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

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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

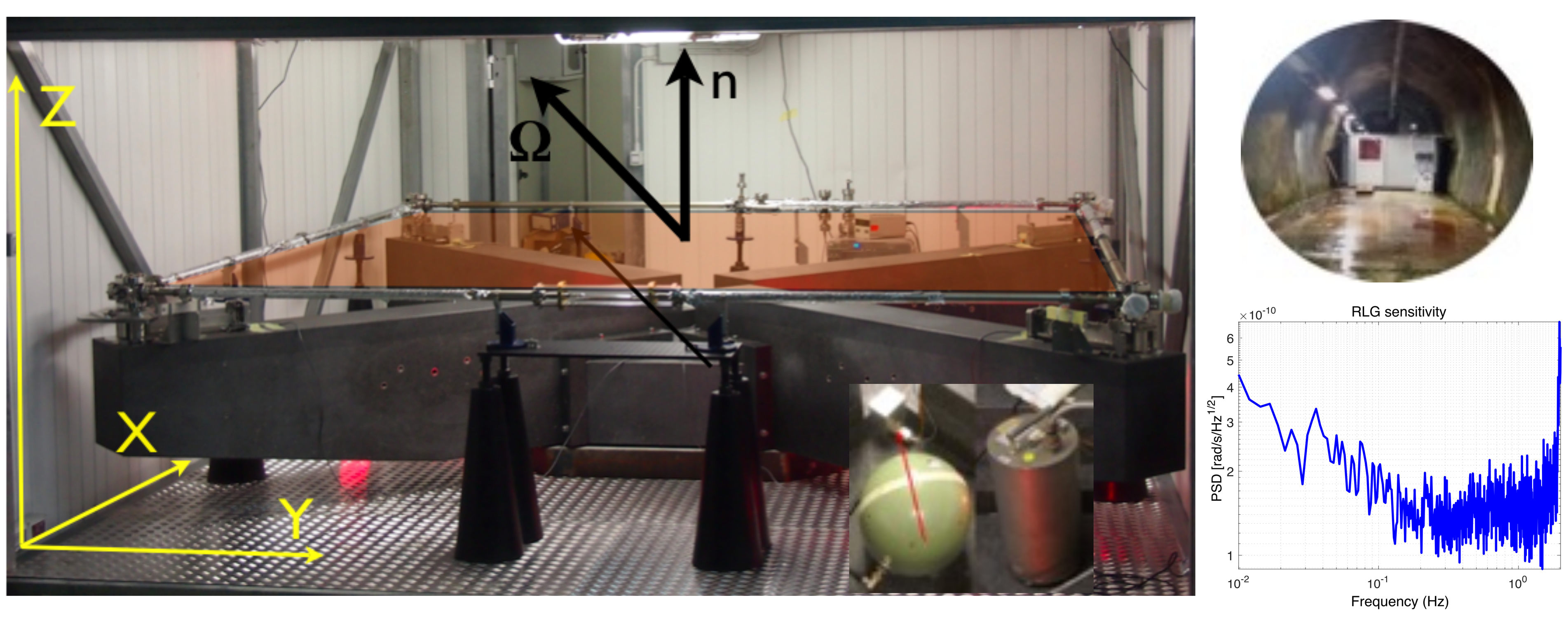


Figure: The GINGERino RLG and the seismometers (Left), The experiment in the LNGS labs (Right-top), Sensitivity plot (Right-bottom)

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 n to the surface enclosed by the ring through the equation:

$$\Omega = \frac{\lambda_{He:Ne}}{L\cos\theta} f \tag{1}$$

where $\lambda_{He:Ne}$ 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.

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

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

$$u_y = Ae^{i\omega(x/C_L - t)} \tag{3}$$

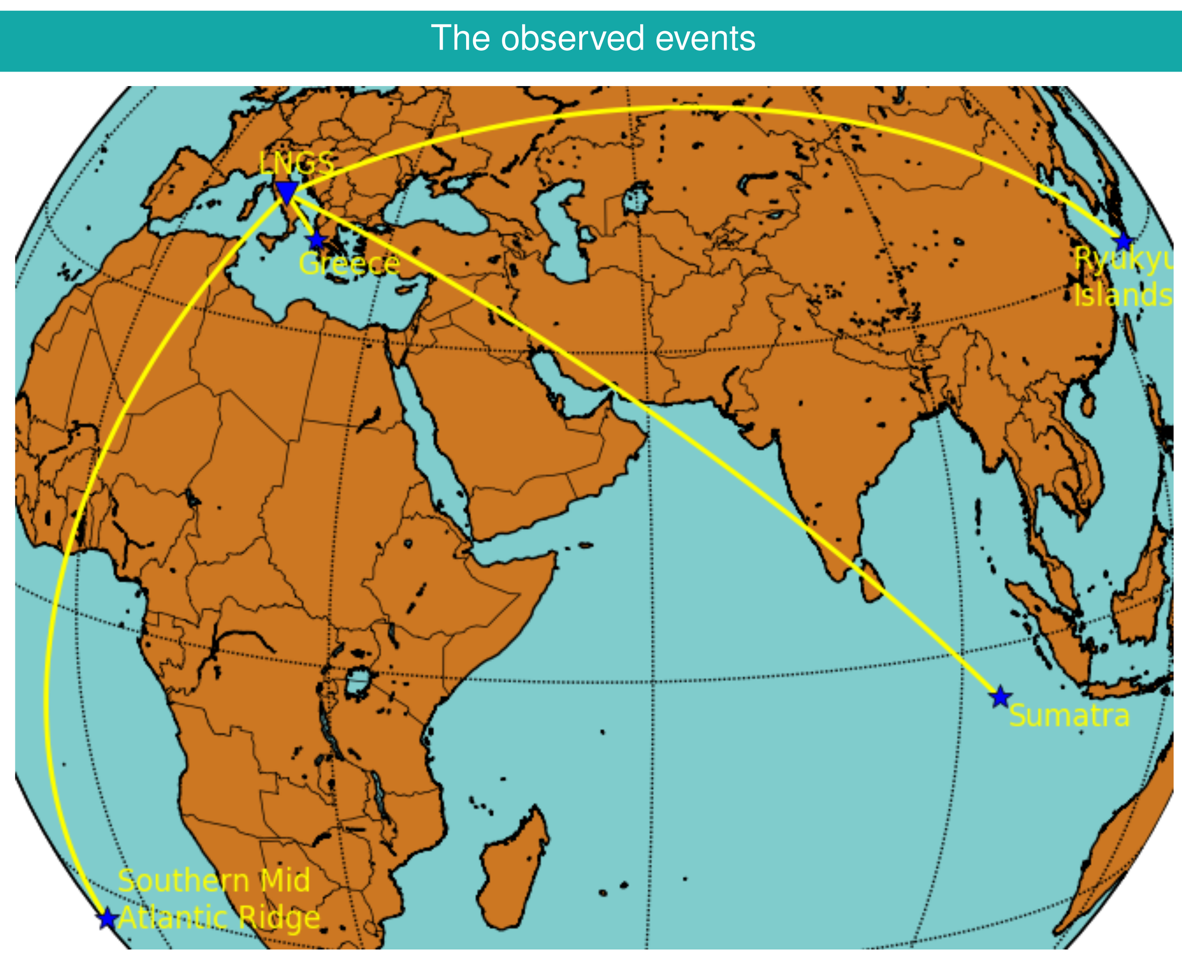
By applying eq. 3 to eq.2 we obtain the relationship:

$$\Omega_z = \frac{\ddot{u}_y}{2c_L} \tag{4}$$

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

Seismological observations

The observed events

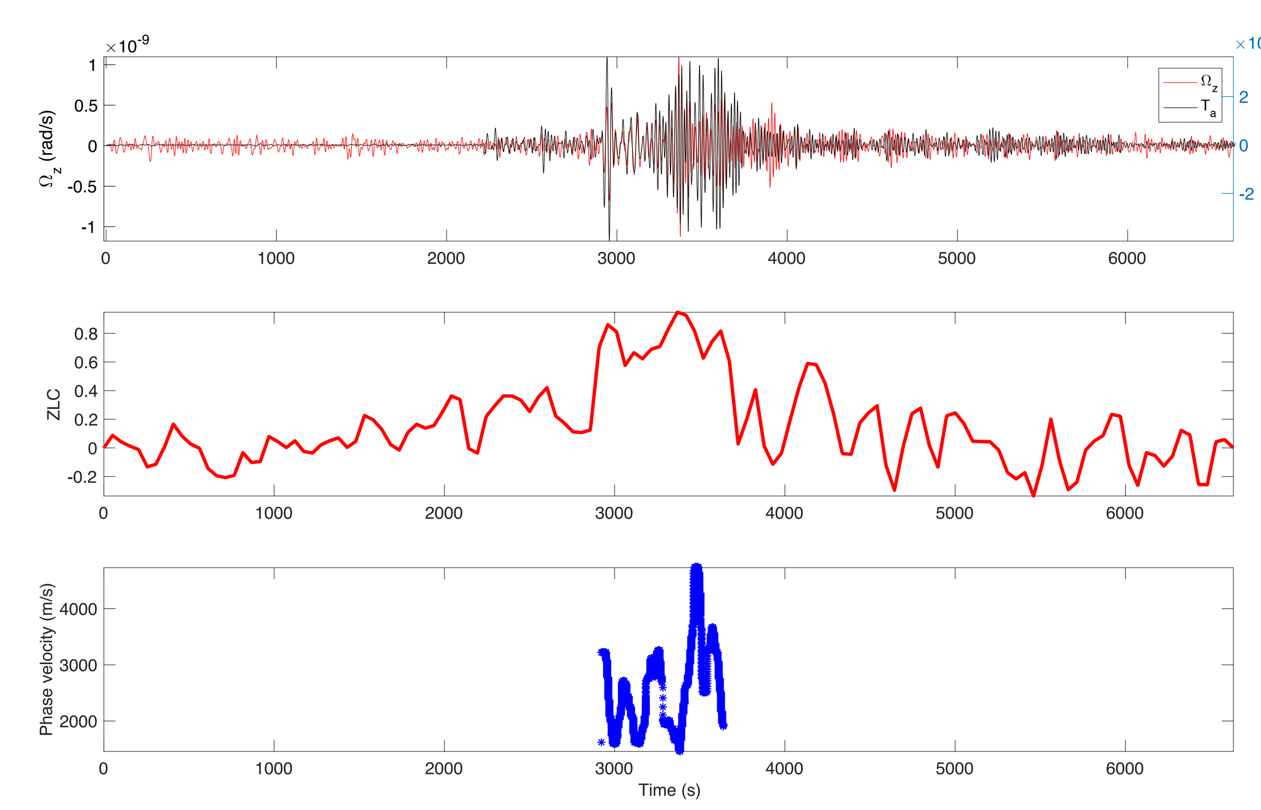


Processing steps

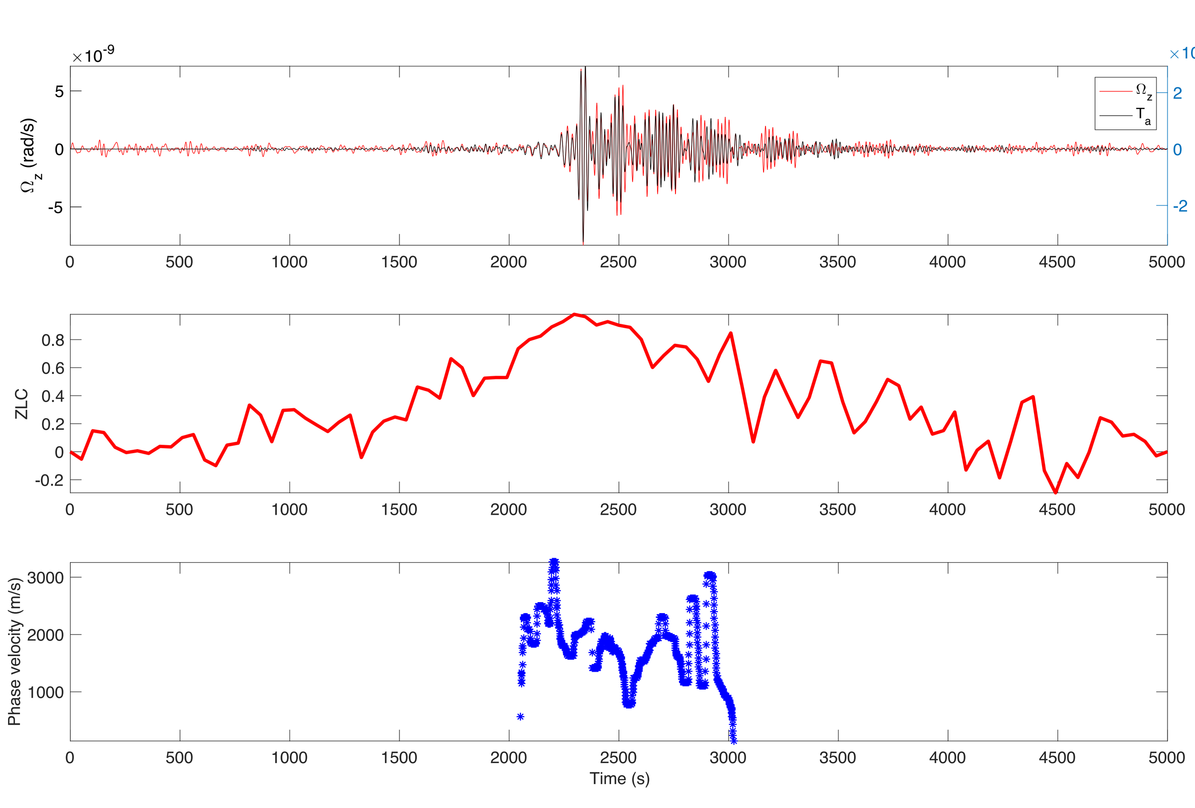
- The Seismometer instrumental response is corrected.
- The N-S and E-W ground displacement traces are rotated with steps of 1° over the 0°, 360° angular range.
- For each rotation step, the zerolag-cross-correlation (ZLCC) between the rotational signal and transverse accelerations is calculated. .The 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

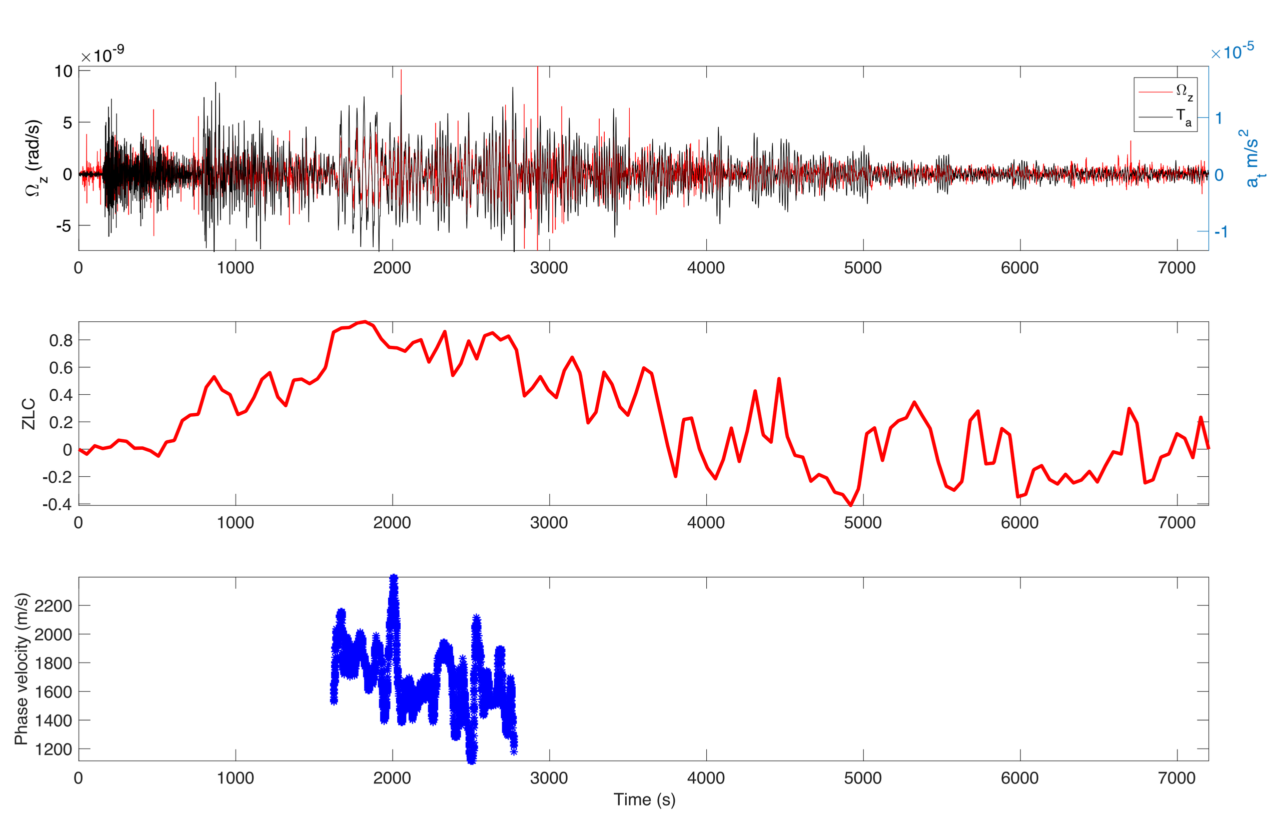
Southern Mid-Atlantic ridge



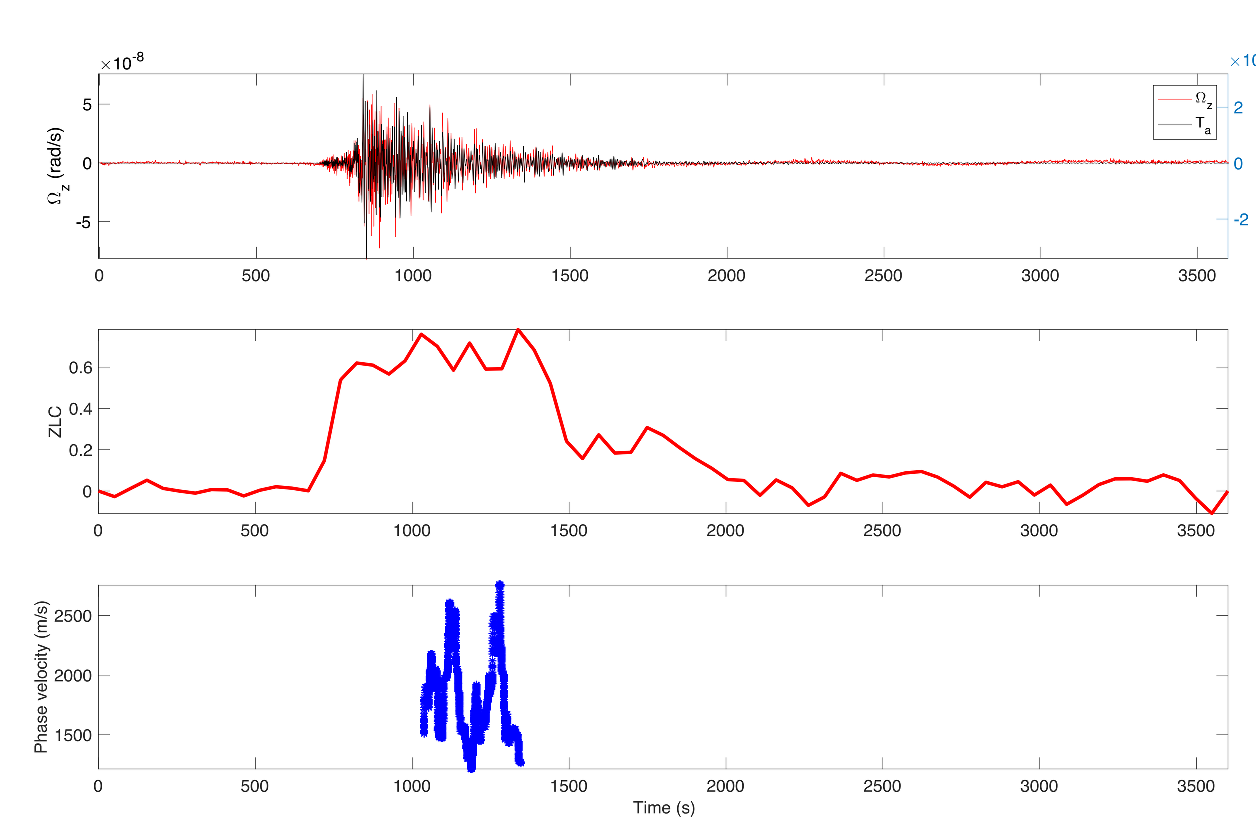
Ryuku Islands



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.

References

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