JGW-G2012212
LVK Operations Meeting
November 5, 2020

Status of KAGRA: Expectations for O4 Sensitivity

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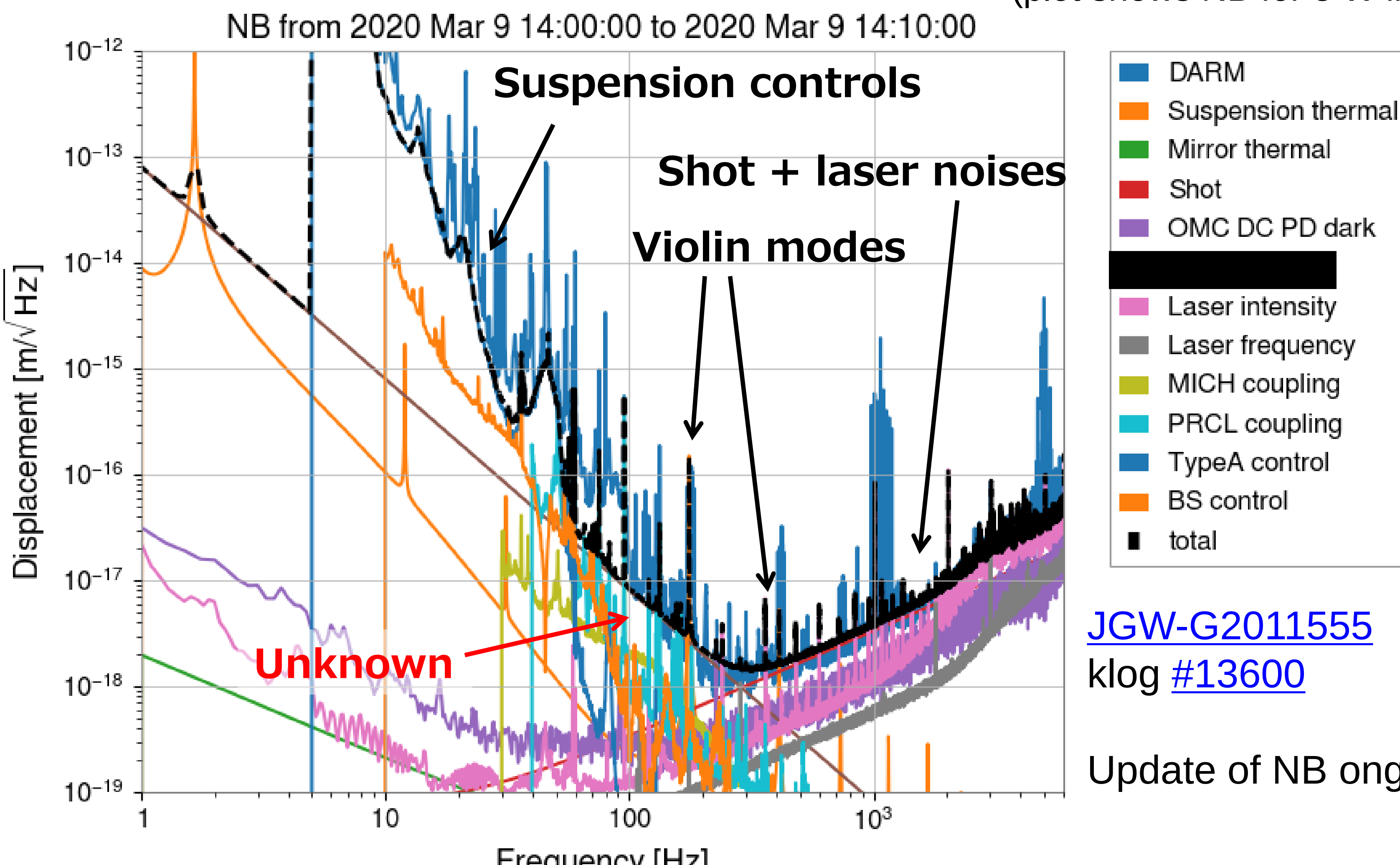
O3 Noise Budget

- ~250 K, PRFPMI, T=30% SRM tilted, DC readout, 3-5 W input

O3 best with 6.6 W input
(plot shows NB for 3 W input)

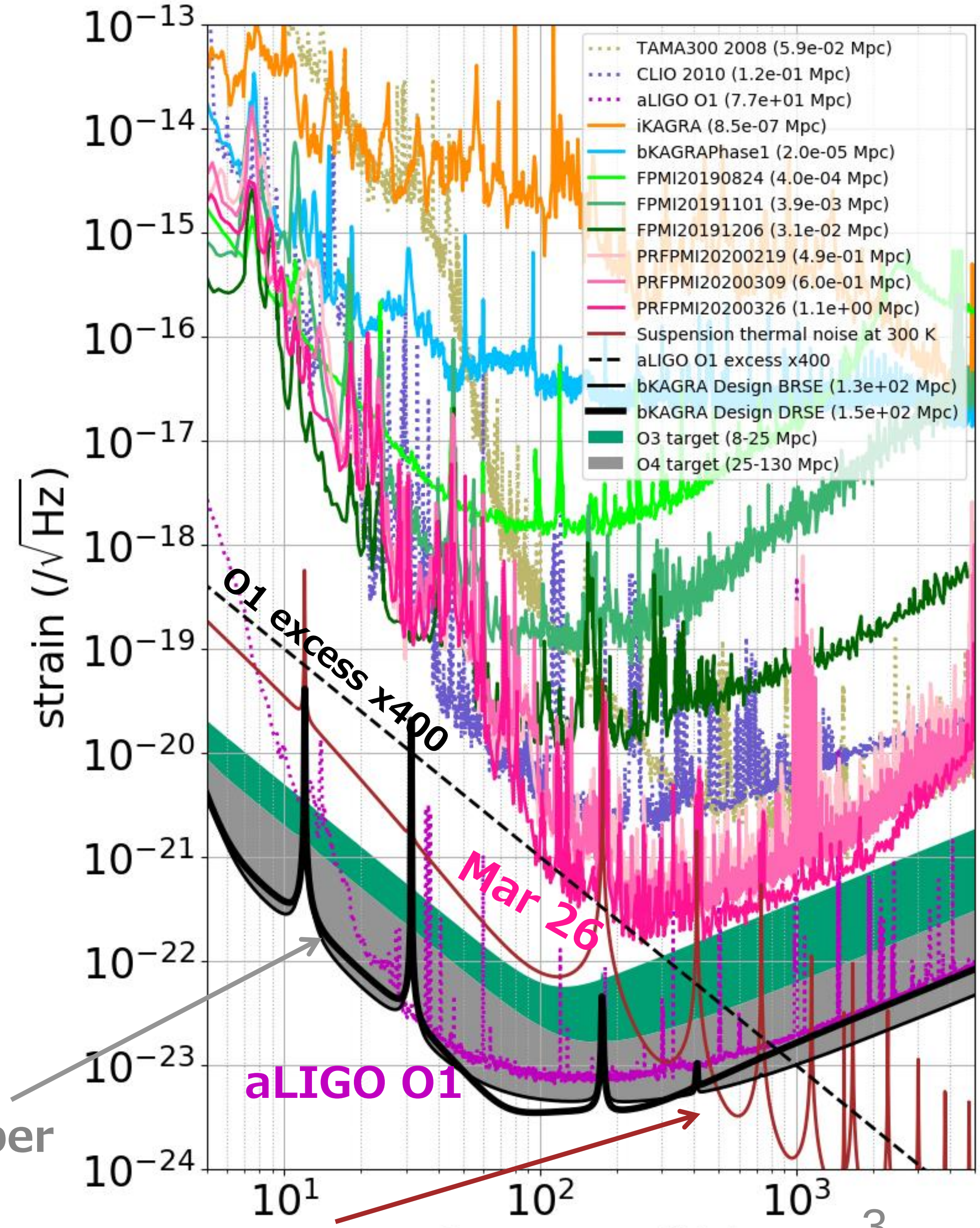


JGW-G2011555
klog #13600

Update of NB ongoing

O4 Target

- Currently ~1 Mpc at best
- Original O4 target was 25-130 Mpc



O4 target on Obs. Scenario Paper 25-130 Mpc by ~2021

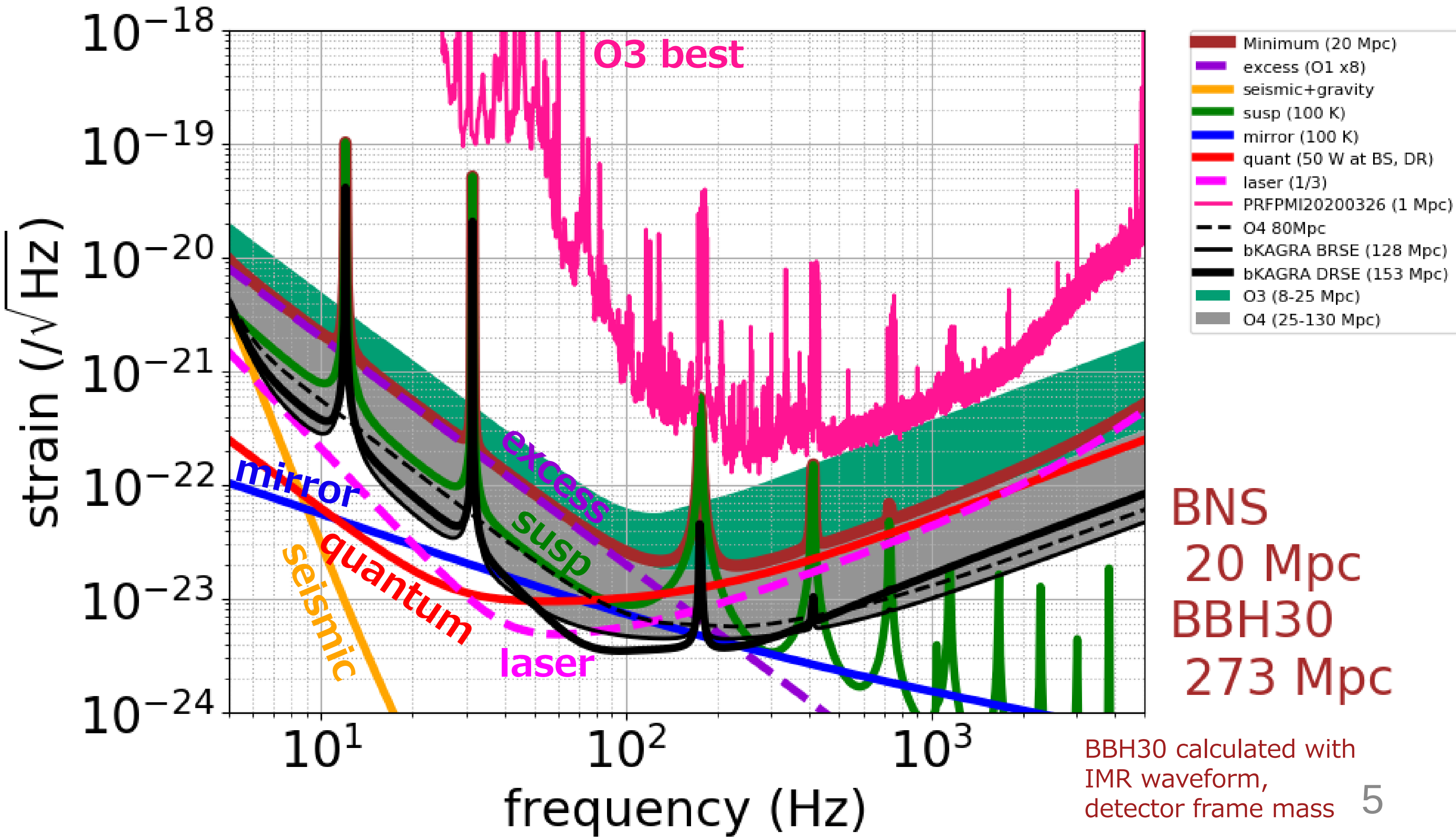
300 K suspension thermal

O4 Considerations

- Temperature ?
  - At least below 100 K required to achieve 25 Mpc (JGW-T2011662)
  - ~40 K seems to be optimum considering the balance between the absorption from the input power and thermal noise (JGW-G2011756)
  - Mirror frosting observed below ~30 K (arXiv:2005.05574)
- PRFPMI or DRFPMI ?
  - lock of DRFPMI not achieved yet, but close (JGW-G201206)
- Input power ?
  - not very critical at this stage (JGW-T2011662)
  - 300 W at BS feasible from laser preparations and TM cooling
- Laser frequency and intensity noise ?
  - coupling larger than expected due to ITM inhomogeneity (JGW-T2011662)
- Unknown excess noise ?
  - At least a reduction by a factor of 50 necessary to achieve 25 Mpc (JGW-T2011662)

O4 “Minimum” Example

- 1/40 excess, 100 K, 50 W at BS, DR, 1/3 laser noise

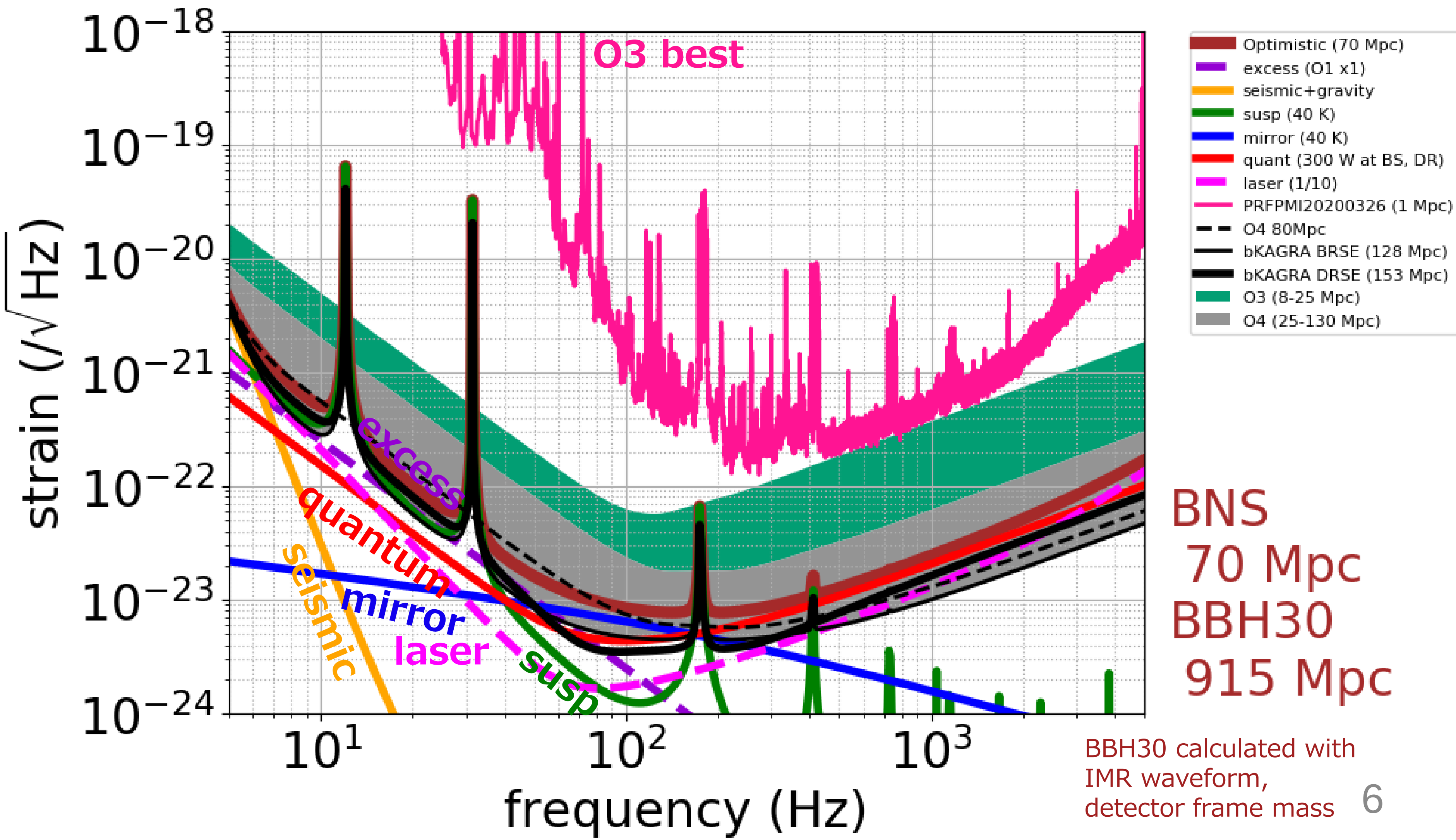


BNS
20 Mpc
BBH30
273 Mpc

BBH30 calculated with IMR waveform, detector frame mass

O4 “Optimistic” Example

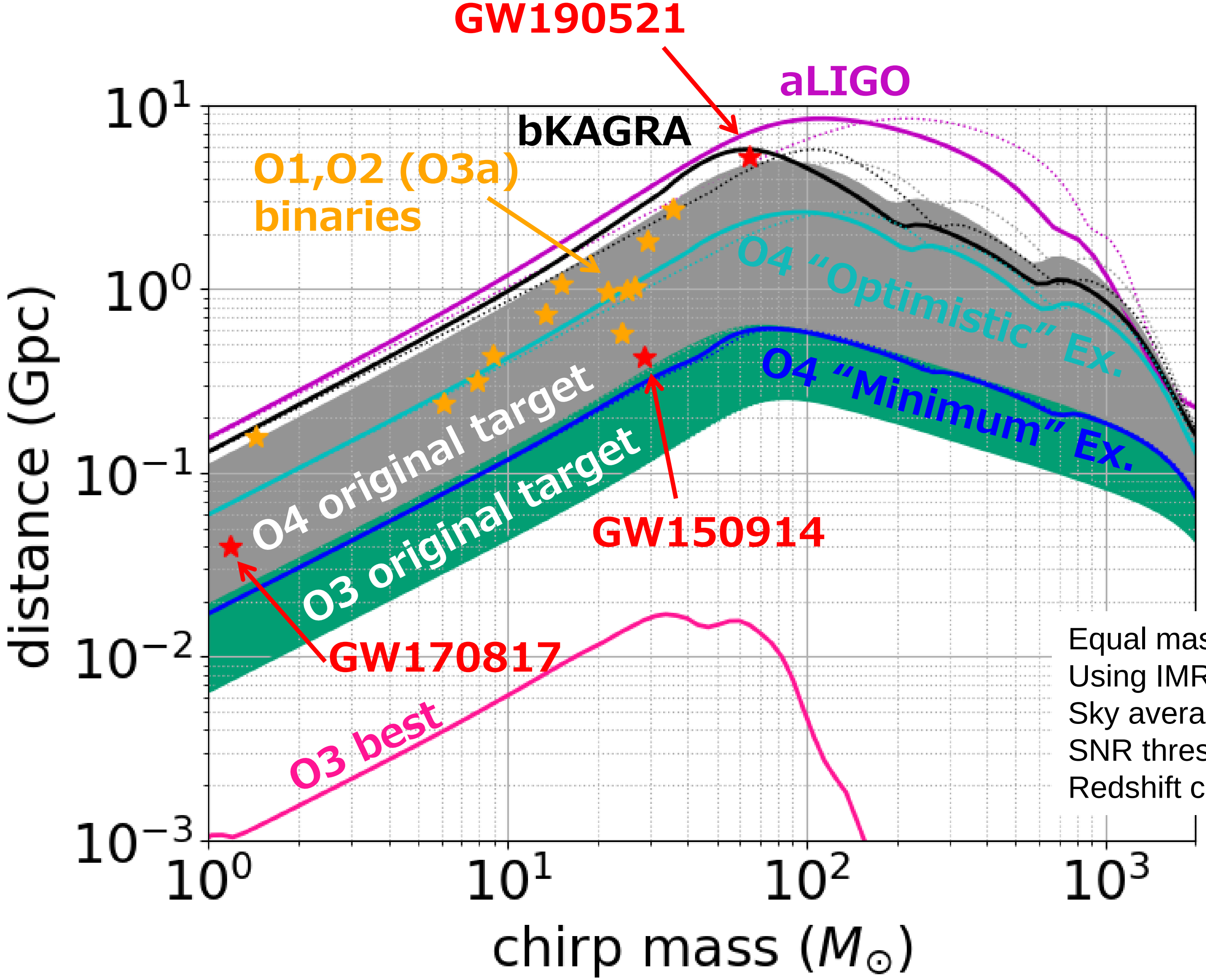
- 1/40 excess, 40 K, 300 W at BS, DR, 1/10 laser noise



BNS
70 Mpc
BBH30
915 Mpc

BBH30 calculated with IMR waveform, detector frame mass

Inspiral Range



Equal mass binary of spin 0.5-0.5
Using IMR waveform
Sky averaged (0.442)
SNR threshold 8
Redshift corrected

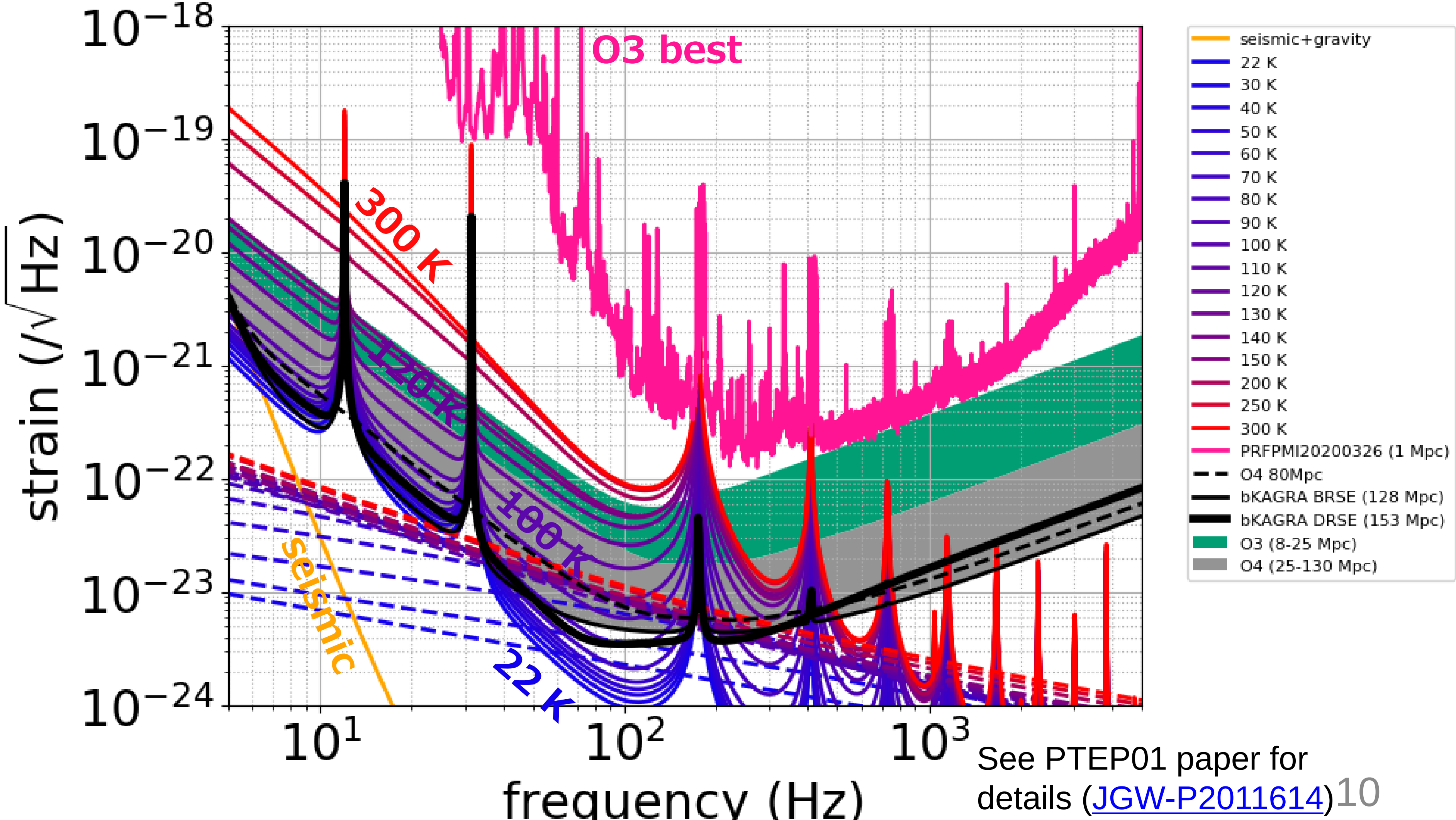
Summary

- Still hard to predict the O4 sensitivity, but we are aiming for 25 Mpc with test mass temperature below ~100 K
- Will be ~70 Mpc even in the optimistic case due to
  - larger laser noise coupling
    from ITM inhomogeneity
  - larger test mass temperature
    from larger thermal resistance (and frosting)

Details

Various Thermal Noise

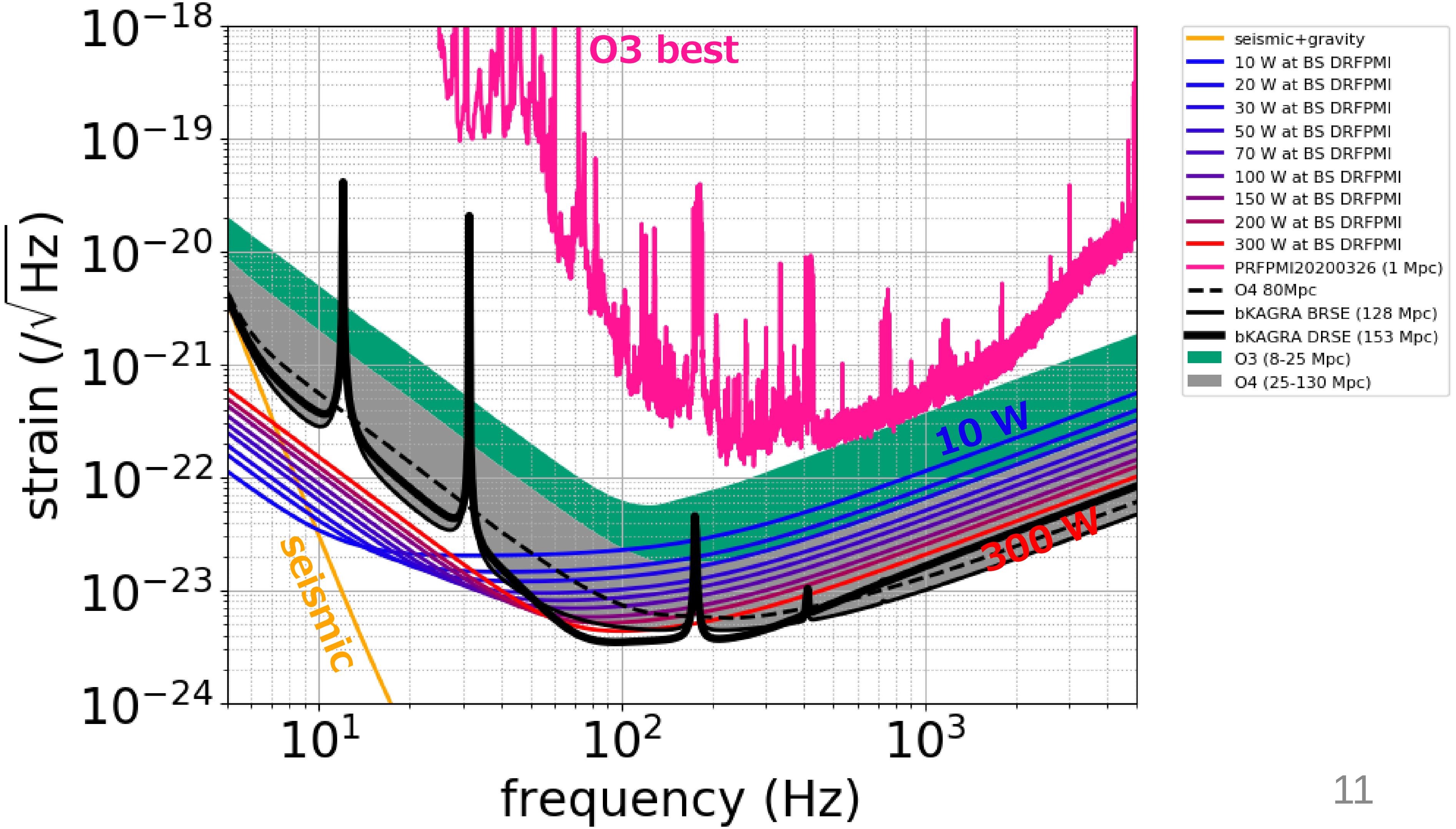
- All temperatures



See PTEP01 paper for details (JGW-P2011614)

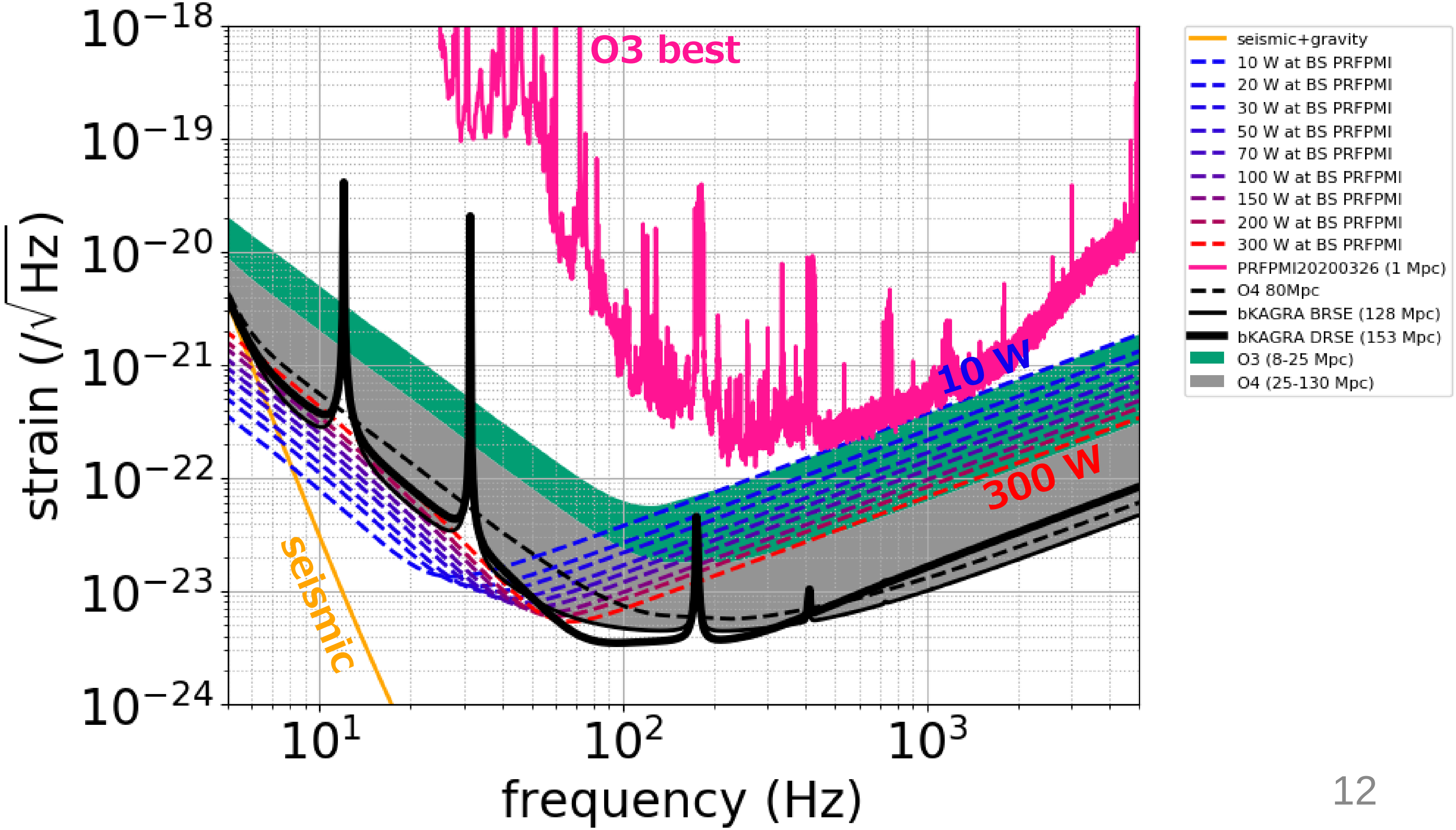
Various Quantum Noise (DR)

- All powers



Various Quantum Noise (PR)

- All powers

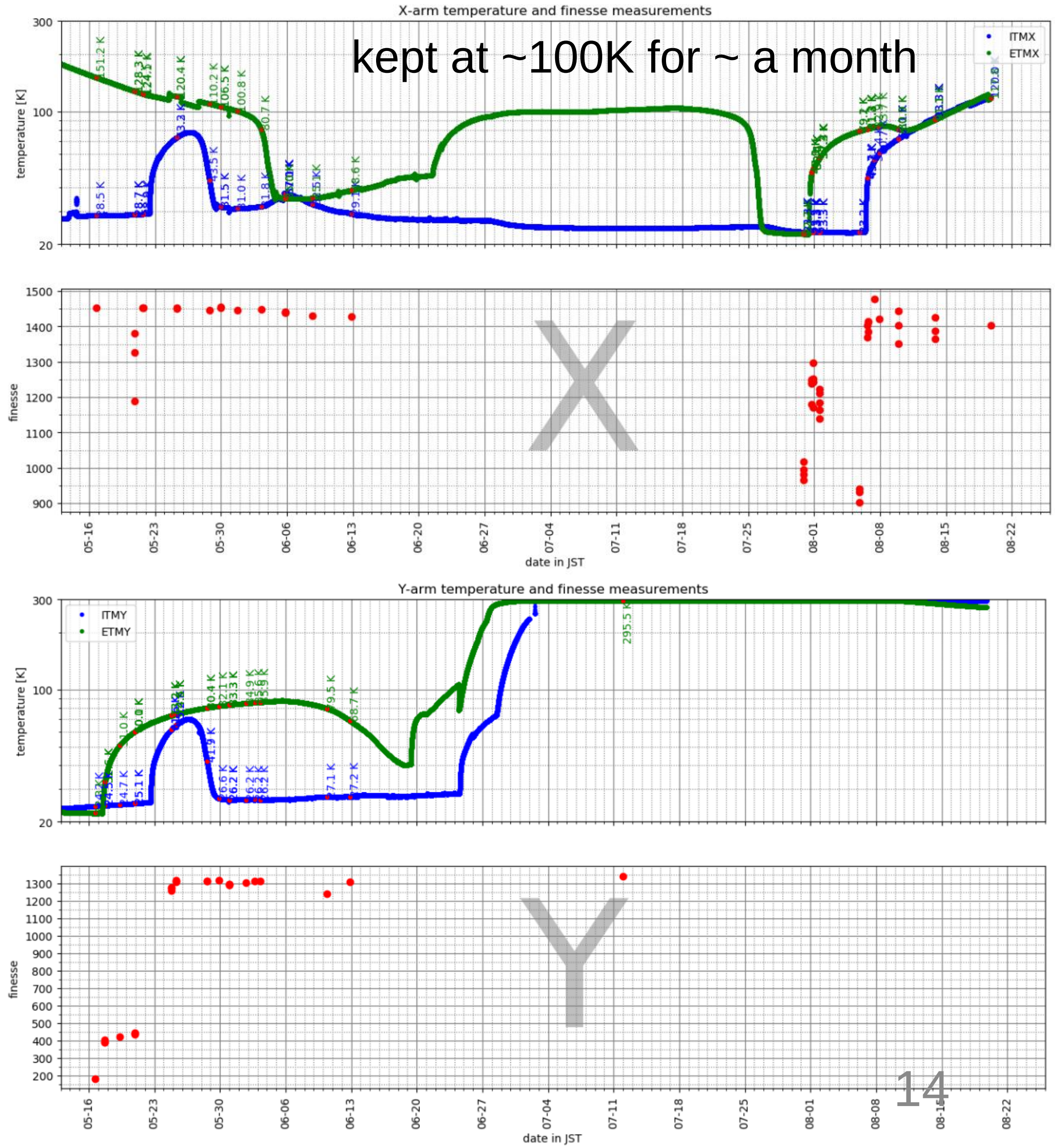


How to Realize 100 K ?

- **Possible cooling process?**
  - First cool the test mass with four cryocooler
  - When reached below ~100 K, turn off two cryocoolers for cryopayload (shields have to be kept cooled); as we have done in July 2019, we can keep the temperature at ~100 K (klog #10033)
  - Turn on two cryocoolers occasionally to keep the temperature ~100 K
- **Maximum input power?**
  - Thermal lensing: At 100 K, thermal lensing is smaller by 1/100~1/300 than 300 K, but larger by 4 orders of magnitude than 20 K. Thermal lensing would be OK below ~130 K (See JPCS 32, 062 (2006)).
  - Cooling power (with 4 cryocoolers): 67 K can be achievable with 0.8 W heat load to the test mass, with current thermal resistance of 70 K/W (according to JGW-G1910569). <300 W at BS would be OK.
  - Cooling power (with 2 cryocoolers): According to the cooling curve from bKAGRA Phase 1 (7 K/day at around 100 K), 0.2 W heat load makes the mirror temperature at steady state (around 100 K, thermal conductivity of sapphire fibers are low). Absorption from light will be ~0.001*P_{BS} where P_{BS} is the power at BS. Therefore, P_{BS}=200 W is good to keep ~100 K.

Frosting of the Test Mass

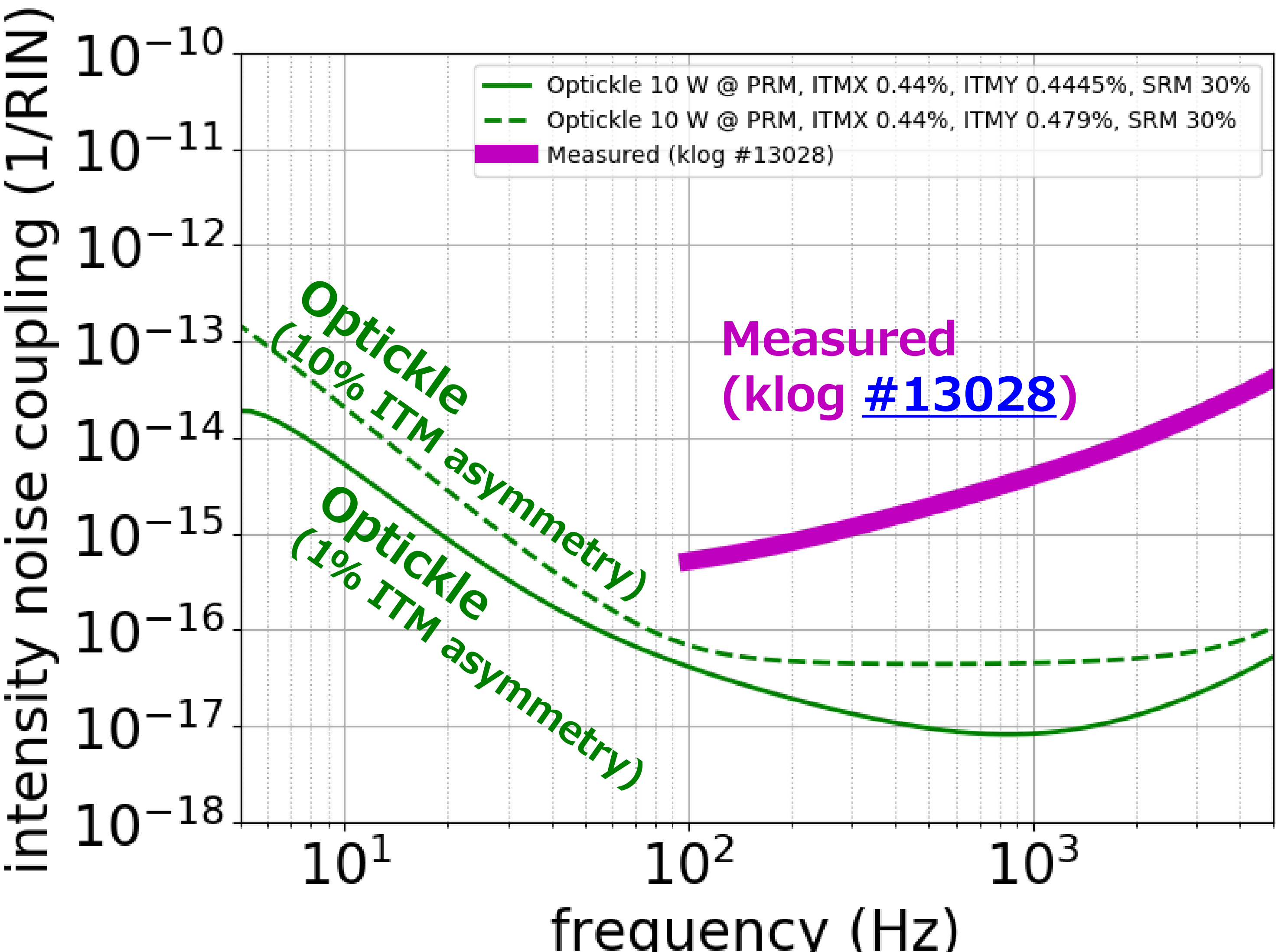
- Finesse drop observed when one of the test mass temperature is below ~30 K



klog [#10033](#10033)

Laser Intensity Noise Coupling

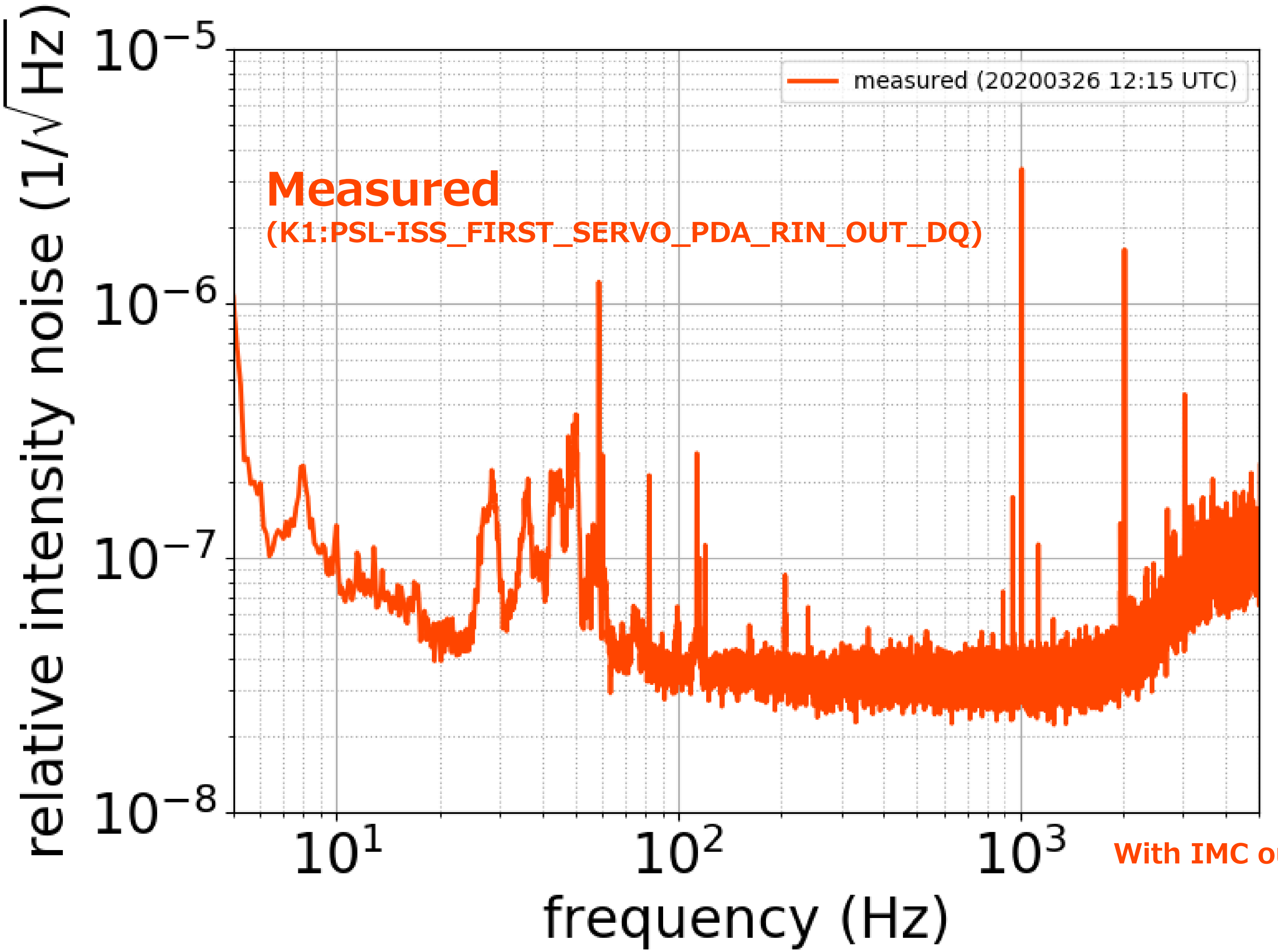
- Measured to be larger than Optickle model



HR, TWE maps and birefringence not included in Optickle model

Laser Intensity Noise

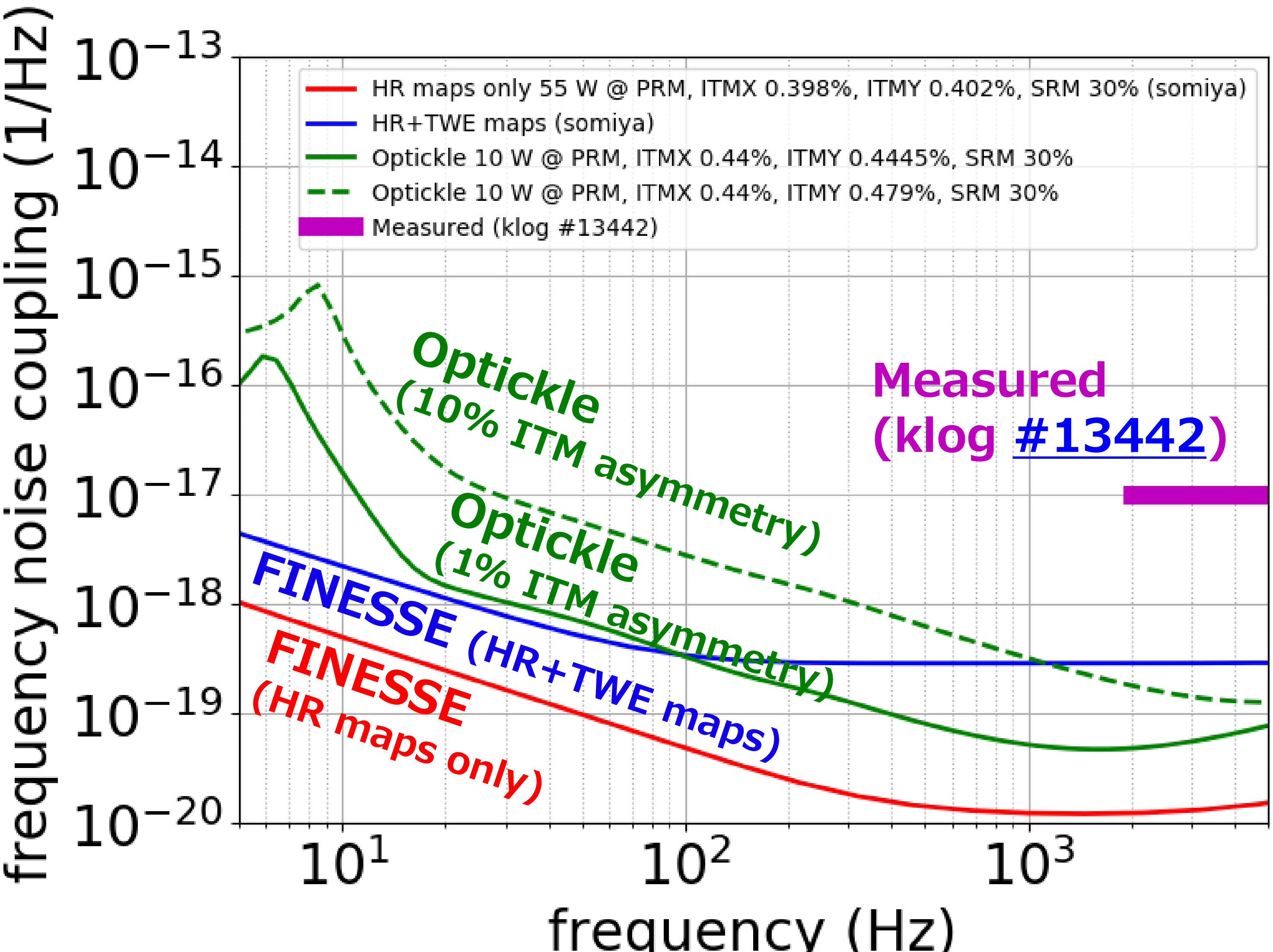
- RIN of 3e-8 /rtHz achieved. 1e-8 /rtHz possible in O4?



With IMC output power of ~6.7 W

Laser Frequency Noise Coupling

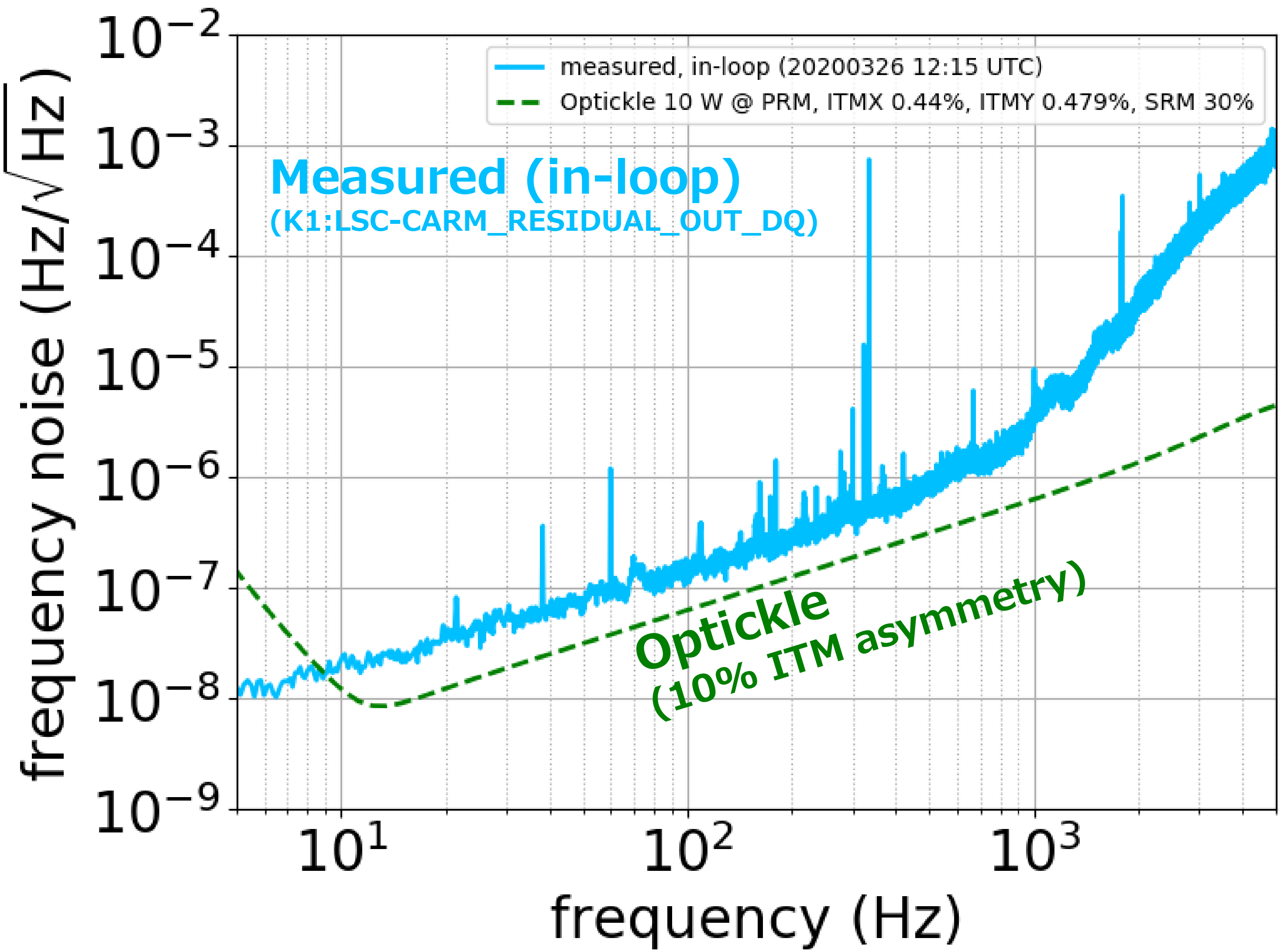
- Measured to be larger than various models



See, also JGW-T1910352

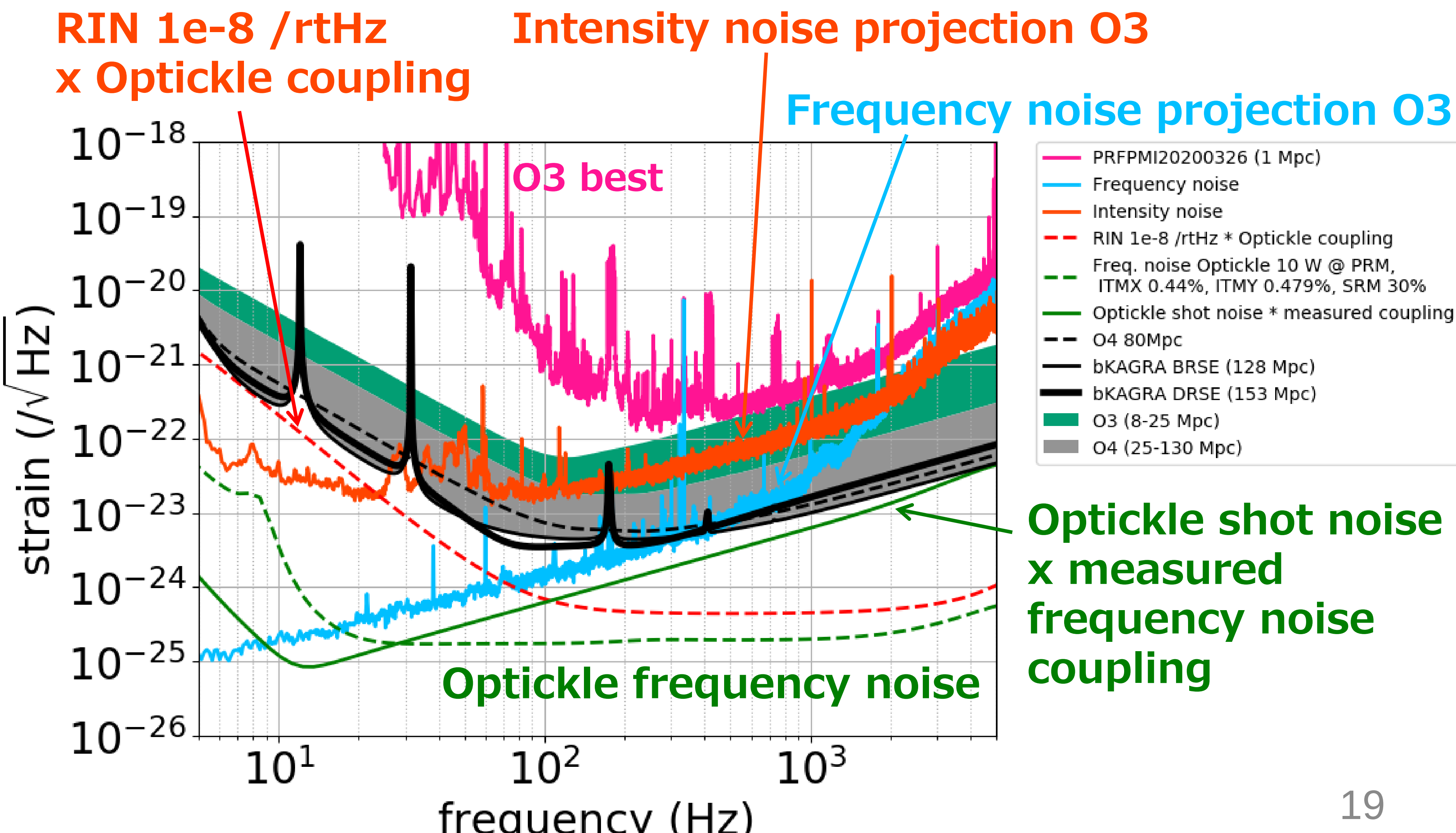
Laser Frequency Noise

- Close to CARM shot noise limit from Optickle



Laser Noise Projections

- Close to CARM shot noise limit from Optickle



Guessing Laser Noise in O4

- Pessimistic case: same as current level
- Optimistic case: RIN of 1e-8 /rtHz x Optickle coupling and CARM shot noise limited x measured coupling