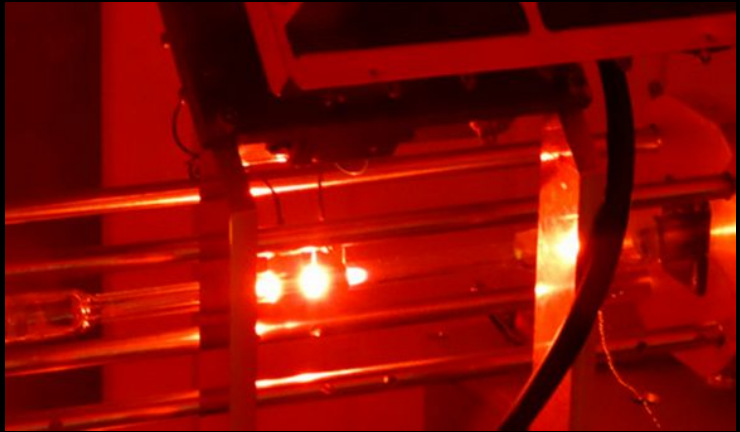
GINGER

(Gyroscopes IN GEneral Relativity)



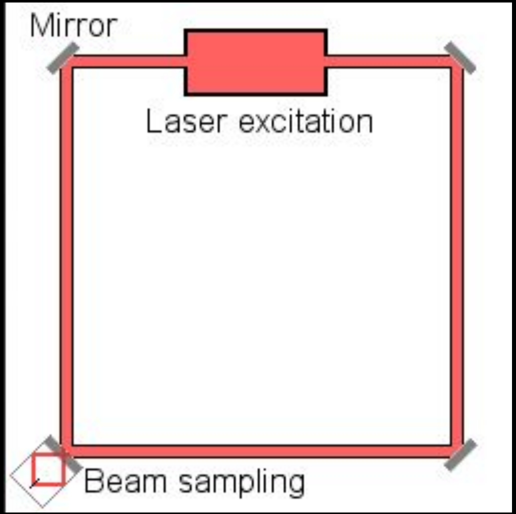
Riya, Sophie Loipolder | Gran Sasso Hands-On 2023 PhD Autumn School | 06.10.2023

Gyroscopes

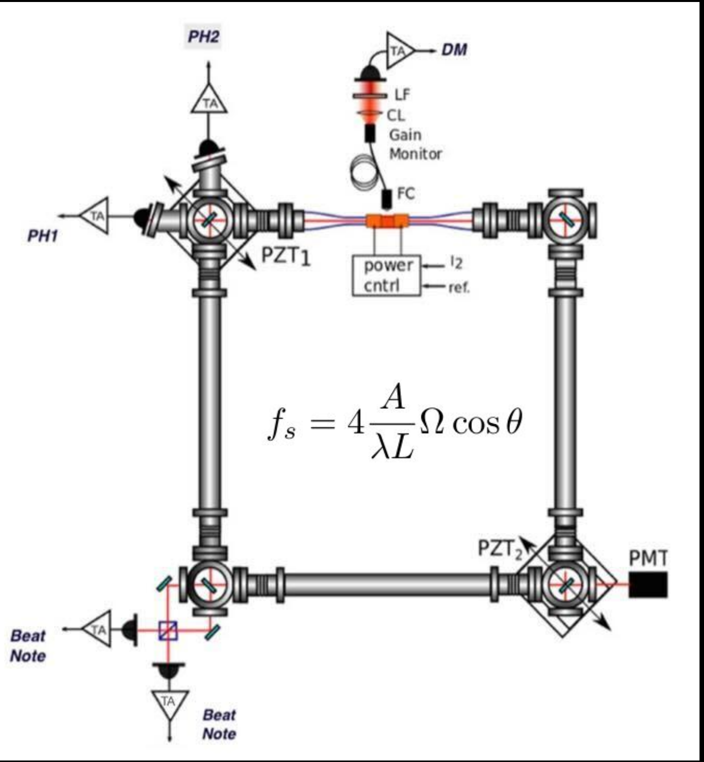
→ measure the orientation or angular velocity of objects

<u>*Sagnac effect:*</u>

In a rotating ring, the path length for two light beams going in opposite directions is different and their frequencies are shifted after the recombination.

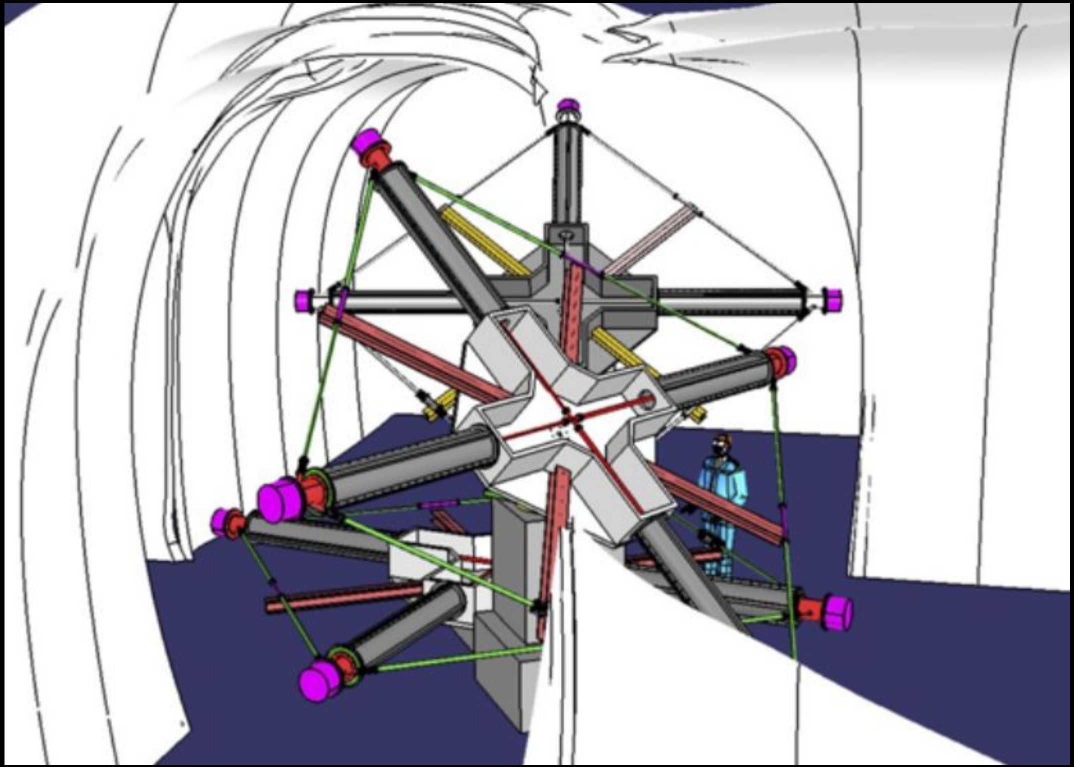


GINGERino



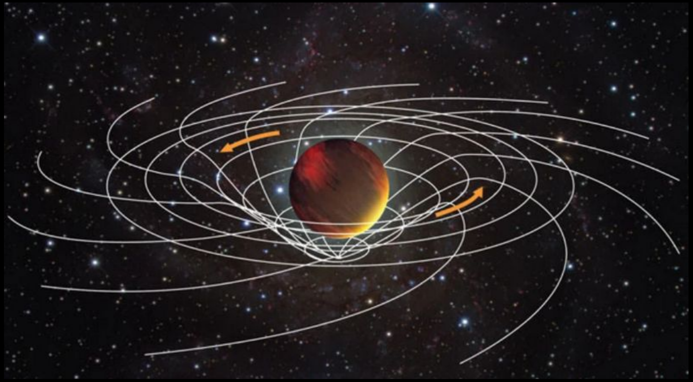
$$f_s = 4\frac{A}{\lambda L}\Omega\cos\theta$$

GINGER



GINGER – Scientific Goals

- measure the Earth's absolute rotation rate (sensitivity higher than prad/s)
- Seismology (earthquakes, prediction in volcanic areas, effects on Earth's rotation axis)
- Geodesy
- Geophysics
- GR effects (Lense-Thirring effect)



Analysis principle - We wrote a python code independently

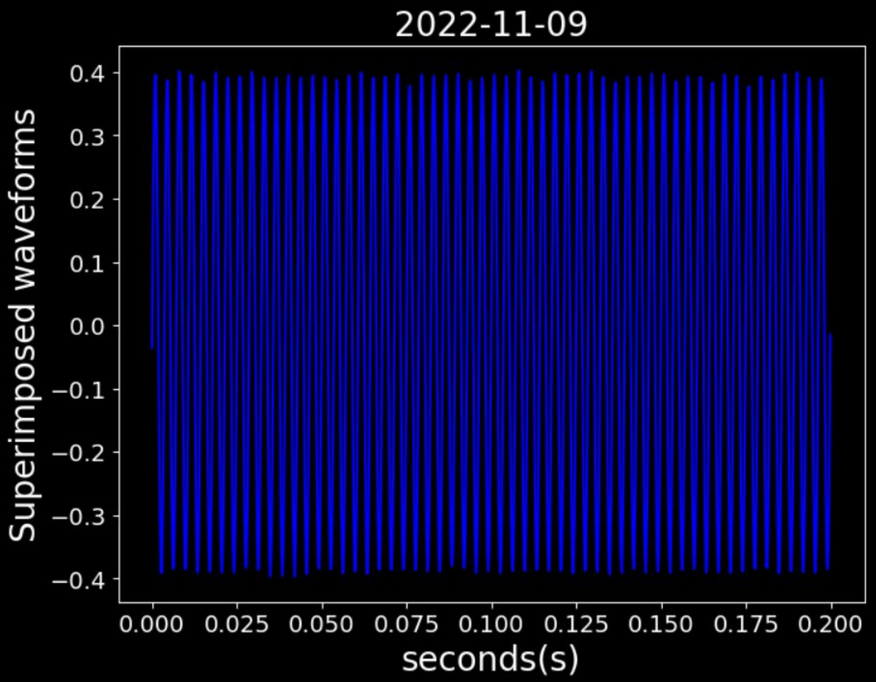
1. Filter Superimposed waveforms
2. Hilbert transformation

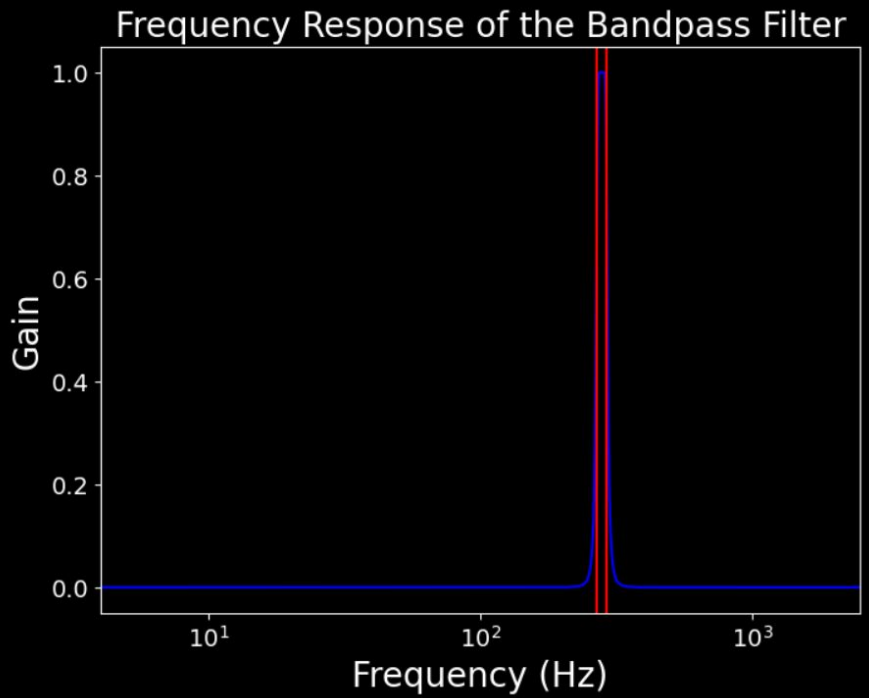
   => phase ($\varphi = \omega t + \phi$)

3. Beat note (ω_m) = $\Delta\varphi / \Delta t$
4. Backscattering corrections => ω_{S0}
5. Corrections due to optical cavity losses

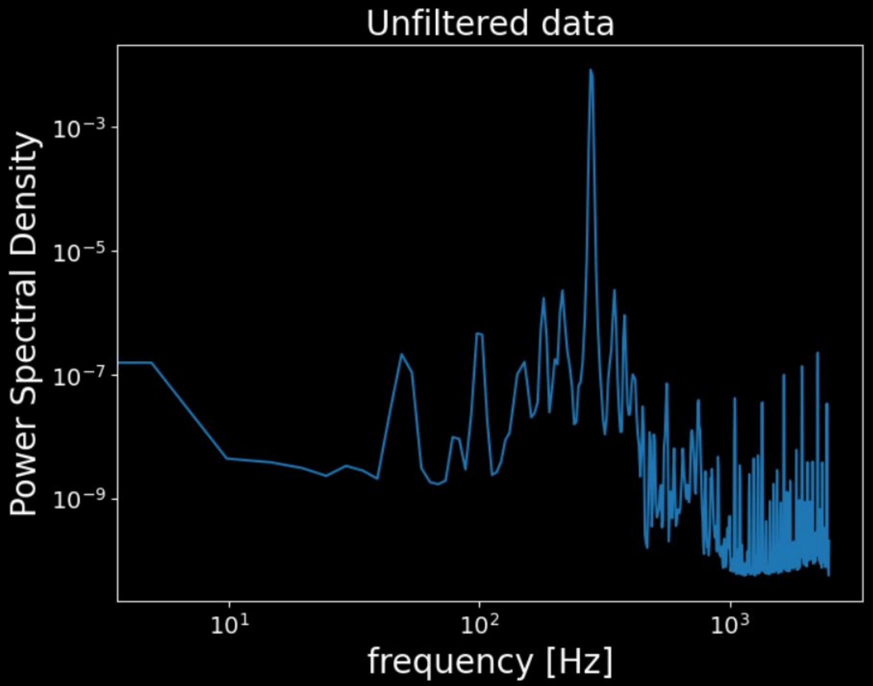
   => f_S

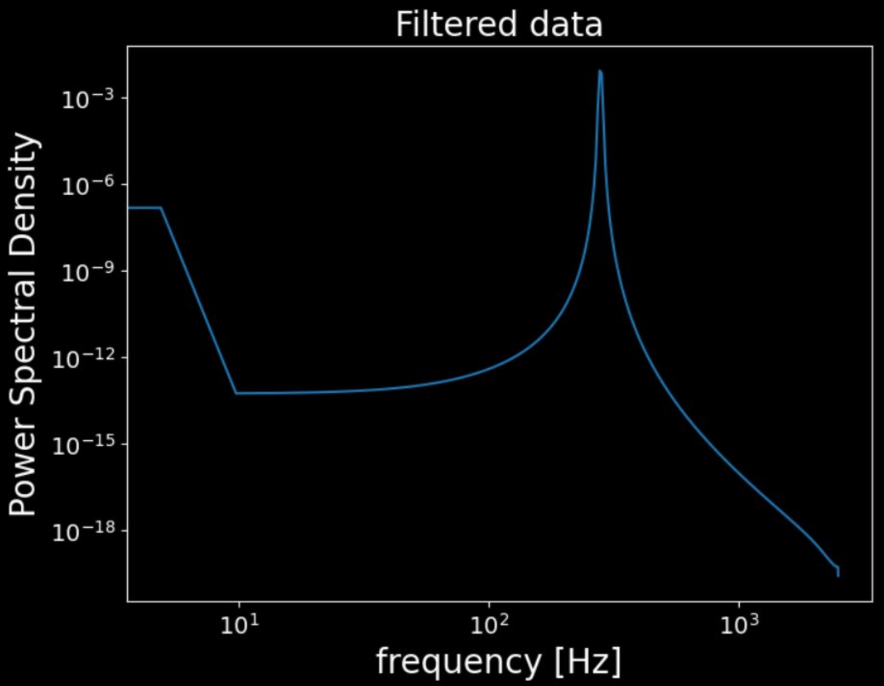
Filter Superimposed waveforms - Butterworth filter



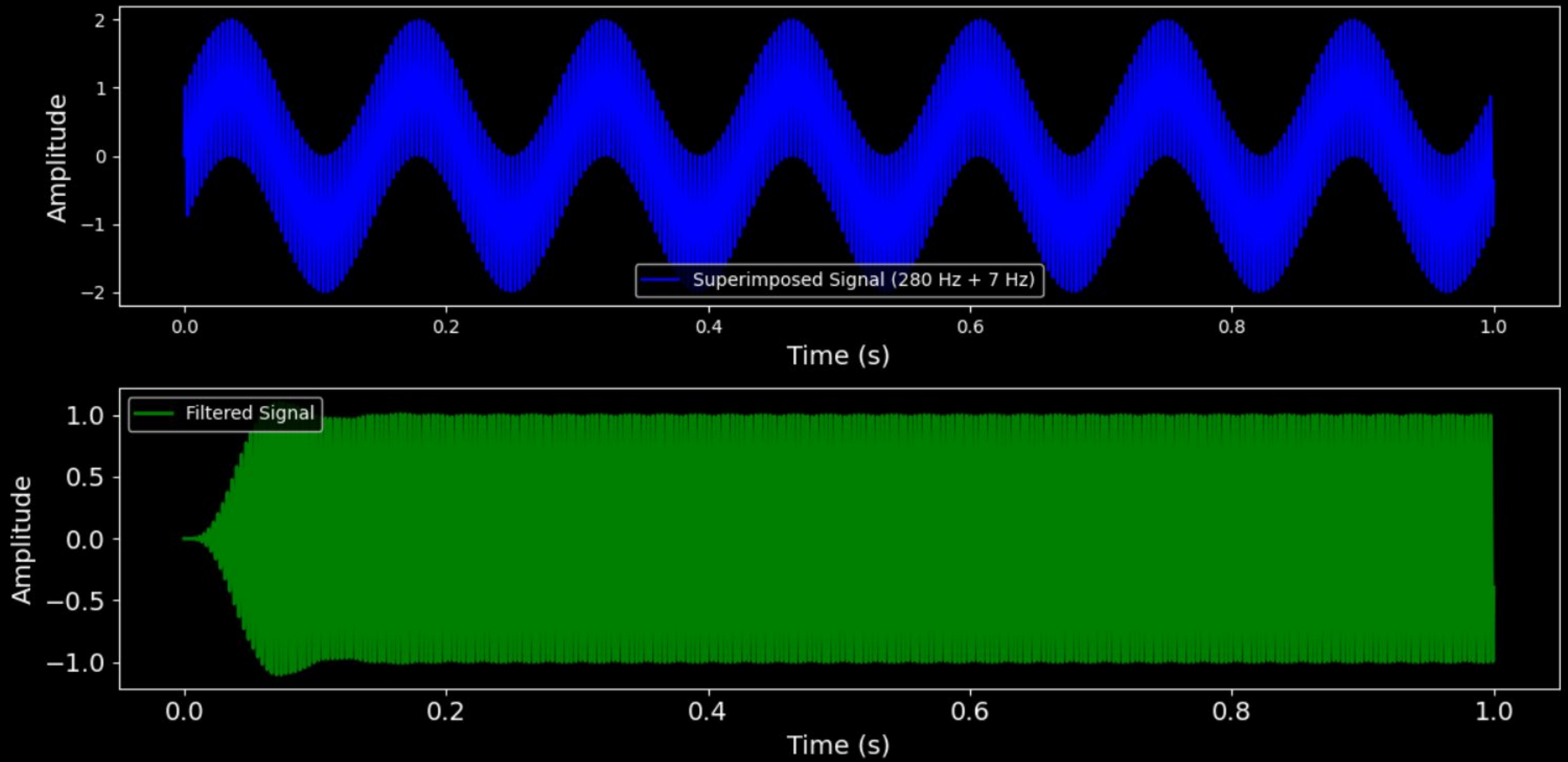


Checking the filter operation

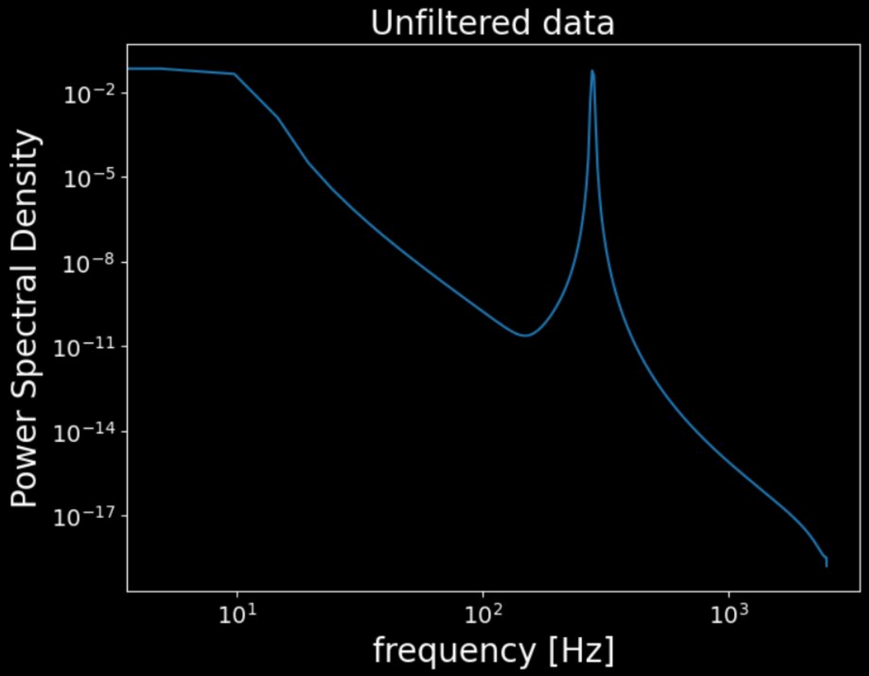


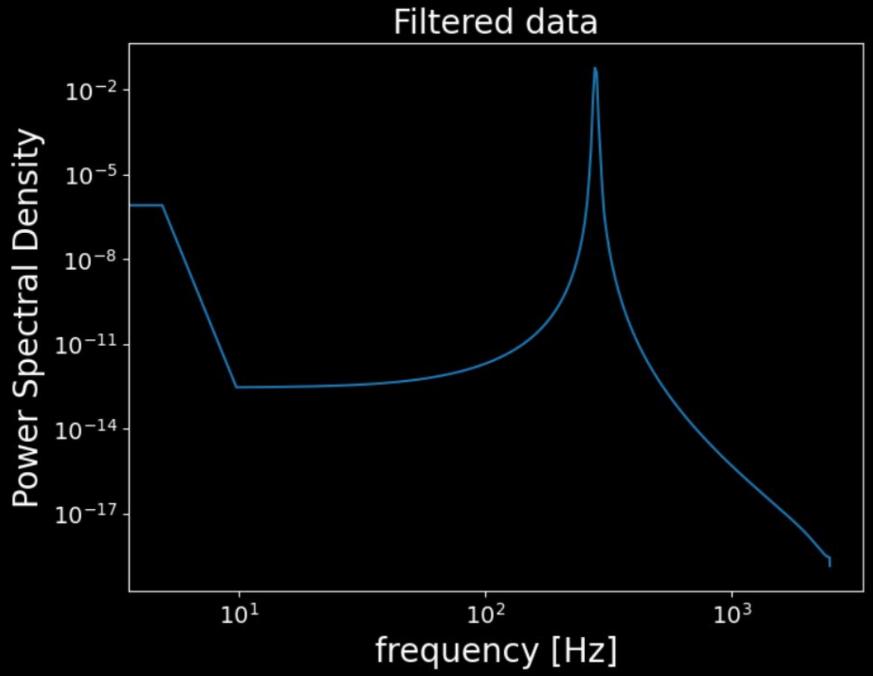


Checking the filter operation



Issue with Power Spectral Density calculation?

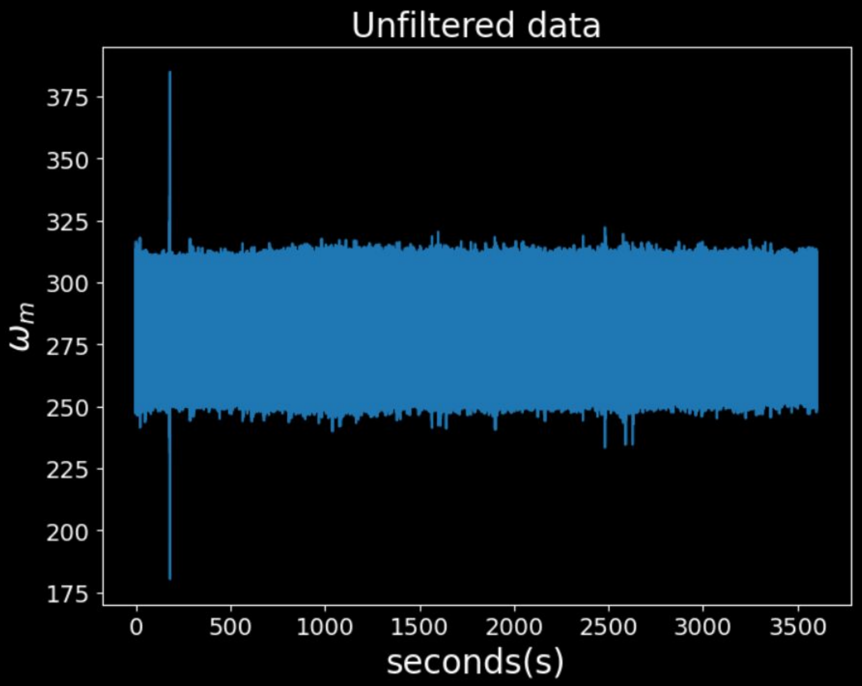


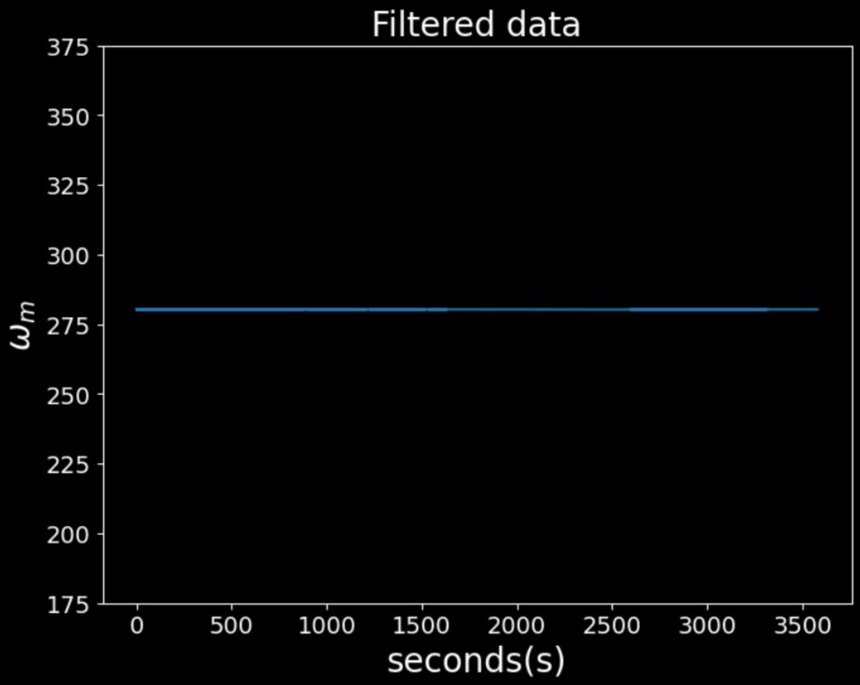


Analysis principle

1. Filter Superimposed waveforms
2. Hilbert transformation => phase ($\varphi = \omega t + \phi$)
3. Beat note (ω_m) = $\Delta\varphi / \Delta t$
4. Backscattering corrections => ω_{S0}
5. Corrections due to optical frequency = f_S

Beat note


Unfiltered data
375
350
325
300
275
250
225
200
175
ω_m
0
500
1000
1500
2000
2500
3000
3500
seconds(s)


Filtered data
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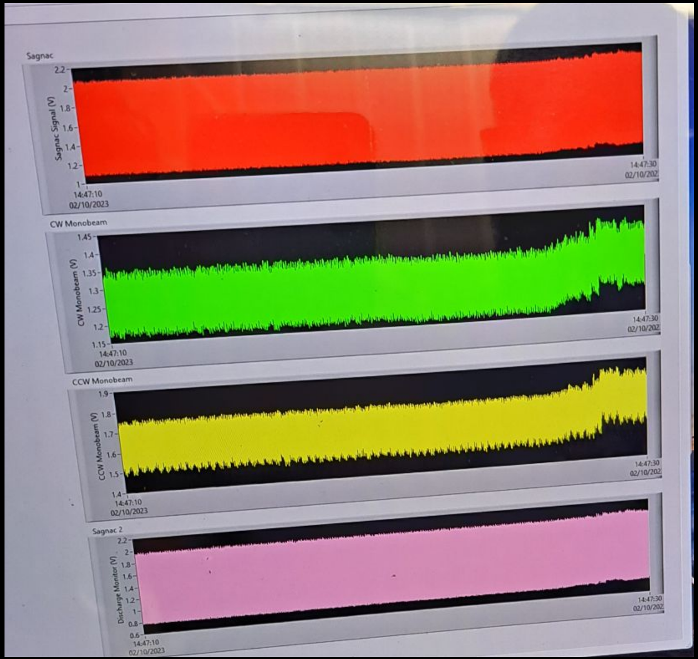
Analysis principle

1. Filter Superimposed waveforms
2. Hilbert transformation => phase ($\varphi = \omega t + \phi$)
3. Beat note (ω_m) = $\Delta\varphi$ / Δt
4. Backscattering corrections => ω_{S0}
5. Corrections due to optical frequency = f_S

$$\omega_{s0} = \frac{1}{2}\sqrt{\frac{2\omega_m^2 I_{S1} I_{S2} \cos(2\epsilon)}{I_1 I_2} + \omega_m^2} + \frac{\omega_m}{2}$$

Online calculation of ω_{S0}



Analysis principle

1. Filter Superimposed waveforms
2. Hilbert transformation => phase ($\varphi = \omega t + \phi$)
3. Beat note (ω_m) = $\Delta\varphi$ / Δt
4. Backscattering corrections => ω_{S0}
5. Corrections due to losses in optical cavity = f_S

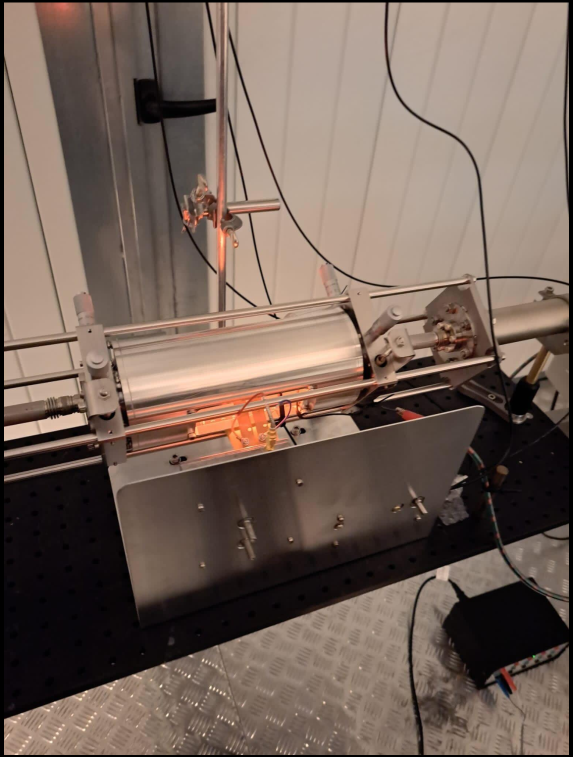
Ring-Down Measurement

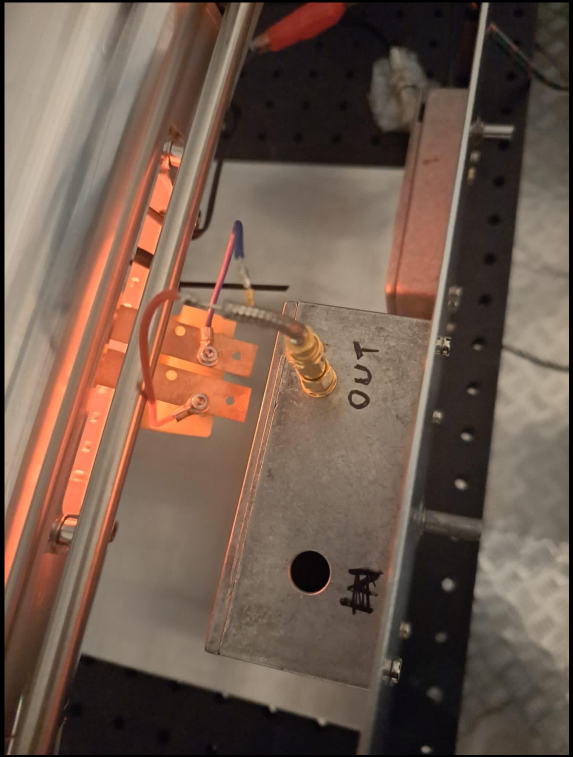
→ know the cavity losses (scattering, absorption)

Approach:

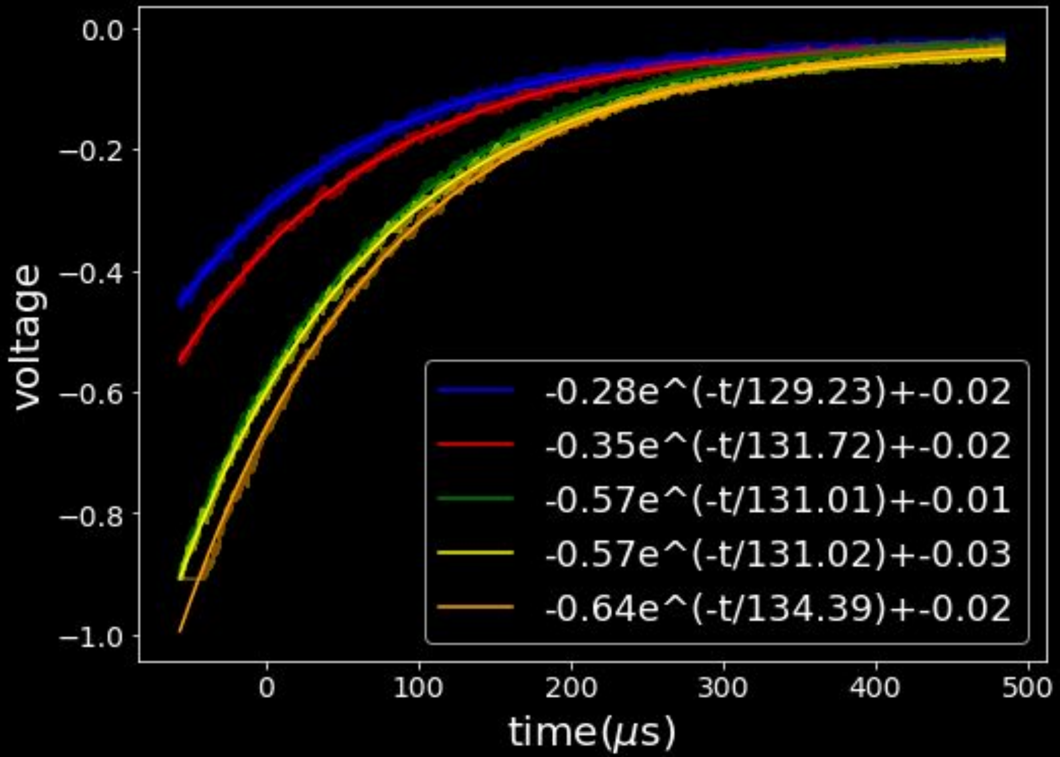
1. Laser in resonance with cavity mode - build up intensity
2. Short-circuit the power supply of the laser
3. Get the ring-down time from the fit of the exponential decrease of intensity: $I(t) = I_0 \exp(-t/\tau)$

Ring-Down Measurement





Ring-Down Measurement



Ring-Down Measurement

<u>Results:</u>

- τ_{avg} = 131.5 μs
- Q-Factor = $2\pi\tau_{avg}\nu_{laser}$ = $2\pi\tau_{avg}$c/(633 nm) ~ 4 x 10^{11}
- Loss of optical cavity = $L_{laser}/(c*\tau_{avg})$ = 365 ppm

Outlook

- Start building GINGER next year
- Improve time precision in DAQ system
- Temperature controlling system

Thank you for the interesting and fun experience and great support to Angela Di Virgilio, Giuseppe Di Somma, Giorgio Carelli, Paolo Marsili, Simone Castellano, Alberto Porzio and Gaetano De Luca!

Sources

Images:

- https://en.wikipedia.org/wiki/Gyroscope#/media/File:3D_Gyroscope.png
- https://upload.wikimedia.org/wikipedia/commons/c/c8/Ring_laser_interferometer.png
- https://thetyee.ca/Culture/2021/07/29/When-Big-Quake-Comes-Coast/
- https://www.vice.com/en/article/8gmy4a/the-learning-corner-805-v18n5
- https://doi.org/10.48550/arXiv.2308.01277
- https://doi.org/10.48550/arXiv.1906.11338
- https://doi.org/10.48550/arXiv.2209.09328

Analysis principle

1. Superimposed waveforms
2. Hilbert transformation => phase (φ = ωt+ϕ)

$$\cos(2\pi f_1 t) + \cos(2\pi f_2 t) = 2\cos\left(2\pi \frac{f_1 - f_2}{2} t\right) \cos\left(2\pi \frac{f_1 + f_2}{2} t\right)$$

$$u(t) = u_m(t) \cdot \cos(\omega t + \phi)$$

Bedrosian's theorem

$$\mathrm{H}(u)(t) = u_m(t) \cdot \sin(\omega t + \phi)$$

$$u_a(t) \triangleq u(t) + i \cdot H(u)(t)$$

3. Beat note (ω_m) = Δφ / Δt