IFO Performance During Earthquakes

Eyal Schwartz 04/08/2020

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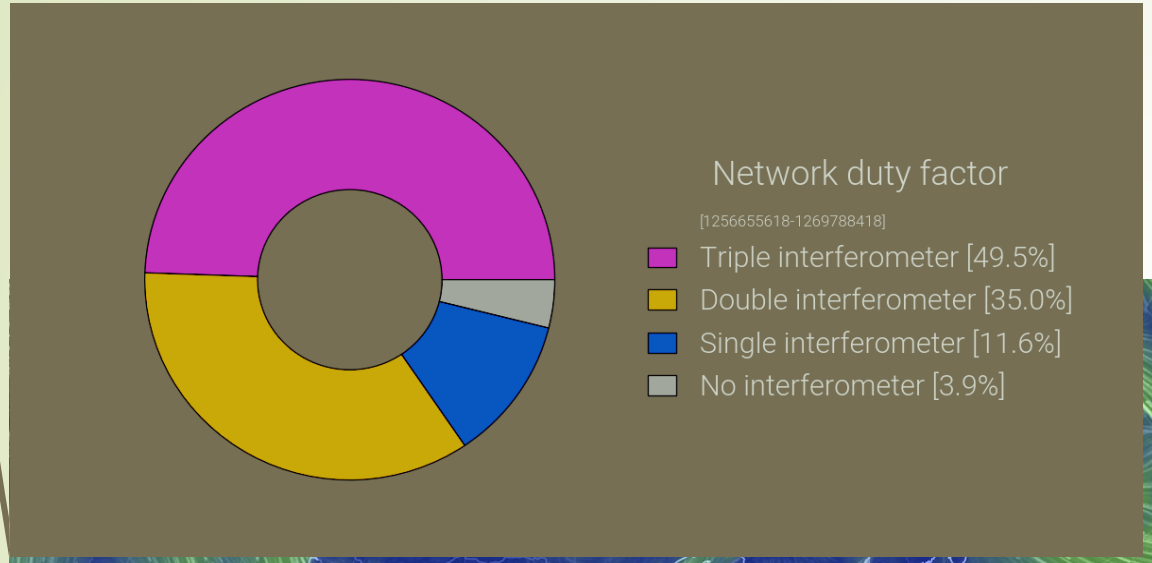
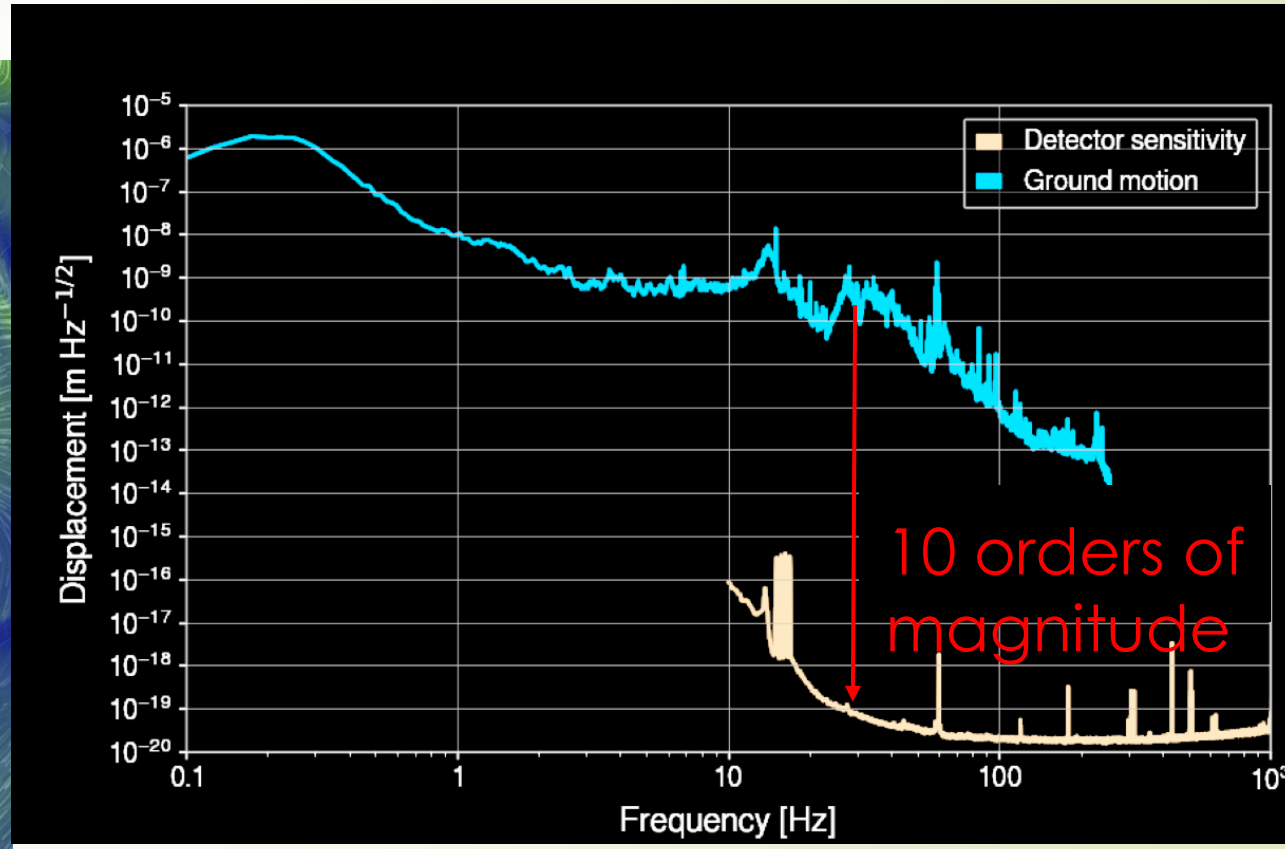
On behalf of LIGO seismic team and many others at the sites

DCC paper: LIGO-P2000072

Why seismic isolation: sensitivity and duty cycle



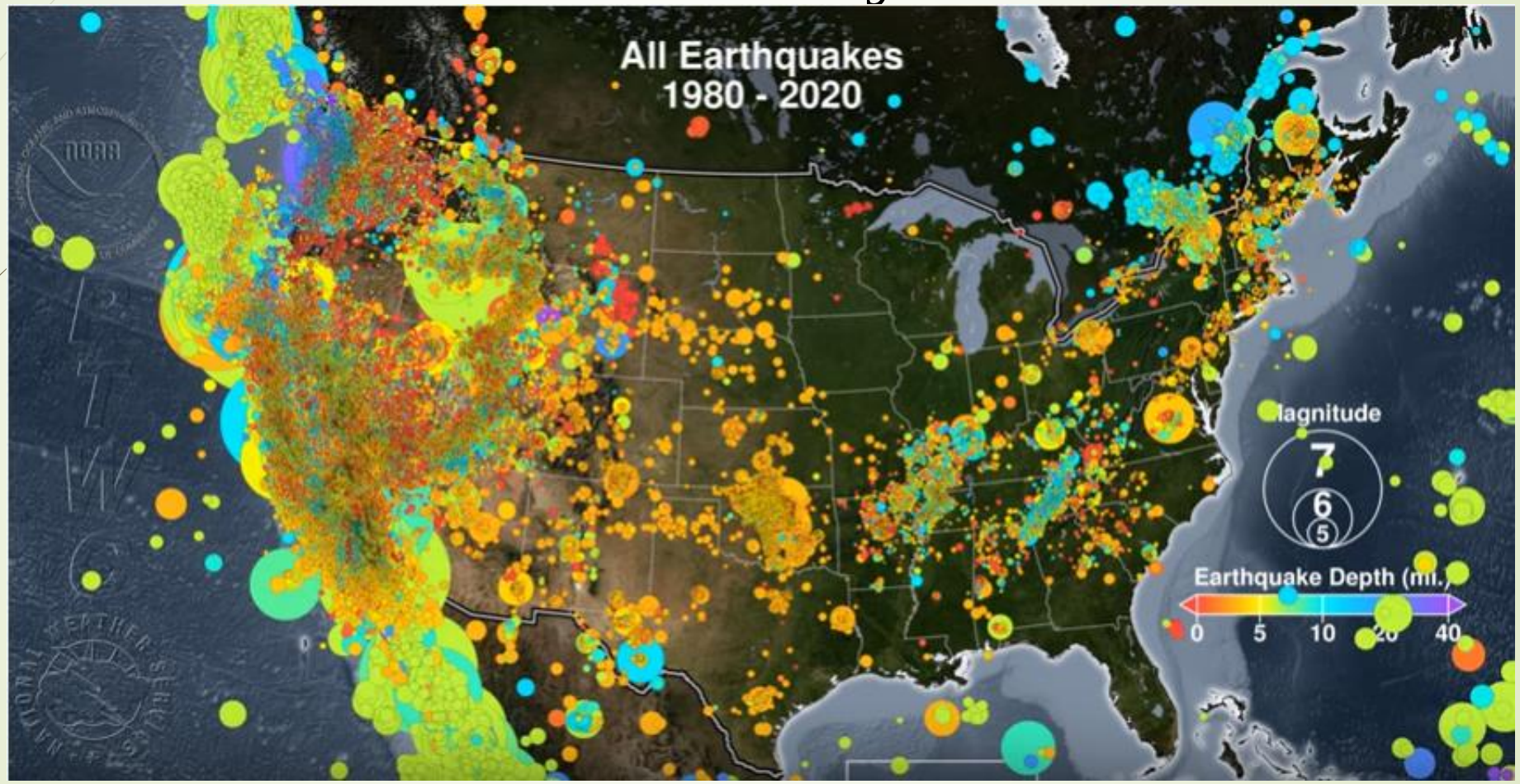
https://earth.nullschool.net/



Vajente, G1900851
Pele, G2000186

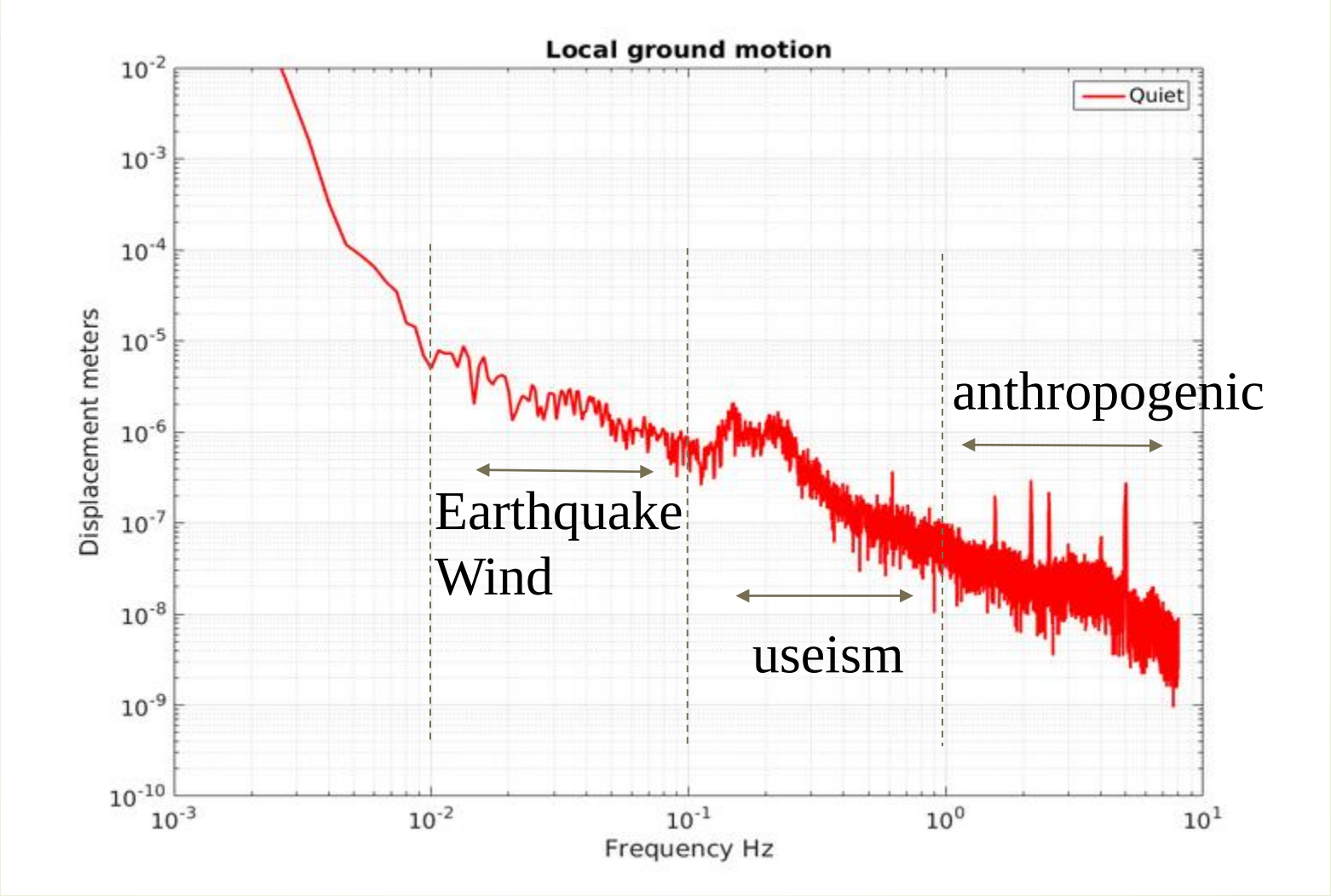
So what is the problem???

Well…. One of many….

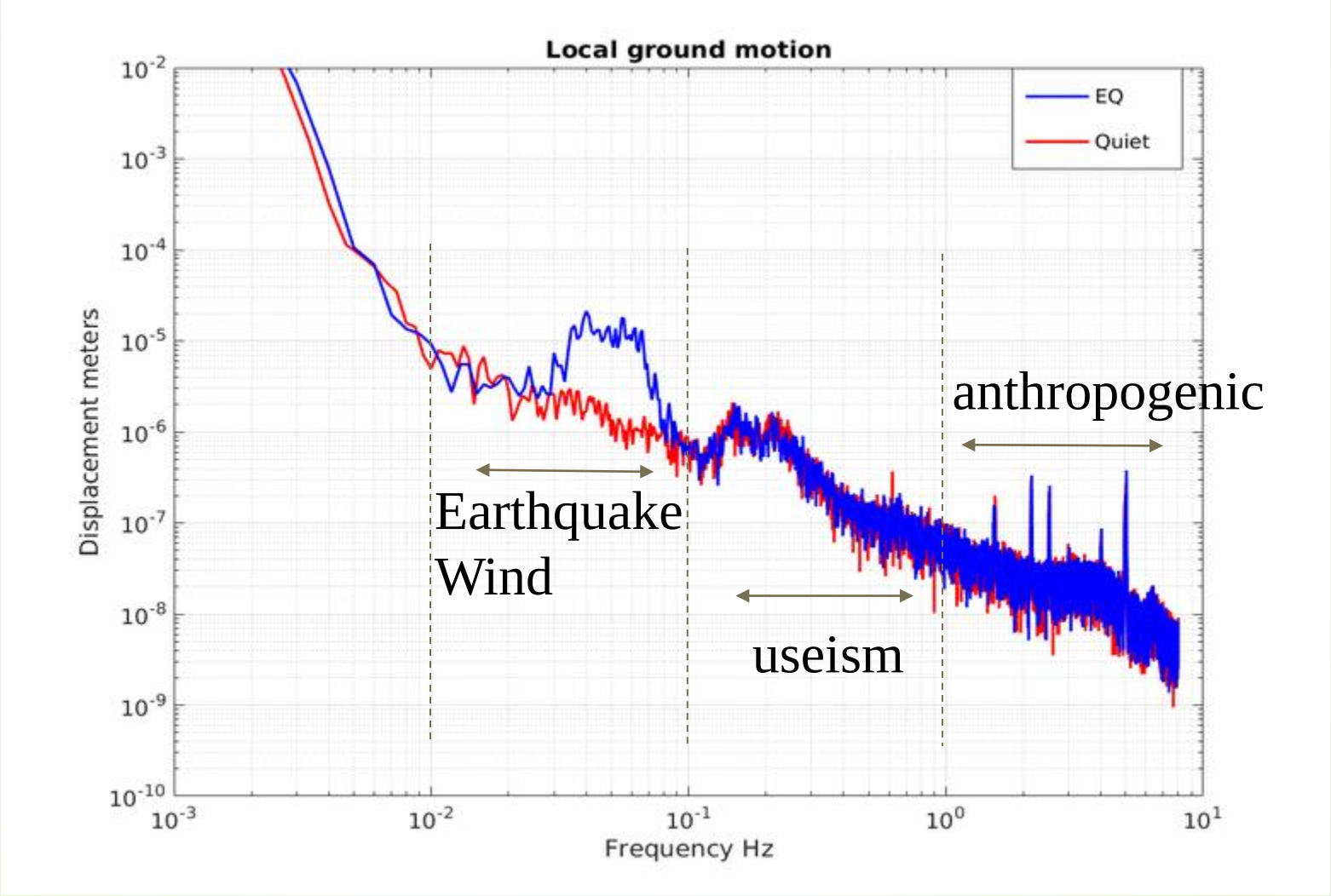


https://youtu.be/sv7JwrWURyQ

So what is the problem???

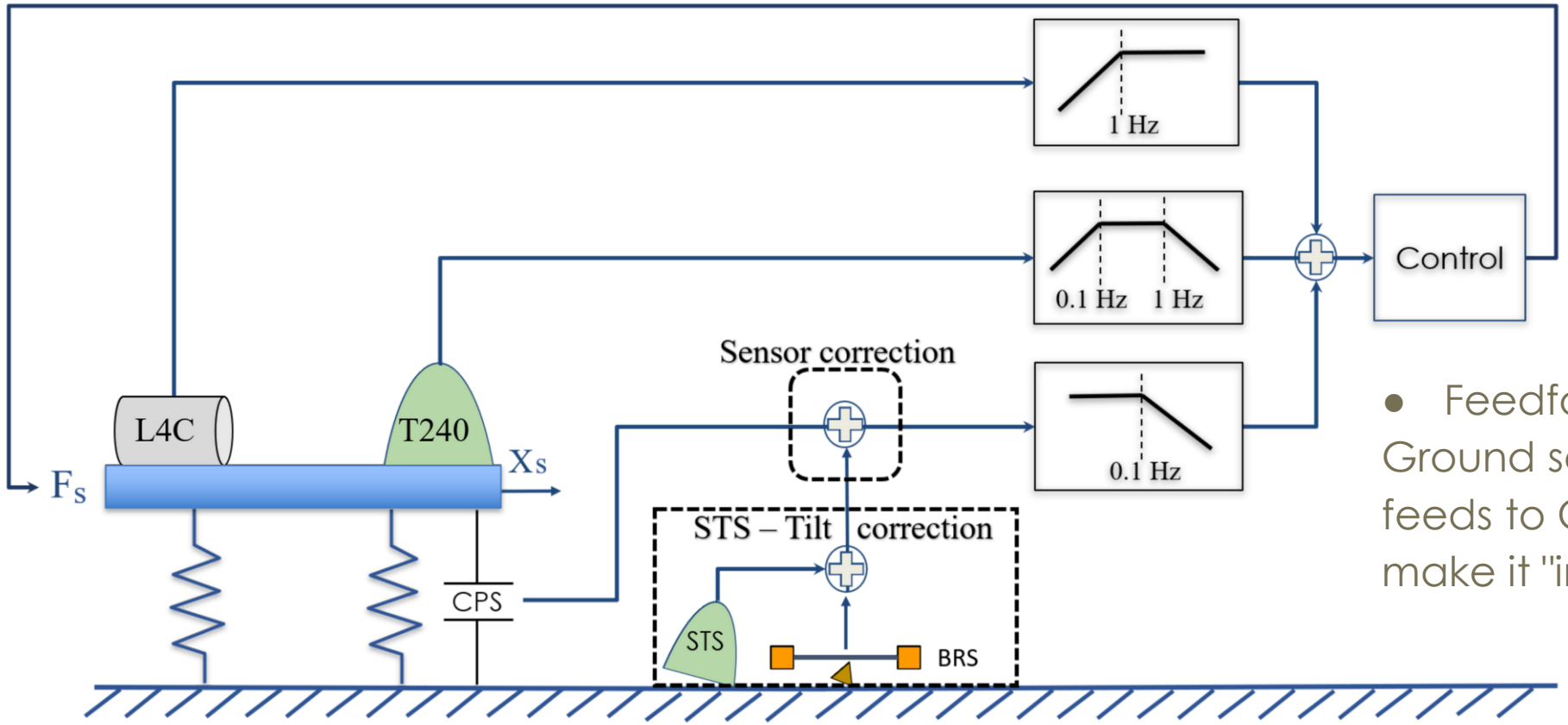


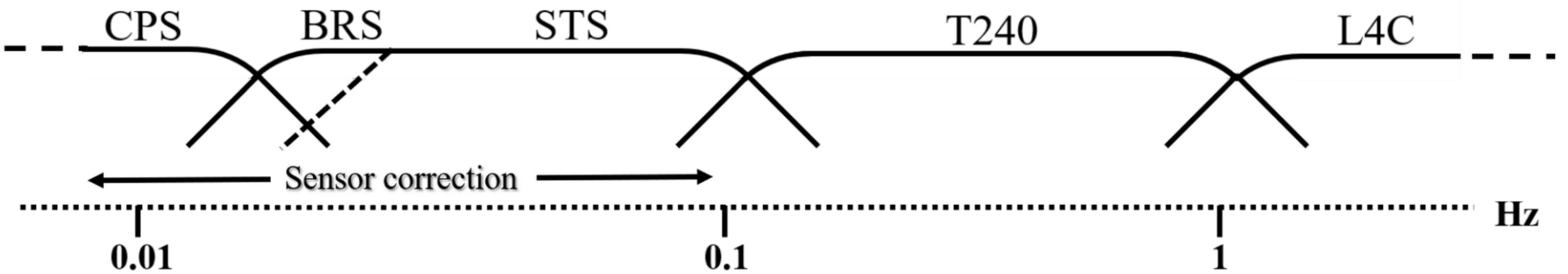
So what is the problem???



Sensor correction 101

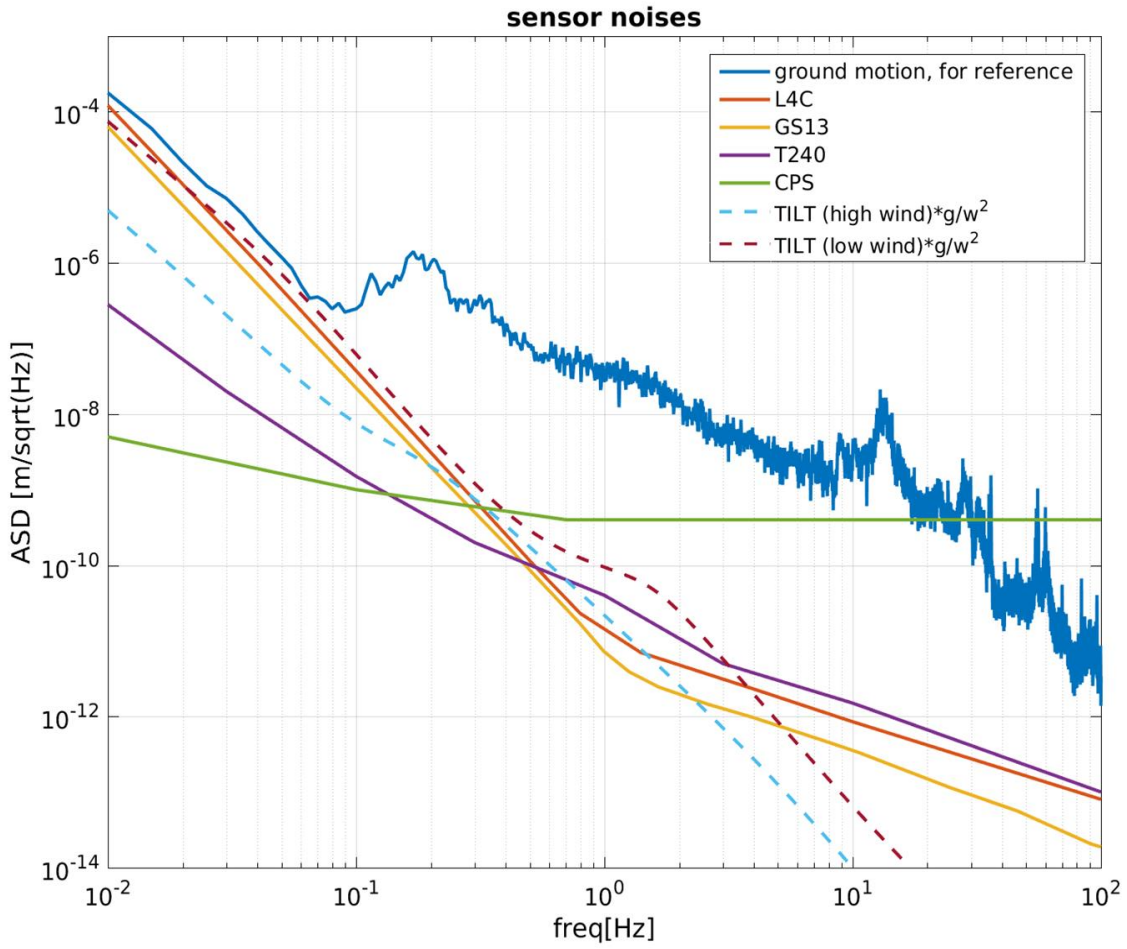
Active isolation, general control scheme

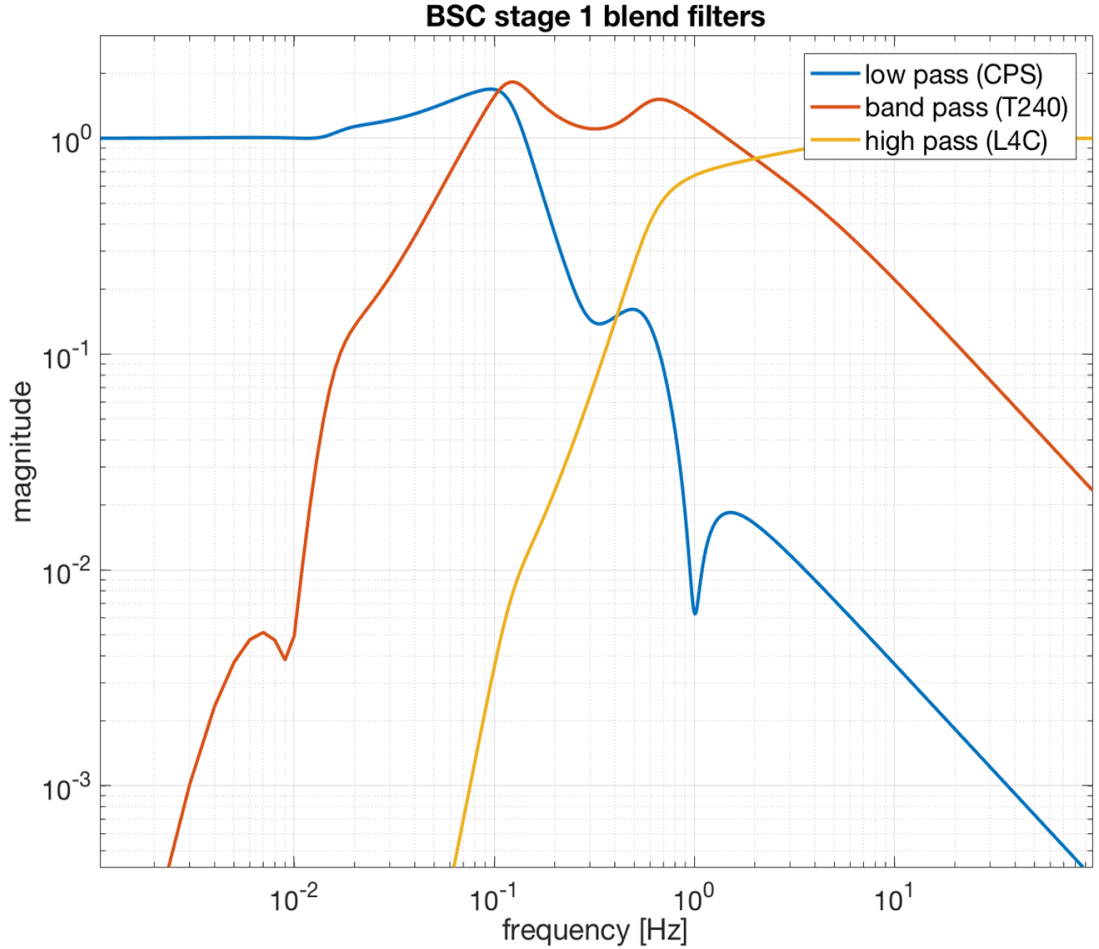




- Feedforward: Ground seismometer feeds to CPS path to make it "inertial"

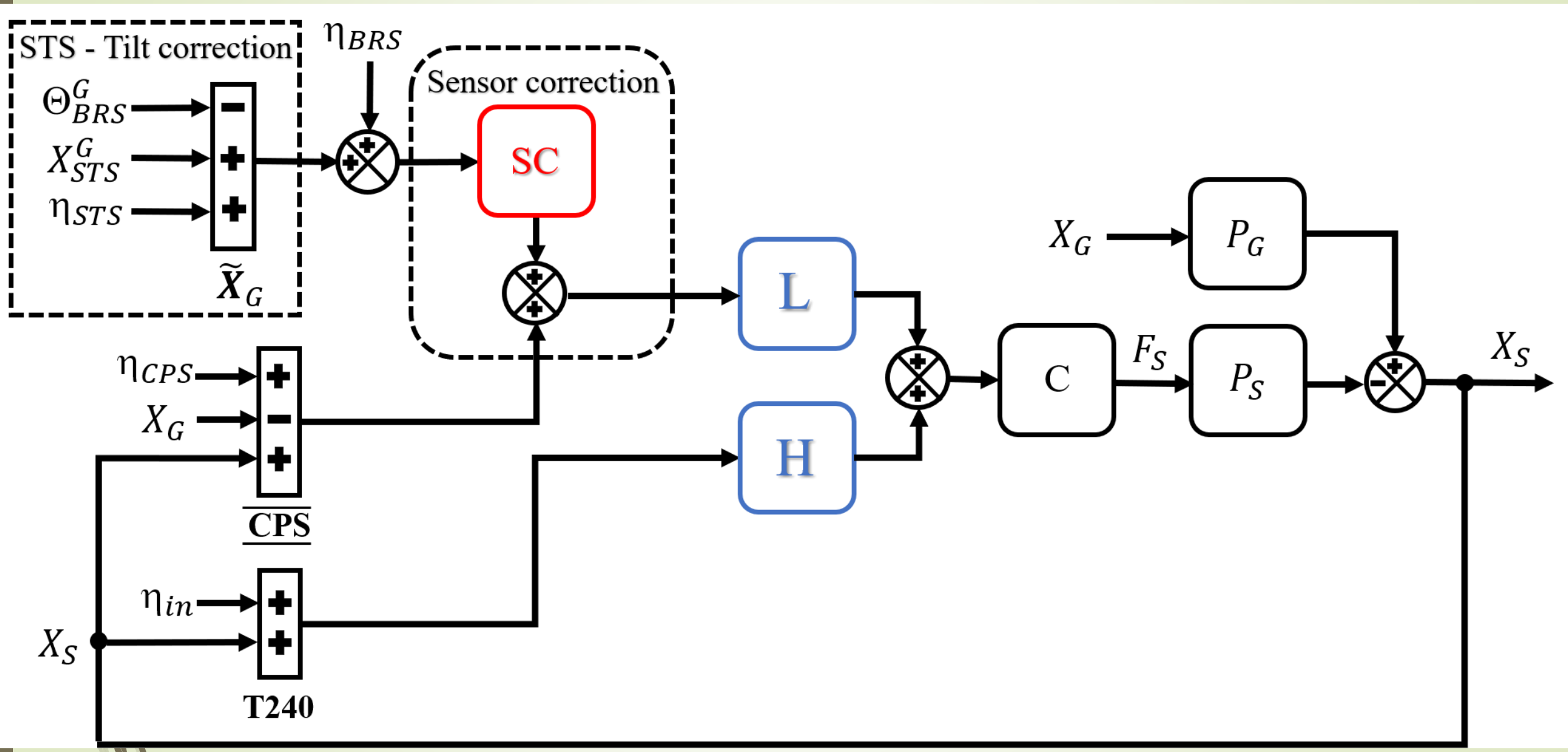
Blend for virtual inertial sensor





Pele, G2000186

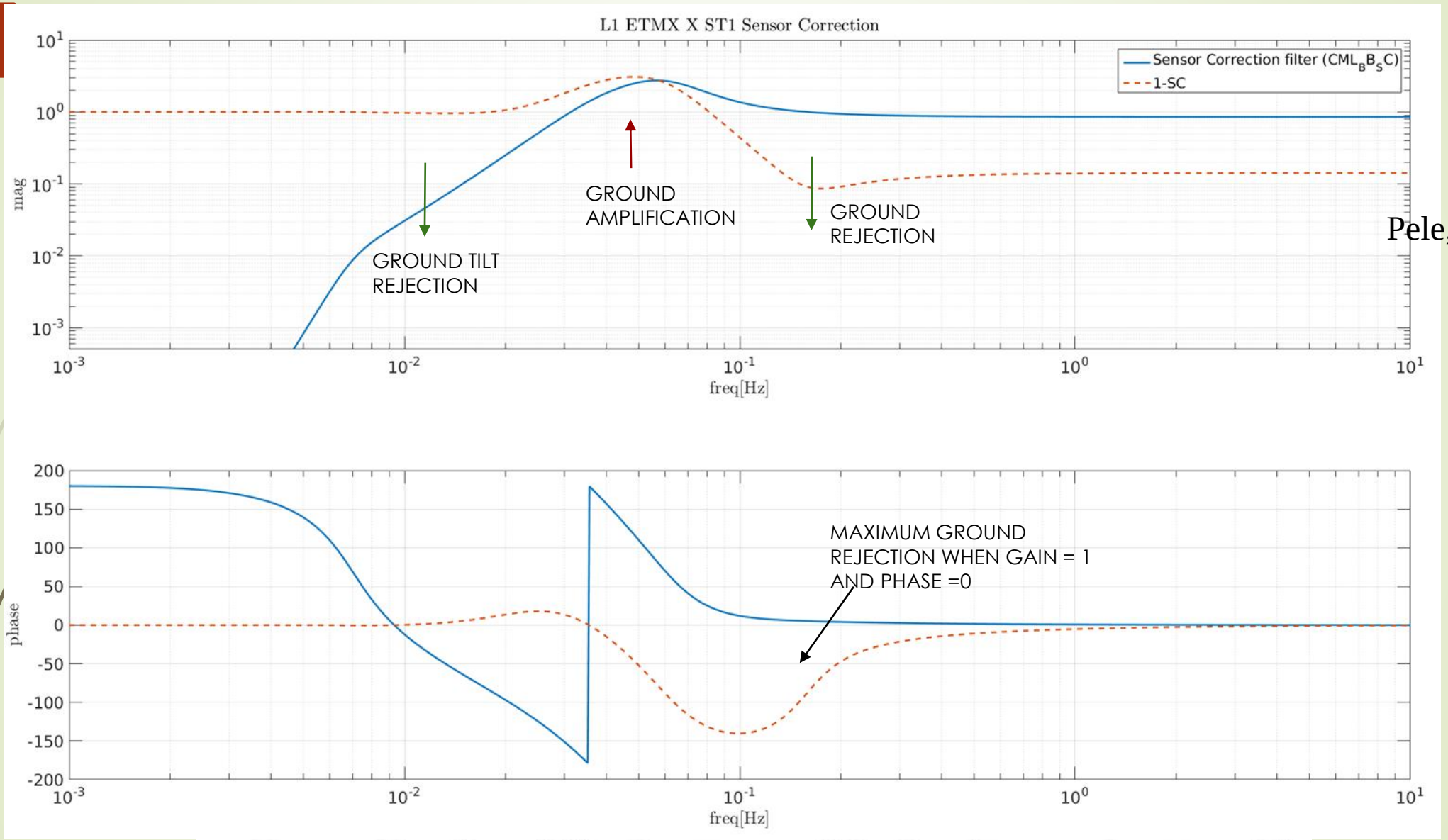
Sensor correction 101



$$\text{Ground} = X^G_{STS} + \frac{g}{\omega^2} * tilt - \Theta^G_{BRS} * \frac{g}{\omega^2} + \eta_{STS} + \eta_{BRS}$$

Venkateswara, P1800038

Sensor correction 101

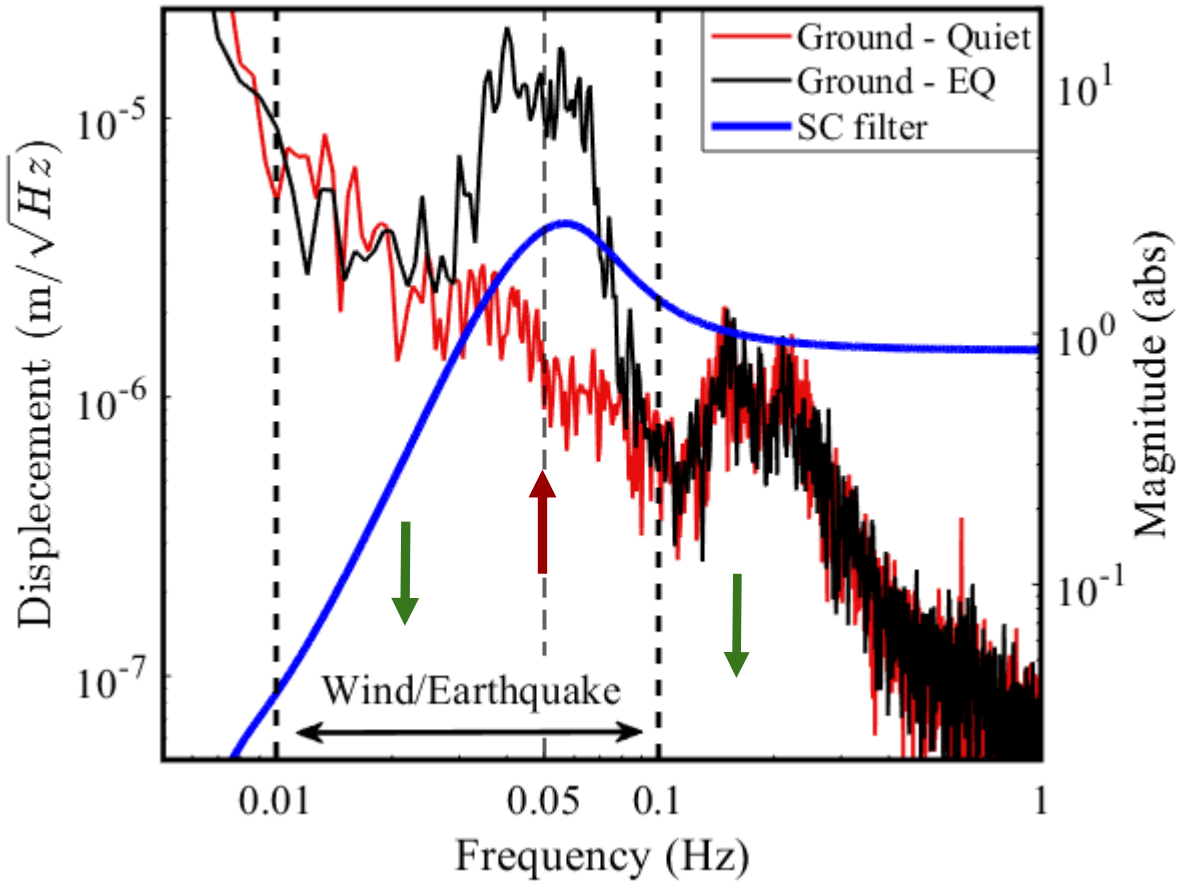


Pele, G2000186

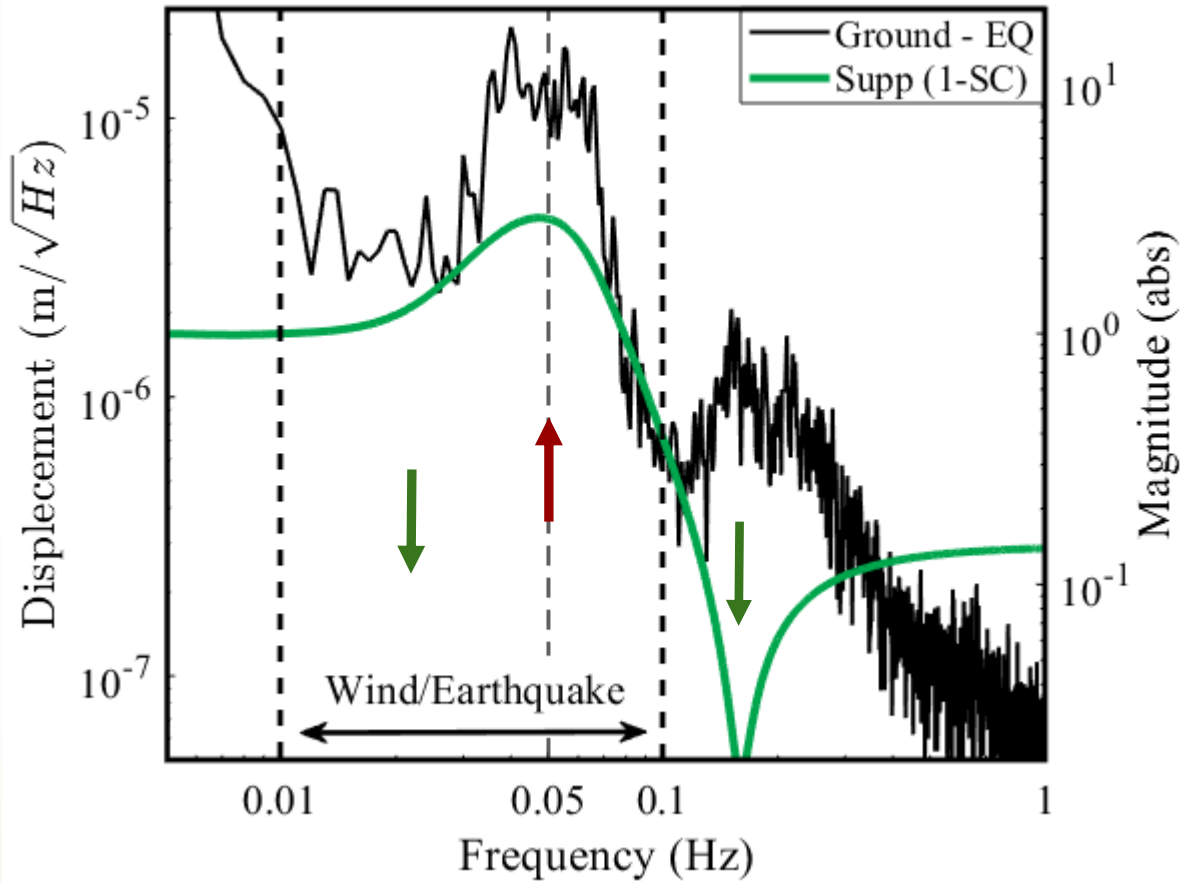
$$\underset{C \cdot P_S \gg 1}{X_S} = X_G \cdot (1 - SC) \cdot L - \eta_{BRS} \cdot SC \cdot L - (\eta_{CPS} \cdot L + \eta_{in} \cdot H)$$

Sensor correction 101

SC Filter



Suppression (1-SC)



$$\underset{C \cdot P_S \gg 1}{X_S} = X_G \cdot (1 - SC) \cdot L - \eta_{BRS} \cdot SC \cdot L - (\eta_{CPS} \cdot L + \eta_{in} \cdot H)$$

Problem:

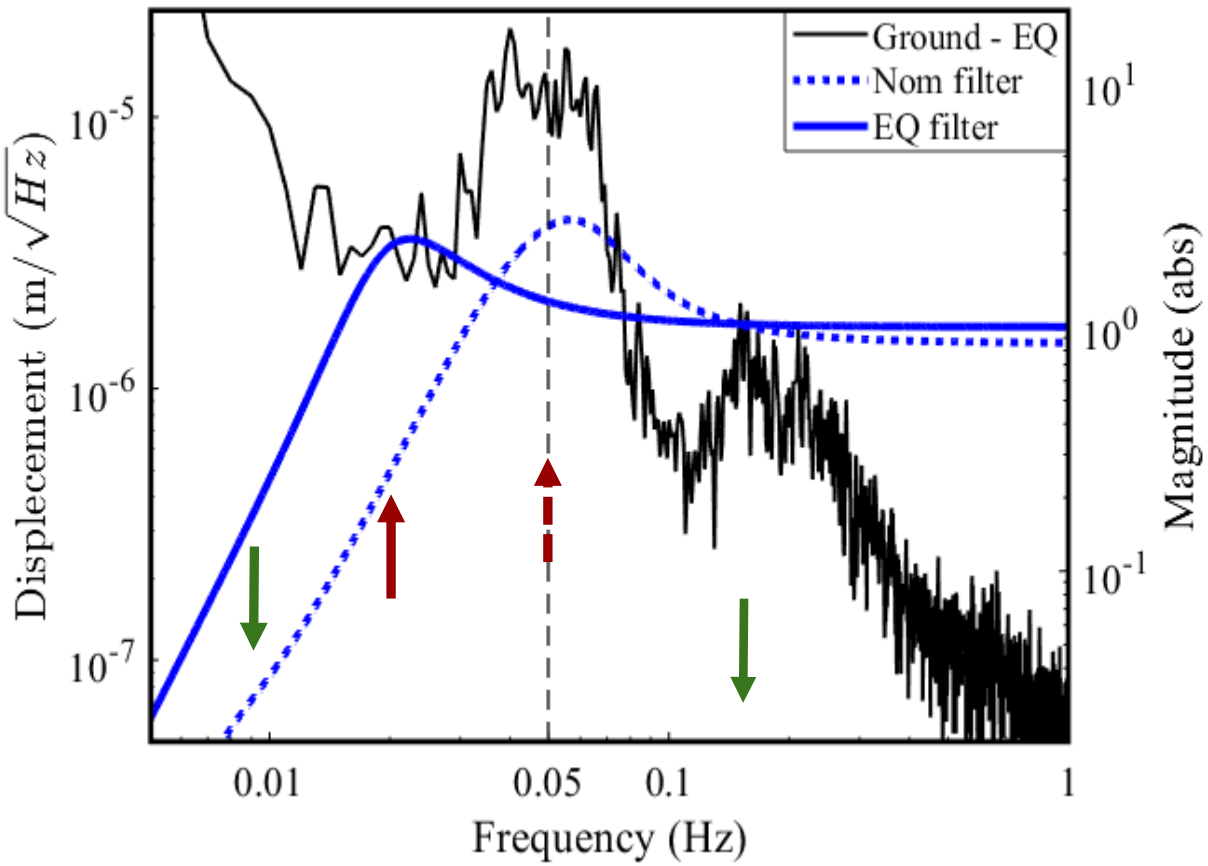
- We get hit right where it hurts… Gain peaking at 50-80 mHz.
- Why we lose lock??

What can we do to deal with this?

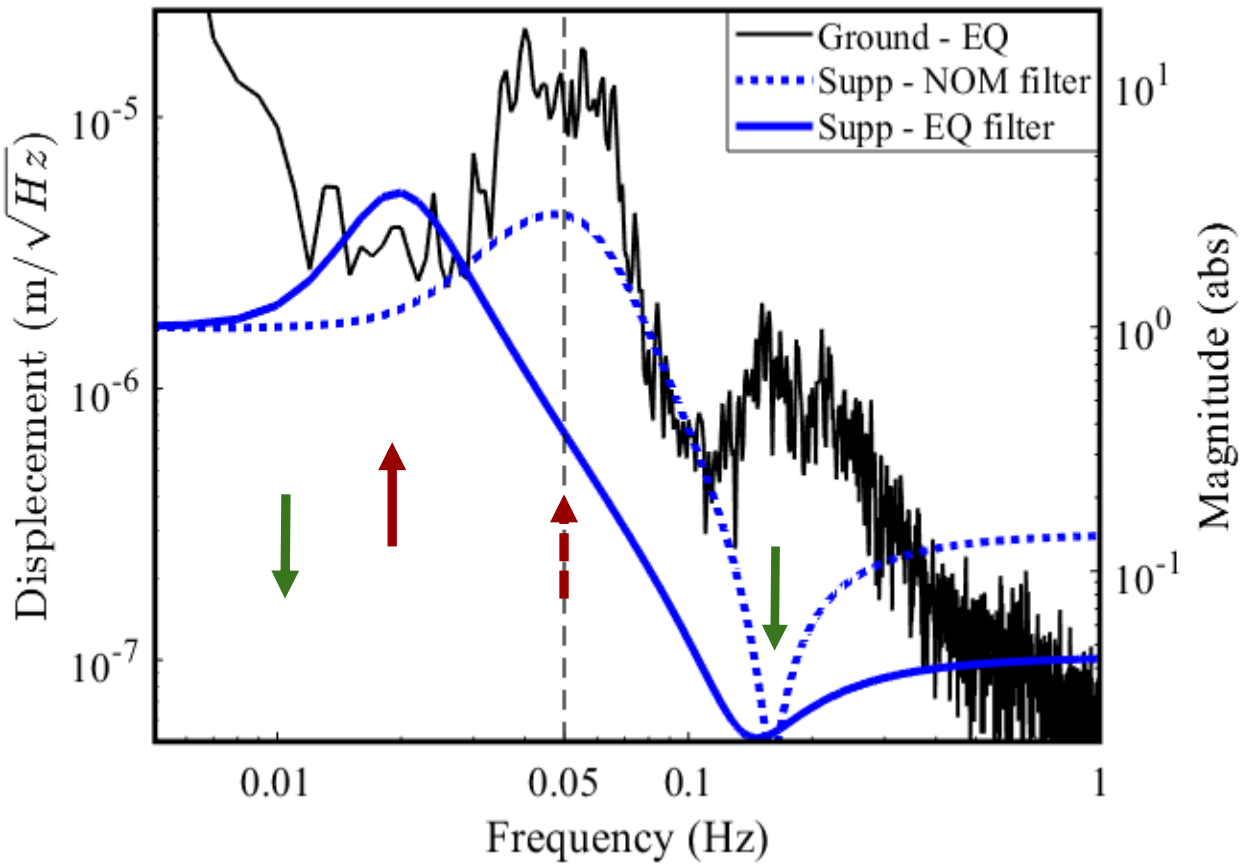
- Better predictions for earthquakes arrival time and magnitude.
- Optimize IFO seismic state for earthquake passing.
- Transition safely between states during lock.
- Understand the local and global behavior.

Sensor correction 102?

SC Filter



Suppression (1-SC)

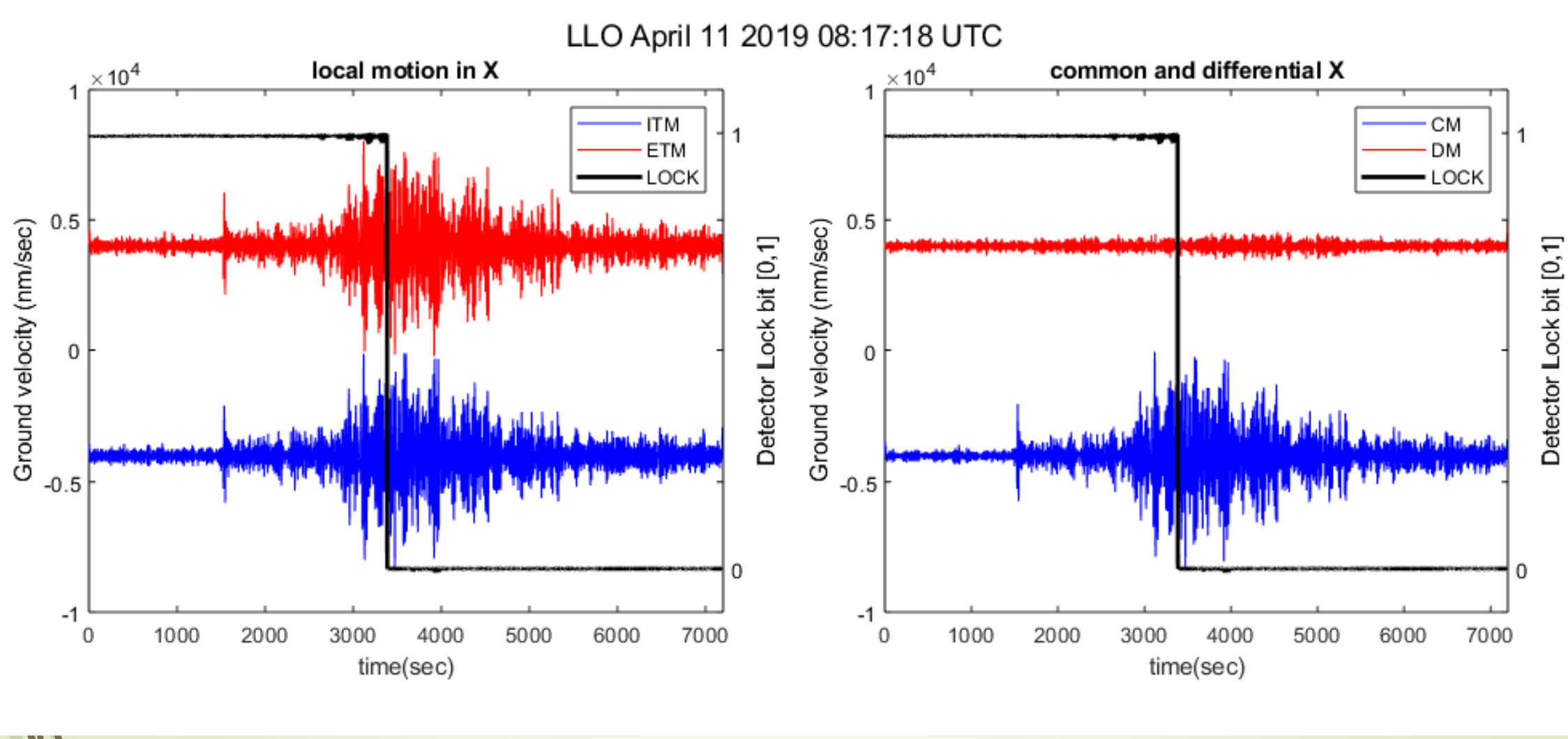


Seismic Optimization

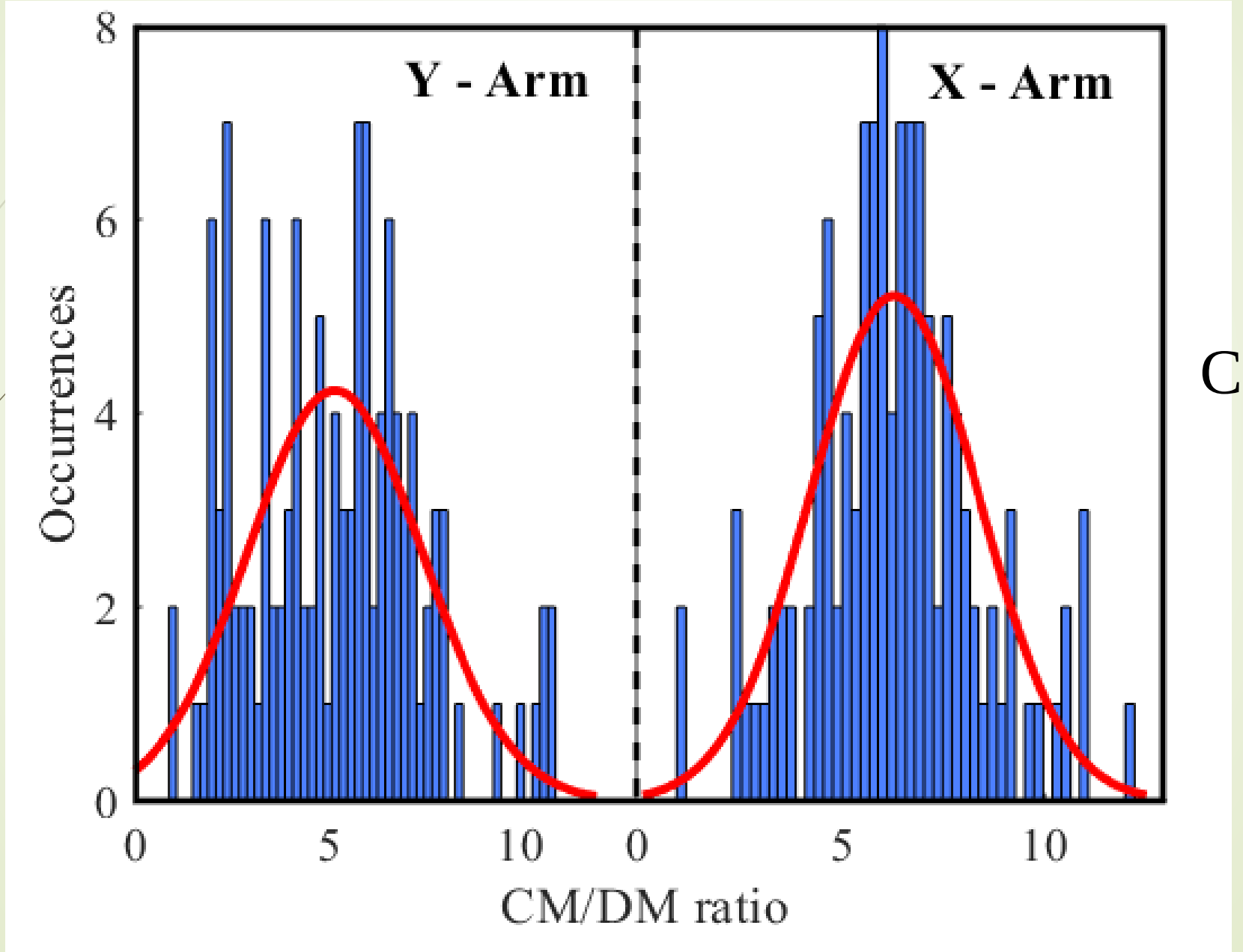
Goals

- REDUCE local platform motion & drive - Local
- REDUCE differential motion of arm – Global
- Keep stability of IFO lock.

Lets look at ground motion during earthquake:

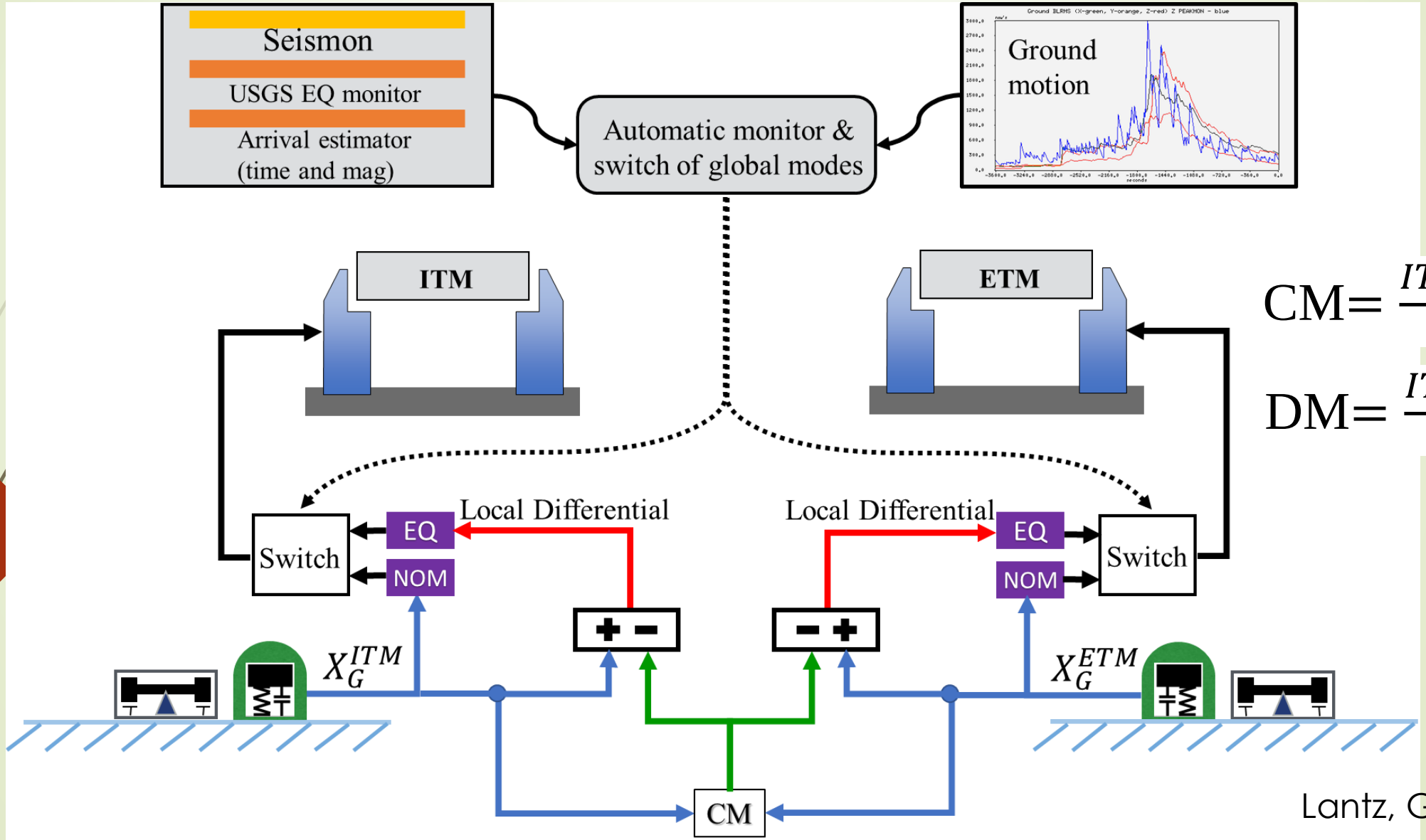


Common mode is dominating – lets take it out!



CM/DM ~ 5-6

The new control scheme for earthquakes



$$CM = \frac{ITM + ETM}{2}$$

$$DM = \frac{ITM - ETM}{2}$$

Lantz, G1800399

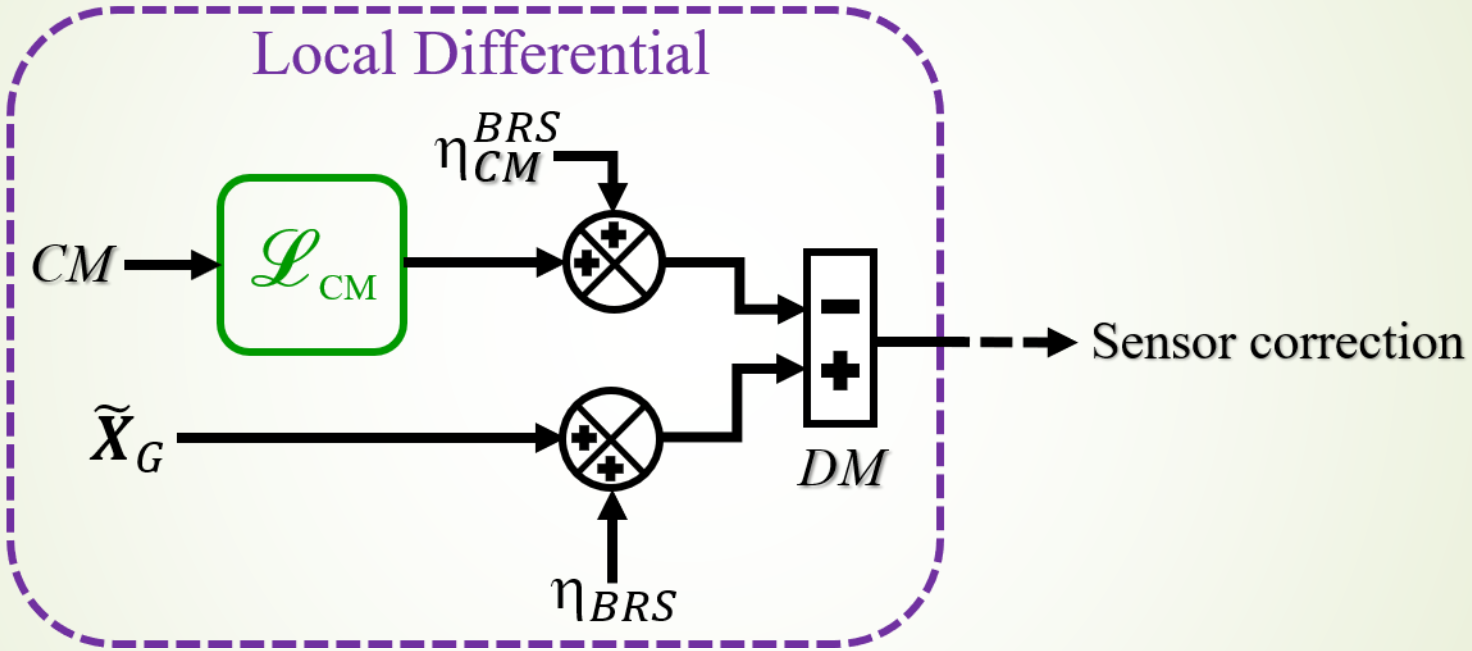
Goals

- REDUCE local platform motion and drive
- REDUCE differential motion of arm

How?

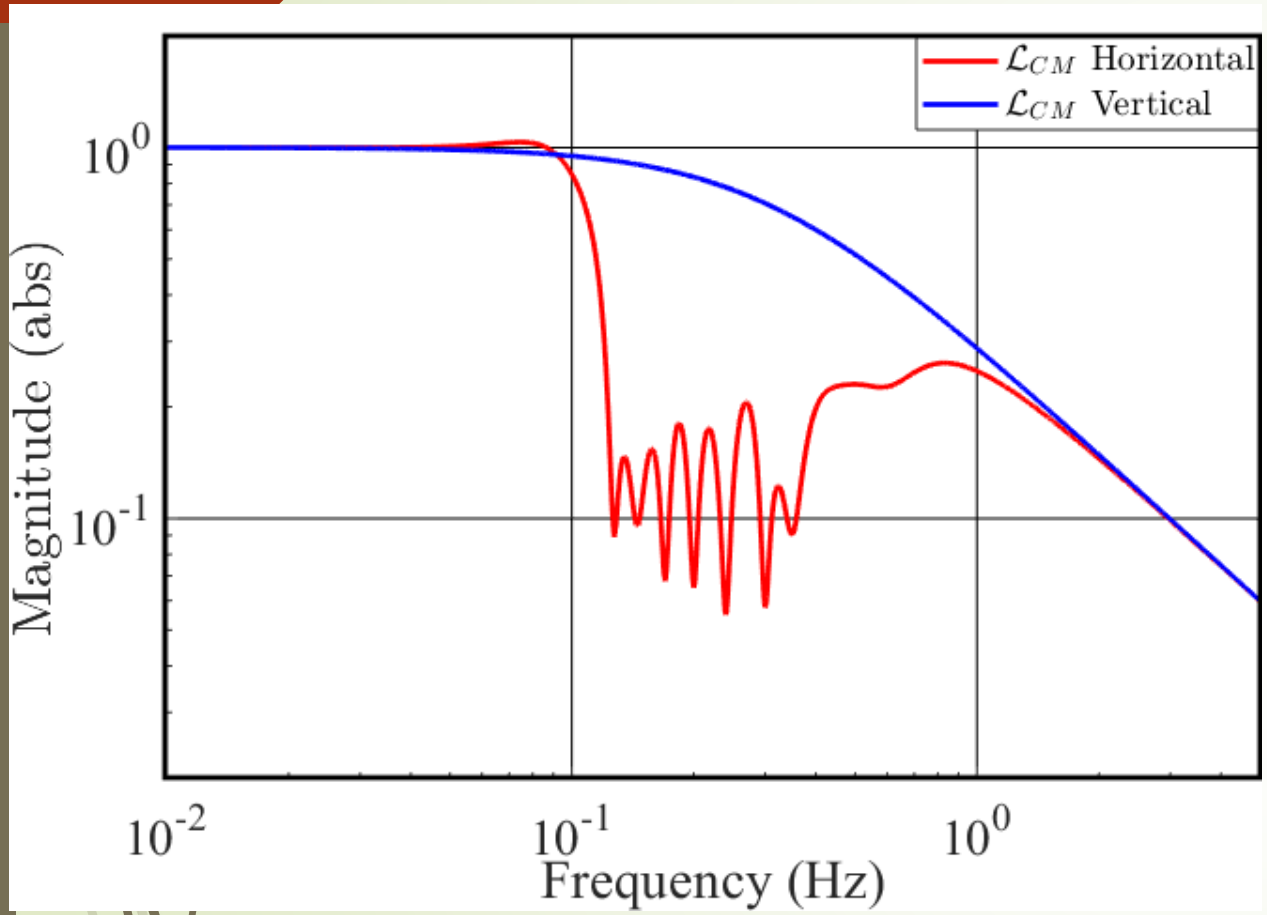
- Remove Common motion at earthquake band.
- Design different sensor correction filter.

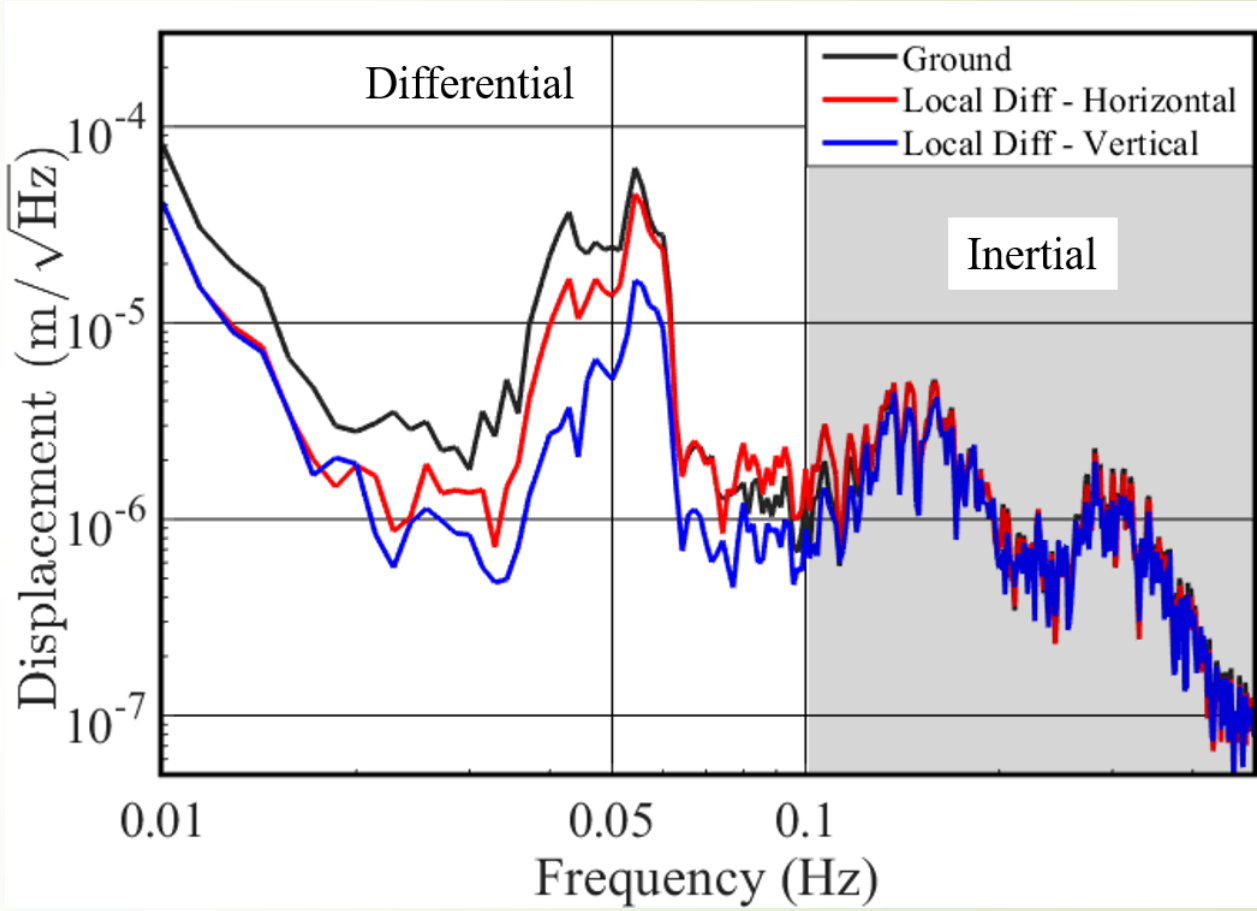
Sensor correction 102?



$$\underset{C\cdot P_S \gg 1}{X_S} = [X_G \cdot (1 - SC) + CM \cdot \mathscr{L}_{CM} \cdot SC] \cdot L - (\eta_{BRS} - \eta_{CM}^{BRS}) \cdot SC \cdot L - (\eta_{CPS} \cdot L + \eta_{in} \cdot H)$$

CM filter



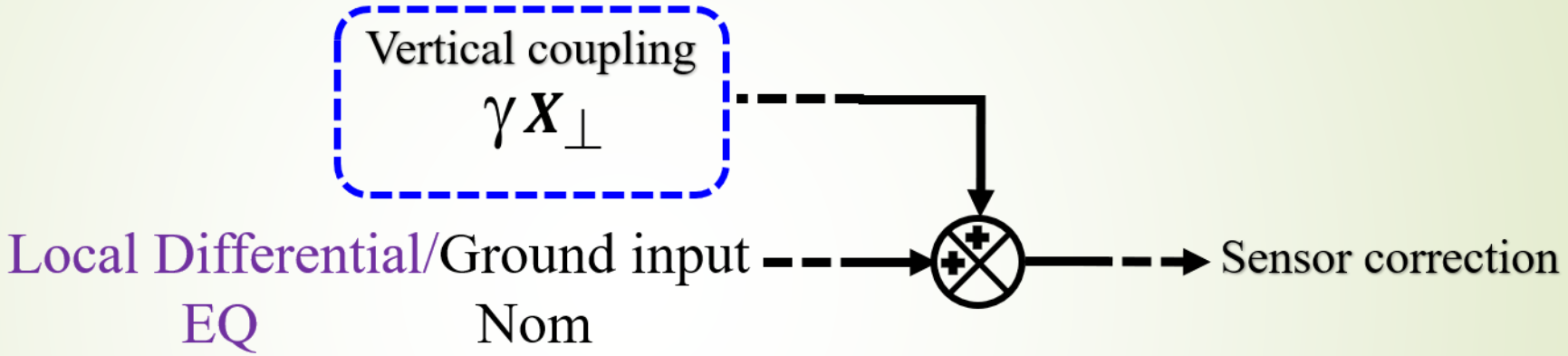


Seismic Optimization

coupling!

Differential platforms motion
Coupling to other DOF – this is just weird…

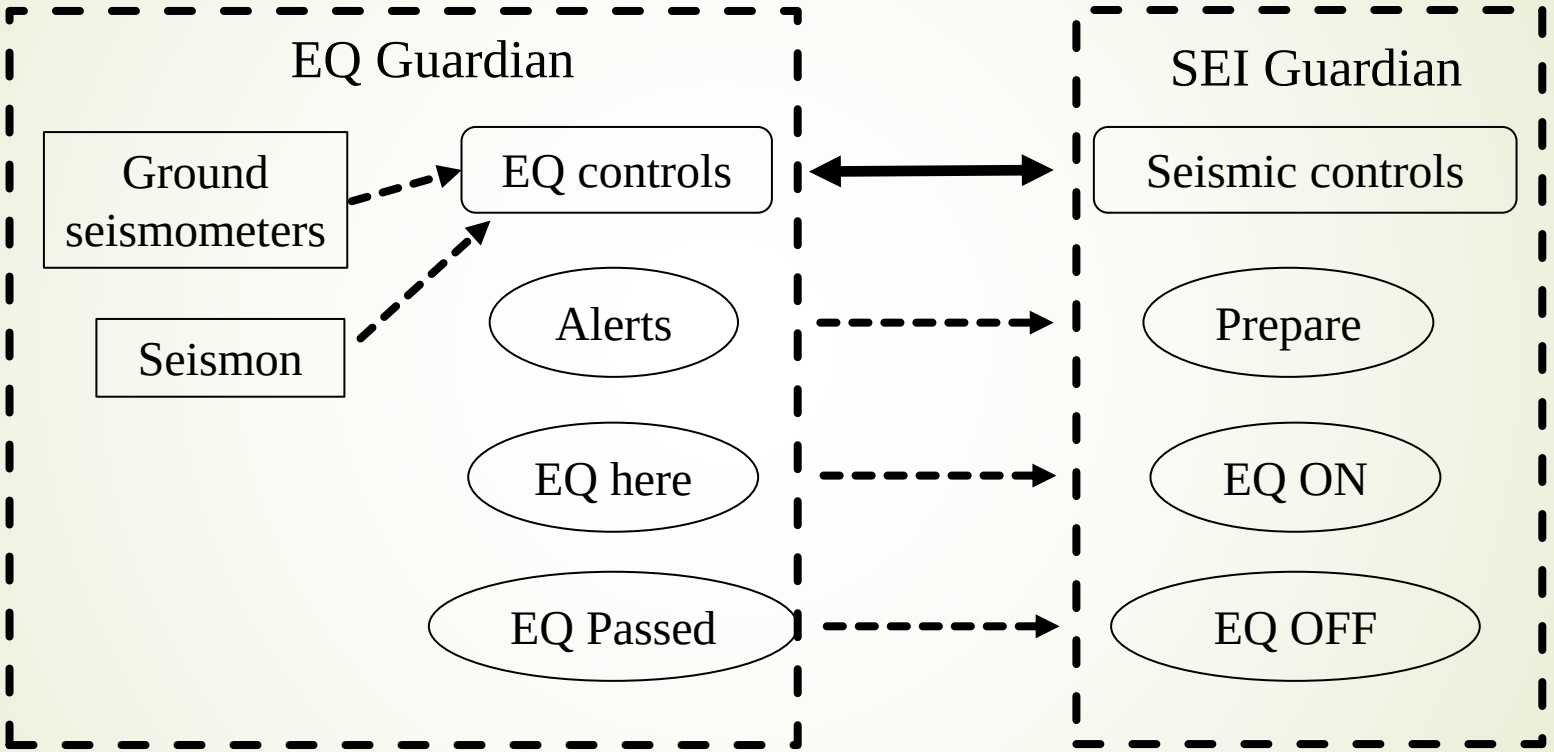
SEI log: 1568



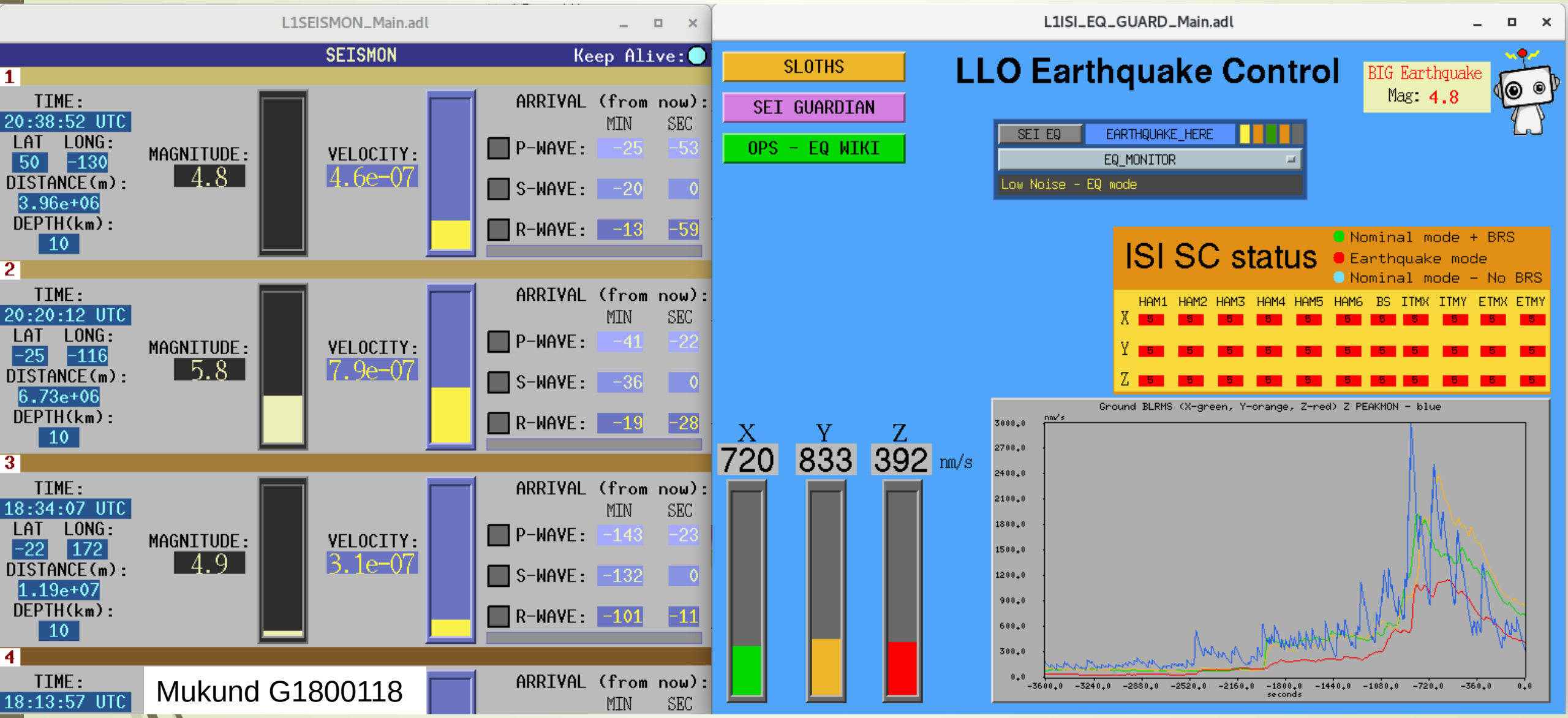
$$X_S^{EQ} = [X_G \cdot (1 - SC) + CM \cdot \mathscr{L}_{CM} \cdot SC + \gamma X_\perp \cdot SC - (\eta_{BRS} - \eta_{CM}^{BRS}) \cdot SC] \cdot L - (\eta_{CPS} \cdot L + \eta_{in} \cdot H)$$

$$X_S^{NOM} = [X_G \cdot (1 - SC) - \eta_{BRS} \cdot SC + \gamma X_\perp \cdot SC] \cdot L - (\eta_{CPS} \cdot L + \eta_{in} \cdot H)$$

Global controls - Automation



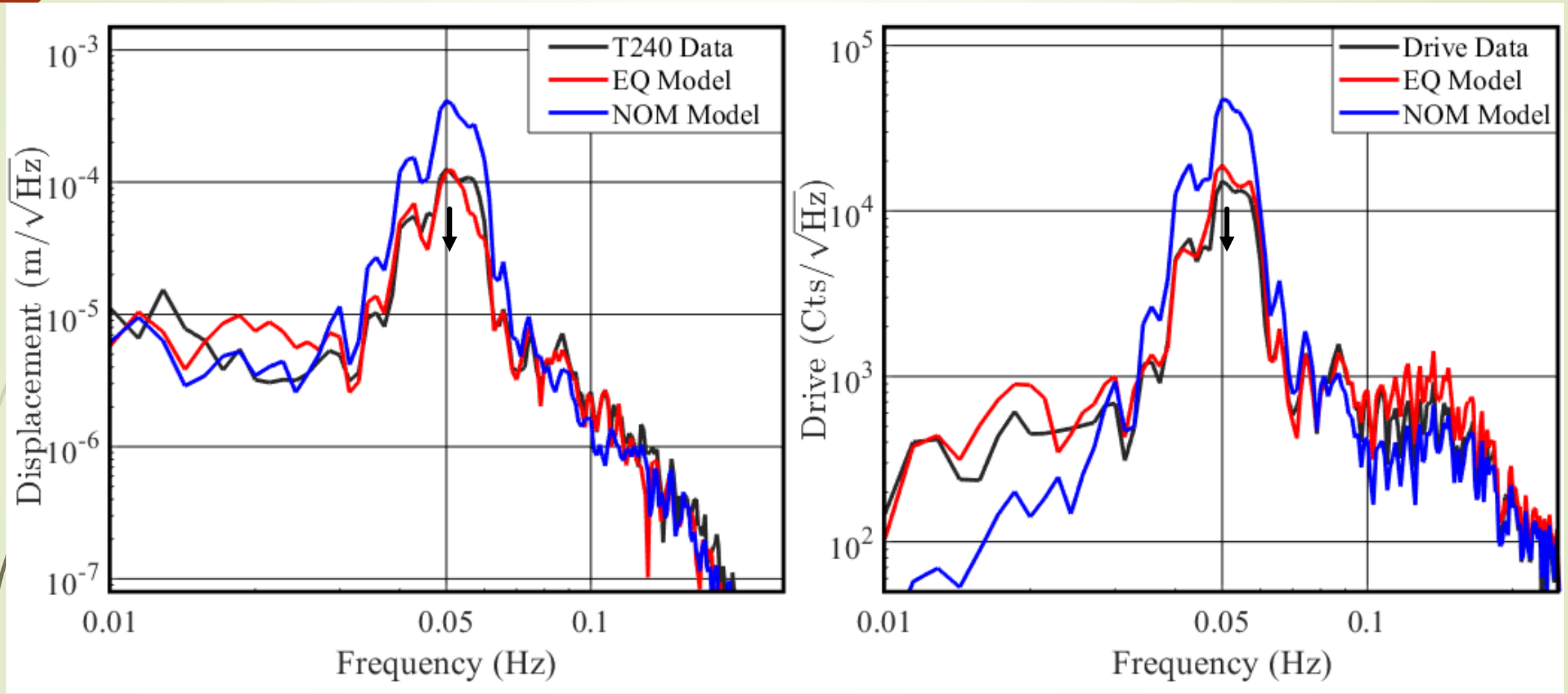
Global controls - Automation



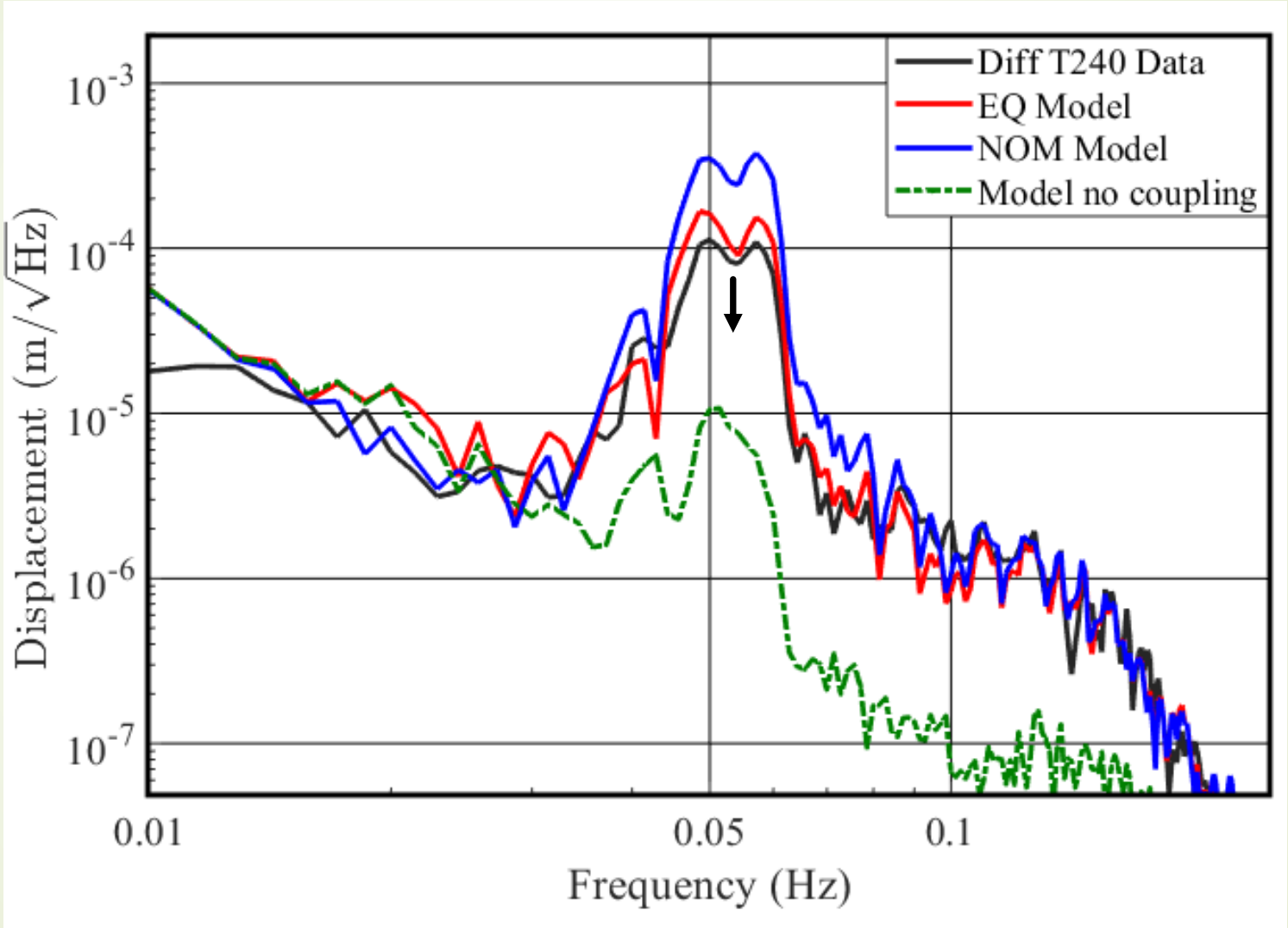
Mukund G1800118

Results!

Local platform motion and drive



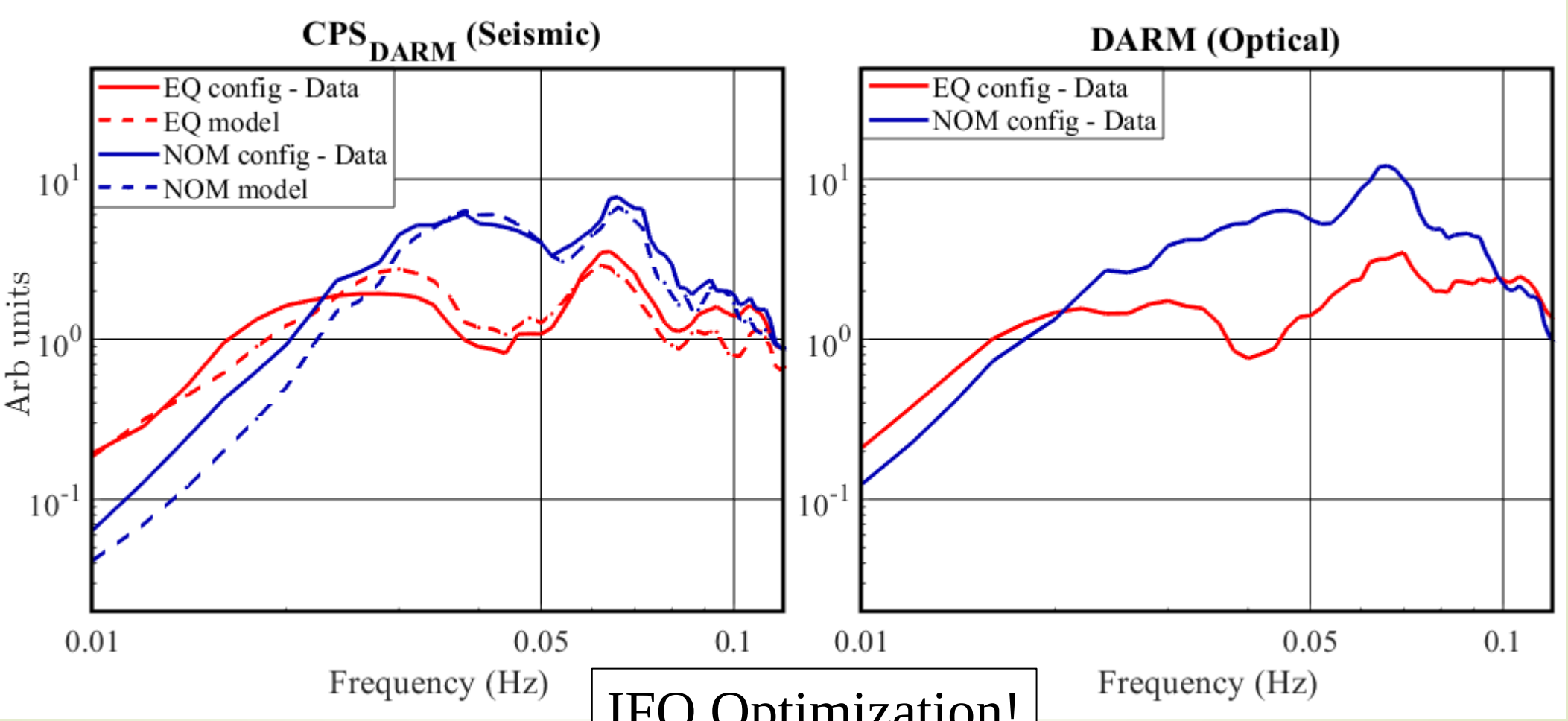
Results! Differential platforms motion



$$X_S^{\Delta} = X_G^{\Delta} \cdot (1 - SC) \cdot L - \eta_{BRS}^{\Delta} \cdot SC \cdot L + \gamma^{\Delta} X_{\perp}^{\Delta} \cdot SC \cdot L$$ + O(Sensor noises)

Results!

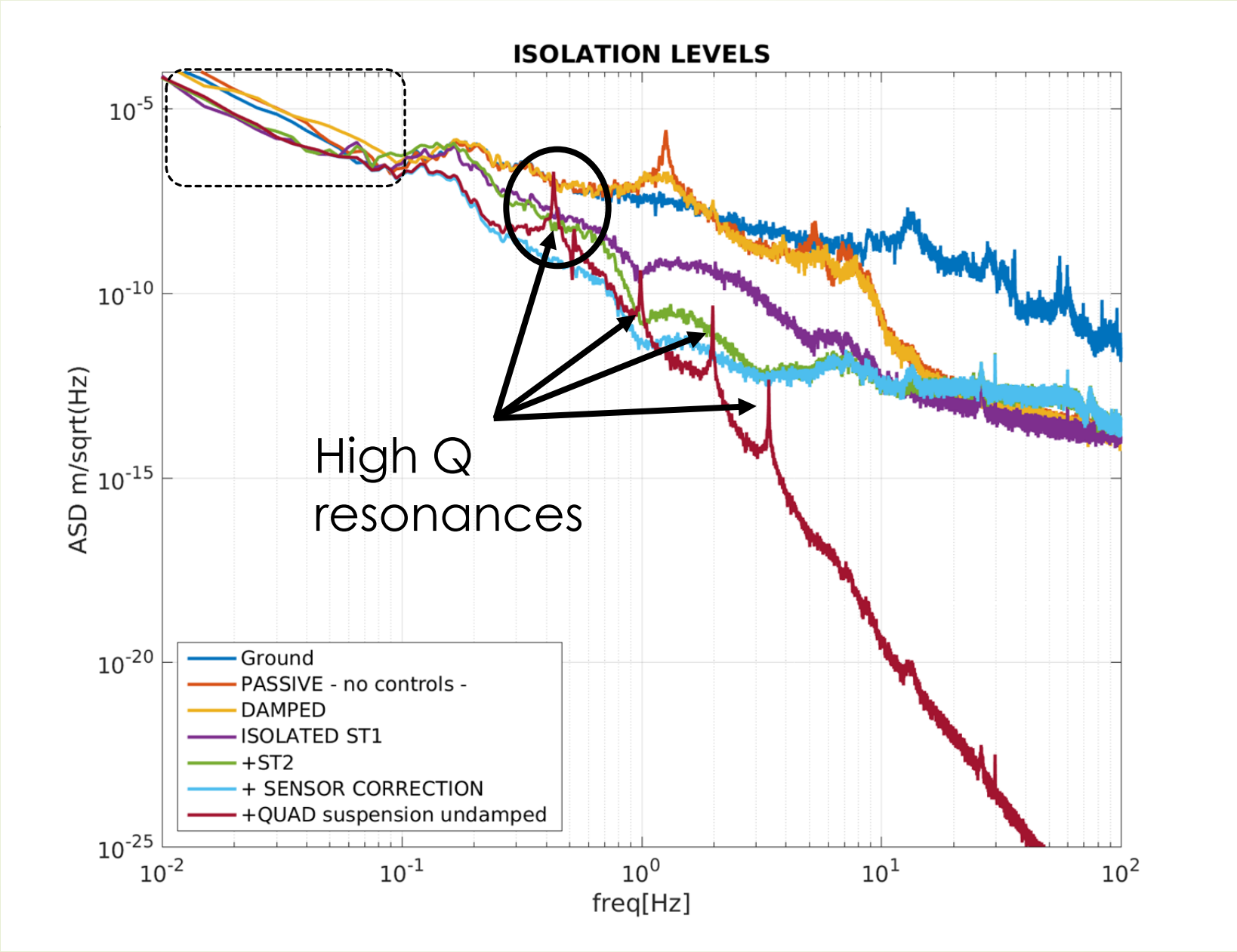
DARM controls



IFO Optimization!

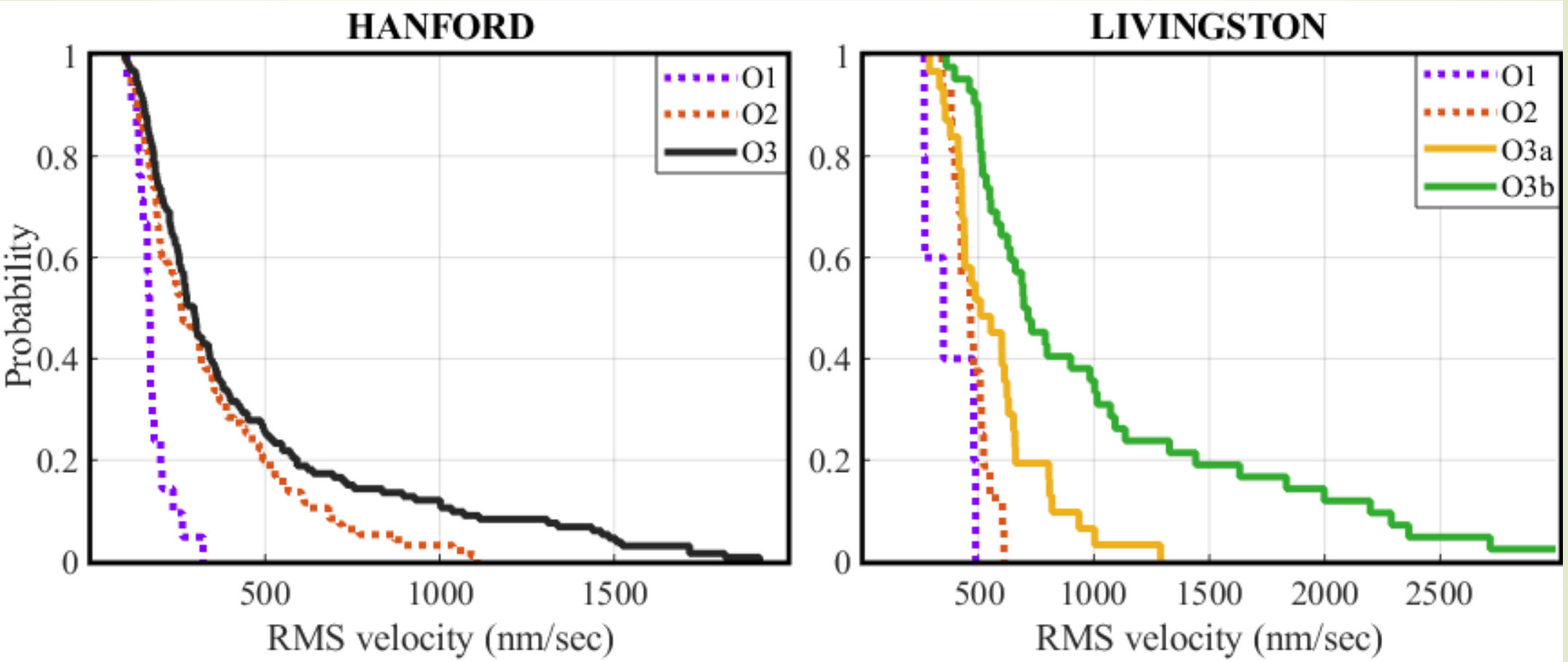
$$\mathrm{CPS_{DARM}} = (\mathrm{CPS_X^{ETMX}} - \mathrm{CPS_X^{ITMX}}) - (\mathrm{CPS_Y^{ITMY}} - \mathrm{CPS_Y^{ETMY}})$$
$$= X_G^{\mathrm{DARM}}[(1 - SC) \cdot L - 1] + [\gamma^{\mathrm{DARM}} X_\perp^{\mathrm{DARM}} - \eta_{BRS}^{\mathrm{DARM}}] \cdot SC \cdot L$$

Optical controls



Pele G2000186

Results - Statistics



Earthquakes are annoying

O3a 1238166018-1253977218 Home Summary Analysis Locking Range Segments Time accounting Links

Time accounting : LLO

Detailed mode information

Detailed observatory mode statistics as recorded in `L1:ODC-OBSERVATORY_MODE`

Index	Name	Active seconds	Hours	%
10	Observing	12127613.9	3368.8	76.7
21	Acquiring	1082494.8	300.7	6.8
22	Aligning	188481.4	52.4	1.2
31	Wind	126785.9	35.2	0.8
32	Seismic	2135.9	0.6	0.0
33	Microseism	121086.2	33.6	0.8
34	Earthquake	624606.0	173.5	4.0
35	Train	3407.2	0.9	0.0
36	Logging	5382.9	1.5	0.0
37	Other	205.2	0.1	0.0
38	Unavoidable	309658.4	86.0	2.0
40	Commissioning	345437.9	96.0	2.2

Earthquakes are a bit less annoying

O3a 1238166018-1253977218 Home Summary Analysis Locking Range Segments Time accounting Links

Time accounting : LLO

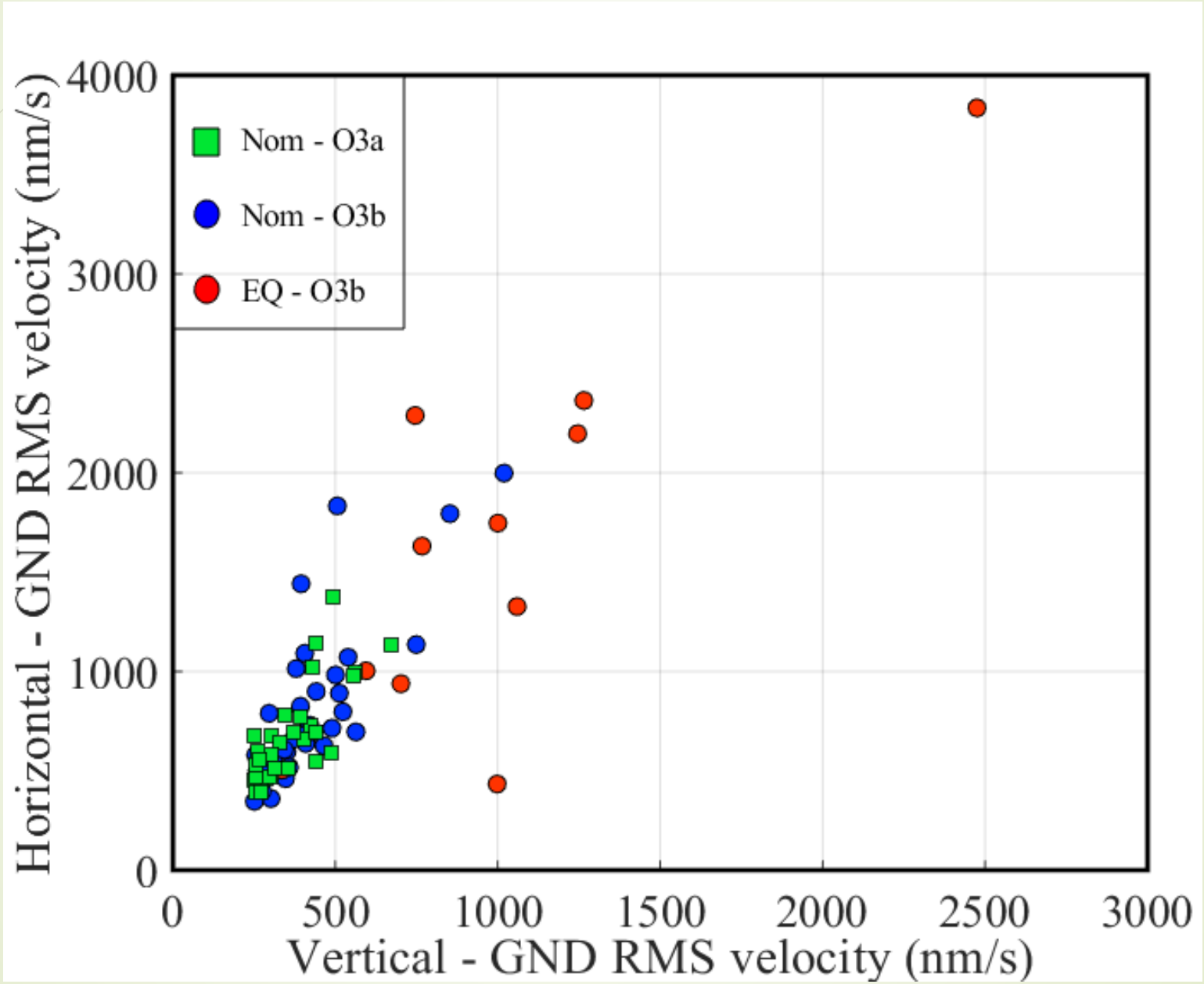
O3b 1256655618-1269363618 Home Summary Analysis Locking Range Segments Time accounting Links

Detailed mode information

Detailed observatory mode statistics as recorded in `L1:ODC-OBSERVATORY_MODE`

Index	Name	Active seconds	Hours	%
10	Observing	10054269.1	2792.9	79.1
21	Acquiring	853029.4	237.0	6.7
22	Aligning	116014.9	32.2	0.9
31	Wind	43746.9	12.2	0.3
32	Seismic	0.0	0.0	0.0
33	Microseism	458210.1	127.3	3.6
34	Earthquake	309364.6	85.9	2.4
35	Train	0.0	0.0	0.0
36	Logging	0.0	0.0	0.0

In action during O3a/b



Summary and what's next?

- We are getting a suppression factor of 3-4 for differential motion and 2-3 for platform motion and drive at EQ band.
- We reduce optical control signals during EQ and can use CPS to optimize the performance in low frequencies.
- Increased duty cycle of interferometers.

Summary and what's next?

- Earthquakes predictions. Seismon, picket fence.
- Multi-scenario optimization – SC & CM filters, blends.
- Optimize for multi-frequency band excitations.
- Understand cross-couplings from all DOF - Tilt.
- Optimize performance of IFO based on seismic at low frequencies.
- Automation, automation, automation….