Global seismic noise subtraction in Advanced GW detectors

GWADW 2012

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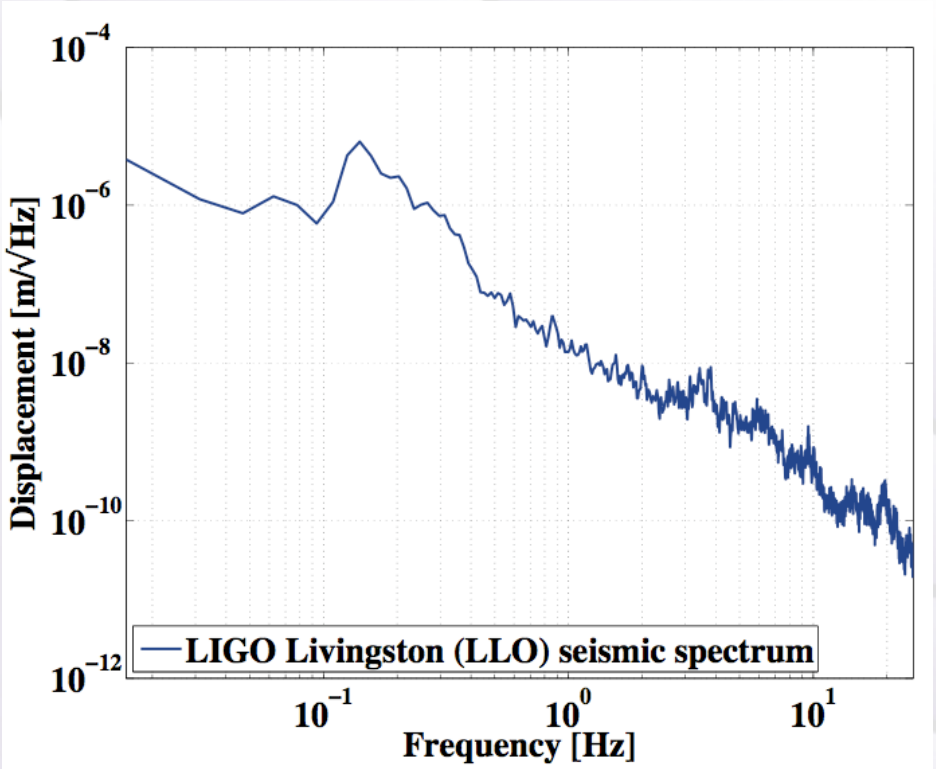
DCC P1000088, arXiv 1204.5504

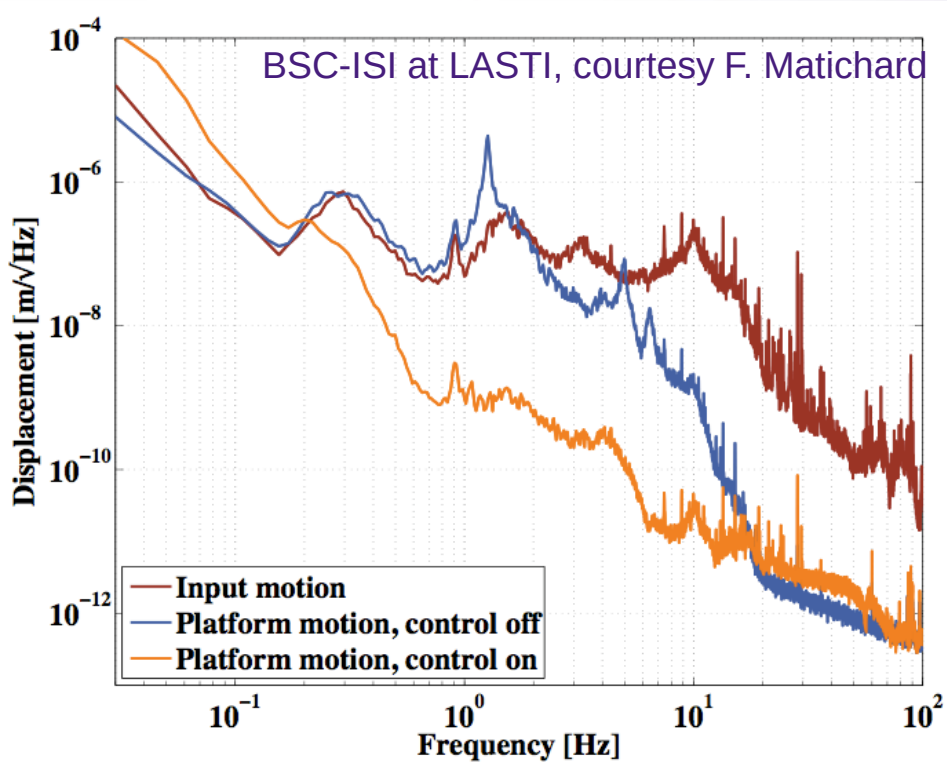
Outline

- Low frequency situation
  - 0.1 to 1 Hz
- Complications
- S6 global feed-forward work
- Further complications
- Things to think about going forward

Low frequency situation

- Seismic spectrum peaks around 0.15 Hz
- Amplitude and frequency of the peak varies as measured at the LIGO observatories
- At the lower edge of active platforms isolation range



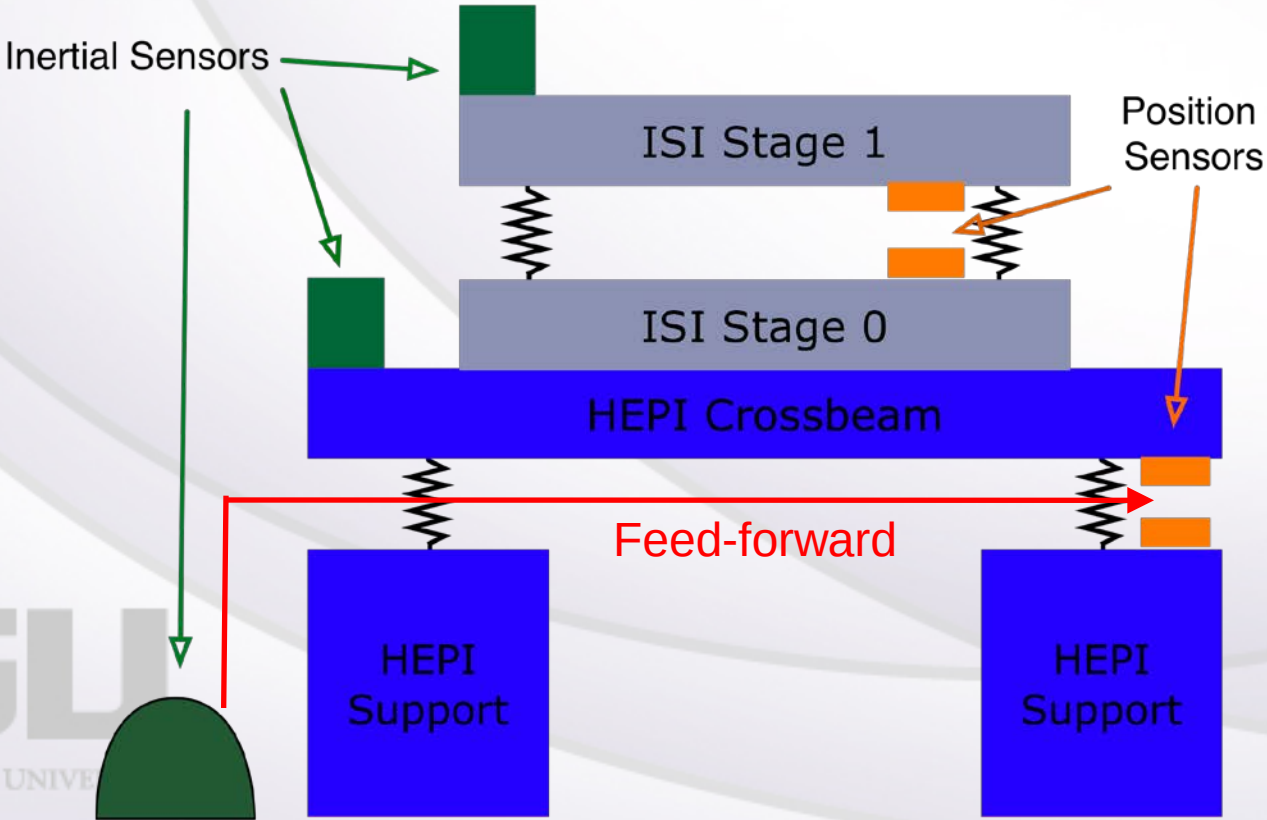


Concerns

- Dynamic range of actuators must be large enough to suppress microseism
- Deleterious side effects of large control signals:
  - Upconversion
  - Cross-coupling
  - Lock acquisition

Solution

- Above ~0.5 Hz feed-back based on inertial sensors is used
- Below ~0.5 Hz derive control signal from position sensors (locks payload to support point)
- Feed-forward from nearby ground sensors to quiet the platform with respect to inertia

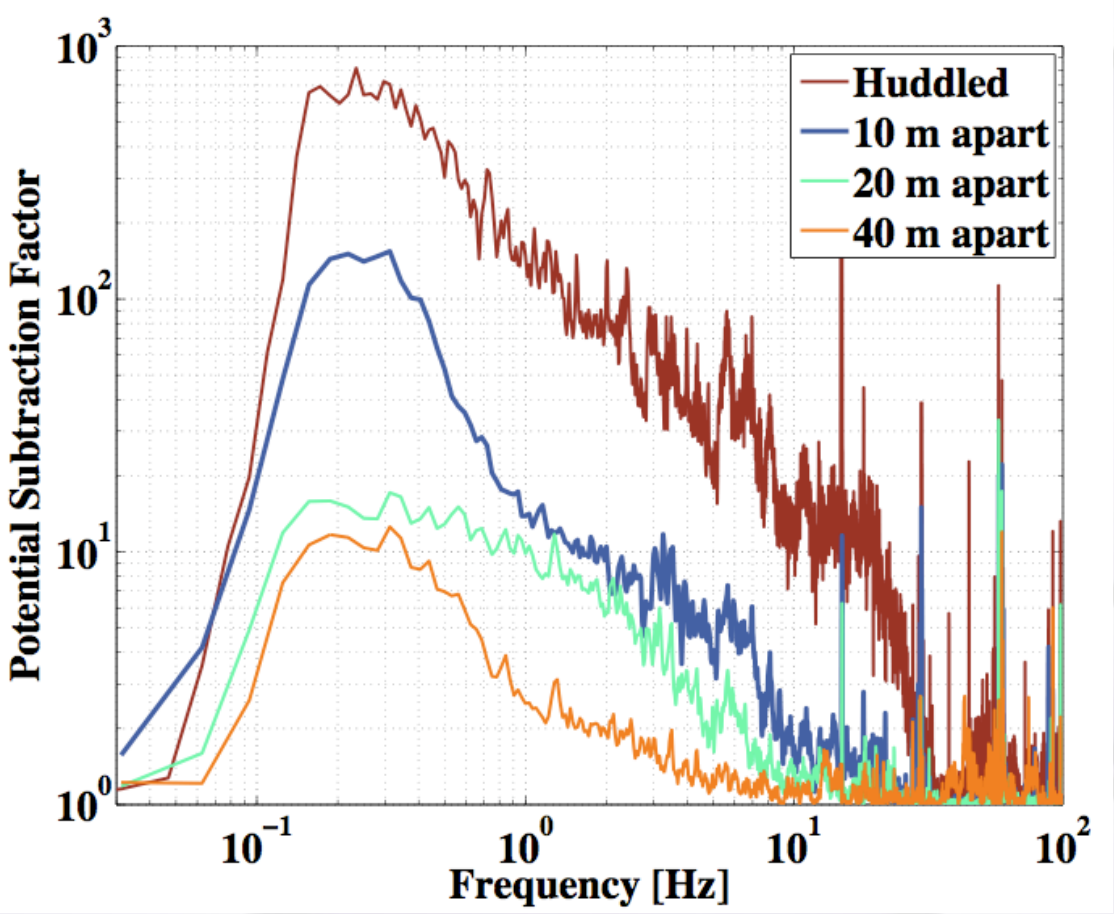


Complications

- In order to have good subtraction, your witness sensor must have high coherence with your target
- Witness signal processing constrained by real-time requirement

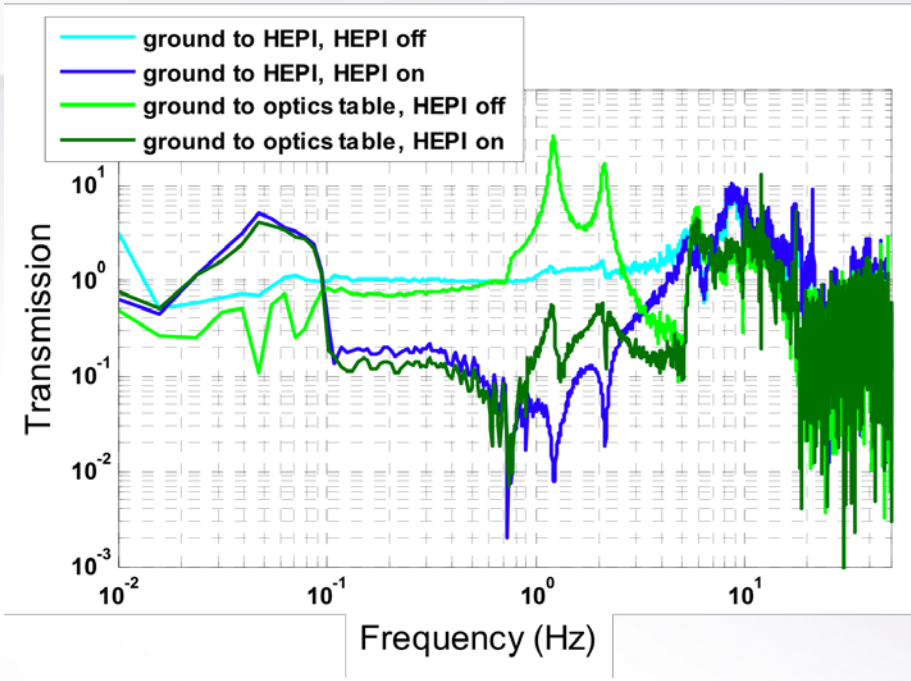
Coherence between seismometers on the LLO LVEA slab, converted to ideal subtraction factor

$$\frac{1}{\sqrt{1-C}}$$



Local vs. Global

HEPI performance plot from S5 (figure 3.22 from S. Wen (LSU) PhD thesis)



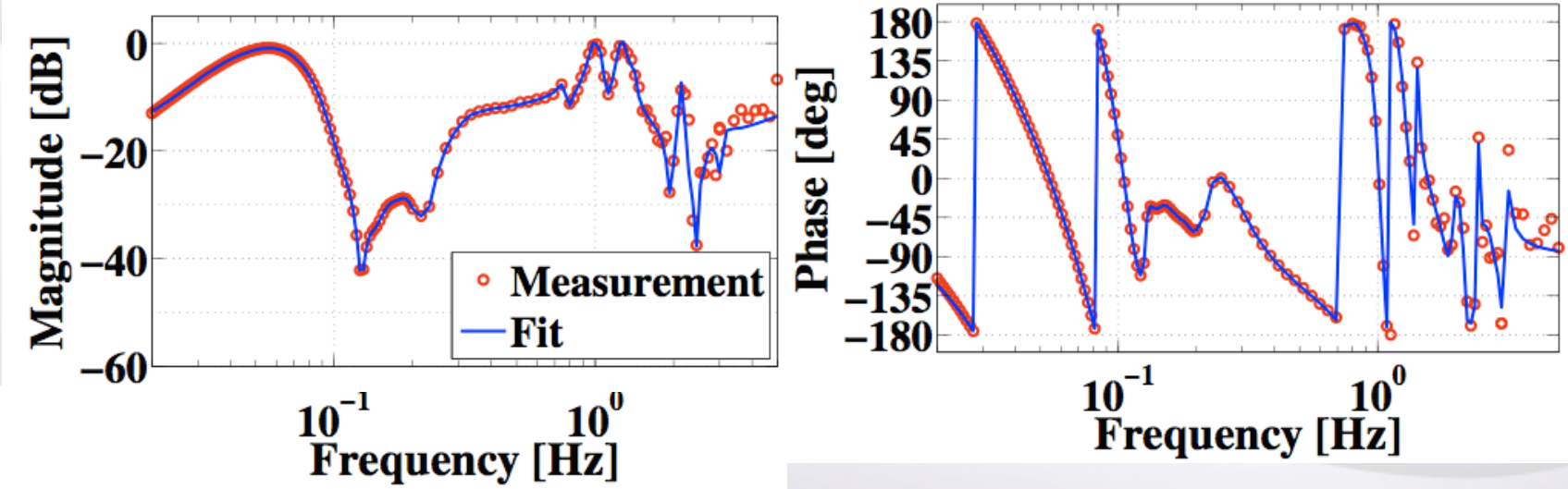
- Despite isolation, the cavity motion at the microseism was problematic during S6
- Feed-forward paths using Wiener filters were implemented
  - WF calculated using control signal as sensor of relative mirror motion, subtracting component which is coherent with ground sensors (minimizes rms)

$$MSE = \frac{1}{2}\sum_i \left[t_i - \sum_{j=0}^{N} h_j w_{i-j} \right]^2$$

$$p_i = \sum_{j=0}^{N} h_j R_{i-j}$$

Local vs. Global

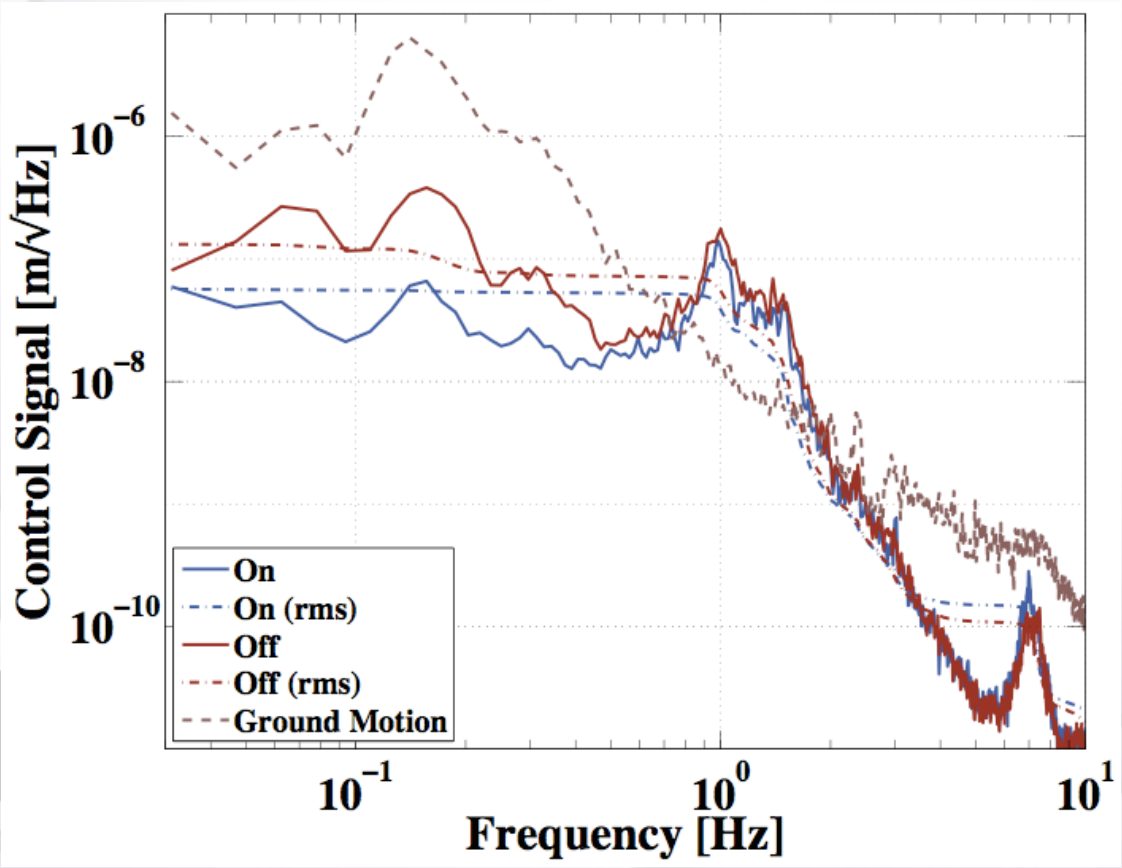
- Global feed-forward was implemented on three cavities at LLO during S6, one at LHO
  - Mode Cleaner (LLO)
  - Power Recycling (LLO)
  - Differential Arm (LLO and LHO)
- FIR filters calculated in MATLAB using ~hours of training data and ~10k taps, then fit to IIR with Vectfit



http://www.energy.sintef.no/Produkt/VECTFIT/index.asp

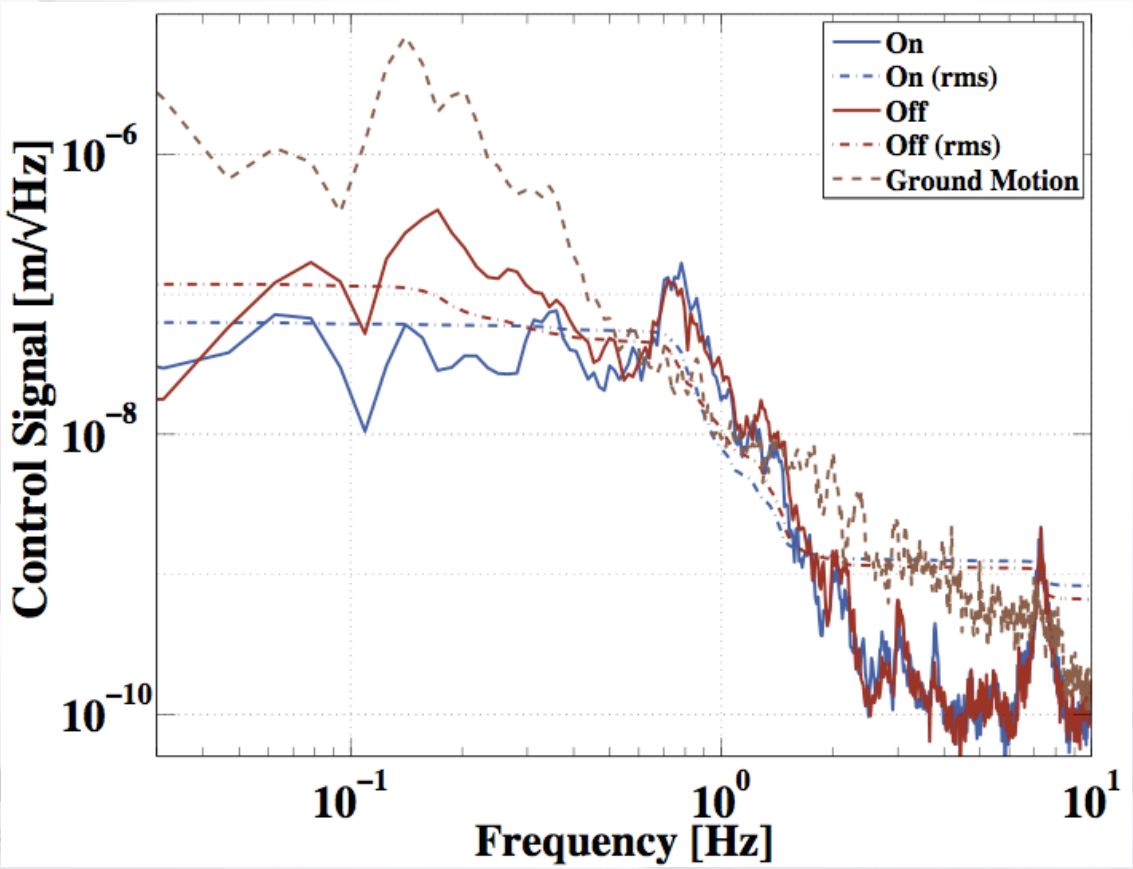
Mode Cleaner

- Served as a testing ground for new technique, not necessary for performance
- Interesting to ask: why does platform control interfere with common mode rejection? (chambers spaced ~10 m apart)



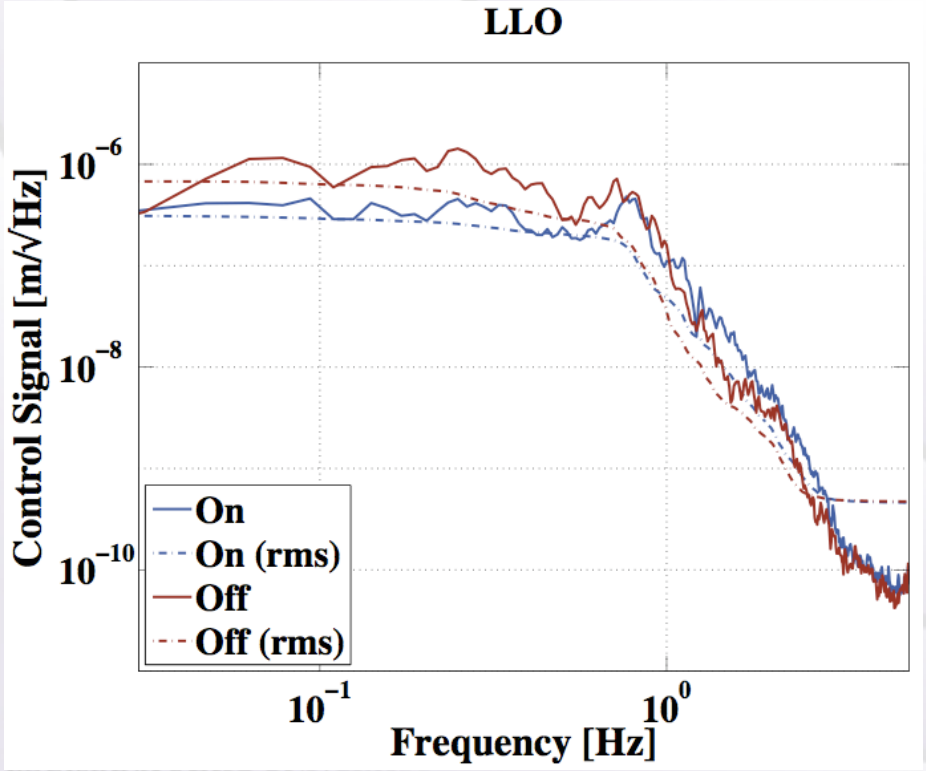
Power Recycling Cavity

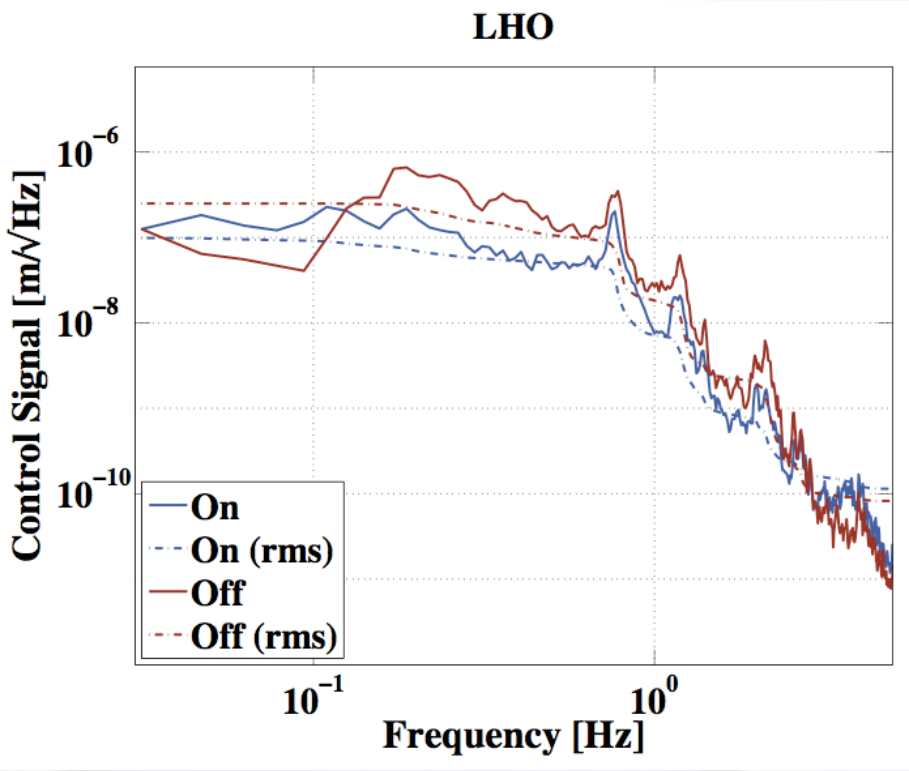
- Large length to angle coupling as well as Z to X
- Power fluctuations from angular motion made it difficult to lock the interferometer



Differential Arm Motion

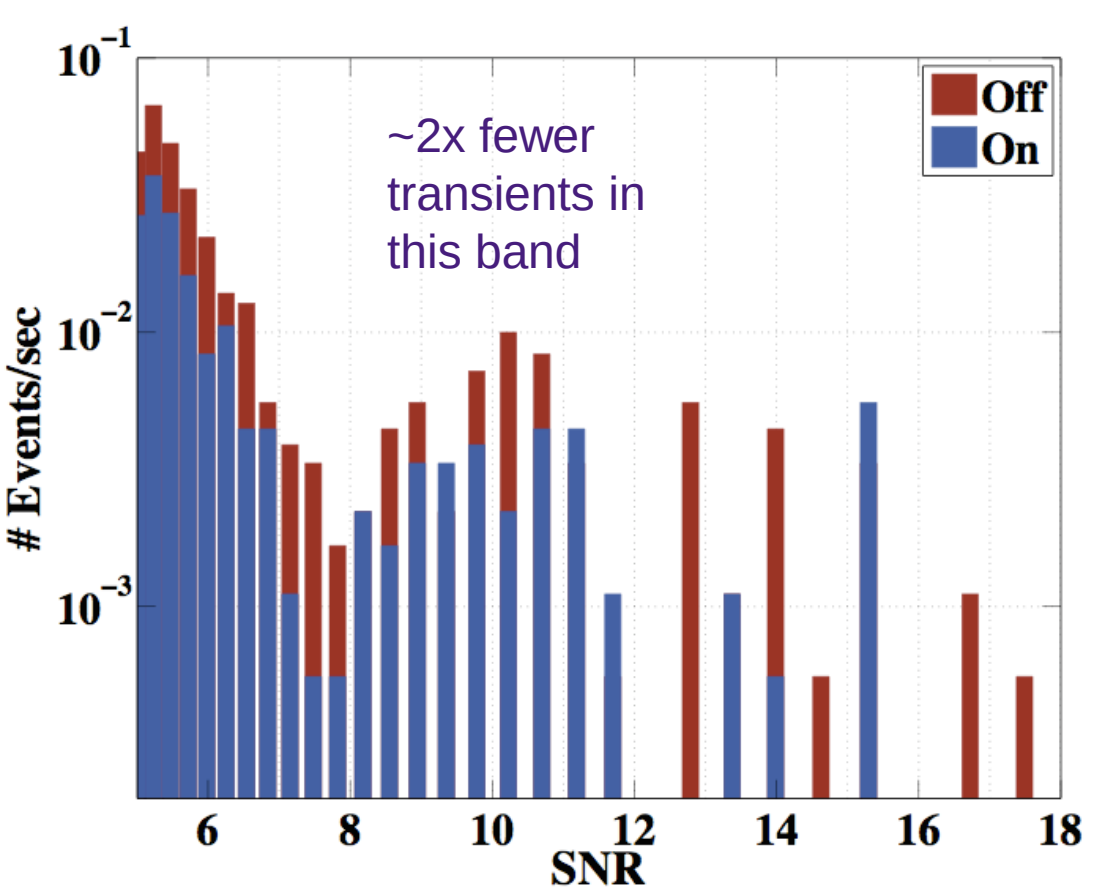
- Sensors positioned in the corner station and each end station
- Actuation signal sent to end station chambers
- RMS decrease similar at both sites, noise injection as well





Transient Rate Improvement

- On/off test reveals effect of reducing the control signal at low frequencies (only triggers between 50 and 200 Hz shown)
- Stationary noise level did not significantly change during test



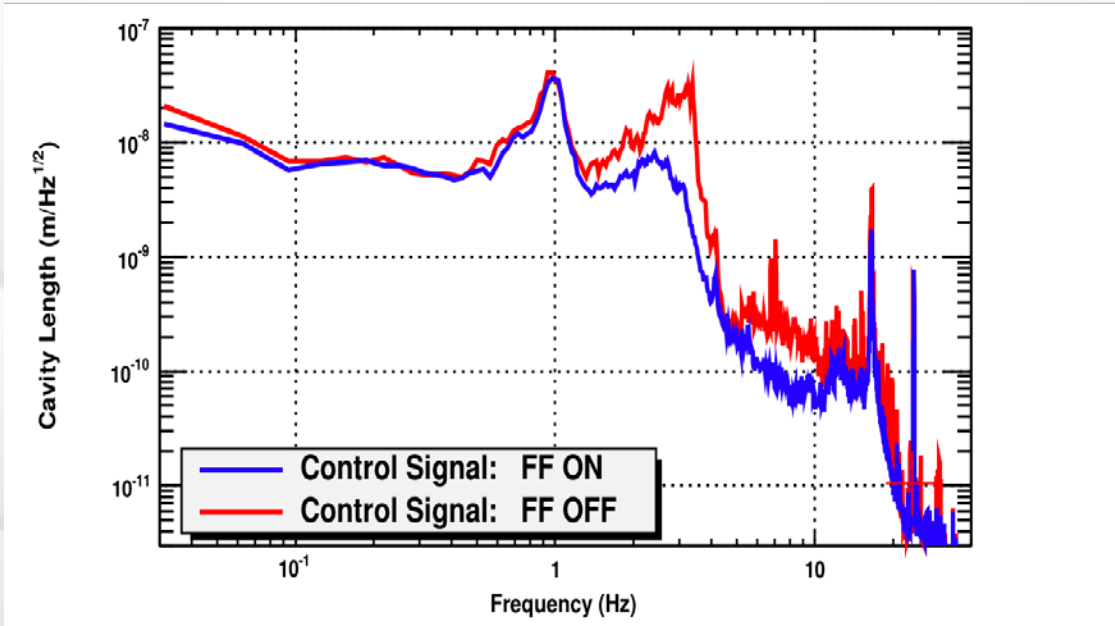
Further Complications

- Coherent witness sensor still a requirement
- Careful measurement of the plant transfer function is required
- Vulnerable to numerical errors in:
  - Wiener filter calculation
  - Wiener filter fitting
  - Transfer function measurement
  - Transfer function fitting
- Need sensors for motion in all degrees of freedom (tilt meters)
- Sensors on all stages from ground to suspension in aLIGO
  - What is the optimal topology for actuation signal routing?

Future

- Adaptive filtering
  - The plant transfer function may be time varying
  - Adjust the filter coefficients in real time
  - Work done at CIT 40m
  - Getting started soon with aLIGO MC at Livingston

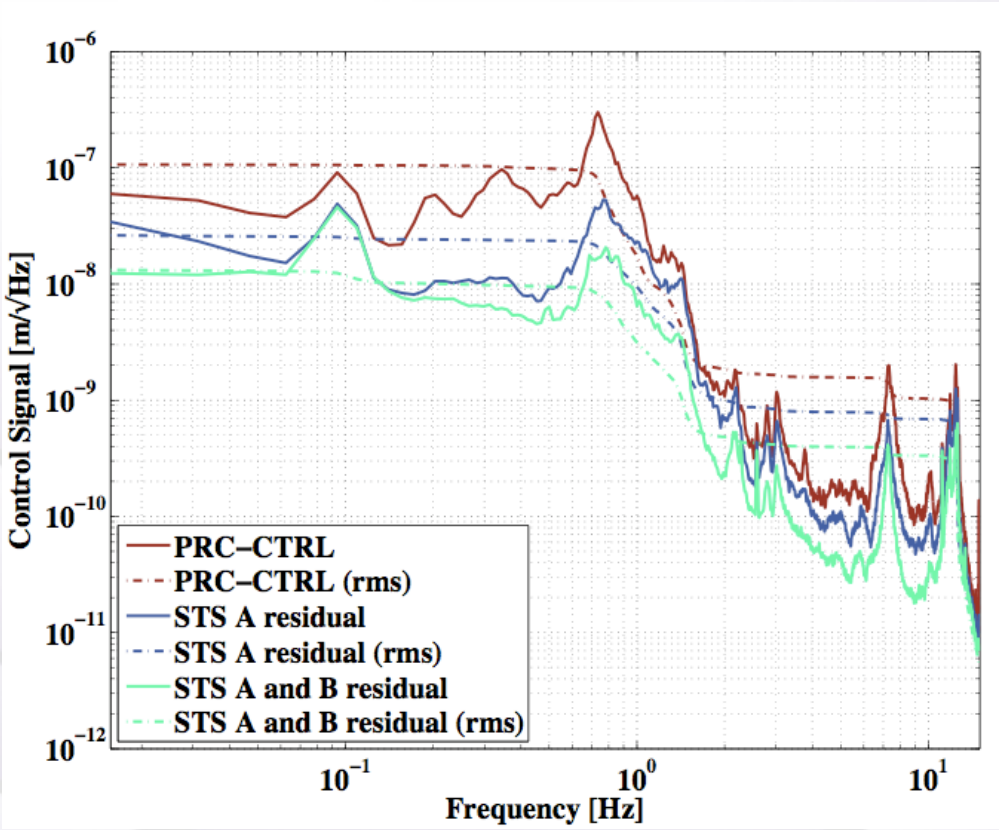
From “Active noise cancellation in a suspended interferometer”, J Driggers, M Evans, K Pepper, and R. Adhikari, RSI 2012



Future

- How many seismometers?
  - Offline calculation using two sensors suggests improvements available at many frequencies
  - One sensor per tank should measure the motion of interest

Using archived data, calculated reduction in control signal possible using Wiener filter subtraction with one or two nearby ground sensors as witnesses (no global feed-forward enabled)



Questions?