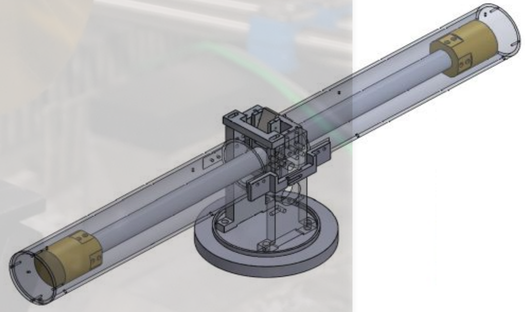
Caltech

Integration of Beam Rotation Sensors to seismic isolation

Arnaud Pele
Michael Ross

Low frequency workshop
Birmingham, Aug 30th 2018



Overview

Introduction on seismic isolation at LIGO

What limits us at low-f ?

BRS installation and challenges

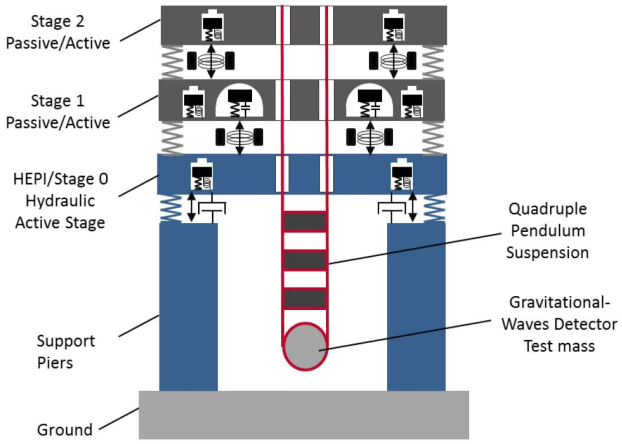
BRS integration to ISI, some projections

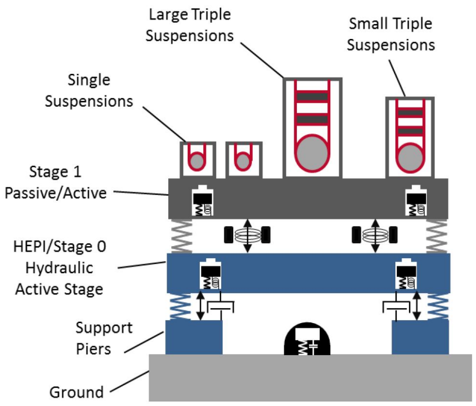
ISI (Internal Seismic Isolation) : Introduction

- Provide **vibration isolated support** for the suspended optics

- Help **maintain** and **acquire** resonance conditions for the optical cavities

- **Distinguish** between mirror vibrations and gravitational wave signals





F. Matichard [4]

ISI (Internal Seismic Isolation) : Introduction

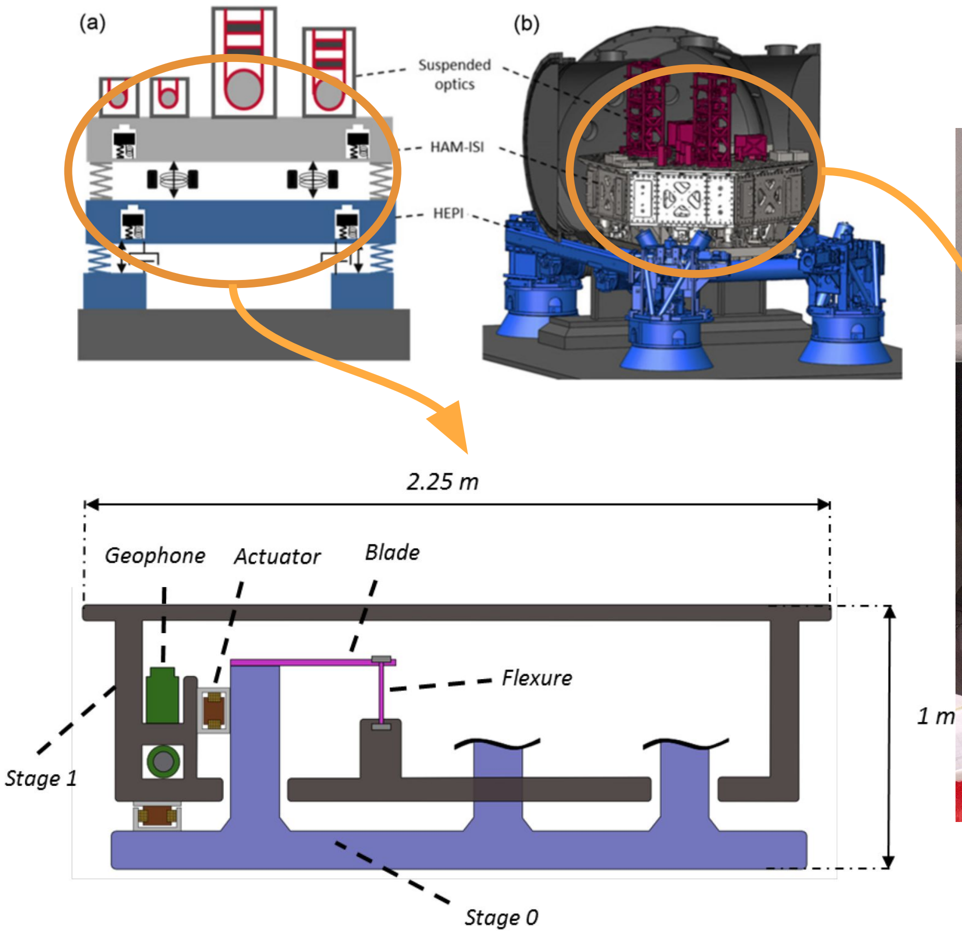
- With single or double mass-spring systems, combination of **passive** and **active isolation** to cancel ground motion

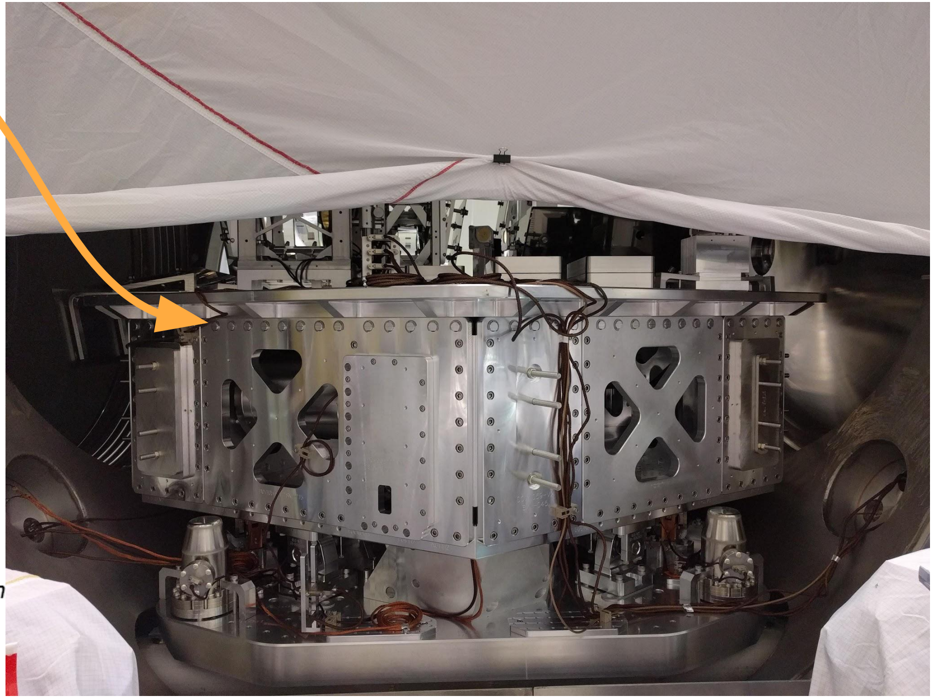
- **Steel blades** and **flexure rods** between the ISI stages for vertical and horizontal passive isolation

- Actively limits the input ground motion from 0.1Hz to ~30Hz with combination of **magnetic** actuators, **position** and **inertial** sensors

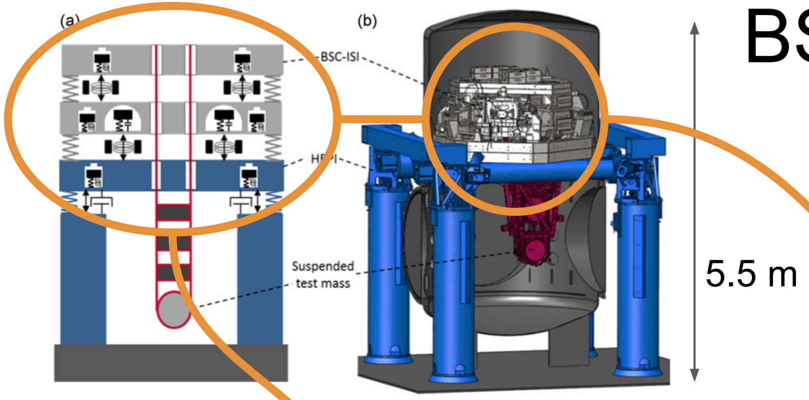
- Maximum total of **7 isolation stages** for the core optics (HEPI + BSC-ISI + QUAD)

HAM-ISI

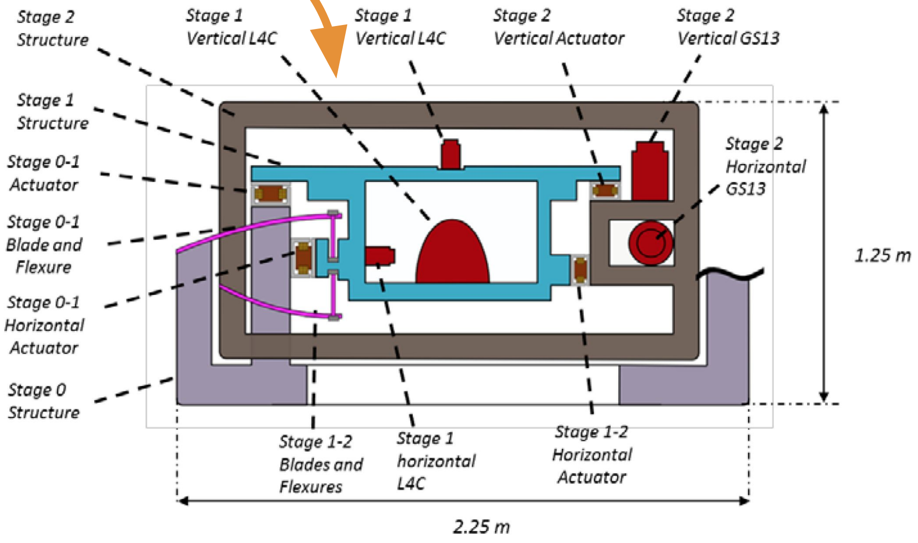

(a)
(b)
Suspended optics
HAM-ISI
HEPI
2.25 m
Geophone
Actuator
Blade
Flexure
Stage 1
Stage 0
1 m



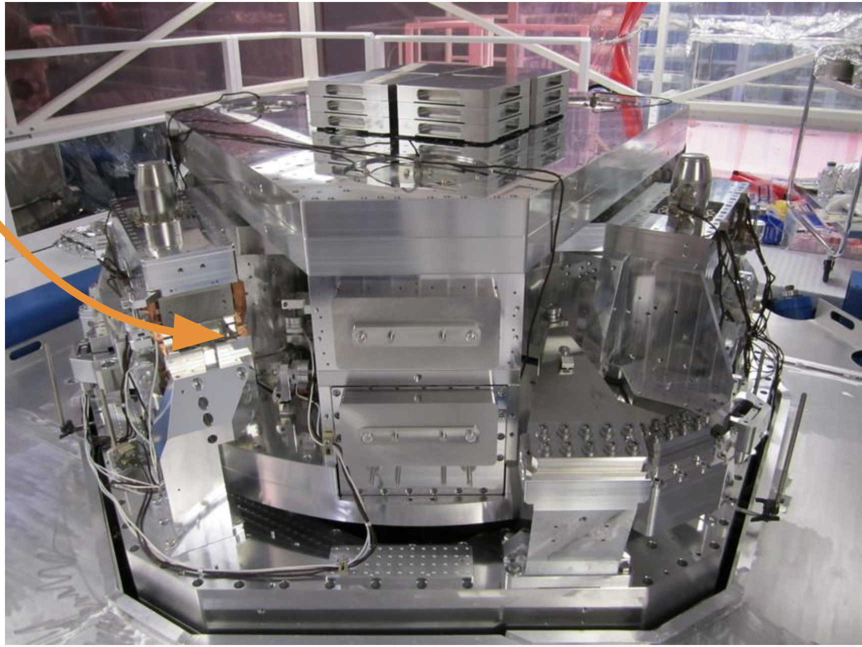
BSC-ISI

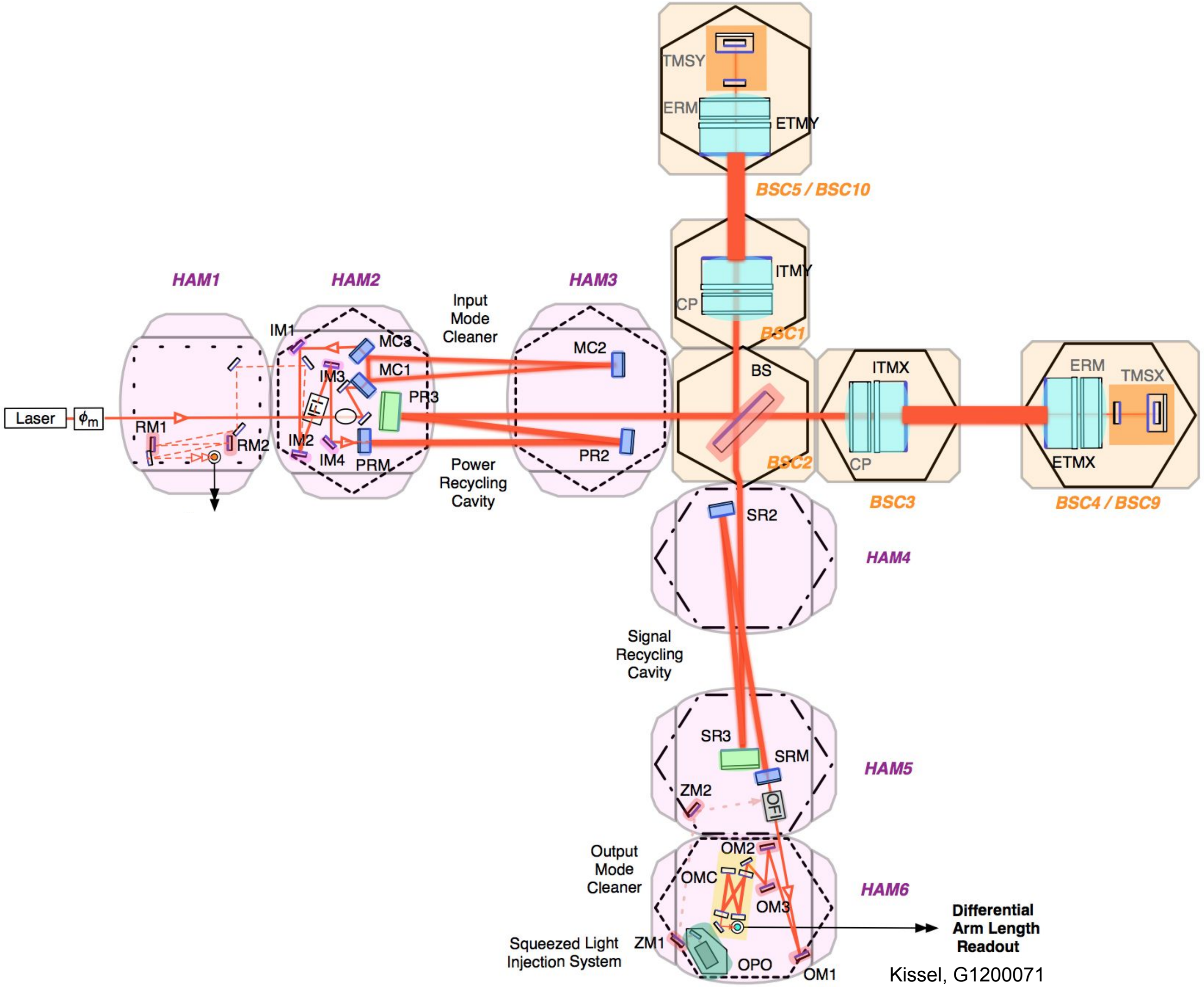


(a)
(b)
BSC-ISI
Suspended test mass
5.5 m



Stage 2 Structure
Stage 1 Vertical L4C
Stage 1 Vertical L4C
Stage 2 Vertical Actuator
Stage 2 Vertical GS13
Stage 1 Structure
Stage 0-1 Actuator
Stage 2 Horizontal GS13
Stage 0-1 Blade and Flexure
1.25 m
Stage 0-1 Horizontal Actuator
Stage 0 Structure
Stage 1-2 Blades and Flexures
Stage 1 horizontal L4C
Stage 1-2 Horizontal Actuator
2.25 m



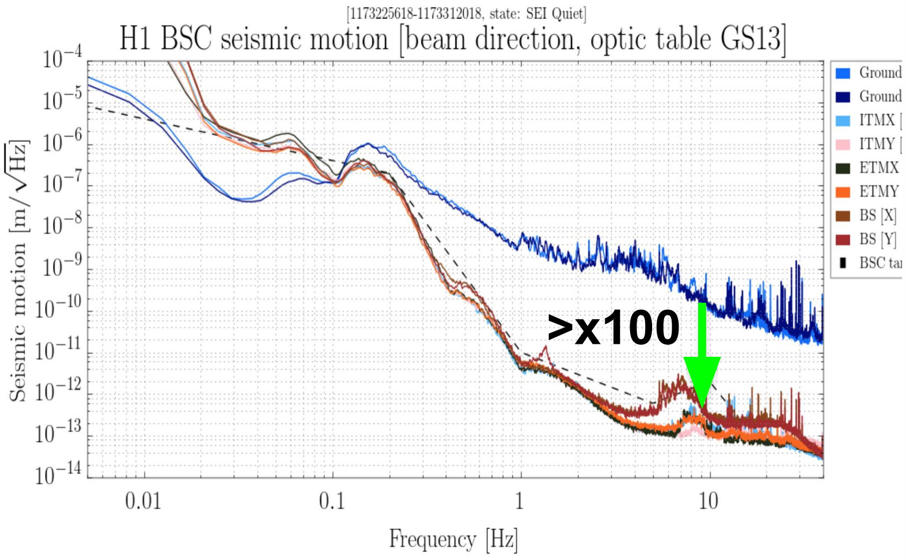


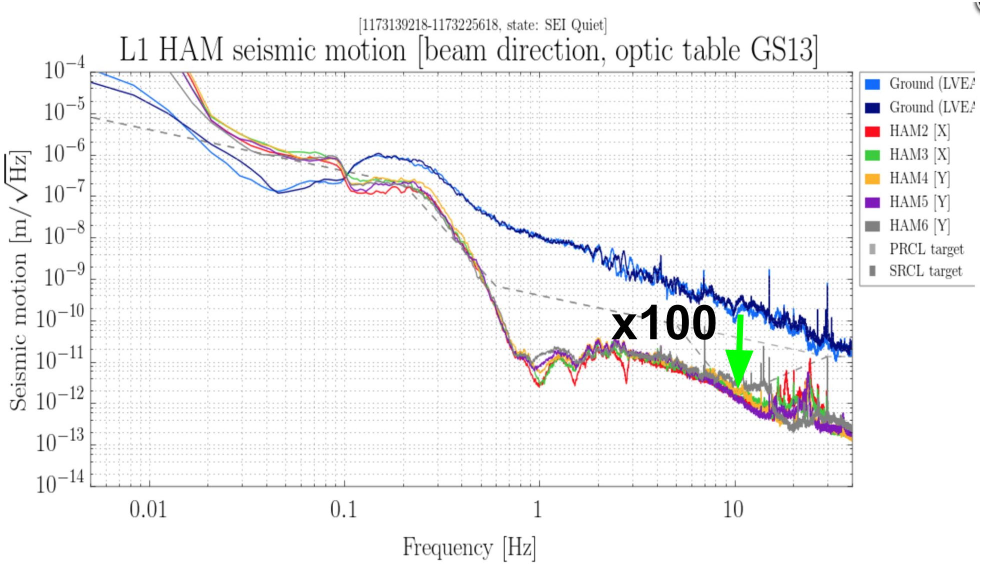
Kissel, G1200071

Requirements for seismic isolation : >1Hz

- At **10Hz** BSC-ISI < **2e-12m/sqrt(Hz)** in all horizontal dofs [1]

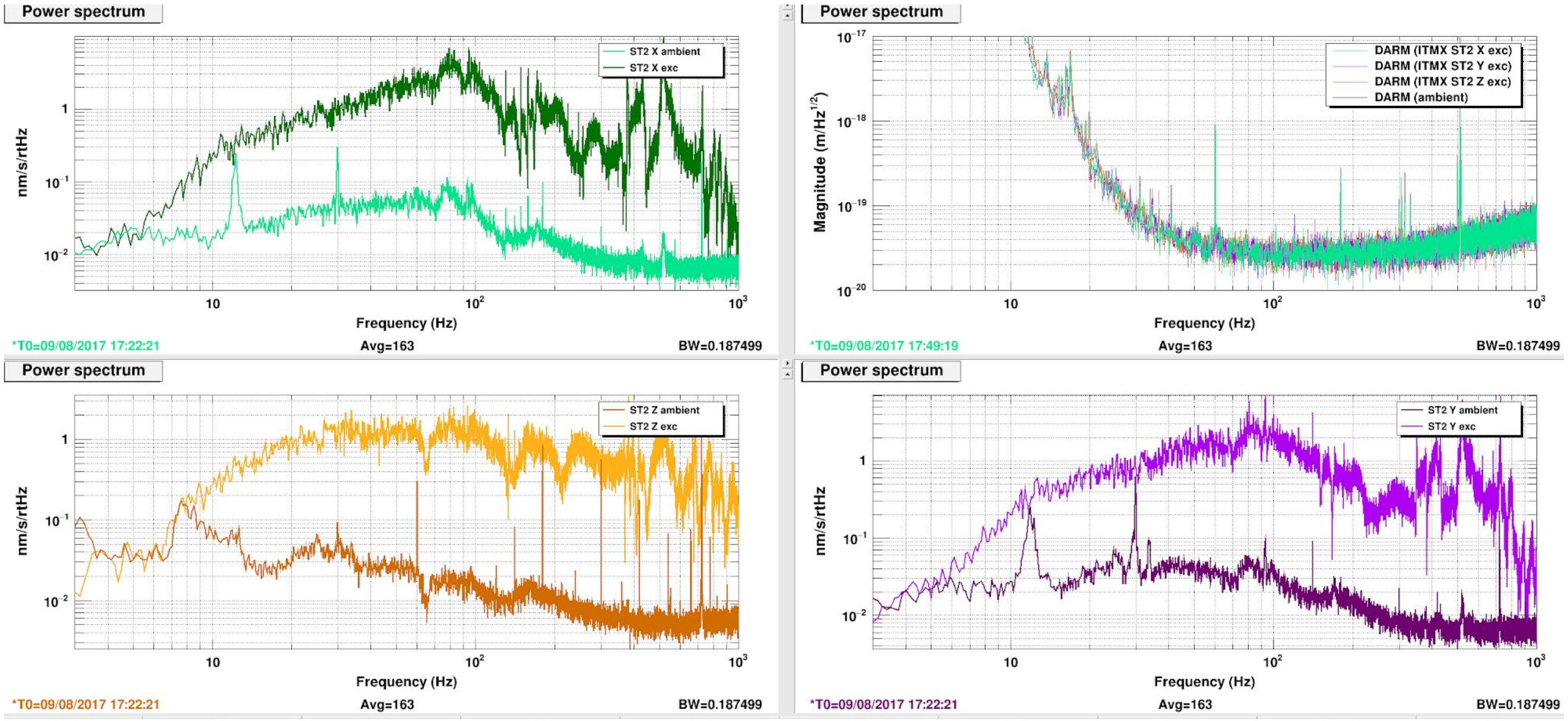
- At **10Hz** HAM-ISI < **4e-11m/sqrt(Hz)** for PRCL and
  4e-12m/sqrt(Hz) for SRCL [3]





Requirements for seismic isolation : >1Hz

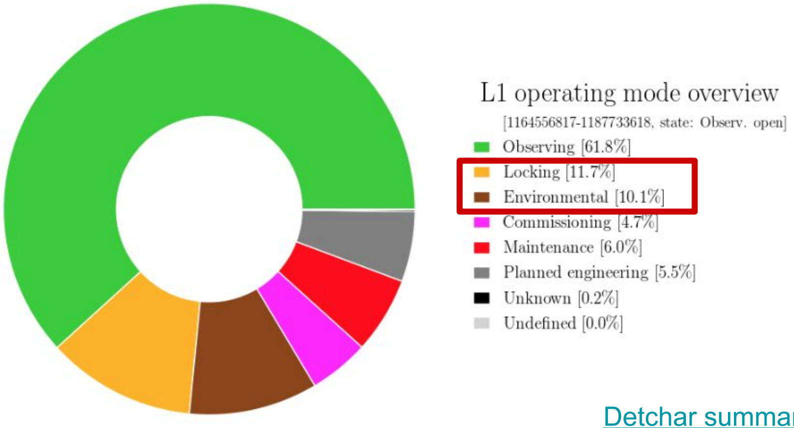
- Certainly good enough : Large injections (x10 ambient noise) from BSC-ISI are not showing in the DARM sensitivity.

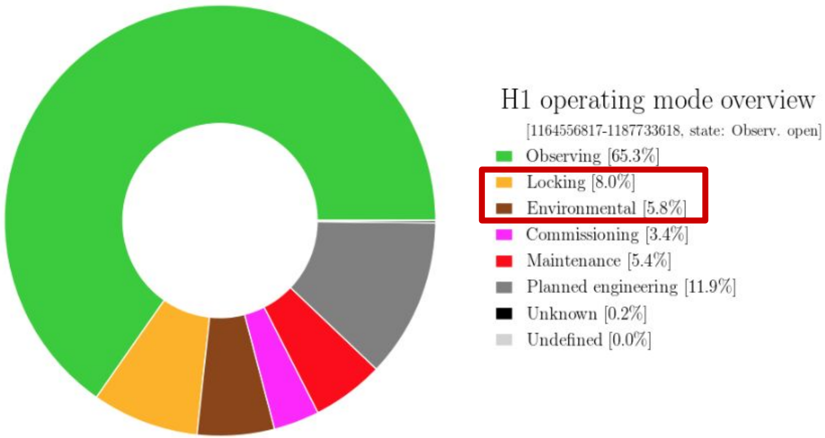


llo alog 35314

Requirements for seismic isolation : <1Hz

- 1-2 µm-rms typical microseismic amplitude suppressed by a factor of 5-10 [2]
- Below 0.1Hz, less clearly defined requirements, hard to measure motion at those frequencies with seismometers
- In reality: hard to lock with>2-3um rms microseism motion (100mHz-400mHz)
  >1um rms earthquake motion (30mHz-100mHz)
- Down time from low-frequency input motion (wind/microseism/earthquakes) : 5-10% at both sites + 10% locking

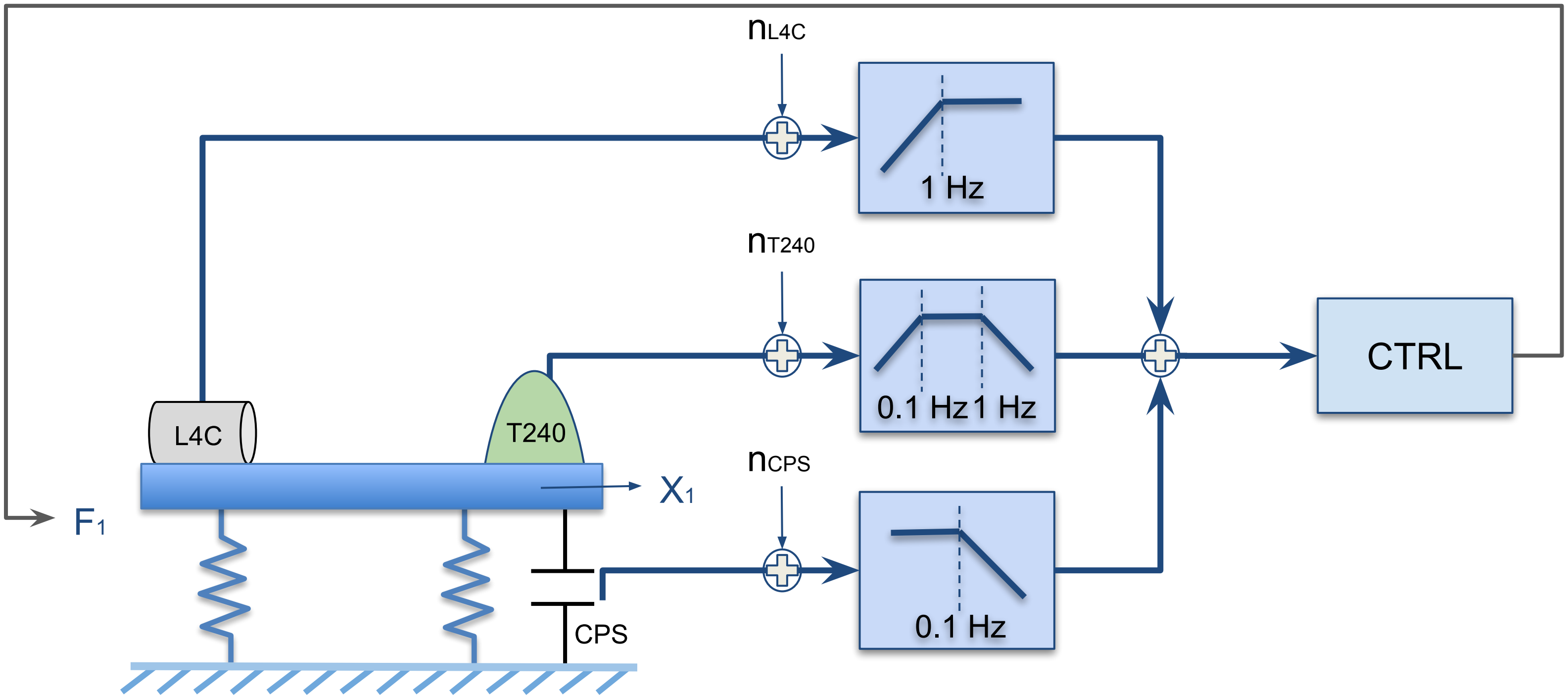




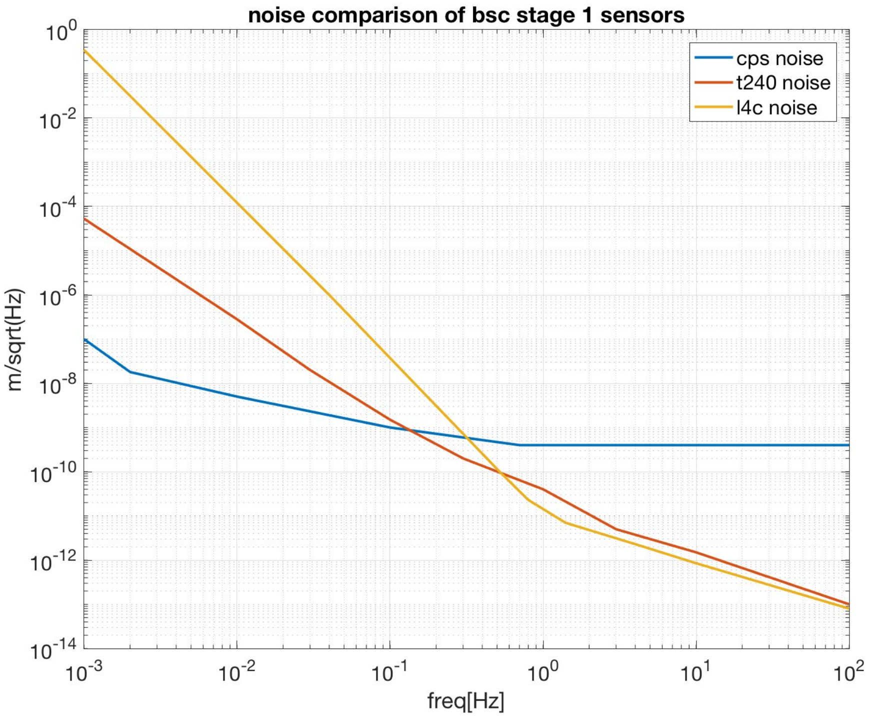
Detchar summary pages

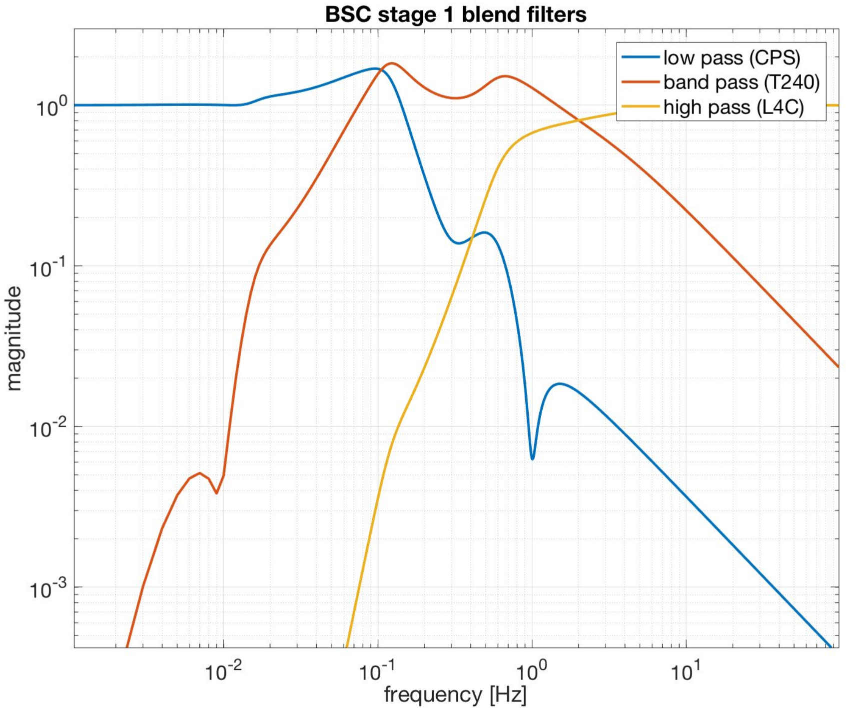
Active isolation, general control scheme

- Feedback: Blending of sensors, one or two inertial sensors > 0.1Hz with position sensors < 0.1Hz, (similar scheme in all 6 dofs)



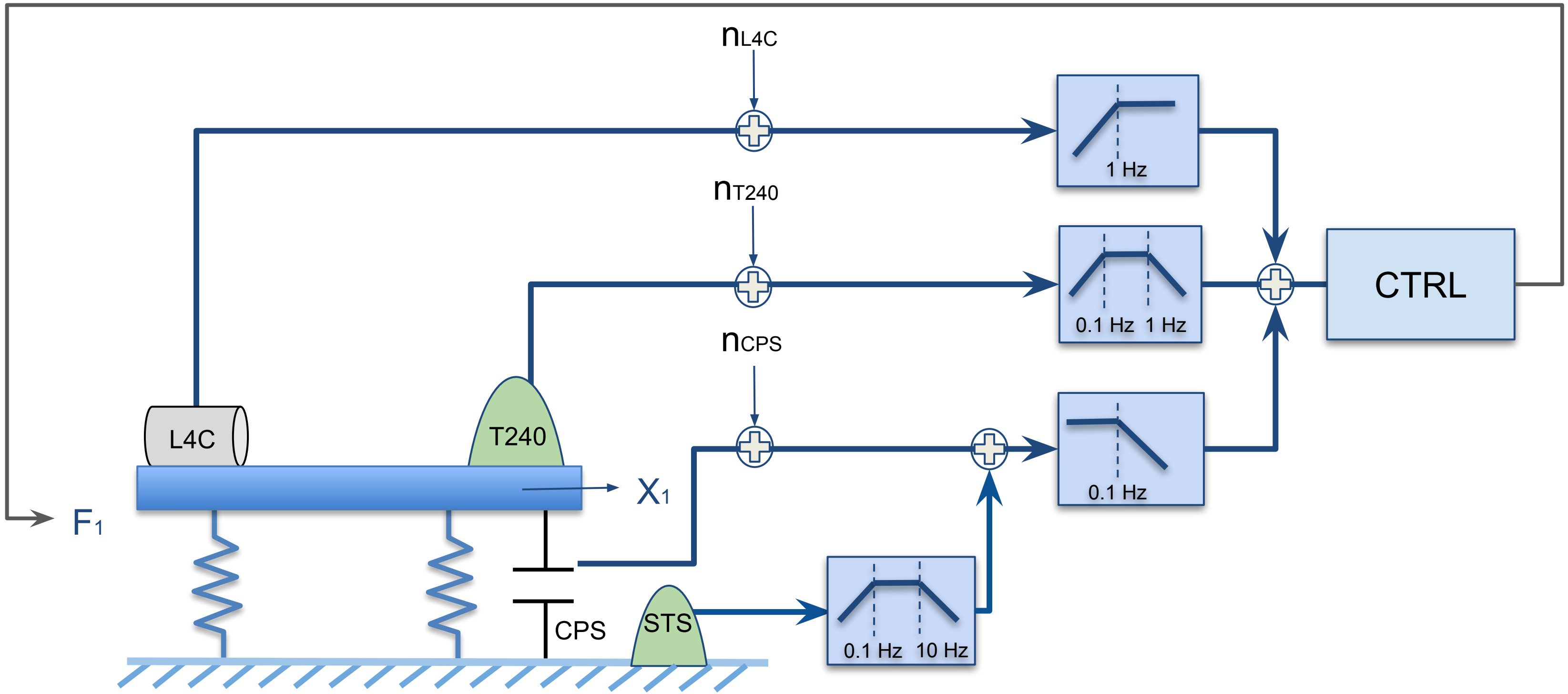
Sensor noise and blend filters





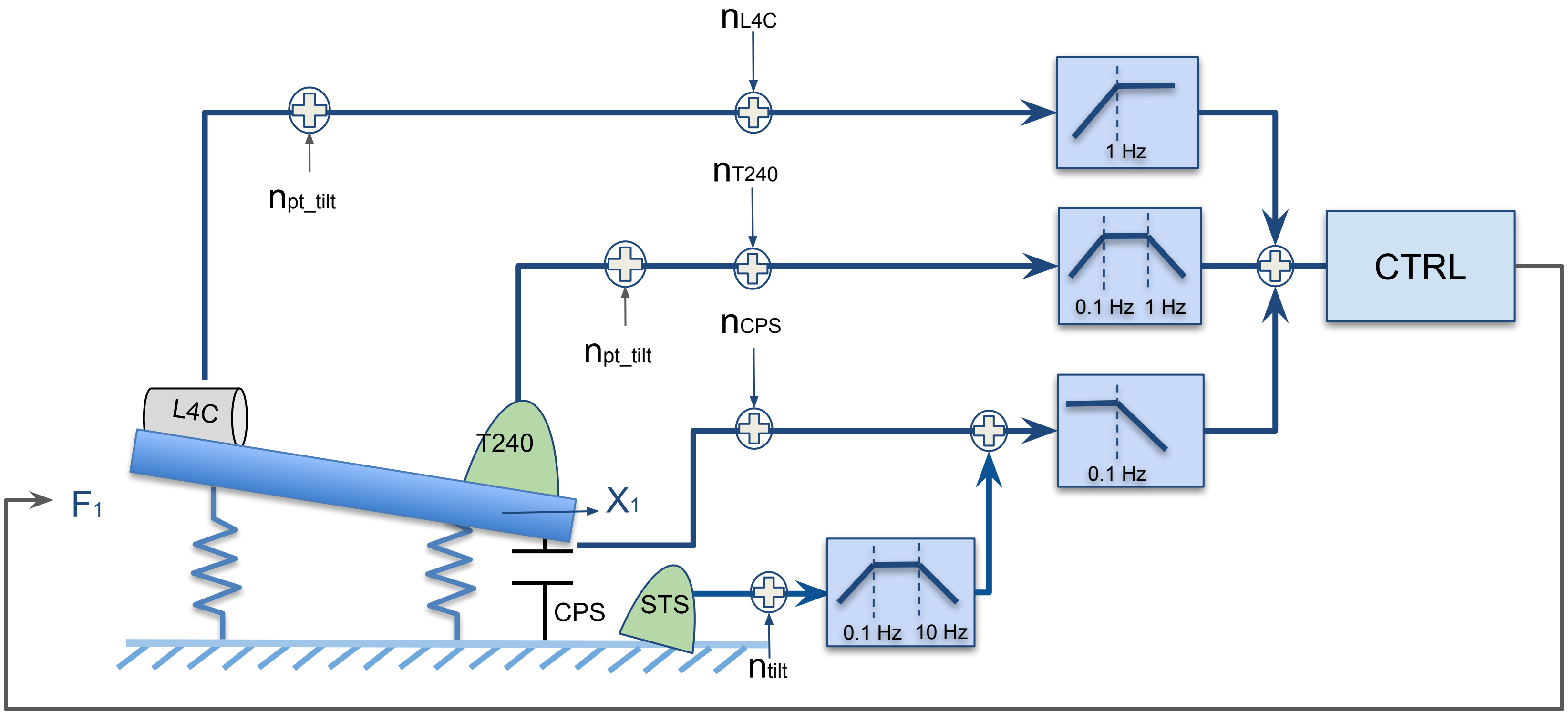
Active isolation, general control scheme

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



Active isolation, general control scheme

- In the corner station, same seismometer signal fed to all platform:
  - Advantage of moving all platforms in common (llo 34878), even w tilt
  - If relying on T240 at low-f, large relative motion (B.Lantz, G1700331)



NB BSC-ISI stage 1 rotation dof, windy

Tilt measured by differential vertical T240

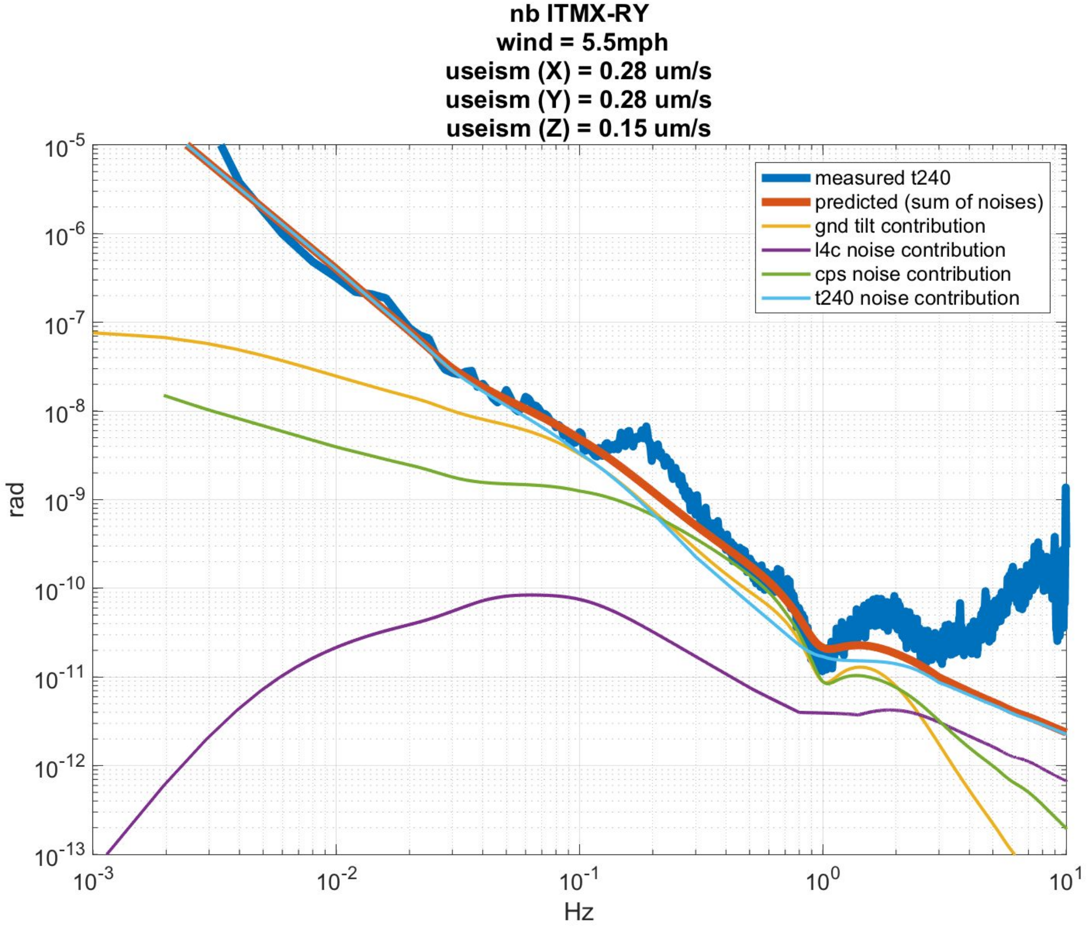
Limited by :

T240 noise < 100mHz

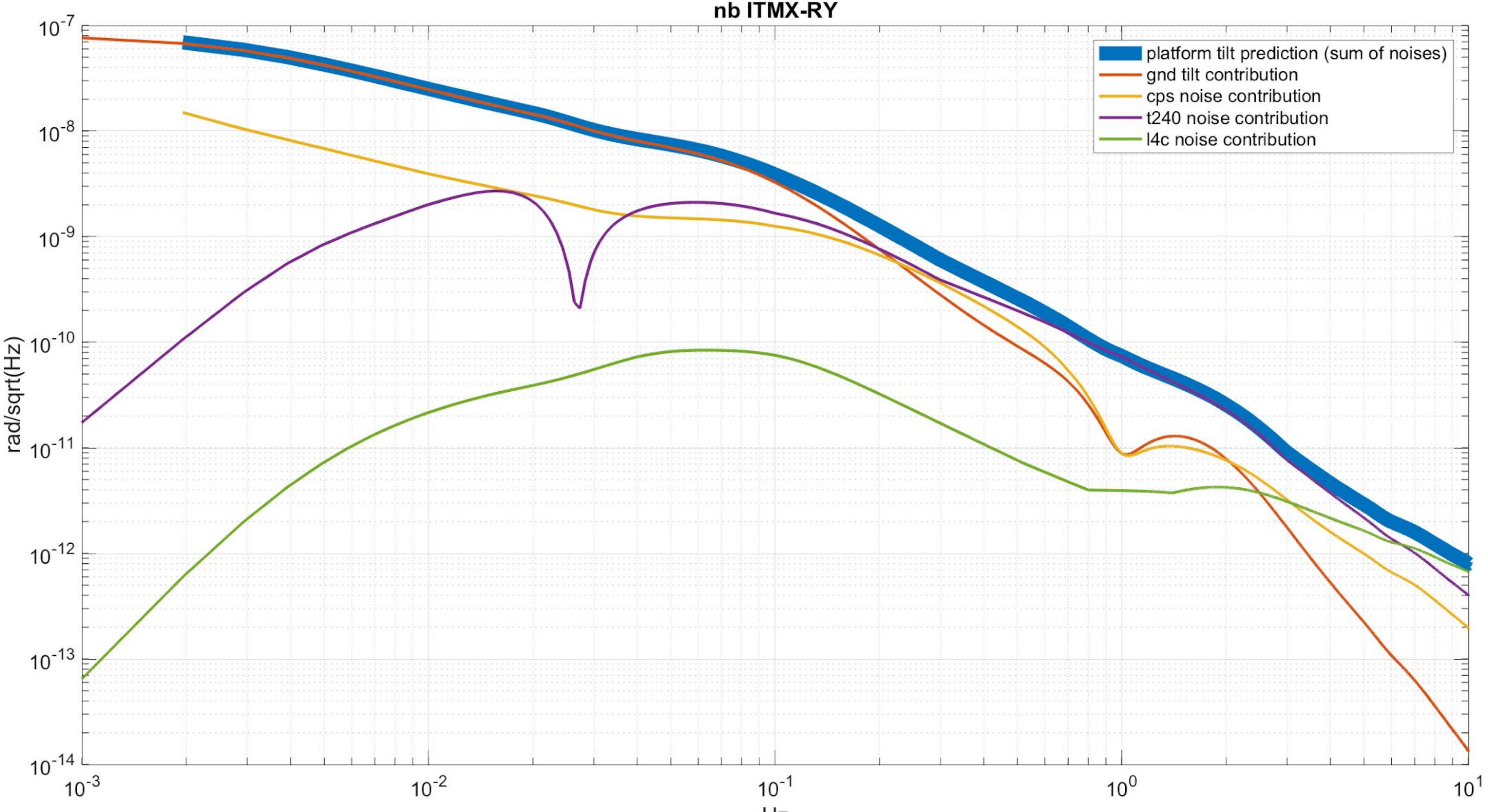
cps noise 0.5Hz-1Hz

Not well understood between 0.1Hz-0.5Hz

Varies with useism, not with ground tilt

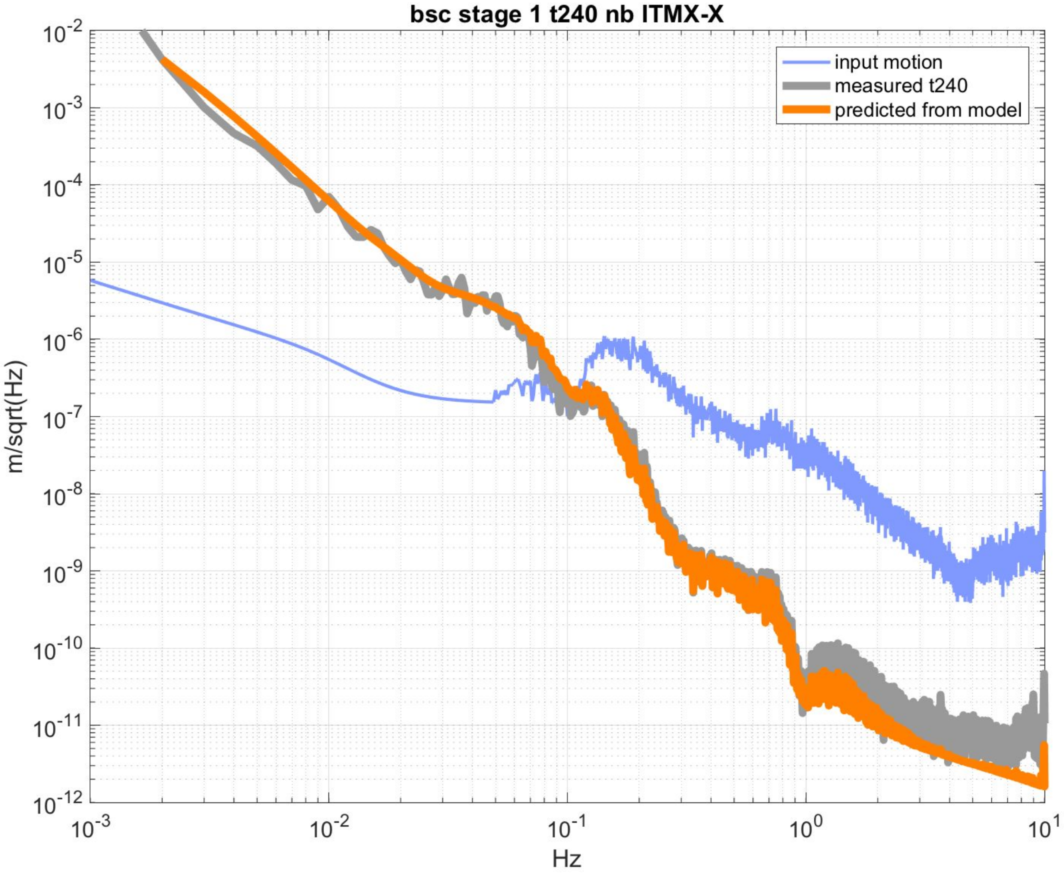


NB BSC-ISI stage 1 rotation dof, windy



NB BSC-ISI stage 1 horizontal dof, windy

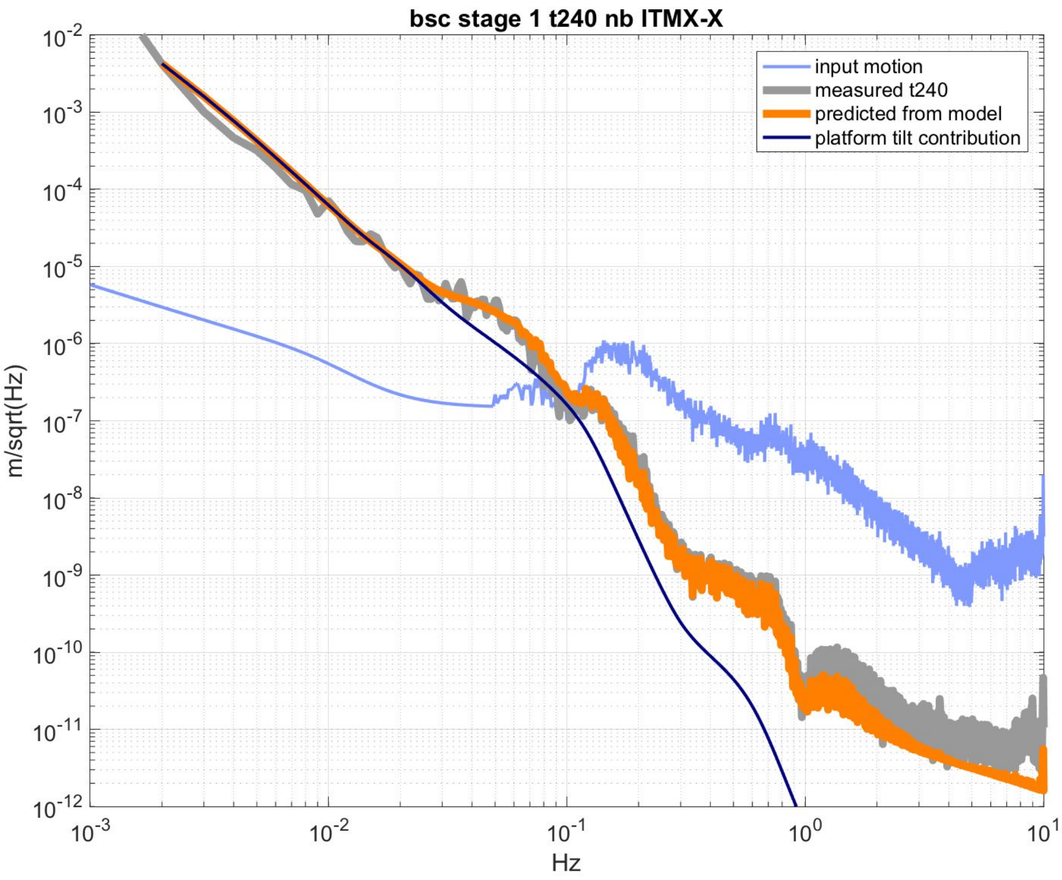
Model matches T240 signal



NB BSC-ISI stage 1 horizontal dof, windy

Model matches T240 signal

T240 dominated by platform tilt below 50mHz

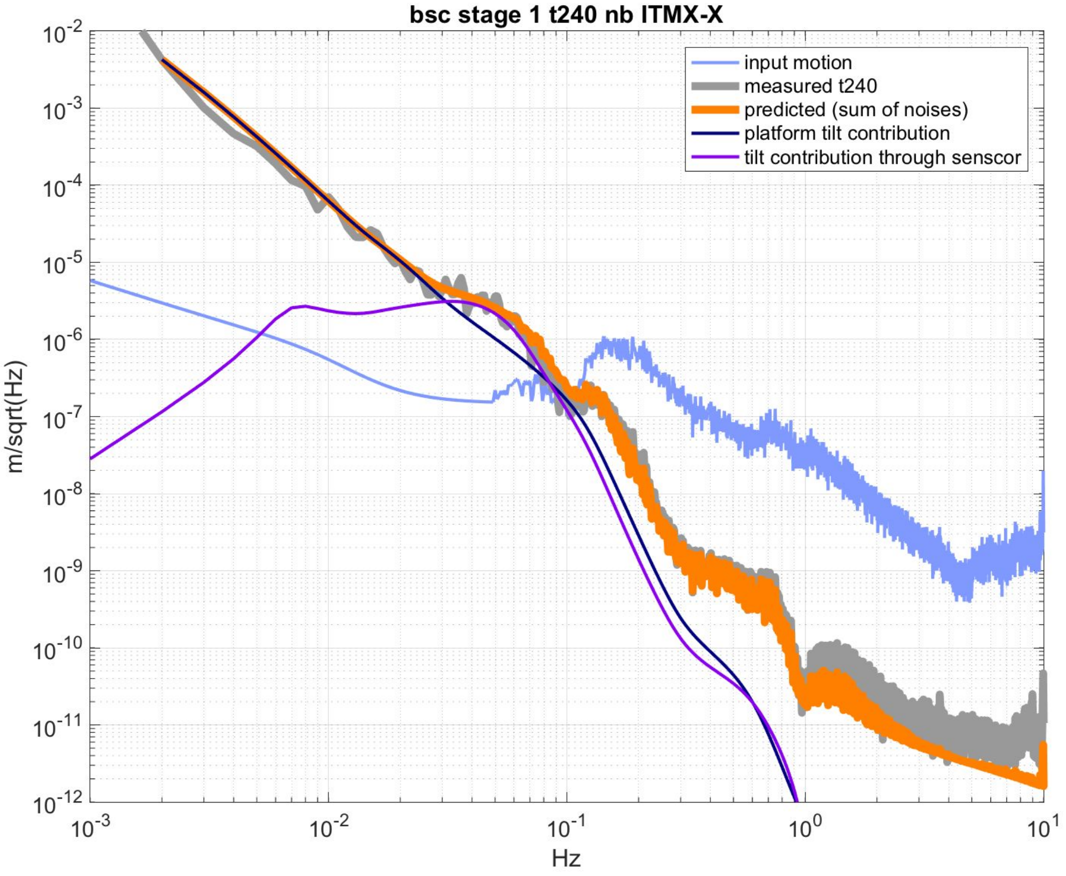


NB BSC-ISI stage 1 horizontal dof, windy

Model matches T240 signal

T240 dominated by platform tilt below 50mHz

T240 dominated by tilt from feedforward (STS) between 50-100mHz



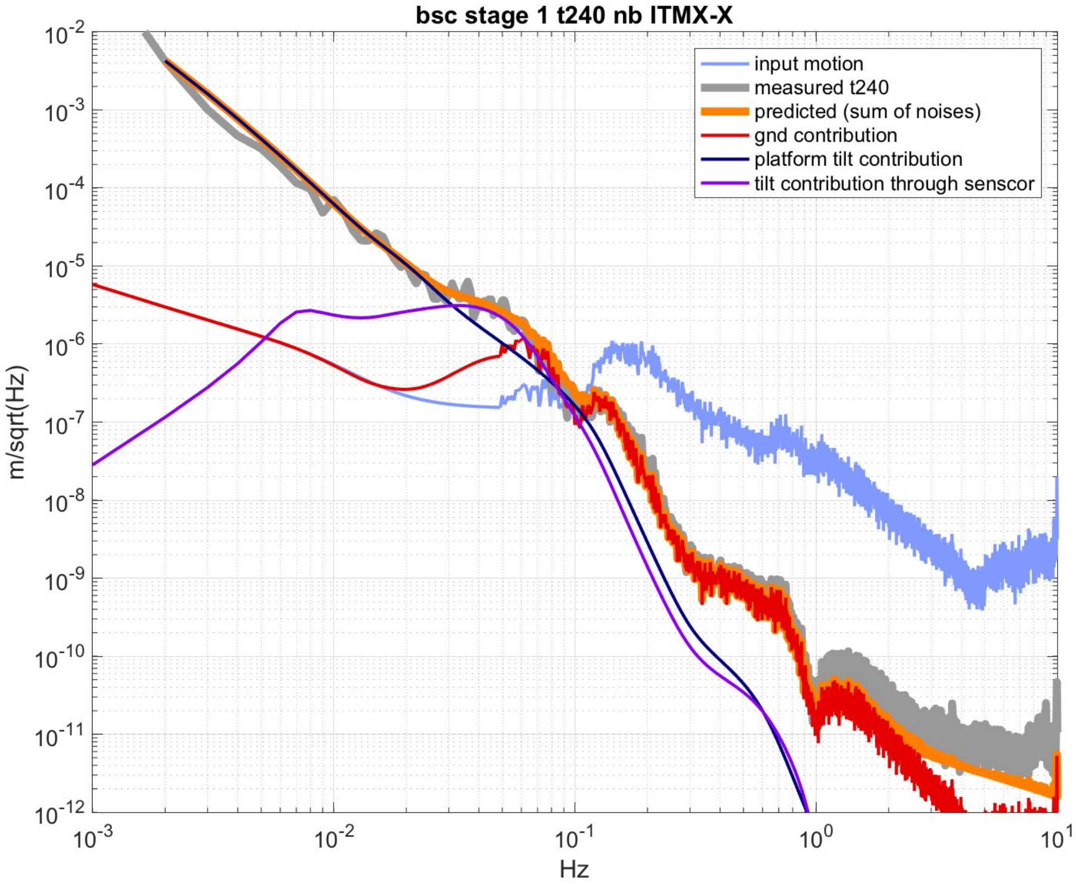
NB BSC-ISI stage 1 horizontal dof, windy

Model matches T240 signal

T240 dominated by platform tilt below 50mHz

T240 dominated by tilt from feedforward (STS) between 50-100mHz

Ground motion via CPS path



NB BSC-ISI stage 1 horizontal dof, windy

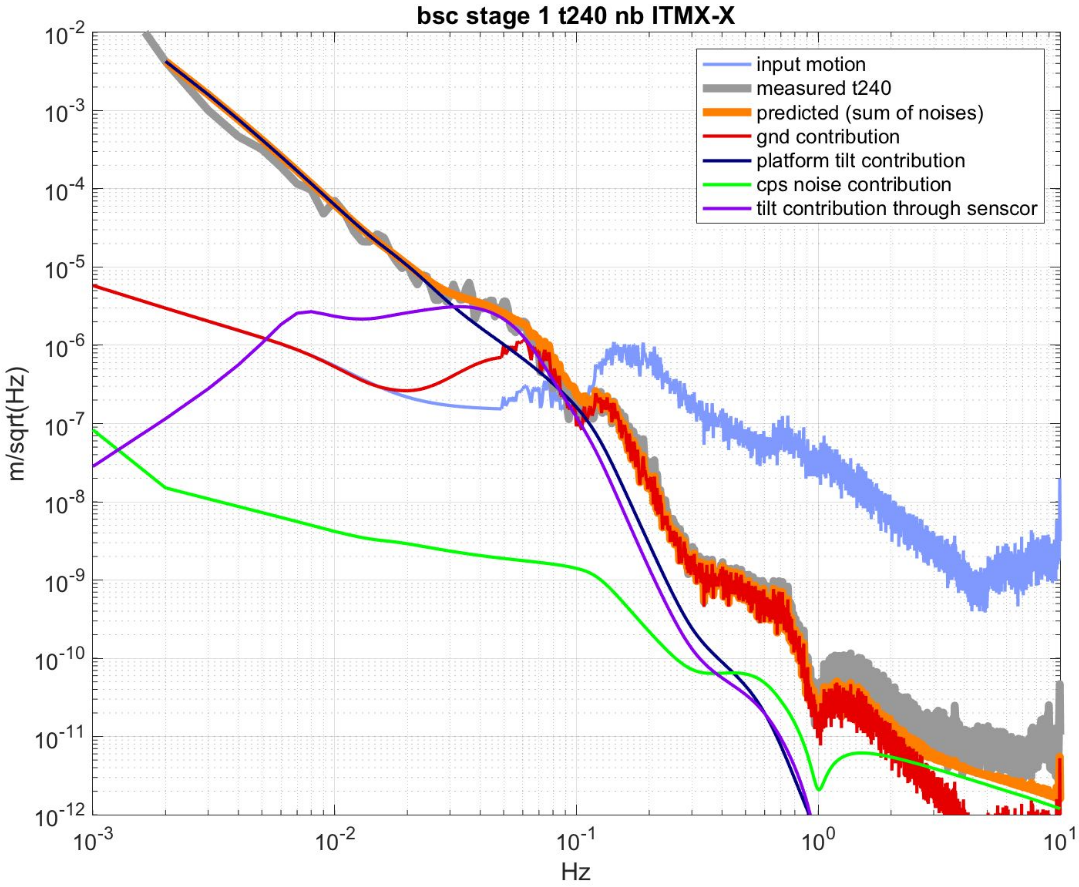
Model matches T240 signal

T240 dominated by platform tilt below 50mHz

T240 dominated by tilt from feedforward (STS) between 50-100mHz

Ground motion via CPS path

CPS noise above 2Hz

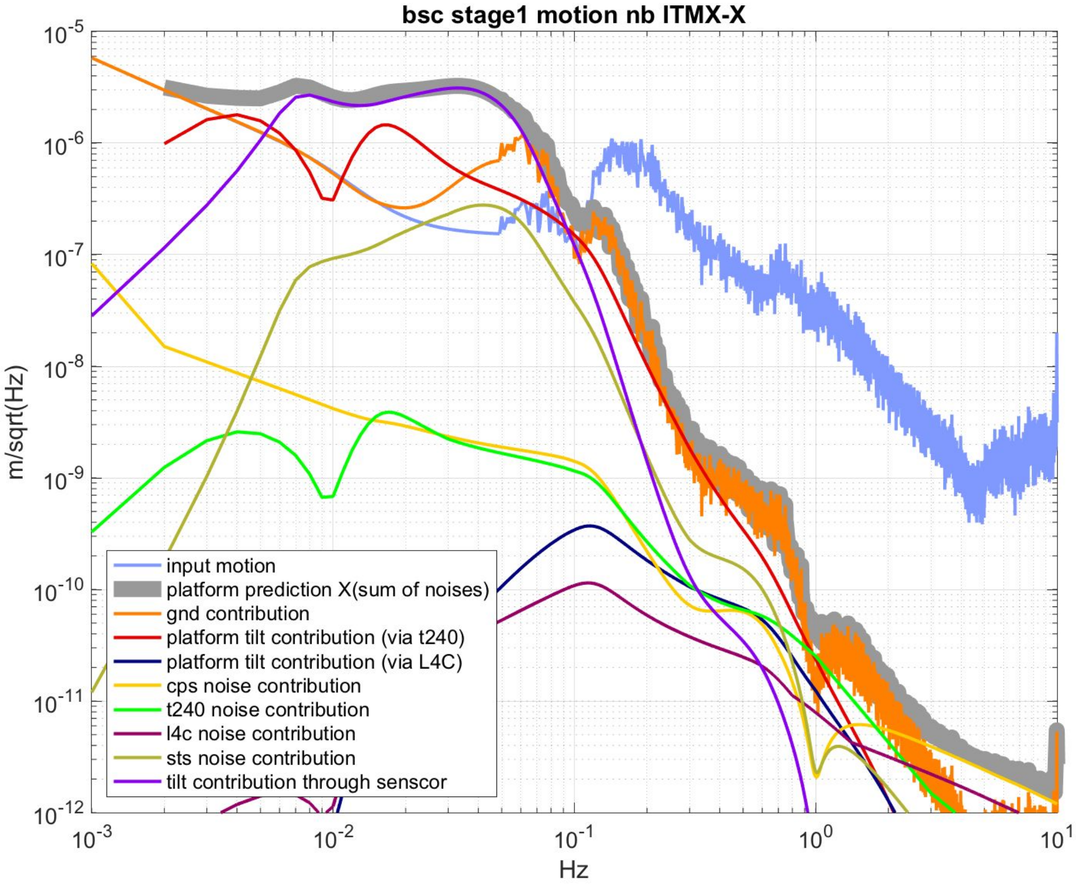


NB BSC-ISI stage 1 horizontal dof, windy

Estimated platform motion

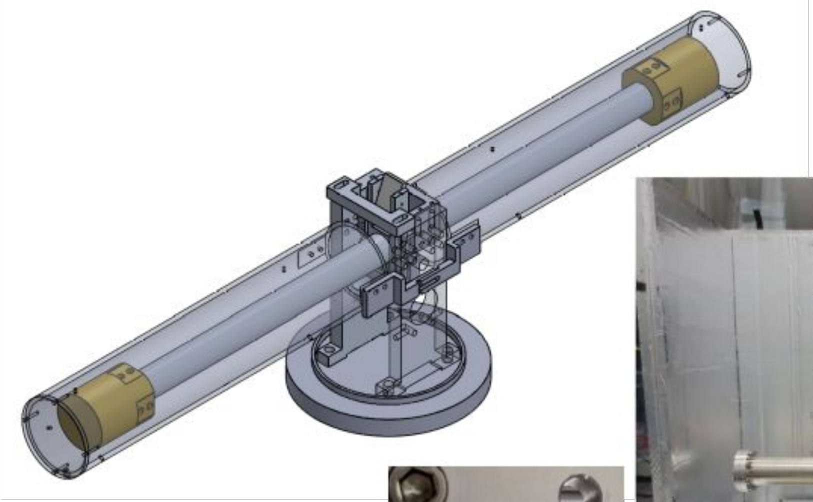
Ground tilt via STS feedforward limits performance between 30-80mHz (earthquake band)

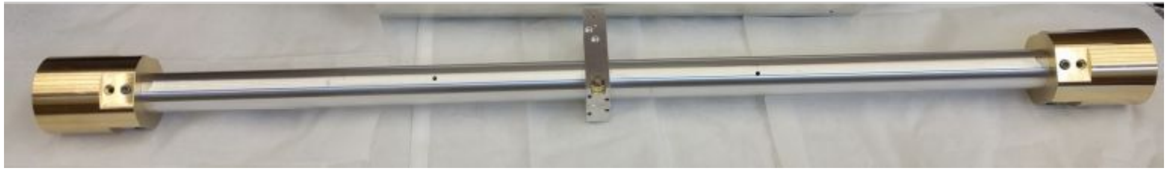
BRS can help reducing this noise



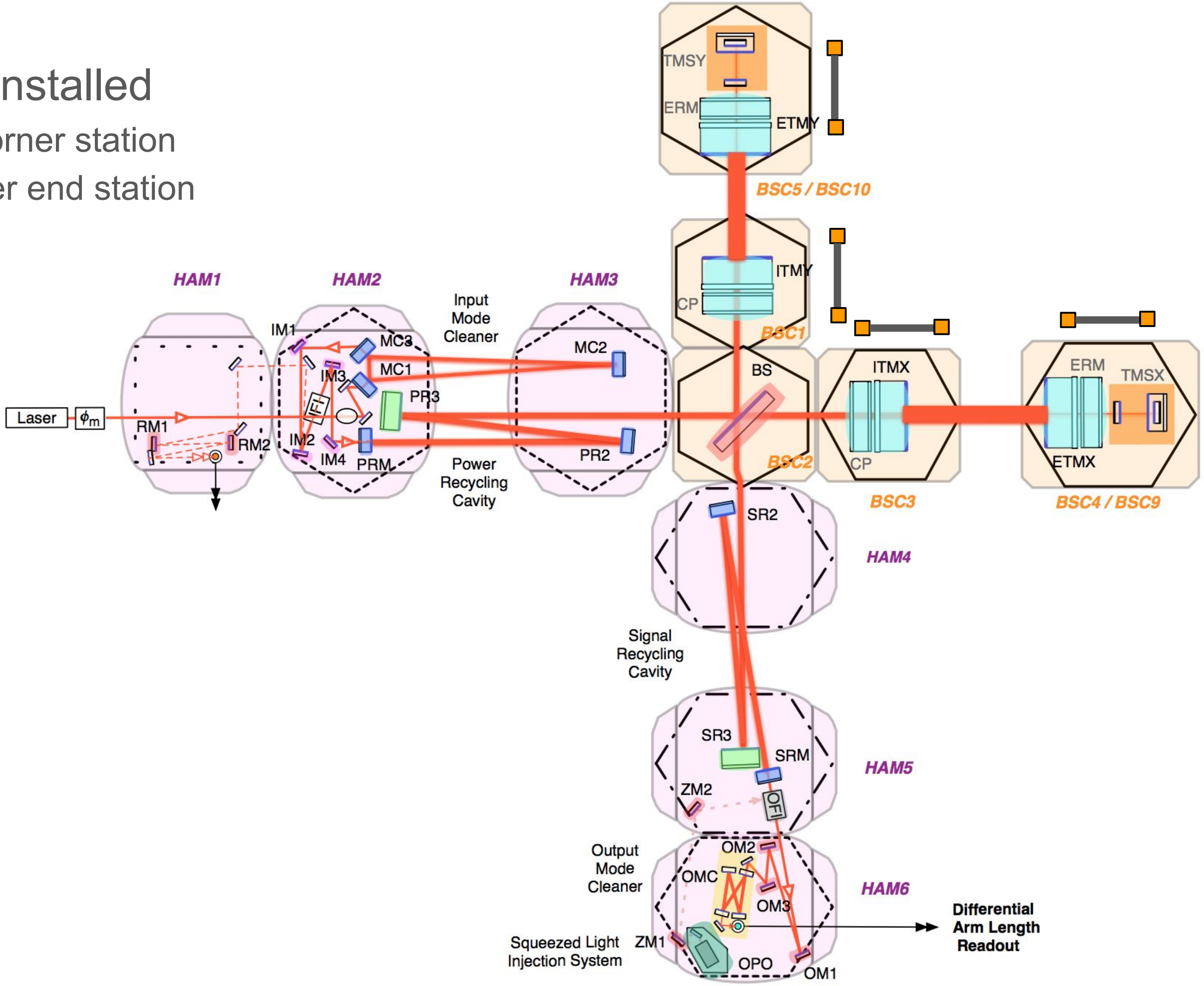
BRS Basics

- Beam:
  - ~1 m long
  - 4.5 kg
  - 10-15 μm thick flexures
  - 3-8 mHz resonance
- Autocollimator Readout
  - ~0.1 nrad/√Hz
- Capacitive Active Dampers



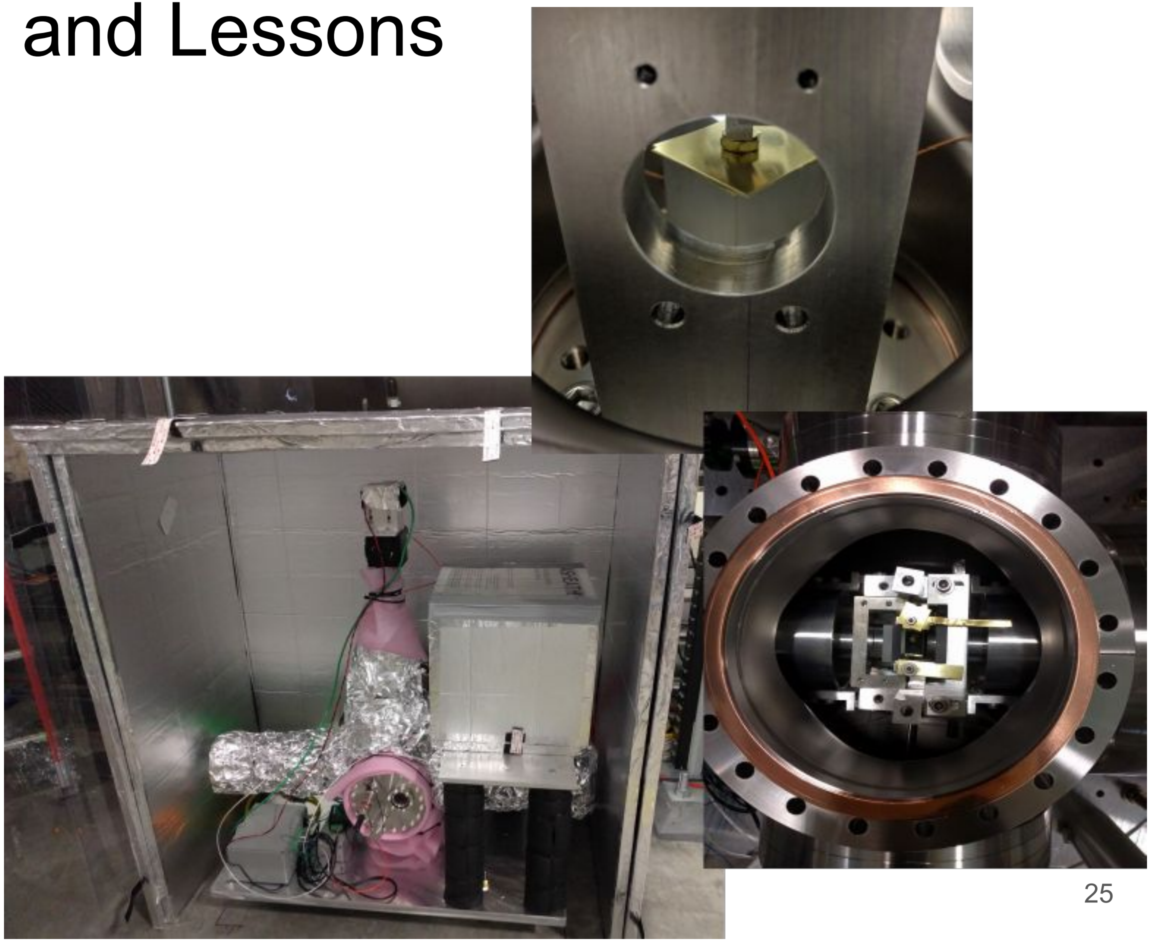


- 4 BRS installed
  - 2 corner station
  - 1 per end station



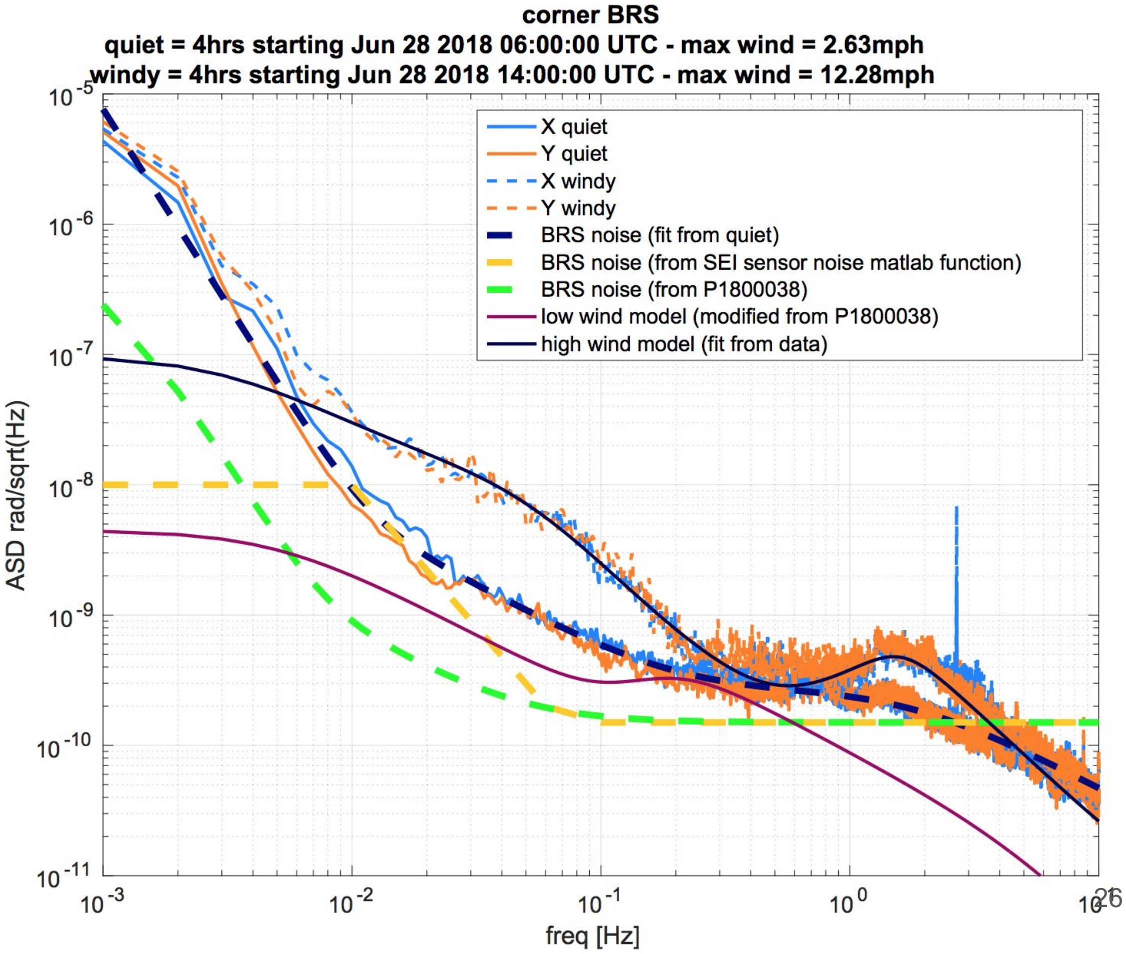
Practical Challenges and Lessons

- Machinists make mistakes
- Mass adjustments
- Temperature variations become more important at lower frequencies
- Tilts lose coherence over short distances (~meters)

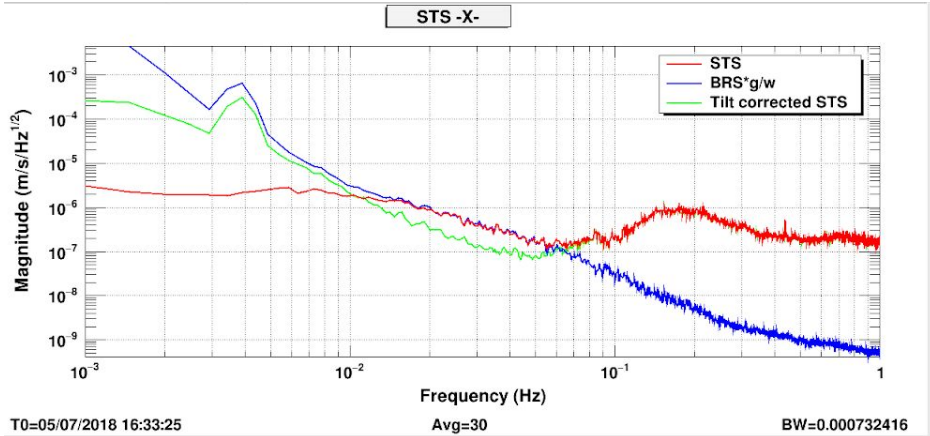


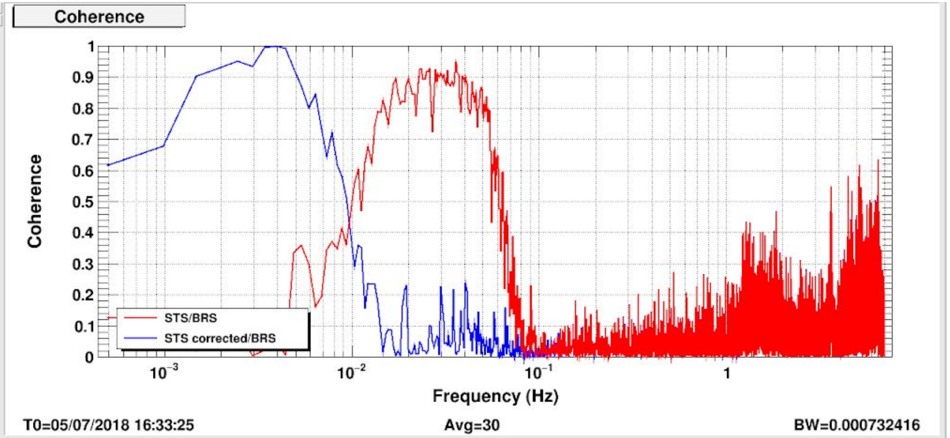
First LLO BRS spectrum (LLO corner station)

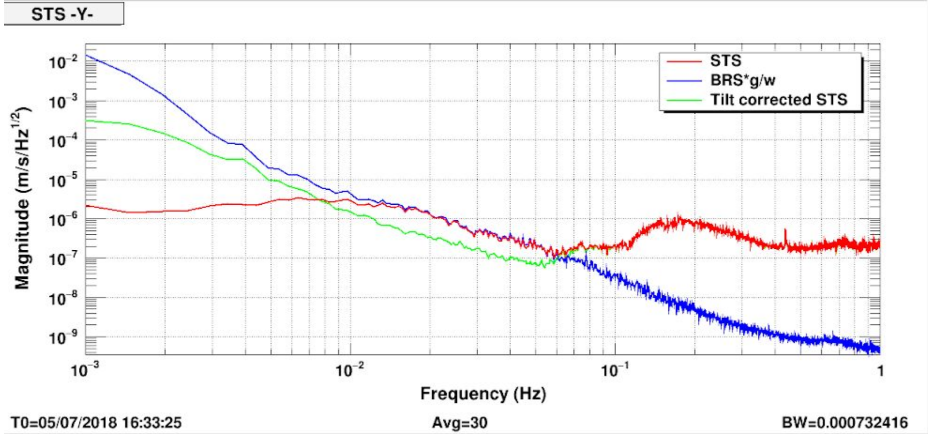
- Both BRS see same level of tilt
- Quiet spectra assumed to be instrument noise (not coherent with STS)

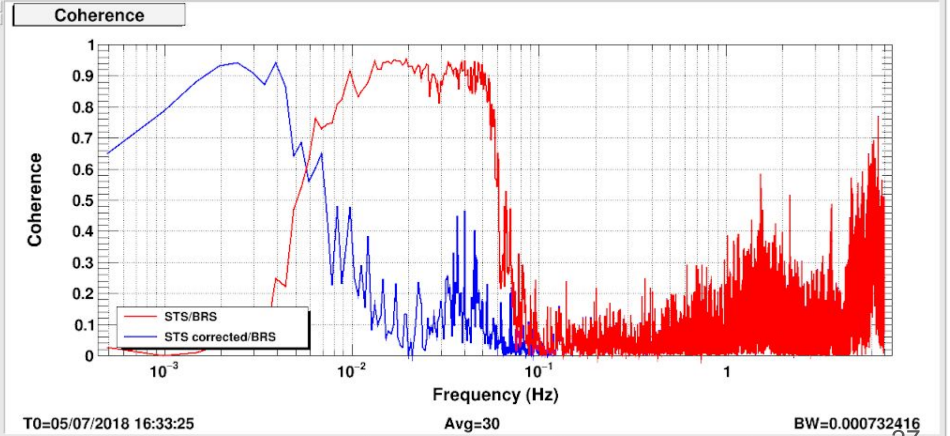


BRS : First subtraction (LLO corner)



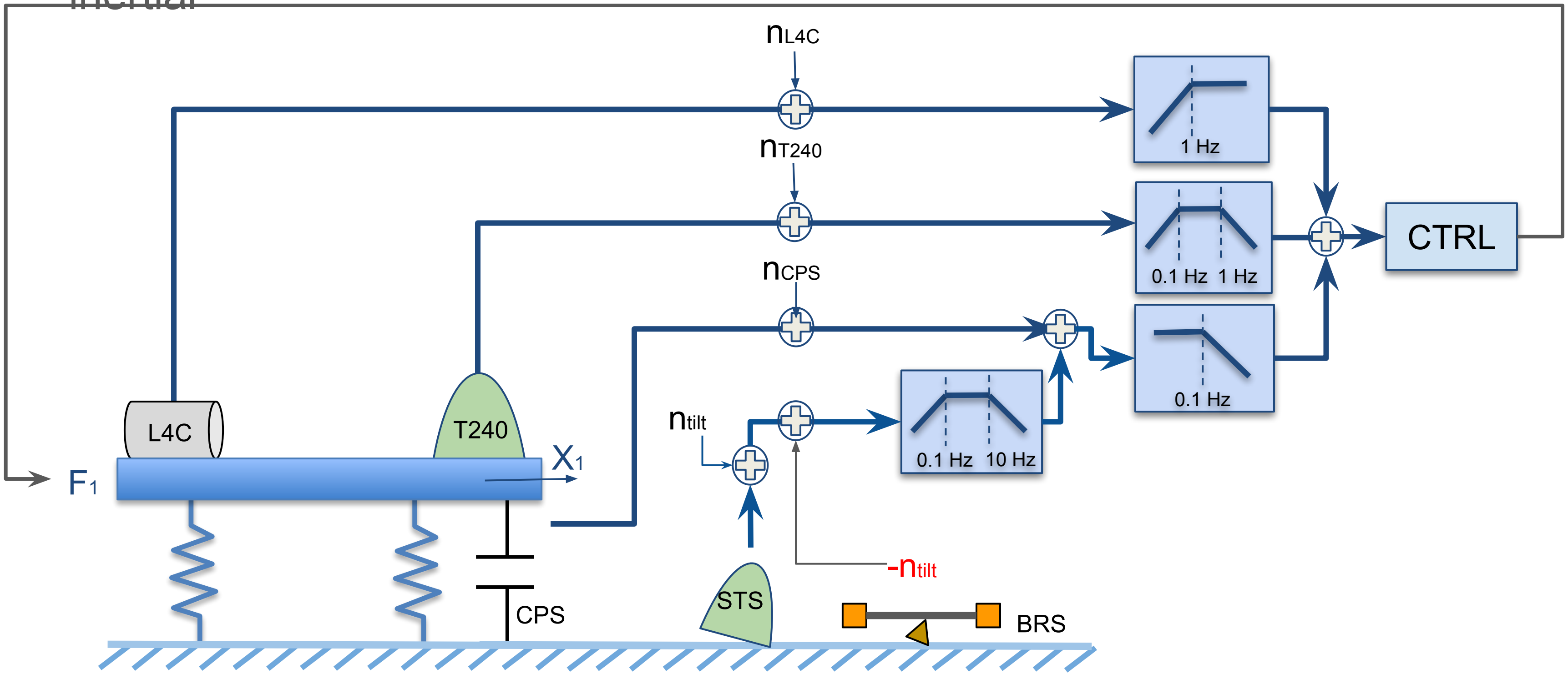




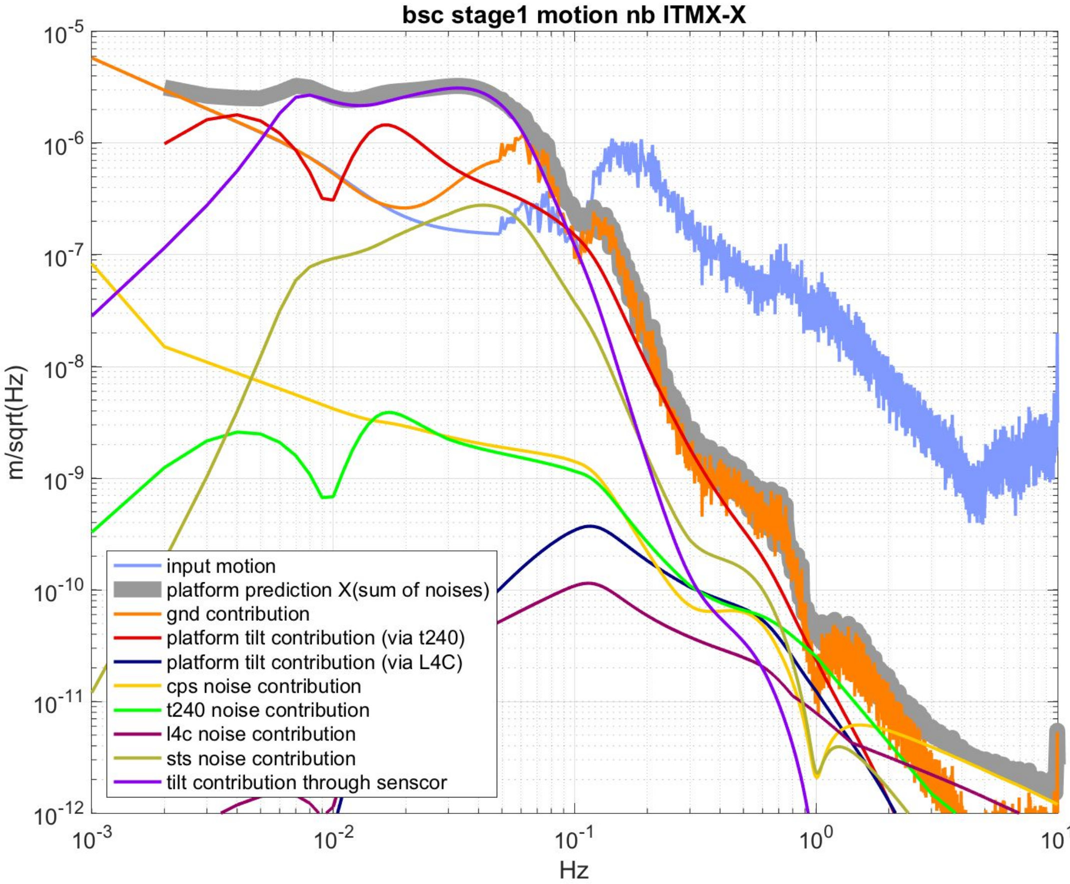


Active isolation, general control scheme

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

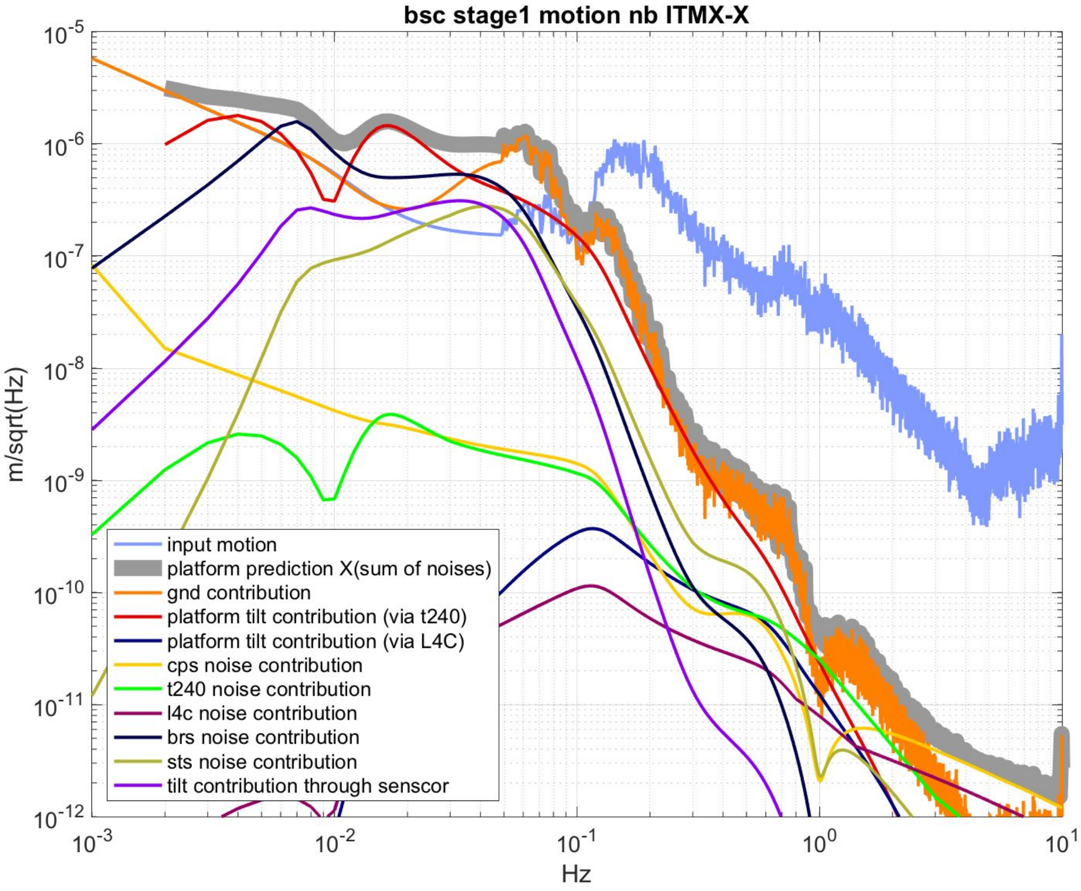


NB BSC-ISI stage 1 horizontal dof, windy, no BRS

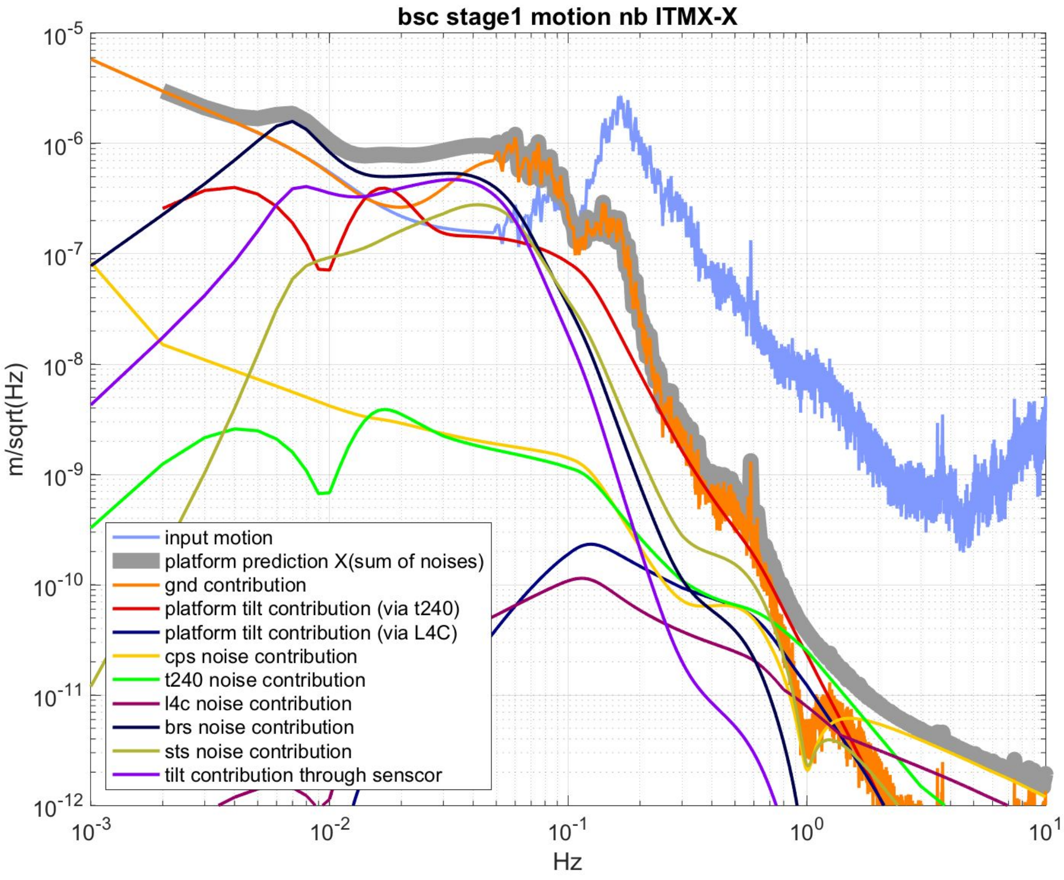


NB BSC-ISI stage 1 horizontal dof, windy, w BRS

Assuming tilt in the ground seismometer is reduced by a factor of ~10



NB not windy (what's next limit at useism ?)

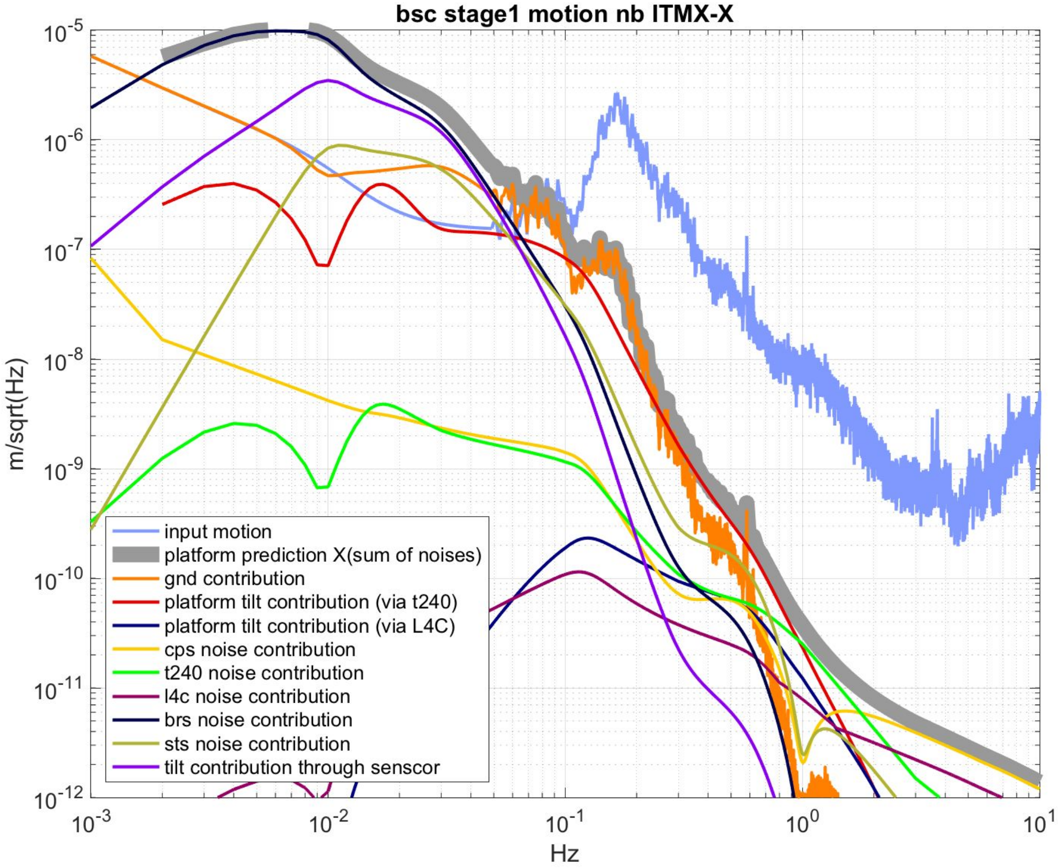


NB not windy (what's next limit at useism ?)

Changing the cut off frequency for the sensor correction

Large injection < 50mHz

x2 improvment at 0.15Hz



Conclusions

Noise requirements are met at 10Hz, could be relaxed, if necessary

Tilt limits platform horizontal motion

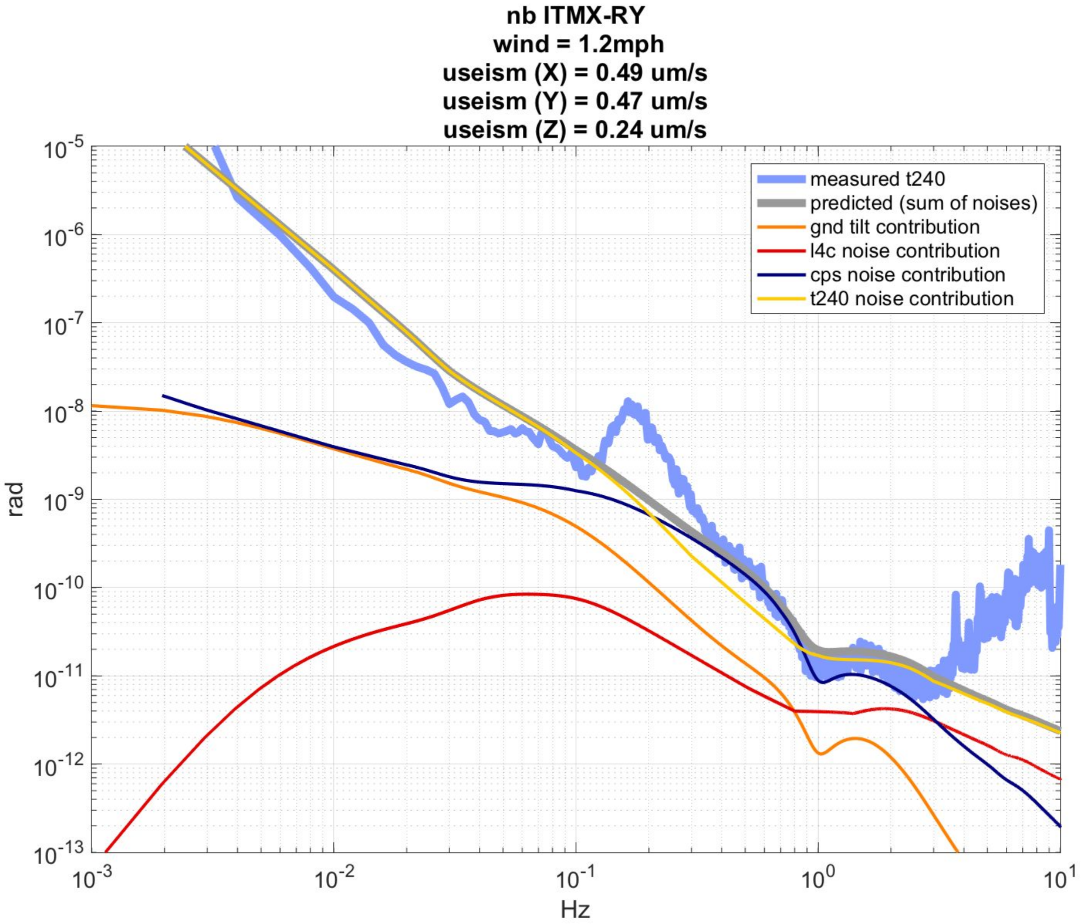
Ground BRS reduces tilt injected to platform in 30mHz-100mHz band

How much injection < 100mHz allowed to improve useism motion ?

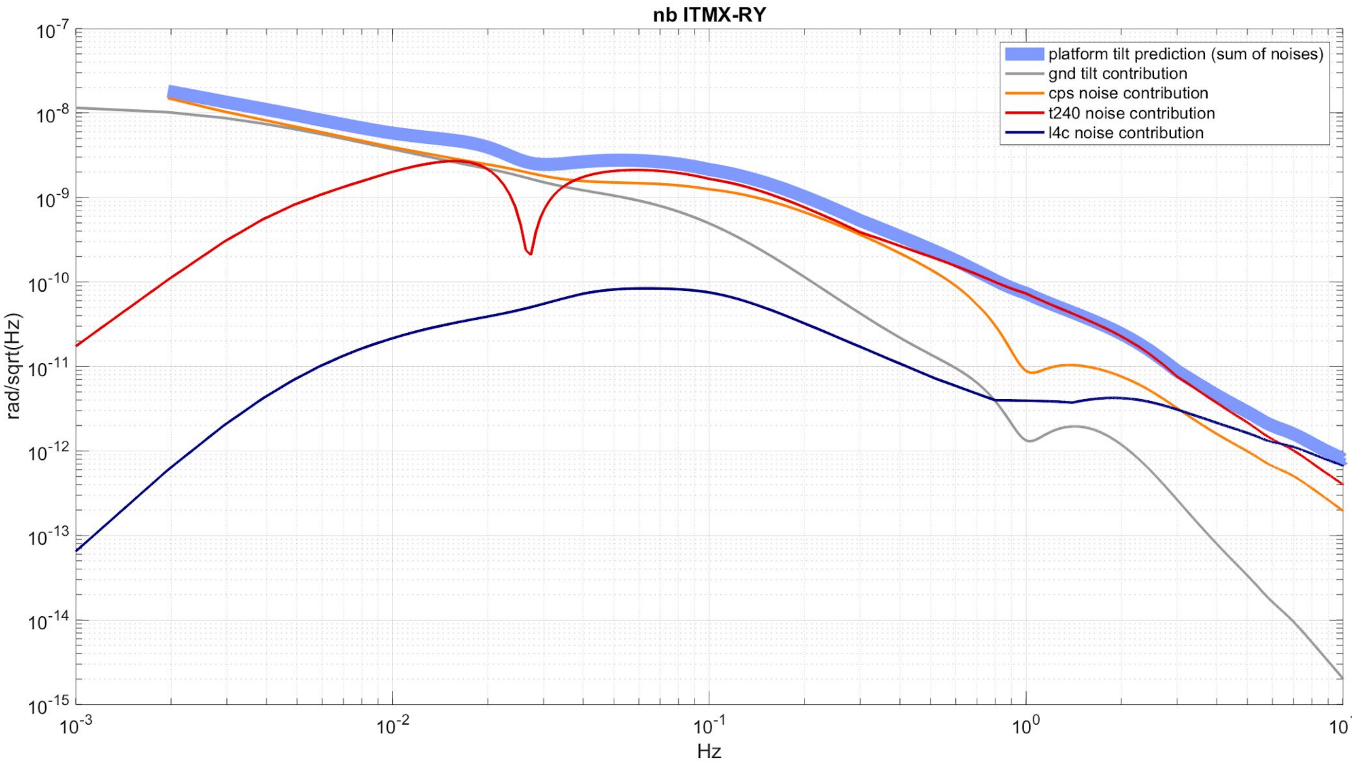
[1] T1500122 Revised BSC-ISI requirement at 10Hz
[2] E990303 Seismic Isolation Subsystem Design Requirements Document
[3] T1000216 Revised BSC-ISI requirement at 10Hz
[4] P1200040 Seismic isolation of Advanced LIGO gravitational waves detectors: Review of strategy, instrumentation, and performance.

Extra slides

NB not windy rotation

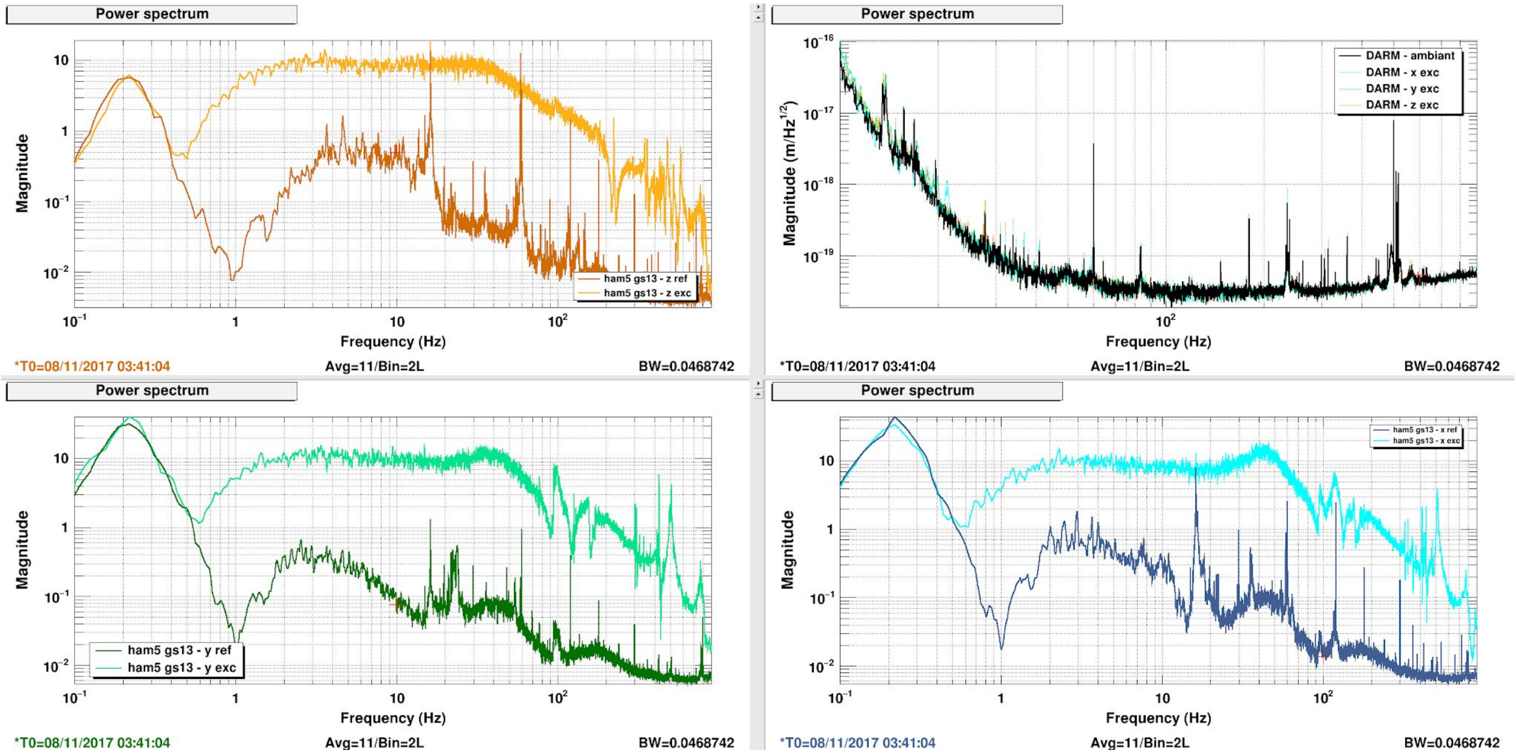


NB not windy rotation



Requirements for seismic isolation : >1Hz

- Similar for HAM-ISI



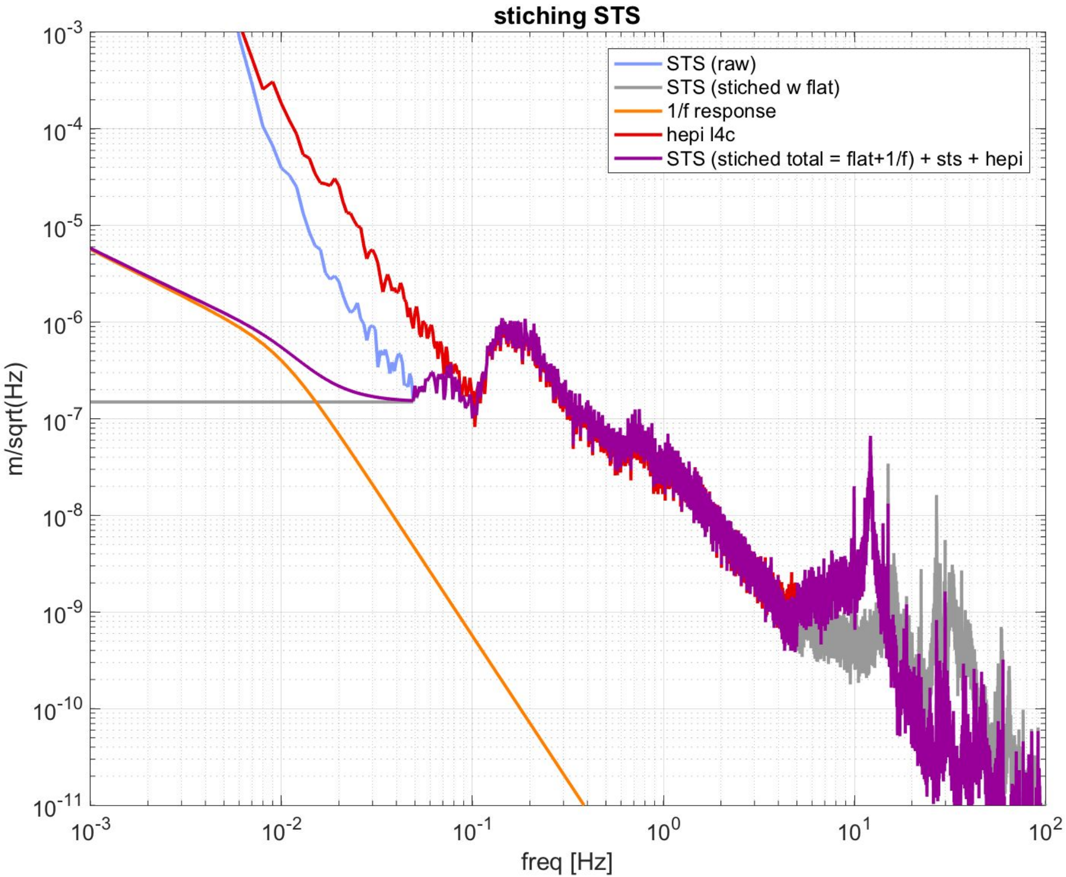
llo alog 36624

Make CPS "inertial"

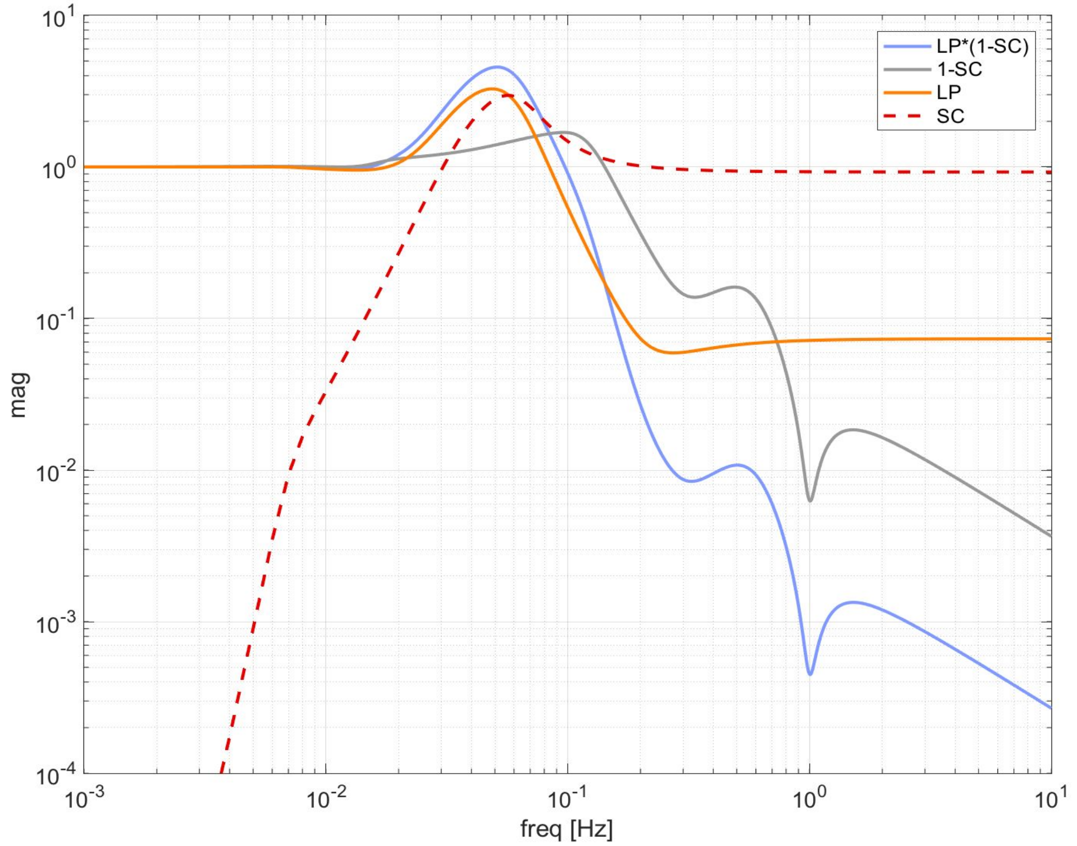
CPS = X1 - Xg
CPSinertial = X1 - Xg + (Xg+nsts)*SC
CPSinertial = X1 - Xg*(1-SC) + nsts*SC

With X1, the platform motion
Xg, the ground motion
nsts, the STS noise including tilt noise
SC, the band pass filter

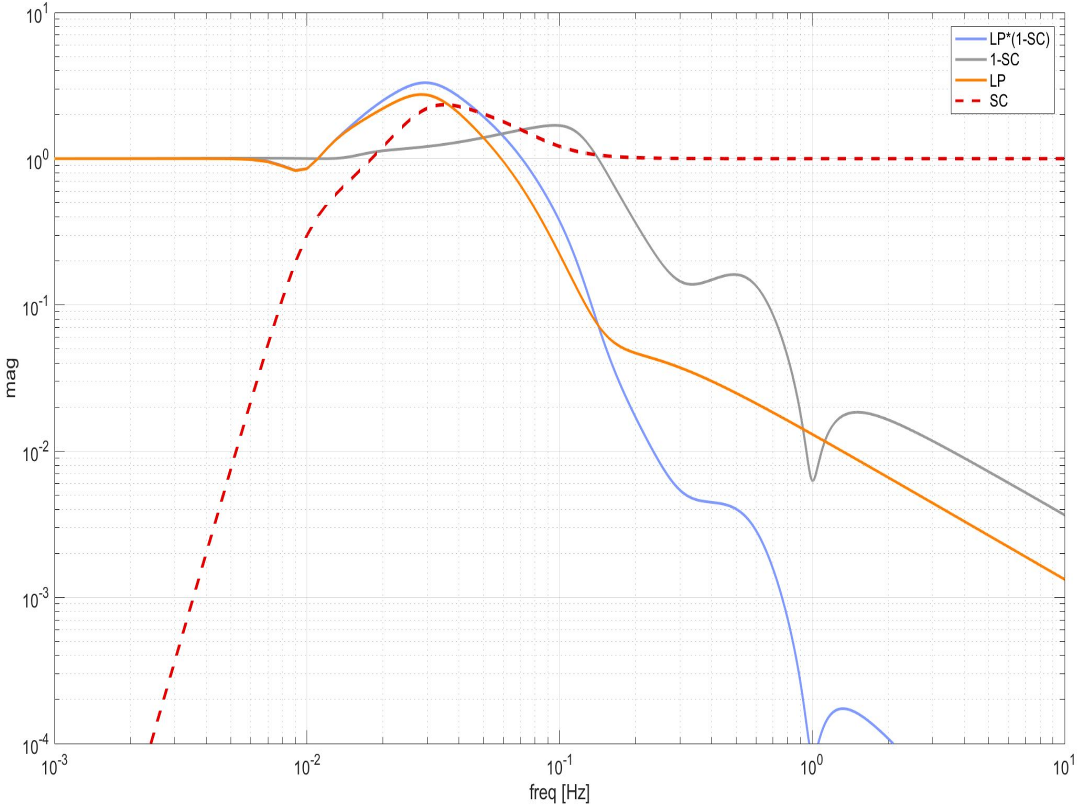
Ground stitching



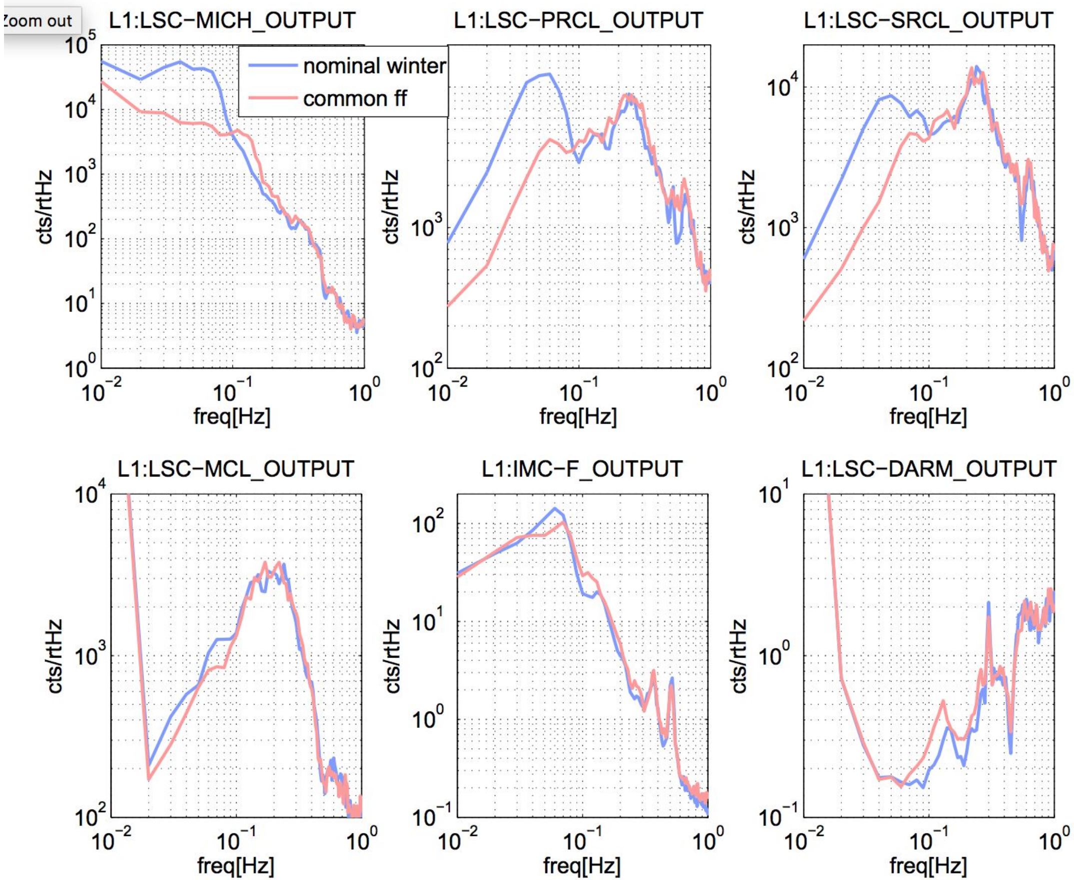
100mHz LP + broadband SC



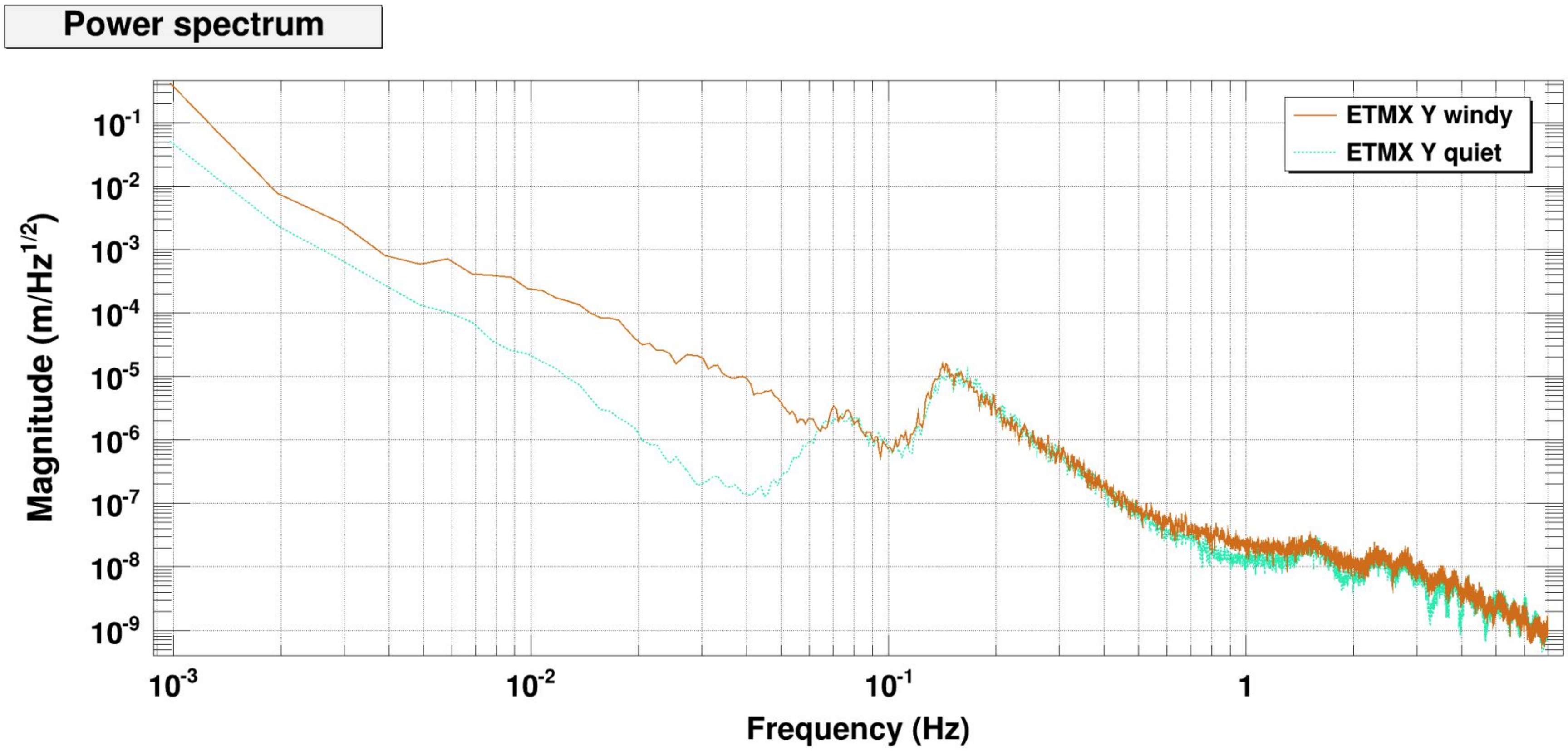
100mHz LP + broadband SC

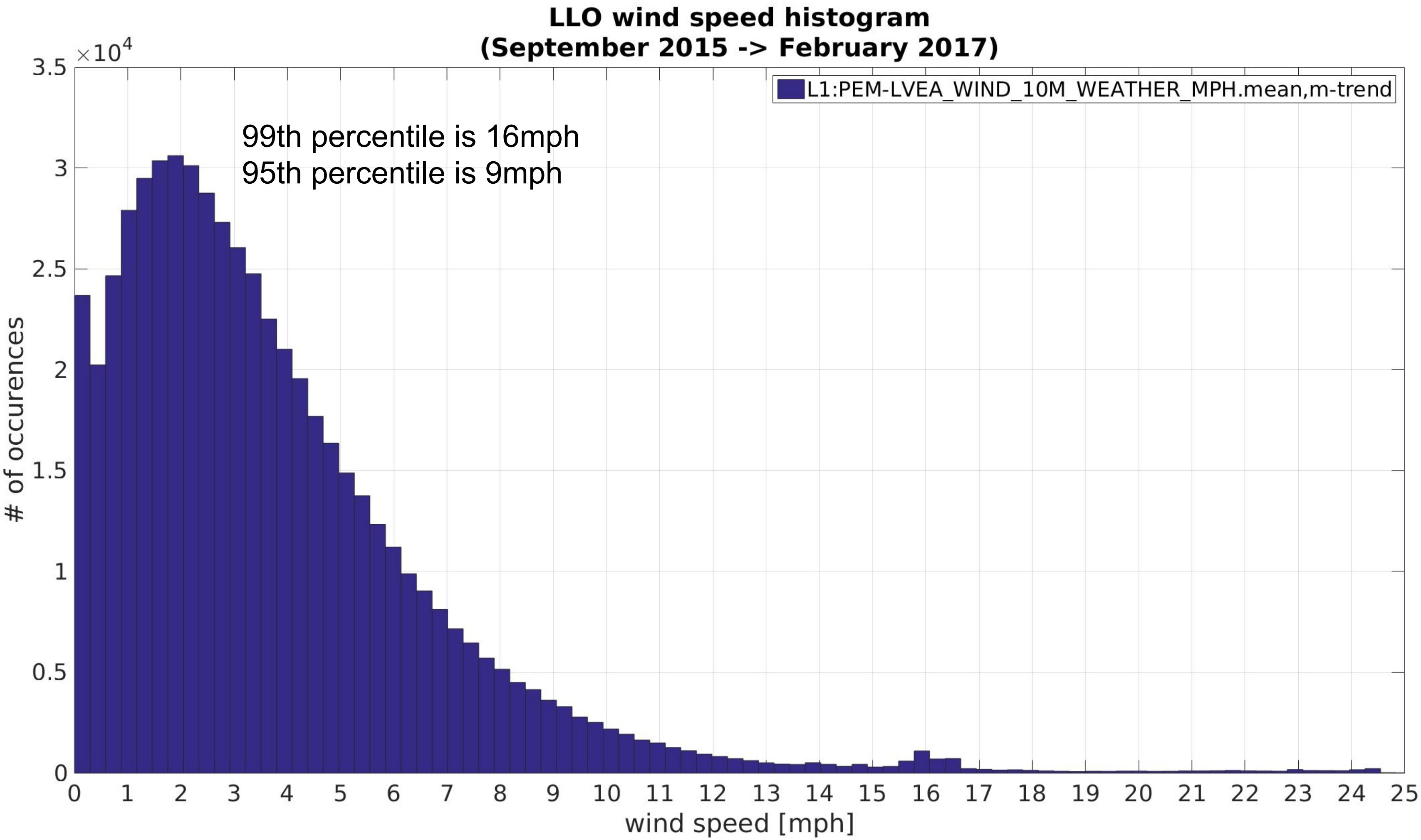


T240 50mHz blend vs common FF

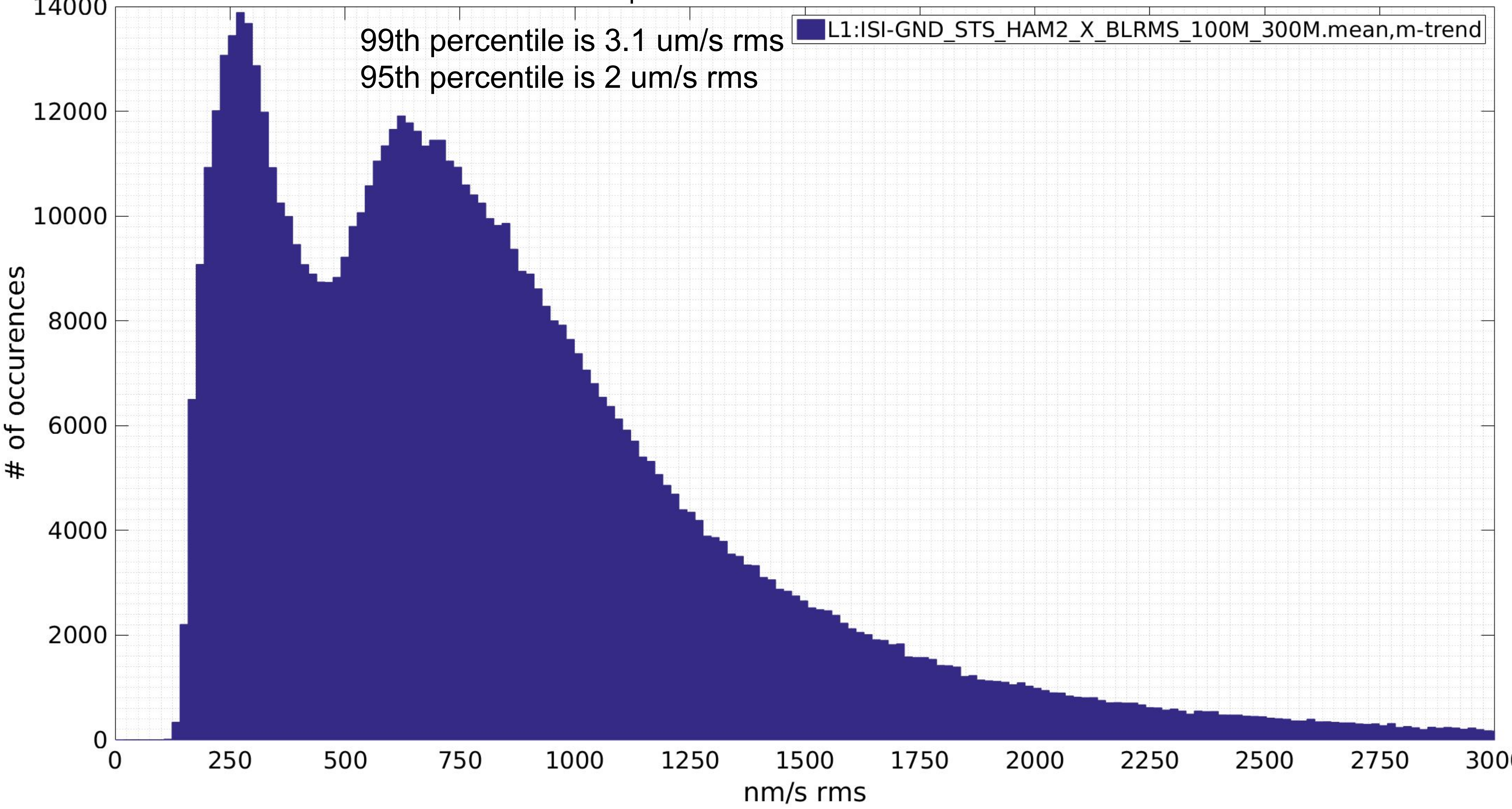


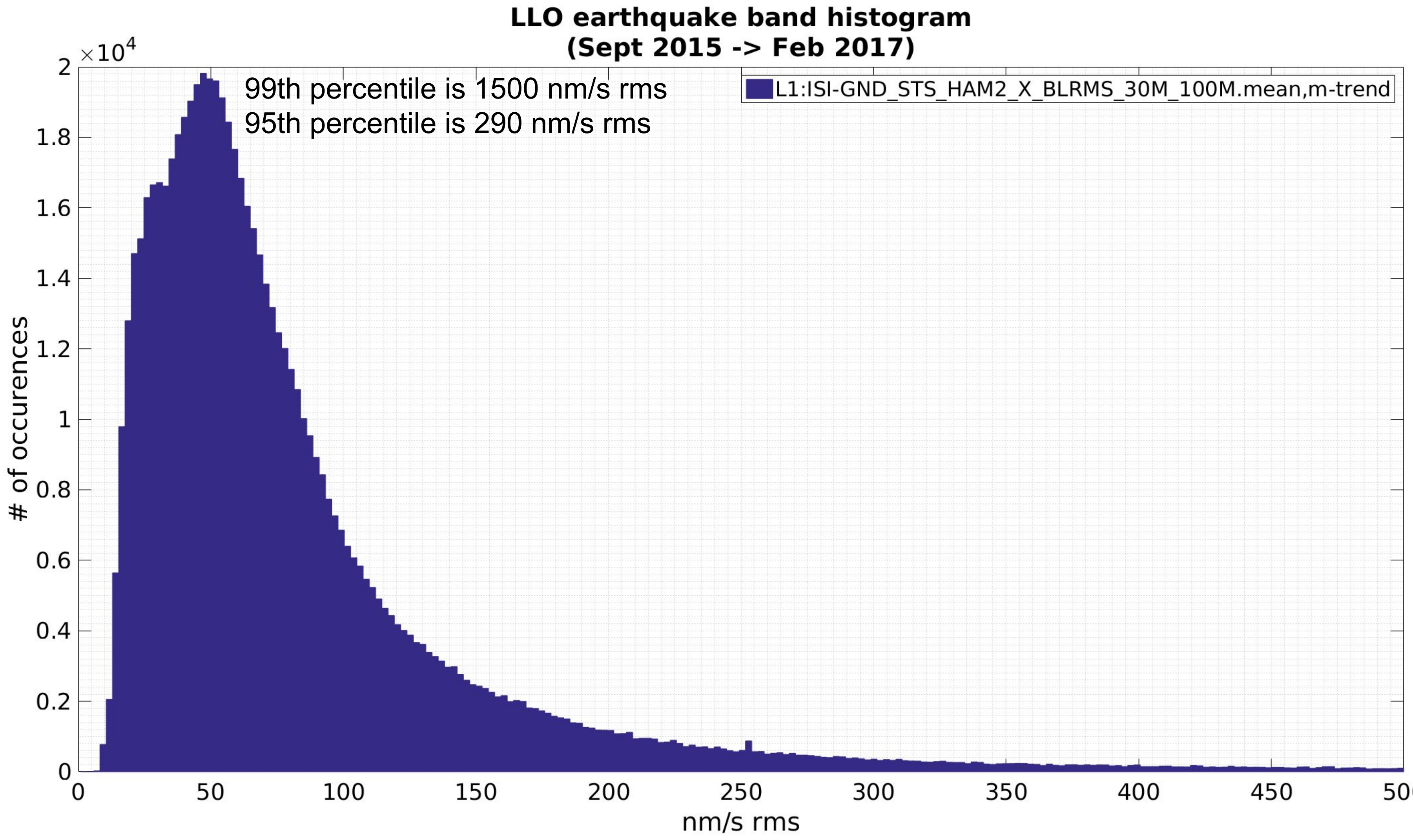
STS noise difference windy vs quiet




LLO wind speed histogram
(September 2015 -> February 2017)
×10^4
L1:PEM-LVEA_WIND_10M_WEATHER_MPH.mean,m-trend
99th percentile is 16mph
95th percentile is 9mph
# of occurences
wind speed [mph]
0 0.5 1 1.5 2 2.5 3 3.5
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25

LLO useism histogram
September 2015 -> Feb 2017




LLO earthquake band histogram
(Sept 2015 -> Feb 2017)
99th percentile is 1500 nm/s rms
95th percentile is 290 nm/s rms
L1:ISI-GND_STS_HAM2_X_BLRMS_30M_100M.mean,m-trend
# of occurences
nm/s rms
×10^4
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
0
50
100
150
200
250
300
350
400
450
500