GINGERINO and The GINGER project

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1. Abstract

GINGER (Gyroscopes IN General Relativity) is a proposal aiming at measuring the Lense-Thirring effect with an experiment based on Earth. It is based on an array of ring lasers, at present the most sensitive inertial sensors to measure the rotation rate of the Earth.
Rotation and angular measurements are of great importance for various fields of science: General Relativity predicts rotation terms originated from the kinetic term, Earth Science studies the Earth's angular velocity with its variations, the tides and related perturbations, the normal modes of the Earth, the angular perturbations associated to the movement of the plates, the deformations of hydrological nature, without neglecting the rotational signals produced by the earthquakes. A ring laser gyroscopes (RLG) integral to the Earth's surface is sensitive not only to the angular rotation of the planet, but also to global and local rotational signals. For this reason GINGER is relevant for geophysics.
GINGERINO is a ring laser prototype installed inside the underground laboratory of the Gran Sasso. Its typical sensitivity is well below 0.1 nrad/s in 1 second measurement, and it is acquiring data on a continuous basis since several years. The most recent data of GINGERINO and the results relevant for geoscience are discussed.
IT IS WELL KNOWN THAT RING LASER GYROSCOPES ARE TOP SENSITIVITY INSTRUMENTS ABLE TO MEASURE THE FAST VARIATIONS OF THE EARTH ROTATION RATE (LOD). AT PRESENT THE RLG OPERATIVE OVER THE WORLD ARE VERY FEW.

2. RING LASER GYROSCOPES: advantages and the the problem of the non linear dynamic of the laser

RLGs have in principle many advantages:

- **sub-prad/s sensitivity in 1 second of measurement has been already demonstrated by G Wettzell, GINGERINO and ROMY**
- **very large bandwidth, fast response, in principle they can provide variations of signals as fast as milliseconds**
- **very large dynamic range. Since it is based on frequency measurement, the same device can record prad/s variations and strong signals from earthquakes**
- **Sagnac gyroscopes based on ring laser can be less expensive since they do not need external laser source to extract the signal, this makes them also rather compact.**
- **insensitive to gravity, allowing to discriminate between effects due to gravity from the ones due to real motion of the Earth**
- **possibility to precisely monitor the fluctuation of the Earth rotation velocity $\Delta\omega_3$ and its rotation axis changes.**
- **capability to measure the Lense-Thirring effect of the Earth in function of the latitude, without the necessity to use the gravity map of the Earth independently measured.**

The problem that has highly limited the use of RLGs is the non linear dynamic of the laser, and the general idea has been to reduce such effects improving the quality of the mirrors and making larger the device. In reality it is difficult to completely remove such non linear effects simply improving the hardware, but it is possible to eliminate such effects with proper data analysis.
The Sagnac effect states that two light beams counter propagating inside a closed path complete the path at different times if the closed path rotates. If the closed path is an optical cavity, for example a square ring cavity, the frequencies of the two counter-propagating beams differ of a quantity proportional to the rotation rate of the apparatus with respect of an inertial frame and this difference is called Sagnac frequency. Based on this principle there are two different devices called passive and active Sagnac gyroscope. The passive one requires an external laser source, for high sensitivity application the source has to be highly stabilised, and as a consequence rather expensive. The RLG is based on this principle, the laser beams are not injected from outside, but an active medium is inserted inside the cavity and the two counter-propagating laser modes are generated inside the ring cavity. There is the drawback to deal with the non linear dynamic of the laser. Despite this problem, at present the RLG has the sensitivity record for angular rotation rate measurement. In general the interference of the two counter-propagating beams is considered equal to the Sagnac frequency. We have shown that the Sagnac frequency can be determined by the interference of the two laser modes and the signals available from the square cavity.
PROBLEM: THE MAIN LIMITATION OF THIS INSTRUMENT IS THE NON LINEAR DYNAMIC OF THE LASER. HOWEVER WE HAVE SHOWN THAT THIS PROBLEM CAN BE SOLVED ANALYTICALLY.
The solution we have elaborated utilises the signals coming from the instrument: the beat note of the two laser beams, and the signals of each mode. The Sagnac frequency can be recovered as the linear sum of several terms, each term being analytically determined by the instrumental geometry, the mirror properties, and the laser working parameters. In summary the two main problems are the backscatter noise and the null shift.

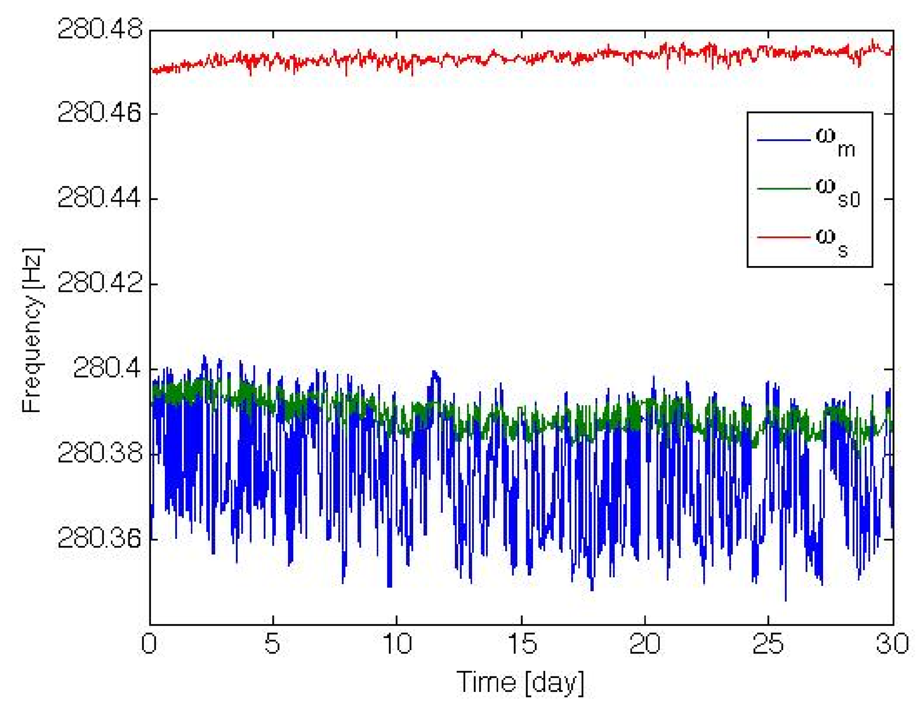

Figure 1: ***Different steps of analysis for GINGERINO, 600s bandwidth. ω_m is the beat note of the RLG, ω_{s0} in our analysis scheme is the first level of the analysis, free from backscatter noise, ω_s is the final reconstructed Sagnac frequency also the null shift term is considered. The average level of the signal changes in the different steps, showing that the laser dynamics affects also the accuracy of the measurement. In the present analysis scheme the RLG is cross calibrated with IERS.***

3. GINGERINO: polar motion and $\Delta\omega_3$ estimation

GINGERINO is located inside the underground laboratory of Gran Sasso, it is taking data with high duty cycle since several years. With statistical means We have recovered the polar motion from the data, using our analysis approach and the environmental monitor to remove the environmental disturbances from the data. The analysis is done utilising the IERS data about the Annual and Chandler wobbles, the daily polar motion and the evaluated $\Delta\omega_3$. The compatibility of the expected signals with the available GINGERINO data is done with a linear regression based on minimum square. Two different sets of data have been used, and a paper has been recently submitted and is available in the archive URL:$https://arxiv.org/abs/2003.11819?context=gr-qc$. In this paper we show that the signals are well reproduced, also $\Delta\omega_3$ is well reproduced, demonstrating that the sensitivity of GINGERINO is below prad/s in 1 second measurement. Fig. 2 shows the reconstruction of the polar motion and of $\Delta\omega_3$ for the 70 days in autumn 2019 (starting from October the first 2019).

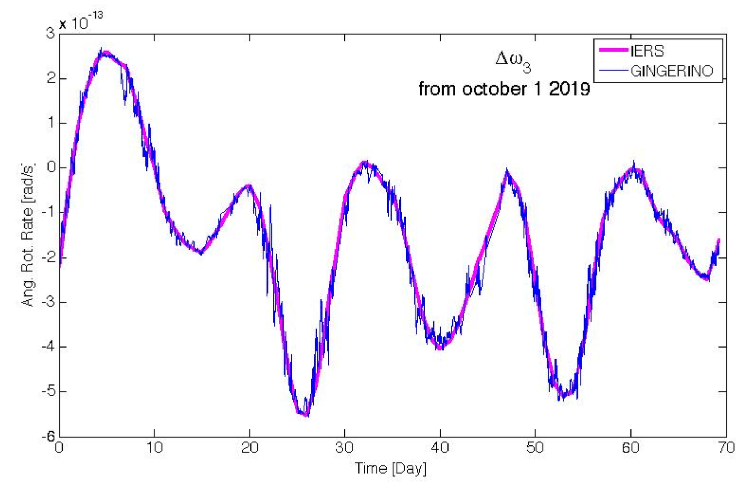

Figure 2: ***$\Delta\omega_3$ evaluated with GINGERINO and the IERS data.***

THE SAGNAC FREQUENCY IS EVALUATED BY A LINEAR COMBINATION OF DIFFERENT TERMS. THE ENVIRONMENTAL PROBES PROVIDE THE POSSIBILITY TO REMOVE THE LOCAL DISTURBANCES AND THE MAIN GEODETIC SIGNALS ARE RECOVERED. THE SENSITIVITY IS BETTER THAN PRAD/S IN 1 S.

4. Status of the GINGER project

GINGERINO is a single RLG, it cannot distinguish between rotation and inclination, the co-located tiltmeter allows to recover the geodetic signals, but it is not the ideal instrument, since it provides the variation with respect to the local vertical, while the variation should be with respect to the axis of rotation. An array of RLG can provide all necessary information. We have already shown that the optimal solution is to have at least 3 equal RLGs, one oriented at the maximum Sagnac signal, one horizontal and the other with area vector outside the meridian plane. It is as well necessary to improve the geometry control of the array, to keep stable the scale factor and to improve the absolute calibration of the gyroscopes. GINGERINO is a basic instrument, it is not equipped for this purpose. In any case it has shown the advantages to be underground located, a quiet and naturally thermally stable environment. Fig. 3 shows a picture of the proposed GINGER. WE HAVE BEEN ABLE TO CORRECTLY RECOVER THE TRUE SAGNAC FREQUENCY TAKING INTO ACCOUNT LASER DYNAMIC, DEMONSTRATING THAT GINGERINO SENSITIVITY IS BELOW PRAD/S, AND CORRECTLY RECOVERING THE GEODETIC SIGNALS, POLAR MOTIONS AND $\Delta\omega_3$

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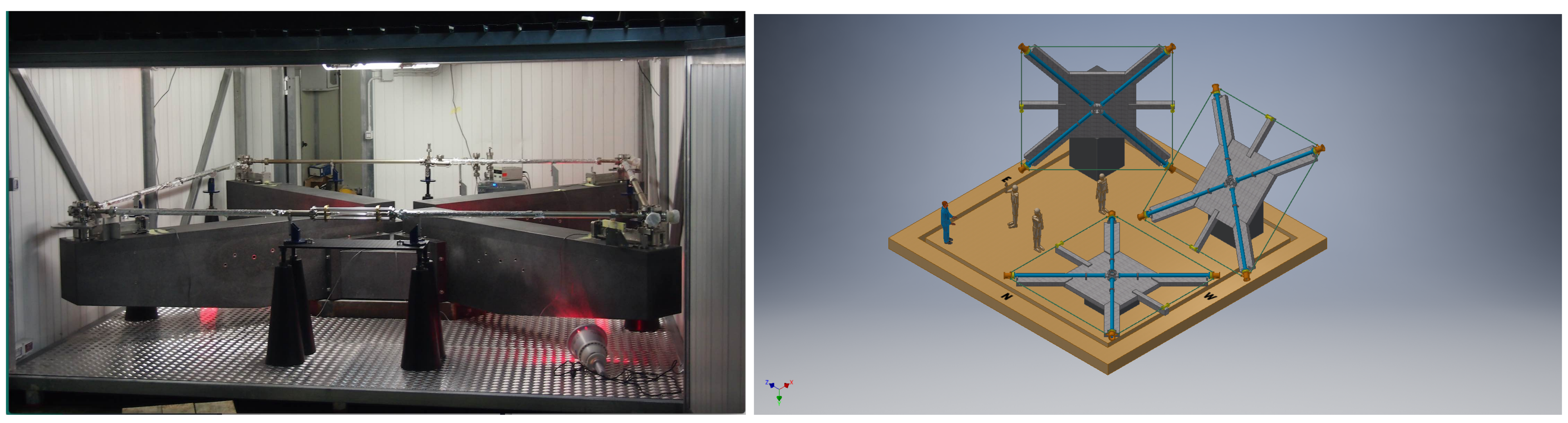

Figure 3: *LEFT: GINGERINO is a basic RLG composed of a simple hetero-lithic mechanical structure supported by a central monument. RIGHT: Artistic view of the GINGER project: the first two RLGs have area vector inside the meridian plane, one RLG is aligned at the maximum Sagnac signal, the second is horizontal, the third has area vector outside the meridian plane, its exact orientation depends on the final location and the available space. The RLGs could also be attached to the same monument.*

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