GINGER Collaboration

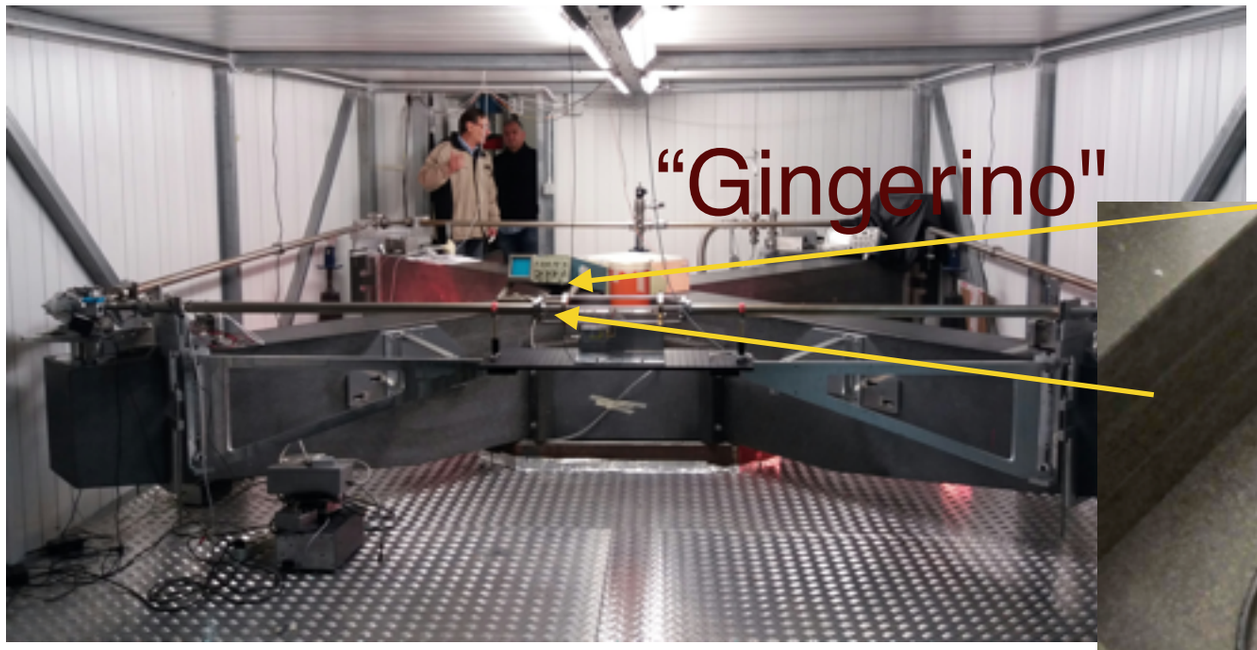
A seismic rotational observatory in Gran Sasso underground laboratories

Nicolò Beverini
Andreino Simonelli

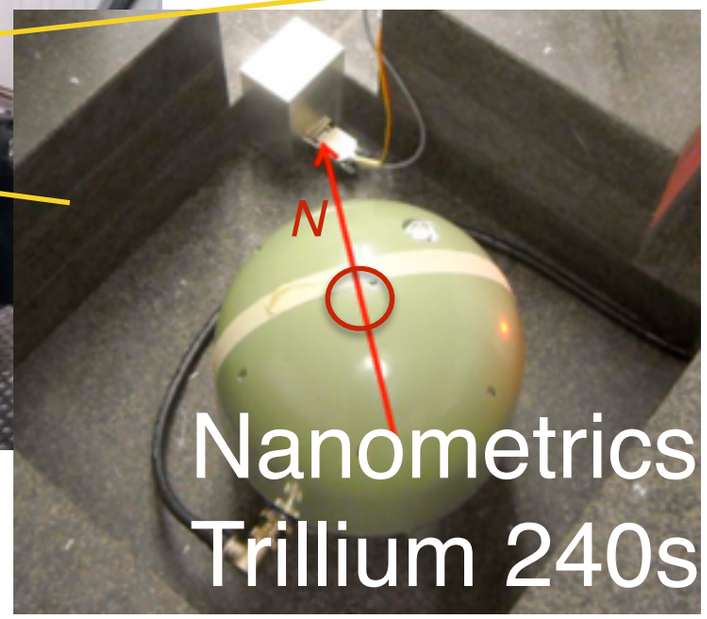
GINGER
Giroscopes in General Relativity
Istituto Nazionale di Fisica Nucleare, Pisa

GINGERino seismic station

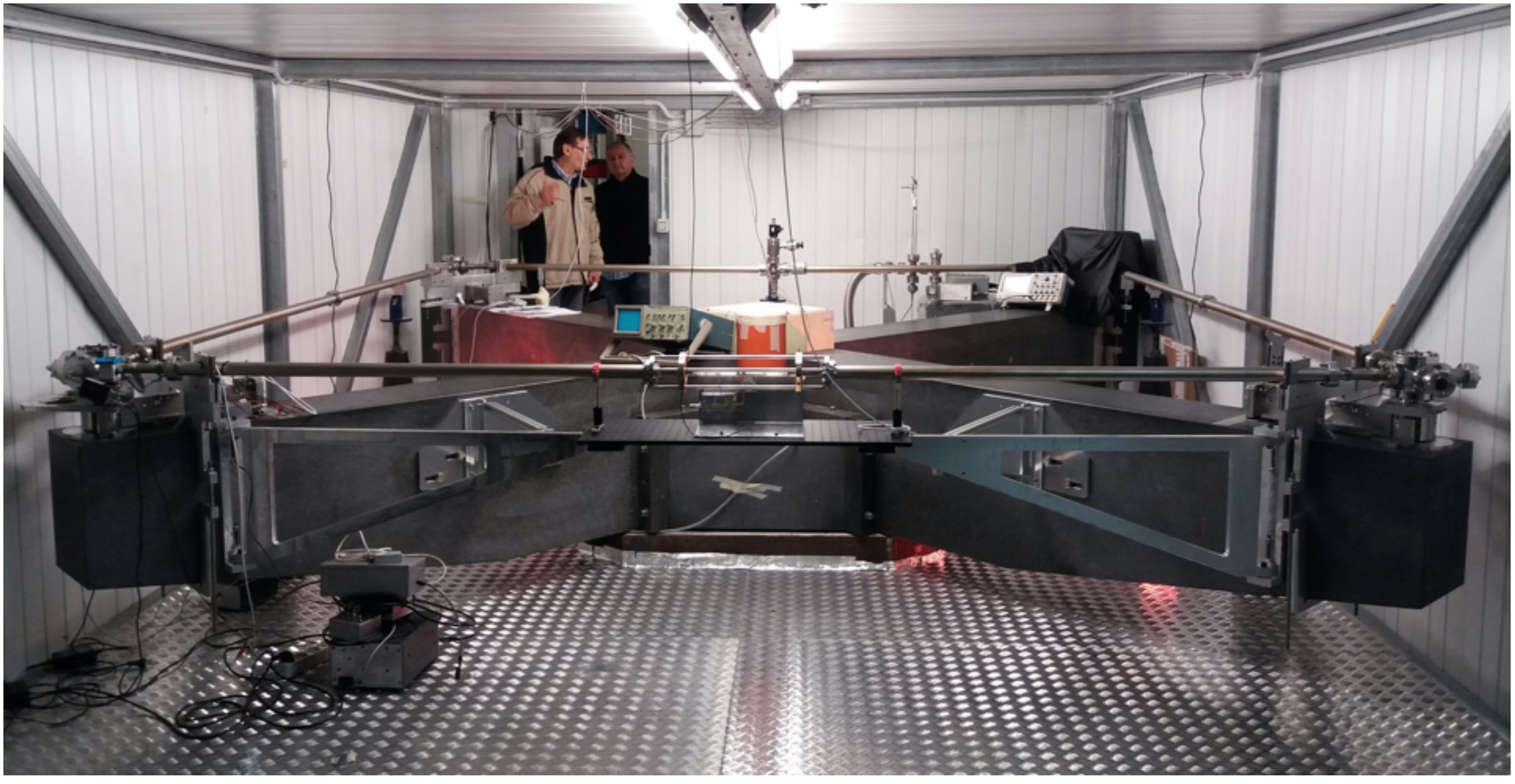
- **He:Ne ring laser:** 3.6 meters side square cavity active ring laser installed over a granite structure bodily linked to the rock. Expected sensitivity better than 10^{-12} rad/s in the 1000s-50 Hz band.
- **Nanometrics Trillium 240s seismometer,** which is installed at the center of the RLG granite frame. It is part of the INGV National earthquake monitoring program.
- **Lipmann 2-K digital tilt-meter** with a resolution better then 1 nrad
- a second **broadband seismometer (Guralp CMG 3T–360s)**, in order to obtain estimates of differential velocities and for data redundancy



Lipmann 2-K
digital tilt-meter



GINGERino seismic station



Data Acquisition

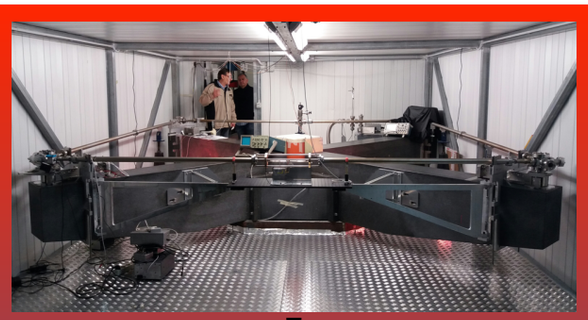
Gyroscope's Sagnac frequency is acquired and stored at 5 ksample/s

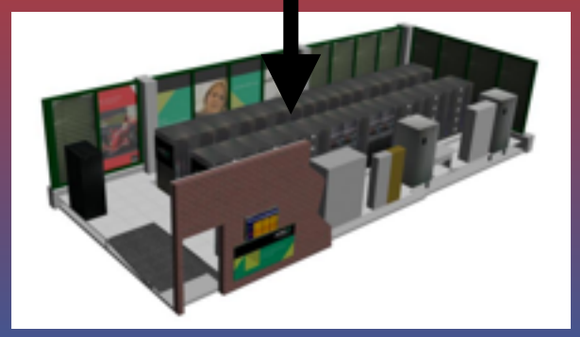
Seismic data (6 channels) are acquired through a GAIA digitizer (INGV standard). Data of Trillium 240 are stored in EIDA database (Network: IV Station:GIGS)

Time synchronization given by GPS - PPS signal

Environment diagnostic signals (temperature, humidity, pressure) acquired at 5 sample/s

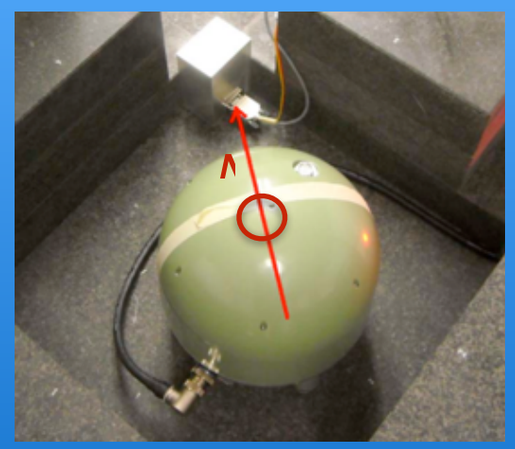
Data fetching





Raw data

GRID INFN PISA



EIDA IV.GIGS.HH*

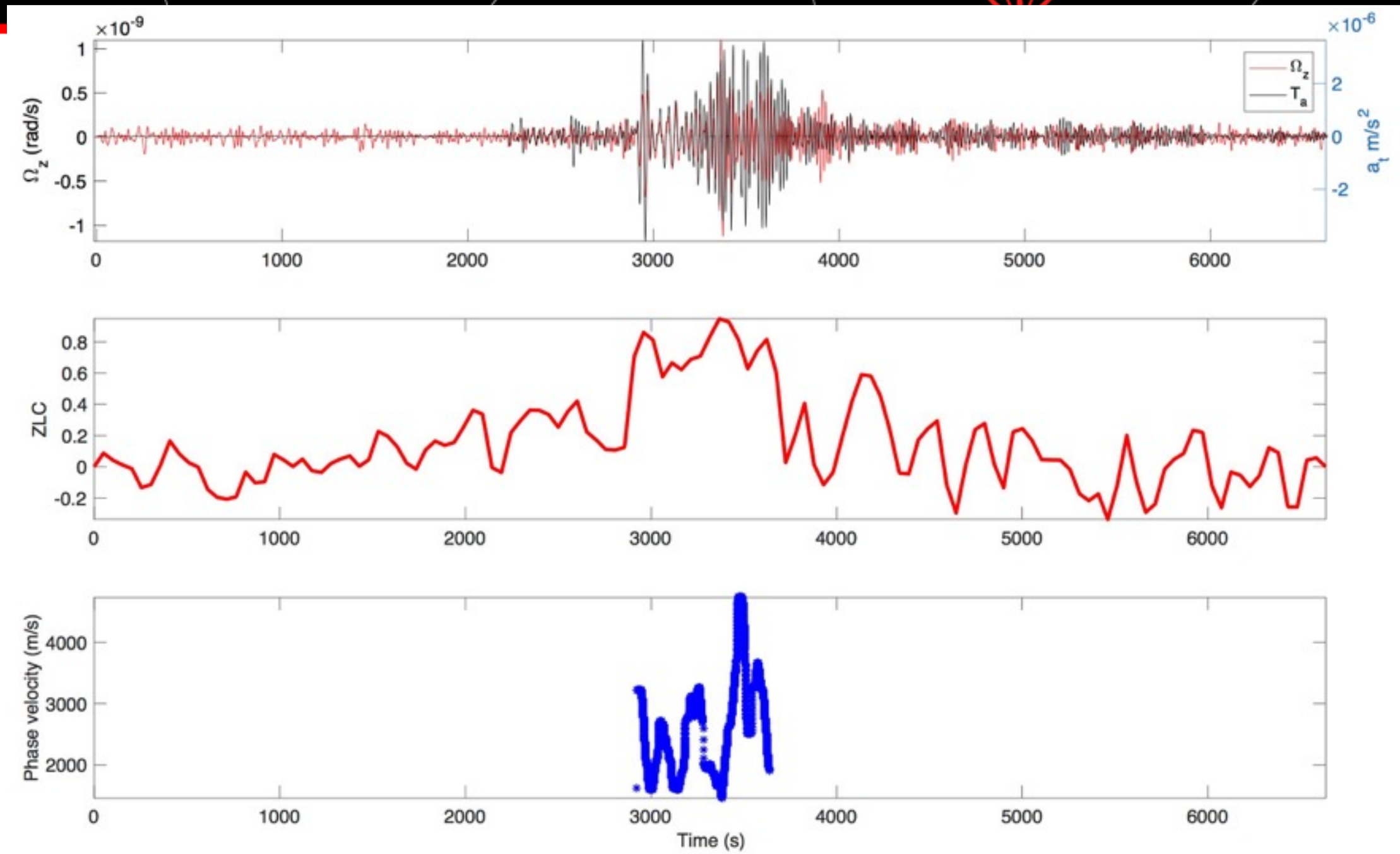
FetchGNG(startime,endtime)

Back scattering observables

$\{r_{+-}, \epsilon, \vec{a}, \omega_z\}$

Seismological analysis:
ZLC, BAZ, Amplitude ratios

First event: Mid Atlantic ridge, June 17, 2015, MWW 7



Simonelli et al. (2016). **First deep underground observation of rotational signals from an earthquake at teleseismic distance using a large ring laser gyroscope.** *Annals Of Geophysics, 59*.

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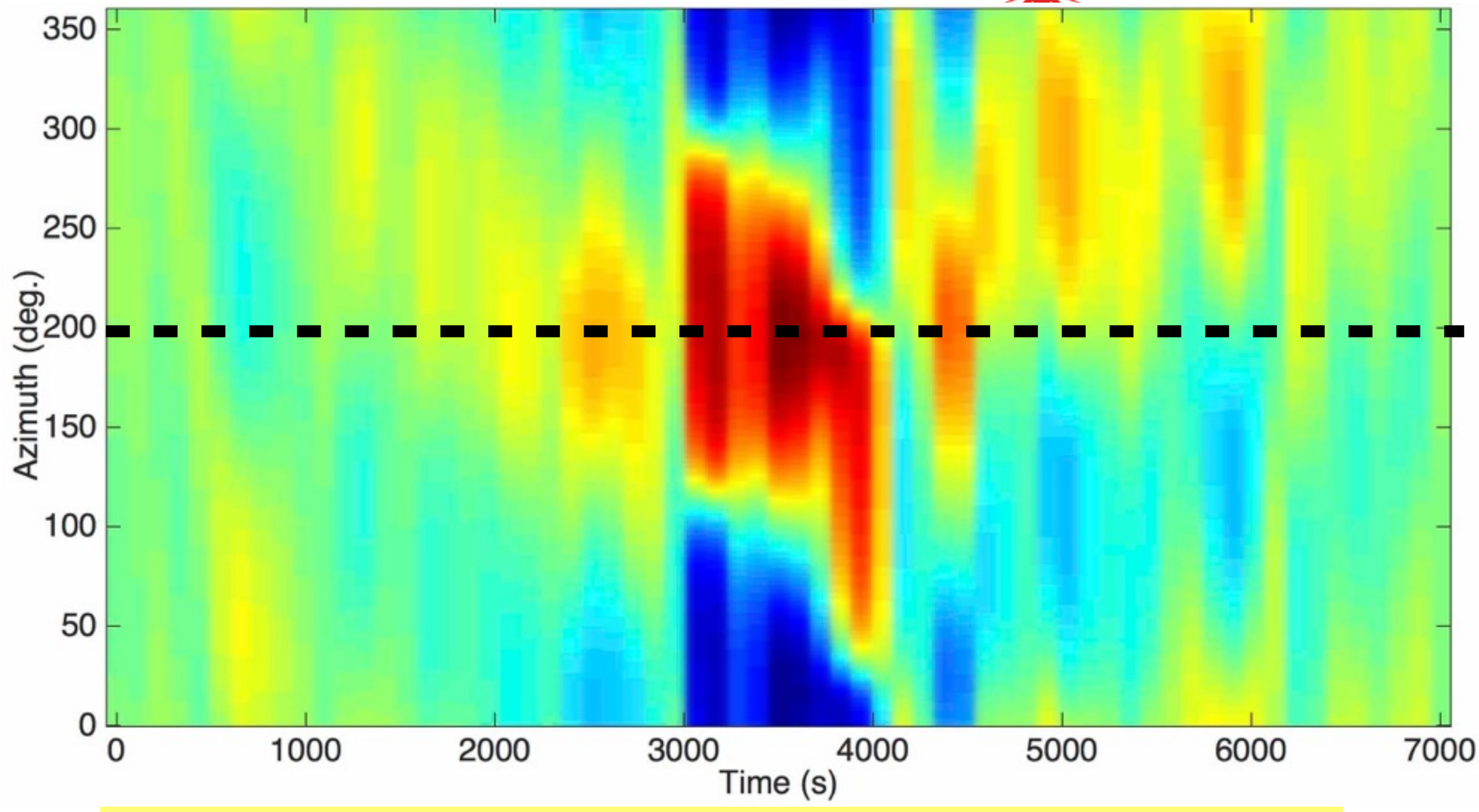


Simonelli et al. (2016). **First deep underground observation of rotational signals from an earthquake at teleseismic distance using a large ring laser gyroscope.** *Annals Of Geophysics, 59*.

Other events from the last year…please find it on this poster!

The GINGERino ring laser gyroscope, seismological observations at one year from the first light

Andreino Simonelli[1,3,6,*], Jacopo Belfi[1], Nicolò Beverini[1,2], Giorgio Carelli[1,2], Angela Di Virgilio[1], Enrico Maccioni[1,2], Gaetano De Luca[5], Gilberto Saccorotti[4]

[1]Istituto Nazionale di Fisica Nucleare, Pisa, Italy, [2]Università di Pisa, Dipartimento di Fisica "E. Fermi", Pisa, Italy, [3]Ludwig-Maximilians-Universität, Munich, Germany, [4]Istituto Nazionale di Geofisica e Vulcanologia, Pisa, Italy, [5]Istituto Nazionale di Geofisica e Vulcanologia, Centro Nazionale Terremoti, Rome, Italy. [6]"Regional doctoral school in Earth Sciences", XXX cycle, Pisa, Italy

Abstract

The GINGERino ring laser gyroscope (RLG) is a new large observatory-class RLG located inside the Gran Sasso underground laboratory (LNGS) (Belfi et al. (2016)), one national laboratory of the INFN (Istituto Nazionale di Fisica Nucleare). The GINGERino apparatus funded by INFN in the context of a larger project of fundamental physics is intended as a pathfinder instrument to reach the high sensitivity needed to observe general relativity effects; more details are found at the URL (https://web2.infn.it/GINGER/index.php/it). The sensitivity reached by our instrument in the first year after the set up permitted us to acquire seismological data of ground rotations during the transit of seismic waves generated by seisms at different epicentral distances. RLGs are in fact the best sensors for capturing the rotational motions associated with the transit of seismic waves, thanks to the optical measurement principle, these instruments are in fact insensitive to translations. Ground translations are recorded by two seismometers: a Nanometrics Trillium 240 s and Guralp CMG 3T 360 s, the first instrument is part of the national earthquake monitoring program of the Istituto Nazionale di Geofisica e Vulcanologia (INGV) and provides the ground translation data to be compared to the RLG rotational data. We report the waveforms and the seismological analysis of some seismic events recorded during our first year of activity inside the LNGS laboratory (Simonelli et al. (2016)).

Instrument and Method

Figure: The GINGERino RLG and the seismometers (Left), The experiment in the LNGS labs (Right-top), Sensitivity plot (Right-bottom)

RLGs essentially consist of two laser beams counter-propagating within a closed-loop optical cavity (ring).If the cavity undergoes a rotation with respect to an inertial reference frame, then the optical path of the two beams changes, inducing a slight frequency shift between the clockwise and anti-clockwise propagating waves (Sagnac effect). This tiny frequency separation produces a characteristic beat note once the two beams are mixed outside the ring. The beat frequency f , also called the Sagnac frequency, is related to the rotation rate around the normal vector $\hat{n}$ to the surface enclosed by the ring through the equation:

$$\Omega = \frac{\lambda_{He\text{-}Ne}}{4\,\cos\theta\, L^2} f \qquad (1)$$

where $\lambda_{He\text{-}Ne}$ is the wavelength of the He-Ne laser (632 nm), L is the square side length of the optical cavity and θ is the angle between the versor $\hat{n}$ and $\vec{\Omega}$. We know from theory (Aki and Richards (2009)) that rotations can be retrieved from ground displacement as the curl of the wave-field.

$$\vec{\Omega} = \frac{1}{2}(\nabla \times \vec{u}) \qquad (2)$$

For example, the displacement caused by a Love wave traveling as a plane wave along the x direction is expressed through the equation:

$$u_y = A e^{i\omega(x/C_L - t)} \qquad (3)$$

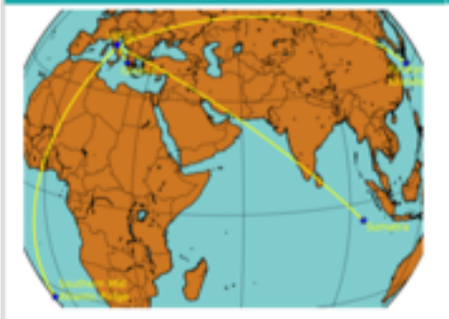
By applying eq. 3 to eq.2 we obtain the relationship:

$$\Omega_z = \frac{\ddot{u}_y}{2C_L} \qquad (4)$$

which provides a direct estimation of the phase velocity C_L from a single-site measurement.

Seismological observations

The observed events

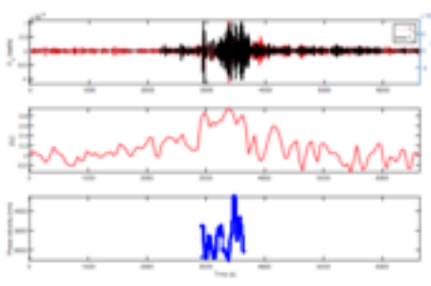


Processing steps

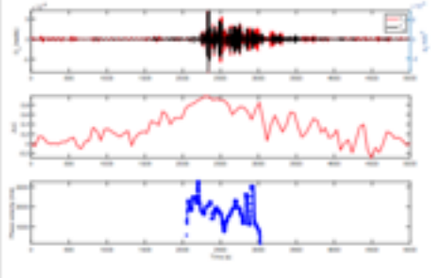
- The Seismometer instrumental response is corrected.
- The N-S and E-W ground displacement traces are rotated with steps of 1° over the 0°..360° angular range.
- For each rotation step, the zerolag-cross-correlation (ZLCC) between the rotational signal and transverse accelerations is calculated. .The ZLCC between translational and rotational traces is calculated using a time window, sliding with 50% overlap, the leght of the window varies from 100 s to 10 s depending on the epicentral distance.
- In the time gaps where ZLCC is above a threshold of 0.8, the amplitude ratio between the maxima of the rotational and translational envelopes (evaluated via Hilbert transform) provides a direct measure of phase velocity.

Event	Date	Magnitude	Distance	Max ZLC
Mid Atlantic ridge	June 17, 2015, 12:51 p.m.	MWW 7	82.7°	0.96
Ryukyu Islands	Nov. 13, 2015, 8:51 p.m.	MWC 6.8	85.6°	0.98
Greece	Nov. 17, 2015, 7:10 a.m.	MWC 6.5	6.5°	0.87
Sumatra	March 2, 2016, 12:49 p.m.	MWC 7.8	79.6°	0.93

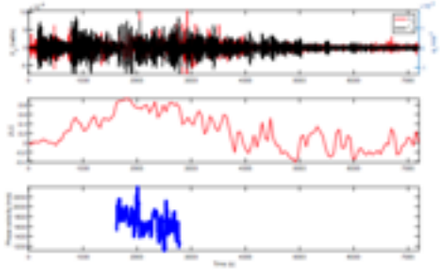
Southern Mid-Atlantic ridge



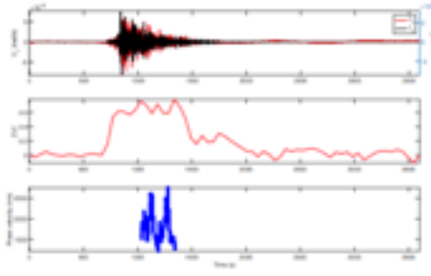
Ryuku Islands



Sumatra



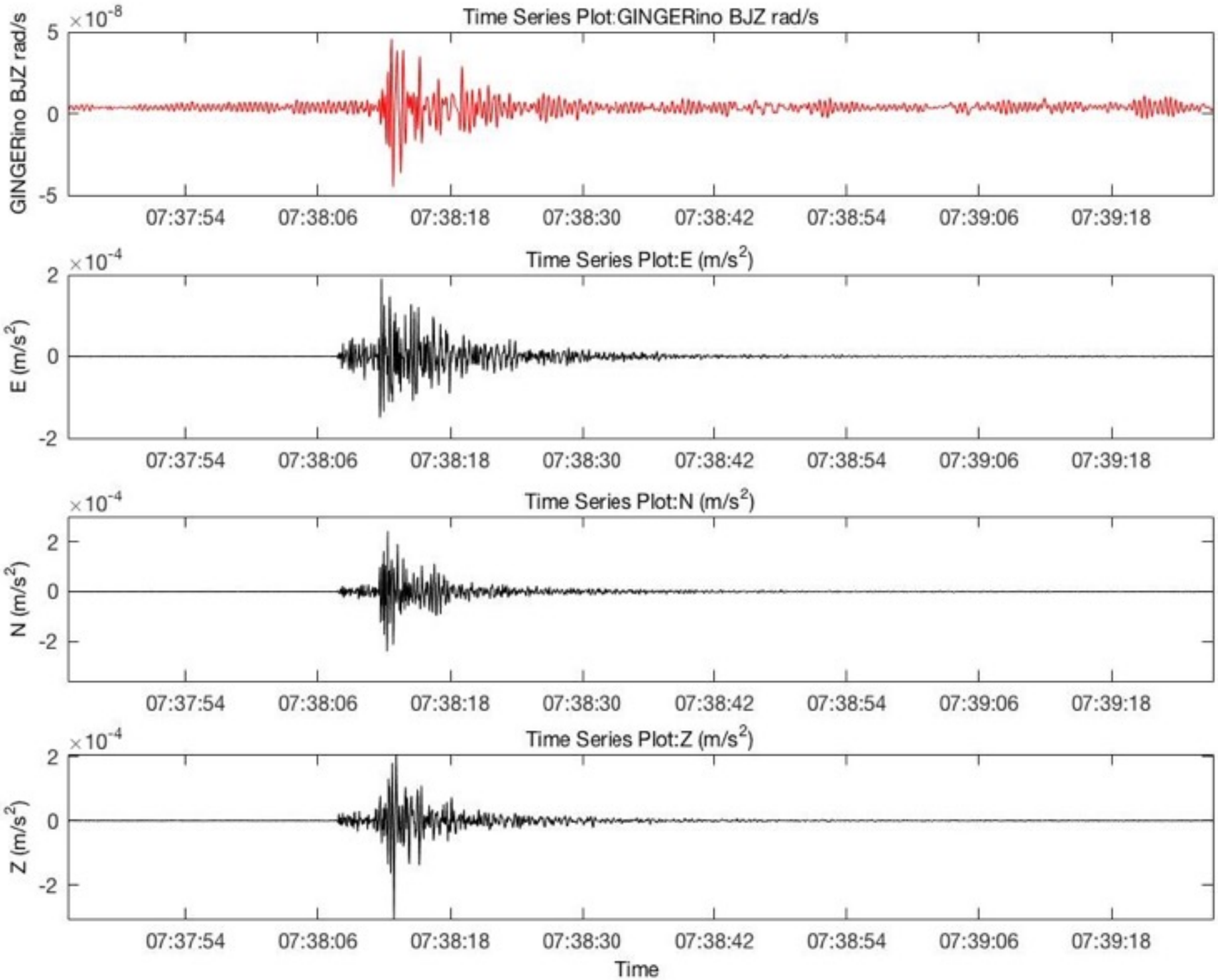
Greece (Ionic coast)

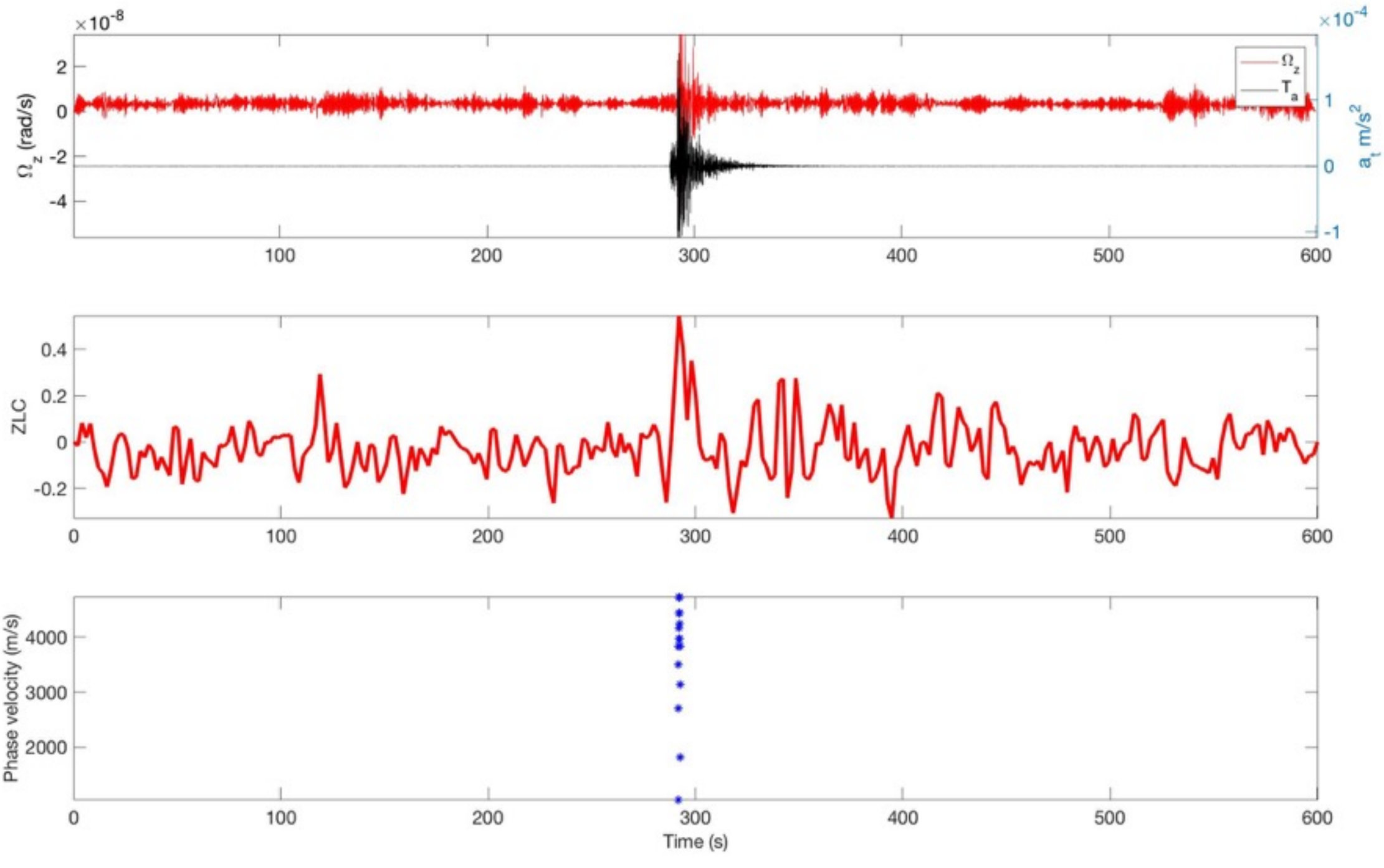


Conclusions

We presented the preliminary results from the operation of GINGERino, a Ring Laser Gyroscope co-located with a broad-band seismometer inside the INFN's Gran Sasso laboratories. Our data constitute the very first underground observations of earthquake-generated rotational motions. For those time intervals in which the translational and rotational signals are significantly correlated, we also obtained estimates of Love-wave phase velocities, which span the 2000m/s – 4500m/s range over the 10s-50s period interval. GINGERino is presently running in a preliminary test mode: current efforts are aimed at optimizing the experimental settings in order to increase the sensitivity and to achieve continuous acquisition. Such improvements will allow extending the seismological analyses to a ranges of magnitude larger than those considered until now (Belfi et al. (2012)). The simultaneous measurement of broad-band ground translation and rotation will thus permit the definition of the dispersive properties of Love waves over a broad frequency range, from which a local shear-wave velocity profile can be inferred with resolutions on the order of 100 m and penetration depths up to several tens of kilometers. Sensitivity improvements will also permit studying the partition of elastic energy in the microseism wavefield, whose main spectral peaks at the test site (3s and 10s) are at present only a factor five below our noise floor.

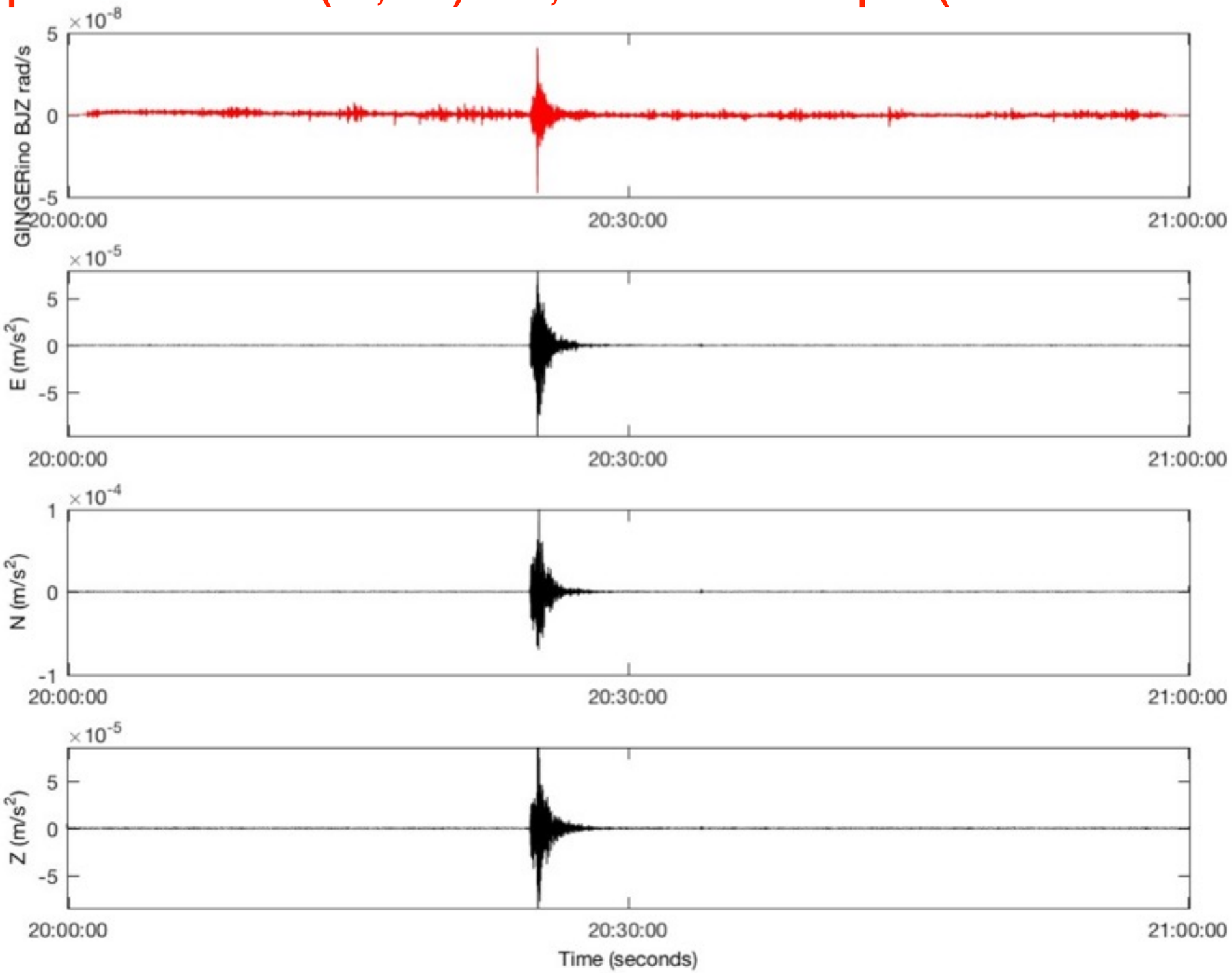
Yesterday….ML 2.8 in L' Aquila 14 km depth, 8 km from LNGS



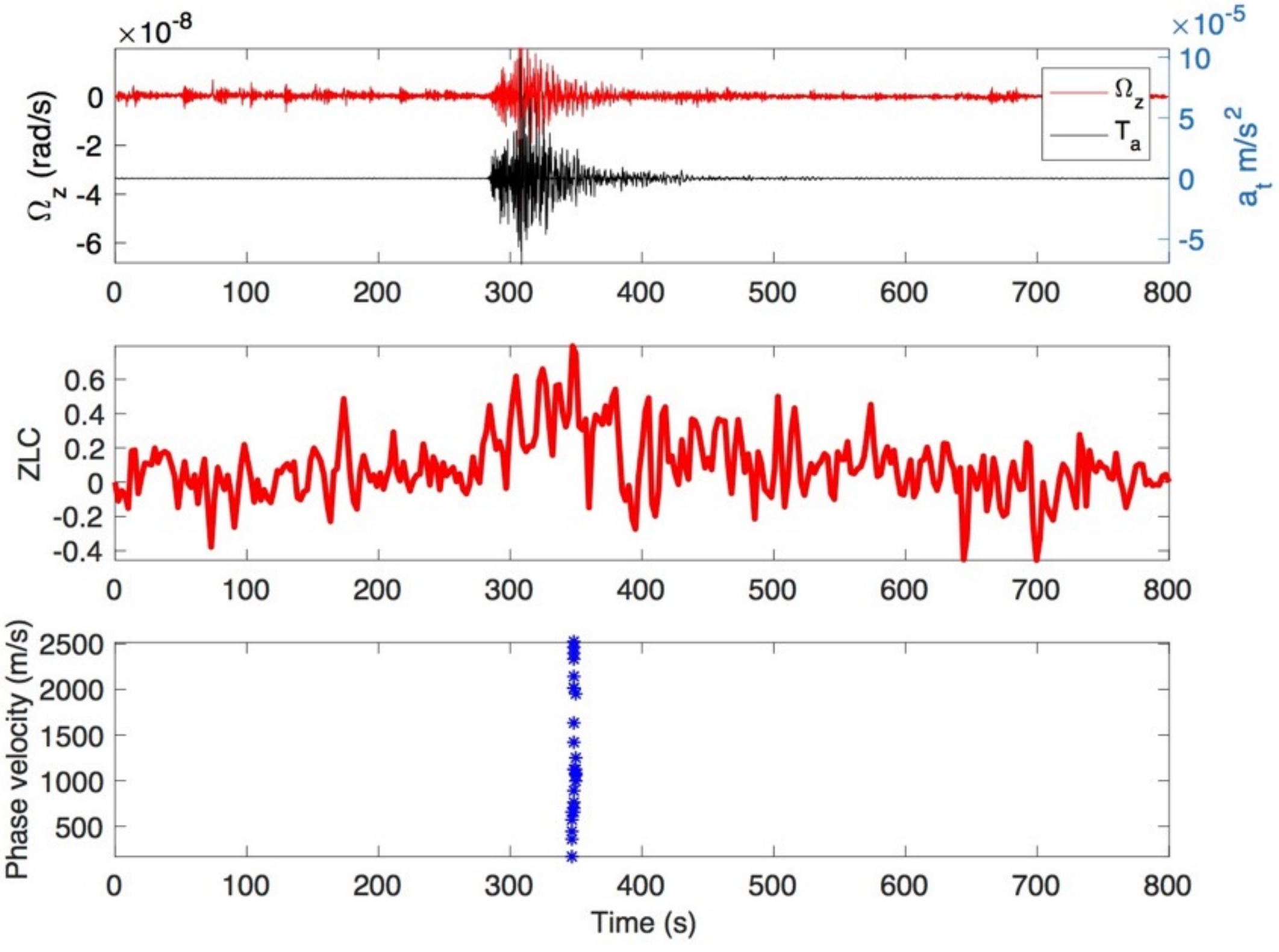

×10^-8
Ω_z (rad/s)
2
0
-2
-4
×10^-4
a_t m/s^2
1
0
-1
Ω_z
T_a
100
200
300
400
500
600
ZLC
0.4
0.2
0
-0.2
0
100
200
300
400
500
600
Phase velocity (m/s)
4000
3000
2000
0
100
200
300
400
500
600
Time (s)

After the last improvements, (J. Belfi's talk)

Mw 4.1 earthquake occurred in the Terni region on 30-05-2016 20:24:20 (UTC) 22 days ago and geographic coordinates (lat, lon) 42.7, 11.98 at 8 km depth. (133 km from GS-labs)

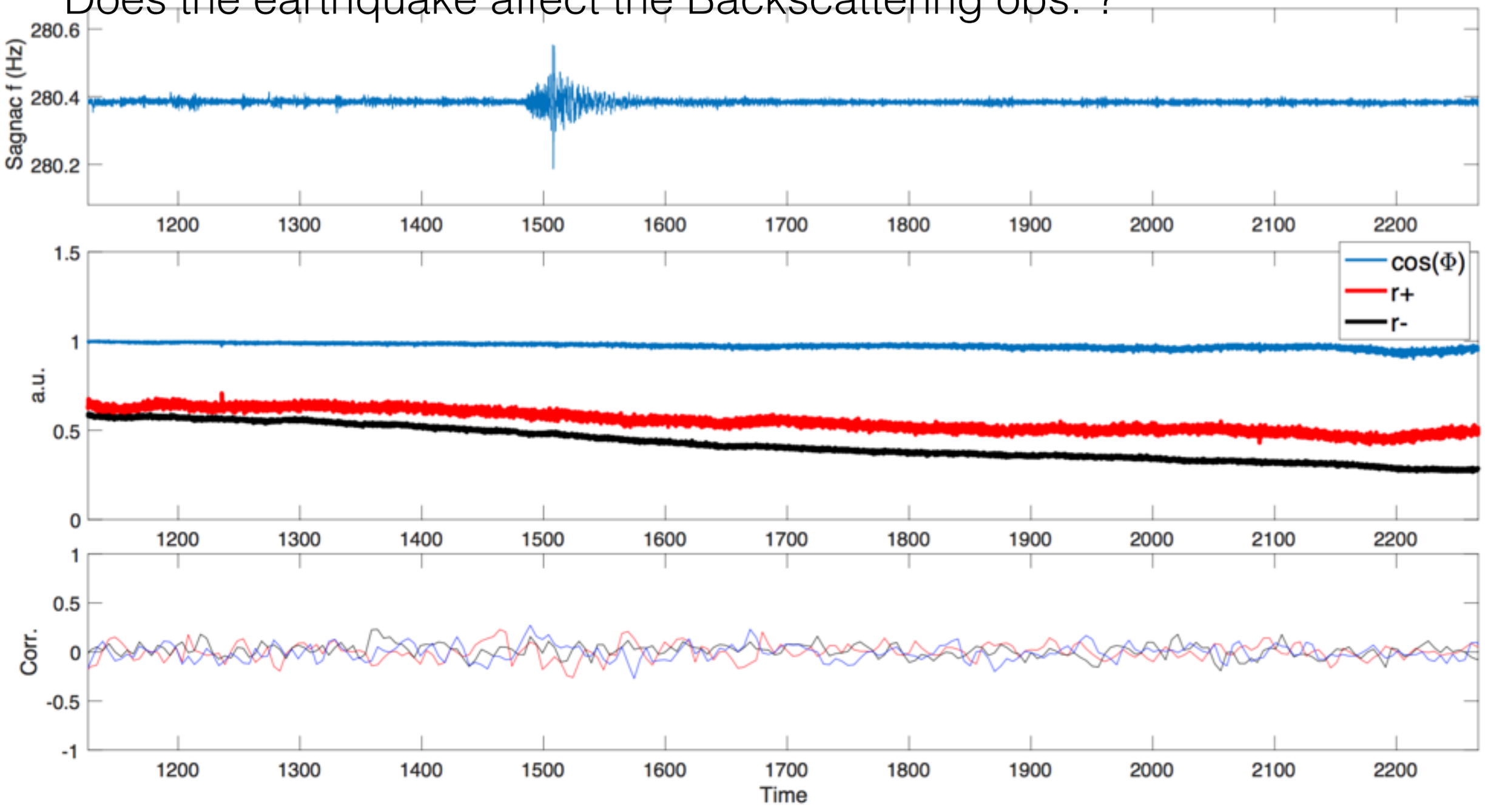


After the last improvements, (J. Belfi's talk)



After the last improvements, (J. Belfi's talk)

Does the earthquake affect the Backscattering obs. ?



Perspectives

- An institutional agreement between INGV/INFN will permit the long term maintenance for the GINGERino station.
- We are planning to add the BJZ rotational component from gyro to the IV.GIGS station on EIDA.
- Store observations of events in order to create a database for rotational seismology.
- Access to geodetic signals and seismic noise.