ONERA accelerometers for future gravity mission

ONERA THE FRENCH AEROSPACE LAB — return on innovation

Online Poster, Session G4.1

Online session

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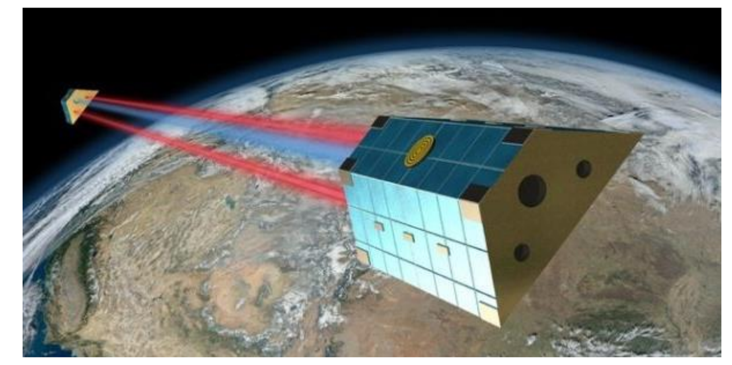
Future Gravity Missions

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 continued 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

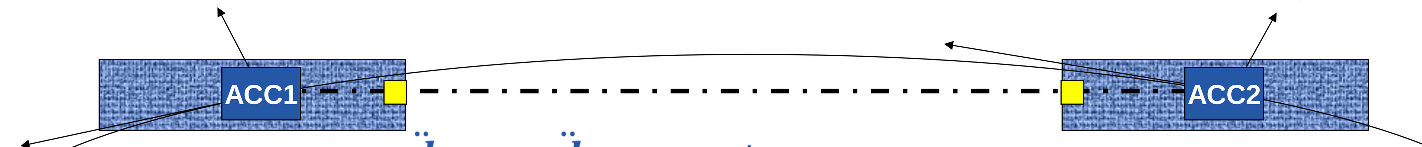
The gravity field is reconstructed
from distance measurement between satellites



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

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

It is the role of the accelerometer to measure the residual drag



$$\ddot{d}_{1/2} = \ddot{d}_{1/2,grav} + a_{2,drag} - a_{1,drag}$$

KBR LRI — gravity field — ACC

Accelerometer measurement

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

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

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)

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

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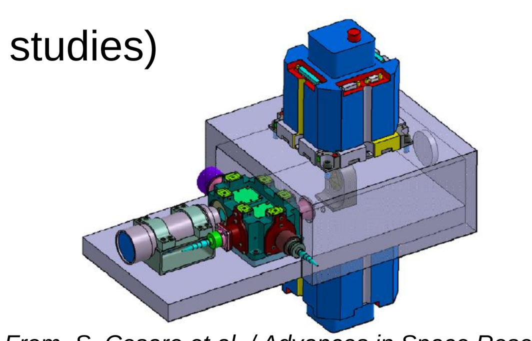
Two accelerometers part of CoM (one concept in NGGM studies)

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

$\Delta\vec{a}_{meas} = \left(-[Grad\,\vec{g}] + [\dot{\Omega}_S] + [\Omega_S^2]\right)\vec{x}_{P_1P_2}$

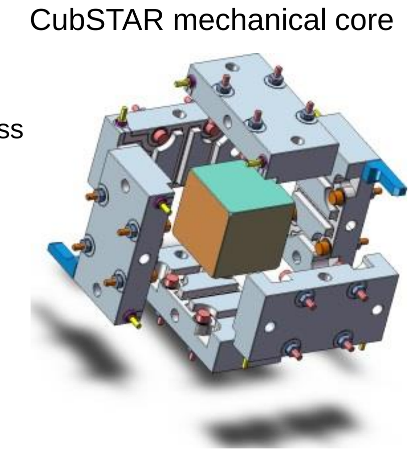


From S. Cesare et al. / Advances in Space Research 57 (2016) 1047–1064 © Thales Alenia Space

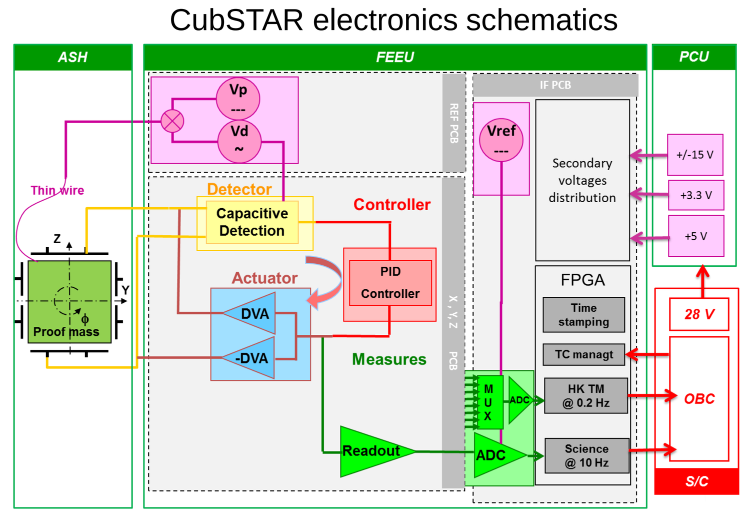
CubSTAR – Electrostatic ACC for Cubesat

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

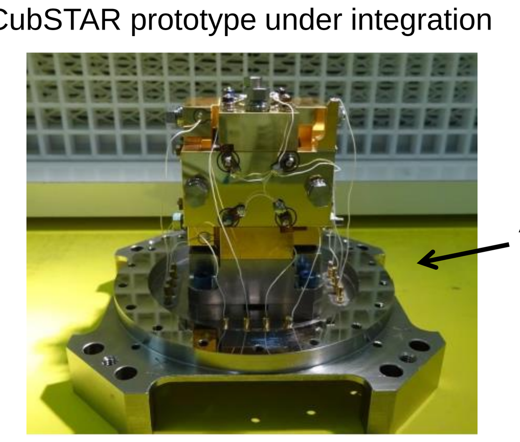
CubSTAR mechanical core

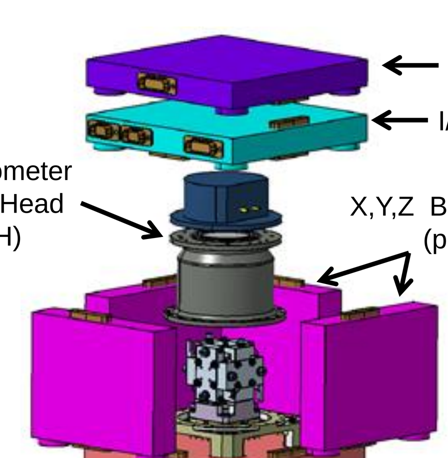


CubSTAR electronics schematics

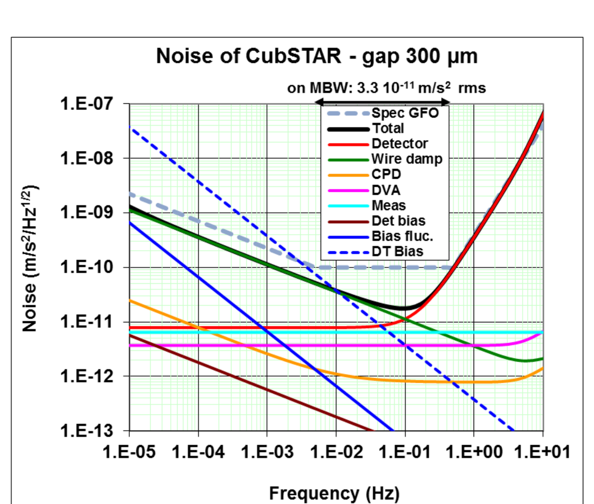


CubSTAR prototype under integration



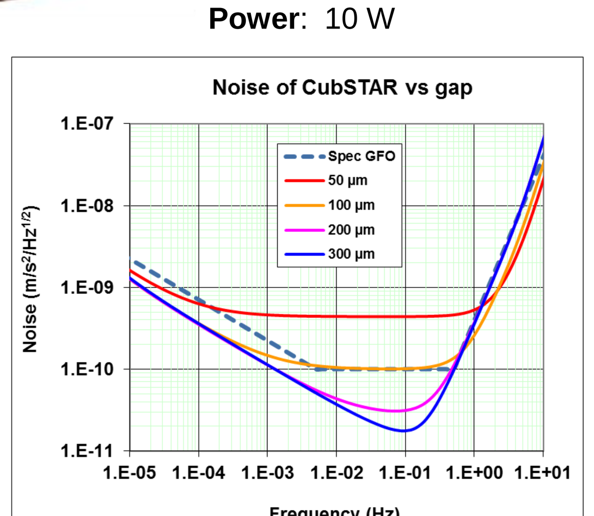


Volume : 150x150x200 mm (1U for ASH)
Weight: 4.5 kg (1,4 kg for ASH)
Power: 10 W



Variation of noise with respect to the gap between proof-mass and electrode:

Possible to adapt the design for various missions

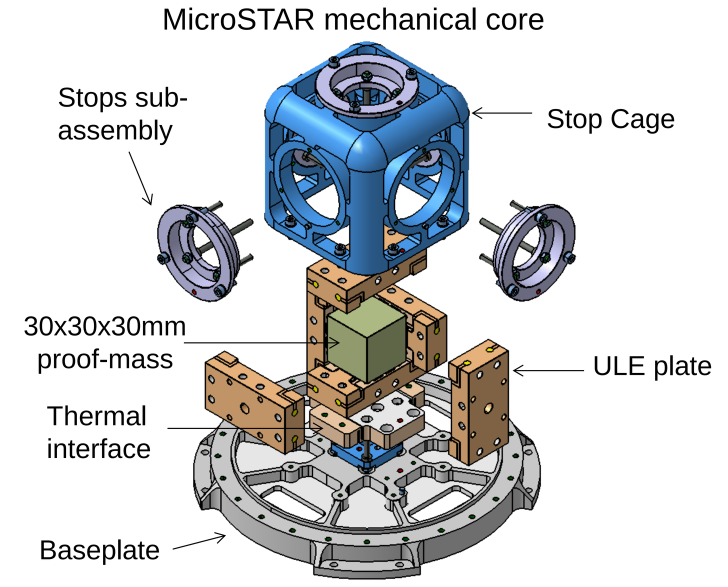


Measurement range : ± 1.3 10^{-4} m/s²
Measurement noise : 3.3 10^{-11} m/s² rms in [5 - 500]mHz
Thermal sensitivity : 2.1 10^{-8} m/s²/K @ 0.1mHz

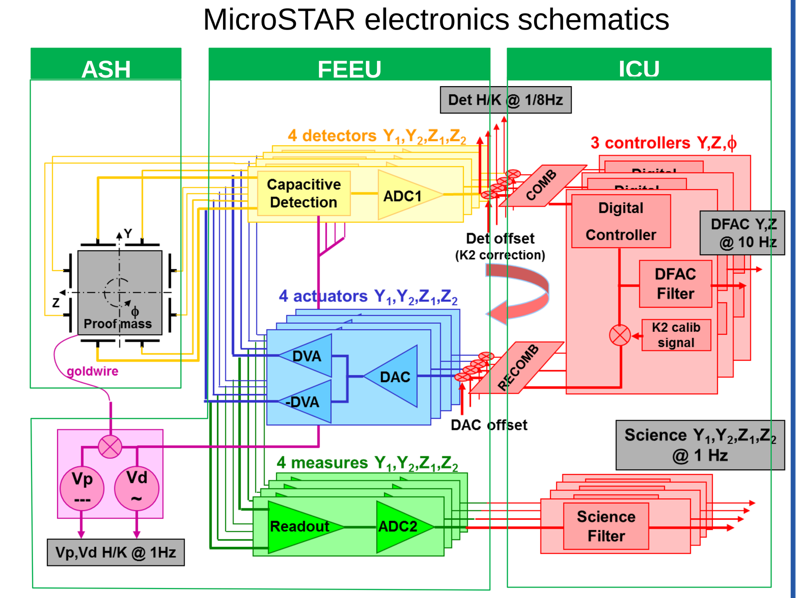
MicroSTAR – High performance electrostatic ACC

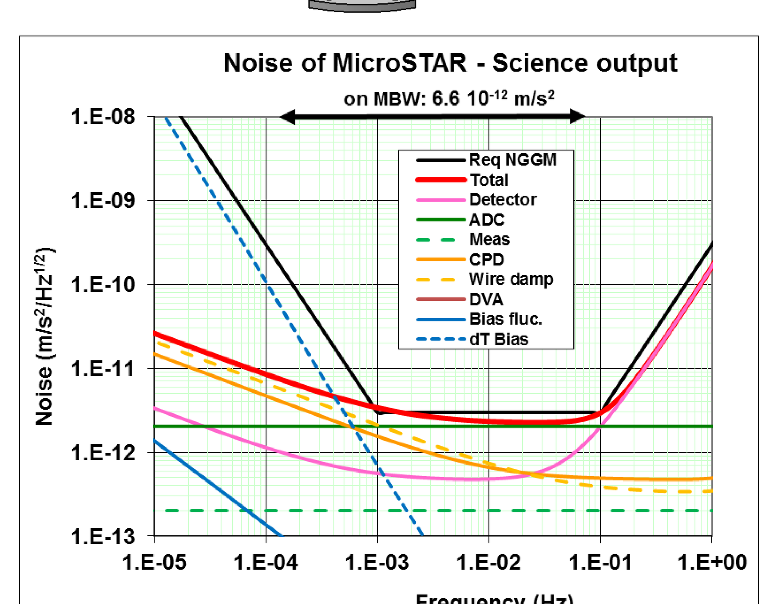
Accelerometer with a cubic proof-mass 3cm side :
- 3 linear acceleration with the same performance
- 3 angular acceleration for helping attitude recovery
- High performance
- Digital control of the proof-mass for flexibility (analog control also possible for lower consumption)

MicroSTAR mechanical core

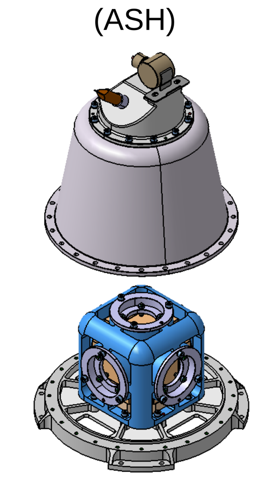


MicroSTAR electronics schematics

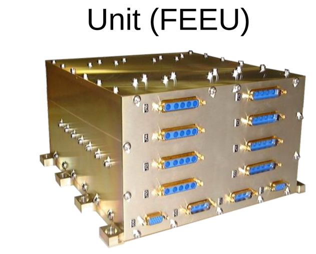




MicroSTAR Accelerometer Sensor Head (ASH)



MicroSTAR Front-End Electronic Unit (FEEU)



For 2 accelerometers
Image of GOCE FEEU

Proof-mass of 218g, gap of 400µm

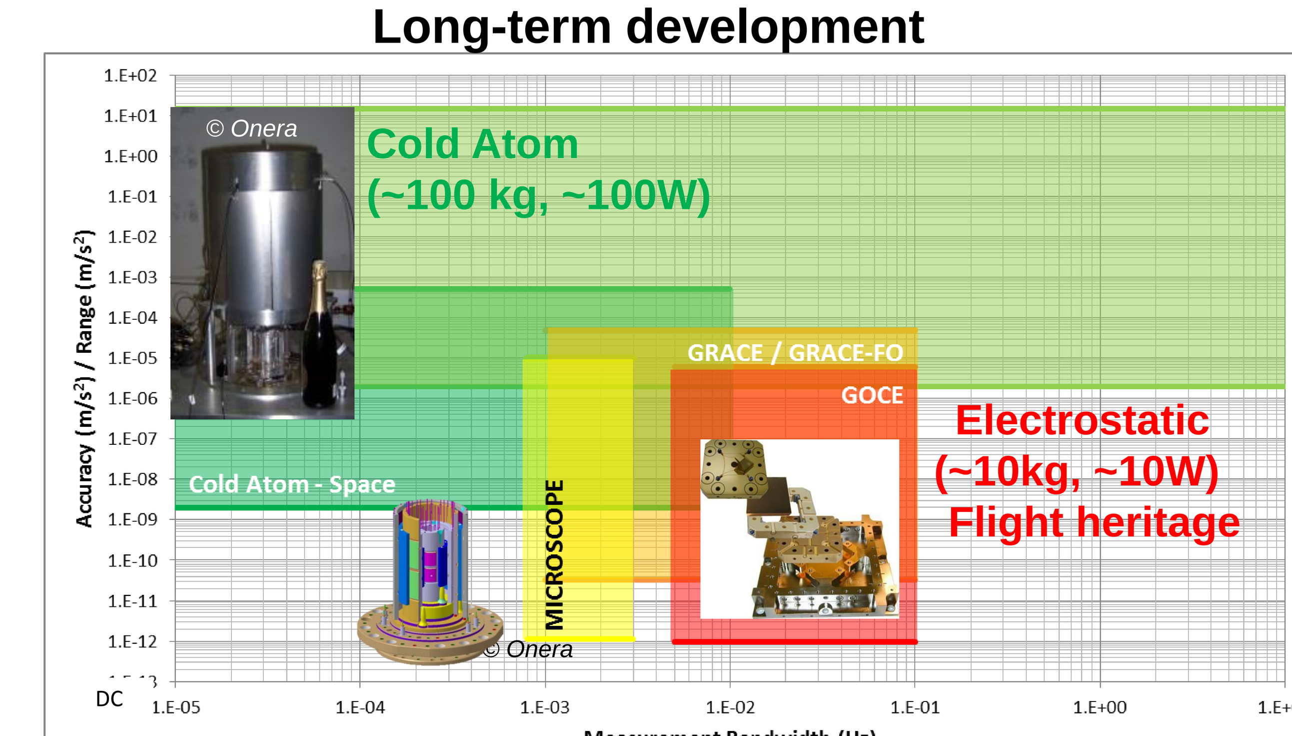
Measurement range : ±6.4 10^{-6} m/s²
Measurement noise : 6.6 10^{-12} m/s² rms in [0,2 - 100]mHz
Thermal sensitivity : 7.0 10^{-11} m/s²/K @ 0.1mHz

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

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

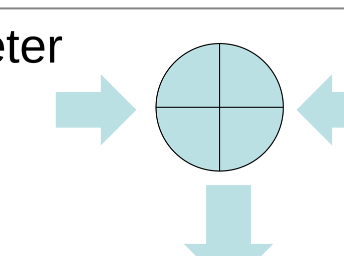
Hybrid-STAR : Atomic / Electrostatic ACC

Long-term development

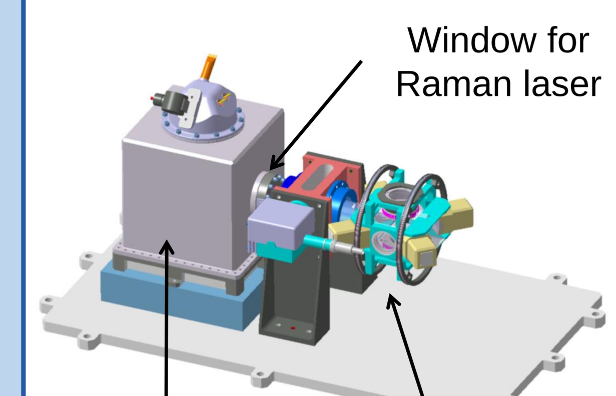


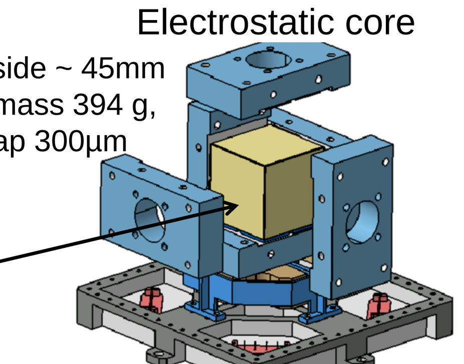
Cold atom interferometer
Stability

Electrostatic accelerometer
High accuracy in MBW

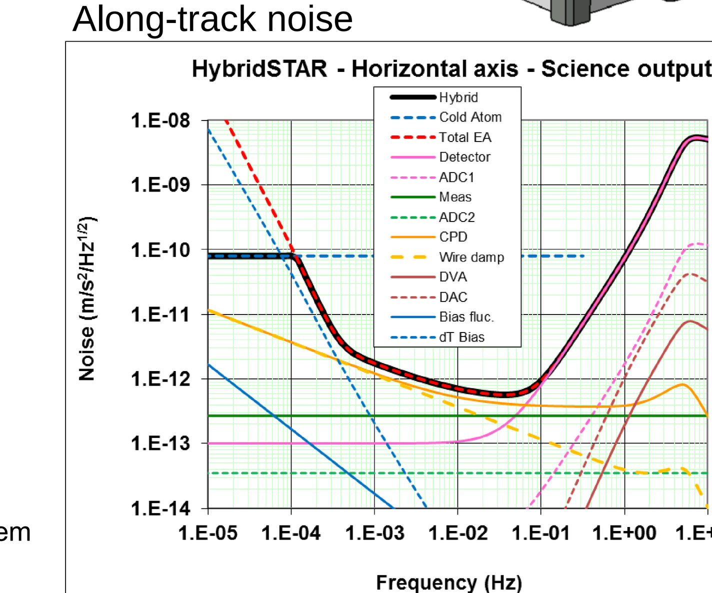


Hybrid-STAR
Use of the proof-mass as mirror for Raman laser





Along-track noise



Electrostatic + Atom Mechanics: 25kg
Atom optics: 150L, 40kg, 200W

With mature technology, for T=1s with ~2x10⁶ detected atoms:
Measurement range : ±3.7 10^{-6} m/s²
Measurement noise : 2 10^{-12} m/s² rms in [1 - 100]mHz
Thermal sensitivity : 7.0 10^{-11} m/s²/K @ 0.1mHz

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/NL/FF/mg funded by the European Space Agency.