Seismic Platform Interferometer for improved low frequency performance of aLIGO

Alec Engl, Sydney Yan, Dr. Brian Lantz, Dr. Sina Köhlenbeck

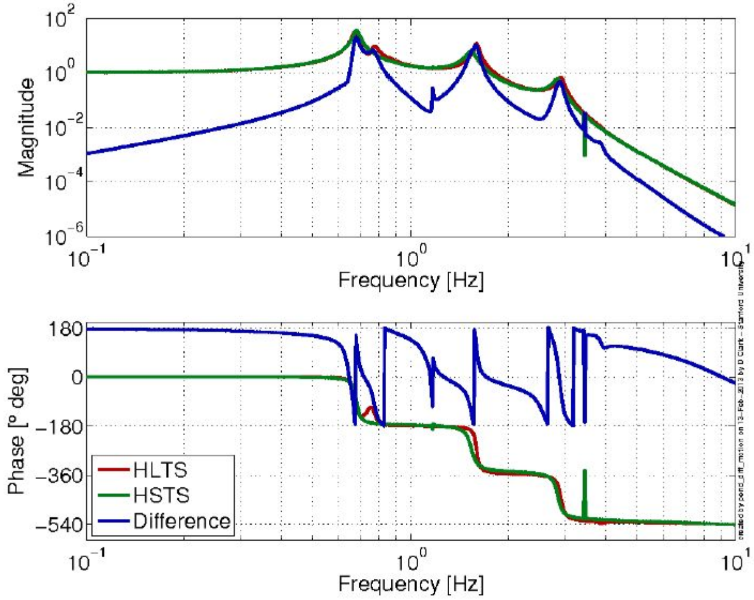
9/12/2022

Supported by NSF

LIGO-G2201531

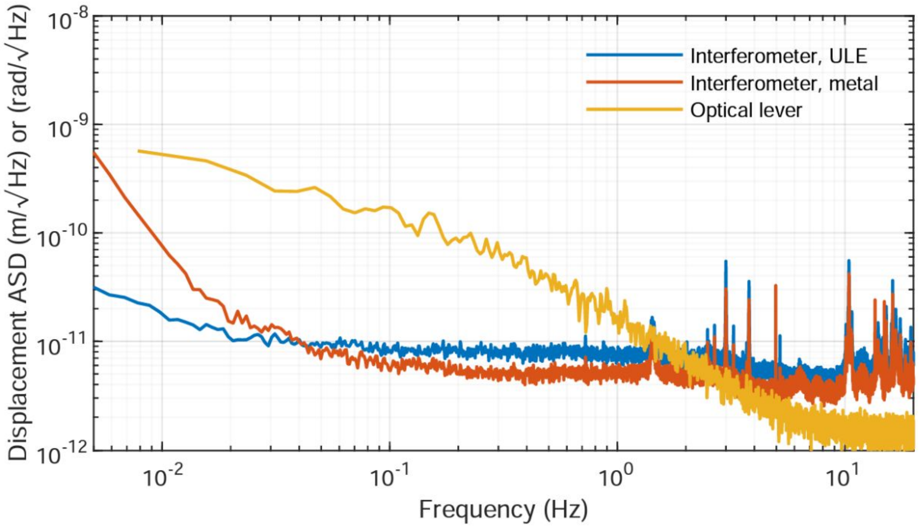
Motivation: differential sensing + control

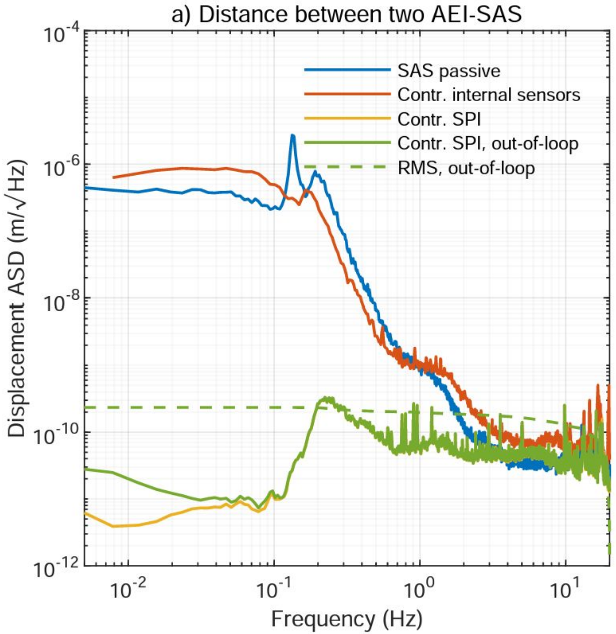
- All inertial sensors are worse at low frequencies
- Also, tilt-horizontal coupling…



P1300043, f4.1

Previous work - S. Köhlenbeck



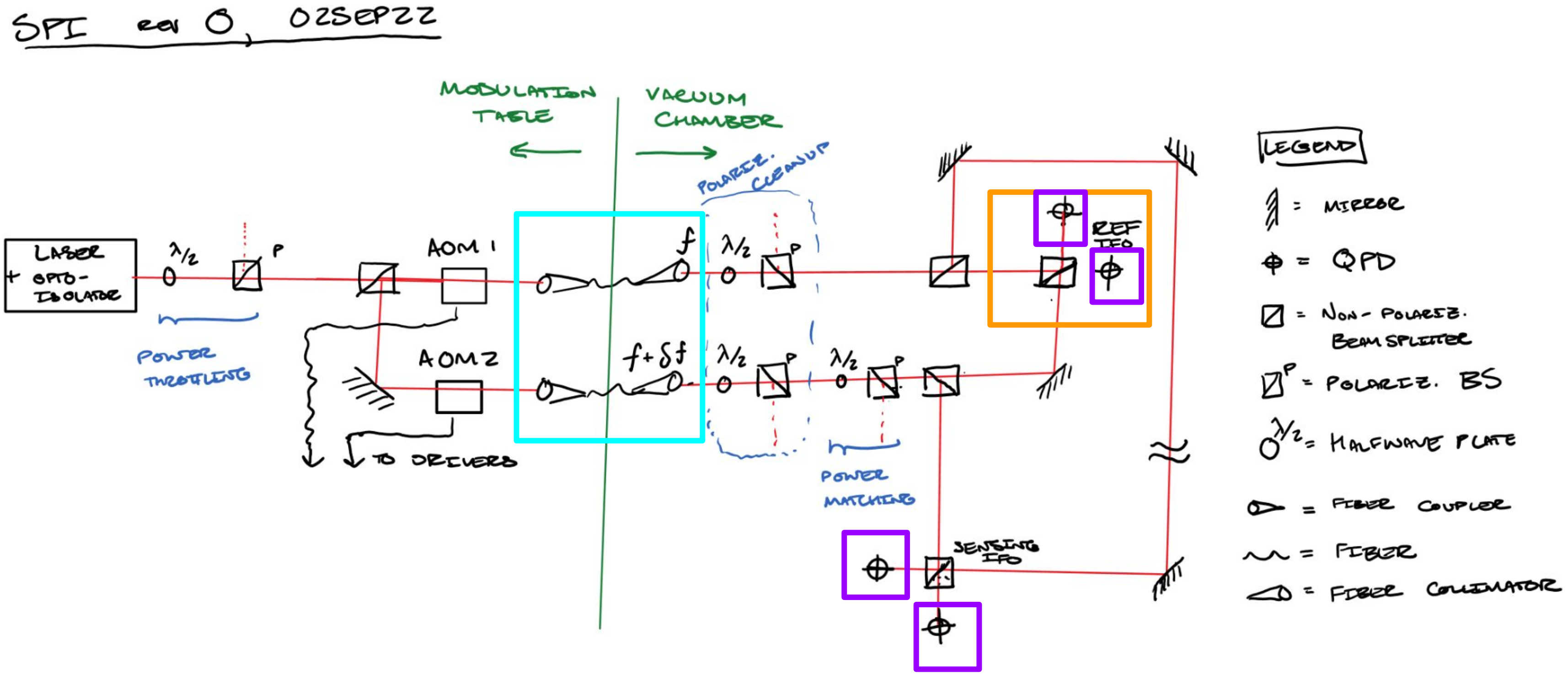


P2200259, f5,1a

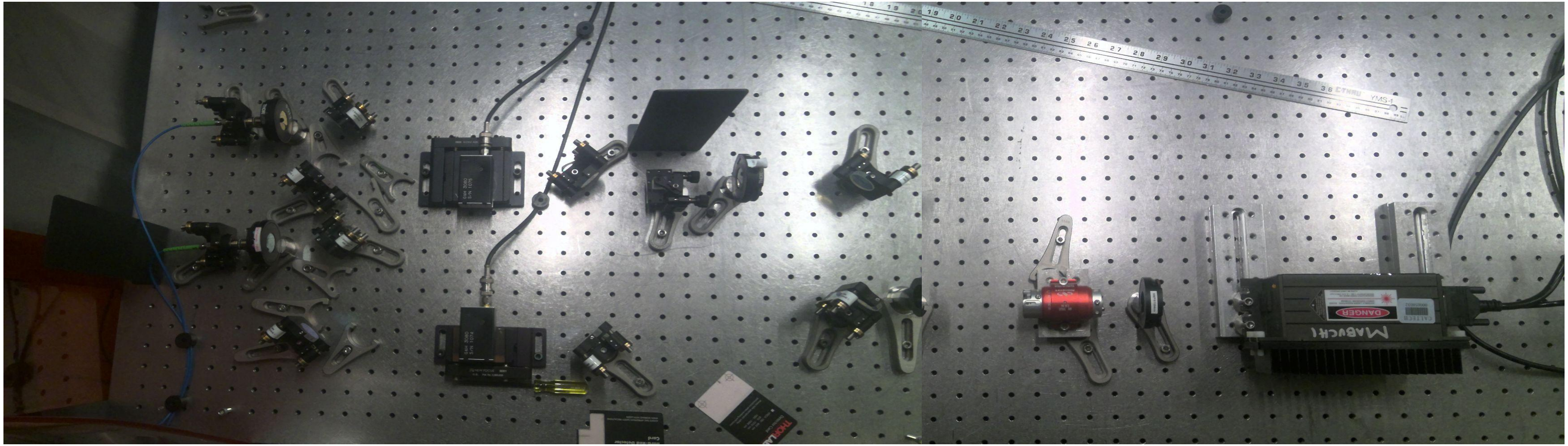
Goals for SPI @ Stanford

1. Document and UHV-rate SPI fabrication
2. Integrate with LIGO real-time system (CDS)
3. Demonstrate low noise floor
4. Test optical pointing stability (and other characteristics)
5. Distribute to (LIGO) sites

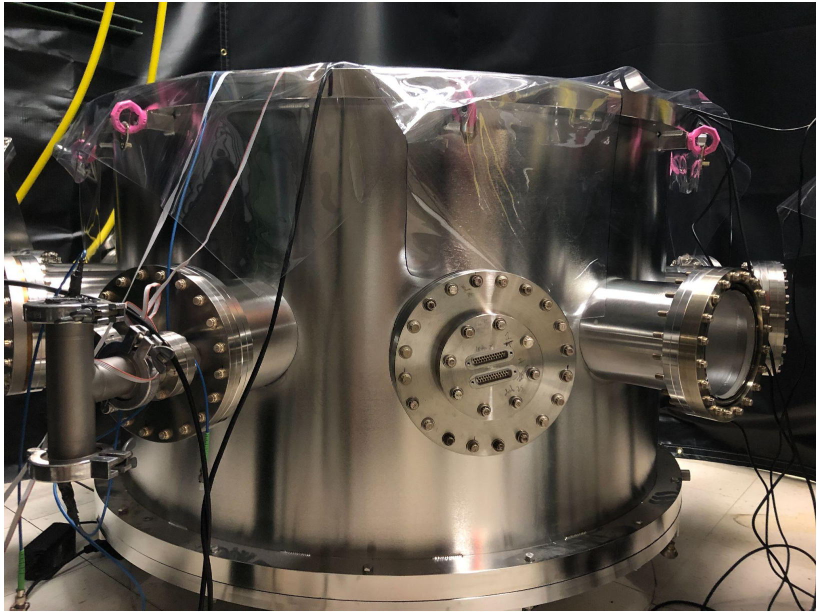
Optical Schematic

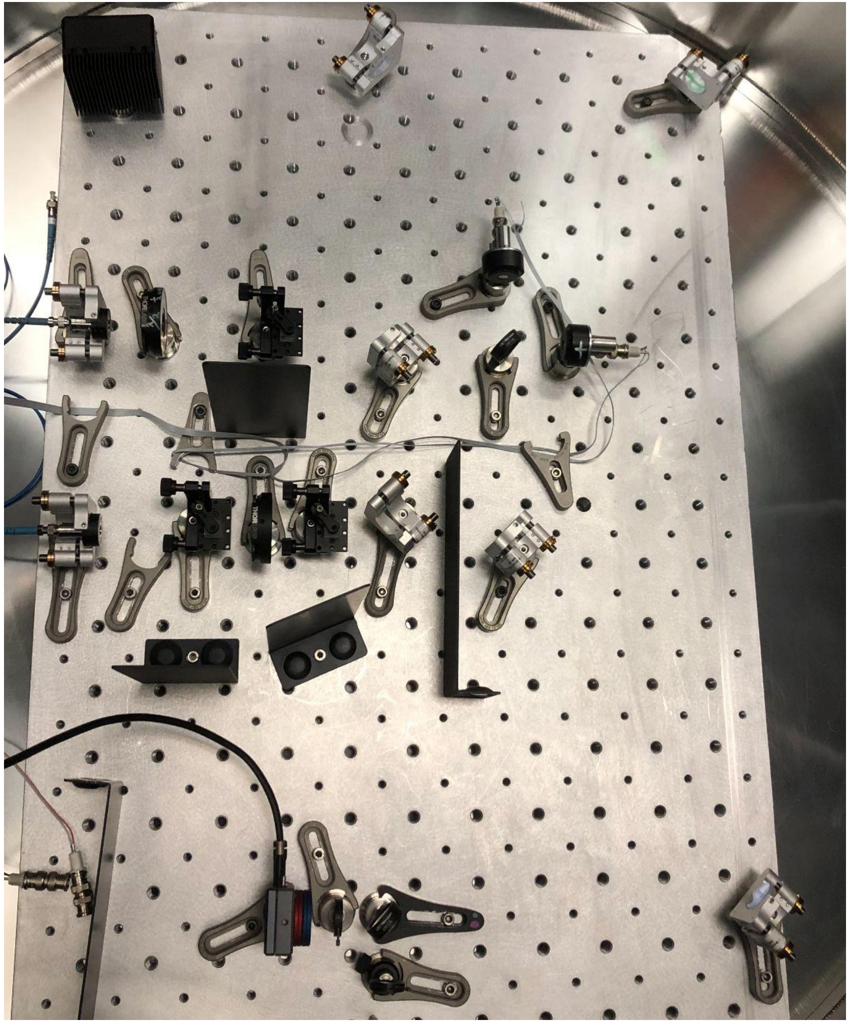


Physical build

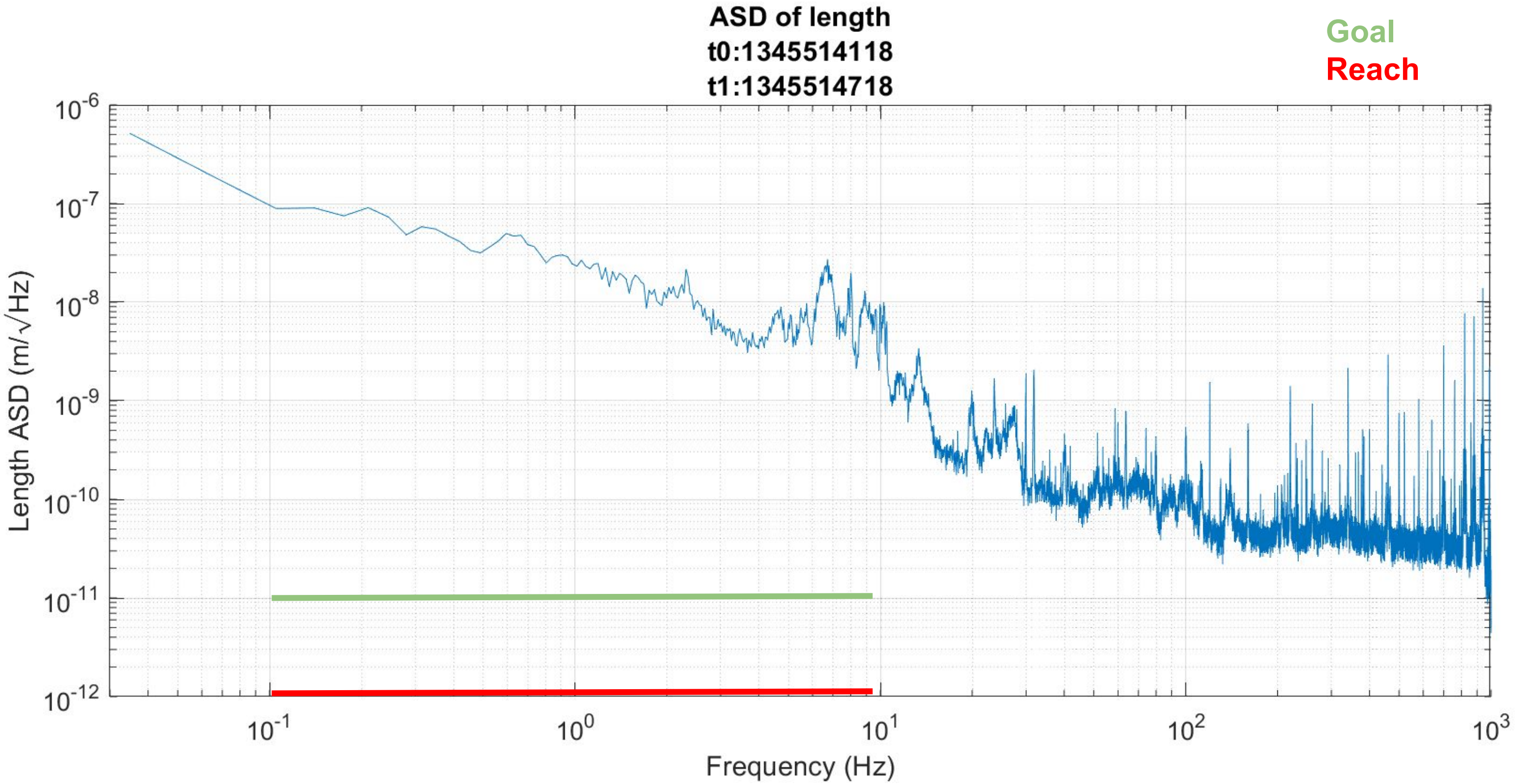


Physical build cont.





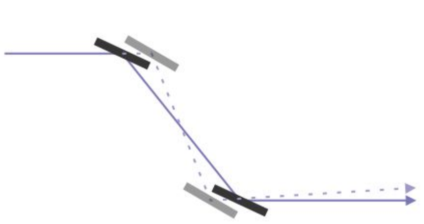
Latest Noise Spectrum



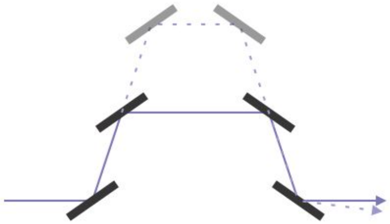
Long-term points of improvement

- Better handling of fiber optics
- Dealing with problems due to in-air section
- Further noise hunting

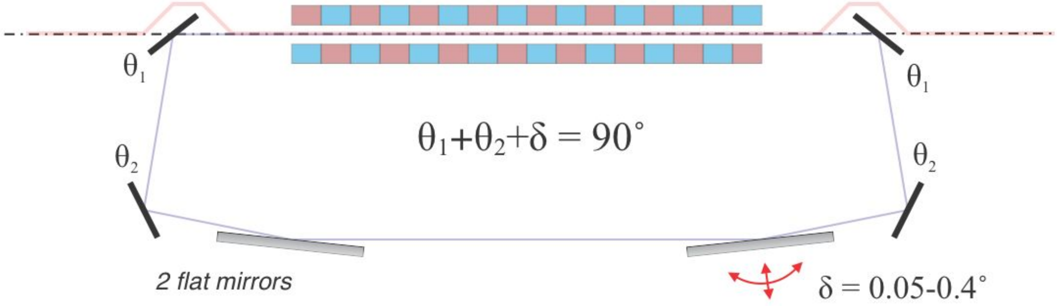
Collaboration with NNXO



(a) double crystal x-ray monochromator



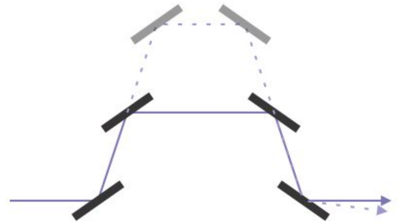
(b) 4-bounce x-ray delay line



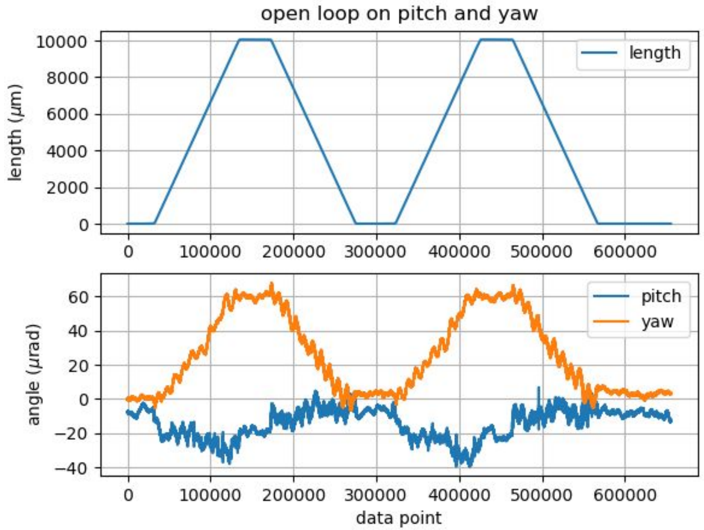
(c) tunable hard x-ray cavity for future X-FELs

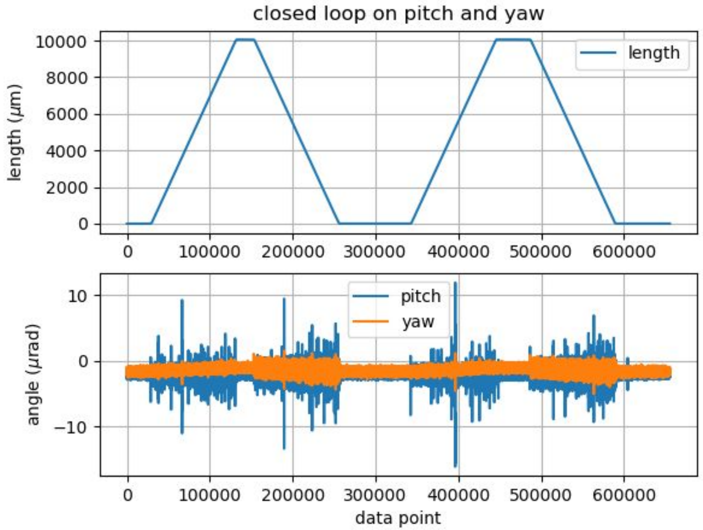
Cr: NNXO proposal

Collaboration with NNXO cont.



(b) 4-bounce x-ray delay line





Conclusion

- Excellent performance demonstrated at AEI
- Stanford engineering model has cleared software integration hurdles
- Noise hunting ongoing

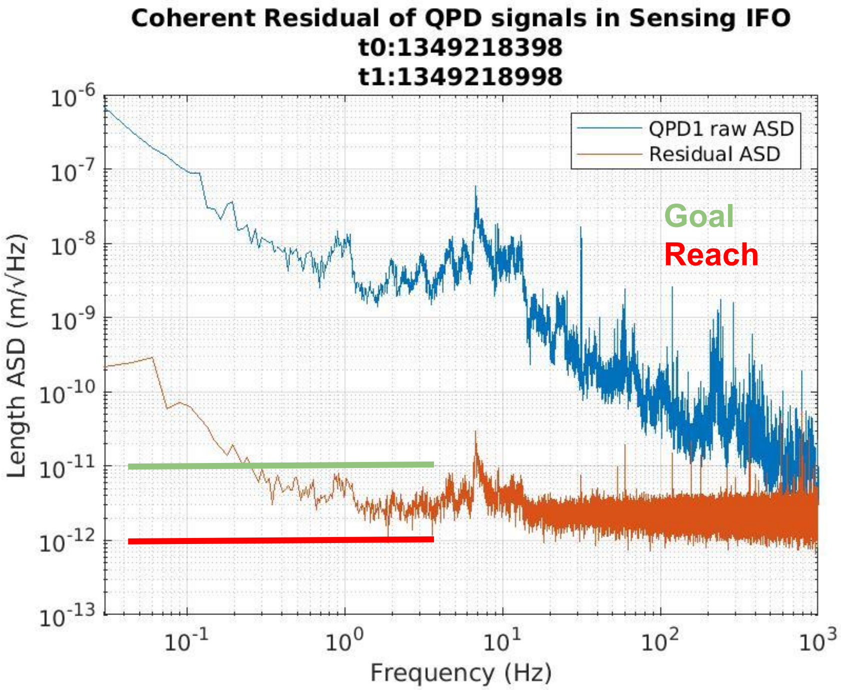
Onwards to A+!

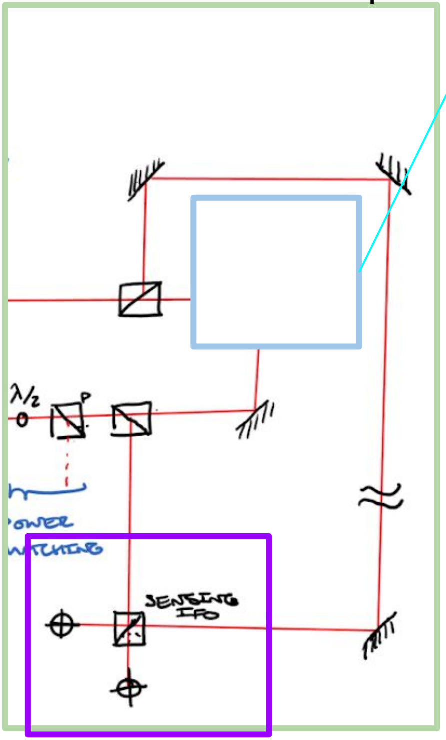
EDIT

- The following two slides show analysis performed the week after this presentation was originally given, but demonstrate the capabilities of the SPI setup at the time of the conference.

Split readout noise limit measurement

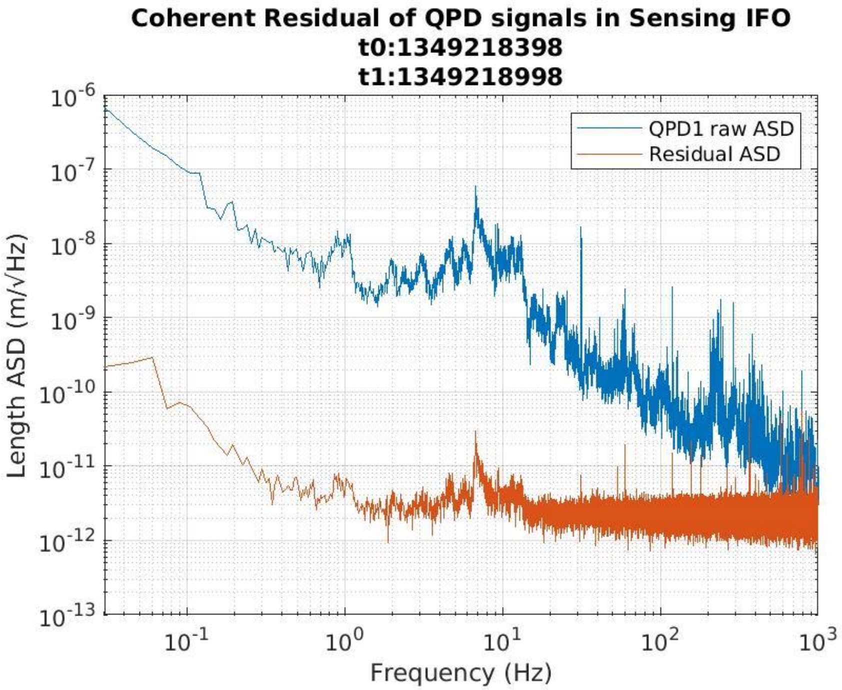
Note:
ref IFO not
implemented yet





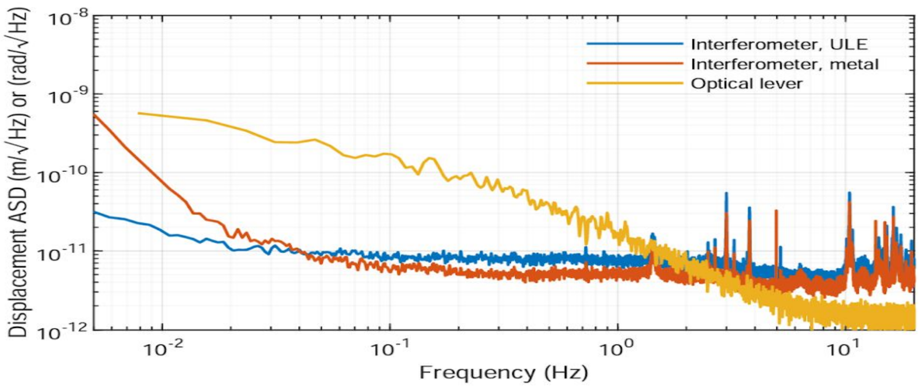
Math: coherently subtract QPD1 and QPD2 length signals (least squares fit of spectral data via mccs2)

Split readout noise limit comparison with AEI data



Observations:

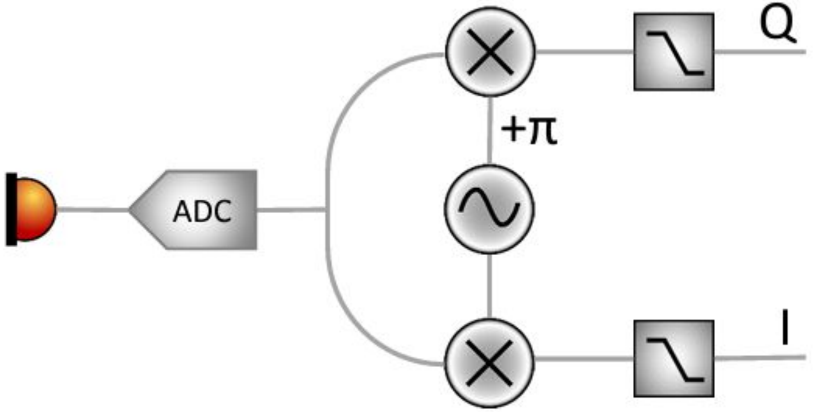
- Strong features at ~1Hz, 6Hz
- **This with vacuum chamber lightly-covered, at Patm**
- Compares favorably with work at AEI, though not quite there



P2200259, f5

Hidden slides:

Heterodyne phase detection

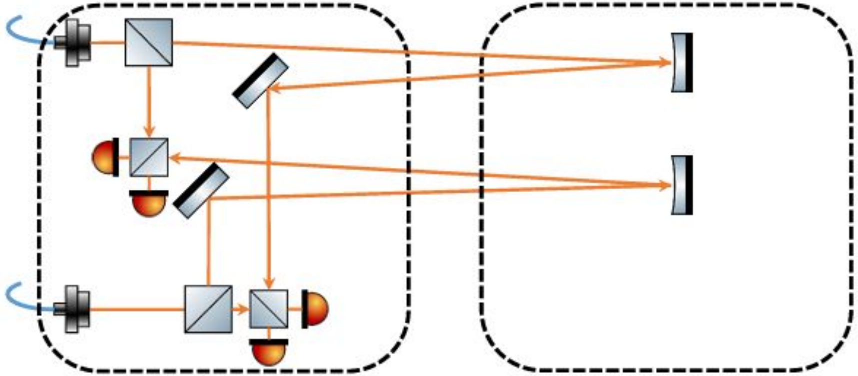


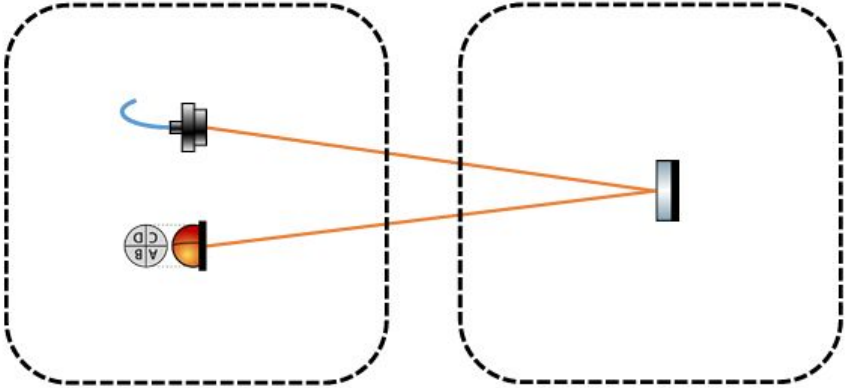
$$\varphi = \tan^{-1}\frac{Q}{I}$$

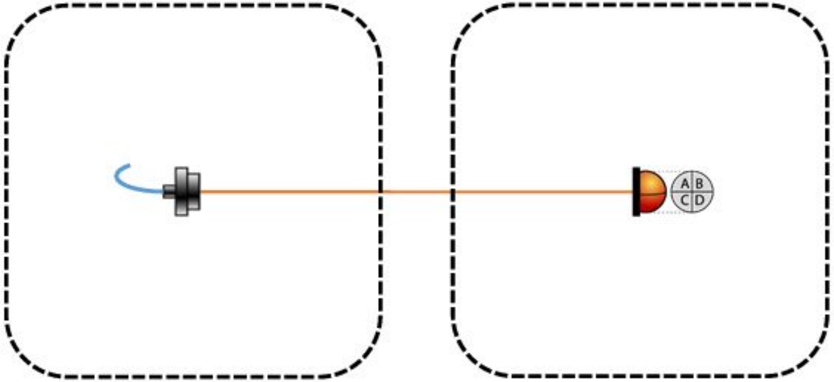
$$P = \sqrt{I^2 + Q^2}$$

Cr: G2100582,9

Angle: other possible geometries



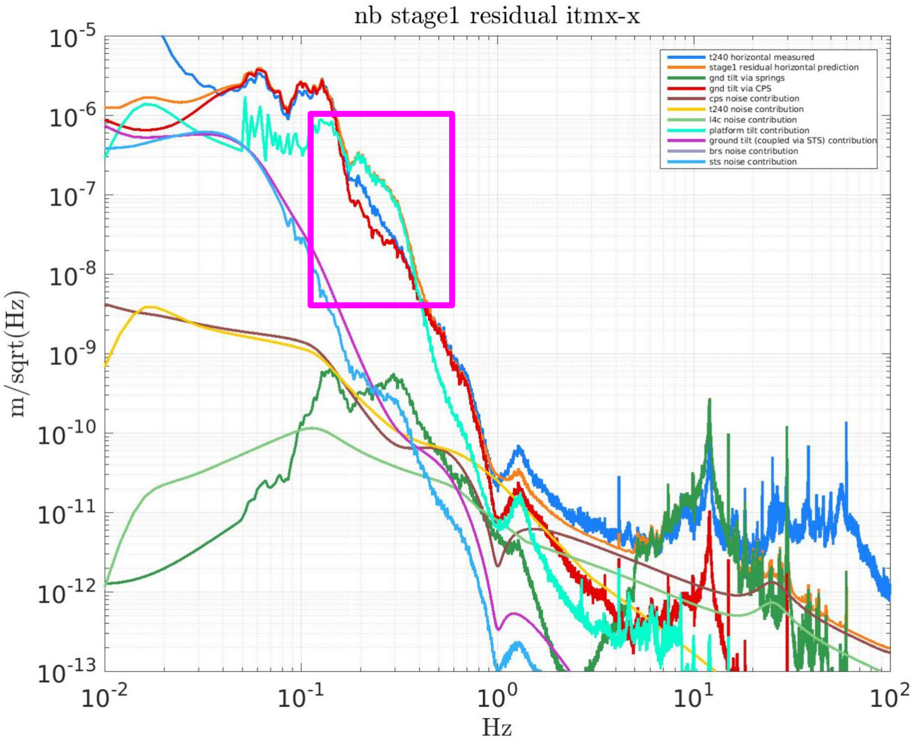




Cr: G2100582, 15-17

Parallel work - CRS/BRS

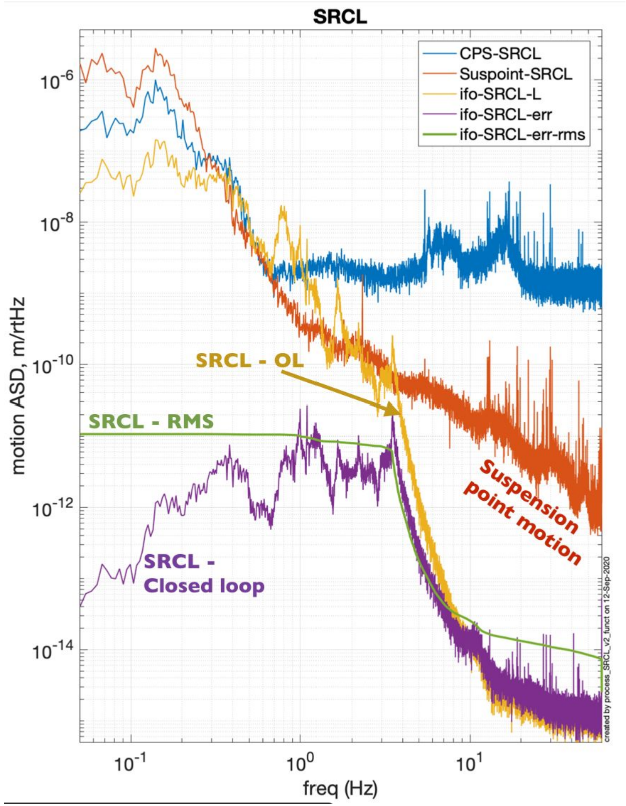
(picture of cBRS @ Stanford)



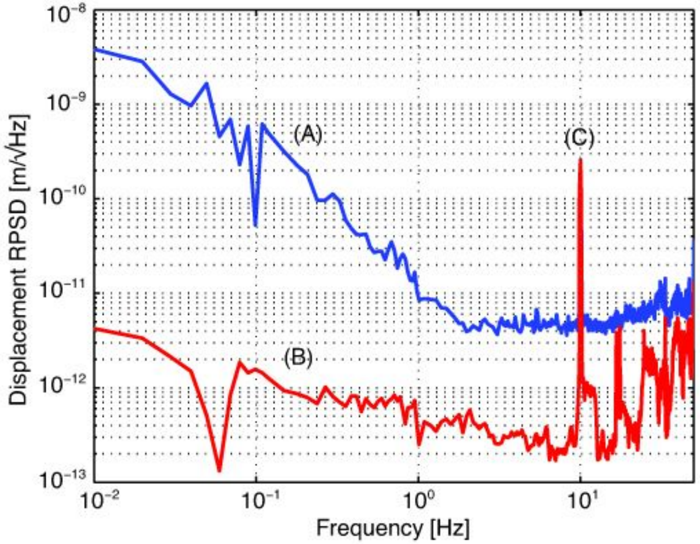
G2100779 p17

Parallel work - Improved state estimation in suspension

- While μseism important, it does not dominate RMS motion at SRCL!
- That comes from the ~f^-6 noise from the OSEMs
- Attend Edgard Bonilla's talk for more info!

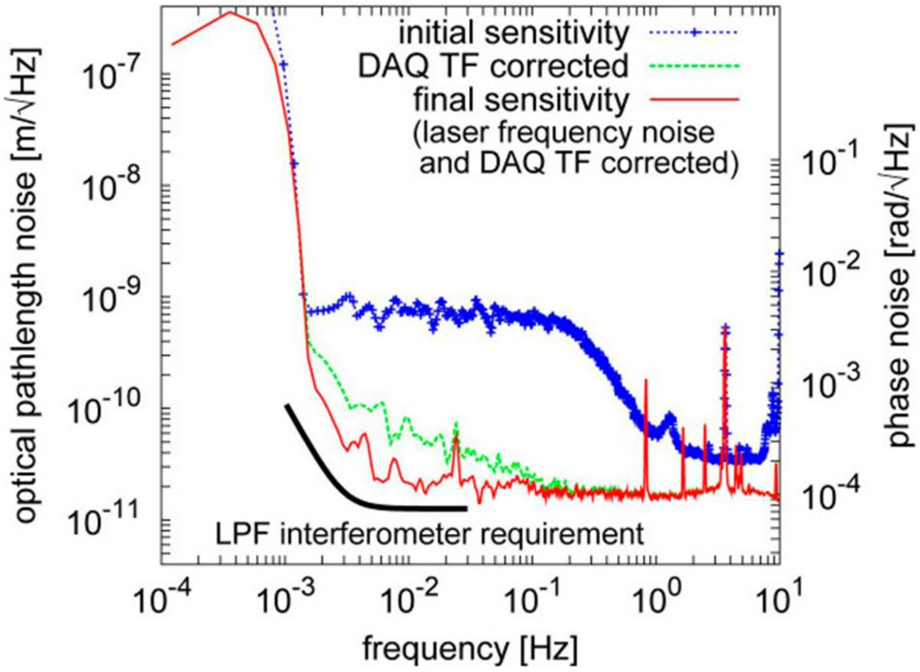


Parallel work - Digitally Enhanced Interferometry



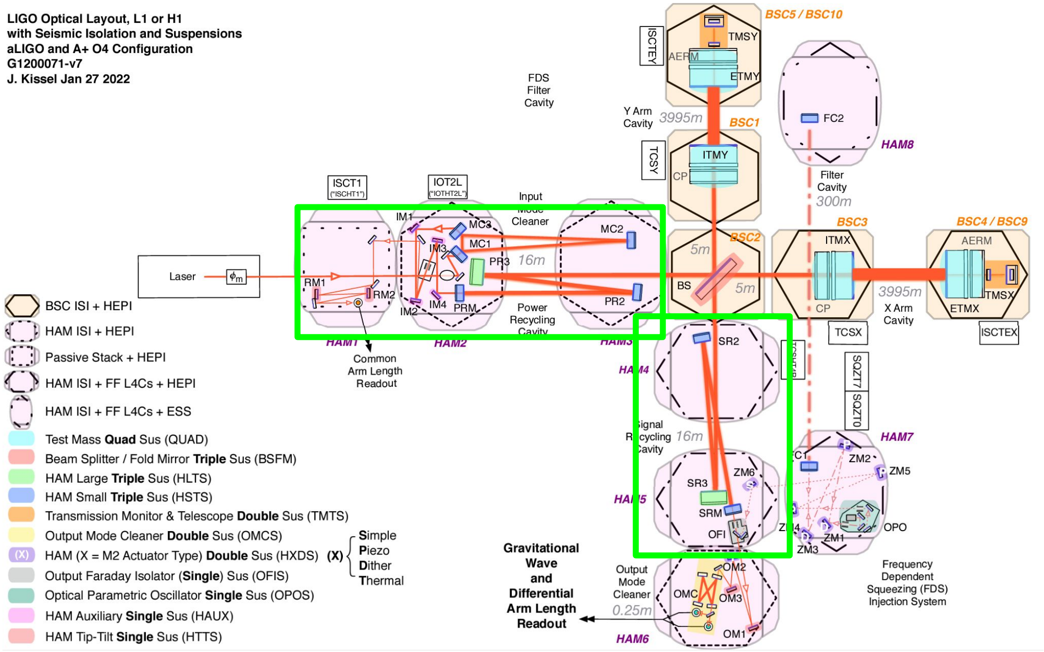
Glenn de Vine, David S. Rabeling, Bram J. J. Slagmolen, Timothy T-Y. Lam, Sheon Chua, Danielle M. Wuchenich, David E. McClelland, and Daniel A. Shaddock, "Picometer level displacement metrology with digitally enhanced heterodyne interferometry," Opt. Express 17, 828-837 (2009)

Parallel work cont. - Deep phase modulation



Gerhard Heinzel, Felipe Guzmán Cervantes, Antonio F. García Marín, Joachim Kullmann, Wang Feng, Karsten Danzmann, "Deep phase modulation interferometry," Opt. Express **18,** 19076-19086 (2010); https://www.osapublishing.org/oe/abstract.cfm?uri=oe-18-18-19076

Where would we put an SPI?



(largest contributors to rel noise)

Previous work - D. Clark

Table 1.1: Differential length, pitch, and yaw expected noise floor relative to the first stage platform target in the LIGO vertex.

Noise Floor and Target	0.01 Hz	0.1 Hz	1 Hz	10 Hz
Optical lever pitch and yaw (rad/$\sqrt{\text{Hz}}$)	$1.7 \cdot 10^{-7}$	$1.9 \cdot 10^{-8}$	$6.3 \cdot 10^{-10}$	$1.3 \cdot 10^{-10}$
Optical lever target, HAM 4-5	$5.5 \cdot 10^{-6}$	$5.5 \cdot 10^{-7}$	$5.5 \cdot 10^{-10}$	$5.5 \cdot 10^{-11}$
Length sensing noise floor (m/$\sqrt{\text{Hz}}$)	$4.5 \cdot 10^{-9}$	$5 \cdot 10^{-10}$	$6 \cdot 10^{-11}$	$9.5 \cdot 10^{-12}$
Length target, HAM 4-5	$5.5 \cdot 10^{-6}$	$5.5 \cdot 10^{-7}$	$5.5 \cdot 10^{-10}$	$4 \cdot 5.5^{-11}$

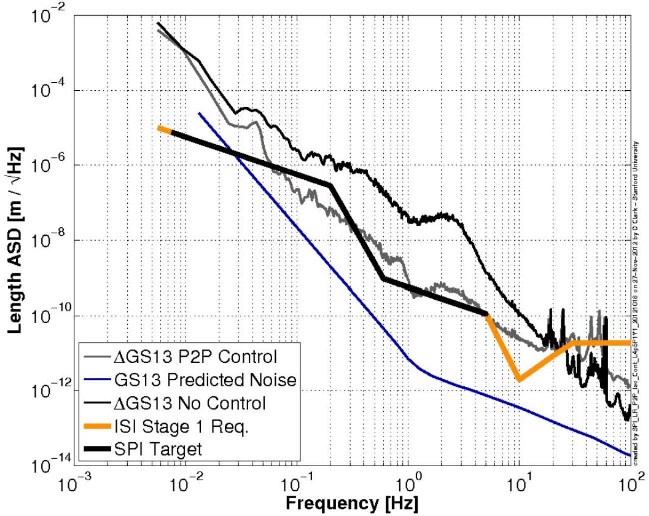


Figure 6.7: The differential GS-13 signal measuring the length between the RPP and the Tech Demo platforms is reduced when the RPP is controlled using the SPI L signal.

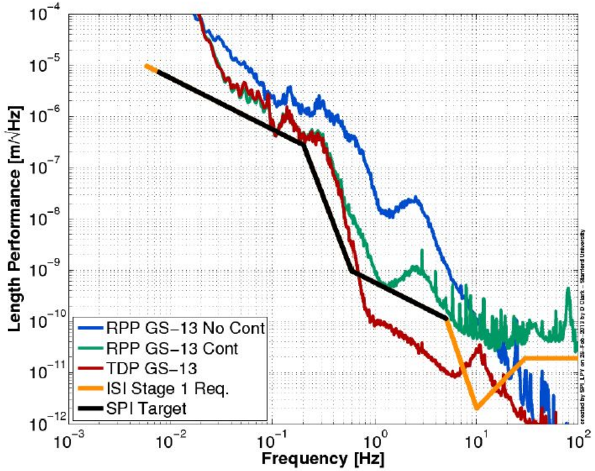
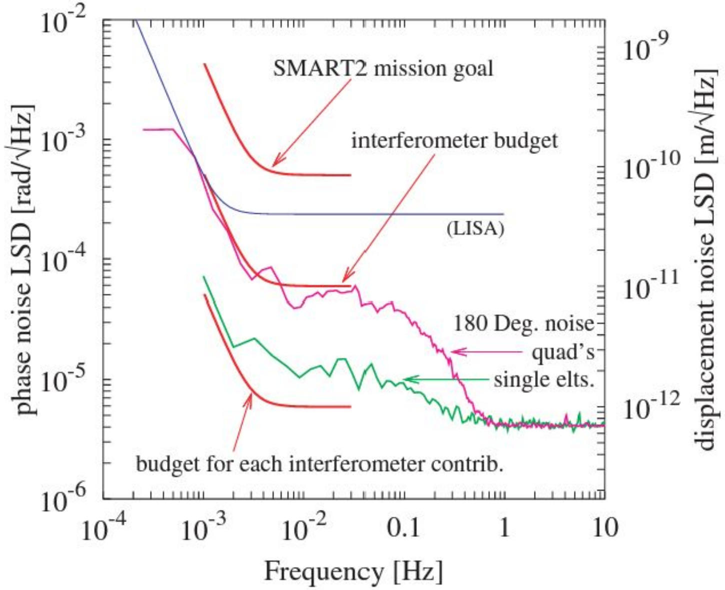


Figure 6.18: In general, the ΔGS-13 motion is almost entirely dominated by the RPP motion. The RPP motion at low frequencies is decreased when under SPI enabled control because the RPP can reference the superior sensors on the TDP. The RPP motion is elevated at higher frequencies because of SPI sensor noise being projected onto the platform.

P1300043, Clark

Previous work cont. - LISA project

(10^-5 radians ~ 1.67 * 10^-11 m @ 1064nm)



G. Heinzel, V. Wand, A. García, O. Jennrich, C. Braxmaier, D. Robertson, K. Middleton, D. Hoyland, A. Rüdiger, R. Schilling, U. Johann, and K. Danzmann, “The LTP interferometer and phasemeter,” Class. Quantum Grav. 21, S581 (2004).