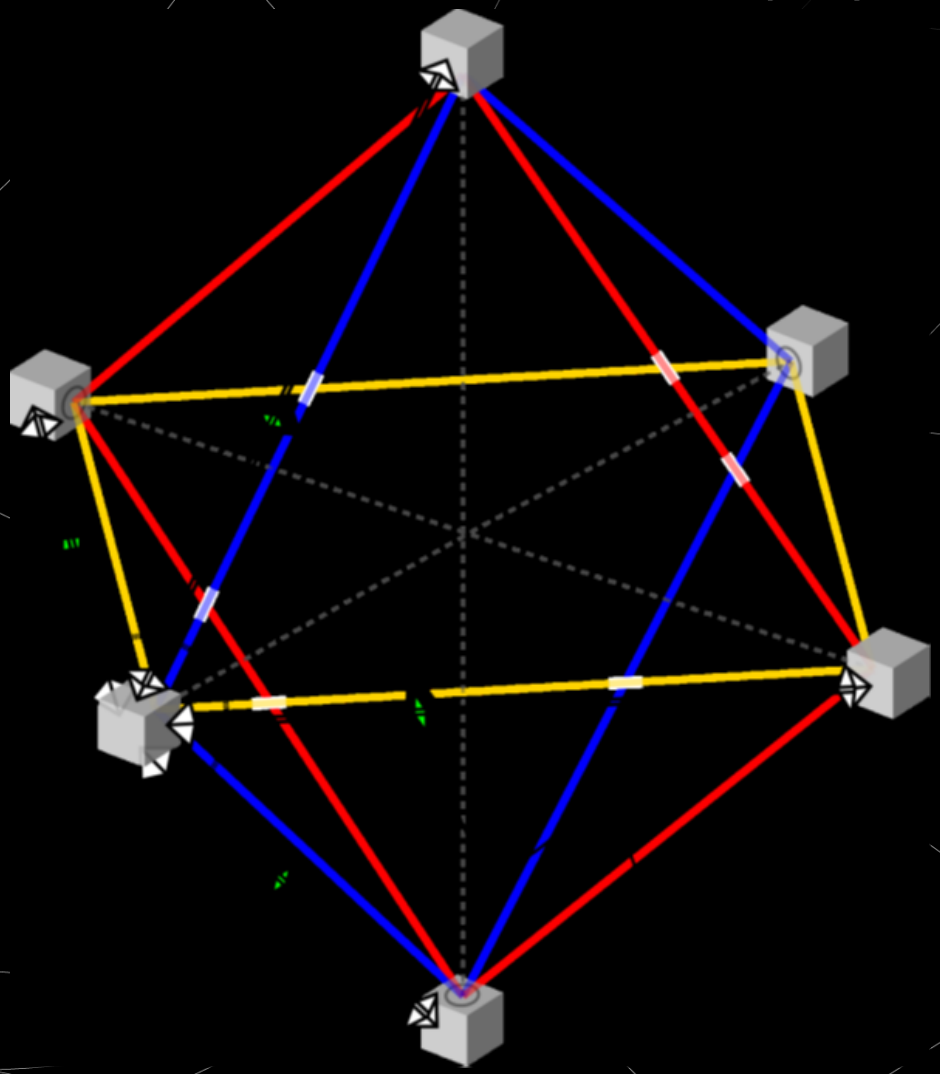
G-GranSasso

Preventivi 2016

Pisa

G-GranSasso GINGERino

Pisa/LNL/Napoli/Torino
CNR-SPI and DEI-Padova
INGV, INRIM
in coll. with U. Schreiber TUM, H. Igel LMU and JP Wells (Christchurch NZ)



GINGER (Gyroscopes IN GEneral Relativity)

Testing GR with a very accurate measurement of Earth's rotation rate

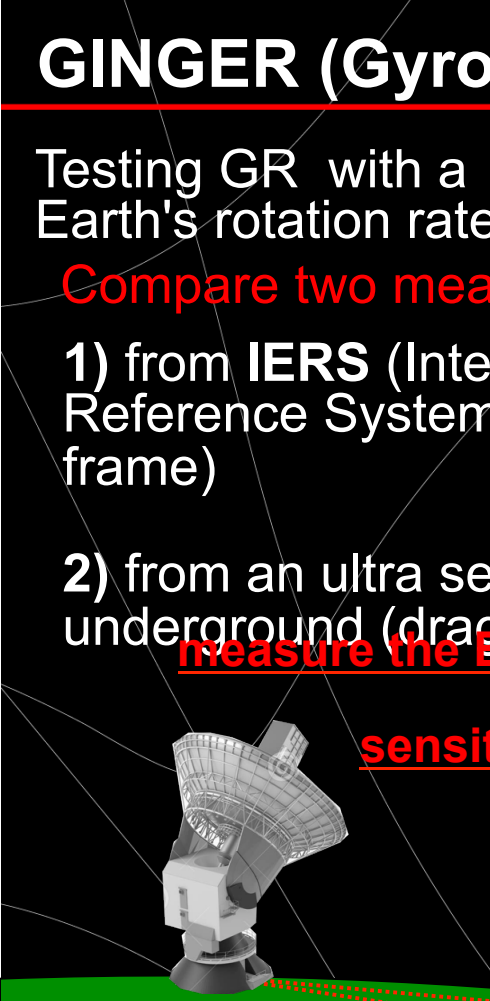
Compare two measurements

1) from **IERS** (International Earth Rotation and Reference System Service) system (inertial reference frame)

2) from an ultra sensitive Gyroscopes array located underground (dragged reference frame)

measure the Earth angular rotation Ω better than 1 part 10^9 Ω_E

sensitivity goal: 10^{-14} rad/s integrating 1 day

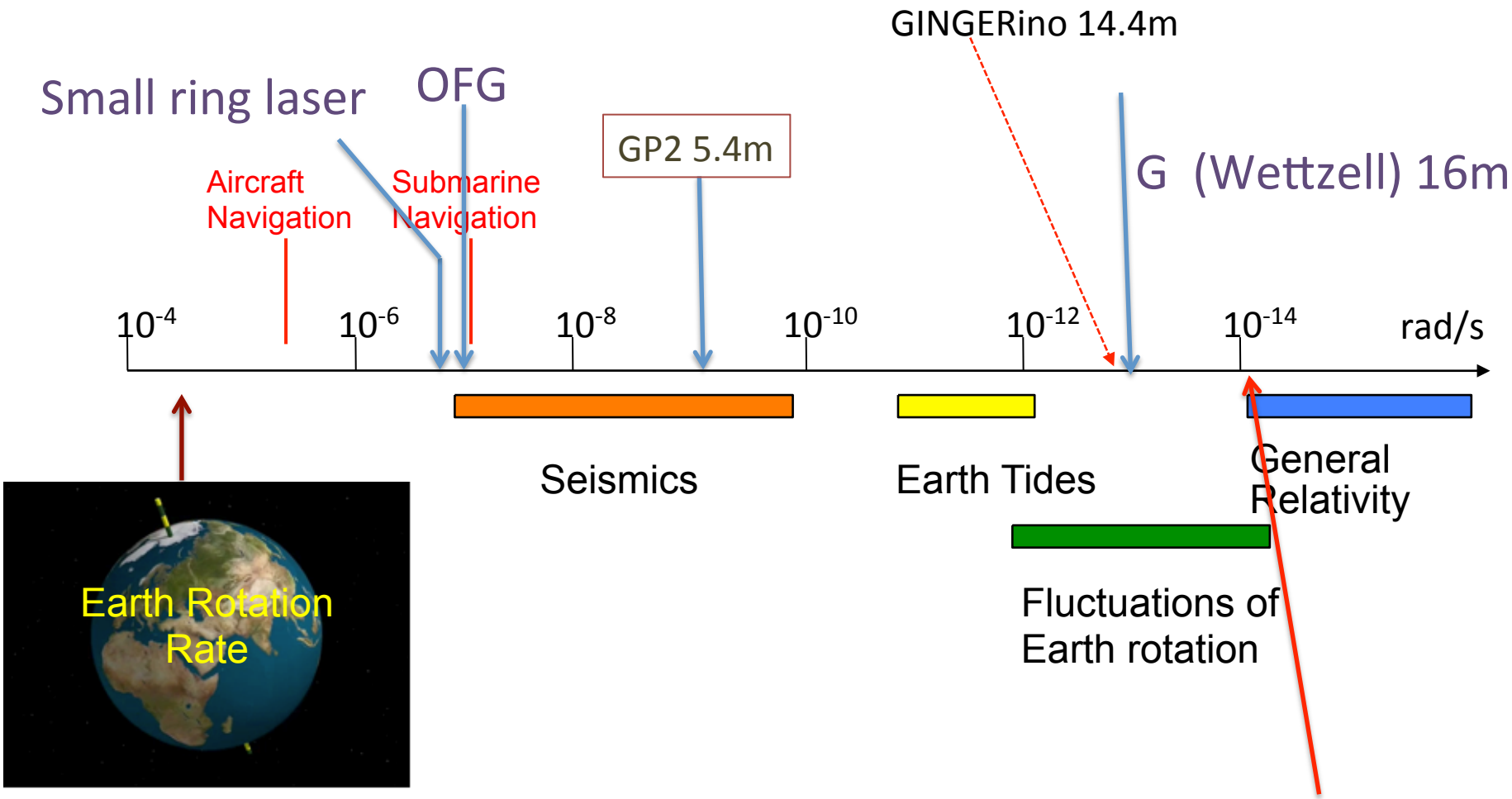


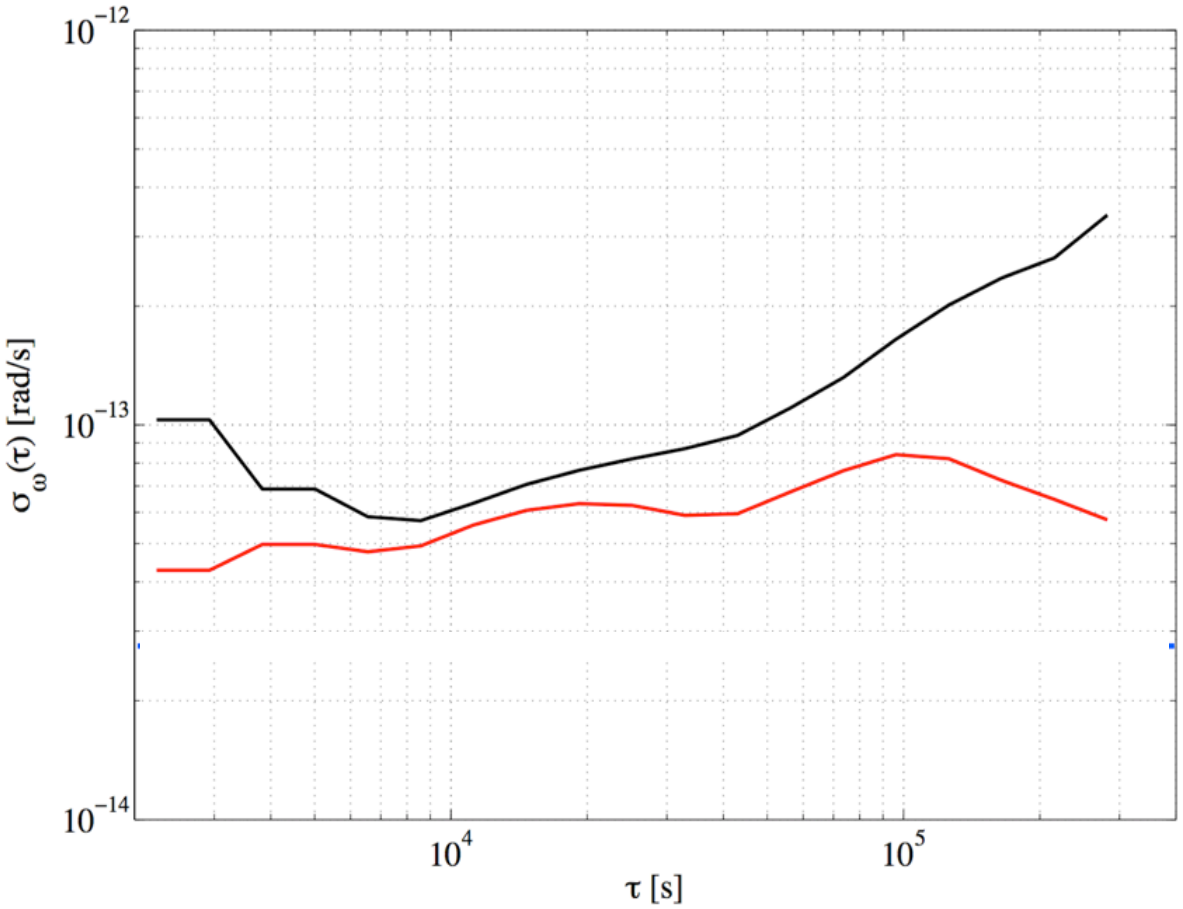
Quasars

"Inertial-frame" VLBI rotation measurement

3-axial Ring-Laser

$\vec{\Omega}_E'$ Local rotation measurement


GINGERino 14.4m
Small ring laser
OFG
GP2 5.4m
G (Wettzell) 16m
Aircraft Navigation
Submarine Navigation
10^{-4}
10^{-6}
10^{-8}
10^{-10}
10^{-12}
10^{-14}
rad/s
Seismics
Earth Tides
General Relativity
Fluctuations of Earth rotation
Earth Rotation Rate



Black line: recent data of G Wettzell

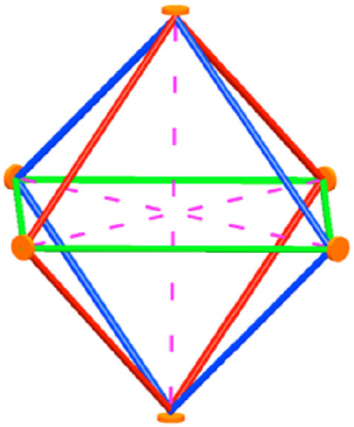
Red line: backscattering subtraction using our Kalman filter

Sensitivity very close to the required one
accuracy is an issue

- G-Wettzell has shown that locally the Earth Angular velocity can be measured with accuracy close to 1 part 10^9

- ***Necessary improvements:***
- And array of rings in order to measure the whole vector
- Underground in order to reduce low frequency disturbances
- **Main specifications**
- Stability 1 part 10^{10}
- Relative angle between rings monitored with nrad accuracy

Measuring gravitomagnetic effects by a multi-ring-laser gyroscope
Phys. Rev. D 84, 122002 – Published 9 December 2011



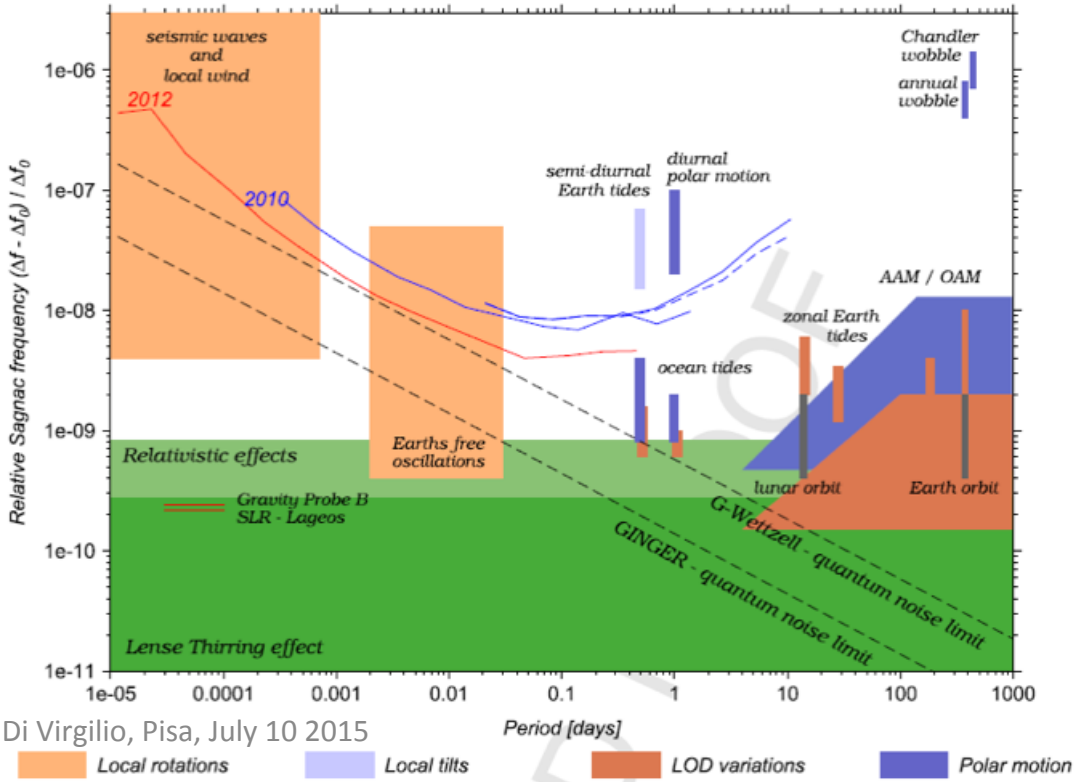
Use a tri-axial gyro of 3 ring lasers: no absolute orientation with respect VLBI reference system is required by comparing the modulus of Earth rotation vector.

$$\nu_i \cong 4\frac{A}{\lambda p}\vec{\Omega}_E \cdot \vec{n}_i + shot + syst. \qquad i = 1,2,3$$

$$\left|\vec{\Omega}_E\right| = \left(\frac{\lambda p}{4A}\right)\left(\nu_1^2 + \nu_2^2 + \nu_3^2\right)^{1/2} + \delta\left|\vec{\Omega}_E\right|$$

$$\frac{\delta\left|\vec{\Omega}_E\right|}{\left|\vec{\Omega}_E\right|} \leq 10^{-10}$$

- Geometry of the rings must be controlled actively at 1 part in 10^1 (optical frequency references)
- Rigidity can be obtained by lockin internal degrees of freedom: 3 diagonals + 3 cavity perimeters (+ external metrology)
- Minimize laser non-reciprocal effects (e.g. L > 6m) + accurate modeling of non linea dynamics of the laser
- Monitor of relative angle of the rin (external metrology)

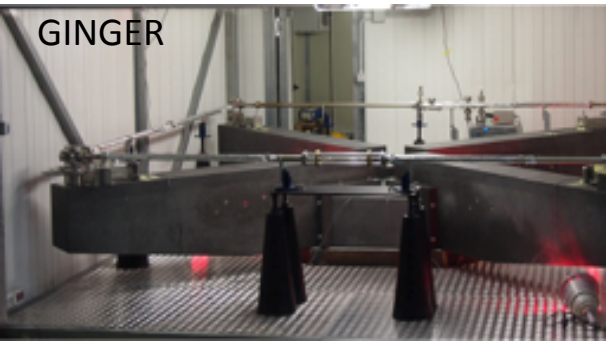


- We are testing 3 prototypes to achieve the GINGER goal
  - SENSITIVITY: 10^{-14} rad/sec
  - LONG TERM STABILITY: 1 day
  - ACCURACY: 1 part in 10^{10} of Earth rotation rate

- The 3 key issues we will address in 2016 with the 3 prototypes:
  - LNGS rotational noise ➔ GINGERino @ LNGS
  - Stability of geometry by active control ➔ GP-2 @Pisa
  - Monitor of relative angle ➔ GEMS @Padova

GINGER(ino)

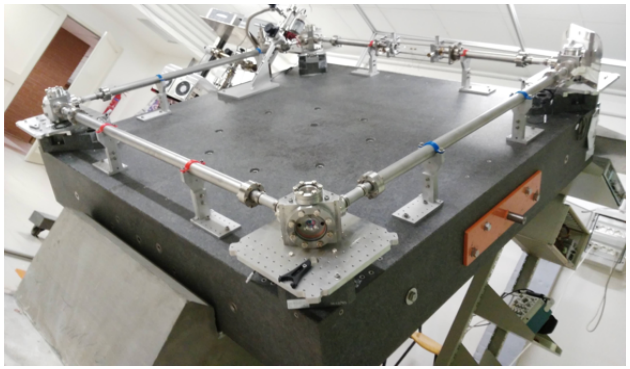
GINGERino is a ring laser with 3.6 m side, installed inside the LNGS laboratory for Geodesy, Geophysics measurements and to test if LNGS is a suitable location for GINGER



GP2: control geometry

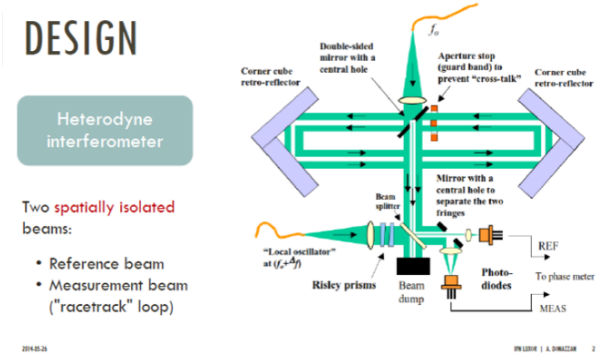
Inject the 2 Fabry-Perot cavities along diagonals with external laser and measure the 2 absolute lengths.

Set them equal by controlling mirrors positions by means of the 6 PZT and search for a saddle point of perimeter

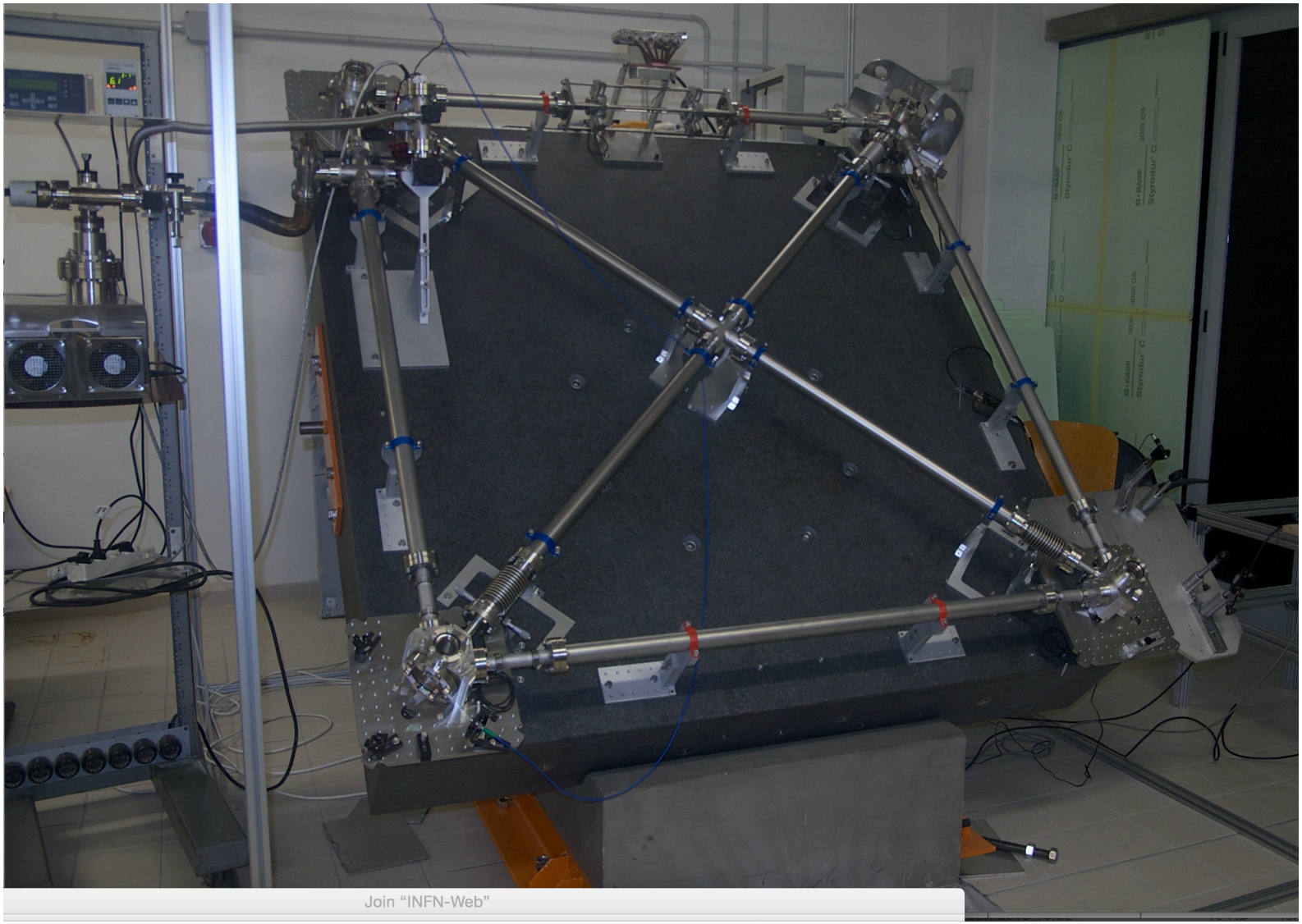


GINGER External Metrological System GEMS

Based on the interferometric method developped for the NASA mission SIM light.
Picometer accuracy required.

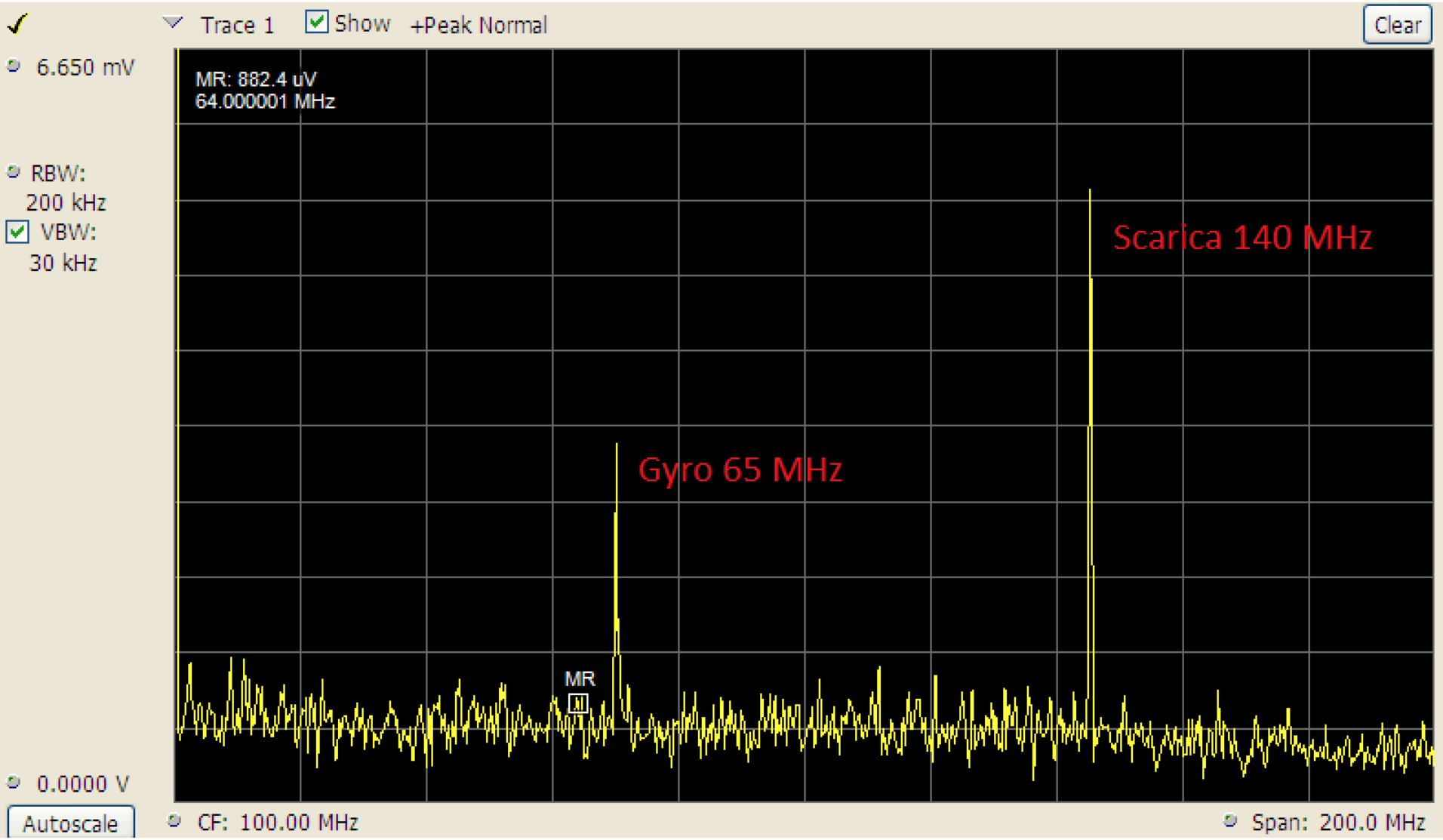


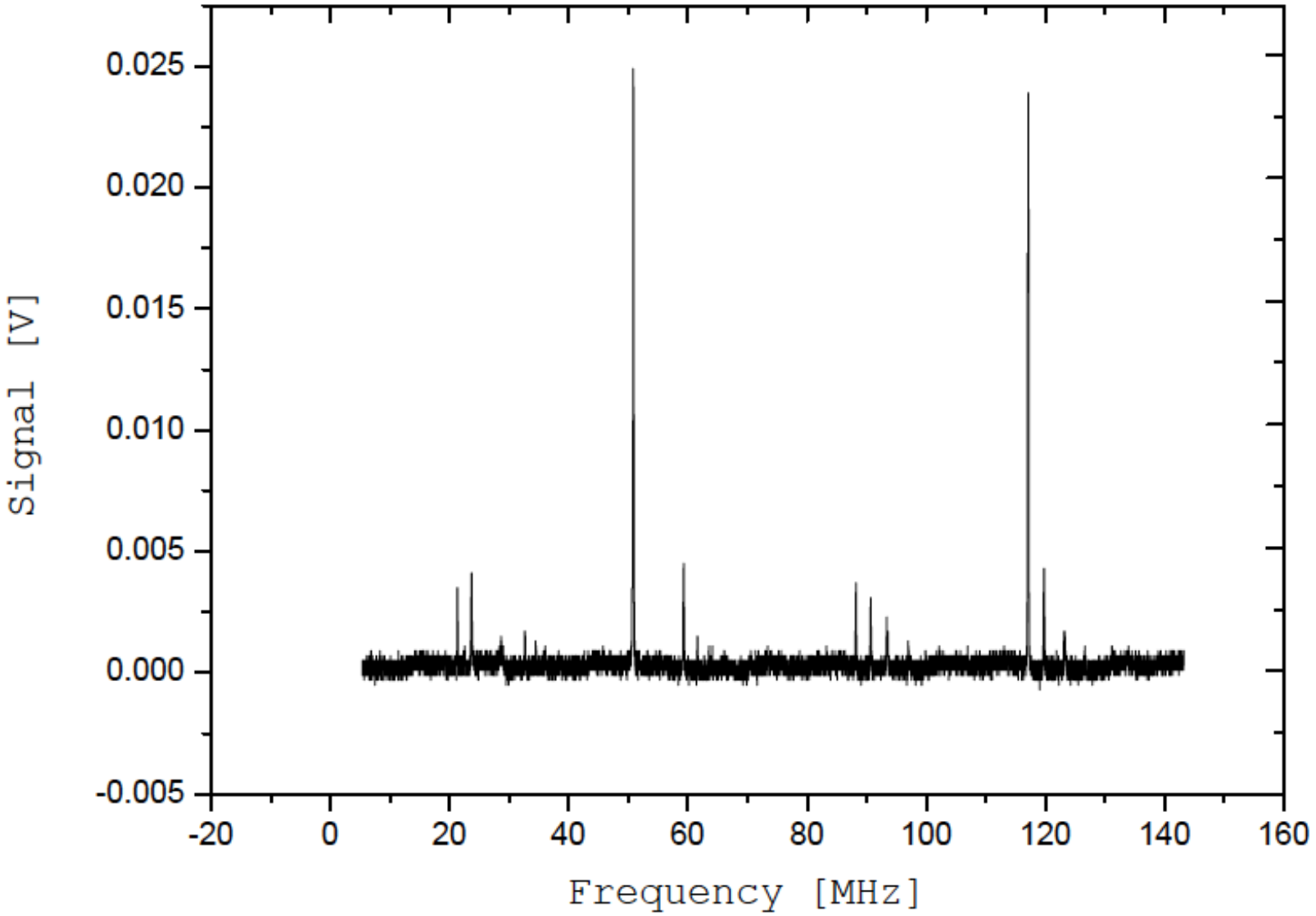
GP-2, geometry control prototype



- GP2: sviluppo del controllo della geometria primo prototipo sviluppato per il controllo, al momento ha 6 attuatori.

Su GP2 si stanno facendo I primi esercizi di controllo: lasera e stiamo allineando le due cavita' lineari diagonali (una e' gia' funzionante)


Trace 1
Show
+Peak Normal
Clear
6.650 mV
MR: 882.4 uV
64.000001 MHz
RBW:
200 kHz
VBW:
30 kHz
Scarica 140 MHz
Gyro 65 MHz
MR
0.0000 V
Autoscale
CF: 100.00 MHz
Span: 200.0 MHz


0.025
0.020
0.015
0.010
0.005
0.000
-0.005
Signal [V]
-20
0
20
40
60
80
100
120
140
160
Frequency [MHz]

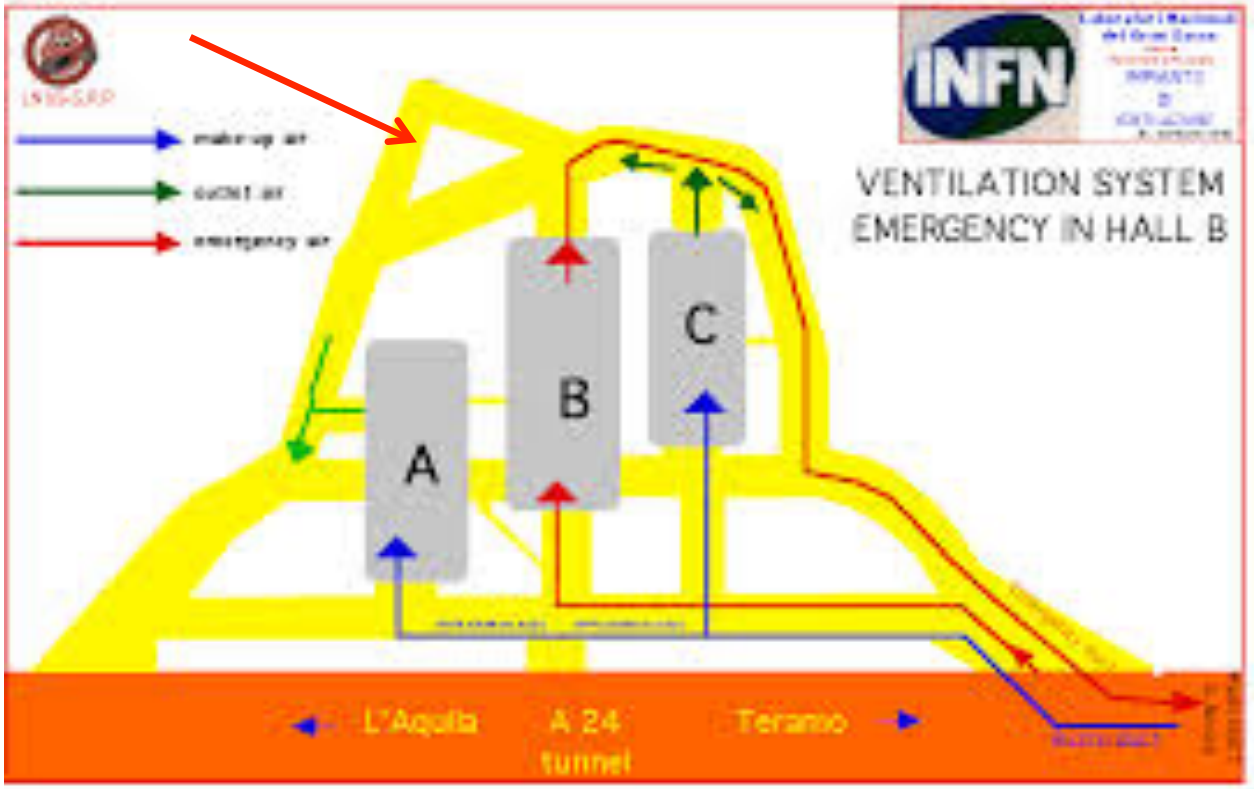
Stato attuale i due prototipi GINGERino e GP2

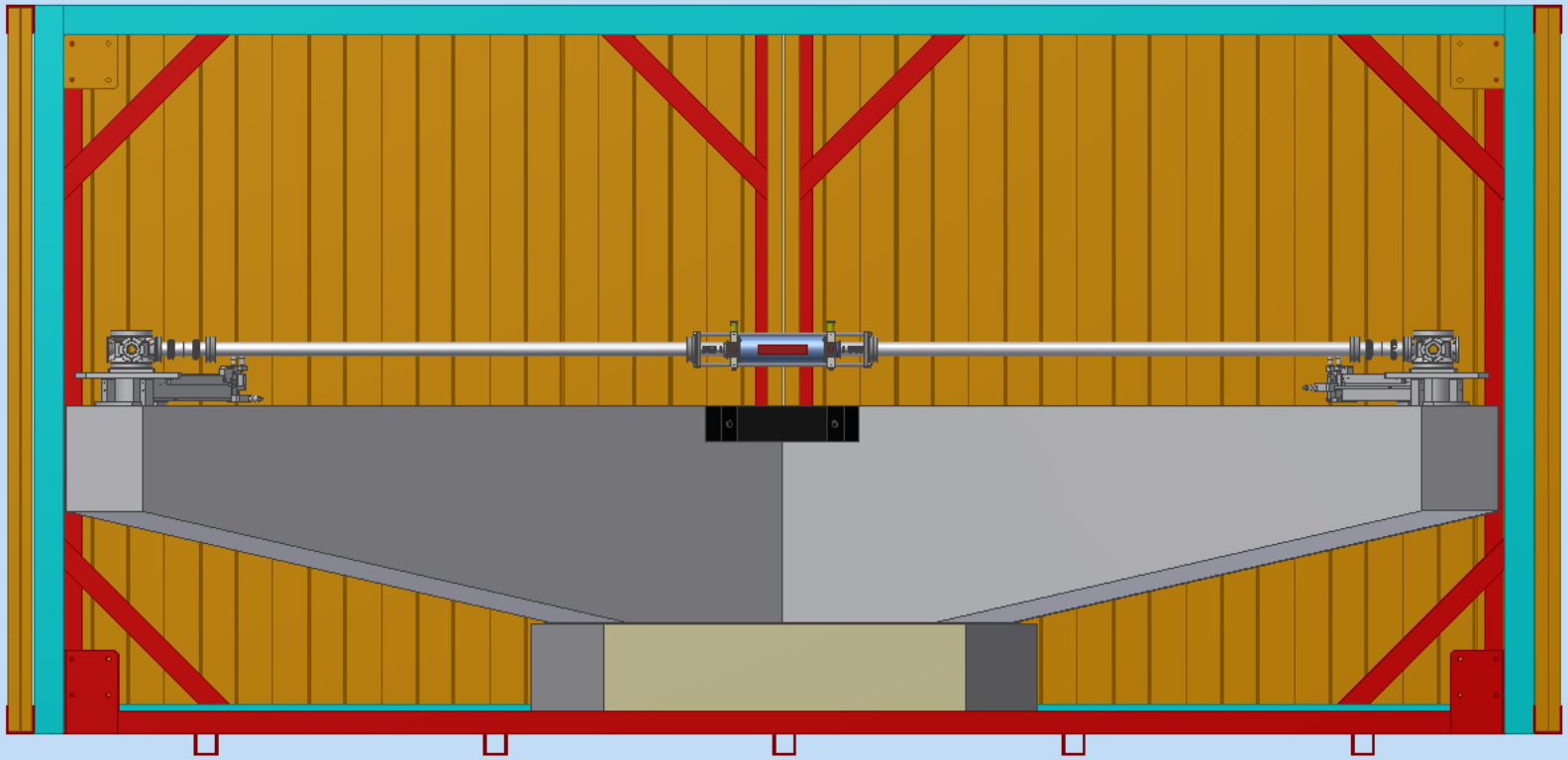
- GINGERino: in presa dati in modo discontinuo

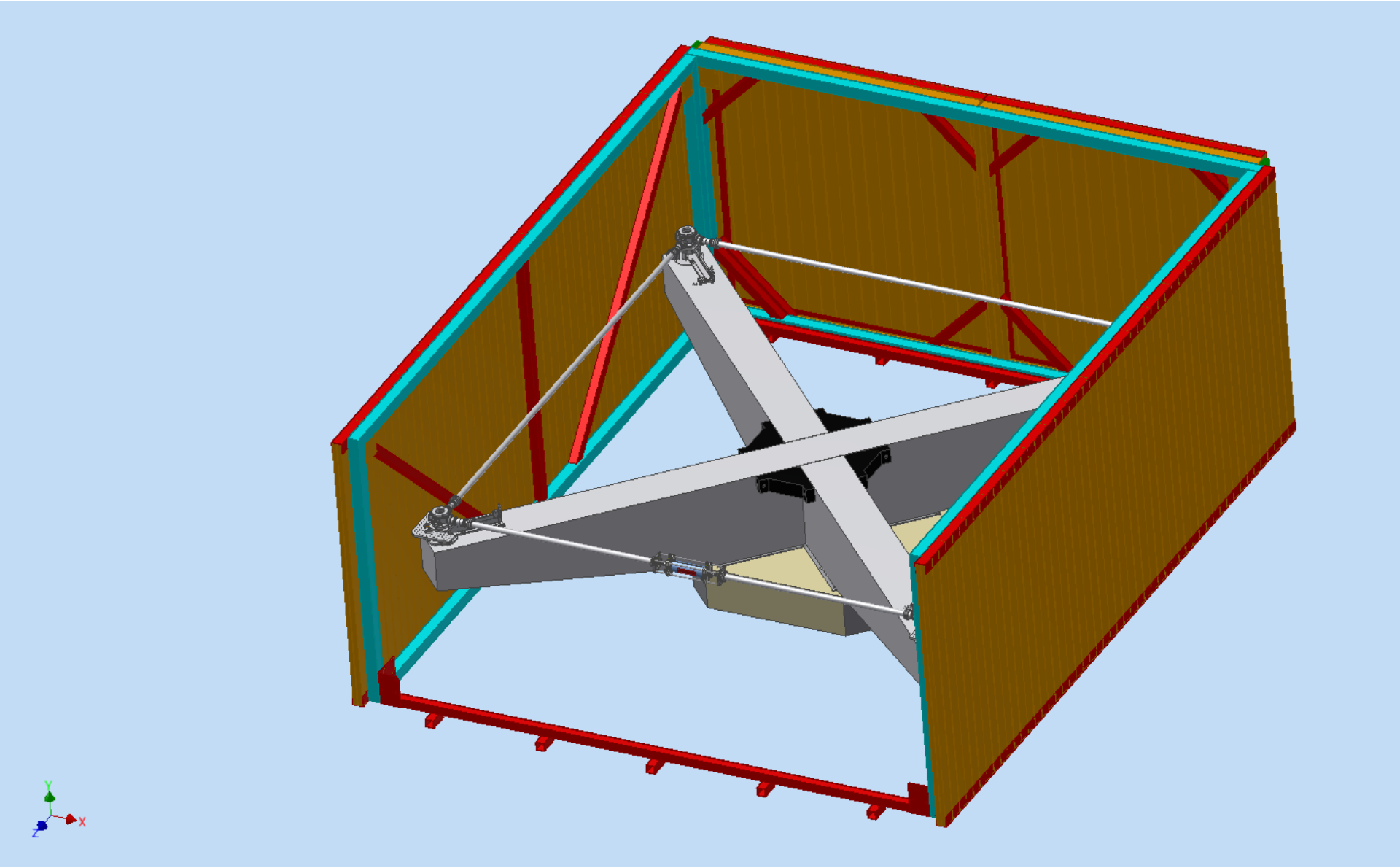
  analisi dati per valutare la bonta' del sito LNGS

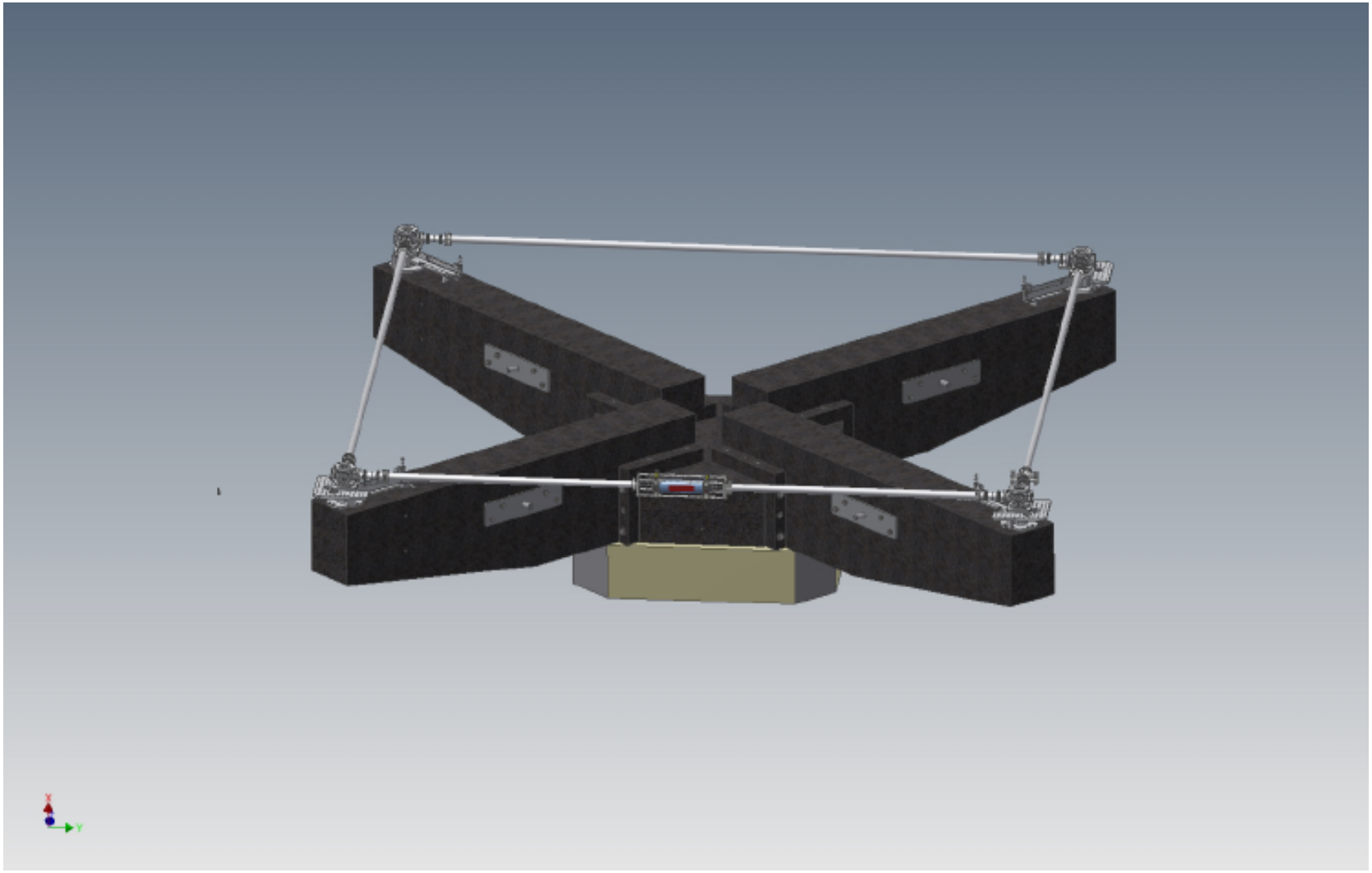
(nota: al momento adopera il nostro primo prototipo G-Pisa, che non e' molto stabile nel tempo perche' ha specchi 'sospesi'

LNGS-Node A,
polar motions should be observed



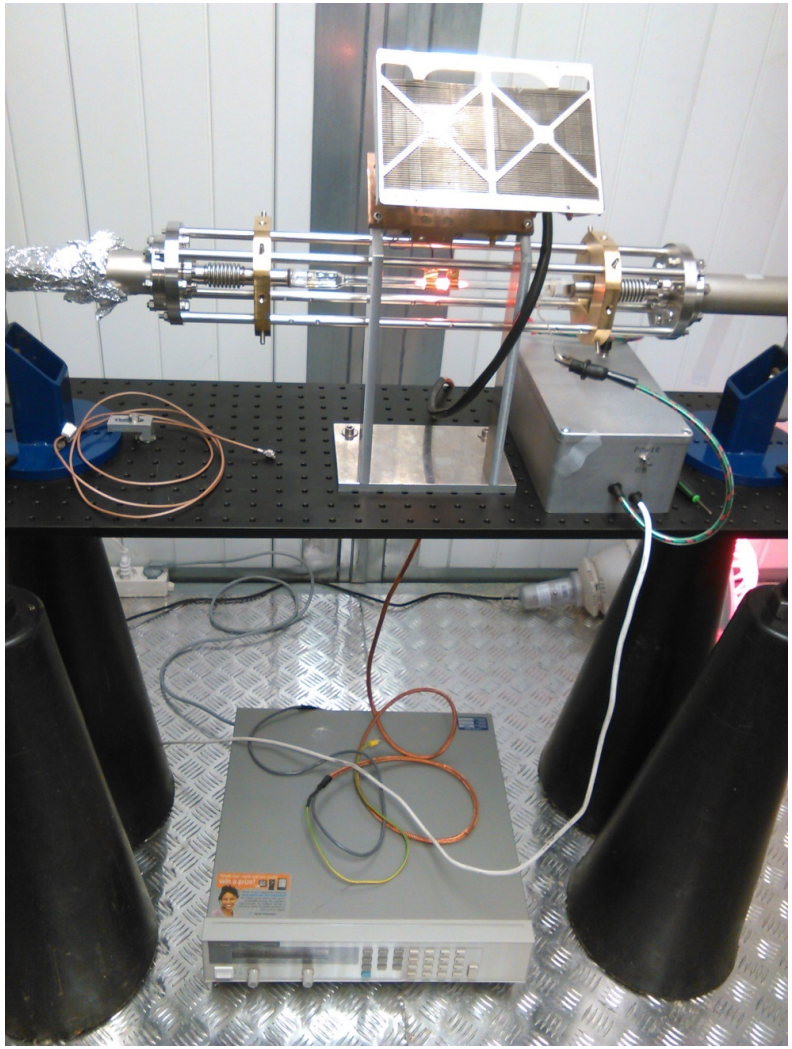

Y
X

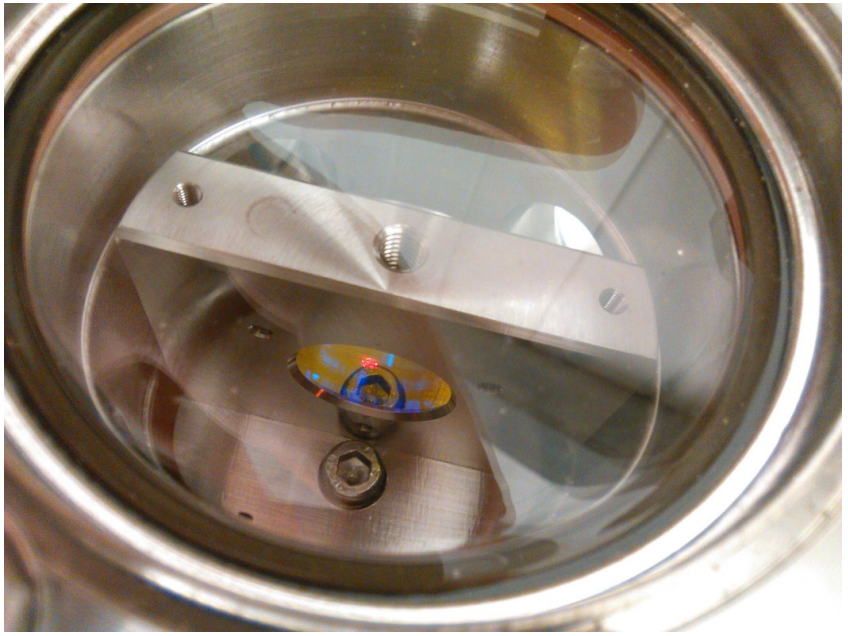




First step....

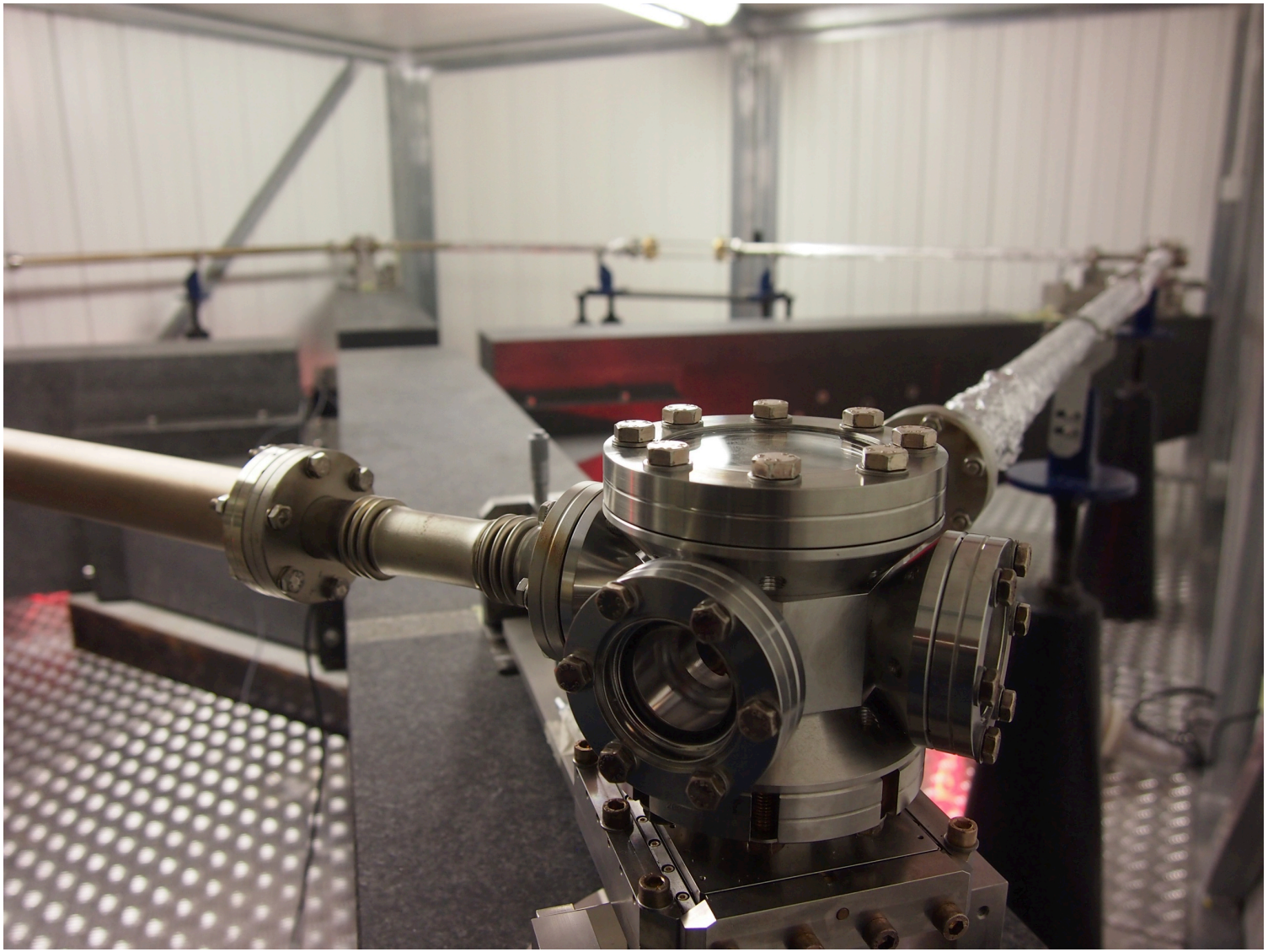

22-10-2014
First signals in December? We hope so, but we cannot guarantee



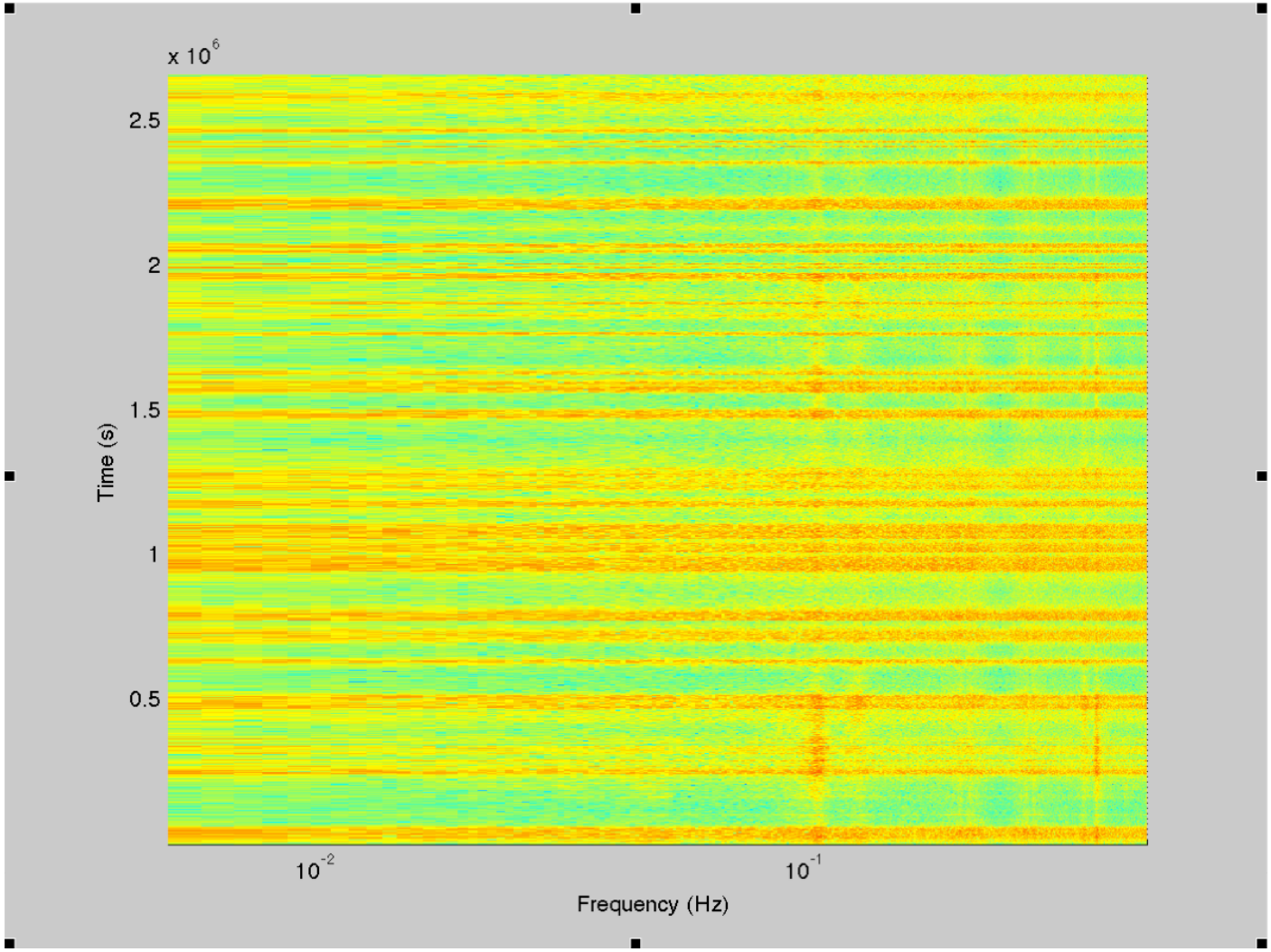


Sagnac Signal 280Hz has been observed

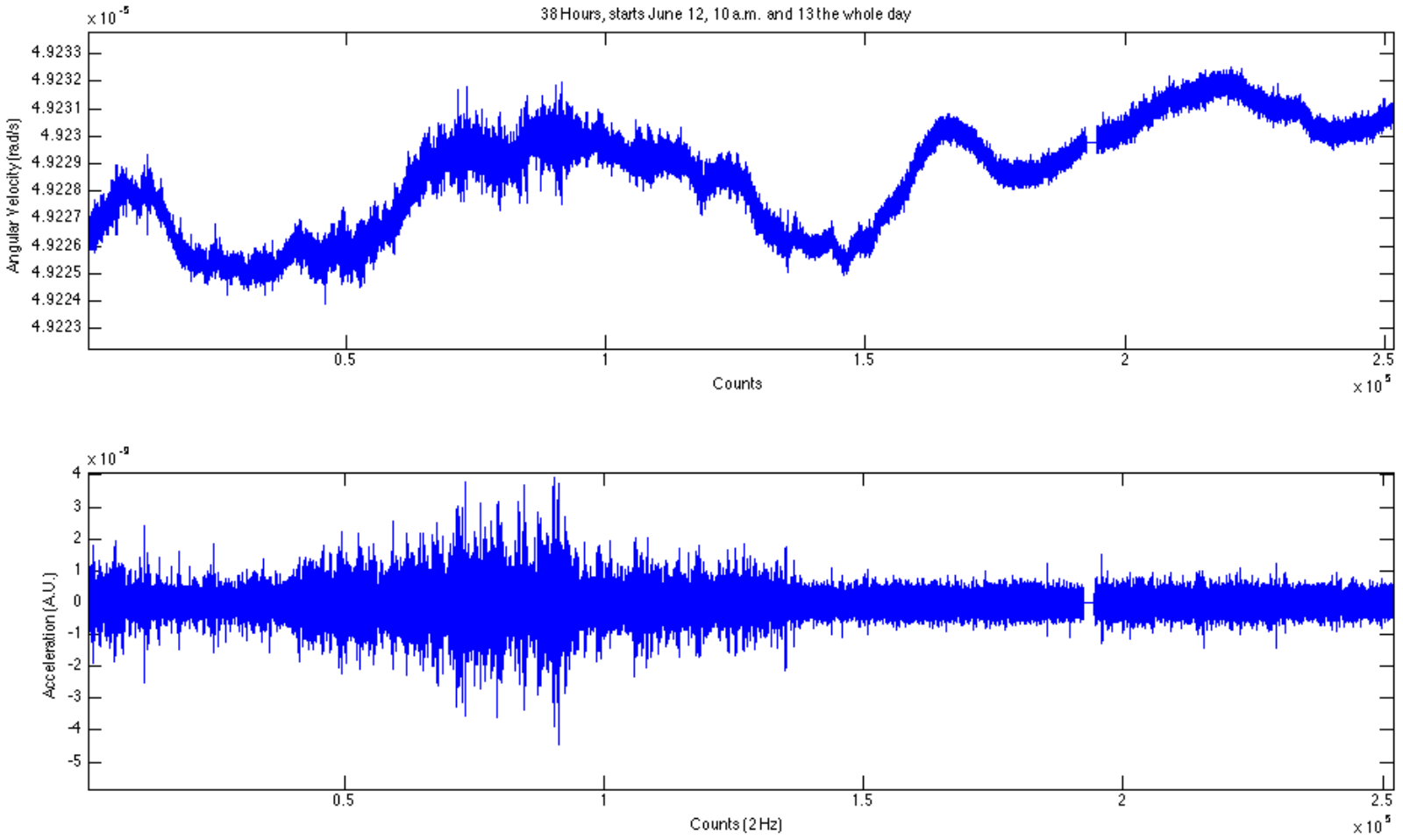
Work still in progress

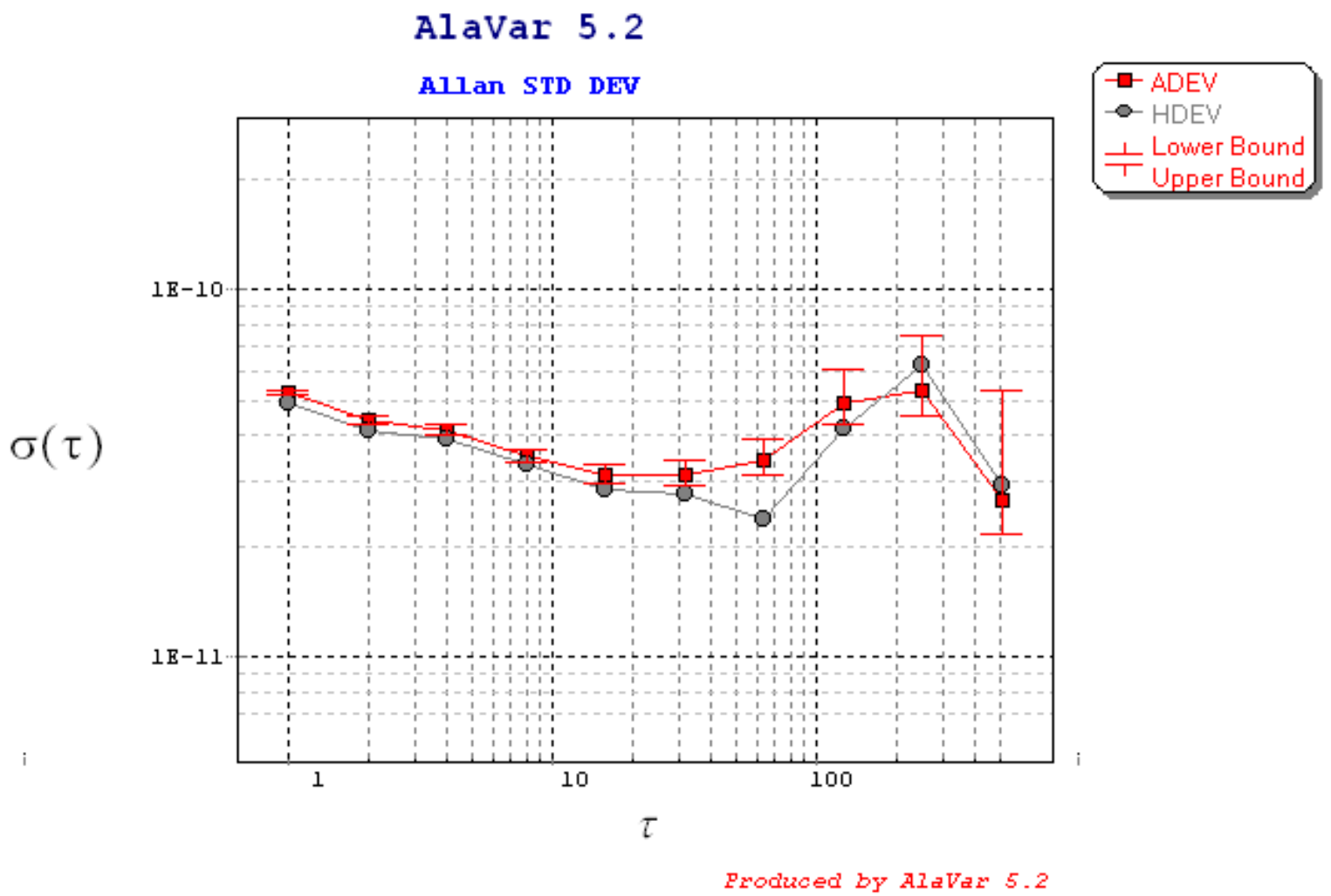


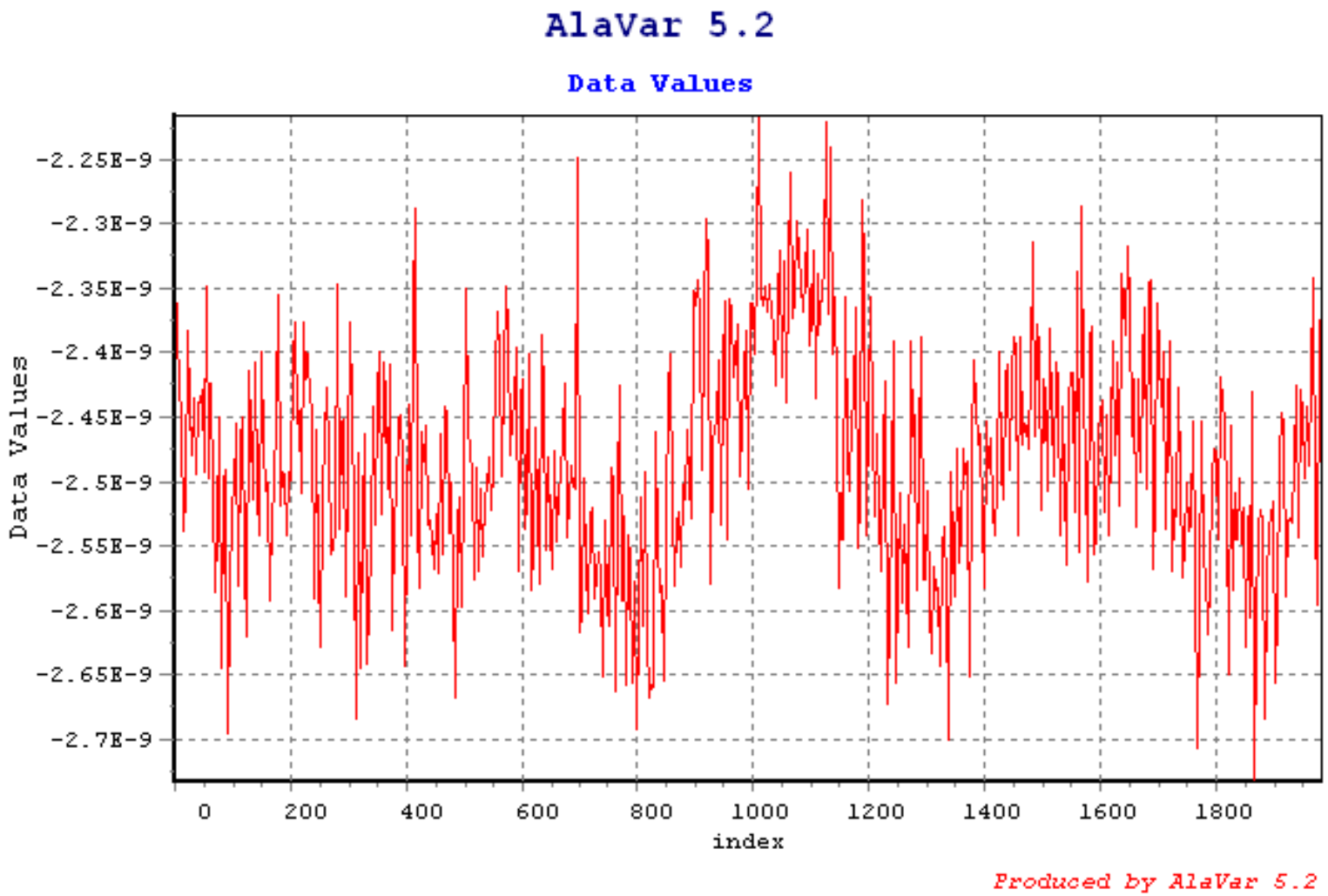
Angela Di Virgilio, Pisa, July 10 2015

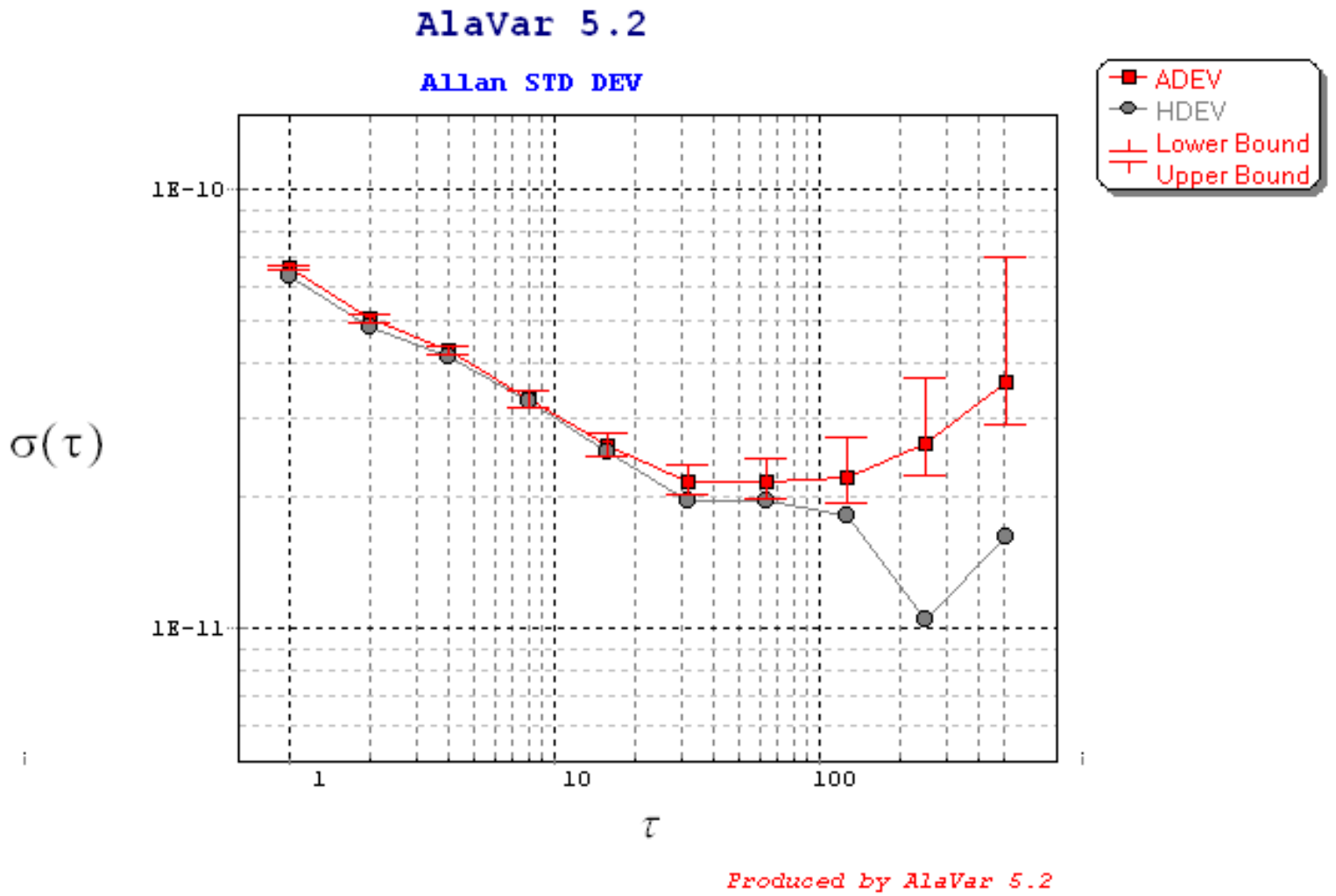


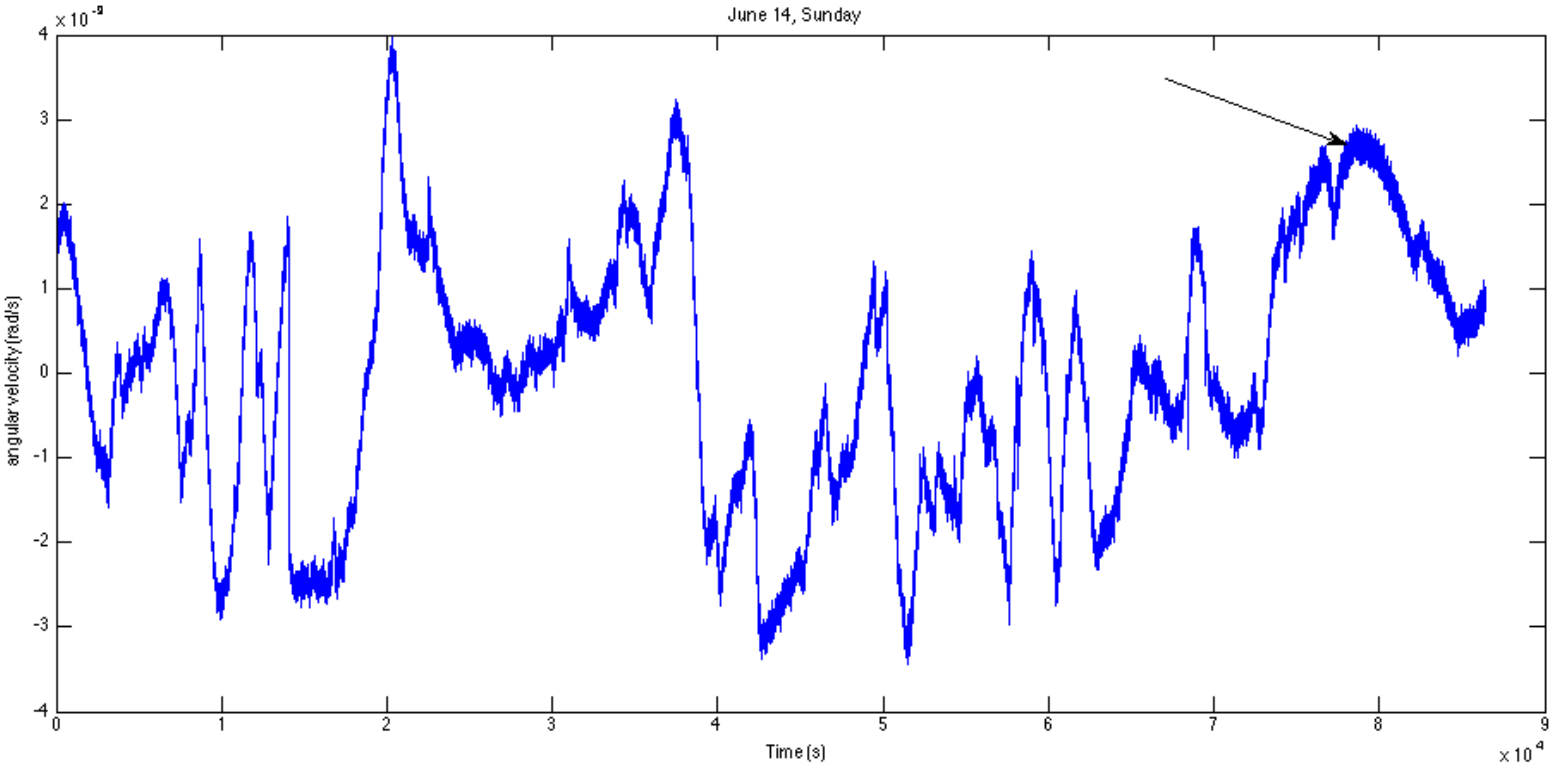
12-13 June, ac rate 1Hz,
data 5000Hz reconstructed

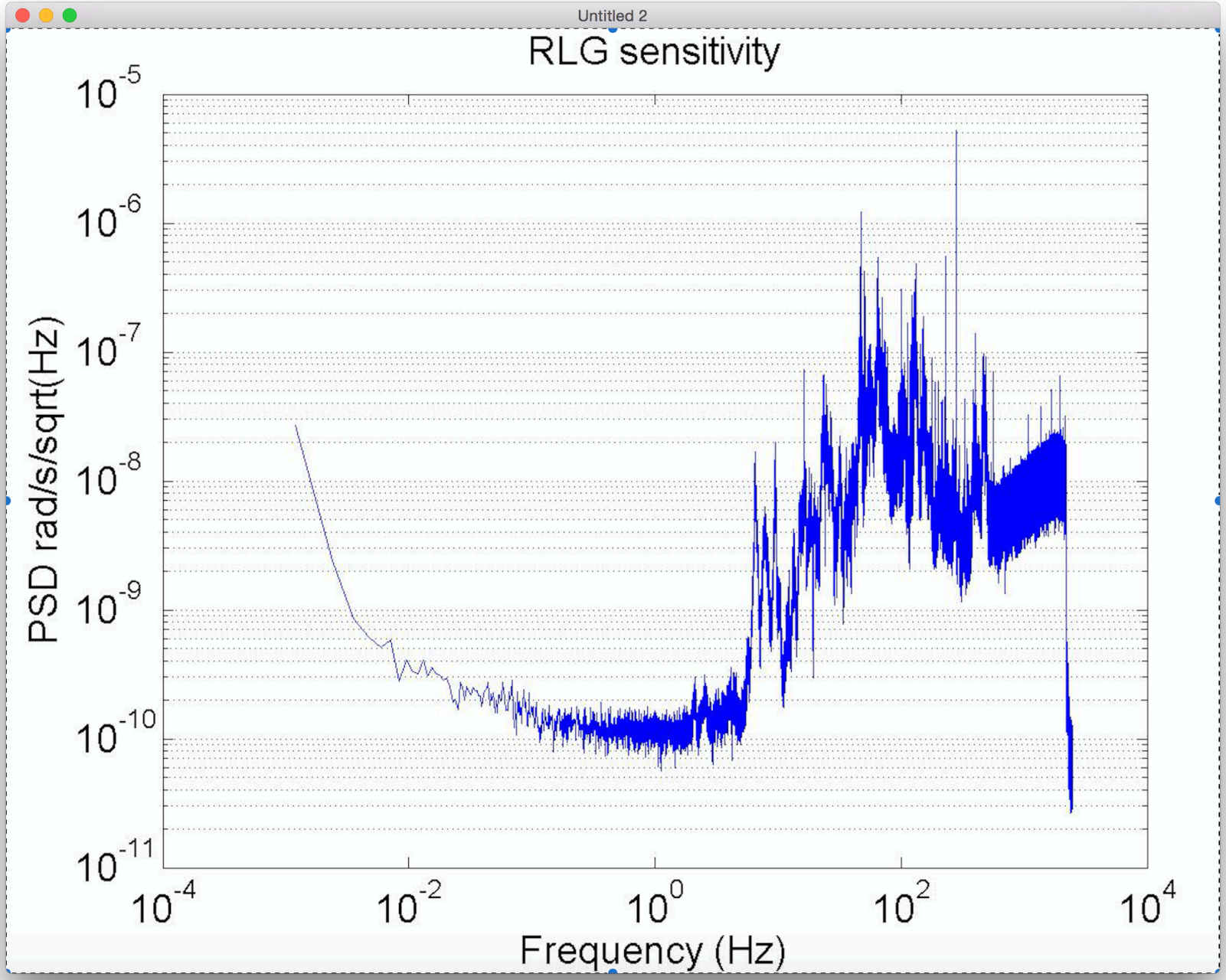

38 Hours, starts June 12, 10 a.m. and 13 the whole day
x 10^-5
4.9233
4.9232
4.9231
4.923
4.9229
4.9228
4.9227
4.9226
4.9225
4.9224
4.9223
Angular Velocity (rad/s)
0.5
1
1.5
2
2.5
Counts
x 10^5
x 10^-9
4
3
2
1
0
-1
-2
-3
-4
-5
Acceleration (A.U.)
0.5
1
1.5
2
2.5
Counts (2 Hz)
x 10^5

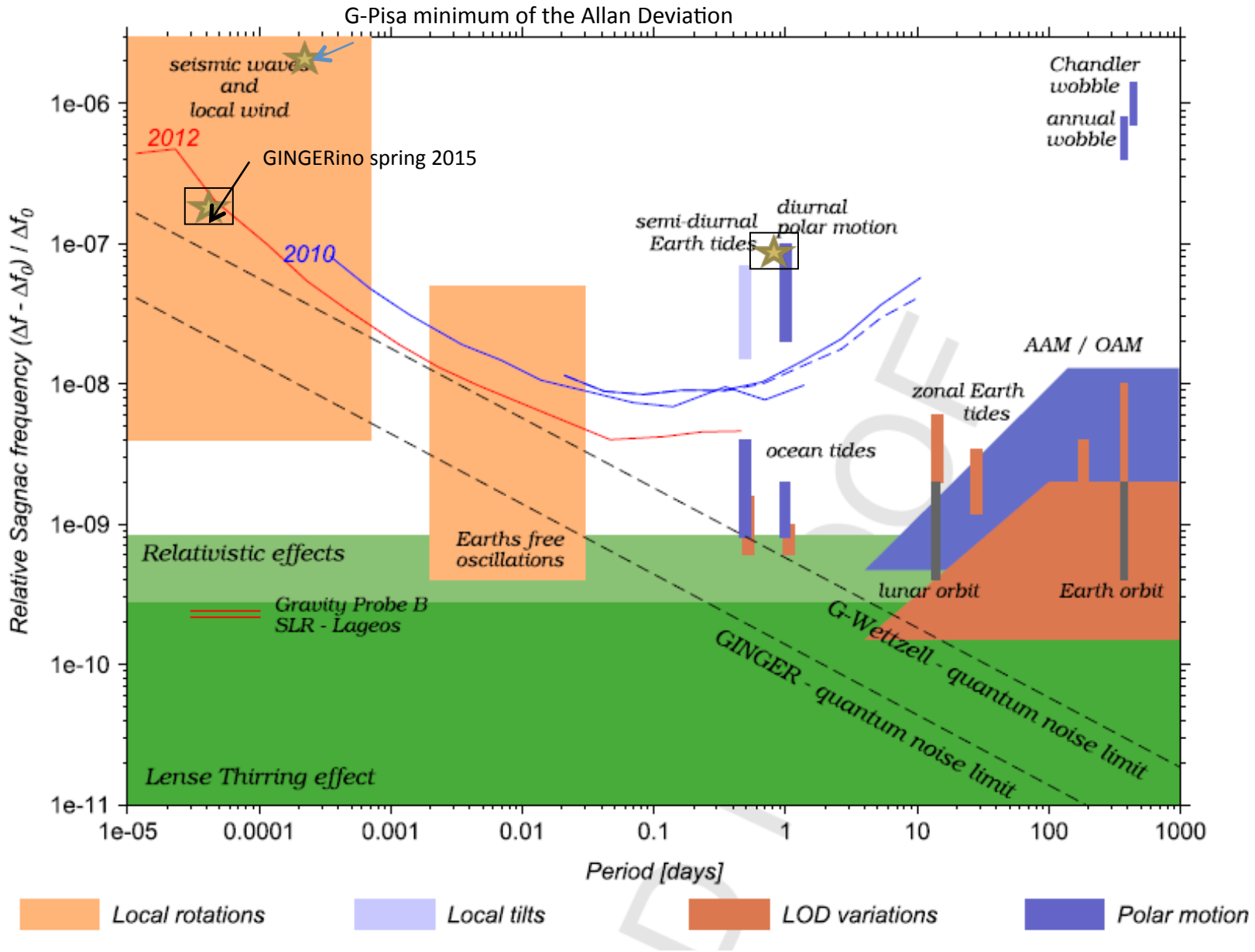

AlaVar 5.2
Allan STD DEV
ADEV
HDEV
Lower Bound
Upper Bound
1E-10
1E-11
σ(τ)
1
10
100
τ
Produced by AlaVar 5.2

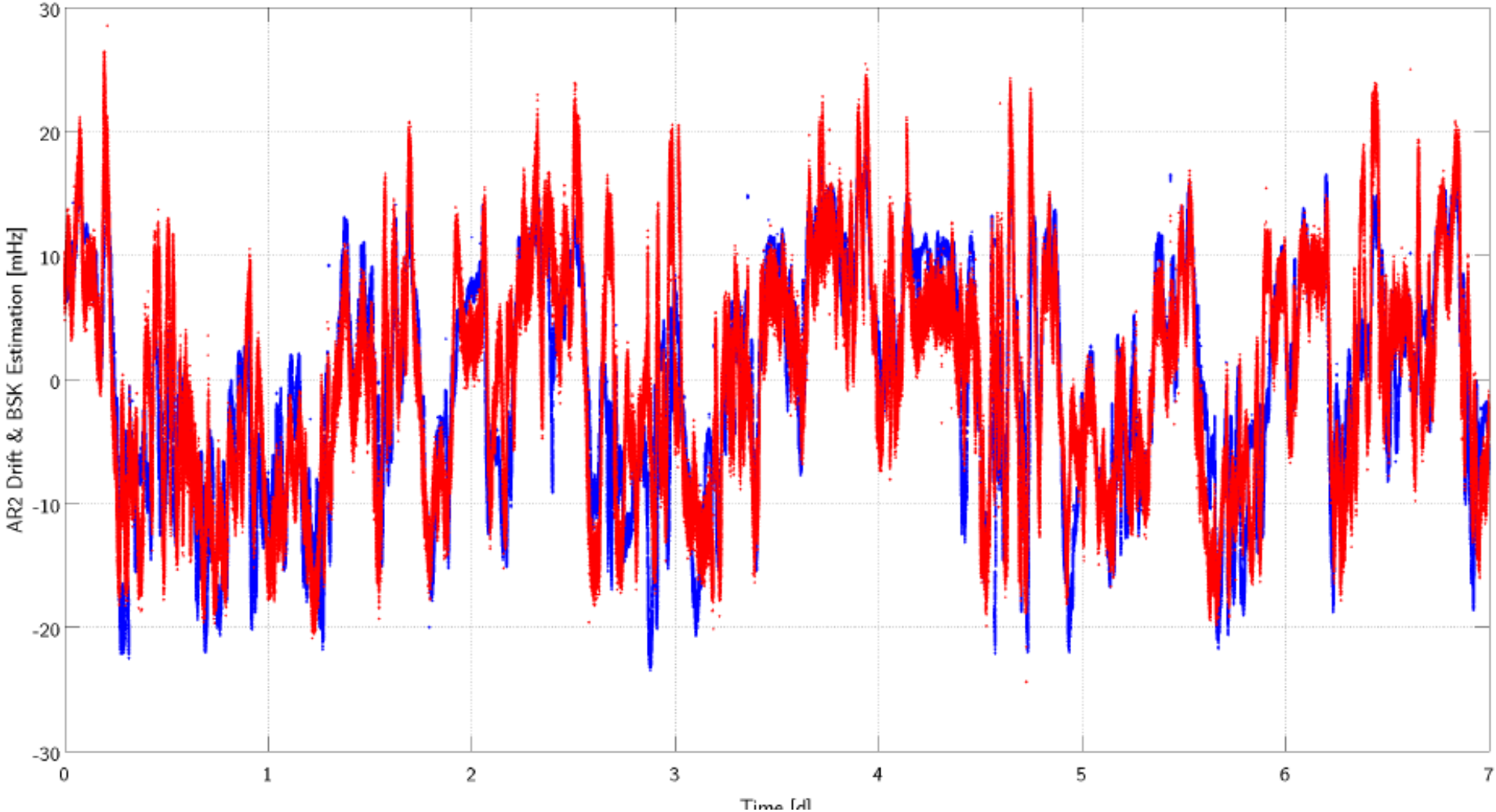

AlaVar 5.2
Data Values
-2.25E-9
-2.3E-9
-2.35E-9
-2.4E-9
-2.45E-9
-2.5E-9
-2.55E-9
-2.6E-9
-2.65E-9
-2.7E-9
Data Values
0
200
400
600
800
1000
1200
1400
1600
1800
index
Produced by AlaVar 5.2


AlaVar 5.2
Allan STD DEV
ADEV
HDEV
Lower Bound
Upper Bound
1E-10
1E-11
σ(τ)
1
10
100
τ
Produced by AlaVar 5.2

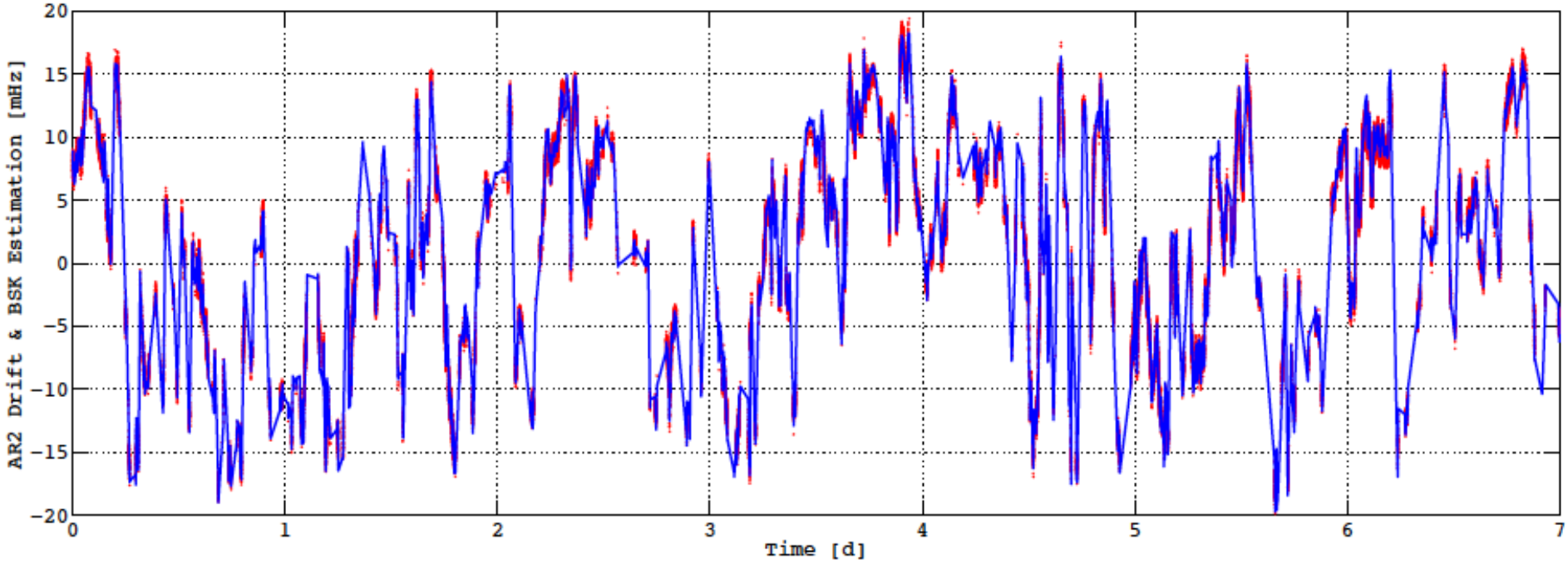

June 14, Sunday
x 10^-9
4
3
2
1
0
-1
-2
-3
-4
angular velocity (rad/s)
0
1
2
3
4
5
6
7
8
9
Time (s)
x 10^4

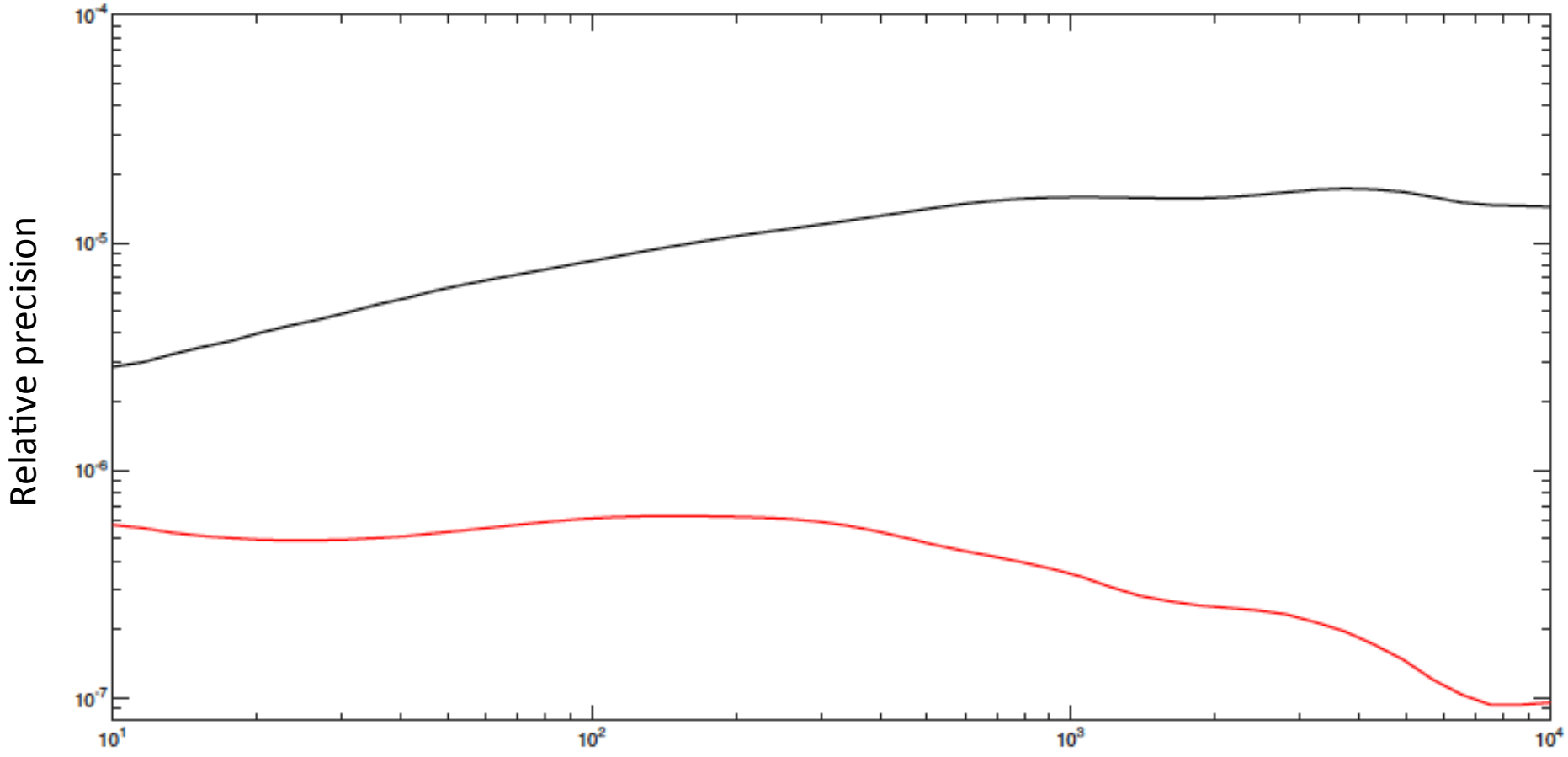

Untitled 2
RLG sensitivity
PSD rad/s/sqrt(Hz)
10^-5
10^-6
10^-7
10^-8
10^-9
10^-10
10^-11
10^-4
10^-2
10^0
10^2
10^4
Frequency (Hz)


G-Pisa minimum of the Allan Deviation
seismic waves and local wind
2012
GINGERino spring 2015
2010
Chandler wobble
annual wobble
semi-diurnal Earth tides
diurnal polar motion
AAM / OAM
zonal Earth tides
ocean tides
Earths free oscillations
Relativistic effects
Gravity Probe B
SLR - Lageos
lunar orbit
Earth orbit
G-Wettzell - quantum noise limit
GINGER - quantum noise limit
Lense Thirring effect
Relative Sagnac frequency (Δf - Δf0) / Δf0
1e-06
1e-07
1e-08
1e-09
1e-10
1e-11
1e-05
0.0001
0.001
0.01
0.1
1
10
100
1000
Period [days]
Local rotations
Local tilts
LOD variations
Polar motion


AR2 Drift & BSK Estimation [mHz]
30
20
10
0
-10
-20
-30
0
1
2
3
4
5
6
7
Time [d]

Backscattering subtracted,
Kept only data with best coherence with backscattering (30%)





About 5 10^{-12} rad/s

Improve:

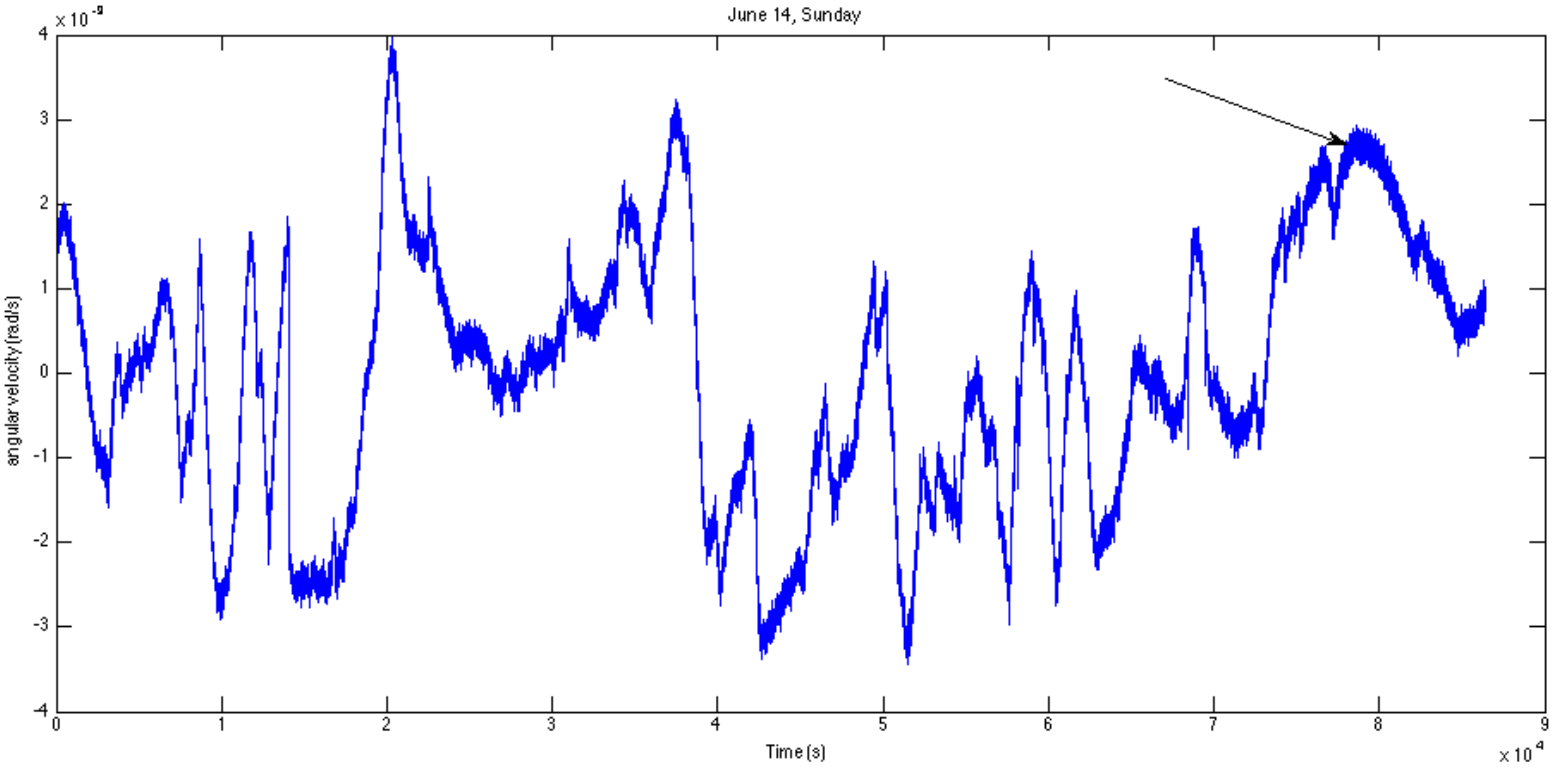
gain monitoring for the subtraction

Short term stability

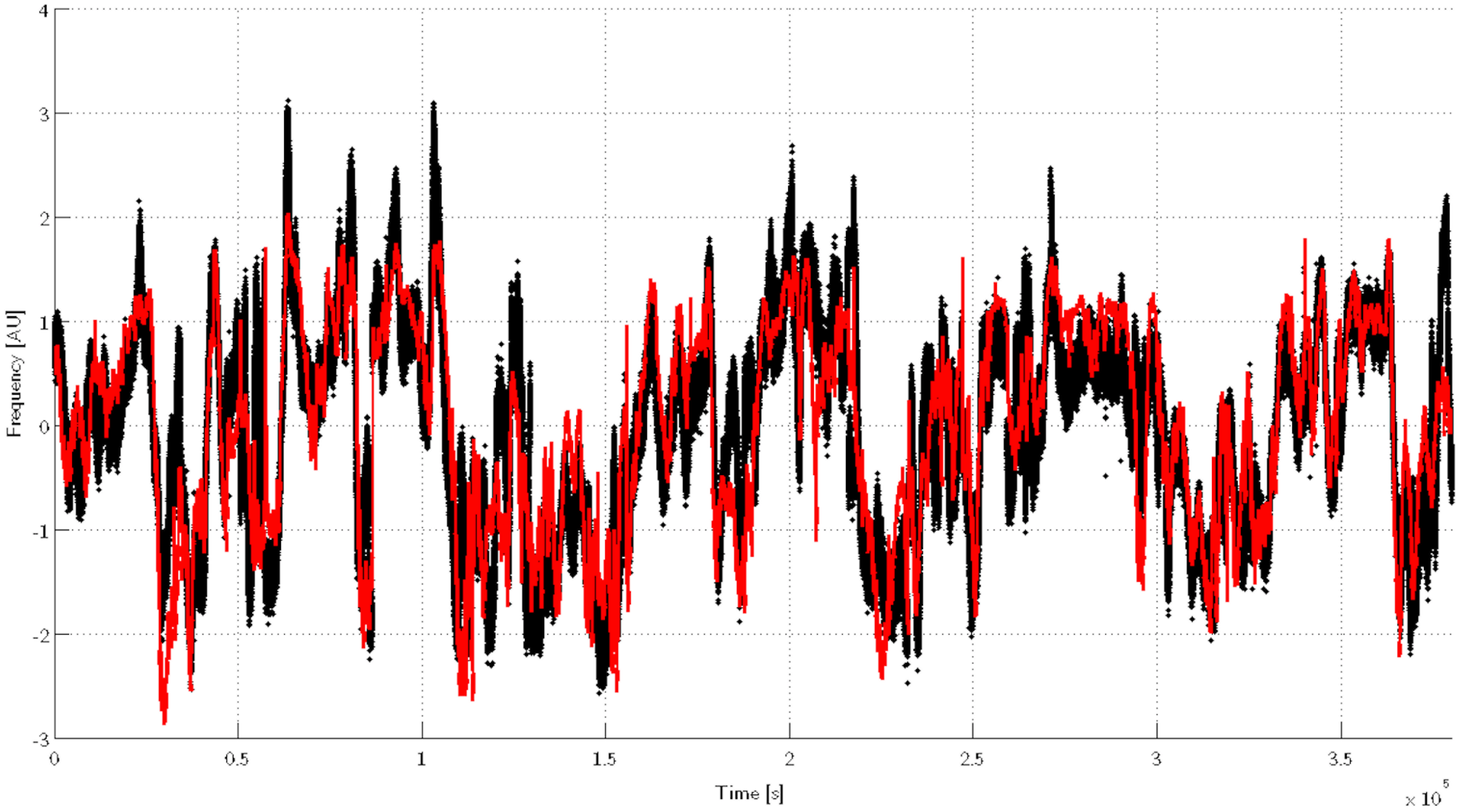
Scopo di GINGERino “validare il sito di LNGS per GINGER”

- Presa dati e data analisi
- Misure con sismometri e tiltmetri

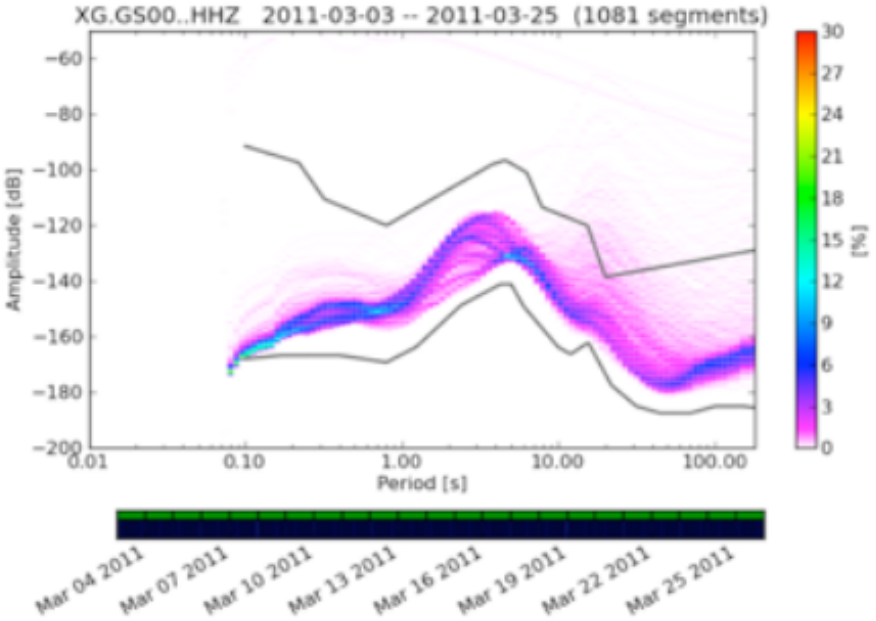
Il prototipo G-Pisa non e' particolarmente stabile



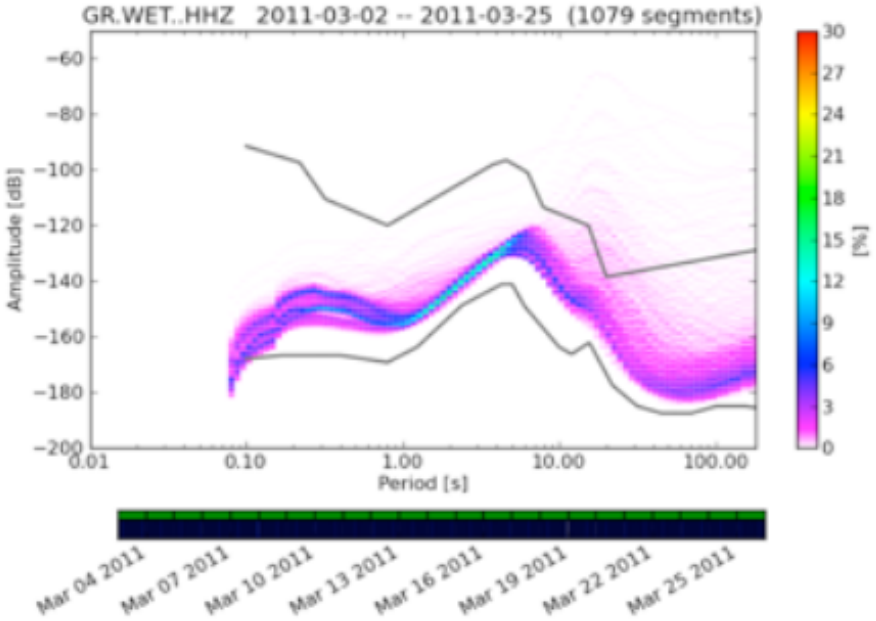
Sagnac signal compared with evaluated backscattering



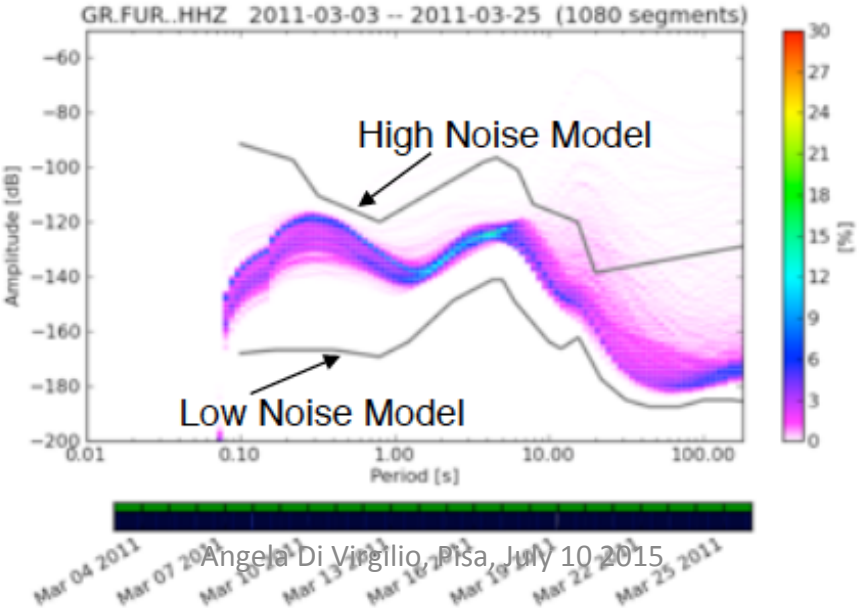
Noise Level of Trillium Gran Sasso - Z



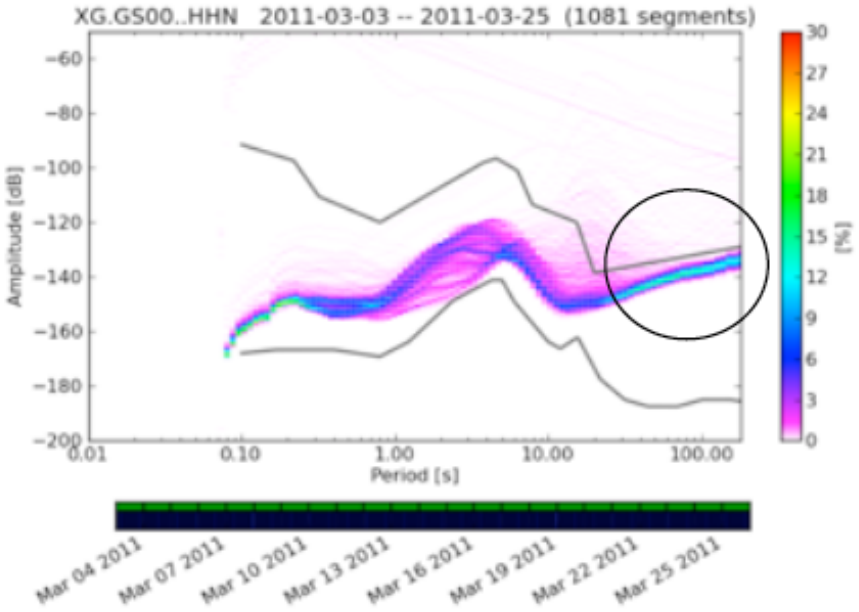
Noise Level of STS-2 Wettzell - Z



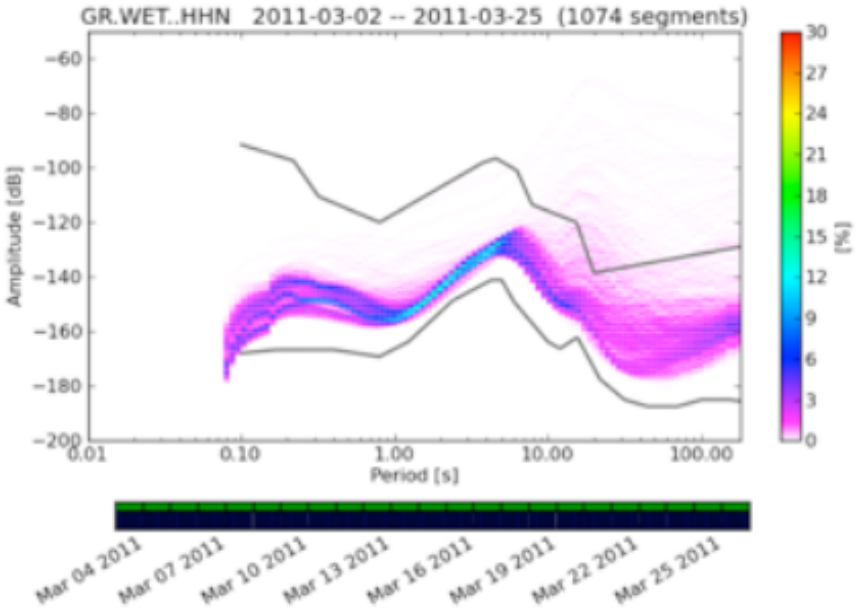
Noise Level of STS-2 BFC



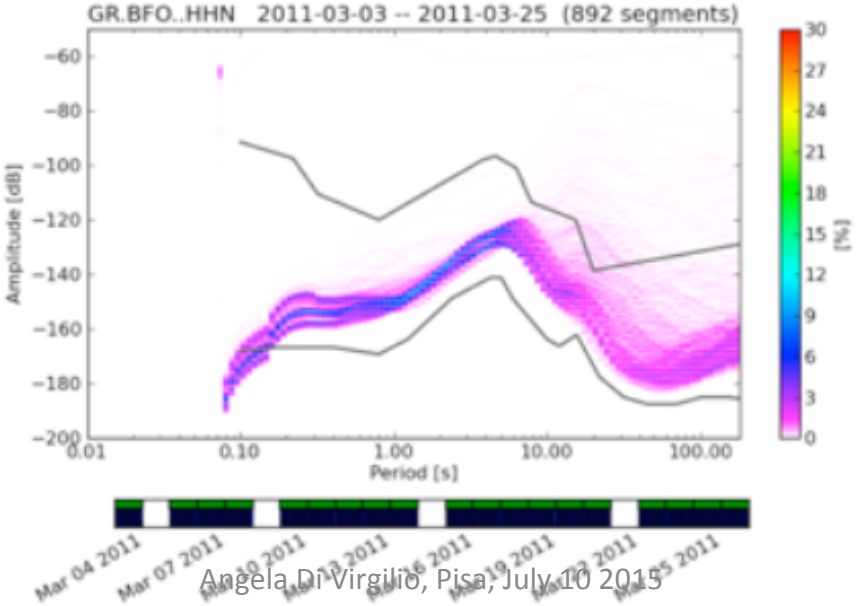
Noise Level of Trillium Gran Sasso -N



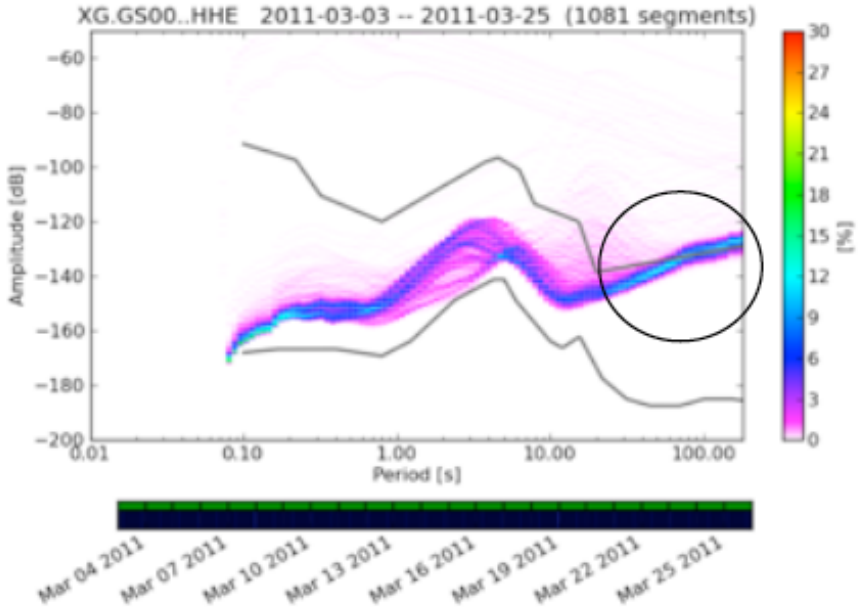
Noise Level of STS-2 Wettzell - N



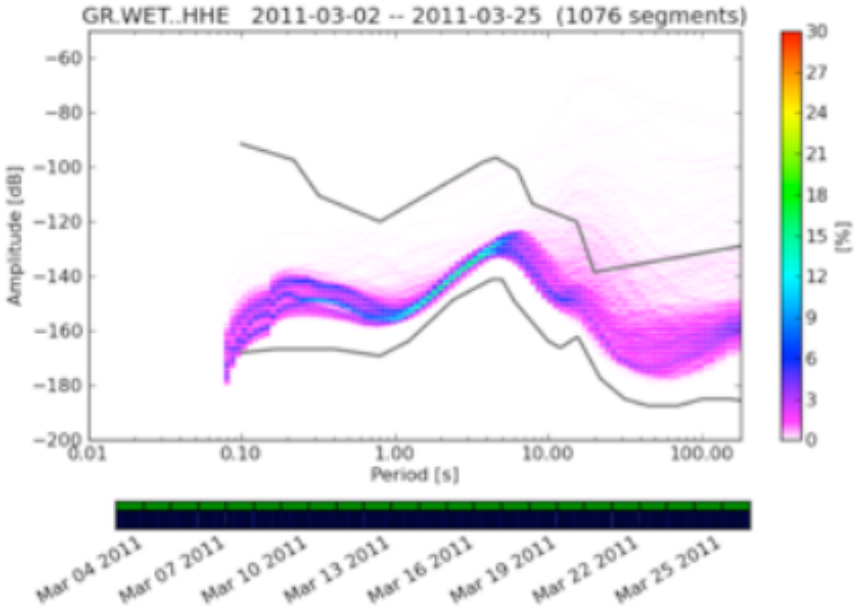
Noise Level of STS-2 BFO



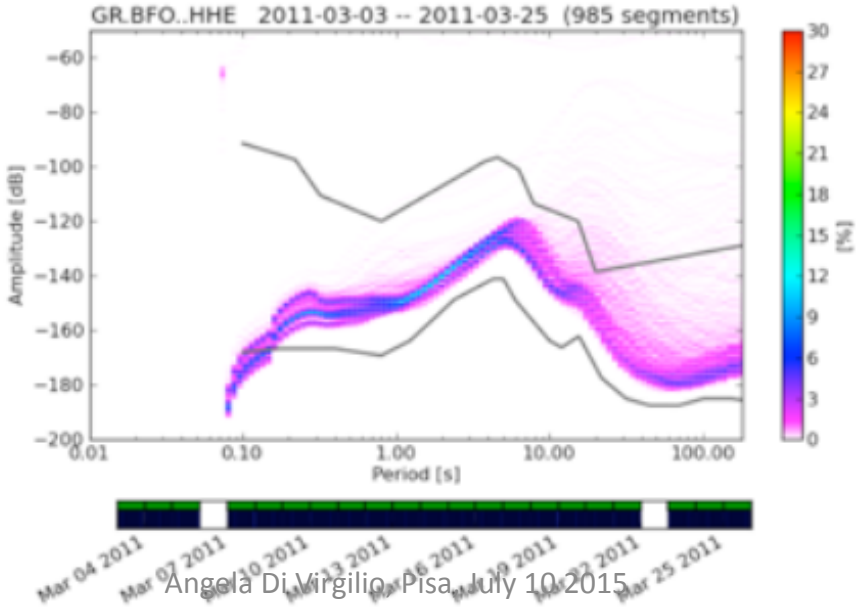
Noise Level of Trillium Gran Sasso -EW

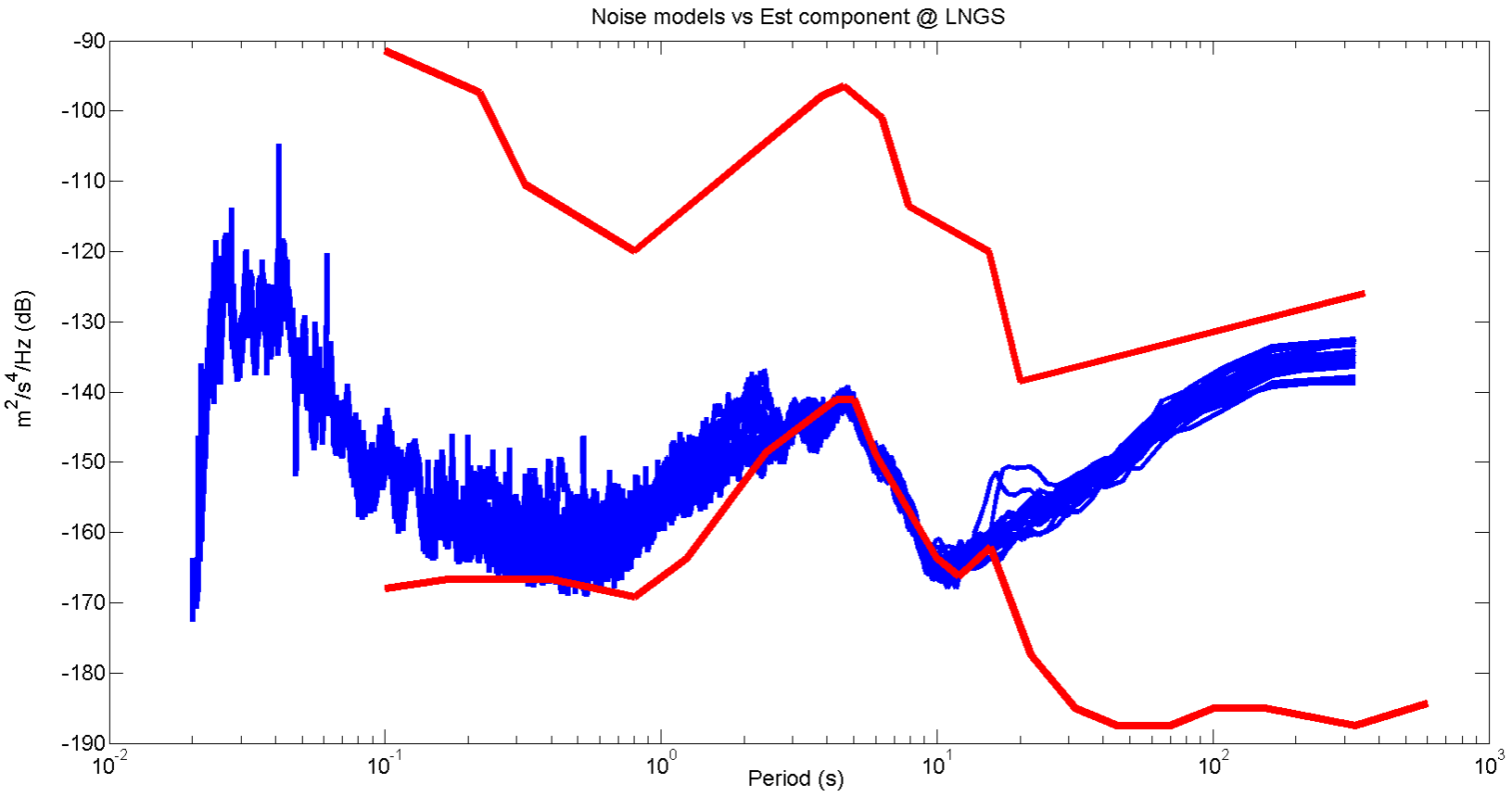


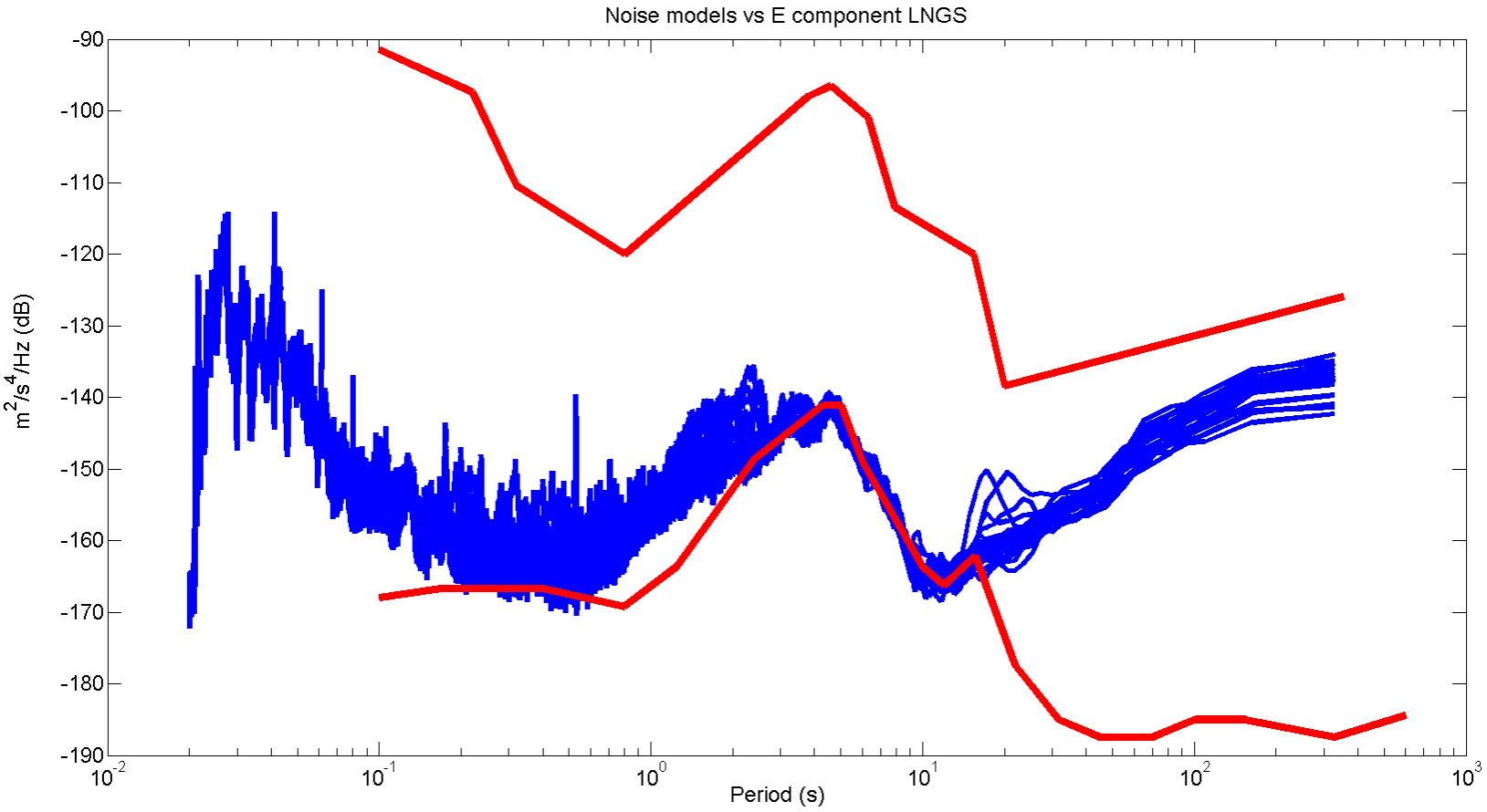
Noise Level of STS-2 Wettzell - EW

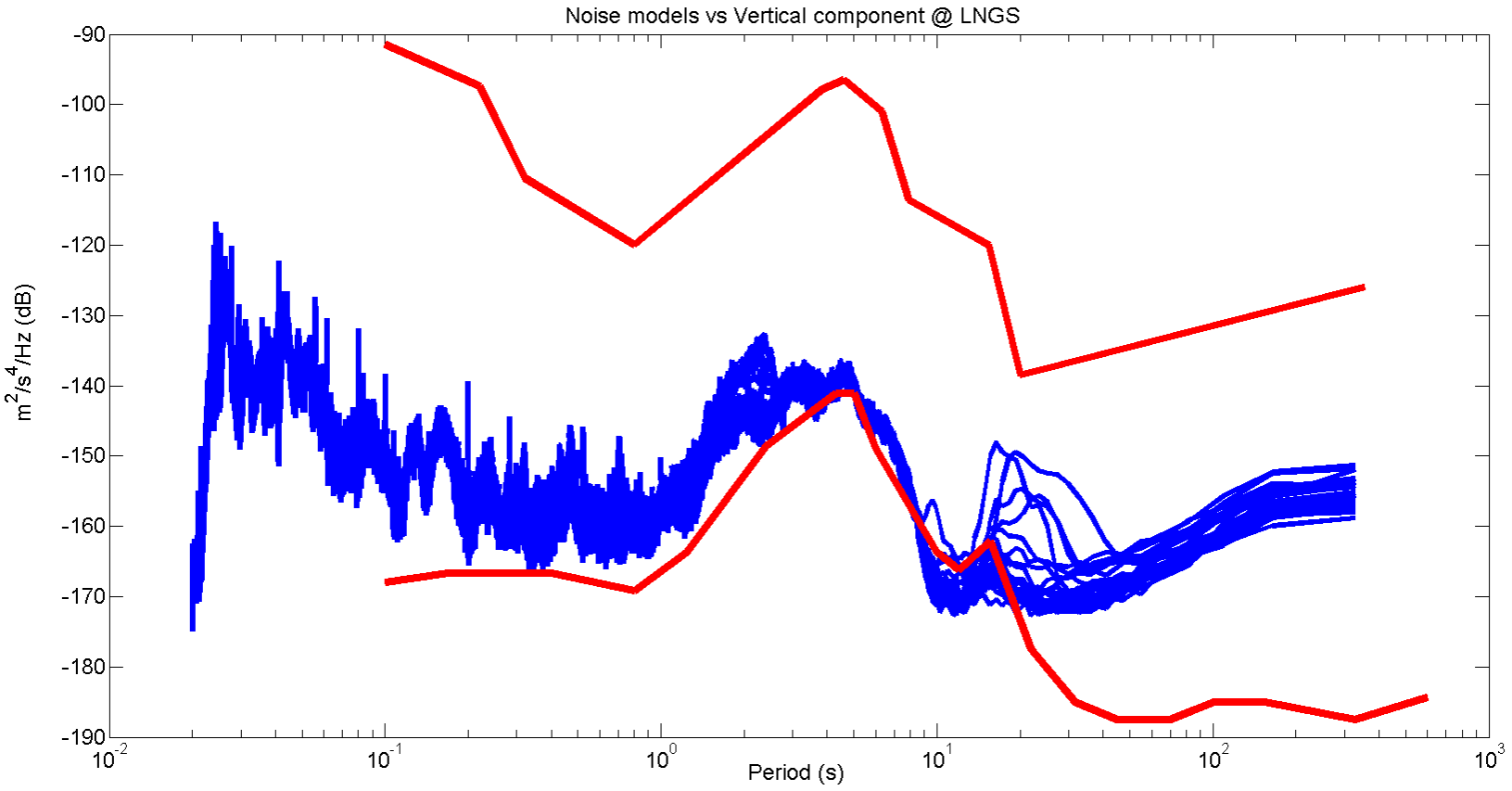


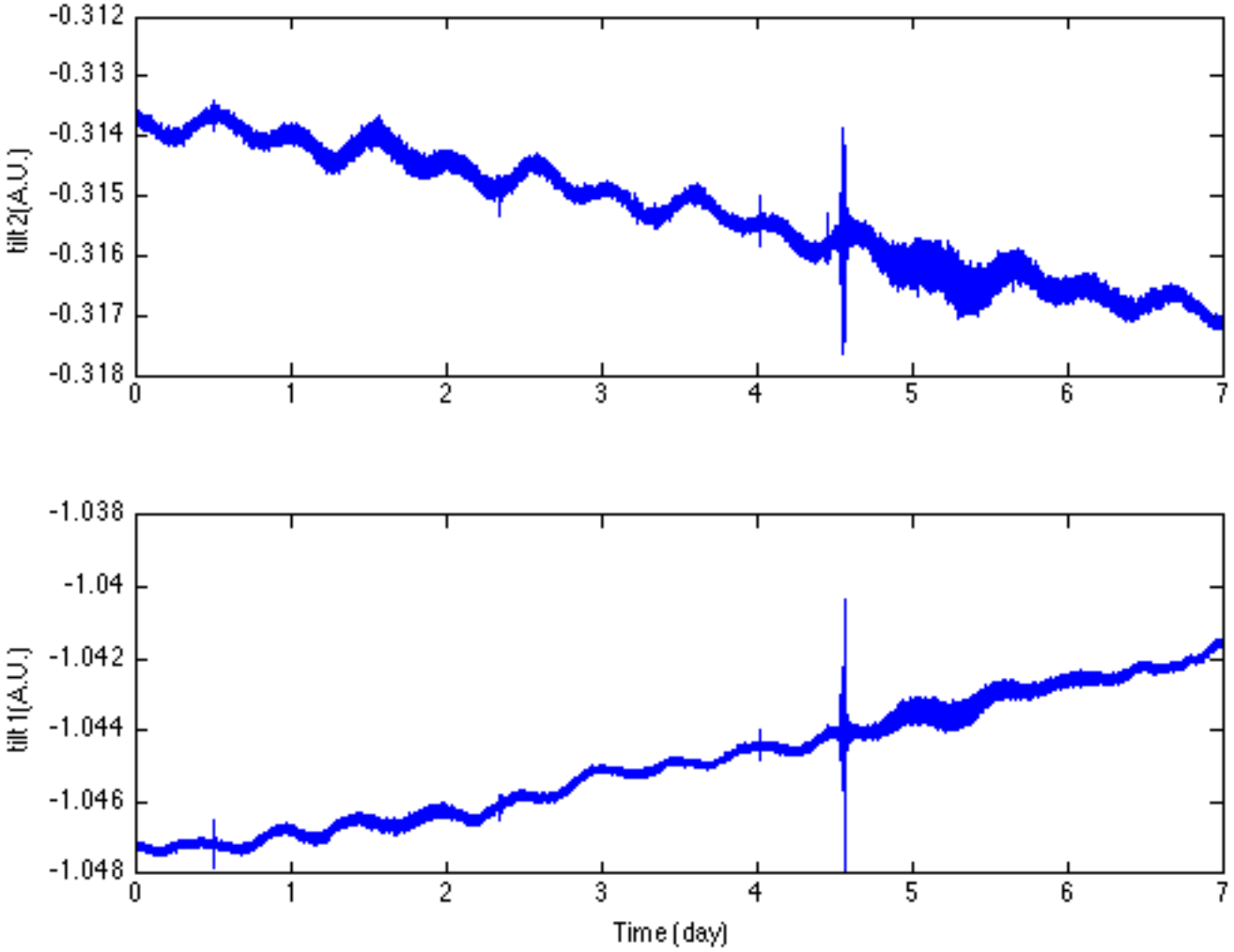
Noise Level of STS-2
BFO - EW




Noise models vs Est component @ LNGS
-90
-100
-110
-120
-130
-140
-150
-160
-170
-180
-190
m2/s4/Hz (dB)
10-2
10-1
100
101
102
103
Period (s)


Noise models vs E component LNGS
-90
-100
-110
-120
-130
-140
-150
-160
-170
-180
-190
m2/s4/Hz (dB)
10-2
10-1
100
101
102
103
Period (s)

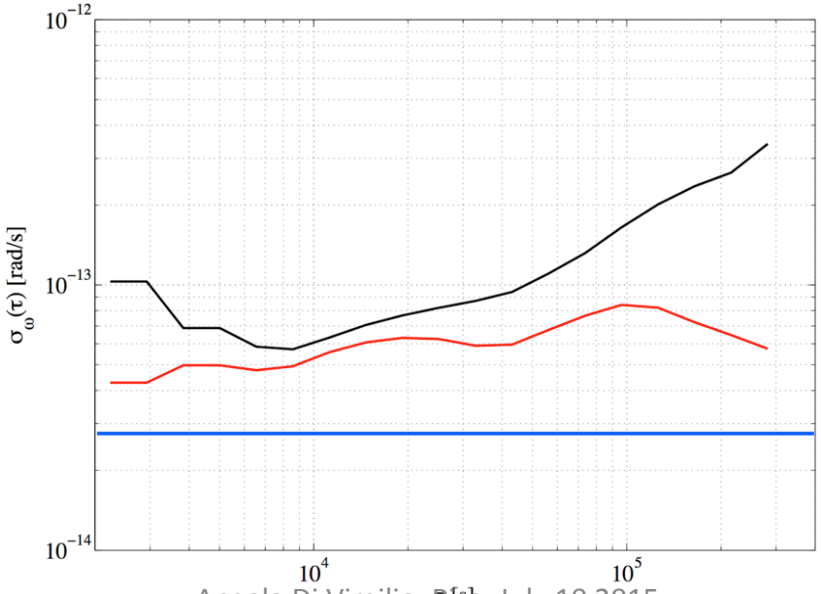

Noise models vs Vertical component @ LNGS
-90
-100
-110
-120
-130
-140
-150
-160
-170
-180
-190
m2/s4/Hz (dB)
10-2
10-1
100
101
102
103
Period (s)



Tiltmeter 1 and 2

EURAM-Calibrazione

- progetto ERC, EURAM, un ringlaser dedicato alla calibrazione assoluta dello strumento
- CALIBRAZIONE PROBLEMA FONDAMENTALE DEI RINGLASERS



- Il prototipo ‘eterolitico’ la cui stabilita’ e’ basata sul controllo da’ il vantaggio di poter muovere, vibrare etc. gli specchi in modo da applicare rotazioni note al giroscopo
- Con questi movimenti e vibrazioni e’ possibile ottimizzare l’allineamento e l’orientazione del ringlaser

Sperimentazione a Pisa 2016

- Necessita' di una nuova sorgente stabilizzata
- Sperimentazioni sulla scarica e filtro spaziale
- Sperimentazione sul sistema di read-out con prisma
- Studio dell'ottimizzazione della geometria e relativo controllo
- aumentare il numero di attuatori a 12
- Revisione critica di GP2 per realizzare GP3: 12 attuatori e aggiunta del 'tilt' alle movimentazioni 'rough'

Sperimentazione di GINGERino

- Tenuto in misura per quanto possibile anche per I segnali di tipo sismico e per eventuali osservazioni di segnali geodetici
- Necessario implementare il controllo del perimetro
- Migliorie studiate su GP2 potrebbero essere implementate (ottimizzazione scarica, filtro spaziale,

Alcuni dettagli

- Scarica: forma ed elettrodi
- Filtro spaziale separato dal capillare
- Prima per lettura sotto vuoto (la stiamo sperimentando su RLG-INRIM)

Costo sperimentazione circa 10kE consumi

Costi stimati upgrading GINGERino

- Trasporti 2kE
- Elettronica di controllo 20kE (necessaria anche con il prototipo attuale)
- Consumi vari (ottica-vuoto-prove per la scarica e lettura Sagnac con prima sottovuoto etc) 20kE
- Cabinet-cleanroom portatile 20kE (?)
- Secondo ZURICH 30kE

GP2

- **2016 dedicato a implementare su G-Pisa il controllo e iniziare ad usare tecniche di modulazione per ottimizzare l'allineamento e valutare il fattore di scala**
- 2 specchi + 1 attuatore (10kE)+ 1 attuatore a 3 gradi di liberta' (20kE)
- Nuova Sorgente stabilizzata assoluta 90kE
- Consumi vari (ottica+vuoto+ gas) 20kE
- Cabinet a flusso lamonare portatile 20kE

missioni

- Nel 2016 occorrera’ avere piu’ scambi con I colleghi tedeschi 50kE

Risorse di sezione

- 10% Filippo: adeguamento lab. Di GP2, e revisione critica della meccanica di GP2
- 1 MeseUomo alte tecnologie
- Contributo di elettronica sarebbe molto benvenuto (non e' mai stato esplicitato, ma abbiamo sempre avuto un supporto)
- 20% G. Terreni: trasferimento dati etc.
- 2Mese-Uomo officina: sviluppo dei test sulla scarica etc.
- Piccola percentuale risorse di calcolo: 1 MeseUomo