G-GranSasso→ GINGER

- G-GranSasso --- completato

- GINGER: TDR pronto per il 1 luglio 2021, presentazione in CSN2 il 12 luglio

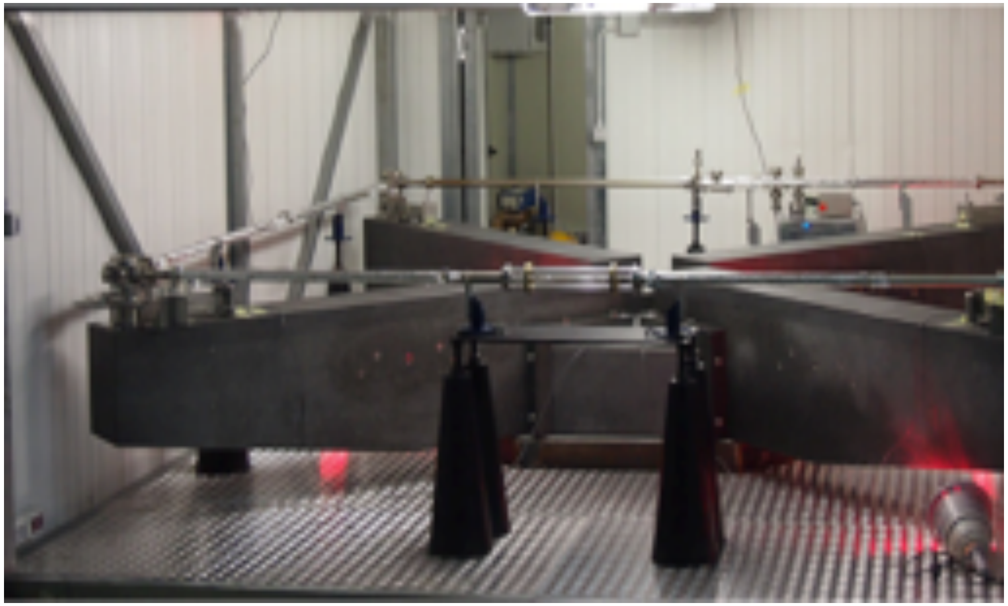
GINGERINO results

Phys. Rev. Res. **2**, 032069(R) (2020)

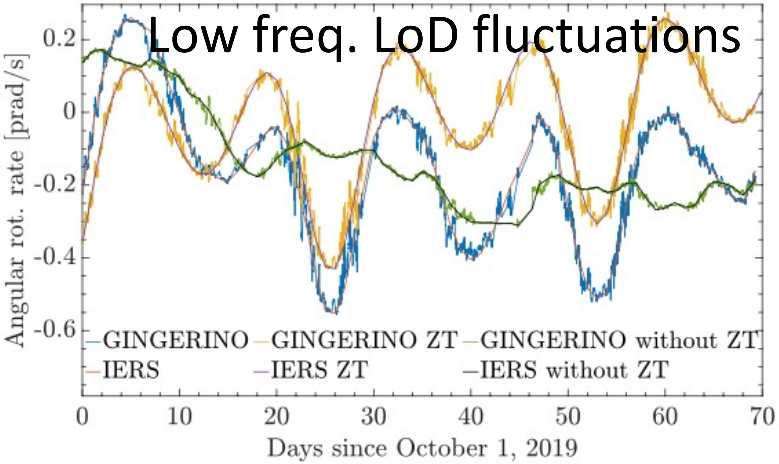
Eur. Phys. J. **C 81**, 400 (2021)

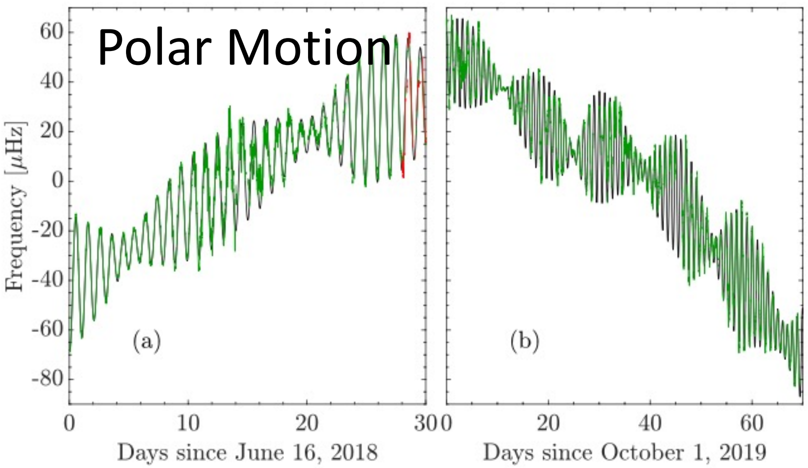
GINGERino @ LNGS

- Demonstrated sensitivity: 0.1 femtorad/sec (LNGS noise compatible with GINGER operation)
- Suitable for geodesy: e.g. polar motion and Length of the Day fluctuations (LoD) measurements …
- Suitable for geophysics: e.g. teleseisms, rotational seismology,… (collaboration with INGV)



Comparison between GINGERino (local) and Earth rotation (global) measurements by IERS





CONCLUSIONI

- I giroscopi Sagnac, interferometri altamente 'simmetrici', permettono di investigare il grado di libertà 'rotazionale', sia in geofisica che in fisica fondamentale, oltre che la natura del fotone stesso.

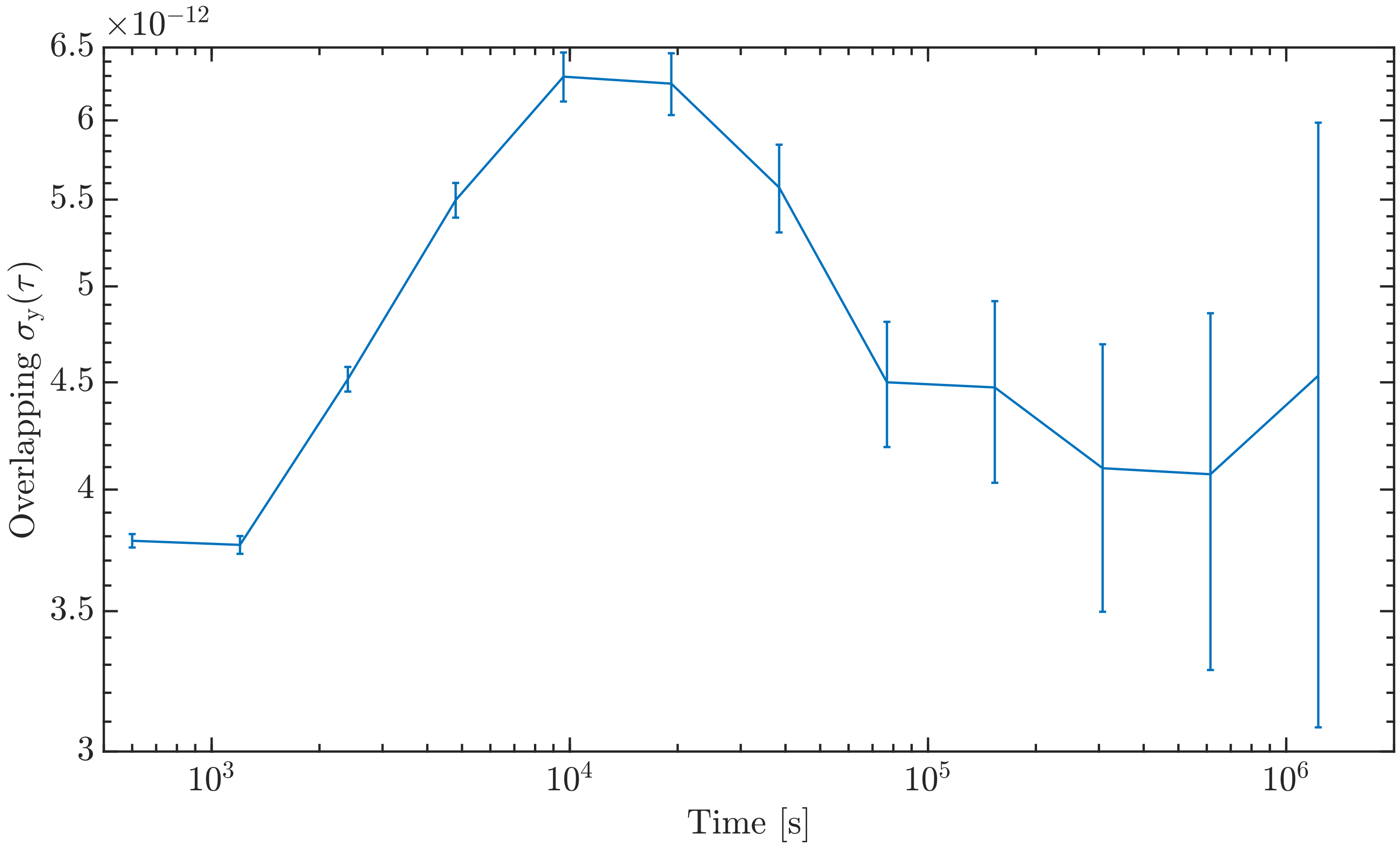
- Per essere significativi per la fisica fondamentale occorre investivare le rotazioni a livello $\geq$ 1 parte in 10^9 di $\Omega_\oplus$ (ordine 10^{-14} rad/s)

- La domanda è: quale sensibilità abbiamo?

- Usiamo I segnali geodetici come 'test beam' per studiare l'apparato

Eur. Phys. J. **C 81**, 400 (2021)
10^{-16} rad/s

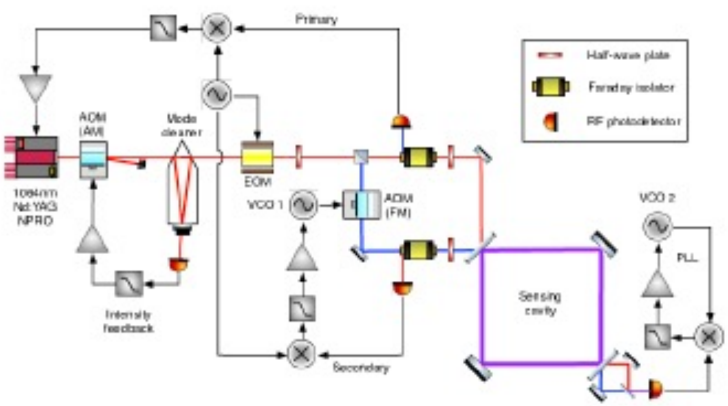
https://home.infn.it/it/news-infn/4478-gingerino-misura-la-velocita-di-rotazione-e-il-campo-gravitazionale-della-terra



I giroscopi Sagnac e il pregiudizio

https://caltechexperimentalgravity.github.io/research/laser-gyroscope-for-rotation-sensing.html

EXPERIMENTAL GRAVITATIONAL PHYSICS MENU



used in aerospace and defense applications, these devices have more recently been used for precision seismology and in other research settings. In particular, mid-sized (~m-scale) laser gyros have been under development as tilt sensors to augment the adaptive active seismic isolation systems in terrestrial interferometric gravitational wave detectors. The most prevalent design is the ``active'' gyroscope, in which the optical ring cavity used to measure the Sagnac degeneracy breaking is itself a laser resonator. In this article, we describe another topology: a ``passive'' gyroscope, in which the sensing cavity is not itself a laser but is instead tracked using external laser beams. While subject to its own limitations, this design is free from the deleterious lock-in effects observed in active systems, and has the advantage that it can be constructed using commercially available components. We demonstrate that our device achieves comparable sensitivity to those of similarly sized active laser gyroscopes.

G-GranSasso ha riportato questi strumenti nel novero degli strumenti utili per test di fisica fondamentale

- Noi abbiamo mostrato che la dinamica non lineare del laser, nel caso di un giroscopio ‘statico’, può essere risolto con una adeguata analisi basata sulle equazioni che regolano il laser e tenendo conto dei segnali di diagnostica che l’apparato fornisce

- Il rumore, stimato sul modello semi-classico del laser, è maggiore a quello misurato, questo è un punto che andrà investigato con maggior dettaglio. Ma non viola nessuna legge fondamentale della fisica.

- MOLTO IMPORTANTE: nei RLG la misura si basa su di un battimento e sulla luce

- misura di una frequenza--> alto range dinamico

- La luce garantisce larga banda della misura

- Cioè lo stesso apparato può misurare telesismi, terremoti locati e avere sensibilità molto elevate alle frequenze ultrabasse.

INTERDISCIPLINARE

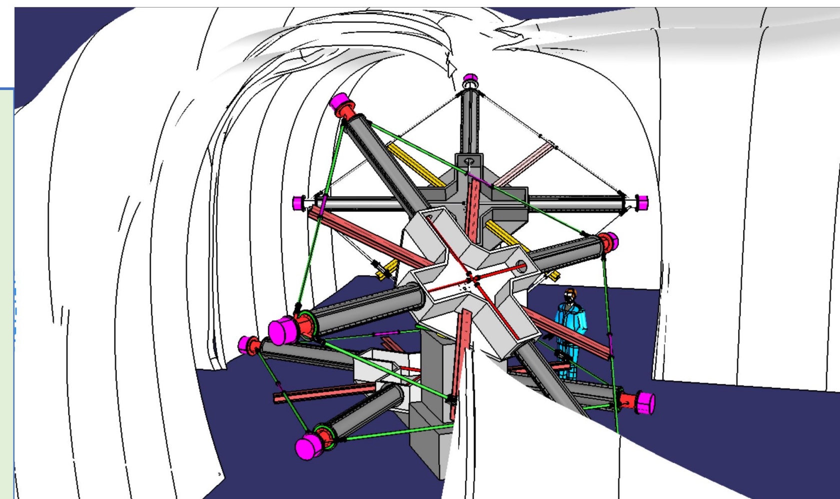
GINGERINO ha mostrato di essere utile per la sismologia

- Dati raw di GINGERINO disponibili sul data base della sismologia da febbraio 2020
- Circa 1 articolo l’anno pubblicato su argomenti di sismologia

GINGER Gyroscopes IN General Relativity
(nuova sigla)

GINGER: Test GR extension/modification and Lorentz violation with a very accurate measurement of Earth's rotation rate (picorad/sec) using an array of ring lasers

INFN: Pisa/LNL/Napoli/LNGS
and
INGV: L'Aquila, ROMA



Scientific goals: test GR (modif/ext) on Earth; "beyond GR theories"; minimum spacetime scale (holometer); test of Lorentz invariance …

Gyroscope goals: measure the Earth angular rotation Ω relatively to the local inertial frame better than 1 part in 10^9 i.e. reach a rotational sensitivity of 0.1 femtorad/sec (impact on Geodesy and Geophysics)

motivazioni teoriche e Technical Design Report in preparazione

The Sagnac Effect

- For pedestrian: When you run on top of a turning table the time necessary to complete the turn depends on the direction
- For scientist: the confrontation of the time required to complete a closed path in the two opposite directions depends on not reciprocal effects

Sagnac effect: inertial angular rotation rate Ω

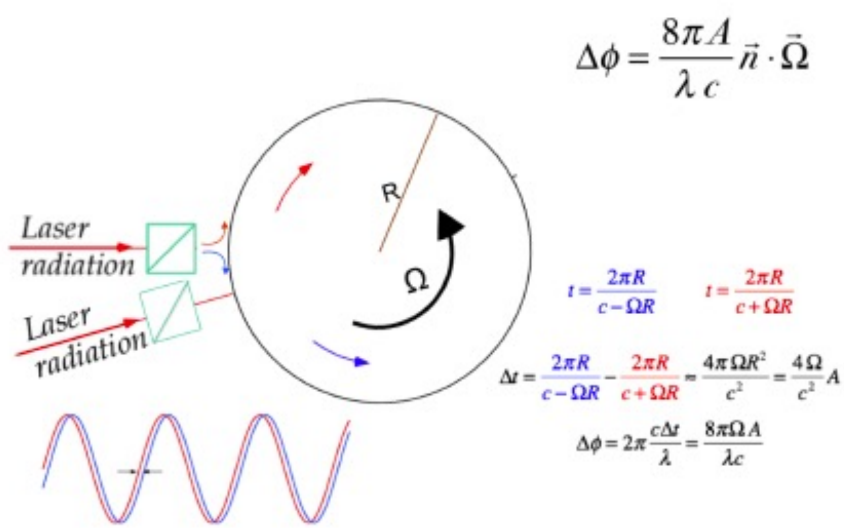
$\Omega \propto \delta t$ proportionality constant depends on the geometry

a very special instrument

absolute angular rotation -> rigid apparatus, no moving parts

The Sagnac gyroscopes

- Different schemes: using light (resonant cavity or optical fibers), cold atoms, and helium superfluid.
- a special kind of interferometer
- the sensitivity record belongs to the Sagnac gyroscope based on active square cavity (ring laser gyroscope RLG, $ASD \leq 10^{-9} - 10^{-12}$rad/s, 1 s).



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

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

RLG a very special instrument

- unattended continuous operation for months
- typically sub-prad/s sensitivity in 1 second of measurement
- very large bandwidth, fast response, in principle as fast as milli-seconds
- very large dynamic range. Since it is based on frequency measurement, the same device can record sub-prad/s variations and strong signals from near by earthquakes
- they can be oriented at will in order to reconstruct in 3D the angular rotation vector

Lorentz Violation, PRD 100 (2019) 6, 064031

Jay Tasson, and coauthors, have pointed out that RLG can effectively contribute to the Lorentz Violation quest.
We note that the LV test pursued following Tasson calculation is looking at some modulated effect, so very high accuracy is not required.
We are in touch with Jay providing data samples useful for his students.

sensitivity of 1 part in 10^9 of the Earth rotation rate would provide interesting measurements of two Lorentz-violating terms in the framework of the Standard-Model Extension.
In one case, sensitivities that are competitive with recent laboratory and perhaps solar system tests would result.
For the other term, measurements competitive with the best existing limits, which currently comes from radio pulsar studies, would result.

GINGER constraints... Capozziello et al.

Constraints taking into account Extended Theories of Gravity. From the weak-field limit of the theory, it is possible to relate the gyroscopic and Lense-Thirring effect with the parameters of the further degrees of freedom present in the theory. GINGER puts an upper limit to the first derivative of the function $f(R, R^{\mu\nu}R_{\mu\nu}, \phi)$ with respect to the second-order curvature invariant $R^{\mu\nu}R_{\mu\nu}$ obtaining $m_\gamma > 1.88 \cdot 10^{-6} m^{-1}$

Let's consider specific matter Lagrangian of Horava-Lifshitz gravity, a_1 and a_2 are parameters theoretically un-constrained. In the weak field limit, a relation between the two constants and the value of the effective gravitational constant G_{HL} can be found. From the LT term it is possible to obtain $0.999 G_N < G_{HL} < 1.001 G_N$ and a_1 and a_2 are fixed through data with the direct measurement.

S. Capozziello et al, Eur. Phys. J. Plus (2021) 136: 394

sensitivity relative to the Earth rot. rate

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

Salvatore Capozziello

sensitivity windows $10^9 - 10^{13}$, low rate, DC and accurate, IERS required.

Jay Tasson

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.

- GINGER: membri storici di G-GranSasso (Pisa, Napoli, LNL e To)+
  Salvatore Capozziello (Na) e Gaetano Lambiase (Sa)
  INGV: Bauer, De Luca, Di Stefano, Devoti, Govoni.   (CNT, ROMA1 e Arezzo)
  Univ. Dell'Aquila (ingegneria): Dell'Isola, Giorgio, Tallini…

Il GranSasso è una delle aree più importanti da un punto di vista sismologico e geofisico

nel Gran Sasso stiamo costituendo un osservatorio multiparametrico: sismometri, gravimetri, gps e GINGER

Accordo di programma INGV-INFN e convenzione con LNGS in preparazione

Attività G-GRANSASSO/GINGER 2022

- Perfezionamento dell’analisi e della simulazione
- GINGERINO on e dati su EIDA finchè ci sono
- (smontare GINGERINO?)
- GINGER ?

Le richieste dipendono dall’approvazione di GINGER

Alte tecnologie e officina

- (0.5 MU montaggio)
- 4MU Basti
- (1MU preparazione e smontaggio GINGERINO)
- 2MU officina

Elettronica e calcolo

- 1MU elettronica
- 1MU calcolo

SPAZI

- Laboratorio di ottica.
- Cabinet nella camera pulita.

People

- Giorgio Carelli
- Donatella Ciampini
- Angela Di Virgilio
- Francesco Fuso
- Umberto Giacomelli (GSSI, associato Pisa)
- Andrea Basti
- Enrico Maccioni
- Fabio Morsani
- Paolo Marsili
- Giuseppe Terreni