SG - Superconducting Gravimetry

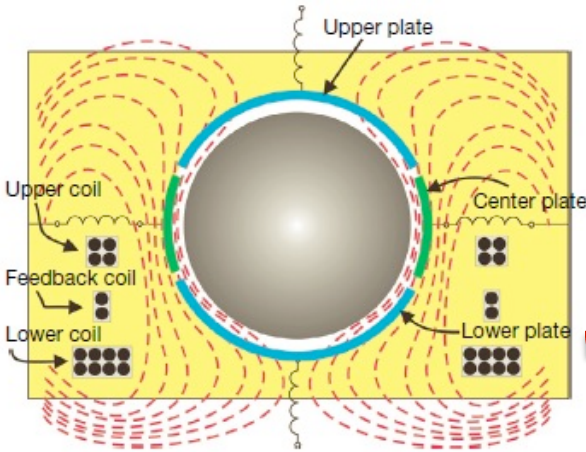
Monitoring of time-gravity changes using superconducting gravimeters

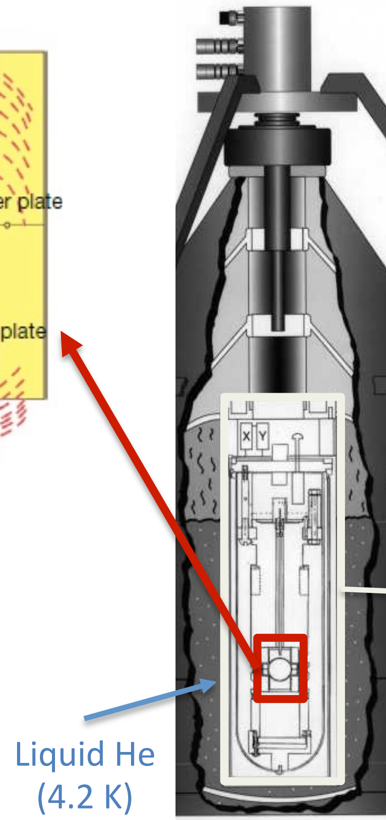
Séverine Rosat

Institut de Physique du Globe de Strasbourg; UMR 7516, Université de Strasbourg/EOST, CNRS

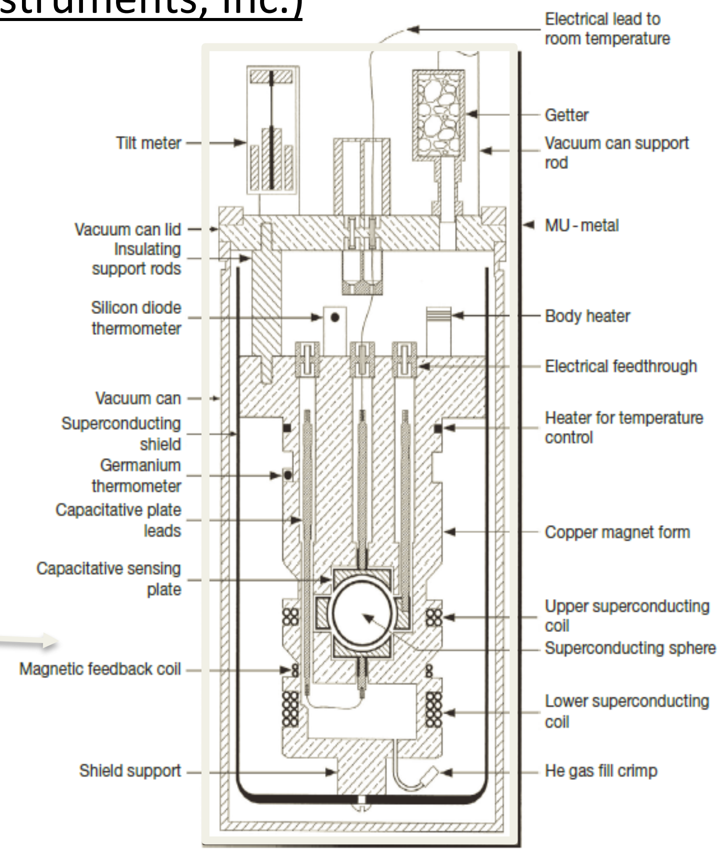
SUPERCONDUCTING GRAVIMETER: SENSOR

Components of the SG sensor (GWR Instruments, Inc.)





Cryogenic dewar



The levitation force is produced by the interaction between the magnetic field from the coils and the currents induced on the surface of the superconducting sphere.

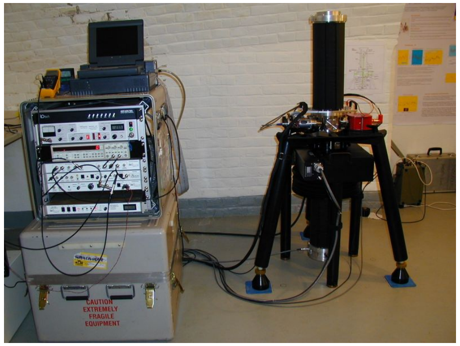
Magnetic feedback → **very low instrumental drift**

(a few μGal/year, where 1 μGal ~ 10^{-8} m/s²)

Very high sensitivity at the nanogal level (~ 10^{-12} g)

SUPERCONDUCTING GRAVIMETER: CALIBRATION AND INSTRUMENTAL DRIFT

→ Using absolute values of gravity

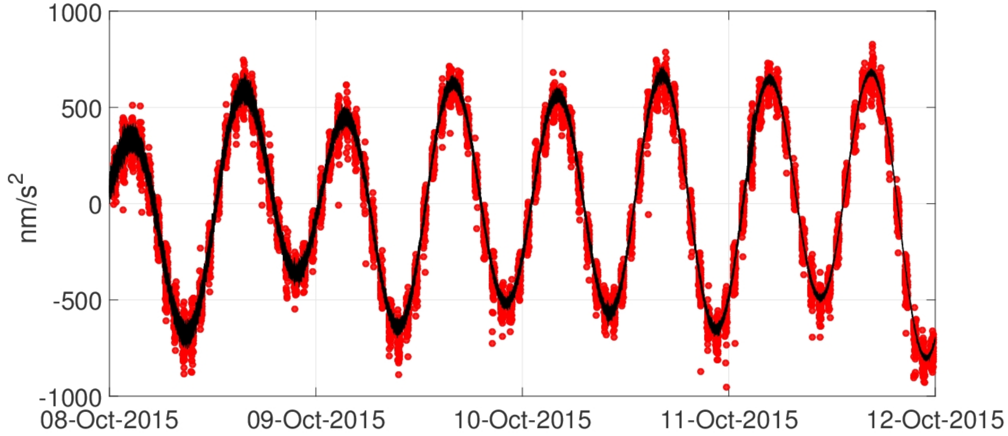


least-squares adjustment

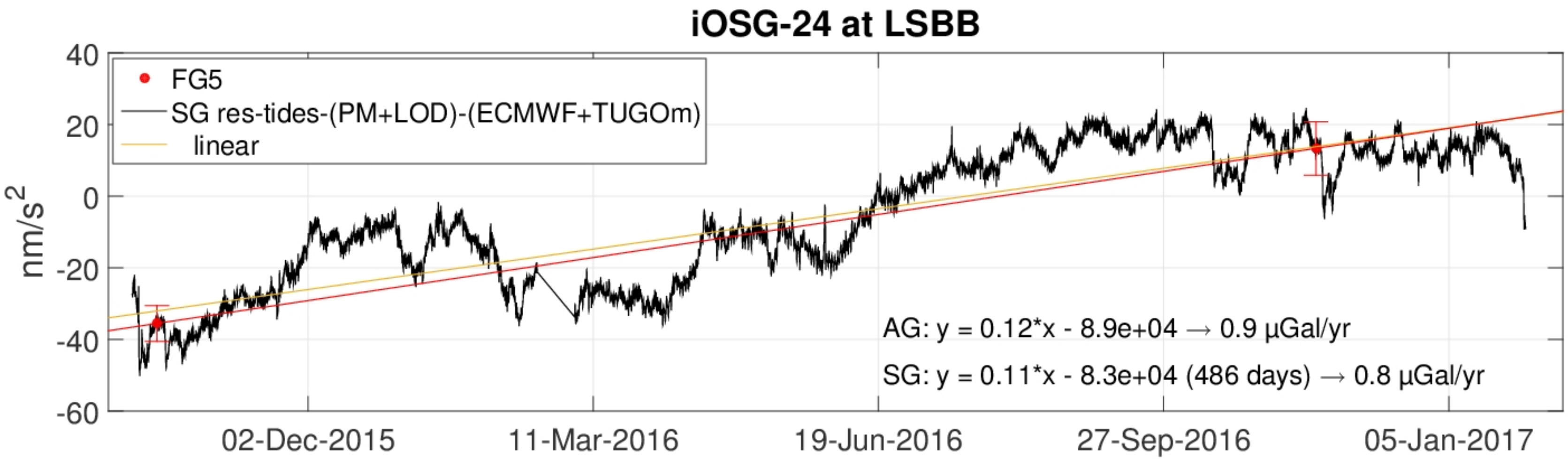
Scale factor = -451 ± 3 nm/s²/V

(relative error of 0.7 %)

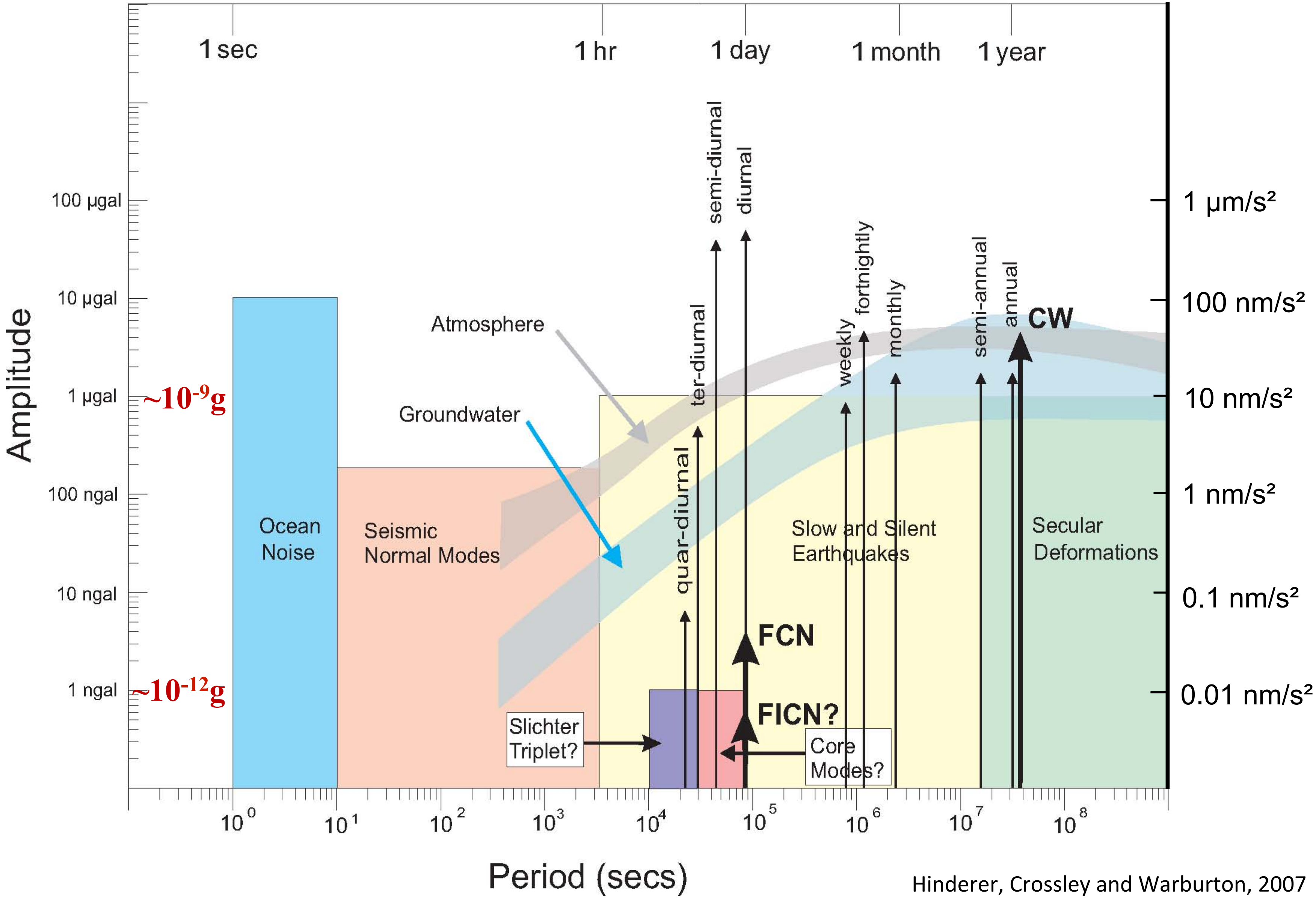
Example of iOSG-24 with FG5#206



Very small instrumental drift ~ 0.8 μGal/year



SPECTRUM OF TIME-VARYING GRAVITY CHANGES



Hinderer, Crossley and Warburton, 2007

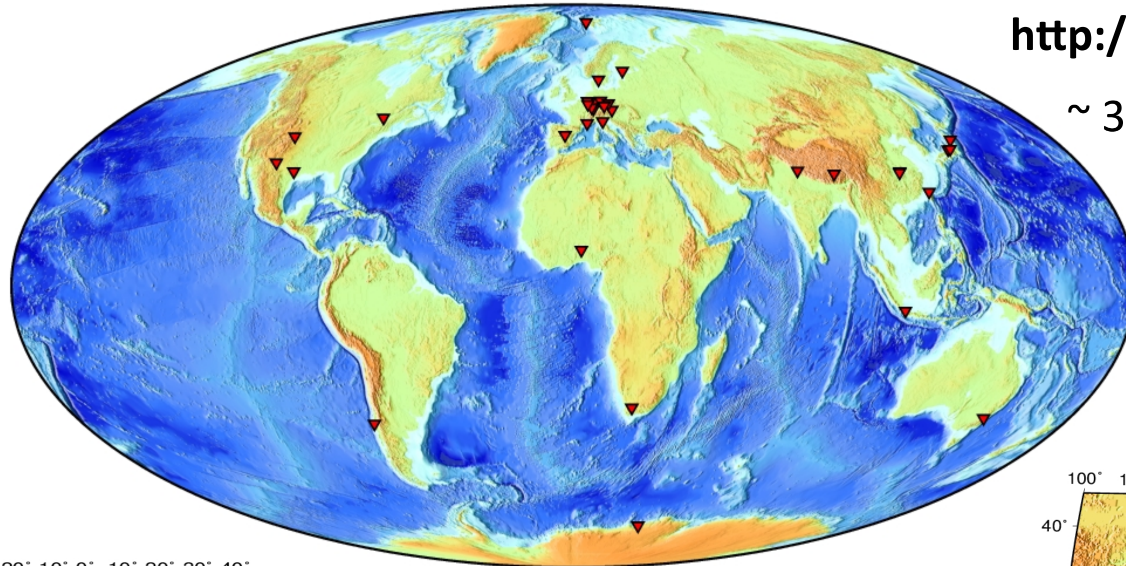
SG - Superconducting Gravimetry

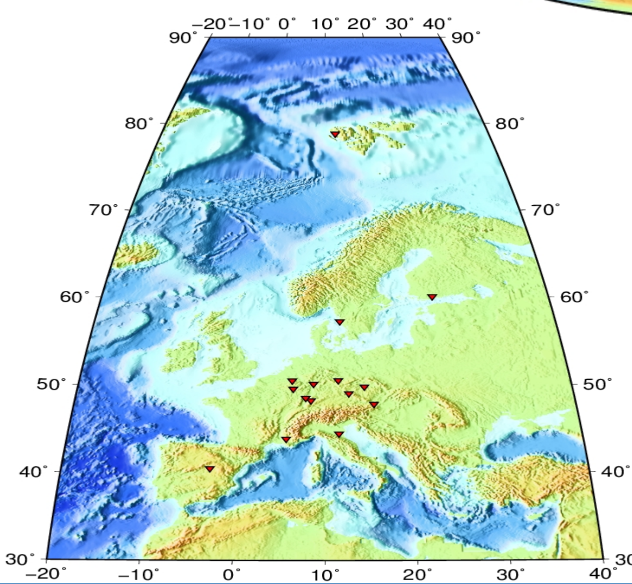
SUPERCONDUCTING GRAVIMETER NETWORK

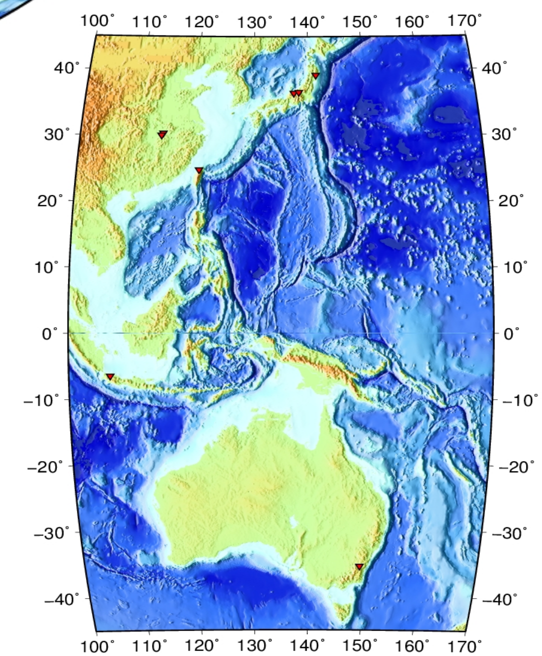
International Geodynamics and Earth Tide Service (IGETS)

http://igets.u-strasbg.fr/

~ 30 SGs worldwide







SUPERCONDUCTING GRAVIMETER

Size, difficulty of installation and price →

Early commercial model
TT instruments
~1981 - 1994
200 L dewar

Compact SG
1994 - 2002
125 L dewar

Observatory SG
2003 - 2012
42 L dewar

*i*OSG
Since 2012
35 L dewar

Field SG

*i*Grav
Since 2012
16 L dewar

Niobium sphere: 2.54 cm diameter, **mass ~4.3g**

GWR Instruments, Inc.

TODAY'S SUPERCONDUCTING GRAVIMETERS

*i*OSG

- **Super stable**: Drift rate < 0.5 μGal/month ; Scale factor constant to < 0.01 % over decades
- **Super precise**: 0.1 nanoGal (10^{-3} nm/s²) resolution in frequency domain; < 0.3 nm/s² resolution in the time domain for 2 minute averaging
- **Super low noise**: < 1 (nm/s²)²/Hz in seismic band (1 to 8 mHz)

Observatory SG

GWR Instruments, Inc.

Field SG

*i*Grav

- **Super stable**: Drift rate < 0.5 μGal/month ; Scale factor constant to better than 1 part in 10^4 for years
- **Super precise**: 1 nanoGal (10^{-2} nm/s²) in frequency domain; 0.05 μGal in the time domain for 1 minute averaging
- **Super low noise**: 0.3 μGal/(Hz)½ ~ 1 (nm/s²)²/Hz in seismic band
- **Smaller and cheaper** (~ 250 k€)

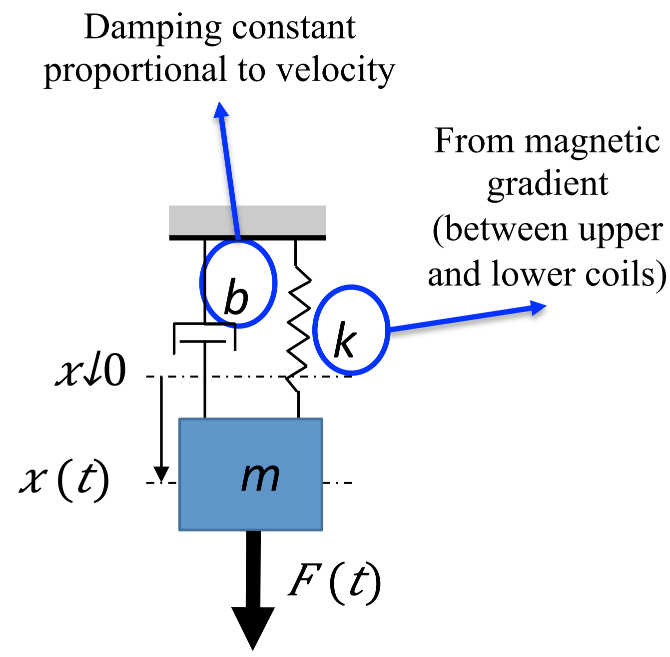
GWR Instruments, Inc.

SUPERCONDUCTING GRAVIMETER

SG as a damped harmonic oscillator:

$$kx(t) + b\frac{dx}{dt}(t) + m\Delta g(t) = -F(t)$$

x: relative displacement of the sphere wrt its equilibrium position



→ Brownian noise given by:

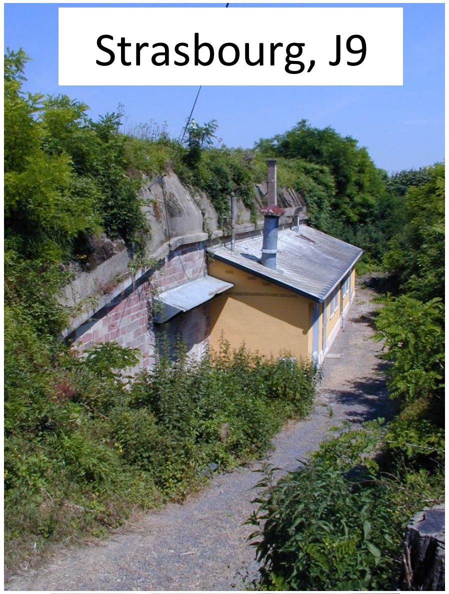
$$P_{thermal} = 4k_B T \frac{\omega_0}{mQ}$$

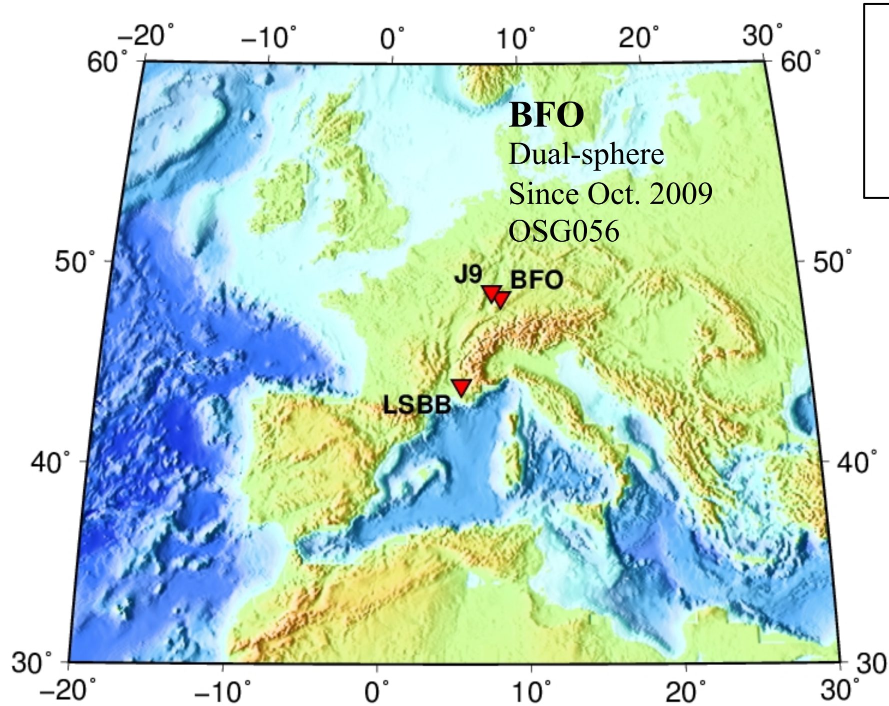
$\omega_0 = \sqrt{k/m}$, $Q = \sqrt{km}/b$

where ω_0 is the natural frequency of the oscillator, Q its quality factor and m is the mass of the oscillating sphere (Warburton et al., 2010); k_B is the Boltzmann constant and T the temperature.

Increase mass of levitated sphere → decrease noise due to Brownian motion
(as long as field at surface of sphere remains << critical value)

SUPERCONDUCTING GRAVIMETER





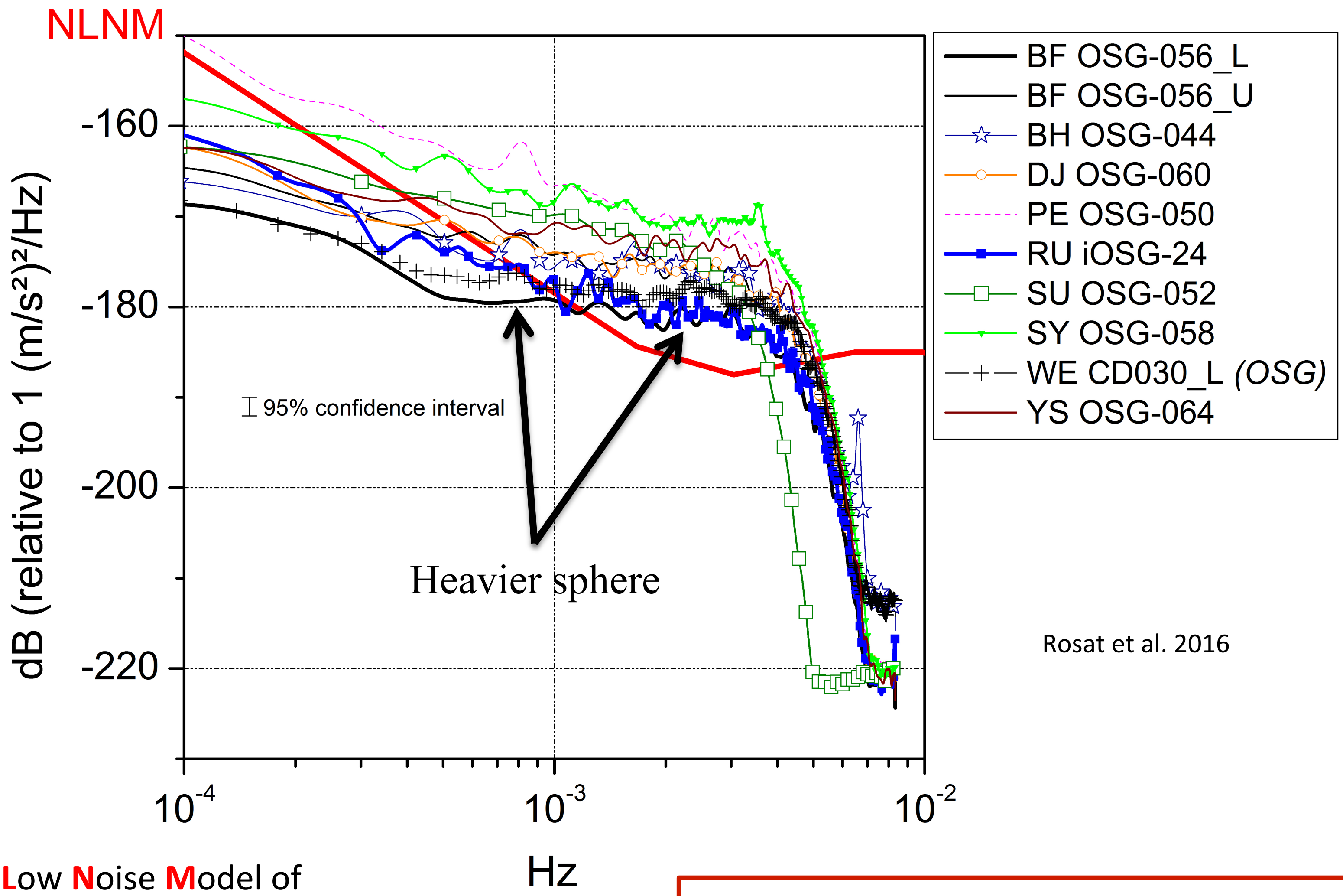
2 iOSGs
+ prototype
OSG-56 (BFO)

Since Feb. 2016
iOSG-23
RESIF

Mass of the levitating sphere
~17.7g for iOSG (ex. at LSBB and J9)

Since July 2015
iOSG-24
MIGA

SEISMIC NOISE LEVELS: *i*OSGs VS. SGs (5 QUIETEST DAYS)



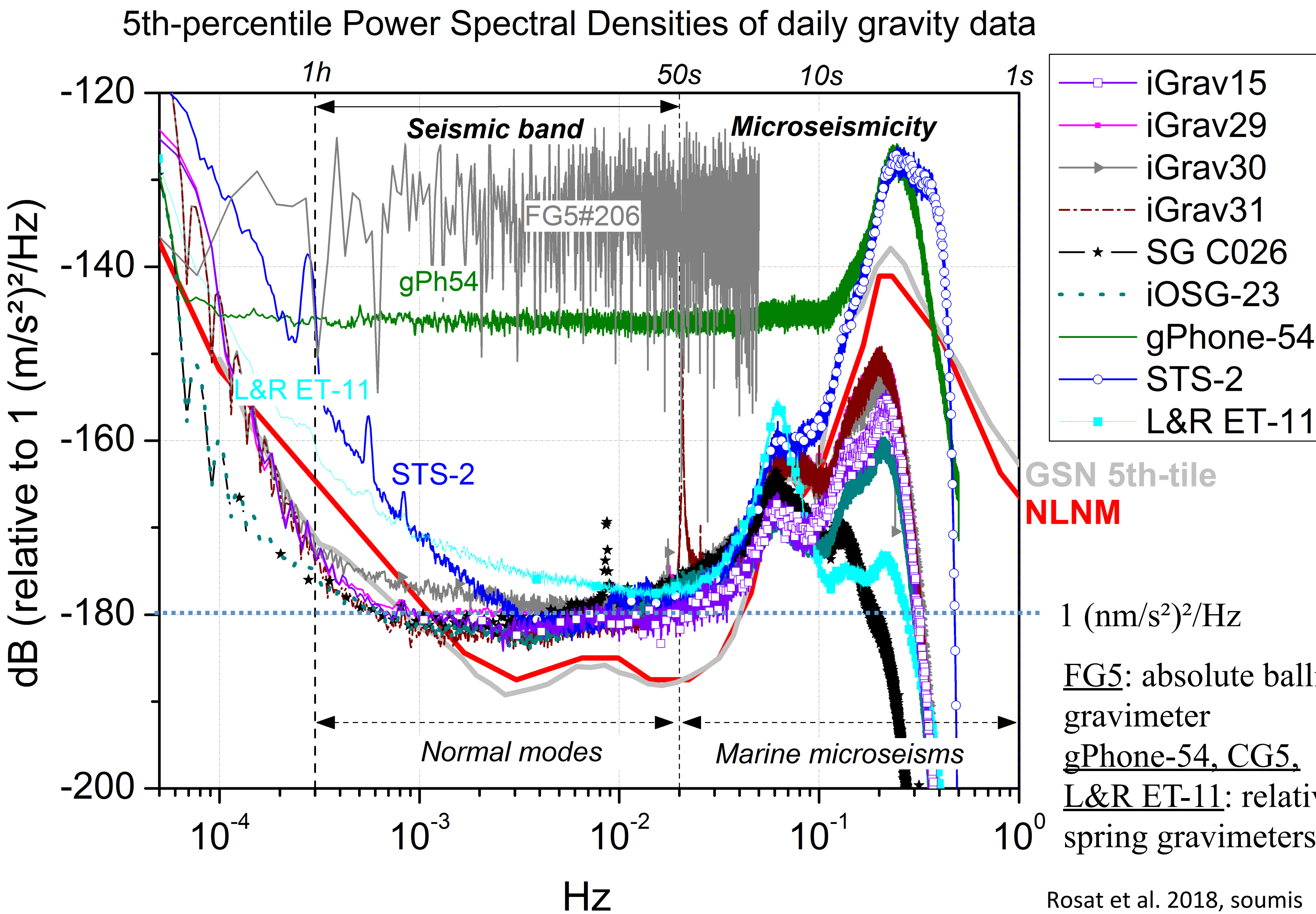
Rosat et al. 2016

New **L**ow **N**oise **M**odel of Peterson (1993) = seismological noise model

iOSG-24 (and OSG-56_L) → lowest noise level in the seismic band

(Modified from Rosat & Hinderer 2011)

SEISMIC NOISE LEVELS AT J9: SG VS. OTHER INSTRUMENTS

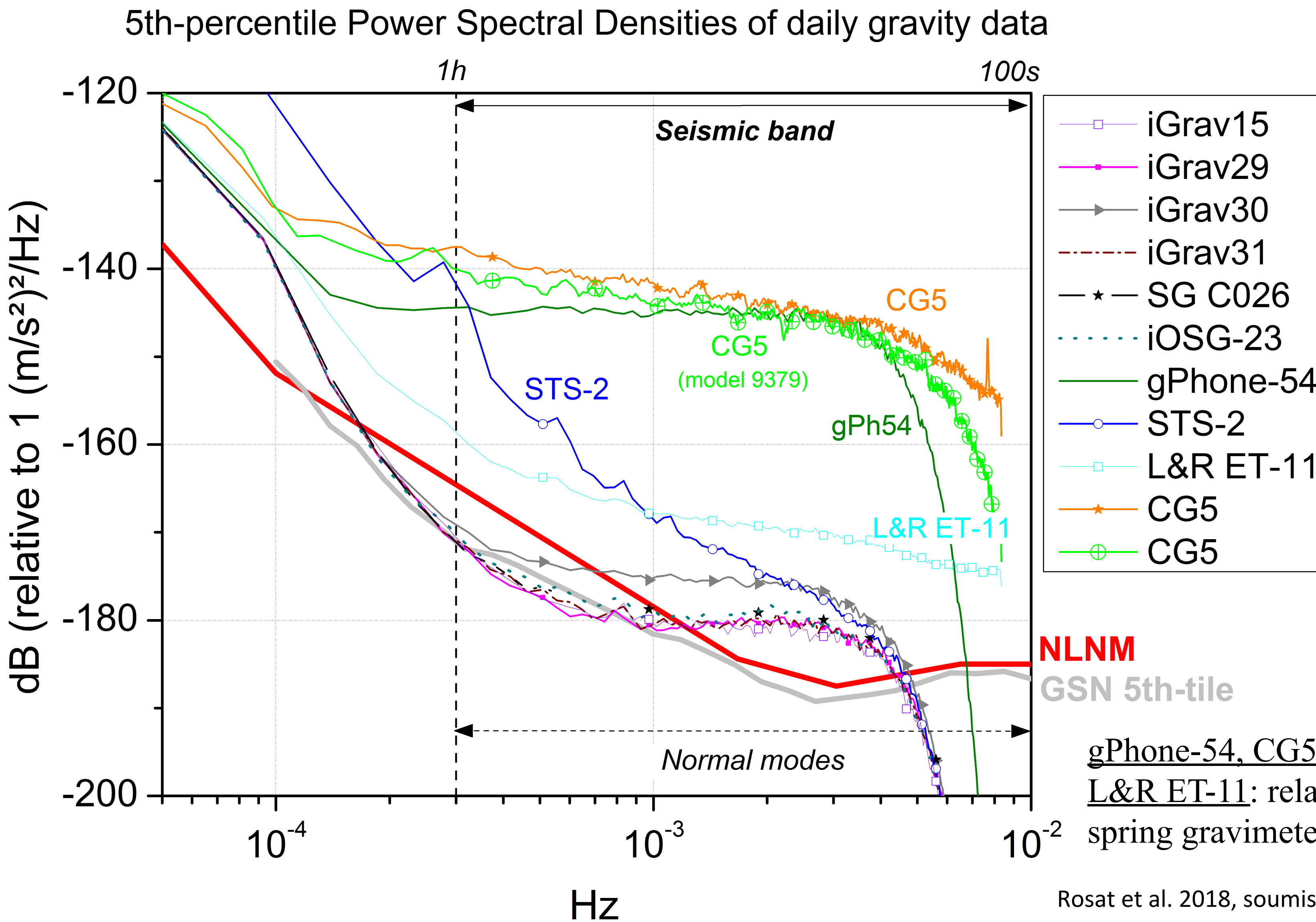


FG5: absolute ballistic gravimeter

gPhone-54, CG5, L&R ET-11: relative spring gravimeters

Rosat et al. 2018, soumis

SEISMIC NOISE LEVELS AT J9: SG VS. OTHER INSTRUMENTS

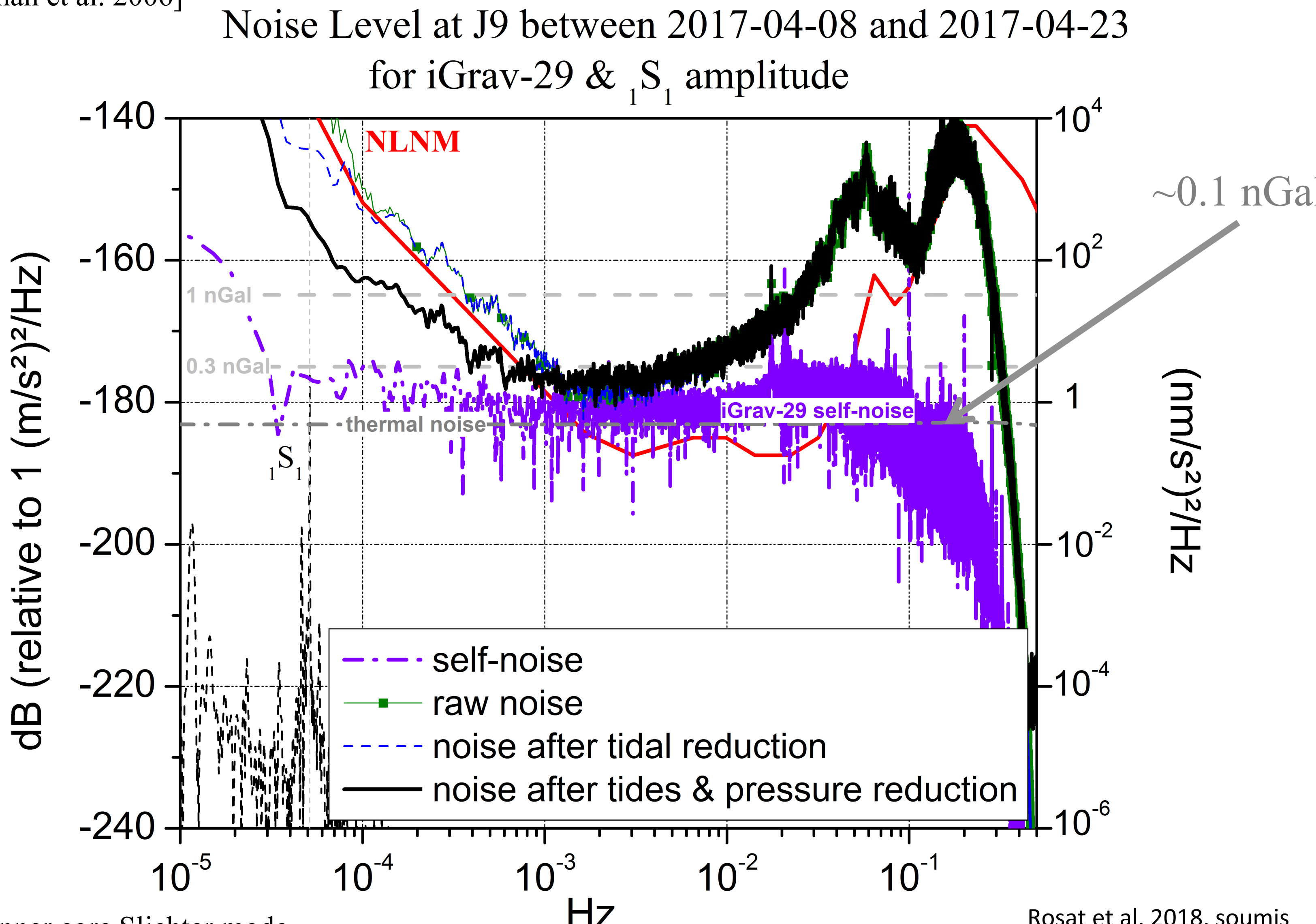


gPhone-54, CG5, L&R ET-11: relative spring gravimeters

Rosat et al. 2018, soumis

SELF-NOISE EXTRACTED FROM A 3-CHANNEL CORRELATION ANALYSIS

[Sleeman et al. 2006]

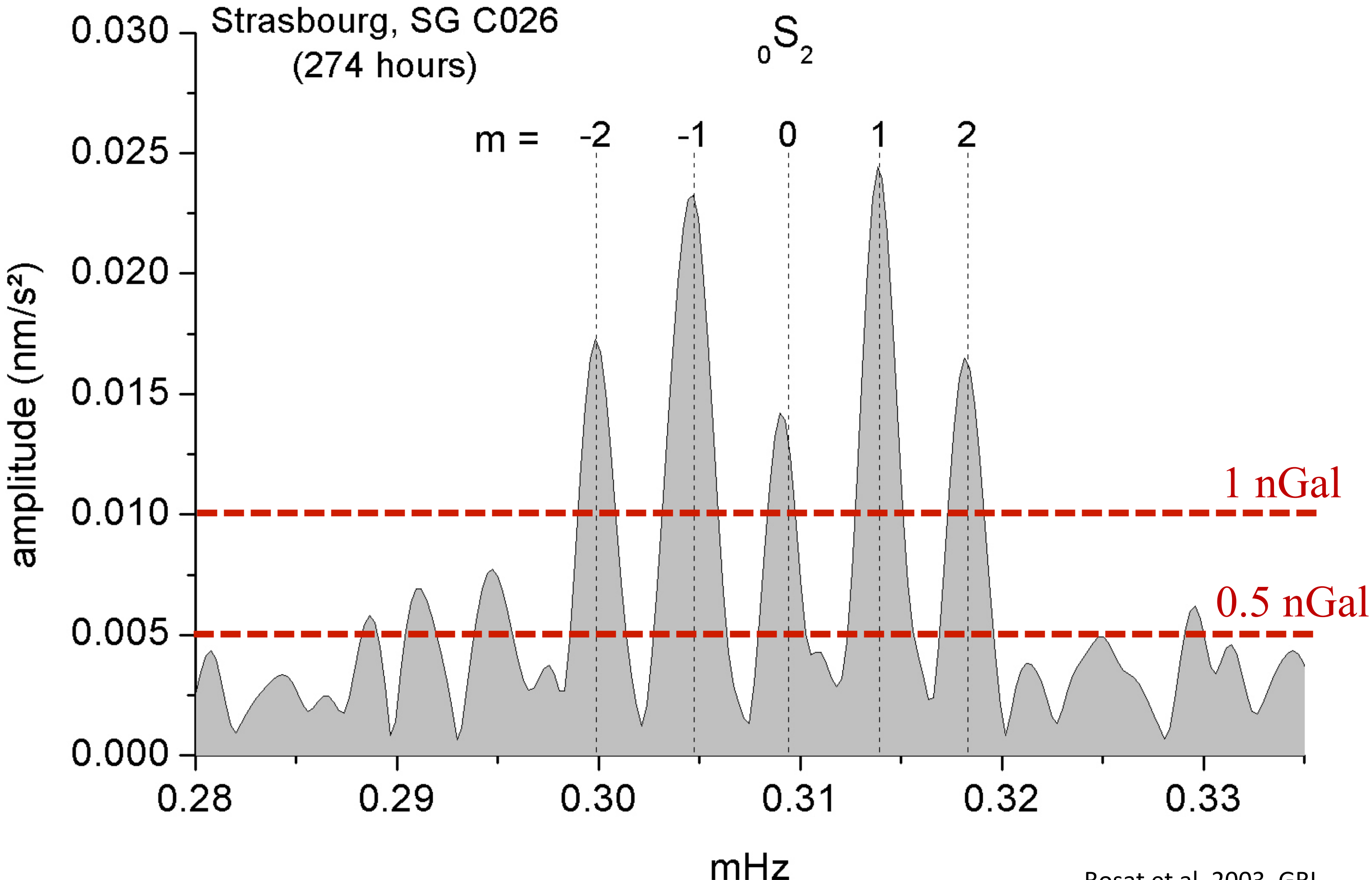


$_1S_1$: inner core Slichter mode

Rosat et al. 2018, soumis

SUPERCONDUCTING GRAVIMETER: SEISMIC MODES

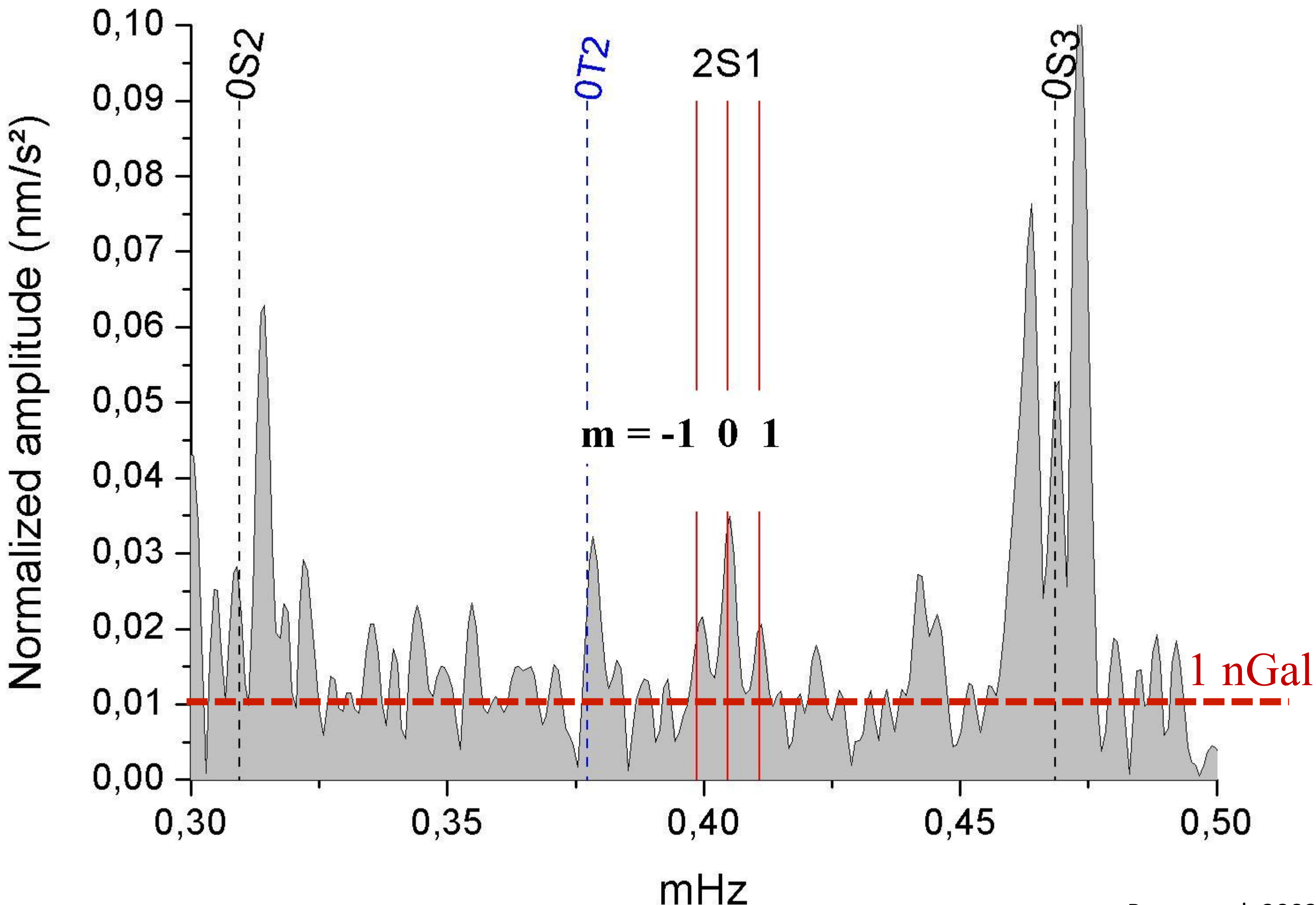
Ex: High-resolution frequency analysis after the 2001 M_w 8.4 Peru earthquake



Rosat et al. 2003, GRL

SUPERCONDUCTING GRAVIMETER: SEISMIC MODES

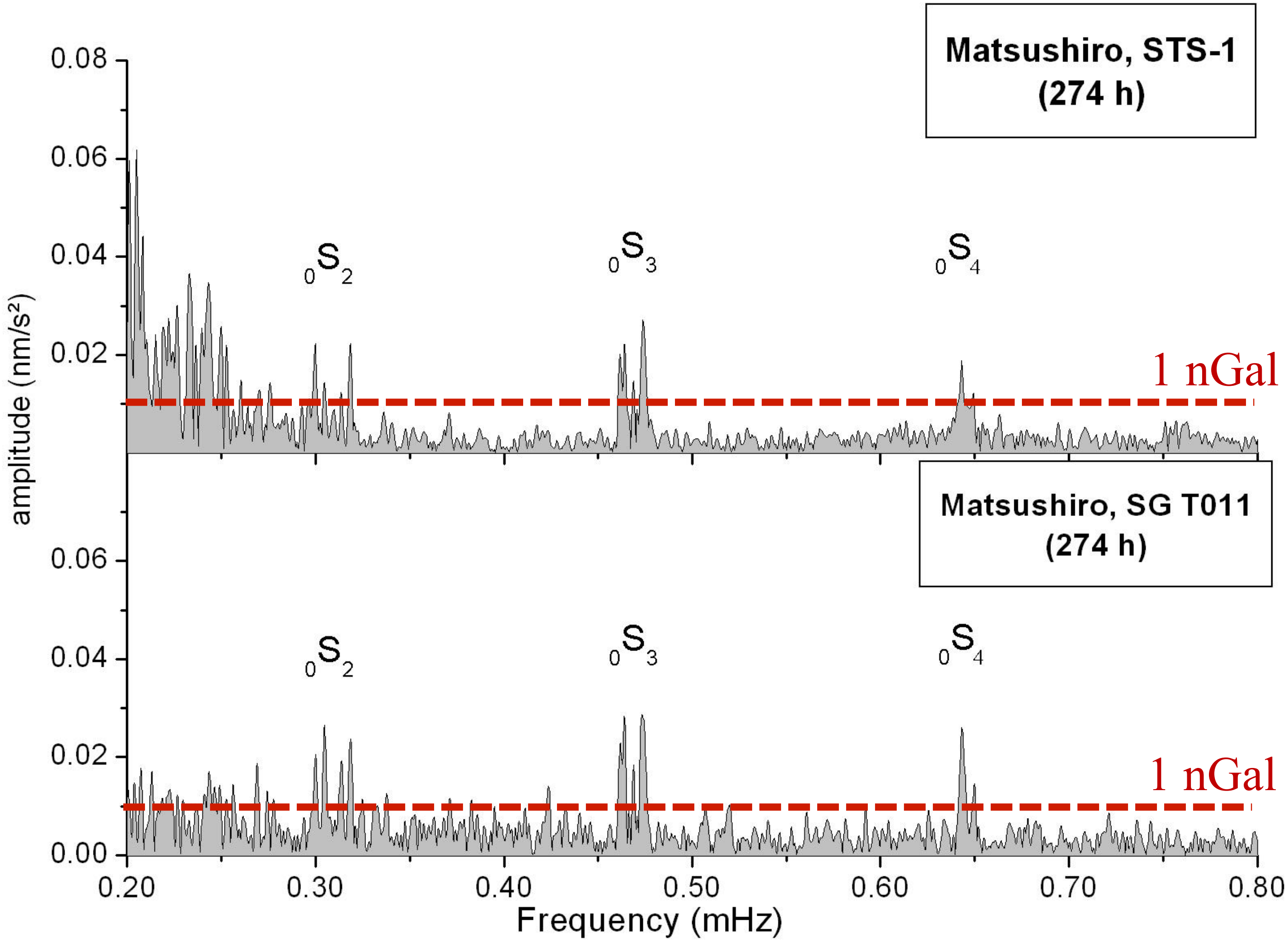
Ex: 1st detection of $_2S_1$ mode after the 2001 M_w 8.4 Peru earthquake



Rosat et al. 2003, GRL

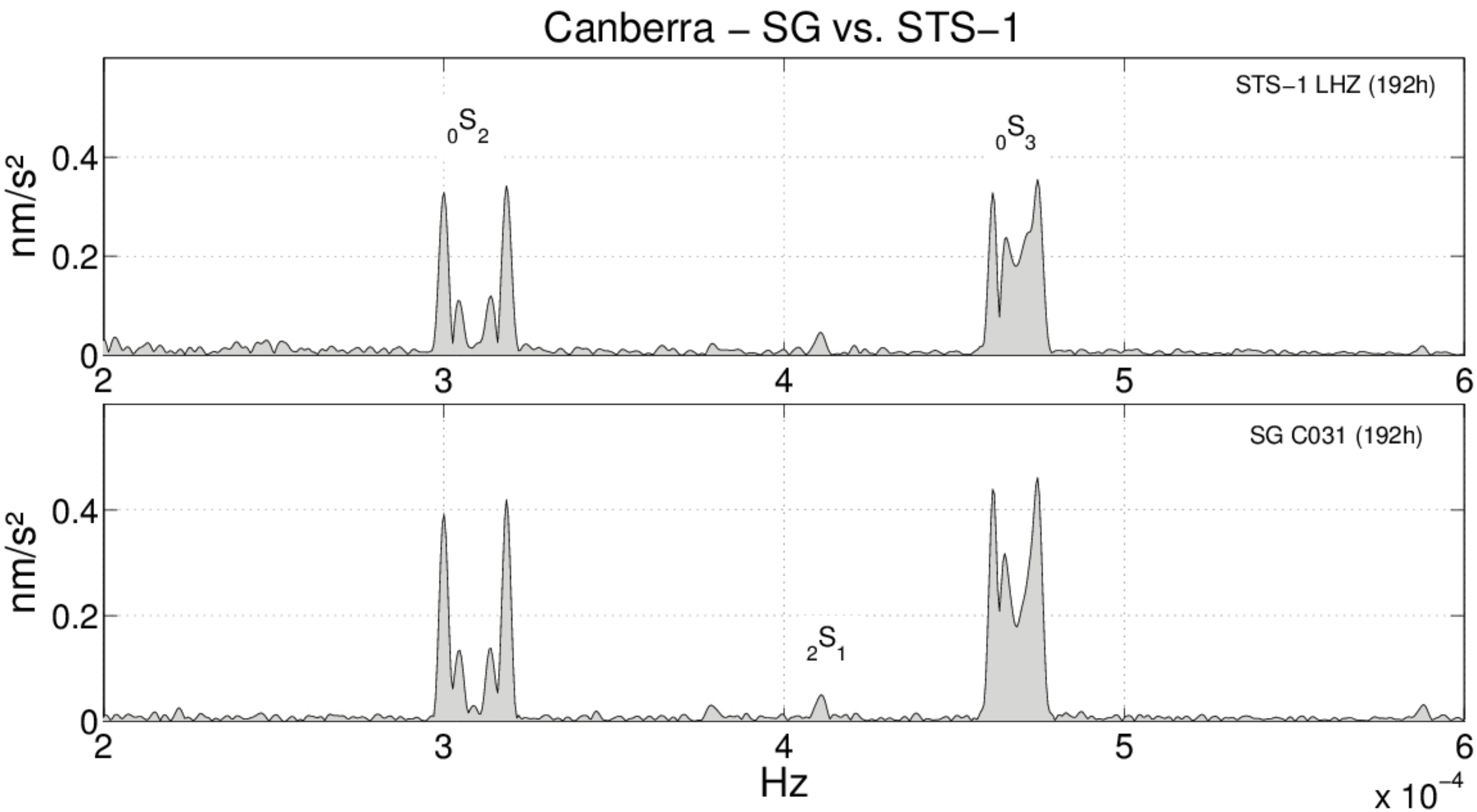
SUPERCONDUCTING GRAVIMETER: SEISMIC MODES

Ex: STS-1 vs. SG after the 2001 M_w 8.4 Peru earthquake



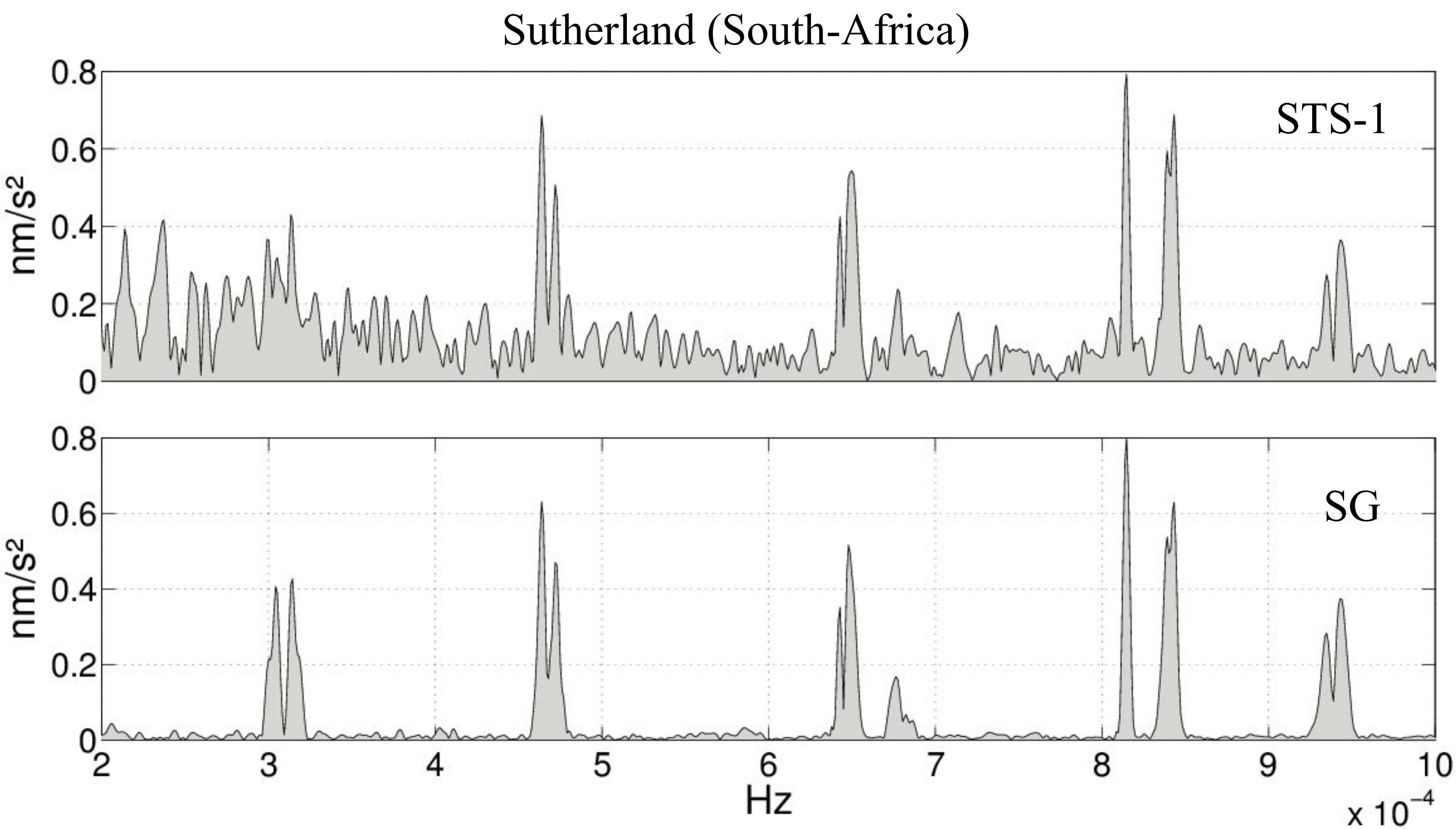
SUPERCONDUCTING GRAVIMETER: SEISMIC MODES

Ex: STS-1 vs. SG after the 2004 M_w 9.1 Sumatra-Andaman earthquake



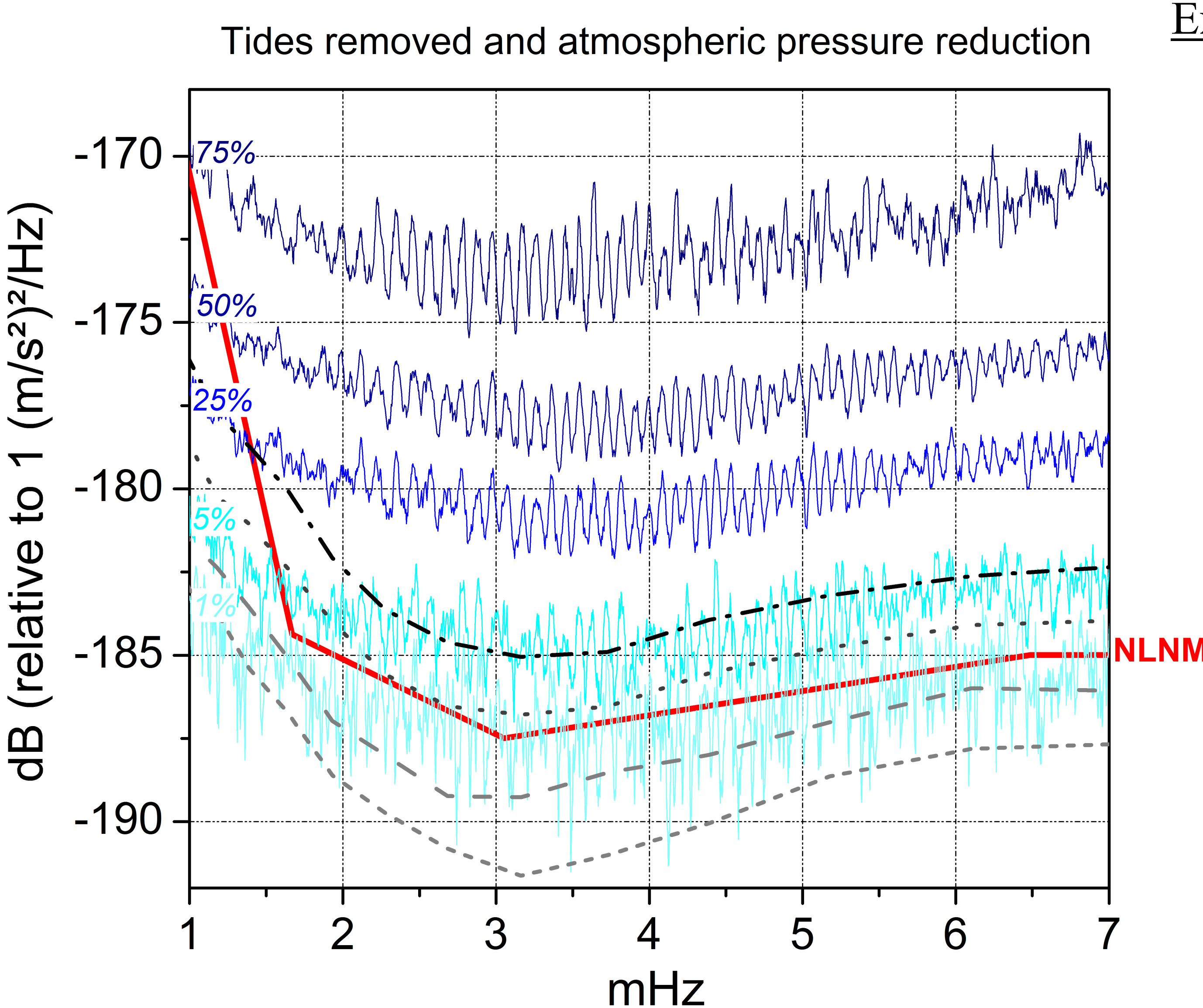
SUPERCONDUCTING GRAVIMETER: SEISMIC MODES

Ex: STS-1 vs. SG after the 2011 M_w 9.0 Tohoku earthquake



SUPERCONDUCTING GRAVIMETER: HUM

Ex: iOSG-24 at LSBB



CONCLUSION

SGs:

- Perform better than long-period seismometers at frequencies lower than 1 mHz
- Have a linear response to local atmospheric pressure changes → better noise reduction than STS-1
- Resolution close to 0.1 nGal at seismic frequencies

Application to gravity-based earthquake early warning:

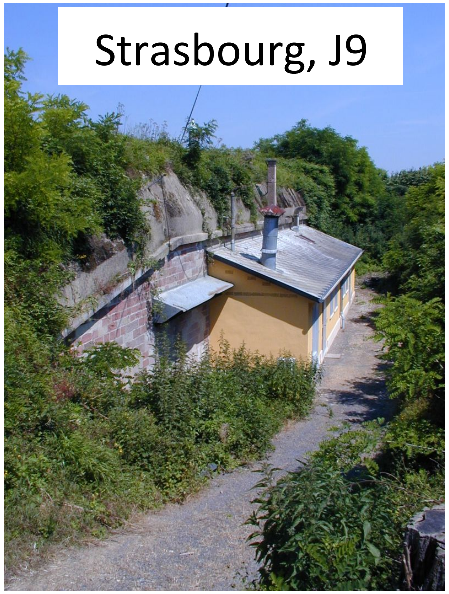
Successful detection after 2011 Tohoku EQ (Montagner et al. 2015) but some difficulties for future early warning system:

- Poor geographical coverage of SGs
- Signal to be detected is small and transient → needs to be separated from other possible disturbances

THANK YOU

Severine.Rosat@unistra.fr

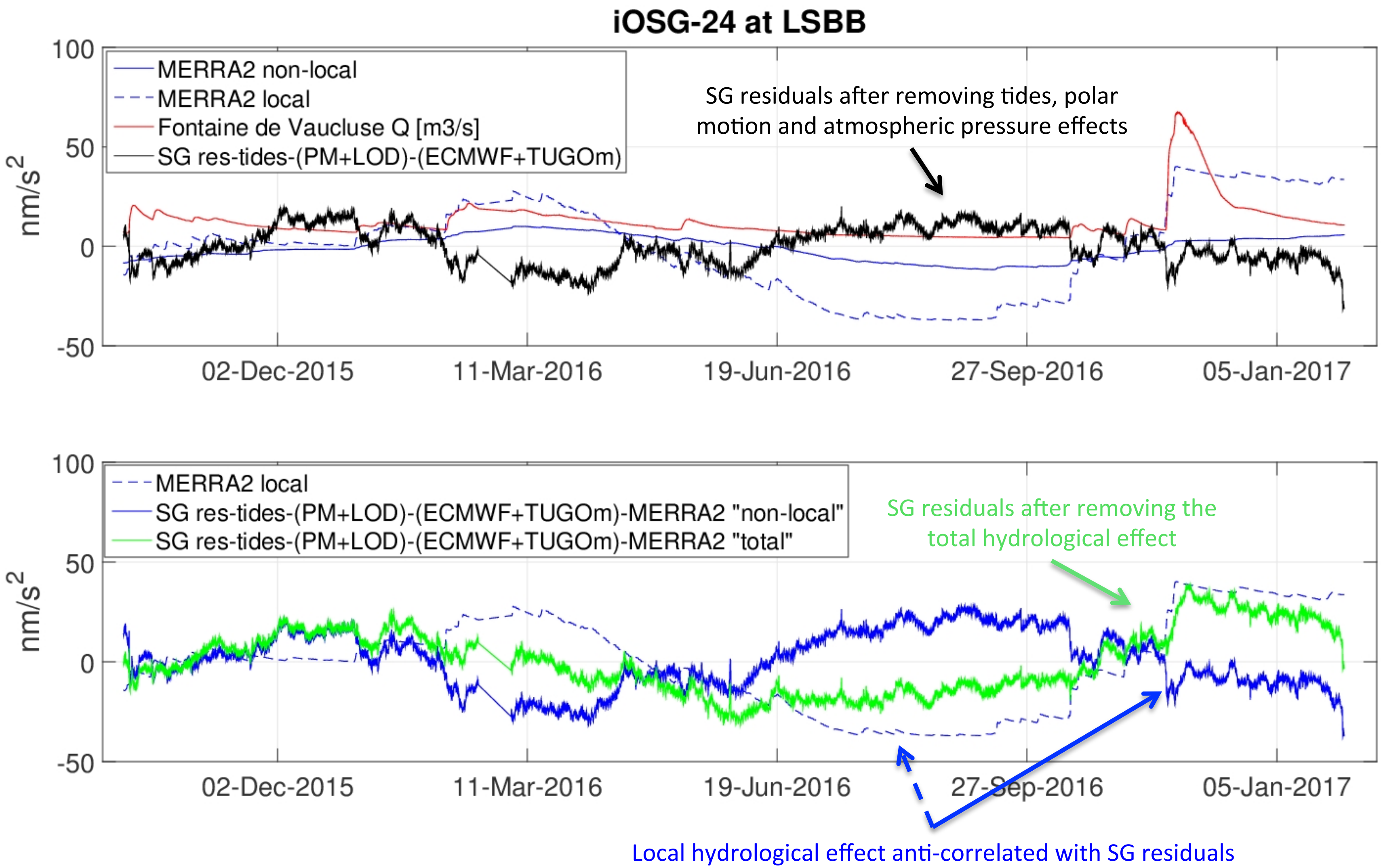
SUPERCONDUCTING GRAVIMETERS



iOSG23 and iGrav30 parallely recording

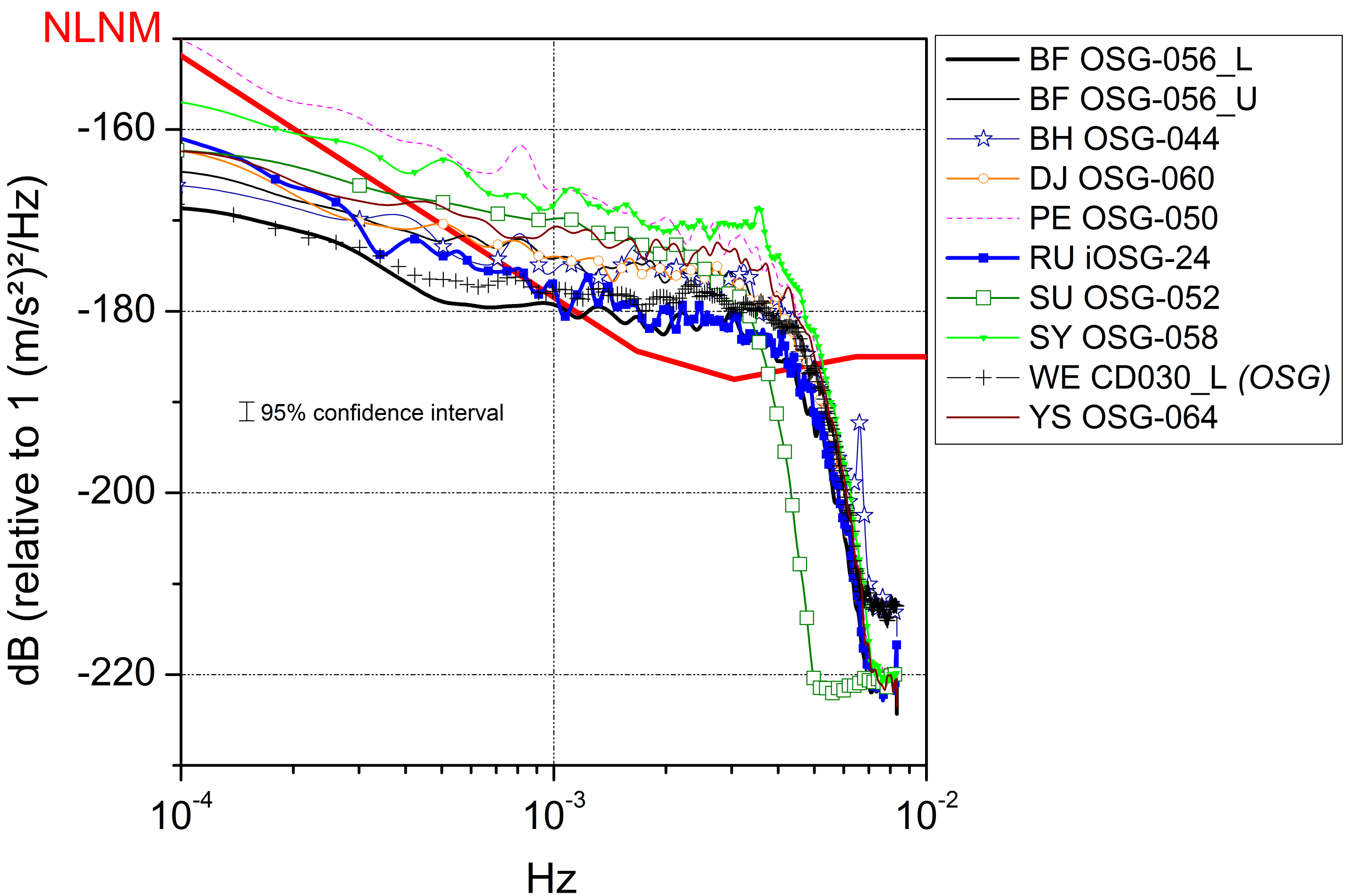
SUPERCONDUCTING GRAVIMETER

Hydrological effect on iOSG-24 using MERRA2 hydrological model



SUPERCONDUCTING GRAVIMETER: SEISMIC NOISE LEVEL

Statistical Noise levels of some worldwide SGs



New **L**ow **N**oise **M**odel of Peterson (1993) = seismological noise model

Rosat et al. 2016