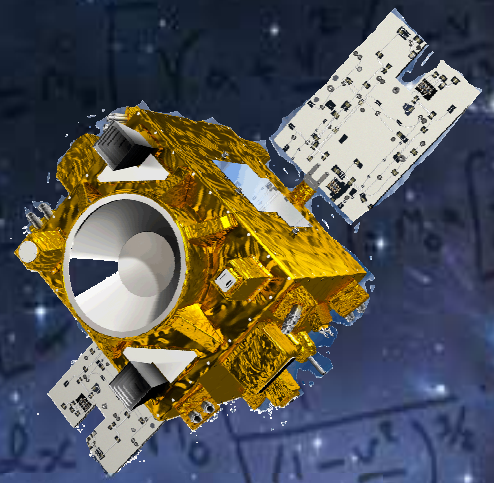
MICROSCOPE

A test of the Equivalence Principle in Space – 6 months of operation in orbit



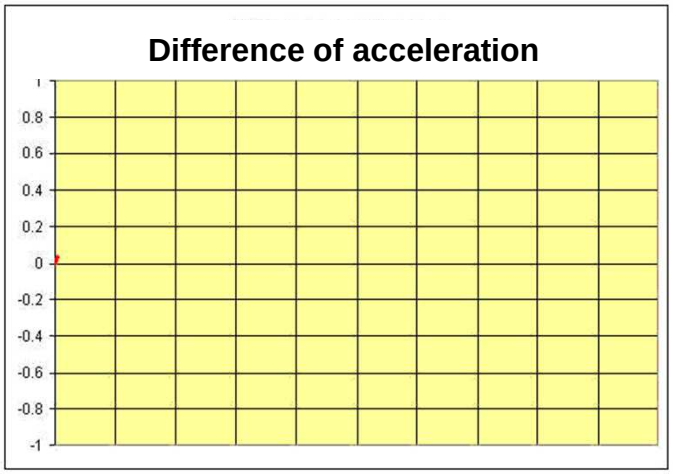
Manuel Rodrigues , project manager in Onera
On behalf of MICROSCOPE team

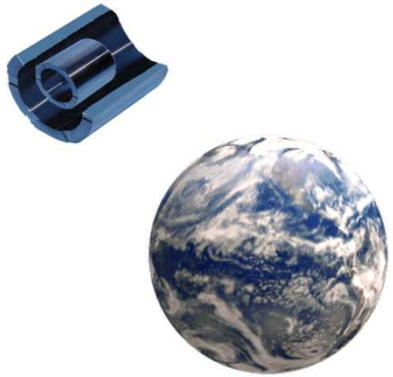
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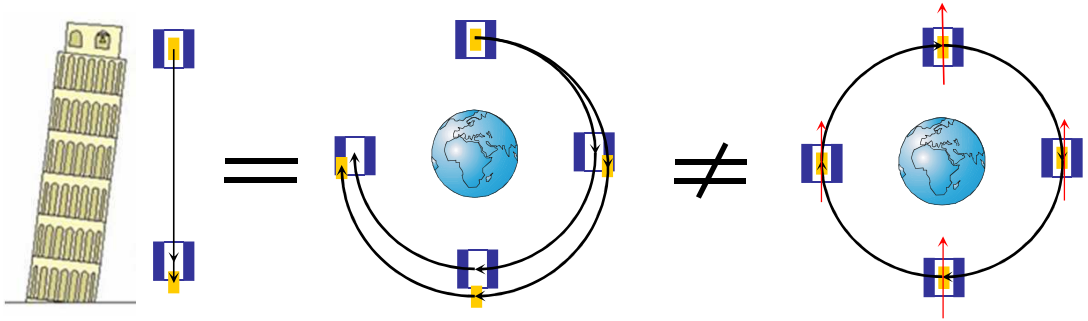
Géo AZUR

Universality of free-fall test – MICROSCOPE





$$\eta = \frac{a1-a2}{\frac{1}{2}(a1+a2)}$$ evaluated @ 1E-15 accuracy



Galileo Galilei «Free-Fall » in space Microscope

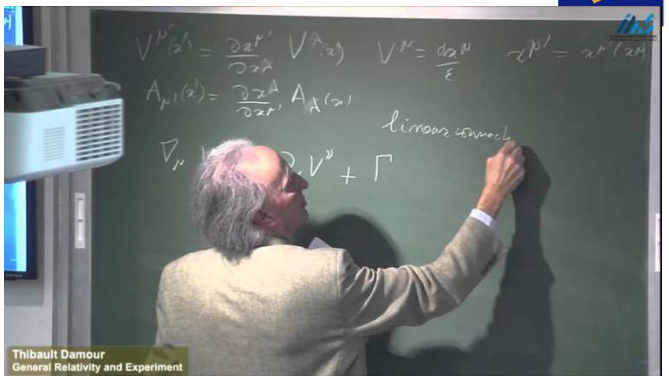
Comparison of 2 test-masses acceleration

Ultrasensitive Accelerometer

Need to measure 10^{-15}g @ orbital frequency

WHY TO TEST THE EP AT SUCH A LEVEL ?





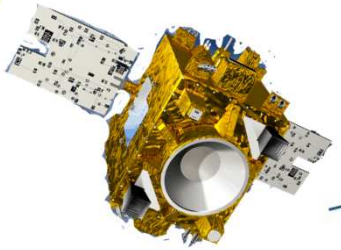
Physicians say something is missing in General Relativity, link to quantum mechanics, blablabla very complicated things …. ?

⇒ In summary = new interaction, extension of GR or modification

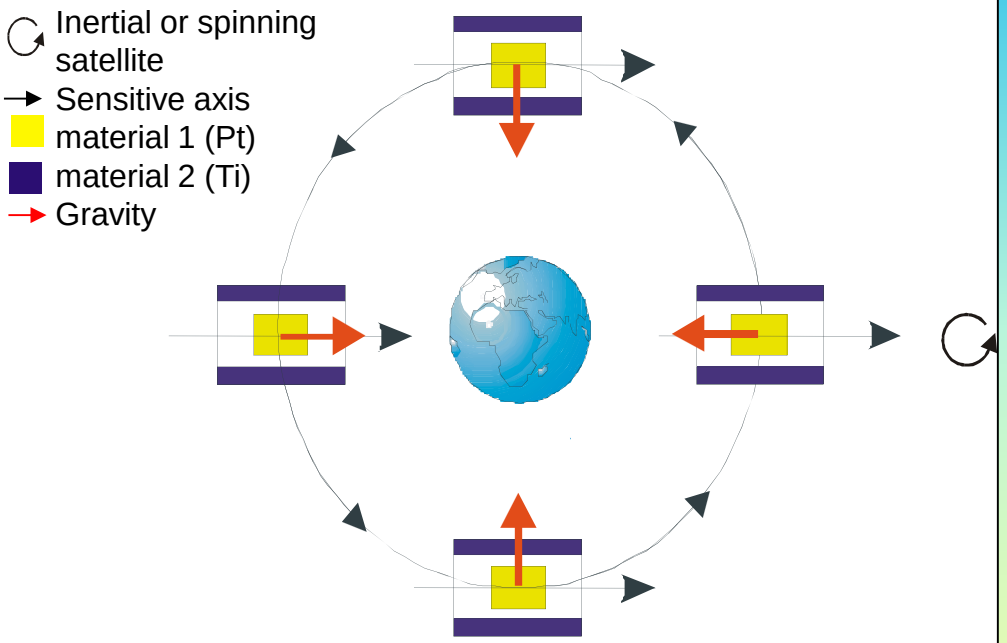
⇒ expected EP violation < 10^{-13} limit of today's best experiments (Adelberger & al)

- Testing EP in space with MICROSCOPE to 10^{-15} levels

⇒ leads to a breakthrough in Physics by giving new constrains



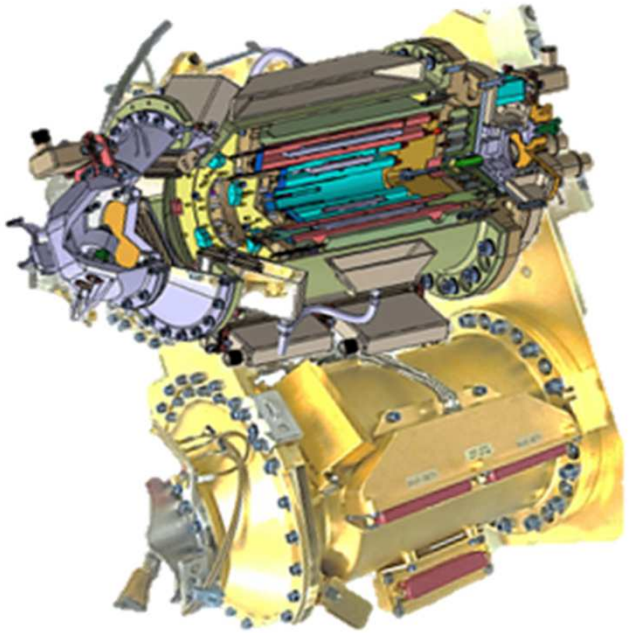
The main figures of the orbit and S/C control



CNES MYRIADE Microsatellite key specs

- Circular Orbit: 710 km, $e < 5.10^{-3}$
- Inertial or Rotating:
- $f_{ep} = f_{orb} + f_{spin}$
  - Inertial mode: $f_{spin} = 0$
  - Spinning mode: $f_{spin} = 7/2, 9/2, 35/2\ f_{orb}$
- Mission duration: 2 years
- Mass of microsatellite : 320 kg
- Payload budgets: 35 kg, 40 Watts
- Draf free control satellite
  - Linear acc < 10^{-12} m/s² @fep
  - Ang. acc < 10^{-11} rad/s² @fep
- 2 differential electrostatic accelerometers
  (2 pairs of masses: Pt/Pt & Pt/Ti)

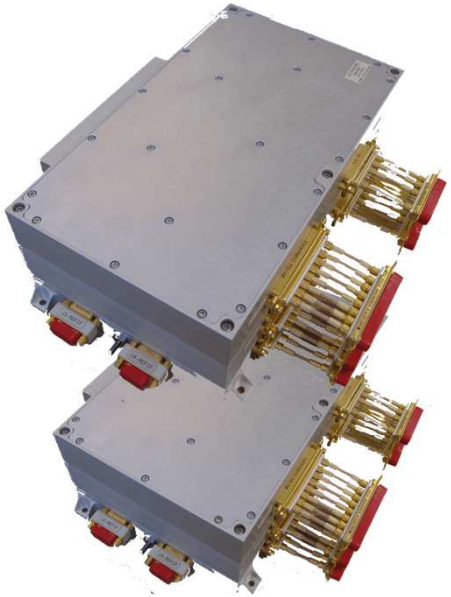
T-SAGE , Twin Space Accelerometer for Gravitation Experiment – micrometer & microvolt accuracy inherited from GOCE, GRACE ONERA know how



Sensors: SU PE + SU REF

2 double-accelerometers

Each SU give a TM difference of acceleration to femto-g level



Analog Front End Electronics :
1 FEEU for each SU

Low Noise voltage references
0.2µV $Hz^{-1/2}$

Low noise measurement
pick-up <1µV $Hz^{-1/2}$



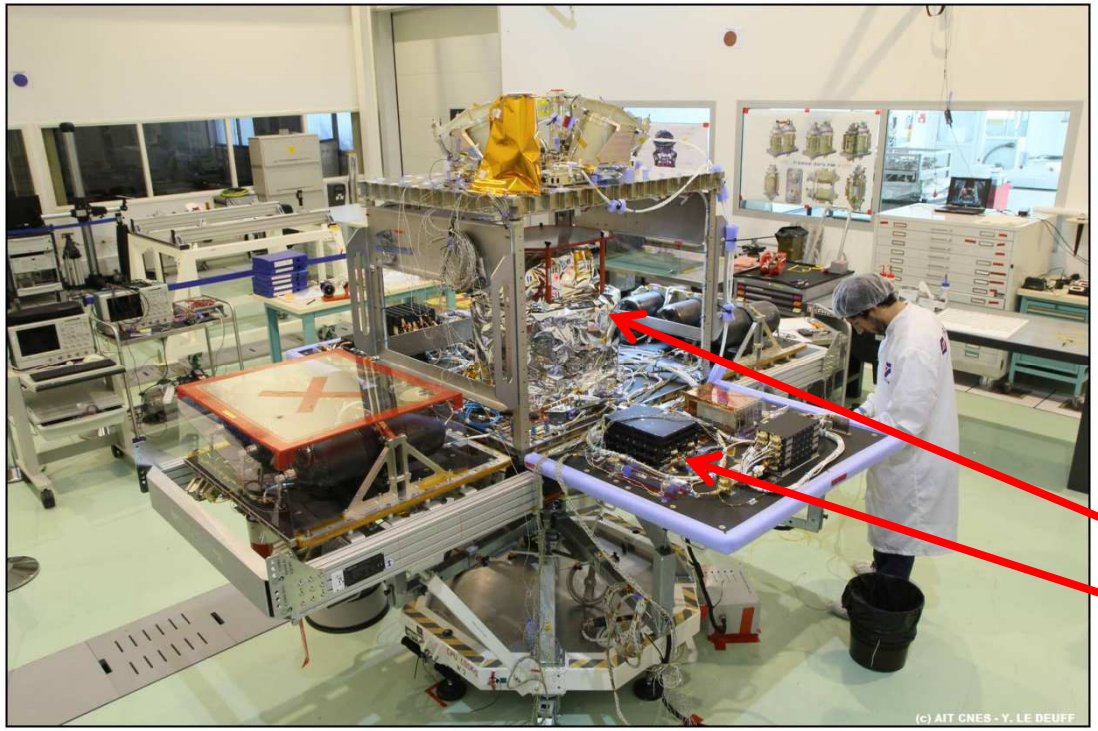
Digital Interface Electronics:
2 stacked ICU

DSP + FPGA
Control loop handling
2x 24 x 40bits signals @ 1kHz

Science TM = 24bits @ 4Hz

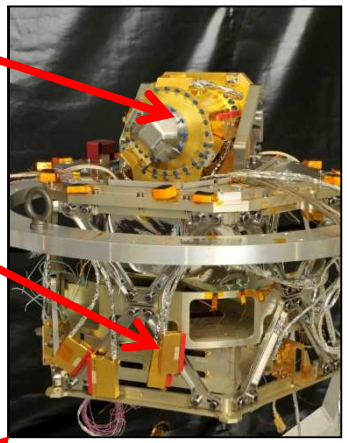
Instrument accommodation design: a dedicated passive thermal control

- ❑ *Heliosynchronous orbit : steady external configuration*
- ❑ *3 locations for the payload units versus thermal requirements*
- ❑ *Fine passive decoupling and well protected radiator from Earth radiations*
- ❑ *Models and dedicated Tests performed in 2009 + during acceptance tests 2016 confirm :*
- ✓ *the thermal case fine insulation*
- ✓ *the instrument low sensitivities of mechanical core & Electronics*
- ✓ *the low power consumption and fluctuations*



Spec on SU = 1mK

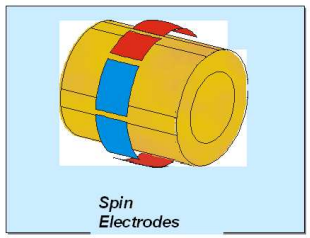
Spec on FEEU = 5mK

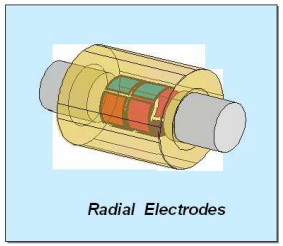


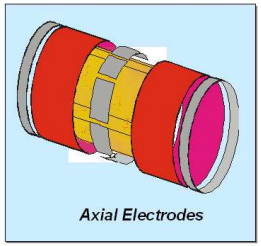
Paylod case – passive thermal stab.

Spec on ICUME = 1K

Instrument Measurement

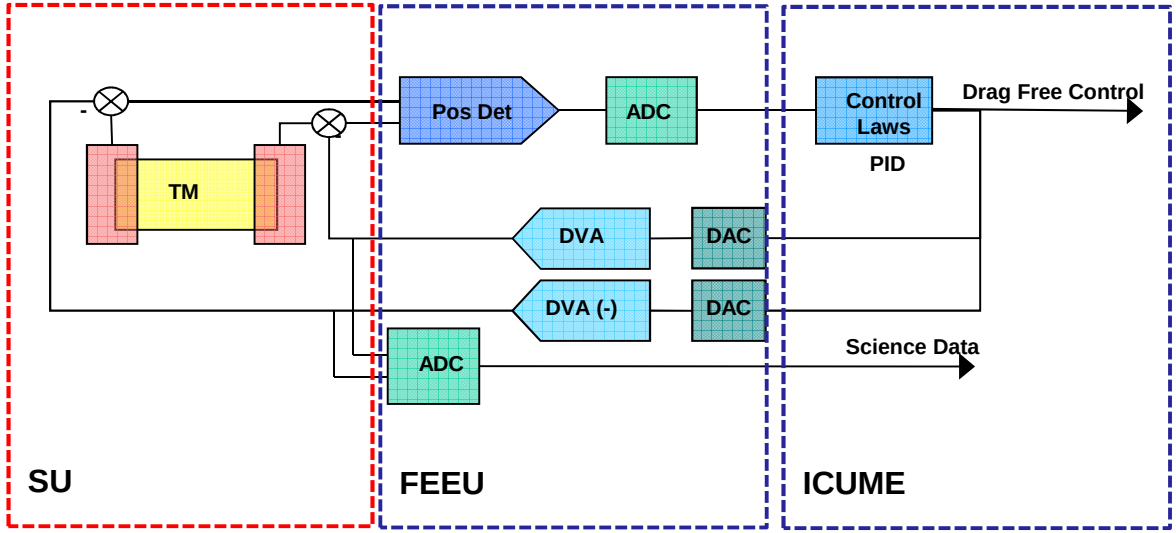




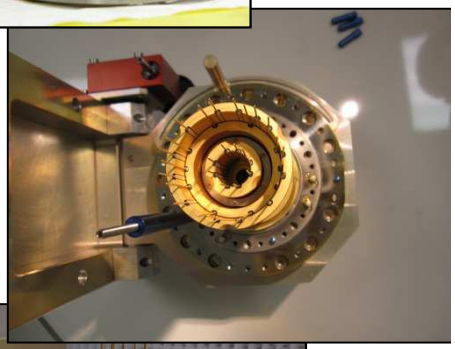


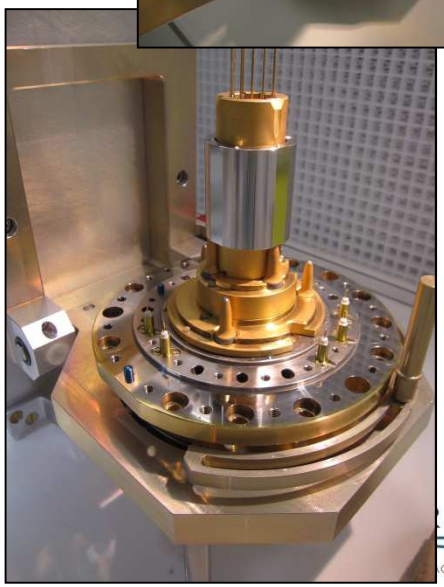
For each mass :
3 types of electrodes to control all six degrees of freedom
→ 6 servo-loop channels :

- ☞ **Axial x, position = ring electrodes**
- ☞ **Rotation about x = 4 pairs of electrodes in regard to the mass flat areas**
- ☞ **Radial y and z, position and rotation = quadrant electrodes**





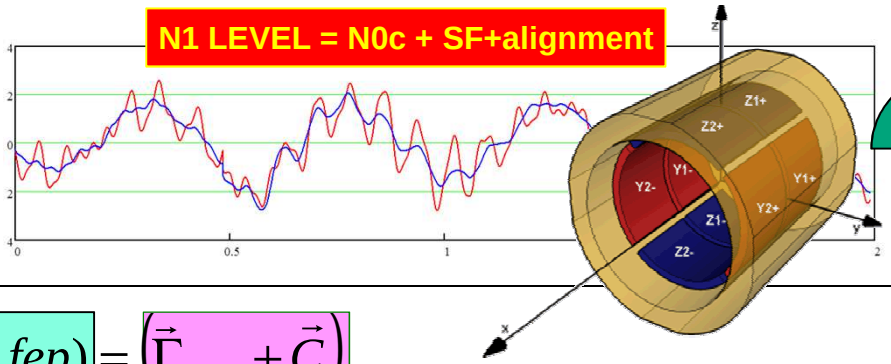




What do we measure? = Each mass acceleration

$\vec{\Gamma}_{mes,is2}$

$\vec{\Gamma}_{mes,is1}$



$$\vec{\Gamma}_{mes,c} = \frac{1}{2}\left(\vec{\Gamma}_{mes,is2} + \vec{\Gamma}_{mes,is1}\right)$$

$$\vec{\Gamma}_{mes,d} = \frac{1}{2}\left(\vec{\Gamma}_{mes,is2} - \vec{\Gamma}_{mes,is1}\right)$$

N2 LEVEL

$$\vec{\Gamma}_{mes,c}(fep) = \left(\vec{\Gamma}_{res_{df}} + \vec{C}\right)$$

Reduced by drag-free & attitude control

$$\Gamma_{mes,dx}(fep) = \frac{1}{2} K_{1cx} \cdot \delta \cdot g_{x/sat}$$

Searched EP signal

$$+\frac{1}{2}\begin{bmatrix} K_{1cx} \\ \eta_{cz} + \theta_{cz} \\ \eta_{cy} - \theta_{cy} \end{bmatrix}^t \cdot [T - In] \cdot \begin{bmatrix} \Delta_x \\ \Delta_y \\ \Delta_z \end{bmatrix}$$

Impact of gravity gradient and s/c angular motion

$$+\begin{bmatrix} K_{1dx} \\ \eta_{dz} + \theta_{dz} \\ \eta_{dy} - \theta_{dy} \end{bmatrix}^t \cdot \left(\vec{\Gamma}_{res_{df}} + \vec{C}\right)$$

Impact of residual acceleration through the difference of 2 TM matching

$$+2 \cdot K_{2cxx} \cdot \left(\Gamma_{app,dx} + b_{1dx}\right) \cdot \left(\Gamma_{res_{df},x} + C_x - b_{0cx}\right)$$

$$+K_{2dxx} \cdot \left(\left(\Gamma_{res_{df},x} + C_x - b_{0cx}\right)^2 + \left(\Gamma_{app,dx} + b_{1dx}\right)^2\right)$$

Impact of non linear terms

MEASURED | CALIBRATED FOR CORRECTION | CALIBRATED FOR VERIFICATION

6 months of in orbit operation in a timelapse



And now what happened since April 2016

- **Commissioning phase: 25th of April 2016 to 14th of November 2016**

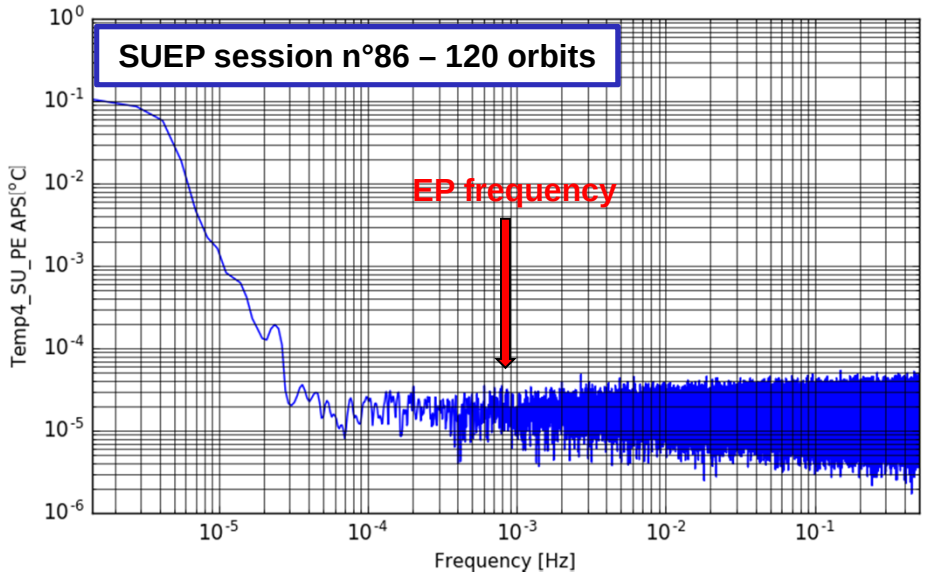
  Satellite & subsystems (including payload) have been tested

  - All DFACS modes tested (10 modes of calibrations, 4 modes of science) with 38 servo-loops are operating in harmony : OK
  - Cold gaz thrusters are nominal and within the specs ~0.3µN.Hz$^{-1/2}$: OK
  - Star Sensor : OK
  - Calibration on the 2 SU have been successfully tested : OK
  - T-SAGE:
    - SUREF : some troubles on voltage reference due to capacitance short-circuit, but still operating with no impact on performance
    - SUEP: nominal, currently operating in science mode an cumulating data: OK

- **Science began on 16th of November 2016**

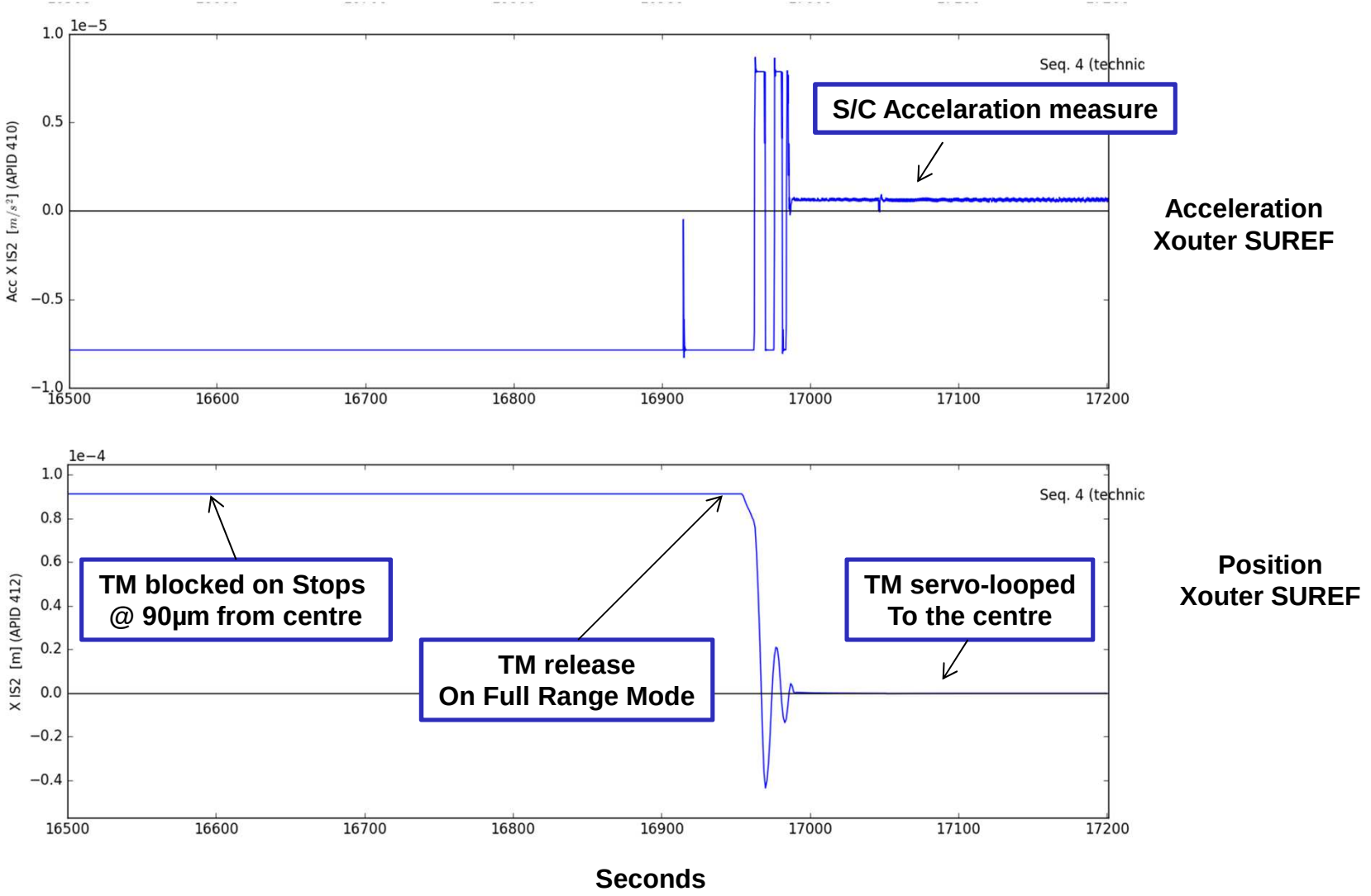
Best of satellite performances @ EP frequency

- **Excentricity of orbit ~ 1.5^{E}-3** better than the expected 5E-3.
- **Orbit determination accuracy < 1m** (needs = 7 m).
- **DFACS perfo** <0.2 10^{-12} m/s² (needs = 10^{-12} m/s²).
- **Payload case thermal stability < 0.03mK** (needs = 1mK).



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2nd of May 2016 : 1st Swich On of TSAGE in orbit

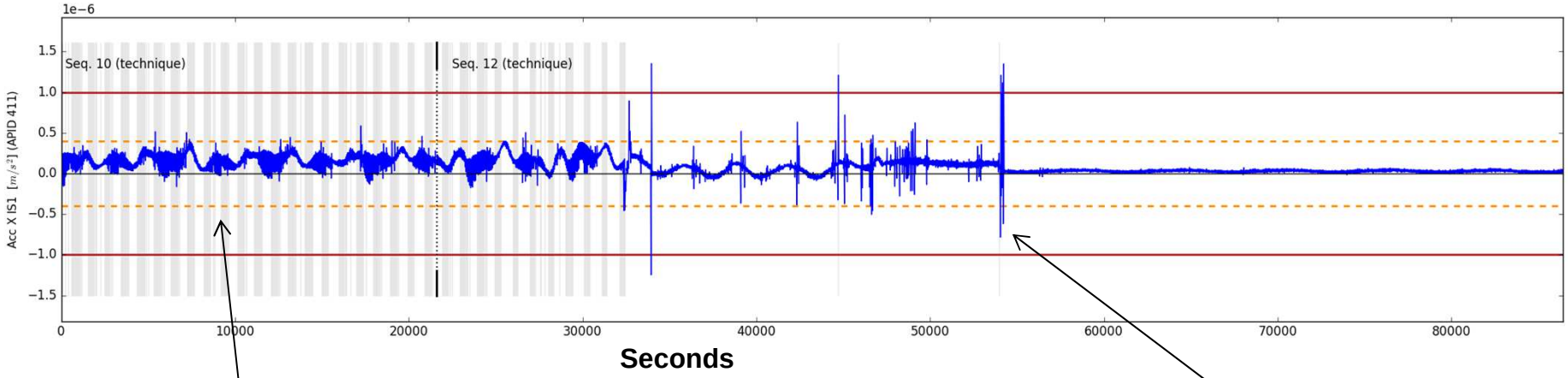


Acceleration Xouter SUREF

Position Xouter SUREF

11th of May 2016 : Switch from Full Range Mode to High Resolution Mode (HRM)

Acceleration of Xinner of SUEP

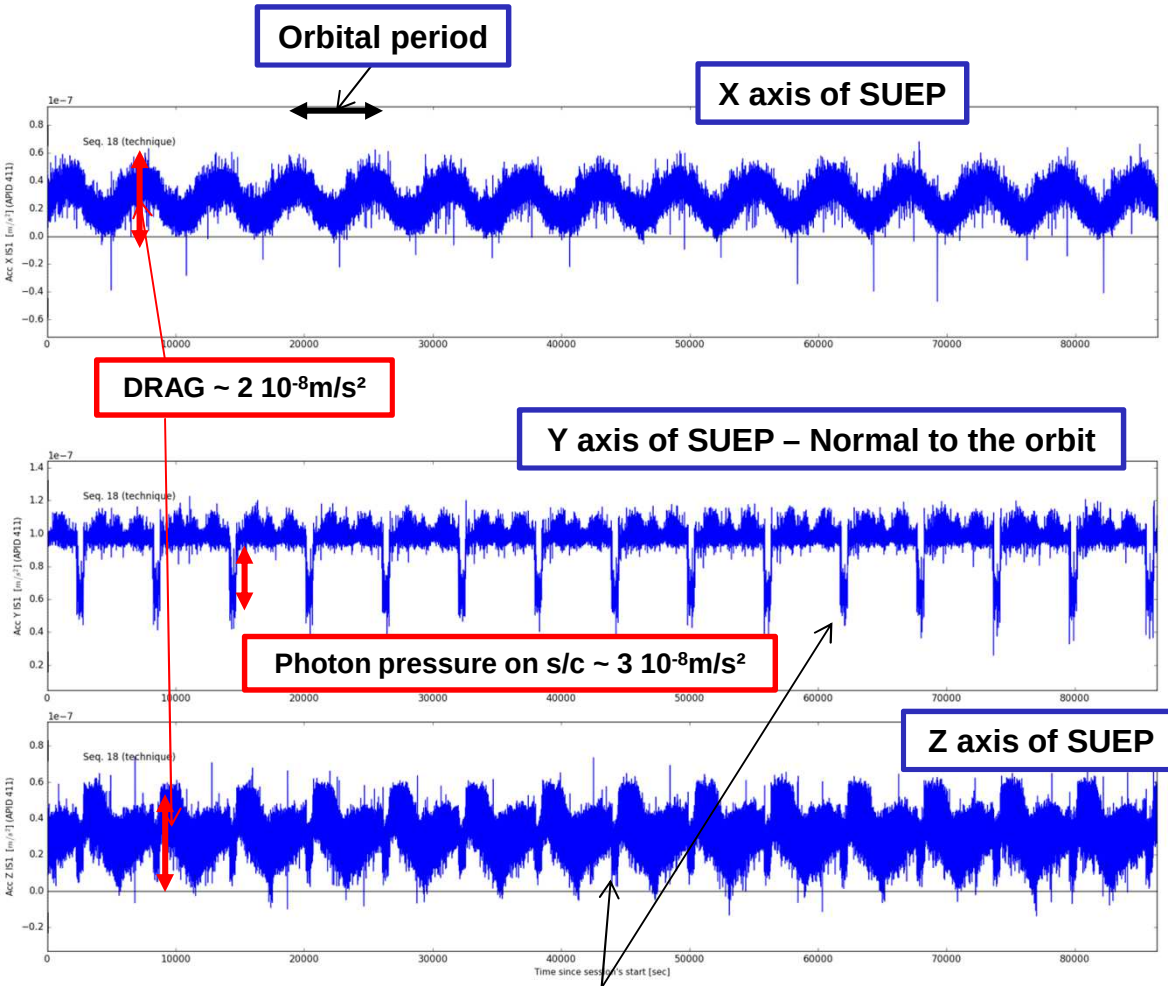


S/C is in MNOG Magnetotorquer Control Of the Attitude

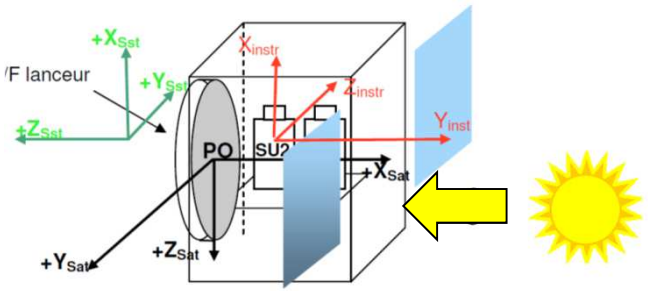
Cold Gaz Thrusters used in combination with SST to Finely control the attitude of S/C.

First Swith on of HRM (science mode). S/C is rotating with a small conic motion

Inertial pointing during 1 day

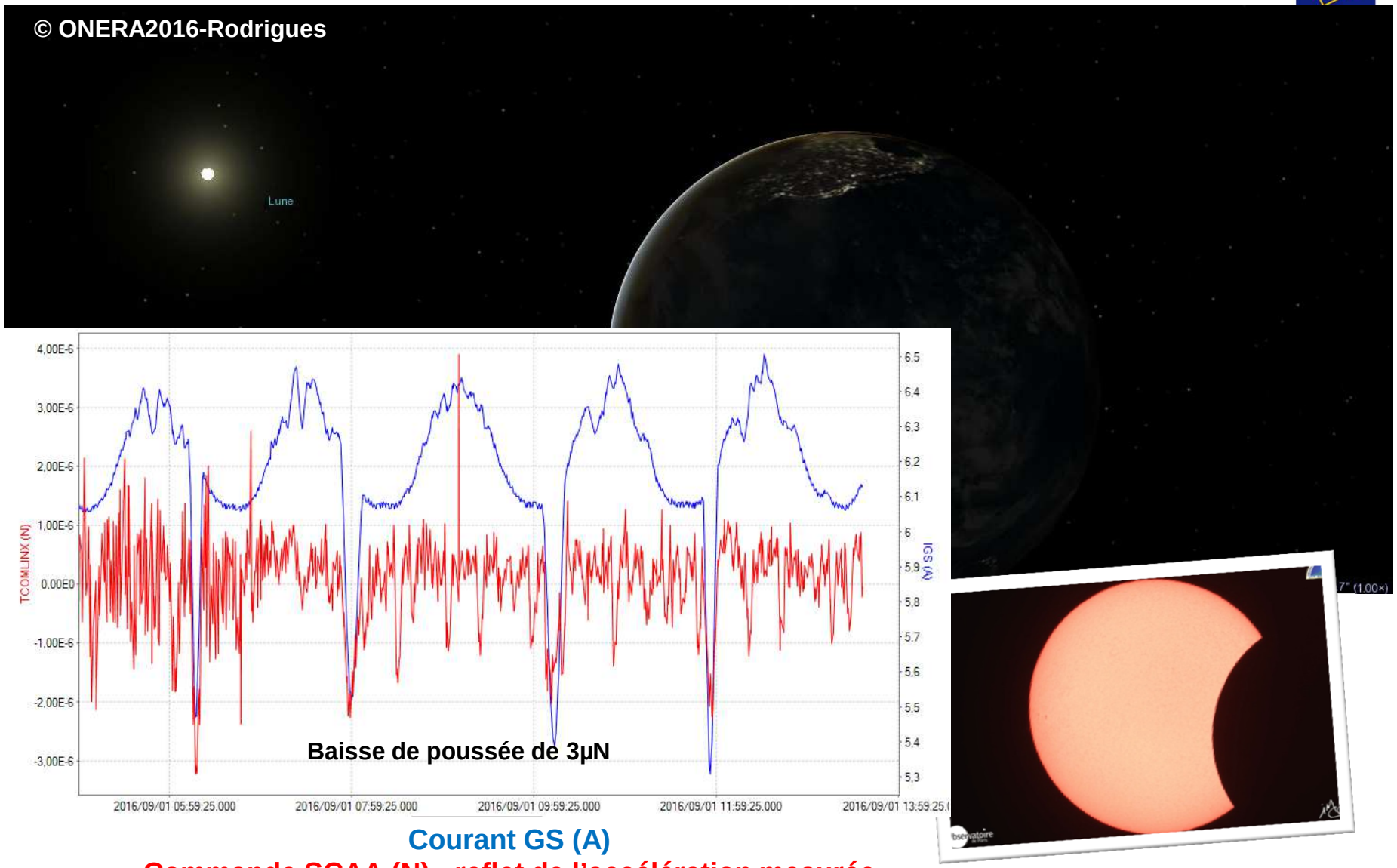






Effect of Earth's eclipse: the Sun radiation is no more pushing on the satellite => ~3 10-8m/s² is the acceleration due to photons Pressure on satellite

01/09/2016: Microscope saw the moon eclipse



Courant GS (A)

Commande SCAA (N) : reflet de l'accélération mesurée

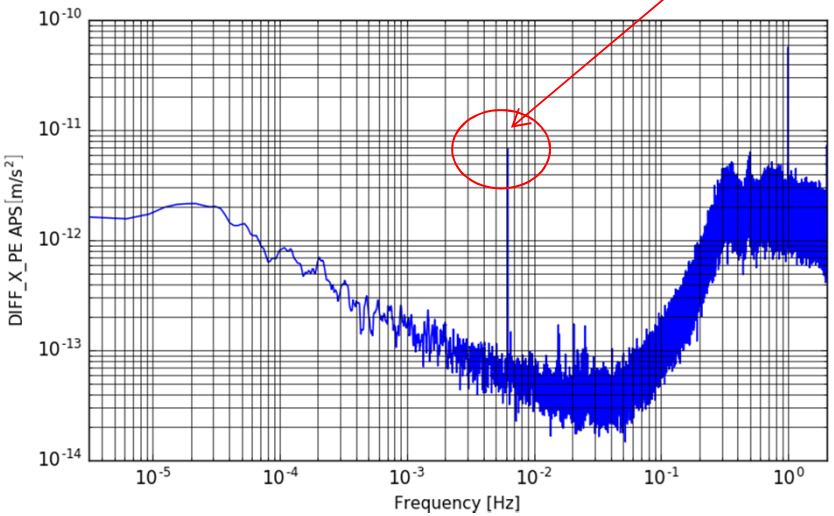
Earth's gravity gradient @2fep $= \nabla g . \Delta x$

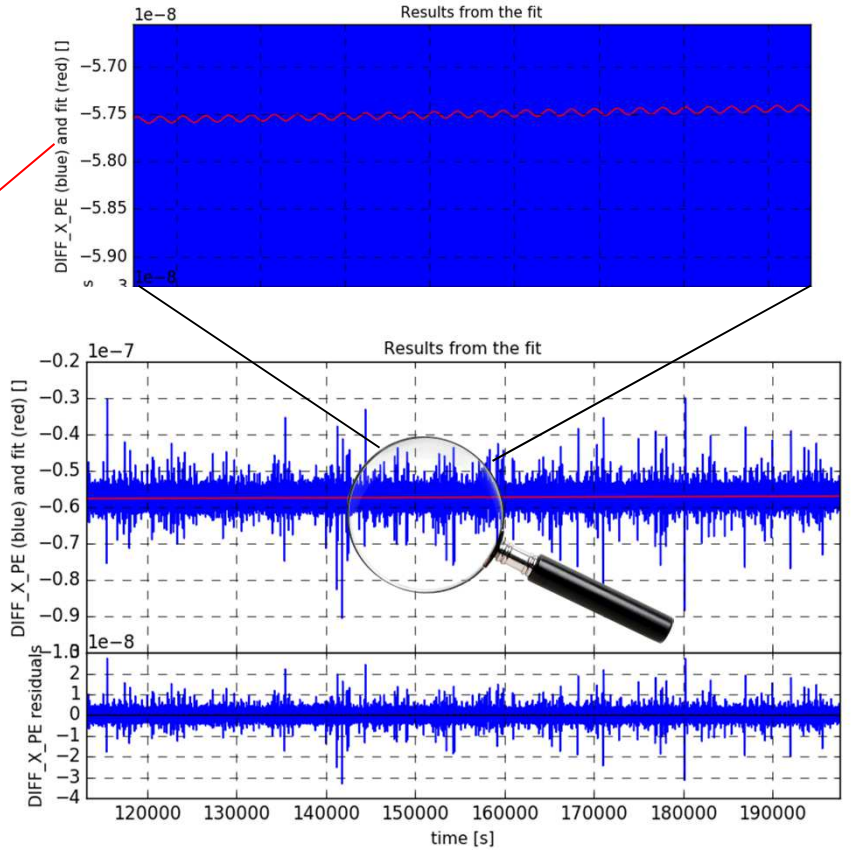
Preliminary analysis without calibration

SUREF : Session 120 => Δx = -36,41µm
(meas on ground ~ -34+/-4µm)

SUEP: Session 86 => Δx = 19,85µm
(meas on ground ~ 29+/-4µm)

Rough Difference of acc. Measured on X - FFT





When will we know more about EP test results ?

- Today's results are confidential and to be validated by the MICROSCOPE Science working Group :
  - *The expected sensitivity is much better than the ground results….*

- **<u>In May 2017</u>**, just before of the Sun Eclipse period (mission in pause) :
  - 300 orbits should be cumulated with SUREF (120 orbits already done)
  - 1200 orbits should be cumulated with SUEP (220 orbits already cumulated….by end of this week 260 orbits available)



  - Then the expected performance of SUREF & SUEP should be the same after integration of all these data (just analyzing noise + systematics)

<u>Objective</u> : *EP sensitivity at 5 E-15 level in May 2017 with non full calibrated data,* ***as a first step for a preliminary paper on mission performance***

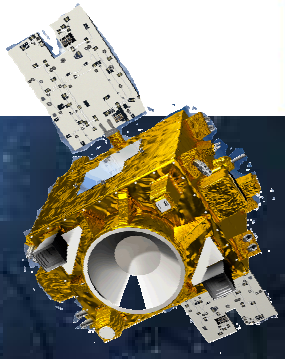
When will we know more about EP test results ?

- Today's results are confidential and to be validated by the MICROSCOPE Science working Group :
  - *The expected sensitivity is much better than the ground results….*

- **<u>In April 2018</u>**:
  - Full calibrated data should be available
  - Objective: test of EP @ 1E-15 level
  - Paper to be published in 2018
  - 1 Year Extension of the mission could be envisaged if valuable improvement on performance is demonstrated

THANK YOU FOR YOUR ATTENTION

http://microscope.onera.fr









Science Mission Centre team













Payload team



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