IGETS, 1st workshop, Potsdam, 18-20 June 2018

SELF-NOISE CORRELATION ANALYSIS OF SUPERCONDUCTING GRAVIMETERS AT THE J9 GRAVIMETRIC OBSERVATORY OF STRASBOURG, FRANCE

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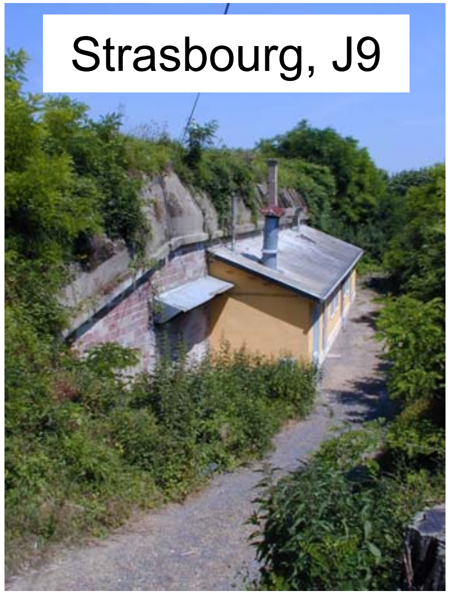
SG instruments and installation at J9


Strasbourg, J9

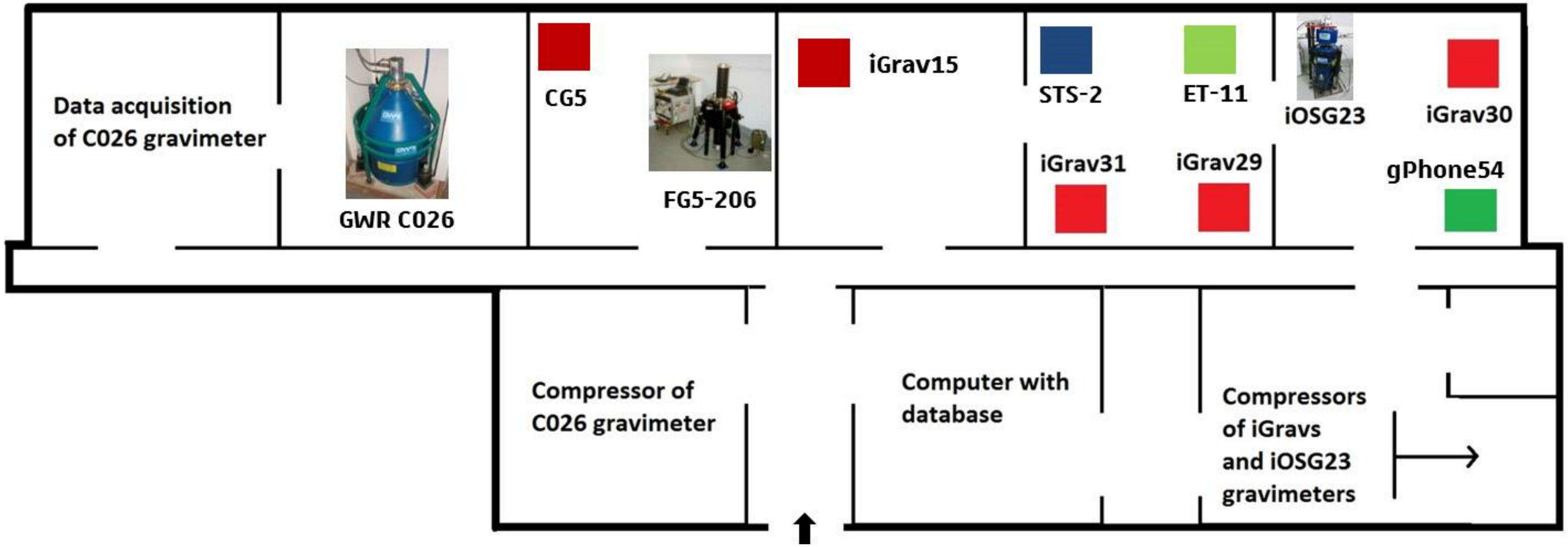

Since July 1996
C026

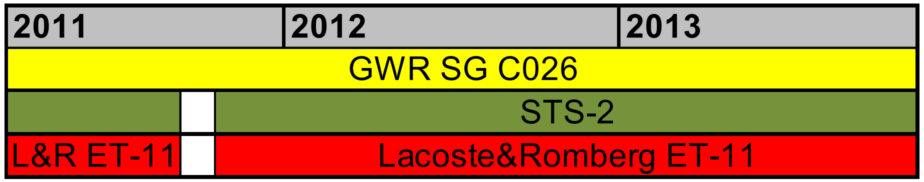

Since Feb. 2016
iOSG-23

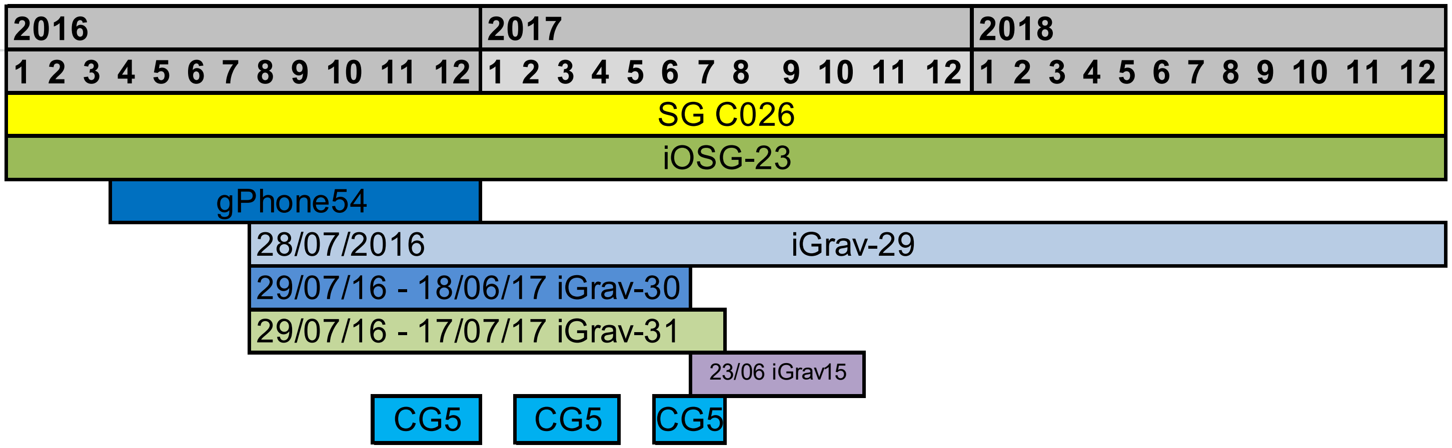

iOSG-23 & iGrav30


iGrav29 & iGrav31

SG instruments and installation at J9







Seismic noise levels

PROCEDURE

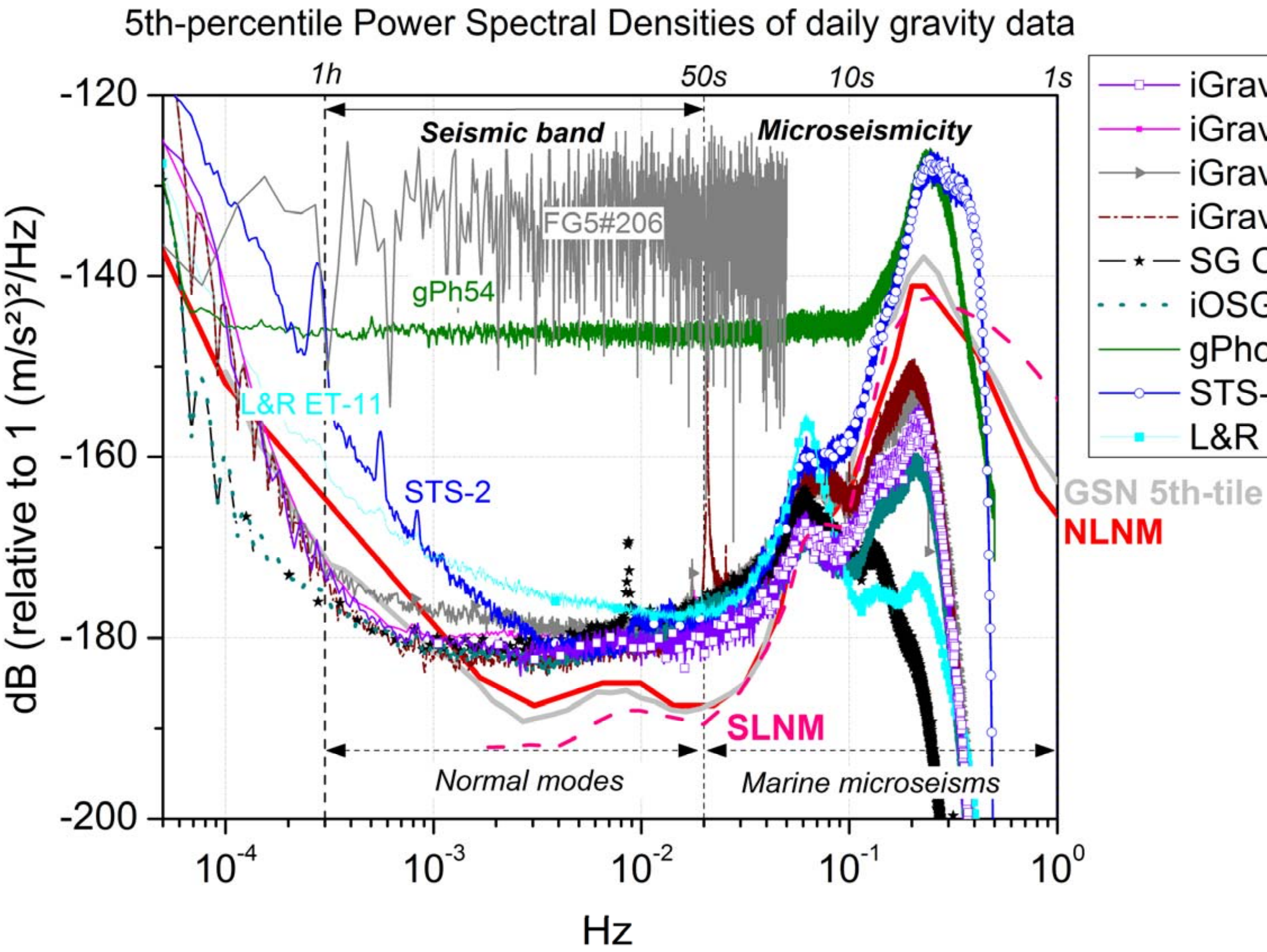
- Calibration of raw (or decimated 1-min) data using the scale factor determined by FG5 parallel measurement or provided by the manufacturer (gPhone, CG5)

- Computation of Power Spectral Densities using a modified Welch-periodogram technique based on the average of a certain number of 12 h-time windows with an overlap of 75%

- Statistical distribution of the PSDs and computation of the 1st, 5th, 25th and 50th percentiles but we have selected only the 5th-tile for the plots

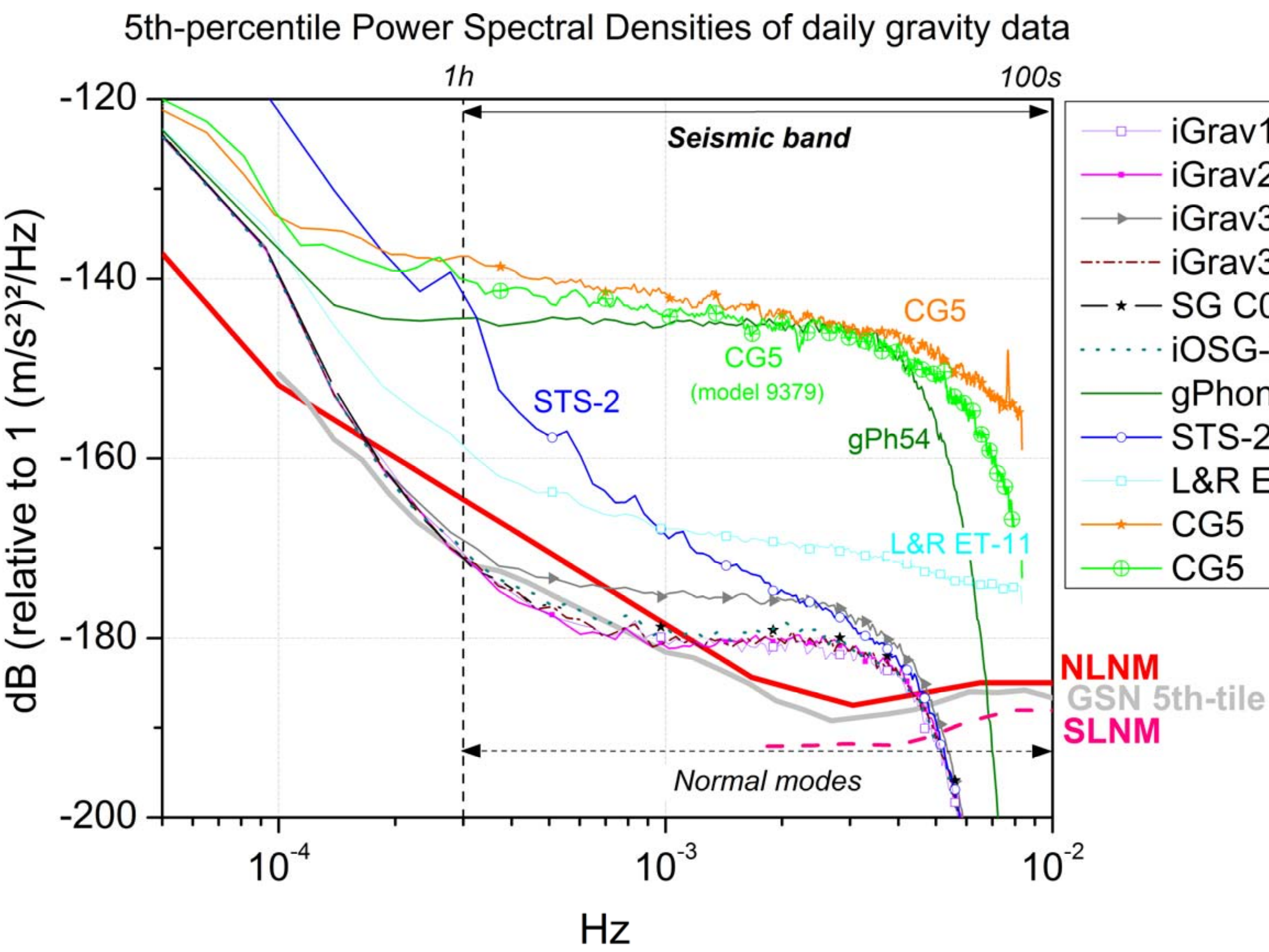
NB: No removal of tides and atmospheric pressure effects

Seismic noise levels on 1-sec data



New Low Noise Model (NLNM) of Peterson (1993)
Statistical Low Noise Model (SLNM) of Castellaro and Mulargia (2012)
Dashed gray lines: Global Seismographic Network 5th-tile of Berger et al. (2004)

Seismic noise levels on 1-minute data



Self-noise levels

PROCEDURE

Using a 3-channel correlation technique (Sleeman et al. 2006)

→ *We do not need to know the transfer function of the channel*

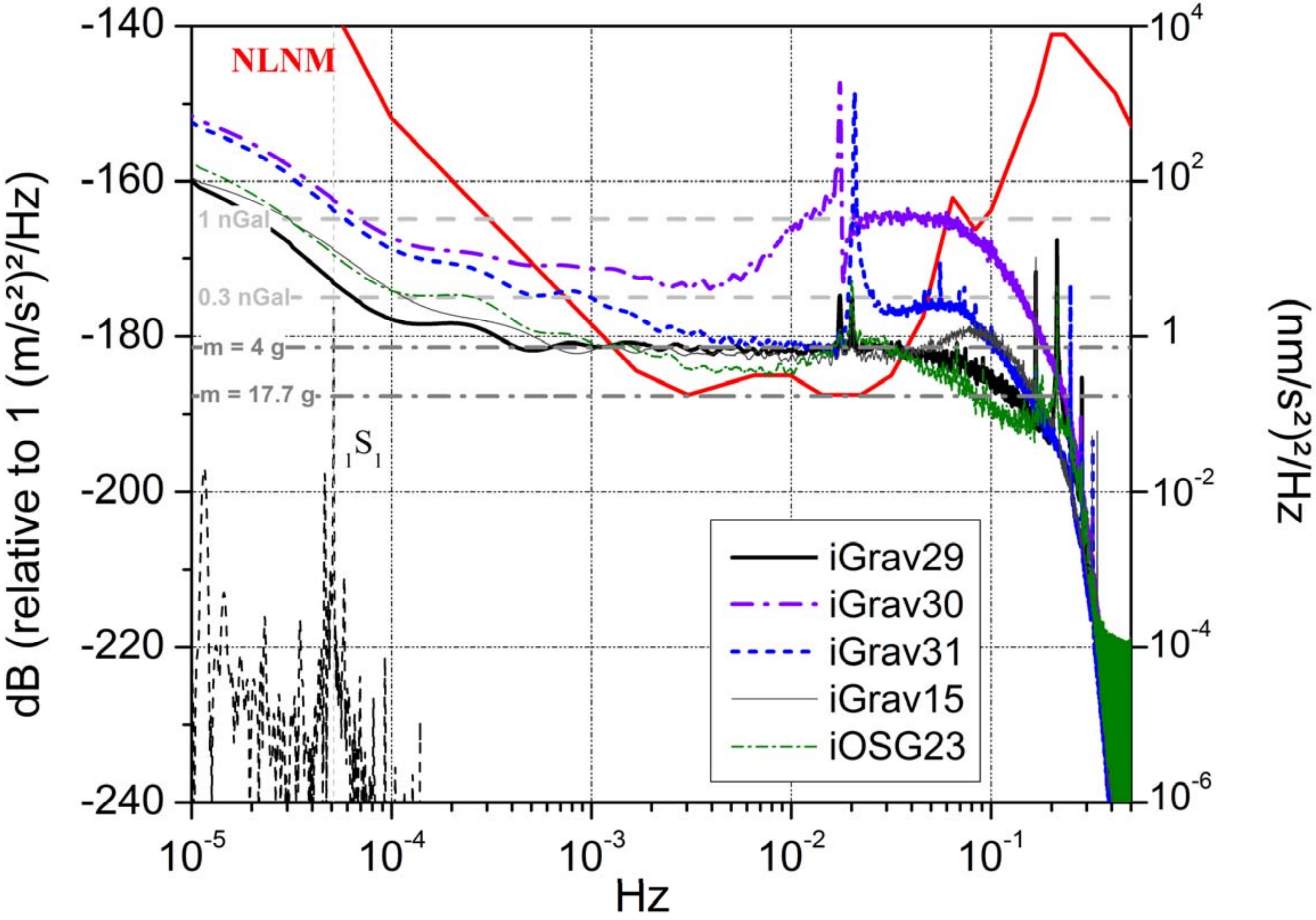
$$\boxed{\text{self–noise: } N_{ii} = P_{ii} - P_{ji}P_{ik}/P_{jk}}$$

PSD of channel *i*

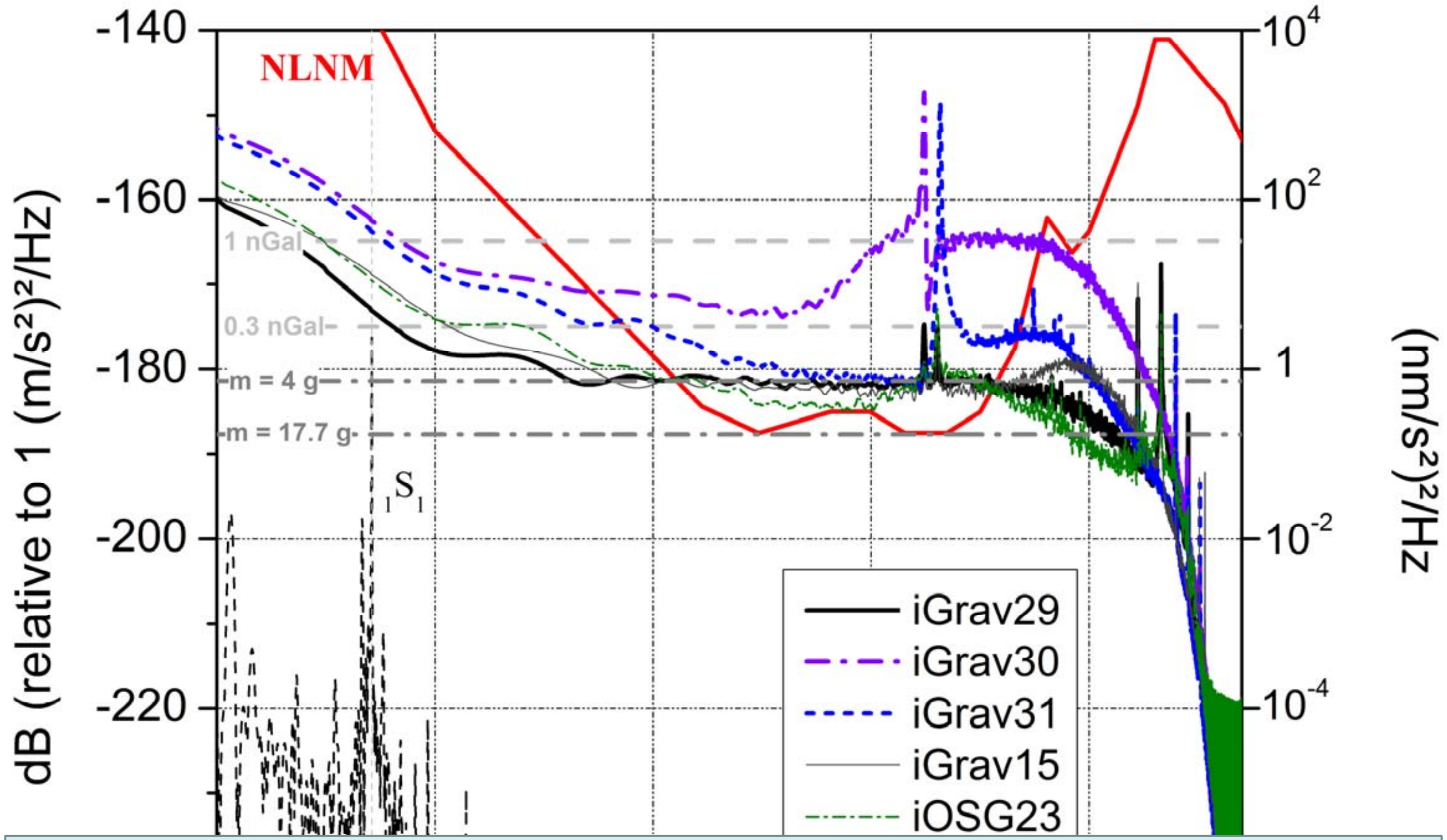
Cross-PSD between *i* and *k*

Instrumental noise + installation + configuration
+ very local effects

Self-noise levels



Self-noise levels



<u>iGrav30</u>: installation problem (confirmed by checking the tilt signals) - instrument pods only partially decoupled from the ground

<u>iGrav31</u>: malfunctioning cold-head

<u>iGrav15</u>: installed directly on the ground

Self-noise levels

THERMAL NOISE MODEL

thermal force noise associated with Brownian motion in a simple damped mechanical oscillator (Saulson, 1990, Warburton et al., 2010)

$$\boxed{\frac{d^2z}{dt^2} + \frac{\boldsymbol{b}}{\boldsymbol{m}}\frac{dz}{dt} + \boldsymbol{\omega_0^2}\, z(t) = \mathrm{F(t)}}$$

z: relative displacement of the sphere wrt its equilibrium position

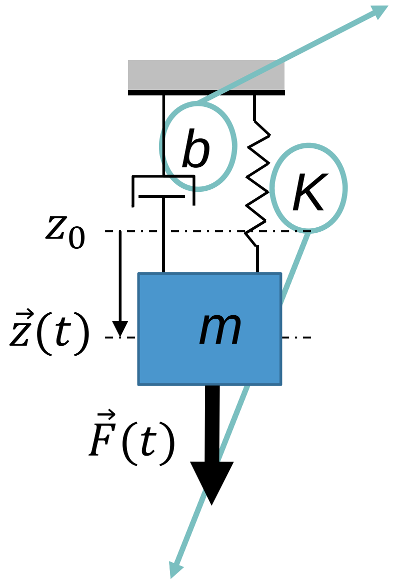
$$\omega_0 = \sqrt{\frac{K}{m}}, \quad Q = \frac{\sqrt{Km}}{b}$$

$$P_{thermal} = 4k_B T \frac{B}{m^2}$$

or

$$\boxed{P_{thermal} = 4k_B T \frac{\omega_0}{mQ}}$$

Damping constant proportional to velocity



K: From magnetic gradient (between upper and lower coils)
K<<1 → a small gravity change → a large displacement of the sphere

where ω_0 is the natural frequency of the oscillator, Q its quality factor and m is the mass of the oscillating sphere; k_B is the Boltzmann constant and T the temperature.

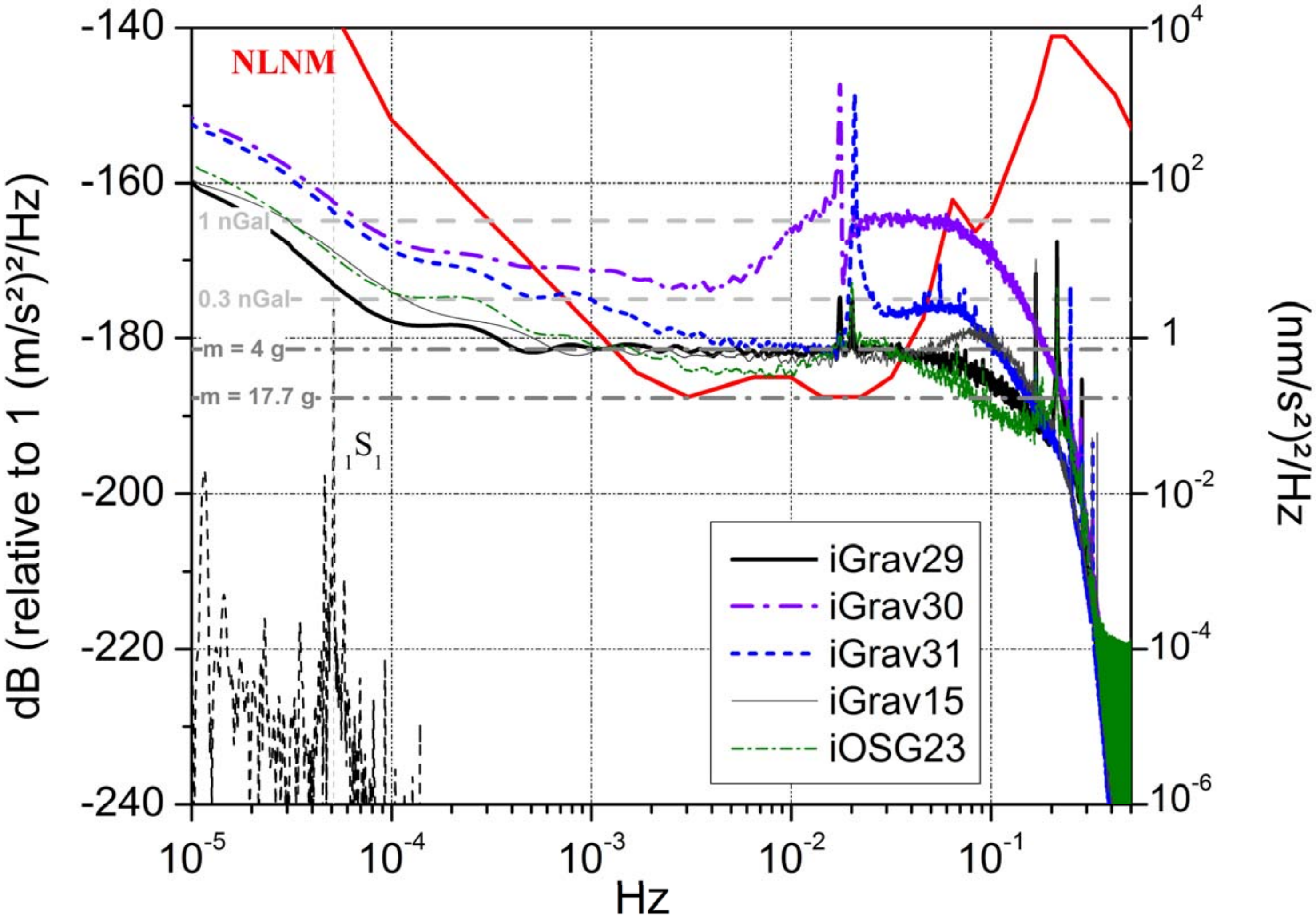
Self-noise levels

THERMAL NOISE MODEL

- Determination of the oscillator parameters *K* and *b* by R. Warburton (*personal communication*)

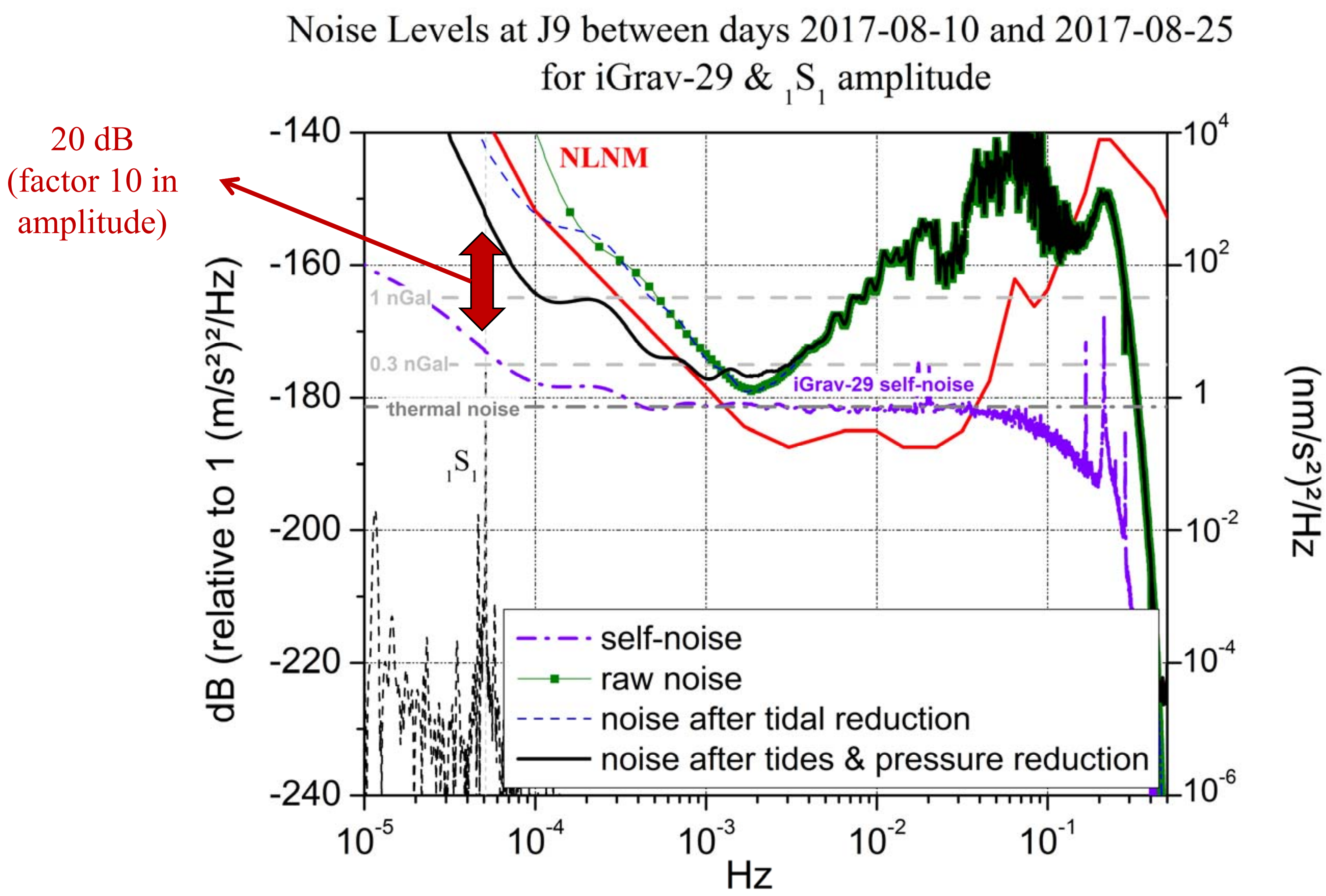
Parameters	Unit	iGrav29	iOSG-23
Mass m	g	4.02	17.67
Frequency f_0	Hz	0.24	0.10
Q		0.142	0.05
Spring constant K	N/m	0.0090	0.0076
Damping factor b	kg/s	0.051	0.232
Power Spectral Density	dB	**-181**	**-188**

Self-noise levels



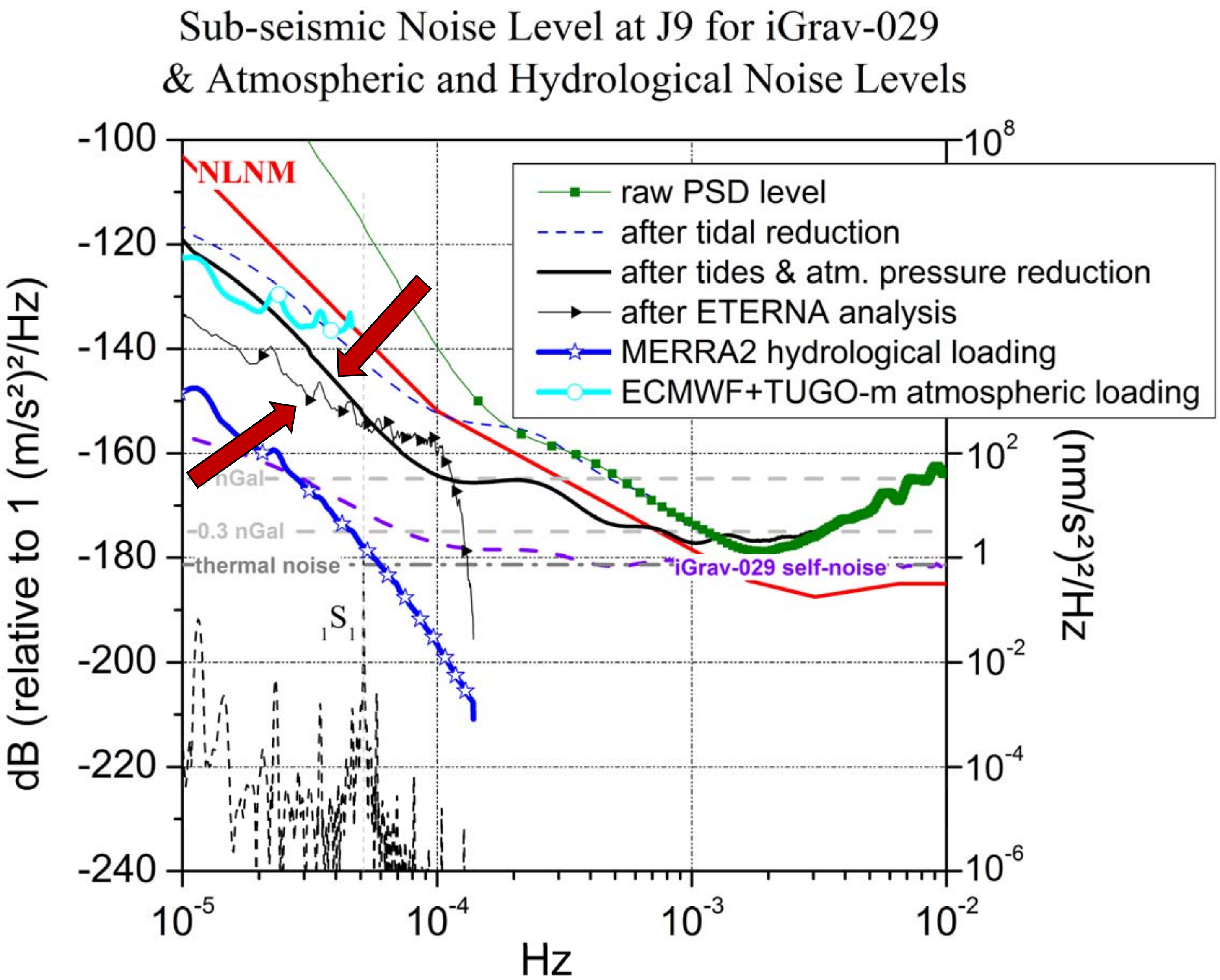
In the mHz frequency band:
<u>iGrav29, iGrav15:</u> self-noise = thermal noise model
<u>iOSG-23</u>: 5 dB above thermal noise (m = 17.7 g)

Self vs. observed noise levels



At sub-seismic frequencies (T>1h)
Observed noise level >> self-noise level → environmental origin not instrumental

Self vs. observed noise levels



After ETERNA tidal analysis → lower PSD than subtraction of a local model

Conclusion

- We have shown an exhaustive noise level comparison of various gravimeters and a long-period STS-2 seismometer at a same site

- At seismic frequencies (mHz range), for iGrav-29 and iGrav-15, self-noise level perfectly explained by the thermal noise model of a damped mechanical oscillator

- Why iOSG-23 self-noise is larger than thermal noise model, is it due to the installation, configuration (magnetic gradient) or is it an impossibility to decrease the self-noise below the seismic NLNM?

- At sub-seismic frequencies, self-noise increases with period but much less than the observed noise level → **the noise level increase at long periods is barely of instrumental origin but mostly environmental**

- Self-noise of iGrav29 is at the 0.3 nGal detection threshold at 5 h-period

→ *Instrumental noise is NOT the main factor that prevents us to detect the inner core free oscillations (Slichter mode)*

Acknowledgments

- We are grateful to Richard Reineman for the installation of the iGrav and iOSG-23 and to Richard Warburton for the determination of the values of the parameters entering the damped oscillator model

- We thank GWR for the lend of the iGrav-15

- We thank IGN Madrid and Marta Calvo for the lend of the gPhone-54

Thank YOU for your attention!

Self-noise levels

PROCEDURE

Using a 3-channel correlation technique (Sleeman et al. 2006)

$$Y_i = X \cdot H_i + N_i$$

Common input signal

Transfer function

$$P_{ij} = Y_i \cdot Y_j^{\;*} = P_{xx} \cdot H_i \cdot H_j^{\;*} + N_{ij}$$

Assumption $N_{ij} = 0$ (uncorrelated noise)

$$\frac{P_{ji}}{P_{ki}} = \frac{H_j}{H_k} \text{ and } \frac{P_{ii}}{P_{ji}} = \frac{H_i}{H_j} + \frac{N_{ii}}{P_{ji}}$$

$$\text{self-noise: } N_{ii} = P_{ii} - P_{ji}P_{ik}/P_{jk}$$

PSD of channel i

Cross-PSD between i and k

Self-noise levels

DETERMINATION OF OSCILLATOR PARAMETERS K AND b

After Warburton R. (personal communication)

The spring constant K is determined by measuring the displacement of the sphere in response to an applied force. The force is produced by generating a small current in the feedback coil and the displacement is measured by the capacitance bridge. This requires careful calibration of the capacitance bridge (C_{4095}) and feedback coil (G_F) by experimental measurements.

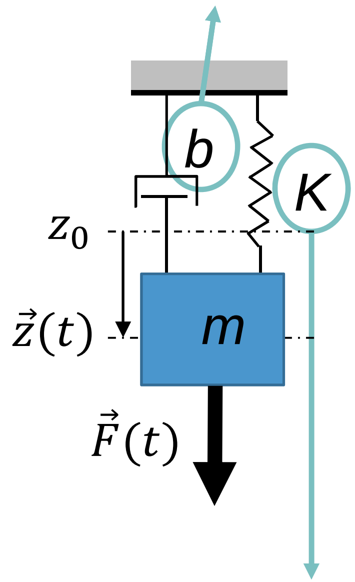
- Using step function

$$1/K = C_{4095} \text{ x } \Delta V / (G_F \text{ x } \Delta i)$$

- Using tide model and in open loop (need to know C_{OL})

$$K = (m \text{ x } C_{OL})/C_{4095}$$

Damping constant proportional to velocity



K: From magnetic gradient (between upper and lower coils)
K<<1 → a small gravity change
→ a large displacement of the sphere

The constant b is the slope of the linear dependency between phase delay and sensitivity (1/K) in Open Loop for different Gradient Coil currents.