RingLaser as Gyroscope

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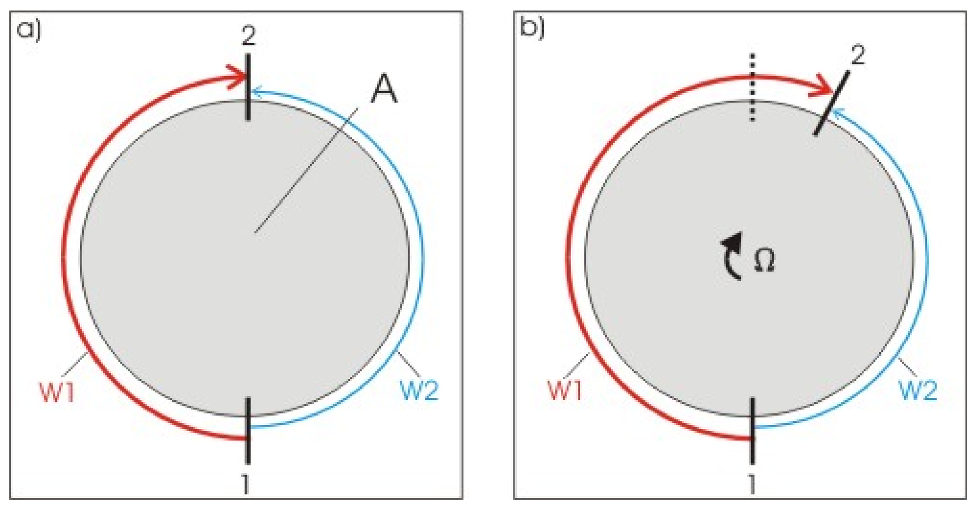
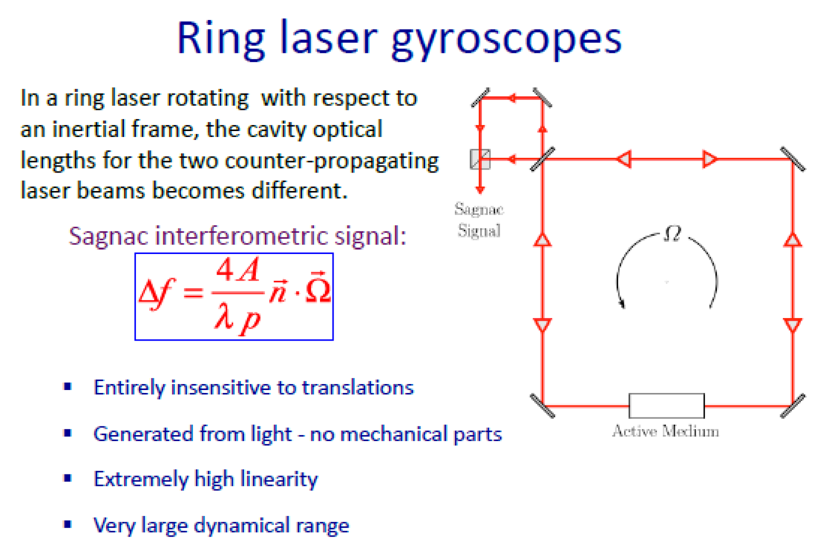
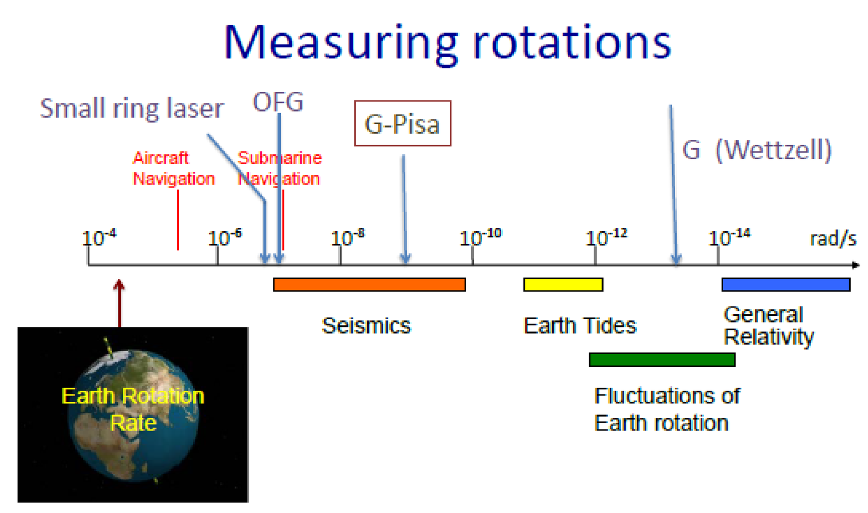
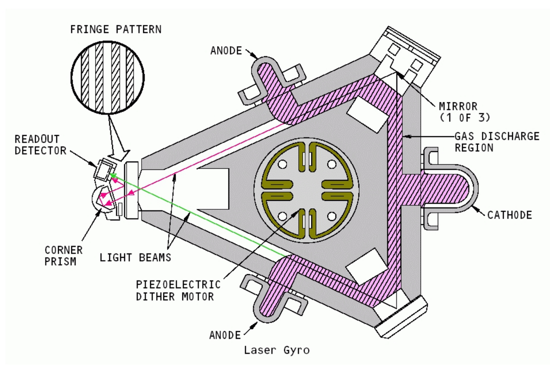
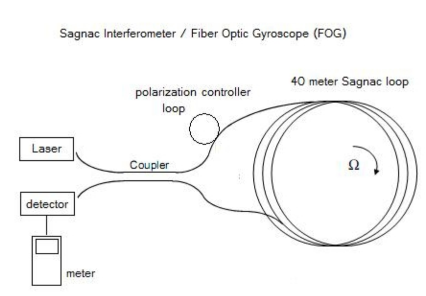
The Sagnac Effect is based on a simple observation: Two beams counter-propagating inside a ring of radius R complete the path at different time if the ring is rotating with angular velocity Ω: $\Delta t = \frac{4\pi R^2\Omega}{c^2}$

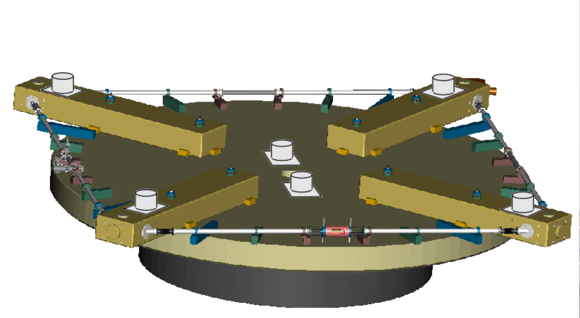
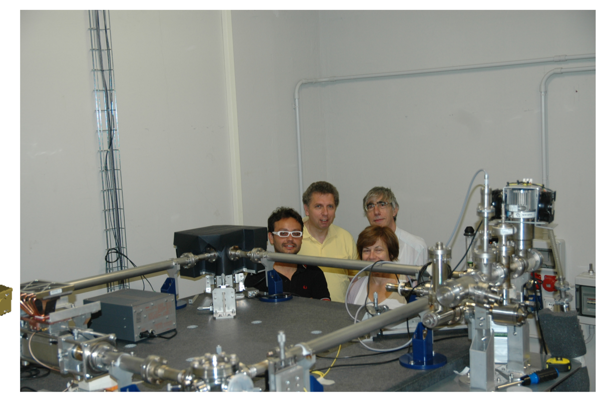






Several Devices have been developed based on: fiber optics (FOG),passive resonant cavity, and active cavity (ring-laser, gyro-laser). Not only light, but atom interferometry is used as well. They are very special gyroscopes, since they measure absolute (inertial) angular velocity.
Several instruments have been developed for different purpose, in general inertial navigation (air-plane, submarine...) and more recently for geophysics study. The main advantage of this kind of devices is that there are not moving parts, and the response of the apparatus is a pure rotation. It must be taken into account that the linear motions of the Earth crust is much higher than the rotations and tilts in general, so why is very difficult to provide good rotational motion measurements if the device has a coupling with the other degrees of freedom.

In general FOGs have applications when $10^{-4} rad/s$ is required, ringlasers can have higher sensitivity and accuracy; pushing to the shot noise limit the performance of ringlasers it is possible to make not only important measurements on Geodesy, but as well General Relativity tests

GINGER (Gyroscopes IN GEneral Relativity), in collaboration with U. Schreiber (TUM, Munich), H. Igel (LMU, Munich) and JP Wells (Canterbuty University, Christchurch, NewZealand)

GINGER (G-GranSasso) is a proposal, and an experiment of INFN Group II, to measure the gravito-magnetic effect with and array of ring-lasers in an underground laboratory, (PHYSICAL REVIEW D 84, 122002 (2011), theoretical calculations-Turin Politecnico) In general, the light must follow:

$$g_{00}dt^2 + g_{rr}dr^2 + g_{\theta\theta}d\theta^2 + g_{\phi\phi}d\phi^2 + 2g_{0\phi}dtd\phi = 0$$
$$\delta T = T_+ - T_- \approx 2\oint \frac{g_{0\phi}}{g_{00}}d\phi \neq 0$$

...and at first approximation

$$g_{0\phi} \cong (2\frac{j}{R} - R^2\frac{\omega}{c} - 2\mu R\frac{\Omega}{c})\sin^2\theta$$
$$g_{00} \cong 1 - 2\frac{\omega^2R^2}{c^2}\sin^2\theta$$

where

$$\mu = G\frac{M_\oplus}{c^2} \approx 4.4\times 10^{-3}m$$
$$j = G\frac{J_\oplus}{c^3} \approx 1.75\times 10^{-2}m^2$$

Ω = angular velocity of the Earth
ω = angular velocity of the instrument
θ = colatitude

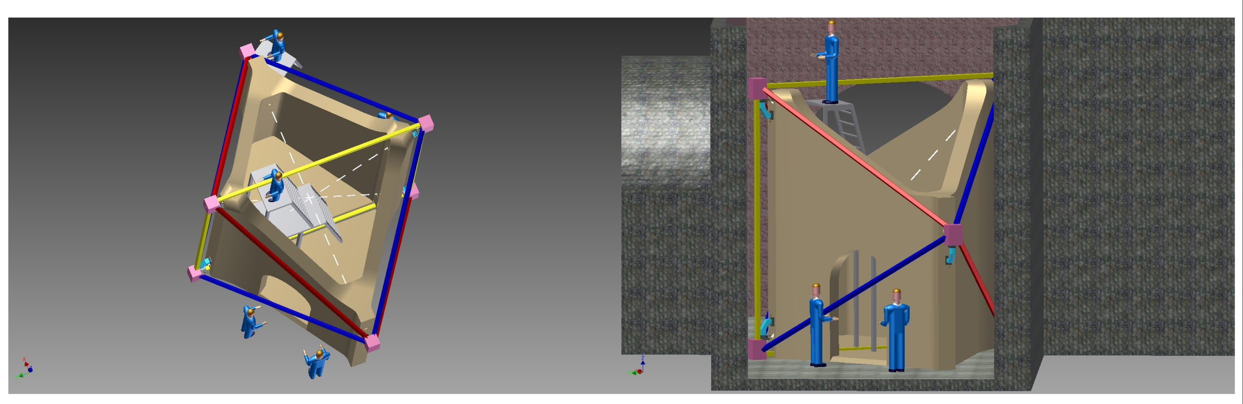
In a ring-laser the measured quantity is the beat note between the two laser modes $f_b = \delta\nu/2 = \frac{c^2}{\lambda P}\delta T$
where P is the length of the path (Perimeter); so for a ring laser attached to the Earth:
$\delta\nu = 4\frac{A}{\lambda P}[\Omega - 2\frac{\mu}{R}\sin\theta\hat{u}_\theta + \frac{GJ_\oplus}{c^2R^3}(2\cos(\theta)\hat{u}_r + \sin(\theta)\hat{u}_\theta)]$

- The beat note has 3 terms: the Sagnac one, the de Sitter (Geodetic term) and the Gravitomagnetic one (LenseThirring)
- The Earth angular velocity is measured with very high accuracy by VLBI, which measure the Earth rotation with respect to the fixed stars

the Relativistic terms can be obtained by subtracting from the ring-laser data the Sagnac term measured by VLBI
The required sensitivity for the measurement is around $10^{-14}rad/s/\sqrt{Hz}$, and the Earth angular velocity has to be measured with accuracy one part in 10^9. So far, sensitivity and accuracy so high has been obtained by the square ring G in Wettzell (4 m side).
In order to test General Relativity it is necessry to:

- Ω is a vector, so at least 3 independent rings are necessary
- Underground Location, in order to be far away from the Earth crust, which is perturbed by atmospheric changes (pressure, wind, rain....)
- increase the sensitivity and the time of integration: larger rings (from 4 m to 6 m), and integration time from 4 hours to 1 day (underground location, reduce as much as possible problems coming from backscatter noise).

Required accuracy: 1 in 10^{10}, necessary in order to cancel out the pure Sagnac term



The Shot Noise Limit, G in Wettzell is shot noise limited

$$\delta\omega_{sn} = \frac{cP}{4AQ}\sqrt{\frac{h\nu_l}{WT}}rad/s$$

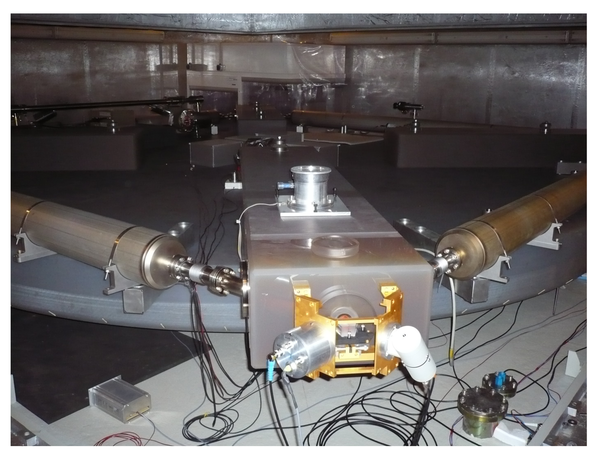
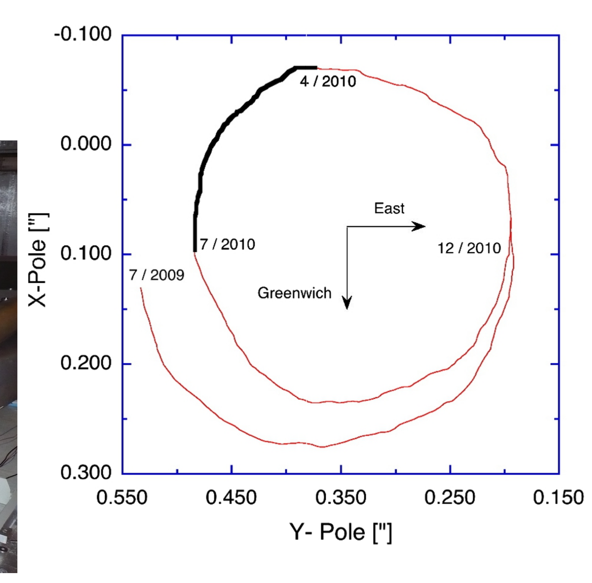
Systematics of the Laser

Laser equations are non linear, backscattering can spoil the performance of the ring, in collaboration with Legnaro, Napoli and Padova we are developing and extensive model of the whole apparatus and the laser itself

$$\frac{2L}{c}\frac{\dot{E_+}}{E_+} = \alpha_+ - \beta_+\sqrt{E_+} - \theta_\pm\sqrt{E_-} - 2r_-\frac{E_-}{E_+}\cos(\Psi + \varepsilon_-)$$
$$\frac{2L}{c}\frac{\dot{E_-}}{E_-} = \alpha_- - \beta_-\sqrt{E_-} - \theta_\mp\sqrt{E_+} - 2r_+\frac{E_+}{E_-}\cos(\Psi - \varepsilon_+)$$
$$\omega_+ + \dot{\phi_+} = \Omega_+ + \sigma_+ + \tau_\pm\sqrt{E_-} - \frac{c}{L}r_-\frac{E_-}{E_+}\sin(\Psi + \varepsilon_-)$$
$$\omega_- + \dot{\phi_-} = \Omega_- + \sigma_- + \tau_\mp\sqrt{E_+} - \frac{c}{L}r_+\frac{E_+}{E_-}\sin(\Psi - \varepsilon_+) \quad ,$$

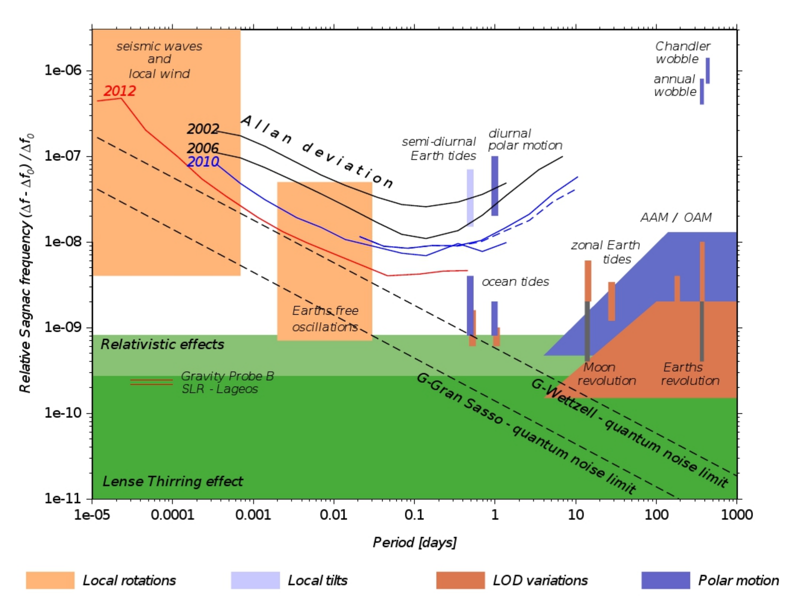
G in Wettzell, the most accurate RingLaser in the world and the Chandler Wobbler measurement

G is a square ring with 4 m side, which operates inside the Wettzell laser ranging station. It is based on a monolithic design, which uses a single block of Zerodur, a very low thermal expansion glass. It has been constructed for Geodesy.

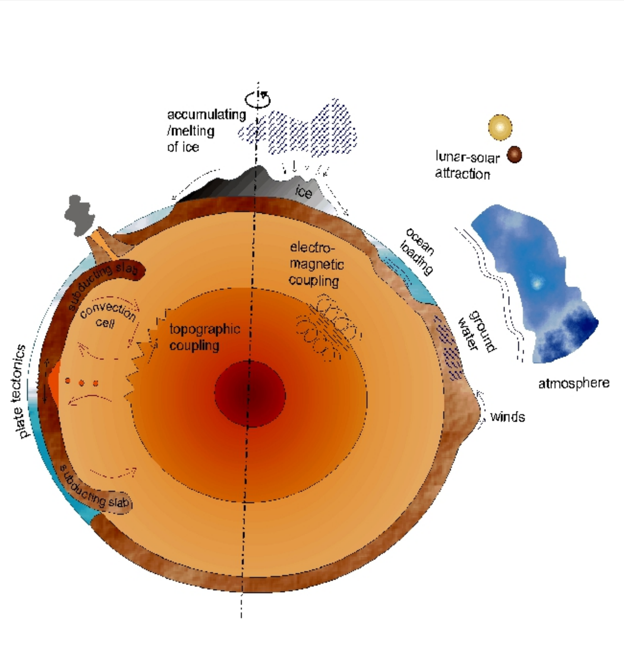



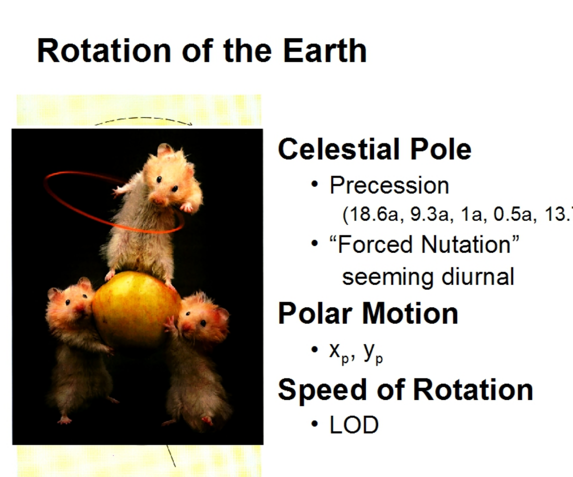
U. Schreiber et al., PRL 107, 173904 (2011), highlighted and reported from Science, Nature Photonics News and Views, local newspapers in Germany and Italy as well

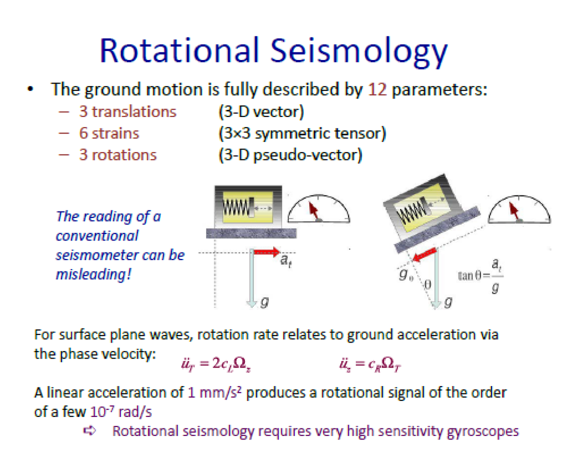
Signals and Accuracy (Allan Deviation of G in Wettzell)



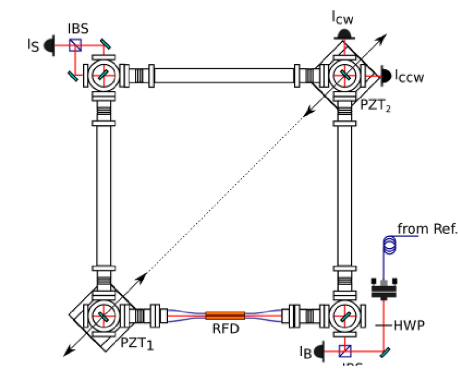
An apparatus directly linked to the Earth: Fundamental Physics, Geodesy and Geophysics



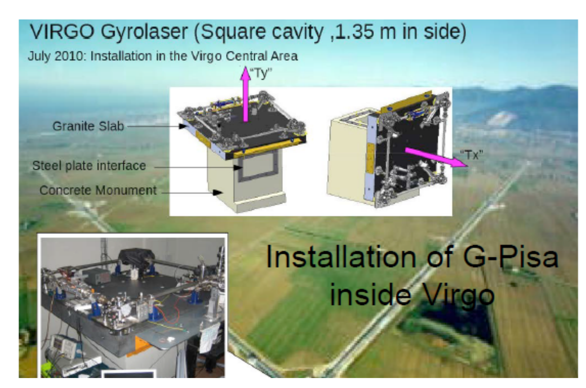


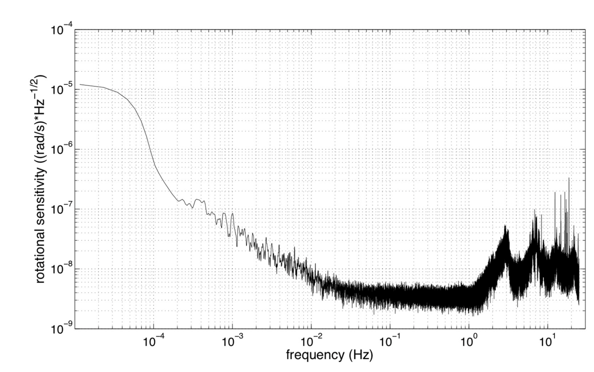


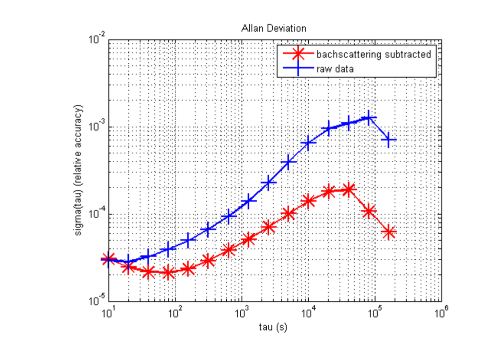
G-Pisa, our prototype



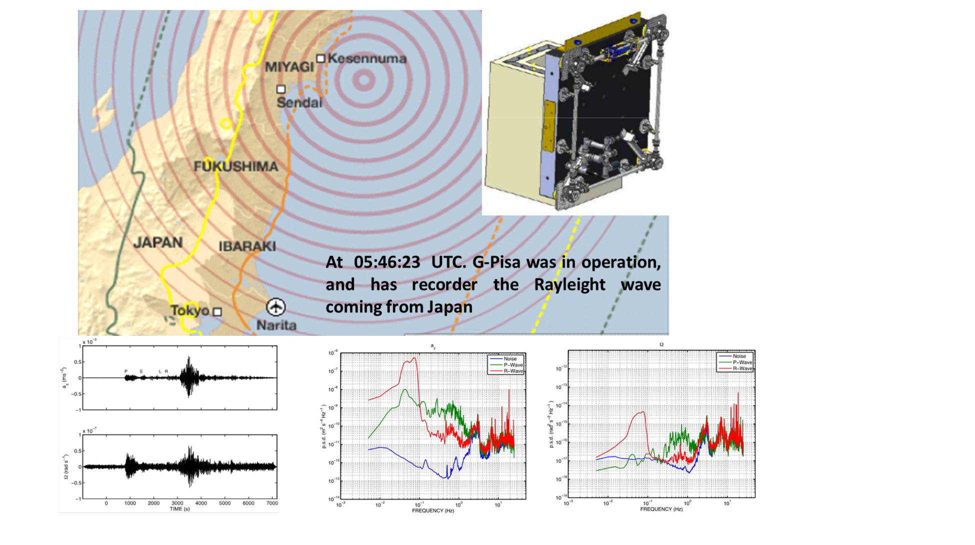

G-Pisa is a middle size ring-laser with side around 1.4 m, based on a cheap mechanical design, which provides a lay-out easily adjustable. Other advantages are that the mirrors are easily accessible and it is transportable. Since it is in steel, temperature changes must be compensated. Our device keeps constant the operation controlling the perimeter with a stable reference laser. In this way mounts of continuous operation have been obtained. Our devices has been running horizontally and vertically oriented, the two modes of operation show no difference. It has been running for more that one year inside the Virgo central area, at the moment it is installed in the S.Piero a Grado laboratory of the Pisa INFN section.







Geophysic with G-Pisa, in collaboration with G. Saccorotti (INGV)



Gyro and epicensor signals have been compared. Power spectral estimates for the time series of $5-h-long$ noise window preceding the earthquake, a 600-s-long window encompassing the P-wave arrivals and coda, and a $1800-s-long$ window starting at the Rayleigh-wave arrival. Power spectra are obtained by averaging and then squaring individual spectral estimates obtained over a 200-s-long window sliding by 50% of its length along the selected signal segments. Before transformation, individual signal slices were detrended, demeaned, and tapered by a 5% Tukey window

Conclusion...so far

RingLasers are the most accurate sensors for the measurement of absolute angular velocity, employed not only for inertial navigation, but as well in geodesy and geophysics. Monolithic devices have reached accuracy so high that the measurement of the terrestrial gravito-magnetism seams feasible (GINGER, G-GranSasso). We are working in order to make the ring with a mechanical design equivalent to the monolithic one by means of suitable controls. Work is in progress as well to understand the systematics of the laser. In the near future we plan to install our prototype inside LNGS, in order to verify if it is a suitable choice for the installation of GINGER.