# GINGER status report

Ring Laser Gyroscope: very unique device:

Optical Cavity +

Active Medium +

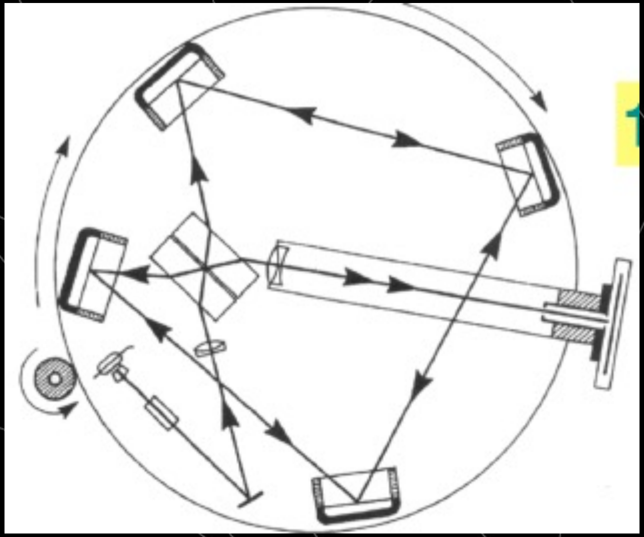
Equal arms interferometer +

2 independent beat notes +

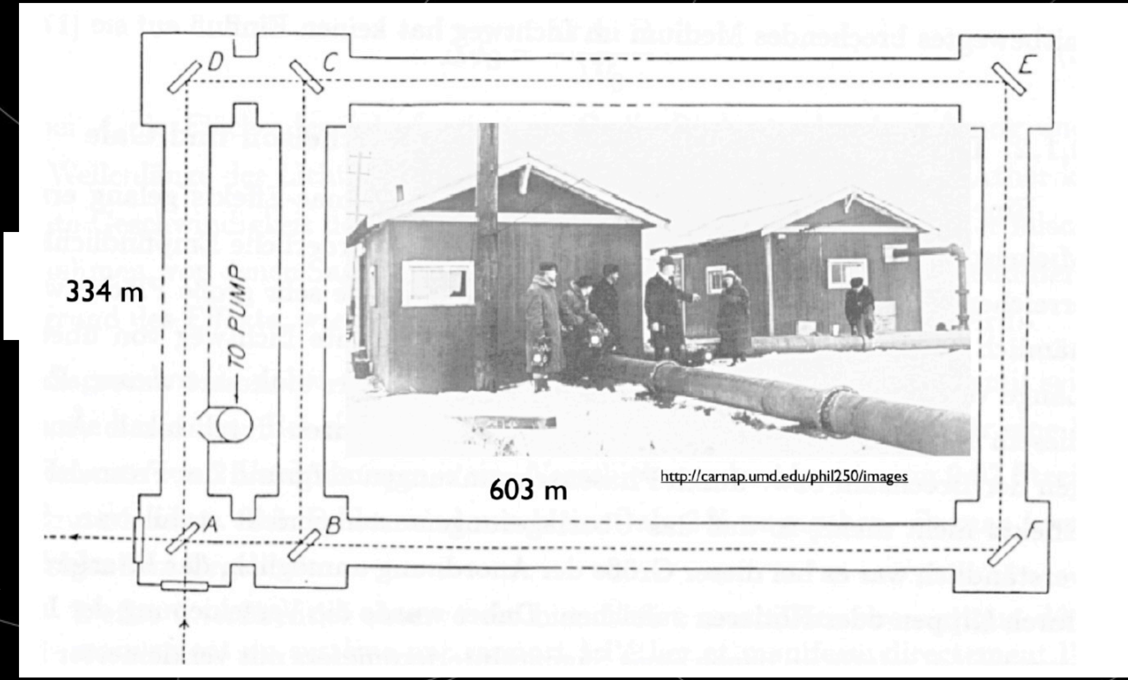
the solid crust of our Earth

# Interferometry and Sagnac effect are 100 years hold

- Georges Sagnac (1913) realized the first gyroscope to disprove Einstein relativity



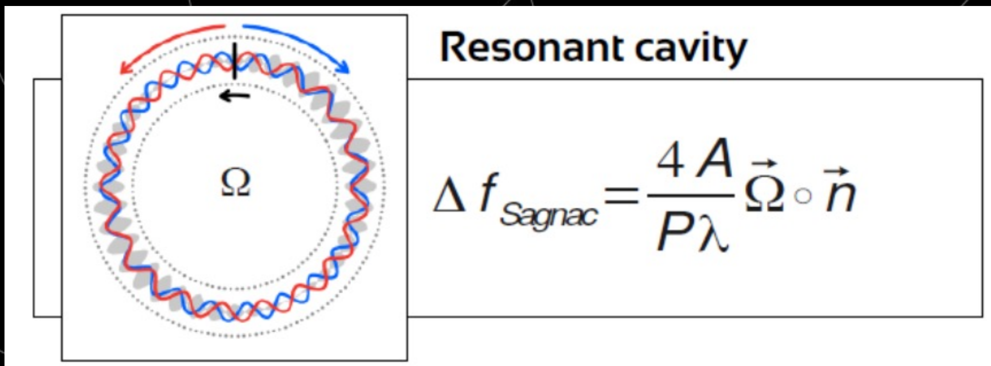
Fringe pattern solely caused by Earth rotation




We aim at exploiting Sagnac effect to prove General Relativity by measuring the Earth rotation rate

Michelson - Gale Interferometer in Clearing, Illinois (1925)

# Sagnac effect in an empty cavity

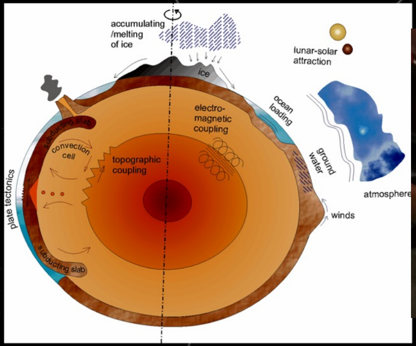



- from an *e.m.* point of view in a rotating ring cavity the time difference become a shift for the cavity resonances
- the shift depends on the area (A), the path length (P), the wavelength (λ), and the projection of the angular speed onto the path versor

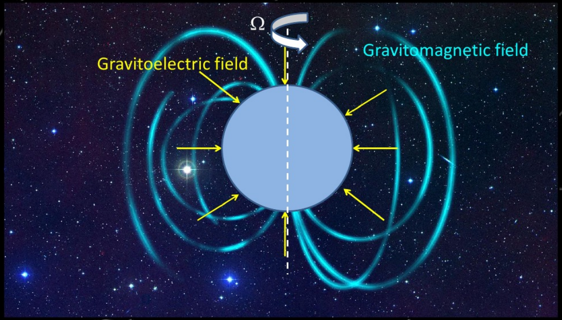
The Ω measure is affected by:

- the scale factor of the cavity ring
- the orientation with respect to the rotation axis

# Angular rotation/ sensitivity








$10^{-4}$ $10^{-6}$ $10^{-8}$ $10^{-10}$ $10^{-12}$ $10^{-14}$ rad/sec

Sidereal day

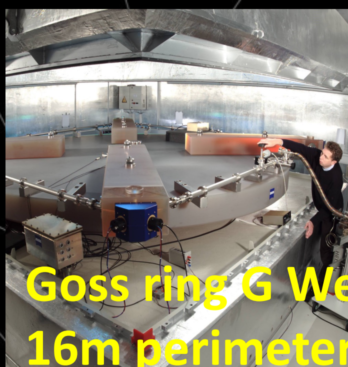
seismology

tides

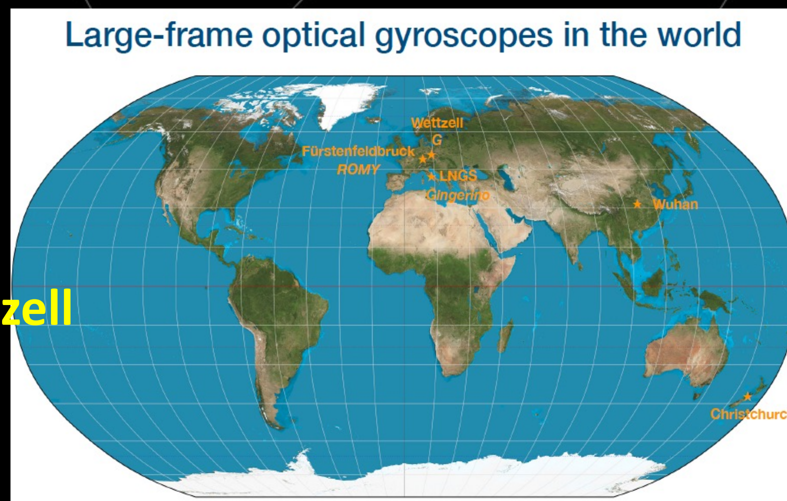
geodesy

General Relativity

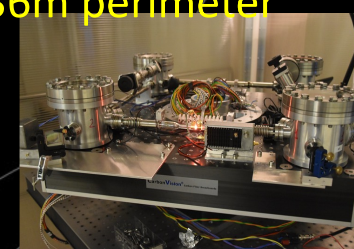
# RLG in the worls



Goss ring G Wettzell
16m perimeter




ROMY 4 RLGs, ERC
36m perimeter



so fare large frame RLG have top sensitivity for Earth rotation

# Main Noise sources in RLG, for whom we have developed solutions

Backscattering

- Scattered photons at the mirrors couple to the reverse resonating mode of the cavity

**By Monitoring the two beams this contribution is analytically cancel out**

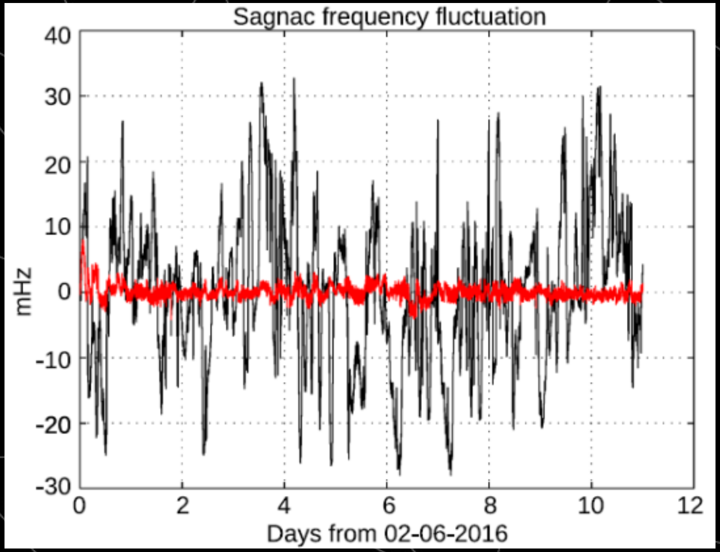
Laser dynamics (null shift)

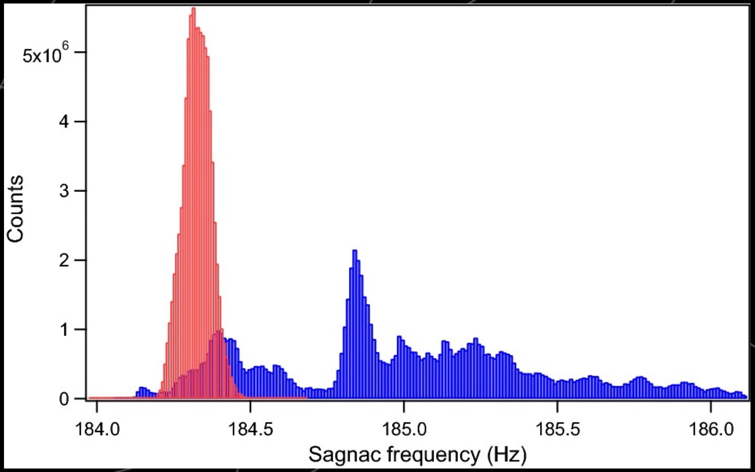
- The laser dynamics is a rather complex non-linear process.

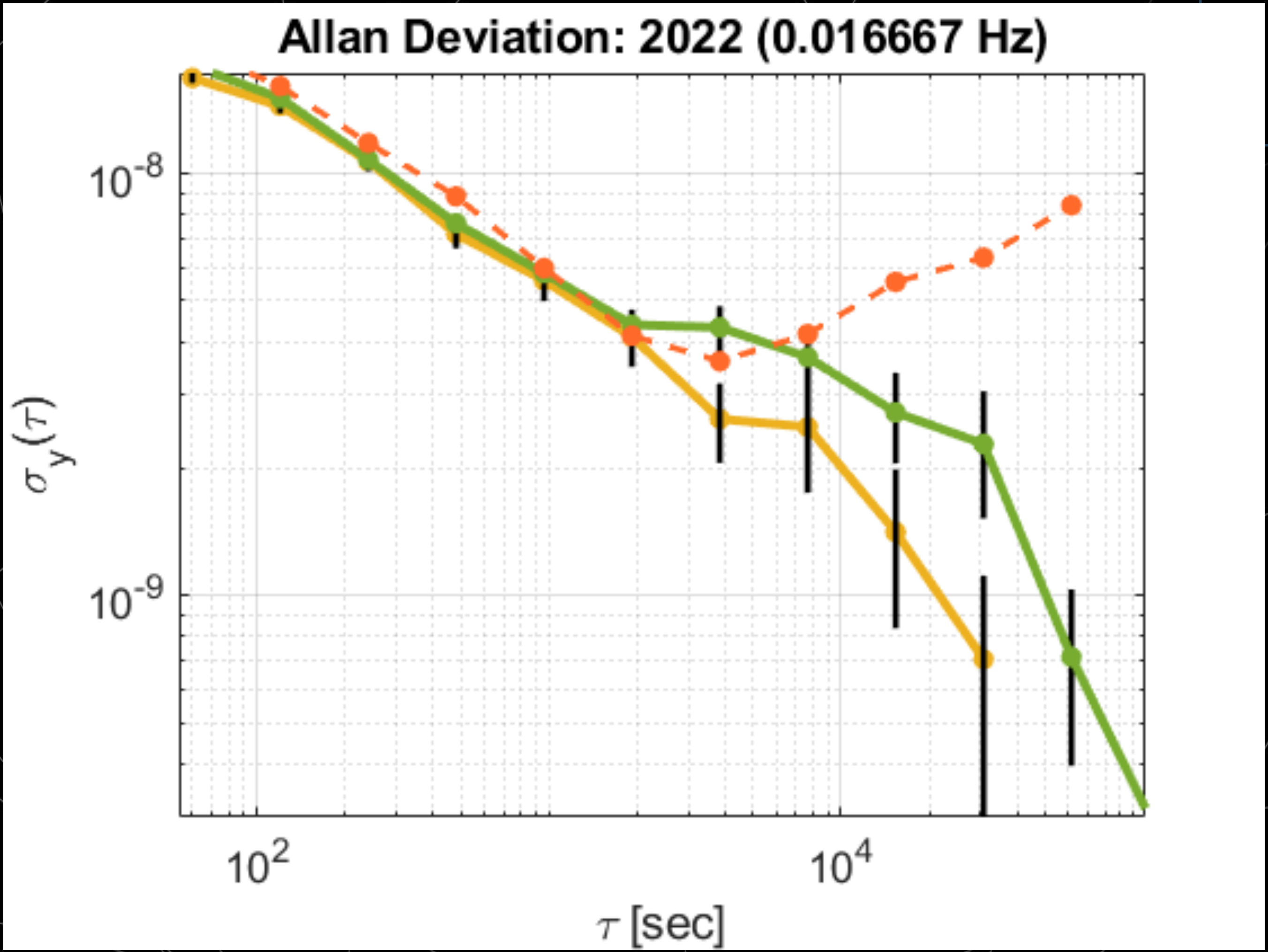
**We have developed an original methods to remove such systematics through the estimation of Lamb parameters in a semiclassical approach.**

# Example of the data analysis improvements

- Typical raw data (black) and backscattering corrected one (red) from GINGERINO in 2016



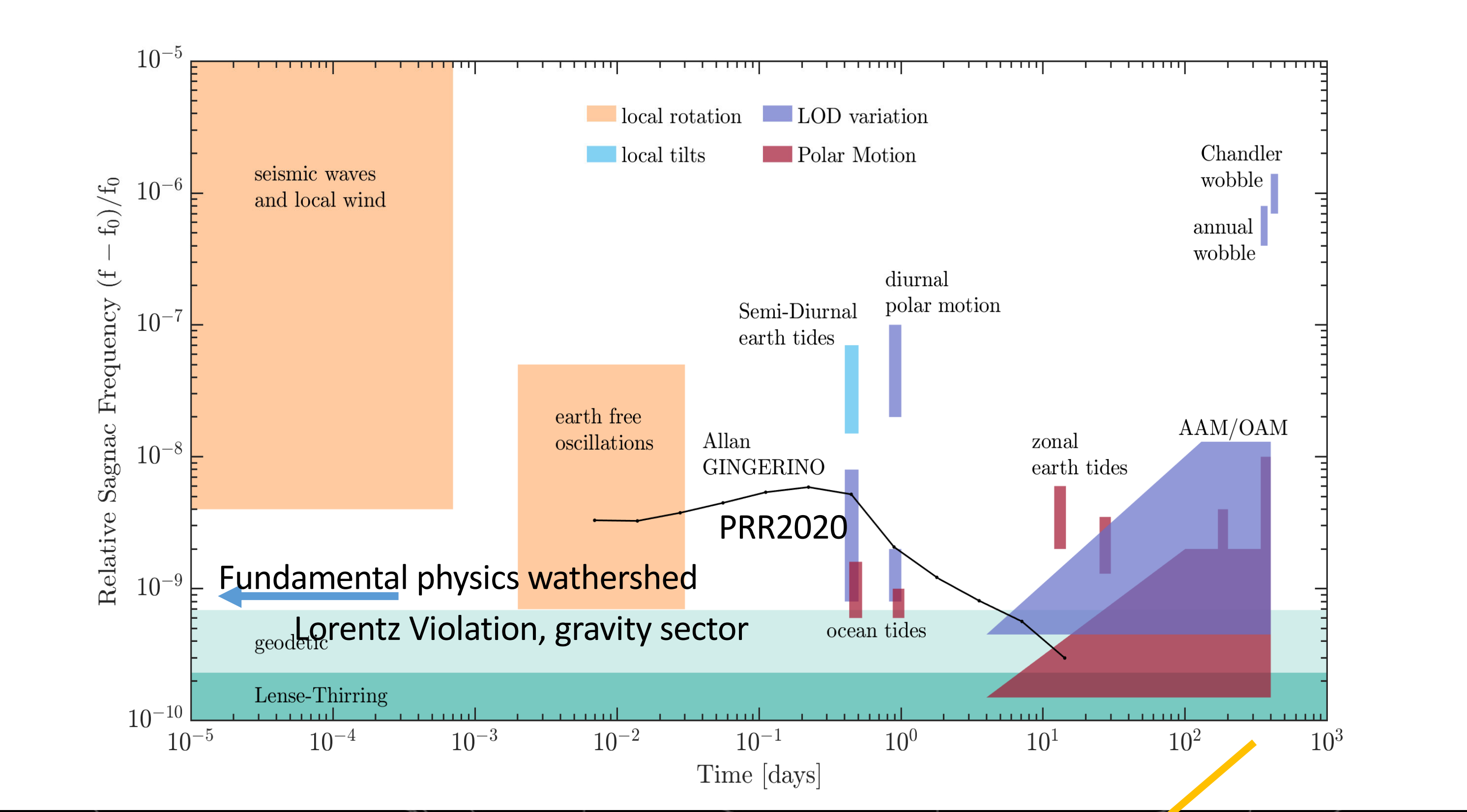



https://doi.org/10.1140/epjc/s10052-022-10798-9

Data analysis of GINGERINO applied to the G Wettzell ring laser

# Earth Multimessenger!

**GINGER is attached to the Earth, which provides a natural 'test-beam': highly interdisciplinary**




**Fundamental Physics**
**Geophysics**
**Geodesy --> FUNDAMENTAL SCIENCE**

**..a natural playground to test the apparatus**

**inertial platforms, next generation GW detector space missions**

**Most recent measurements indicates feasible to reach 1 part $10^{11}$**

# GINGER is part of UGGS

*(Underground Geophysics at Gran Sasso)*

# GINGER People

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# GINGER

# Gyroscopes In GEneral Relativity

- Thought for measuring the LenseThirring effect with an Earth based experiment (at fixed latitude, not averaged and gravity map not needed) with <1% accuracy -> to set different bounds on the validity of alternative theory of gravity
- We are completing the details of the project to send the orders asap, planning to start construction by the beginning of 2025 and operation by the end of 2025


- *Bosi et al.* PRD 84:122002 (2011) "Measuring gravitomagnetic effects by a multi-ring-laser gyroscope"
- *Di Virgilio et al.* EPJ ***Plus*** 132:157 (2017) "GINGER – a Feasibility study"
- *Capozziello et al.* EPJ ***Plus*** 136:394 (2021) "Constraining theories of gravity by GINGER experiment"

# GINGER – Measurement principle

$$\delta f = \frac{4A}{\lambda P} \mathbf{u}_n \cdot \boldsymbol{\Omega},$$

$$\boldsymbol{\Omega} = \boldsymbol{\Omega}_{\oplus} + \boldsymbol{\Omega}'$$

Along with the pure kinematic Sagnac term it comes a relativistic contribution
It includes 4 terms and amounts to about $10^{-9}$ x the Earth rotation rate ($10^{-14}$ rad/sec)

$$\boldsymbol{\Omega}' = \boldsymbol{\Omega}_G + \boldsymbol{\Omega}_B + \boldsymbol{\Omega}_W + \boldsymbol{\Omega}_T$$

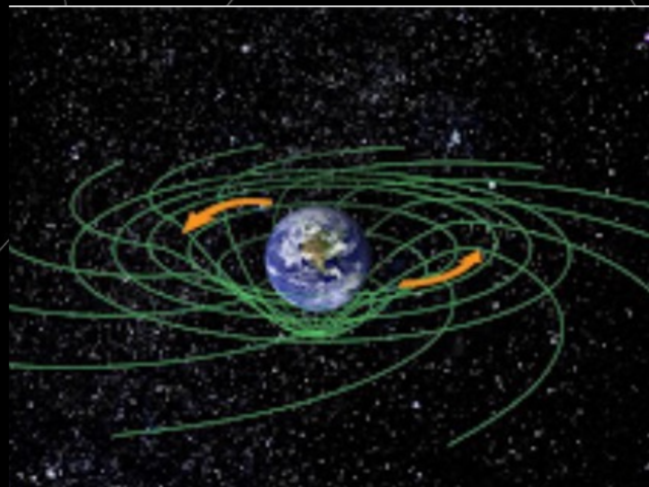
- (i) the geodetic or de Sitter precession $\Omega_G$;
- (ii) the Lense-Thirring precession $\Omega_B$ ;
- (iii) $\Omega_W$ the preferred frames effect;
- (iv) the Thomas precession $W_T$

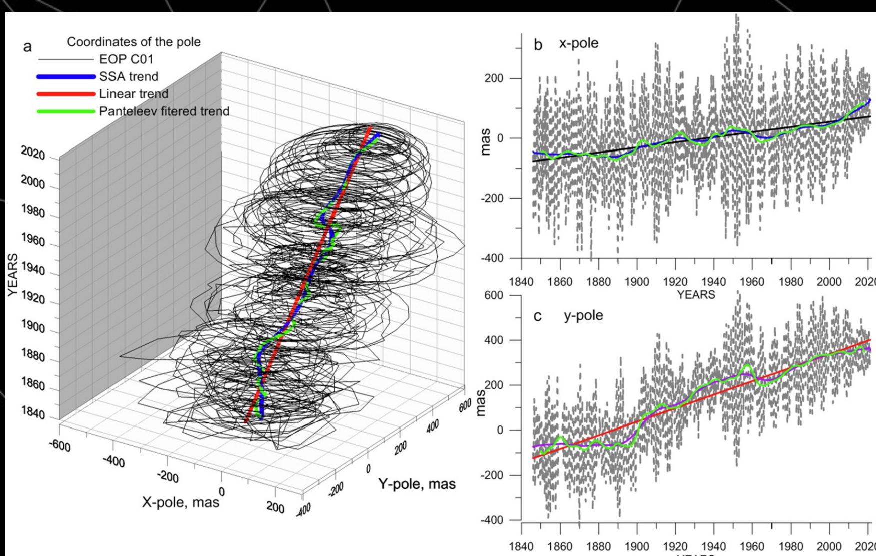
The last two terms are orders of magnitude smaller than the others so they are neglected

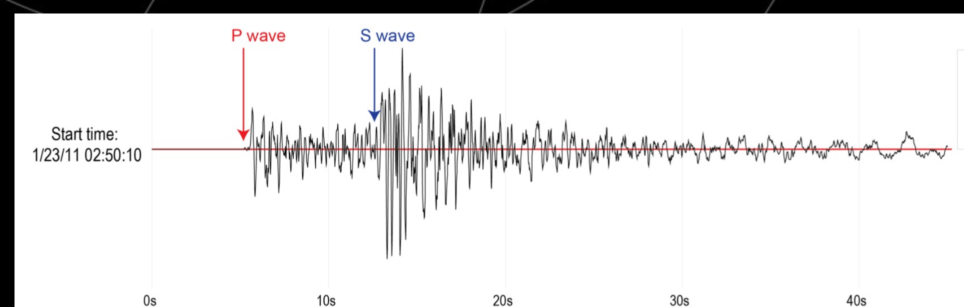
# GINGER hints

- Lense-Thirring (and de Sitter) act on the RLG as angular rotation vector summed to the Earth rotation rate. These are the most important effects of GR on our planet
- First direct measurement of Post Newtonian effects on the Earth surface with sensitivity better than 1 part $10^9$ of the Earth rotation rate
- DIRECT MESUREMENT: controllable, repeatable, replicable, here (on the Earth) and now (real time data analysis)
- Discriminate among different theories implies to find small differences in the measurements.
- The measurement precision will indicate a limit to alternative theories of gravity like Horava–Lifshitz

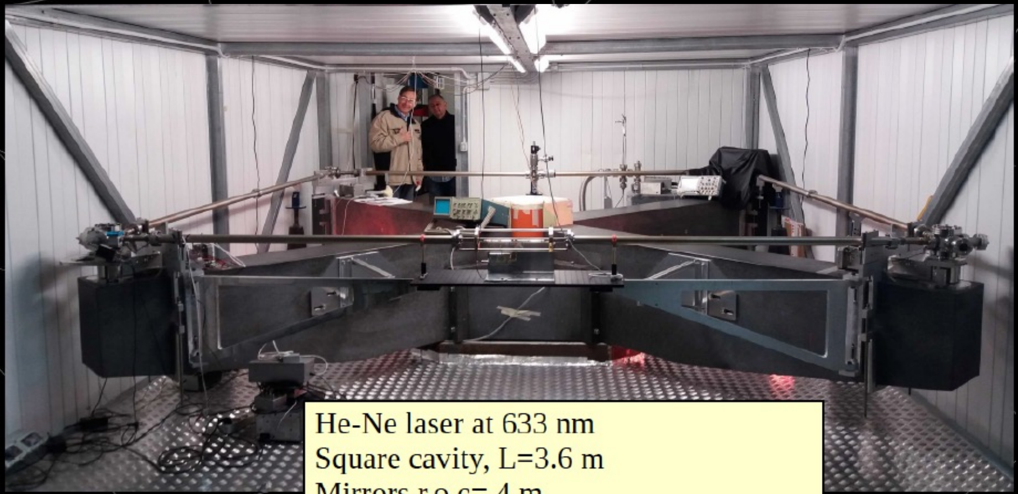
# GR tests
# Lorentz V., gravity sec.
# Geophysics & Geodesy



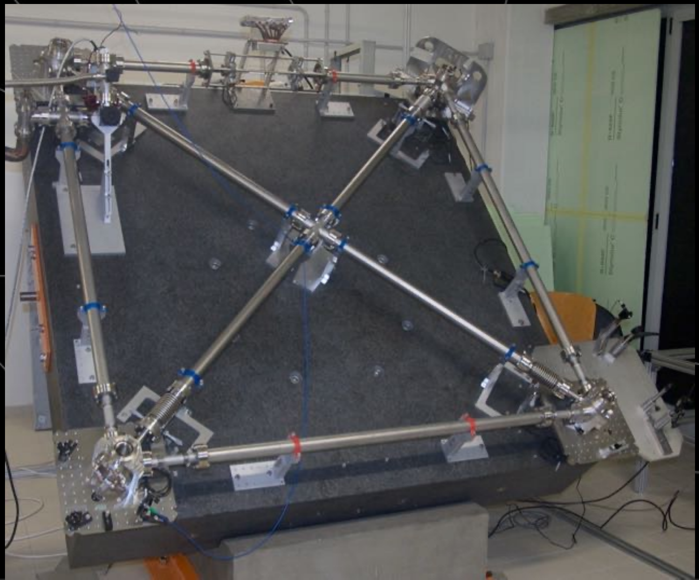


# PROTOTYPES: GINGERINO@ LNGS, GP2 @INFN-Pisa-bas.



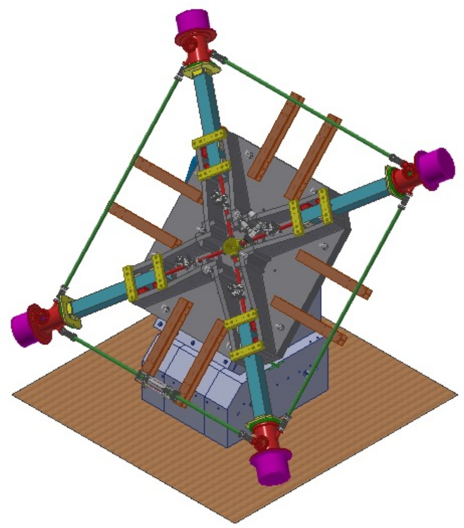
He-Ne laser at 633 nm
Square cavity, L=3.6 m
Mirrors r.o.c= 4 m
Earth rotation Sagnac bias: fs=280.4 Hz



- A 3.6m ring cavity inside LNGS, operative since 2015
- No active controls
- Runs completely unattended – remote ignition
- Off-line data analysis for very low frequency study
- Online data transferred to EIDA data base for seismology study (0.01-100Hz)

- GP2, 1.6m side, oriented at the maximum signal, used to develop geometry control and measurement and remote control of apparatus

# The ring laser gyro not monolithic



*GINGER GP3 design*

- He-Neon laser gain medium is inside the cavity
- the two laser beams will feel different cavities and the two emission will be frequency split
- This concept has been demonstrated on monolithic structure, we develop hetero-lithic structures
- GINGER design is based on the experience gained with our prototypes

# Main requiremens

<u>to keep GINGERINO sensitivity</u>

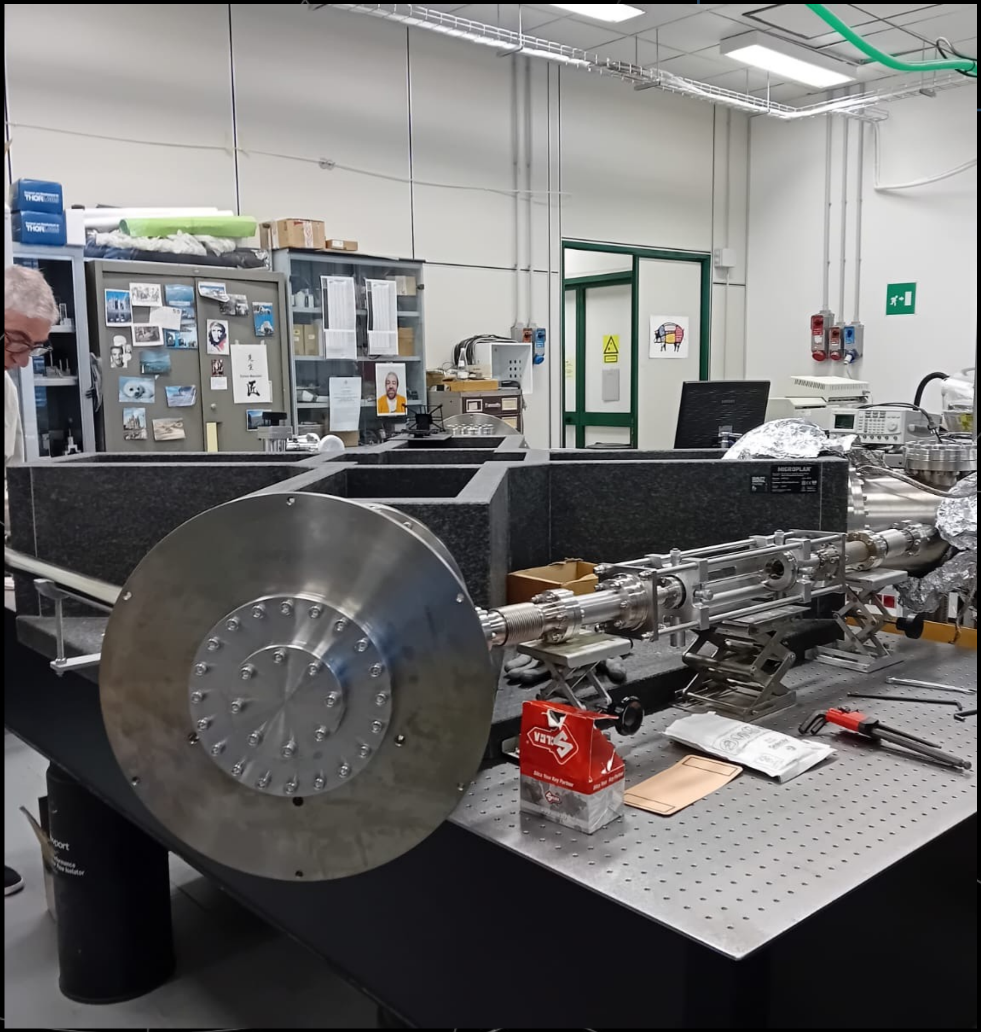
Perimeter between 12-16m

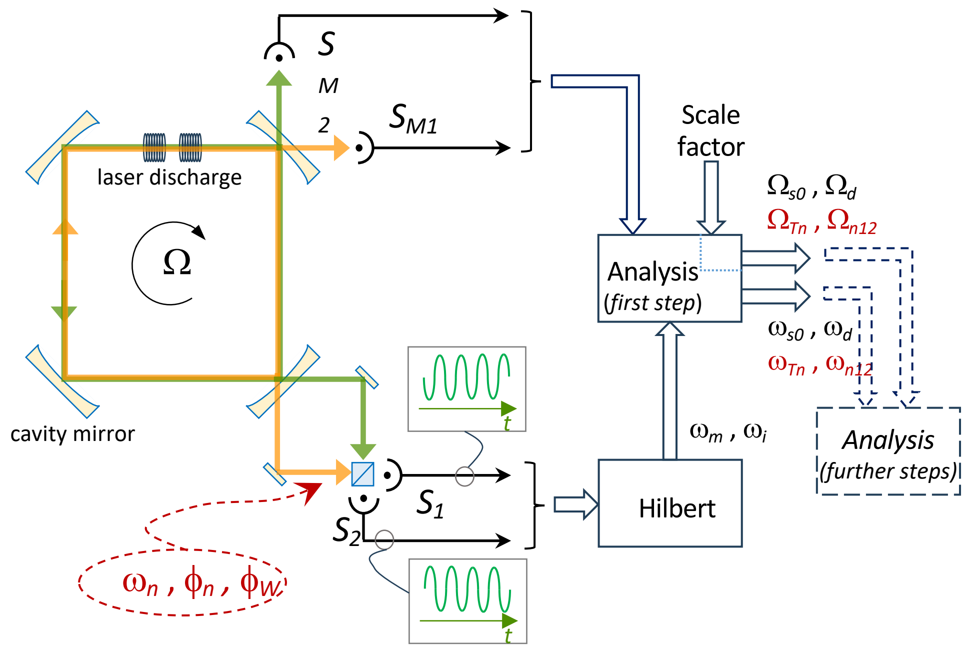
Beat-note >= 200Hz (GINGERINO)

<u>homogeneous materials</u>

GRANITE GNU, spacers in silicon carbide, mechanical parts in titanium, avoid mechanical couplings between mirrors

All machined with high mechanical precision

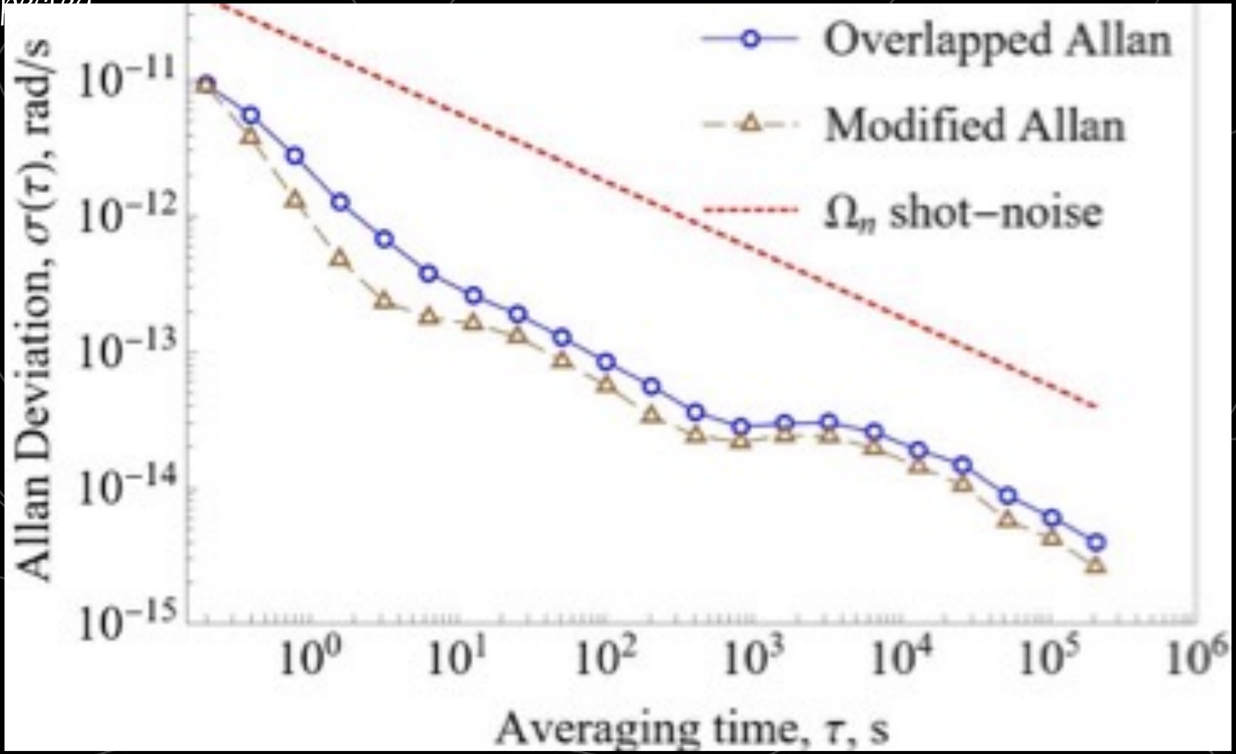




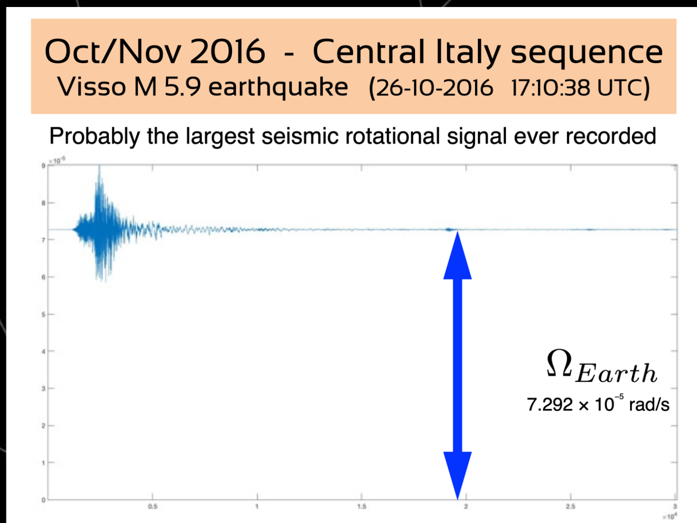

The reconstructed Sagnac frequency $f_s$ Is proportional to the scalar product between $\Omega$ and the area vector and the ratio area over perimeter.

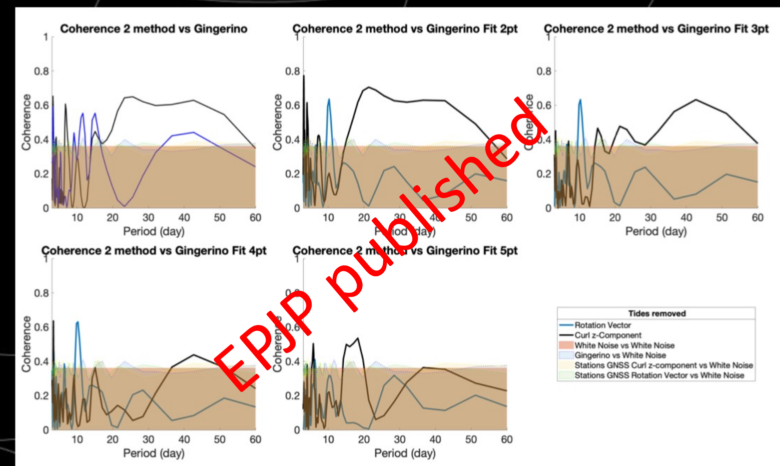
$$fs = \frac{A}{p\lambda}\Omega\cos(\theta)$$

- The first H-L RLG able to run unattended for months and to provide suitable data for earthquakes studies
- it has shown the importance to be underground located and the validity of LNGS for GINGER
- With its data we have been able to test novel analysis strategies to pick up from the data the true Sagnac frequency. We have completely changed the RLG analysis paradigm, demonstrating that the 'backscatter' problem can be completely solved analytically and developing algorithms to subtract the null-shift, which is the real problem for very low frequency investigation, completely ignored in previous analysis.
- It has given the opportunity to directly verify the limiting noise of RLG at low frequency, showing that the 'standard noise estimation' is not correct, and the low frequency fundamental limit is much lower than expected.

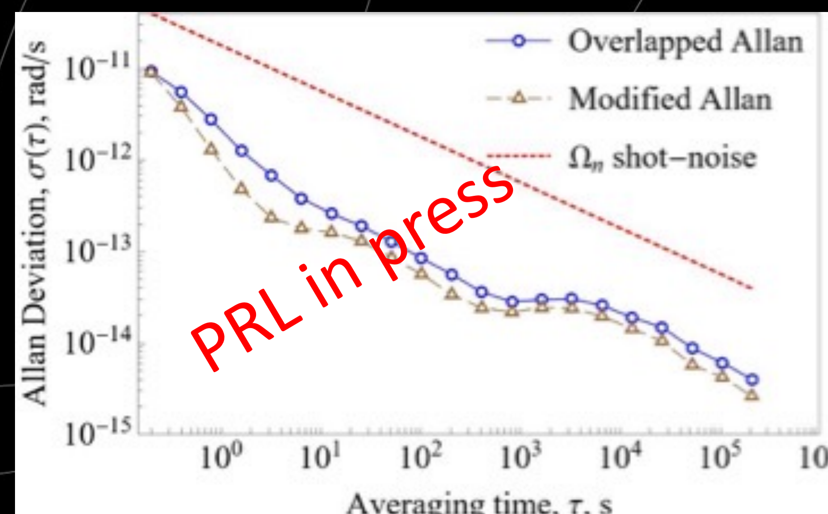


# Interdisciplinarity/test of the apparatus

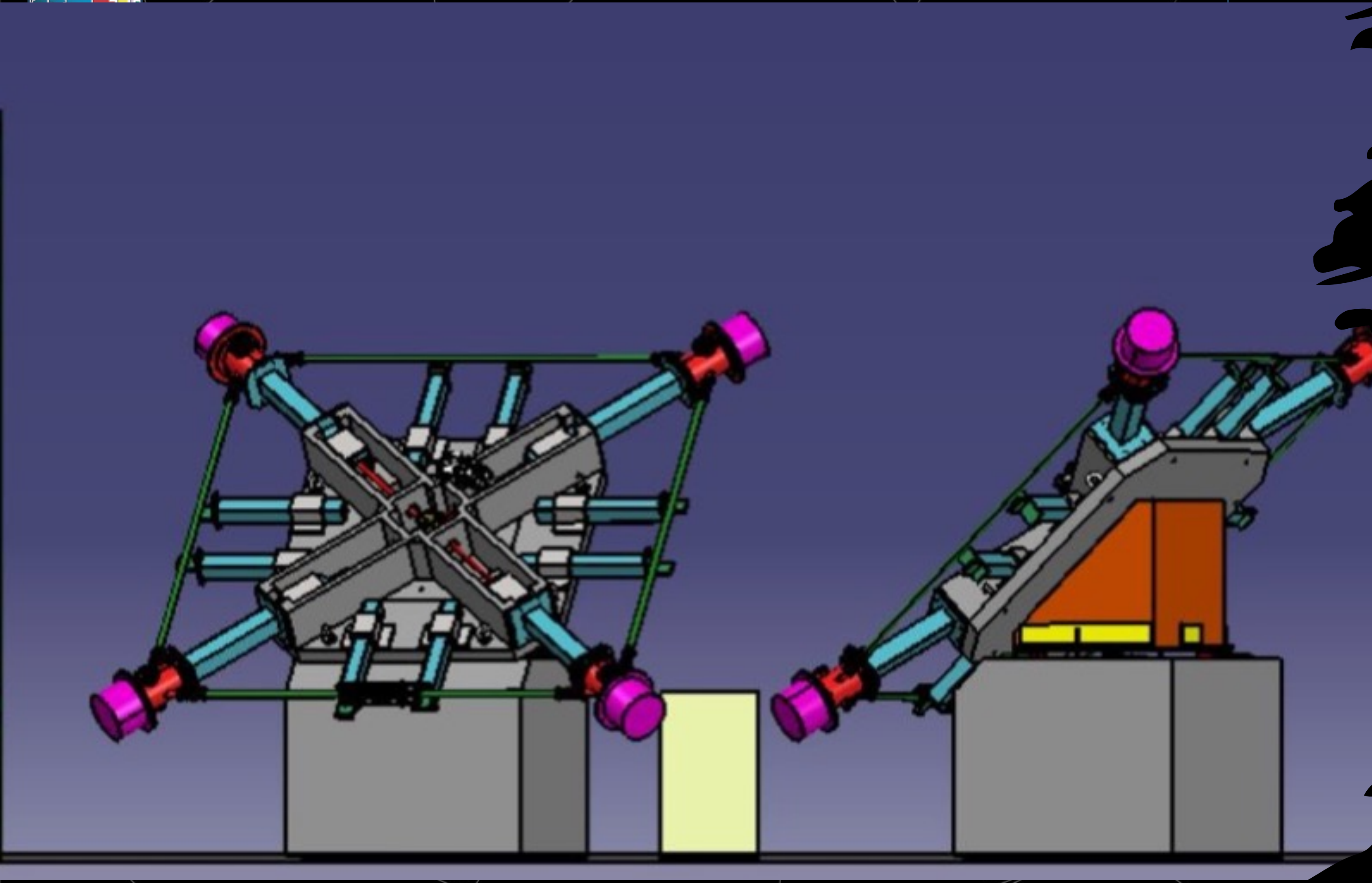



**GINGER status report**
**Featured Paper of**
**AVS Quantum Science**



INFN GINGER



# Most recent bibliogaphy


1. C. Altucci et al., GINGER, Vol. 11 (2023), No. 2, 203–234, DOI: 10.2140/memocs.2023.11.203

2. C. Altucci et al., Status of the GINGER project, AVS Quantum Science, (2023), American Vacuum Society, DOI: 10.1116/5.0167940

3. S. Capozziello, *et al.*, Constraining theories of gravity by GINGER experiment. *Eur. Phys. J. Plus* 136, 394 (2021). https://doi.org/10.1140/epjp/s13360-021-01373-4

4. F. Giovinetti et al., GINGERINO: a high sensitivity ring laser gyroscope for fundamental, and quantum physics investigation, Frontiers in Quantum Science and Technology 10.3389/frqst.2024.1363409

5. G. Di Somma et al., Possible Tests of Fundamental Physics with GINGER, *Astronomy* 2024, *3*(1), 21-28; https://doi.org/10.3390/astronomy3010003

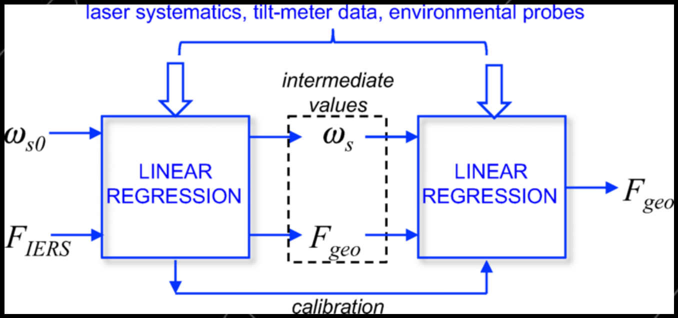
6. A. D. V. Di Virgilio et al., Noise level of a ring laser gyroscope in the femto-rad/s range, Phys. Rev. Letters June 2024 in press

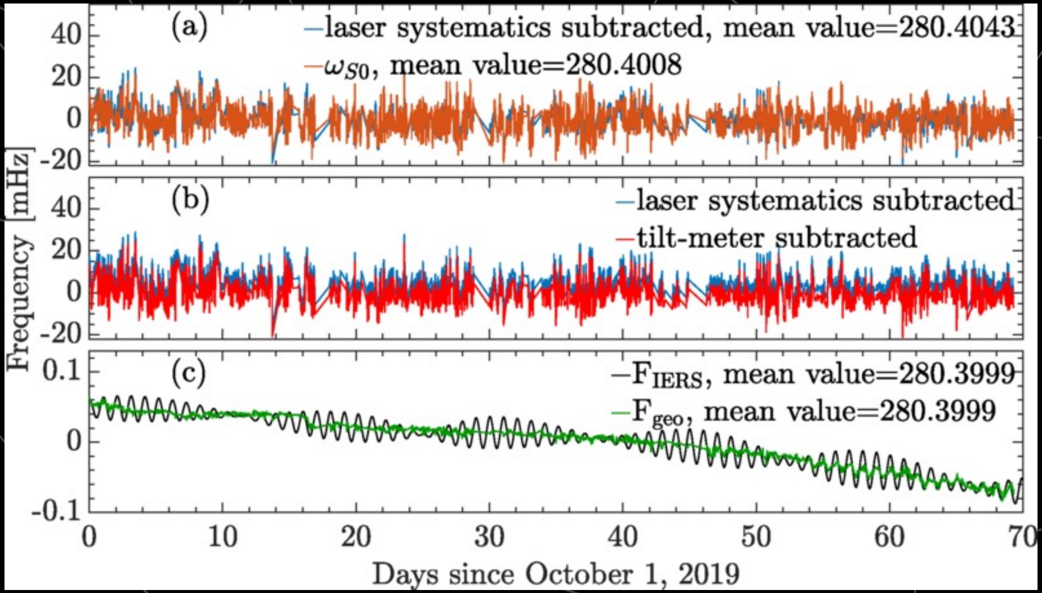
# Conclusions…so far

- RLGs are suitable for fundamental physic tests, sensitivity is the key point, at least 1 part $10^9$ of the earth rotation rate
- GINGER is now under construction, expected to be ready in 1-2 years. First target 1 part $10^9$ of the earth rotation rate, final target 1 part $10^{11}$
- GINGER is affected by many signals of geophysical origin, which are important by their own, providing a natural 'test beam' for GINGER
- GINGER uses an improved mechanical design (GP3) based on the experience gained with our 2 protypes.
- Similar apparata can be easily built on  earth, we are in touch with SURF lab.

# GINGERINO and geodesy

At the end of 2019 GINGERINO run for more than 2 months continuously




This allowed to perform a more complete analysis to identify, using the linear regression method, known geodetical signals

Detecting geodetic signals, some of them measured independently by other groups and systems make it possible to calibrate the instrument response and further investigate the statistical residuals thus evaluating the actual noise level of the instrument

$F_{geo}$ measured by GINGERINO reproduces all main geodetic features, such as annual and Chandler wobbles, daily polar motion, and the very low-frequency contribution due to LOD and zonal tides.