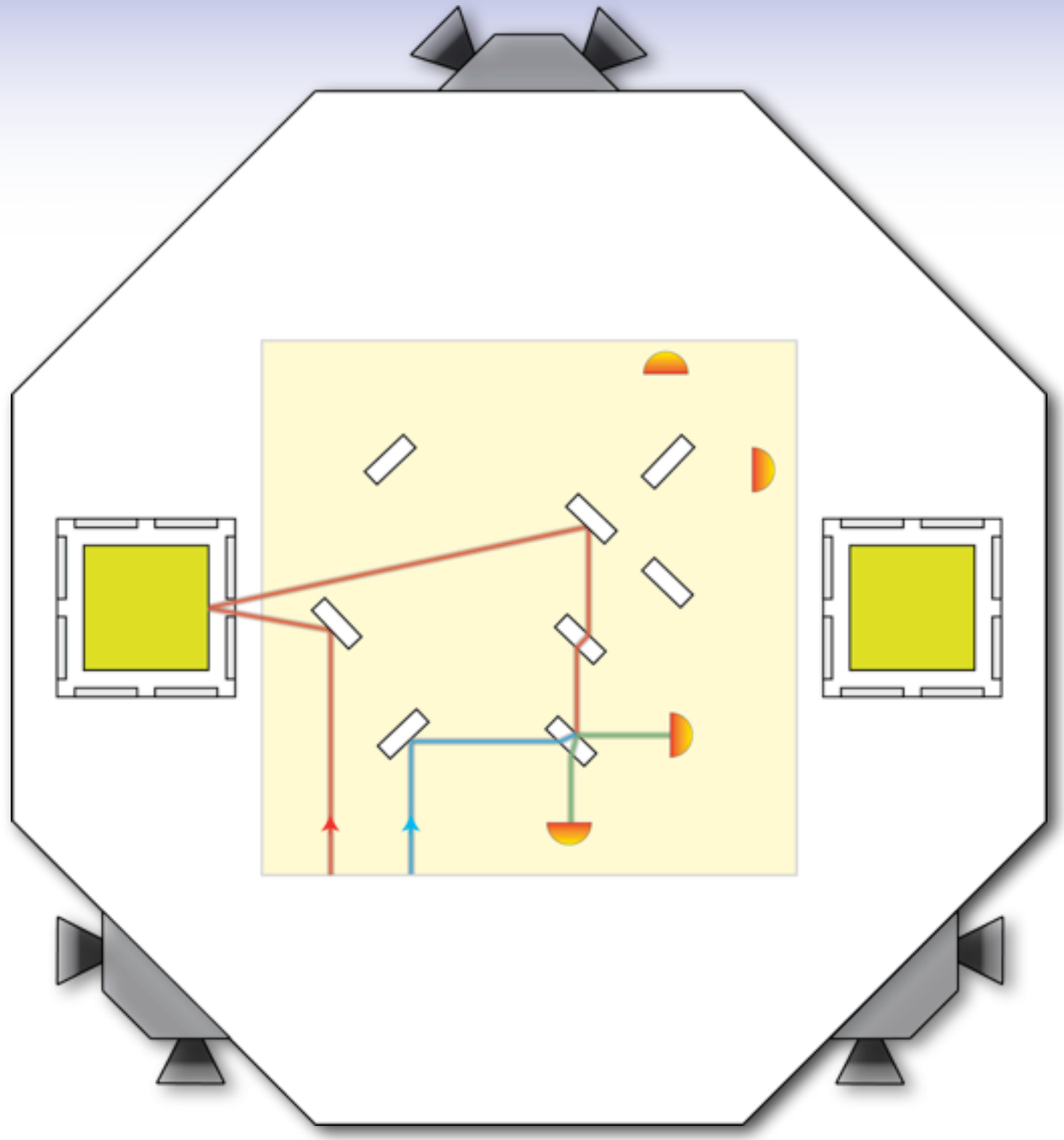
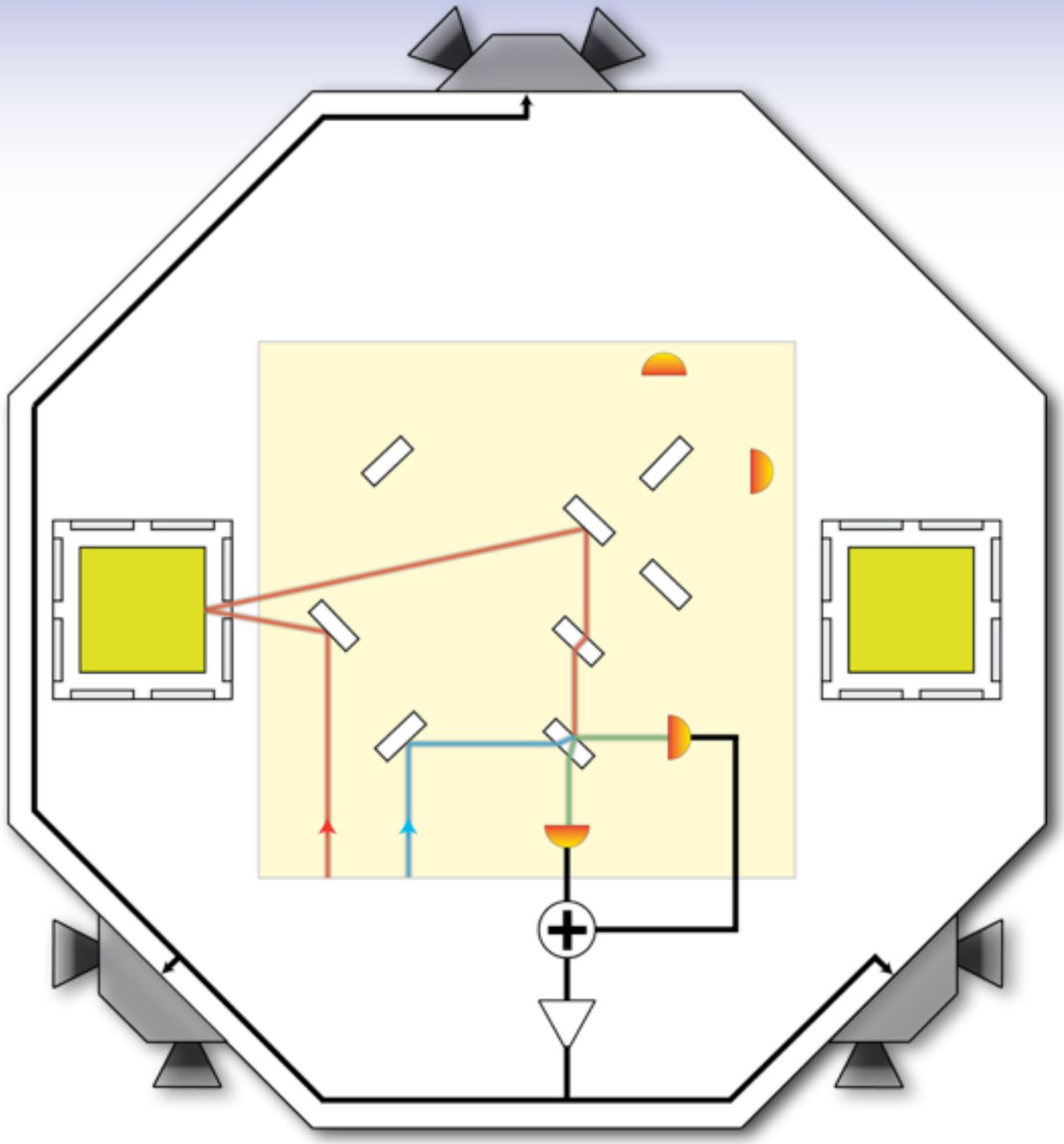
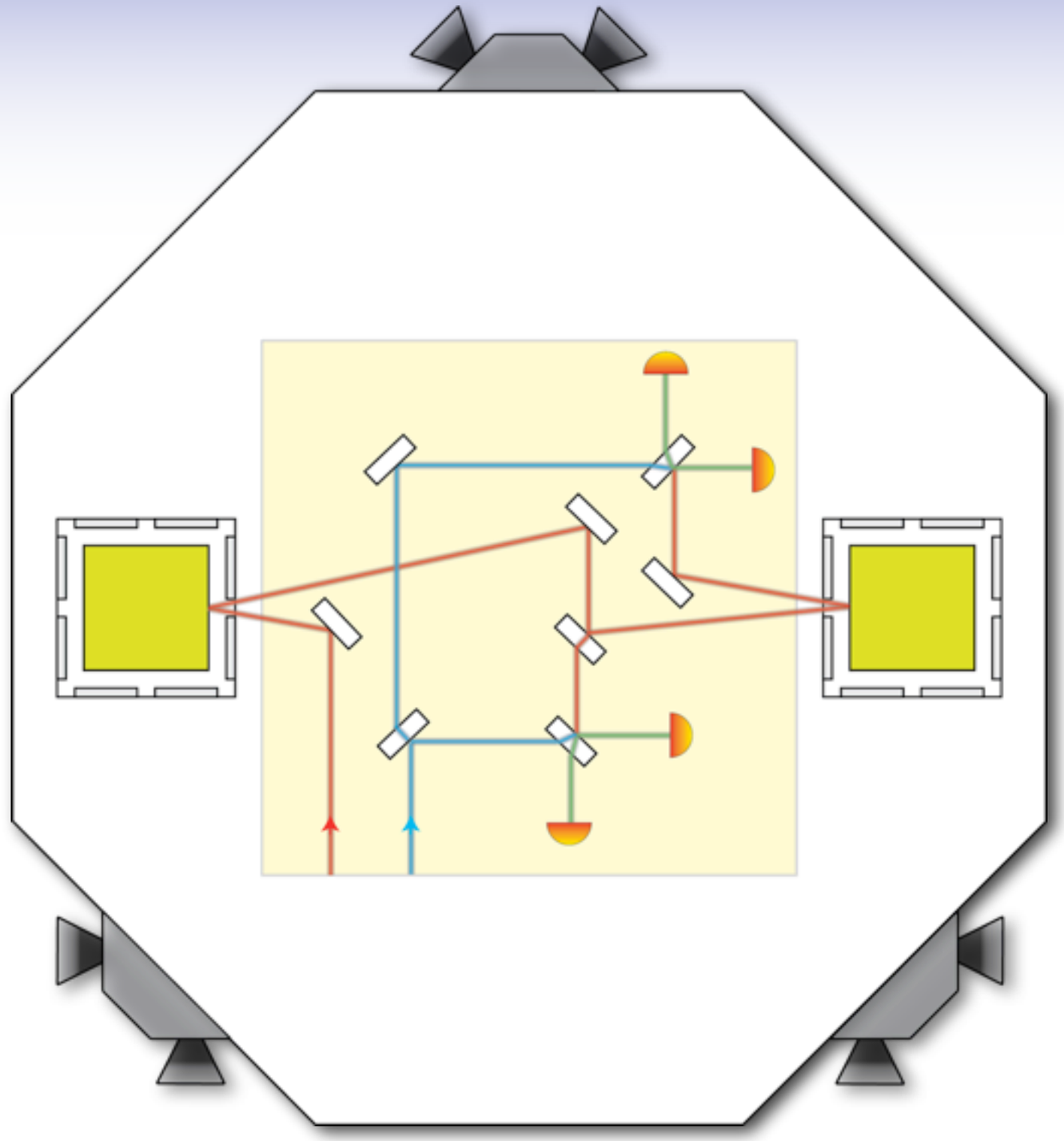
x_1 interferometer



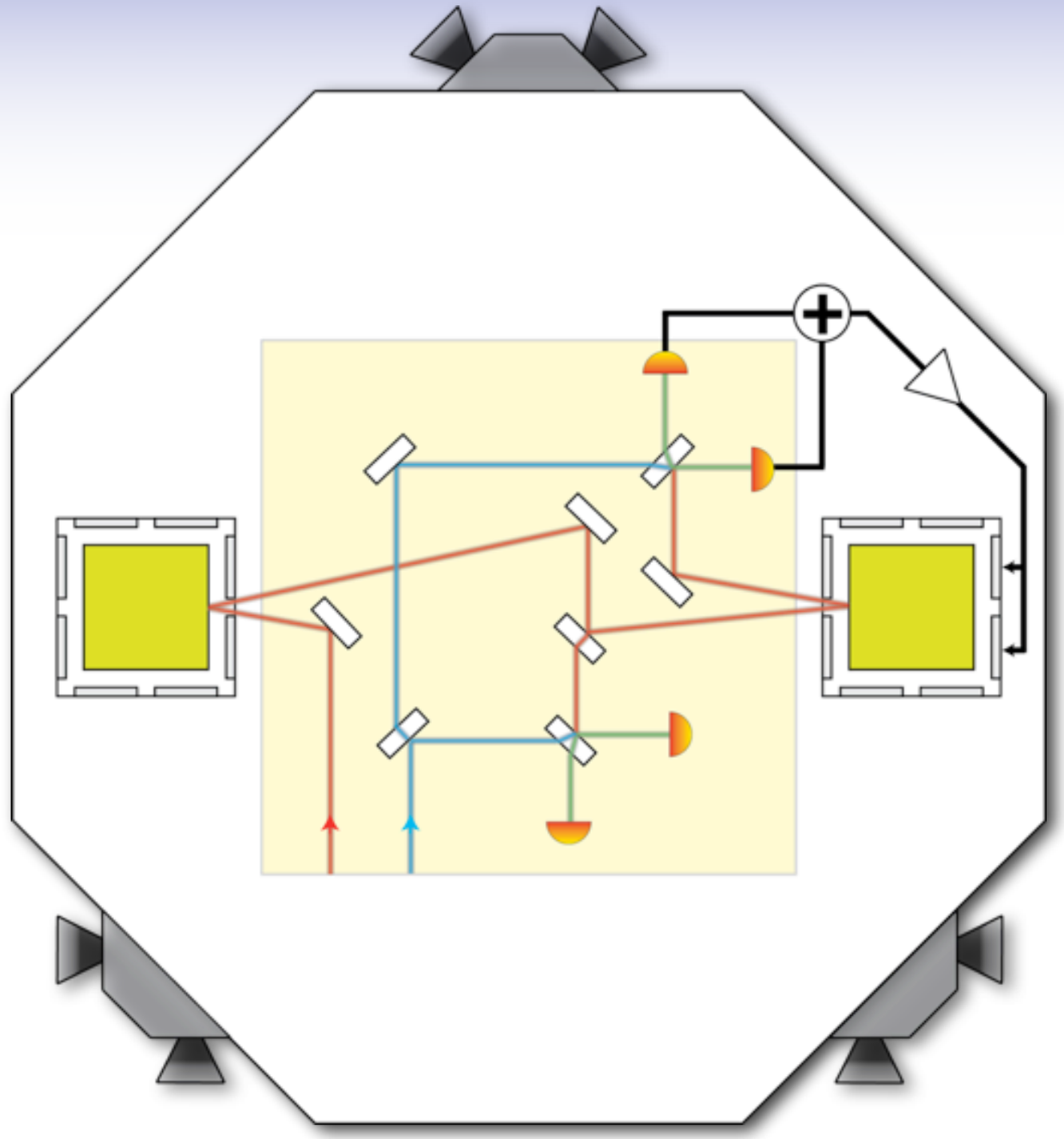
x_1 Drag Free



x_2-x_1 Interferometer



x2 low frequency control



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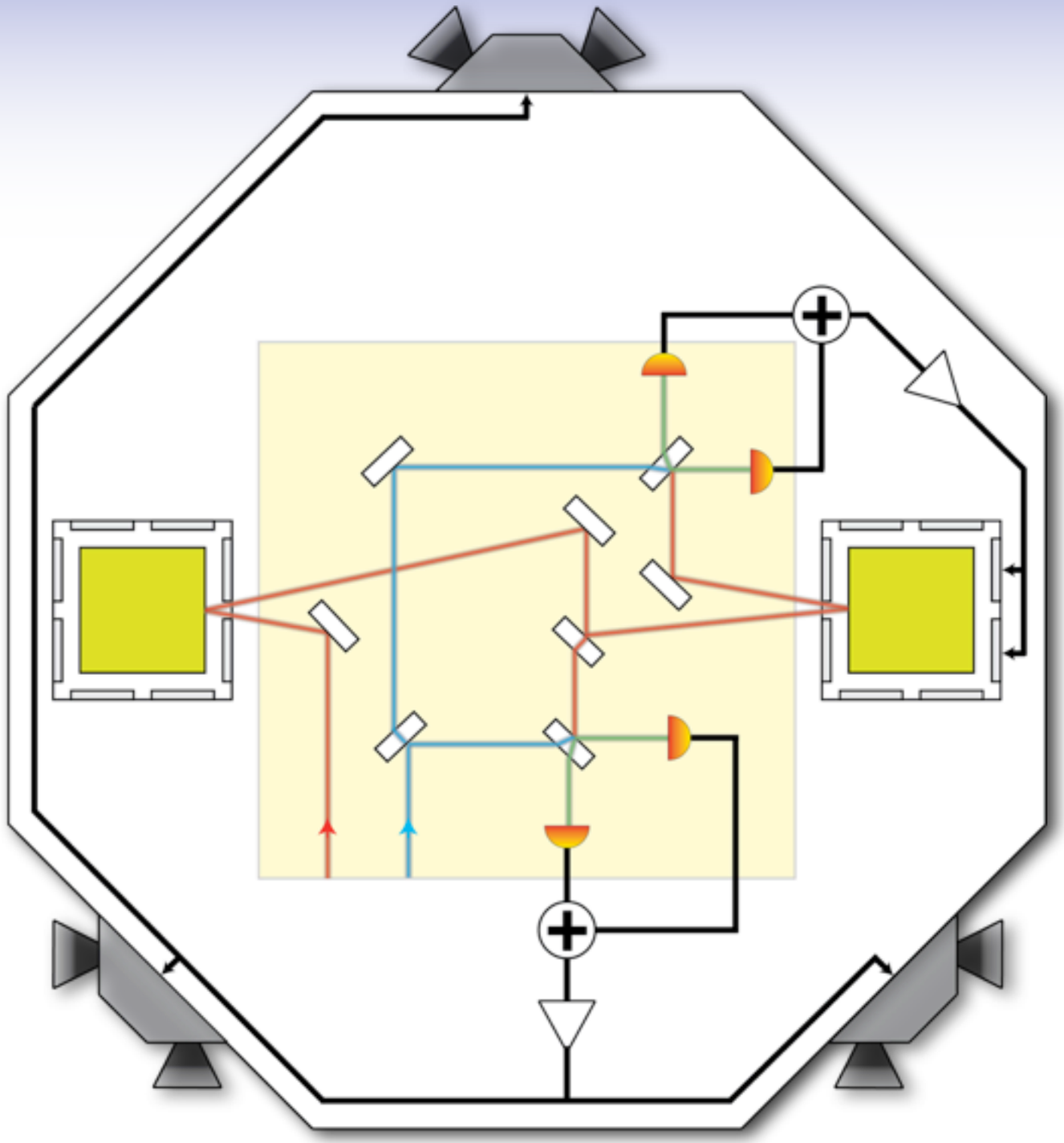
DFACS



LPF Development Approach

- LPF is a *Pathfinder* for spaceborne gravitational wave detectors
  - System design is for NGO
- Relaxation of performance requirements is only allowed to make testing conditions achievable. It shall not affect the design.
- Implications:
  - When one subsystem reaches a given level of readiness for LISA Pathfinder (CDR, QR, FAR, etc) it reaches the same level of readiness for NGO too.
  - All the development risks up to that stage are consequently retired also for NGO
  - Risk of unforeseen system level problems (estimated to be low) is finally retired by the flight.

NGO basic design items

- **Free flying test mass subject to very low parasitic forces:**
  - Drag free control of spacecraft (non-contacting spacecraft)
  - Low noise microthruster to implement drag-free
  - Large gaps, heavy masses with caging mechanism
  - High stability electrical actuation on cross degrees of freedom
  - Non contacting discharging of test-masses
  - High thermo-mechanical stability of S/C
  - Gravitational field cancellation
- **Precision interferometric, *local* ranging of test-mass and spacecraft:**
  - pm resolution ranging, sub-mrad alignments
  - High stability monolithic optical assemblies
- **Precision 1 million km spacecraft to spacecraft precision ranging:**
  - High stability telescopes
  - High accuracy phase-meter
  - High accuracy frequency stabilization
  - Constellation acquisition
  - Precision attitude control of S/C

Items that can only be validated in flight

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Items benefiting from in-flight validation

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NGO Design Items Validated By LISA Pathfinder

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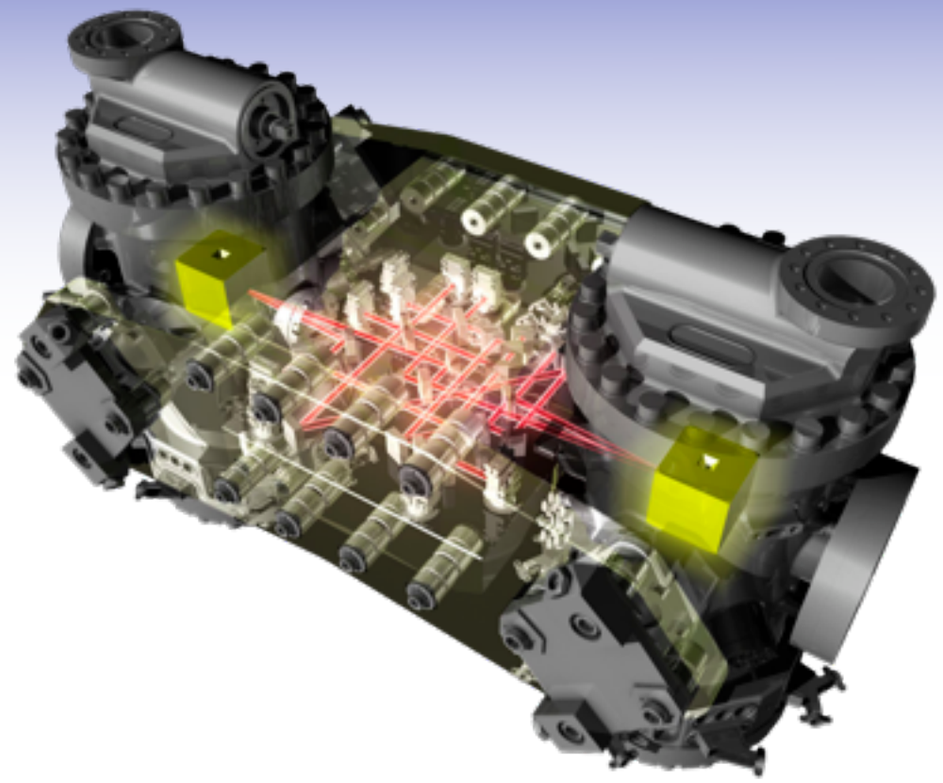
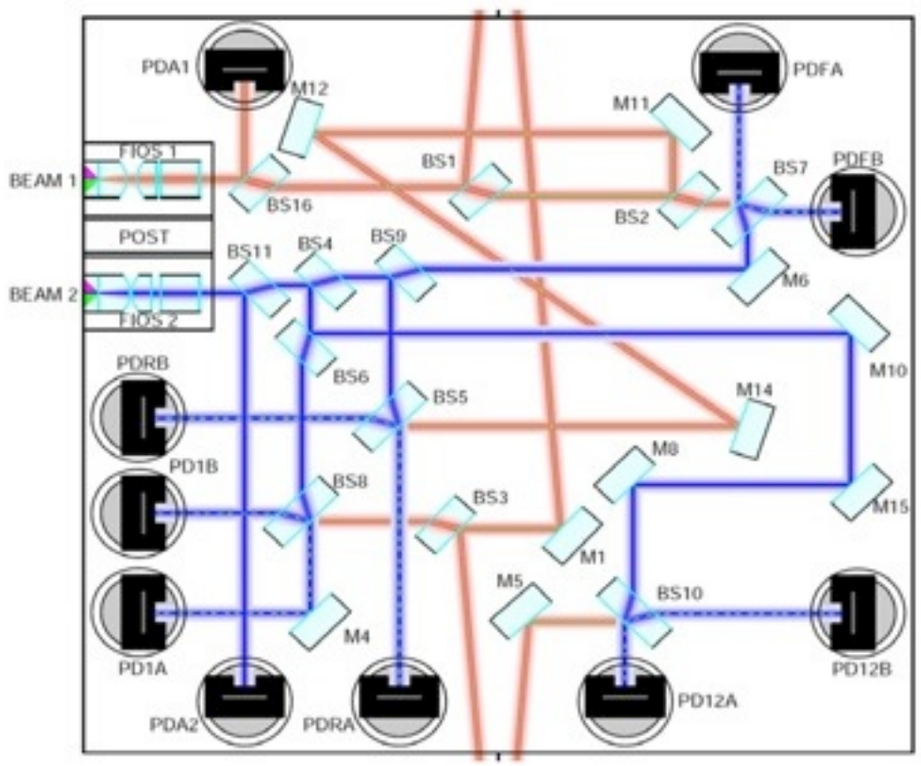
LTP Salient Features

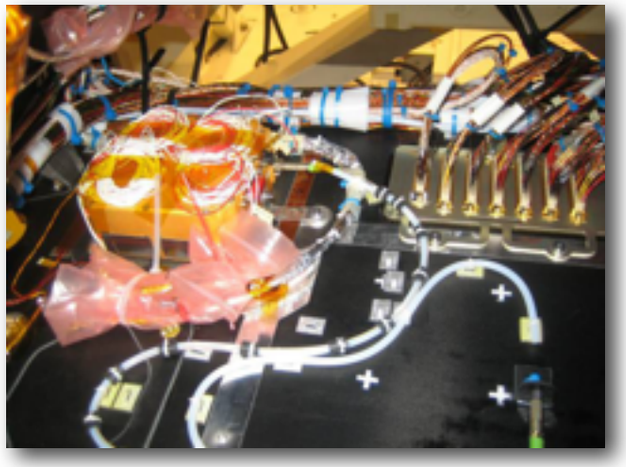
- LISA Technology Package (LTP) is the European instrument payload of LPF
- Two Au:Pt test masses housed in separate vacuum enclosures
- Relative position of test masses read-out by:
  - Heterodyne laser interferometry on sensitive axis
  - Capacitive sensing on all axes
- Four interferometers on ultra-low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



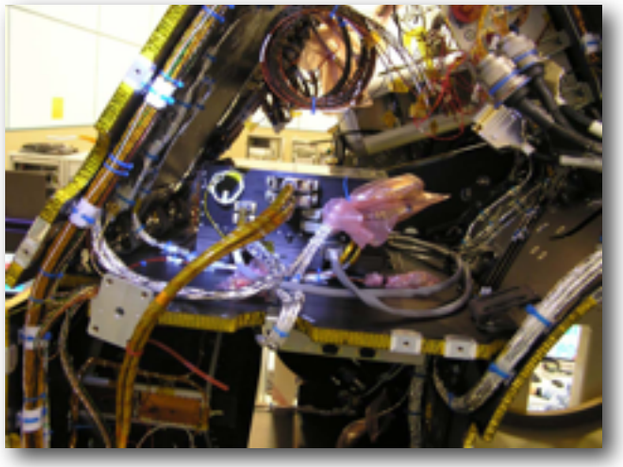


LTP Status

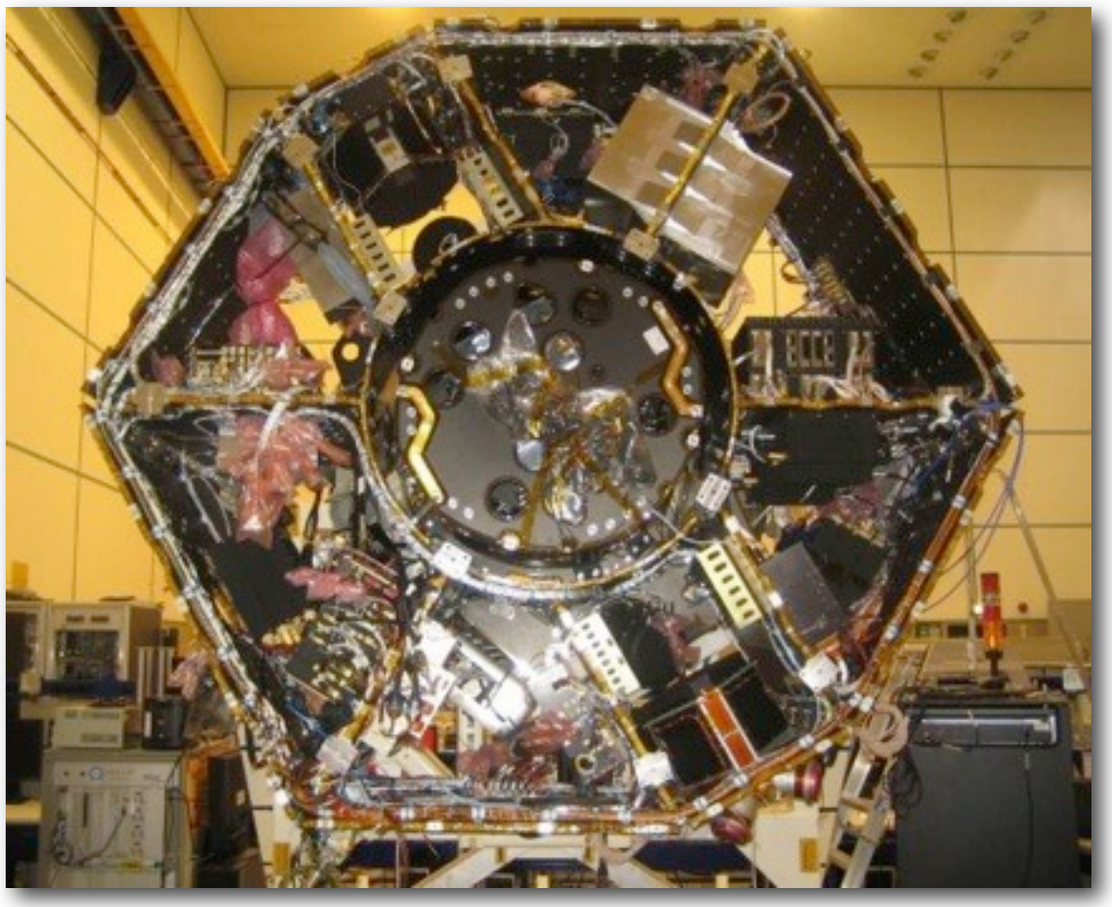
- All electronic units have been delivered and integrated to the spacecraft
  - Laser, laser modulator, phasemeter, payload computer, UV lamp unit, ISS front-end electronics, diagnostics



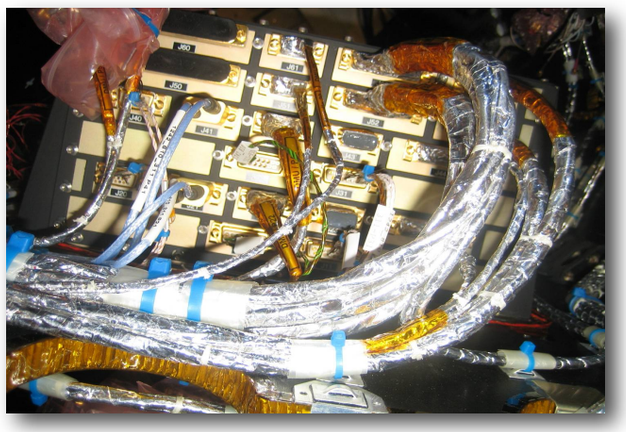
Reference Laser Unit



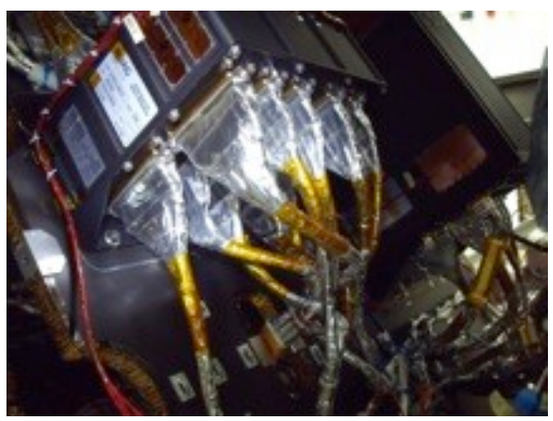
Phasemeter



LPF during AIT at Astrium UK



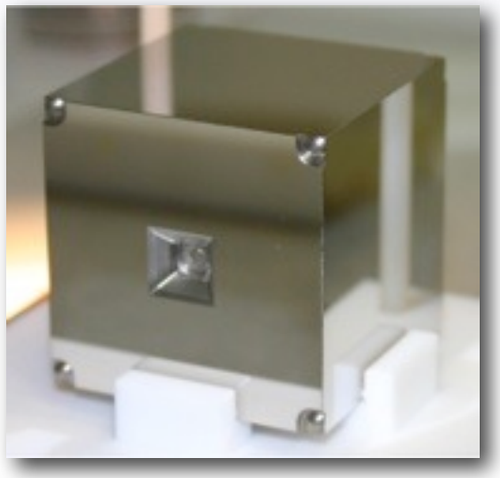
Payload Computer



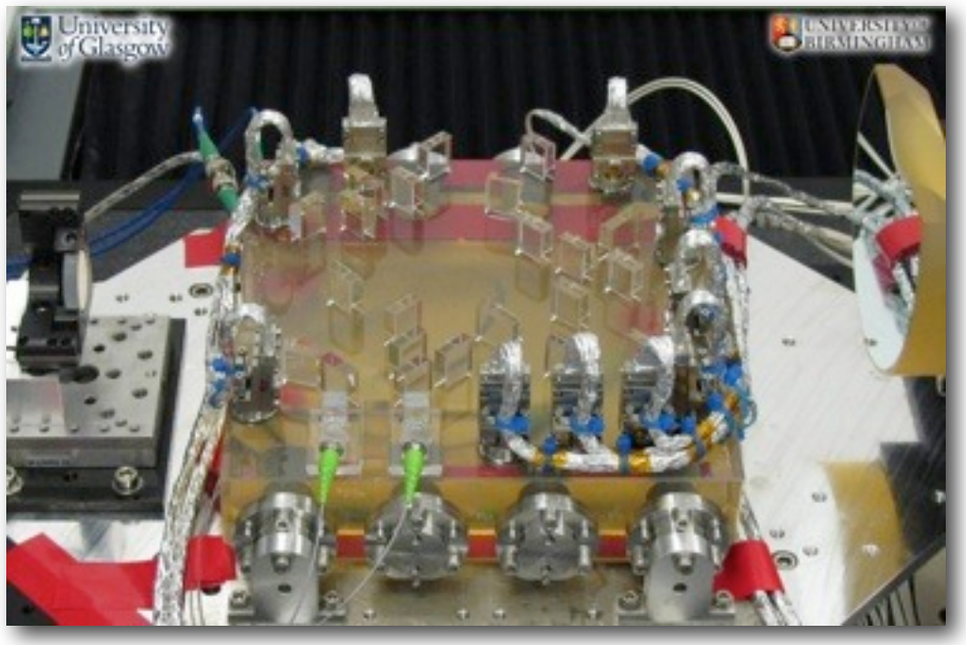
ISS Front-End Electronics

LTP Status

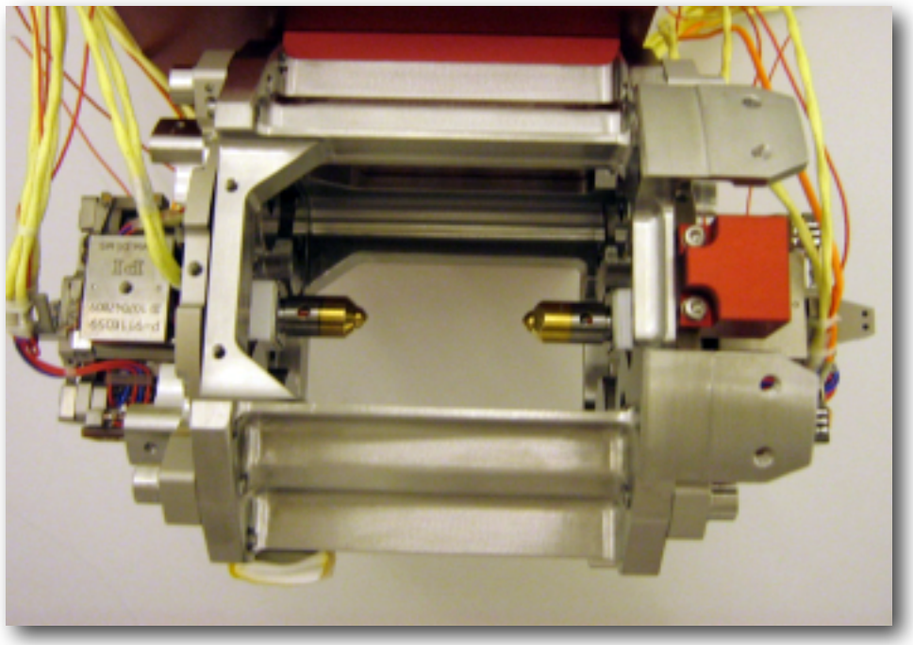
- Most of the components of the LTP Core Assembly are ready, however subsequent integration has been delayed.
  - Optical bench
  - Inertial sensor
    - Test Masses
    - Vacuum enclosure
    - Grabbing, positioning and release mechanism



Uncoated Au:Pt Test Mass



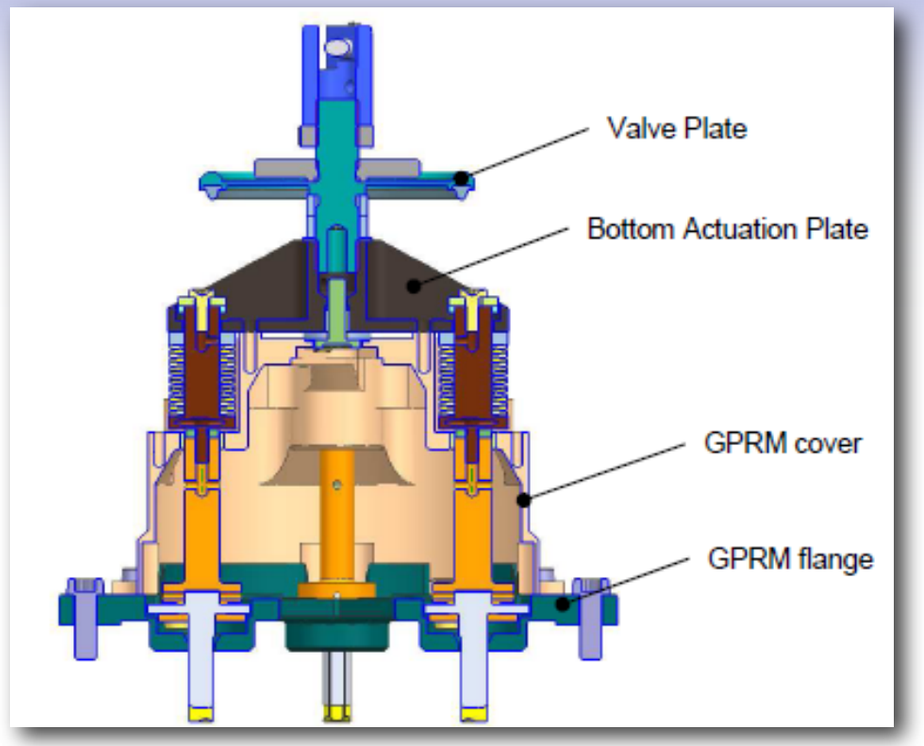
Optical Bench

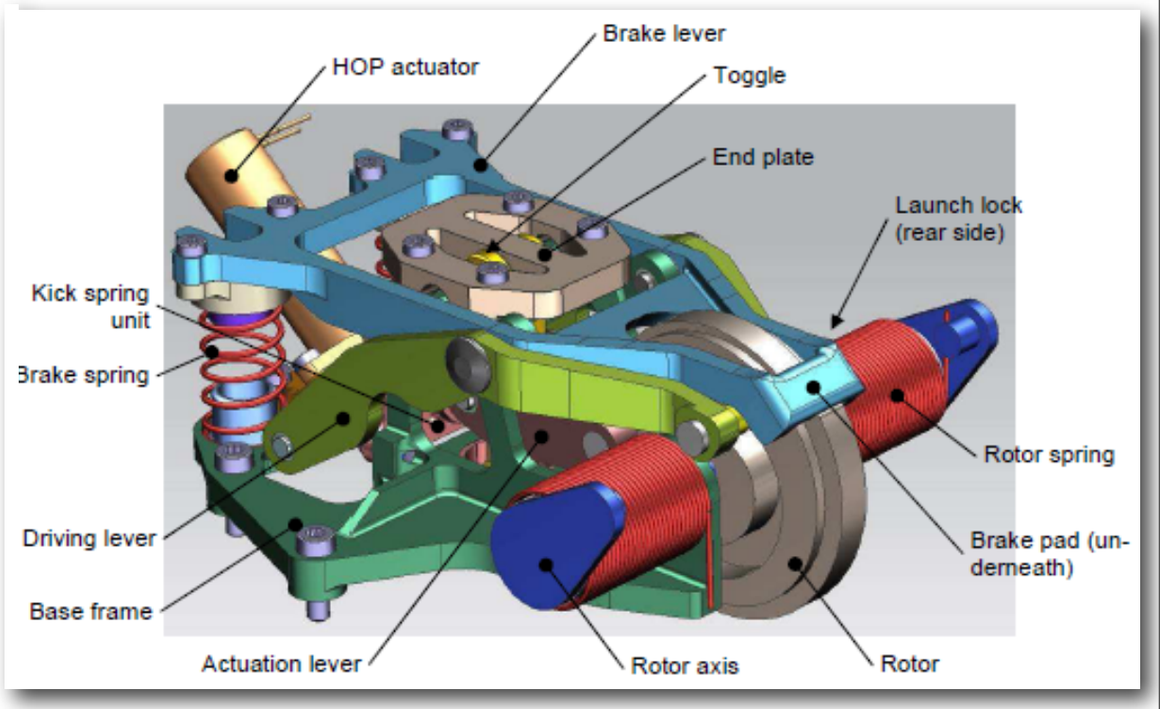


Test Mass Grabbing, positioning and Release Mechanism (GPRM)

LTP Status

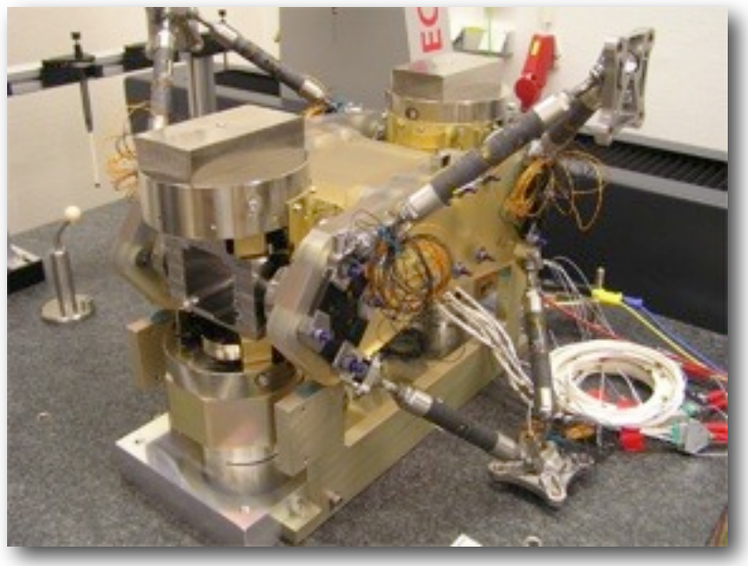
- Delays in the integration, and delivery, of the LTP Core Assembly are due to problems with the test mass launch lock
  - Original (hydraulic) launch lock failed during testing
  - A new design has now been selected, and flight units are being manufactured
    - New design is a much simpler, single-shot mechanism utilising a paraffin actuator
    - Delivery of FMs is scheduled for September 2012

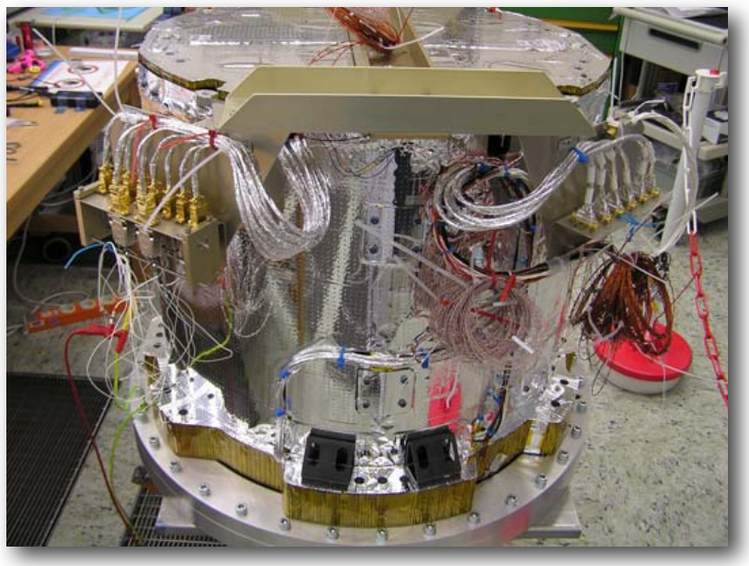


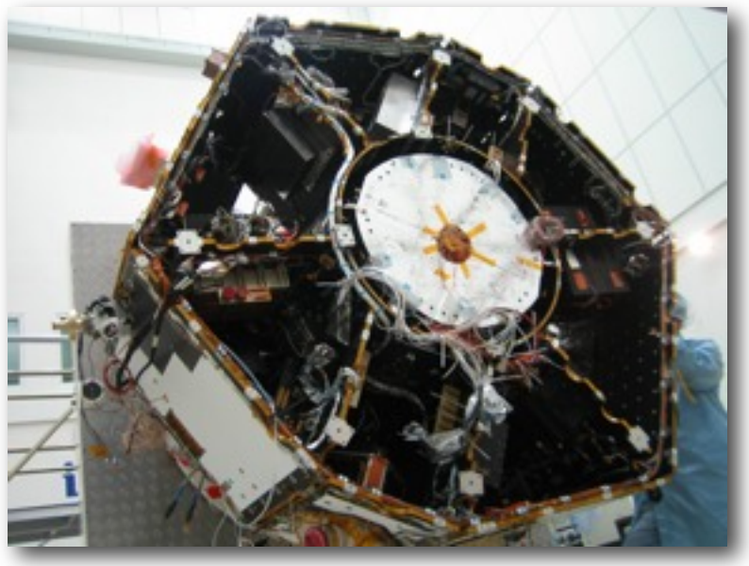


TOQM

- In-lieu of the LCA, a *Thermal-Optical Qualification Model* (TOQM) was created to allow the environmental testing of the spacecraft to proceed
  - Consists of a flight optical bench, with flight mounting struts, and thermal mass dummies of the inertial sensors







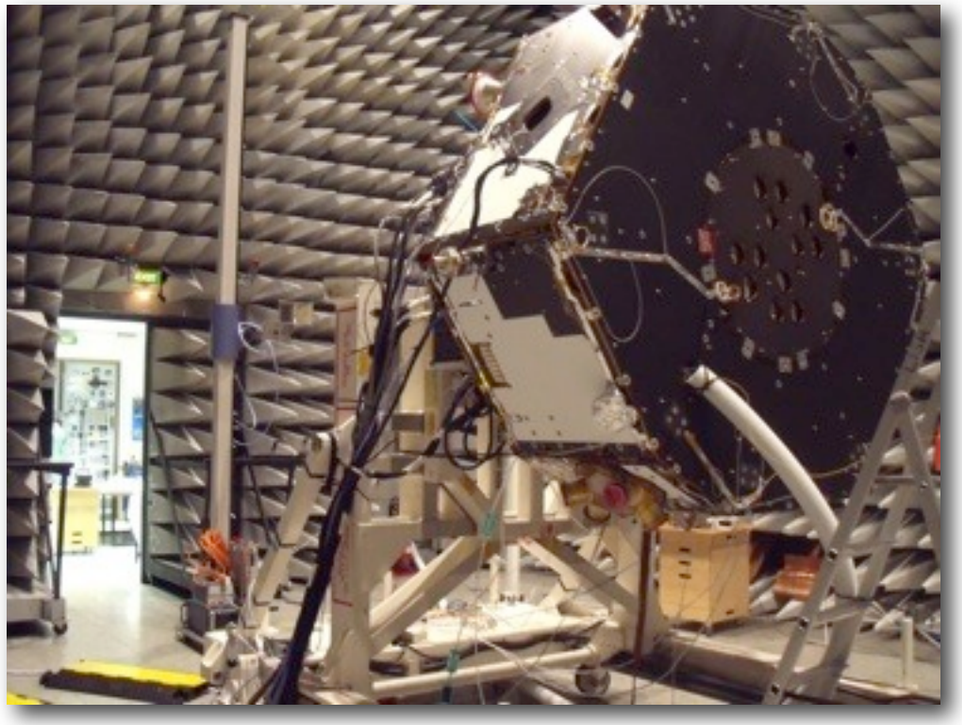
LPF Spacecraft Bus

- All units of the spacecraft bus have been delivered and integrated
  - Only units not yet integrated are the micro-thrusters (which are mounted on the outside on the spacecraft)
- System environmental tests are now complete
- Following closed-loop tests in January, spacecraft will be put into storage awaiting the delivery of the LCA

System Test Campaigns

Sine Vibration

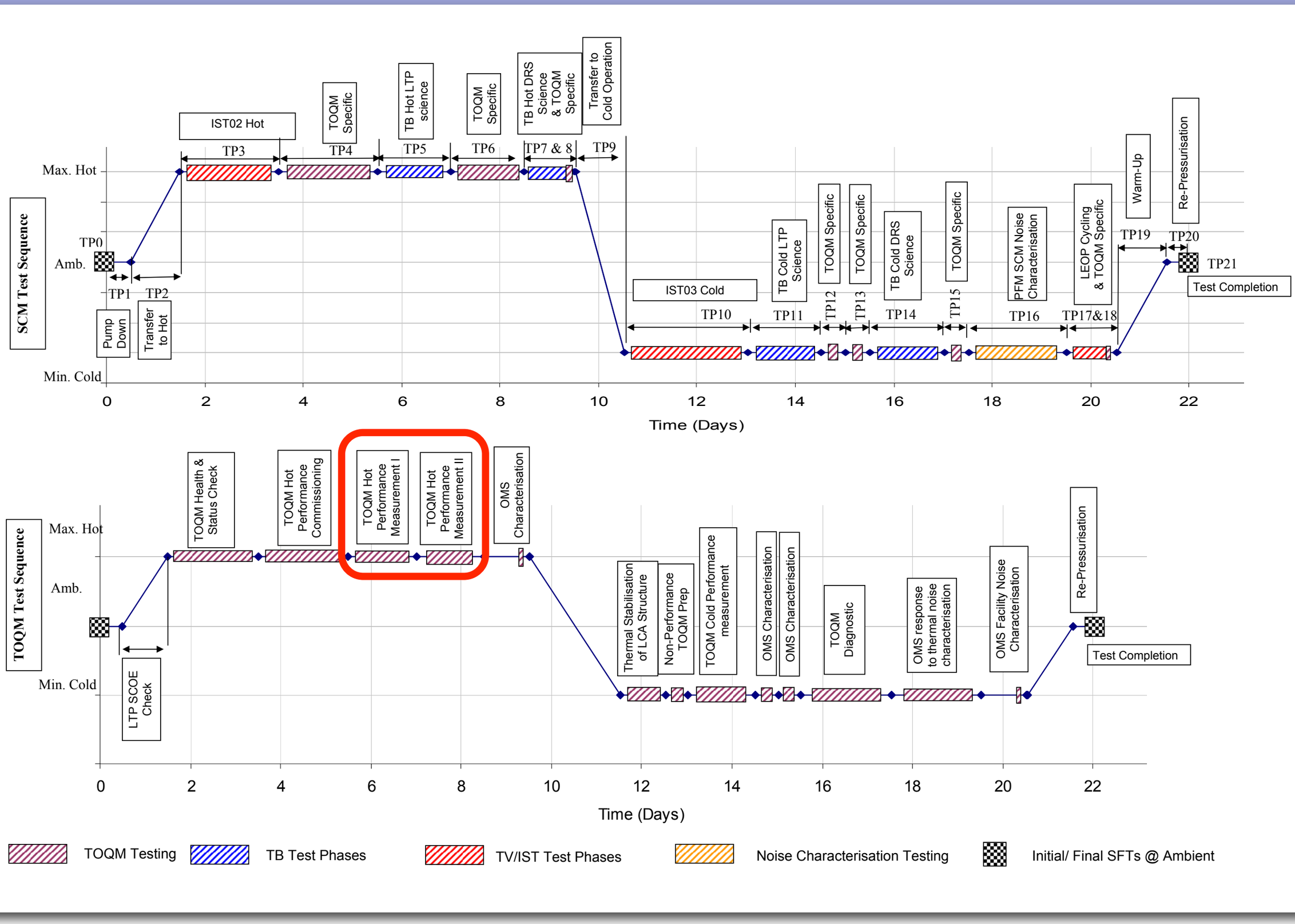
Transfer Orbit Thermal Test



EMC

On-Station Thermal Test

OSTT Sequence



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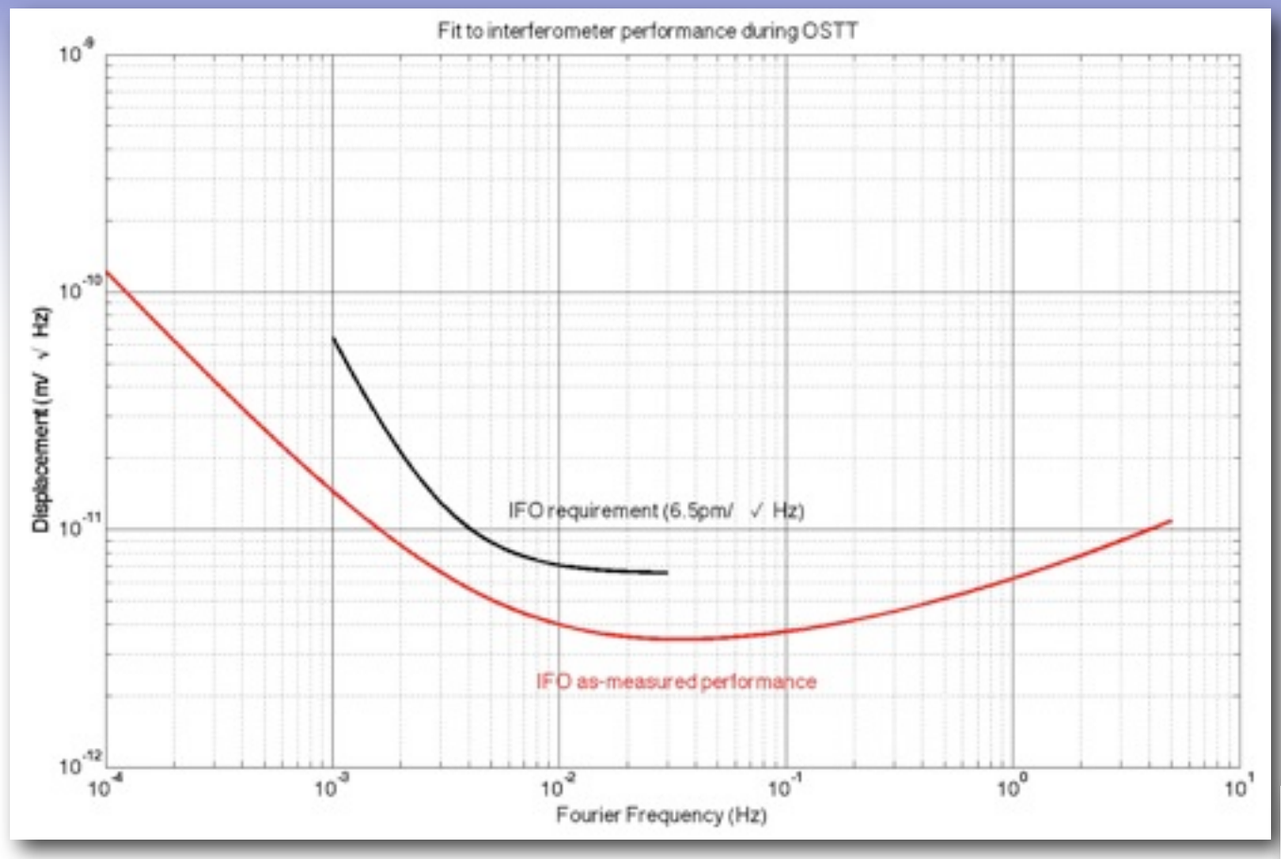
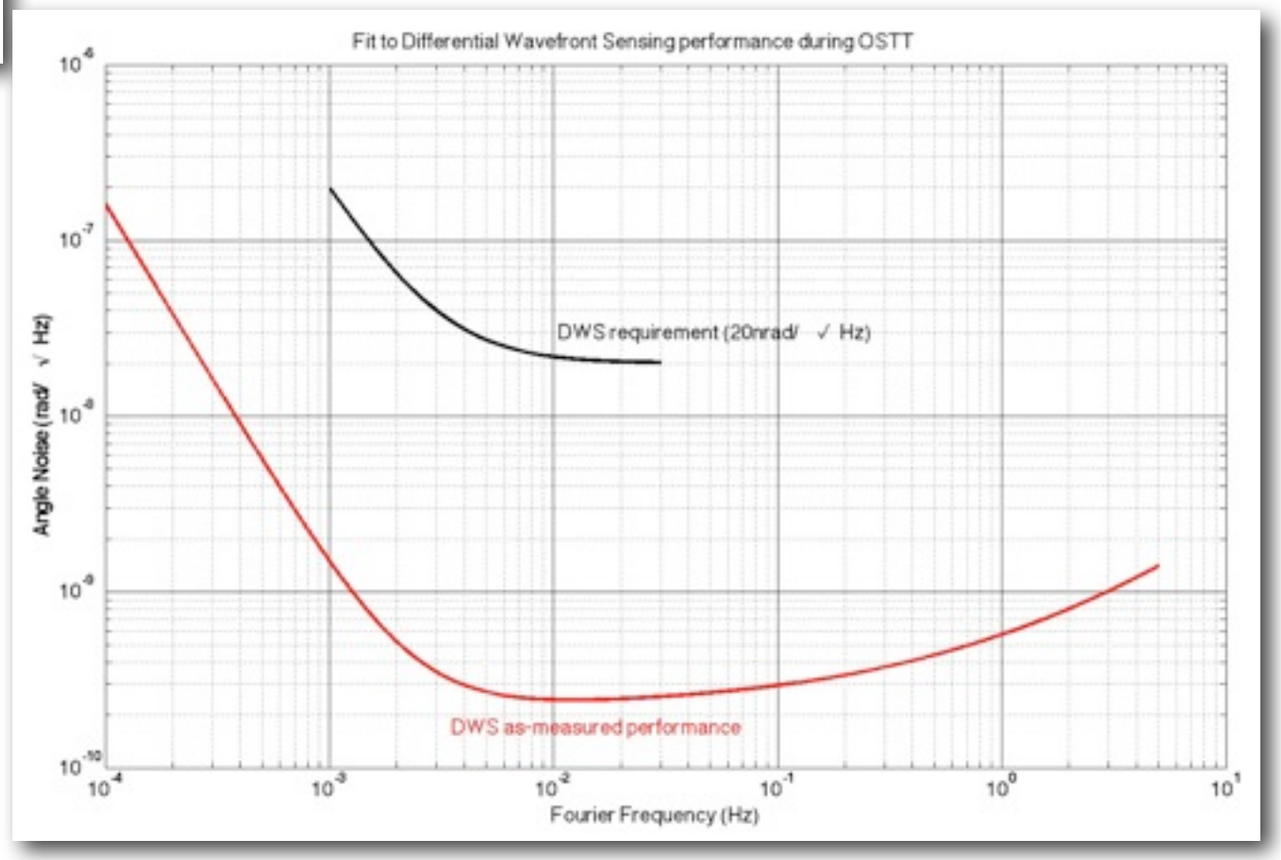
Fit to OSTT Performance





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Micro-thrusters

- LPF will carry two sets of micro-thrusters
  - The NASA supplied Colloidal Thrusters
  - European supplied thrusters
- The baseline thruster for LPF is the Cs Field Emission Electric Propulsion (FEEP) thruster
- Due to delays in the qualification schedule of the FEEPs, the project has recently instigated a review of the use alternative thrusters for LPF
  - Cold Gas thrusters (the GAIA thruster)
  - Micro Radio-frequency Ionisation Thrusters (μ-RIT)

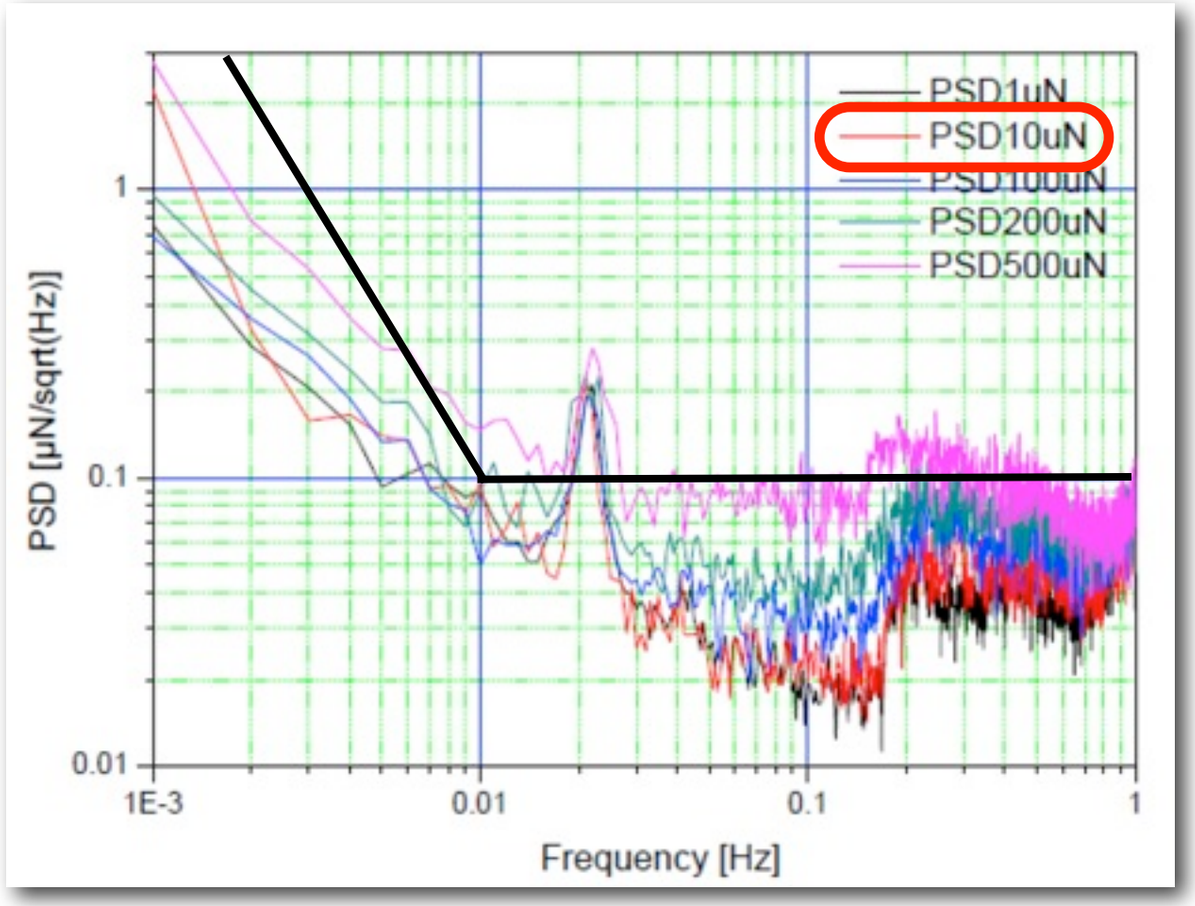
Micro-Thrusters

Review Board Conclusions (May 2011):

- Continue FEEP development, culminating in two tests demonstrating the LPF lifetime (600Ns) by June 2012
- Industry to study the cold gas thrusters, with PDR to be held in October 2011
- Industry to study micro-RIT thrusters with SRR in September 2011, and PDR by the end of the year

As of now:

- Cold Gas PDR was successful
  - Major issue is the schedule for the delivery of the thruster units
  - Board recommended to start the procurement of the long-lead items before the decision is made on the flight thruster technology
- Micro-RIT
  - SRR has been held
  - Development of the technology will continue up to PDR level



Measured thrust noise of GAIA thrusters

Micro-Thrusters

- Review Board requested that the FEEP tests continue into next year
  - Culminating in two thruster assembly endurance tests, both of which must demonstrate the full LPF total impulse requirements.
- After thorough investigation, the FEEP thruster head has been redesigned to limit caesium leakage from the emitter slit
  - Achieved in part by narrowing the slit width from 1.3μm to 0.7μm
- Ongoing thruster unit validation test is demonstrating that the new design of thruster is working perfectly!!
- Downselect on which thruster to take to flight will be made in June 2012.

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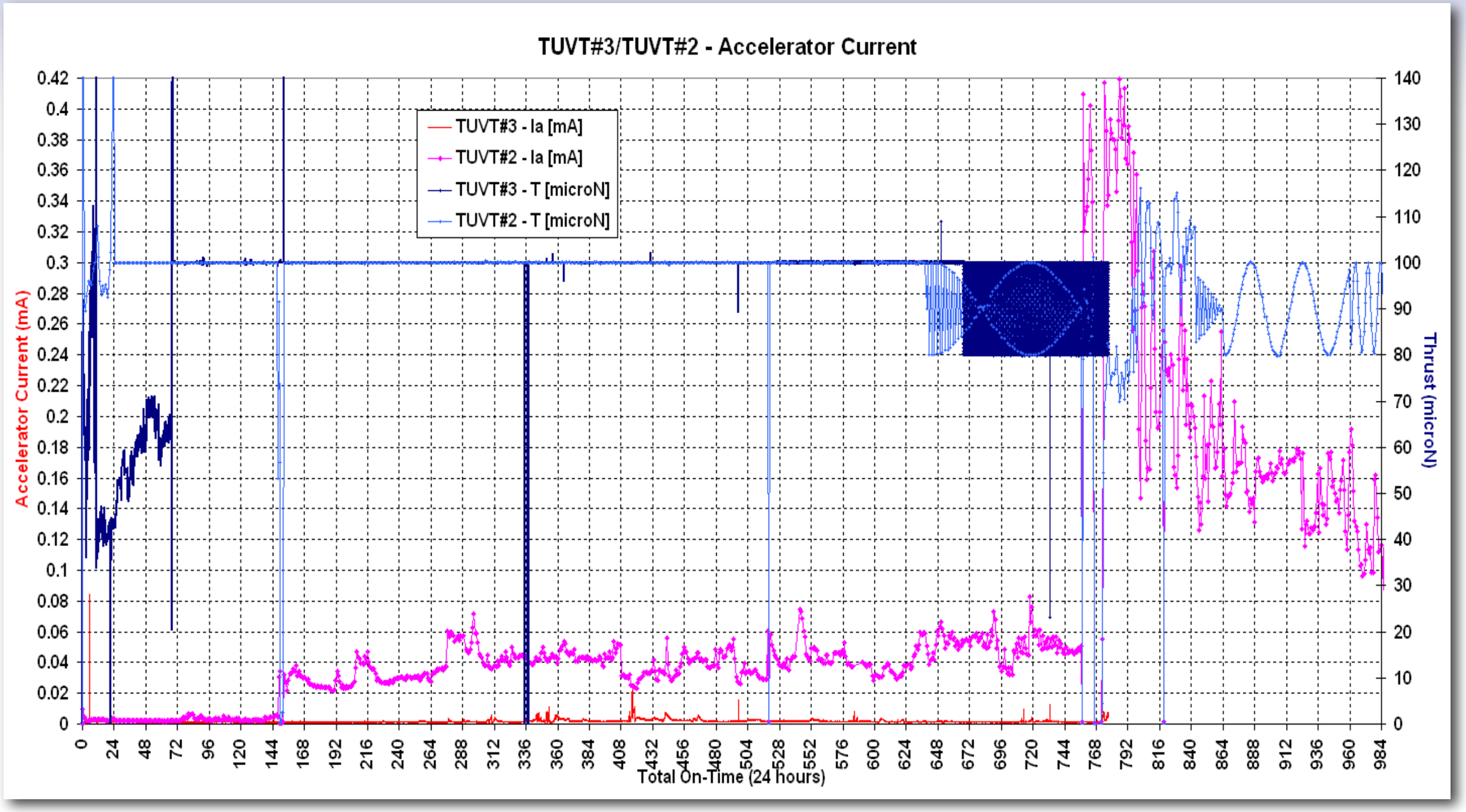
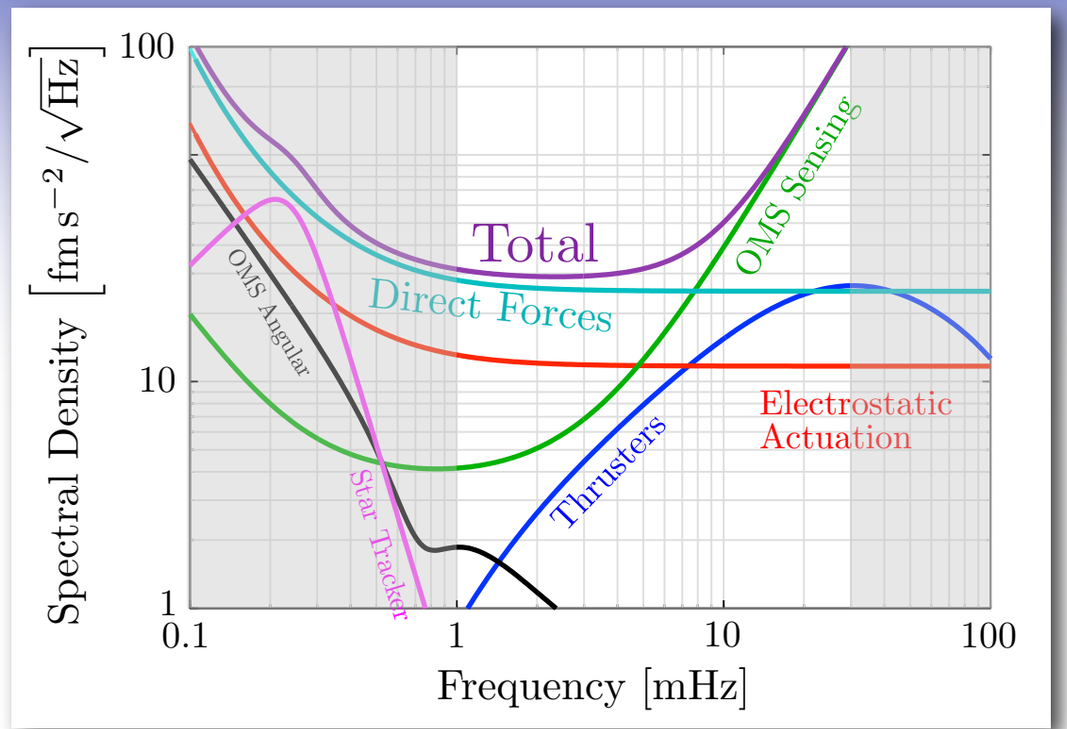
Micro-Thrusters



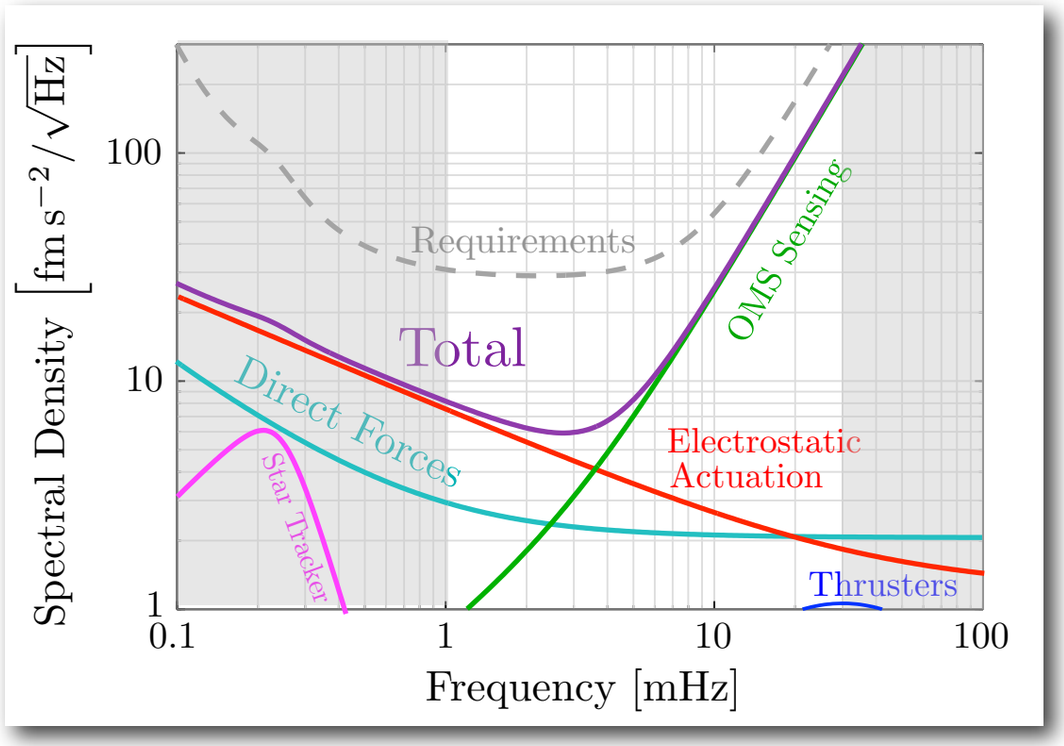
NB: As of today, total impulse now at ~300Ns (~900hours). Equivalent to ~50% of LPF total impulse requirement

LPF Performance

- Extensive performance noise model has been developed by both the PI and industry
- The main goal of LPF is to validate this noise model
- Model is updated as ground test results become available
- Current Best Estimate of LPF is now approaching the NGO requirements!



Requirements noise projection



Current Best Estimate

In Summary

- All environmental tests complete
- The caging mechanism launch lock drives the critical path
- Results from OSTT (TOQM) demonstrate performance better than requirements
- Cold Gas thrusters are a viable alternative to the FEEPs.
- The project will enter hibernation at the beginning of next year
  - Hibernation is scheduled to last ~15months
- Launch is scheduled for June 2014.

Thank you

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- University of Trento
- Albert Einstein Institute
- University of Glasgow
- University of Birmingham
- Imperial College London
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