Suspensions, Cryogenics (and controls) Panel Discussion

Members:
Brian Lantz - chair (Stanford), Giles Hammond - co-chair (Glasgow),
Jenne Driggers (LIGO Hanford), Stefan Hild (Maastrick), Kevin Kuns (MIT),
Denis Martynov (Birmingham), Chris Wipf (Caltech),

Kevin - Current system thinking for CE Suspensions

~ 5 minutes each to present

- Challenges for CE
- How to meet those challenges/ interesting ongoing work
- Impact on current facilities

~ 5 minutes of discussion

Giles - Large suspensions and optics
Brian - Control noise/ SPI
Den - Control noise/ 6-D isolator. Room temperature 1550 nm design
Chris - Cryogenics for Voyager, Mariner Prototype
Stefan - Cryogenics & the ET prototype at Maastricht

Isolation & Control

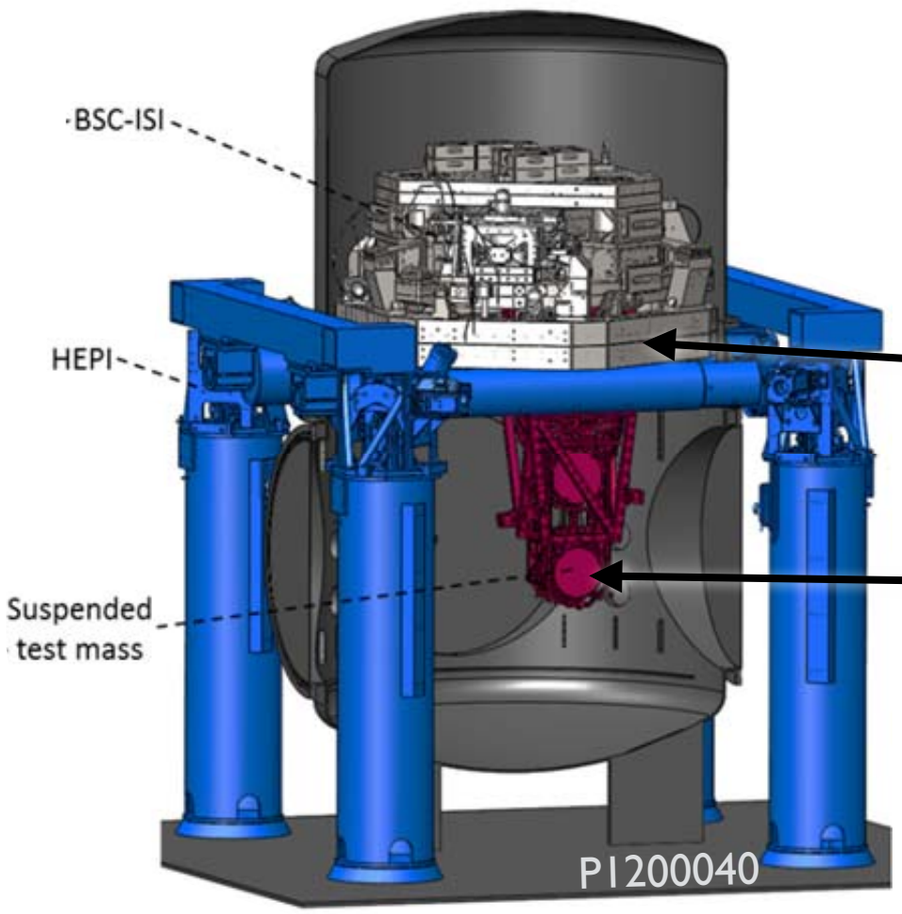
Seismic Platform Interferometers (SPI) as part of better system integration of Seismic and Suspensions

1) Improve detector stability
   (large ground motion results in glitches and lock-loss)
2) Lower DARM noise (see G2001539)

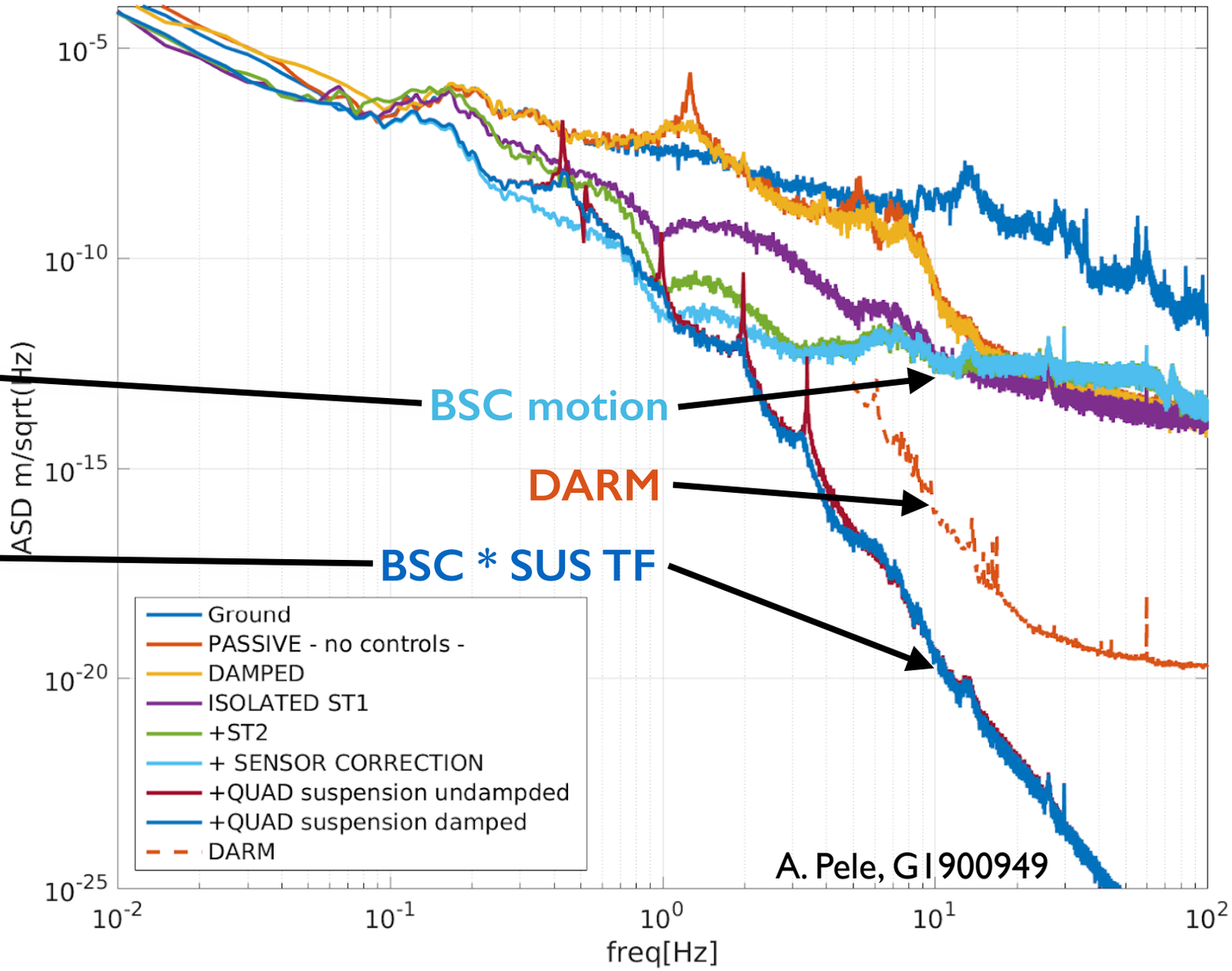
Driven by desire to improve current detectors, clear implications for 3G

aLIGO Isolation is good

- ISI + SUS provide excellent isolation at 10 Hz
- Ground motion does not directly limit DARM at 10 Hz*
- Seems like a good design approach for CE,
- But…



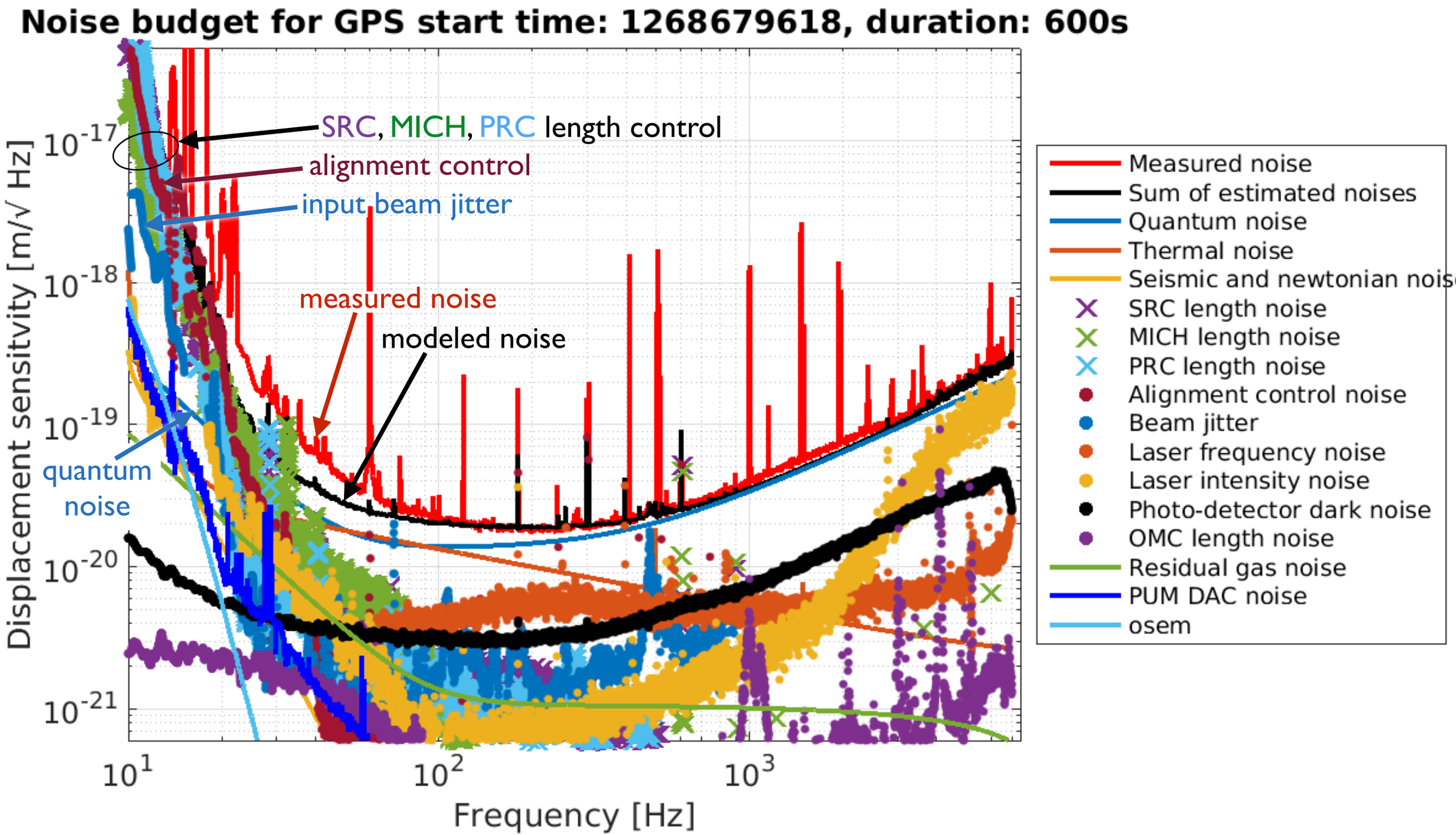
Longitudinal Motion of an LLO Test Mass at the start of O3



* via direct, linear coupling

Control noise dominates the ‘known’ noise below 50 Hz

LHO O3 noise budget, S. Dwyer LHO log 55755



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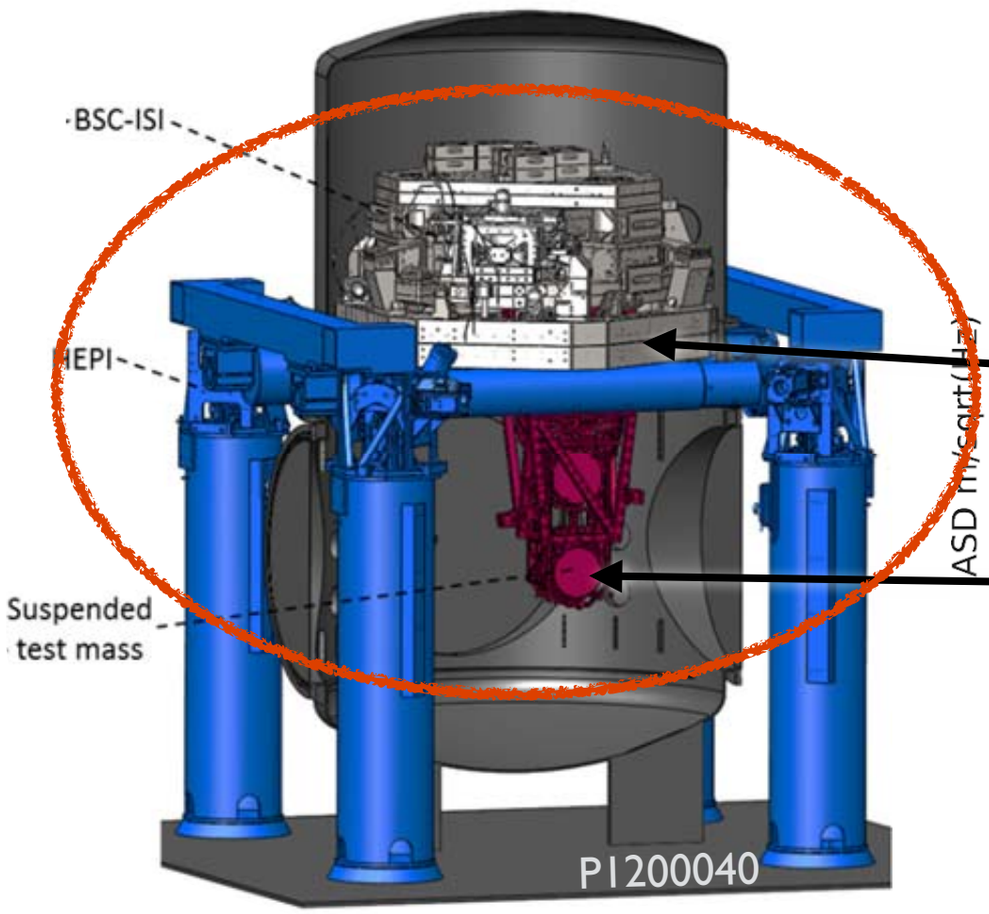
This is not the system



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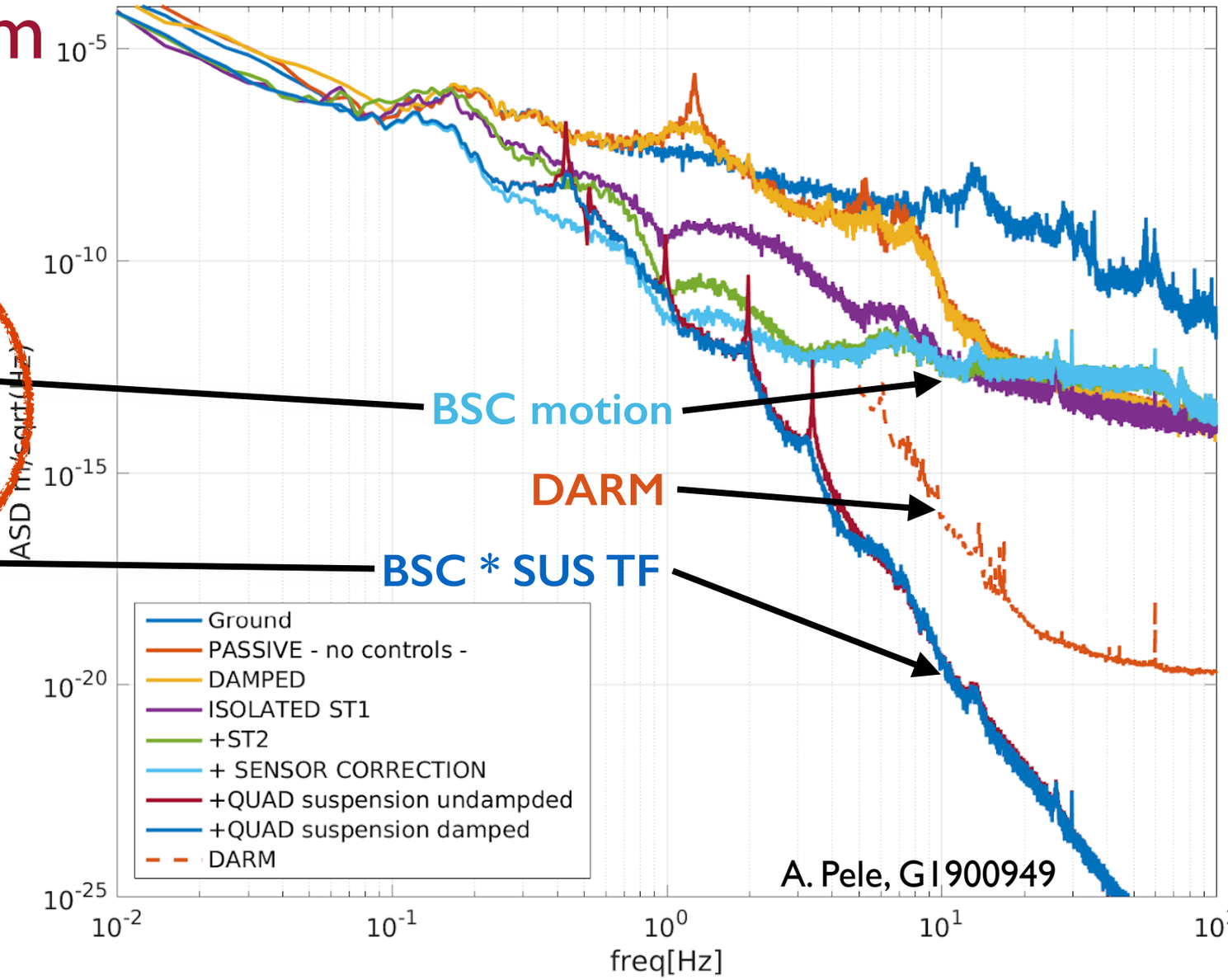

* via direct, linear coupling

This is (most of) a system

Purpose of the system is to minimize stray forces on, and relative motion between, all these optics.

Tables and suspensions provide isolation from ground motion.
Residual differential motion between optics is controlled by pushing on the optics (ISC)

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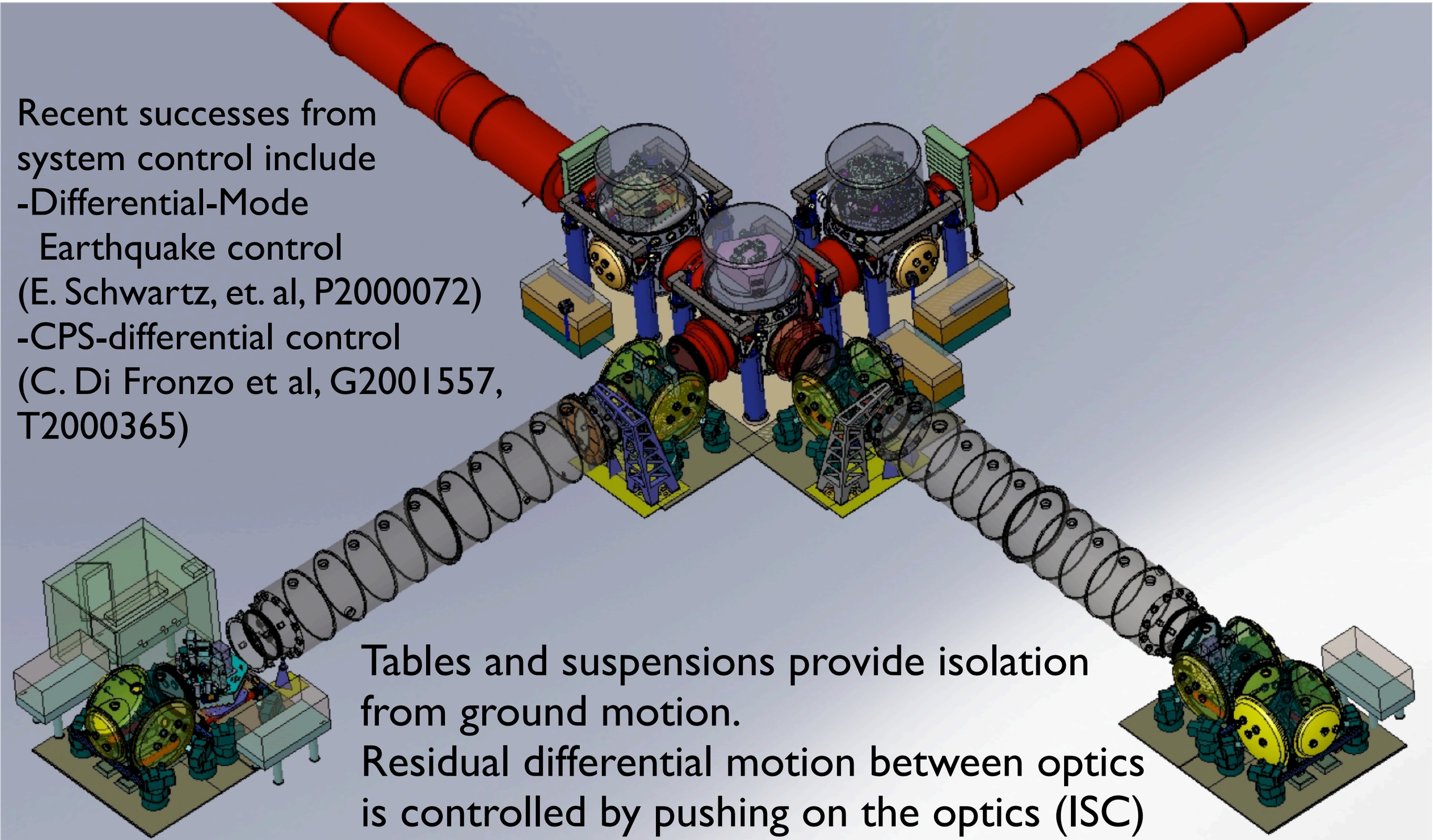
Recent successes from system control include
-Differential-Mode Earthquake control
(E. Schwartz, et. al, P2000072)
-CPS-differential control
(C. Di Fronzo et al, G2001557, T2000365)



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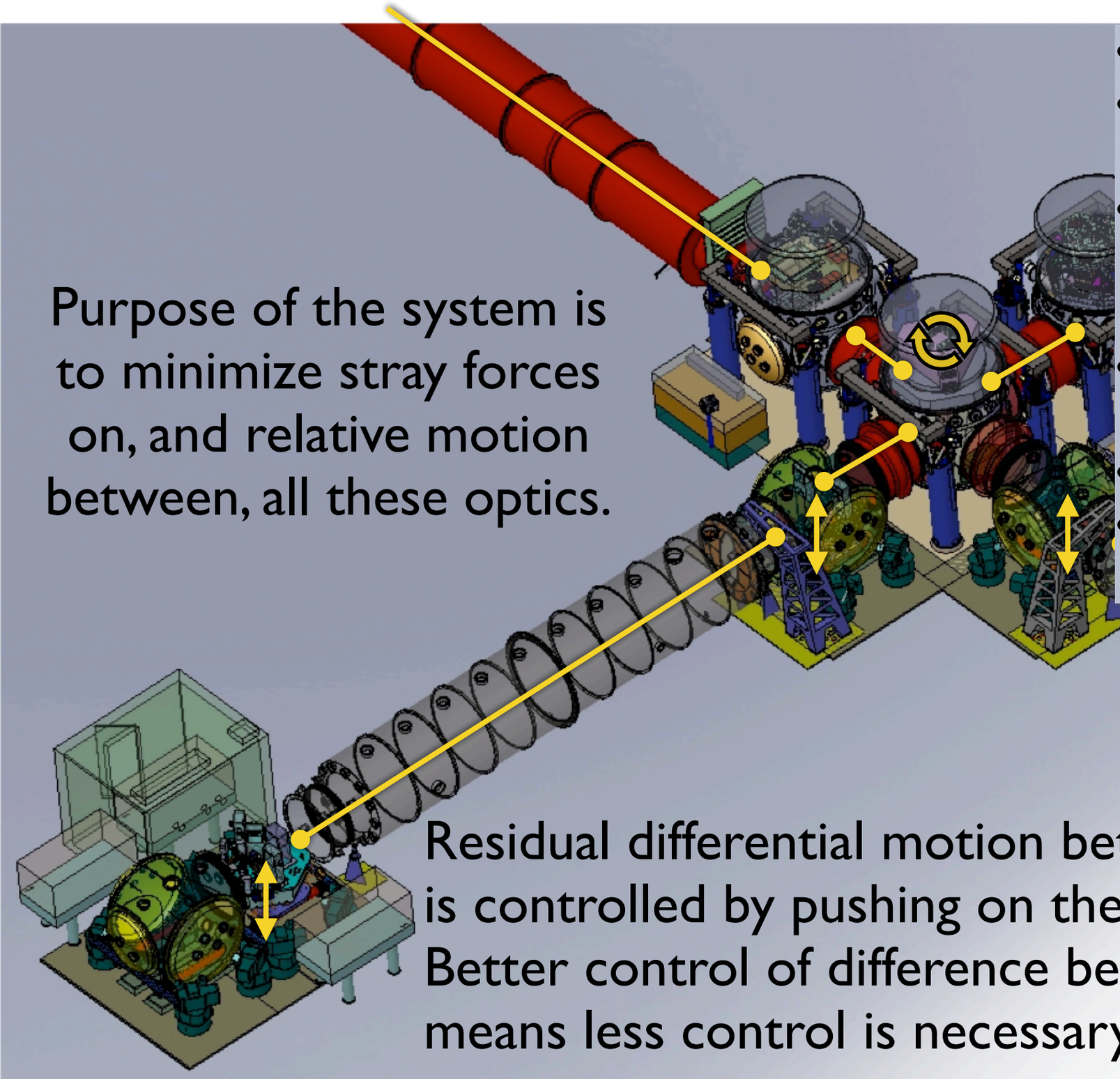


- cBRS at BS to lower tilt
- 1 new LF seismometer per HAM to reduce vertical motion
- SPIs between tables to reduce relative translation (integrated with opt. lev.)
- optical levers between tables for tilt.
- lower noise OSEMs
- (another talk - reduce BW of HARD loops)

Residual differential motion between optics is controlled by pushing on the optics (ISC) Better control of difference between tables means less control is necessary at the optic.

SPI

Seismic Platform Interferometer

Thesis work by Sina Köhlenbeck et. al at AEI
Heterodyne IFO and optical levers

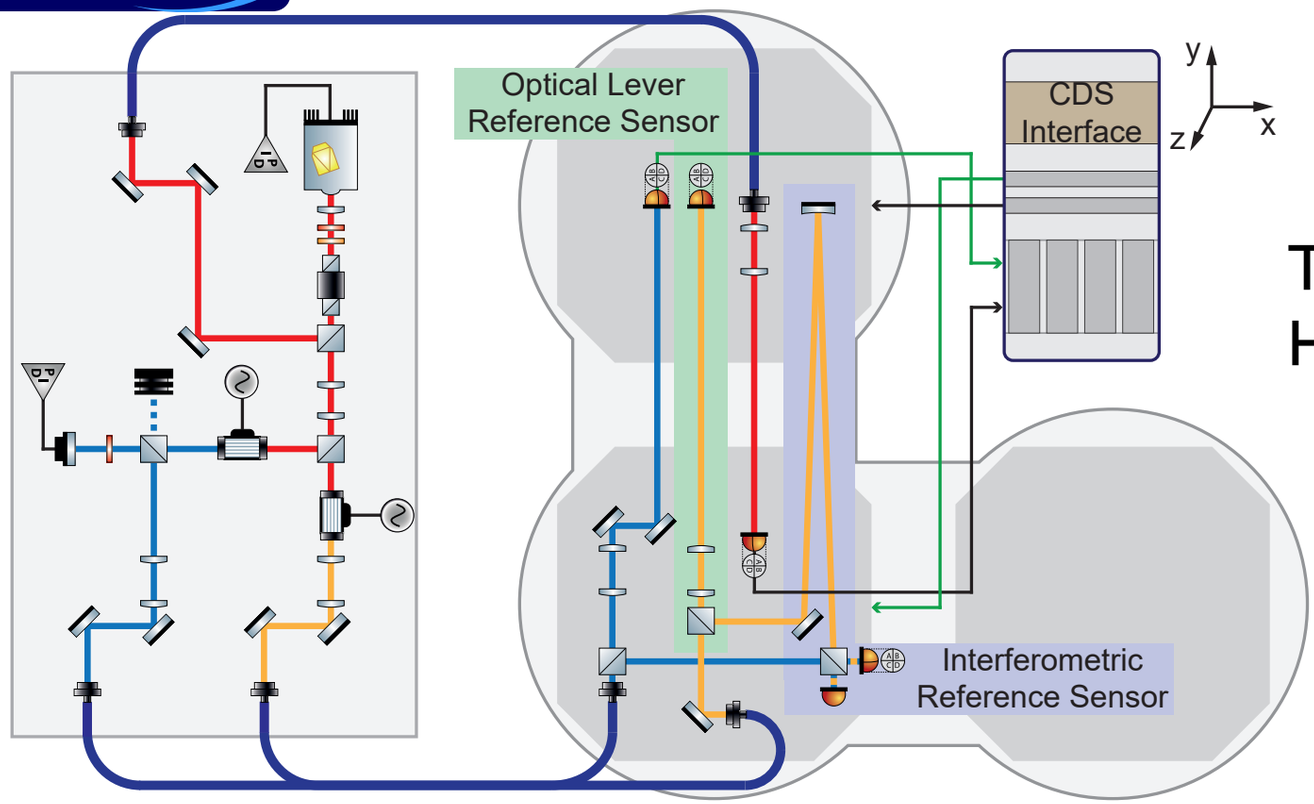
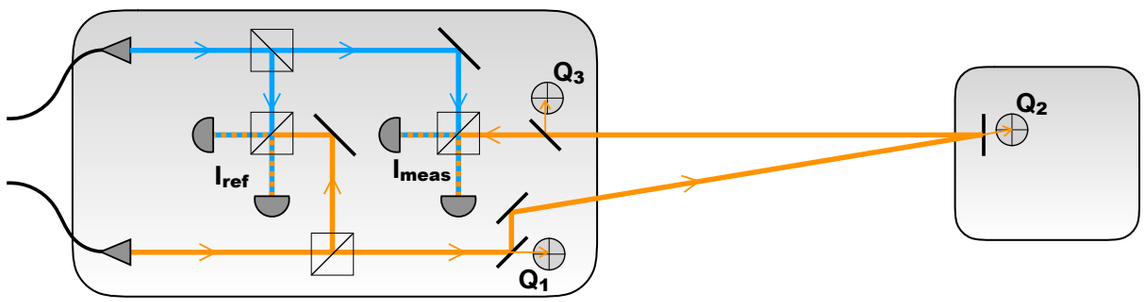


Figure 4.1: Schematic overview of the optical lever positions and the reference sensors. These



simplified schematic to measure
2 pitch, 2 yaw, and 1 length DOF

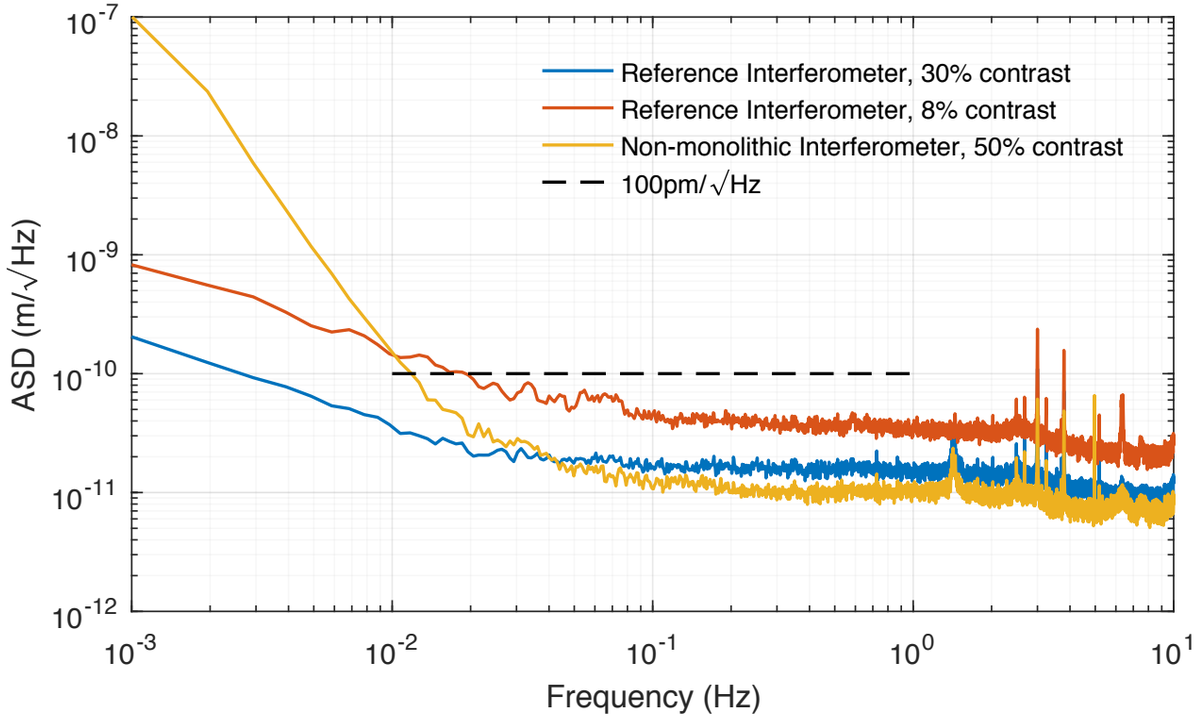


Figure 2.7: Displacement ASD of the two reference interferometers and the non-monolithic test

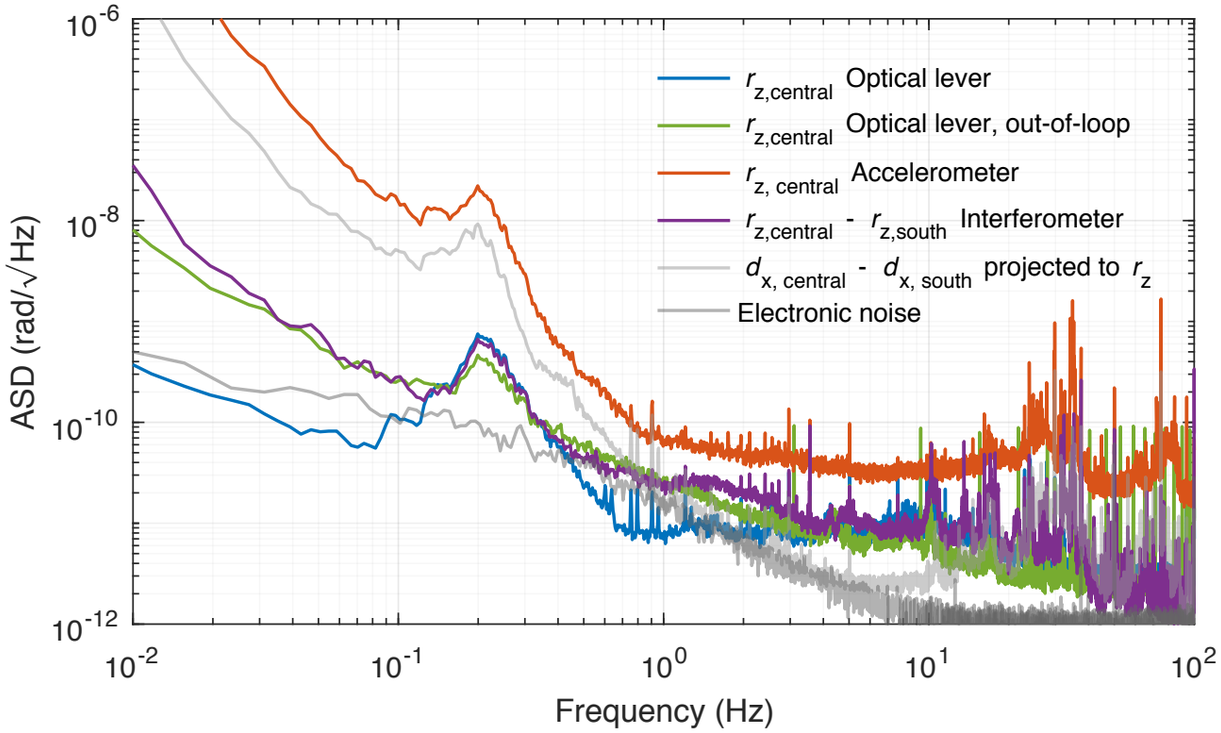


Figure 4.6: Angular displacement ASD of r_z of the central table. In blue, the measurement o

SPI/ system modeling

1) G2001539

SPI - HAM4-5 rms from ~ a micron?
to 600 nm with SPI angle sensors,
to 10 nm with SPI length sensing,
SRCL BW from 12 Hz now to 5 Hz.
limit is the 3 Hz mode SR2

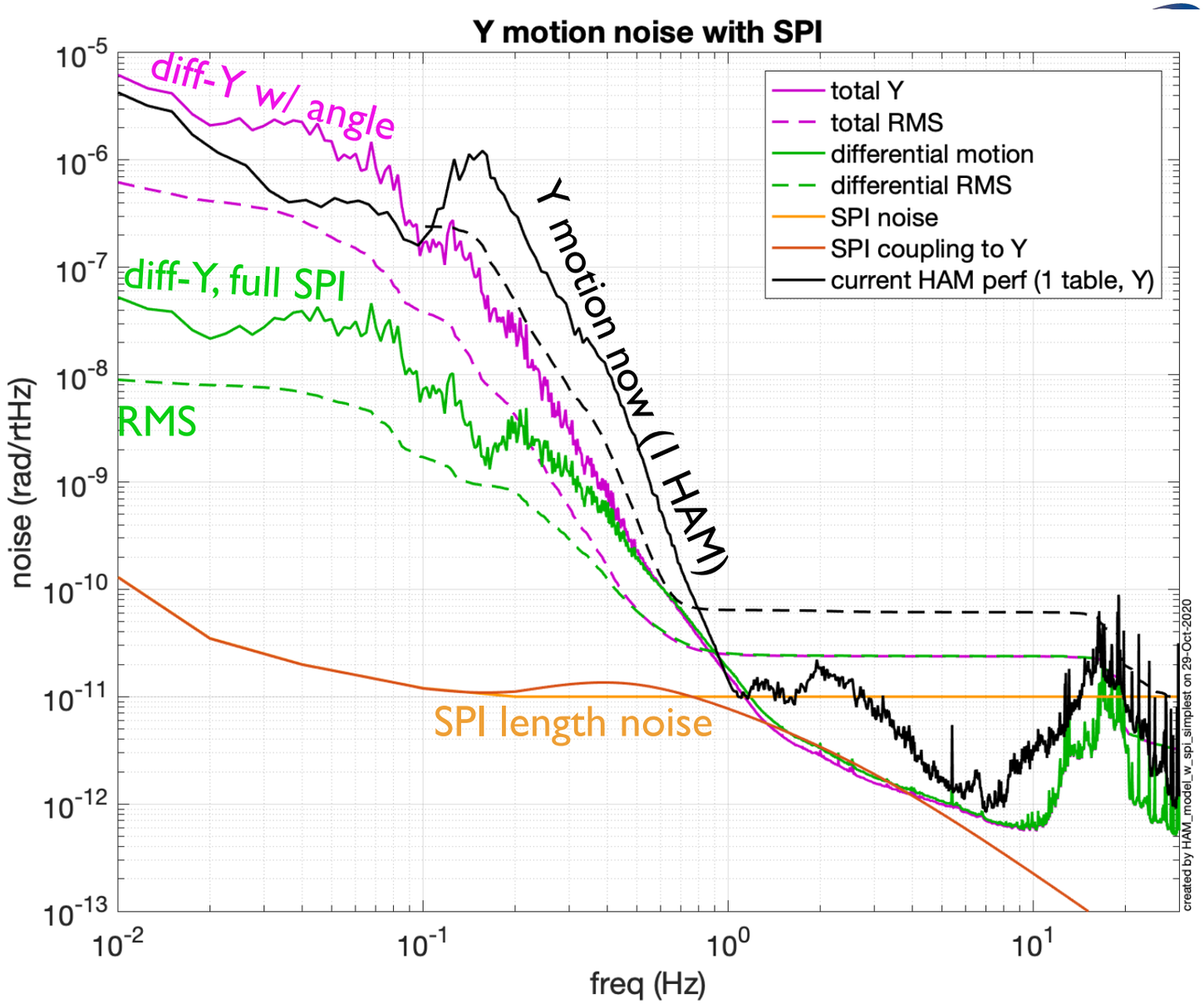
SPI model for HAM 4-5

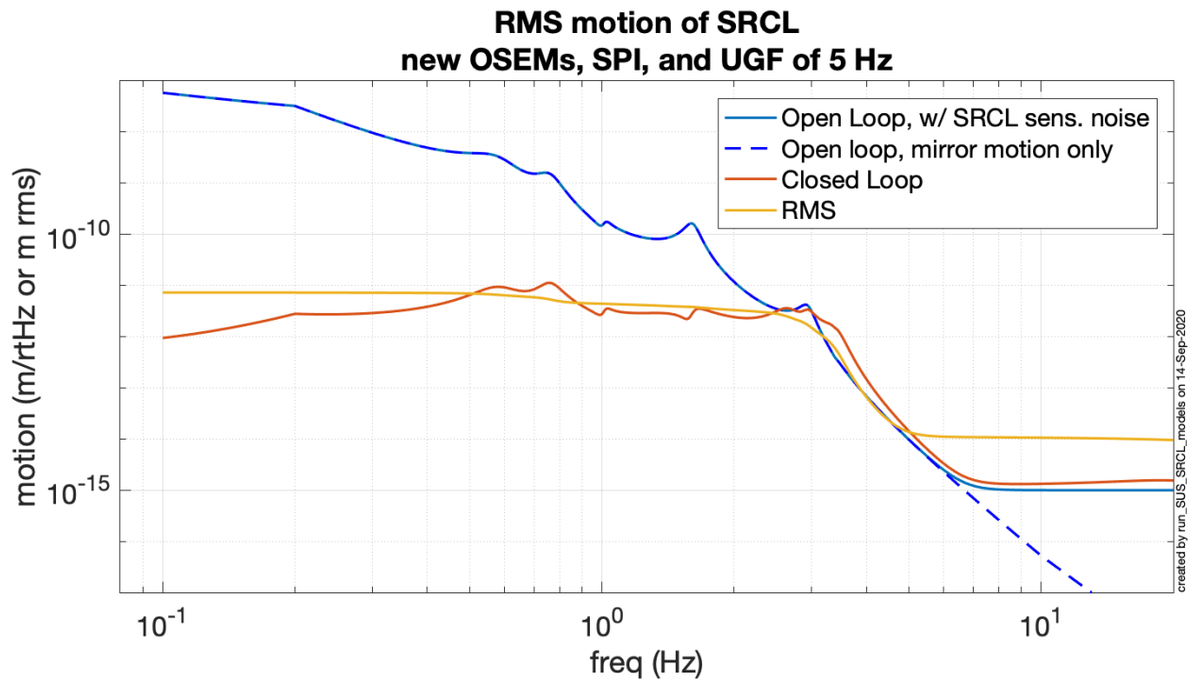
Model for the HAM-ISI shows new angle sensing improves absolute motion of each HAM-ISI.

Length sensing from the SPI improves the relative motion below ~0.6 Hz

Relative ISI motion drops from several hundred nanometers to ~10 nanometers

SRCL BW from 12 Hz now to 5 Hz. limit is the 3 Hz mode SR2





Suspensions

Observations on the aLIGO suspensions:

- Excellent isolation and thermal noise,
- Lower noise OSEMs are needed, but expensive, and bulky, not a trivial upgrade.
- Can 3G designs maintain isolation and thermal noise, but improve lower the cross-couplings to tilt and yaw? (tune masses, moments of inertia, attachment points, etc?)
- Can we get better damping of the modal damping and lower the cross-couplings? (additional sensors, modal damping, …)

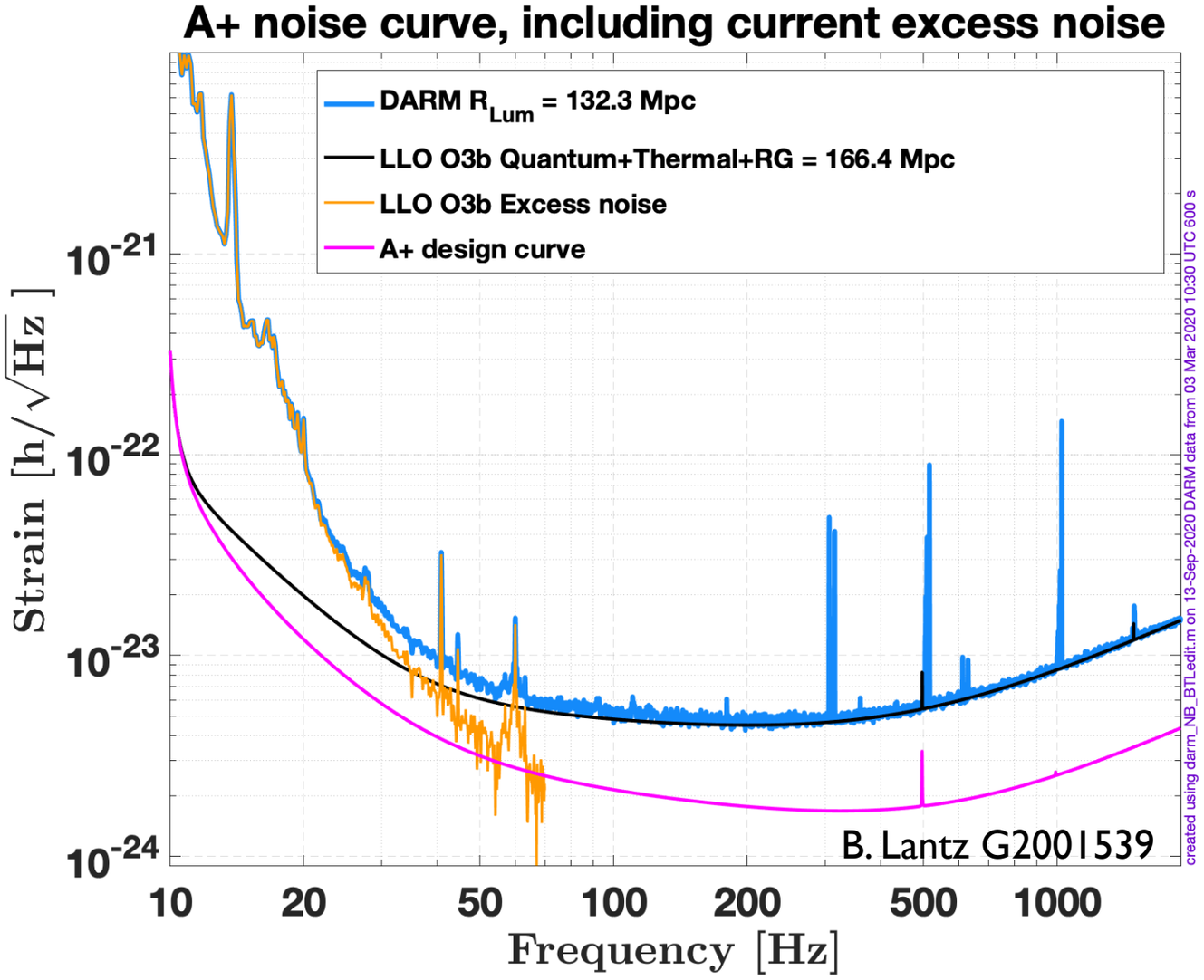
Final thoughts

Excess noise is now
(and has always been) limiting our performance at low frequency.

aLIGO has a remarkably good understanding of the origins of this noise, and the noise budgets provide a map of where we need to be working.

Upgrades to the the isolation and suspension systems can reduce the stress on the IFO controls, and (probably) improve DARM.

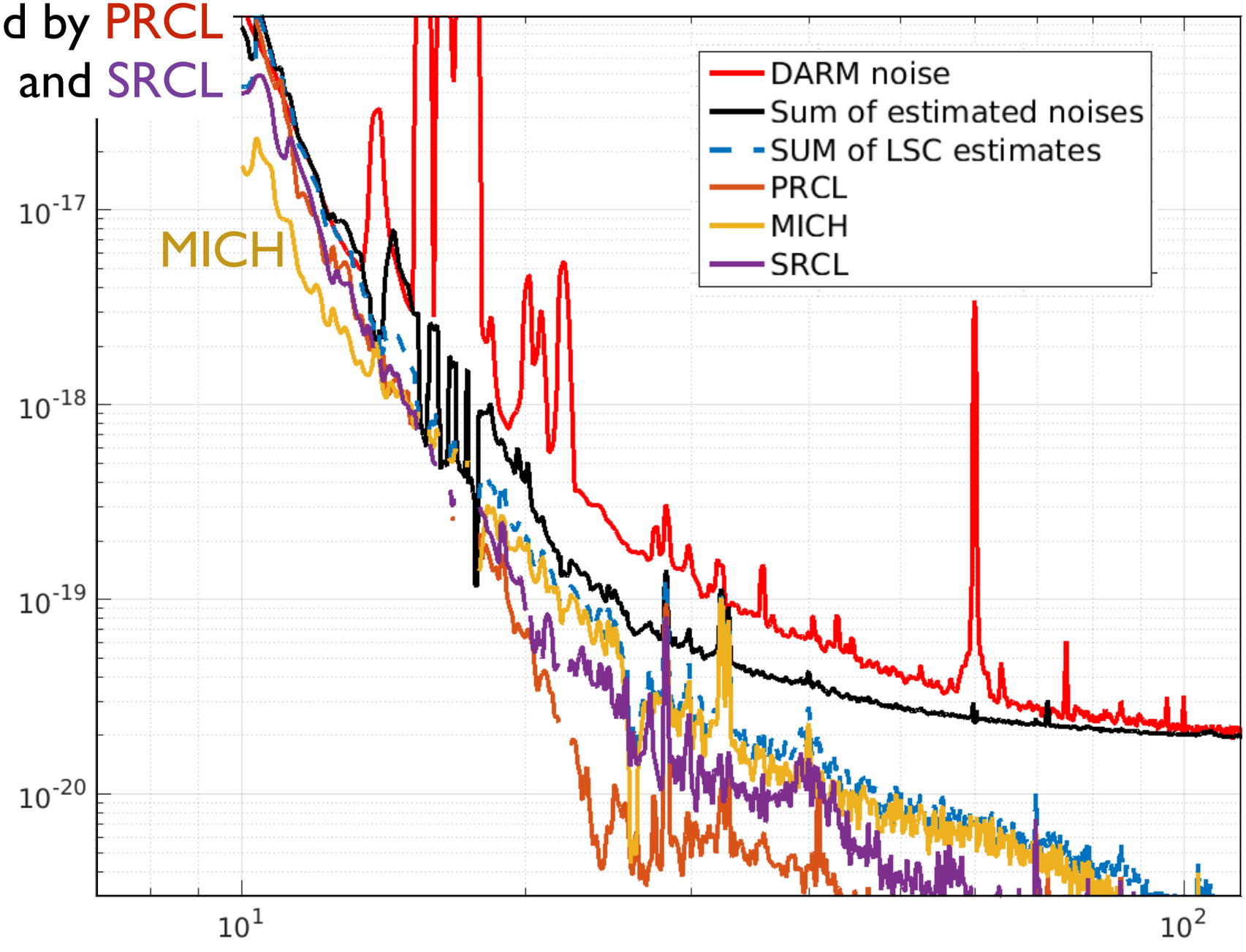
This type of system-level thinking about the isolation systems is going to be essential to achieve quantum noise at low frequency.



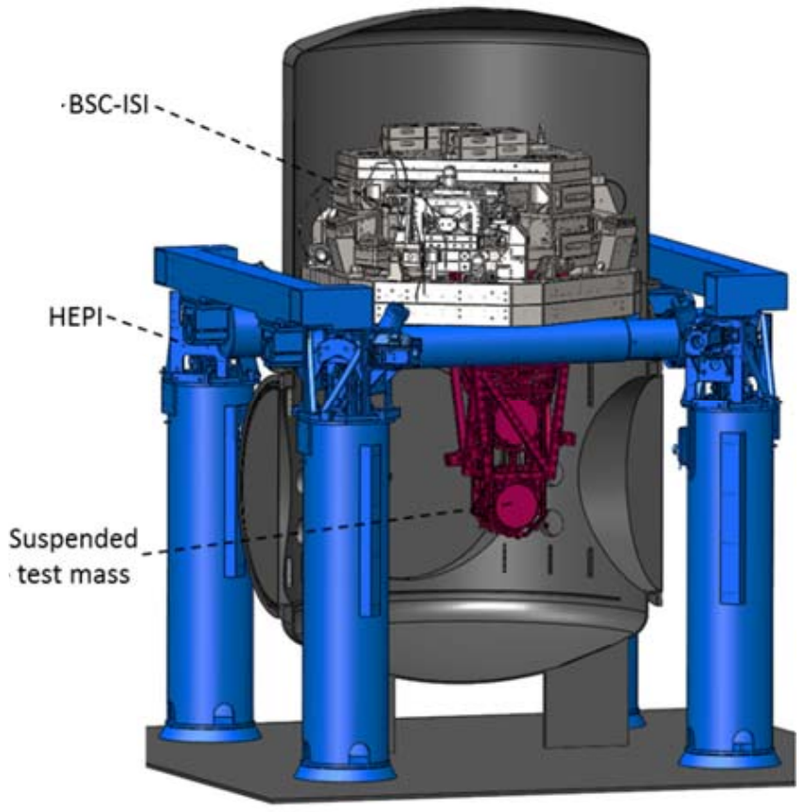
Detail of the noise budget

LSC noise contributions to DARM

dominated by PRCL and SRCL



from LHO log 55755, S Dwyer


BSC-ISI
HEPI
Suspended
test mass

Outline

Seismic noise is not a *Direct* limit for DARM anywhere above 10 Hz,
so why should we try to improve the Isolation System?

Stable operation with low noise.

Better Seismic Isolation system could:
- Improve the science by improving the interferometers' up-time
- Improve the science by improving the stability of the interferometers
- Improve the science by reducing noise in DARM.

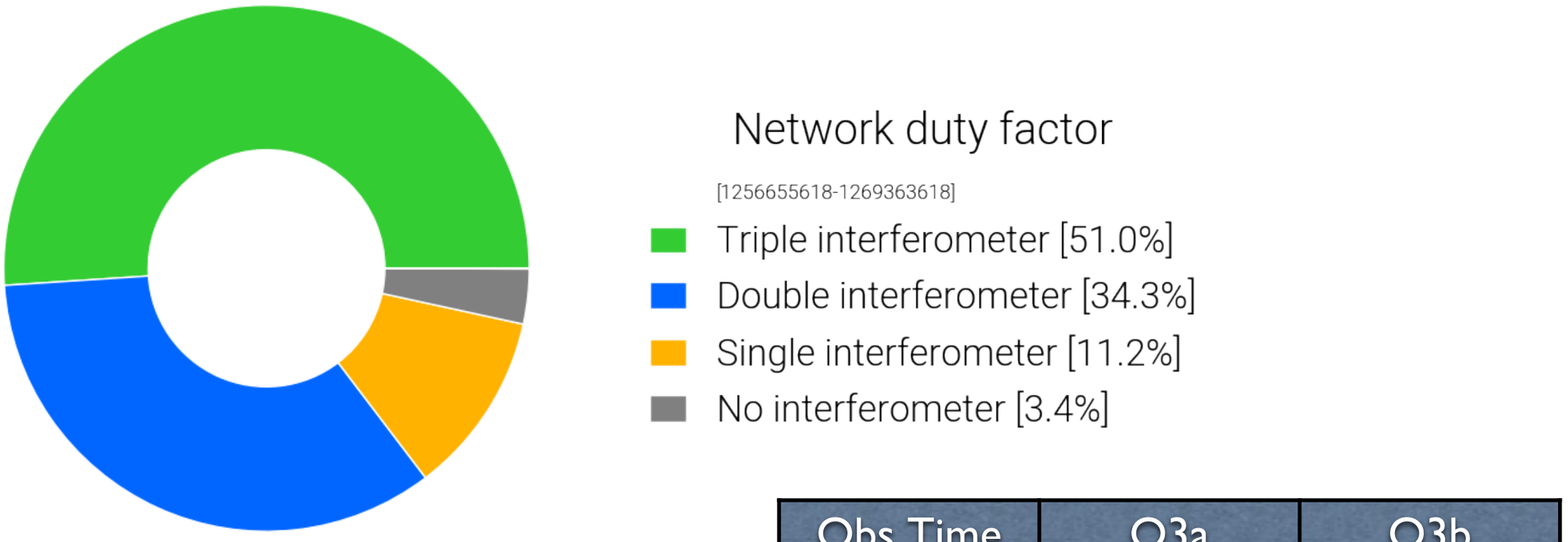
Today:
- Improve the tilt sensing of the platforms (better absolute motion)
- Integrate the seismic tables with direct platform-to-platform sensors
  Seismic Platform Interferometers (SPIs) to
  dramatically reduce the relative motion of the tables (~10 nm RMS)
- Reduce the motion of the optics below 10 Hz
- Reduce the noise (bandwidth) of the controls on the mirrors.

Work through 1 example (SRCL) to show what's going on.
Implement system-wide for "beyond A+"

Duty cycle

Good source location wants 3 detectors running,
but now this is only true about 1/2 of the time.

It's getting better - but we're a long way from "breaker-to-breaker"

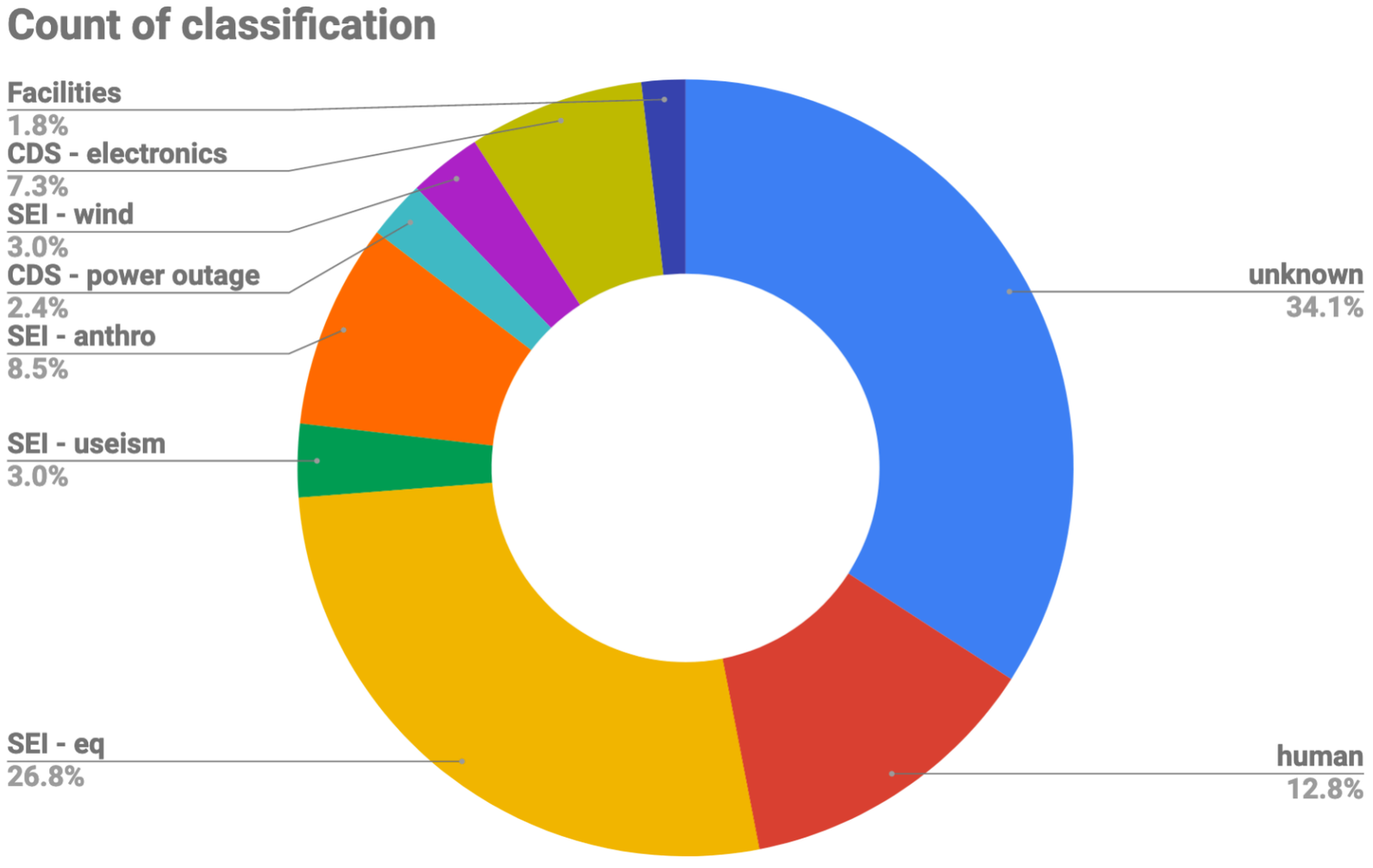


Obs. Time	O3a	O3b
Triple	44.5%	51.0%
LHO	71.2%	78.8%
LLO	75.8%	78.6%
Virgo	76.3%	75.6%

https://ldas-jobs.ligo.caltech.edu/~detchar/summary/O3a/

Duty cycle

Unusually large seismic activity is the largest source of "known" lock-losses (LLO data).
Large motions range across the low frequency bands (wind, EQs typically < 100 mHz, microseism is ~150 - 300 mHz, anthropogenic is a few hertz.)



data from LLO lockloss spreadsheet

cBRS

Michael Ross Thesis, P2000198

The Compact BRS

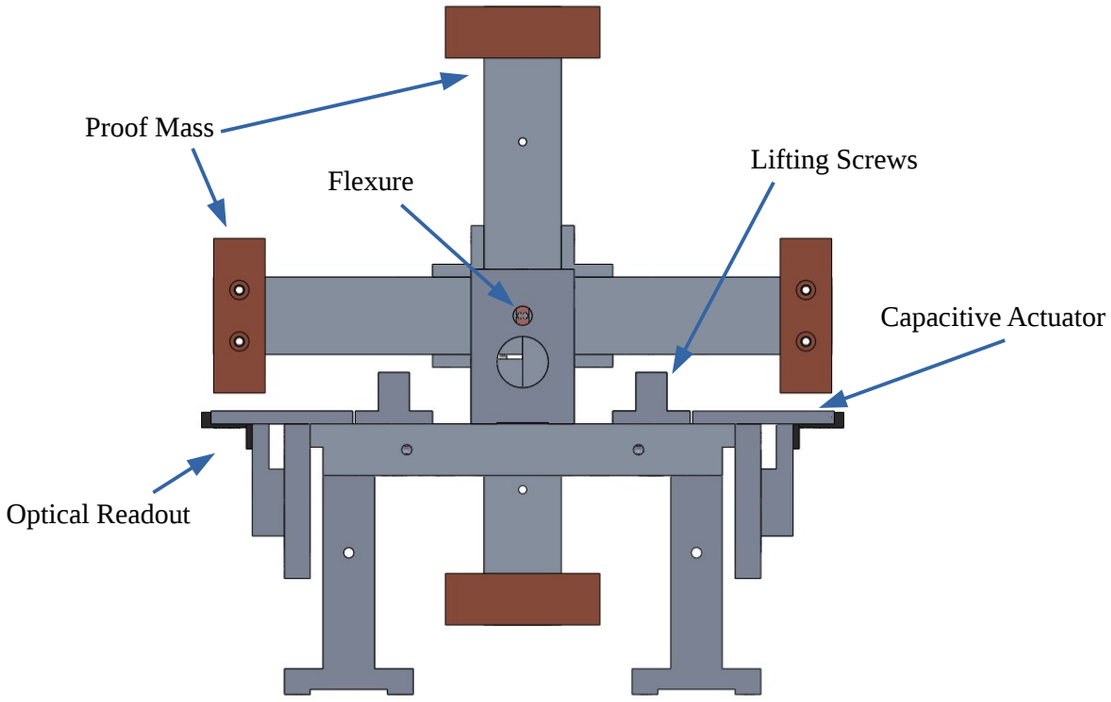


Figure 3.4: CAD rendering of the compact BRS (cBRS) showing the cross with its copper end masses which is hung from the flexures from the surrounding support structure. The translation stages which hold the fiber interferometer readouts can be seen on either end of the support below the two horizontal end masses.

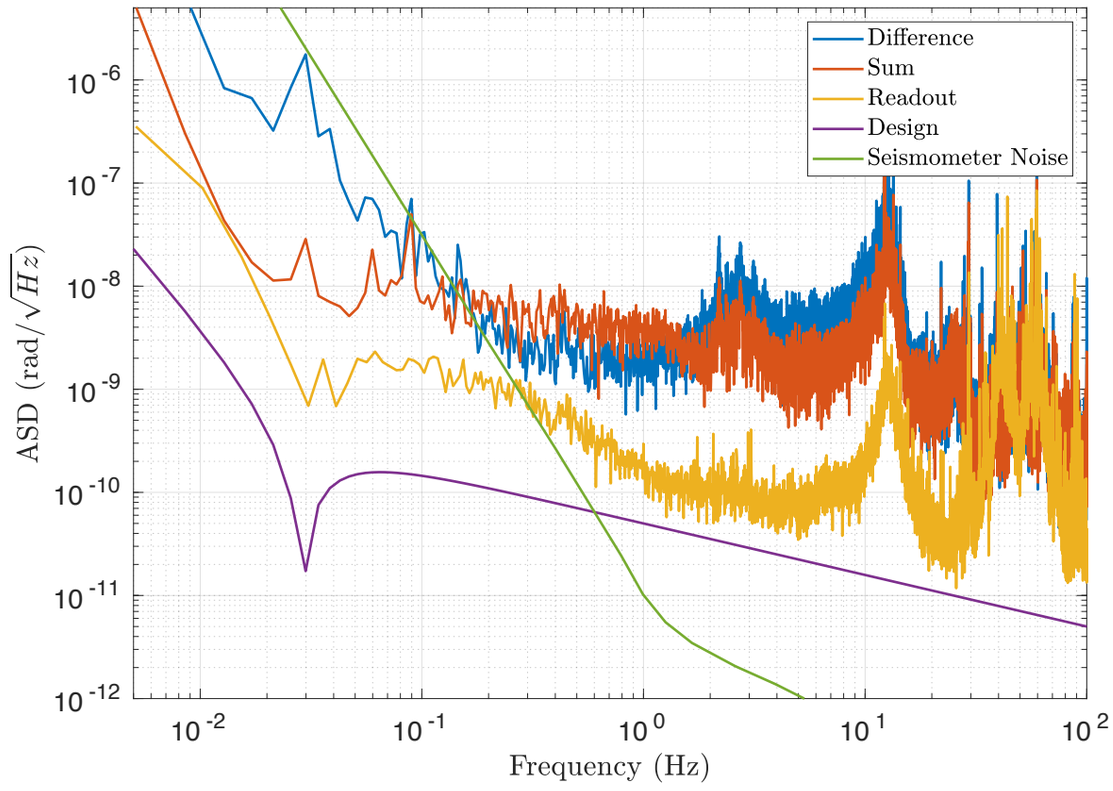


Figure 3.11: Prototype cBRS noise performance showing the sum and difference of the two readouts. Additionally shown are the readout noise measured while the beam balance was mechanically locked, the design sensitivity, and the sensitivity of the current Stage 2 rotational sensors.

The performance of the ASC system was modeled for the seismic performance with the cBRS installed, Figure 3.19, and without, Figure 3.1. In both situations, the high frequency performance is limited by sensor noise which leaks into the gravitational wave band. The primary retuning that can be made with the inclusion of the cBRS is a decrease in the ASC UGF from 5.23 Hz to 2.93 Hz. Above this the residual falls off as $1/f^5$.

Figure 3.20 compares the modeled residual for a system with and without the cBRS. As expected, adding the cBRS reduces the residual between ∼50-500 mHz due to the increased performance of the seismic isolation system. This allows a shift in the UGF to lower frequencies which reduces the residual above ∼5 Hz.

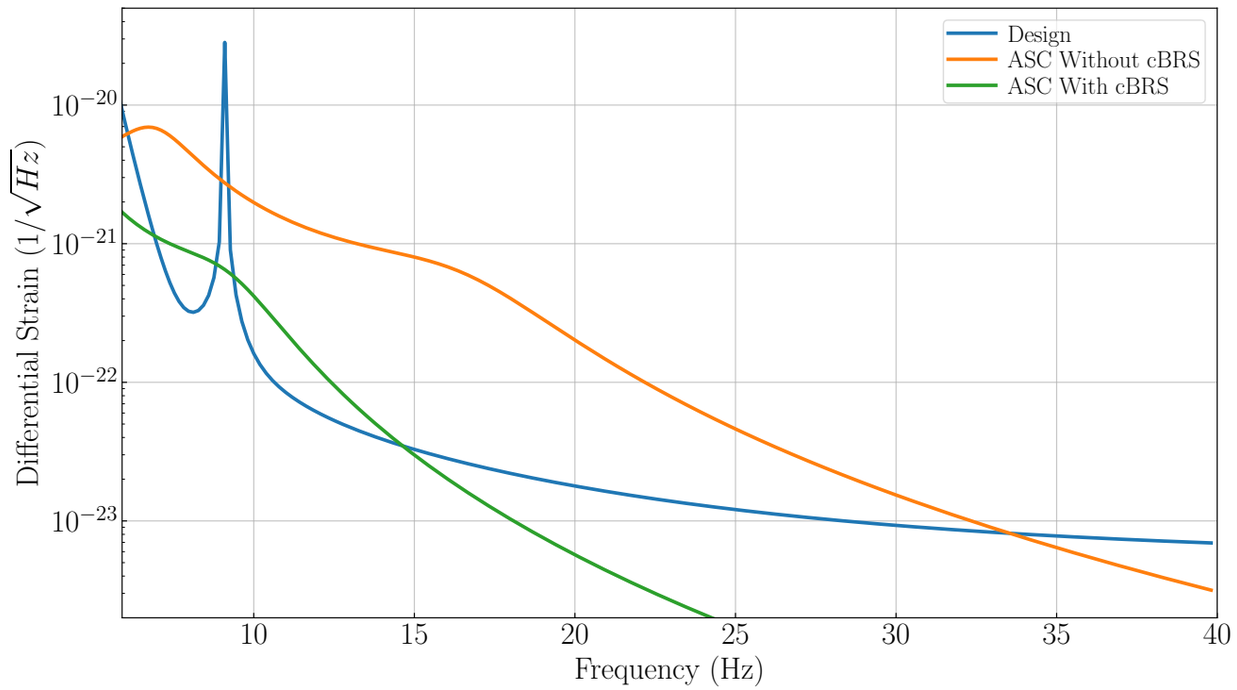
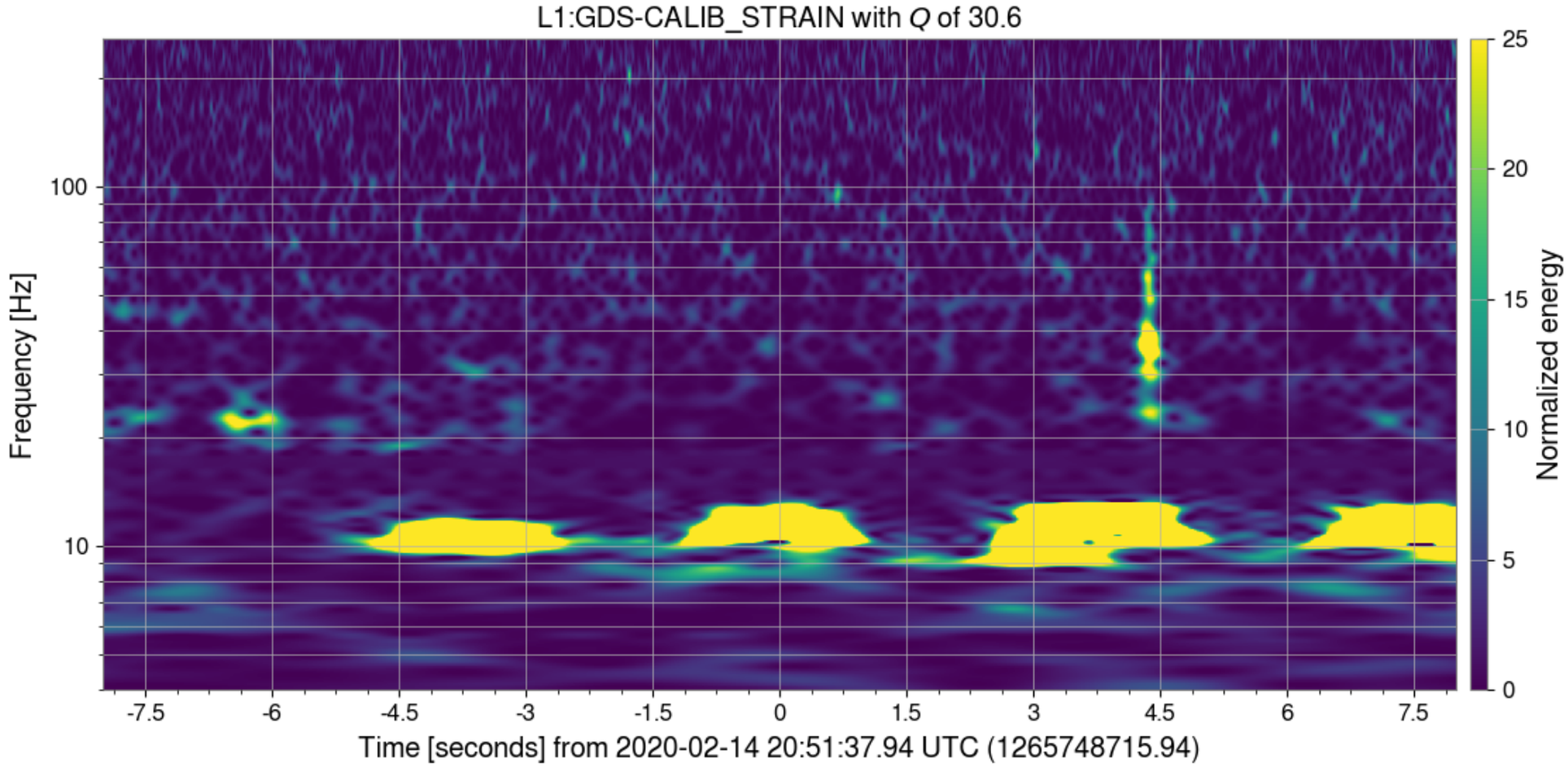


Figure 3.21: Projected low frequency strain noise with and without the cBRS along with aLIGO design sensitivity. [16]

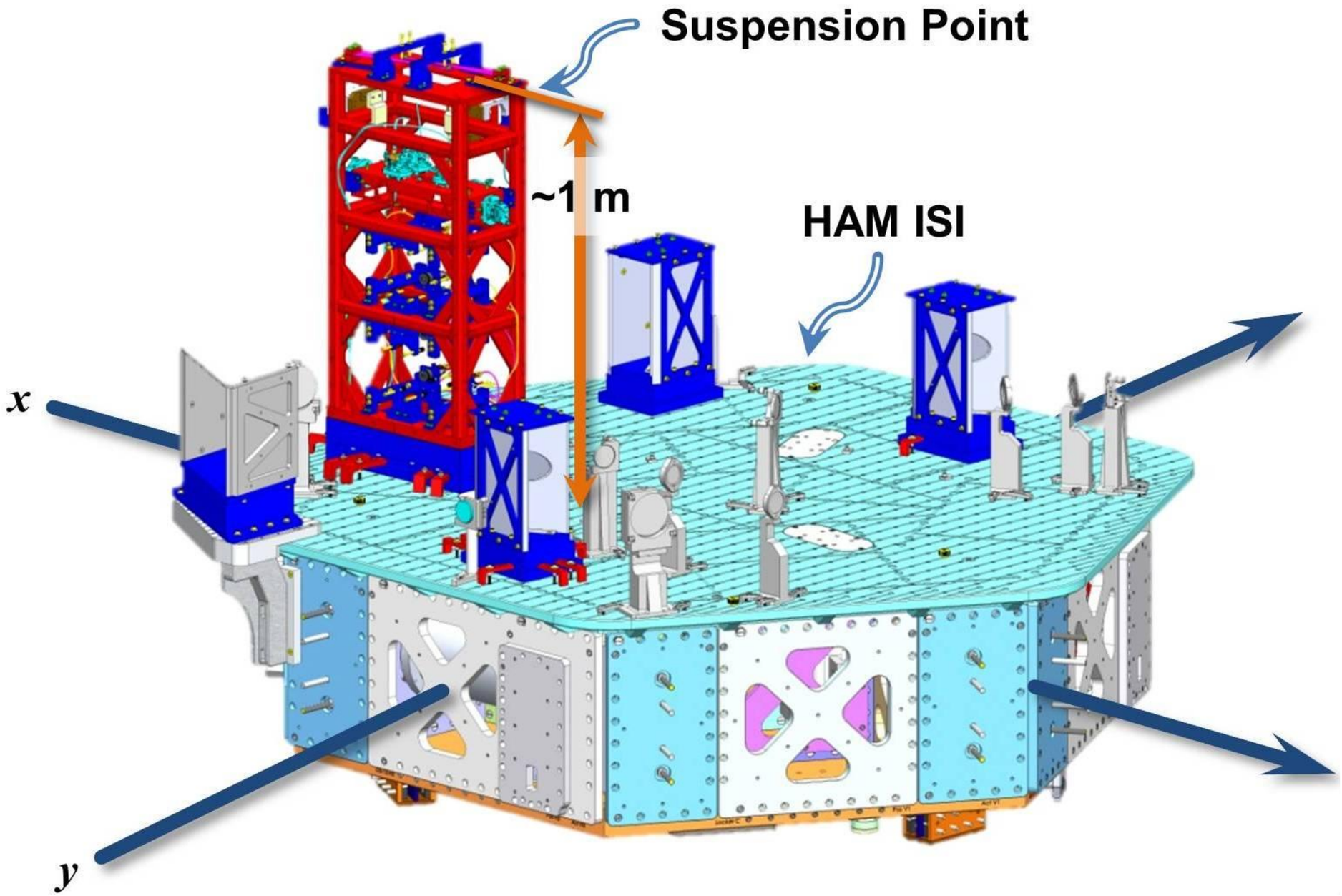
Relative motion between optics causes glitches

Scattering arches from relative motion between ETM and the transmon telescope (not fixed by R0 tracking)
(11 March, 2020, Corey, Anamaria, Gaby, Sidd)



https://alog.ligo-la.caltech.edu/aLOG/index.php?callRep=52071

This is not a system



Excess noise and DARM

LLO has best range now.
Excess noise reduces detection volume by (132.5/166.4)^3 = 0.505