SAGNAC GYROSCOPE AND FUNDAMENTAL PHYSICS

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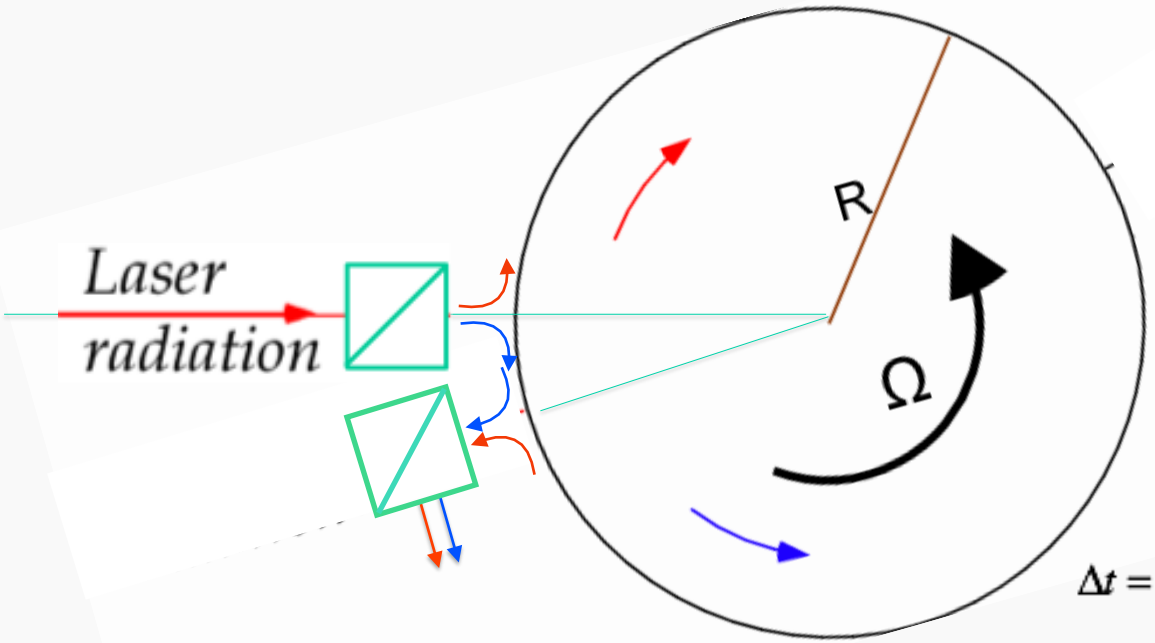
- **Ring laser and the experimental problem of the Lense-Thirring measurement on Earth(GINGER)**
- **The measurements we can provide: a multi purpose apparatus**
- **Final remarks**

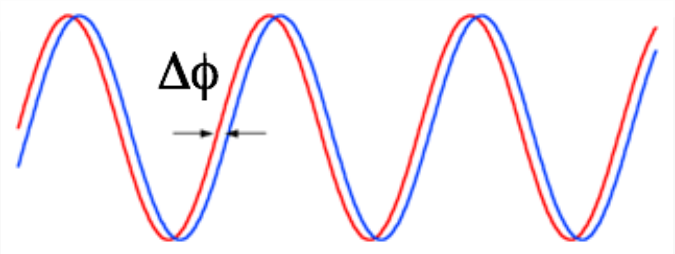
THE SAGNAC EFFECT

$$\Delta\phi = \frac{8\pi A}{\lambda\, c}\,\vec{n}\cdot\vec{\Omega}$$



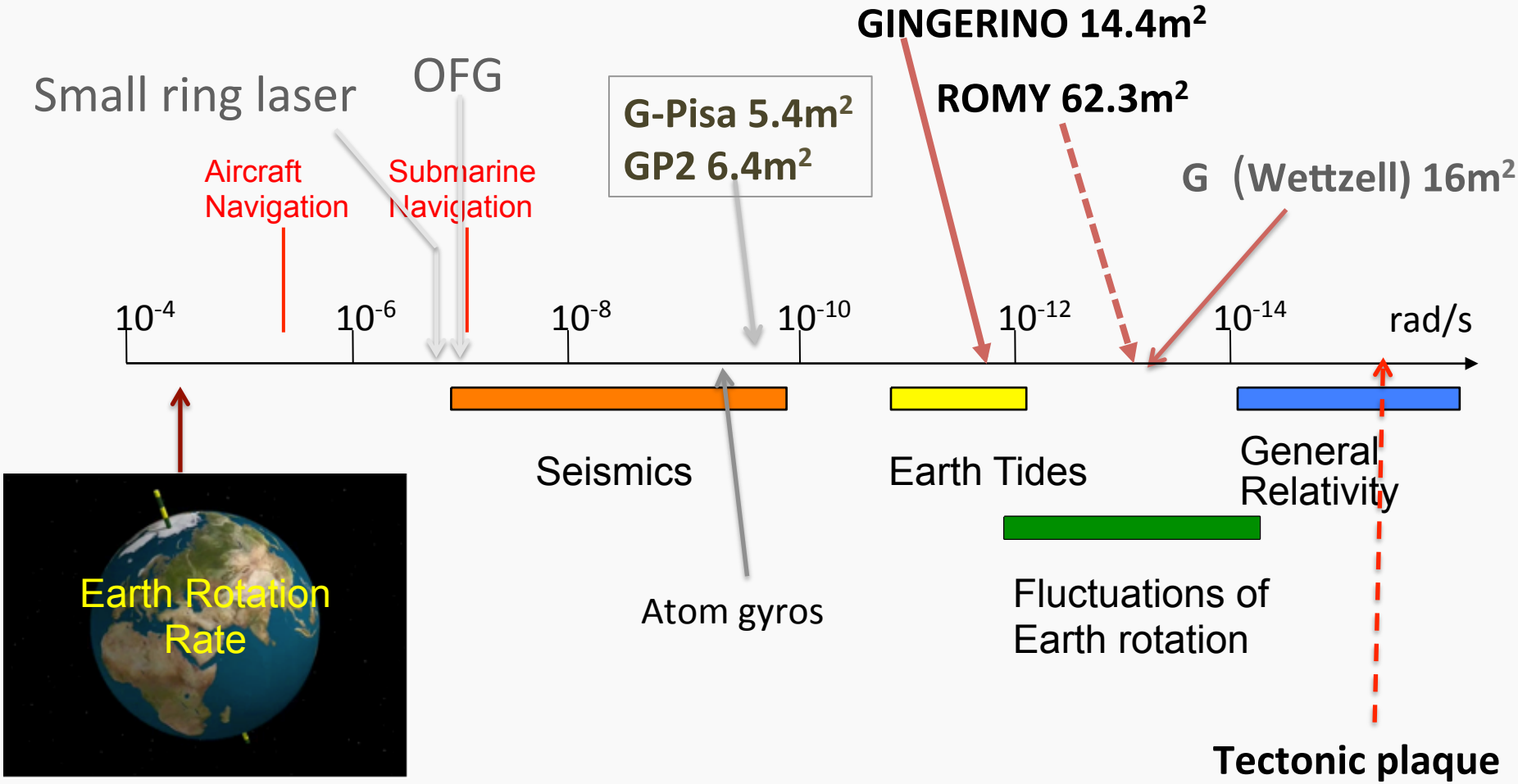
$$t = \frac{2\pi R}{c-\Omega R} \qquad t = \frac{2\pi R}{c+\Omega R}$$

$$\Delta t = \frac{2\pi R}{c-\Omega R} - \frac{2\pi R}{c+\Omega R} \approx \frac{4\pi\Omega R^2}{c^2} = \frac{4\,\Omega}{c^2}A$$



$$\Delta\phi = 2\pi\frac{c\Delta t}{\lambda} = \frac{8\pi\Omega\, A}{\lambda c}$$

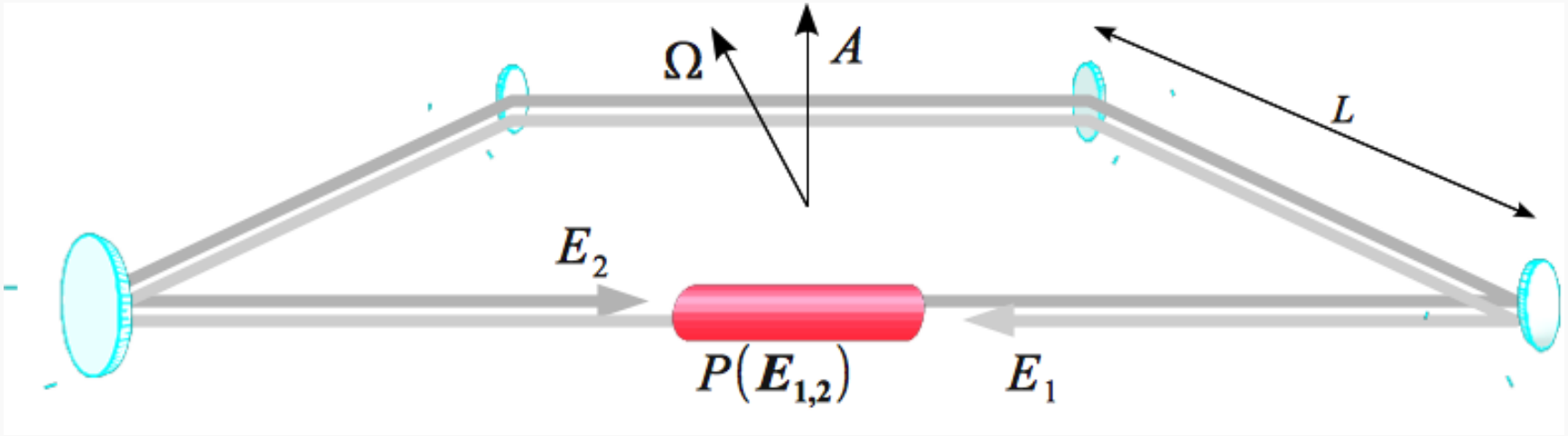
INERTIAL ANGULAR ROTATION MEASUREMENT

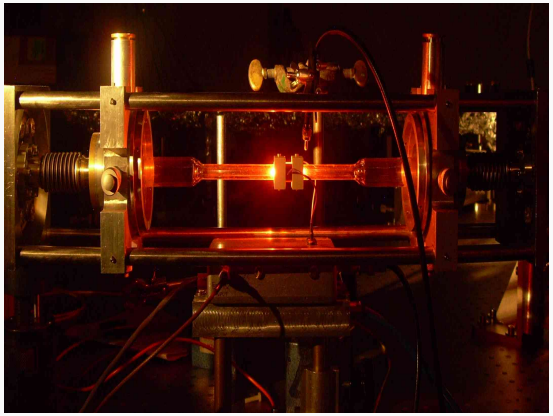


Impossible to distinguish among geophysics and fundamental physics signals

SAGNAC GYROS ACTIVE/PASSIVE RING LASER GYROSCOPES

…THE LASER DOES THE WORK FOR YOU….





When the ring is rotating, the difference in optical path in the two direction is translated in a frequency difference:

$$f_{Sagnac} = \left| f_{CW} - f_{CCW} \right| = \frac{4\vec{A}\cdot\vec{\Omega}}{\lambda p}$$

INFN/FUNDAMENTAL PHYSICS

GINGER: Gyroscopes IN GEneral Relativity
Lense Thirring effect, on Earth, 1% precision

General aim is to provide measurements able to pose constraints on the parameters of the theories

Confrontation space/earth based apparatus?

INFN Sections: Pisa, LNGS, Legnaro, Napoli and Padova
Department of Physics of Pisa (condensed matter and applied physics)

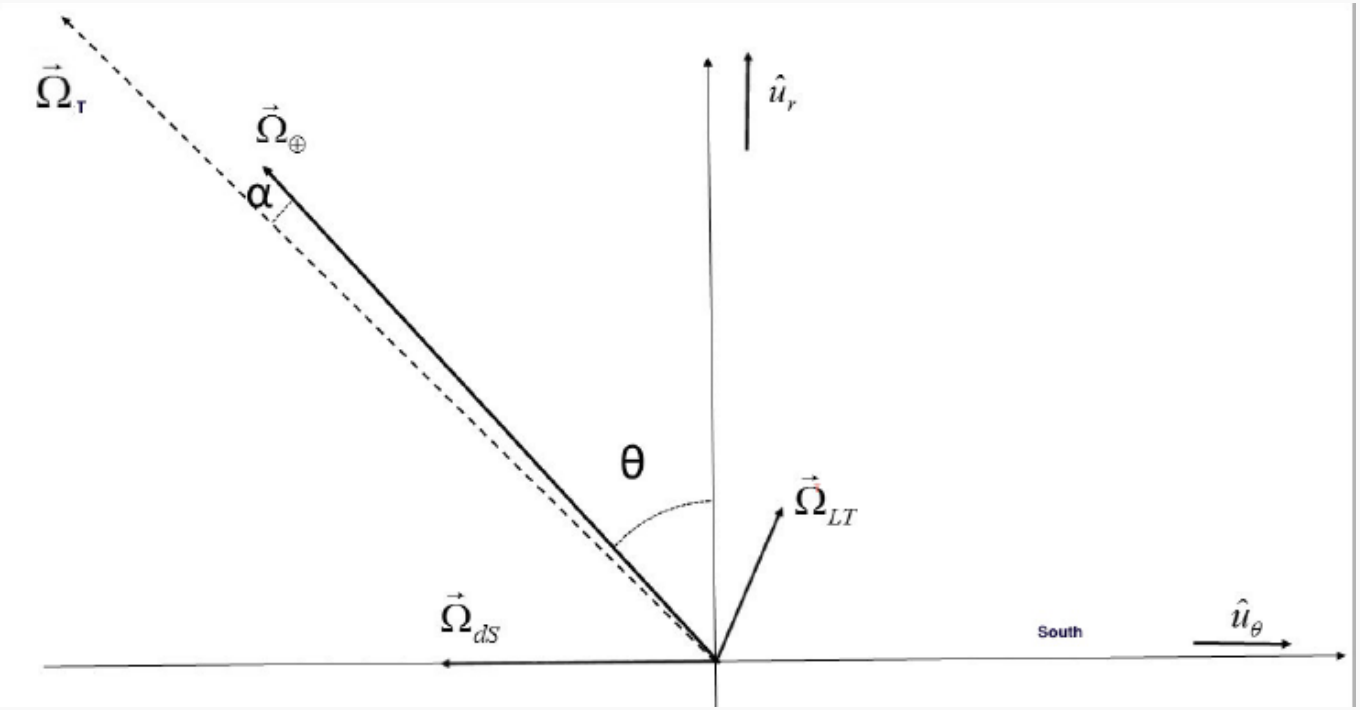
THE GR TERMS

measured by IERS

deSitter *Lense Thirring*

$$f = \frac{4A}{\lambda P}\left[\Omega_{\oplus} - 2\frac{m}{r}\Omega_{\oplus}\sin\theta\hat{u}_{\theta} + G\frac{I\Omega_{\oplus}}{c^2 r^3}\left(2\cos\theta\hat{u}_r + \sin\theta\hat{u}_{\theta}\right)\right]\cdot\hat{u}_n = S\left(\Omega_{\oplus} + \Omega_{dS} + \Omega_{LT}\right)\cdot\hat{u}_n.$$

A. Tartaglia, A. Di Virgilio et al. Eur. Phys. J. Plus (2017) 132: 73



The deSitter and LenseThirring terms are equivalent to an extra rotation 9-12 orders of magnitude below the Earth rotation rate.

GINGER

2017 PAPERS DEFINES THE REQUIREMENTS FOR GINGER

Highlighted by springer and eurekalert

Angela D. V. Di Virgilio et al. "GINGER: A feasibility study". In: *The European Physical Journal Plus* 132.4 (2017), p. 157. ISSN: 2190-5444. DOI: 10.1140/epjp/i2017-11452-6. URL: https://doi.org/10.1140/epjp/i2017-11452-6.

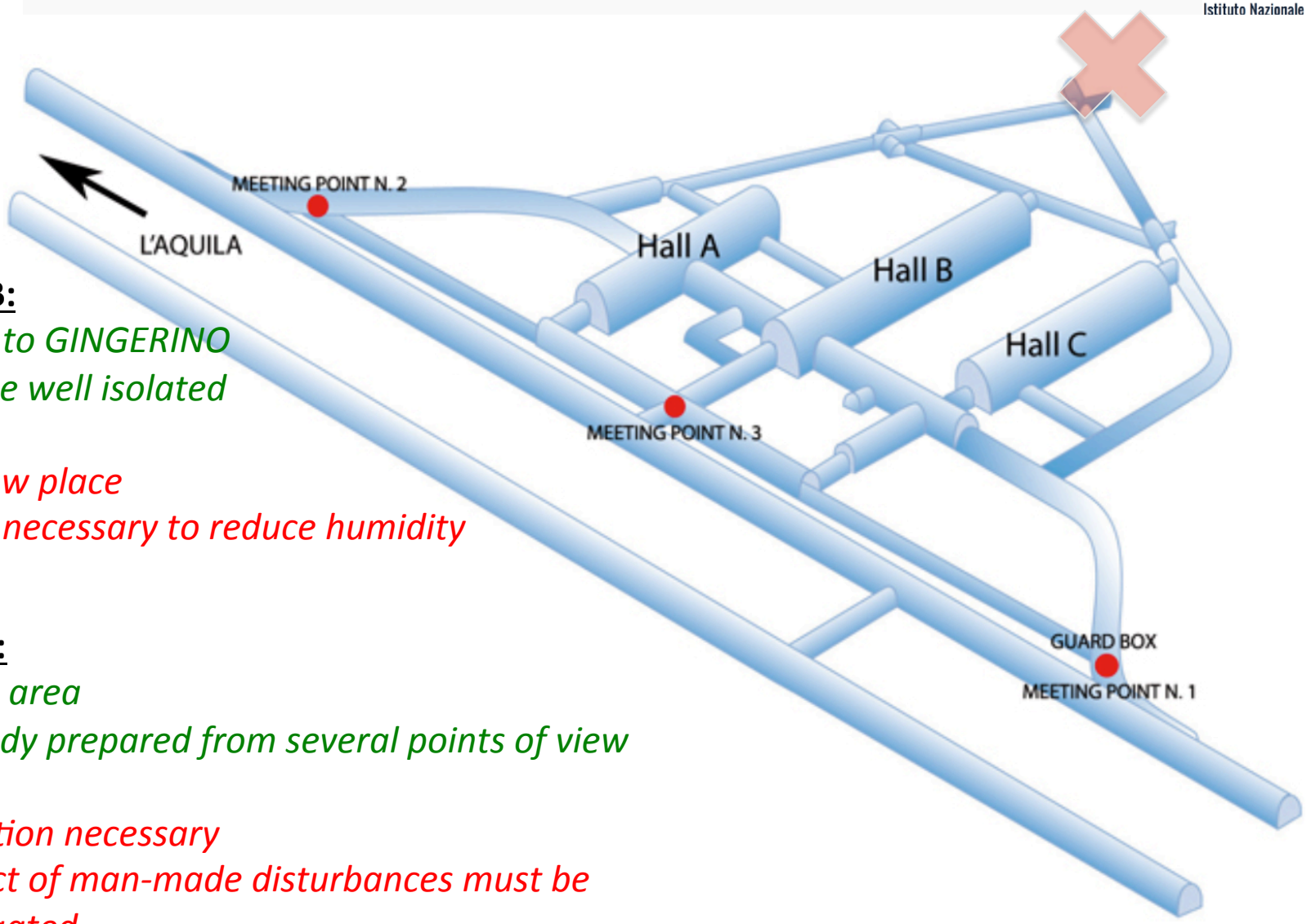
Highlighted as 'Change the World'

Angelo Tartaglia et al. "Testing general relativity by means of ring lasers". In: *The European Physical Journal Plus* 132.2 (2017), p. 73. ISSN: 2190-5444. DOI: 10.1140/epjp/i2017-11372-5. URL: https://doi.org/10.1140/epjp/i2017-11372-5.

The most prestigious Repubblica e Nature

For example:
General relativity Going underground
Luke Fleet *Nature Physics* **volume 13**, page 321 (2017)

Europhysics news



NODE B:

close to GINGERINO

can be well isolated

narrow place

work necessary to reduce humidity

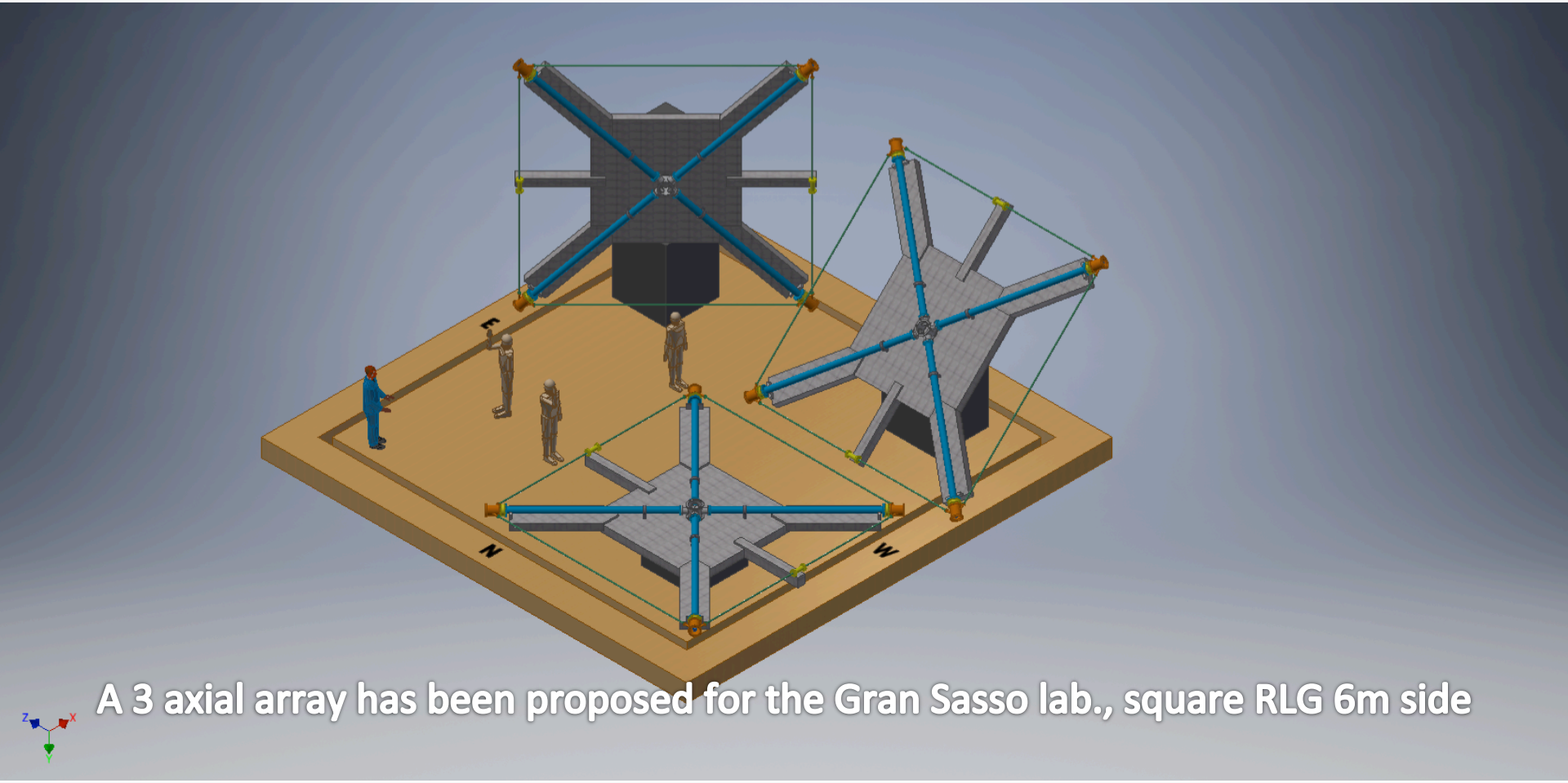
HALL B:

large area

already prepared from several points of view

Isolation necessary

impact of man-made disturbances must be investigated



A 3 axial array has been proposed for the Gran Sasso lab., square RLG 6m side

The RL_1 at maximum signal is the best solution to measure the amplitude of Ω_T (η parallel)

- RL_2 provides redundancy and the link between the angle Ω_T and the local vertical or horizontal plane. It could be vertical or horizontal

- Linking RL_2 with the local common reference (vertical/ horizontal) the angle α can be measured (η perpendicular)

- One RL with area versor outside the meridian plane should be added in a second time. This requires to measure the angles with respect RL_2

WHAT GINGER DELIVERS

- *Variation of the earth rotation rate with relative precision ~ 10^{-9}-10^{-12}*
- *Variation of the rotation axis (local)*
- *Lense Thirring 1% comparing with IERS data*

- *Other measurements connected to the sidereal day modulation are feasible (for example Lorenz Invariance)*

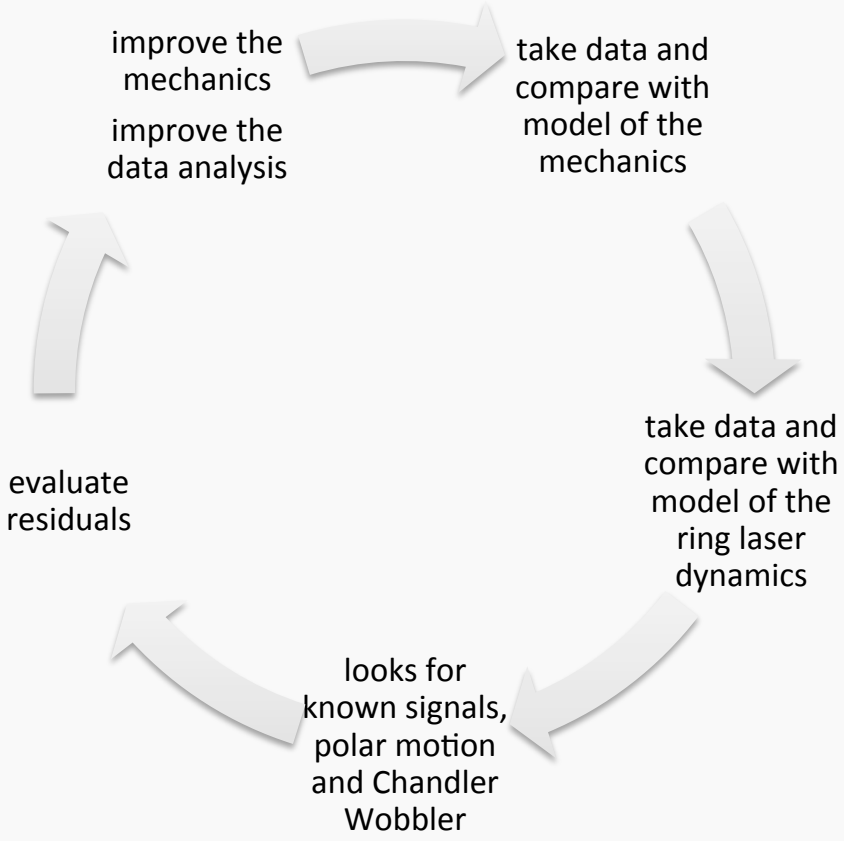
MOREOVER…

- *LenseThirring constrain parameters of the EGT.* ***Capozziello, Lambiase et al. , Phys. Rev. D 91, 044012 (2015)***
- *Angelo Tartaglia: link between the gravitomagnetic measurement (i.e. angular moment) and the Dark Matter* **A. Tartaglia, in *General Relativity and Gravitational Physics*, AIP Conference Proceedings, 751 , 136-145, (2004) A. Tartaglia et al., *Gen Rel. Grav*., 50-9, 1-22 (2018)**
- **Lorenz invariance tests feasible with GINGER**

- **High sensitivity (~nrad/s) inertial sensors are very important to improve the performance at LOW FREQUENCY of the GW antennas**
- **inertial platform in general**
- **Seismology and geophysics in general**

……..SENSITIVY IS NEVER ENOUGH!....

PROTOTYPES ARE VERY USEFUL TO IMPROVE THE DESIGN AND THE COMPREHENSION OF THE INSTRUMENT



MAIN LIMITATION FOR SENSITIVITY: BACKSCATTER NOISE

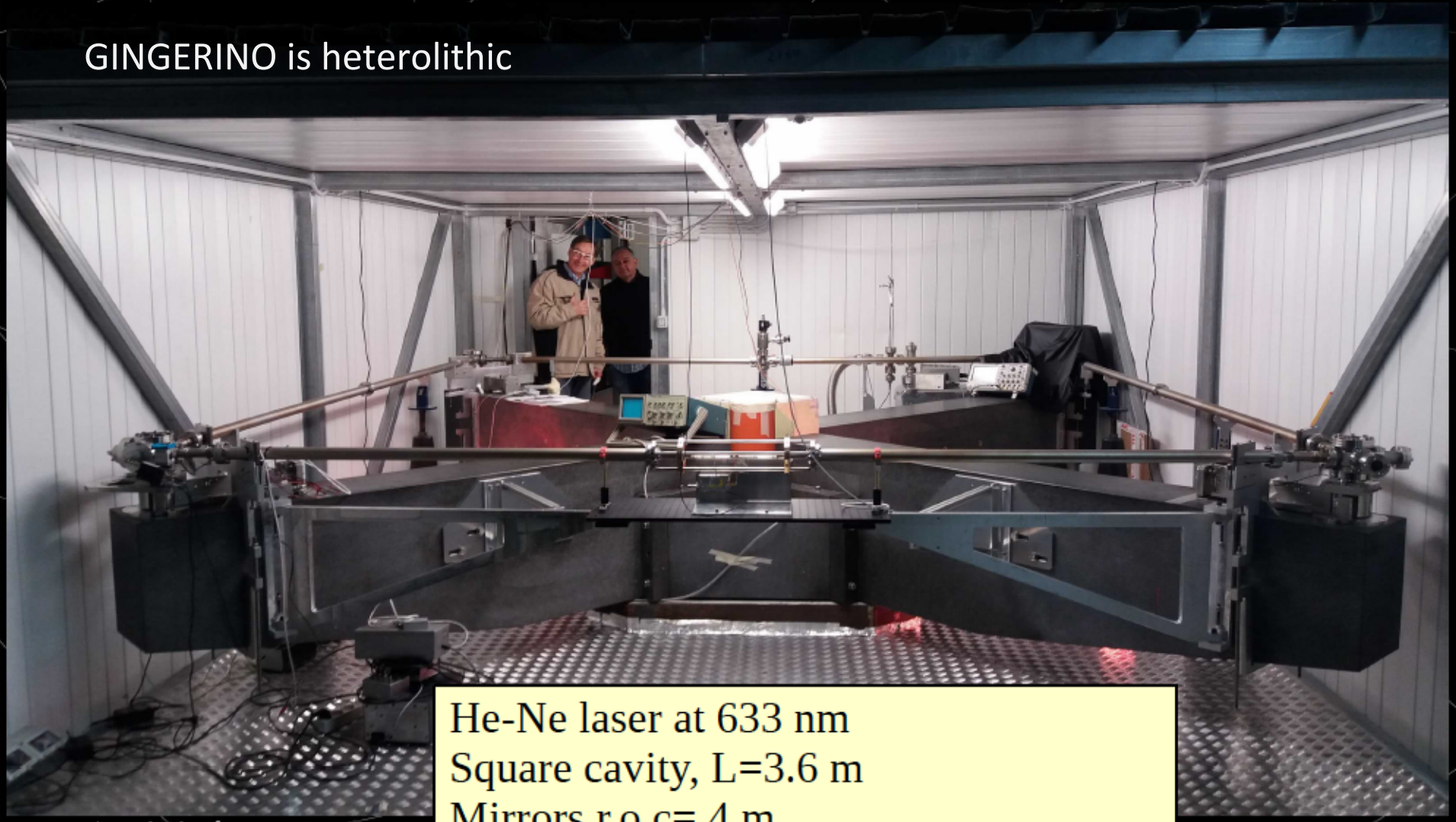
- Laser dynamics is not linear and backscatter noise is the main limitation
- Small scale instruments limited by backscatter noise
- IT IS A PROBLEM FOR PASSIVE GYROS AS WELL

GINGERino: deep underground ring laser

GINGER-ino (INFN-LNGS)+ Seismometers (INGV)

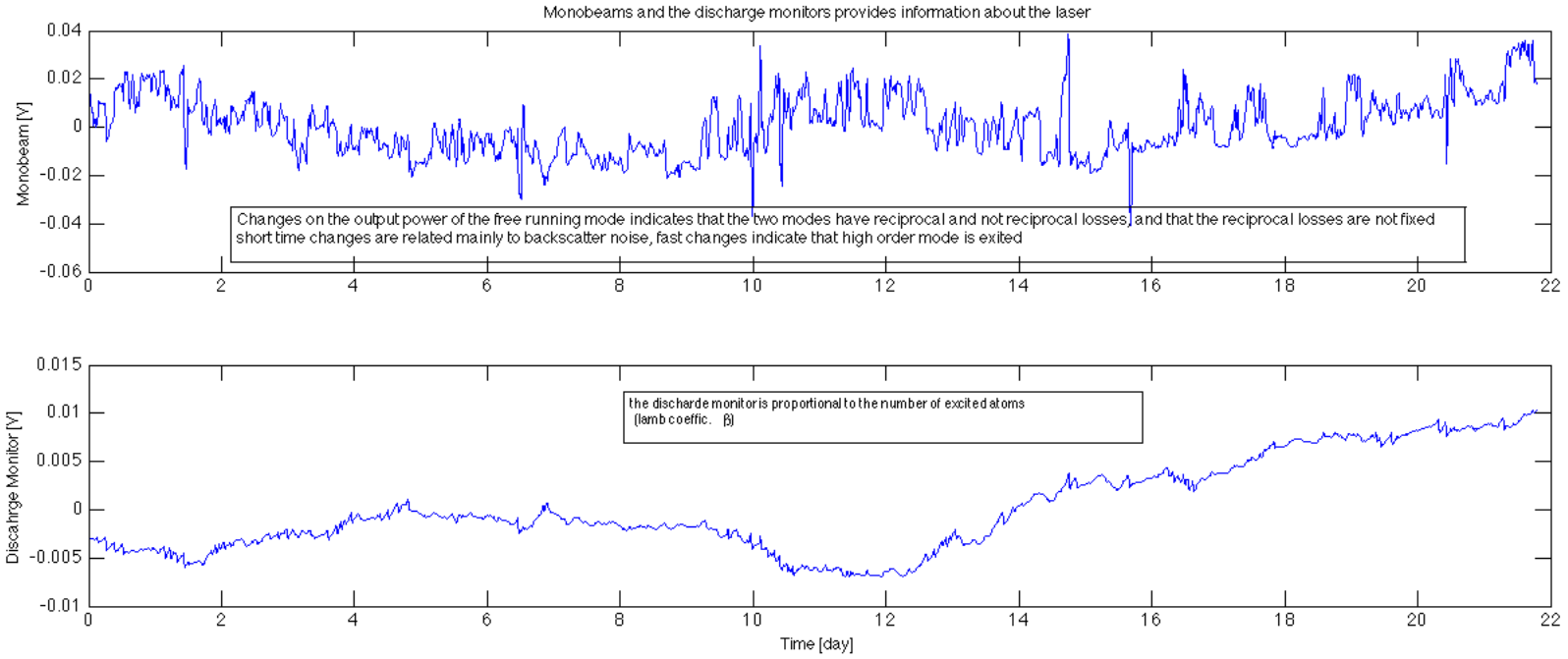
GINGER

GINGERINO is heterolithic



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**

Laser dynamics is not linear but well defined, it provides a lot of information about what it is going on



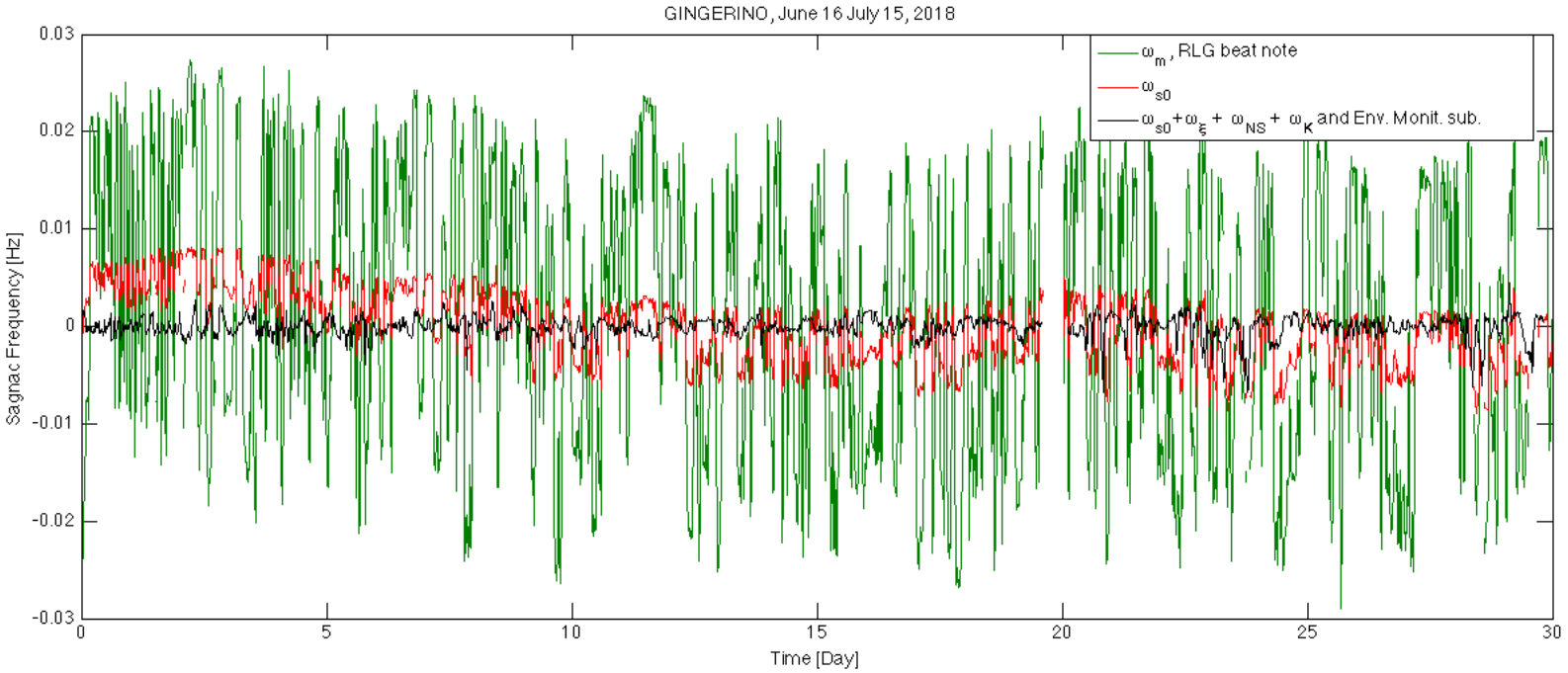
Analysis taking into account the laser dynamics

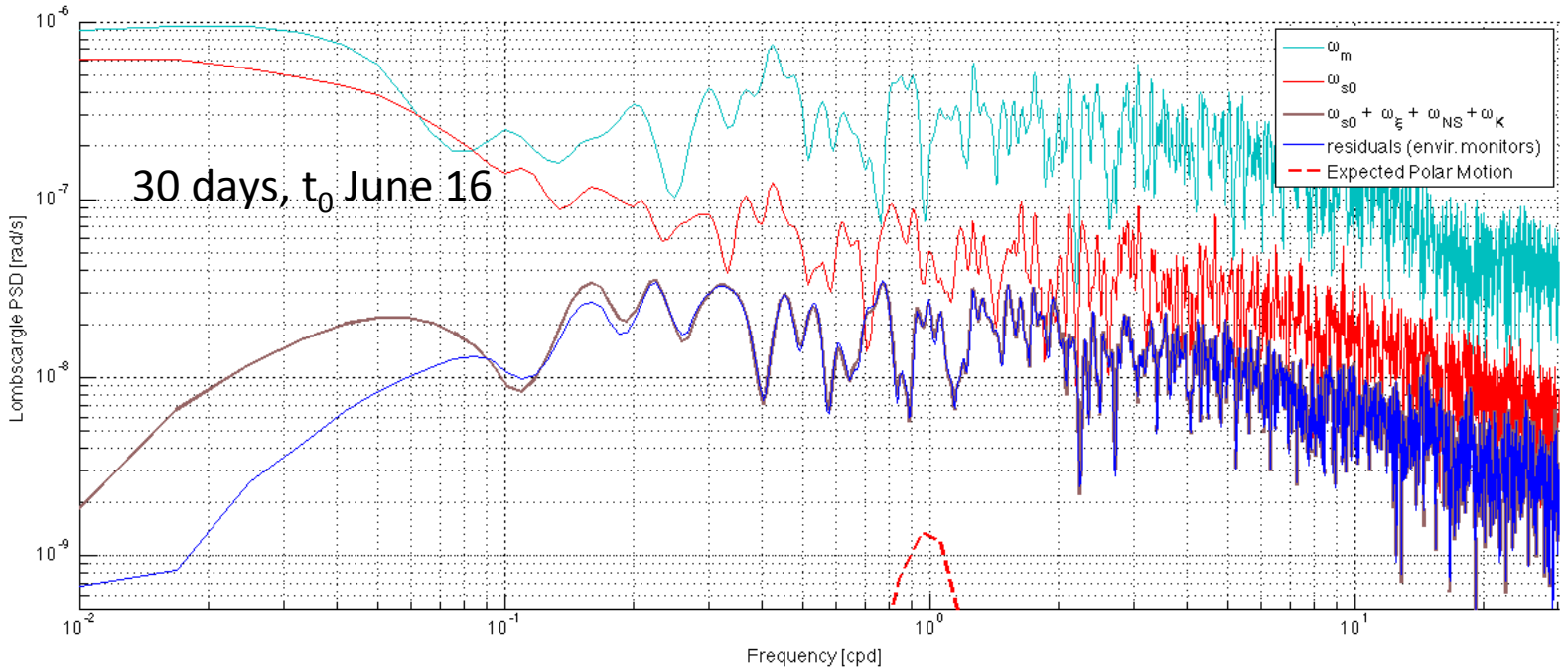
- 2012: Reconstruction of the gyro signals based on the laser dynamics and kalman filters
- 2018-2019: Analytical reconstruction of the signals taking into account the laser dynamics and the main parameters of the ring-laser (cavity losses μ, and backscatter light)

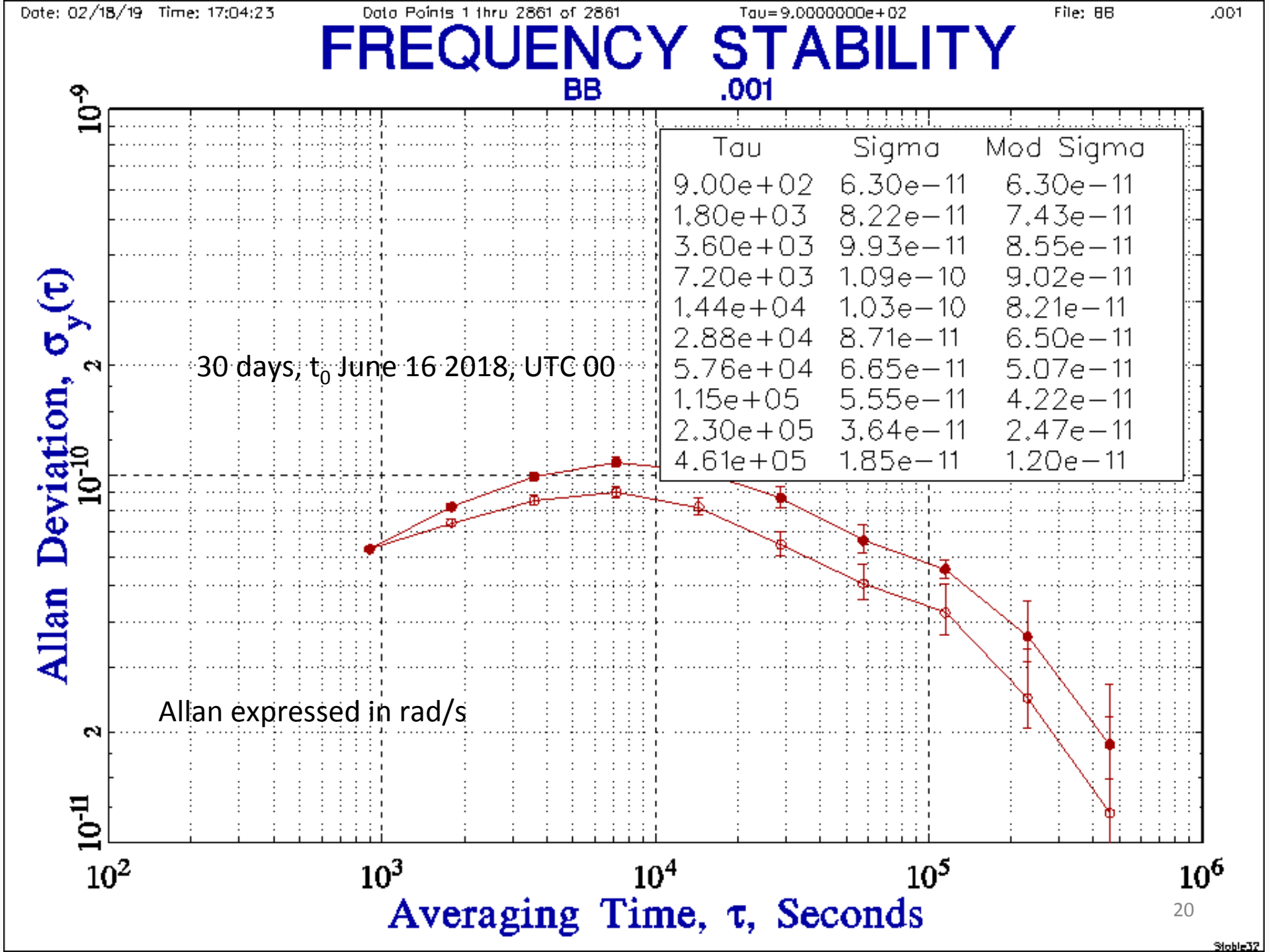
$$\omega_{s0} \quad \omega_{\xi} \quad \omega_{NS} \quad \omega_{K}$$

A. Di Virgilio et al, RLG data analysis taking into account ring laser dynamics

Shortly available on ARXIV

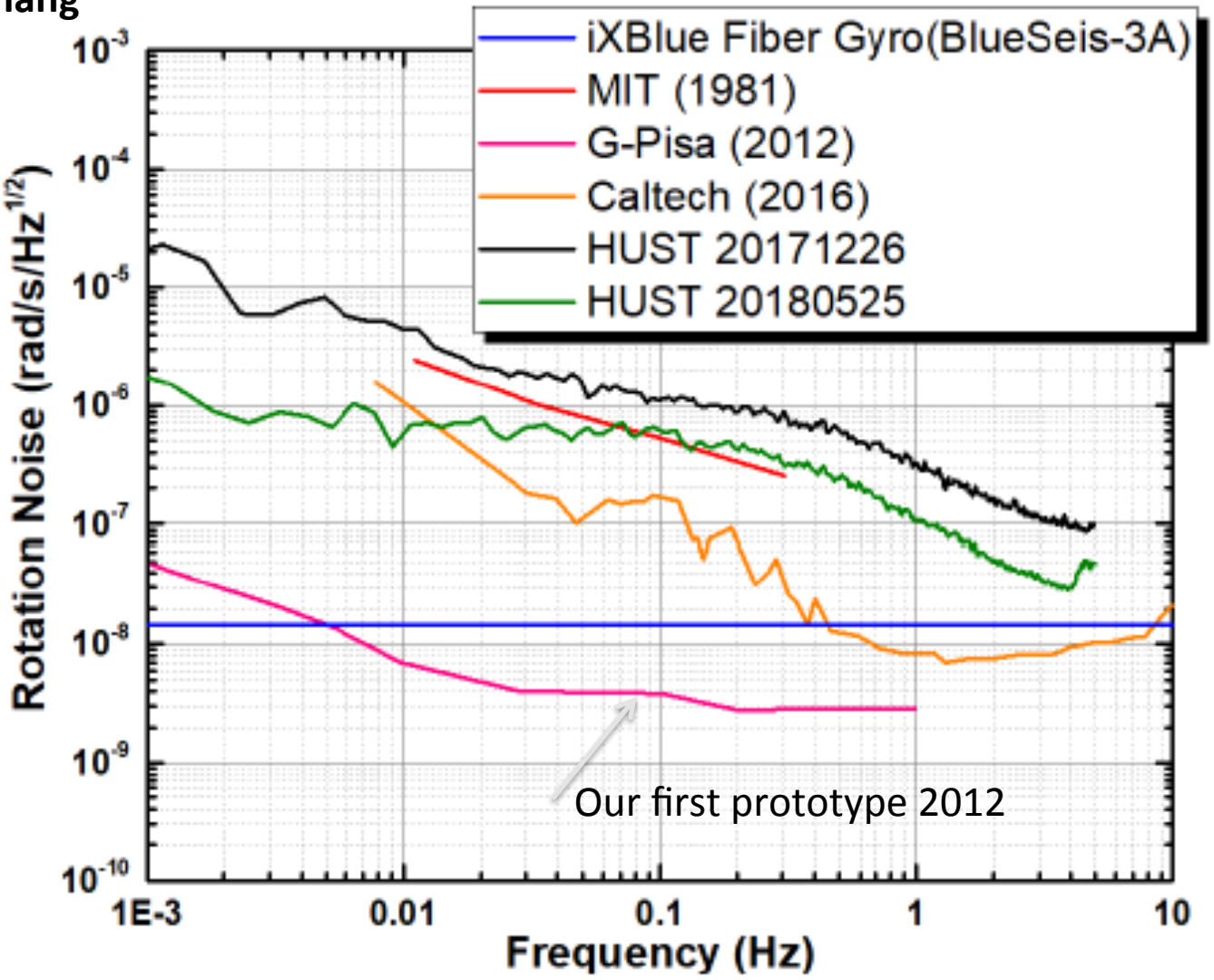

GINGERINO, June 16 July 15, 2018
ω_m, RLG beat note
ω_{s0}
$\omega_{s0}+\omega_\xi + \omega_{NS} + \omega_K$ and Env. Monit. sub.
Sagnac Frequency [Hz]
Time [Day]
0.03
0.02
0.01
0
-0.01
-0.02
-0.03
0
5
10
15
20
25
30

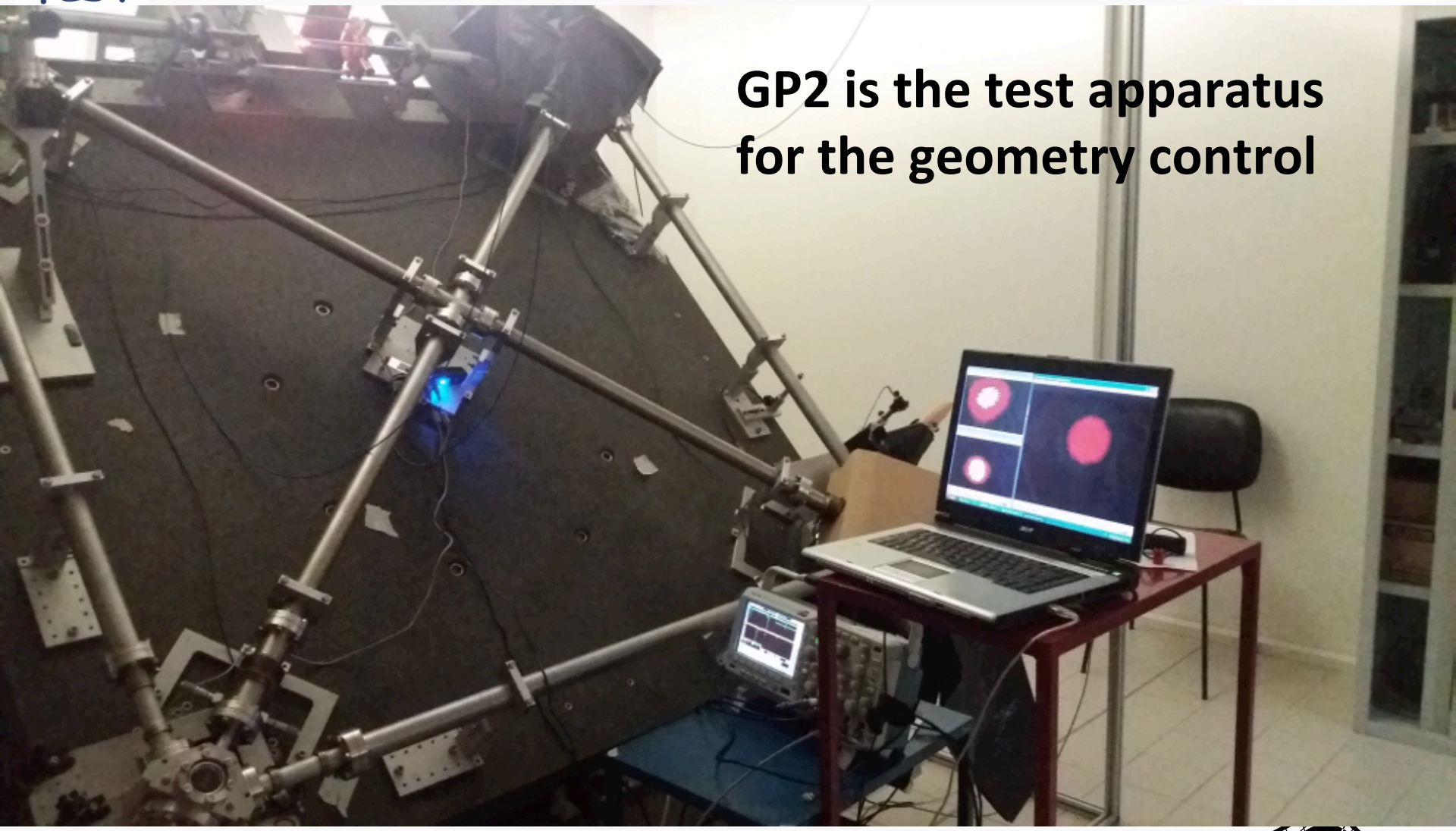

30 days, t0 June 16
ωm
ωs0
ωs0 + ωξ + ωNS + ωK
residuals (envir. monitors)
Expected Polar Motion
Lombscargle PSD [rad/s]
Frequency [cpd]
10-6
10-7
10-8
10-9
10-2
10-1
100
101


Date: 02/18/19 Time: 17:04:23
Data Points 1 thru 2861 of 2861
Tau=9.0000000e+02
File: BB .001
FREQUENCY STABILITY
BB .001
Tau Sigma Mod Sigma
9.00e+02 6.30e-11 6.30e-11
1.80e+03 8.22e-11 7.43e-11
3.60e+03 9.93e-11 8.55e-11
7.20e+03 1.09e-10 9.02e-11
1.44e+04 1.03e-10 8.21e-11
2.88e+04 8.71e-11 6.50e-11
5.76e+04 6.65e-11 5.07e-11
1.15e+05 5.55e-11 4.22e-11
2.30e+05 3.64e-11 2.47e-11
4.61e+05 1.85e-11 1.20e-11
30 days, t0 June 16 2018, UTC 00
Allan expressed in rad/s
Allan Deviation, σy(τ)
Averaging Time, τ, Seconds
10-9
10-10
10-11
2
2
10^2
10^3
10^4
10^5
10^6

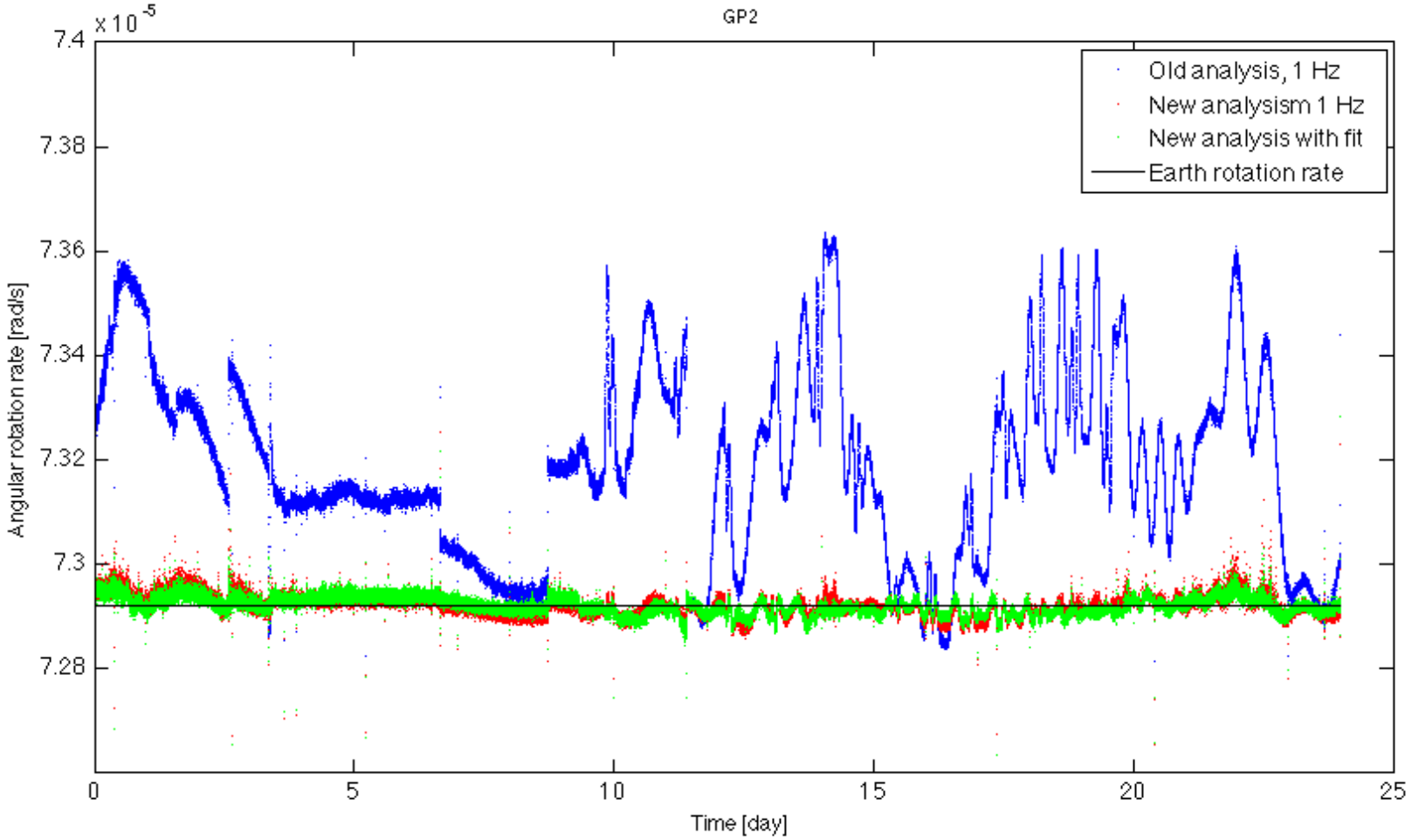
1 m×1 m prototype result

Courtesy Jie Zhang
Hurst




GP2 is the test apparatus
for the geometry control

GP2, middle size RLG, has reached 2nrad/s sensitivity



https://arxiv.org/abs/1902.02993

CONCLUSIONS

- Gyros based on the Sagnac effect, active or passive, are very powerful instruments.
- For fundamental physics they could provide Lense Thirring tests independent on the gravitational map, and in function of the latitude
- For fundamental physics they could also acts to improve the performances of the GW antennas at low frequency
- GINGERINO and GP2 are utilized to refine the analysis taking into account the laser dynamics
- Highly interdisciplinary