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Gyroscopes in General Relativity
Istituto Nazionale di Fisica Nucleare
GINGER

GINGER ANALYSIS PIPELINE

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Data Analysis pipeline:

Data analysis based on Hilbert transform:
- power spectrum and filter around Sagnac frequency
- angular velocity: derivative of the Hilbert phase

ω_{s0} **: the 1st product of the analysis**
- provides correction for laser backscattering;
- it is calculated from raw data

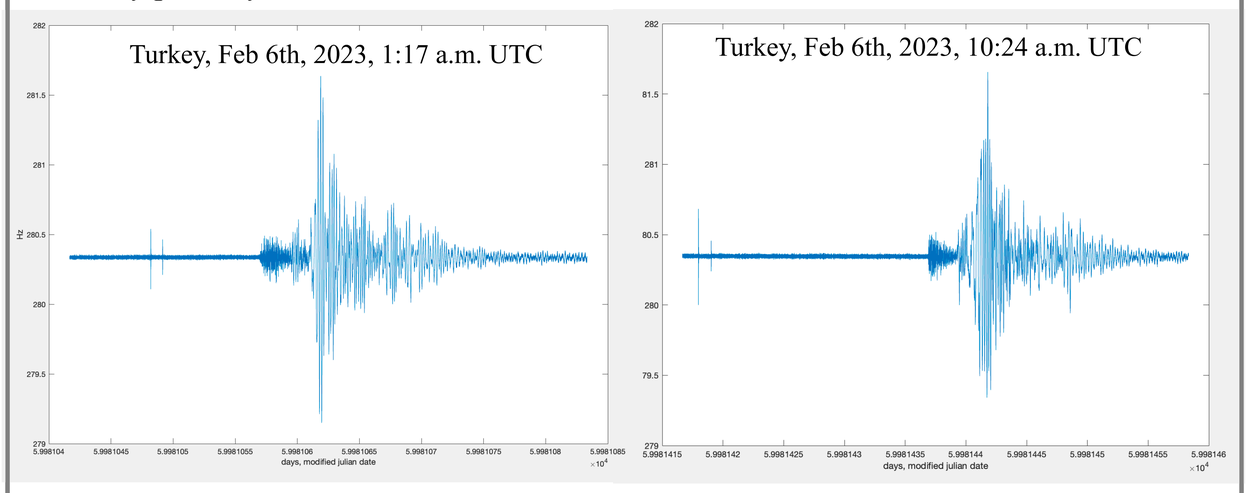
$$\omega_{s0} = \frac{1}{2}\sqrt{\frac{2I_{S1}I_{S2}\omega_m^2 cos(2\epsilon)}{PH_1PH_2} + \omega_m^2} + \frac{\omega_m}{2}$$

Where:
- $PH_{1,2}$ are the monobeam intensities
- ω_m is the measured Sagnac frequency
- $I_{S1,S2}$ monobeams modules, at the Sagnac frequency
- ϵ is the phase difference between the 2 monobeams

"complete":
- 12 Hz bandwidth, 10 Hz decimated data
- Double Sagnac signal processed, as difference between 2 Sagnac signals in phase opposition
- **First products:** ω_{s01}, ω_{s02} , ω_{s0D} (difference), ϵ_1 , fringe contrast (20 Hz) and other laser diagnostics
- Higher order terms of the Sagnac frequency are evaluated by using linear regression methods
- Suitable for very low frequency signals analysis, ~1mHz and lower
- DAQ: "PXI"

"light":
- single Sagnac signal processed
- 50 Hz bandwidth; 100 Hz decimated data
- products: ω_{s0} , contrast (100 Hz)
- for geophysics
- DAQ: "Centaurus"
- Delay possibly as short as 1s

Gingerino currently detects the rotational component of earthquakes, data are sent to INGV researchers.

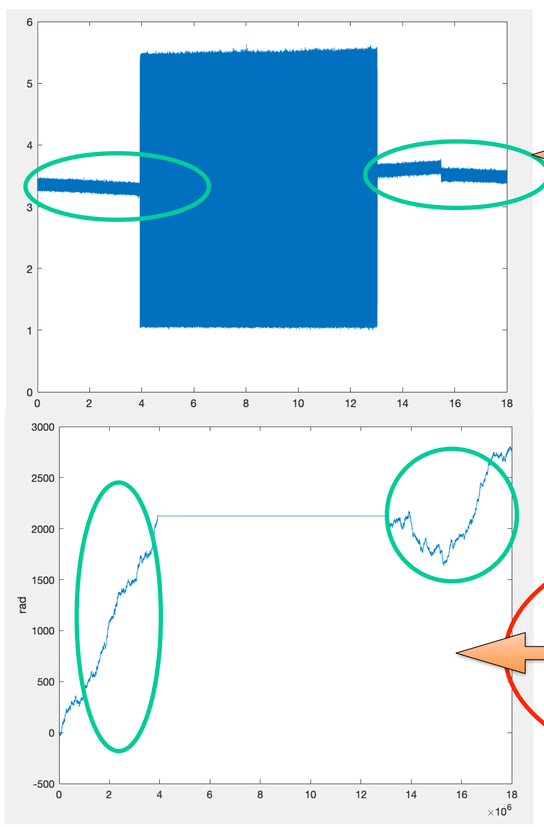


*Earthquakes images are obtained with 12 Hz bandpass filtered data

Diagnostics: fringe contrast

$$\text{Contrast} = \frac{max(Sagn) - min(Sagn)}{max(Sagn)}$$

where "Sagn" is the Sagnac beat note. It indicates the quality of the Sagnac signal. Data are considered good if contrast > 0.5.
Alarms are implemented to report a possible "split mode" (fig.below) if contrast < 0.5 for more than 3 seconds.



Laser split-modes: fringe contrast goes to values much smaller than 0.5 (consider a good contrast around 0.85, for comparison in the figure)

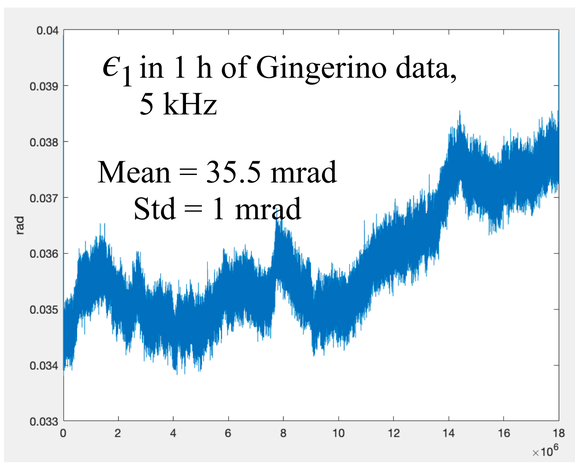
Diagnostics: ϵ_1

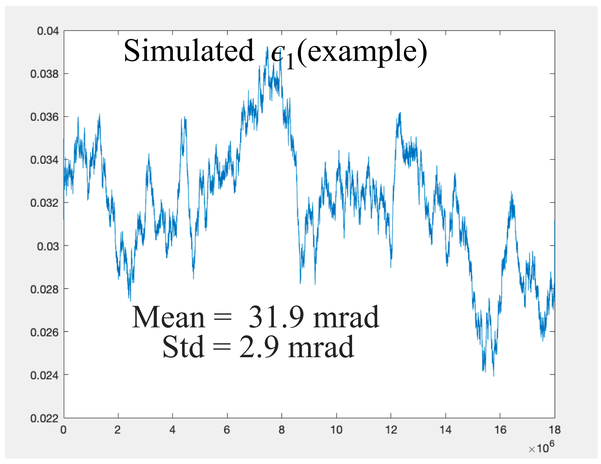
In case of "split-mode," such parameter undergoes huge variations, if compared to its usual behavior

The phase shift ϵ_1 is also a parameter for data quality monitoring.
- It should not exceed a few 10 mrad, maximum ~100 mrad.
- Alarms to be implemented

"ϵ_1**, phase shift** between the 2 Sagnac signals":
- 2 Sagnac signals are not perfectly in phase opposition
- A "shift" has been measured, of the order of a few ~10 mrad, both in GP2 and Gingerino

The phase shift ϵ_1 can be seen as a disturbance between the 2 Sagnac signals:
- Such disturbance was simulated and its effect evaluated in terms of ϵ_1.





- NOTE: The difference signal "S1-S2" is the best choice for data analysis, it increases the signal-to-noise ratio of $\sqrt{2}$, and it eliminates common-mode noise. The effect of the common mode part of such disturbance is meant to be canceled in ω_{s0D} .

ϵ_1

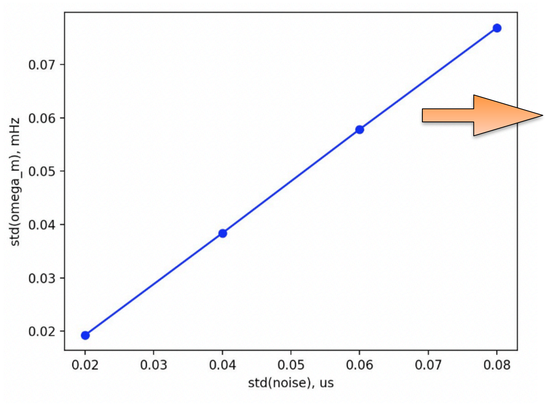
Non-reciprocal laser effects.. Faraday effect?
* Preliminary upper limits

Mechanical, electrical disturbance?

Actions & Further investigations..
- **Installation of a geophone, for mechanical noise**
- **Evaluation of Faraday effect, upper limits**
- **Study of cavity non-planarity, affecting beam Polarization**

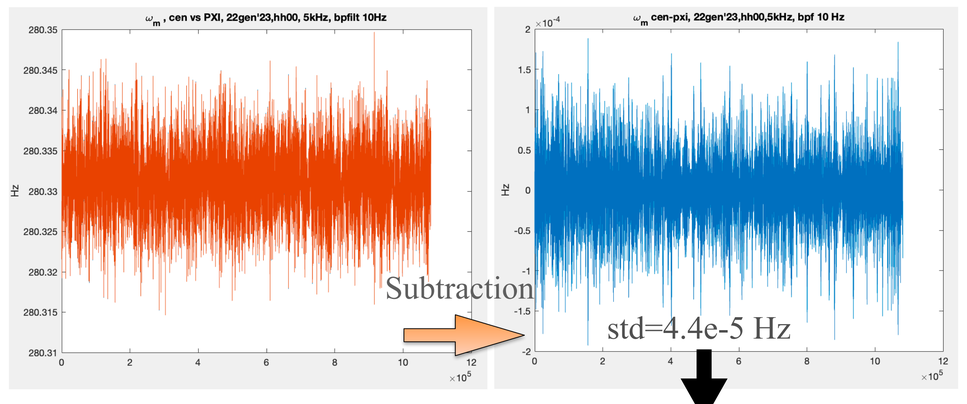
Diagnostics: time jitter upper limits

Setting an upper limit to time jitter:
- subtraction of same ω_m signal from PXI and Centaurus
- Interpretation of the residual as due to time jitter, and evaluation
- data from PXI and Centaurus are synchronized with cross-correlation



A few simulations provide a relationship between an induced time jitter (over time steps of 200 us), and the fluctuations on ω_m (Bp filter 280±10 Hz, no decimation)

Such result stays unchanged if evaluated using the double Sagnac signal



Upper limit on time jitter noise: 0.046 μs/200 μs

Conclusions:

- **Based on the Gingerino experience, the GINGER data analysis pipelines are being implemented.**
- **The "light" pipeline is currently working, ω_{s0} product will soon be on EIDA platform in place of ω_m, the measured beat note.**
- **The evaluated error on seismic signals is ~10 times lower if considering ω_{s0} instead of ω_m , a few nrad/s.**
- **The "complete" pipeline automatization is in progress.**