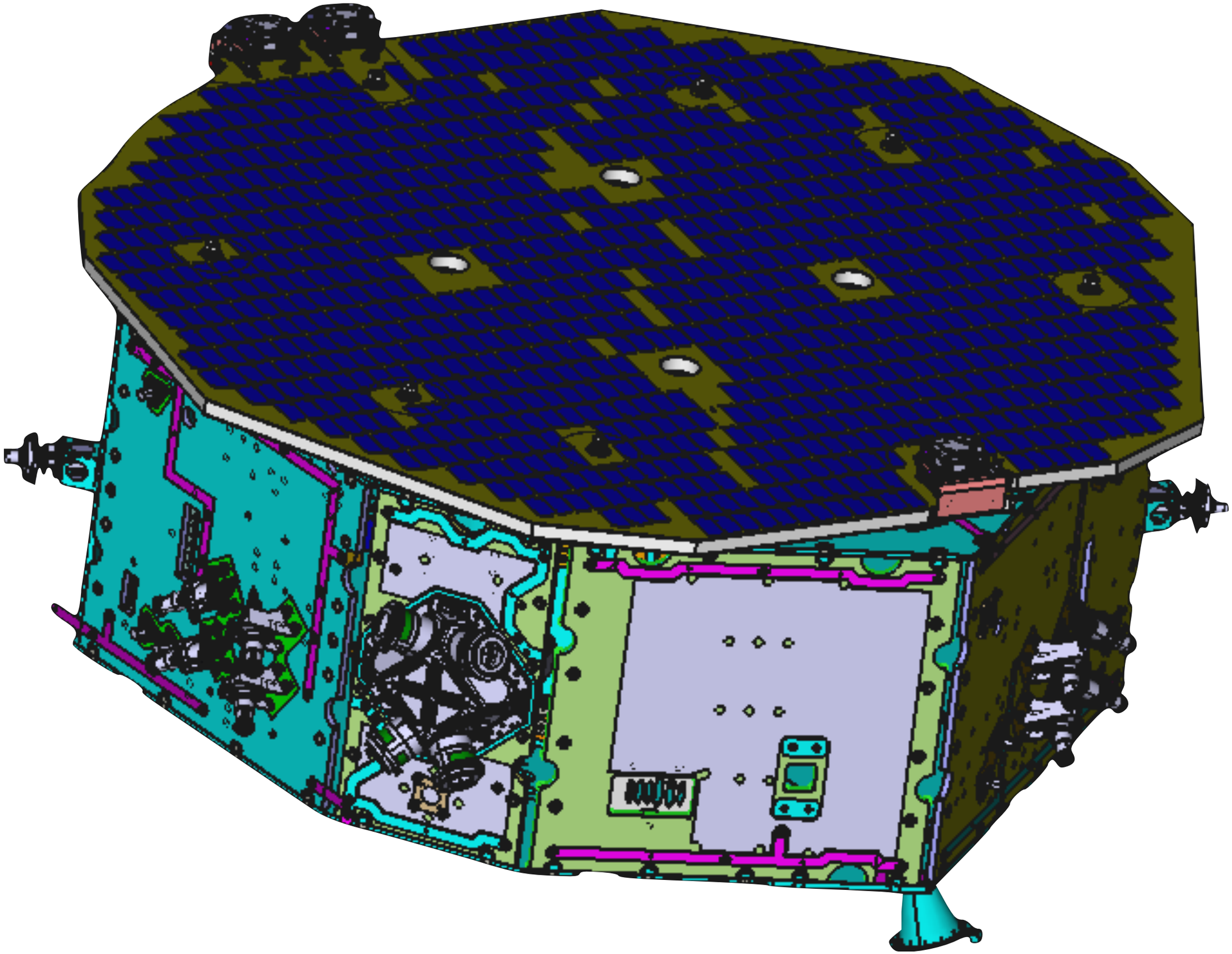
LisaPathfinder μ-Thruster Characterization

E.Plagnol(APC/Paris)

- The μ-thrusters are among the most important/critical components of LISAPathfinder/eLISA.
- They allow the S/C to follow the test masses in Drag -Free flight, correcting for external forces that apply to the S/C, e.g. solar winds. They also take care of the Attitude Control of the S/C.
- LPF has two kinds of μ-thrusters : cold gas (ESA) and colloidal (NASA).
- The purpose of this presentation is to expose a possible strategy to characterize the performances of the μ-thruster.
- The characteristics of the thrusters that we are interested in are:
    - The amplitude gain
    - The amplitude noise
    - The "average" direction
    - The "flutter" (directional) noise
- Most of the examples given will correspond to the FEEP system as data for the Cold Gas system are not yet available.
- *The general idea behind the strategy presented is due to Walter Fichter and coll. (IFR, Stuttgart)*

μ-Thruster Characterization



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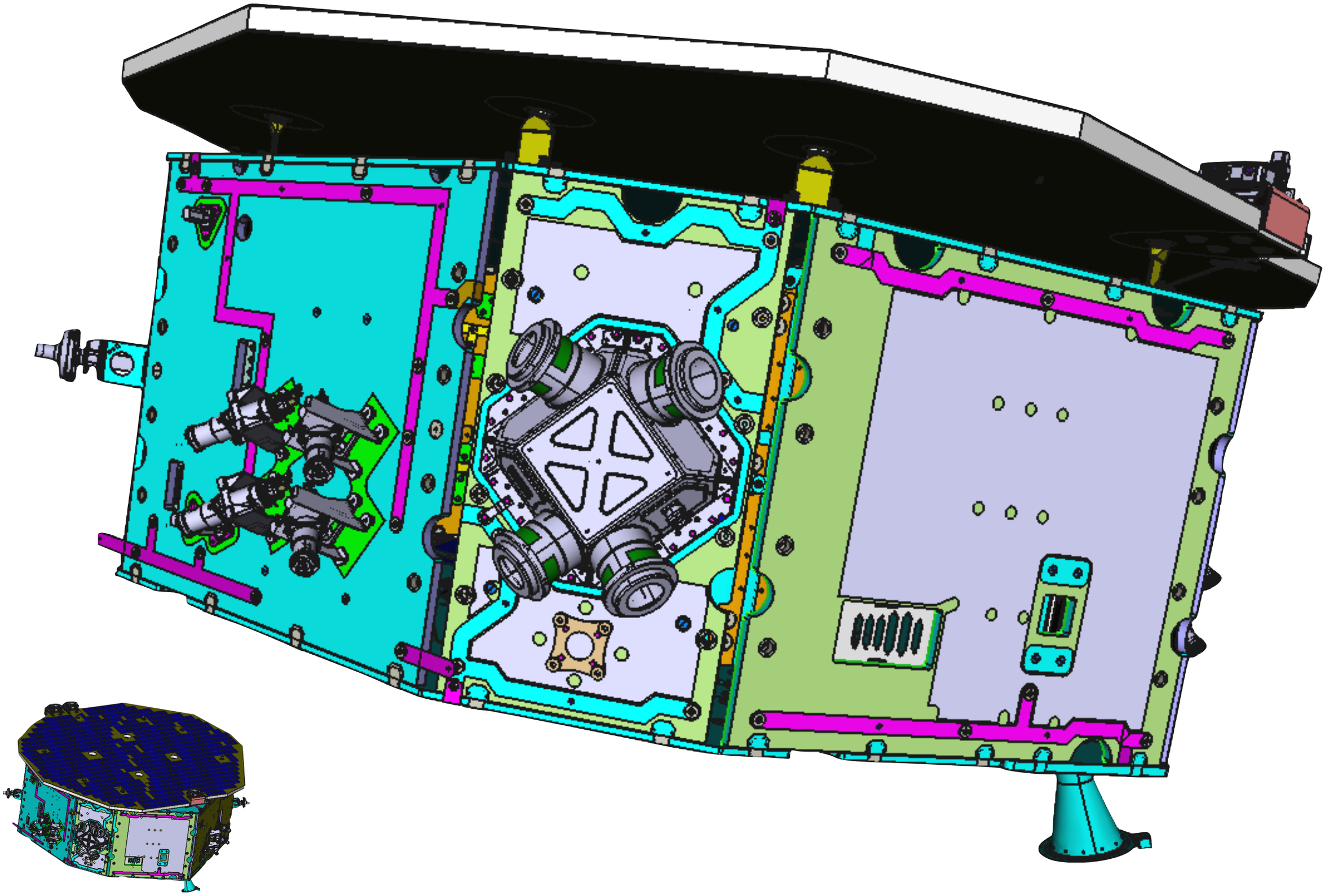

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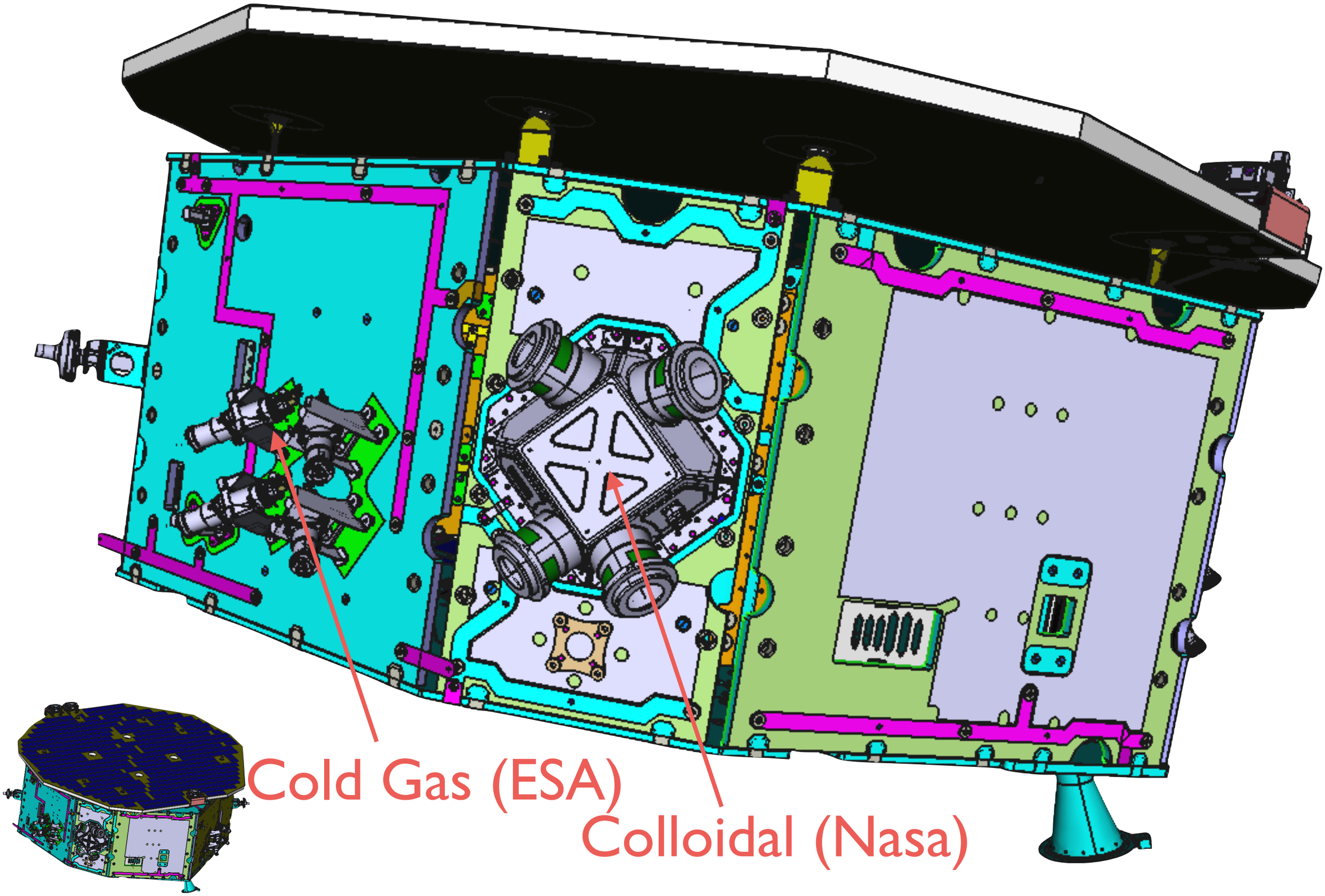
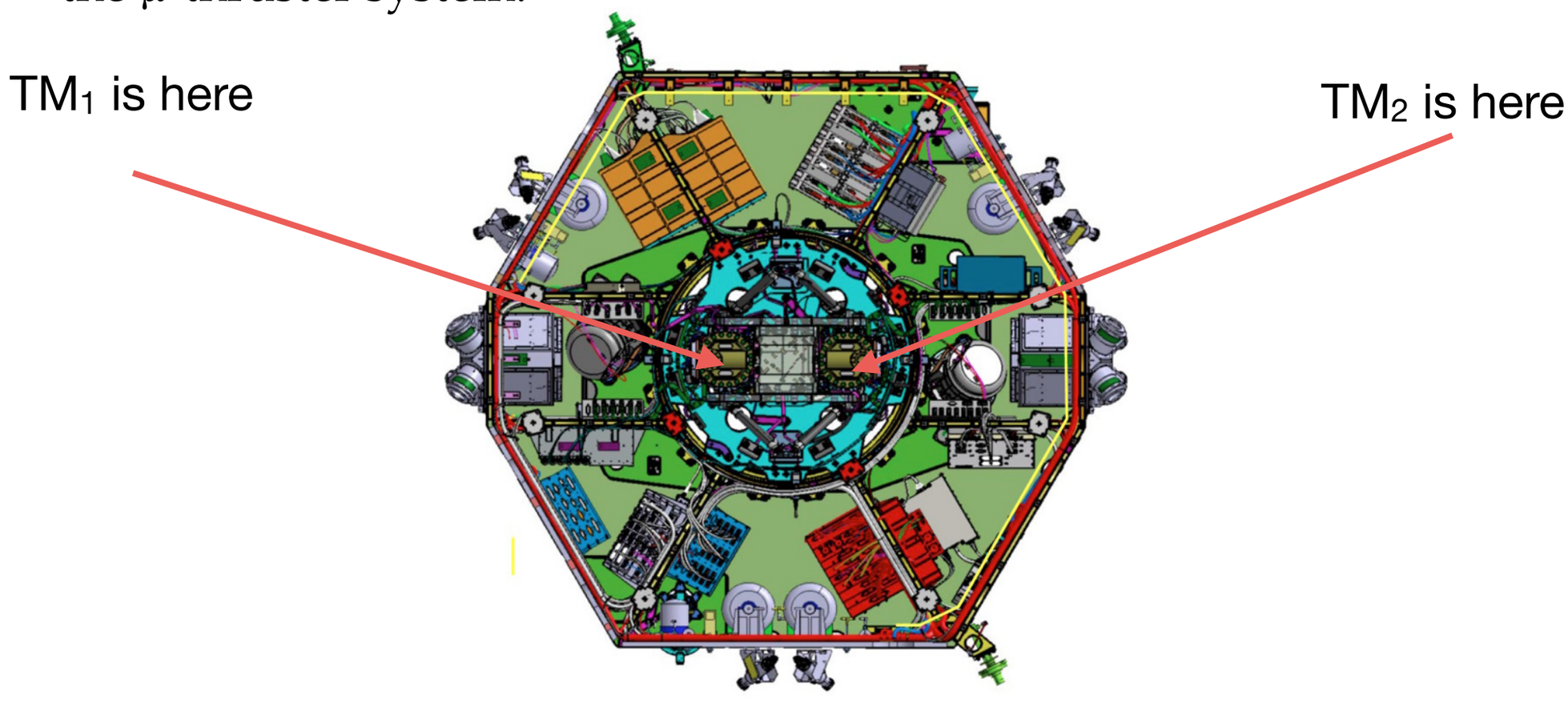


μ-Thruster Characterization : FEEPS and Cold gas

- LISAPathfinder was originally set up with 12 FEEP thrusters
  - Their "orientation" allowed to move the S/C in 6 degrees of freedom:
    - translation along ±X, ±Y and ±Z and rotation around X,Y and Z
- Because of development issues, they are now replaced by 6 cold-gas thruster whose geometry allow to apply translation along ±X, ±Y but only +Z and rotation around X, Y and Z
  - This set-up uses the solar pressure (~ -20 μN) on the -Z direction to allow for forces along the 6 degrees of freedom.
- Note that as the thruster may only apply a "positive force", they are permanently activated with a DC level (a few μ Newtons) yielding a total zero force/torque so that all possible movement of the S/C are allowed.

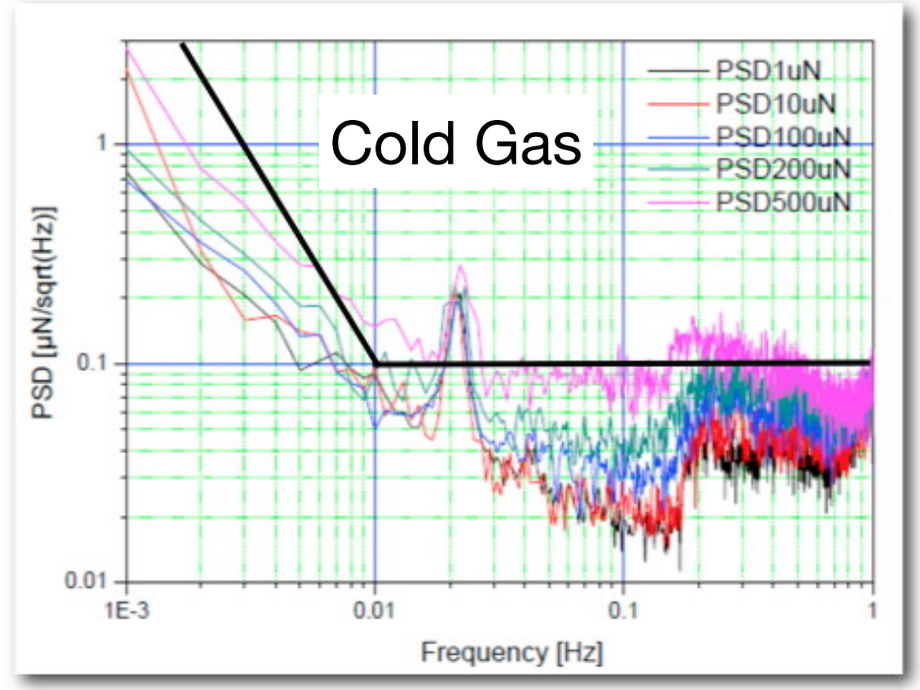
The Characterization Strategy

- In LPF, the measurement of the position of TM1 is measured (optically or by capacitive sensors) with respect to the S/C.
- The movement of TM1 therefore reflects the movement of the S/C (to within the small stiffness effects),.
- Observing the "acceleration" of TM1, taking into account the commanded forces, is therefore equivalent to measuring the acceleration/force applied to the S/C.
- The measurement of the acceleration of TM1 will therefore be used to characterize the μ-thruster system.



The Thruster parameters and Geometry

	FEEPs	Cold Gas
Thrust Range	1 - 150 μN	2 - 100 μN
Thrust Resolution	< 0.1 μN	0.3 μN
Thrust Noise	0.1 μN/Hz	0.2 μN/Hz
Flutter Noise	< degree ?	< degree ?
Thruster command Frequency	10 Hz	10 Hz



The geometry of the thruster system is such that:

FEEPS (12 thrusters) :

For 1 µ N on each thruster, i.e. 12 µN total:

- 3.75 µN is project on X
- 3.75 µN is project on Y
- 4.5 µN is project on Z

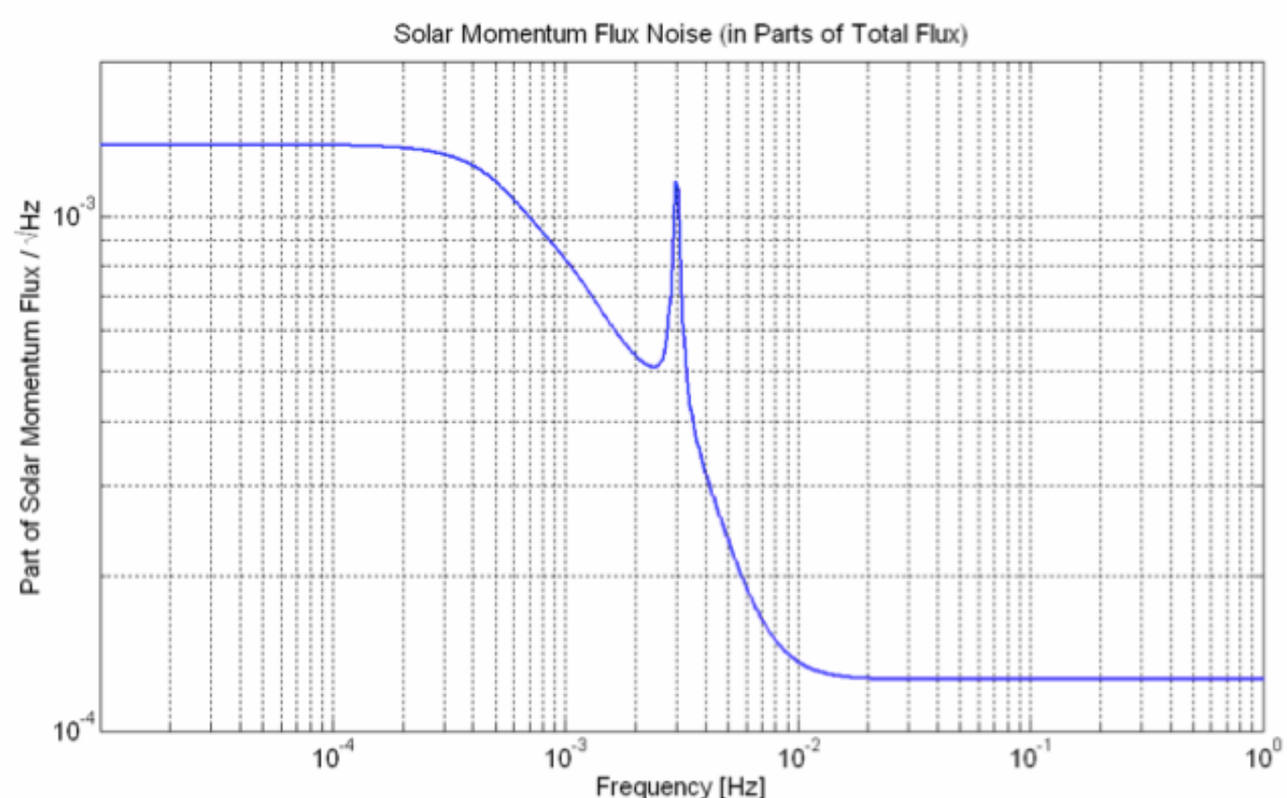
ColdGas (6 thrusters), i.e. 6 µN total :

For 1 µ N on each thruster :

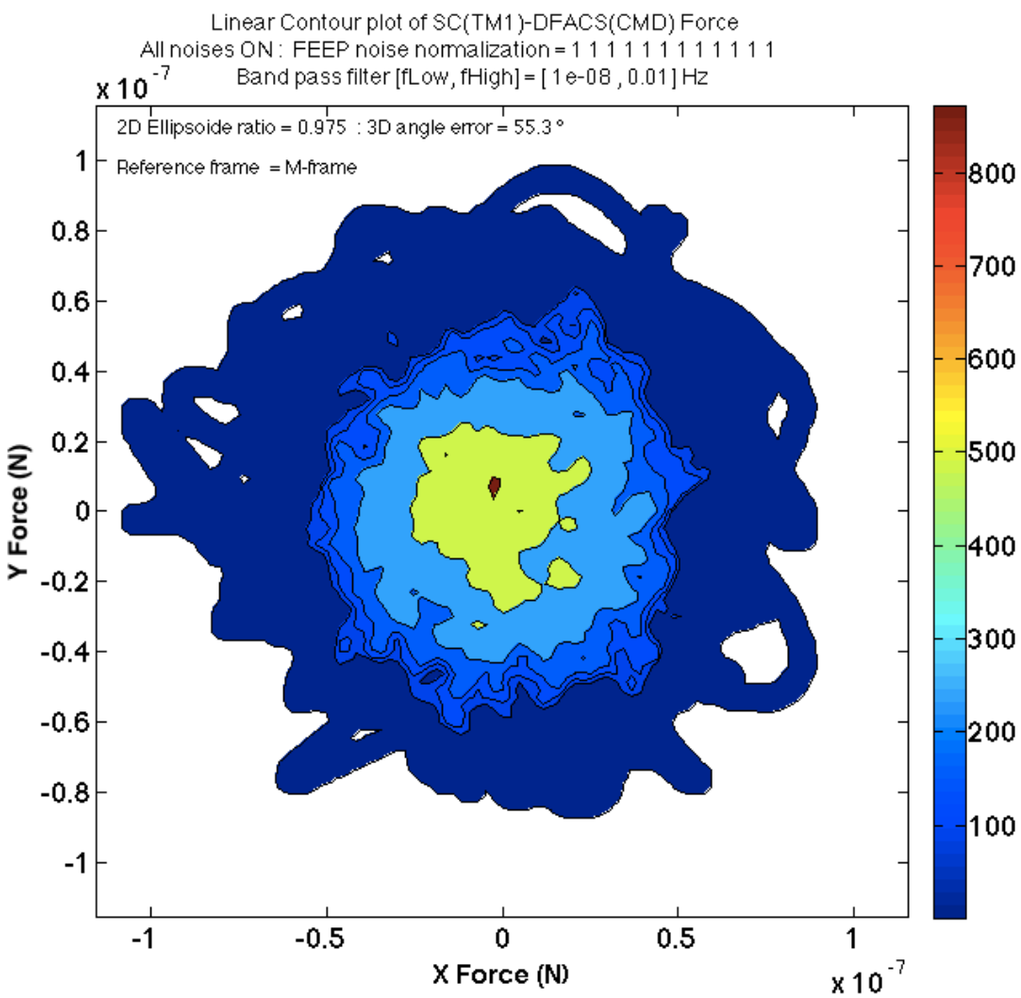
- 2.26 µN is project on X
- 2.26 µN is project on Y
- 1.48 µN is project on Z

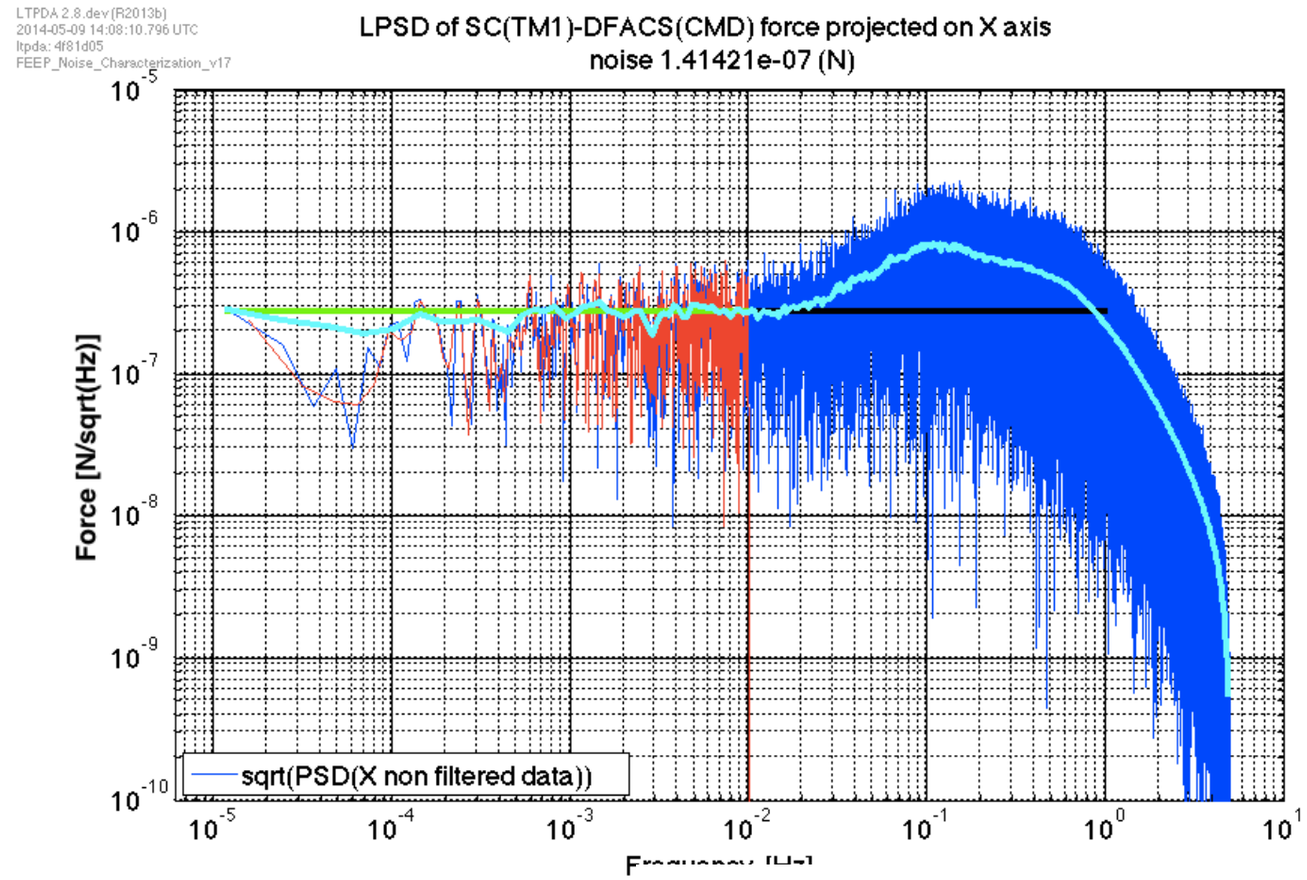
Solar Pressure

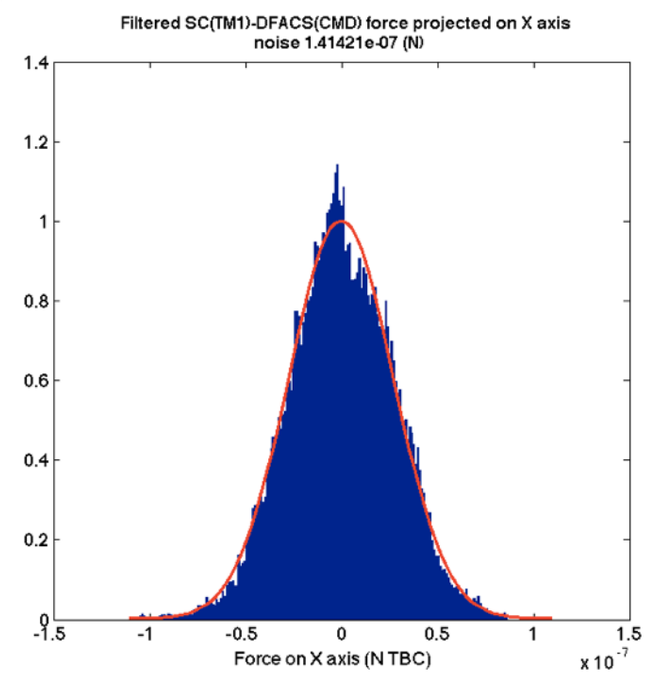
Fx, Fy, Fz = $5.84 \cdot 10^{-7}$ N, $5.84 \cdot 10^{-7}$ N, **$-1.98 \cdot 10^{-5}$ N**



µ-Thruster Characterization : White Noise study

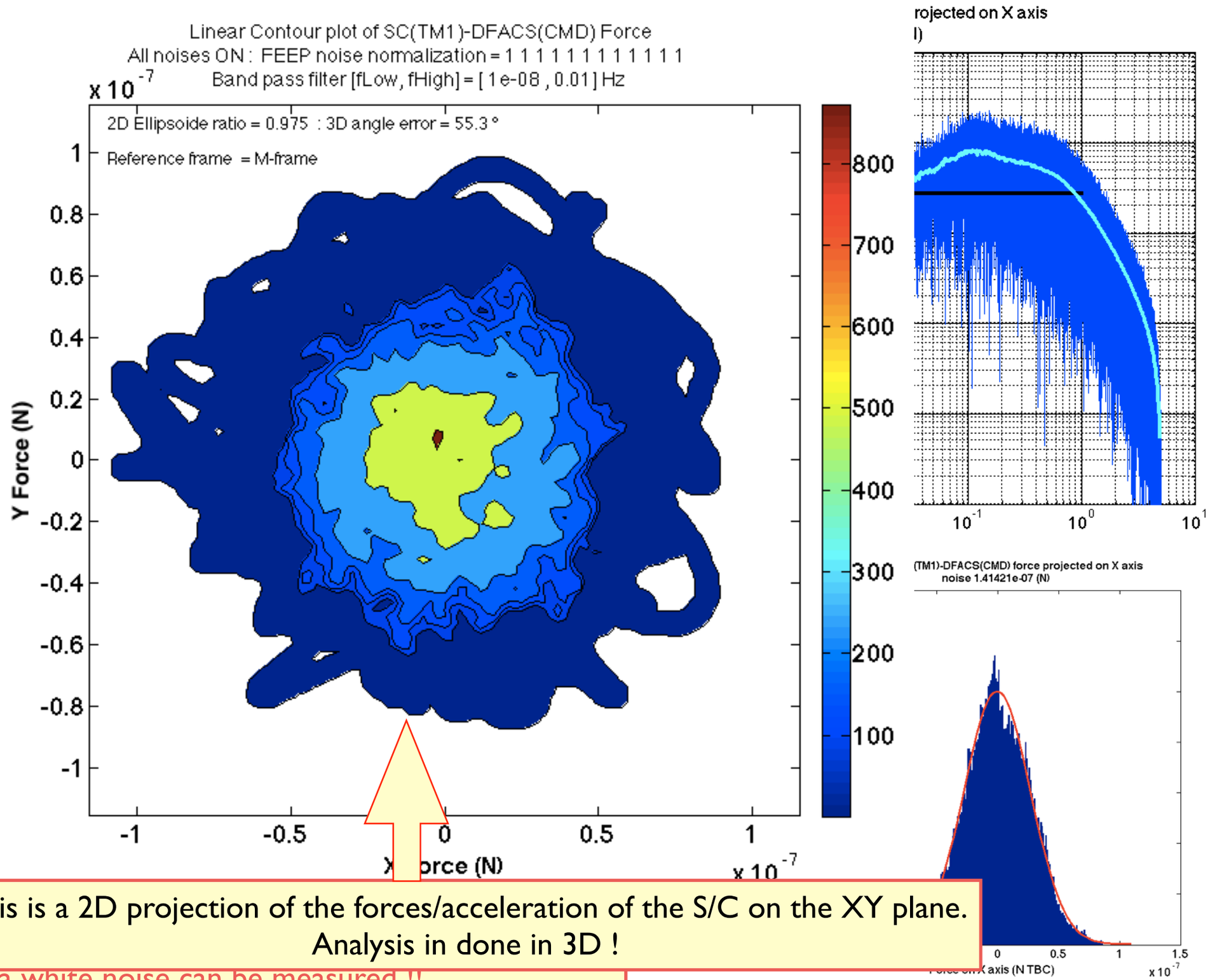






X : Power measured/Power expected = 0.92
Y : Power measured/Power expected = 1.02
Z : Power measured/Power expected = 1.04
Total power filtered in band = 2.395e-15 : Expected = 2.39e-15 :
Ratio = 0.999
So a white noise can be measured !!

µ-Thruster Characterization : White Noise study

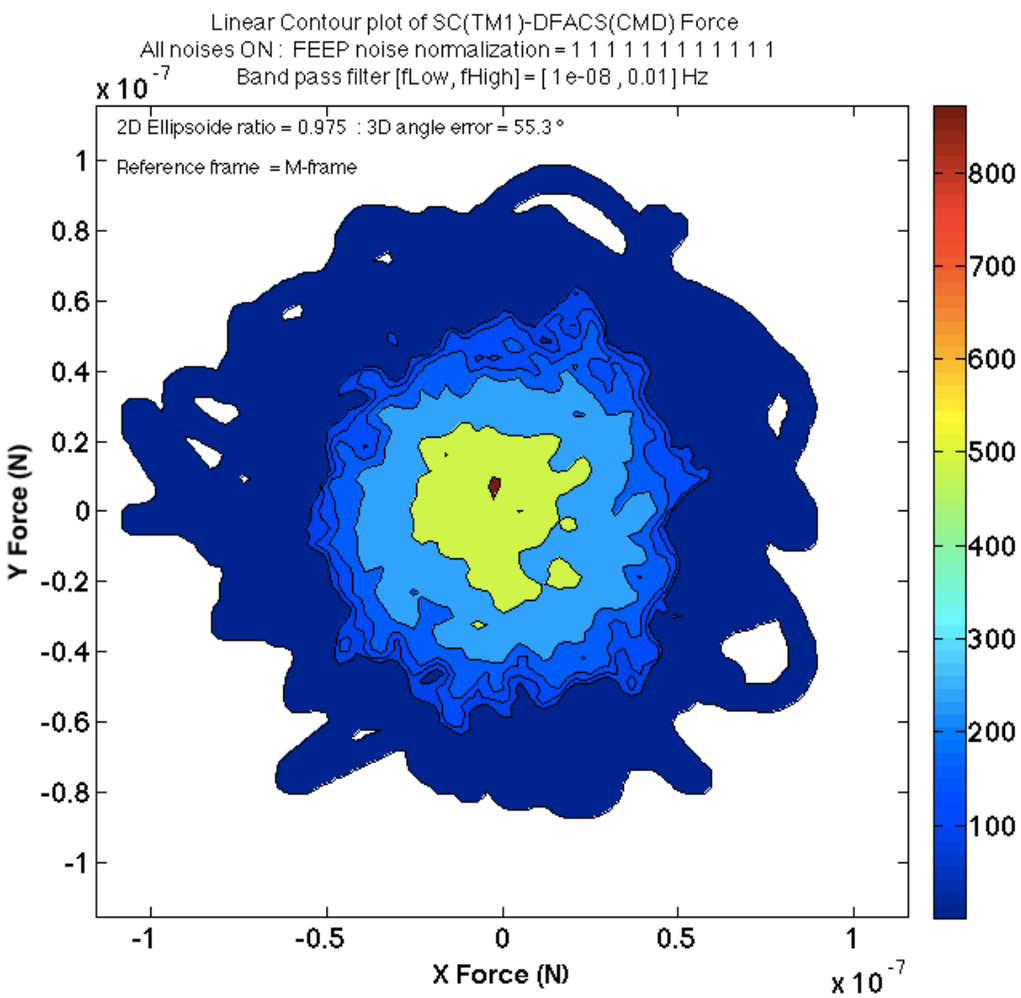


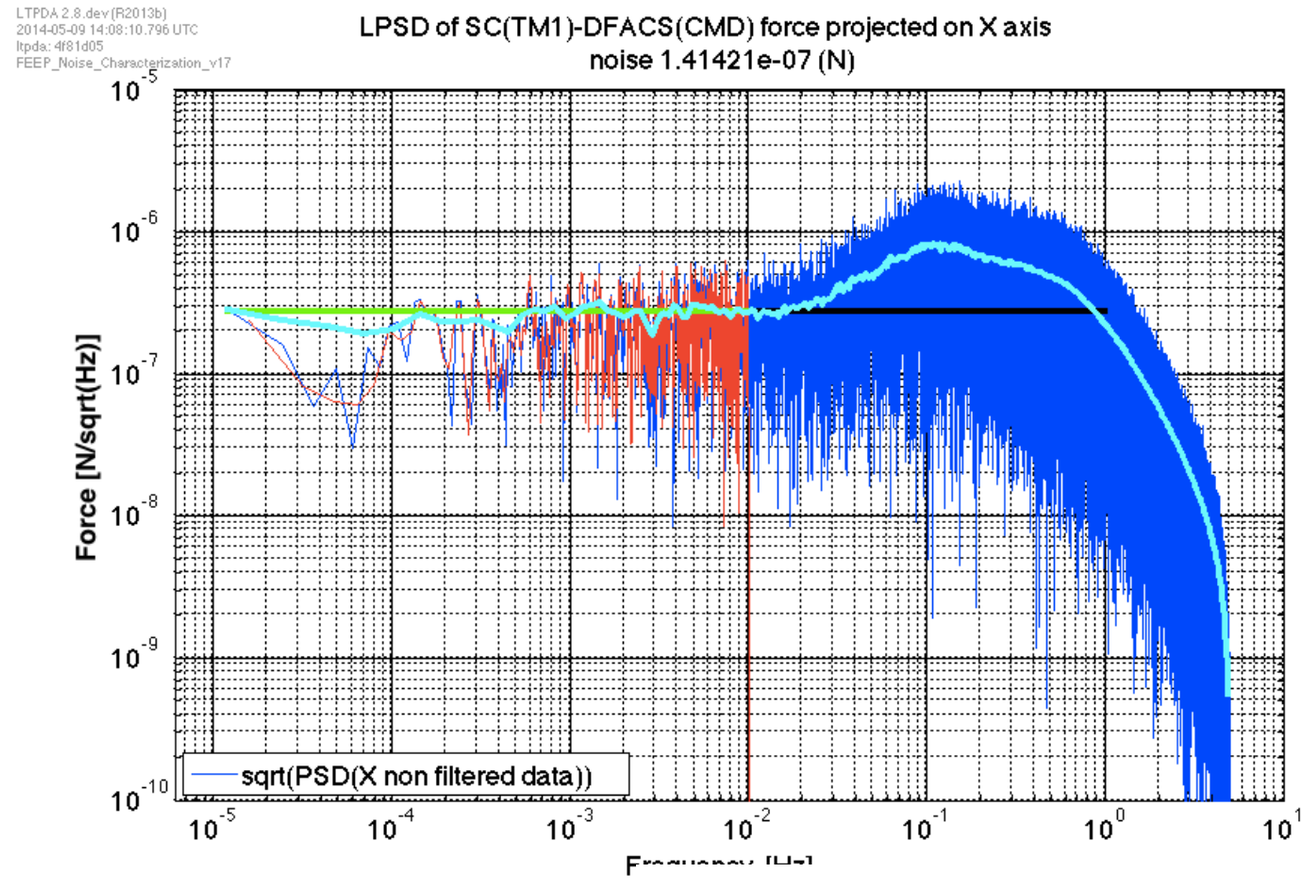
X : Power measu
Y : Power measu
Z : Power measu
Total power fil

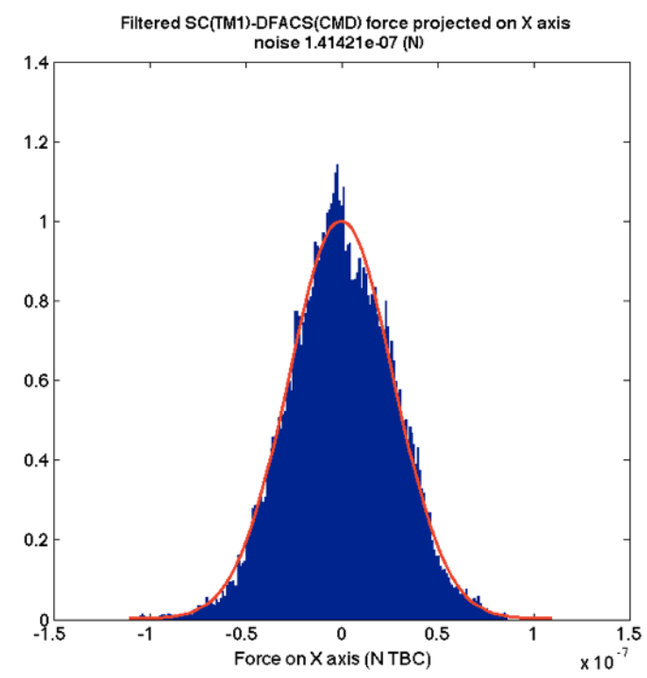
This is a 2D projection of the forces/acceleration of the S/C on the XY plane.
Analysis in done in 3D !

So a white noise can be measured !!

µ-Thruster Characterization : White Noise study







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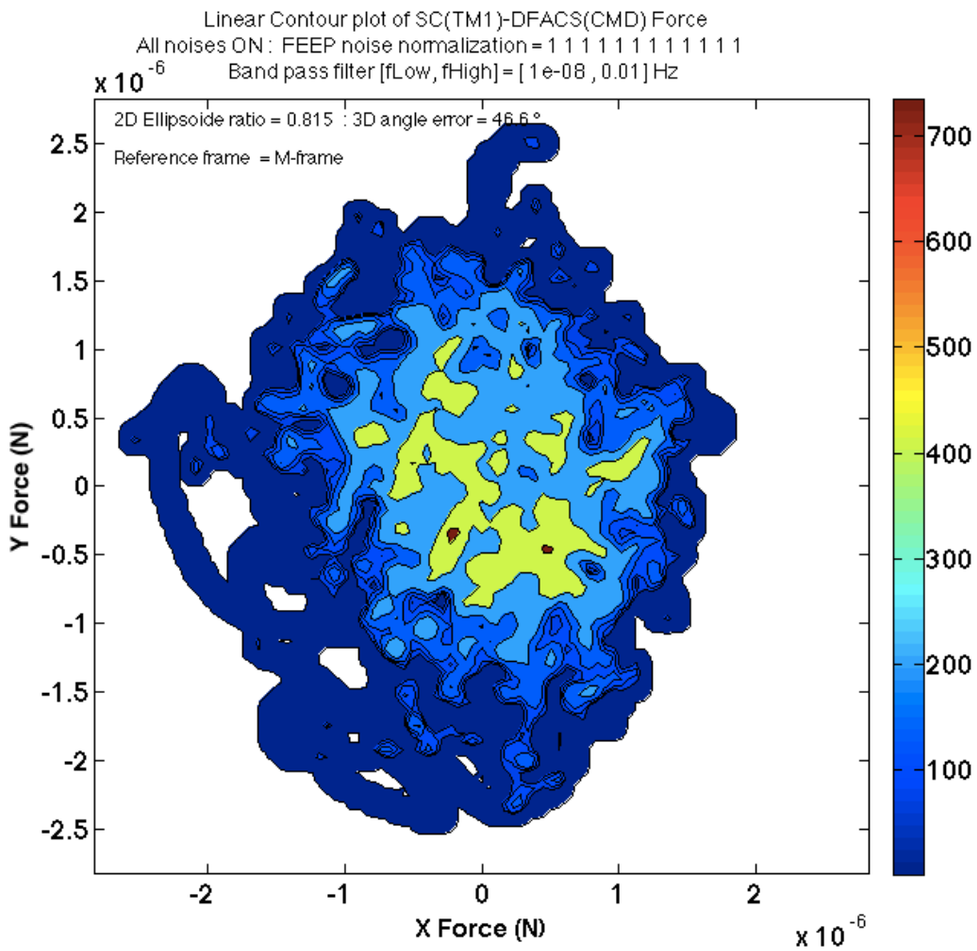
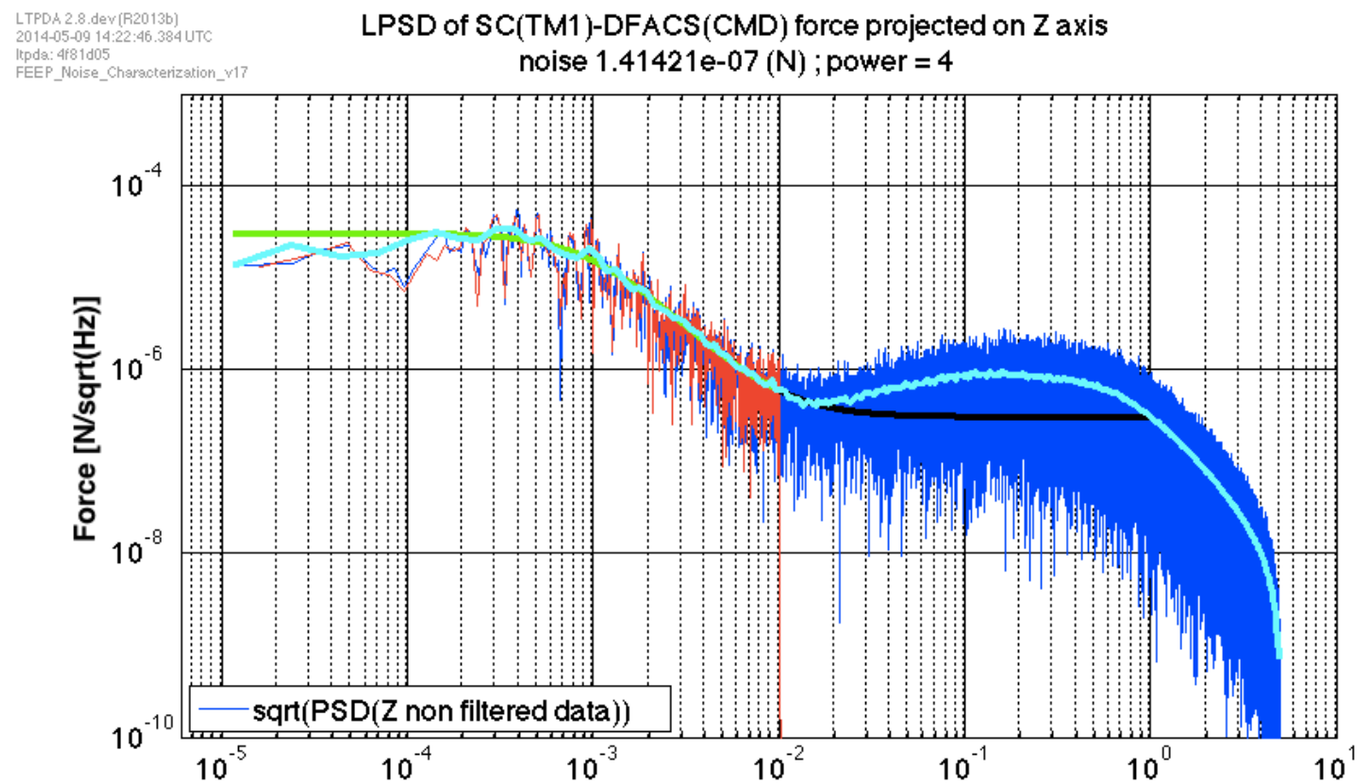
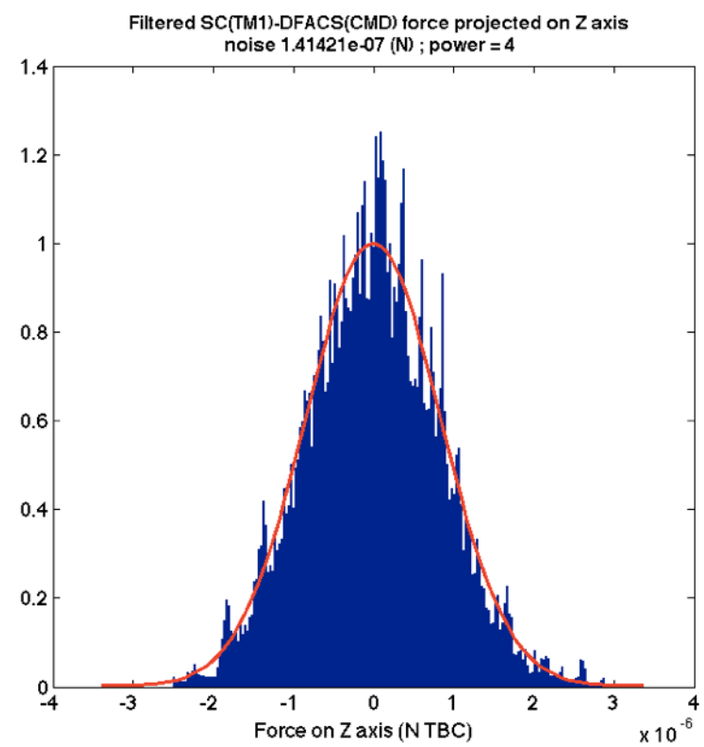
µ-Thruster Characterization : "Colored" Noise study

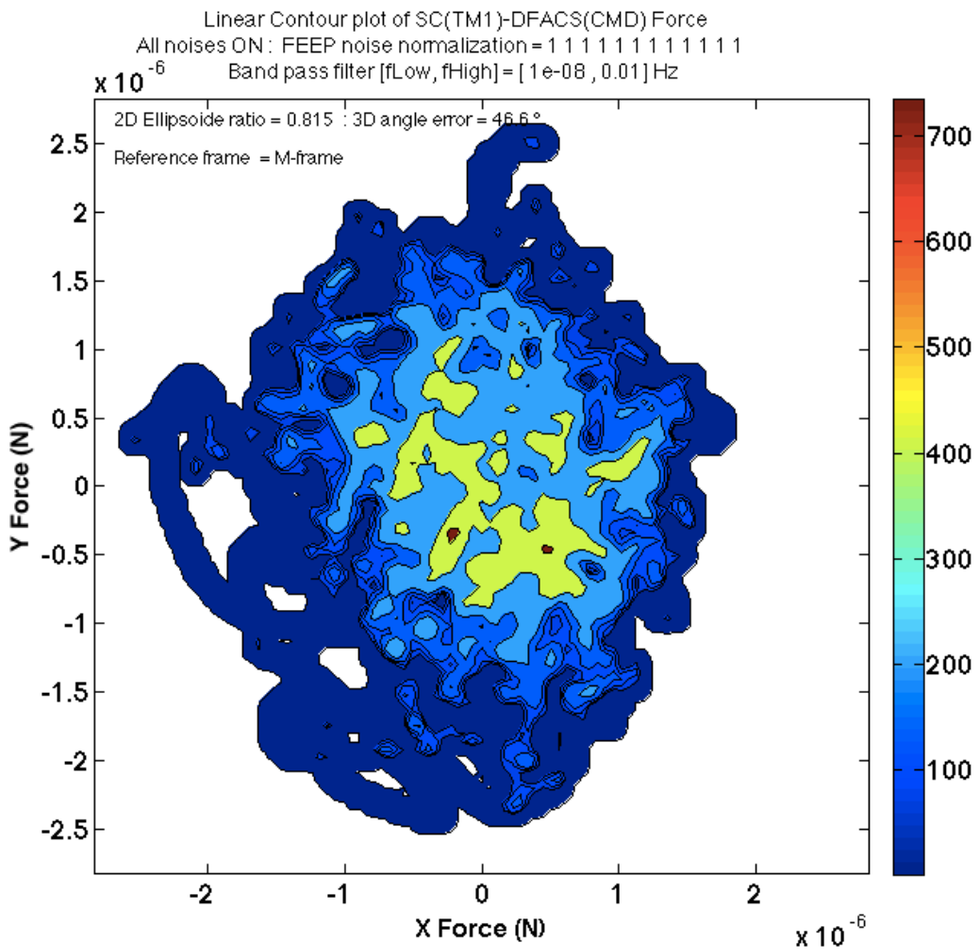


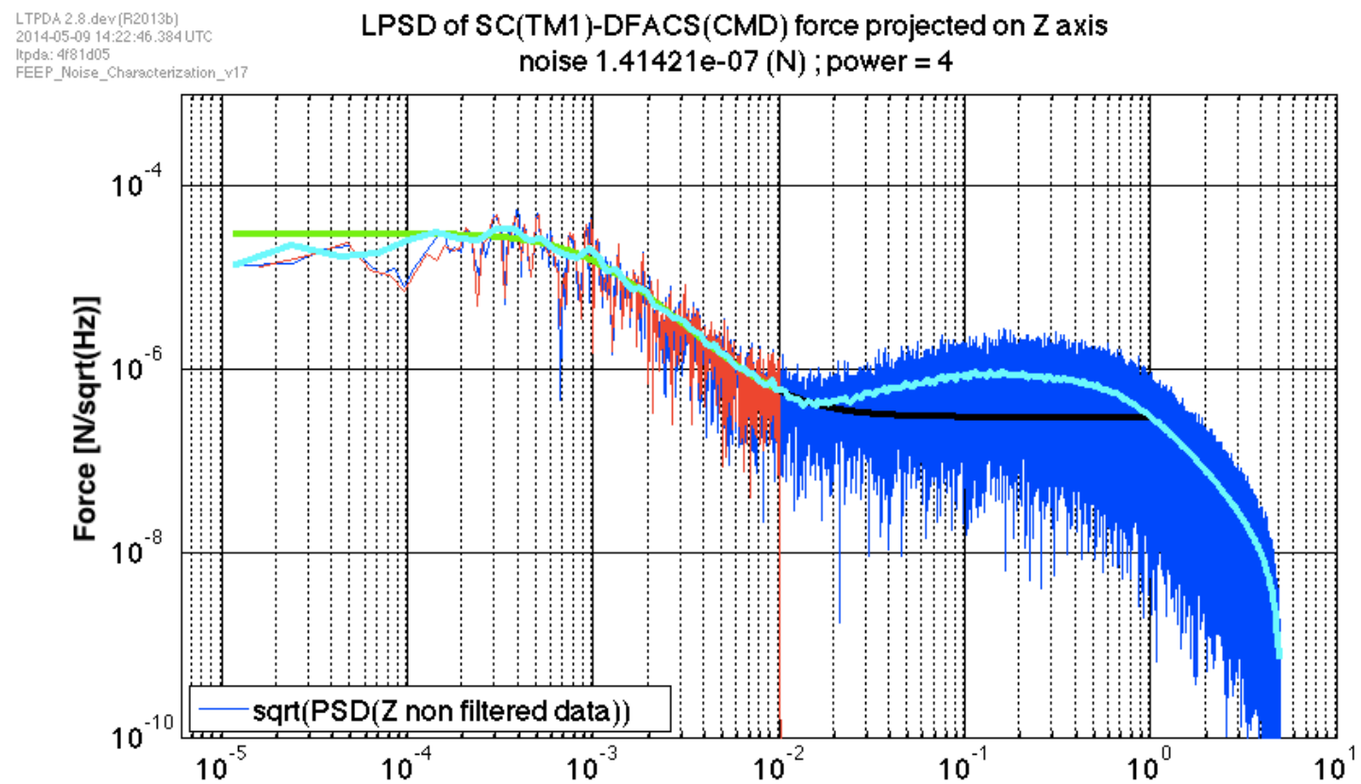


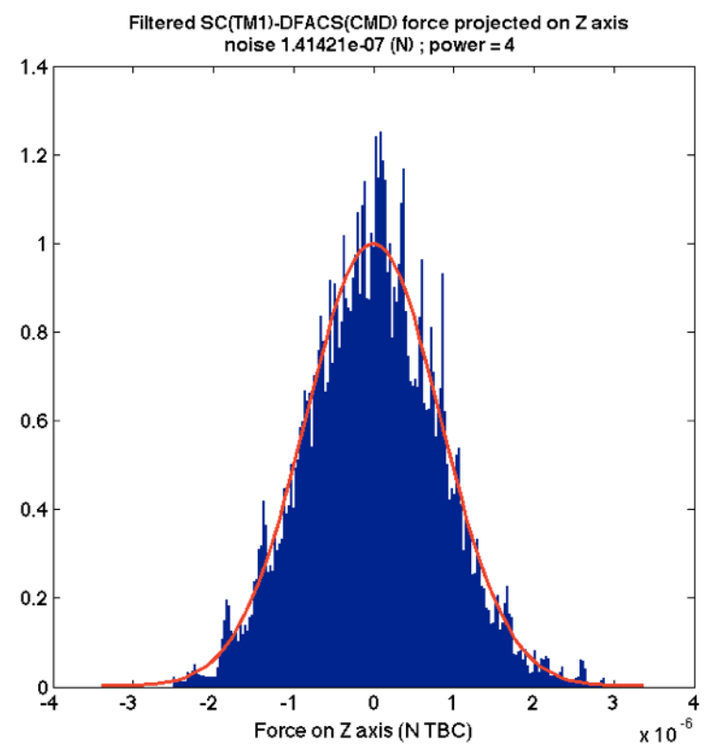


X : Power measured/Power expected = 0.69
Y : Power measured/Power expected = 1.02
Z : Power measured/Power expected = 1.07
Total power filtered in band = 1.76e-12 : Expected = 1.89e-12 :
Ratio = 0.933
So a colored noise can be measured also !!

µ-Thruster Characterization : "Colored" Noise study







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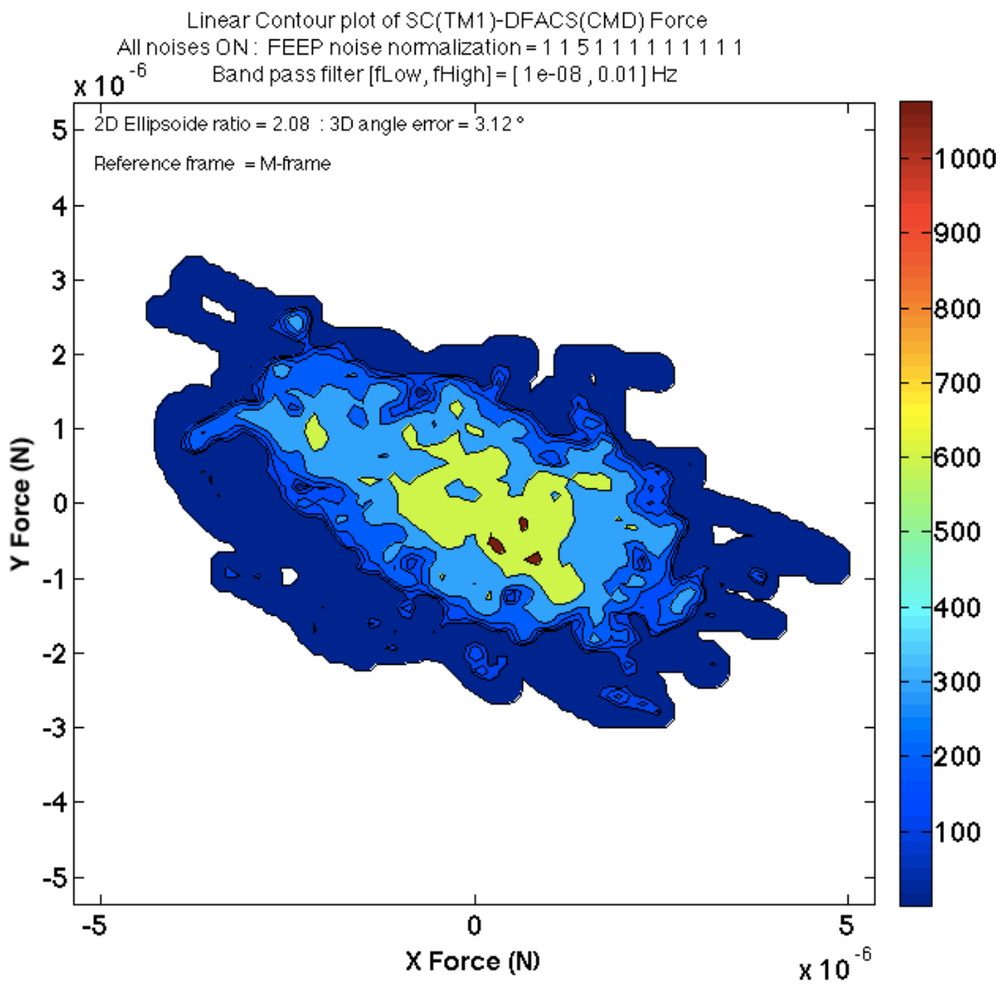
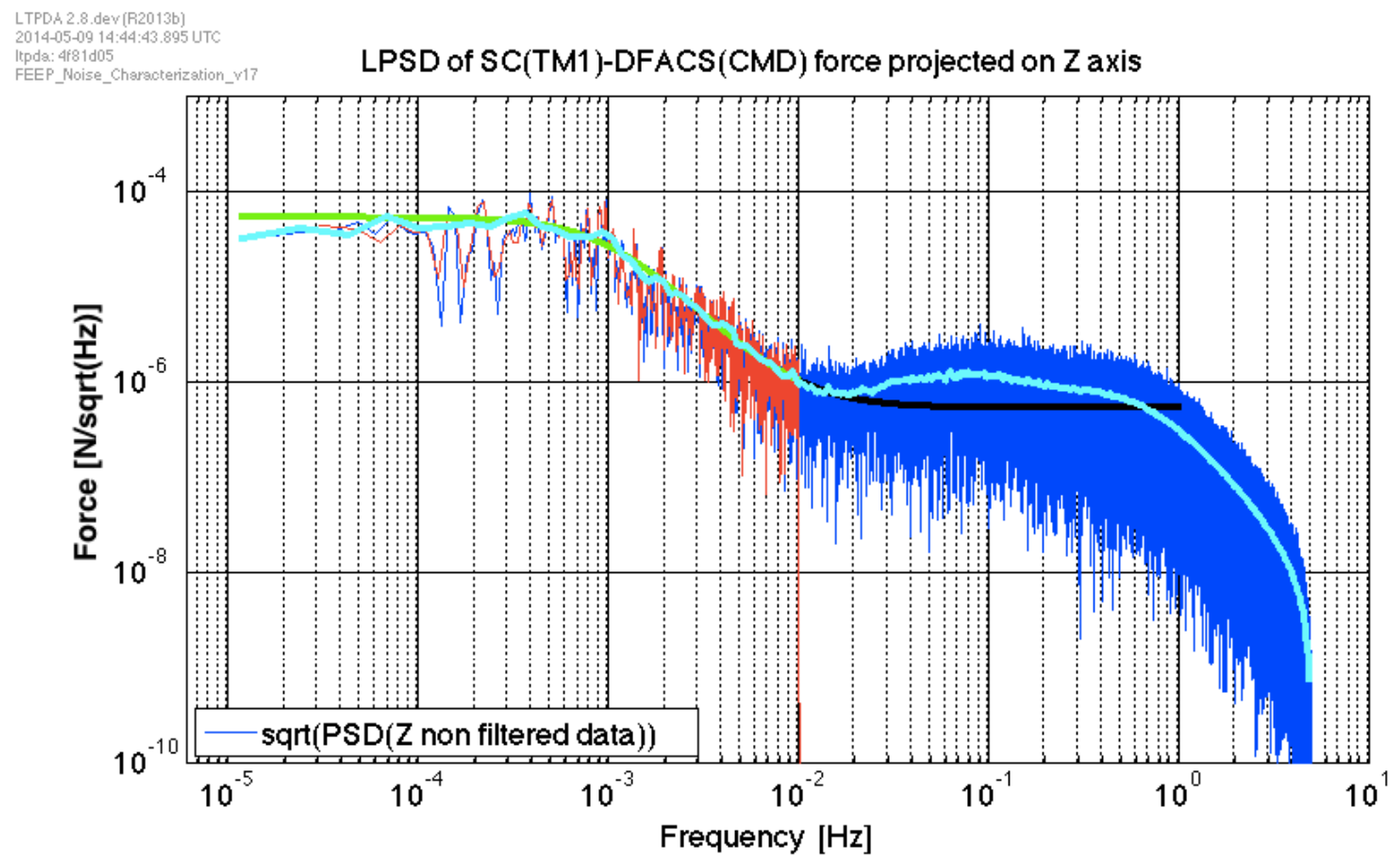
Total power filtered in band = 1.76e-12 : Expected = 1.89e-12 :
Ratio = 0.933
So a colored noise can be measured also !!

µ-Thruster Characterization : Noise Excess study

The noise on thruster N°5 has been increased by a factor 5 : 0.5 µ N





Total power filtered in band = 2.39e-15 : Expected = 2.40e-15 :

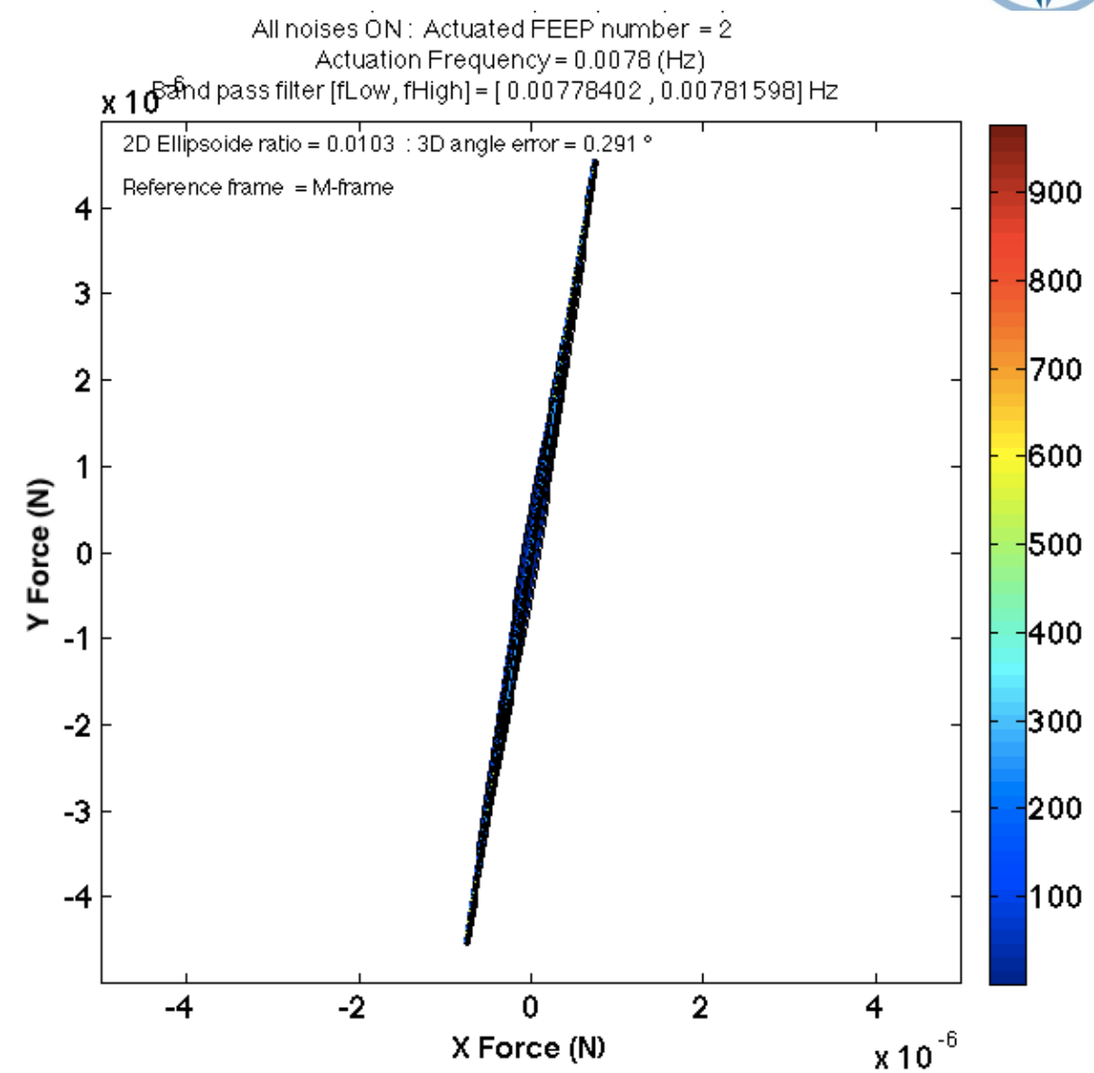
Ratio = 0.996

So a an excess of noise can also be measured.

3D : Angle between nominal thruster direction and main eigenvector = ~ 3 deg

µ-Thruster Characterization : direction study

- The direction of a given thruster can be obtained by actuating it with a given sine wave of given frequency and amplitude:
  - force = 5*sin(2πft) + 8 µN
    f ≈ 1 mHz
- Analyzing the movement of the spacecraft, the direction of thrust can be extracted (24h).
- Choosing different frequencies ($\Delta f = 2\ 10^{-4}$ Hz)for each thruster, the actuations can be performed simultaneously.
- Typical direction errors are ≈ 0.1 - 0.4°



Thruster Nb	1	2	3	4	5	6	7	8	9	10	11	12
	White Noise											
Direction Error (°)	0.31	0.39	0.23	0.13	0.22	0.19	0.13	0.11	0.15	0.12	0.15	0.11
Amplitude ratio to input	1.14	1.13	1.15	1.14	1.13	1.12	1.11	1.11	1.11	1.12	1.14	1.14
	Standard Noise											
Direction Error (°)	0.29	0.35	0.25	0.11	0.20	0.21	0.20	0.15	0.18	0.12	0.10	0.09
Amplitude ratio to input	1.13	1.13	1.15	1.14	1.13	1.12	1.12	1.11	1.11	1.12	1.15	1.14

µ-Thruster Characterization : direction study

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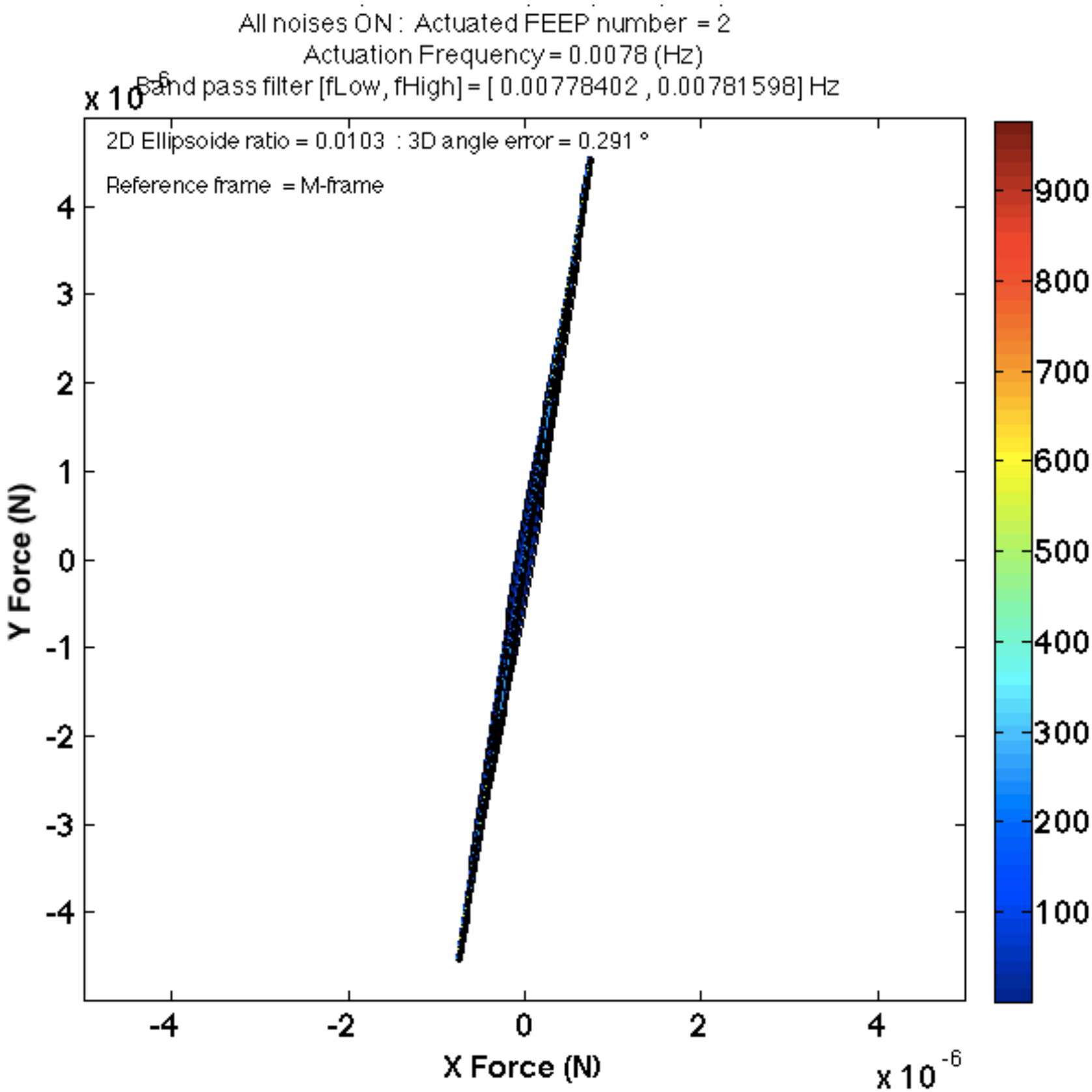

Thruster	12
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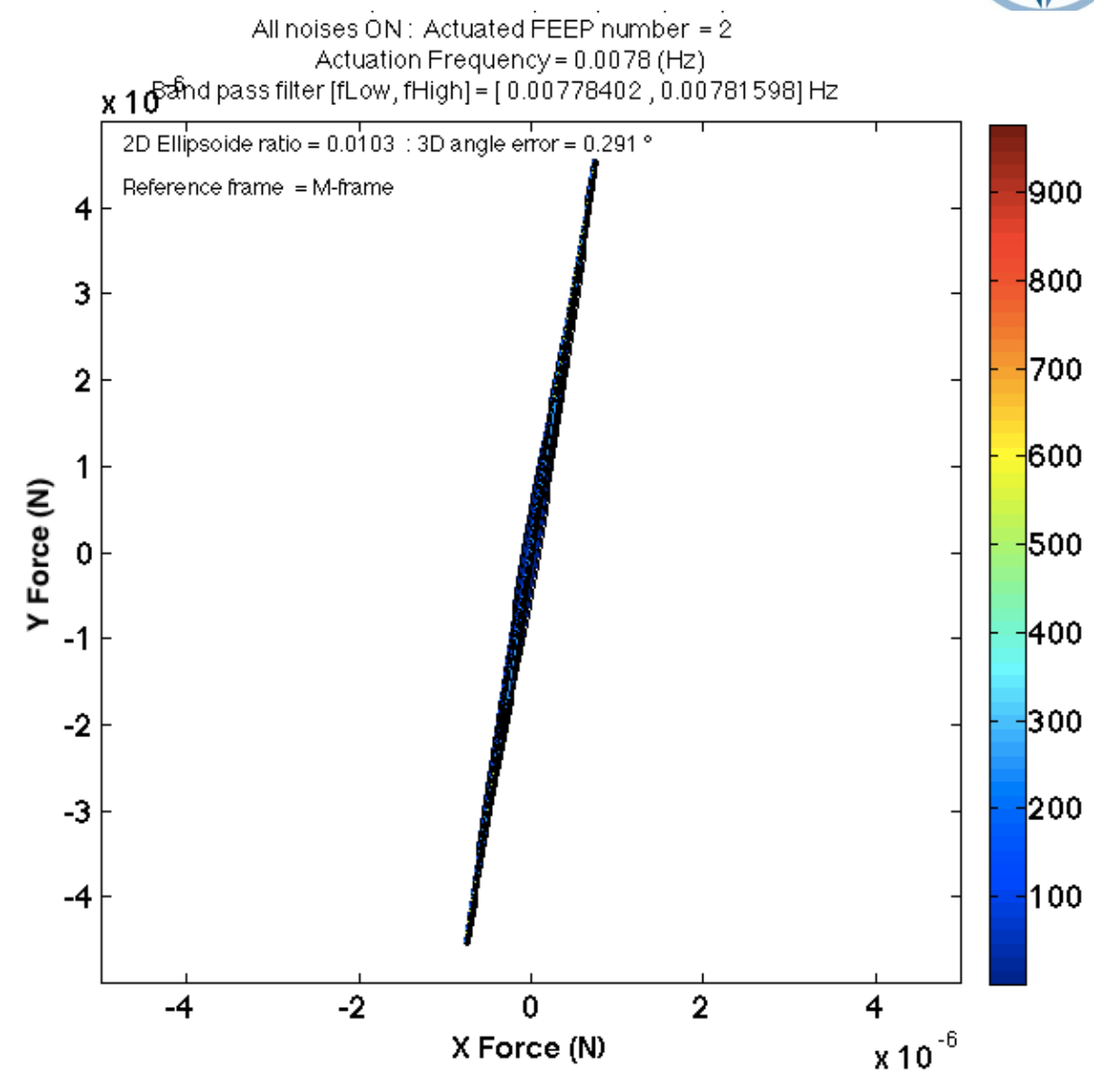

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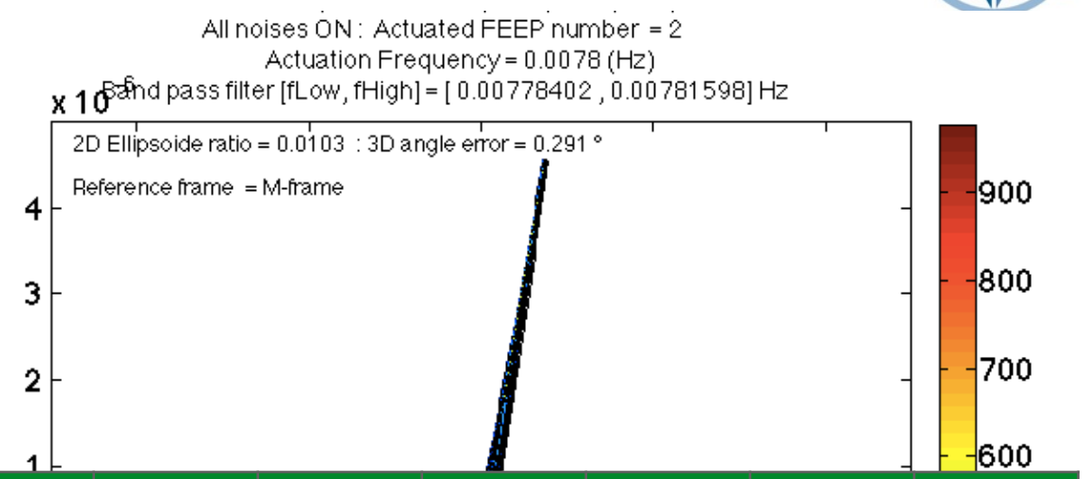

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Amplitude ratio to input	1.009	0.998	1.005	1.001	0.998	1.001	0.999	0.999	1.001	1.002	1.003	0.999
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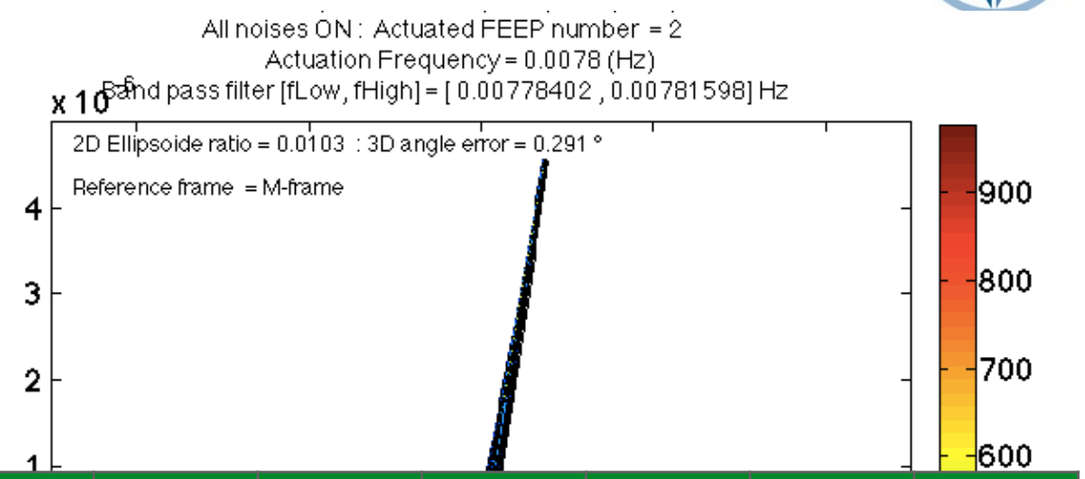

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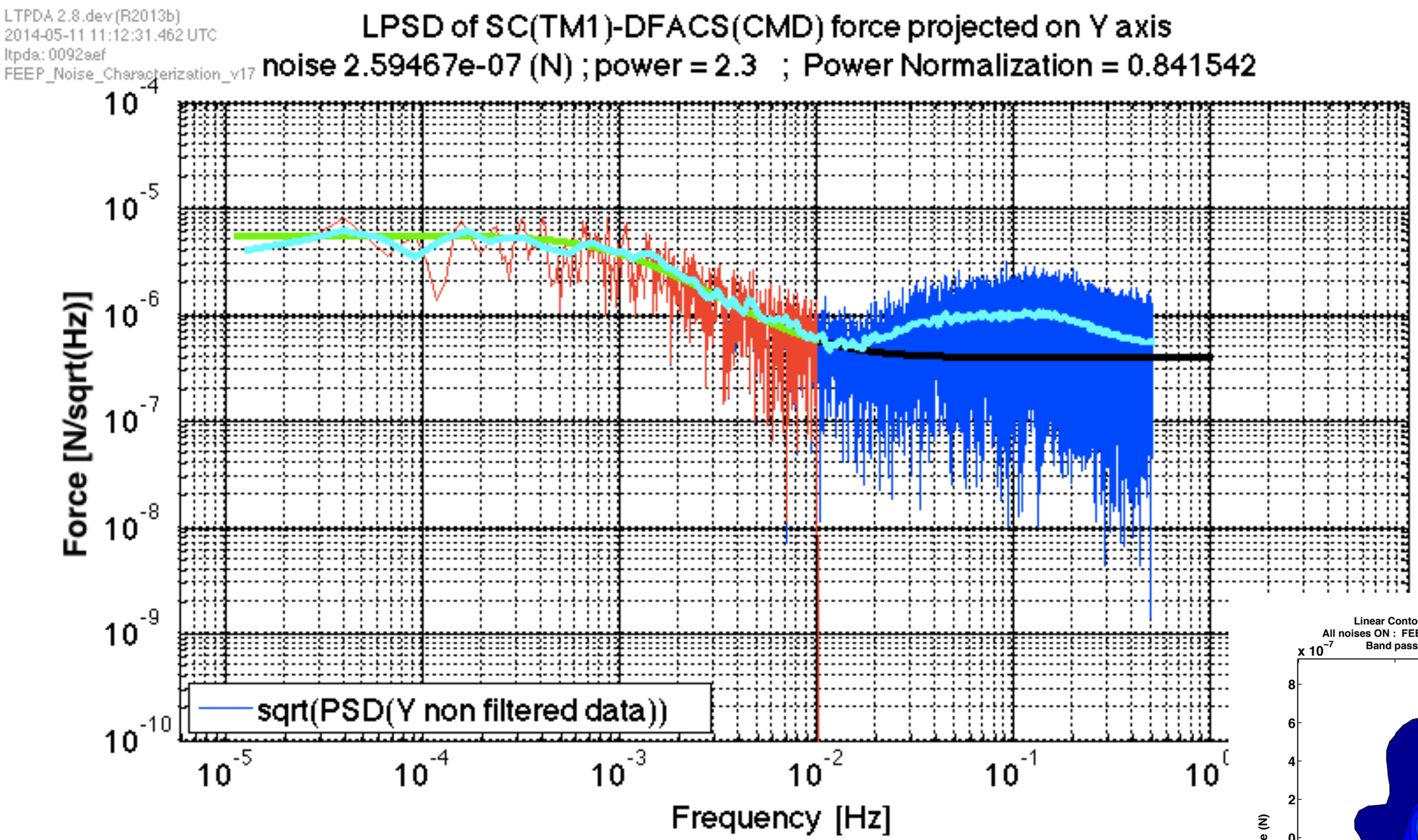
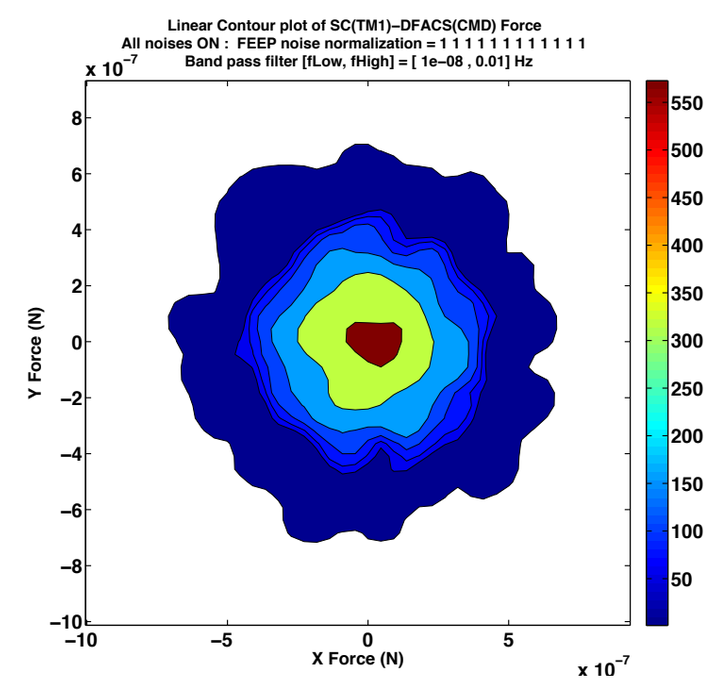
In these calculations, all instrumental noises are included

Summary

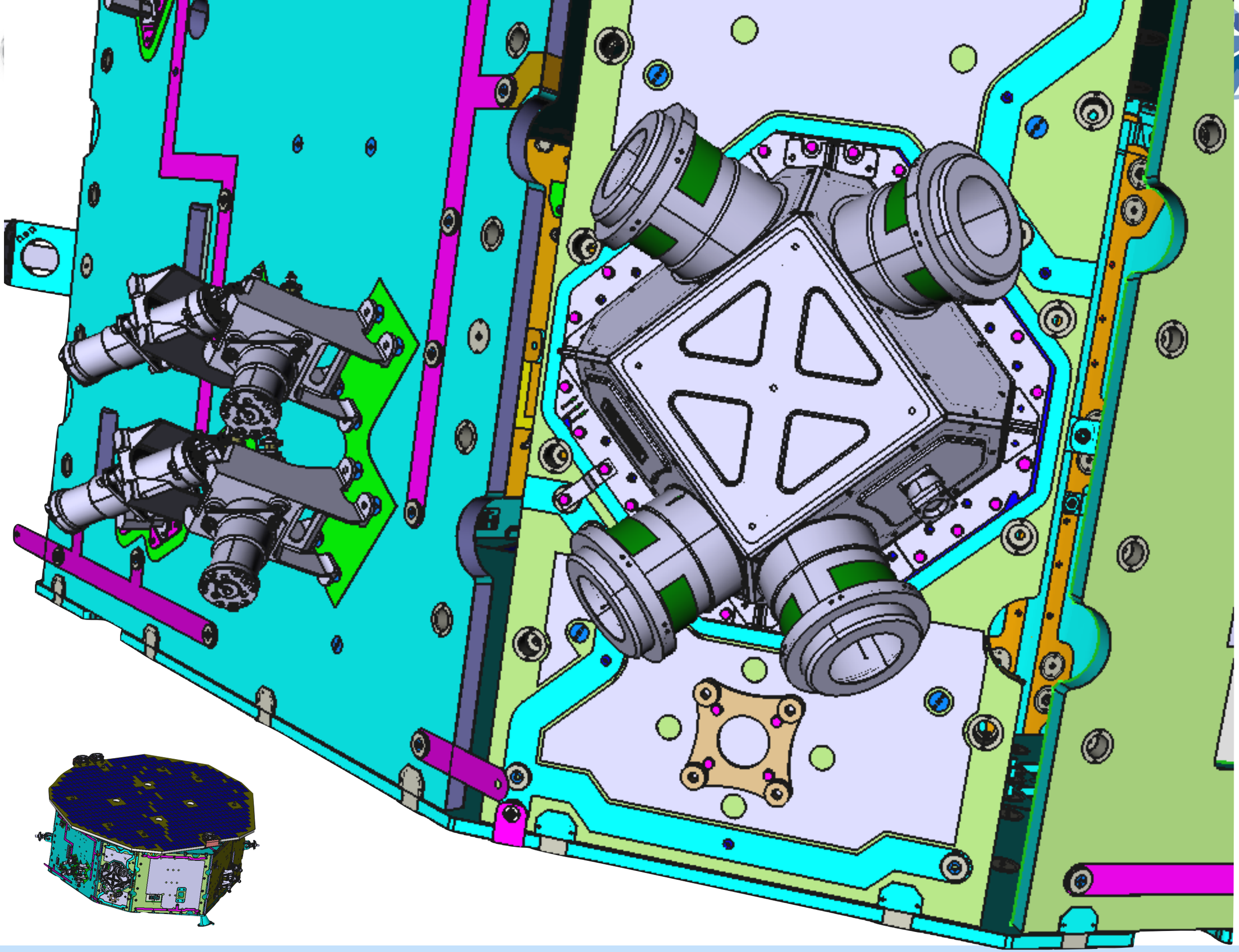
- Based on studies with an LPF/SSM model:
  - The overall noise of system can be measured,
  - An excess of noise (x5) on a given thruster can be detected and measured,
  - By applying a sinusoidal force on each thruster (simultaneously), the direction of each thruster can be measured to a fraction of a degree.
  - Such an investigation takes of the order of 24h.
  - The measurement of the "flutter" noise is not yet implemented.
  - We have not looked at the torques…
  - There is much to improve in the analysis part.
- We have checked that this works also for the Cold Gas SSM simulator
- We are waiting for the ESA/AirBus D&S simulator data to validate this investigation in order to use it during the mission.

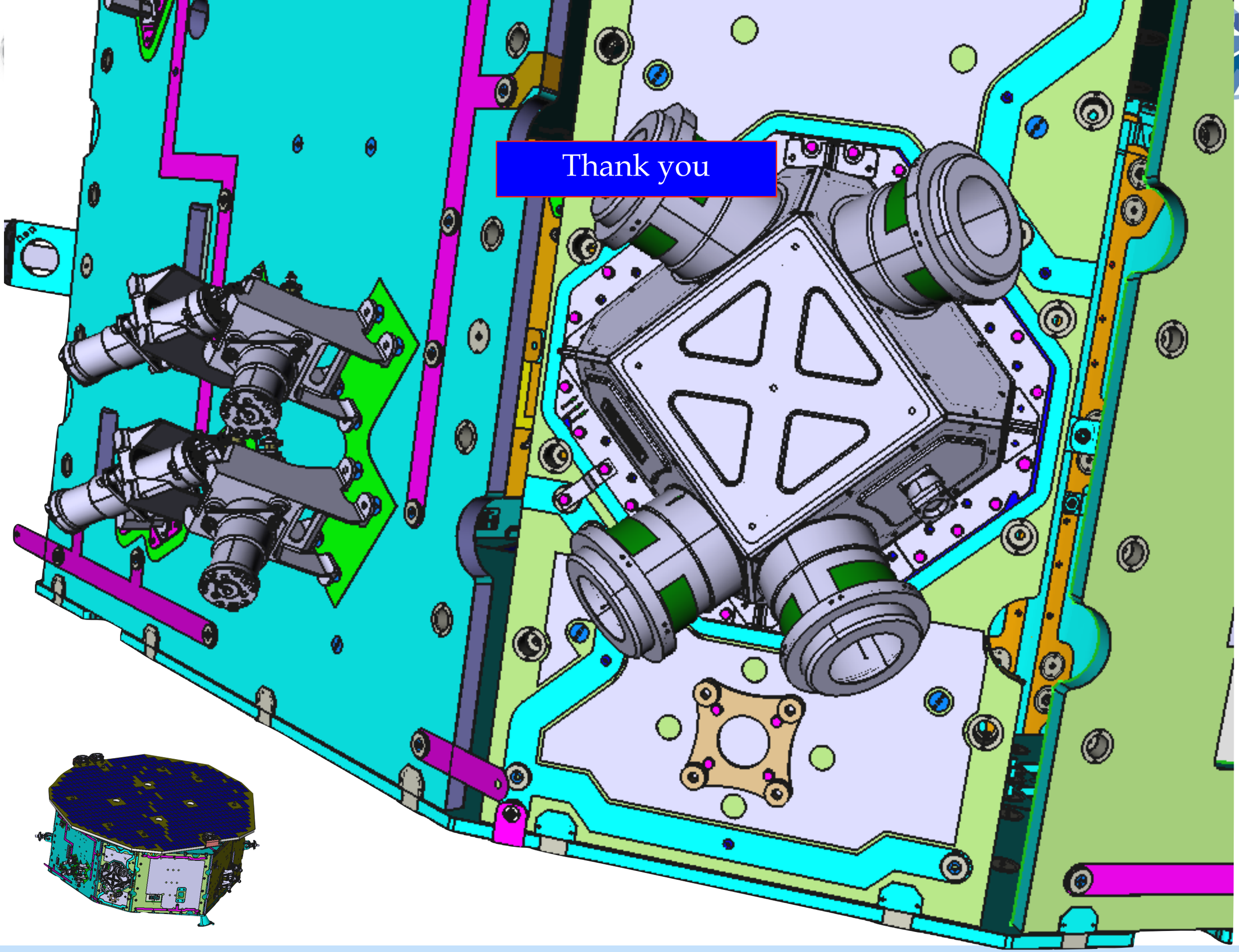
µ-Thruster Characterization : Cold gas OSE data





X : Ratio of measured power to expected = 0.90
Y : Ratio of measured power to expected = 1.04
Z : Ratio of measured power to expected = 1.09
Ratio of total power = 1.00




Thank you