Suspension Design Concepts for LIGO A#

Brian Lantz (commenting on the work of many people),
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Work I foresee for the Large suspension subgroup

Opportunities for the Large Optics subgroup

Designing new suspensions gives us the chance to incorporate new ideas to improve the Suspension performance

What we are pretty sure about: (see T2200287)

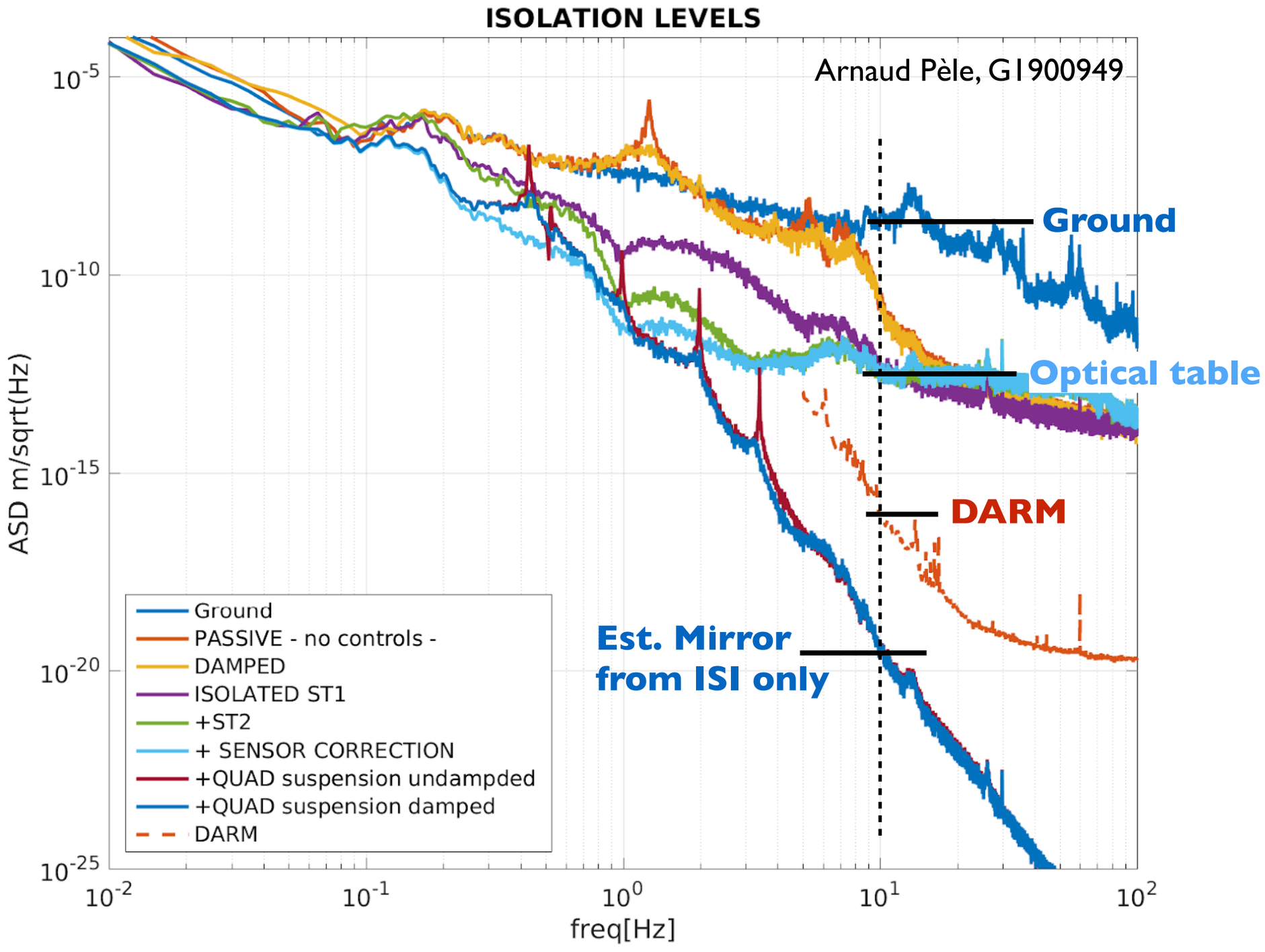
- 100 kg test mass & ~400 kg main chain mass
  (better radiation pressure noise, better Sidles-Sigg performance)
- Higher stress fibers, but no springs from the PUM to the test mass
  (aLIGO is 800 MPa, go to at least 1.2 GPa with a target of 1.6 GPa)
  Lower bounce mode, higher violin modes, better suspension thermal noise
- Same total length for the suspension. Building from the current BSC-ISI.
- Beam size unchanged for amorphous coatings, or maybe smaller for AlGaAs.

What we would like to do:

- Improve DARM at 10-30 Hz by reducing the measurement-band control noise by an order of magnitude, particularly in angle.
- Reduce uncertainties for Cosmic Explorer (not the goal, but a significant benefit)

We need better control

We don't need better isolation. We don't need better SUS thermal noise



Can we design and build a BIG suspension with better control noise?

5 questions to address (highly related)

1. How do you design a Suspension beast this large?
2. What should the reaction chain look like?
3. How much can we reduce the angular excitation of the mirror?
4. Can we improve the damping and reduce the noise from the OSEMs? What other control improvement could we make?
5. How do the SUS performance to ASC performance interact? How much can-we/ must-we lower the bandwidth of the ASC loops? What requirements can we set for ASC bandwidth, angular excitation of the mirror, modal frequencies, etc.
   Can we use ASC to set control requirements on the SUS design?

Heavy Optic needs Heavy Chain

Test Mass should only be 1/3 to 1/4 of the total suspension chain mass,
The top mass should be the heaviest.

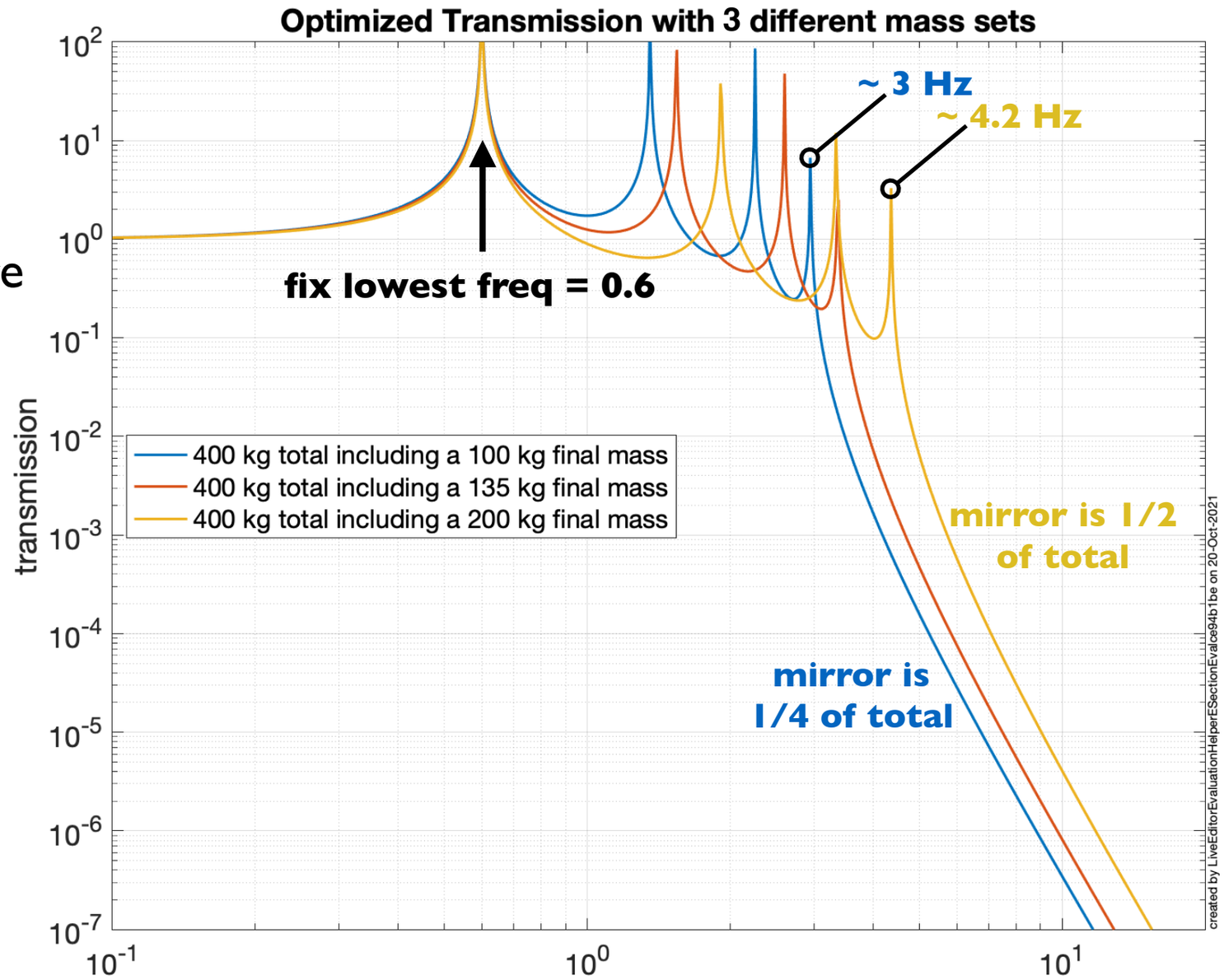
Illustrate with simple model - 4 stage mass-spring system,
Set mirror mass, total mass at 400 kg, and first mode at 0.6 Hz.
Find springs and masses to get best 10 Hz isolation.

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



Size of the Beast

Q1: How do you design a Suspension beast this large?

- 100 kg mirror is big - LIGO aspect ratio yields 46 cm diameter x 27 cm thick
- To keep the set of vibration modes low,
  make the upper masses as heavy as possible.
- Maximizing dimensions give better moments of inertia.
- What do you do with a 148 kg top mass? ('Hurking')
  130 kg aluminum box, 2 cm thick walls, 25 cm tall is 90 cm across.
- Big moments of inertia! Big separation between angle OSEMs!
  (aLIGO top: 22 kg, pitch moment is 0.0069, yaw is 0.046 kg m^2 (T1000286)
  (hurking box: 130 kg, pitch moment 12, yaw is 24 kg m^2)
- You just can't scale the existing suspensions this way.
- Maybe the cage goes through the top mass? Maybe there is no equivalent mass on the reaction chain? Maybe you can put a fancy seismometer in there?
- What about all the other stuff (203 kg transmon, baffles, electrometer, etc)

Reaction chain?

Q2: What about the Reaction Chain?

- If the main chain is 400 kg, the reaction chain is probably limited to 200 kg.
- Can it be a triple, with the main chain reacting against a stage with fewer stages of isolation? How about a double?
- What do the reaction chain dynamics do to the control of the main chain?
- How do you incorporate a cage for the whole contraption? (around, through, use the previous stage?)

Angular Excitation?

Q3: How much can you reduce the angular excitation of the mirror?

- We know that most of the angular motion of the mirror DOES NOT come from the angular motion of the ISI. (2 wire suspension)
- Above 0.7 Hz, the WFS signals are't really correlated to ISI motion at all. (Marie Kasprzack, G2100751)
- Fix the known sources
  - ISI Length cross coupling
  - ISC Length drive cross-coupling
    (4 wires, close alignment of attachment points, see Regina Lee)
  - (also reduce the ISI length input)
  - Noise in OSEMs
  - WFS and HAM1-Z shenanigans (Lower the BW, install an ISI)
- Find the unknown sources (Noise around 1-2 Hz in WFS loops not identified)

Damping and OSEM noise?

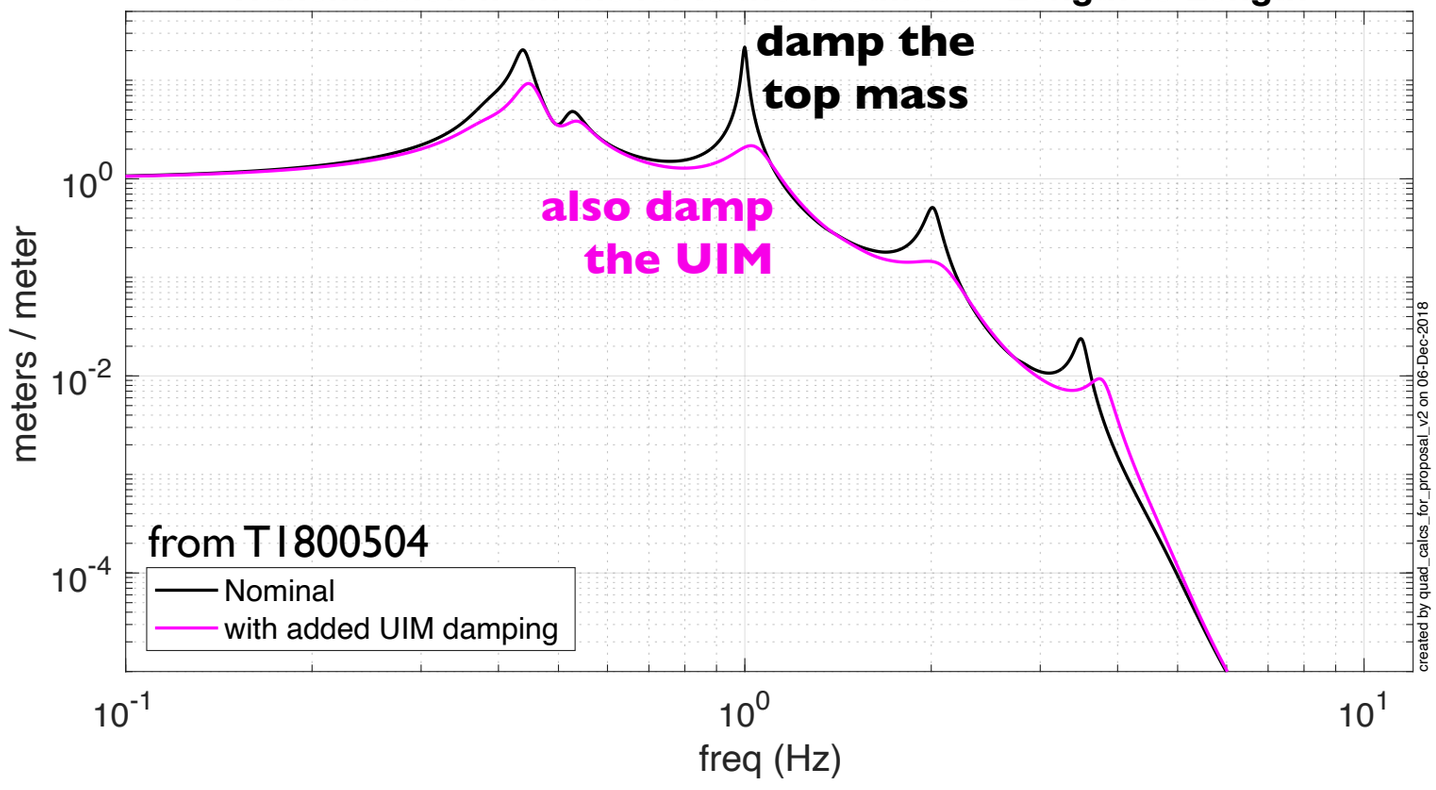
Q4: Can we improve the damping
and reduce the noise from the OSEMs?

- Quad modes are now lightly damped, esp. the higher order modes.
  Partly to reduce the coupling of OSEM noise, partly because the sensing and actuation is at the top mass.
- How much do we win by putting local IFO sensors at the top and at the UIM?
  - e.g. aLIGO quad (T1800504) and Beam Splitter (P210122)

- Seismometers in the top mass?

- How about fancy control?
  - State Estimation,
  - cavity-basis damping, etc

  How to make it deployable?
  (usable/ robust/ maintainable)



Relate SUS and ASC

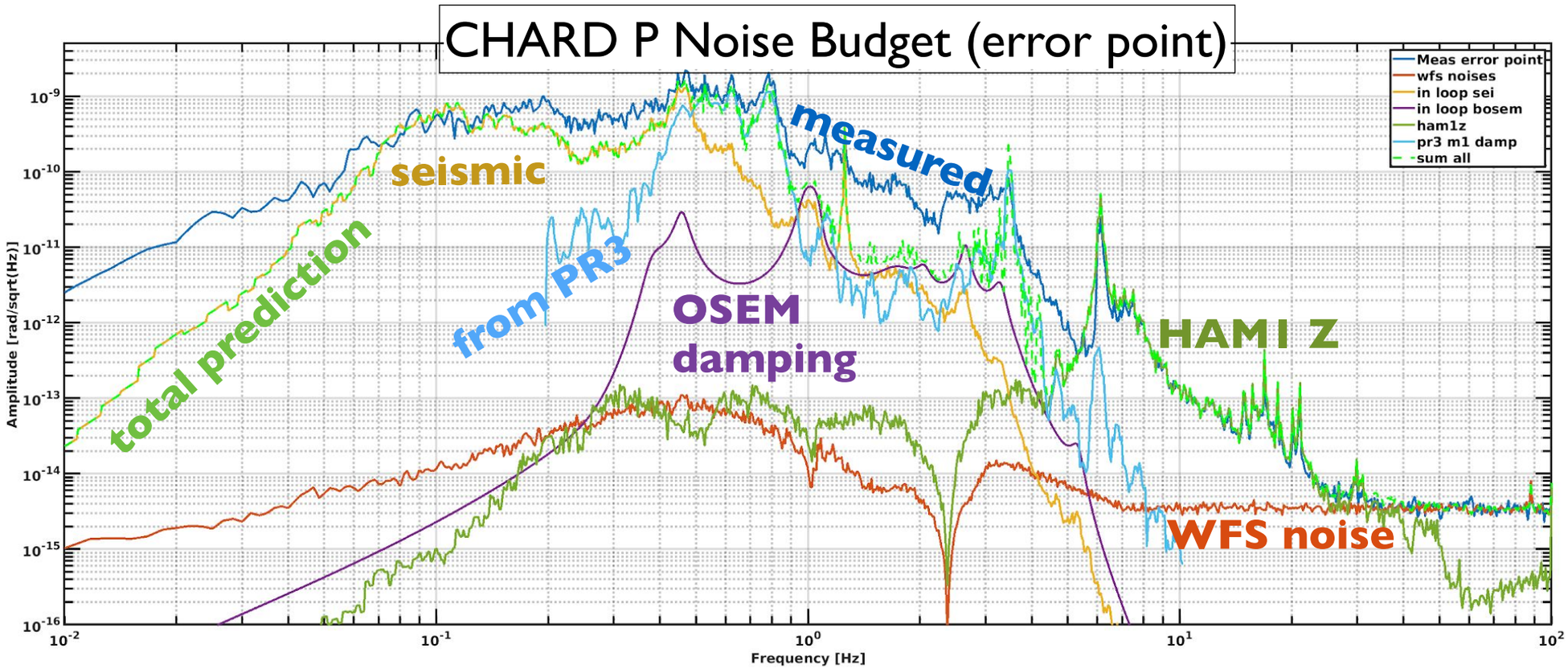
Q5: How do the SUS performance to ASC performance interact?

- Suspension models need to be related to models of the ASC loops
  - How much can reduce the bandwidth of the ASC loops?
  - How much do we need to reduce that bandwidth to be useful?
- What insight and/or requirements can we set for the allowed angular excitation of the mirrors?
- Hopefully this can allow us to set targets for the final design which are more useful than "make wire break-off really close to the center of mass"

Finally

- We have a great opportunity
- I've tried to make some specific questions, many can be answered with 'not much' work by the people in the SWG.
- I'd like to start meeting once a month to talk about these ideas and get folks to start working on the questions listed here.
- Suggest that we coordinate with SWG schedule, maybe use the first Wed of the month at 8:30 am Pacific and ??? for the folks in Australia (Wed evening US/ Thursday morning in Australia?)

adapted from Marie Kasprzack, G2100751



- 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

G2100751