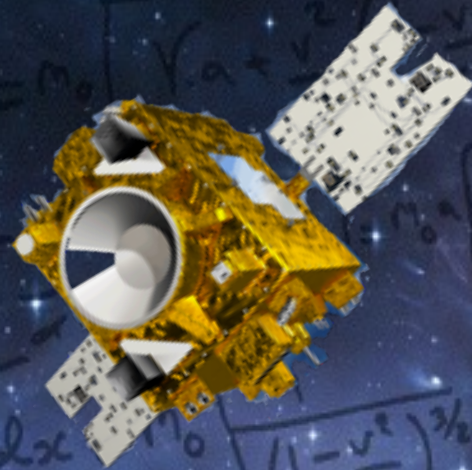
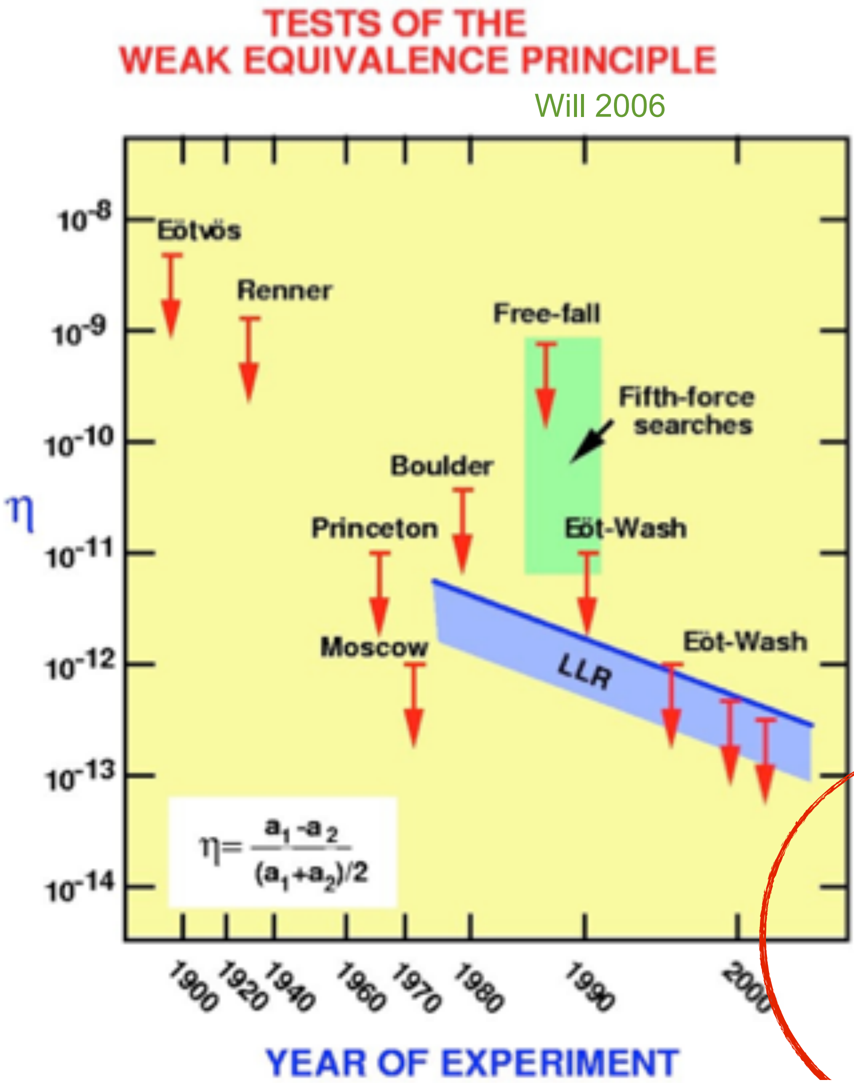
MICROSCOPE

A test of the Equivalence Principle in Space – 8 months of operation in orbit



Joel Bergé (ONERA)
On behalf of the MICROSCOPE team

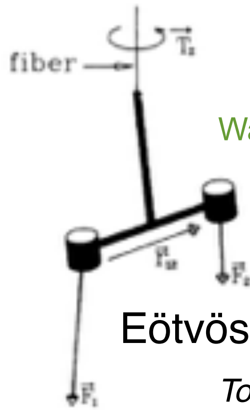
MICROSCOPE: test the WEP @10^{-15}



Will 2006

Microscope
10^{-15}
2017

Expected violations (string theory, new scalar fields...)



Wagner+ 2012

Eötvös, Eöt-Wash

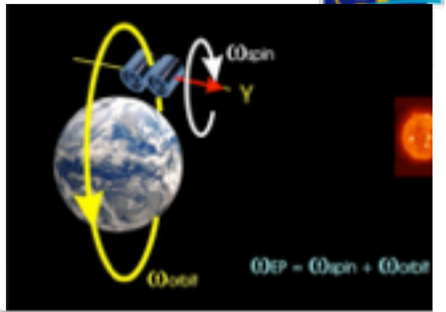
Torsion balance

Lunar Laser Range

Williams+ 1996

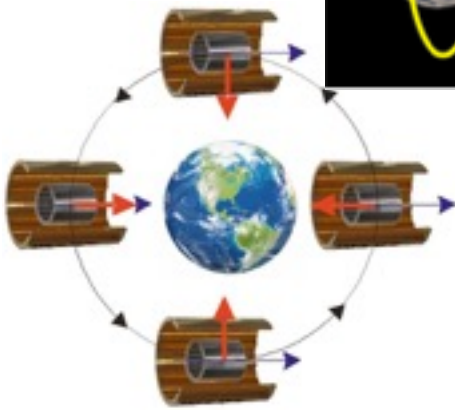
Probes fall of Earth and Moon towards the Sun

MICROSCOPE measurement principle



Free-fall test of two test bodies in the Earth gravity field

Sensors forced to follow the same orbit (permanent pico-meter control) => we measure the electrostatic forces needed to keep the sensors centered.
Signal measured along an ultra-sensitive axis.

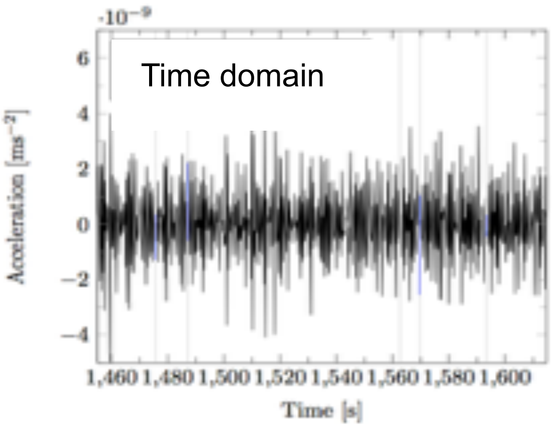


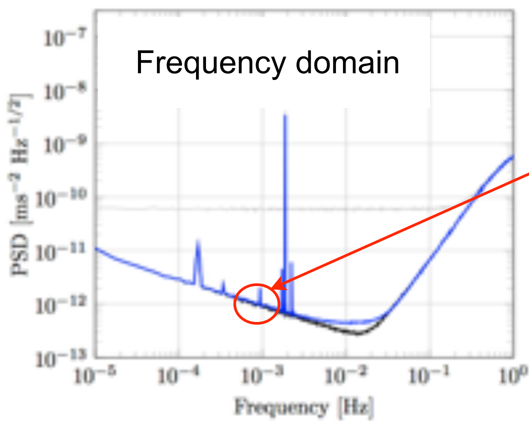
<u>Signal</u>: gravity field modulated by satellite's motion around the Earth => sine of known frequency f_{EP}

f_{EP} can be varied by either:

- Keeping the satellite in inertial motion
- Or spinning it

<u>How to extract the signal?</u> Easy! We must look for a noise-dominated sine in measured time series.





Simulated Equivalence Principle Violation (3×10^{-15})

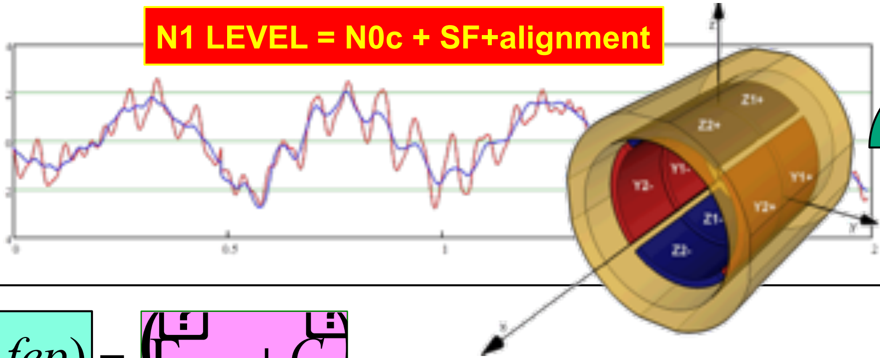
Joel Bergé, Testing Gravity 2017 (01/28/2017)

What do we measure? = Each mass acceleration

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

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

N1 LEVEL = N0c + SF+alignment



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

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

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

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

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

Impact of non linear terms

MEASURED | CALIBRATED FOR CORRECTION | CALIBRATED FOR VERIFICATION

MICROSCOPE: mission and satellite

Launched April 25, 2016 from Kourou

Aim: test $m_i = m_g$ at the 10^{-15} level

10^{-15}: difference of weight of a 500,000 ton-tanker with or without a 0.5 mg drosophilia on board

$$\eta_{1,2} = \frac{a_1 - a_2}{(a_1 + a_2)/2} = \frac{(m_g/m_i)_1 - (m_g/m_i)_2}{[(m_g/m_i)_1 + (m_g/m_i)_2]/2}$$

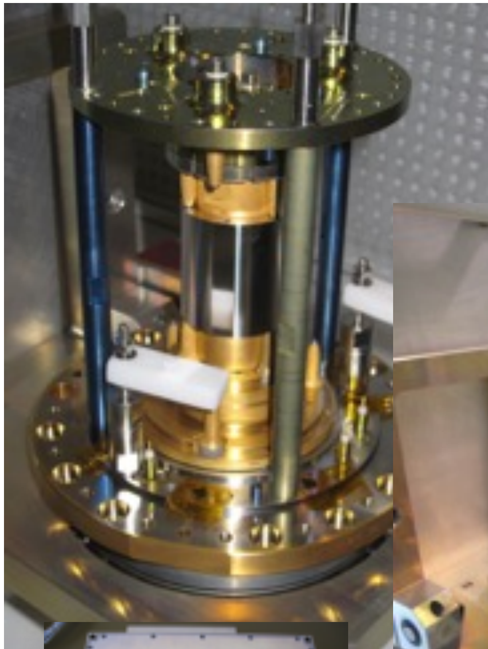
CNES MYRIADE Microsatellite key specs

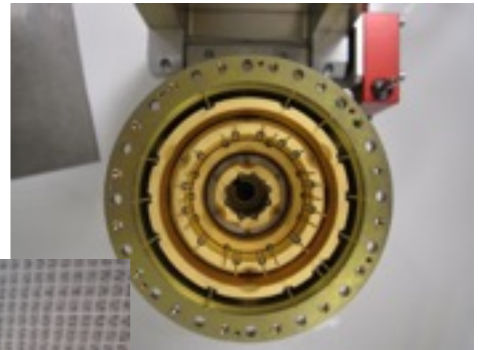
- Circular Orbit: 710 km, e < 5.10^{-3}
- Inertial or Rotating:
- $f_{ep} = f_{orb} + f_{spin}$
  - Inertial mode: $f_{spin} = 0$
  - Spinning mode: $f_{spin} = 7/2, 9/2, 35/2\ f_{orb}$
- Mission duration: 2 years
- Mass of microsatellite : 320 kg
- Payload budgets: 35 kg, 40 Watts
- Drag free control 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)

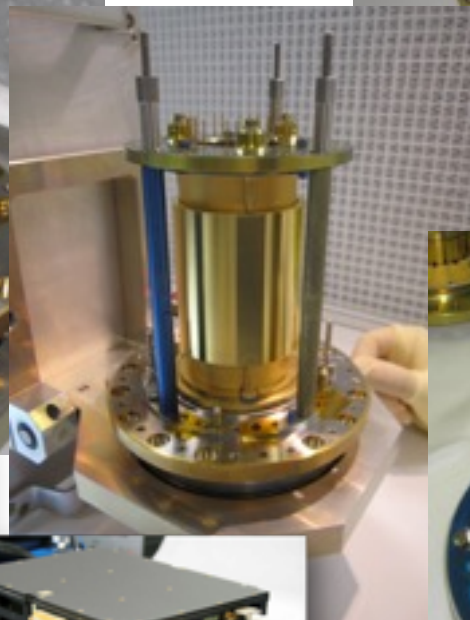
MICROSCOPE instrument: TSage (Twin Space Accelerometer for Gravitation Experiment)

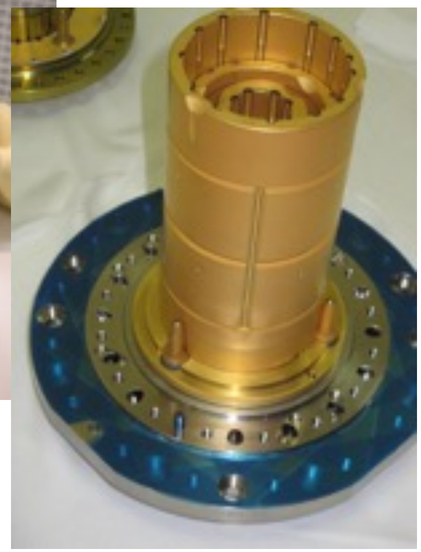
2 differential accelerometers

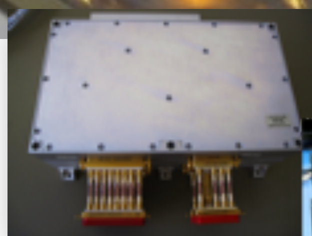
- SUREF: reference, test masses of the same material (Pt/Rh)
- SUEP: used for Equivalence Principal test, test masses of different materials (Pt/Rh, Ti)











What happened since April 2016

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

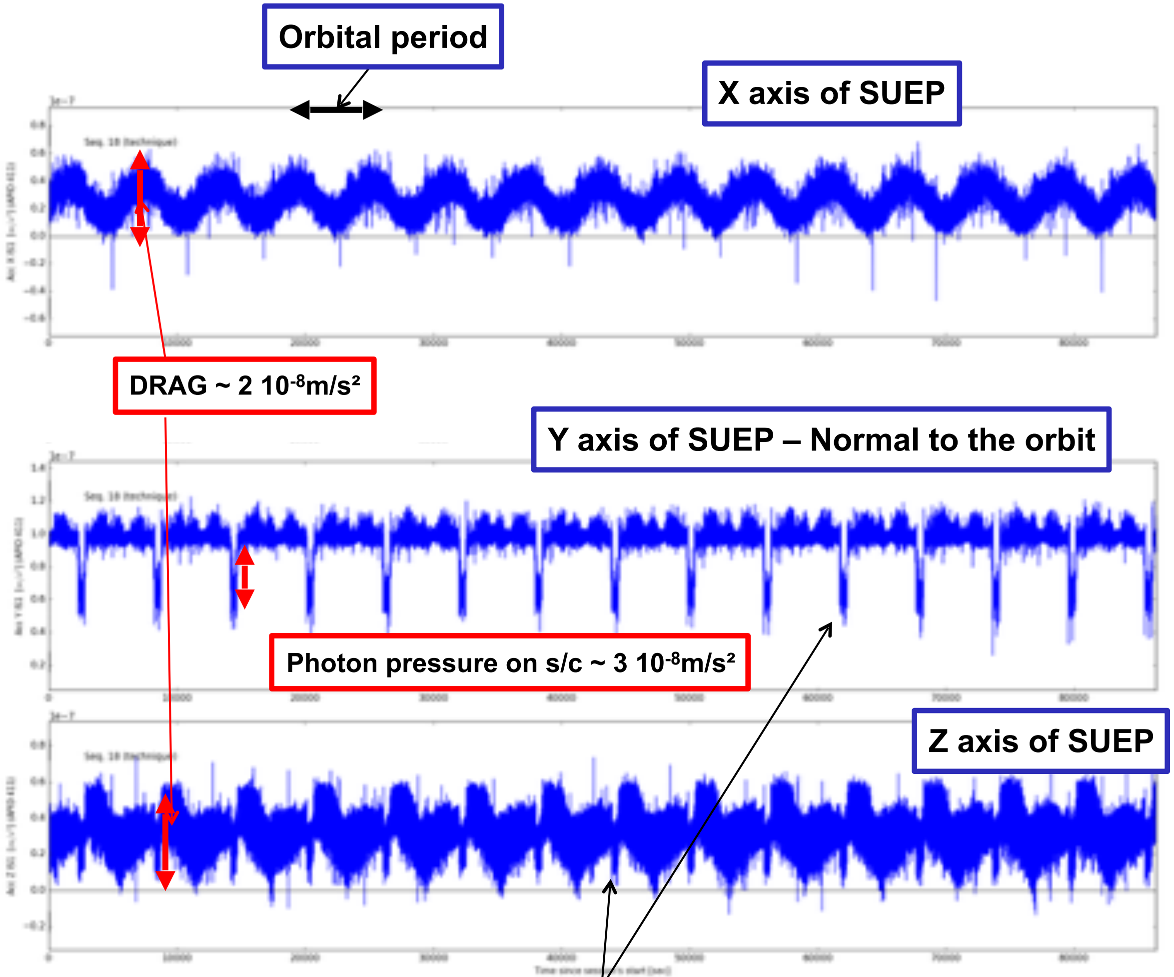
  Satellite & subsystems (including payload) have been tested

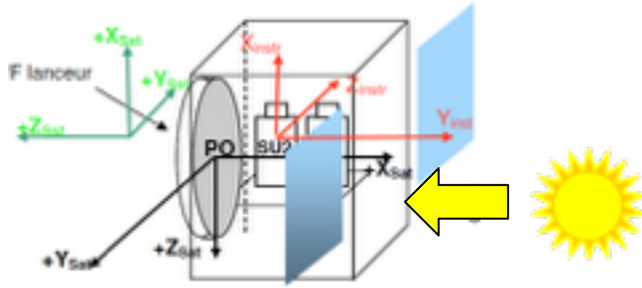
  - All DFACS modes tested (10 modes of calibrations, 4 modes of science) with 38 servo-loops are operating in harmony : OK
  - Cold gas thrusters are nominal and within the specs ~$0.3\mu N.Hz^{-1/2}$: OK
  - Star Sensor : OK
  - Calibration on the 2 SU have been successfully tested : OK
  - T-SAGE:
    - 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**

A very sensitive instrument

Inertial pointing during 1 day

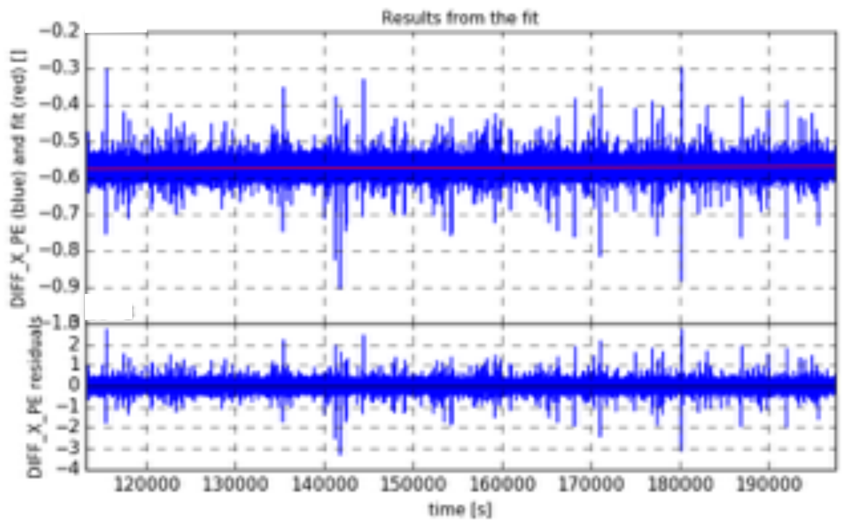


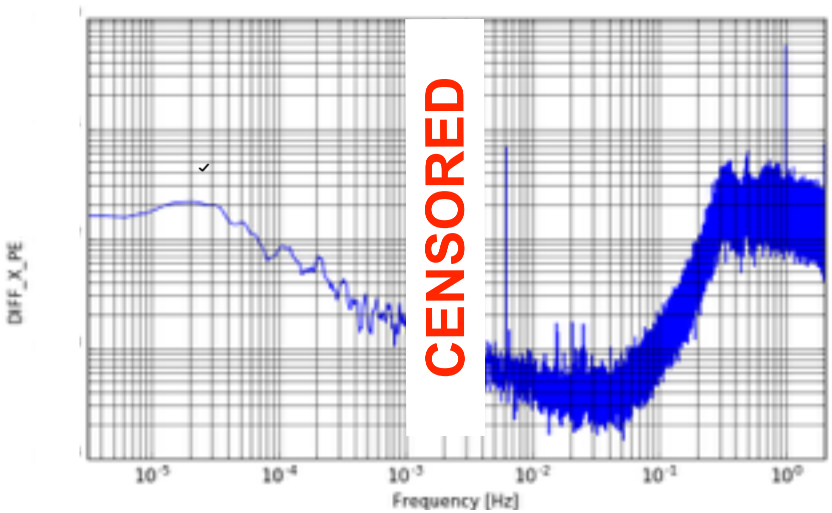


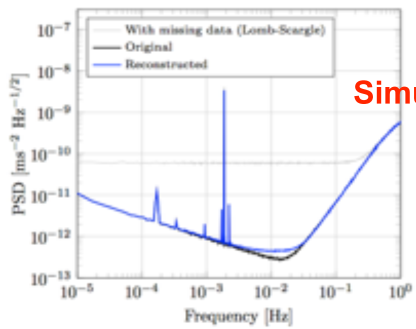
Effect of Earth's eclipse: the Sun radiation is no more pushing on the satellite => ~3 10^{-8}m/s² is the acceleration due to photons Pressure on satellite

Preliminary noise spectrum (EP test)

- Differential acceleration
- Drag-free mode on 6 degrees of freedom
- Data not calibrated







Simulation

When will you 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….*

- **In May 2017**, just before 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)

Objective **:** *EP sensitivity at $5x10^{-15}$ level in May 2017 with non full calibrated data,* ***as a first step for a preliminary paper on mission performance***

When will you 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 @ 10^{-15} level
  - Paper to be published in 2018
  - 1 Year Extension of the mission could be envisaged if valuable improvement on performance is demonstrated

Summary

- MICROSCOPE is working
- Stay tuned for the results

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