JGW-T1910352

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On the effect of arm cavity finesse asymmetry to O3 sensitivity

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Background

- Transmission measured to be
  ITMX: 0.444 % ITMY: 0.479% (JGW-T1809173)
- So the asymmetry was 0.076 although MIF requirement was 2*|(T1-T2)/(T1+T2)| < 0.01 (wiki)
- Arm cavity finesse recently measured to be
  Xarm 1440(10) at cryo 1411(2) at room temp.
  klog 9215, 9156, 9097, 9052, 9033, 9014, 8999 and 7307
  Yarm 1300(20) at cryo
  klog 9211, 9169, 9052, 9047, 9040, 9023, 9014, 8995

- ITMs also have inhomogeneity issues as studied in, for example, JGW-G1909955

Finesse and ITM transmission

- Xarm 1440(10) [1411(2)]means
  ITMX transmission + losses = 0.436(3) % [0.445(1) %]
  0.444 % according to JGW-T1809173
- Yarm 1300(20) means
  ITMY transmission + losses = 0.483(7) %
  0.479 % according to JGW-T1809173

- Yarm sounds reasonable but Xarm finesse seems to be too high
  - could be due to finesse measurement at cryogenic temperatures
  - could be due to some systematic errors

Effects of Finesse Asymmetry

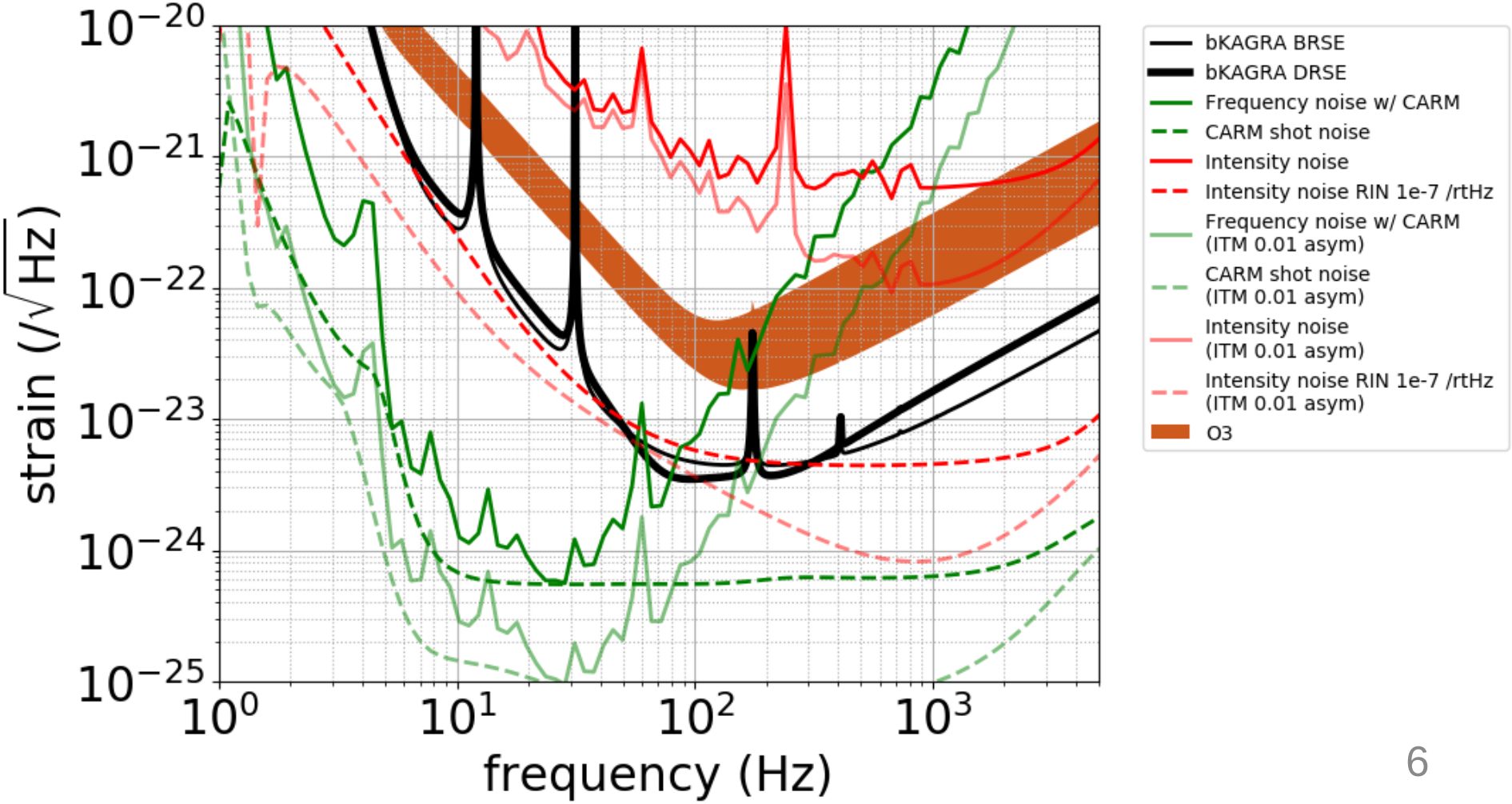
- Larger laser frequency noise
- Larger laser intensity noise
- These effects are presented below

- Note that these effects will be even larger with ITM inhomogeneity
- With ITM inhomogeneity, shot noise will be worse due to larger HOMs but the effect would be small (~14 % increase according to JGW-G1909955)

Method for Calculations

- Simulate frequency/intensity noise coupling with Optickle (JGW-T1910341)
  - Note that it gives transfer function from laser frequency noise without CARM suppression to strain sensitivity (CARM openloop gain assumed)
  - Used power at BS 10 W, ITMX 0.44% ITMY 0.479 % case (ITMX 0.44% ITMY 0.4445% as comparison)
- Multiply the coupling factor to frequency noise and intensity noise of IMC transmitted beam
  - frequency noise: 1 Hz/rtHz @ 100 Hz (klog #9291)
  - intensity noise: 2e-5 /rtHz @ 100 Hz without intensity stabilization (klog #9259)

Result

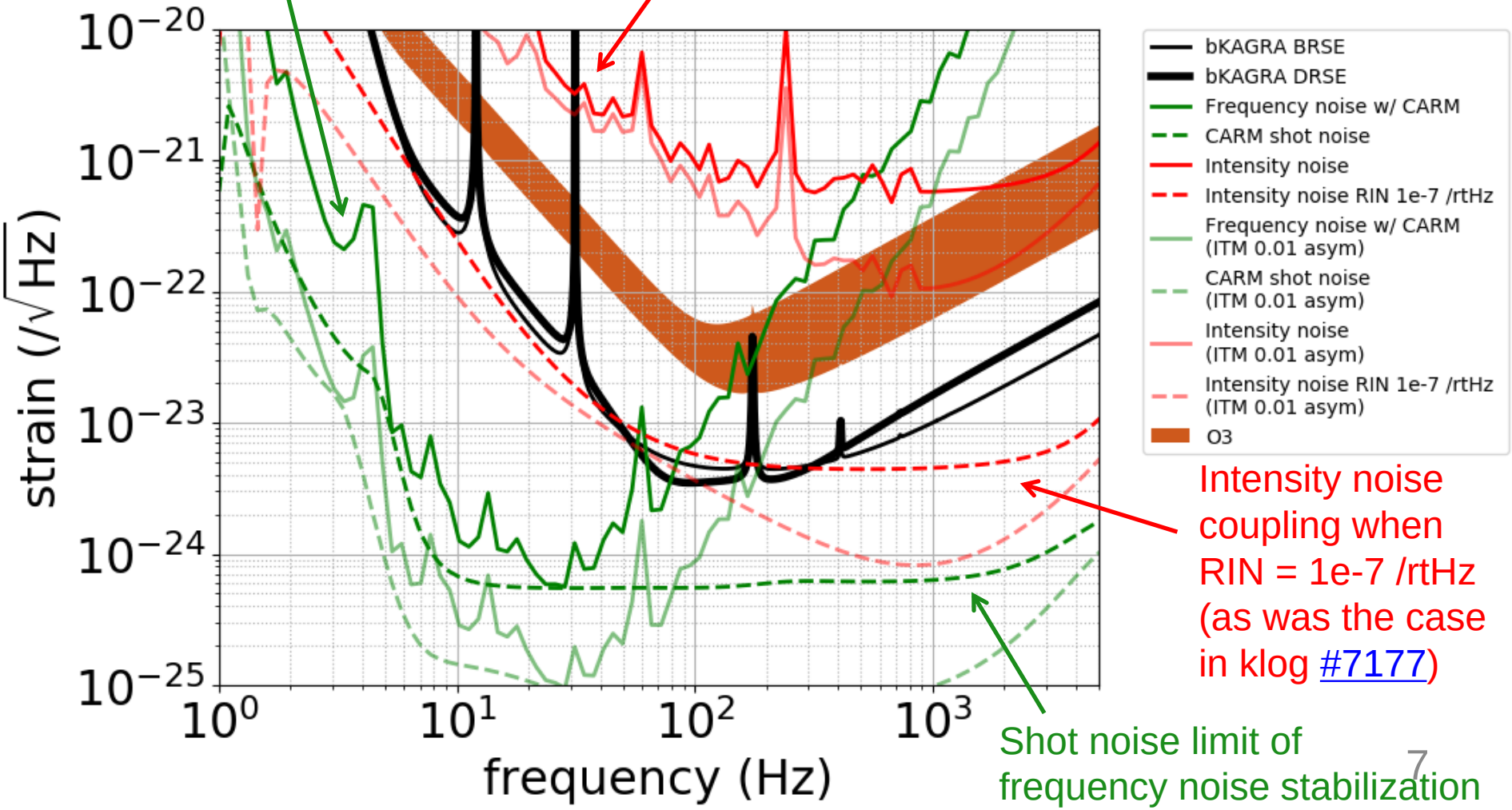

strain ($/\sqrt{\mathrm{Hz}}$)
10^{-20}
10^{-21}
10^{-22}
10^{-23}
10^{-24}
10^{-25}
10^{0}
10^{1}
10^{2}
10^{3}
frequency (Hz)
bKAGRA BRSE
bKAGRA DRSE
Frequency noise w/ CARM
CARM shot noise
Intensity noise
Intensity noise RIN 1e-7 /rtHz
Frequency noise w/ CARM (ITM 0.01 asym)
CARM shot noise (ITM 0.01 asym)
Intensity noise (ITM 0.01 asym)
Intensity noise RIN 1e-7 /rtHz (ITM 0.01 asym)
O3

Result

Frequency noise coupling estimated with current measured frequency noise; CARM loop turned on (could be limited by measurement noise at high frequencies)

Intensity noise coupling estimated with current measured intensity noise (stabilization servo not on yet)

Dim lines represent same curves when ITM transmission asymmetry was 0.01



Intensity noise coupling when RIN = 1e-7 /rtHz (as was the case in klog #7177)

Shot noise limit of frequency noise stabilization

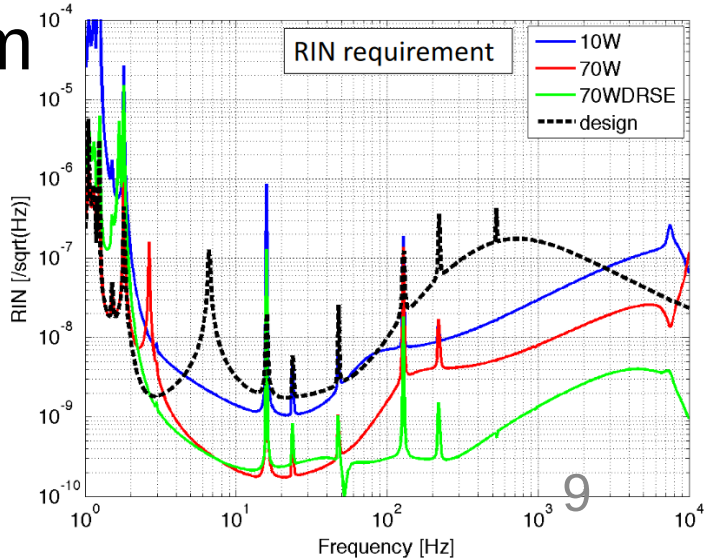
Implications for O3

- Current frequency noise and intensity noise do not meet the requirement
- The situation don’t change much even if ITM transmission asymmetry was 0.01
- As for the frequency noise, we should identify the noise at high frequencies
- As for the intensity noise, we should wait for intensity stabilization result. If relative intensity noise reaches 1e-7 /rtHz, intensity noise won’t be a problem.

Implications for O4 (designed sensitivity)

- Frequency noise seem to be OK with ITM transmission asymmetry if frequency stabilization servo work fine (if frequency noise reach CARM shot noise limit)
- But frequency noise is probably not OK considering ITM inhomogeneity (requirement will be an order of magnitude tougher at ~kHz)
- Intensity noise will be a problem since RIN requirement will be ~2e-10 /rtHz @ 10 Hz (with safety factor of 10)

JGW-T1707565



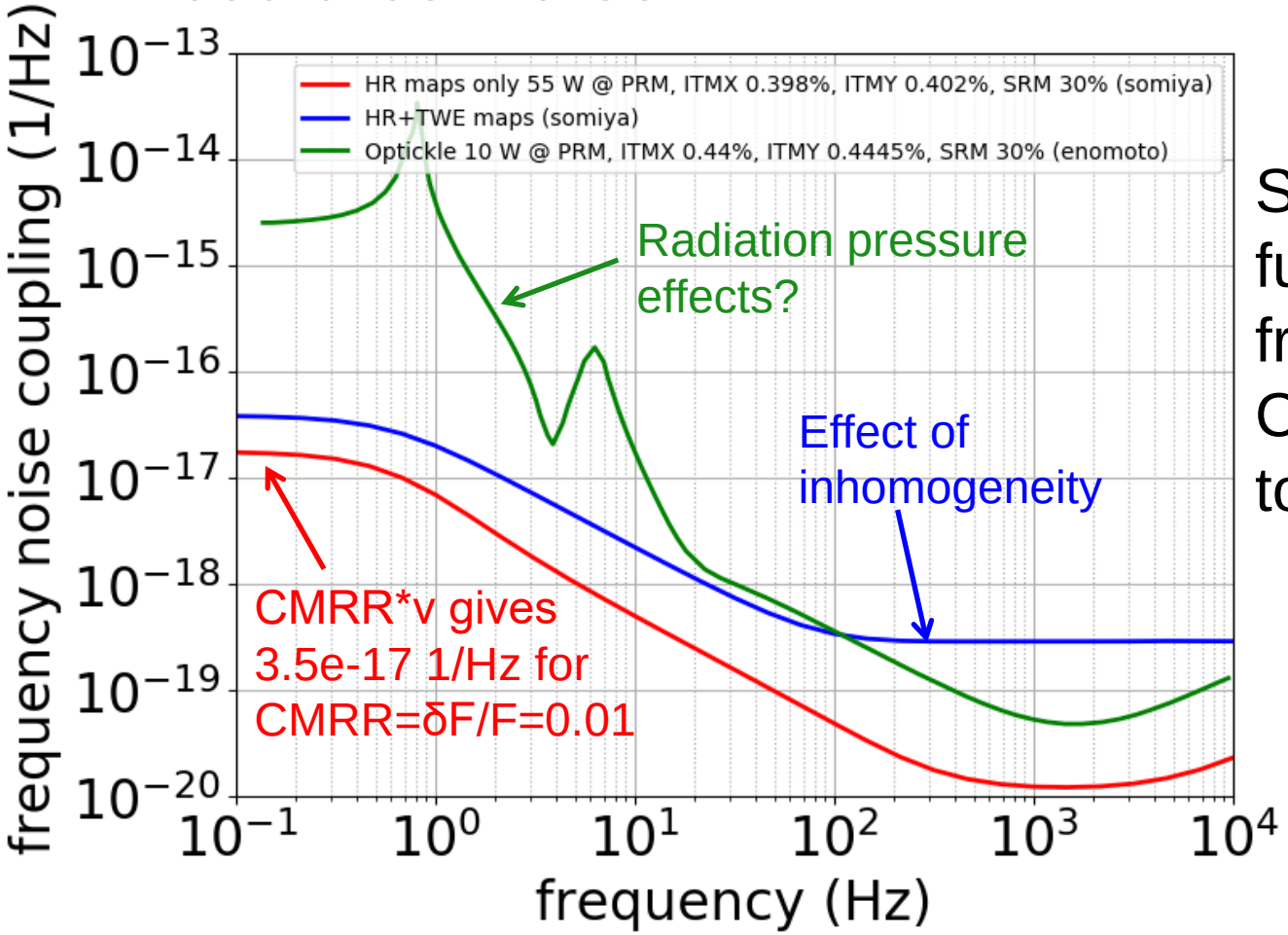
Conclusions

- Measured arm cavity finesse asymmetry can be basically explained by ITM transmission asymmetry but we cannot say that ITM transmission asymmetry is the only reason
- We cannot say much if current finesse asymmetry is acceptable for O3 or not since frequency noise and intensity noise is bad at this moment.
- Frequency noise do not meet the O3 requirement at high frequencies. We should identify the noise at high frequencies and try to reduce it.
- Intensity noise without stabilization do not meet the O3 requirement. We need to wait for the stabilization result.
- This finesse asymmetry and ITM inhomogeneity will likely to be an issue for achieving the design sensitivity.

Some More Details

Optickle vs FINESSE

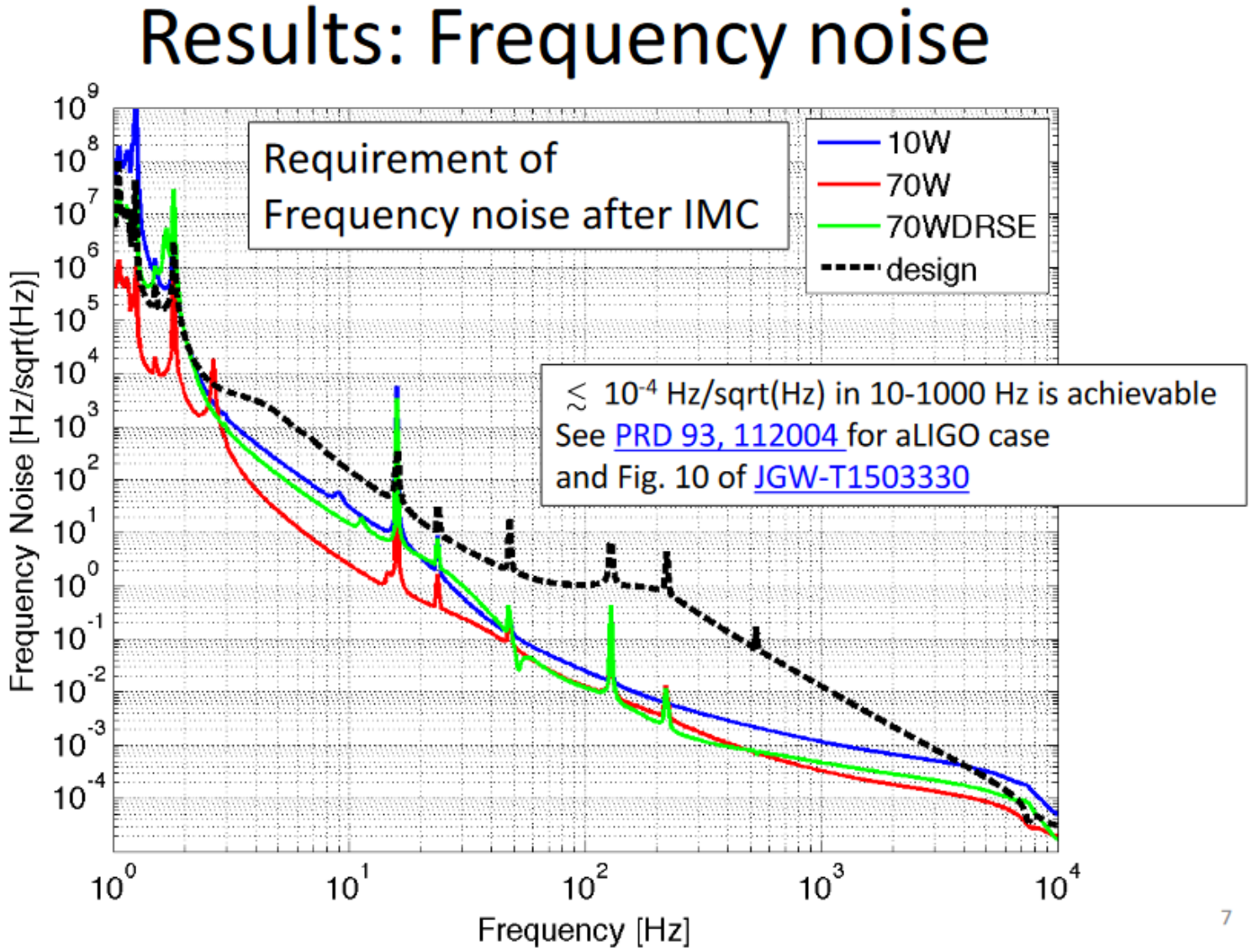
- Optickle calculation do not include ITM HR maps and inhomogeneity; Frequency noise coupling could be worse



Simulated transfer functions from frequency noise with CARM suppression to strain sensitivity

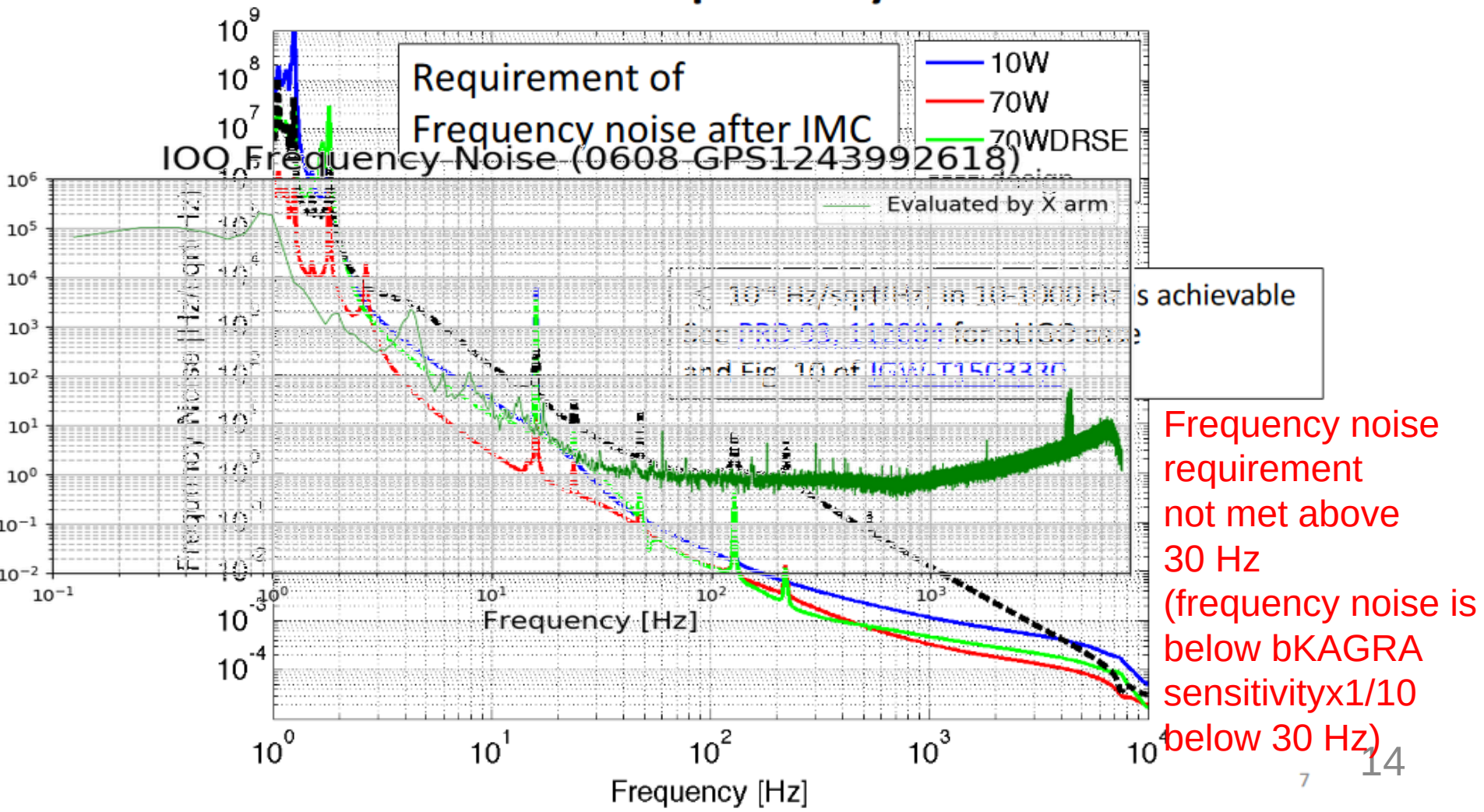
Frequency Noise Requirements

- See JGW-T1707565 (ITM 0.4% and 0.5%, SRM 30%)



Frequency Noise Requirements

- Compared with measurements (klog #9256)



Frequency noise requirement not met above 30 Hz (frequency noise is below bKAGRA sensitivityx1/10 below 30 Hz)