

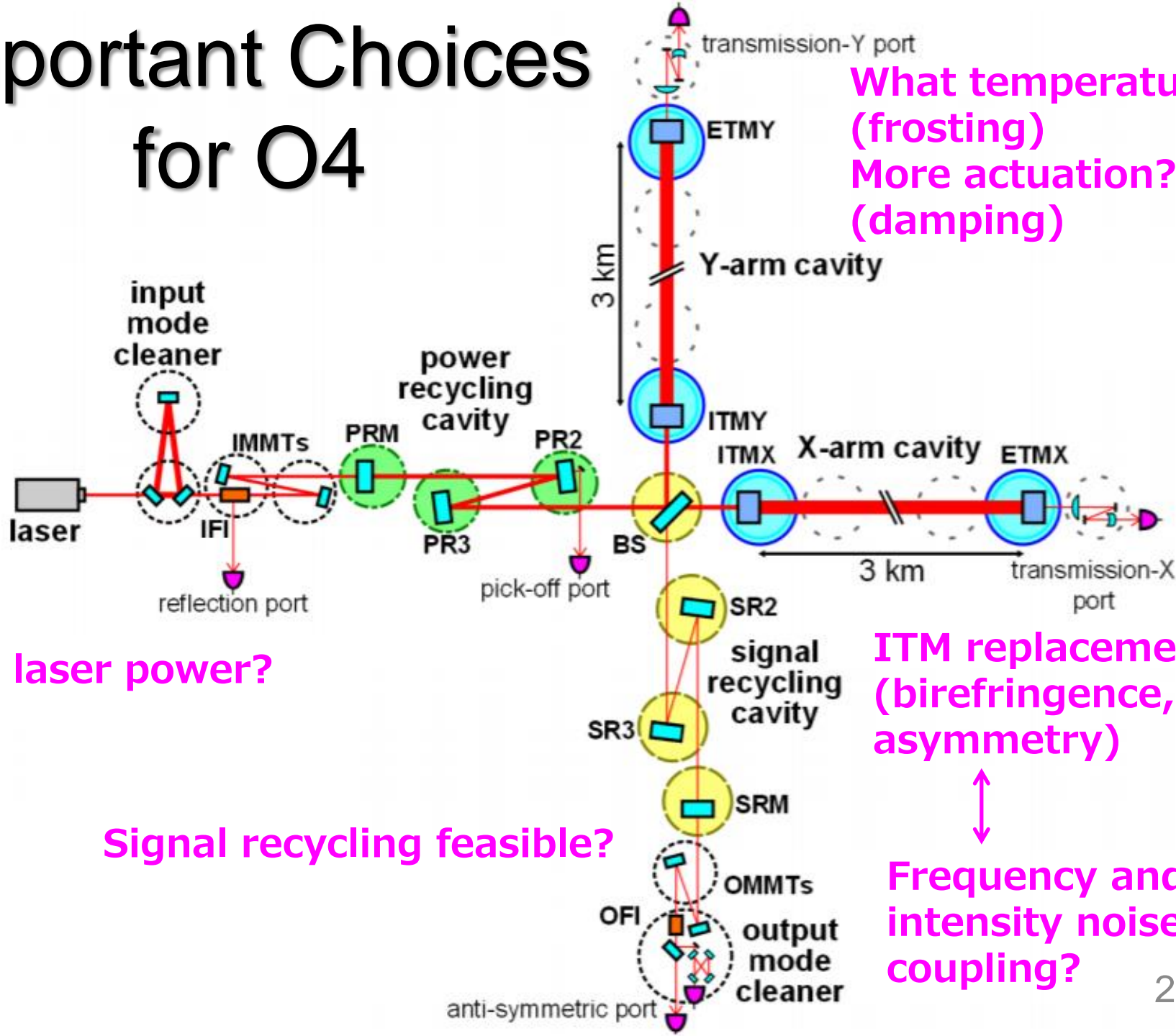
# Summary of Sensitivity Estimate for O4 in Various Interferometer Configurations

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# Important Choices for O4



What temperature?  
(frosting)  
More actuation?  
(damping)

What laser power?

Signal recycling feasible?

ITM replacement?  
(birefringence,  
asymmetry)

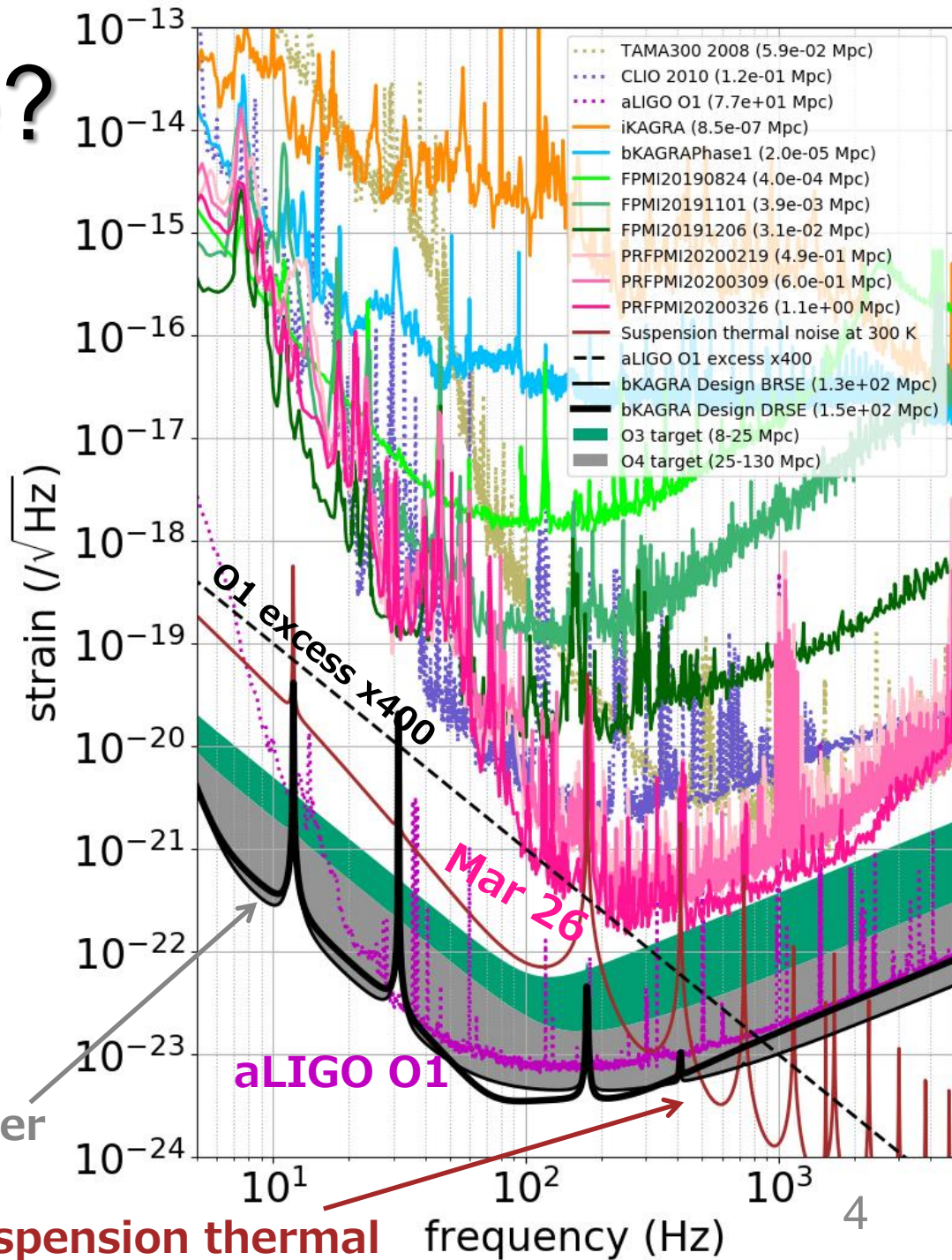
↕  
Frequency and  
intensity noise  
coupling?

# Assumptions for Estimation

- IFO configuration: PRFPMI with 0% SRM or DRFPMI with 70% SRM, upto 300 W at BS (no shot noise coupling considered)
- Temperature: 22 K to 300 K (heat extraction capability not considered); see [JGW-P2011614](#)
- Frequency and intensity noise: current level or estimated noise in [JGW-T1910352](#)
  - Assume ITMs are not replaced (see [JGW-G2011541](#))
- Actuator noise: Not significant for O4 if we do it right (see [JGW-T2011661](#))

# Where Are We?

- ~1 Mpc at best
- PRFPMI with 70% SRM tilted, 3-5 W to PRM, ~250 K, DC readout
- O1 excess x400
- Almost shot noise limited at high freq. (klog [#13475](#))



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

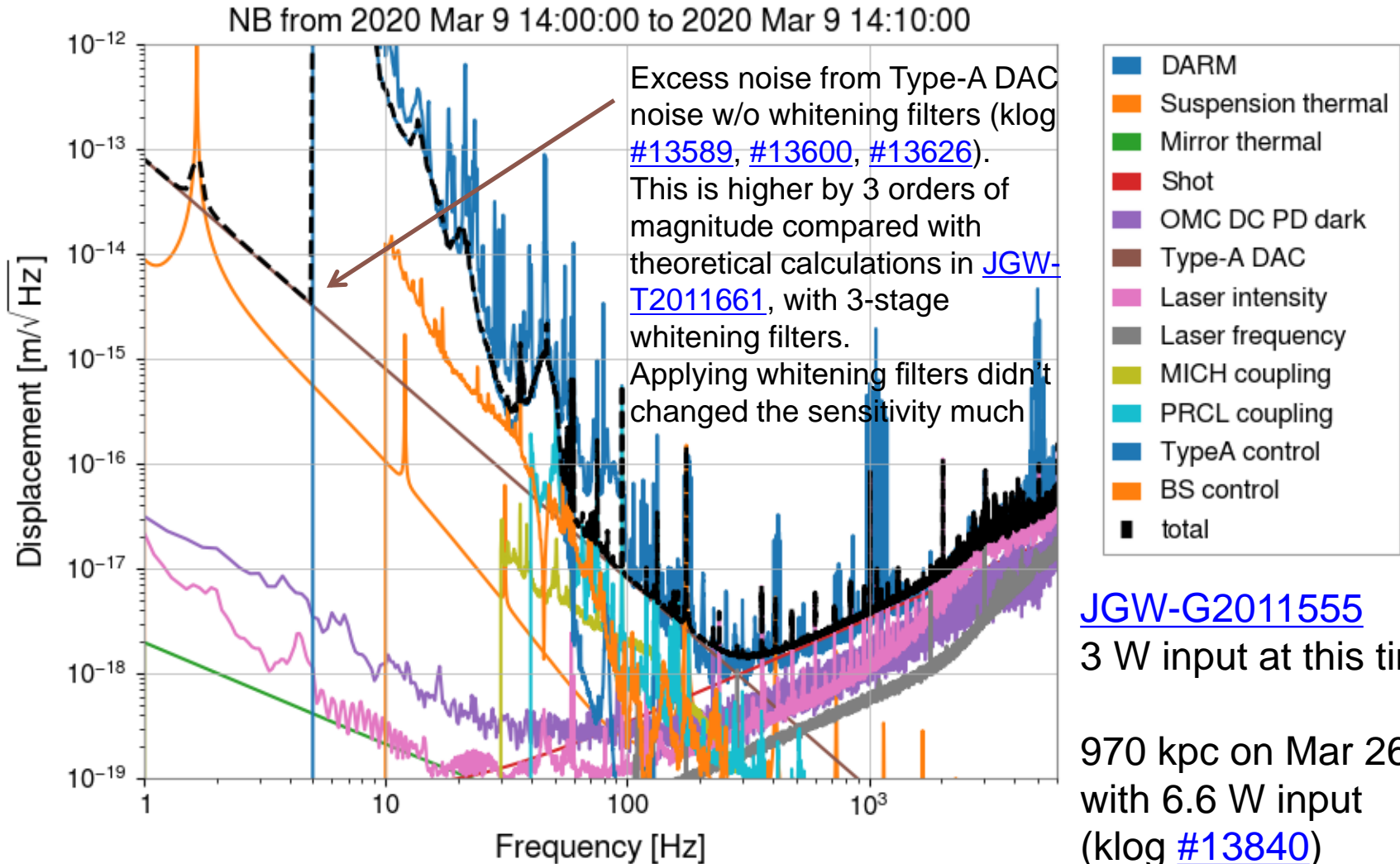
# O3 best and O4 Target

	Mirror temp.	Power at BS	SRM reflectivity	Detuning angle	Homodyne angle	Excess noise
<b>O3 best</b>	<b>~250 K</b>	<b>30-50 W</b>	<b>70% tilted</b>	<b>~90 deg (PRFPMI)</b>	<b>~90 deg (conventional)</b>	<b>O1 x 400</b>
O3 low	22 K	10 W	0 %	90 deg (PRFPMI)	90 deg (conventional)	O1 x 20
O3-15Mpc	22 K	10 W	70 %	90 deg	90 deg	O1 x12
O3 high / O4 low	22 K	33 W	70 %	90 deg (BRSE)	90 deg (conventional)	O1 x 8
<b>O4 80Mpc</b>	<b>22 K</b>	<b>404 W</b>	<b>85 %</b>	<b>90 deg</b>	<b>90 deg</b>	<b>O1 x 2</b>
O4 high	22 K	673 W	85 %	90 deg (BRSE)	90 deg (conventional)	no excess
Design	22 K	673 W	85 %	86.5 deg	135.1 deg	no excess

For details, see [JGW-T1809078](#)

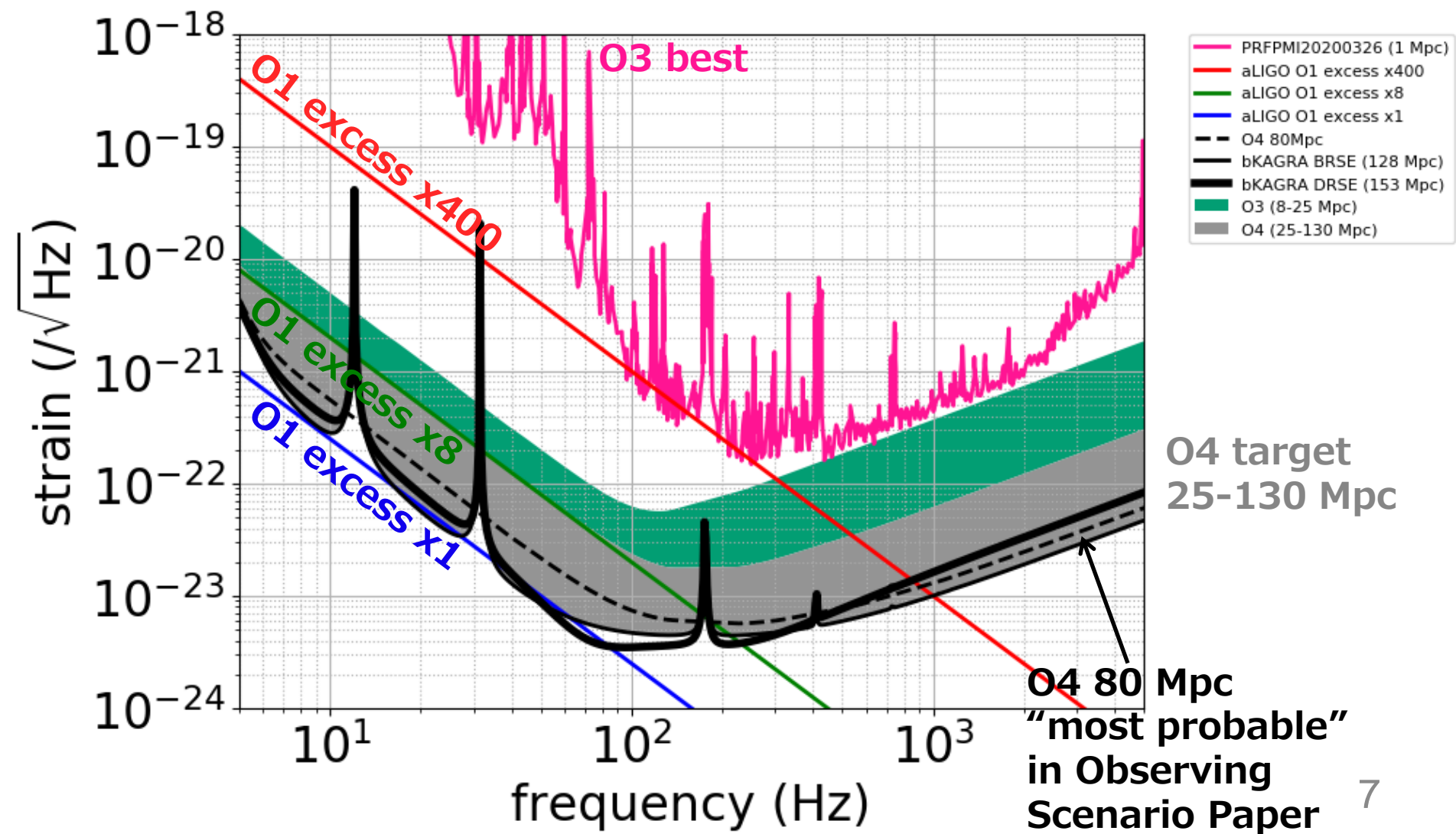
# Noise Budget (for 0.6 Mpc 20200309)

- Some excess noises at mid freq, shot noise at high freq



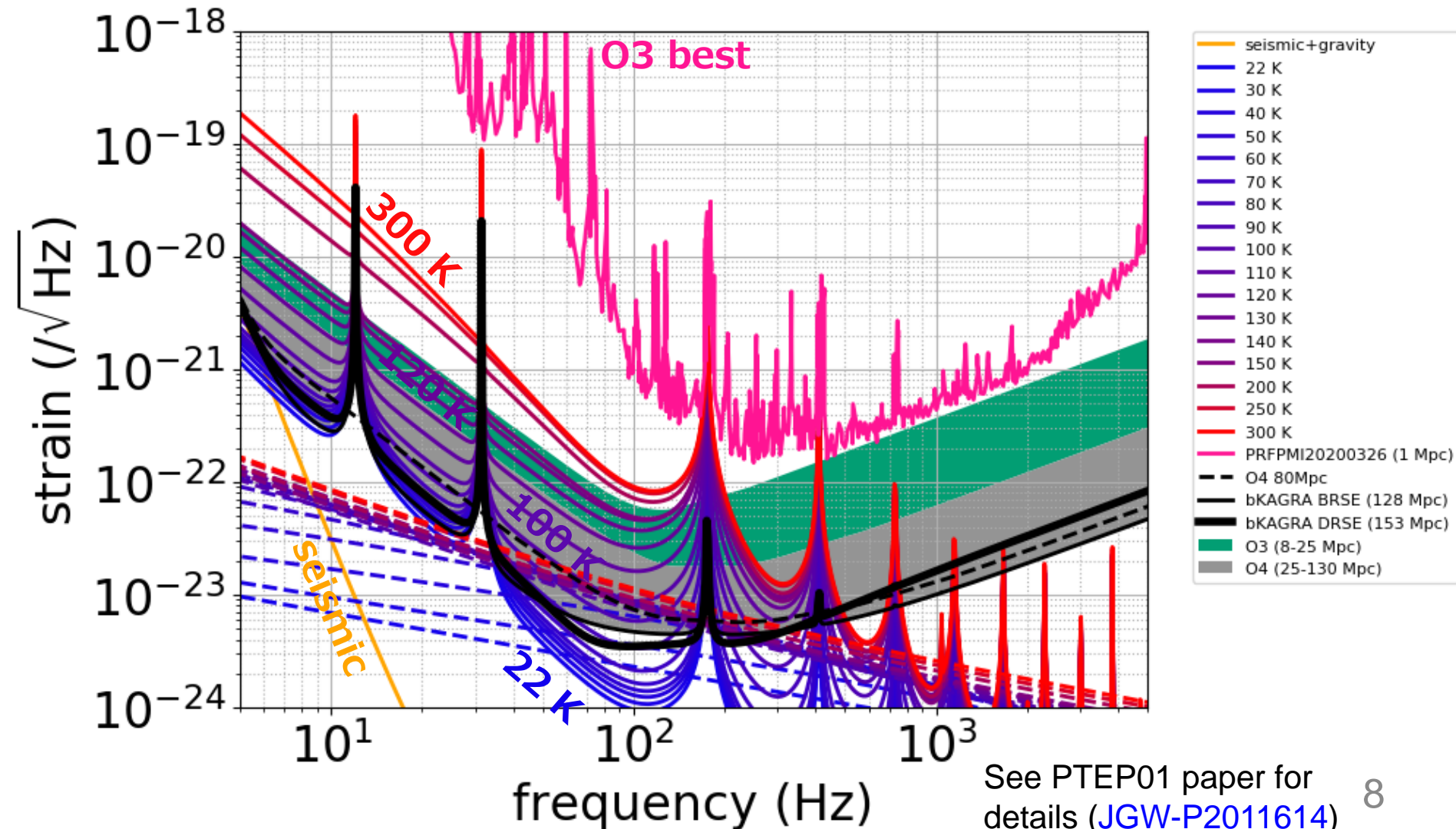
# O3 best and O4 Target

- Excess noise should be reduced by at least  $\sim 1/20$



# Various Thermal Noise

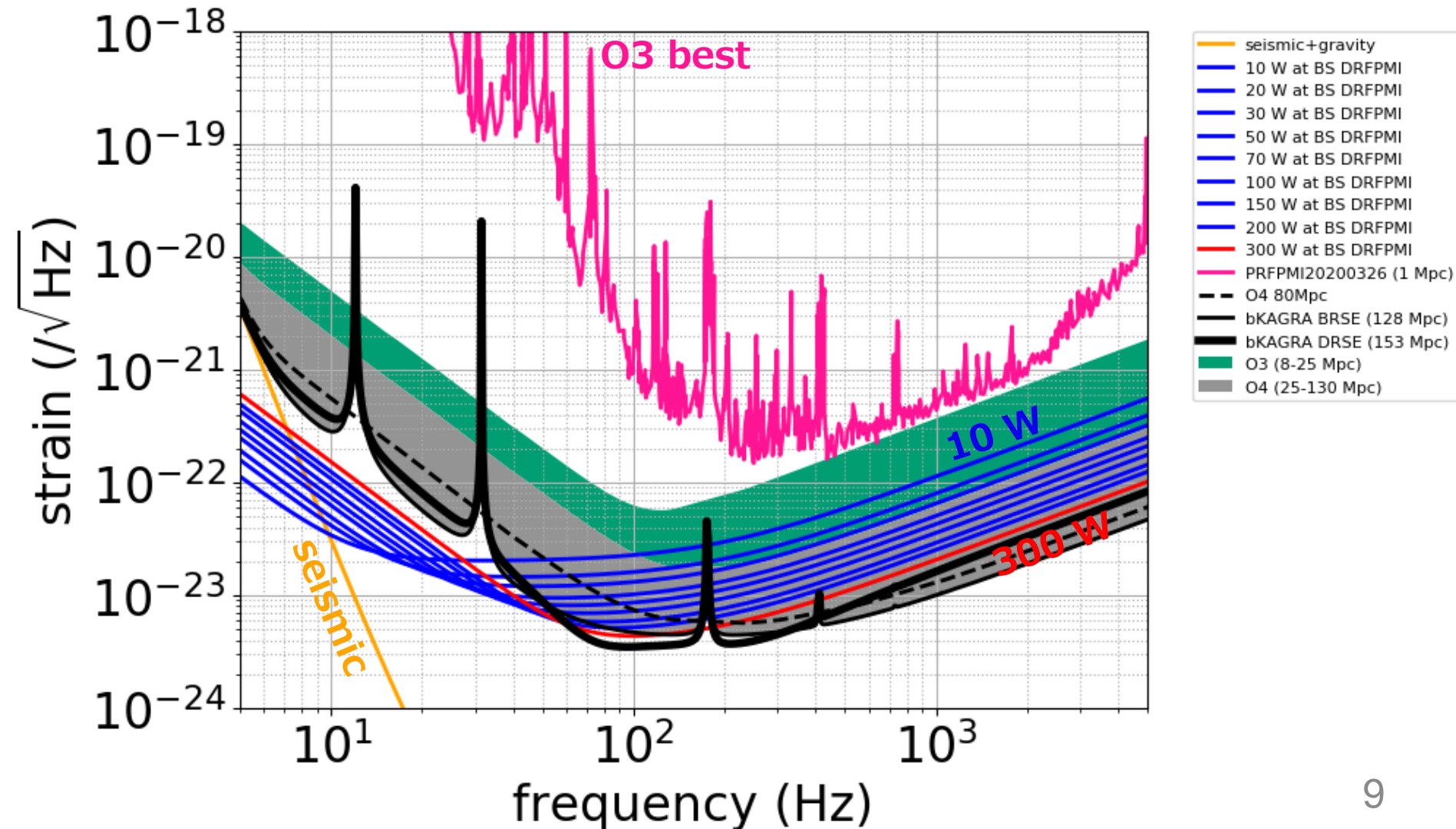
- 120 K thermal is comparable to x8 O1





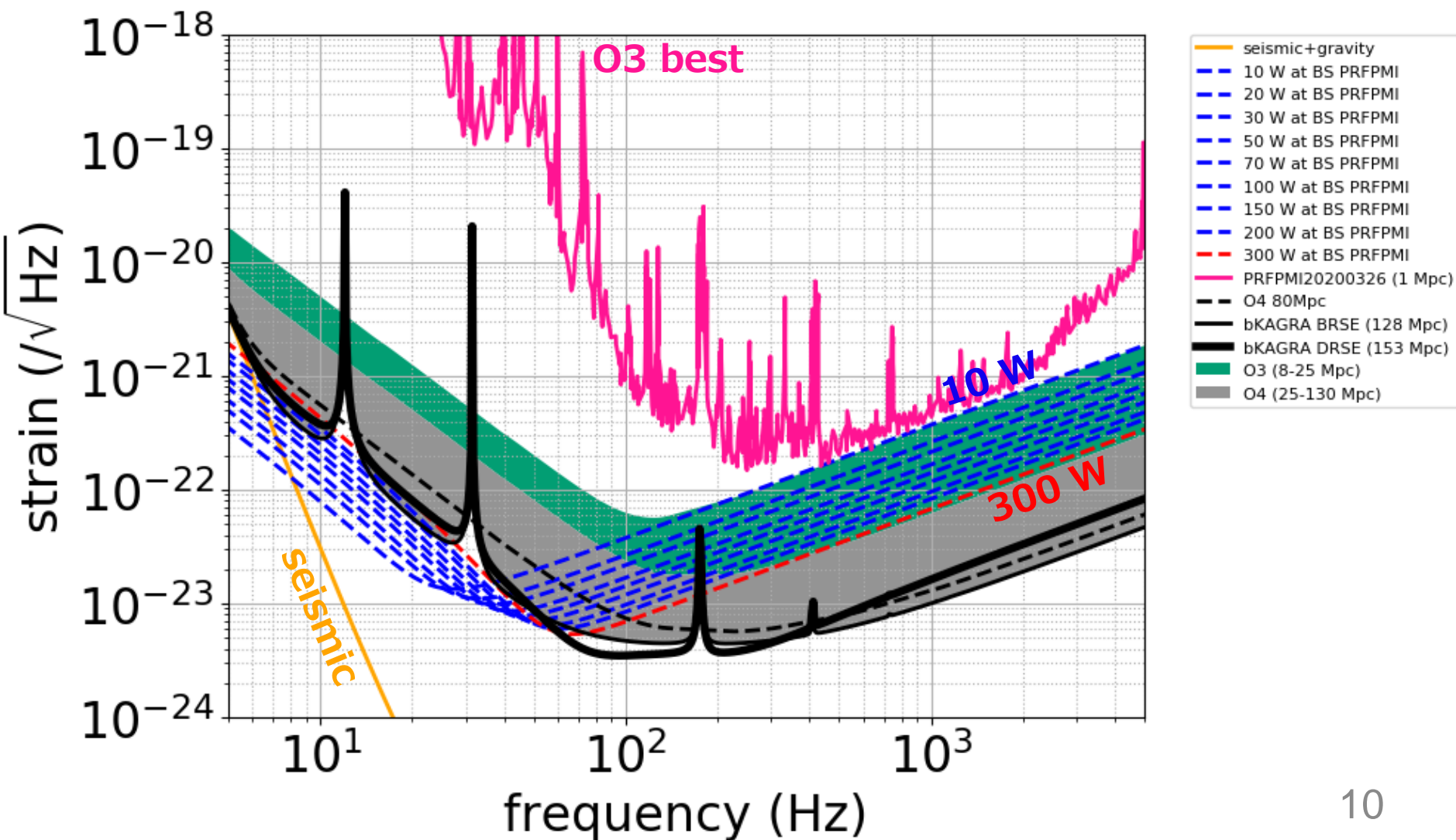
# Various Quantum Noise (DR)

- 30 W at BS would be OK



# Various Quantum Noise (PR)

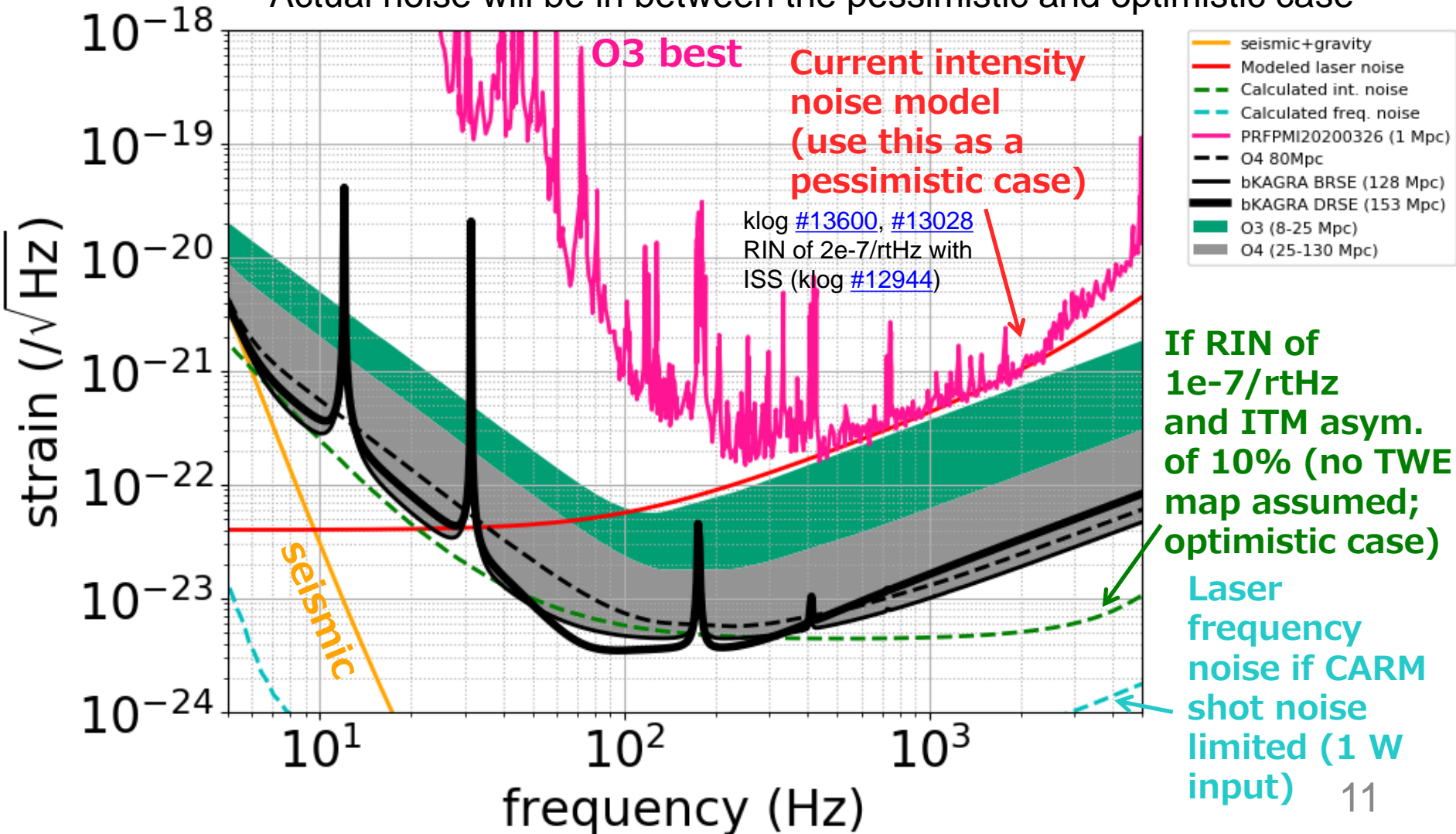
- DR necessary if excess noise is more than x8 O1



# Laser Noises

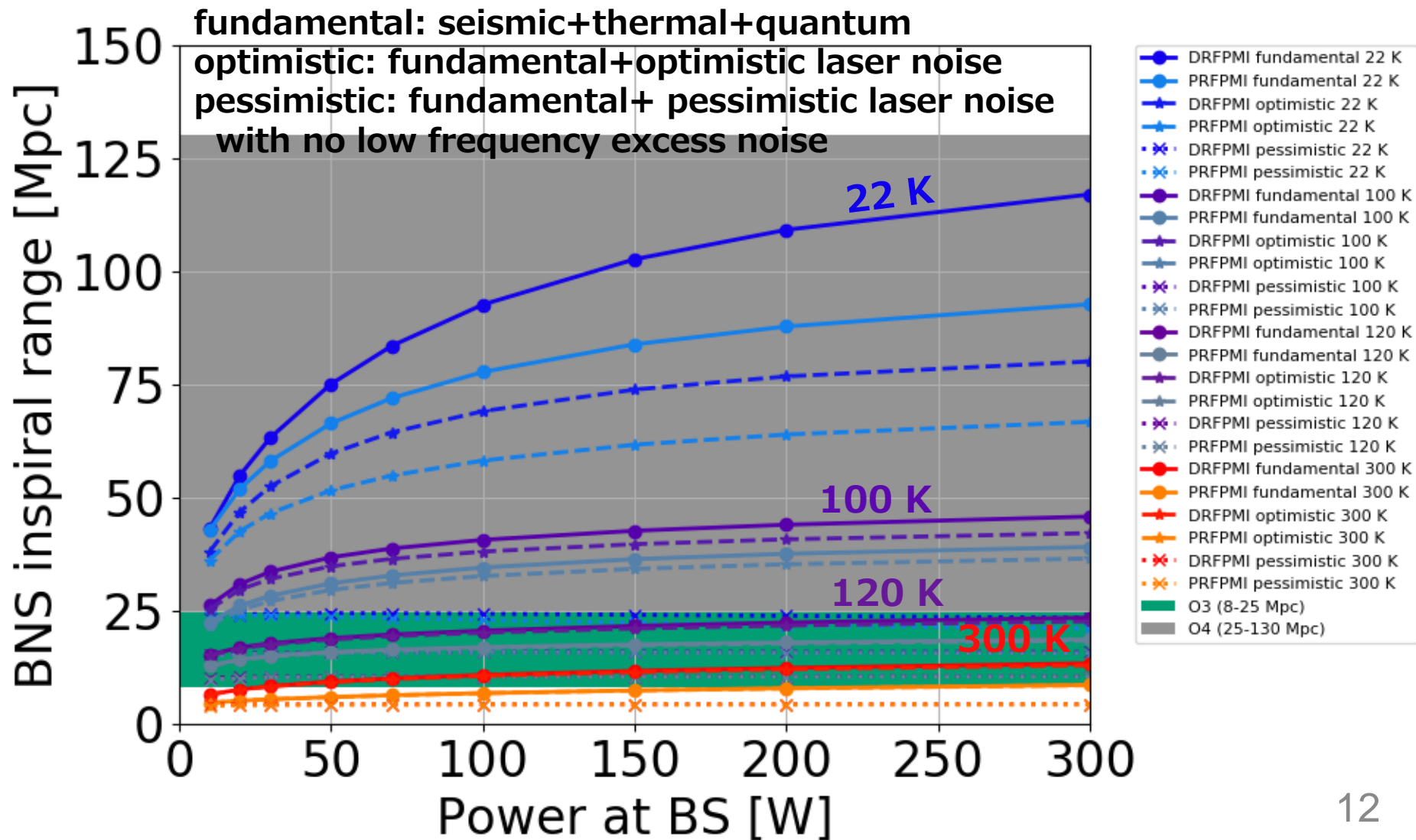
- Hard to predict without measurements

Actual noise will be in between the pessimistic and optimistic case



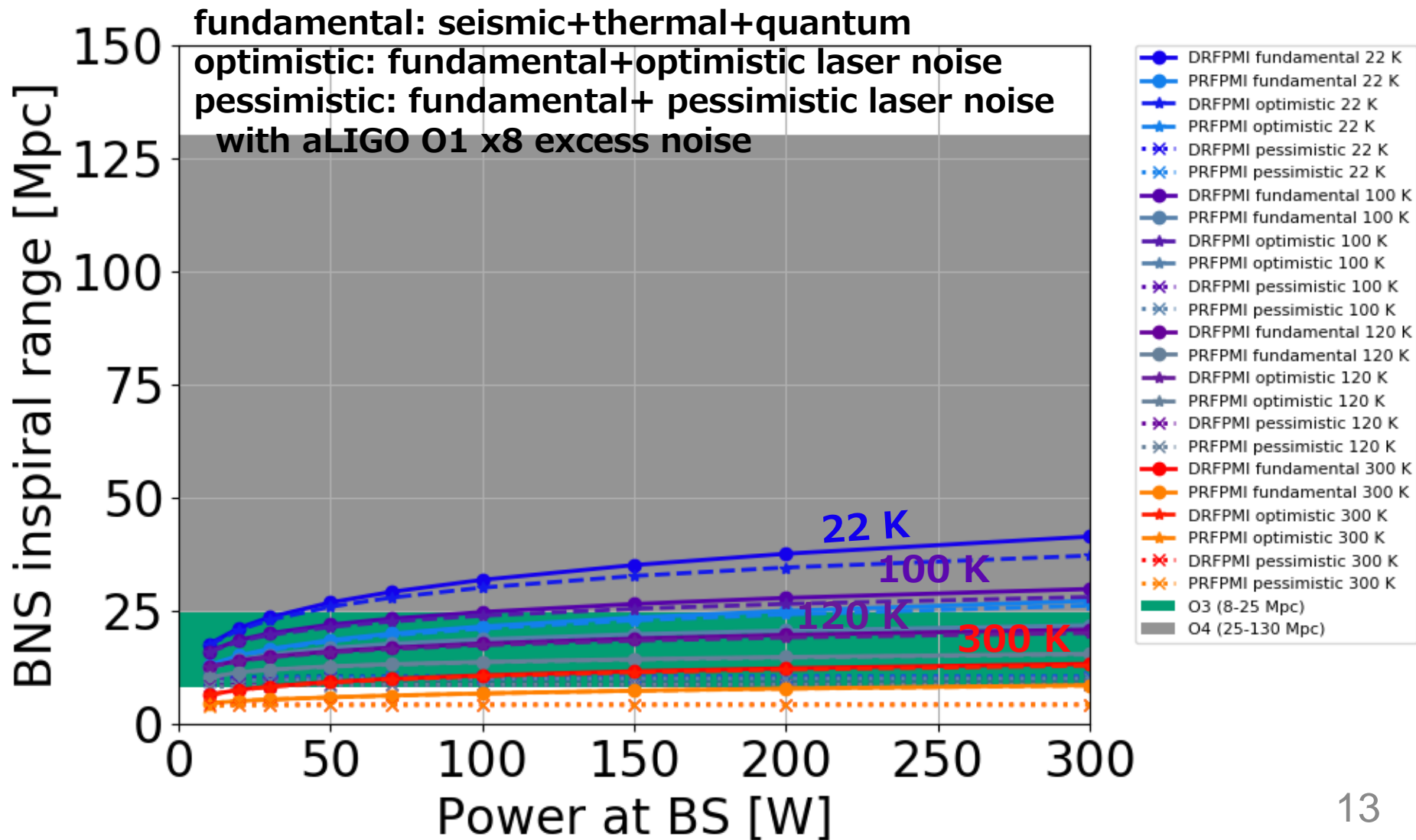
# Inspiral Range vs Power (x0 O1)

- Power change not so significant with other noises



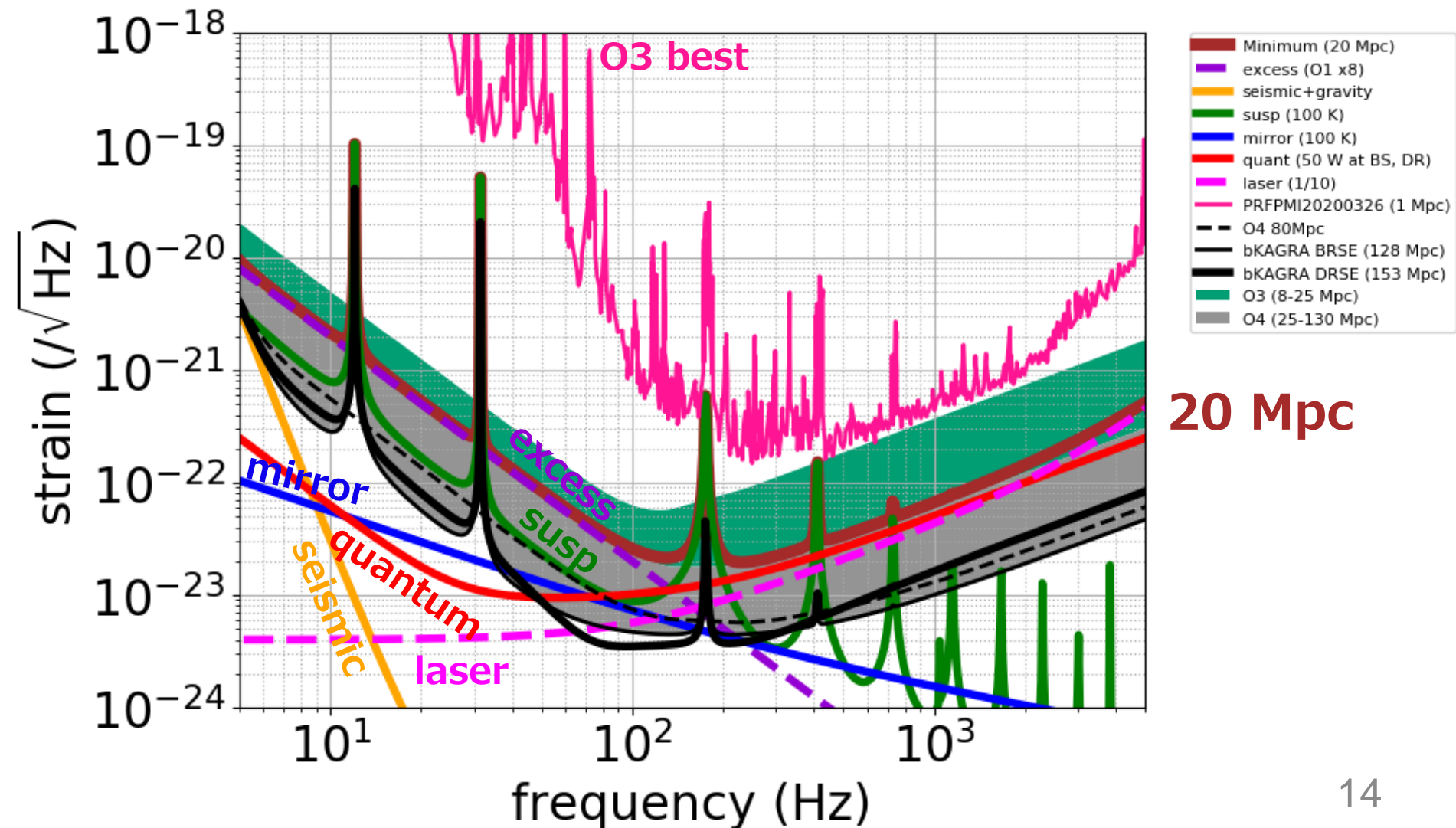
# Inspiral Range vs Power (x8 O1)

- Power change not so significant with other noises



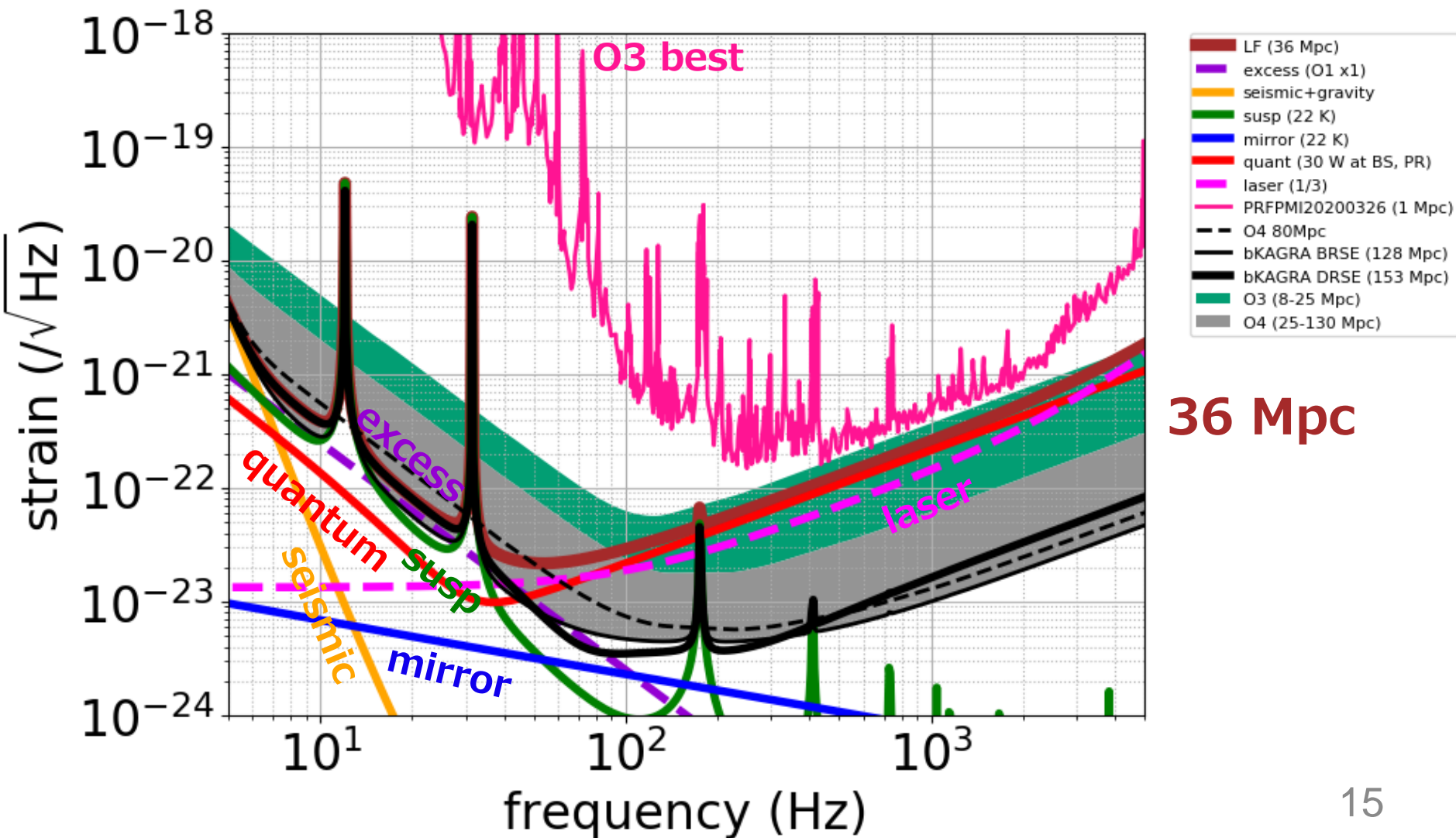
# O4 “Minimum” Example

- x8 O1, 100 K, 50 W at BS, DR, 1/10 laser noise



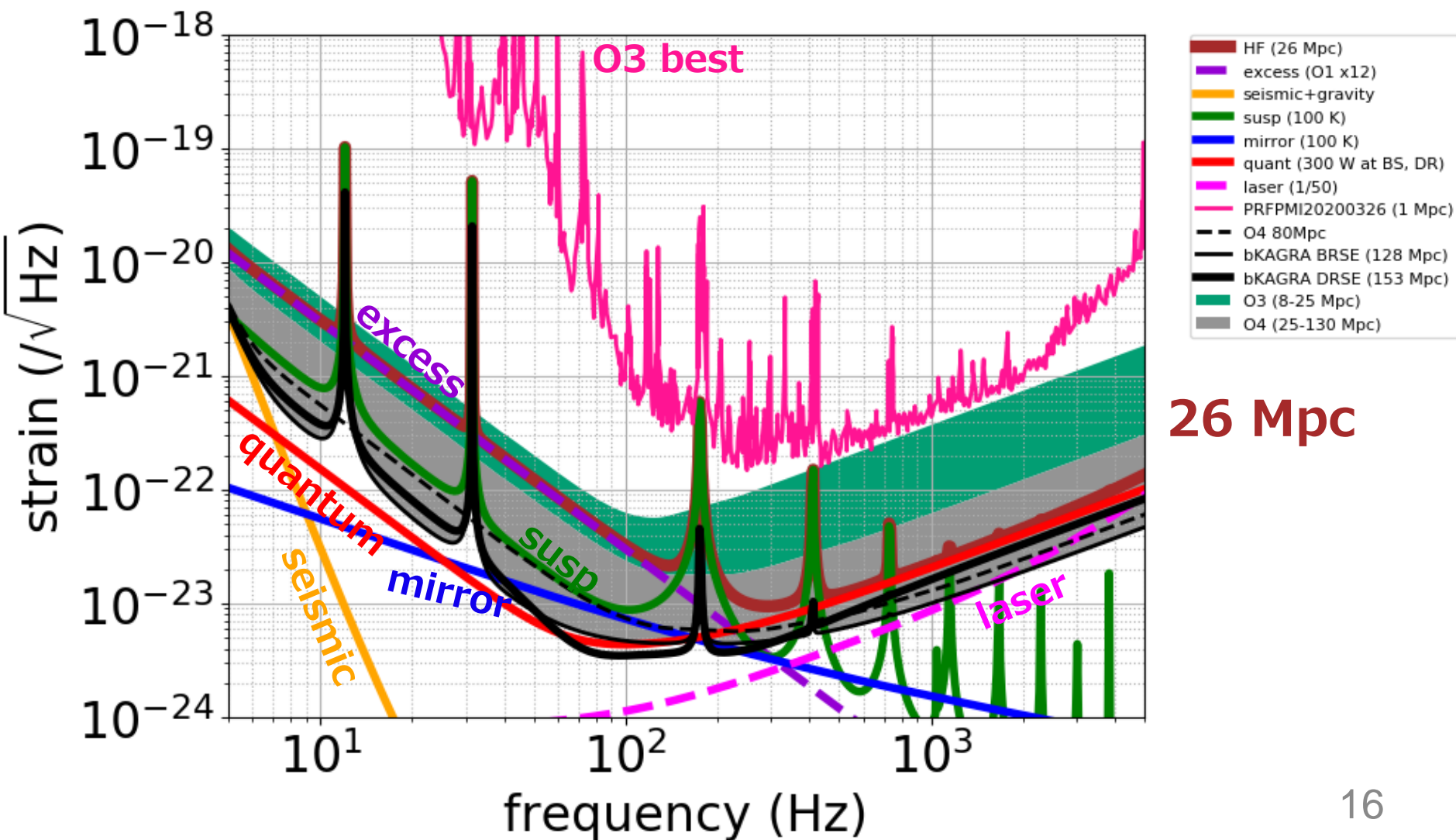
# O4 “Low Frequency” Example

- x1 O1, 22 K, 30 W at BS, PR, 1/3 laser noise



# O4 “High Frequency” Example

- x12 O1, 100 K, 300 W at BS, DR, 1/100 laser noise





# Conclusions So Far

- Should be **below  $\sim 100$  K** (achieving O4 target **above 120 K is not possible**)
- Low-mid frequency noise should be reduced at least by a factor of  **$\sim 20$**  (more at low frequencies)
- **DR necessary** if excess noise is more than x8 O1
- Higher power is better, but not so important especially when other noises are high ( **$\sim 30$  W at BS would be enough**)
- Apparently, **laser noise have to be reduced** (by subtraction, better alignment, further stabilization etc.)
  - RIN of  $\sim 1e-8$  /rtHz is OK even with current coupling
- *As we have been keep saying, investigations on current noises are very important (low frequency noise; laser intensity and frequency noise) for estimating the sensitivity in O4*

# How to Realize 100 K ?

- Possible cooling process?
  - First cool the test mass with four cryocooler
  - When reached below  $\sim 100$  K, turn off two cryocoolers for cryopayload
  - Turn on two cryocoolers occasionally to keep the temperature  $\sim 100$  K
- Maximum input power?
  - Thermal lensing: At 100 K, thermal lensing is smaller by  $1/100 \sim 1/300$  than 300 K, but larger by 4 orders of magnitude than 20 K. Thermal lensing would be OK below  $\sim 130$  K.
  - 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): Heat flow from two cryocoolers at room temperature will be very roughly 0.2-0.3 W (according to K. Yamamoto). Absorption from light will be  $\sim 0.001 * P_{BS}$  where  $P_{BS}$  is the power at BS. Radiation from 100 K is  $\sim 0.5$  W.  $P_{BS} = 200-300$  W is good to keep  $\sim 100$  K.