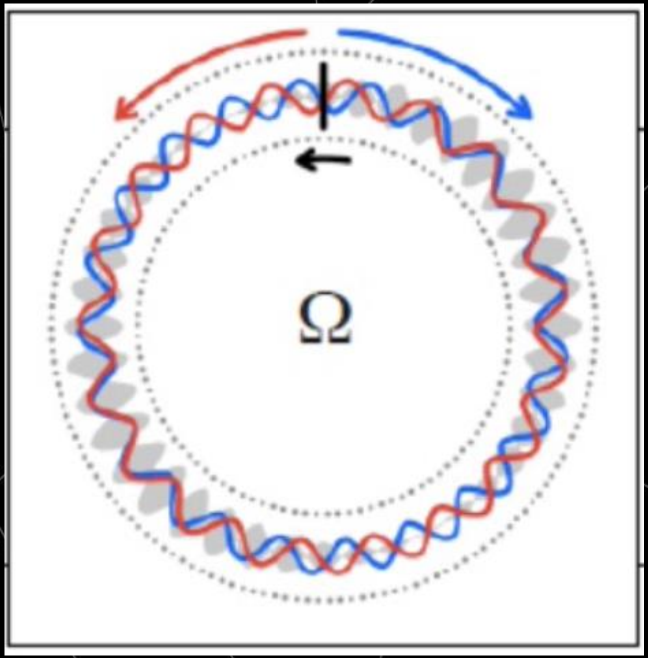
Ring Laser gyroscopes and Gravitational waves research

- Ring laser and the Sagnac effect
- GINGERINO and the sensitivity measurement
- Possibility for GW research

Sagnac effect



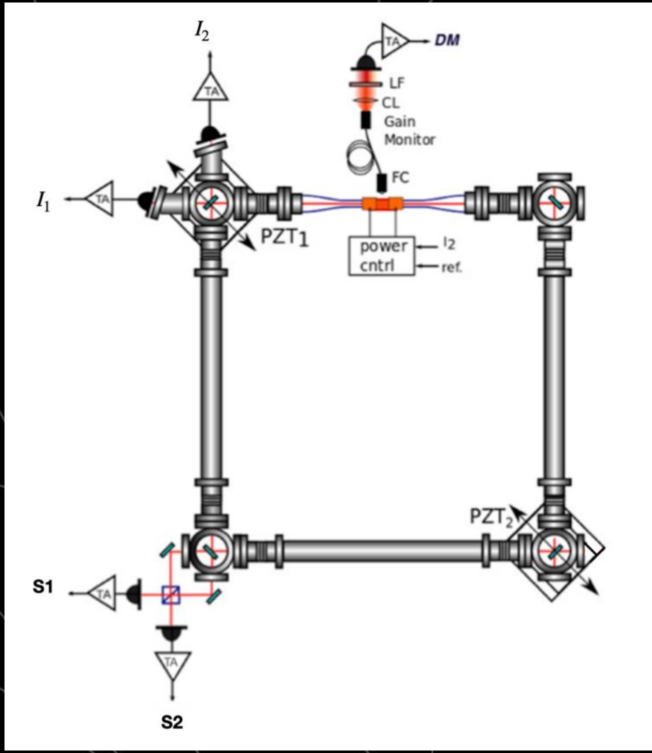
$\vec{\Omega}$ closed path angular rotation

$$\Delta\phi = 8\pi/(\lambda c)\, \vec{\Omega}\, \vec{A}$$

- two counter-propagating beams in a closed path (interferometer with equal arms)
- The phase shift $\Delta\phi$ between the two waves is proportional to non reciprocity
- When the path rotates, the shift depends on the scalar product angular rotation and area vector **Ω A**

WIDELY USED FOR NAVIGATION

Ring laser in short (high sensitivity ones)



$$\Delta f_{Sagnac} = \frac{4A}{P\lambda} \vec{\Omega} \circ \vec{n}$$

- Three+four mirrors define a high finess optical cavity
- Perimeter above 10m

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

Advantages with respect to mechanical gyroscope

- No moving part i.e. no contribution from other degrees of freedom
- Continuous operation with high duty cycle
- Signal based on frequency reconstruction, i.e. huge dynamical range, free running operation feasible
- High frequency stability **input source not required**

Our 3 main research lines

- Improve the rigidity of the optical laser cavity in order to avoid instrumental rotation due to external forces acting of the apparatus

- Analyse data in order to identify the true f_s and test the validity of the analysy

- Active and remote control, and data quality

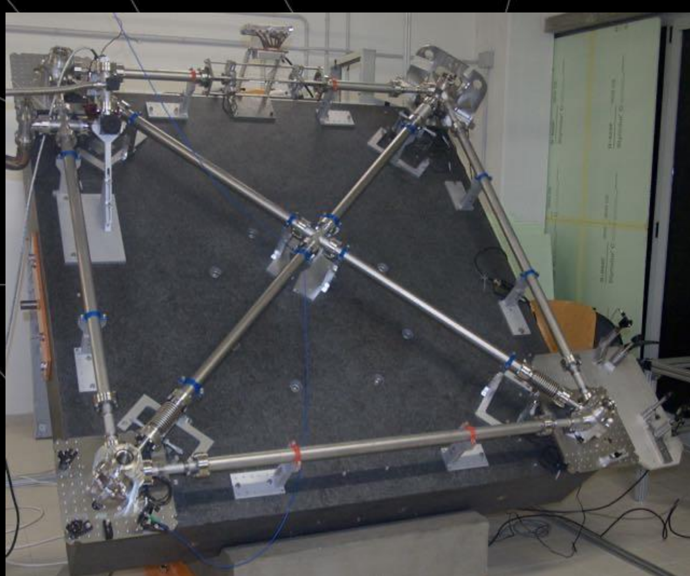
OUR third prototypes, TRIO is under development in Pisa

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**

TRIO, Transportable

Umproved long term cavity stability (GINGER design)

Faster control loop for geometry control



Laser non linearity has limited RLG diffusion

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

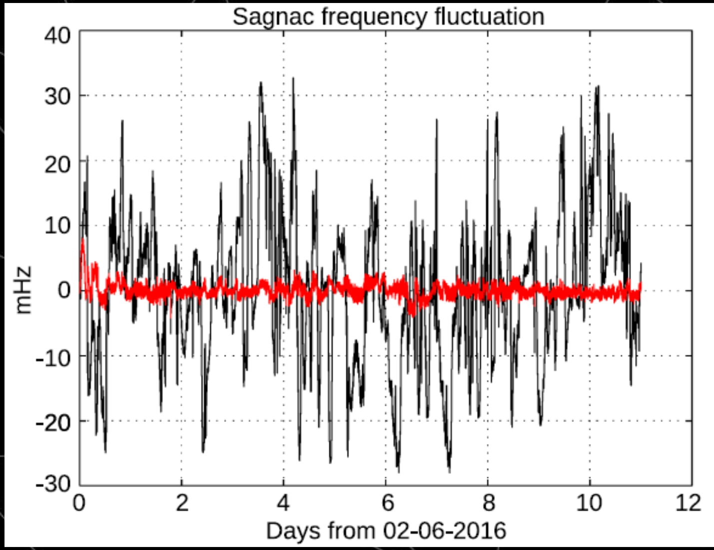
Laser dynamics (null shift)

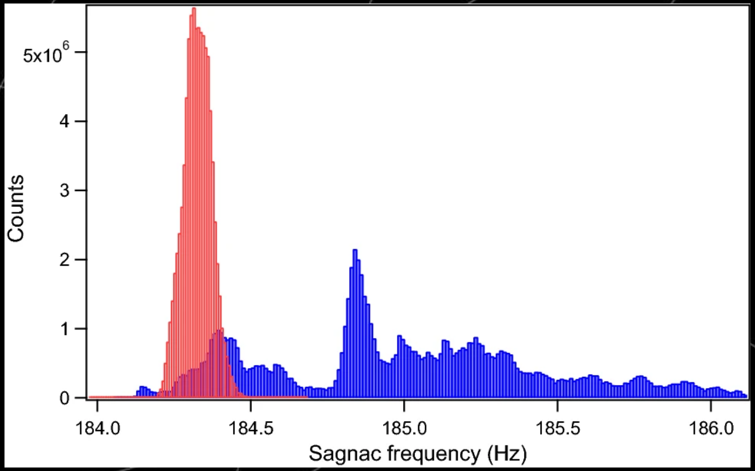
- The laser dynamics is a rather complex non-linear process.

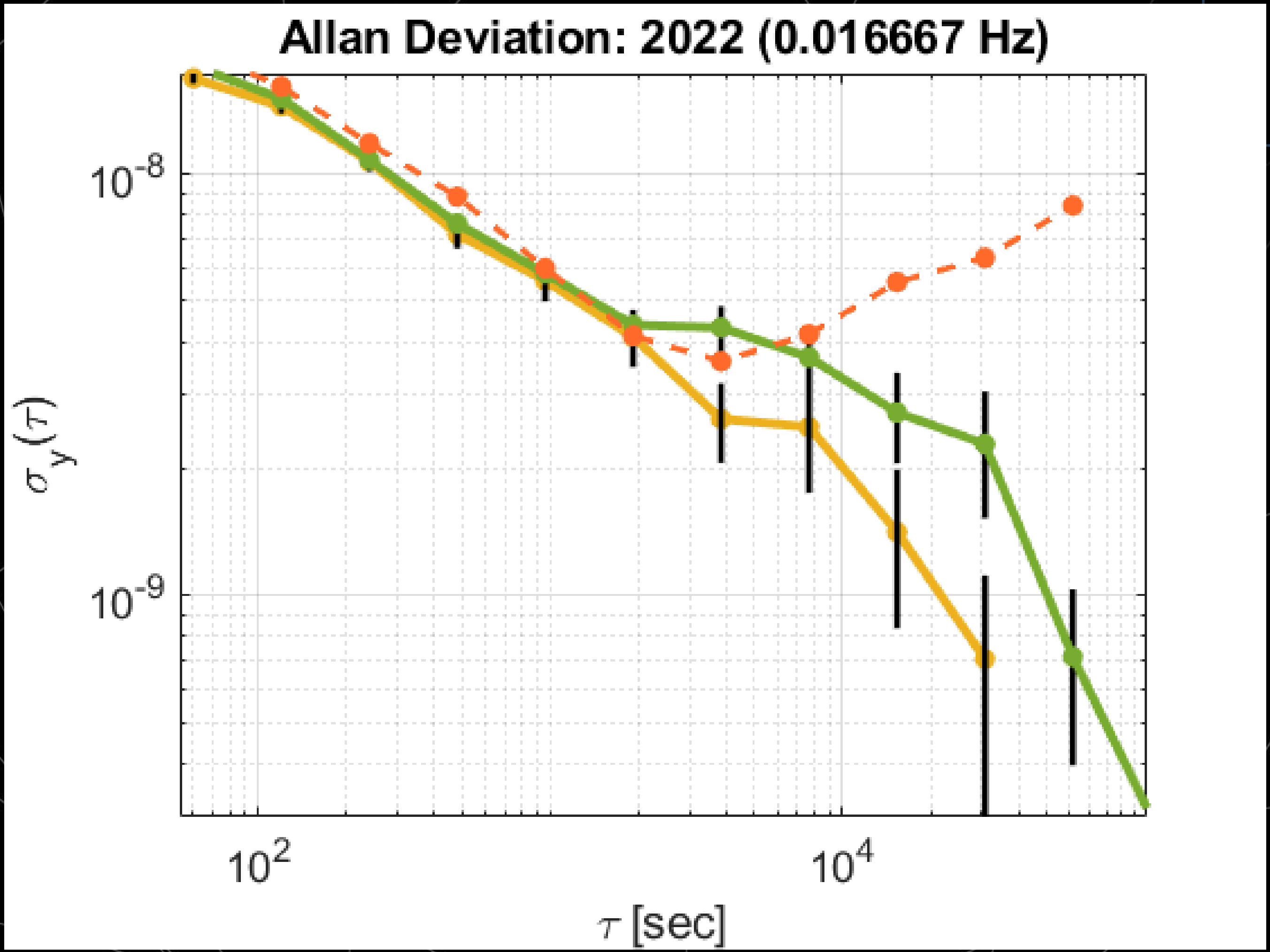
We have developed an original methods to remove such systematics through the estimation of Lamb parameters in a semiclassical approach.

Example of the data analysis improvements

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







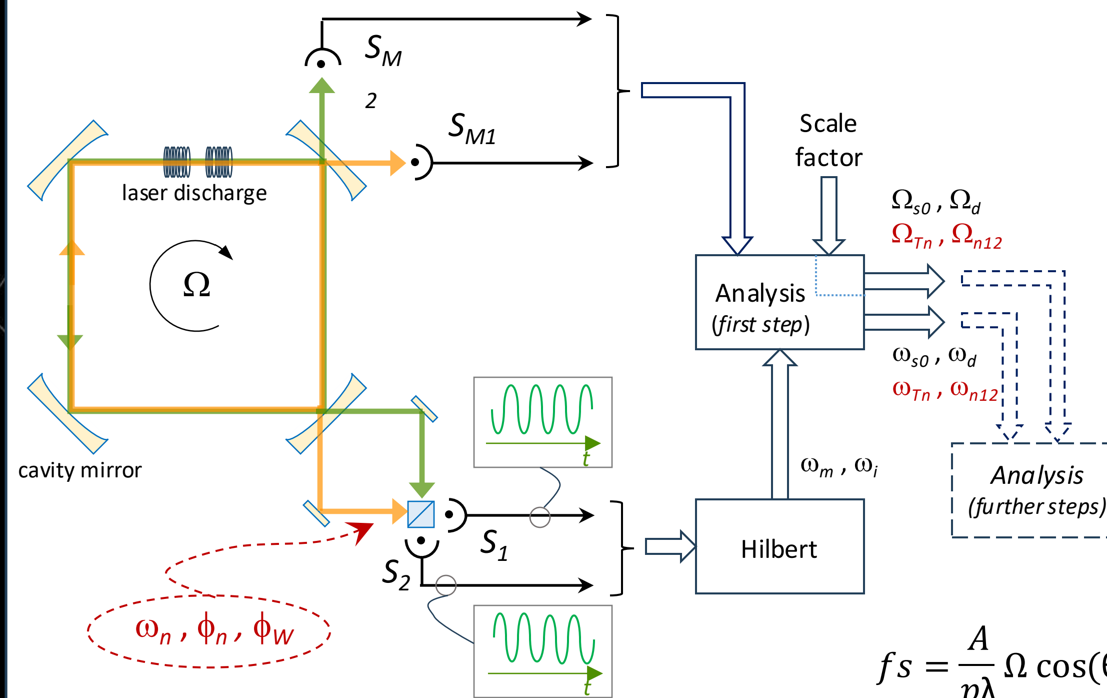
https://doi.org/10.1140/epjc/s10052-022-10798-9

Data analysis of GINGERINO applied to the G Wettzell ring laser

Frequency reconstruction requires time…

Hilbert transfrom. High sensitivity, at least 1 sec delay

Artificial intelligenze can be fast, but not so accurate (Di Somma PhD thesis, in preparation

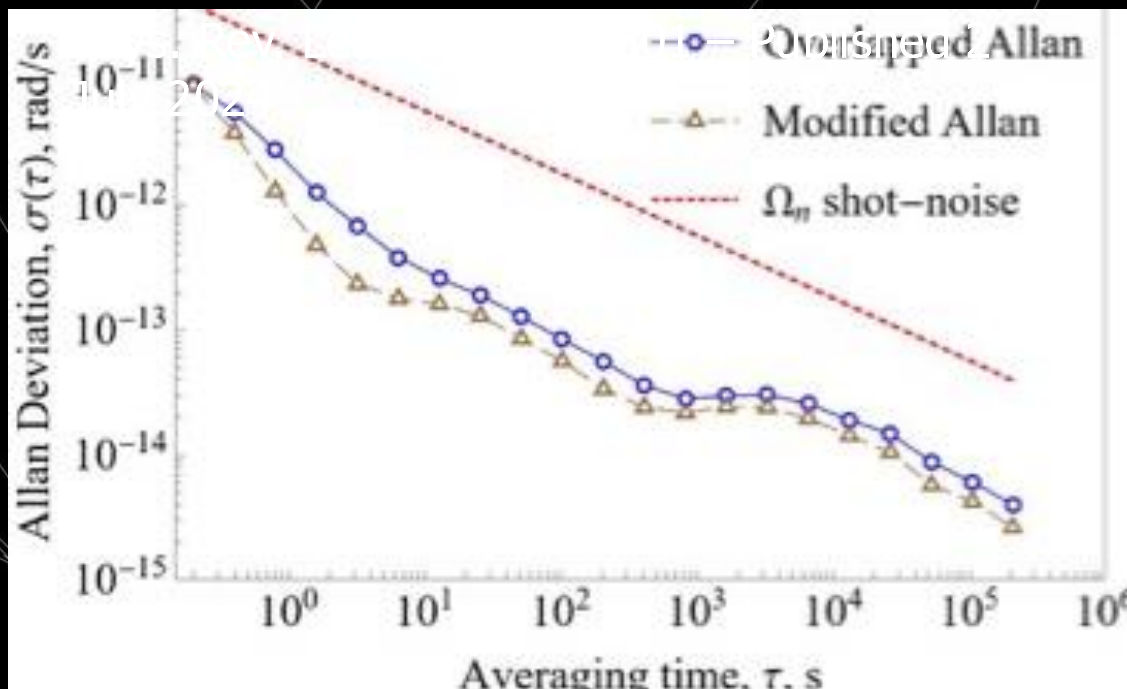


$$fs = \frac{A}{p\lambda}\Omega\cos(\theta)$$

$S_{1,2}$ are the two output signals,
signal processing is necessary to reconstruct the beat-note f_m
using the moonbeam signals it is possible to reconstruct f

GINGERINO

- 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



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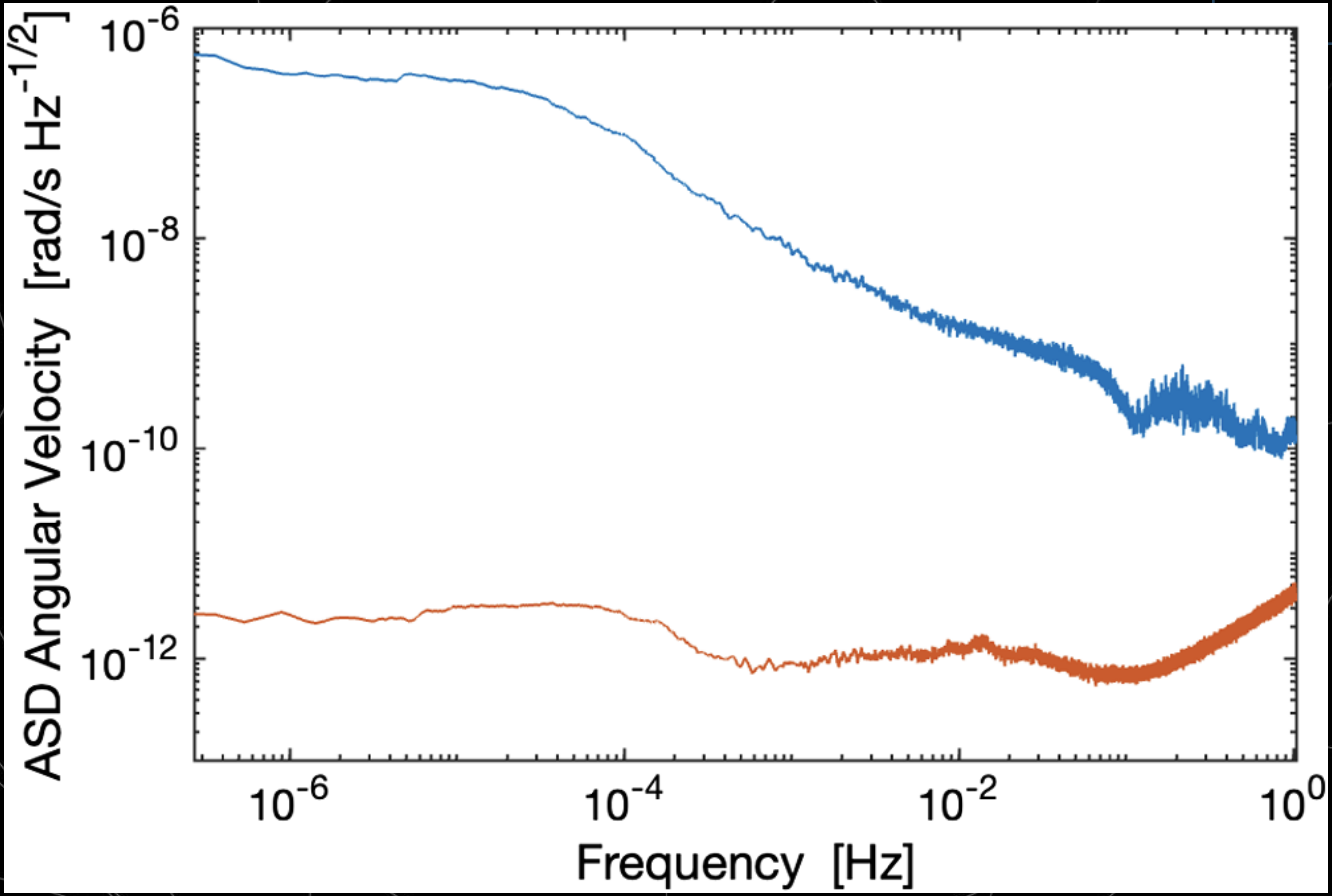
Power spectrum



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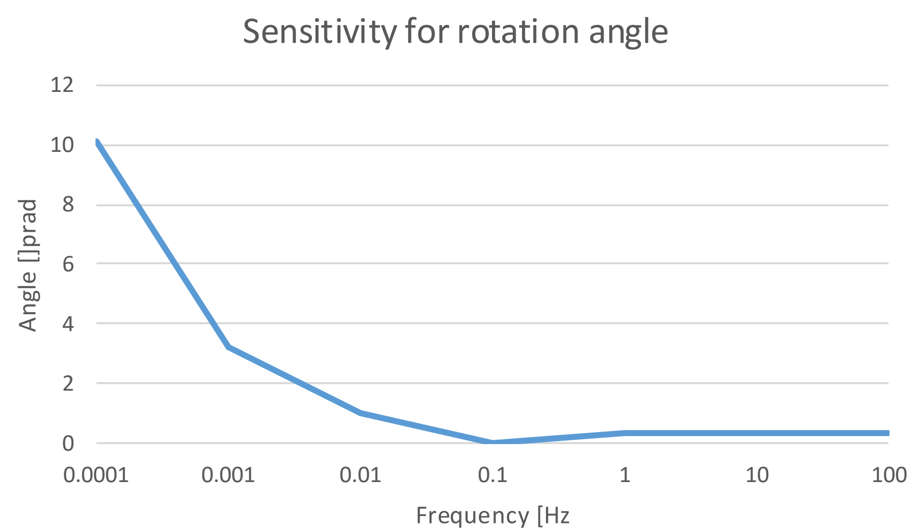
Sensitivity as δθ

- Flat above ν> 0.1 Hz 0.32 prad/sqrt(Hz)
- N< 0.1 Hz rises with sqrt of time
- Obviously it is necessary to remove laser non linear dynamic systematics



- This activity was born in 2009 inside the Virgo collaboration, and has proposed a new experiment, GINGER, actually under construction at LNGS

- Let see now whether it can be useful for GW research

GINGER

Angela Di Virgilio - NOTE VIRGO

	Code		Title	Date	Author(s)
A1	VIR-0579B-11	VIRGO	Study of gyrolaser dynamics and robust identification of its parameters	06/10/11	J. Belfi, N. Beverini, B. Bouhadef, D. Cuccato, A. Di Virgilio, A. Ortolan
A2	VIR-0255A-11	VIRGO	Gyro-Laser Status	02/05/11	A. Di Virgilio
A3	VIR-0149A-11	VIRGO	Gyro-Laser measurements	08/03/11	A. Di Virgilio
A4	VIR-0014A-11	VIRGO	G-Pisa Ring Laser - Virgo Discussion about data and sensitivity	11/01/11	A. di Virgilio
A5	VIR-0444A-10	PUBLIC	Premininary Analysis of the Gyrolaser G-Pisa	19/07/10	Angela Di Virgilio
A6	VIR-0443A-10	VIRGO	Preliminary Analysis of G-Pisa Gyrolaser	19/07/10	Angela Di Virgilio
A7	VIR-0011B-10	LVC	Advanced Virgo change request for SAT: Tilts measurements on Virgo Central Area with GPisa ringlaser	09/03/10	J. Belfi, N. Beverini, G. Carelli, A. Di Virgilio, F. Bosi, E. Maccioni, R.Passaquieti, F. Stefani
A8	VIR-0651A-09	LVC	In situ tilt measurement with the Sagnac sensor G-Pisa	28/10/09	A. Di Virgilio
A9	VIR-0021A-09	PUBLIC	G-Pisa gyrolaser after 1 year of operation and consideration about its use to improve Virgo Inverted Pendulum control	13/08/09	M. Allegrini, J. Belfi, N. Beverini, F. Bosi, G. Carelli, A. Di Virgilio, E. Maccioni, M. Pizzocaro, A. Porzio, S. Solimeno and F. Sorrentino
A10	VIR-0880A-07	VIRGO	Some considerations about far away strong EarthQuakes	18/10/07	A.Di Virgilio
A11	VIR-0019E-07	PUBLIC	About the use of gyro-lasers in gravitational waves interferometric detectors	16/07/07	A. Di Virgilio, N. Beverini, C.Bradaschia, G. Carelli, I. Ferrante, A. Gennai, E. Maccioni, D. Passuello, A. Porzio, U. Schreiber, S. Solimeno, F. Sorrentino, J-P. Wells
A12	VIR-0868A-07	VIRGO	Comparison of different runs Focusing around 1050Hz	02/04/07	A.Di Virgilio
A13	VIR-0835A-07	VIRGO	Some Analysis around 10 Hz	29/01/07	A.Di Virgilio
A14	VIR-NOT-PIS-1390-334	PUBLIC	Seismic and thermal noise upper limits at 10 Hz for the Virgo suspensions	06/12/06	Angela Di Virgilio
A15	VIR-0814A-06	VIRGO	The noise of the SA suspension at 10 Hz	19/09/06	A.Di Virgilio
A16	VIR-NOT-PIS-1390-245	PUBLIC	Evaluation of the relative speed of a Fabry-Perot cavity from the trasmitted power	22/05/03	A. Di Virgilio, M. Fazzi, P. La Penna and I. Ricciardi
A17	VIR-NOT-PIS-1390-241	PUBLIC	Preliminary analysis of the Low Frequency Facility Experiment data	14/04/03	Angela Di Virgilio
A18	VIR-NOT-PIS-1390-231	PUBLIC	Status Report of the Low Frequency Facility	01/12/02	A. Di Virgilio et al
A19	VIR-NOT-PIS-1390-231	PUBLIC	Status Report of the Low Frequency Facility	01/12/02	A. Di Virgilio et al
A20	VIR-NOT-PIS-1390-150	PUBLIC	Alignment method of the Filter7-Marionetta System	23/05/00	A.di Virgilio , M.Pasotti

Possible links between RLG and GW apparata

- Environmental monitor: G-Pisa prototype has been operating for one year in the Virgo central area and has able to measure the strong wind induced tilt

- A10: how to use a RLG as active element on the SA suspention

- **For the interferometer alignment having as reference the Earth angular rotation axis**

- presently under investigation the RLG to improve by a factor 100 satelites AOCS (Attitude and Orbit Control). This could be relevant for LISA

Note: I'm not sure the output can be used for feed-backs, since it is not real time with high sensitivity

RLG main advantage: very high sensitivity down to DC

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. Lett. **133**, 013601 INFN NEWS

Conclusions...so far

- The RLG research in Italy has to be considered an out-come of the GW reasearch, and it has proposed the GINGER experiment under construction at LNGS, 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} , suitable for fundamental physic tests

- Applications of RLG for GW experiments are outlined