HIGH SENSITIVITY GYROSCOPES: GINGER AND GINGERINO

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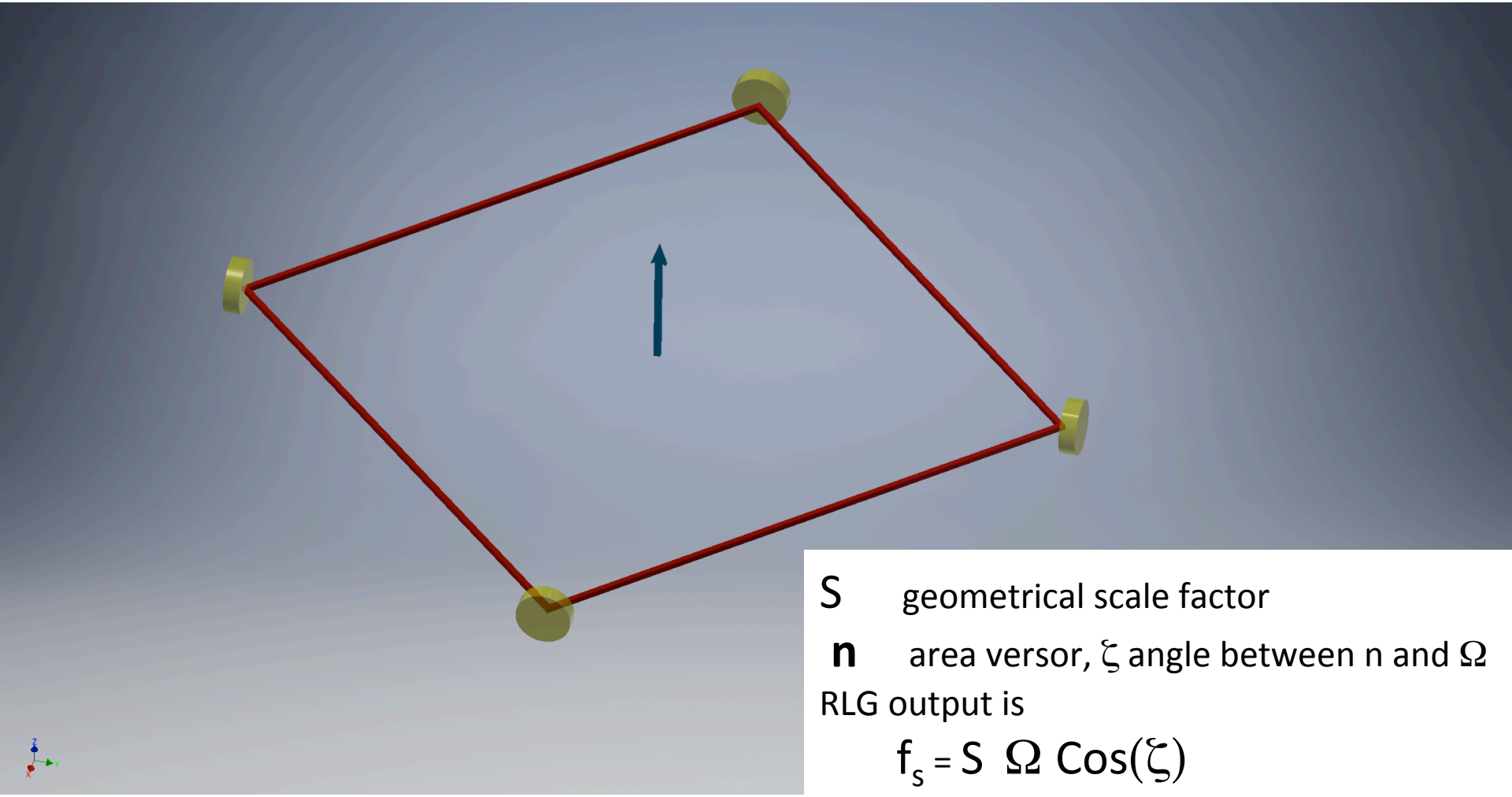
- ✓ *Why we are involved in RLG*
- ✓ *Hetero-Lithic RLG a mature technique: GINGERINO-95% of duty cycle*
- ✓ *What we could do in the near future: 3D apparatus inside the Gran Sasso ?*
- ✓ *Conclusions*

Each RLG is a projector,
4 mirrors: a very simple apparatus, photons do not interact with the outside world



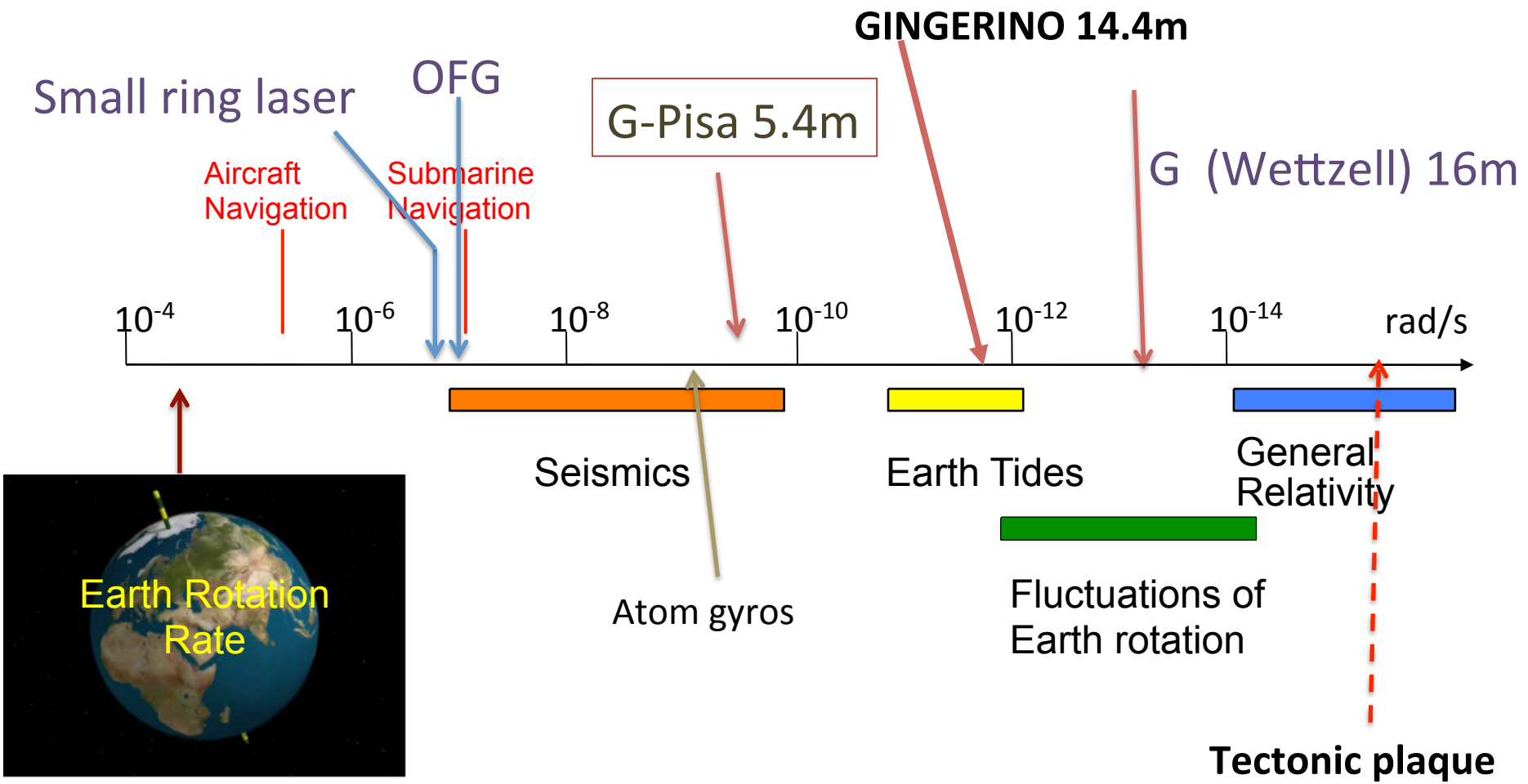
S geometrical scale factor

n area versor, ζ angle between n and Ω

RLG output is

$$f_s = S\ \Omega\ \mathrm{Cos}(\zeta)$$

INERTIAL ANGULAR ROTATION MEASUREMENT



ROMY, 4 RLG, ERC for seismology has about the same sensitivity of G of Wettzel

Impossible to distinguish among geophysics and fundamental physics signals

INFN/FUNDAMENTAL PHYSICS

- *Ring lasers (RLG) are the most sensitive gyroscope for an earth based experiment*
- *Project GINGER: Gyroscopes IN GEneral Relativity*
- *Lense Thirring effect, on Earth, 1% precision*

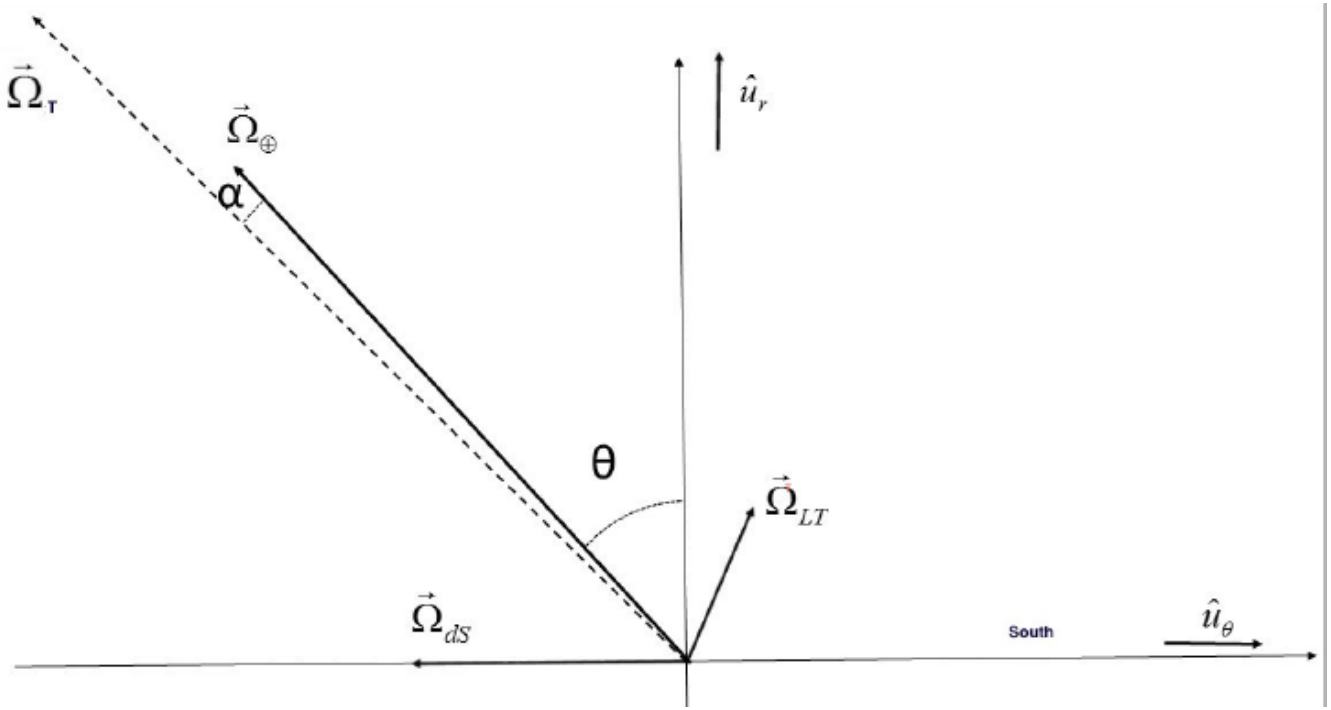
THE GR TERMS

measured by IERS

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

deSitter *Lense Thirring*

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.

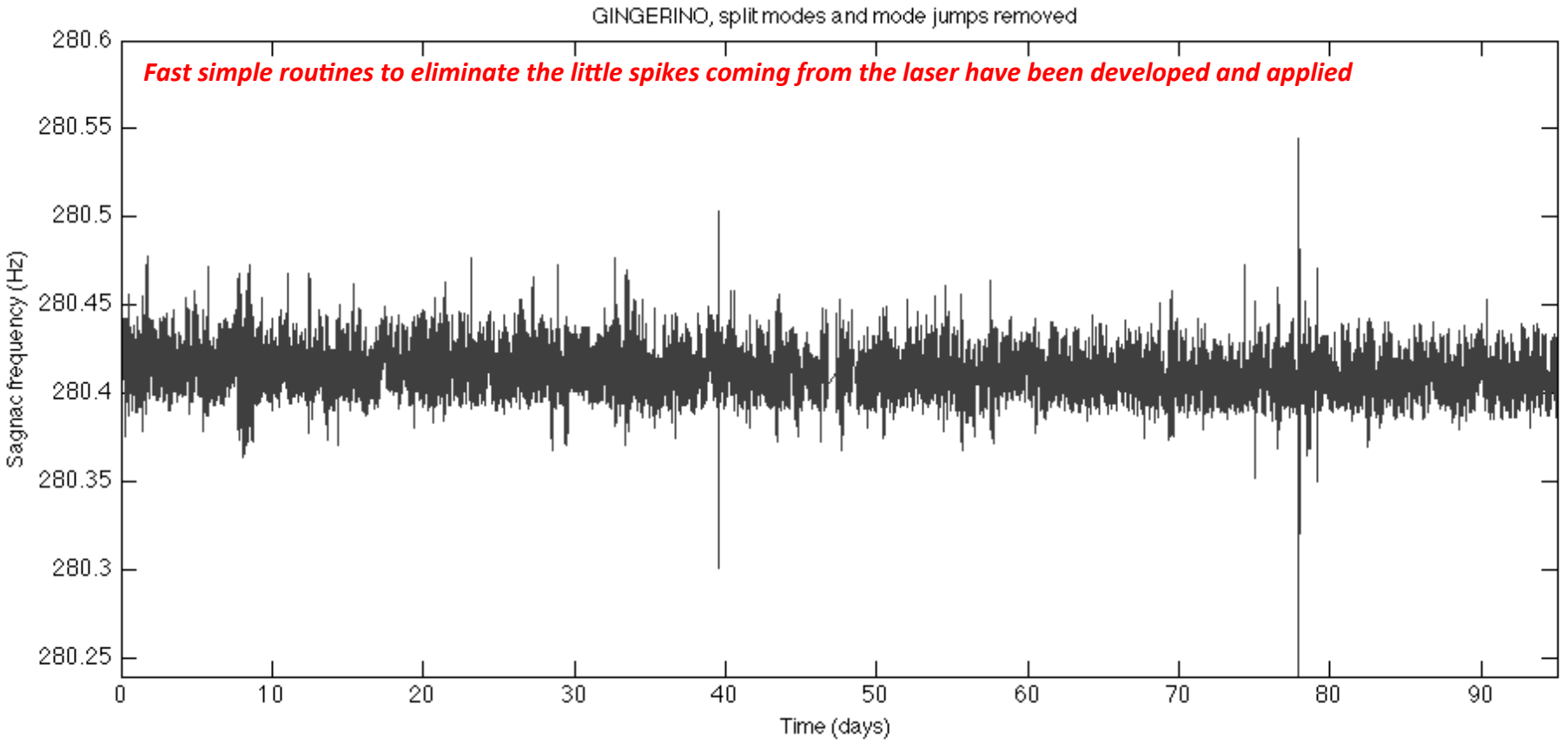
GINGERINO

- *GINGERINO has observed part of the recent central Italy swan and several papers have been written about regional and non regional teleseismic*

- *GINGERINO is taking data since May 2017 in a continuous basis*

- *The analysis of the first 96 days has been recently submitted and is in the archive https://arxiv.org/abs/1804.02569*

GINGERINO is taking data since May 2017, a few days have been lost



First 90 days:
Less than 2% of the time GINGERINO was in split mode
Overall duty cycle > 95%

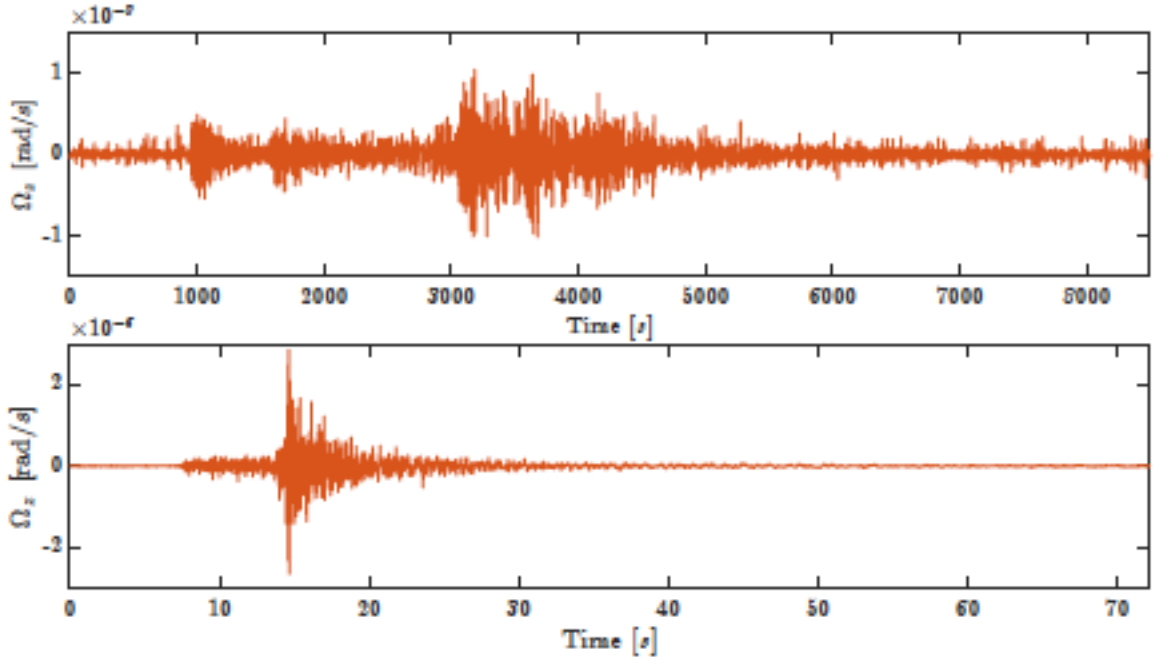


Fig. 2. Typical signal from far away strong Earthquake, the tele-seismic event on July 18 2017, around 00 : 00 (UTC), Kamchatka, Russia, M 7.6 (TOP) and a typical signal of regional Earthquake, on October 16 2016 09:32:35 (UTC), Rieti, Italy Mw 4.0 (BOTTOM)

We have investigated the lower part of the spectrum

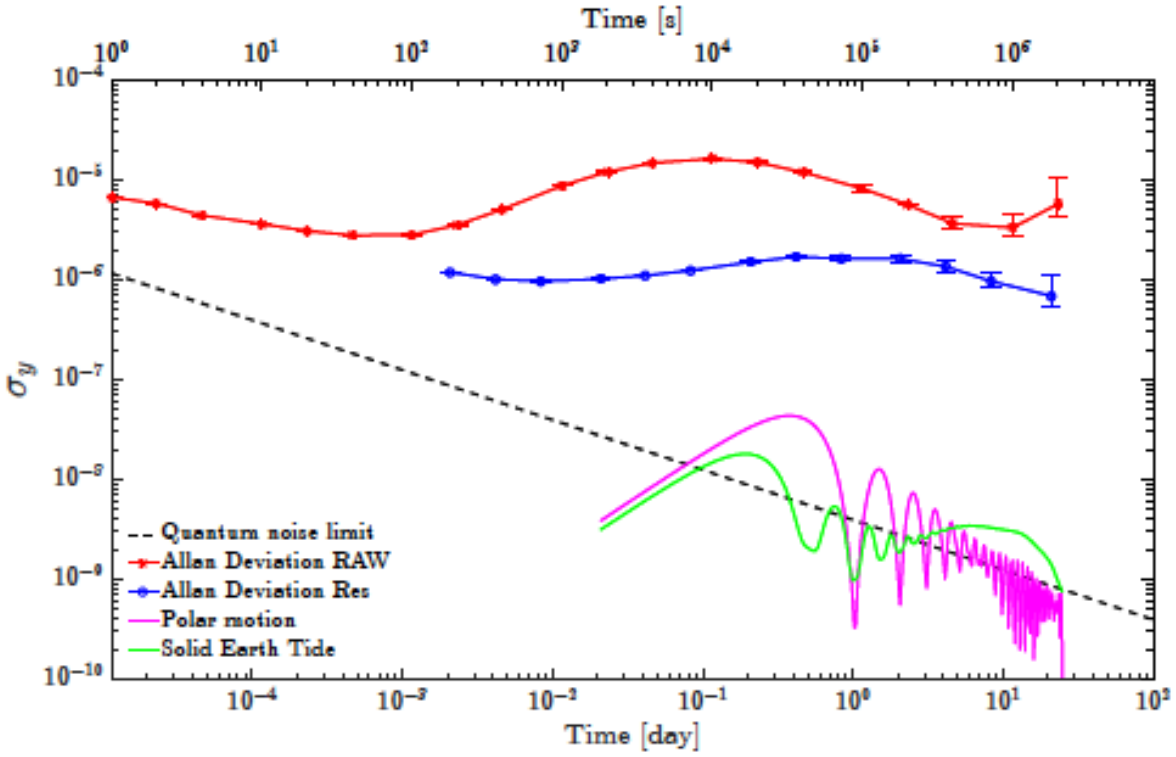
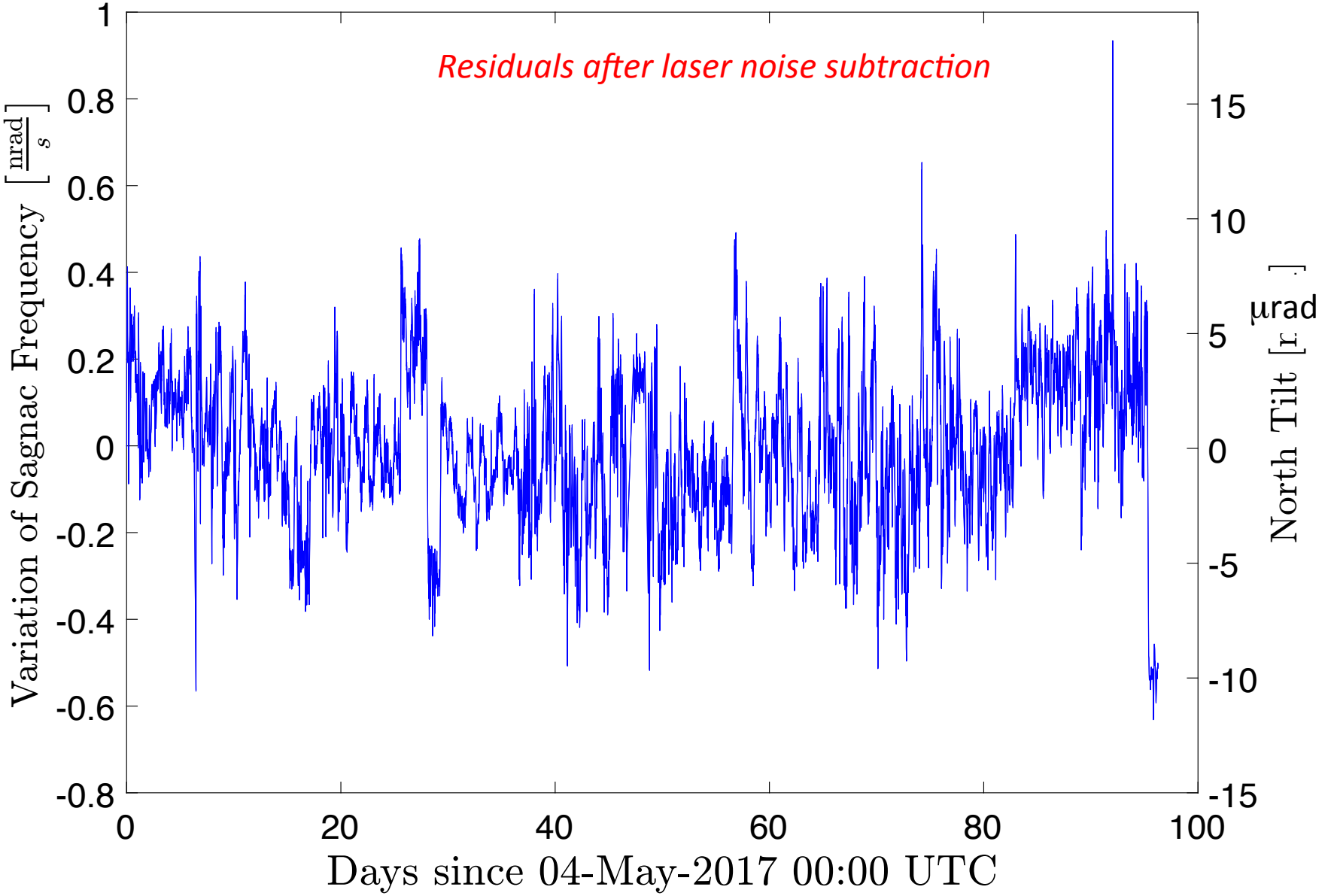
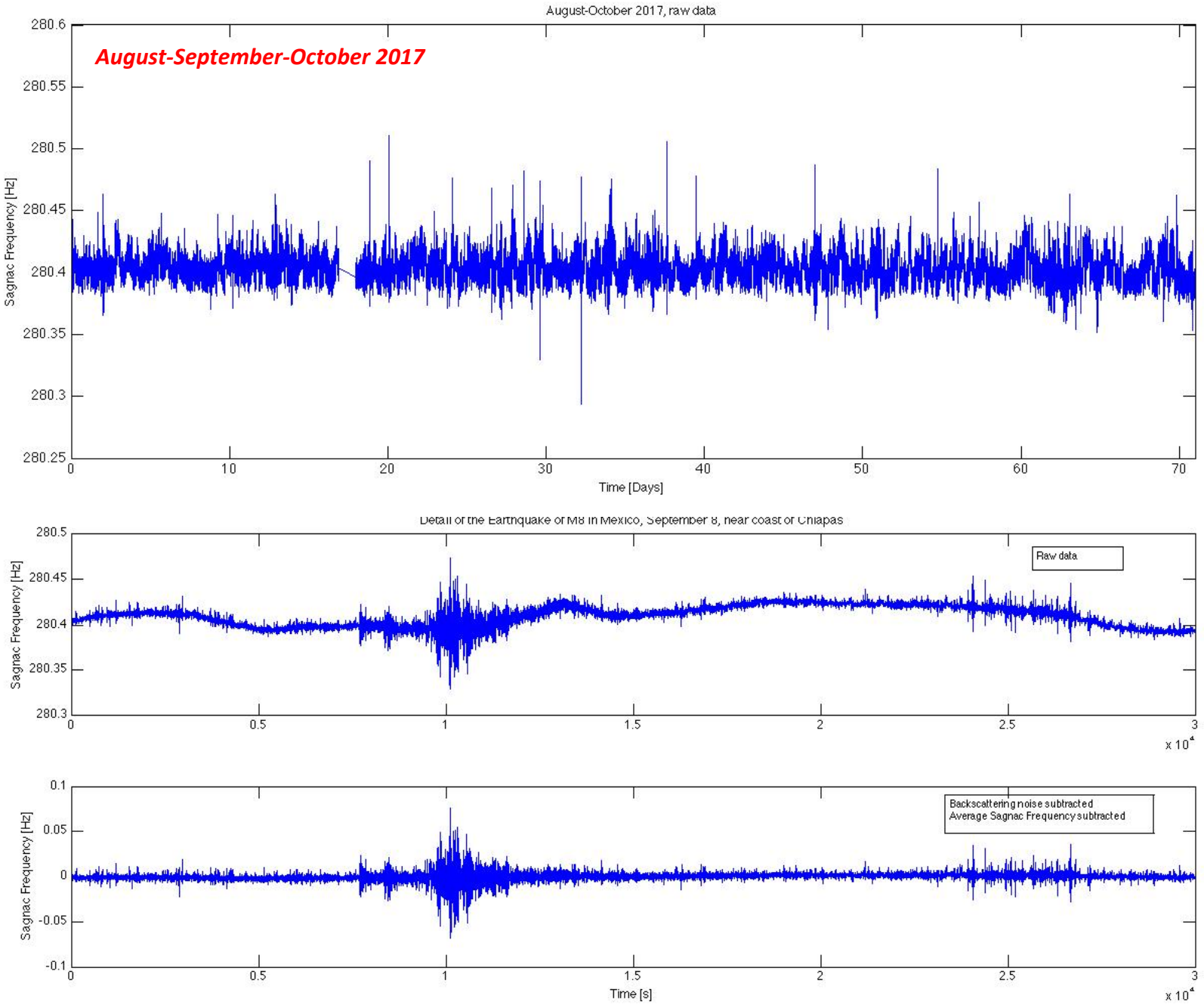


Fig. 12. Overlapping Allan deviation of raw data (red curve) and the residuals (blue curve) compared with the quantum noise limit (dashed line) and the Polar motion (magenta curve) and Solid Earth Tide (green curve) of GINGERINO site. Due to computational needs the residuals overlapping Allan deviation has been calculated using data sampled at 180*s*

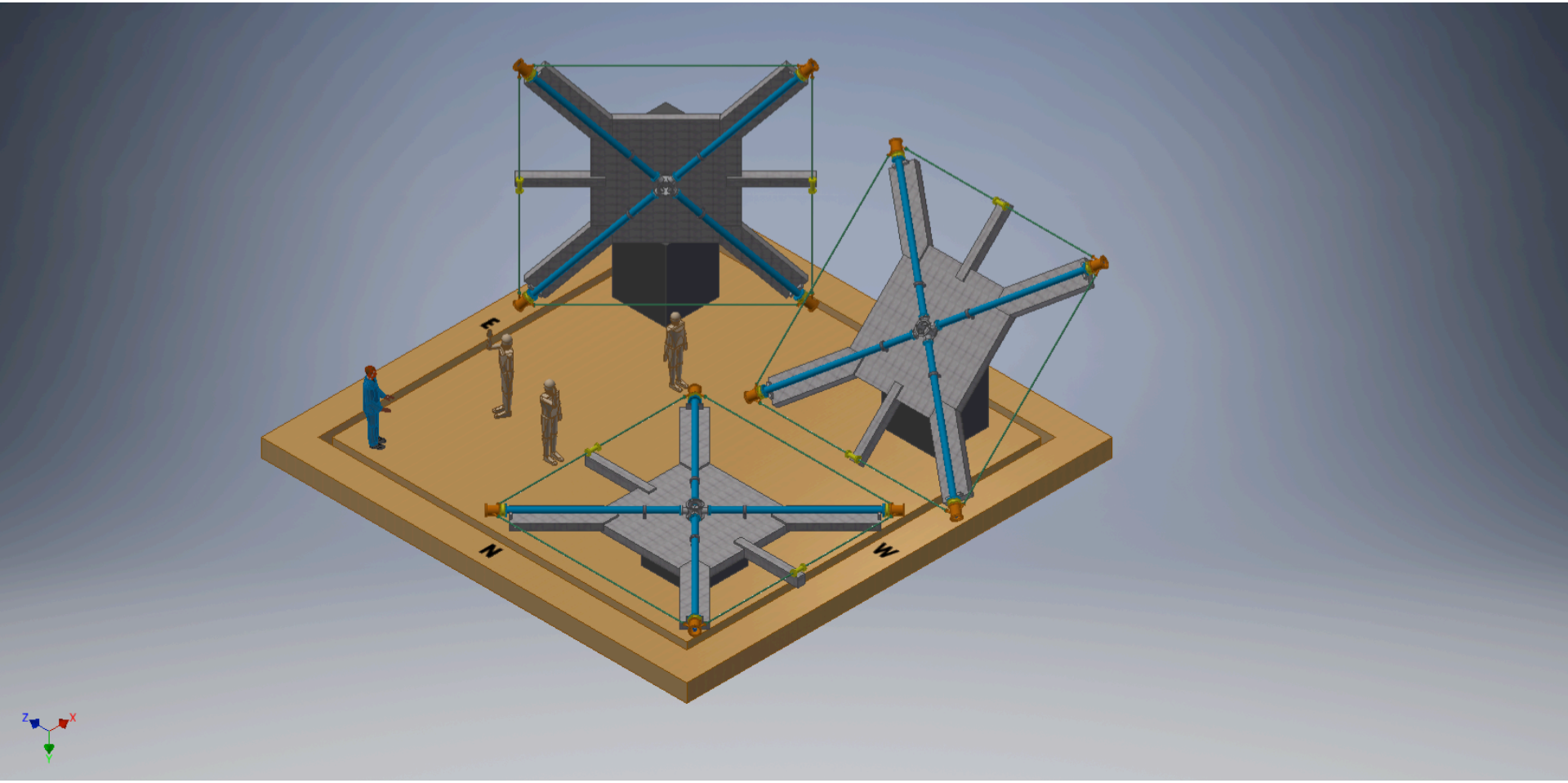
We have investigated the lower part of the frequency spectrum

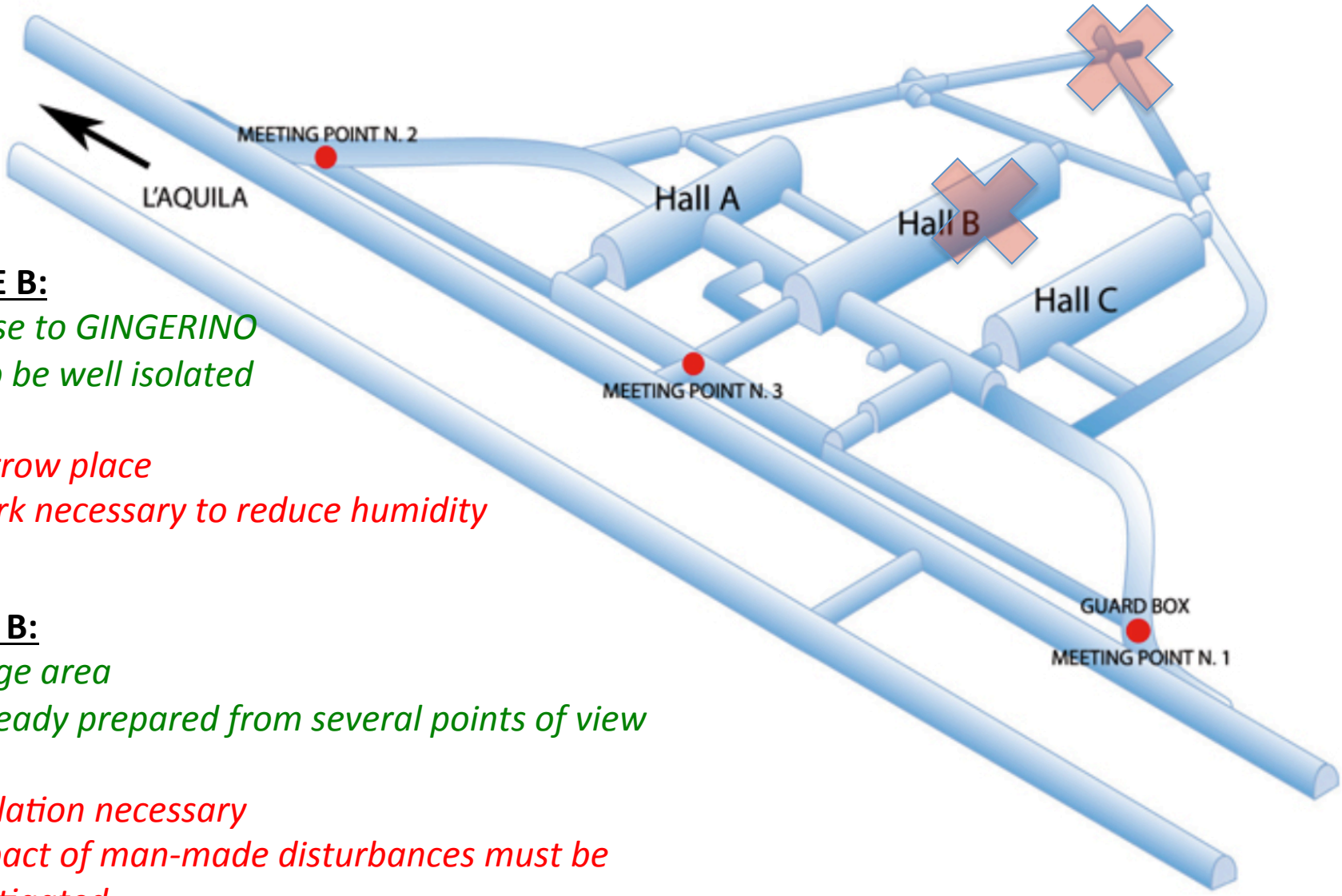



August-October 2017, raw data
August-September-October 2017
Sagnac Frequency [Hz]
Time [Days]
Detail of the Earthquake of M8 in Mexico, September 8, near coast of Chiapas
Raw data
Backscattering noise subtracted
Average Sagnac Frequency subtracted
Time [s]

THE ARRAY PROPOSED FOR LNGS

- *Align one RLG at the maximum Sagnac signal (versor area parallel to the earth axis)*
- *Use the horizontal and vertical plane to avoid the metrology to measure the relative angle between different RLG*
- *The alignment of the third RLG will depend as well on the final location (Node B or Hall B)*


E
N
W



NODE B:

close to GINGERINO
cab be well isolated

narrow place
work necessary to reduce humidity

HALL B:

large area
already prepared from several points of view

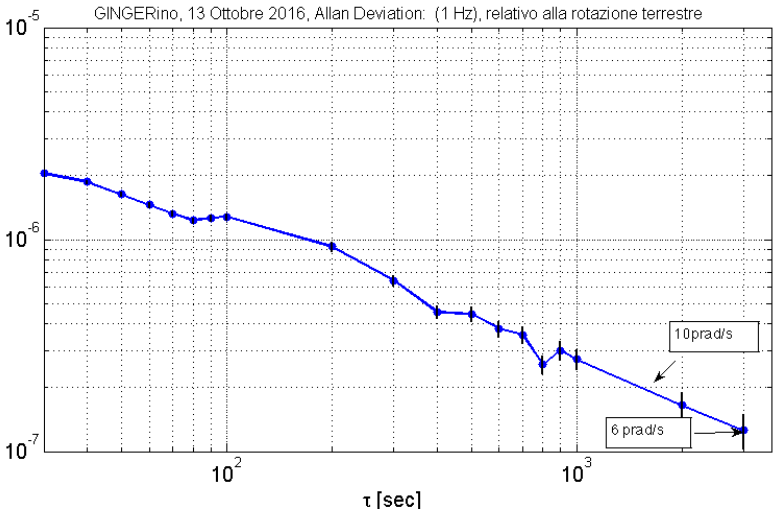
Isolation necessary
impact of man-made disturbances must be investigated

KEEP IN MIND: SENSITIVITY IS AN ISSUE
SHOT NOISE LIMIT

- *RLG are shot noise limited*
- *The shot noise depends on the size L and the mirror losses*

$$\delta f_{sn} \propto \frac{\text{Losses}}{L^2}$$

L side of the ring cavity
Losses: mirror losses



Present limit for L ~ 4m (G&GINGERINO)

$$10^{-10} - 0.6\ 10^{-12}\ \frac{\text{rad}}{\sqrt{\text{Hz}}\ \text{s}}$$

SHOT NOISE LIMIT, L=7M (5M)

STATUS OF ART MIRRORS

- *angular rotation rate $\delta\omega \sim 2\ 10^{-13}$ ($4\ 10^{-13}$) rad/s/√Hz*
- *Angle $\delta\zeta \sim 6.5\ 10^{-11}$ ($1.2\ 10^{-10}$) rad (1 hour integration time)*

- *Other disturbances will limit the sensitivity, care is necessary to limit those disturbances and remain as close as possible to the shot noise limit*
- *In the near future I will address the problem of thermal noise*

VARIATIONS: $\delta\Omega_T$ δS and $\delta\zeta$

For a single RLG with angle ζ with the rotation axis

$$f_S = S\,(\Omega_T)\cos(\zeta),\ \text{assuming}\ \Omega_T \sim \Omega_\oplus$$

$$\delta f_S = S\,\Omega_T \sin(\zeta)\,\delta\zeta + \delta S\,(\Omega_T)\cos(\zeta) + S\,(\delta\Omega_T)\cos(\zeta)$$

The control eliminates the changes δS
$\delta\Omega_T$ and $\delta\zeta$ two cannot be distinguished

In short a RLG system can measure the variation of the angle $\delta\zeta$

COMBINING MORE RL IT IS POSSIBLE TO DISCRIMINATE AMONG THE TWO EFFECTS: ζ AND Ω_T

$$\zeta = \tan^{-1} \frac{f_1 - f_2 \cos(\gamma)}{f_2 \sin(\gamma)}$$

$$\Omega_T = \frac{\sqrt{f_1^2 + f_2^2 - 2 f_1 f_2 \cos(\gamma)}}{S \sin(\gamma)}$$

, f_1 and f_2 are the response of two RLG

γ is the angle between the two RL

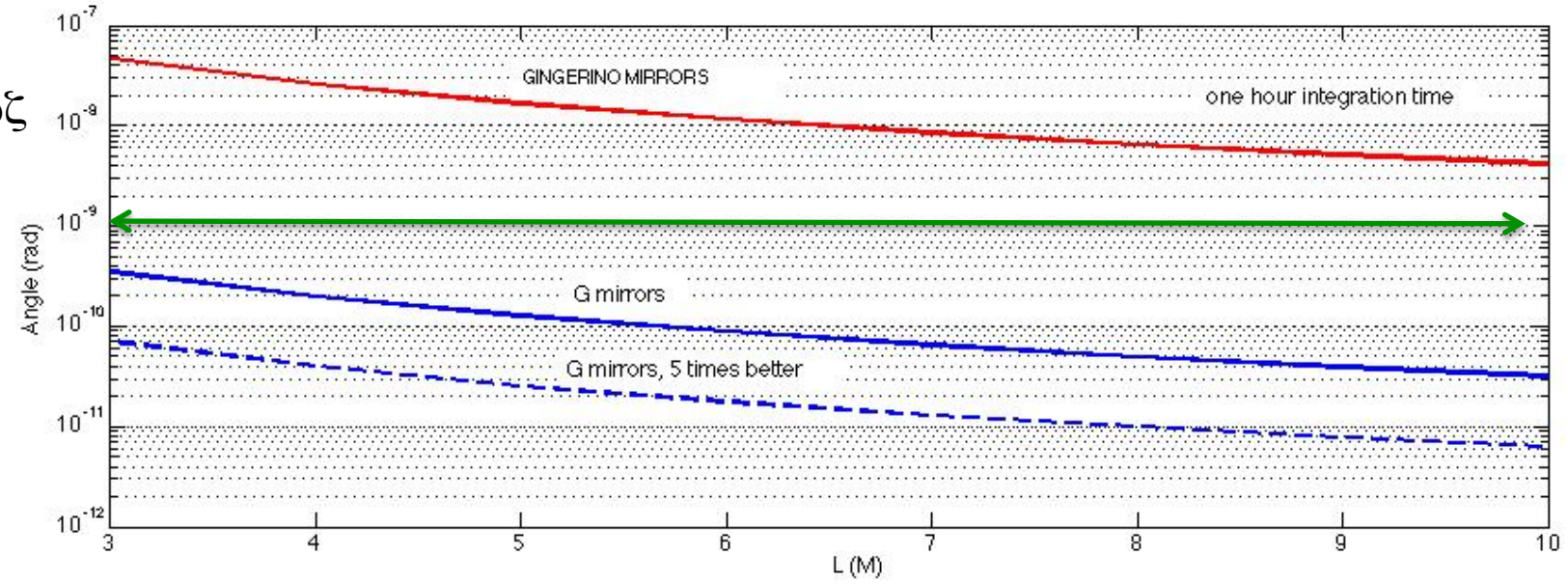
independent measurement of γ is mandatory (difficult task)

This can be avoided with ad-hoc orientation of the RLG

Di Virgilio, A.D.V., Belfi, J., Ni, WT. et al. Eur. Phys. J. Plus (2017) 132: 157.

Shot noise limit to the variation $\delta\zeta$, expressed in rad

$\delta\zeta$



CONCLUSIONS

- *Large frame ring lasers are based on a mature technique: 3 large installation operative in Germany and Italy providing data for rotational seismology (G of Wettzel for geodesy as well)*
- *GINGERINO is operative in a continuous basis, we will try to improve it installing better mirrors*
- *The response of the instrument is excellent in the frequency window above 0.1 Hz (~ 0.1 nrad/s in 1 second), and we are trying to improve the low frequency response, the present limit is about tens of prad/s.*
- *3D RLG array has been recently proposed, it would measure with un-precedent sensitivity the motion of the crust in an critical region as Gran Sasso*

Germany and Italy are leaders in this technique

sensitivity & stability
key points to access very low frequency signals
Underground←→Stability