LISA Pathfinder

Europe paving the way to gravitational wave astronomy

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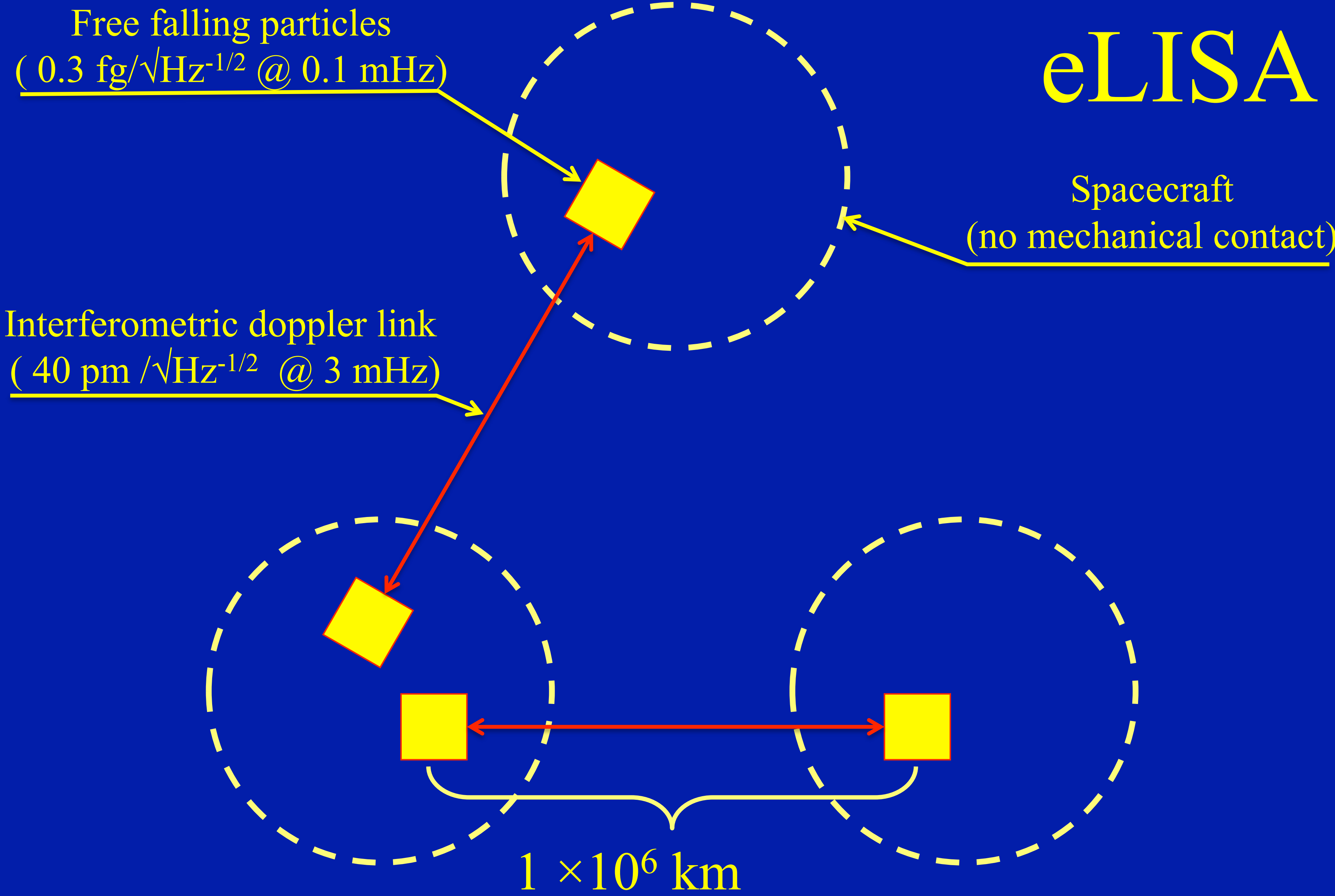
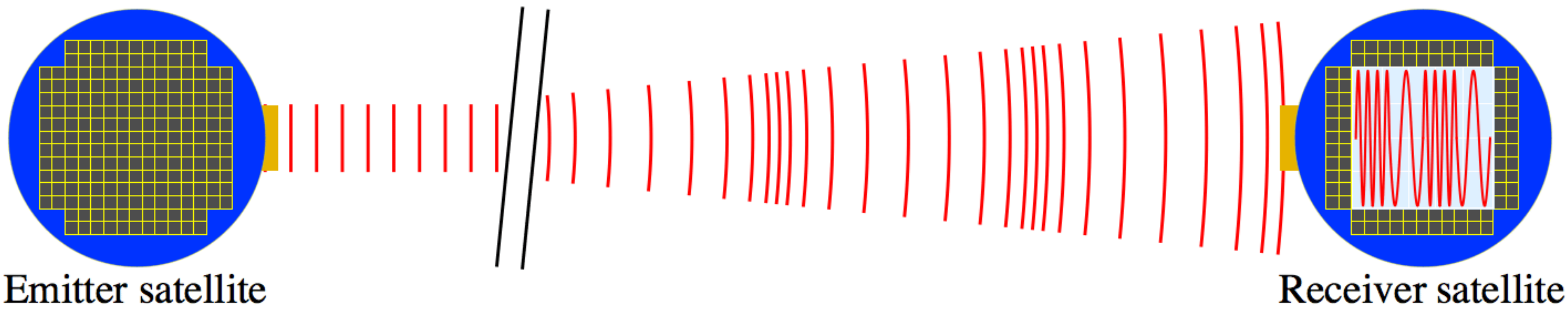
eLISA



Free falling particles
(0.3 fg/√Hz$^{-1/2}$ @ 0.1 mHz)
Spacecraft
(no mechanical contact)
Interferometric doppler link
(40 pm /√Hz$^{-1/2}$ @ 3 mHz)
1×10^6 km

The basic measurement concept: the Doppler link

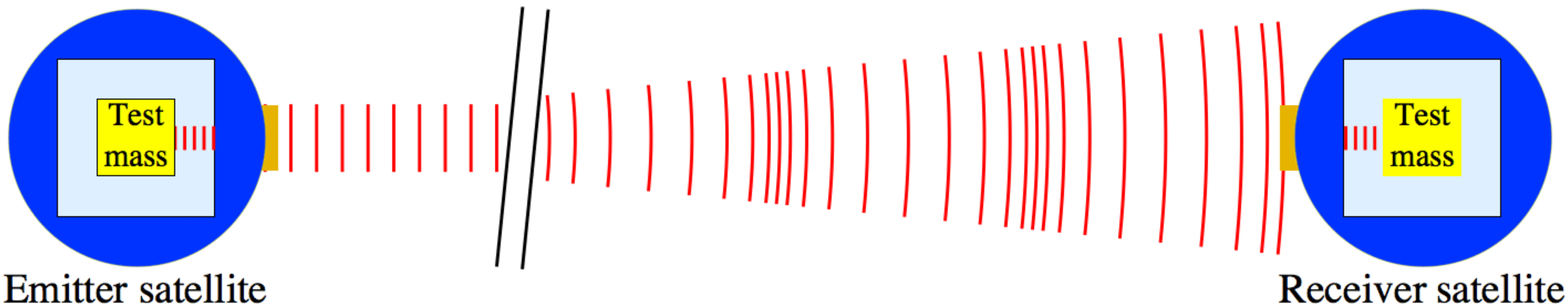


- GW modulates the frequency of the received beam

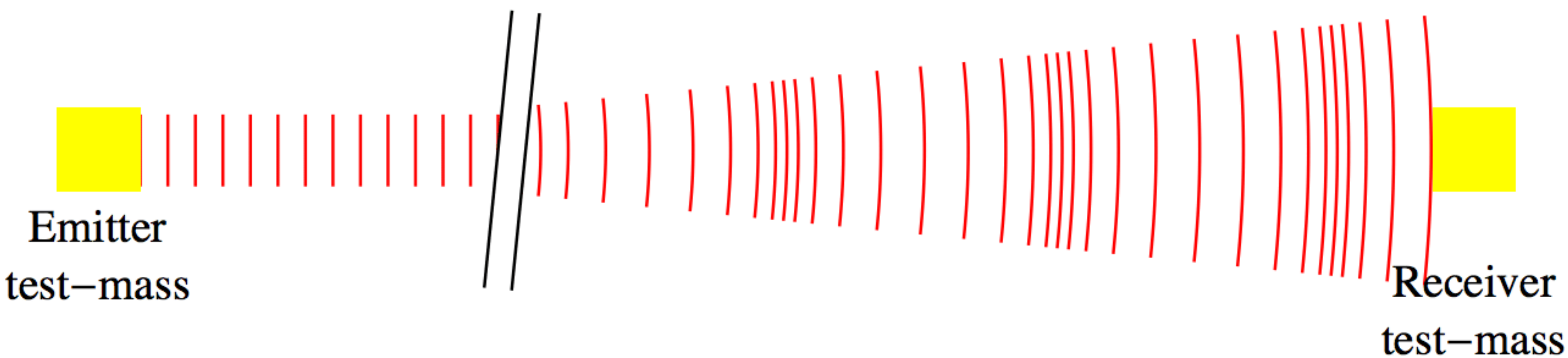
$$\left(c/\nu_o\right)\left(\dot{\nu}_{receiver}-\dot{\nu}_{emitter}\right)=c\left\{\dot{h}_{receiver}\left(t\right)-\dot{h}_{emitter}\left(t-L/c\right)\right\}$$
$$+a_{receiver}\left(t\right)-a_{emitter}\left(t-L/c\right)$$

- As accelerations of satellites relative to their local inertial frame also do.

The basic measurement concept: the Doppler link

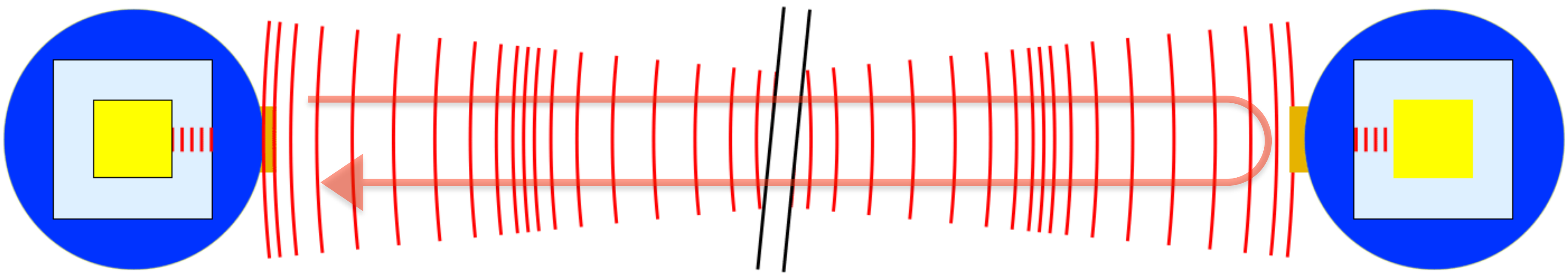


- Inertial reference test-masses are used to correct for satellite acceleration

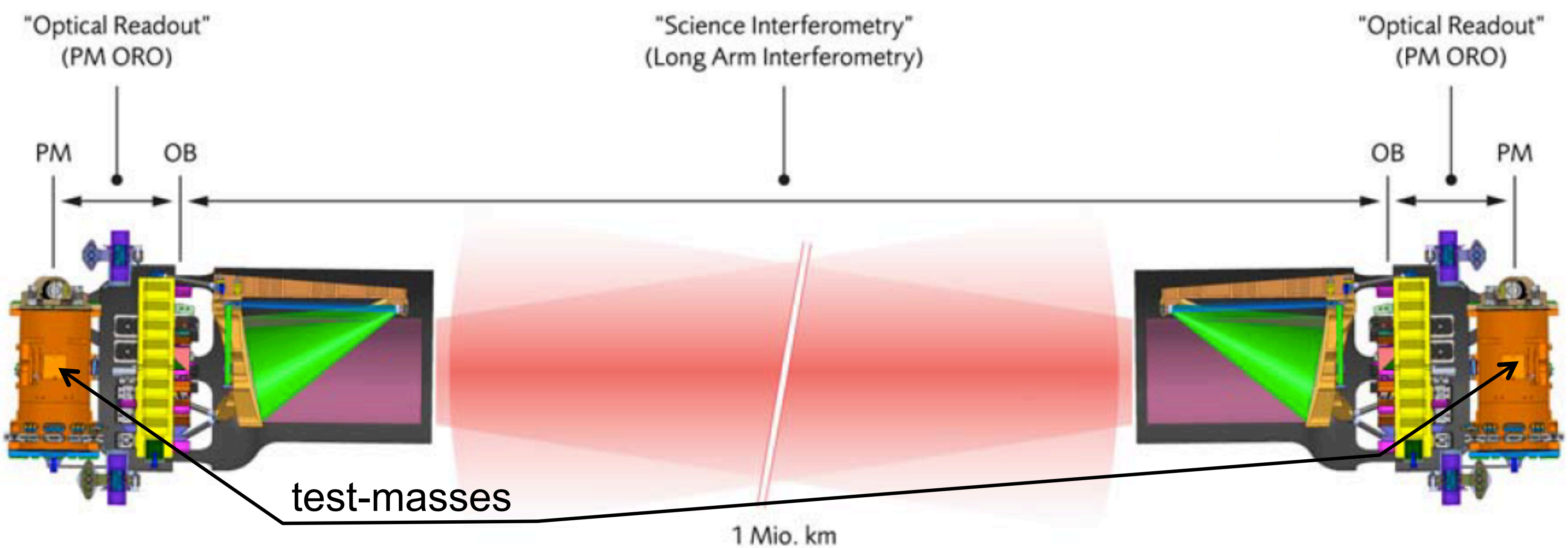


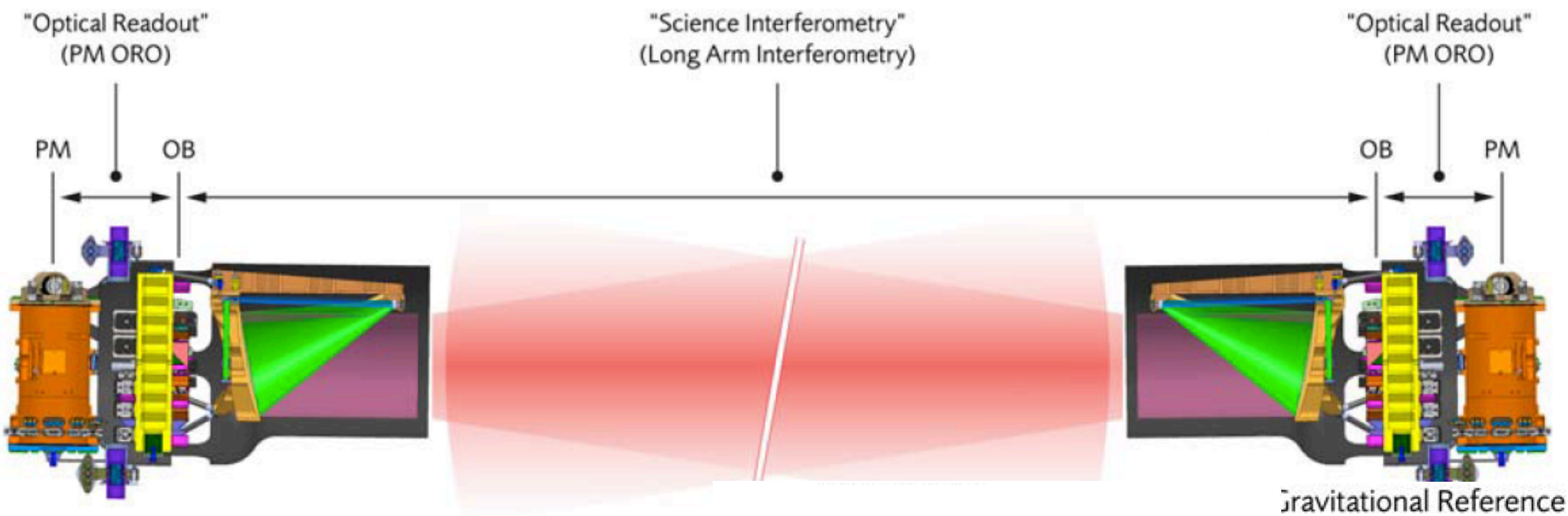
- Equivalent to directly tracking test-masses

The detector arm

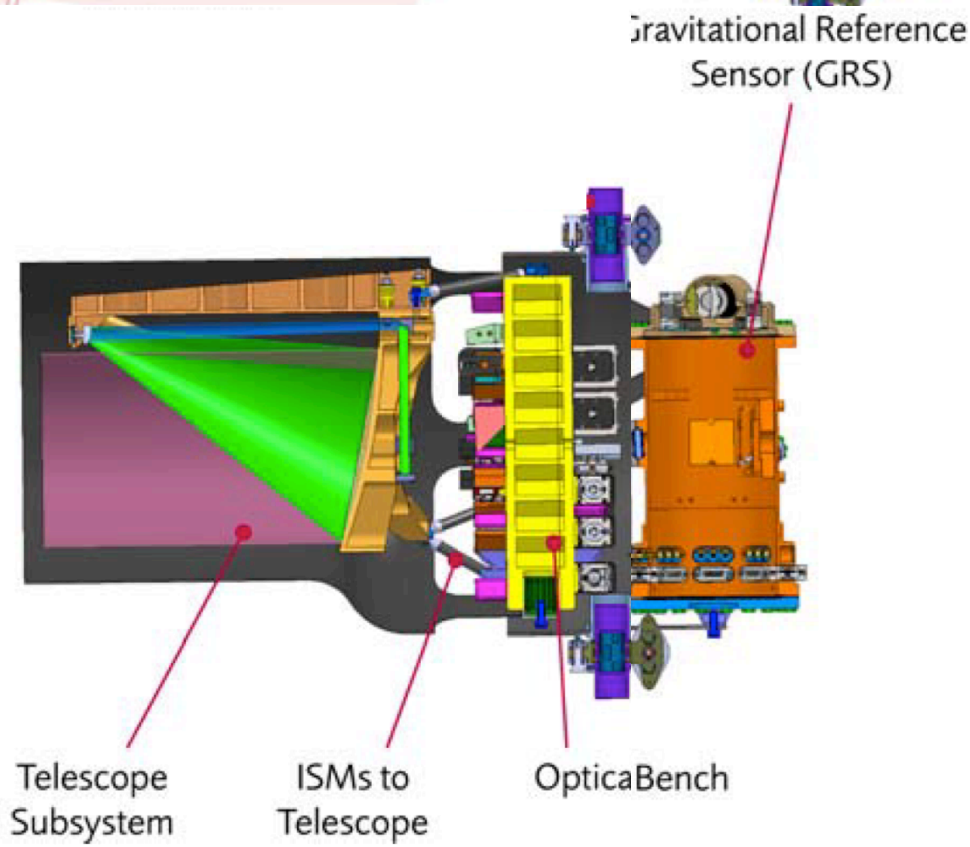


- Two counter-propagating, phase-locked links



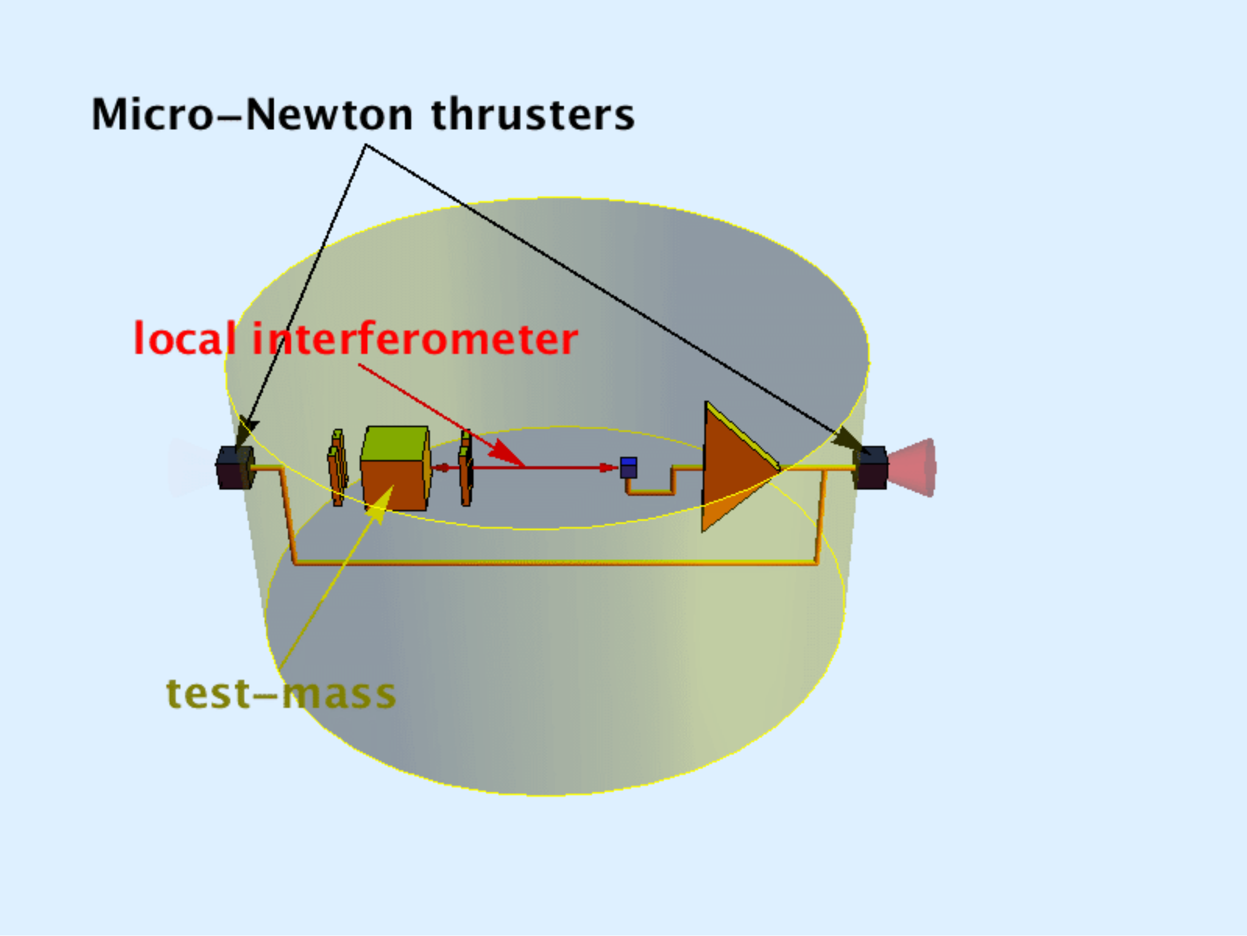


- eLISA instrument key elements:
  - The Gravitational Reference Sensor with the test-mass
  - The Optical Bench with the complete interferometry
  - A telescope to exchange light with the far satellite



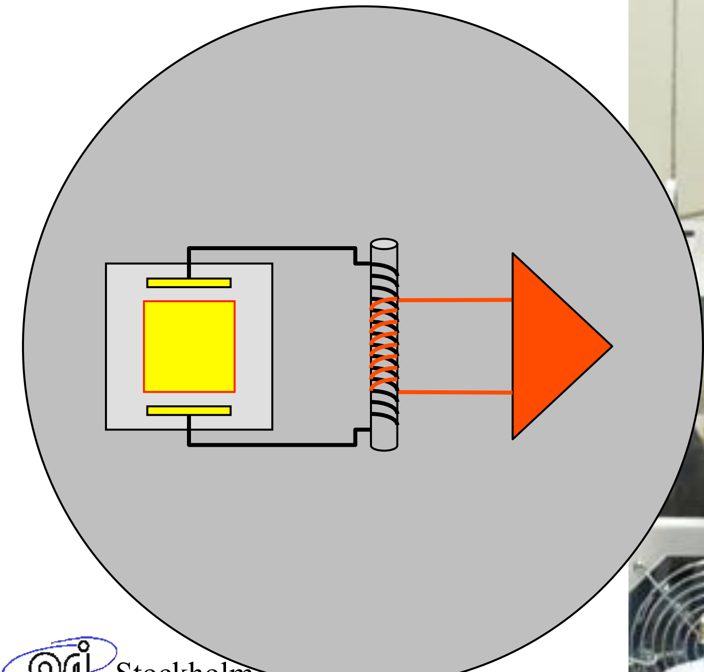
The non-contacting satellite (drag-free)

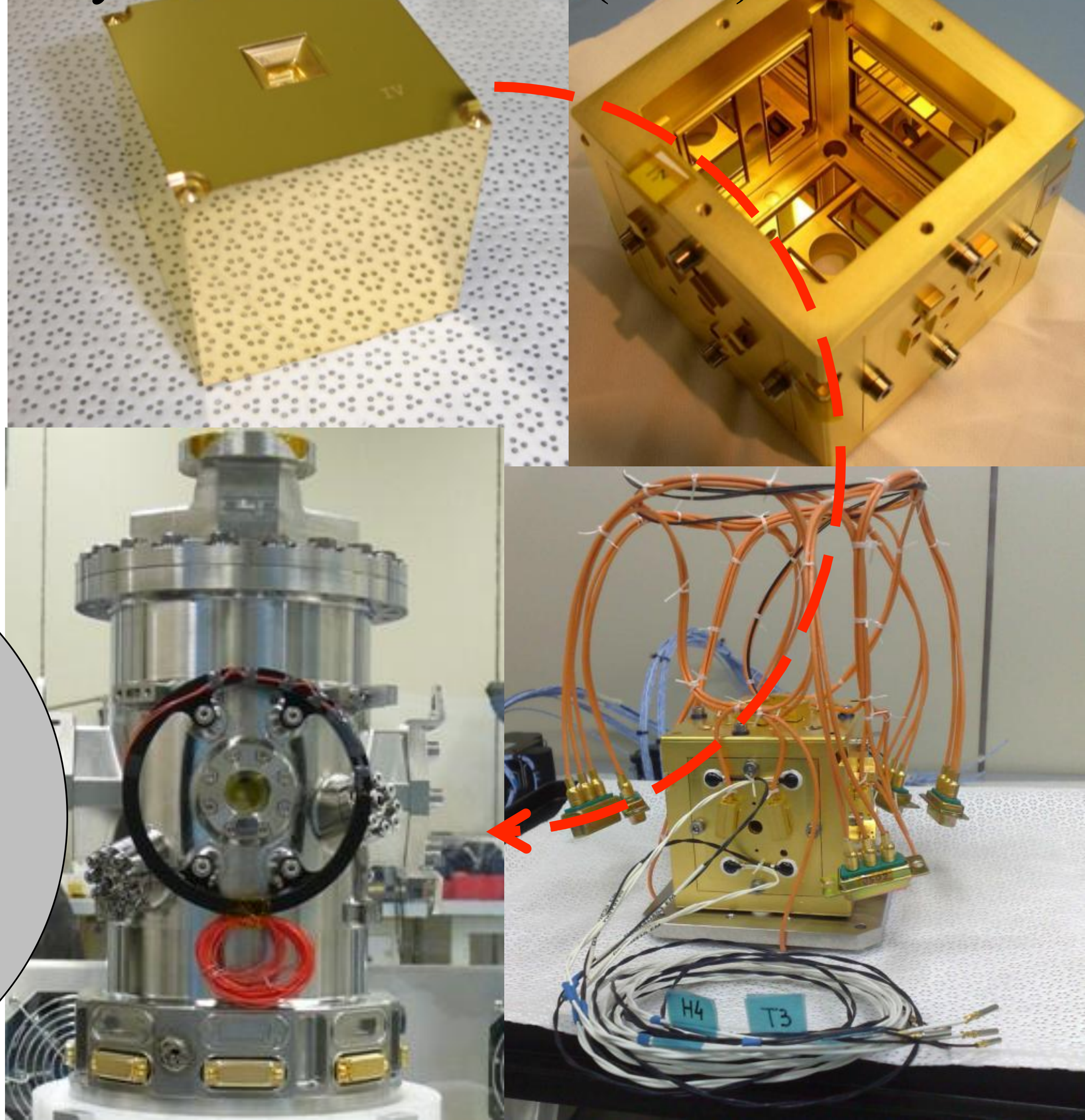
- Position of spacecraft relative to test-mass is measured by local interferometer
- Spacecraft is kept centered on test-mass by acting on micro-Newton thrusters.



The Gravity reference Sensor (GRS)

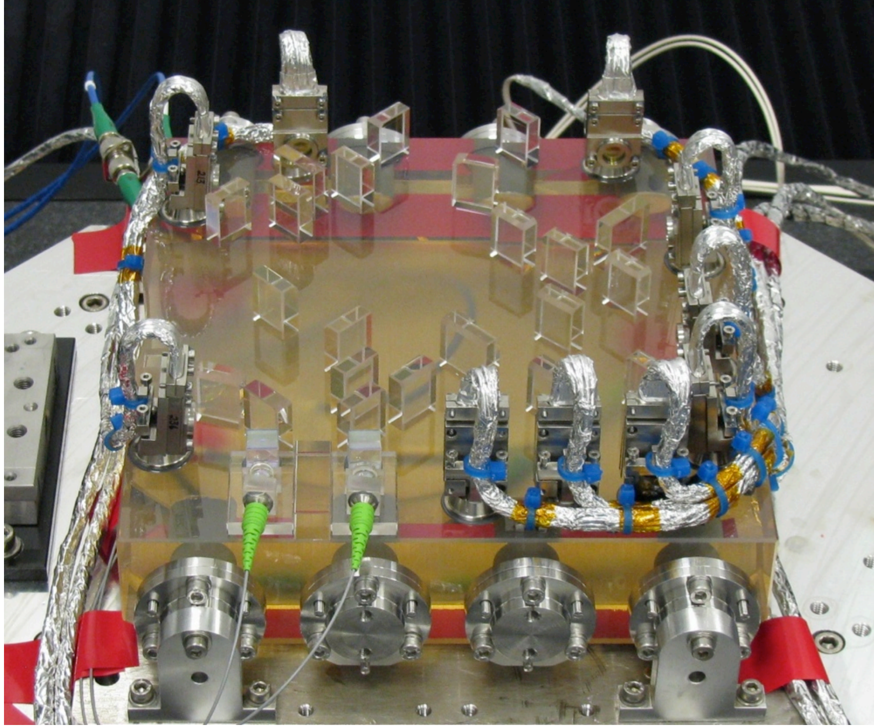
- Drag-free along sensitive direction
- Test-mass (TM) control along the remaining ones

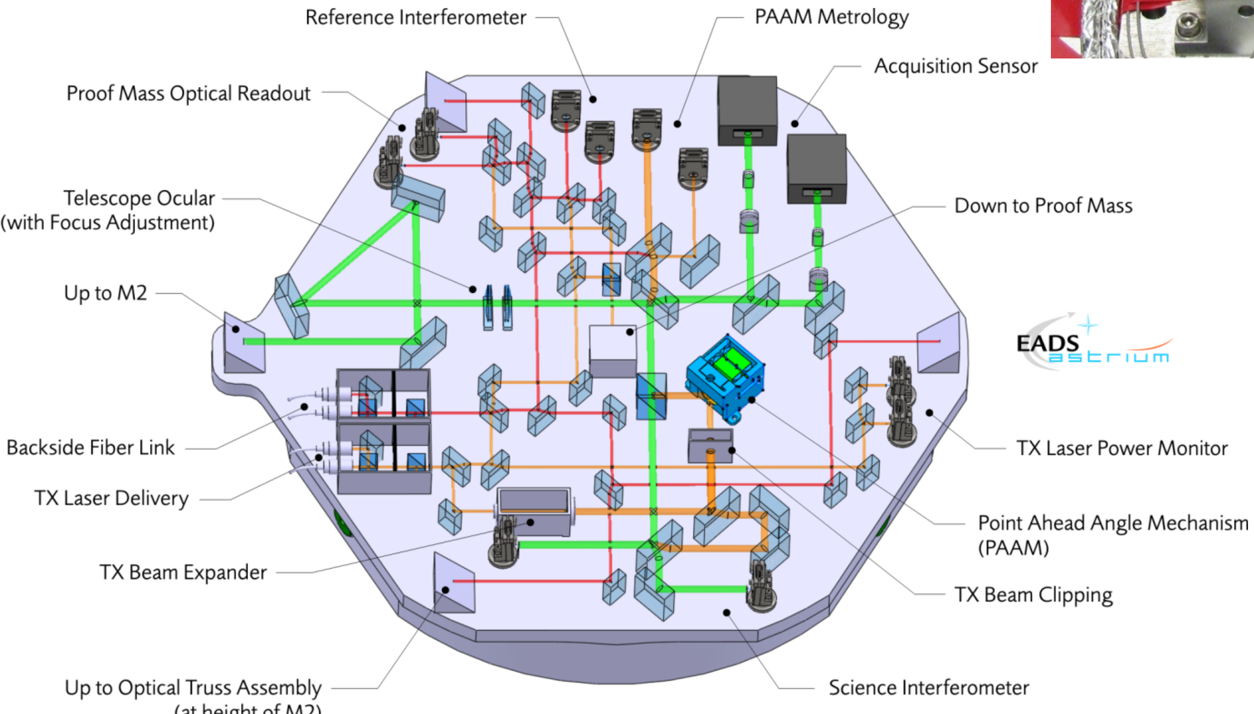




The optical bench

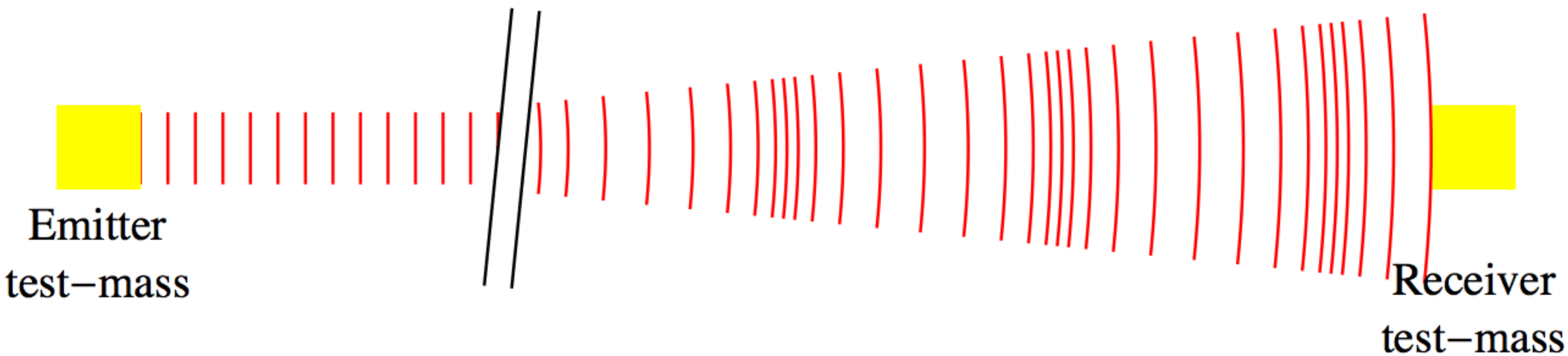
- Carries on all needed interferometry
- Monolithic ultra-stable structure obtained by silica hydroxyl bonding





Disturbances in e-LISA: 1 force noise

- Link measures curvature but also acceleration of emitter and/or receiver, along beam direction.

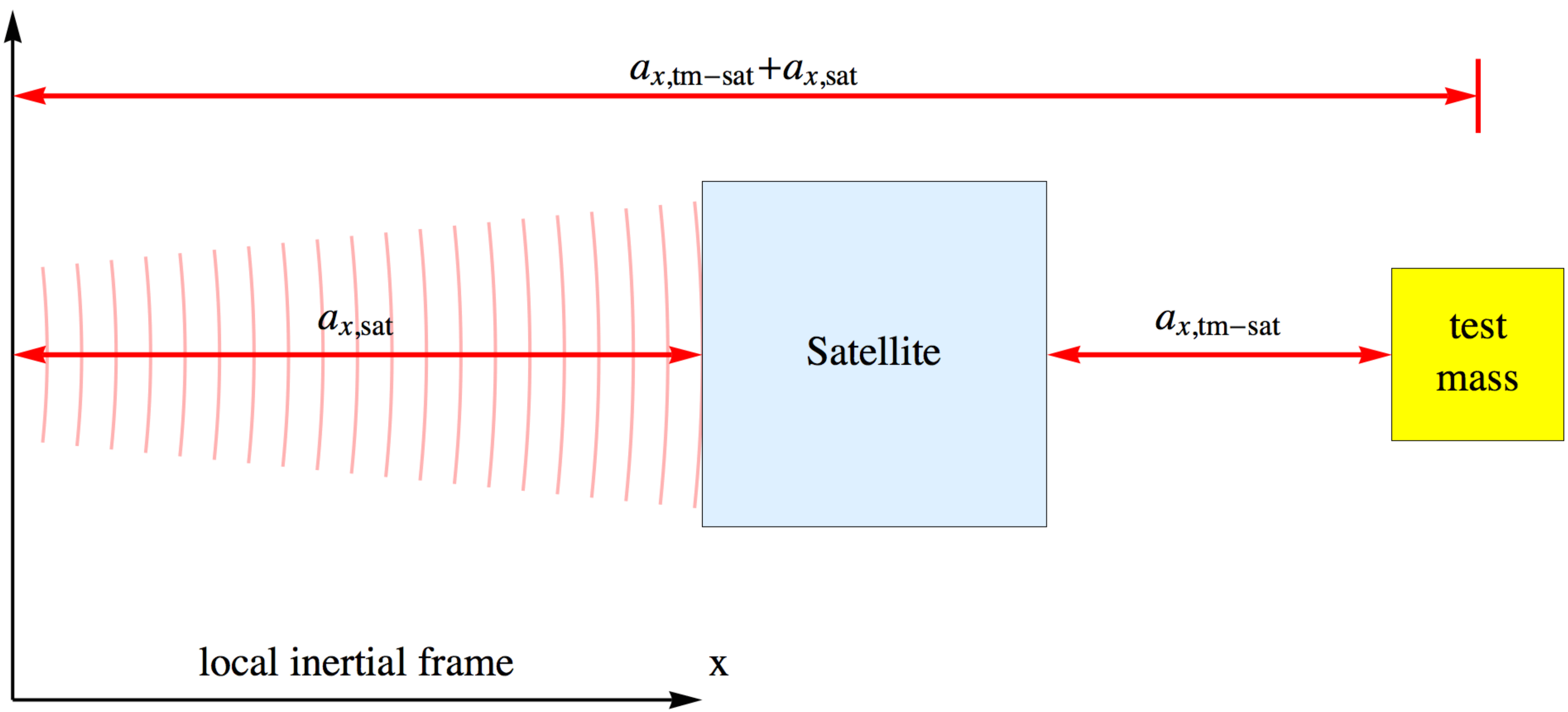


$$\left(c/\nu_o\right)\left(\dot{\nu}_{receiver}-\dot{\nu}_{emitter}\right)=c\left\{\dot{h}_{receiver}\left(t\right)-\dot{h}_{emitter}\left(t-L/c\right)\right\}$$
$$+a_{receiver}\left(t\right)-a_{emitter}\left(t-L/c\right)$$

- Accelerations are relative to *local* inertial frames and due to *true force* noise.

Disturbances in eLISA: 2. local reference frame noise

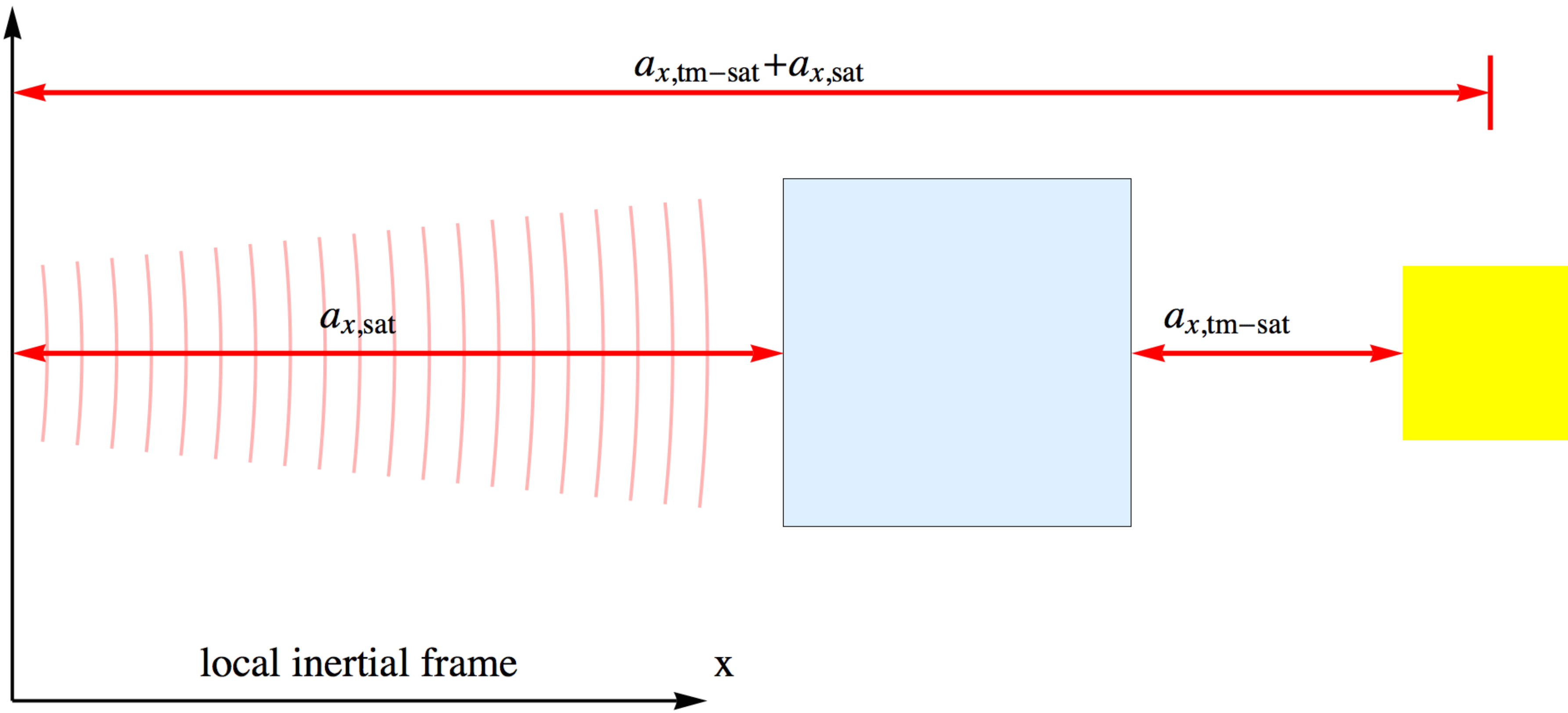
- Acceleration of TM relative to local inertial frame from:
  - A measurement, by local interferometer, of acceleration of TM relative to satellite.
  - A measurement of acceleration of satellite relative to local inertial frame (defined by phase front of laser beam)
  - Acceleration of TM is obtained as $a_{x,tm} = a_{x,tm-sat} + a_{x,sat}$



Disturbances in eLISA: 2. local reference frame noise

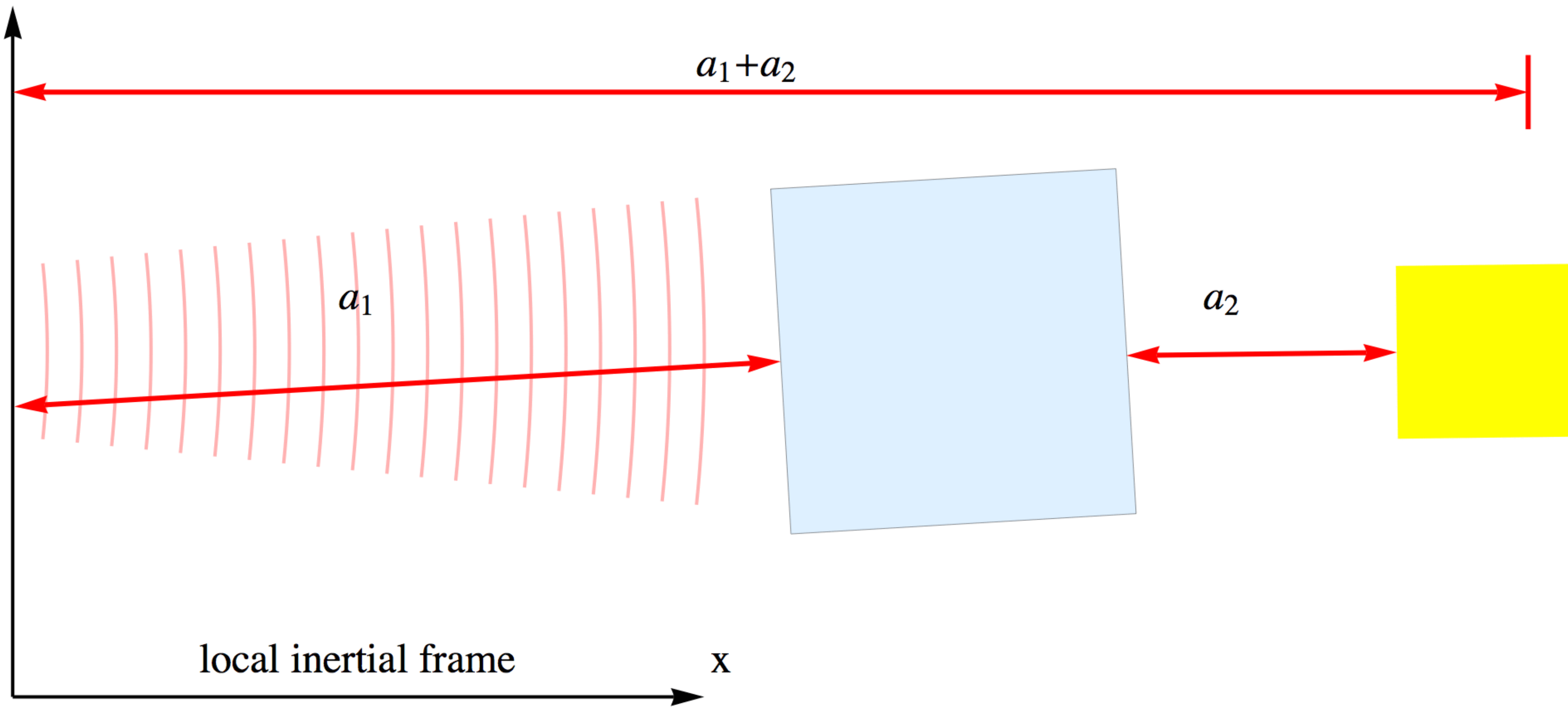
- Combination suppresses large satellite motion

$$\underbrace{a_{x,tm}}_{0.3\ \mathrm{fg}/\sqrt{\mathrm{Hz}}} = \underbrace{a_{x,tm-sat}}_{20\ \mathrm{fg}/\sqrt{\mathrm{Hz}}} + \underbrace{a_{x,sat}}_{20\ \mathrm{fg}/\sqrt{\mathrm{Hz}}}$$

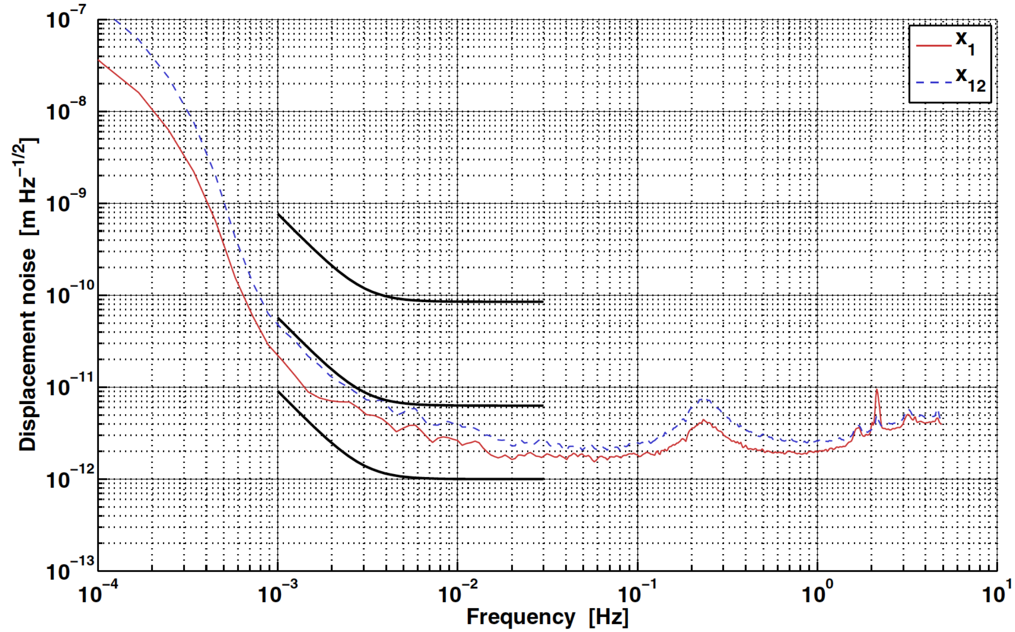


Disturbances in eLISA: 2. local reference frame noise

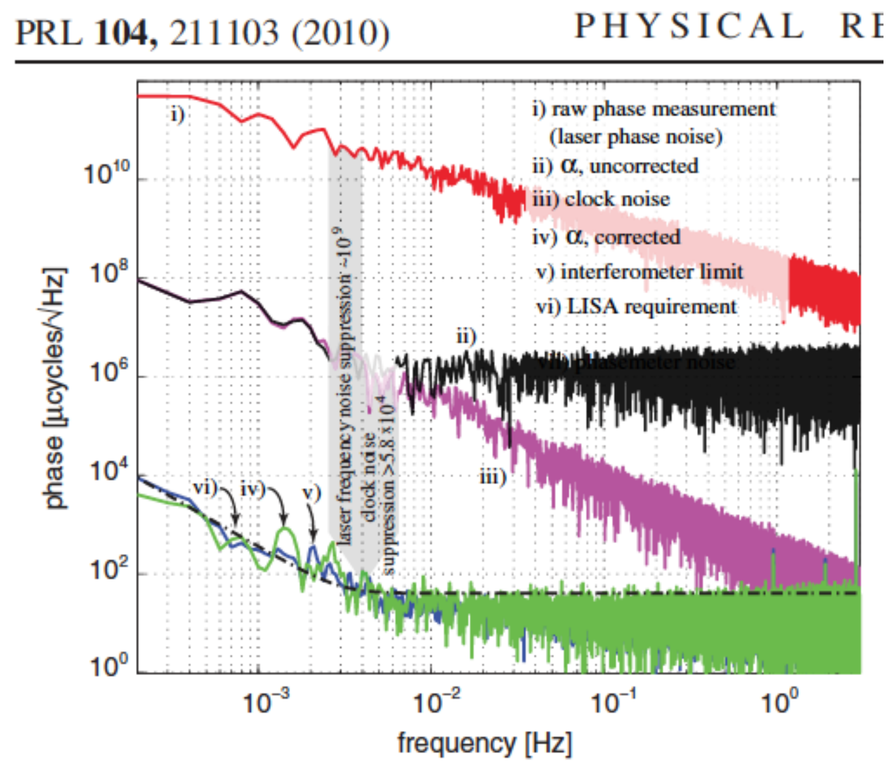
- Suppression of satellite acceleration depends on accuracy of reference frames of combination
- Misalignments, calibration inaccuracies contaminate signal with satellite acceleration



Disturbance in e-LISA. 3. Readout noise



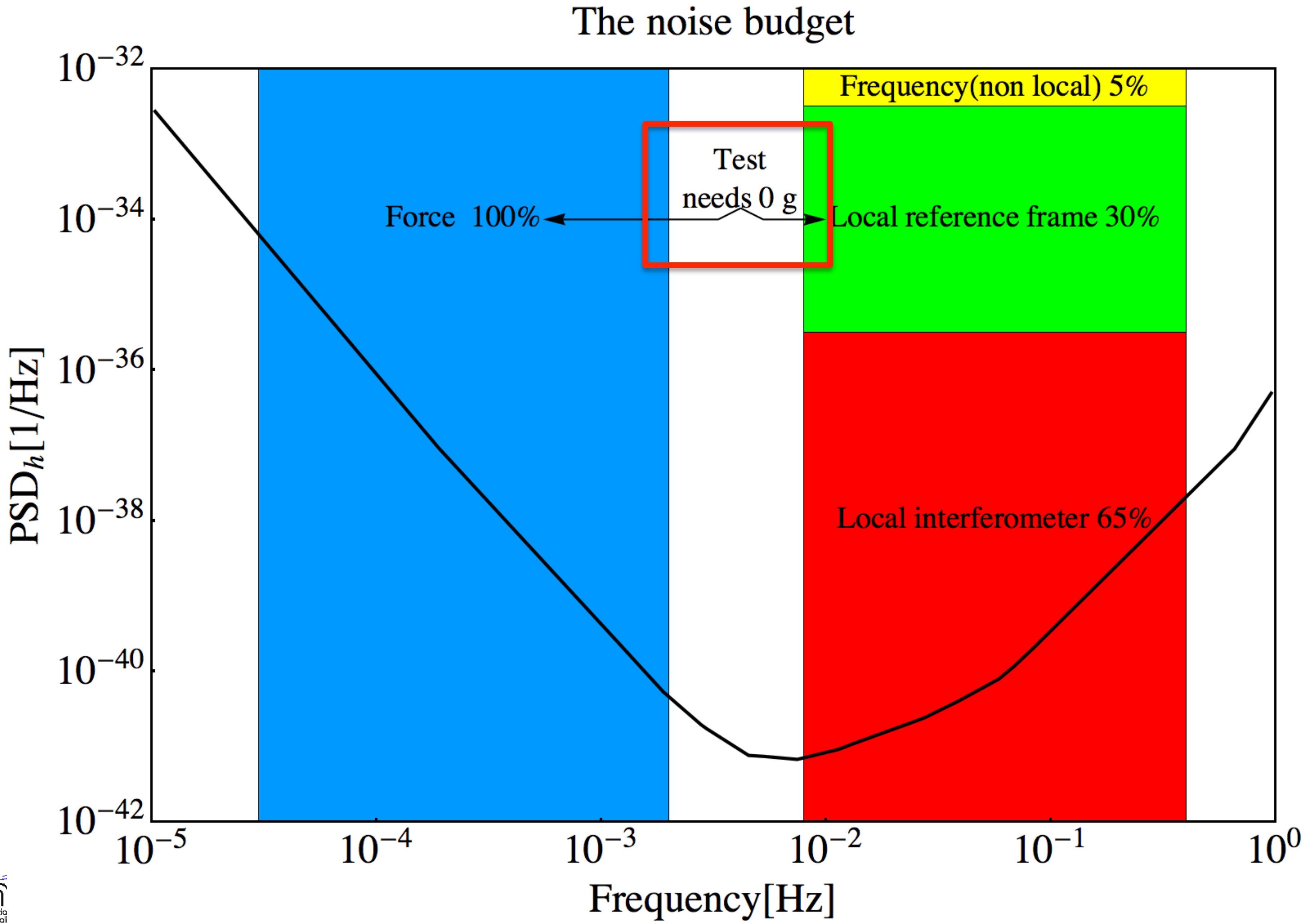
- Local contributions: phase-meter electronics, clock, AOM's….



- Non local contribution: laser frequency noise common to all arms.

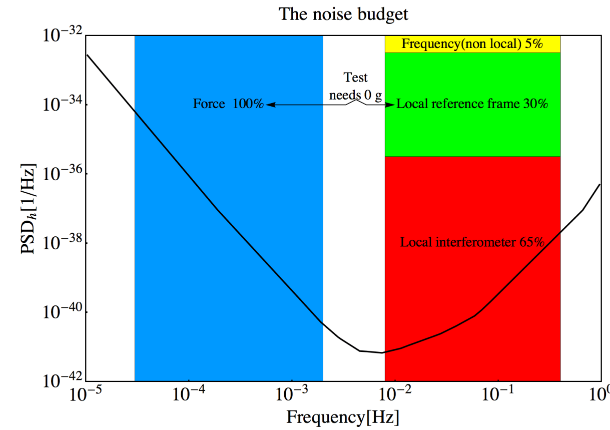
  Suppressed by taking combination of signals from different arms (Time Delayed Interferometry

Most of disturbances are local !



The aims of LISA Pathfinder

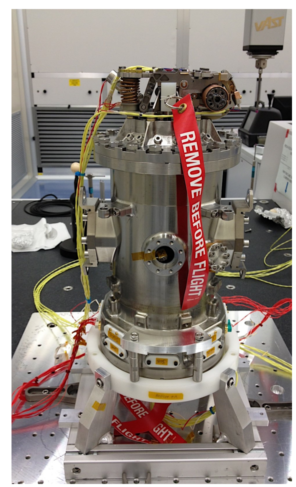
- A test of the entire local measurement (95 % of noise) with a requirement at 3 fg/√Hz @ 1 mHz
- Return a quantitative physical model for test-mass geodesic motion at eLISA requirements

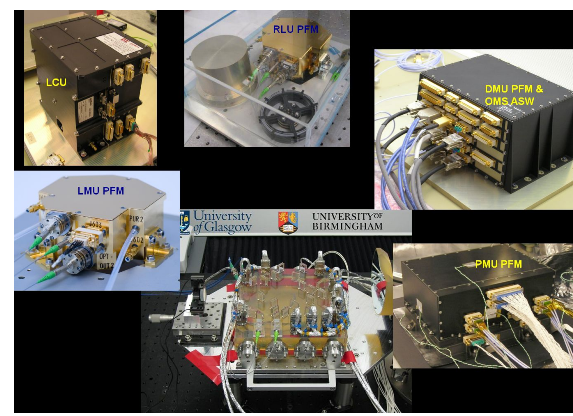


PRL **103,** 140601 (2009) PHYSICAL REVIEW LETTERS week ending 2 OCTOBER 2009

Increased Brownian Force Noise from Molecular Impacts in a Constrained Volume

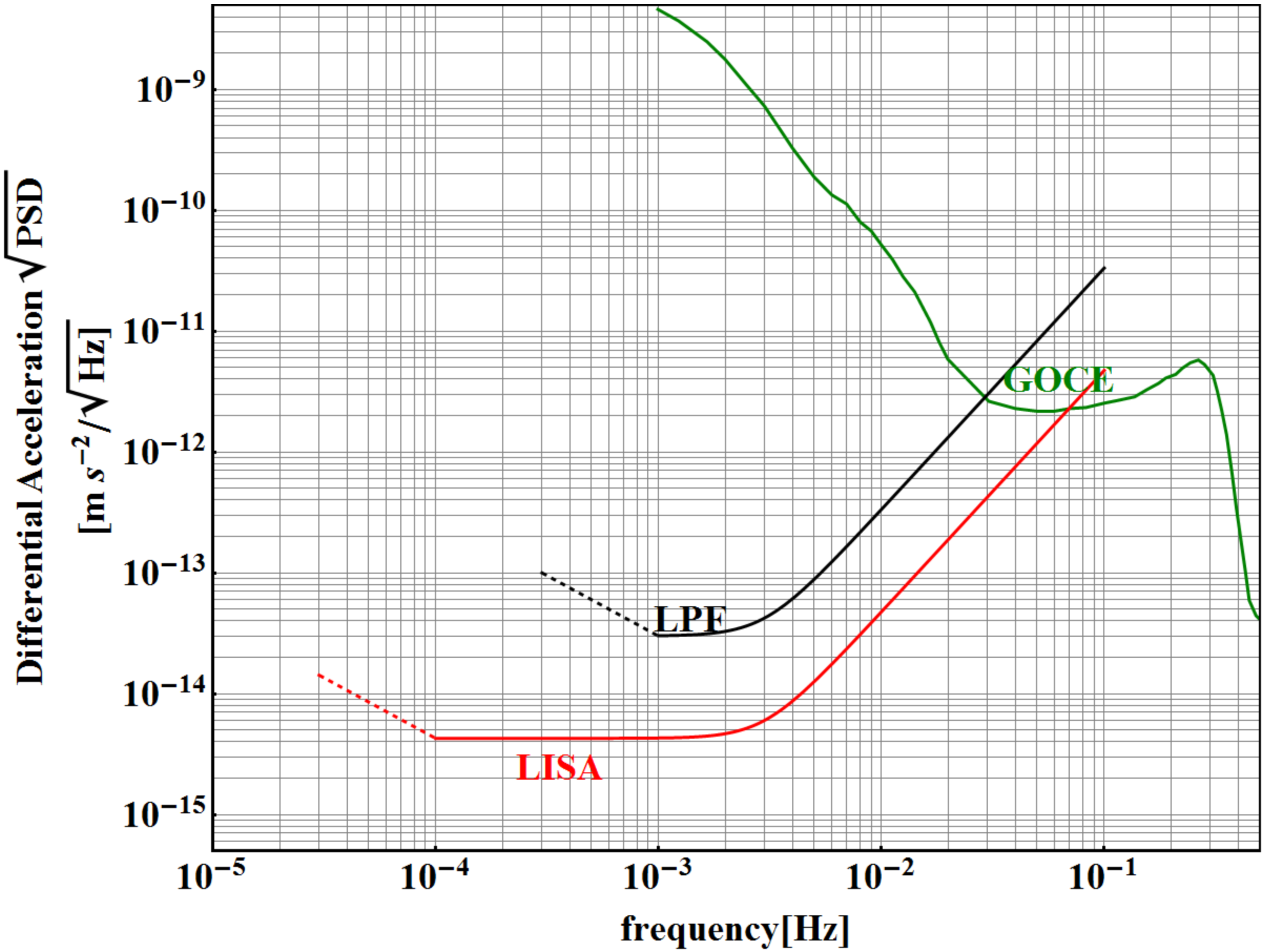
- A verification step in the development of eLISA using same hardware/processes:
  - GRS, Micro-thrusters, Disturbance reduction system, including gravitational control and free test-mass technique (DFACS)
  - Monolithic, silica-bonded optical bench
  - Master laser, low-frequency phase-meter





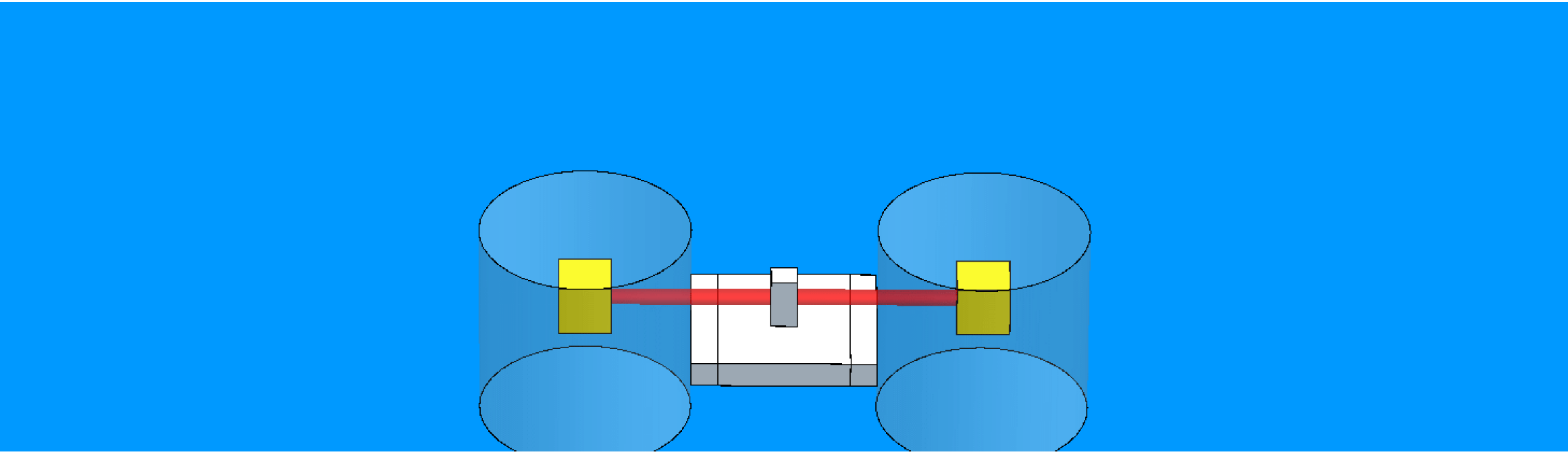
eLISA and LPF requirements

- Relaxation of requirements is for the mission not for the hardware.
- Hardware is designed for eLISA



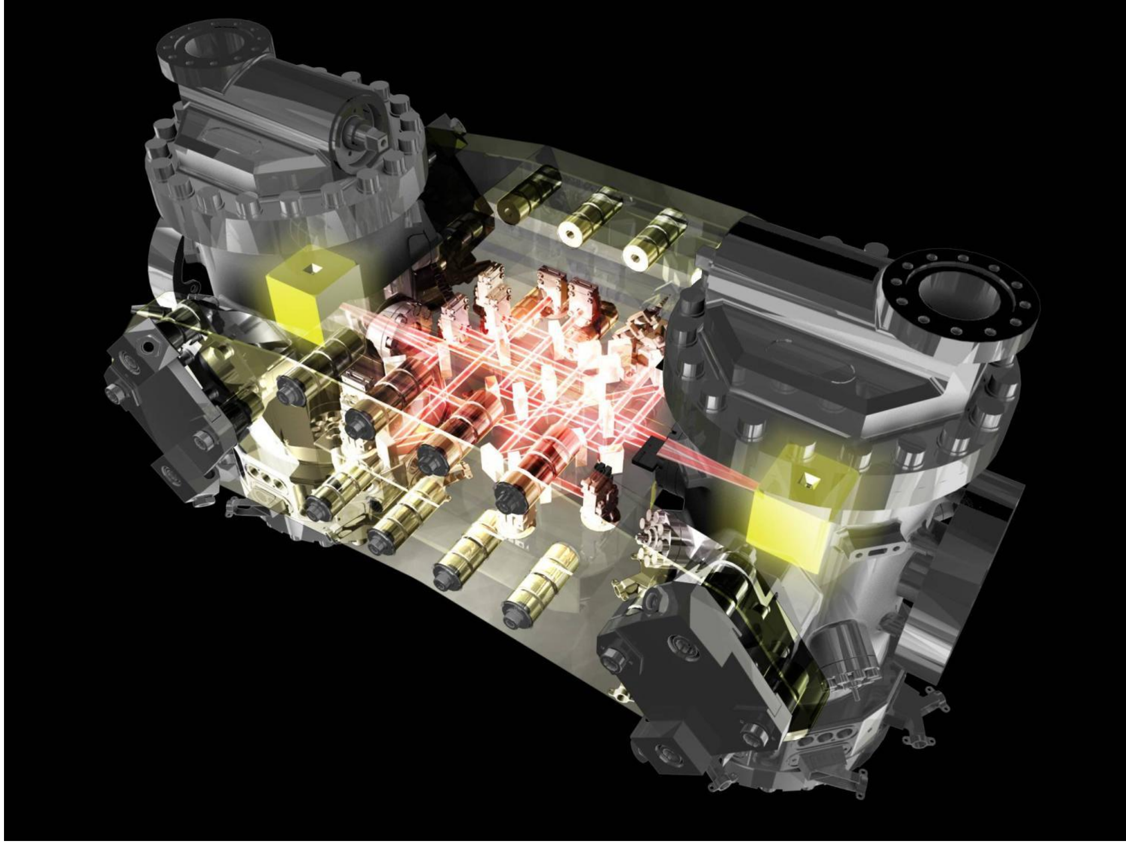
LISA Pathfinder concept

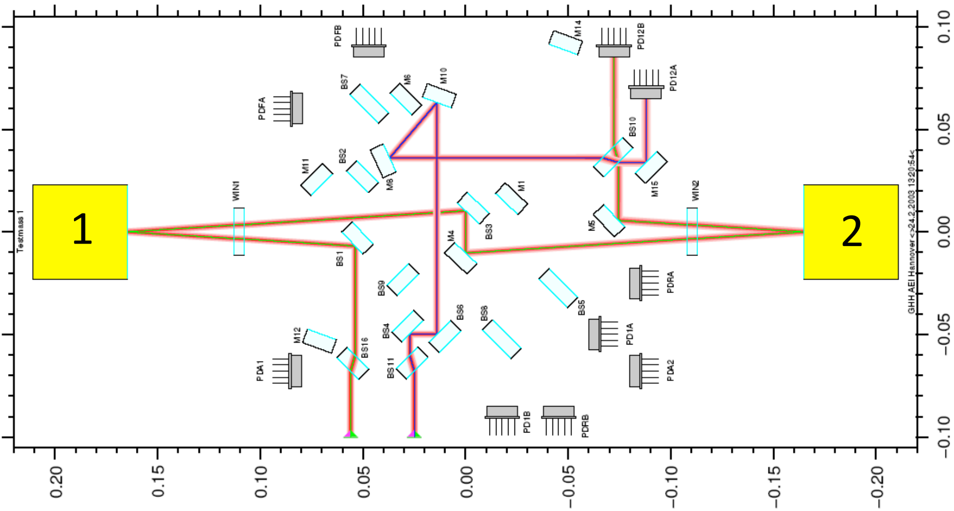
- Take away the long-arm interferometer
- Substitute the long-arm laser beam reference, with a second (quasi-)free test-mass
- One (e-)LISA arm squeezed into one spacecraft

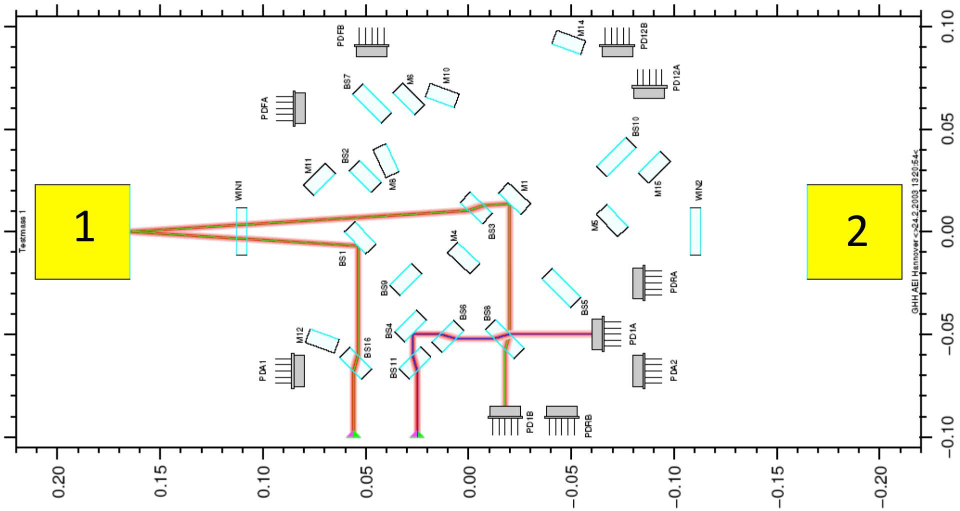


LISA Pathfinder instrument: The LTP

- Two local interferometers on a high stability optical bench
- Two Au-Pt test-masses enclosed in their GRS



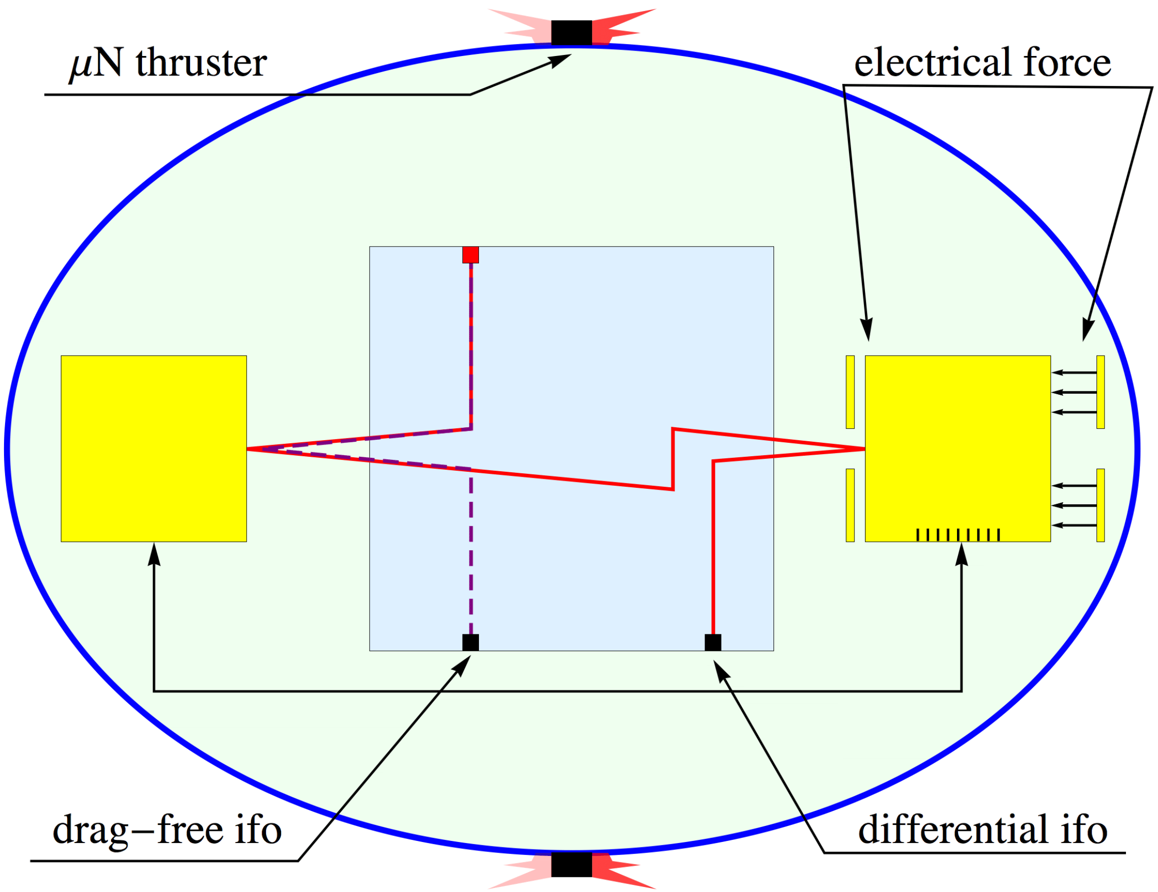




LTP flight configuration

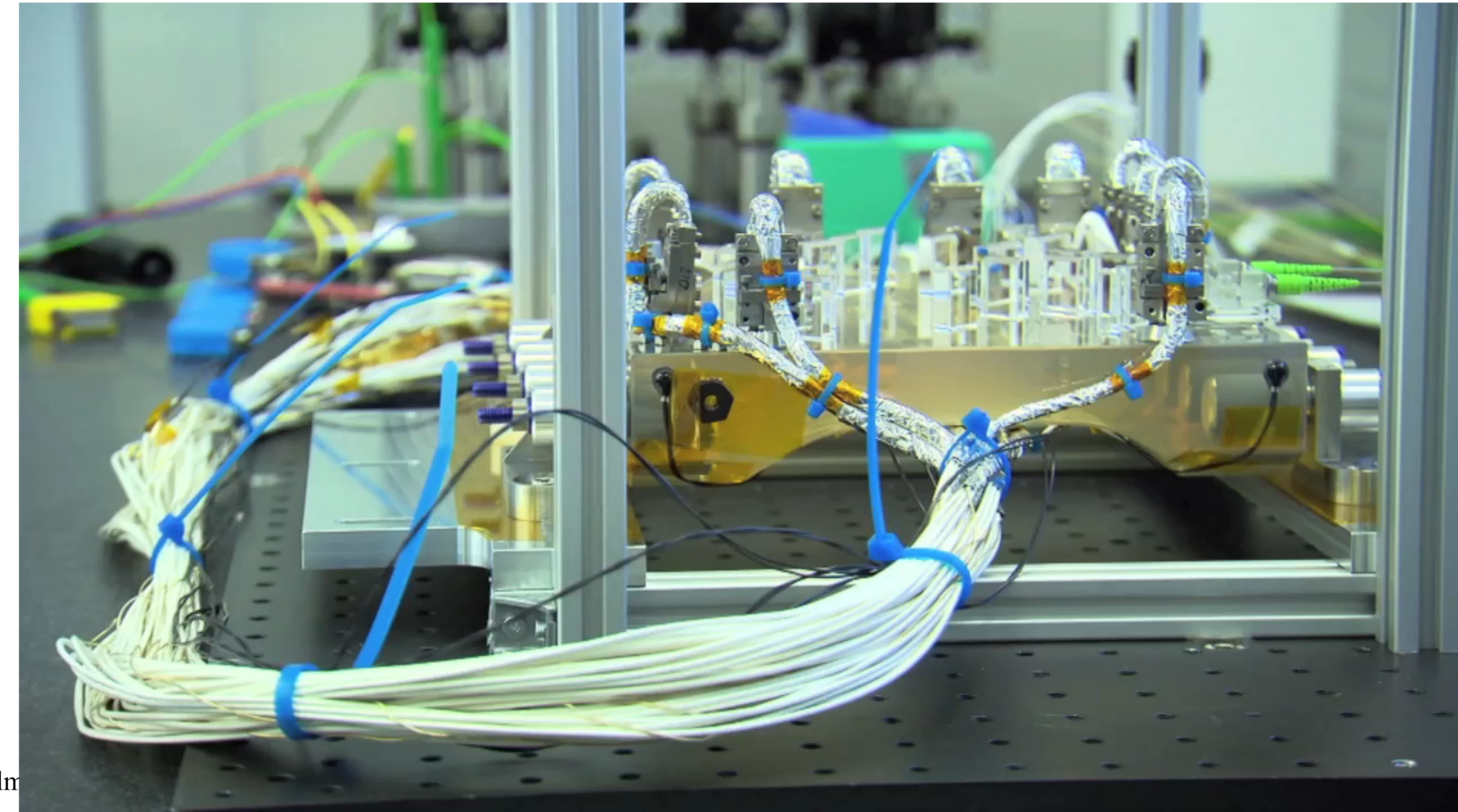
LISA Pathfinder concept. Drag-free

- Non contacting satellite
- Second test-mass forced to follow the first at very low frequency by electrostatics



The Optical Bench and Structure

- Successfully tested end-to-end for optical performance
- Delivered for integration on May 2013



University of Glasgow, ASD, Milde Communicatios

Stockholm

The Optical Bench and Structure

- Delivered in May 2013, currently under integration

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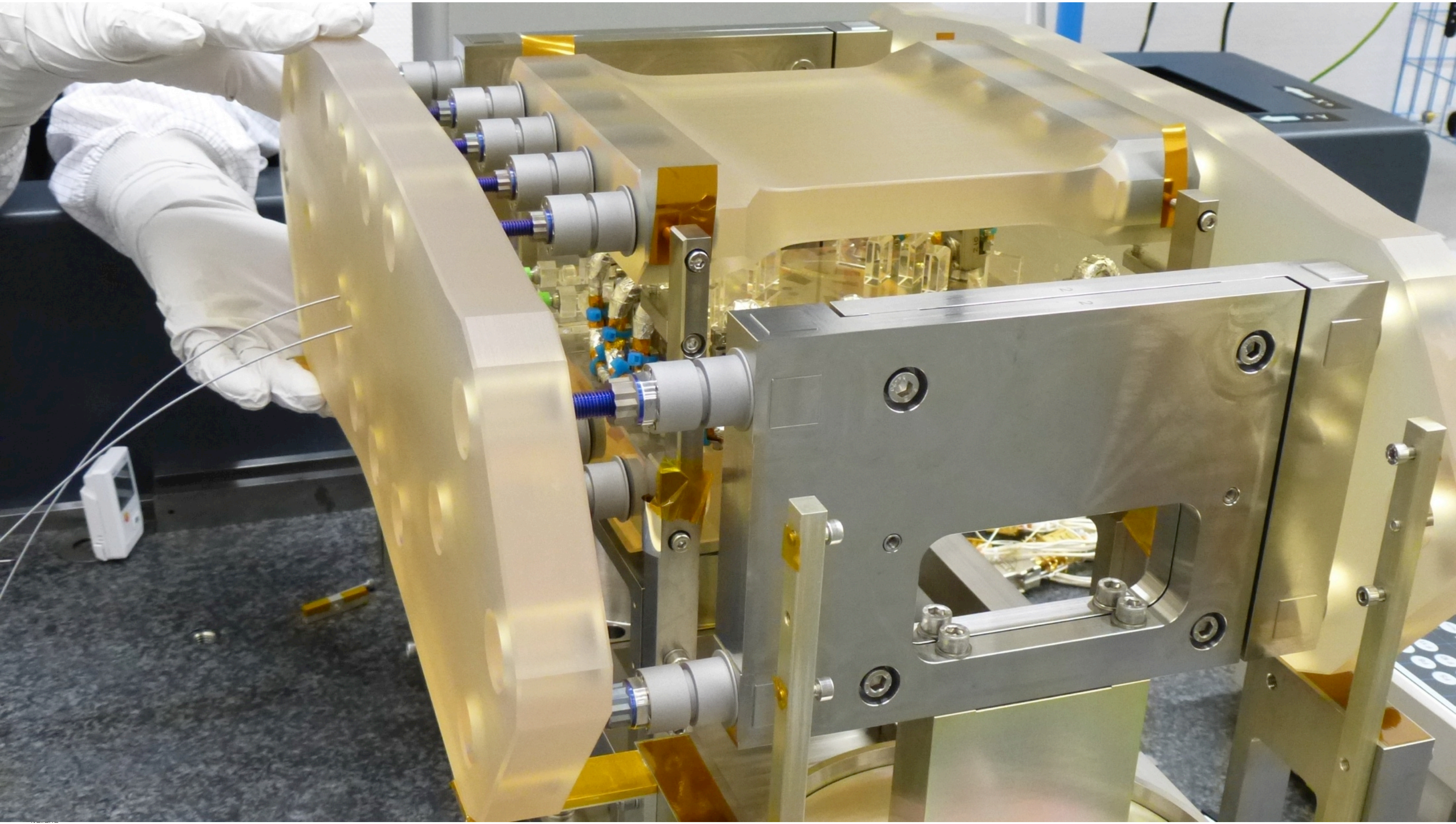
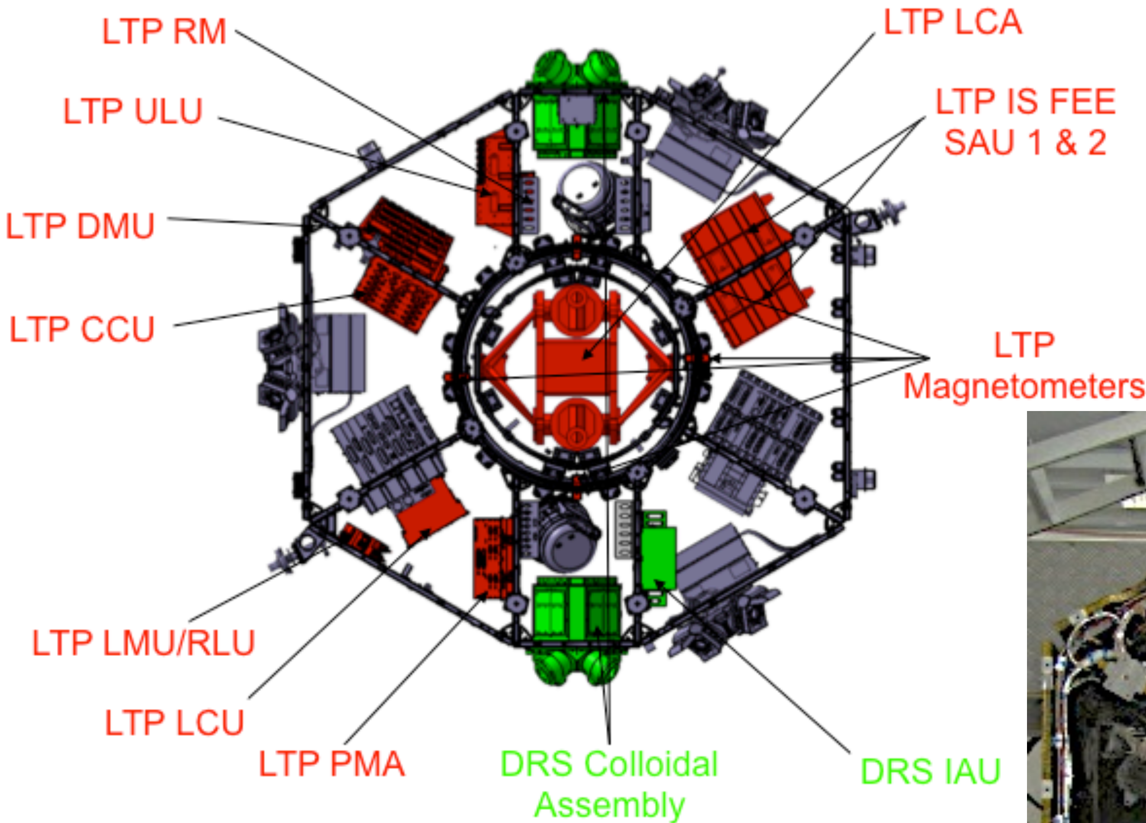
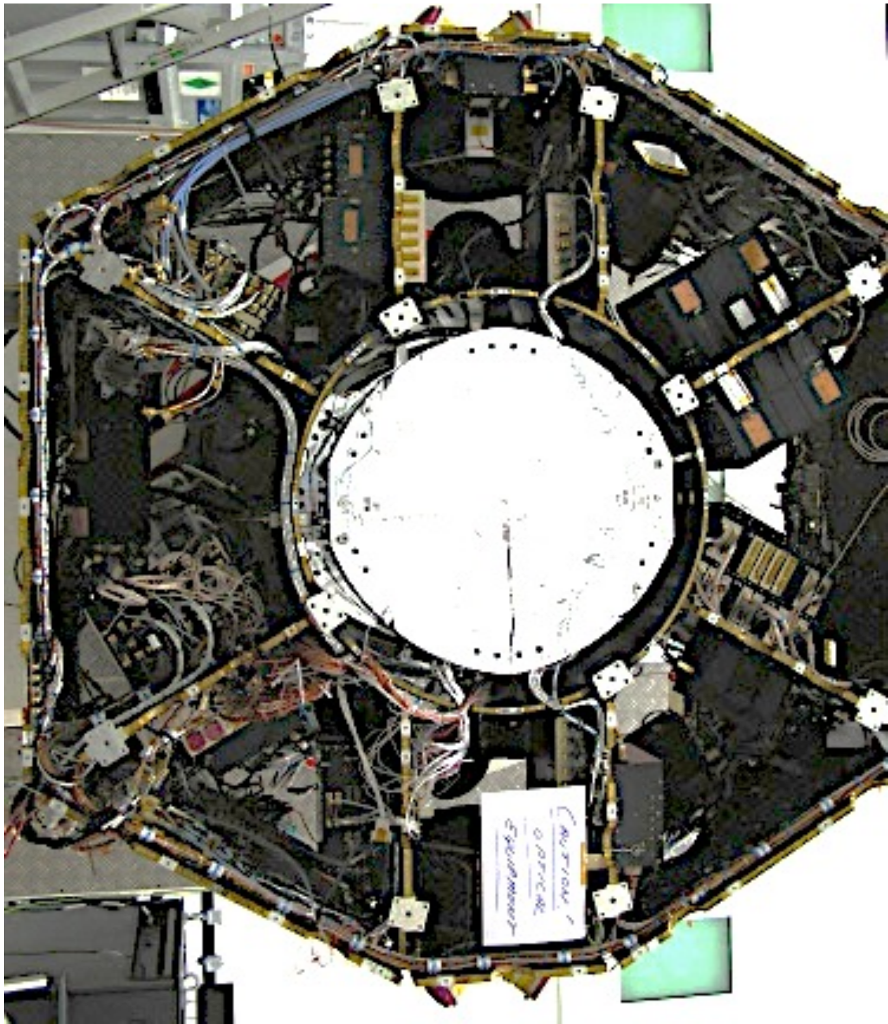
- Delivered in May 2013, currently under integration



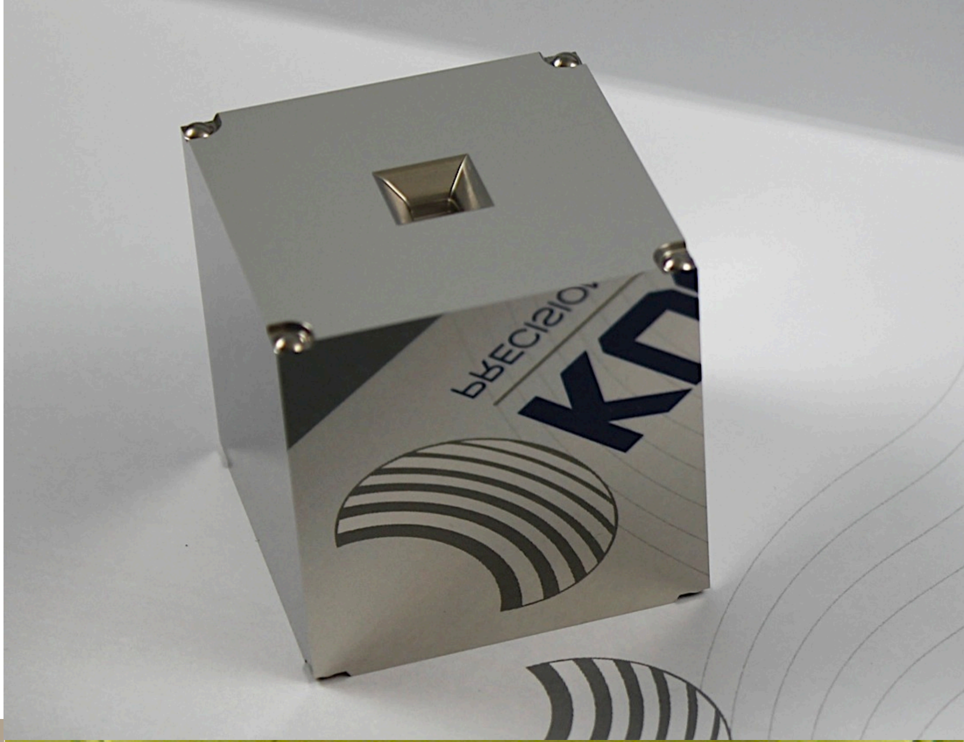


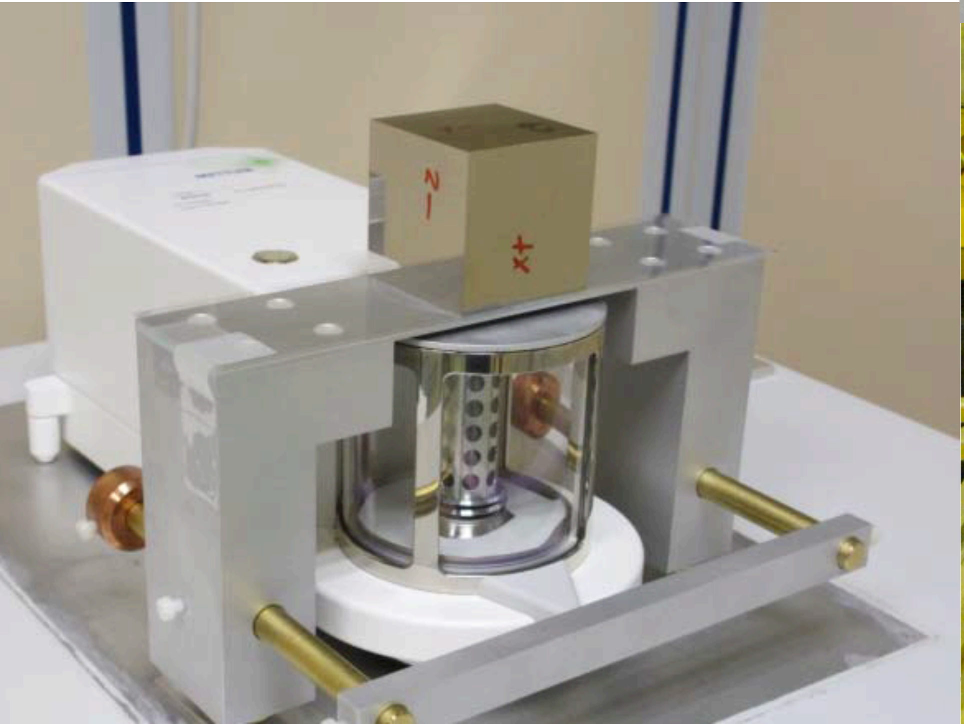


LTP electronic and optical units

The GRS: test-mass

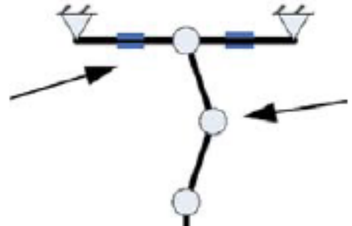
- Flight test-masses (2 kg, 46 mm)
- Very high density homogeneity (<<1μm pores)
- CoG at geometrical center within ±2 μm
- Magnetic susceptibility at $\chi = -(2.3\pm0.2)\times10^{-5}$
- Magnetic moment < 4 nAm^2

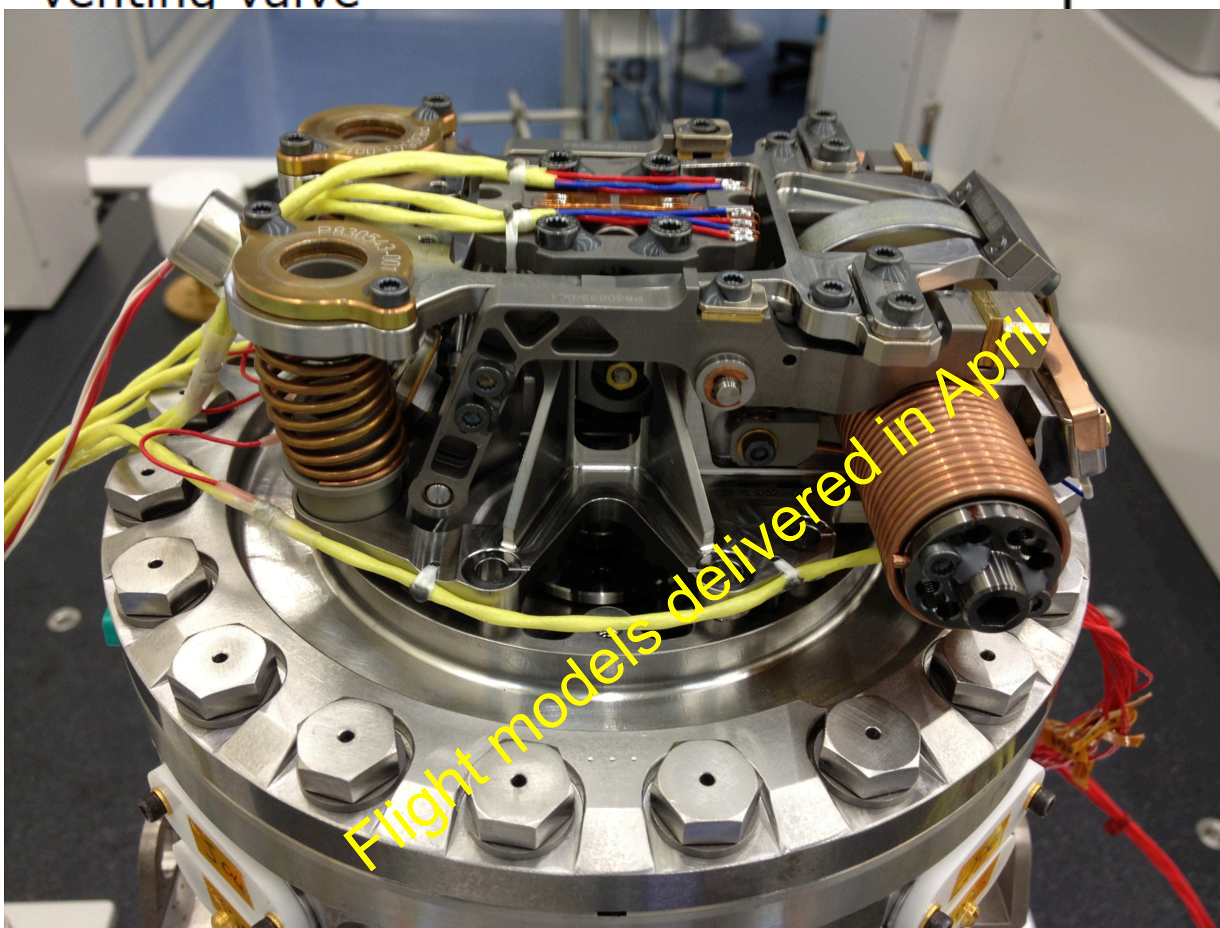


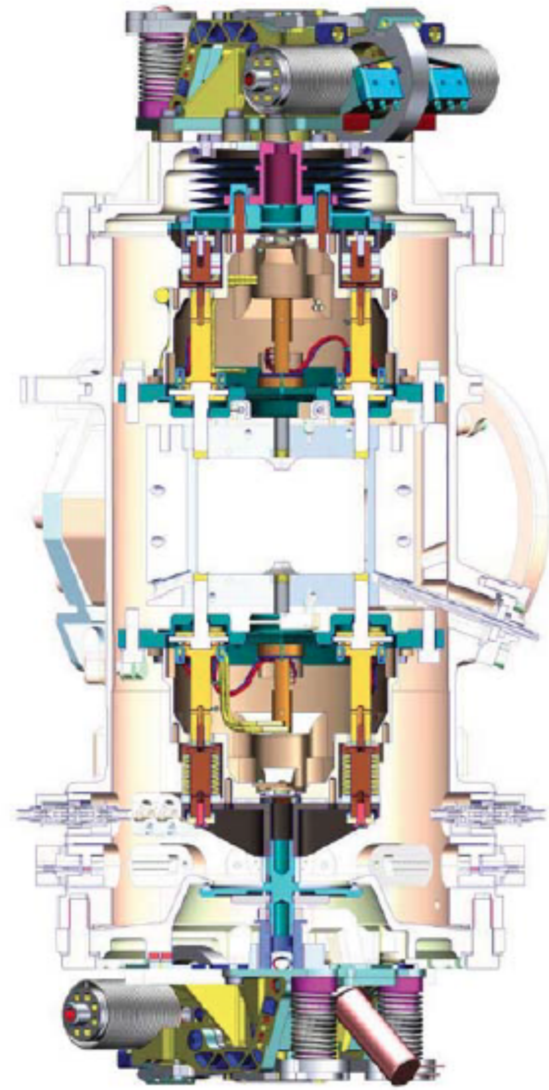


LTP: Inertial sensor caging mechanism

Caging mechanism: new design adopted in 2011, one-shot release mechanism with vacuum venting valve

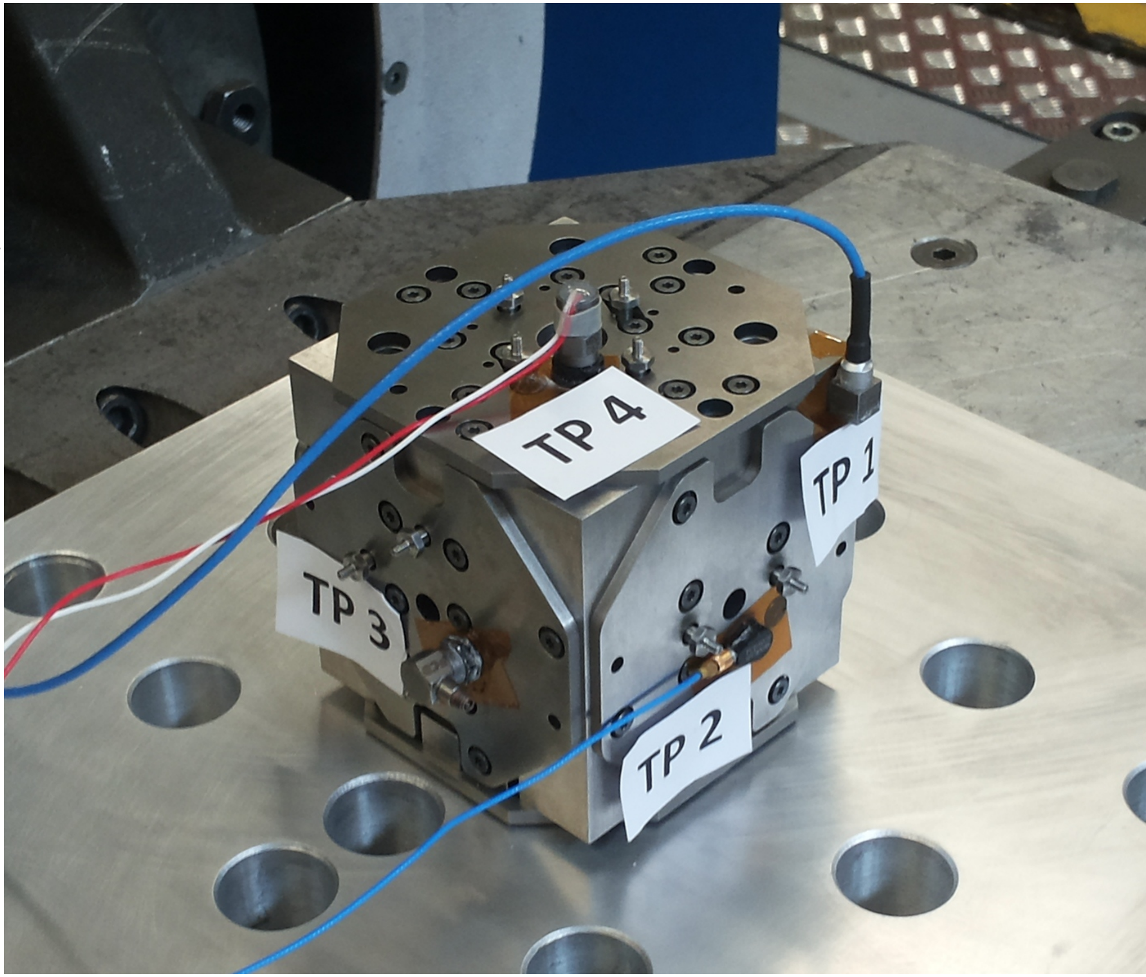






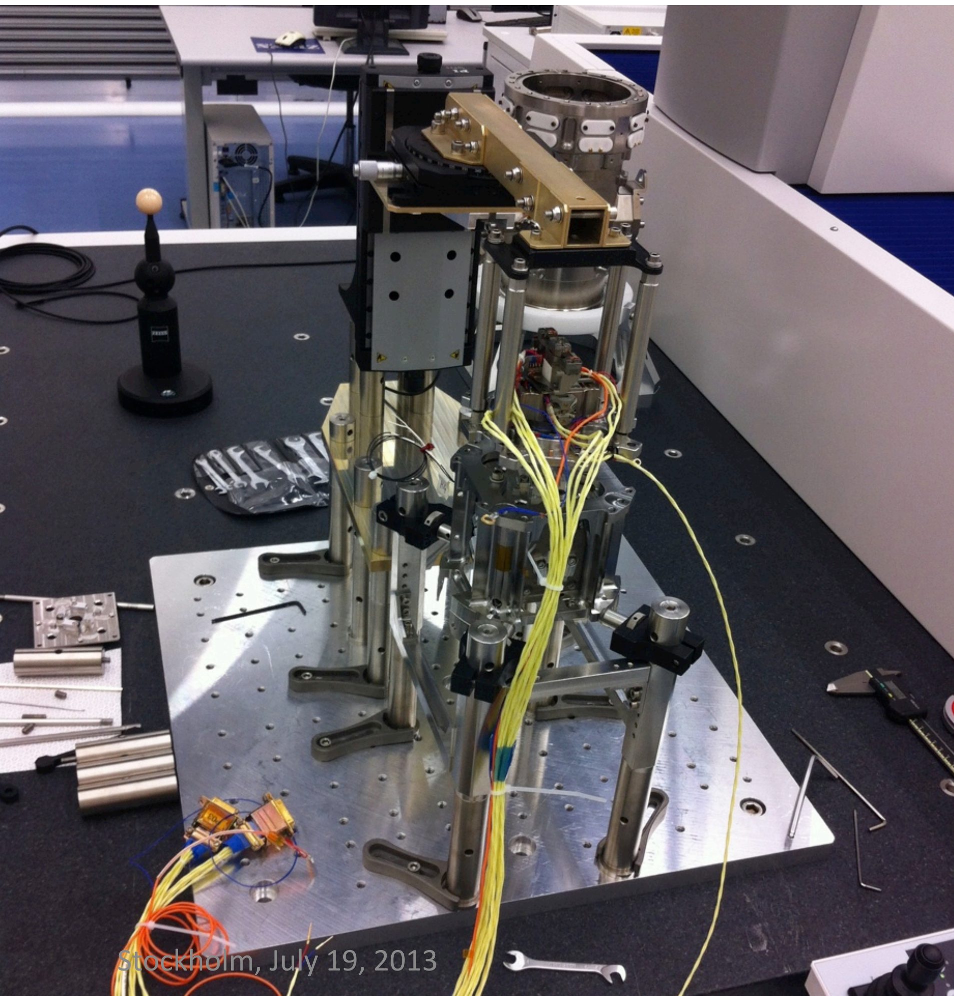
The GRS: electrode housing

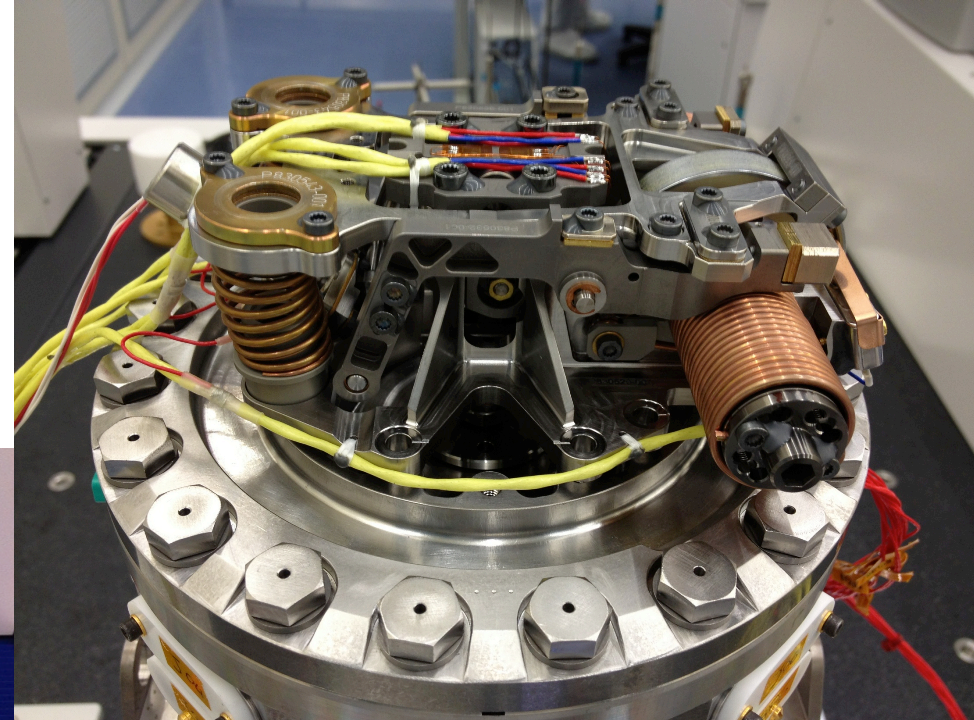
- Failure during flight model vibration test
- Partial modification of assembly technique
- Already through the design review process
- Qualification model successfully tested
- ***Delivery in September 2013***

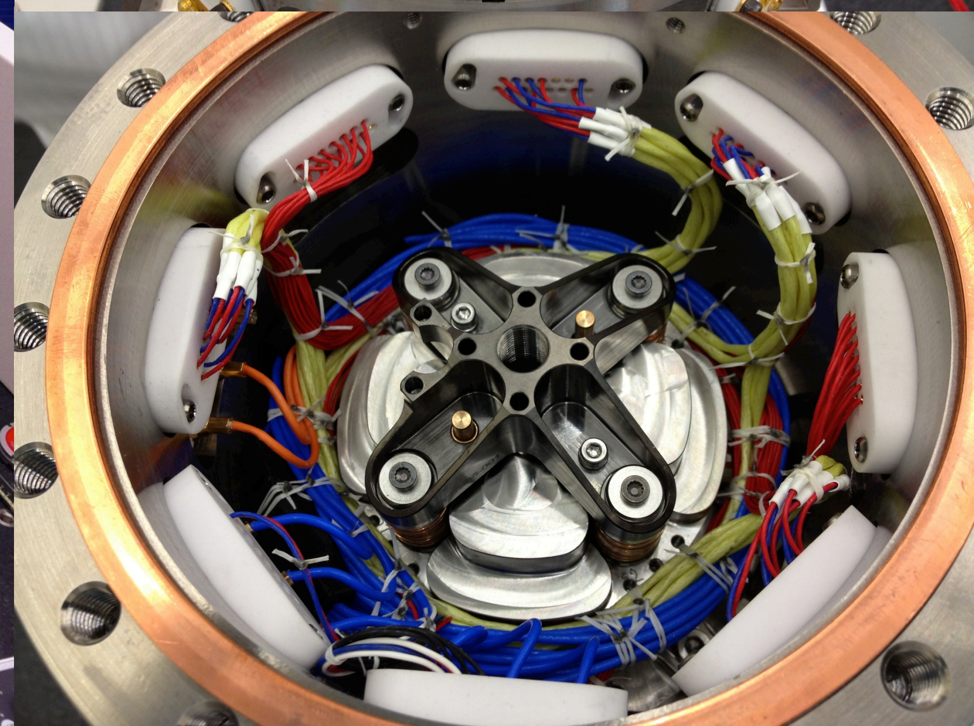


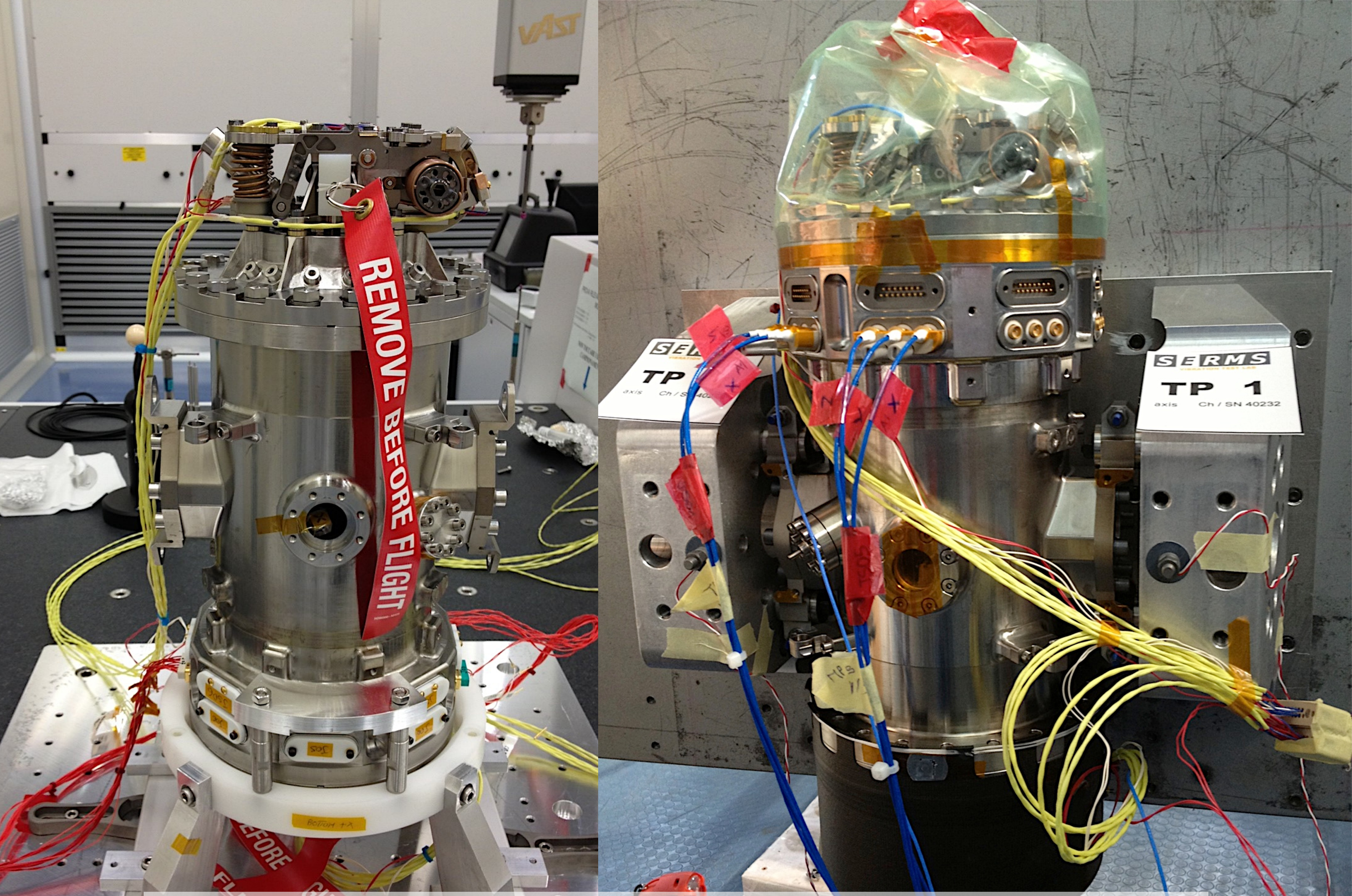
GRS Qualification Model

A qualification test of the entire assembly procedure







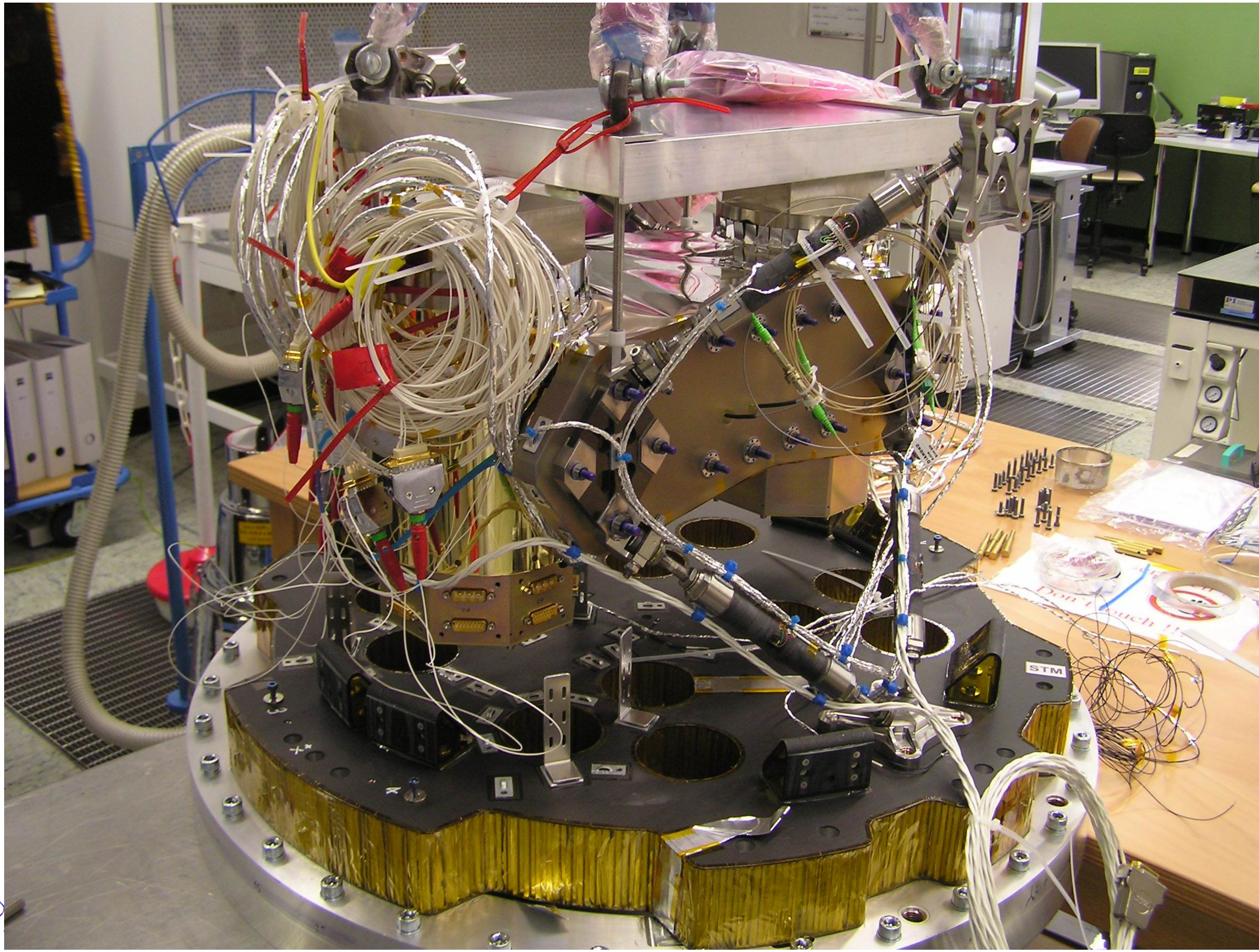


Successful

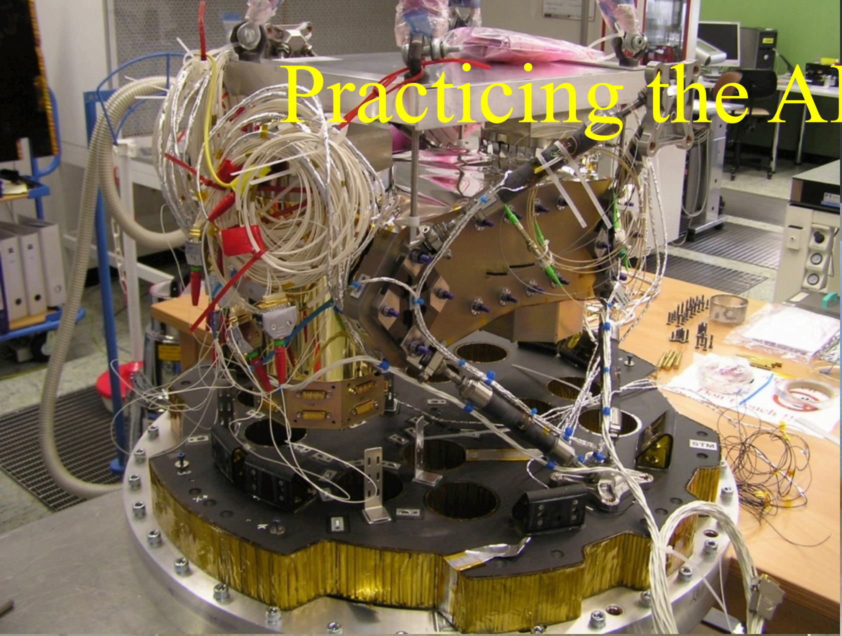
Integration, functional and vibration tests

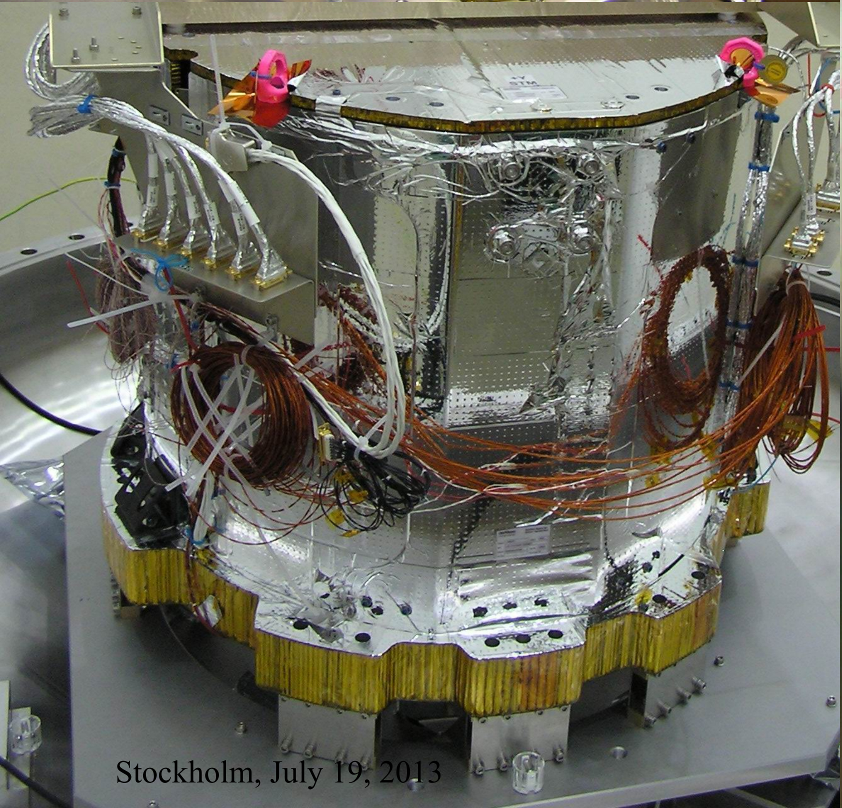
Integration of full complement

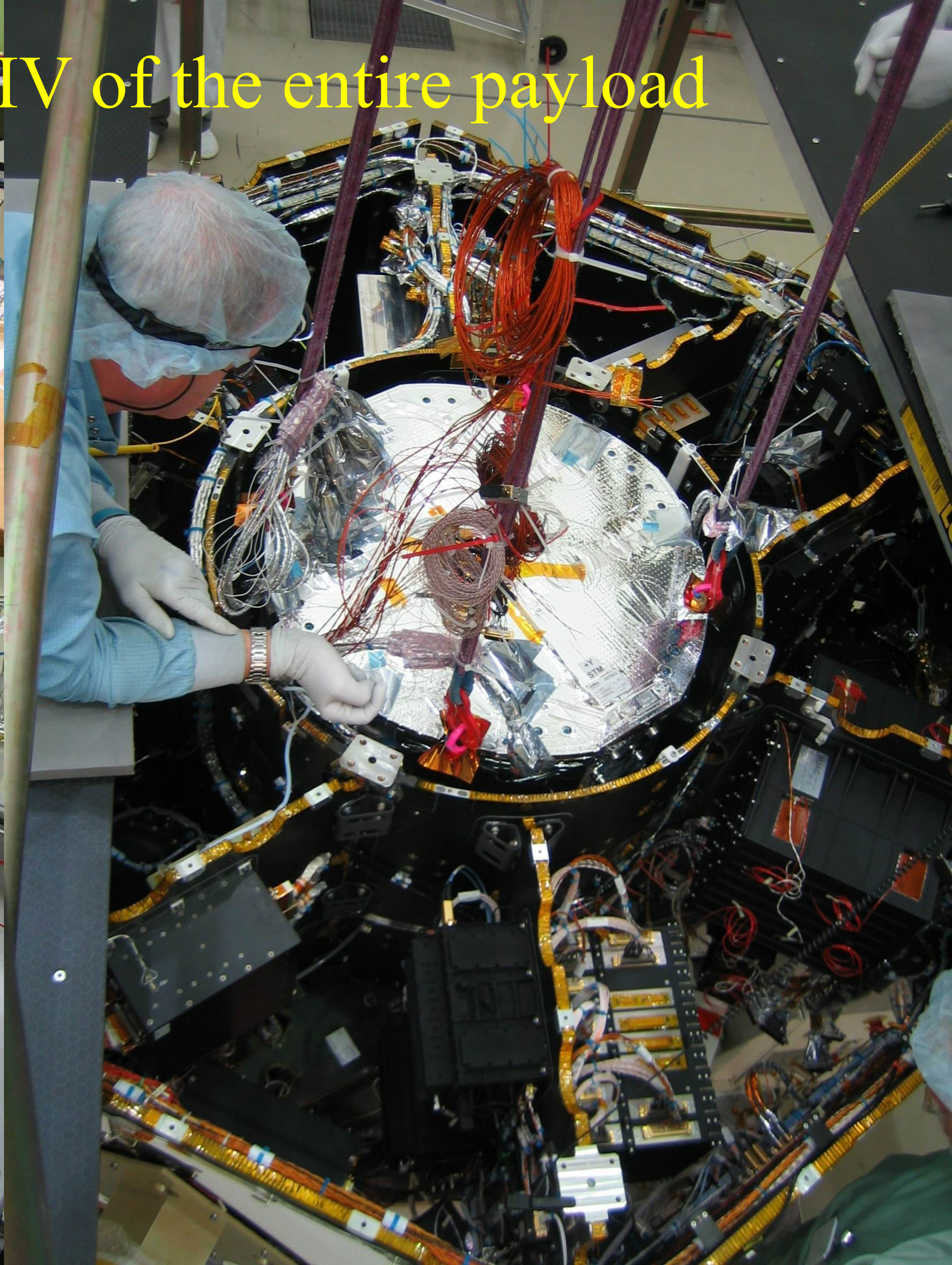
Practicing with the entire structure



Practicing the AIV of the entire payload



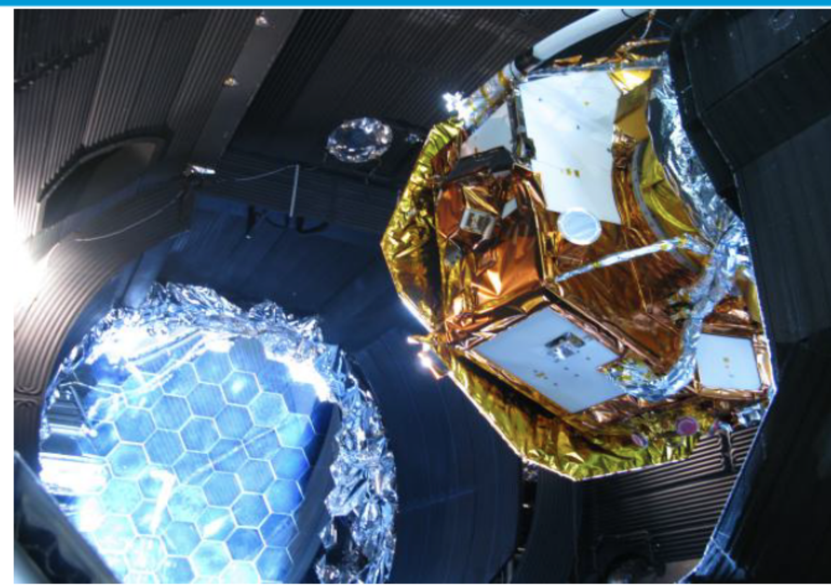




System testing

- All test completed:
  - Vibration (s)
  - Shock (s)
  - Electromagnetics
  - Magnetic cleanliness
  - On station thermal

System tests: On-Station Thermal



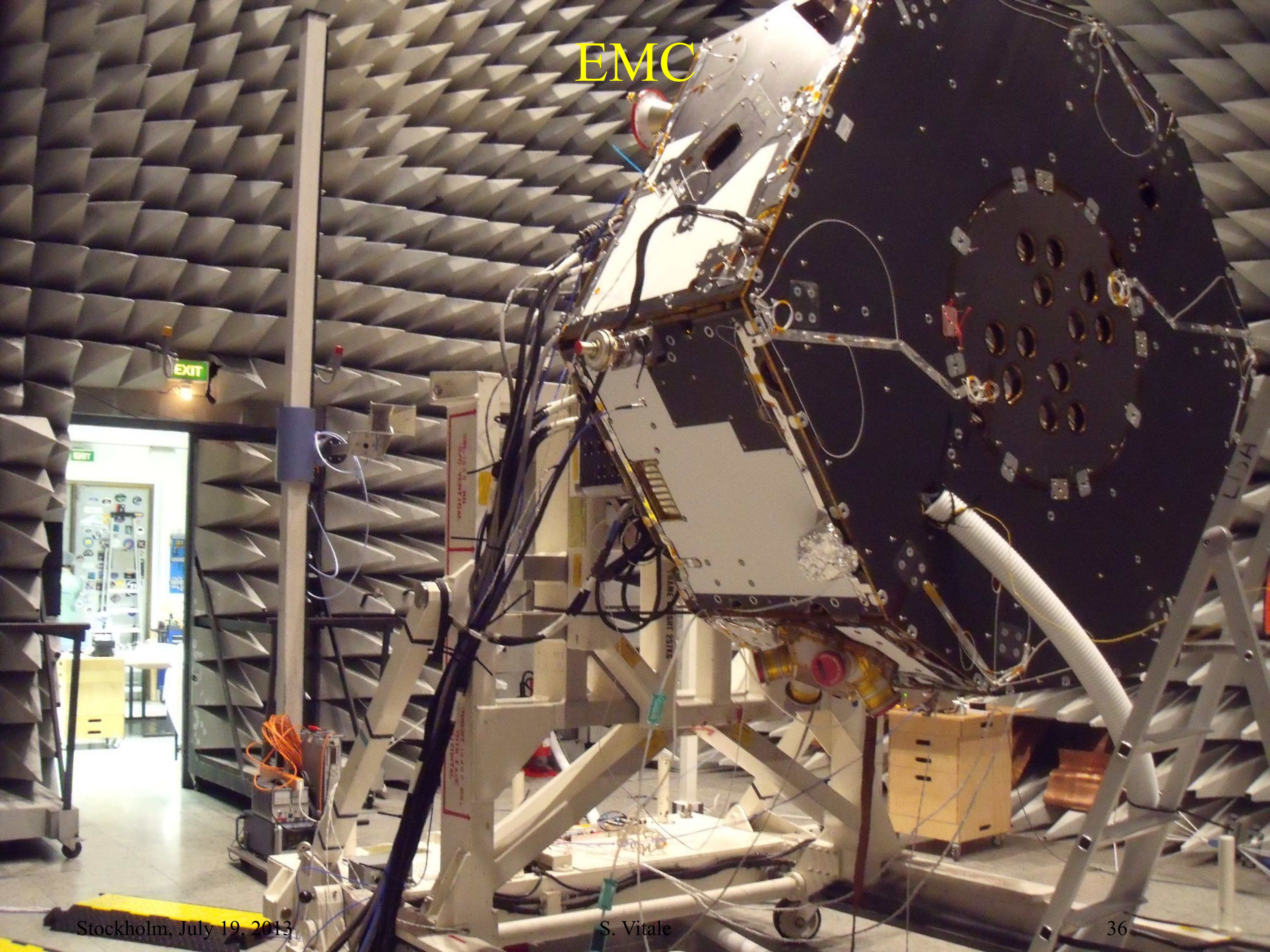
- LPF On-Station Thermal Test
- Test performed at IABG Test Facilities in October-November 2011

Sine Vibration Test

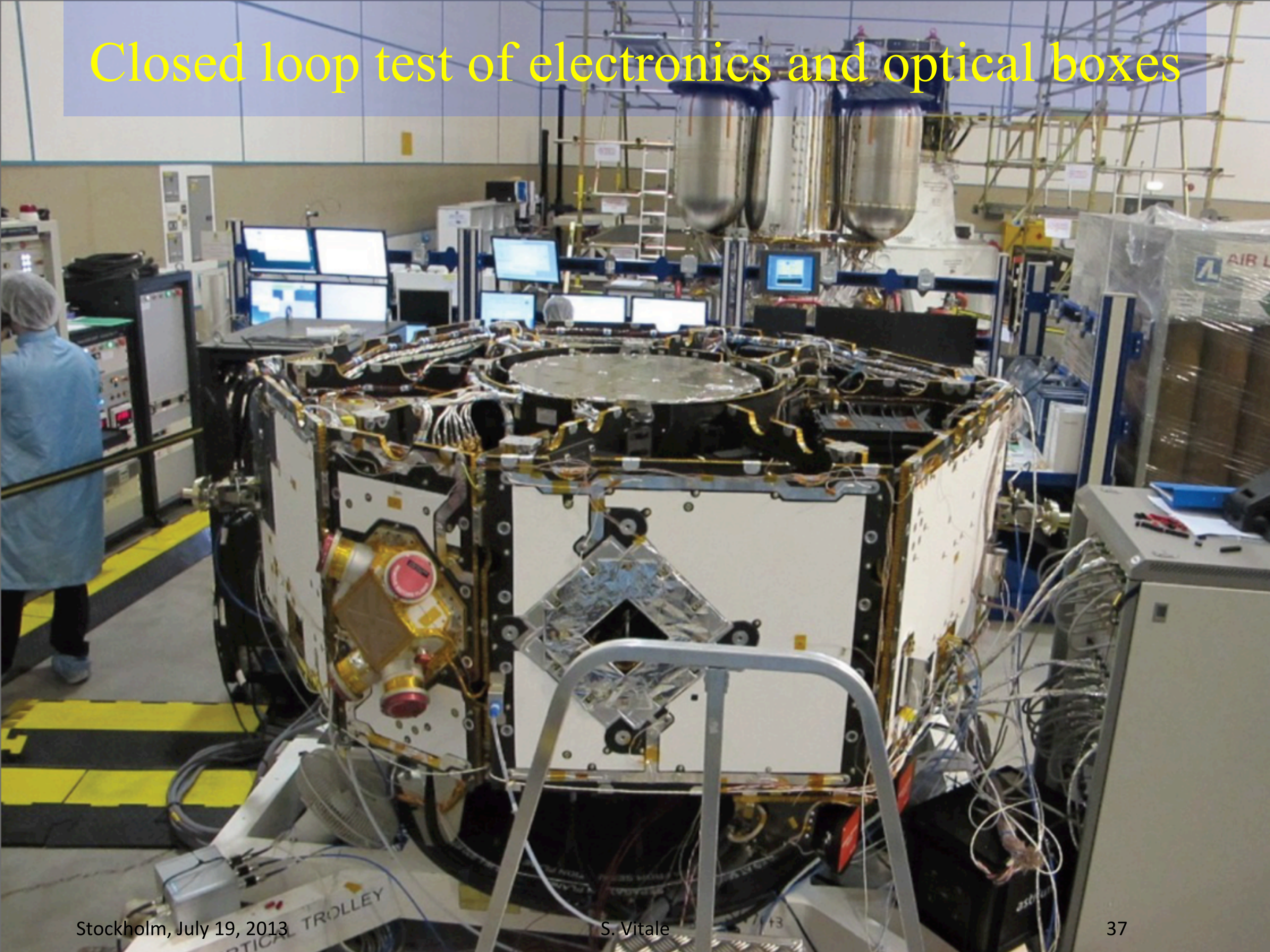
G.D.Racca | Science Working Team, ESTEC, Noordwijk 30th November 2011

European Space Agency

EMC

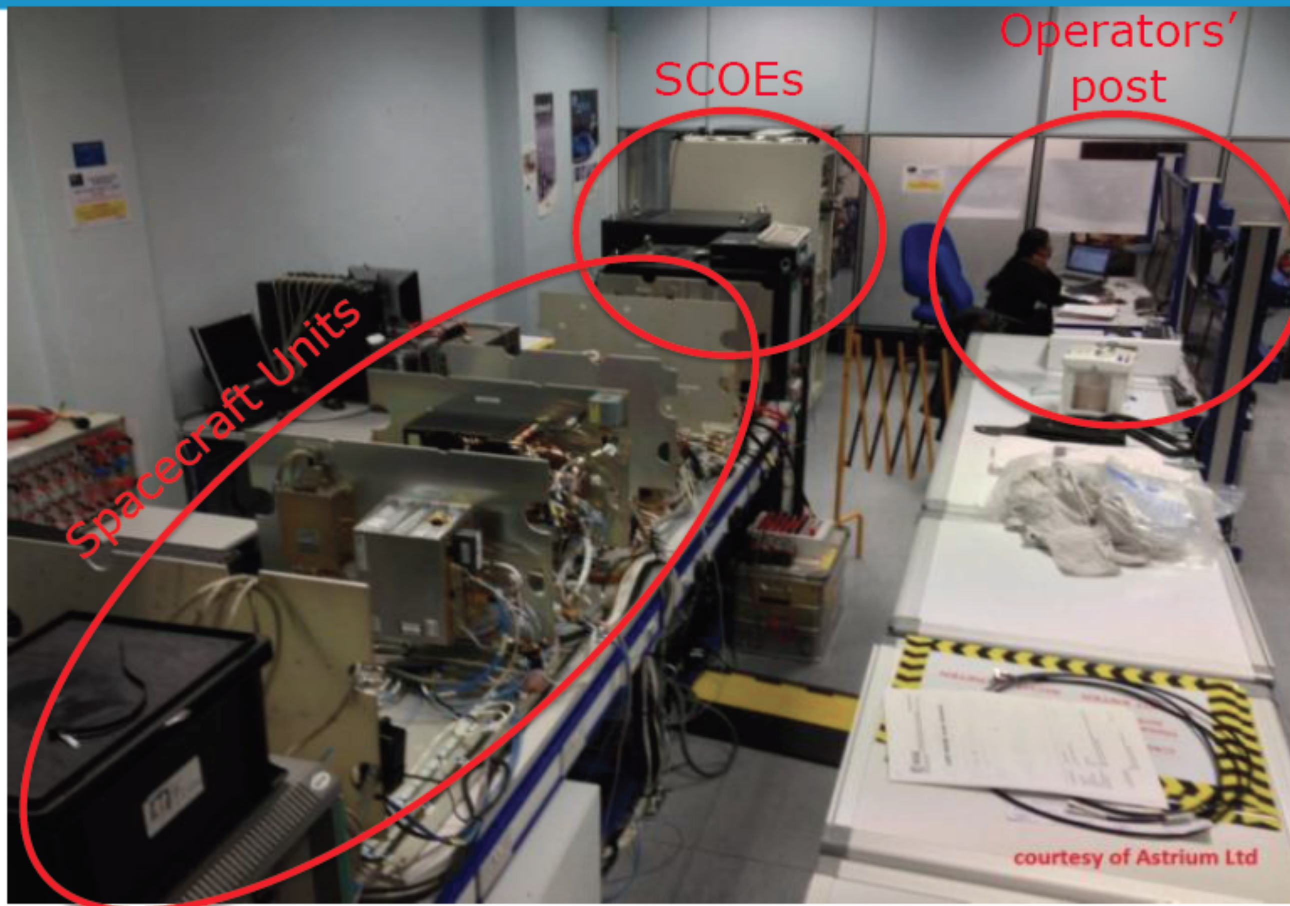


Closed loop test of electronics and optical boxes



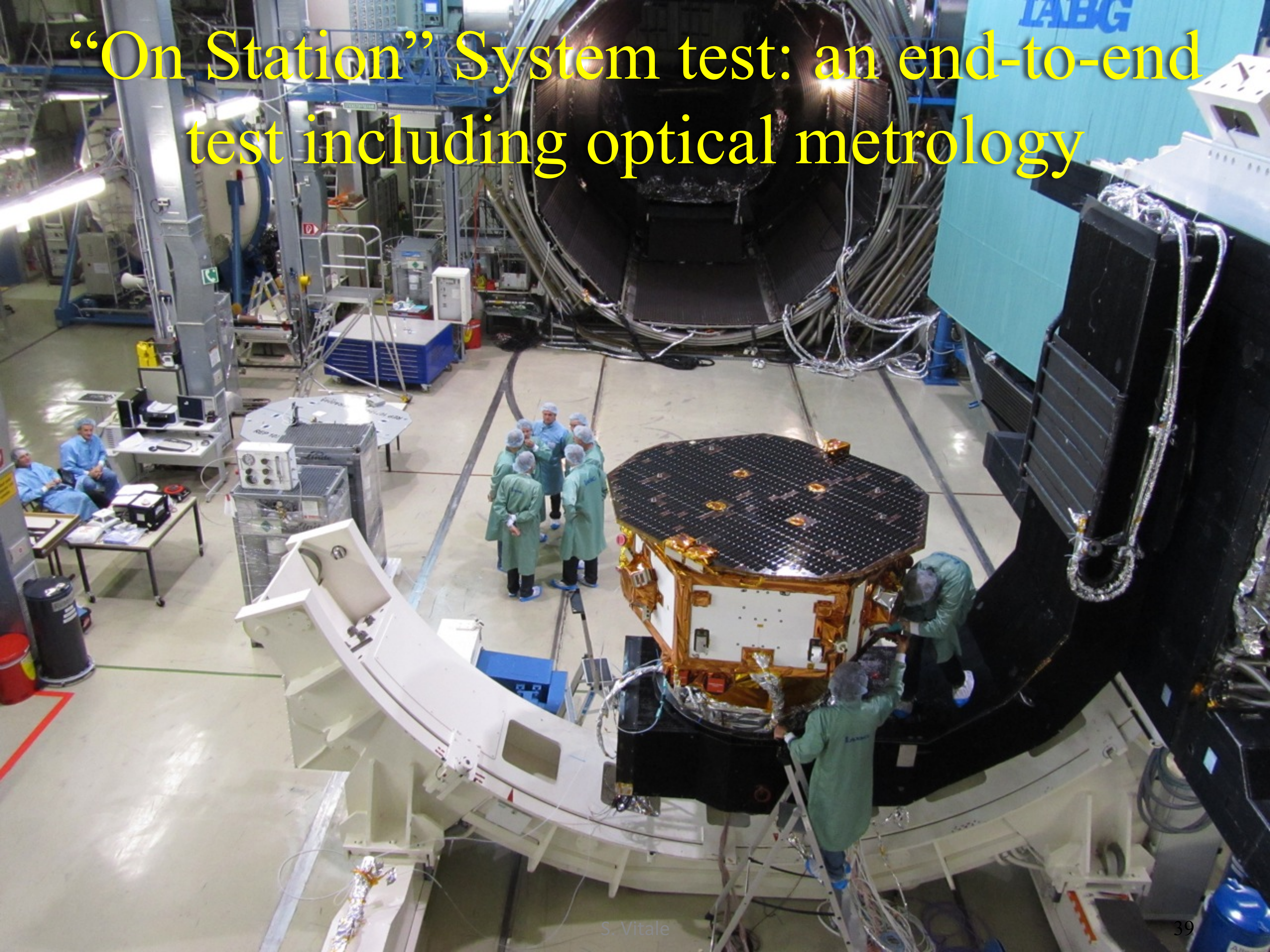
Software test with real electronics

RTB Overview



LISA Pathfinder | Presentation to NPM#36 | ETHZ | 13th March 2013

"On Station" System test: an end-to-end test including optical metrology

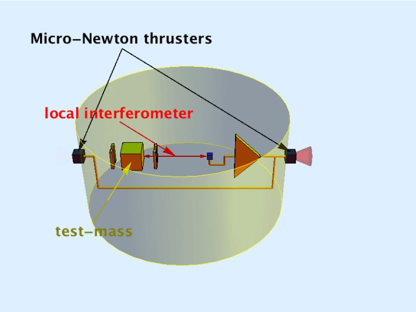


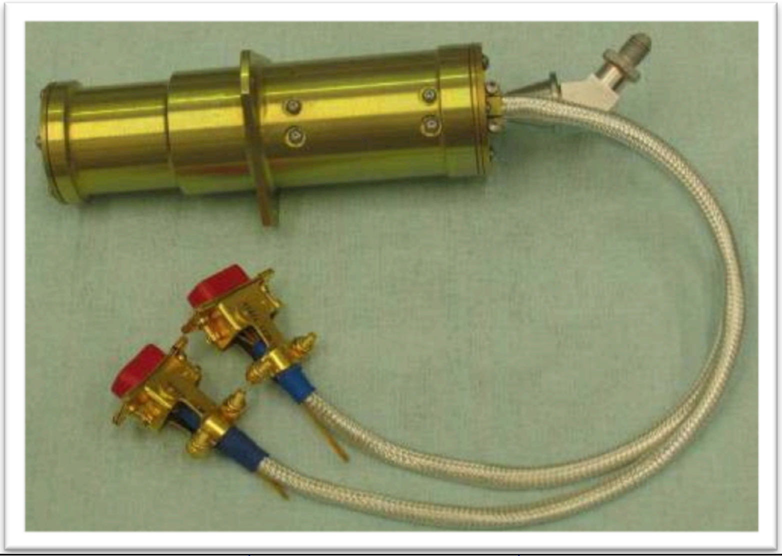
LTP

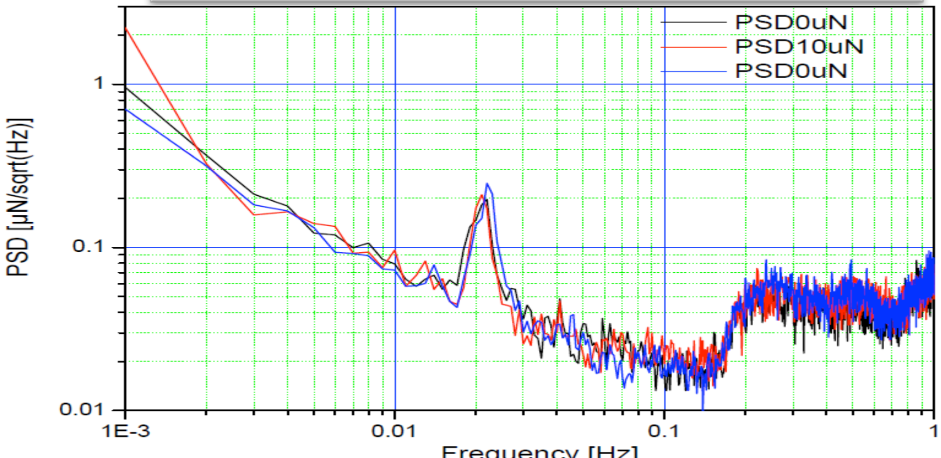
Hibernation

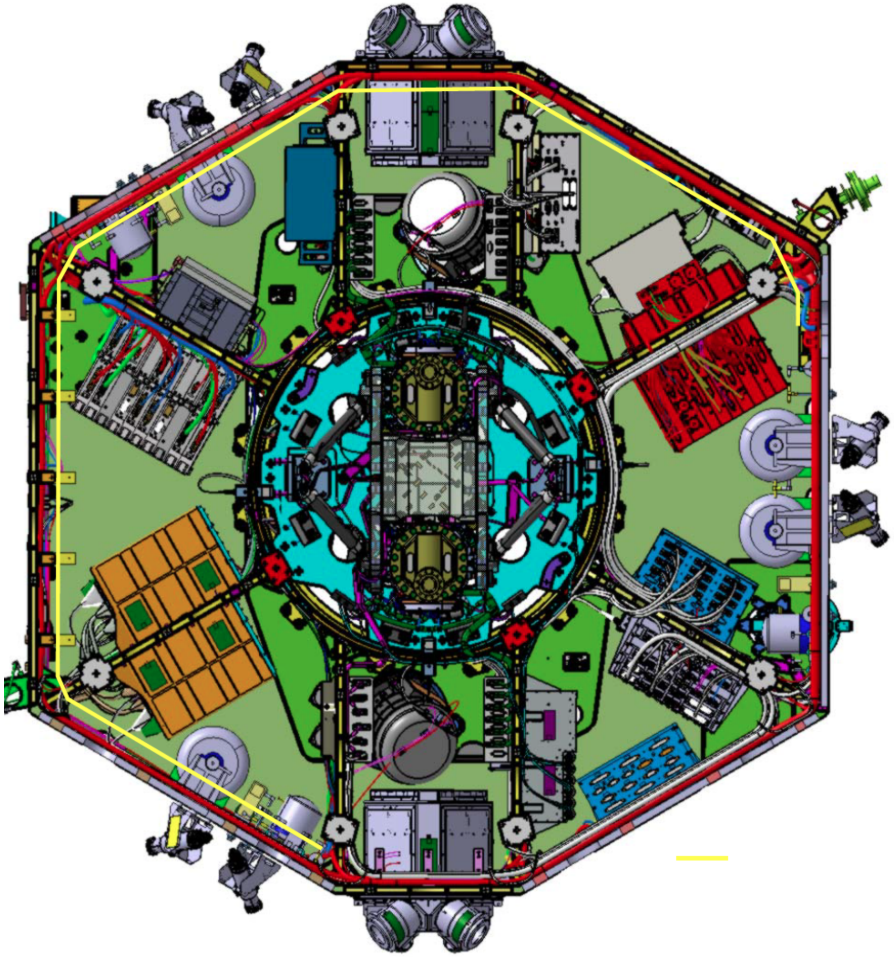
Cold gas thrusters

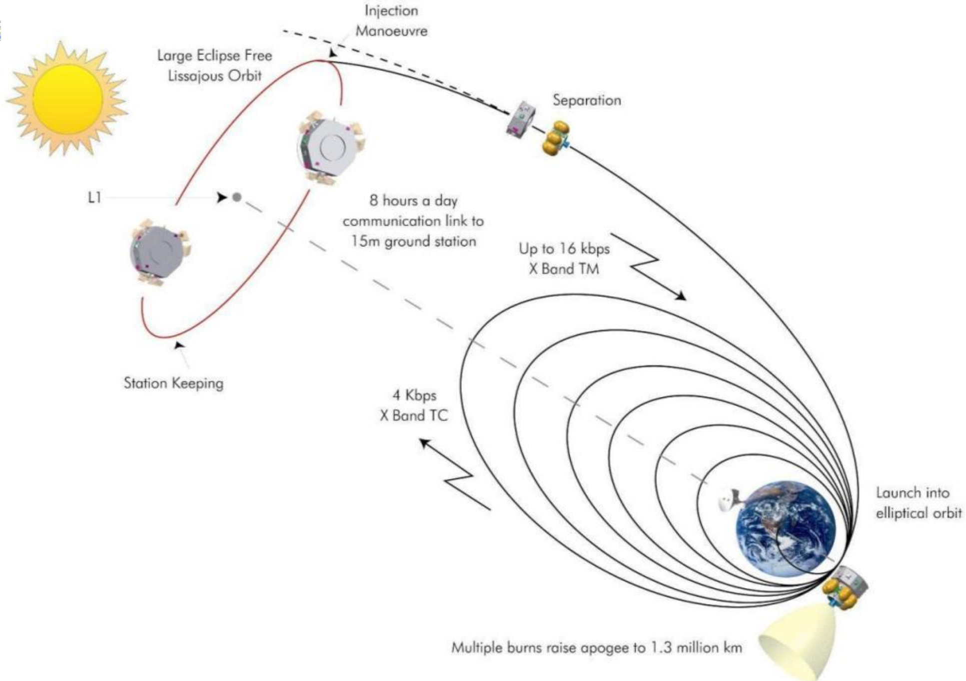
- Choice of Micro-Newton thrusters had to be changed
- Cold gas developed for Gaia better than requirements
- Can be used on eLISA as well










Injection
Manoeuvre
Large Eclipse Free
Lissajous Orbit
Separation
L1
8 hours a day
communication link to
15m ground station
Up to 16 kbps
X Band TM
Station Keeping
4 Kbps
X Band TC
Launch into
elliptical orbit
Multiple burns raise apogee to 1.3 million km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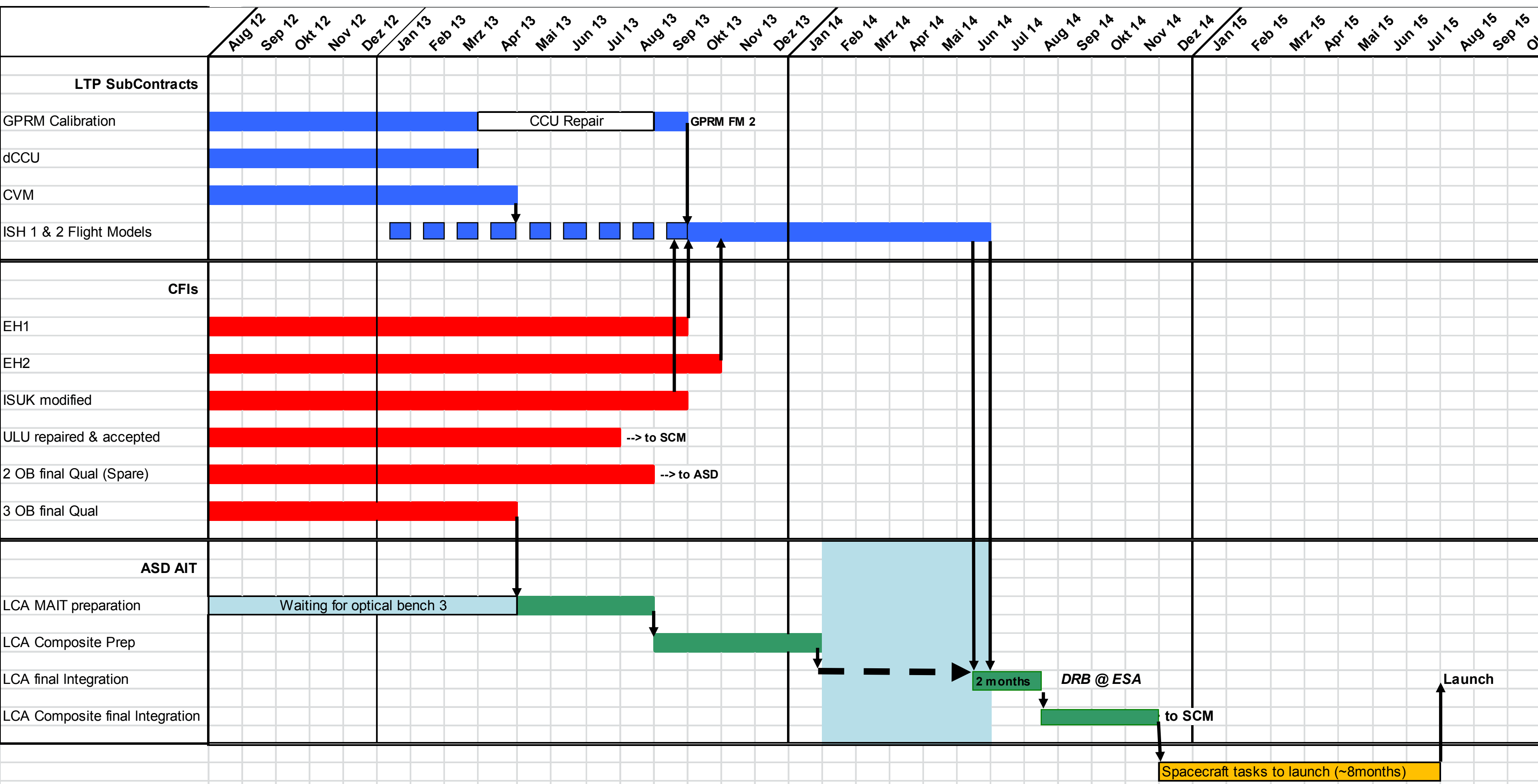
service & solutions
Fairing of Vega
Scale1:10°
Lisa Pathfinder
Arianespace will launch this ESA/NASA mission from CSG.

Schedule

- Launch July 2015



The experiment: an investigation campaign

- Measurement of parasitic forces
  - Calibration of 3-body dynamical parameters
- Noise projection
  - Force gradient coupling
  - Reference frame noise
  - Magnetic force
  - Thermal gradient force
  - Laser radiation pressure noise
- Verification of gravitational flattening
- Measurement and compensation of patch-potentials
- Verification of cosmic ray charging model
- Measurement of charge fluctuations
- Calibration of LPF bench noise

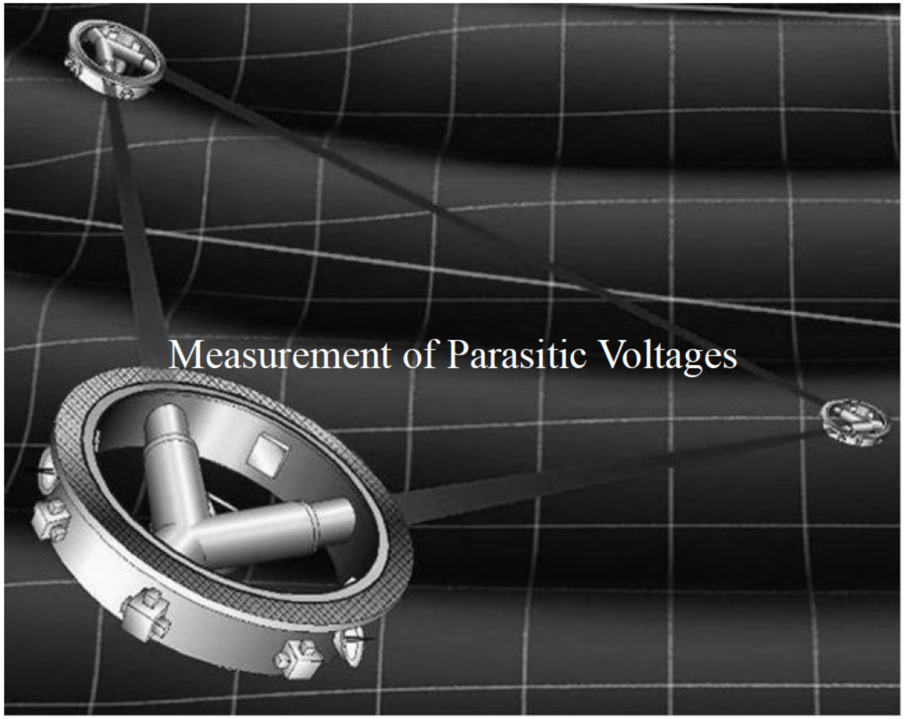

DOCUMENT

LISA Pathfinder
Experiments Master Plan

LISA Pathfinder Project

Experiment implementation

- Method: a sequence of dedicated investigations in a closed packed arrangement
- Preparation:
  - Experiment design and theoretical analysis
  - Experiment simulation on mission simulator
  - Supporting experiments in the laboratory and from flight hardware testing campaign

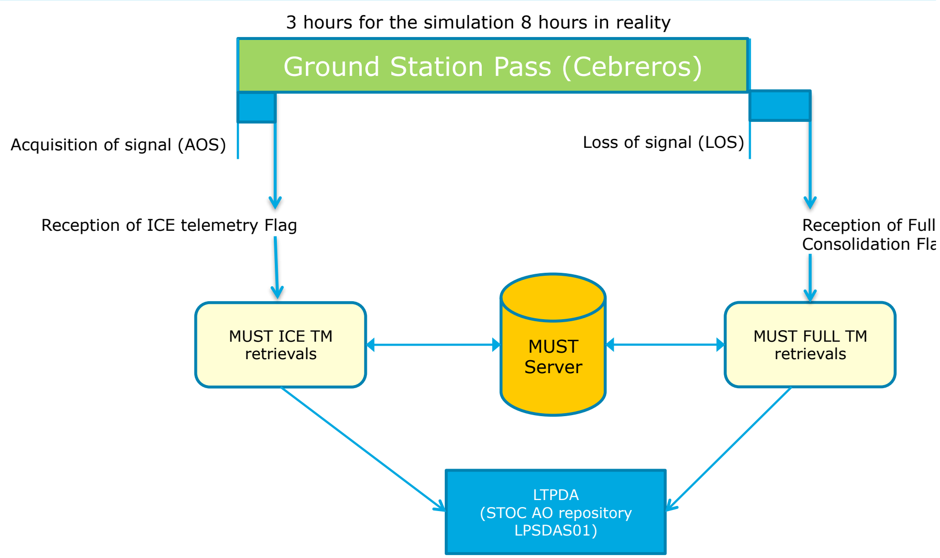


S2-UTN-TN-3066

Issue/Rev. 1.0

End-to-end operation simulations

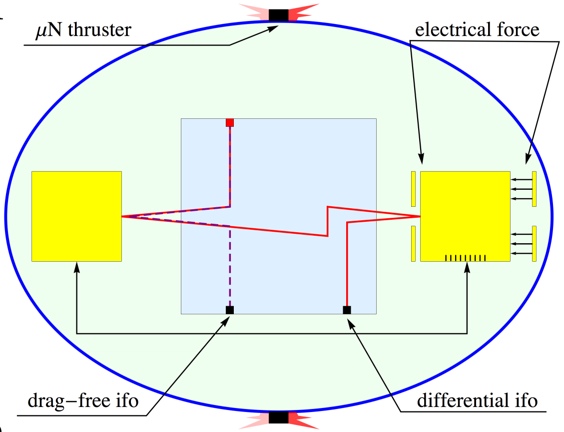
Simulation execution and operational timeline

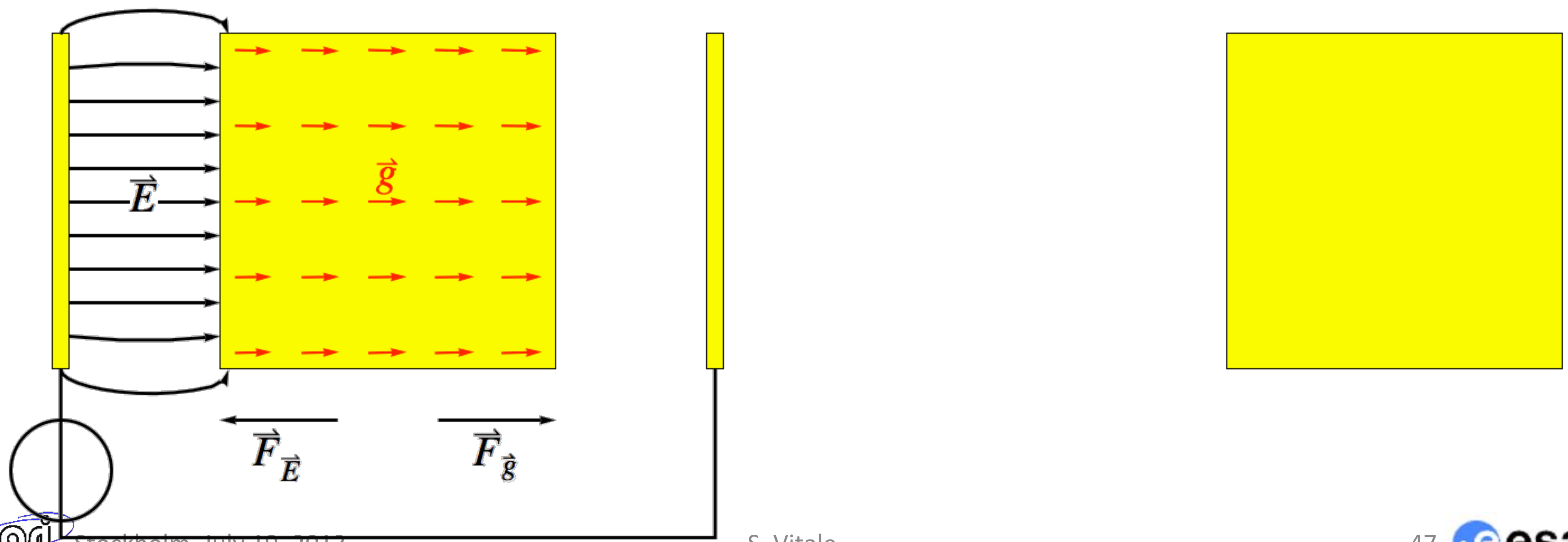


Simulation preparation and STOC system layout DAY1

Start Time	End Time	Duration	Investigation Name	Investigation Description
161T 08:00:00	161T09:00:00	3600	inv04021:V003	Patch fields measurements and compensation on surface of TM2
161T 09:00:00	161T 11:00:00	7200	inv04024:V003	Patch fields measurements and compensation on surface of TM2.
161T 11:00:00	161T 17:00:00	21600	inv04123:V002	Patch fields measurements and compensation on surface of TM2.
161T 17:00:00	161T 23:00:00	21600	inv04122:V002	Patch fields measurements and compensation on surface of TM2.
161T23:00:00	161T05:00:00	21600	inv04121:V002	Patch fields measurements and compensation on surface of TM2.
161T05:00:00	161T06:00:00	3600	inv04021:V003	Patch fields measurements and compensation on surface of TM2.
161T06:00:00	161T08:00:00	7200	inv04024:V003	Patch fields measurements and compensation on surface of TM2.

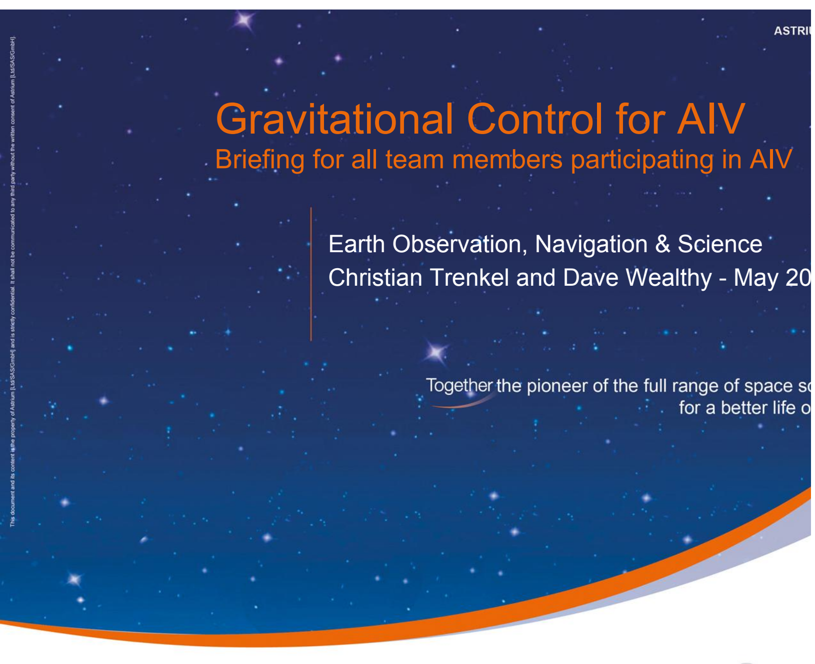
- In eLISA each test-mass is free along laser beam direction
- In LPF a control loop applies (noisy) electrostatic forces to test-mass 2 to avoid it drifting away from test-mass 1.
- Largest part of force is at dc and compensates for unbalanced gravitational force on test-mass 2 ($< 10^{-10}$ g)





Gravitational field control

- Gravitational field must be suppressed on eLISA and LPF at 0.1 ng
- Suppression of gravitational field is based on:
  - Measurement of mass and position of component
  - Numerical calculation of field
  - Compensation by balance masses
- Required accuracy <50 pg to include margin
- Gravitational field measurement on board LPF, sole opportunity of verification of method



AIV= Assembly, Integration and verification

EADS astrium	LISA Pathfinder	S2.ASU.TN.2412 Issue 1.0 No. ____

Gravitational Control During AIV
Briefing Completion Sign-off Sheet

Introduction

In order to meet the mission performance requirements of LISA Pathfinder it is necessary to maintain very tight control and knowledge of the mass distribution of the FM spacecraft. All members of the team involved in AIV activities are required to attend a briefing on the gravitational control procedures for the mission.

I understand the criticality of maintaining strict control over the mass distribution during AIV and understand my responsibility in ensuring that the mission performance requirements are met.	☐
Each time I add any item to the FM spacecraft (flight or non-flight) I will ensure that its mass and location are recorded in the mass log.	☐
Each time I remove any item from the FM spacecraft (flight or non-flight) I will ensure that its mass and location are recorded in the mass log.	☐
I shall report any differences I observe between the design and the actual installation to PA and the LISA Pathfinder Systems Team.	☐

Measuring and keeping track

- Mass and position measured
- ~2000 entries in budget.

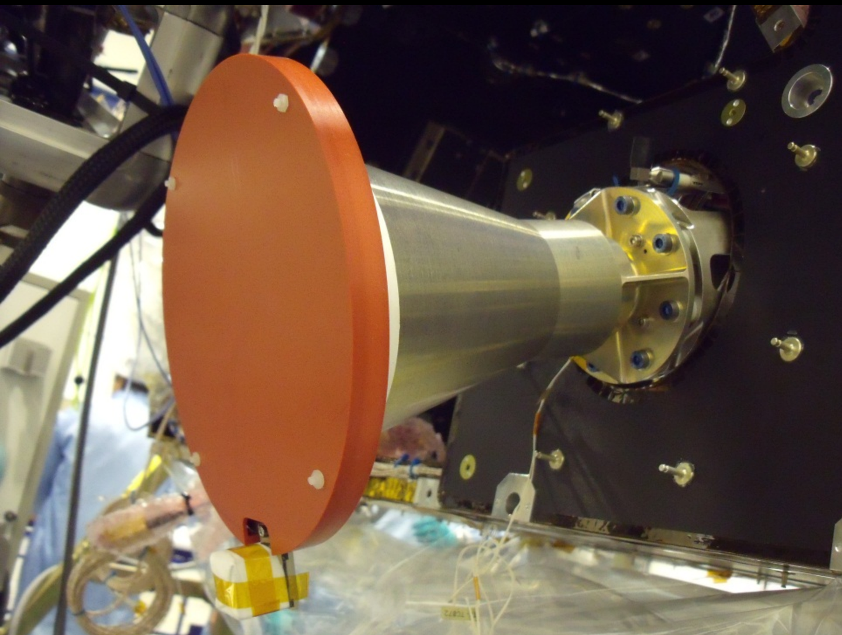
EADS astrium

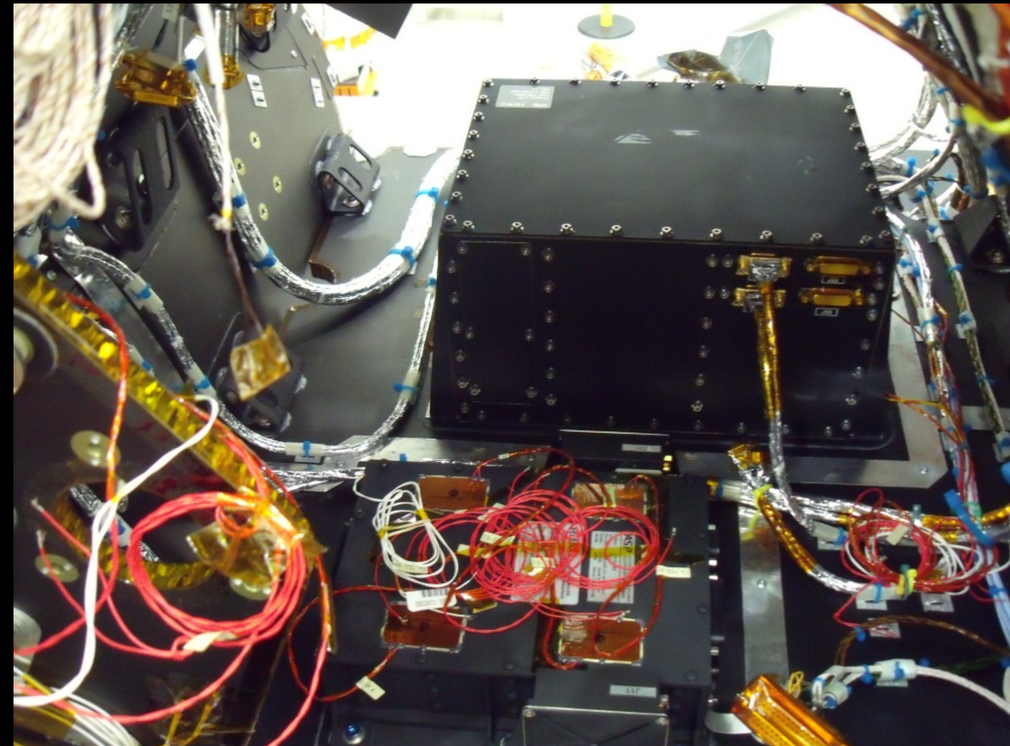
LISA Pathfinder
AIV Mass Tracking Log

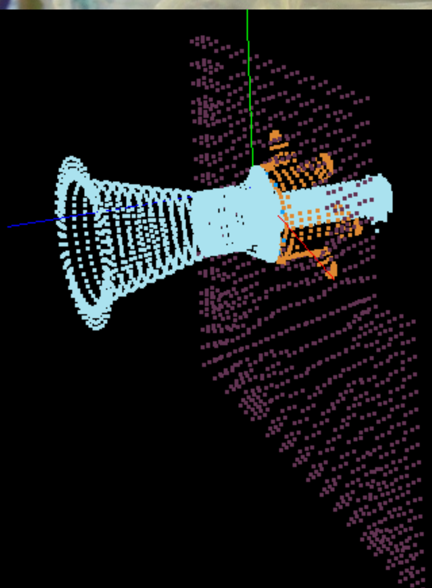
S2.ASU.TN.2275
Page No. 52

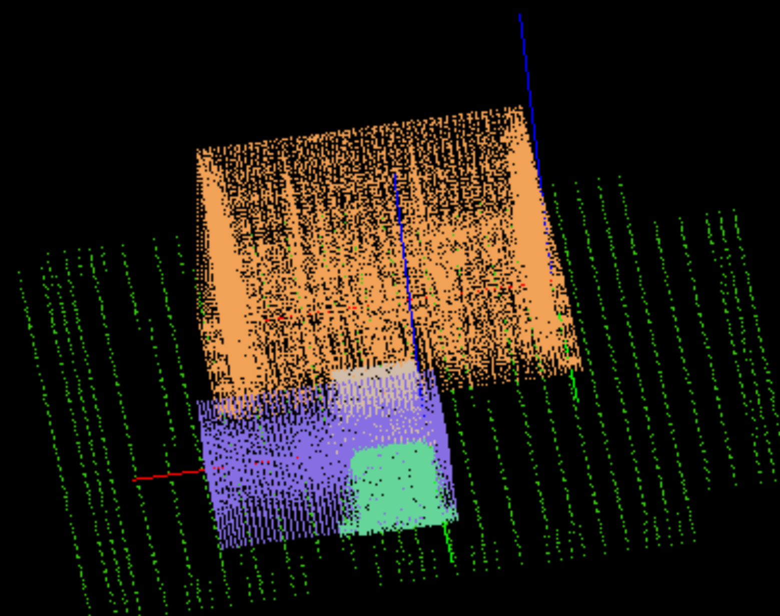
Line Item	Date	Time	Initials	ACS Reference	Description of Items Added/Removed (Use Multiple Lines, if Required)	Description of Location	Item Mass (kg)	Add/ Subtract	Running Total Mass (kg)	Temporary		In Model (For Use by Systems Team)
										Y/N	Line Item Removed	
1842	20/04/12	AM	MH	FM 394	PCU connector cover on SCM	MXMY radial	0.008065	+	315.212205	Y		
1843	20/04/12	AM	MH	FM394	PCU + filters + fittings + sigraflex	MXMY radial	1.695	−	313.517205	Y		
1844	20-4-12	PM	D.S	FM 392	PY SKIN CONNECTOR BRACKET AND FIXINGS	PY LONG PANEL	0.0916	−	313.425605	Y		
1845	4-5-12	AM	D.S	FM 394	FEEP PCU2 ACCELEROMETER PIN BROKEN OFF	+Y −X MEDIUM PANEL	0.004386	−	313.421219	Y		
1846	5-5-12	AM	GH		Dust caps fitted to FEEP PCNU 9off + 2off harness caps	−Y long external	0.006415	+	313.427634	Y		
1847	8/5/12	PM	MH	FM403	PCU3 + fittings + kapton/tyraps etc	MY long external	5.919748	−	307.507886	Y		
1848	9/5/12	AM	DI	FM403	SIGRAFLEX + KAPTON	MY LONG EXT.	0.0174	−	307.490486	Y		
1849	9-05-12	PM	MM	FM339	ALL BLANKETS REMOVED	ALL PANELS	2008g	−	305.482486	Y		
1850	9-05-12	PM	MM	FM339	ALL BLANKET FIXINGS	ALL PANELS	58.5g	−	305.423986	Y		
1851	9/05/12	PM	MH	FM 384	Thermal harness disconnector 8+14	all over	0.03609	−	305.387896	Y		
1852	10-05-12	AM	MM	FM339	MORE BLANKETS REMOVED	ALL PANELS	2418g	−	302.969896	Y		
1853	15/05/12	PM	MH	FM 406	Remove DSS1	Fab plate PXMY SCM adaptor	0.393712	−	302.576184	Y		
1854	15/05/12	PM	MH	FM405	Remove foam protection	Top of ext + rad panels	0.131	−	302.445184	Y		
1855	16/05/12	AM	MH	FM405	Install MY upper closure panel	MY PZ	2.2790	+	304.724184	Y		
1856	16/05/12	AM	MH	FM405	Install PY upper closure panel	PY PZ	2.3000	+	307.024184	Y		
1857	16/05/12	PM	MH	FM 408	Solar array blades + fixings	PZ	2.4592	+	309.483384	Y		
1858	17/05/12	AM	MH	FM408	Solar array + fixings	PZ	49.2162	+	358.699584	Y		
1859	17/5/12	PM	DI	FM394	FEEP PCU HVC J14 connector	FEEP PCU 2	0.006848	+	358.706432	Y		
1860	18/05/12	AM	MH	FM409	Perm mating guide brackets	Not weighed		+		Y		
1861	21/05/12	AM	MH	FM409	Kapton tape + chofoil	MZ umbilicals	0.002119	−	358.704313	Y		
1862	21/05/12	AM	MH	FM409	SSB box + plate, DSS plate + fixings	SCM adaptor	4.4222	−	354.282113	Y		
1863	30/05/12	AM	MN	?	Heater cable (not connected either end)	MY external	0.090827	−	354.191286	N		
1864	30/05/12	AM	MH	FM 417	SCM alignment guide rods	Not weighed				Y	see 1860	
1865	6/6/12	AM	DI	NCR 533	HI POWER CONNECTORS	FEEP 2 MX+Y MED	0.00948	+	354.200781	Y		
1866	6/6/12	AM	DI	NCR 533	"	FEEP 1 +X +Y MED	0.01467	+	354.215451	Y		
1867	7/6/12	PM	D.S	FM 420	SKIN CONNECTOR PY BRACKET + FIXINGS	PY LONG PANEL	0.0872	+	354.302651	N		
1868	12/6/12	PM	D.S	FM 418	ADDED TEMPORARY TYRAPS	MY LONG AND MY+X SMALL	0.00886	+	354.391511	Y		
1869	12/6/12	PM	MH	FM418	Lower closure panel MX	MZ MX	1.6432	+	356.034711	Y		
1870	12/6/12	PM	MH	FM418	Lower closure panel PX	MZ PX	1.6836	+	357.718311	Y		
1871	21/6/12	PM	MH	FM423	Remove lower closure panel MX	MZ MX	1.6194	−	356.098911	Y		
1872	21/06/12	PM	MH	FM423	Remove lower closure panel PX	MZ PX	1.6920	−	354.406911	Y		
1873	29/06/12	AM	MH	FM425	Solar array + all fittings + cover	PZ	51.66785	−	302.739061	Y		
1874	02/07/12	AM	MH	FM 423	Remove upper closure PY + fitting	PZ	2.3572	−	300.381861	Y		
1875	02/07/12	AM	MH	FM423	Remove upper closure MY fitting	PZ	2.3042	−	298.077661	Y		
1876	31/07/12	PM	MH	FM 430	Remove battery	rad shear PXMY 7.94486	7.94486	−	290.132801	Y		
1877	2/8/12	PM	DI	FM 438	HARNESS REDRESS TYWRAP of NTF	RAD SHEAR PX−Y	0.205934	+	289.926867	Y		
~~1878~~	~~24-8-12~~	~~PM~~	~~D.S~~	~~FM 433~~	~~LACING CORD CHOFOIL REMOVED AT PCU PO4 SAU2 PO1~~	~~MY MX RADIAL SHEAR MPY RADIAL SHEAR~~	~~0.01758~~	~~−~~				
1878	24/8/12	PM	D.S	FM 433	LACING CORD CHOFOIL REMOVED AT PCU PO4 DMU PO	MY MX RADIAL SHEAR	0.00935	−	289.917517	N		
1879	24/8/12	PM	D.S	FM 433	LACING CORD CHOFOIL REMOVED AT SAU2 PO1,4	MX MPY RADIAL SHEAR	0.00823	−	289.909287	N		

Modeling

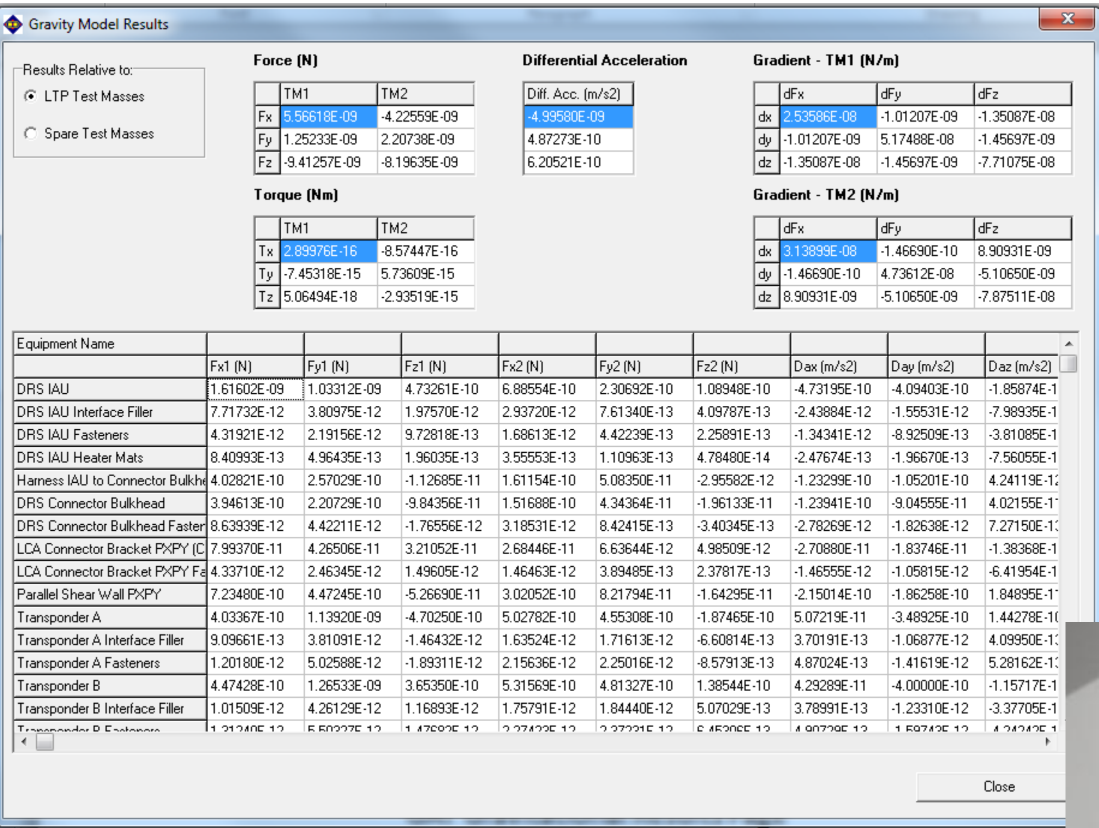








Calculating field and compensating



Gravity Model Results

Results Relative to:
- (•) LTP Test Masses
- ( ) Spare Test Masses

Force (N)

	TM1	TM2
Fx	5.56618E-09	-4.22559E-09
Fy	1.25233E-09	2.20738E-09
Fz	-9.41257E-09	-8.19635E-09

Differential Acceleration

Diff. Acc. (m/s2)
-4.99580E-09
4.87273E-10
6.20521E-10

Gradient - TM1 (N/m)

	dFx	dFy	dFz
dx	2.53586E-08	-1.01207E-09	-1.35087E-08
dy	-1.01207E-09	5.17488E-08	-1.45697E-09
dz	-1.35087E-08	-1.45697E-09	-7.71075E-08

Torque (Nm)

	TM1	TM2
Tx	2.89976E-16	-8.57447E-16
Ty	-7.45318E-15	5.73609E-15
Tz	5.06494E-18	-2.93519E-15

Gradient - TM2 (N/m)

	dFx	dFy	dFz
dx	3.13899E-08	-1.46690E-10	8.90931E-09
dy	-1.46690E-10	4.73612E-08	-5.10650E-09
dz	8.90931E-09	-5.10650E-09	-7.87511E-08

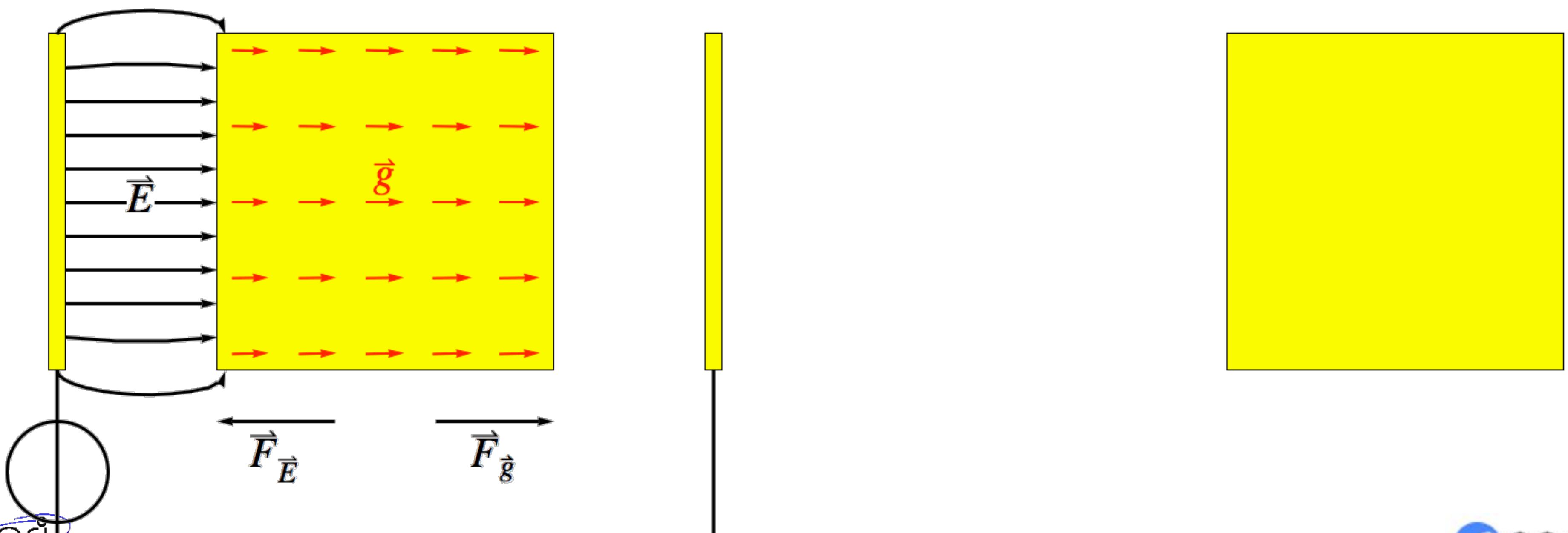
Equipment Name	Fx1 (N)	Fy1 (N)	Fz1 (N)	Fx2 (N)	Fy2 (N)	Fz2 (N)	Dax (m/s2)	Day (m/s2)	Daz (m/s2)
DRS IAU	1.61602E-09	1.03312E-09	4.73261E-10	6.88554E-10	2.30692E-10	1.08948E-10	-4.73195E-10	-4.09403E-10	-1.85874E-1
DRS IAU Interface Filler	7.71732E-12	3.80975E-12	1.97570E-12	2.93720E-12	7.61340E-13	4.09787E-13	-2.43884E-12	-1.55531E-12	-7.98935E-1
DRS IAU Fasteners	4.31921E-12	2.19156E-12	9.72818E-13	1.68613E-12	4.42239E-13	2.25891E-13	-1.34341E-12	-8.92509E-13	-3.81085E-1
DRS IAU Heater Mats	8.40993E-13	4.96435E-13	1.96035E-13	3.55553E-13	1.10963E-13	4.78480E-14	-2.47674E-13	-1.96670E-13	-7.56055E-1
Harness IAU to Connector Bulkhe	4.02821E-10	2.57029E-10	-1.12685E-11	1.61154E-10	5.08350E-11	-2.95582E-12	-1.23299E-10	-1.05201E-10	4.24119E-1
DRS Connector Bulkhead	3.94613E-10	2.20729E-10	-9.84356E-11	1.51688E-10	4.34364E-11	-1.96133E-11	-1.23941E-10	-9.04555E-11	4.02155E-1
DRS Connector Bulkhead Faster	8.63939E-12	4.42211E-12	-1.76556E-12	3.18531E-12	8.42415E-13	-3.40345E-13	-2.78269E-12	-1.82638E-12	7.27150E-1
LCA Connector Bracket PXPY (C	7.99370E-11	4.26506E-11	3.21052E-11	2.68446E-11	6.63644E-12	4.98509E-12	-2.70880E-11	-1.83746E-11	-1.38368E-1
LCA Connector Bracket PXPY Fa	4.33710E-12	2.46345E-12	1.49605E-12	1.46463E-12	3.89485E-13	2.37817E-13	-1.46555E-12	-1.05815E-12	-6.41954E-1
Parallel Shear Wall PXPY	7.23480E-10	4.47245E-10	-5.26690E-11	3.02052E-10	8.21794E-11	-1.64295E-11	-2.15014E-10	-1.86258E-10	1.84895E-1
Transponder A	4.03367E-10	1.13920E-09	-4.70250E-10	5.02782E-10	4.55308E-10	-1.87465E-10	5.07219E-11	-3.48925E-10	1.44278E-1
Transponder A Interface Filler	9.09661E-13	3.81091E-12	-1.46432E-12	1.63524E-12	1.71613E-12	-6.60814E-13	3.70191E-13	-1.06877E-12	4.09950E-1
Transponder A Fasteners	1.20180E-12	5.02588E-12	-1.89311E-12	2.15636E-12	2.25016E-12	-8.57913E-13	4.87024E-13	-1.41619E-12	5.28162E-1
Transponder B	4.47428E-10	1.26533E-09	3.65350E-10	5.31569E-10	4.81327E-10	1.38544E-10	4.29289E-11	-4.00000E-10	-1.15717E-1
Transponder B Interface Filler	1.01509E-12	4.26129E-12	1.16893E-12	1.75791E-12	1.84440E-12	5.07029E-13	3.78991E-13	-1.23310E-12	-3.37705E-1
Transponder B Fasteners	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Close

Gravitational balance masses in tungsten

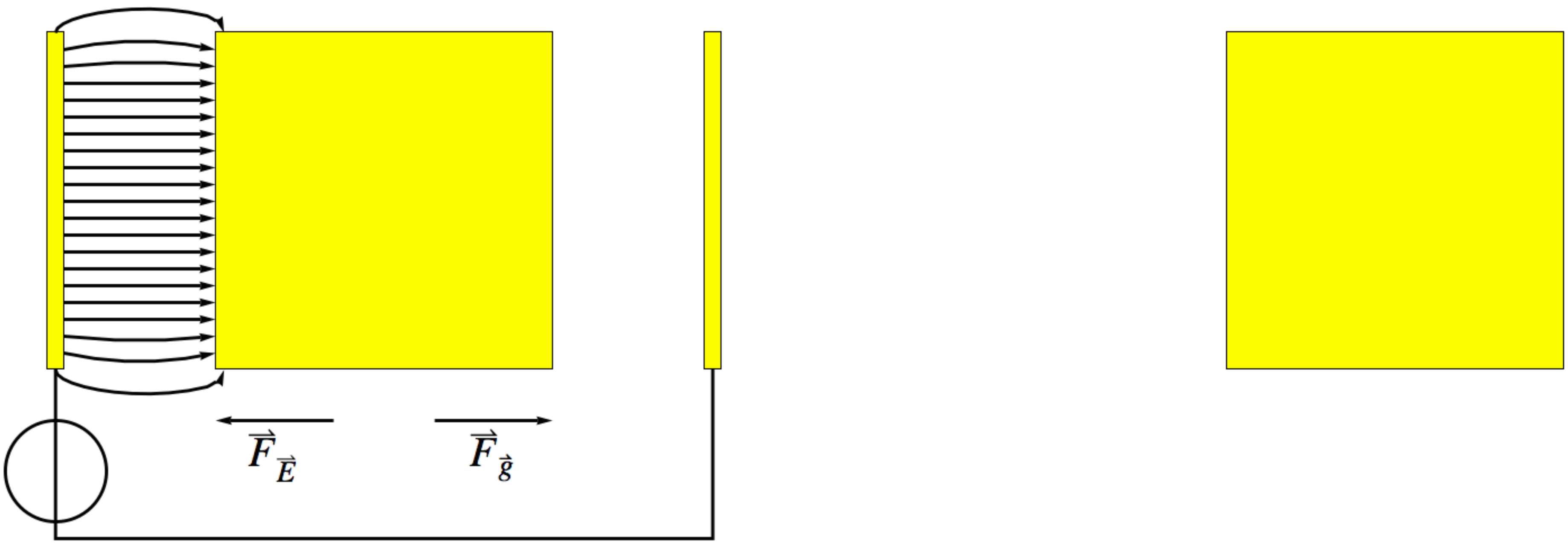
Back to LPF "test-bench noise"

- Getting rid of electrostatic forces needed to compensate for gravitational field
- Parabolic flight at 0.1 ng



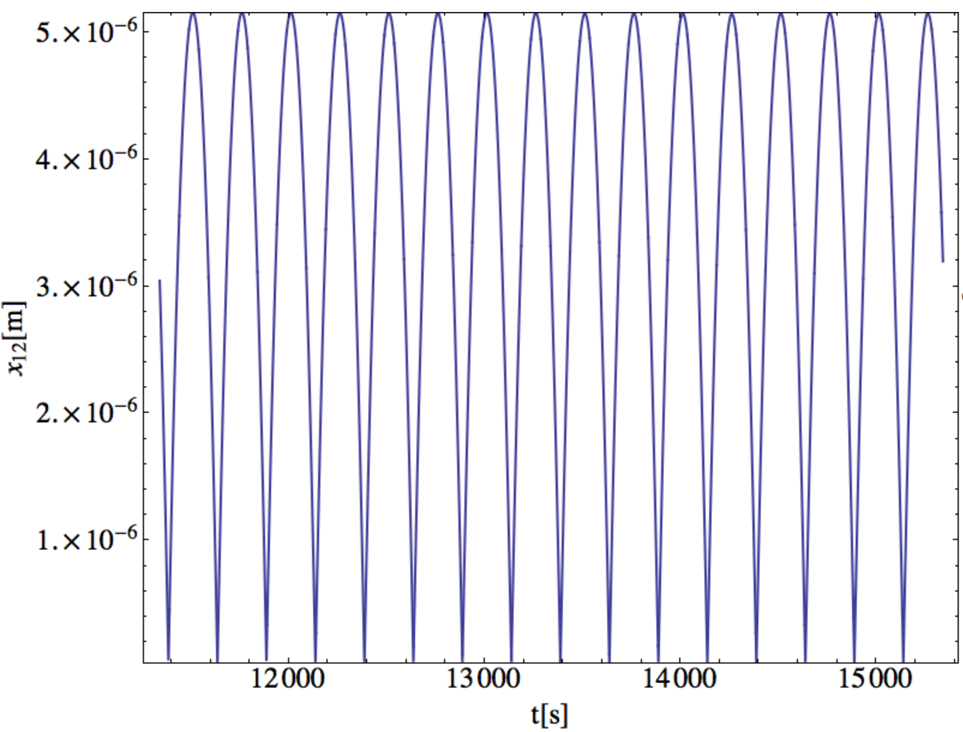
Beating test-bench noise: the free-fall mode

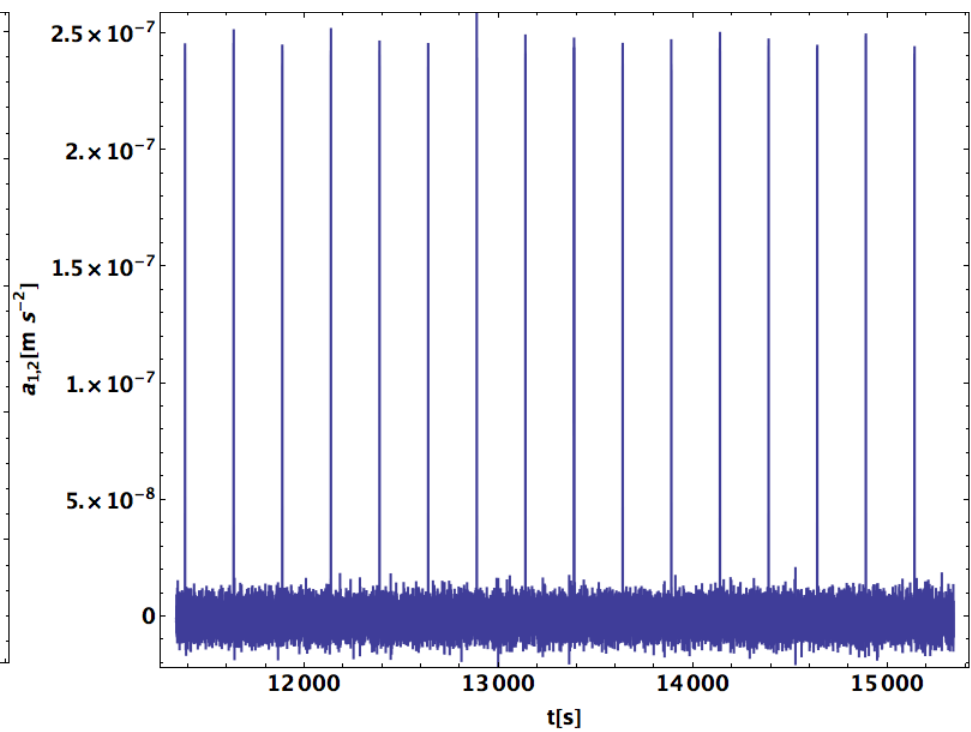
- Actuation is turned off for most of the time
- Force pulses are given intermittently for short time
- Data during short pulses are chopped off
- Noise is estimated from remaining data, immune to actuation noise



Data from end-to-end simulation: displacement vs acceleration

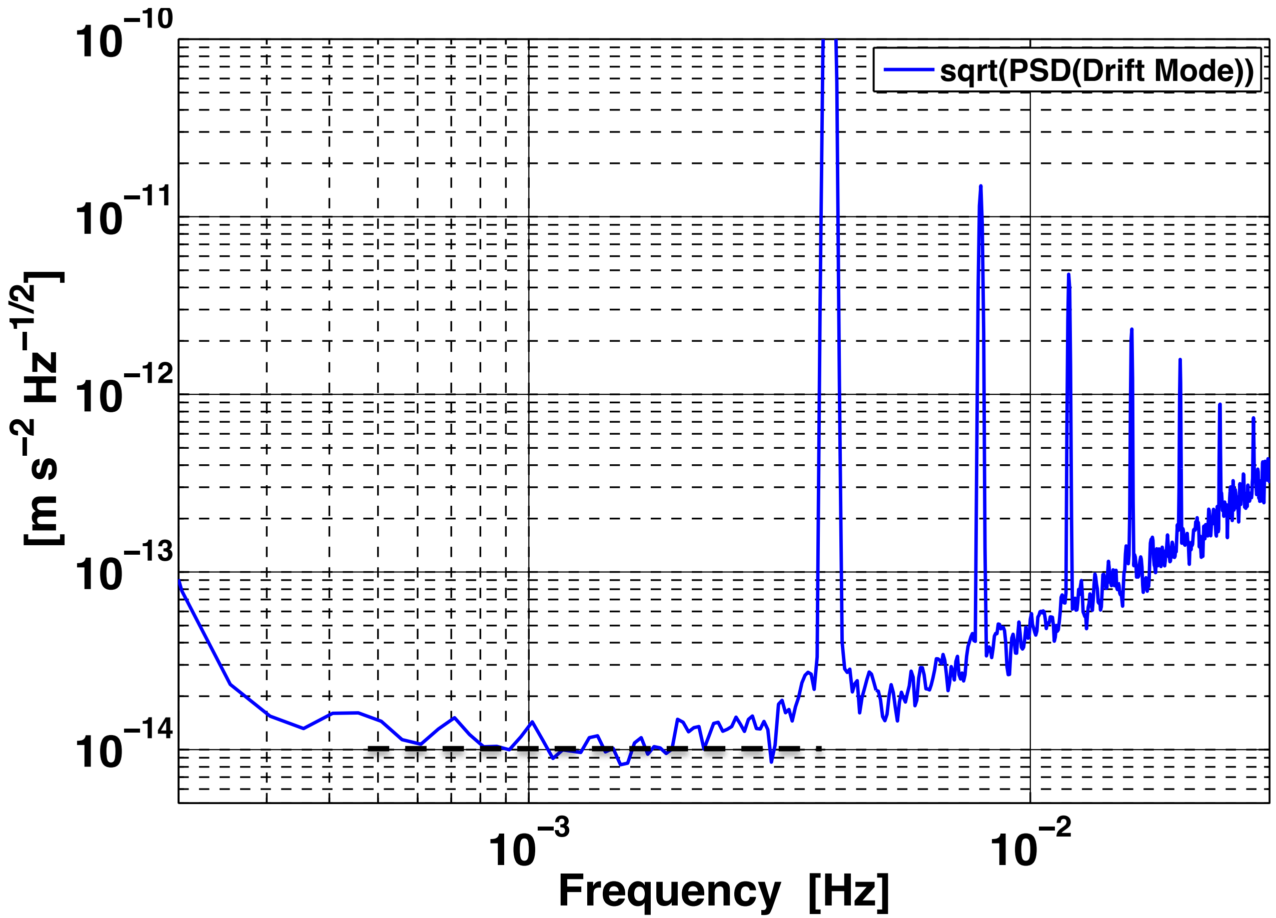
- Displacement plot show parabolas of constant acceleration motion
- Double time derivation converts data into acceleration: force pulses show up as very short duration peaks
- Data between two peaks have low noise





Data from end-to-end simulation: Power Spectral Density of residual force

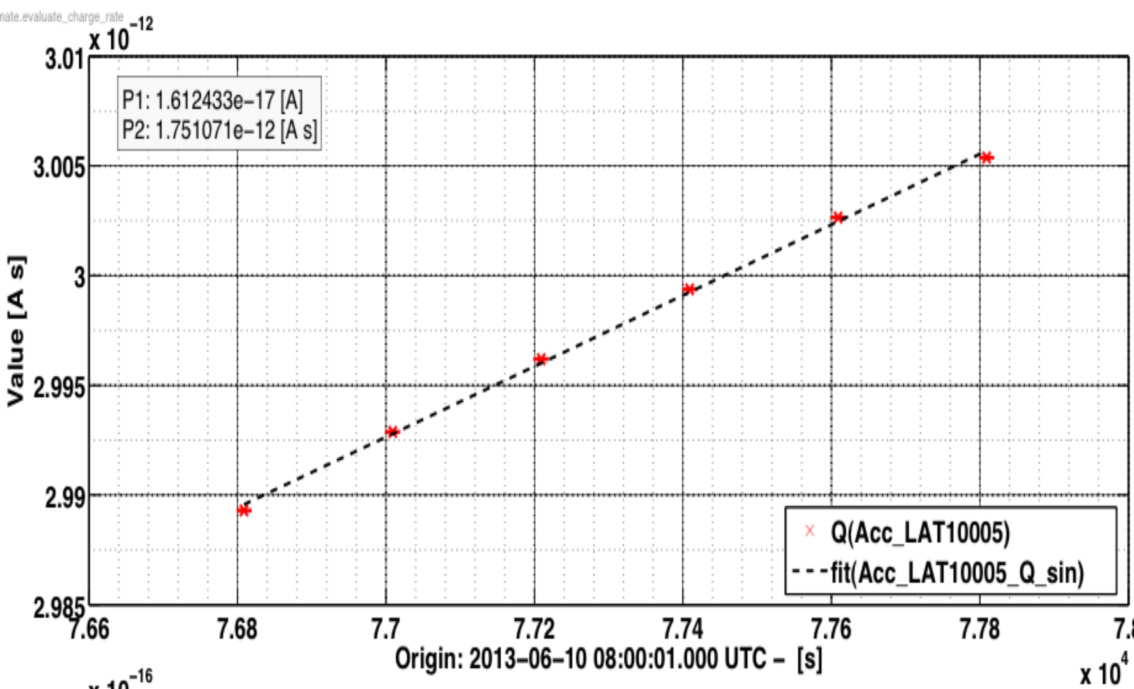
- Data gaps produce bright peaks
- PSD below first peak agrees with expected noise floor
- Static gravity measured to 0.5 pg
- Static gravity gradient measured to 20 pg/m

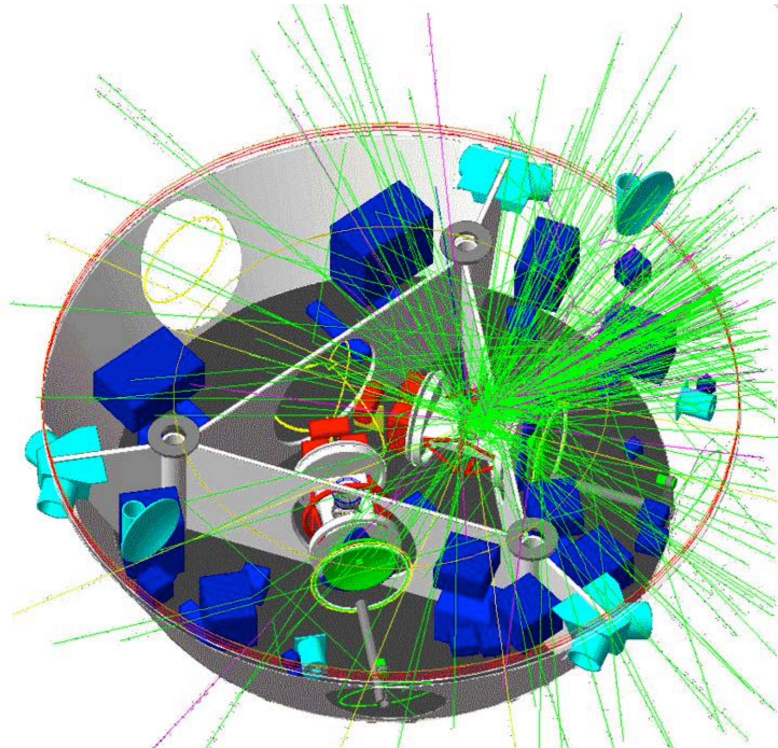


TM Charging model verification

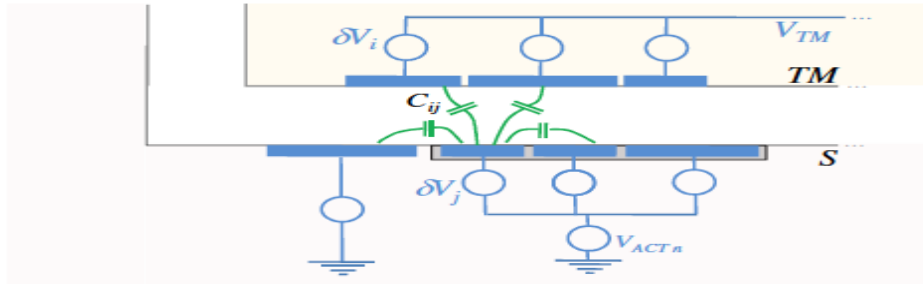
INFN Istituto Nazionale di Fisica Nucleare
UNIVERSITÀ DEGLI STUDI DI TRENTO

- TM charges up from cosmic rays
- Modeled with Geant/Fluka
- Charge flux measured by charge monitor
- Test-mass charge measured from coupling to applied voltage
- Resolution ~1000 *e* over an hour (simulator and torsion pendulum)
- A test of eLISA TM charging model



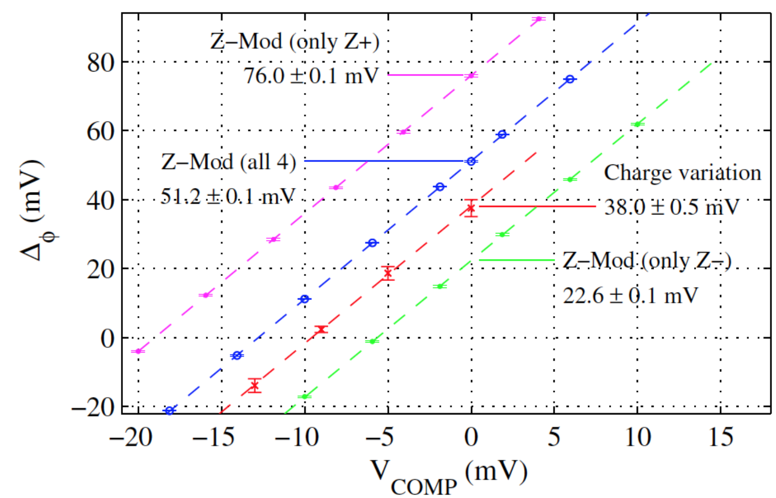


- Conducting surfaces are covered by stray potential patches (“charge patches”)
- Electric field couples to noisy charge and gives noisy forces
- Electric field can be suppressed by properly biasing the electrodes surrounding the TM. eLISA requires < 50 mV
- In the lab

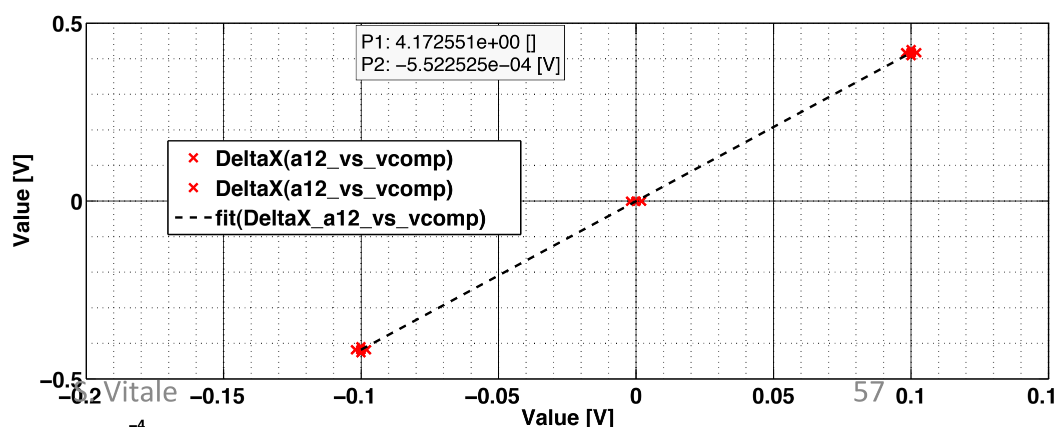


PRL **108,** 181101 (2012) PHYSICAL REVIEW LETTERS week ending 4 MAY 2012

Interaction between Stray Electrostatic Fields and a Charged Free-Falling Test Mass



- Now in the simulator (<1 mv accuracy and precision)

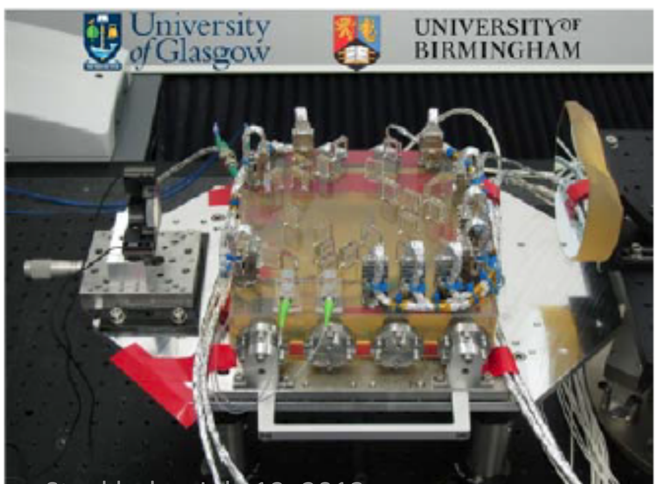


Estimating expected performance: 1) optical metrology

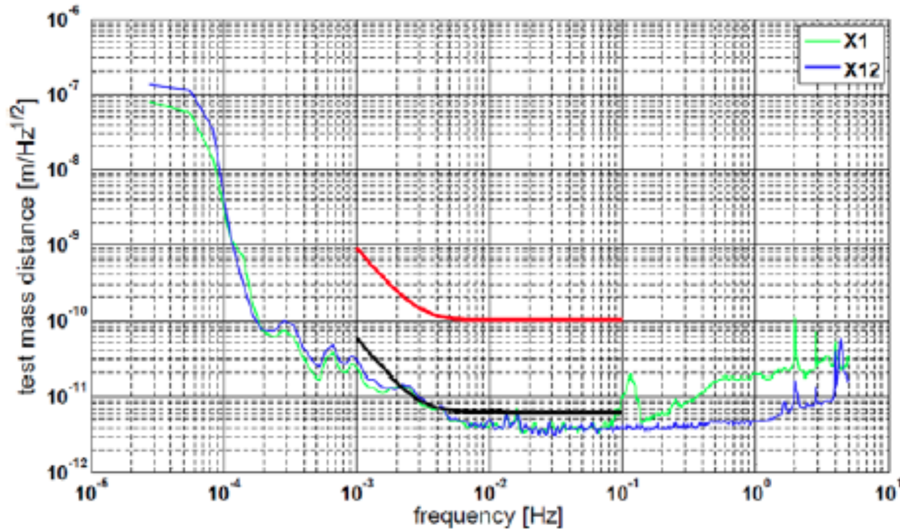
Optical metrology performance at hot/cold confirmed.

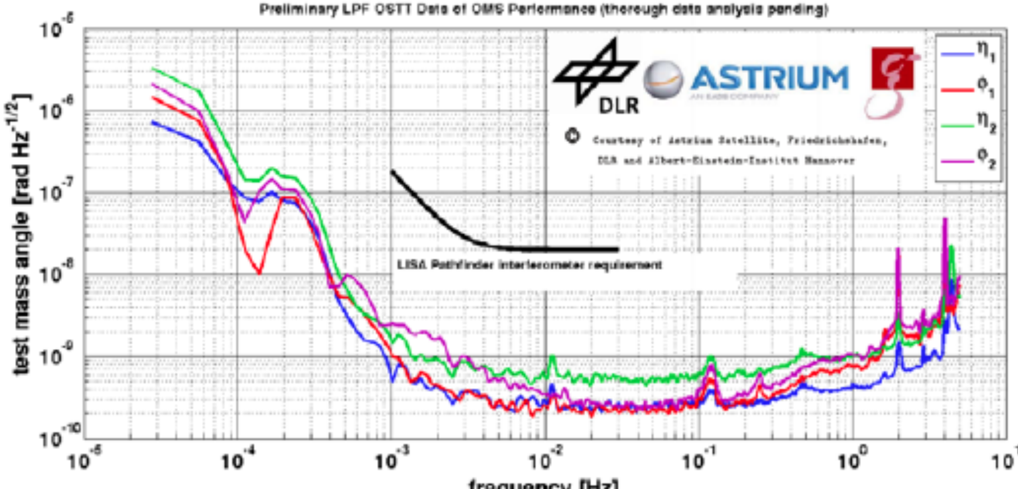
- Test mirror translation noise <6 pm/sqrtHz
- Test mirror rotational noise <1 nrad/sqrtHz

In-orbit performance expected to be better than in test chamber.

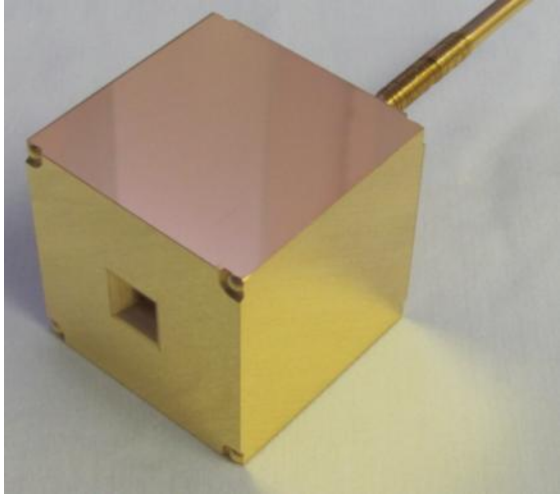


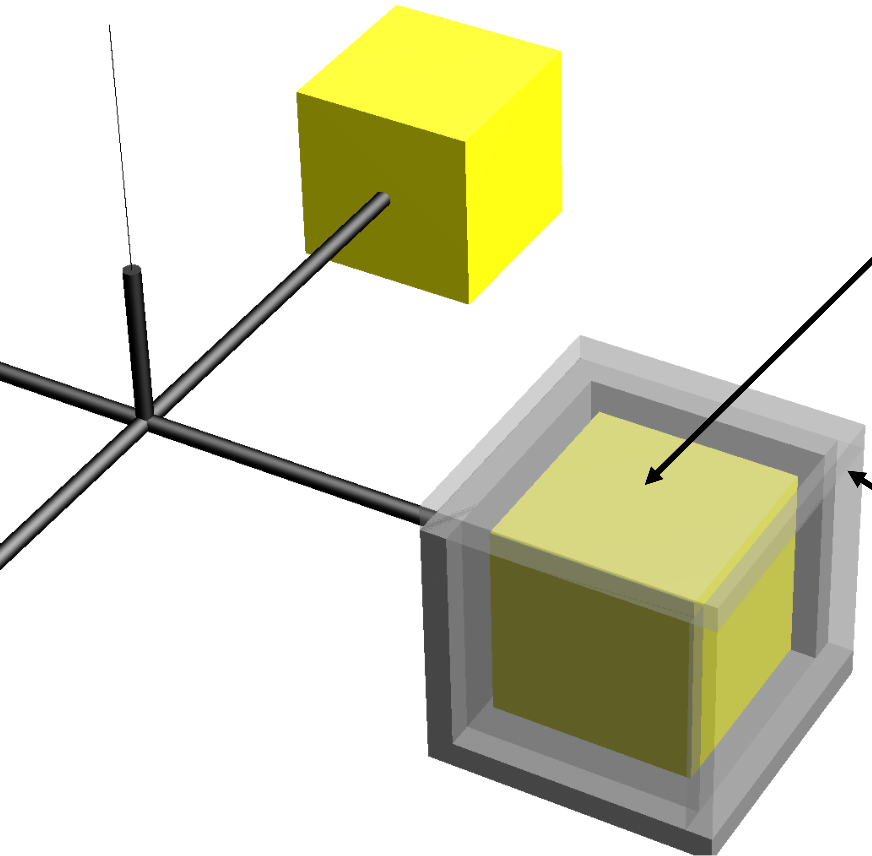
13th Mar



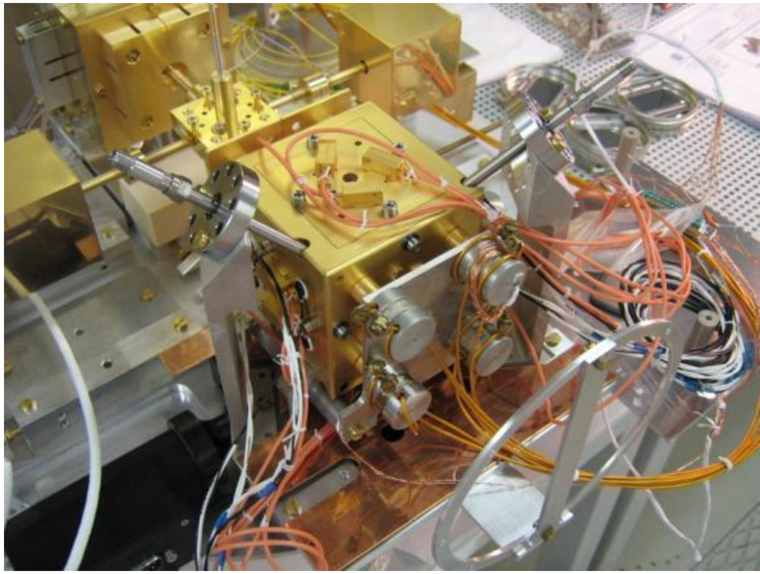


Estimating the expected performance with ground testing
2) GRS testing with torsion Pendulum (surface forces)





Test-mass (hollow)



Disturbing surroundings (GRS)

PHYSICAL REVIEW D **76,** 102003 (2007)

Thermal gradient-induced forces on geodesic reference masses for LISA

PRL **103,** 140601 (2009) PHYSICAL REVIEW LETTERS week ending 2 OCTOBER 2009

Increased Brownian Force Noise from Molecular Impacts in a Constrained Volume

PRL **108,** 181101 (2012) PHYSICAL REVIEW LETTERS week ending 4 MAY 2012

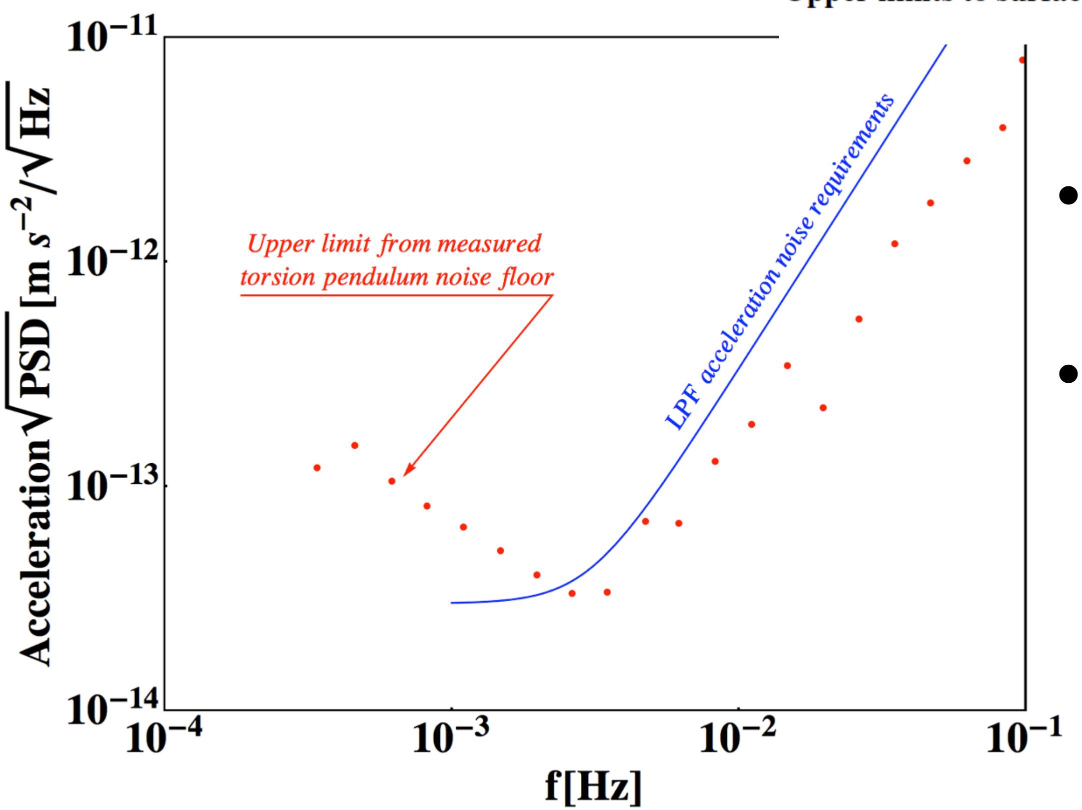
Interaction between Stray Electrostatic Fields and a Charged Free-Falling Test Mass

VOLUME 91, NUMBER 15 PHYSICAL REVIEW LETTERS week ending 10 OCTOBER 2003

Achieving Geodetic Motion for LISA Test Masses: Ground Testing Results

PHYSICAL REVIEW D **75,** 042001 (2007)

Upper limits to surface-force disturbances on LISA proof masses and the possibility of observing galactic binaries



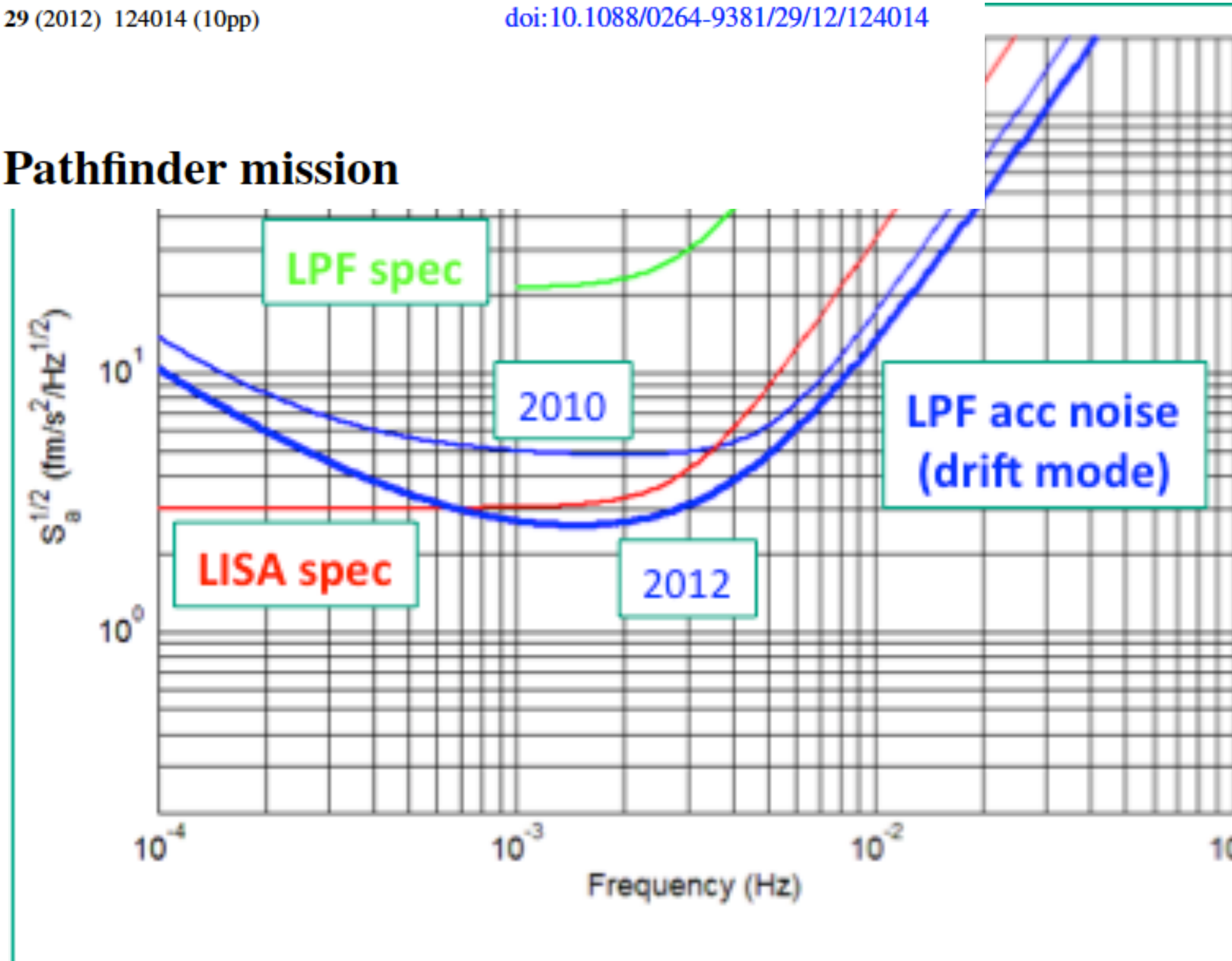
- Requirements on single effects verified
- Overall upper limit on surface forces close to LPF requirements

Estimated performance keeps improving

IOP PUBLISHING CLASSICAL AND QUANTUM GRAVITY

Class. Quantum Grav. 29 (2012) 124014 (10pp) doi:10.1088/0264-9381/29/12/124014

The LISA Pathfinder mission



See you at launch!!!