Gravity Advanced Package (GAP) : an accelerometer for Jupiter Ganymede Orbiter

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on behalf of the GAP Instrument Team

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ONERA
THE FRENCH AEROSPACE LAB

3rd Instrument Meeting, Noordwijck, 18-20 January 2010

Scientific Objectives

GAP is an accelerometer for gravity test in the Solar System (to be combined with radio-science)

Fundamental Physics

Test of scale dependent gravity at $5\ 10^{-11}$ m/s^2 from FPAG recommendation confirmed by FP Roadmap

Precise orbit determination of interplanetary spacecraft is an excellent tool to test general relativity and alternate theories of gravity. […] This is of particular interest for missions that cover large parts of the solar system (e.g. missions to the outer planets and Kuiper belt) in the light of scale dependent gravity.

Planetary Physics

Determination of gravity field at 10^{-8} m/s^2. from JGO Science Matrix

Coefficients of spherical harmonic expansion of gravitational field for geophysical analysis and interpretation in terms of interior structure. Time variations of the degree-2 field to an accuracy of 10^{-8} m/s^2 to yield tidally-induced distortion of satellite interior.

Why GAP is not in core payload ?

Decision of the EJSM JSDT on 17th of July, 2009

based on preliminary GAP WG report

- Fundamental Physics
  - Test of the inverse square gravity law(*) remains an open question, which is on the agenda of the ESA FPR-AT

Draft report of the FPR-AT is now in line:
http://sci.esa.int/fprat

- Gravity science at the Galilean moons
  - Two main views have been expressed. No consensus exists as to the benefit of including a GAP in the model payload for improving the science return with regard moon interiors and tidal coupling processes

(*) Wording of ESA-BR-247 (2005) Cosmic Vision 2015-2025 for scale dependent gravity, answering the following question:
Does Einstein's theory of gravity hold at very large distances?

Fundamental Physic Roadmap Report (Draft)

Scale dependent gravity is in the Fundamental Physics Roadmap

- Theories, which are candidates for achieving forces unification tend to lead to tiny violations of basic principles: …, the law of gravity may be modified at some scale (from microscopic to cosmological), …
- Given the immense challenge posed by the observed large scale behaviours (dark matter, dark energy), it is important to test the gravitational laws at all possible distances. The largest scales reachable with controlled, man-made experiments are of the size of the solar system, and thus space probes to the outer solar system play a special role in this context.

Importance to include Fundamental Physics objectives early in the mission design

- Planetary missions to the outer planets […] are optimized for their primary (planetary) objectives, and as a result the information available on fundamental physics is not always unambiguous and/or sufficiently precise. In future planetary missions, it would therefore be desirable to include fundamental physics objectives, and if necessary related instruments (when possible), at the earliest possible stages of the mission design.

Fundamental Physic Roadmap Report (Draft)

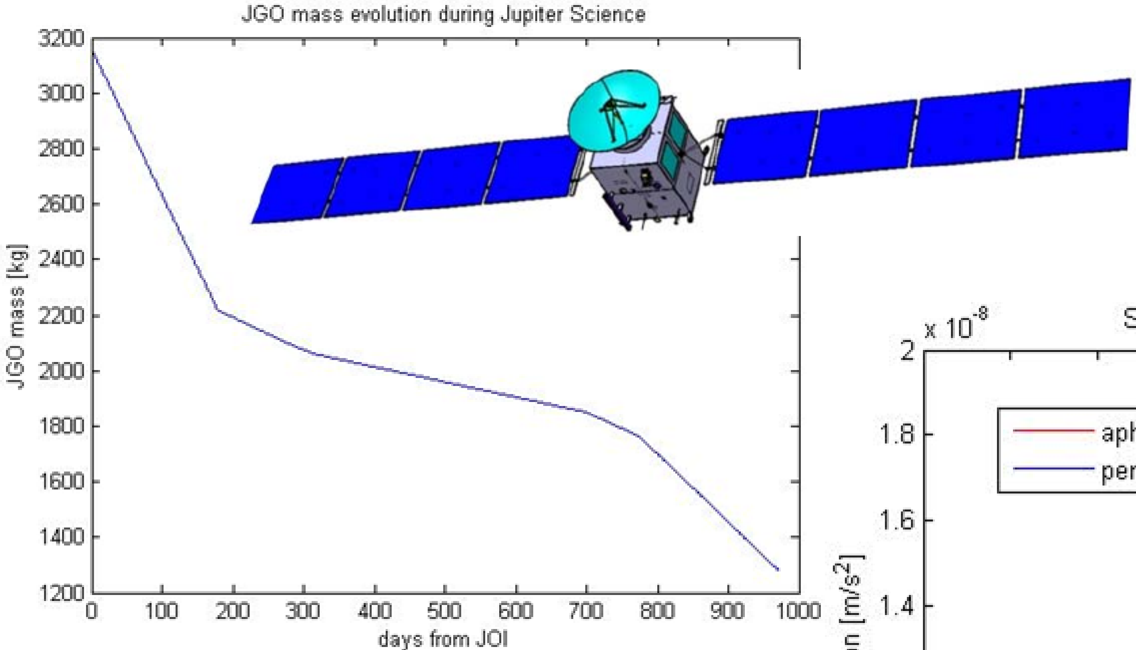
Use of an accelerometer is important for Fundamental Physics

- The use of a spacecraft as a proof mass for gravity tests requires an adequate knowledge (or estimation) of the non-gravitational accelerations.
- Quite generally, any instrument allowing significant reduction in the measurement uncertainty of the crucial observables is important for fundamental physics and other applications.

Use of an accelerometer is important for scale dependent gravity test

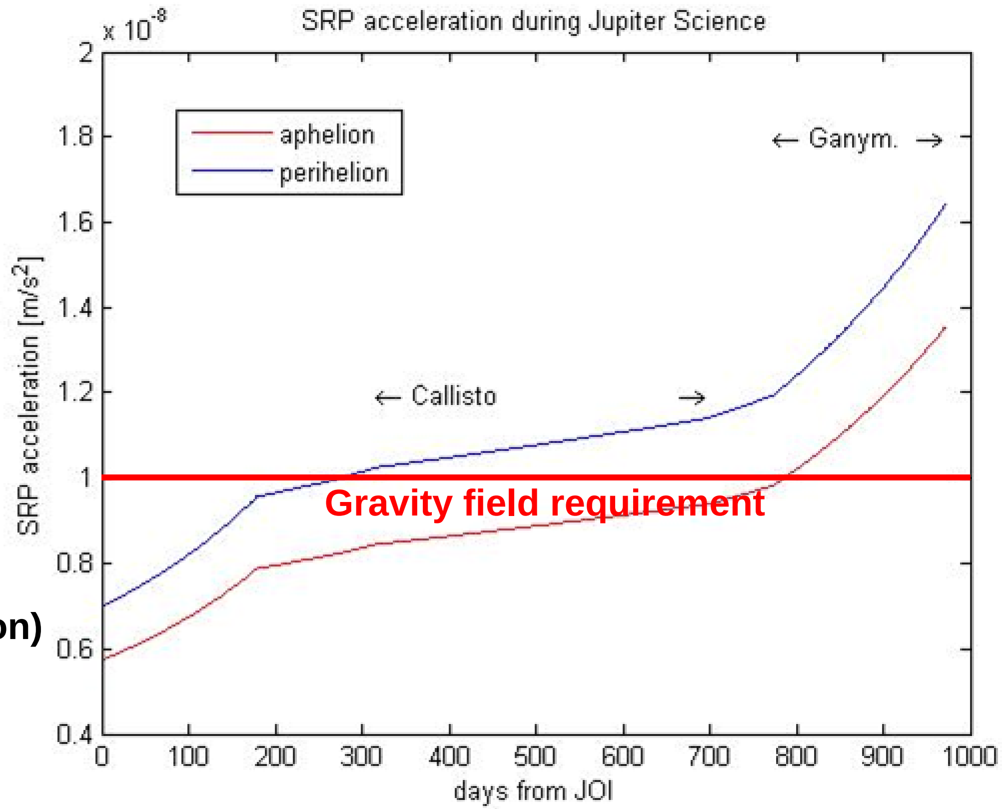
- In future missions to the outer solar system, the key technologies for the efficient study of scale dependent gravity are those required for precise spacecraft navigation and high precision timing: accelerometers and drag free technology, atomic clocks, high performance radio and/or optical links. Ideally, a combination of all of those technologies on a trajectory reaching the outer solar system would provide the most complete mapping of gravity at all attainable scales by man-made artifacts.
- More modestly, partial inclusion of such technology (with sufficient performance) on planetary missions and/or planetary landers would continue to provide useful information for fundamental physics.

Why an accelerometer for gravity field ?
- Direct Solar radiation pressure



$$a_{direct} = \frac{1}{m}(1+q)\cdot S\frac{P}{c},$$

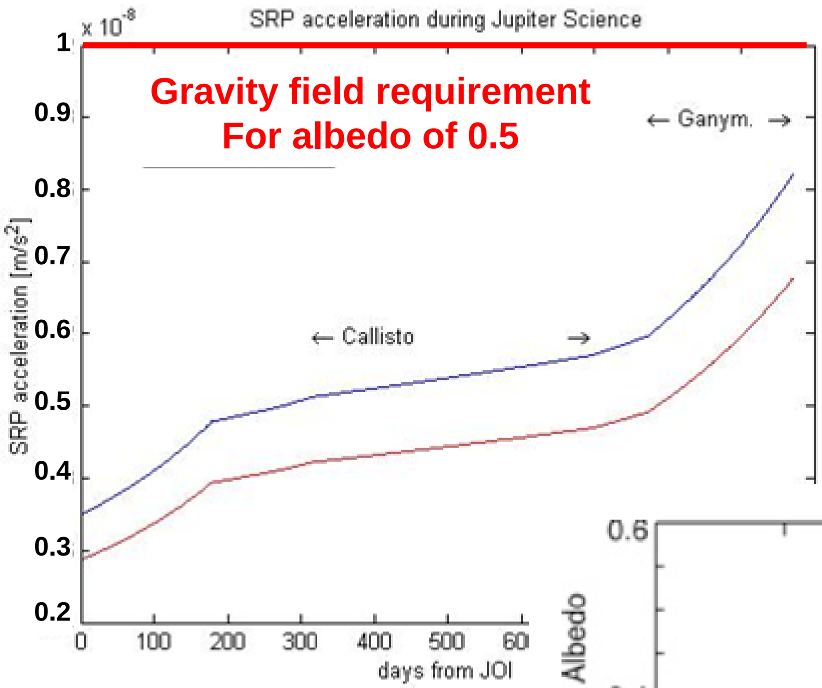
$$P = P_{Earth}\left(\frac{d_{Earth}}{d_{S/C}}\right)^2$$



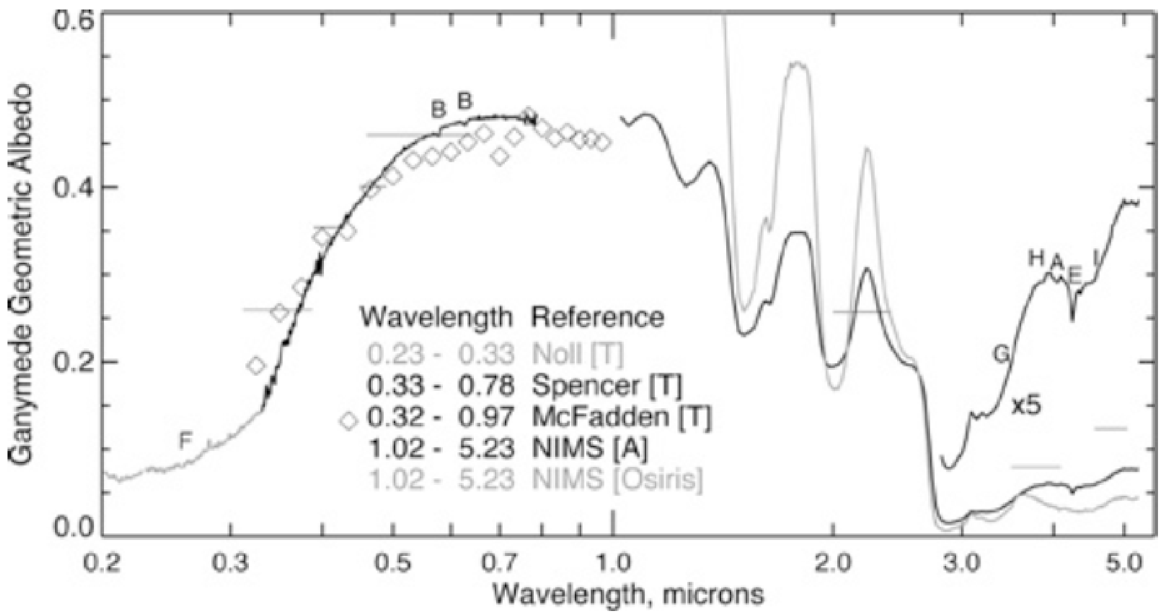
Based on ESA assessment study
- **Solar panel of 51 m²**
- **HGA of 2.8 m diameter**
- **Dry mass of 1264 kg**

From industrial studies (C. Erd presentation)
- **Solar panel > 60 m²**
- **HGA of 3.2 – 3.4 m diameter**
- **Dry mass of 1500 kg**

Why an accelerometer for gravity field ?
- Retro-diffused Solar radiation pressure

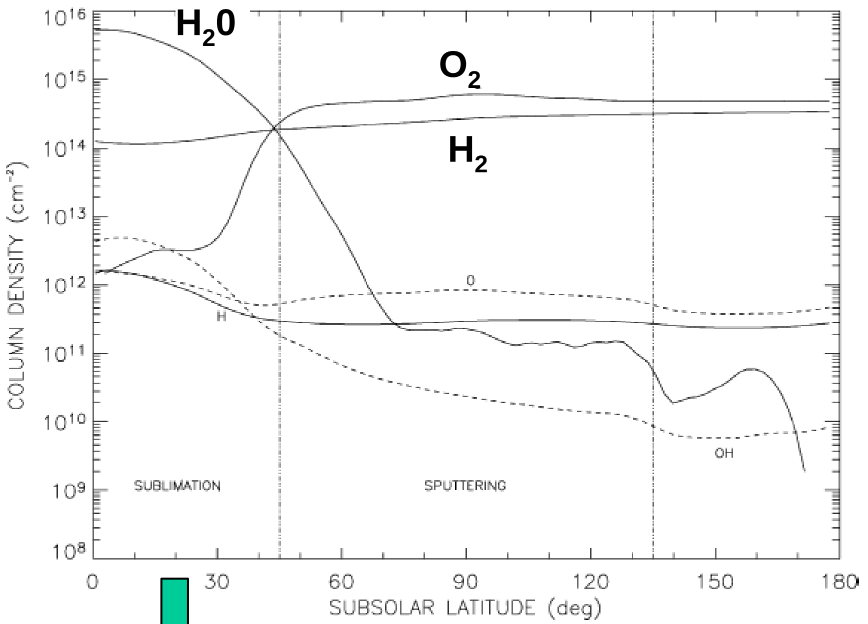


$$a_{albedo} = \frac{1}{m}(1+q)\cdot S\frac{P}{c}\cdot\alpha,$$



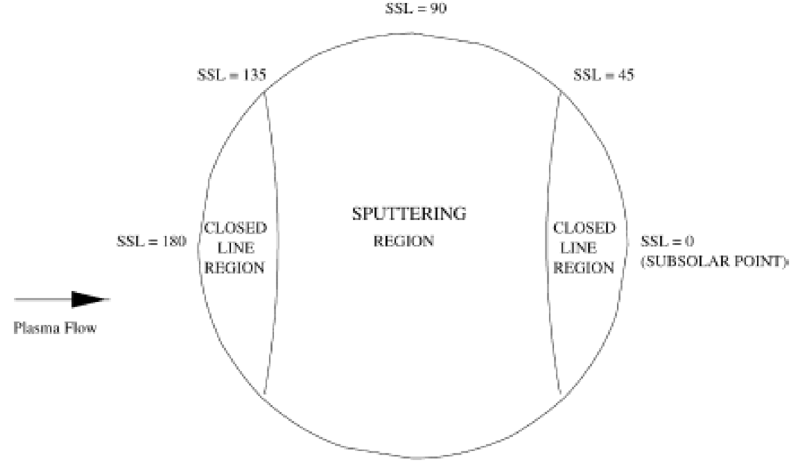
From Spencer et al. 2004: Appendix in: Jupiter: the planet, satellites and Magnetosphere, Bagenal, Dowling and McKinnon Eds., Cambridge Univ. Press (2004)

Why an accelerometer for gravity field ? - drag from tenous atmosphere

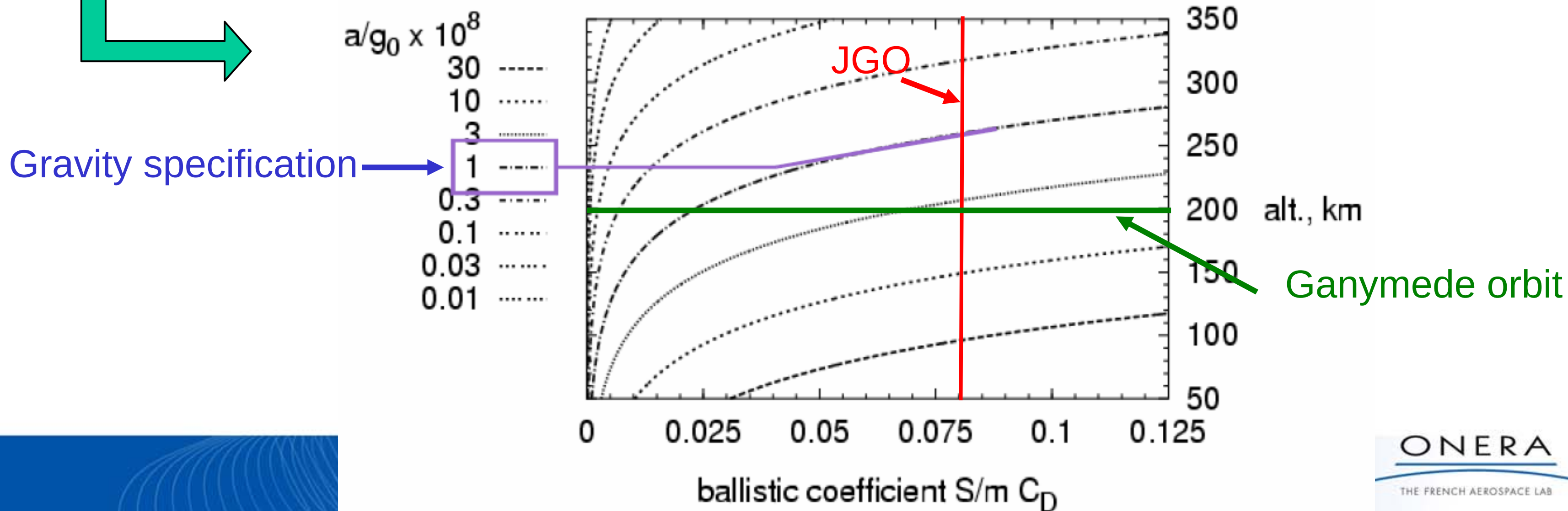


Ganymede (H_2O)

Kinetic model of Ganymede Atmosphere

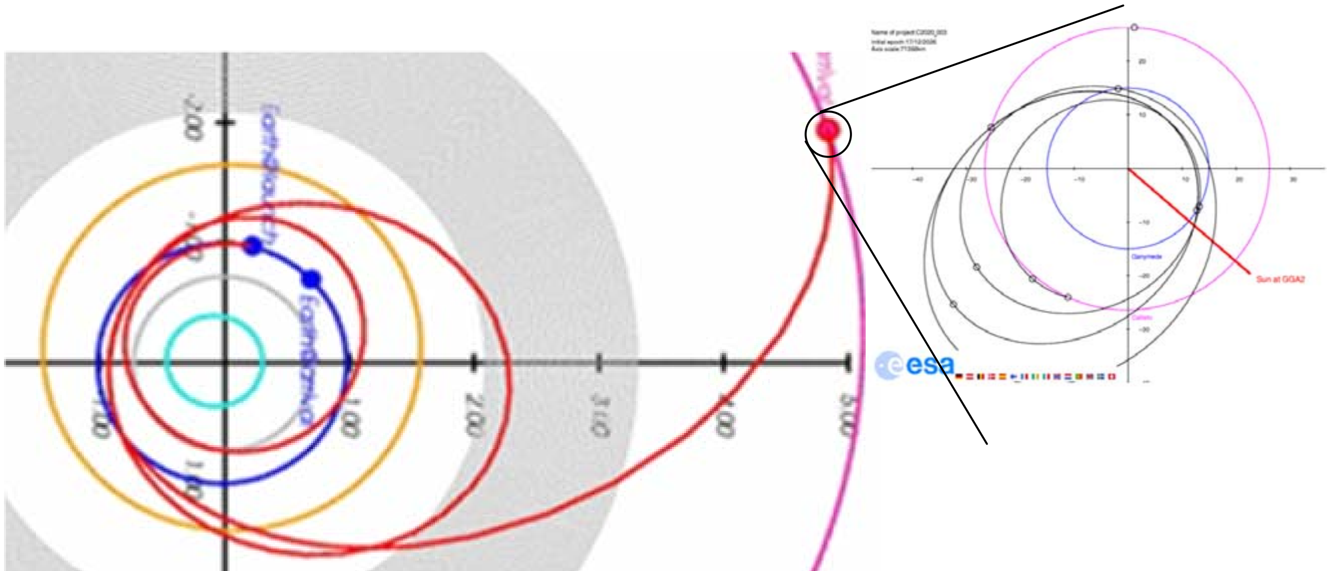


From Marconi, Icarus 190 (2007)



Main Scientific objectives of GAP

	Fundamental Physics	Jupiter System
Scientific objectives	Scale dependent Gravity	Ganymede interior Gravity
Requirements	$\delta a < 0.05\ nm/s^2$ DC – 10^{-4} Hz	$\delta a < 10\ nm/s^2$ 10^{-5} – 10^{-1} Hz
Period of measurement	Interplanetary cruise	Ganymede orbit

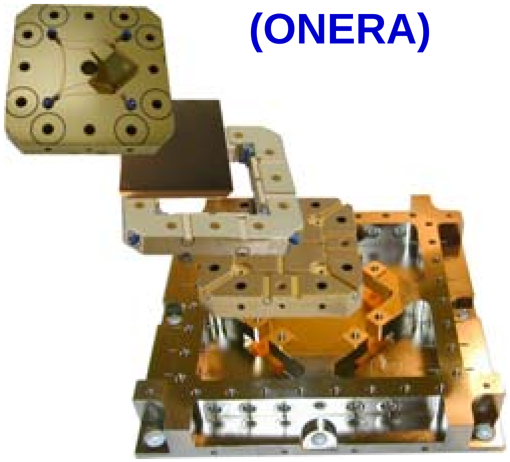


From ESA assessment study

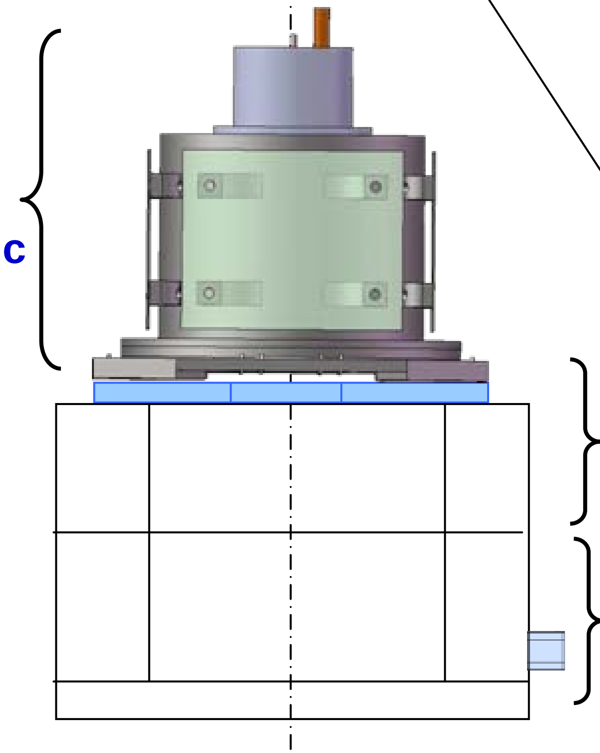
GAP: Accelerometer with "null" bias

Accurate accelerometer in DC domain for fundamental physics

MICROSTAR
Sensor Unit
Front-End Electronic
(ONERA)



ONERA heritage
GRACE - GOCE



Bias Rejection System
Rotative stage
(ZARM/DLR)

ICU
(ONERA)

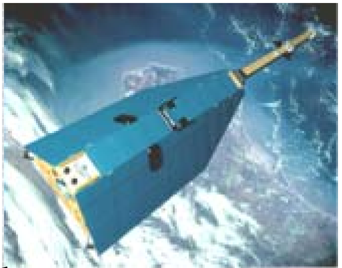
Volume = 3 l
Mass = 3 kg
Consumption = 3 W
Data rate = 300 bits/10s

Heritage of space rotary stage or filter wheel

ONERA Electrostatic Accelerometer

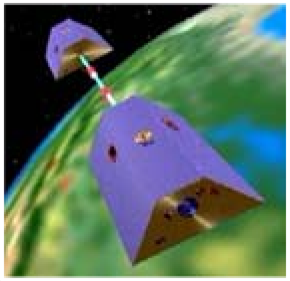
Earth Observation: geodesy, geophysics, oceanography, hydrography, climatology

CHAMP (CNES-DLR), July 2000



Range :	10^{-3} ms^{-2}
Noise :	9×10^{-10} ms^{-2}/Hz$^{1/2}$
MBW :	[0.1 - 100 mHz]
Bias :	1.6×10^{-5} ms^{-2}
	5.7×10^{-9} ms^{-2}/°C

GRACE (NASA-JPL), March 2002



Range :	2.5×10^{-4} ms^{-2}
Noise :	0.8×10^{-10} ms^{-2}/Hz$^{1/2}$
MBW :	[0.1 – 40 mHz]
Bias :	1.6×10^{-6} ms^{-2}
	4.7×10^{-10} ms^{-2}/°C

GOCE (ESA), March 2009

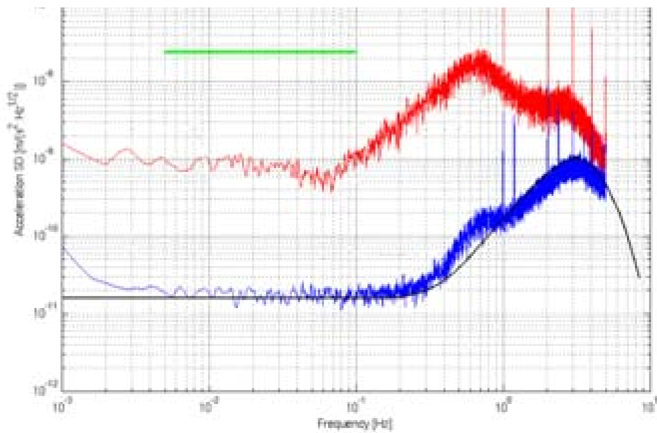
Range :	6×10^{-6} ms^{-2}
Noise :	2×10^{-12} ms^{-2}/Hz$^{1/2}$
MBW :	[5 – 100 mHz]
Bias :	1.3×10^{-7} m/s^2
	2.6×10^{-11} ms^{-2}/°C (Elec)
	7.8×10^{-11} ms^{-2}/°C (Meca)

Fundamental Physics: test of the Equivalence Principle, ...

MICROSCOPE (CNES-ONERA)

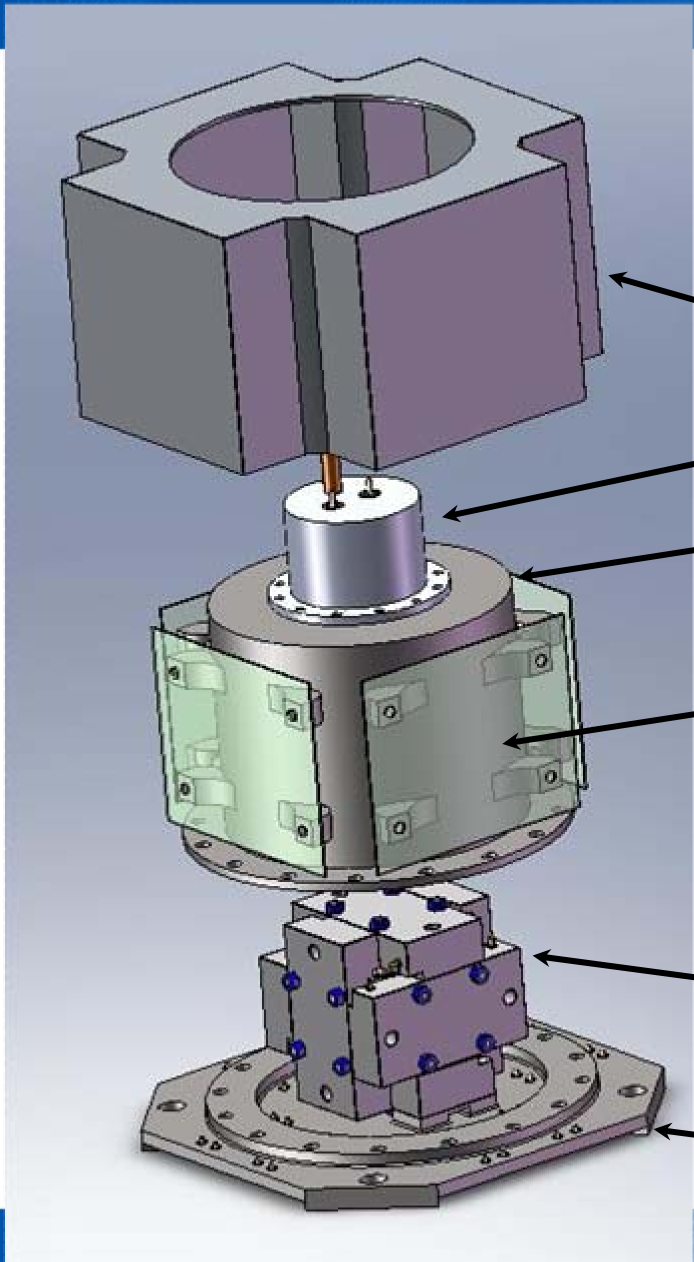
Range :	5×10^{-7} ms^{-2}
Noise :	10^{-12} ms^{-2}/Hz$^{1/2}$
MBW :	[0.1 – 30 mHz]
Bias :	10^{-8} m/s^2
	10^{-13} ms^{-2}/°C (Elec)
	10^{-12} ms^{-2}/°C (Meca)

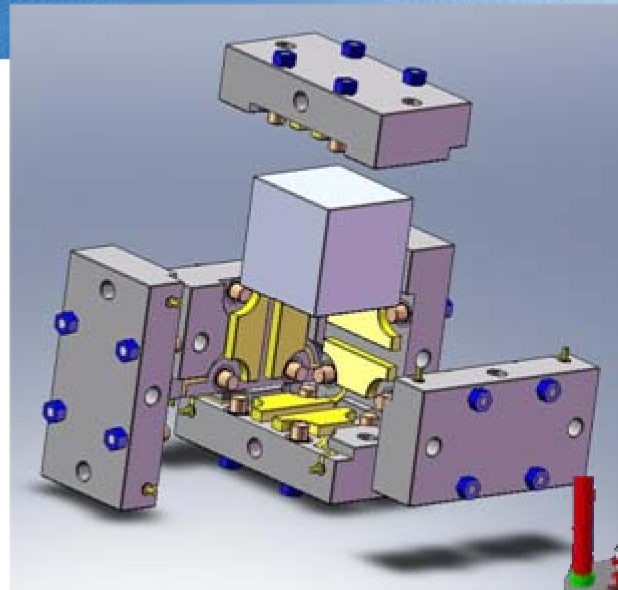
A.Allasio, D.Muzi, et al,
EUCASS 2009, Versailles France.



9 accelerometers in orbit

MICROSTAR Accelerometer Design

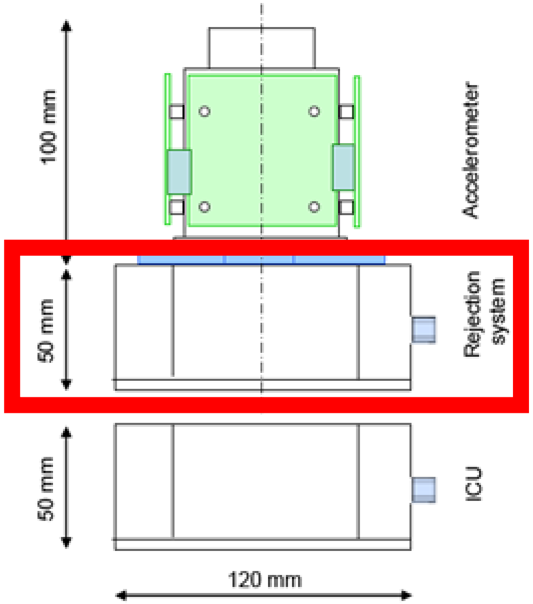




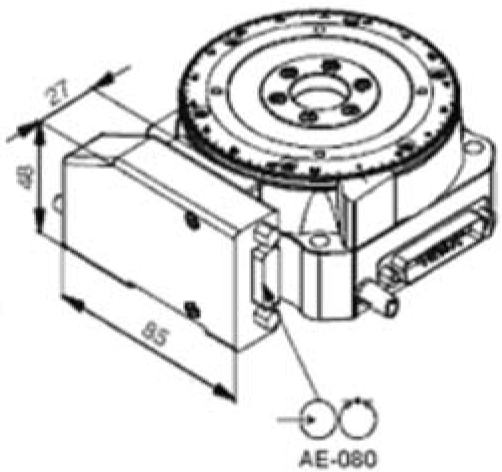
Prototype for ground testing under manufacturing

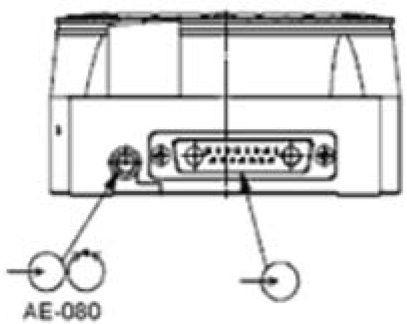
GAP subsystem - bias rejection system - ZARM

Side view



Design in progress



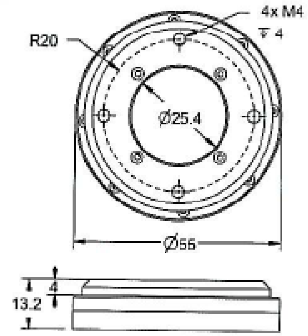


Contribution of ZARM:

Development of the Bias rejection system (rotative stage)

Thermal analysis

Actuator



Piezo-electric motor

SmarAct SR 5513-S

Angular encoder included

Light weight, robust, reliable

Interface to ICU and SU

under development

Space qualification

Space qualified piezo electric systems already exist. Example : Components by Cedrat Recherche SA for Rosetta/Midas

TRL 5 until end of 2012 possible

GAP subsystem - bias rejection system - ZARM

Functional Analysis for bias rejection system		Requirements for GAP	Feasibility with ZARM concept
		2.5 years (5.5 years) Spatial	
Rotation	Motor (with electronic) Trasnmission System Reductor	7500 flips Accuracy < 0.001° Rotation in 18''/s Consumption 6 W max (0.12 W moy)	✓
Guidance	Bearings	7500 180° flips Accuracy < 0.001° Load 2 kg	✓
Angular measure	Encodeur	Accuracy < 0.0005° No consumption when no flip	✓
Angular control	Motor control Open / Closed Loop in ICU	tbd	✓
Initialisation	Put at position 0° at start	Précision < 0.001°	✓
Kinetic moment compensation	S/C perturbation minimisation (at modulation calibration)	tbd	✓
Electric/data transmission	Power supply to accelerometer Data transmission to ICU	3 voltage supply (+/- 15 V, +5 V) 6 Digital Measure 24 bits	✓

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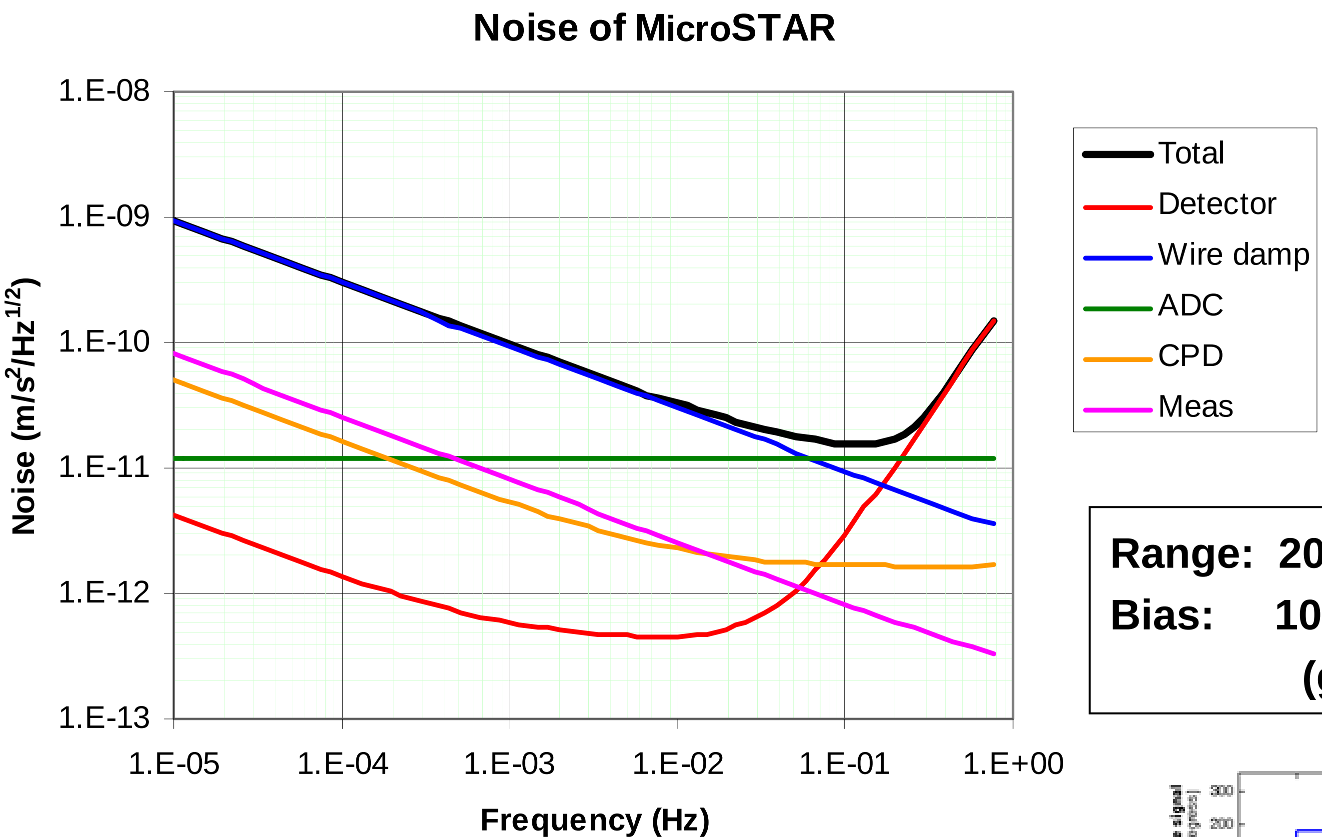
Accelerometer noise

Noise without bias fluctuation:



Hypotheses:

Vp = 7 V

Vd = 5 V

Gap = 600 µm

Proof-mass in ULE

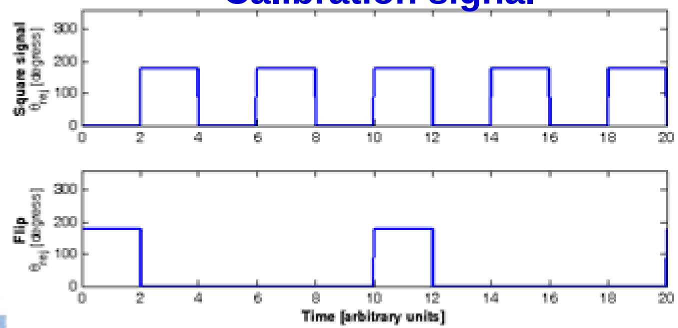
2 gold wires Ø 5µm

Range: **20 µm/s²**

Bias: **10 µm/s² (before rejection)**

(gold wire stiffness)

Calibration signal

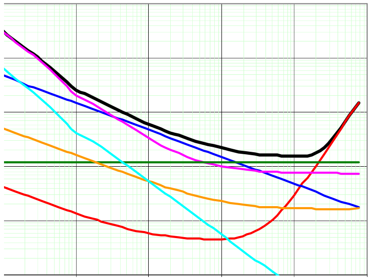


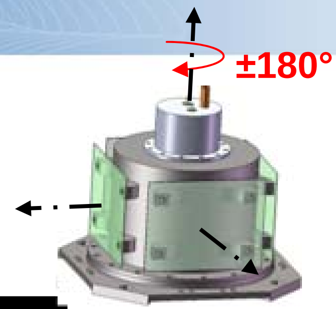
Noise:

1.4 pm/s² rms integrated @ 1 mHz ± 0.1 mHz

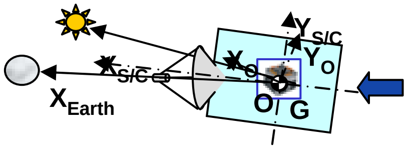
8.6 pm/s² rms integrated between 10^4s and 4,5 years

GAP on JGO - Science Error Budget

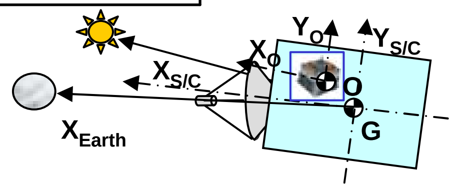


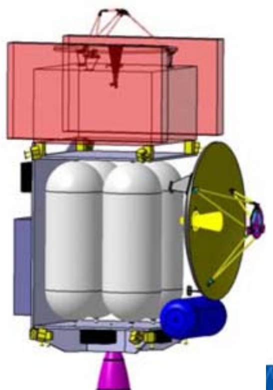


Error budget for Scale Dependent Gravity Test



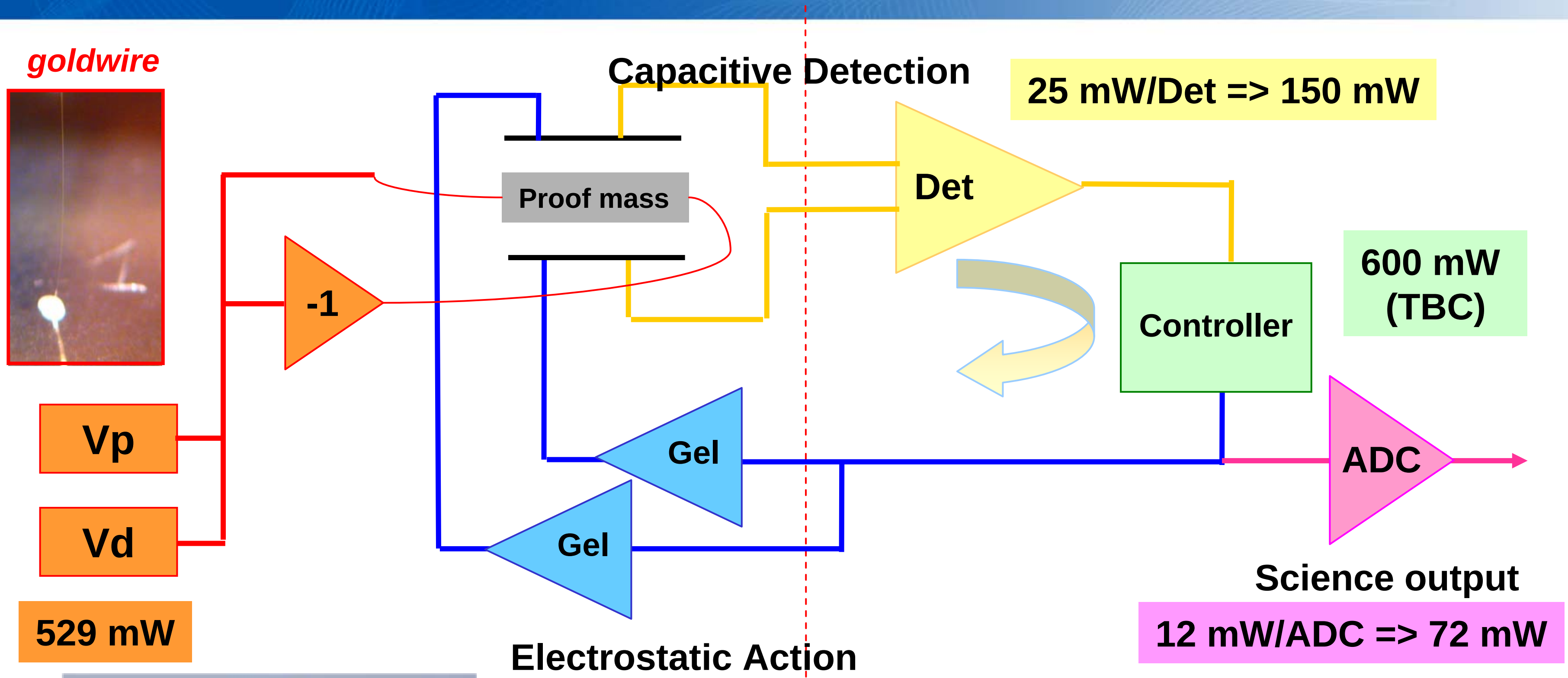
Source of errors	Impact on performance between 0–10^{-4} Hz
Noise of the accelerometer	9 pm/s^2
Error of bias rejection	20 pm/s^2
Misalignment of accelerometer axis	10 pm/s^2
Coupling with spacecraft angular motion	4 pm/s^2
Spacecraft self-gravity	40 pm/s^2
Other source of errors	10 pm/s^2
Total (quadratic sum)	**50 pm/s^2**

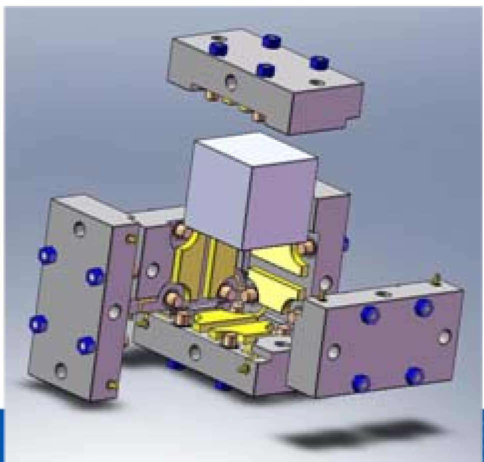




Important to take into account the accelerometer in the design of the S/C

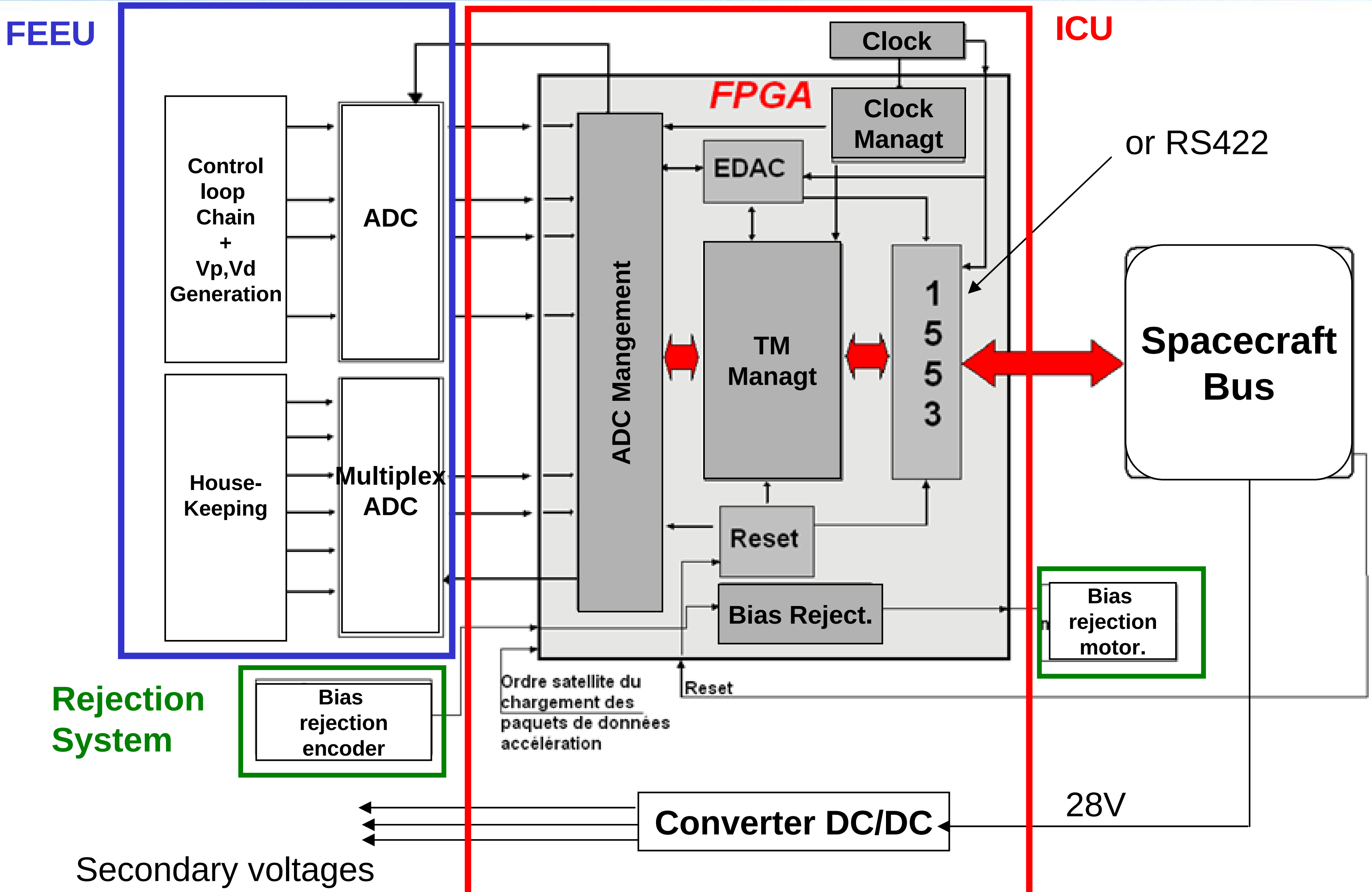
Accelerometer Electronic Consumption





Consumption = 1 266 mW (without Housekeeping)
Requirement = 1 400 mW (with H/K)

Definition of the ICU



Radiation / Planetary Protection

Radiation

- Radiation only for Planetary objectives
- Natural mitigation : Instrument in the heart of the S/C
- Search for Radhard component (FPGA, ADC, …) compatible with performance requirement
- Computation of shielding needed

Planetary protection

- No sterilisation needed for JGO
- Accelerometer already heat for outgassing at 100°C
- Accelerometer integrated in class 1000/10 000
  then testing in class 100 000

Thank you for your attention

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