GINGER

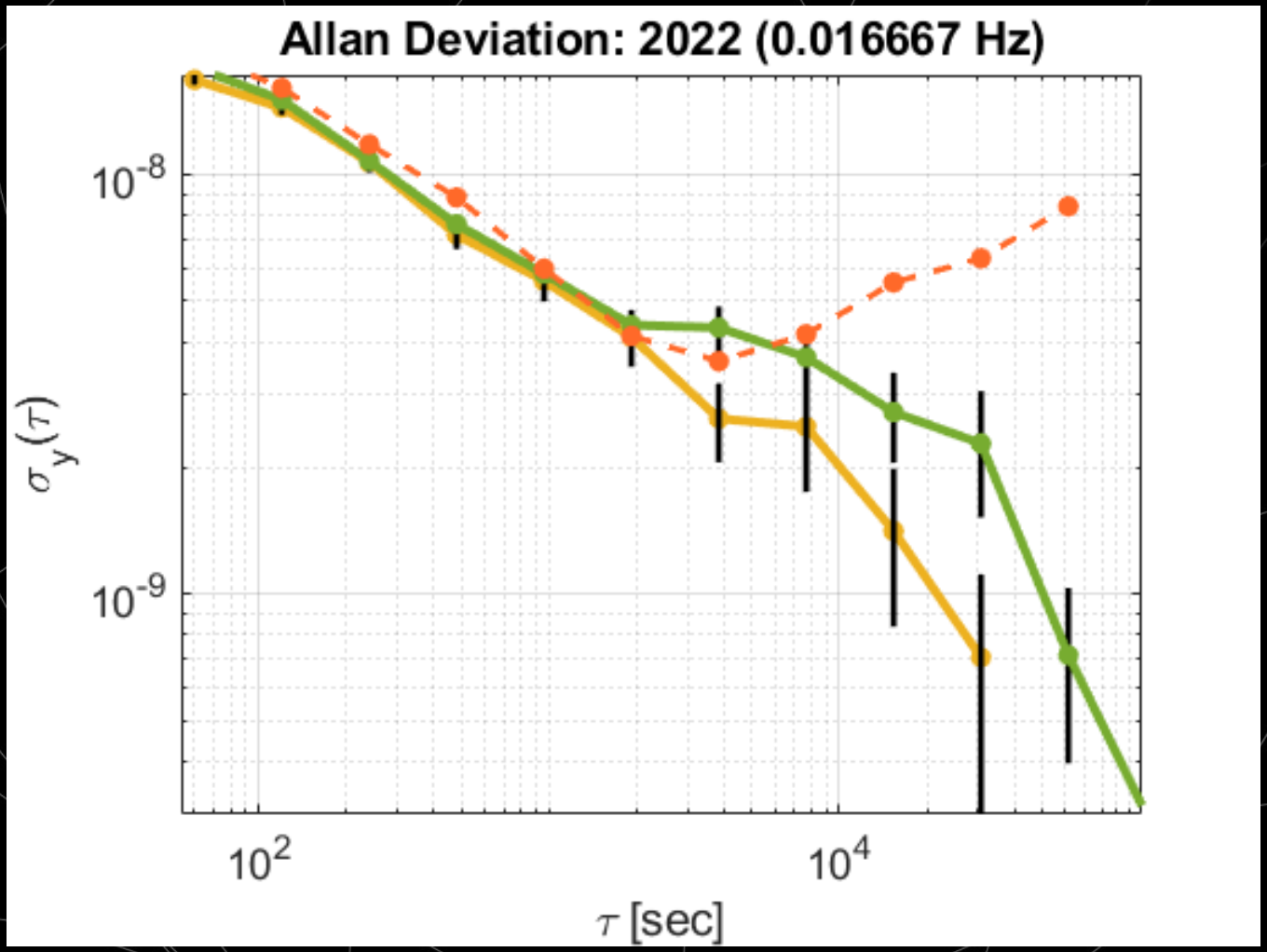
A very unique device:

Optical Cavity +
Active Medium +
Equal arms interferometer +
2 independent beat notes +
the solid crust of our Earth

GINGER is an array of high sensitivity laser gyroscopes (Ring Laser Gyroscopes, RLG). RLG are based on a square active cavity where two counter-propagating modes circulate. The two modes are in general highly symmetric, but non reciprocity is present and the RLG signal gathers information on non reciprocity on the light propagation in different directions. Very small variations are expected in General relativity, the larger being due to the de Sitter and Lense Thirring effect on the Earth surface, Lorentz violation tests on the gravity sector in the Standard Model extended formalism, and on the non classical electromagnetism. The larger effect is certainly the Sagnac effect, which links the RLG response with the absolute rotation rate of the optical cavity. This is a large effect on the Earth surface, and at present RLG has top sensitivity to measure Earth absolute angular rotation rate in order to investigate any tiny deviations.

GINGER is highly interdisciplinary and able to provide data not only for fundamental physics but also for geophysics and geodesy.

Relevant target: ***to reach and go behind the sensitivity of 1 part in 10^9 of the Earth rotation rate***, *target that has been already demonstrated.*



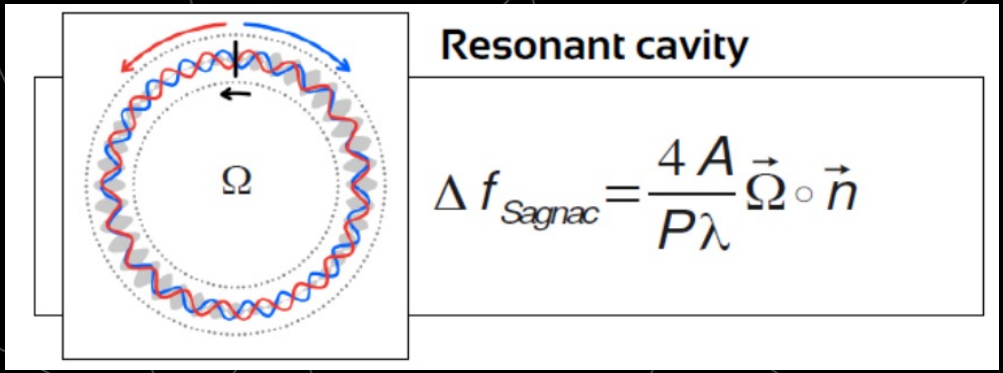
https://doi.org/10.1140/epjc/s10052-022-10798-9

Data analysis of GINGERINO applied to the G Wettzell ring laser

Outline

- A ring laser gyroscope (RLG) at a glance
- GINGERINO the Great
- The GINGER experiment
- Future plan and Conclusion

Sagnac effect in an empty cavity

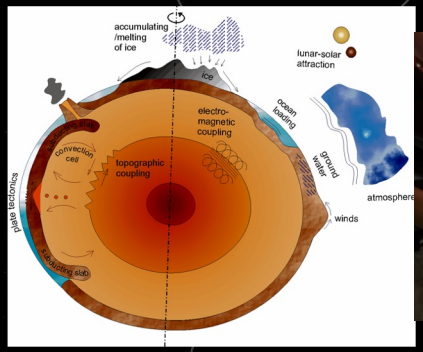


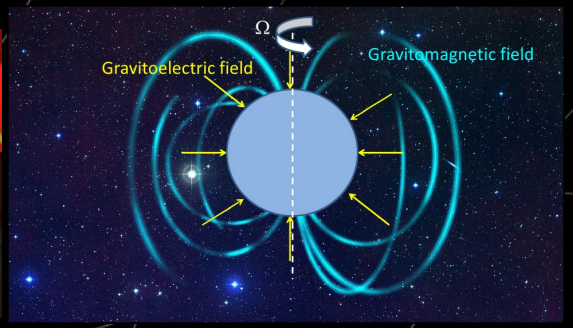
The Ω measure is affected by:

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

- 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

Angular rotation/Feasible measurements





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

Sidereal day

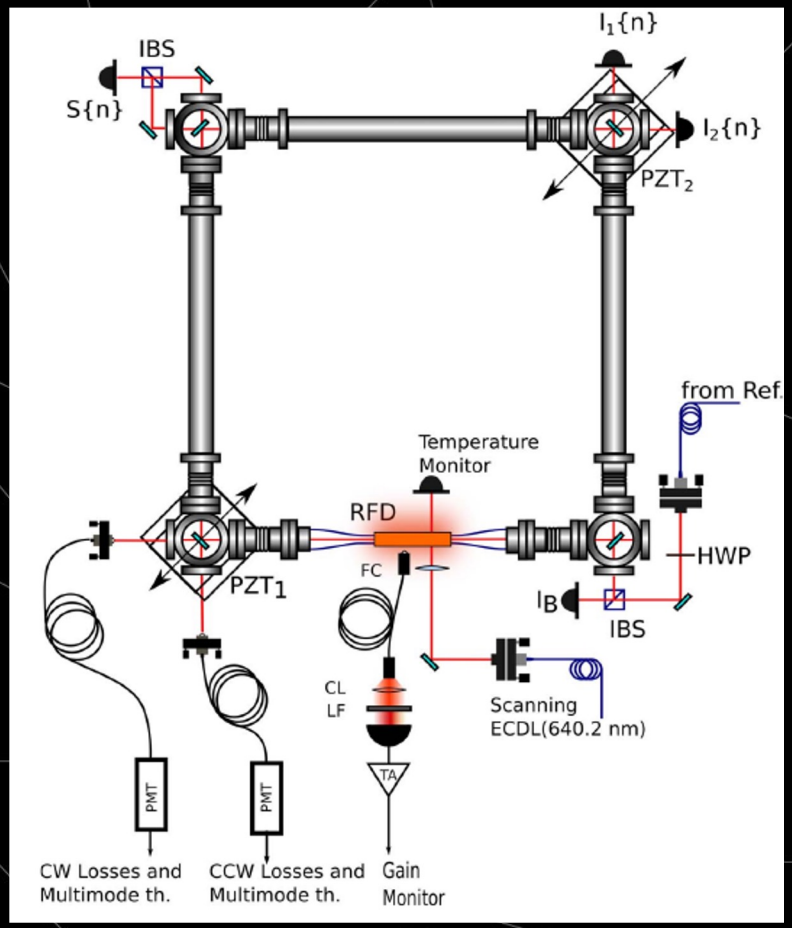
seismology

tides

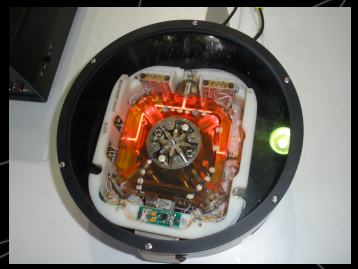
geodesy

General Relativity

The ring laser gyro



- 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

Gyroscopes In GEneral Relativity

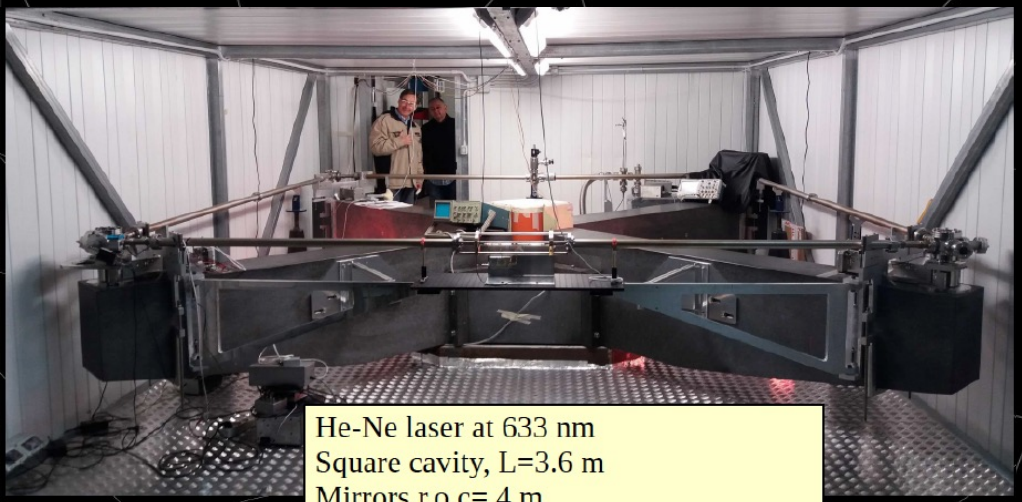
- Thought for measuring the LenseThirring effect with an Earth based experiment (at fixed latitude, not averaged and gravity map not needed) with <1% accuracy -> to set different bounds on the validity of alternative theory of gravity
- We are completing the details of the project to send the orders asap, planning to start construction by the end of 2024 and operation in 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"

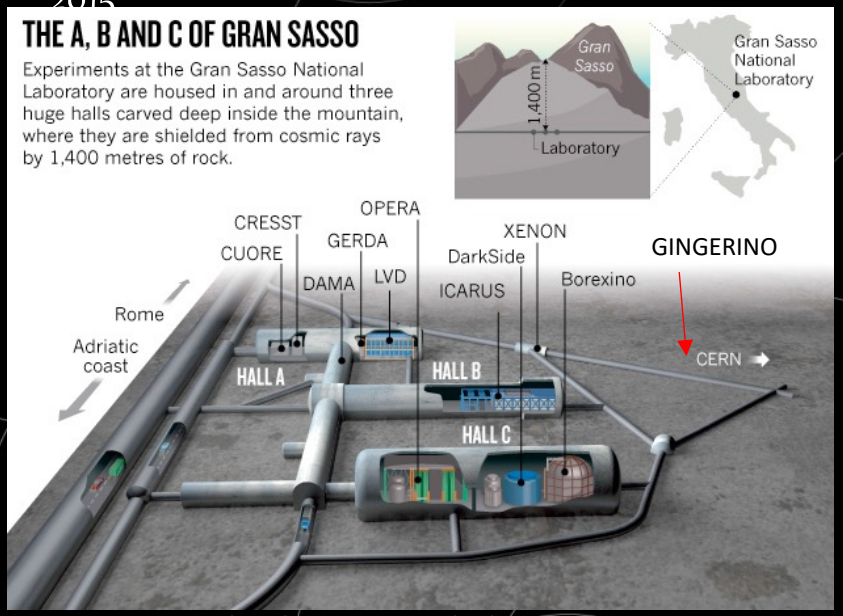
GINGER hints

- Lense-Thirring (and de Sitter) acts 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

GINGERINO the Great– the GINGER prototype @ LNGS



- A 3.6m ring cavity inside LNGS, operative since 2015



- 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)

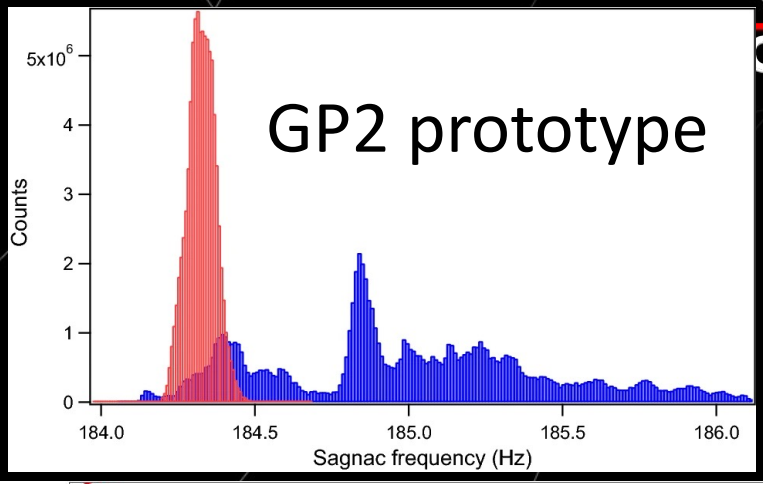
GINGERINO In short.....

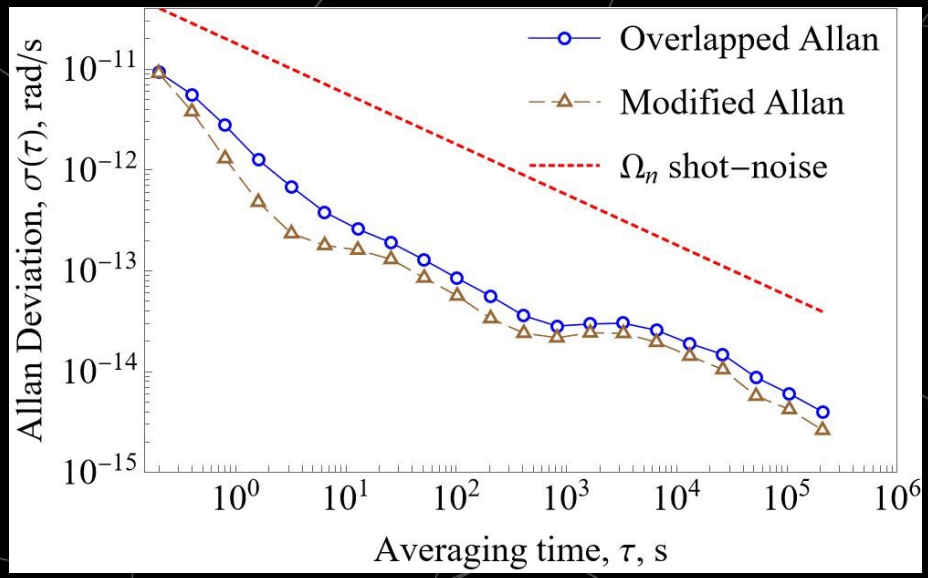
The first H-L RLG able to run unattended for months and to provide suitable data for earthquakes studies

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





GINGER collaboration

- Pisa University: RLG laser and optics, responsible of the RLG realization and maintenance;
- INFN Pisa and LNL: coordination of the Sagnac frequency reconstruction;
- Naples: optics simulation and quantum noise;
- LNL, Naples, Salerno and Turin: interface with fundamental physics;
- INGV: DAQ and remote control of the apparatus;
- INGV: interface with geophysics analysis;
- UNIVAQ: mechanics simulation and test.

INFN Sez. di Pisa
Angela D. V. Di Virgilio
Fabio Morsani
Università di Pisa
Andrea Basti
Nicolò Beverini
Giorgio Carelli
Donatella Ciampini
Giuseppe Di Somma
Francesco Fuso
Enrico Maccioni
Paolo Marsili

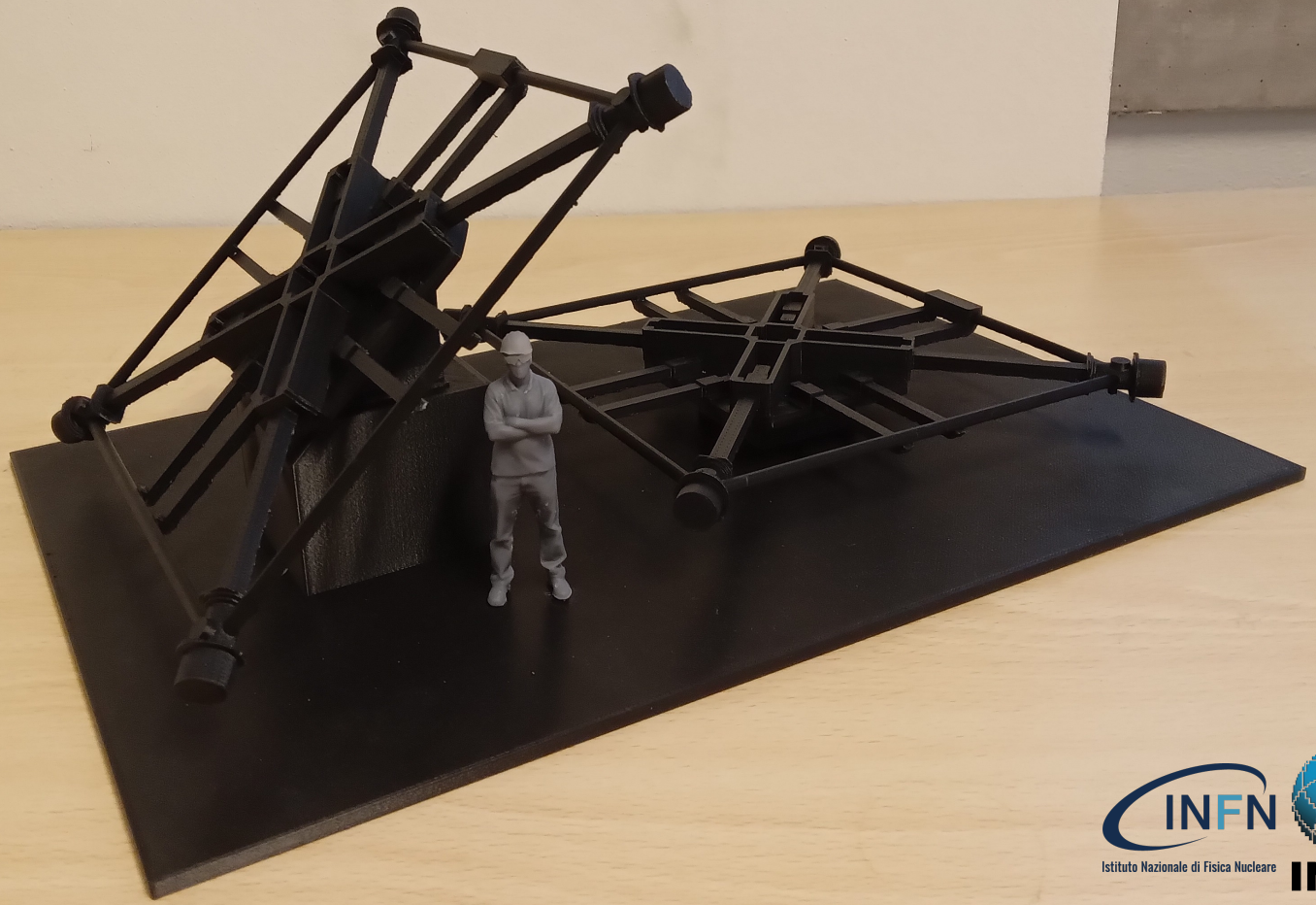
INGV
INFN Laboratorio del Gran Sasso
Thomas Braun
Gaetano De Luca
Giuseppe Di Stefano
Roberto Devoti
Daniela Famiani
Alberto Frepoli
Aladino Govoni
Alessia Mercuri

Università dell'Aquila
Ivan Giorgio
Francesco Dell'Isola
Marco Tallini
Politecnico delle Marche
Fabrizio Davì

GSSI
Simone Castellano

INFN Laboratorio di Legnaro
Antonello Ortolan
Università di Torino
Matteo Luca Ruggiero

INFN Sezione di Napoli
Università di Napoli
Carlo Altucci
Francesco Bajardi
Salvatore Capozziello
Alberto Porzio *(CNR-SPIN)*
Raffaele Velotta
Università di Salerno
Gaetano Lambiase



INFN
Istituto Nazionale di Fisica Nucleare
INGV

Main requiremens

to keep GINGERINO sensitivity

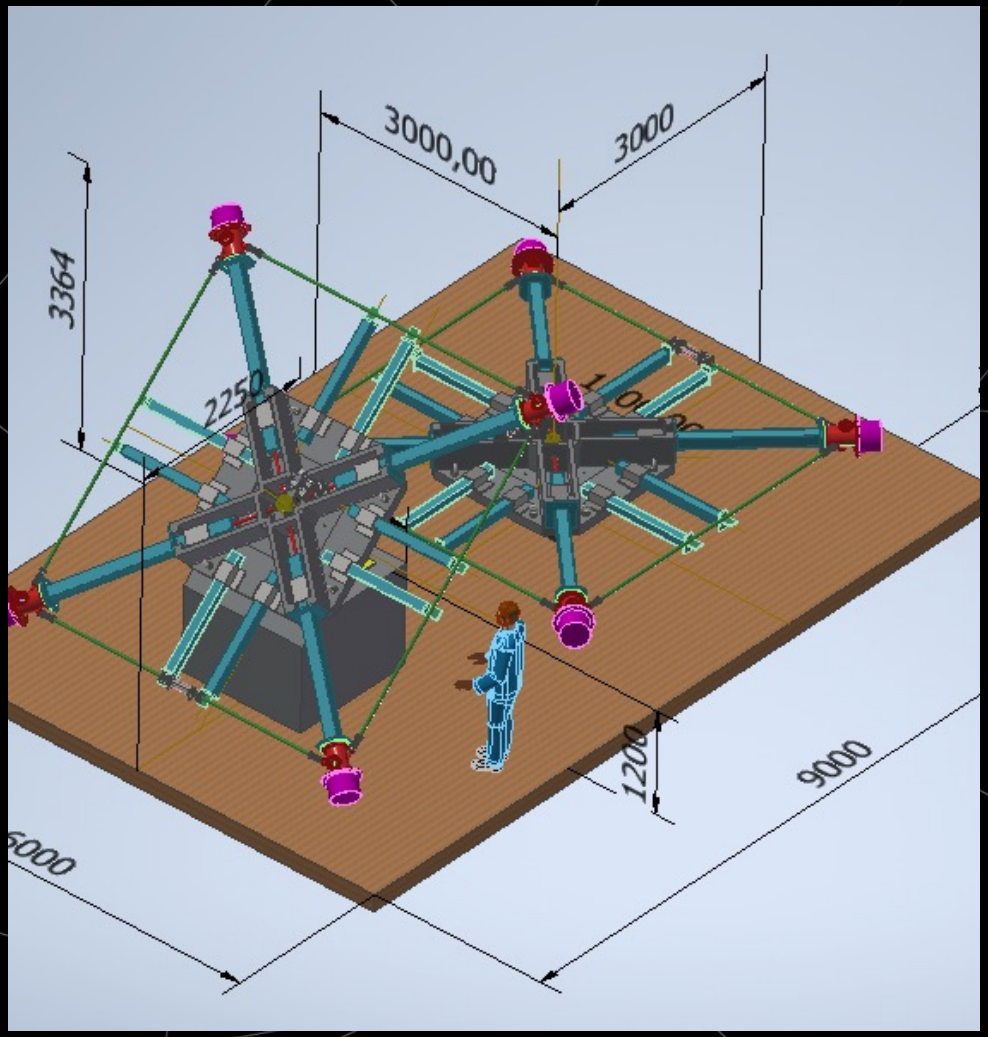
Perimeter between 14.4-16m

Beat-note >= 280Hz (GINGERINO)

homogeneous materials

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

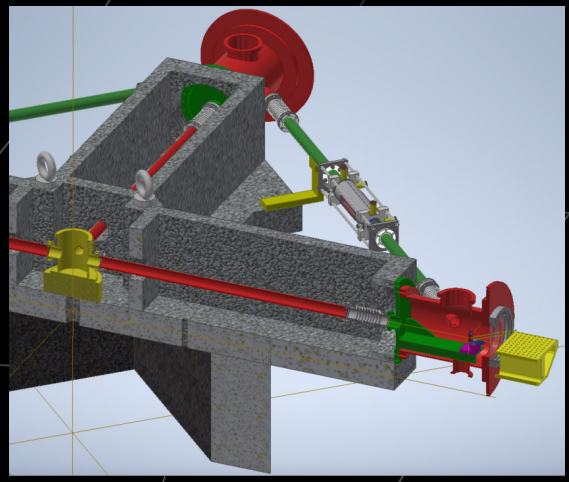
All machined with high mechanical precision

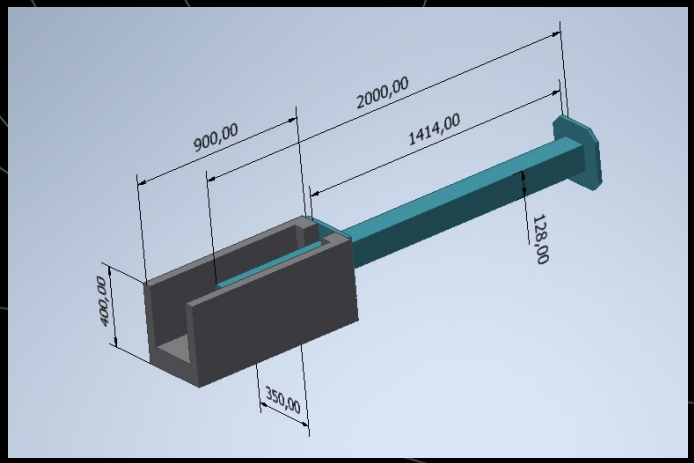


GINGER tests on going

- TRIO (STRIC+ project) first test of the improved cavity mechanics
- spacers, mainly to test the joints,

the piece will be used in GINGER





Some details

- Set the orders asap, 6 months maximum delivery time
- Start assembling by the end of 2024
- The system is operative as soon as the lasers are on

We expect:

- 1 post-doc from Camerino (STRIC+) for TRIO
- 2-3 from INGV

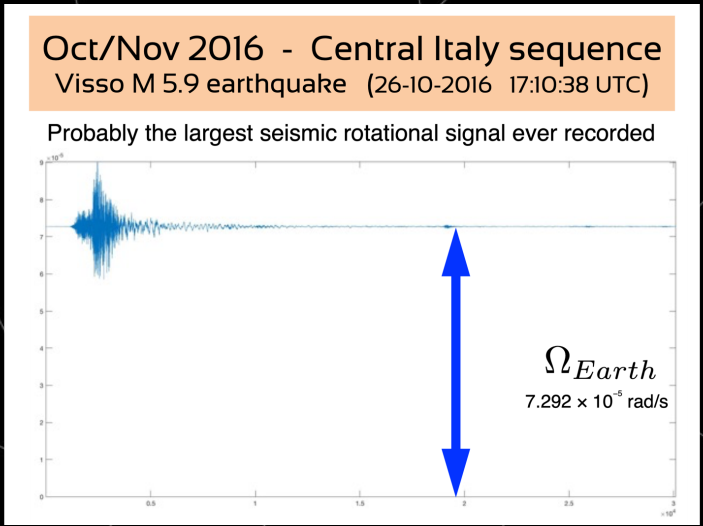
The LNGS available space

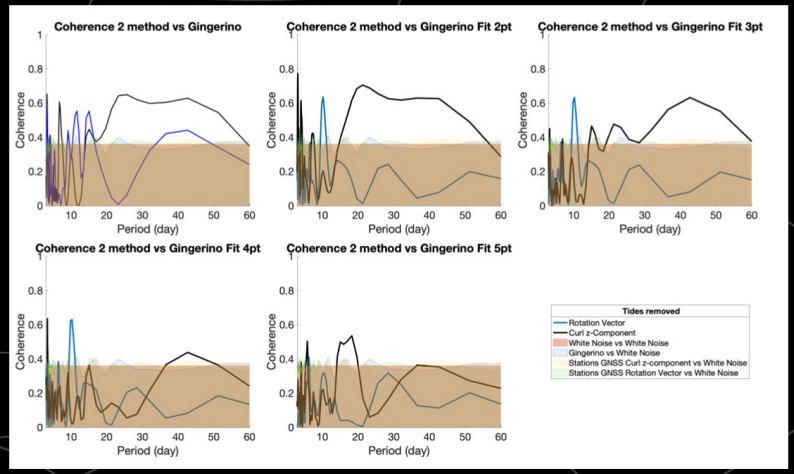
- Ten days ago we have been asked to move GINGER from NODE B to the corridor close to GINGERINO

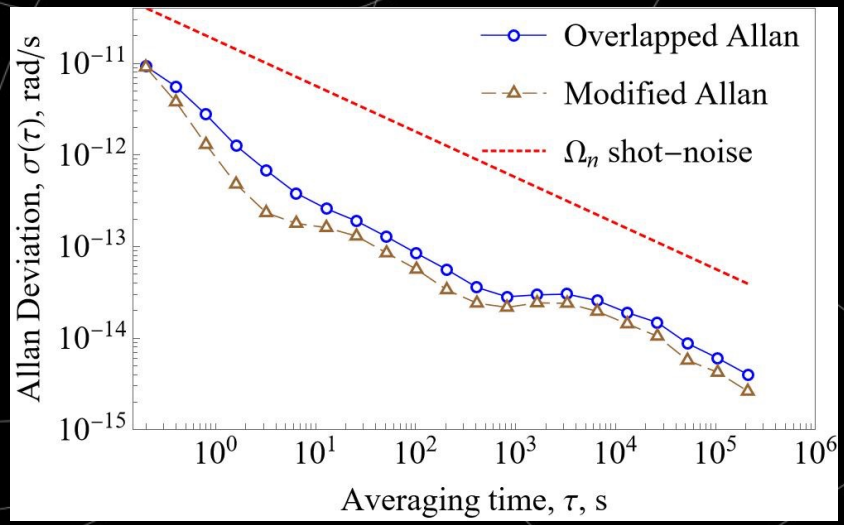
- We are going to redesign the installation keeping in mind to preserve the expected sensitivity and we will discuss with LNGS in the near future.

- Of course, in almost 1 year, it is necessary to prepare the available space

Interdisciplinarity/test of the apparatus







GINGER status report
Featured Paper of
AVS Quantum Science

Conclusions...so far

The group is working in order to:

- Make the final design of GINGER @ LNGS and set the orders asap
- keep and extend the group of people able to set.-up and manage the array of RLG
- Complete the analysis of the GINGERINO data providing the analysis tools for GINGER
- Merge the competences to properly analyse and use the data for geophysics/(data test and calibration)