AIRBORNE ATOM SENSORS : FROM GROUND TO SPACE

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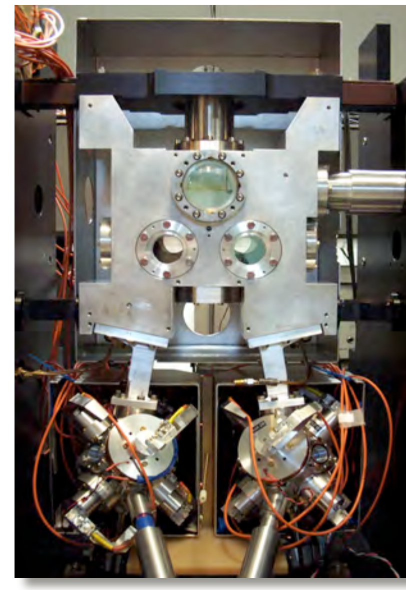
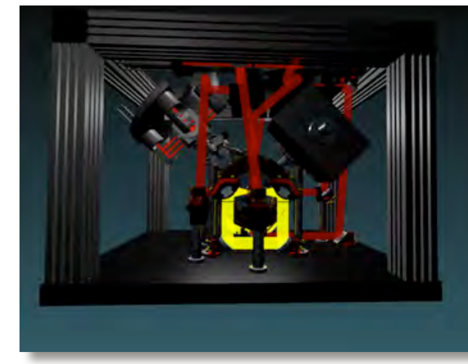
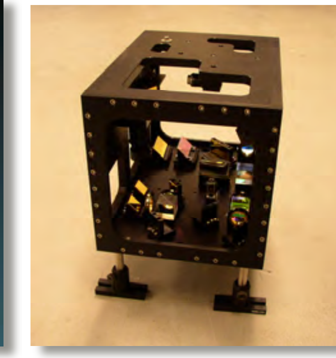
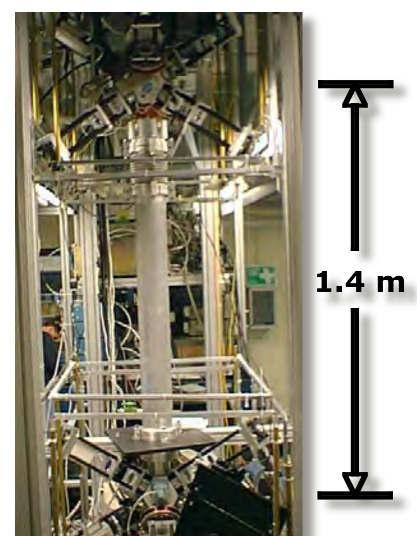
ATOM-BASE INERTIAL SENSORS

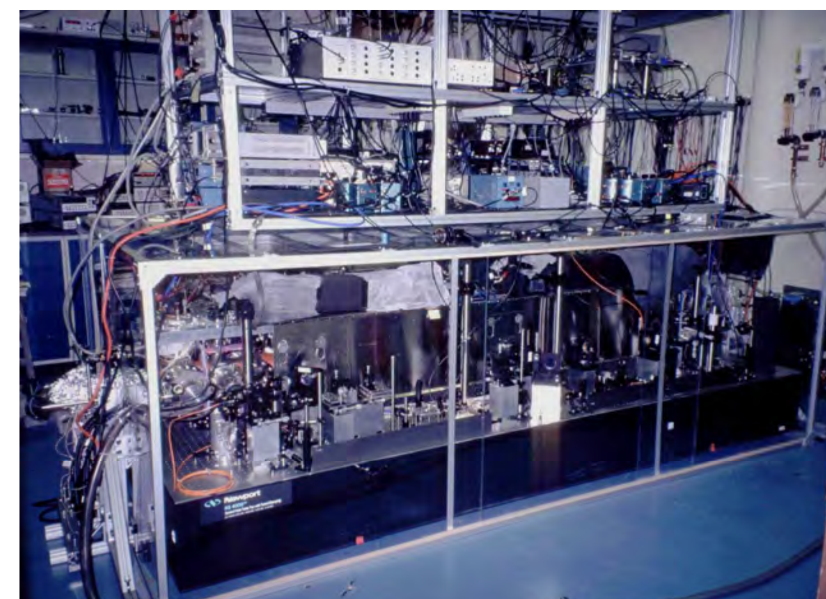
- Atom-based Inertial Sensors are based on the manipulation and the control at the "quantum level" of atoms using light or magnetic fields.
- Atomic interferometry has demonstrated over the past 10 years chat it can be more sensitive than other techniques (optical interferometry, vibrating system ...).
- Starts to be many laboratory experiments in the world (in US, France, Germany, Italy): 3 leading laboratories in France and US (Stanford, Palaiseau, Paris) have demonstrated the feasibility of a transportable inertial base using atom interferometry.



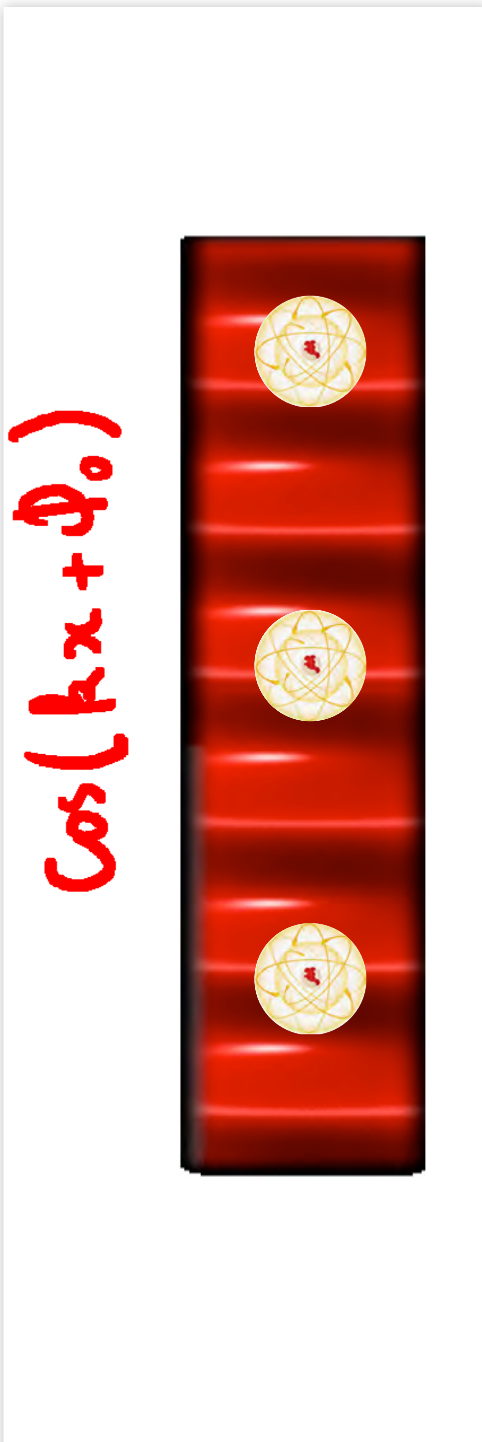






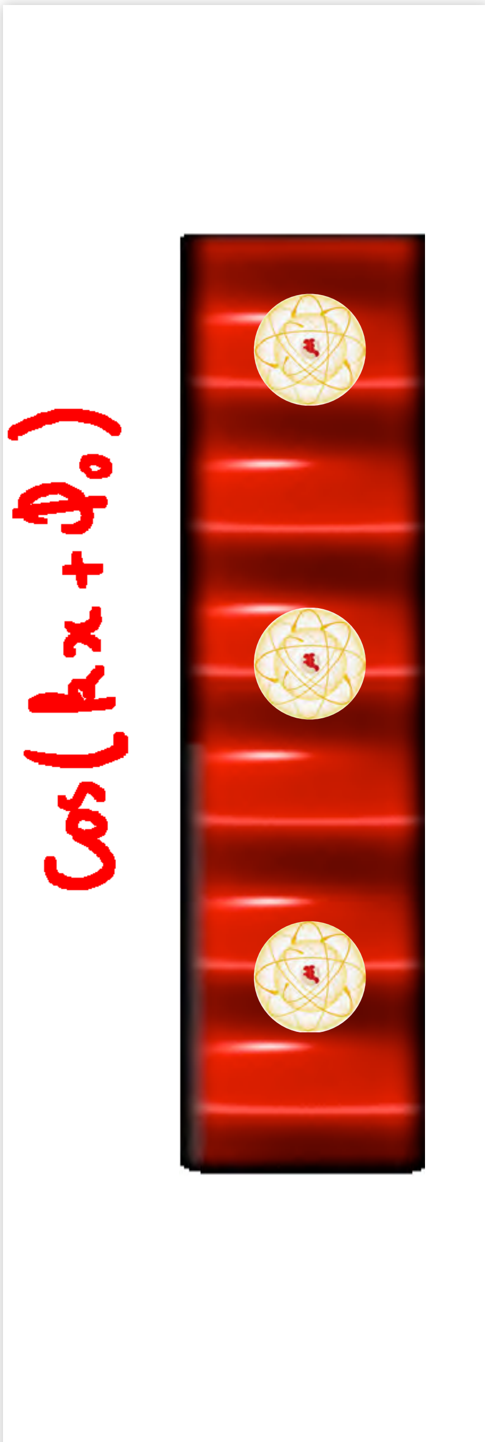


ATOM-BASE ACCELEROMER : BASIC PRINCIPLE

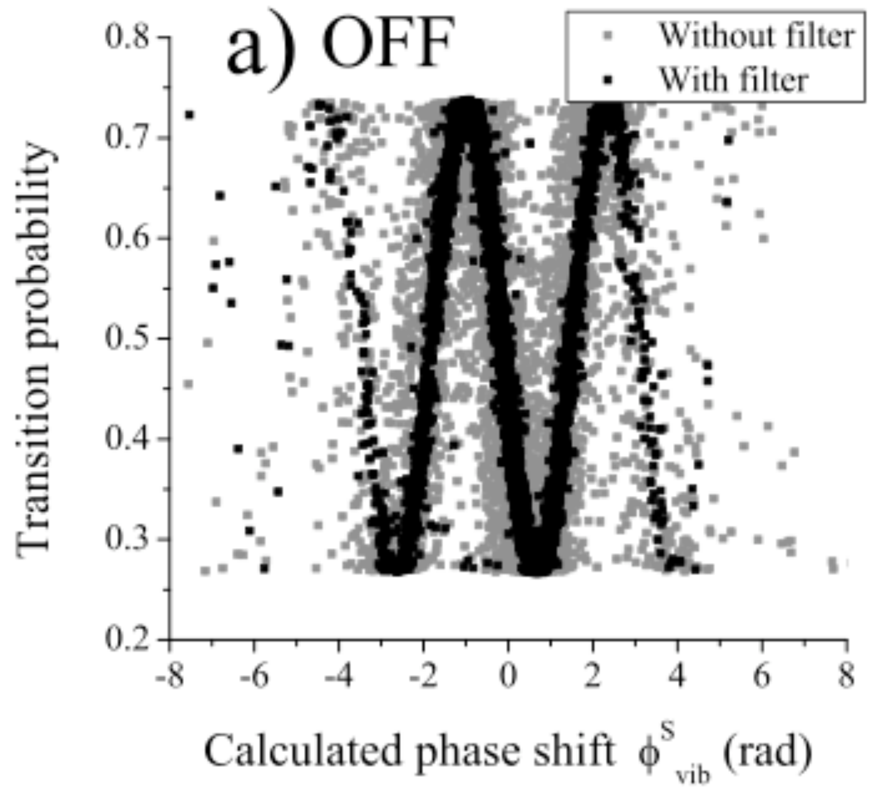


- We use an (optical) ruler to precisely measure the (atomic) test mass position
- Similar to falling corner cube gravimeter (FG5)
  - FG 5 : Laser phase is read by optical interferometry
  - Atom sensor : Laser phase is read by atom interferometry.
- An Atom Interferometer “reads” the position of an atom proof mass using “atom/laser telemetry”

ATOM-BASE ACCELEROMER : BASIC PRINCIPLE



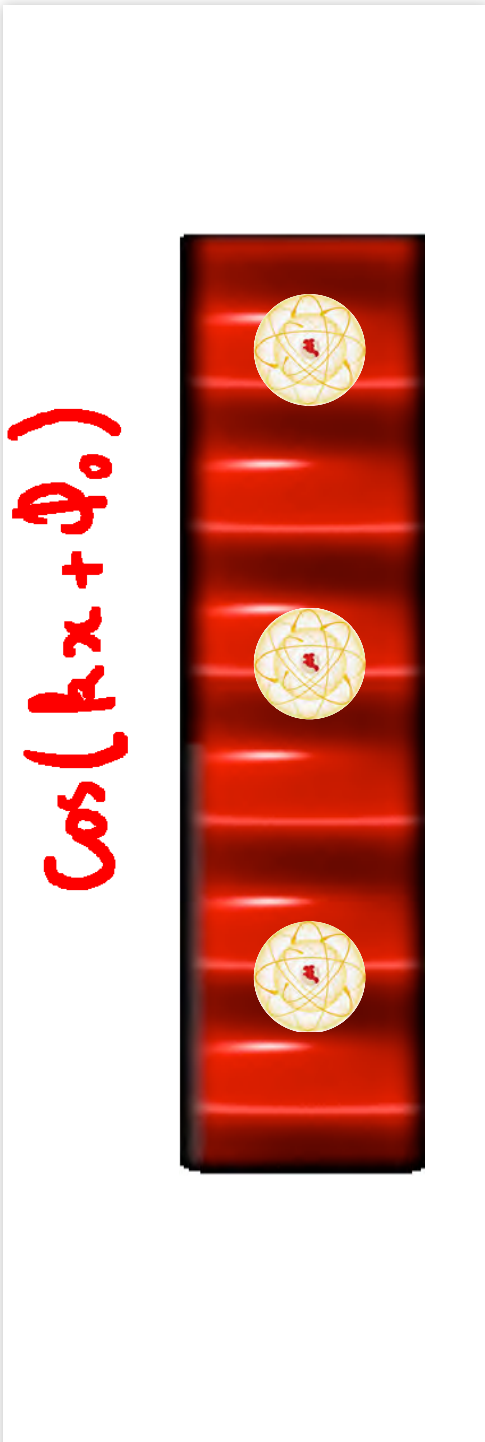
- Interference fringes : $N_{at} \sim \cos(2\pi a T^2/\lambda + \Phi)$



From S. Merlet, *et al.* arXiv:0806.0164v1

- Extract acceleration from interference signal

ATOM-BASE ACCELEROMER : BASIC PRINCIPLE



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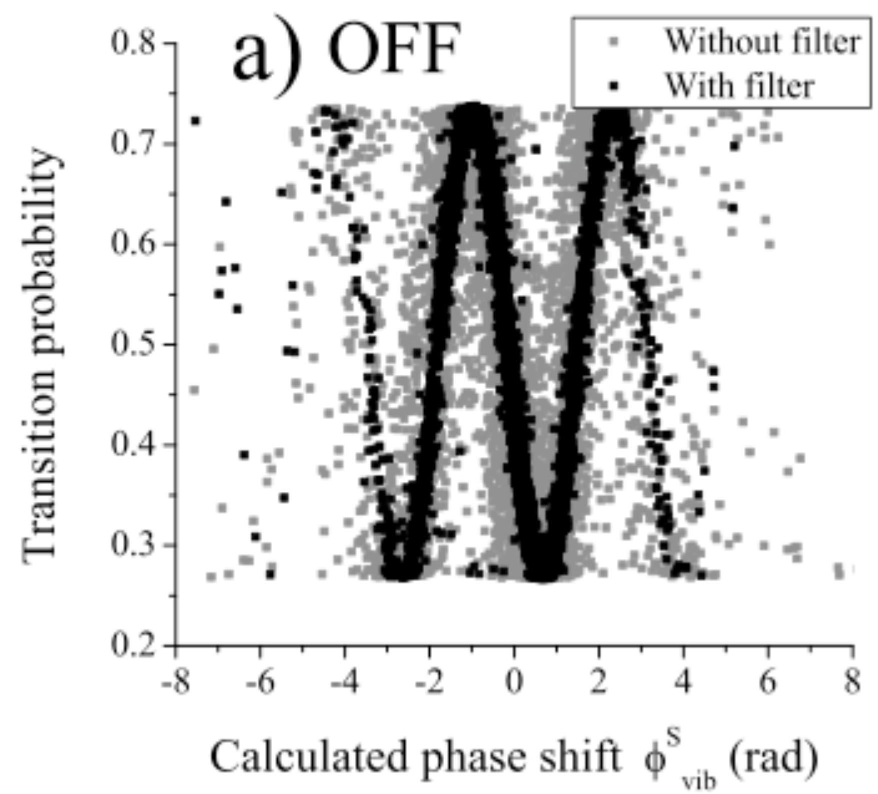
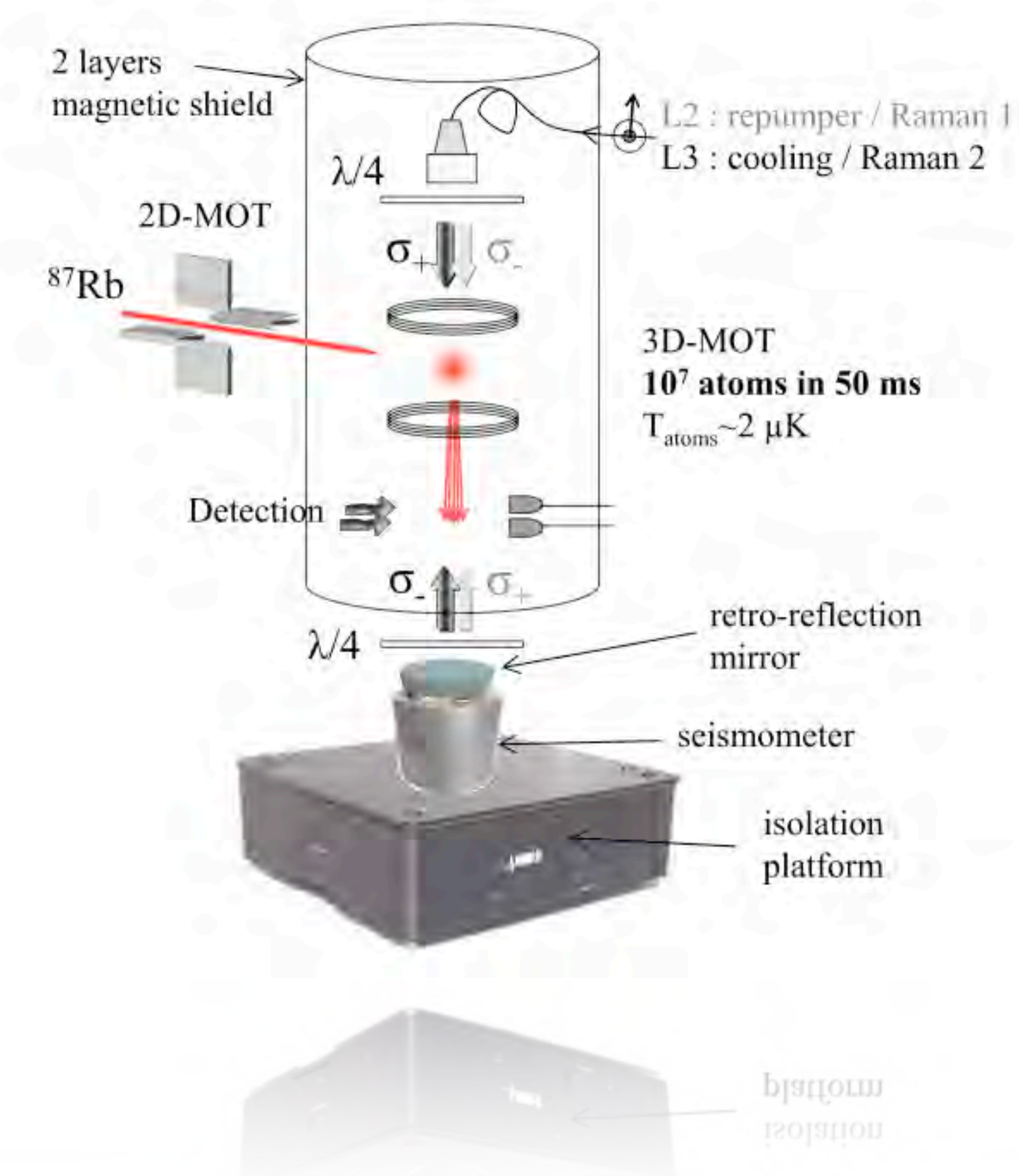


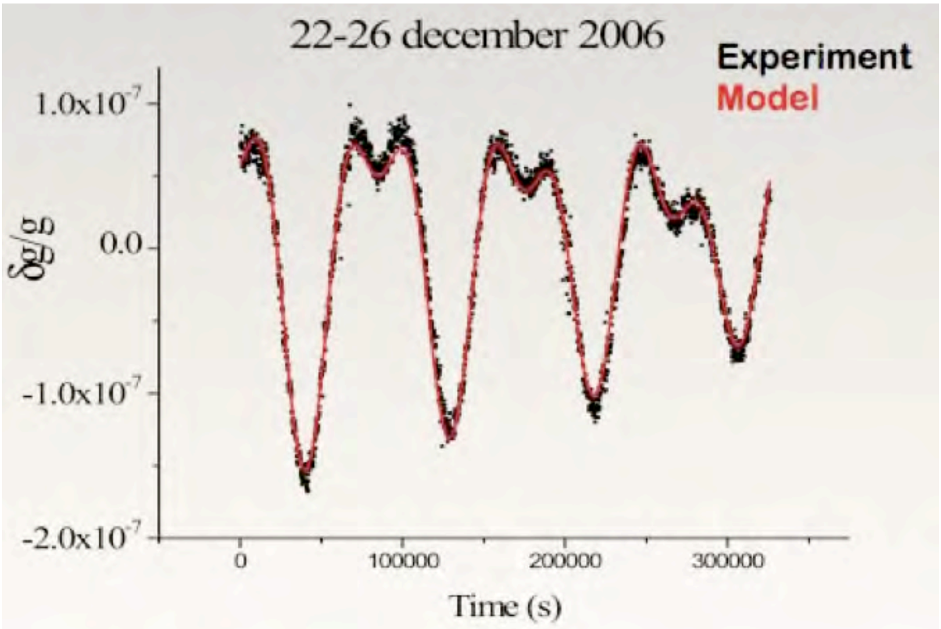
From S. Merlet, *et al.* arXiv:0806.0164v1

- Extract acceleration from interference signal

$$\Delta a_{min} = \frac{a|_{\Delta\phi_{acc}=1\,rad}}{\sqrt{N}} = \frac{1}{k T^2 \sqrt{N}}$$

ATOM-BASE GRAVIMETER

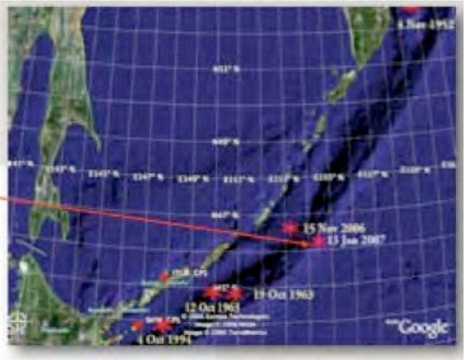




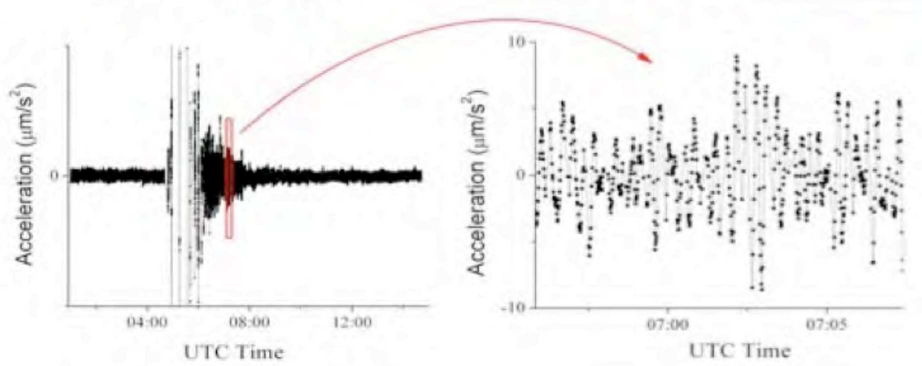
Bias fluctuations : ± 10^{-8} g

Very robust experiment

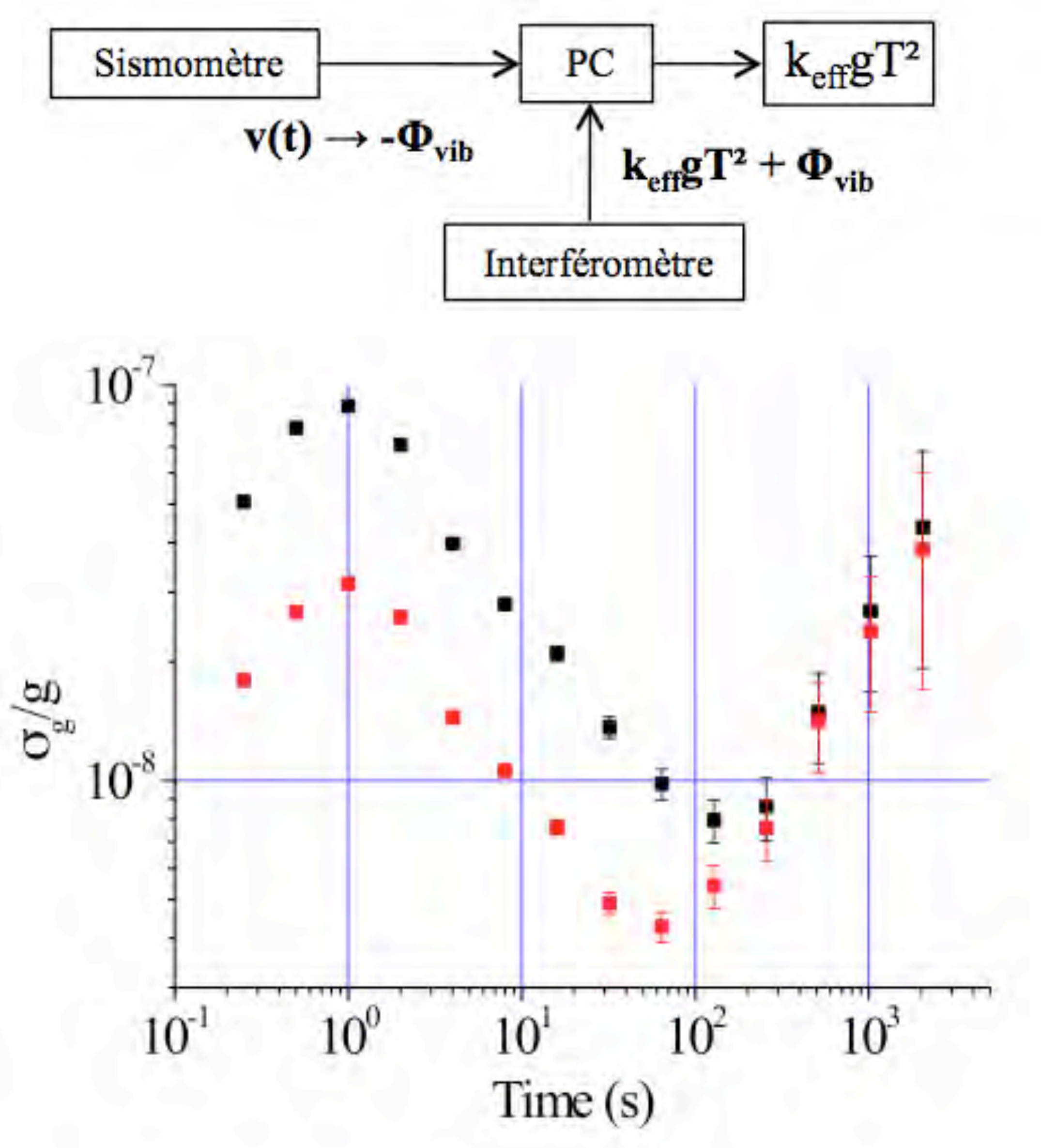
2007, January 13 - 04:23 UTC
Kuril Islands Magnitude 8.1

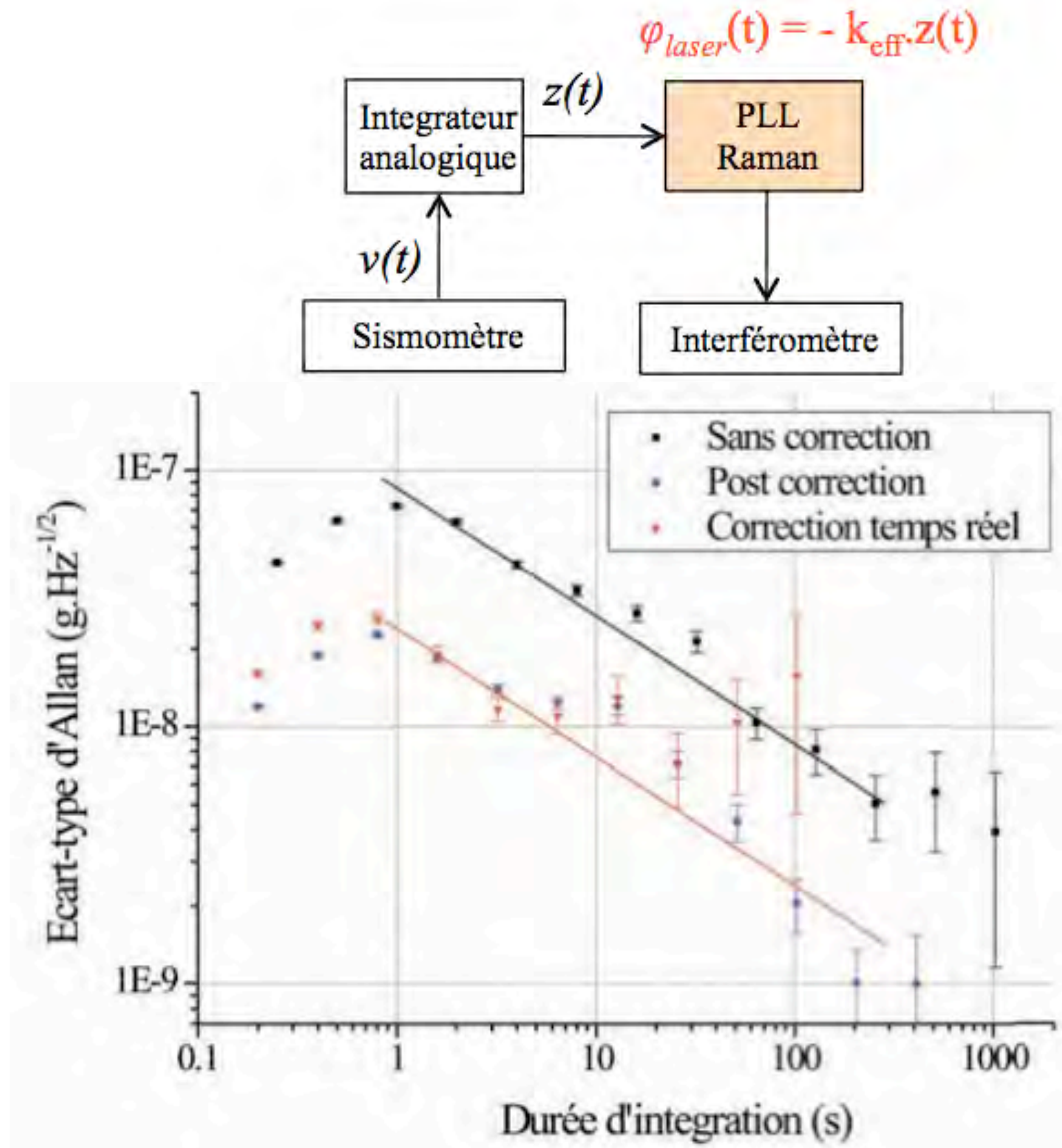


Signal in Paris **Period ~ 17 s**



Passive/Active

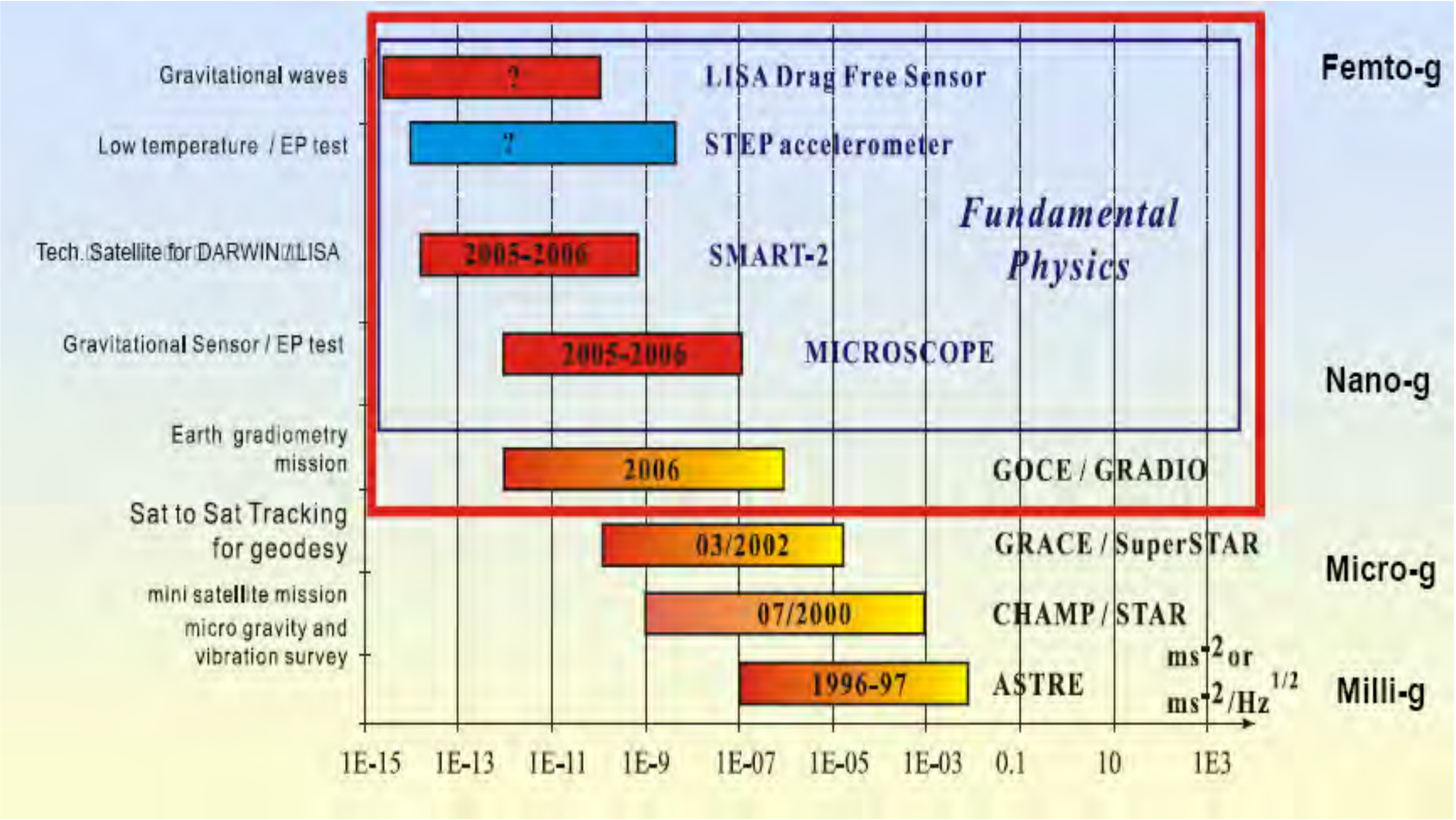




Sensitivity improved from 80 to 30 ng/√Hz

Sensitivity improved from 80 to 20 ng/√Hz

ULTIMATE SENSITIVITY : LONG BASELINE AND SPACE



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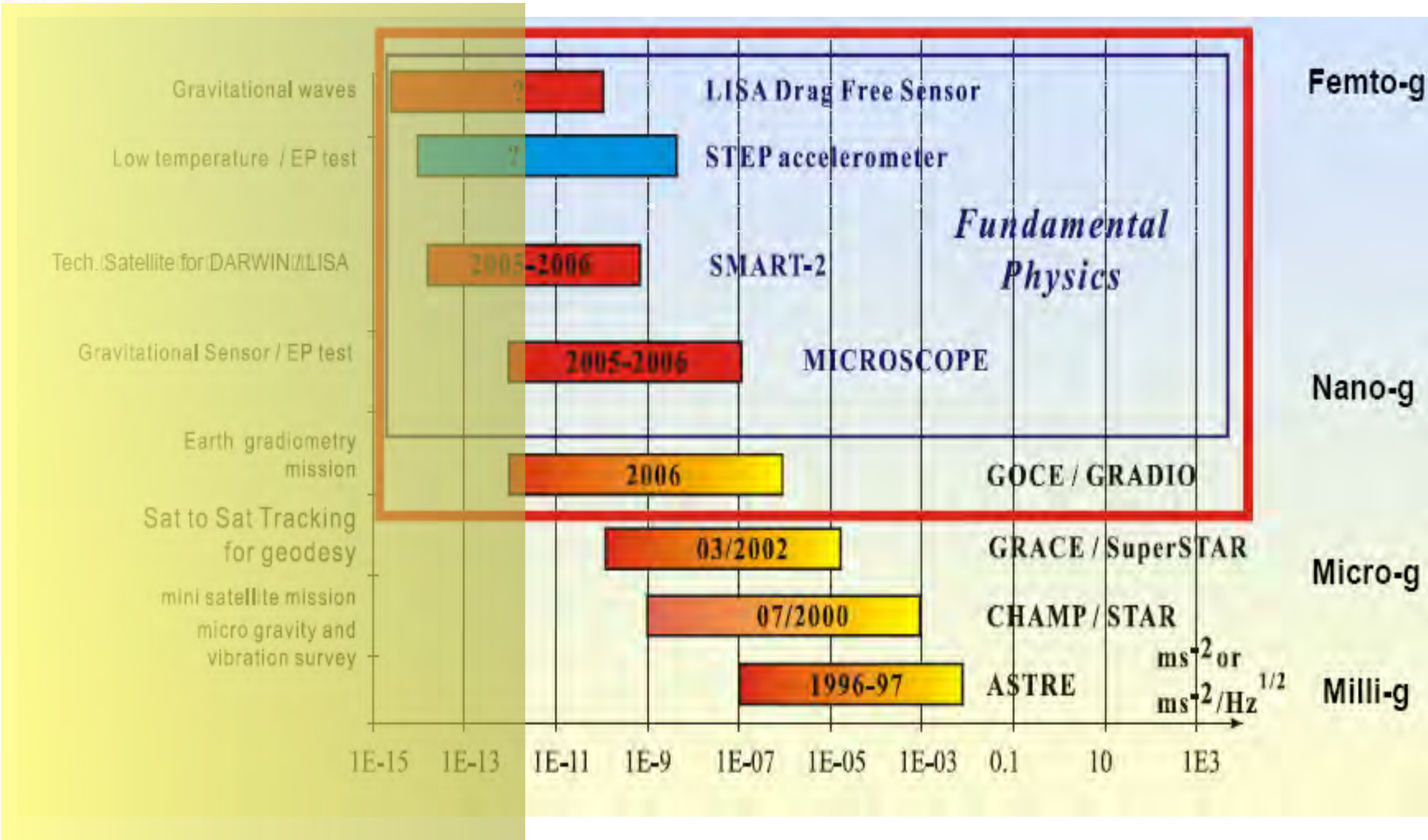
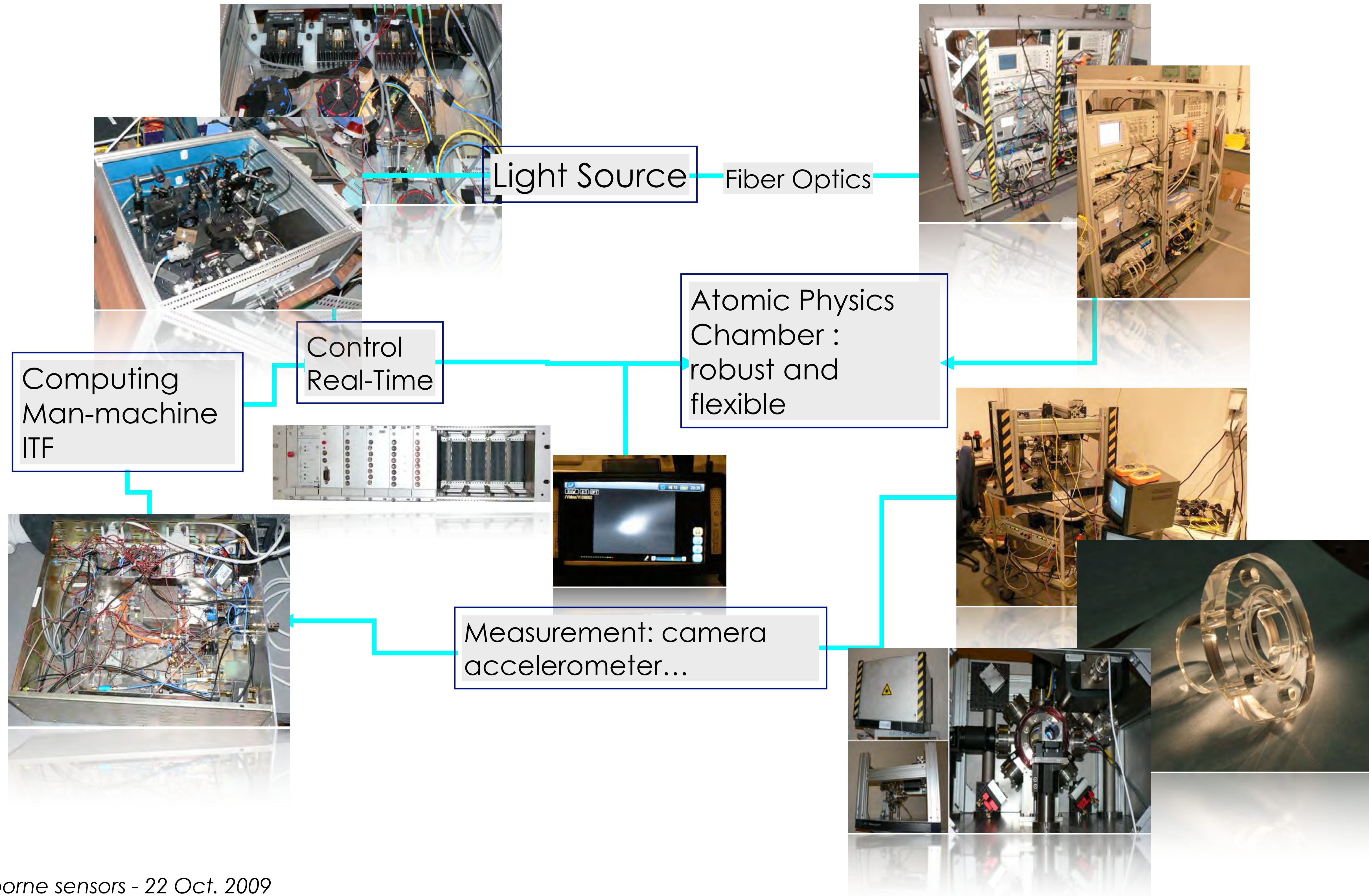


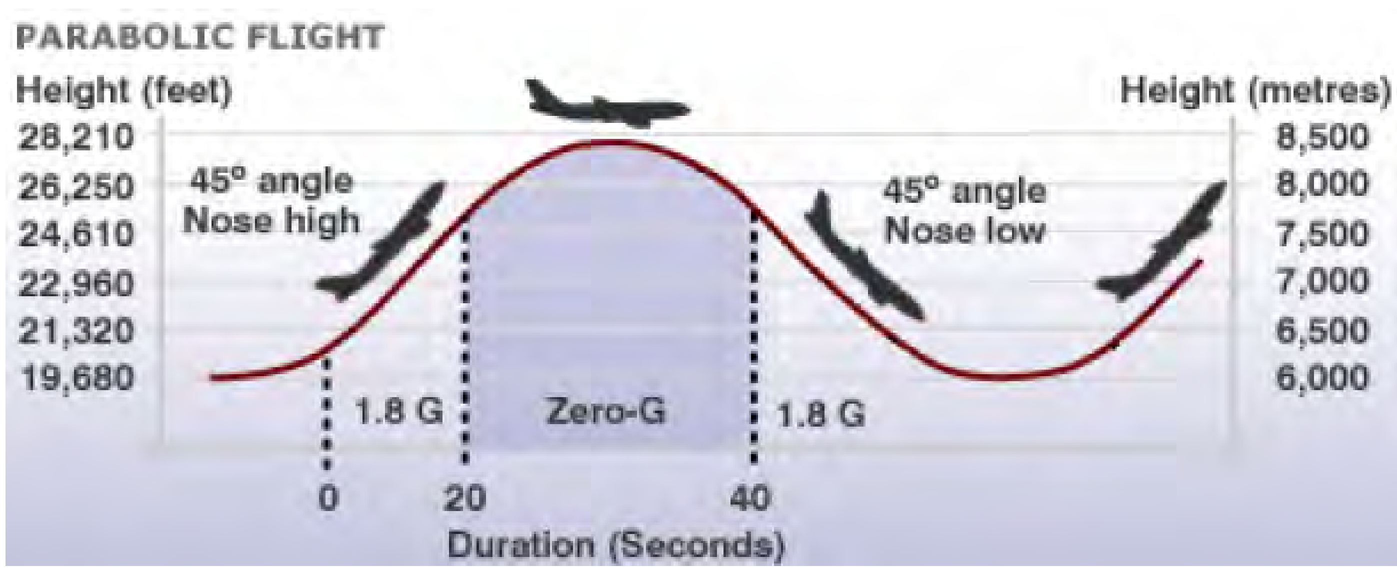
FROM GROUND TO AIRBORNE IN 0-G FLIGHT

DEVELOPMENT OF AIRBORNE COMPONENTS



I.C.E. : 0-G TESTS

First tests in March 2007 : 500 parabolas since then.



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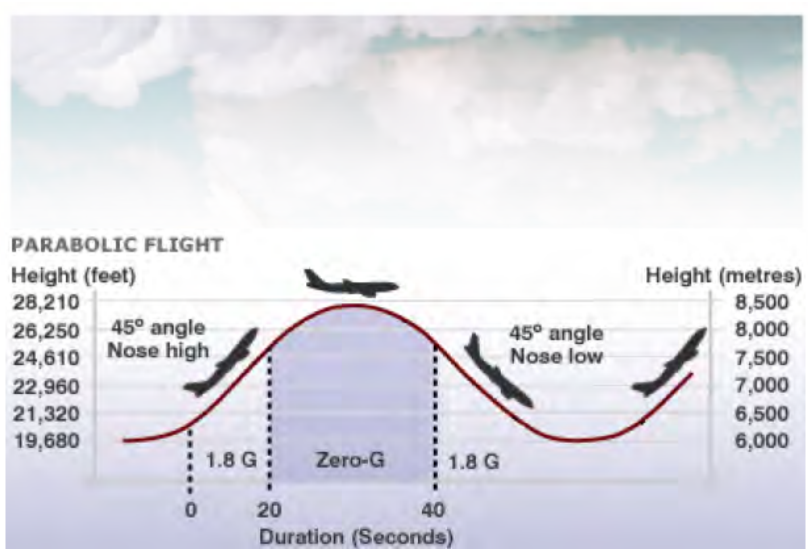
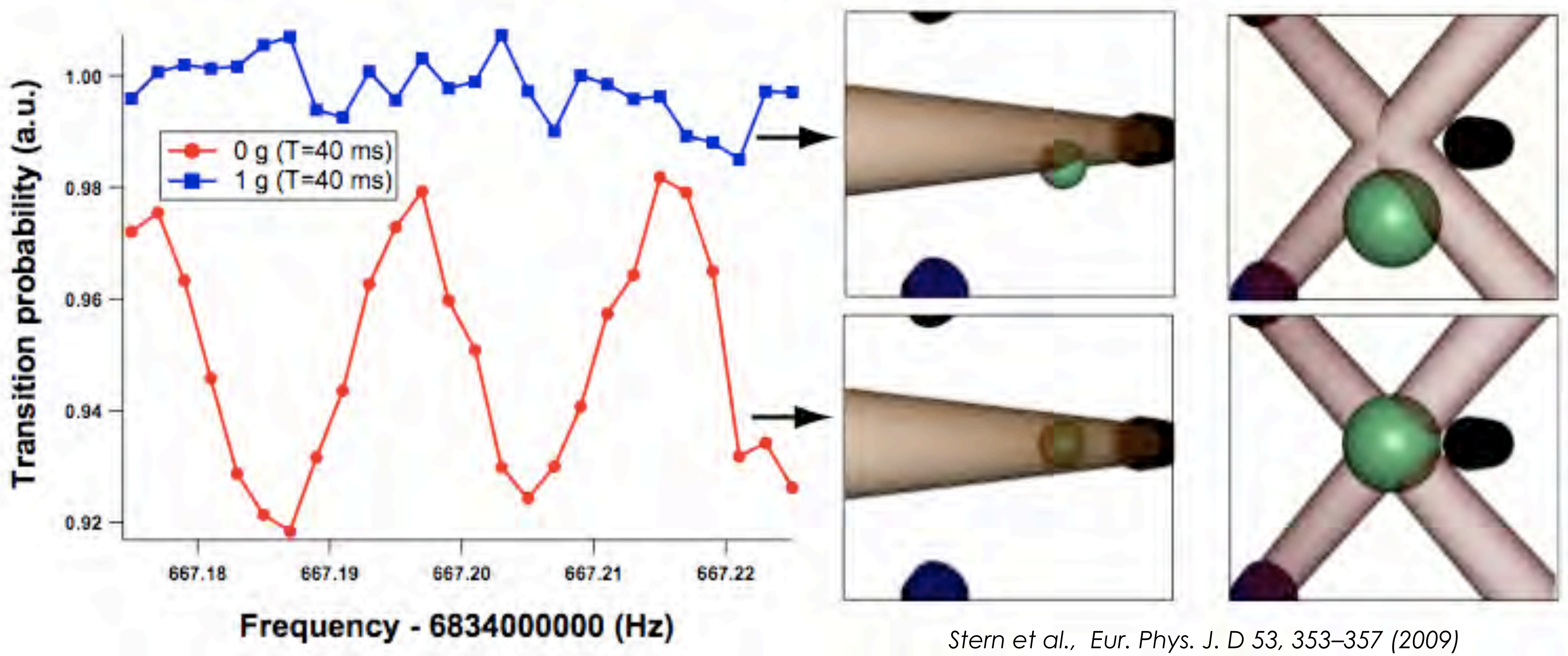
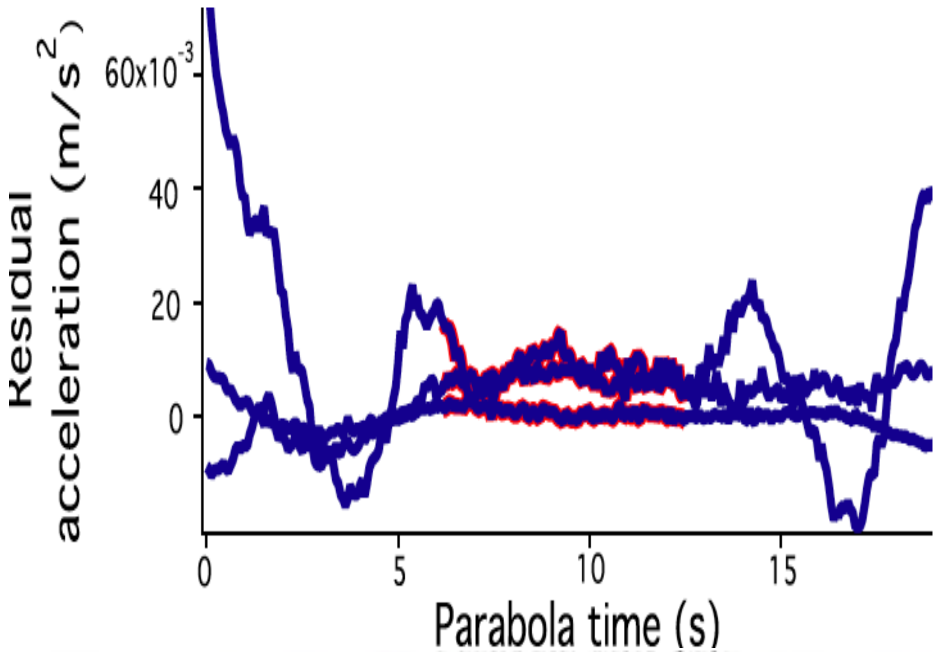
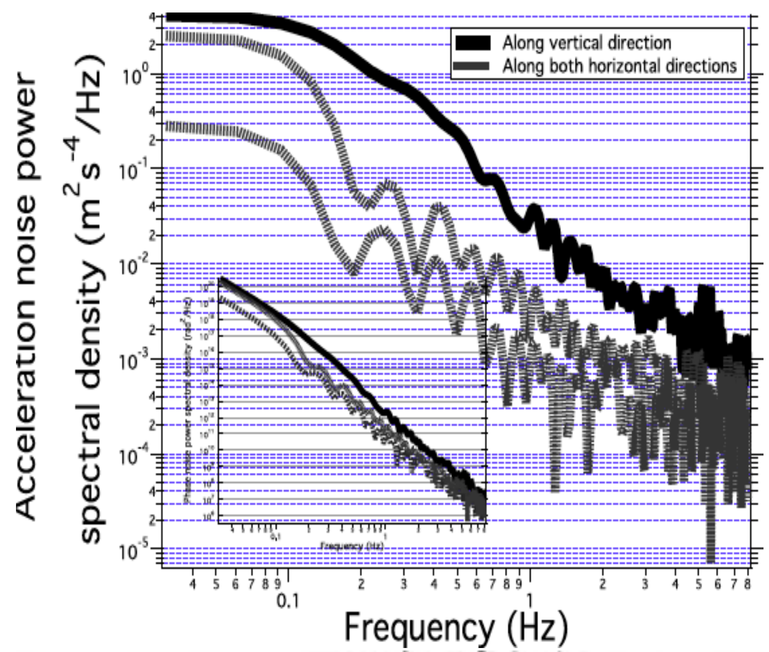


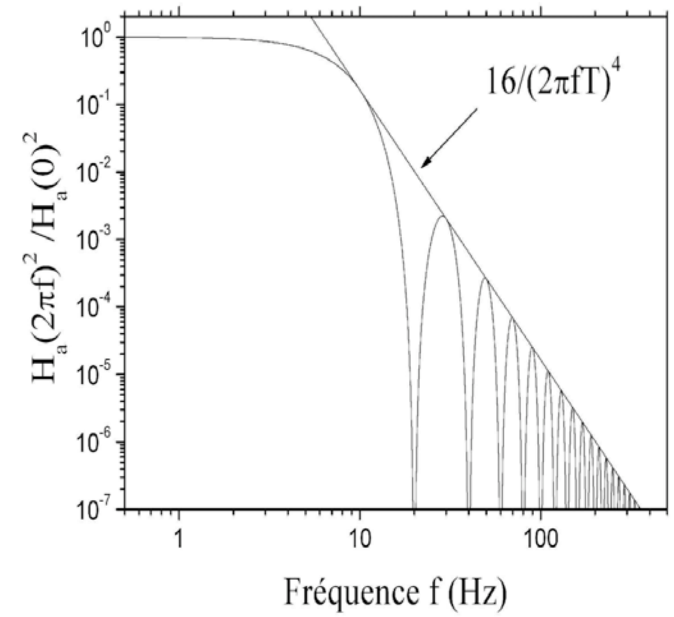


Stern et al., Eur. Phys. J. D 53, 353–357 (2009)

VIBRATIONS

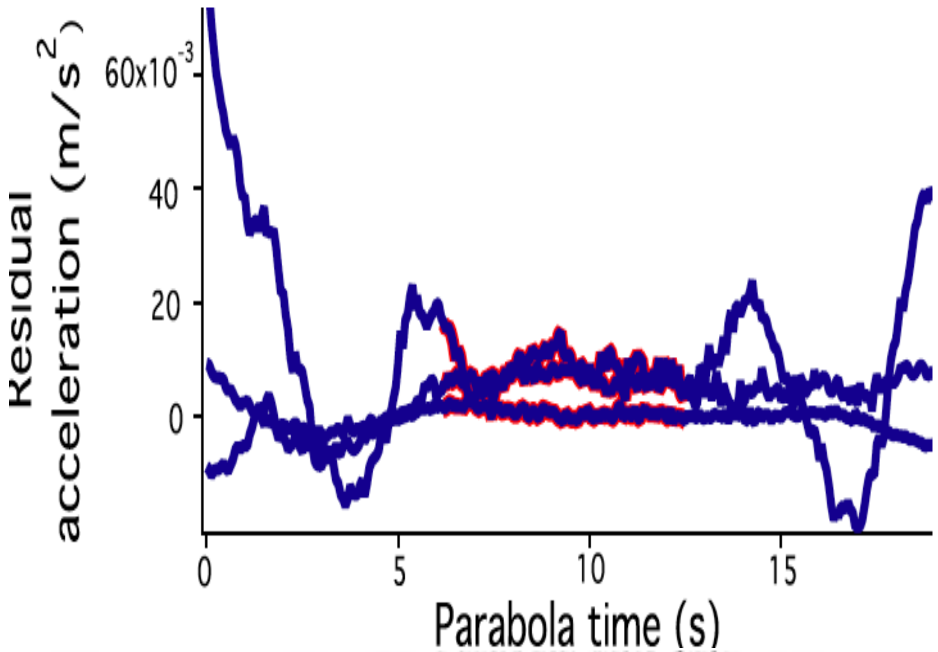


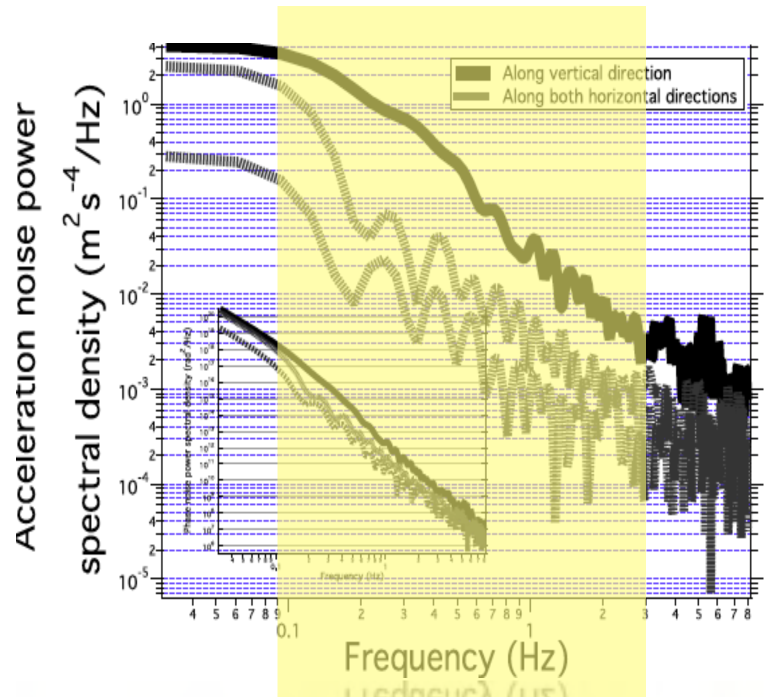


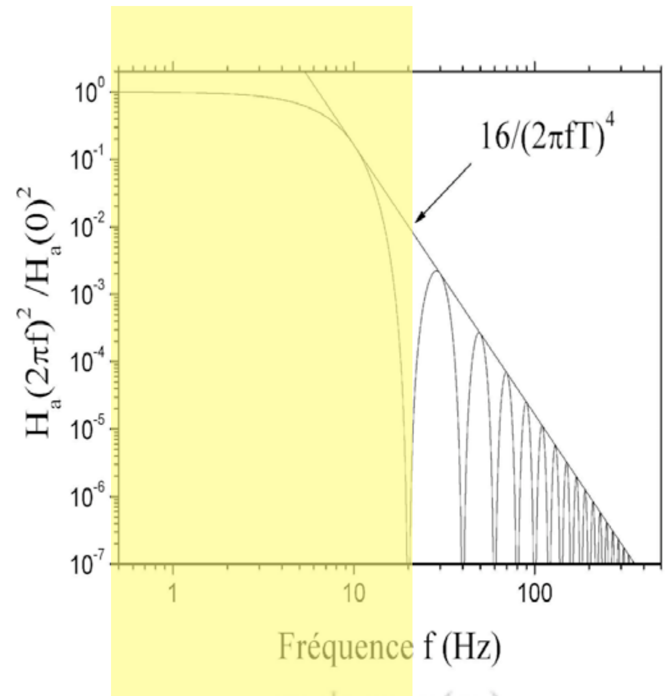


- Env. 10 mg max = 1s interrogation
  - Performances : 10^{-10} m.s^{-2} .Hz$^{-1/2}$
  - 100 measures ⇒ 10^{-11} m.s^{-2}
  - Need special isolation strategy

Vibrations

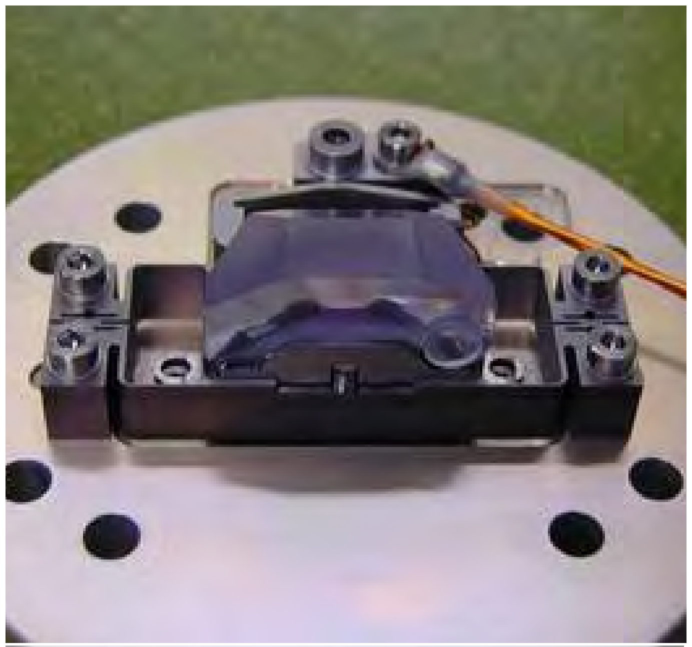




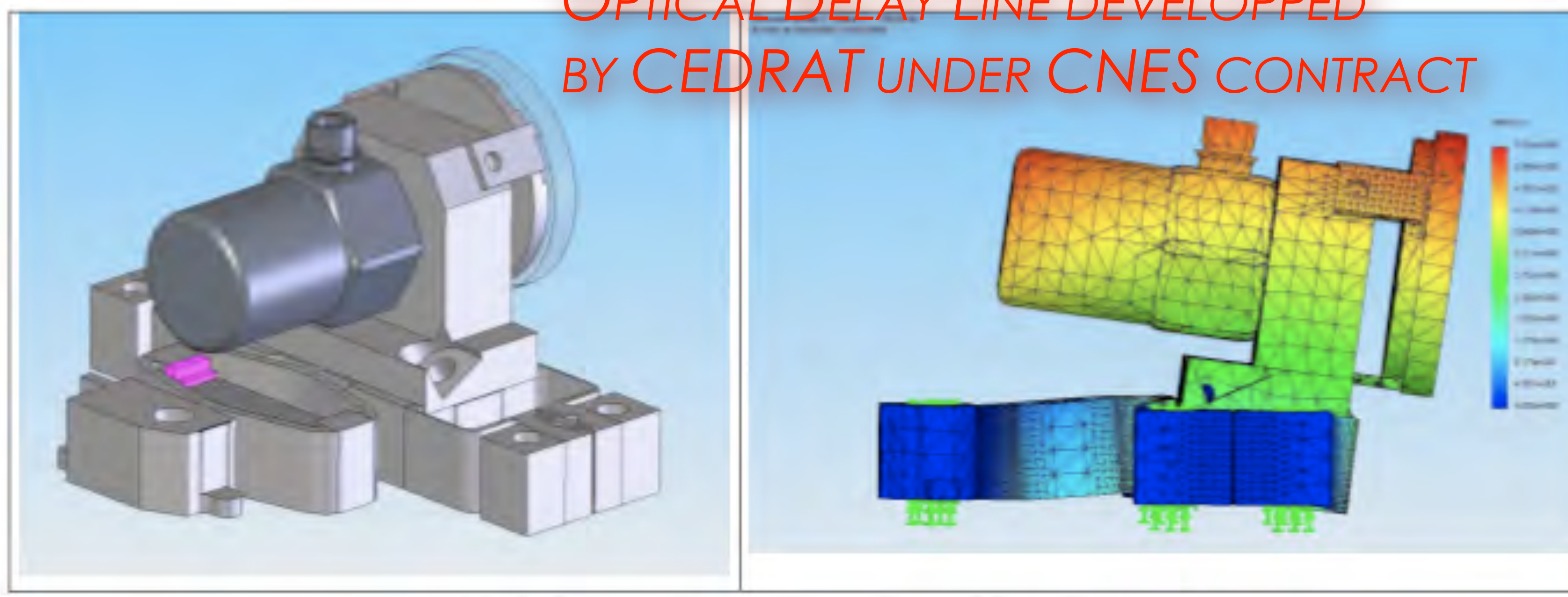


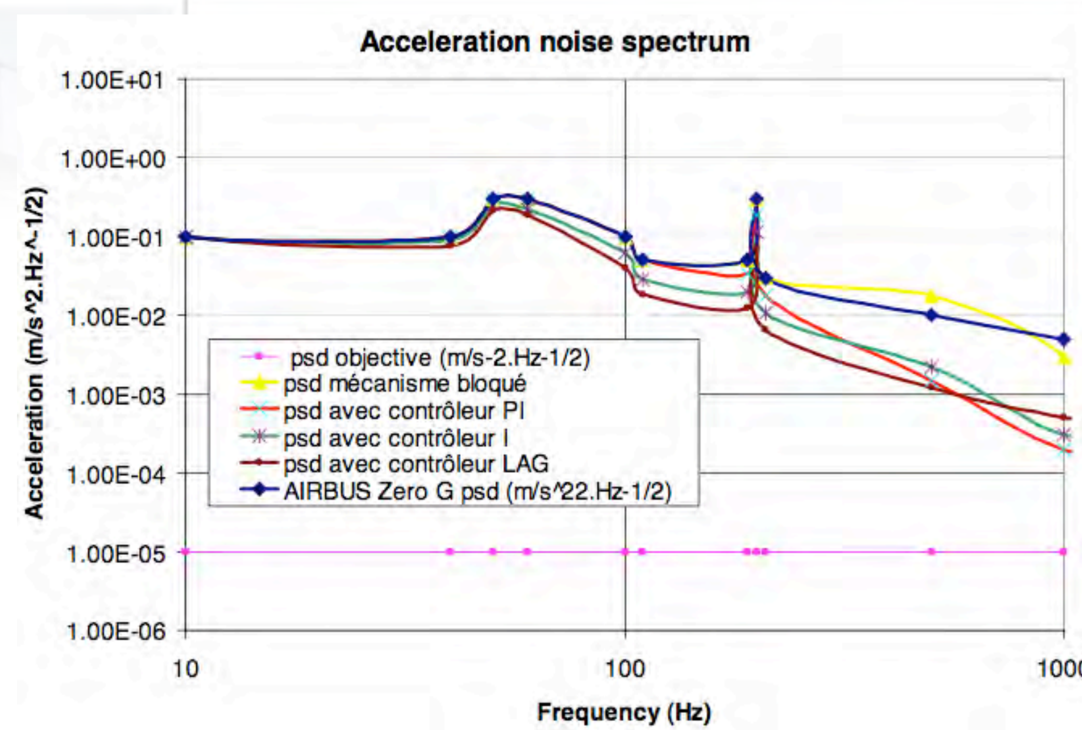
- One frequency range needs to be cancelled (directly averaged in interference signal)

Vibration isolation



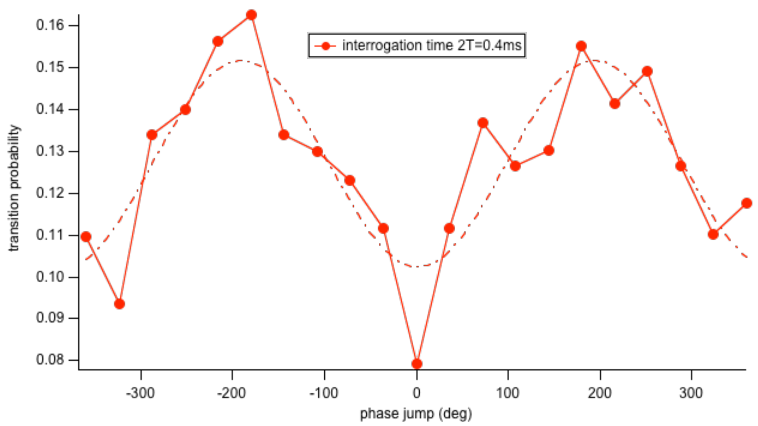
Optical Delay Line developped by CEDRAT under CNES contract



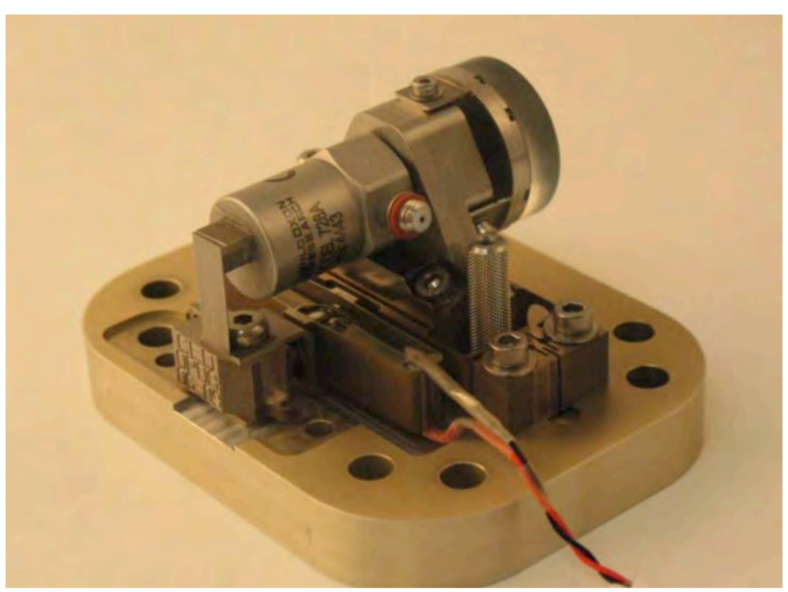


- Need to stabilize the retroreflecting mirror.
- Use of piezzo-accelerometer readout and optical delay line (developped for LISA)

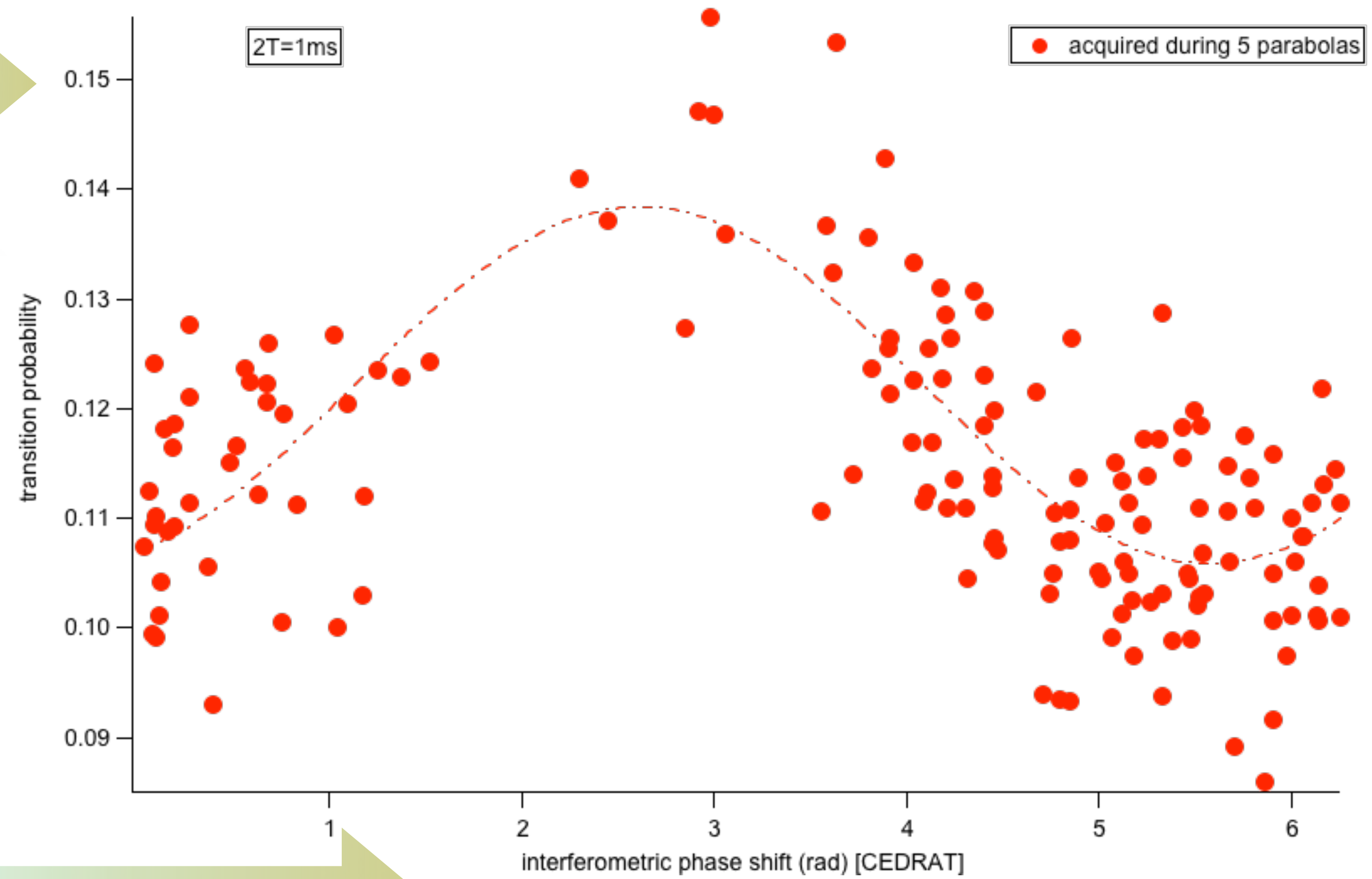
Vibrations in the plane



Atom interferometer fringes



Accelerometer wilcoxon 728 A



1 ms interrogation: 1 mg/√Hz

With better reference accelerometer : 0.1 µg/√Hz

TOWARDS COMPACT AIRBORNE SENSOR

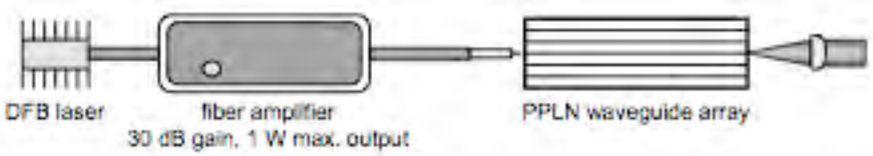
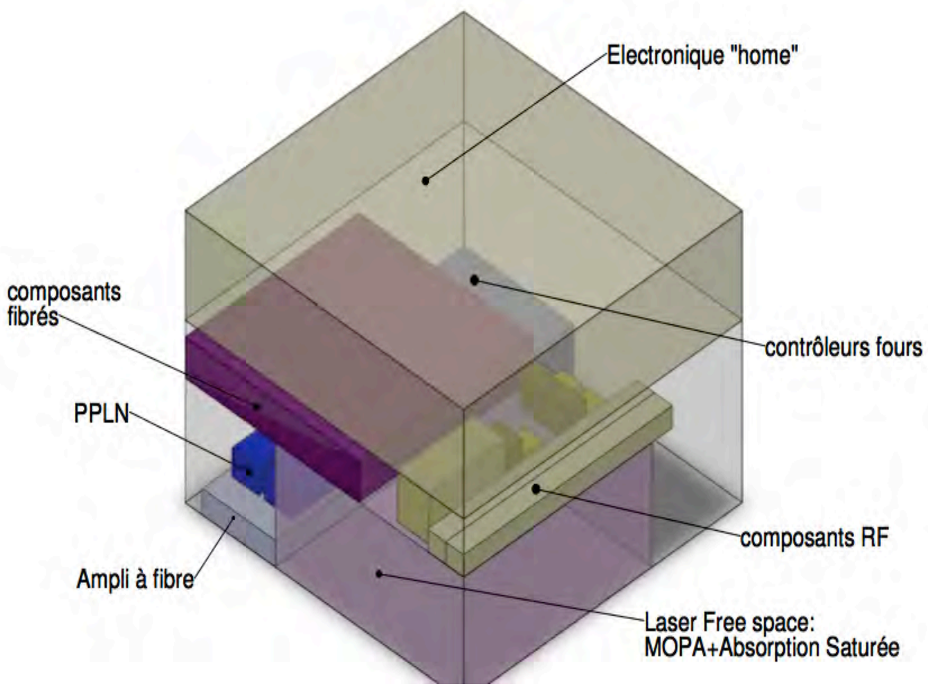
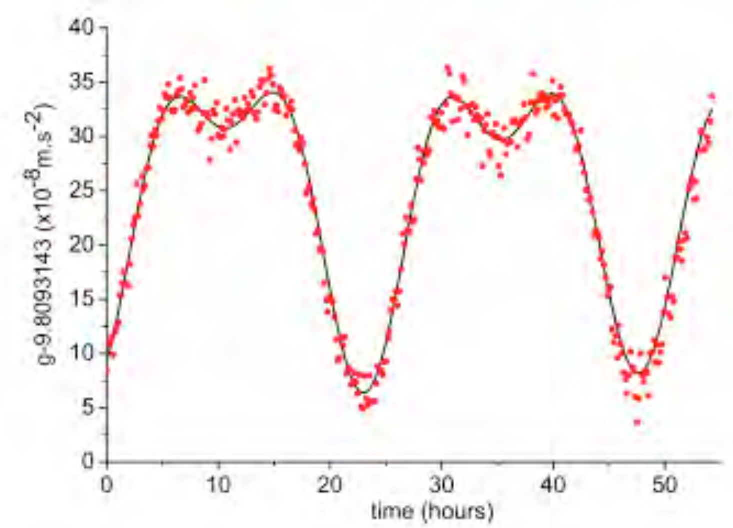
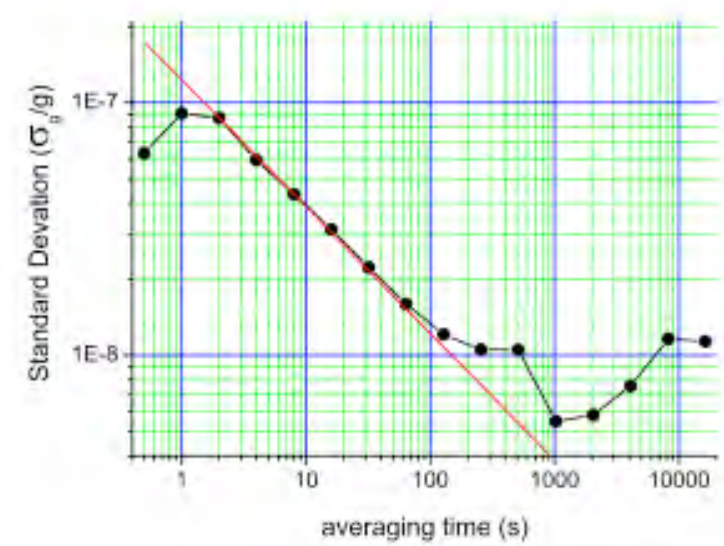


Figure 1: Schematic of apparatus used to generate 780 nm light from a telecom laser.

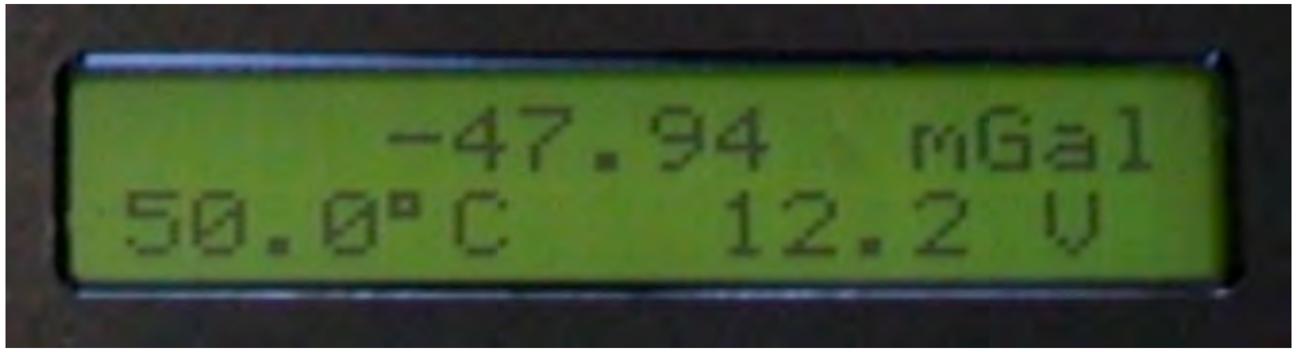


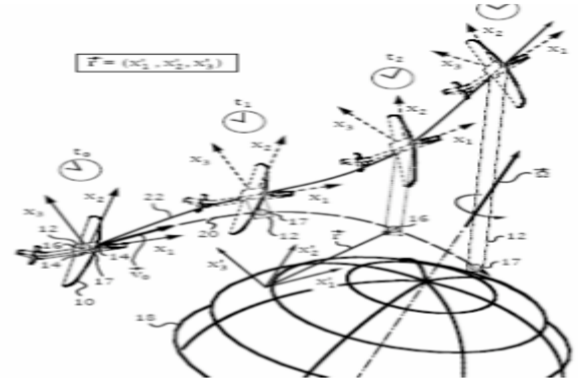


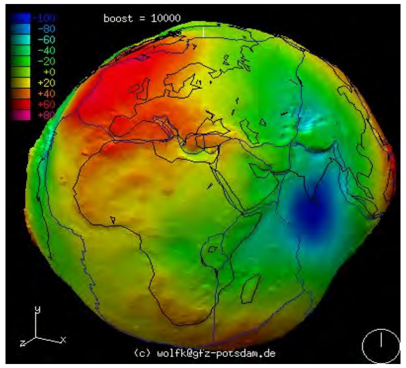


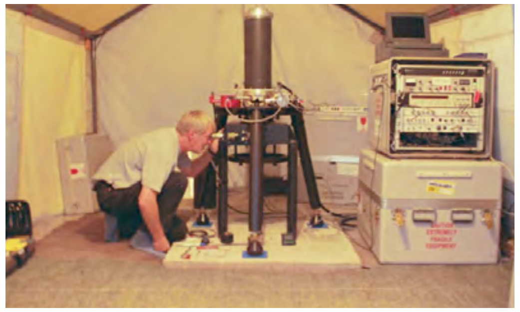
- Integrated telecoms technology (all integrated optics).
- Compact and simple sensor head (10 x 10 x 50 mm^3).
- Scalable sensitivity/accuracy : 10 ng demonstrated

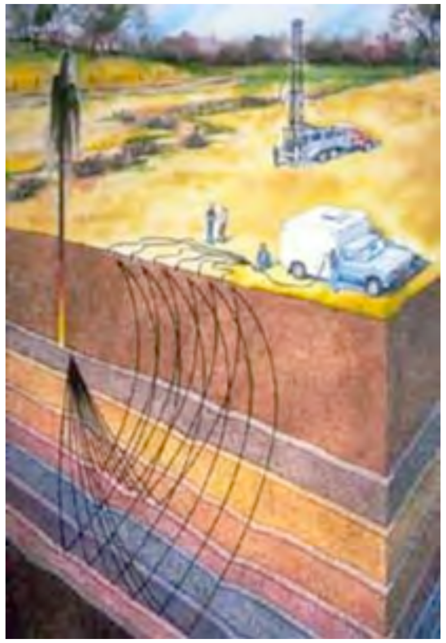
TRANSPORTABLE SENSORS FOR GRAVITY MONITORING











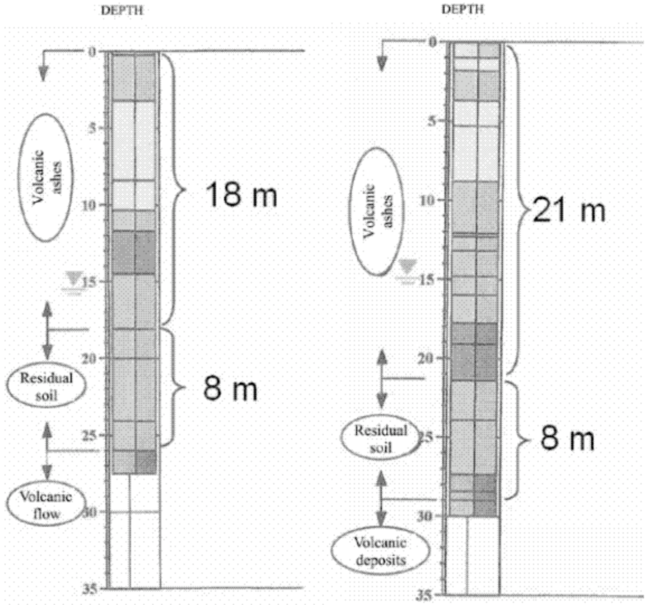


Figure 2. Boreholes P4 and P6 corresponding to Puerto Espejo and University of Quindio.

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