LISA Pathfinder

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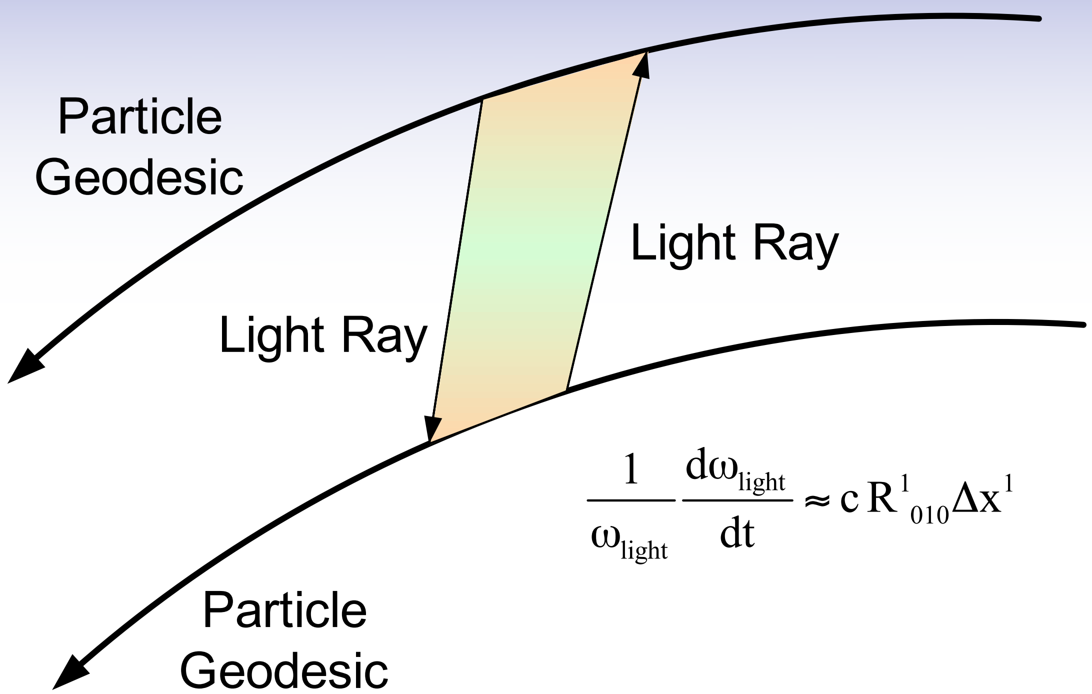
Why LISA Pathfinder?

- The science case for LISA is extremely compelling and has continually been highly ranked by independent review boards
- However, both ESA and NASA believed that the risk was too high to fly LISA with an unproven measurement concept
- LISA Pathfinder (LPF) was instigated by ESA to test the concept of low-frequency gravitational wave detection
- The LPF development has shown that the technologies required for LISA are difficult, but not impossible
  - LPF has already solved many of the challenges associated with low frequency gravitational wave detection

LISA Pathfinder Introduction

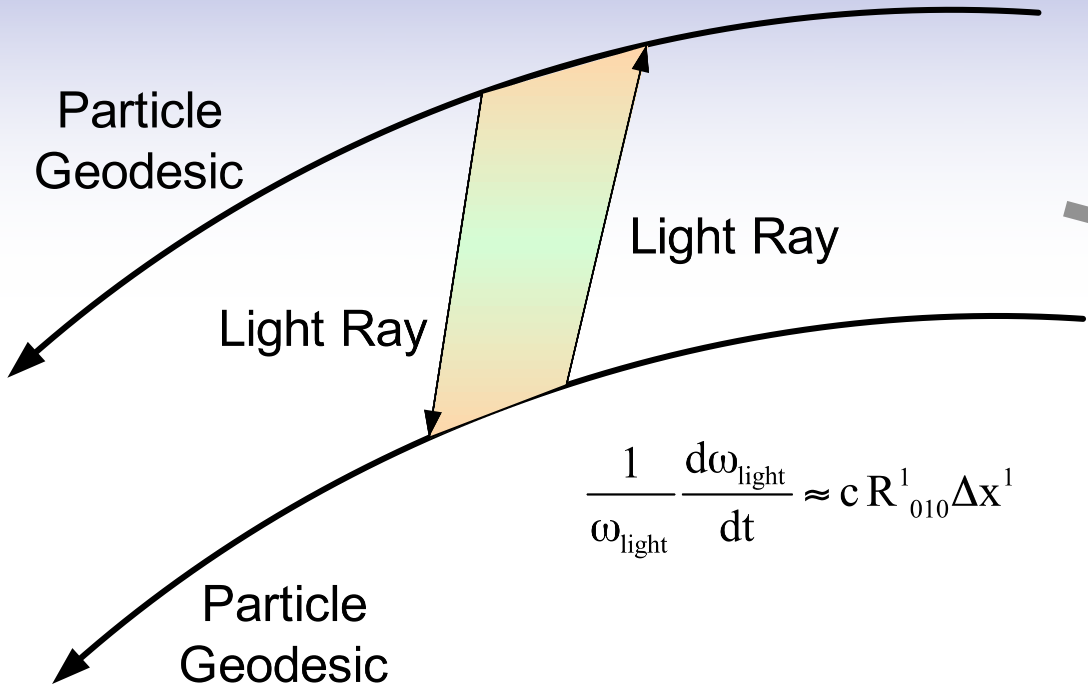
- The LISA Pathfinder mission will test in flight:
  - Inertial sensors
  - Precision interferometry between free floating test masses
  - Drag Free and Attitude Control System (DFACS)
  - Micro-Newton propulsion technology
    - Field Emission Electric Propulsion (FEEP)
    - Colloidal thrusters (provided by NASA - JPL)
- The basic idea of LISA Pathfinder is to squeeze one arm of the LISA constellation from 5 million km to a few tens of cm!
  - Fully tests LISA short arm interferometry

Mission Concept



$$\frac{1}{\omega_{light}}\frac{d\omega_{light}}{dt} \approx c\,R^{1}{}_{010}\Delta x^{1}$$

Mission Concept



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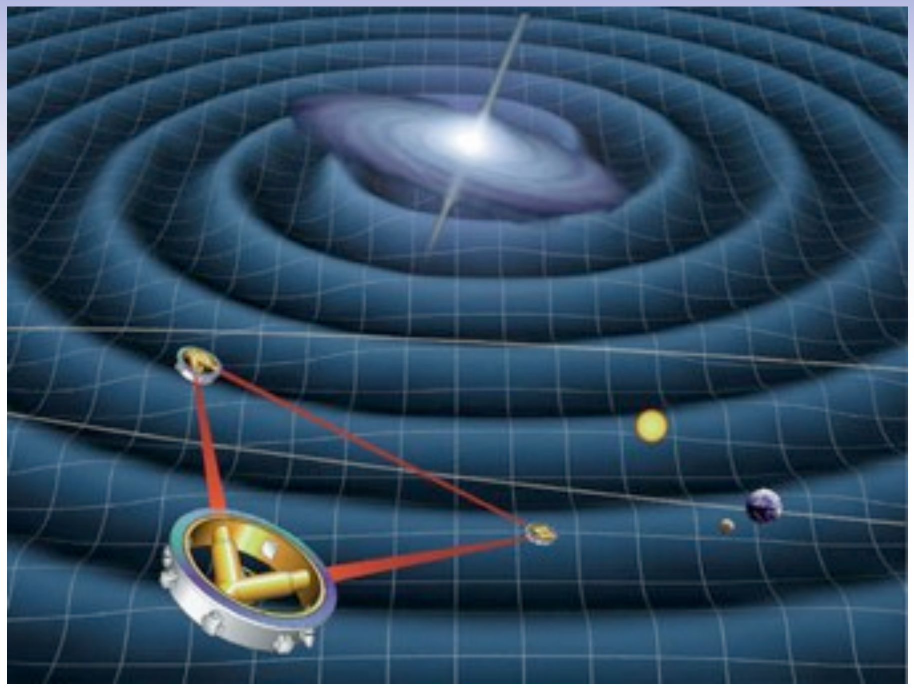

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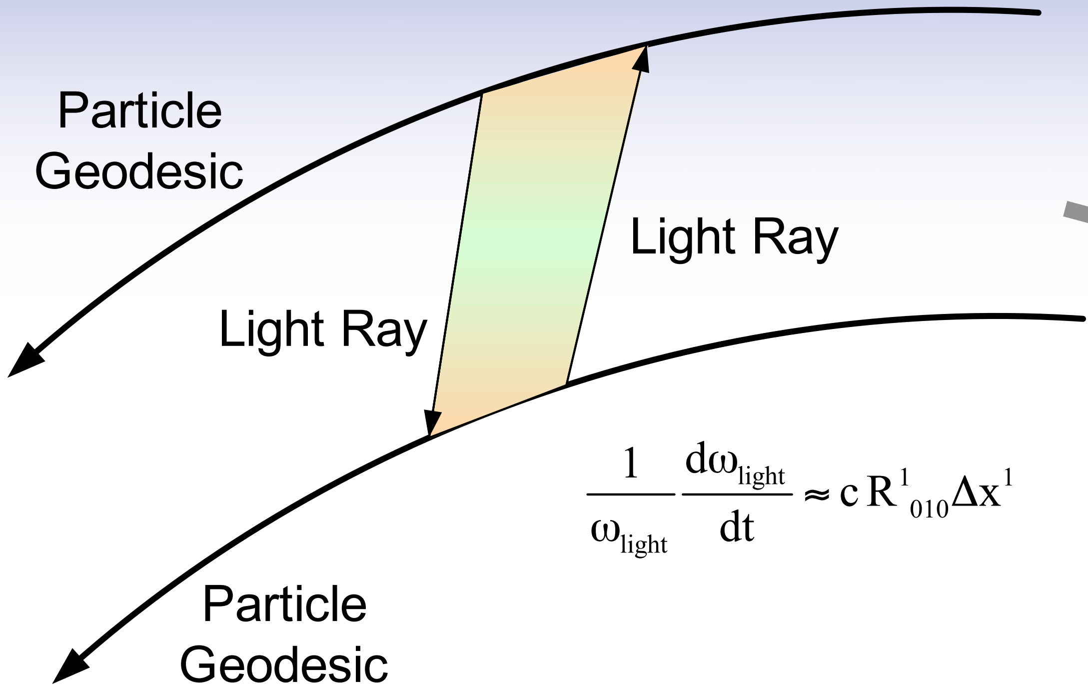

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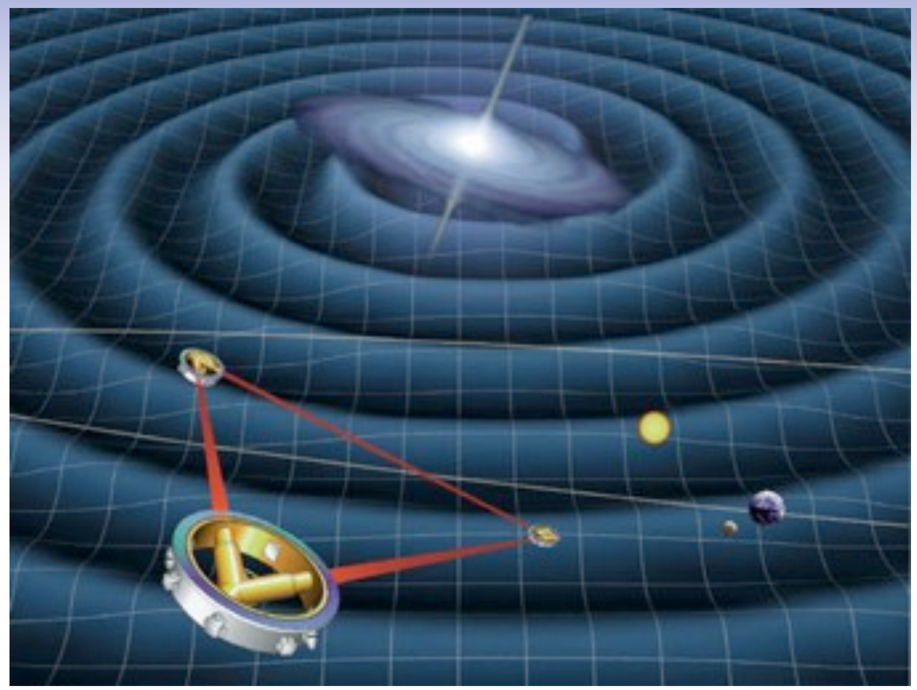

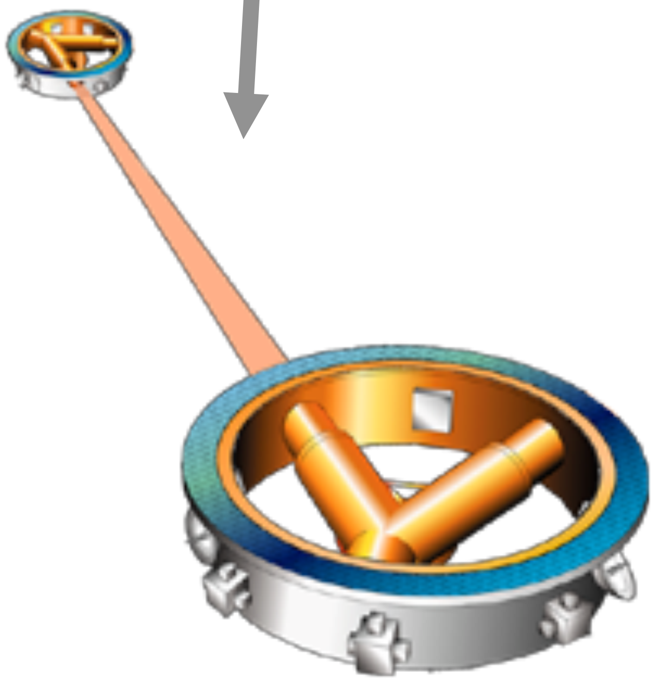

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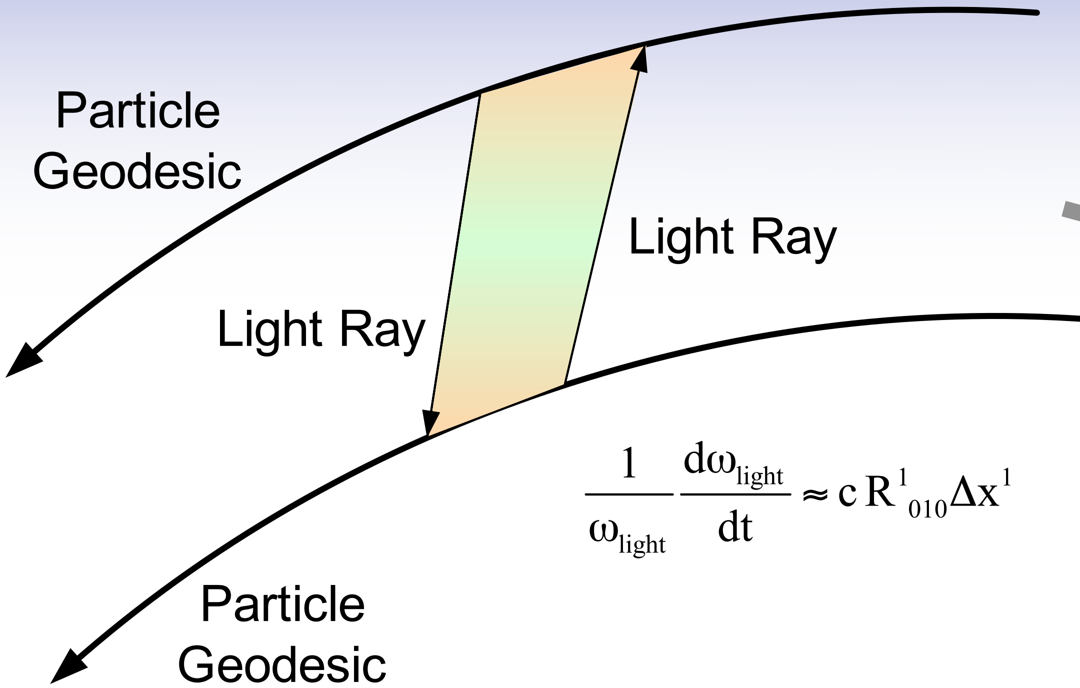

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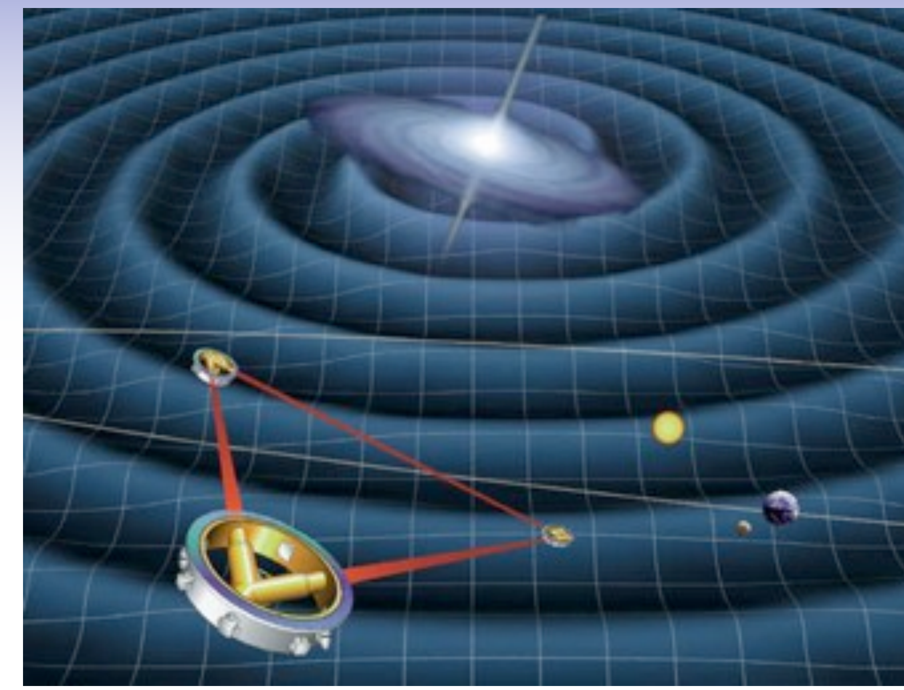

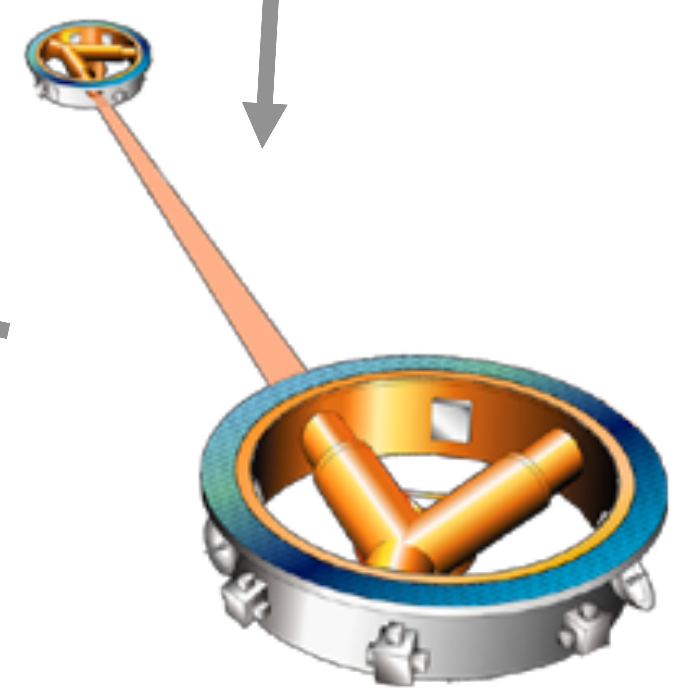

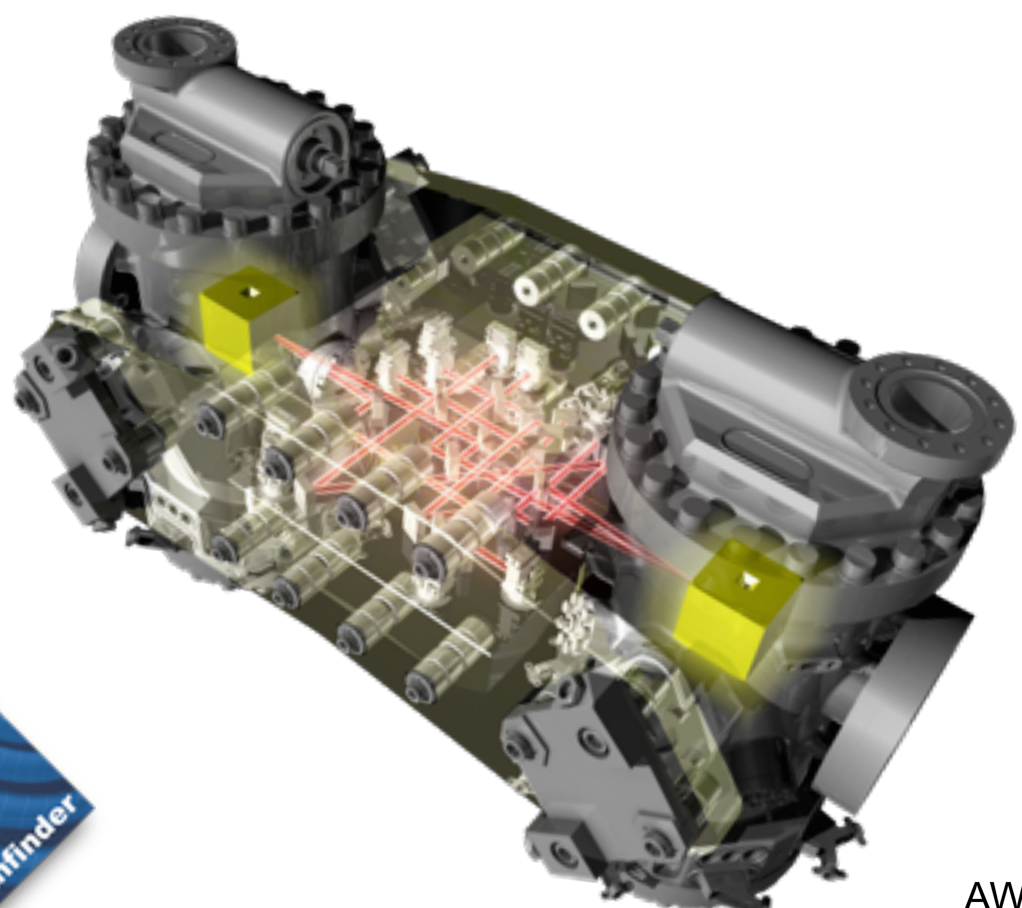

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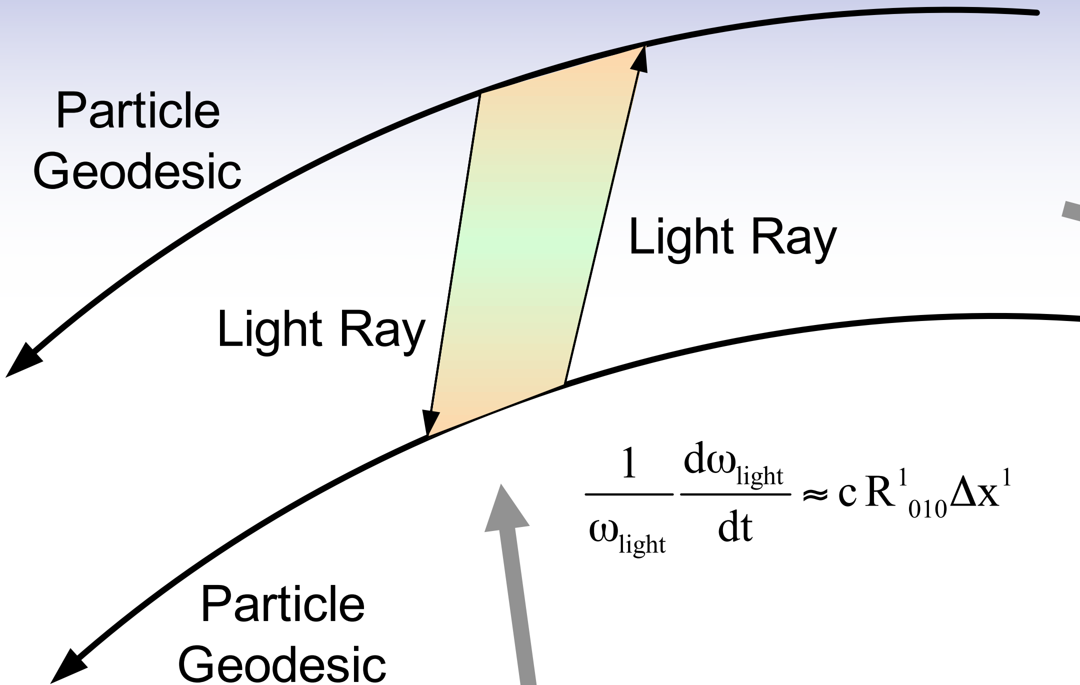

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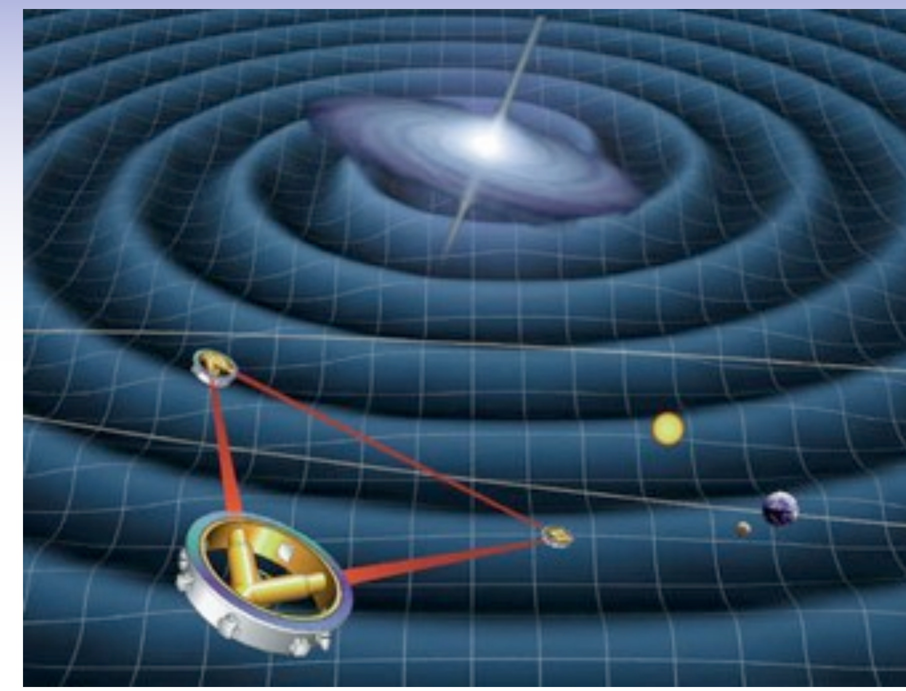
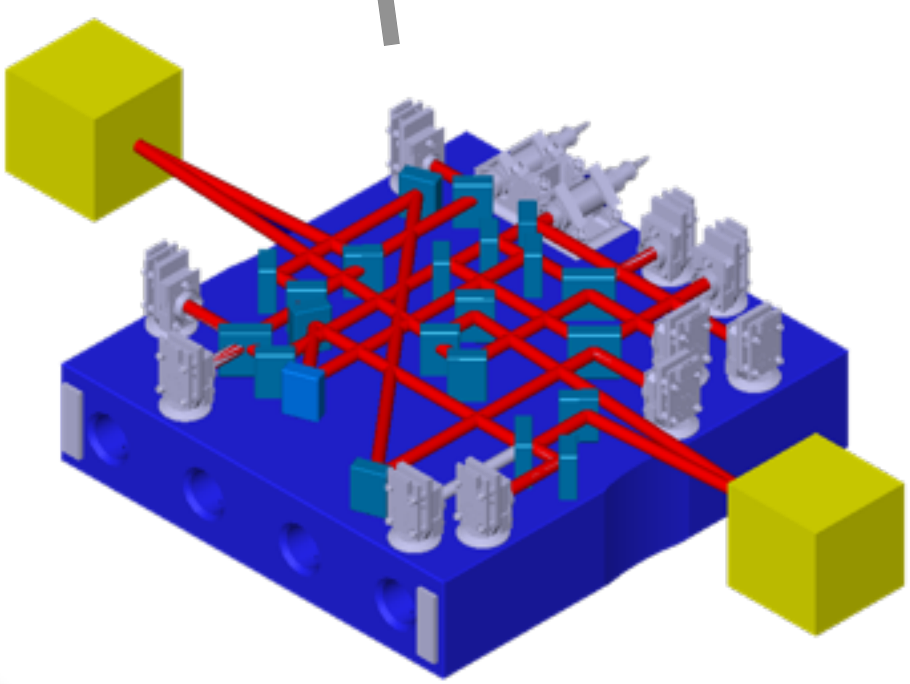
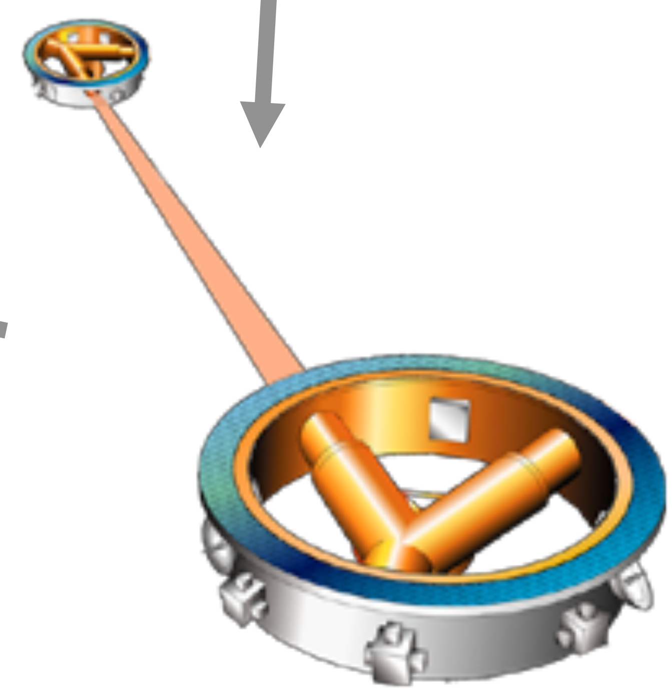
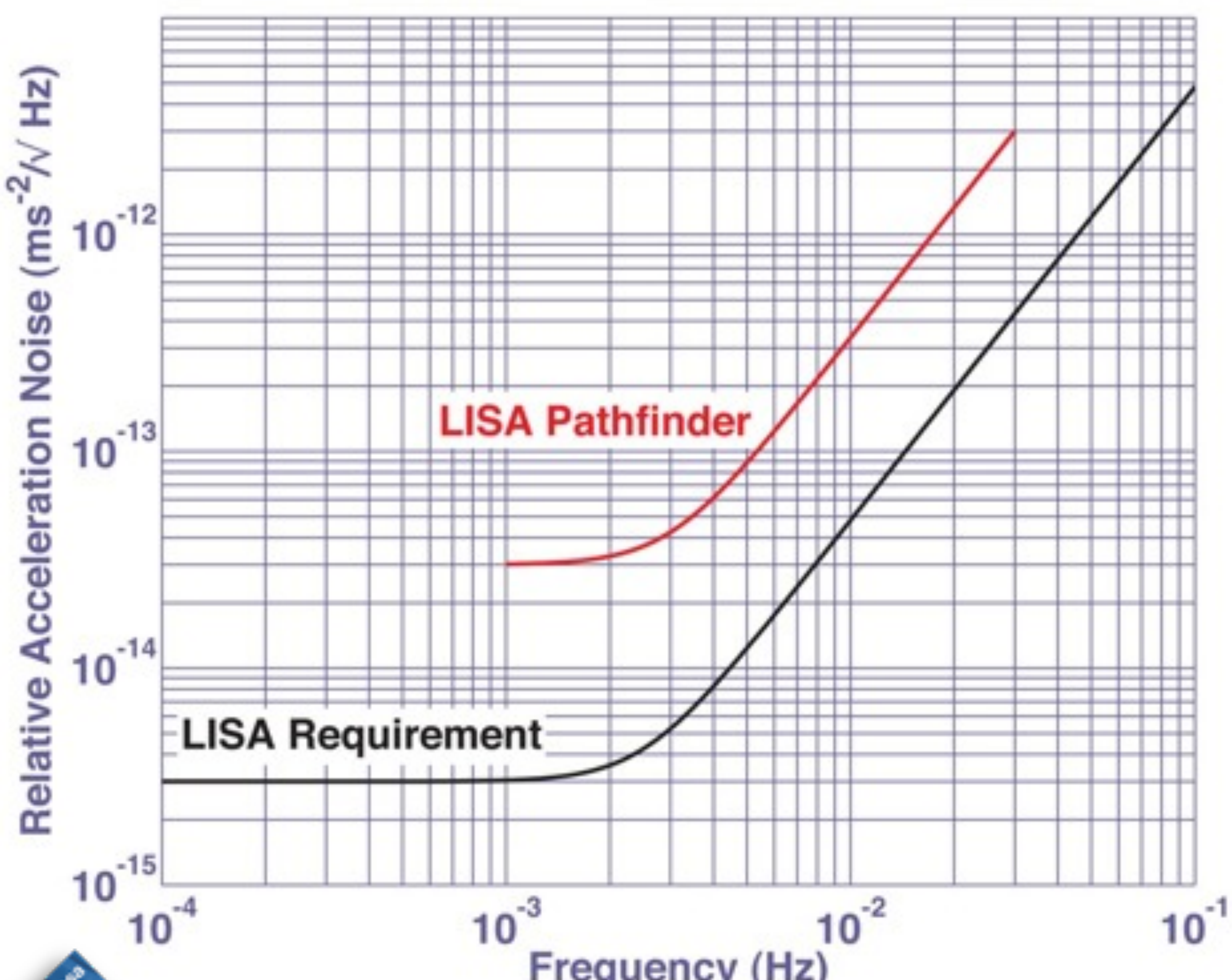




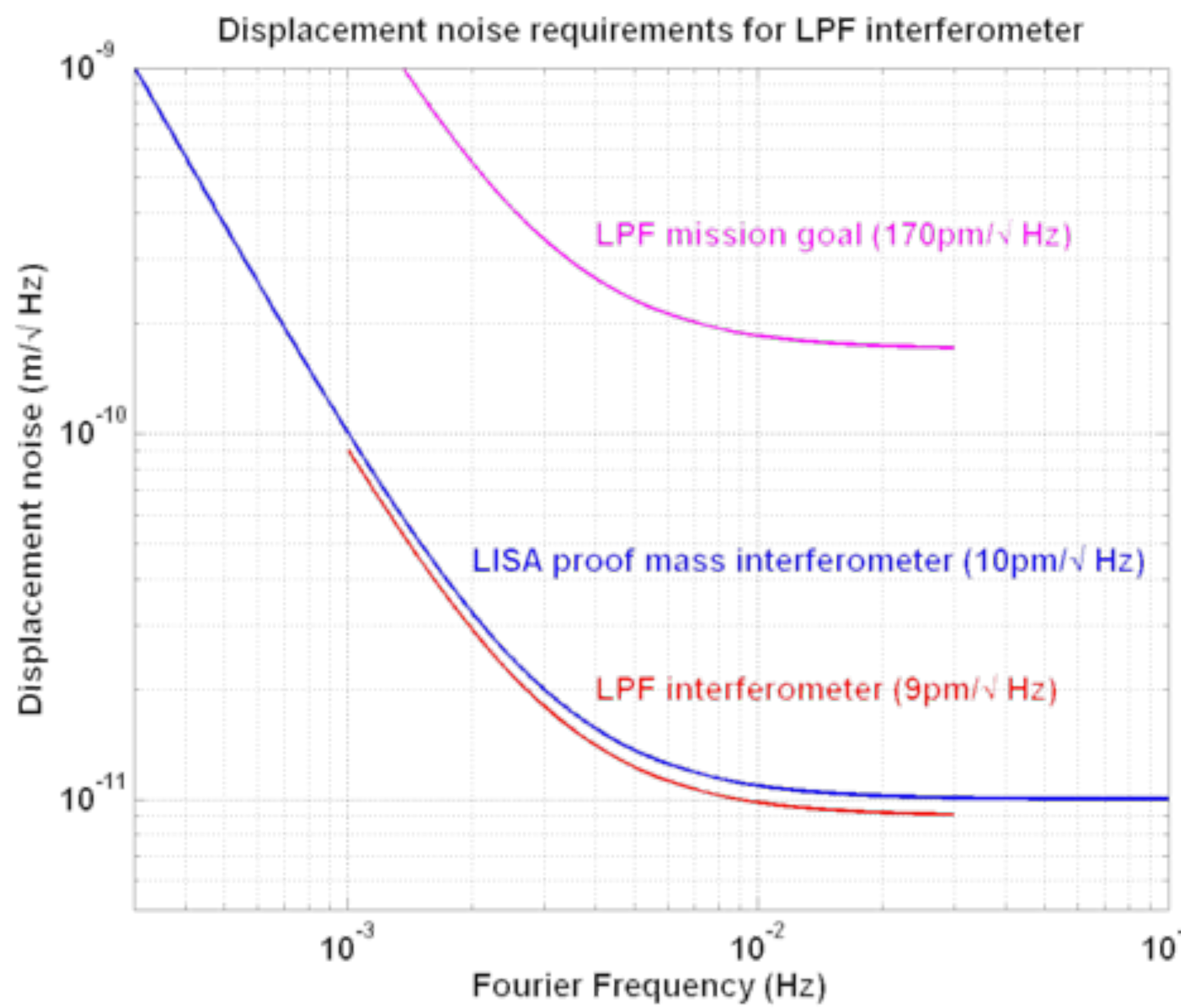


Primary Science Requirements

- LISA Pathfinder has two main science requirements
  - Differential Acceleration noise
  - Displacement noise

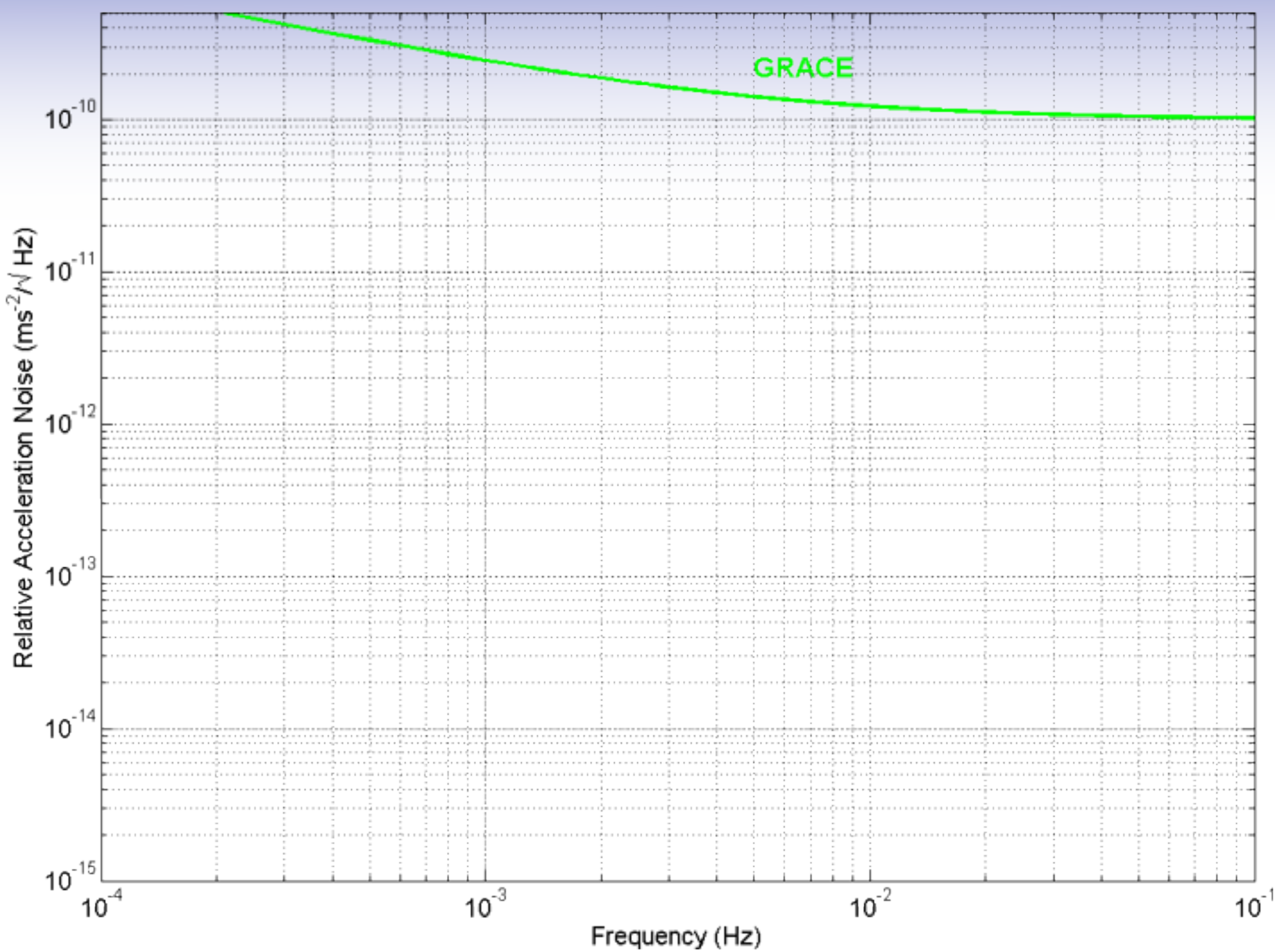


Acceleration Noise



Displacement Noise

Performance Comparison



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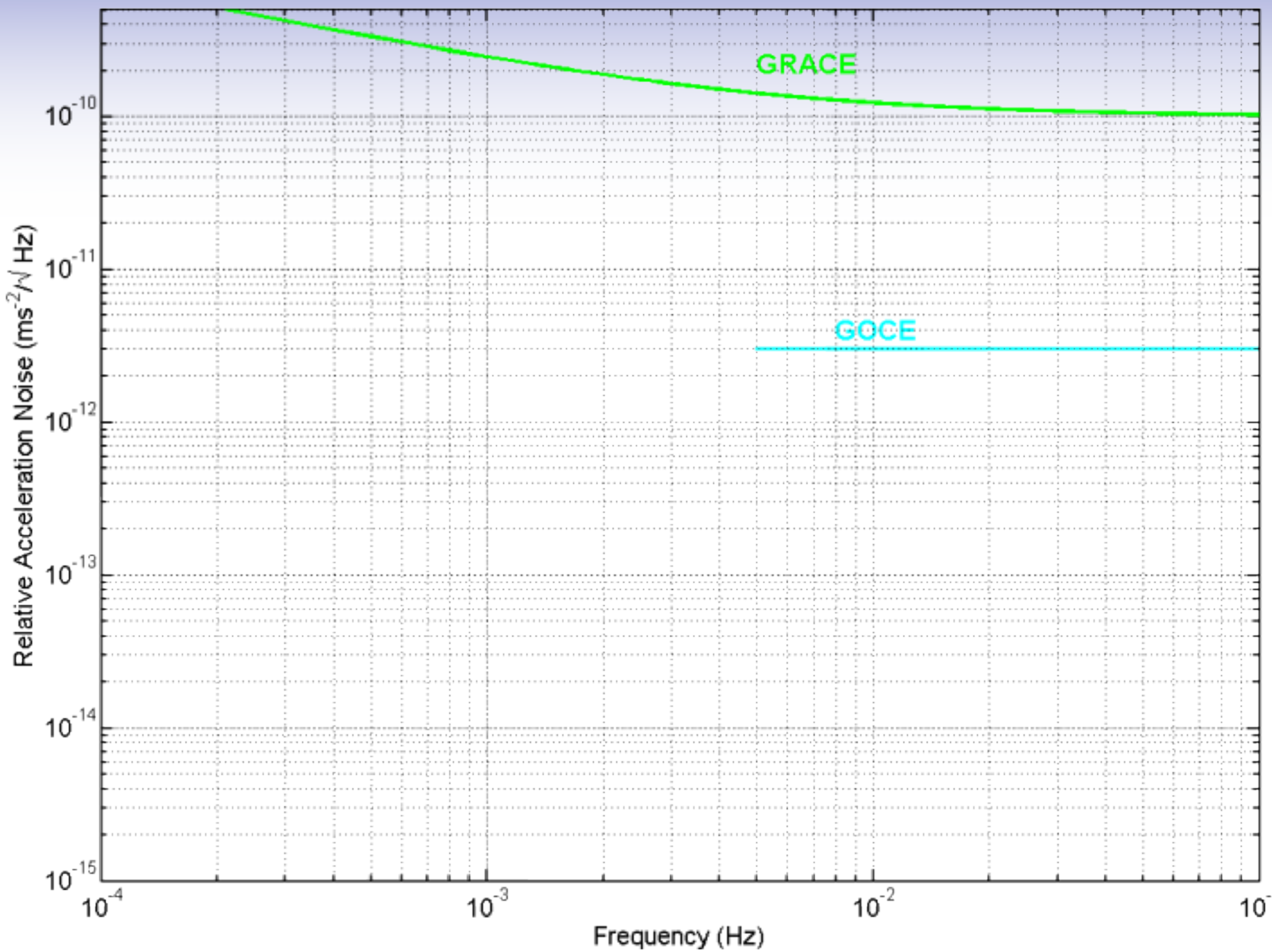

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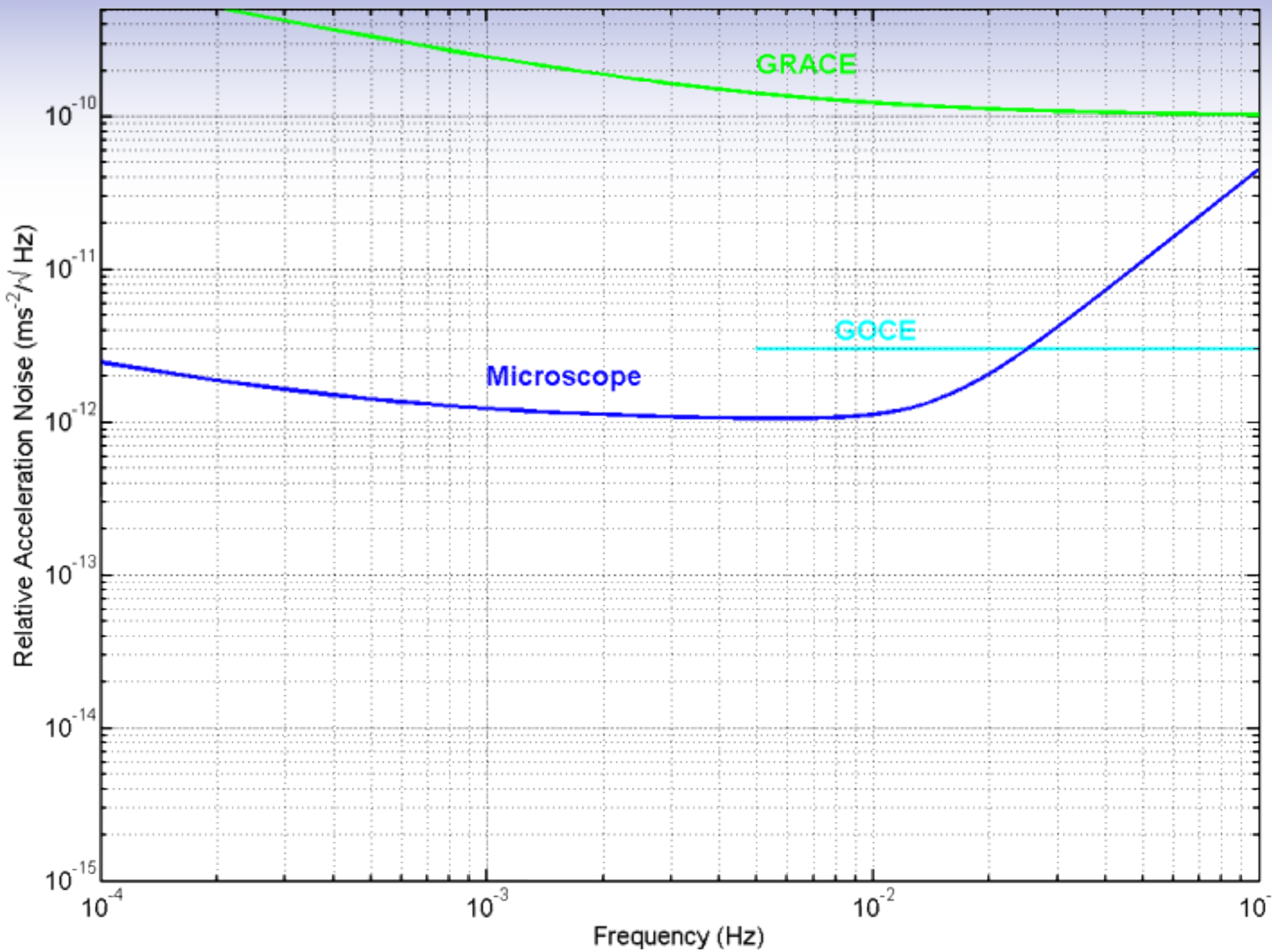
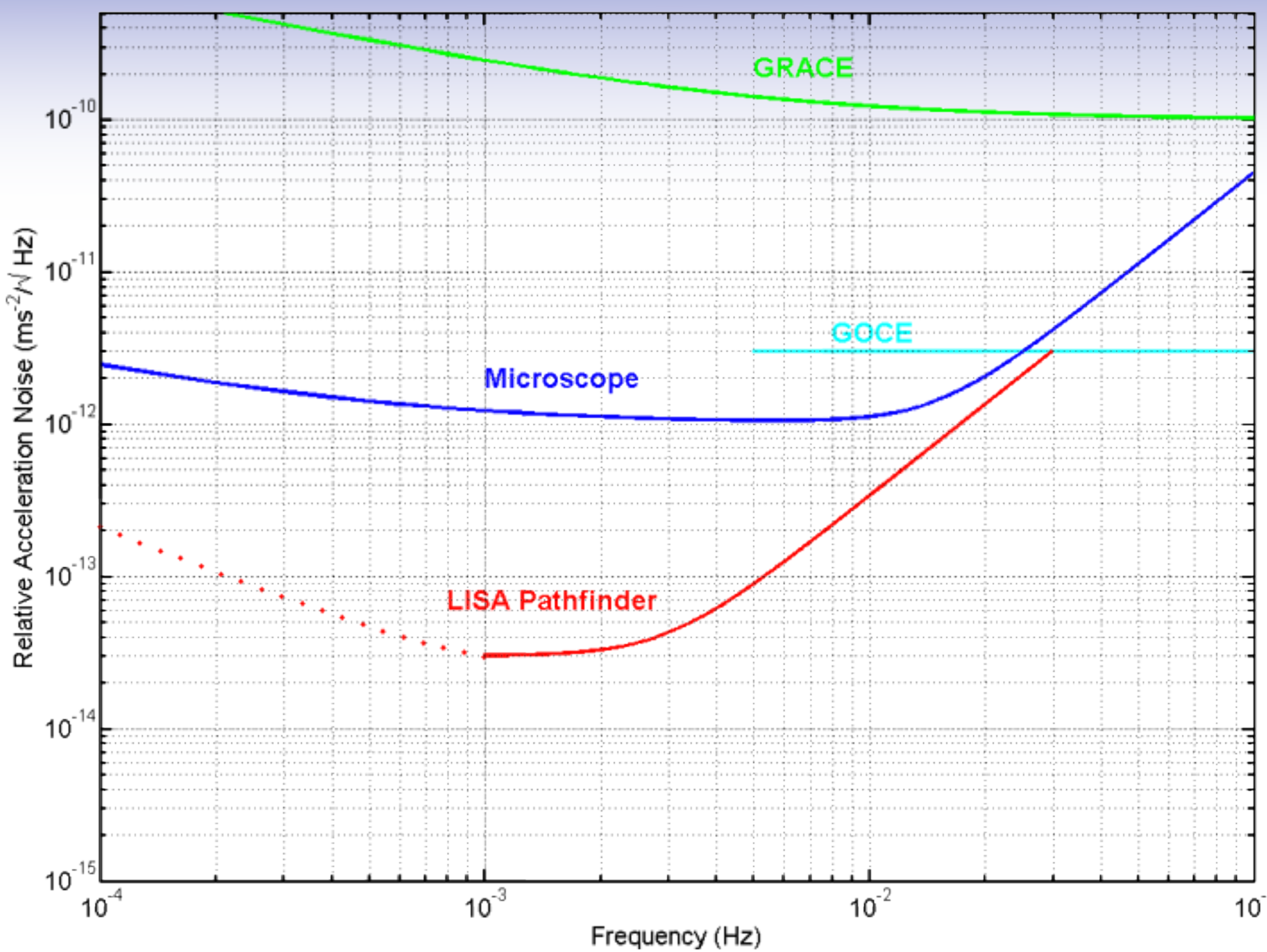


esa SCIENCE

Performance Comparison



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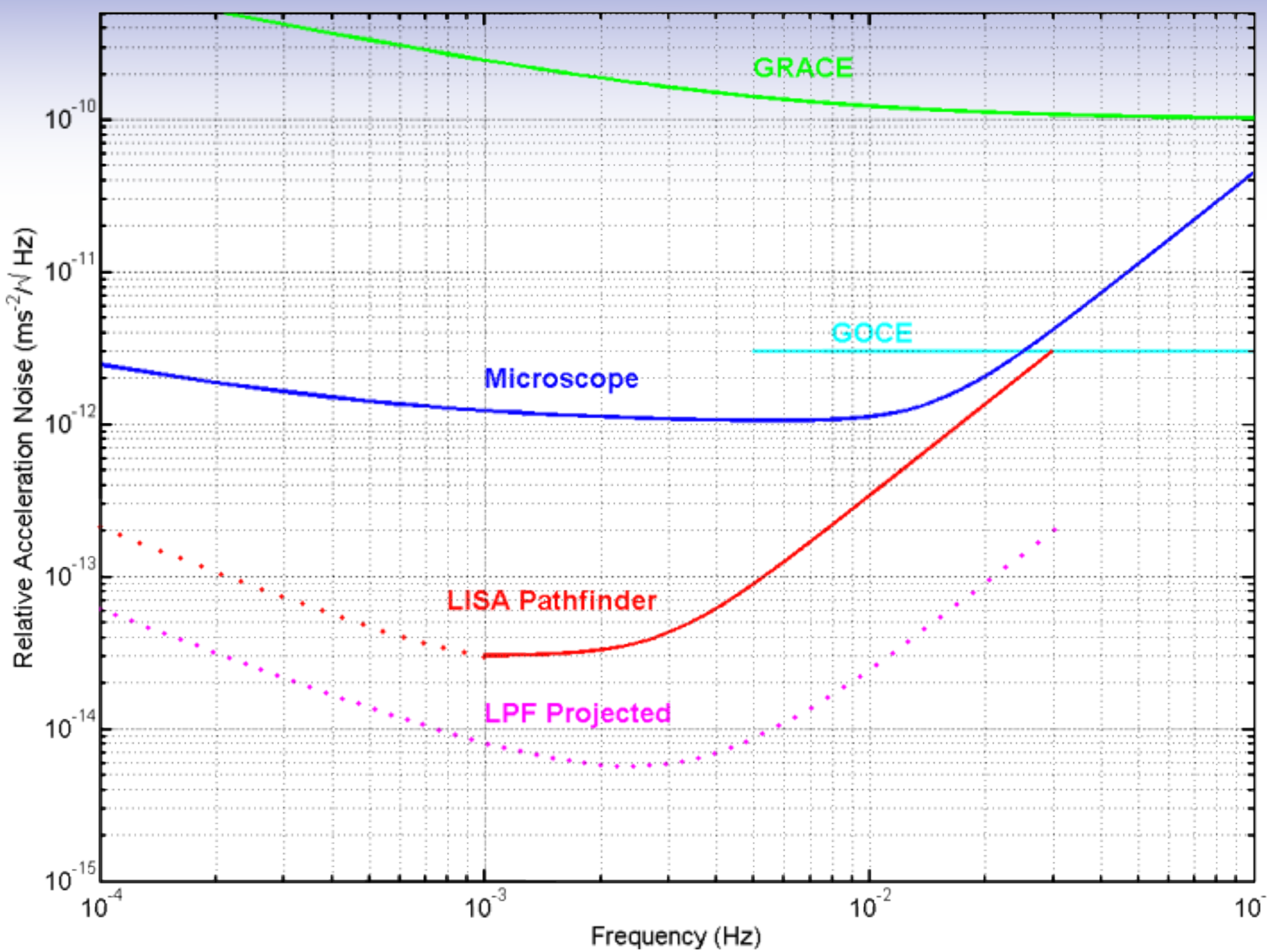

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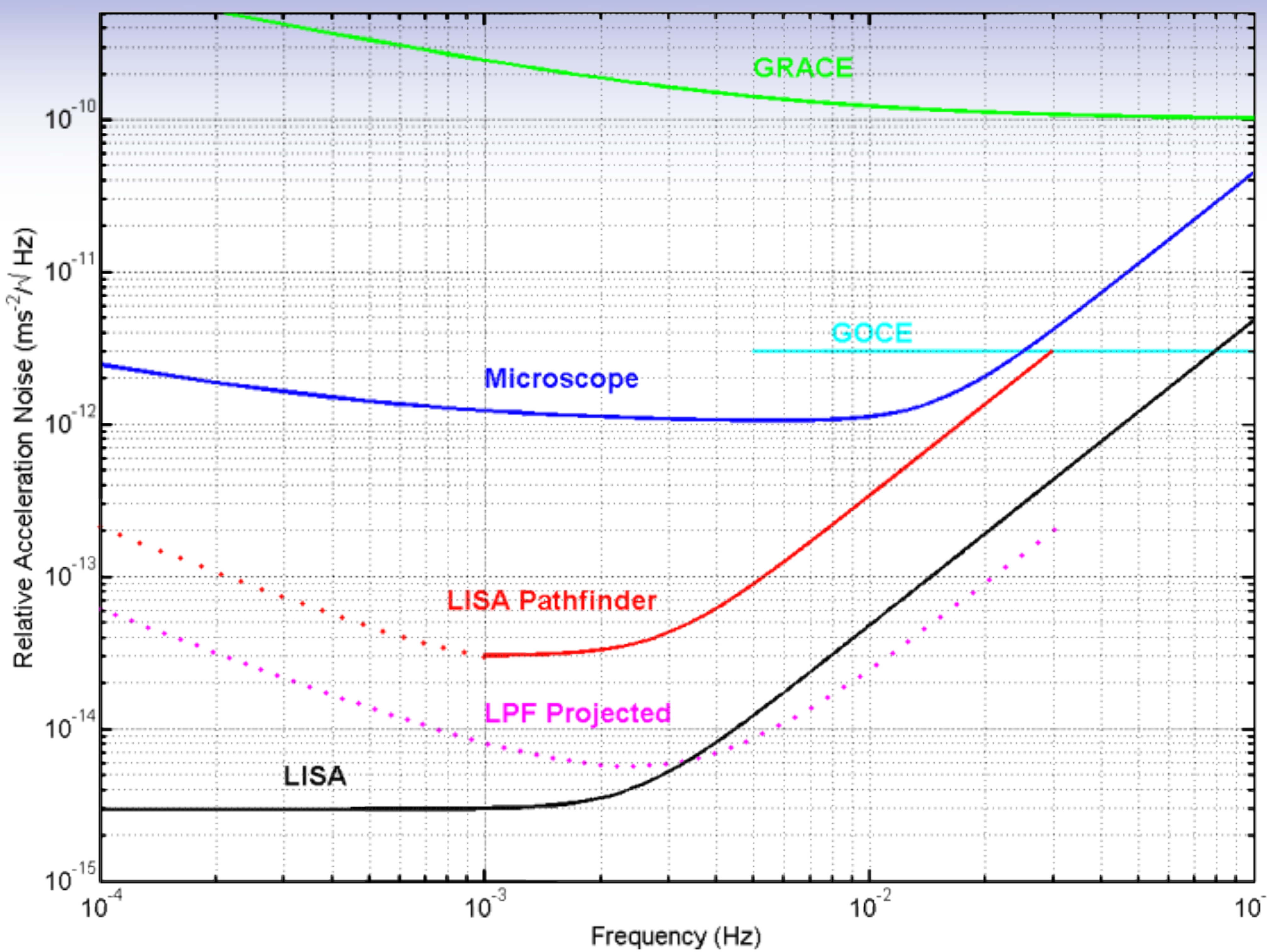
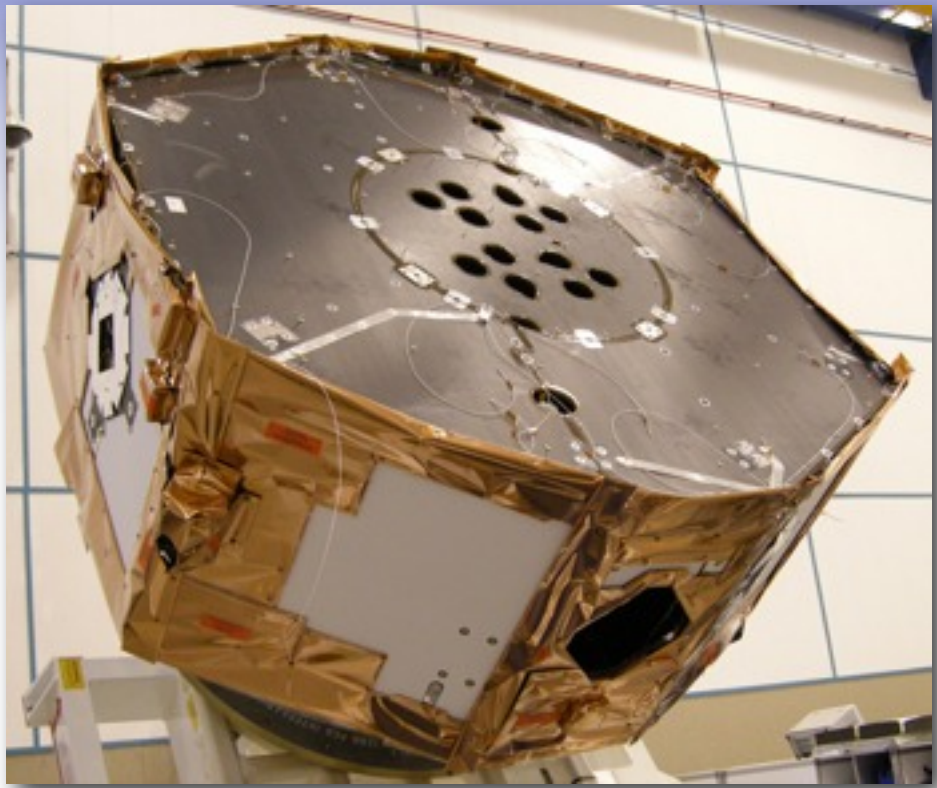


LPF: Current Status

- LTP[1] CDR[2] passed in November 2007
- LPF CDR passed in December 2008
- LPF STOC[3] CDR passed in Sept 2009

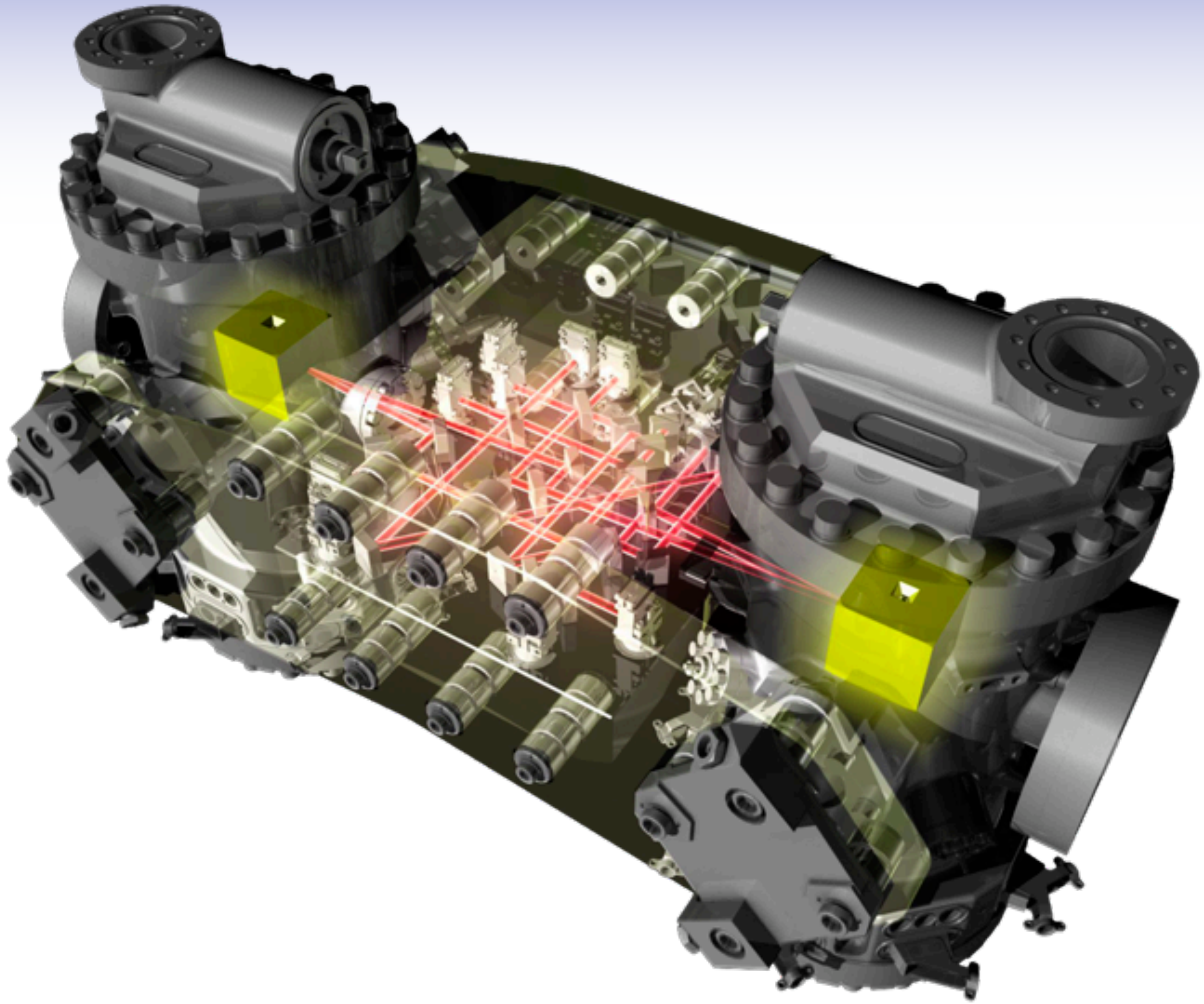
- Sciencecraft magnetic test campaign underway at IABG (Munich)
- DFACS testing on Software Verification Facility (SVF) complete
  – Hardware-in-the-loop testing underway
- Most flight units are now available

- Launch scheduled for 2nd Qtr 2012
- Launch vehicle: VEGA



[1]LTP = LISA Technology Package
[2]CDR = Critical Design Review
[3]STOC = Science and Technology Operations Centre

LISA Technology Package (LTP)



Optical Metrology System

Optical Metrology System

- The Optical Metrology System (OMS) comprises four main subsystems

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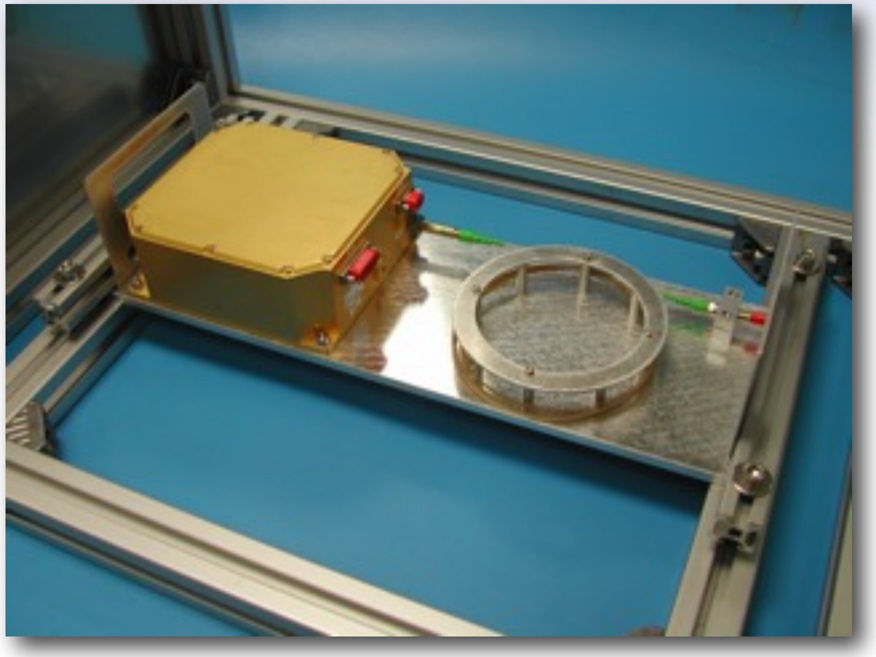
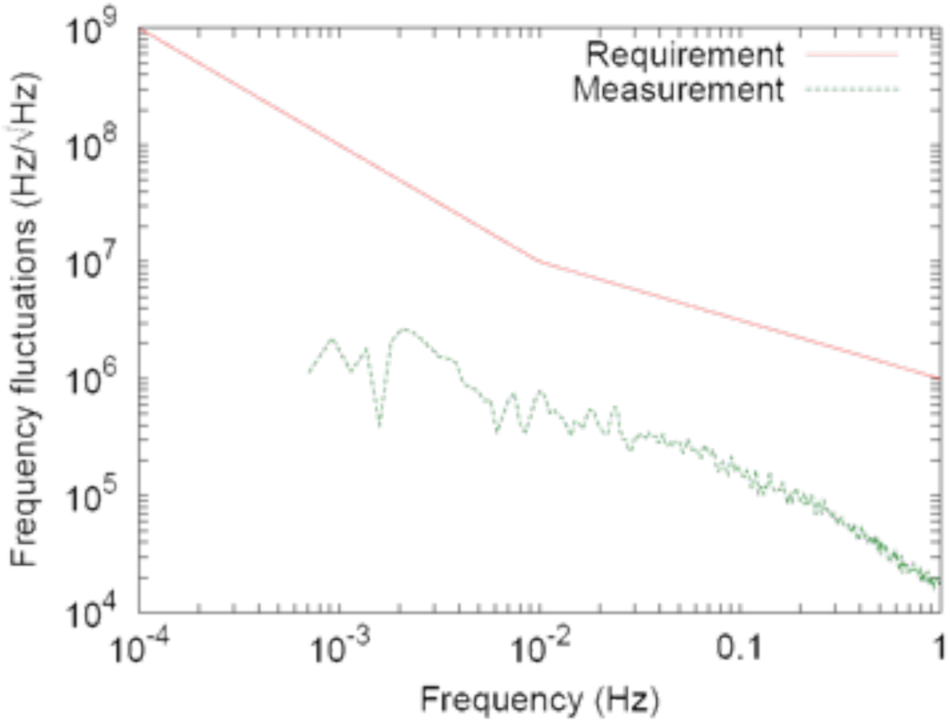
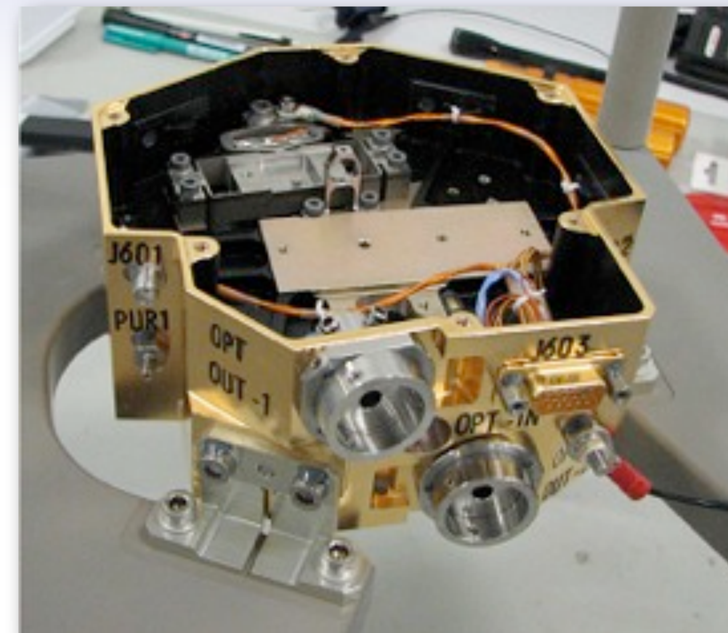
  - – Reference Laser Unit

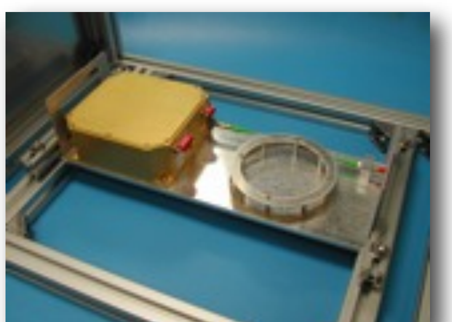




Optical Metrology System

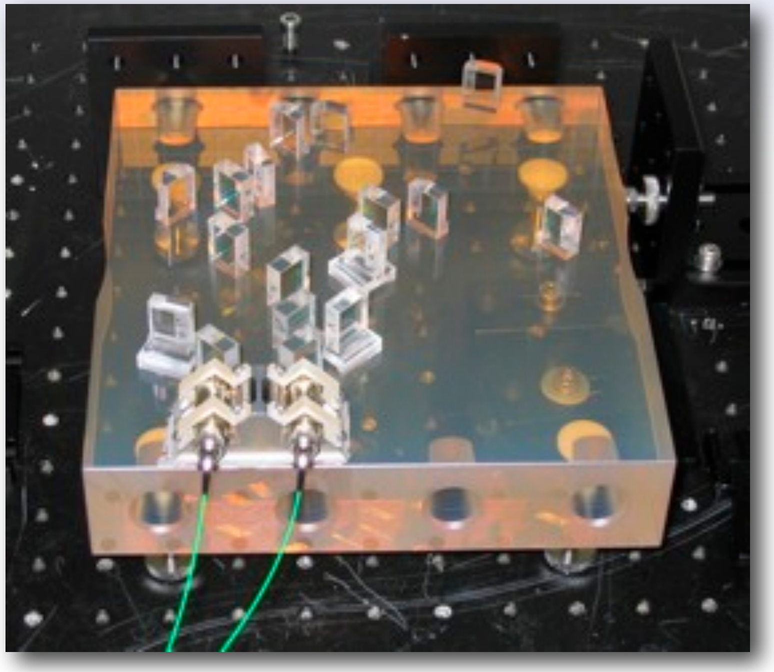
- The Optical Metrology System (OMS) comprises four main subsystems
  – Reference Laser Unit
  – Acousto-Optic Modulator

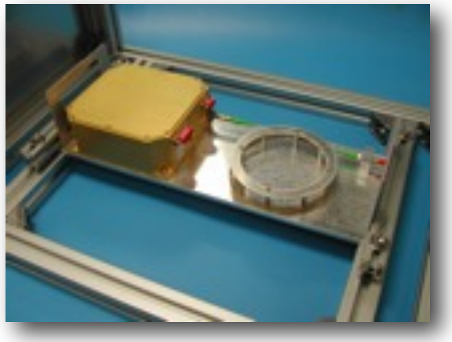


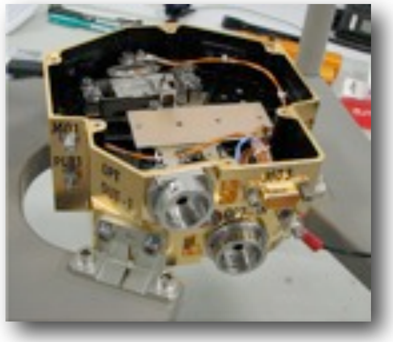


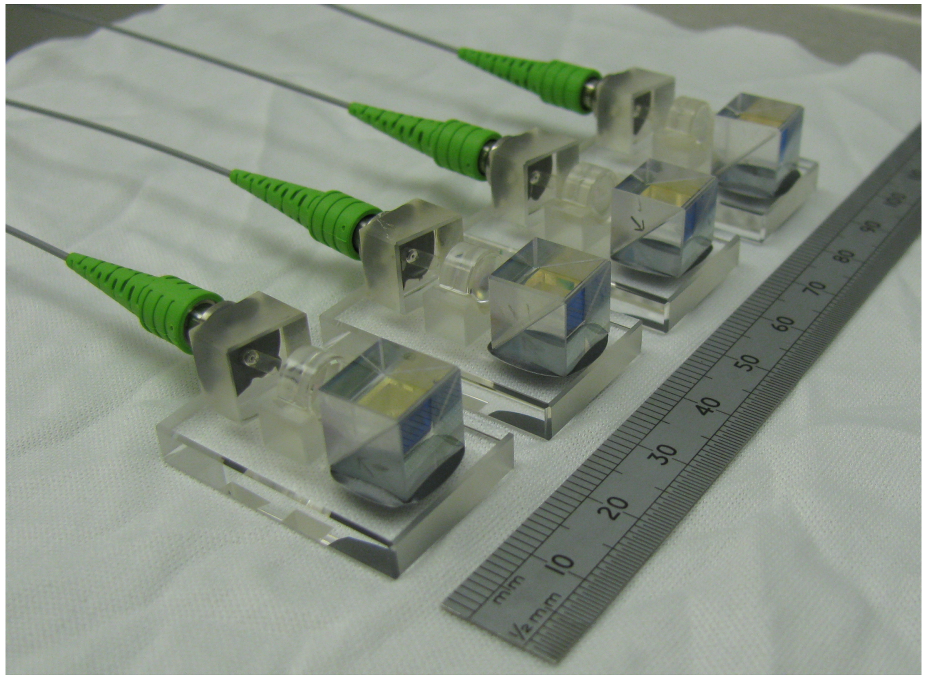
Optical Metrology System

- The Optical Metrology System (OMS) comprises four main subsystems
  - – Reference Laser Unit
  - – Acousto-Optic Modulator
  - – Optical Bench



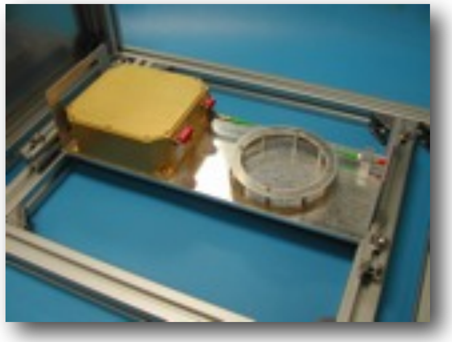


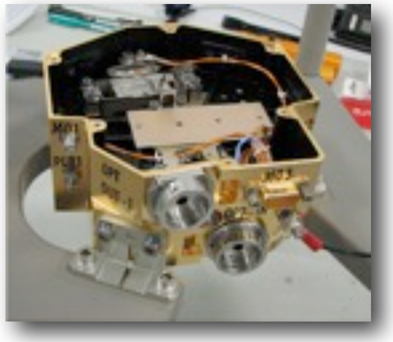


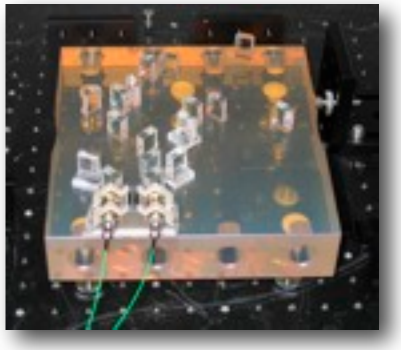


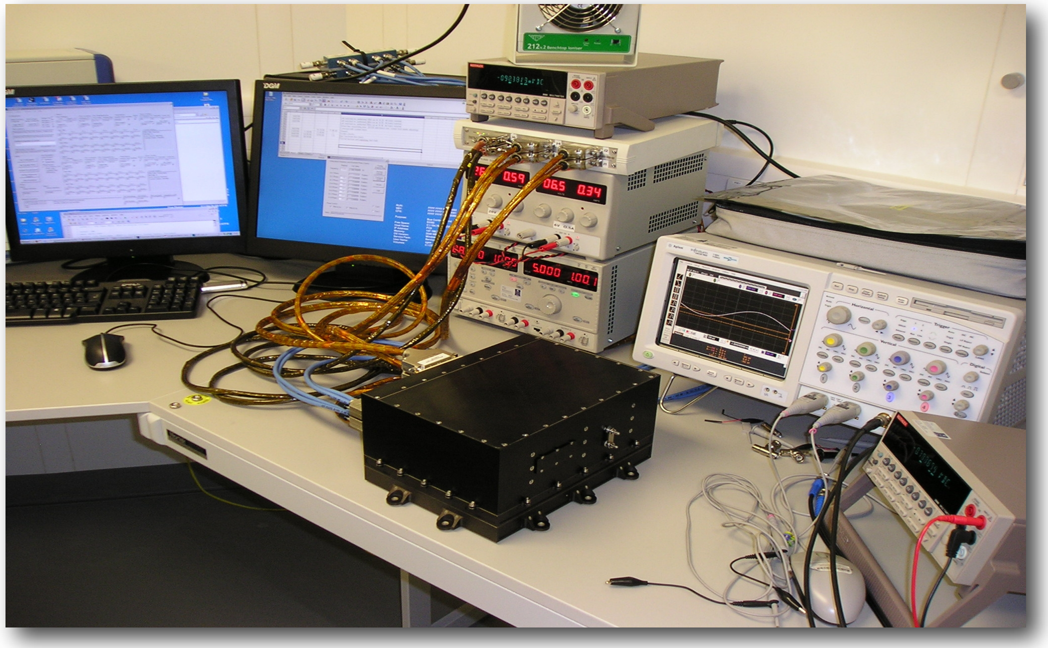
Optical Metrology System

- The Optical Metrology System (OMS) comprises four main subsystems
  – Reference Laser Unit
  – Acousto-Optic Modulator
  – Optical Bench
  – Phase-meter







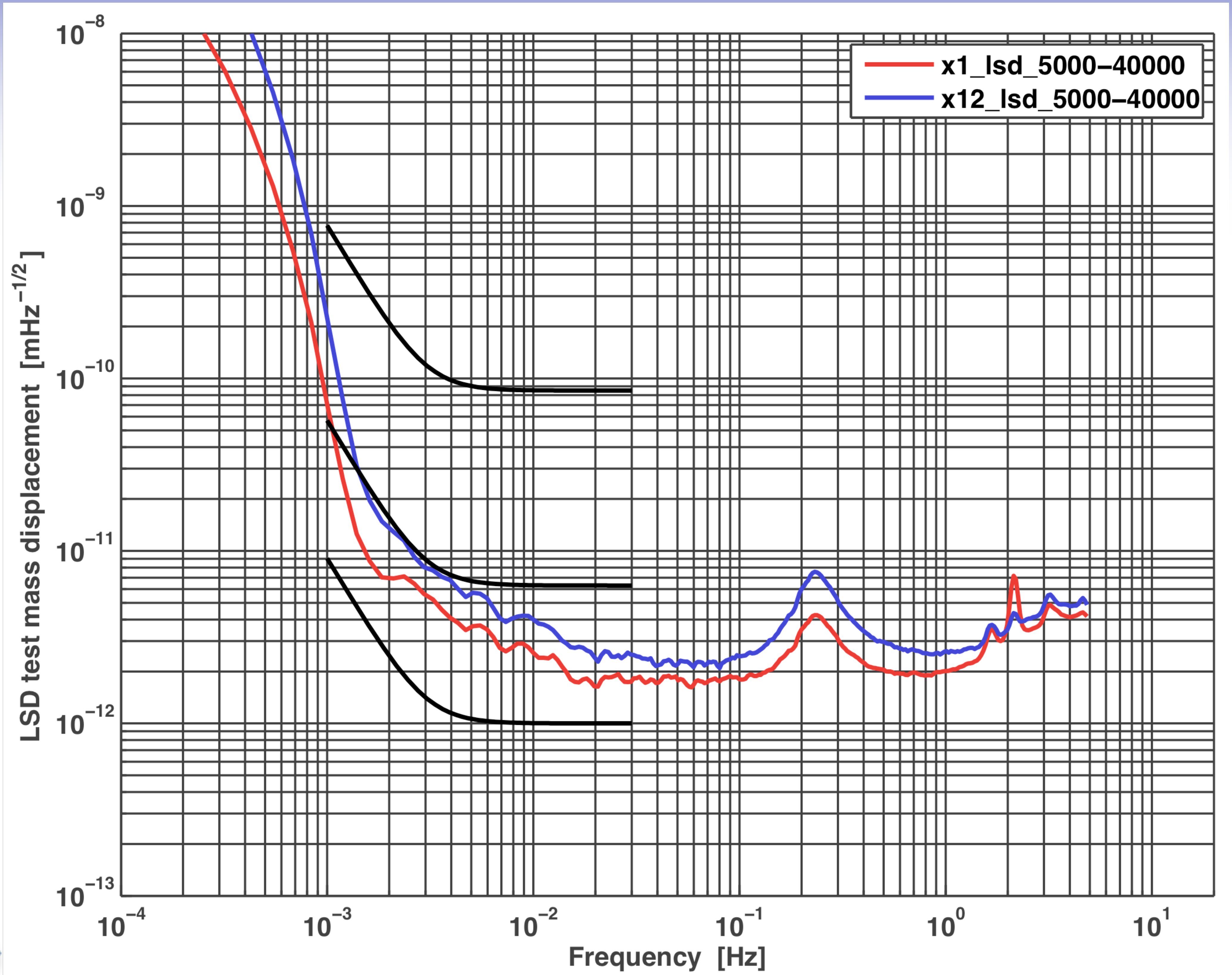


Status of OMS

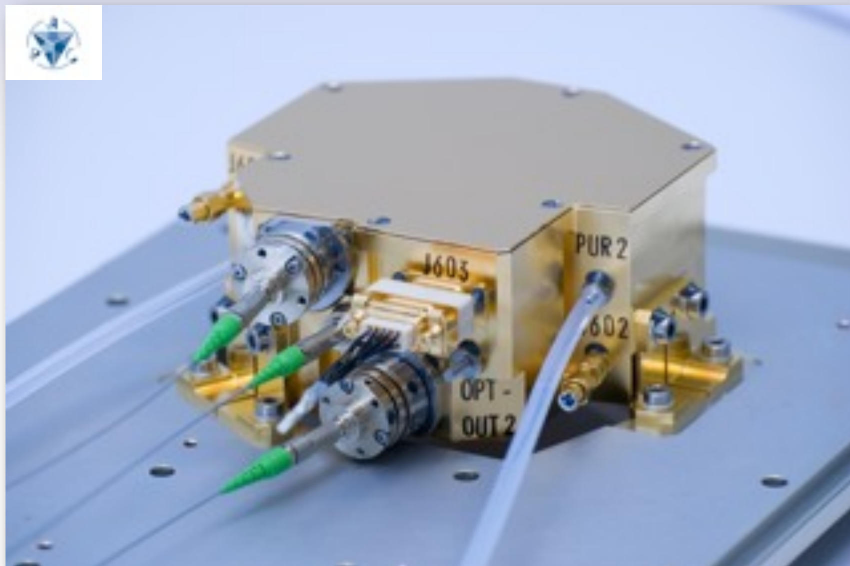
- Reference Laser Unit FM completed thermal vacuum tests
  - Delivered to Kaiser-Threde for integration into the Laser Assembly
- Laser Modulator
  - Delivered to Kaiser-Threde for integration into the Laser assembly
- Optical bench
  - All mirrors bonded to bench
  - Next step is to glue the photodiodes in place
  - Delivery scheduled for March 2010
- Phase-meter
  - Phase-meter Delivery Review Board on Friday 5th February
  - Photodiodes
    - Only 4 single-element photodiodes passed qualification....we require 4 + spares for flight
      - Now planning to use quadrant PDs in place of single element PDs
    - Quadrant diodes delivered from OSI (USA) were all contaminated
      - Uni Birmingham has spent significant time cleaning the diodes and cables
- *OMS EM test campaign successfully held at AEI Hannover last year*

LISA Pathfinder

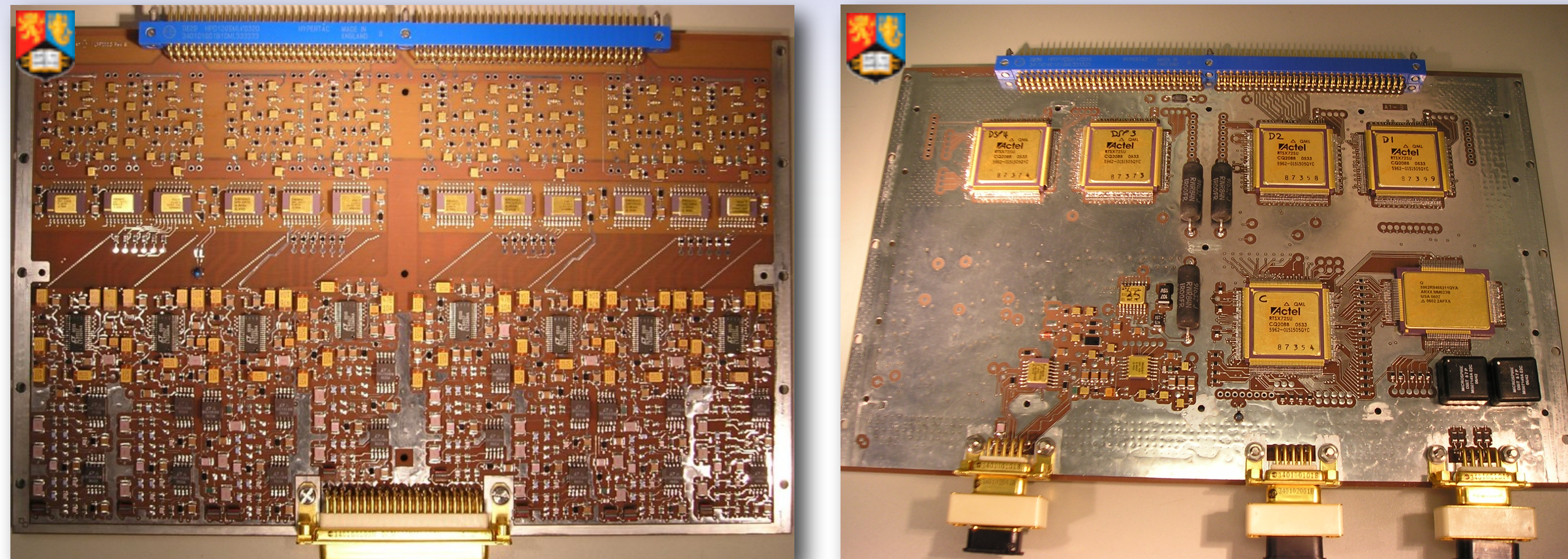
OMS EM Campaign



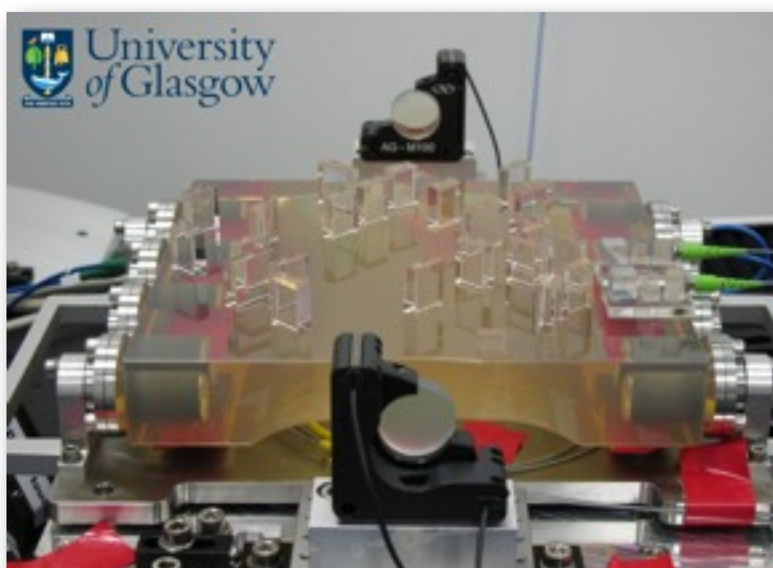
Photos of OMS flight hardware



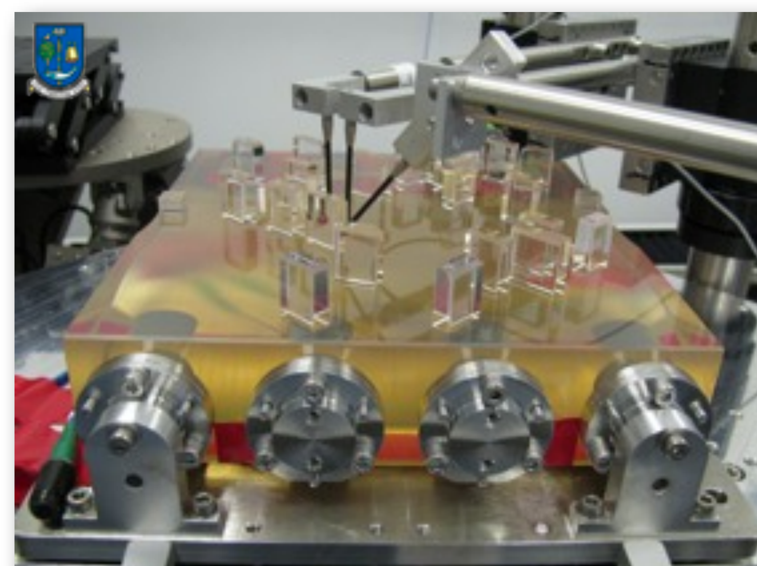
Laser Modulator flight unit



Phasemeter analogue and digital proto-flight boards

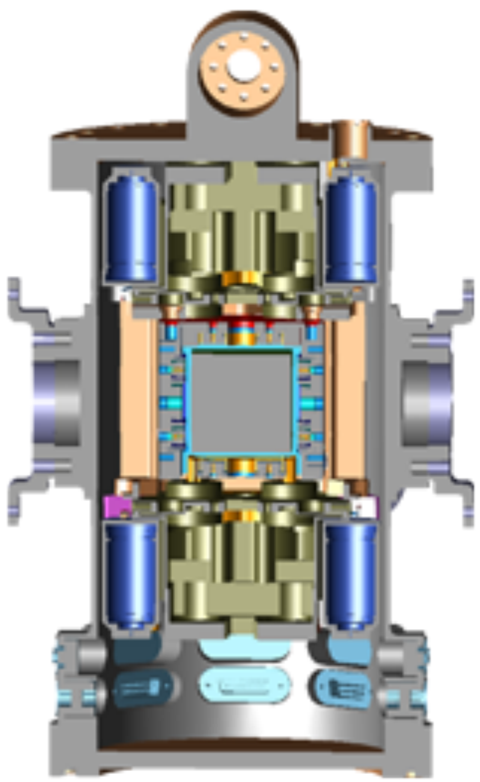


Fully Bonded Optical Bench



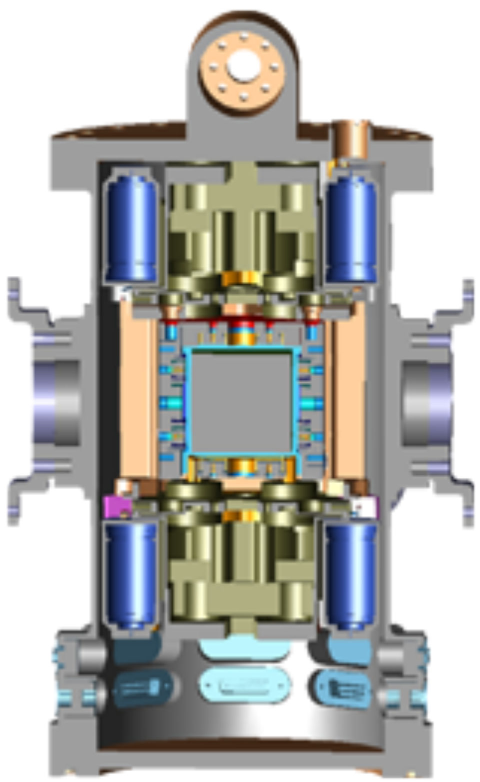
Optical bench construction

Inertial Sensor System



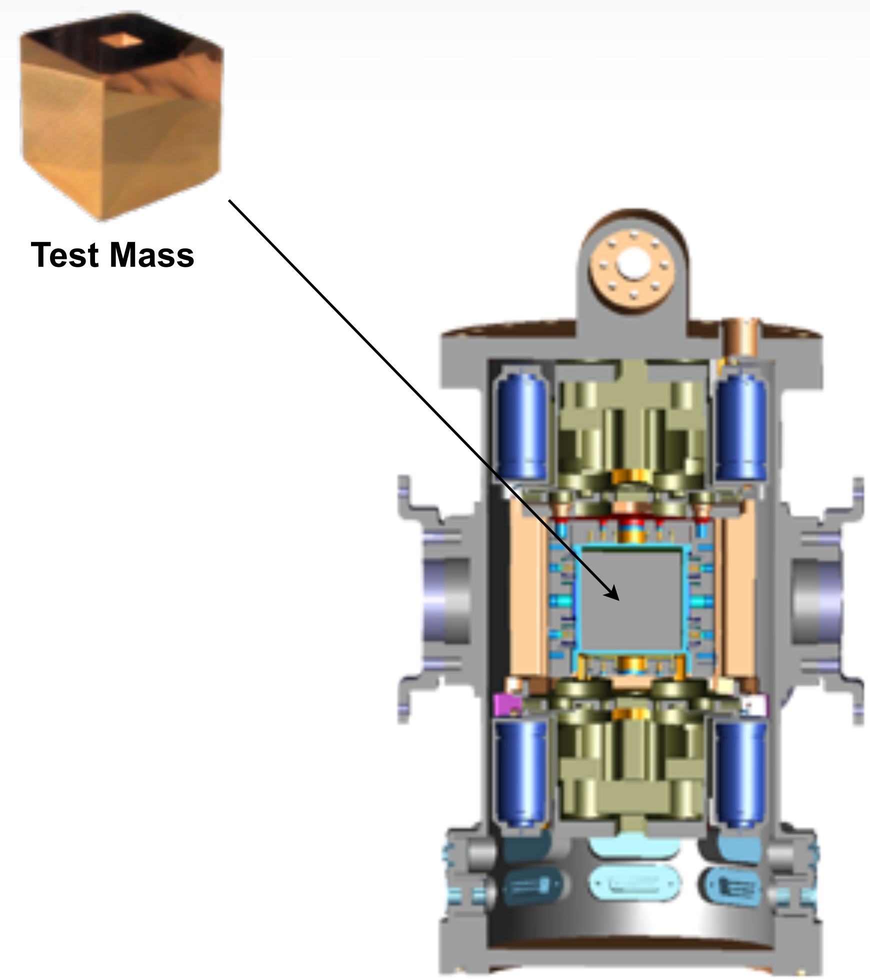
Inertial Sensor System

- The Inertial Sensor System comprises six main subsystems



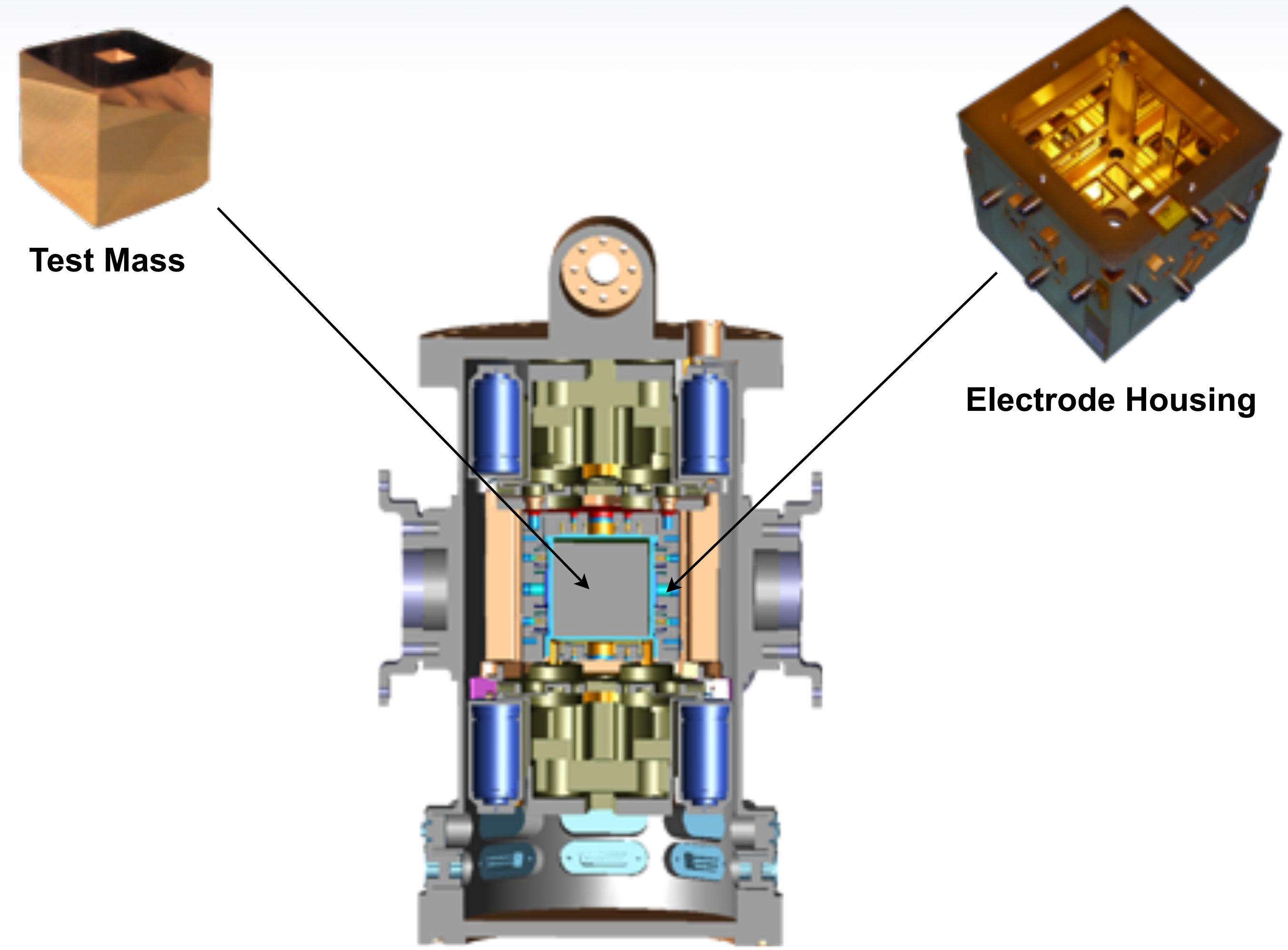
Inertial Sensor System

- The Inertial Sensor System comprises six main subsystems
  - Test mass



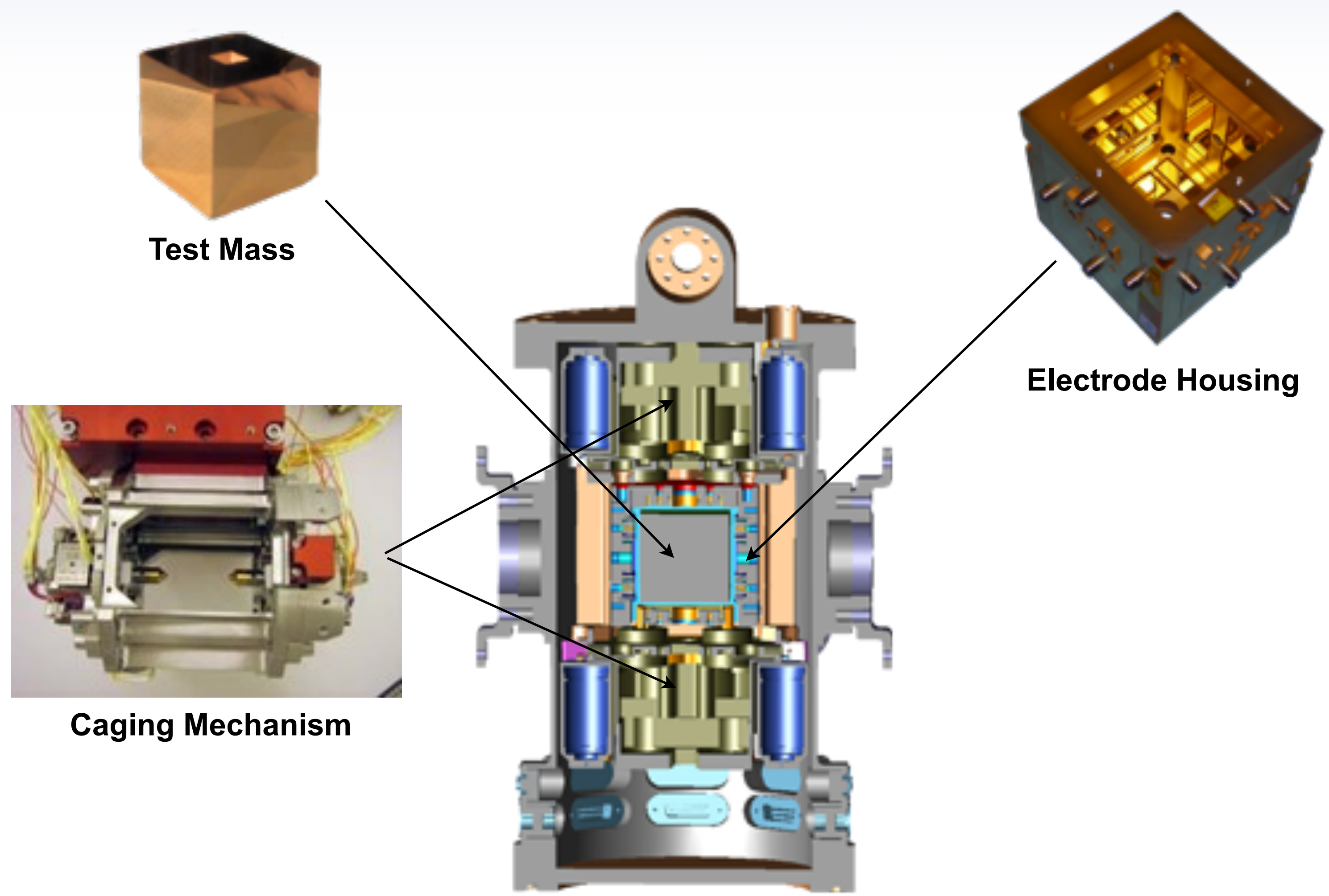
Inertial Sensor System

- The Inertial Sensor System comprises six main subsystems
  - – Test mass
  - – Electrode housing



Inertial Sensor System

- The Inertial Sensor System comprises six main subsystems
  - – Test mass
  - – Electrode housing
  - – Caging mechanism



Inertial Sensor System

- The Inertial Sensor System comprises six main subsystems
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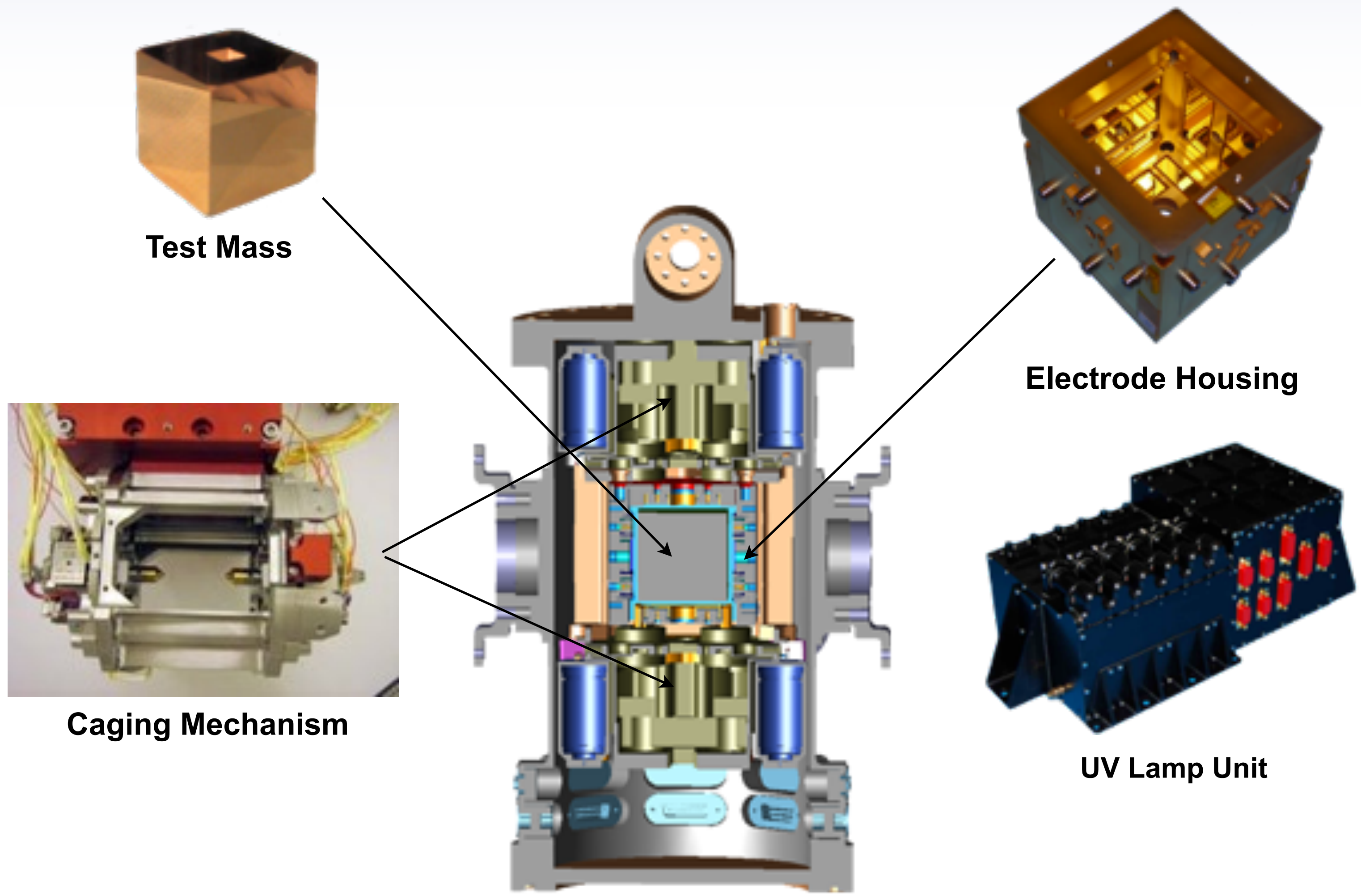
  - – Electrode housing
  - – Caging mechanism
  - – UV discharge system



Inertial Sensor System

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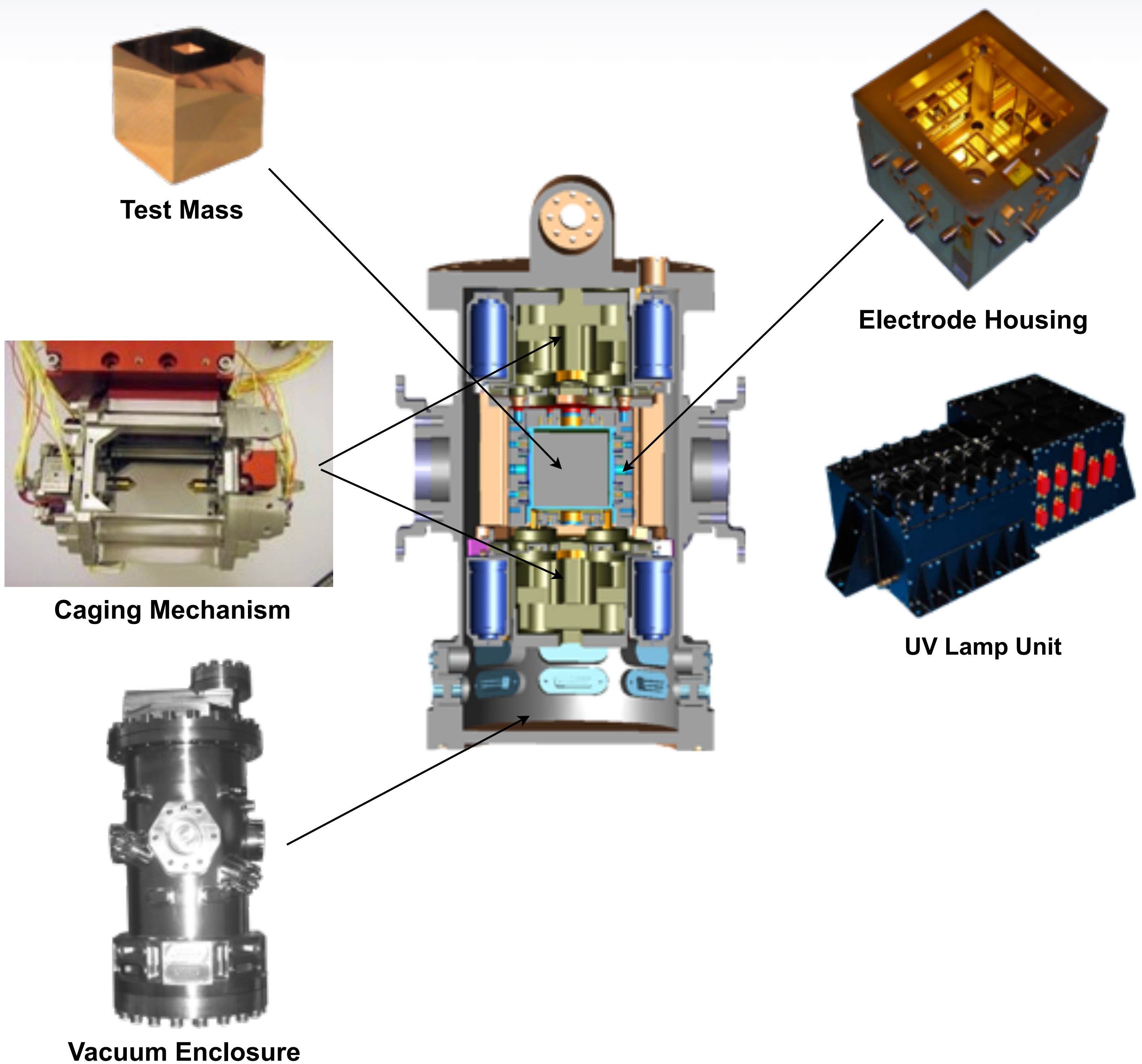
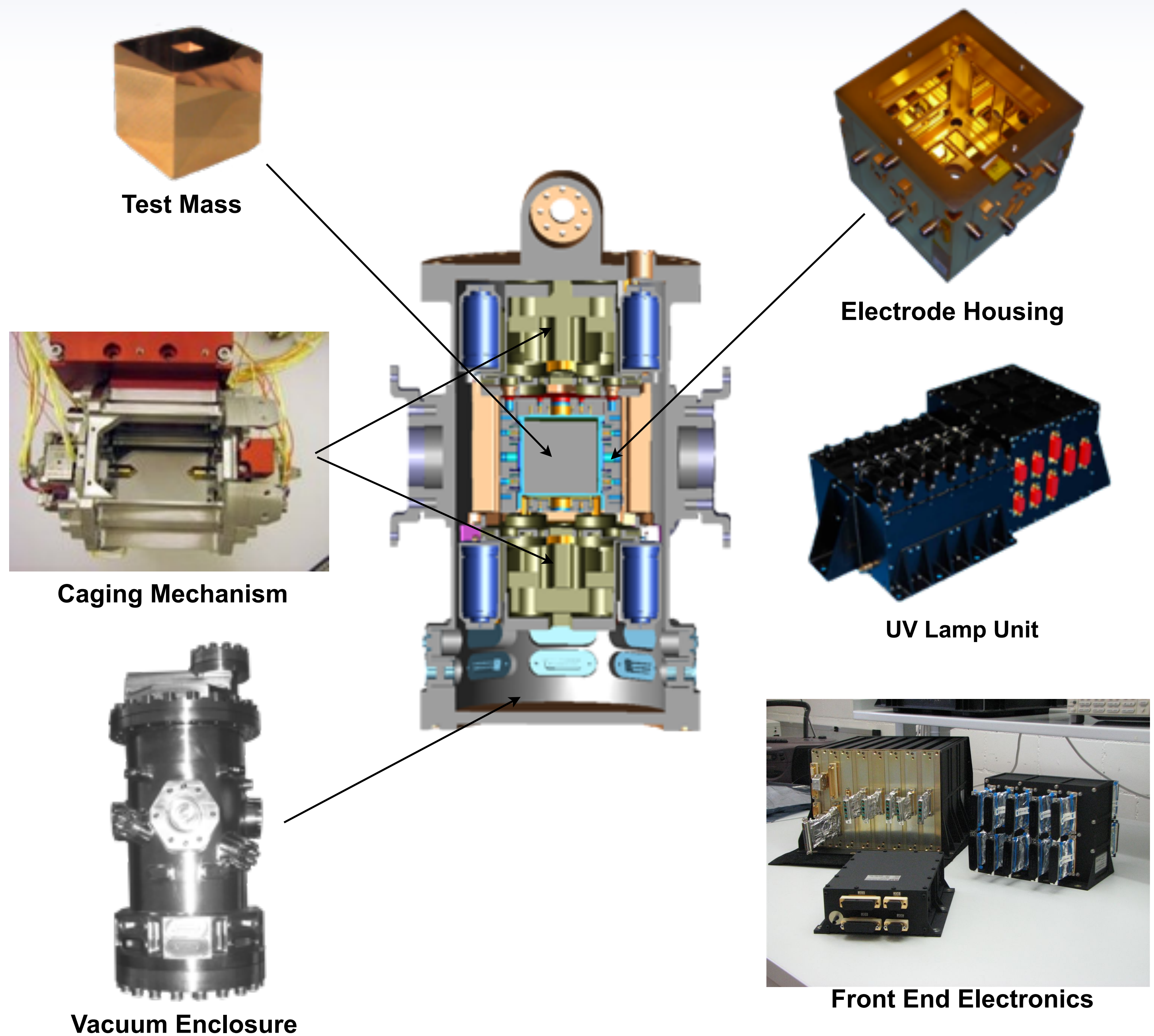
  - – Electrode housing
  - – Caging mechanism
  - – UV discharge system
  - – Vacuum System



Inertial Sensor System

- The Inertial Sensor System comprises six main subsystems
  – Test mass
  – Electrode housing
  – Caging mechanism
  – UV discharge system
  – Vacuum System
  – Front end electronics



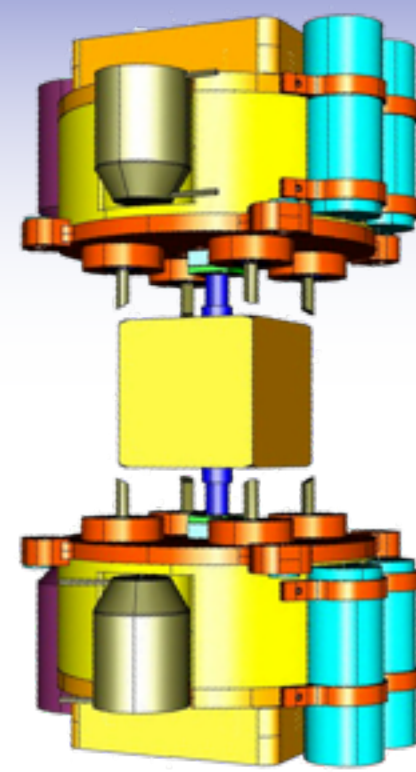
ISS Summary

- Test Mass
  - Flight unit Au:Pt test mass is being polished
- Electrode Housing
  - Flight replica under test with torsion pendulum in Trento
  - FM Test Readiness Review held last week (Thursday, 28th Jan)
- Caging Mechanism
  - See following slides
- Charge Management Unit
  - Fibre feedthrough FMs have been delivered
  - Two lamps failed to strike during thermal cycle test at ESTEC
  - HK became corrupted at low temperatures
    - Currently being investigated
- Vacuum Enclosure
  - All unit tests passed, awaiting system test
    - Requires a caging mechanism for the system test
- Inertial Sensor Subsystem Front-End Electronics
  - Flight Units delivered

Caging Mechanism Reqs

- Clamp the test-mass in position and sustain launch load
  – Pre-load = 1200N
- Break large adhesion created by vibration under load
  – No lubricants possible
  – All surfaces gold coated
- Release the test-mass around the centre of the electrode housing with low enough kinetic energy such that proof mass can be electrostatically captured
  – Released position <200μm from “null”
  – Release velocity <5μm/s!
- Vibration requirements: 50g rms

Caging Mechanism



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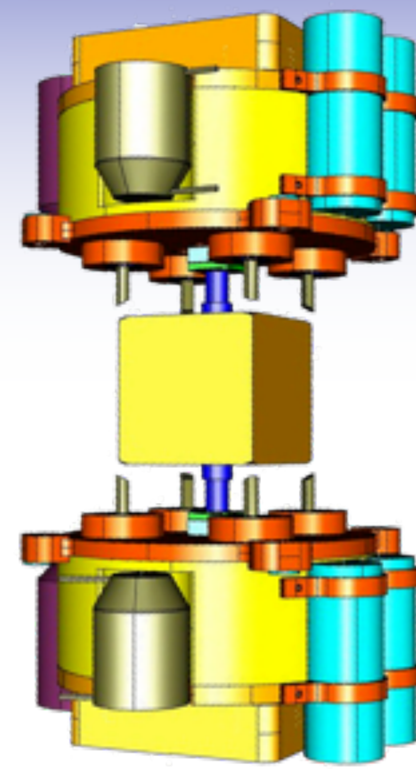
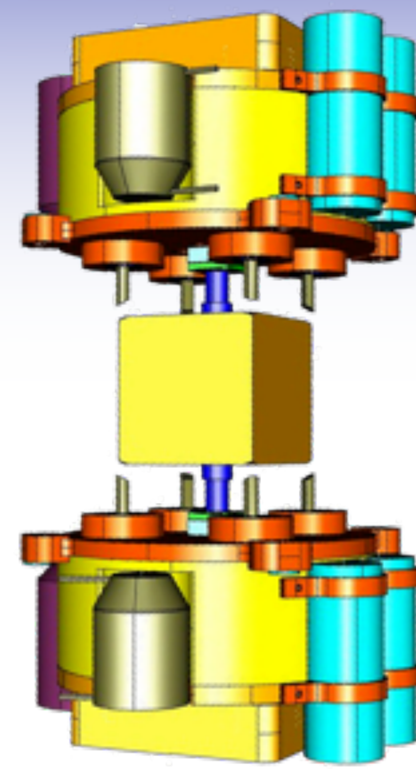
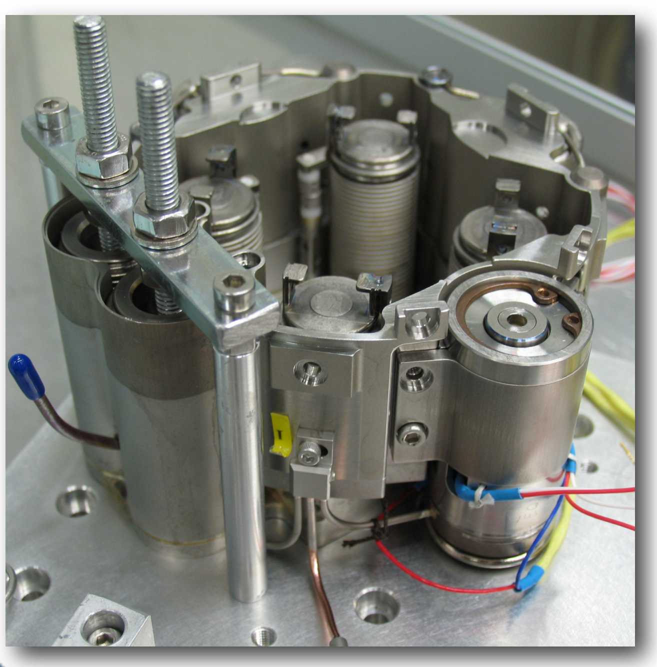


Launch Lock
(3000N)

Caging Mechanism





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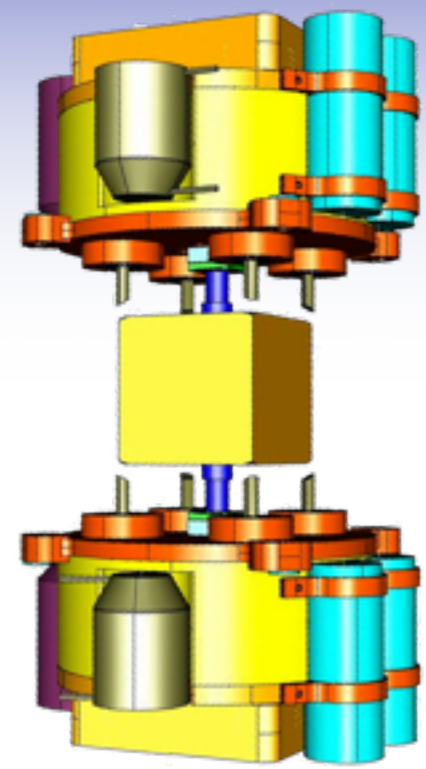
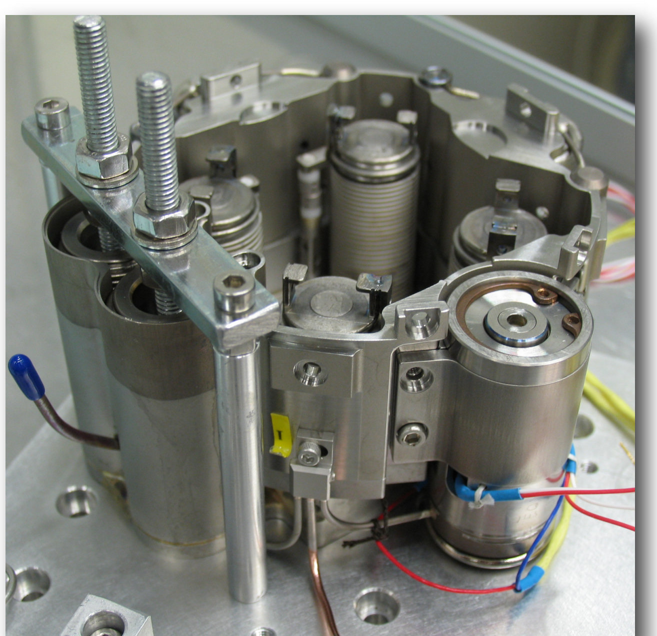
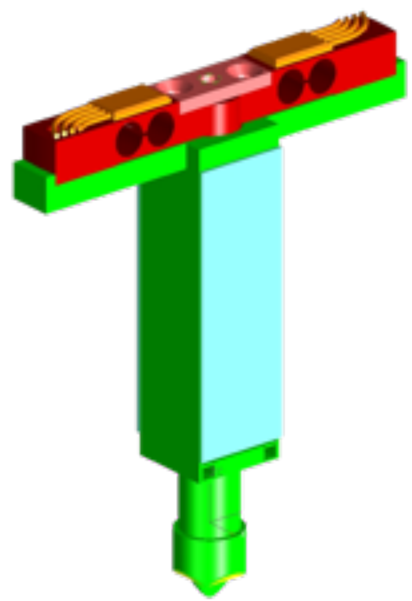
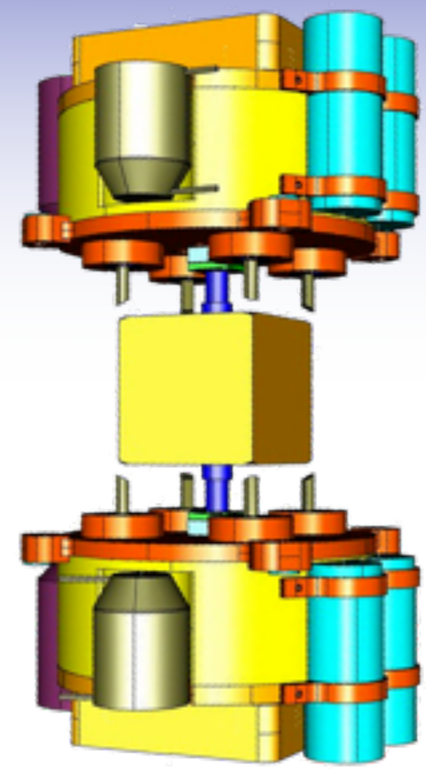


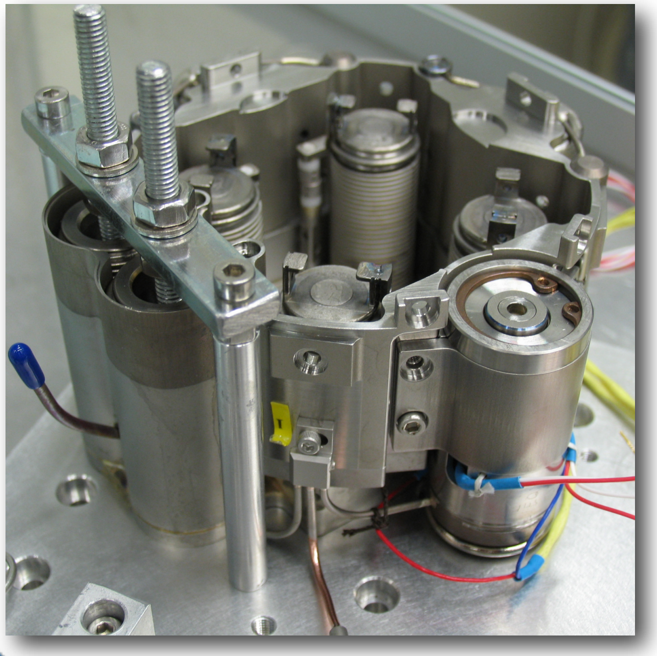


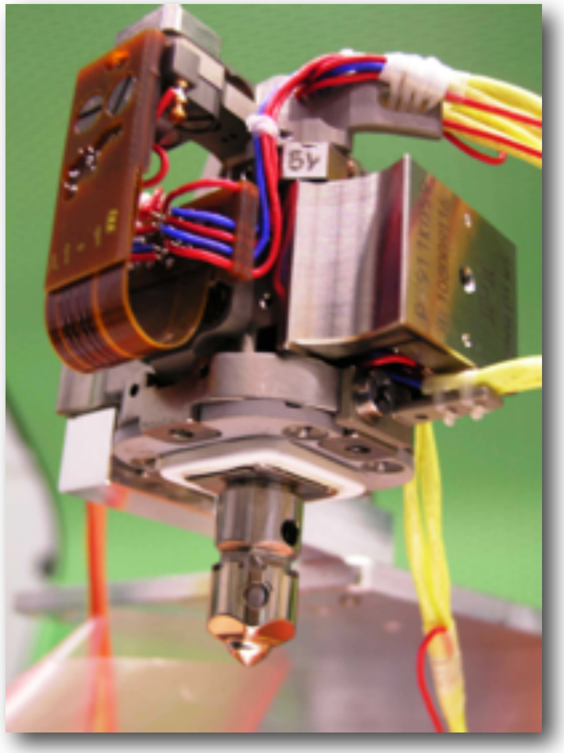


Positioning Actuator (100N)

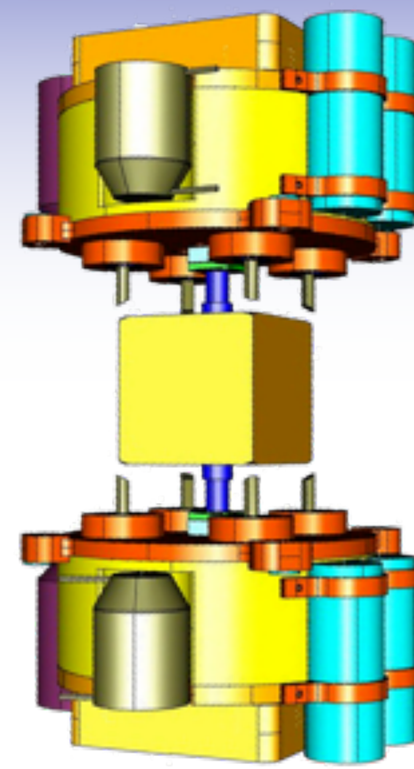
Caging Mechanism

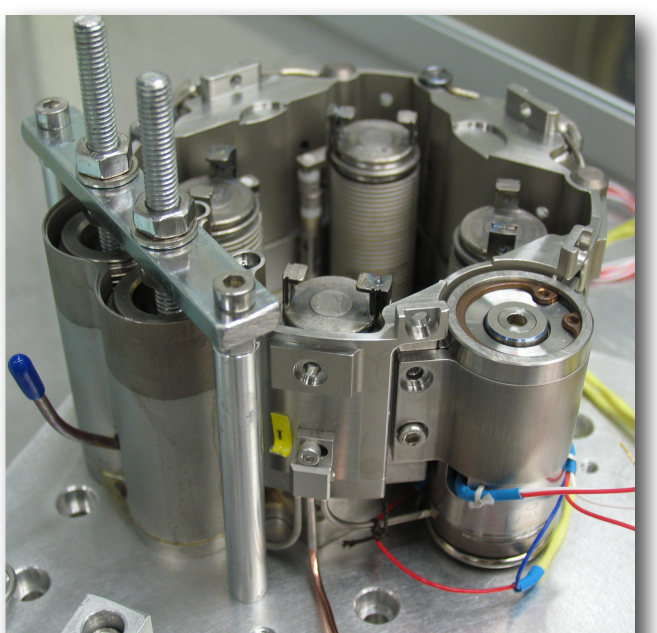


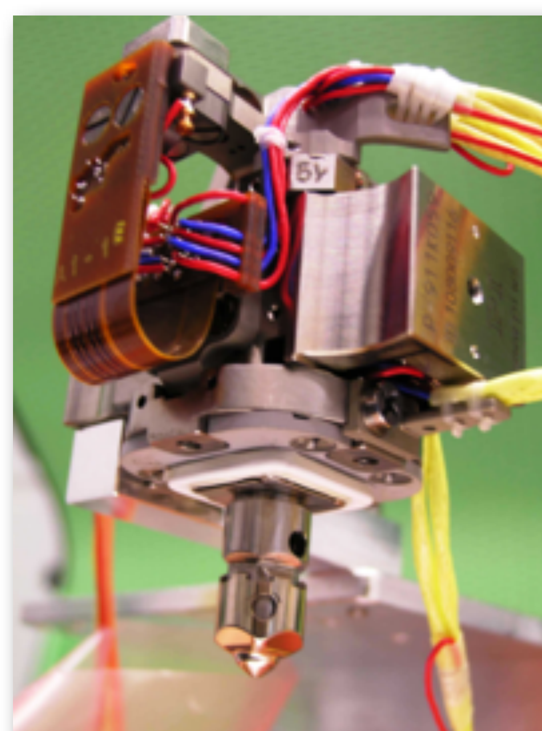


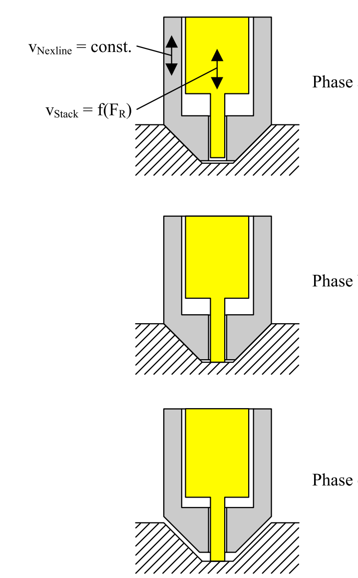


Caging Mechanism



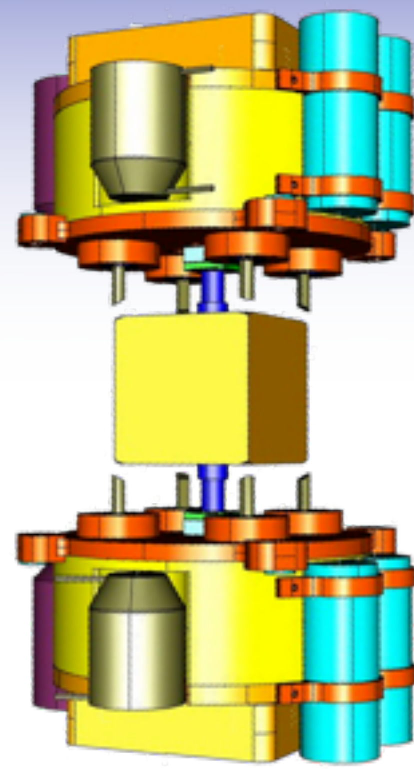


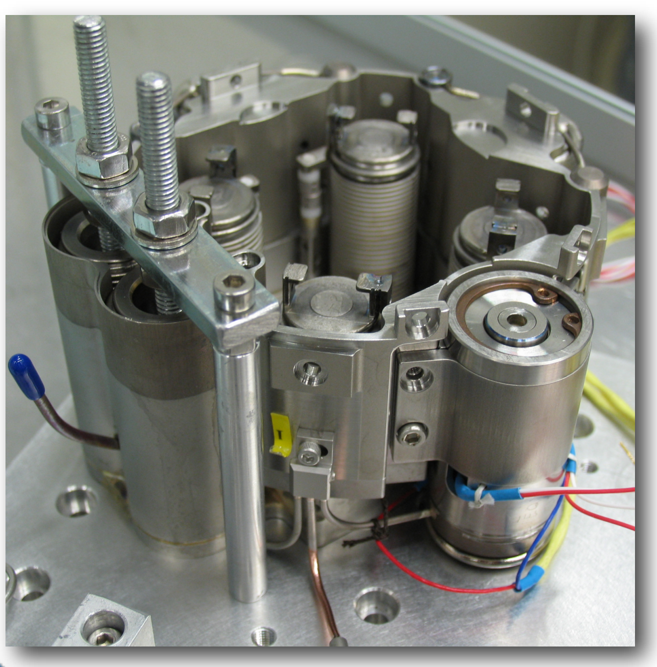


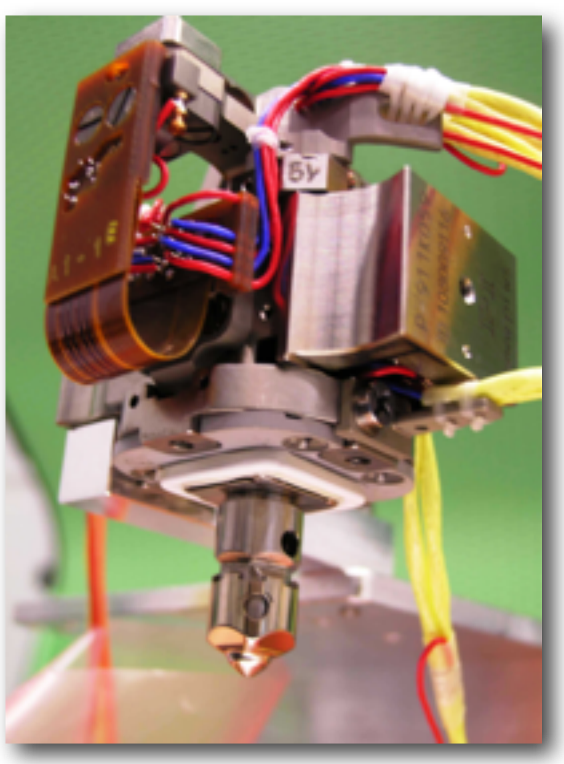


Release Actuator (10N)

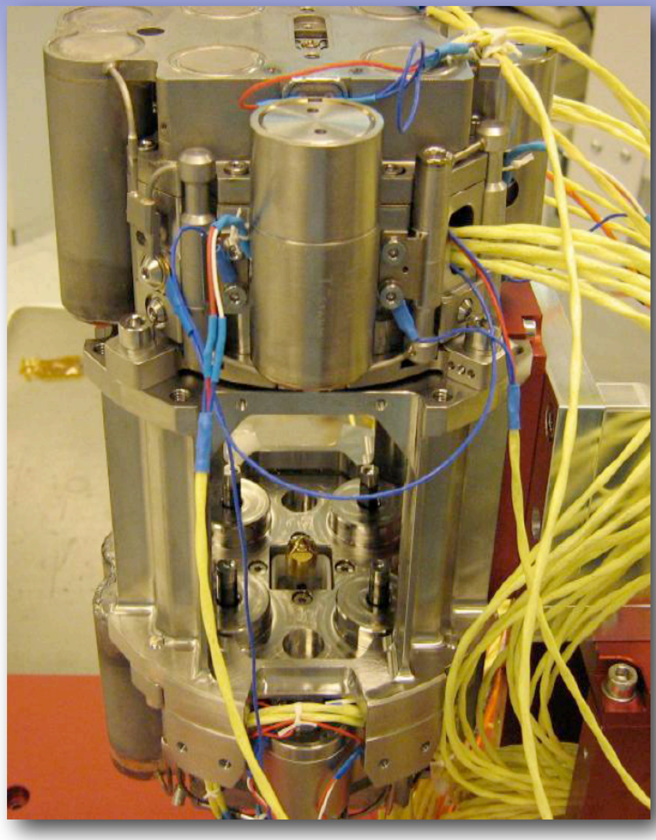
Caging Mechanism

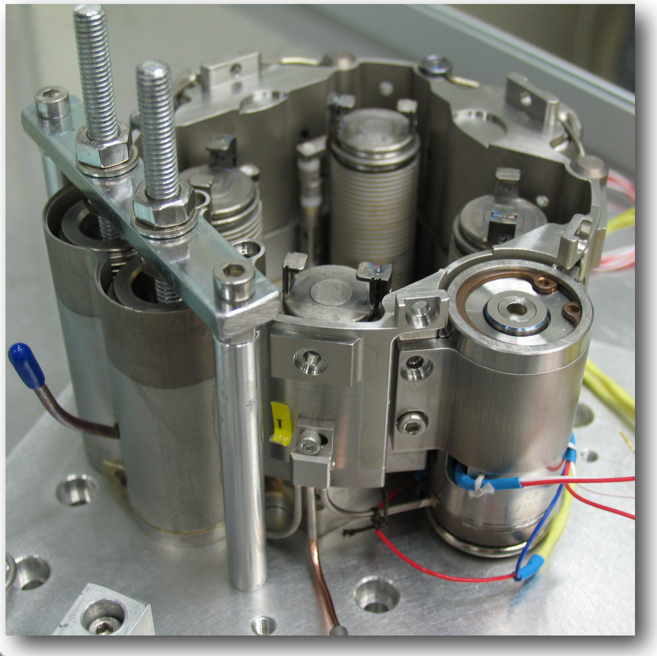


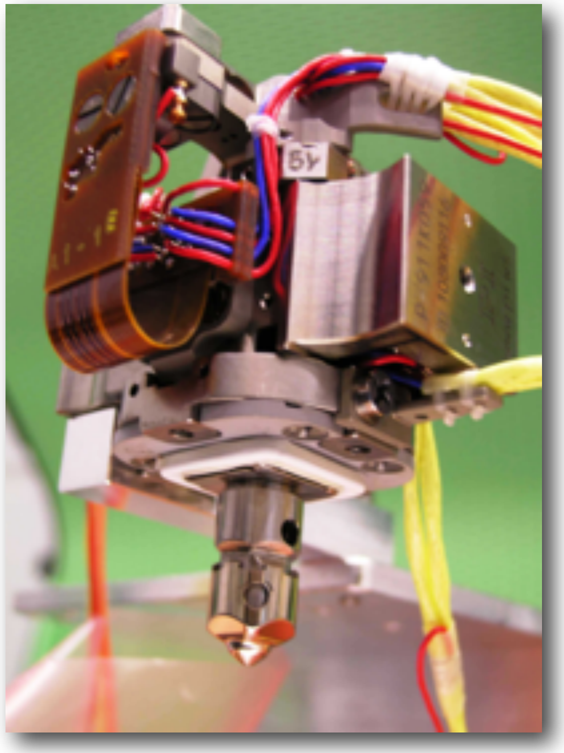




Caging Mechanism



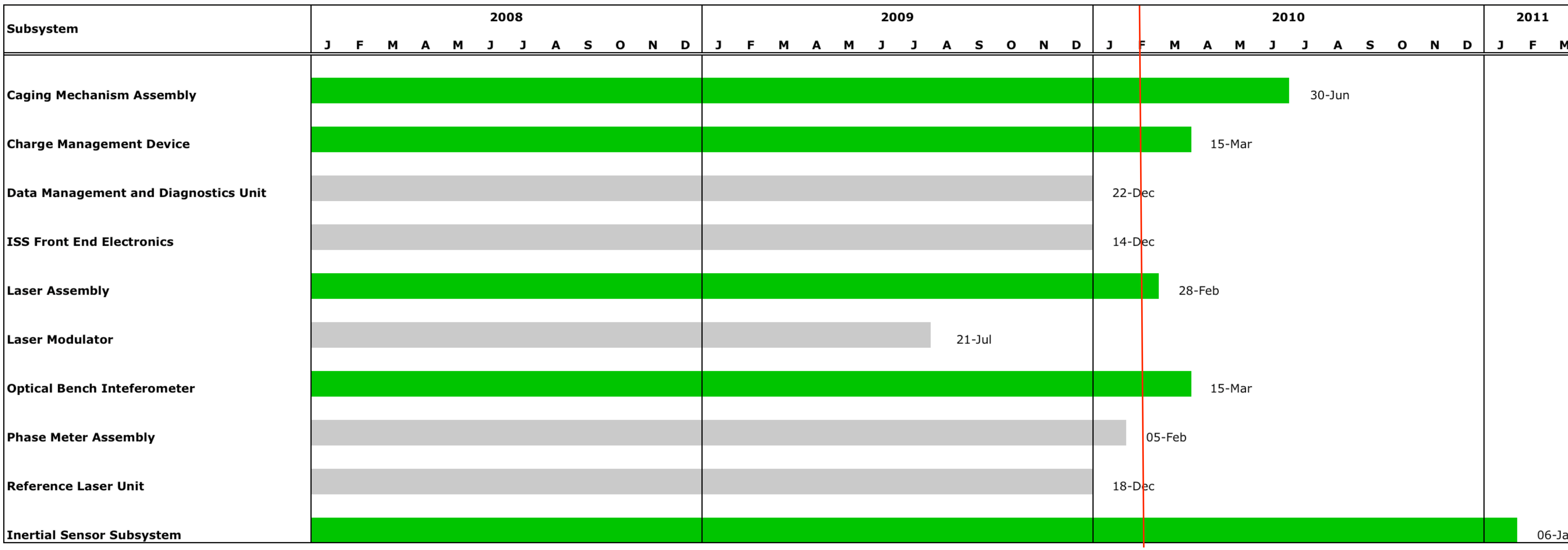




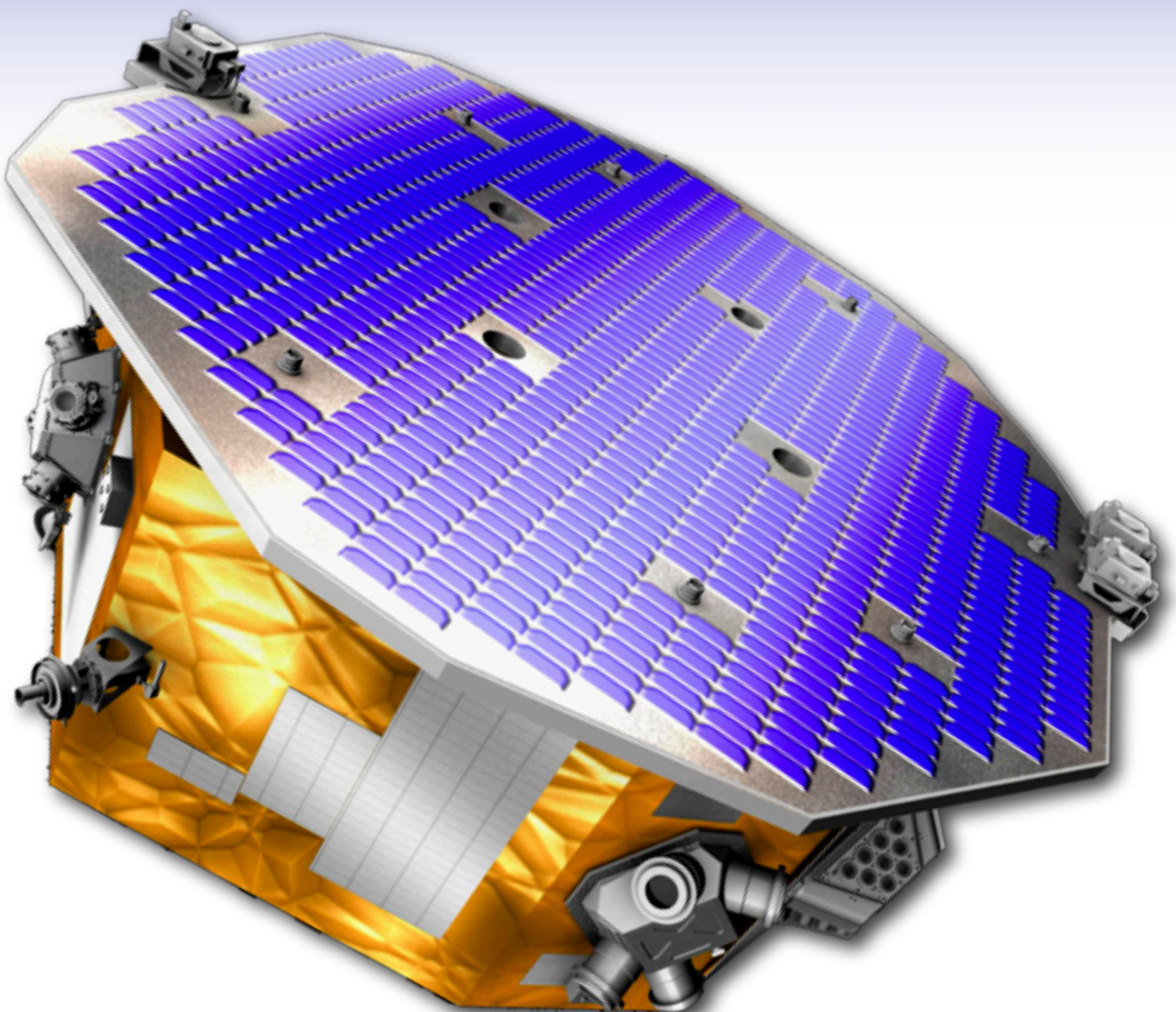
Caging Mechanism Status

- Grabbing, Positioning and Release mechanisms (GPRM) flight units have been successfully tested and are awaiting delivery
- Hydraulic launch lock EQM failed during testing
  - Debris was found in the hydraulic system of +z Caging Mechanism (CM)
    - Caused piezo pump to fail
    - Debris possibly entered system during replacement of a pressure sensor
  - Pressure sensors (x2) in -z CM also failed prior to test
- However, the test can proceed (in limited capacity) using the remaining pressure sensor
  - Full load random vibration due to take place today
- First CMA FM scheduled for delivery May 2010
  - 2nd flight unit to be delivered in June 2010
- *Caging mechanism delivery is on the critical path for the full LPF mission*

Delivery Schedule

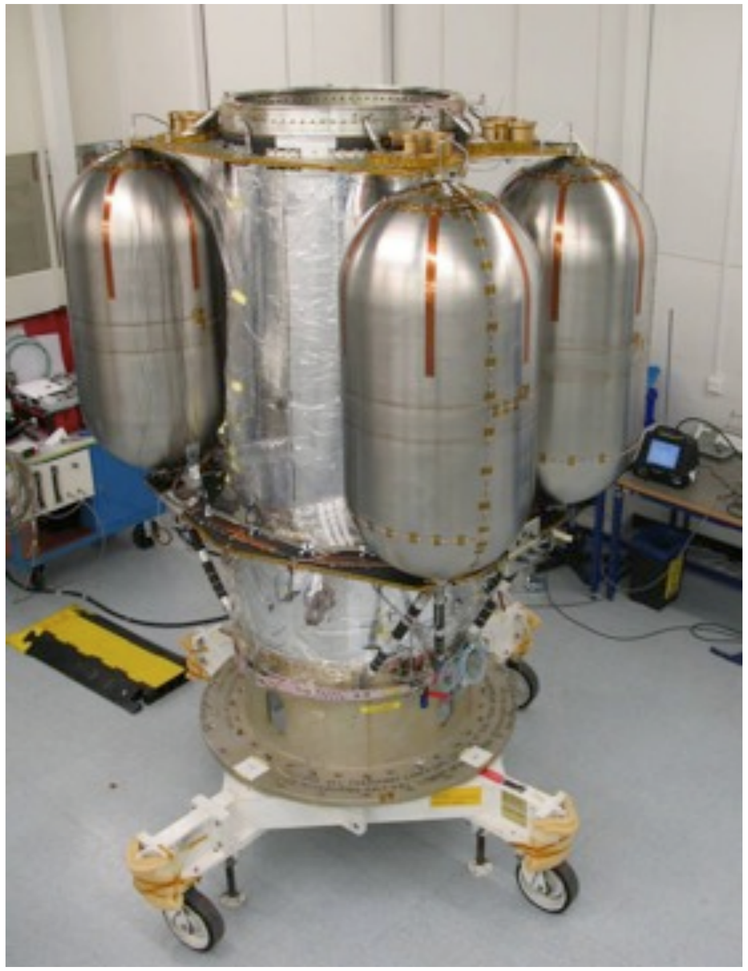


Sciencecraft



Sciencecraft

- Sciencecraft integration is mostly complete at Astrium UK
  - Sciencecraft is now in IABG for magnetic test campaign
    - Test Readiness Review of magnetic test was yesterday (3rd February)
- Propulsion module integration is ongoing
  - Flight Model propulsion module Delivery Review Board (DRB) scheduled for April 2010



Sciencecraft FM status

FM units at the Astrium

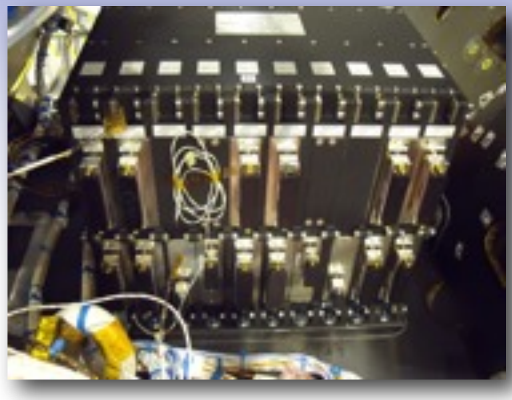
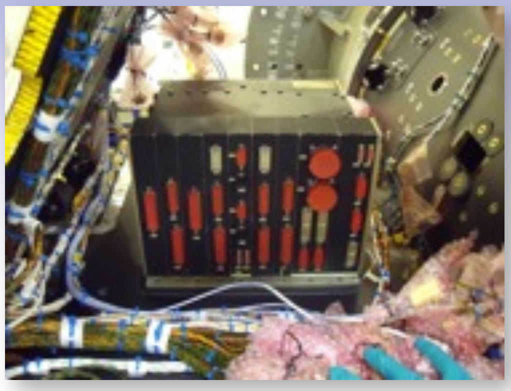
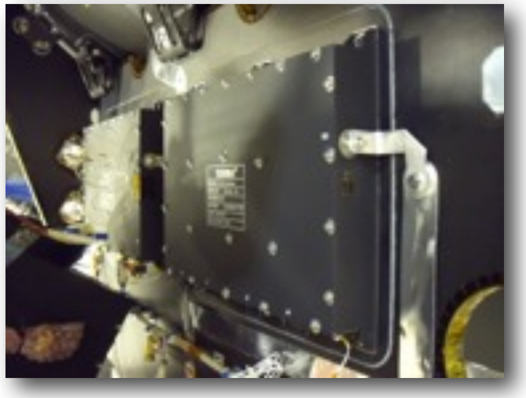
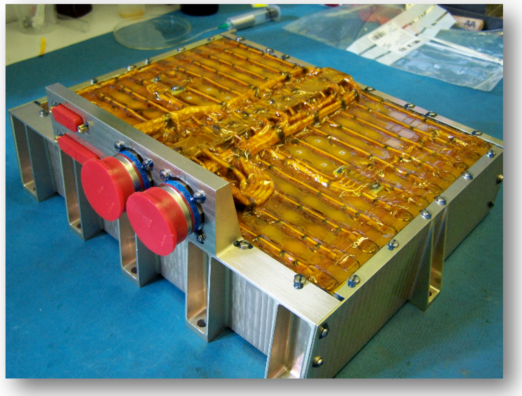
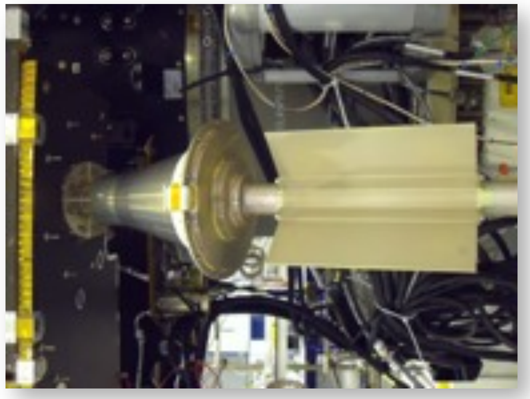
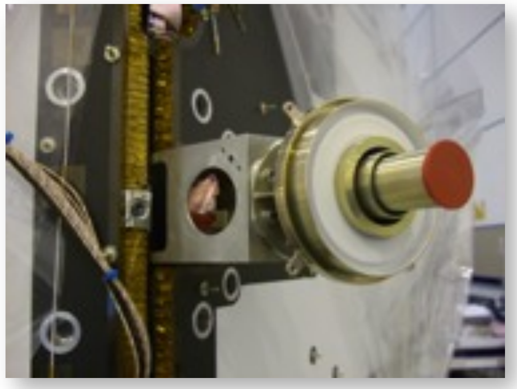
- Antennas (LGA/MGA)
- Digital Sun Sensors
- On-Board Computer
- Power Control & Distr. Unit
- Star Trackers
- Gyros
- Battery
- Thermal HW
- Harness
- Complete JPL Disturbance Reduction System (DRS)

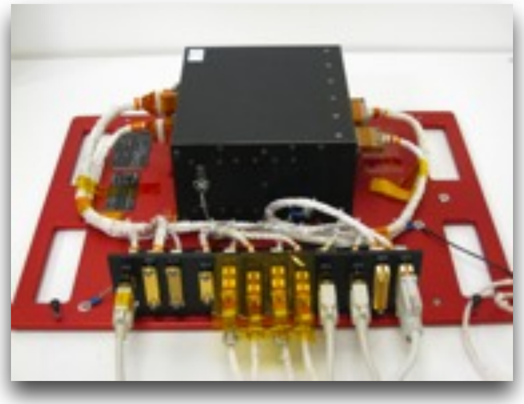
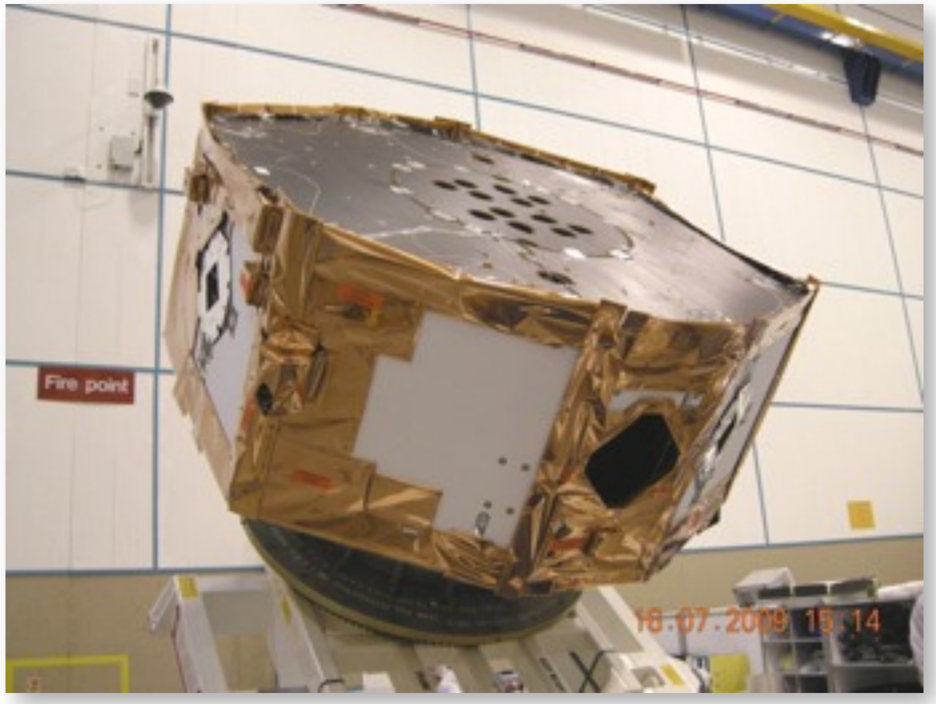
FM to be delivered

- Transponders
  - 2nd Transponder (March 2010)
- Solar Array
  - Awaiting DRB
- FEEP Clusters
  - Num 1 (Nov 2010)
  - Num 2,3 (May 2011)

Units already integrated to s/c

- On-Board Computer
- Power Control and Distribution Unit
- Star Tracker Digital Processing Units
- Battery
- Gyros
- TTC switches
- Low and Medium Gain antennae
- FEEP Power Control Unit (EQM)
- DRS IAU and thrusters

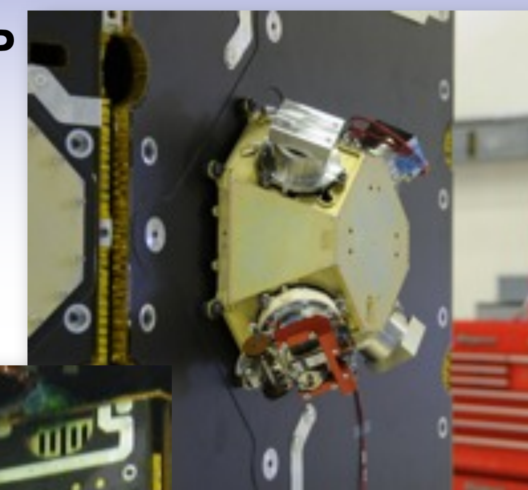







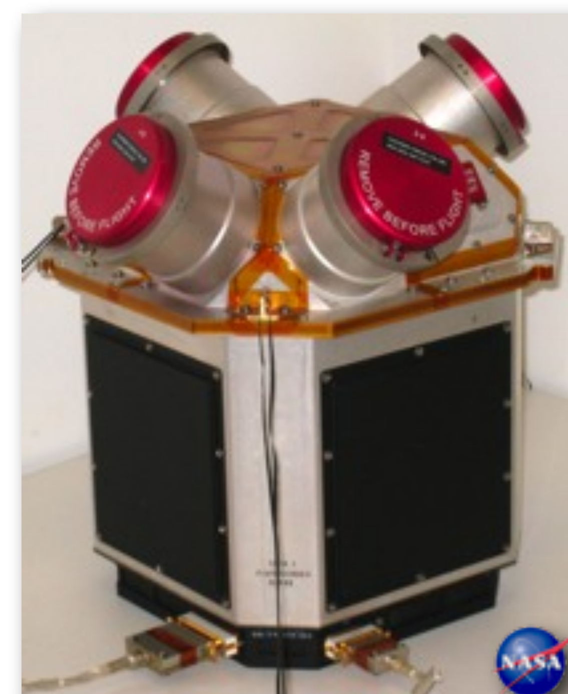
Micro-Newton Thrusters

- Europe are developing two types of Field Emission Electric Propulsion (FEEP)
  - – Slit FEEP with Caesium propellant
    - Now been chosen for flight
  - – Needle FEEP with Indium propellant
    - Developed as back-up
- Cs FEEP has now demonstrated >3000hours of operation
- NASA Colloidal thruster flight units have been integrated to the sciencecraft

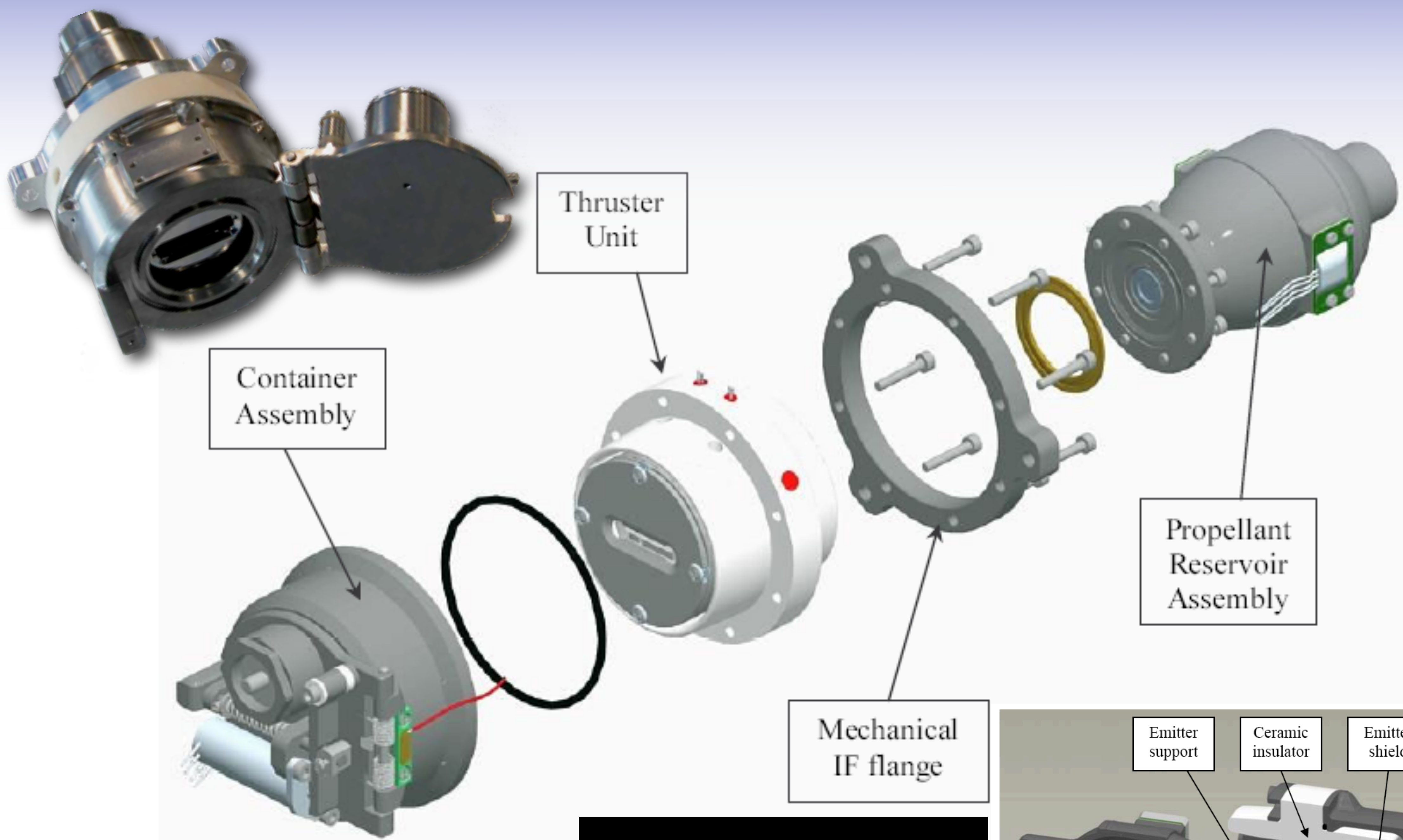
Slit FEEP

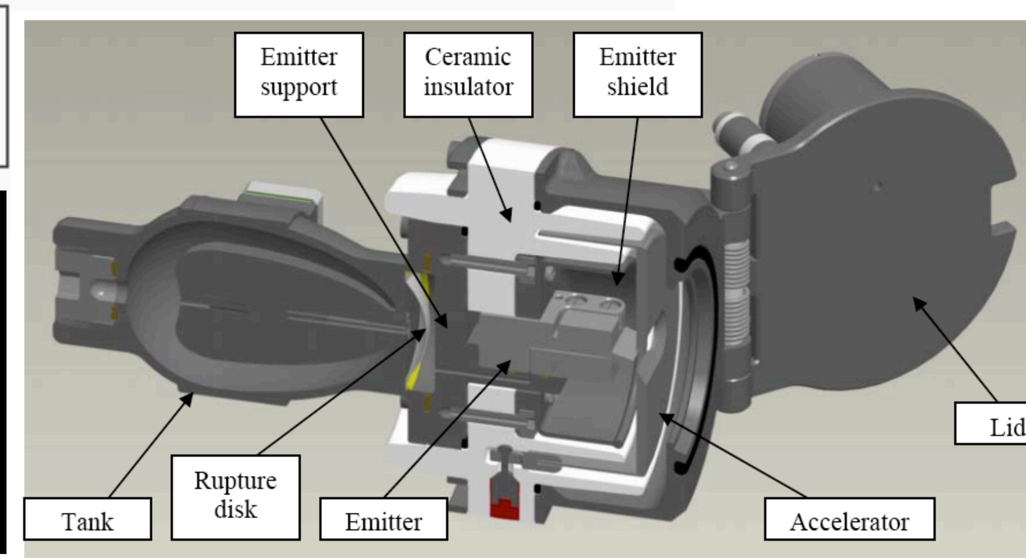


Needle FEEP



Anatomy of a FEEP



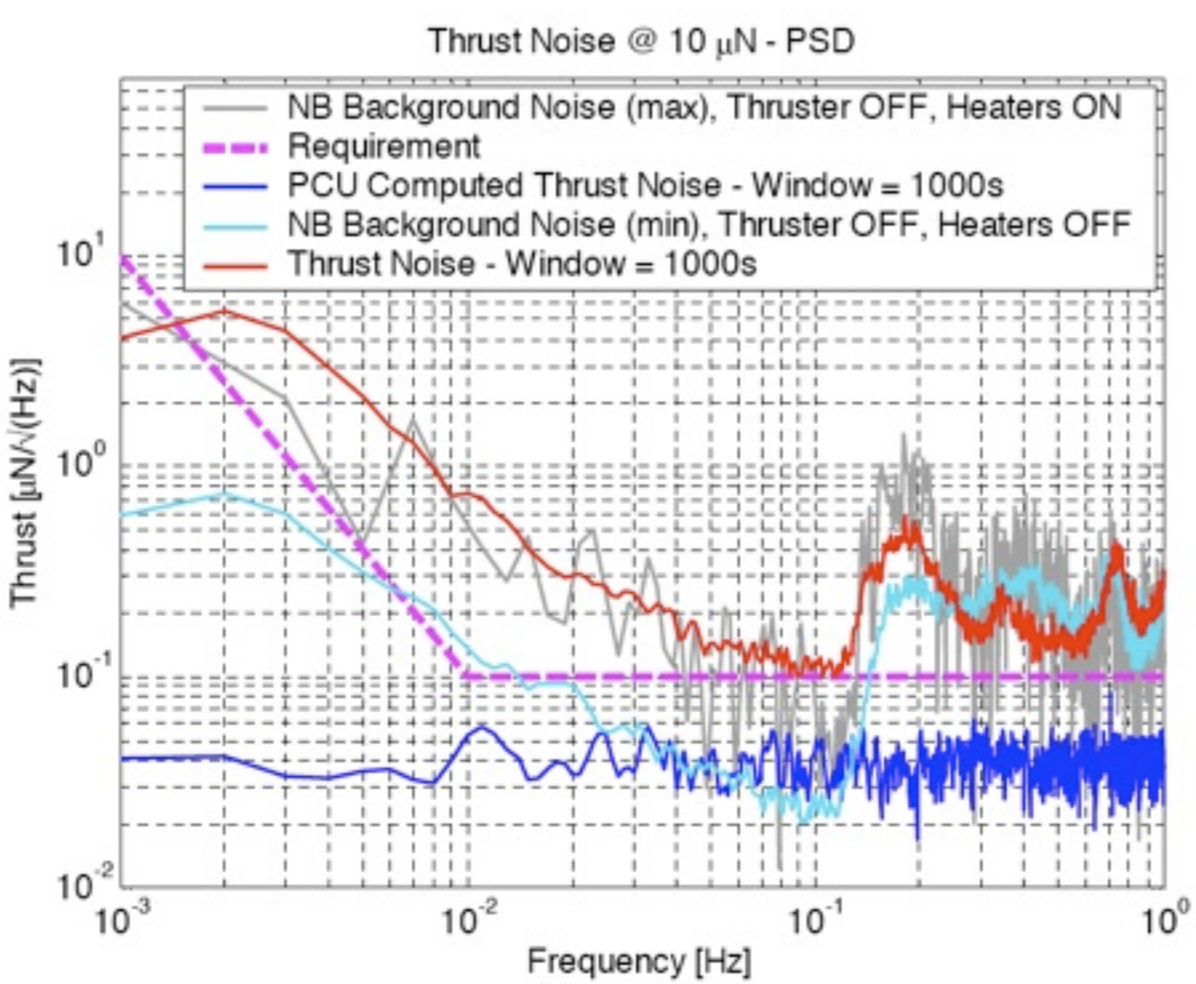


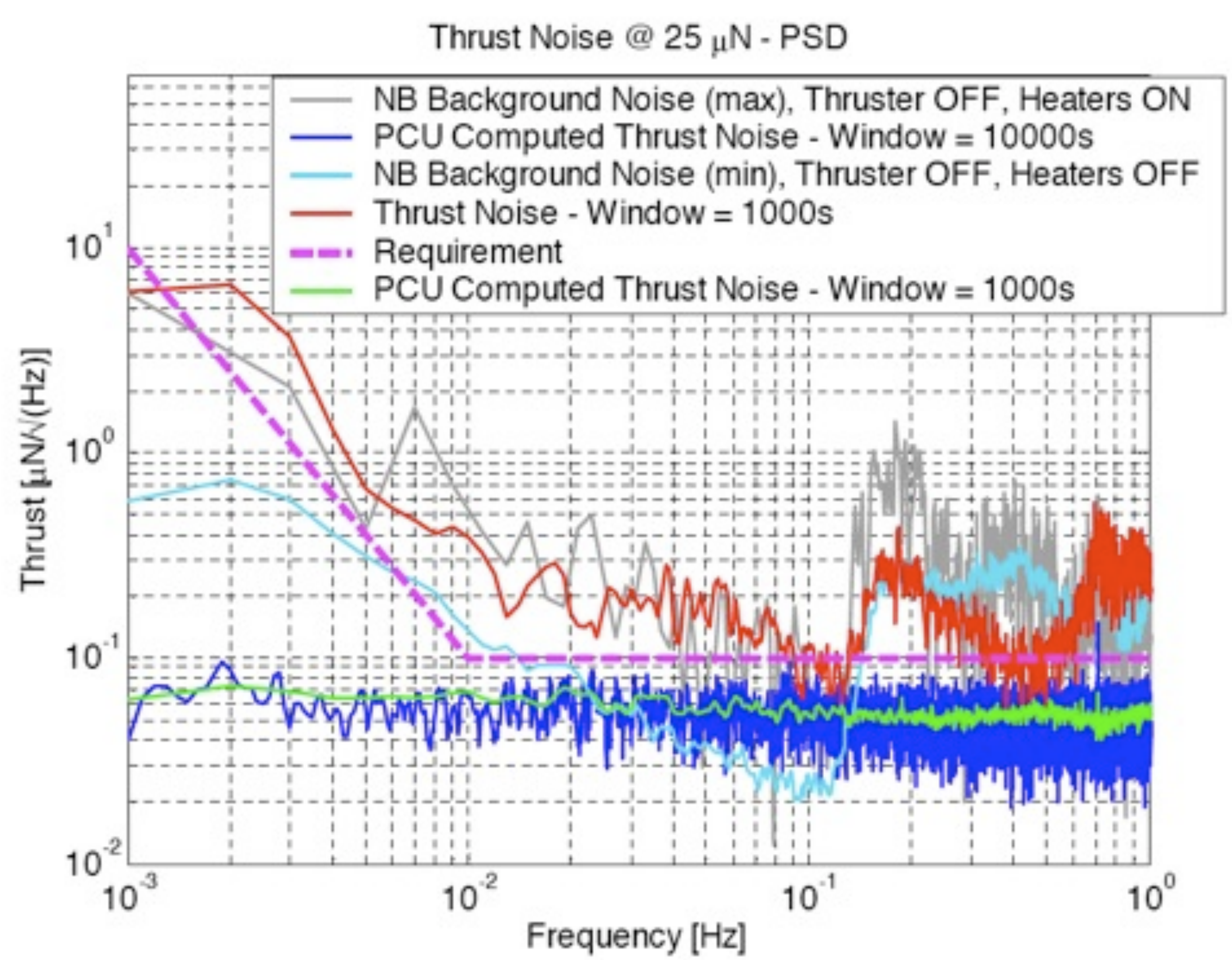
FEEPS Status [1]

- Full thruster assembly tested (two priming tests, extended firing test, thruster/PCU performance test)
- Priming procedure repeatedly demonstrated by test
- Mechanical tests of Structural/Thermal Model of a cluster performed successfully
- >3200hours (>900Ns) achieved in extended firing test on flight representative device (~1500Ns required for flight, including failure case and 50% margin)
- All thruster functions (mechanism opening, disk rupture, forced priming, emitter performance) demonstrated by repeatable tests
- Plume characterisation test completed

FEEPS Status [2]

- Nanobalance test completed
  - Nanobalance used to characterise the thruster
  - Noise performance measurements limited by facility performance
  - Demonstrated thrust noise is within factor 5 of requirement

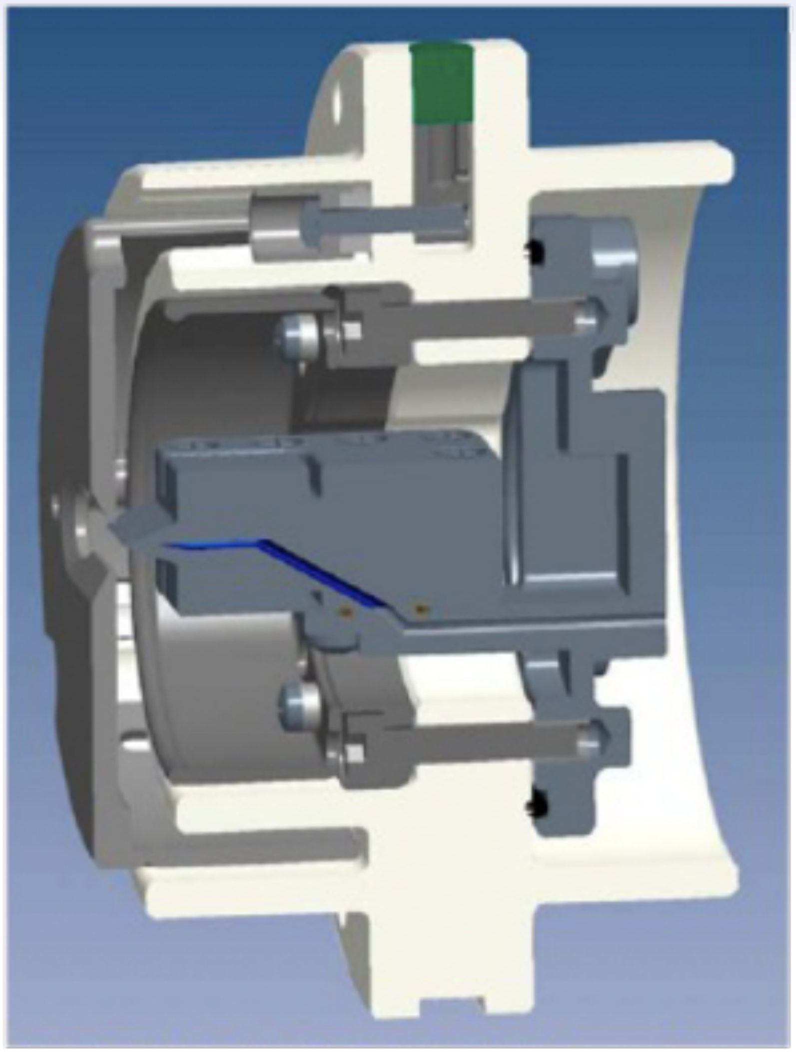
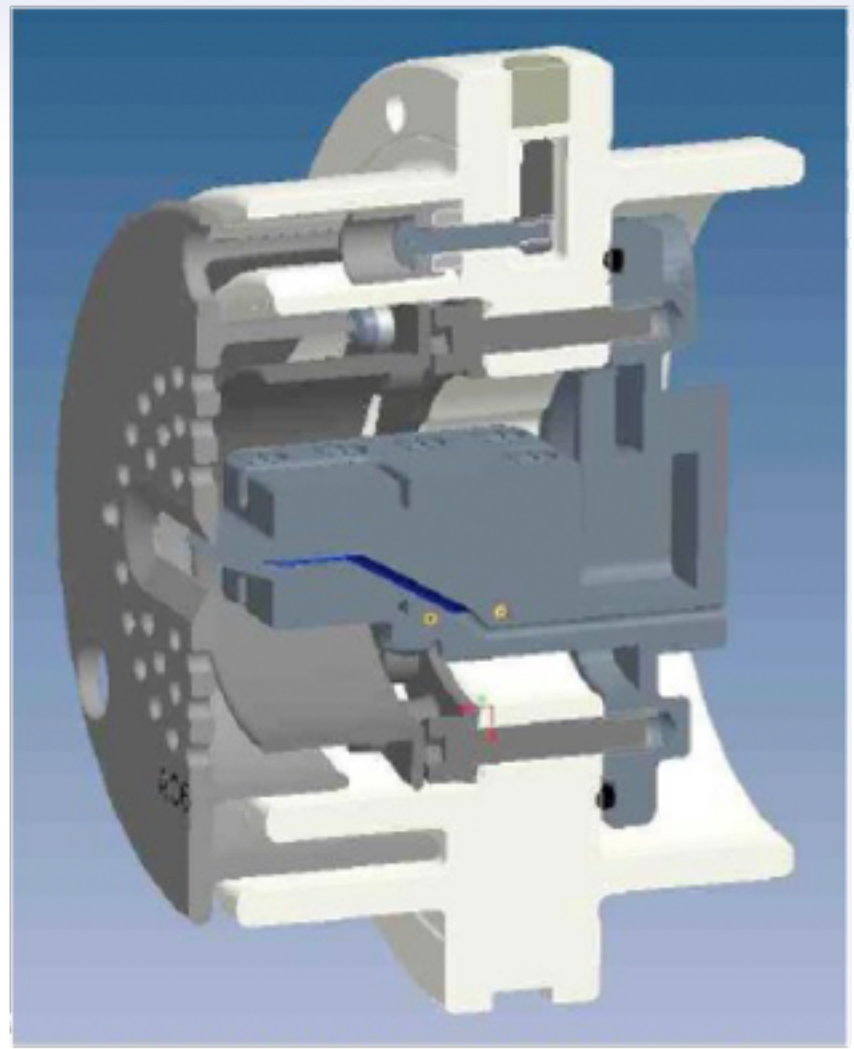
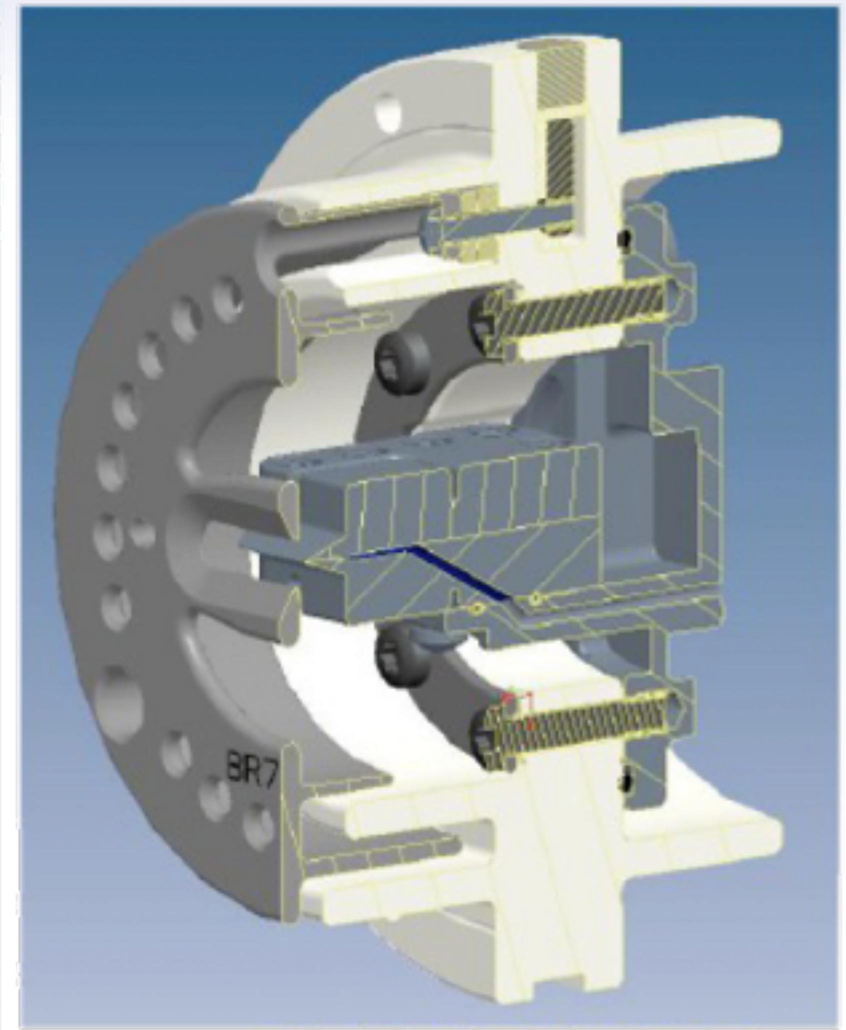




FEEPS Status [2]

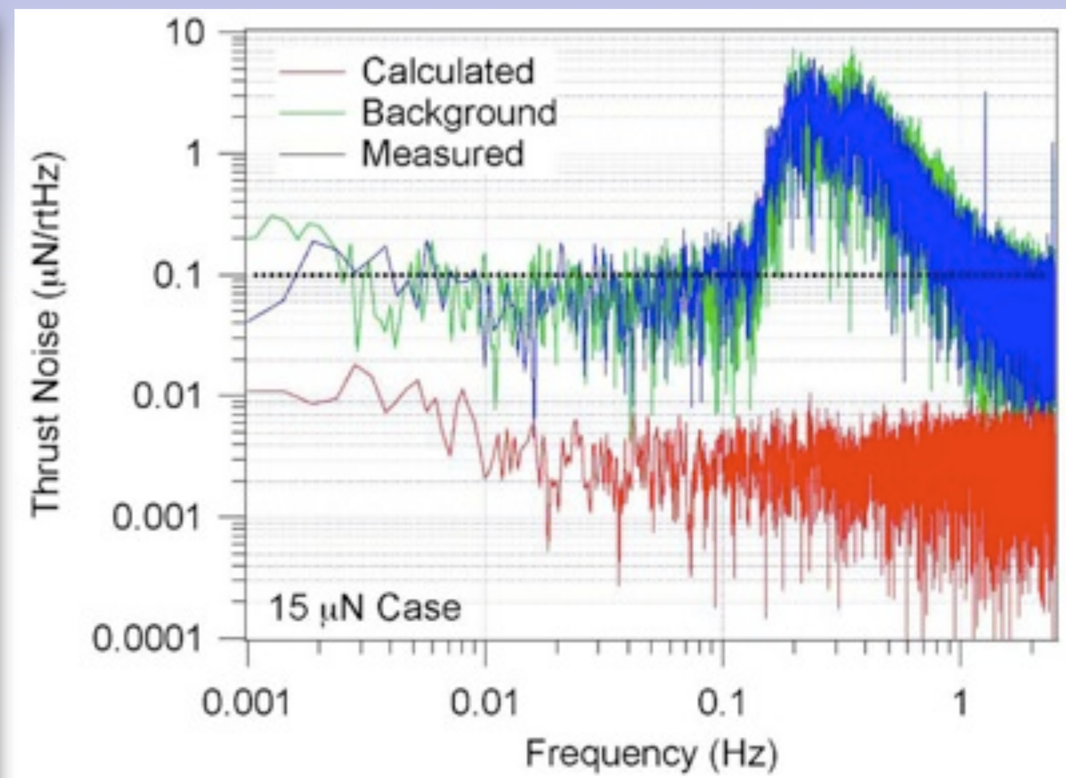
- Nanobalance test completed
  - Nanobalance used to characterise the thruster
  - Noise performance measurements limited by facility performance
  - Demonstrated thrust noise is within factor 5 of requirement
- Neutralisation test successfully completed at ESTEC
- Power control unit completed
- FEEP Cluster Assembly nearly completed, but.....
  - Problem discovered in the latest design modification
    - Tiger Team established by ESA to investigate failure
  - Tiger Team report focusses on three points:
    - Material of the emitter
      - Previously stainless steel, now investigating Molybdenum and Nickel
    - Geometry of the accelerator
      - Number of holes, opening angle, chamfer radius
    - Propellant feed system
      - Previous design allowed thruster to prime easily, however at the cost of delivering too much Caesium to the slit.
  - Future tests will be tailored to validate on one aspect of the design at a time

Thruster design evolution

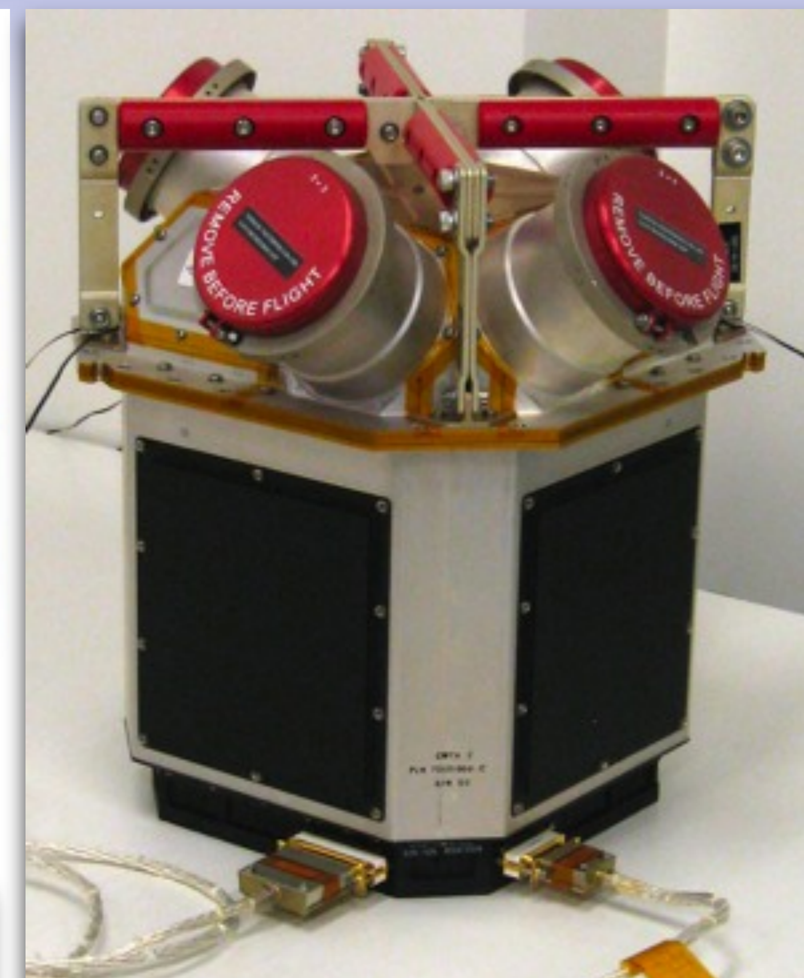
TDR	CDR	Post-CDR proposal
		
S2-ALT-RP-2003 iss.4 (21/04/2008)	S2-ALT-RP-2003 iss.5 (05/12/2008)	S2-ALT-TN-2037 (15/06/2009)

ST-7 DRS Flight Hardware

Thruster Cluster 1



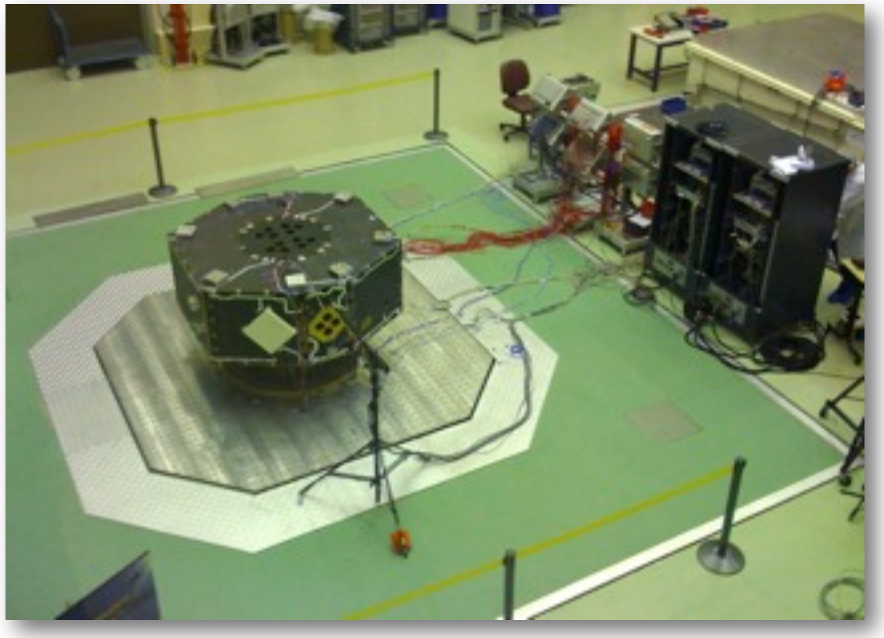
Integrated Avionics Unit



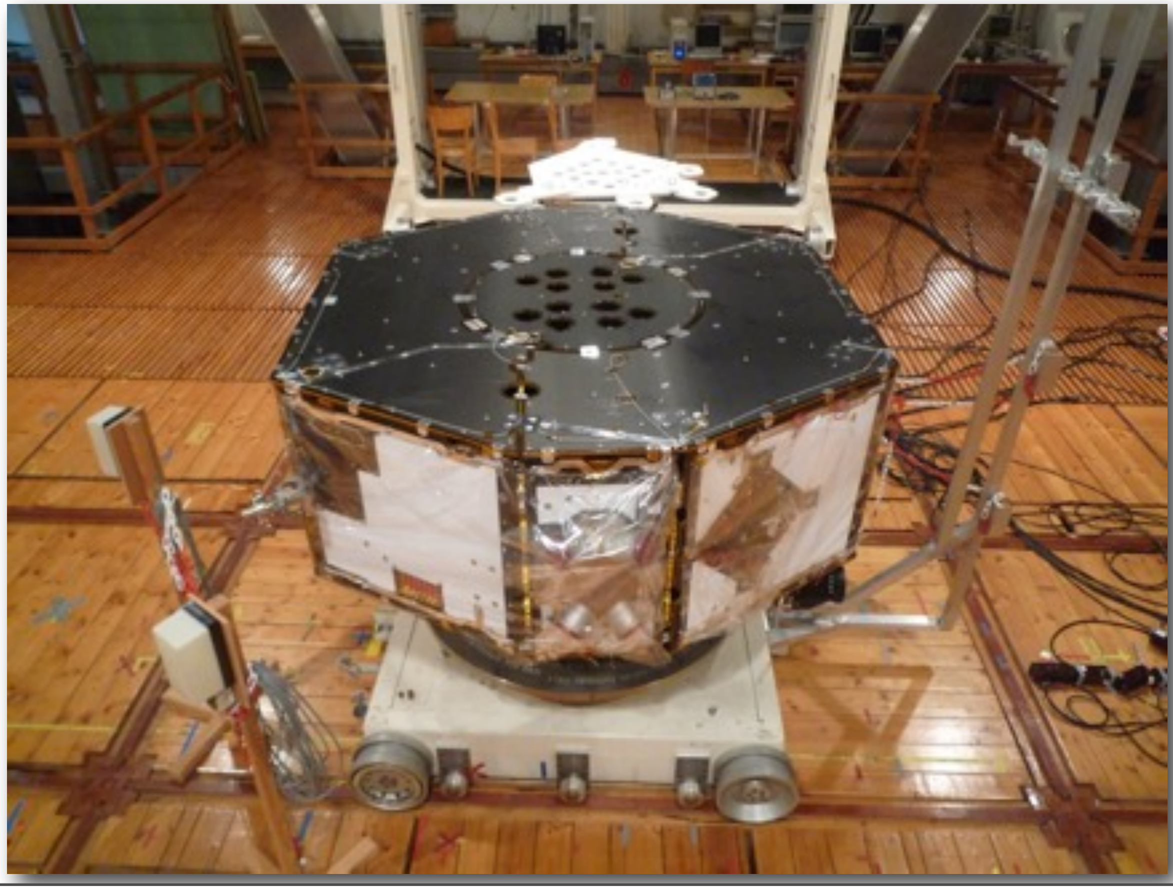
Thruster Cluster 2

Sciencecraft Summary

- Structural testing on spacecraft and propulsion module complete
- Integration of sciencecraft mostly complete (not including LTP)
- First system environmental test (magnetic) starting imminently
- Integration and Test schedule is being re-worked to minimise delays due to late LTP delivery.



Hot of the press....
Magnetic Testing at IABG



Sciencecraft Schedule

- ESA want to decouple the Assembly, Integration and Test (AIT) of the s/c from the delivery of the LTP Core Assembly (LCA)
- AIT flow is being designed to allow some environmental tests to be performed using structural/thermal dummies of the LCA
  - Only launch composite acoustic and separation tests will be performed with flight LCA
- If LTP incurs further delays, s/c will be put in storage
  - As of today, this is will not be required

Launcher

- Baseline launcher is the new European VEGA launcher
- VEGA first qualification launch is scheduled for end 2010 earliest
- LPF is scheduled to be on 3rd launch after qualification
- Backup Rockot launcher is still maintained in the event of VEGA not being ready
  - Rockot *<u>cannot</u>* put LPF into orbit around L1
  - Backup Highly Elliptical Orbit being studied

Artists impression of VEGA launcher

VEGA main engine test

Conclusion

- System testing of the integrated sciencecraft has now started
- Most of the flight units of the LTP have been delivered, with all units scheduled to be delivered by May 2010
- The caging mechanism remains on the critical path
  - Risk mitigation is in place: sciencecraft will be put in storage if LTP is not available on time
- Launch is scheduled for 2nd Quarter 2012

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

- Laben
- Carlo Gavazzi Space
- ALTA
- ARCS
- Contraves
- Kaiser Threde
- NTE
- SCISYS
- Spacebel
- SRON
- Technologica
- TESAT
- ZARM
- JPL
- NASA Goddard
- BUSEK