*Workshop sulla Gravitazione Sperimentale: misure laser, fisica fondamentale e applicazioni in INFN-CSN2*

# GINGER: are Sagnac gyroscopes suitable for fundamental physics?

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# Overview

Overview

- The Sagnac effect
- The ring laser gyroscope
- Our experience
- recent result

absolute rotation measurement

a very special instrument

our prototypes, see Beverini's talk at 15:30

GINGERINO's sensitivity

# G-GranSasso-RD

- G-GranSasso was started after 2 years in CSN5
- founded by a collaboration between Pisa, Naples, LNL and Polito
- in CSN2 since 2012
- at present there are 8 Fte in Pisa, Naples and Legnaro

# The Sagnac Effect

- For pedestrian: When you run on top of a turning table you complete the turn earlier if you go clockwise
- For scientist: the confrontation of the time required to complete a turn in a closed path in the two opposite directions depends on not reciprocal effects
- any scientist could think: interferometers based on photons or atoms could contain very interesting features

**Sagnac effect: inertial angular rotation rate $\Omega$**

$\Omega \propto \delta t$ proportionality constant depends on the geometry

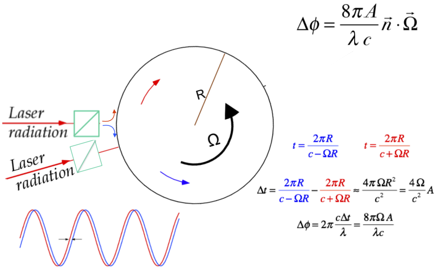
**a very special instrument**

high sensitivity, fast, continuously running, high dynamic range

# The Sagnac Effect

Different schemes have been realised in order to pick up the Sagnac signal, using light (resonant cavity or optical fibers), cold atoms, and helium superfluid.
By several orders of magnitude, the sensitivity record belongs to the Sagnac gyroscope based on active square cavity (ring laser gyroscope RLG, $ASD \leq 10^{-9}$rad/s).
Signal for the RLG:

$$\omega_s = |\omega_{cw} - \omega_{ccw}| = \frac{4\vec{A}\cdot\vec{\Omega}}{\lambda p}$$

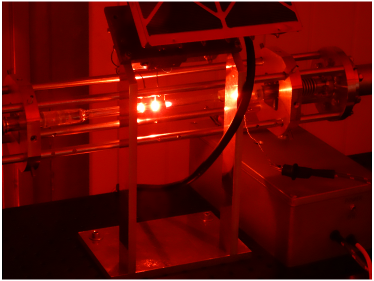



In general:

$$\Delta t = 4\frac{\vec{\Omega}\cdot\vec{A}}{c^2}; \Delta\phi = \frac{8\pi\vec{\Omega}\cdot\vec{A}}{\lambda c}$$

# Our prototypes: G-Pisa

...it has been very hard to have G-Pisa working, but as soon as the gain tube had a bright red color life become easier....

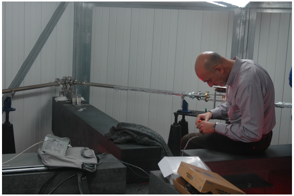


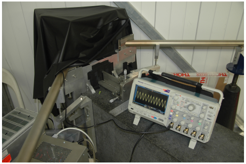
...2011 G-Pisa operative in the Virgo Central area, it has measured the effect of the strong wind on the central building. For one year, it has operated horizontal and vertical to measure tilts due to strong wind.

# Our prototypes: GINGERINO

GINGERINO, 3.6m in side was the maximum size for a square cavity inside the tunnel.

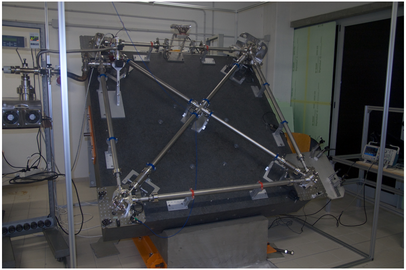
...a lot of patience required... the signal of the beat note



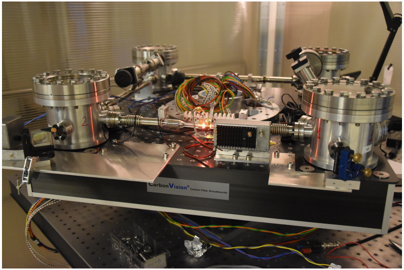


# Our prototypes: GP2 and GLAS

GP2 1.6m side, in Pisa and used for tests, is oriented at the maximum Sagnac signal.



GLAS the INRIM goniometer, progetto premiale.



# Fundamental Physics requirements

- de Sitter and Lense Thirring effects, function of the latitude, independent from the gravity map of the Earth.
- Lorents Violation, in the SME framework
- Gravitational waves exciting the Earth quadrupole moment
- space-time structure in the noise spectral density (Craig Hogan-Holometer)

sensitivity relative to $\Omega_{\oplus}$ and bandwidth required

**GR tests, Capozziello at 12:15**

1 part $10^9 - 10^{11}$ rate, DC and accurate, IERS required.

**Tasson at 16:45**

1 part $10^9$ or better, fractions of hours

**...here sensitivity is never enough..**

sensitivity better than 1 part $10^{12}$ at 1 hour frequency.
very high frequency, MHz and high accuracy.

# Main requirements

- Watershed between applications only and fundamental physics: sensitivity higher than $10^{-9}$ of the Earth rotation rate $\Omega_\oplus$,
- operative in almost continuous basis
- accuracy; for Sagnac gyroscopes is based on optical metrology to monitor and control the geometry of the cavity

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In the following the sensitivity of GINGERINO is analysed in detail

# The problem of the RLG

The use of the active cavity is extremely advantageous, but has the drawback that the data are affected by the non linear laser dynamic. We have elaborated an original analysis technique which takes into account the laser dynamic, and reconstruct $\omega_s$ using the available signals of the laser: the beat note $\omega_m$, the intensities of the two laser modes (DC and at $\omega_m$) and their relative phase. It is necessary to know the losses of the cavity $\mu$, at present $\mu$ is evaluated with statistical means.

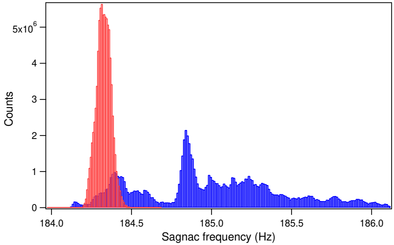


Figure: Caption: Distribution of the signal of GP2, with and without taking into account the dynamic of the laser

# Sensitivity of GINGERINO

GINGERINO is running in a continuous basis, unattended and free running since 2017. We know that inside its data is contained the global signal $\Omega_\oplus$, which is independently measured by IERS, $F_{IERS}$. It contains also local disturbances $\omega_{local}$, in principle due to geophysical phenomena or instrumental. Aim is to identify $\omega_{local}$ with a linear regression using the laser dynamic, the available environmental signals, temperature, pressure and tiltmeters signals $\zeta_{1,2}$ to reconstruct the global signal $F_{IERS}$.

$$\omega_s = CAL \cdot F_{IERS} + LD_T\mu + \omega_{local}$$
$$F_{IERS} \propto \vec{A} \cdot < \vec{\Omega}_\oplus > + CW + PM$$
$$\Omega_\oplus = < \Omega_\oplus > + \Delta\omega_3$$

CW and PM are the effect of GINGERINO of the Annual and Chandler wobble and the daily polar motion, depending on the scale factor SF.

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IERS data are used to cross calibrate and evaluate the absolute orientation and the effective scale factor SF in an arbitrary point $T_0$, to evaluate CAL.

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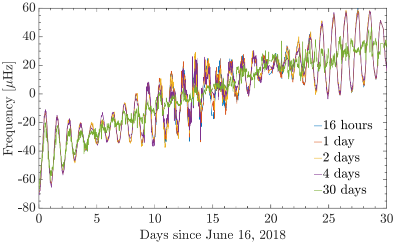
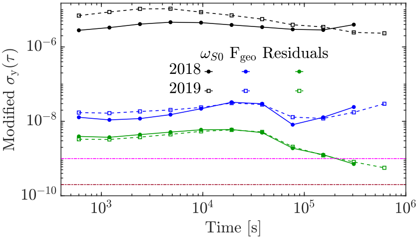
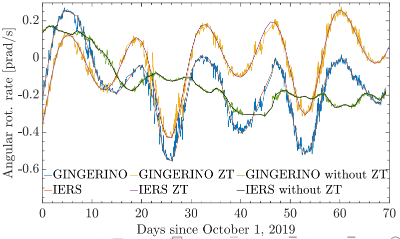



sensitivity limit 40 frad/s after 3.5 integration days: meaningful for GR test and Lorentz violation study.

Please note that MAD is still decreasing.

$F_{geo}$ is $F_{IERS}$ reconstructed by the linear regression.



# Available signals

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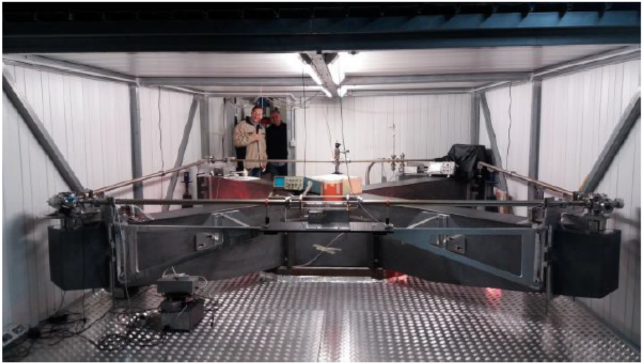
Signals:

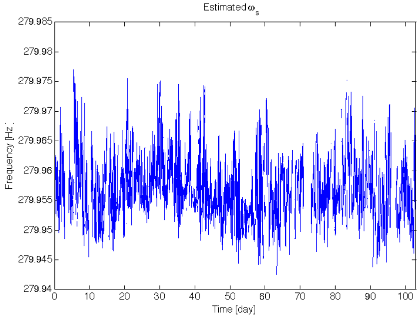
Gyroscope signals: beat note $\omega_m$, amplitude of the two modes $I_1$ and $I_2$, amplitude of the two modes at the beat note frequency $IS_1$ and $IS_2$, relative phase $\varepsilon$, power at the discharge GM

Environmental signals: Temperature, Pressure, Tiltmeter $\zeta_1$ and $\zeta_2$



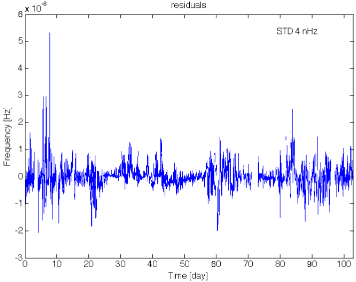
$\zeta_{1,2}$ play a dominant role in the identification of $\omega_{local}$. More explanatory variables are added to the linear regression, obtaining:

- residuals gaussian distributed, typically STD $10-4$nHz (close to frad/s)
- estimation of the sensitivity limits using two sinusoidal signals added to the signal and to the LR: period 40 and 0.5 days, sensitivity of the order of 0.3nHz (0.05frad/s).

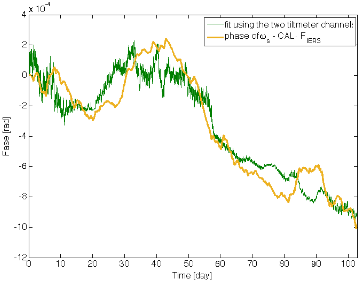


# The disturbances have instrumental origin

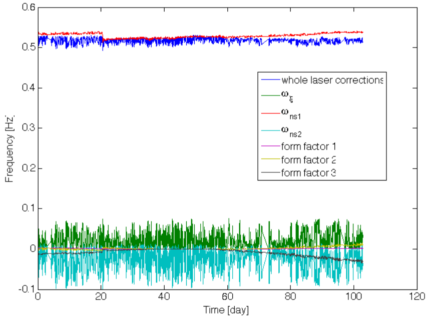
Typical residuals, STD 4nHz.

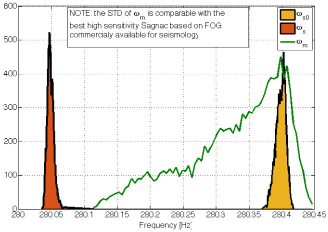



$\omega_{local}$ is instrumental, when the monument tilts the mechanical structure of GINGERINO rotates



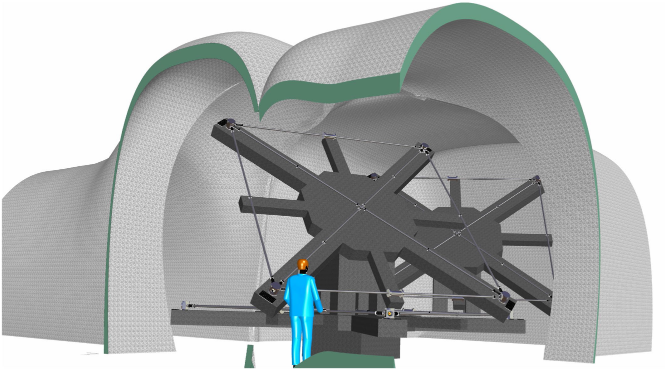
# Laser corrections and typical distribution



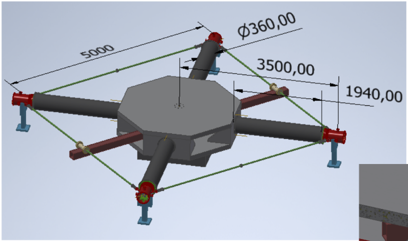
# GINGER, Gyroscopes IN GEneral Relativity

The RLG at the maximum signals provides $|\Omega_\oplus|$ and the relative orientation of the other two RLG with the Earth rotation axis, in this way the measurement is limited by the shot noise of the RLG, and not by the error in the evaluation of the relative angles between different RLGs.

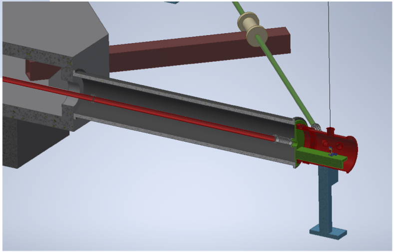


# Improved mechanical drawings

## GP3 mechanics – new ideas:




- The gyrolaser plane is coincident with the support structure central plane.



- Carbon fiber tubes hold in position the supports of the mirrors at the corners.
- The total structure is lighter.

# RLG and fundamental physics

Discriminate among different theories implies to find small differences in the measurements. De Sitter and Lense-Thirring effects are the most important effects of GR on our planet, accordingly their measurements are meaningful for GR tests, where to test means to provide effective ways to discriminate among theories. The main objective of fundamental physics is to select the theory to describe the world.

# Near future plan and conclusions

The analysis indicates a sensitivity adequate for GR tests and fundamental physics in general. It is necessary to develop the laser dynamic simulation, in order to make a monte carlo of the linear regression. Accuracy is absolutely necessary and will be necessary for GINGER to avoid the cross calibration.

GINGER has been designed using one of the RLG at the maximum Sagnac signal, in order to provide a measurement limited by the RLG sensitivity only. The RLG at maximum gives the orientation of the other two with respect to the axis of rotation. Rotation of the whole structure must be avoided.