100 kg optic on an upgraded suspension for LIGO A#

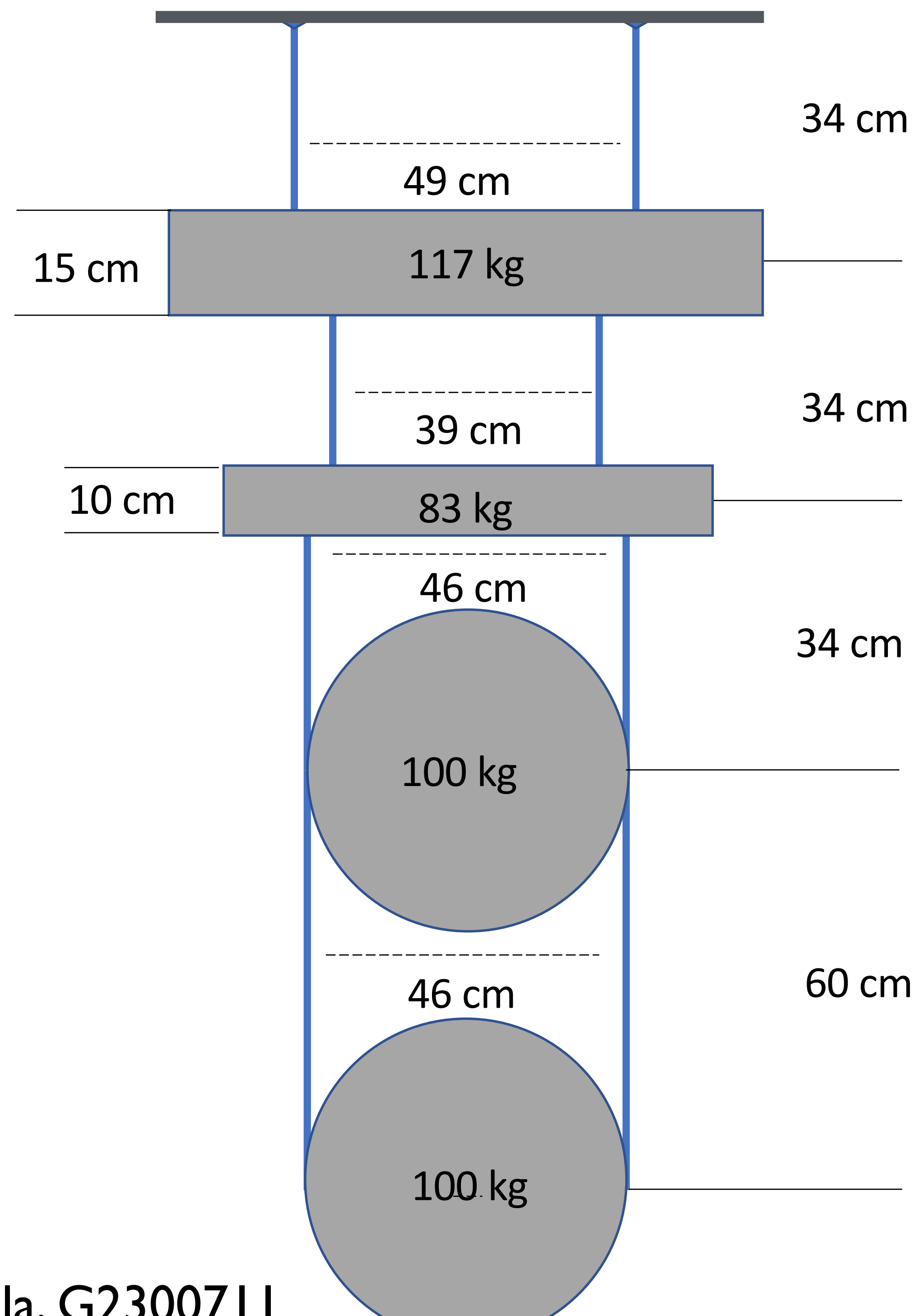
LVK meeting, Toyama

Brian Lantz, Sept 2023, drawing extensively from Heavy suspension subgroup of the LSC - esp. Edgard Bonilla, Calum Torrie, Eddie Sanchez, Betsy Weaver, Conor Mow-Lowry, Giles Hammond, Peter Fritschel

G2301746

LIGO A#

- LIGO A# is the recommend path forward for upgrading the existing LIGO detectors after O5
- Key upgrade is 100 kg optics & suspensions, see 'Post 05 report' LIGO-T2200287
- "Heavy SUS" or BHQS
- "workshop parameters" (T2300137)
  - same length as aLIGO
  - same aspect ratio
    ~ 27 cm thick, 46 cm diam.
  - fibers at 1.6 GPa (2x current)
  - 400 kg main chain
  - Set to "middle" of the ISI to remove the balancing masses
  - allowed a larger footprint
  - double reaction chain



E Bonilla, G2300711

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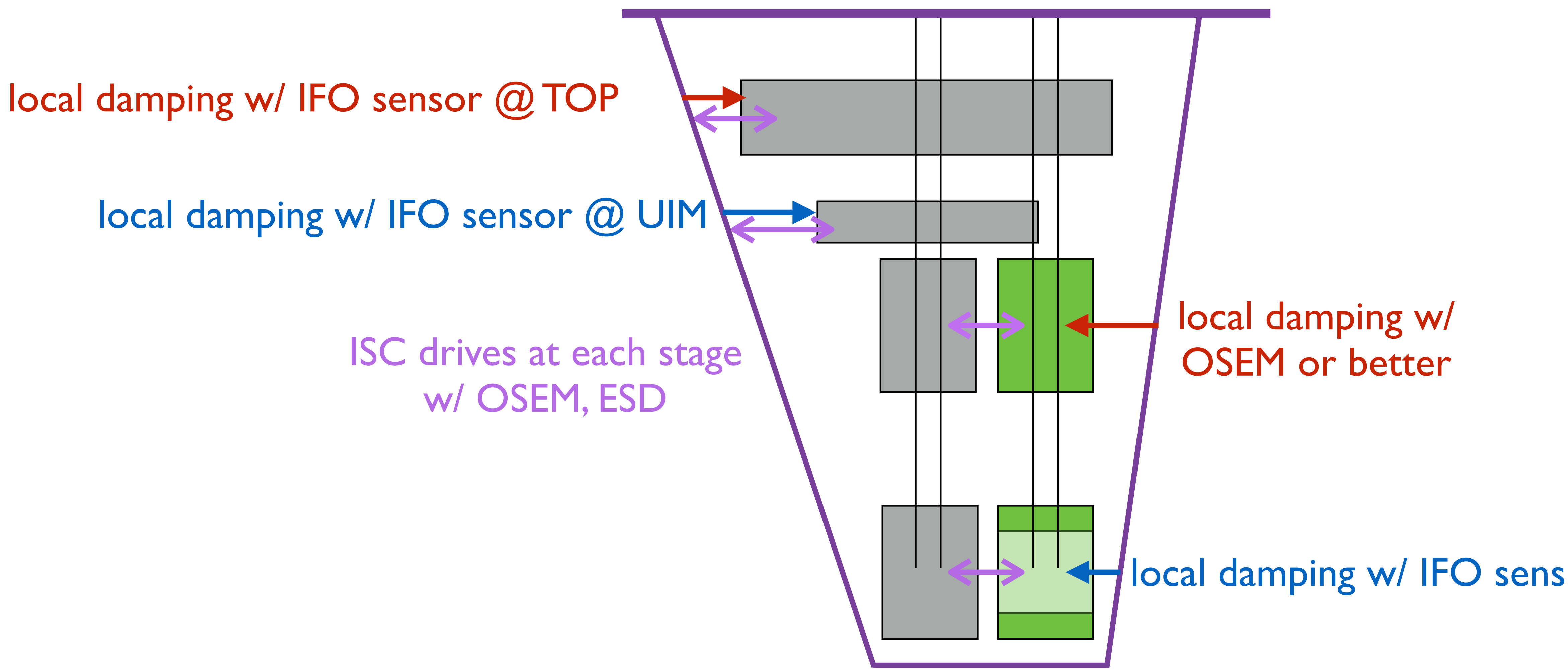
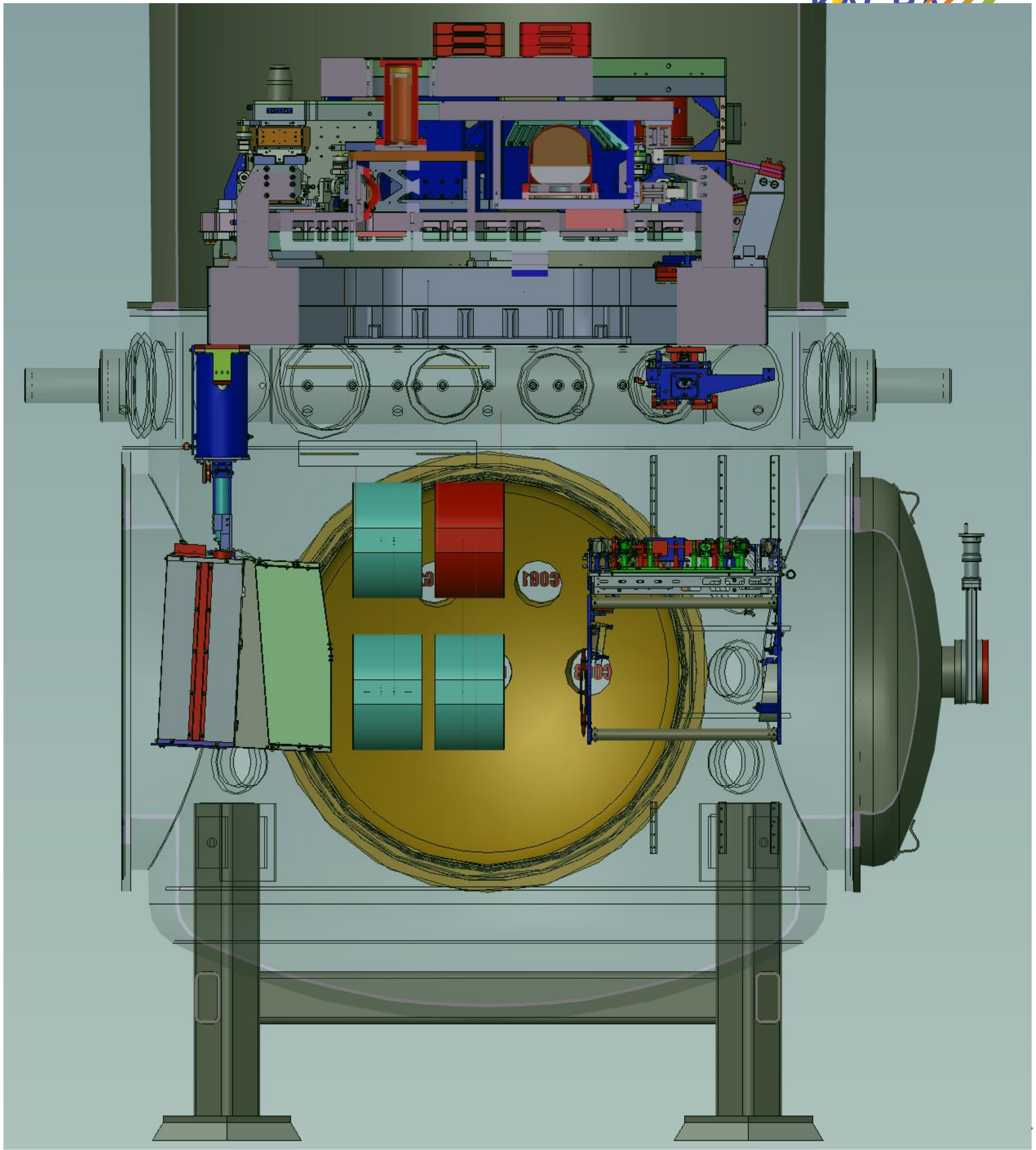


LIGO A#

- CAD sketch by Eddie Sanchez, D2300132
- Keep the existing ISI
- Fit is an issue,
  esp. for transmon
- All install to be done
  "cartridge" style



Why 100 kg?

- Larger suspensions possible because H2 is moving to India
- Heavier optics have lower thermal noise
  and better 'radiation pressure' noise
- Heavier optics (higher moment) have lower Sigg-Sidles frequencies - leads to lower ASC noise
- Hard to push above 100 kg - AdvVirgo+ optics are ~ 100 kg, and so the LMA fixturing in the coating machines is an issue
- ISI total payload is 1000-1100, so main chain limited to about 400 kg. If the test mass gets to be a larger fraction of the total chain mass, the 10 Hz isolation gets worse.

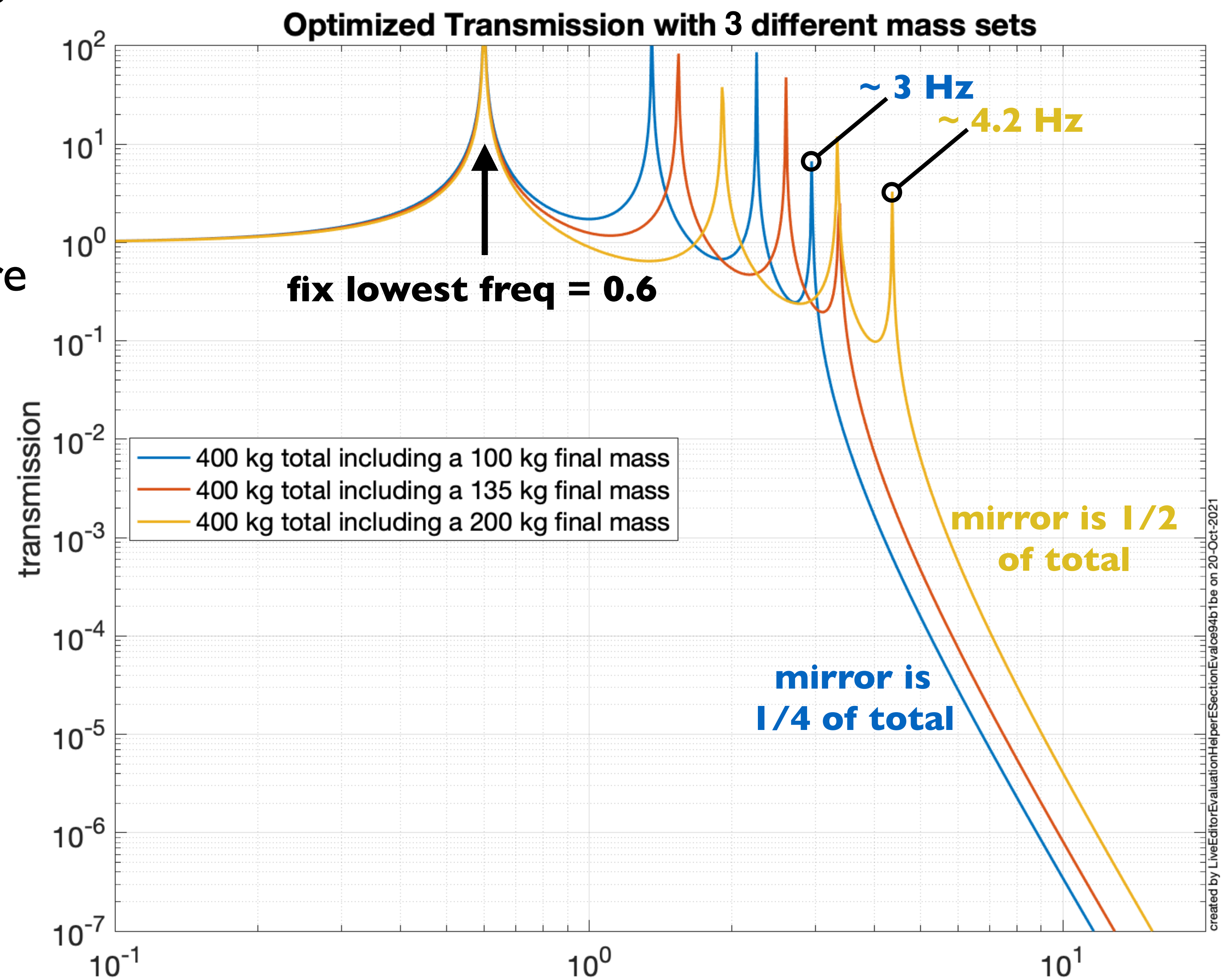
Heavy Optic needs Heavy Chain

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

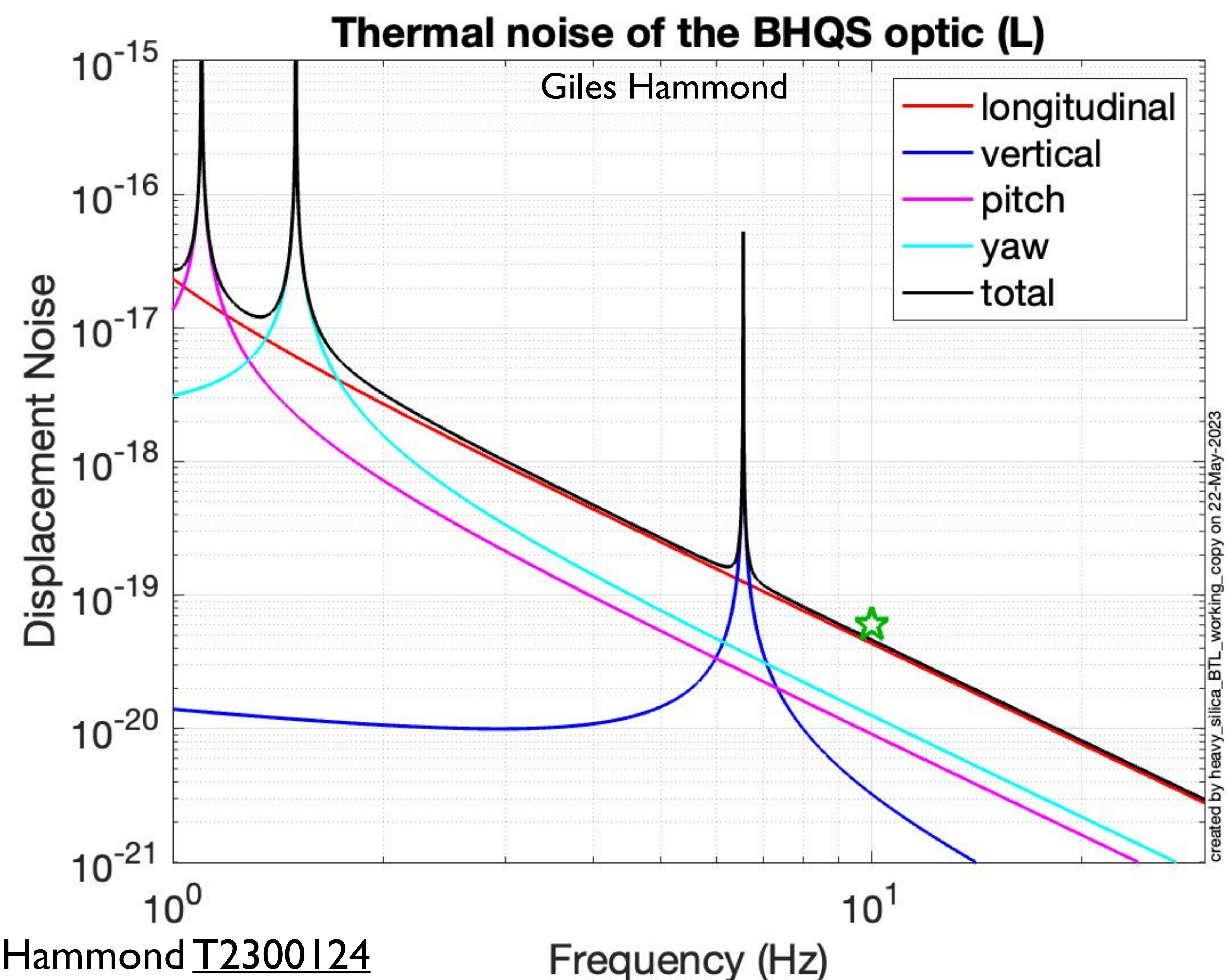
Thermal noise

Thermal noise at 10 Hz is about 5e-20 m/rtHz

Design target is 6e-20 m/rtHz (☆)

Fibers stressed to 1.6 GPa (2x aLIGO), see Glasgow presentations

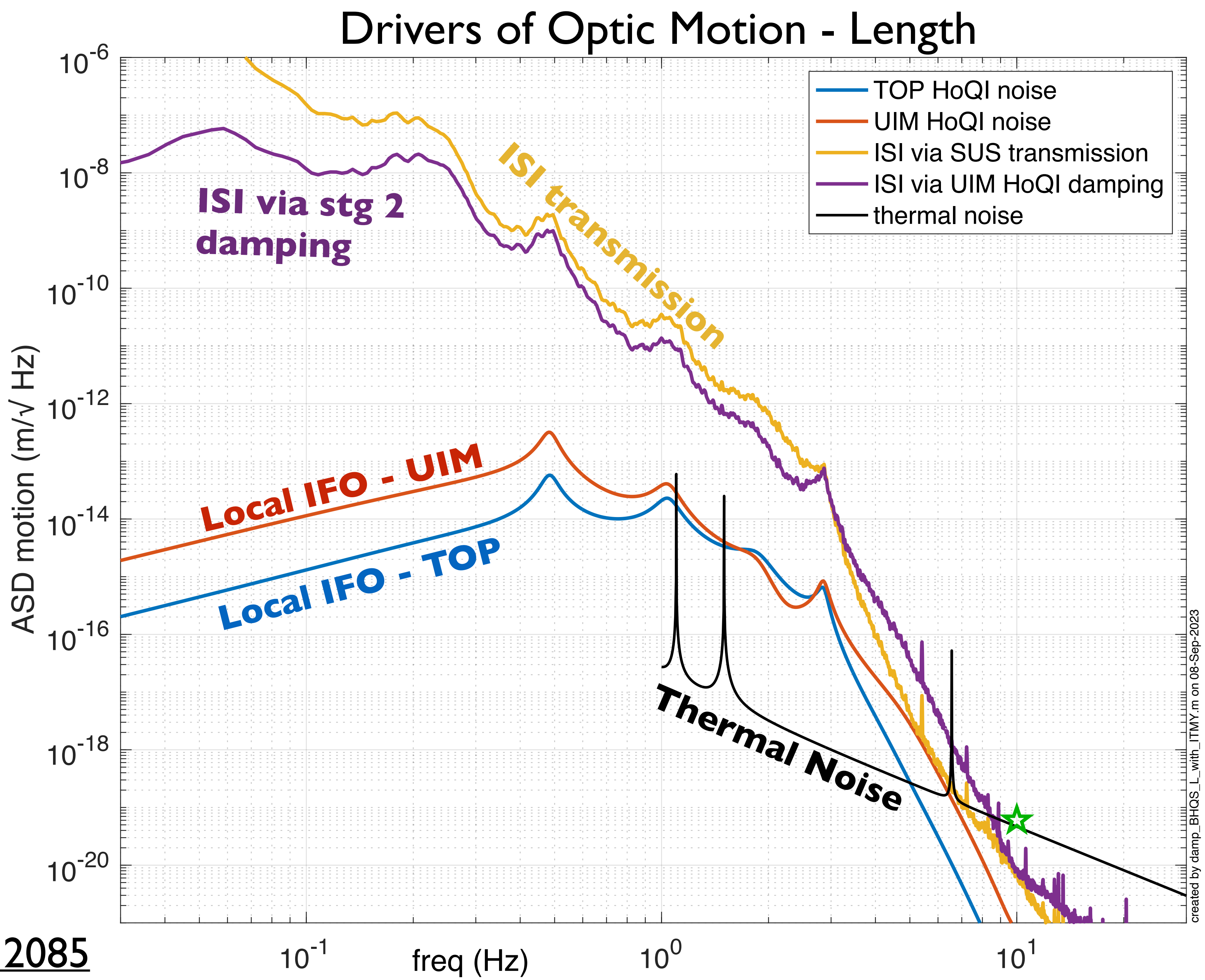
Higher stress fibers also puts bounce/ roll modes at 6.2 Hz & 8.7 Hz



adapted from G. Hammond T2300124

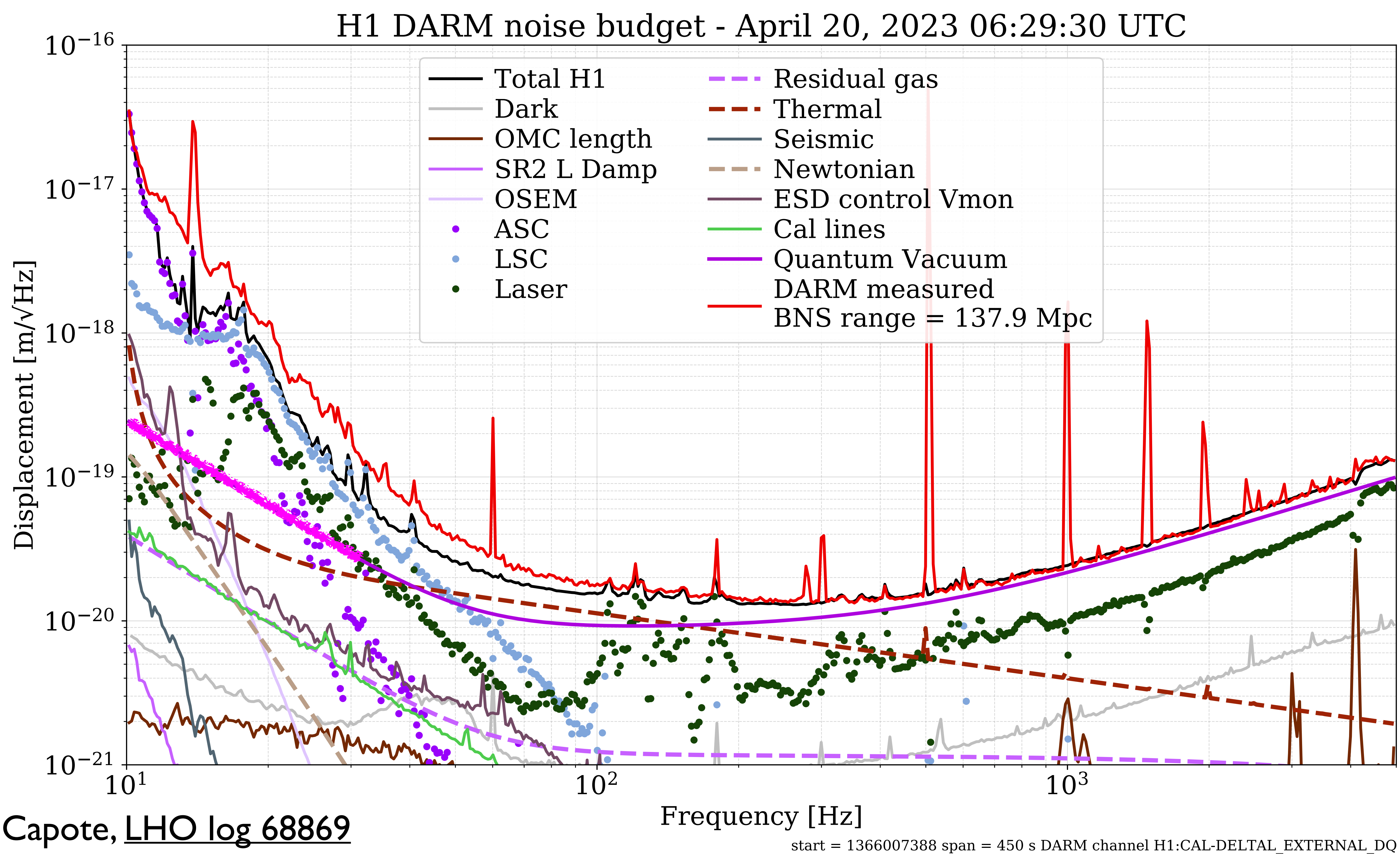
Length Isolation

- Total is below the 6e-20 target @10 Hz
- Assumes local IFO sensors on the TOP and UIM (HoQI, COBRI, SmarAct)
  - the ISI motion dominates at all frequencies (best chamber, quite time)
  - opportunity for better ISI sensors (fused silica seism., 6D, CRS, SPI)



It’s the controls

Noise budgets continue to show ASC noise significantly above quantum noise at low end of the detection band



E Capote, LHO log 68869

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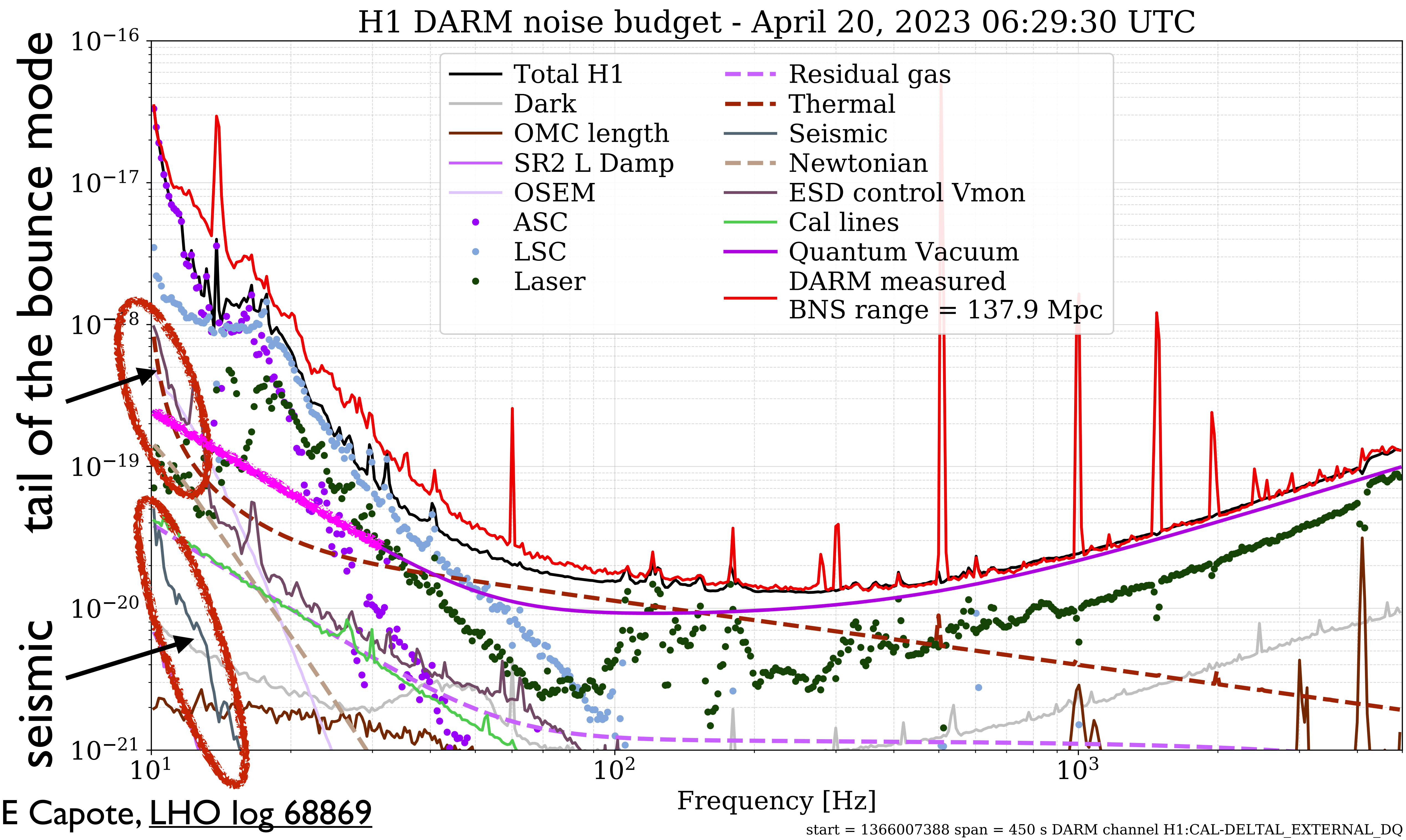

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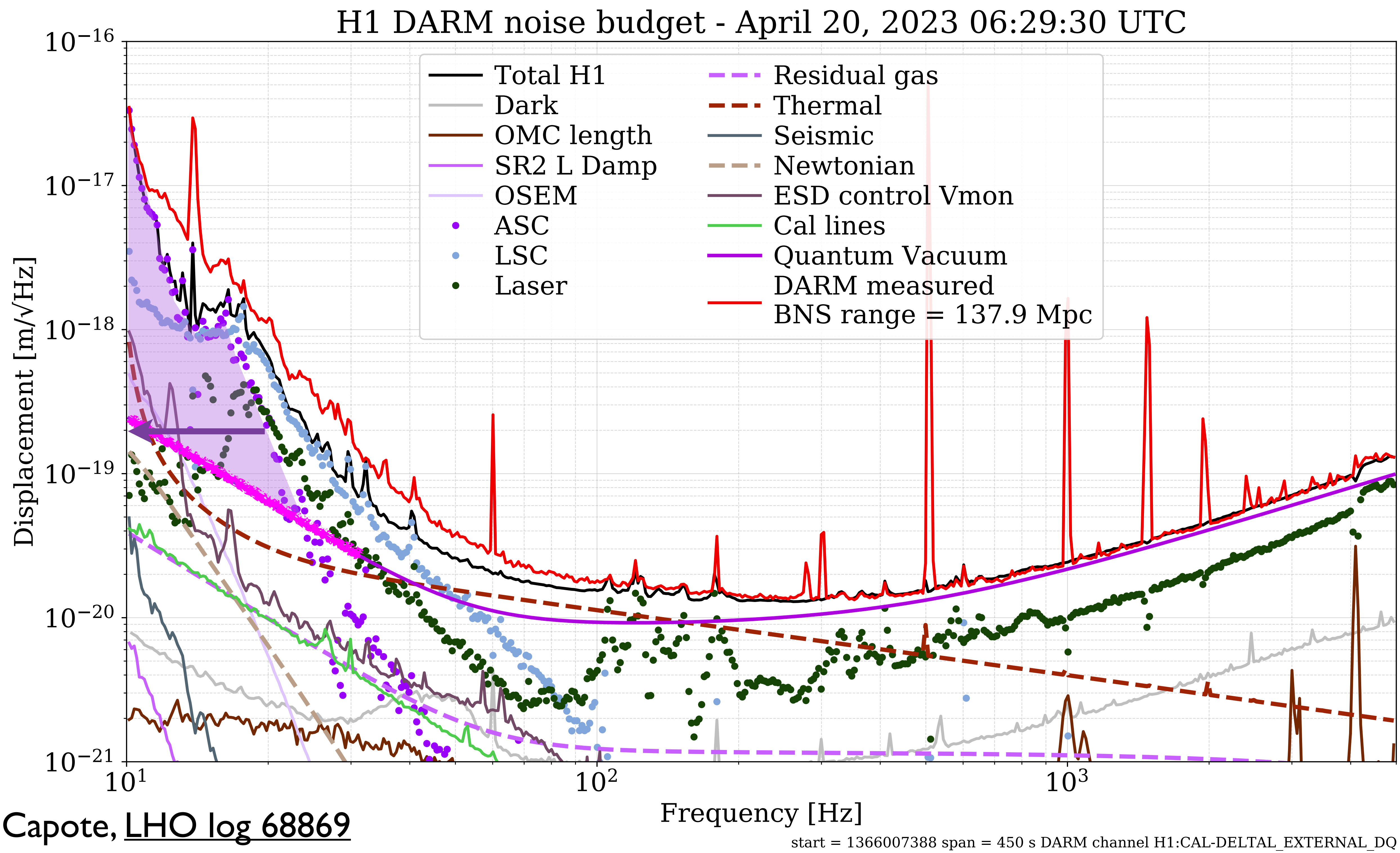


E Capote, LHO log 68869

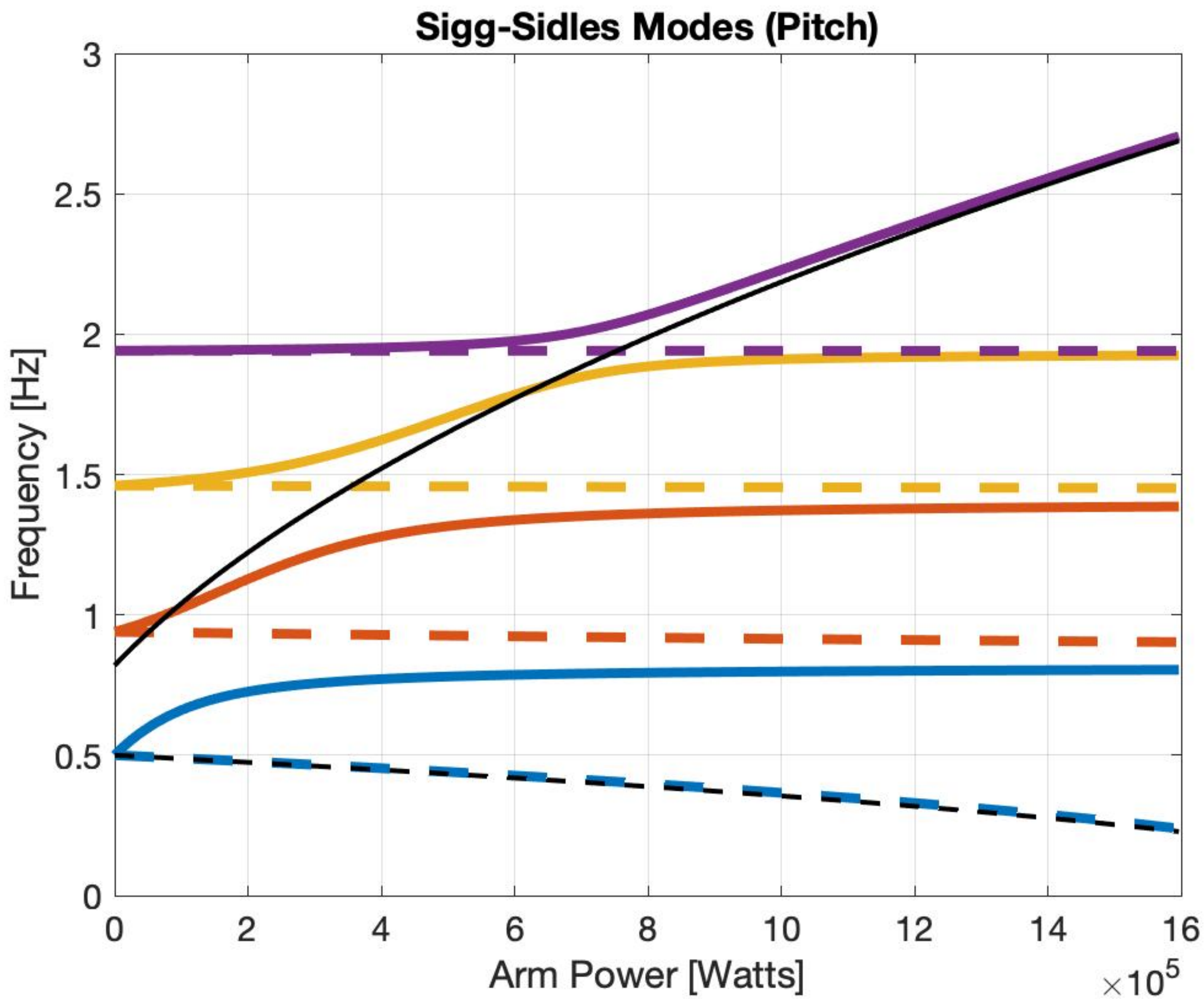
Can we modify the suspension to reduce control noise?

- In particular - reduce the ASC noise
- Heavy (High-moment) test mass to reduce the Sigg - Sidles mode frequency - damping this mode drives the ASC control.
- Reduce all the angular excitations of the mirror - seismic, local damping, and cross coupling from LSC. Reduce the BW of the alignment control needed to achieve 1e-9 radians RMS.
- (Also reduce the ASC sensing noise,
  and coupling of ASC to length,
    but not in this talk)

Sigg-Sidles modes

- at 1.5 MW, Pitch and yaw modes set by Sigg-Sidles & optic

- can damp with ASC, and keep the 1e-17 rad/rtHz at 10 Hz, - ***only*** *(probably)* - if the ASC rms control is well separated from the 2.6 Hz damping



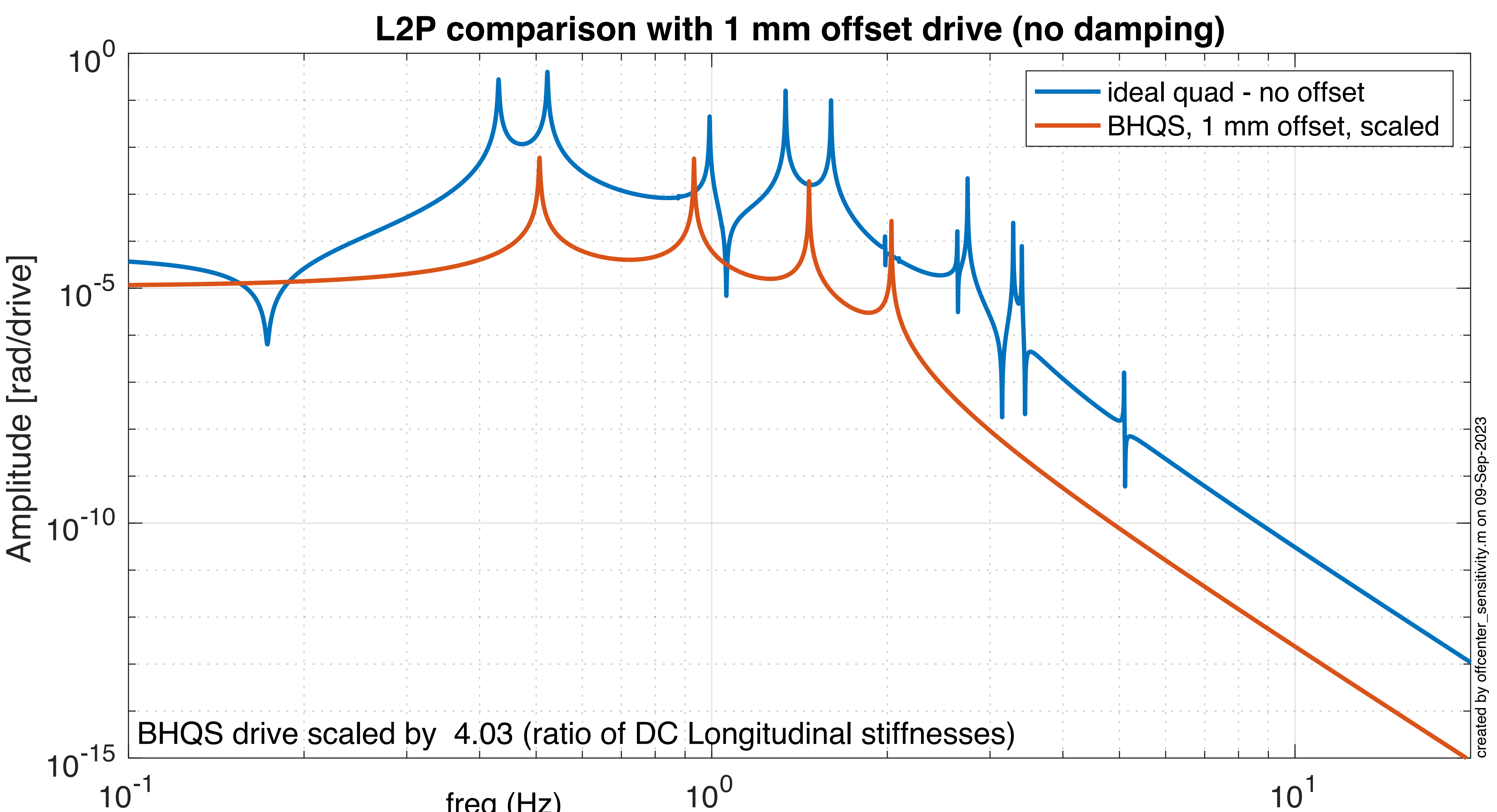
Edgard Bonilla, G2300771, T2300150

Decouple Length & Pitch

- Current Quads have 2 wires at the top,
  so optic pitch is all from the control and ISI Length
- New "workshop parameters" have 4 wires at the top,
  more coupling from ISI pitch, less from length
- Puts all the wires vertical
  (OK if the springs take up big footprint on the ISI)
- Attach all the wires "at" the center of mass

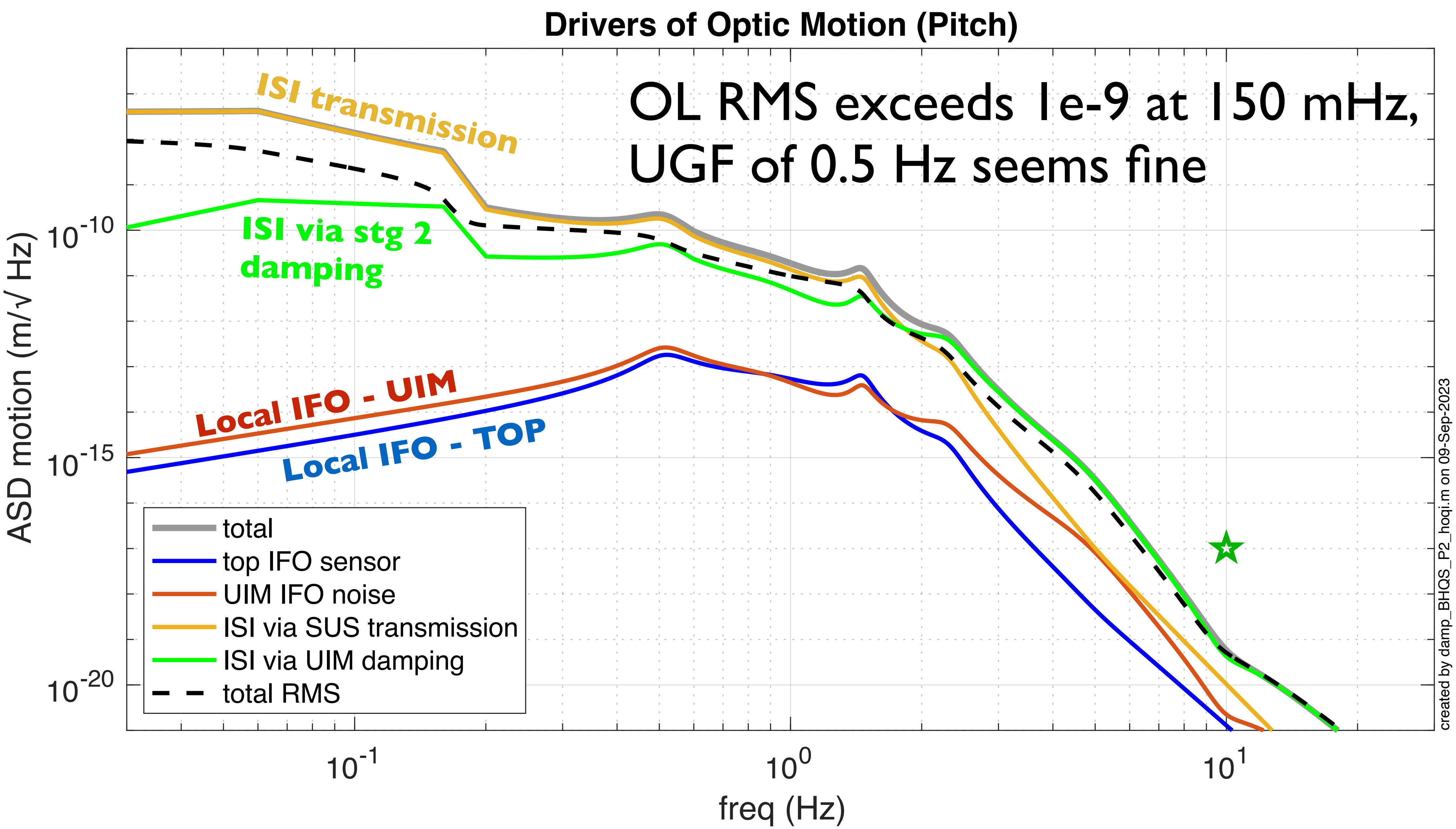
Decouple Length & Pitch

Cross coupling is greatly reduced in design:
- nominal is 0, because attachments, cg, and actuators aligned
- Large moments lower compliance of pitch/ yaw
- simpler pitch plant makes compensation practical



RMS angle of the mirror

- Angular motion of the optic from ISI & SUS sensors is very small. Again, ISI dominates at all frequencies
- Cross-coupling from LSC is small
- Very promising for improved ASC noise couping



Upgrades, upgrades!

(we're trying to learn from experience)

- Faster installation - full assembly and integration outside the chamber (Betsy, Calum)
- Baffles incorporated with the cage (Calum, Alena)
- FROSTI for improved thermal compensation (Cao
- Violin-mode dampers (Georgia Mansell & Trent Gayer)
- Automatic control design (Ian MacMillan & Lee McCuller)
- Cage Design and SUS prototyping at MIT (Regina Lee and JD Heyns)

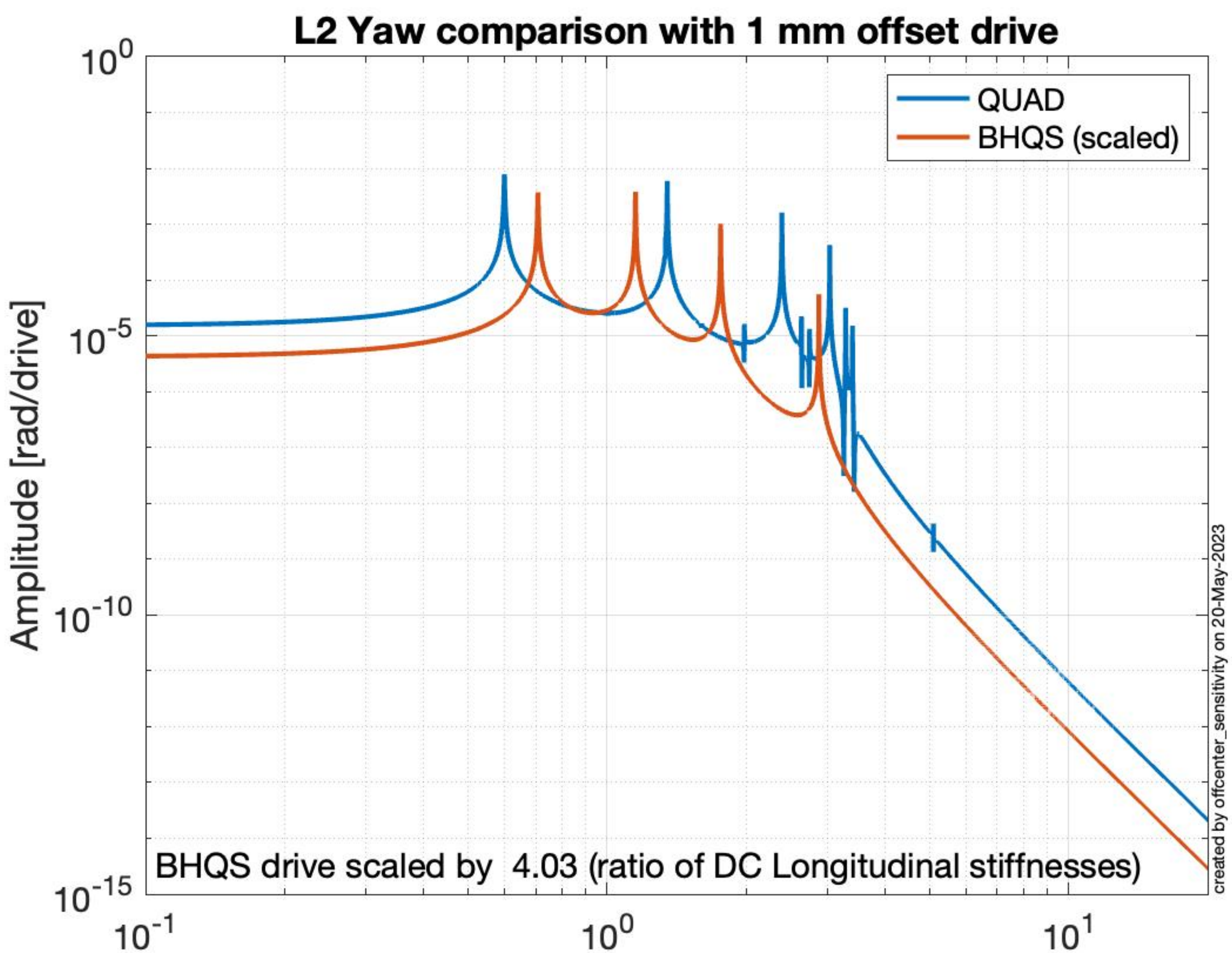
and so…

- Significant effort underway to design the A# suspension (BHQS)
- High stress fibers improve the suspension thermal noise
- Bigger mass manages Sigg-Sidles modes
- Update to GEO/ aLIGO design to improve control, and addition of new sensors should improve the "control" noise so that we can appreciate better thermal noise

  \- but -
- Just starting on the ASC modeling and actuator noise
- Can we fit a top mass that big?
- Should we add other sensors?
- Double reaction chain? really?
- Where to put the transmon suspension? etc. etc.
- Significant update, we've learned a lot from aLIGO, and it's a step leading directly towards Cosmic Explorer

concerns

- Compensation plate - what are the requirements?
- Where to put FROSTI and TransMon
- angular dynamics at high power
- what excites the SS mode?
-


L2 Yaw comparison with 1 mm offset drive
QUAD
BHQS (scaled)
Amplitude [rad/drive]
BHQS drive scaled by 4.03 (ratio of DC Longitudinal stiffnesses)
created by offcenter_sensitivity on 20-May-2023
10^{0}
10^{-5}
10^{-10}
10^{-15}
10^{-1}
10^{0}
10^{1}