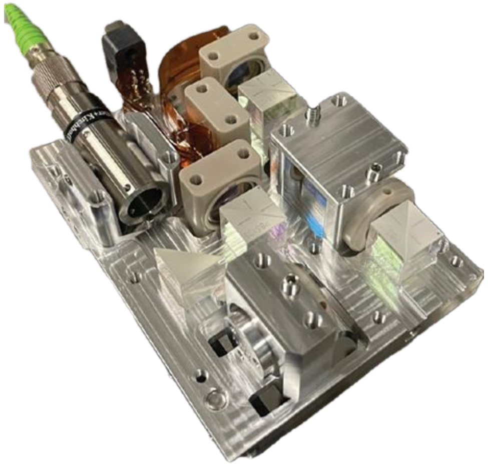
LIGO sensor testing

LVK Colorado September 2025

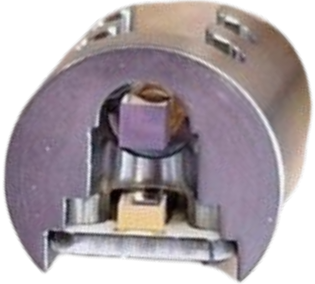
Alexandra Mitchell

Regina Lee, Brian Lantz, Edgard Bonilla,
Rich Mittleman, Peter Fritschel

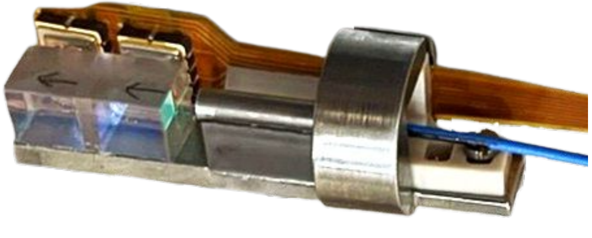
Let’s implement new technology in the detector!
Needed for A♯



HoQI



SmarAct



COBRI

Others?

Experiment goals

1. Have **all sensors** being tested in the **same place** measuring the **same thing** at the **same time**

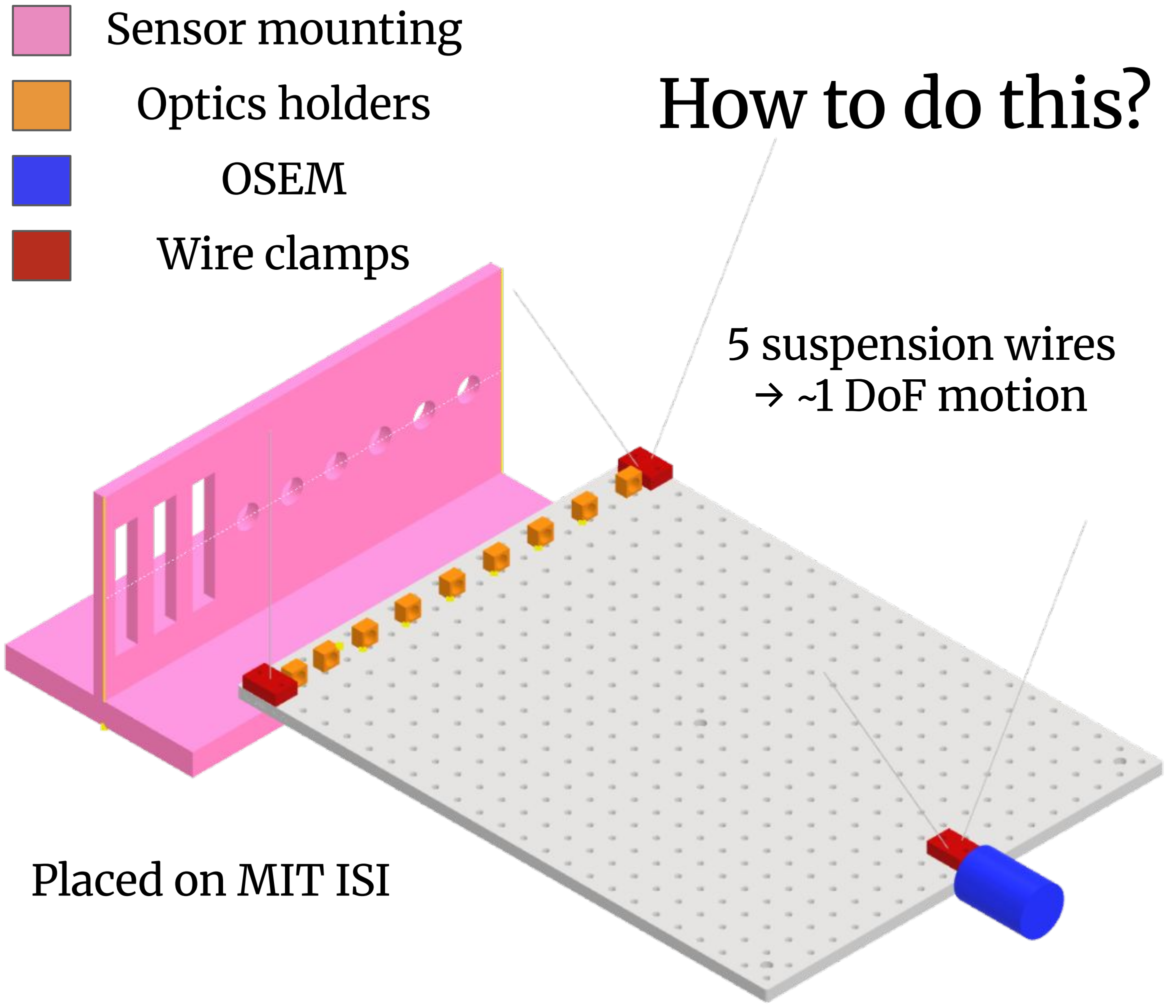
2. Compare **usability and practicality** of each sensor

3. Compare the **longitudinal performance** of each sensor

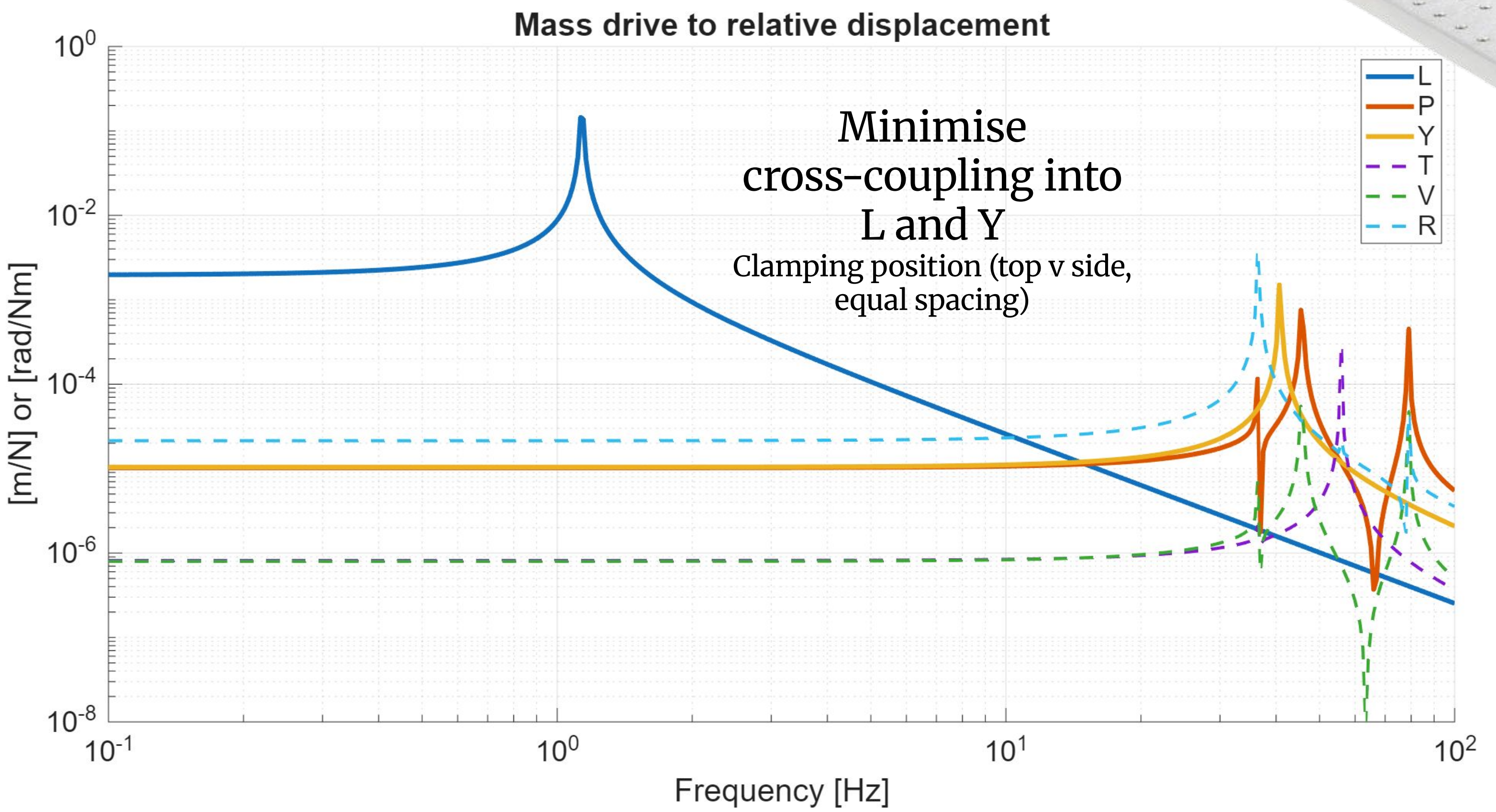
4. Determine the impact of **non-longitudinal** motion on the sensor performance

5. Test for **non-linearities** and compare the linear limits of the sensors

How to do this?



Experimental design



Minimise cross-coupling into L and Y

Clamping position (top v side, equal spacing)

Thorlabs breadboard for ease

Stiff design

Larger breadboard, clamps at edges

1. Have all sensors being tested in the same place measuring the same thing at the same time

Fulfilled by successful construction, installation and commissioning of the sensors to measure the suspended mass in the MIT vacuum chamber

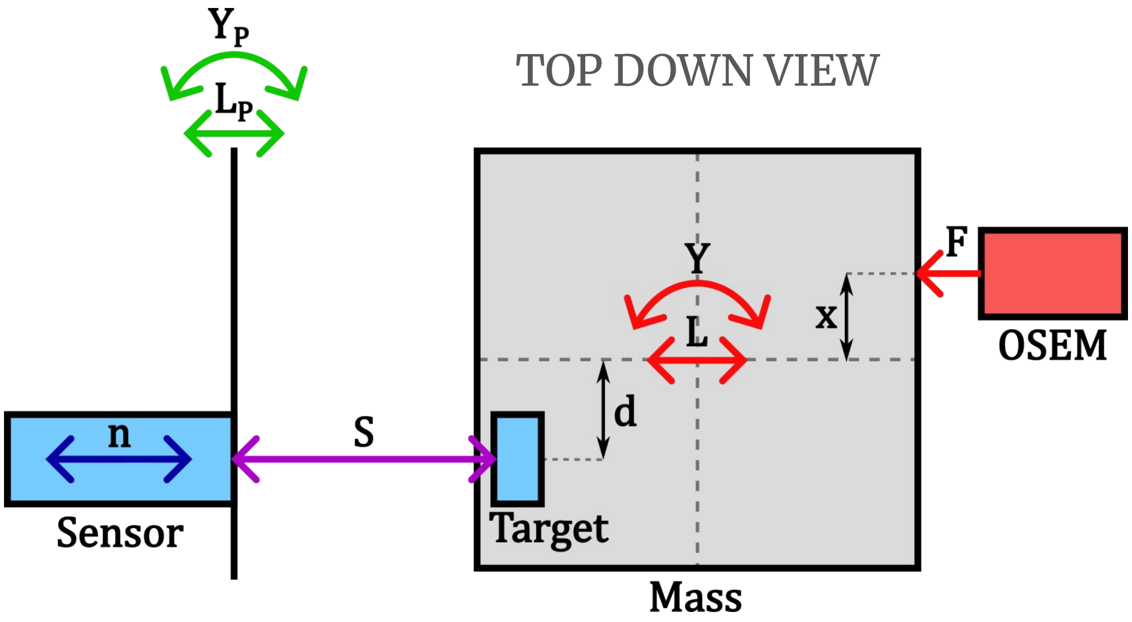
2. Compare usability and practicality of each sensor

Fulfilled by noting usability and practical issues during construction, installation and commissioning of sensors.

Flag and categorise issues: changeable, how big an issue, potential for disruption in detector

3. Compare the longitudinal performance of each sensor

Sensors are aligned on vertical CoM so see same pitch, will measure long and each sensor will see a different yaw

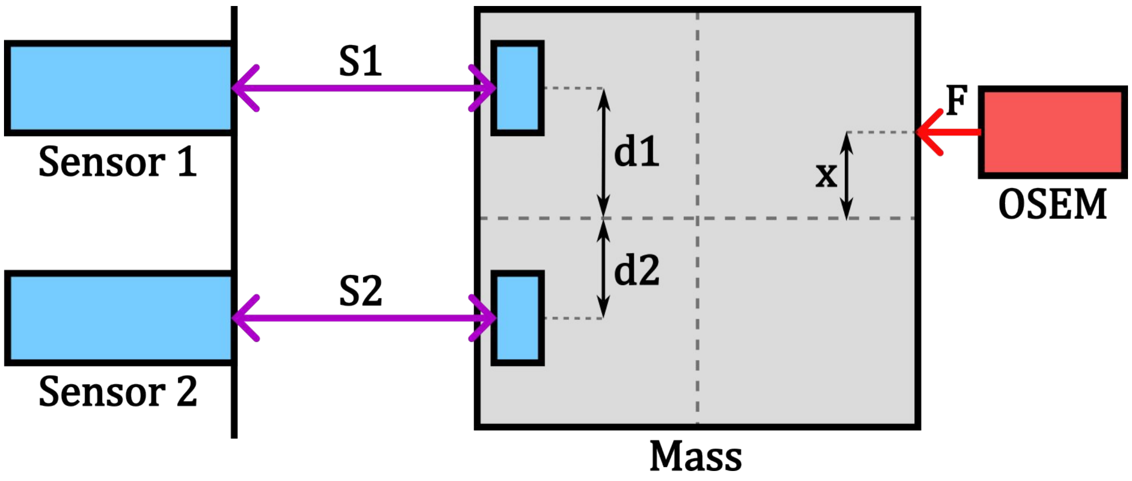


S = sensor readout
n = sensor noise
F = OSEM force
Y = mass yaw
L = mass long
Y_P = ISI platform yaw
L_P = ISI platform long

3. Compare the longitudinal performance of each sensor

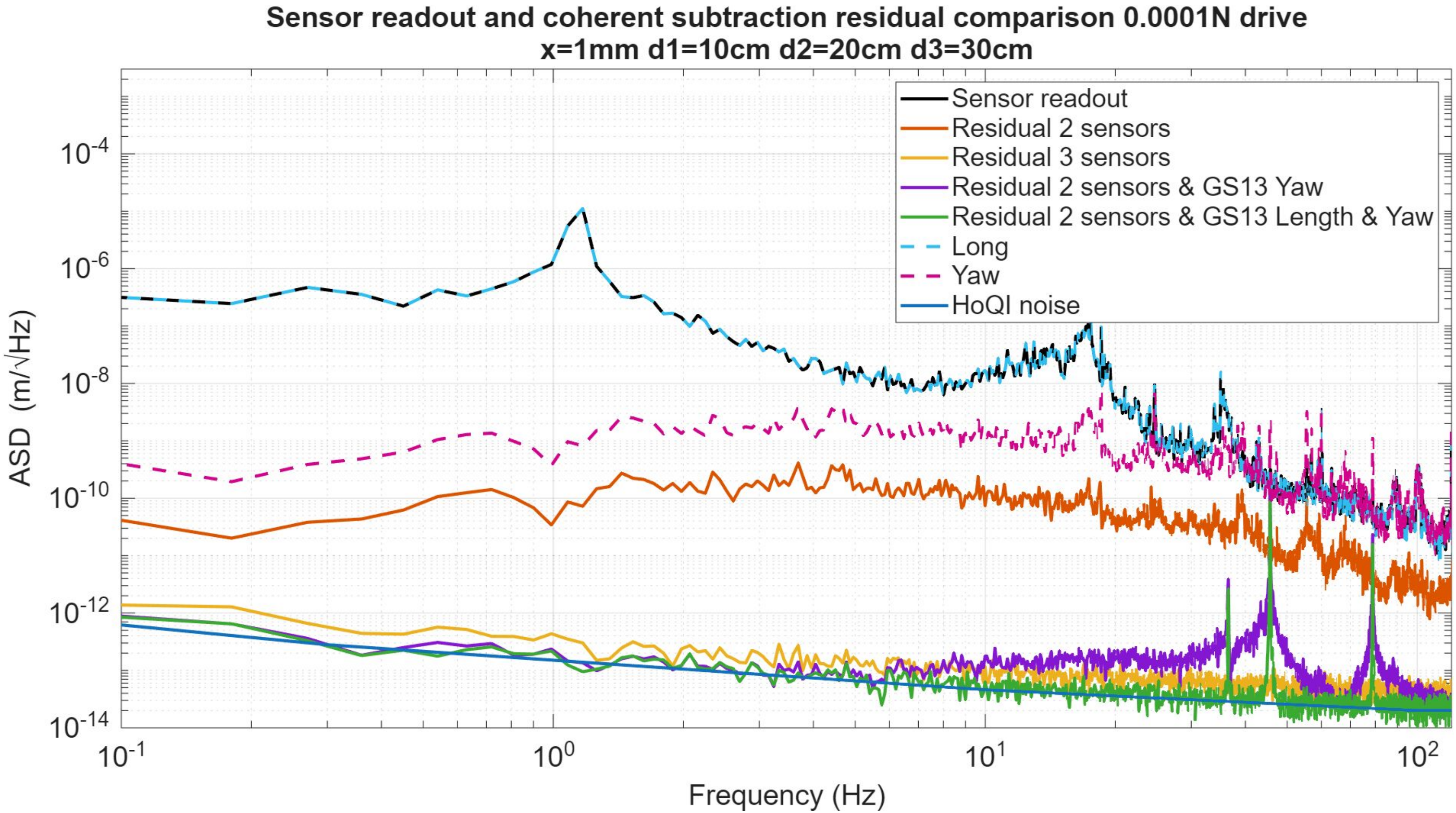
Using multiple of each sensor means we can use multi-channel coherent subtraction (mccs2) to get rid of common motion, i.e. long and yaw

TOP DOWN VIEW

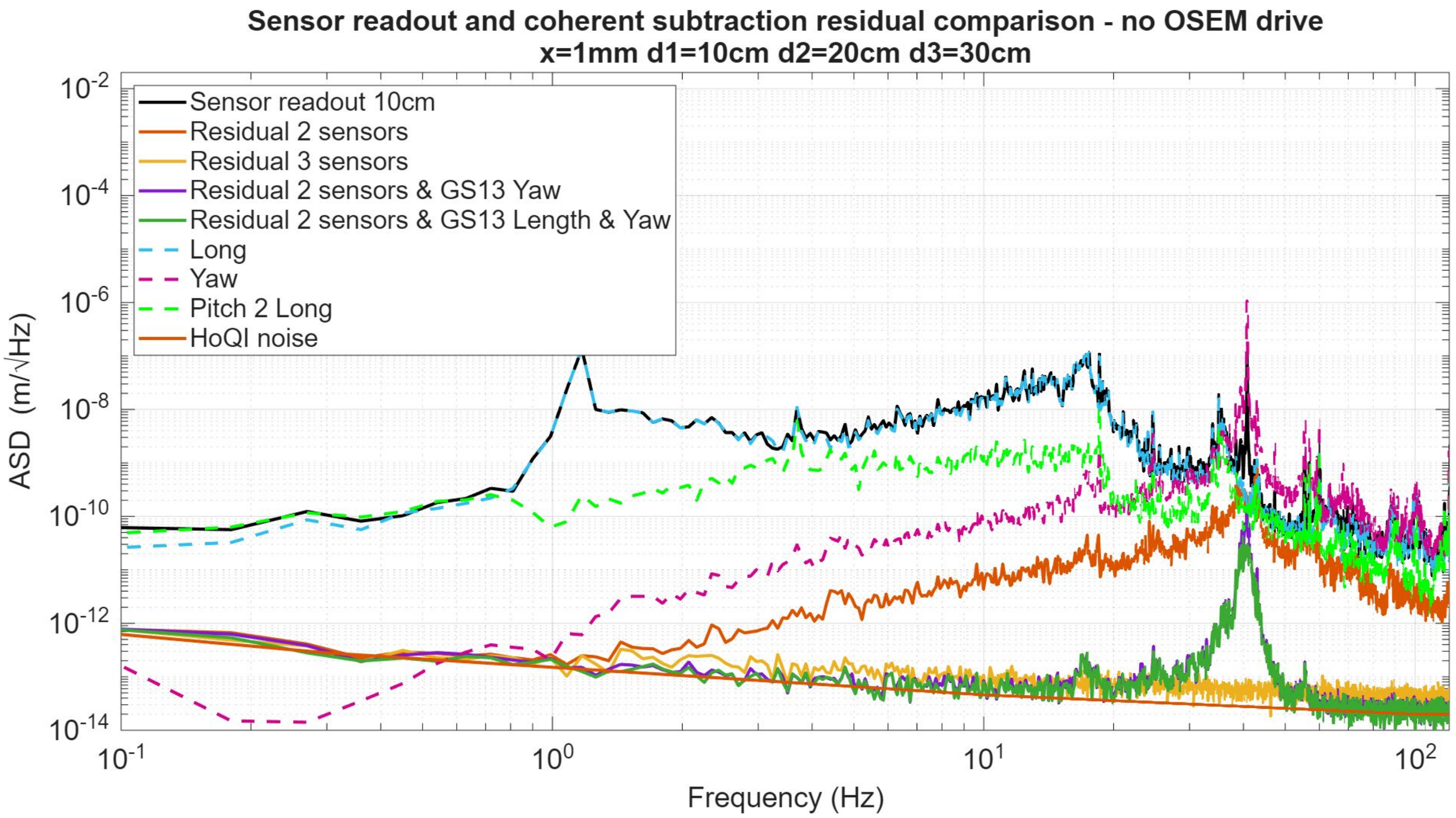


S1 = sensor 1 readout
S2 = sensor 2 readout
F = OSEM force
d1 = distance to sensor 1 target from CoM
d2 = distance to sensor 2 target from CoM
x = distance to OSEM from CoM

3. Compare the longitudinal performance of each sensor



3. Compare the longitudinal performance of each sensor



4. Determine the impact of non-longitudinal motion on the sensor performance

Impact on the sensor performance from motion in other DoFs will be measured

Tested by either:

- Sensors on side of mass (sees transverse/yaw in signal)
- OSEM on other side of mass (easier? Need to think about mass motion)

Measurement

- Noise (could change throughout swing - doesn't give location information)
- Fringe visibility (can be tracked across range of motion… Is this good metric for DFMIs? I think yes but needs more thought)

5. Test for non-linearities and compare the linear limits of the sensors

Non-linearities are differences between the measured and actual phase change seen by the interferometer.

1. Testing linear limits

Drive mass fast and look for disjointed signals and discontinuities in position

2. If we cannot get to the expected noise floor, we can test for non-linearities

Drive 2 non-harmonic sine waves (e.g. 7993/4096~2Hz and 13001/4096~3.2Hz)

Look for up/down-conversion around the driven frequencies

Planning

1. Finalise the design
    - Support structure
    - Clamps (based on MIT design)
    - Sensor mounting & requirements (in collab with other groups)
    - ANSYS modelling

2. Stanford prototype
    - HoQIs (caltech CRS?), on ISI, less stringent vacuum

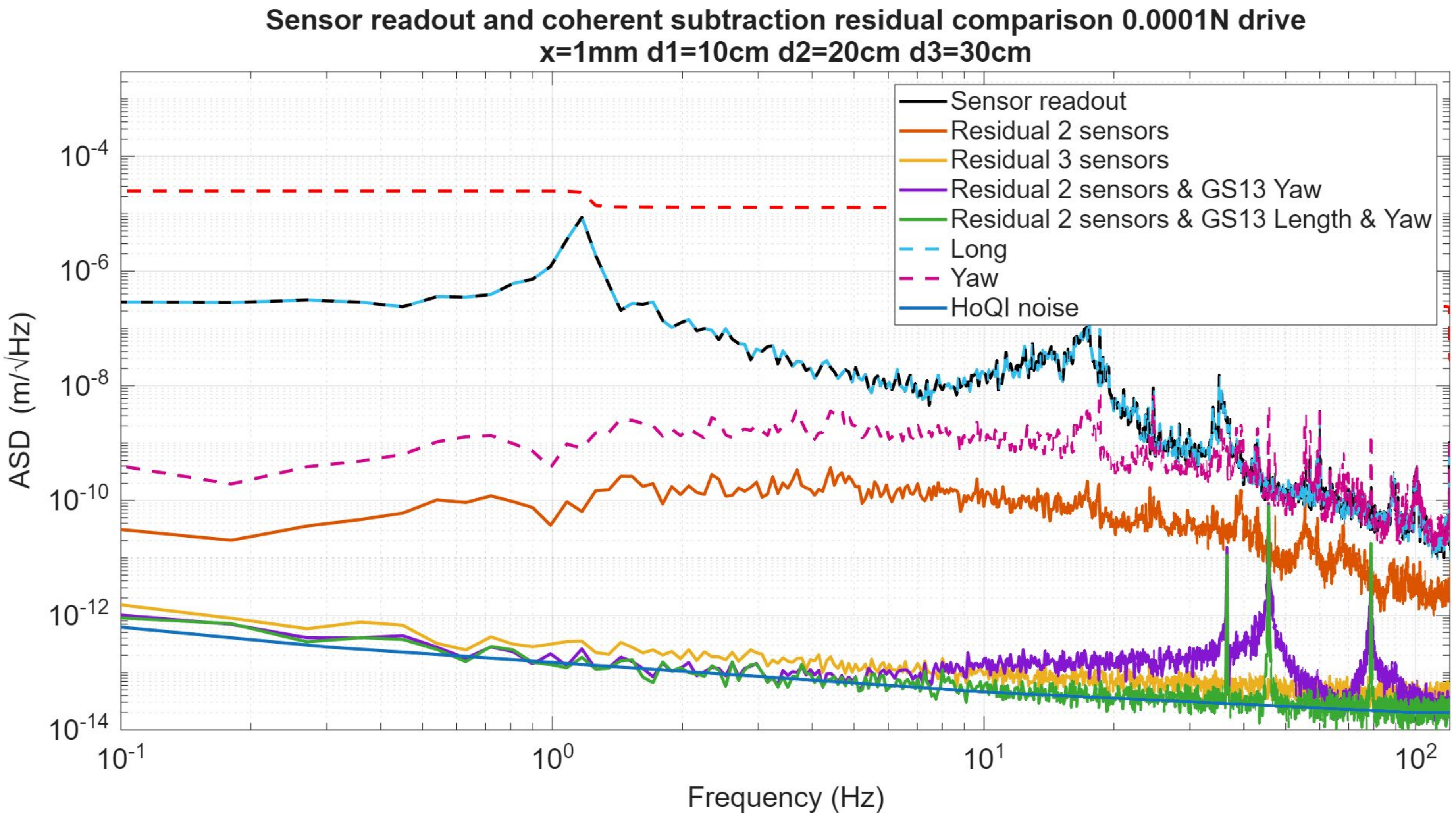
3. Full setup at MIT
    - First half of next year?

GW10 3 part series!

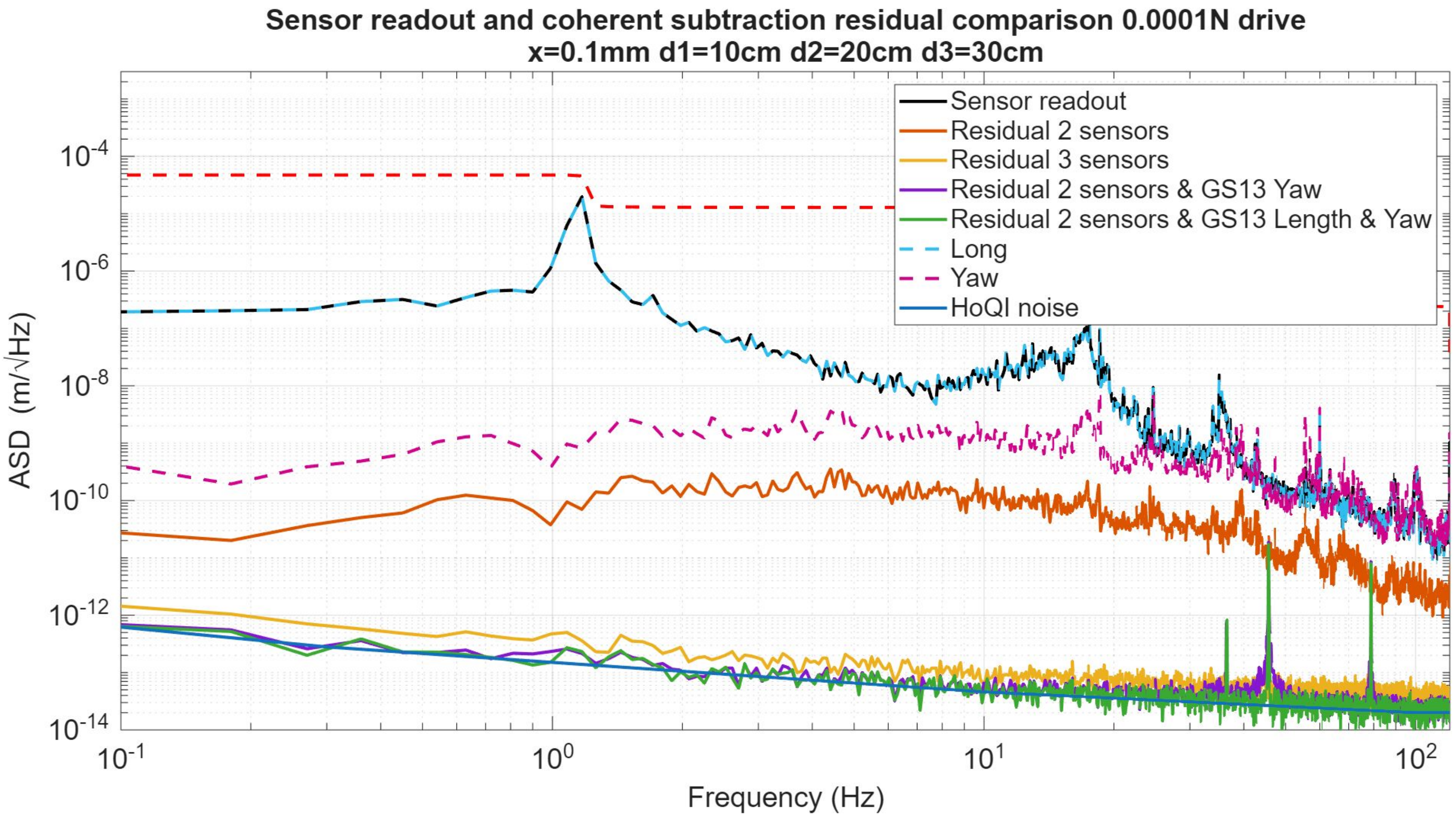
Introduction released Wednesday

Interviews with Kip Thorne & Barry Barish released Sunday

Find it wherever you get your podcasts!



Sensor readout and coherent subtraction residual comparison 0.0001N drive
x=1mm d1=10cm d2=20cm d3=30cm
Sensor readout
Residual 2 sensors
Residual 3 sensors
Residual 2 sensors & GS13 Yaw
Residual 2 sensors & GS13 Length & Yaw
Long
Yaw
HoQI noise
ASD (m/√Hz)
Frequency (Hz)
10^-4
10^-6
10^-8
10^-10
10^-12
10^-14
10^-1
10^0
10^1
10^2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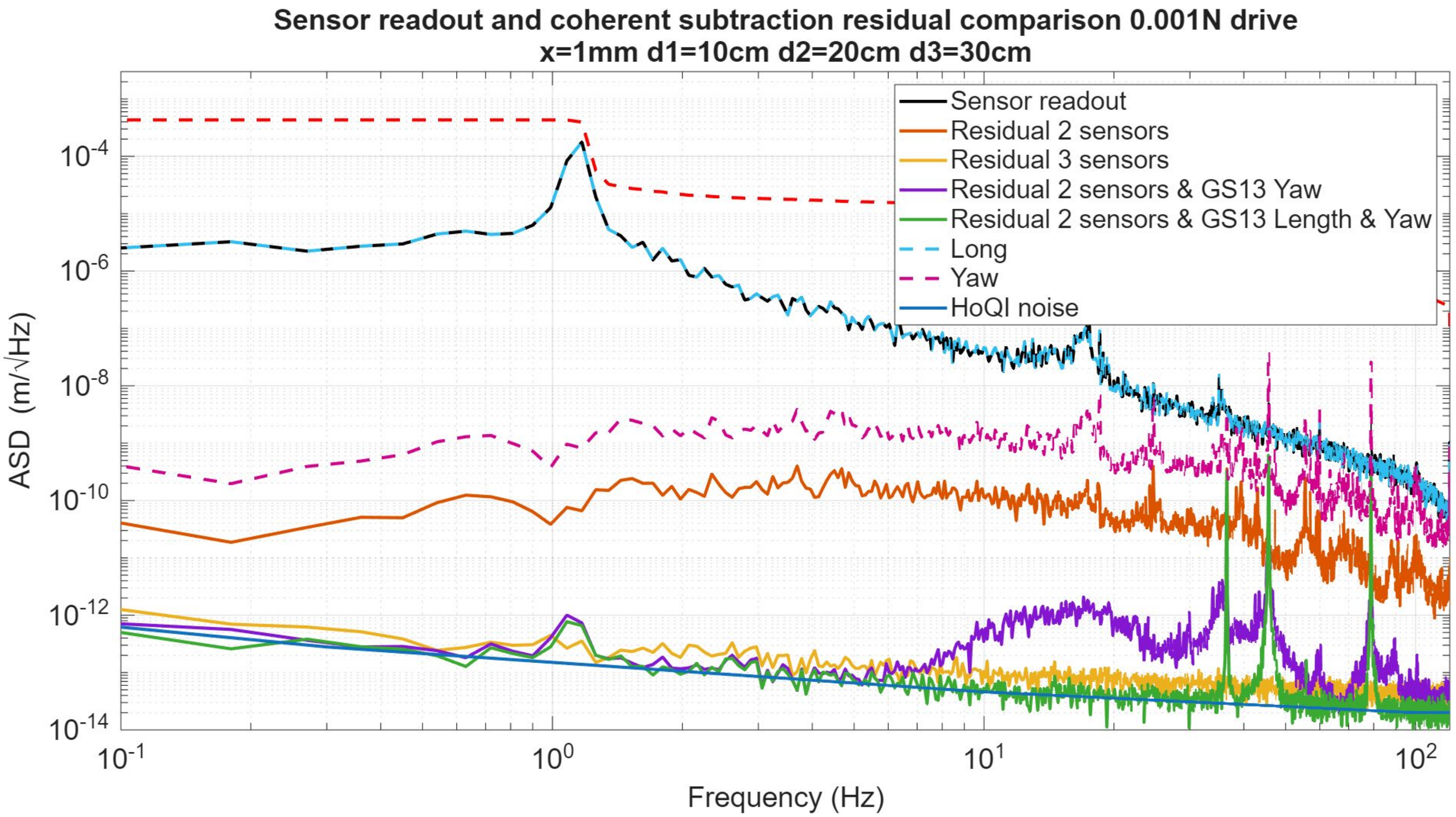
102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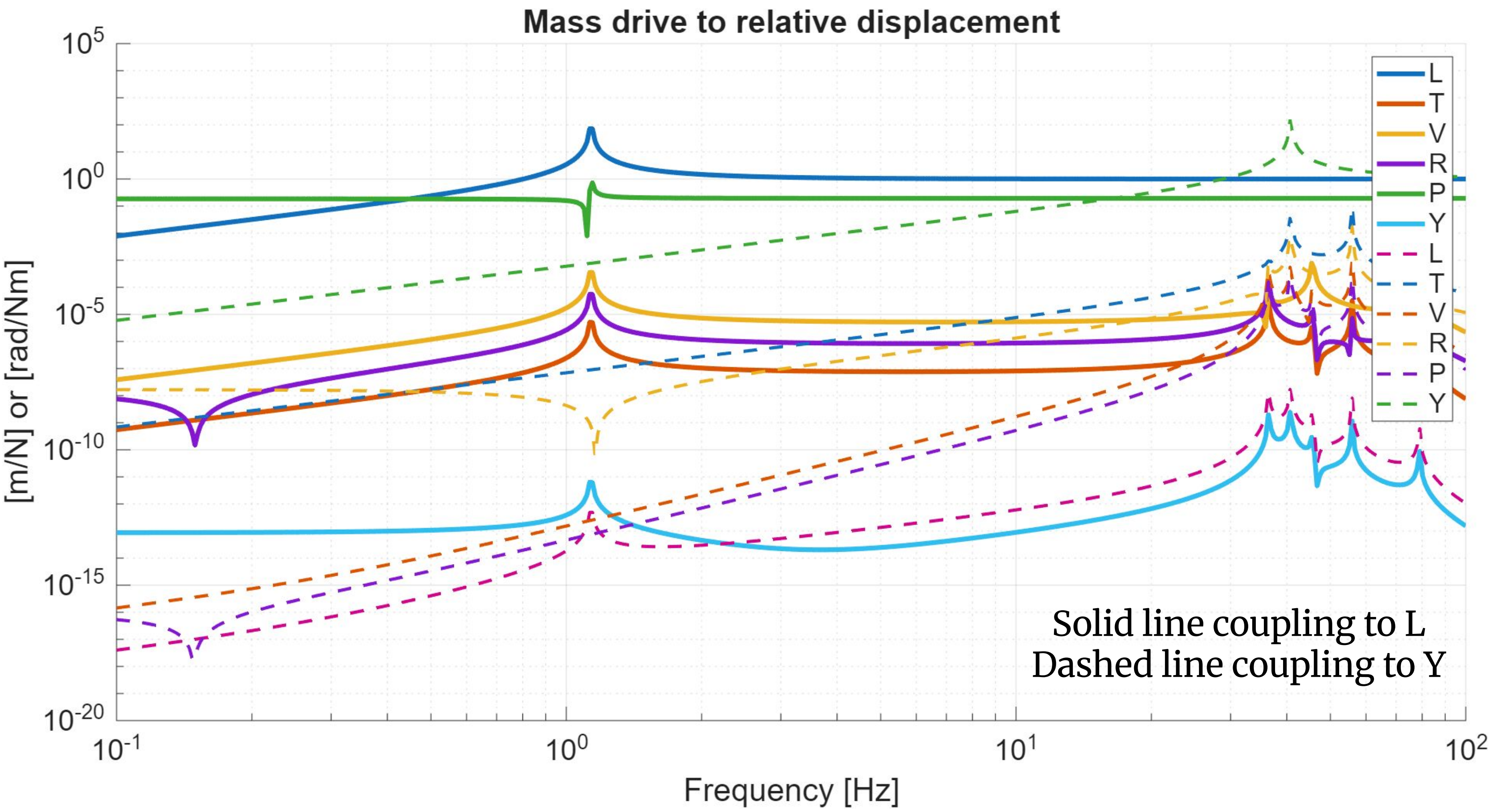
10^1
10^2



Mass drive to relative displacement
10^{5}
10^{0}
10^{-5}
10^{-10}
10^{-15}
10^{-20}
[m/N] or [rad/Nm]
10^{-1}
10^{0}
10^{1}
10^{2}
Frequency [Hz]
L
T
V
R
P
Y
L
T
V
R
P
Y
Solid line coupling to L
Dashed line coupling to Y


G = P.K
OC but less cross
Means we should've gotten (in math)