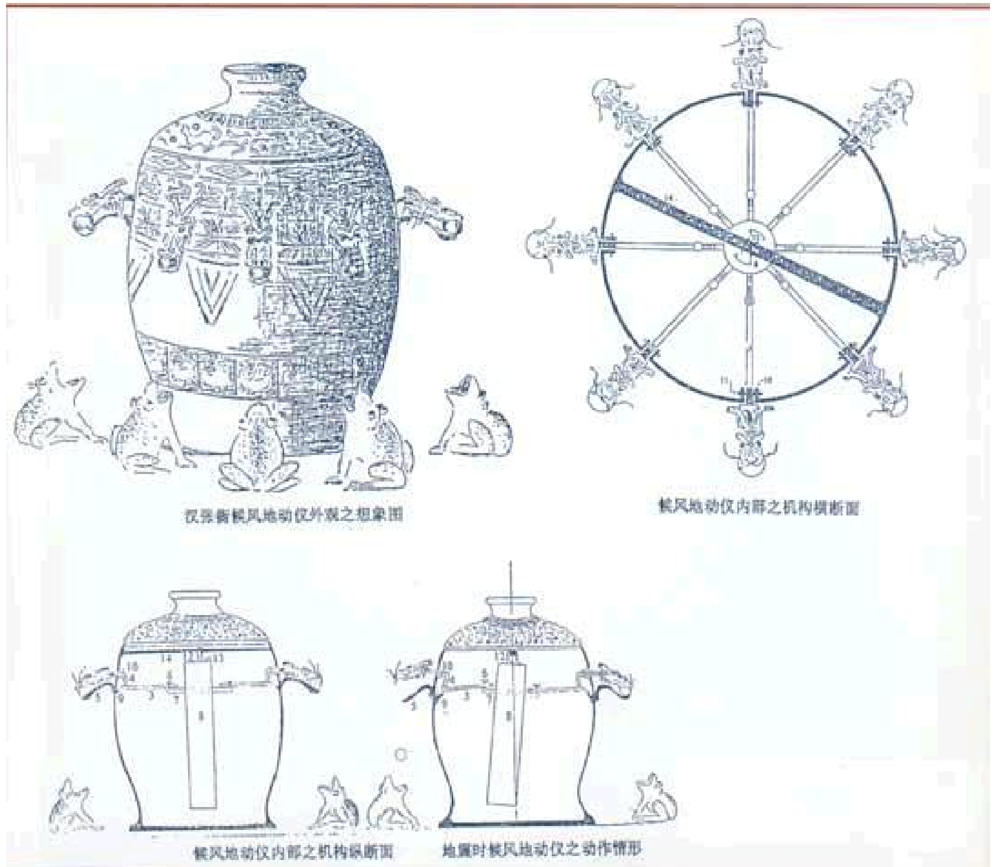
About Seismometers

Pascal Bernard, IPGP

Didong Yi
Earthquake detector with pearls, dragons and frogs
First known Seismograph

Zhang Heng, 132 AD
Dynastie Han, Chine



张衡地震仪想象图
王振铎
据《燕京学报》1938年20期22卷

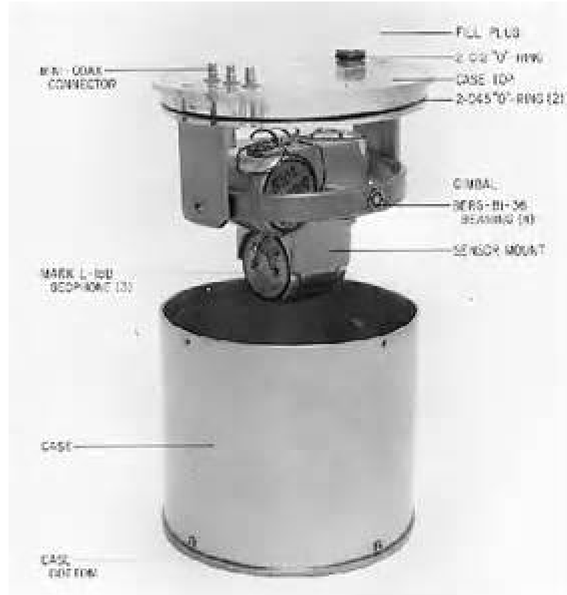
The imaginal ancient seismoscope by Zhang Heng.
By Wang Zhendu.
From"*Journal of Yanjing*" Vol.22,No.20,1938.

Principle of Seismograph = deformable system

- Shaking of ground (elastic waves)

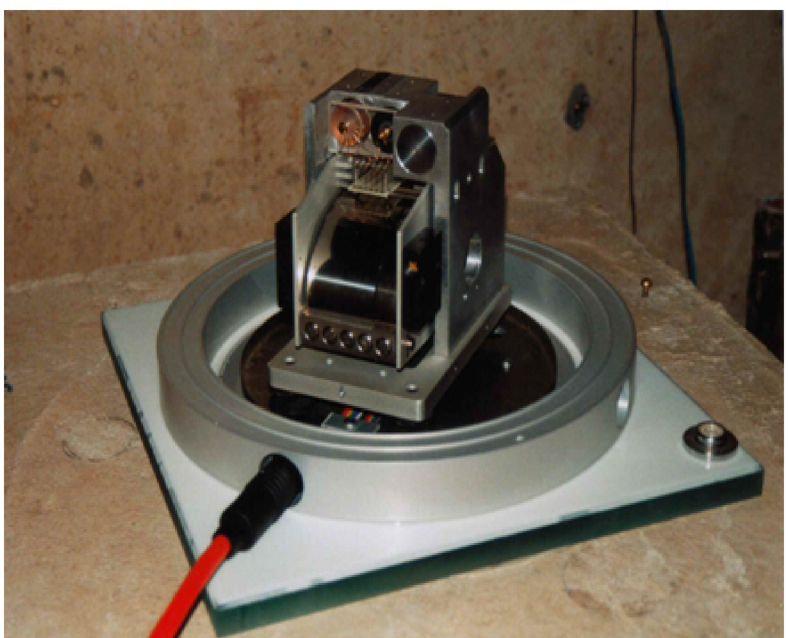
- Gravity or EM change (gravitational/EM waves)


Compact
Trillium
Nanometrics
N

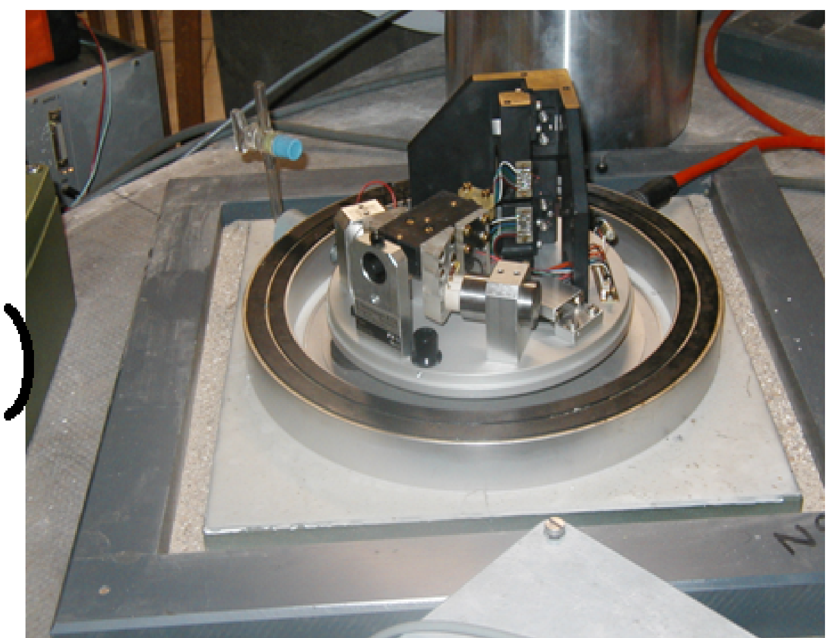


GEOPHONE 4.5 Hz

VBB 360 s - STS1

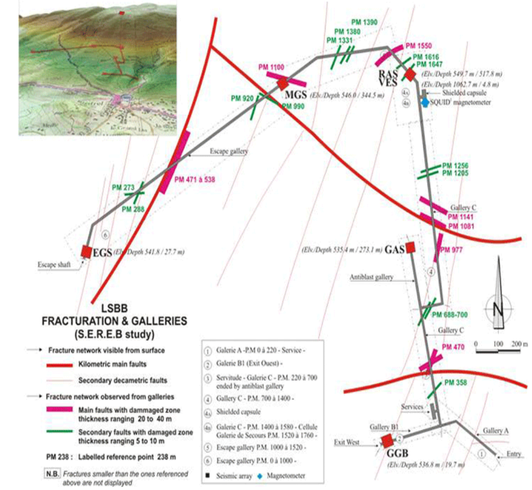


a)



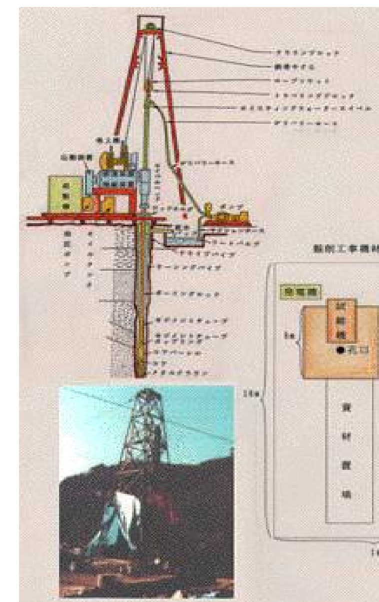
Installations:
Temperature
atmospheric pressure
… rain, hydrology...

Deep
galleries
100 - 500 m



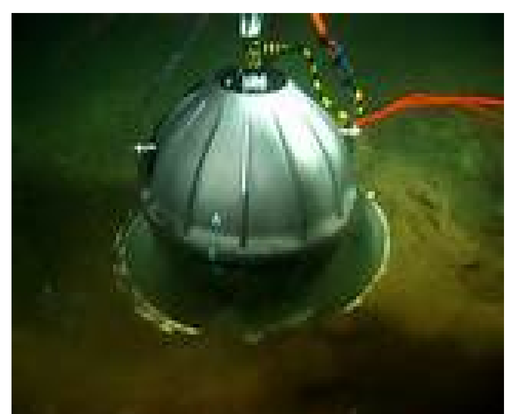
Standard Vault
3-50 m

0.5 – 1 m
Temporary
installations

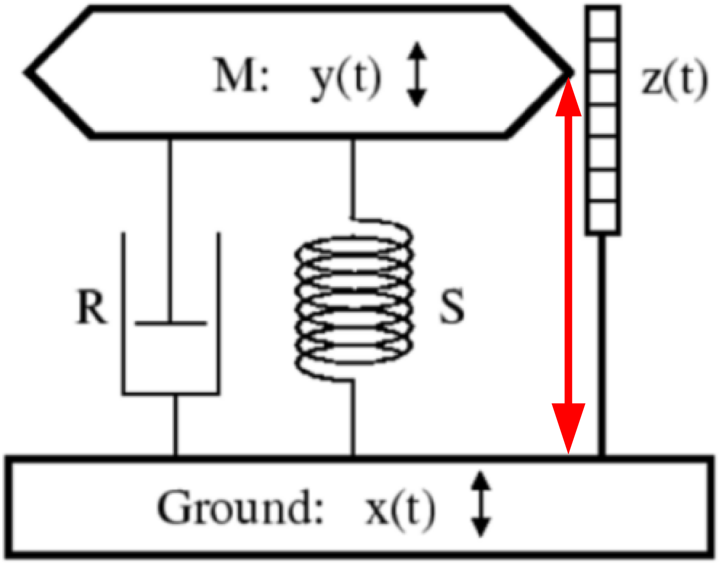


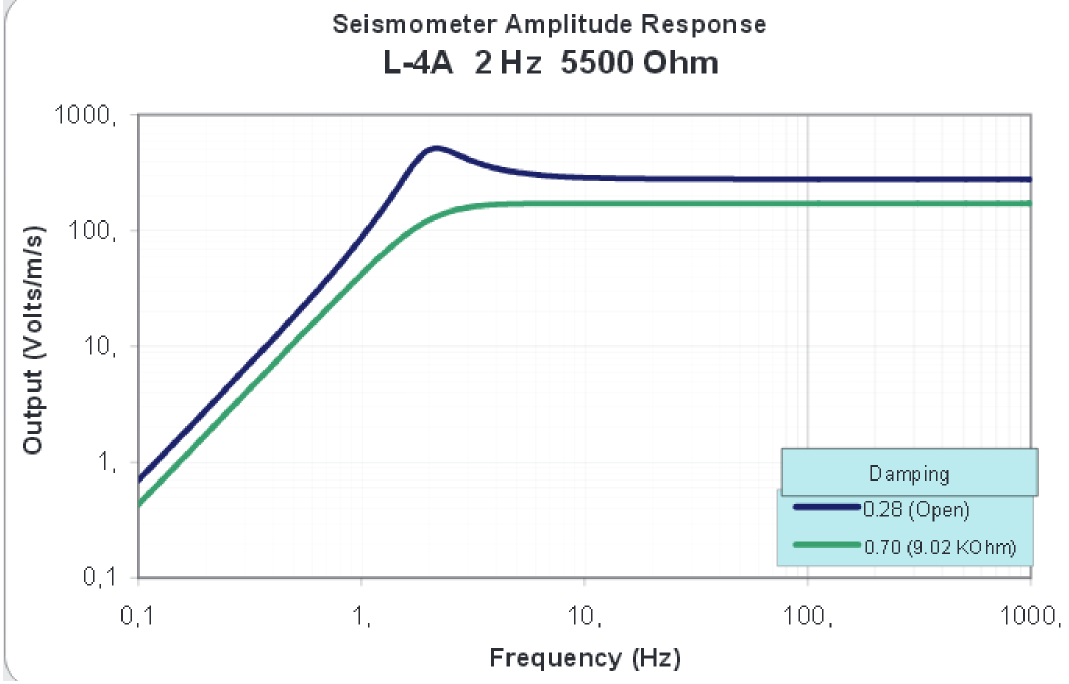
Boreholes:
Hundred meters
To
Kilometers deep

Offshore:
OBS
Ocean Botom Seismometer



Passive seismograph - Geophone





Geophone 1 Hz – velocity to Volts

- Damped mechanical oscillator (1D)

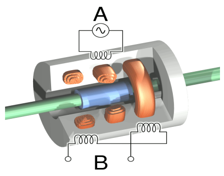
- differential motion of the mobile mass

- **detection of the relative motion**
 :

  - **Position:** graph
   Capacitive , inductive (LVDT), optical (FP, Michelson)

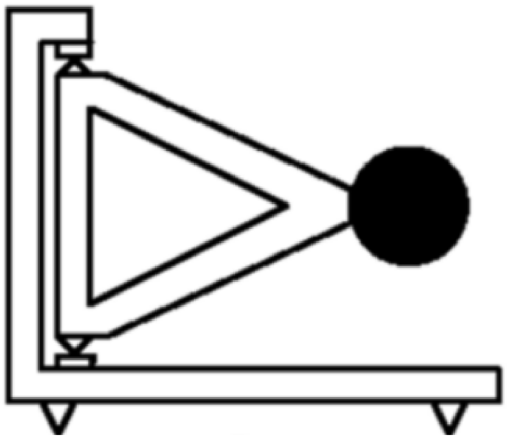
  - **Velocity :** (electromagnetic induction : coil and magnet)

LVDT

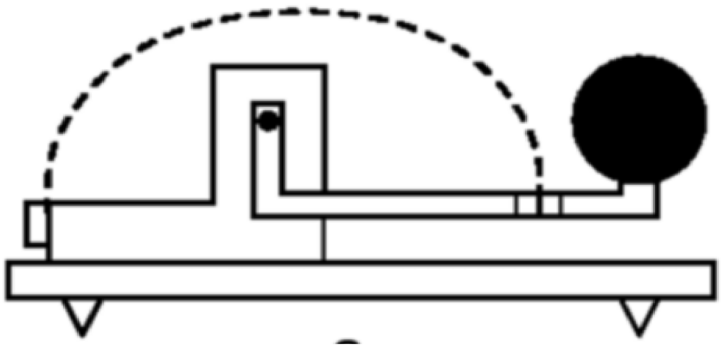


Eigen-frequency fo:

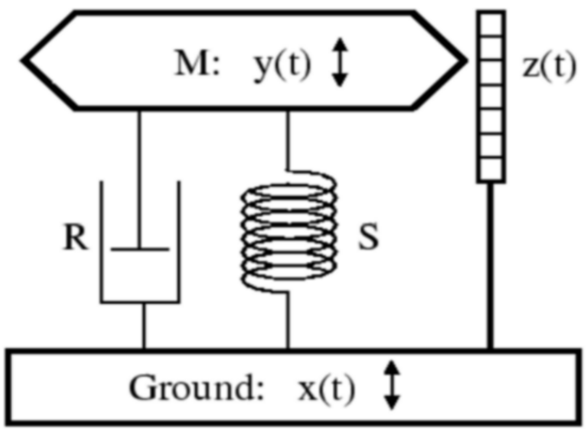
- HF (f<<fo): relative displacement = - displacement of the ground f^0
- LF(f>>fo): relative displacement ~ acceleration of the ground : f^2



horizontal



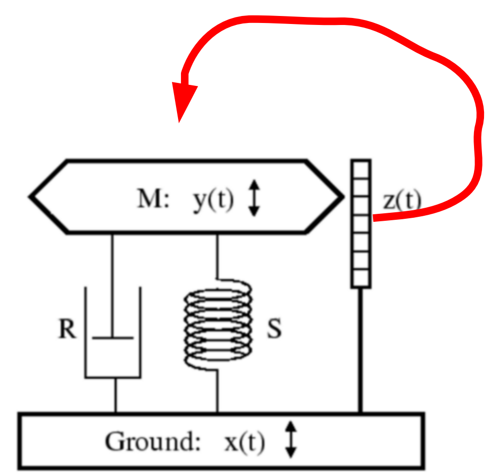
vertical



Problems with geophones:
- non linearity of the spring
- hysteresis of the spring
- small eigen periods

Force-balanced seismometers

Feedback loop



Detection of relative displacement

Feedback loop on the mass for keeping it ifxed with respect to the ground (zero relative displacement)

Inductive Force F ~ current I

F ~ mobile mass acceleration = ground acceleration

Hence : **current I ~ ground acceleration**

Measure of potential U ~ measure of ground acceleration

Force Balance Accelerometer, FBA

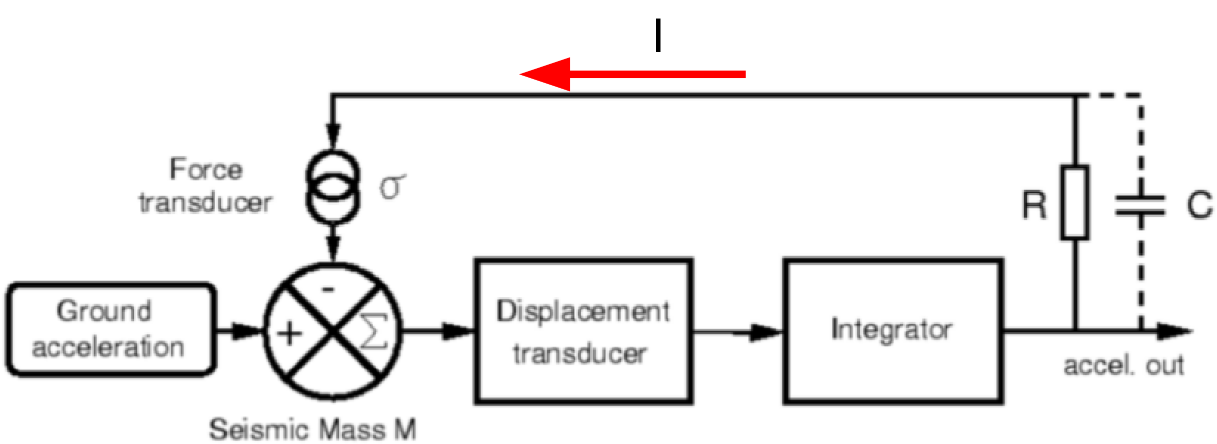
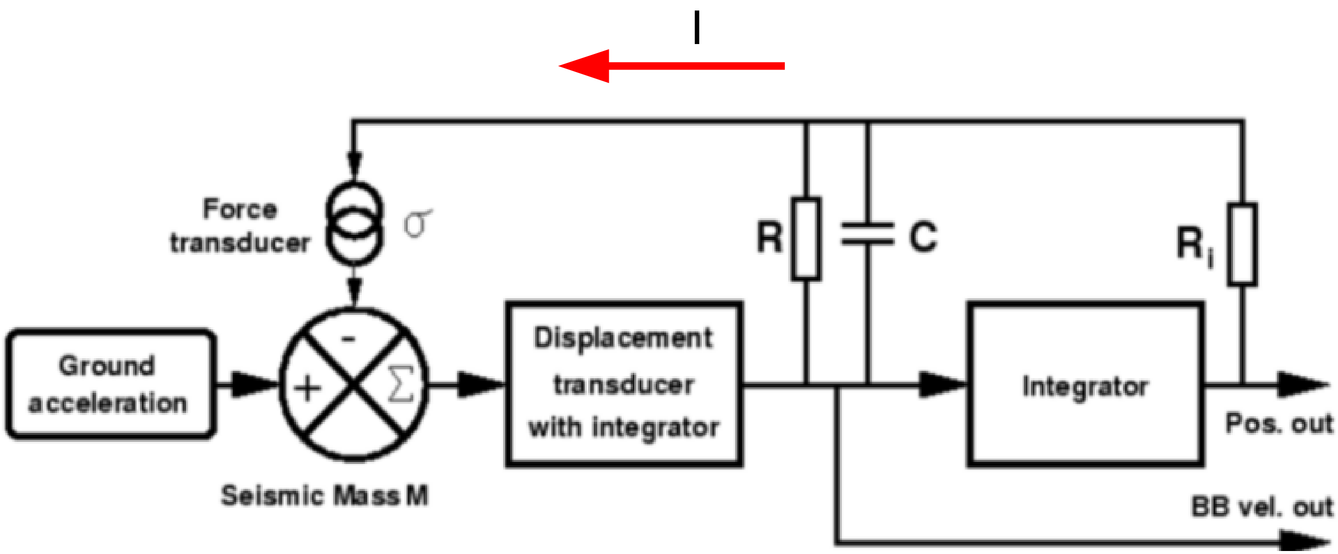


Figure 6: FBA feedback circuit

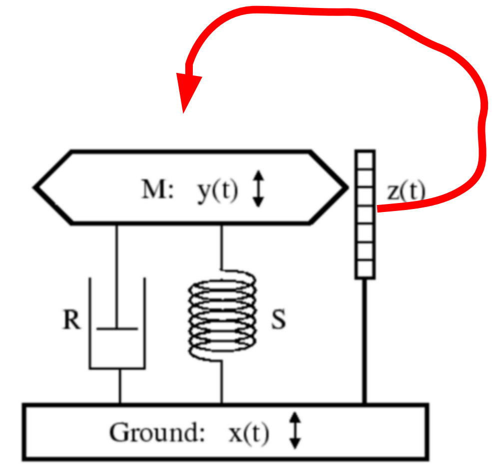
Problem: seismic signal with flat acceleration spectra –
time signal dominated by the highest frequencies

Force-balanced seismometers

Feed back loop:
Resistance, Capacitive, Integrator in parallel

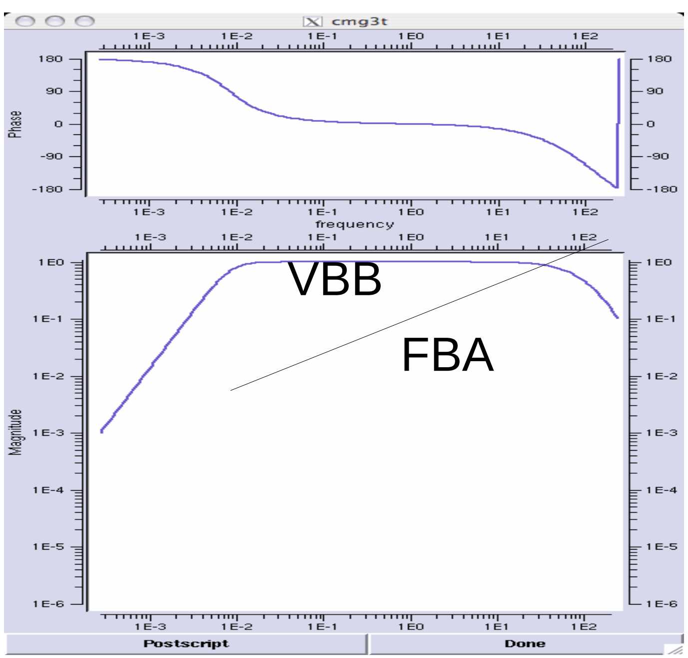


Feedback loop



At high frequencies (dominant signal) :
The current I passes through the capactive circuit
Electric Potential U ~ velocity v (I ~ acc)

Velocity Broad Band Seismometer, VBB



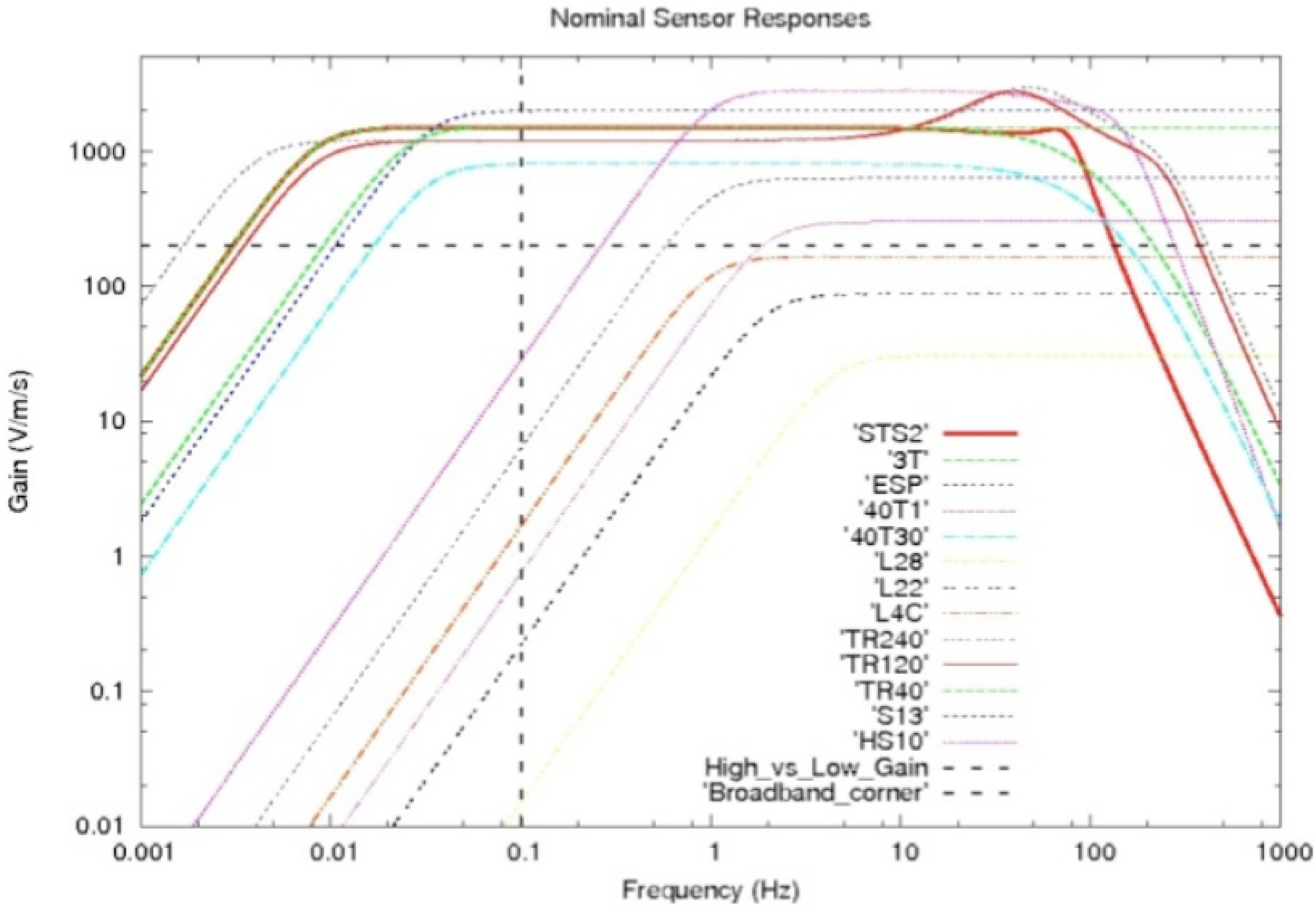
At low frequency:
The current passes in the integrator circuit
U ~ d/dt (acceleration)

Resistance damps the resonance

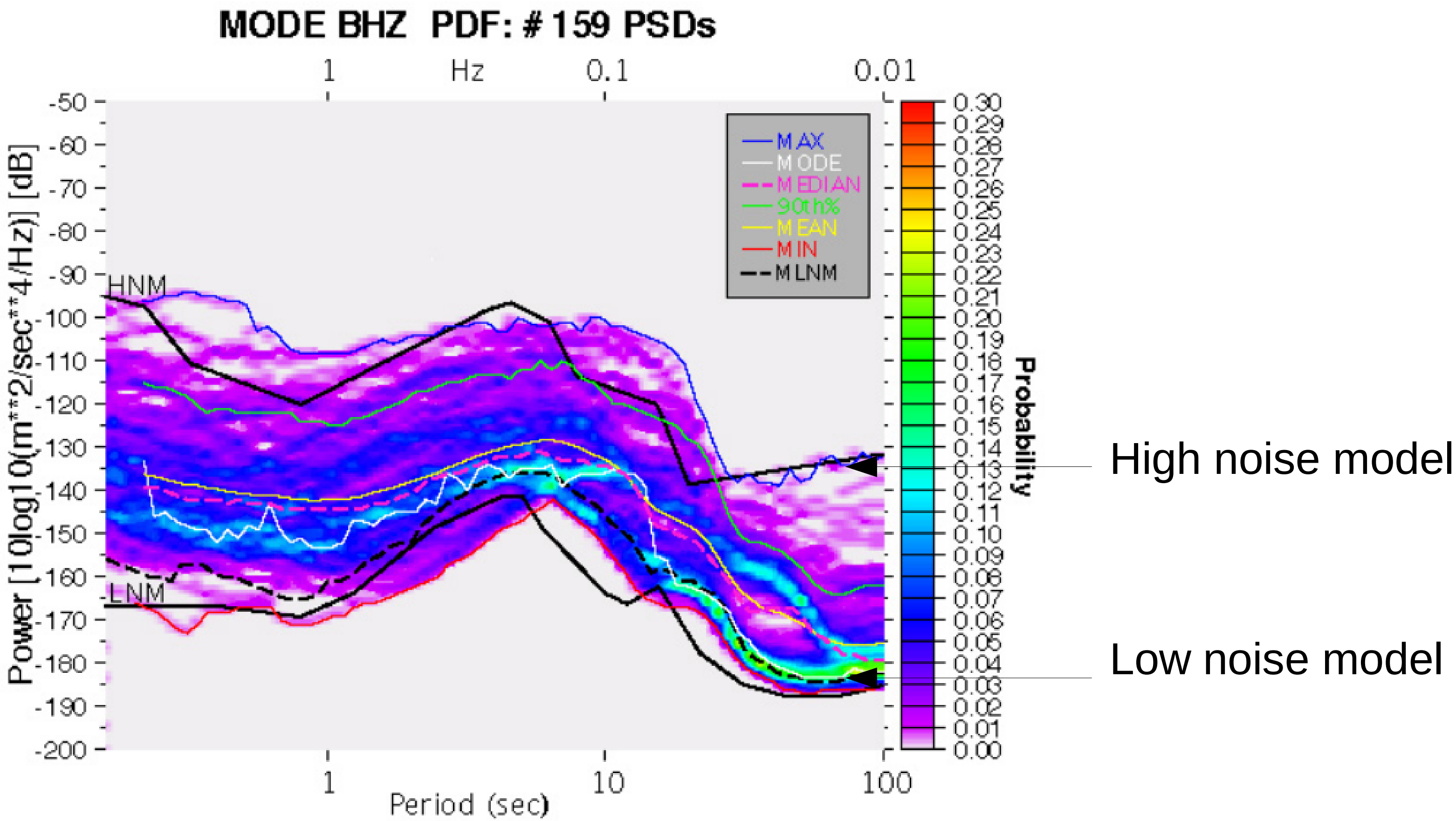
http://www.passcal.nmt.edu/content/instrumentation/sensors/sensor-comparison-chart

Plot of selected Sensor Amplitudes f(FQ)

VBB seismometers and geophones



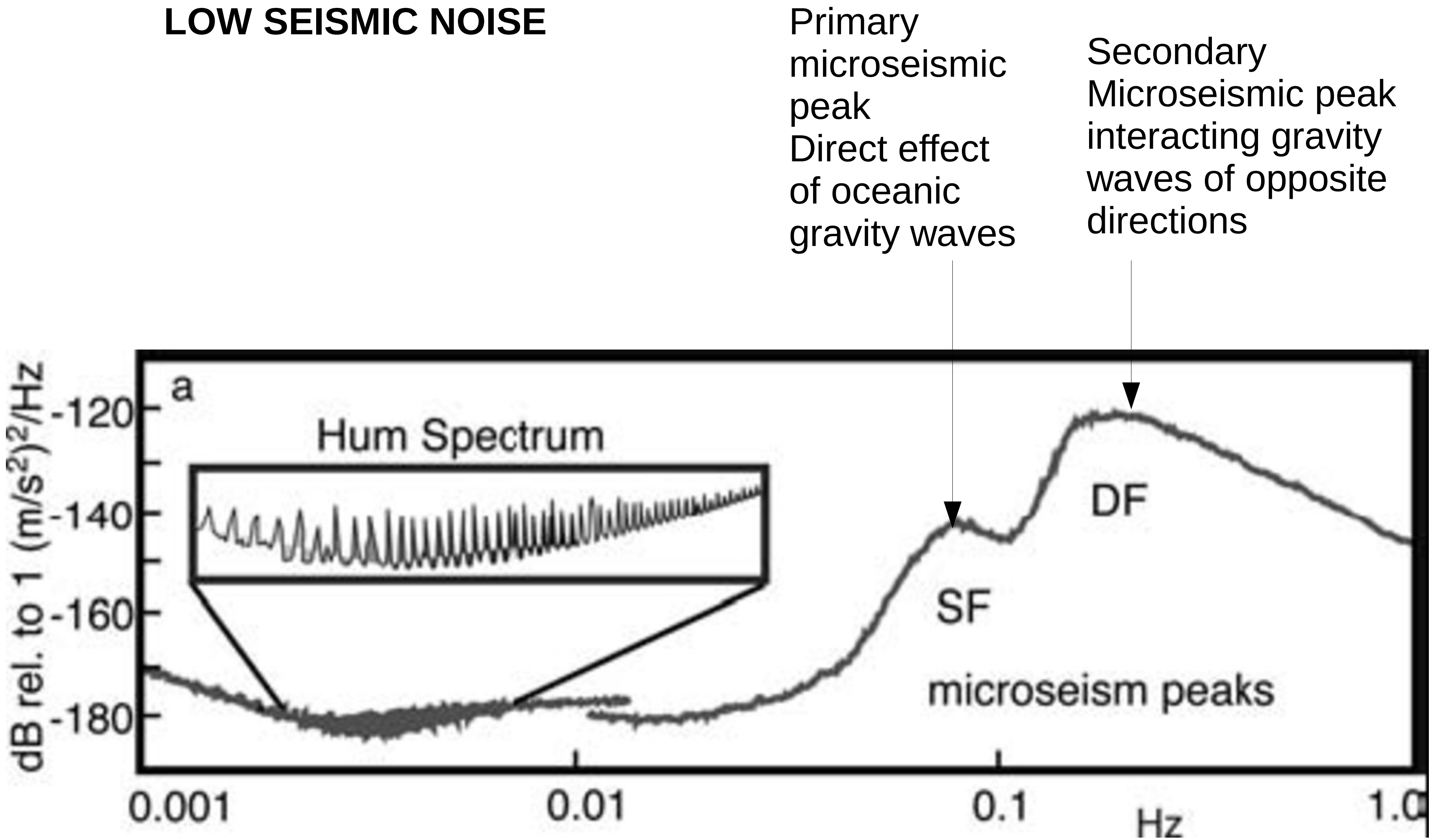
Ambiant Seismic Noise on Earth



(Figure 2: McNamara et al., 2004)

McNamara,D.E.andR.P.Buland,AmbientNoiseLevelsintheContinentalUnitedStates, Bull. Seism. Soc. Am., 94,4,1517-1527, 2004.

LOW SEISMIC NOISE

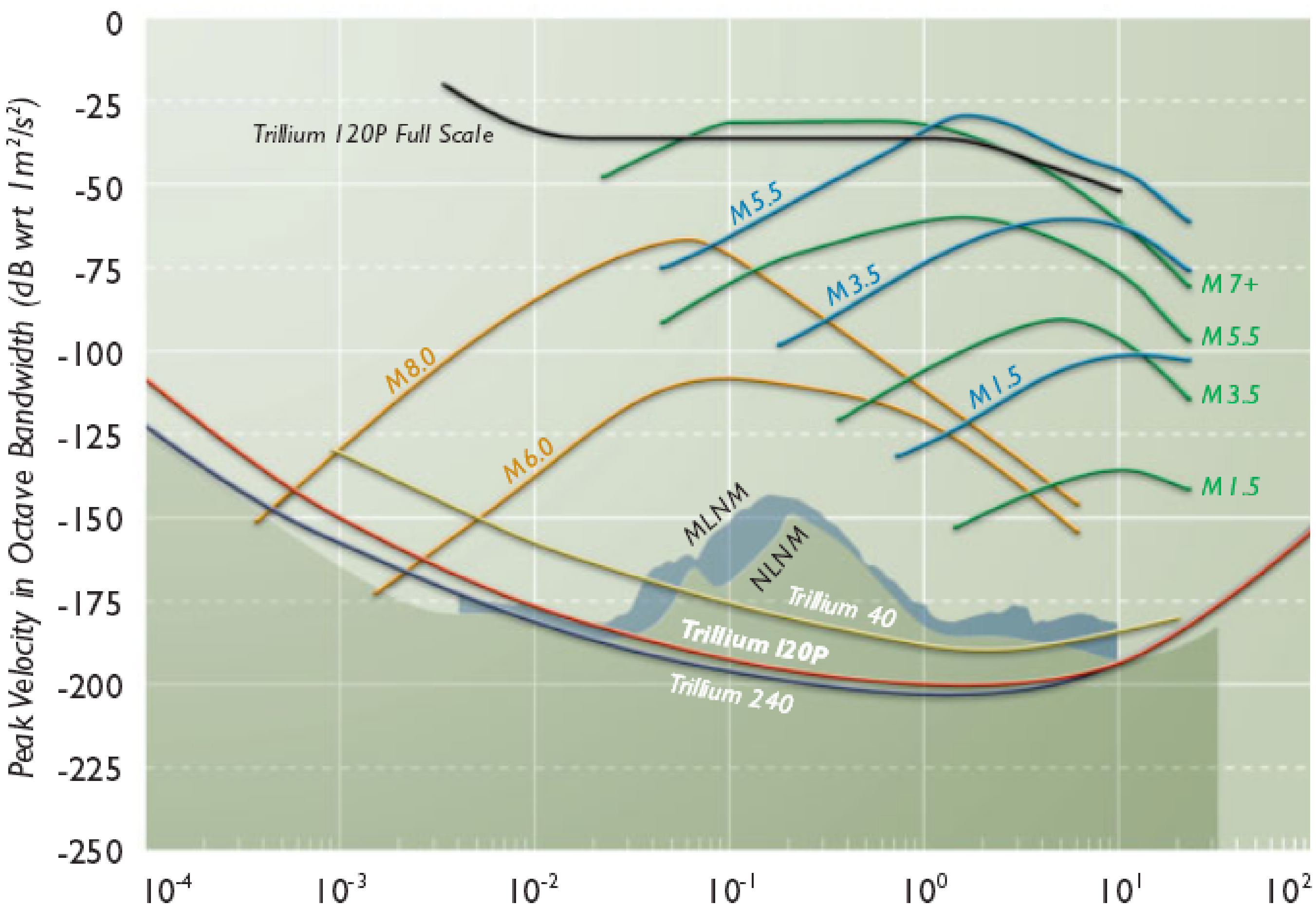


Vertical Acceleration spectrum from a quiet site (BFO) redrawn from figure by R. Widmer-Schnidvig.

Spahr C. Webb Geophys. J. Int. 2008;174:542-566

http://www.upc.edu/cdsarti/OBSEA/mdSensors/Datasheet/Datasheet_Sismometro.pdf

The Earthquake Spectrum



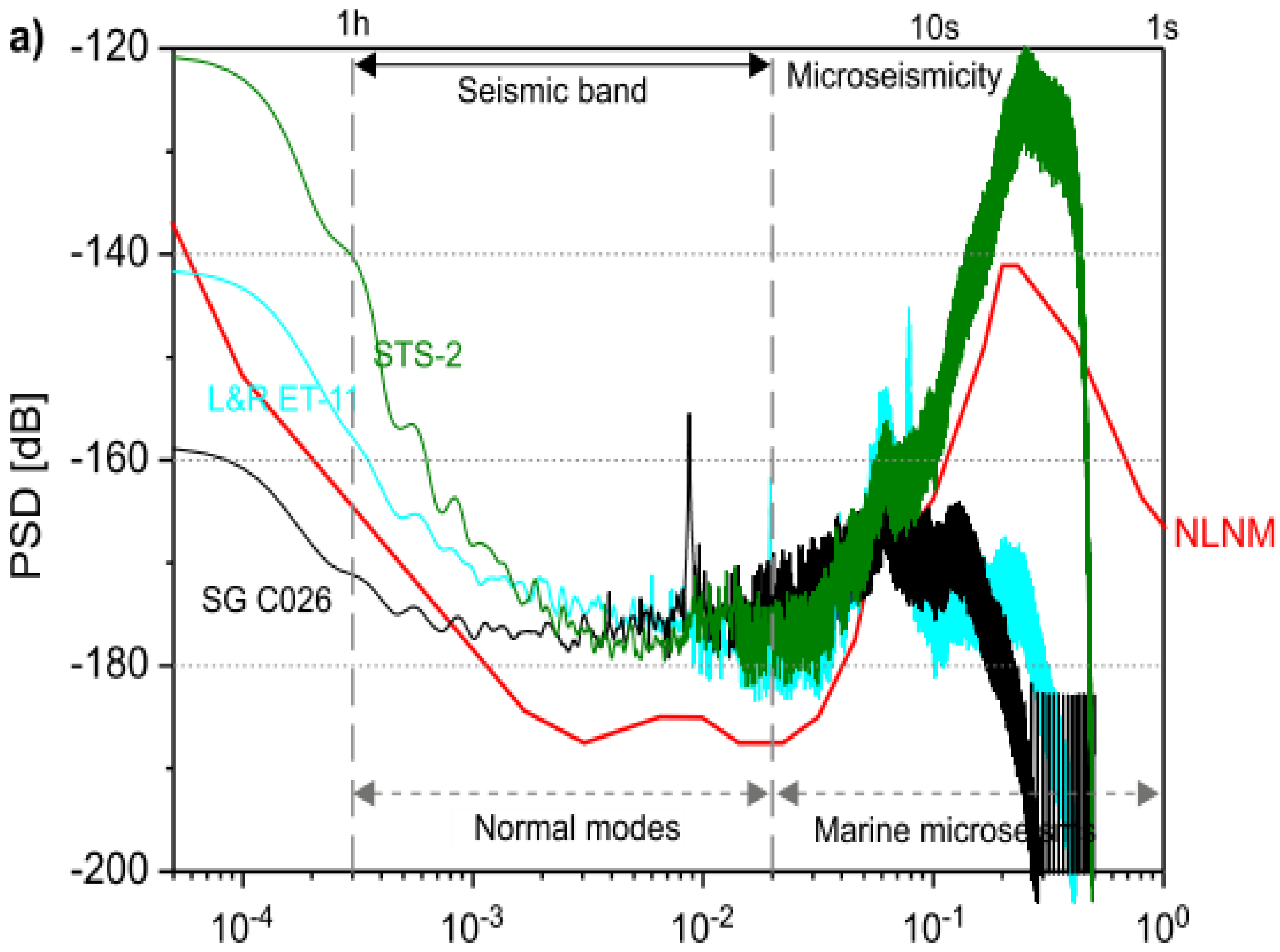
After Clinton & Heaton (Seis.Res.Let.73.3.2002)

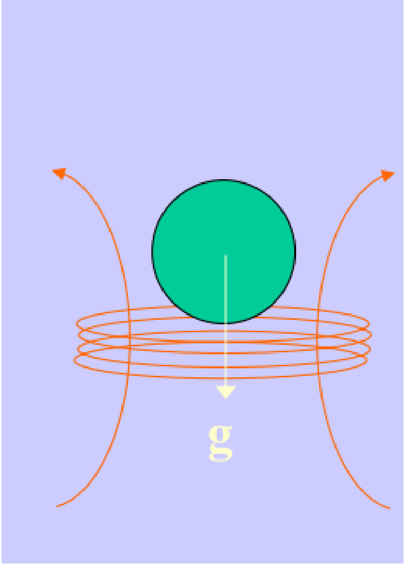
Earthquake Categories

■	Local events	<~10 km	Several seconds to 30 Hz
■	Regional	>~10 km	30 seconds to 10 Hz
■	Teleseismic	>~3000 km	3600 seconds to 2 seconds

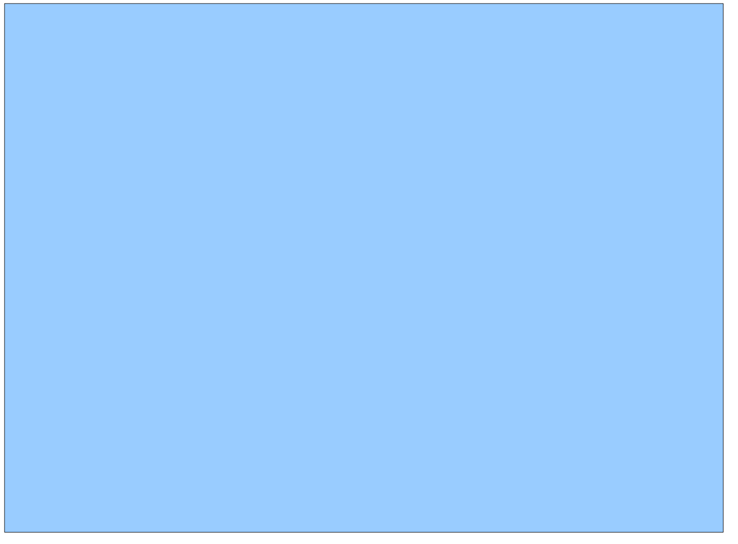
Note: Sensor noise floors and earth noise models have been converted to equivalent peak amplitudes using a full octave bandwidth assuming Gaussian distribution and 95% probability.

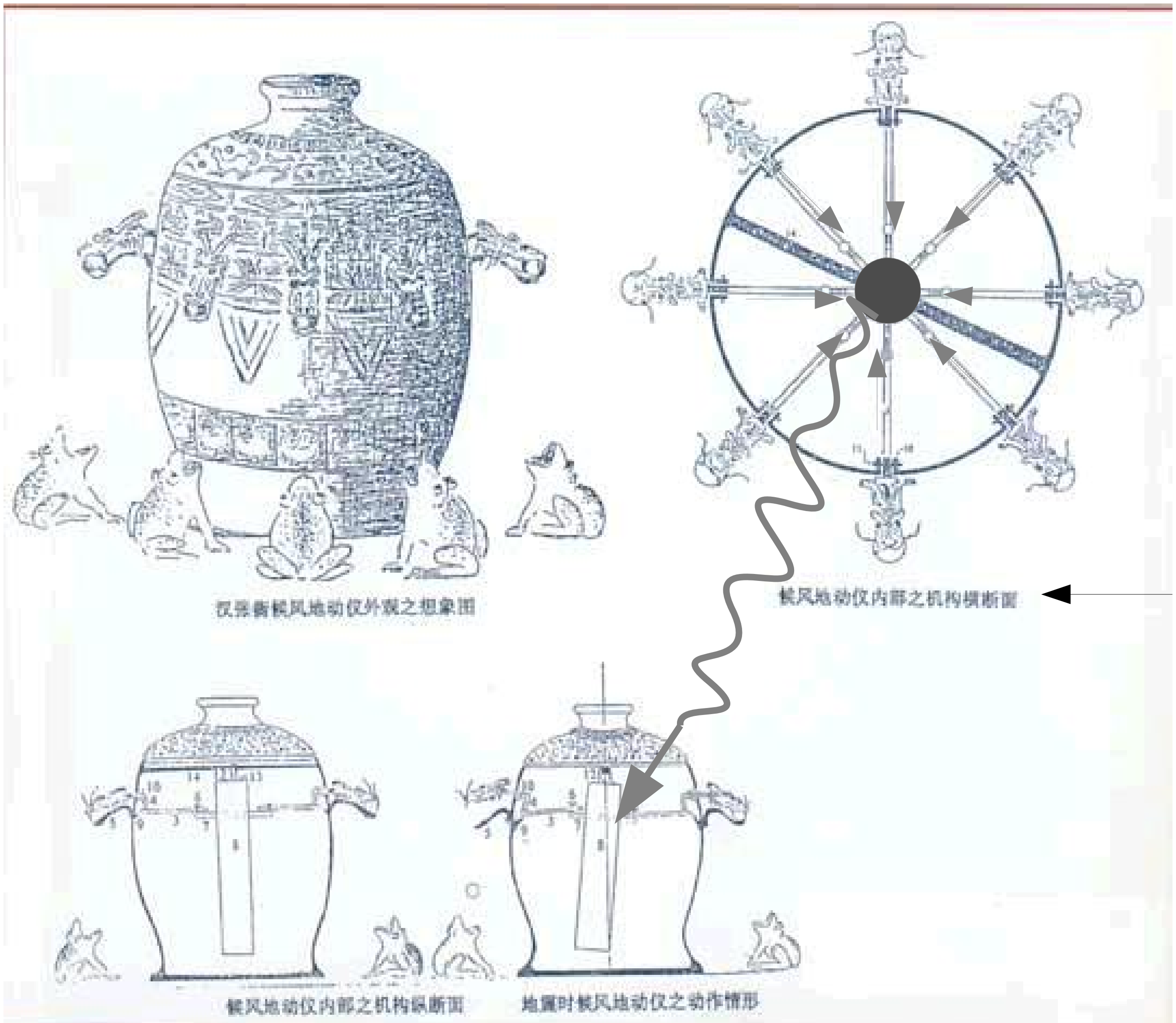
SEISMOMETERS/
SUPERCONDUCTING GRAVIMETERS





Rosat, 2014





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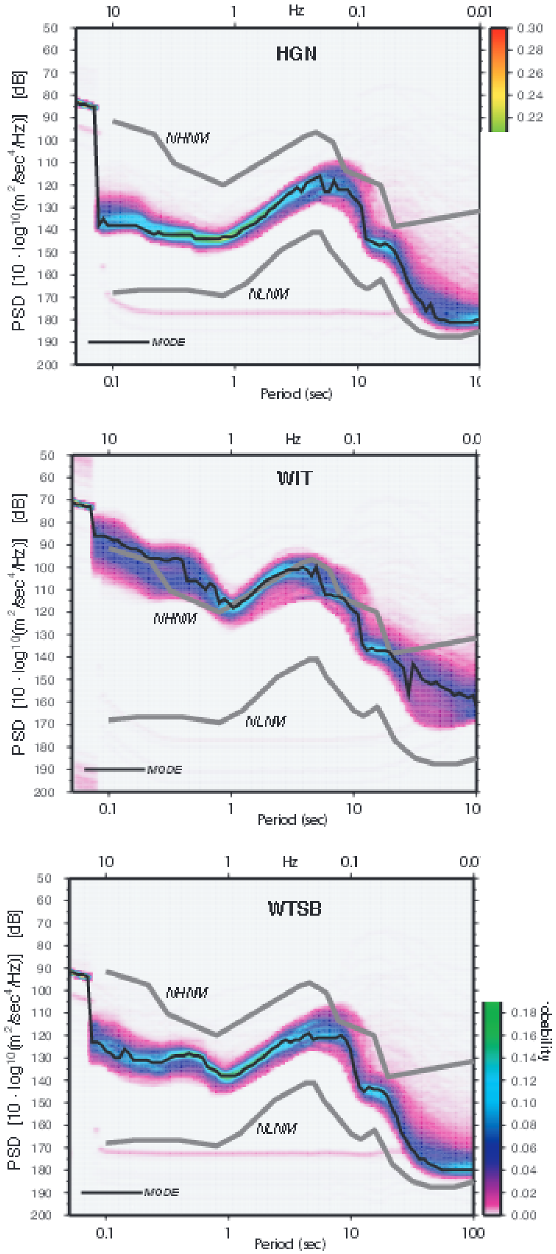
By Wang Zhendu.
From "*Journal of Yanjing*" Vol.22,No.20,1938.

Trou noir
en
formation

„Onde gravitationnelle“



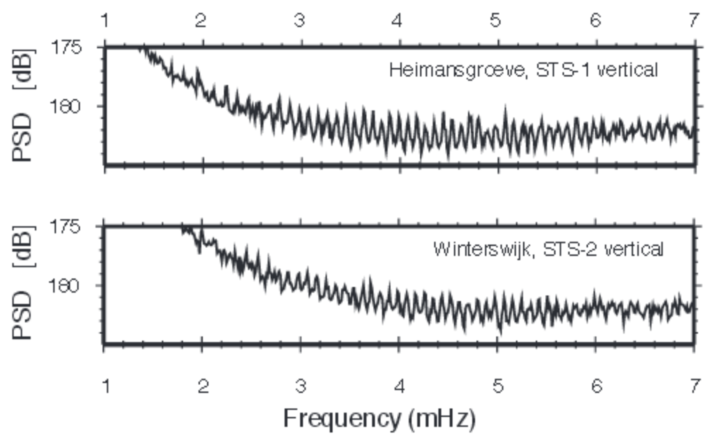


Figure 2. Average power spectral densities of seismic 'noise' at stations HGN and WIT in 2005, after barometric pressure correction. The spectral 'comb' structure is known as the 'hum' and represents the continuous oscillations of the Earth.

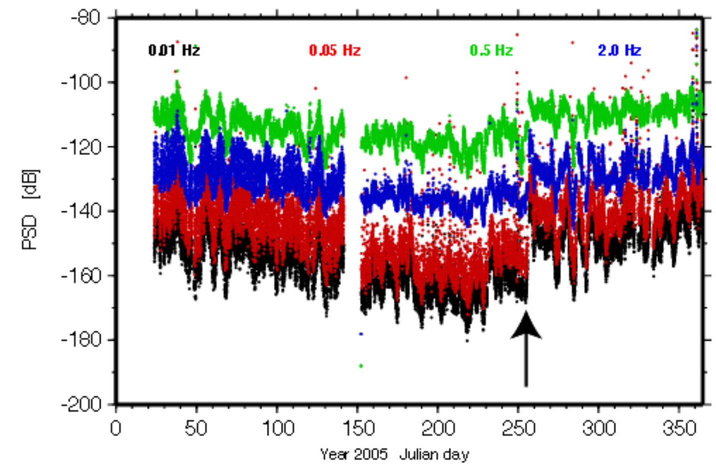
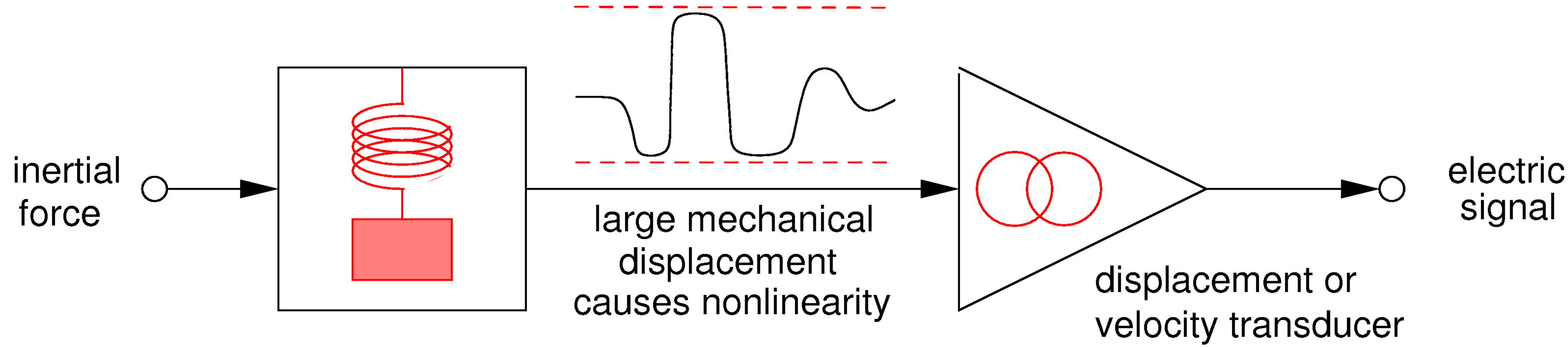


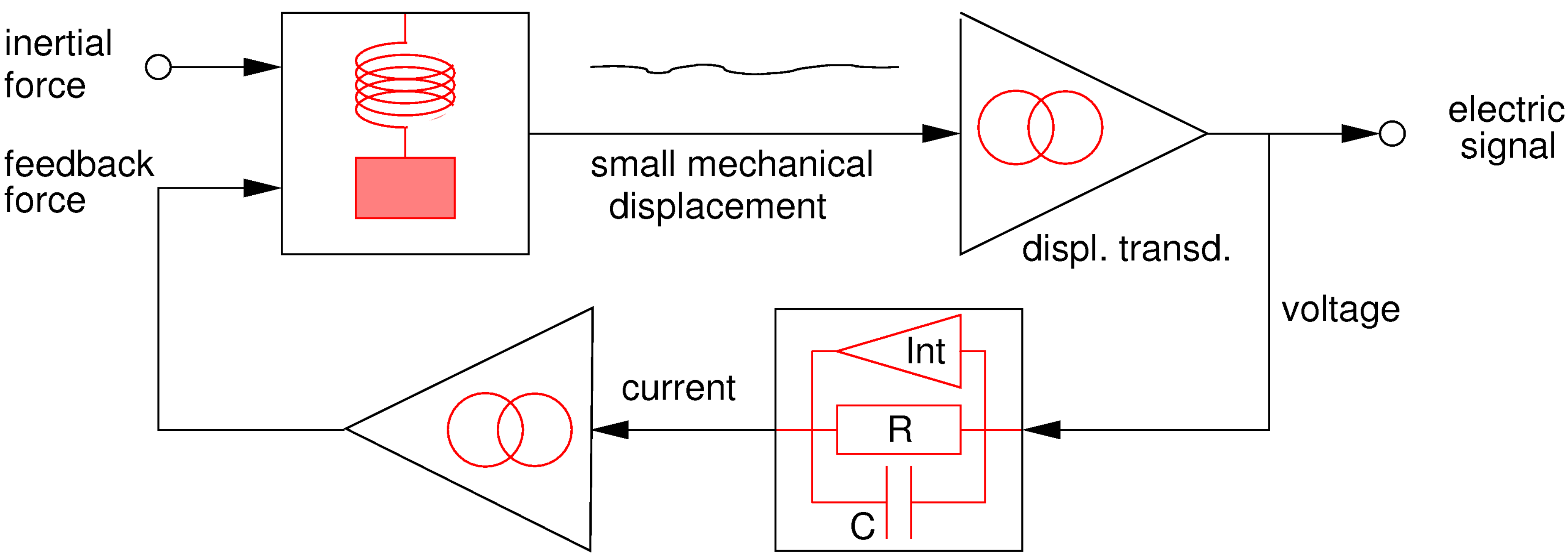
Figure 3. Variation of seismic background noise as function of time at a seismic station. This example illustrates the seasonal variation of the background noise for all frequencies, with lowest noise levels during the northern hemisphere summer. The sudden change in PSD levels around day 250 reflects a change of instrumentation.

http://www.knmi.nl/research/biennial/05-06_Noise.pdf

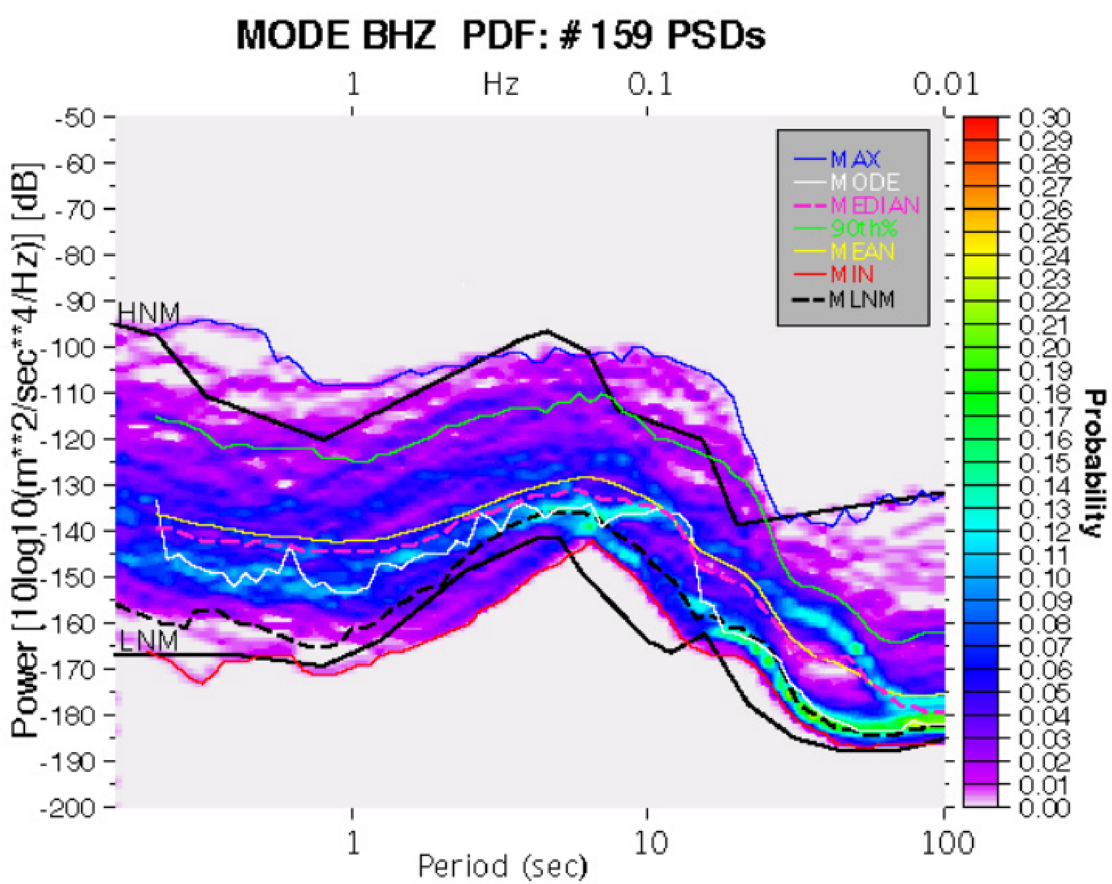
Seismometer without feedback



Force–Balance Seismometer



Wieland, Stuttgart



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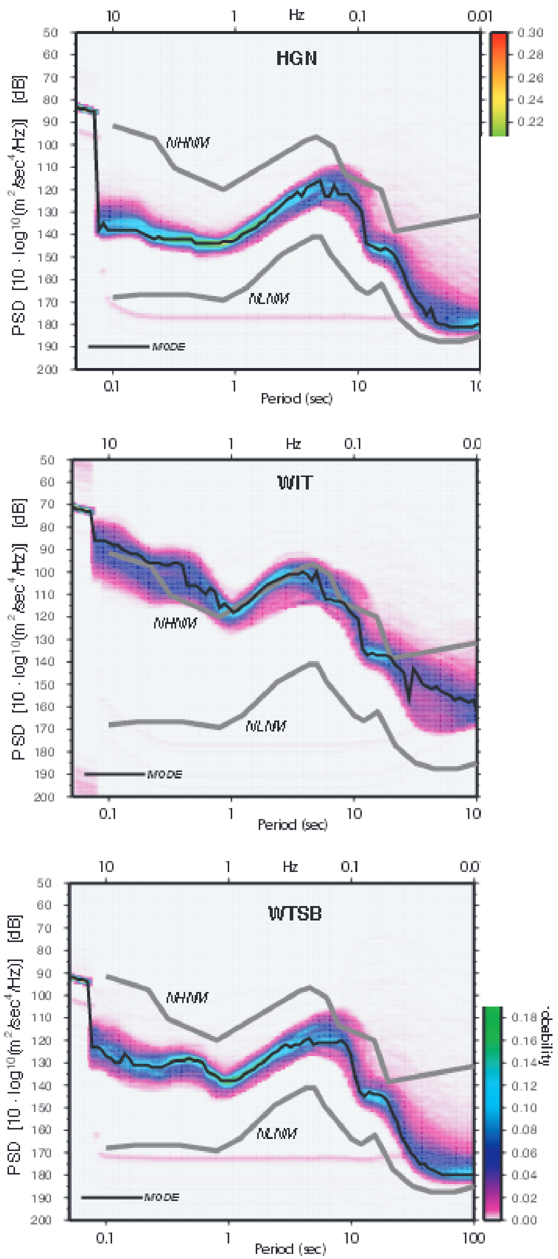

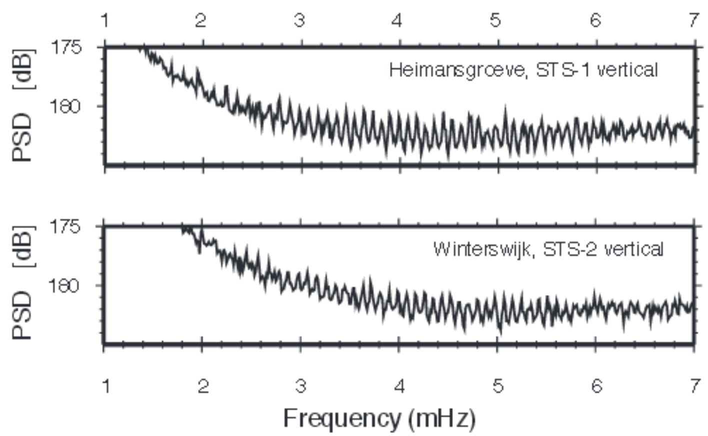

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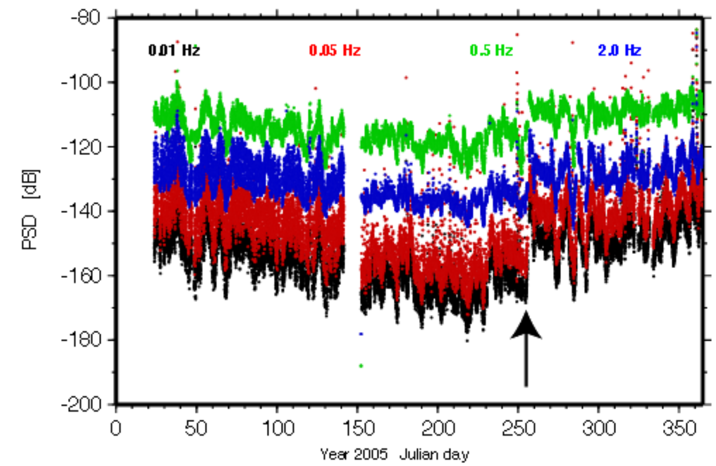

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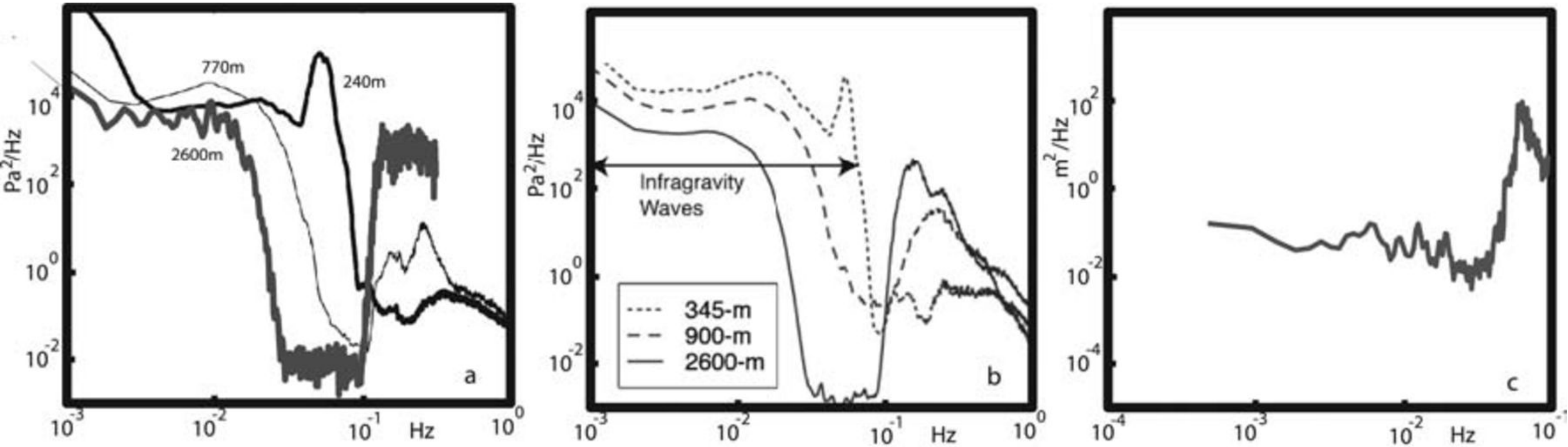
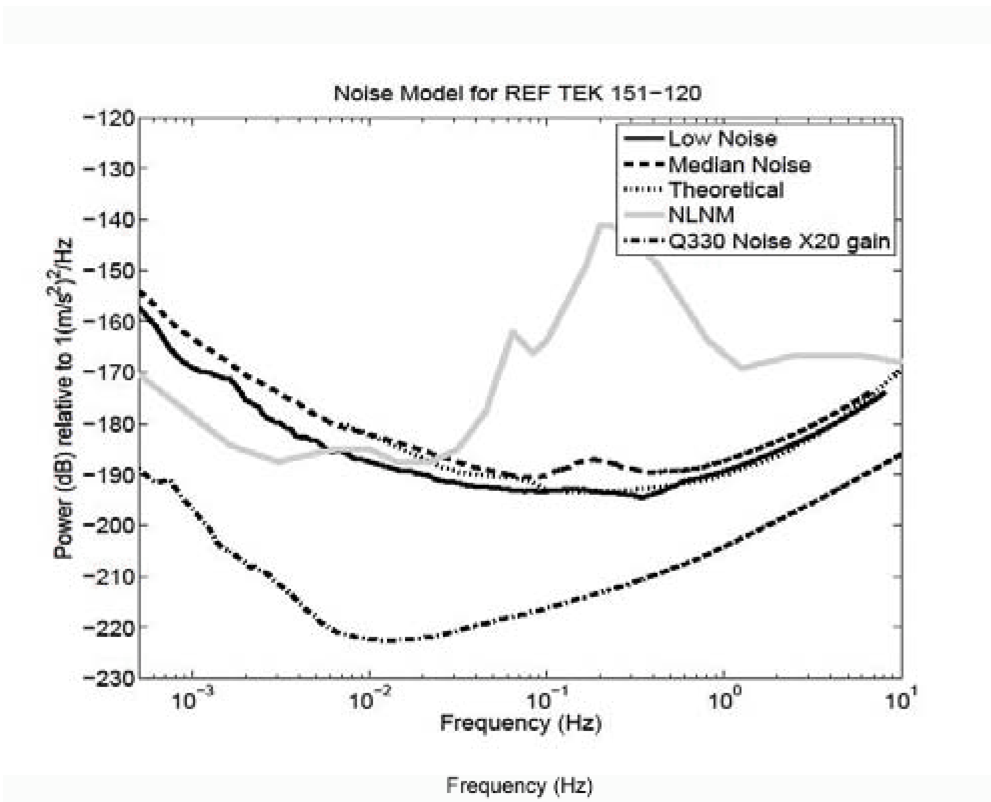
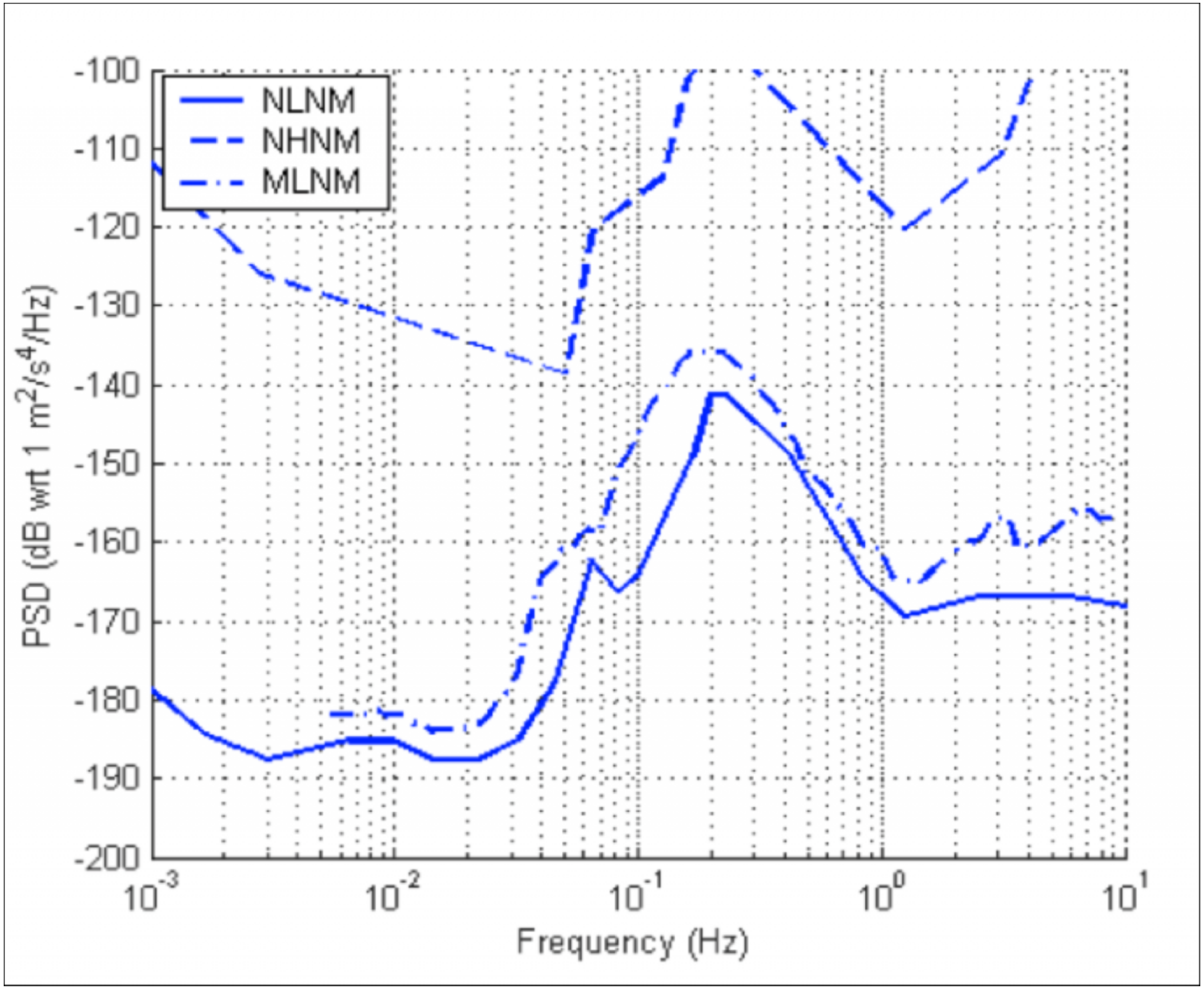


Figure 3.

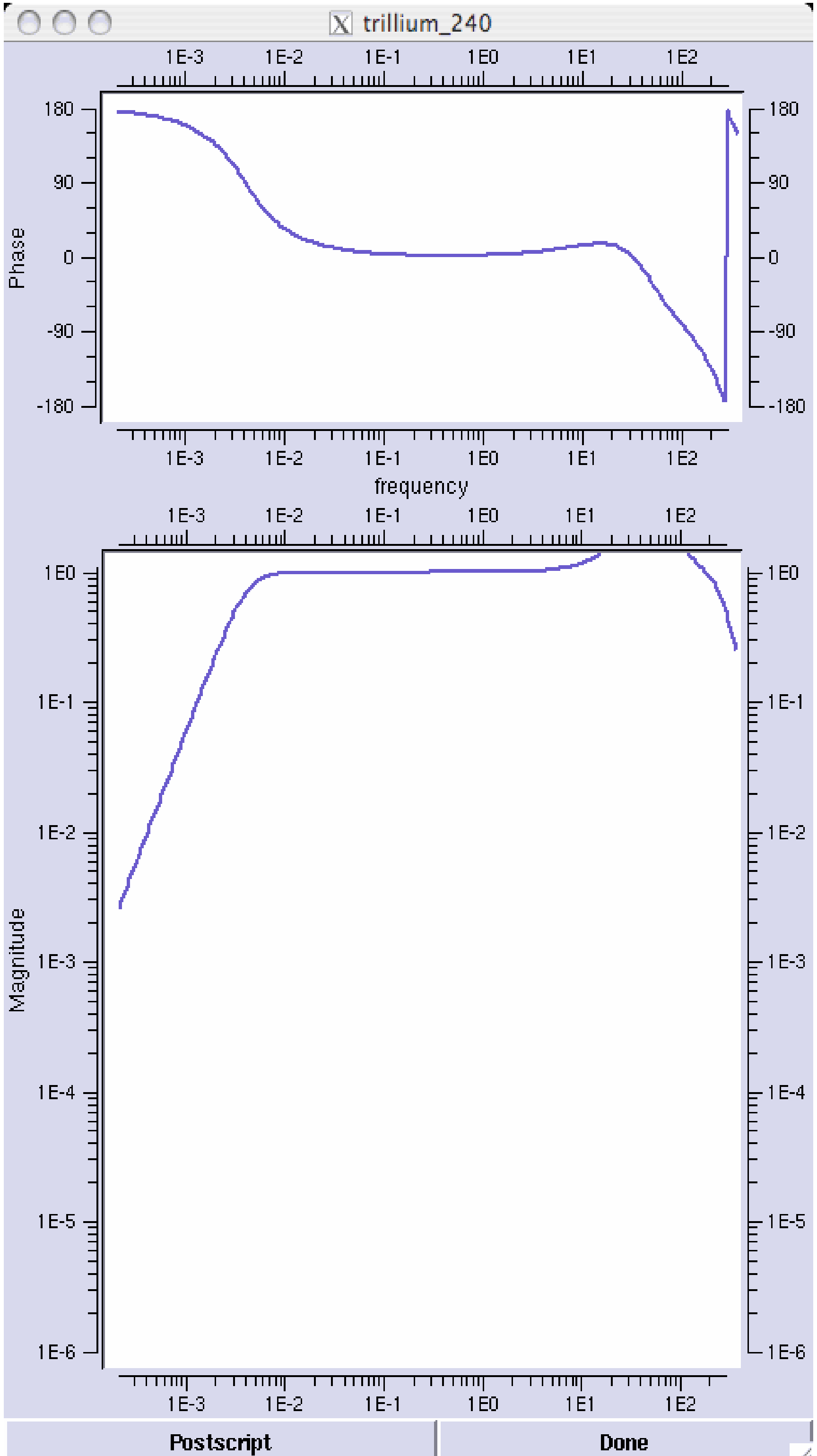
(a) Pressure spectra from three water depths in the Northern Pacific. The two shallow sites are from near San Diego, the deep site is from the East Pacific Rise near 10°N. (b) Pressure spectra from three water depths in the Northern Atlantic near the Faroes Islands (Crawford et al. 2005). (c) Energetic wave height spectra from offshore of Florida (redrawn from Herbers 2006).

REFTEK
Model 151B-120 / 151B-60 / 151B-30





More recently McNamara and Buland (2004) published a survey of approximately sixty sites scattered across the continental United States. From this survey they computed a more realistic low-noise model using Probability Distribution Functions (PDFs). They have named this model the PDF Mode Low Noise Model or MNLM. They conclude that "For a vast majority of stations within the United States, such low levels of noise [as the NLNM] are unattainable, suggesting that for routine monitoring purposes our MLNM represents a more realistic noise threshhold".

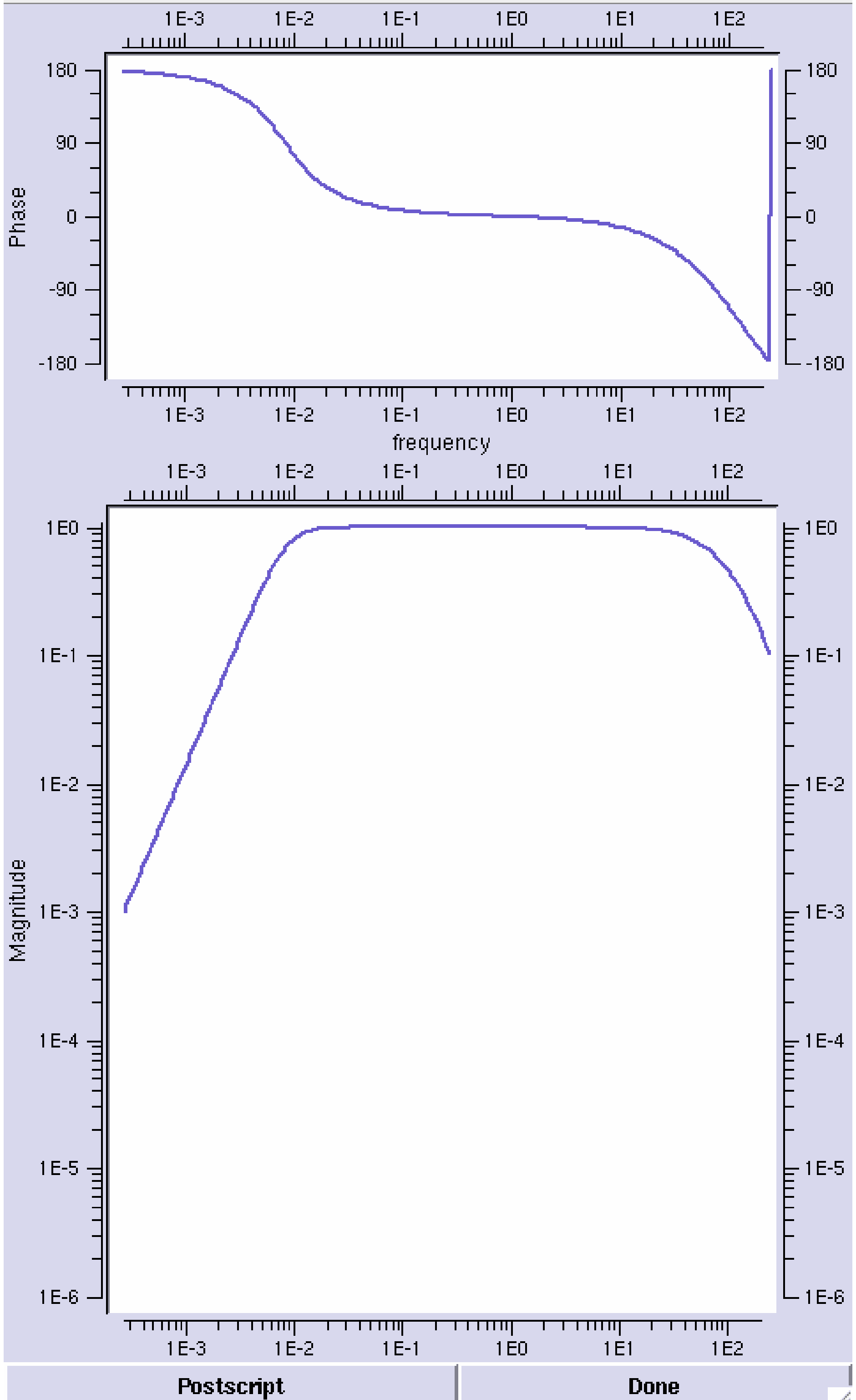


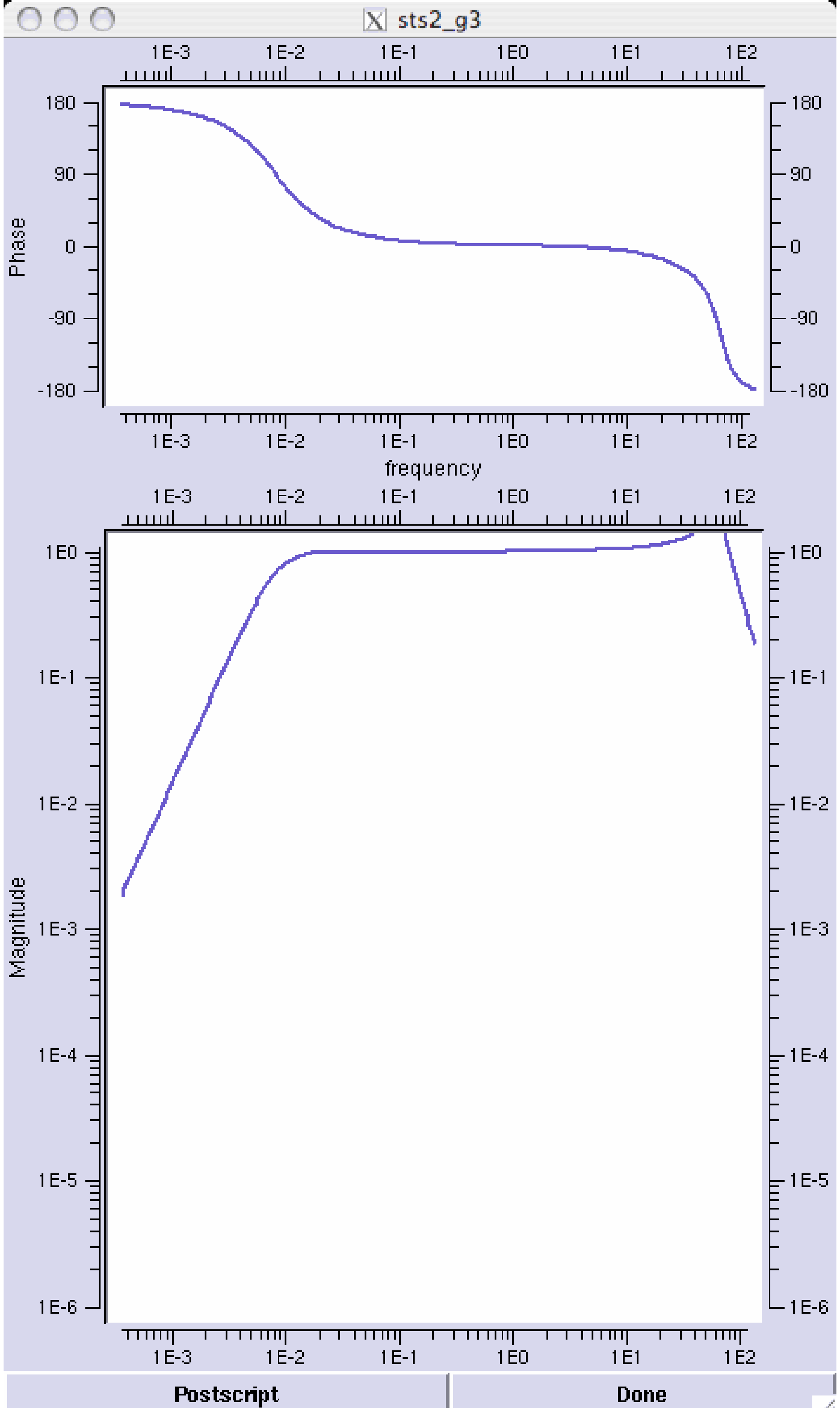
Nanometrics Trillium 240 Broadband Senso

Flat response to velocity from 240 seconds to 35 Hz
and has a self noise level below the
Low Noise model (NLNM) from 100 seconds to 10 Hz.

Guralp CMG-3T Broadband Sensor

120s - 50 Hz flat velocity response



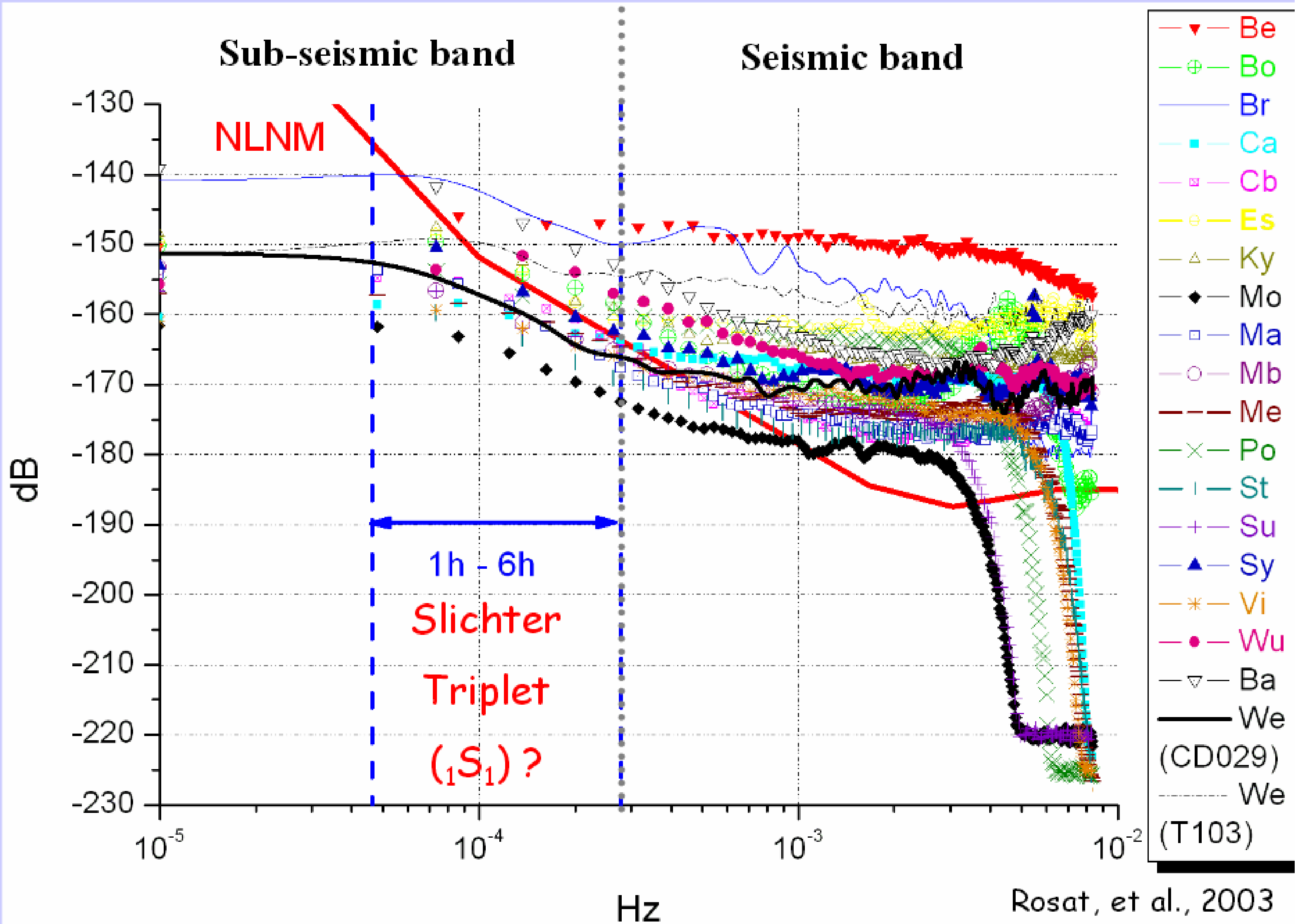


Streckeisen STS-2 Broadband Sensor

Flat response to velocity from
120 seconds to about 10 Hz

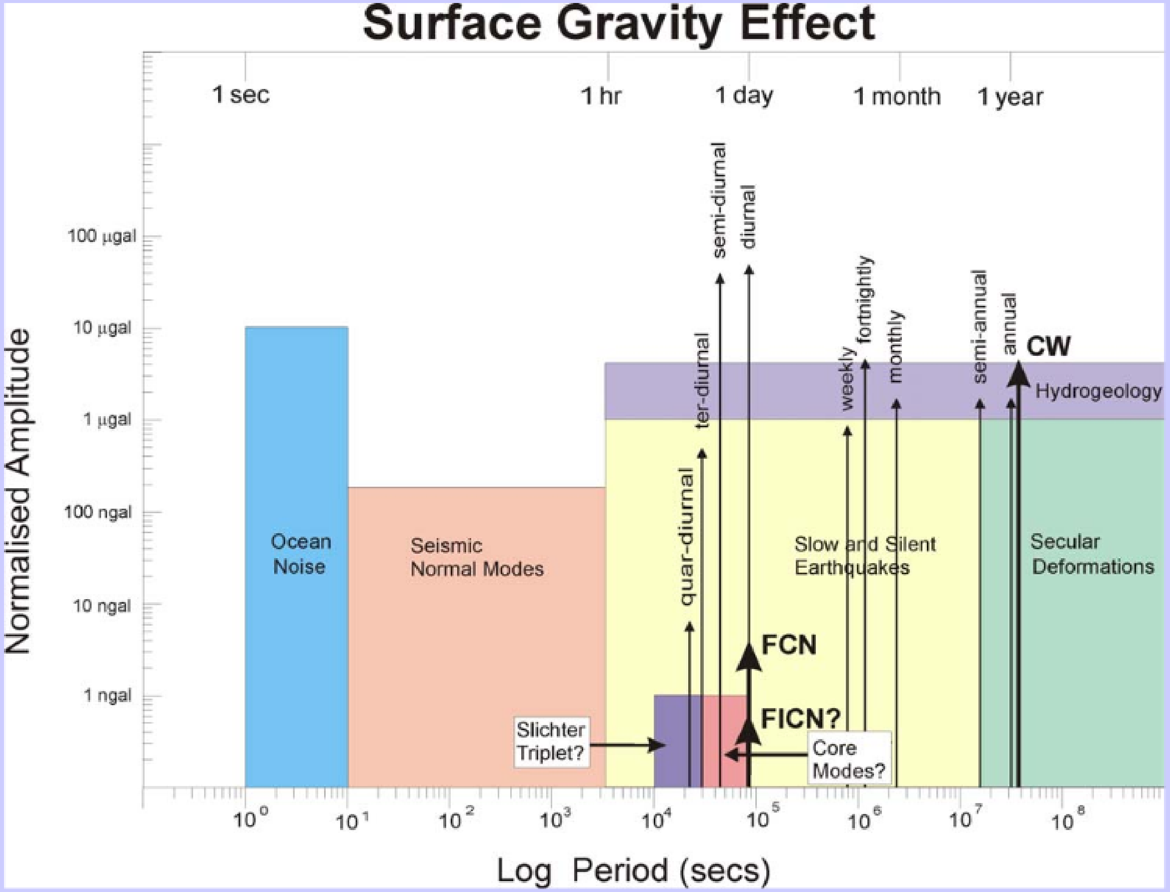
Noise levels of the GGP stations

(PSD in db relative to 1 $(m/s^2)^2/Hz$)



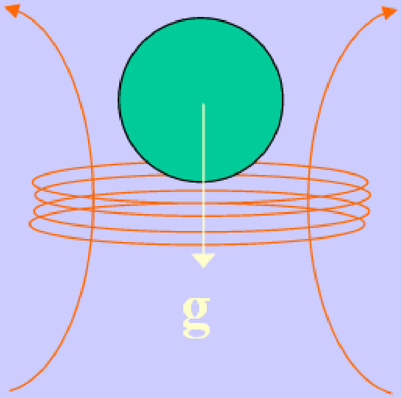
grande précision (10-2 nm/s² ≈ 10-12g où g est valeur de la gravité en surface)

Spectre des variations de gravité observables par les gravimètres supraconducteurs



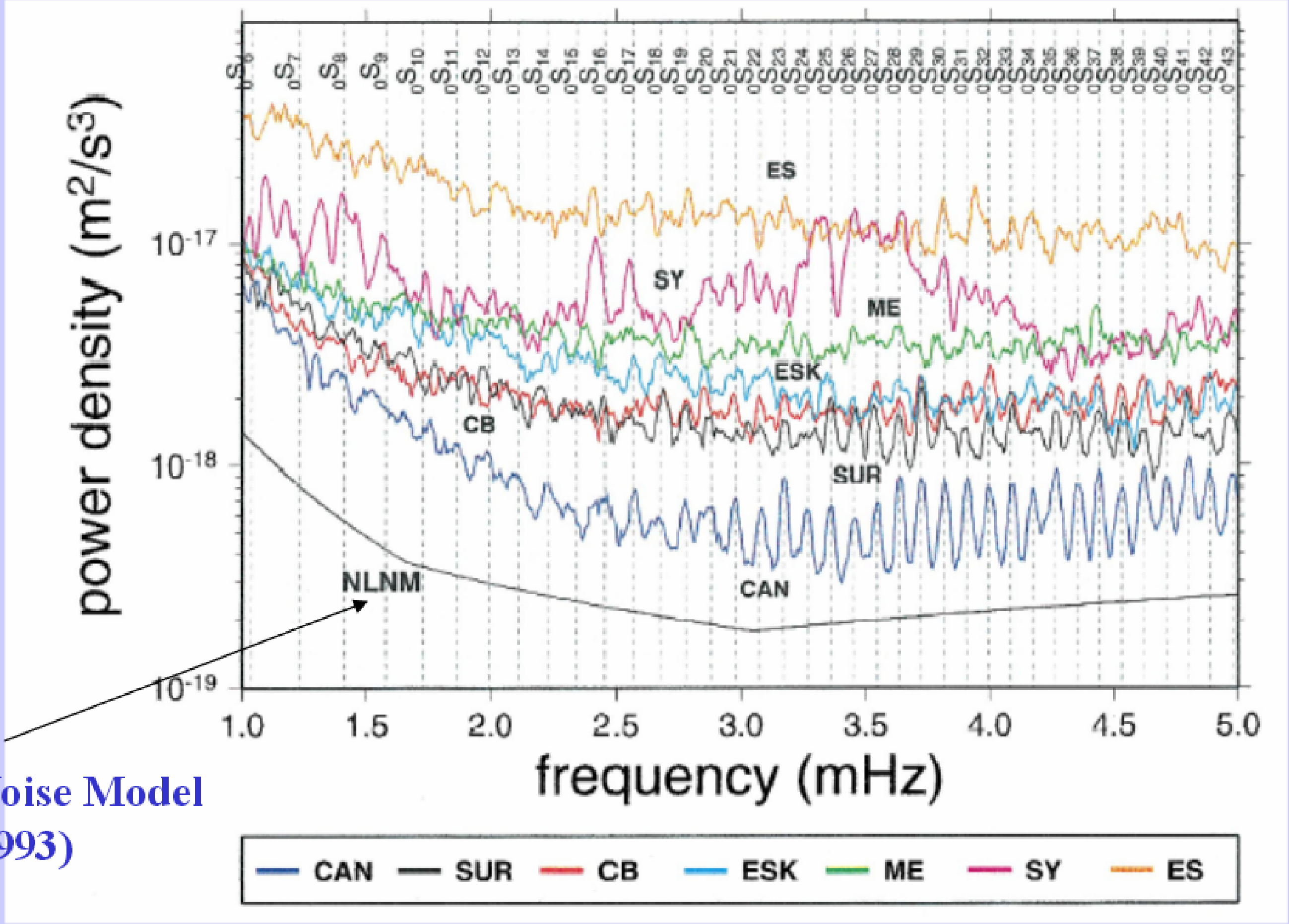
+ effets atmosphériques sur tout le spectre

Le gravimètre supraconducteur SG (cryogénique)



Lévitation magnétique

Incessant excitation of the Earth's free oscillations (hum)



New Low Noise Model
Peterson (1993)

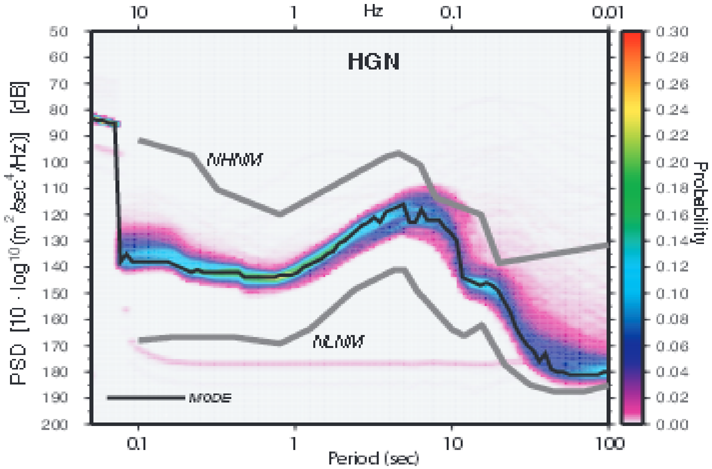
Canberra, Esashi, Metsahovi, Syowa SG

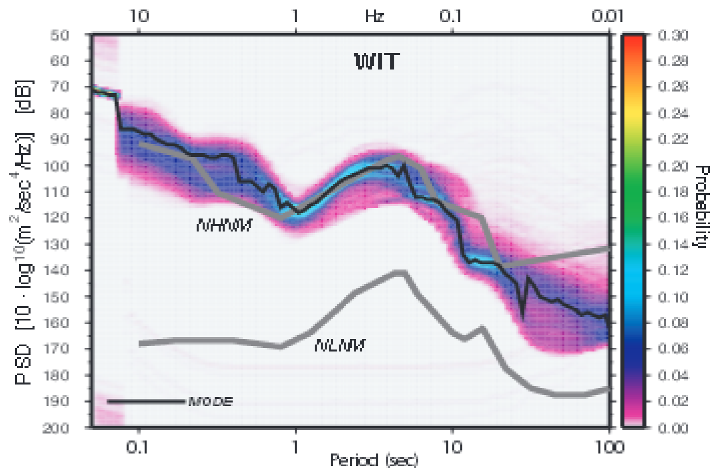
First seen on Syowa SG
Nawa et al. 1998

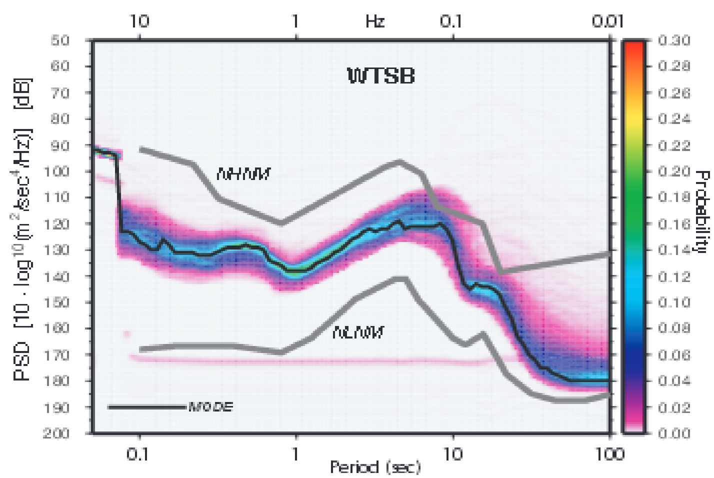
Nawa et al. 2000

Gravitation °+ loaing effect = -3.5 (nm/s2) /hPa
Buoyancy compensator

SEISMIC NOISE







Sensor	Manufacturer	Power	Corner Frequency	Damping	Sensitivity	Poles and Zeroes
STS-2	Streckeisen	30 ma @ 12vdc	0.0083 Hz	0.707 critical	1500 v/m/s	*Depends on generation: Generic, Gen.1, Gen.2, Gen.3
CMG-3T	Guralp	70 ma @ 12vdc	0.0083 Hz	0.707 critical	1500 v/m/s	5 poles, 2 zeros
CMG3-ESP	Guralp	70 ma @ 12vdc	0.033 Hz	0.707 critical	2000 v/m/s	5 poles, 2 zeros
CMG-40T	Guralp	50 ma @ 12vdc	0.033 Hz	0.707 critical	800 v/m/s	5 poles, 2 zeros
CMG-40-1	Guralp	50 ma @ 12vdc	1.0 Hz	0.707 critical	2000 v/m/s	6 poles, 2 zeros
Trillium 240 Update	Nanometrics	54 ma @ 12vdc	0.0042 Hz	0.707 critical	1200 v/m/s	Gen 1 (s/n 0-399): 7 poles 5 zeros Gen 2 (s/n 400+): 7 poles 5 zeros
Trillium 120PA Update	Nanometrics	54 ma @ 12vdc	0.008 Hz	0.707 critical	1200 v/m/s	7 poles, 5 zeros
Trillium 40	Nanometrics	46 ma @ 12vdc	0.025 Hz	0.707 critical	1500 v/m/s	7 poles, 5 zeros
Compact Trillium	Nanometrics	14 ma @ 12vdc	0.008 Hz	0.707 critical	749.1 v/m/s	7 poles, 3 zeros
L-22-3D	Mark Products	passive	2.0 Hz	0.707 critical	88 v/m/s	2 poles, 2 zeros
L-28-3D	Mark Products	passive	4.5 Hz	0.707 critical	30.4 v/m/s	2 poles, 2 zeros
Y-28-3D	Oyo-Geospace	passive	4.5 Hz	0.707 critical	32 v/m/s	2 poles, 2 zeros
GS11	Oyo-Geospace	passive	4.5 Hz	0.707 critical	100 v/m/s	2 poles, 2 zeros
L-40	Mark Products	passive	40 Hz	0.707 critical	22.34 v/m/s	2 poles, 2 zeros
L-4C	Mark Products	passive	1.0 Hz	0.707 critical	166.54 v/m/s	2 poles, 2 zeros
S-13	Teledyne Geotech	passive	1.0 Hz	0.707 critical	629 v/m/s	2 poles, 2 zeros

Also See

- PH5 vs SEG-Y: Archival Data Format Comparison
- Nanometrics Trillium 240 Broadband Sensor
- Cold-rated Guralp CMG-3T Sensor
- Sensors
- Broadband Sensors

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