JGW-T2011755

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Estimated sensitivity for auxiliary degrees of freedom of KAGRA interferometer

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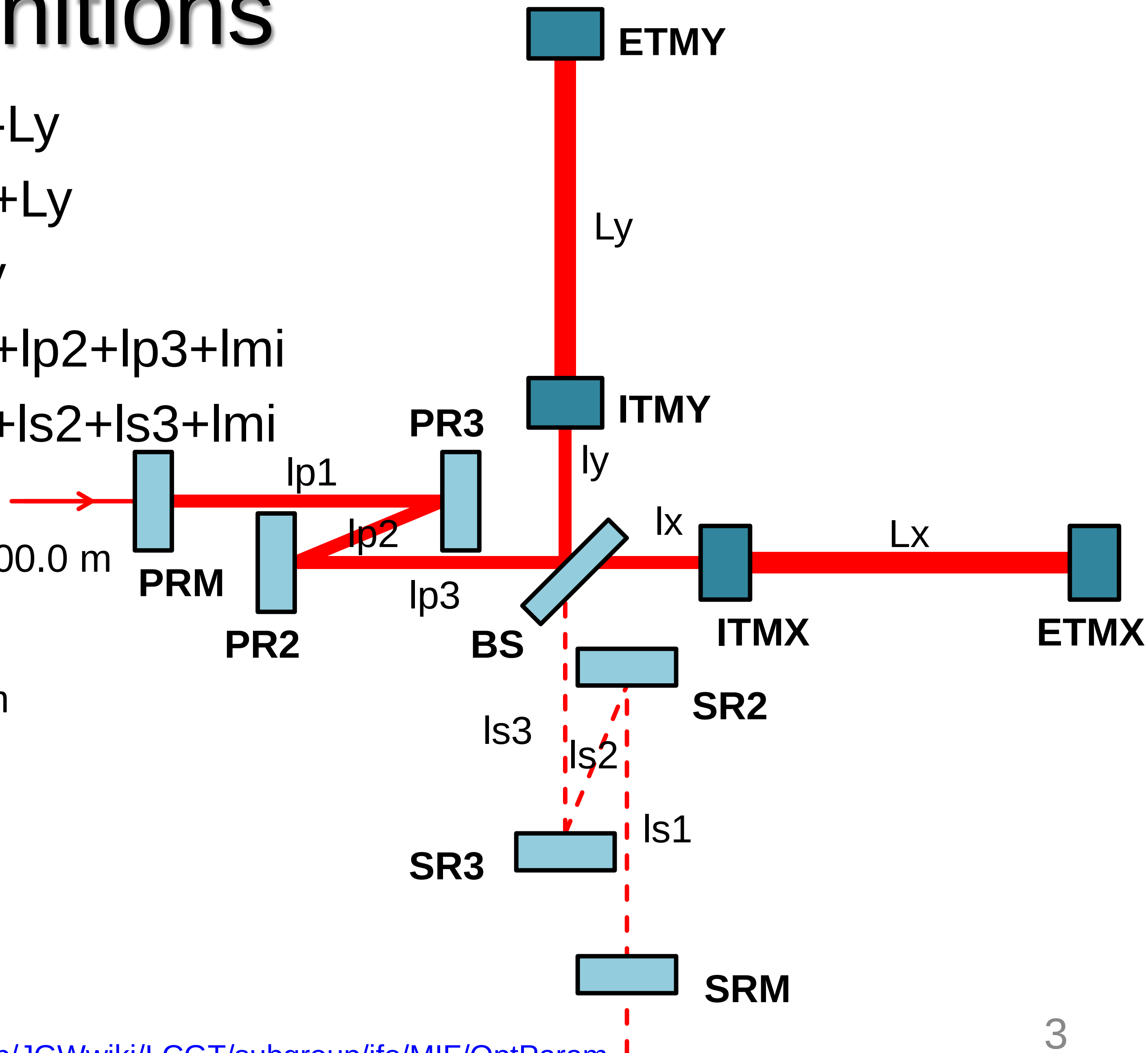
Scope

- Estimate the displacement sensitivity for CARM, MICH, PRCL, SRCL
  - useful for the noise budget of auxiliary DoFs
- Based on the latest estimated sensitivity code (JGW-T1707038)
- Seismic noise
  - fitted function from suspension model
- Suspension thermal noise
  - analytical calculation
- Mirror thermal noise
  - analytical calculation (we have to guess coating thickness)
- Quantum noise
  - analytical calculation for DARM, fitting of Optickle result for auxiliary DoFs

Definitions

- DARM: Lx-Ly
- CARM: Lx+Ly
- MICH: lx-ly
- PRCL: lp1+lp2+lp3+lmi
- SRCL: ls1+ls2+ls3+lmi

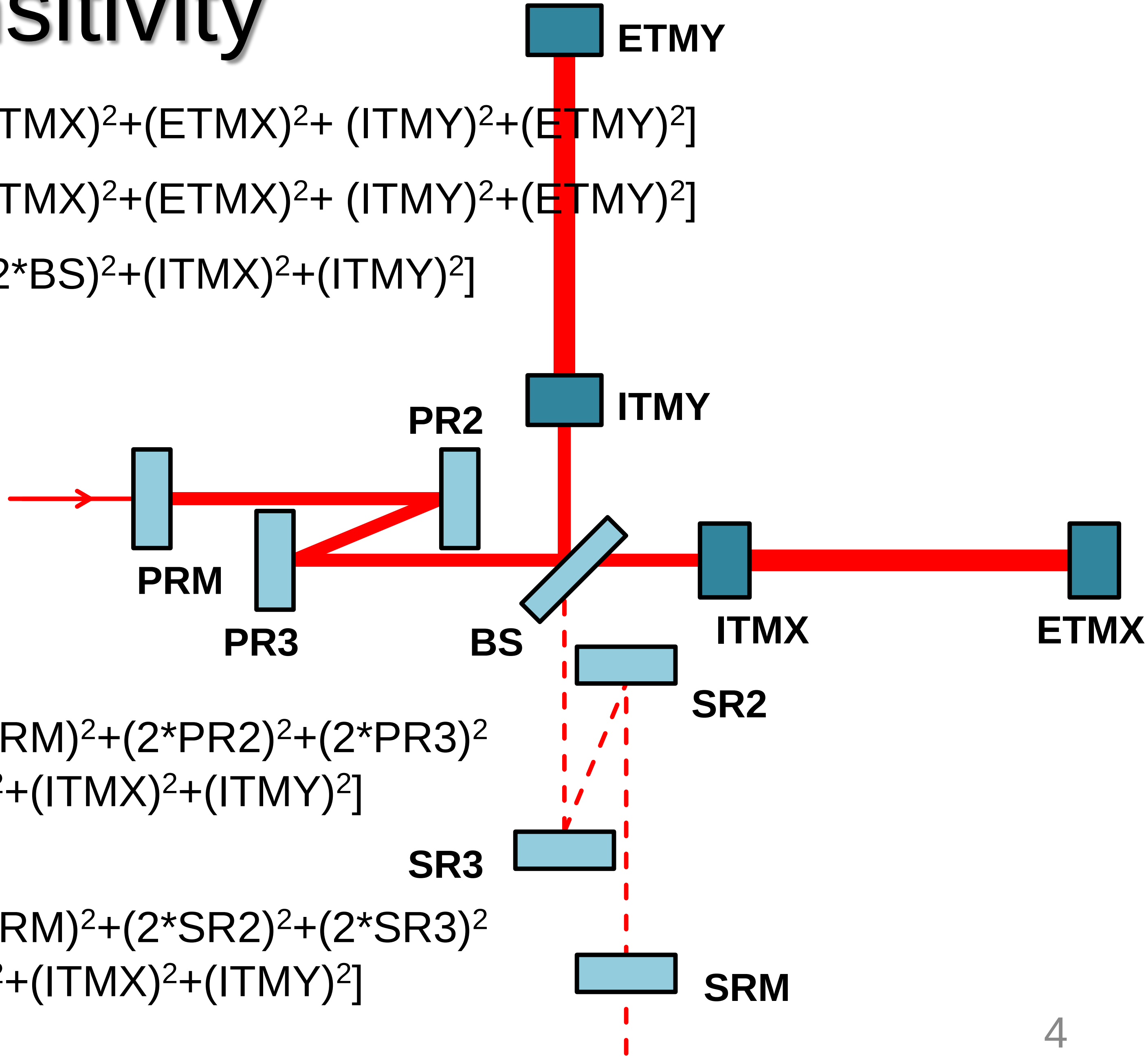


Lx = Ly = Larm = 3000.0 m
lx = 26.6649 m
ly = 23.3351 m
lmi = (lx+ly)/2 = 25 m
lp1 = 14.7615 m
lp2 = 11.0661 m
lp3 = 15.7638 m
ls1 = 14.7412 m
ls2 = 11.1115 m
ls2 = 15.7386 m

http://gwwiki.icrr.u-tokyo.ac.jp/JGWwiki/LCGT/subgroup/ifo/MIF/OptParam

Sensitivity

- DARM: $\sqrt{[(ITMX)^2+(ETMX)^2+(ITMY)^2+(ETMY)^2]}$
- CARM: $\sqrt{[(ITMX)^2+(ETMX)^2+(ITMY)^2+(ETMY)^2]}$
- MICH: $\sqrt{[(\sqrt{2}*BS)^2+(ITMX)^2+(ITMY)^2]}$

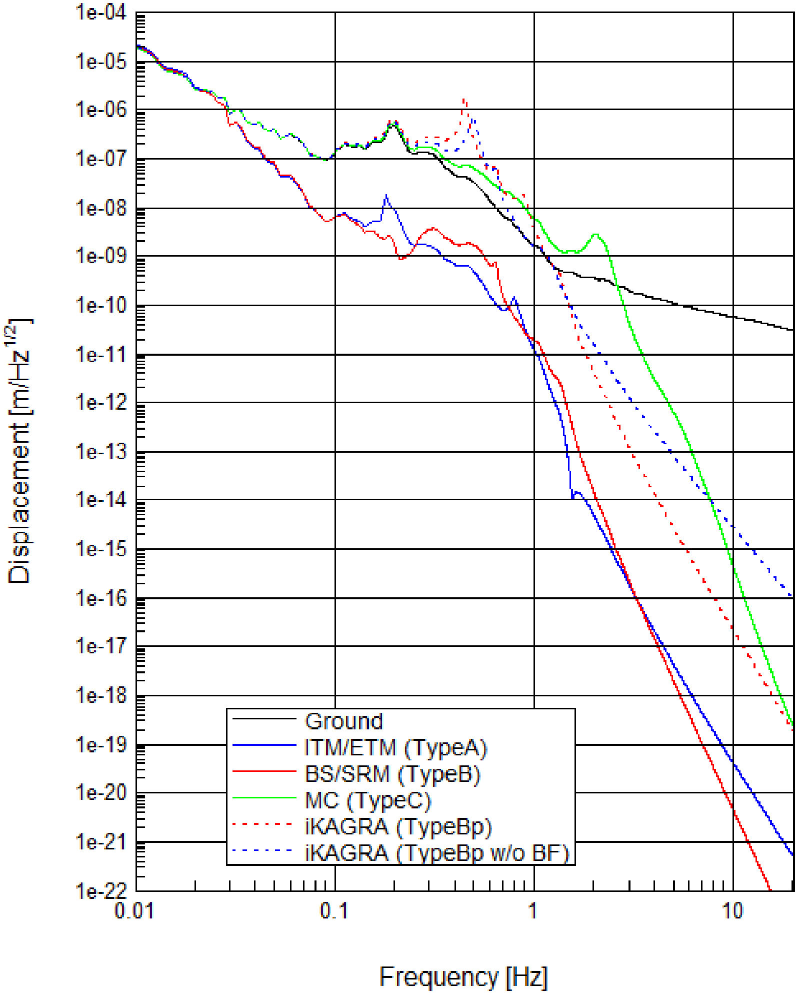


- PRCL: $\sqrt{[(PRM)^2+(2*PR2)^2+(2*PR3)^2 +(\sqrt{2}/2*BS)^2+(ITMX)^2+(ITMY)^2]}$
- SRCL: $\sqrt{[(SRM)^2+(2*SR2)^2+(2*SR3)^2 +(\sqrt{2}/2*BS)^2+(ITMX)^2+(ITMY)^2]}$

Seismic noise

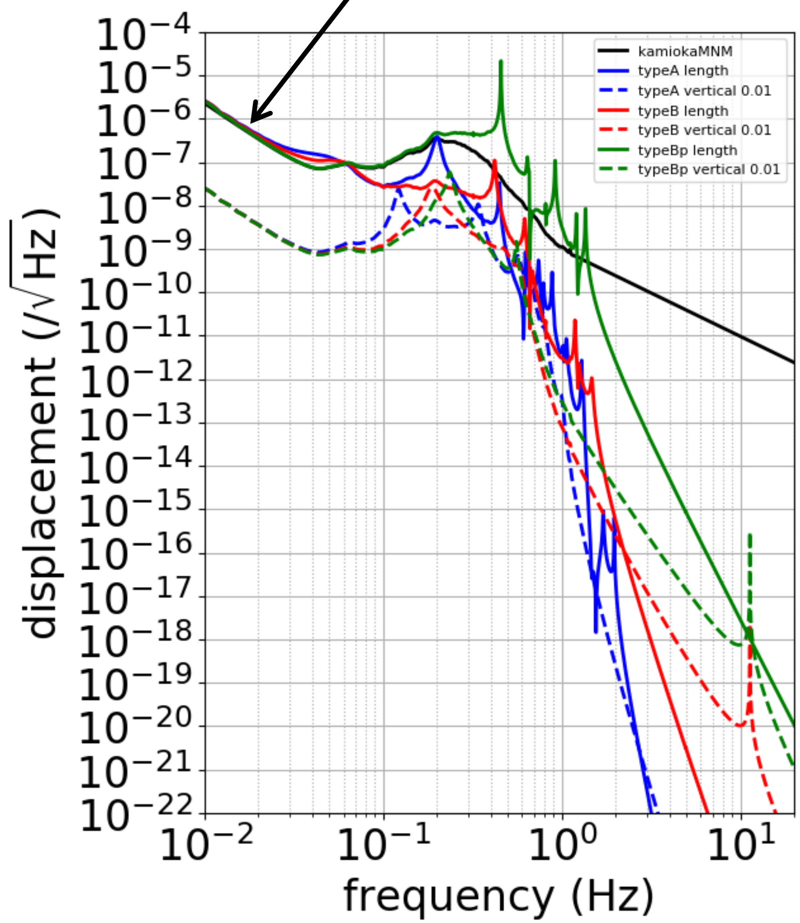
Models

- There exists several models



TypeA-C rev3.png
from R. Takahashi
(used for K. Somiya's fitting)

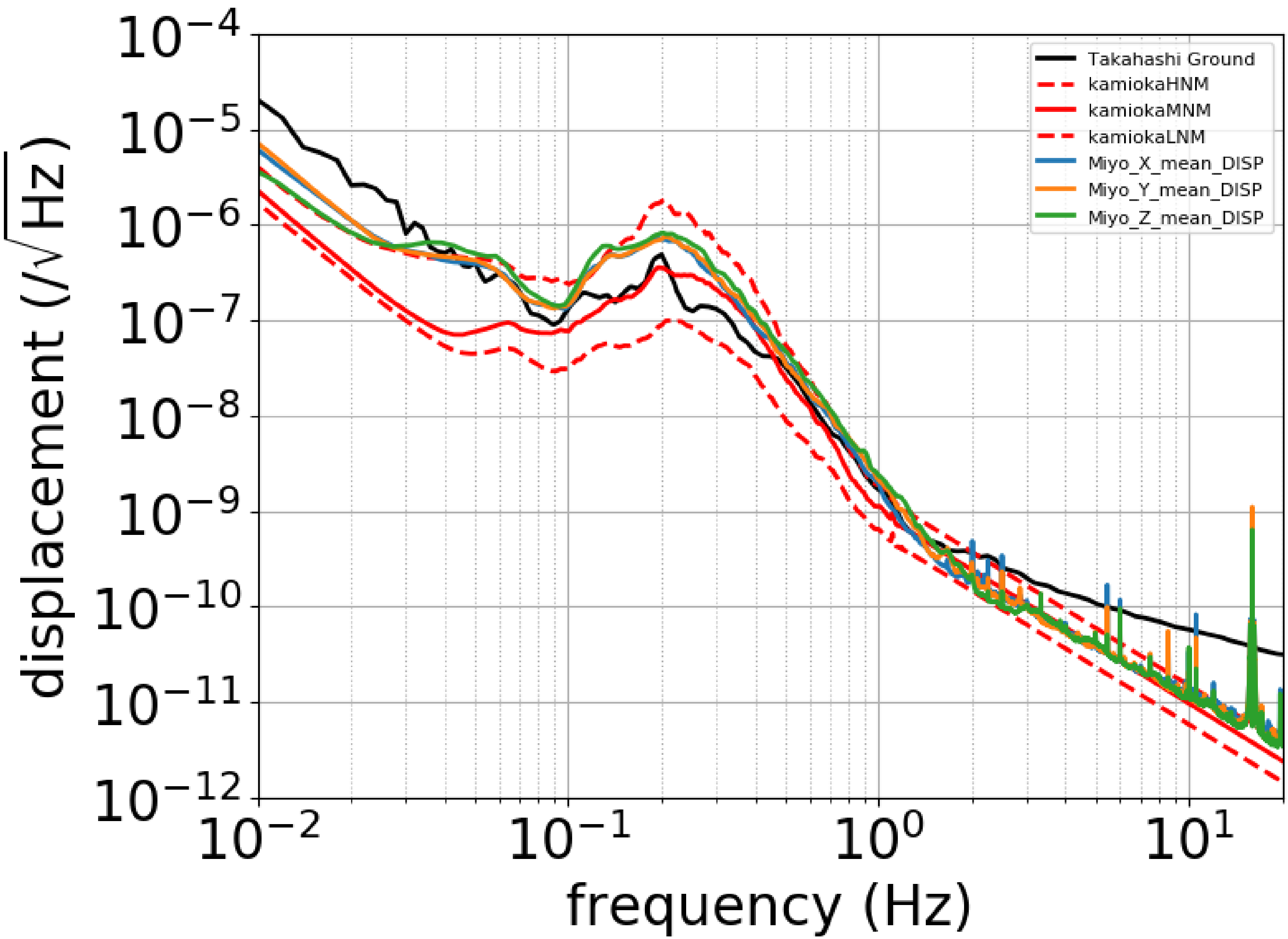
Medium Noise Model
from JGW-T1402971



Model from T. Sekiguchi
(used for actuator modeling in JGW-P1707051)

Seismic Noise Spectra

- Let's just use JGW-T1402971 MNM for simplicity



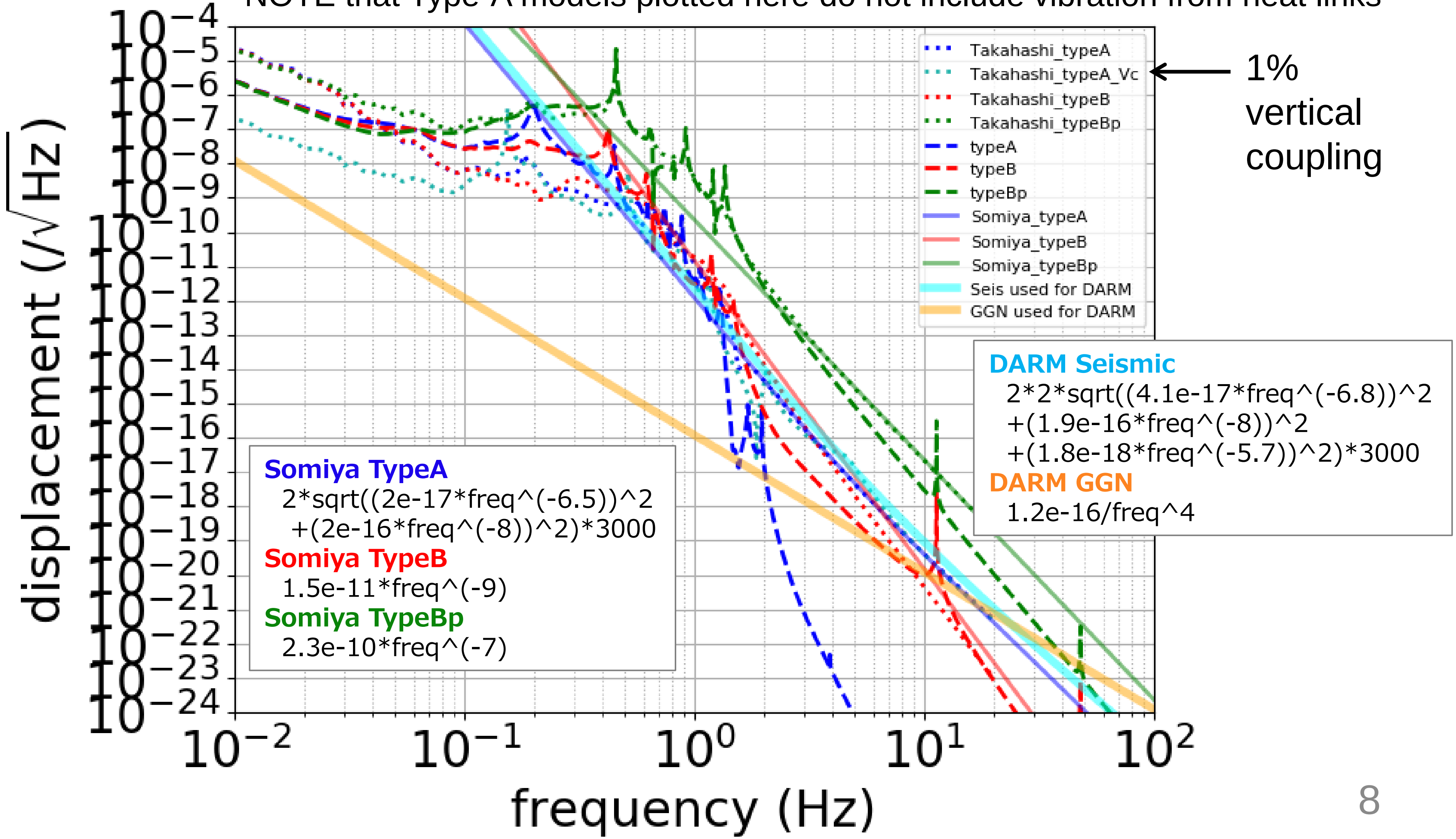
By Sekiguchi
JGW-T1402971

By Miyo
JGW-T1910436

Comparison Between Models

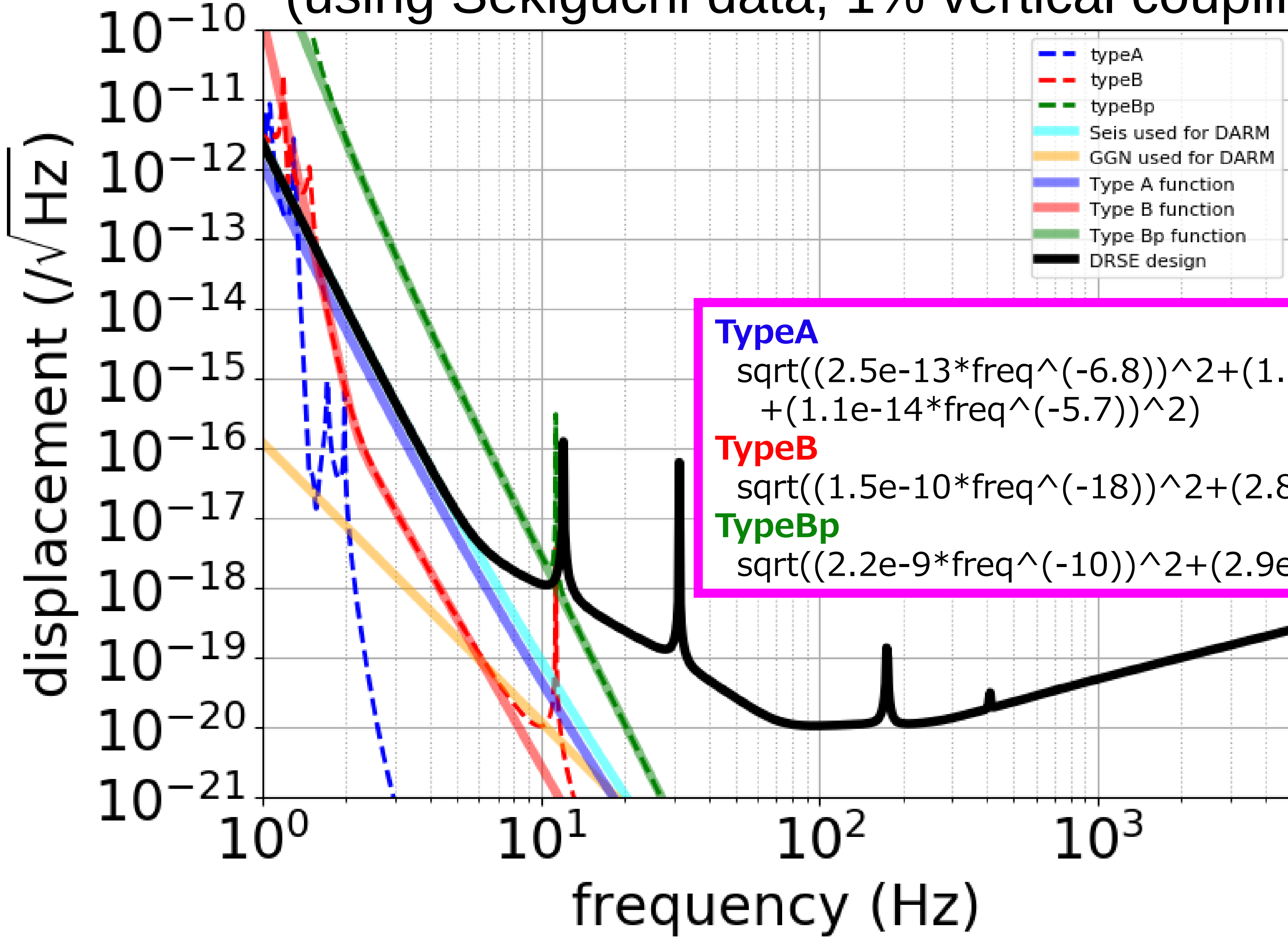
- Fitting function by Somiya based on Takahashi model

NOTE that Type-A models plotted here do not include vibration from heat links



New Seismic Function

- Function for one optic that work above ~3 Hz (using Sekiguchi data, 1% vertical coupling assumed)



The ones used for bKAGRA design sensitivity

TypeA
sqrt((2.5e-13*freq^(-6.8))^2+(1.1e-12*freq^(-8))^2 +(1.1e-14*freq^(-5.7))^2)

TypeB
sqrt((1.5e-10*freq^(-18))^2+(2.8e-14*freq^(-7))^2)

TypeBp
sqrt((2.2e-9*freq^(-10))^2+(2.9e-10*freq^(-8))^2)

Suspension thermal noise

Type-A Payload Configuration

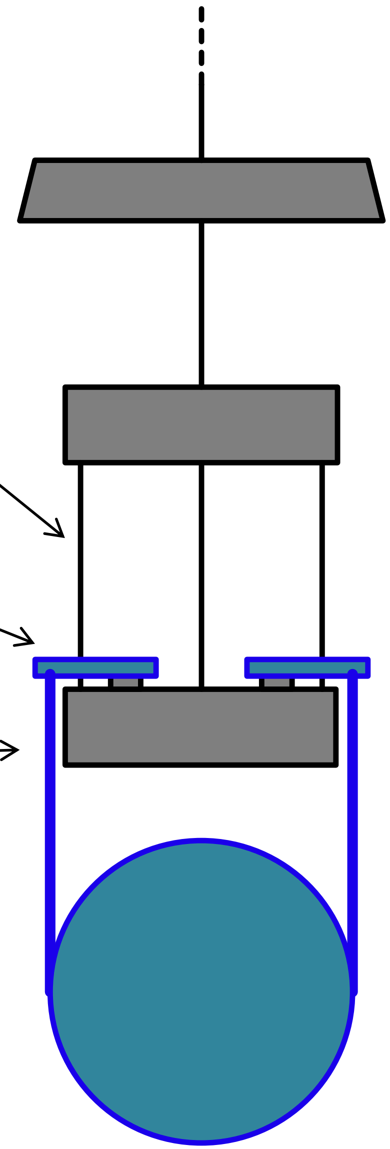
CQG 34, 225001 (2017)

IM suspension
4 CuBe wires
16 K
26.1 cm long, 0.6 mm dia.
loss angle 5e-6

Blade springs
4 Sapphire
55 g each
16 K
loss angle 7e-7

TM suspension
4 Sapphire fibers
19 K (average of 16 K and 22 K)
35 cm long, 1.6 mm dia.
loss angle 2e-7

Vertical to horizontal coupling 1/200



Platform

Marionette
16 K

Intermediate mass
16 K
20.5 kg

Test mass
22 K
22.8 kg

Type-B Payload Configuration

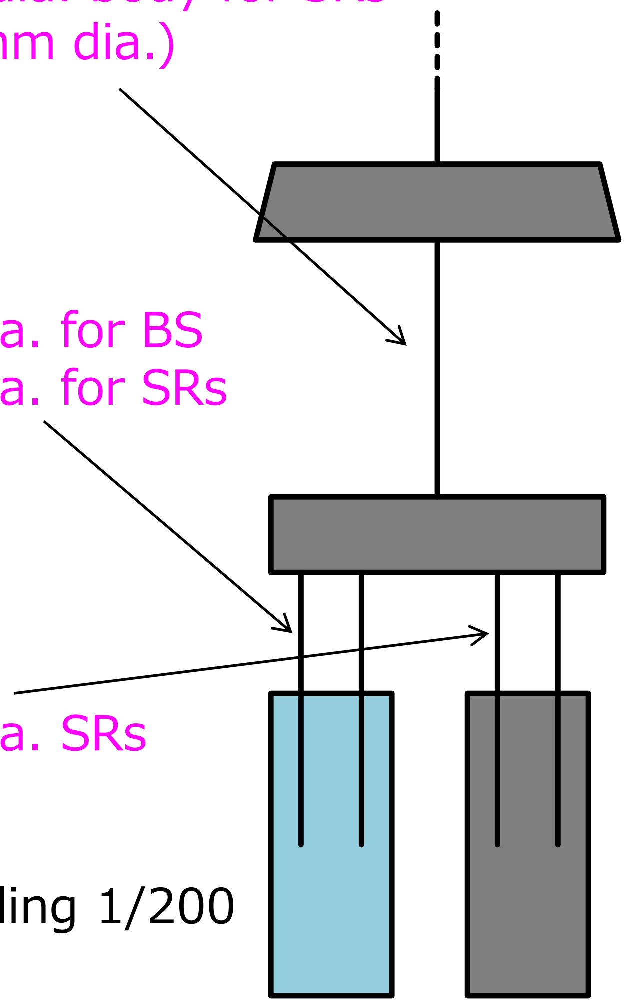
IM suspension
1 maraging steel rod
62.5 cm long, 3.6 m dia. body for BS
59.85 cm long, 2.5 mm dia. body for SRs
(neck 2.65 cm long, 2 mm dia.)
loss angle ??

TM suspension
4 piano wires
55.1 cm long, 0.3 mm dia. for BS
58.7 cm long, 0.2 mm dia. for SRs
loss angle ??

RM suspension
4 tungsten wires
??? for BS
58.7 cm long, 0.6 mm dia. SRs
loss angle ??

Vertical to horizontal coupling 1/200

CQG 34, 225001 (2017)
Type-B info from Fabian
Type-B maraging rod JGW-D1605614
BS mass budget JGW-E1604966



Bottom filter

Intermediate mass
34.6 kg for BS
15.6 kg for SRs

Test mass
18.71 kg for BS
10.71 kg for SRs

Recoil mass
22.3 kg for BS
12.036 kg for SRs

Type-Bp Payload Configuration

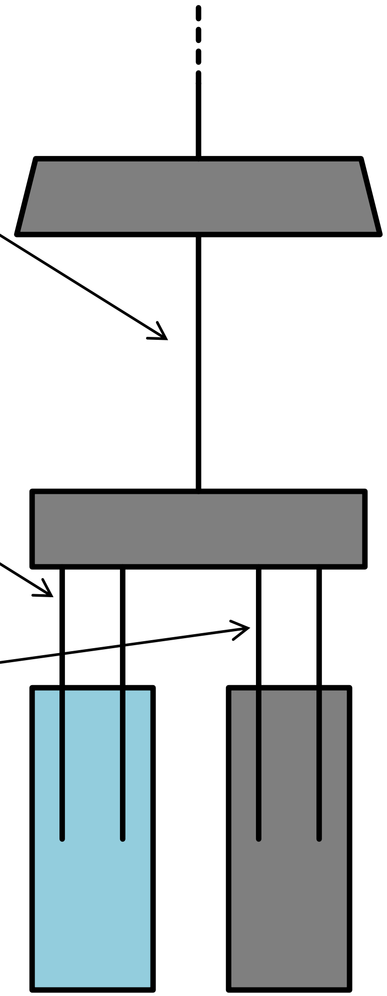
IM suspension
1 maraging steel rod
59.85 cm long, 2.5 mm dia. body for PRs
(neck 2.65 cm long, 2 mm dia.)
loss angle ??

[CQG 34, 225001 (2017)](#)
Type-Bp info from Shoda (same design as SRs)

TM suspension
4 piano wires
58.7 cm long, 0.2 mm dia. for PRs
loss angle ??

RM suspension
4 tungsten wires
58.7 cm long, 0.6 mm dia. PRs
loss angle ??

Vertical to horizontal coupling 1/200



Bottom filter

Intermediate mass
15.6 kg for PRs

Test mass
10.71 kg for PRs

Recoil mass
12.036 kg for PRs

Mirror thermal noise

Mirror and Coating Parameters

- Coating: silica/tantala (loss angle: 3e-4 / 5e-4)

	ITM/ETM	BS	SRM/2/3	PRM/2/3
Material	Sapphire	Fused silica	Fused silica	Fused silica
Diameter	22 cm	37 cm	25 cm	25 cm
Thickness	15 cm	8 cm	10 cm	10 cm
Mass	22.8 kg	18.9 kg	10.8 kg	10.8 kg
Temperature	22 K	290 K	290 K	290 K
Substrate loss angle	1e-8	**1/(6.5e-12/thickness+7.6e-12*f^0.77)** Physics Letters A 352, 3 (2006)		
Coating layers	22 / 40	**4**	**4 / 18 / 18**	**4 / 18 / 18**
Beam radius	3.5 cm	3.62 cm	0.43 / 0.43 / 3.67 cm	0.46 / 0.46 / 3.66 cm

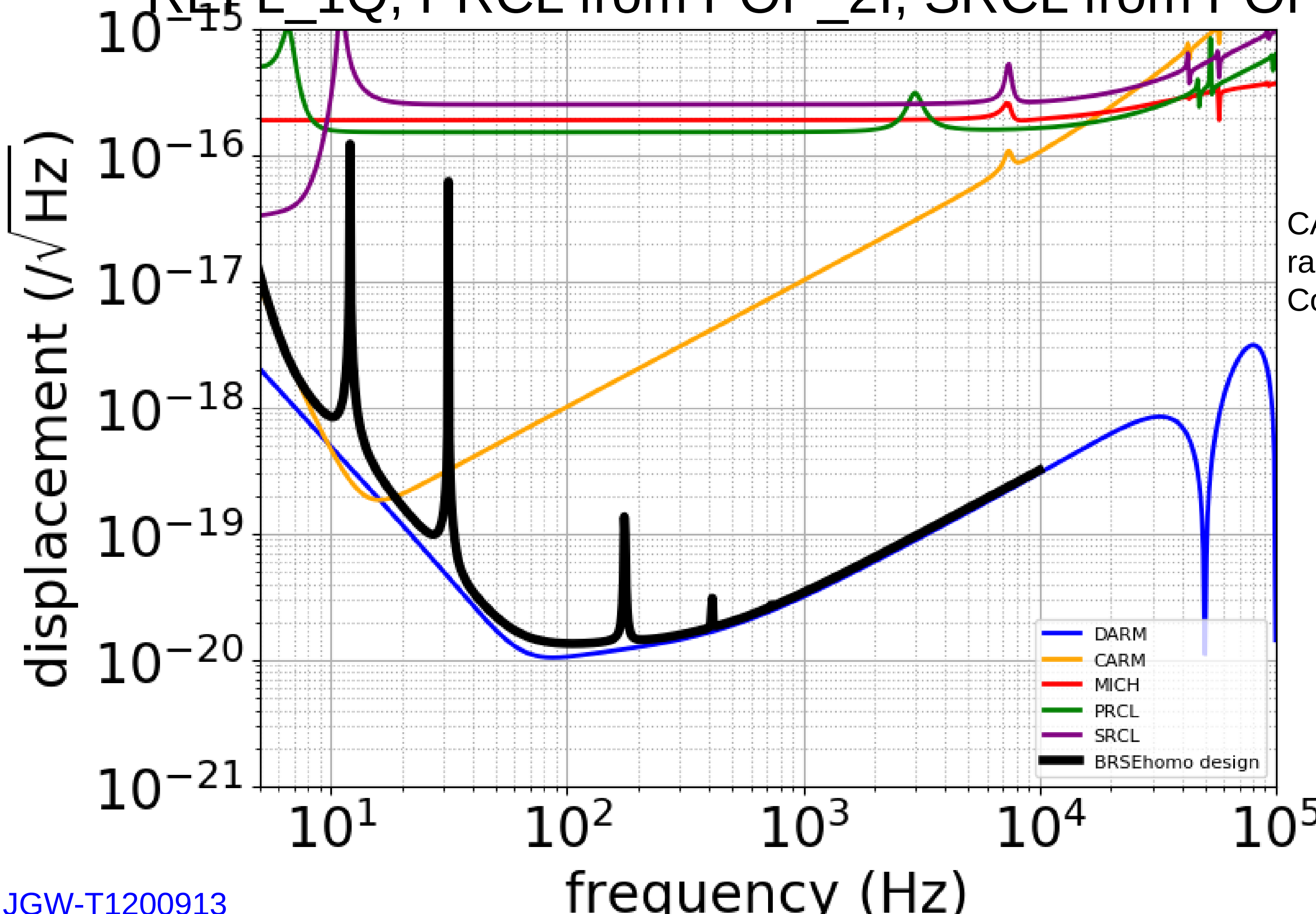
Number of coating layers for fused silica mirrors are derived from calculation using reflectivity. Coating thermal noise of Type-B/Bp suspensions are not very important since quantum noises for auxiliary DOFs are quite high.
BS thermal noise is tricky (LIGO-T0900209) but not considered carefully here.

JGW-T1707038
Classical and Quantum Gravity 34, 225001 (2017)
http://gwwiki.icrr.u-tokyo.ac.jp/JGWwiki/LCGT/subgroup/ifo/MIF/OptParam

Quantum noise

Optickle Simulation (BRSE Aso)

- DARM from AS_DC, CARM from REFL_1I, MICH from REFL_1Q, PRCL from POP_2I, SRCL from POP_1I

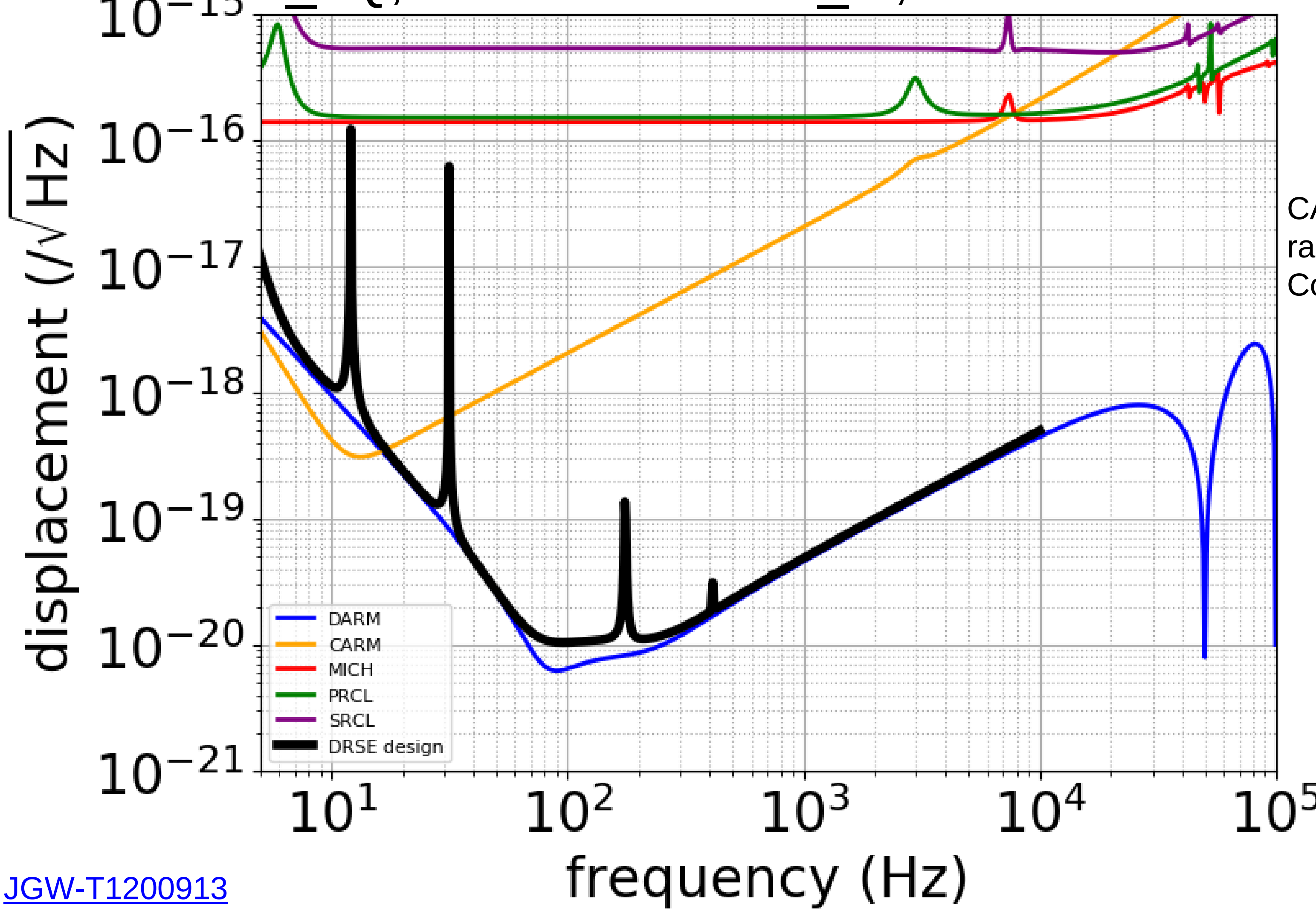


CARM originally in rad/rtHz. Corrected to m/rtHz

JGW-T1200913

Optickle Simulation (DRSE Aso)

- DARM from AS_DC, CARM from REFL_2I, MICH from REFL_1Q, PRCL from POP_2I, SRCL from POP_1I

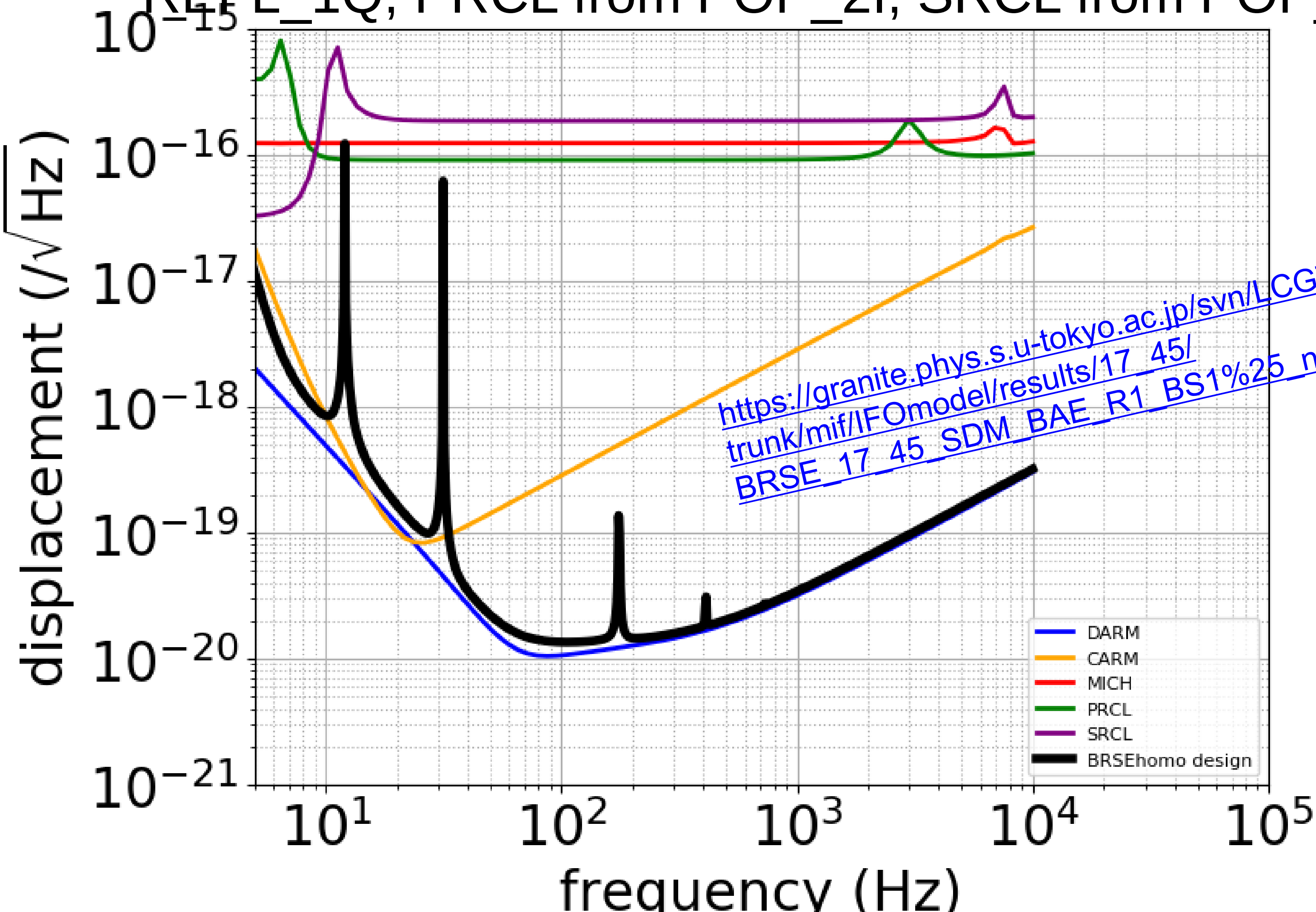


CARM originally in rad/rtHz.
Corrected to m/rtHz

JGW-T1200913

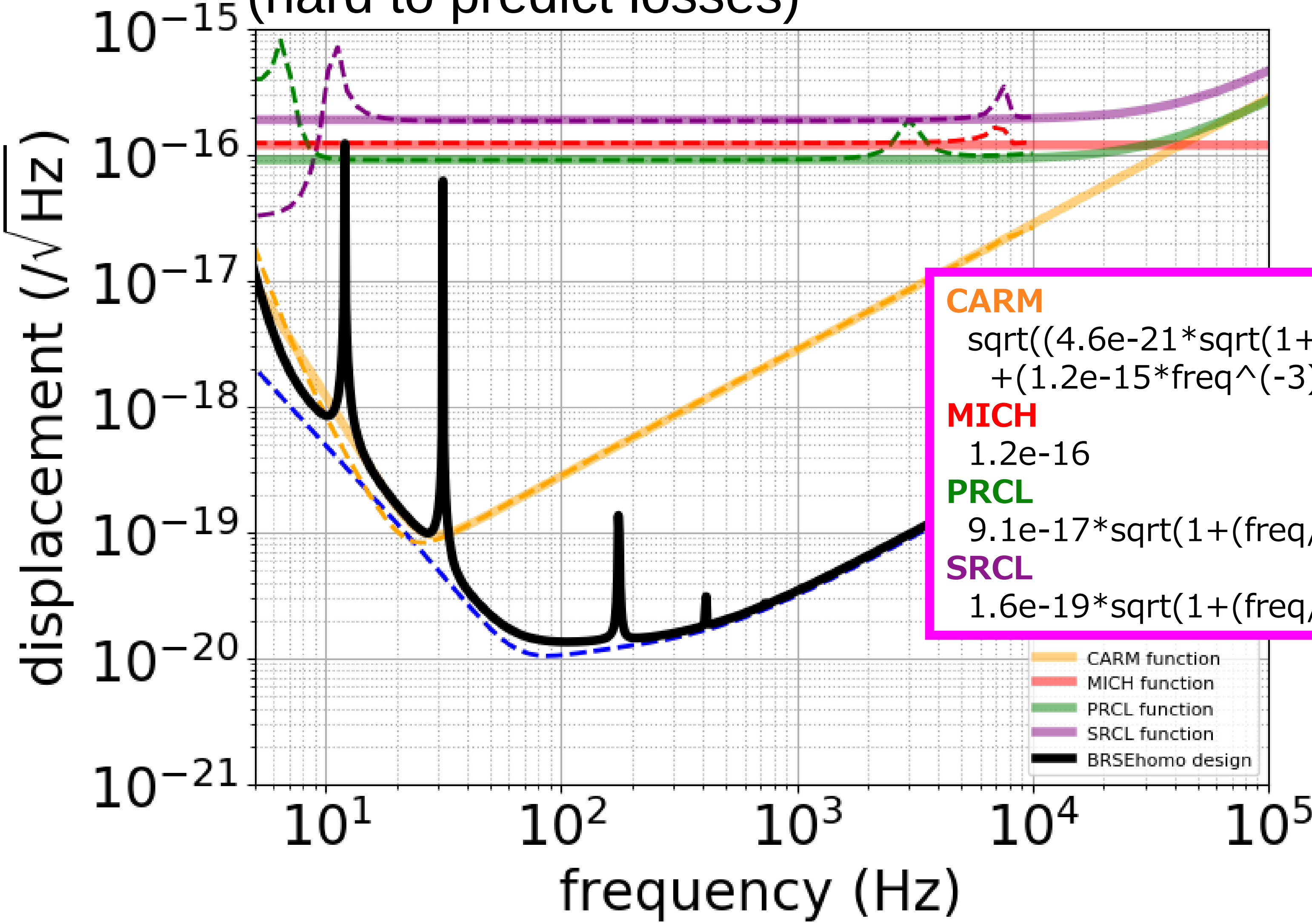
Optickle Simulation (BRSE Enomoto)

- DARM from AS_DC, CARM from REFL_1I, MICH from REFL_1Q, PRCL from POP_2I, SRCL from POP_1I



Quantum Function

- Use fitted function instead of doing analytical calculation (hard to predict losses)



CARM

sqrt((4.6e-21*sqrt(1+(freq/1.6)^2))^2 +(1.2e-15*freq^(-3))^2)

MICH

1.2e-16

PRCL

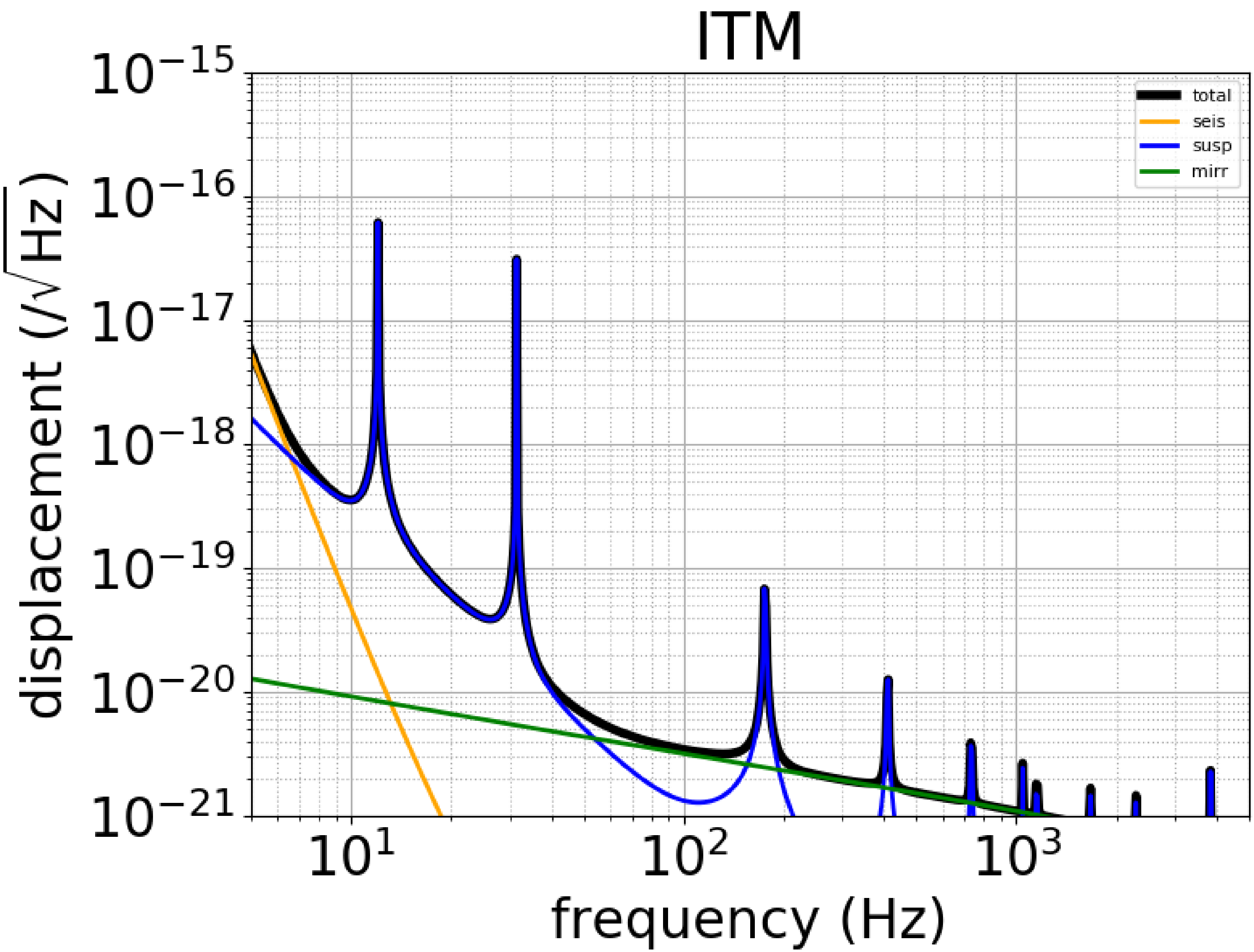
9.1e-17*sqrt(1+(freq/3.6e4)^2)

SRCL

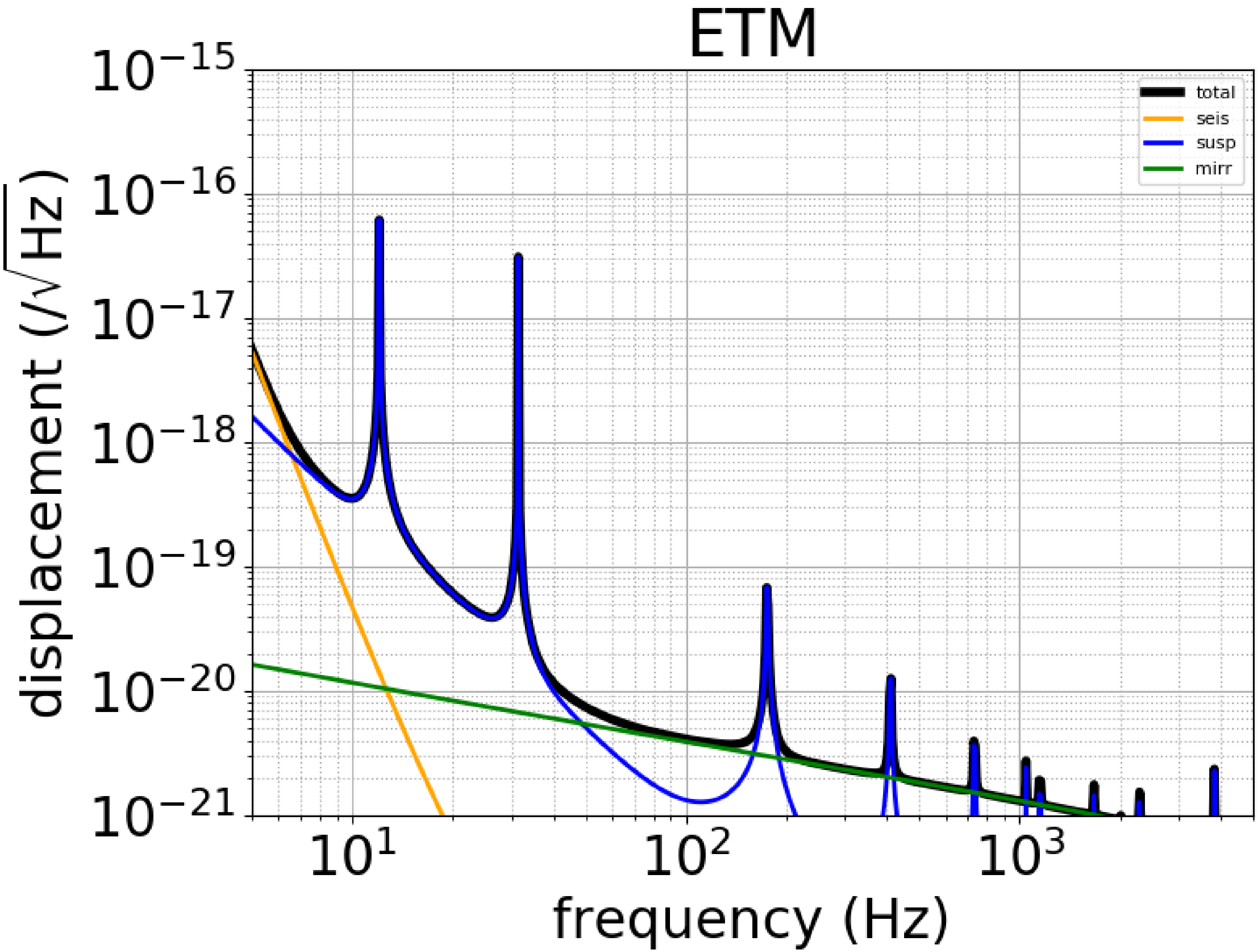
1.6e-19*sqrt(1+(freq/4.5e4)^2)

Displacement sensitivity

Displacement Noise: ITM



Displacement Noise: ETM

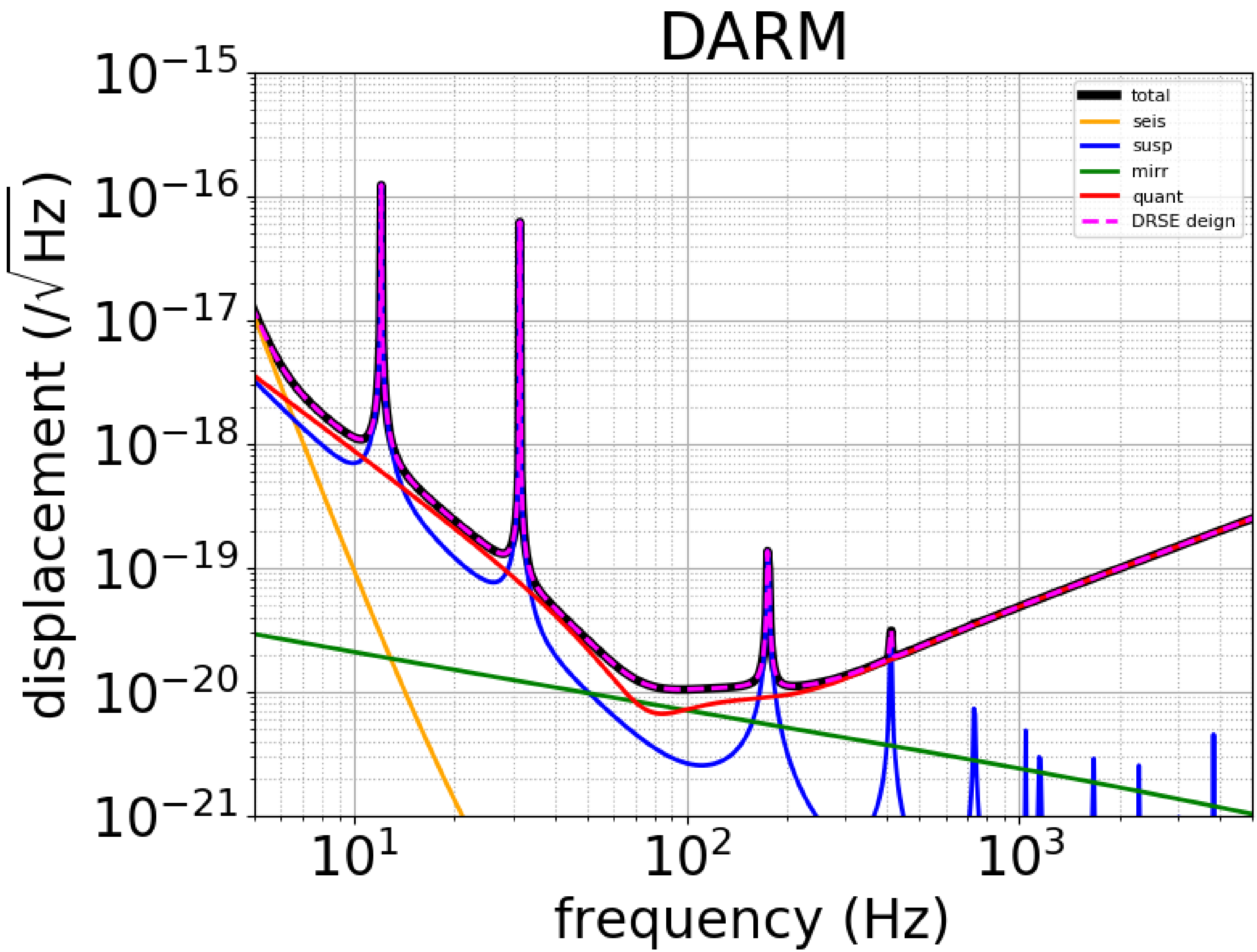


Displacement Noise: BS

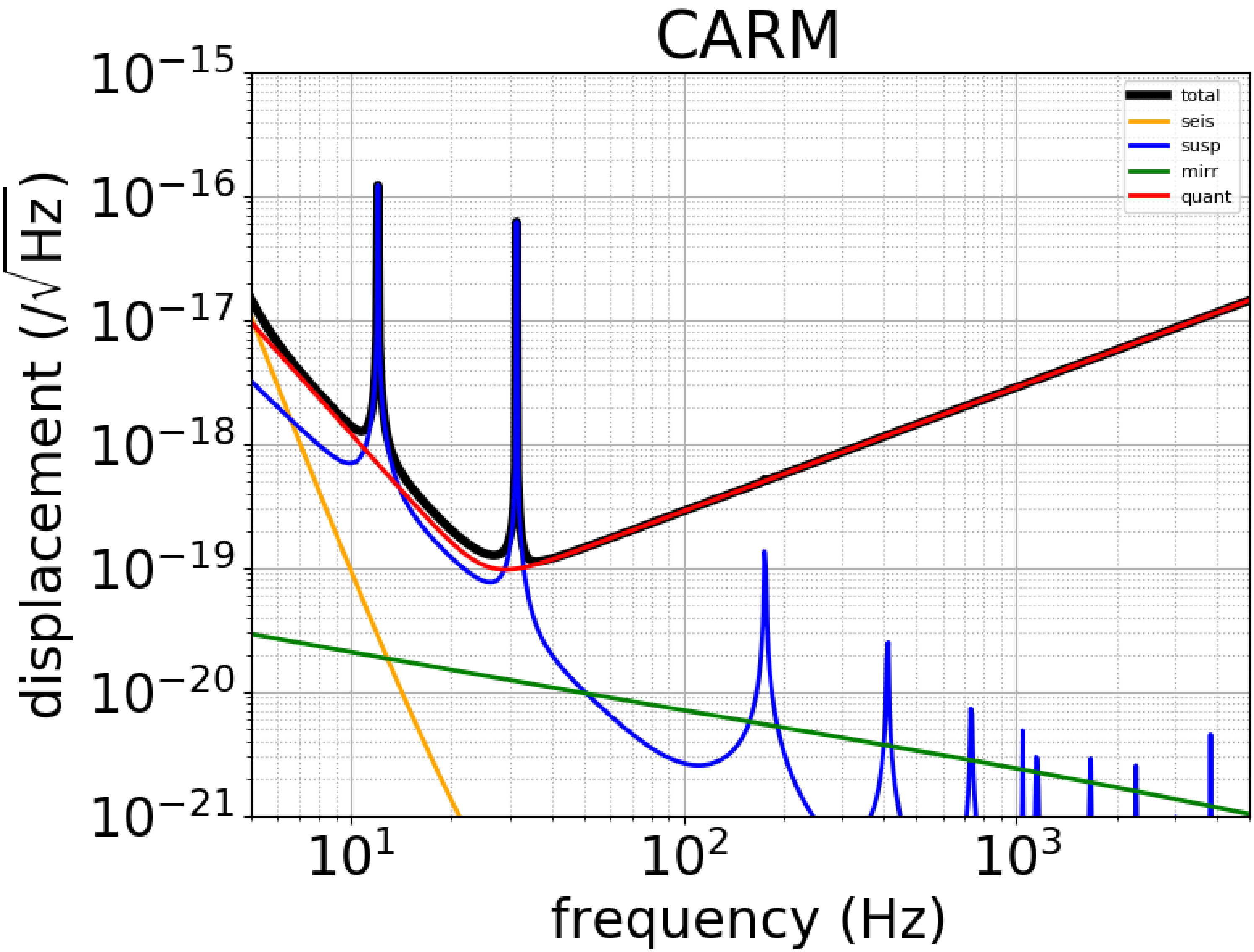
Displacement Noise: SRM

Displacement Noise: PRM

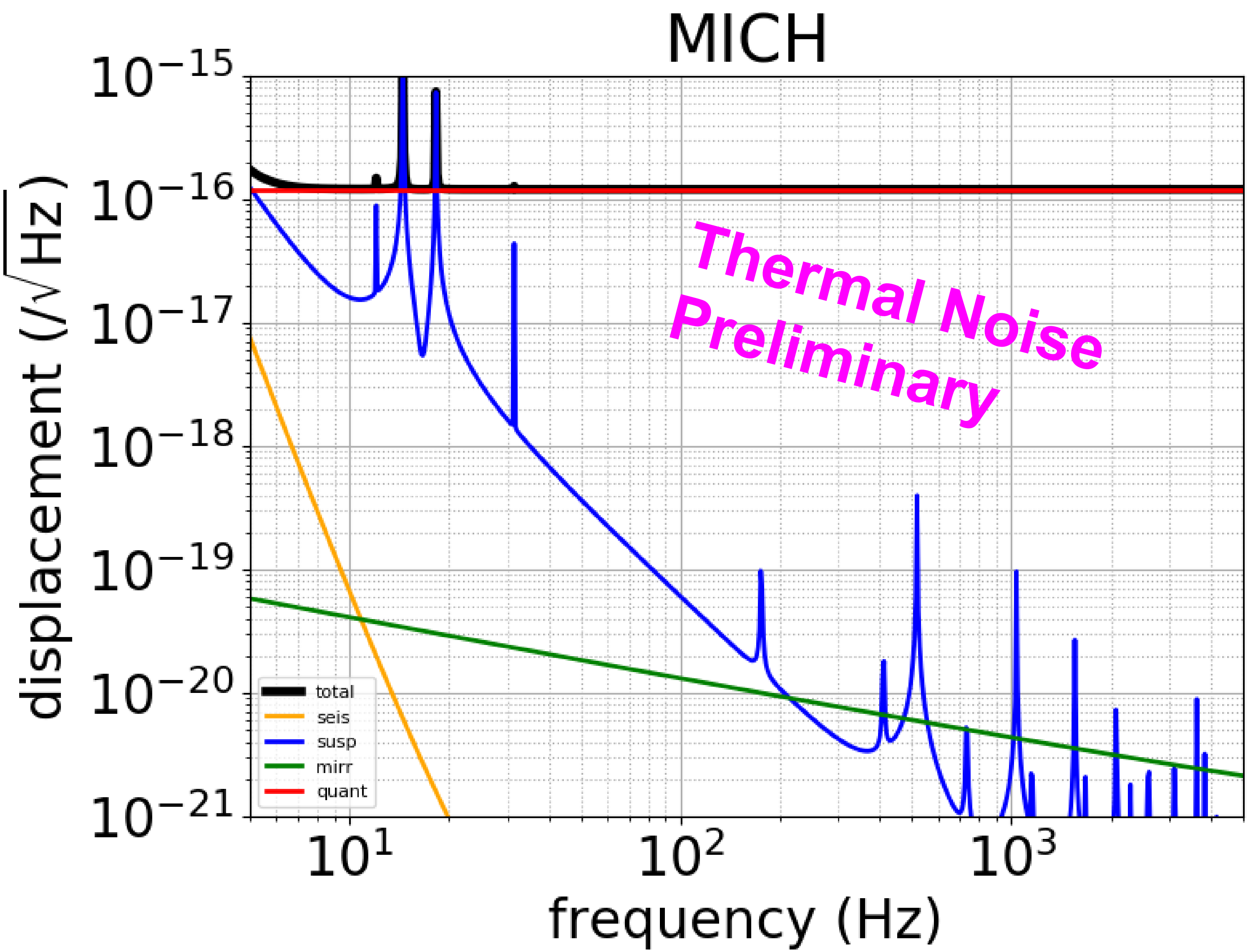
Displacement Sensitivity: DARM



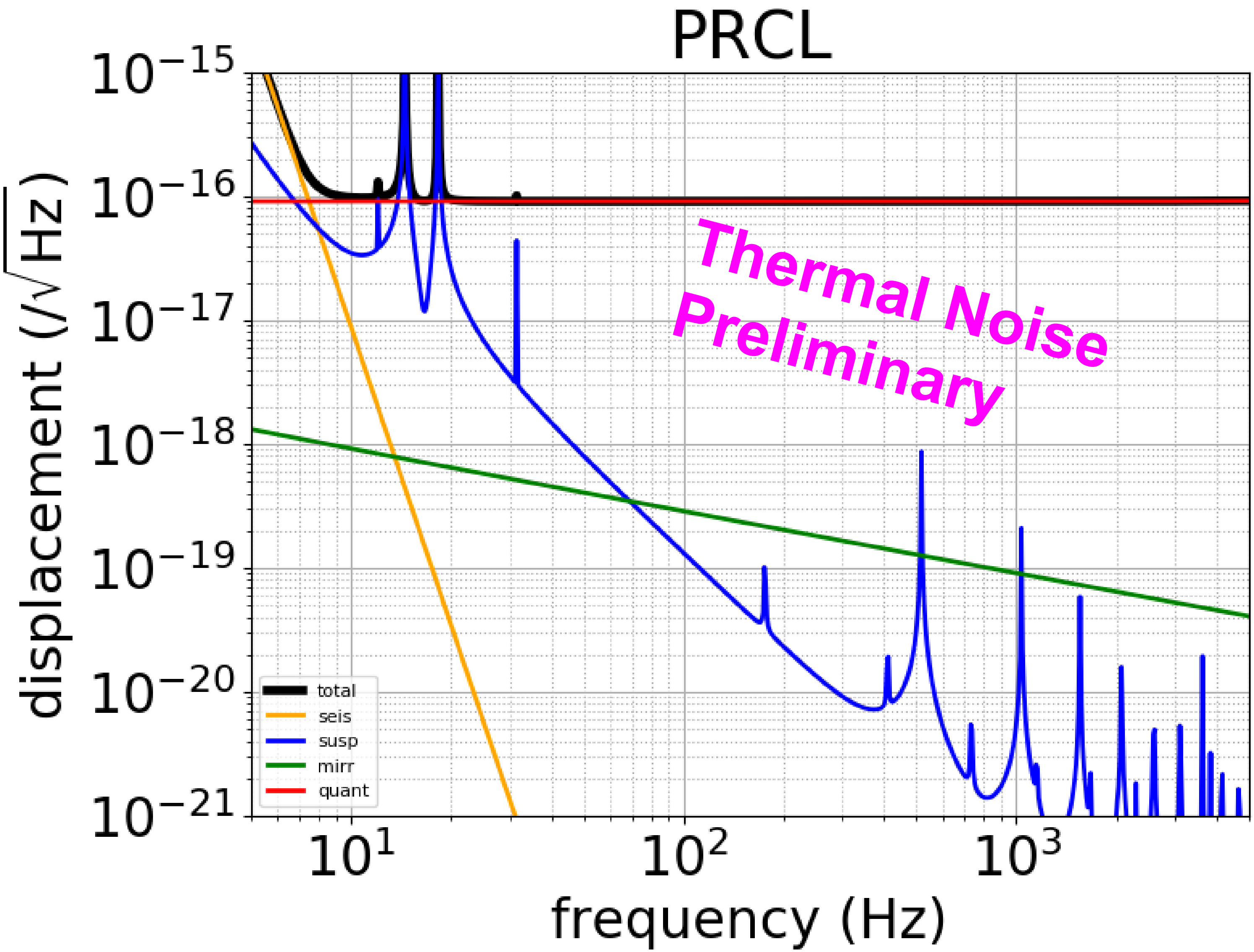
Displacement Sensitivity: CARM



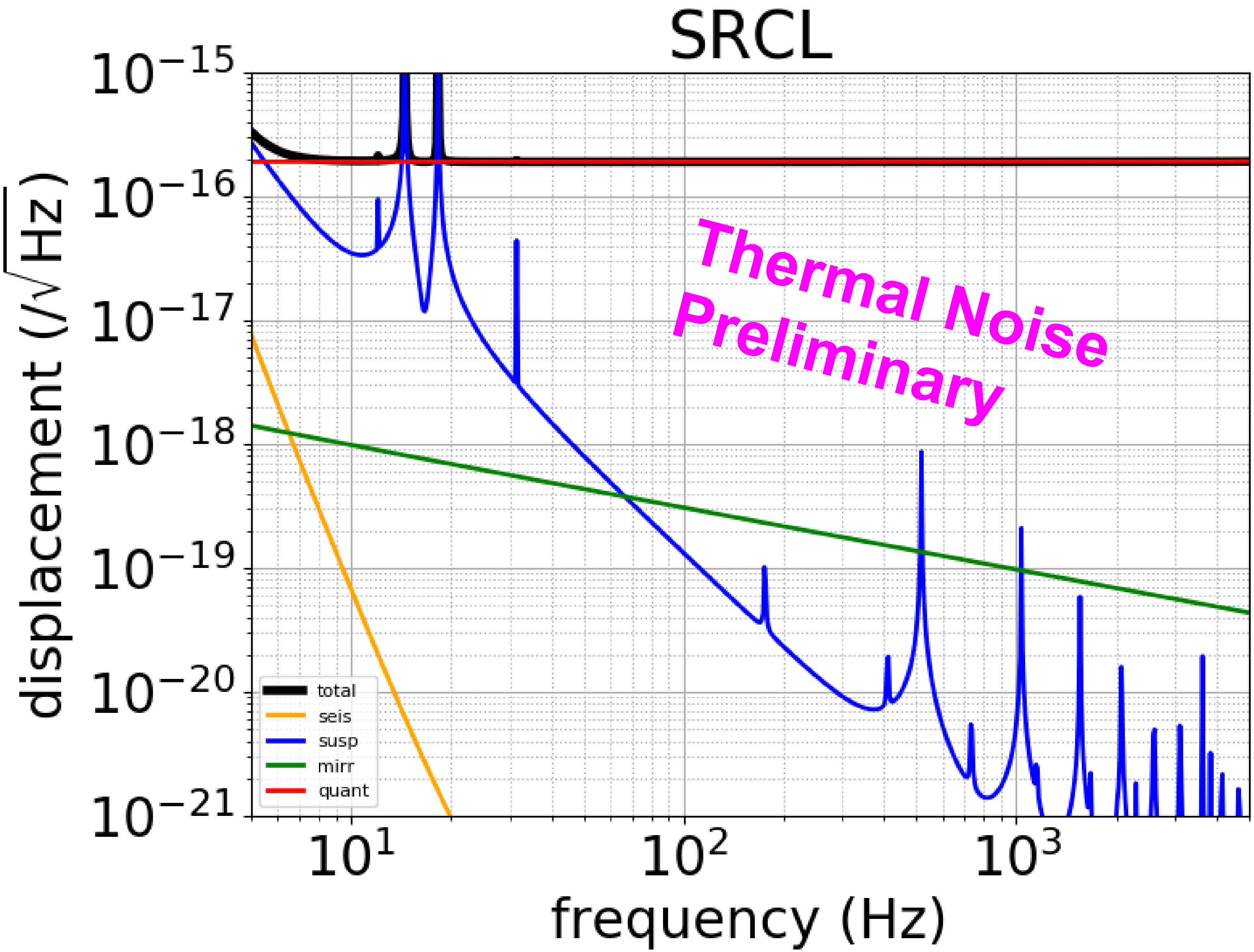
Displacement Sensitivity: MICH



Displacement Sensitivity: PRCL



Displacement Sensitivity: SRCL



Displacement Sensitivity Summary