A double pendulum for lab testing of free fall on 2 DoFs

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Talk overview

- goal of the activity
- Description of the apparatus (PeTeR)
- present status and results
- next steps and perspectives

Goal of the R&D activity

The use of torsion pendulums for testing of the flight hardware of Lisa-like space experiments has been already illustrated (see talk by Bill Weber).

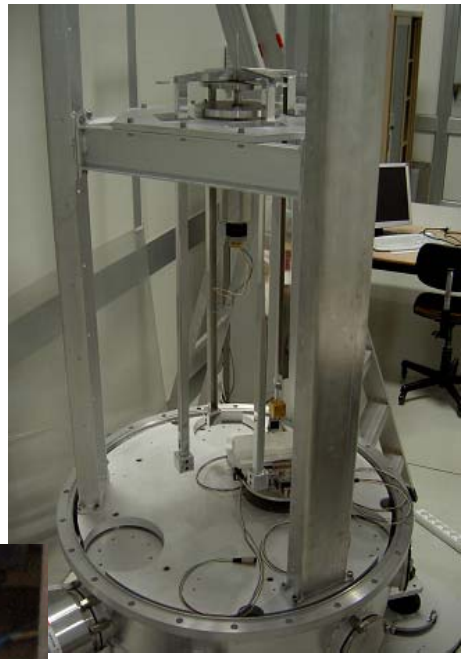
Hour goal is the development and a torsion pendulum that is "soft" in 2 DOFs so that the TM is in free-fall in 2 DOFs.
This will permit contemporary measurement of force and torque acting on the TM allowing:

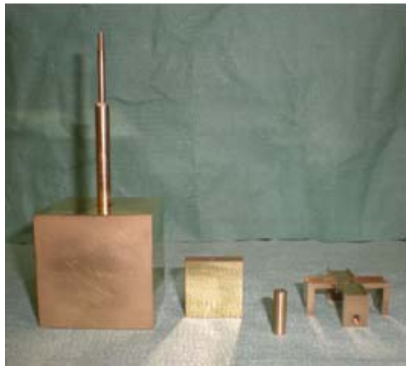
- measurement of stray forces and torques on TM
- measurement cross-couplings between different DOFs both in read-out and actuation.
- measurement of residual stiffness (force acting on the TM due to GRS motion) both in angle and displacement
- other measurements also permitted by single pendulums (charge, thermal effects, ...)

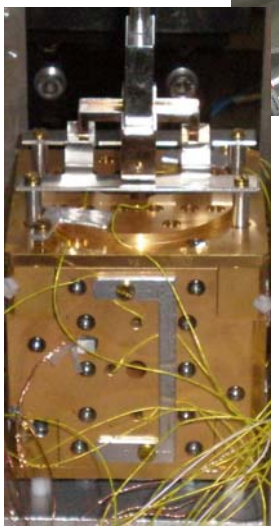
The experimental apparatus (PETER)

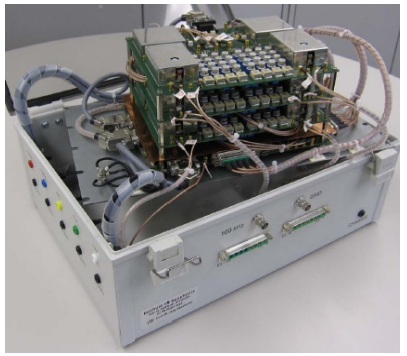
PETER (Pendolo Traslazionale E Rotazionale = translational and rotational pendulum) is a two stage torsion pendulum developed in Florence with strong support from the Trento Group.

- We borrowed from Trento a copy of the LISA-PF GRS engineering model (4mm gap sensor in Mo and SHAPAL) and a hollow 46mm TM in Al).
- The GRS electronics (from ETHZ) is similar to the LISA-PF one.
- The total length is about 1.7 m
- The double pendulum is enclosed in a vacuum tank (residual pressure about 10^{-4} Pa).



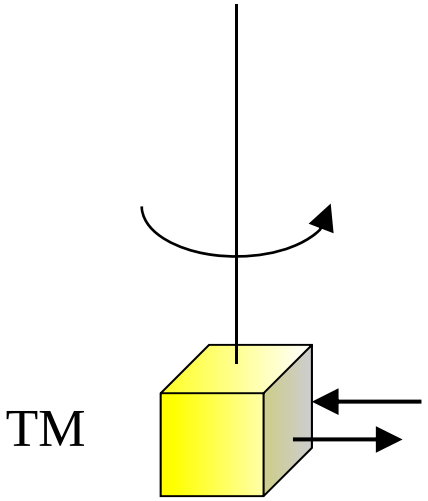




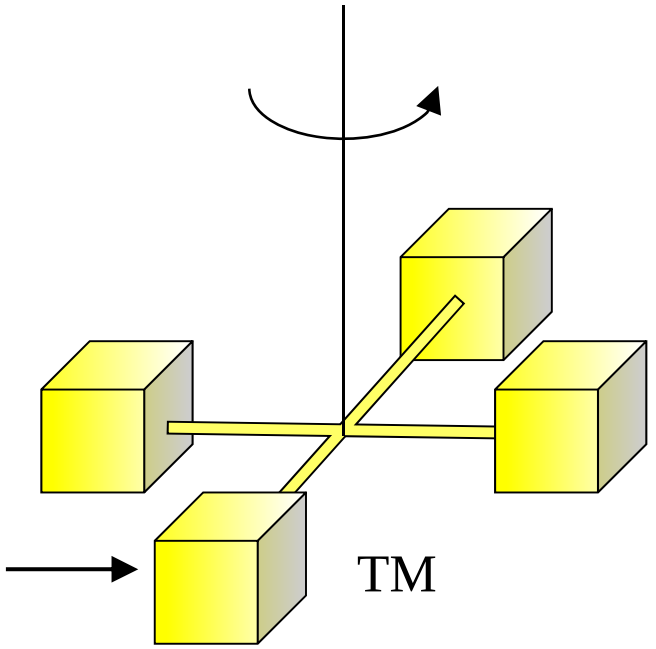


Single stage torsion pendulum configurations

Single mass torsion pendulum



four mass torsion pendulum



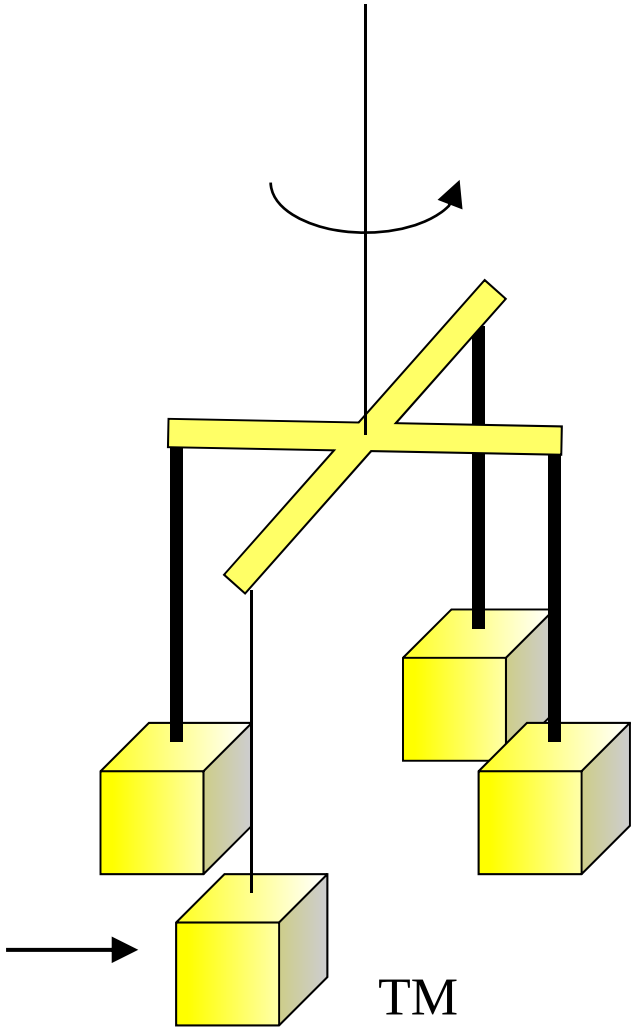
In this case we can only measure a torque acting on the TM

In this case we can only measure a force acting on the TM

Principle of operation of PETER

With a two stages torsion pendulum we can get two soft DOFs

in this case we can measure both force

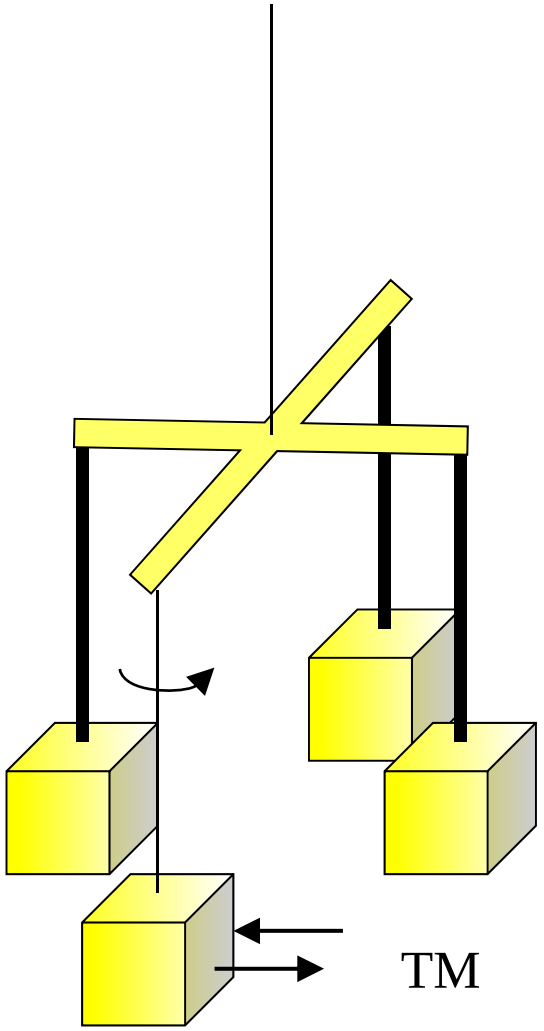


Principle of operation of PETER

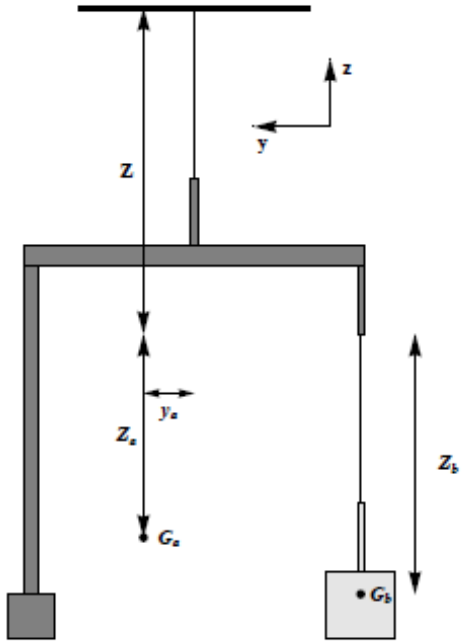
With a two stages torsion pendulum we can get two soft DOFs

in this case we can measure both force

and torque



We have developed a quasi complete analytical model of the pendulum (8 out of 12 DOFs)



Inertia matrices (units= [kg m^2])	
$I^a_{11} = 0.182$	$I^b_{11} = 2.76 \cdot 10^{-4}$
$I^a_{22} = 0.184$	$I^b_{22} = 2.77 \cdot 10^{-4}$
$I^a_{33} = 2.38 \cdot 10^{-2}$	$I^b_{33} = 3.71 \cdot 10^{-5}$
$I^a_{23} = -8.13 \cdot 10^{-3}$	
$I^a_{12} = I^b_{12} = I^a_{13} = I^b_{13} = I^b_{23} = 0$	
Masses [kg]	
m_a=1.2	m_b=0.11
Torsional constants [kg m^2 s^{-2}]	
$k_a = 1.8 \cdot 10^{-6}$	$k_b = 7.1 \cdot 10^{-9}$
Bouncing constants [kg s^{-2}]	
$\kappa_{c,a} = 4804$	$\kappa_{c,b} = 300$
Lengths [cm]	
d=15; h_c=3.4; $\mathcal{Z}$=87; $\mathcal{Z}_b$=76; $\mathcal{Z}_a$=43	

Normal modes frequencies			
mode #	calculated	measured	unit
ν_1	1.3 ± 0.1	1.331	mHz
ν_2	2.2 ± 0.2	2.117	mHz
ν_3	0.41 ± 0.01	0.406	Hz
ν_4	0.42 ± 0.01	0.4065	Hz
ν_5	0.59 ± 0.01	0.58815	Hz
ν_6	0.62 ± 0.01	0.6170	Hz
ν_7	8.05 ± 0.6	7.926	Hz
ν_8	10.9 ± 0.8	10.393	Hz

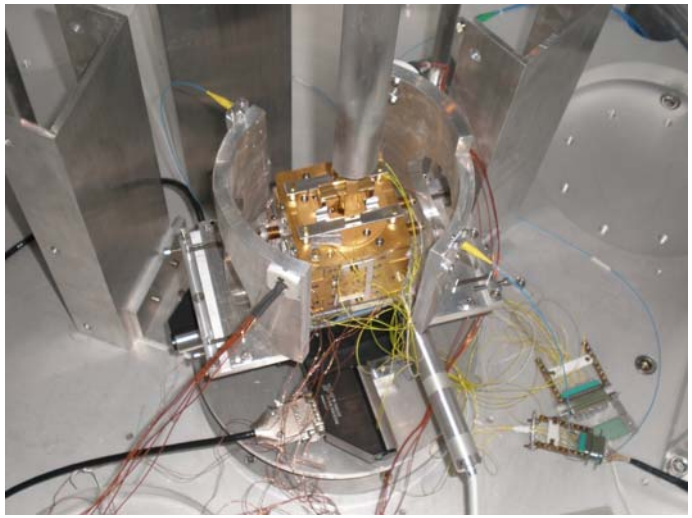
for details see:

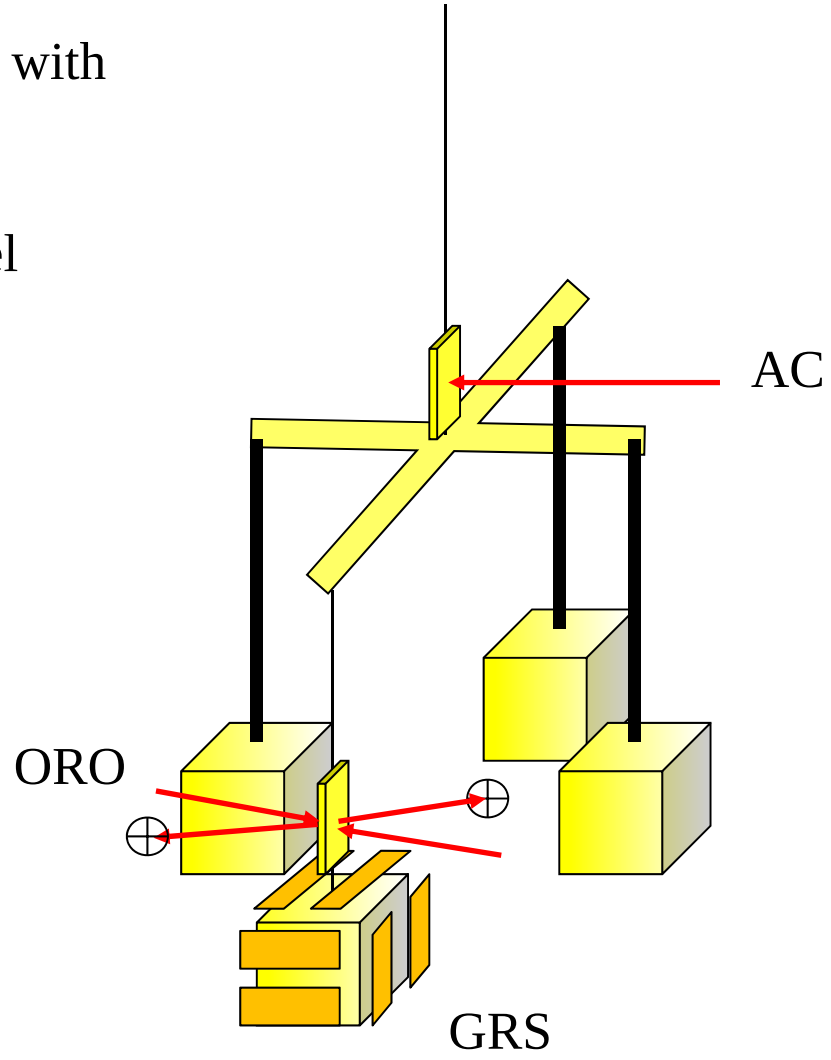
arXiv:1303.6407v1 [gr-qc] 26 Mar 2013

Readout scheme of PETER

The facility ha a redundant readout with combination of different sensors

- Autocollimator at the cross level
- GRS at the TM level
- ORO at the TM level





Some history

The activity was started few years ago by the Florence and Rome groups

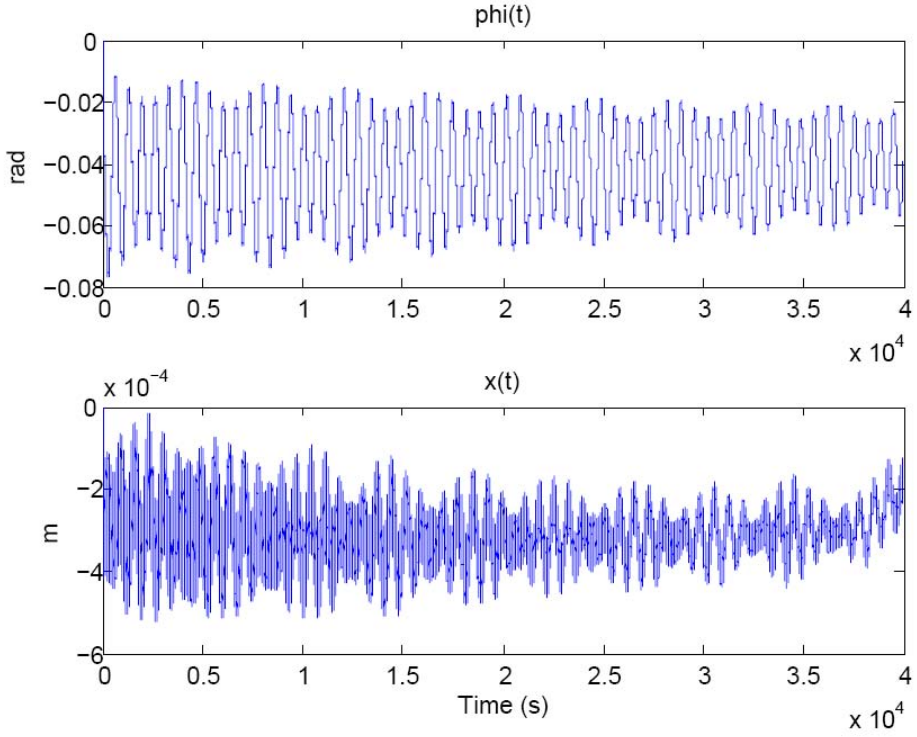
After a long debugging and commissioning phase, the facility became operational with the two soft DOFs in 2012

At that time the Napoli group started to collaborate to the activity, at the beginning by developing the servo-loops for pendulum damping and designing an auxiliary TM Optical Read-Out based on optical levers.

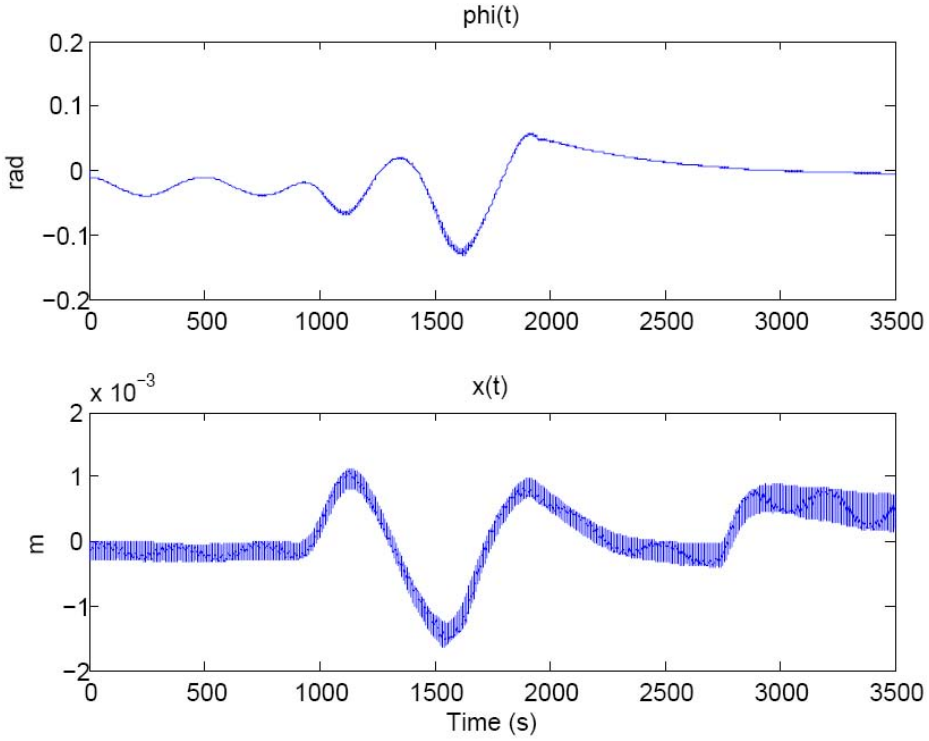
The three groups are now working together in a joint effort for the operation of the facility.

There was already a lot of experimental activity devoted to the characterization and debugging of the facility

Present status: It works !

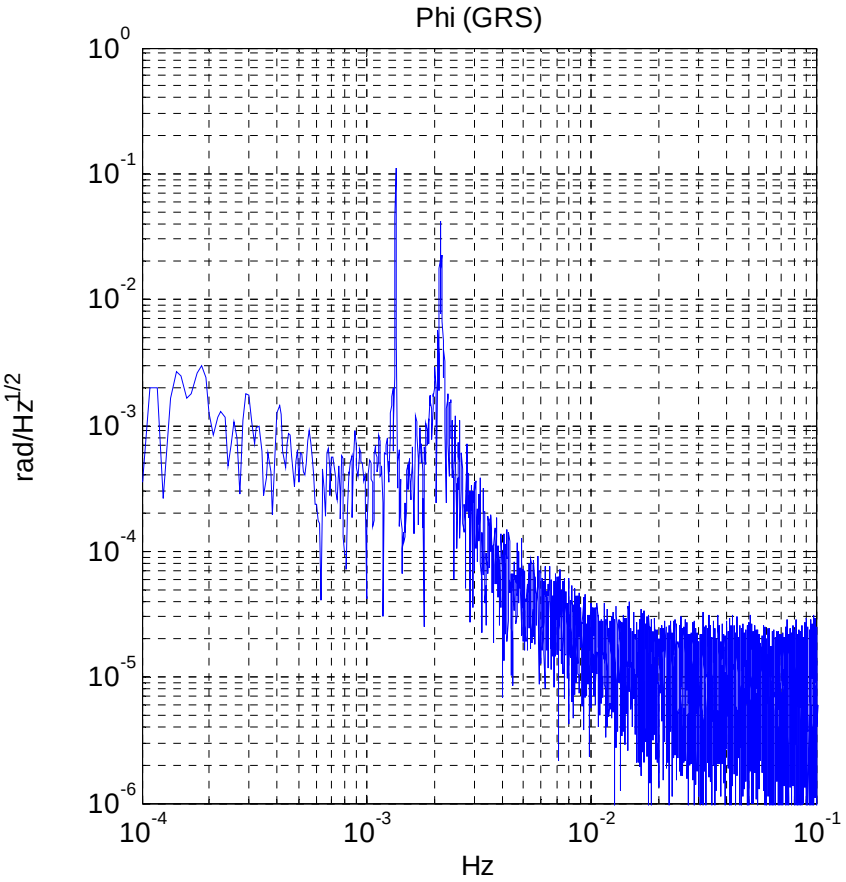


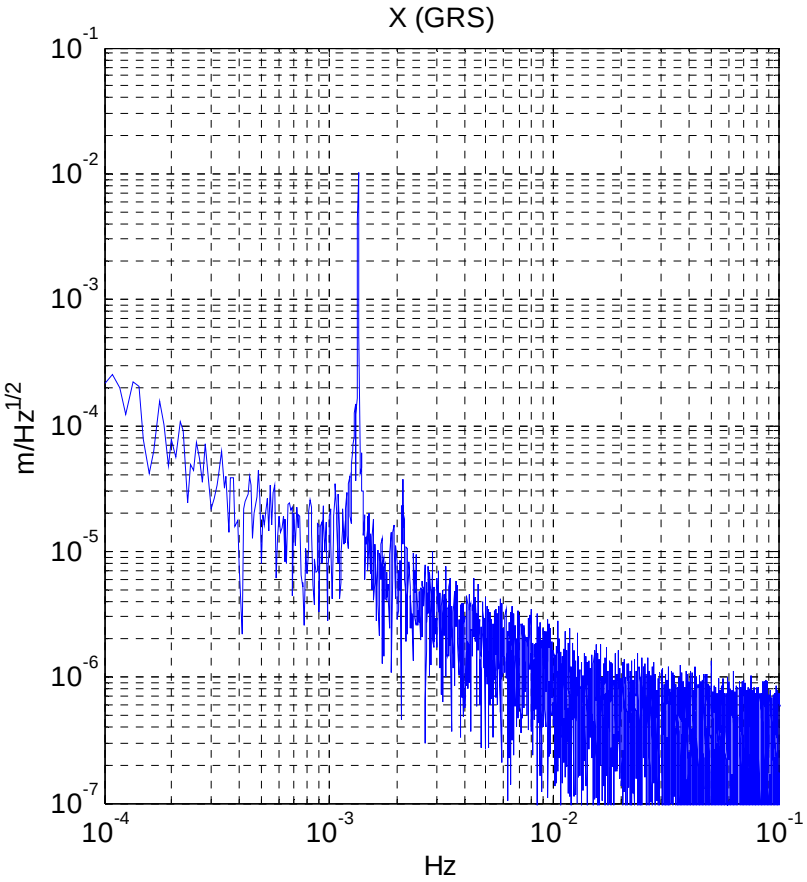
- Free oscillations of the 2 DoFs.



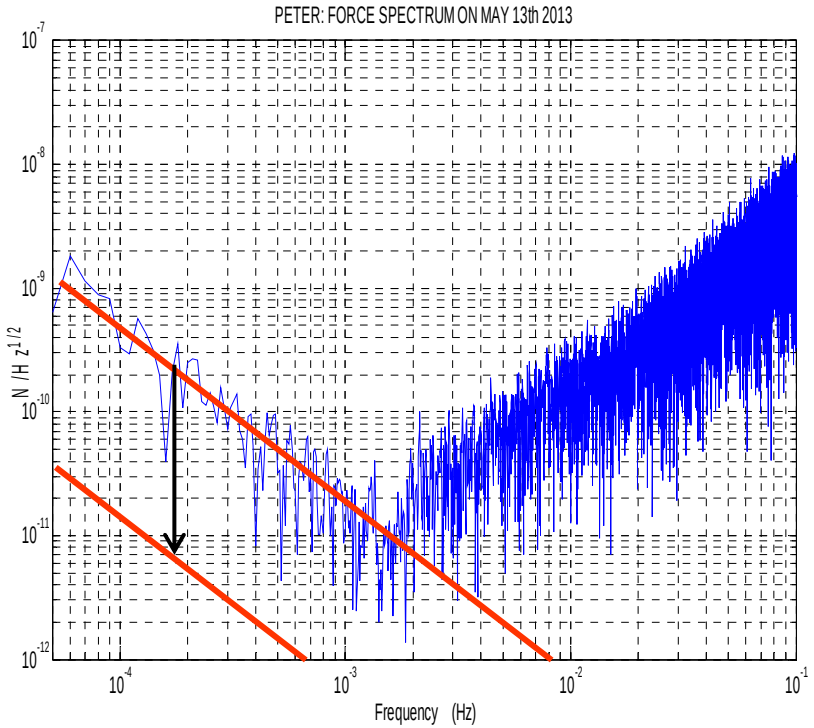
- Control of the 2 DoFs.

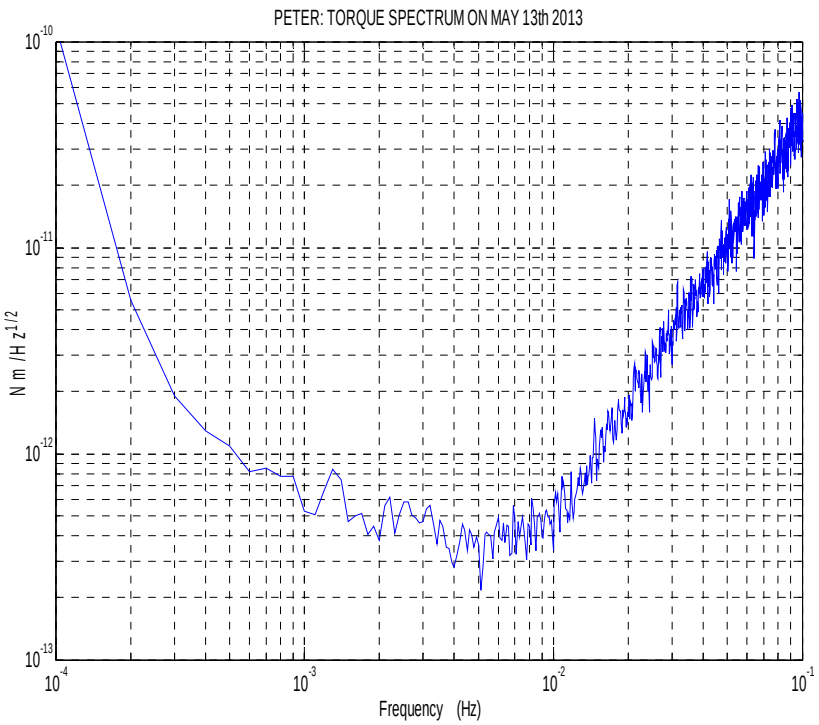
Present status: phi and X measurement





Present status: acceleration and force measurement





It is clear that the sensitivity is in a large frequency range limited by the large pendulum motion due to environmental noise.

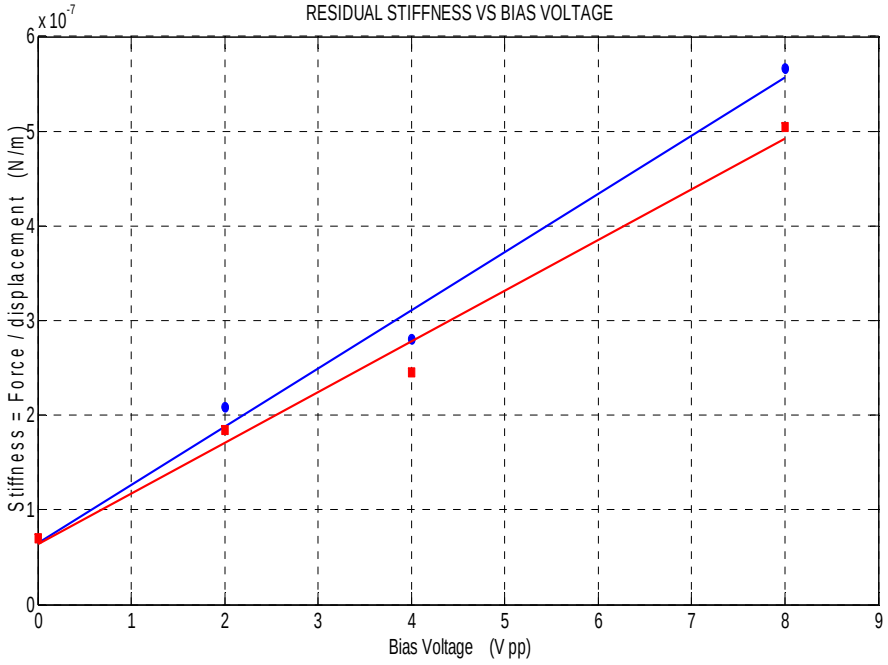
- We need to reduce environmental noise if we want to increase the sensitivity.
- Some work on readout noise is also required

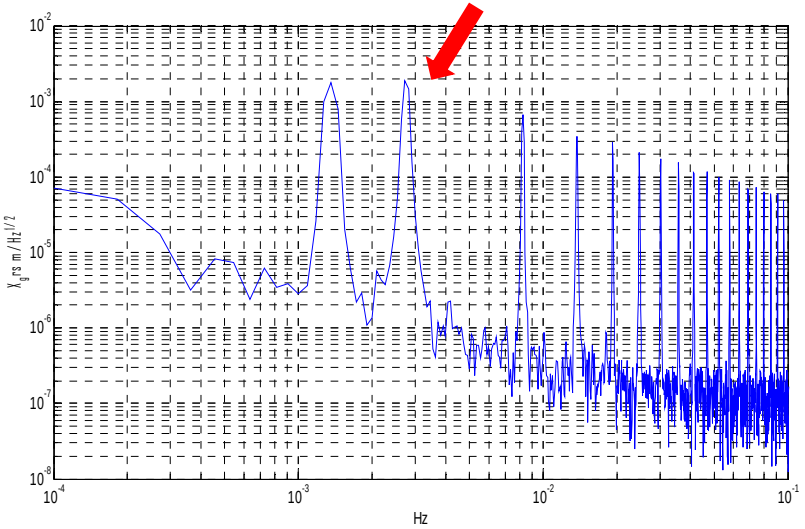
Other testing example: Stiffness measurement

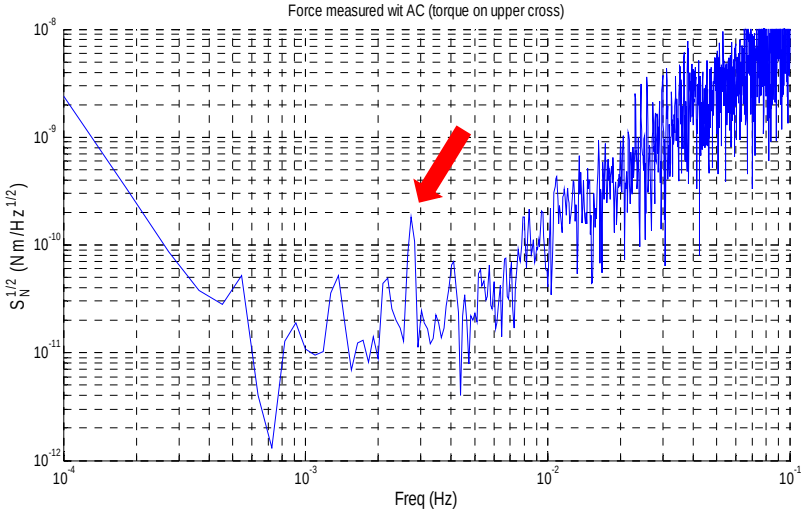
The residual stiffness is the (unwanted) force on TM due to GRS motion.
It is in large part due to GRS electronic bias

It can be measured by moving (square wave 2.8 mHz) the GRS respect to TM of a known amount and measuring the force on the TM

We present here only very preliminary results







Moving PETER from Florence to Napoli

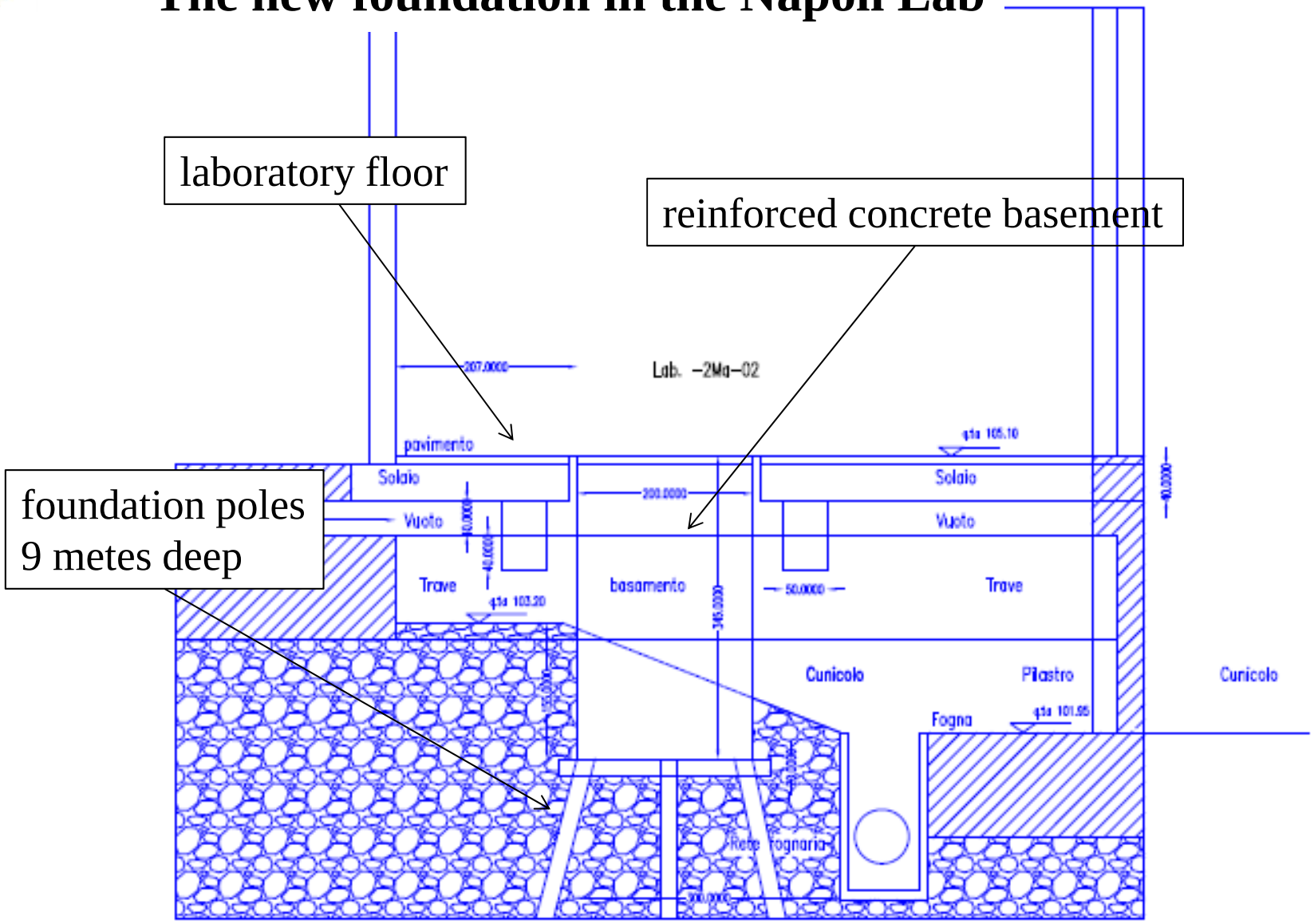
An important motivation is the environmental condition of the lab

- the facility is housed in a large open space building, with lot of human activity around, large temperature fluctuations, air currents etc.
- the base is a large floor connected to the building, it is not very stable and is affected by extra seismic noise due to people moving around.

For this reasons we decided to transfer the activity to Napoli INFN lab and to prepare the lab for receiving the facility:

- We will built a platform with an independent foundation separated by the rest of the building and from the floor of the lab.
- We will house the facility in a thermally isolated chamber

The new foundation in the Napoli Lab

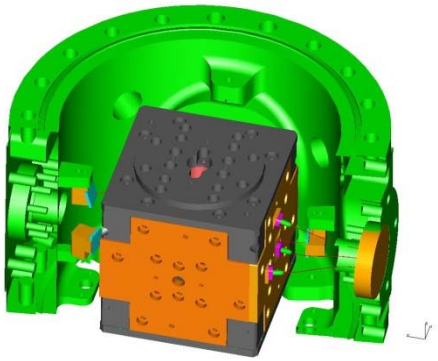


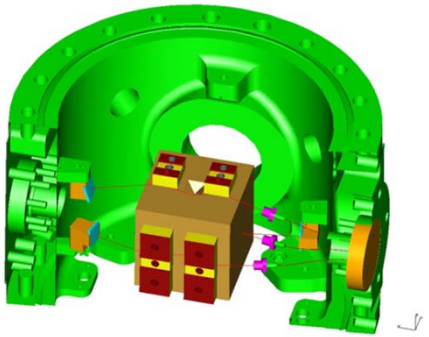
PETER: Test of the ORO for GRS

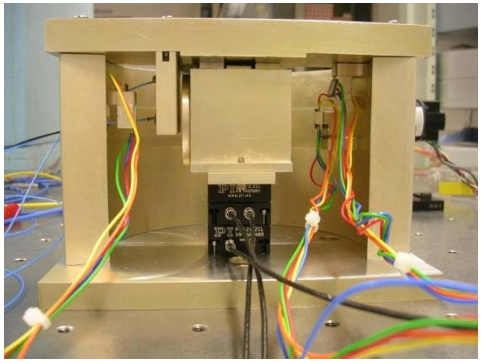
We developed in Napoli an Optical Read-Out system to be integrated with the capacitive one in the GRS of future LISA-Like missions

It was extensively tested with bench top prototypes, but only limited testing was performed in free fall condition in collaboration with the Trento group (four mass torsion pendulum)

PETER will be very useful for a complete testing of the proposed ORO set-up in free fall condition







for details see: Astrop. Phys. 34 (2011) 394–400

Conclusions

• PETER is a double pendulum for lab testing of free fall on 2 DoFs

• The facility was completely commissioned and is now operative in Florence INFN lab. The main limitation in sensitivity are due to bad environmental condition in the lab.

• The facility will be transferred to Napoli INFN lab where there should be better environmental conditions.

• The civil ingeniering work in the Napoli lab should start soon and we hope to have PETER up and running in Napoli by the end of this year and to be ready to start the testing activity at the beginning of 2014.

• PETER will be a unique facility for contemporary characterization in two DOFs of the flight hardware of LISA-like space GW missions.

Thank you for your attention