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# The GINGER Project and status of the ring-laser of LNGS

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A ring-laser attached to the Earth measures the absolute angular velocity of the Earth summed to the relativistic precessions, de Sitter and Lense-Thirring. GINGER (Gyroscopes IN GEneral Relativity) is a project aiming at measuring the LenseThirring effect with a ground based detector; it is based on an array of ring-lasers. Comparing the Earth angular velocity measured by IERS and the measurement done with the GINGER array, the Lense-Thirring effect can be evaluated. Compared to the existing space experiments, GINGER provides a local measurement, not the averaged value and it is unnecessary to model the gravitational field. It is a proposal, but it is not far from being a reality. In fact the GrossRing G of the Geodesy Observatory of Wettzell has a sensitivity very close to the necessary one. G of Wettzell is part of the IERS system which provides the measure of the Length Of the DAY (LOD); G provides information on the fast component of LOD. In the last few years, a roadmap toward GINGER has been outlined. The experiment G-GranSasso, financed by the INFN Commission II, is developing instrumentations and tests along the roadmap of GINGER. In this short paper the main activities of G-GranSasso and some results will be presented. The first results of GINGERino will be reported, GINGERino is the large ring-laser installed inside LNGS and now in the commissioning phase. Ring-lasers provide as well important informations for geophysics, in particular the rotational seismology, which is an emerging field of science. GINGERino is one of the three experiments of common interest between INFN and INGV.

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## 1. Introduction

Ring-lasers gyroscopes (RL) are inertial sensors able to measure absolute rotations [1, 2]. A RL attached to the Earth crust is able to measure the Earth rotation rate $\vec{\Omega}_\oplus$ and as well the relativistic precessions de Sitter and Lense-Thirring. Ultra sensitive, large frame RLs are promising detectors for ground based tests of General Relativity (frame-dragging). Earth's rotation frame-dragging or Lense-Thirring effect consists in a dragging of the local inertial frame of reference caused by the perturbation of the local metrics in the proximity of a spinning massive body, like the Earth [3]. On the Earth surface, relativistic effects are of the order of 1 part in $10^9$ of $\vec{\Omega}_\oplus$. In few words to detect LenseThirring on Earth it is necessary to measure the Earth rotation rate with a precision better than 1 part in $10^{10}$, or in other words with a precision better than $10^{-14}$ $rad/s$, with measurements of several hours. Frame dragging effects have been experimentally observed up to now only in space-experiments using orbiting satellites [4] [5].

The GINGER (Gyroscopes IN GEneral Relativity) project [6] [7] aims at measuring the Lense-Thirring effect for the first time in an Earth-based laboratory, by using an array of large RLs. Large RL are square, or triangular devices with side length between few meters up to 10-12m. Ring-lasers are based on the Sagnac effect. The basic setup of a RL is made up of a stable square or triangular optical cavity along which an active medium, typically a He-Ne mixture, is present. Two laser beams are generated and propagate in opposite directions inside the ring. By mixing on a photodiode the beams exiting the cavity in the opposite directions, a Sagnac beat frequency is measured:

$$f_S = \frac{4\vec{A}\cdot\vec{\Omega}}{\lambda P}, \tag{1.1}$$

where $\vec{\Omega} = \vec{\Omega}_\oplus + \vec{\Omega}'$ is the rotation relative to the local Lorentz inertial frame (being $\Omega'$ any correction term), $\vec{A}$ is the area vector enclosed by the ring optical path $P$ and $\lambda$ is the wavelength of the laser. The sensitivity limit of a RL is given by the shot-noise:

$$\Omega_{sn} = \frac{vP}{4AQ}\sqrt{\frac{hf}{W_{out}T}}, \tag{1.2}$$

where $v$ is the velocity of the laser beam along the cavity, $Q$ is the quality factor of the resonator, $h$ the Planck constant, $W_{out}$ the detected optical power and $T$ the measuring time. From equation 1.1 two important features follow: the dependence of Sagnac frequency $f_S$ on the laser path geometry via the scale factor $k_S = 4A/\lambda P$, and the scalar nature of the sensor, being measured only the projection of the velocity vector $\vec{\Omega}$ along the area vector $\vec{A}$.

In recent years the Gross Ring G of the Geodesy Observatory of Wettzell has obtained top level results: as far as the Earth rotation rate is concerned it is a factor 3-4 far from the precision of 1 part in $10^9$, and its data are used in IERS to reduce the error in the evaluation of the fast component of LOD [8, 9]. Starting from the experience of G, it has been possible to deduce that the development of a high sensitivity RL requires:

- the development of the so called 'heterolithic' structure, in which the mirrors can be moved with high precision actuators in order to allow for the control of the geometry of the ring, and a suitable strategy based on the active control of the relative position of the mirrors of

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the cavity is required in order to guarantee the long term stability of the detector. The Gross Ring G is based on a monolithic structure which cannot be extended to form an array. All our prototypes are based on 4 boxes containing the four mirrors, the boxes are connected by vacuum pipes, the whole volume is vacuum tight and filled with a mixture of Helium and two isotopes of Neon, between two mirrors is inserted the discharge to create the plasma and to generate the laser.

- Underground installation should guarantee a good isolation from external disturbances and a natural good thermal stability. The installation of Wettzell has shown that superficial installations are not suitable for very high precision apparatus, since environmental disturbances, as rain, wind etc., usually spoil the resolution.

- it is necessary to develop a suitable technique to monitor the relative angle. In fact, In order to reconstruct the whole Earth rotation rate vector, it is necessary to monitor with nano-radiants accuracy(or even better)the relative angles between the different RLs of GINGER.

G-GranSasso is an experiment of the INFN Commission II, which is working in order to make GINGER a reality. At the moment the research activity is following the points listed above. Since almost 10 years we have we built and studied 'heterolithic' prototypes. At present, two prototypes are working: GP-2, located inside the INFN Pisa section, is a prototype designed to test the control strategy, and GINGERino, which is a square ring-laser 3.6m in side. It is built inside the LNGS underground laboratory, and is in the commissioning phase. GINGERino will provide important informations about the low frequency disturbances of LNGS. Fig. 1 shows GINGERino in December 2014.

## 2. GINGERino and its first data

GINGERino is a small apparatus compared to the average size of the LNGS experiments, nevertheless it is composed of several parts and other high sensitivity instruments are co-located, as tilt meters with a few nrad resolution and high performance seismometers, for details please see the LNGS annual reports 2013 and 2014 available at http://www.lngs.infn.it/en/life-work/library/annual-report-preprint. The seismometers and tilt-meters will improve the comprehension of the behaviour of the location, and will be very helpful in the interpretation of geophysical data. In the following the different components will be described.

GINGERino uses the mechanics of the prototype G-Pisa, which is made up of 4 mirror boxes connected by vacuum pipes, see Fig. 1. This mechanical structure is an evolution of the design (called GEOSENSOR) developed by U. Schreiber for seismological applications; each box is equipped with mechanical tools to tilt and align the four mirrors of the square cavity. Two piezoelectric translators are used to stabilize the perimeter in order to compensate for the thermal expansion of the cavity. This avoids mode jumps of the laser, allowing the device to run continuously. Actually G-Pisa has been the first large size RL able to run continuously and unattended for more than one month, it has been installed in several different locations (Virgo central area, Pisa-INFN and LNGS) and as well with horizontal and vertical orientation. To build GINGERino,

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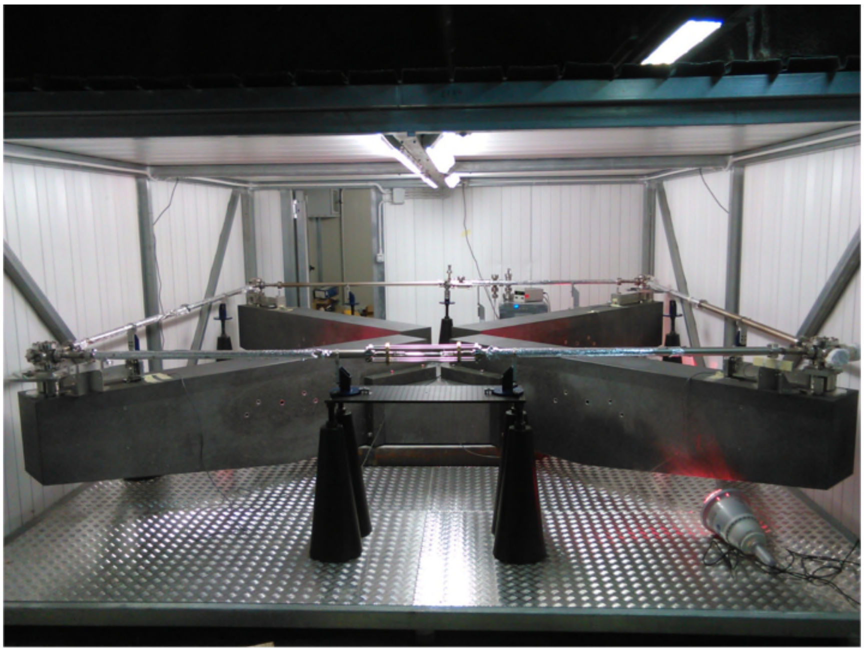

**Figure 1: The main structure of GINGERino is shown, it is composed of the mechanical structure of our first prototype G-Pisa. The RL is attached to a structure in granire, which has the shape of a cross, the whole is attached to the bedrock with a concrete solid structure.**

a new set of vacuum pipes has been manufactured; its size (3.6m side length) is the maximum for a square ring in the present location.

The ringlaser is attached to a cross granite structure, composed by a central octagonal massive block of granite, and four arms on lightened granite. The granite structure is screwed to a reinforced concrete block integral to the underneath bedrock, that has been installed at the beginning of May 2014. The black granite of Africa can be machined with high precision and has a good thermal expansion coefficient ($7 \times 10^{-6}$ $/degree$). This 5 parts structure has been designed having in mind that a crane is not present there. The installation was carefully prepared, developing several tools to handle such heavy structures (the octagonal central piece is about 3 tons in weight and each arm is about 800 kg). An anechoic box protects the whole installation in order to reduce the external acoustic disturbances and the very high local value of the humidity. As well most of the electronics is installed outside the box containing the RL. A first simple solution to the humidity problem was to warm up the box with infrared lamps, thermal stability plays a fundamental role in this apparatus. So far, this system has been running for several months, and has shown that it keeps the GINGERino area within 0.1 degrees, the main problem is that it takes more than one day to reach the thermal equilibrium, when someone enters inside the room. We will investigate later how to improve the thermal stability. The first light in GINGERino has been observed just before Christmas 2014, but several small changes to the apparatus have been done in order to obtain a stable and good operation of the RL. GINGERino is still in the commissioning phase, and the first set of data has been acquired starting from April 2015. In the following the typical power spectrum and Allan deviation for this early phase of GINGERino are shown see, Fig. 2 and 3.

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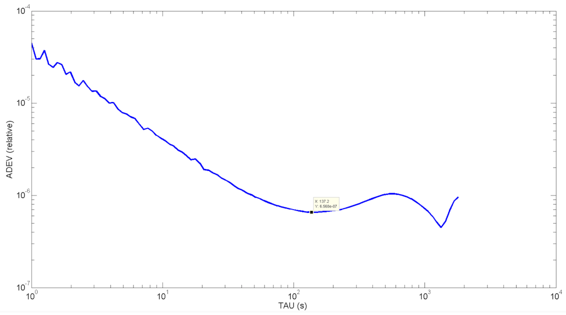


**Figure 2:** Modified Allan deviation of the data of GINGERino, the data are row. The minimum indicates the best sensitivity, in this case it is approximately $10^{-6}$ times the Earth rotation rate ($4 \times 10^{-11} rad/s$)

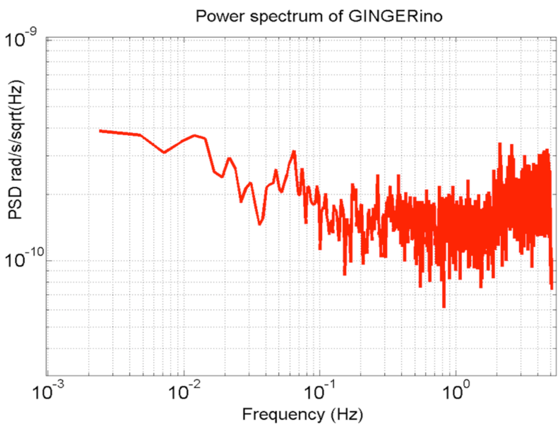


**Figure 3:** Typical power spectrum of GINGERino in this early phase of the commissioning

## 3. Conclusions

GINGERino is in the commissioning phase, in the near future the effort will be devoted to analyse the data taken and improve the stability and the thermal stability, in order to obtain longer integration time. It will be necessary to improve the quality of the mirrors in order to increase the Q of the resonator. We collaborate with INGV, which provides seismometers, and which will analyse the tele seismic events. The work along the roadmap of GINGER is as well progressing, the control of the geometry is under test with the prototype GP2 [**?**, **?**, **?**], and a system to monitor the relative angle (GEMS) is under development in Padova.

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