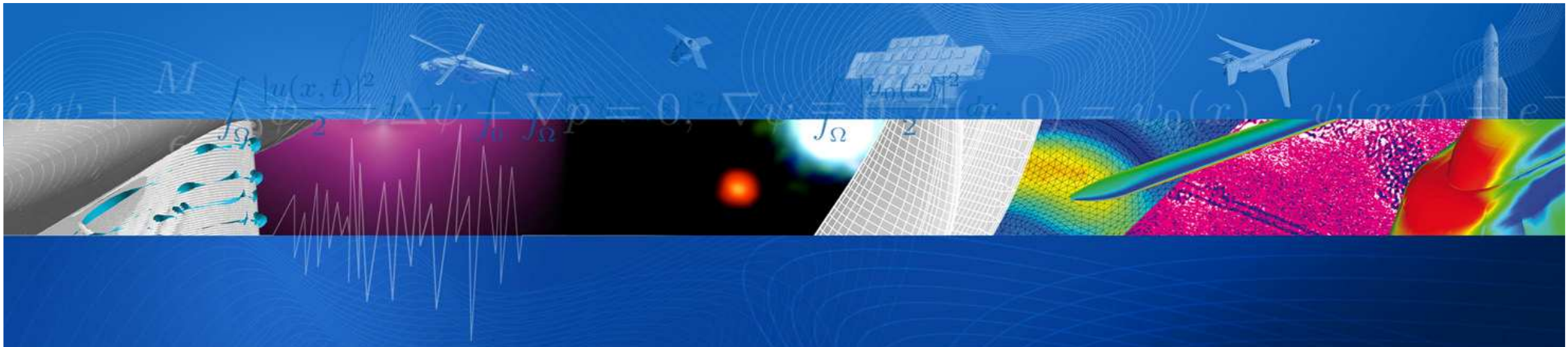


STATUS OF GAP: AN ELECTROSTATIC ACCELEROMETER FOR INTERPLANETARY FUNDAMENTAL PHYSICS

Françoise Liorzou, ONERA/DMPH

ONERA

THE FRENCH AEROSPACE LAB

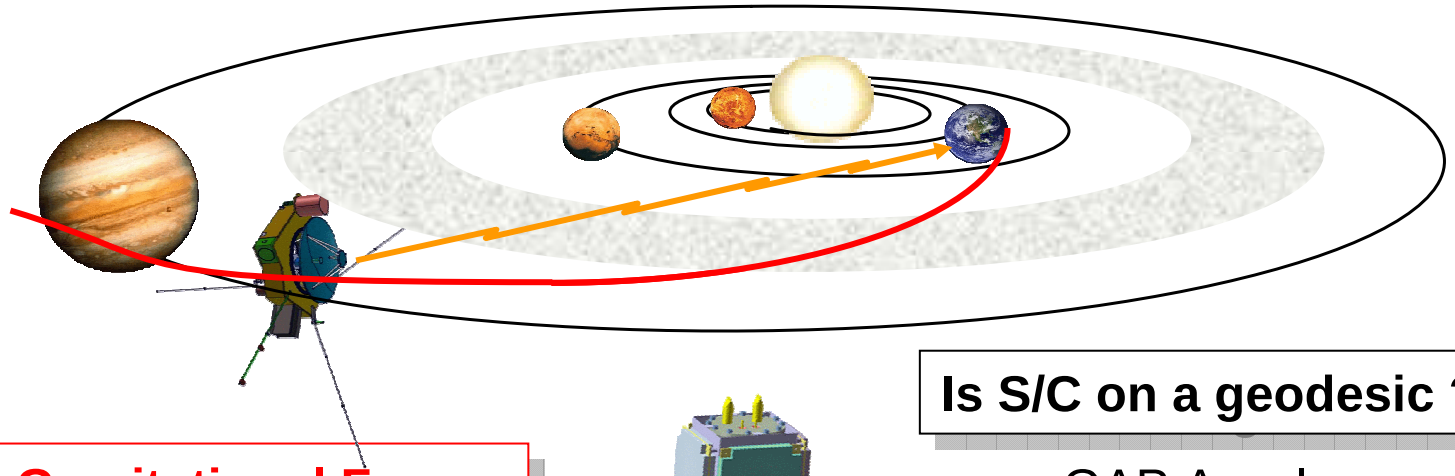
return on innovation

GAP (Gravity Advance Package) instrument purpose

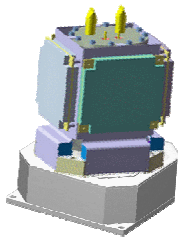
General Relativity shall be deeply tested to find deviation allowing unification of the four fundamental forces.

Some tests could be done through accurate navigation of S/C in the Solar system, with an DC accelerometer on board.

GAP (3.5kg, 3W), electrostatic accelerometer based on heritage of Earth gravity mission adapted for interplanetary mission



Non Gravitational Forces



Is S/C on a geodesic ?

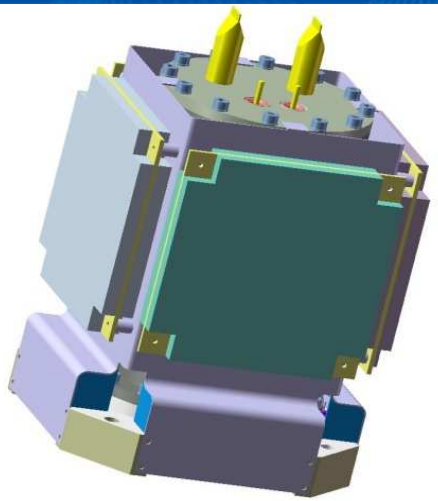
GAP Accelerometer
< 10 pm/s^2

Content of the presentation

ONERA is currently developping a GAP prototype

- **GAP prototype**
  - Principle of electrostatic accelerometer
  - Heritage
  - Principle of the bias rejection
  - Accelerometer Design
  - Manufacturing, Integration and Testing
  - GAP prototype status

GAP - Description of the instrument

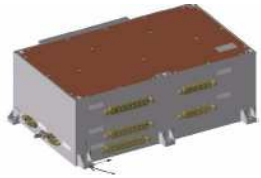


Electrostatic accelerometer

CHAMP, GRACE and GOCE missions

1.4 kg

1.4 W



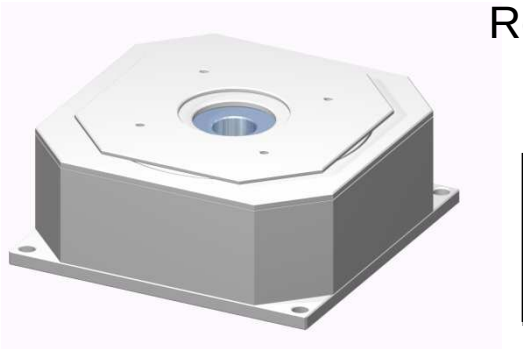
Interface and Control Unit

1.0 kg

1.4 W

Bias rejection system

Rotating stage with piezo-electric motor



1.1 kg

0.2 W

MicroSTAR

Gravity Advanced Package (GAP)

3.5 kg

3 W

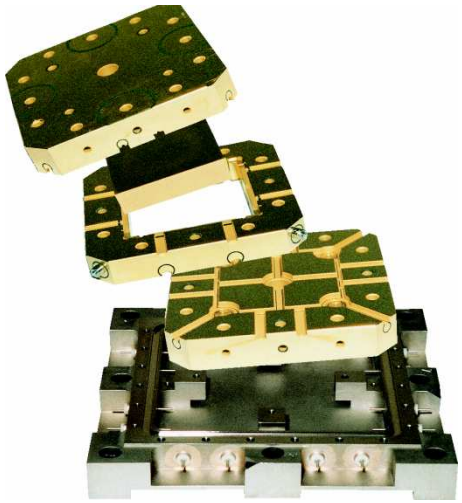
ONERA ULTRA SENSITIVE ACCELEROMETER : a specific concept for micro-gravity range and high resolution

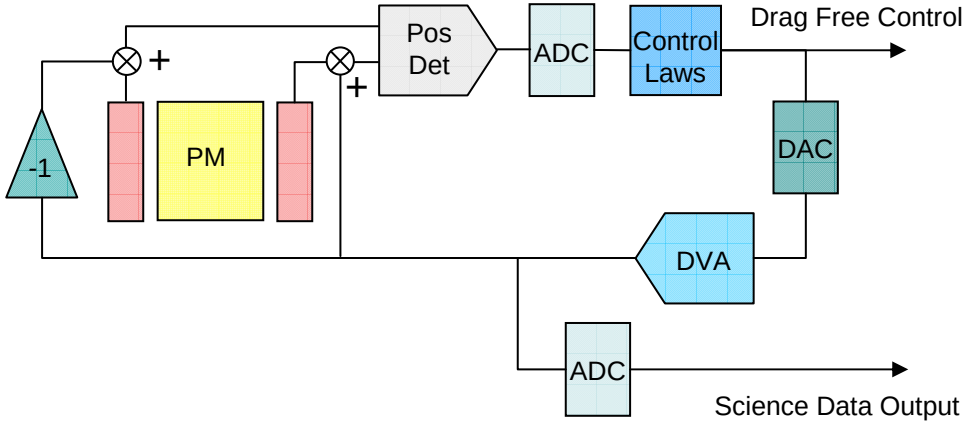
To measure weak acceleration in space environment **:**

- **One inertial mass, in free fall, quasi free of any motion**

→ **Very high capacitive position sensing accuracy : < 0.1 Angström**

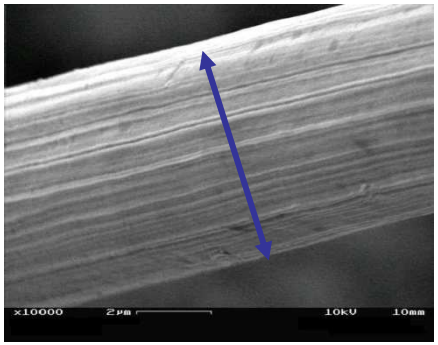
→ **Very weak electrostatic forces, servo-controlled and finely measured**





Gold wire

Glue spot and gold wire



Electrostatic levitation of the inertial mass (6 axes) :

Six channels with capacitive position sensing & electrostatic actuators using same electrodes

→ ***Very steady and accurate geometrical and electrical configuration : gold coated silica glass***

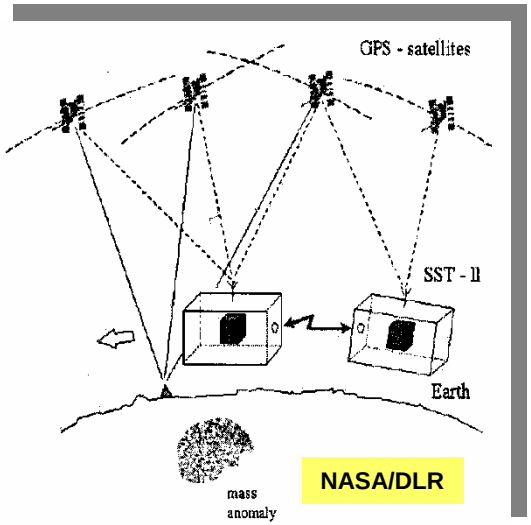
→ ***All 6 DoF servo-controlled to maintain the mass motionless*** **wrt the electrode cage**

→ ***Measurement of all electrical potentials surrounding the mass***

→ ***6 delivered accelerations***

ONERA ULTRA SENSITIVE ACCELEROMETER
Recent space missions

GRACE (March 02-->)
GRACE-FO (2017 →)

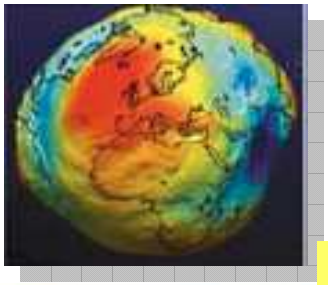


NASA/DLR

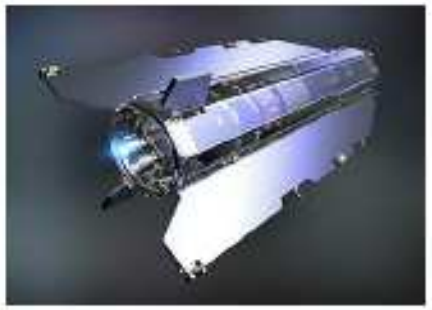
2 Accelerometers to measure the non gravitational S/C accel.
+ GPS receiver
+ Doppler radio link

Earth field seasonal variations
→ hydro., ice, geophysics, clim.
10^{-10}ms-2/sqrt(Hz)
1µms^{-1}

GOCE (March09-->)



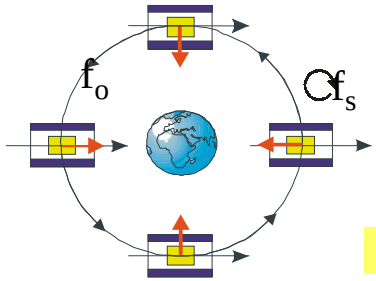
ESA



6 Accelerometers to measure the
- Gravity Gradient Tensor
- non gravitational S/C accel.
-S/C attitude motion
+ GPS receiver

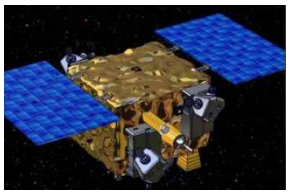
Earth field high harmonics
→ accurate mean ref. model
2.10^{-12}ms-2/sqrt(Hz)
6 mE

MICROSCOPE (2016-->)



CNES

Platinum
Titanium



2 differential Accelerometers
-Control of the masses
on the same orbit
- Control of S/C attitude motion
+ GPS receiver

Equivalence principle test
→ accurate of 10^{-15}

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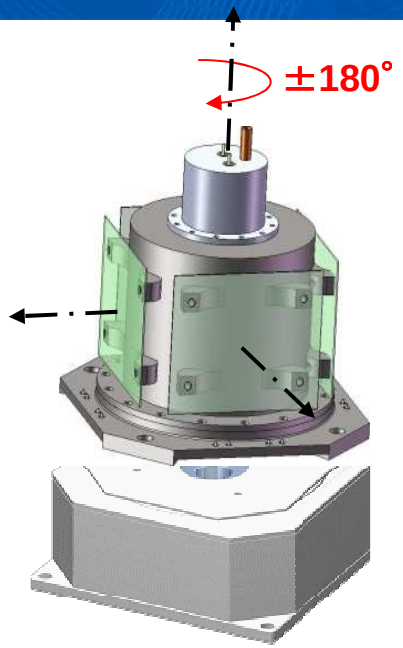
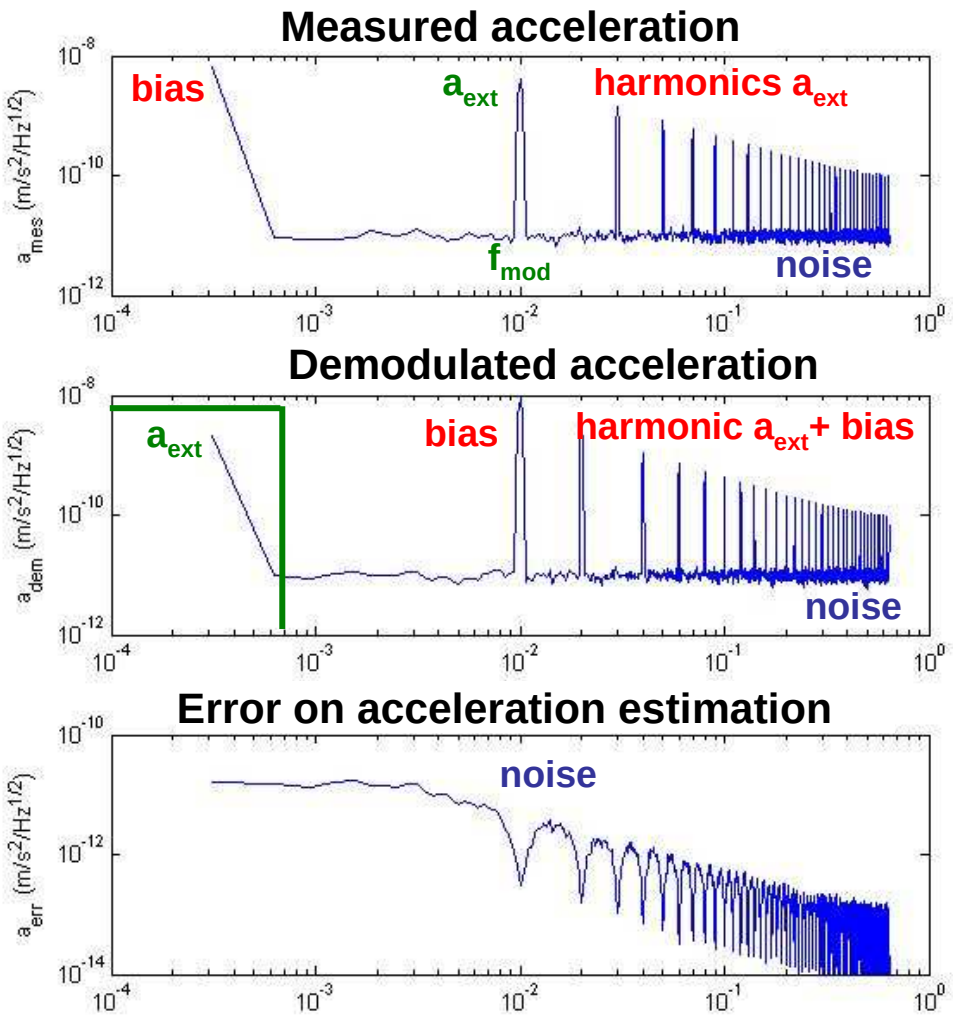
Bias rejection principle

Frequential Domain



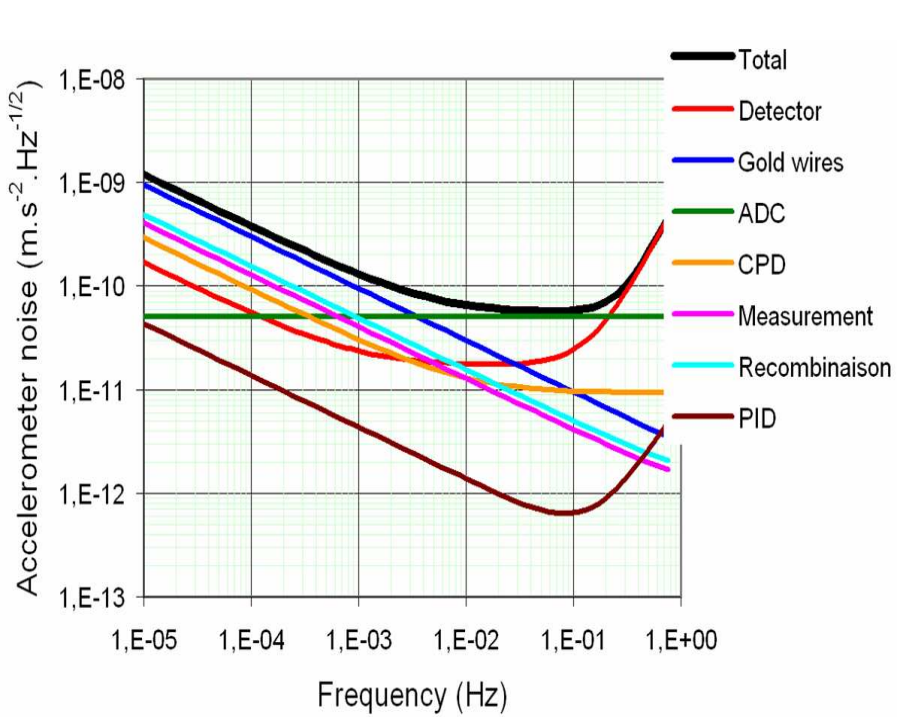
The bias rejection system is based on the well known heterodyne principle.

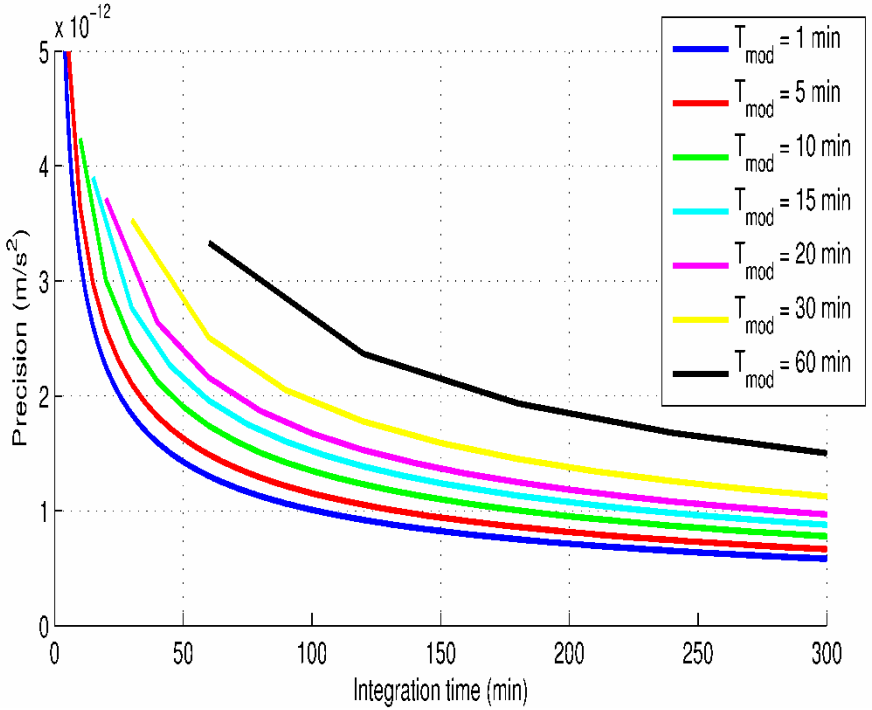
The usefull signal is modulated in the measurement by regular turn-over of the accelerometer itself. It allows to separate in the frequency domain, the bias from the external acceleration and to take advantage of the good accuracy of the accelerometer at the frequency of modulation.



<u>Ground processing</u>:
Demodulation
Low-pass filtering

GAP - Precision of the measurement



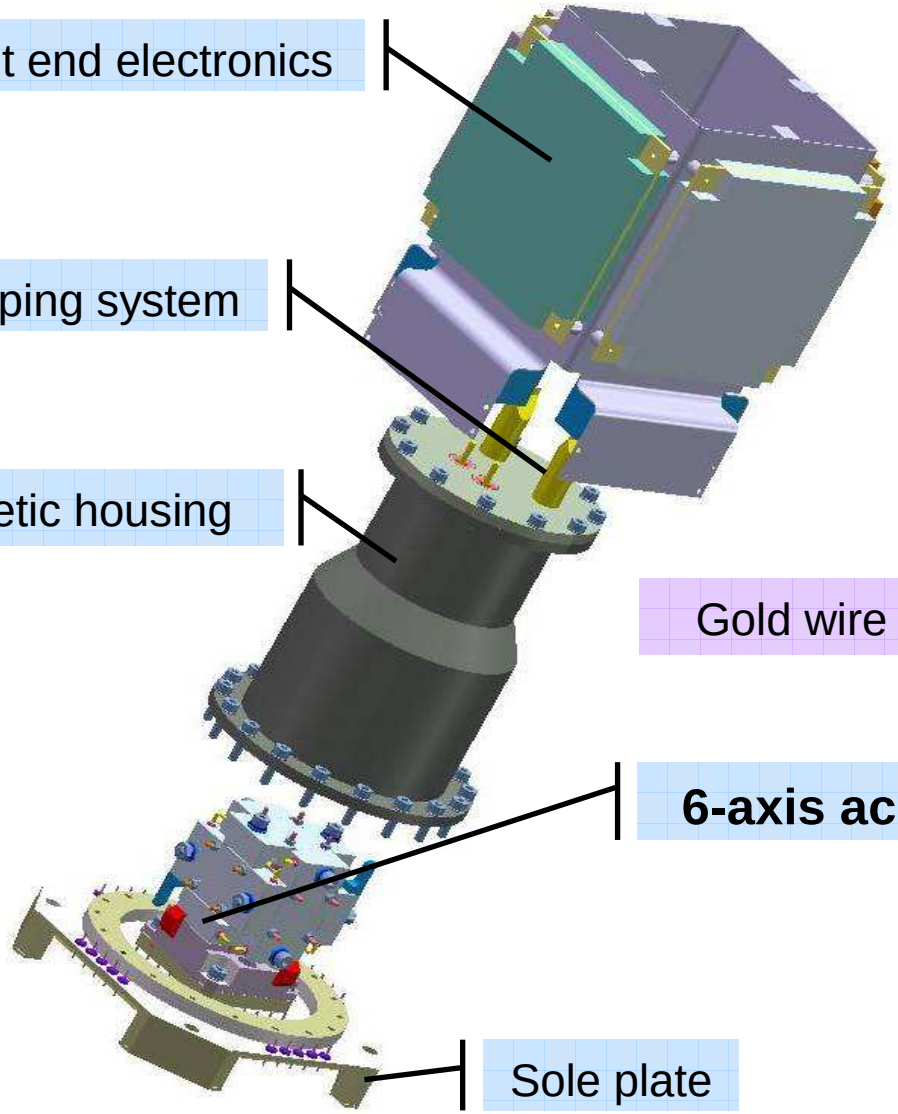


B. Lenoir, B. Christophe & S. Reynaud, 2011. Unbiased acceleration measurements with an electrostatic accelerometer. arXiv:1105.4979.

Precision = **1 pm.s^{-2}** for a modulation period of **10 min** and an integration time of **3 hours**.

But the final performance depends also on the integration in the S/C

GAP - Description of the Microstar accelerometer



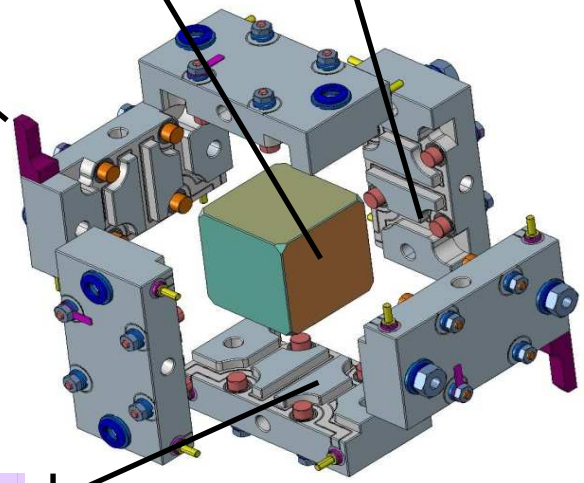
Front end electronics

Pumping system

Hermetic housing

6-axis accelerometer

Sole plate



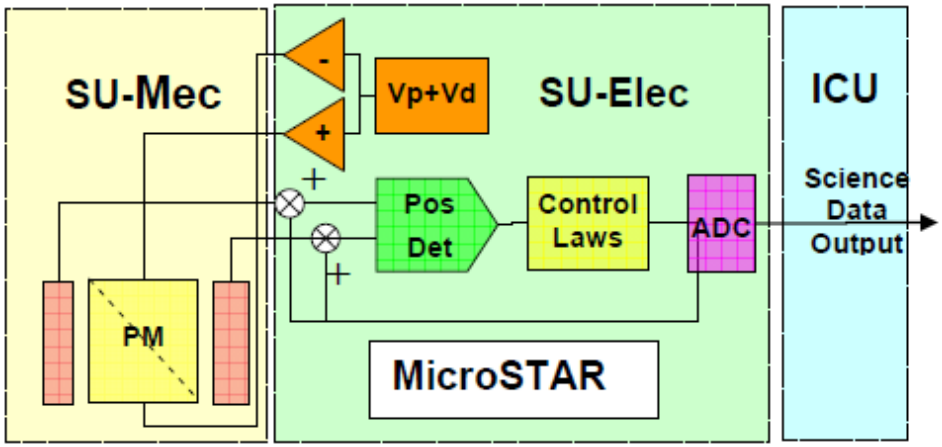
Stops

Proof mass (ULE)

Gold wire holder (ULE)

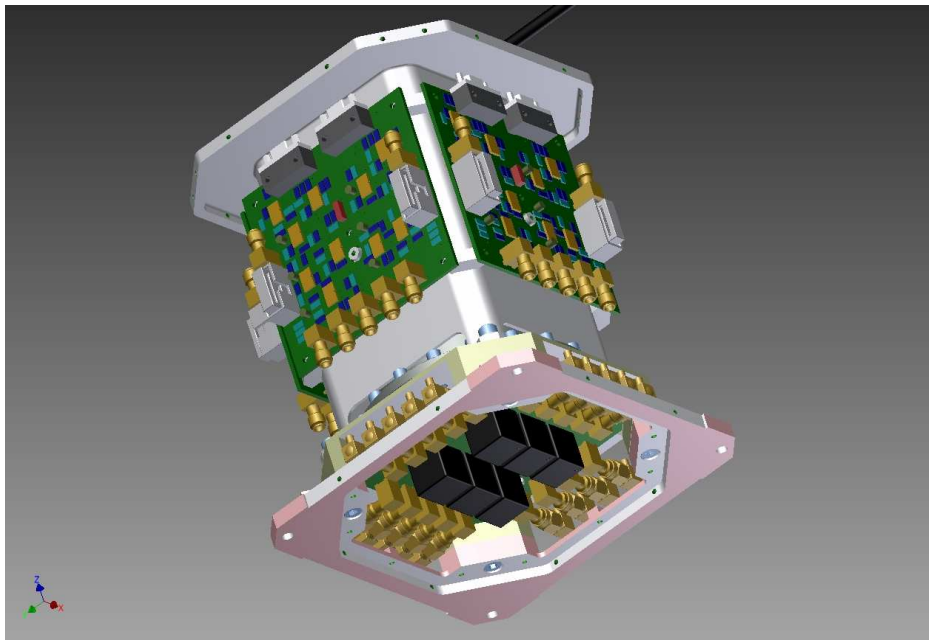
Electrodes (ULE)

GAP – Microstar Characteristics



Mechanical characteristic : Prototype testable on ground

	X	Y	Z
Proof mass dimension	20.400 mm ±0.002	20.900 mm ±0.002	20.900 mm ±0.002
Mass		22.5 g (Zerodur, density 2.53)	
Gap	**300 µm**	50 µm	50 µm
Free motion	± 30 µm	± 15 µm	± 15 µm
Electrode surface	0.94 cm^2	0.94 cm^2	0.94 cm^2
Electrode capacitance	2.7pF	16.6pF	16.6pF
Gold wire		Length 17 mm, diameter 5 µm	



Electrical characteristics:

	X	Y	Z
Detection polarisation (Vd)		5 Vrms	
Polarisation voltage (Vp)		10 V	
detector Gain	12 V/pF	0.67 V/pF	0.67 V/pF
Maximum control voltage	15 V (7.5 V linear et 7.5 V angular)	15 V (7.5 V linear et 7.5 V angular)	15 V (7.5 V linear et 7.5 V angular)
Control laws	PID	PID	PID
Control range	1.75 10^{-4} m/s^2	4.4 10^{-3} m/s^2	4.4 10^{-3} m/s^2

Consumption: **1.19W**

	Nombre de circuits	Consommation / circuit	Consommation totale
Détecteurs	6	31 mW	186 mW
PID	6	50 mW	300 mW
Mesures scientifiques	8	15 mW	120 mW
Mesures auxiliaires	2 (8 mesures / circuit)	30 mW	60 mW
Générateur Vp/Vd	1	529 mW	529 mW
		Total	**1.19 W**

Microstar accelerometer - Realisation

1. ULE plate on ultra-sonic machine (ONERA patent)

2. Control

3. Gold coating

4. Gold cutting for isolating electrodes

5. Integration in clean room

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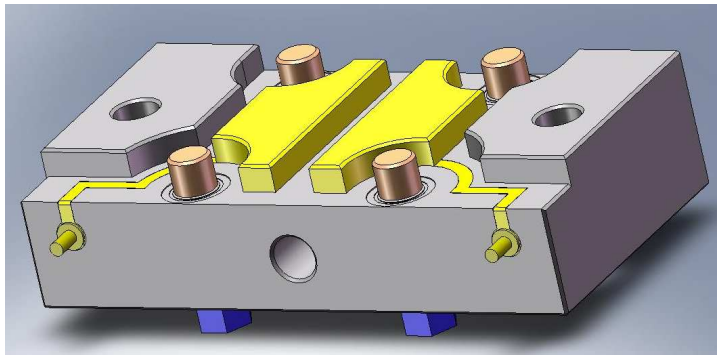
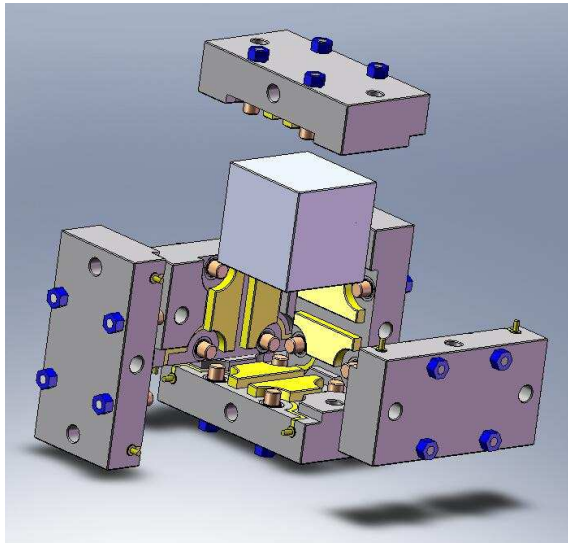
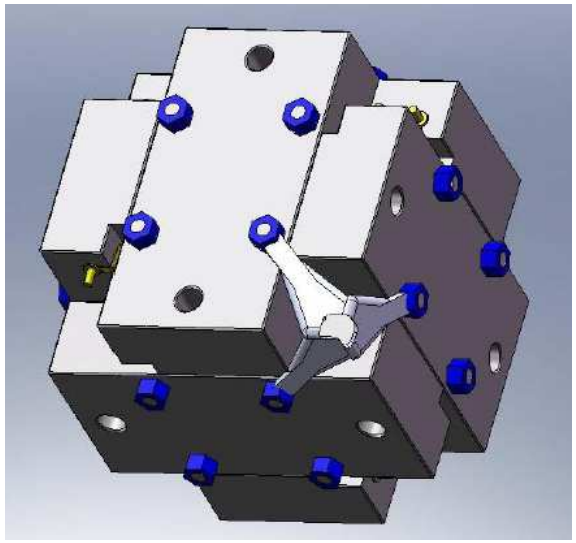
GAP - integration of Microstar

Electrodes plate

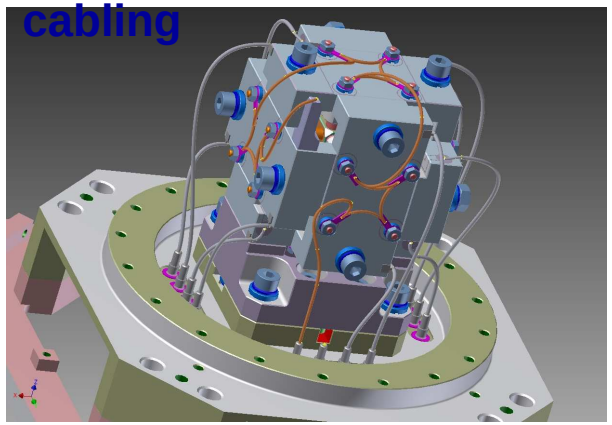


Accelerometer core

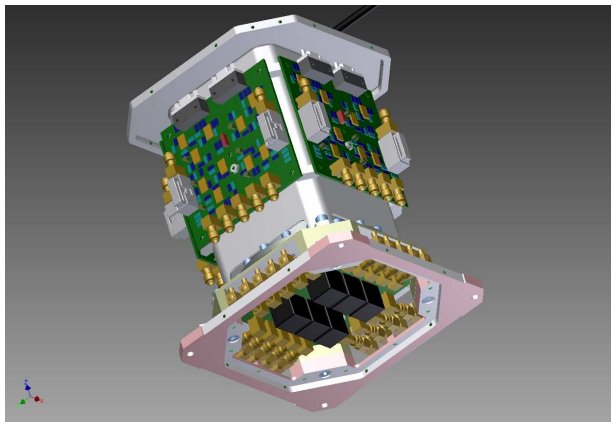




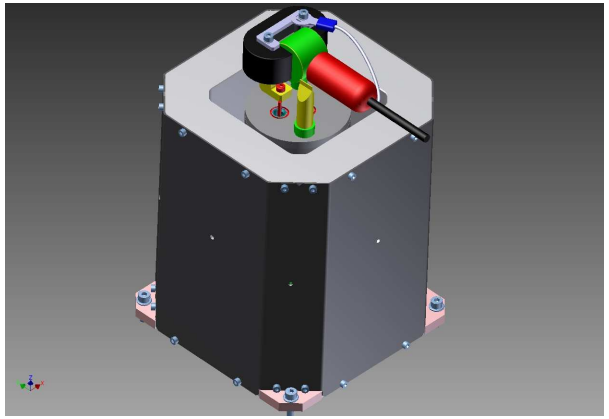
Electrodes internal cabling



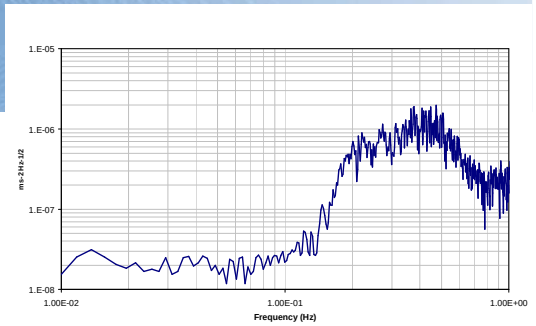
Electronic integration

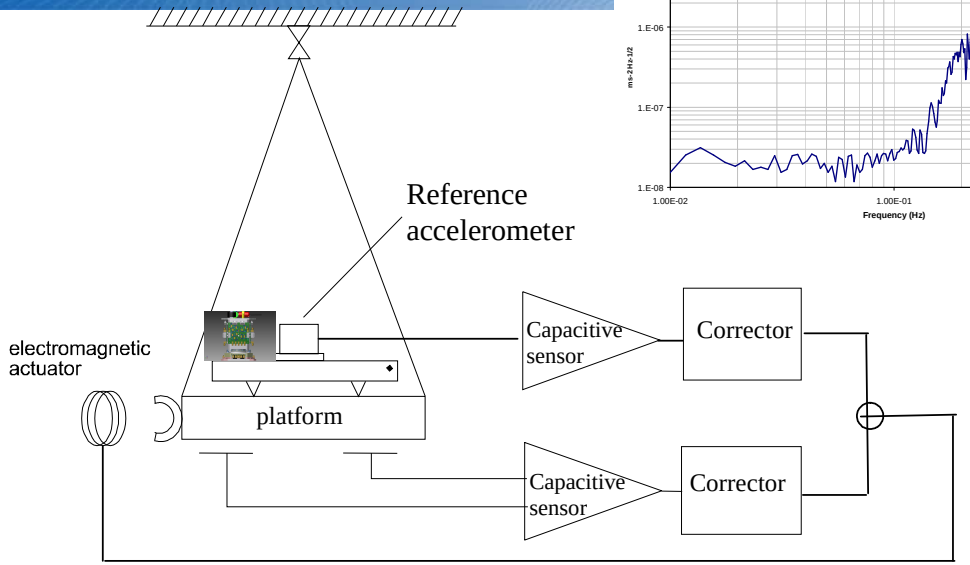


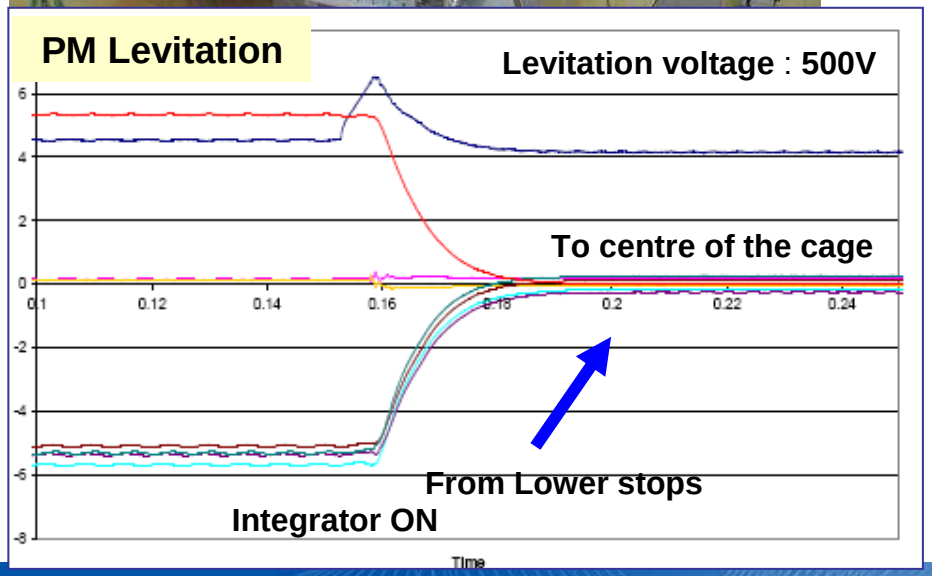
Final packaging



Microstar accelerometer – Testing on pendulum







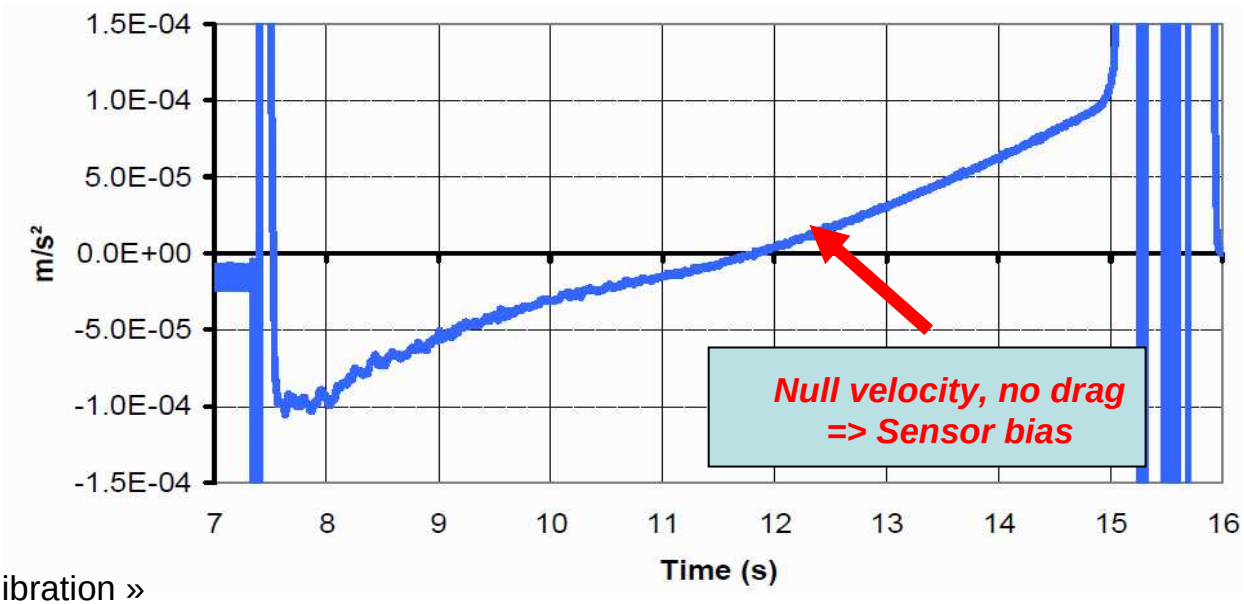
Suspended platform, servo-controlled by capacitive sensing of both the platform orientation and a reference accelerometer=> microgravity environment on the horizontal plane

Performance: about 3.10^{-8} $m.s^{-2}$/ sqr Hz from 0.01 to 0,1 Hz.

- **Test of Microstar accelerometer in the horizontal plane**
- **Test of the rejection bias system**

Microstar accelerometer – Testing on drop tower

The measurement of the acceleration along the drop axis coupled with the analysis of the capsule trajectory offers a practical way of assessing the sensor bias[1].



[1] « MICROSCOPE on-ground and in-orbit calibration »
Vincent Josselin, Pierre Touboul, Manuel Rodrigues, Françoise Liorzou

Conclusion

GAP (3.5kg, 3W), electrostatic accelerometer based on heritage of Earth gravity mission adapted for interplanetary mission

Bias of GAP is rejected, leading to an accuracy of 1 pm/s^2 at low-frequency ([0 – 10^{-4} Hz]

- **GAP accelerometer prototype status**
  - All procurements are achieved
  - The mechanical core is under manufacturing
  - The electronic is ready
    - Test of the accelerometer prototype foreseen in 2014
    - Test of the accelerometer prototype with the bias rejection system foreseen in 2015

=> Proposal for participation for missions towards Uranus and Neptune
(ESA Call for Science Themes – 2013)