

Estimated sensitivity for auxiliary degrees of freedom of KAGRA interferometer

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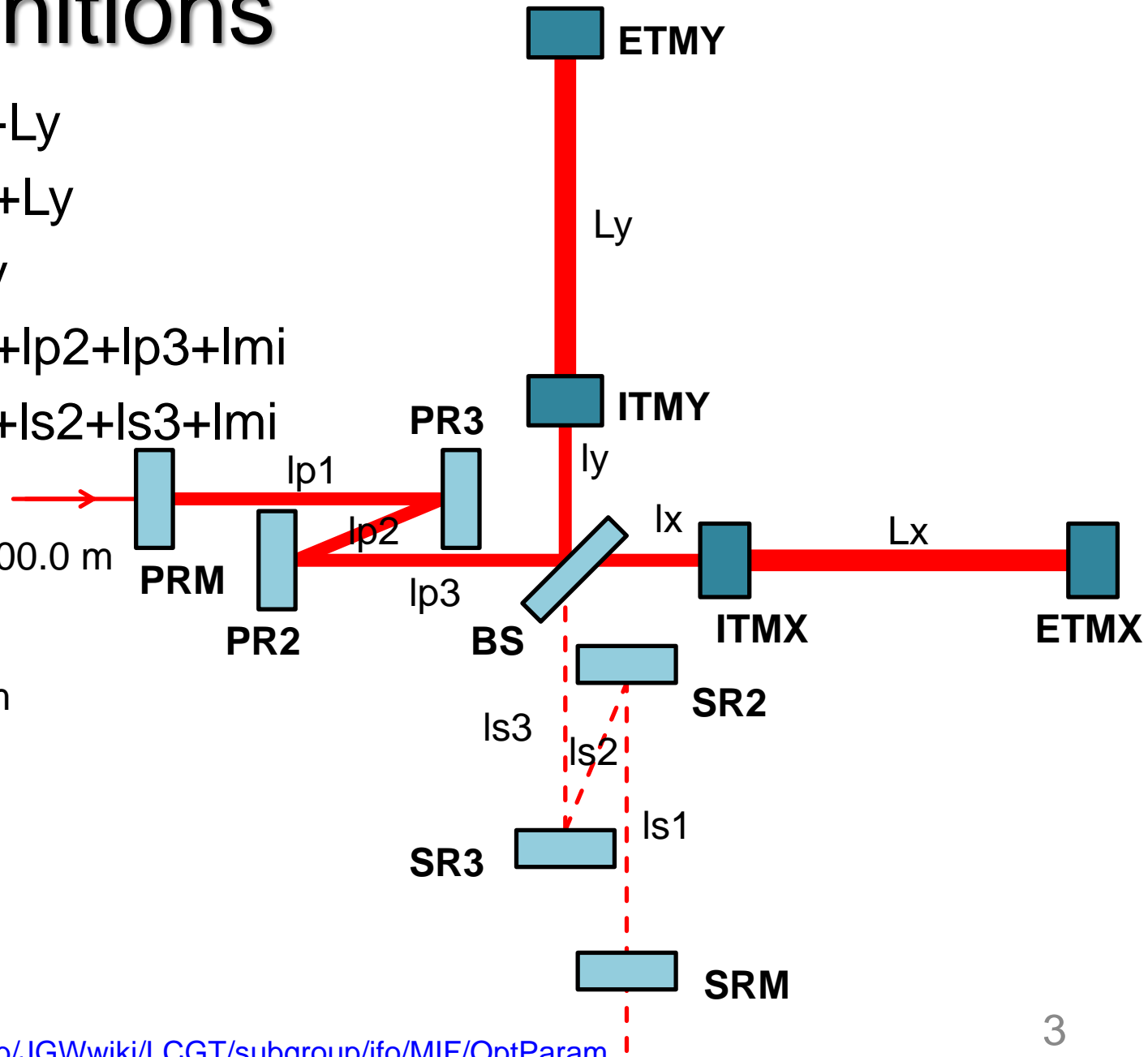
Scope

- 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

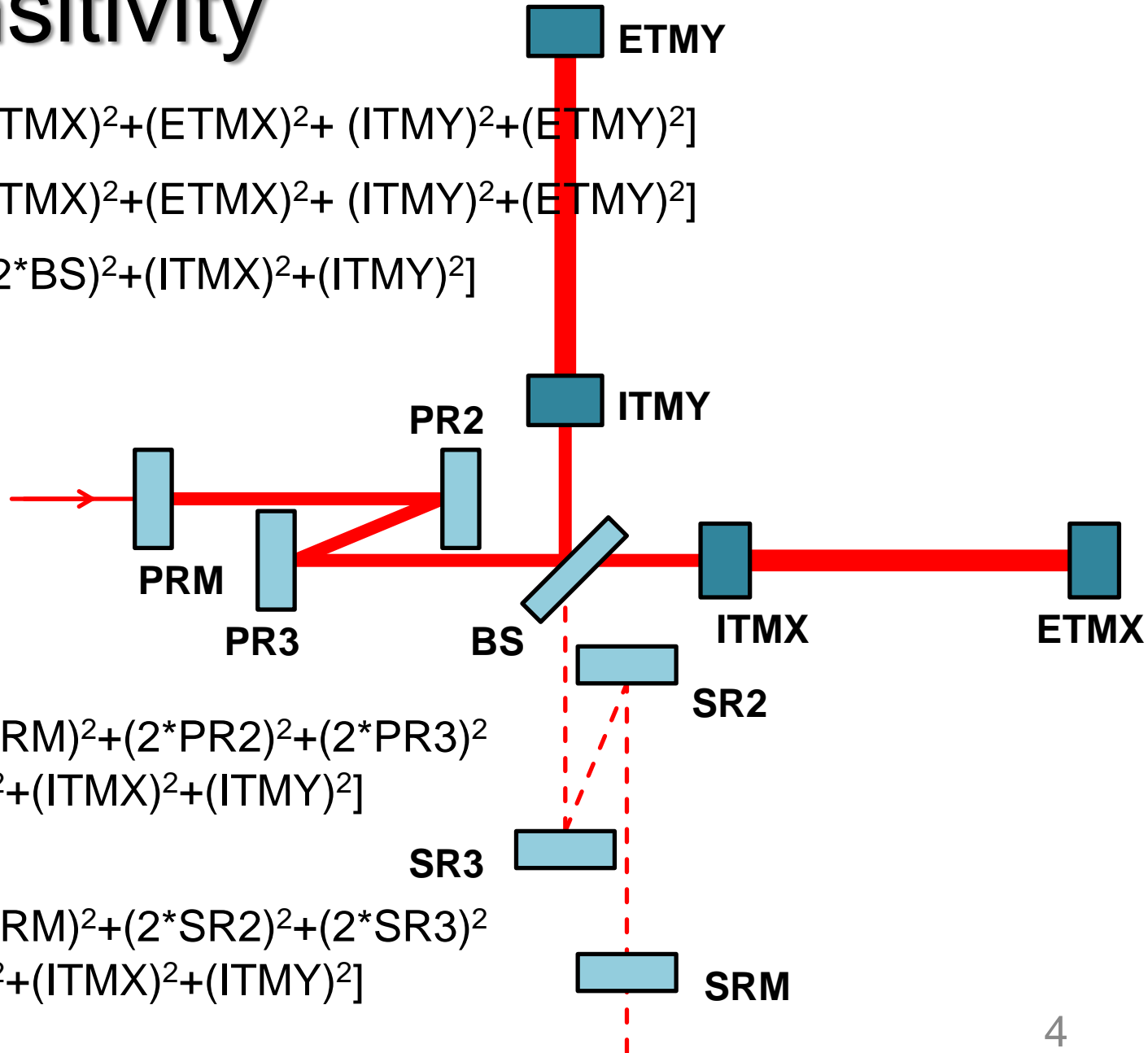
- DARM: $L_x - L_y$
- CARM: $L_x + L_y$
- MICH: $l_x - l_y$
- PRCL: $l_{p1} + l_{p2} + l_{p3} + l_{mi}$
- SRCL: $l_{s1} + l_{s2} + l_{s3} + l_{mi}$

$L_x = L_y = L_{arm} = 3000.0 \text{ m}$
 $L_x = 26.6649 \text{ m}$
 $l_y = 23.3351 \text{ m}$
 $l_{mi} = (l_x + l_y) / 2 = 25 \text{ m}$
 $l_{p1} = 14.7615 \text{ m}$
 $l_{p2} = 11.0661 \text{ m}$
 $l_{p3} = 15.7638 \text{ m}$
 $l_{s1} = 14.7412 \text{ m}$
 $l_{s2} = 11.1115 \text{ m}$
 $l_{s3} = 15.7386 \text{ m}$



Sensitivity

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

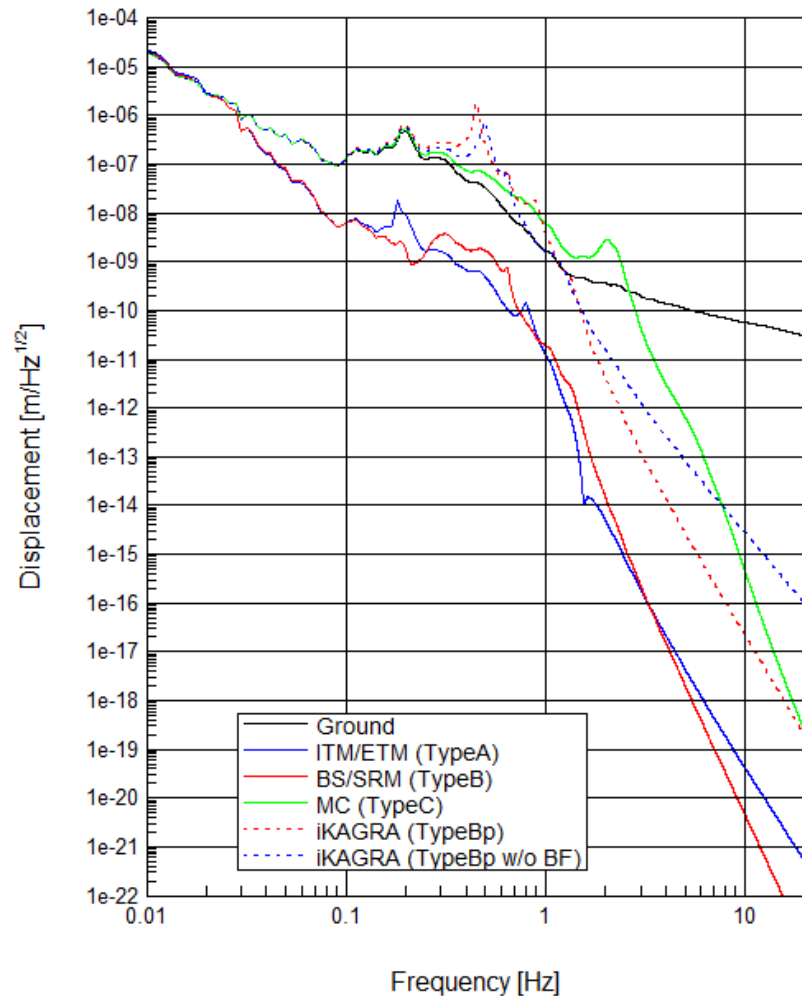


- PRCL: $\sqrt{[(PRM)^2+(2*PR2)^2+(2*PR3)^2 +(\sqrt{2}/2*BS)^2+(ITMX)^2+(ITMY)^2]}$
- SRCL: $\sqrt{[(SRM)^2+(2*SR2)^2+(2*SR3)^2 +(\sqrt{2}/2*BS)^2+(ITMX)^2+(ITMY)^2]}$

Seismic noise

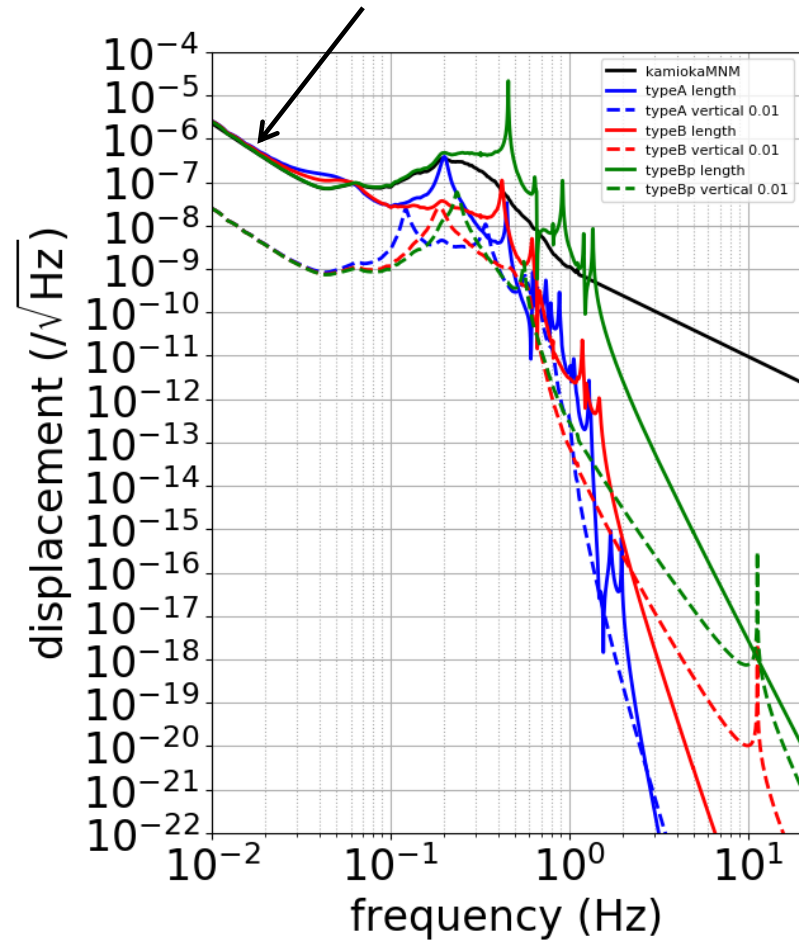
Models

- There exists several models



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

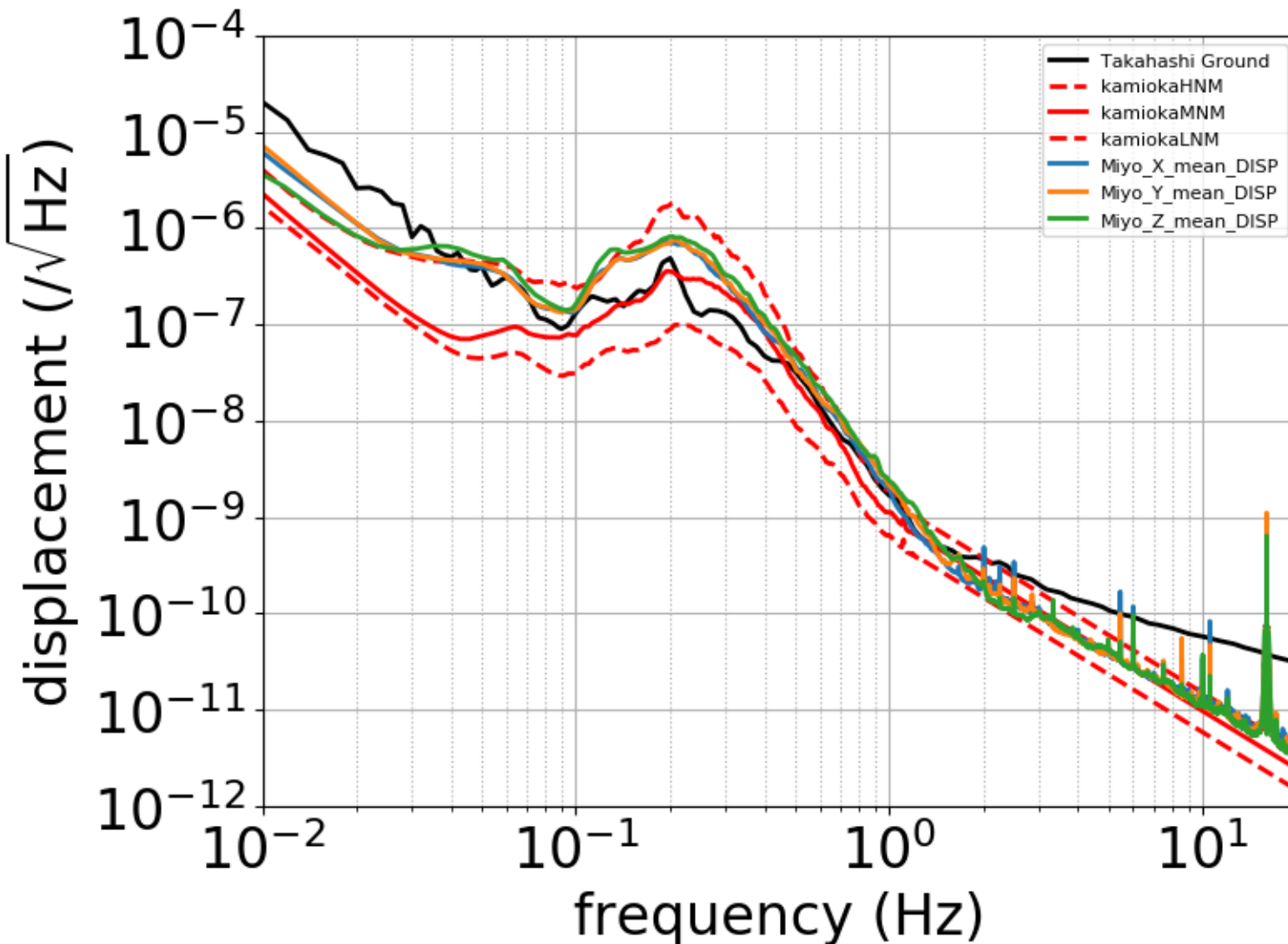
Medium Noise Model
 from [JGW-T1402971](https://www.jgwg.org/jgw-t1402971)



Model from T. Sekiguchi
 (used for actuator modeling in
[JGW-P1707051](https://www.jgwg.org/jgw-p1707051))

Seismic Noise Spectra

- Let's just use [JGW-T1402971](#) MNM for simplicity



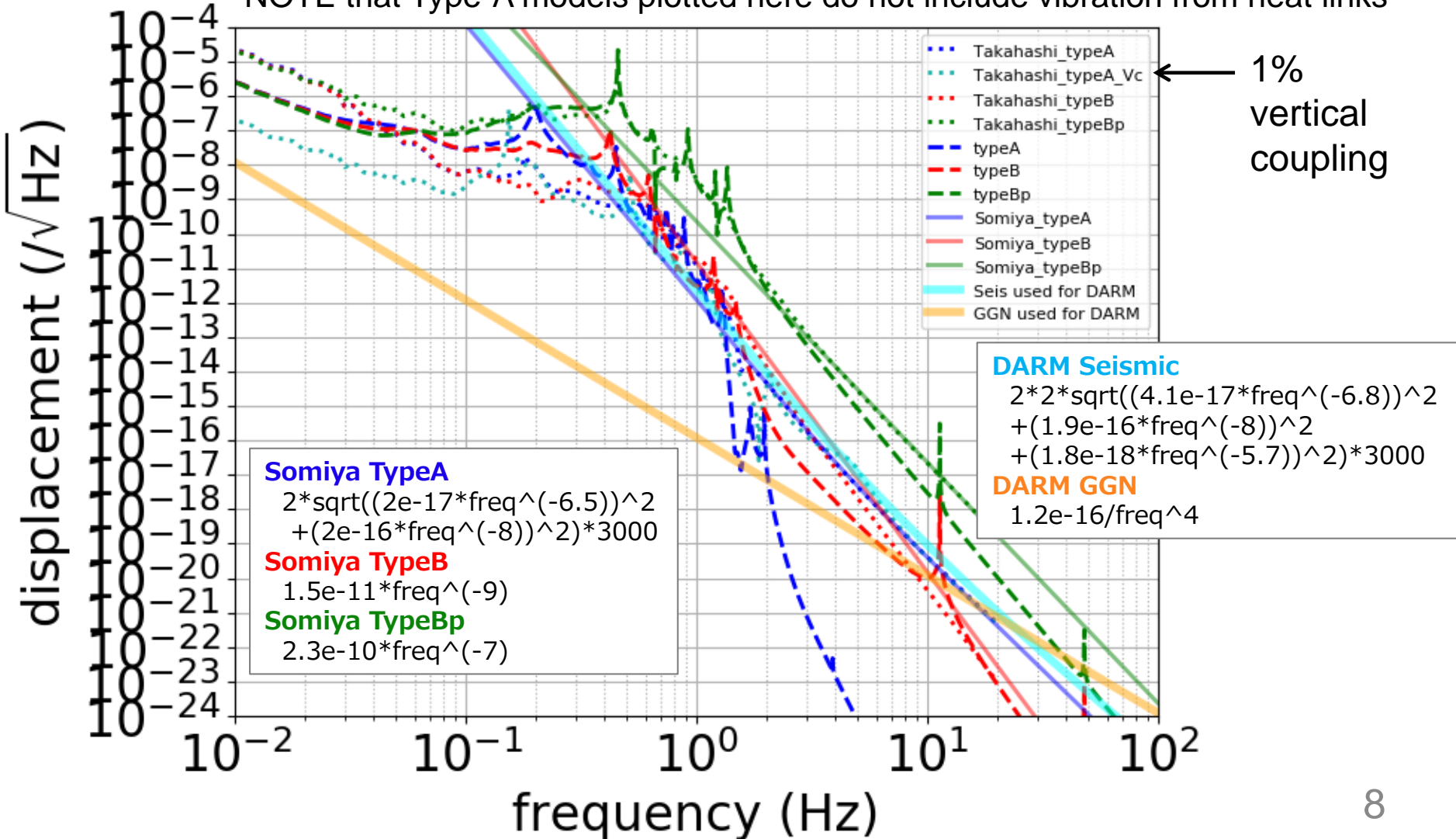
By Sekiguchi
[JGW-T1402971](#)

By Miyo
[JGW-T1910436](#)

Comparison Between Models

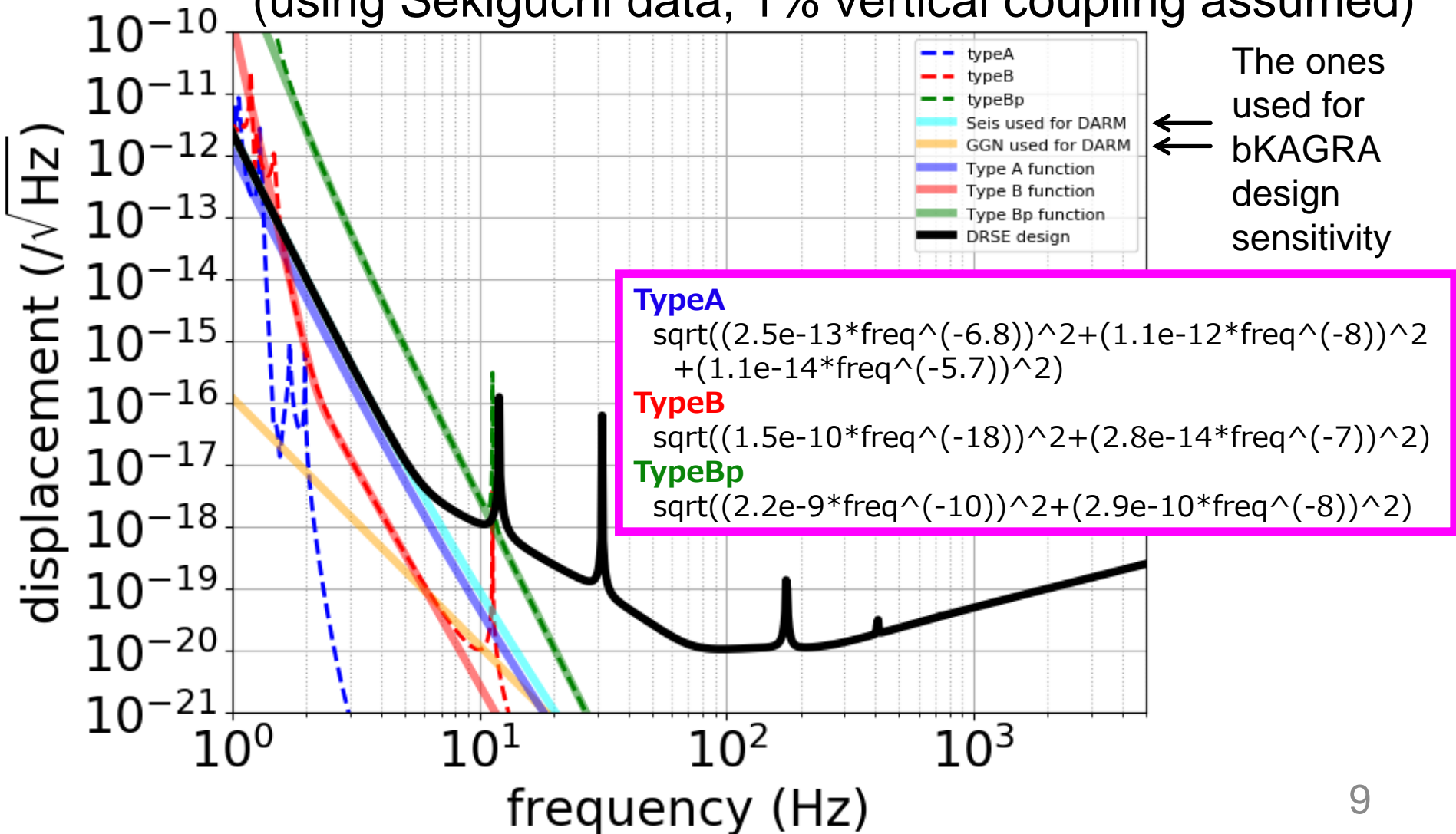
- Fitting function by Somiya based on Takahashi model

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)



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 $5e-6$

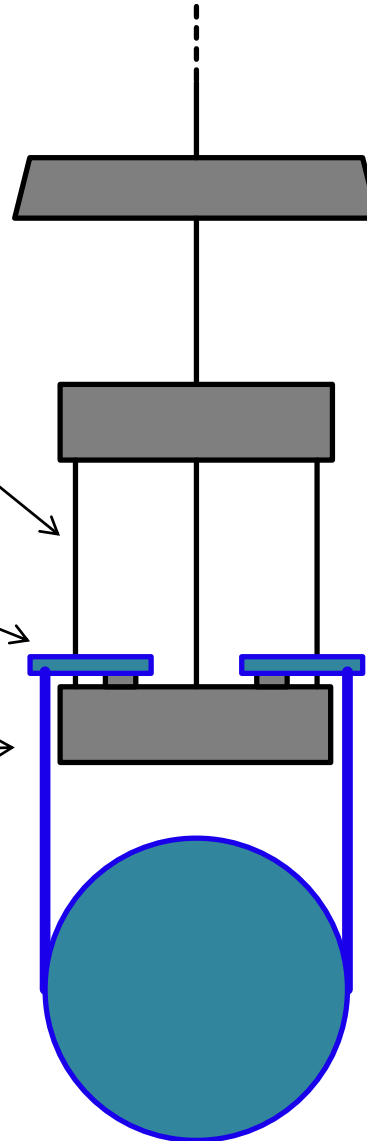
Blade springs

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 ??

[CQG 34, 225001 \(2017\)](#)

Type-B info from Fabian

Type-B maraging rod [JGW-D1605614](#)

BS mass budget [JGW-E1604966](#)

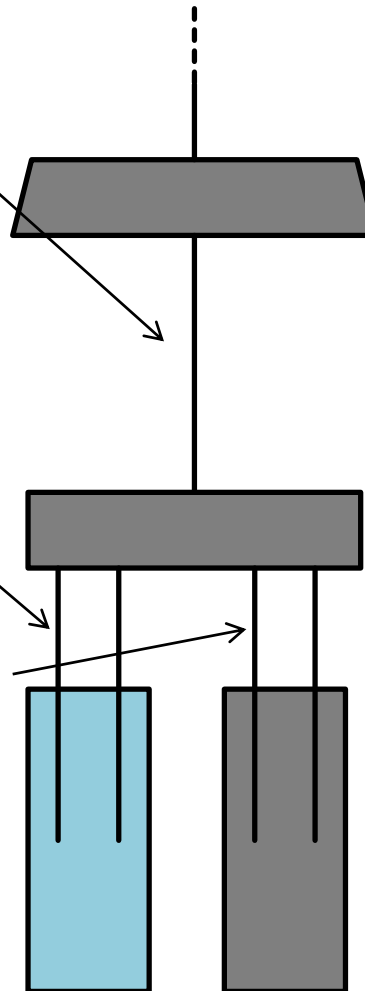
TM suspension

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
55.1 cm long, 0.65 mm dia. for BS
58.7 cm long, 0.6 mm dia. for SRs
loss angle ??

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 ??

[CQG 34, 225001 \(2017\)](#)

Type-Bp info from Shoda (same as SRs)

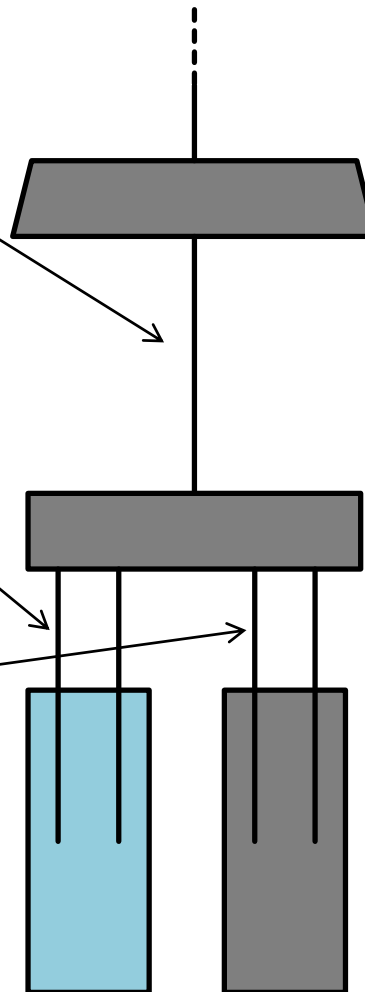
TM suspension

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 | 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](#)

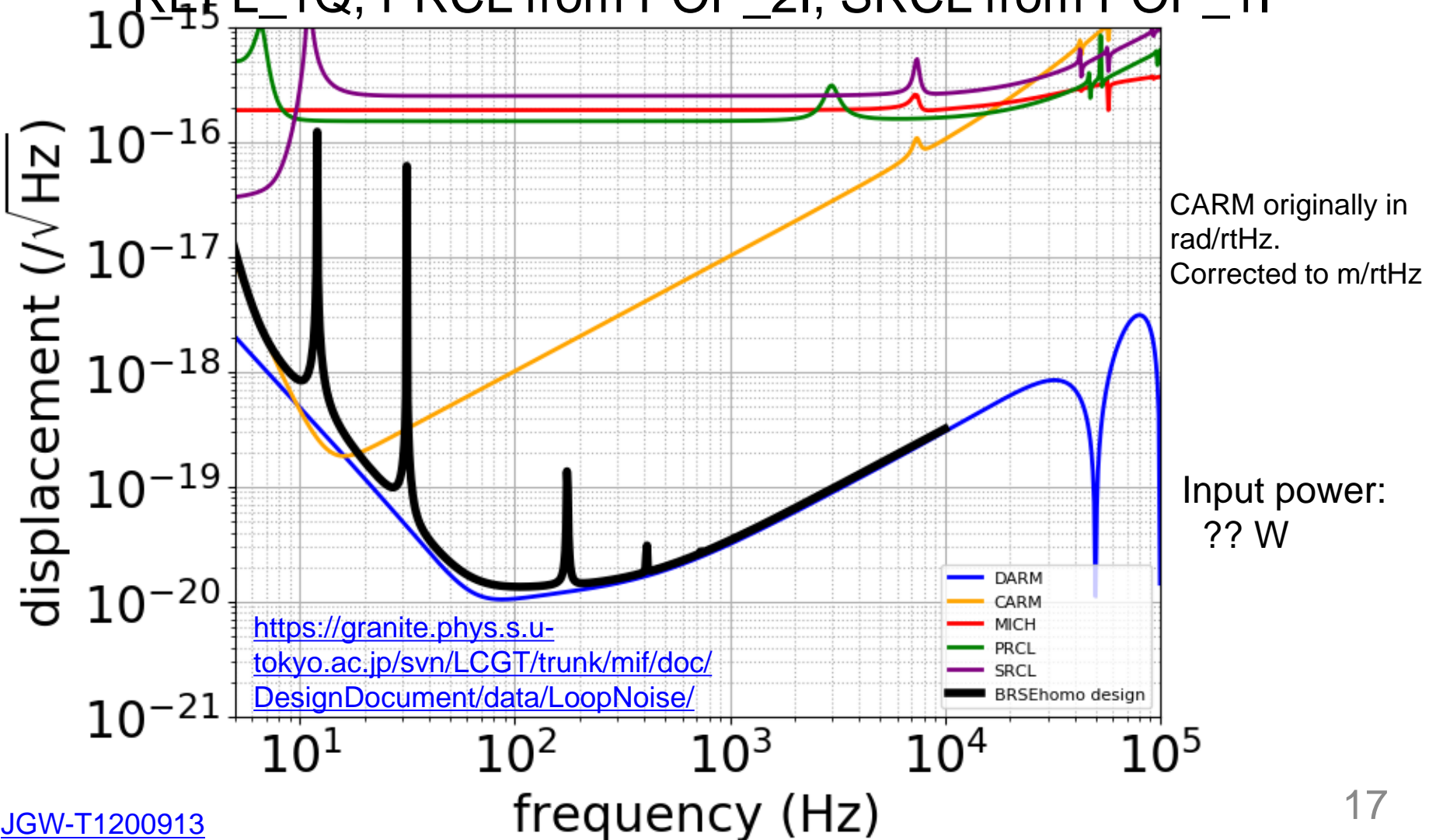
[Classical and Quantum Gravity 34, 225001 \(2017\)](#)

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

Quantum noise

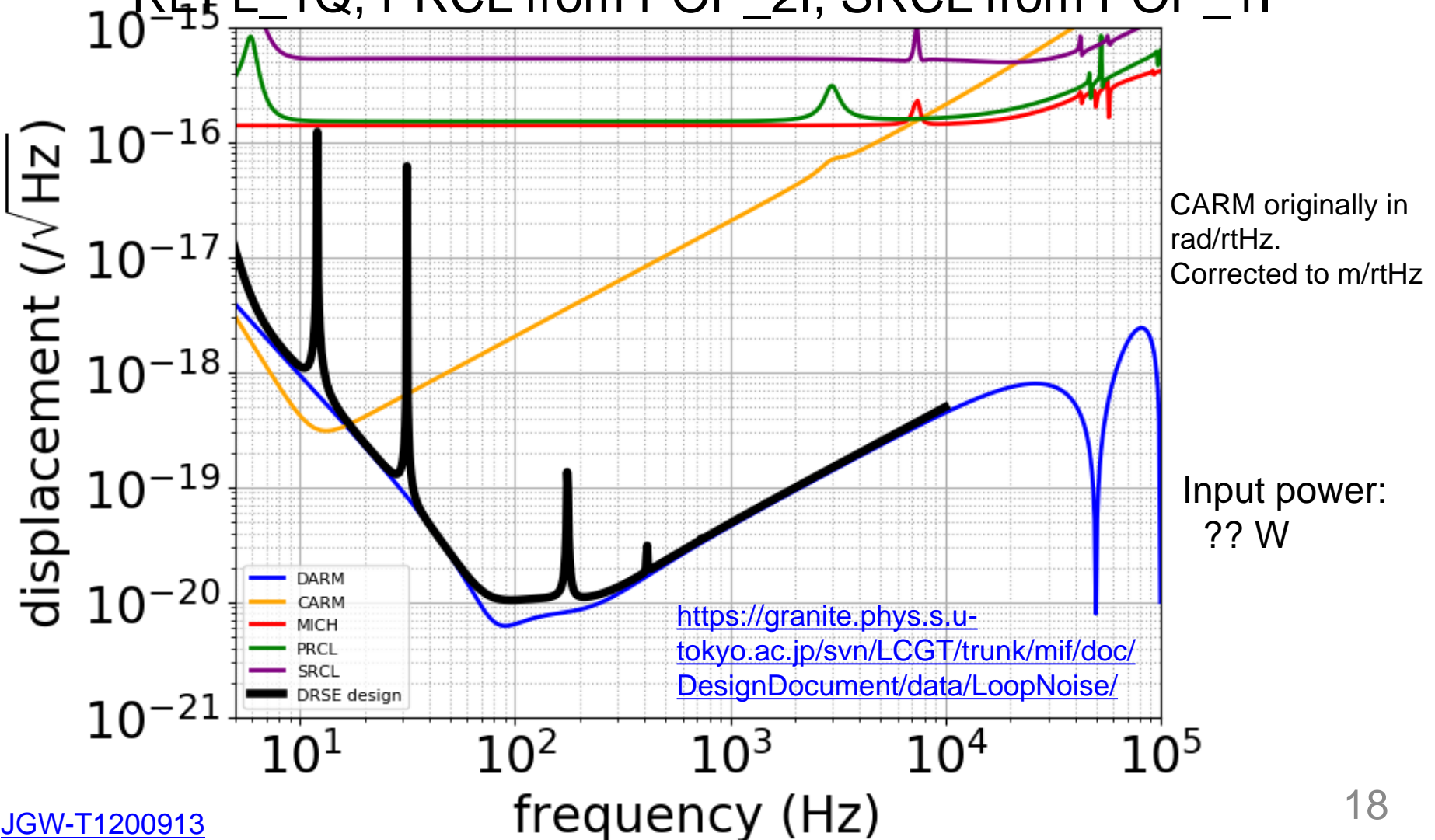
Optickle Simulation (BRSE Aso)

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



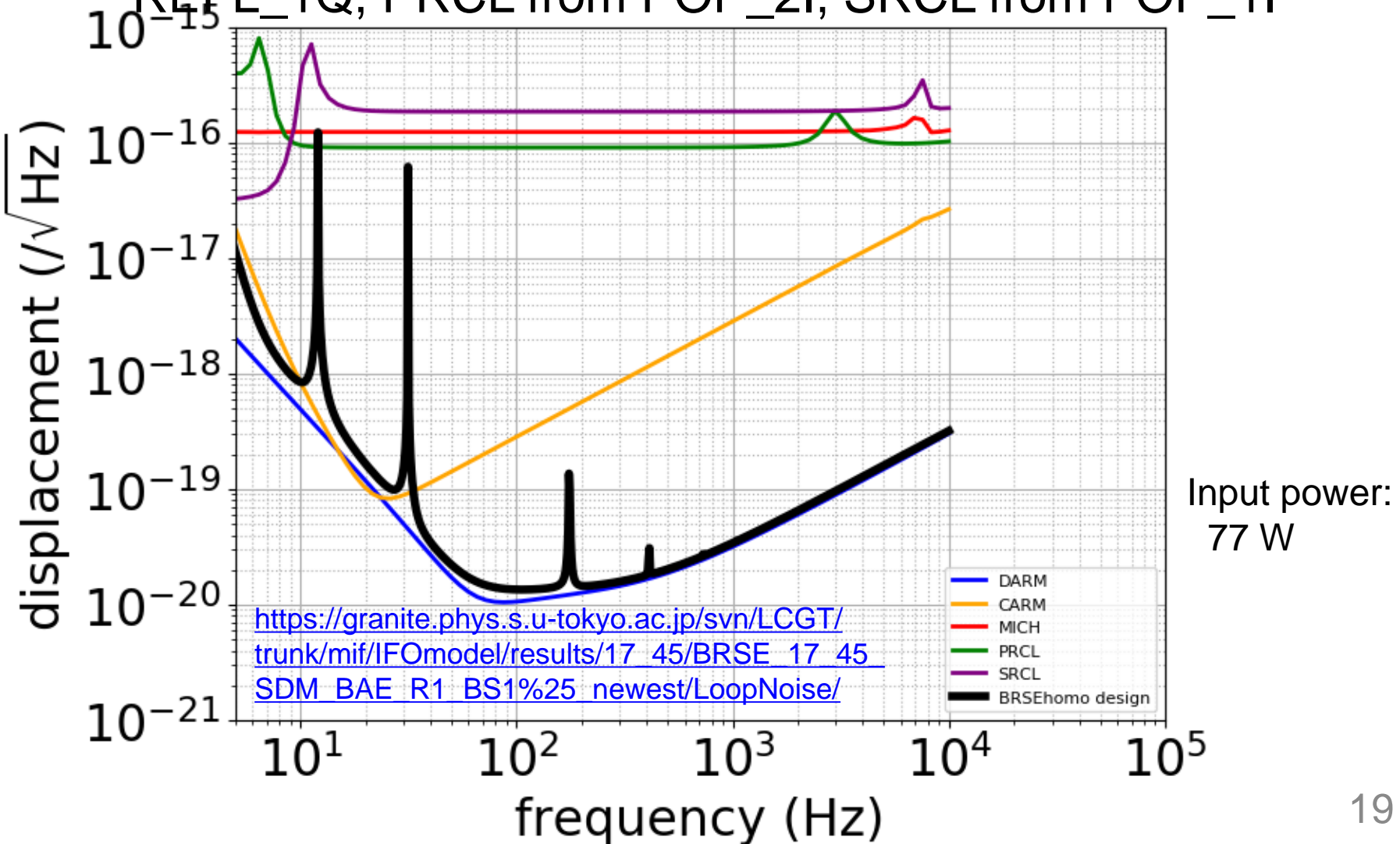
Optickle Simulation (DRSE Aso)

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



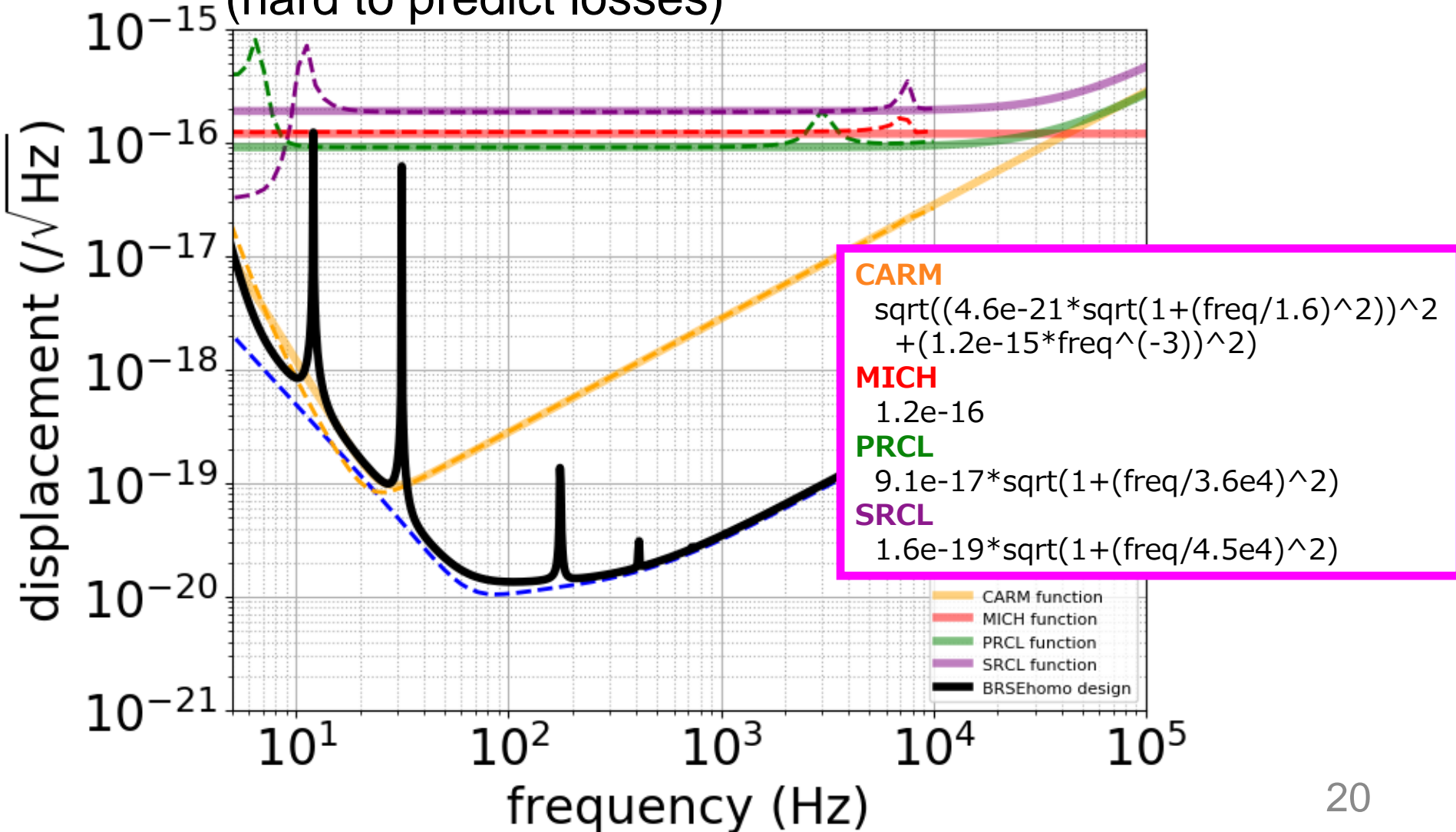
Optickle Simulation (BRSE Enomoto)

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



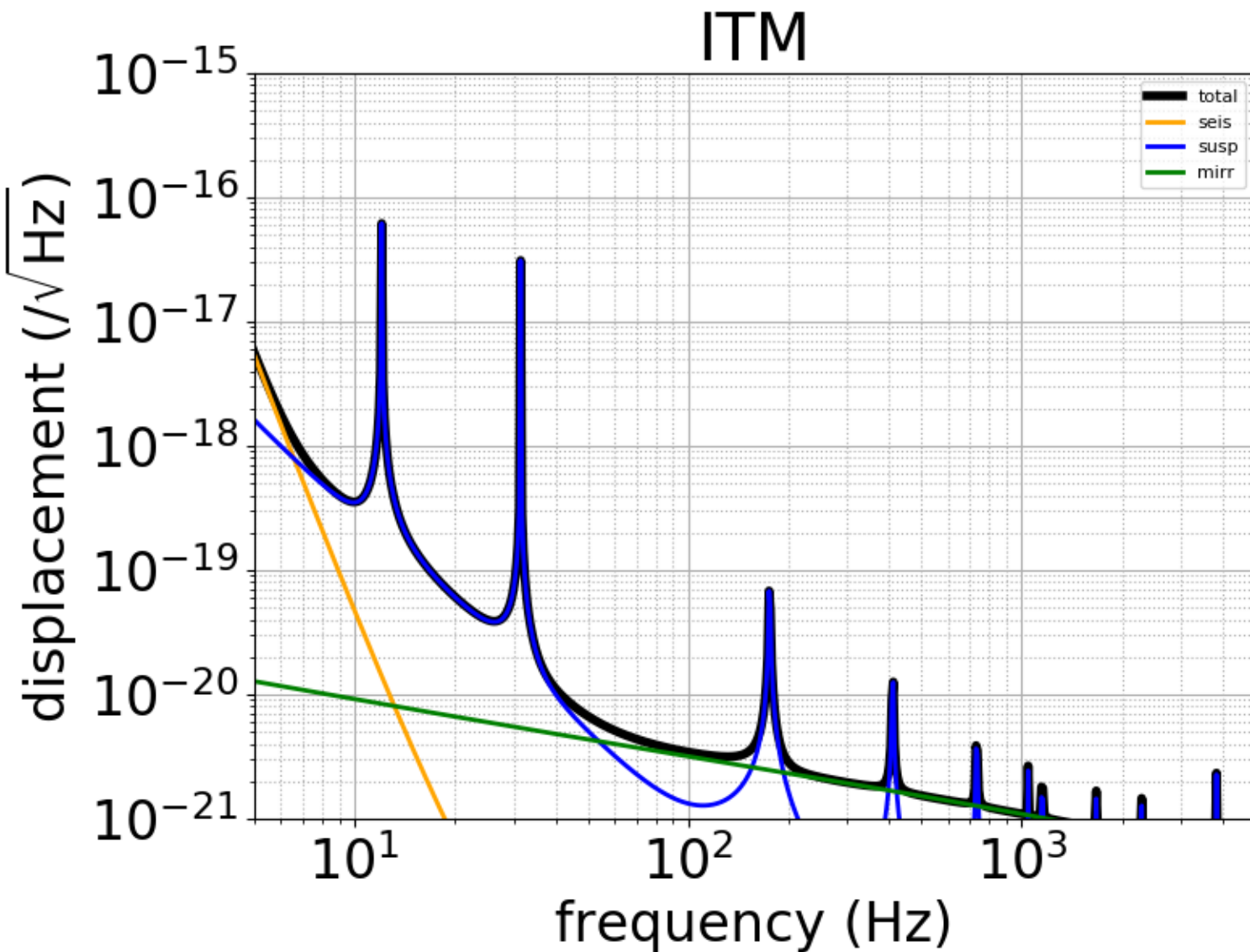
Quantum Function

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

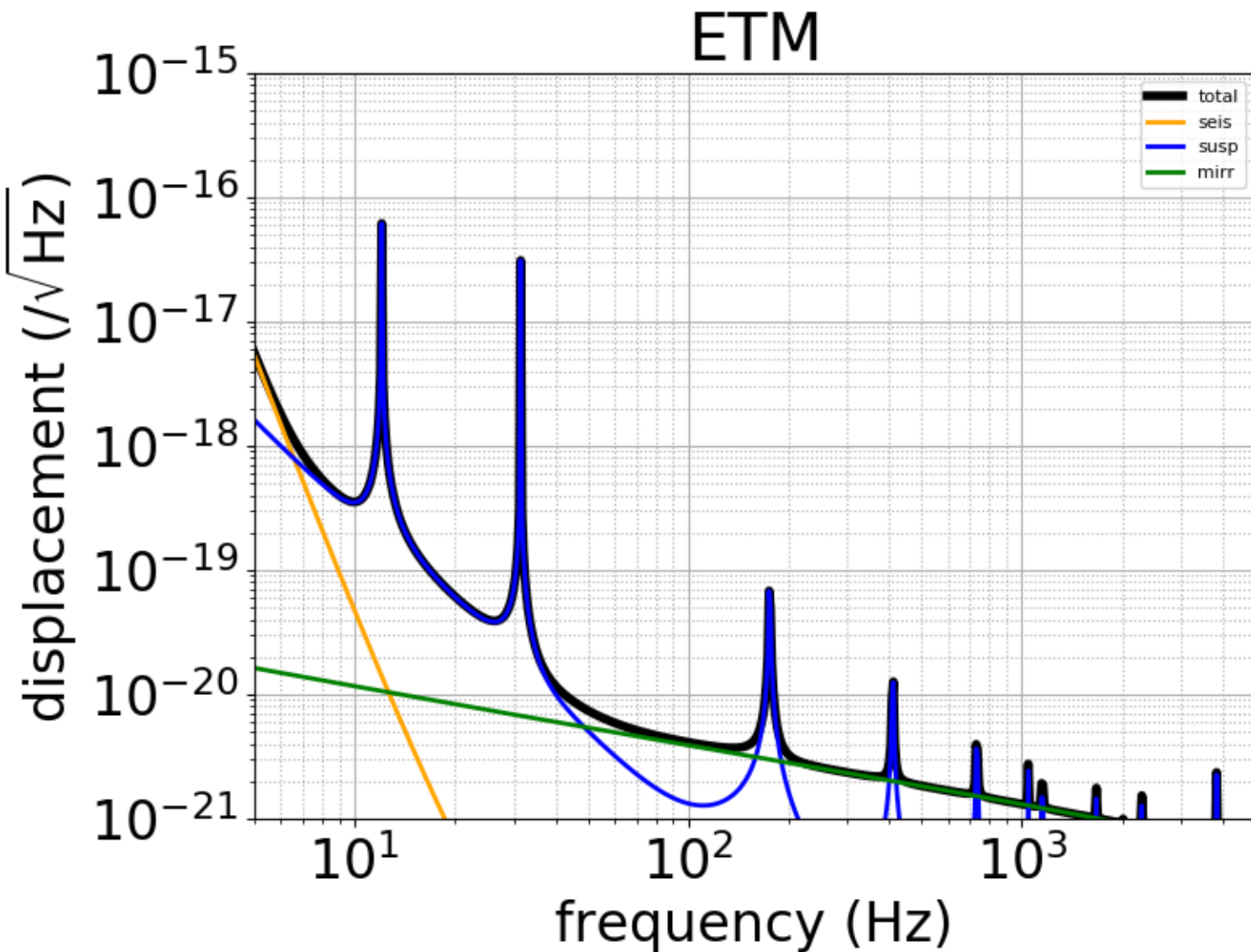


Displacement sensitivity

Displacement Noise: ITM



Displacement Noise: ETM

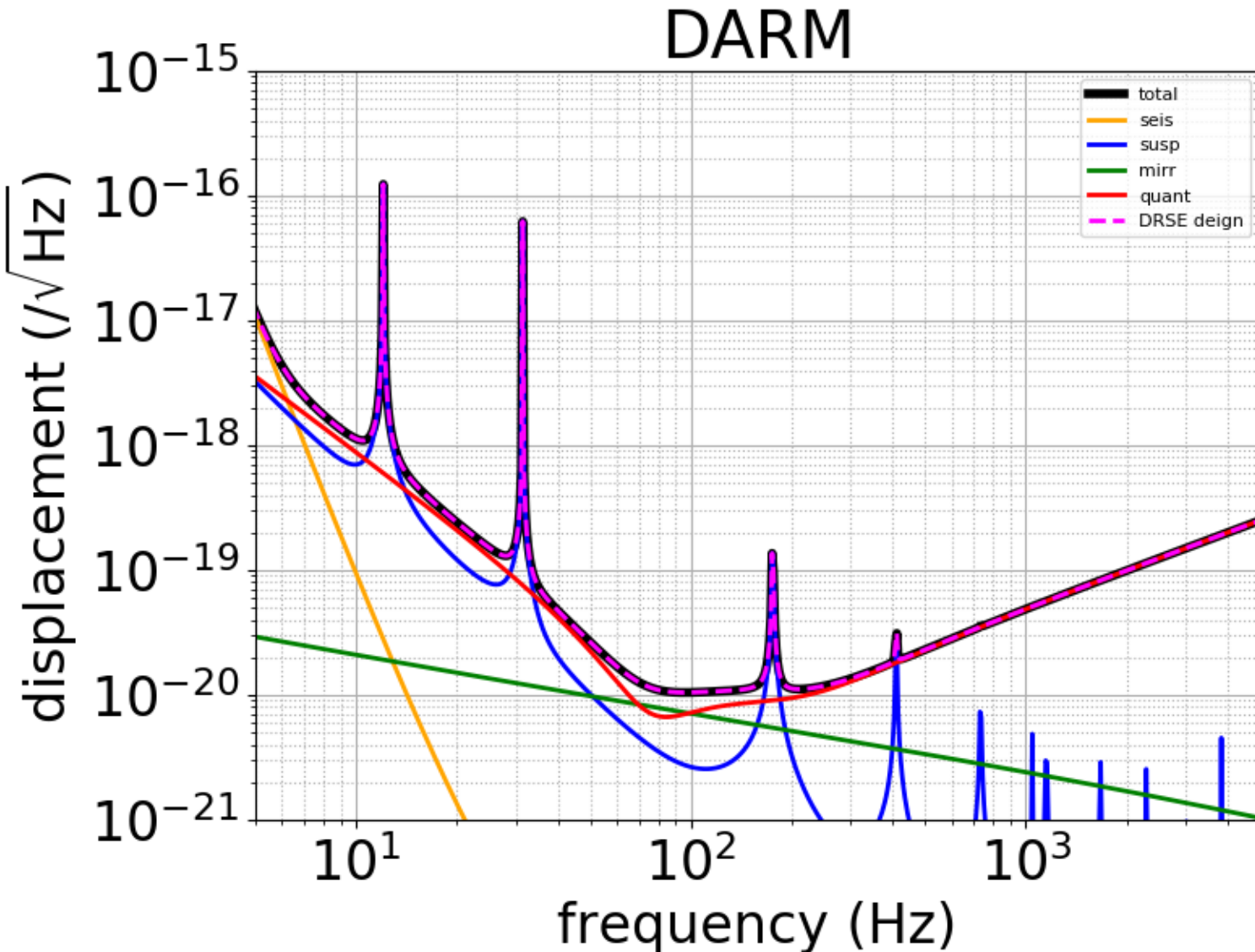


Displacement Noise: BS

Displacement Noise: SRM

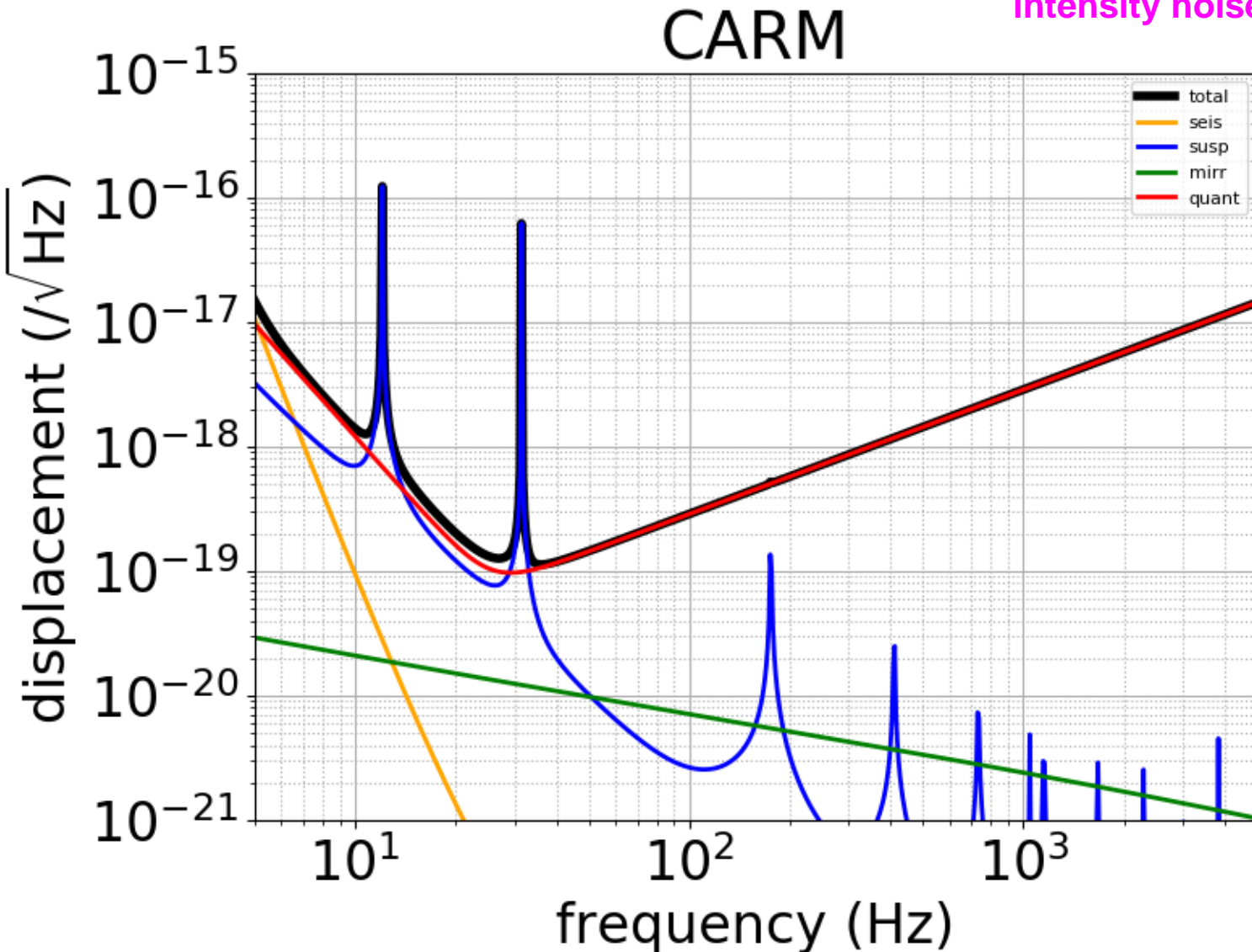
Displacement Noise: PRM

Displacement Sensitivity: DARM

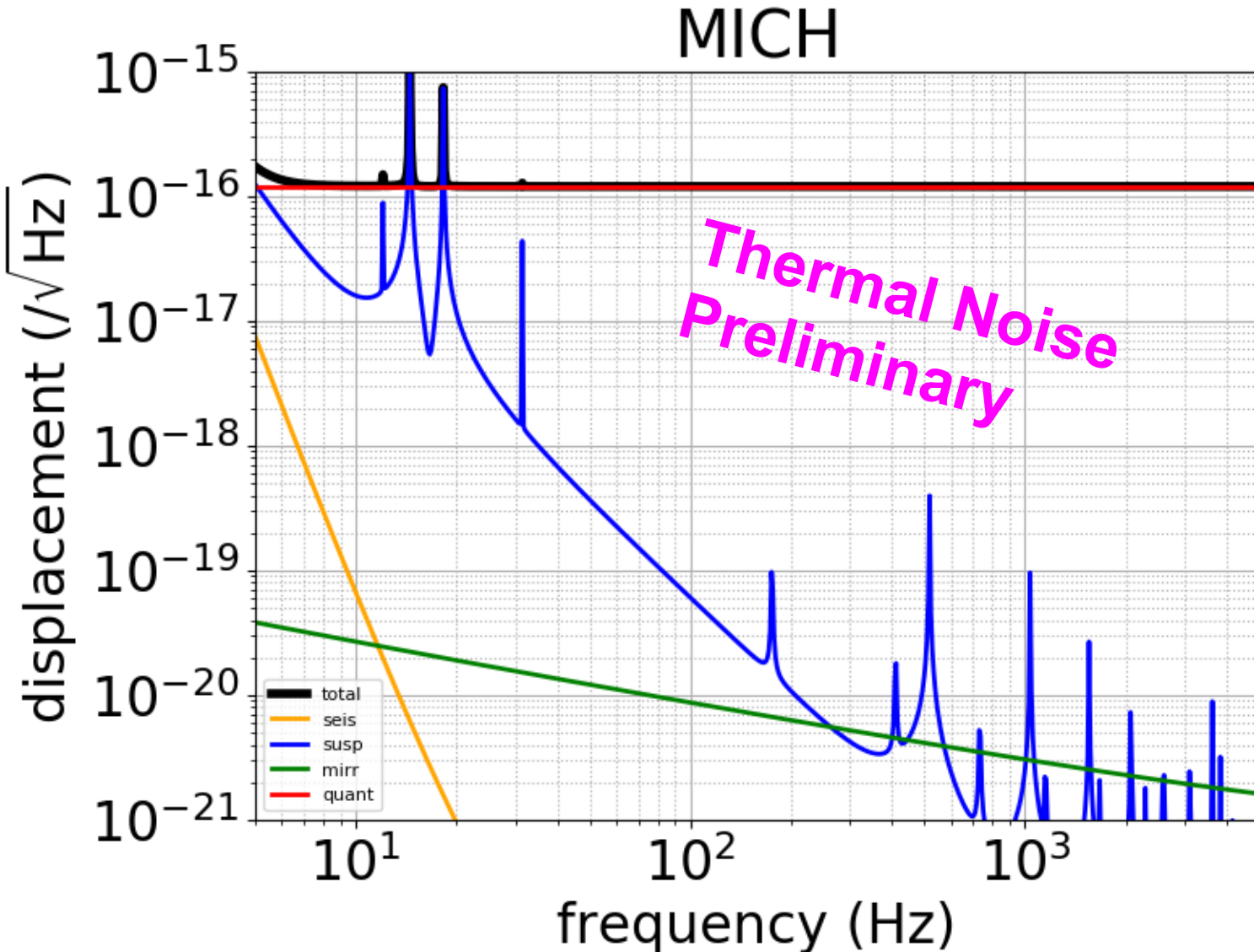


Displacement Sensitivity: CARM

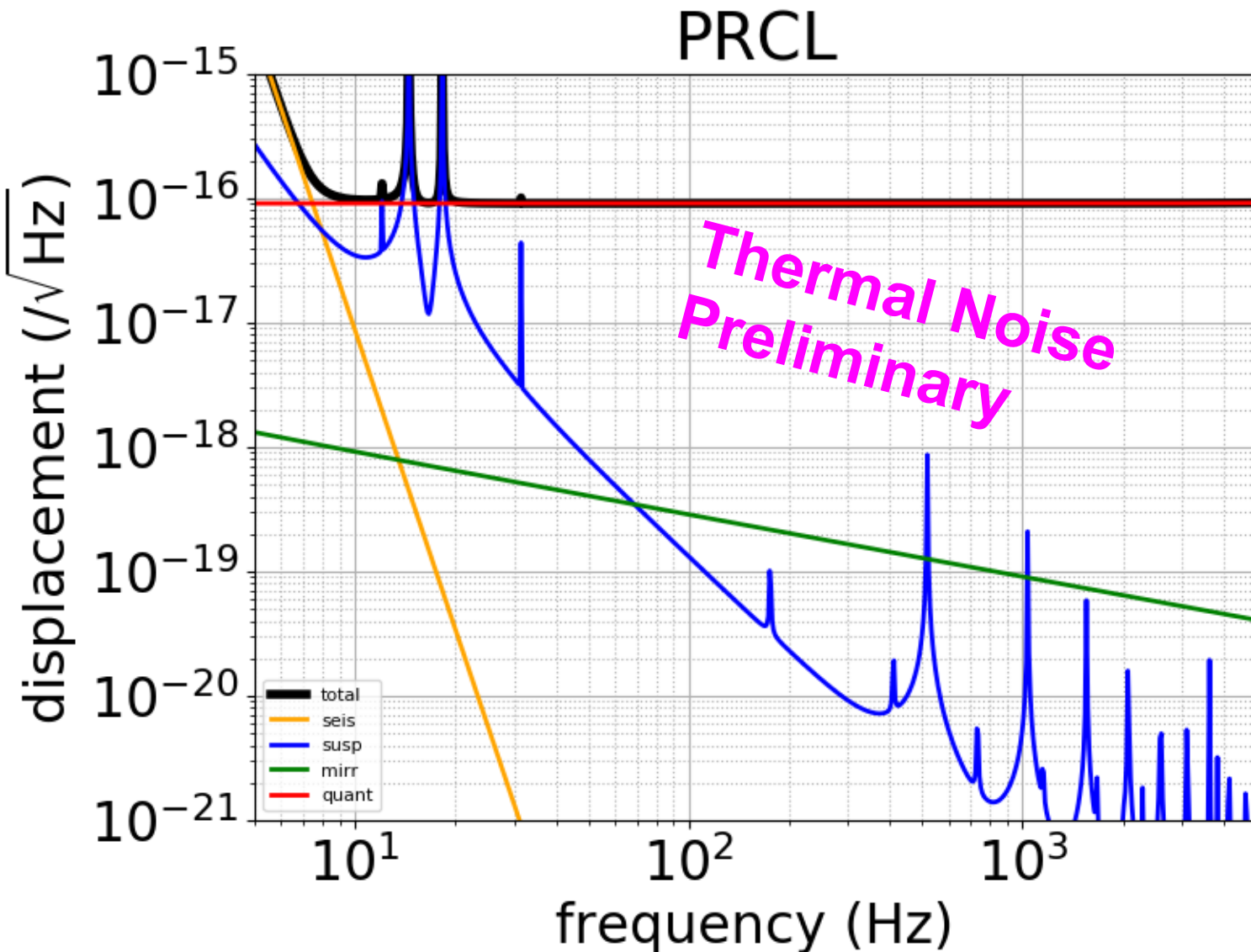
NOTE: frequency noise and intensity noise not considered



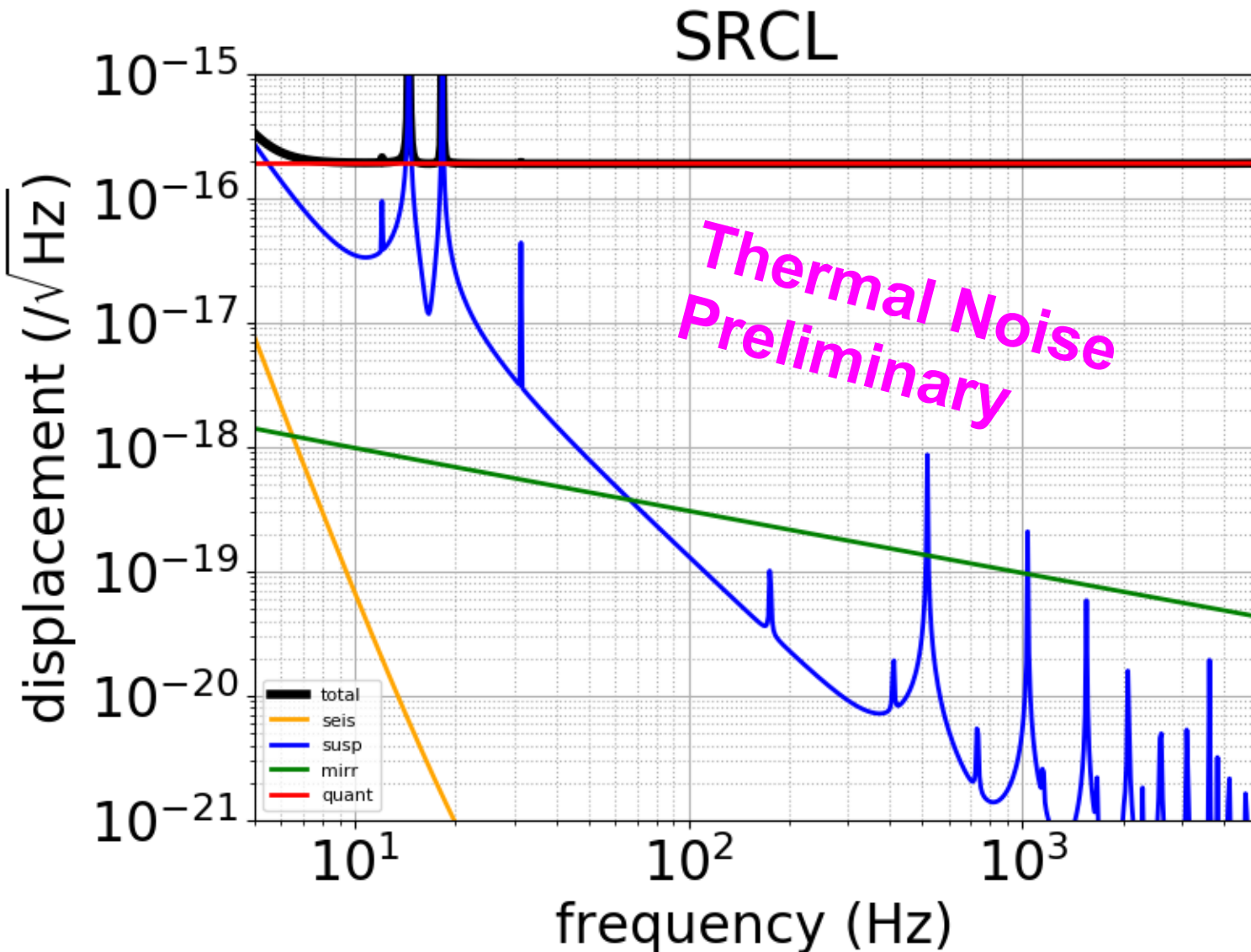
Displacement Sensitivity: MICH



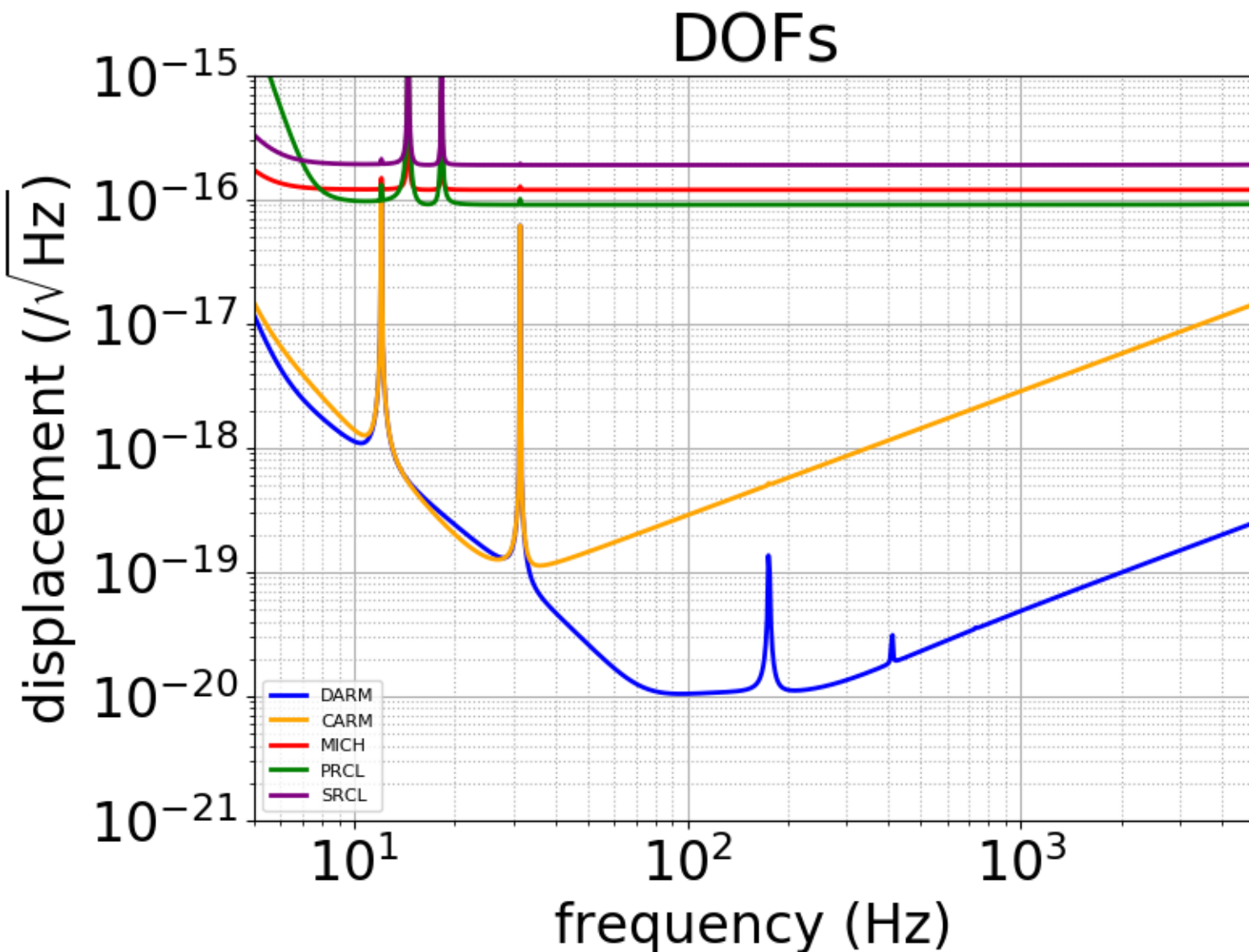
Displacement Sensitivity: PRCL



Displacement Sensitivity: SRCL



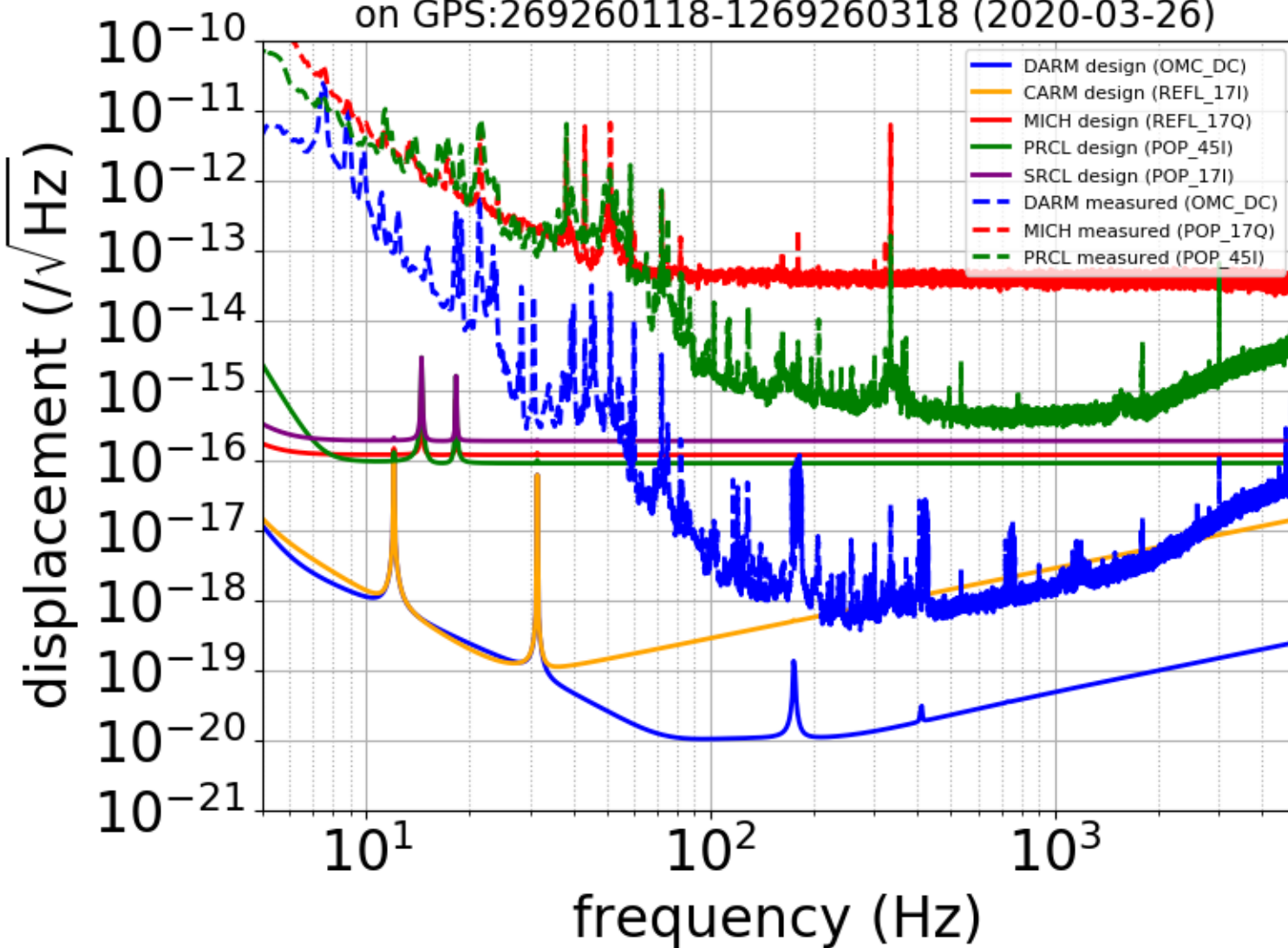
Displacement Sensitivity Summary



NOTE: frequency noise and intensity noise not considered for CARM

Mar 26, 2020 Sensitivity

Designed vs measured sensitivity
on GPS:269260118-1269260318 (2020-03-26)



MICH and PRCL calibrated offline (see [klog #14556](#))