Rotational Seismology from G-Pisa Ring-Laser Gyroscope

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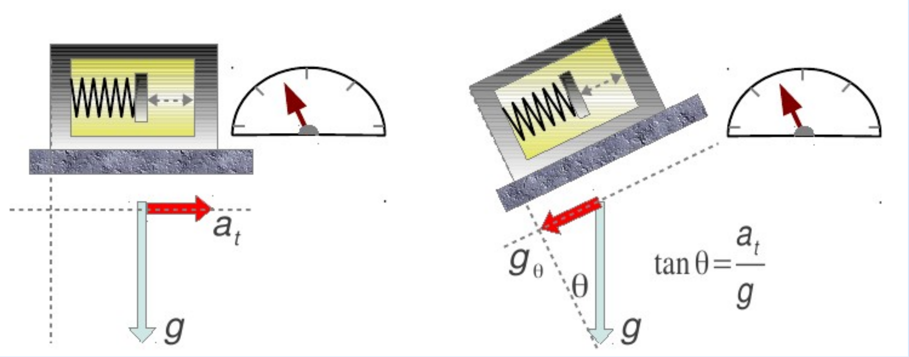
Basics of R.S.

GROUND MOTION is fully described by:

Translations (3c vector)
Strains (3 x 3 symmetric tensor)
Rotations (3c pseudo-vector)

Conventional Seismology, but...



Ground rotation is the curl of the seismic wavefield:

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

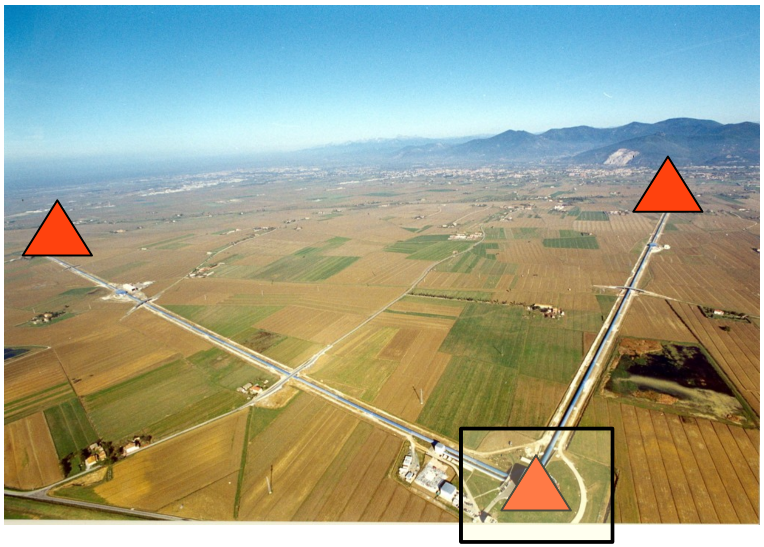
For plane waves propagating along the surface, rotation rate relates to ground acceleration via the phase velocity:

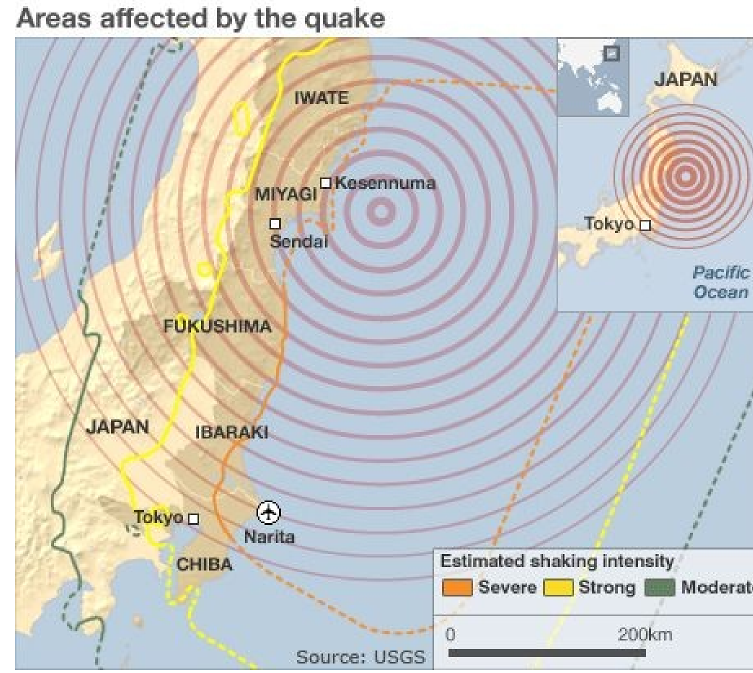
$$\ddot{u}_T = 2c_L\Omega_z \qquad \ddot{u}_z = \Omega_x c_R$$

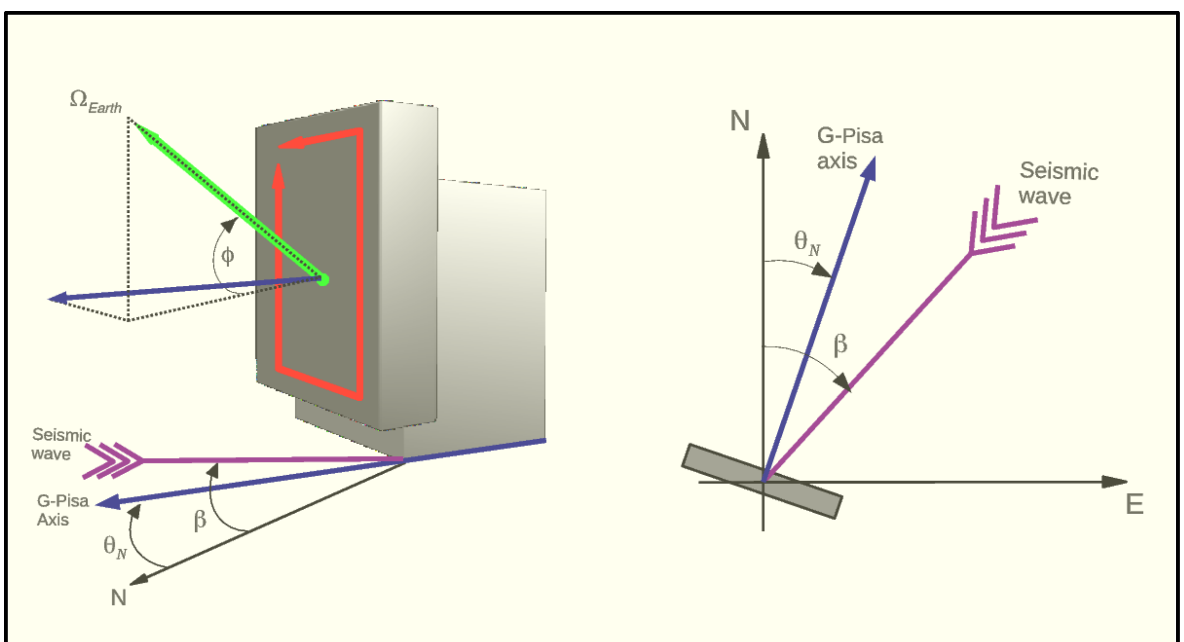
What we are getting out from G-Pisa for RS studies

- General validation of the instrument
- Phase Velocities
- Propagation Directions
- Cross-validation with tripartite array
- Local velocity structure
- Seismometer's response to rotation

Case Study 1: The March 11, 2011, Mw=9.0 Tohoku-Honshu Earthquake





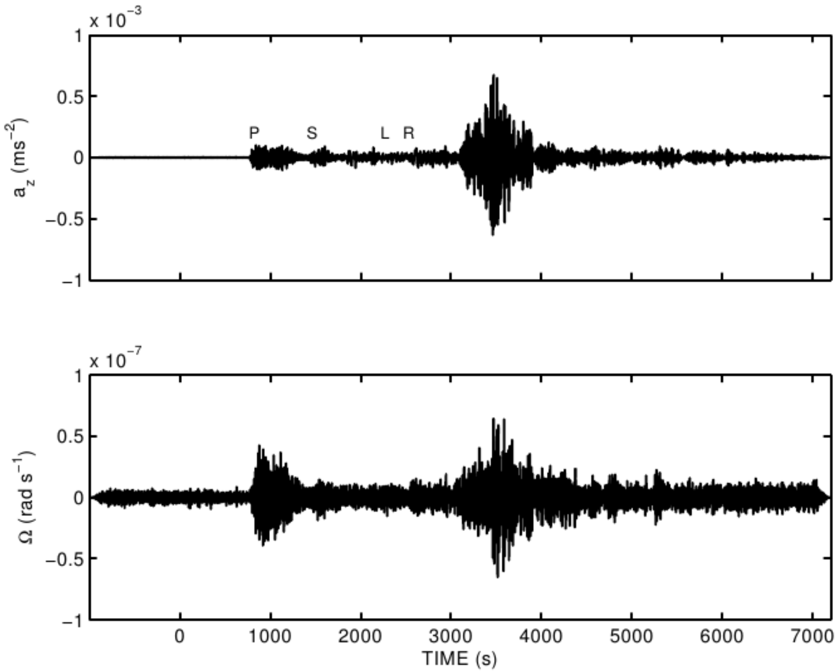


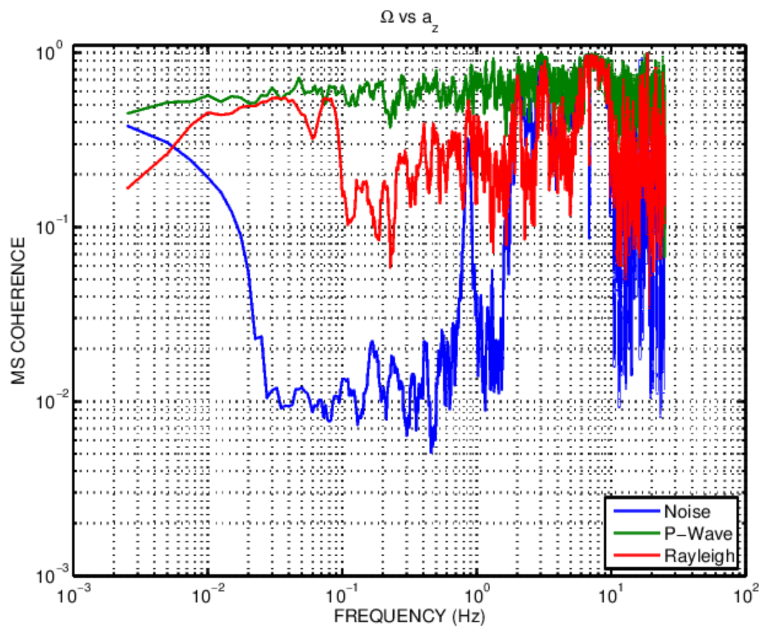
Unique observations of EQ rotations (tilt) by an **horizontal-axis** Gyro.

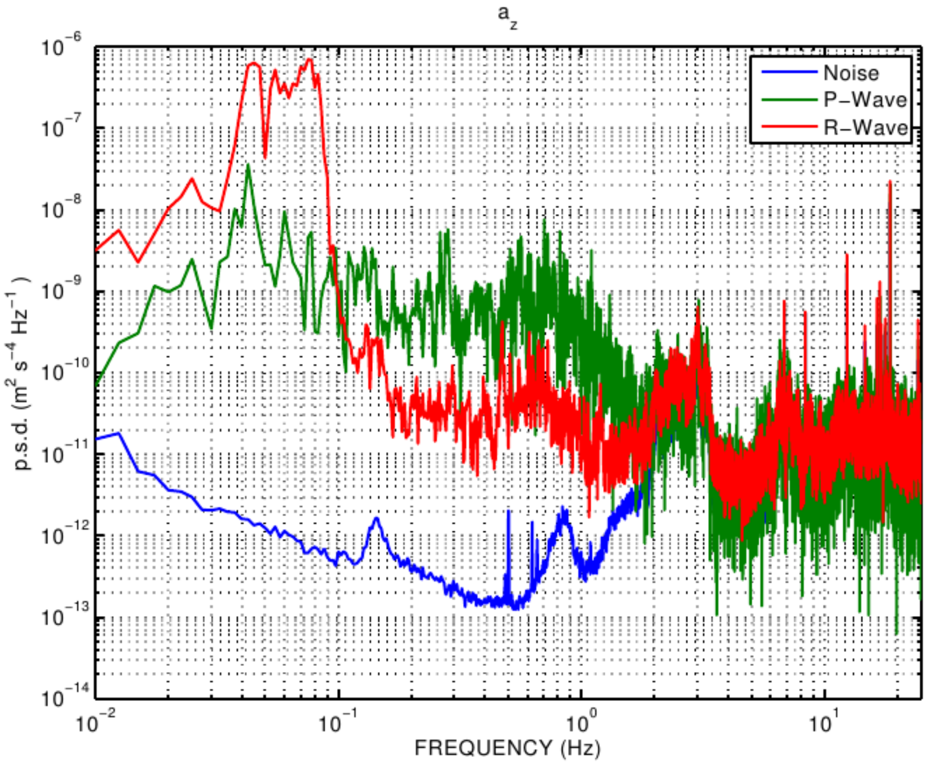
▲ FBA Accelerometers

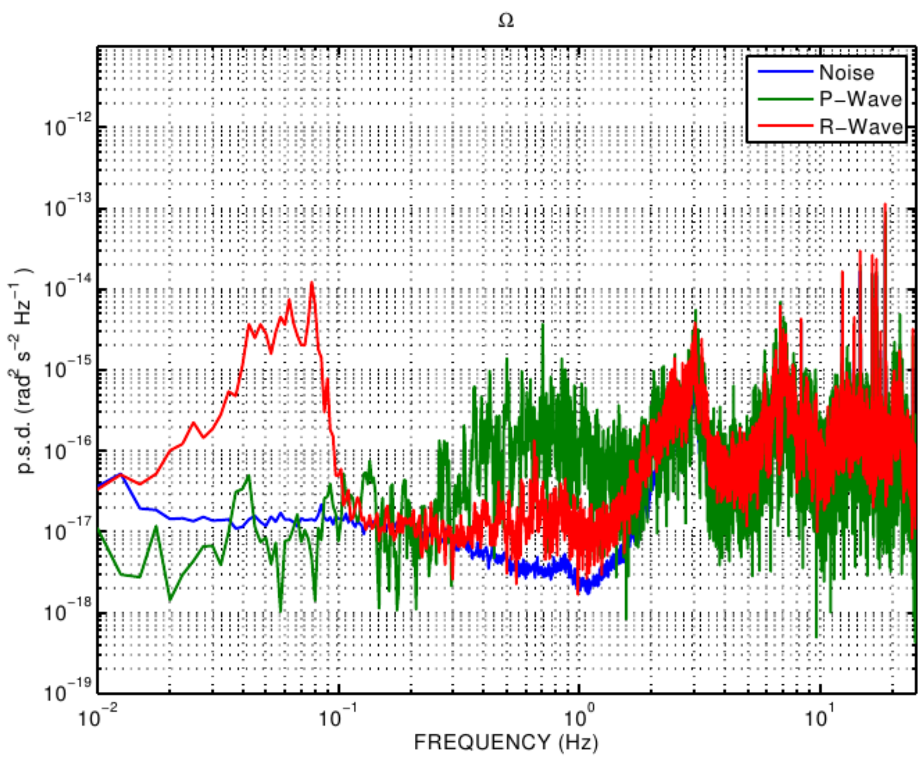
□ G-Pisa

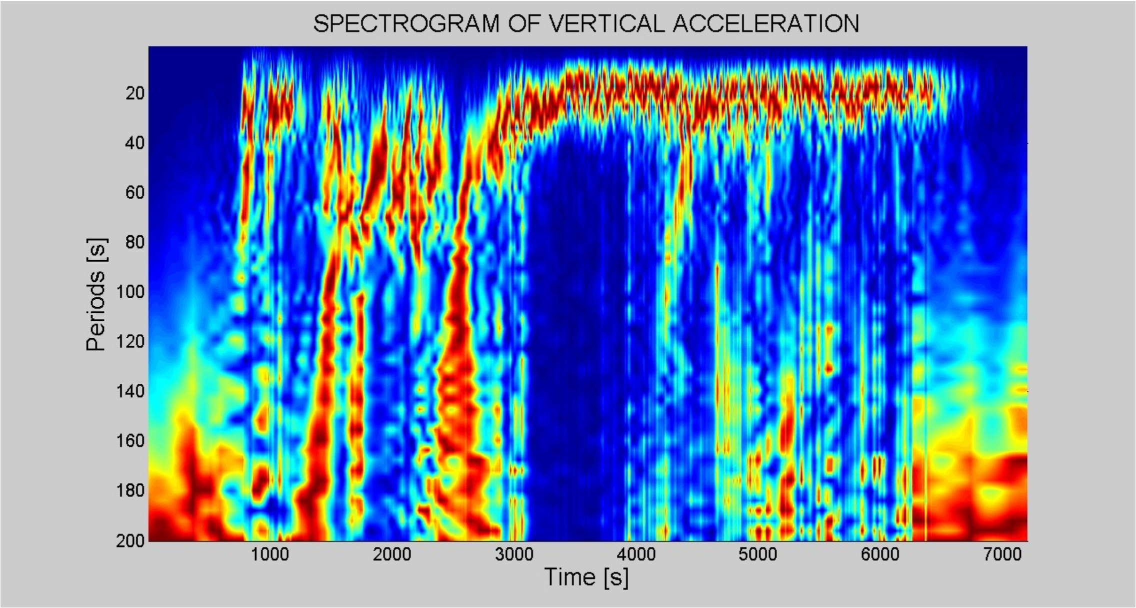
Time series, power spectra & coherence

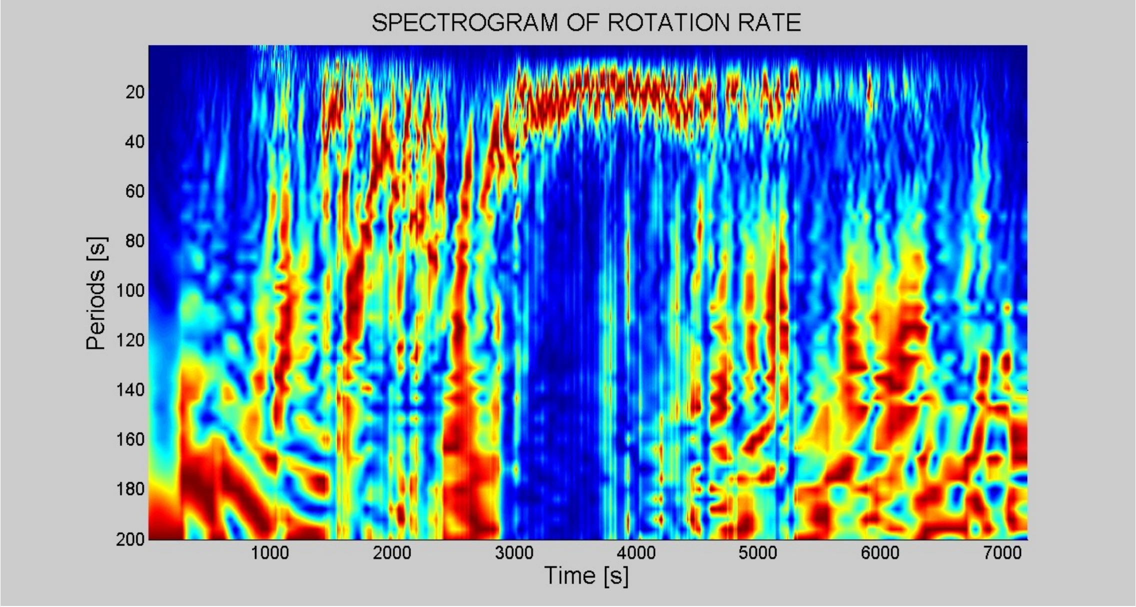








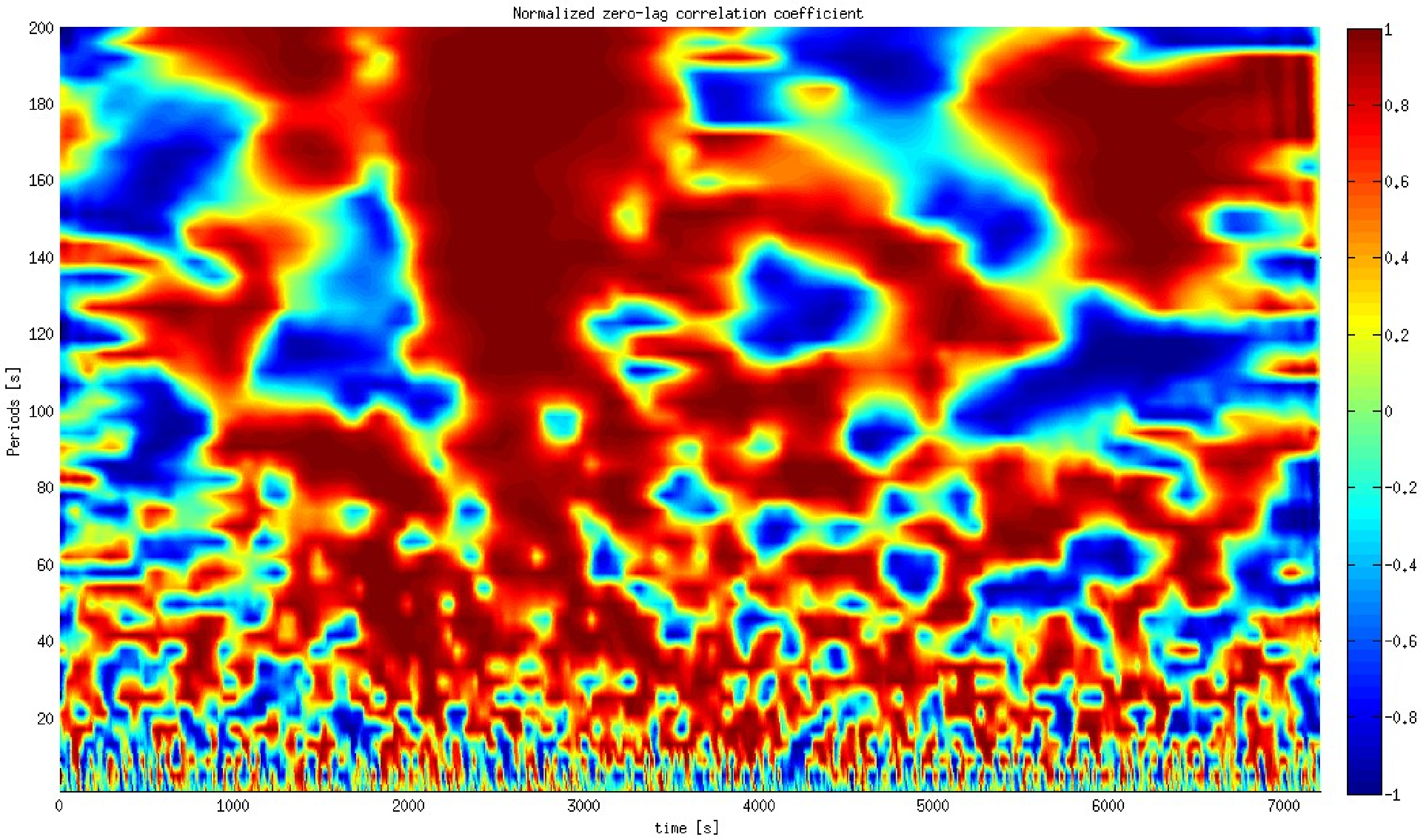




Time-Frequency Analysis

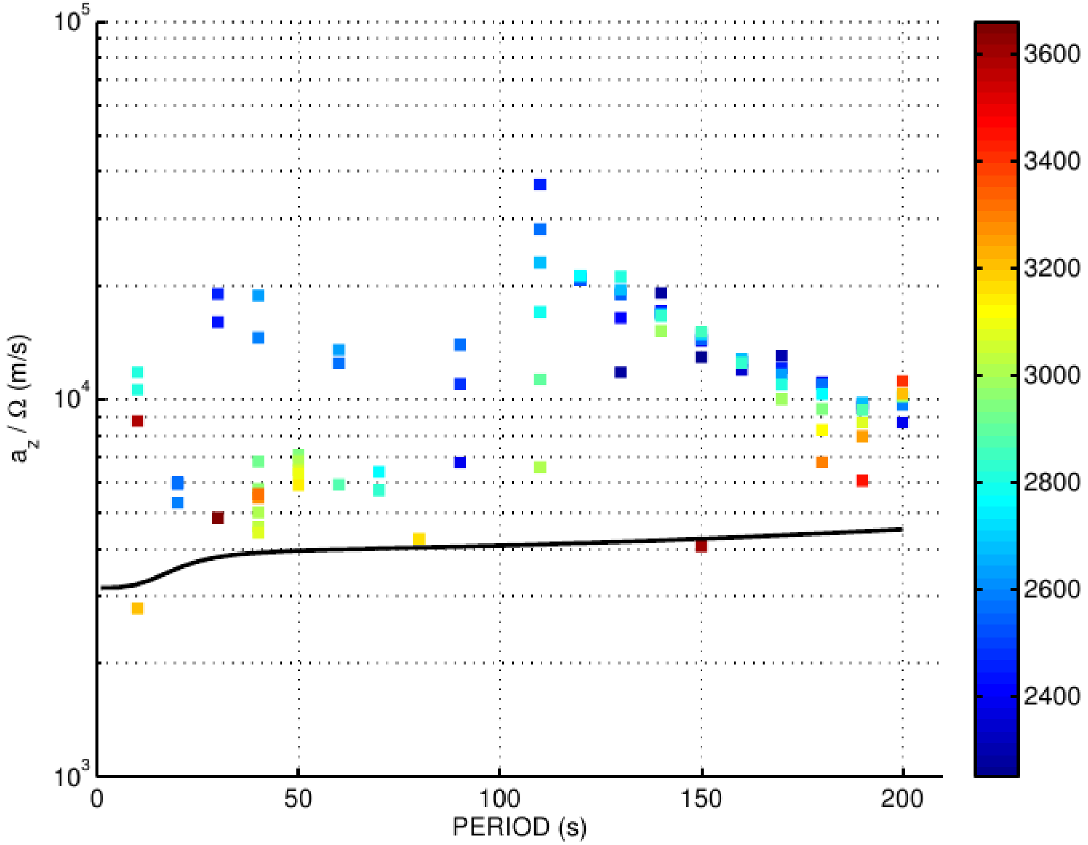
- Rotational components in P-coda;
- Dispersion is clearly observed.
- Wide-band correspondence between rotation and acceleration.
- VLP energy in the background noise: artifices or true (**Earth's hum...**)?

Multi-Band, zero-lag Waveform Correlation



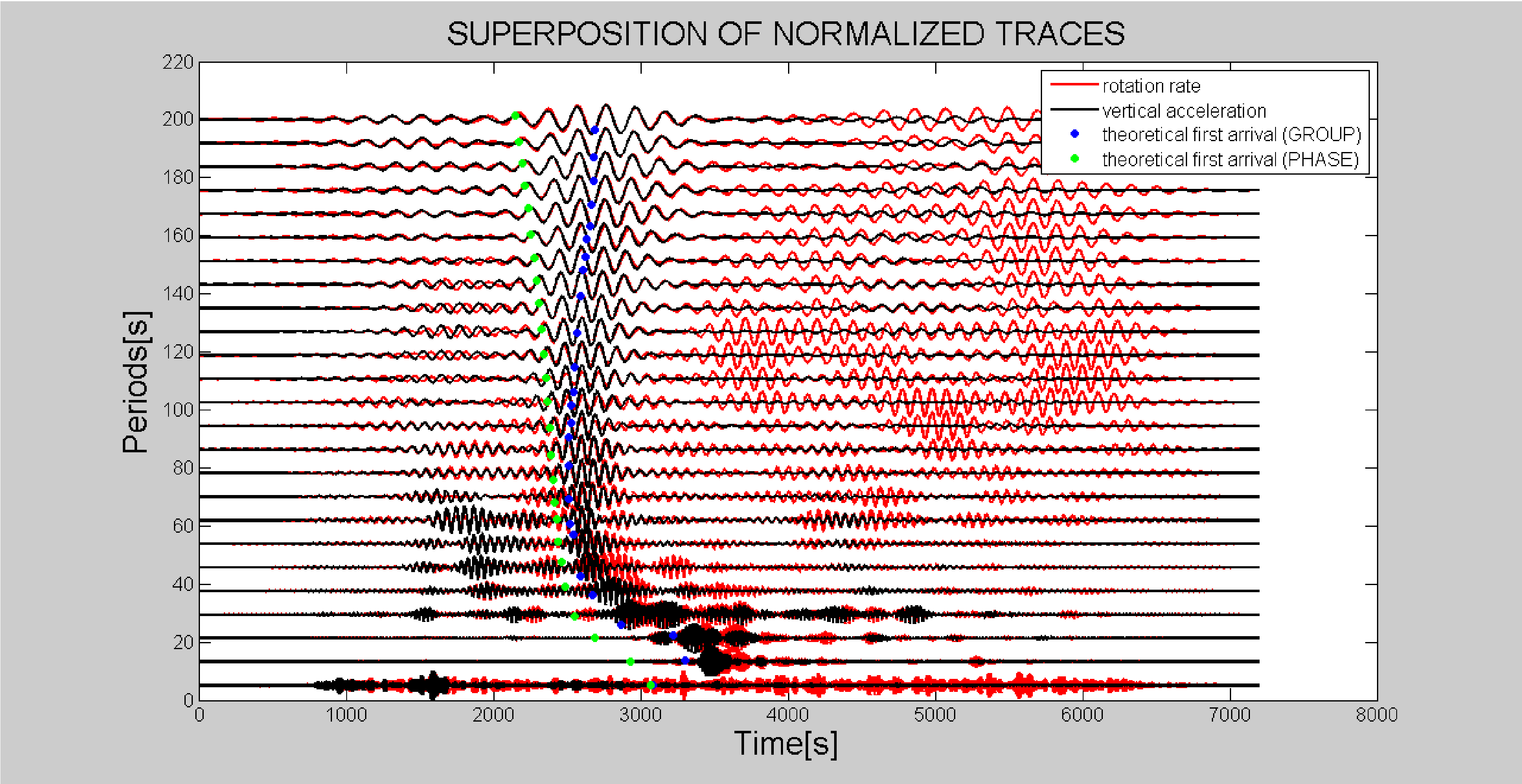
Derivation of Apparent Phase Velocities

T-F patches with significant correlation are used to infer apparent phase velocities from a / ω ratios.



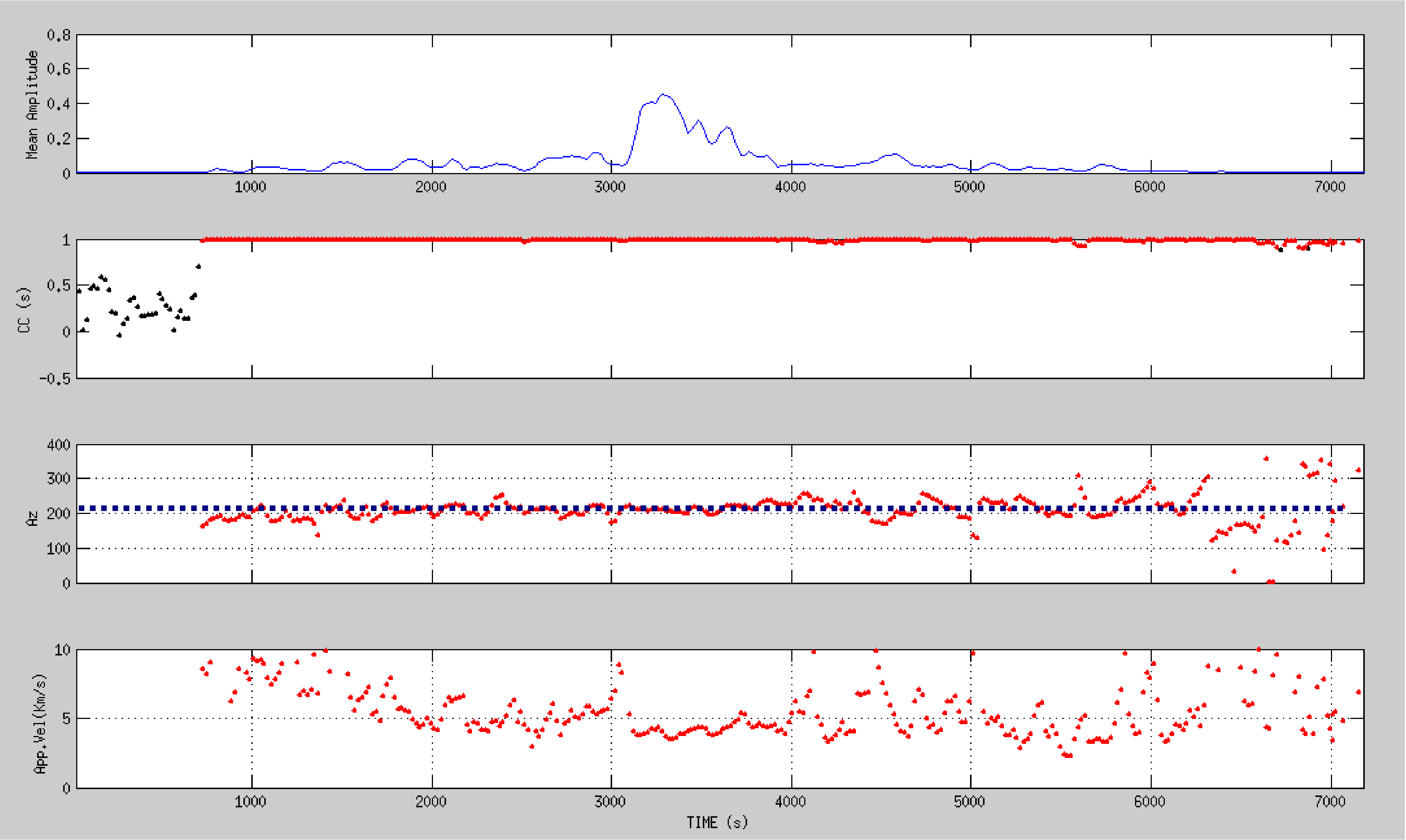
As a consequence of the oblique mounting of the gyroscope, apparent phase velocities are larger than, or equal to, the theoretical dispersion curve predicted by AK135 Earth Model

Comparison with theoretical dispersion curves



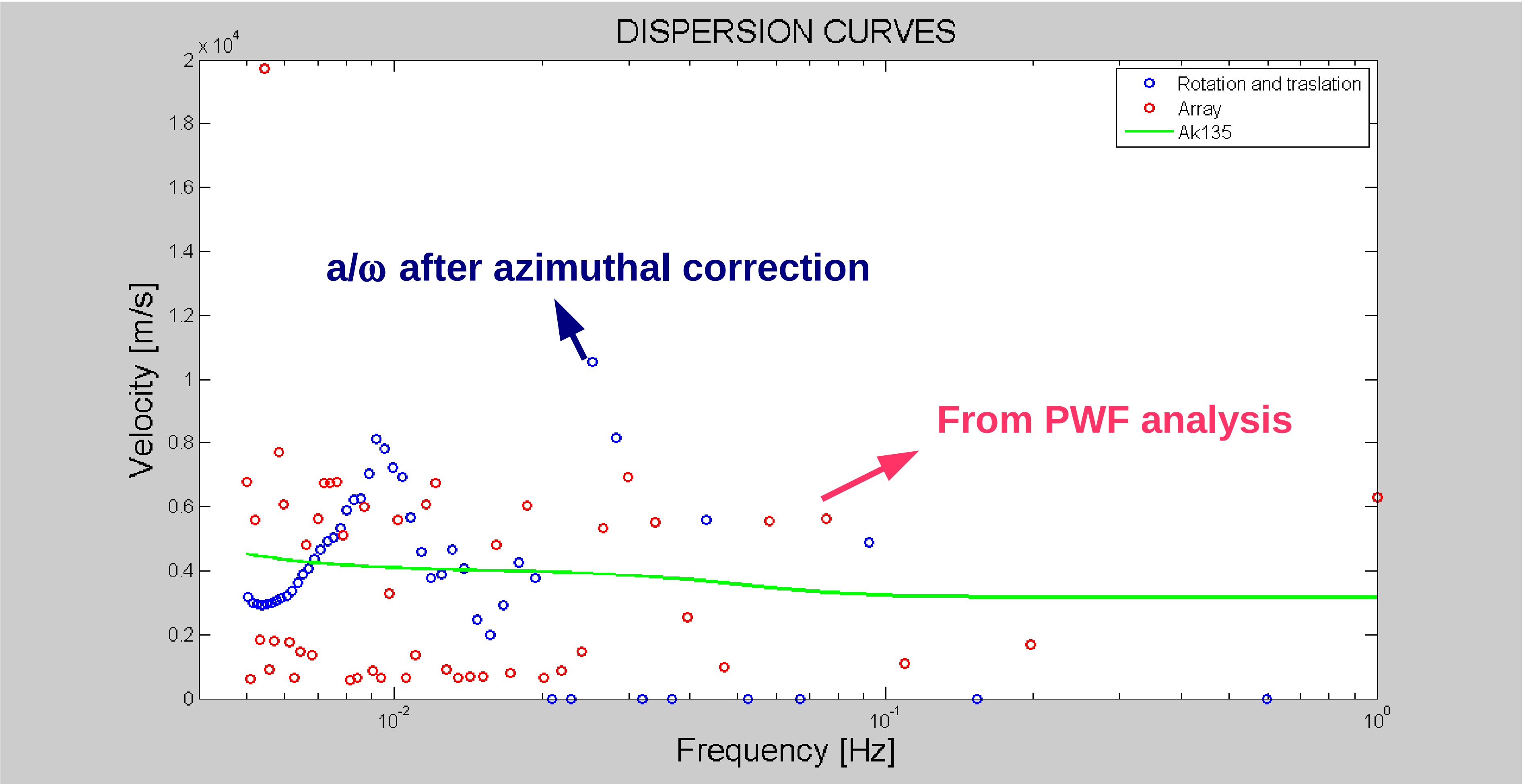
Significant divergence from model for T < 60s; waves are **slower** than expected. Effects of the local shallow structure ?

Array estimates of propagation direction and phase velocity



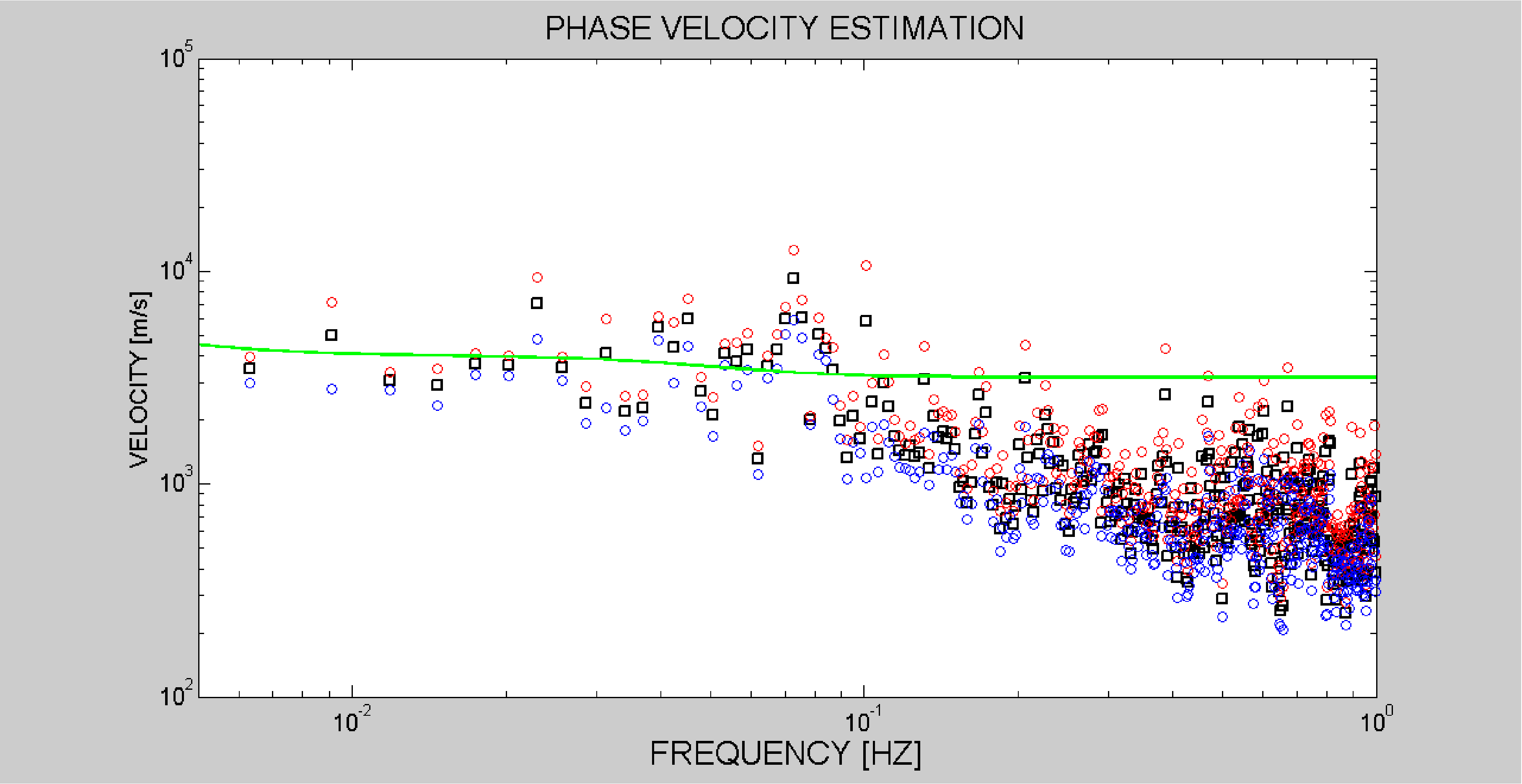
Determination of the wave vector from plane-wave fitting of inter-station delay times [BW=0.02 - 0.05 Hz]

Correction of phase-velocity for wave DOA determined from array analyses



Not encouraging! Need some further playing with frequency bands, and data selection criteria.

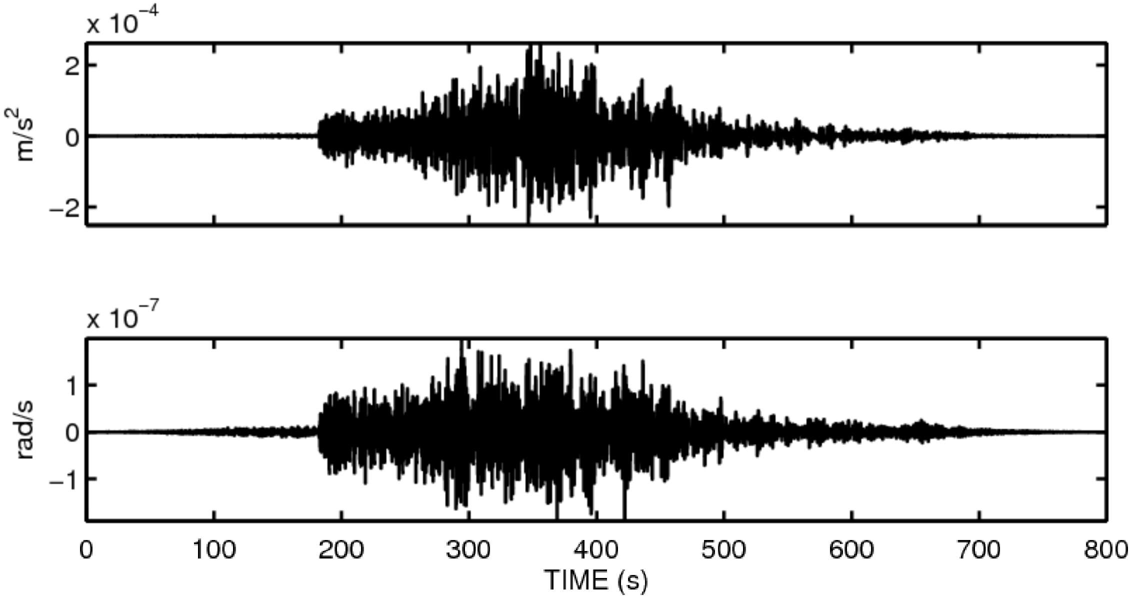
Phase velocities from spectral ratios (w/ azimuthal correction)



General consistency with model up to 100 mHz. Above this limit, it **underestimates** velocities predicted from model (see later...)

Case Study II

2010.11.03 - 00:56:55.40 43.76°N   20.73°E   Mw=5.5 (Croatia)

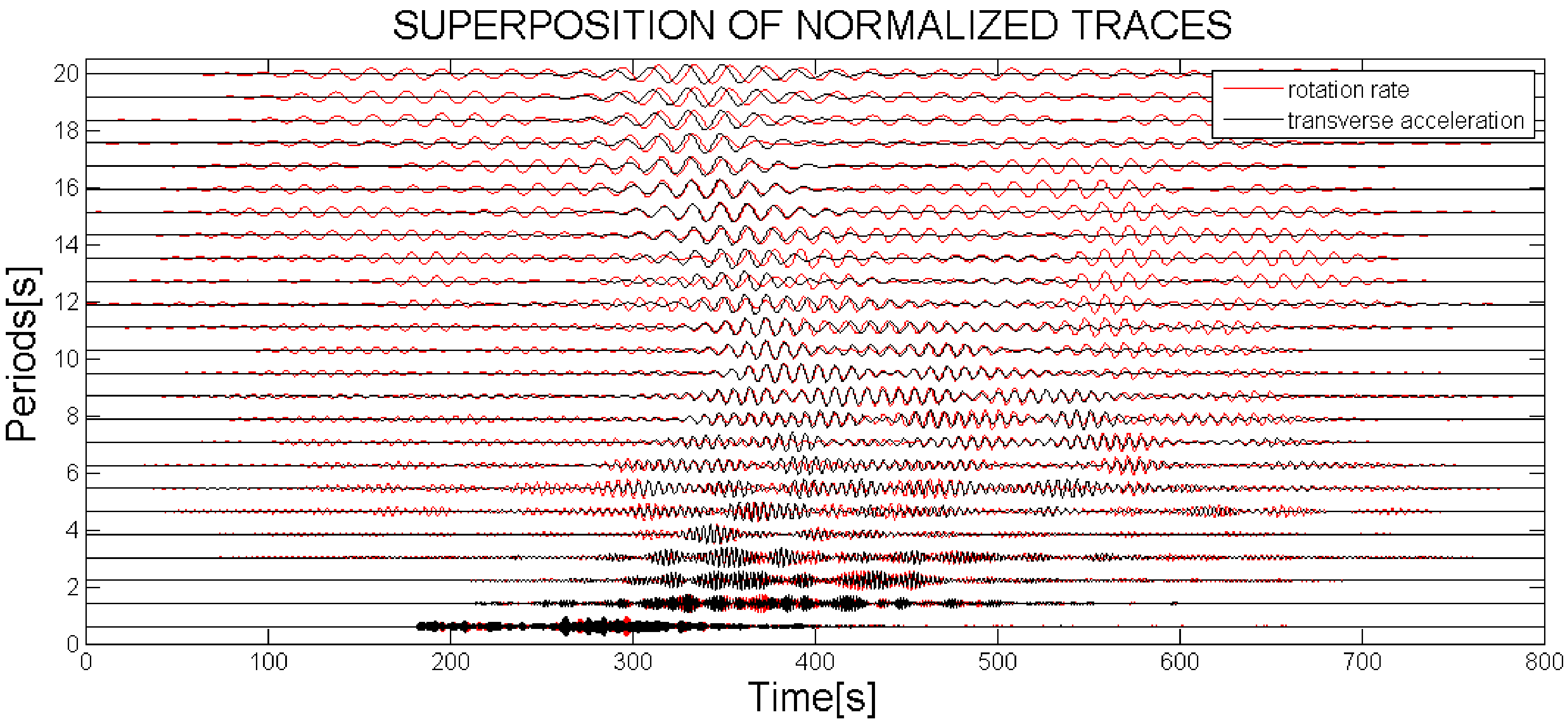


Vertical-axis gyro → Sensitivity to horizontally-polarised shear waves (SH, **Love**);

For horizontal, plane waves (Love) → $a / \omega = 2c$ independently from wave azimuth;

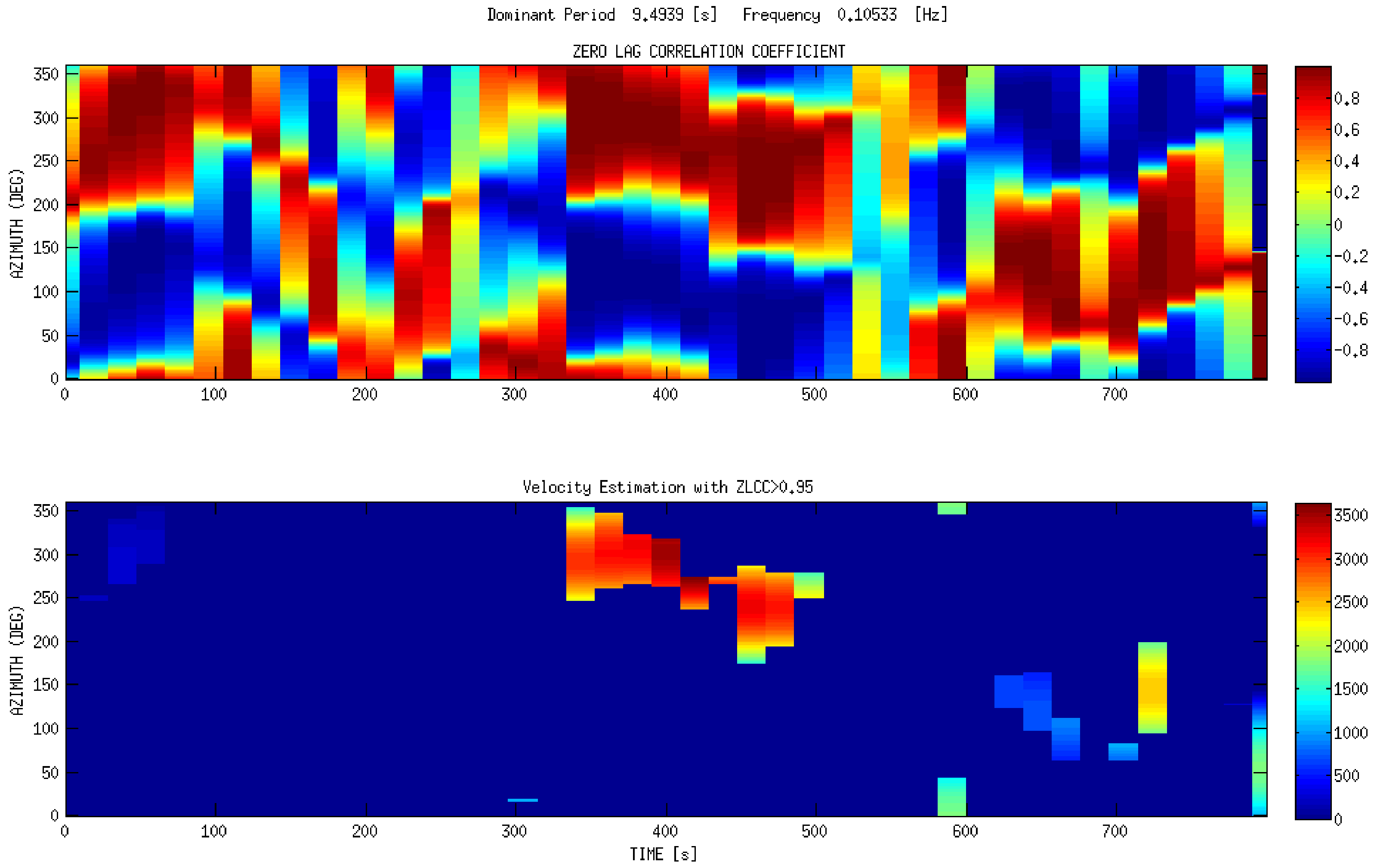
Correlation is maximum for transverse components → determination of source backazimuth.

Multi-band correlation analysis



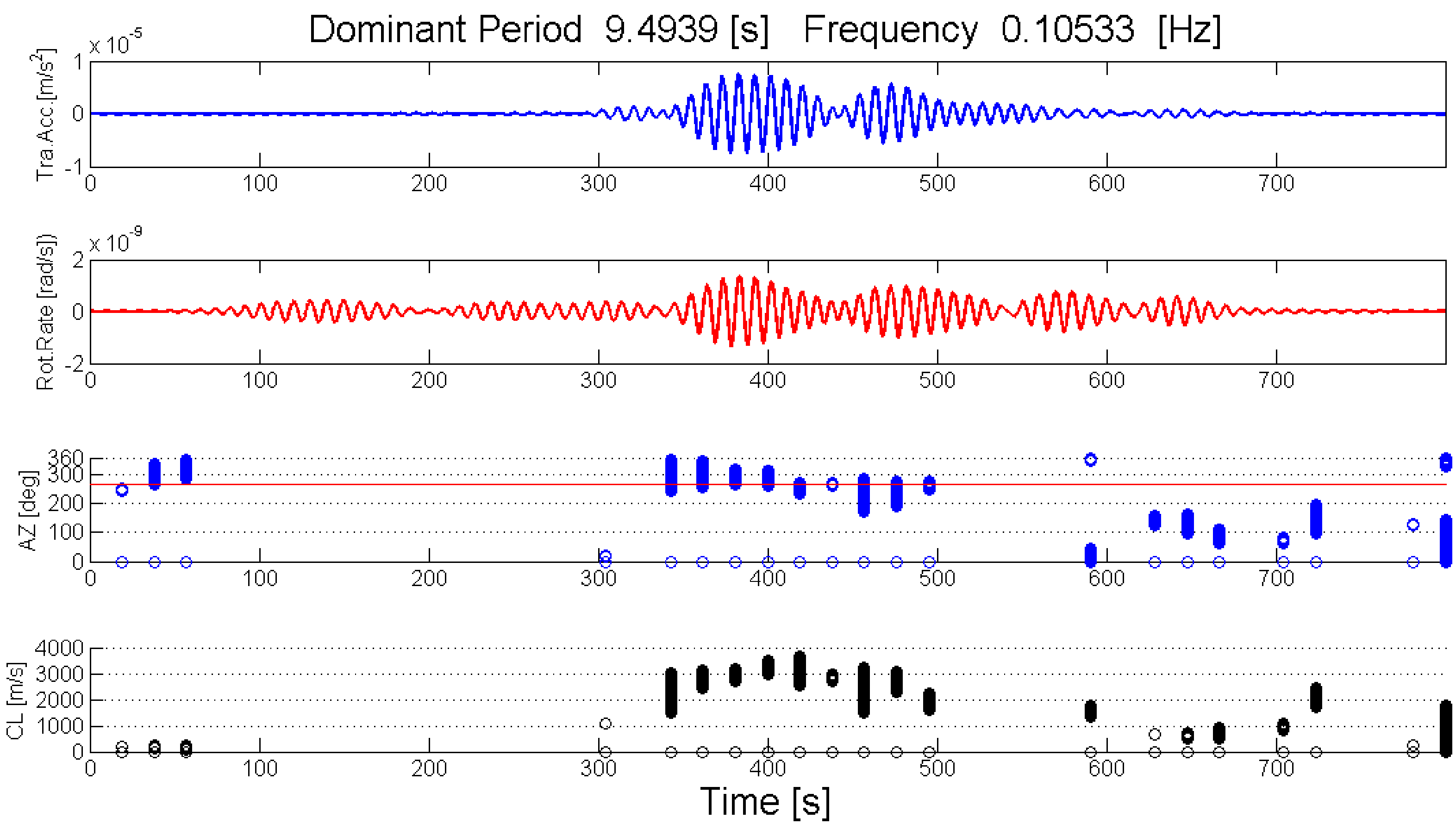
Excellent Love-waves correlation over the 8-16s period interval !

Multi-angle correlation analysis



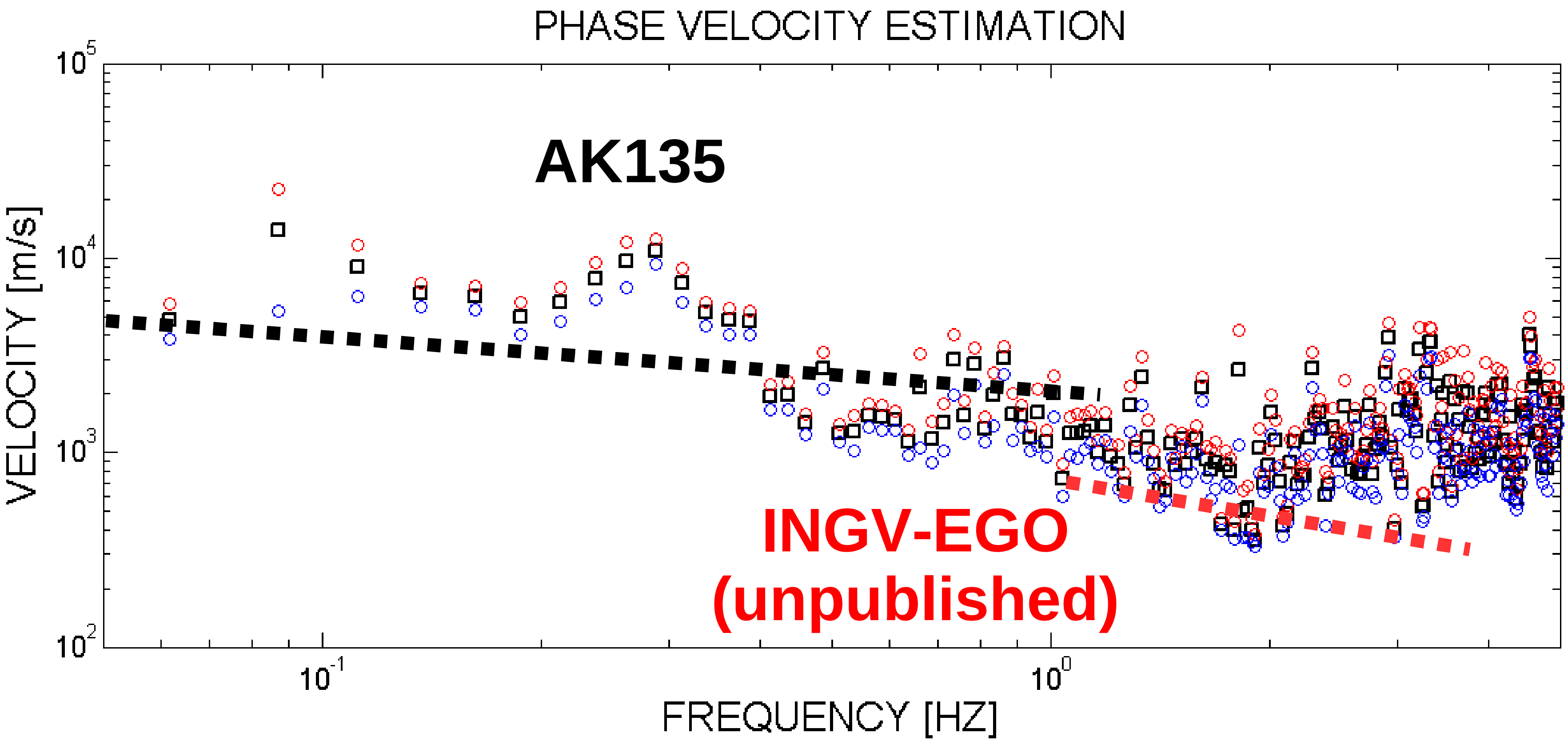
Zero-lag correlation vs time and rotation angle at T ~ 10s. Phase Velocities derived from amplitude ratios (cc > 0.95) are consistent with standard Earth's models (~3000 m/s).

Multi-angle correlation analysis



Rotational signal exhibits the largest correlation when horizontal trace is oriented transversally to the direction of the source (here 270°ACW from N) → constrain on event's location!

Phase velocity from spectral ratios



Phase velocities are overestimated w/respect to what predicted by both AK135 model and observed in an independent study.

Need to improve knowledge of the local structure from independent data.

What's Next

1. Extend the analysis to a larger data set for both the H and V gyroscopes;

2. Refine phase velocity determinations from a/w ratios → Need to understand discrepancies

3. Obtain independent estimates of phase velocities and dispersions (past array data from INGV-EGO collaboration);

4. Establishment of a semi-permanent 4C observatory (BB seismic + gyroscope) in S.Piero in Grado.

5. Joint array-gyro estimates of ground rotation (if financed!)