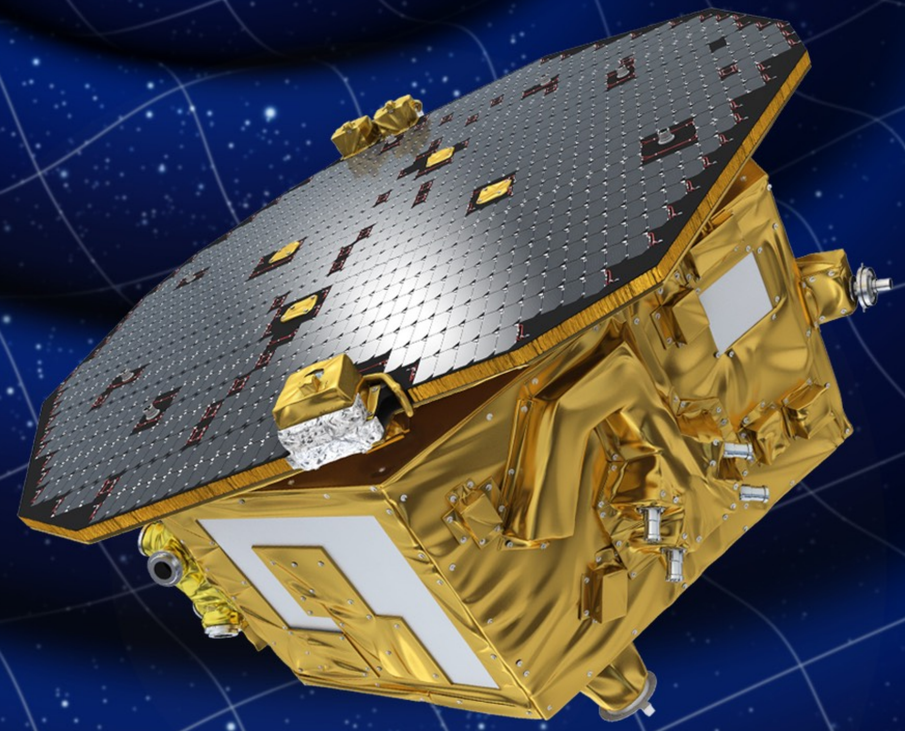
lisa pathfinder

FIRST STEPS TO OBSERVING
GRAVITATIONAL WAVES FROM SPACE

LISA Pathfinder and the route to LISA



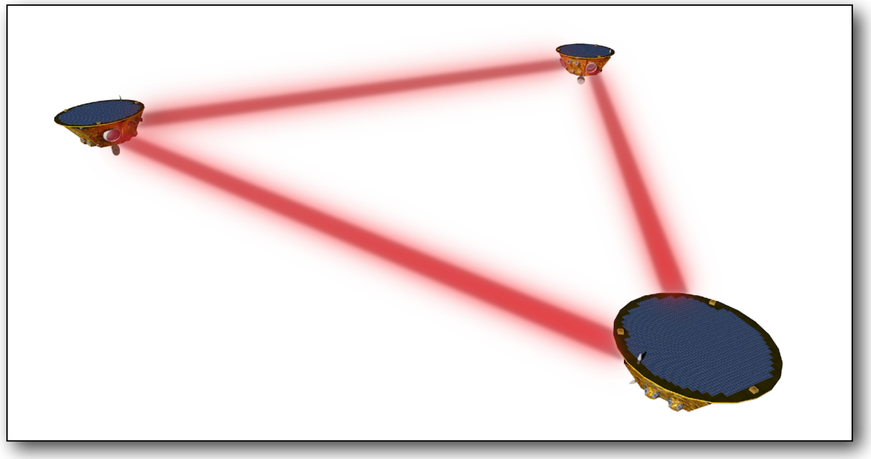
Paul McNamara
ACES workshop
Paris, October 2019

Introduction

- LISA Pathfinder (LPF) is the first step in the observation of gravitational waves from space
- LPF launched on a VEGA launcher from Kourou on 3 December 2015
- Goal of mission: demonstrate free-fall within one order of magnitude of that required by LISA
  - ***Performance surpassed even our most optimistic expectations!***

- LPF essentially shrinks one arm of LISA from ~million km down to ~40cm
  - Gives up the sensitivity to gravitational waves
  - Maintains (and worsens) the instrument noise which could dominate the GW signal

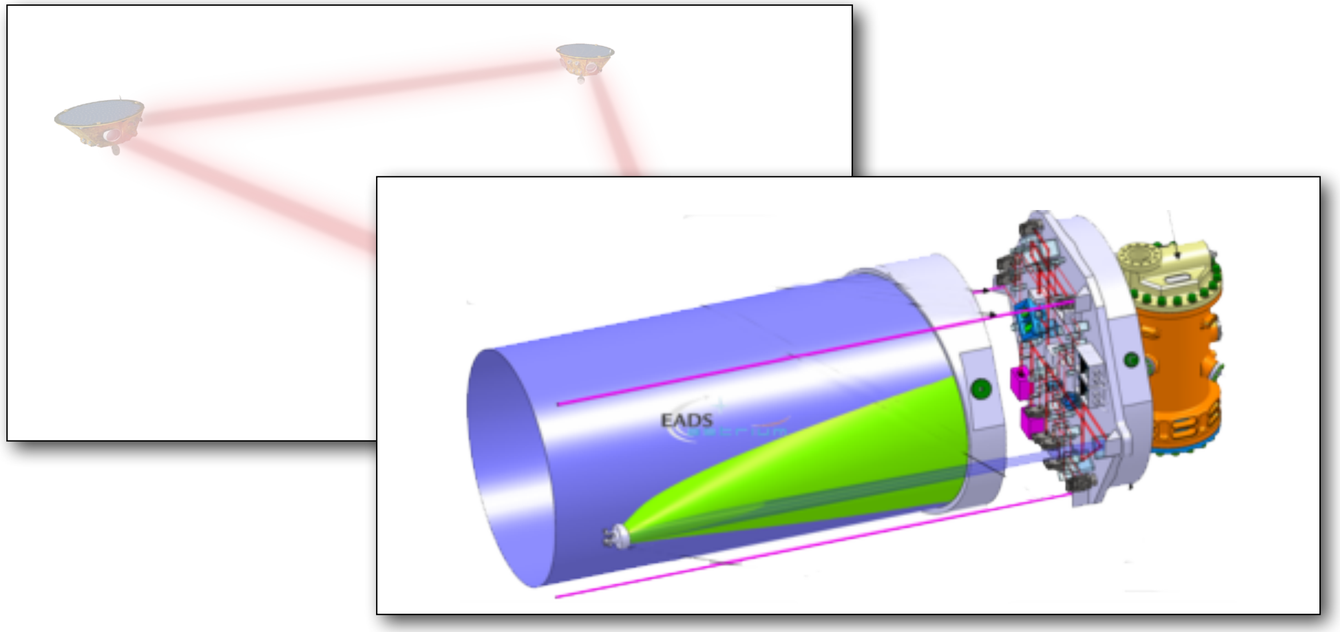
LISA to LISA Pathfinder



LISA:

- 3 spacecraft, separated by ~million km
- Role of each spacecraft is to protect the fiducial test masses from external forces

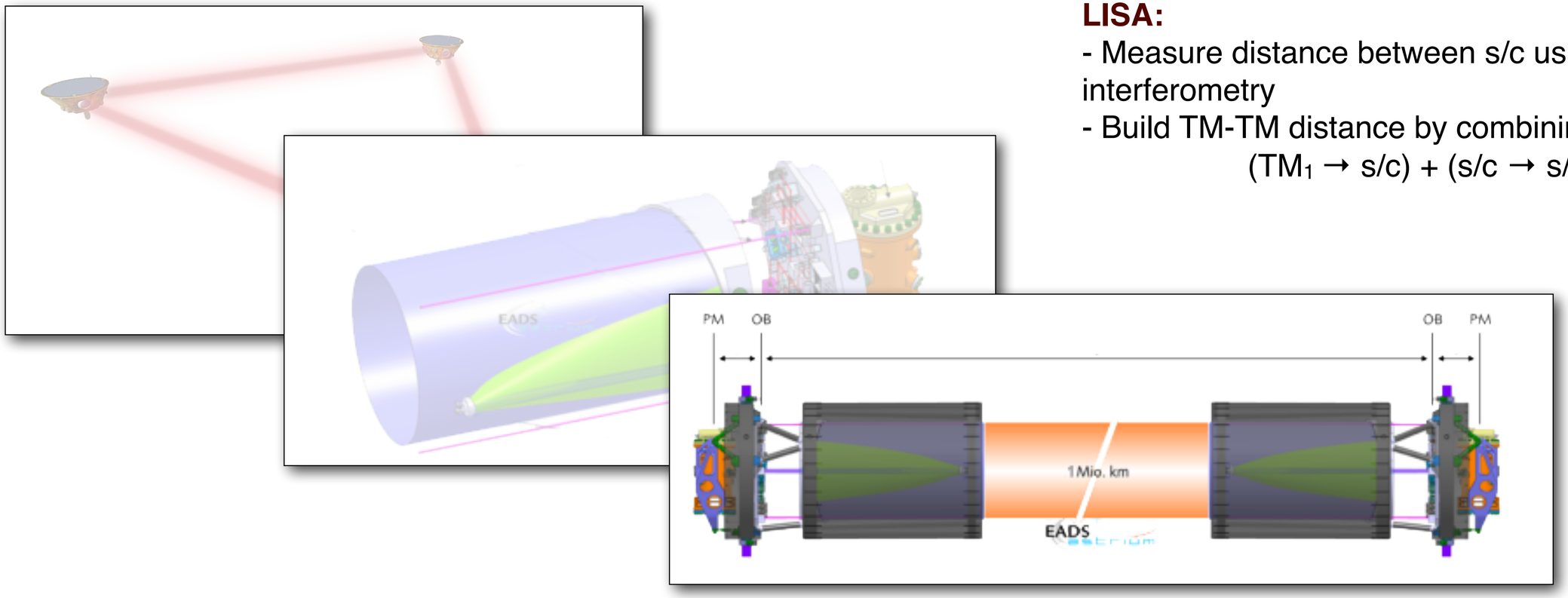
LISA to LISA Pathfinder



LISA:

- Locally measure distance from TM to s/c using:
  - Laser interferometry along sensitive axis (between s/c)
  - Capacitive sensing on orthogonal axes
- TM displacement measurements are used as input to DFACS which controls position and attitude of s/c with respect to the TM

LISA to LISA Pathfinder



LISA:

- Measure distance between s/c using laser interferometry
- Build TM-TM distance by combining:

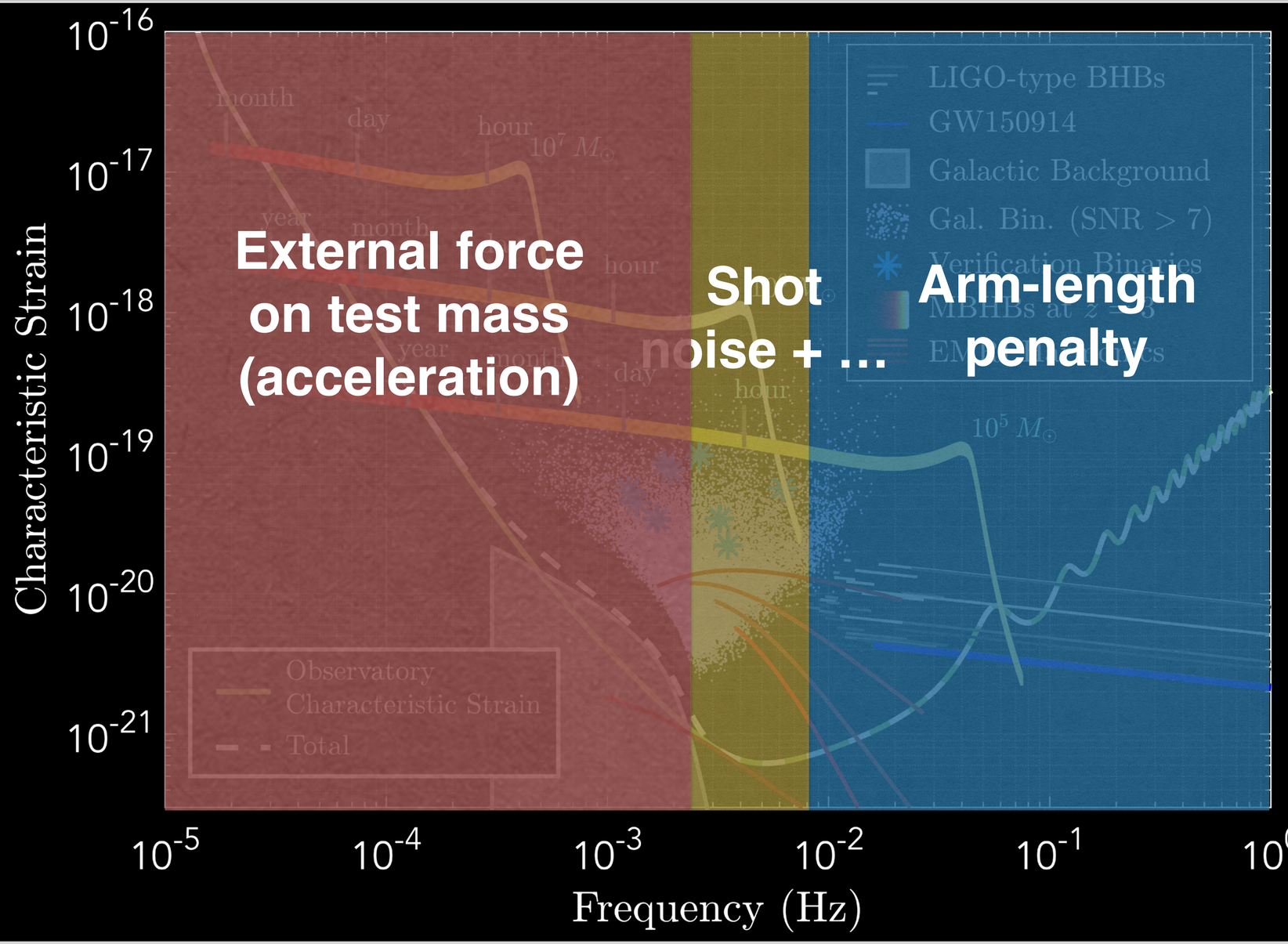
$$(TM_1 \rightarrow s/c) + (s/c \rightarrow s/c) + (s/c \rightarrow TM_2)$$

LISA to LISA Pathfinder

LISA Pathfinder:

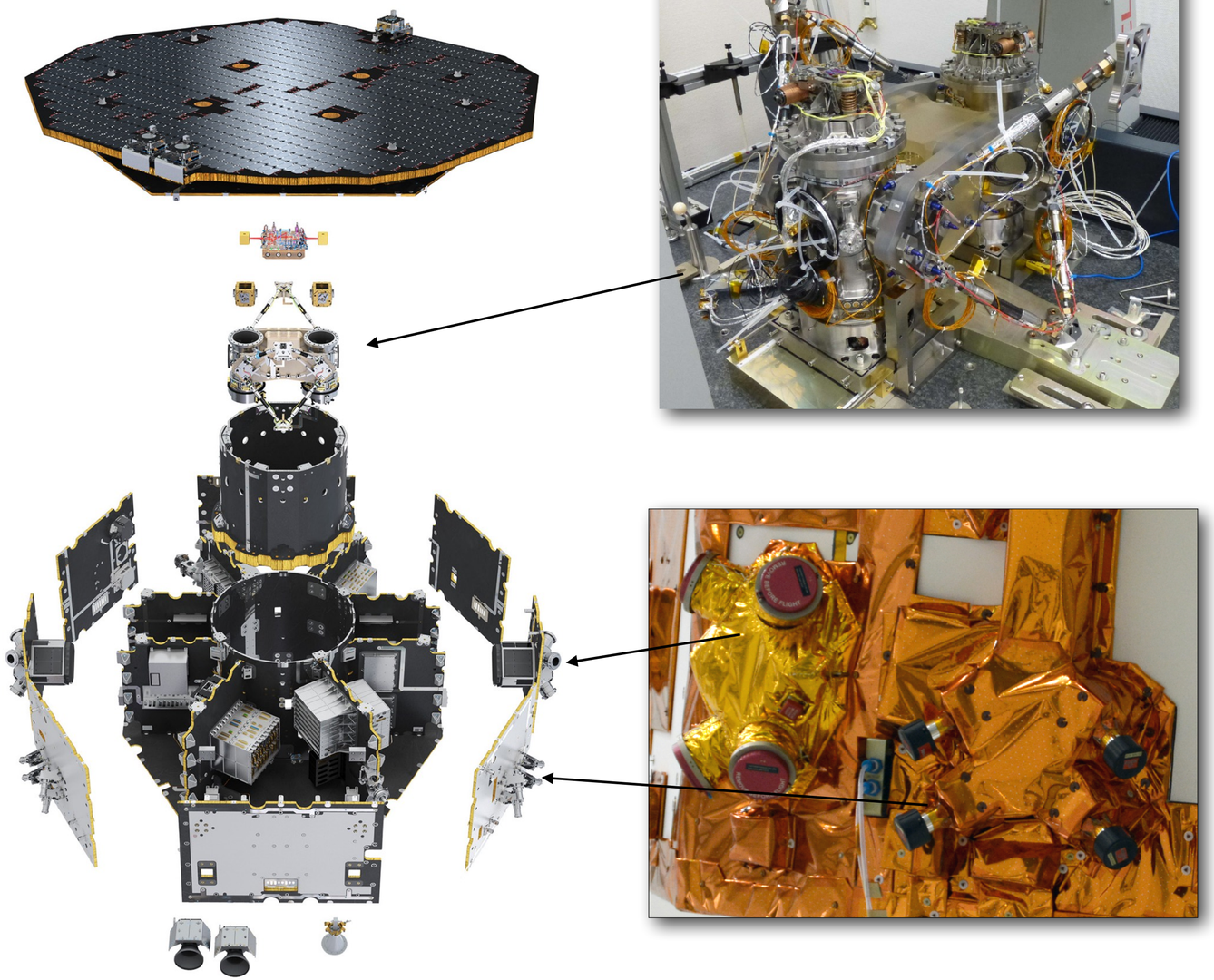
- Two test masses/two inertial sensors
- Laser interferometric readout of $TM_1 \rightarrow s/c$ & $TM_1 \rightarrow TM_2$
- Capacitive readout of all 6dof of test masses
- Drag-Free and Attitude Control System
- Micro-Newton Thrusters

LPF and LISA

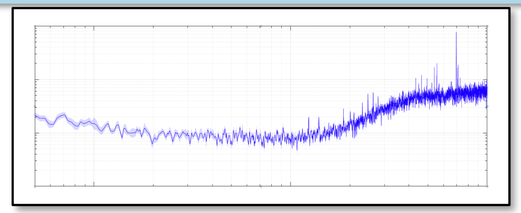

External force on test mass (acceleration)
Shot noise + …
Arm-length penalty
LIGO-type BHBs
GW150914
Galactic Background
Gal. Bin. (SNR > 7)
Verification Binaries
Observatory Characteristic Strain
Total
month
day
hour
year
$10^7\,M_\odot$
$10^5\,M_\odot$
Characteristic Strain
10^{-16}
10^{-17}
10^{-18}
10^{-19}
10^{-20}
10^{-21}
10^{-5}
10^{-4}
10^{-3}
10^{-2}
10^{-1}
10^{0}
Frequency (Hz)

LISA Pathfinder

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



A orbiting physics lab



Experiment Planning

Analysis Products

Data Analysis

Investigation description

Telemetry (Analysis Objects)

STOC (Science Operations)

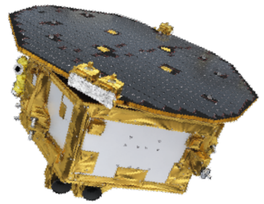
Telecommand Sequence

Telemetry (ascii)

MOC (Mission Operations)

Telecommands

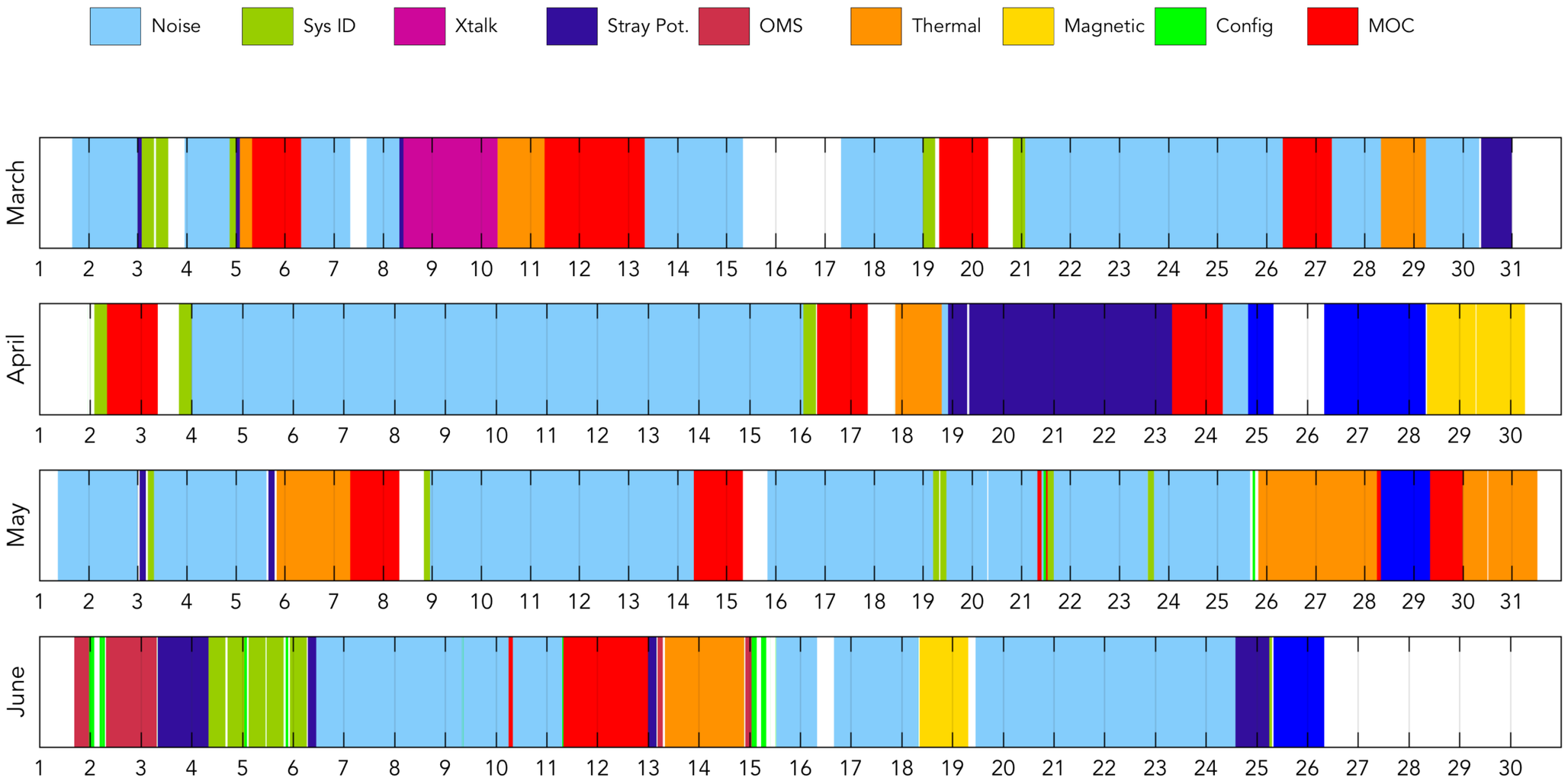
Telemetry (Packets)



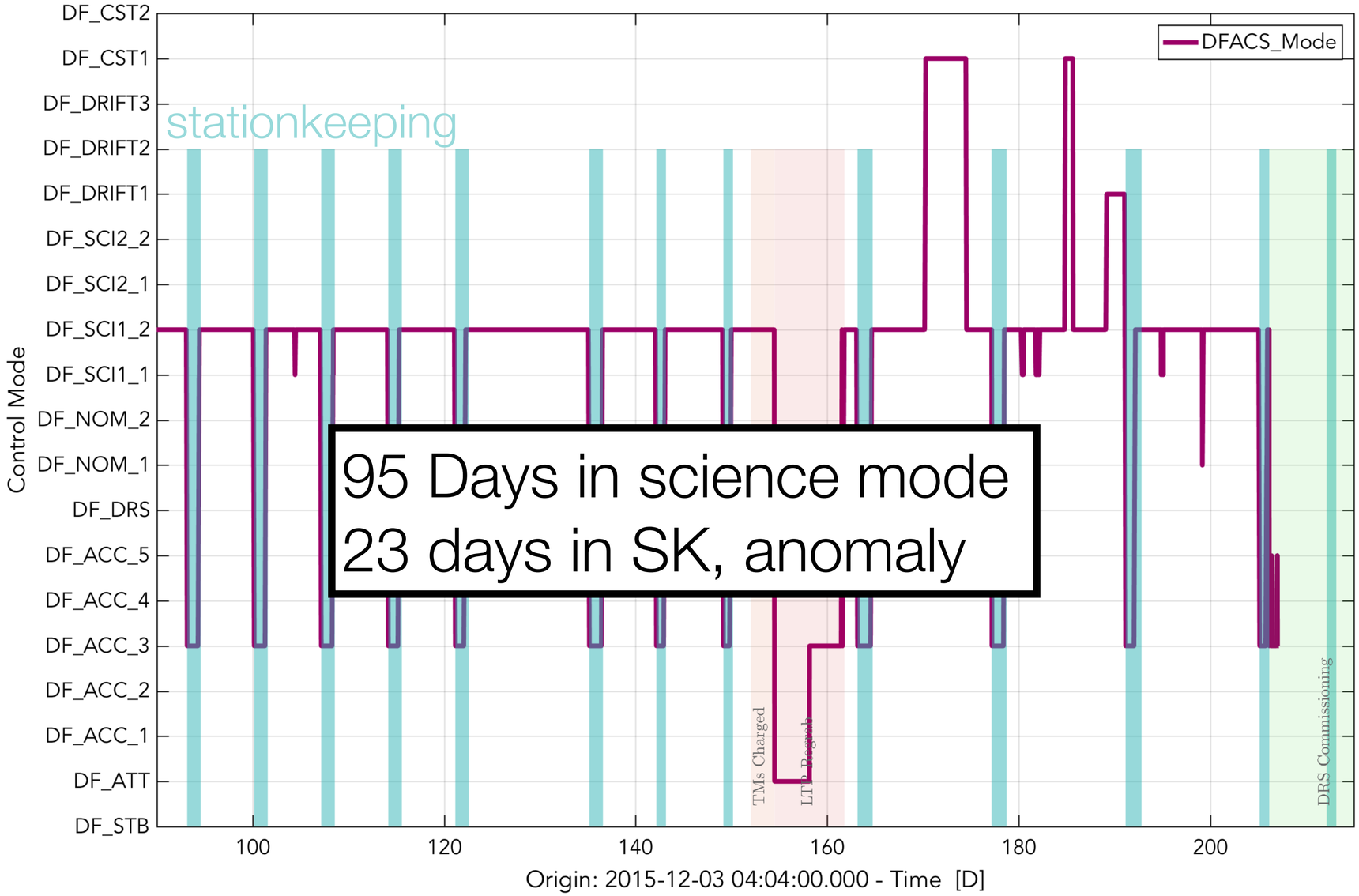
Simulator

Simulator

Experiments Performed



Time in science mode

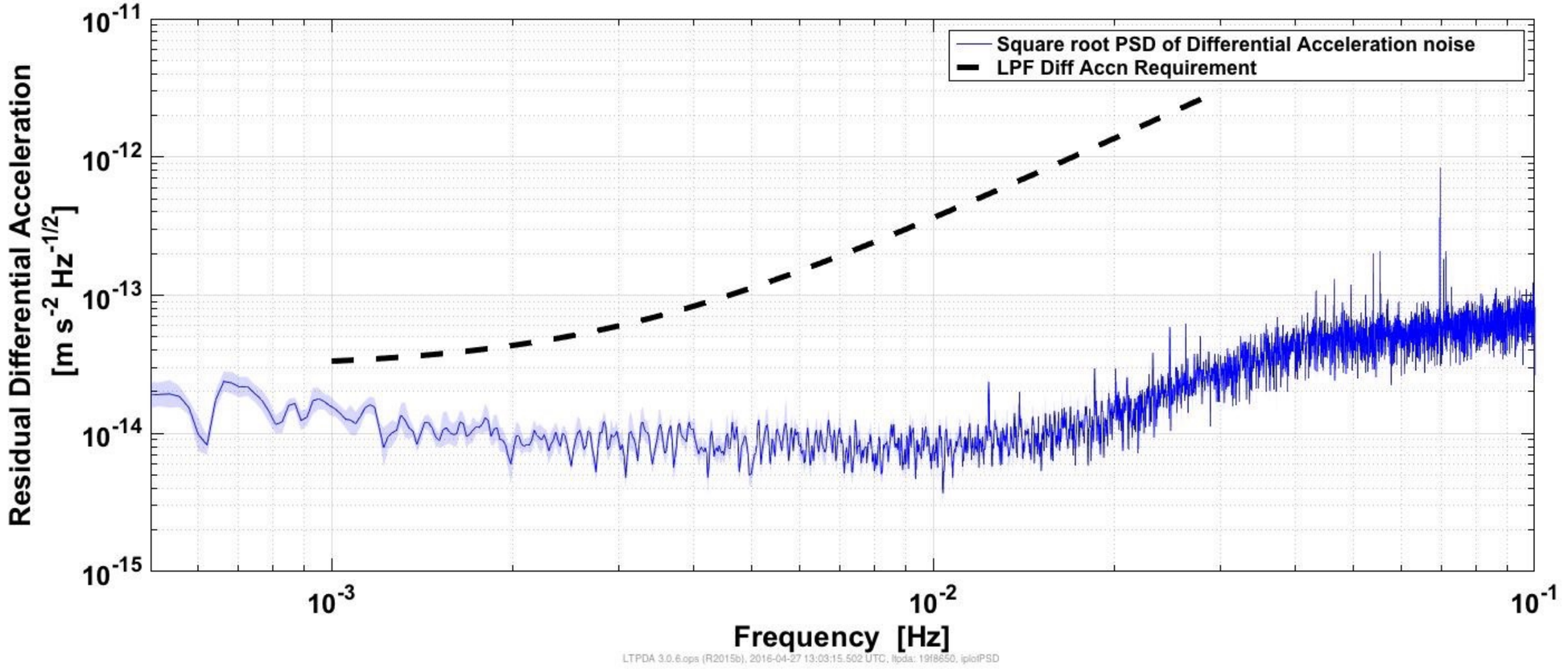


95 Days in science mode
23 days in SK, anomaly

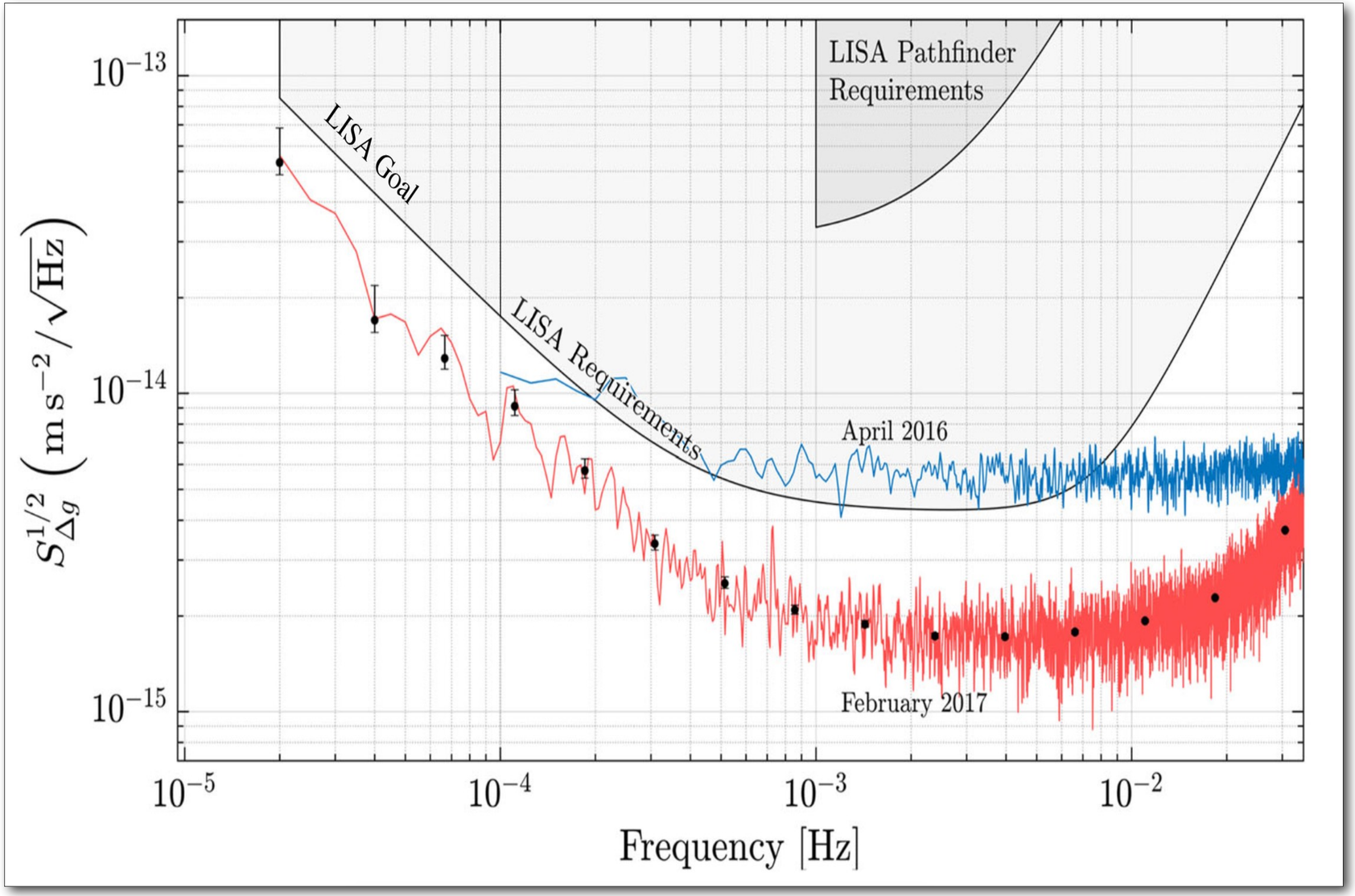
Differential Acceleration

- The differential acceleration between the test masses (known as “delta-g”) is the primary performance requirement of the mission…

  …and was met during commissioning!

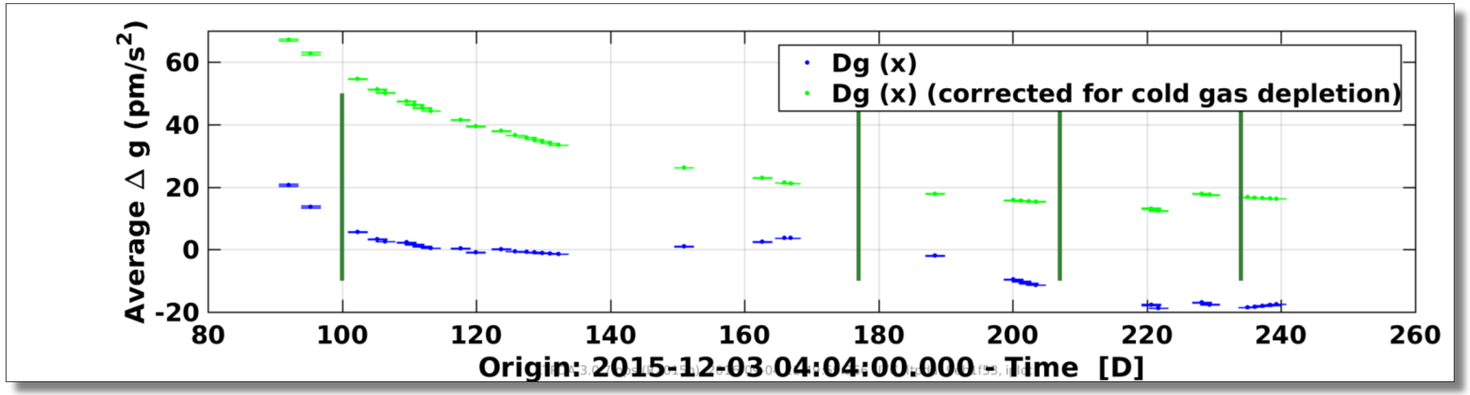


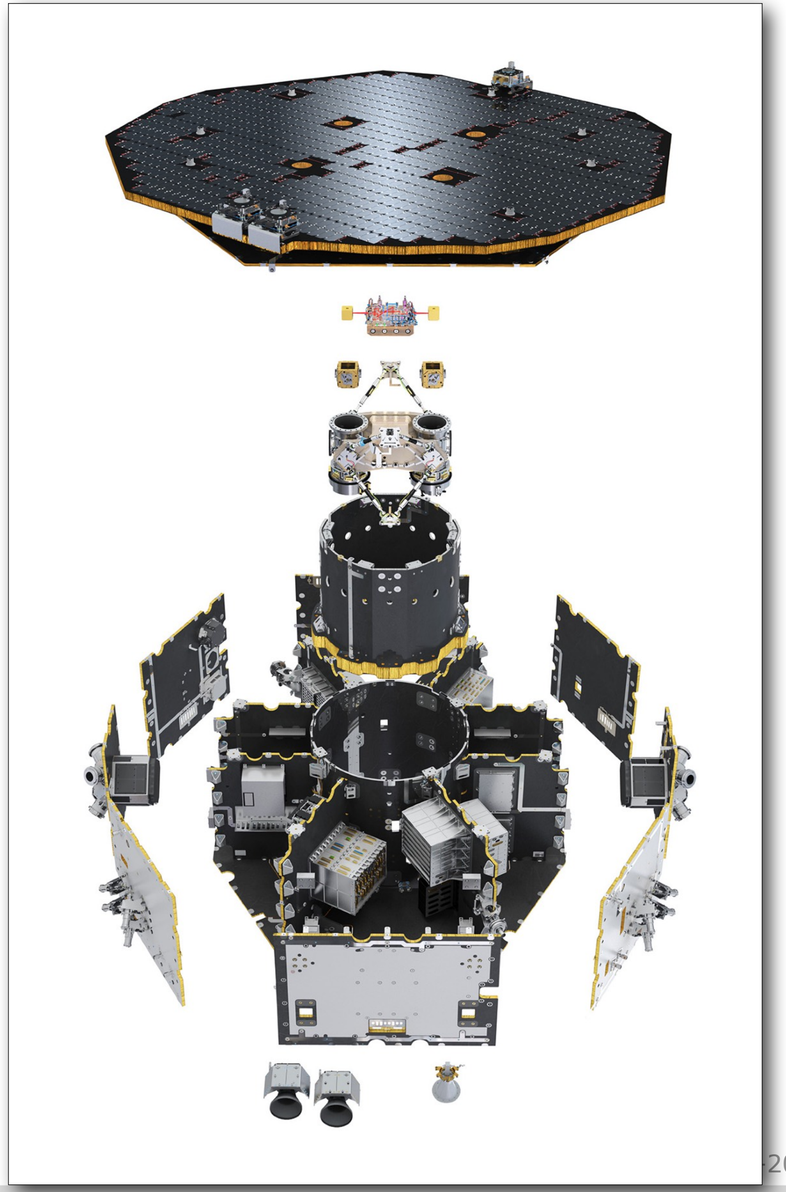
After 1 year on orbit…



Why so good?

Pre-launch requirement:1000pm/s²





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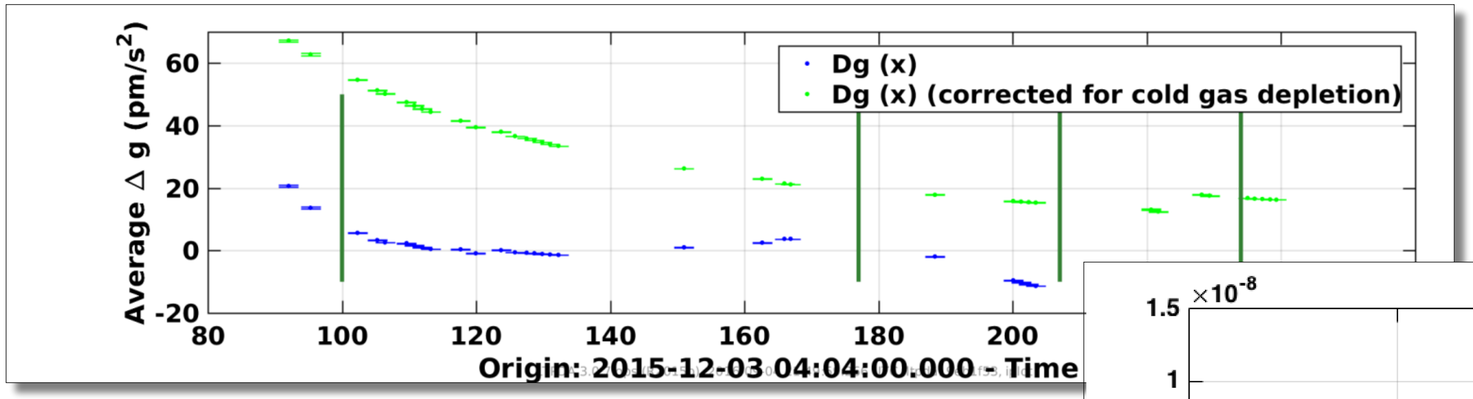
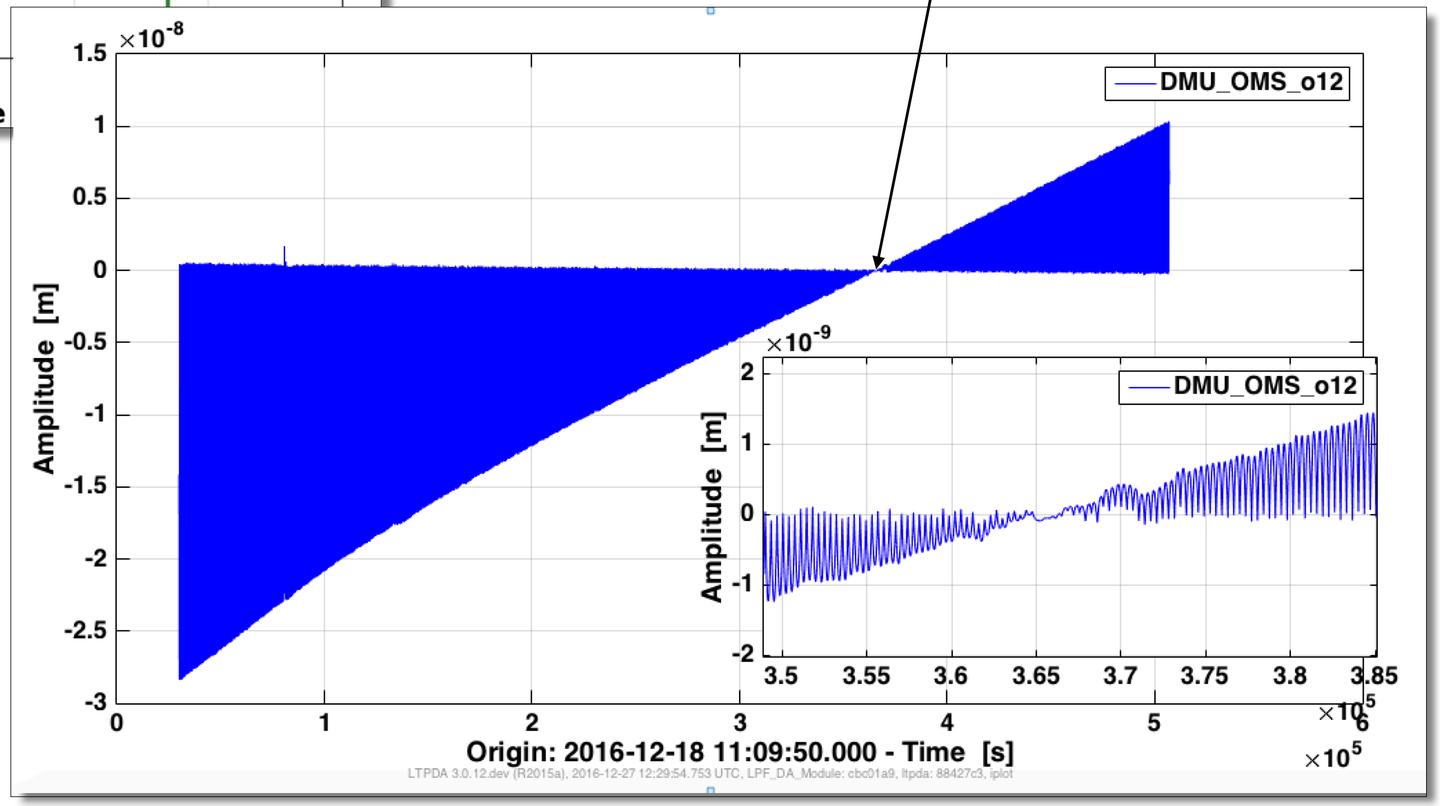
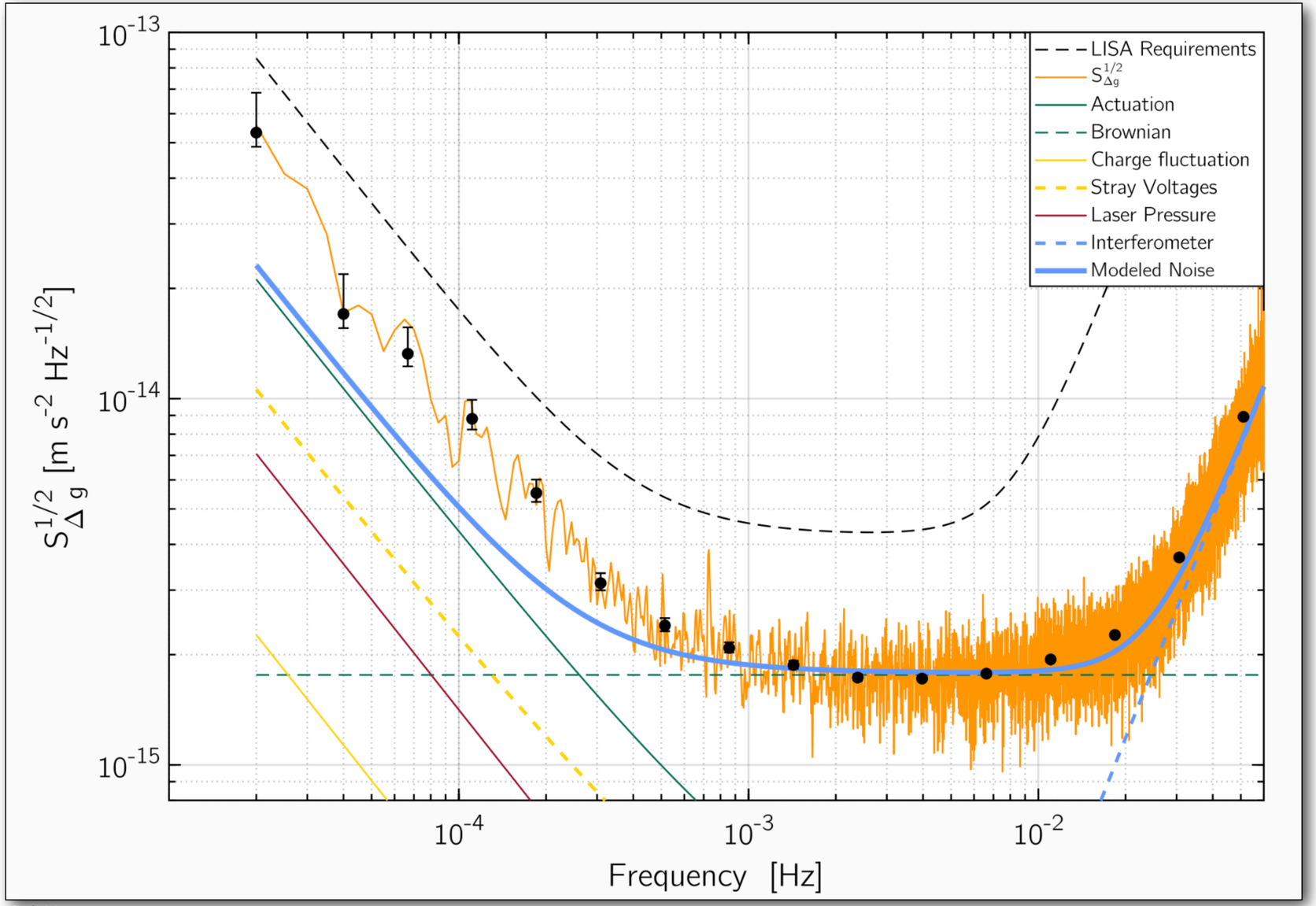


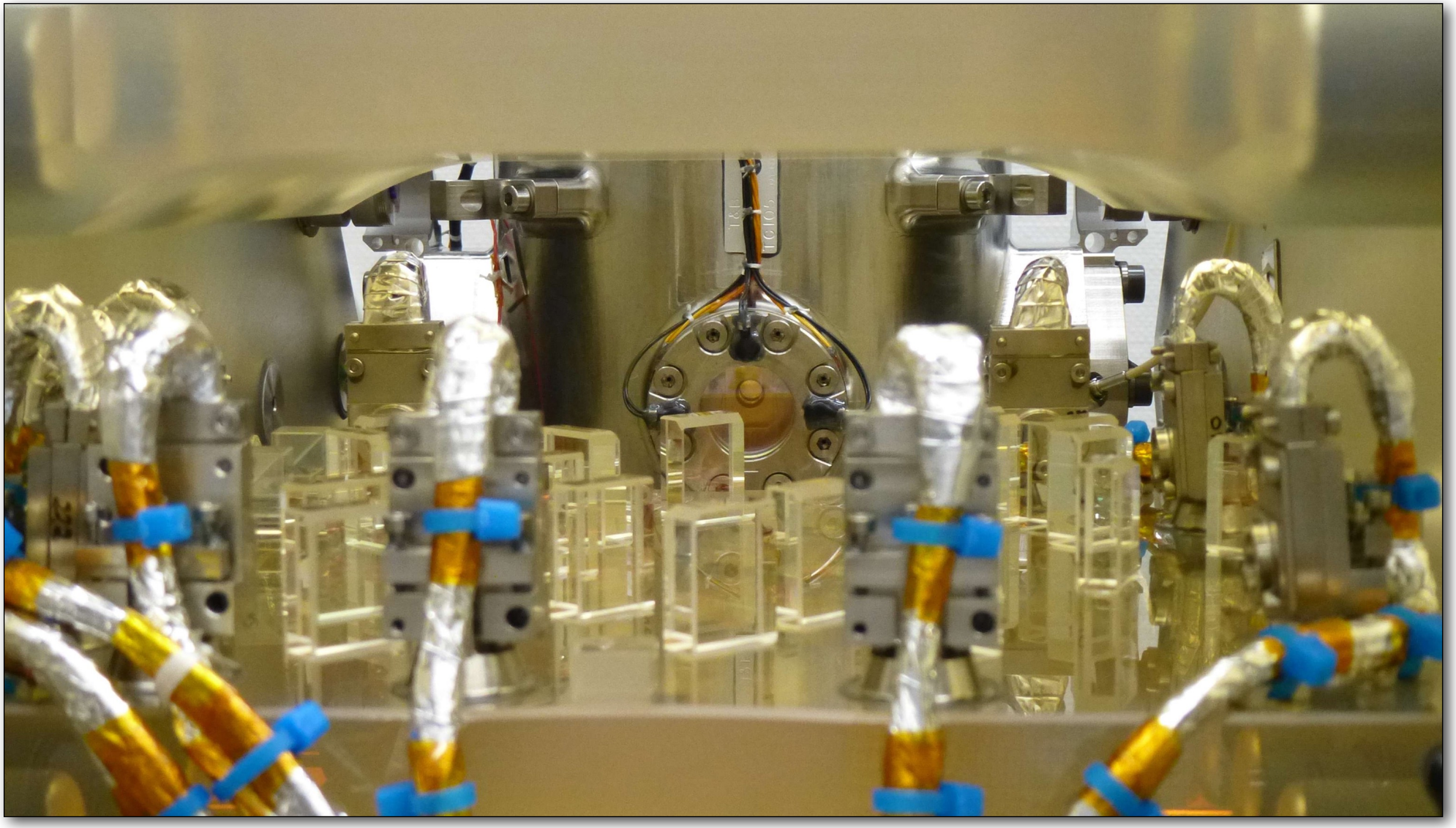
***Zero* differential field**



What we understand

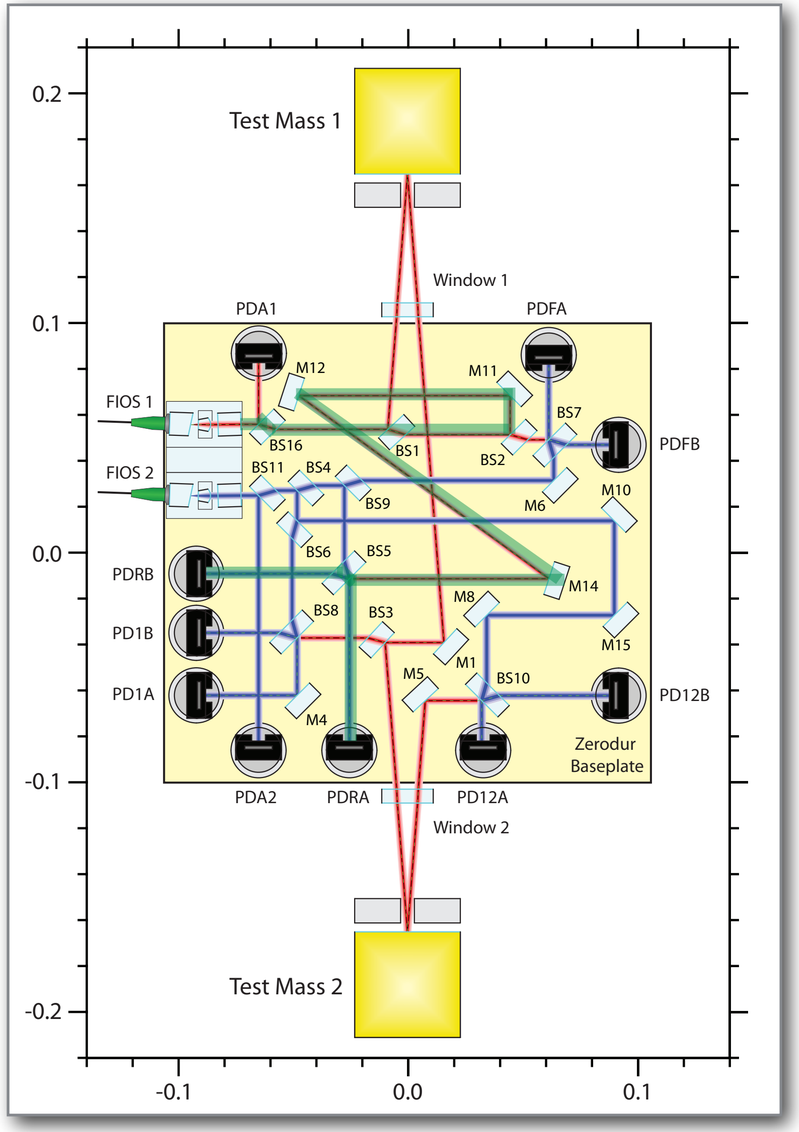


Optical Metrology System



Beam alignment (from ground to space)

- One major worry was OMS alignment change from ground to space
- Any distortion of the optical bench shows up as large misalignment due to lever arm of optical path on bench
- Optical bench alignment can be measured using the fixed interferometers
  - Reference ifo measurement beam is most sensitive to bench distortion



Alignment from ground to space

Measurement Beam

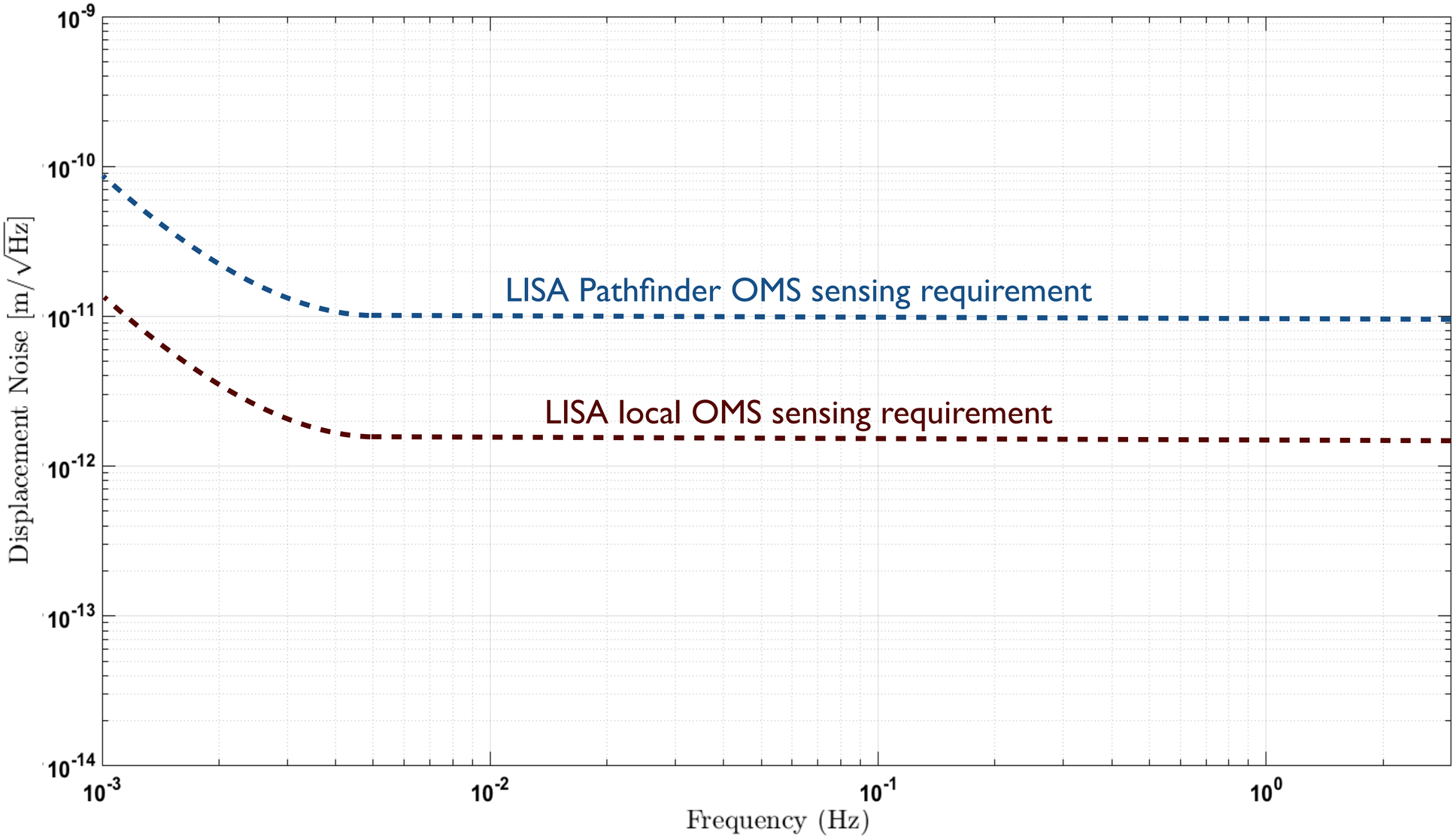
[um]			Flight	IABG	UGL	Flight - UGL	IABG - UGL	Flight - IABG
X1	A	x	34	35				-1
		y	-353	-343				-10
	B	x	13	13				0
		y	-350	-336				-14
X12	A	x	80	84				-4
		y	-389	-400				11
	B	x	-74	-76				2
		y	-390	-394				4
XF	A	x	21	21	21	0	0	0
		y	-40	-35	-32	-8	-3	-5
	B	x	13	9	6	7	3	4
		y	-25	-20	-15	-10	-5	-5
XR	A	x	7	9	6	1	3	-2
		y	-29	-15	-6	-23	-9	-14
	B	x	43	36	35	8	1	7
		y	70	79	83	-13	-4	-9

Reference Beam

[um]			Flight	IABG	UGL	Flight - UGL	IABG - UGL	Flight - IABG
X1	A	x	12	18				-6
		y	-3	-7				4
	B	x	-5	-4				-1
		y	-9	-16				7
X12	A	x	18	13				5
		y	-23	-23				0
	B	x	8	11				-3
		y	16	16				0
XF	A	x	26	19	21	5	-2	7
		y	-35	-35	-29	-6	-6	0
	B	x	7	11	8	-1	3	-4
		y	-19	-20	-13	-6	-7	1
XR	A	x	-8	-11	-13	5	2	3
		y	-10	-12	-6	-4	-6	2
	B	x	60	59	58	2	1	1
		y	89	83	89	0	-6	6

University of Glasgow

Performance: On-Orbit results



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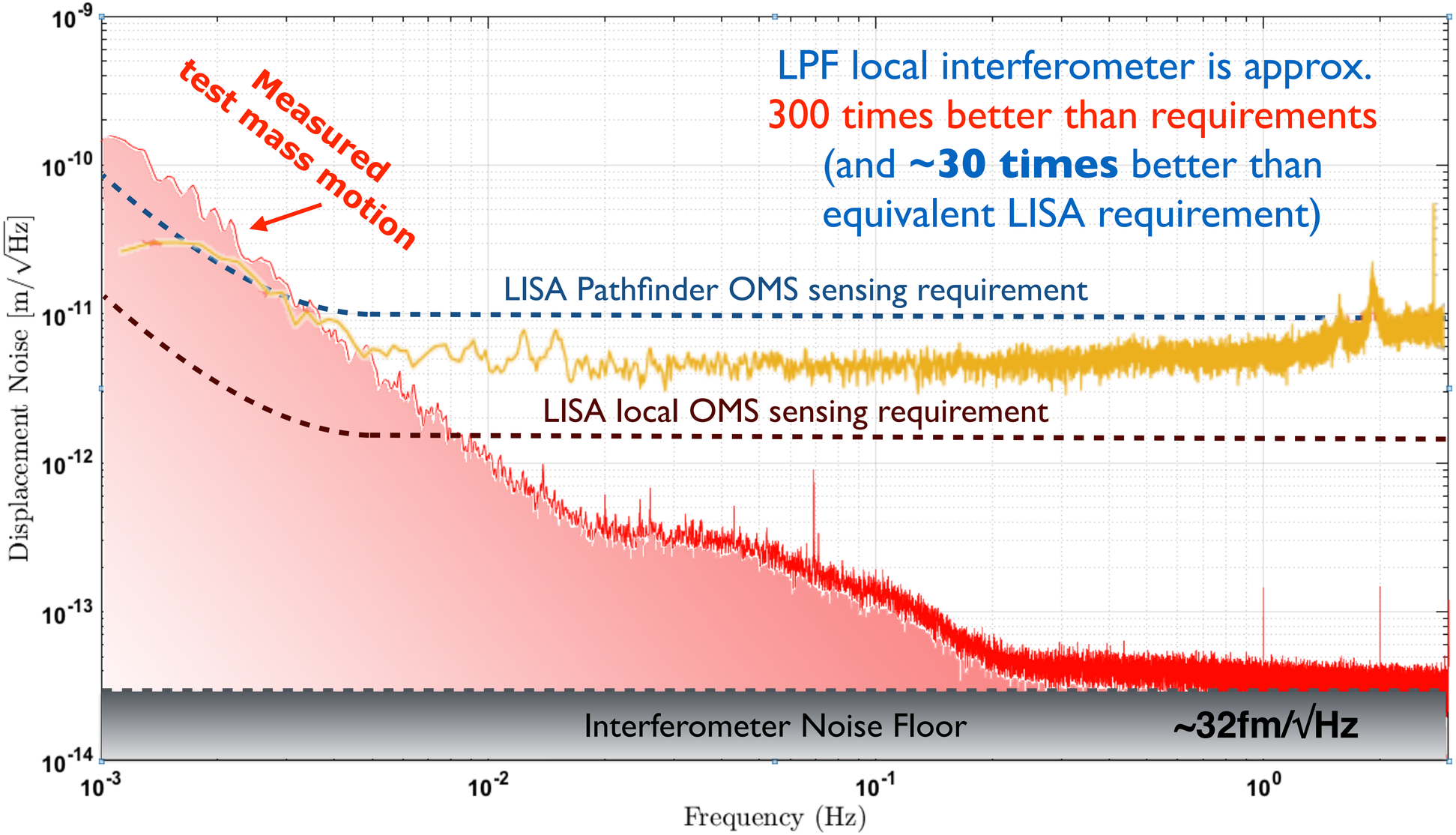
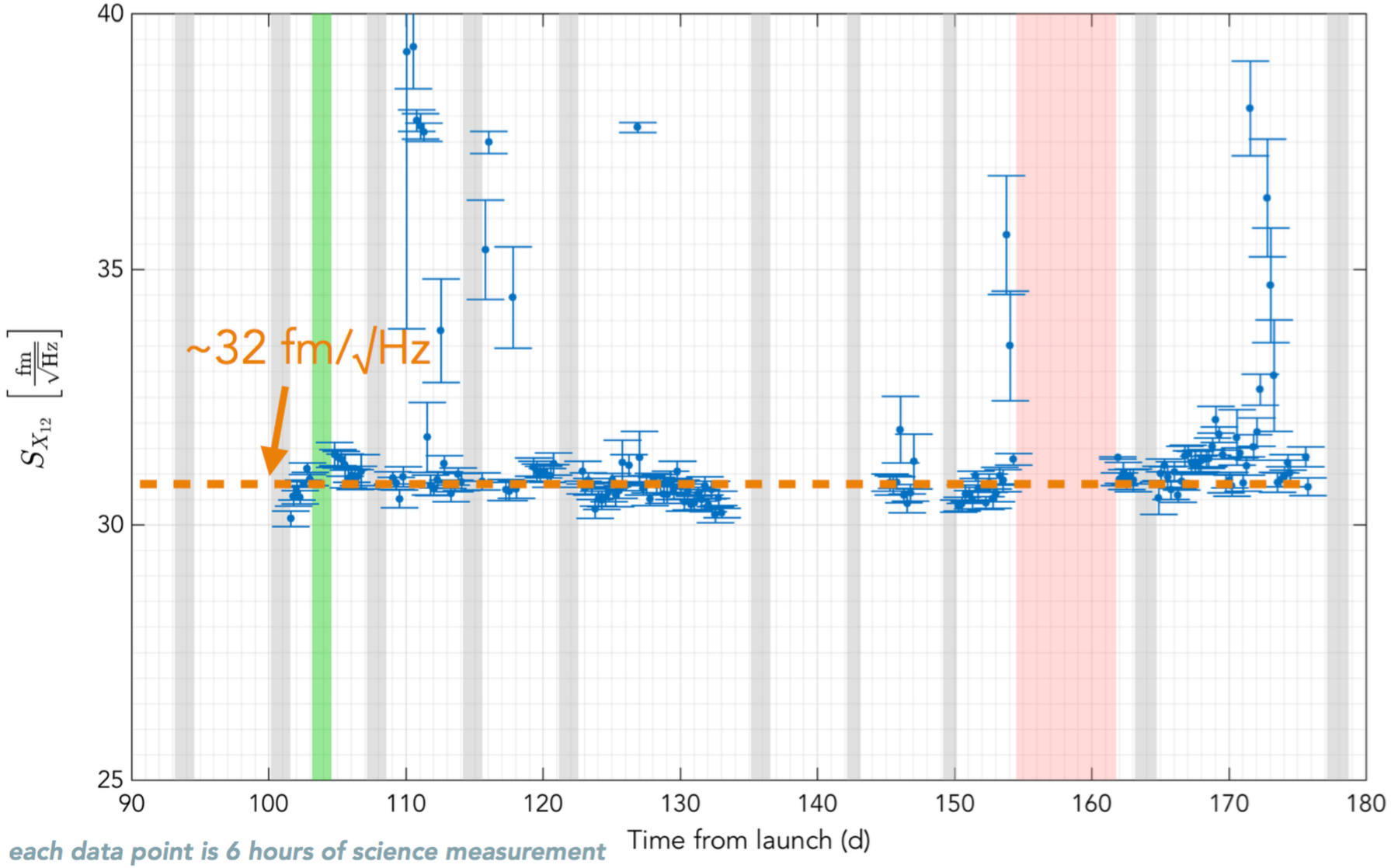
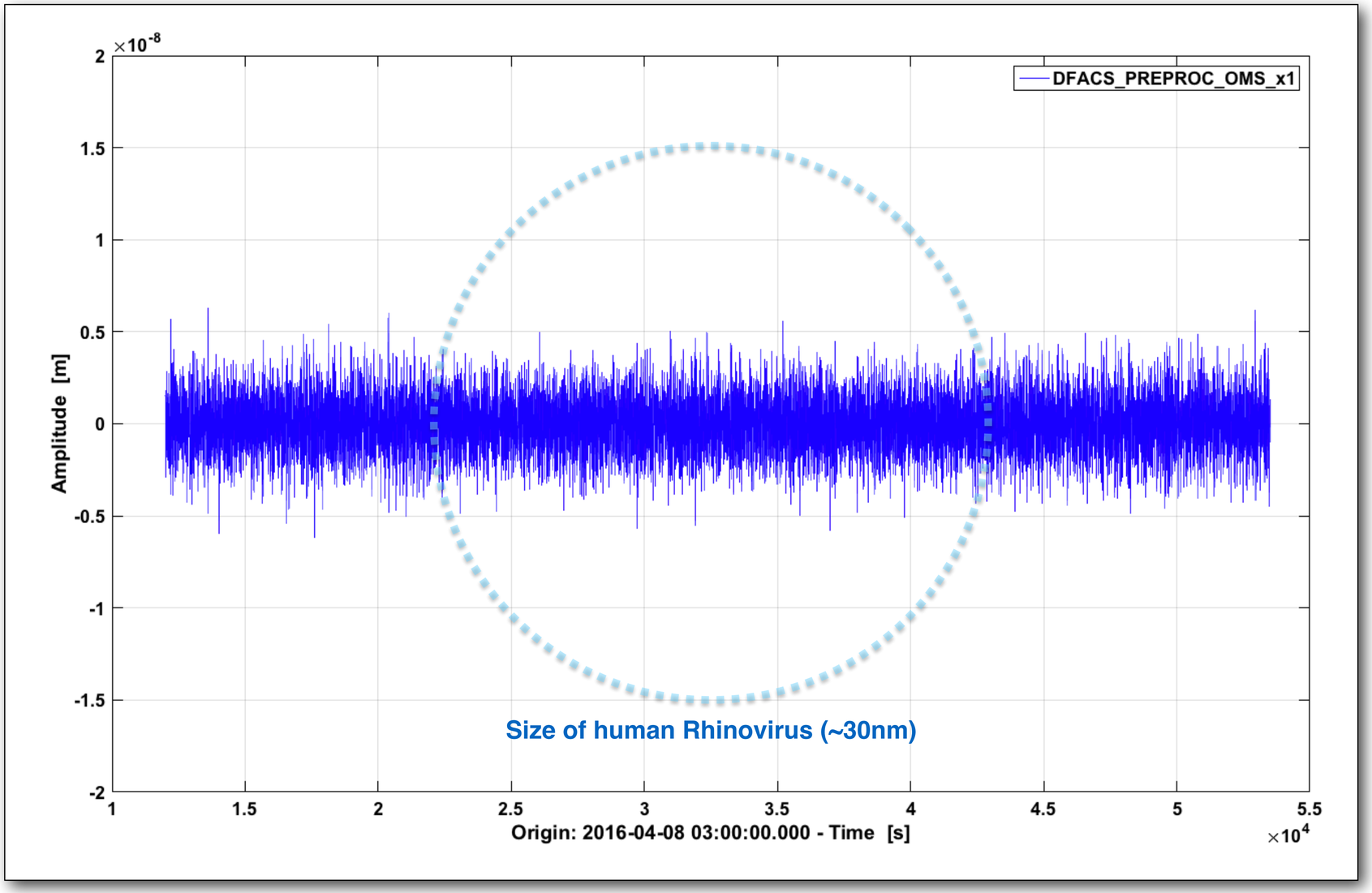


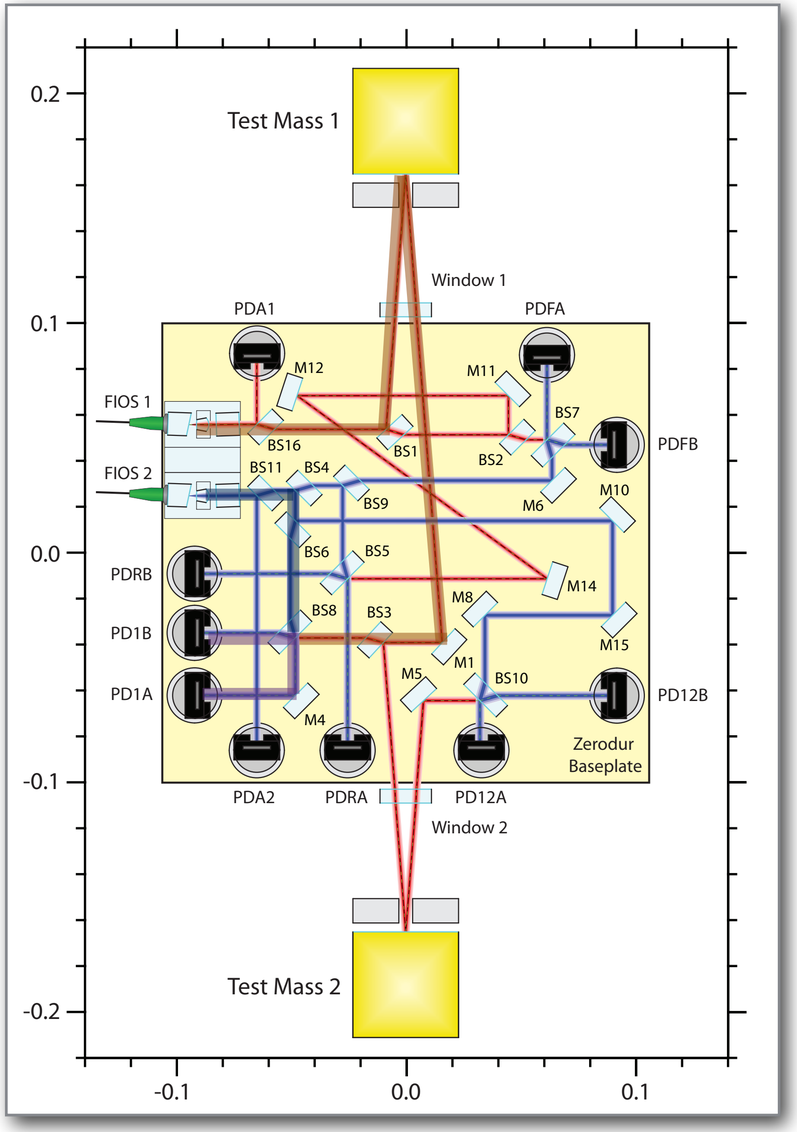
Stability of performance



each data point is 6 hours of science measurement

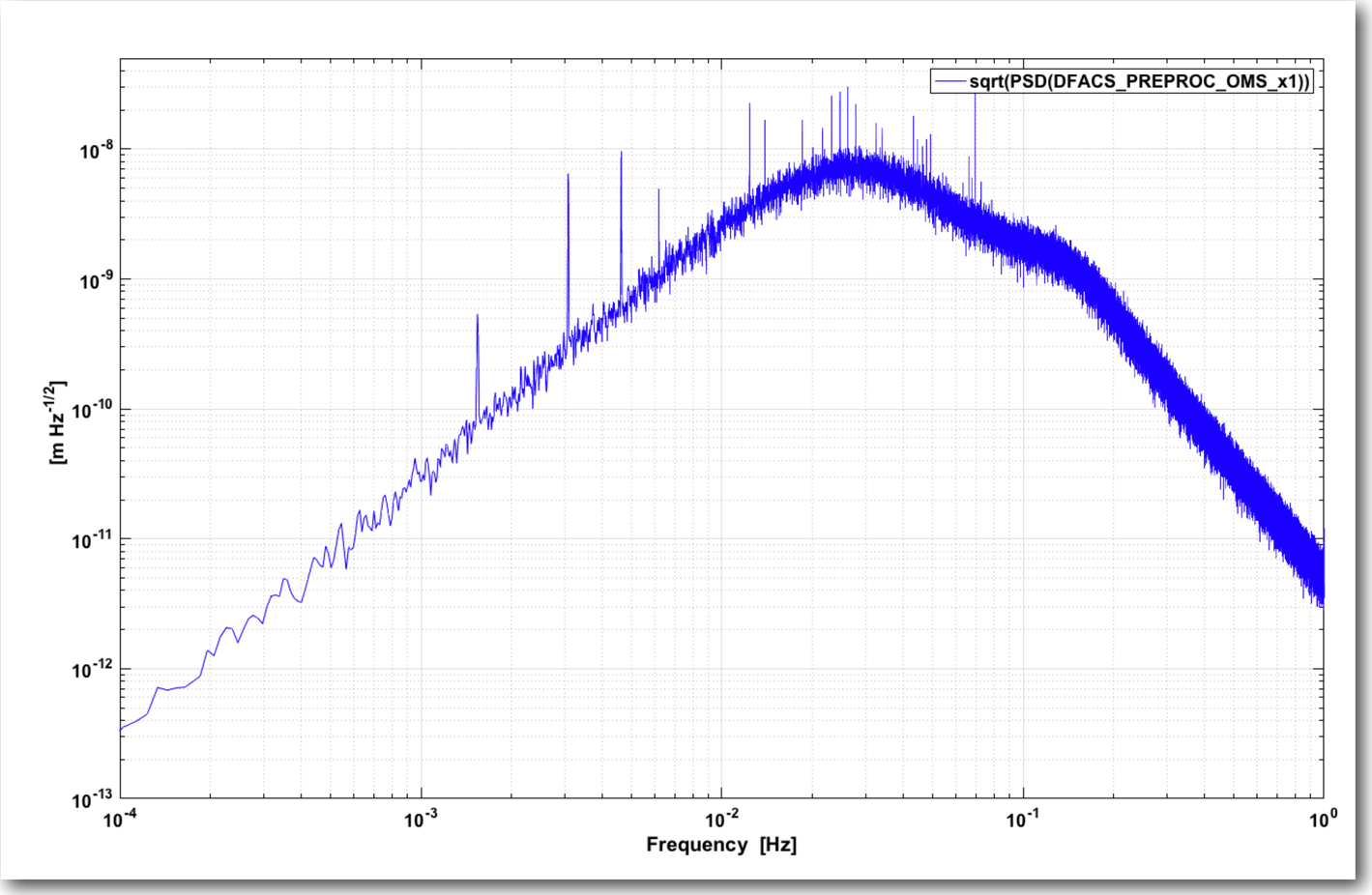
What about the satellite stability?





Platform Stability

- By looking at the position of one test mass with respect to the optical bench (spacecraft), the only thing we measure is thruster noise!



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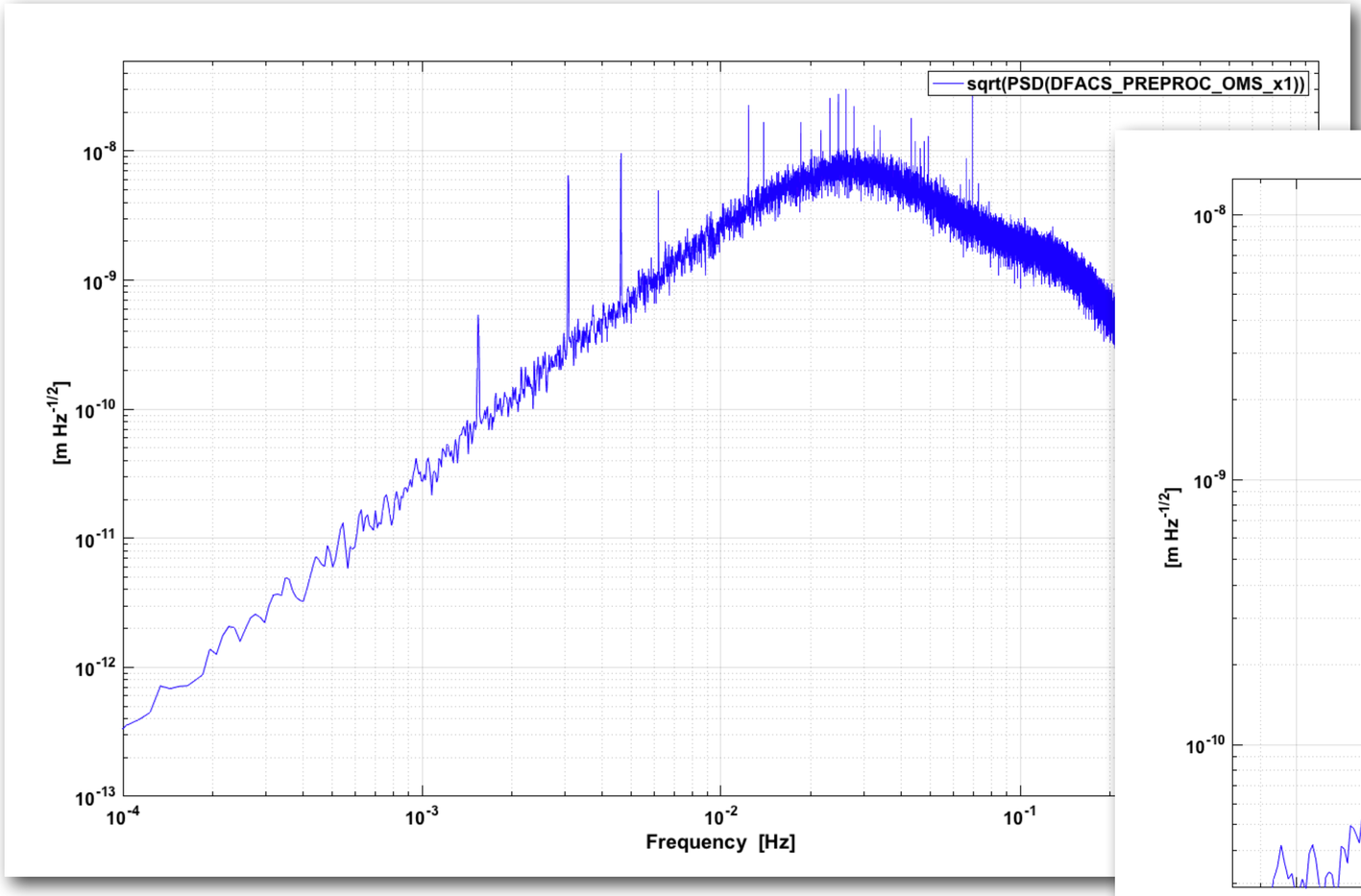
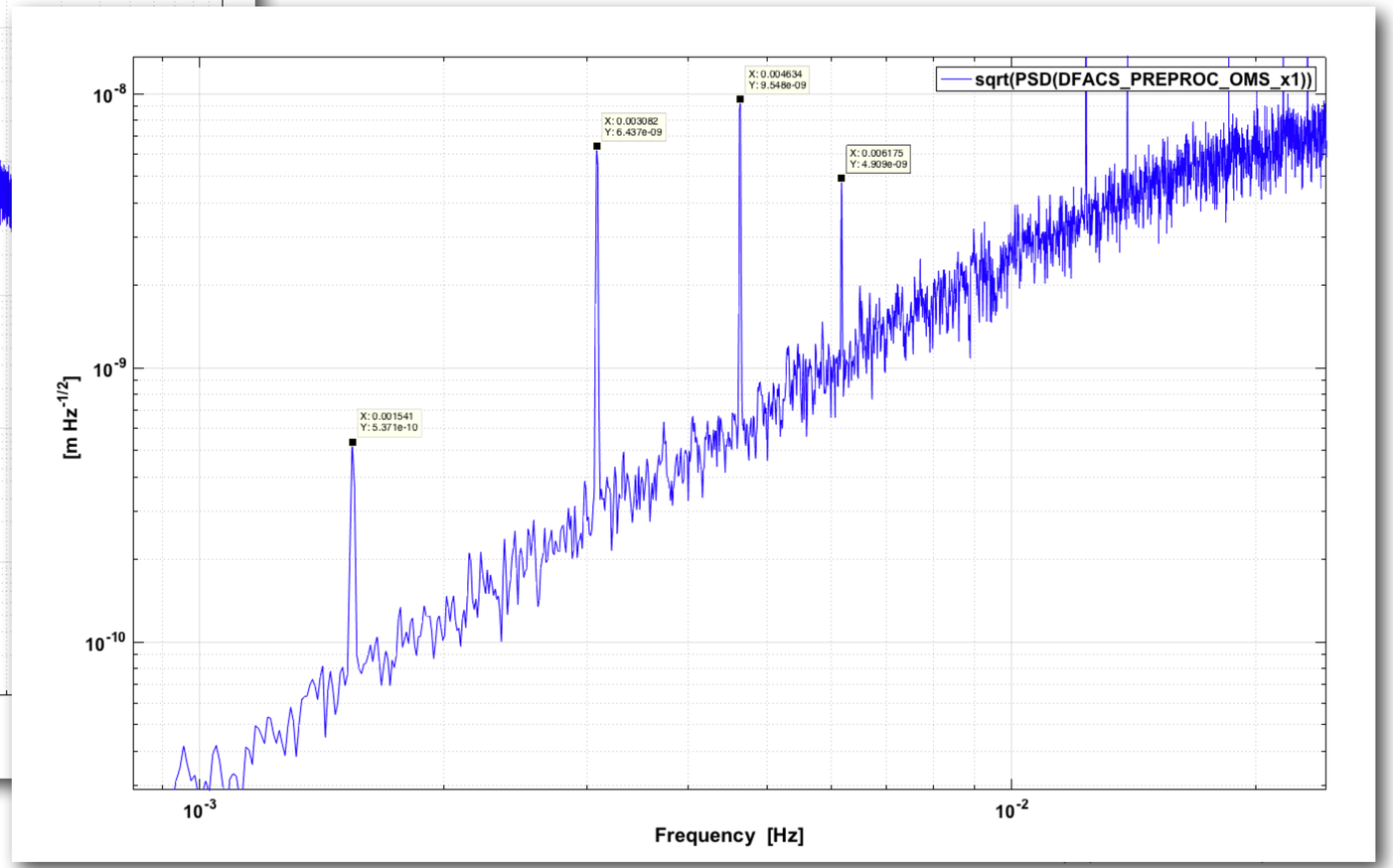
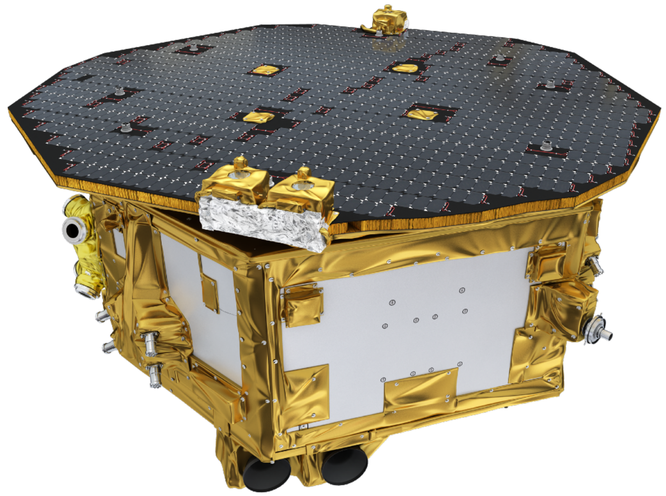




Conclusions

- LISA Pathfinder has been a great success
  - Performance of both OMS and GRS have vastly exceeded requirements
- Success of LPF led to the early selection of LISA as the 3rd L-class mission in the Cosmic Vision Programme
  - LISA Mission Consolidation Review (mid Phase A review) was closed last week
- In addition, we have proven that fundamental physics missions are possible
- Lessons learned from LPF are being directly transferred to the LISA development



Thank you

ESA ESTEC
ESA ESAC
ESA ESOC
Airbus Defence and Space UK
Airbus Defence and Space D
University of Trento
Albert Einstein Institute
University of Glasgow
University of Birmingham
Imperial College London
ETH Zurich
University of Zurich
Institut d-Estudis Espacials de Catalunya
Universidad Politecnica de Barcelona
APC Paris

IFR Stuttgart
Thales Alenia Italy
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