ASC modeling for Advanced LIGO

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LIGO-G0900278-v1

Outlines

- Some numbers for soft/hard angular modes

- Results from a new Optickle model with:
  - updated optical parameters (T0900043-03)
  - Quad suspension transfer functions
  - (more) reasonable input seismic noise

- Side outcomes:
  - expected ISI performance (based on Fabrice's measurement @ LASTI)
  - residual PITCH and YAW motion of the test mass
  - check of matching parameters

Hard/Soft Expectations

Parameter	LIGO	advLIGO
P	15	830
g_1	0.460	± 0.927
g_2	0.726	± 0.927
κ_{pendulum}	~ 0.51	~ 6.0
κ_{major}	-0.96	∓ 301
κ_{minor}	0.25	± 11.5

$$f_{soft} = \frac{1}{2\pi}\sqrt{\frac{k_{major} + k_{pend}}{I}}$$

$$f_{hard} = \frac{1}{2\pi}\sqrt{\frac{k_{minor} + k_{pend}}{I}}$$

Sidles, Sigg - Physics Letters A 354 (2006) 167-172

PITCH	Pcav (kW)	fsoft (Hz)	fhard (Hz)
iLIGO	15.0	-0.28	0.7
eLIGO 25W	87.5	-1.5	1
advLIGO	830.0	-0.57	4.2

→ Better than eLIGO, worse than iLIGO

Final Advanced LIGO Design

- Intra cavity power P:

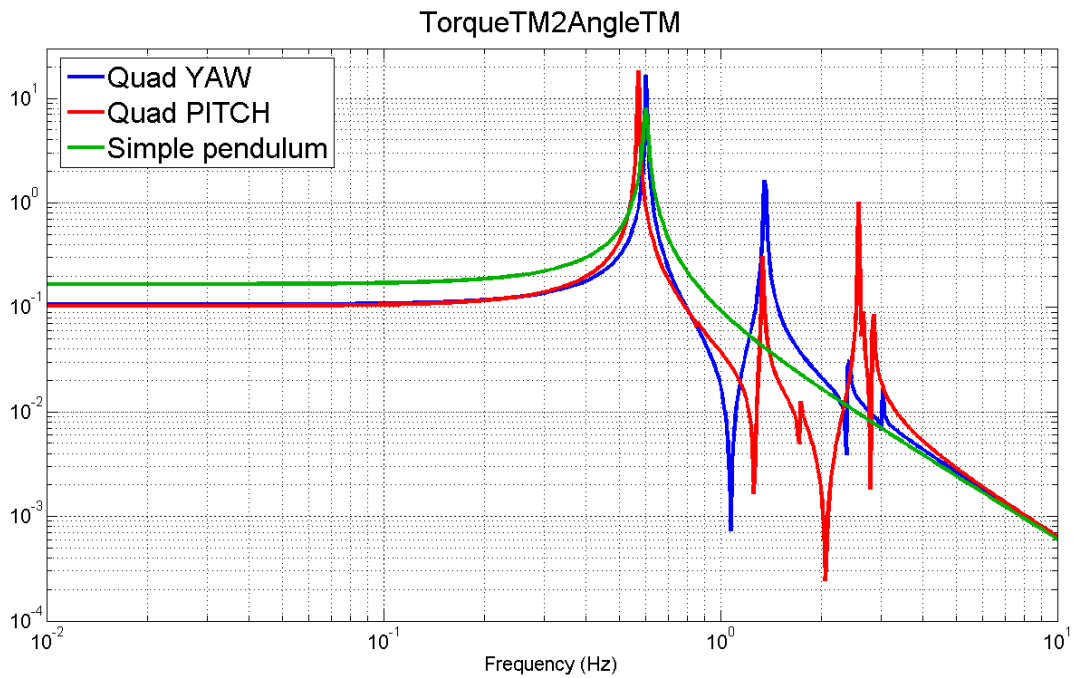
$$P = \frac{125 \times 43.5}{2} \times \frac{2 \times 443}{\pi} \sim 770\,\mathrm{kW} \rightarrow 720\ \mathrm{kW}$$

Losses in the recycling cavity, PR2 transmission, Rar ITMs

- Radiation pressure torque: $k_{major} = -9.9$ $k_{minor} = +218$

- Quad restoring torques:

  $k_{pitch} = +9.71$
  $k_{yaw} = +9.42$
  $(k_{pend} = +6)$



Modes of Operation

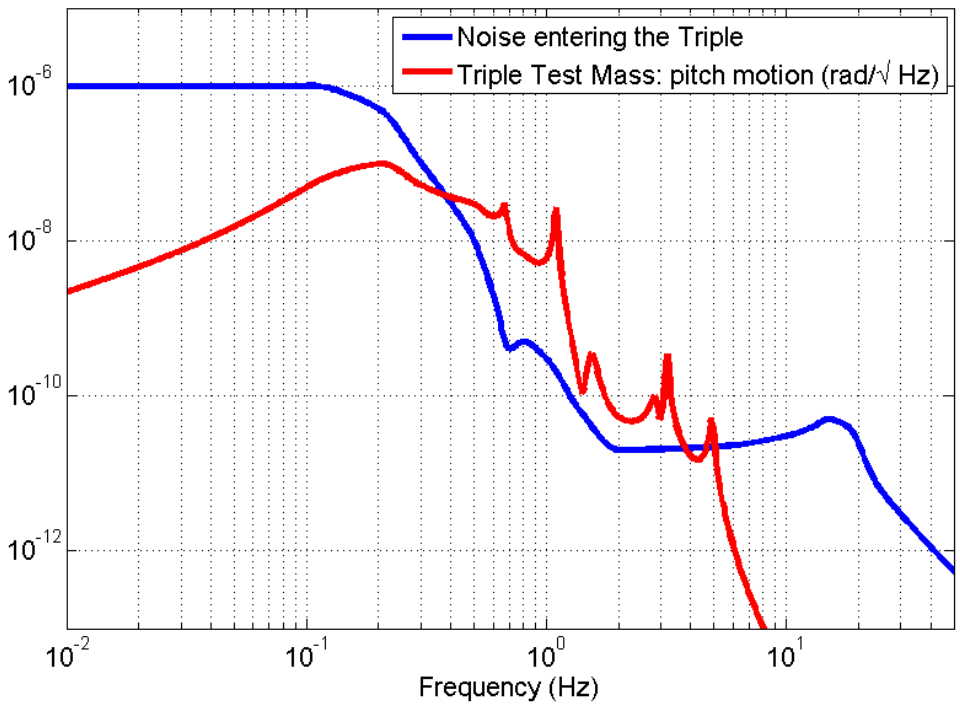
INPUT POWER (W)	INTRA CAVITY POWER (kW)	fsoft PITCH (Hz)	fsoft YAW (Hz)
1	~6.15	+0.567	+0.597
10	~61.5	+0.545	+0.572
25	~155	+0.504	+0.528
100	~615	+0.205	+0.19
125	~770	-0.17	-0.21
125*	~720	-0.08	-0.14

→ No unstable mode for intra-cavity power < 685 kW

→ Ugf don't need to be more than 1 Hz for unstable modes

Optickle Model

- 125 W input power, stable cavities, broad band
- 100 mW on each WFS, 1% power taken at the AS port power (about 3mW with 10 pm DARM offset)
- Quad TFs, actuation from the PM
- Estimated PITCH motion for the Quad and for the Triple



Sensing Matrix

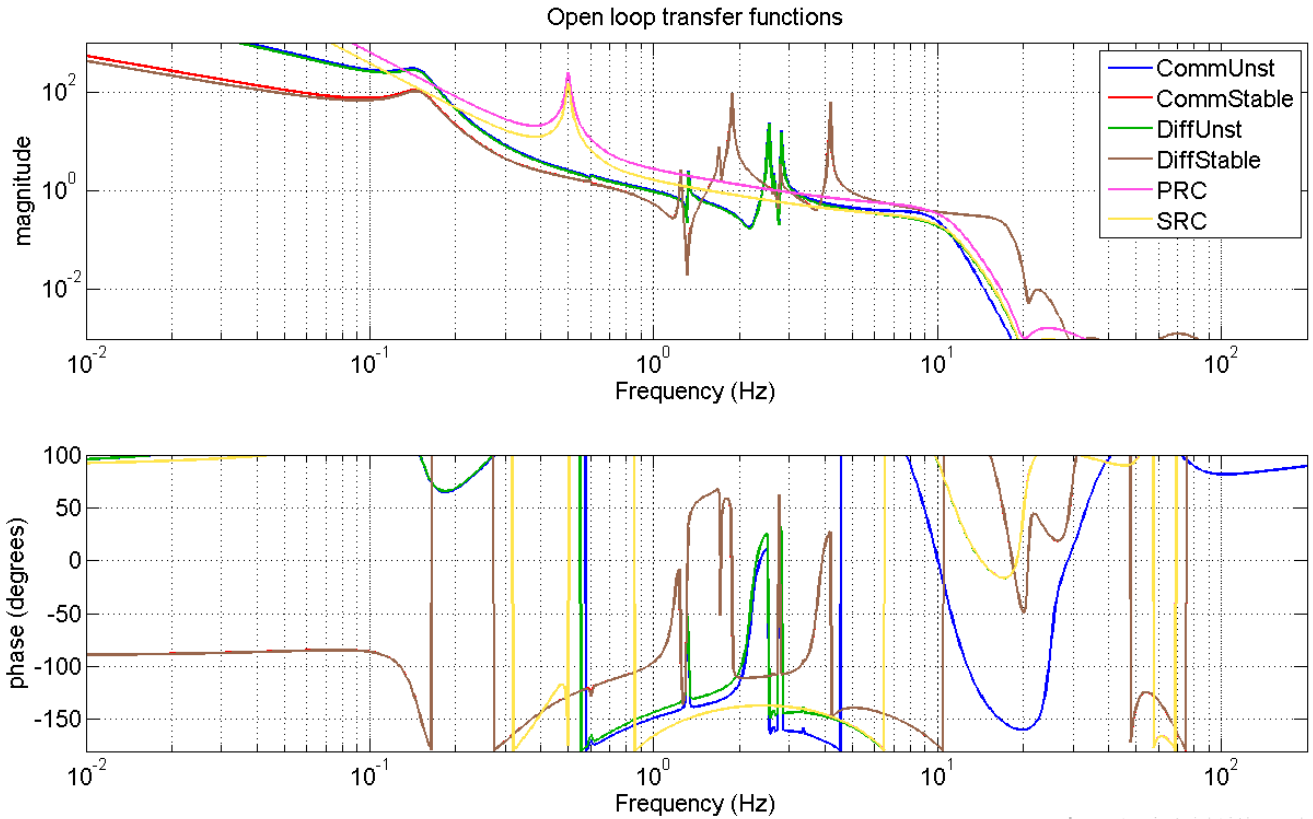
- Based on Valera's sensing matrix
- Optimized Gouy phases and demod phases

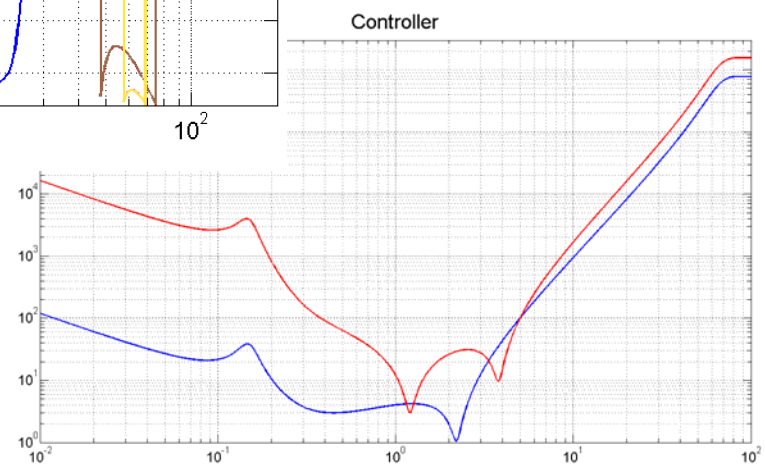
$$\begin{pmatrix} \text{POP I1}(140^\circ) \\ \text{REFL\_B I1}(70^\circ) \\ \text{OMCr\_B QM}(106^\circ) \\ \text{AS Q2}(80^\circ) \\ \text{REFL\_A I1}(160^\circ) \\ \text{OMCr\_B I22}(106^\circ) \end{pmatrix} = \begin{bmatrix} 297 & -4956 & 0 & 0 & 0 & 0 \\ 0 & 8.82e5 & 0 & 0 & 0 & 0 \\ 0 & 0 & -1.78e5 & 1.54e5 & 0 & 0 \\ 0 & 0 & -1.21e4 & -1.96e5 & 0 & 0 \\ 0 & -3338 & 0 & 0 & 1966 & 0 \\ -4503 & 5358 & -1.28e4 & 1.2e4 & 0 & 697.44 \end{bmatrix} \begin{bmatrix} \text{CSoft} \\ \text{CHard} \\ \text{DSoft} \\ \text{DHard} \\ \text{PR} \\ \text{SR} \end{bmatrix}$$

$$\begin{pmatrix} \text{POP I1}(140^\circ) \\ \text{REFL\_B I1}(70^\circ) \\ \text{OMCr\_B QM}(106^\circ) \\ \text{AS Q2}(80^\circ) \\ \text{REFL\_A I1}(160^\circ) \\ \text{OMCr\_B I22}(106^\circ) \end{pmatrix} = \begin{bmatrix} 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0.62 & 0 & 0 \\ 0 & 0 & 0 & -0.79 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0.05 & 0 & 1 \end{bmatrix} \begin{bmatrix} \text{CSoft} \\ \text{CHard} \\ \text{DSoft} \\ \text{DHard} \\ \text{PR} \\ \text{SR} \end{bmatrix}$$

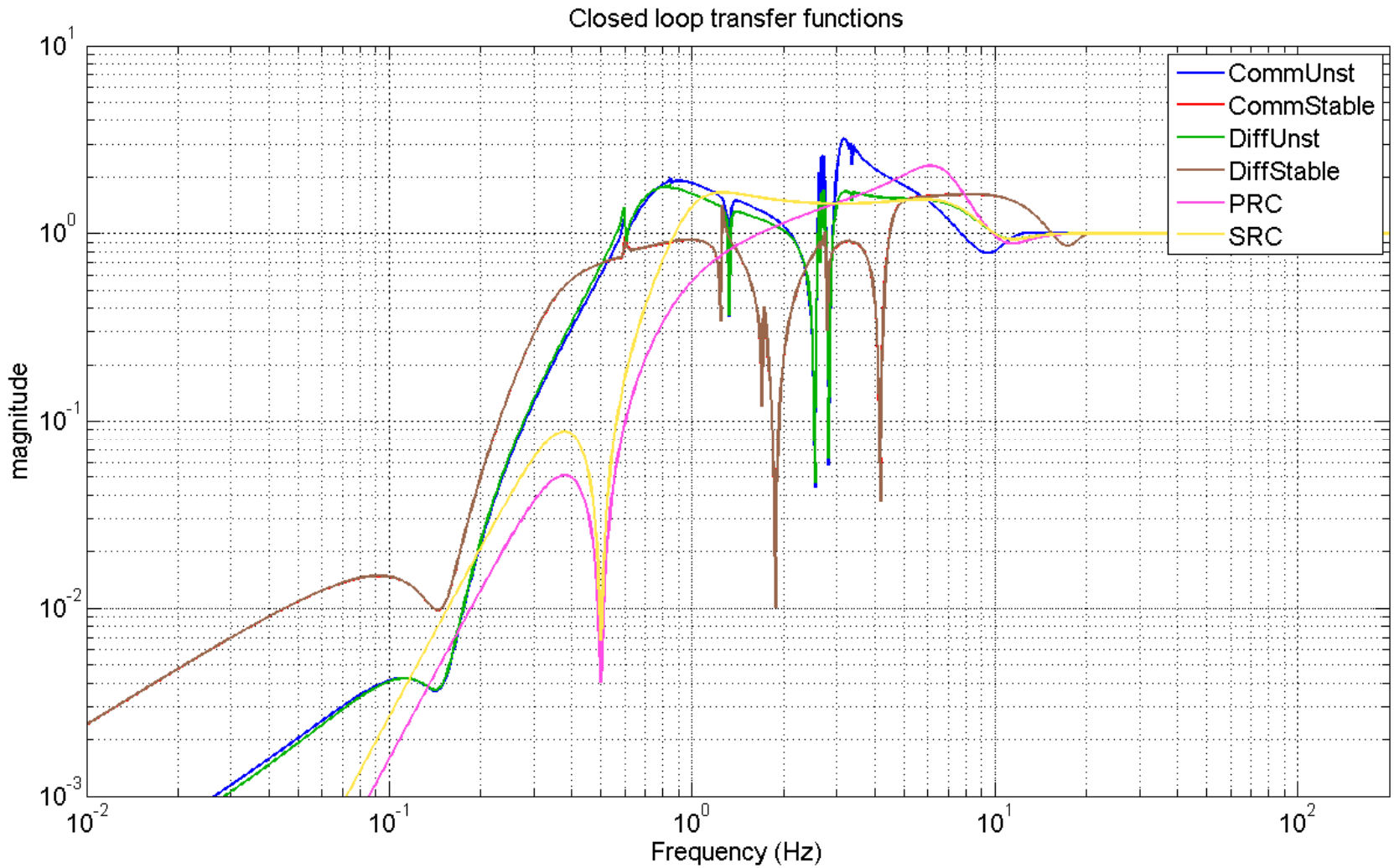
Condition Number = 1.9

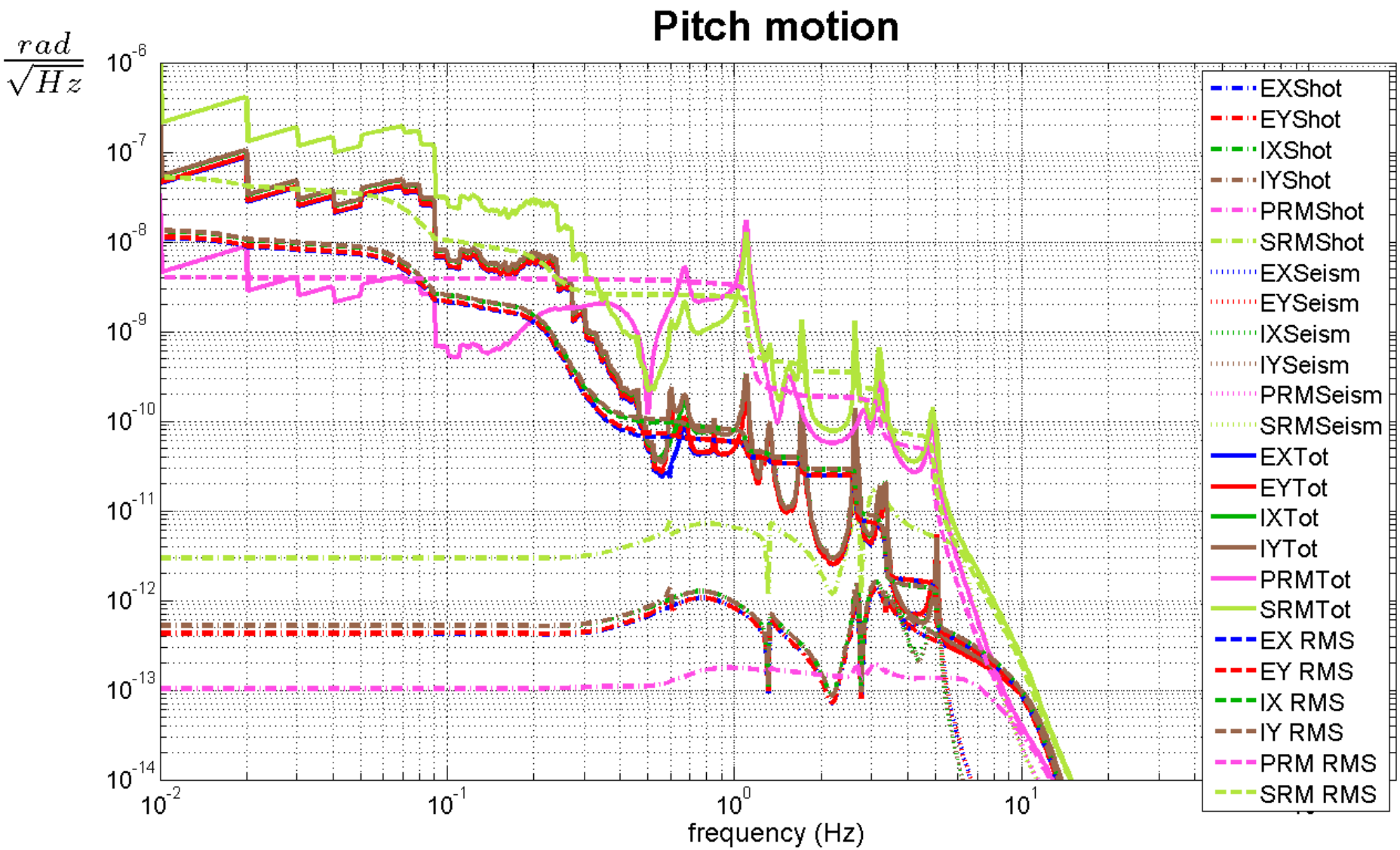
Loops (PM actuation)

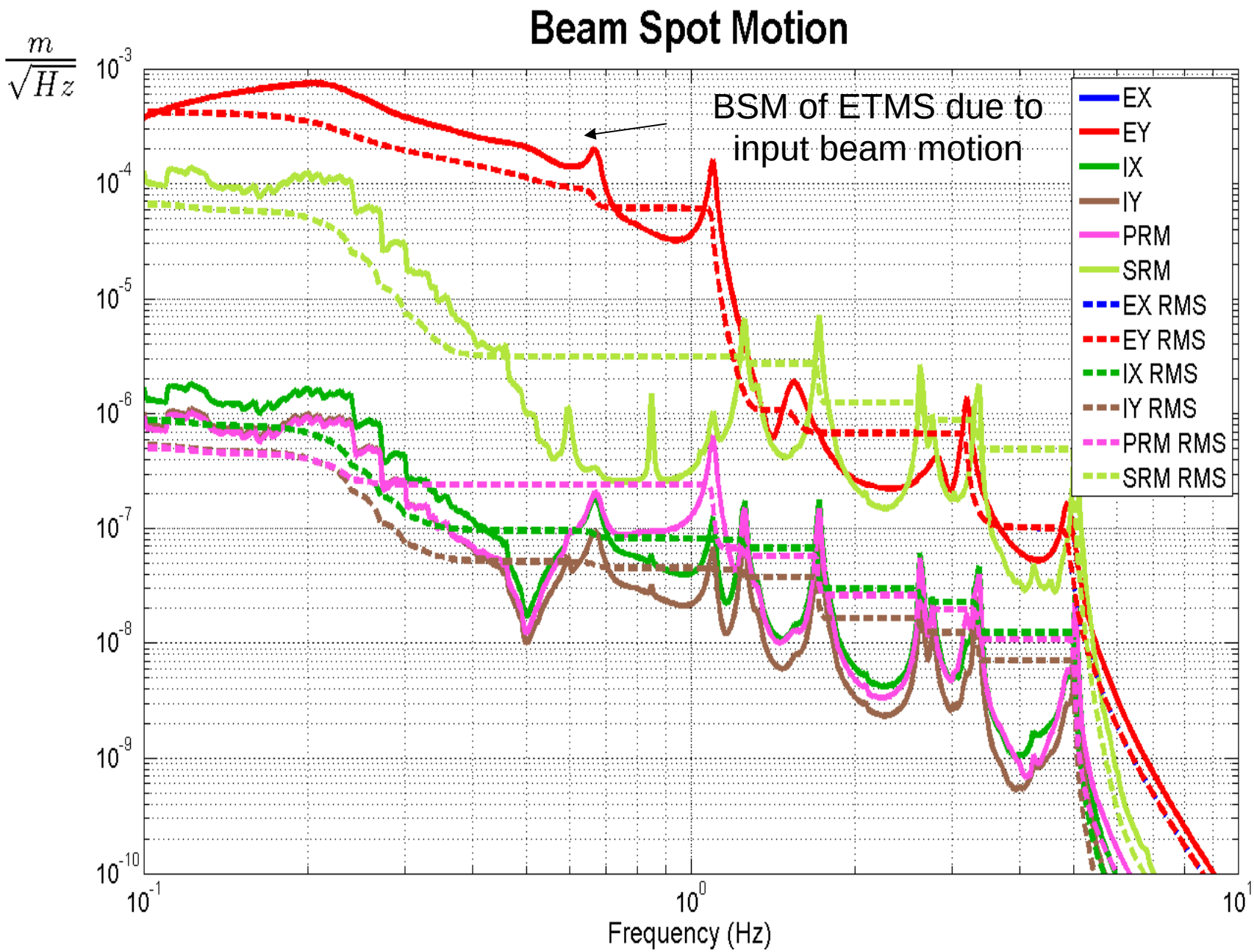




Loops (PM actuation)

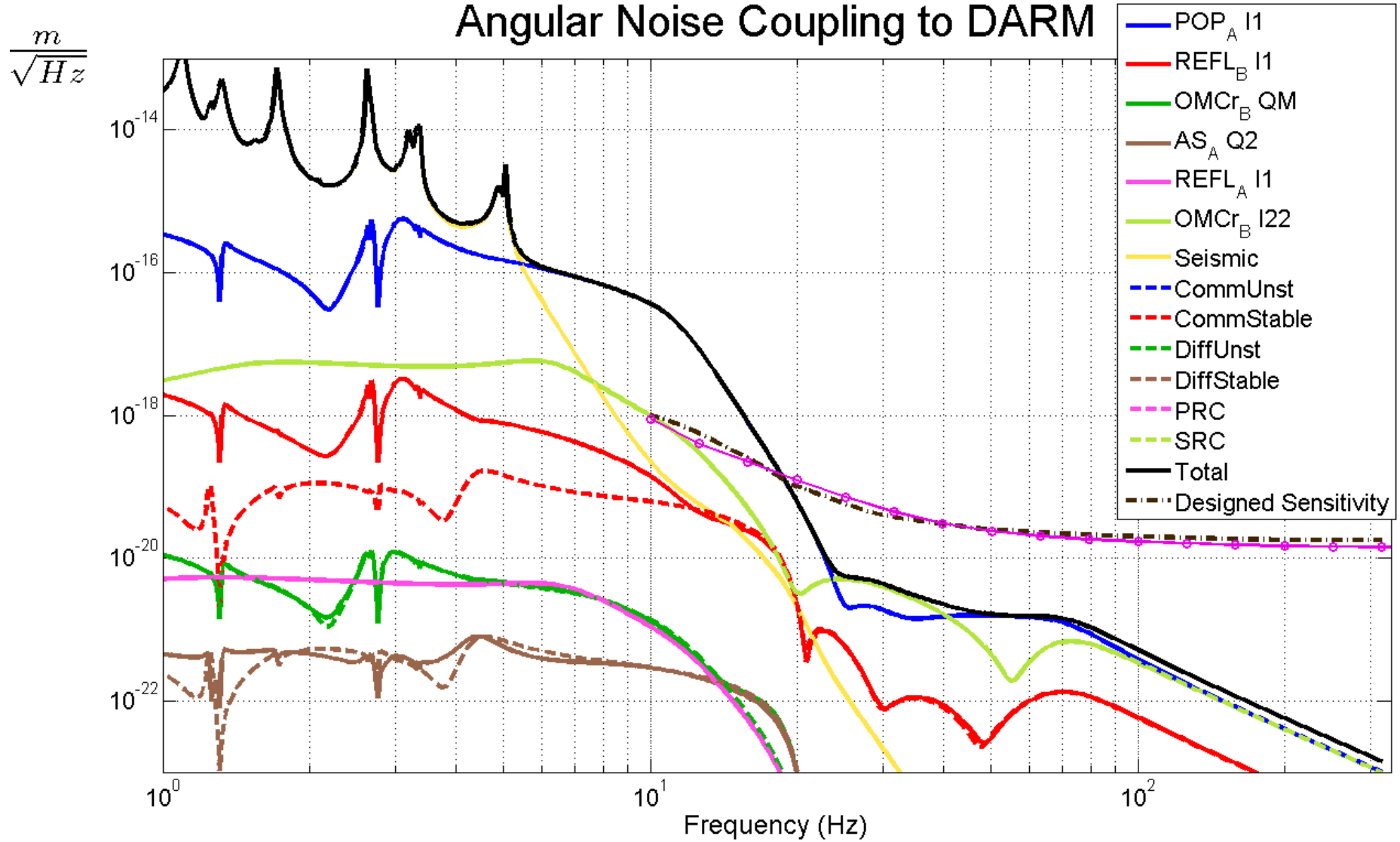



Pitch motion
$\frac{rad}{\sqrt{Hz}}$
10^{-6}
10^{-7}
10^{-8}
10^{-9}
10^{-10}
10^{-11}
10^{-12}
10^{-13}
10^{-14}
10^{-2}
10^{-1}
10^{0}
10^{1}
frequency (Hz)
EXShot
EYShot
IXShot
IYShot
PRMShot
SRMShot
EXSeism
EYSeism
IXSeism
IYSeism
PRMSeism
SRMSeism
EXTot
EYTot
IXTot
IYTot
PRMTot
SRMTot
EX RMS
EY RMS
IX RMS
IY RMS
PRM RMS
SRM RMS

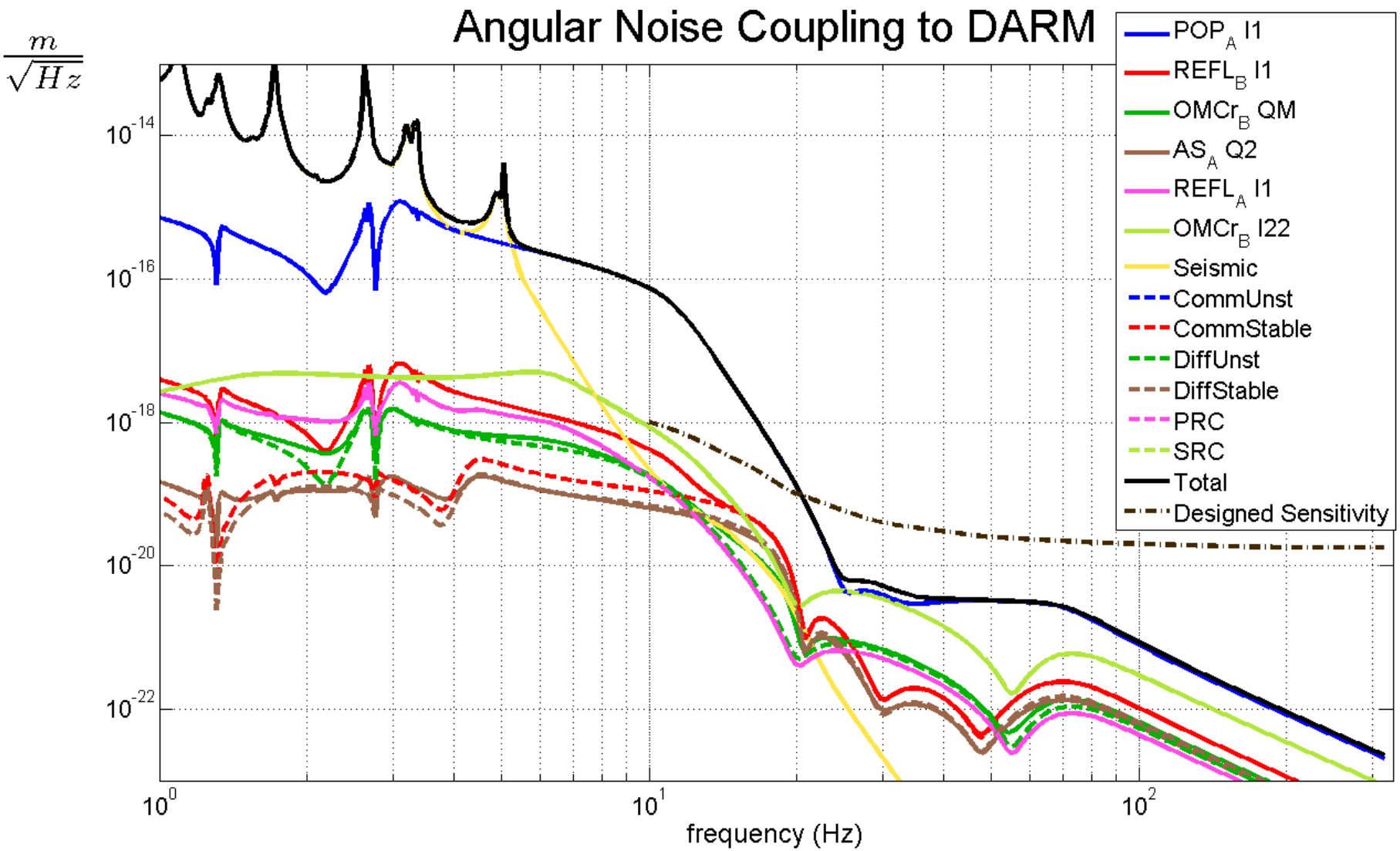

Beam Spot Motion
$\frac{m}{\sqrt{Hz}}$
BSM of ETMS due to input beam motion
EX
EY
IX
IY
PRM
SRM
EX RMS
EY RMS
IX RMS
IY RMS
PRM RMS
SRM RMS
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
10^{-8}
10^{-9}
10^{-10}
10^{-1}
10^{0}
10^{1}
Frequency (Hz)

Angular noise coupling to DARM

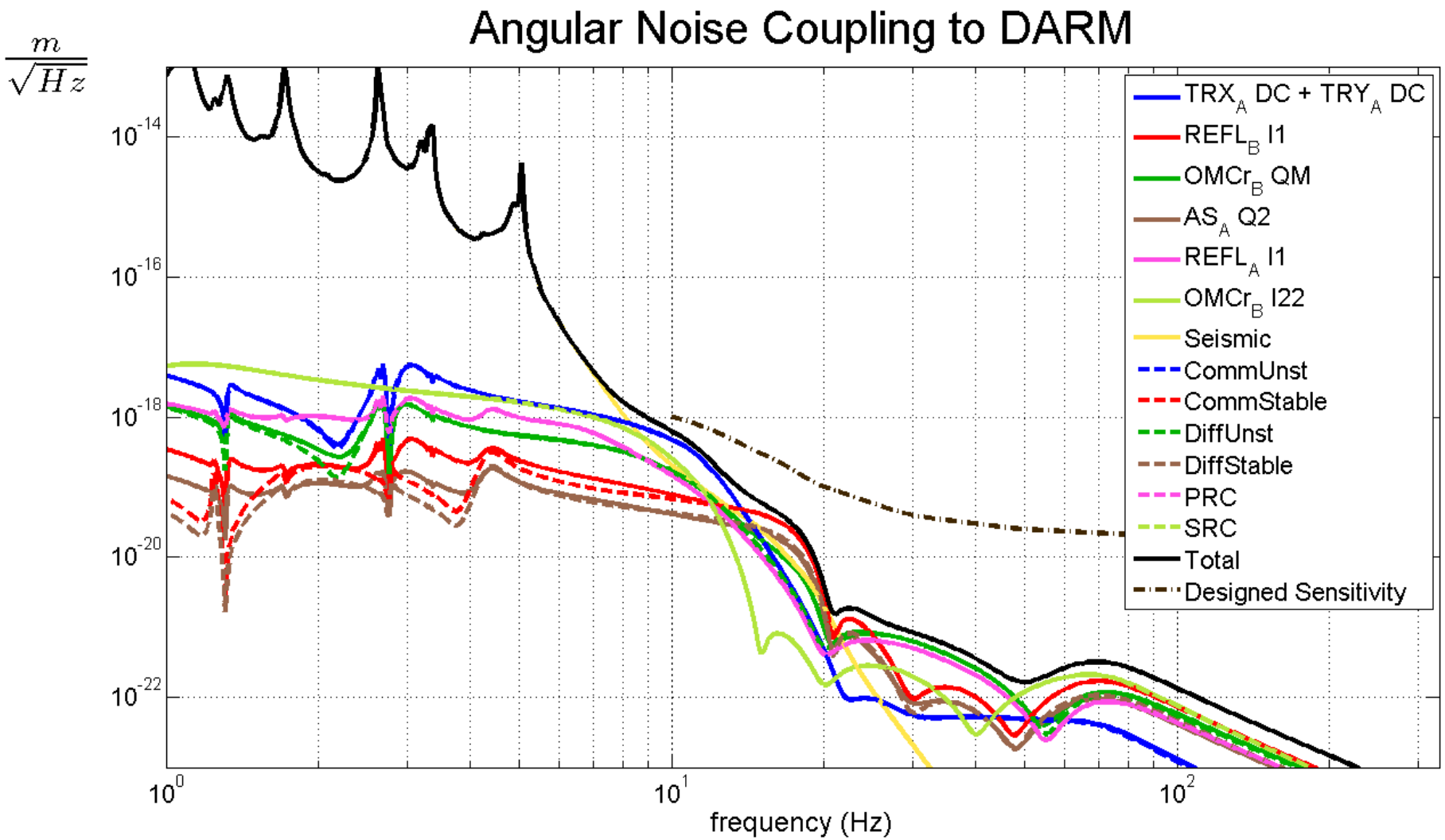
- BSM * Angular motion for each mirror
- 1% coupling PR to DARM
- 2% coupling SR to DARM


Angular Noise Coupling to DARM
$\frac{m}{\sqrt{Hz}}$
10^{-14}
10^{-16}
10^{-18}
10^{-20}
10^{-22}
10^{0}
10^{1}
10^{2}
Frequency (Hz)
POP$_A$ I1
REFL$_B$ I1
OMCr$_B$ QM
AS$_A$ Q2
REFL$_A$ I1
OMCr$_B$ I22
Seismic
CommUnst
CommStable
DiffUnst
DiffStable
PRC
SRC
Total
Designed Sensitivity

Fixed coupling (400 um BSM RMS)



QPDs in transmission instead of POP?

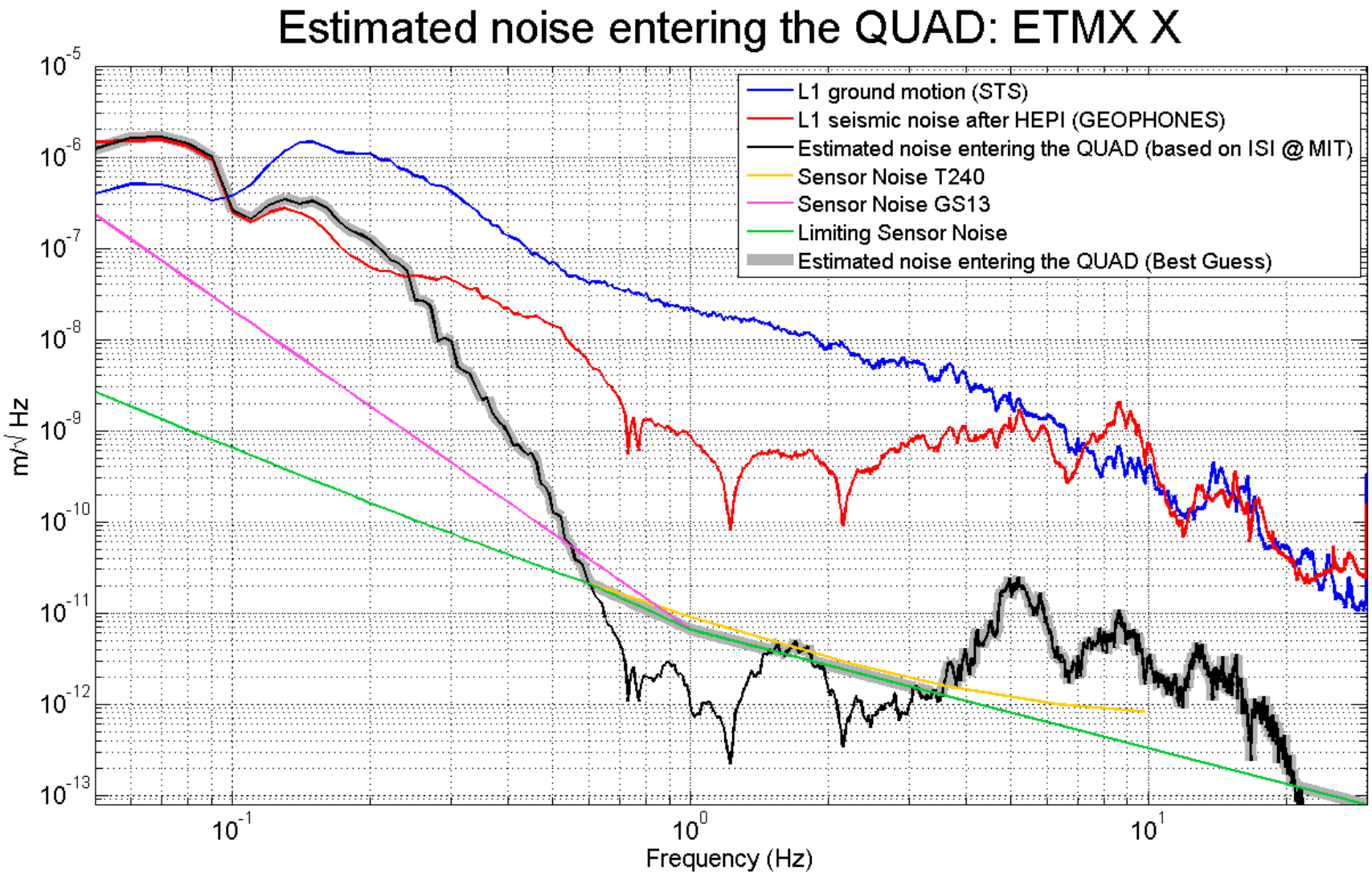


Blending?

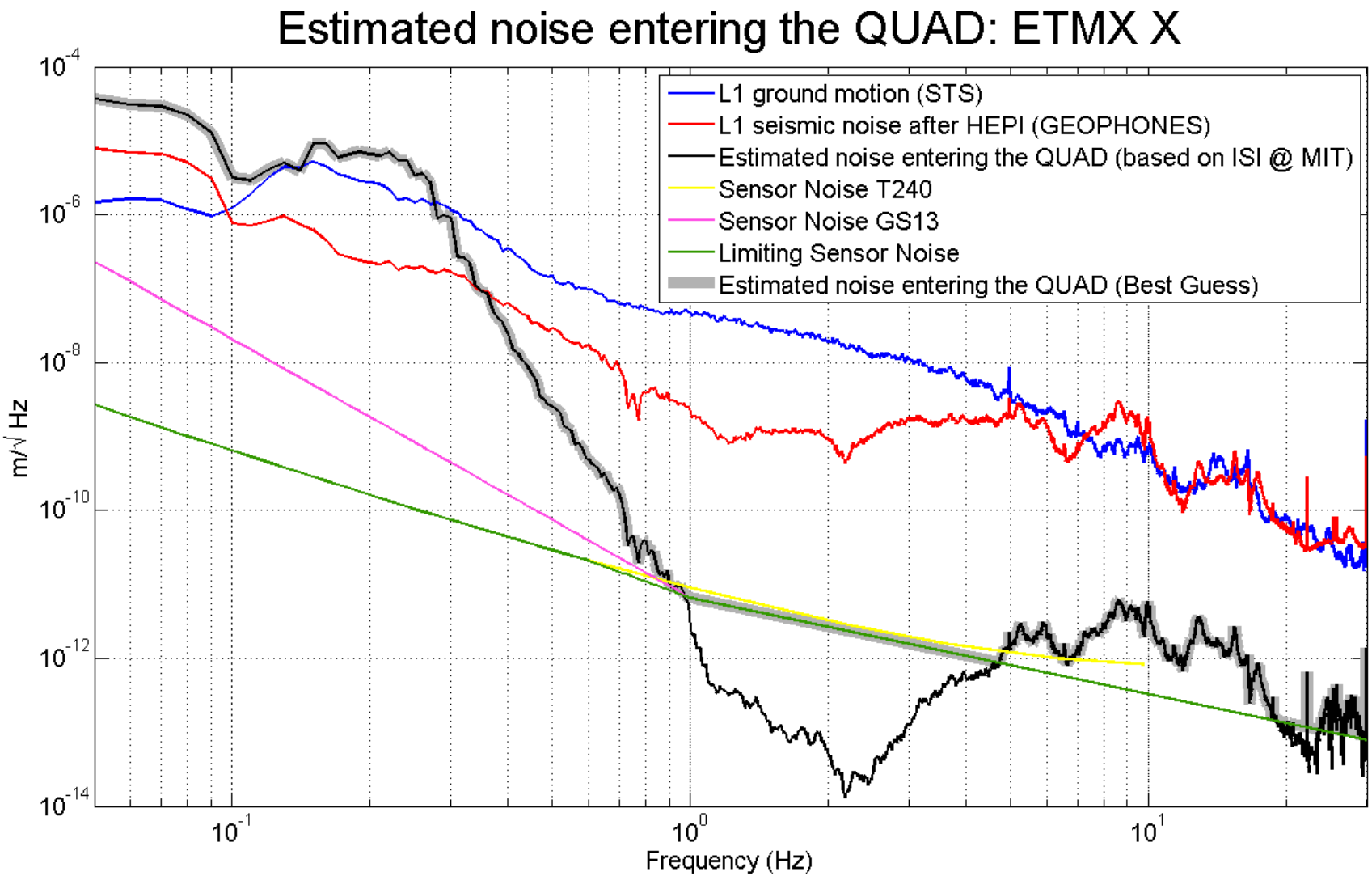
- QPDs high frequency, POP below
- QPDs nominally image ETM
  - Need to image cavity center
  - 90 degrees Gouy phase from ETM image
  - Need 2 QPDs at each end

The Message

- It doesn’t look like radiation pressure will be an issue in advLIGO
- I need a signal for Common Unstable
- I have to write a “to do list” and actually do it.

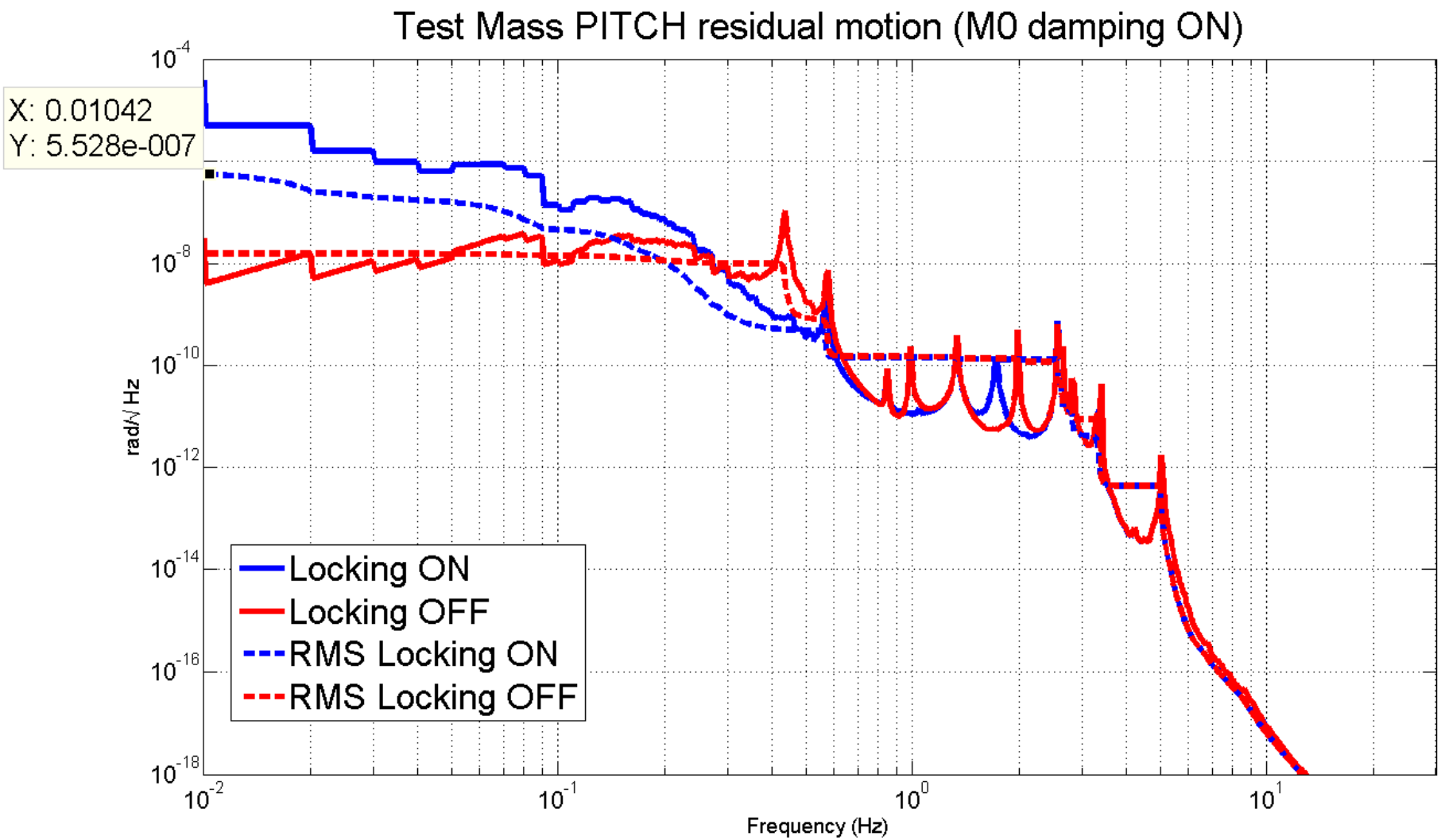


Medium level of seismic noise, vertical attenuation (Z)



High level of seismic noise, actual X attenuation

PITCH motion QUAD



Mode Matching

❑ ROC with Optickle:

- par.PRM.ROC = 9.65; (9.35) ➔ +20 cm
- par.PR2.ROC = -2.27;
- par.PR3.ROC = 34.00;
- par.SR3.ROC = 34.00;
- par.SR2.ROC = -3.77;
- par.SRM.ROC = -11.9; (-11.77) ➔ -12 cm

Beam Size

	Beam size(mm)	Z0(mm)	Z(mm)
PR	1.9	4.82e3	5.2e3
PR2	3.3	4.82e3	11.40e3
PR3	54.0	34.4	17.2e3
SR	2.1	…	
SR2	5.5		…
SR3	54.0		