Suspension thoughts

- Issue - aLIGO isn't limited by seismic or thermal noise, it's limited by control noise - so, how do we improve the control noise?
- Control noise, esp from angular control on the main masses is a limit.
- Control noise from aux. DOFs also a big problem - not really addressed here, but still important, and the suspension ideas are the same. We probably need some new small suspensions.

Still a Quad suspension with a reaction chain, mass on vertical glass fibers

Elements of a design update should include:

- Heavier masses - Noise Budget Benefit is radiation pressure,
  Real benefit is control updates in a SUS update.
- Longer suspensions - Seems good, not sure about implementation.
- Relatively heavier intermediate masses with higher moment/ mass ratios
- Lower noise OSEMs & bigger separation of OSEMs for angular sensing
- Improved length-angle decoupling
- Generally reduced cross couplings
- Damping at UIM
- Optical levers on test mass from the ISI optical table

Heavier mass

- Total load for the ISI is about 1100 kg.
  BUT - this includes all the balance mass, SUS cage, reaction chain, cables, new BRS sensors, clamps, baffles, heaters, electric field monitors, etc, etc…
- Current Quad SUS main chain is about 120 kg (20, 20, 40, 40).
- ISI design was to have this 20 cm off center, allow a folding mirror for H2, and an 300 kg of extra margin and ballast (original load spec was 800 kg)
- Seems reasonable to have a 400 kg main chain, if the total SUS is well centered. BTL guess is that this will leave enough margin for everything else. Maybe we can get more?
- If the test mass is 100 kg, then the rest of the chain is 300 kg and it's good, if the test mass is 200 kg, this is a problem. There is some optimization to be done.

- My Guess:
  - From a control perspective - no reason to push mass past 135 kg
  - Lightening everything except the main chain is beneficial - allows heavier main chain

heavy optic needs heavy chain

If the test mass is a large fraction of the total mass of the chain, it compromises the isolation performance (bad) and raises the frequencies of the higher modes
(also bad for coupling of control noise)

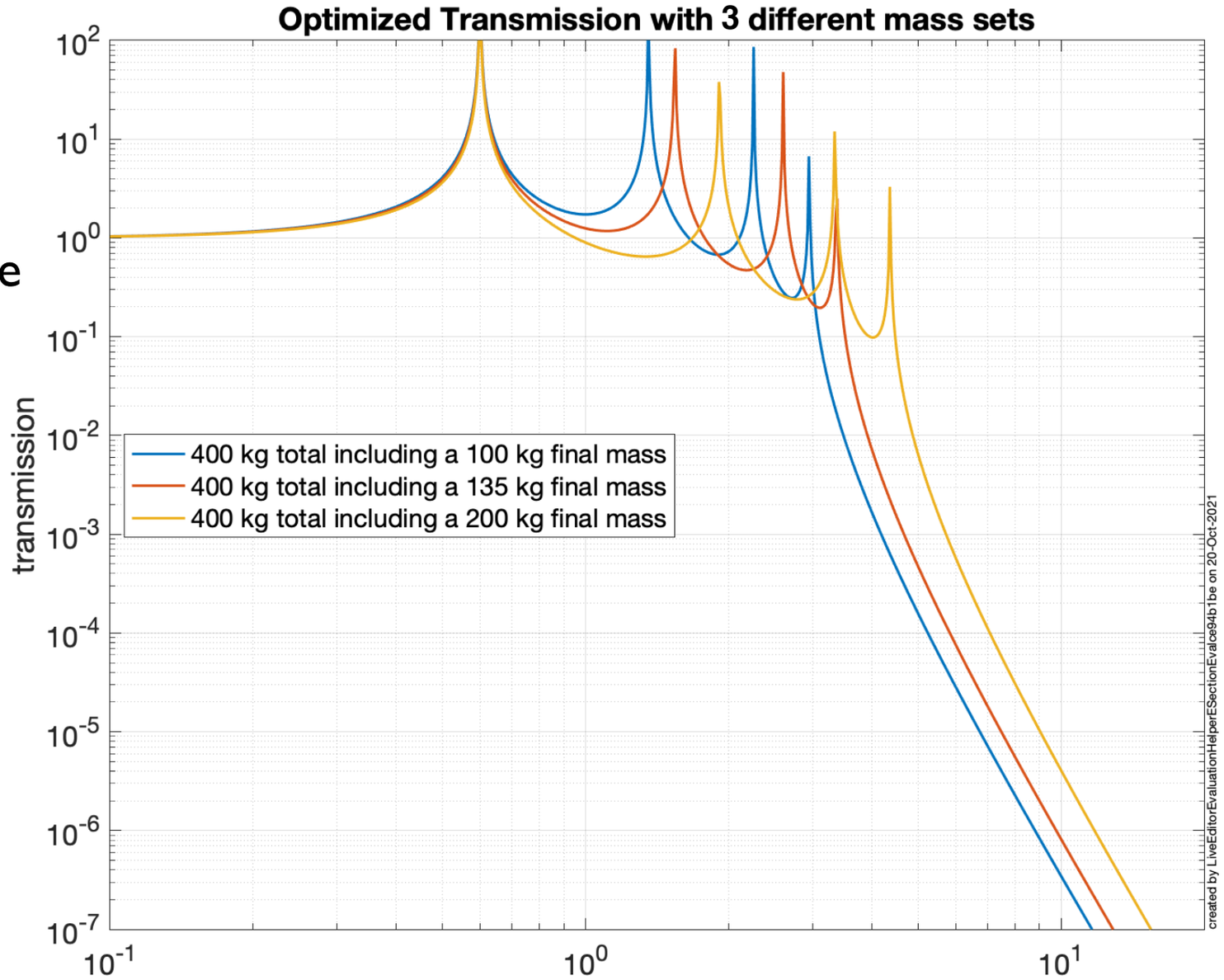
Illustrated with simple model - 4 stage mass-spring system, fix total mass at 400 kg, find springs to get lowest mode at 0.6 Hz and best 10 Hz isolation.

3 cases - final mass of 100 kg, 135 kg, & 200 kg

This optimization has more freedom than is realistic, but illustrates point that mass probably shouldn't be more than about 1/4 to 1/3 of the total suspension chain mass.

chain 1:	chain 2:	chain 3:
m1:148.0	m1: 121.5	m1: 82.5
m2: 93.2	m2: 84.6	m2: 65.5
m3: 58.8	m3: 58.9	m3: 52.0
m4: 100	m4: 135	m4: 200

calculated with T2100287



Longer suspension

Longer suspensions are probably needed to lower the 10 Hz edge of the detector

Can improve the thermal noise of the final stage

Final bounce/ roll modes can be lowered with longer fibers, higher stress fibers, and springs to support the test mass. Longer fibers are the easiest thing on this list.

But, it's not clear how to achieve this - this needs attention

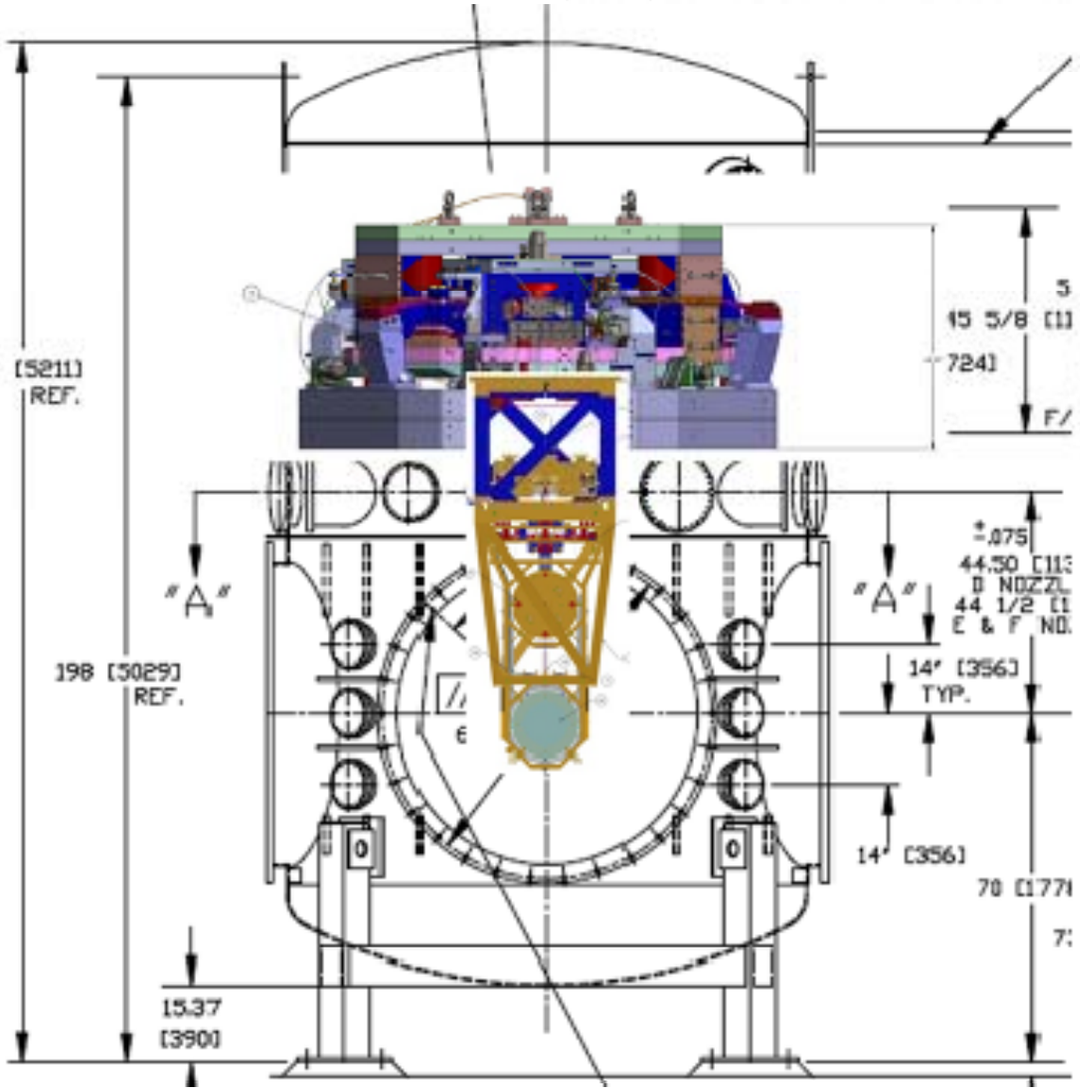
Some choices:

- Raise the ISI (e.g. Giles Hammond G1300191, Madeleine Waller G1300824)
  But this sort of interface arrangement is likely a set of retrofitted, bolted do-dads which will be more compliant that the highly designed stage 0 (floppy) and less precise (sloppy). Likely to make the microseismic tilt issue worse and overall make the control noise worse
- Thread the wire from the top blade to the top mass through the ISI - position the top mass just below the stg 2 optical table.
  But - Cutting holes through the ISI is messy.
  The top wire now is only ~ 45 cm, so although eh total SUS can be almost a meter longer, the bottom 3 stages only get ~ 45 cm more total length to distribute.
- Thread through the ISI, and put the top mass of the SUS above stage 2. Position the UIM just below the 'optical table'.
  But - still messy. Uses a lot of space above the ISI,
  how to suspend a reaction mass for the UIM? Very different from our experience.

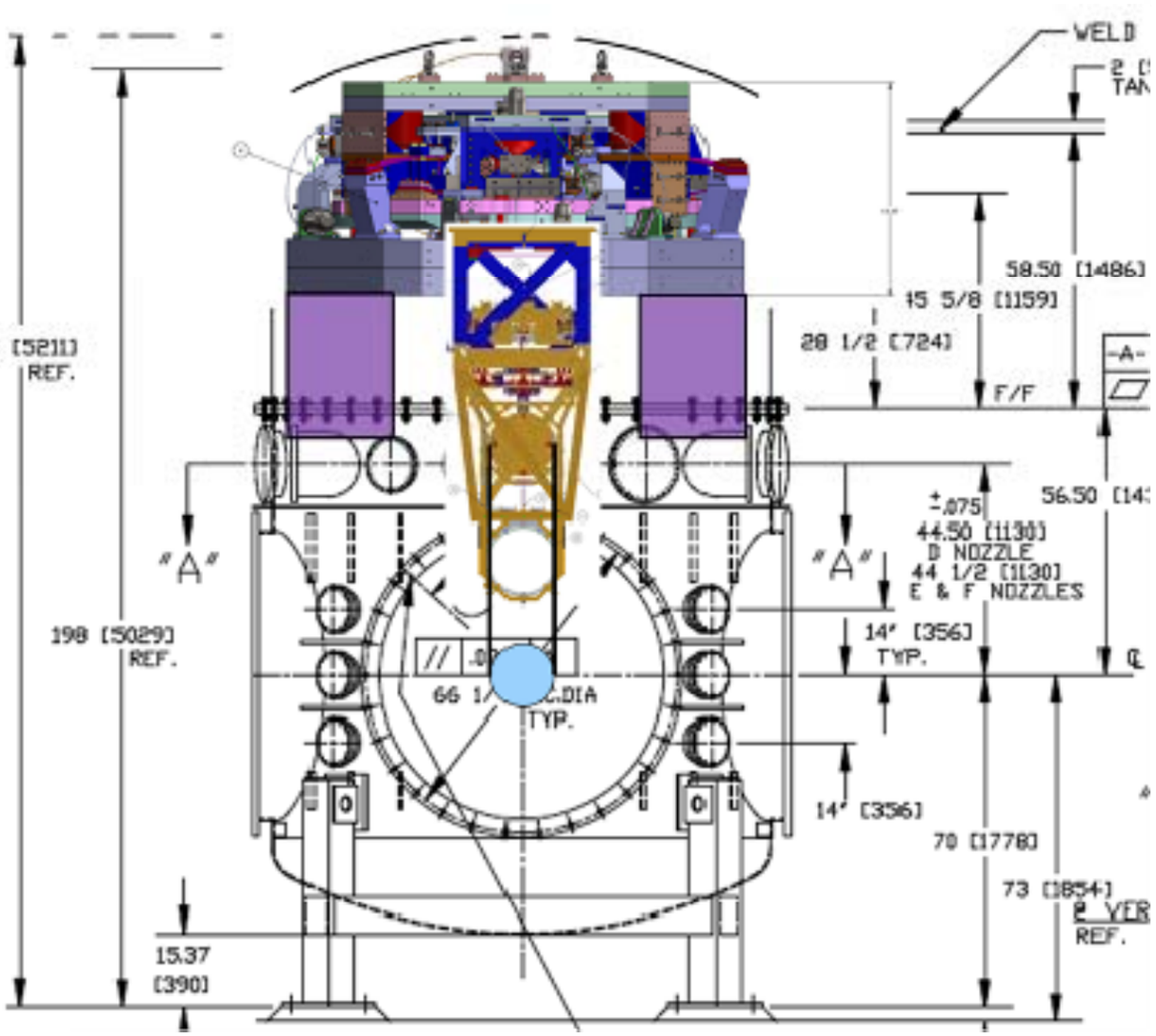
Longer suspension

Feasibility of the Upgrade

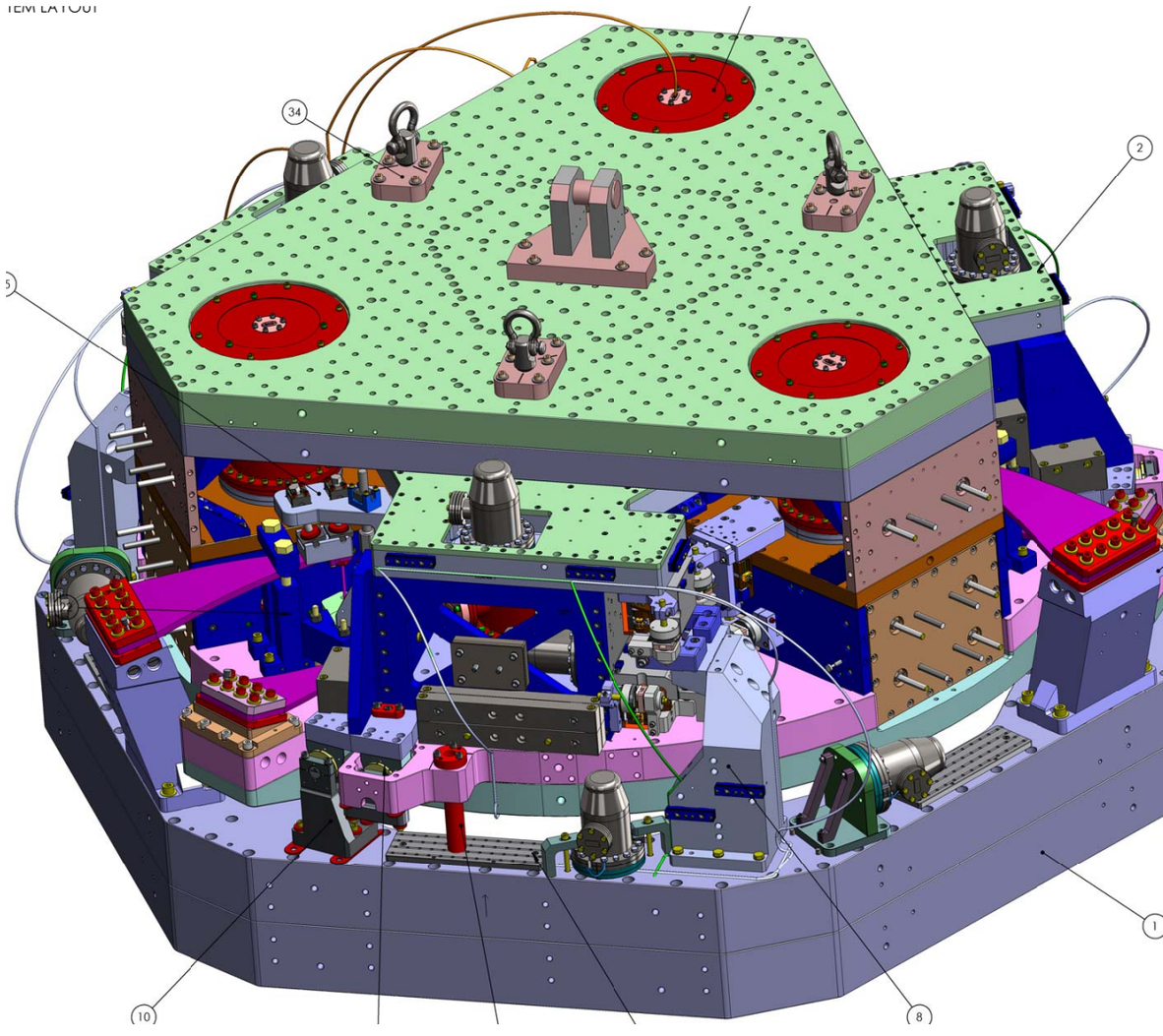
Giles Hammond, G1300191



aLIGO (0.6 m final stage)

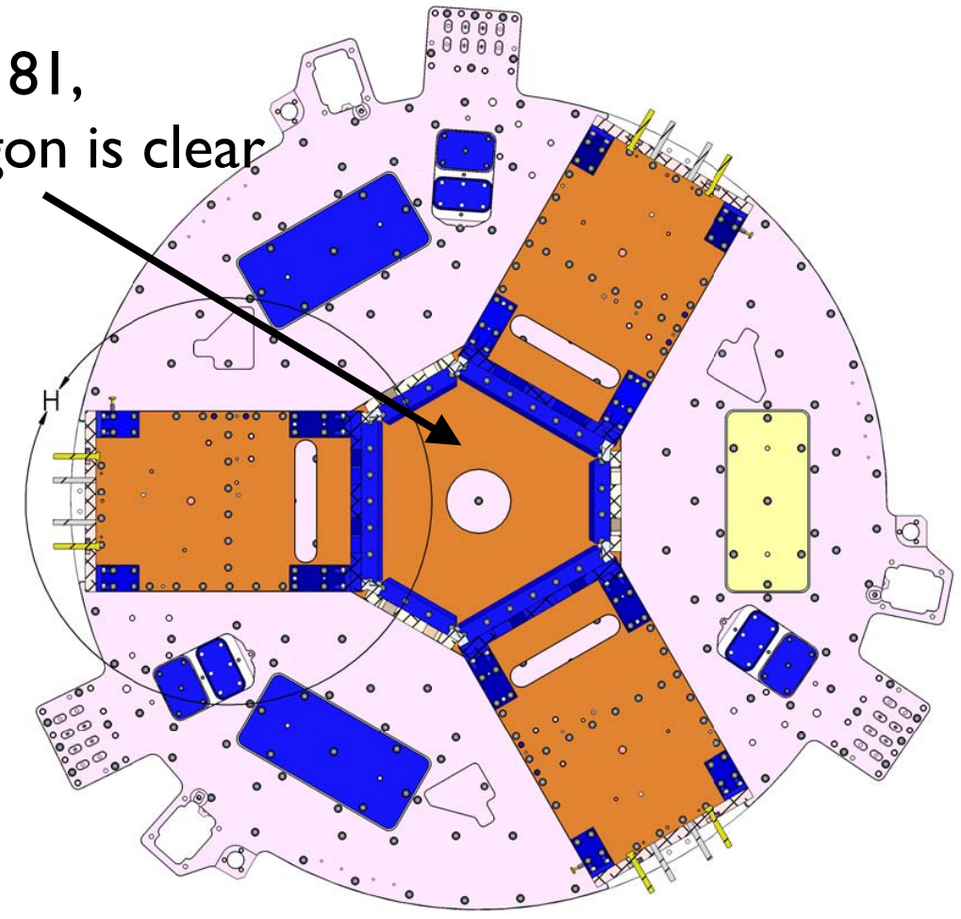


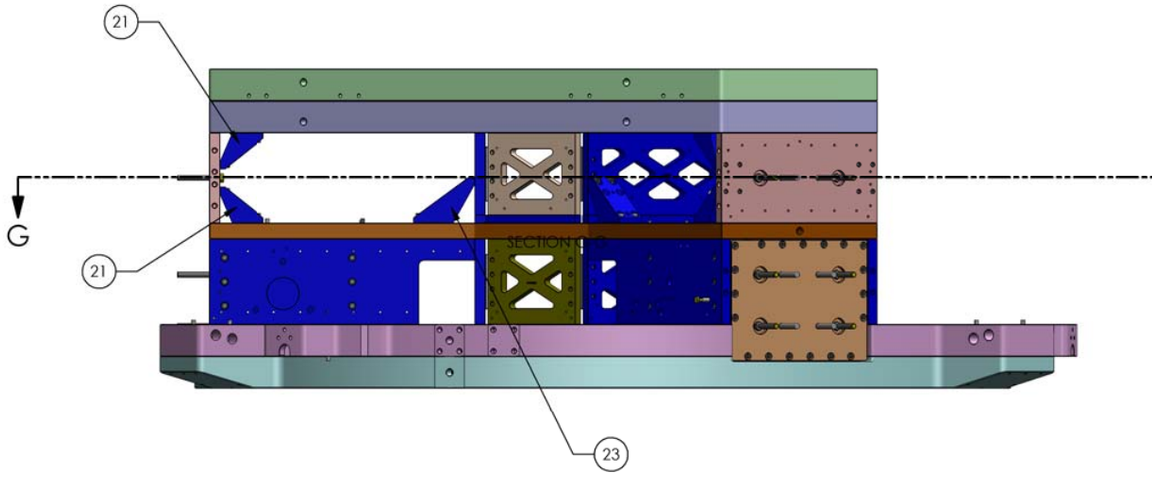
LIGO-3 (≈1.2 m final stage)



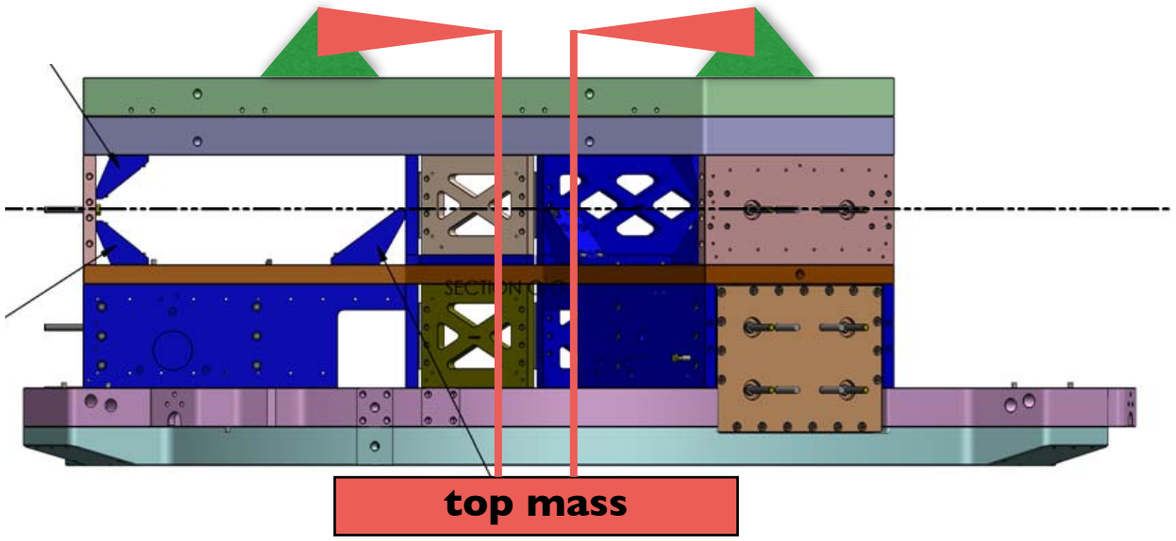
D0901182

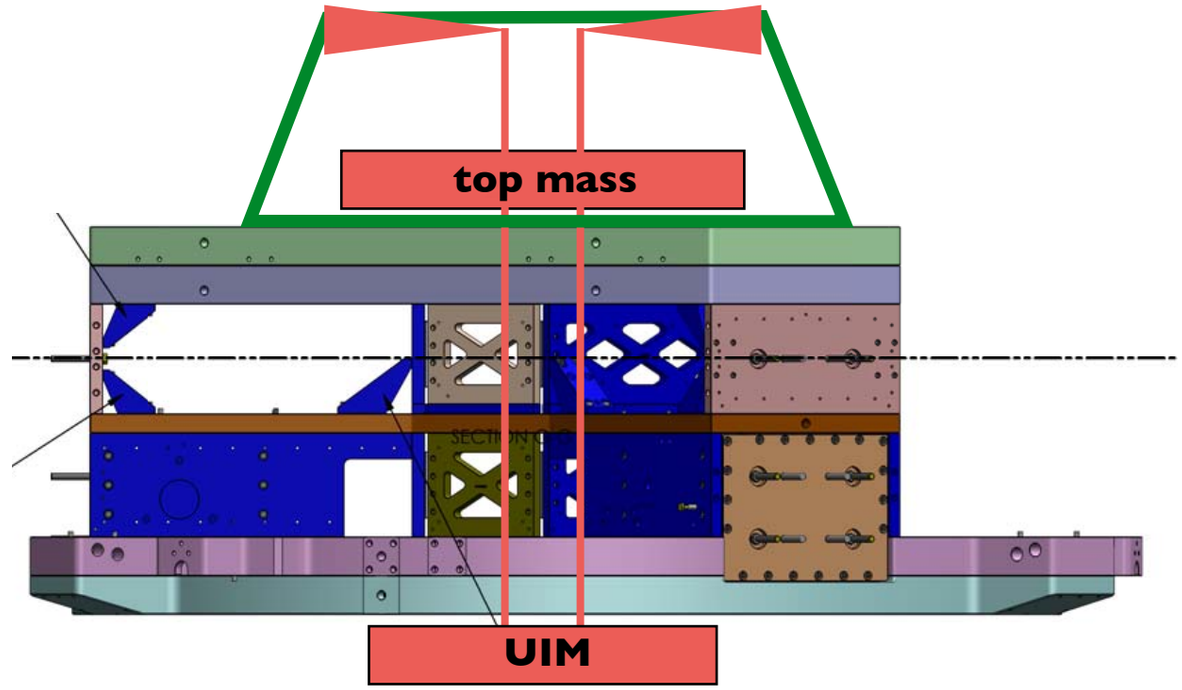
from D0901181,
central hexagon is clear





concept of SUS thru ISI





Notes:

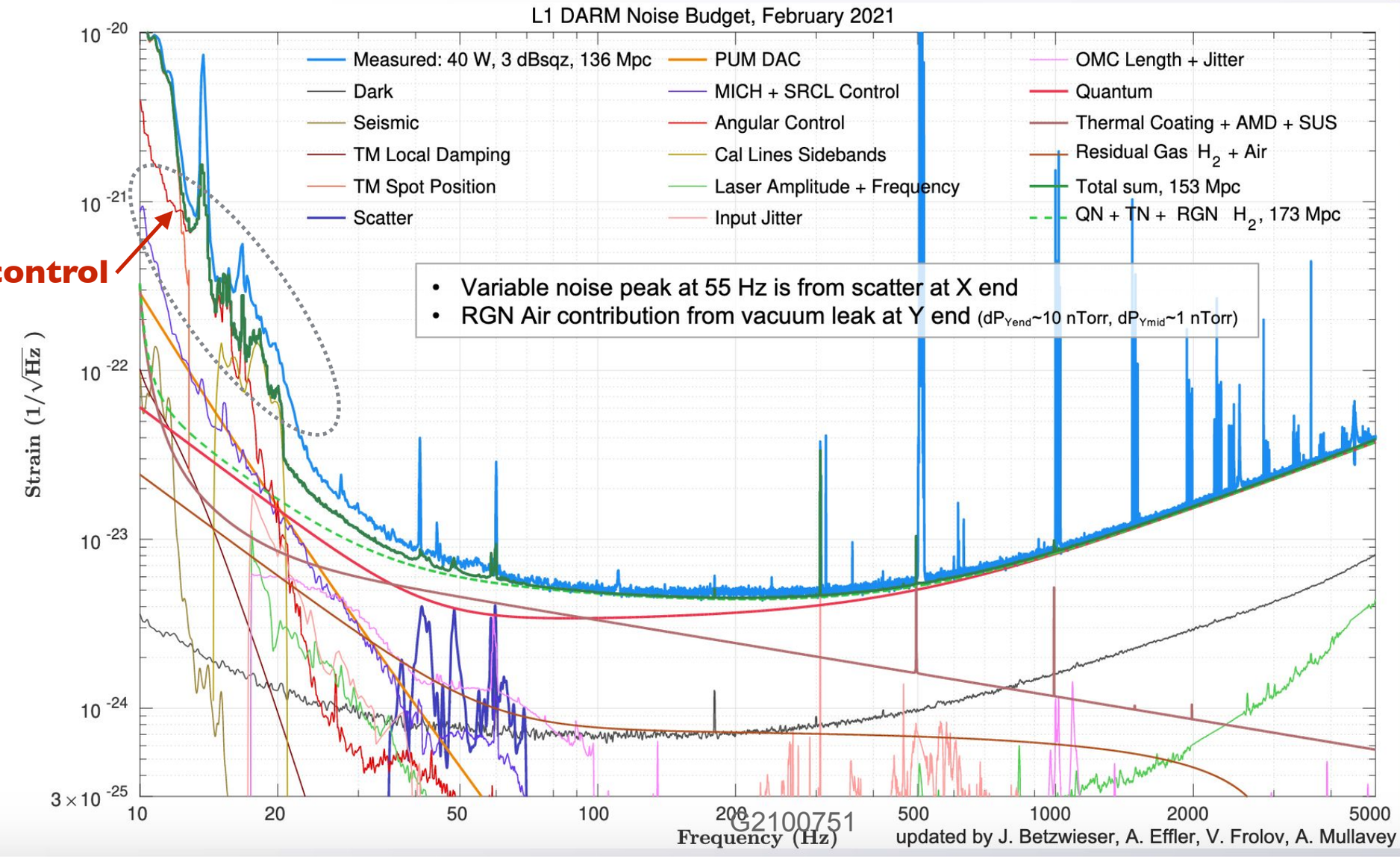
1) Rather different than our experience.
2) Integration can make good use of the ISI structure.
3) What about the reaction chain?
4) takes up lots of the space on the top table
5) check the IP impact on the rotational stiffness of the ISI
6) easy to mount OSEMs and HoQI to the ISI tables
7) how do you assemble this? Access is awkward
   - Betsy can't be at top table and optical table at the same time.

controls stuff

Reduce the angular noise of the optics so that we can reduce the BW of the optical control loops.

- Lower noise OSEMs
- smaller cross coupling from ISI
- move HF modes down by design of heavier intermediate masses
- better damping of the modes

L1 Noise Budget



angular control

3

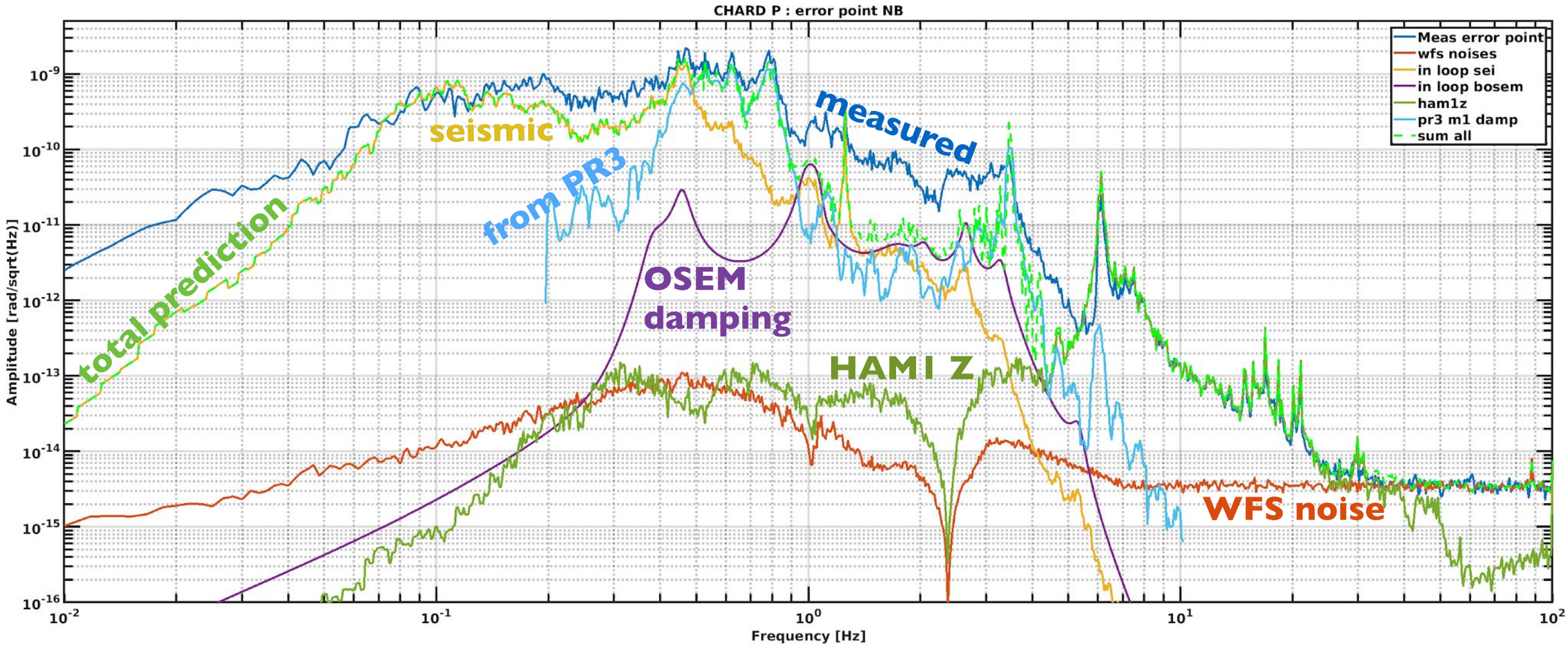
G2100751

angle sensing

selected slides from Marie Kasprzack, G2100751

reduce the seismic coupling, improve the OSEM noise, put ISI into HAM1

CHARD Noise Budget



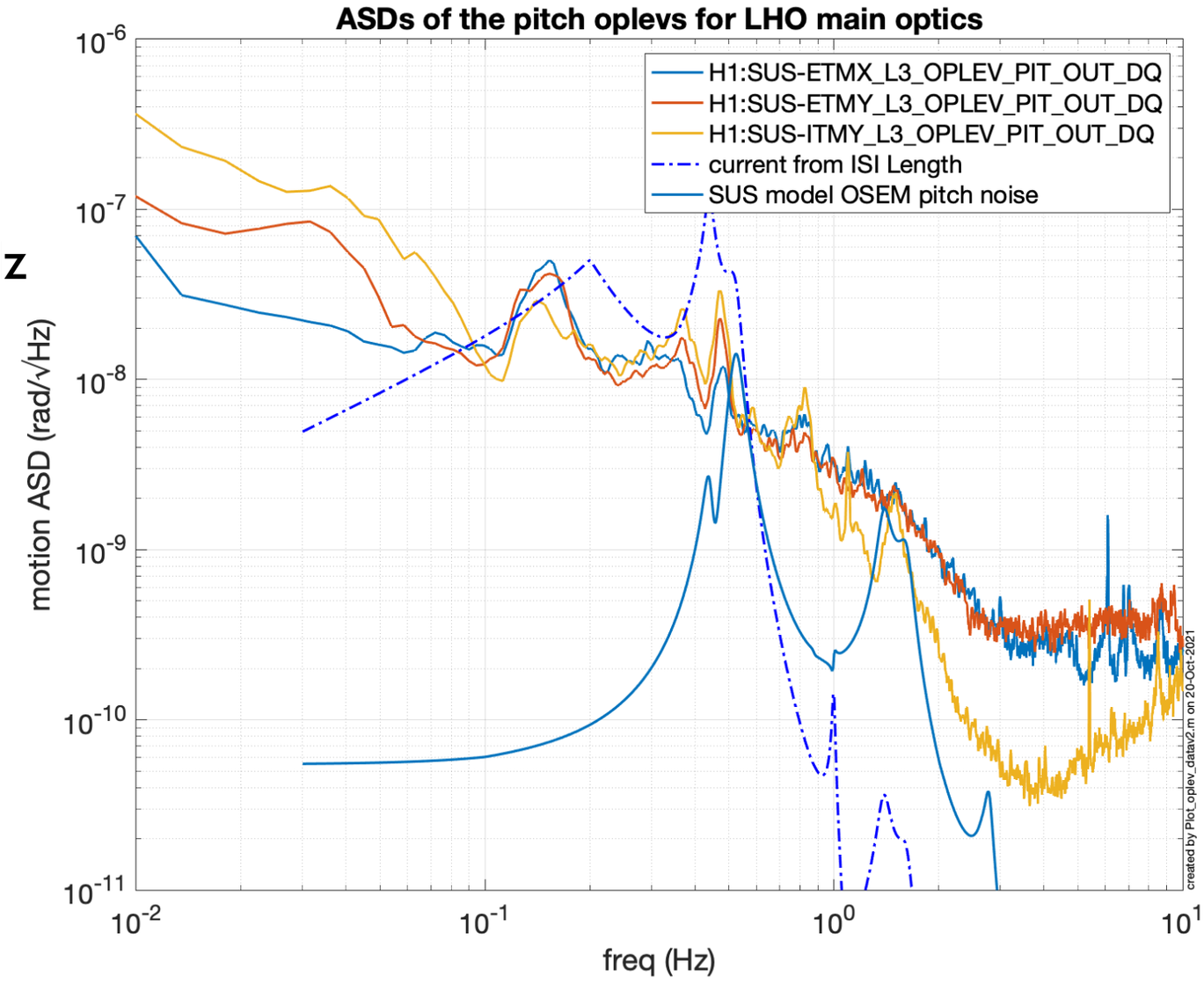
- HAM1 Z is making noise in REFL WFS from 6 to 30 Hz
- PR3 damping makes noise at 3.5 Hz and 0.5-0.8 Hz
- Unexplained noise source between 1 and 3 Hz

similar modeling - explain optical angle for each optic as seen by the optical levels.

OSEM noise in pitch is important at 1/2 and 1.5 Hz

Similar results as Marie:
seismic Length -> optic pitch below 1/2 Hz

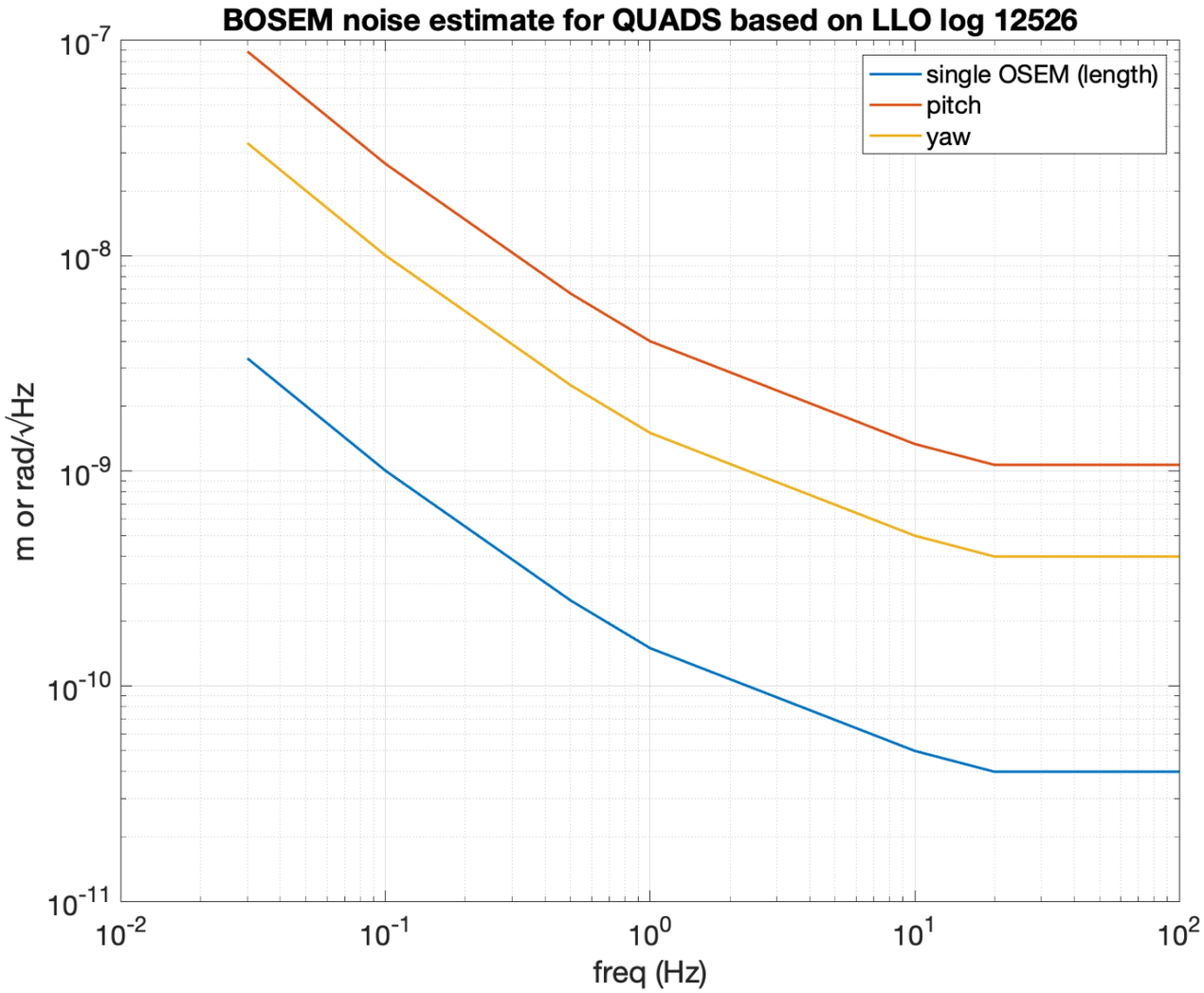
stuff at 1 Hz is a mystery.



OSEM noise for angles

Improving OSEM noise by 5-10x on pitch should be easy by increasing the OSEM separation from ~5 cm to 25-50 cm on a bigger top mass.

A better OSEM would help all the DOFs. At 1 Hz, the OSEM is 5-10x noisier that the ISI.
- is there a 10x quieter OSEM somewhere? HoQI?
- if it were simple to get a 10x quieter OSEM, we would have done that already.

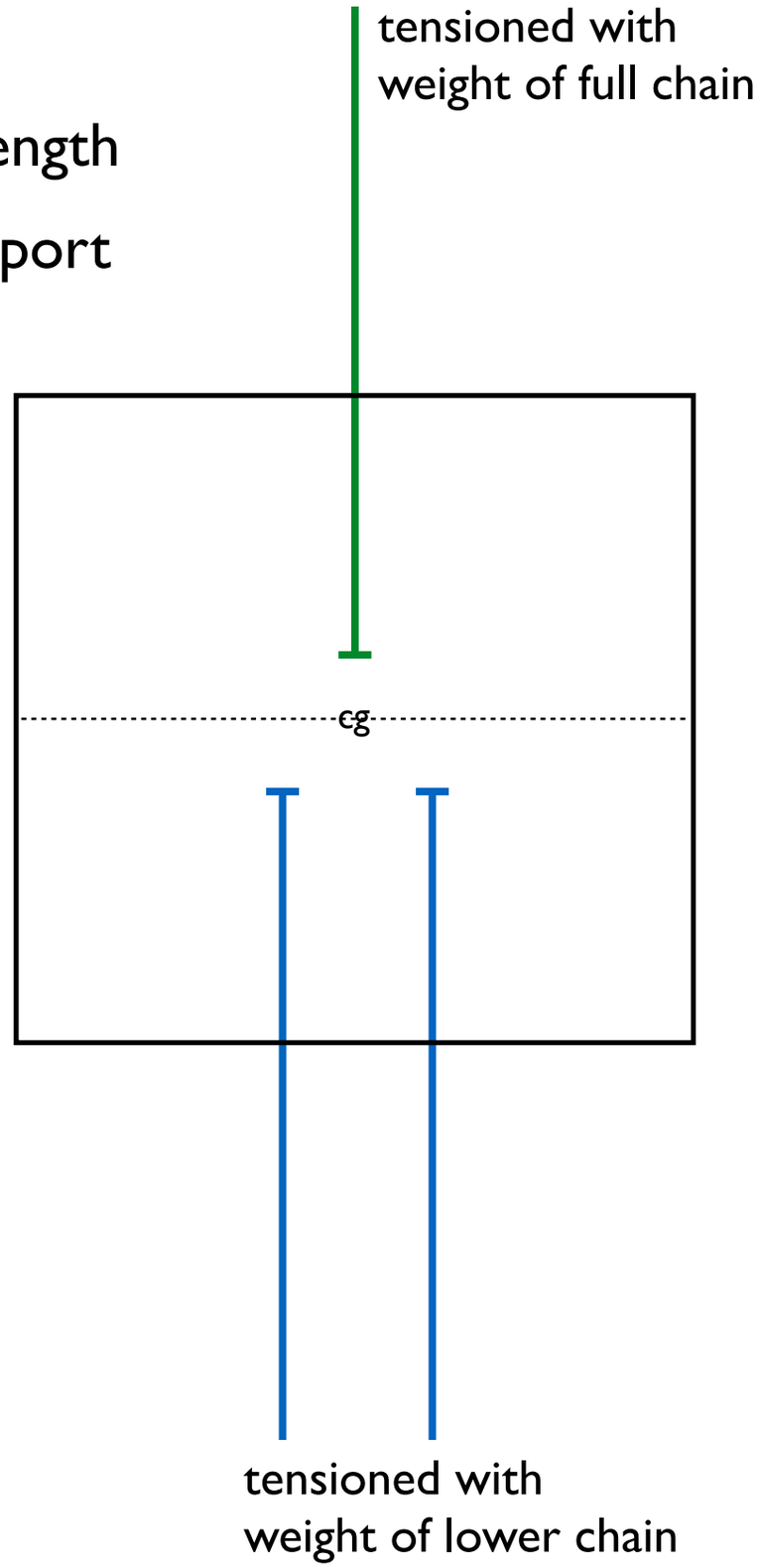


Reduce L-P coupling in the SUS

Length-pitch coupling in the SUS is not small.

Most of the optical pitch below 0.5 is from ISI length

Can be reduced by having 4 wires & springs support the top mass.



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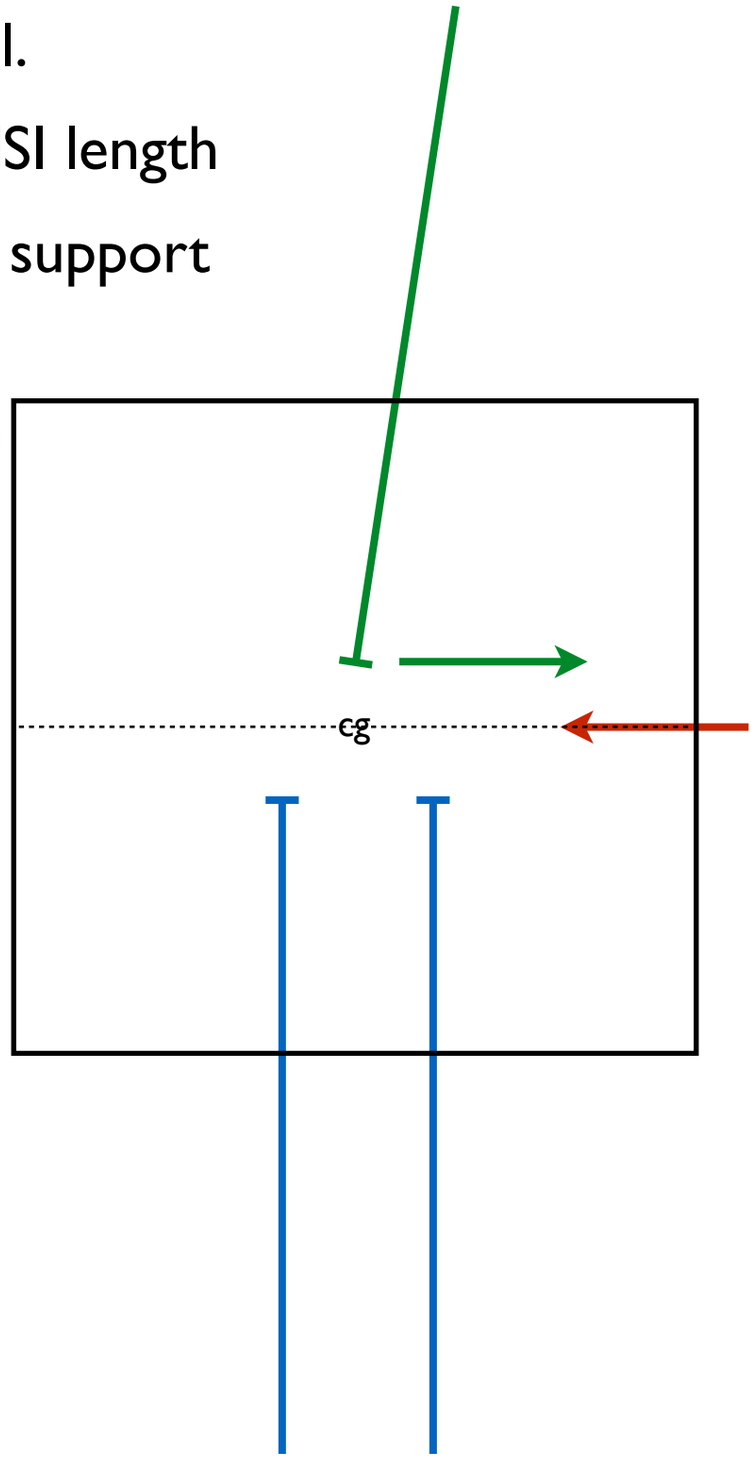
Force on the top mass results in torques on the top mass.

Rotations of the top mass result in horizontal forces.

Means that TFs for length and pitch have at least 8 clean modes to deal with, so it also makes fancy control stuff very difficult to deal with in any practical way



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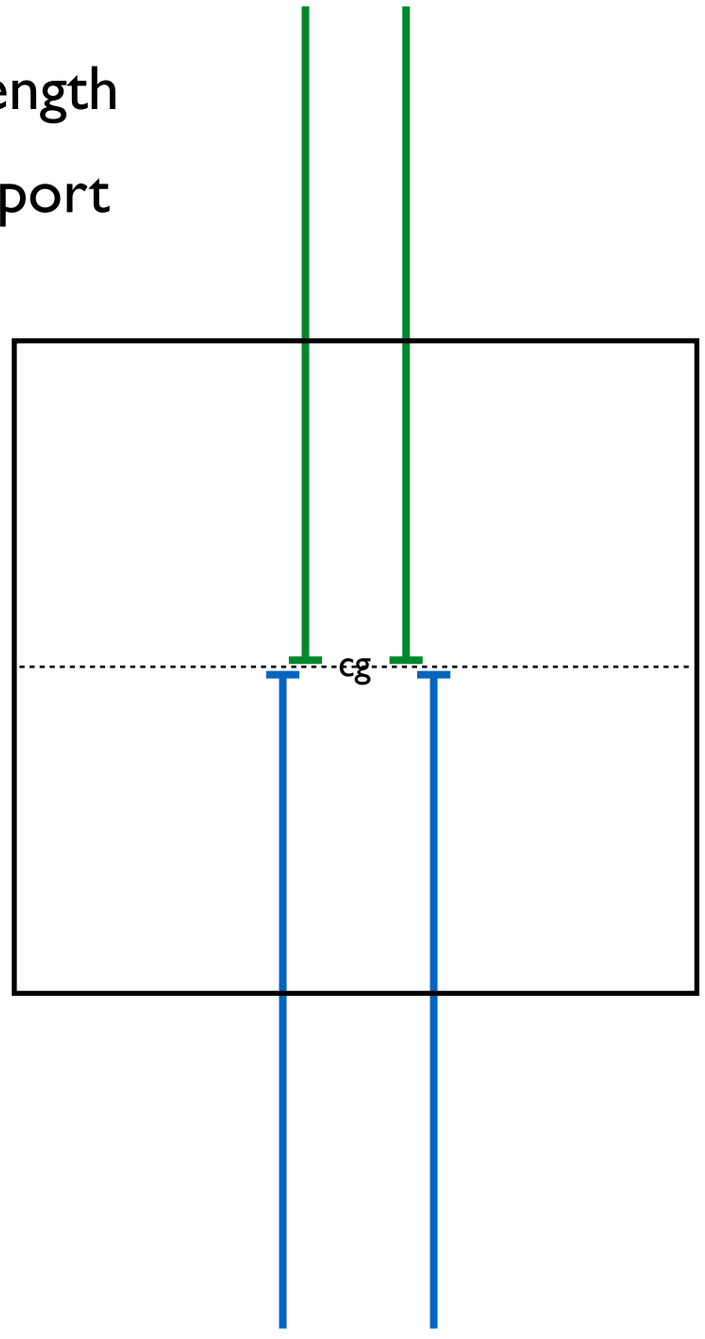


align horizontal actuators, the center of mass, and the effective attachment points (zero-moment planes)

New student Regina Lee, is working with Kevin and Brian on this.

Blue is the current 'Production model' of the quad.

Red uses the same masses and mass locations, but

has 4 wires & springs supporting the top,

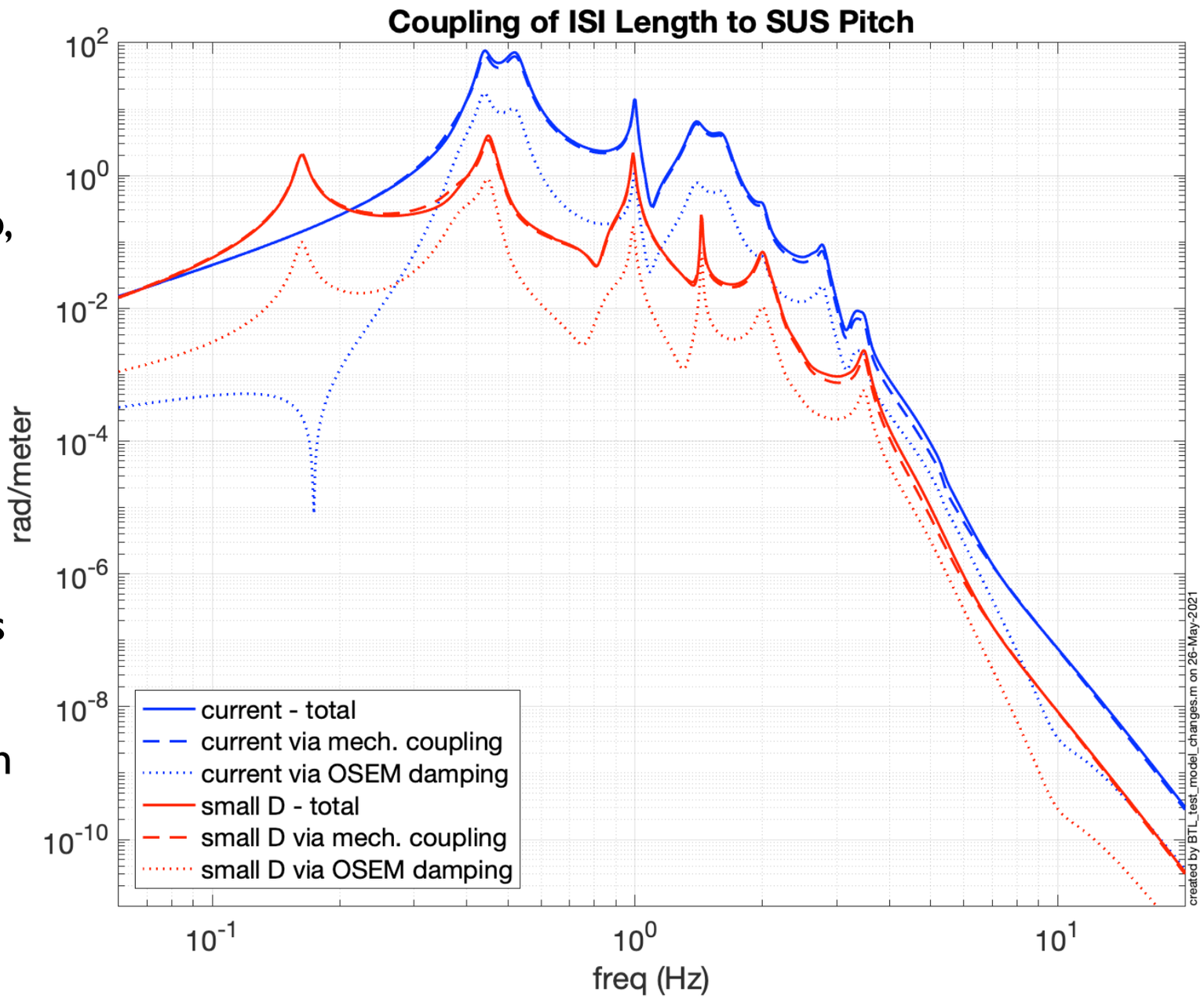
changes the d values to
+/- 0.2 mm (very small) and

adds separation between the wires to add pitch stiffness.

The peaks at 0.4 and 1.0 Hz are much better, the peak at the microseism needs to be moved.

The current "effective" values of d, which include the bending stiffness, etc, are:

% dm: -0.0013
% dn: 0.0088
% d1: 0.0096
% d2: -9.5000e-04
% d3: 0.0078
% d4: 0.0086



https://alog.ligo-la.caltech.edu/SWG/index.php?callRep=11833

UIM damping

plots from T1800504, B. Lantz, E. Bonilla

Design exercise - benefit of adding HoQIs to the existing quad suspensions to damp the UIM against the suspension cage.

Very effective damping, doesn't add 10 Hz noise.

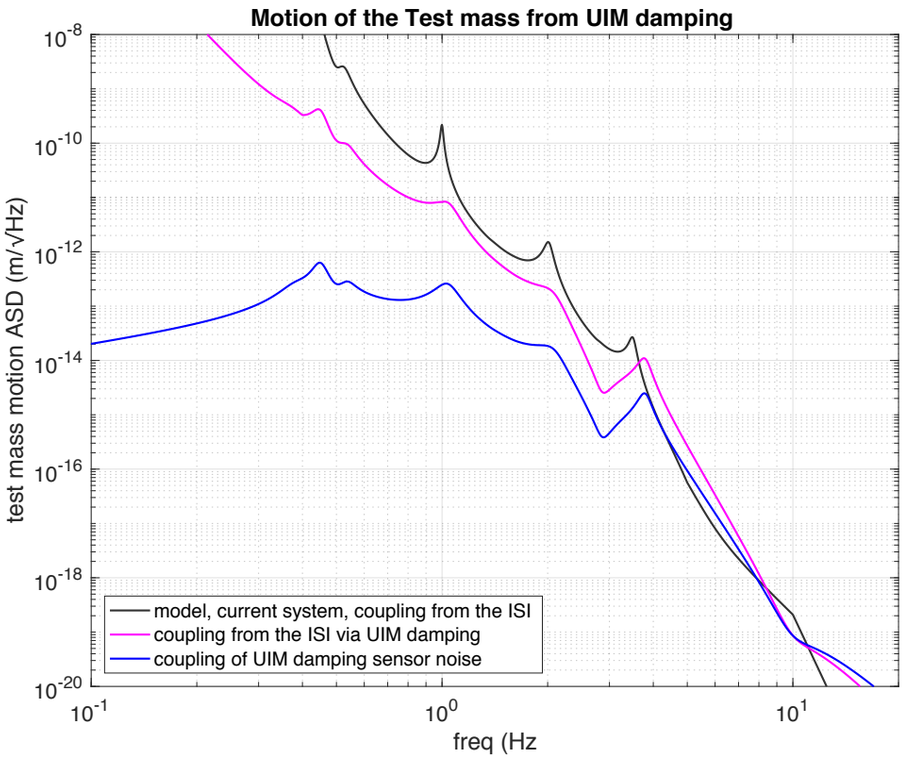


Figure 12: Longitudinal Motion of the test-mass. Inputs include: **black:** current ISI motion requirement * current damped transmission of the suspension from L to L. **magenta:** New ISI motion target * transmission of the suspension from UIM damper coupling to L with added UIM damping. **blue:** Flat sensor noise of $3 \cdot 10^{-13}$ m/$\sqrt{\text{Hz}}$ * transmission through the UIM damper to the test-mass.

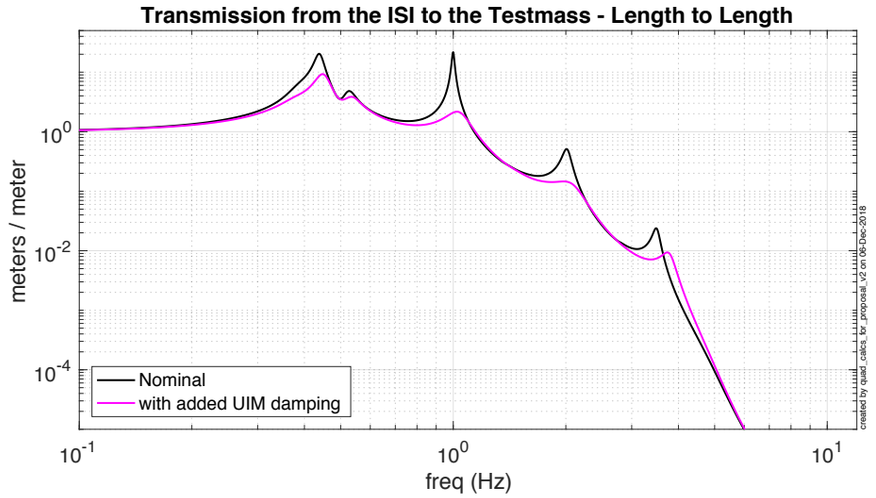


Figure 9: Longitudinal Transmission of the suspension with nominal damping (black) and with the added UIM damping (magenta).

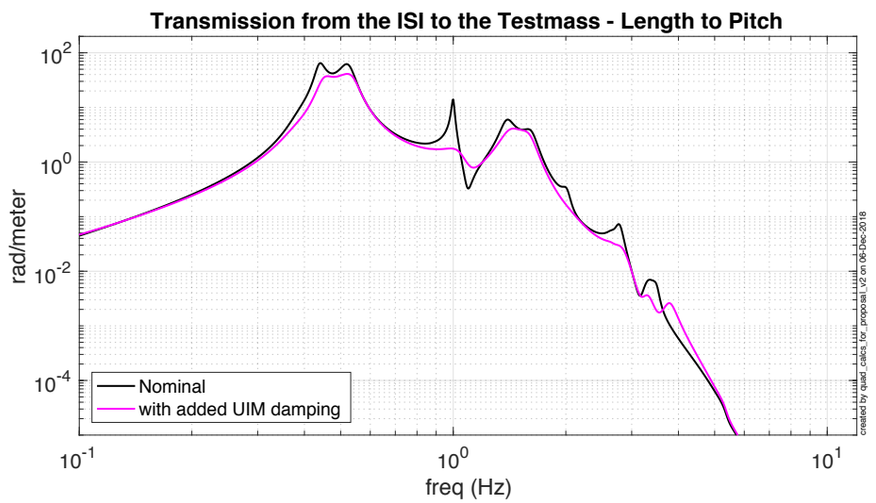


Figure 10: Coupling from ISI translation to test-mass pitch with nominal damping (black) and with the added UIM damping (magenta).

Summary

Angular noise of the optics is a problem which we can make very much better

Still some mysteries

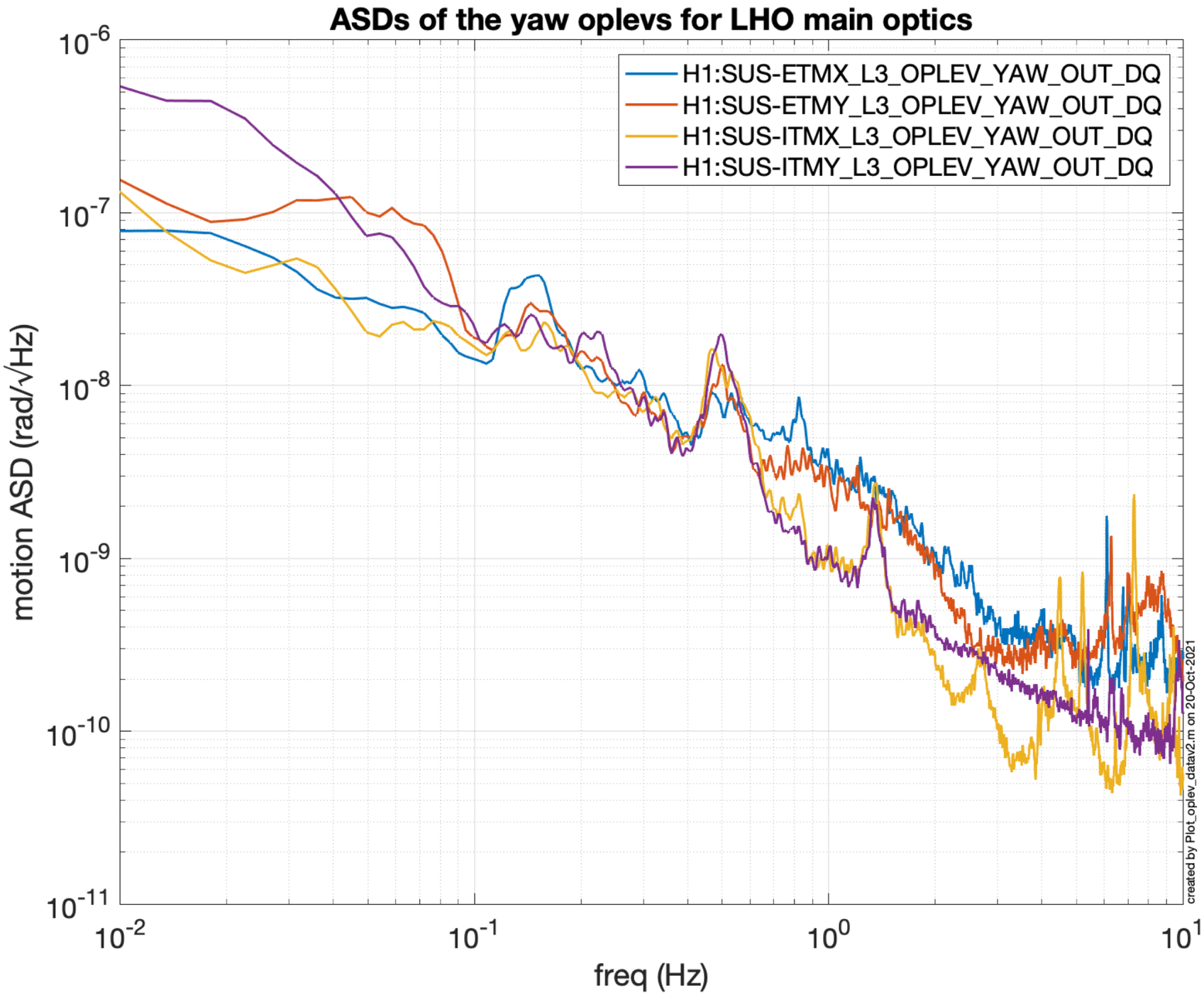
Making a ‘good’ design by march seems unrealistic

Regina is doing some intro design work

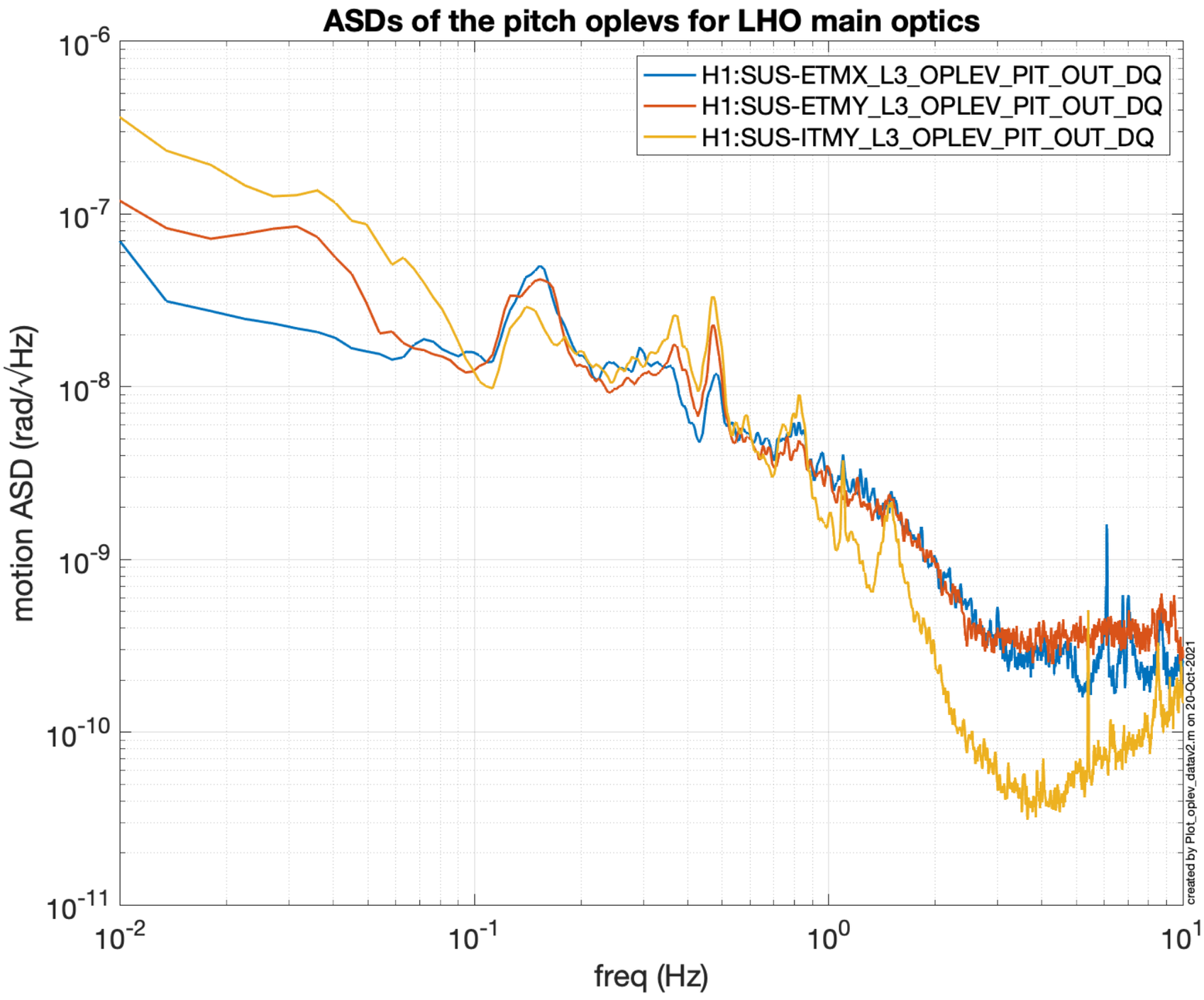
What is the next step?

optical lever on the test mass?

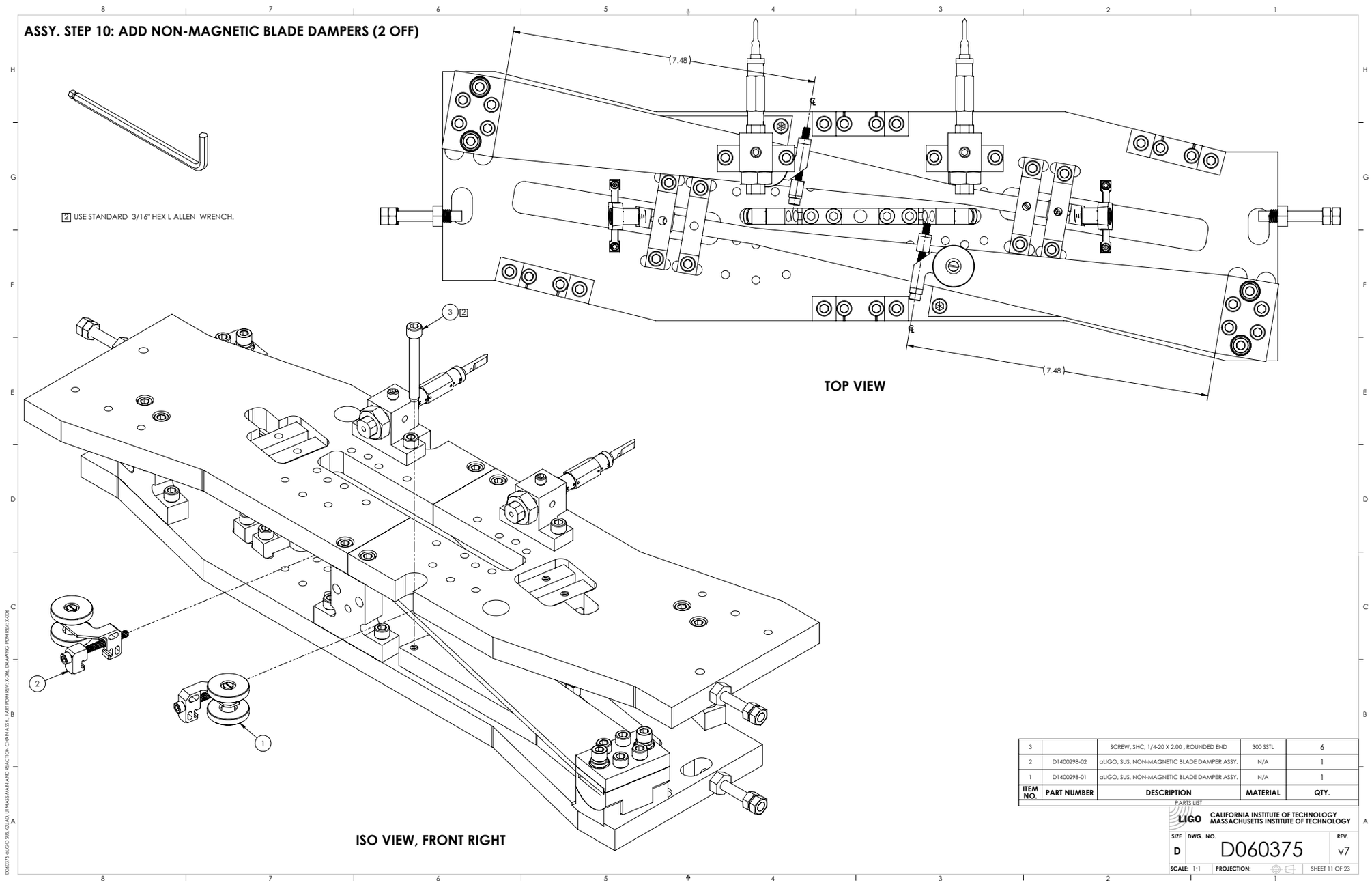
angles of various optics



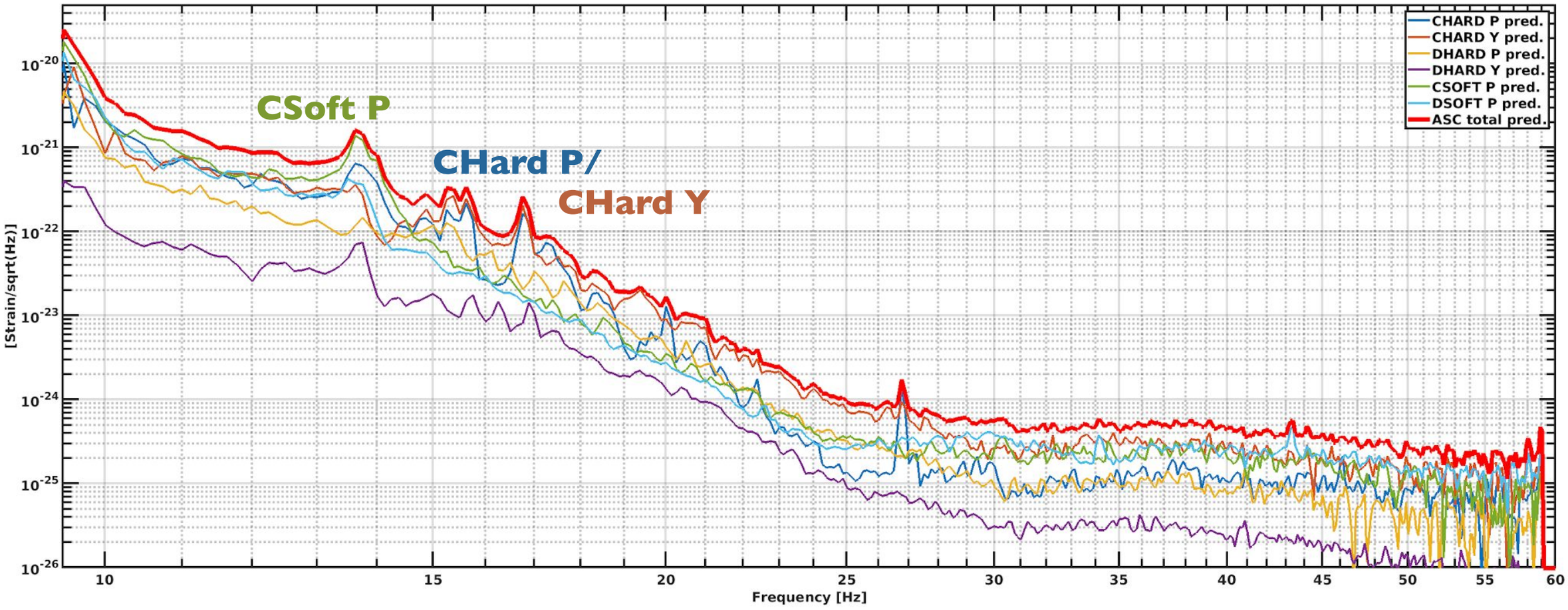
angles of various optics



UIM - Quad suspension has many parts where principle moments and the stiffness are not aligne with the control DOFs, which leads to cross coupling



ASC to DARM, from noise budget Feb 2021, G2100751



Brett did a bunch of work on controls, here's an overview he did on this in May to remind us what he was thinking about.
https://dcc.ligo.org/LIGO-G2100761

ideas about tweaks to the quad suspension, eg.
damping of the UIM - see https://dcc.ligo.org/LIGO-T1800504, Conor Mow-Lowry is thinking hard about this as well
some general thoughts on damping the sigg-sidles mode - https://dcc.ligo.org/LIGO-T1800503
changing the SUS to be 4 wires at the top to reduce the length-to-pitch coupling - see https://alog.ligo-la.caltech.edu/SWG/index.php?callRep=11833
mass optimization - https://dcc.ligo.org/LIGO-T2100287
and a rather old list on SUS upgrade ideas. It's old but it's still good - https://dcc.ligo.org/LIGO-T1300993