aLIGO QUAD "Level 2" Damping Loop Design

(Supplemental to LLO aLOG 6949)

J. Kissel

aLIGO QUAD "Level 2" Damping Loop Design

Mission Statement

Level 1

The damping loops installed during the SUS testing phase

- merely to prove that the suspensions *could* be damped
- damped quickly and robustly
- little-to-no regard to re-injection of sensor noise
- very aggressive, but poorly placed elliptic filters to rolloff noise

Level 2

The mission here was to design a set of loops, that

- doesn't take you years to design and tweak
- isn't on the hairy edge of instability
- doesn't require any "Brett Shapiro" trickery (damping in Modal, Global bases)
- doesn't require and new infrastructure (which Modal and Global damping would),

but still

- designed with what modeling experience we've gained
- gets us *close* to what we'll need for aLIGO, primarily focusing on Longitudinal
- will be sufficient for the first several stages of integrated testing

Damping Loop Design

Model Figures of Merit

- **Stability**: Bode plots of Open and Closed Loop Gain Transfer Functions
- **Cross-Coupling**: The above, Modeled both as SISO and MIMO systems, the below as MIMO
- **Modeled Performance**: Compute all DOF's of Top Mass sensor noise contribution to Test Mass degree of freedom of interest
- **Compare**: with other noise sources, requirements, etc.
- **Measured Performance**: With what we can: Closed Loop TOP2TOP Open and Closed Loop TFs, TOP Sensor ASDs, TOP Control Signal ASDs

Damping Loop Design

Stability (New Filters)

Plant:

$\color{blue}{\text{SISO Model}} = P_L$

Controller:

SISO Model = K_L

Open Loop Gain TF:

SISO Model = $P_L * K_L$

MIMO Model = Full State Space System

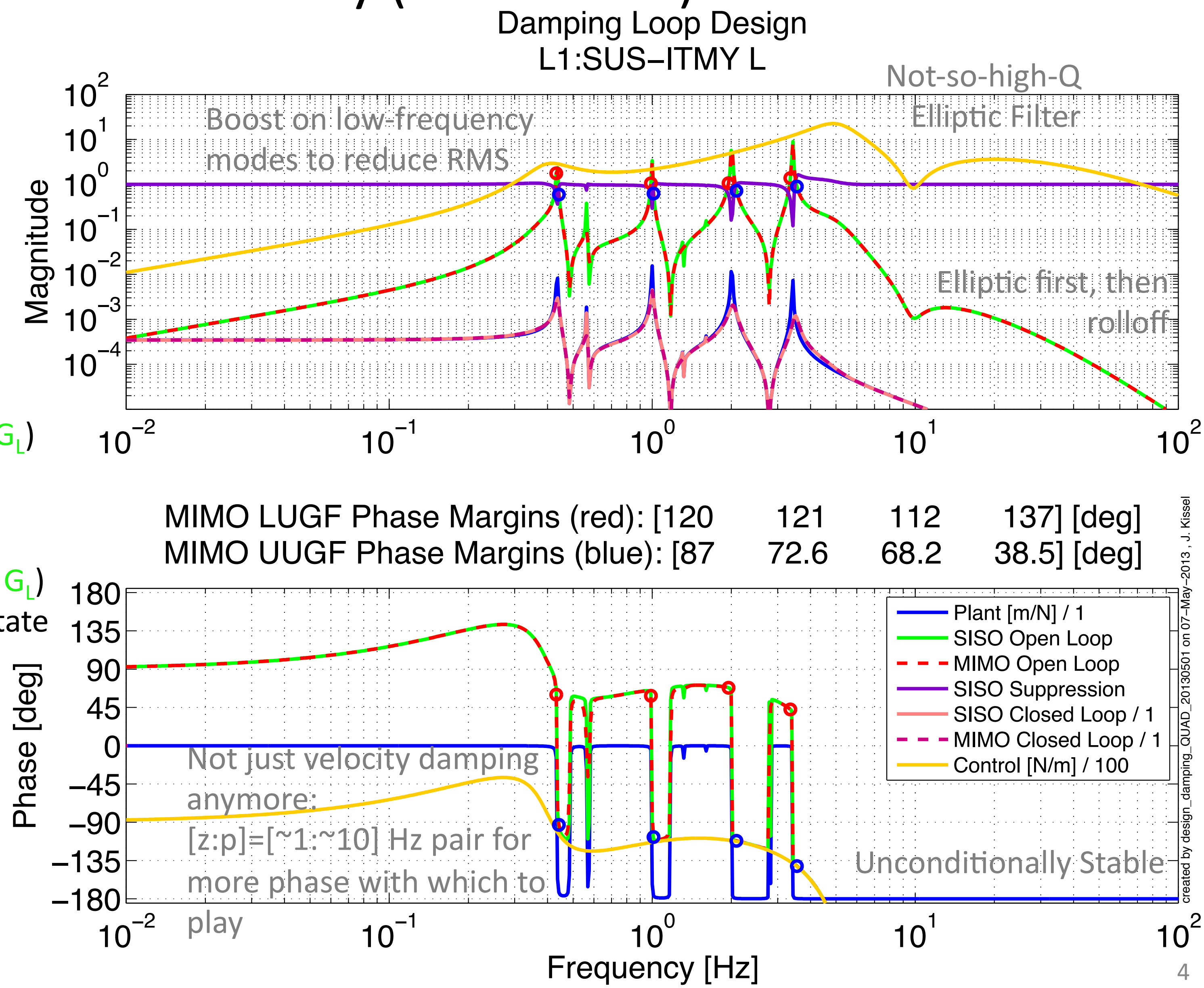
Suppression:

SISO Model = $1 / (1 - G_L)$

Close Loop Gain:

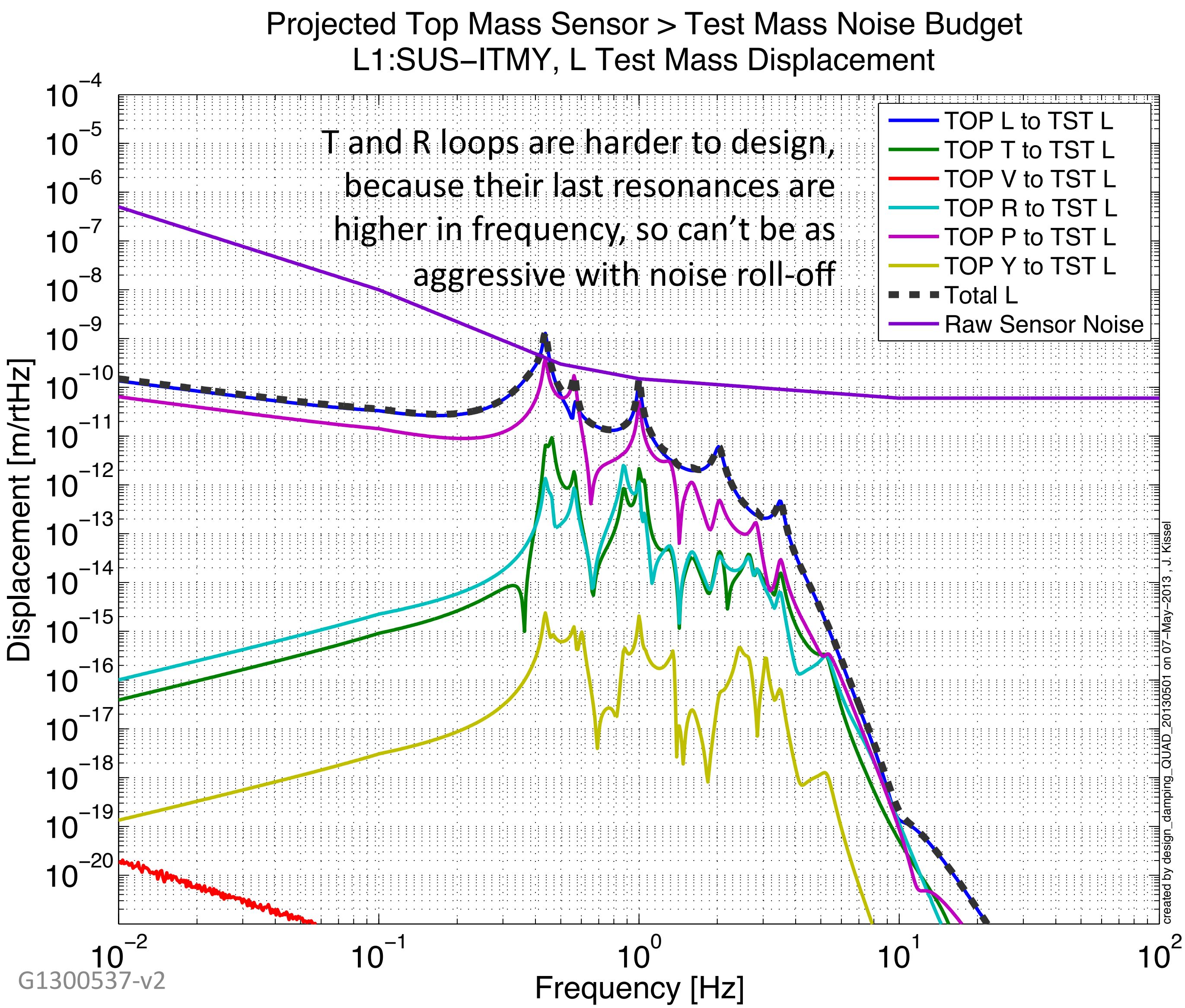
SISO Model = $P_L / (1 - G_L)$

MIMO Model = Full State Space System



Damping Loop Design

All DOF's TOP Sensor Noise Contribution (New Filters)

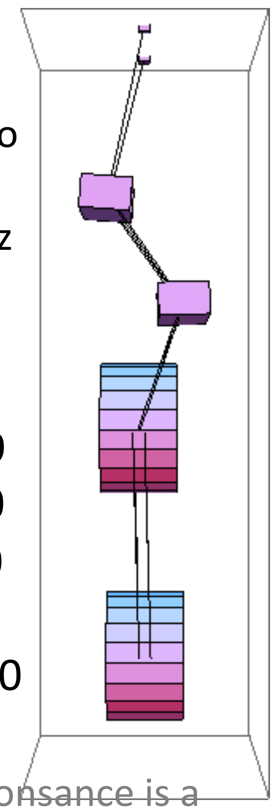


When you start carving out the L contribution to L Test Mass Motion, P, R, and T's contribution are there waiting for you too!

Sensor noise contributions to L Test Mass Motion @ 10Hz [m/rtHz]:

L2L = 2.0e-19
R2L = 1.1e-19
P2L = 8.7e-20
T2L = 5.0e-20

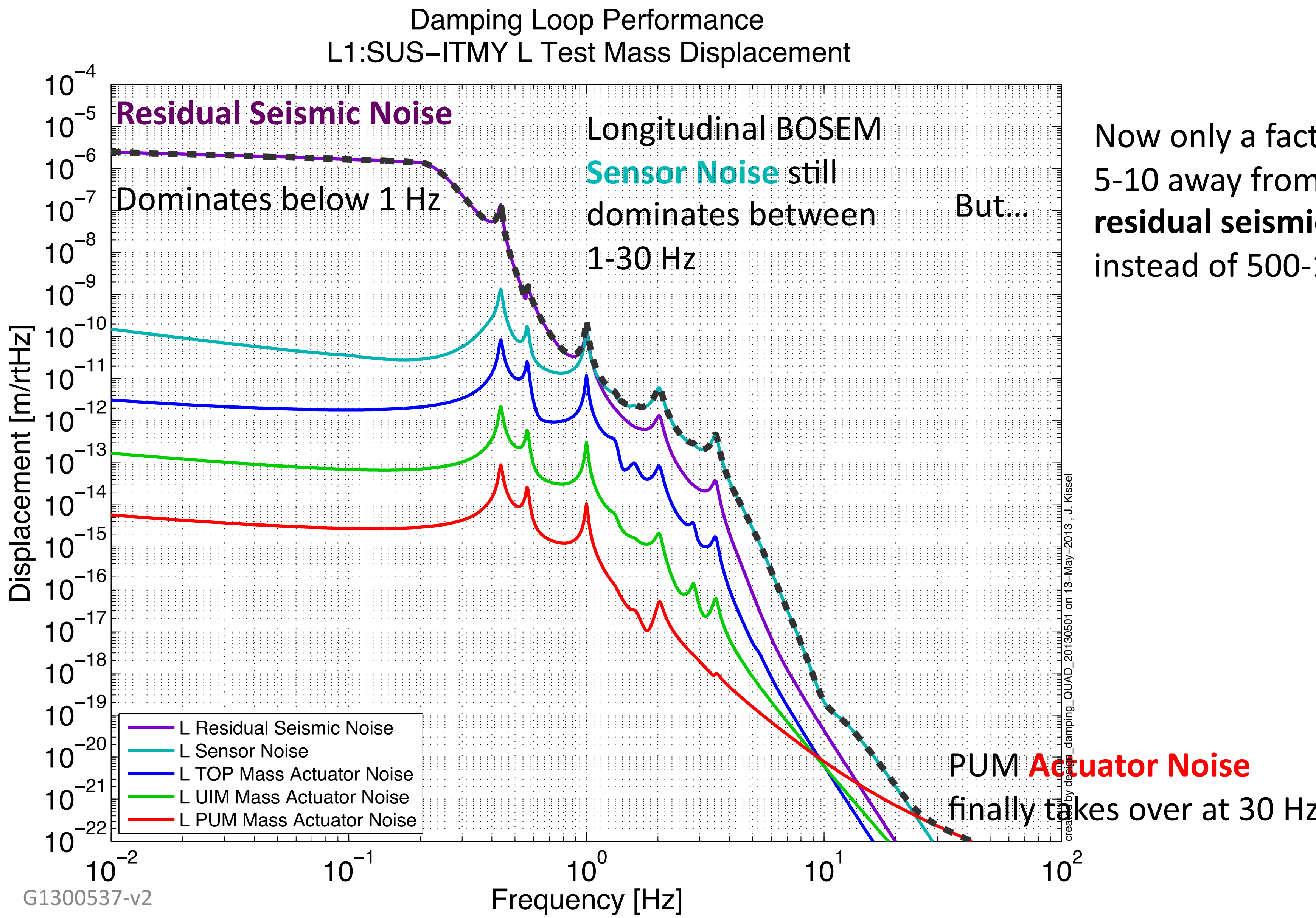
L Reqs = 1e-20



4th "L" resonsance is a mess of L, T, R, and P

Damping Loop Design

Compare with other Noises (New Filters)

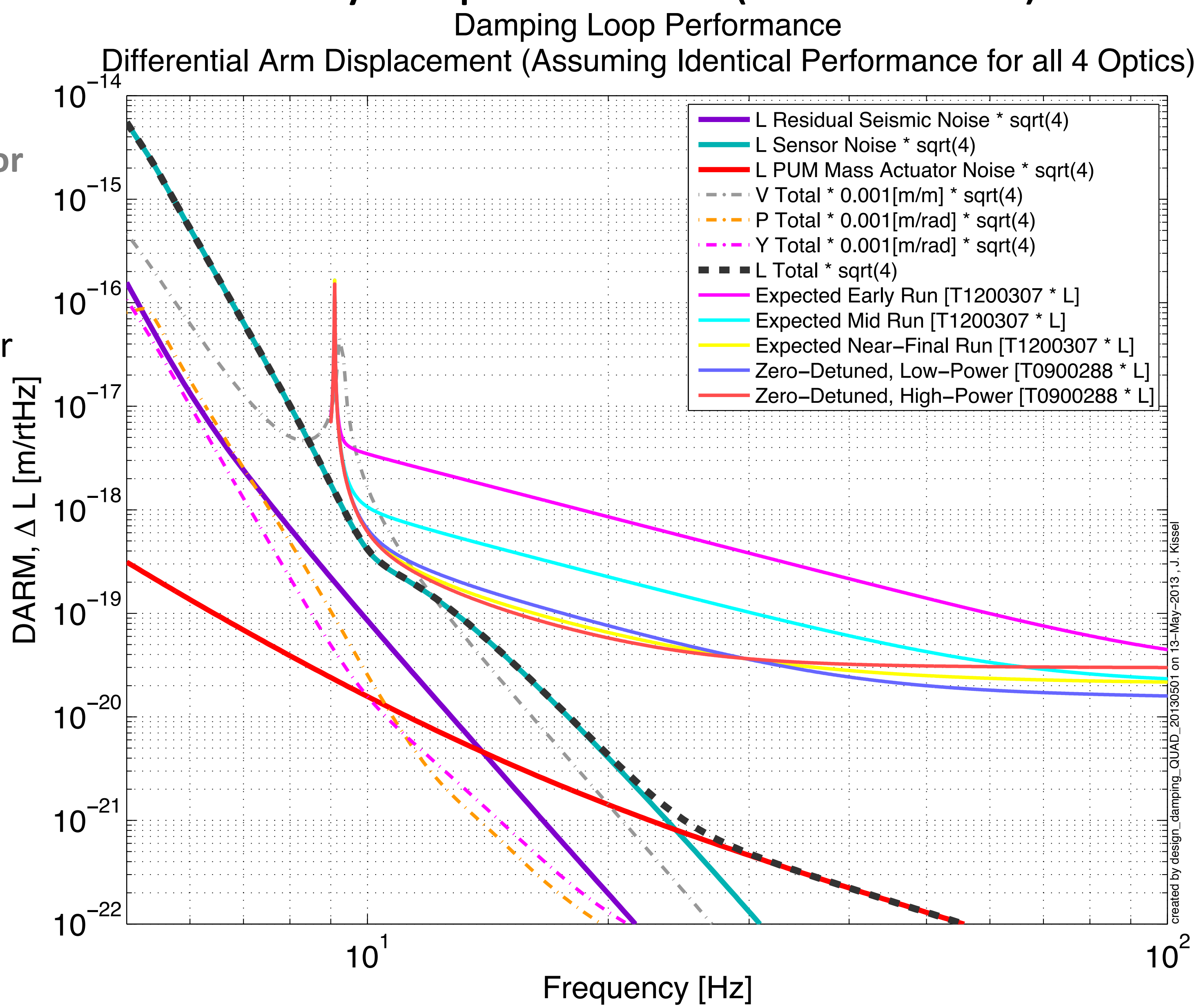


Now only a factor of 5-10 away from **residual seismic**, instead of 500-1000

Damping Loop Design

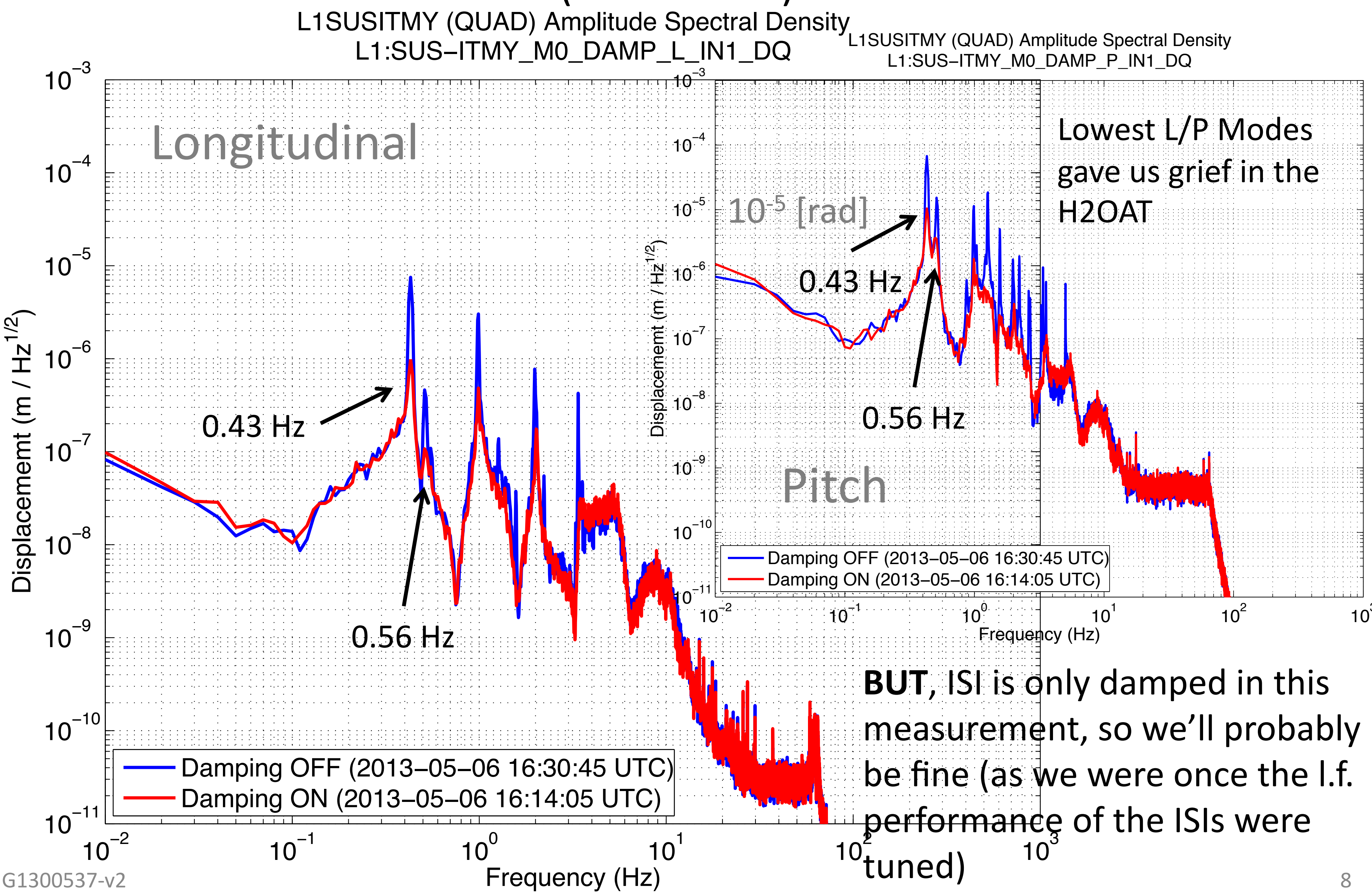
Compare with Cavity Displacement (New Filters)

Vertical DOF is also dominated by **sensor noise** at 10 Hz, and could play a role assuming the 0.001 [m/m] coupling over the 4km arms



TOP Mass ON/OFF Spectra

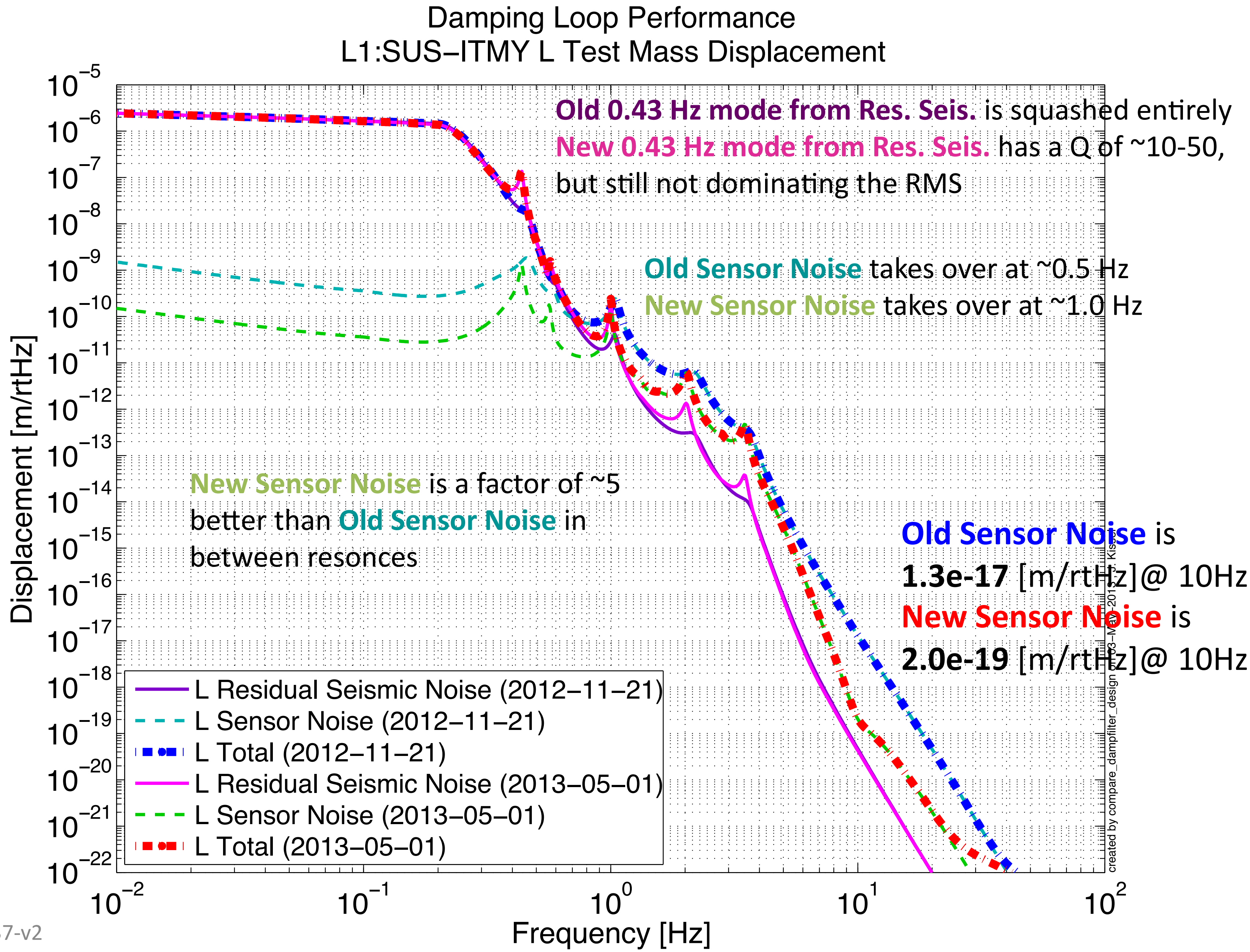
(New Filters)



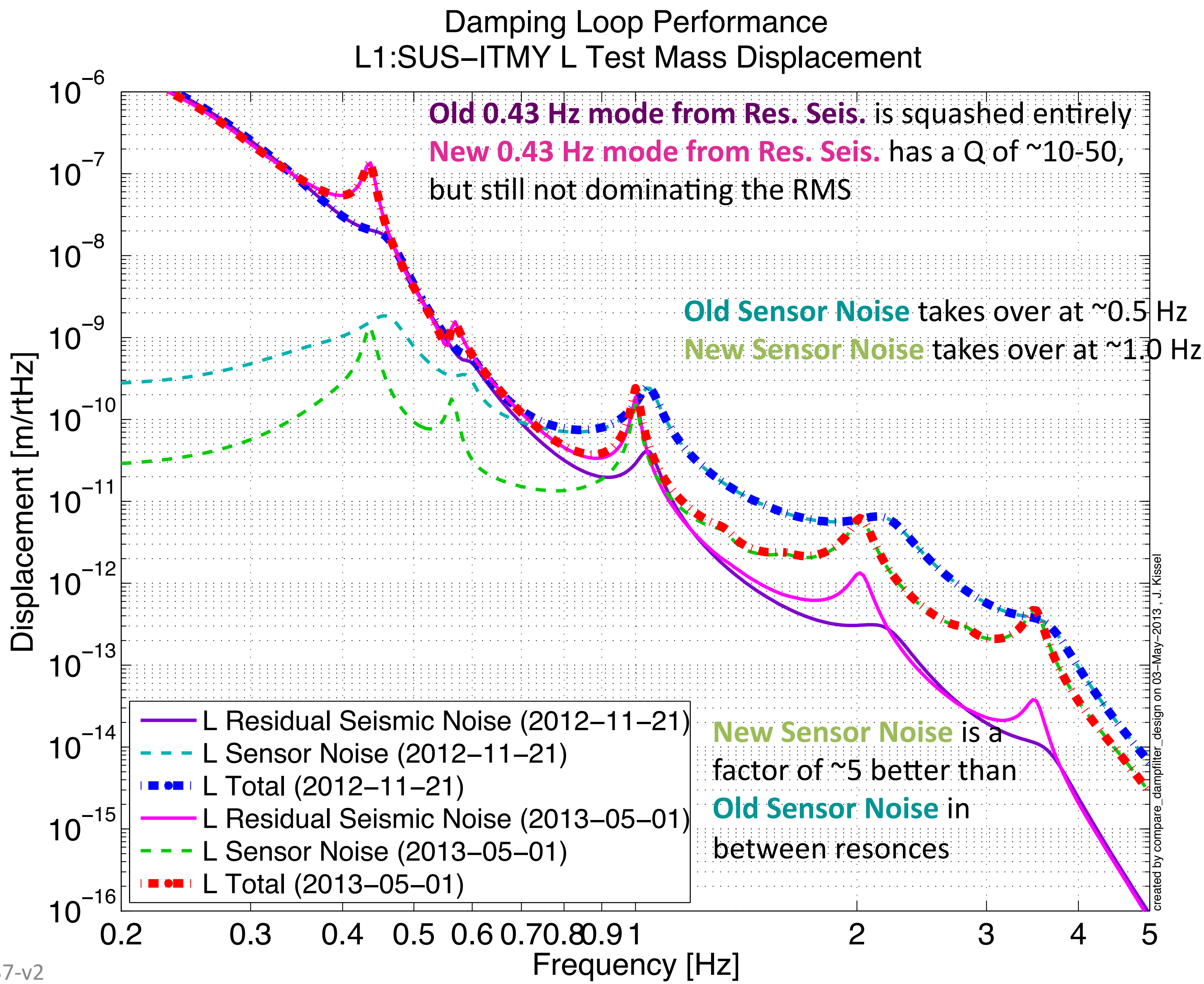
Lowest L/P Modes gave us grief in the H2OAT

BUT, ISI is only damped in this measurement, so we'll probably be fine (as we were once the l.f. performance of the ISIs were tuned)

Level 1 vs. Level 2

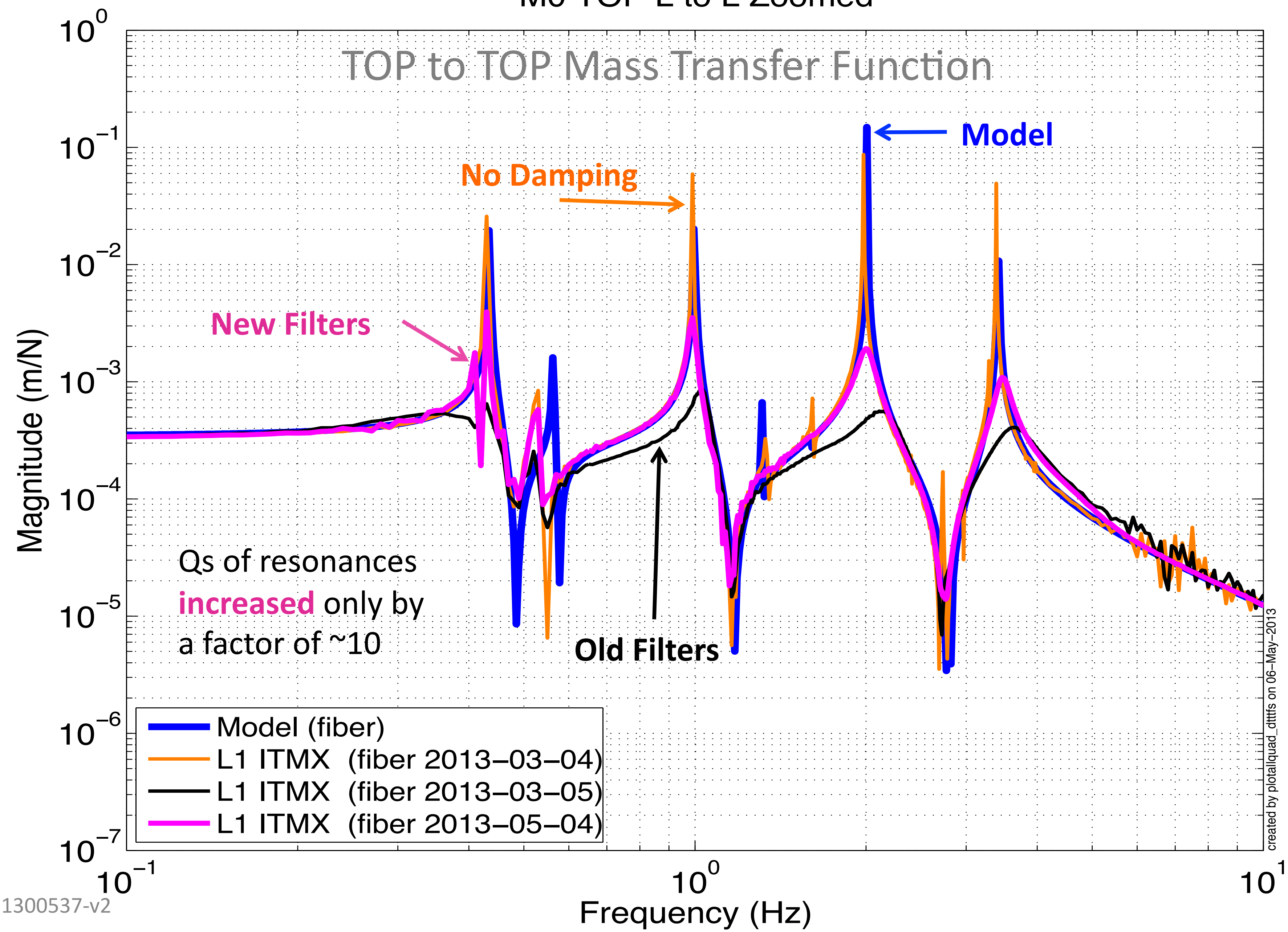


Level 1 vs. Level 2

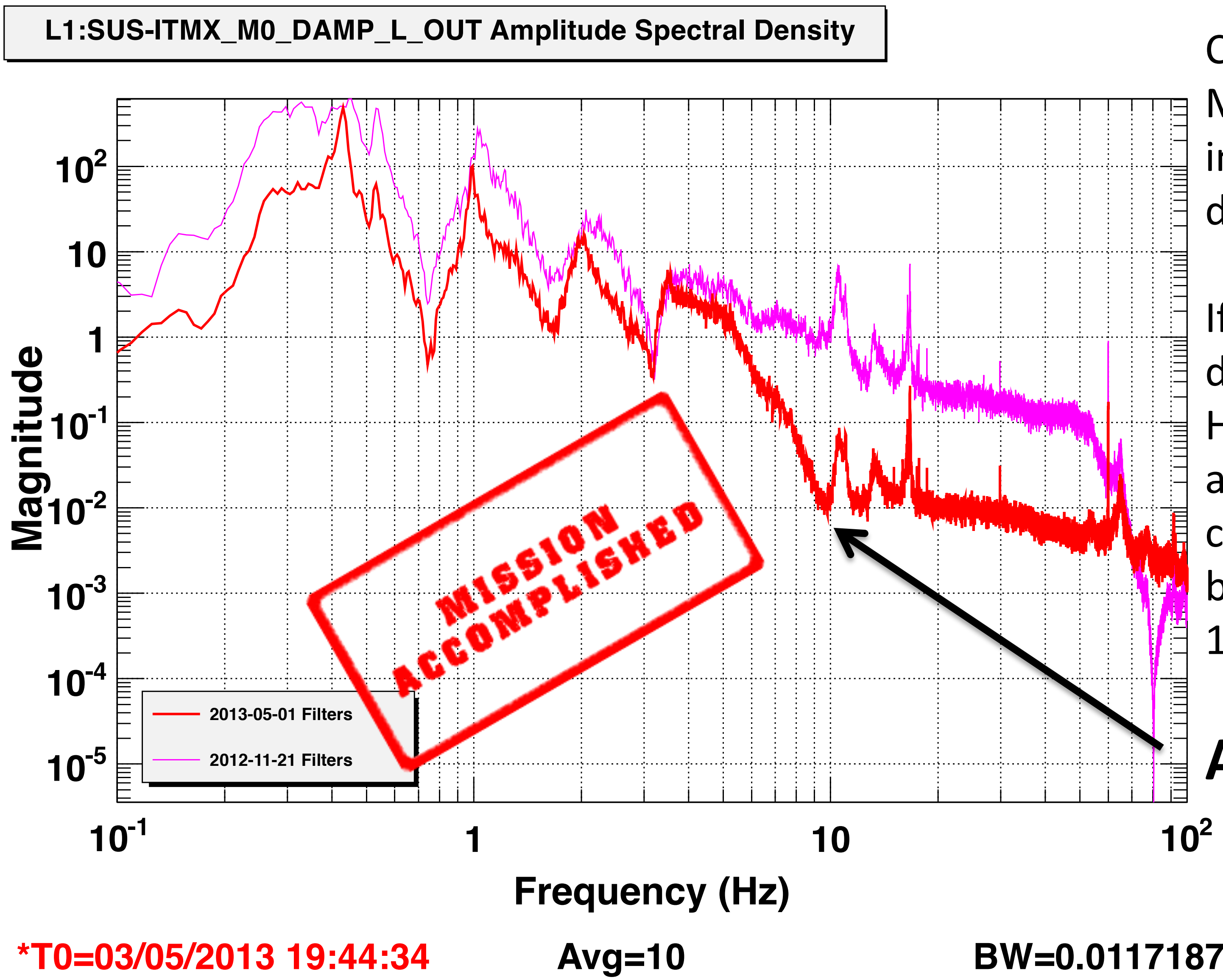


Level 1 vs. Level 2

M0 TOP L to L Zoomed



Level 1 vs. Level 2



Can't measure Test Mass noise improvement directly yet…

If sensor noise dominates above 1 Hz both before and after, then TOP control signal should be ~100 times less at 10 Hz.

And it is!

Remaining Questions

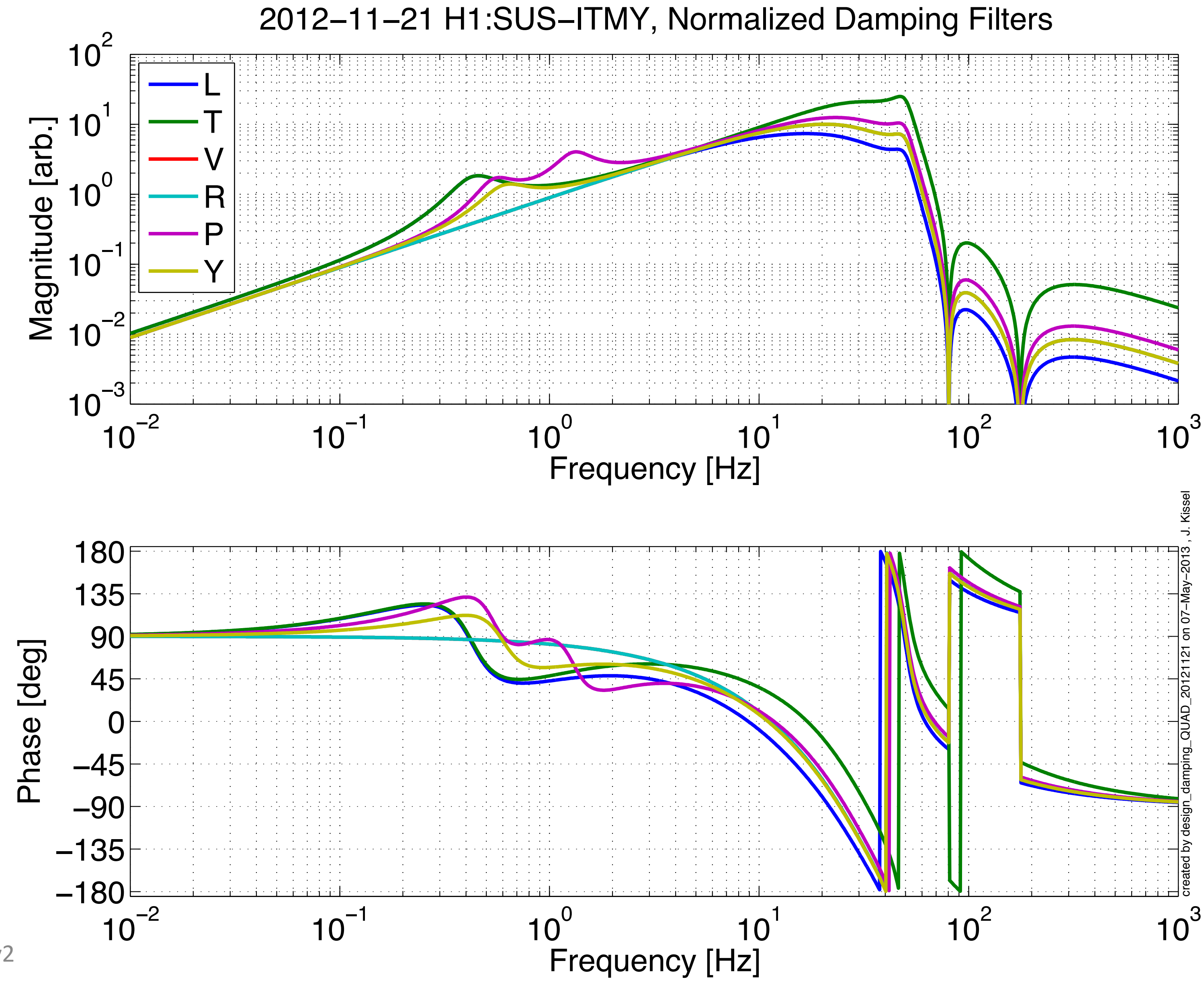
- Is it worth keeping Level 1 around?
  - (As I installed it at L1 ITMs, I removed Level 1)
- Tradition to have the overall gain "tunable" as an EPICs variable. Should it be absorbed in the filter banks?
- Would like to look into
  - Stability of loops if gains are increased to improve ring-down-time (more tradition)
  - Should build infrastructure / standard plot for quantifying ring down

Bonus Material For the Curious

Remember, for even more text, plots, details see LLO aLOG 6949

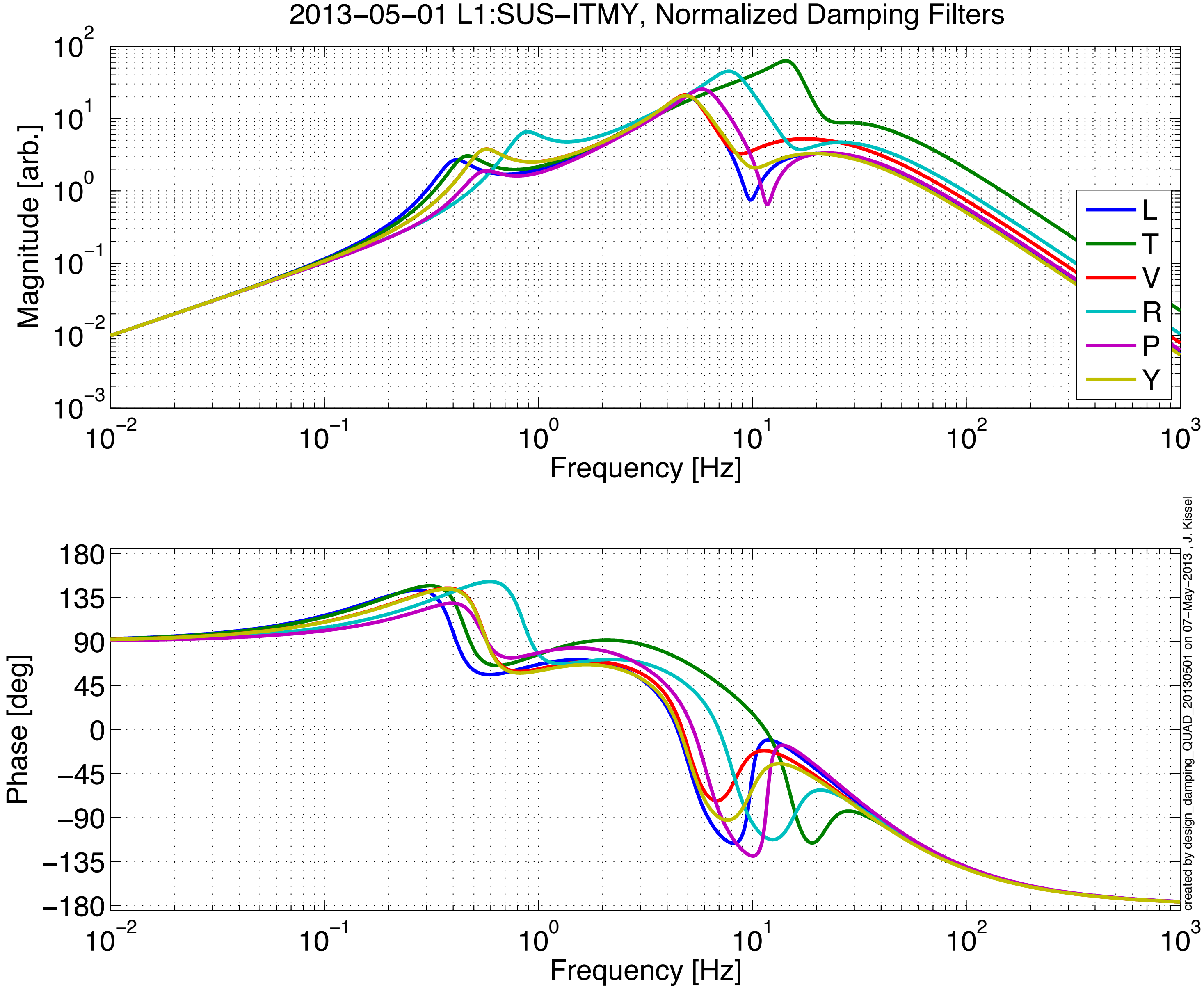
Damping Loop Design

OLD Filters

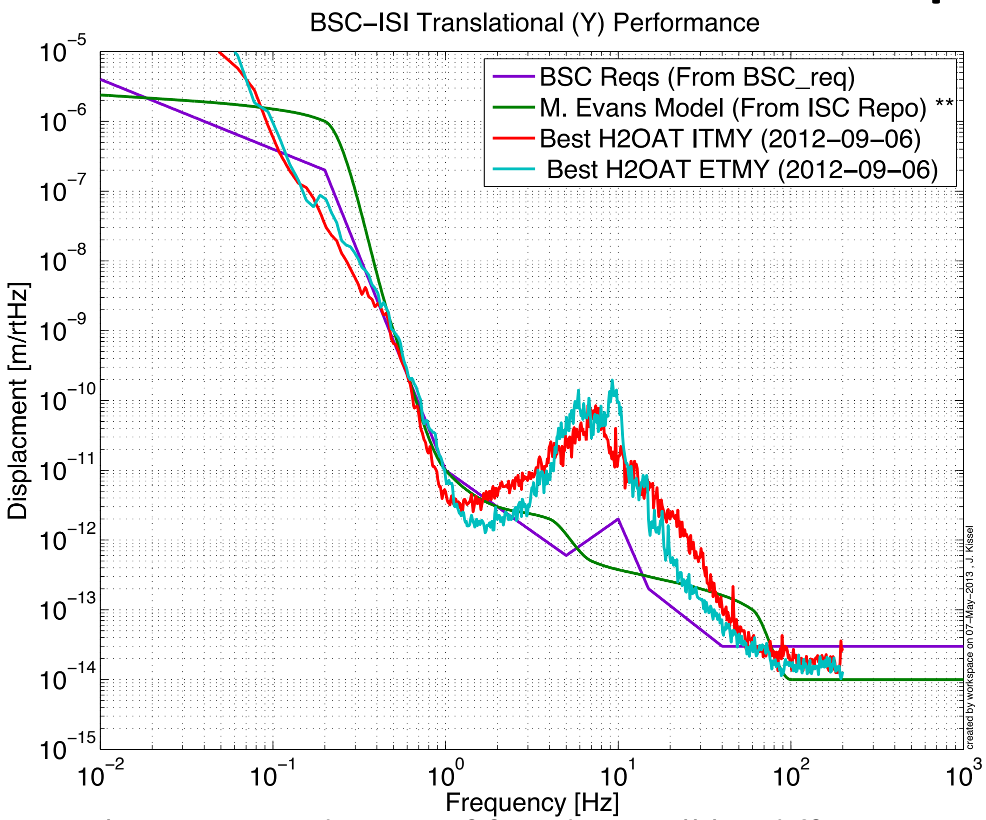


Damping Loop Design

NEW Filters



Seismic Input Motion



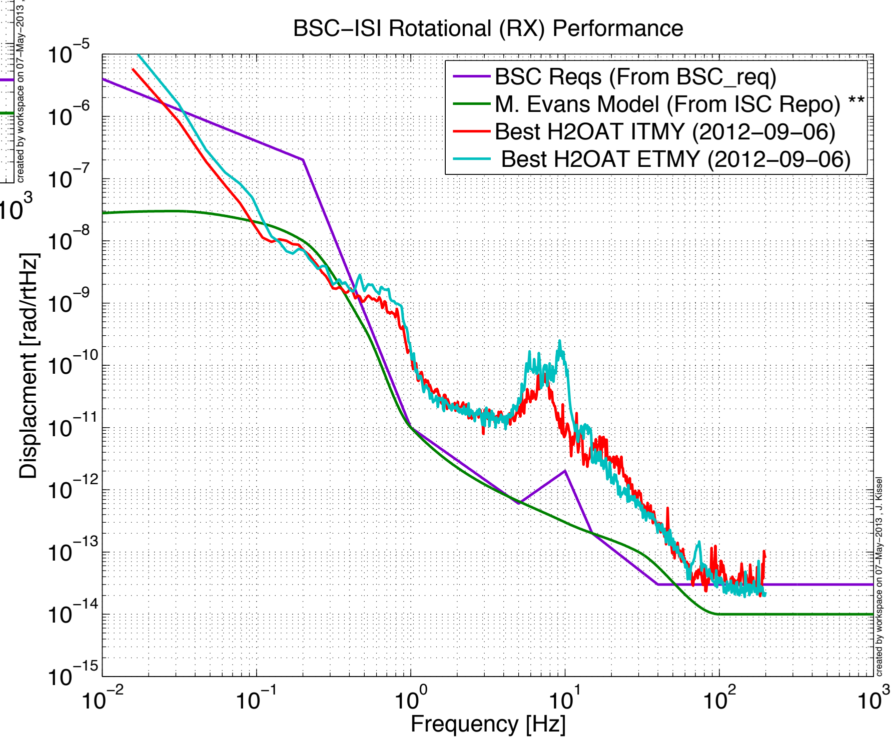
In the absence of real, best-possible performance data from the BSC-ISIs, there are a few choices for Residual Ground Input Motion to the QUAD:

- Use the **Requirements** for all DOFs
- Use **M. Evans' Model** of the "Translation" (same for X, Y, Z) and "Rotational" (same RX, RY, RZ)
- Use not-yet-awesome, but real **H2OAT data** (different for every DOF, and even between ISIs)

We know every degree of freedom will be different, so I don't like using the **Reqs**.

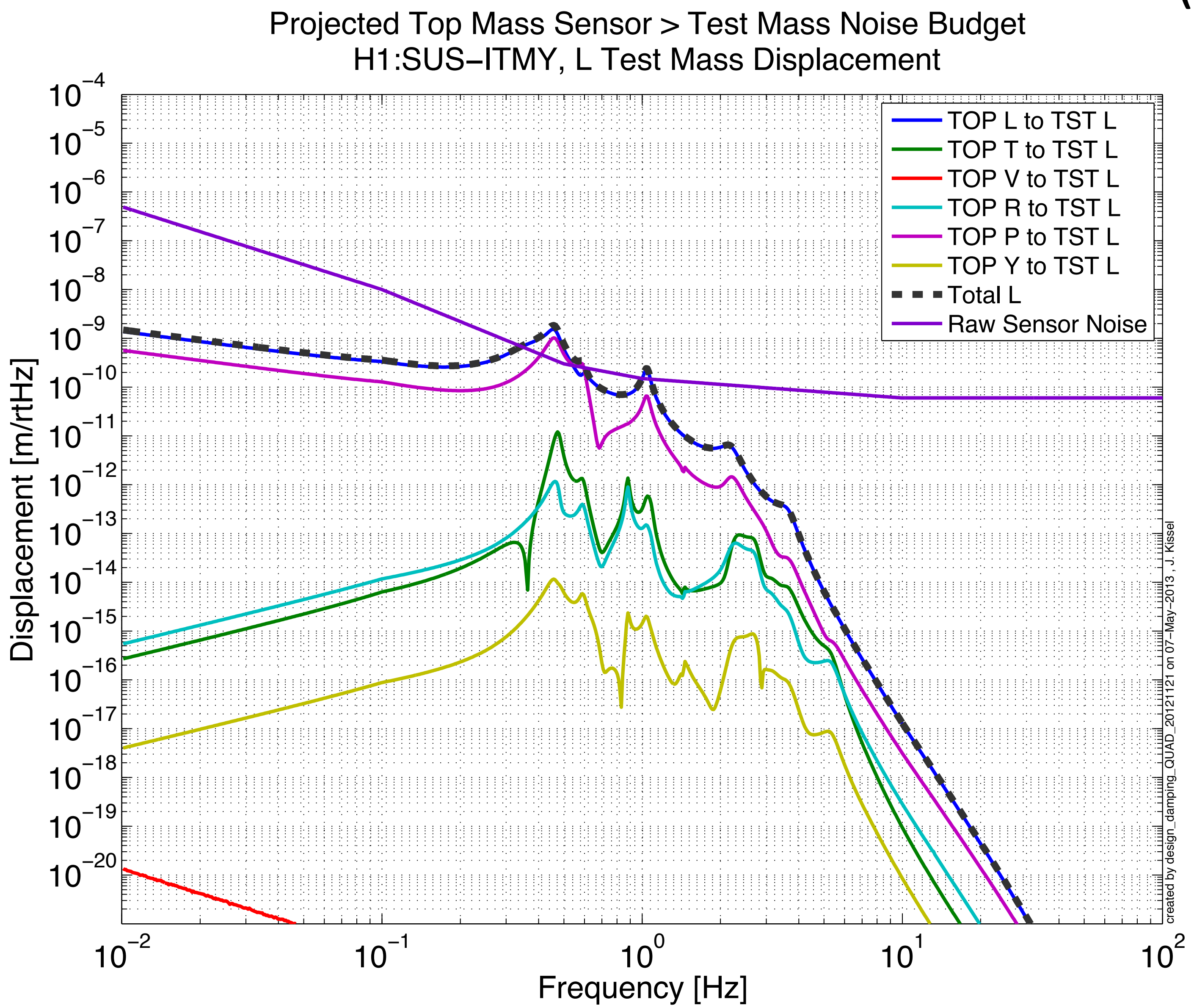
We know the very low frequency data of the **H2OAT data** is all tilt (if not sensor noise), and we know the mid-frequency band will be better

So I went with **Matt's Model** since it seems to fold in the most (optimistic?) realism



Damping Loop Design

All DOF's TOP Sensor Noise Contribution (Old Filters)



Sensor noise contributions to L Test Mass Motion @ 10Hz [m/rtHz]:

L2L = 1.3e-17

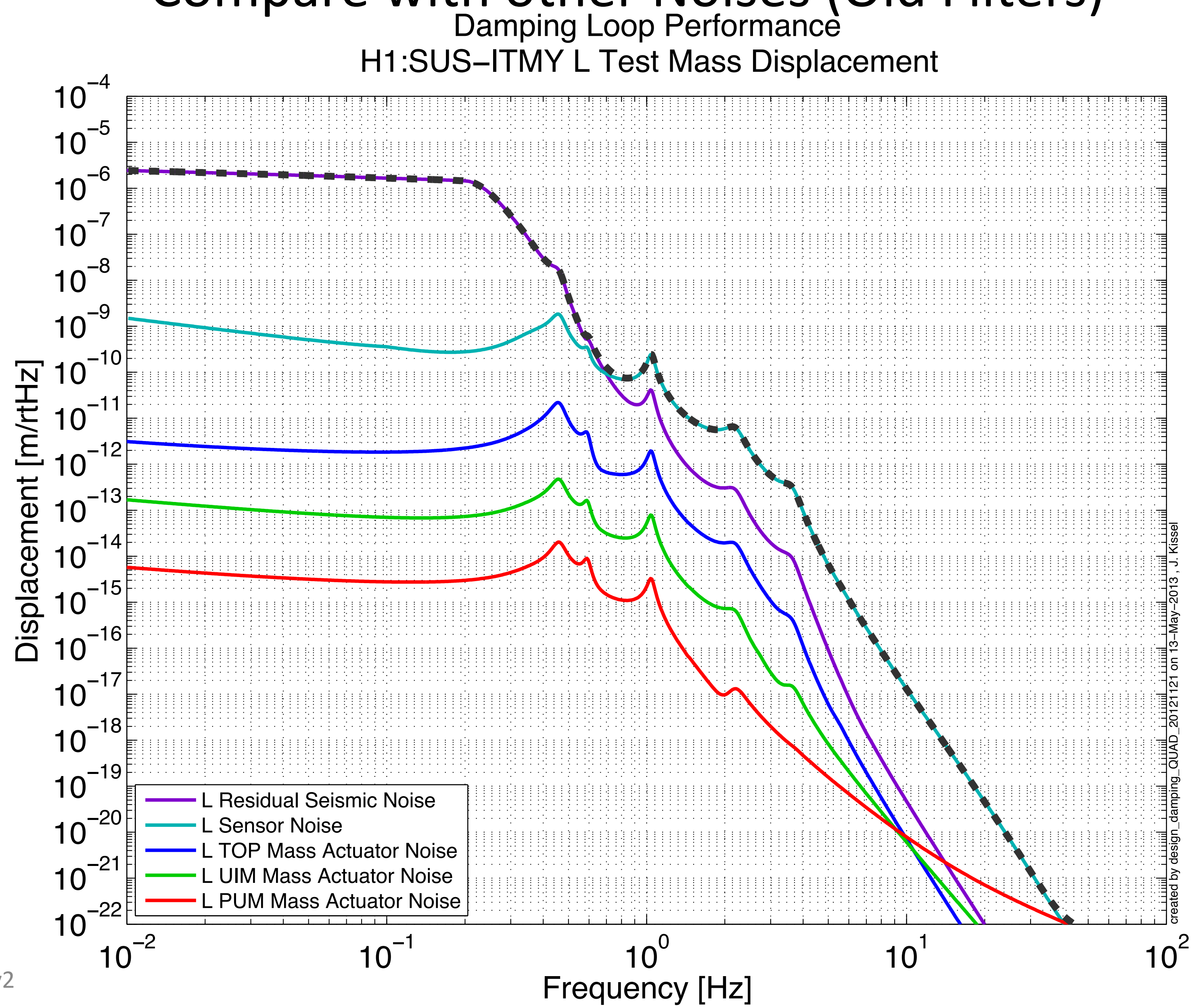
P2L = 3.1e-18

R2L = 2.8e-19

Reqs = 1e-20

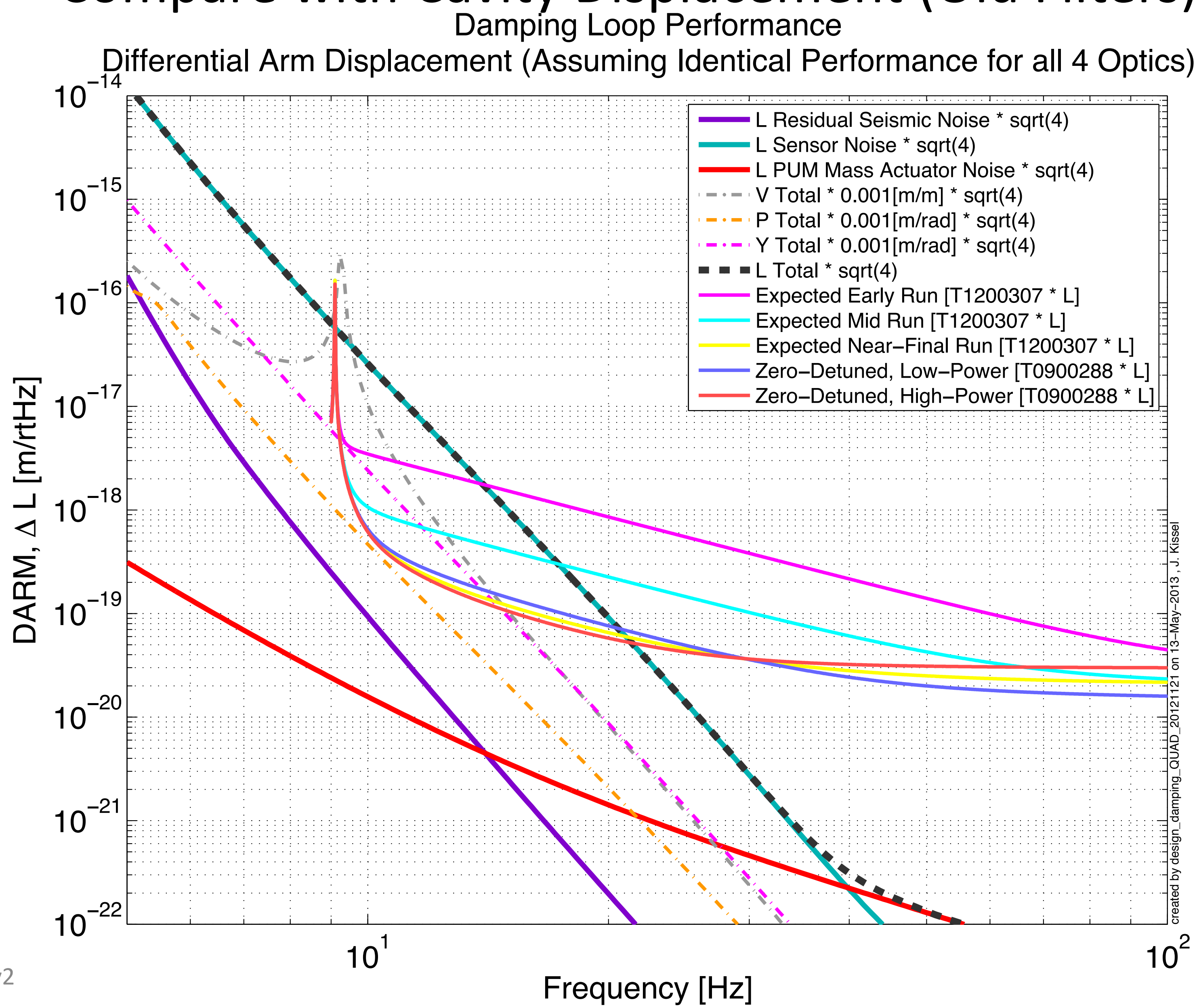
Damping Loop Design

Compare with other Noises (Old Filters)

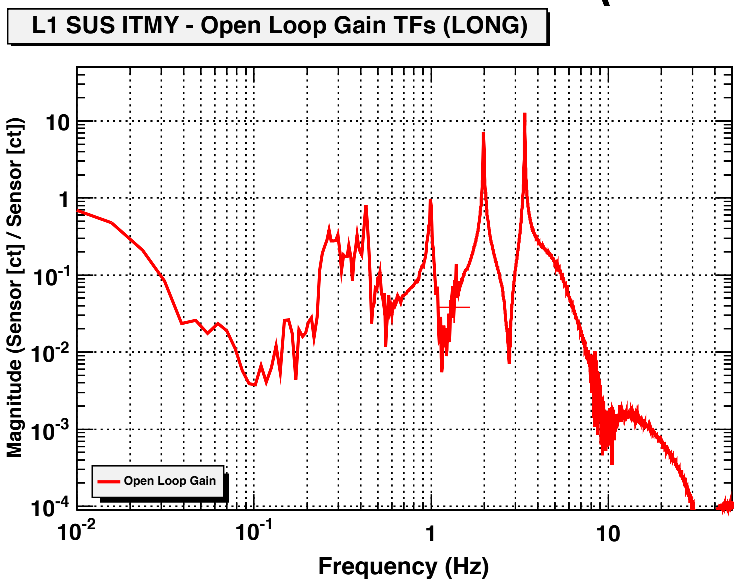


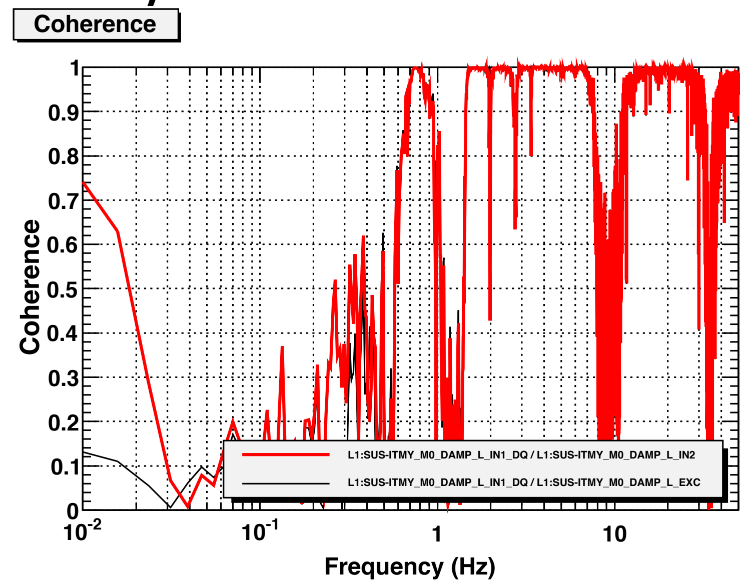
Damping Loop Design

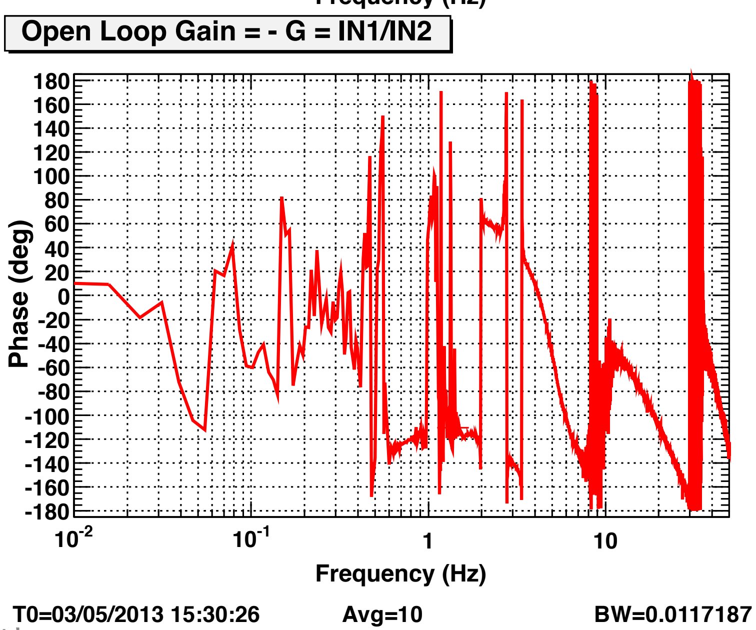
Compare with Cavity Displacement (Old Filters)

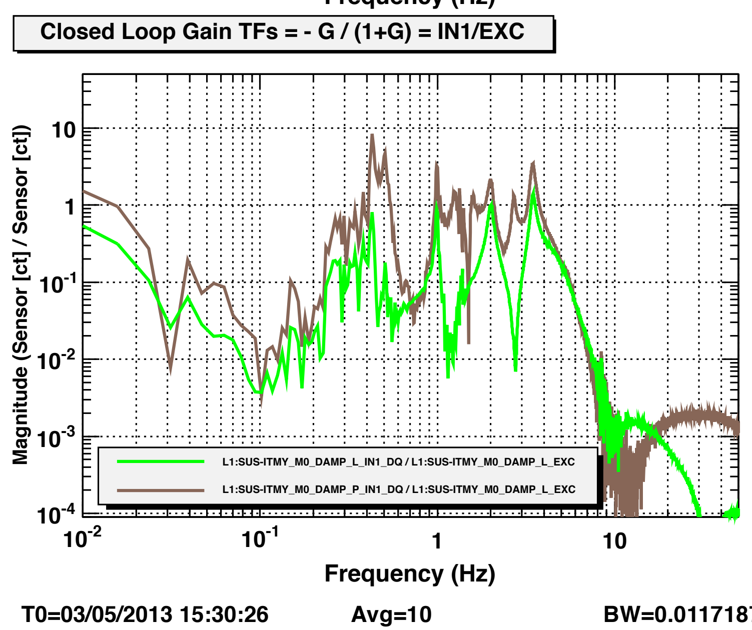


Measured Open Loop Gain TF
(New Filters)



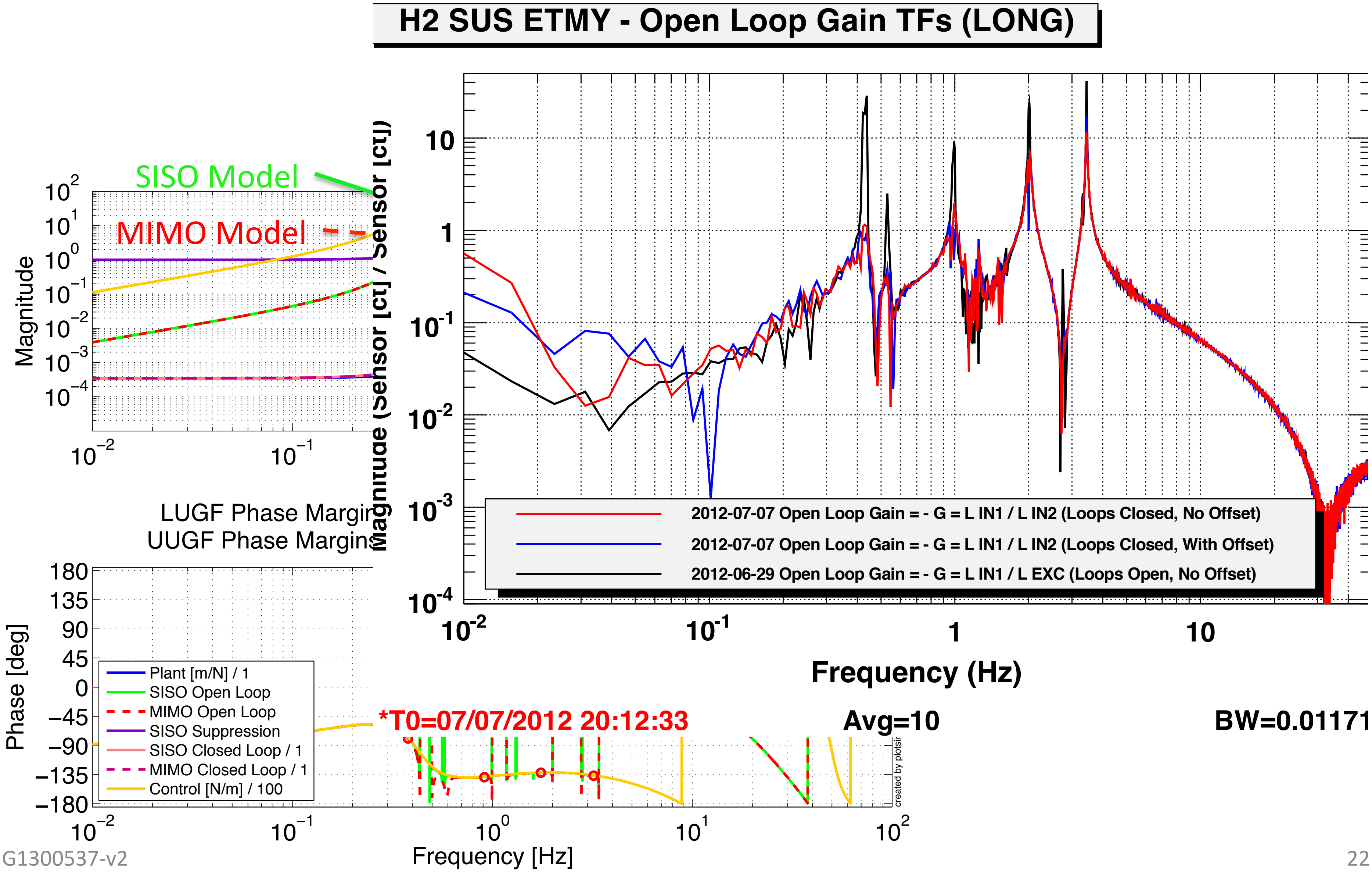






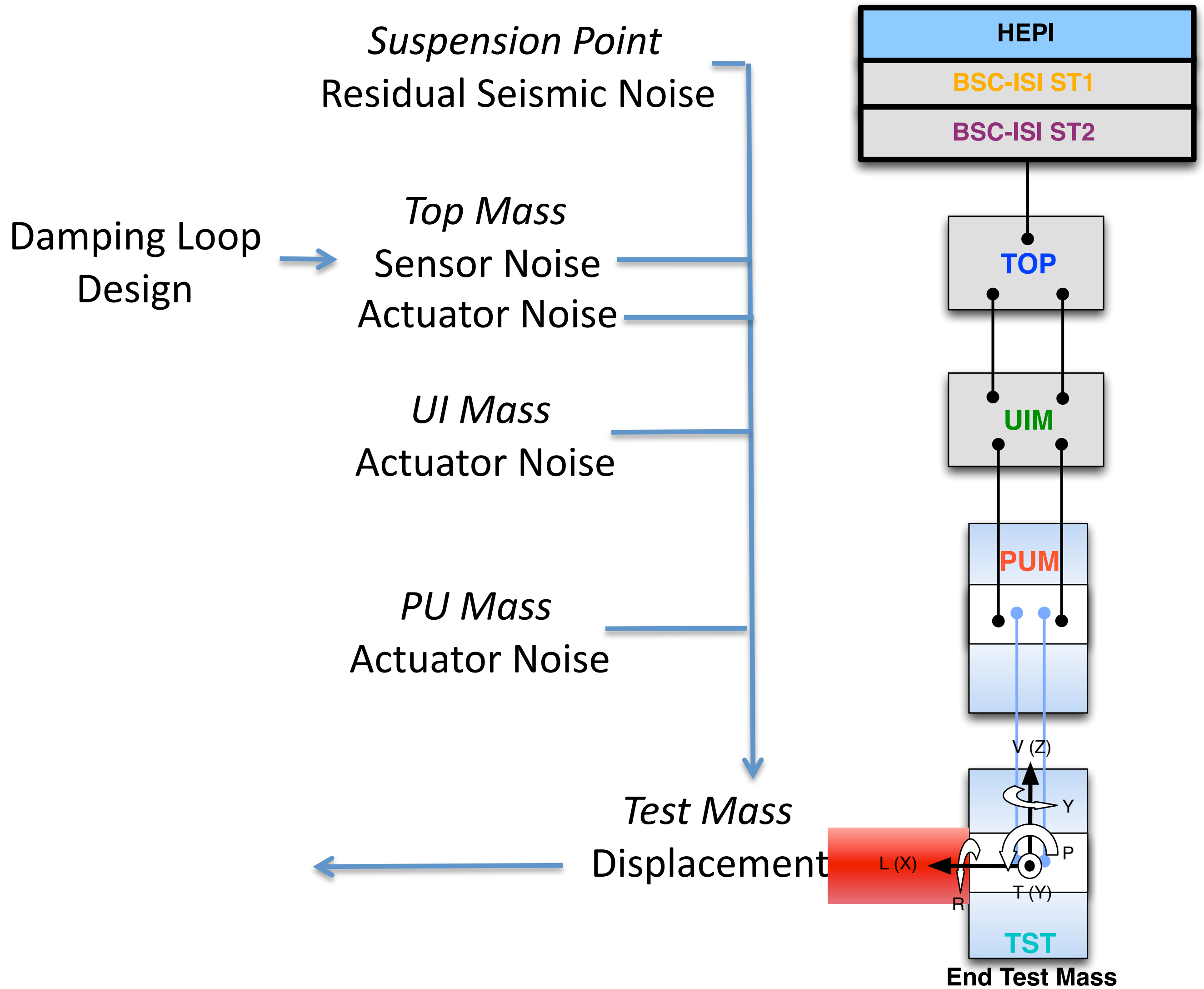
Damping Loop Design

Proof that MIMO Matters!!



QUAD Performance Modeling

All the bits and pieces



Steps to computing test mass motion:

– Measure / compute every DOF of input noise at every stage

– Propogate each stage input DOF to single test mass DOF of interest for cavity (i.e. longitudinal) using SUS model

– Add each stage's input DOF contribution in quadrature