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## **ONERA accelerometers for future gravity mission**

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G51B-0594

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AGU 2019  
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## Future Gravity Missions

GRACE-FO was launched in May 2018 for 5 years mission. Its performance is similar to previous GRACE mission (see principle of GRACE-type mission). For continue climate change survey, a successor to GRACE-FO is envisaged. In Europe, ESA studies the Next Generation Gravity Mission (NGGM), on the same principle than GRACE with a laser link and better performance for the accelerometer. In the United States, NASA has chosen Mass Change Mission as one of the 5 Targeted Observable. An analysis of the different concept is under progress by JPL. Some concepts use nanosat pairs with accelerometers as good as in GRACE-FO, some others are based on GRACE-FO with only the laser link and a better accelerometer by at least a factor 10. In France, the Scientific Prospective Seminar (SPS) has decided to study the mission MARVEL. The concept is a laser link between LEO and MEO satellites, with accelerometers.

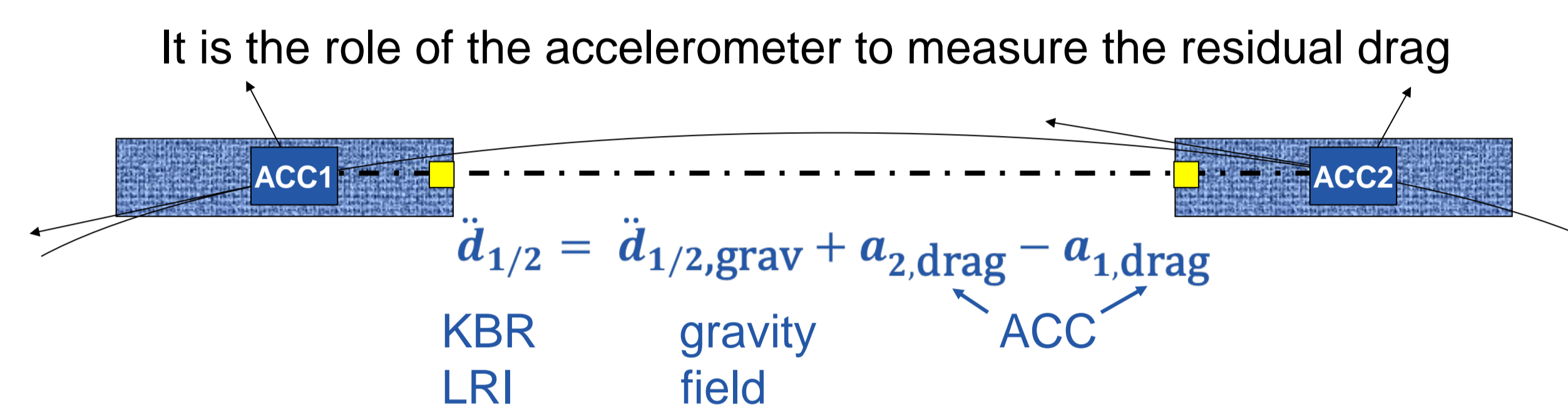
## GRACE-type mission principle

The gravity field is reconstructed from distance measurement between satellites



© Earth: NASA "Blue Marble", satellites: Schütze/AEI

But the distance can vary also due to the difference of residual drag



## Accelerometer measurement

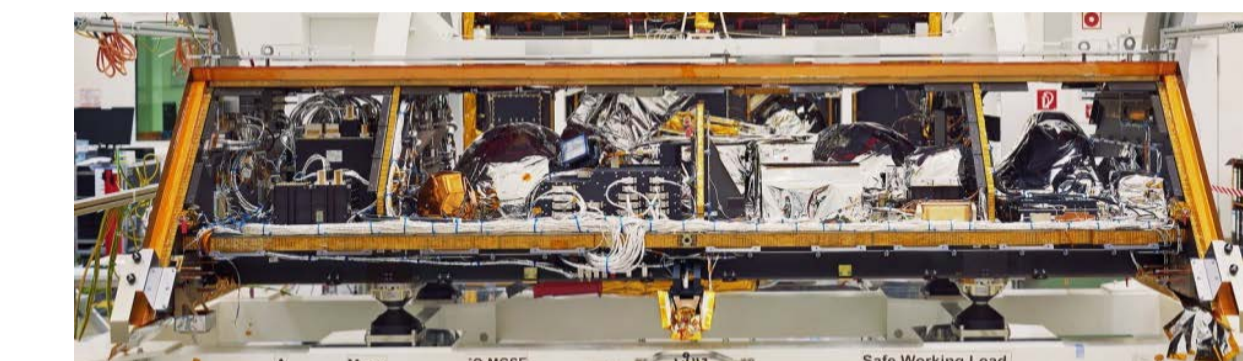
The accelerometer measures the relative acceleration between a proof-mass free inside a cage fixed on the satellite and this cage.

Measure: 
$$\vec{a}_{meas} = \vec{a}_{drag} + \vec{g}_P - \vec{g}_G + ([\dot{\Omega}_S] + [\Omega_S^2])\vec{x}_{GP}$$

Ideal measure without accelerometer default: Satellite non-gravitational acceleration (drag, radiation pressure ...), Gravity at Proof-mass location (P) and Satellite center of mass (G), Coupling off-centering and attitude control

One accelerometer at Center of Mass (as in GRACE and GRACE-FO)

$$\vec{a}_{meas} = \vec{a}_{drag}$$

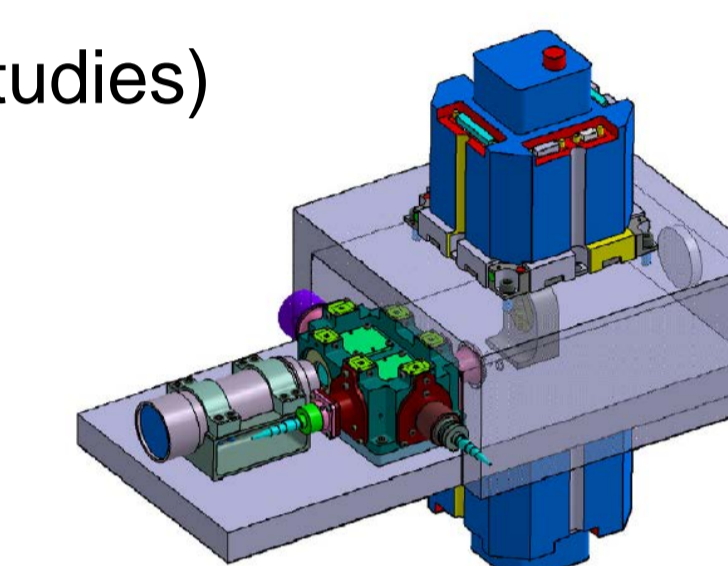


© Thomas Struth for The New York Times

Two accelerometers part of CoM (one concept in NGGM studies)

$$\frac{1}{2} \sum \vec{a}_{meas} = \vec{a}_{drag}$$

$$\Delta \vec{a}_{meas} = (-[Grad \vec{g}] + [\dot{\Omega}_S] + [\Omega_S^2])\vec{x}_{P_1 P_2}$$



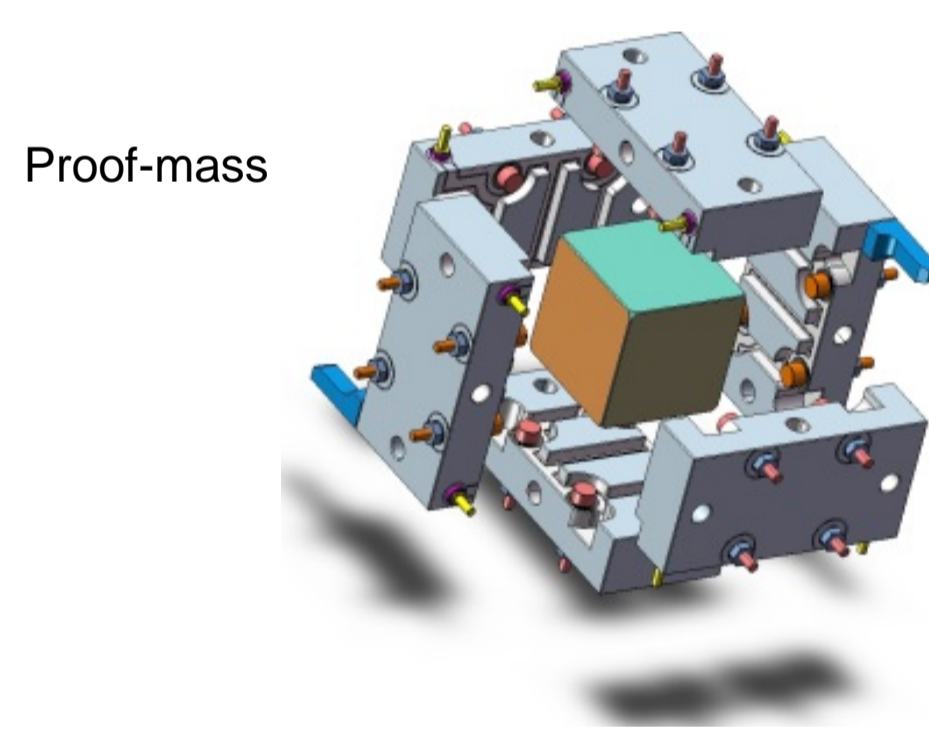
From S. Cesare et al. / Advances in Space Research 57 (2016) 1047–1064 © Thales Alenia Space

## CubSTAR – Electrostatic ACC for Cubesat

Accelerometer with a cubic proof-mass 2cm side :

- 3 linear acceleration with the same performance
- 3 angular acceleration for helping attitude recovery
- Low power, light and reduced volume design
- Analog control of the proof-mass

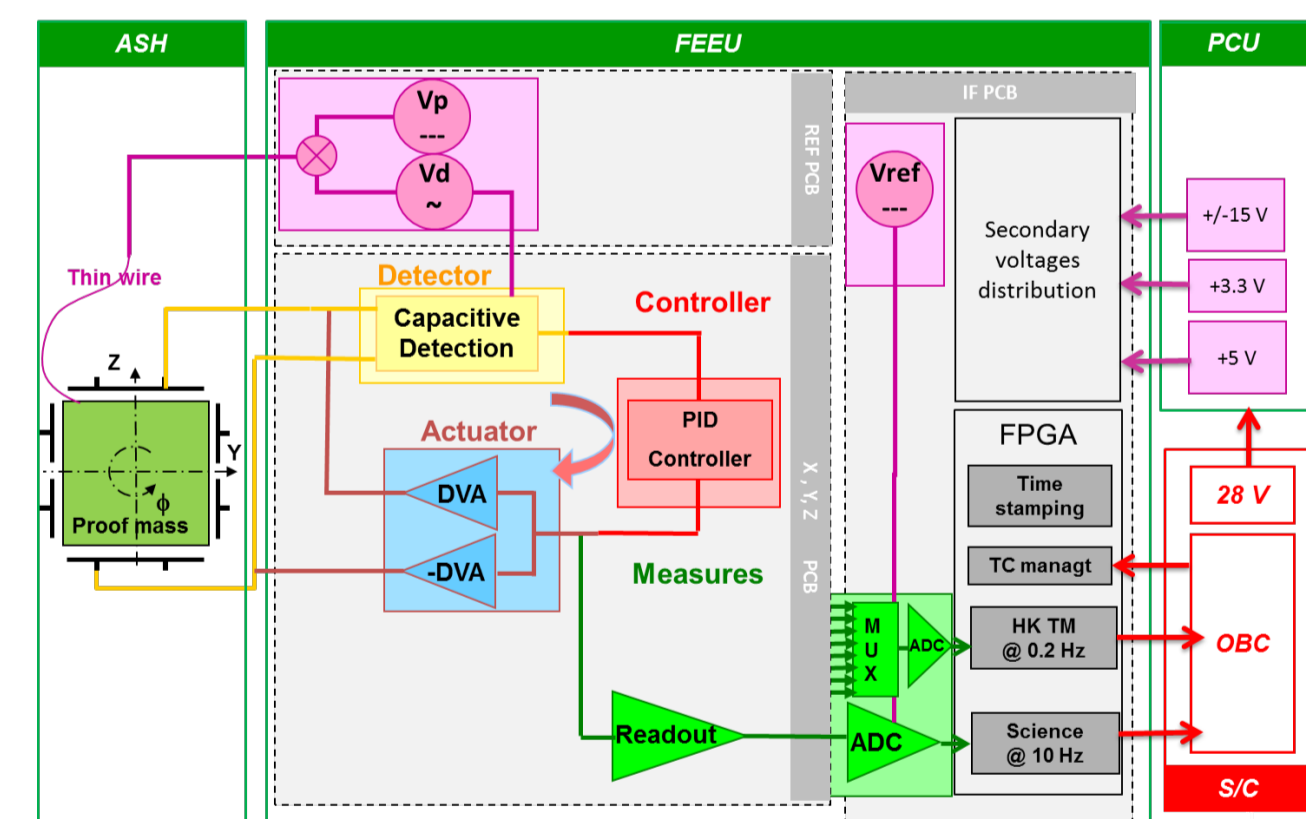
CubSTAR mechanical core



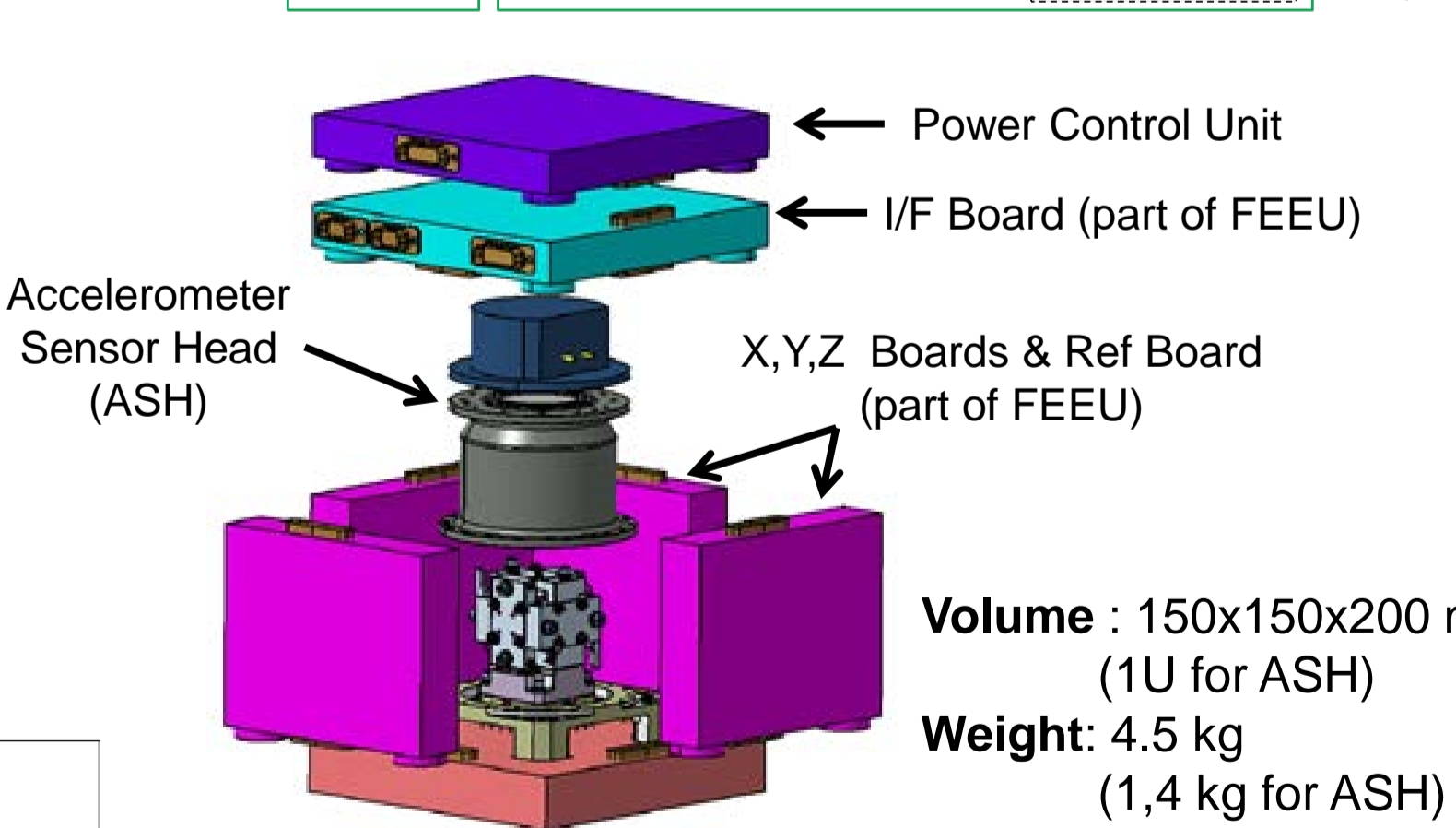
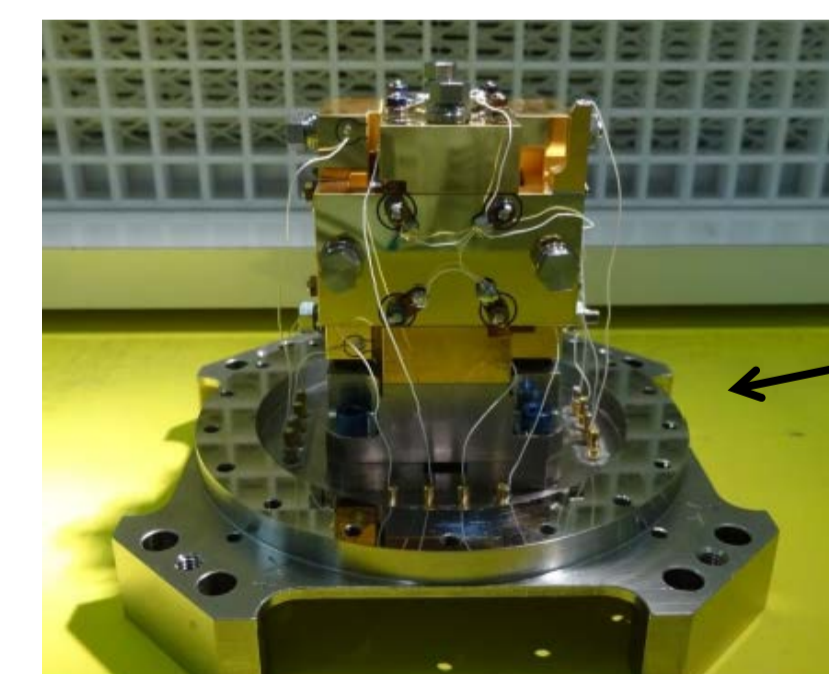
Electrode plate



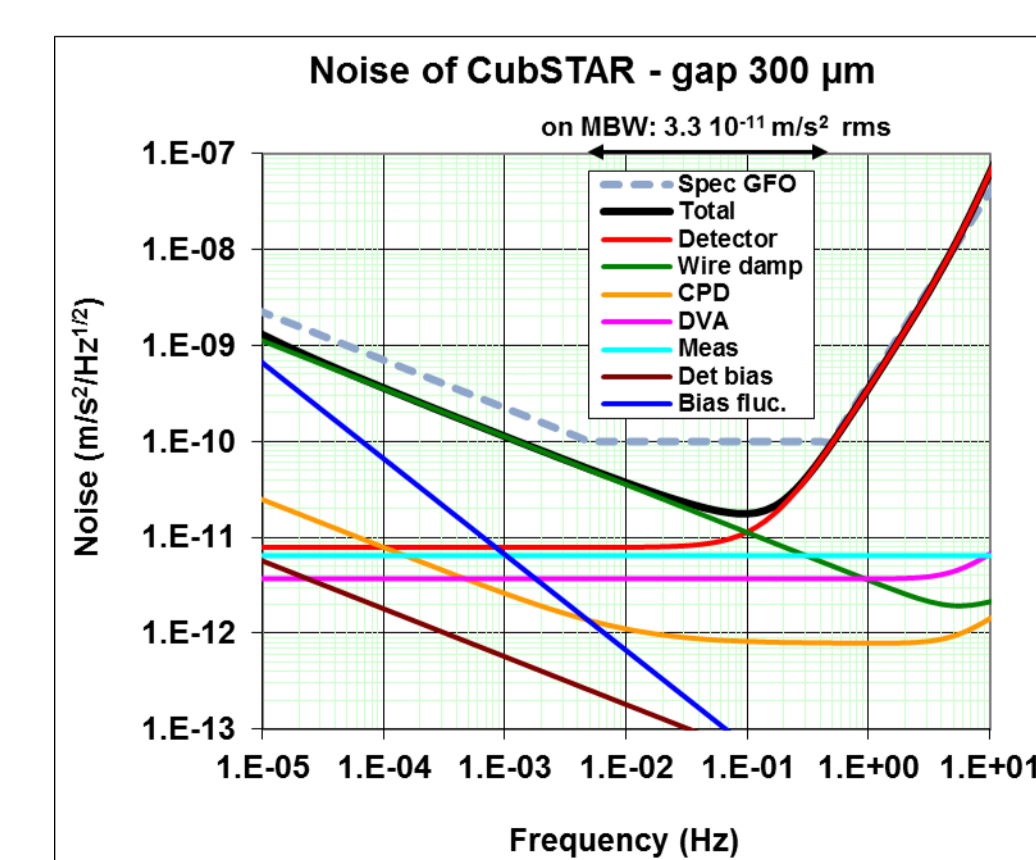
CubSTAR electronics schematics



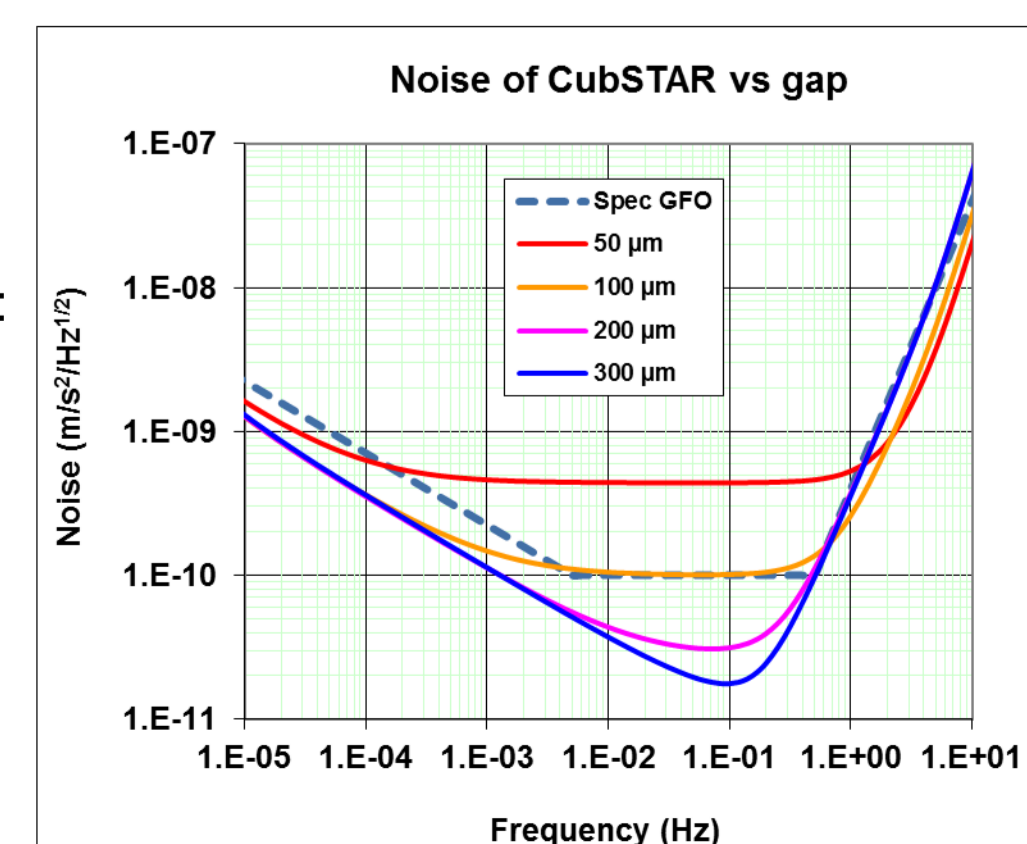
CubSTAR prototype under integration



Volume : 150x150x200 mm (1U for ASH)  
Weight: 4.5 kg (1,4 kg for ASH)  
Power: 10 W



Variation of noise with respect to the gap between proof-mass and electrode:  
Possible to adapt the design for various missions



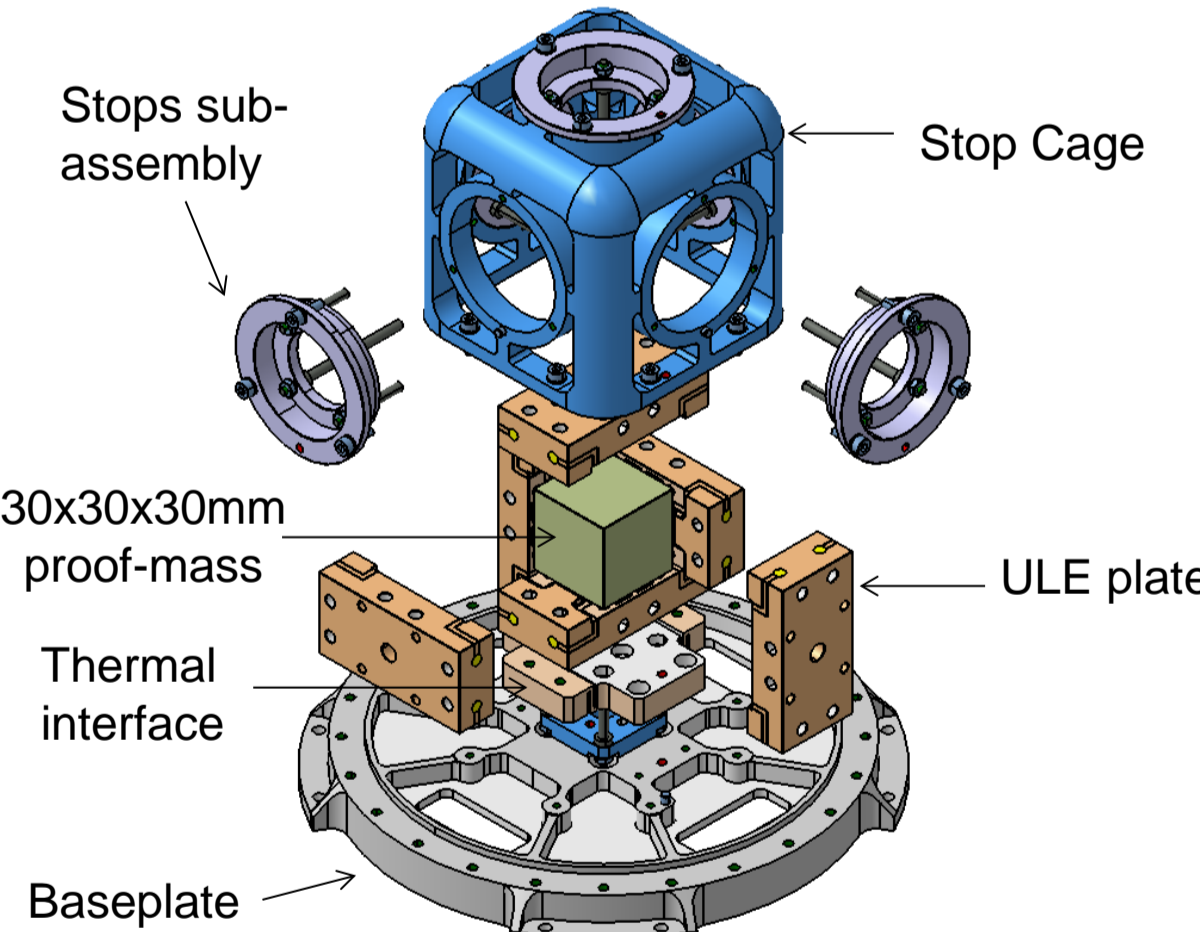
Measurement range : ± 1.3 10<sup>-4</sup> m/s<sup>2</sup>  
Measurement noise : 3.3 10<sup>-11</sup> m/s<sup>2</sup> rms in [5 - 500]mHz  
Thermal sensitivity : 2.1 10<sup>-8</sup> m/s<sup>2</sup>/K @ 0.1mHz

## MicroSTAR – High performance electrostatic ACC

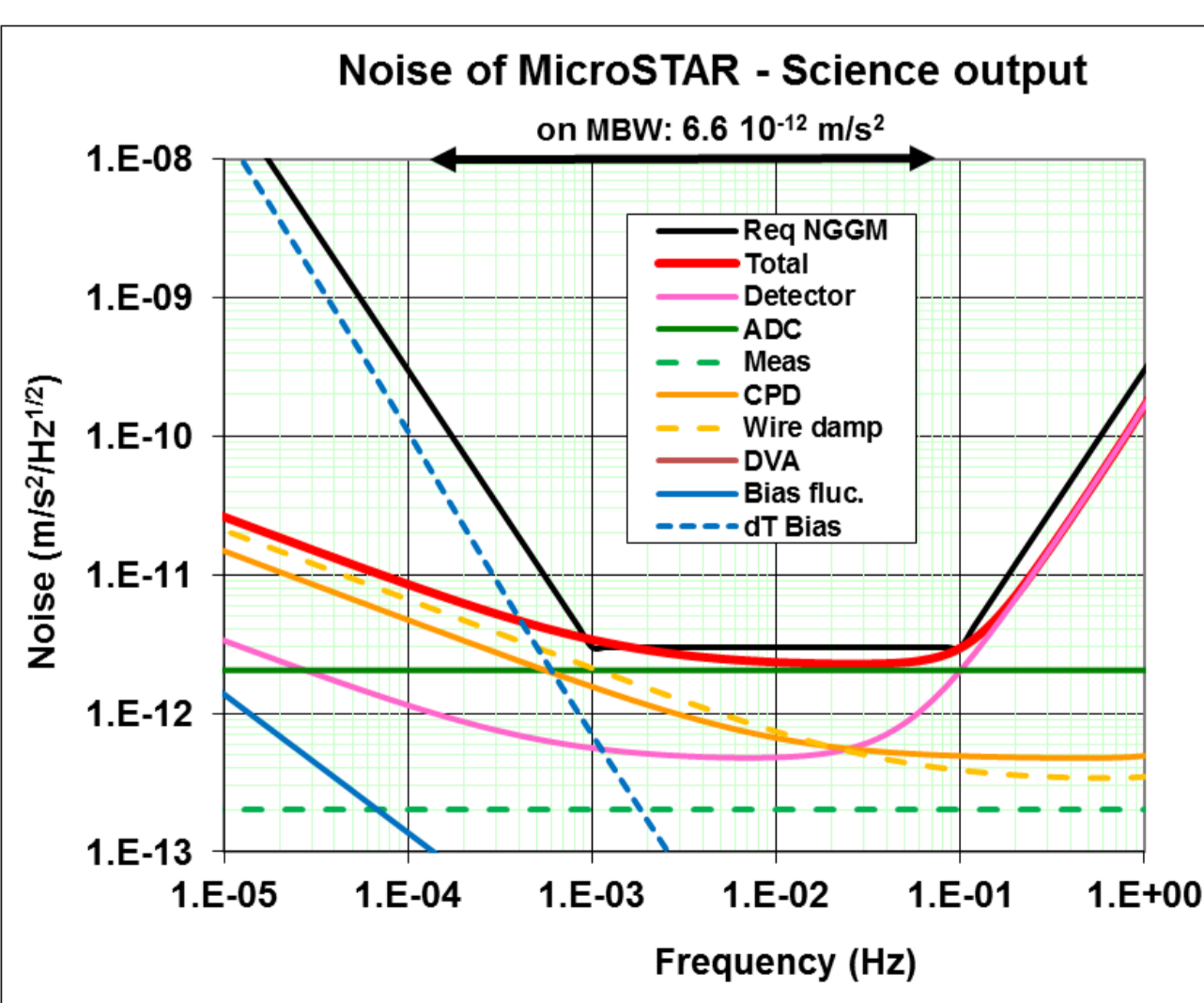
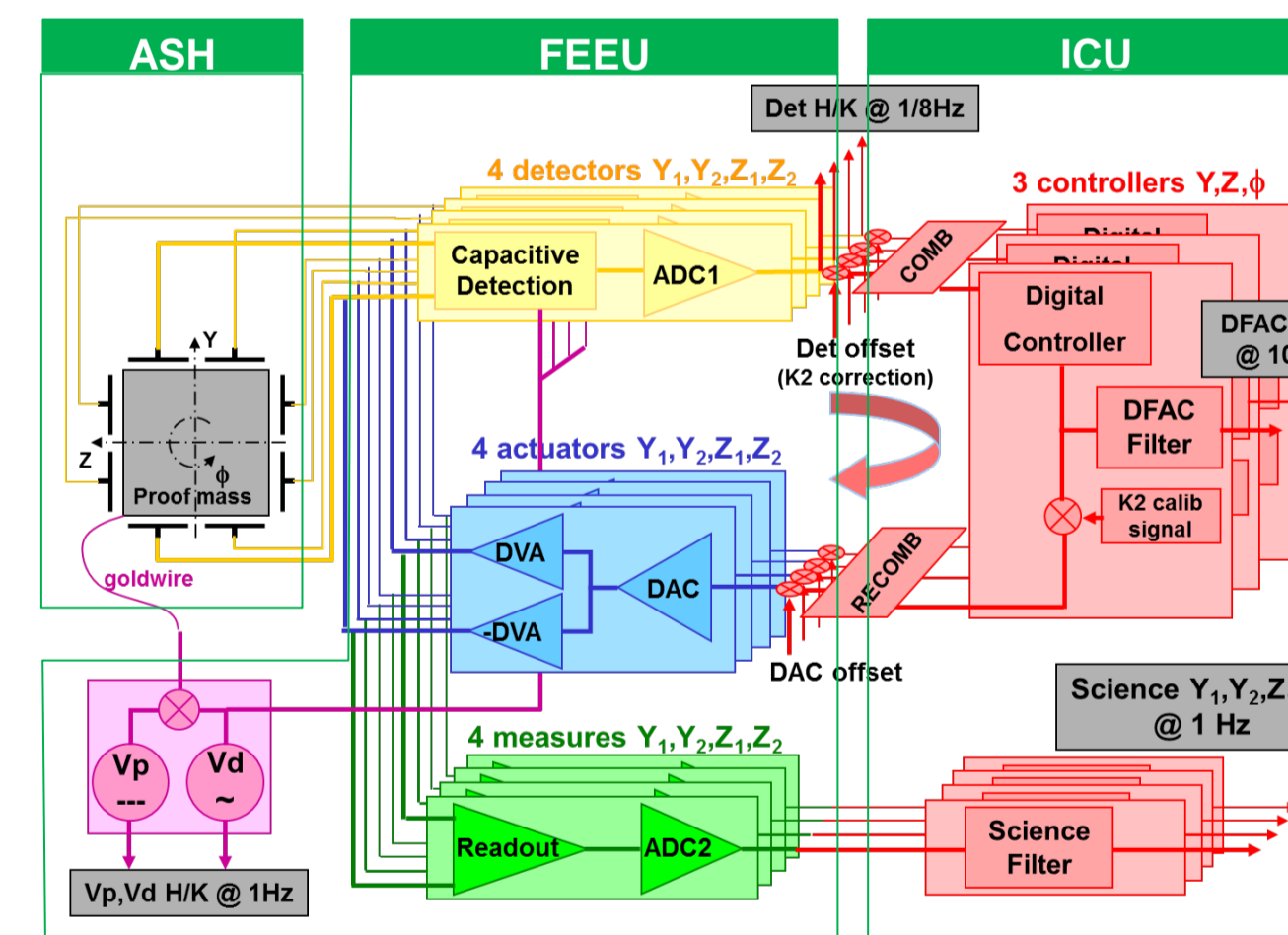
Accelerometer with a cubic proof-mass 3cm side :

- 3 linear acceleration with the same performance
- 3 angular acceleration for helping attitude recovery
- High performance
- Digital control of the proof-mass for flexibility (analog control also possible for lower consumption)

MicroSTAR mechanical core



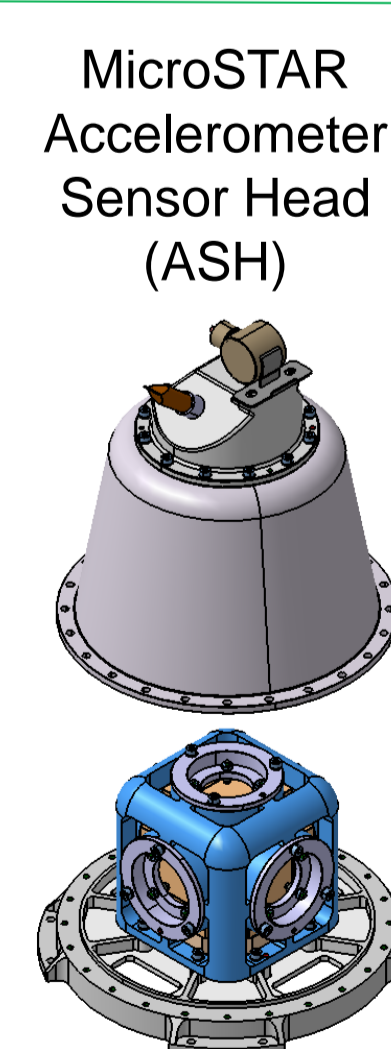
MicroSTAR electronics schematics



Proof-mass of 218g, gap of 400µm

Measurement range : ±6.4 10<sup>-6</sup> m/s<sup>2</sup>  
Measurement noise : 6.6 10<sup>-12</sup> m/s<sup>2</sup> rms in [0.2 - 100]mHz  
Thermal sensitivity : 7.0 10<sup>-11</sup> m/s<sup>2</sup>/K @ 0.1mHz

Christophe B. et al. (2018) Status of Development of the Future Accelerometers for Next Generation Gravity Missions. In: Freymueller J., Sanchez L. (eds) International Symposium on Advancing Geodesy in a Changing World. International Association of Geodesy Symposia, vol 149. Springer, Cham



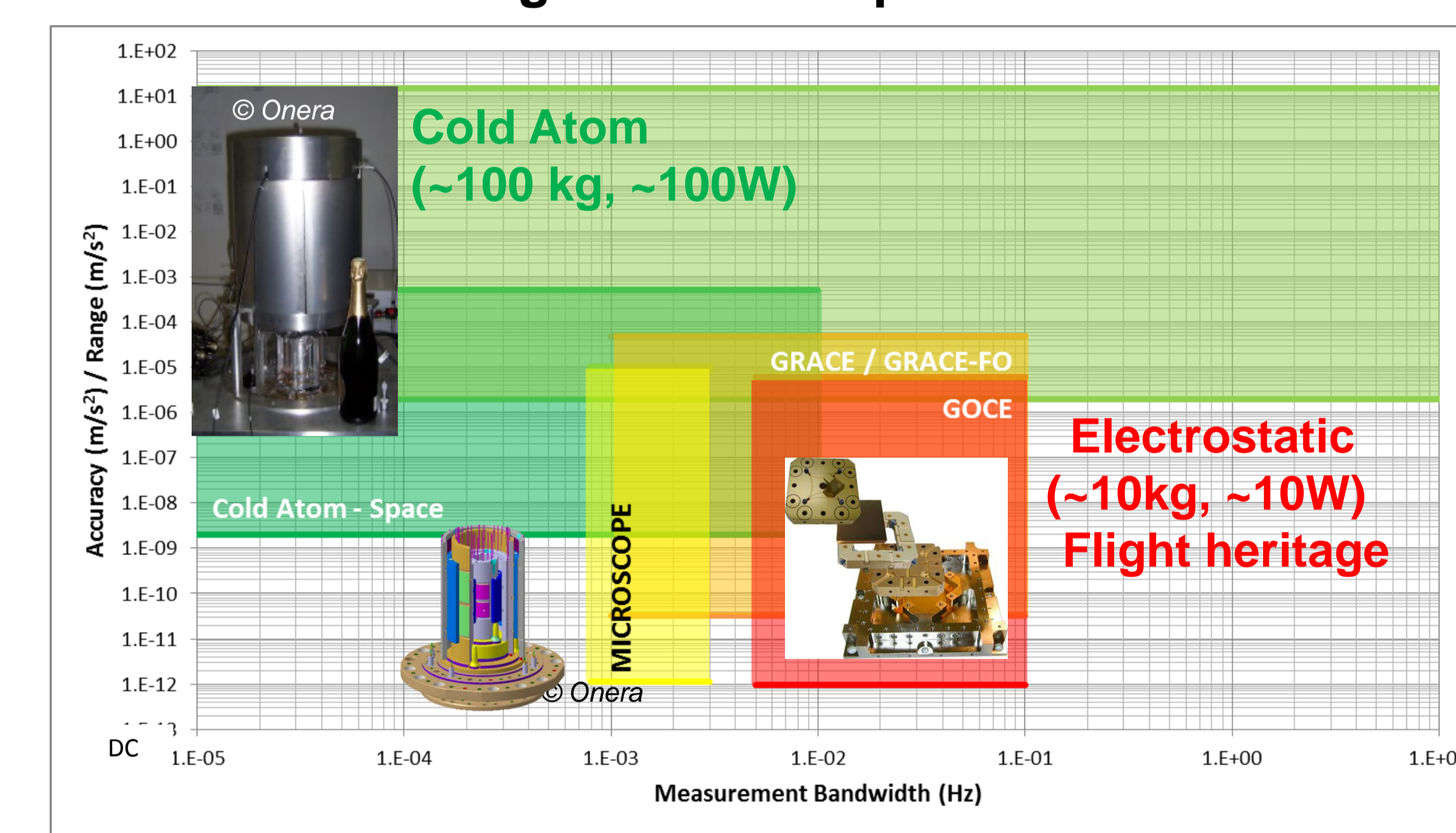
MicroSTAR Front-End Electronic Unit (FEEU)

For 2 accelerometers Image of GOCE FEEU

	Mass	Volume	Power
ASH	5kg	200x200x200mm	
FEEU	4kg	250x250x70mm	16W
ICU	5kg	350x250x70mm	

## Hybrid-STAR : Atomic / Electrostatic ACC

Long-term development

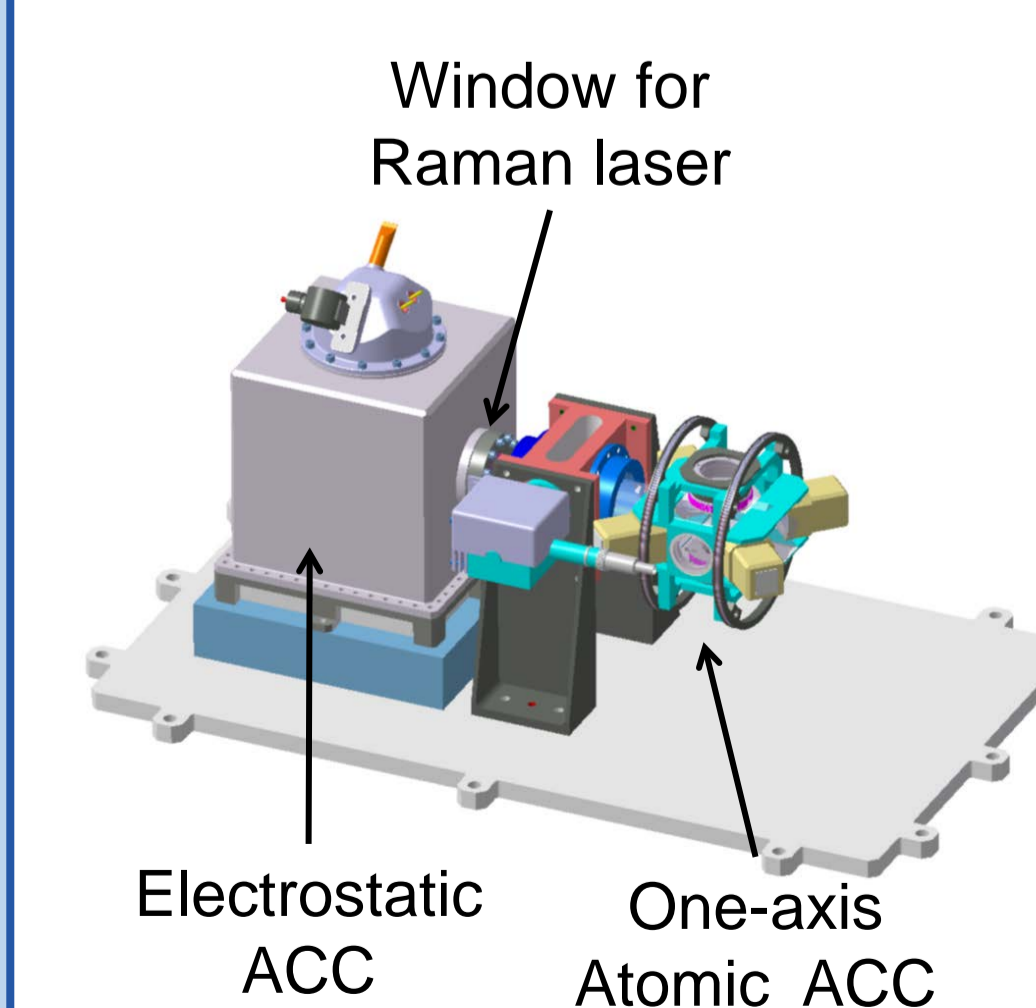


Cold atom interferometer Stability  
With mature technology 8x10<sup>-11</sup>m.s<sup>-2</sup>/√Hz for T=1s with ~2x10<sup>6</sup> detected atoms

Electrostatic accelerometer High accuracy in MBW

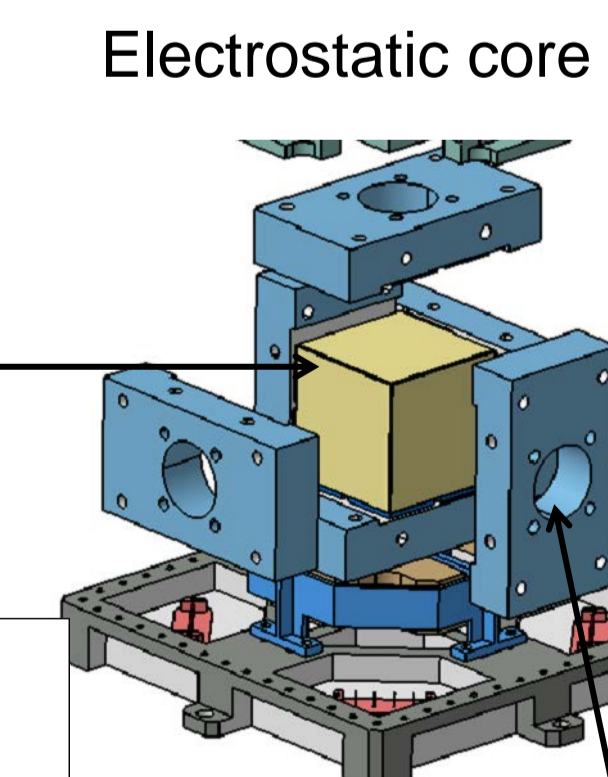
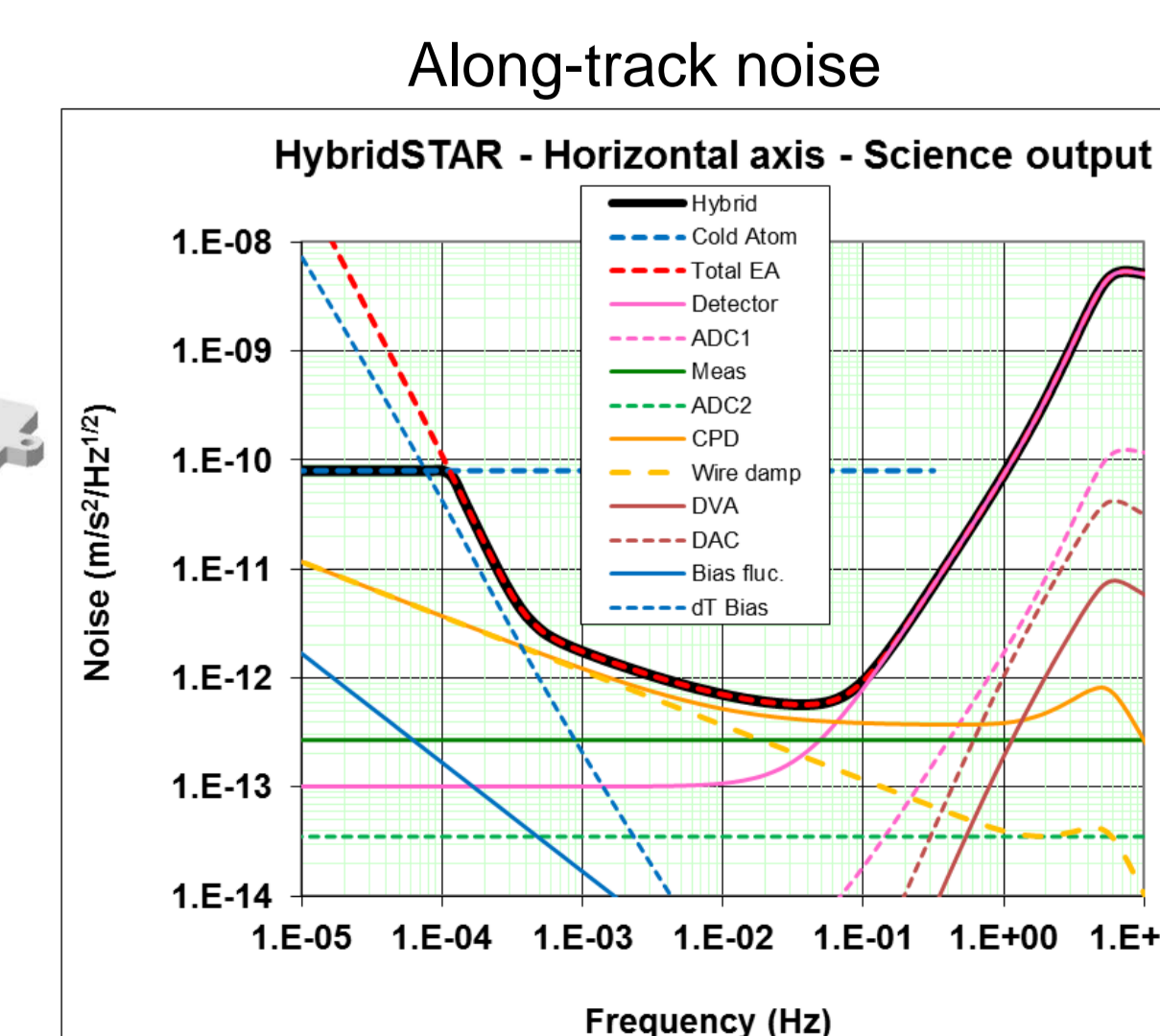
### Hybrid-STAR

Use of the proof-mass as mirror for Raman laser



Electrostatic ACC One-axis Atomic ACC

Work done in the framework of the study "Hybrid Atom Electrostatic System Follow-On for Satellite Geodesy", ESA-ESTEC, Contract No. RFP/3-15194/17/NLFF/mg funded by the European Space Agency.



Hole for Raman laser

PM side ~ 45mm  
PM mass 394 g,  
gap 300µm