22-02-2016

" The two INFN Ring Lasers: GP2 and GINGERino"

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for the GINGER collaboration

GINGER meeting, Pisa 22 Febbbraio 2016

Outline

Intro

- Sagnac interferometry
- Fundamental limits

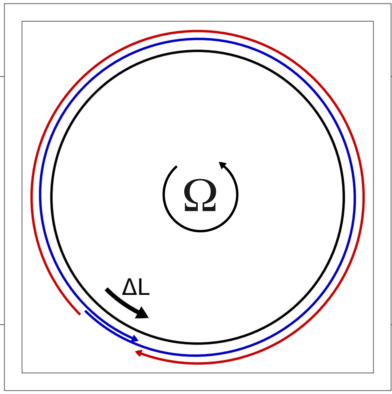
Past activity at INFN: G-Pisa

- Ground tilt measurements at Virgo
- Investigation of ring laser dynamics (S. Piero a Grado)

Today's prototypes

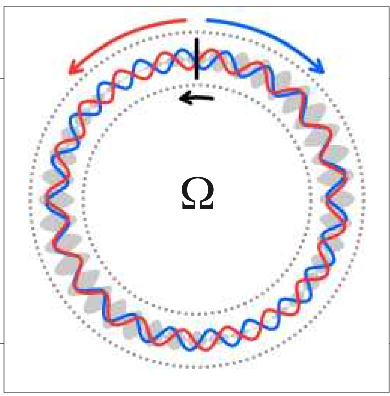
- Advanced control of the cavity geometry: GP2
- Deep underground prototype: GINGERino

Sagnac Interferometers



Sagnac effect

$$\Delta t_{Sagnac} = \frac{4A}{c^2}\vec{\Omega}\cdot\vec{n}$$



Resonant cavity

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

$$= K_s|\vec{\Omega}|$$

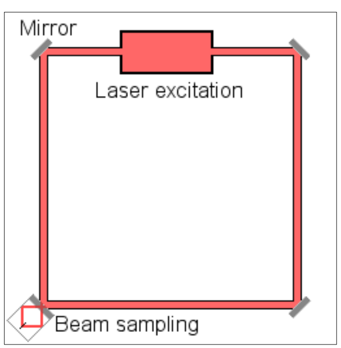
Advantages

- No moving masses
- No signal for a linearly accelerating reference-frame
- L > 1 m → Earth rotation is the bias

Quantum resolution limit

$$\delta\Omega_{shot} = \frac{cP}{8\pi\nu\tau}\left(\frac{h\nu}{2P_{out}t}\right)^{1/2}$$

…an "extremely good" He-Ne ring laser:



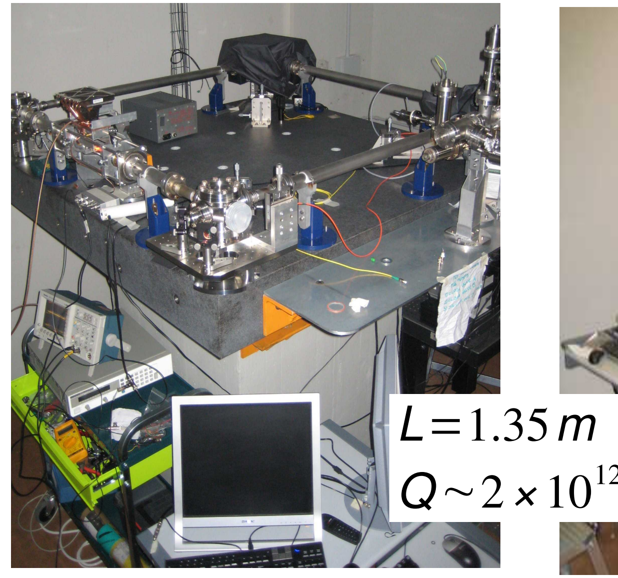
$$\nu = 474\,THz,\ P = 32\,m$$

$$P_{out} = 100\,nW,\ \tau = 2\,ms$$

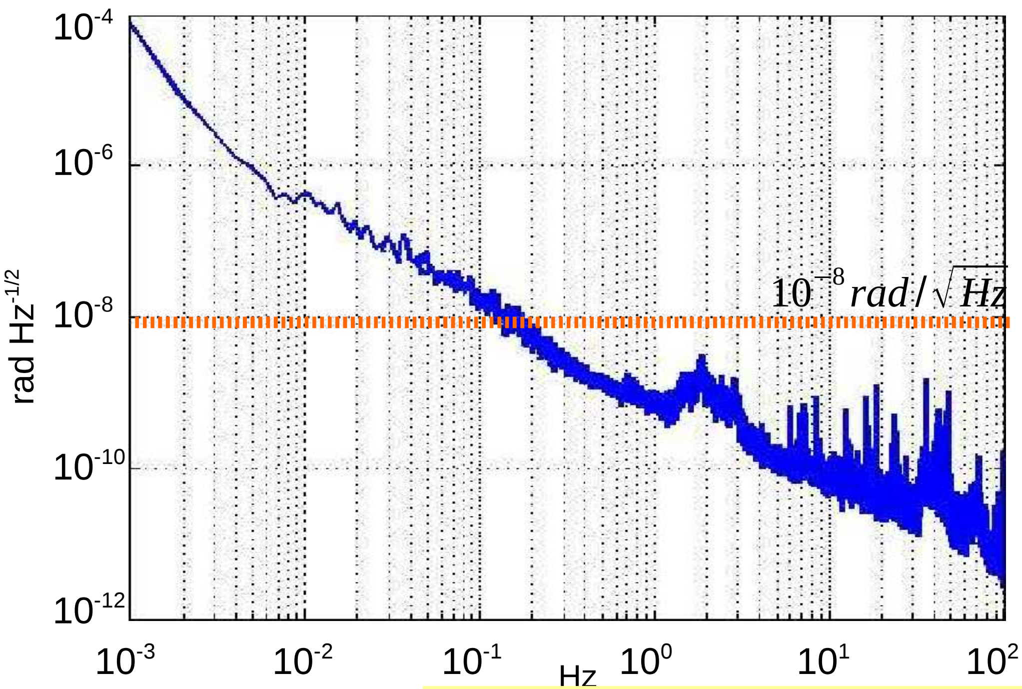
$$t = 3\,hours$$

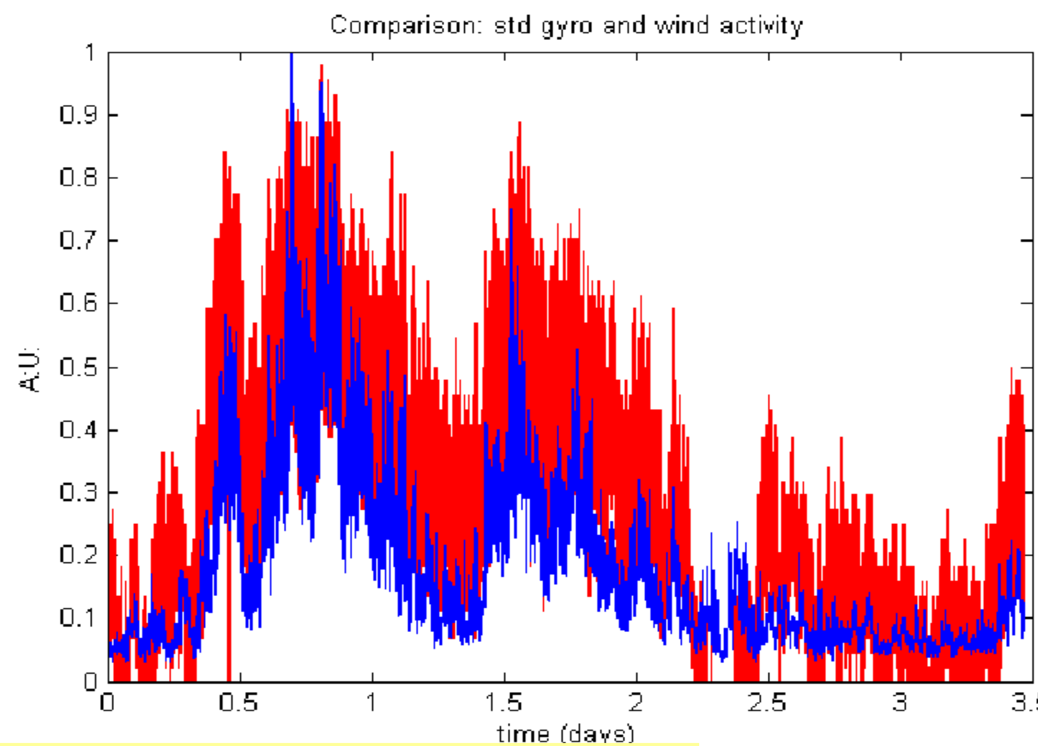
$$\delta\Omega_{shot} = 5\cdot 10^{-15}\,rad/s$$

G-Pisa @ Virgo



Angular sensitivity (Tilt)

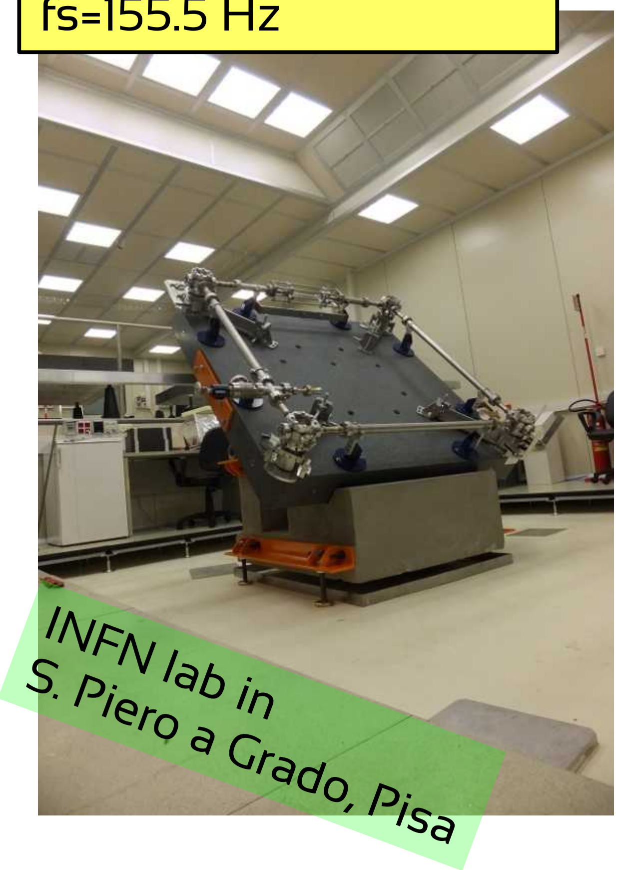


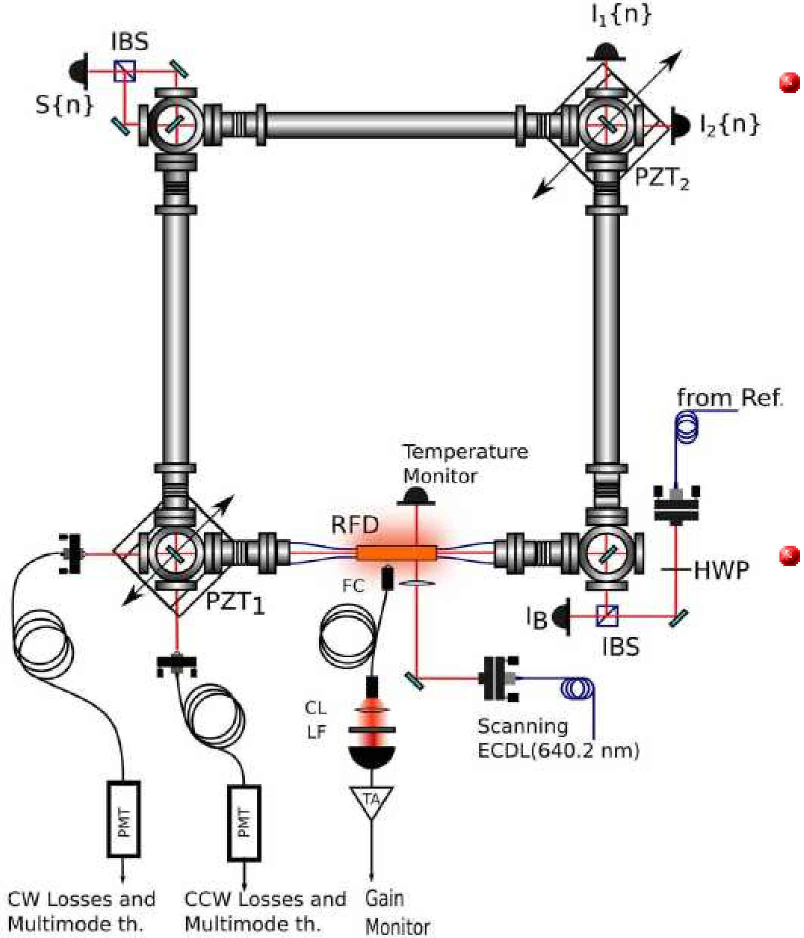


A 1.82 m^2 ring laser gyroscope for nano-rotational motion sensing, *Applied Physics B: Lasers And Optics*, vol. 106, p. 271, 2012

G-Pisa @ S. Piero a Grado: Study of systematics

Max signal orientation:
fs=155.5 Hz





- Observables

$$S(t)=\left|a_1 E_1(t)+a_2 E_2(t)\right|^2$$
$$V_1(t)=\left|b_1 E_1(t)+c_{21} E_2(t)\right|^2$$
$$V_2(t)=\left|b_2 E_2(t)+c_{12} E_1(t)\right|^2$$

- Calibration parameters

$\xi_{1,2}$: *Optical detunings*
p : *Gas pressure*
T_{Ne} : *Atomic temperature*
$k_{20,22}$: *Isotopic ratio*
$\mu_{1,2}$: *cavity total losses*
G : *single pass gain*

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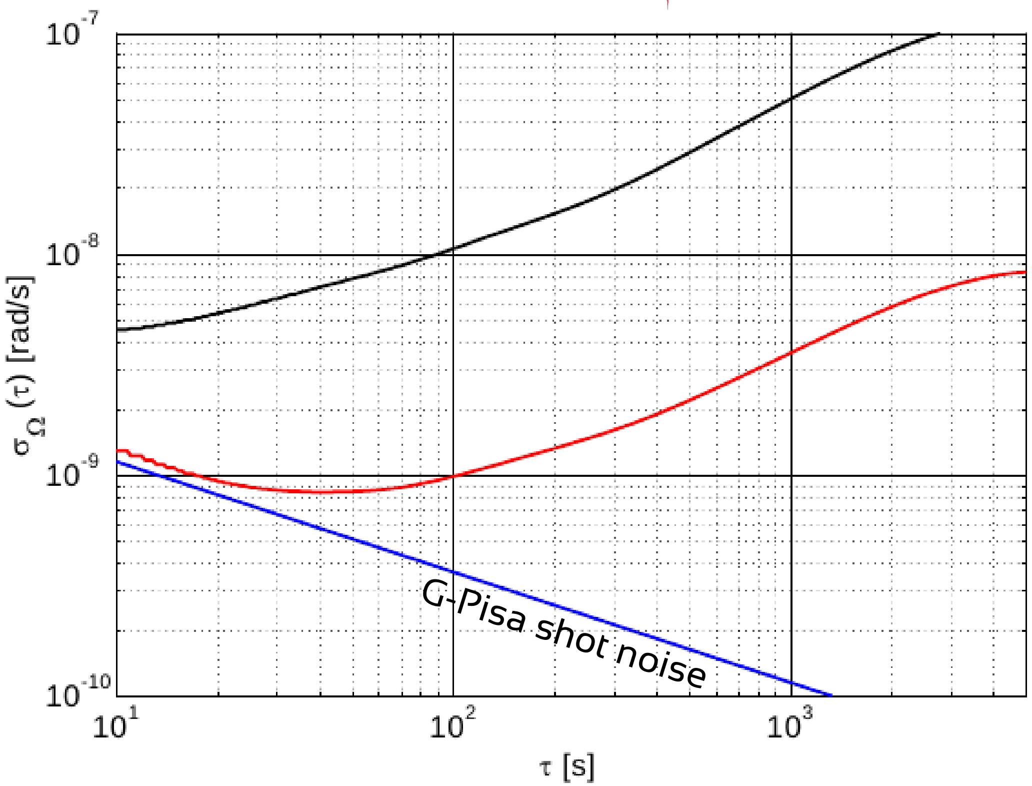
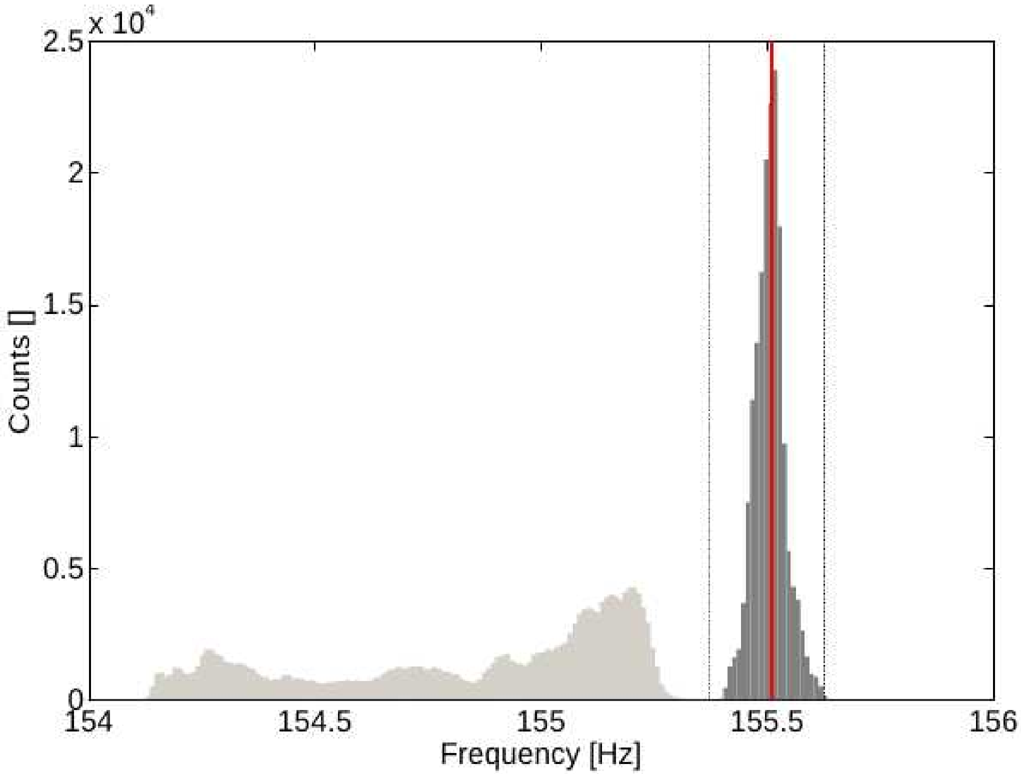
Kalman filter on real data



Allan DEV of AR2 (upper curve) and EKF (lower curve) rotational frequency estimates. The straight line represents the shot noise level of G-PISA



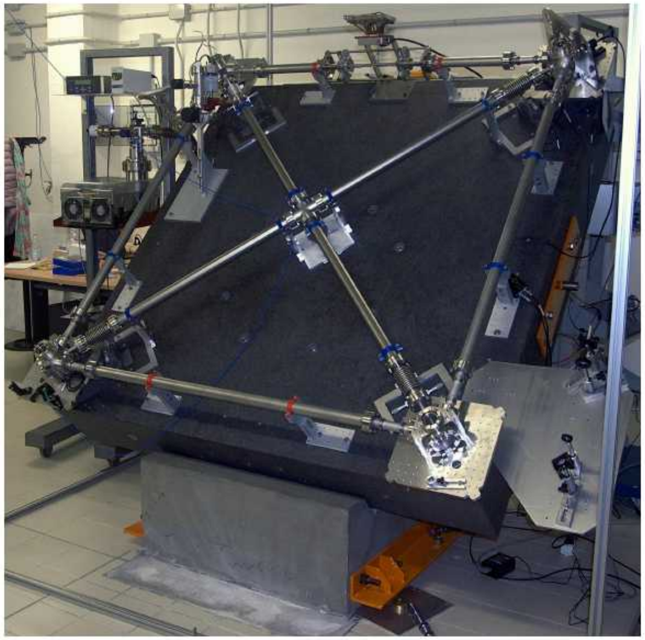
Histograms of the estimates of AR2 (pale gray) and EKF (dark gray) during 2 days of G-PISA data.
Red line: is the expected Sagnac frequency due to Earth rotation,
Dotted lines represent its residual uncertainty bounds due to geometric and orientation tolerances.

Compensation of the laser parameters fluctuations in large ring laser gyros: Kalman filter approach,
Applied Optics 51, 31 (2012),

Controlling the nonlinear intra-cavity dynamics of large He-Ne laser gyroscopes,
Metrologia 51 97 (2014).

TODAY: 2 prototypes for 2 objectives

GP2 (side length 1.60 m)



What?: Test-prototype ring laser equipped with a number of interferometric diagnostics

Where?: INFN-Pisa

Why?: Implement a fully **active stabilization** of the **ring cavity shape**.

GINGERino (side length 3.60 m)

What?: High sensitivity ring laser for high resolution of earth rotation measurement;

Where?: INFN-LNGS

Why?: Evaluate **rotational noise** of a deep underground laboratory. Validate the site for GINGER (f<1 mHz)

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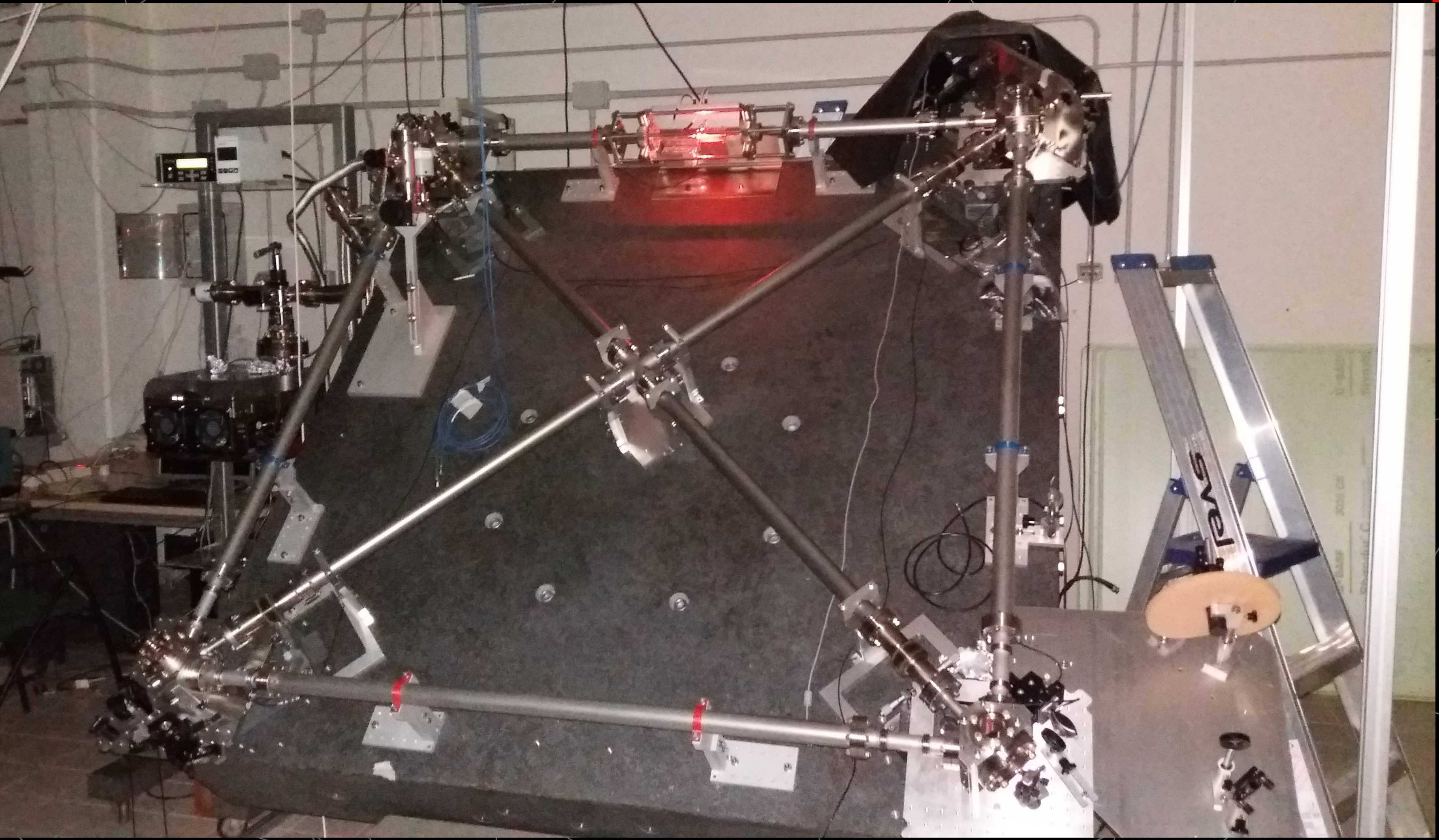


GP2

INFN-Pisa

GP2: Geometry control via interferometry

Problem

The magnitude of the *relativistic frame dragging* term is of 1 part in 10^9 of the Earth rotation

⇨ scale factor k_S stabilization better than 10^{-10}

- accuracy on mirror position better than 1 nm

Approach used in the past

Observable: RL optical frequency (cavity perimeter control)

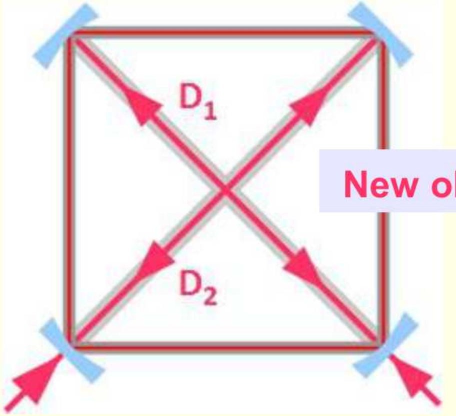
Stabilization methods: comparison with reference laser; by tuning the environmental pressure; by locking to a frequency comb

Limitation: variations of mirror inter-distances remain uncontrolled

Our original approach

Observables: distance between opposite mirrors (& perimeter)

Stabilization methods: lock of diagonal cavities respect to a frequency standard



New observables

Interferometric length metrology for the dimensional control of ultra-stable ring laser gyroscopes, Class. Quantum Grav. 31 (22), 225003, (2014)

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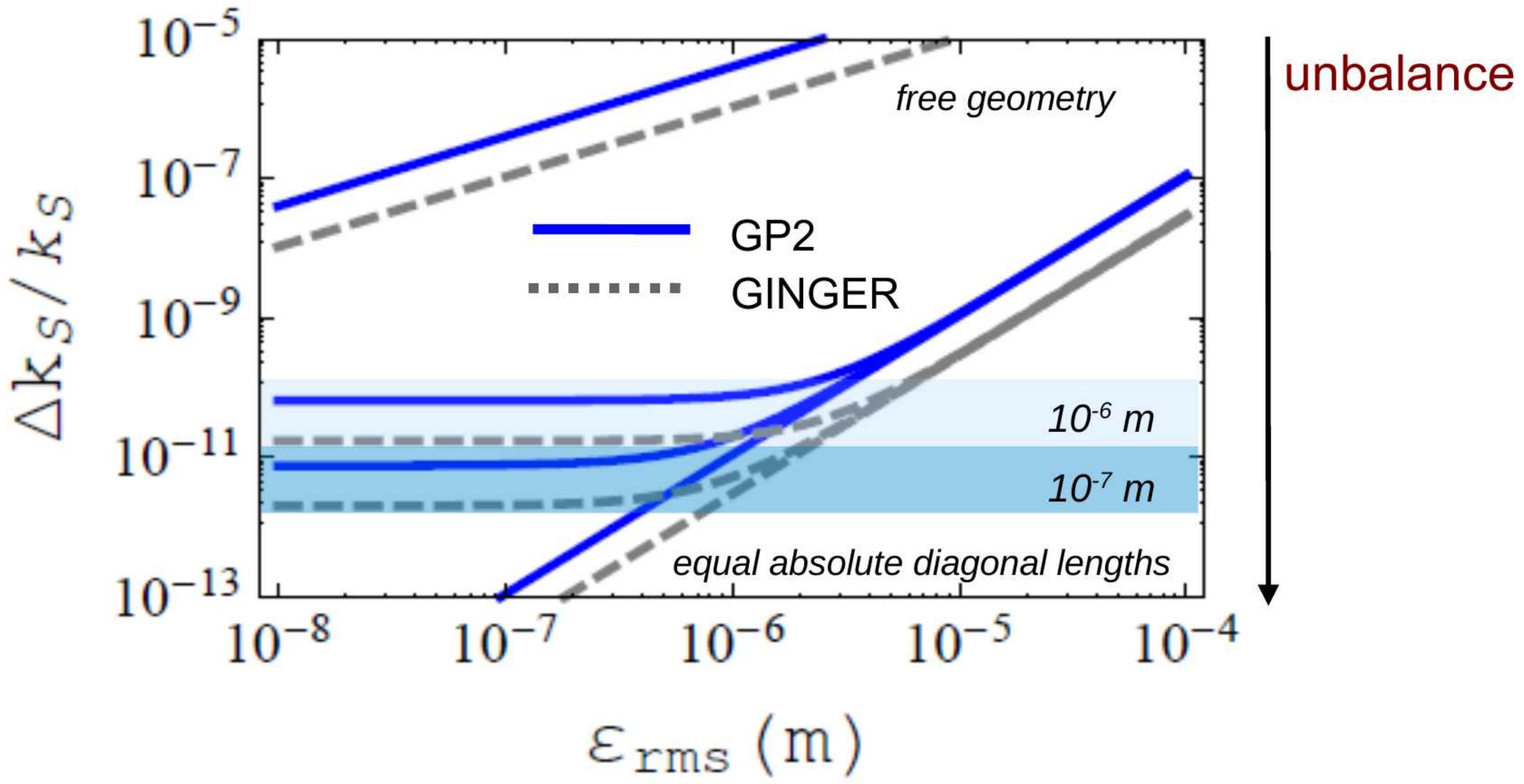
GP2: scale factor stability

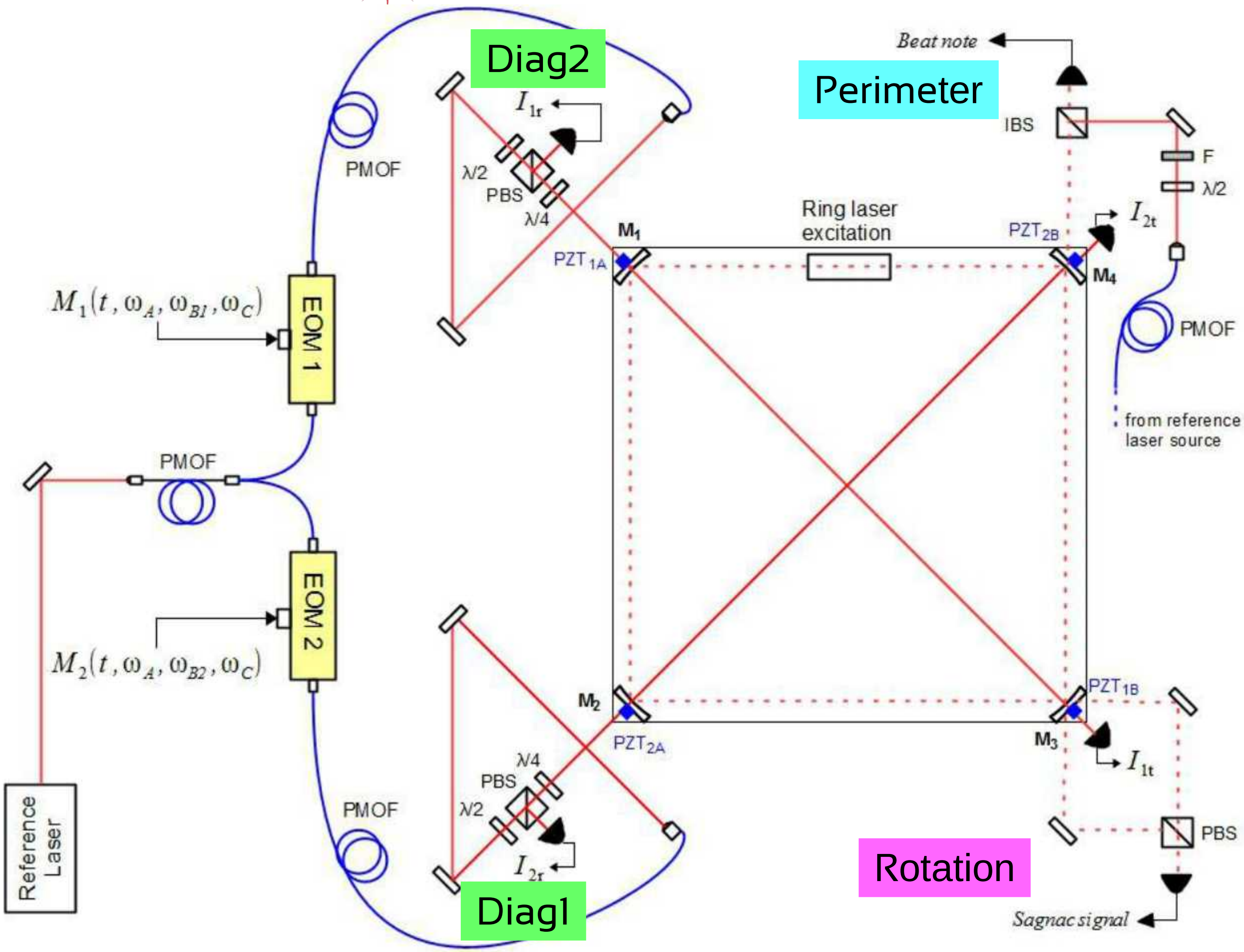


Diagonals lengths stabilization implications:

- the perturbations to the mirror positions affect only quadratically the scale factor
- the mirror fluctuations are reduced at a level of 1 part in 10^{10}, even if the stabilized lengths differ at a micrometric scale

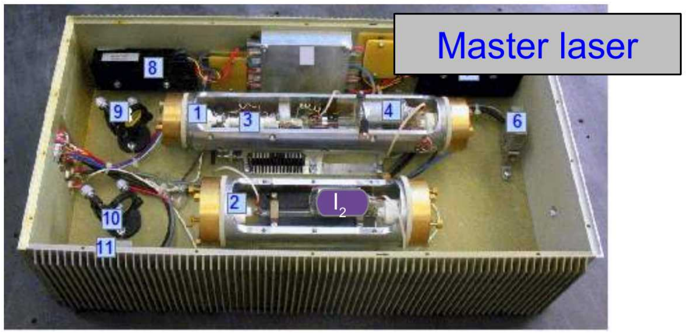
the regular square geometry corresponds to a *saddle-point* of the perimeter

GP2: Optical setup



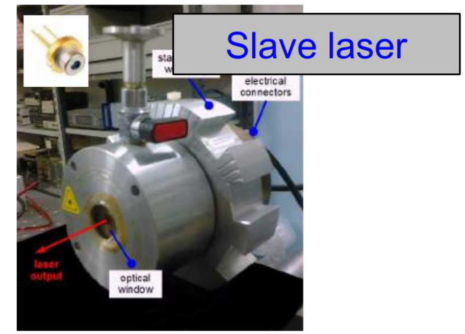
External laser probe

He-Ne/I_2 laser
primary frequency standard



iodine spectral purity

μ-lens coupled cw diode laser
probe laser



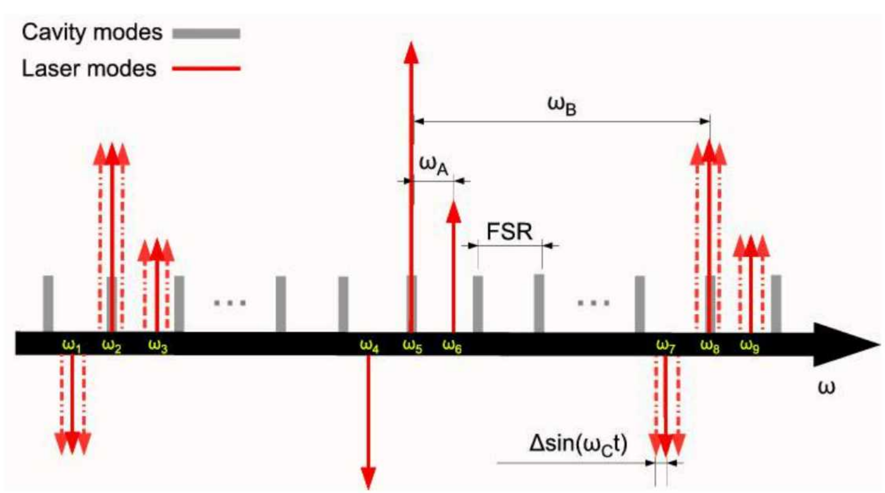
$$E_{in}(t) = E_0 \exp\{i[\omega_0 t + \alpha \sin(\omega_A t) + \beta \sin[(\omega_B + \Delta \sin(\omega_C t))t]]\}$$

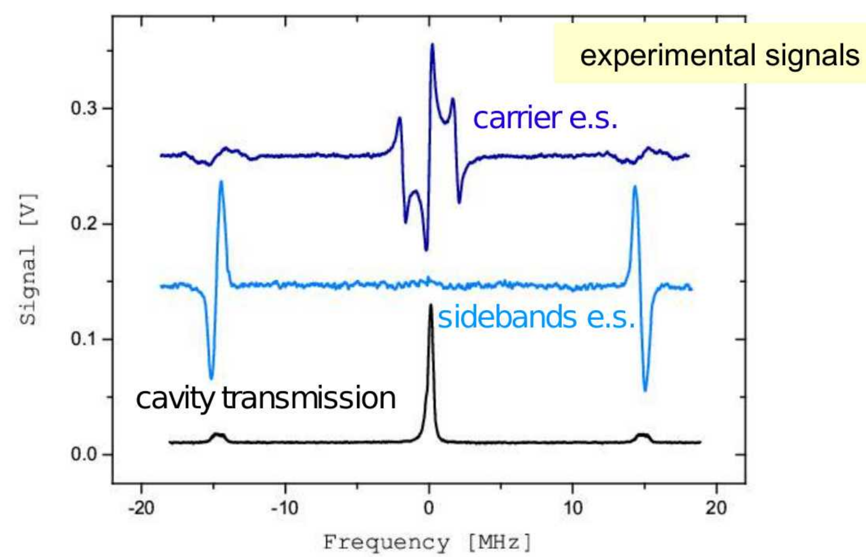
Pound-Drever-Hall for lock f_n to the carrier

dynamic resonance excitation at *mFSR*

dithering applied to ω_B for low-frequency conversion

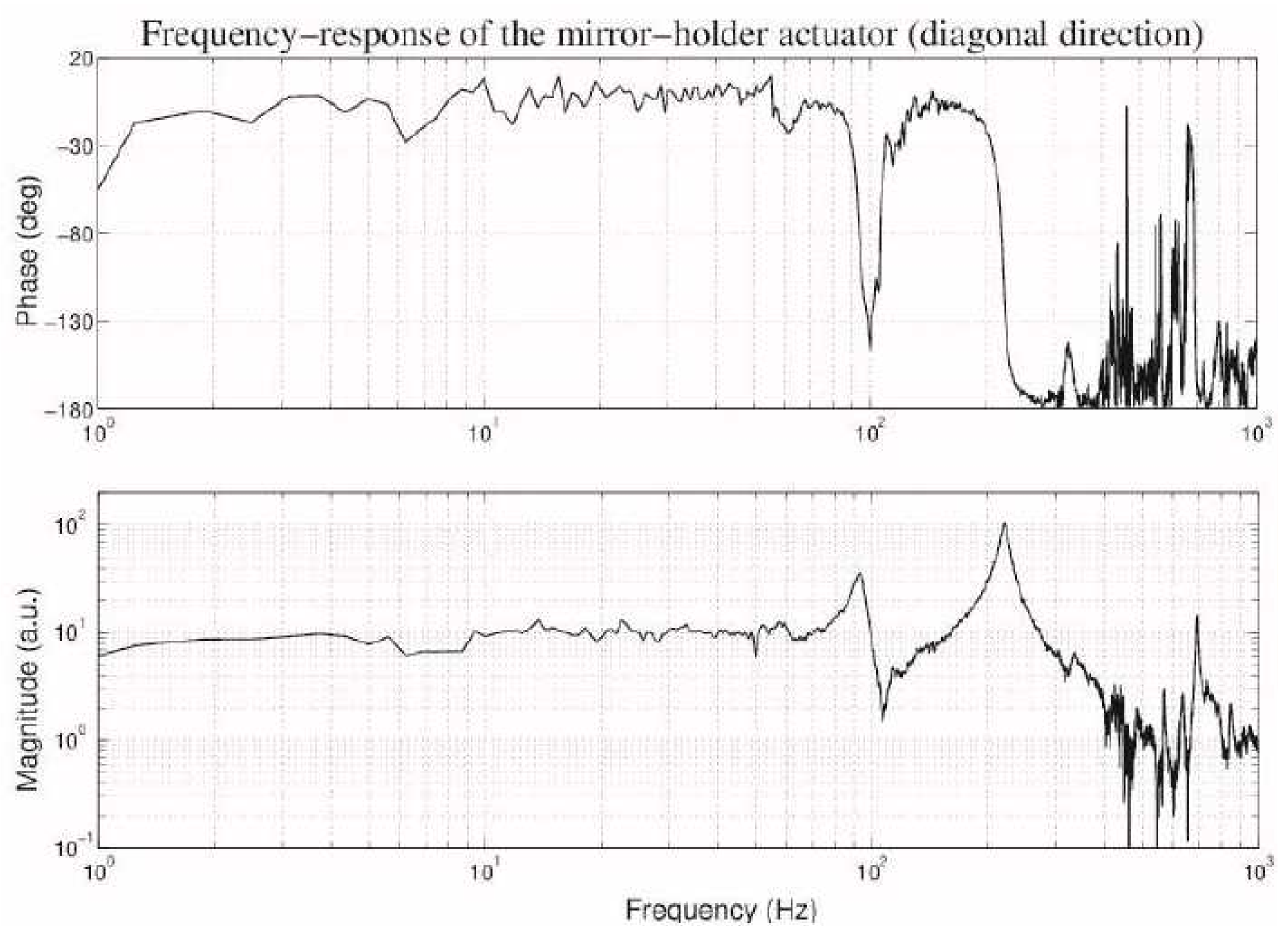
ω_0	optical frequency
α , β	modulation indices
Δ	dithering amplitude

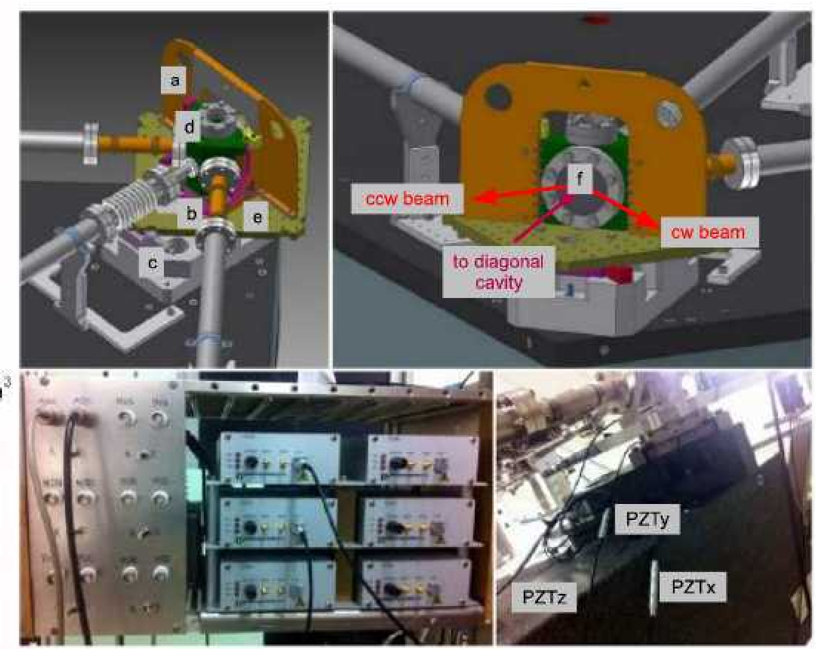




Mirrors position actuators

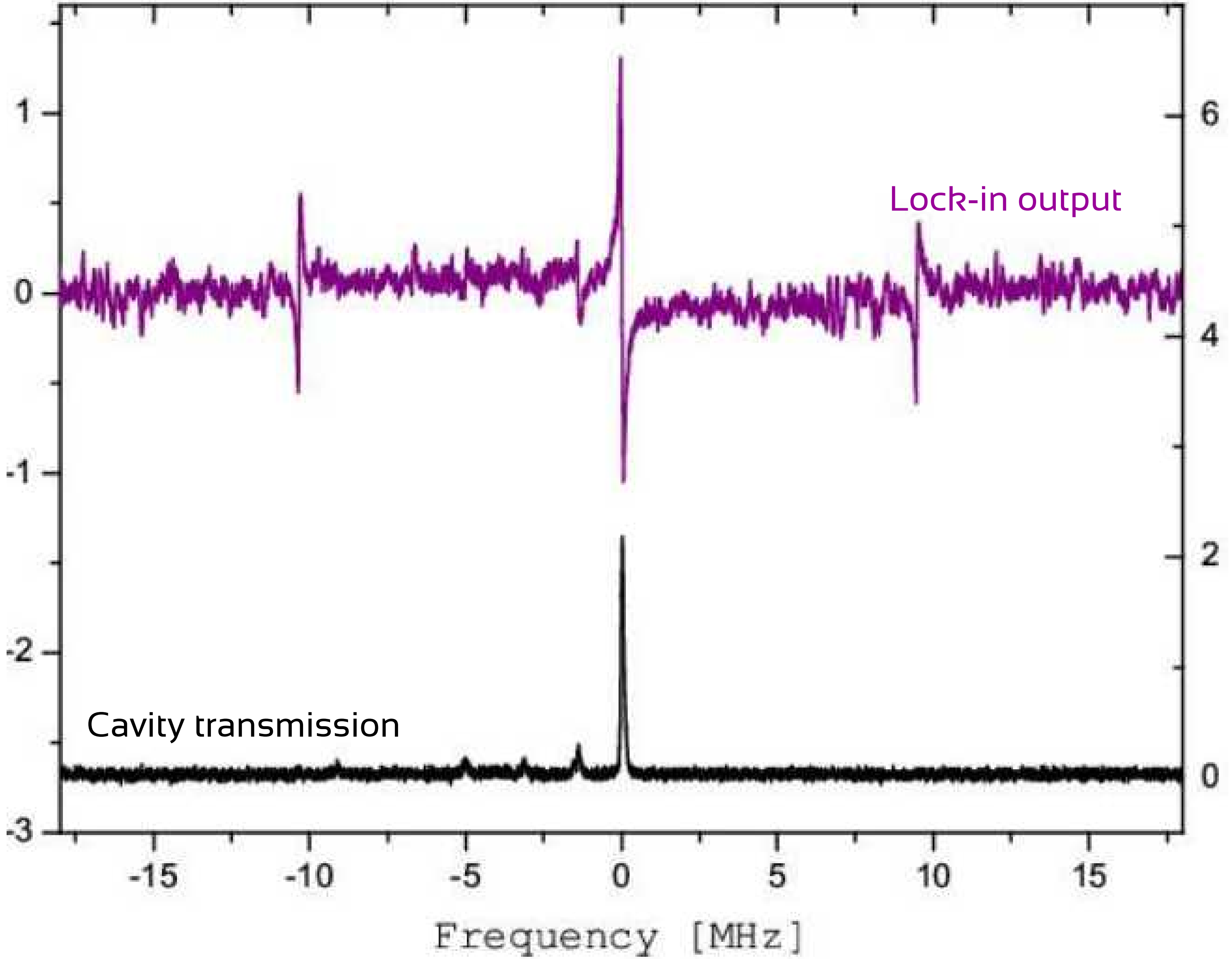
- #3 1-axial PZT; #1 3-axial PZT
- dynamic range (measured): 80 μm
- control bandwidth (measured): few tens of Hz





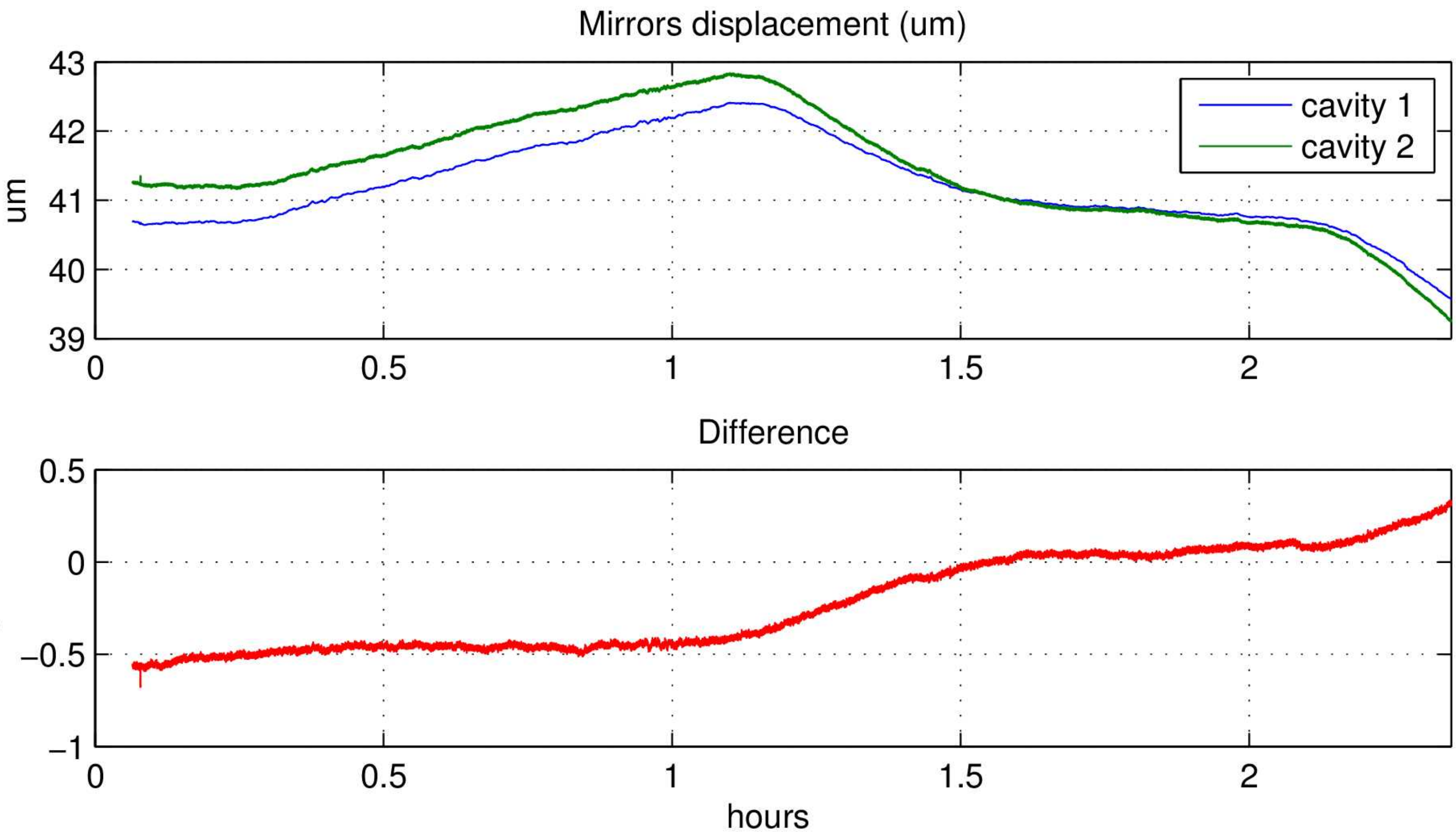
Carrier error signal on GP2

Digital lock-in amplifier



2 diagonals stabilization

Closed-loop correction to the opposite mirrors (digital PI controller)



Sub-nanometer length metrology for ultra-stable ring laser gyroscopes,
R. Santagata's PhD thesis, Siena 2015.

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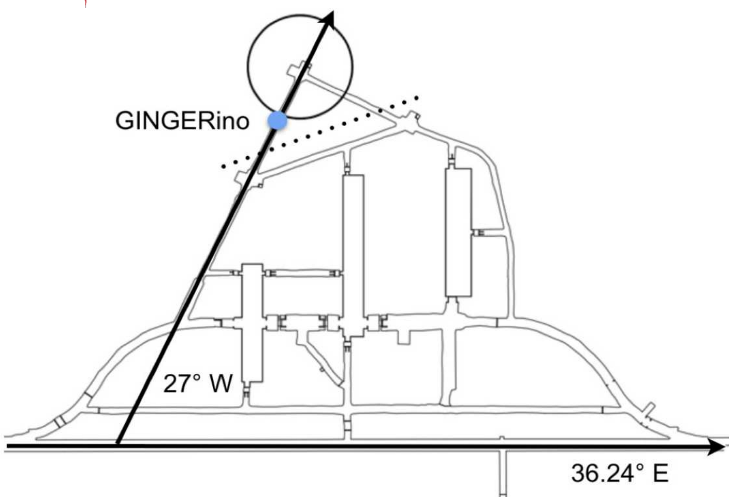
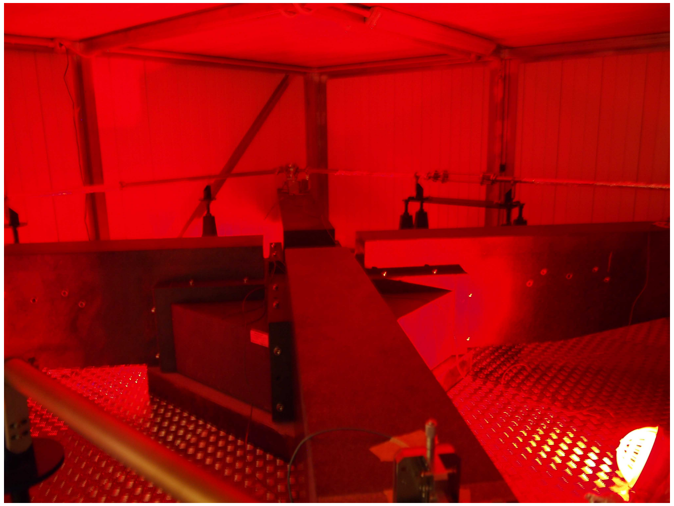
GINGER-ino + Seismometers (INGV)

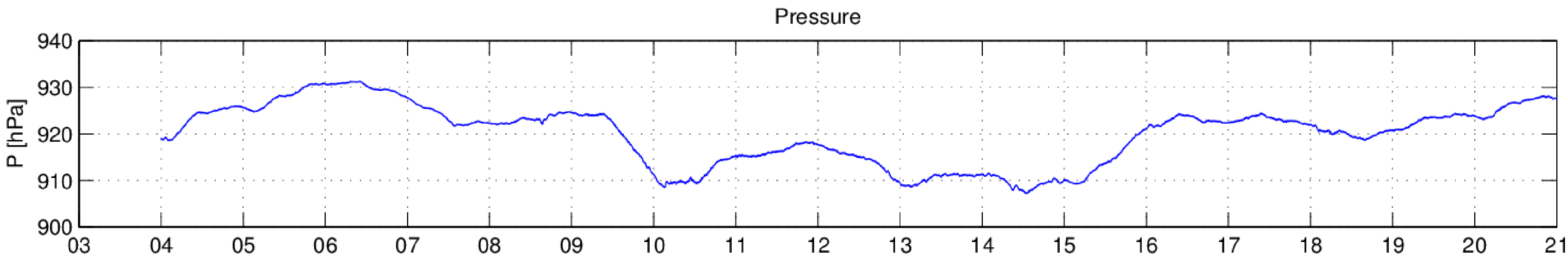
INFN-LNGS

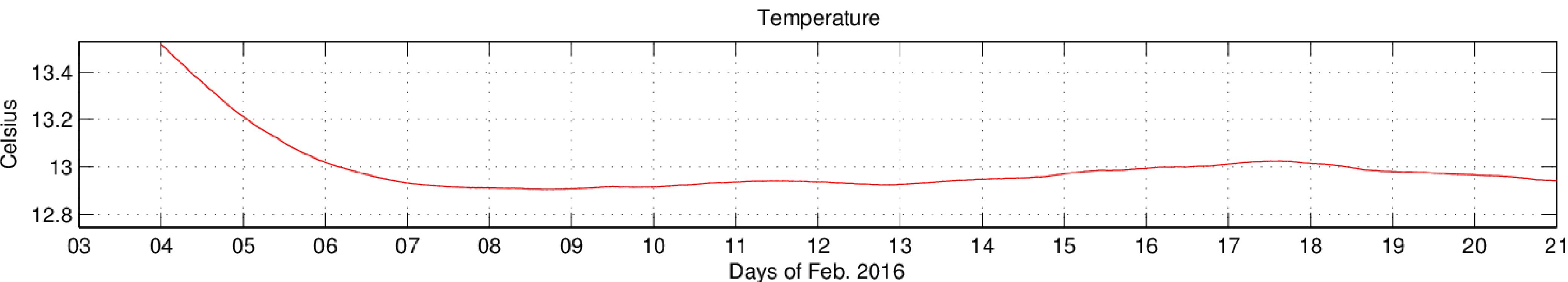
GINGERino: deep underground ring laser





Internal temperature is controlled by IR-lamps T: 8°C--> 13°C, relative humidity--> 60%

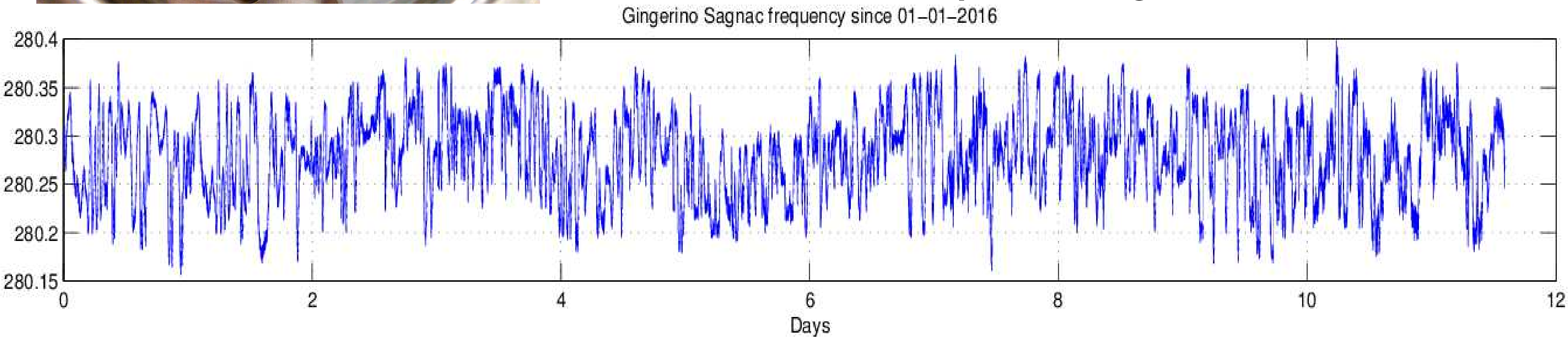




GINGERino: performance, present limitations

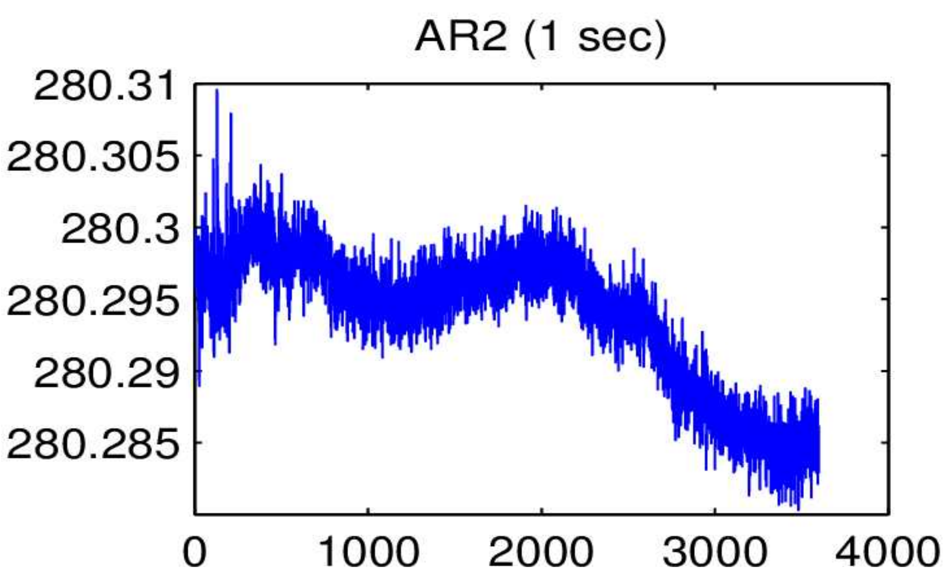
March 2015 first laser ignition in LNGS!

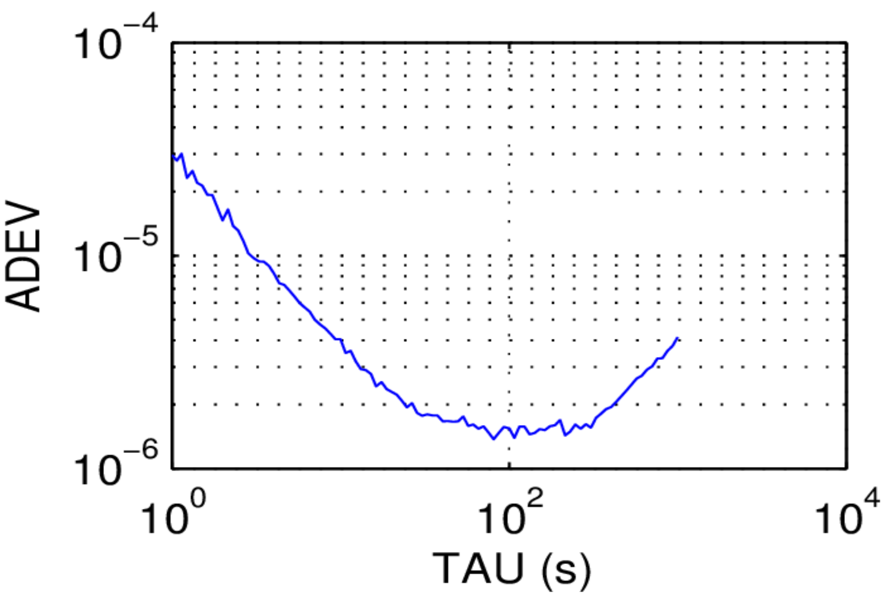
..then **problems** with: **Mirrors, DAQ system, Timing, Getter pumps, Discharge positioning**



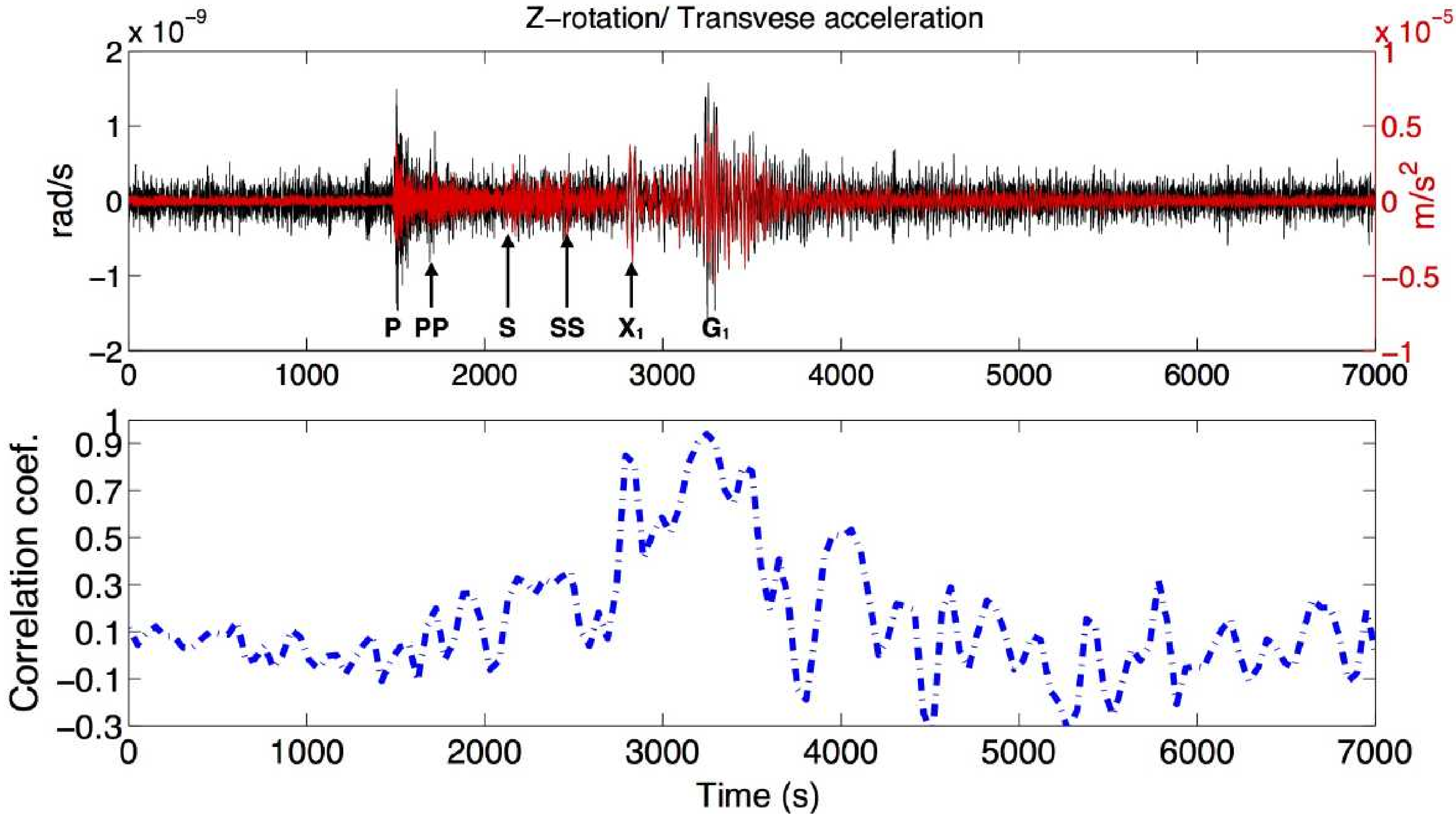
Large amount of Intracavity scattered light: RDT< 150 us (Expected> 1 ms)

"Quiet hour" (00:00 UTC 20th february)





Ground rotations from teleseismic waves



First deep underground observation of rotational signals from an earthquakeat teleseismic distance using a large ring laser gyroscope, *submitted to* Annals of Geophisics-fast track.

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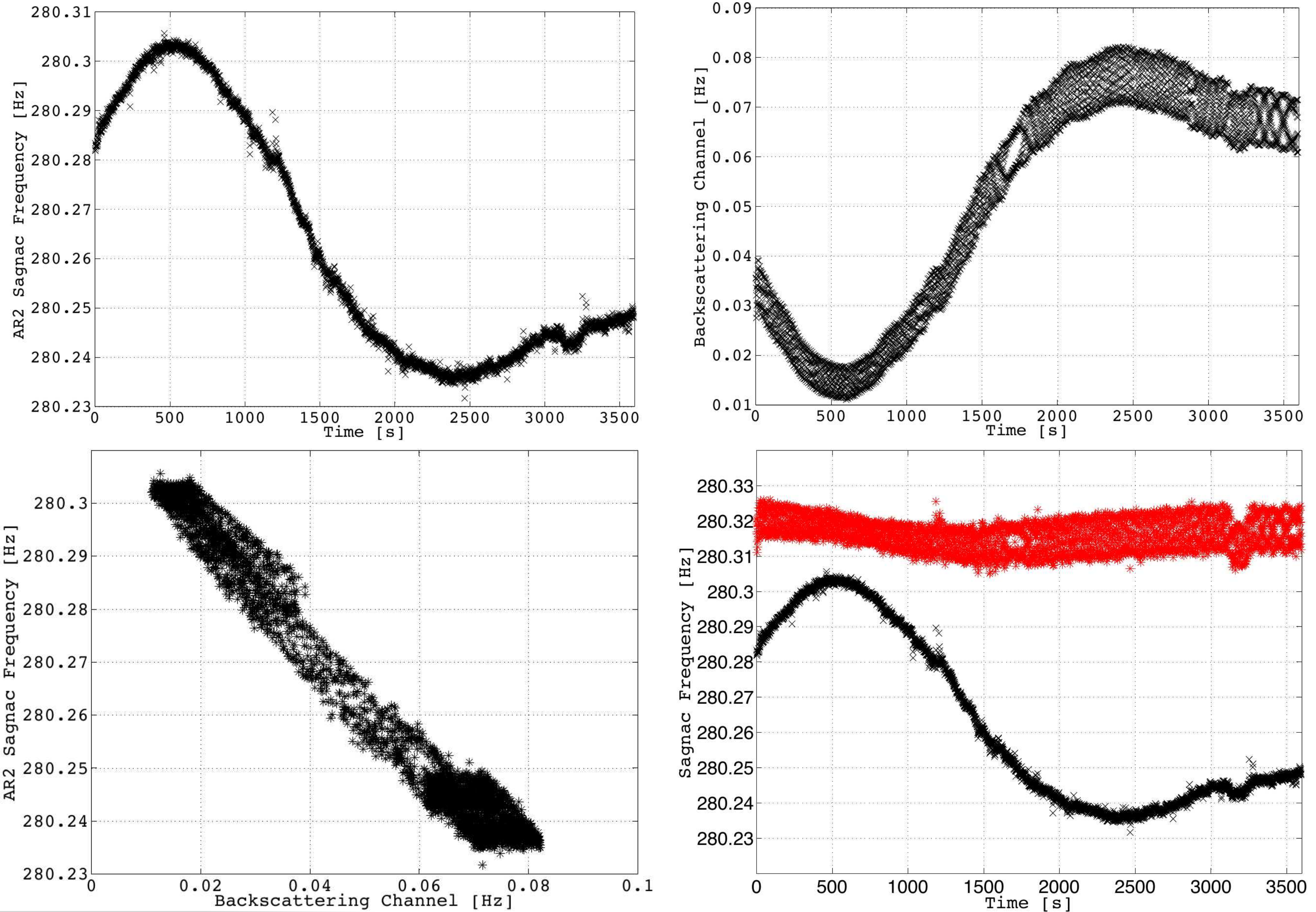
Backscattering analysis (preliminary)

Dedicated acquisition run. Start on february 4th. (Still running)



Conclusion

GP2

- **Laser source** has been developed
- **Diagonals stabilization** has been demonstrated

Next

-Improve **locking bandwidth** (use AOMs)
-Simultaneous control of the **perimeter** (regular square)
-Verify gyroscope's **enhanced stability**

GINGERino

-Unattended run since about **20 days** (and goes on…)
-Several problems emerged (mainly: **mirrors** and **pressure** changes)
-**Fixed several problems** DAQ, Timing, getters
-**Backscattering analysis** is giving first results

Next

-Improve mechanical stability and pressure regulation
-Test **new mirros** from LMA (hopefully excellent)
-**Perimeter** stabilization