UNIVERSITÀ DI PISA

GGG best results
Relevance to GG and evidence for passive reduction of low frequency terrain tilts

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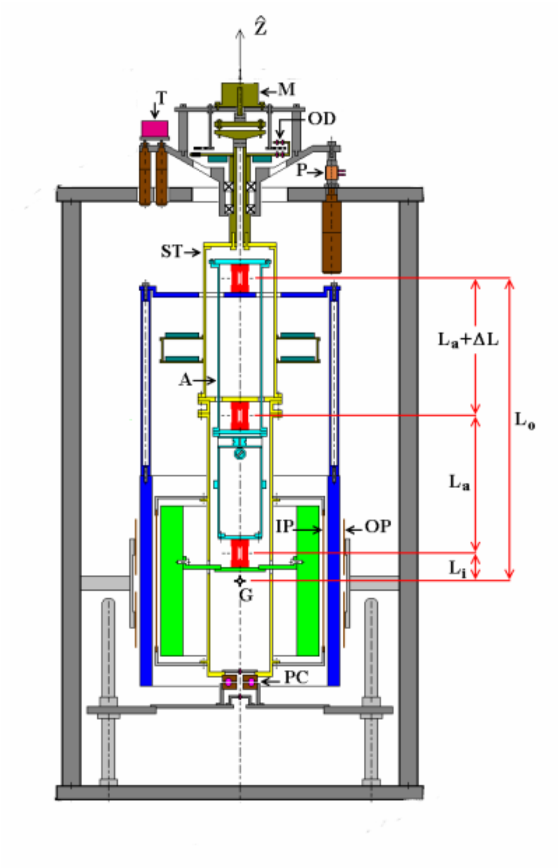
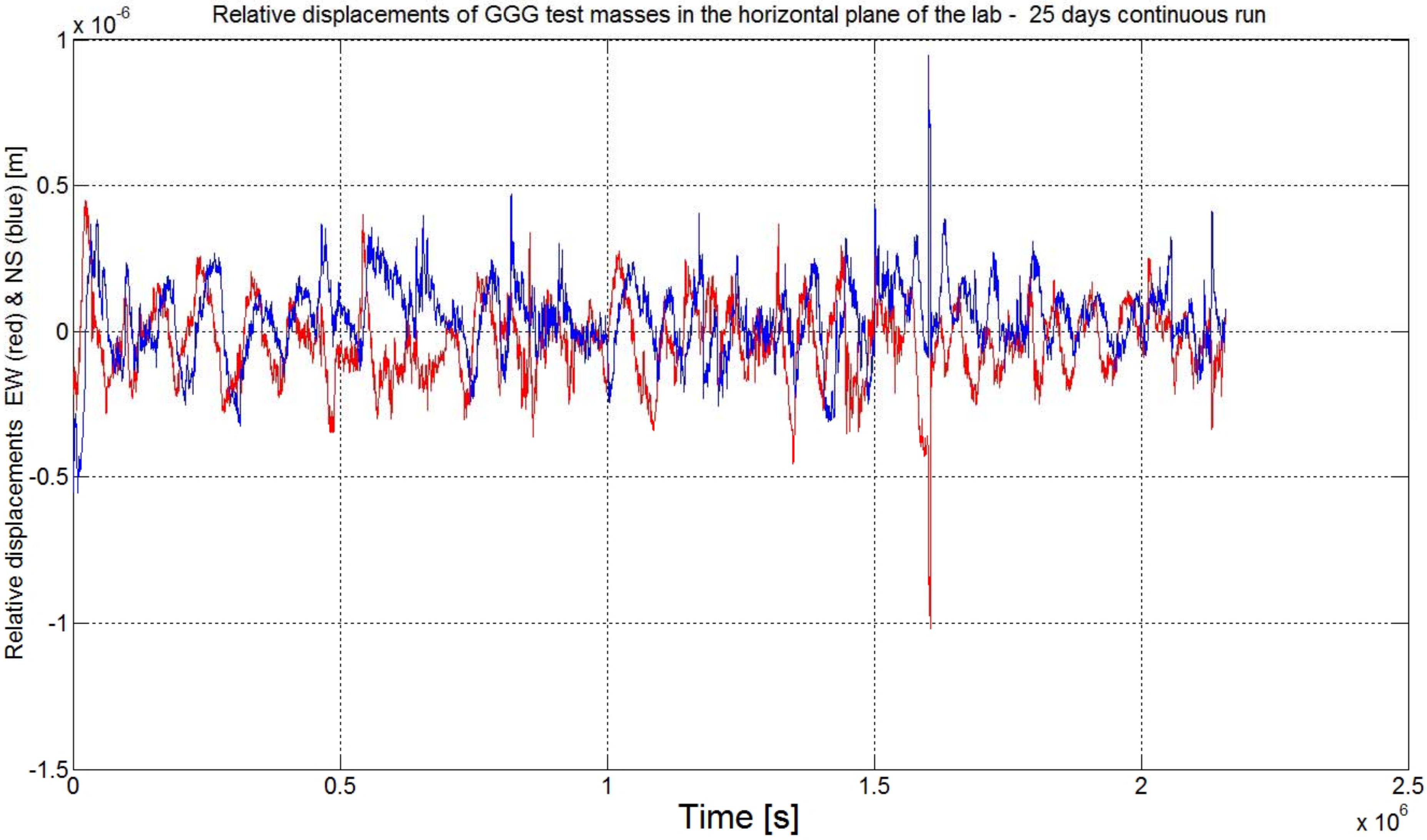
Old GGG in new chamber



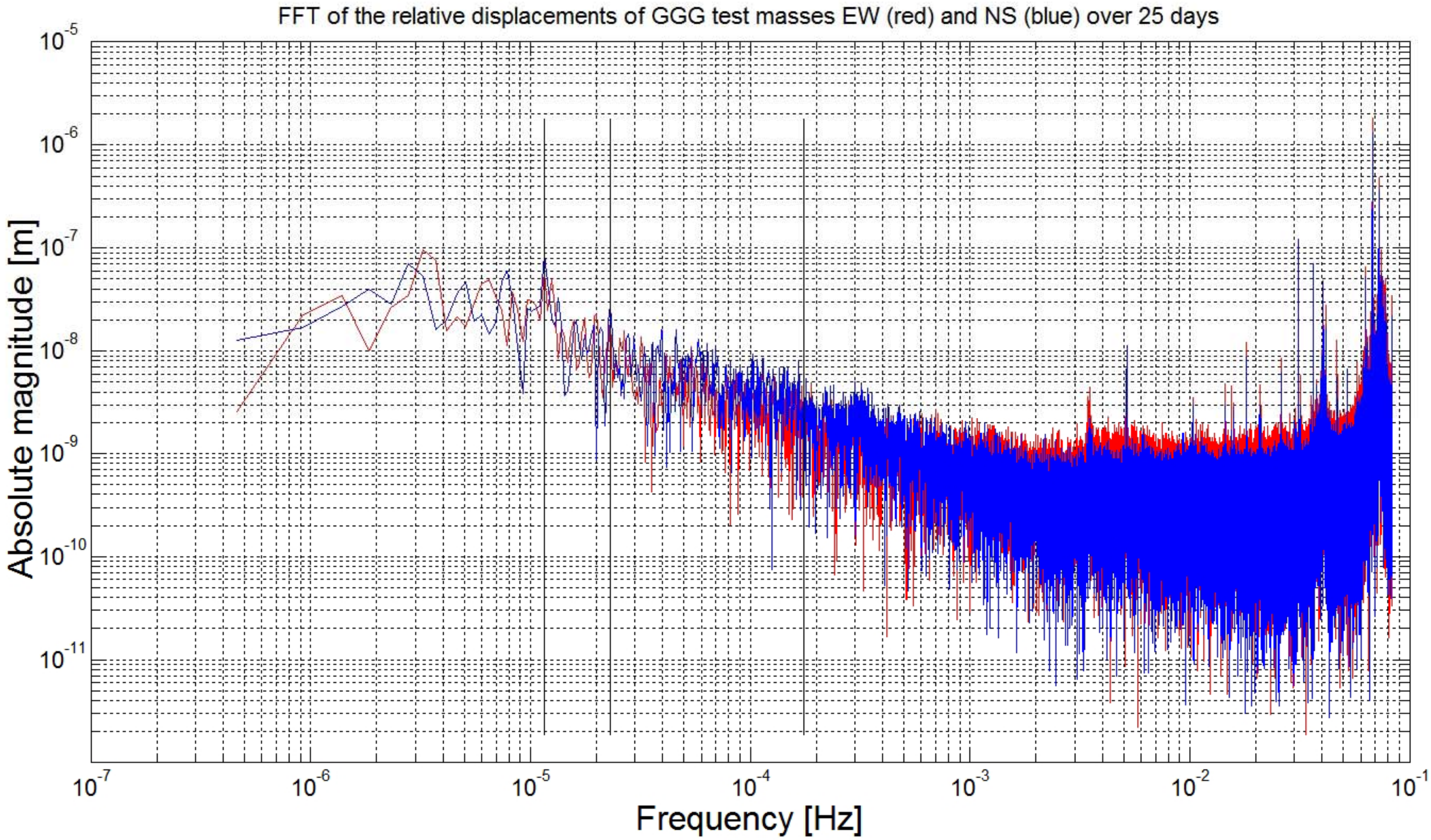
25 days continuous run of old GGG in new chamber (I)



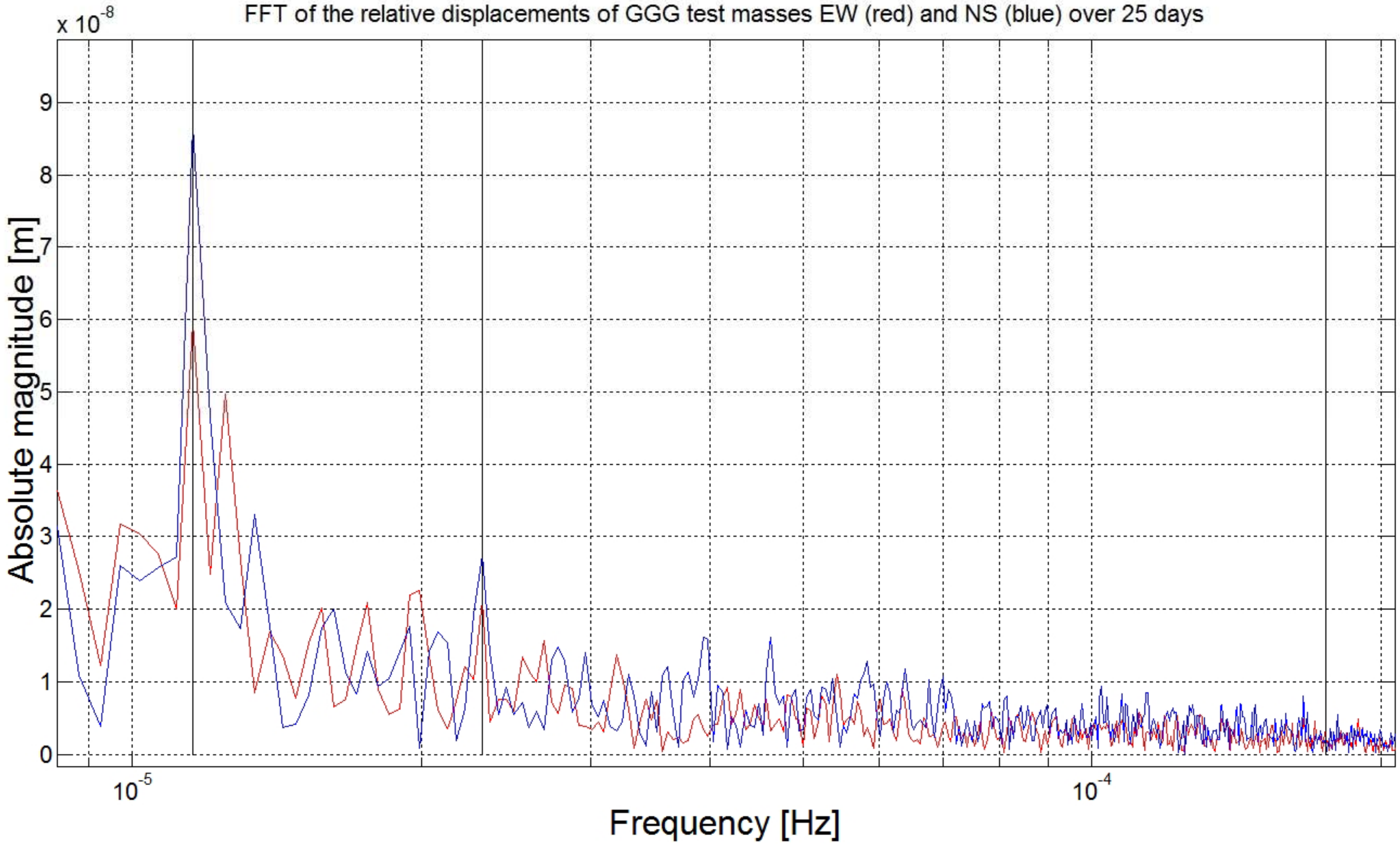
13 November 2009 (17:13 UTC) to 8 December 2009, 0.167 Hz spin rate

(active tilt control on with Geomechanics spirit level tilt sensor and PZT actuators)

25 days continuous run of old GGG in new chamber (II)



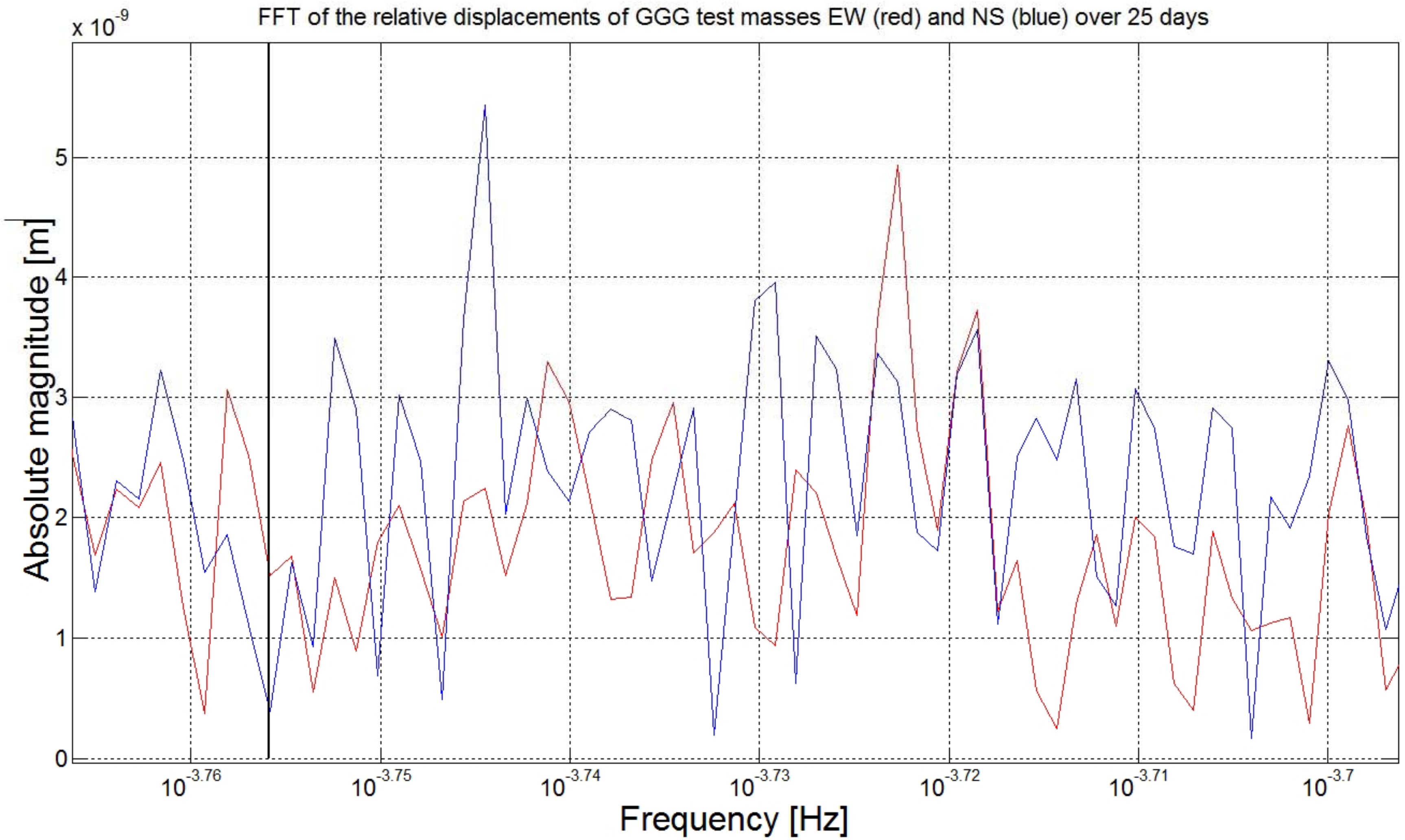
25 days continuous run of old GGG in new chamber (III)



24 hr (1.157×10^{-5} Hz) EW (red) 5.95×10^{-8} m ; NS (blue) 8.69×10^{-8} m

12 hr (2.314×10^{-5} Hz) EW (red) 2.1×10^{-8} m ; NS (blue) 2.76×10^{-8} m

25 days continuous run of old GGG in new chamber (IV)



GG orbital frequency (1.75×10^{-4} Hz) **EW (red) 4.3×10^{-10} m ; NS (blue) 1.57×10^{-9} m**

<u>At this frequency GG must reach 0.5×10^{-12} m</u>

Phase sensitive detection relative to the Sun (I)

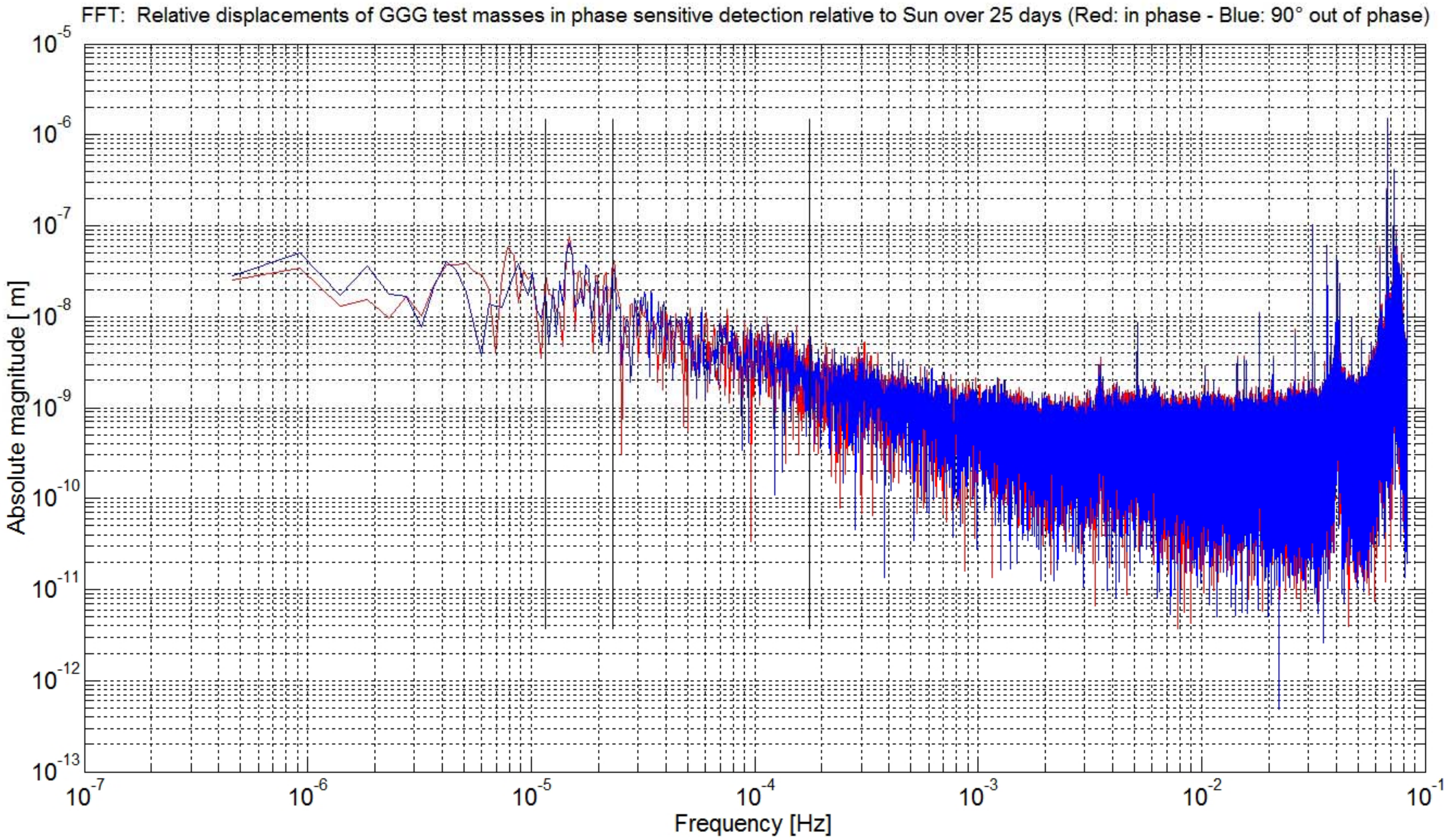
Relative displacement of test masses along the unit vector of the Sun **averaged over 25 days** (integer number) =-$\underline{3.6\times10^{-8}\ \mathrm{m}}$

Relative displacement of test masses along the unit vector 90° from the Sun **averaged over 25 days** (integer number)=+$\underline{4.29\times10^{-8}\ \mathrm{m}}$

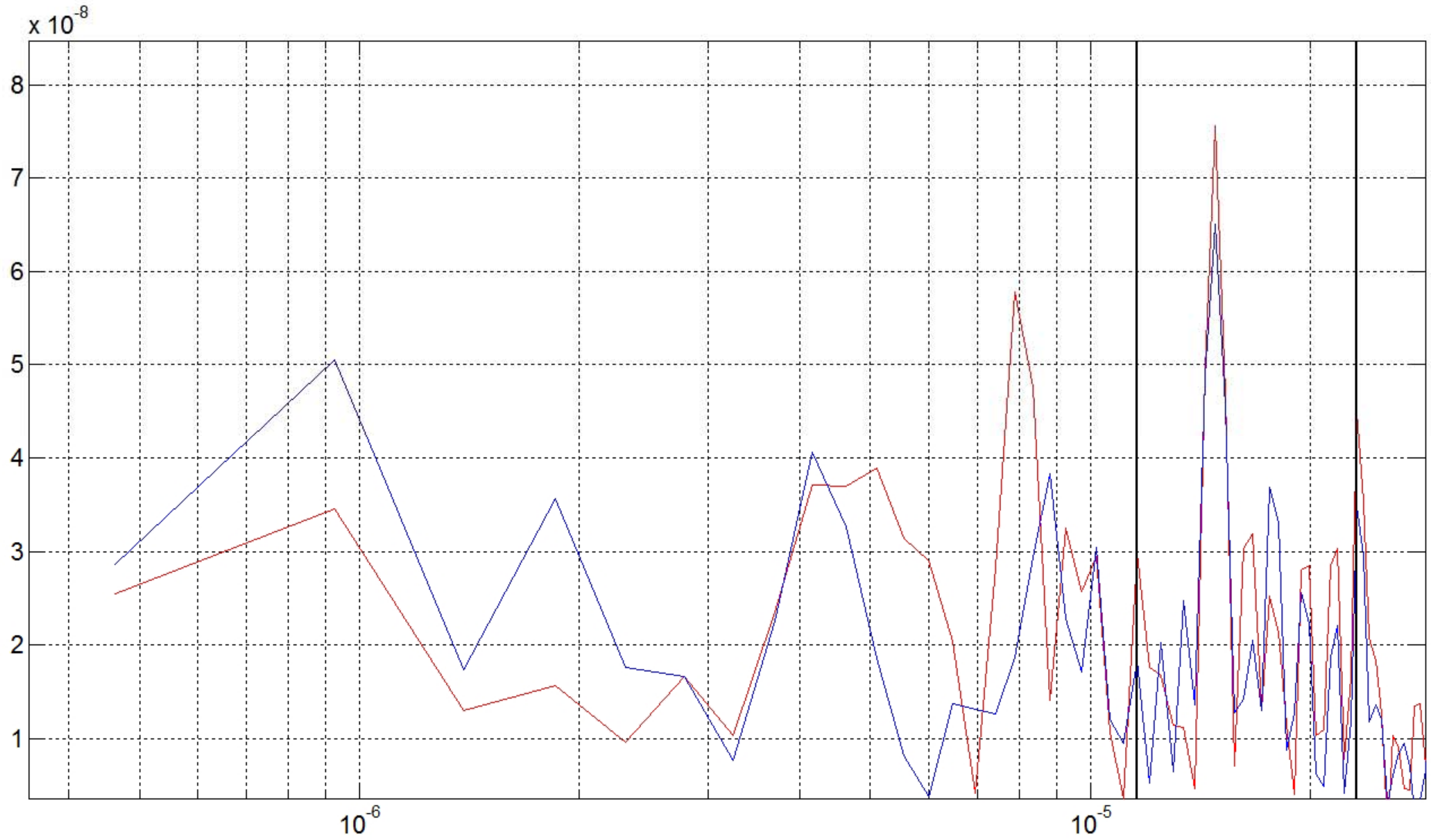
These are the effects of tilts related to the diurnal motion of the Sun through its thermal effects (on the nearby environment, lab, vacuum chamber, tiltmeter sensor, electronics, GGG accelerometer itself…)

Phase sensitive detection relative to the Sun (II)

The remaining amplitude at 24hr will be due to microseismicity not related to the motion of the Sun, while the effects related to the diurnal motion of the Sun are moved to low frequency or to twice the diurnal frequency (12hr)



Phase sensitive detection relative to the Sun (III)



Residuals at 24hr (not related to the diurnal motion of the Sun): $3x10^{-8}$ m (red); $1.8x10^{-8}$ m (blue)

Phase sensitive detection relative to the Sun (IV)

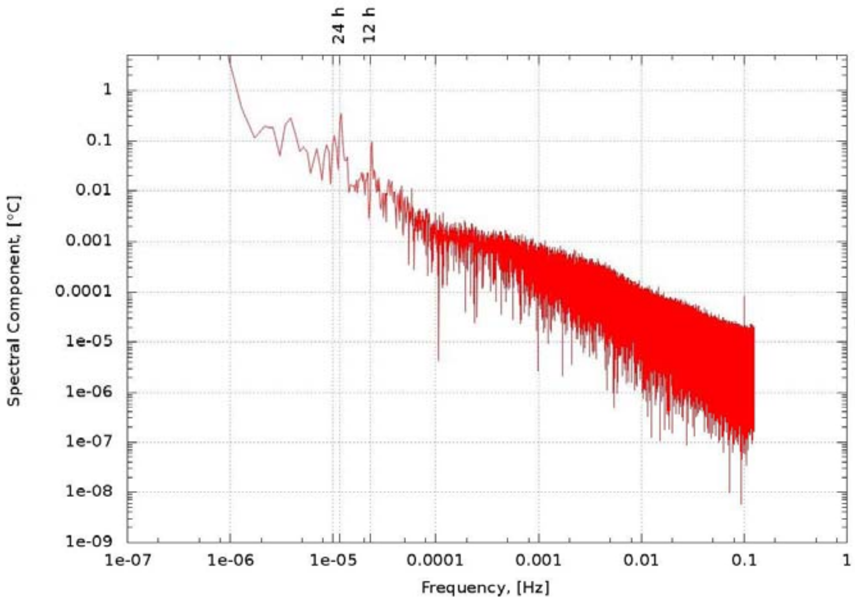
In summary, relative displacements of GGG test masses at diurnal frequency over 25 days (integer number) are as follows:

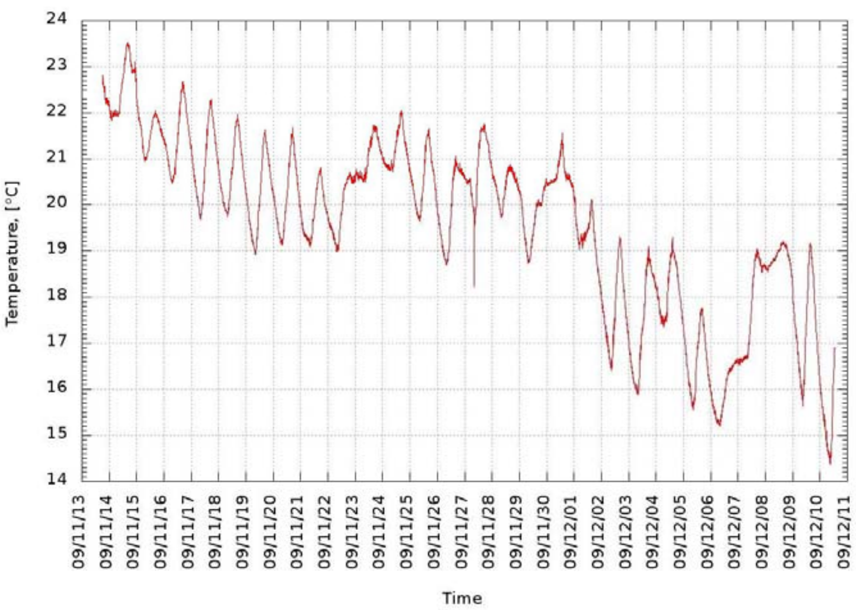
- Contribution related to the diurnal motion of the Sun: + $\underline{3.6\text{x}10^{-8}\text{ m}}$ (in phase) $\underline{-4.29\text{x}10^{-8}\text{ m}}$ (90° out of phase)
- Contribution at 24hr not related to the diurnal motion of the Sun: $\underline{3\text{x}10^{-8}\text{ m}}$; $\underline{1.8\text{x}10^{-8}\text{ m}}$

Considering about $4\text{x}10^{-8}$ m in each component, in GGG this means that such displacements are generated by about $8\text{x}10^{-8}$ rad = 80 nrad tilts

Since the geomechancis tiltmeter is sensitive to the narad level, we should have reached a factor 10 smaller displacements … unless the tiltmeter sensitivity is only nominal because of thermal disturbances…

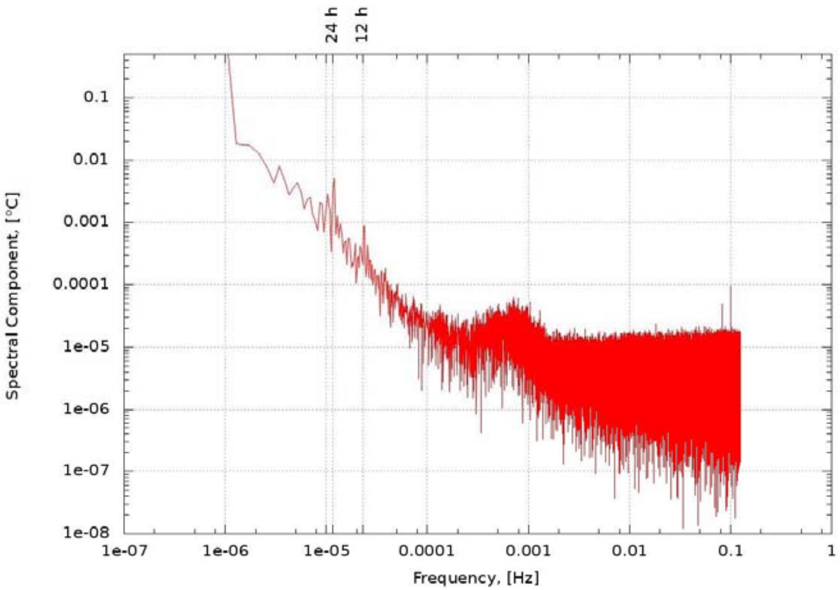
Thermal effects during the run (I)

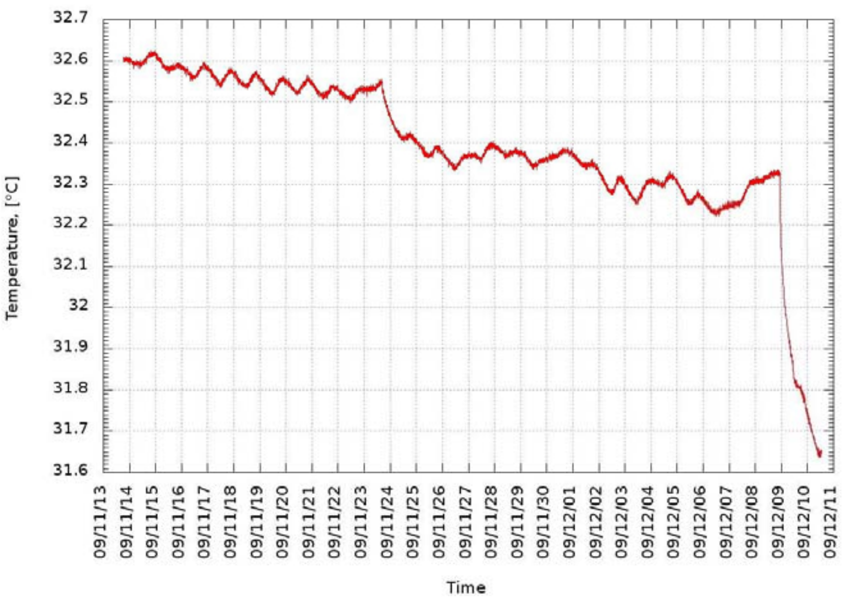




Ambient temperature measured outside the vacuum chamber next to it: it shows the thermal stress the experiment was subjected to (it is apparent that the heating system broke down…)

Thermal effects during the run (II)

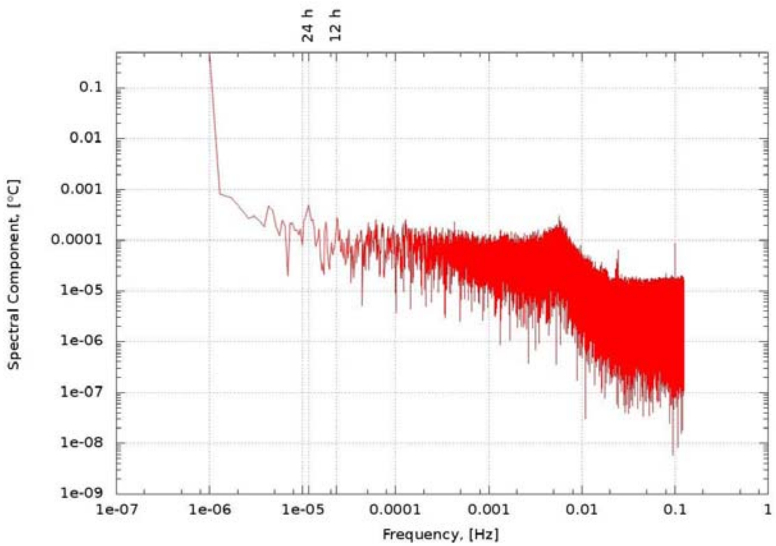


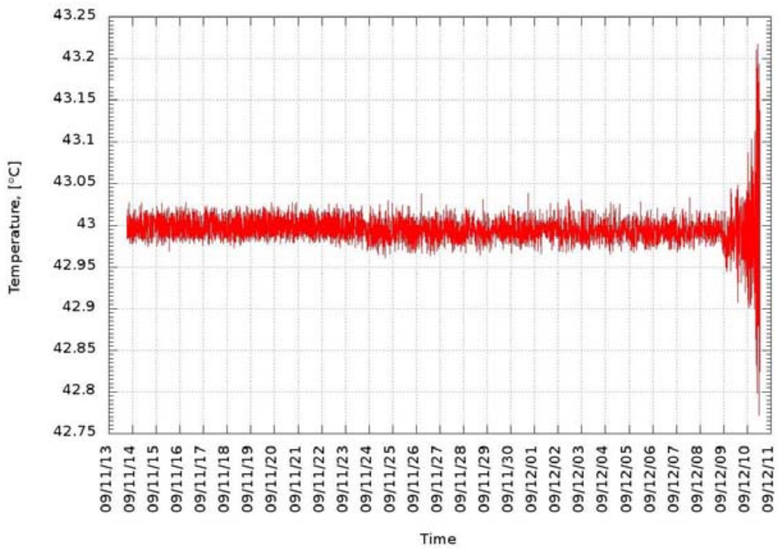


Temperature of base steel flange inside chamber (to which GGG frame is rigidly attached). (the bottom part of the chamber is the most affected by thermal variations)

(Run data after December 8 were discarded because the whole system was highly disturbed… though went back to good operation by itslef…)

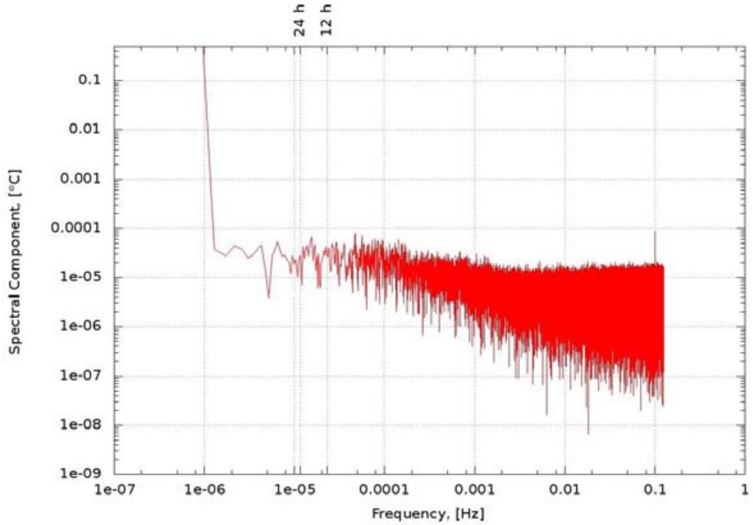
Thermal effects during the run (III)

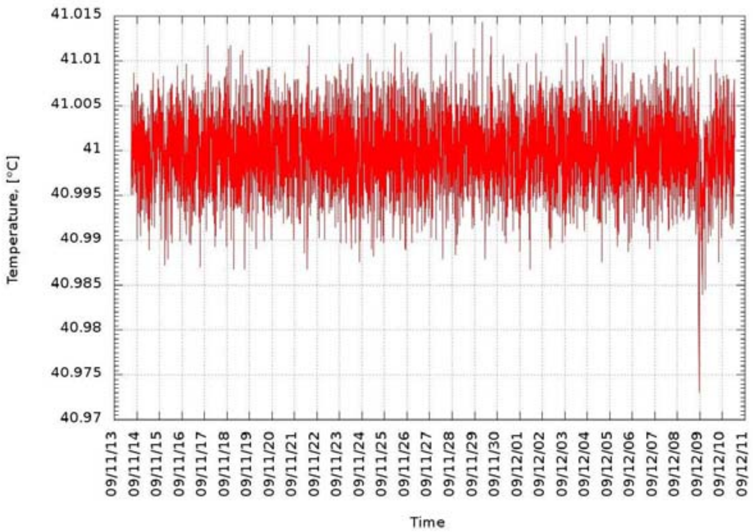




Temperature close to bearings (funnel steel flange). Much more stable

Thermal effects during the run (IV)





Tiltmeter is thermally stabilized by itself (small, requires very low power) . Though this is the temperature recorded by the PT100 on which the loop is closed, so it is too optimistic, it is easy to stabilize the tiltmeter. One of its axes has a very large thermal dependence (1.7×10^{-5} µrad/°C) and would require almost 5×10^{-3} °C diurnal variation to reach 80 nrad…

Other “dangerous” thermal effects are:

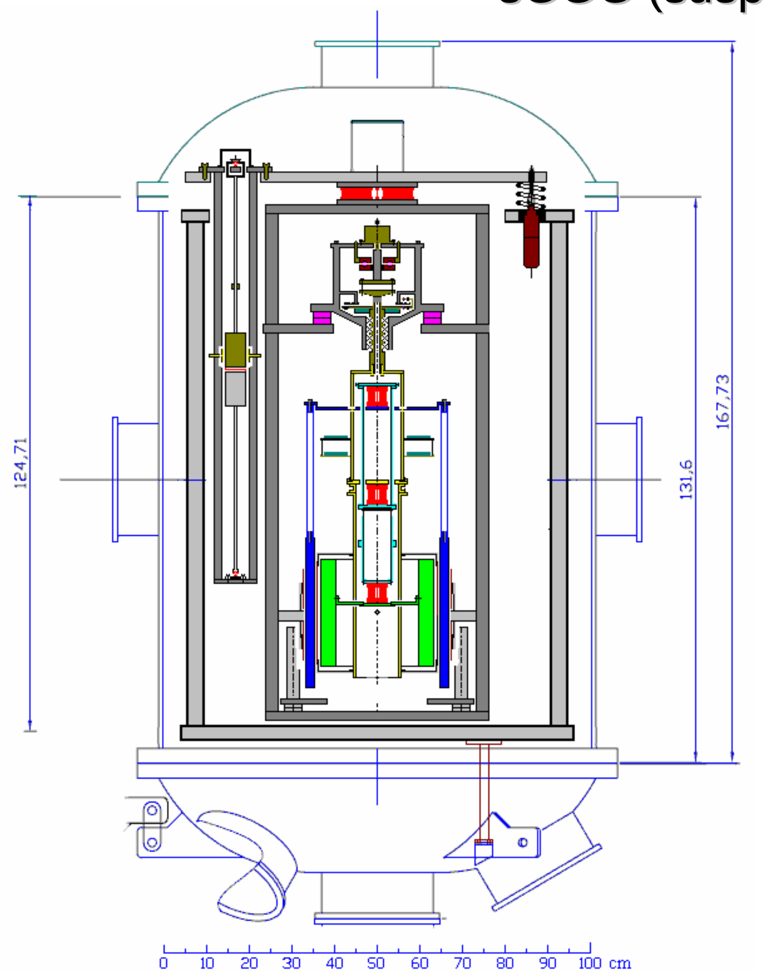
- on NI card used to digitize the tiltmeter data

-on NI card used to acquire PT100 temperature sensors data for closed loop control

(thermally stabilized rack ordered..)

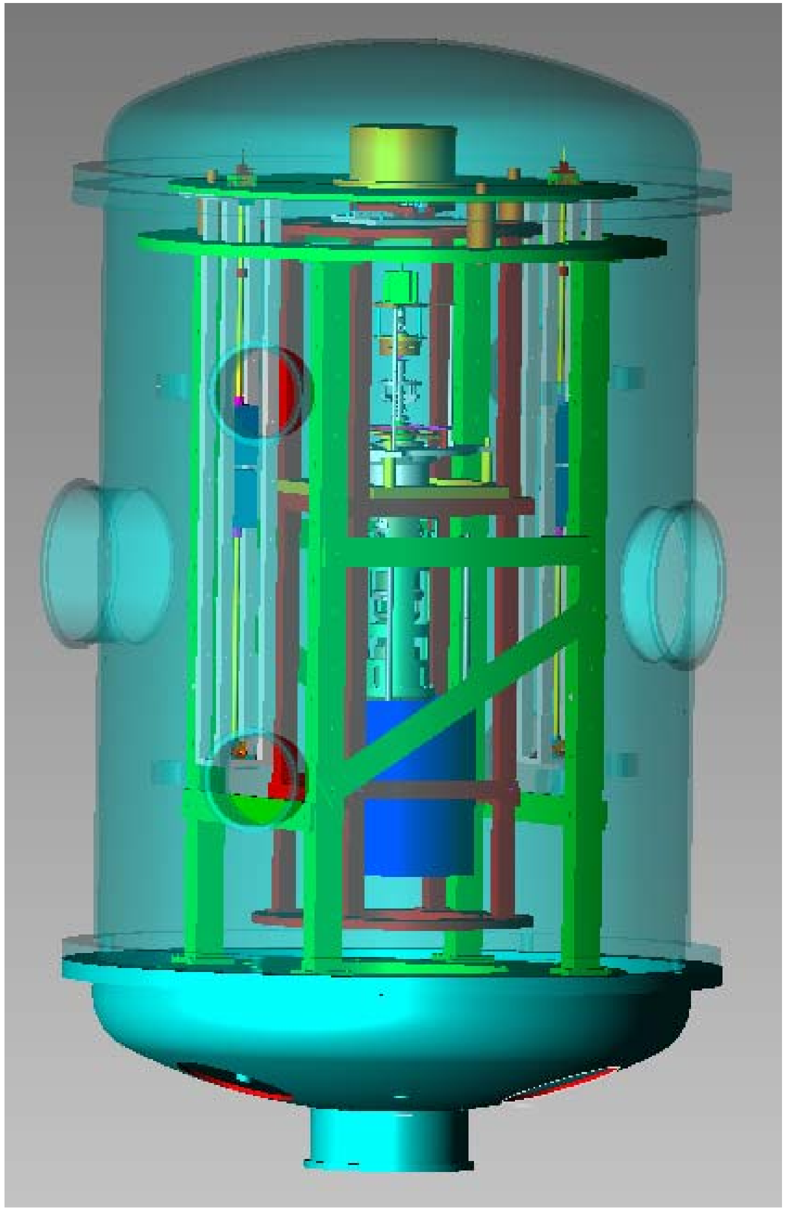
Best cure of all: passive attenuation of low frequency terrain tilts!

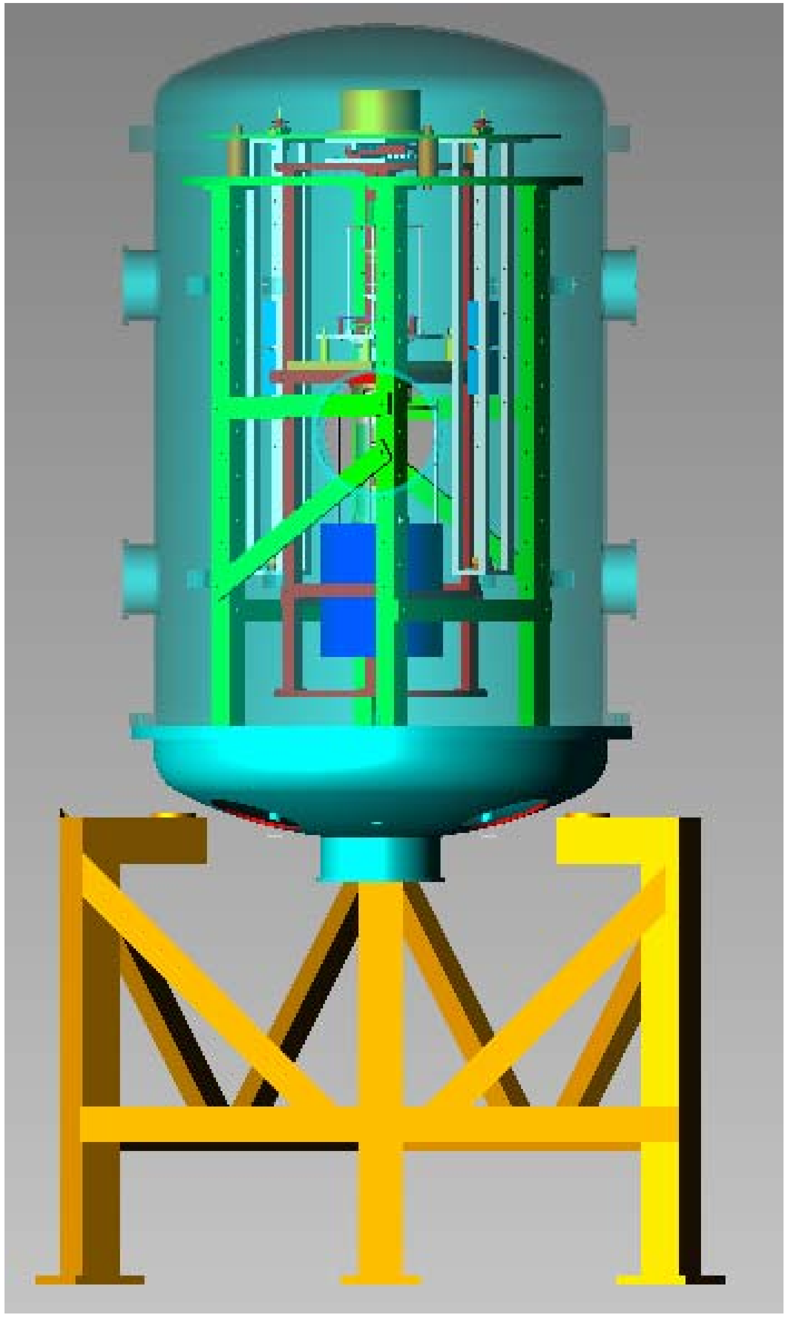
sGGG (suspended GGG) - ASI funds (I)



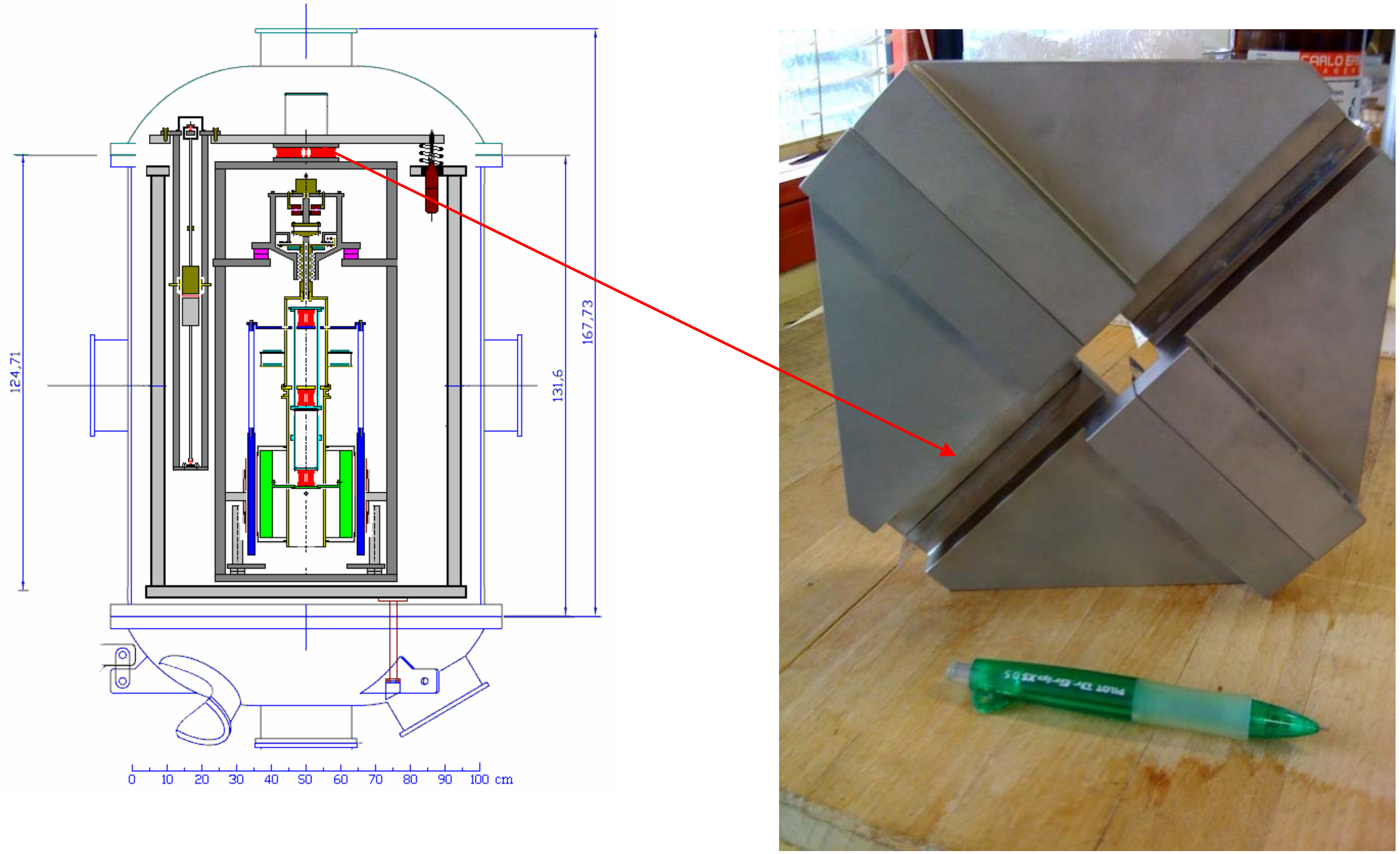
- New chamber has the right symmetry and has been designed to minimize disturbances on GGG experiment
- **sGGG will be suspended inside chamber by cardanic joint** (not rotating) to reduce low frequency terrain tilts passively, in addition to active tilt control now in use (Note: active tilt control is limited by thermal effects on tilt sensor and requires good thermal stabilization to be effective)
- An **Experiment Simulator** will be built by Thales Alenia Space-Italy for the new GGG, similarly to the Simulator built for the space experiment, <u>to be compared with experimental measurements</u> …

sGGG (suspended GGG) - (II)





Passive attenuation of low frequency terrain tilt noise (I)



Cardanic suspension for low frequency attenuation in the plane (only 2 lamellae of 1 direction visible)

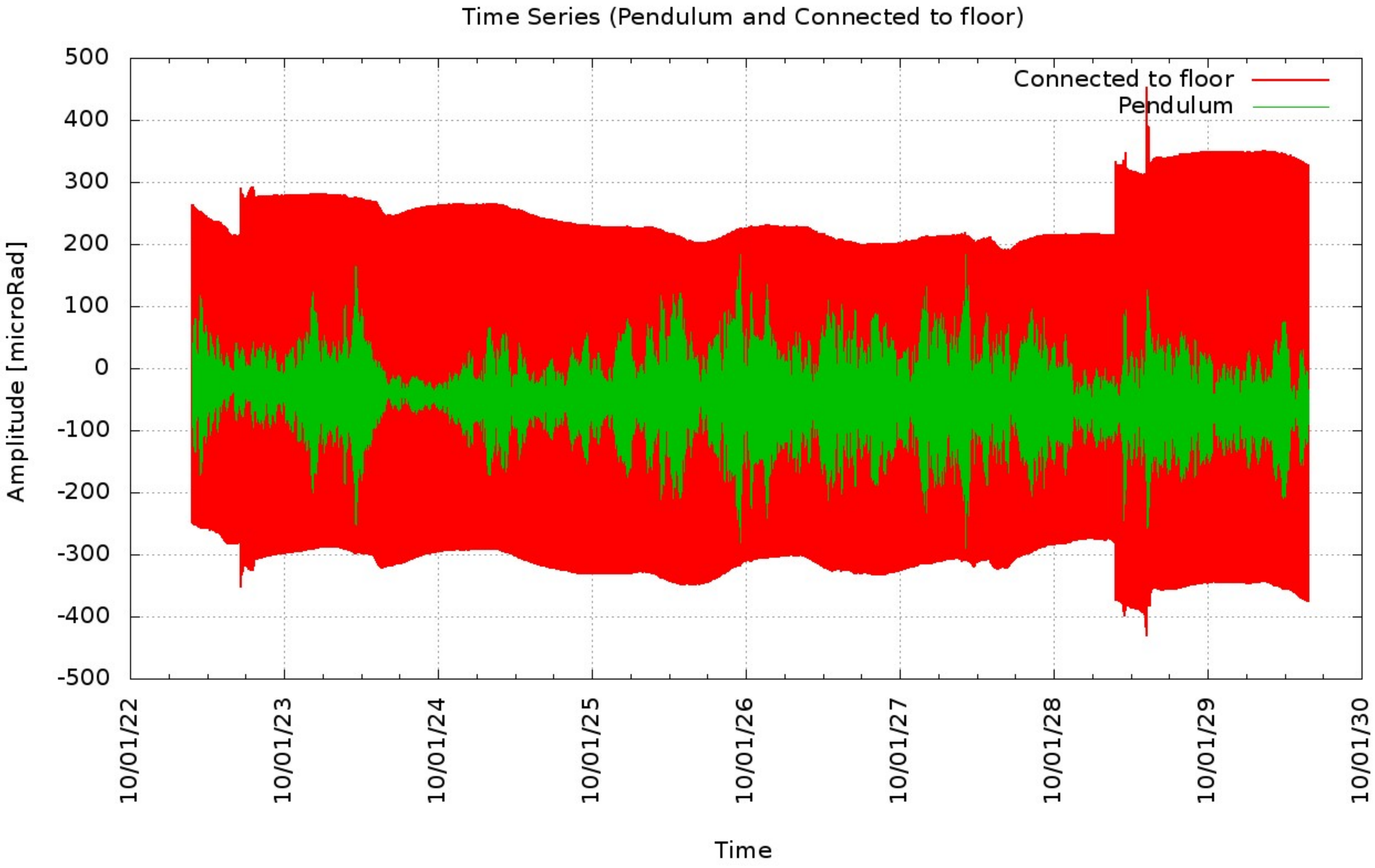
Passive attenuation of low frequency terrain tilt noise (II)

Experimental set up

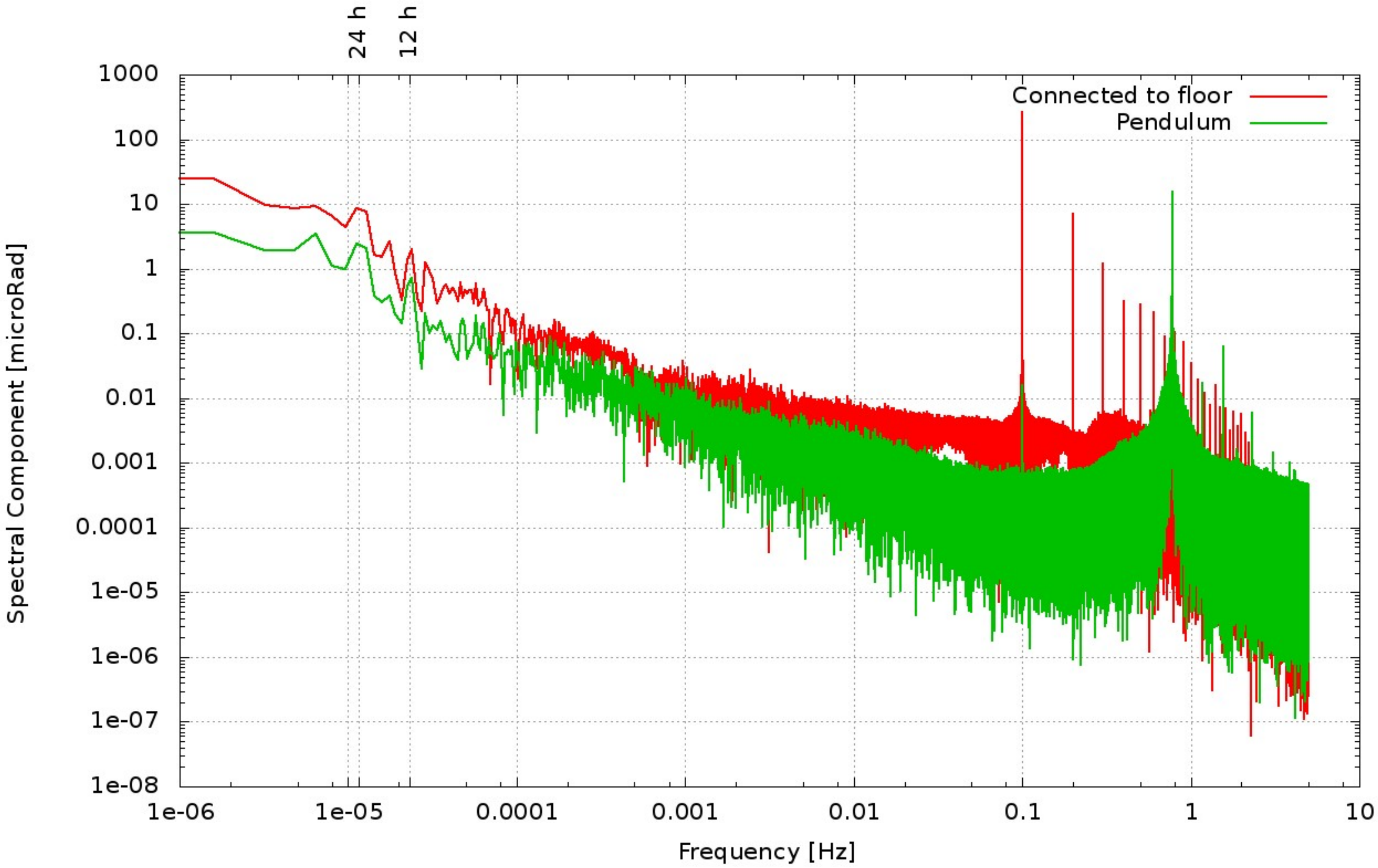
1 lamella of the 2 to be used for tilt attenuation in each direction of the horizontal plane suspends a 64 kg pendulum mass

The bar with the “top” tiltmeter is modulated at a frequency of choice (chosen where noise is low) to measure with another tiltmeter on the pendulum mass how much the modulated signal is attenuated. In air, with large thermal variations and local disturbances this is a good way to establish in a quantitative way the passive attenuation achievable.

Passive attenuation of low frequency terrain tilt noise (III)

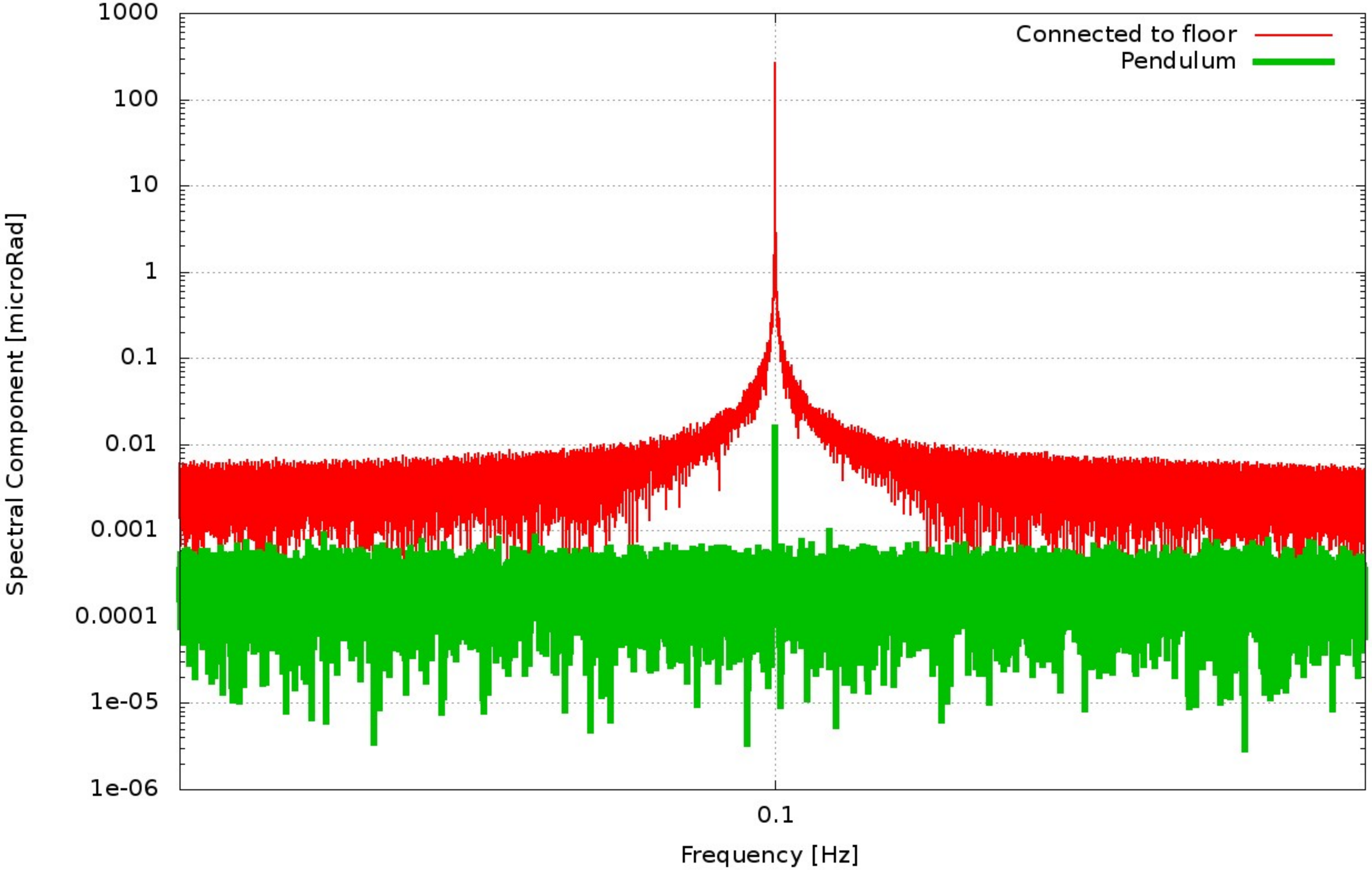


Passive attenuation of low frequency terrain tilt noise (IV)



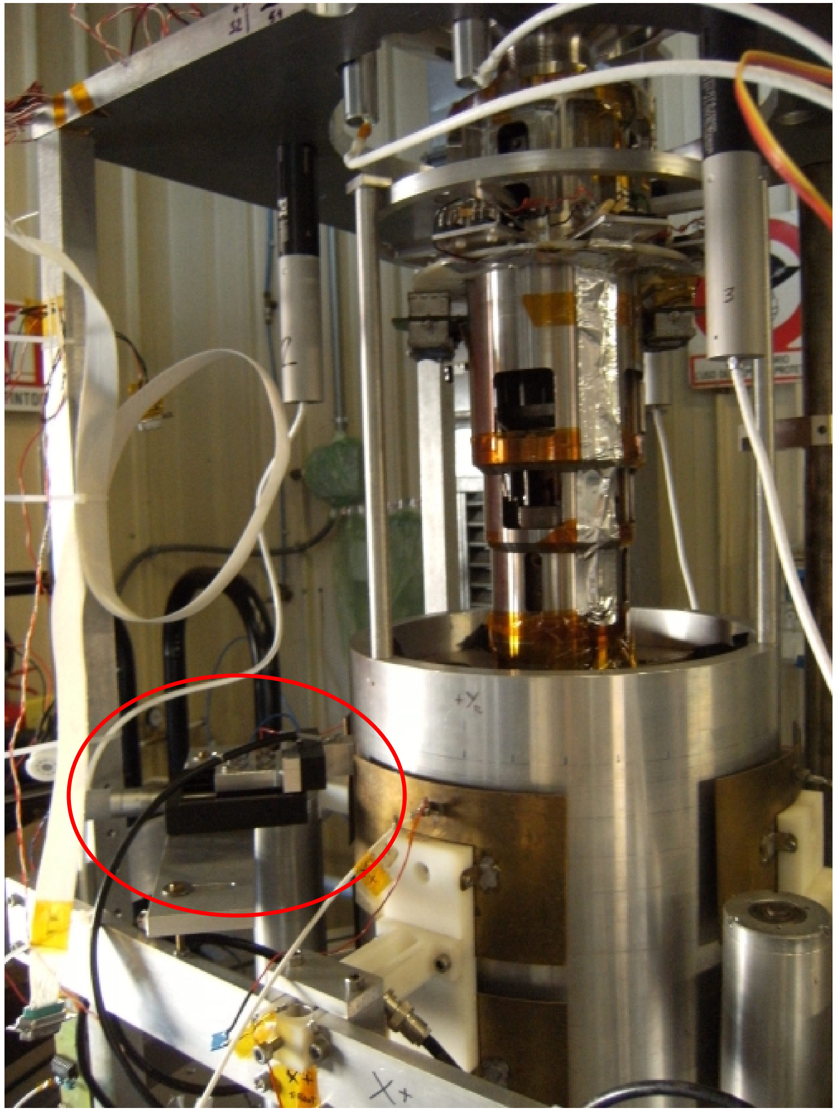
Large diurnal effects are due to the tiltmeter thermal dependence; not that on the pendulum mass the nrad level is achieved, which is the nominal sensitivity of the tiltmeter … BUT IS THIS THE TRUE HORIZONTAL LEVEL ??? Only a more sensitive instrument can telll …

Passive attenuation of low frequency terrain tilt noise (V)



The modulated signal is attenuated by a factor 10000!!!

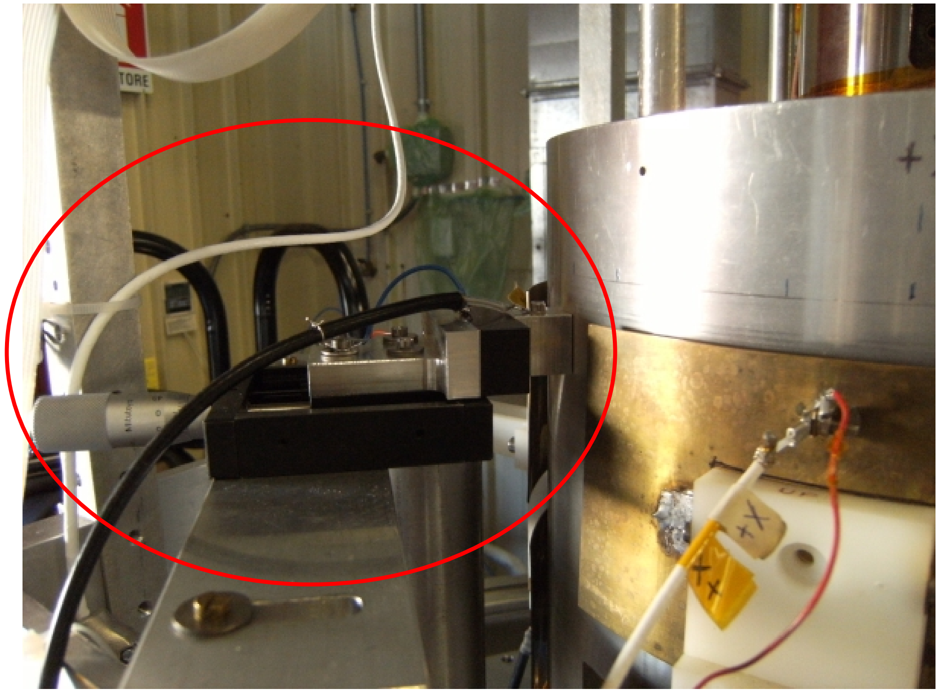
Measurement of electric patch effects (I)



Apply a force to the external test cylinder with a capacitance plate (both grounded)

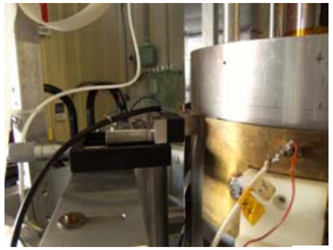
Since outer and inner test cylinders are coupled, they will move relative to each other

Their differential motion is measured by the capacitance bridges (main sensors) located in between the test cylinders



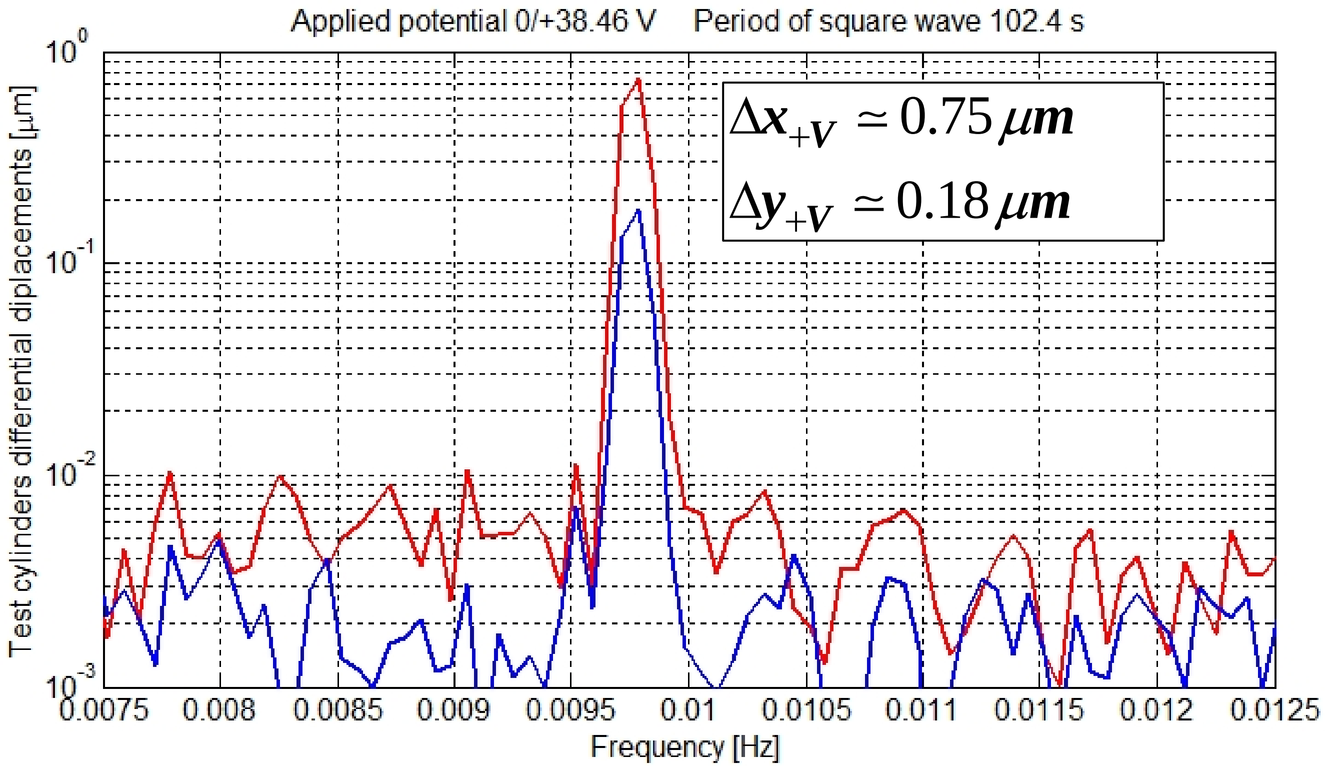
Measurement of electric patch effects (II)

$$F_V = \frac{Q^2}{2\varepsilon_o S}$$

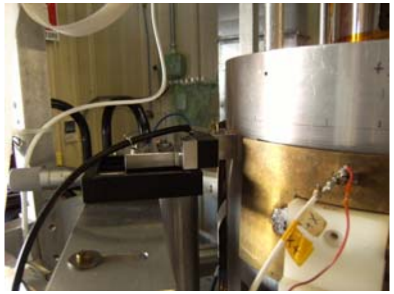


Charge Q changes sign with applied potential, patch charge q <u>does not</u>!

First, apply unipolar potential as square wave and measure effect on TMs at frequency of square wave; **then switch to bipolar potential (square wave with same frequency)** and measure effect on TMs: **the effect of patch charge q (if any) will be upconverted to the frequency of square wave and amplified by factor 4Q/q** (q=0 would give no signal at square wave frequency)



Measurement of electric patch effects (III)



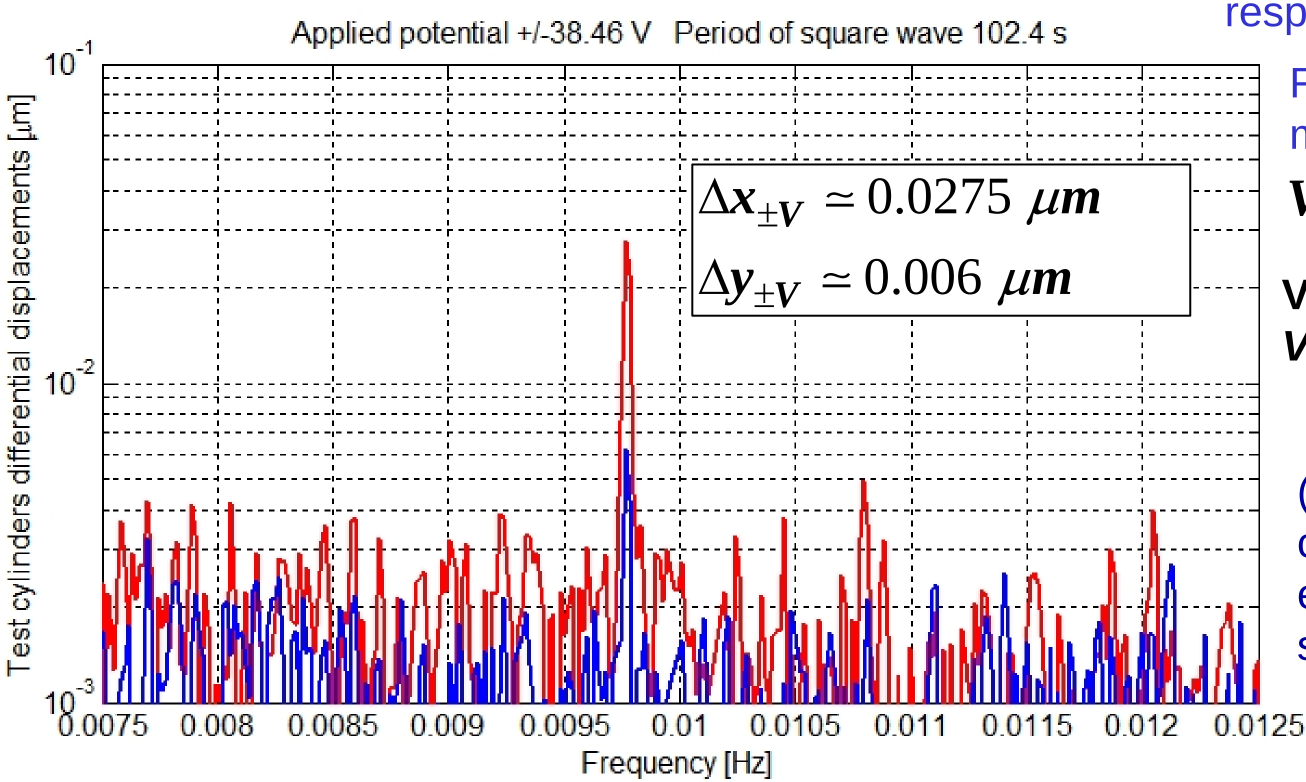
$$F_{\pm V} \equiv F_{patch} = \frac{2Qq}{\varepsilon_o S}$$

q is the charge of patch we want to measure

$$\frac{displacement_{\pm V}}{displacement_{+V}} = 4\frac{q_{patch}}{Q_{+V}} = 4\frac{V_{patch}}{V_{+V}}$$

by measuring the displacements in the two cases we measure V_{patch} …

(no need to know how system responds to



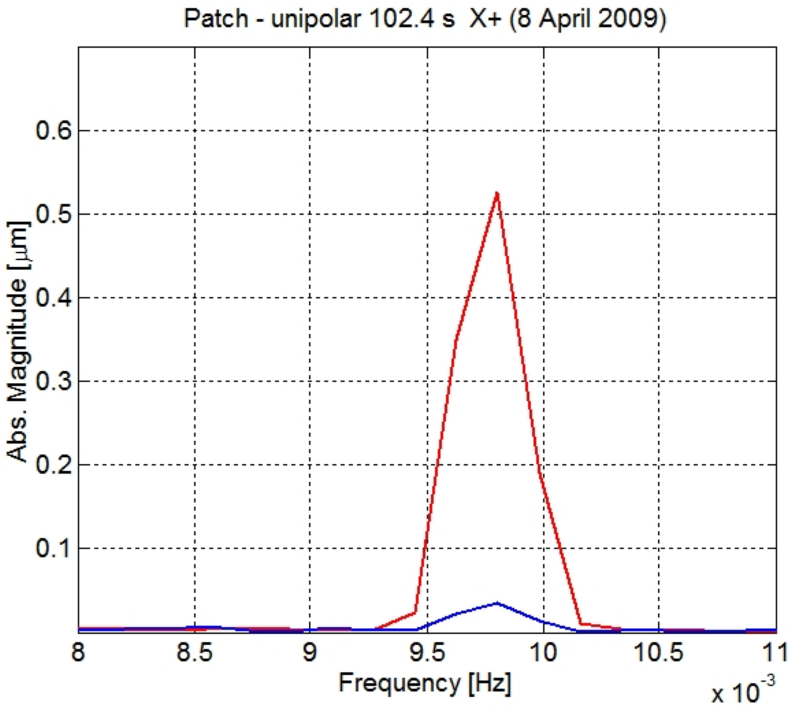
From these measurements:

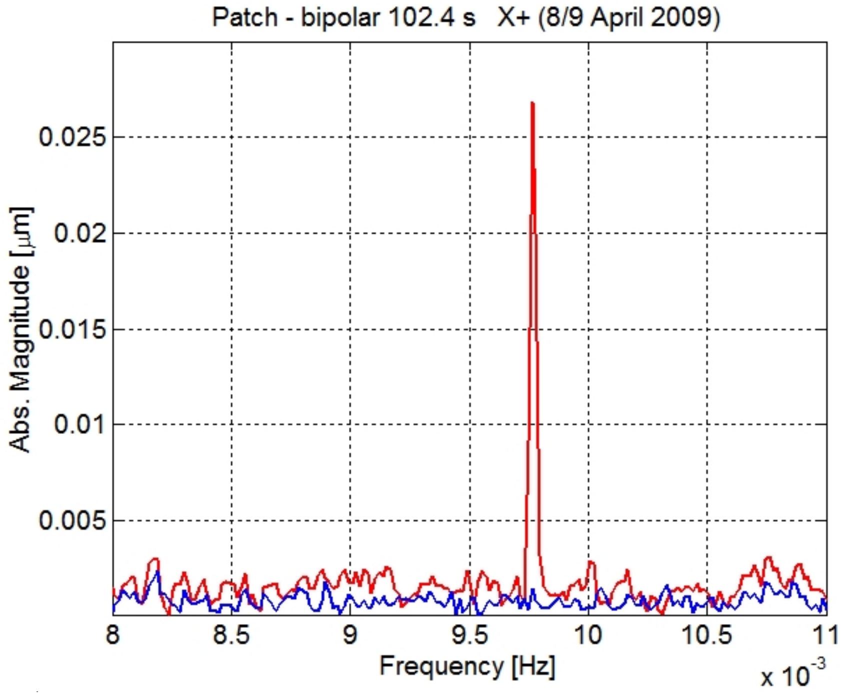
$$V_{patch} \simeq 0.35\ \text{V}$$

Values measured for V_{patch} are 0.3 to 0.5 V

(4 cm^2 Al plate, no gold coating: smaller patches expected for larger surfaces with gold coating)

Measurement of electric patch effects (IV)



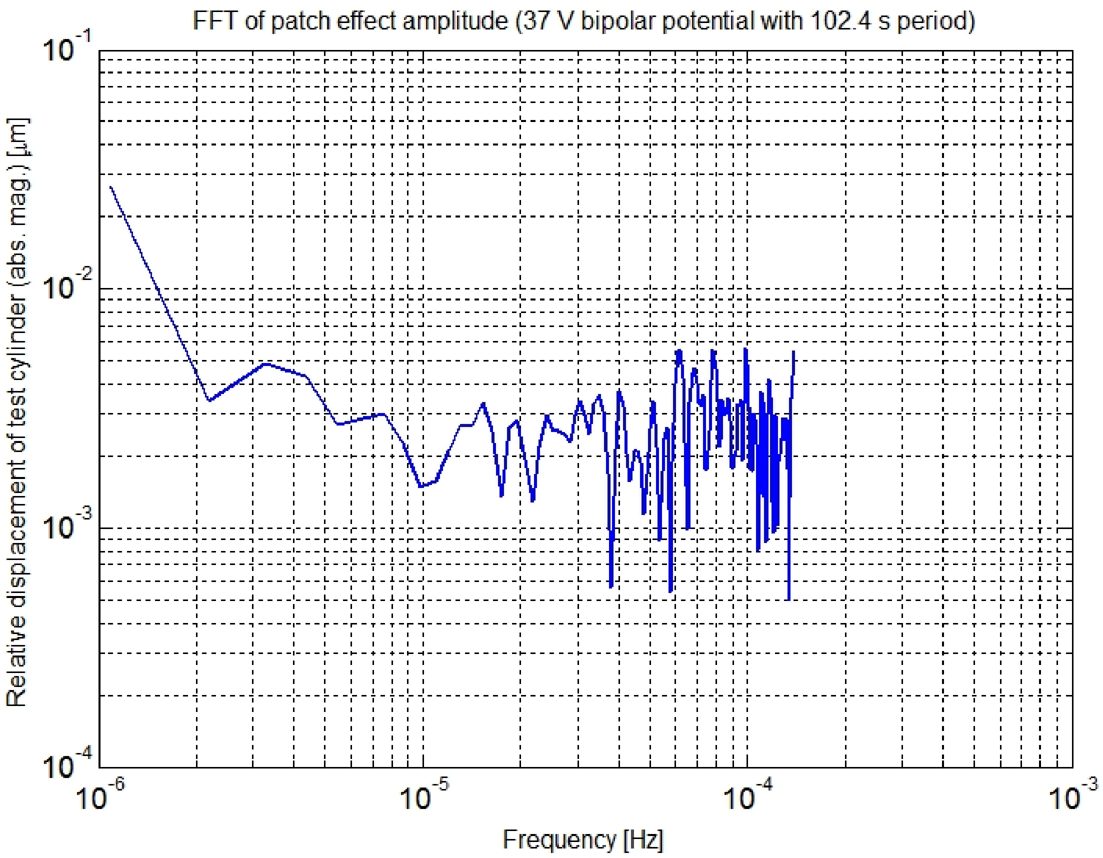


Peak with unipolar potential (38.4 V): 0.525 μm ; peak with bipolar potential 0.0268 μm

V_{patch}= $V_{unipolar}$/4 x (0.268/0.525)= 38.4/4x0.051 V=0.49 V

Measurement of electric patch effects (III)

- No modeling needed, very neat measurement
- You measure directly the effect of patch charges on the tests masses upconverted to known frequency (**can be done also in space for GG test masses**)
- **We have made this measurement with GGG spinning for 10.6 d, in order to measure time variation of patch effect amplitude over such long time….**



Remember: the effect of the patch, in addition to being upconverted to the frequency of the applied potential is also amplified by the factor:

$$4Q/q = 4V_{applied}/V_{patch}$$

Here it is about 300

⇒ At diurnal frequency the effect of patch charges (small surface, no coating…will be reduced) on GGG test masses is 7 pm
(GG target requires to measure 0.5 pm)