GINGERino for seismology

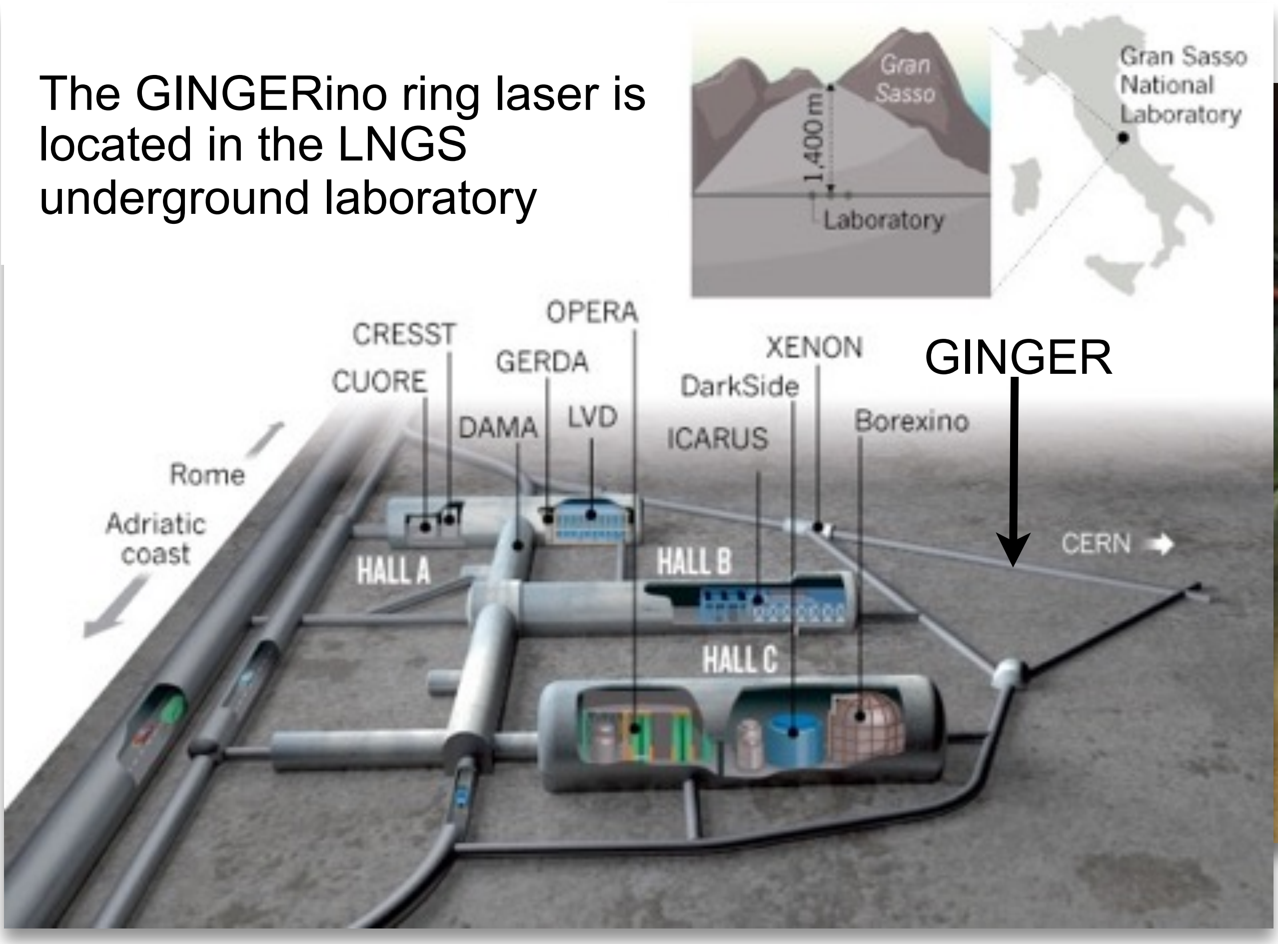
Andrea Simonelli

INFN
Istituto Nazionale di Geofisica e Vulcanologia
UNIVERSITÀ DI PISA

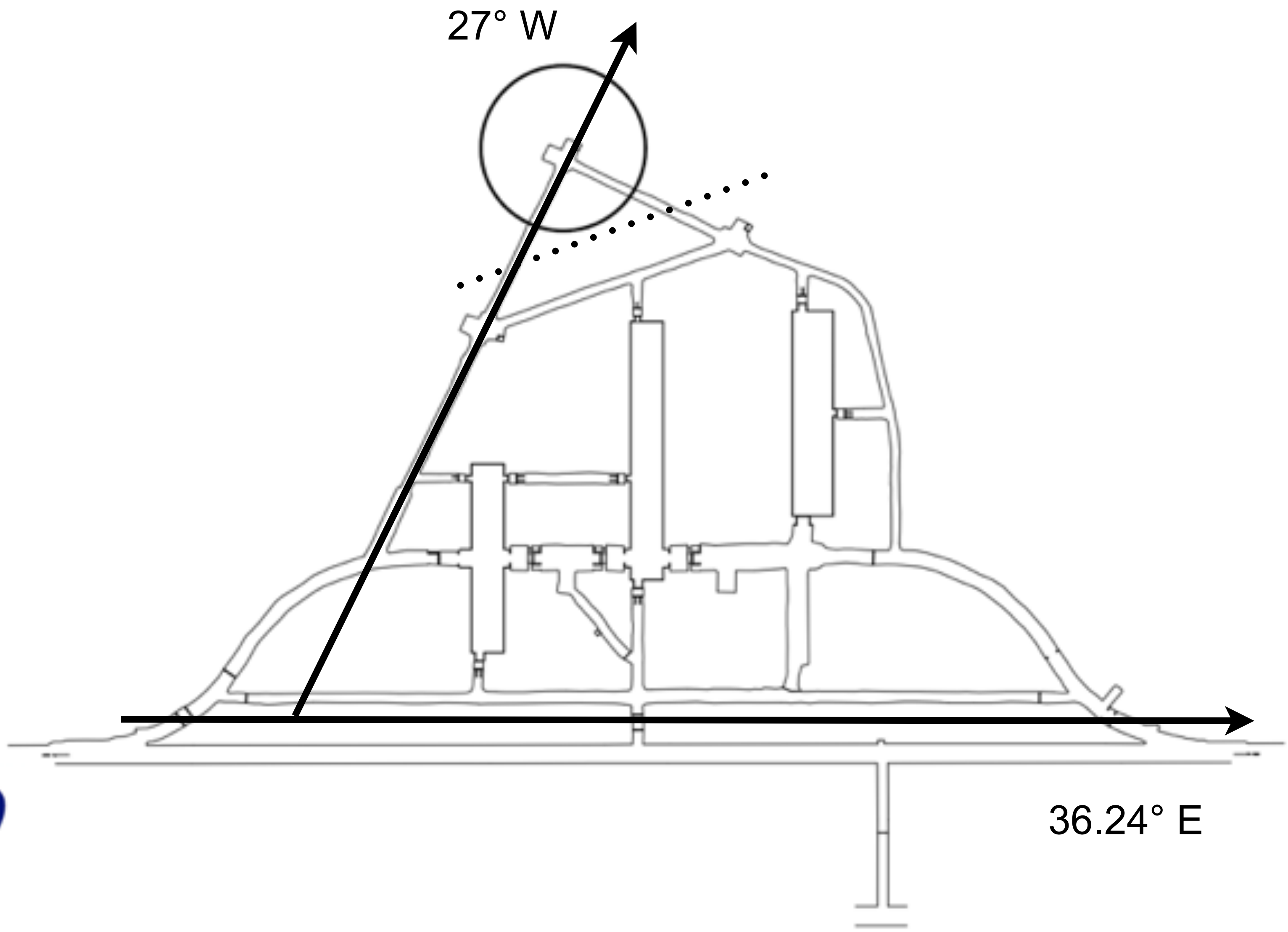
GINGERino

Where we are

The GINGERino ring laser is located in the LNGS underground laboratory

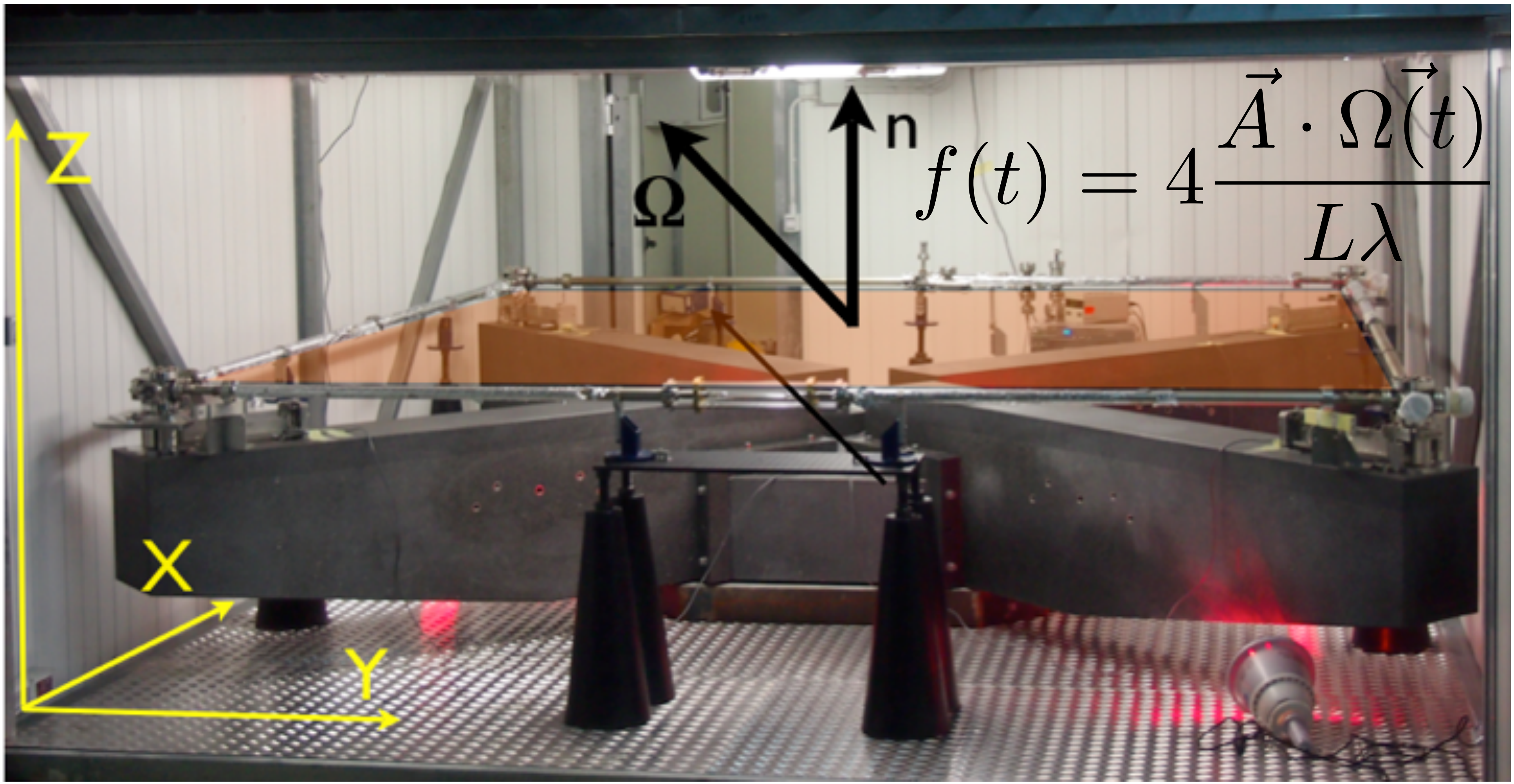


The lab map

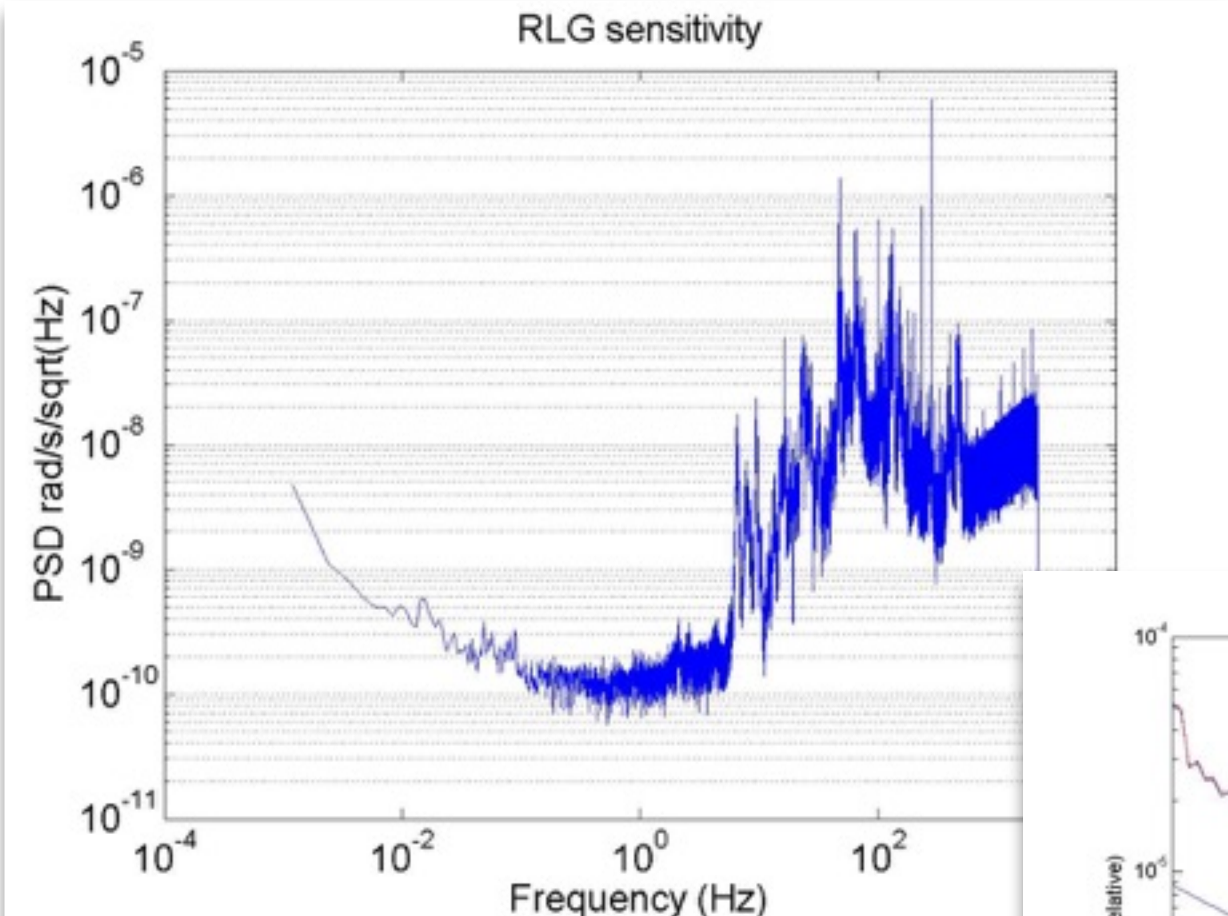


Ring laser gyroscope (RLG) working principle

In a rotating ring laser gyroscope the difference in the optical path as seen by two counter propagating laser beams leads to a difference in the optical frequency between the clockwise and anti-clockwise propagating beams. The beat frequency called also the Sagnac frequency f can be related to the rotation rate around the normal vector to the surface outlined by the square optical path by using the simple equation below.

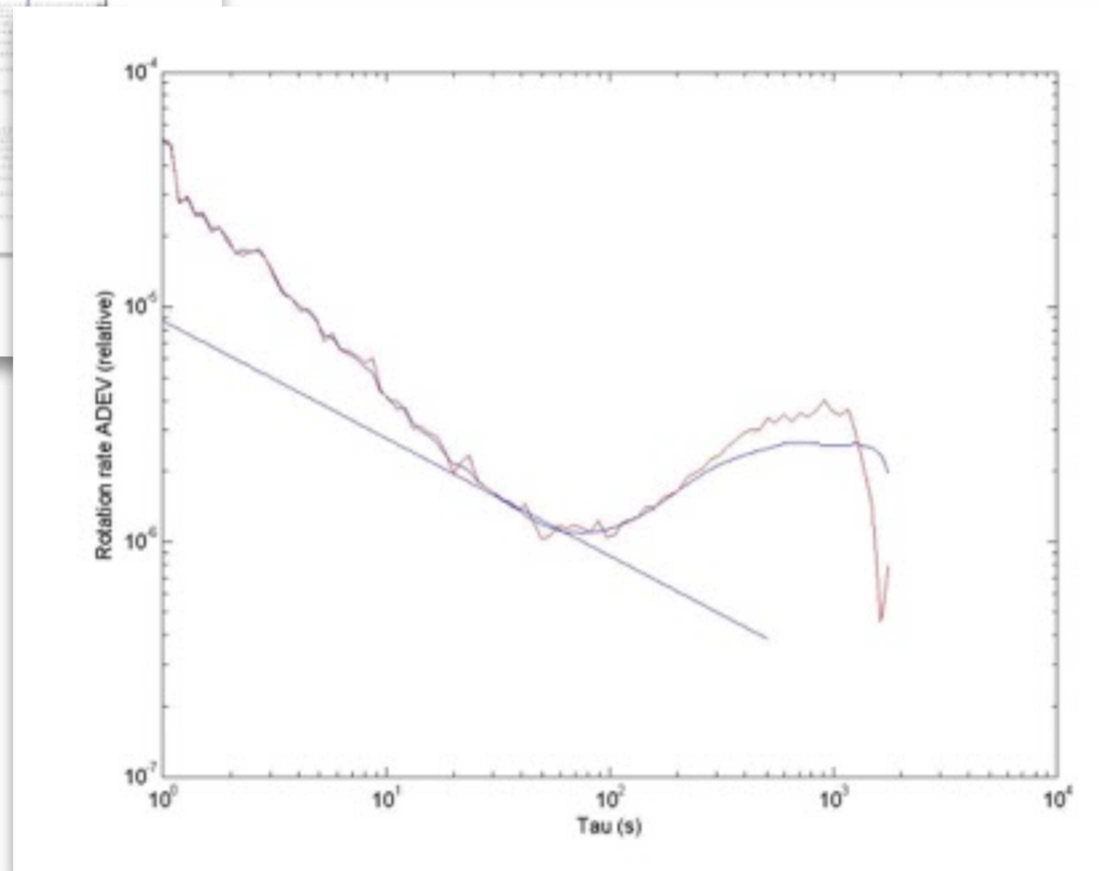


Performances



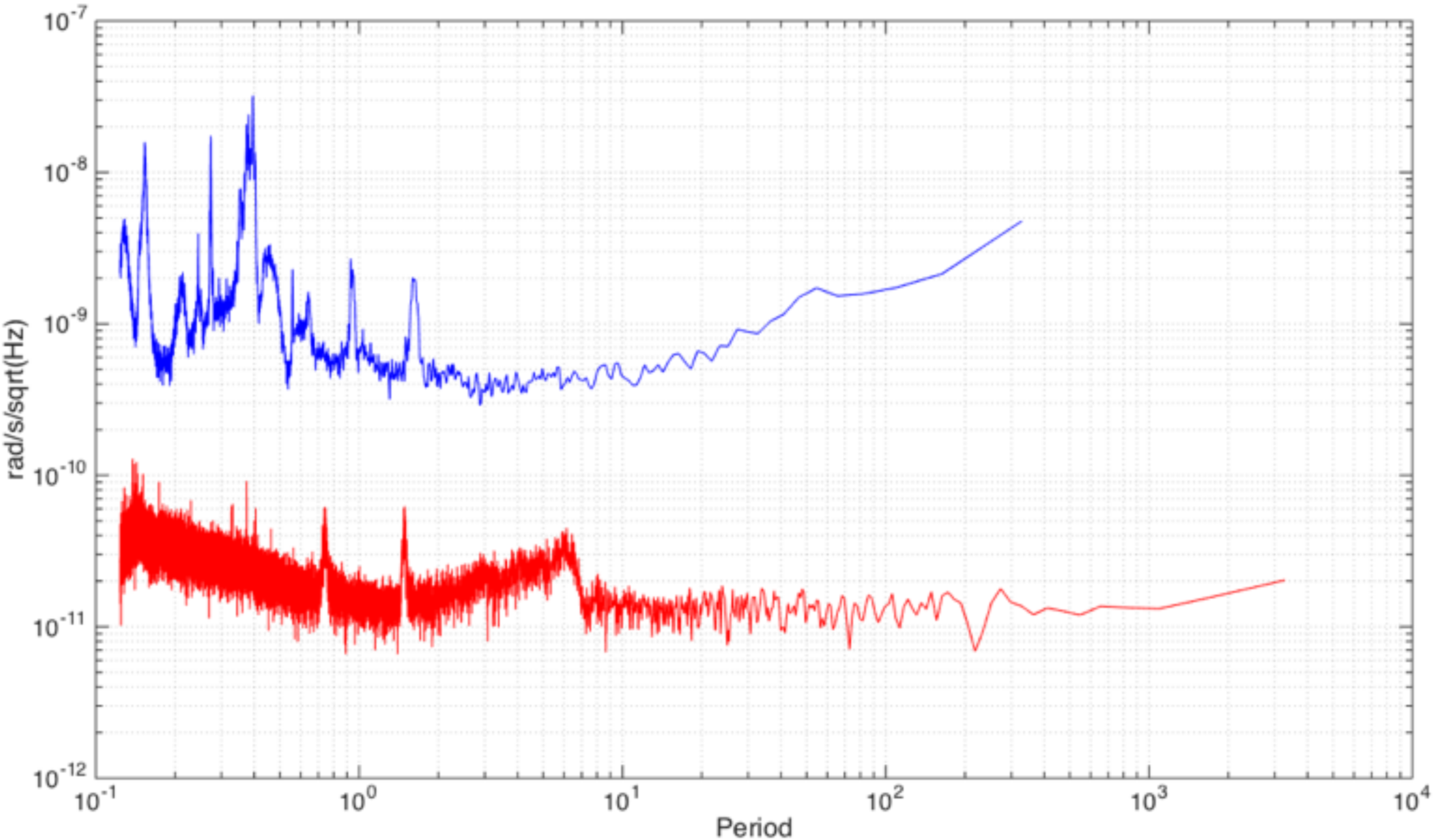
The shot noise limit is calculated using the measured values of power and ring down time according to

$$\delta\Omega = \frac{cP}{4AQ}\sqrt{\frac{hf}{P_x t}}$$



during the first run we measured a ring down time of about 300 us

Seismic band: G and GINGERino



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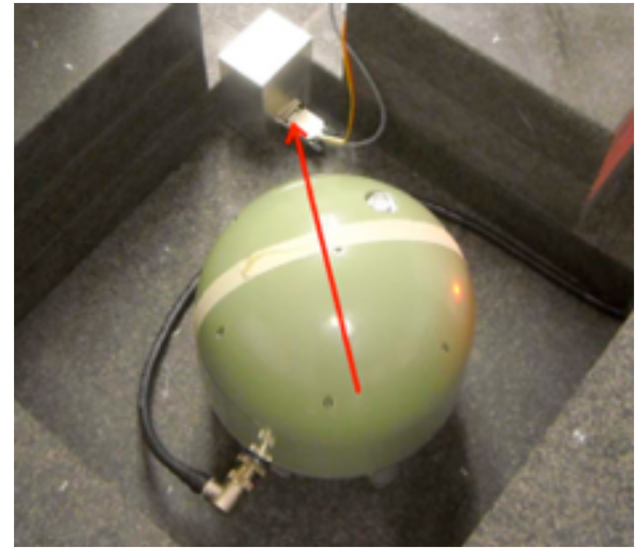
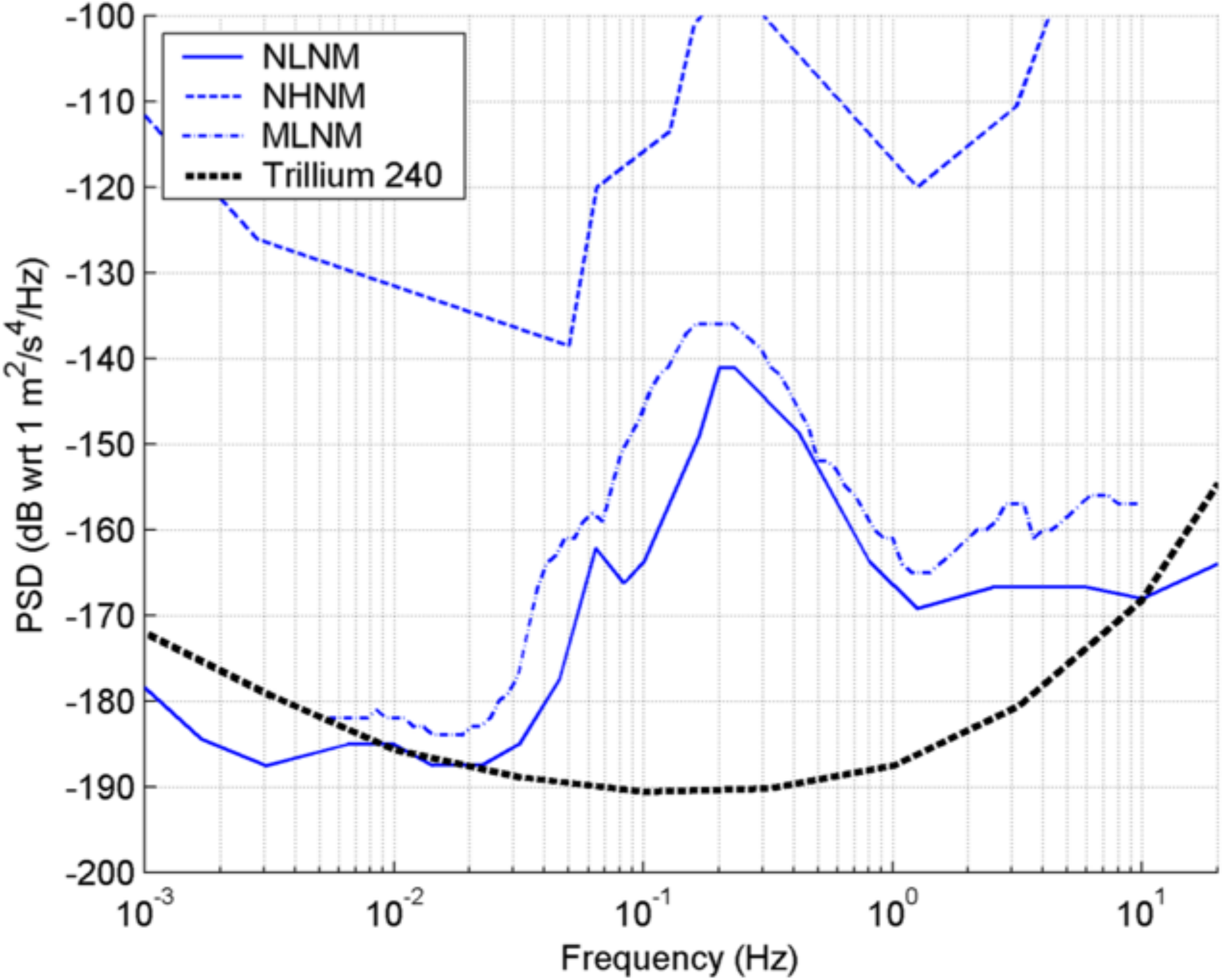
Seismometric equipment



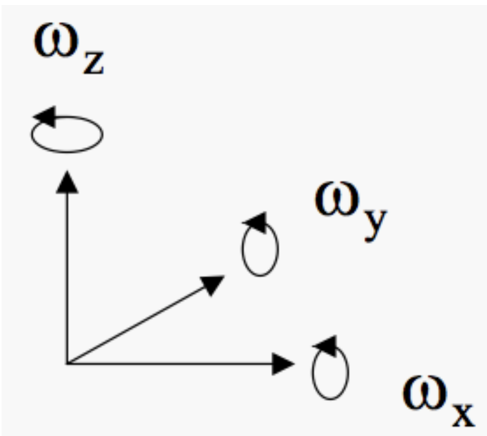
A Nanometrics Trillium 240s seismometer is installed at the center of the RLG granite frame. This instrument, which is part of the national earthquake monitoring program of the Istituto Nazionale di Geofisica e Vulcanologia, provided the data to be compared to the RLG's rotational data in order to infer a phase velocity measure during the transit of shear waves from earthquakes at local, regional and tele seismic distances.

- A second broadband seismometer (Guralp CMG 3T–360s is placed in the central block in order to obtain estimates of differential velocities and for data redundancy.
- A lipmann digital tiltmeter is installed in the center of the frame

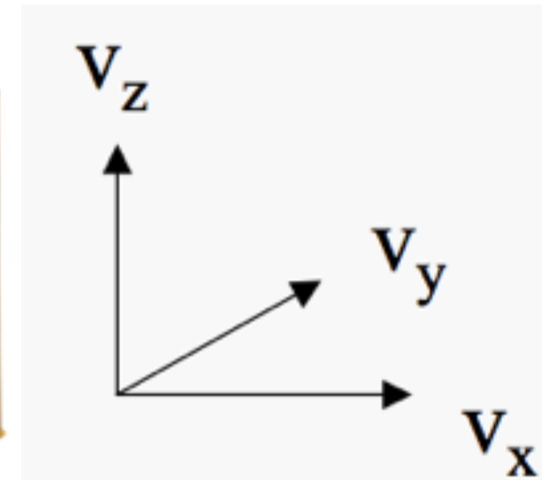

NLNM
NHNM
MLNM
Trillium 240
PSD (dB wrt 1 m²/s⁴/Hz)
Frequency (Hz)
-100
-110
-120
-130
-140
-150
-160
-170
-180
-190
-200
10^-3
10^-2
10^-1
10^0
10^1

Basic theory

$$\begin{pmatrix} \omega_x \\ \omega_y \\ \omega_z \end{pmatrix} = \frac{1}{2}\nabla \times \mathbf{u} = \begin{pmatrix} \frac{\partial u_z}{\partial y} - \frac{\partial u_y}{\partial z} \\ \frac{\partial u_x}{\partial z} - \frac{\partial u_z}{\partial x} \\ \frac{\partial u_y}{\partial x} - \frac{\partial u_x}{\partial y} \end{pmatrix}$$



3d-RLG (next future: ROMY)
today the largest RLGs
(G-wettzel and GINGERino)
measures only vertical rotation



In our setup we expect to be maximally sensible to Love waves induced rotations.
By measuring both transverse acceleration and vertical rotation rate we can obtain phase velocity by using the simple (2.4)

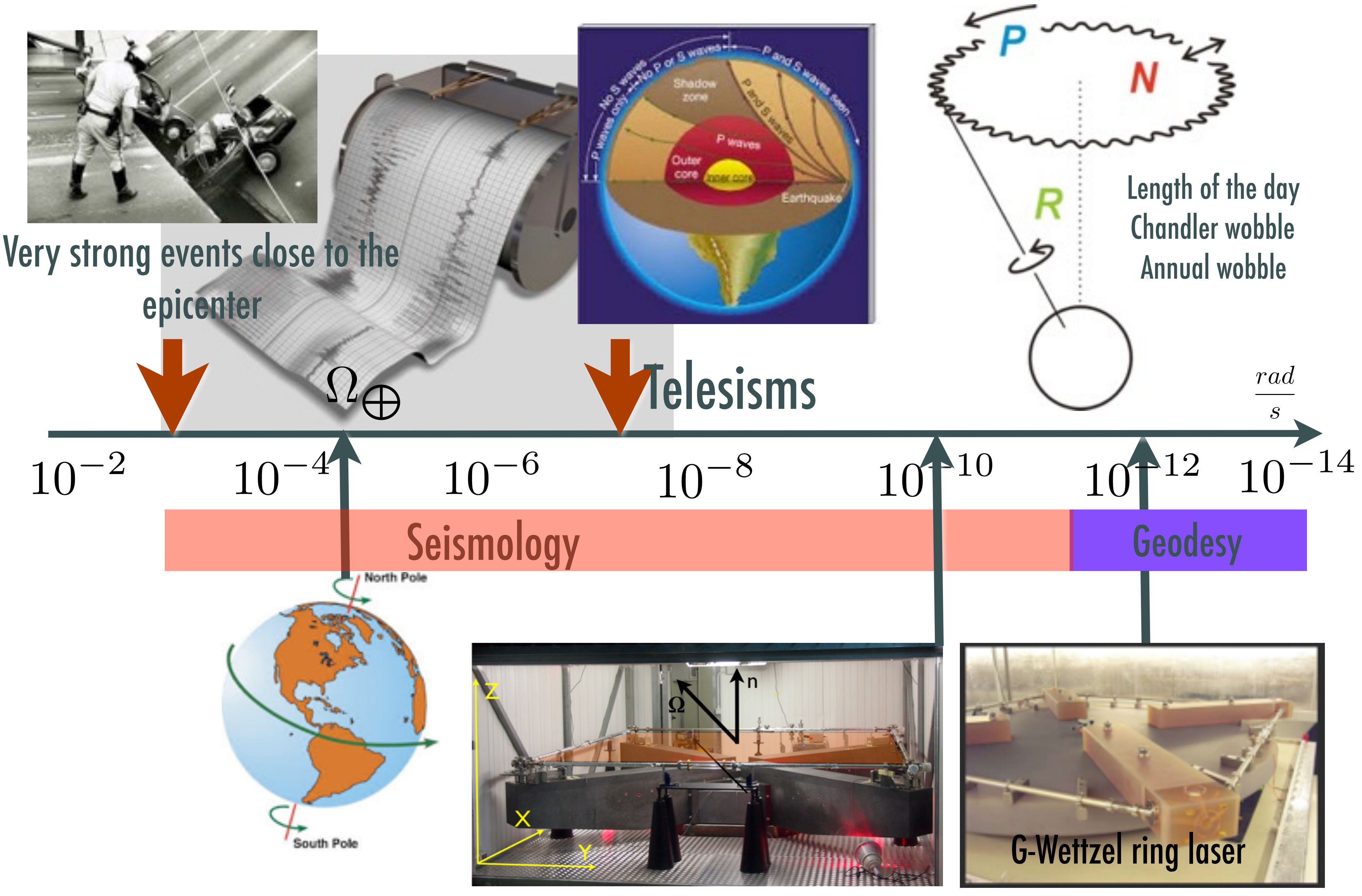
$$u_y = Be^{i\omega\left(\frac{x}{C_L} - t\right)} \quad (2.3)$$

$$\Omega_z = -\frac{1}{2}\frac{\ddot{u}_y}{c_L} \quad (2.4)$$

$$c_L \sim 10^3\, m/s$$

$$\ddot{u} \sim 10^{-3}\, m/s^2 \rightarrow \Omega \sim \mu rad/s$$

Magnitude scale of the rotations of geophysical interest



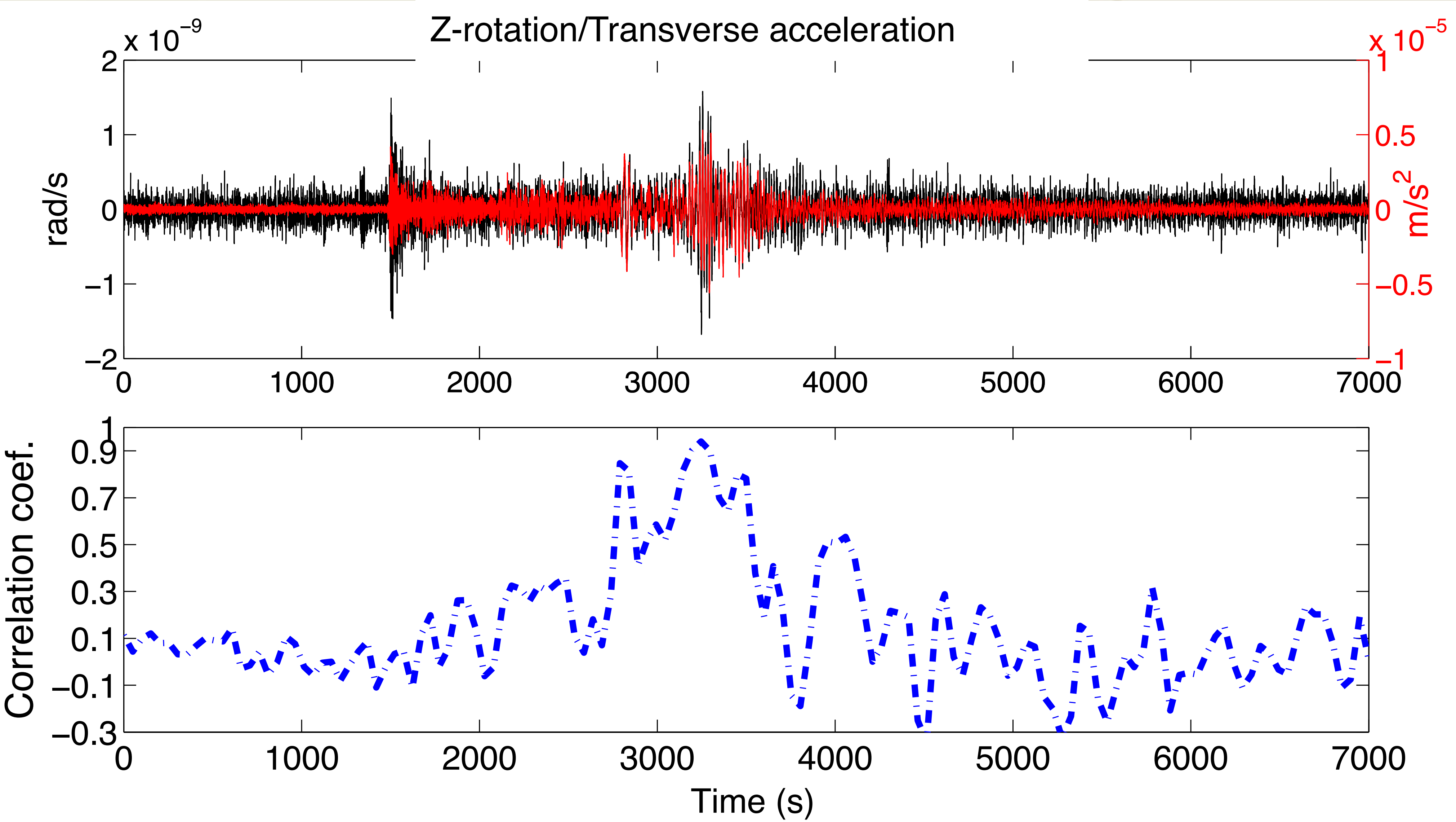
Earthquake with magnitude of 6.4 on date 17-06-2015 and time 12:51:38 (UTC) in region Southern Mid Atlantic Ridge [Sea]

This event has been recorded by our instrument during the longest split mode uninterrupted run from 11/6 to 19/6. Unfortunately the S/N ratio for this event is poor but sufficient to perform some geophysical analysis.

In the next upgrade we hope to increase sensitivity and run time in order to capture
a wide collection of seismic events from regional to tele-seismic scale.

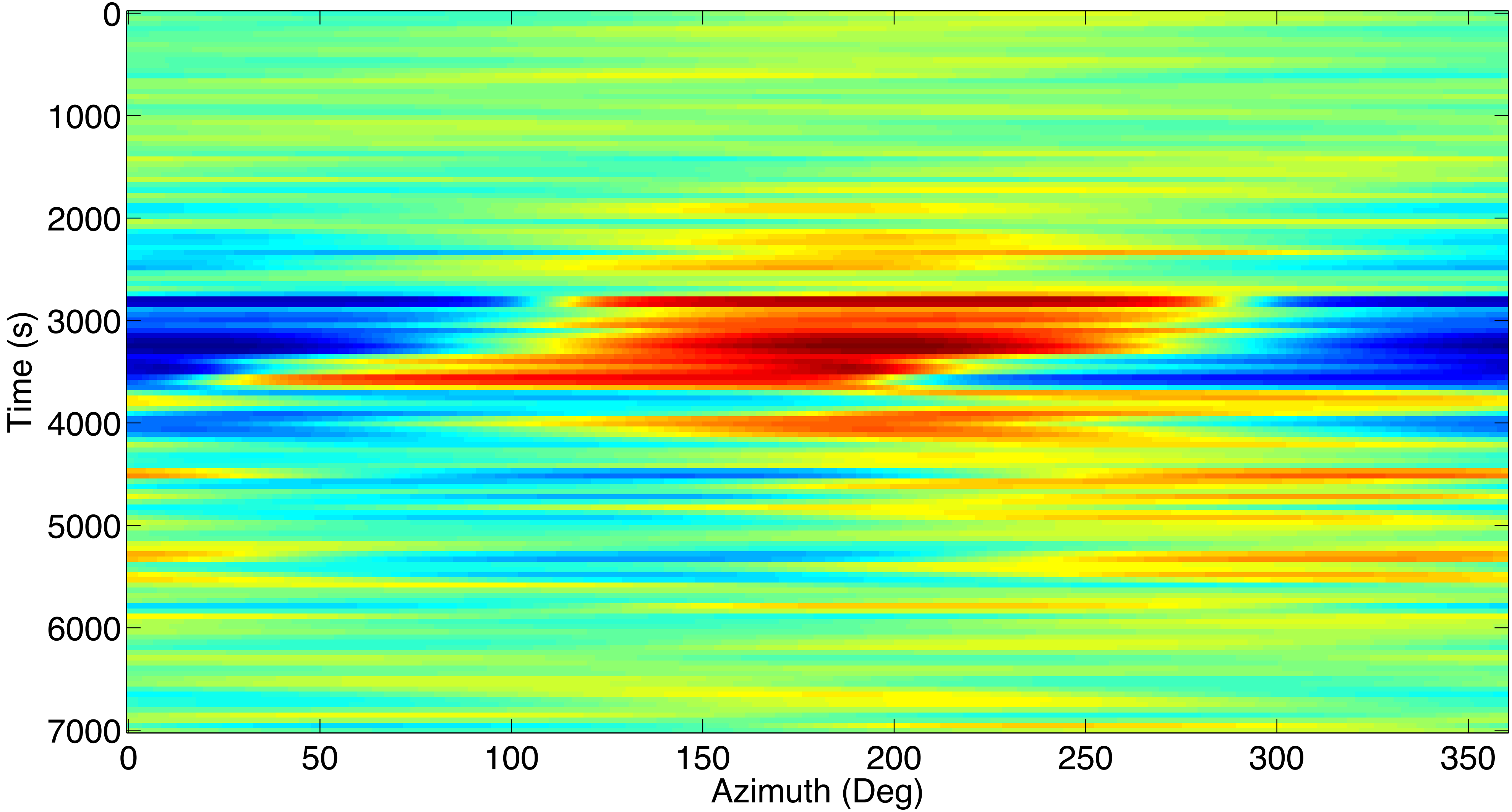
Oral contribution :
"Simonelli, A; Belfi, J; Beverini, N; Carelli, G; Di Virgilio, A; Maccioni, E; Santagata, R; De Luca, G; Saccorotti, G; ",*Measurements of Surface Waves Phase Velocity with a Large Ring Laser Gyroscope and a Seismometer"*,Near Surface Geoscience 2015-21st European Meeting of Environmental and Engineering Geophysics,,,,2015,
….**paper in progress**

The zero lag correlation coefficient (ZLCC) is calculated in a 100 seconds long sliding 50% overlapping window. A clear peak emerging from poor correlation indicates Love waves arrivals (expected from the setup)

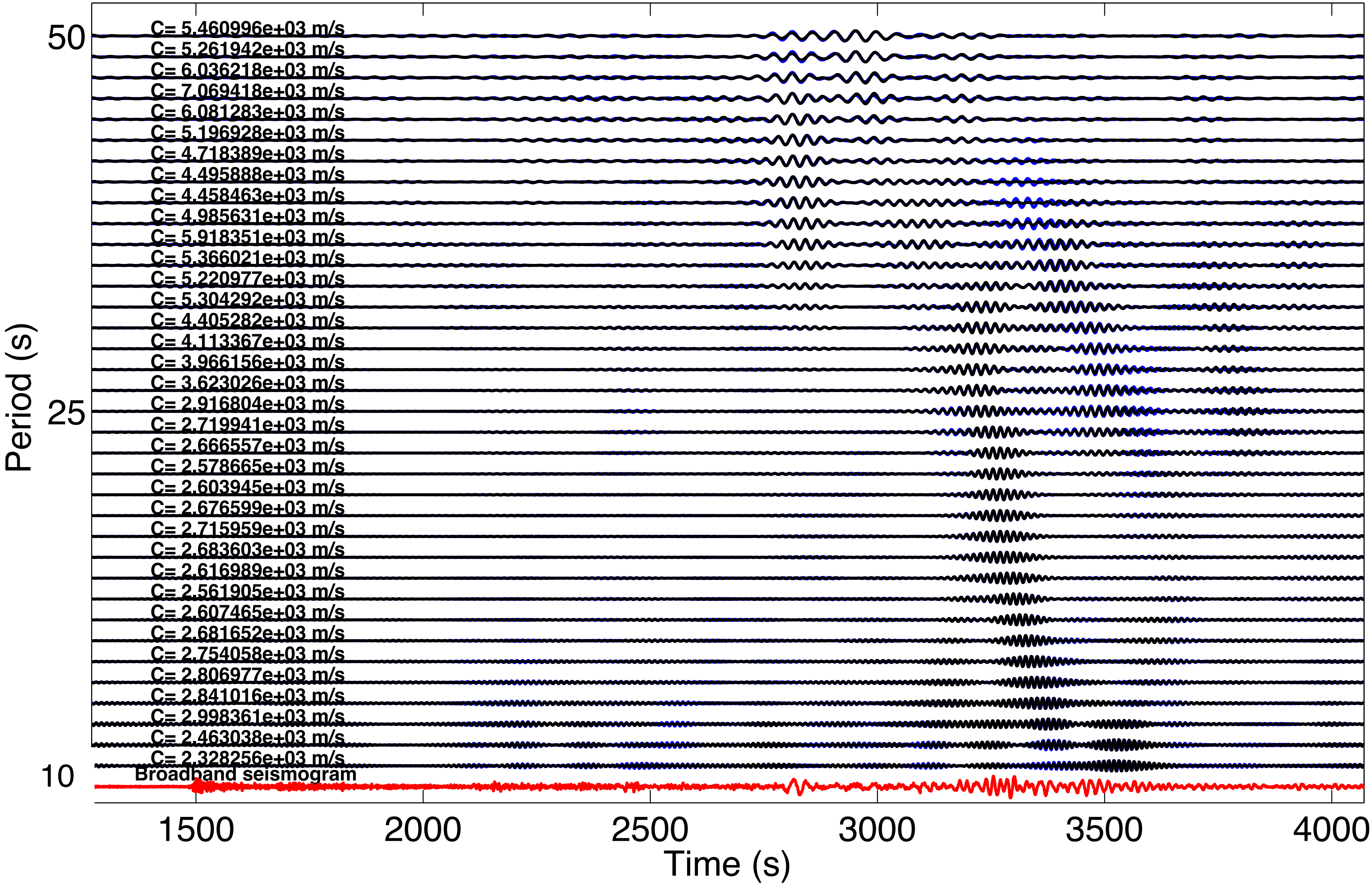


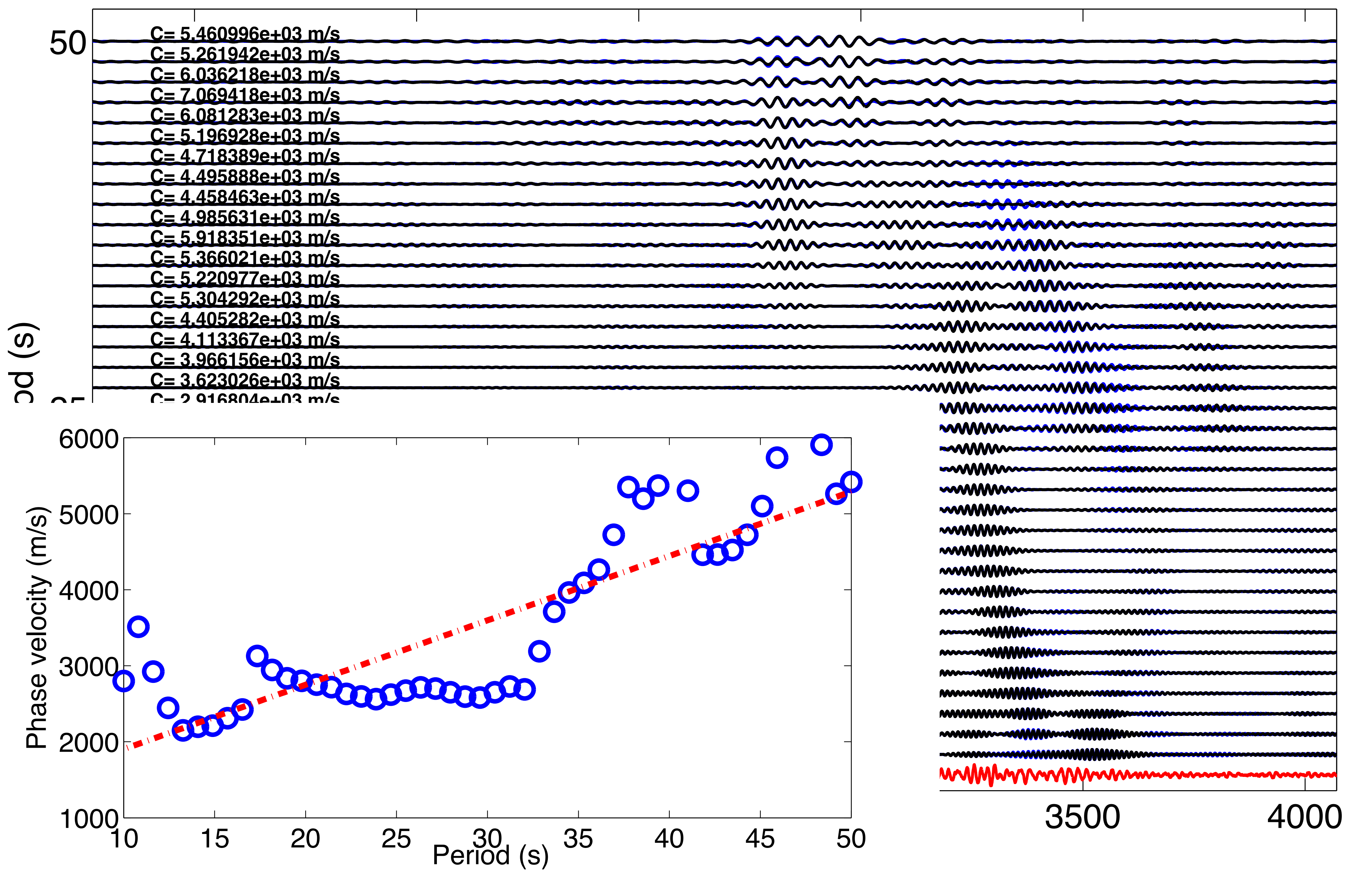
Azimuth estimation

The N-S and E-W seismometer traces are rotated and ZLCC between the rotational signal and transverse acceleration is calculated. The maximum is at 198° deg, the theoretical azimuth is 202°. The measured value lies inside the error of the seismometer orientation (+/-5°)



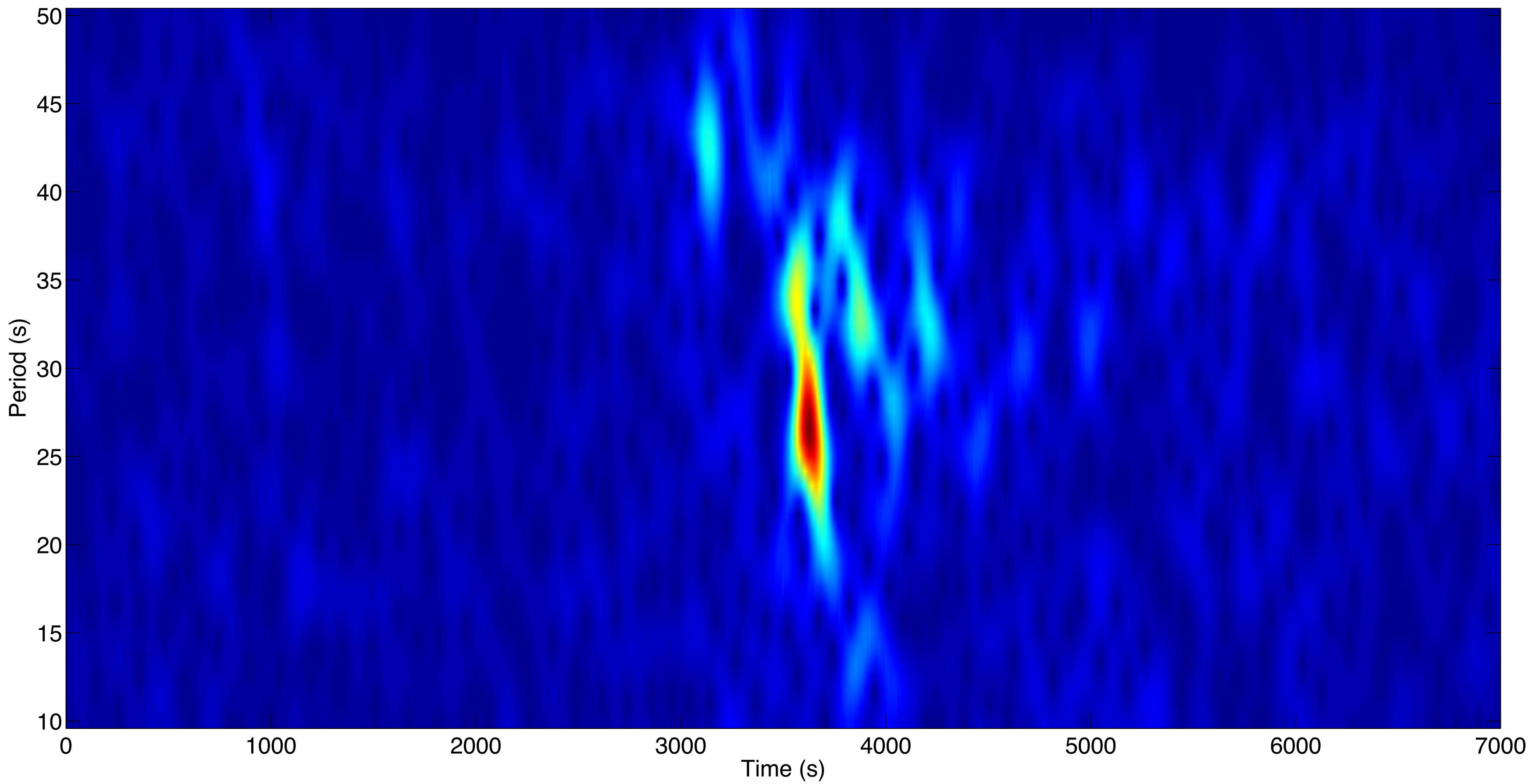
Rotations (blue) and Transverse acc. (black) are narrow band filtered. In the bands where ZLCC is above a threshold the amplitude ratio between the maxima of the Hilbert transform estimated envelopes gives a direct measure of Phase velocity vs period



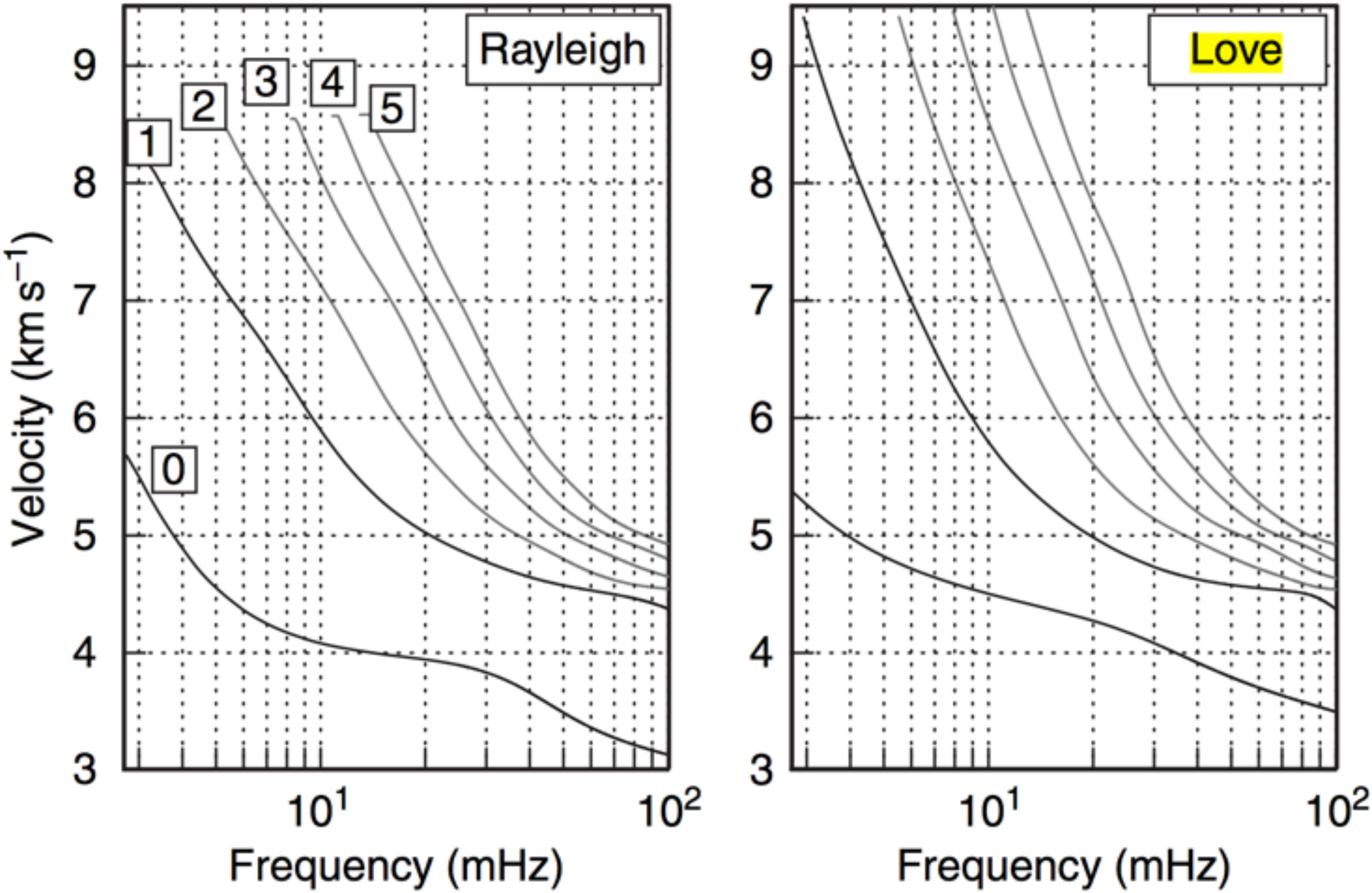


50
C= 5.460996e+03 m/s
C= 5.261942e+03 m/s
C= 6.036218e+03 m/s
C= 7.069418e+03 m/s
C= 6.081283e+03 m/s
C= 5.196928e+03 m/s
C= 4.718389e+03 m/s
C= 4.495888e+03 m/s
C= 4.458463e+03 m/s
C= 4.985631e+03 m/s
C= 5.918351e+03 m/s
C= 5.366021e+03 m/s
C= 5.220977e+03 m/s
C= 5.304292e+03 m/s
C= 4.405282e+03 m/s
C= 4.113367e+03 m/s
C= 3.966156e+03 m/s
C= 3.623026e+03 m/s
Phase velocity (m/s)
6000
5000
4000
3000
2000
1000
10
15
20
25
30
35
40
45
50
Period (s)
3500
4000

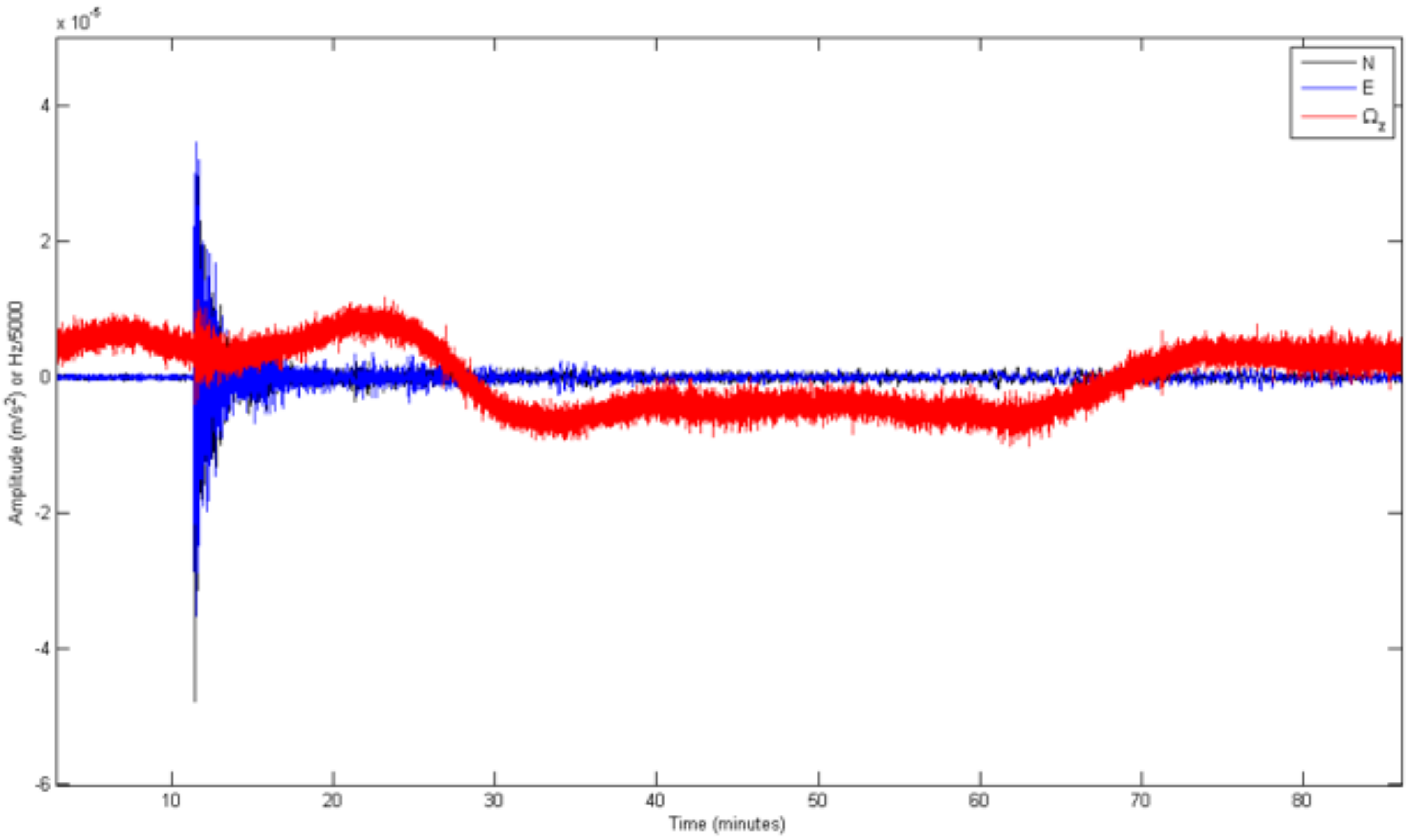
Image of the envelope RLG



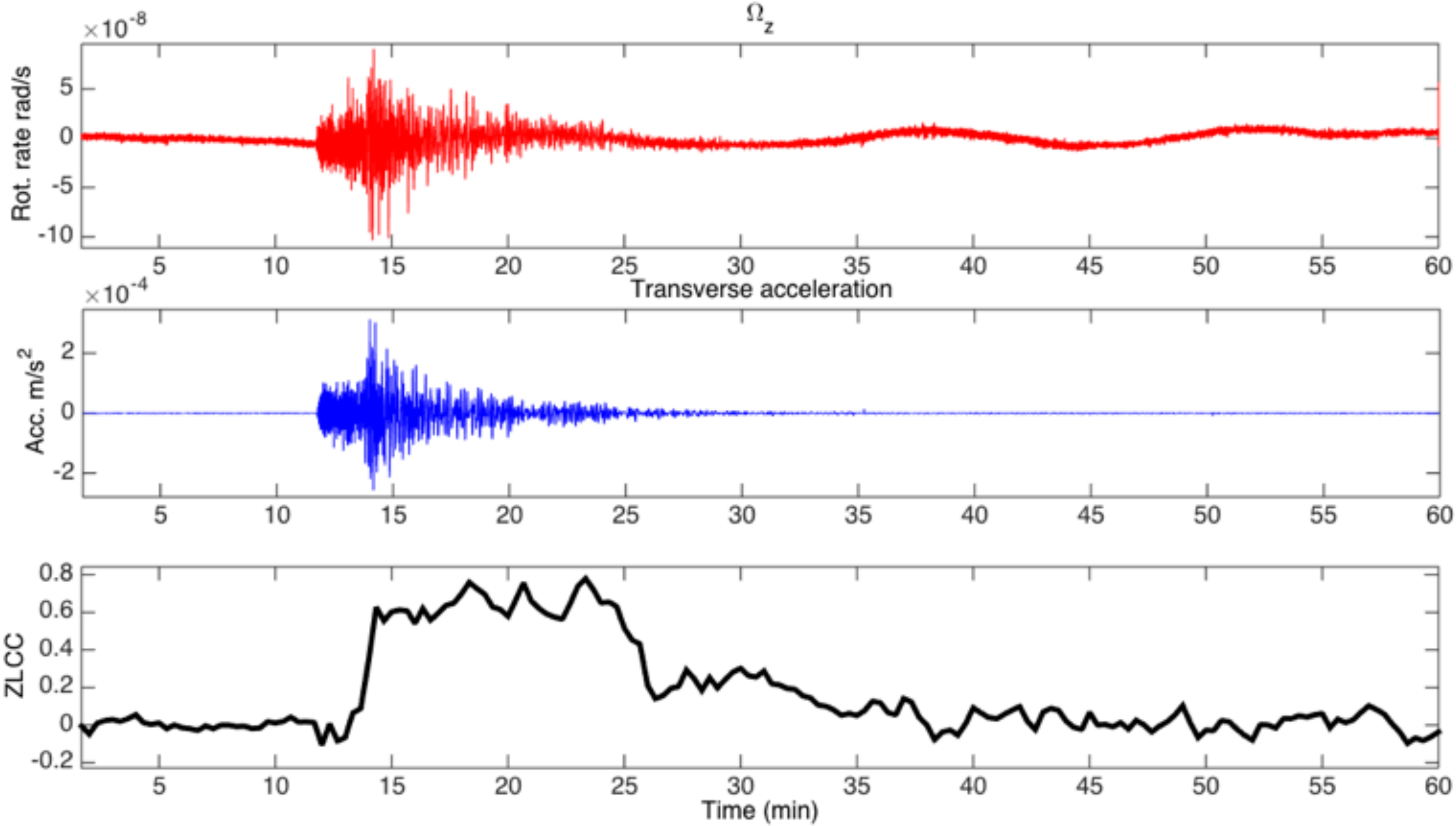
PREM phase velocity (continental)



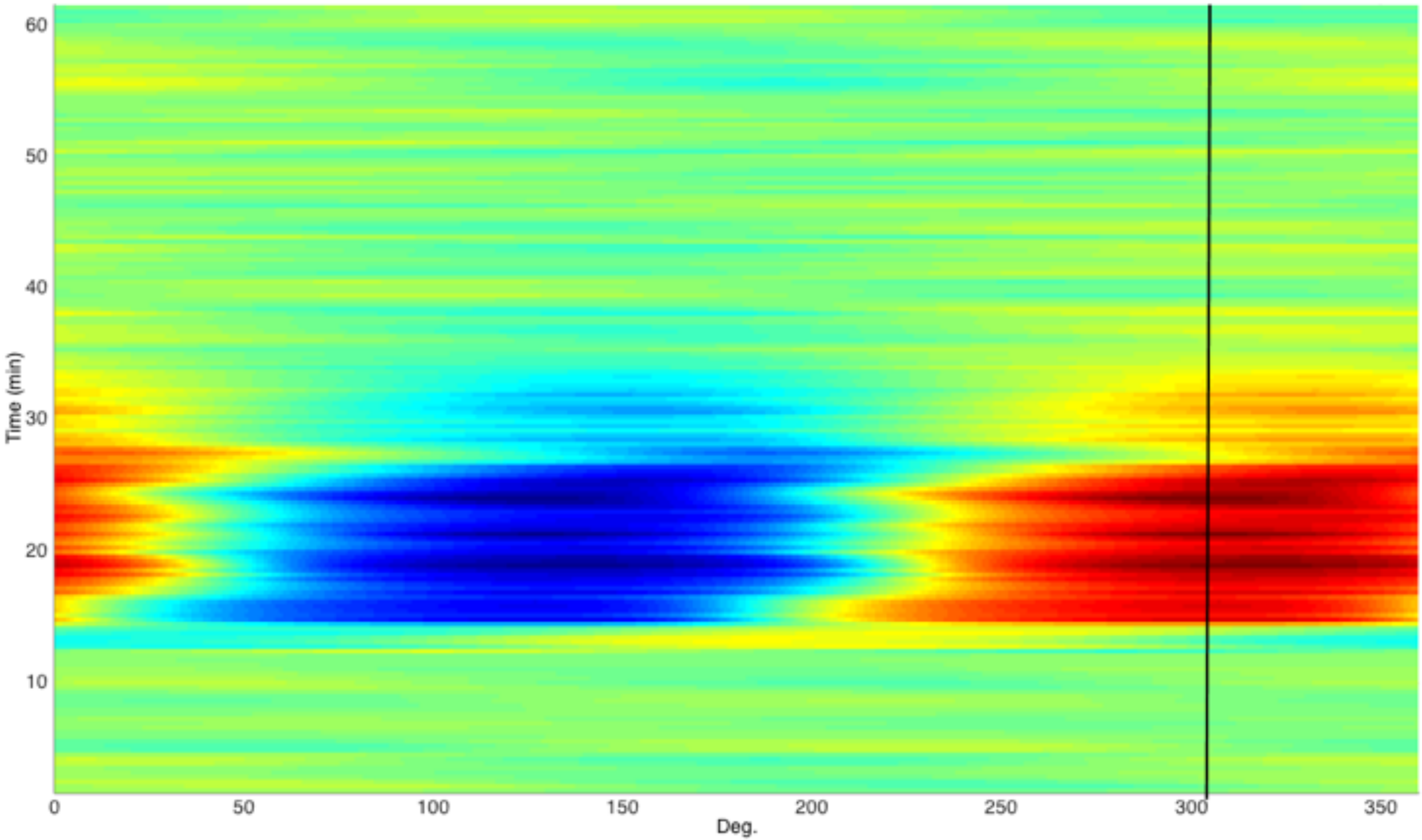
Earthquake with magnitude of 6.8 on date 20-10-2015 and time 21:52:02 (UTC) in region Vanuatu Islands [Sea]



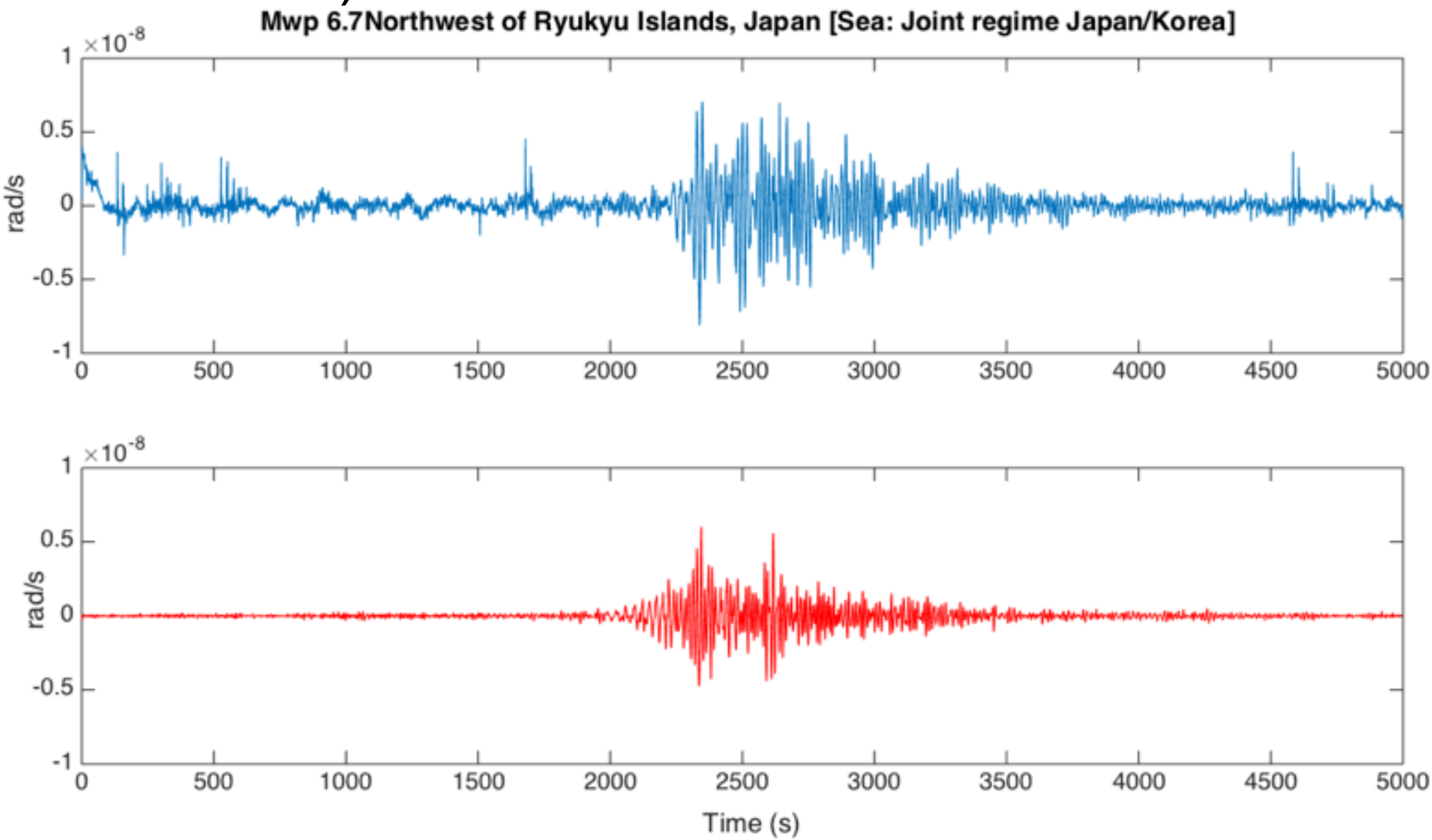
Earthquake with magnitude of 6.5 on date 17-11-2015 and time 07:10:08 (UTC) in region Costa Greca Ionica (GRECIA)



Azimuth estimation



First multi station observation of rotational signals from a tele-seismic event (G_wettzel (red) & GINGERino) !



Evidence of cross talk between Seismic signals and back scattering observables

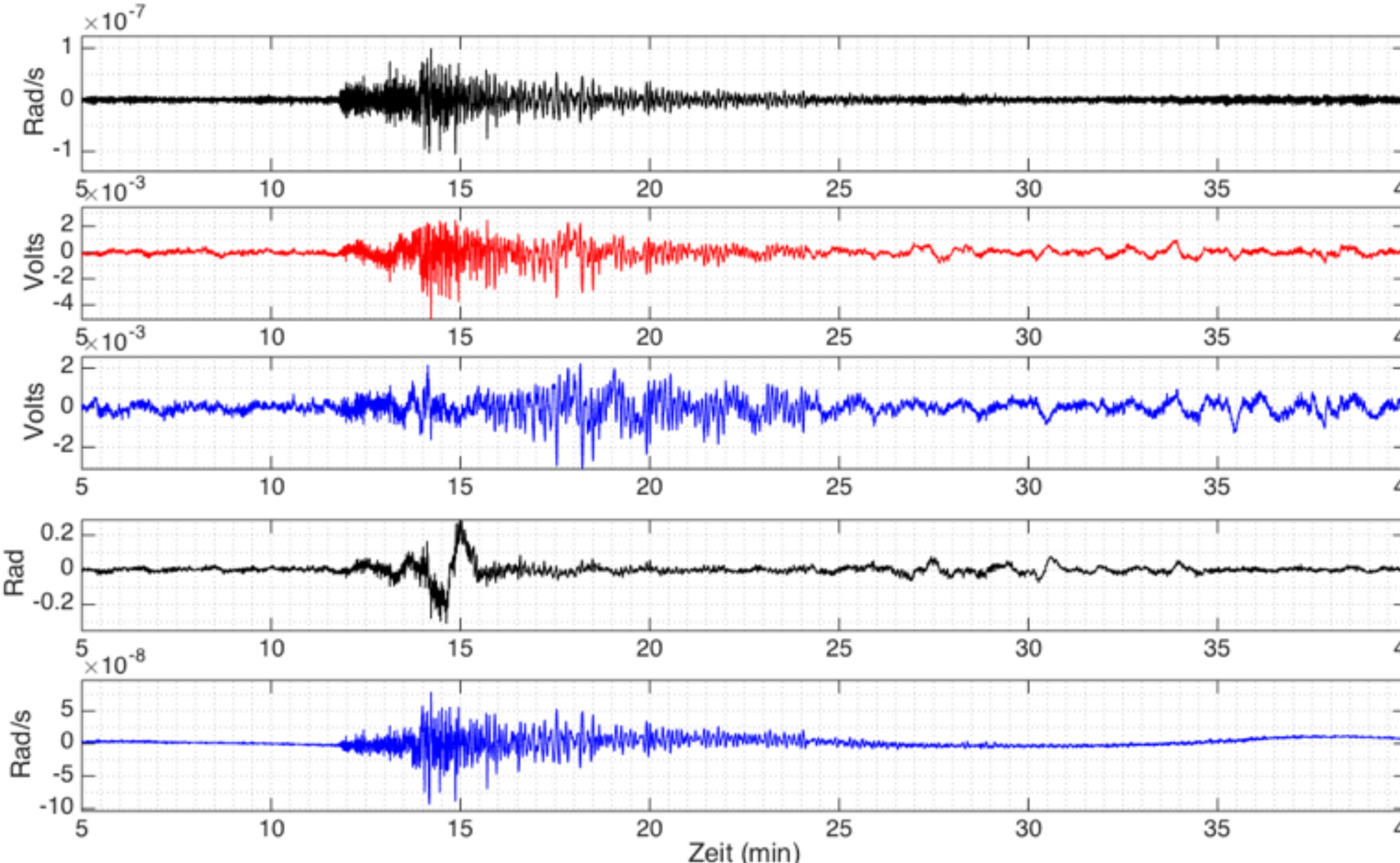
- For the Greece earthquake i performed the standard identification analysis on mono-beams signals and the result is surprising, at least for a strongly back scattering affected RLG……
- Actually the quality of the mirrors is lower, this is the cause of a shorter ring down time, an of the presence of more back scattering (less ideal behavior)

RLG model

$$\frac{1}{E_\pm}\frac{dE_\pm}{dt} = (\pi a - \beta E_\pm^2 - \xi E_\mp^2) + \rho_\mp \cos(\psi \mp \zeta)$$

$$\frac{d\psi}{dt} = 2\pi f(t) - \rho_- \sin(\psi - \zeta) - \rho_+ \sin(\psi + \zeta)$$

where $\rho_\pm = r_\pm \frac{E_\pm}{E_\mp}$ is the amplitude of CW and CCW back scattering coefficients



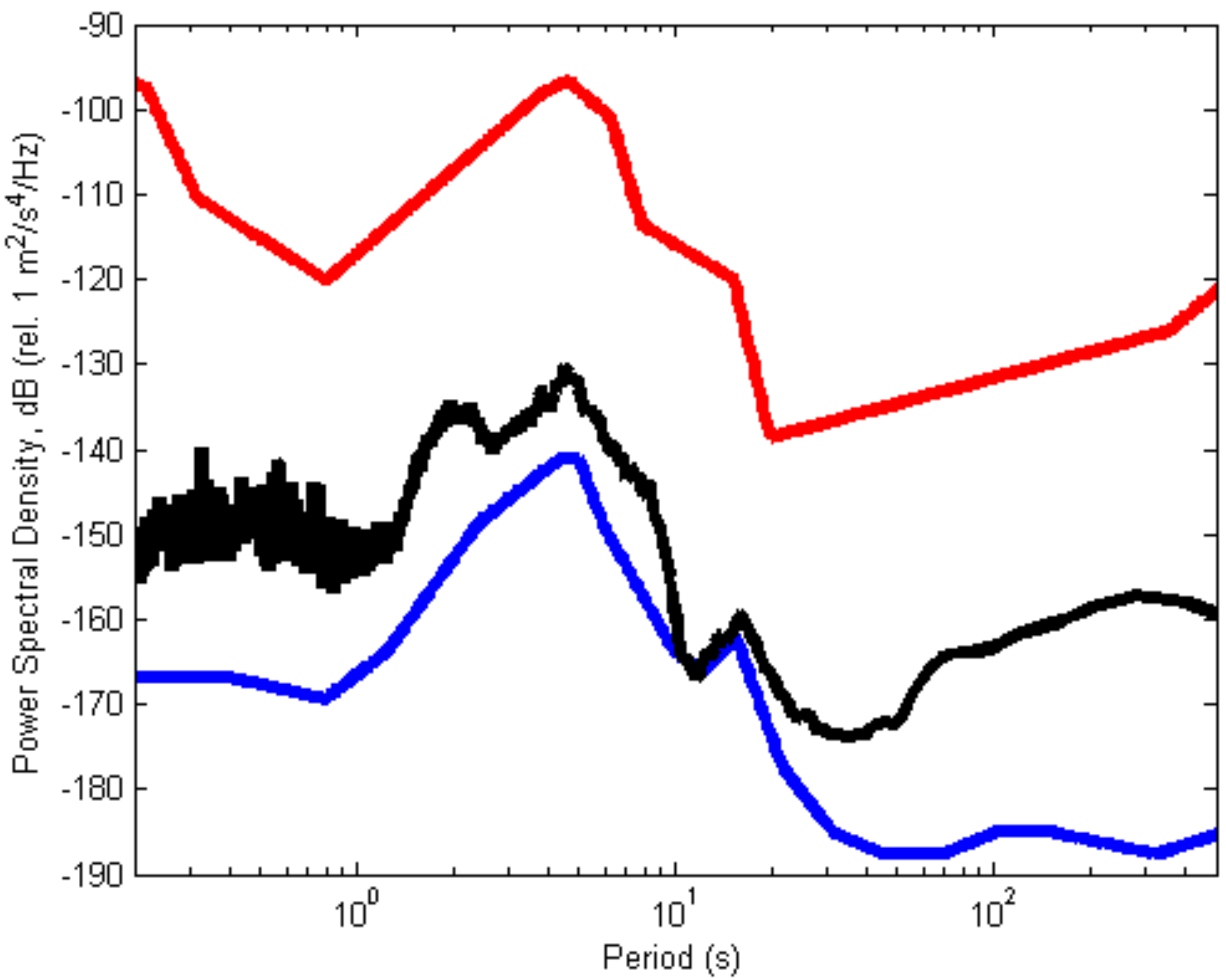
Actually this is my main interest, a paper is in progress about the correction of back scattering while recording seismic data on unideal RLGs

Seismic noise analysis @ gingerino site

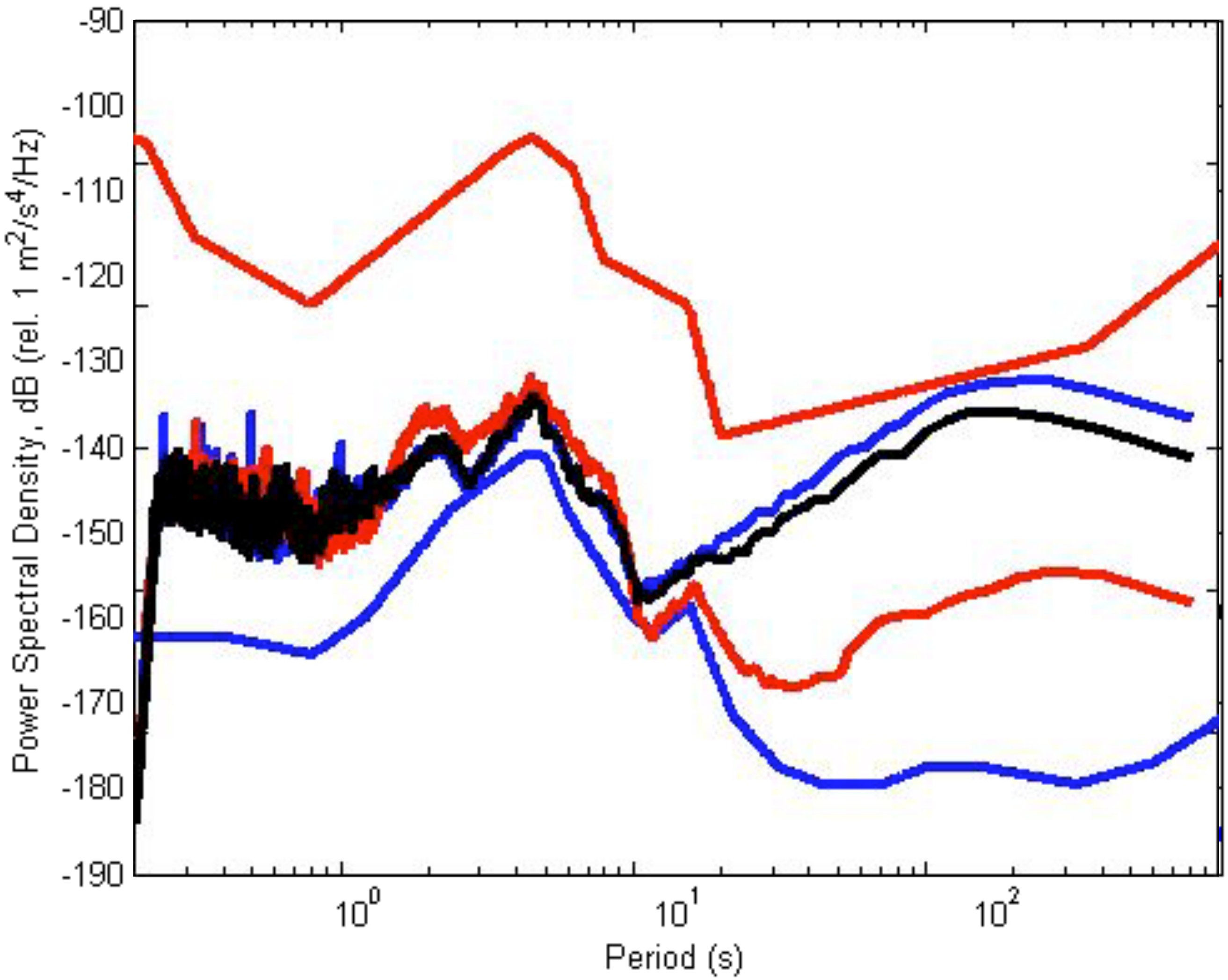
Bormann, P. (2009 online): Seismic Signals and Noise.

"At long periods, horizontal noise power may be significantly larger than vertical noise power.
The ratio increases with the period and may reach a factor of up to 300 (about 50 dB). A site can be considered as still favorable when the horizontal noise at 100 to 300 s is within 20 dB. This is mainly due to tilt, which couples gravity into the horizontal components but not into the vertical. Tilt may be caused by traffic, wind or local fluctuations of barometric pressure. Recording the latter together with the seismic signals may allow correction for this long-period noise (e.g., Beauduin et al.1996). Other reasons for increased long-period noise may be air circulation in the seismometer vault or underneath the sensor cover. Special care in seismometer installation and shielding is therefore required in order to reduce drifts and long-period environmental noise "

Trilium 240 z component



Trilium 240 3 components



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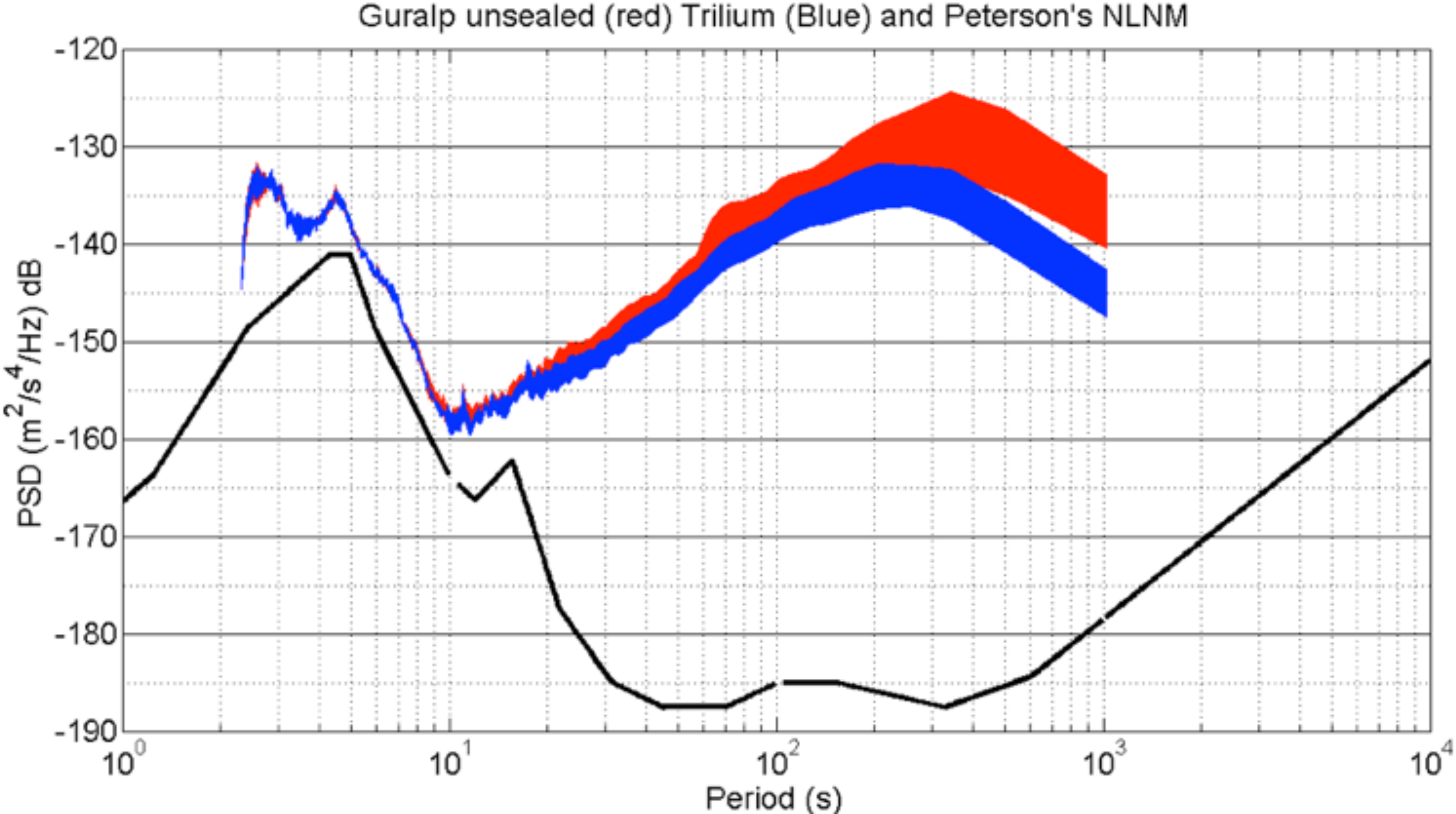
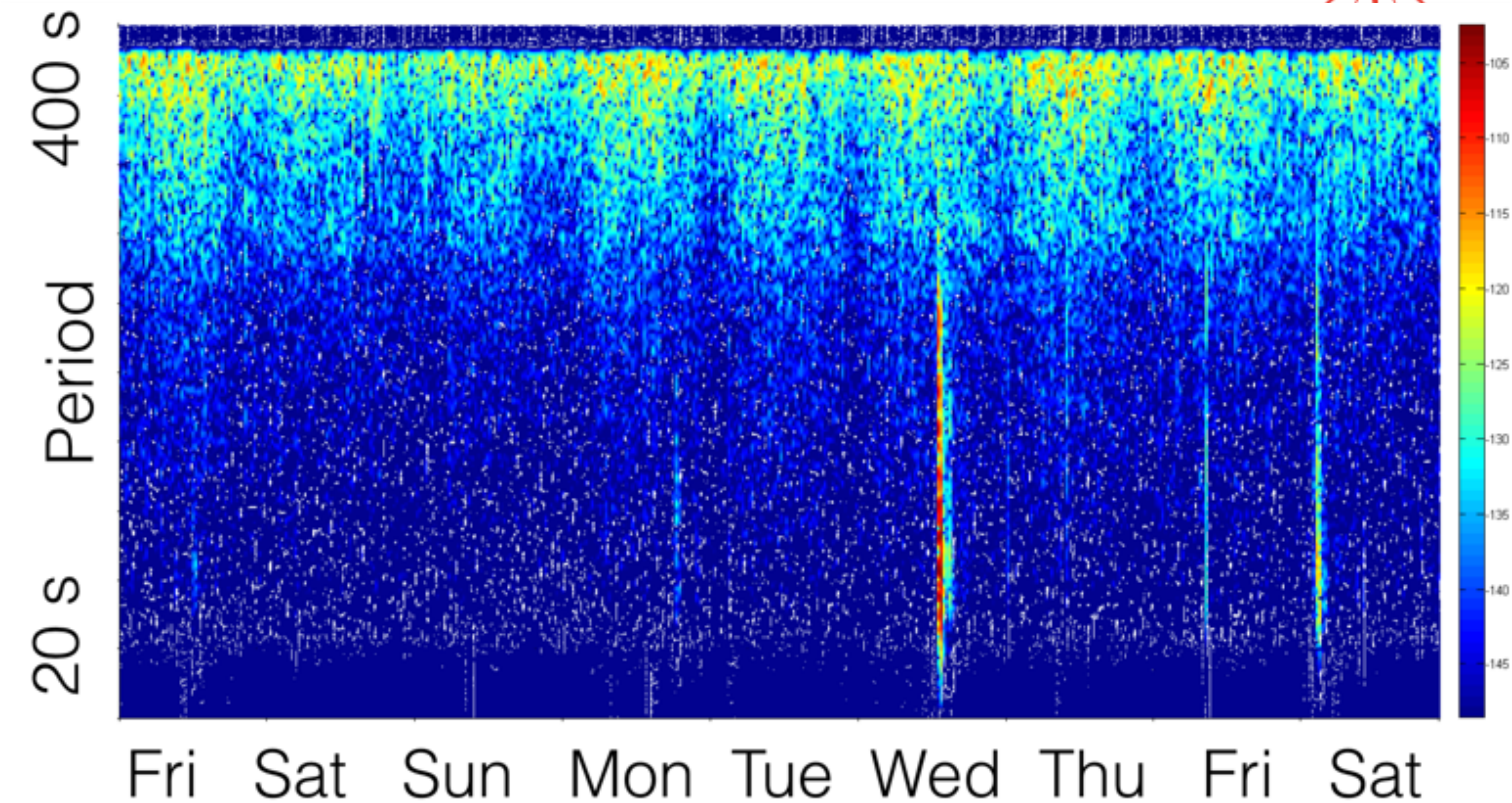
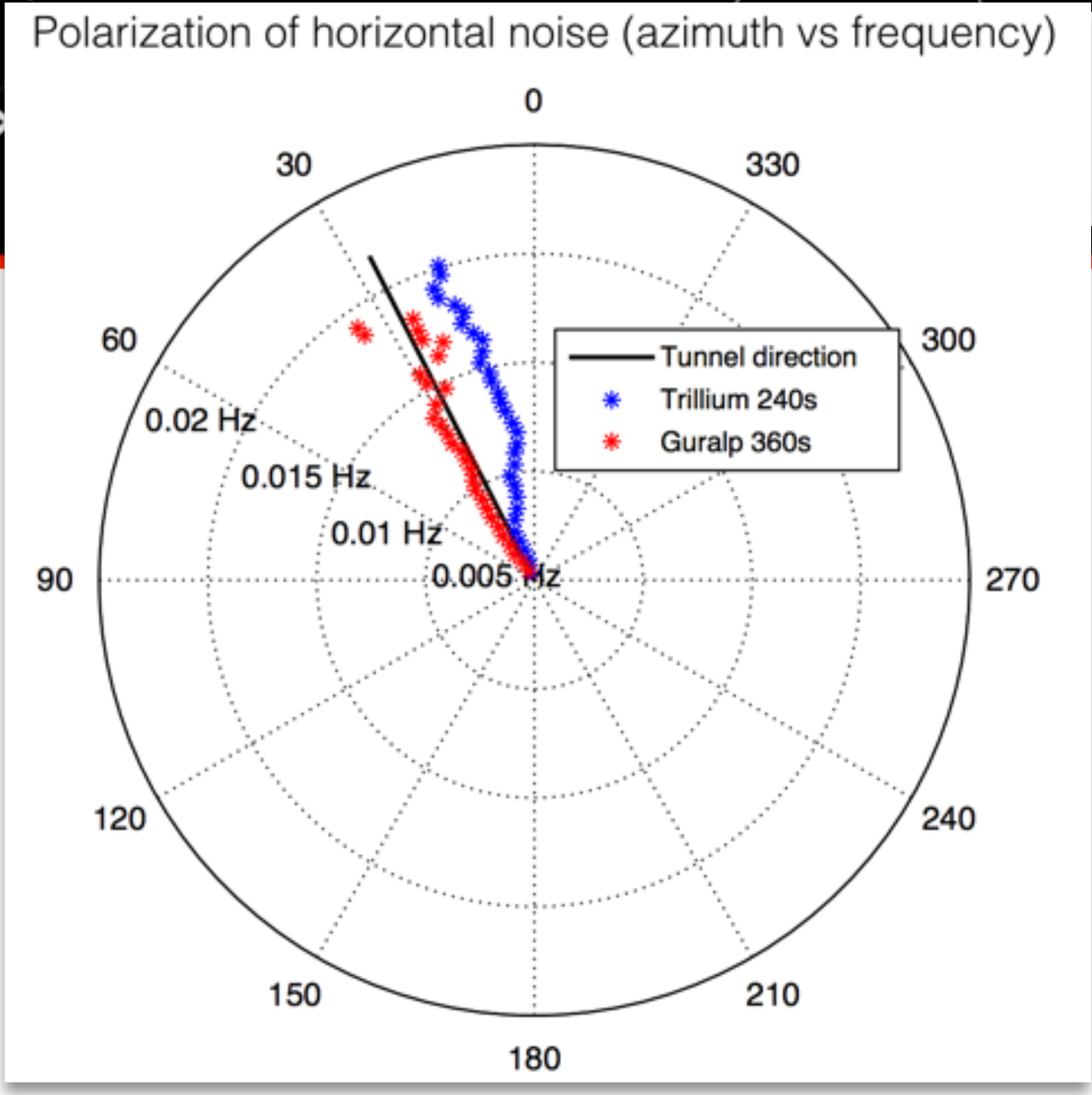


TF analysis of horizontal seismic noise polarized in the tunnel direction





I’m working on the same analysis for the FFB seismos where in a poor installation they have similar tilt noise issues

Conclusions

- To conclude we remark that a seismic station co-located with a RLG has been installed in the underground laboratories of INFN under the Gran Sasso. The Gingerino station is now the second in size and sensitivity in the world.
- For the first time a tele seismic rotational signal has been recorded in an underground environment.
- The Azimuth analysis has shown a very good agreement with the expected ones for more than one eq.
- The noise level in the vertical component is good, not in the horizontal ones, we are waiting for a pressure tight "pot" to be installed over the trillium 240 and in the future we hope to have pressure tight doors to enclose the gallery.
- We are planning to measure by an hot wire anemometer the turbulence level in the tunnel in order to try to correlate it with tilting noise.

Image of the envelope Transverse acc.