Influence of the data process in the determination of the Equivalence Principle violation signal for the MICROSCOPE experiment

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retour sur innovation

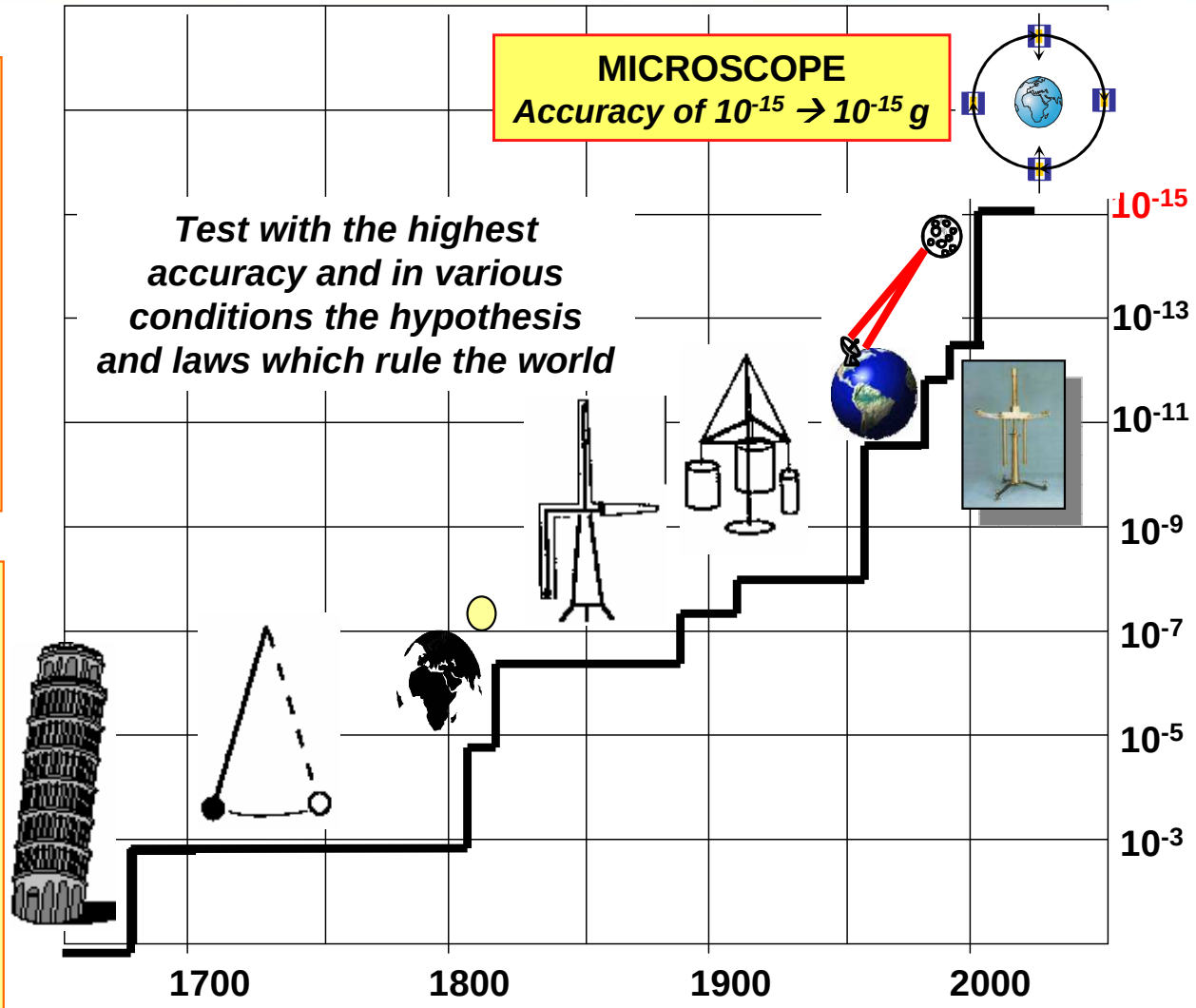
The Equivalence Principle

PE → **Universality of free fall** : all bodies, independently of their mass or intrinsic composition, acquire the same acceleration in the same uniform gravity field

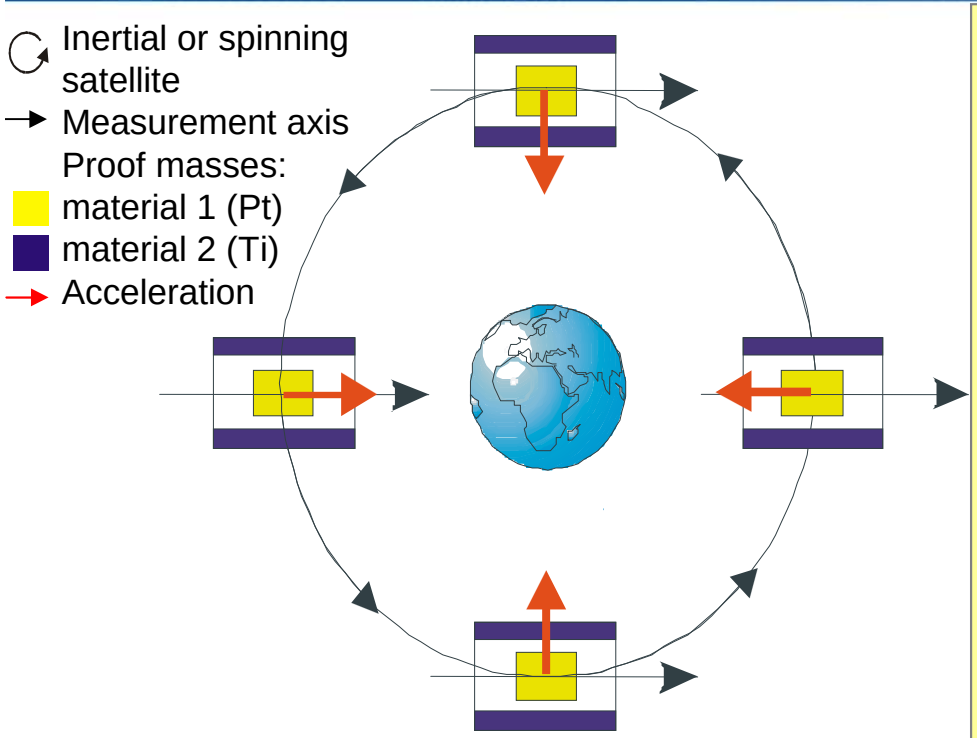
$$\frac{M_G}{M_I} = 1$$

Quantum Mechanics, Standard model: electromagnetic, strong, weak interaction
≠ Geometrical theory of the gravitation
Super-symmetry: Sparticules, LHC
String theory, Branes...
=> New interaction?
⇒Violation of the Equivalence principle?

$$\frac{M_G}{M_I} = 1+\omega$$



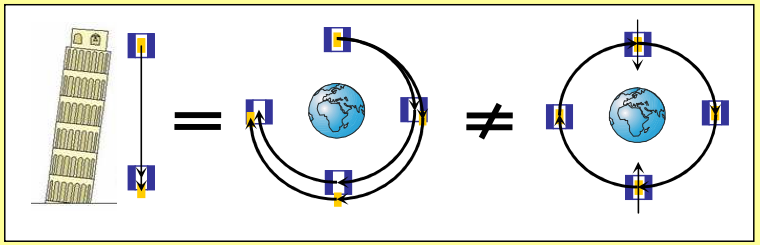
The principle of the MICROSCOPE space mission



CNES MYRIADE Microsatellite

- Circular Orbit: 720 km, e < 5.10^{-3}
- Inertial or Rotating: 7.10^{-3} rd/s
- Mission duration: 12 months
- Mass of microsat: 200 kg
- Payload budgets: 35 kg, 40 Watts
- 2 differential electrostatic accelerometers
  (2 pairs of masses: Pt/Pt & Pt/Ti)

- Gravitational source: **the Earth**
- inertial acceleration: orbital motion
- 2 masses of **different composition**: controlled **on the same orbit** (< 10^{-11}m) thanks to the measured electrostatic forces

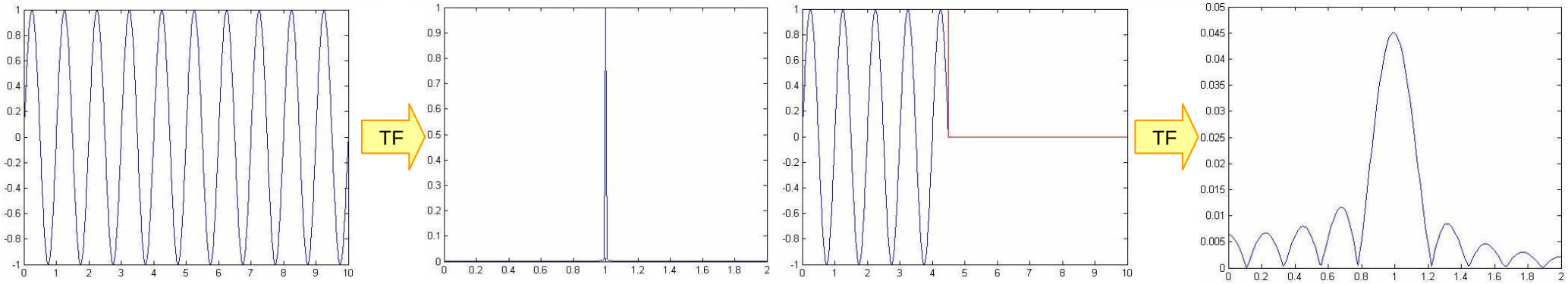


- time span of the measurement: **non limited by the free fall** (> 20 orbits)
- Environment: Very controlled or avoiding perturbations, **drag-free satellite**
- Signal to be detected: phases & frequency are defined **f_{ep} =**

- Inertial mode: f_{orb} = 1/orbit

- Spinning mode: f_{orb}+ f_{spin}

Influence of the observation window



- Aliasing: a perturbation at any frequency has a component at the EP violation frequency (f_{EP})

Projection rate of a perturbation on the EP violation signal at f_{EP}:

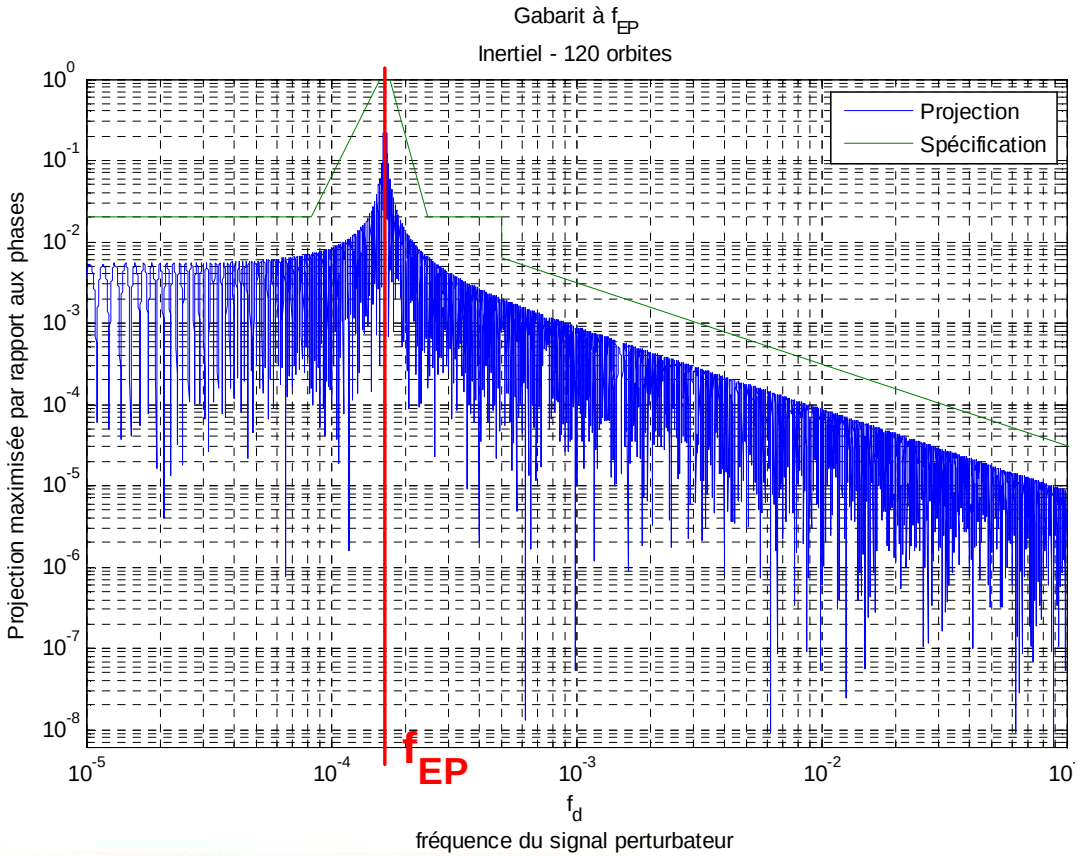
EP violation signal:

$$S_{EP} = A_{EP}\sin(\omega_{EP}t + \varphi_{EP})$$

Disturbance signal:

$$S_d = A_d\sin(\omega_d t + \varphi_d)$$

$$\tau = \frac{< S_{EP}, S_d >}{< S_{EP}, S_{EP} >}$$



Choice of the measurement duration and spin frequency

Main disturbance: due to the orbital or spin motion

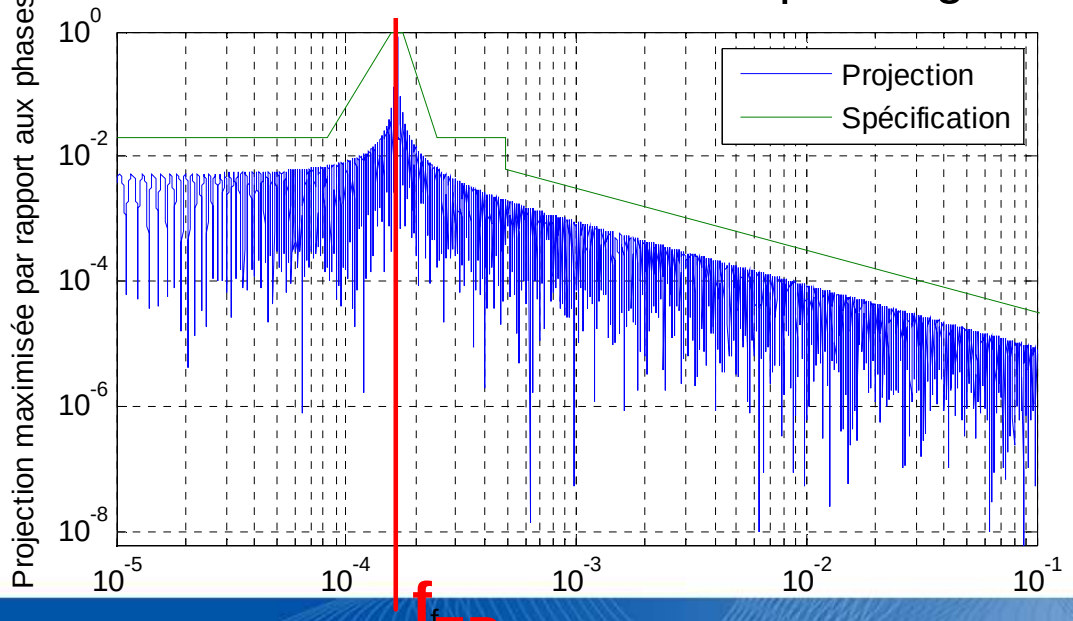
→ choice of f_{spin} and $T_{observation}$ to have minimal projection rates:

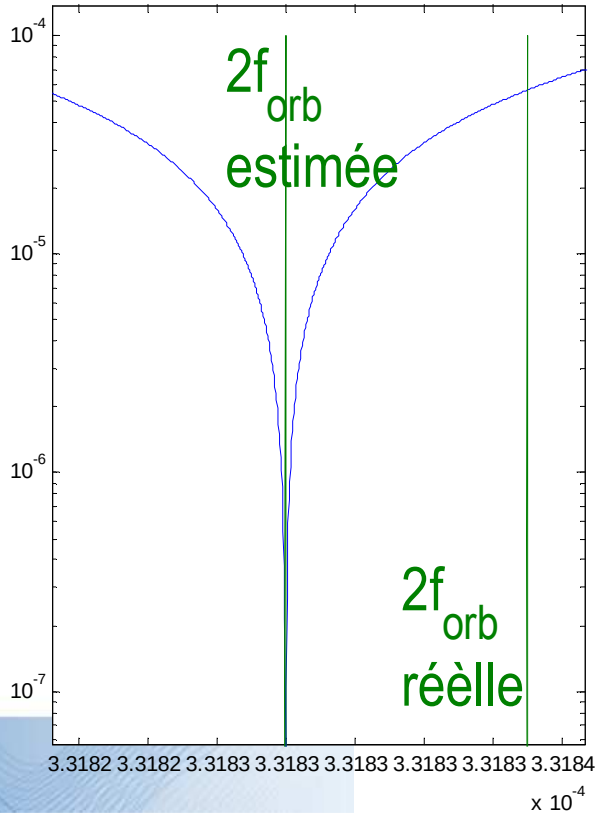
- $T_{observation} = k_1.T_{orb}$
- $T_{observation} = k_2.T_{spin}$

Inertial mode	Spinning mode	
$k_1 = 120$	$k_1 = 20$	to reduce the noise
	$k_2 = 73$	

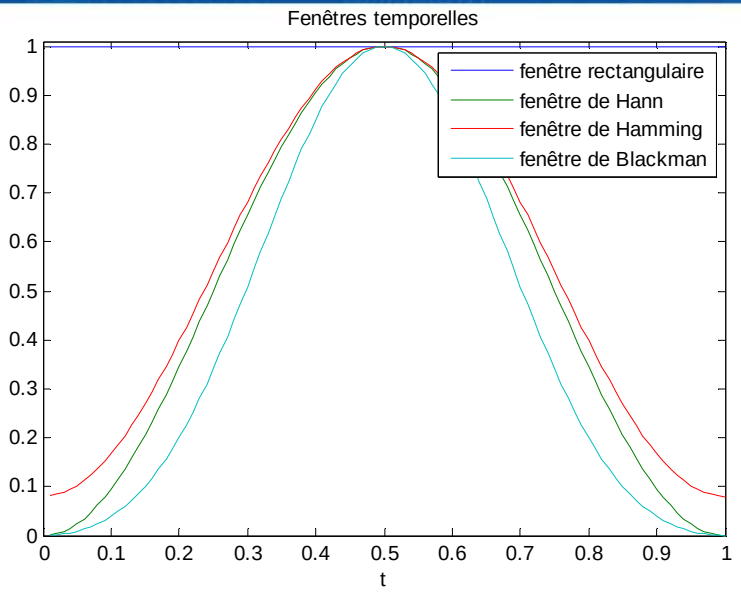
Influence of the incertitude and realisation error:

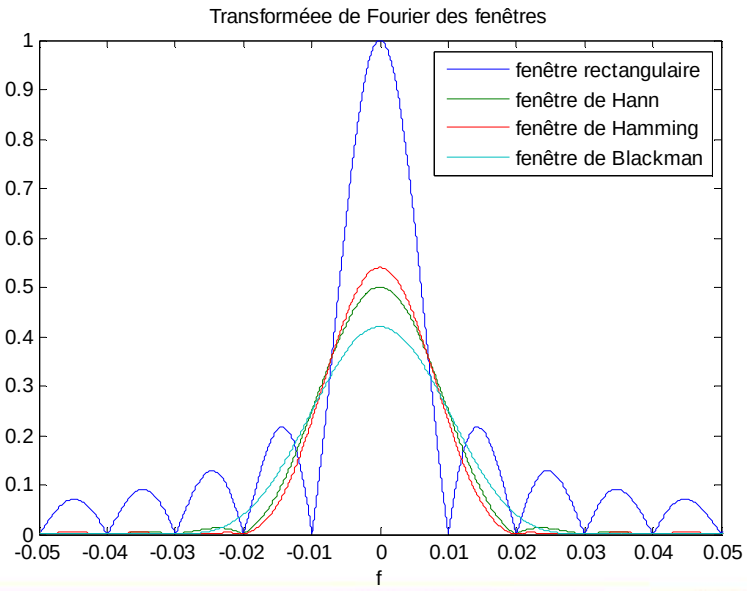
- Incertitude on the orbital frequency : 2.10^{-8}rad/s (↔ 100m for the orbit altitude)
- Command error on the spin frequency: 3.10^{-8}rad/s
- Realisation error on the inertial pointing: 1.10^{-8}rad/s

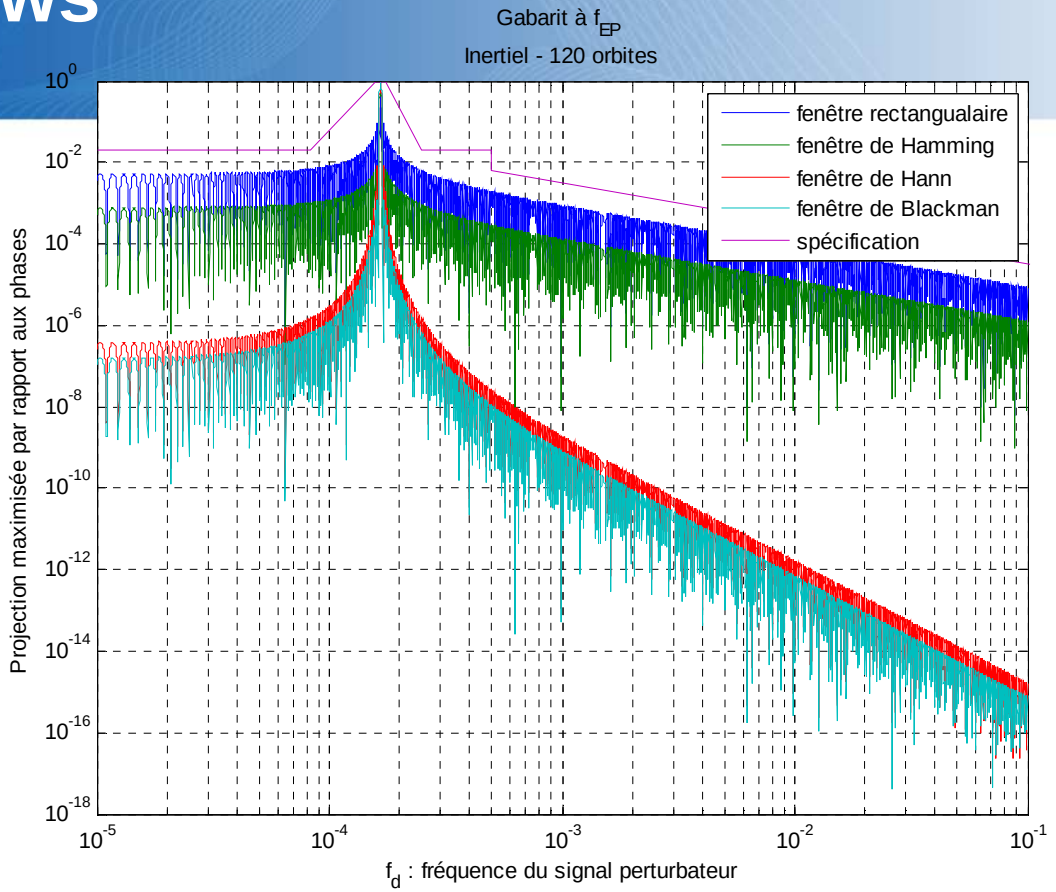




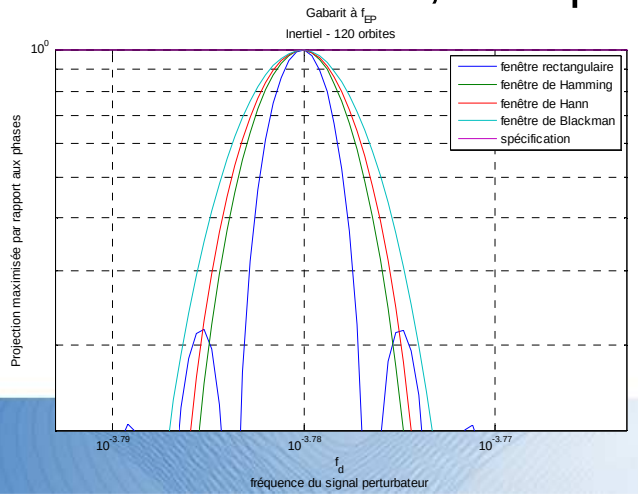
Non-rectangular windows







Comparison between different windows: **important amelioration**, except around f_{EP}



Measurement losses

- **Teletransmission errors**

  Information from the Picard mission:

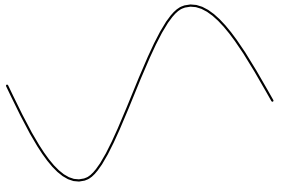
  - **frequency**: about 100 events in 10 months
  - **duration**: seconds - hours

- **Coating crackings**
  - due to the temperature changes (Earth / Space vacuum)
  - **frequency**: for each of the four satellite sides, about 6 times when facing the Earth
  - **duration**: 0.5-0.75s → 2 or 3 measurement points

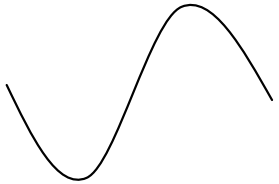
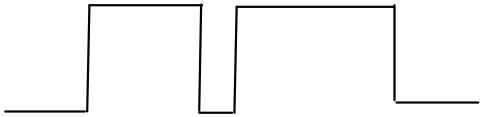
- **Tank crackings**
  - worst case, depending of the gas pressure
  - **frequency**: for each of the 6 tanks, about 43 times/orbit
  - **duration**: 0.5s → 2 measurement points

Measurement losses

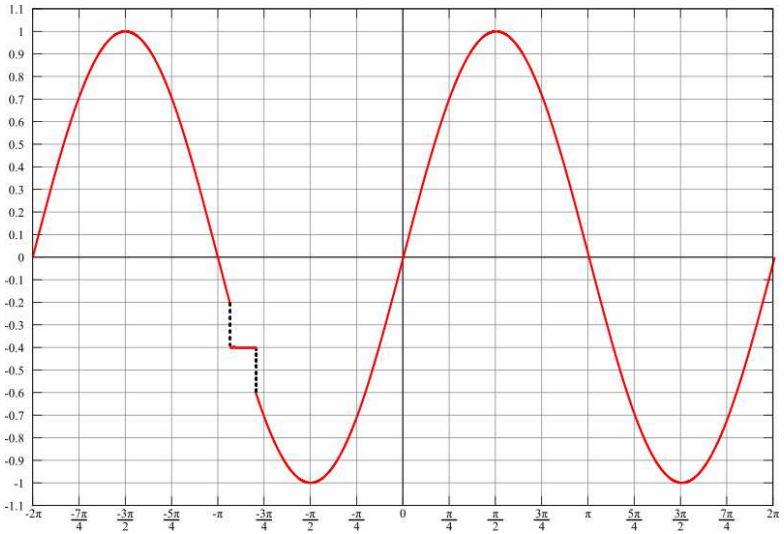
- Without measurement losses:

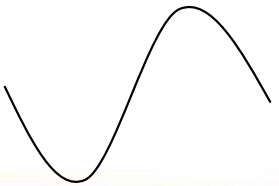
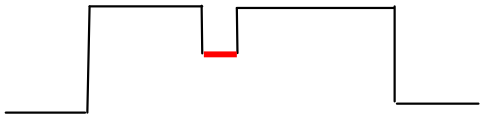
TF(S) = TF()*TF()

- With measurement losses: replacement by zeros

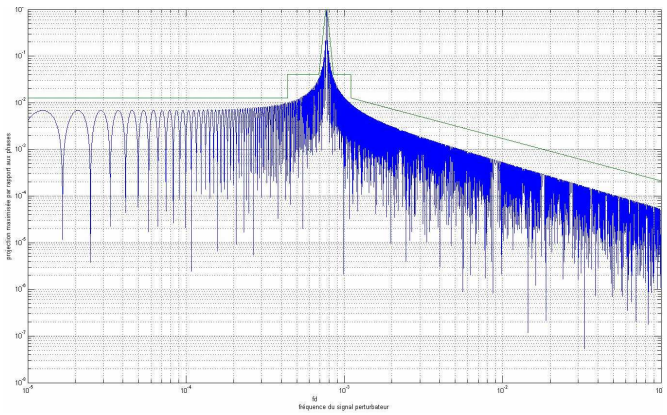
TF(S) = TF()*TF()

- With measurement losses: replacement by the mean value of the measurement before and after the interruption



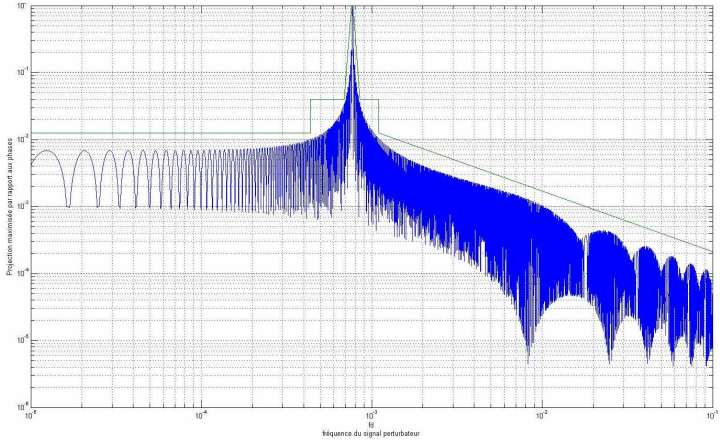
TF(S) = TF()*TF()

Short duration loss



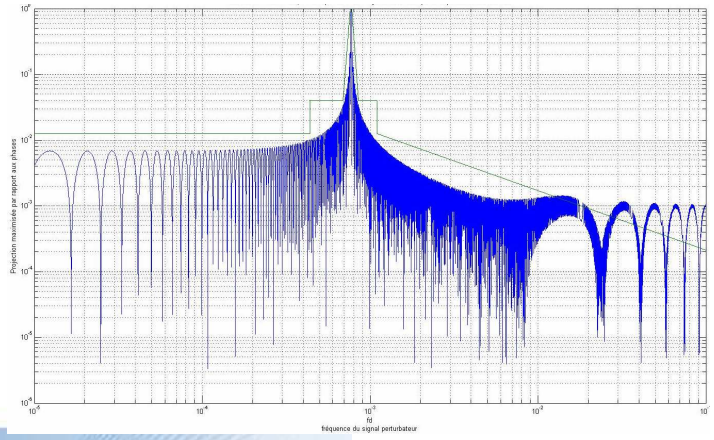
No measurement loss

- one measurement loss
- simulations with different duration
- respect the specifications up to 1 minute



First method: replacement by zeros

Second method: replacement by the mean value before and after the interruption



Division in subsections

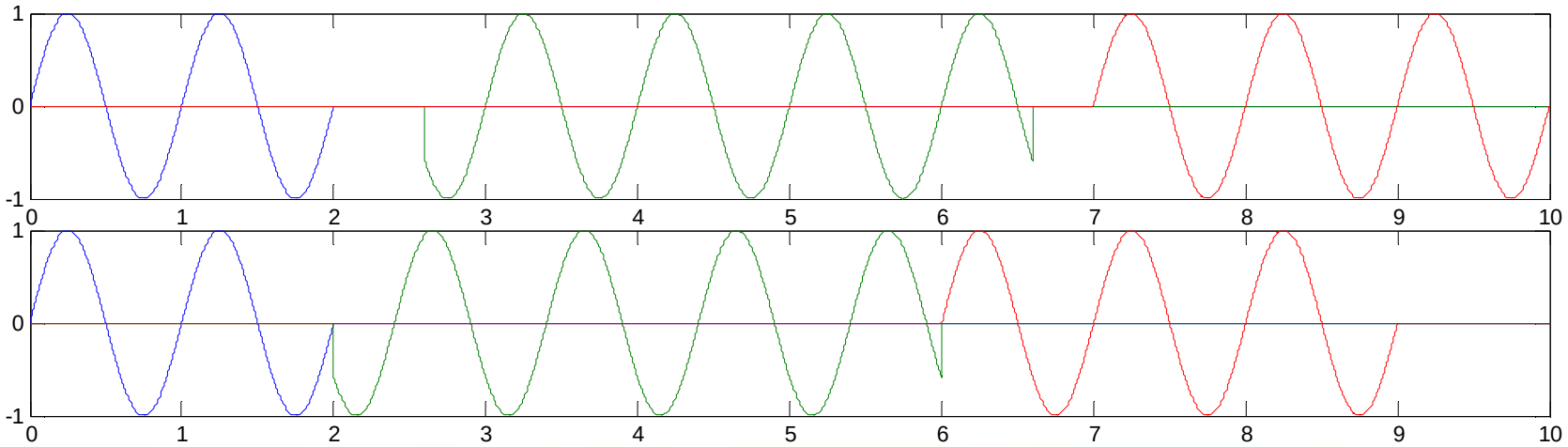
Success criterium: maximal one measurement loss of duration < 1 minute per session

Activity	Probability of failure
Spinning session: 20 orbits	2,9%
Inertial session: 120 orbits	16%

For data losses > 1 minute in inertial session:

→ inertial session of 120 orbits divided in **several subsections**

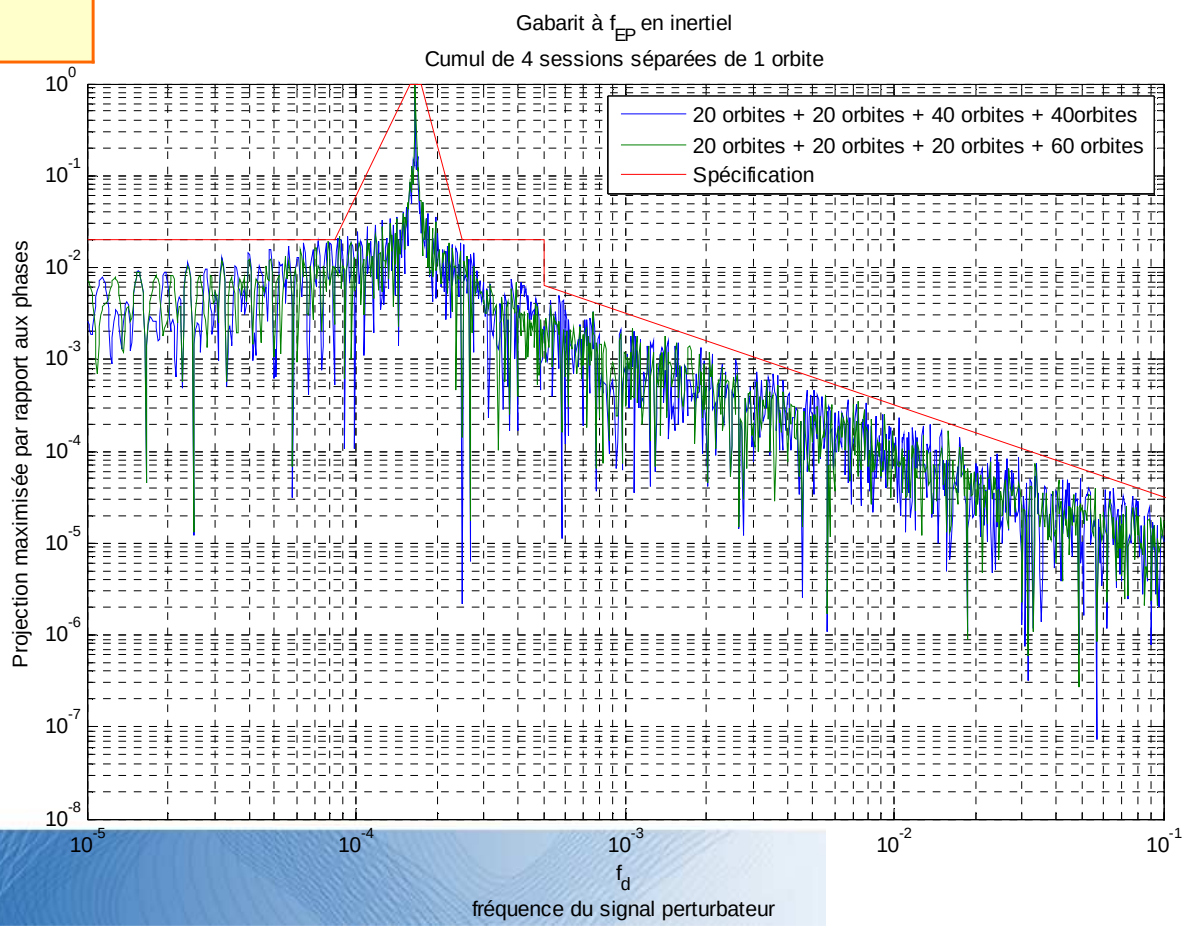
- $T_{subsection,i} = n_i T_{orb}$ (rejection of the main perturbations)



Division in subsections

Number of data loss > 1 minute	Probability over 120 orbits
1	16%
2	2,5%
3	0.4%
4	0,07%

➡ Success probability > 99,5%



Conclusion

- Influence of the observation window
  - Perturbations at any frequency can have a component at the EP frequency
  - Mean perturbations frequencies: adjusted to have minimal projections, but the effects are amplified by the frequencies uncertainty
  - Numerical estimation of the projection rate: compatible with the specification
- Influence of the measurement losses on the projection and rejection rate
  - Numerous very small losses or one loss up to 1 minute: replacement by the mean value of the measurement before and after the interruption
  - Losses > 1 minute: division in separated subsection for the inertial sessions
  - → Acceptable probability of success for the mission
- Possibility of accuracy improvement by using the Hann or Blackman window.