Tests and Understanding of the Virgo+ monolithic suspensions (1)

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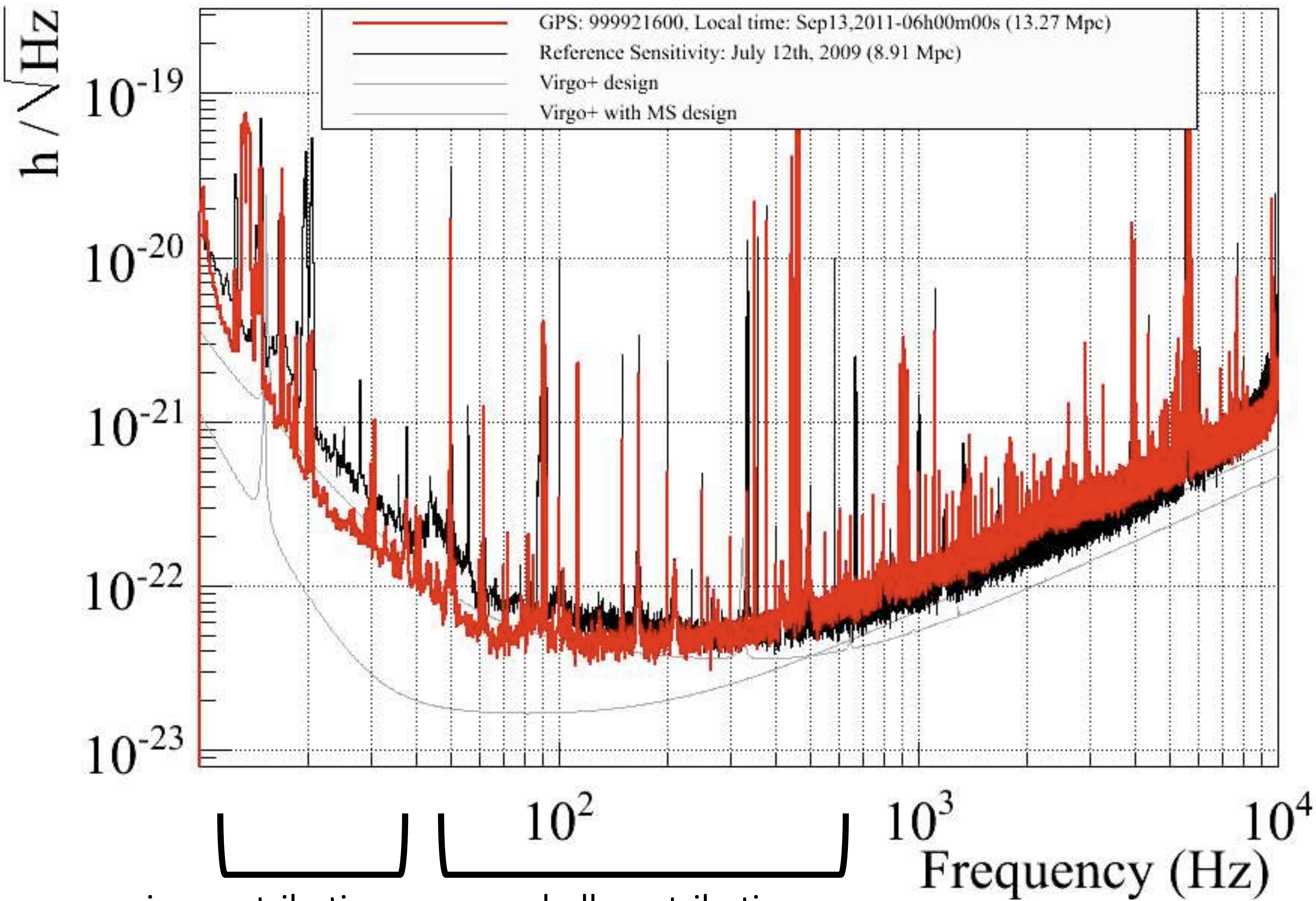
Thermal Noise Workshop

February 23-24 2012

Outline

- Quality Factor measurements:
  purpose and procedures
- experimental results:
  - pendulum
  - vertical
  - violins
  - bulk
- identification problems and temperature correlation

Virgo+ expected Thermal Noise



suspension contribution

bulk contribution

Thermal Noise estimation

We can estimate the Thermal Noise measuring the Quality Factor of the internal modes.

When a payload internal mode is excited, its amplitude decay time is related to the dissipation processes

$$A(t) = A_0 e^{-t/\tau} \Rightarrow Q = \pi \nu \tau$$

Different modes:

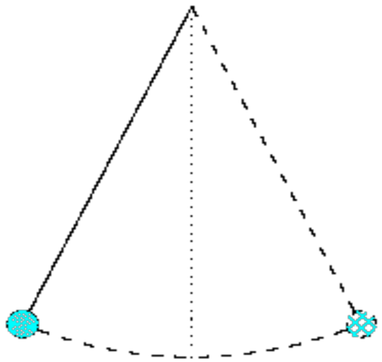
- are connected to different losses (superficial, thermoelastic, structural, recoil…)
- give different contributes to the Thermal Noise

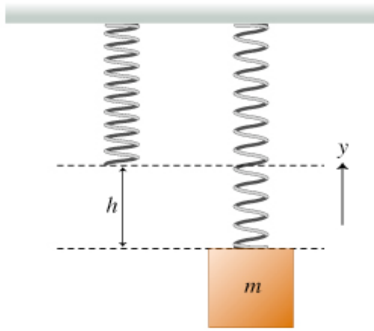
$\Downarrow$

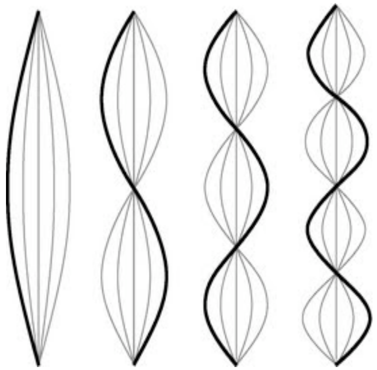
it is crucial to associate correctly each frequency with its own mode

Measured Internal modes

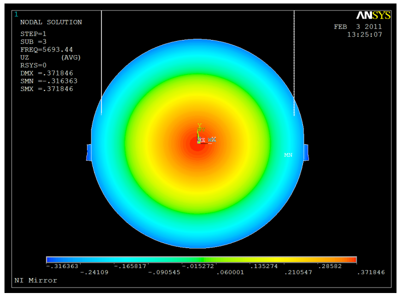
- suspension modes:
  - pendulum;
  - vertical;
  - violins;

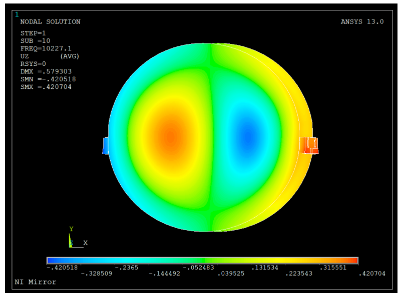


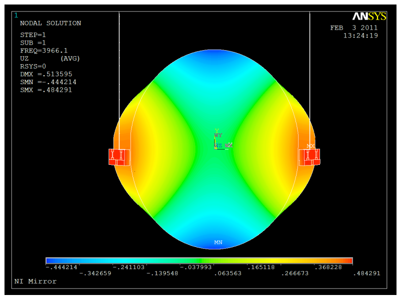


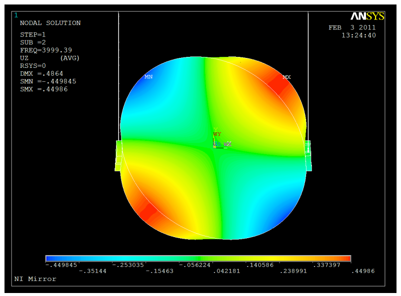


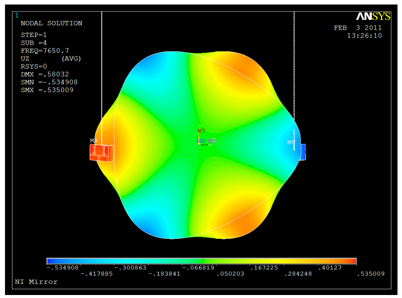
- bulk modes:
  - drum;
  - butterfly;
  - radial;
  - ....











Measurement procedure (up to 20 kHz)

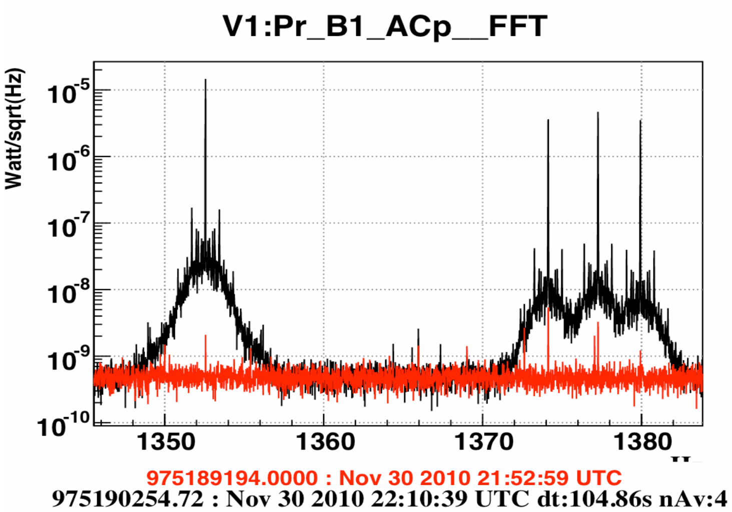
- Excitation ➔ kick (moving the Marionette Balancing Motor by 1 step for each tower)

  ITF locked and stable; different days; at least 1 hour of data

- the excitation effect can be observed directly in the Dark Fringe Pr_B1_Acp

  for the pendulum mode we observe the Local Control signals

- we identify every risen frequency, comparing the quiet signal with the spectra after the excitation
- we follow the decaying amplitude of each resonance at different times.

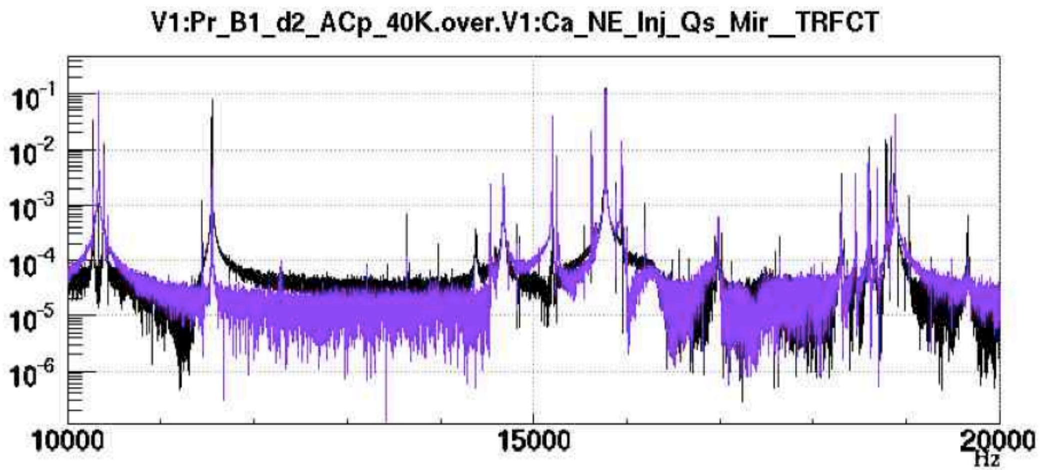


Measurement procedure (up to 40 kHz)

- Excitation → band-limited noise to RM coils (using the Spectrum Analyzer for each tower)

ITF locked and stable; different days; at least 1 hour of data

- the excitation effect can be observed in the Pr_B1_d2_ACp_40K
- we identify resonances using the transfer functions

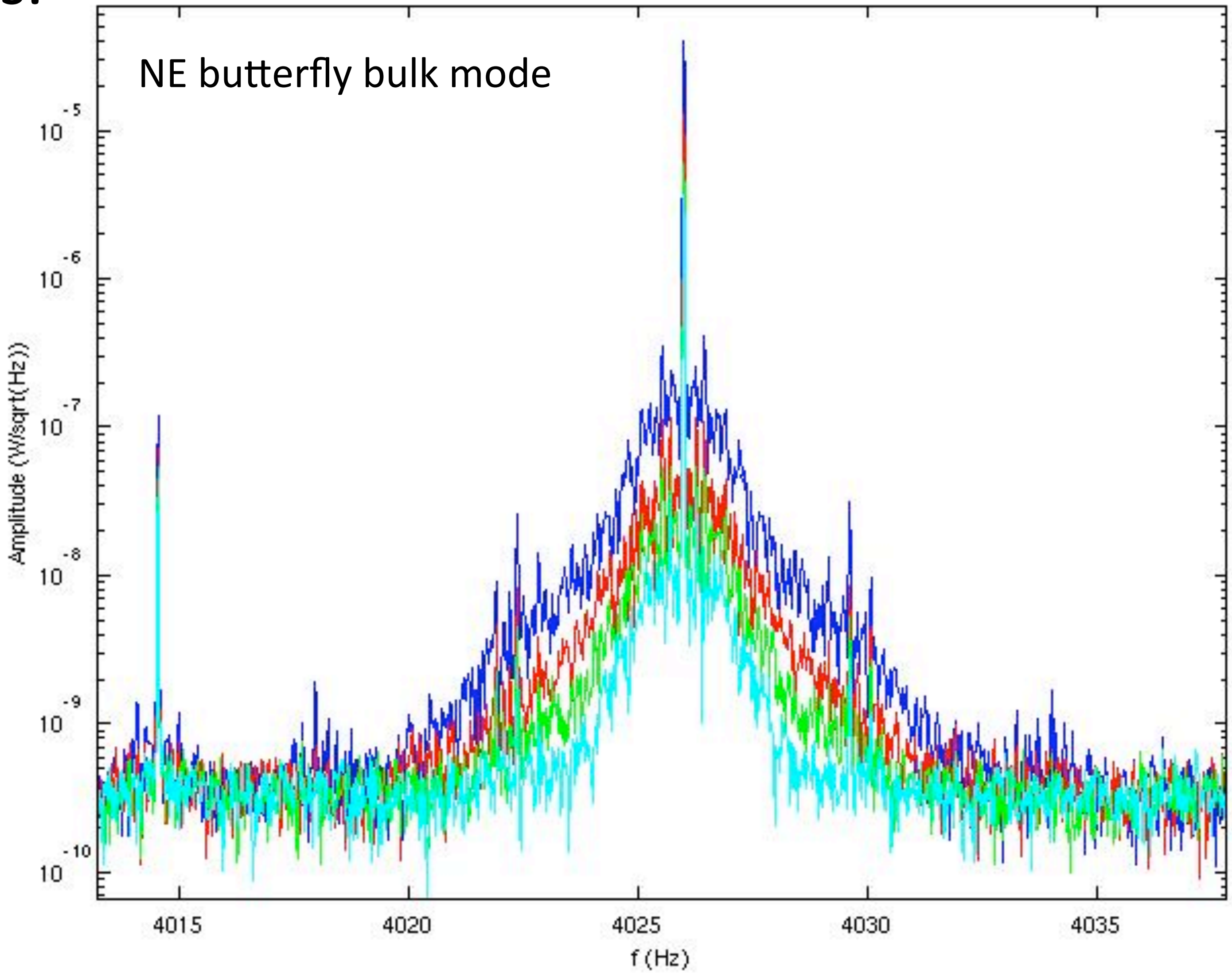


- we follow the decaying amplitude of the spectra for each resonance.

see Logbook entry: 29733, 29748, 29856, 29903

Quality Factor Measurement (1)

For each frequency we take its amplitude at different times.

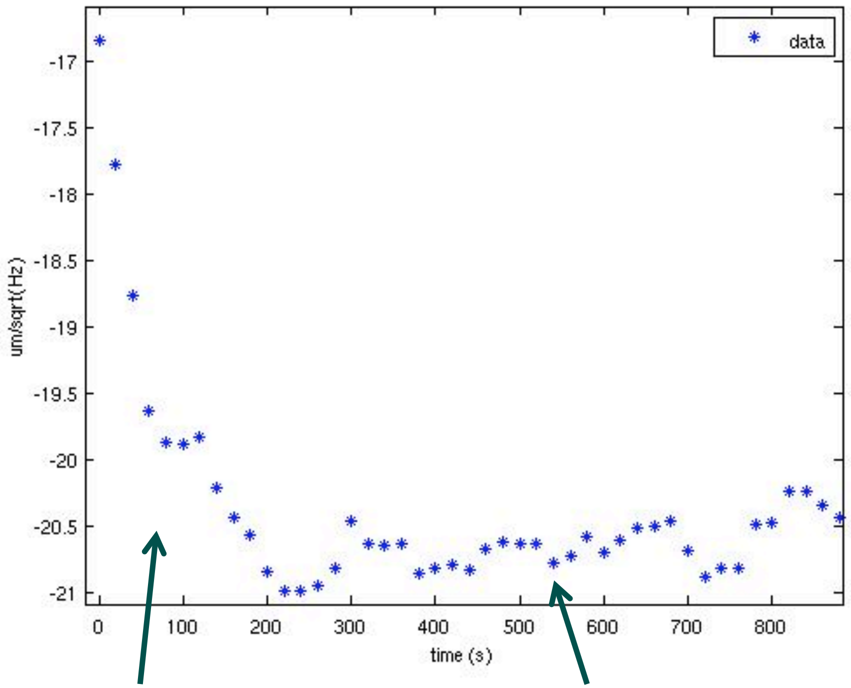


at excitation
after 200 s
after 380 s
after 400 s

Quality Factor Measurement (2)

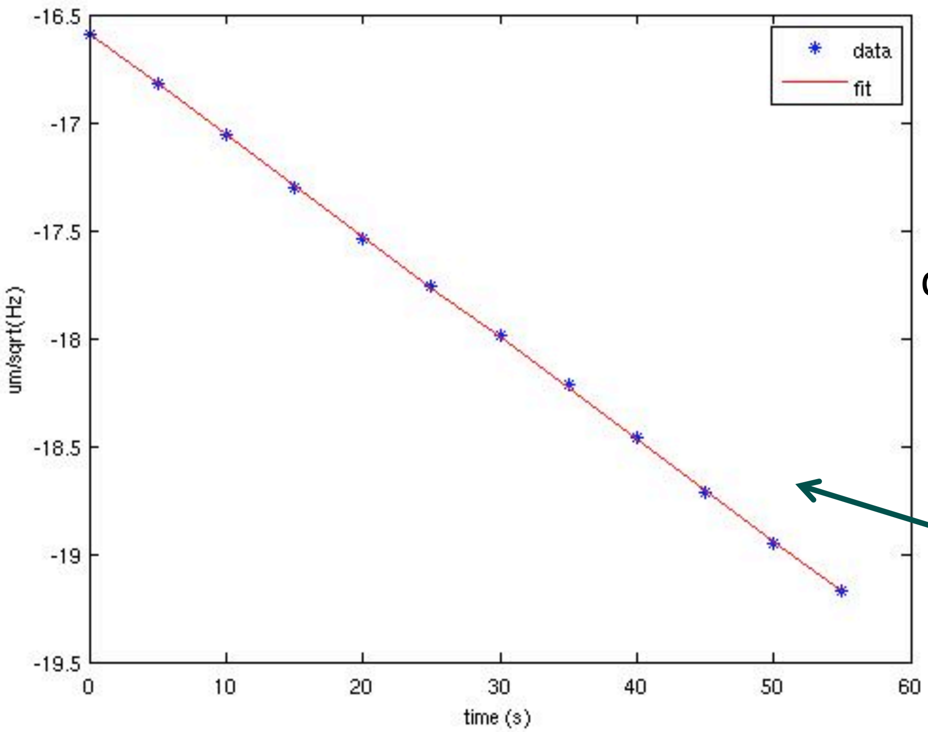
We fit the linearized data using a Matlab script.

Example:
WE f = 4537.17 Hz (X violin)
Q = 3.03 e5



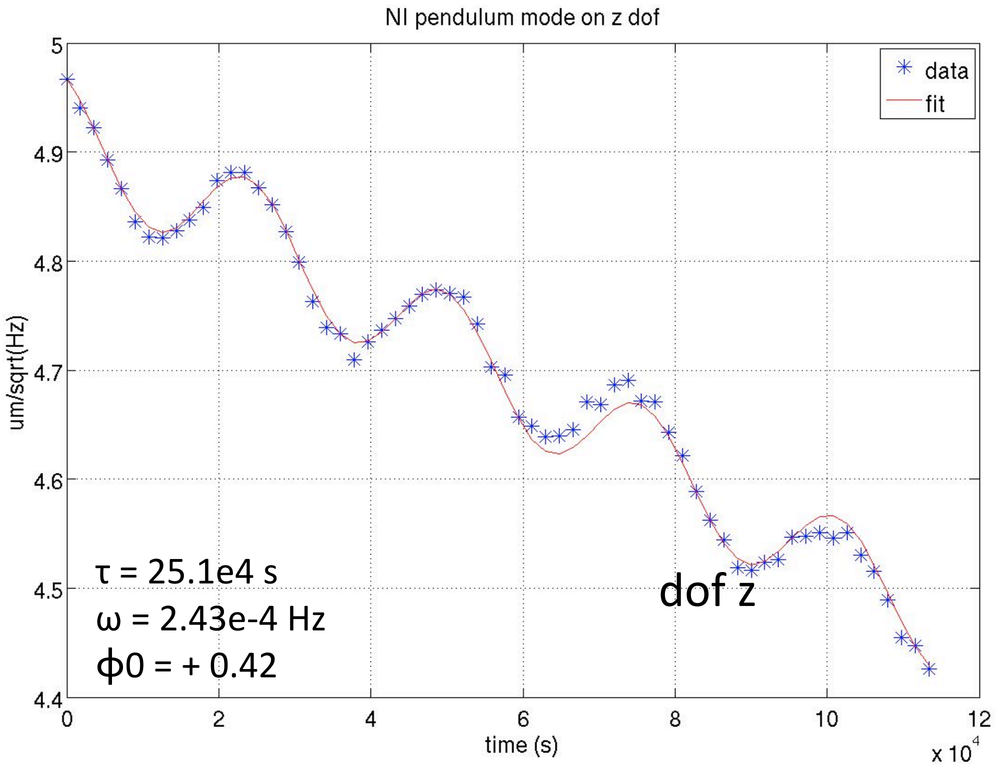
decaying amplitude

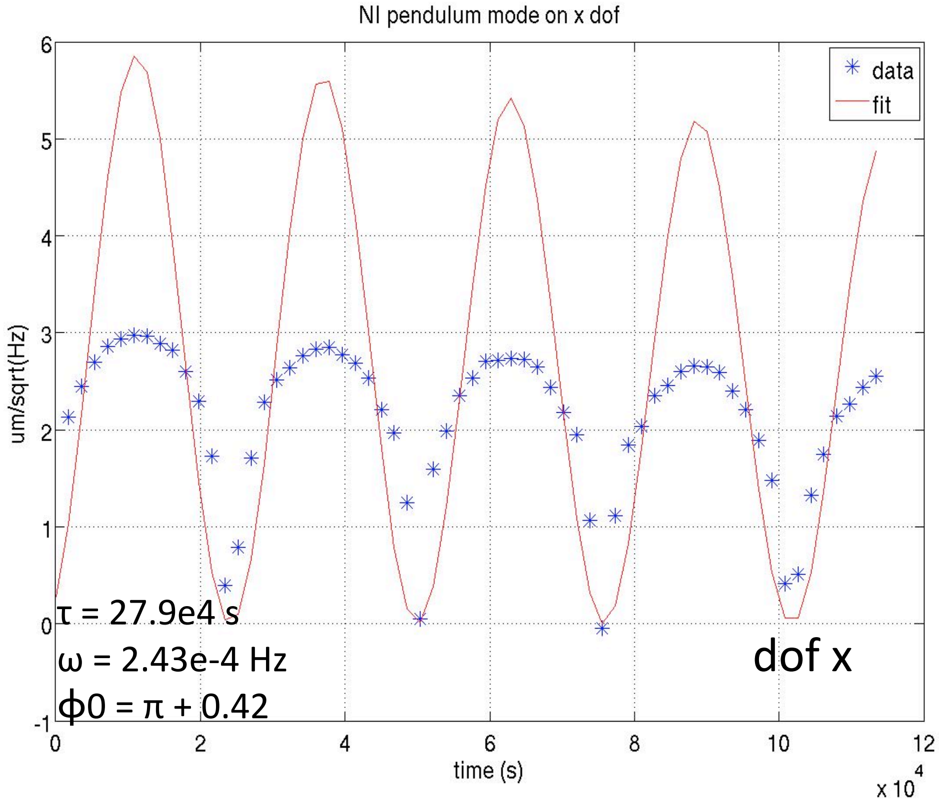
noise
(the peak is not recognizable anymore)



fitted data:
we take only the data with a linear behaviour

Pendulum Mode





NI

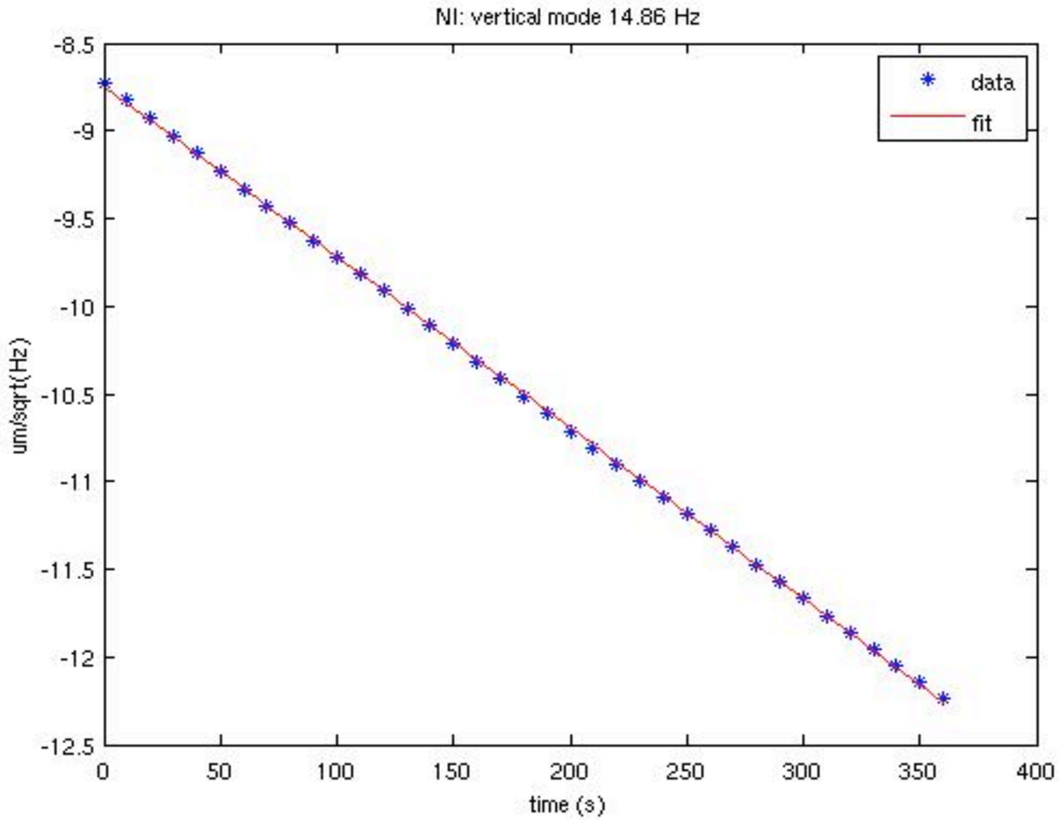
f = 0.59 Hz

There is a coupling between the z dof and the x;
furthermore the PSD on the x dof saturates.

	$\tau(s)\cdot 10^5$	$Q\cdot 10^5$
NI z	2.55	4.80
NI x	2.35	4.43
WI z	5.74	10.8
WI x	6.82	12.8
NE z	1.05	1.98
NE x	1.69	3.18
WE z	7.17	13.5
WE x	3.77	7.11

see VIR-0622A-10

Vertical Modes

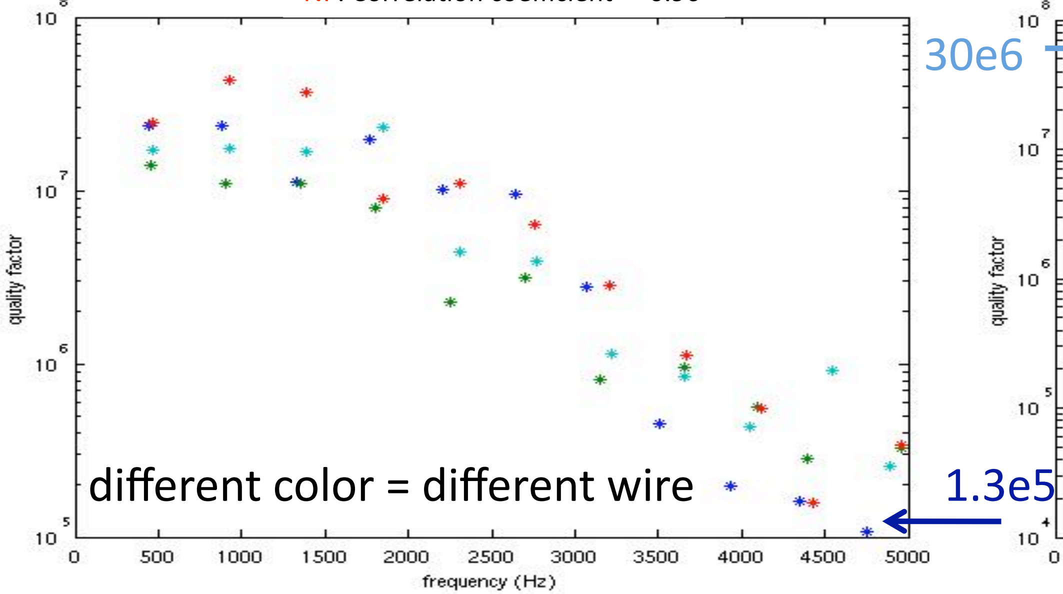


NI
dof y
f = 14.86 Hz

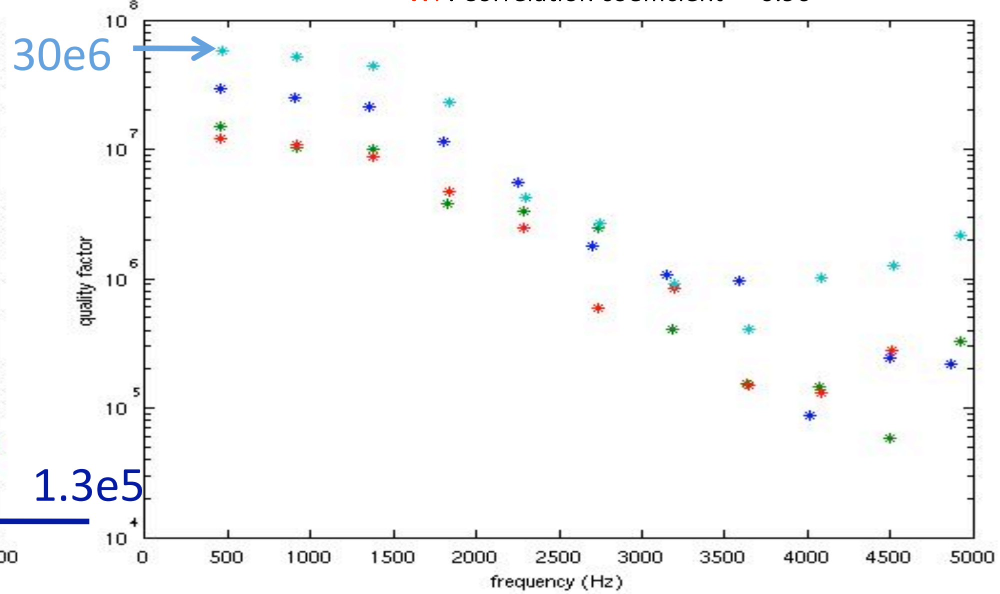
	f (Hz)	$\tau(s)$	$Q \cdot 10^4$
NI	5.97	4450	8.36
	14.86	103	0.48
WI	5.90	1570	2.90
	14.78	101	0.47
NE	5.97	560	1.05
	14.88	65.8	0.31
WE	5.92	134	0.25
	14.78	63.1	0.29

Violin Modes

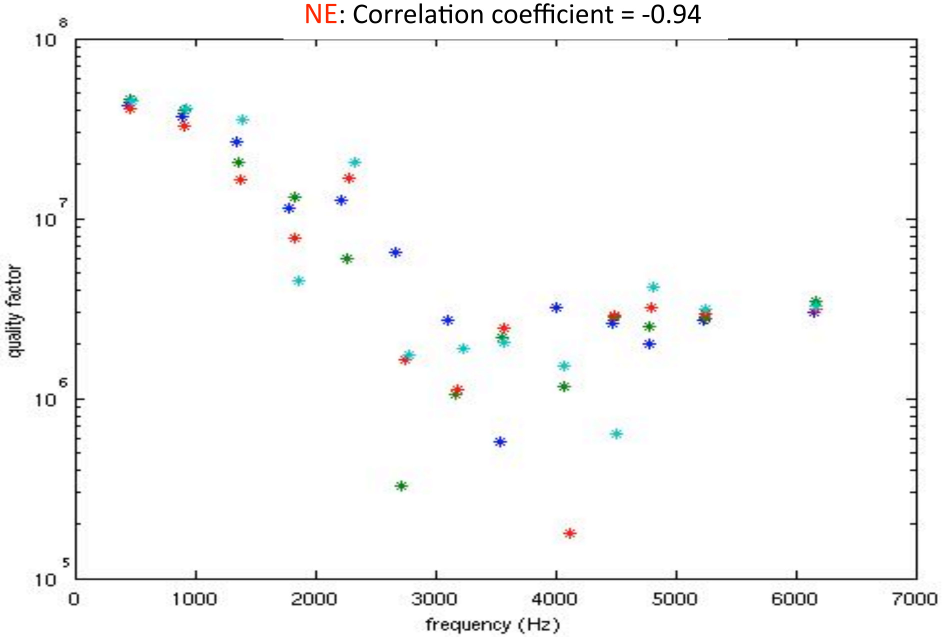
NI : Correlation coefficient = -0.96



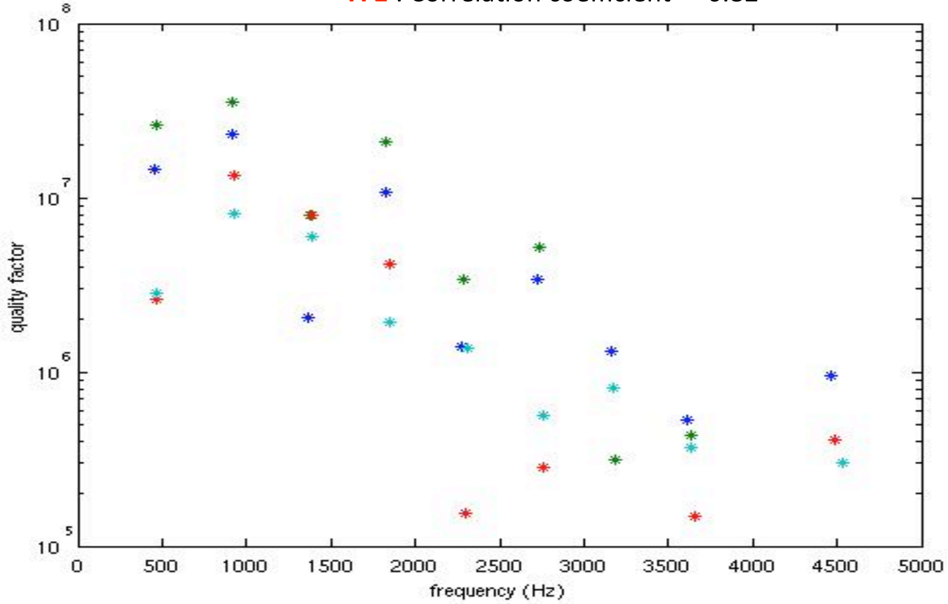
WI : Correlation coefficient = -0.96



NE: Correlation coefficient = -0.94



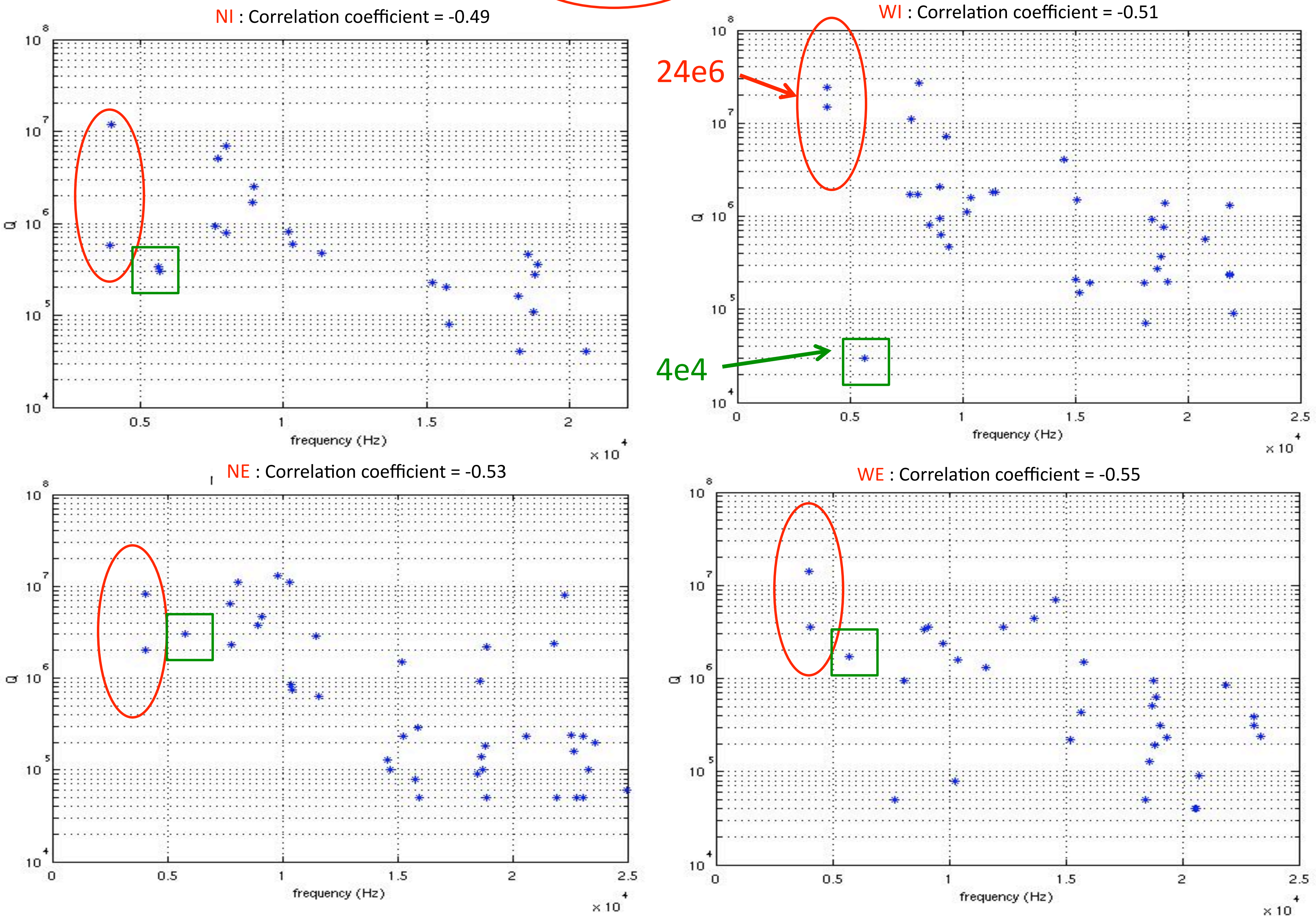
WE : Correlation coefficient = -0.82



Bulk Modes

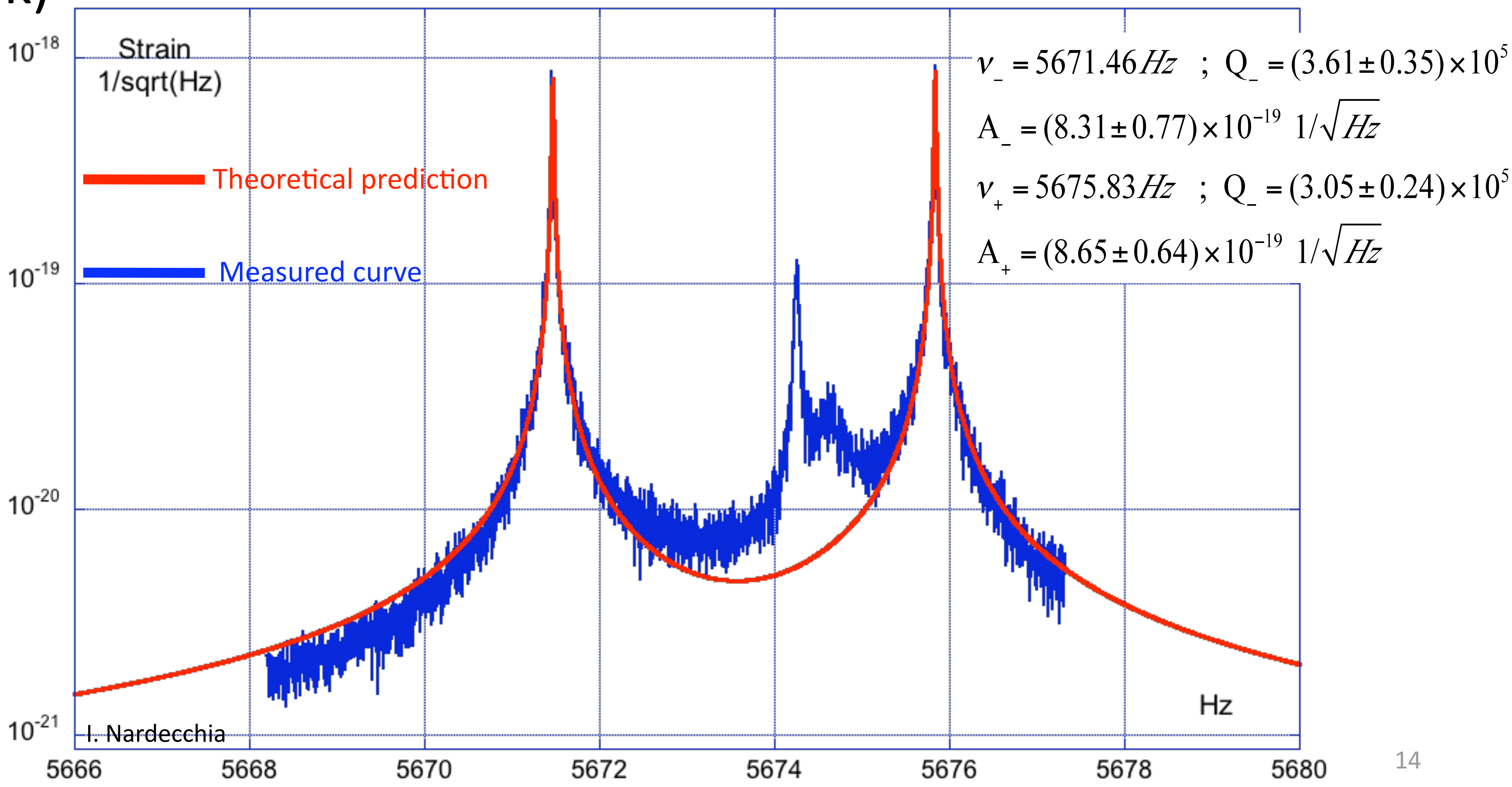
butterfly

drum

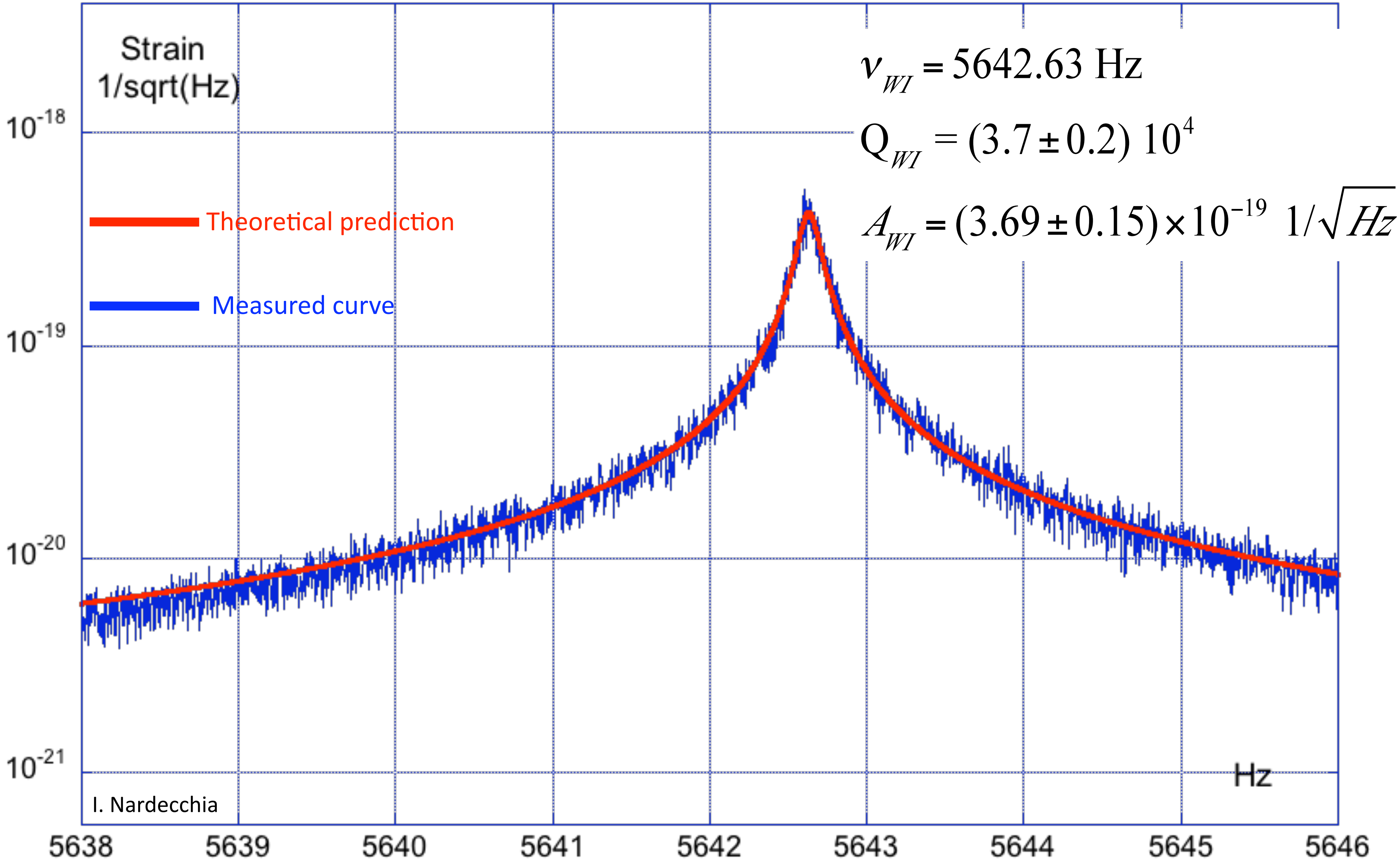


NI Drum modes

We repeat the Q estimation with a Lorentzian fit taking data from a quiet period (for interpretation and details see Puppo's talk)

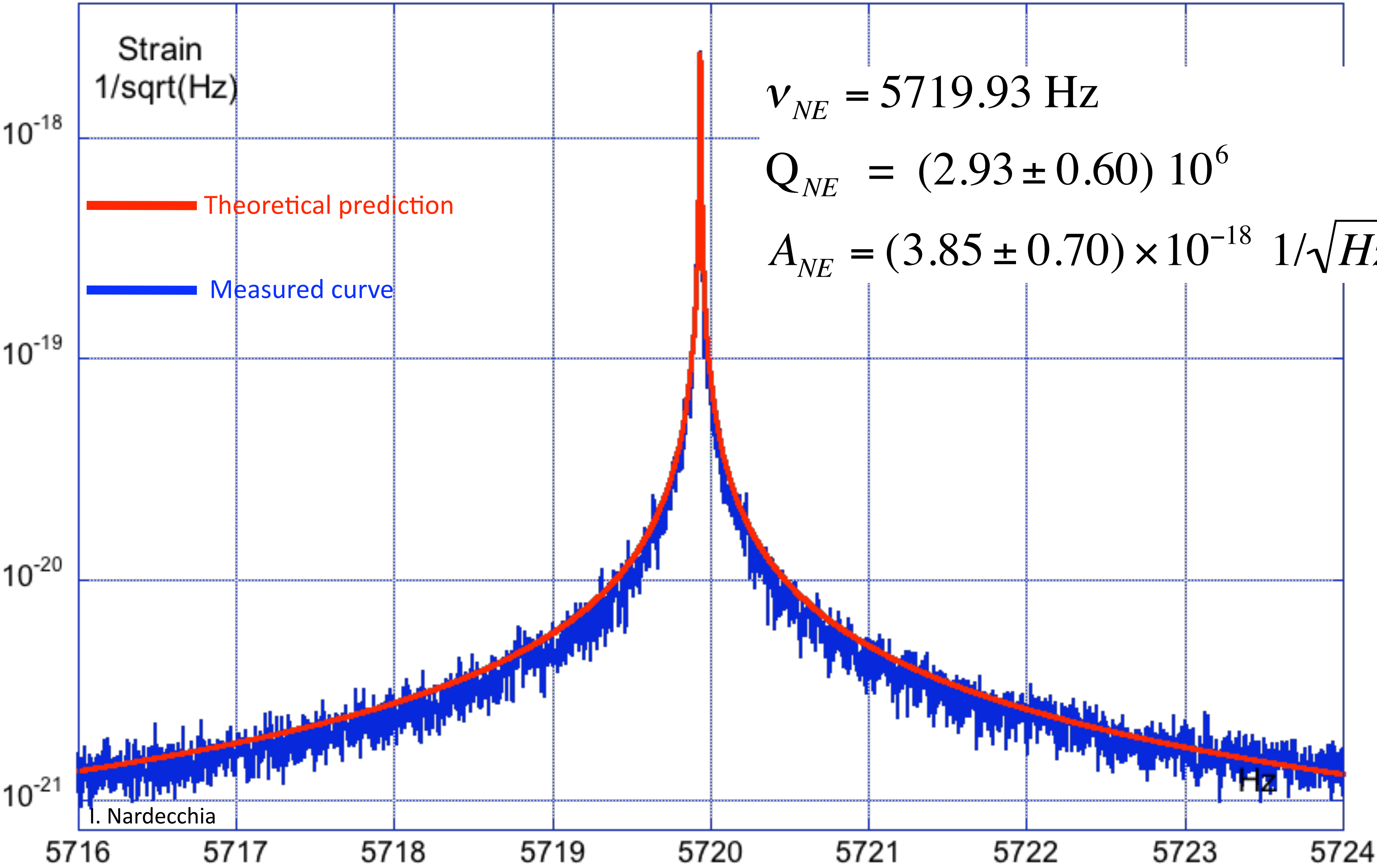


WI Drum mode



Strain
1/sqrt(Hz)
10^{-18}
10^{-19}
10^{-20}
10^{-21}
Theoretical prediction
Measured curve
$\nu_{WI} = 5642.63$ Hz
$Q_{WI} = (3.7 \pm 0.2)\ 10^4$
$A_{WI} = (3.69 \pm 0.15) \times 10^{-19}\ 1/\sqrt{Hz}$
Hz
I. Nardecchia
5638
5639
5640
5641
5642
5643
5644
5645
5646

NE Drum mode

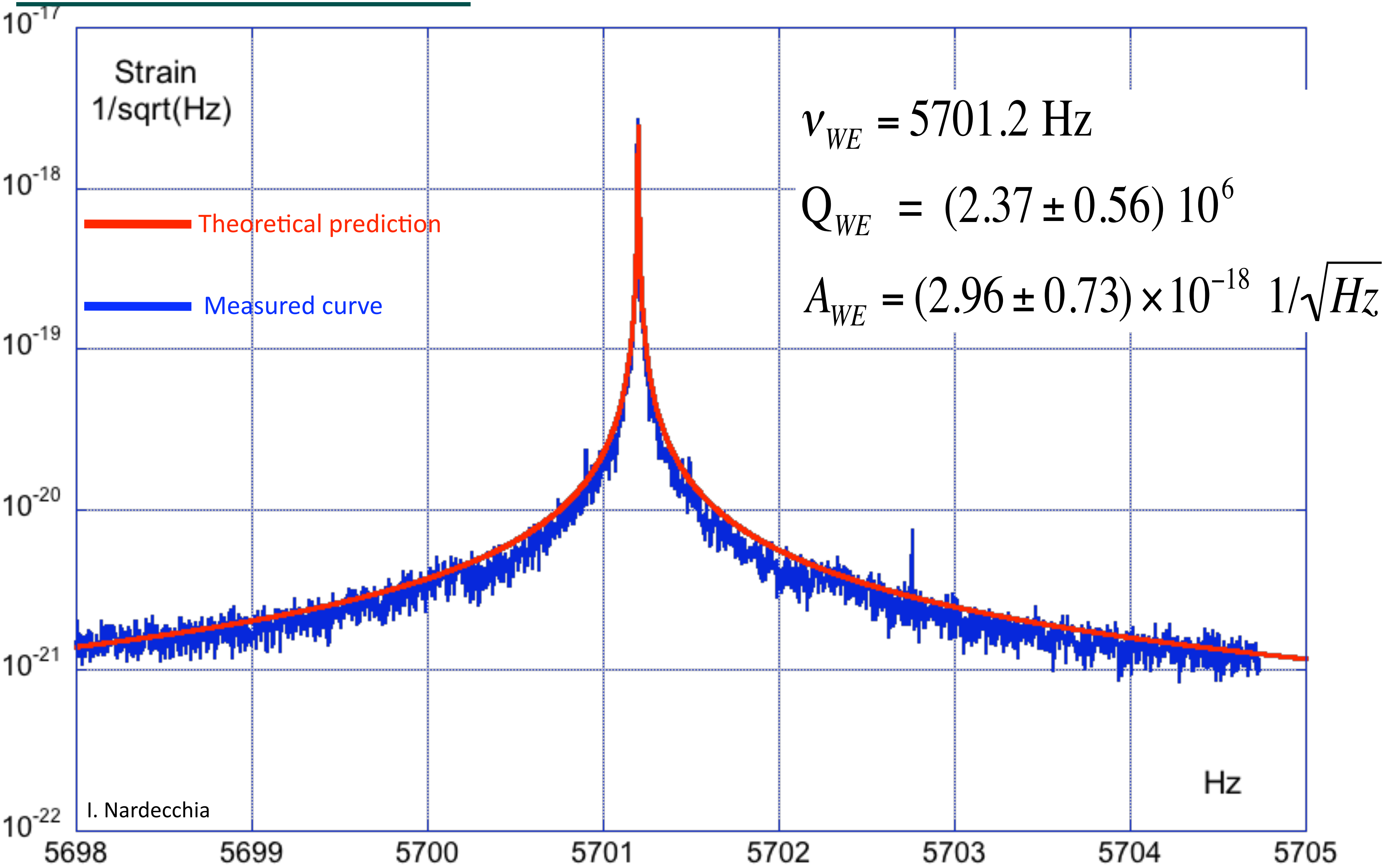


$$\nu_{NE} = 5719.93 \text{ Hz}$$

$$Q_{NE} = (2.93 \pm 0.60)\ 10^{6}$$

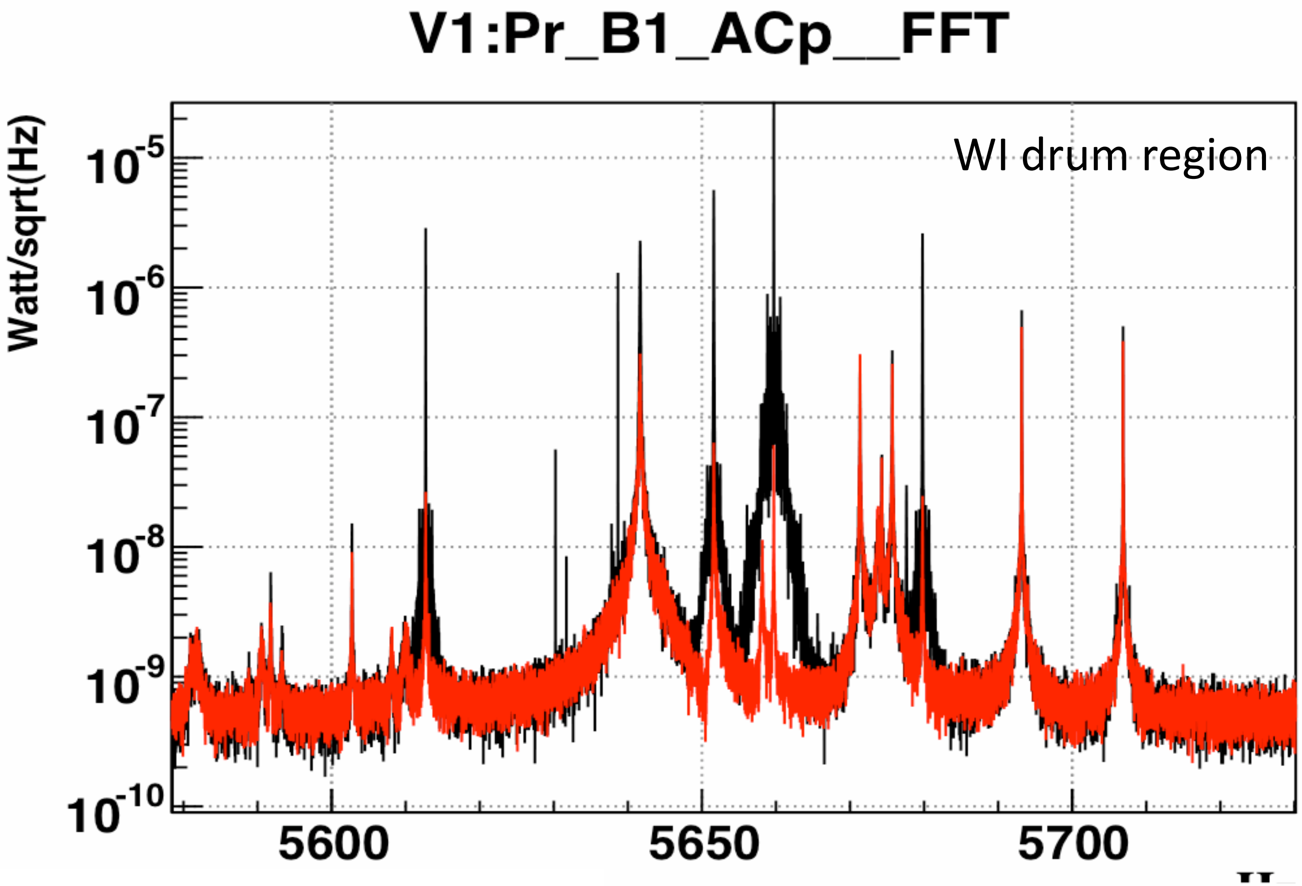
$$A_{NE} = (3.85 \pm 0.70) \times 10^{-18}\ 1/\sqrt{Hz}$$

WE Drum mode


Strain
1/sqrt(Hz)
10^{-17}
10^{-18}
10^{-19}
10^{-20}
10^{-21}
10^{-22}
Theoretical prediction
Measured curve
$\nu_{WE} = 5701.2$ Hz
$Q_{WE} = (2.37 \pm 0.56)\ 10^{6}$
$A_{WE} = (2.96 \pm 0.73) \times 10^{-18}\ 1/\sqrt{Hz}$
Hz
I. Nardecchia
5698
5699
5700
5701
5702
5703
5704
5705

Bulk Modes: Identification problems

The problem is that the violin harmonics often fall in the same region of the butterfly/drum modes.



- 1 drum resonance
- all other frequencies are violins

see VIR-0219A-11
VIR-NOT-ROM-1390-262
logbook entry 27158 (M. Punturo)

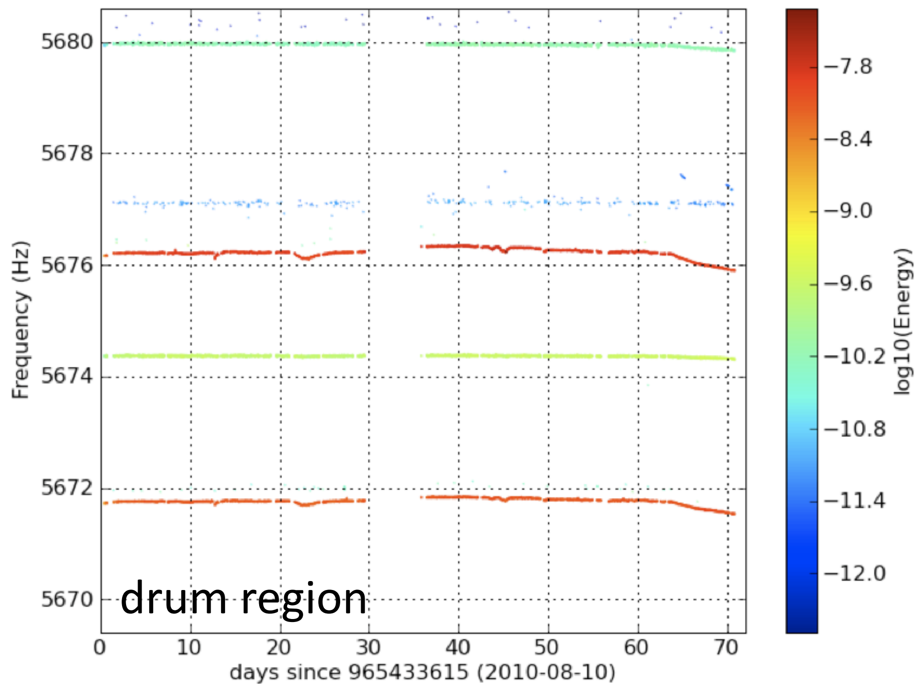
To identify correctly the resonances we use the temperature correlation.

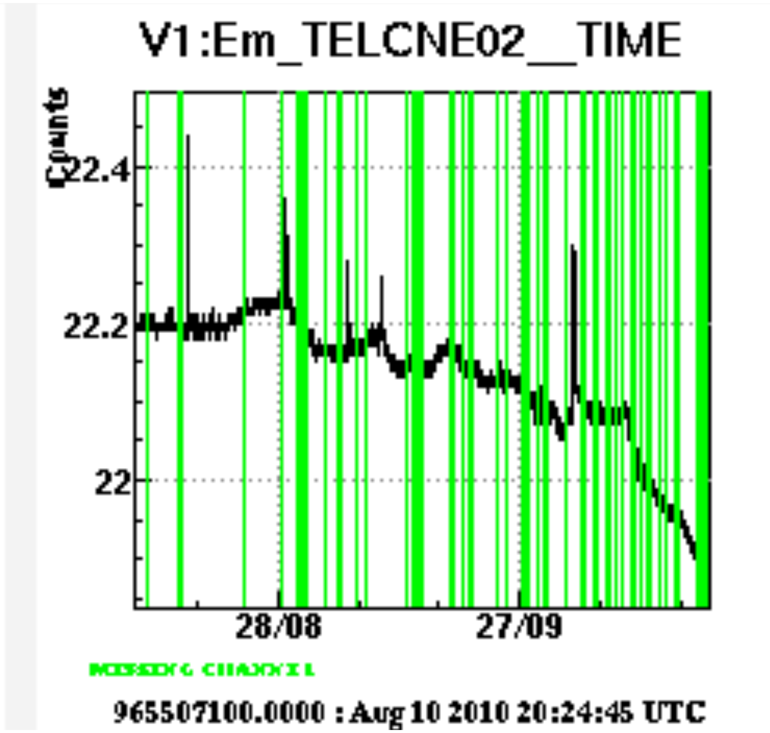
Temperature dependence

To follow:

• the line frequency in time we use the NoEMi tool, developed by the Pulsar and Noise groups;

• the temperature variation we use the sensor placed on the external wall of the towers.

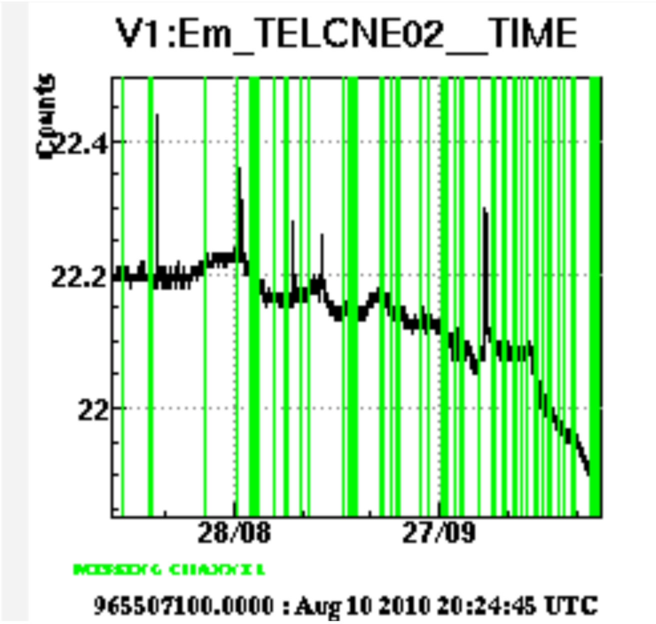


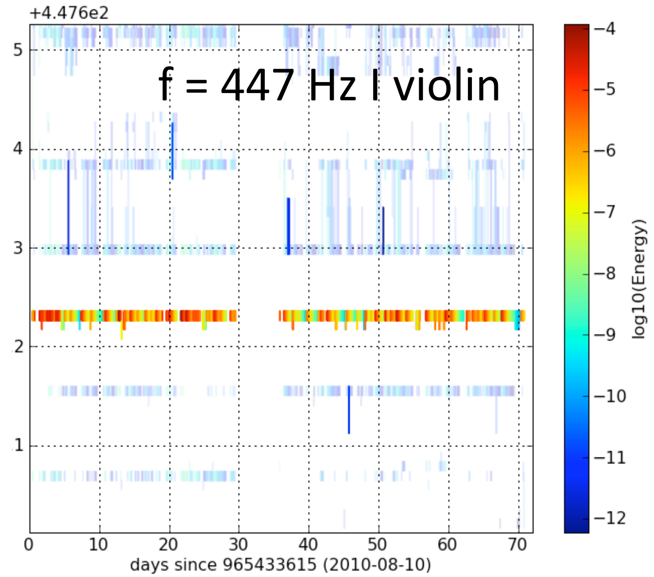


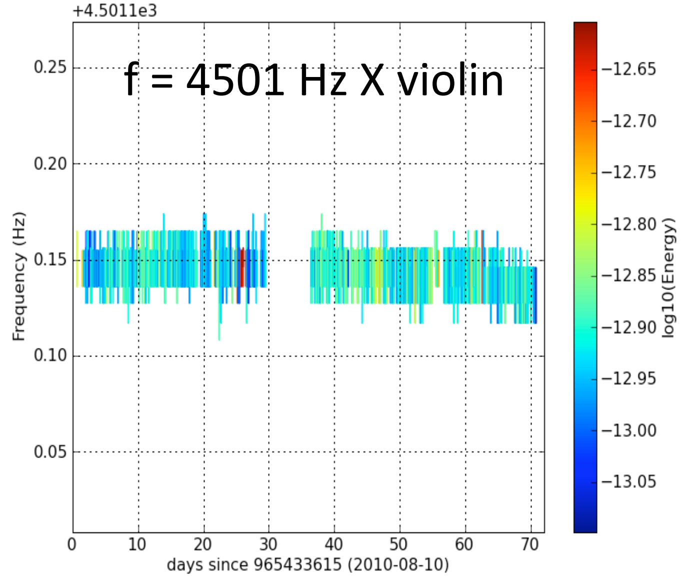
see Colla, VIR-0091A-11

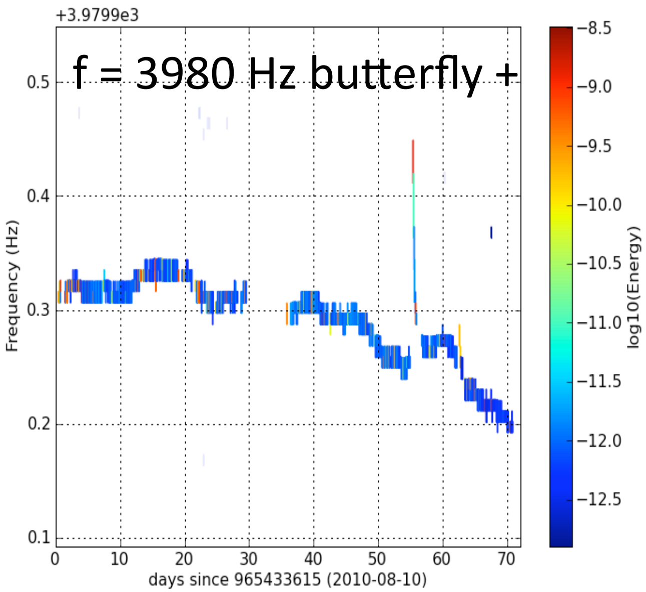
Temperature dependence: NE case

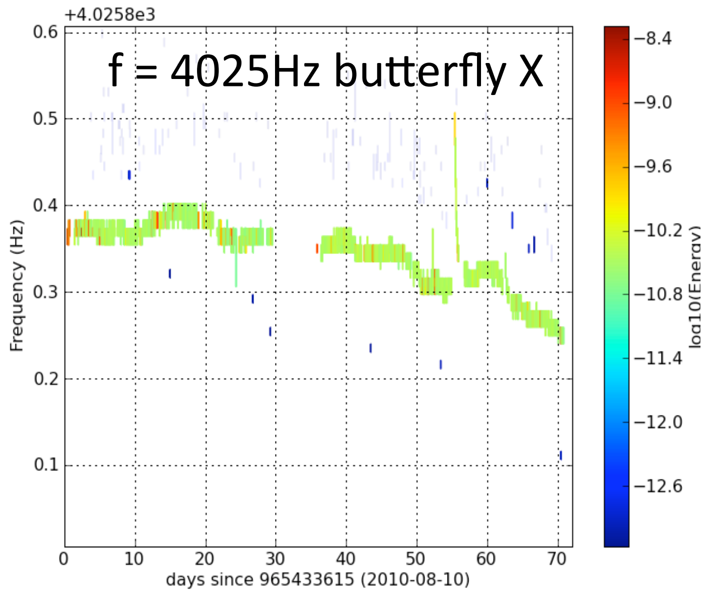
VSR3 data

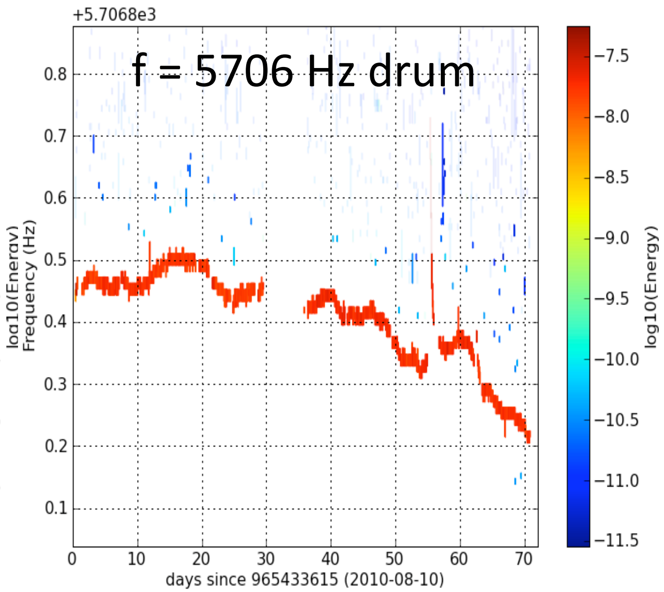






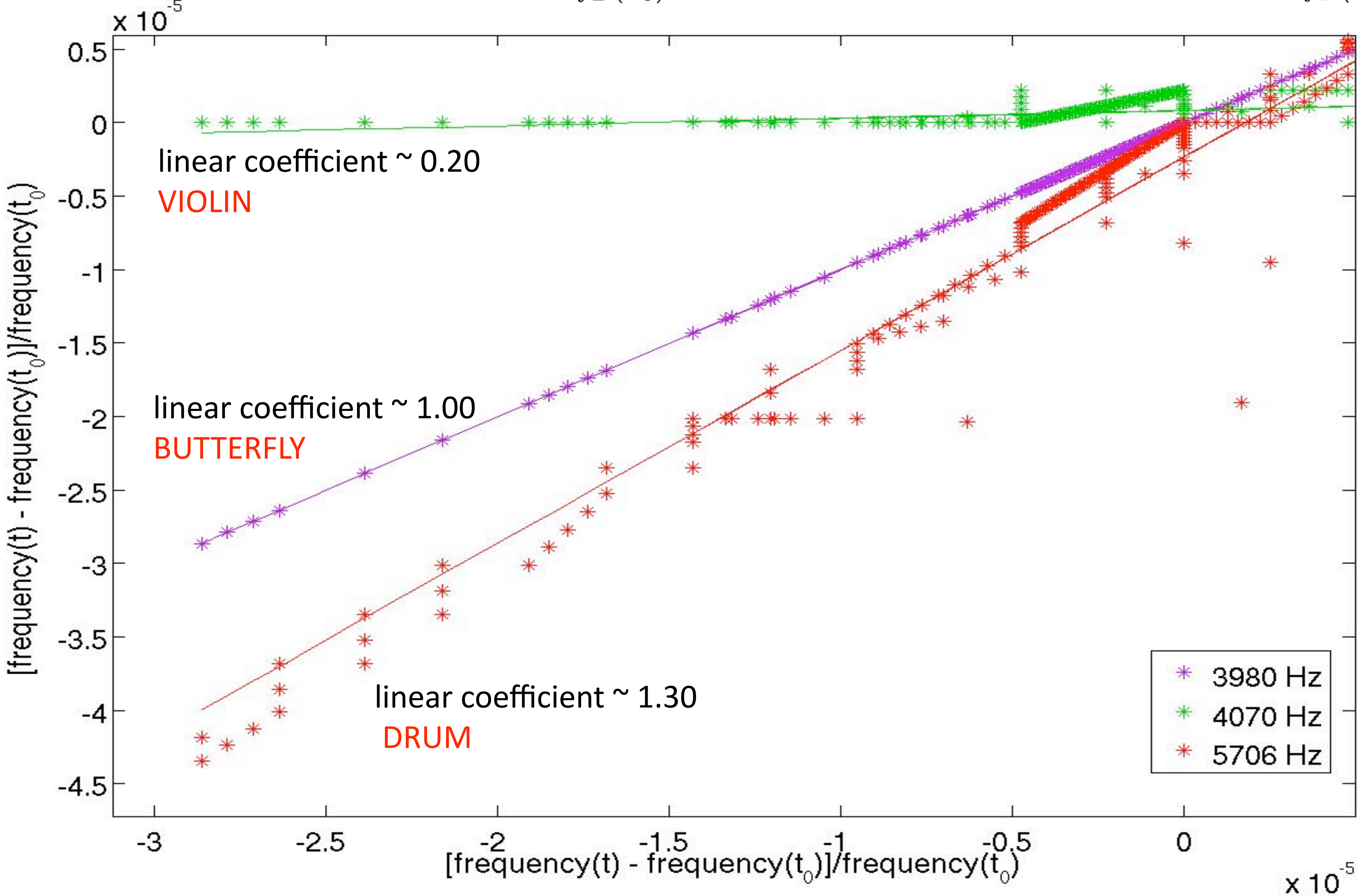






Comparing different modes behaviour

We plot the quantity $\frac{f_B(T) - f_B(T_0)}{f_B(T_0)}$ mode in function of the $\frac{f_B(T) - f_B(T_0)}{f_B(T_0)}$ butt



Conclusion

- we measure the Quality Factor of all the internal resonances of the 4 towers;
- we use the temperature correlation to distinguish between different kind of modes (violins/bulk)
- we obtain Q values lower than the expected ones
- to understand the dissipation processes we need:

- more simulations and models (see Puppo's and Tacca's talks)
- more measurements (on the single dismounted payloads)

Temperature dependence (1)

The temperature dependence is contained in the Young Modulus and we can approximate that as:

$$E(T) = E_0 e^{\beta(T-T_0)}$$

For the violin modes:

$$f_{violin} = \sqrt{\frac{T}{\rho}} \frac{n}{2L} \left[1 + \frac{2}{L}\sqrt{\frac{I}{T}}\sqrt{E} \right]$$

f_1 first order correction

For the bulk modes:

$$f_{bulk} = \frac{\alpha_{lm}\sqrt{E}}{\sqrt{(1 + A_{lm}\sigma)(1 - B_{lm}\sigma)}}$$

see VIR-NOT-ROM-1390-262 (P. Puppo)
and logbook entry 27158 (M. Punturo)

Temperature dependence (2)

Using the Taylor expansion at first order we obtain:

- for violin modes

$$R_V = \frac{f_V(T) - f_V(T_0)}{f_V(T_0)} = \frac{f_1\sqrt{E_0}}{1 + f_1\sqrt{E_0}}\beta(T - T_0)$$

f_1 << 1

- for the bulk modes

$$R_B = \frac{f_B(T) - f_B(T_0)}{f_B(T_0)} = \frac{\beta}{2}(T - T_0)$$

If we compute the ratio R between different modes:

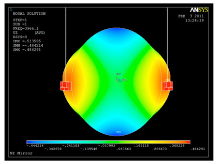
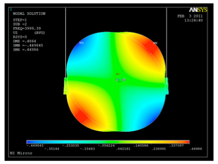
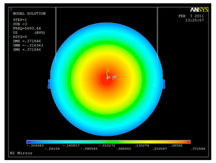
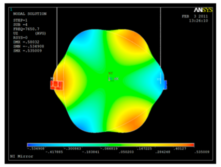
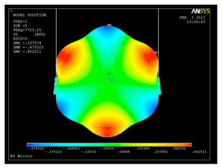
- bulk modes (butterfly or drum) →

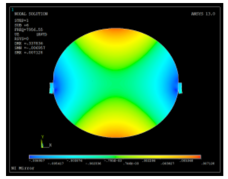
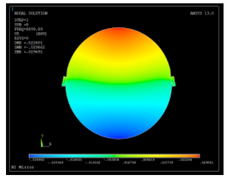
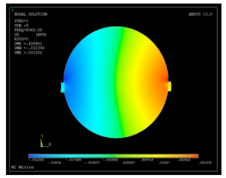
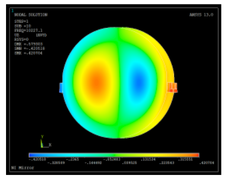
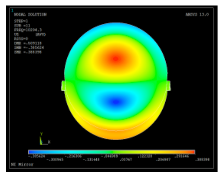
$$R_B(m)/R_B(n) \approx 1$$

- a violin mode and bulk mode →

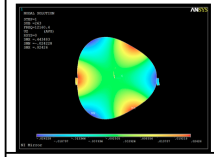
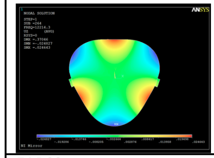
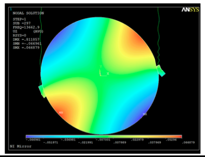
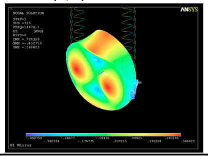
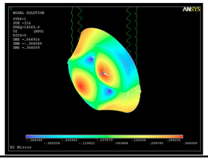
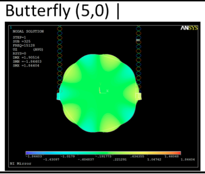
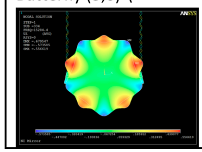
$$R_V/R_B(n) < 1$$

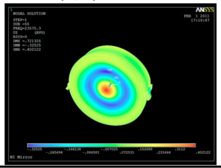
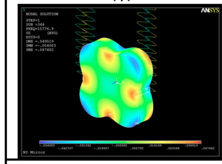
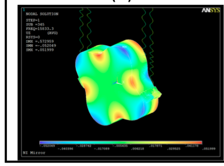
Bulk Mode zoology (1)

Mirror	NI Freq [sym] Q (1e6)	WI Freq [sym] Q (1e6)	NE Freq [sym] Q (1e6)	WE Freq [sym] Q (1e6)
Butterfly (2,0) X 	3964.22Hz [3965.9 Hz] **.571**	3936.1 **15.2**	4025->4032 **2**	4014.6->4018.2 **3.6**
Butterfly (2,0) + 	3996.7 Hz [3999.2Hz] **12**	3969.6 **24.3**	3980->3986 **8**	3969.1->3972 **13.5**
Drum (0,1) 	56751.5-5676 Hz [5689.1 Hz] **.34-.3**	5642 **0.04**	5707->5719 **3**	5693->5700 **1.72**
Butterfly (3,0) + 	7641.27 Hz [7650.7 Hz] **.944**	7606.3 **1.71**	7761->7773 **2.34**	7653->7660 Hz **0.05**
Butterfly (3,0) X 	7710.2 Hz [7723.2 Hz] **5.12**	7679.9 **10.4**	7667->7678 **6.45**	7745->7752 Hz

Egg X 	8022 Hz [7956 Hz] **6.98**	8028.9 Hz **27.2**		
Ears h 	8926.1 Hz [8897.9 Hz] **1.65**	8934.1 Hz **2.15**	8899	8895.5 **3.36**
Ears v 	8984.7 Hz [8959.1 Hz] **2.54**	8992 Hz **7**	8867.4	9081.7 **3.64**
Drum (1,1) I 	10191 Hz [10222.0 Hz] **0.798**	10165.0 **1.57**	10331.0	10245 Hz **0.08**
Drum (1,1) – 	10323 Hz [10289.0 Hz] **.593**	10335.0 **1.79**	10387.0	10313.0 **1.64**

Bulk Mode zoology (2)

EGG3 	[12160 Hz]			12288 Hz
EGG4 	[12214 Hz]			
EARS3 	13669 Hz [13663 Hz]			13639 Hz
Drum (2,1) X 	14344 Hz [14470 Hz]	14262 Hz		
Drum (2,1) + 	14519 Hz [14684 Hz]	14511 Hz 0.21	14382	14524 Hz 7
Butterfly (5,0) | 	15066 Hz [15128 Hz]	15007 Hz 1.46		
Butterfly (5,0) \ 	15223 Hz [15284 Hz] 0.234	15178 Hz 0.14	15209	15183 Hz 2.2

Drum (0,2) 	15673.9 Hz [15726 Hz] 0.205	15659.0 Hz .192	15773	15763 Hz 1.5
Cloverleaf (|) 	15791.0 Hz [15777 Hz] 0.08			
Cloverleaf (X) 	15898.0 Hz [15833 Hz]			