Global Seismic Control

Sebastien Biscans

GWADW – Controls workshop
May 22nd 2019

contact: sbiscans@ligo.mit.edu

Question: what can we do to improve seismic isolation performance?

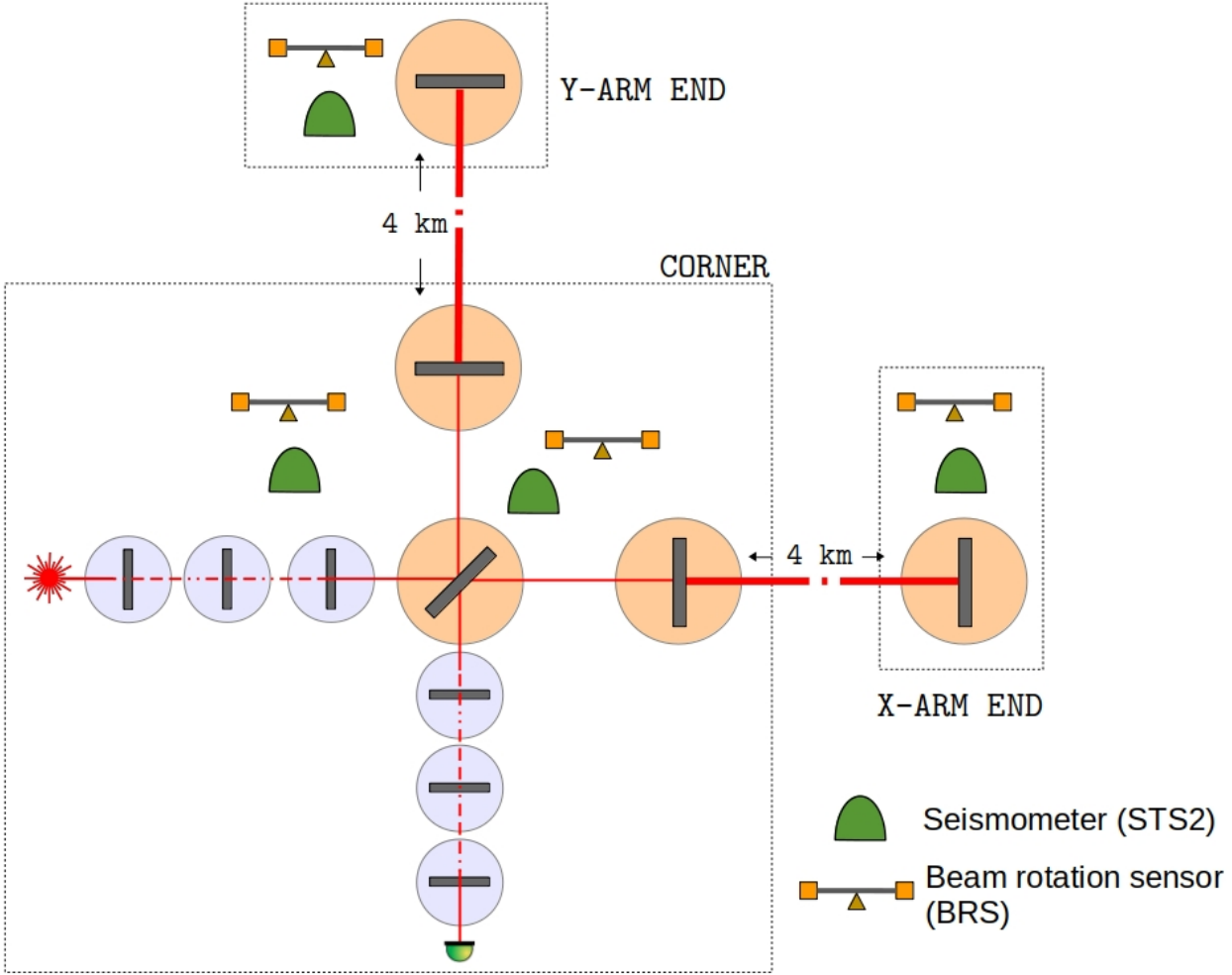
1. Current performance in LIGO

2. Current limitation

3. Ideas to make things better!

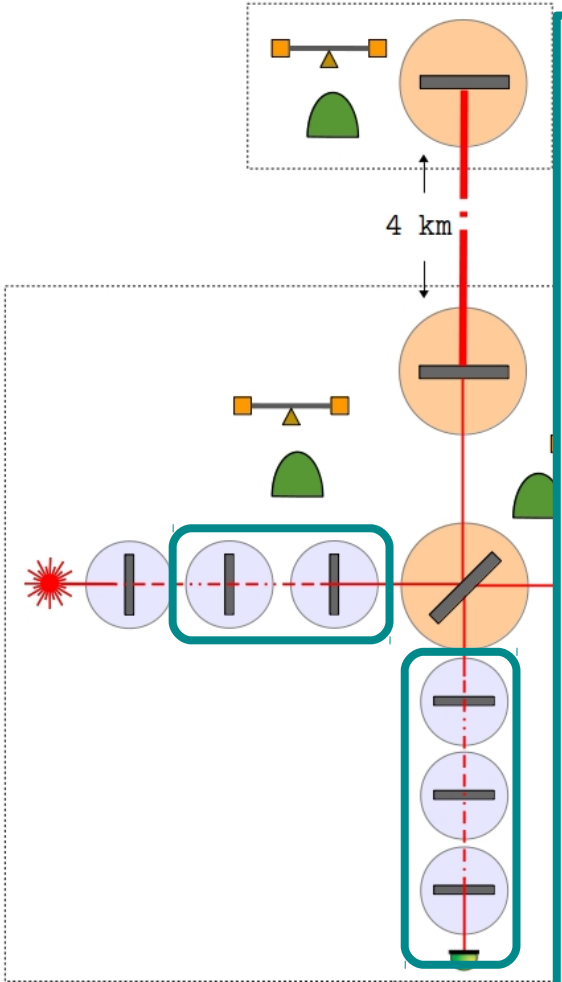
4. What’s worth pursuing in the future?

Seismic platforms



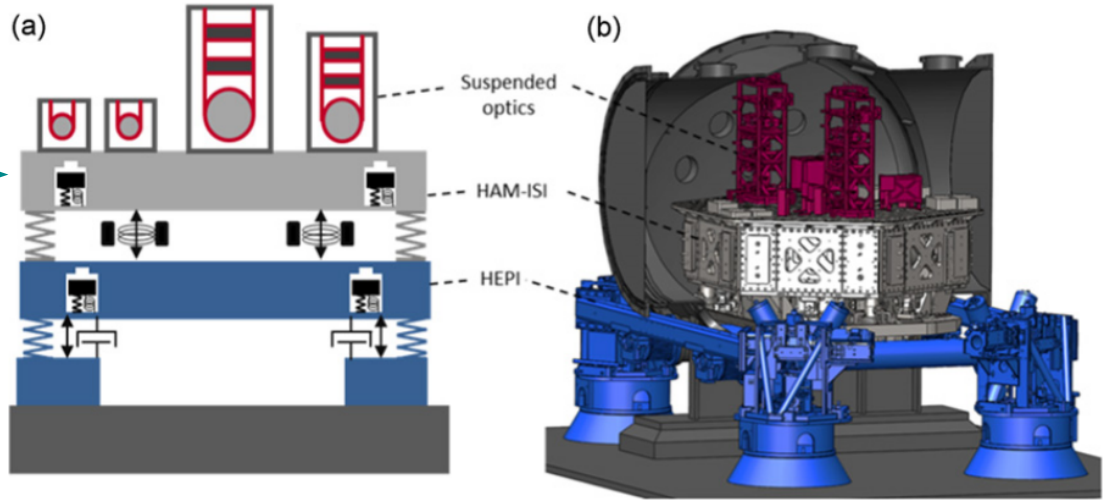
From Biscans, S., et al. Classical and Quantum Gravity 35.5 (2018): 055004

Seismic platforms

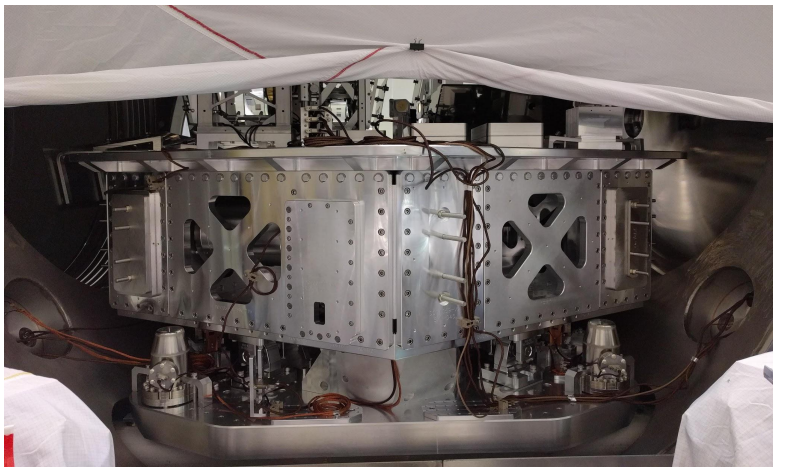


From Biscans, S., et al. Classical and Quantum

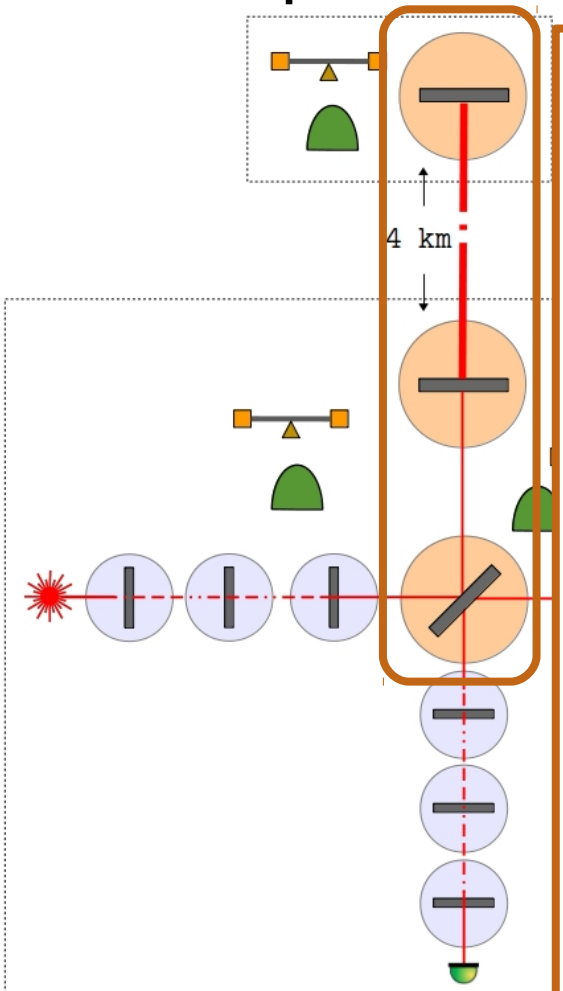
From Matichard, F., et al. Classical and Quantum Gravity 32.18 (2015): 185003.



HAM-ISI (1 stage)

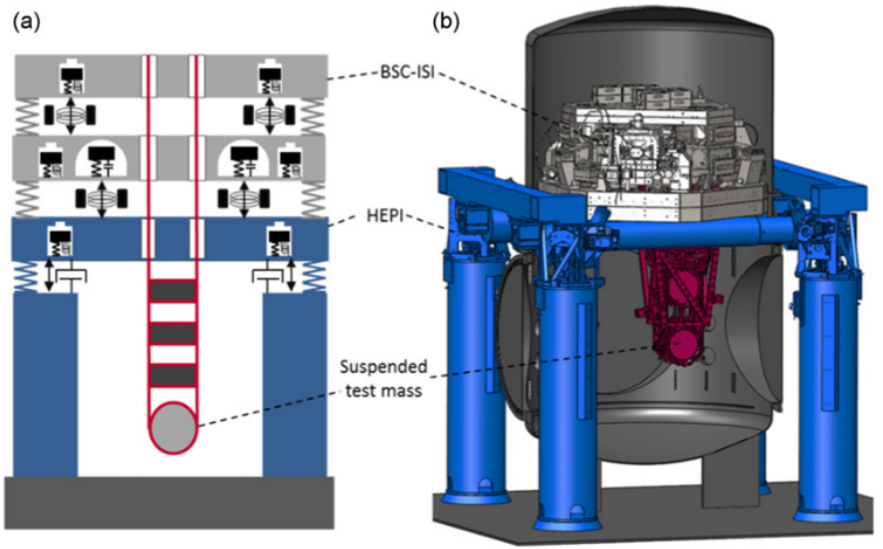


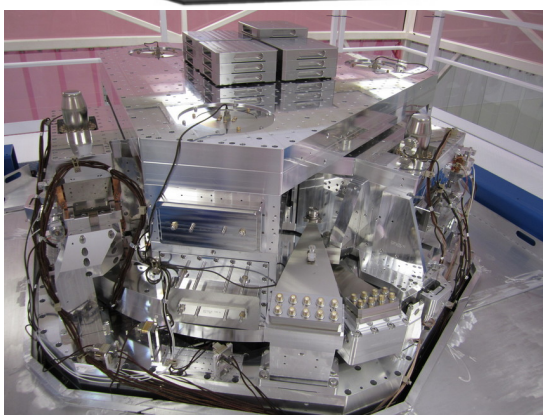
Seismic platforms



From Biscans, S., et al. Classical and Quantum

From Matichard, F., et al. Classical and Quantum Gravity 32.18 (2015): 185003.



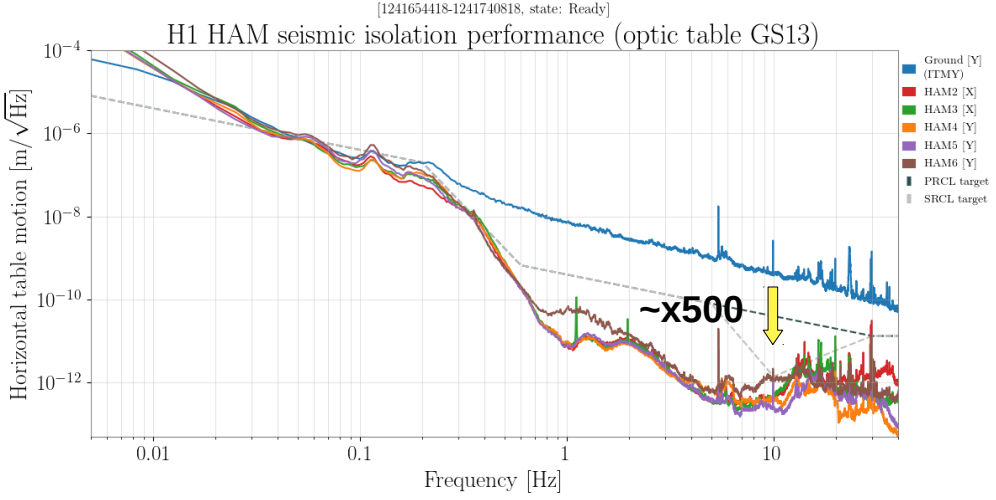


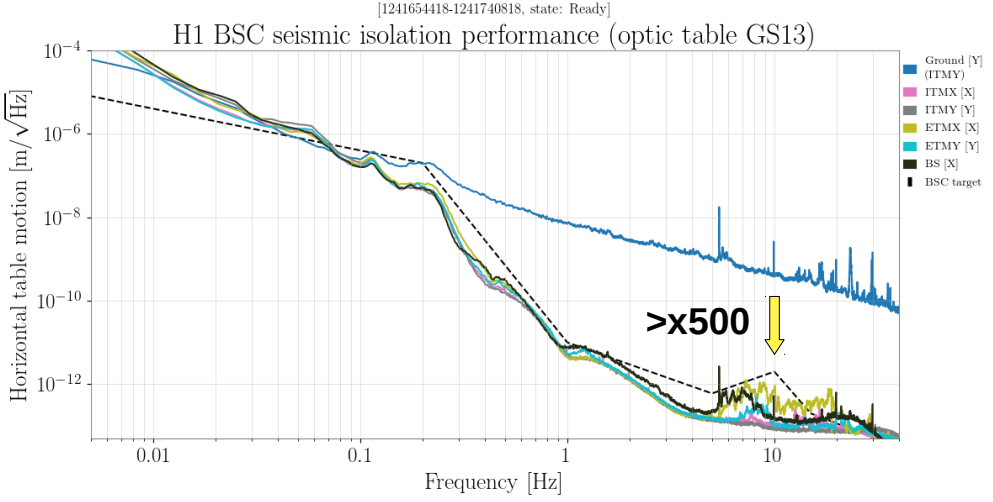
BSC-ISI
(2 stages)

Seismic platforms

All seismic isolation stages operate the same way:

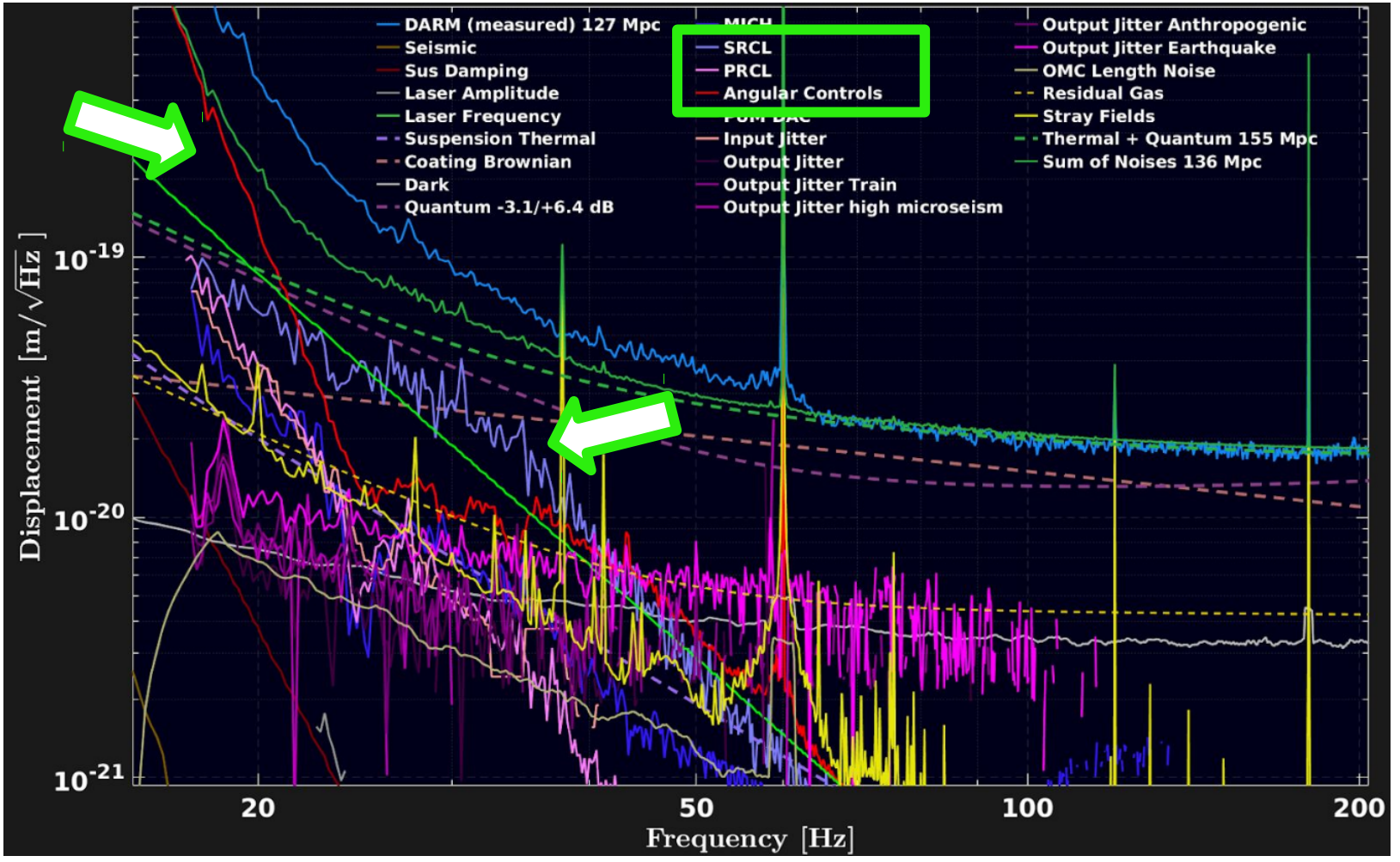
- 6 degrees of freedom
- Passive isolation (1/f^2 from ~1Hz)
- Active isolation from 0.1Hz to ~30Hz
- At **10Hz** BSC-ISI < **2e-12m/sqrt(Hz)** in all horizontal dofs
- At **10Hz** HAM-ISI < **4e-11m/sqrt(Hz)** for PRCL and **4e-12m/sqrt(Hz)** for SRCL





From Detchar summary pages.

Seismic isolation requirements



From M1900080

Seismic isolation requirements

Study (SEI alog 1393) shows that:

- The SRCL BW is currently limited by suspoint motion in 0.7 - 4 Hz.
- The suspoint SRCL motion from 0.7-4 Hz is all from the motion of HAM4 and HAM5
- The suspoint motion from the HAMs in the 0.7 to 4 Hz band is dominated by RX motion.

Reduced LF input motion will reduce angular control noise. Also:

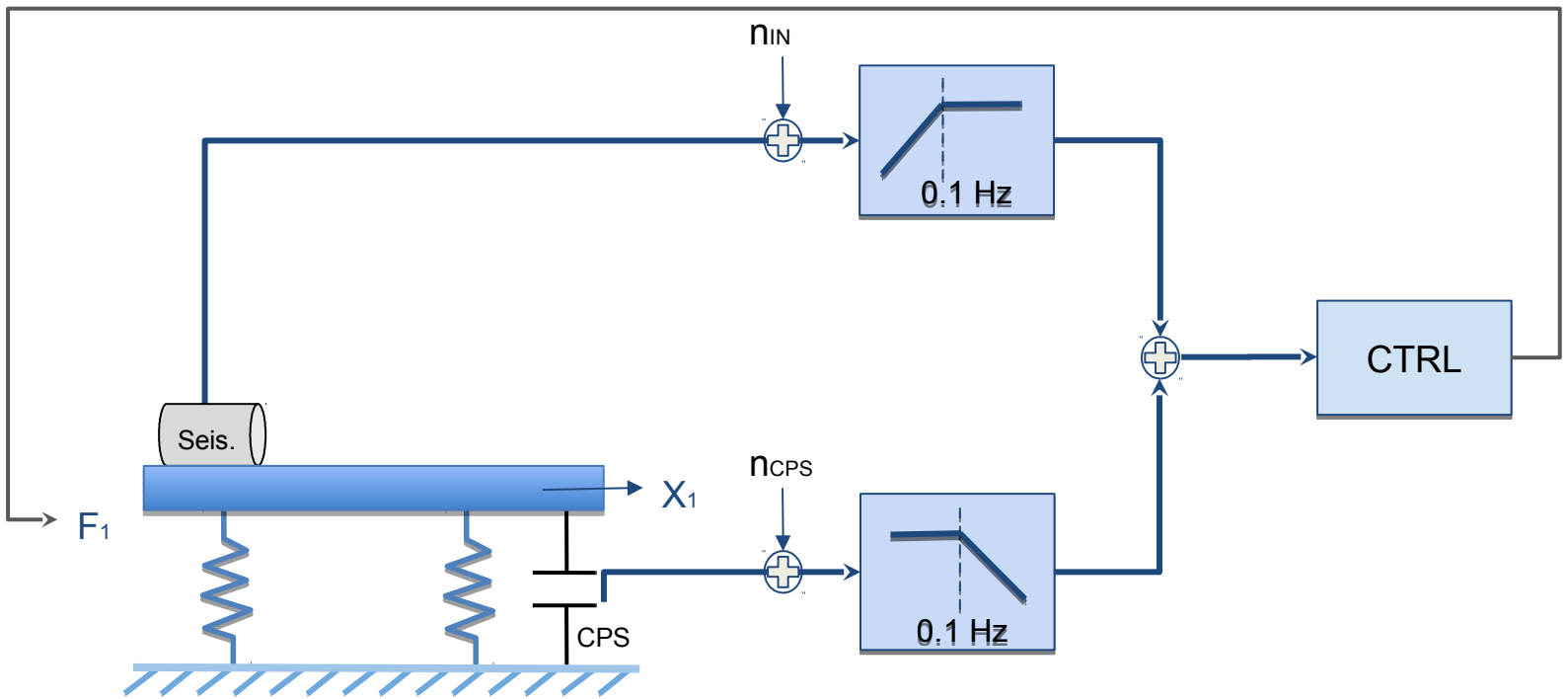
- Hard to lock with >2-3um rms microseism motion (100mHz-400mHz)
  >1um rms earthquake motion (30mHz-100mHz)
- Downtime from low-frequency input motion (wind/microseism/earthquakes): 5-10% at both sites + 8-12% locking during O2

Need to improve HAMs rotational motion between (1-10)Hz
Need to improve low-frequency (below 1Hz) performance

General control scheme for one stage

Each stage controlled separately

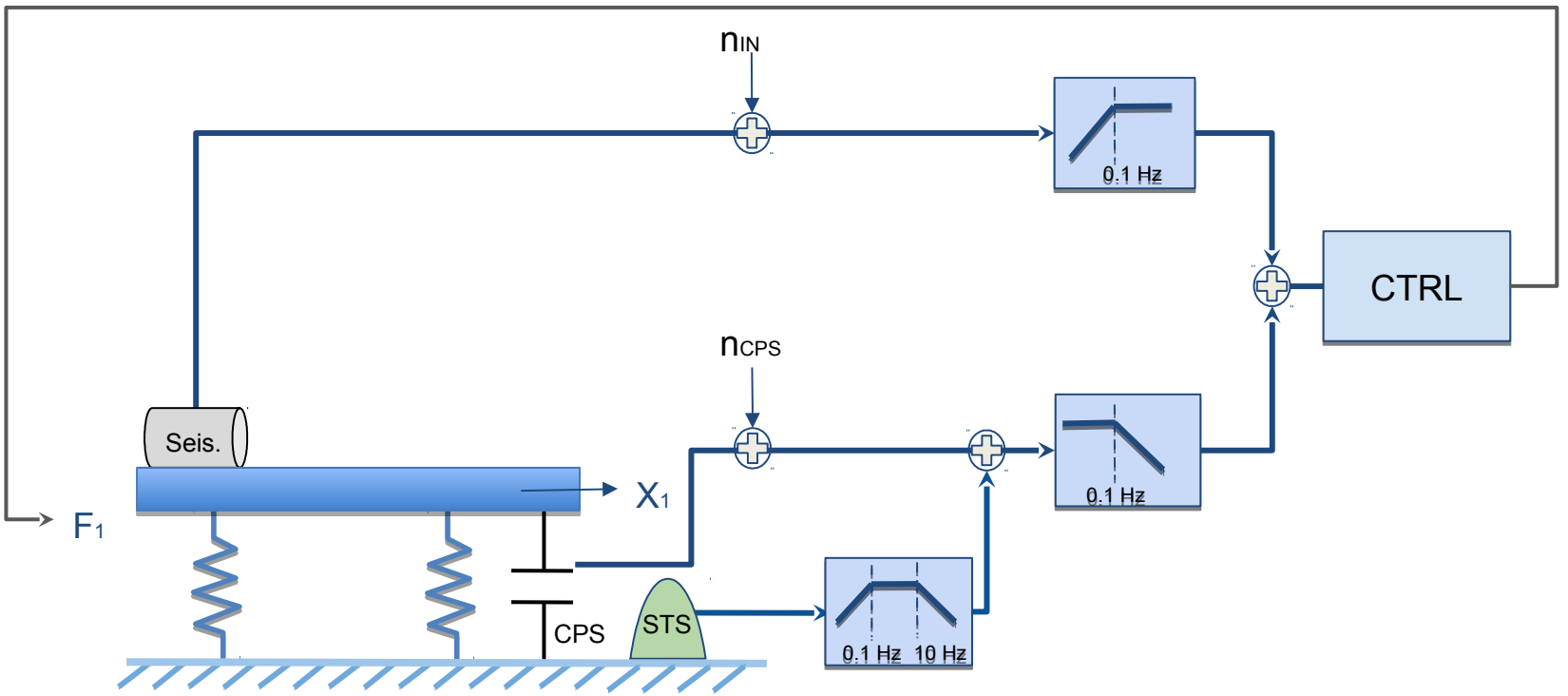
Feedback: blending of sensors, one (or two) inertial sensors >0.1Hz with position sensors <0.1Hz (similar scheme in all 6dofs).



Courtesy of A. Pele, G1801687

General control scheme for one stage

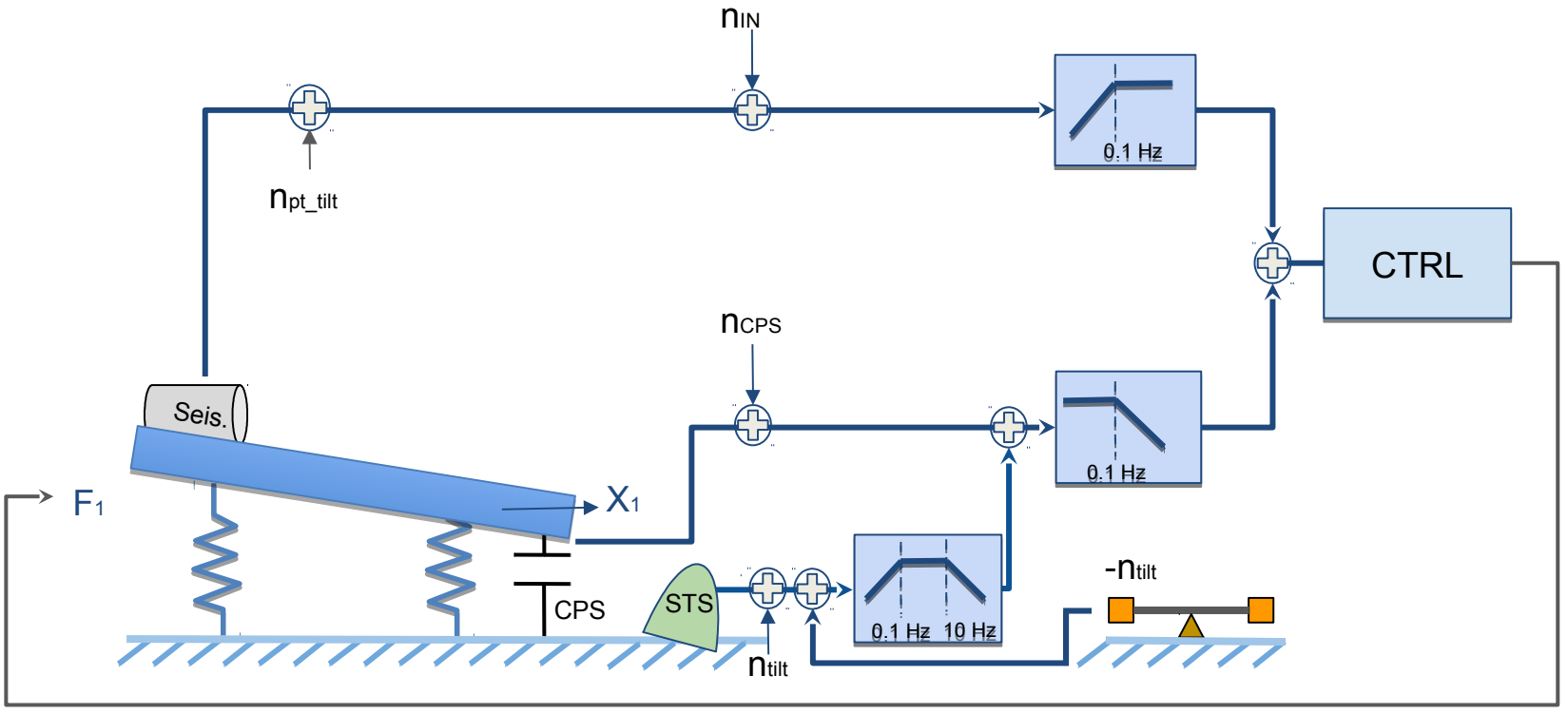
Feedforward/Sensor correction: ground seismometer feeds the CPS path to make it “inertial”



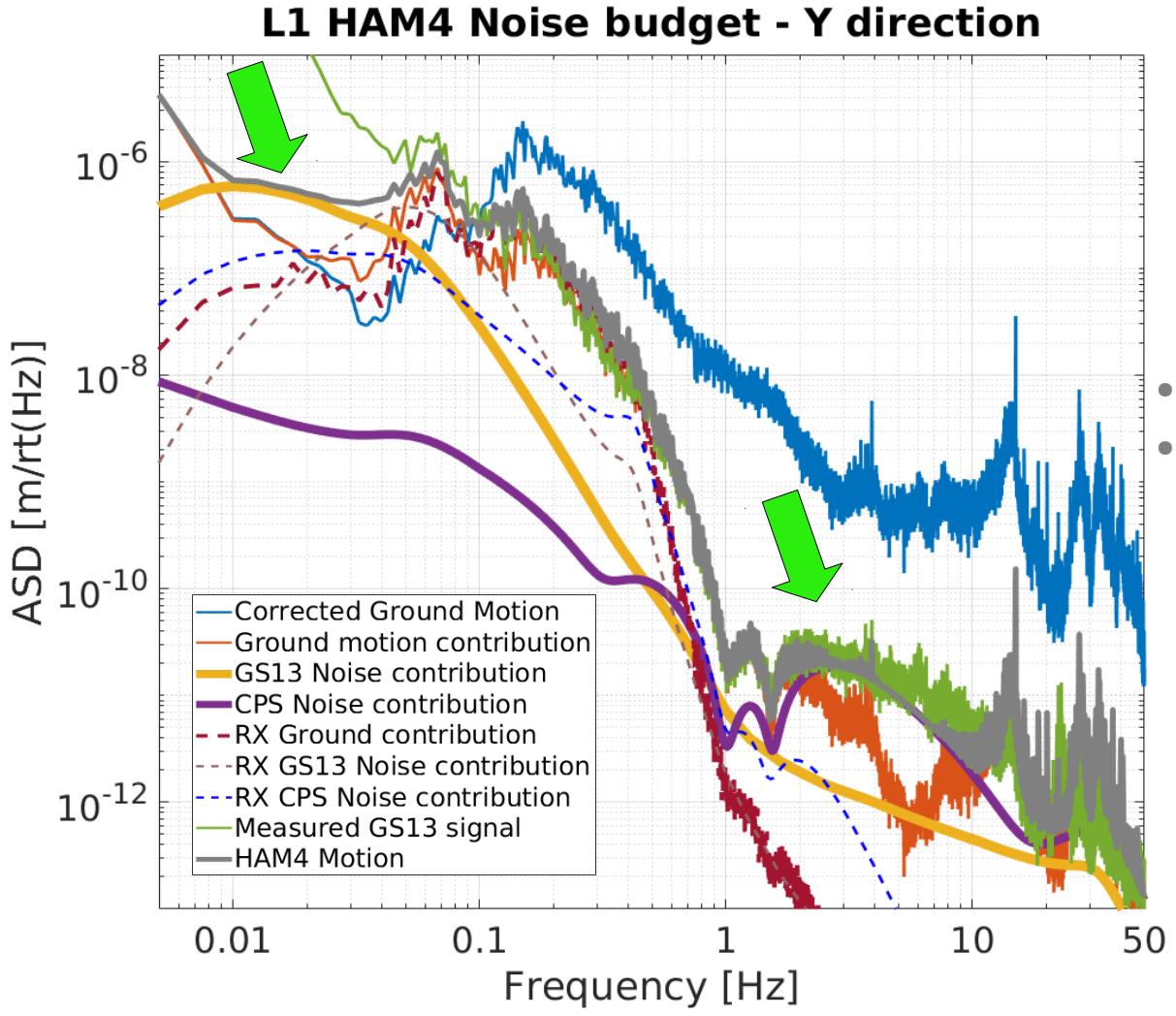
Courtesy of A. Pele, G1801687

General control scheme for one stage

Don’t forget tilt!
BRS feeds the seismometer hozizontal signal to substract tilt

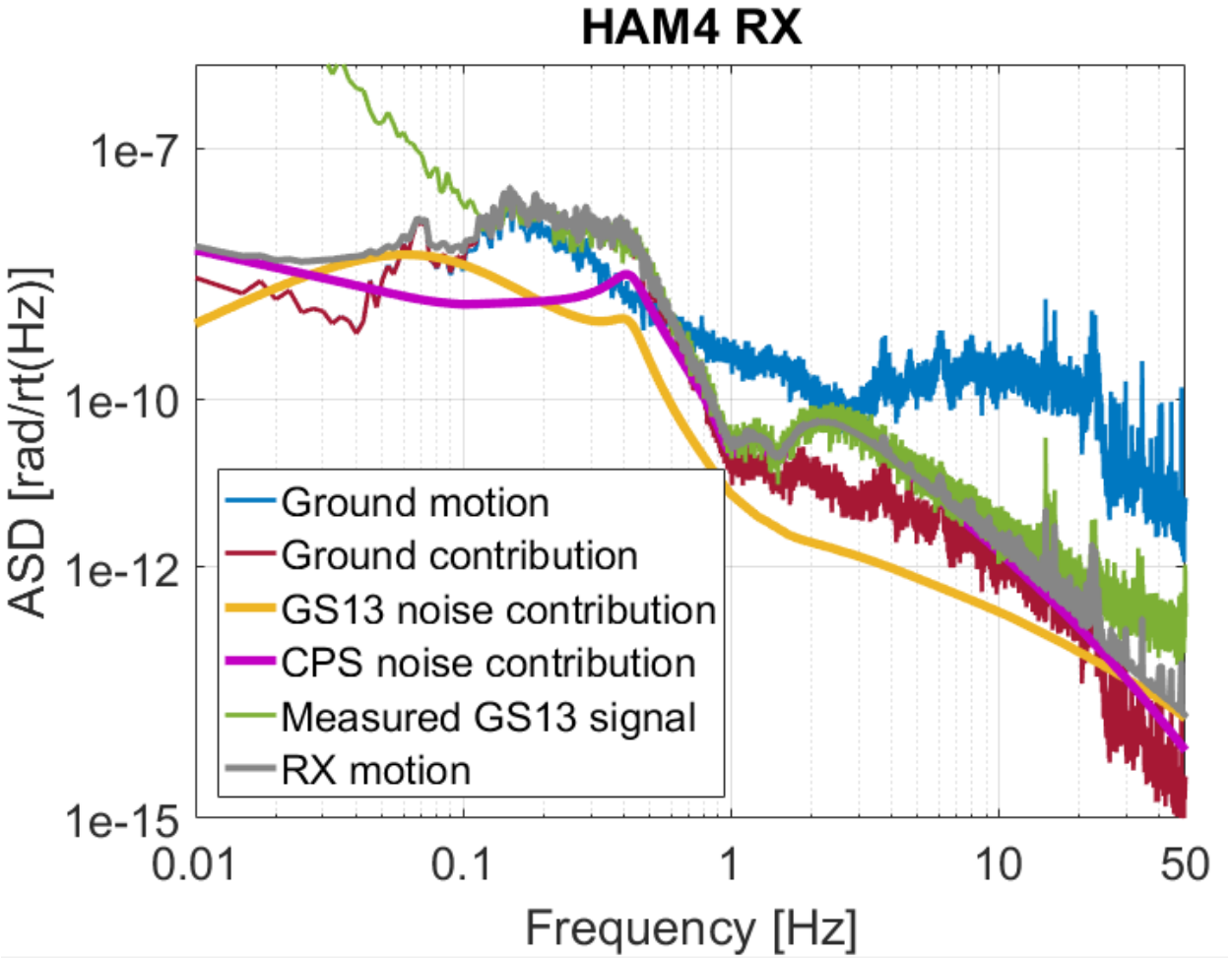


HAM Noise budget



- GS13 noise limited at low frequency
- CPS noise limited at high frequency

HAM Noise budget



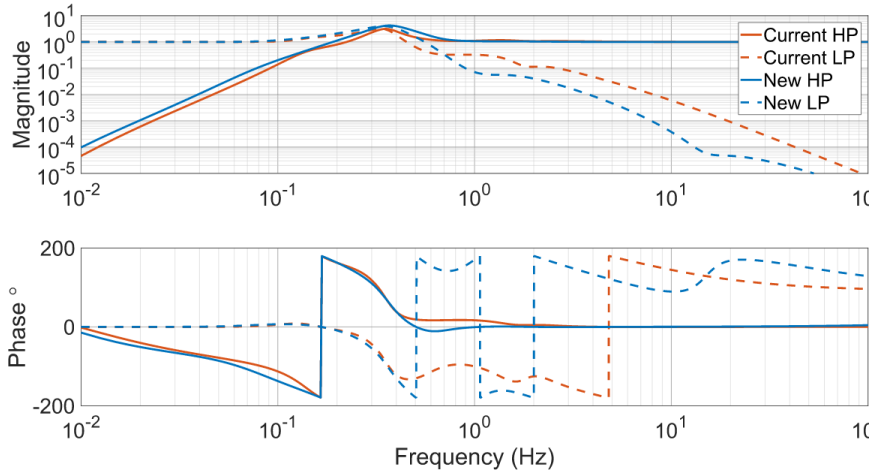
- Similar conclusion for RX

What can we do?

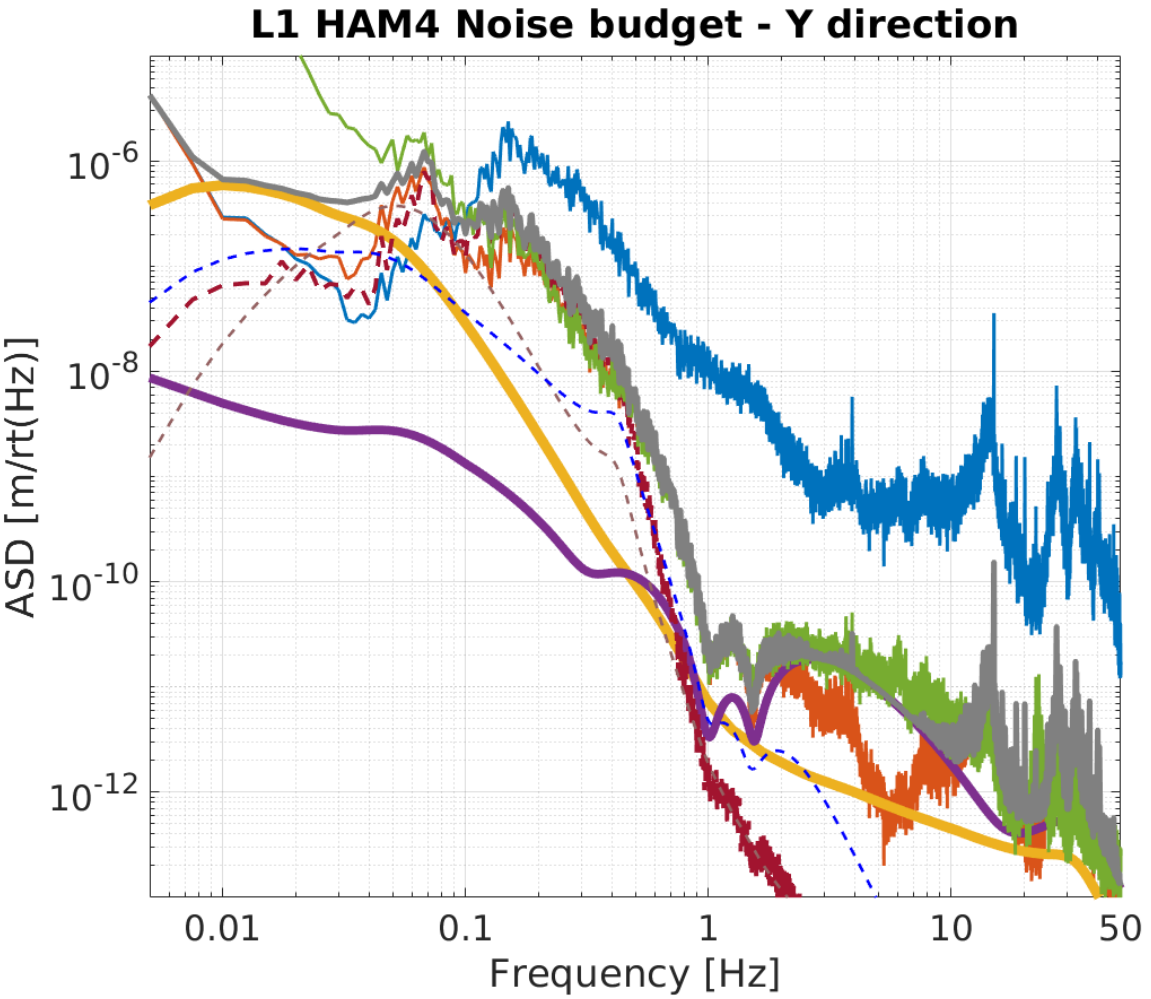
At the stage level:

Tune the blend filters/controllers:

- For all dofs: tune LP filter to reduce the “bump” around a few Hz.
- For RX: change RX blend filters to reduce CPS injection above 1Hz (T1900107)



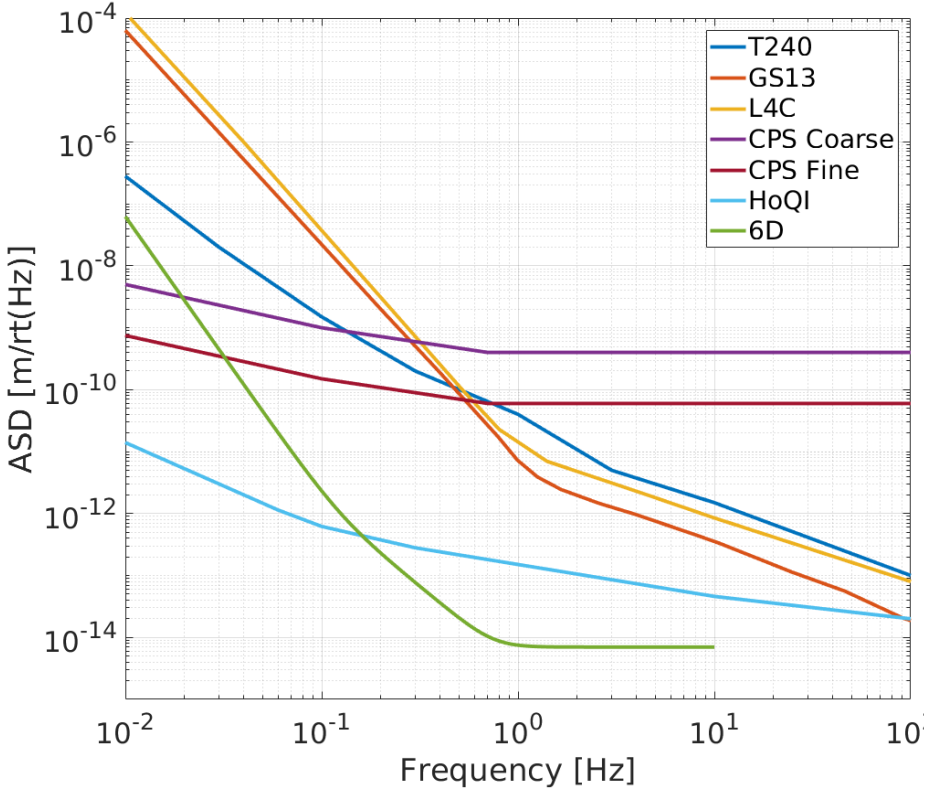
From T1900107

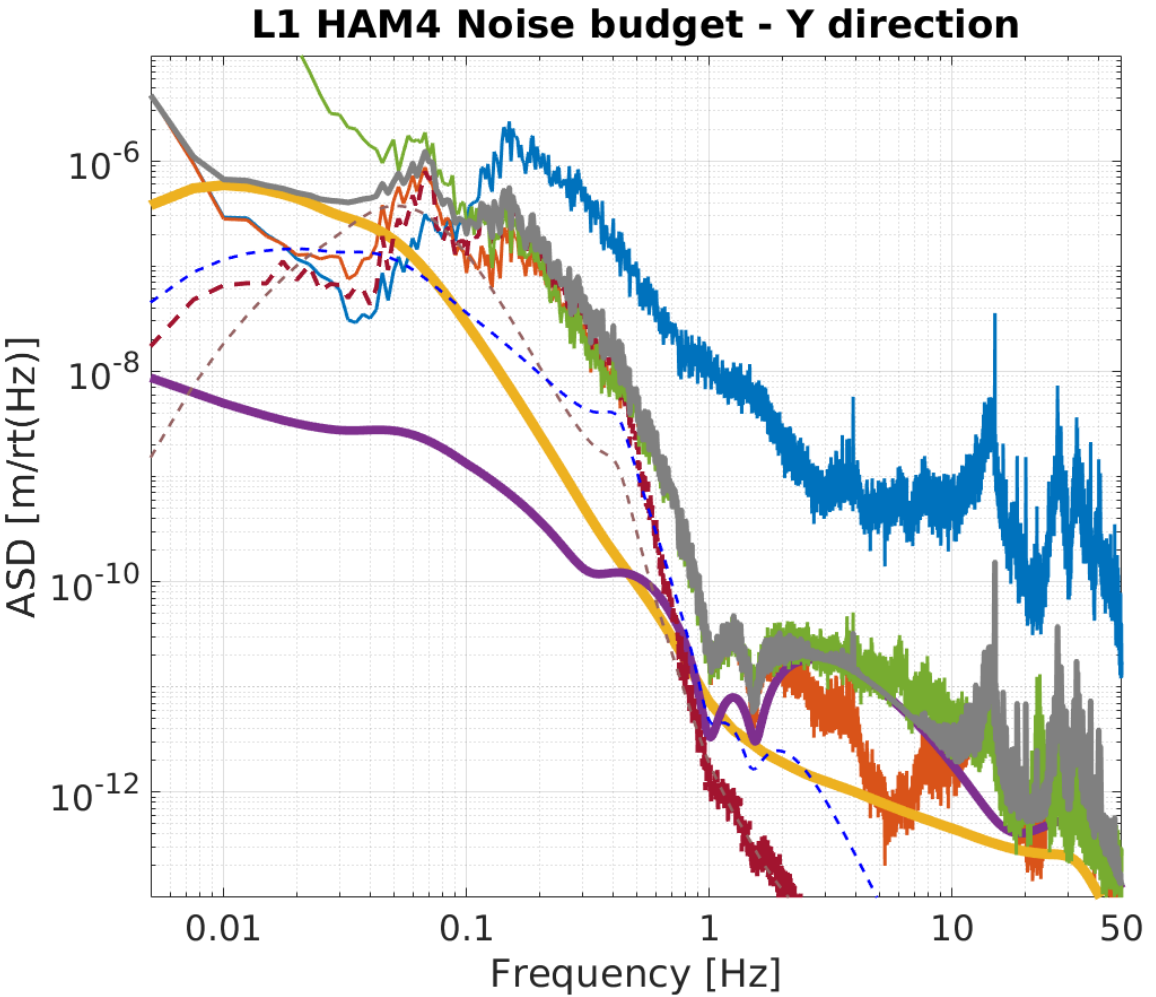


What can we do?

At the stage level:

- Better sensors





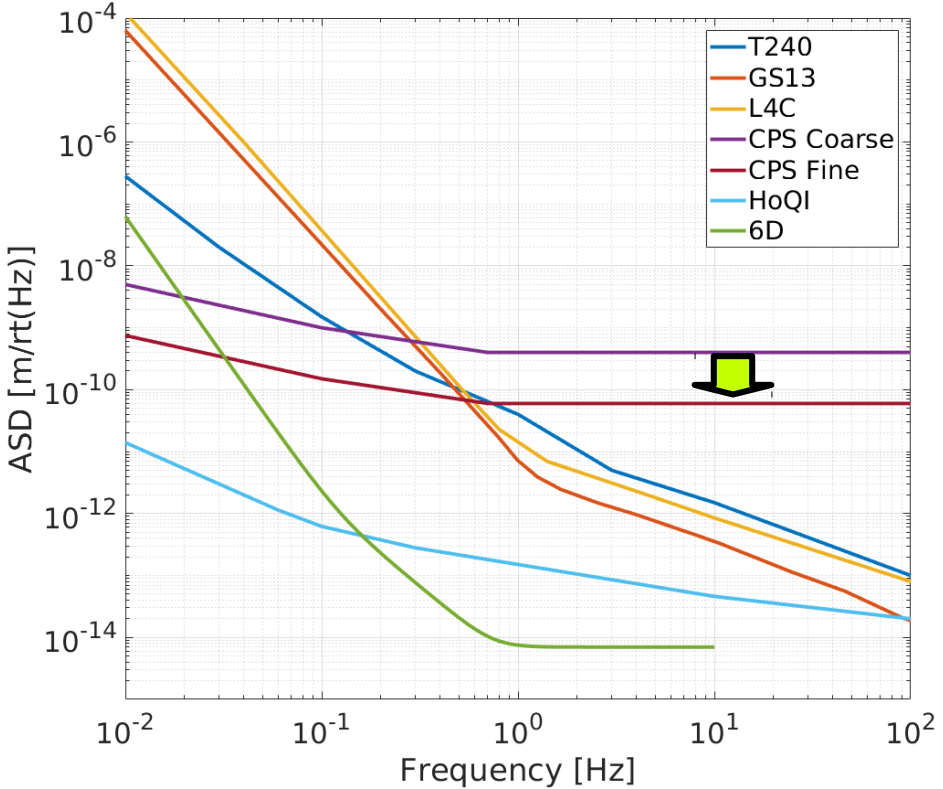
HoQI: Cooper, S. J., et al. Classical and Quantum Gravity 35.9 (2018): 095007.

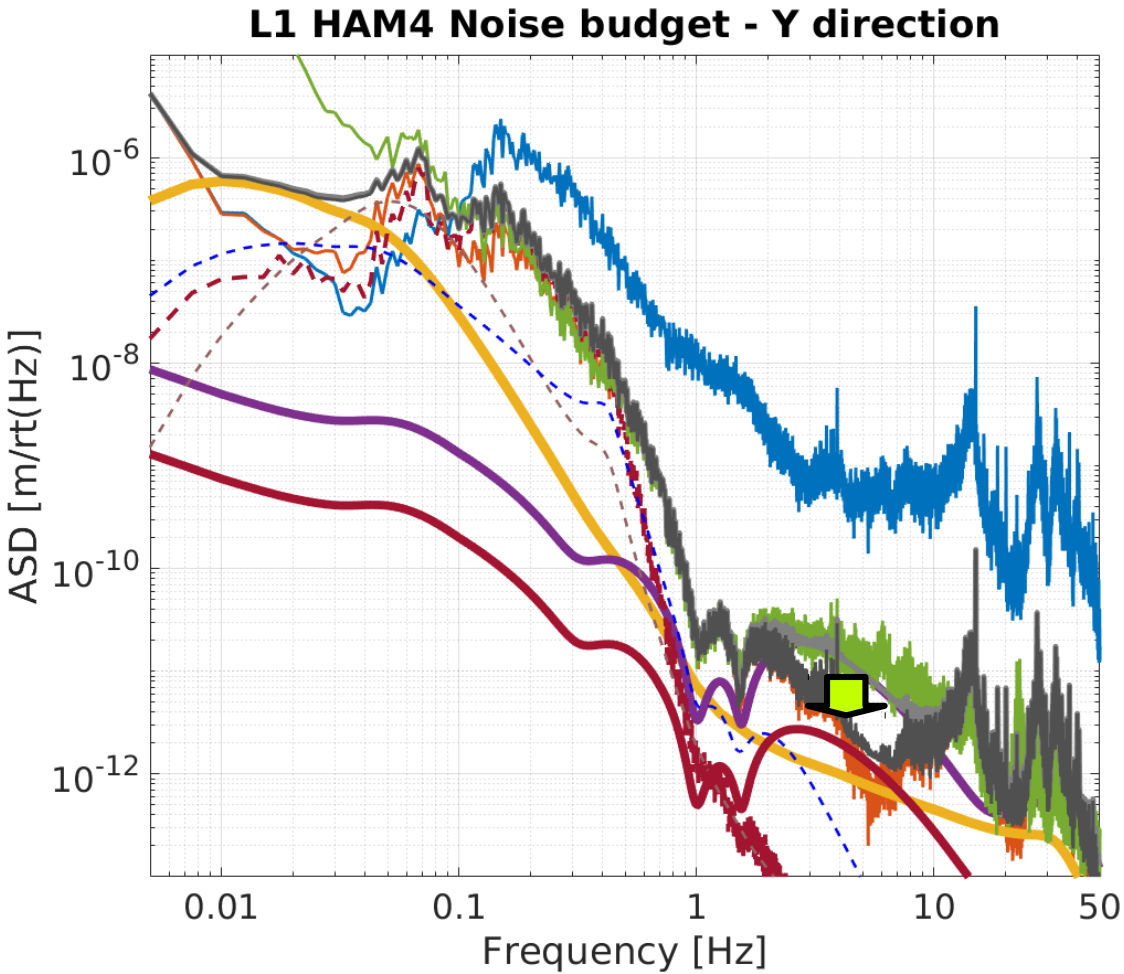
6D seismometer: Mow-Lowry, Conor M., and Denis Martynov. arXiv preprint arXiv:1801.01468 (2018).

What can we do?

At the stage level:

- Better sensors





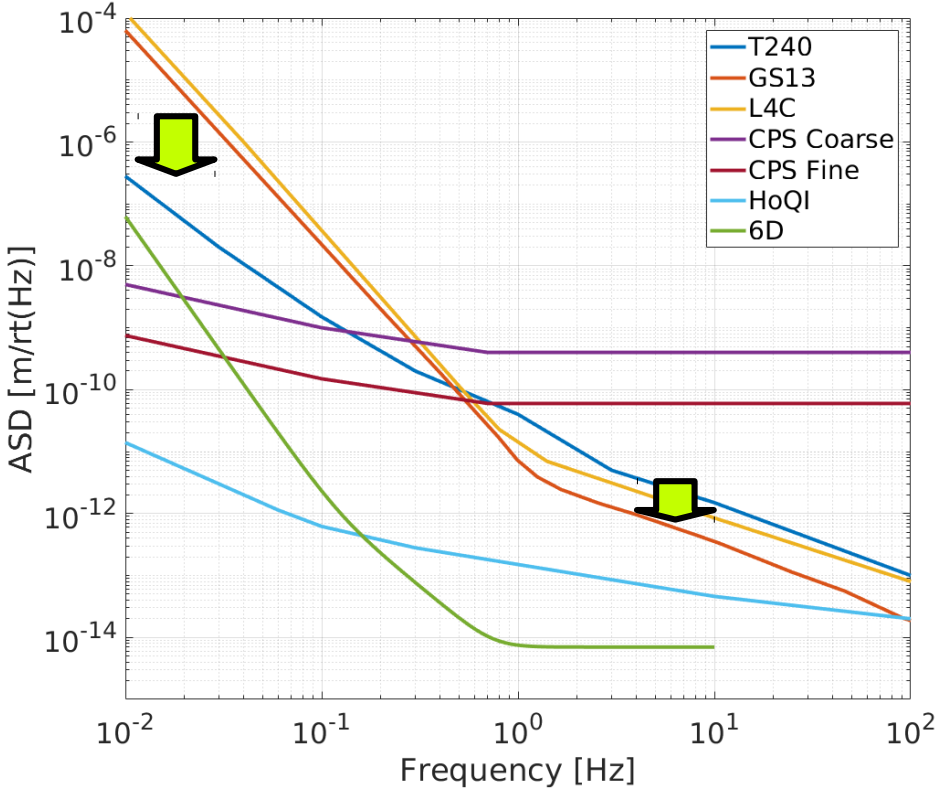
HoQI: Cooper, S. J., et al. Classical and Quantum Gravity 35.9 (2018): 095007.

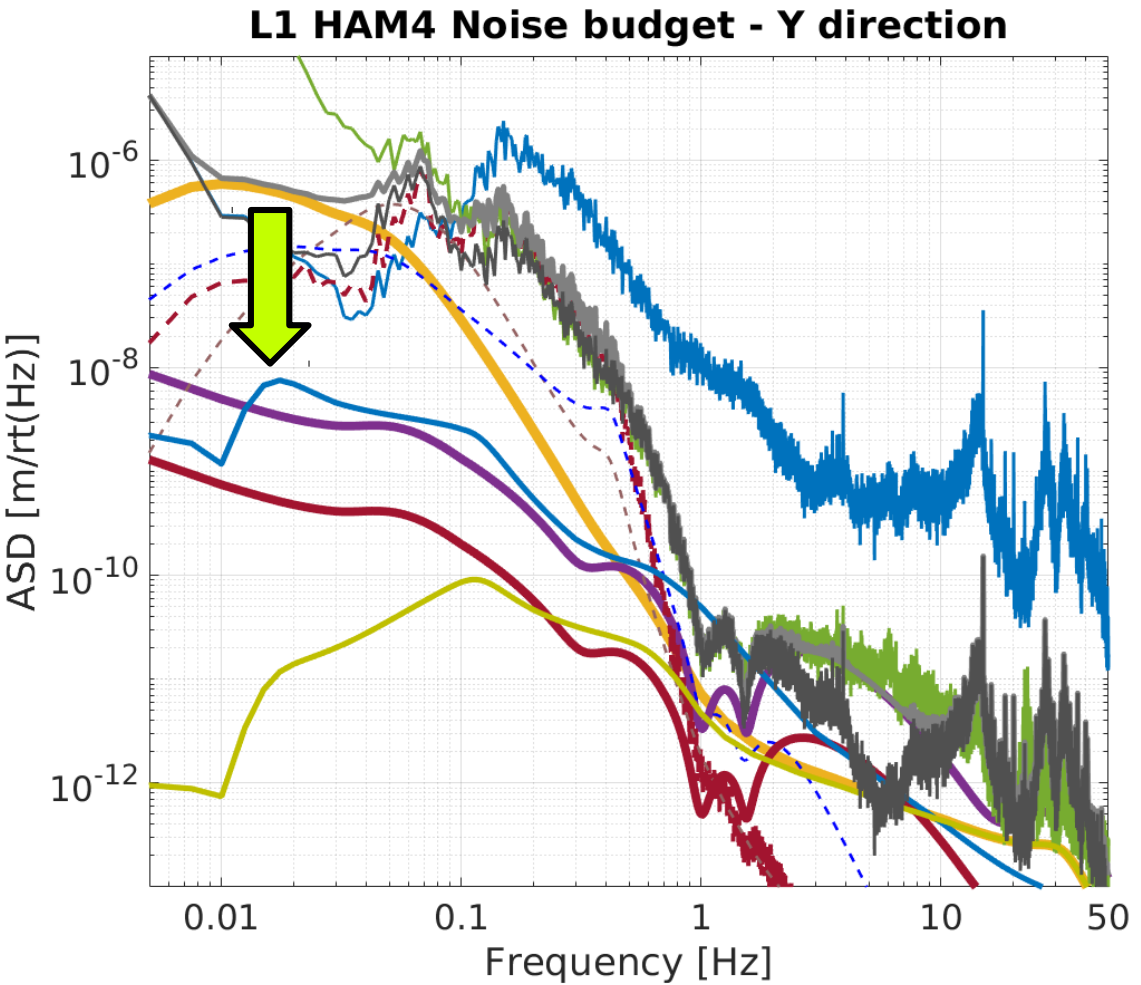
6D seismometer: Mow-Lowry, Conor M., and Denis Martynov. arXiv preprint arXiv:1801.01468 (2018).

What can we do?

At the stage level:

Better sensors





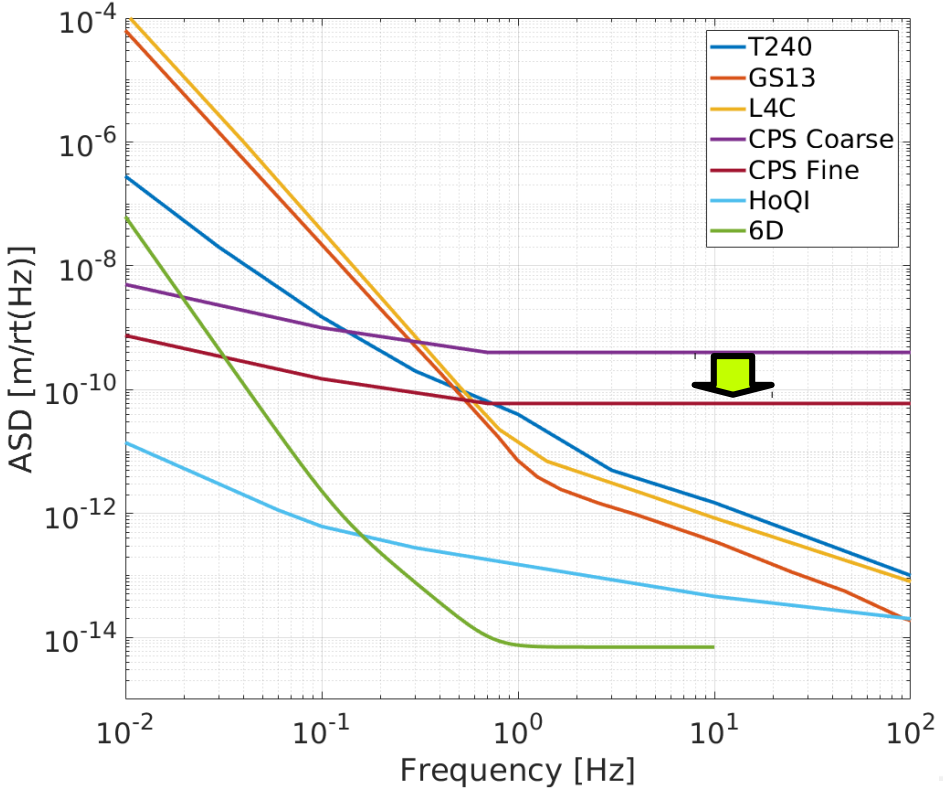
HoQI: Cooper, S. J., et al. Classical and Quantum Gravity 35.9 (2018): 095007.

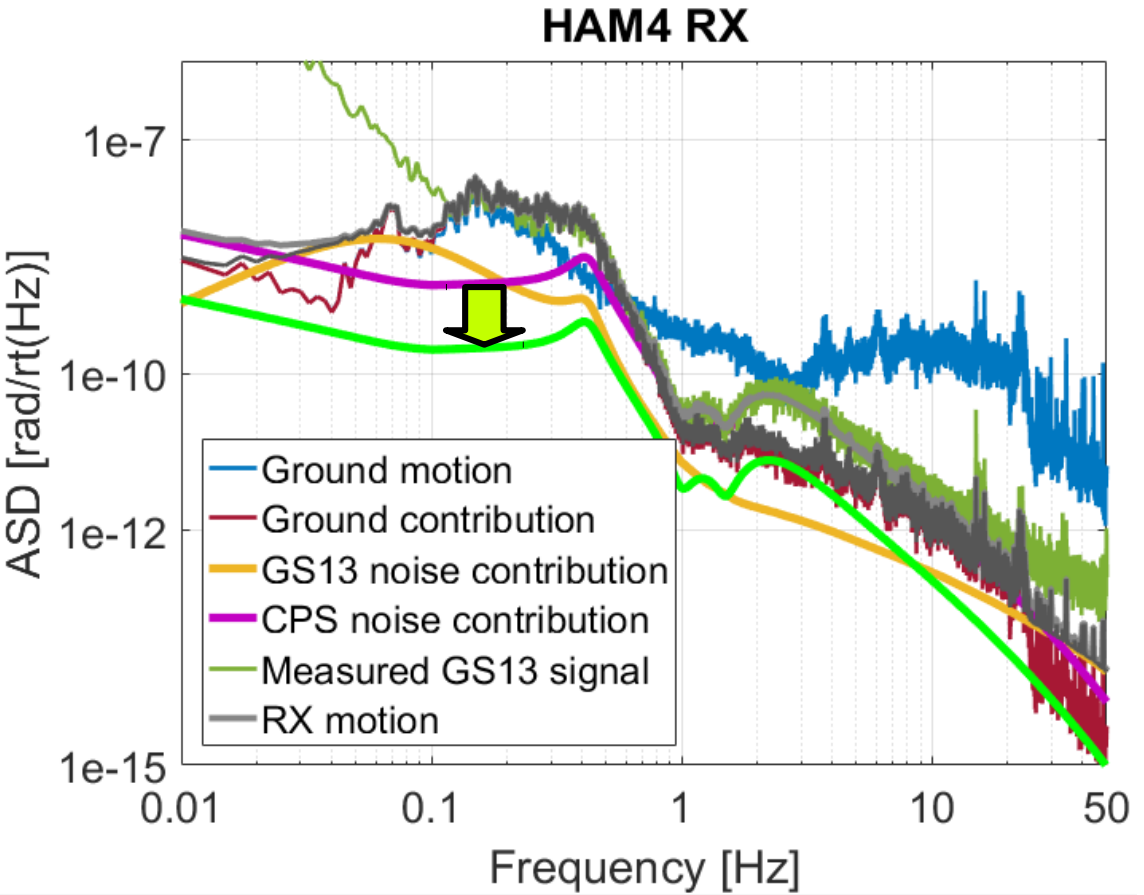
6D seismometer: Mow-Lowry, Conor M., and Denis Martynov. arXiv preprint arXiv:1801.01468 (2018).

What can we do?

At the stage level:

Same for RX





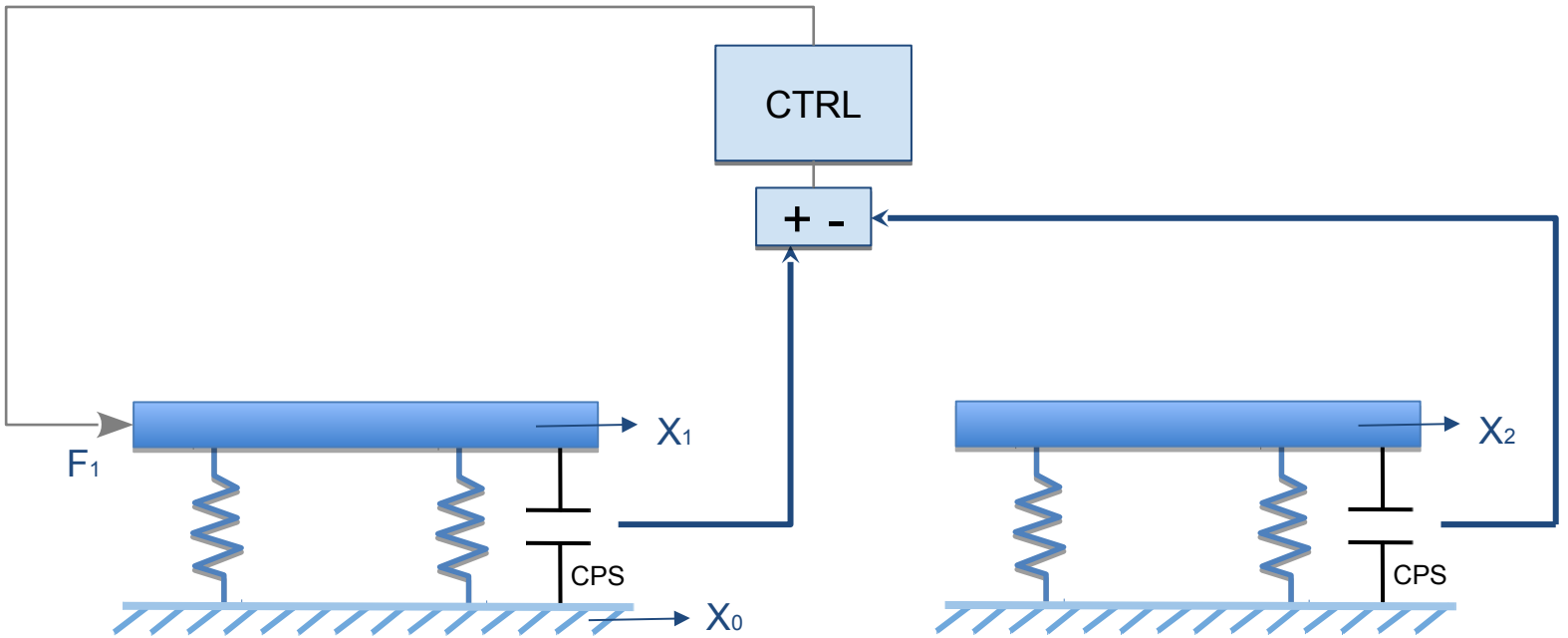
HoQI: Cooper, S. J., et al. Classical and Quantum Gravity 35.9 (2018): 095007.

6D seismometer: Mow-Lowry, Conor M., and Denis Martynov. arXiv preprint arXiv:1801.01468 (2018).

What can we do?

At a global level: Control on differential motion

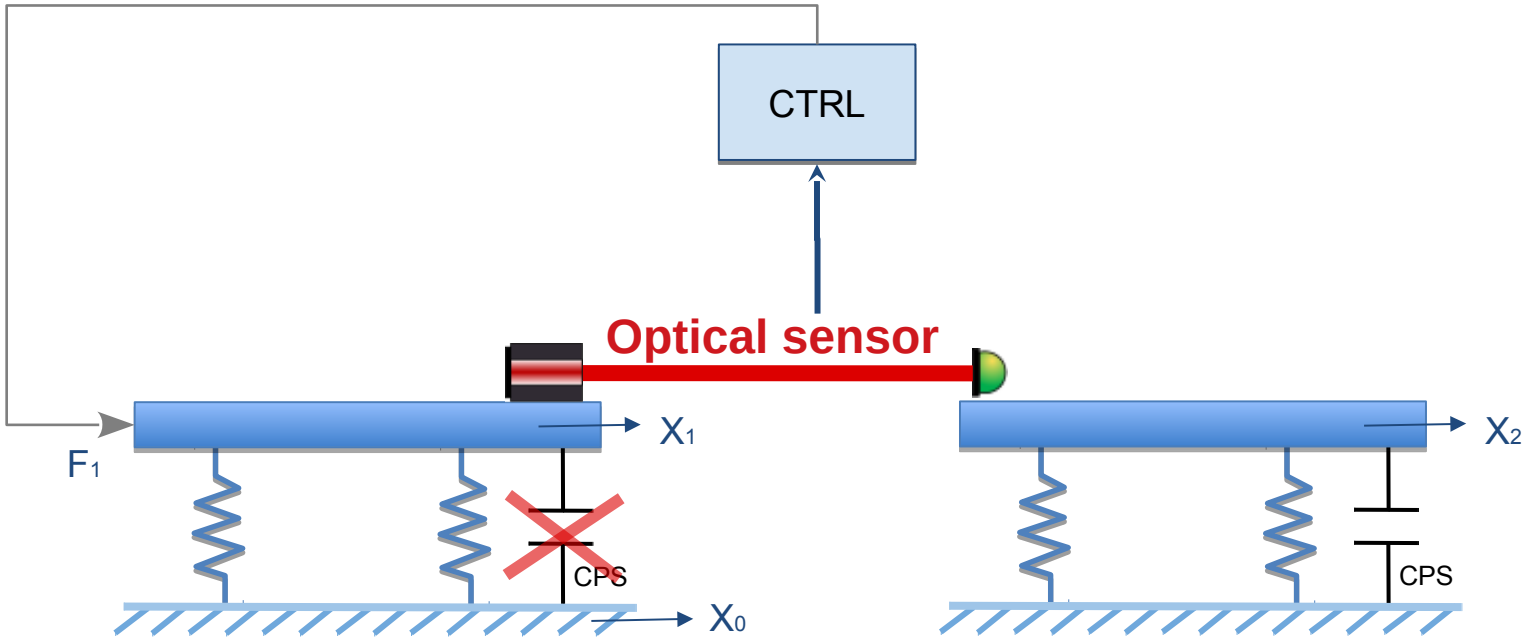
- Change coordinate system from local to global.
- Control on differential motion (better tuning?)
- DARM to CPS?
- Better match of the blend filters between HAM and BSC ISI platforms (alog SEI 1459)



What can we do?

At a global level: Control on differential motion

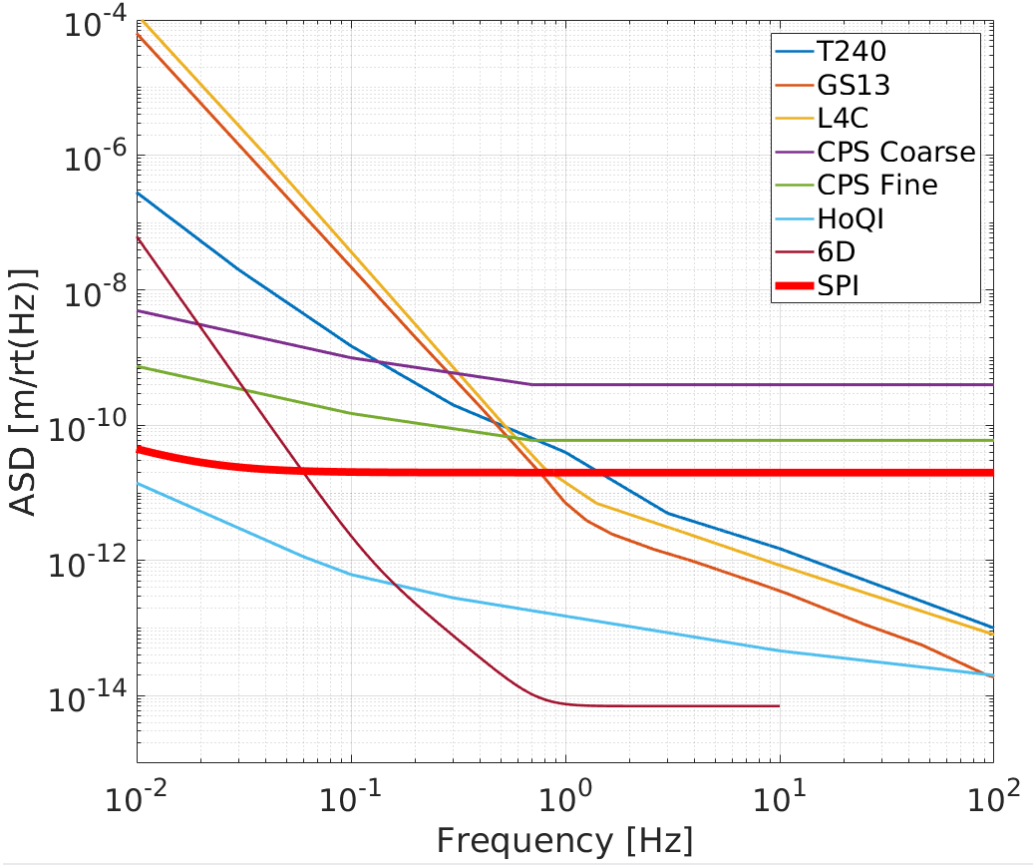
- In length: new IFO sensor to measure differential motion between platform
- Use platform on the right as a reference (nominal configuration)



What can we do?

At a global level:

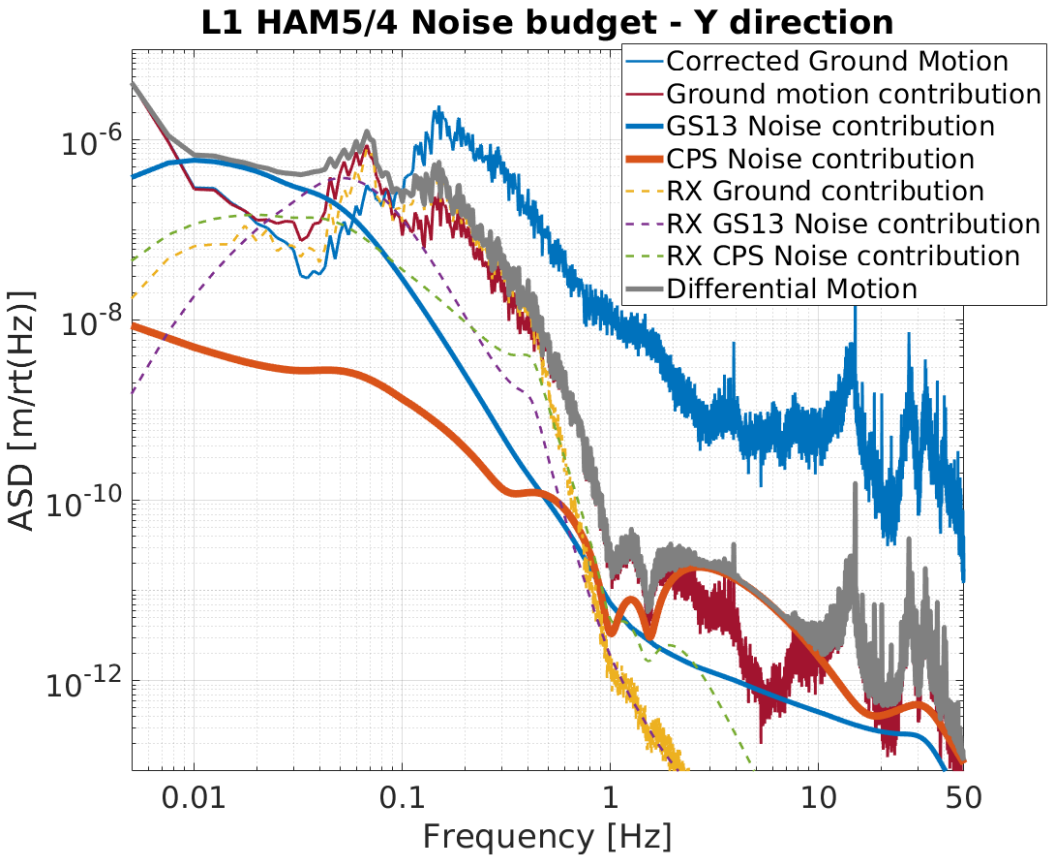
- Example: SPI, used at AEI (see Sina's thesis P1800282)

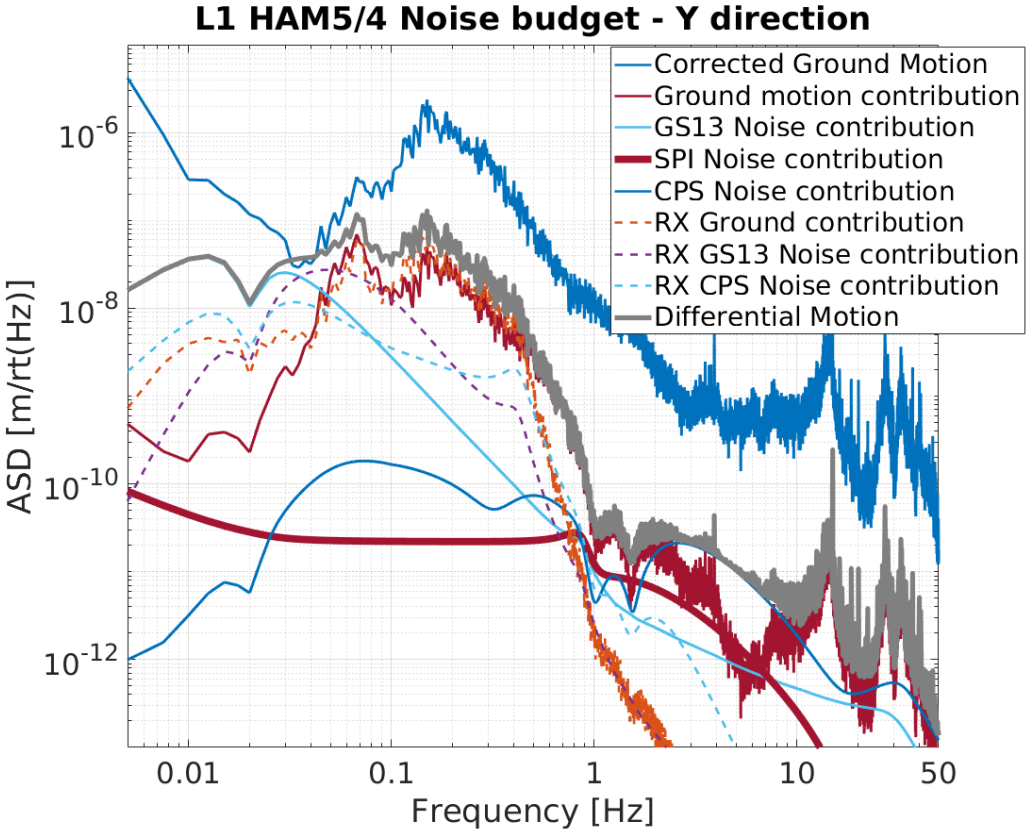


What can we do?

At a global level:

- Example: SPI, used at AEI (see Sina's thesis P1800282)
- Higher blend frequency

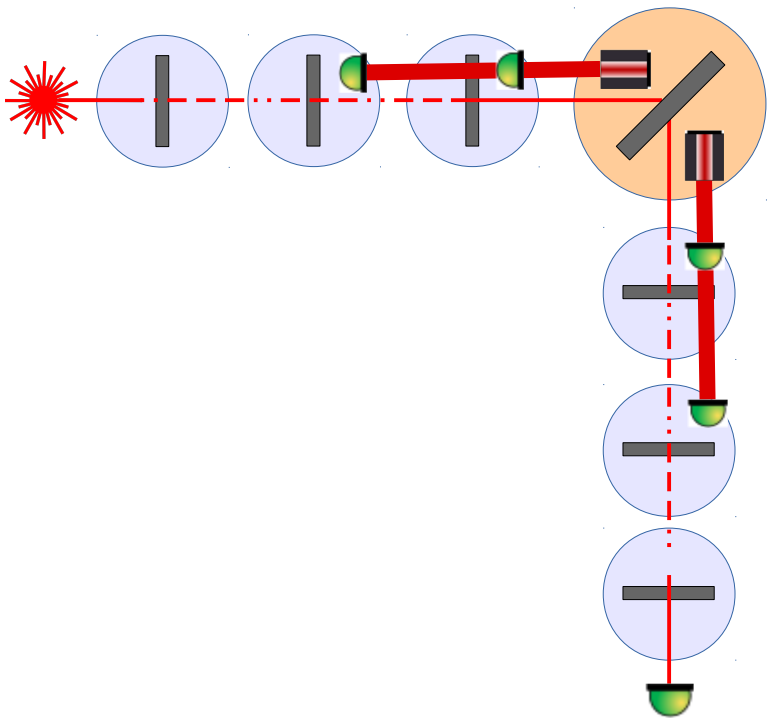


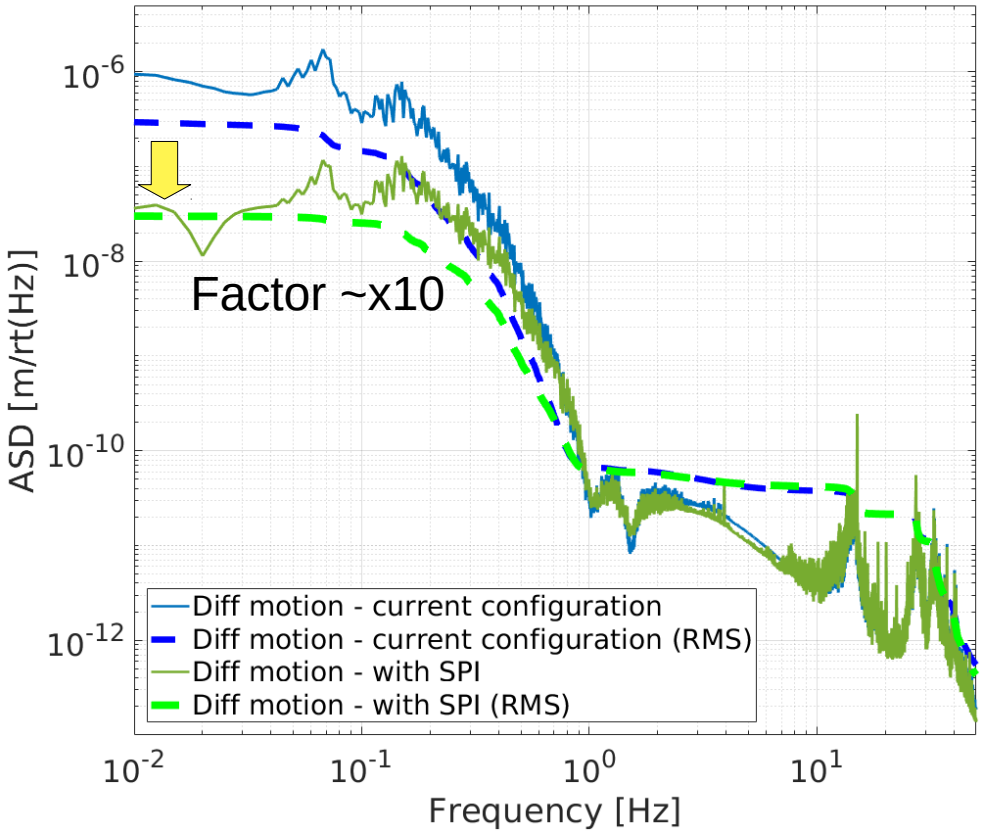


What can we do?

At a global level:

- Example: SPI, used at AEI (see Sina's thesis P1800282)
- Higher blend
- Long term: locking everything to the BS

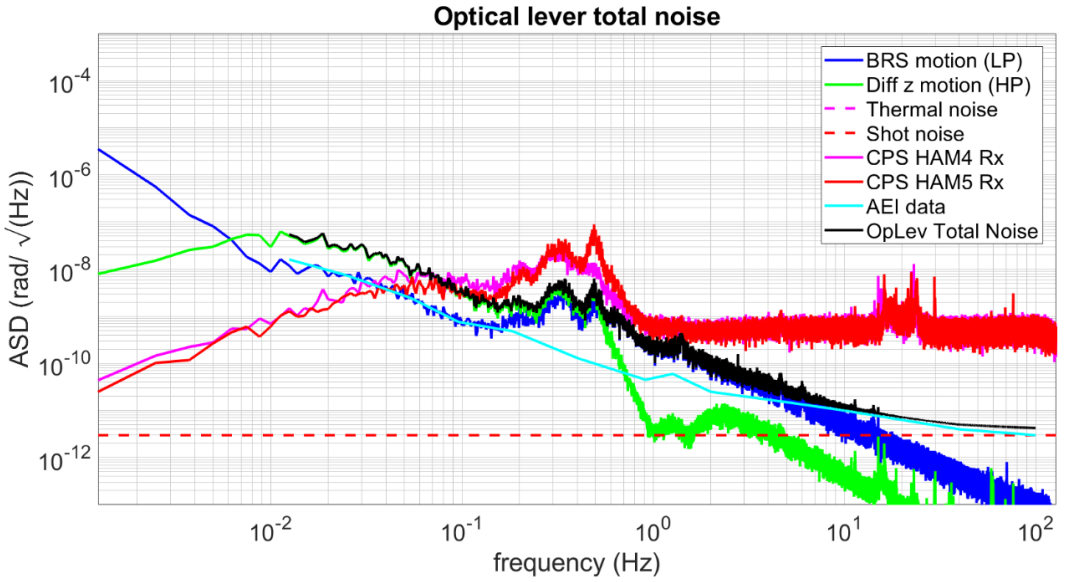




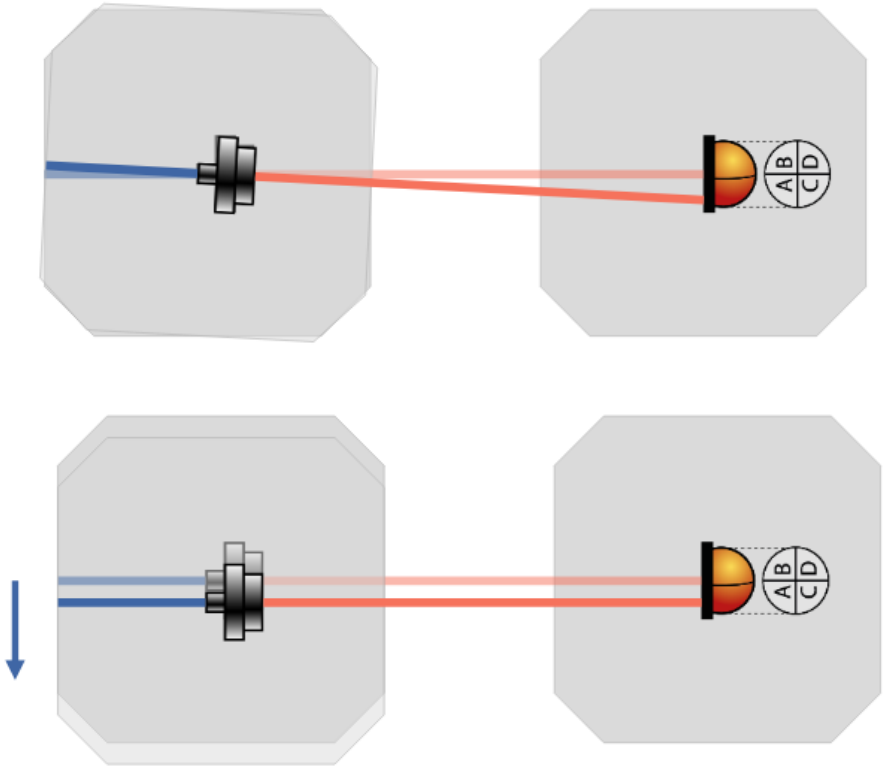
What can we do?

Also:

- In angle: optical levers between stages to improve RX below 1Hz
- “Quasi-inertial” sensor



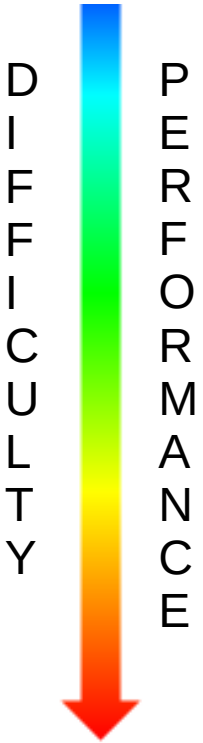
From T1900105



Courtesy of S. Koehlenbeck, G1900916

Conclusion

Lot of things we can do:



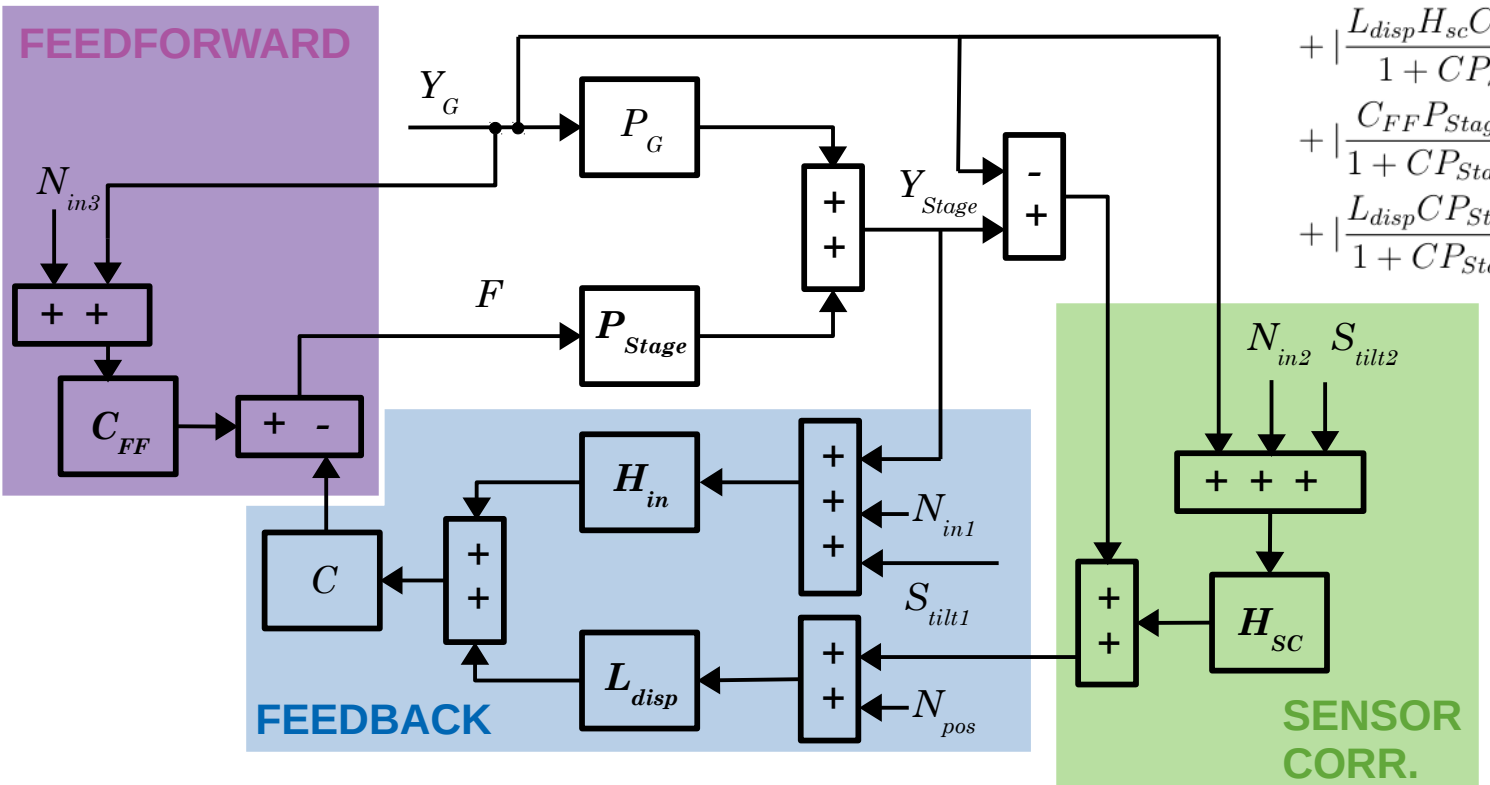
- At the stage level:
  - Control/blend tuning
  - New / better sensors
- At the “global” level:
  - Control on differential motion
  - Differential control in the corner station with IFO sensors
  - Differential control along the arms with IFO sensors

THANK YOU!

EXTRA SLIDES

Current configuration: one platform

$$|Y_{Stage}|^2 = |\frac{P_G + L_{disp}CP_{Stage}(1 - H_{SC}) + C_{FF}P_{Stage}}{1 + CP_{Stage}}Y_G|^2$$
$$+ |\frac{H_{in}CP_{Stage}}{1 + CP_{Stage}}N_{in1}|^2 + |\frac{H_{in}CP_{Stage}}{1 + CP_{Stage}}S_{tilt1}|^2$$
$$+ |\frac{L_{disp}H_{sc}CP_{Stage}}{1 + CP_{Stage}}N_{in2}|^2 + |\frac{L_{disp}H_{sc}CP_{Stage}}{1 + CP_{Stage}}S_{tilt2}|^2$$
$$+ |\frac{C_{FF}P_{Stage}}{1 + CP_{Stage}}N_{in3}|^2$$
$$+ |\frac{L_{disp}CP_{Stage}}{1 + CP_{Stage}}N_{pos}|^2.$$



HAM-ISI control Scheme

Seismic isolation requirements

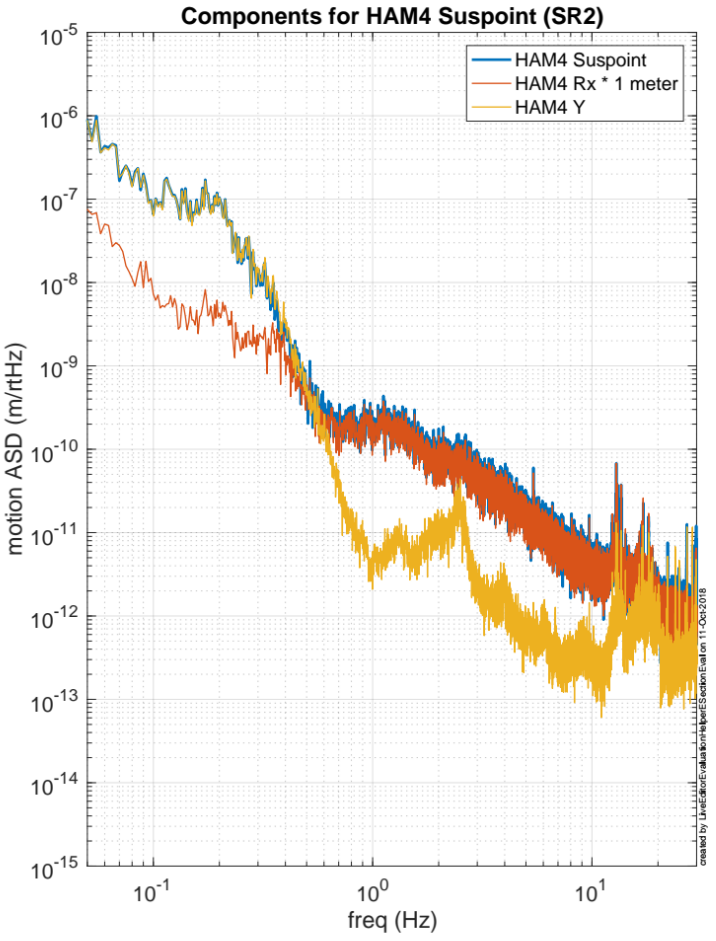
<u>Above 1Hz</u>, seems good enough (below requirements), BUT:

- SRCL is limited by shot noise at above ~10 Hz (SRCL ugf ~ 40 Hz).
- SRCL length is close to being a limiting coupling for DARM.

Study (SEI alog 1393) shows that:

- The SRCL BW is currently limited by suspoint motion in 0.7 - 4 Hz.
- The suspoint SRCL motion from 0.7-4 Hz is all from the motion of HAM4 and HAM5
- The suspoint motion from the HAMs in the 0.7 to 4 Hz band is dominated by RX motion.

Need to improve HAMs rotational motion between (1-10)Hz



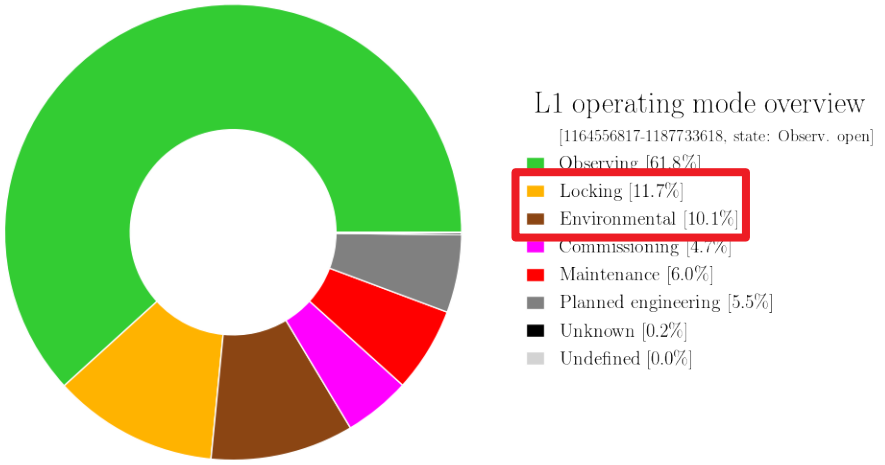
From SEI alog 1393

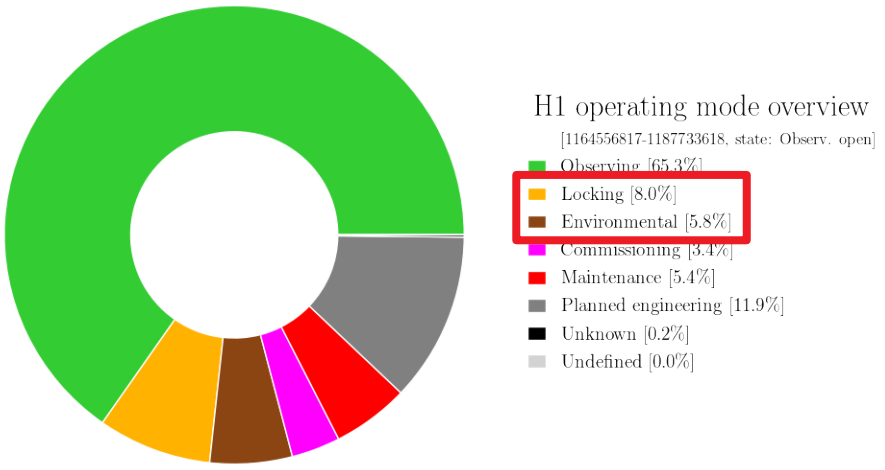
Seismic isolation requirements

Below 1Hz:

- Hard to lock with >2-3um rms microseism motion (100mHz-400mHz)
  >1um rms earthquake motion (30mHz-100mHz)
- Downtime from low-frequency input motion (wind/microseism/earthquakes): 5-10% at both sites + 8-12% locking during O2

From Detchar summary pages.

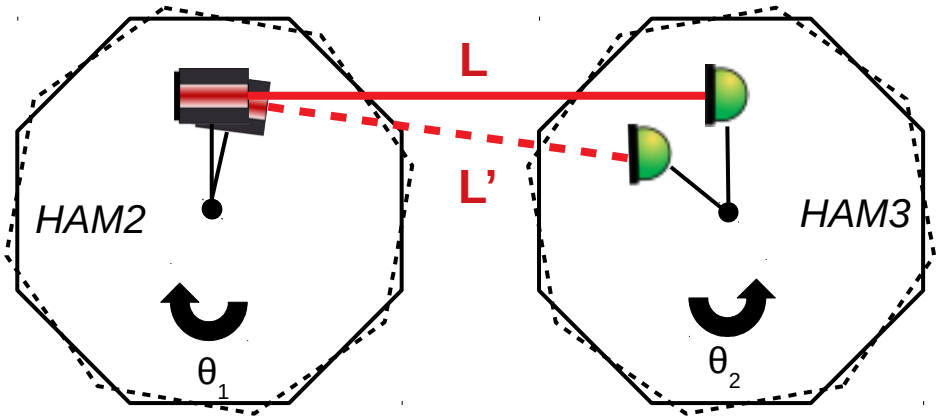




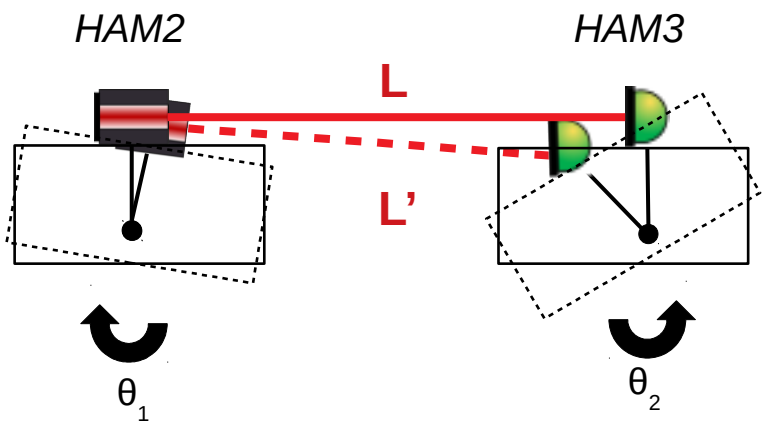
Need to improve low-frequency performance for better duty cycle

Extra couplings: 1st order

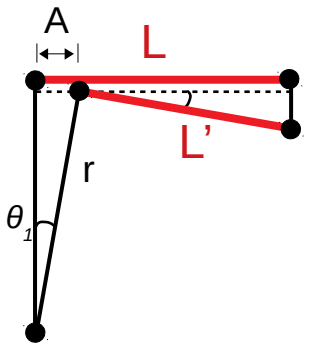
Yaw/RZ



Pitch/RY

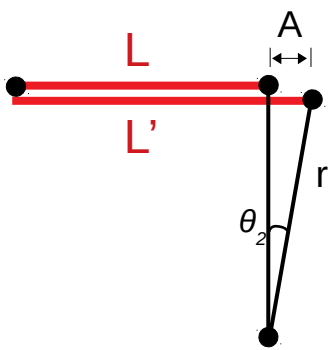


From HAM2



$$\Delta L = L - L' \approx \theta_1 r$$

From HAM3

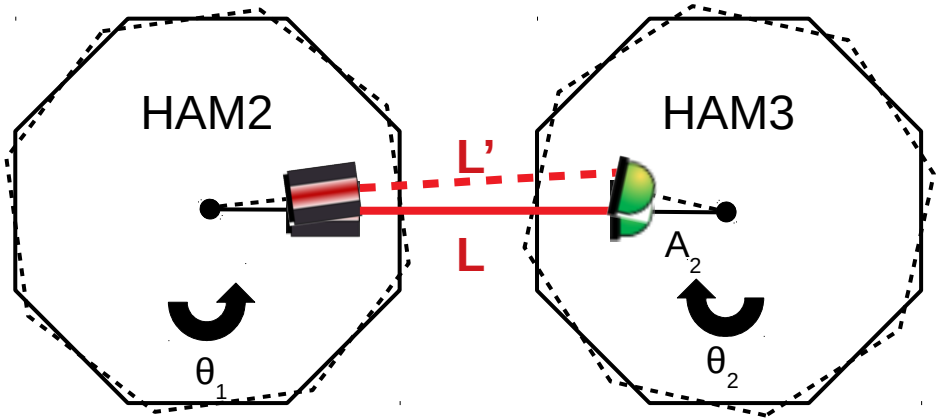


$$\Delta L = L' - L = A = \theta_2 r$$

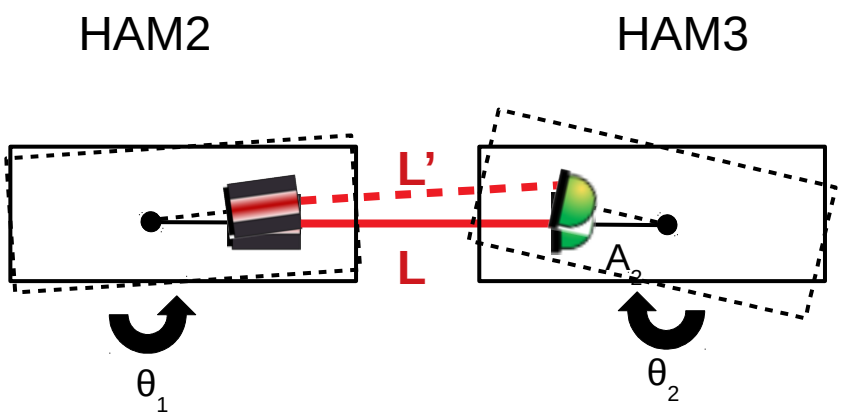
Extra couplings: 2nd order

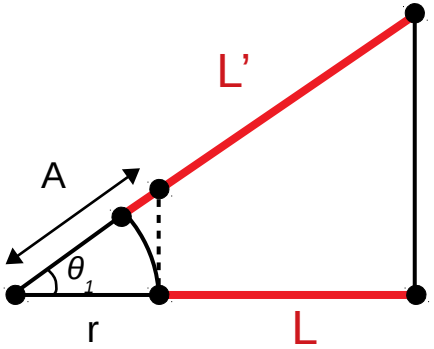
Negligible

Yaw/RZ



Pitch/RY

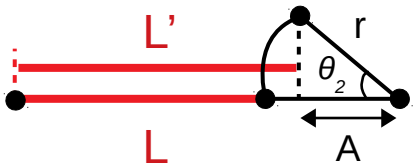




From HAM2

$$\Delta L = L' - L = \frac{\theta_1^{\,2}}{2}(r + L)$$

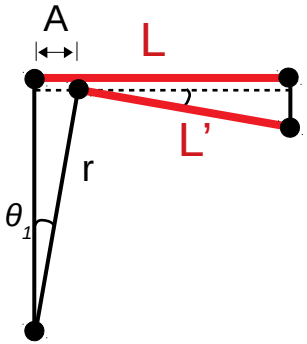
From HAM3



$$\Delta L = r - A = r - \left(1 - \frac{\theta_2}{2}\right) r = \frac{\theta_2^{\,2}}{2} r$$

Appendix: Extra couplings 1st order (math details)

1st case: HAM2

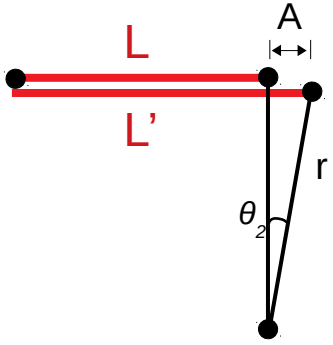


$$\sin\theta_1 \approx \theta_1 = \frac{A}{r}$$

$$\cos\theta_1 = 1 - \frac{{\theta_1}^2}{2} = \frac{L-A}{L'} = \frac{L - r\,\theta_1}{L'} \rightarrow L' = \frac{2\left(L - r\,\theta_1\right)}{2 - {\theta_1}^2}$$

$$\Delta L = L - L' = \frac{2\,\theta_1}{2 - {\theta_1}^2} r - \frac{{\theta_1}^2}{2 - {\theta_1}^2} L \approx \theta_1 r - \frac{{\theta_1}^2}{2} L \approx \theta_1 r$$

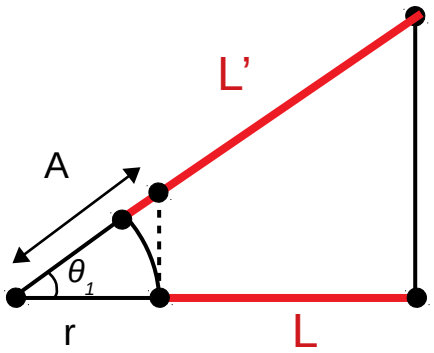
2nd case: HAM3



$$\Delta L = L' - L = A = \theta_2 r$$

Appendix: Extra couplings 2nd (math details)

1st case: HAM2



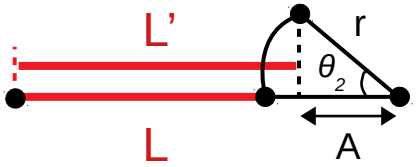
Taylor series approximation: $\cos(\theta_1) = 1 - \frac{\theta_1^2}{2} = \frac{r}{A}$

Thales: $\frac{r}{r+L} = \frac{A}{r+L'}$

$$L' = \frac{A}{r} L + A - r = \frac{2}{2-\theta_1^2} L + \frac{2}{2-\theta_1^2} r - r$$

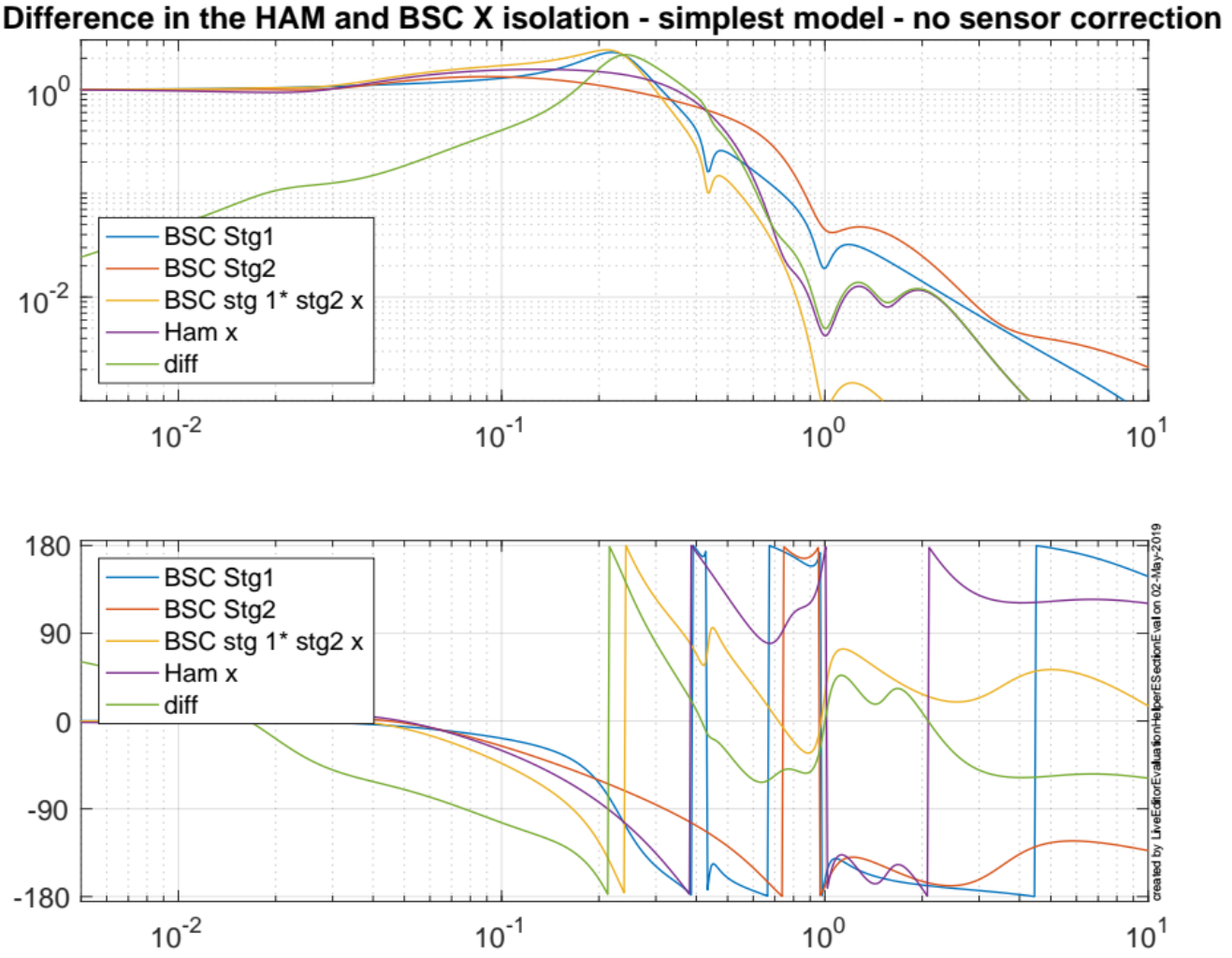
$$\Delta L = L' - L = \frac{\theta_1^2}{2-\theta_1^2}(L+r) \approx \frac{\theta_1^2}{2}(L+r) \qquad (since\ \theta_1^2 \ll 2)$$

2nd case: HAM3



Taylor series approximation: $\cos(\theta_2) = 1 - \frac{\theta_2^2}{2} = \frac{A}{r}$

$$\Delta L = r - A = r - \left(1 - \frac{\theta_2}{2}\right) r = \frac{\theta_2^2}{2} r$$


Difference in the HAM and BSC X isolation - simplest model - no sensor correction
BSC Stg1
BSC Stg2
BSC stg 1* stg2 x
Ham x
diff
created by LiveEditorEvaluationHelperESectionEval on 02-May-2019