JGW-T2011755

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Estimated sensitivity for auxiliary degrees of freedom of KAGRA interferometer

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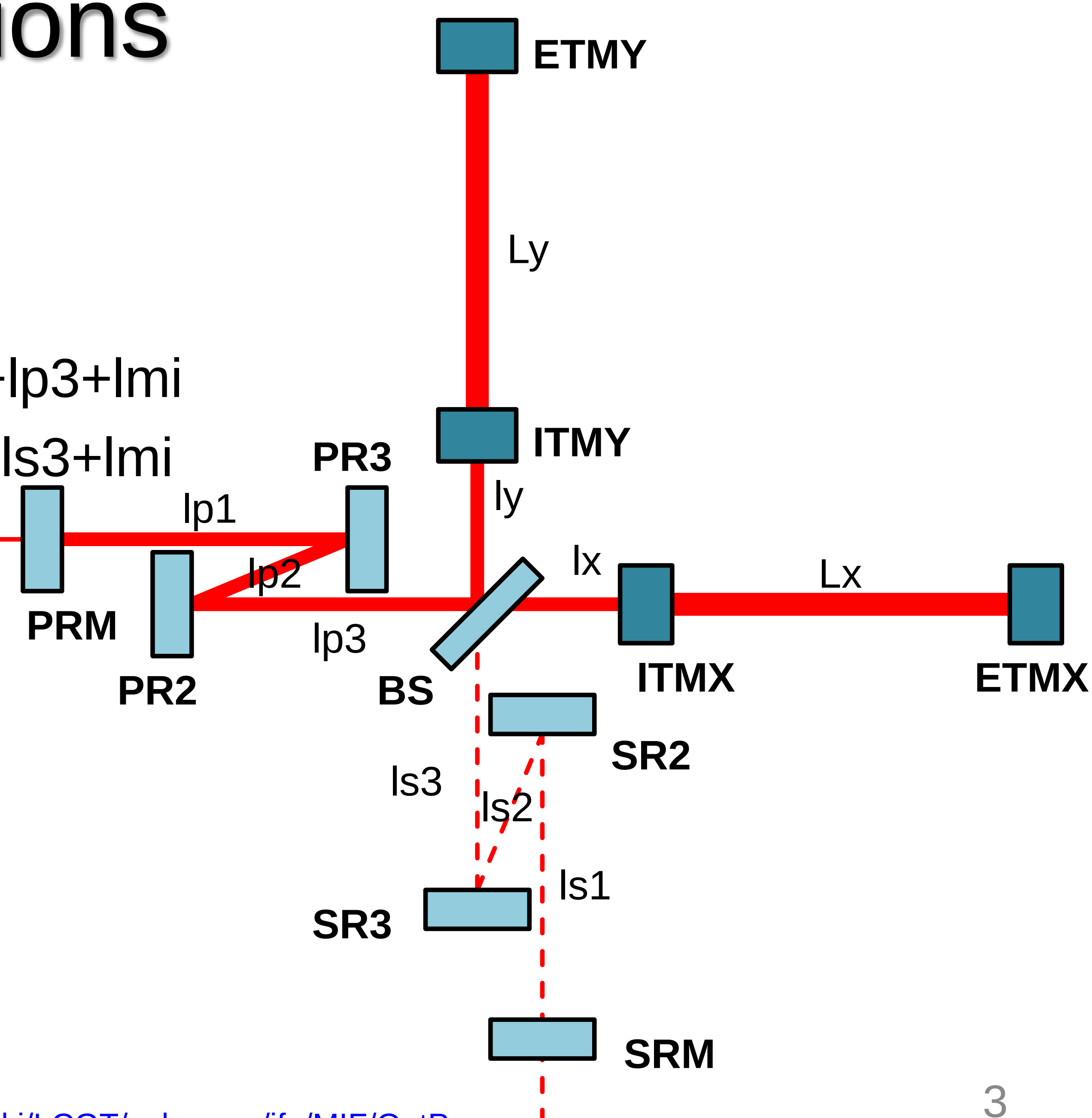
Scope

- 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

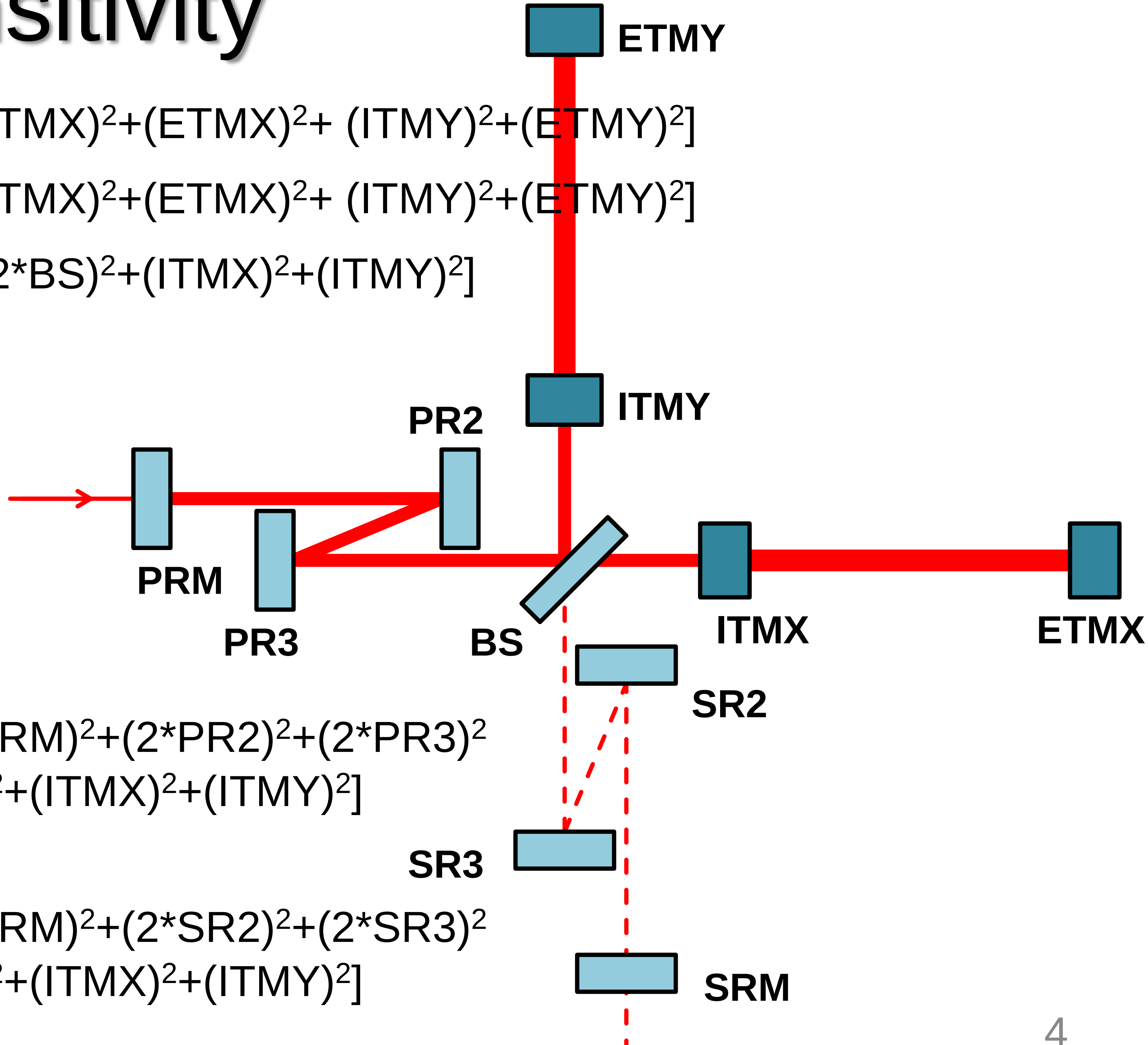


Lx = Ly = Larm = 3000.0 m
Lx = 26.6649 m
ly = 23.3351 m
lmi = (lx+ly)/2 = 25 m
lp1 = 14.7615 m
lp2 = 11.0661 m
lp3 = 15.7638 m
ls1 = 14.7412 m
ls2 = 11.1115 m
ls2 = 15.7386 m

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: $\sqrt{[(\sqrt{2}*BS)^2+(ITMX)^2+(ITMY)^2]}$

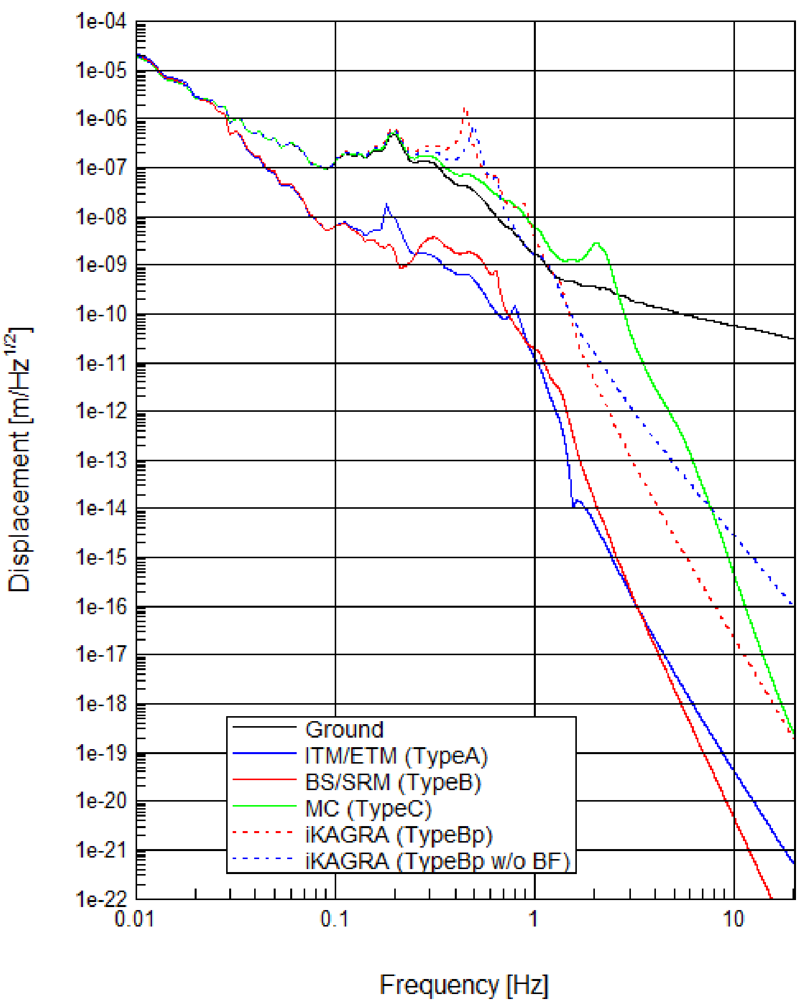


- PRCL: $\sqrt{[(PRM)^2+(2*PR2)^2+(2*PR3)^2 +(\sqrt{2}/2*BS)^2+(ITMX)^2+(ITMY)^2]}$
- SRCL: $\sqrt{[(SRM)^2+(2*SR2)^2+(2*SR3)^2 +(\sqrt{2}/2*BS)^2+(ITMX)^2+(ITMY)^2]}$

Seismic noise

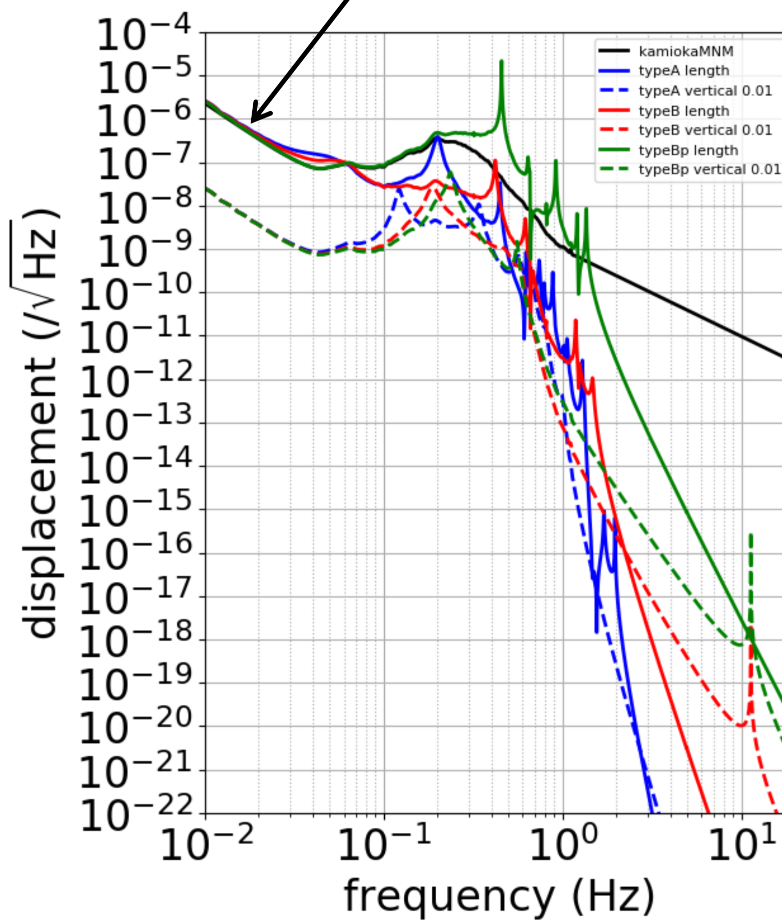
Models

- There exists several models



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

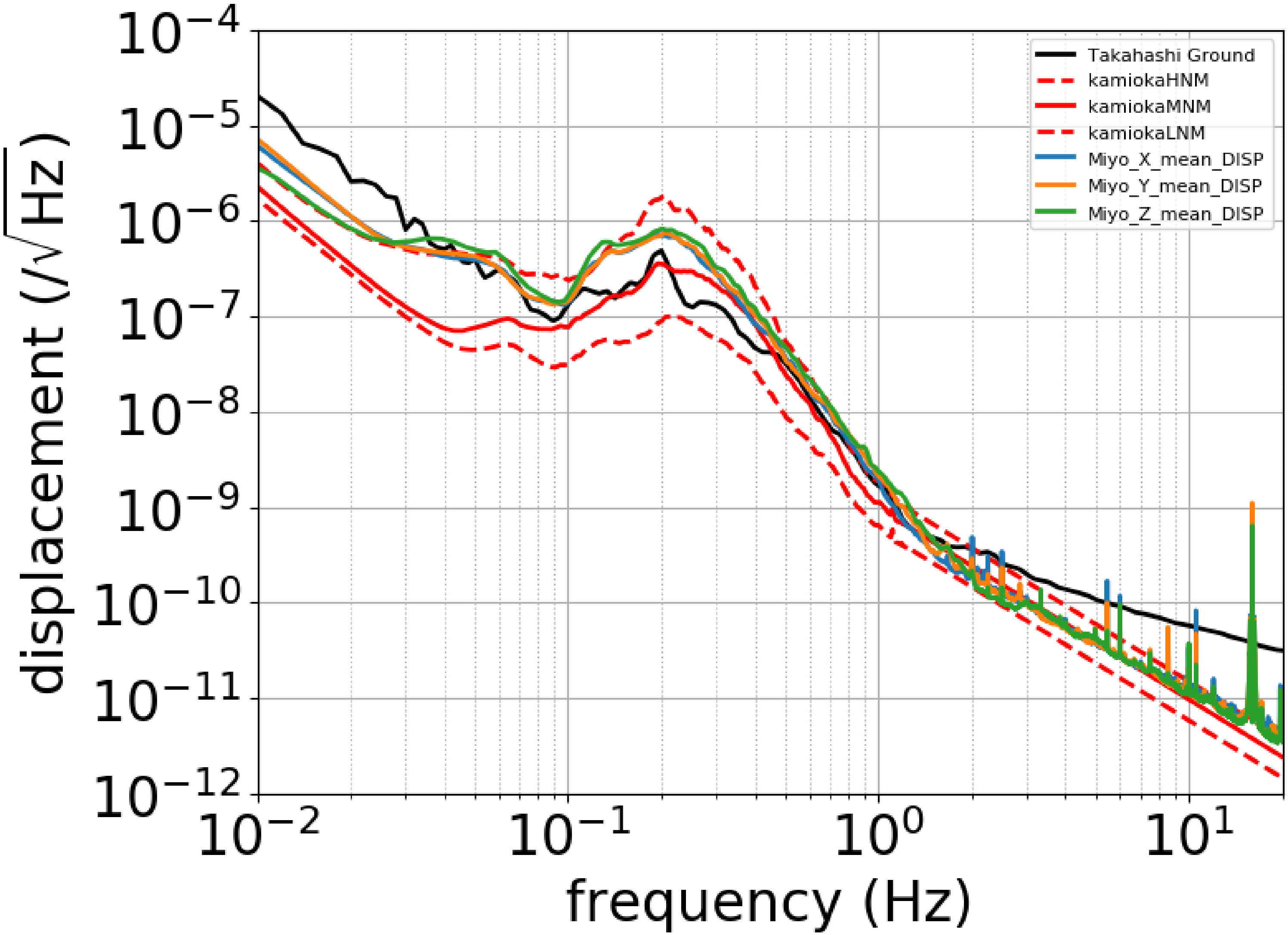
Medium Noise Model
from JGW-T1402971



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

Seismic Noise Spectra

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



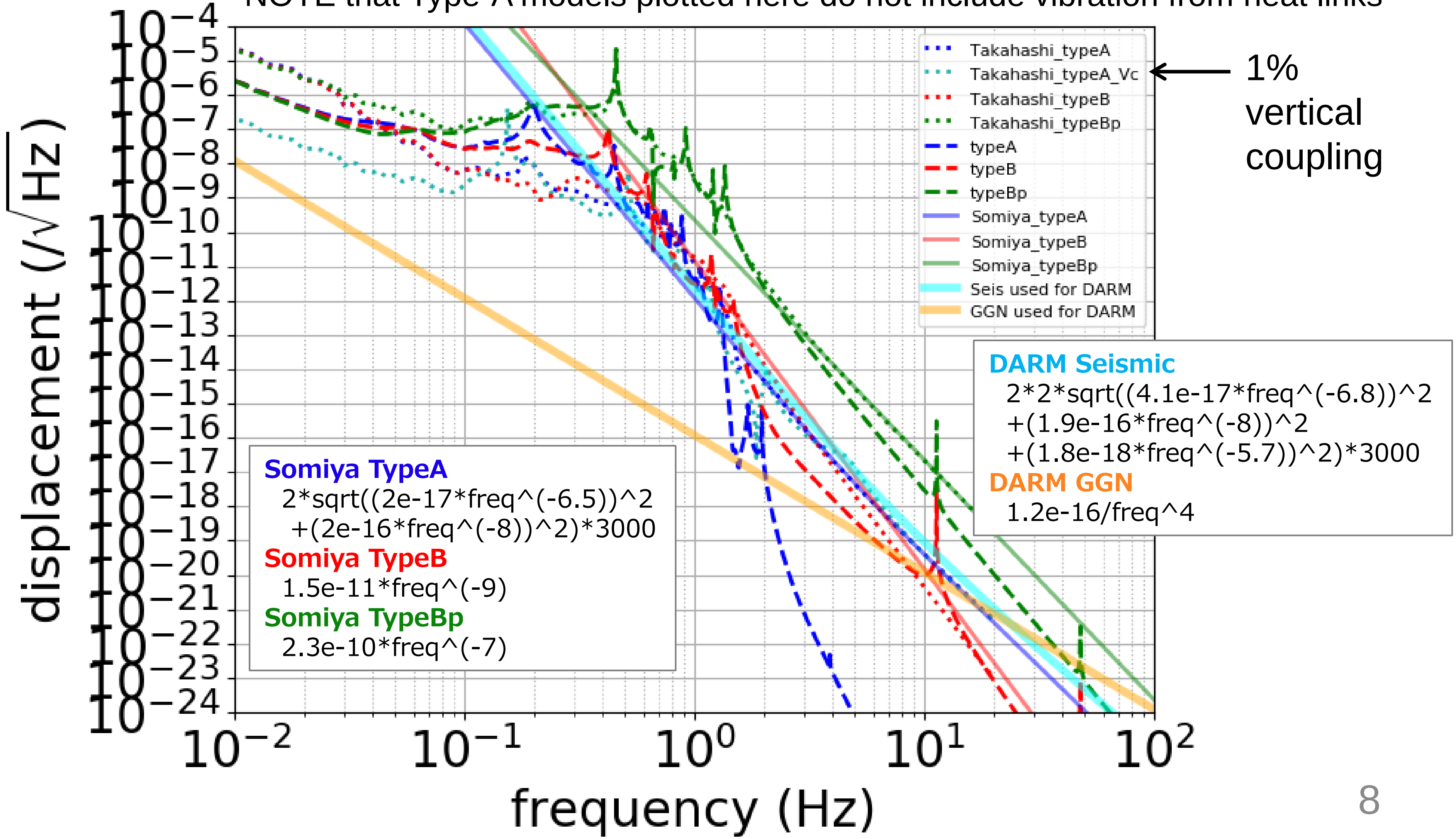
By Sekiguchi
JGW-T1402971

By Miyo
JGW-T1910436

Comparison Between Models

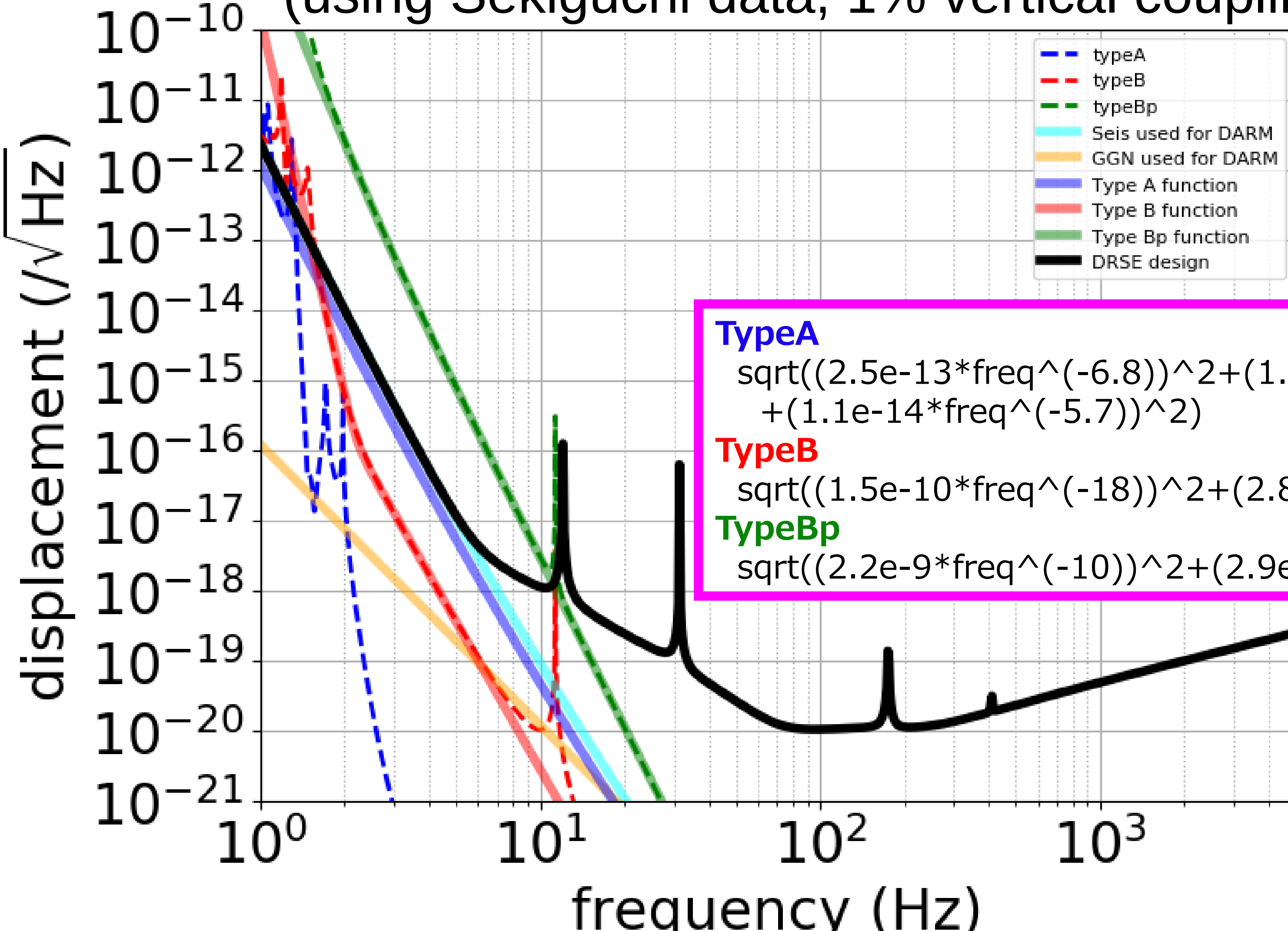
- Fitting function by Somiya based on Takahashi model

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

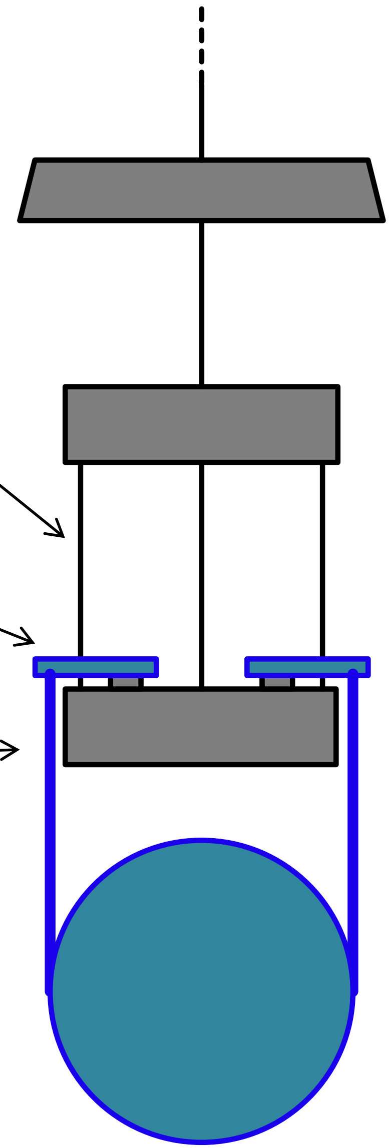
CQG 34, 225001 (2017)

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

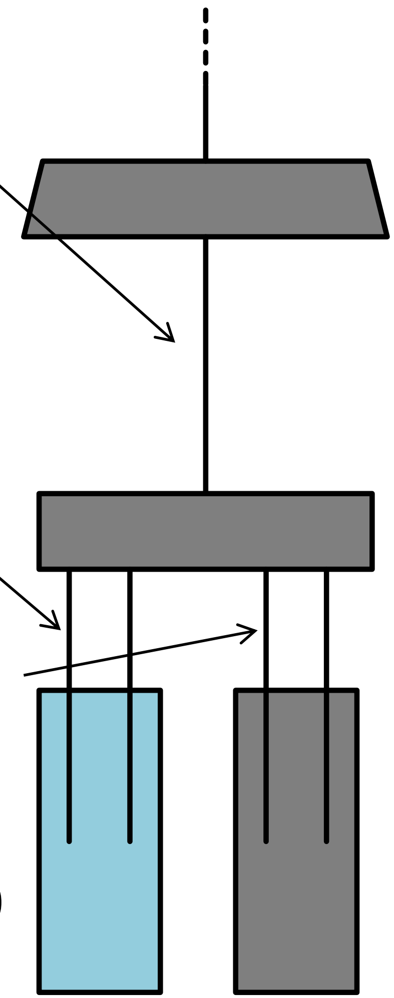
[CQG 34, 225001 (2017)](#)
Type-B info from Fabian
Type-B maraging rod JGW-D1605614
BS mass budget JGW-E1604966

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 2e-4

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 2e-4

RM suspension
- 4 tungsten wires
- 55.1 cm long, 0.65 mm dia. for BS
- 58.7 cm long, 0.6 mm dia. for SRs
- loss angle 1.7e-4

Vertical to horizontal coupling 1/200



Bottom filter

Intermediate mass
- 34.6 kg for BS
- 15.6 kg for SRs

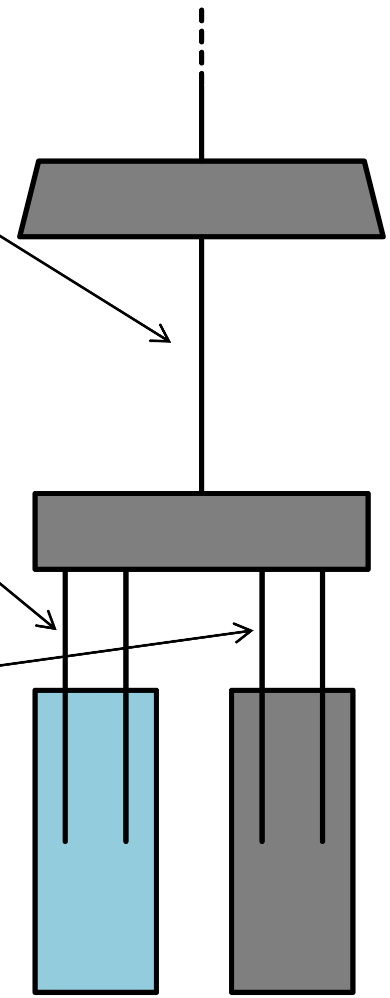
Test mass
- 18.71 kg for BS
- 10.71 kg for SRs

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 2e-4

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



Bottom filter

TM suspension
4 piano wires
58.7 cm long, 0.2 mm dia. for PRs
loss angle 2e-4

Intermediate mass
15.6 kg for PRs

RM suspension
4 tungsten wires
58.7 cm long, 0.6 mm dia. PRs
loss angle 1.7e-4

Test mass
10.71 kg for PRs

Recoil mass
12.036 kg for PRs

Vertical to horizontal coupling 1/200

Material Properties of Wires

- Sapphire (see JGW-T1707038)
  - density: 4.0e3 kg/m^3
  - Young's modulus: 4.0e11 Pa
  - loss angle: 2e-7
- Piano wire
  - density: 7.83e3 kg/m^3 (book)
  - Young's modulus: 2e11 Pa (book)
  - loss angle: 2e-4 (RSI 86, 084501 (2015))
- Tungsten wire
  - density: 19.3 kg/m^3 (matweb)
  - Young's modulus: 4.0e11 Pa (matweb)
  - loss angle: 1.7e-4 (PLA 255, 230 (1999))
- Maraging steel rod
  - density: 7.98 kg/m^3 (matweb)
  - Young's modulus: 1.9e11 Pa (matweb)
  - loss angle: 2e-4 (N. A. Robertson 2001)

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	**tantala/silica/tantala (see p.10 of JGW-T1503347)**	**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

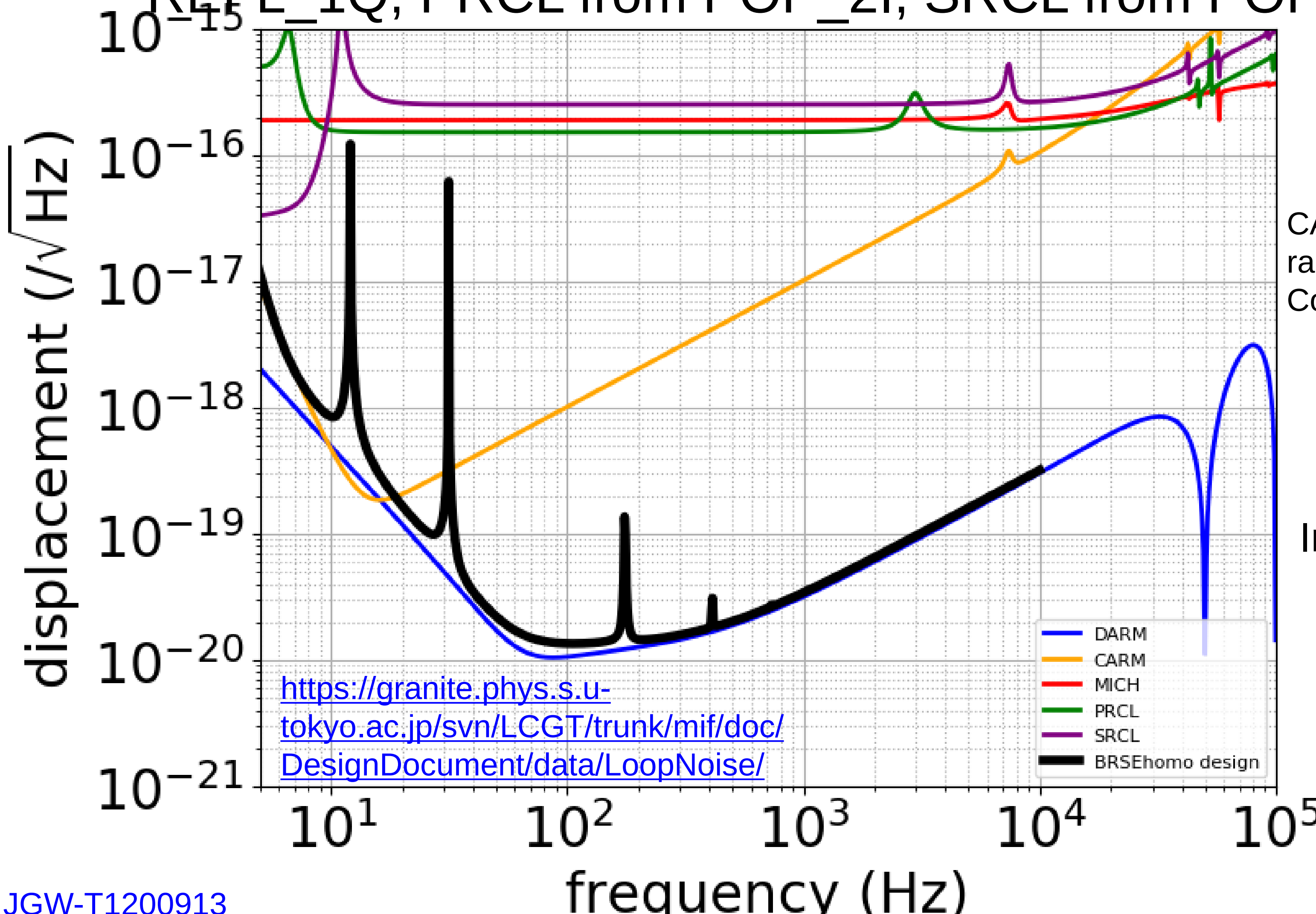
Number of coating layers for fused silica mirrors are derived from calculation using reflectivity. Coating thermal noise of Type-B/Bp suspensions are not very important since quantum noises for auxiliary DOFs are quite high.
BS thermal noise is tricky (LIGO-T0900209) but not considered carefully here.

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



https://granite.phys.s.u-tokyo.ac.jp/svn/LCGT/trunk/mif/doc/DesignDocument/data/LoopNoise/

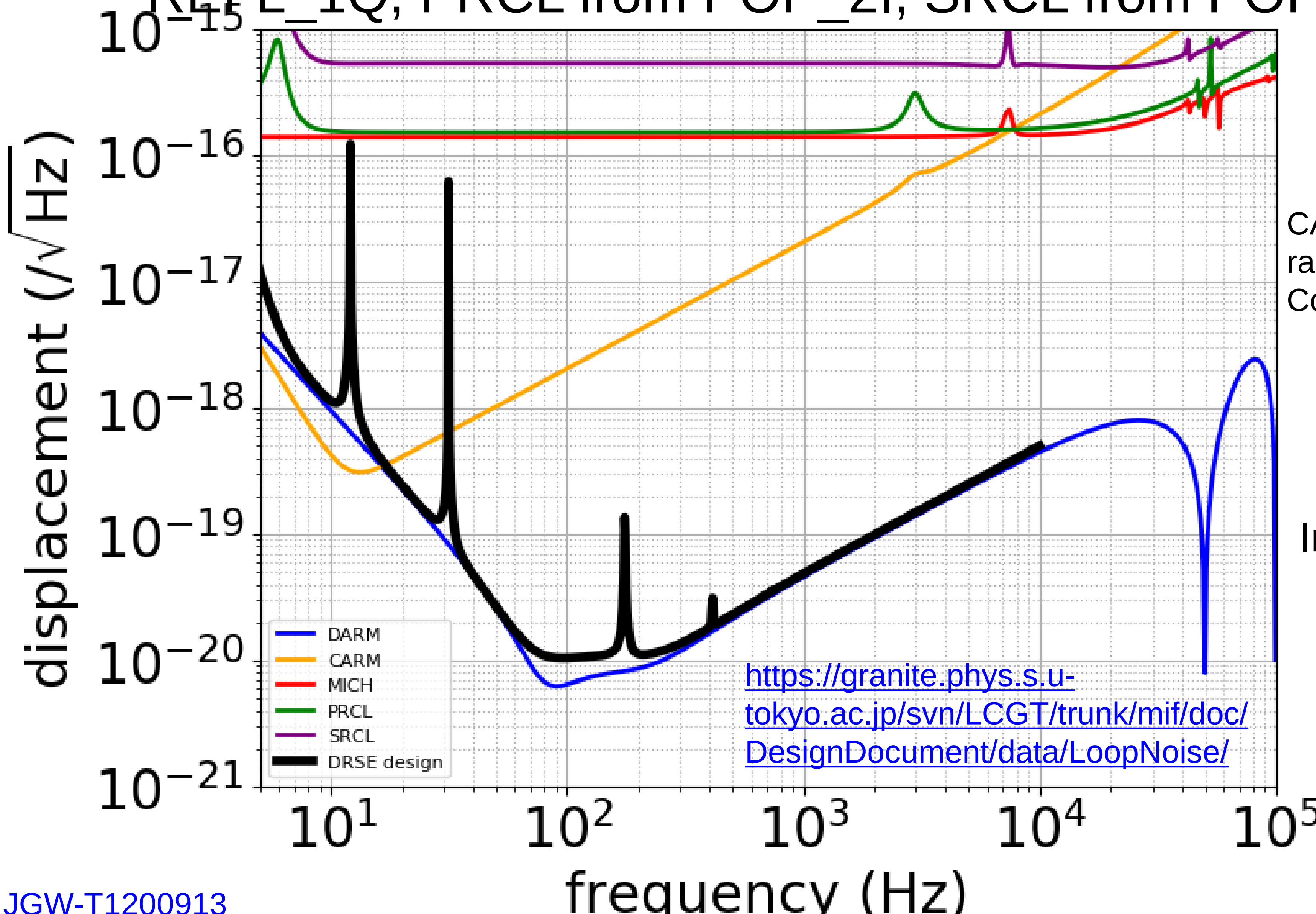
CARM originally in rad/rtHz.
Corrected to m/rtHz

Input power: ?? W

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



https://granite.phys.s.u-tokyo.ac.jp/svn/LCGT/trunk/mif/doc/DesignDocument/data/LoopNoise/

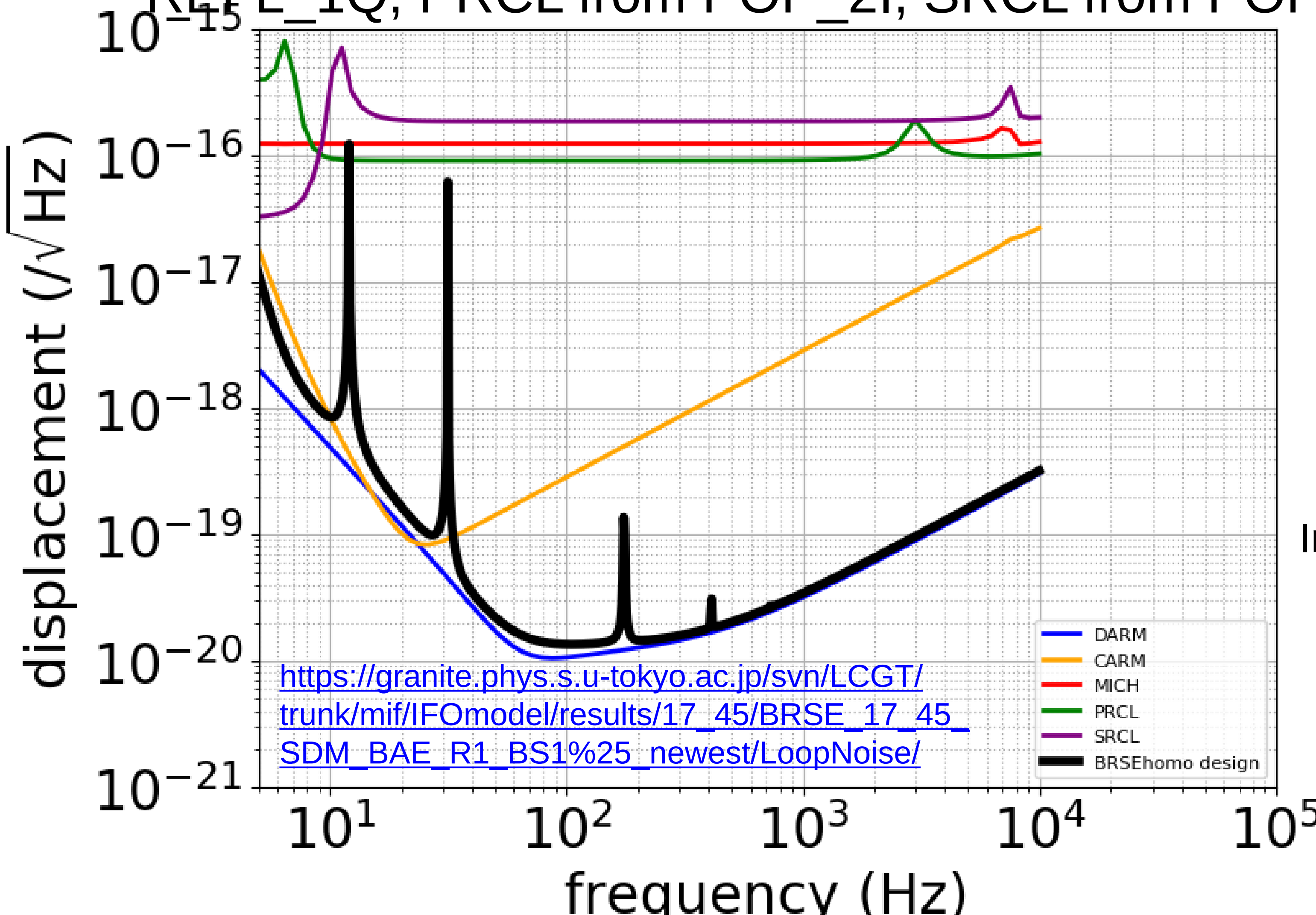
CARM originally in rad/rtHz.
Corrected to m/rtHz

Input power:
?? W

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

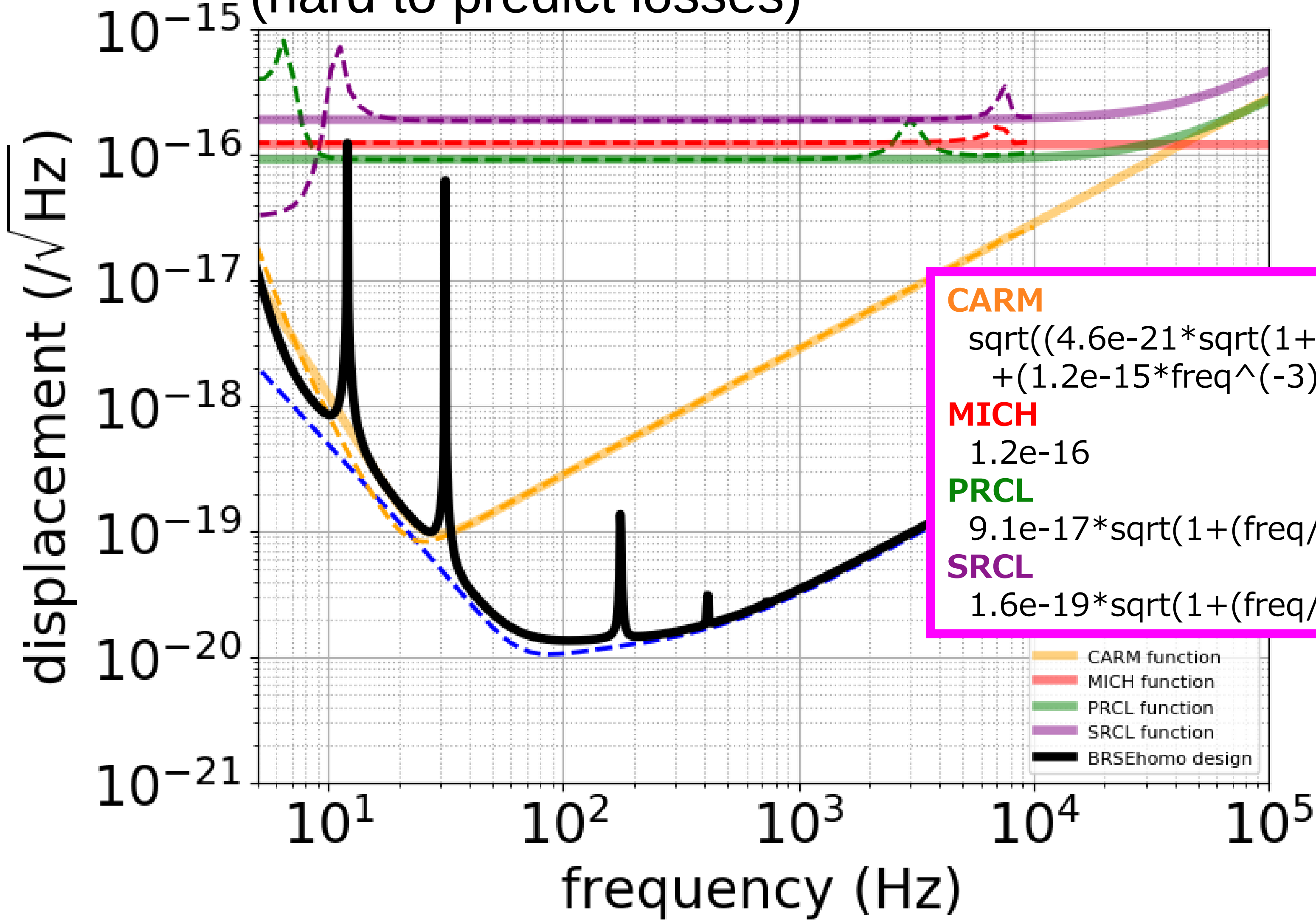


https://granite.phys.s.u-tokyo.ac.jp/svn/LCGT/trunk/mif/IFOmodel/results/17_45/BRSE_17_45_SDM_BAE_R1_BS1%25_newest/LoopNoise/

Input power:
77 W

Quantum Function

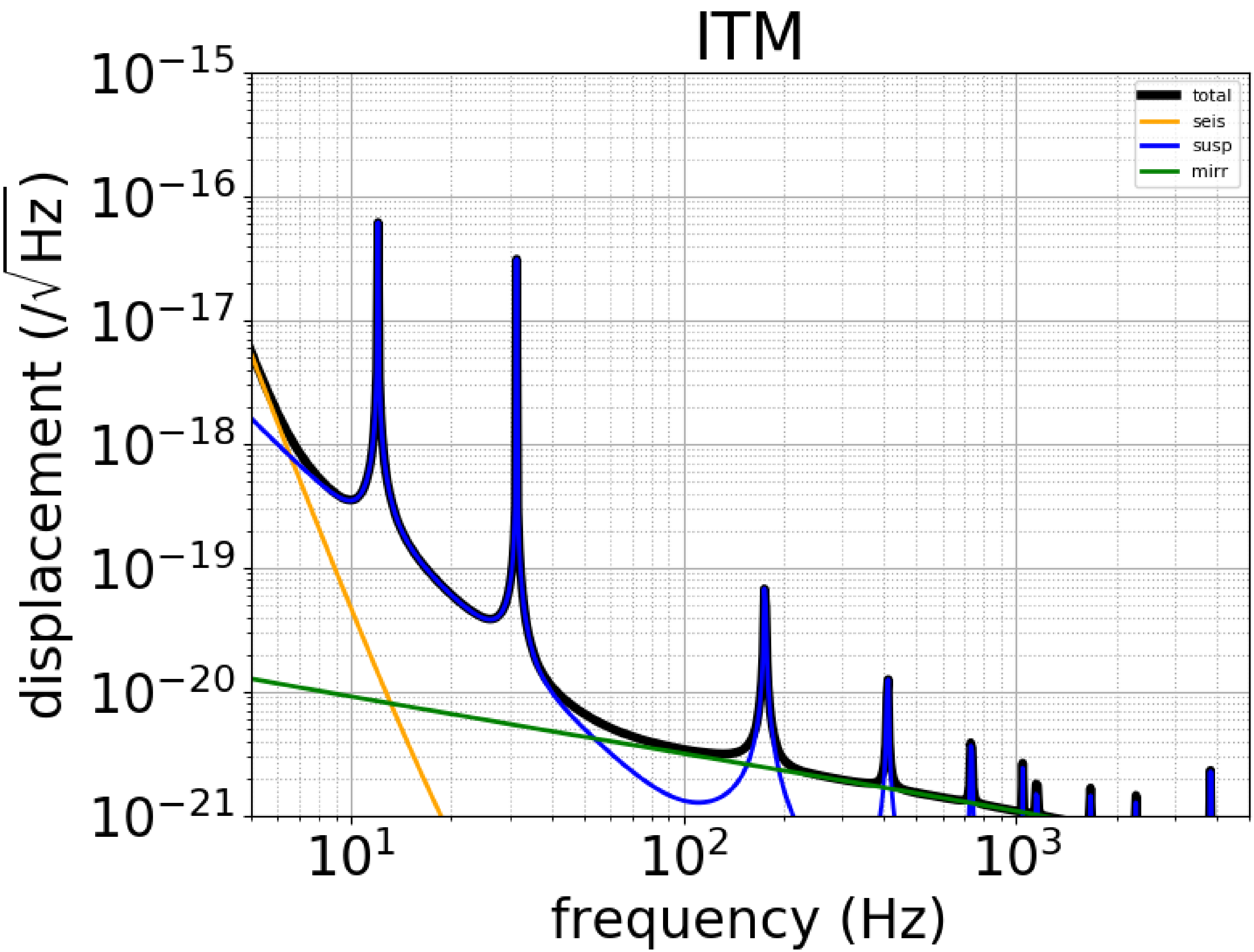
- Use fitted function instead of doing analytical calculation (hard to predict losses)



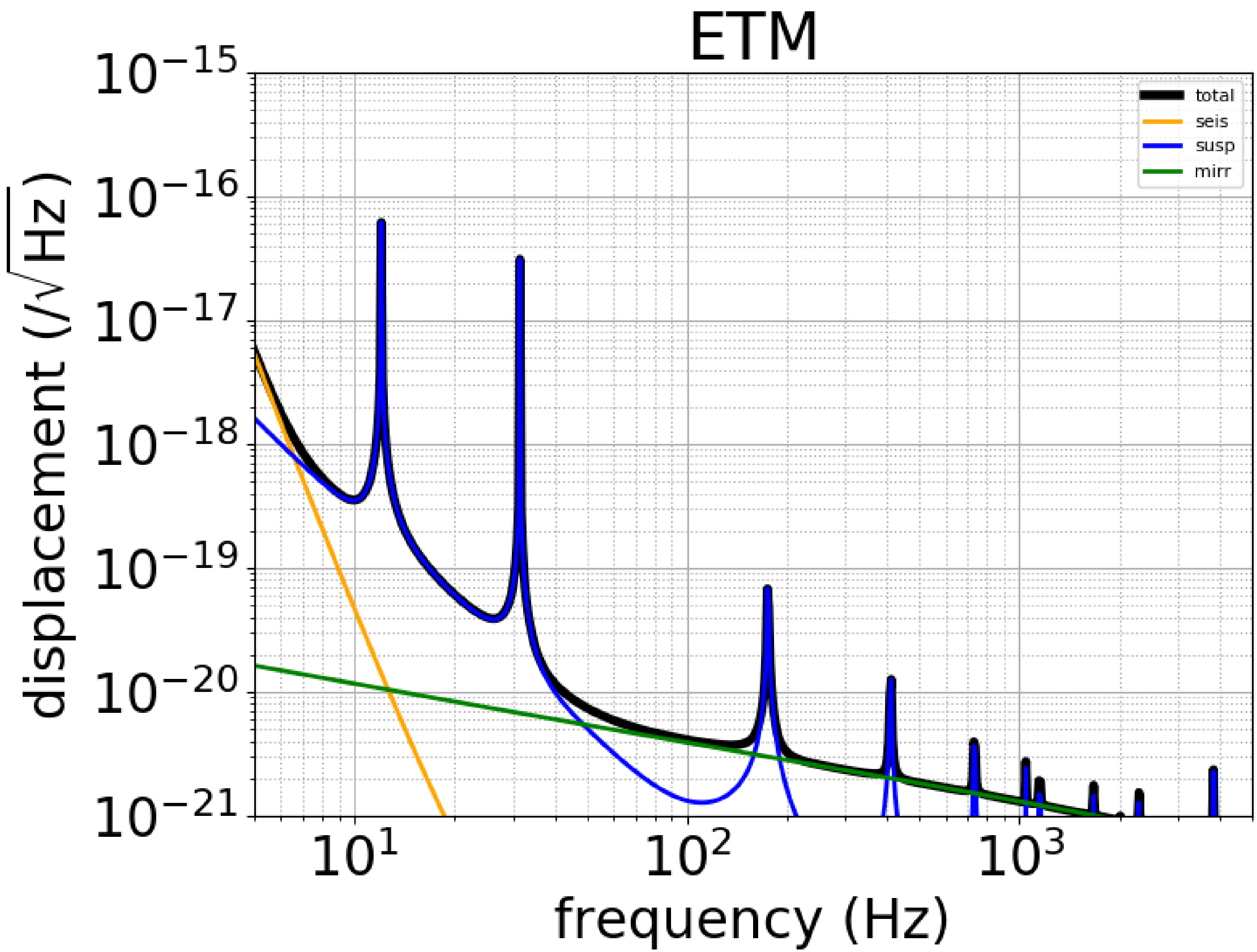
CARM
sqrt((4.6e-21*sqrt(1+(freq/1.6)^2))^2
+(1.2e-15*freq^(-3))^2)
MICH
1.2e-16
PRCL
9.1e-17*sqrt(1+(freq/3.6e4)^2)
SRCL
1.6e-19*sqrt(1+(freq/4.5e4)^2)

Displacement sensitivity

Displacement Noise: ITM



Displacement Noise: ETM

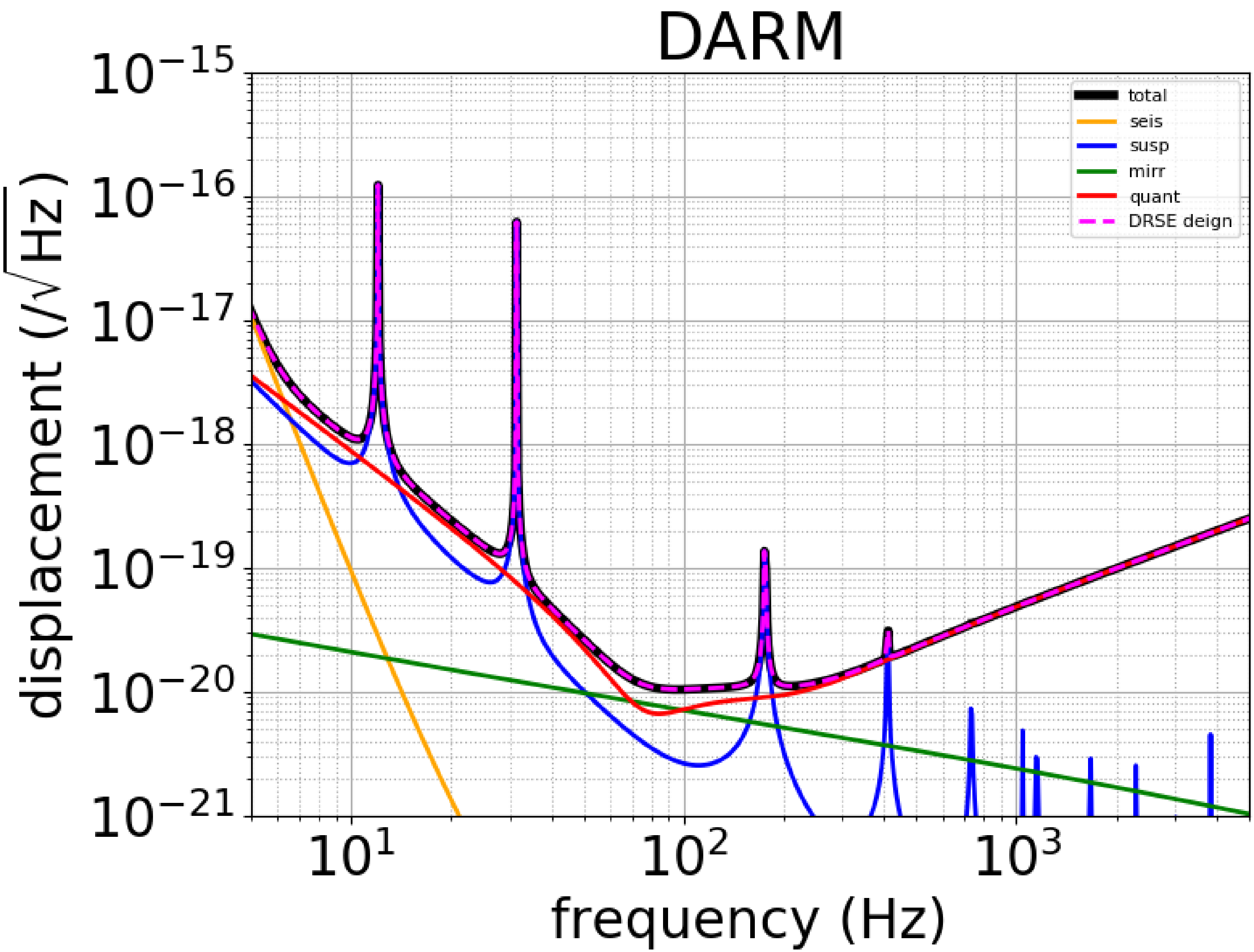


Displacement Noise: BS

Displacement Noise: SRM

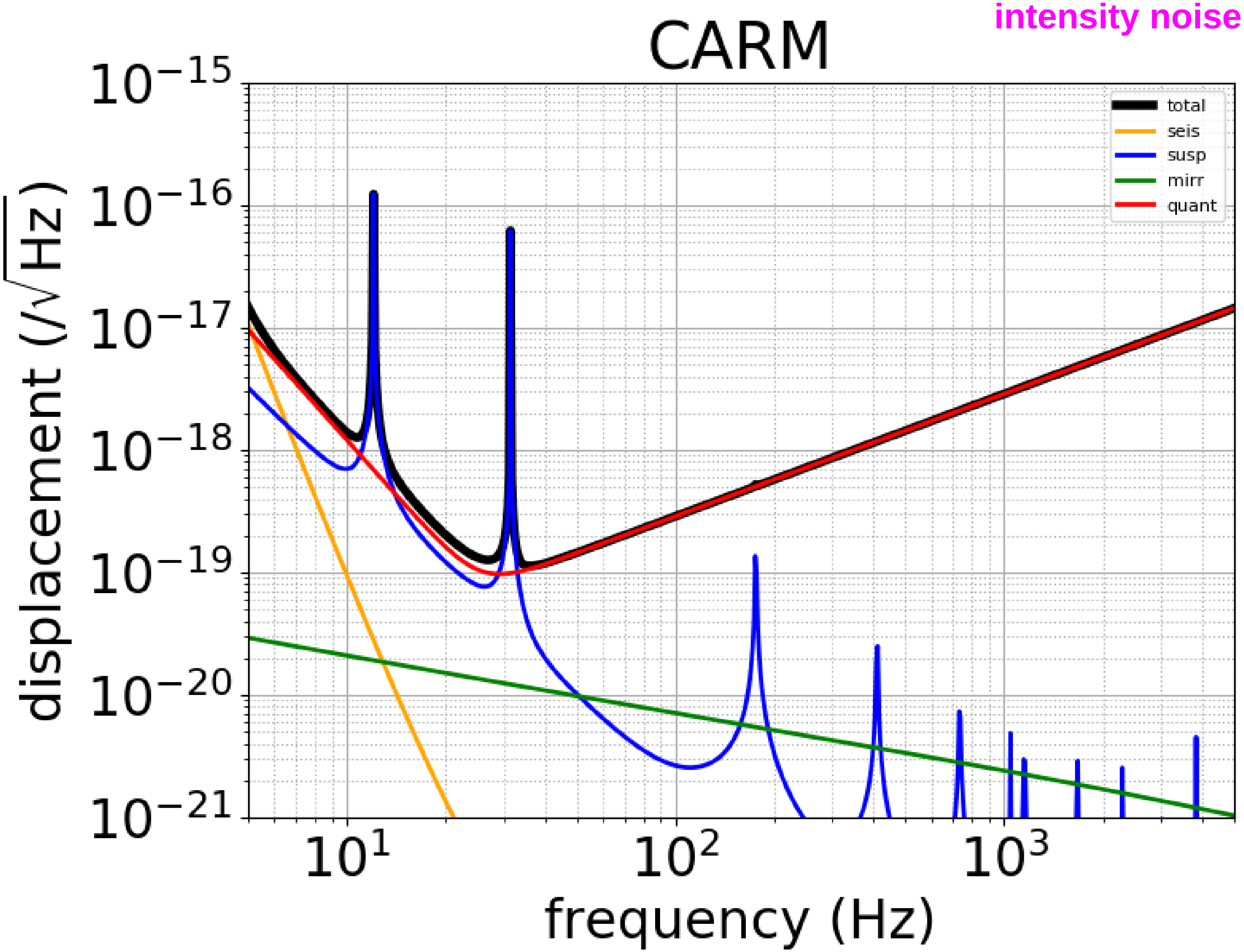
Displacement Noise: PRM

Displacement Sensitivity: DARM

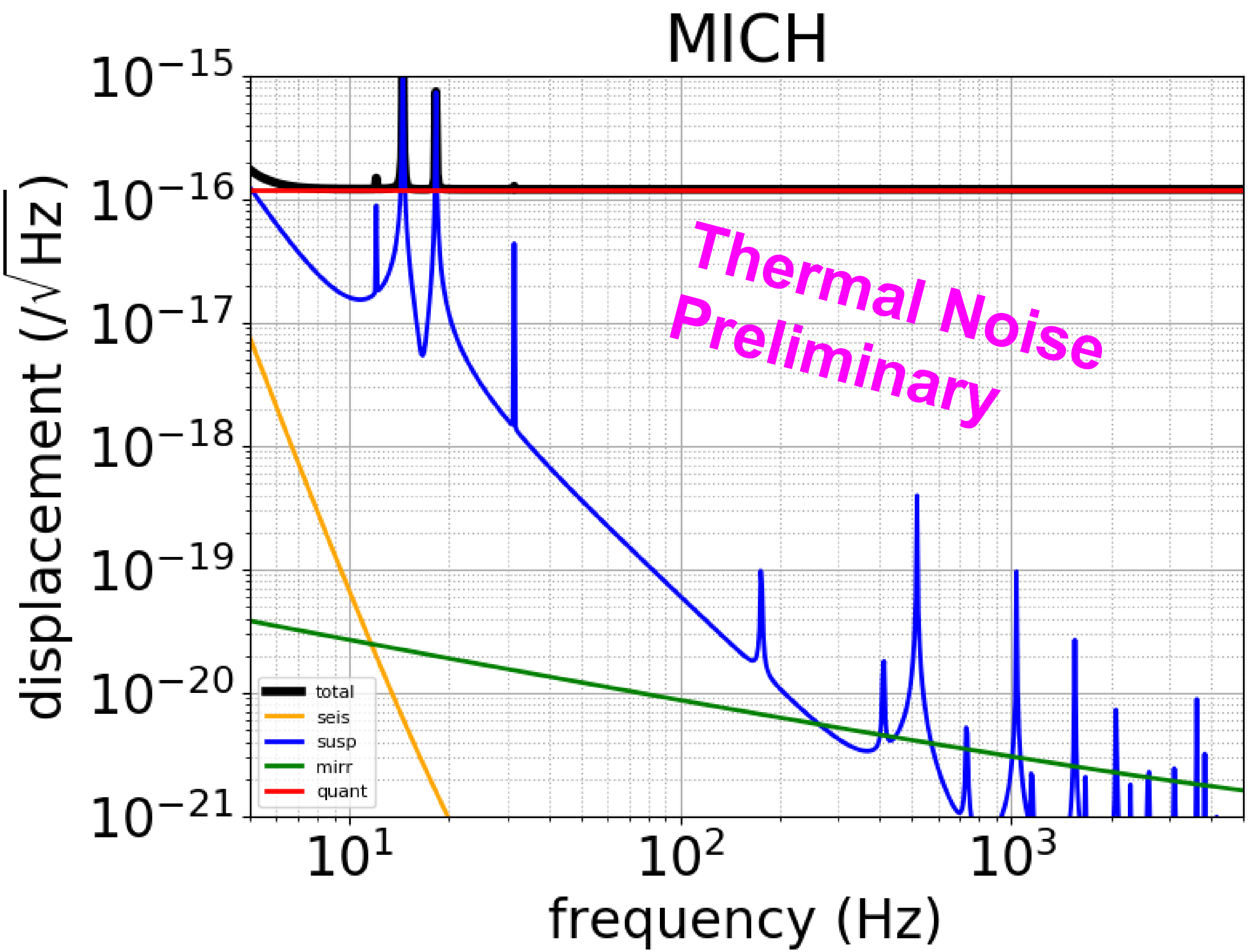


Displacement Sensitivity: CARM

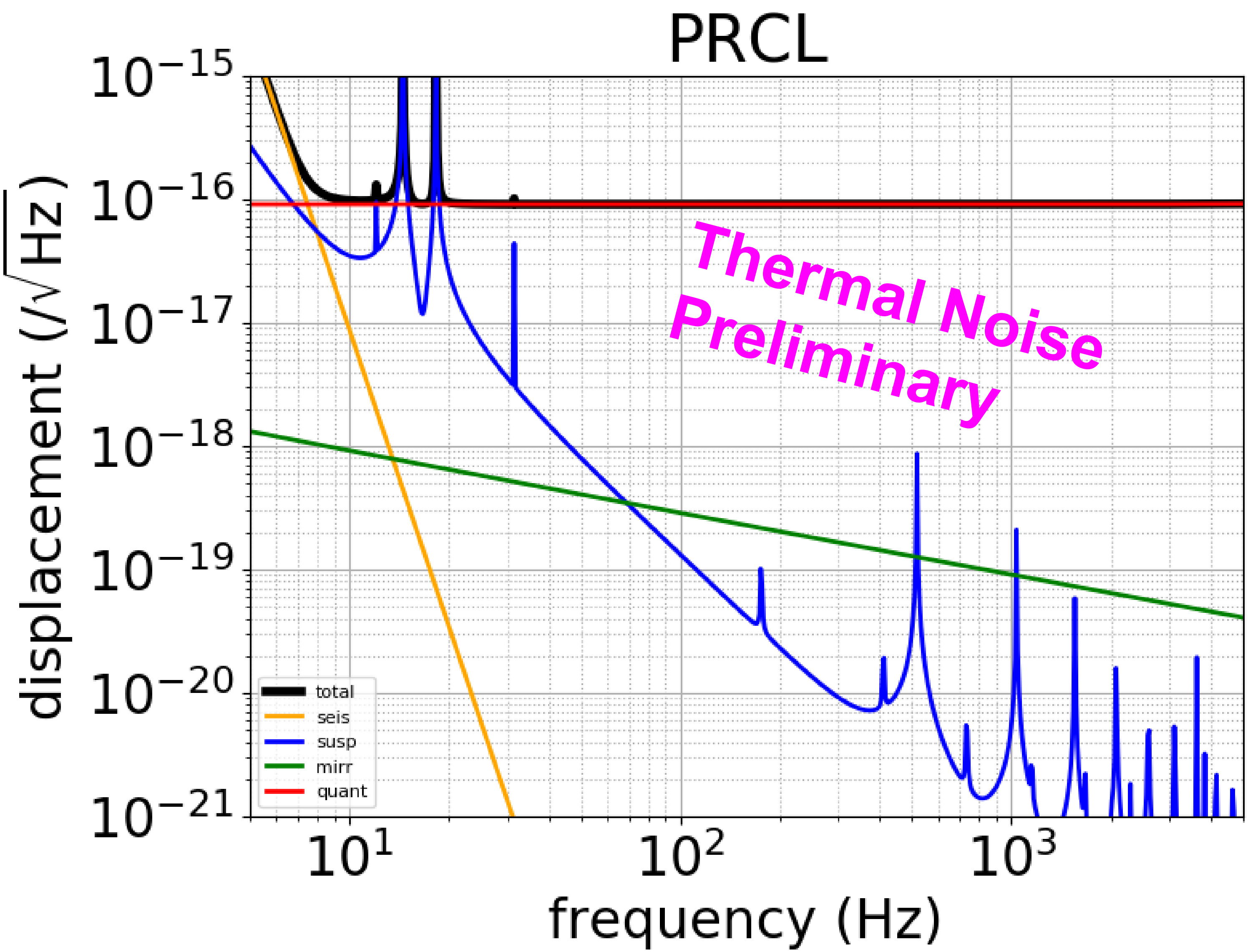
NOTE: frequency noise and intensity noise not considered



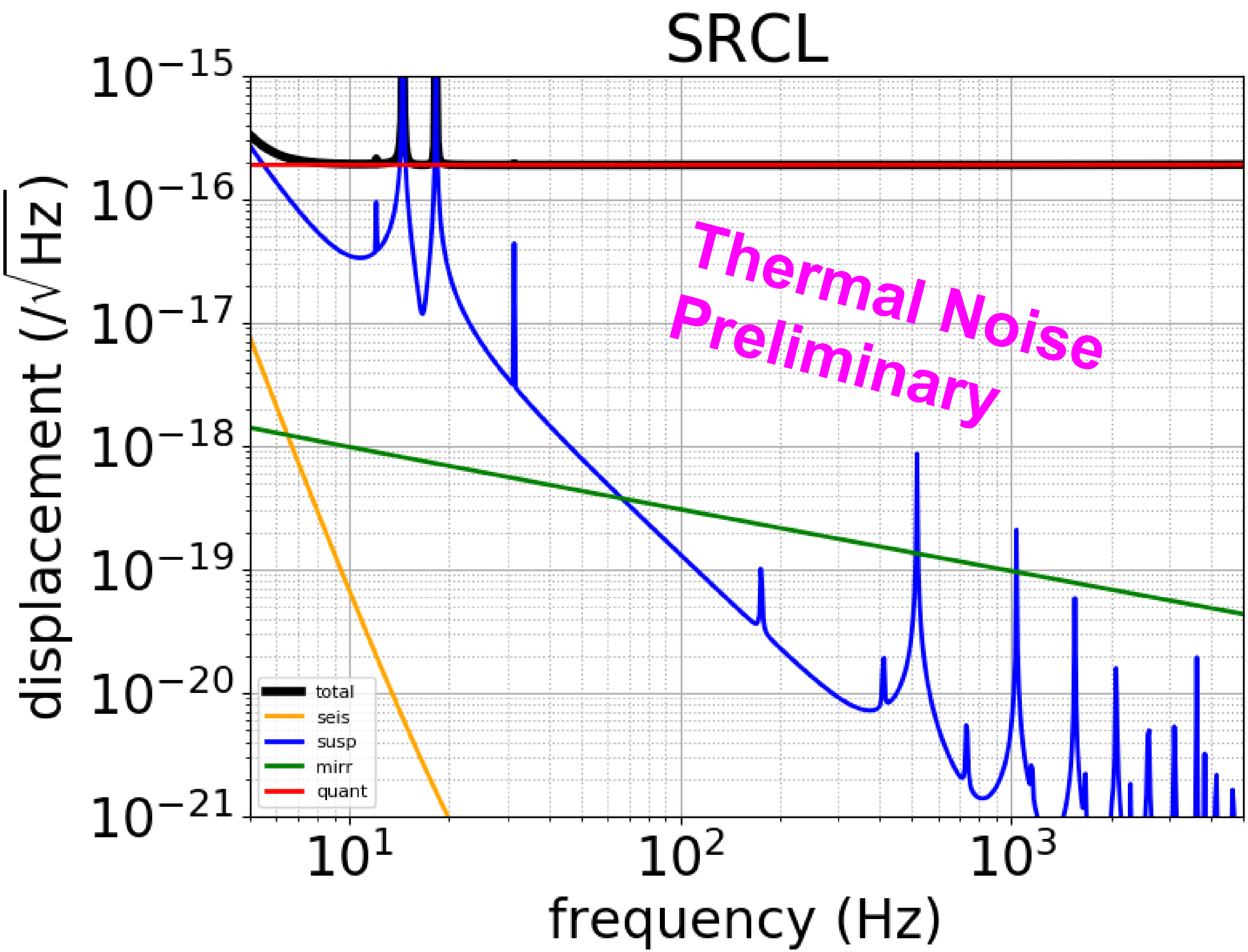
Displacement Sensitivity: MICH



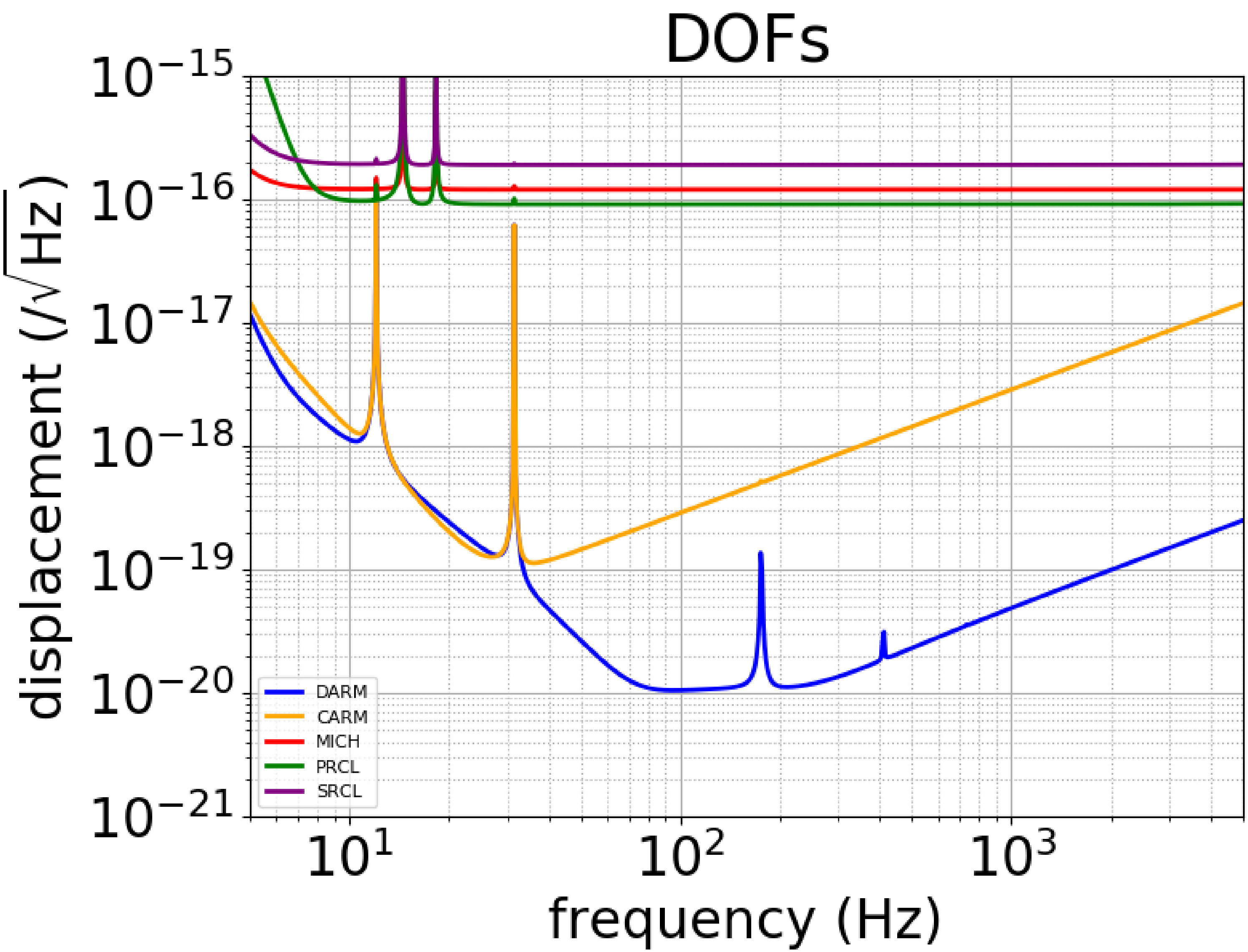
Displacement Sensitivity: PRCL



Displacement Sensitivity: SRCL

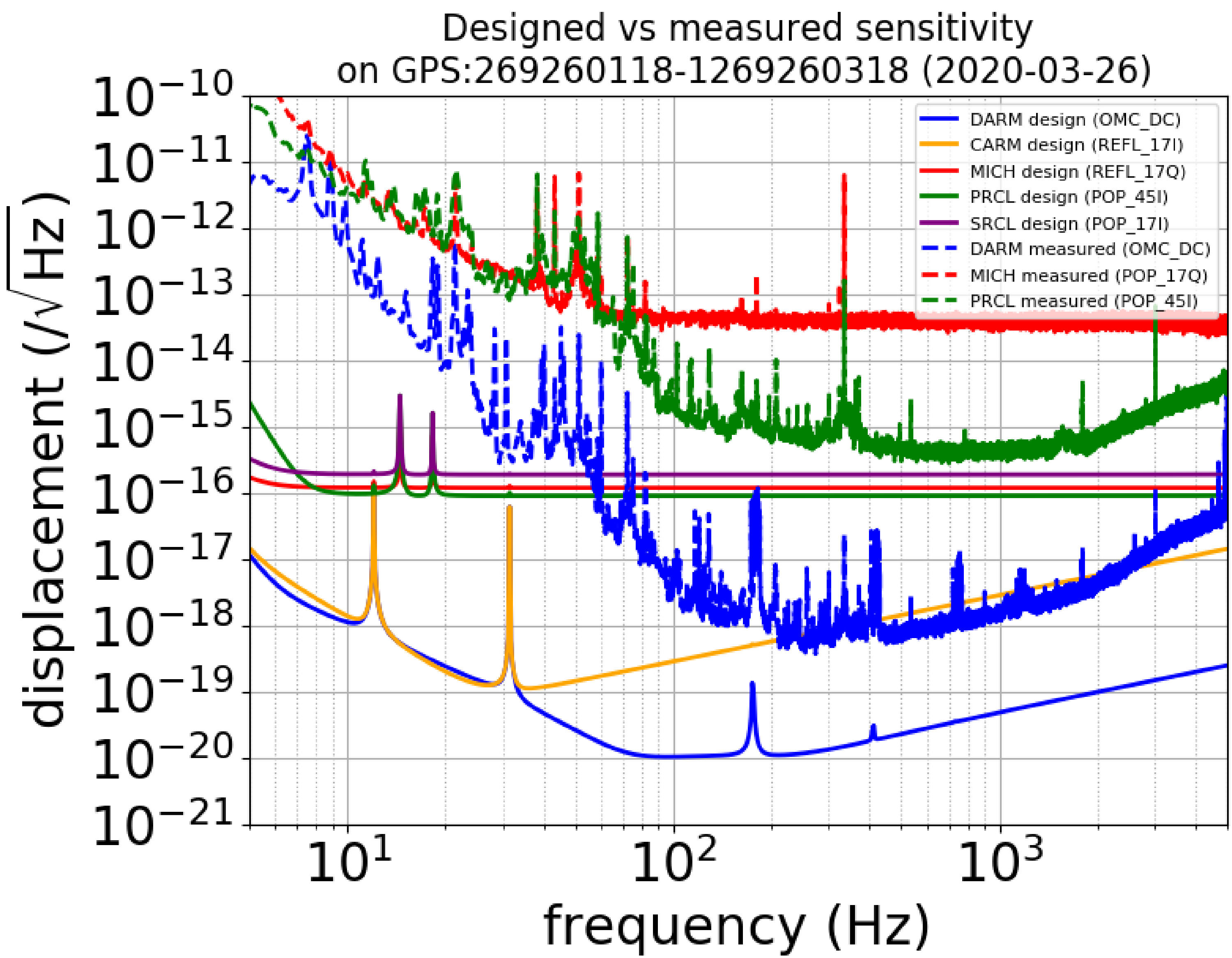


Displacement Sensitivity Summary



NOTE: frequency noise and intensity noise not considered for CARM

Mar 26, 2020 Sensitivity



MICH and PRCL calibrated offline (see klog #14556)