

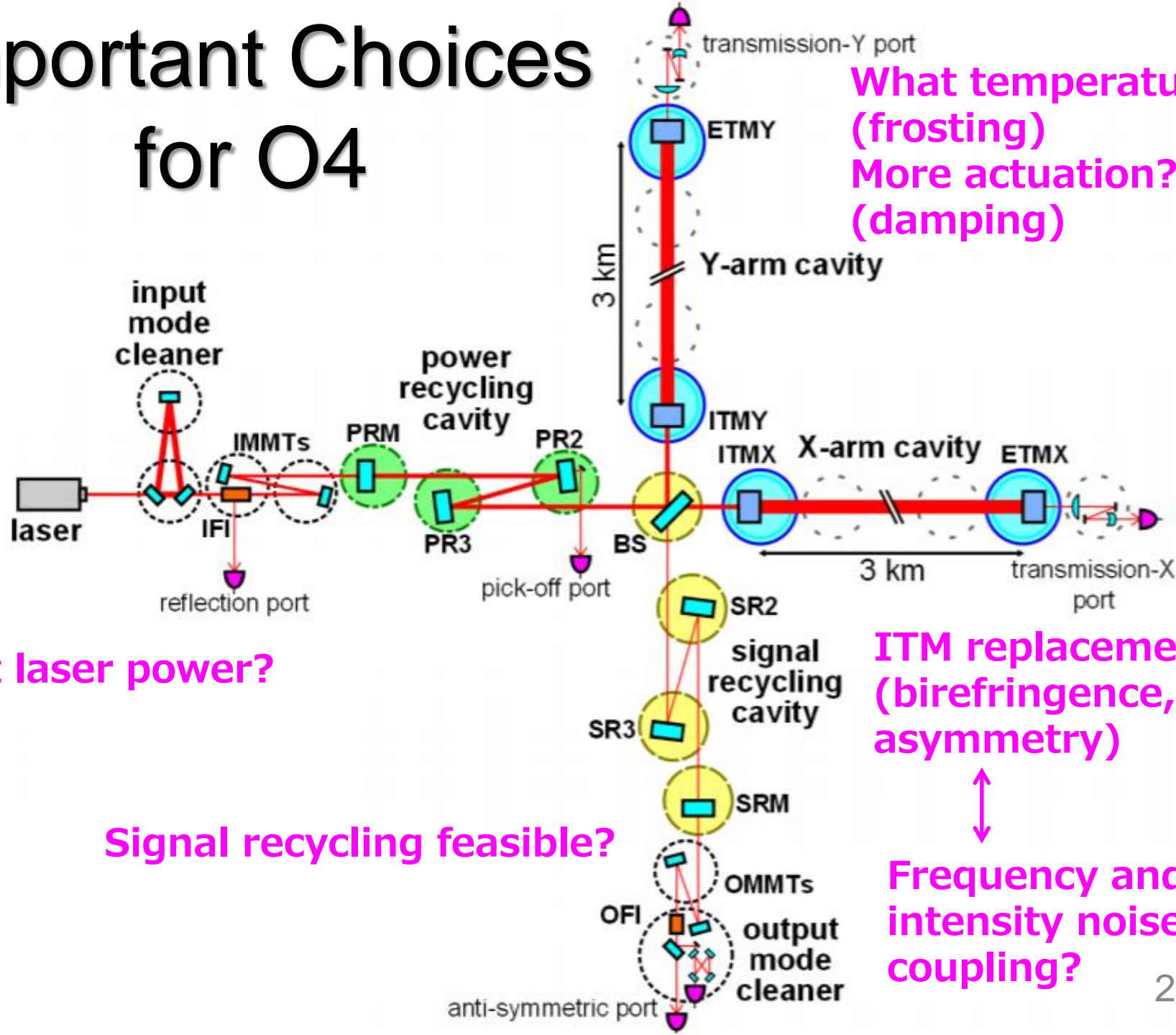
Summary of Sensitivity Estimate for O4 in Various Interferometer Configurations

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Important Choices for O4



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

What laser power?

Signal recycling feasible?

ITM replacement?
(birefringence,
asymmetry)

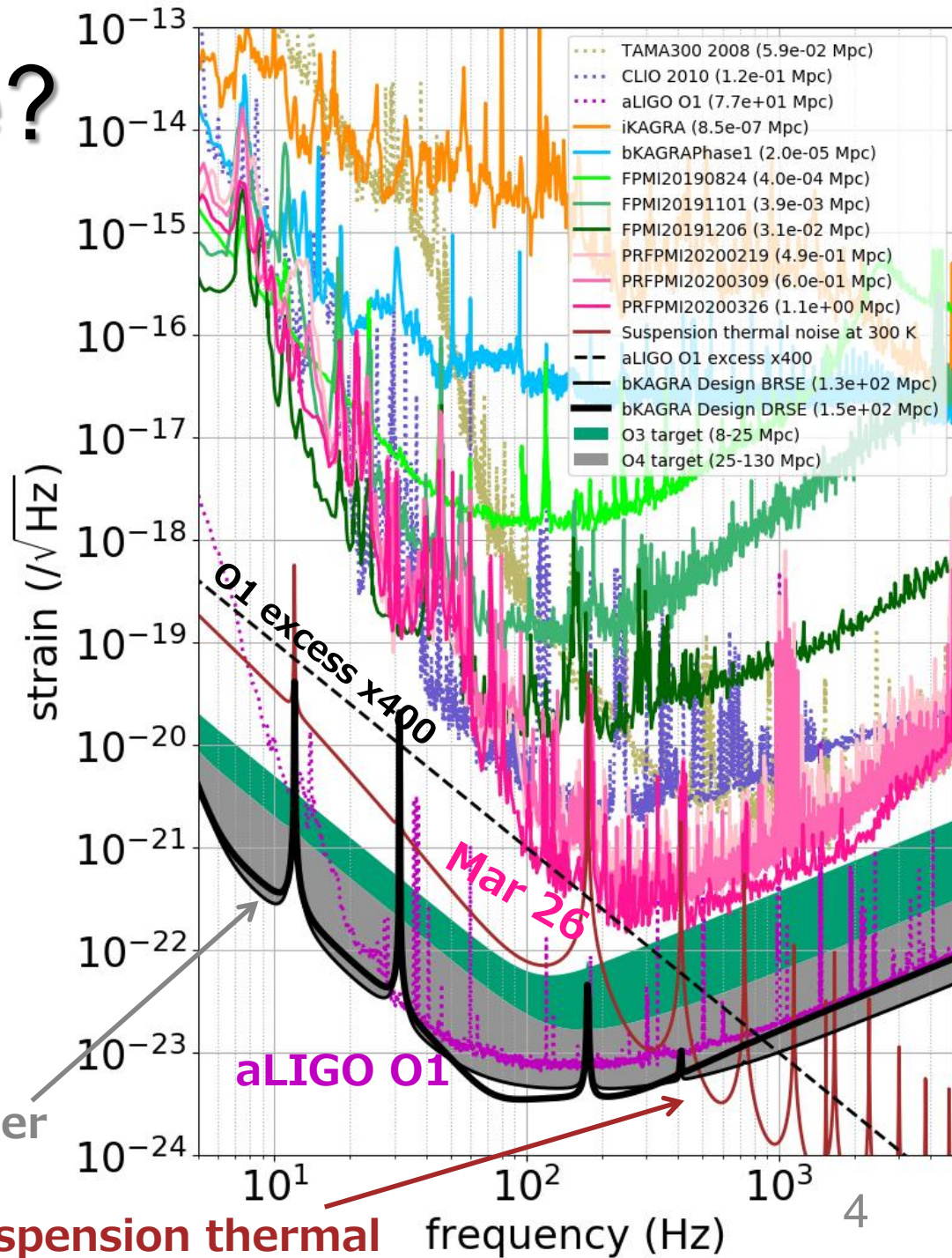
Frequency and
intensity noise
coupling?

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 using Optickle (see [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

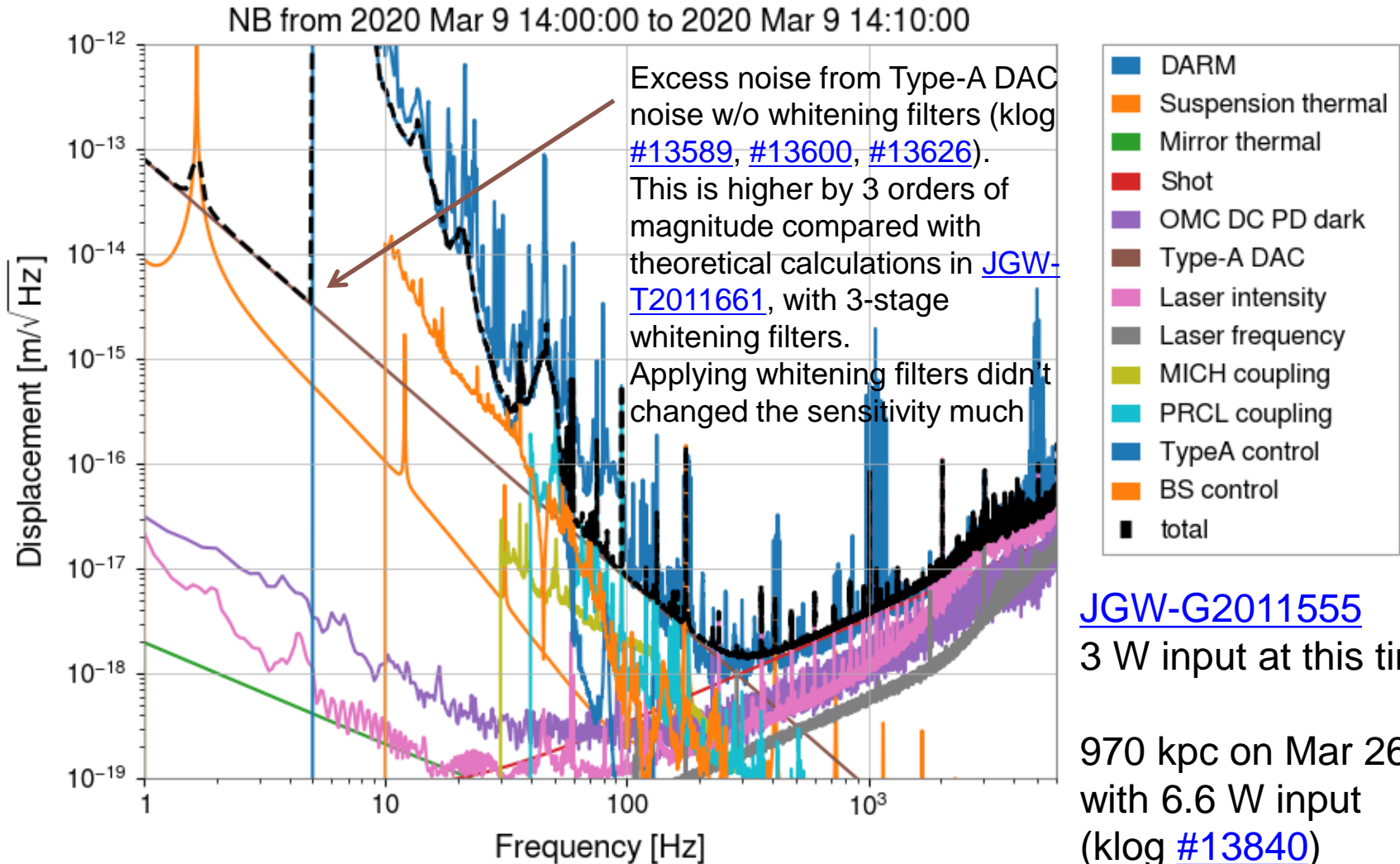
O3 best and O4 Target

	Mirror temp.	Power at BS	SRM reflectivity	Detuning angle	Homodyne angle	Excess noise
O3 best	~250 K	30-50 W	70% tilted	~90 deg (PRFPMI)	~90 deg (conventional)	O1 x 400
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
O4 80Mpc	22 K	404 W	85 %	90 deg	90 deg	O1 x 2
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](#)

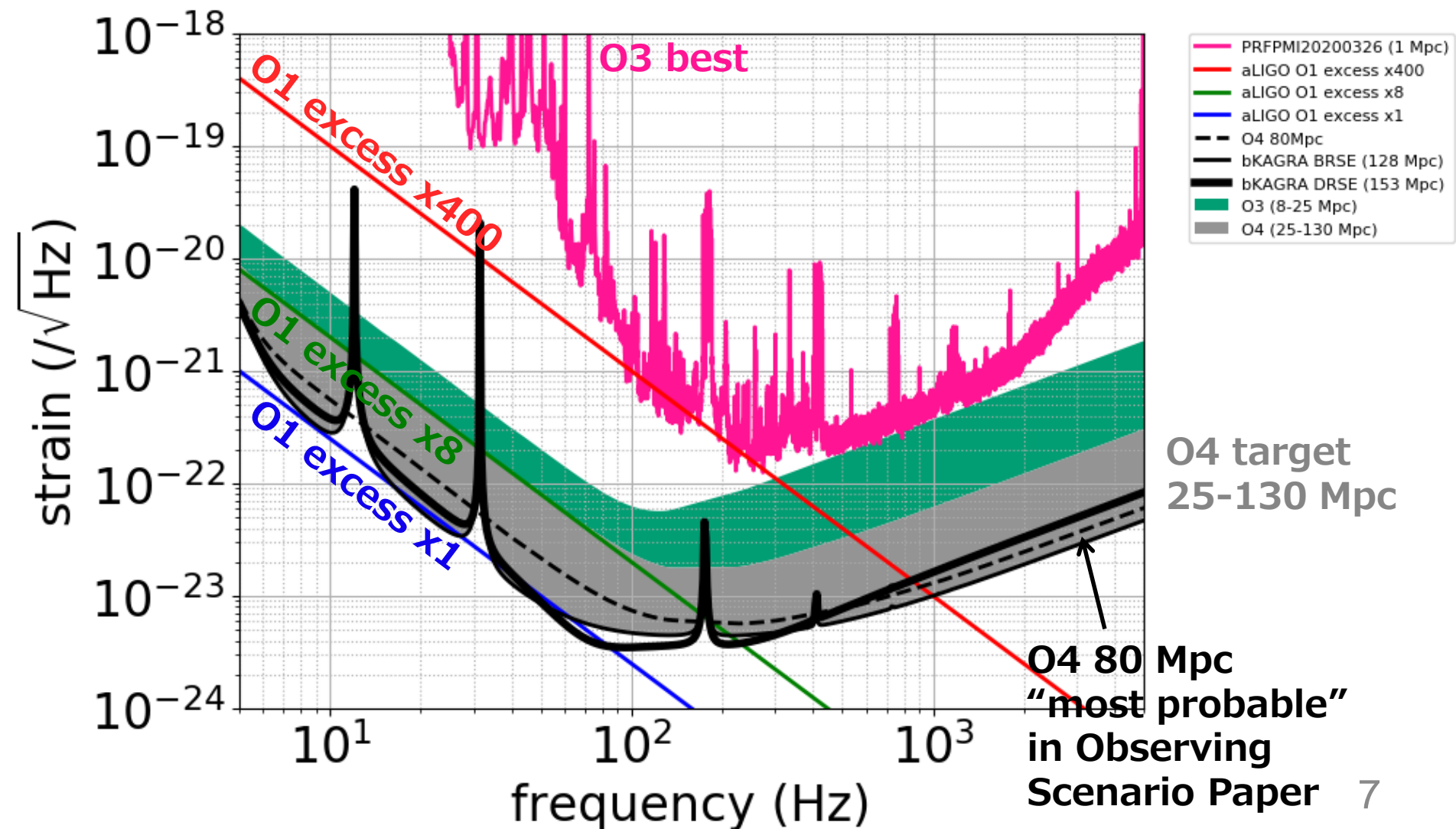
Noise Budget (for 0.6 Mpc 20200309)

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



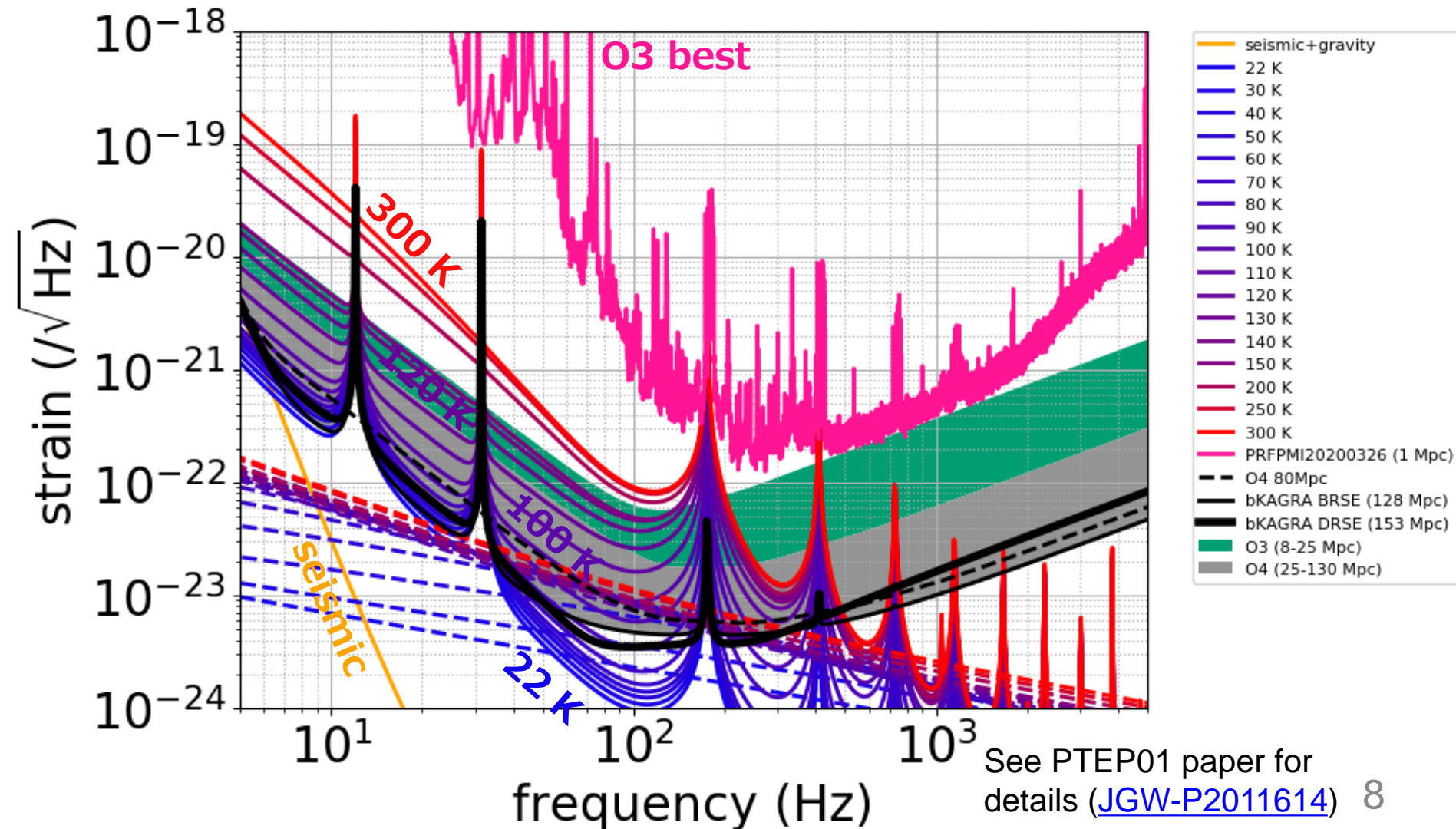
O3 best and O4 Target

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



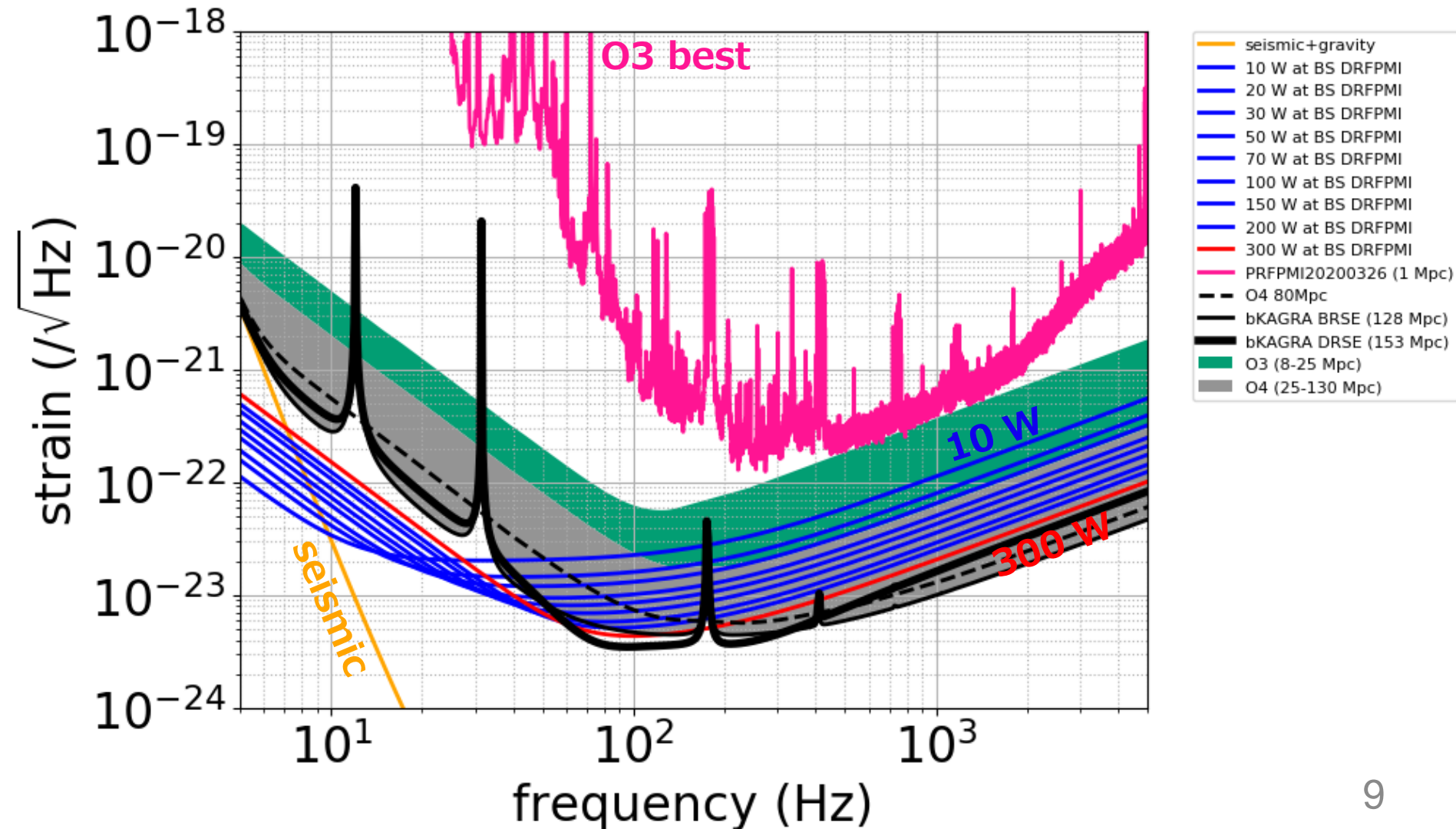
Various Thermal Noise

- 120 K thermal is comparable to x8 O1



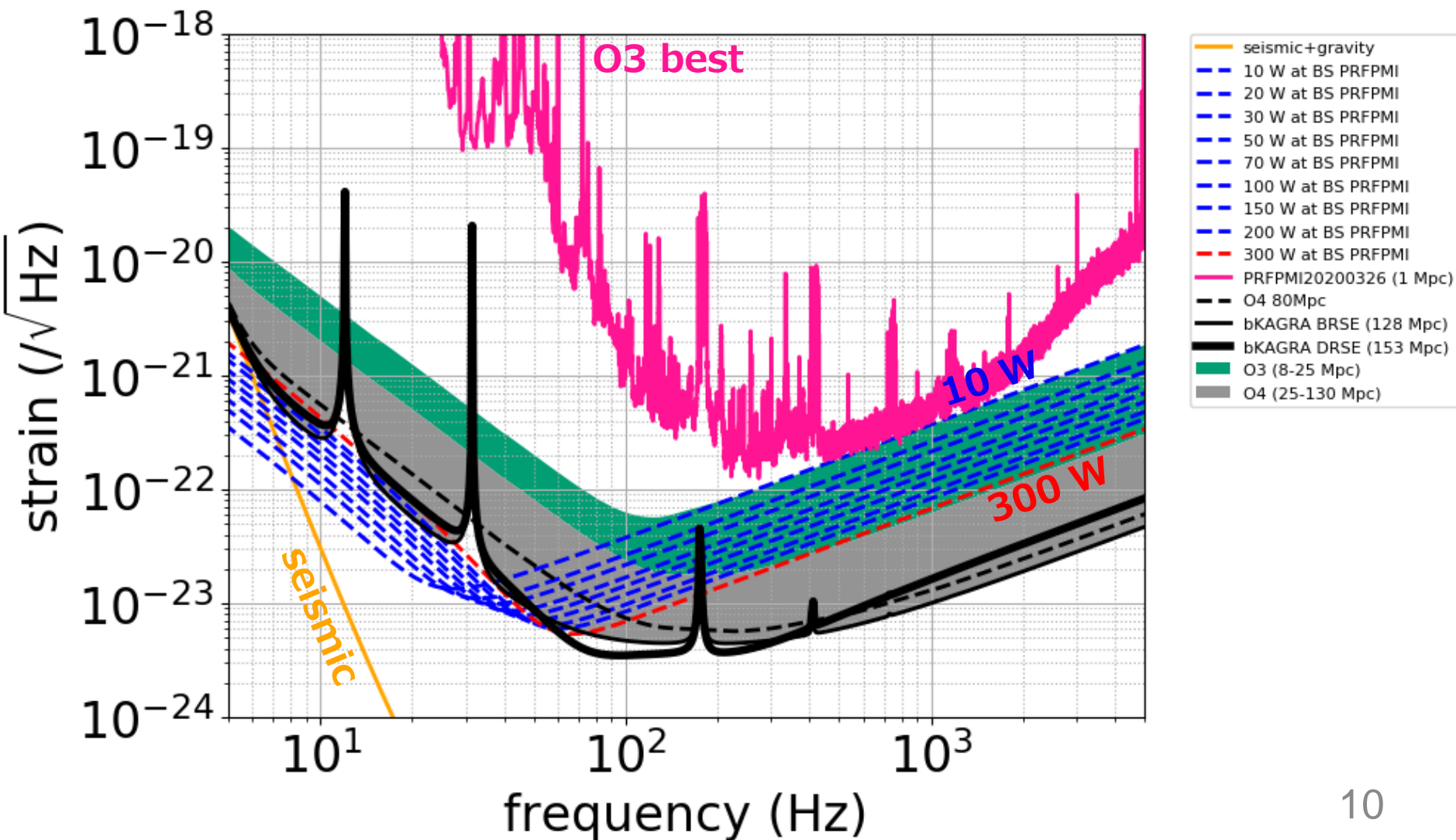
Various Quantum Noise (DR)

- 30 W at BS would be OK



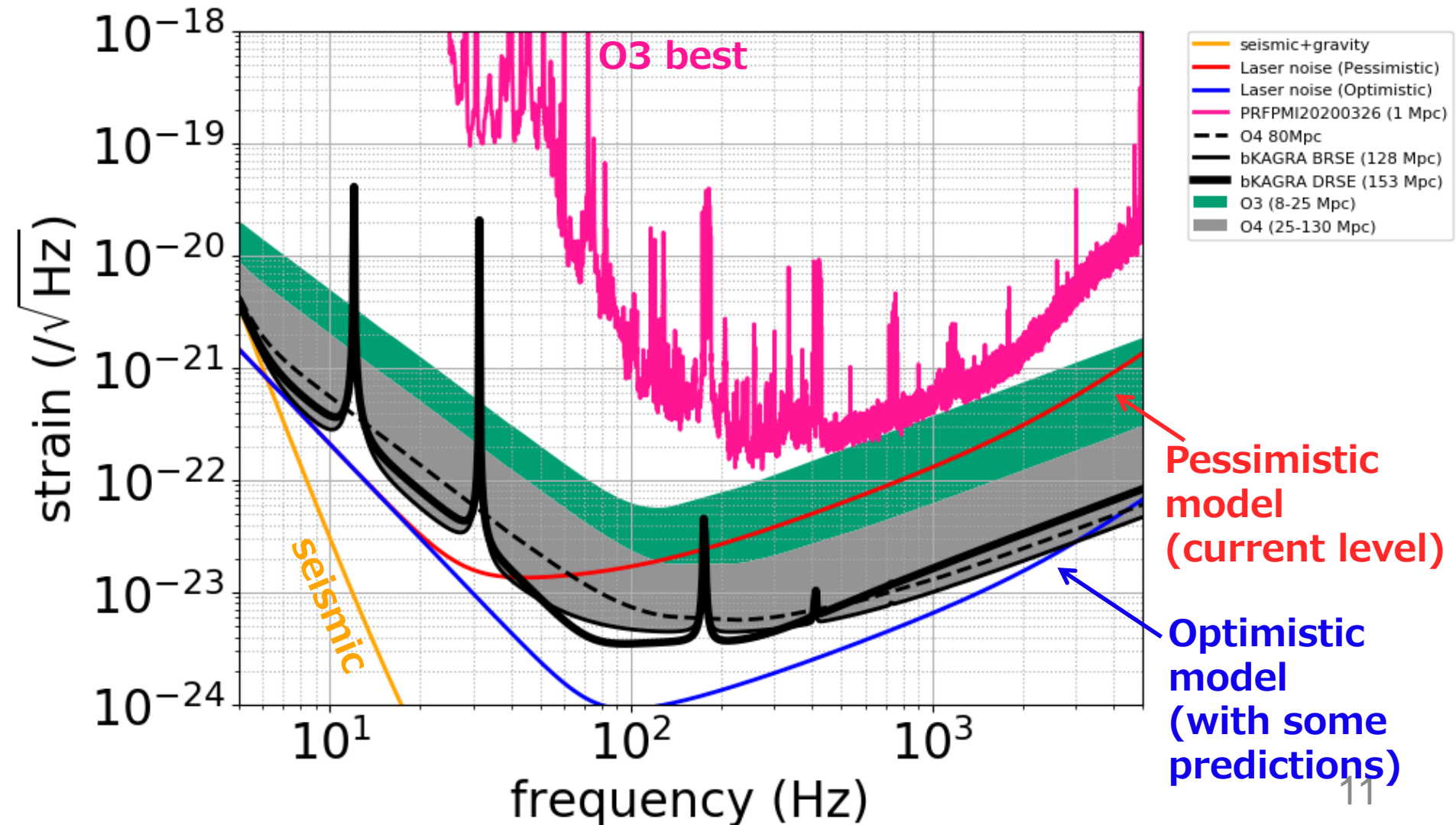
Various Quantum Noise (PR)

- DR necessary if excess noise is more than x8 O1



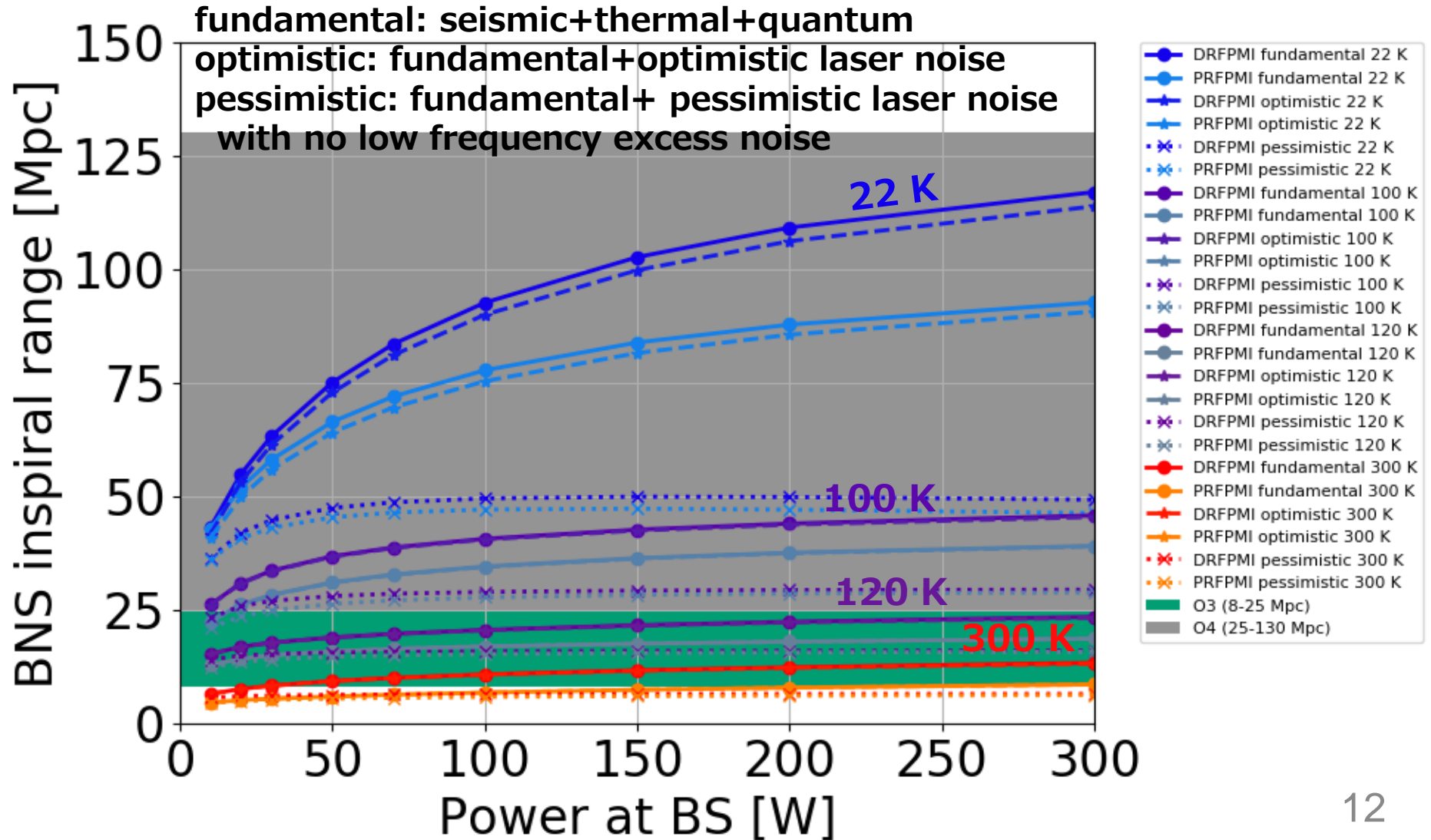
Laser Noises

- Hard to predict; see “Details” attached for details



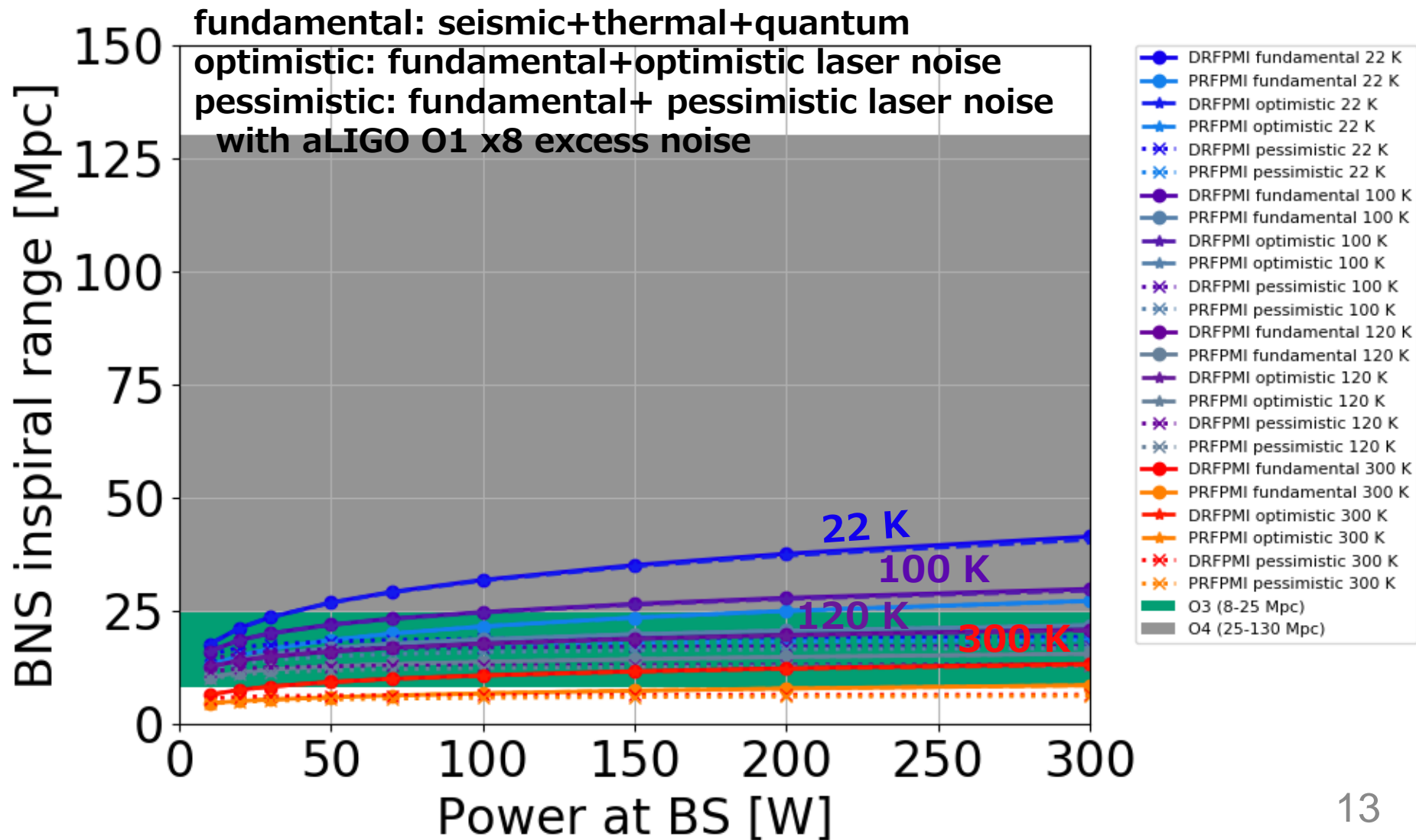
Inspiral Range vs Power (x0 O1)

- Power change not so significant with other noises



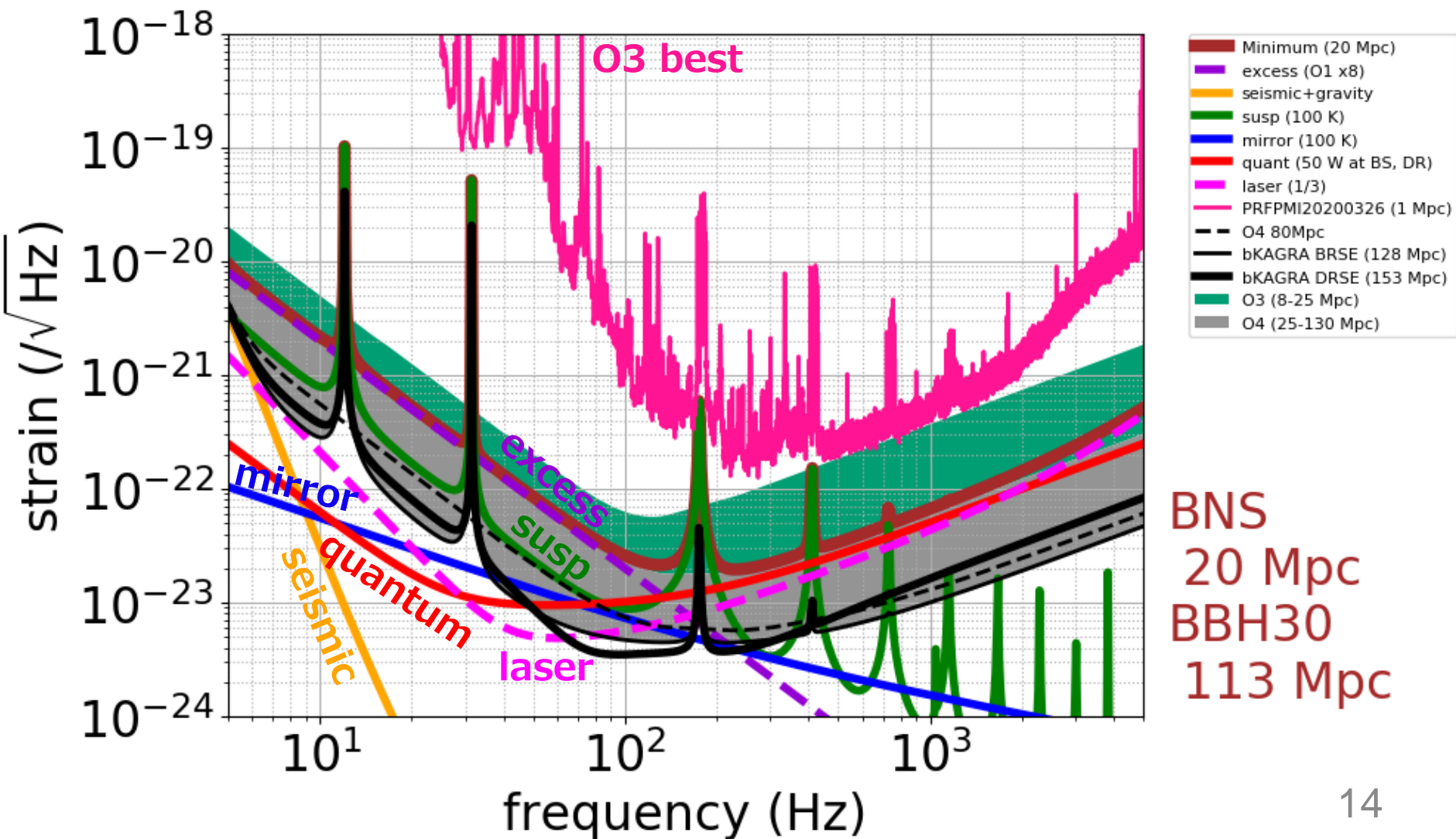
Inspiral Range vs Power (x8 O1)

- Power change not so significant with other noises



O4 “Minimum” Example

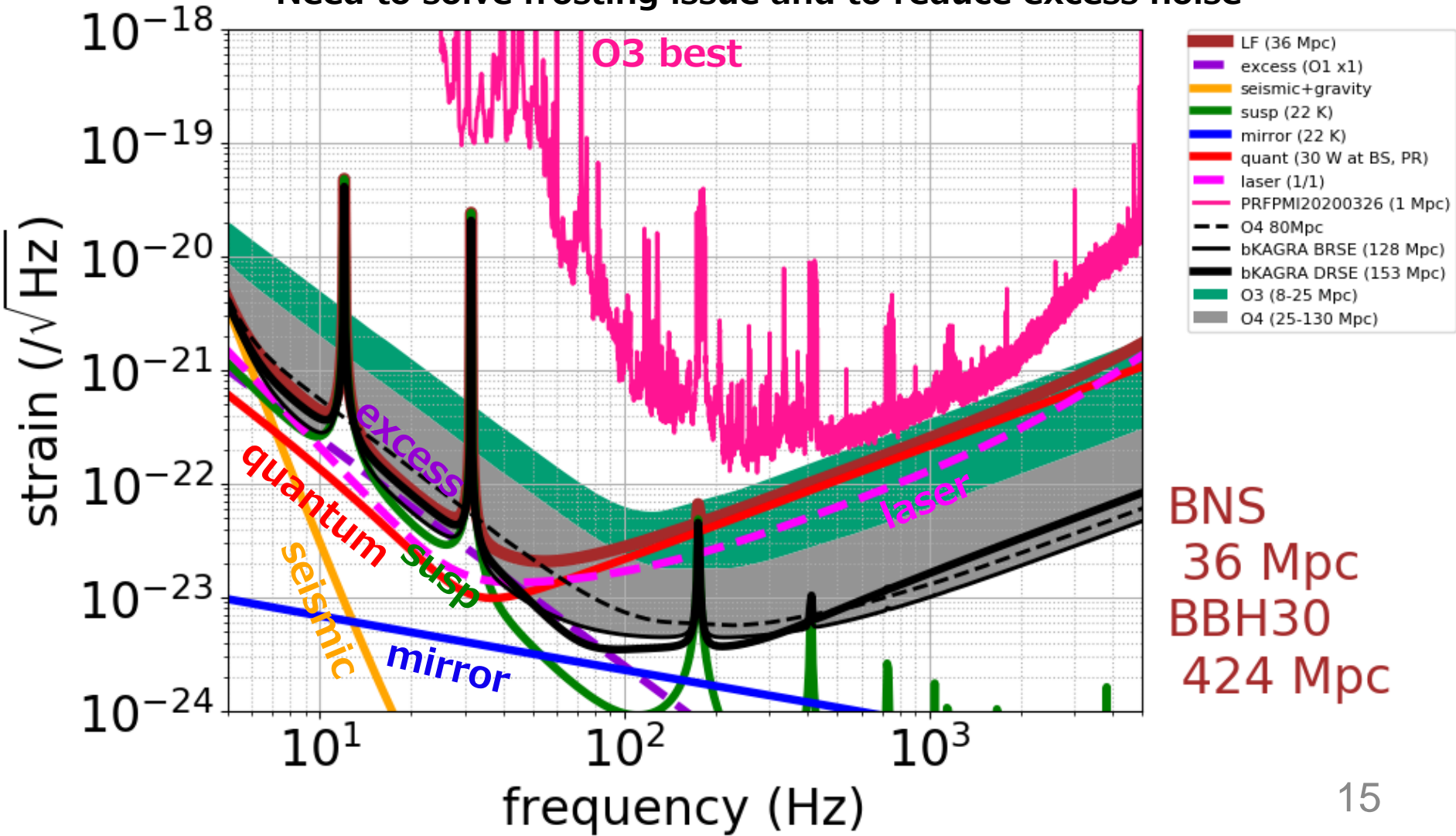
- x8 O1, 100 K, 50 W at BS, DR, 1/3 laser noise



O4 “Low Frequency” Example

- x1 O1, 22 K, 30 W at BS, PR, same laser noise

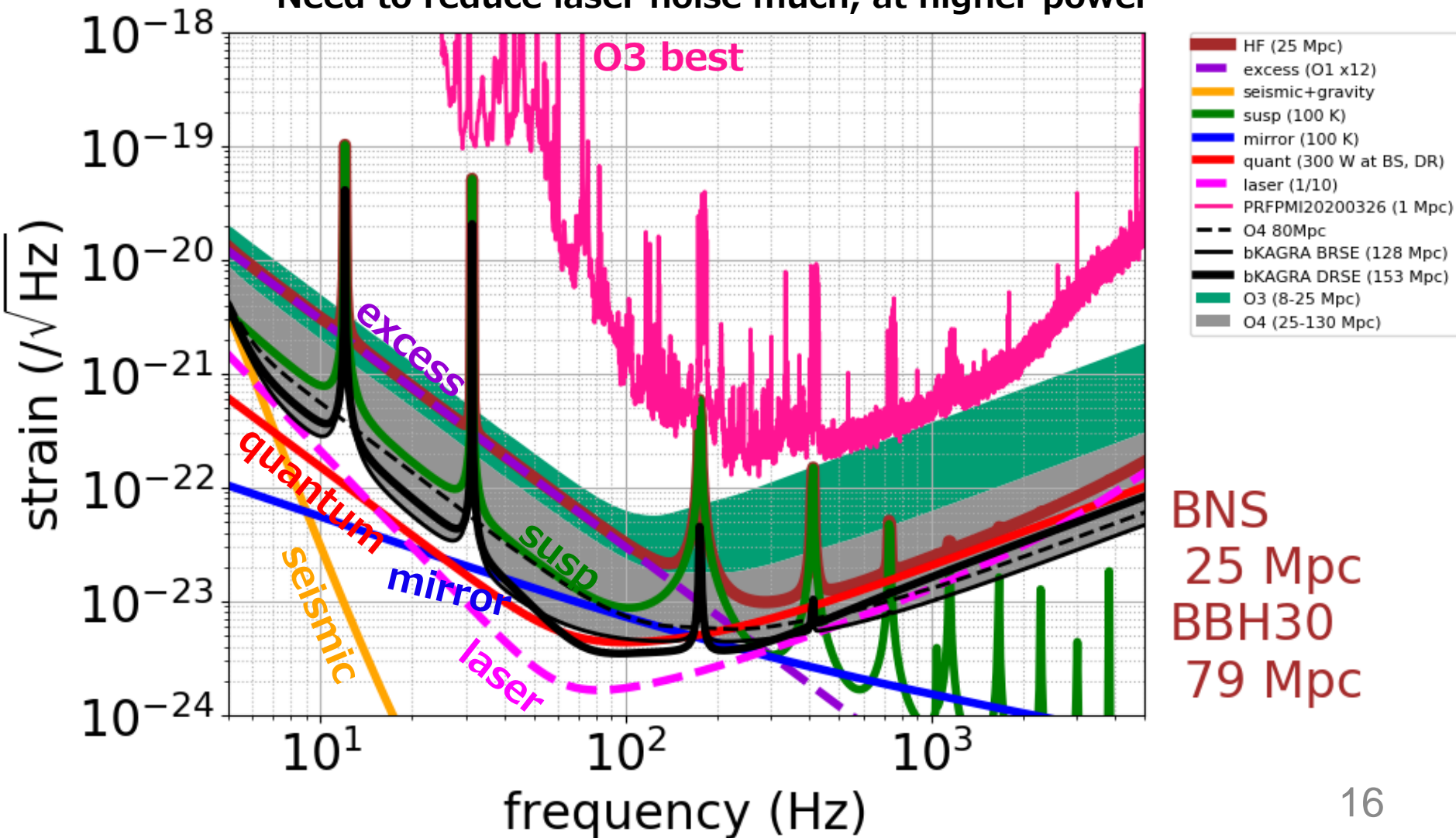
Need to solve frosting issue and to reduce excess noise



O4 “High Frequency” Example

- x12 O1, 100 K, 300 W at BS, DR, 1/10 laser noise

Need to reduce laser noise much, at higher power



Conclusions So Far

- Should be **below ~100 K** (achieving O4 target **above 120 K is not possible**)
- Low-mid frequency noise should be reduced at least by a factor of **~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 (**~30 W at BS would be enough**)
- **Laser noise should be reduced** (by subtraction, better alignment, further stabilization etc.)
- *As we have been keep saying, investigations on current noises and noise coupling mechanisms are very important (low frequency noise; laser intensity and frequency noise) for estimating the sensitivity in O4*

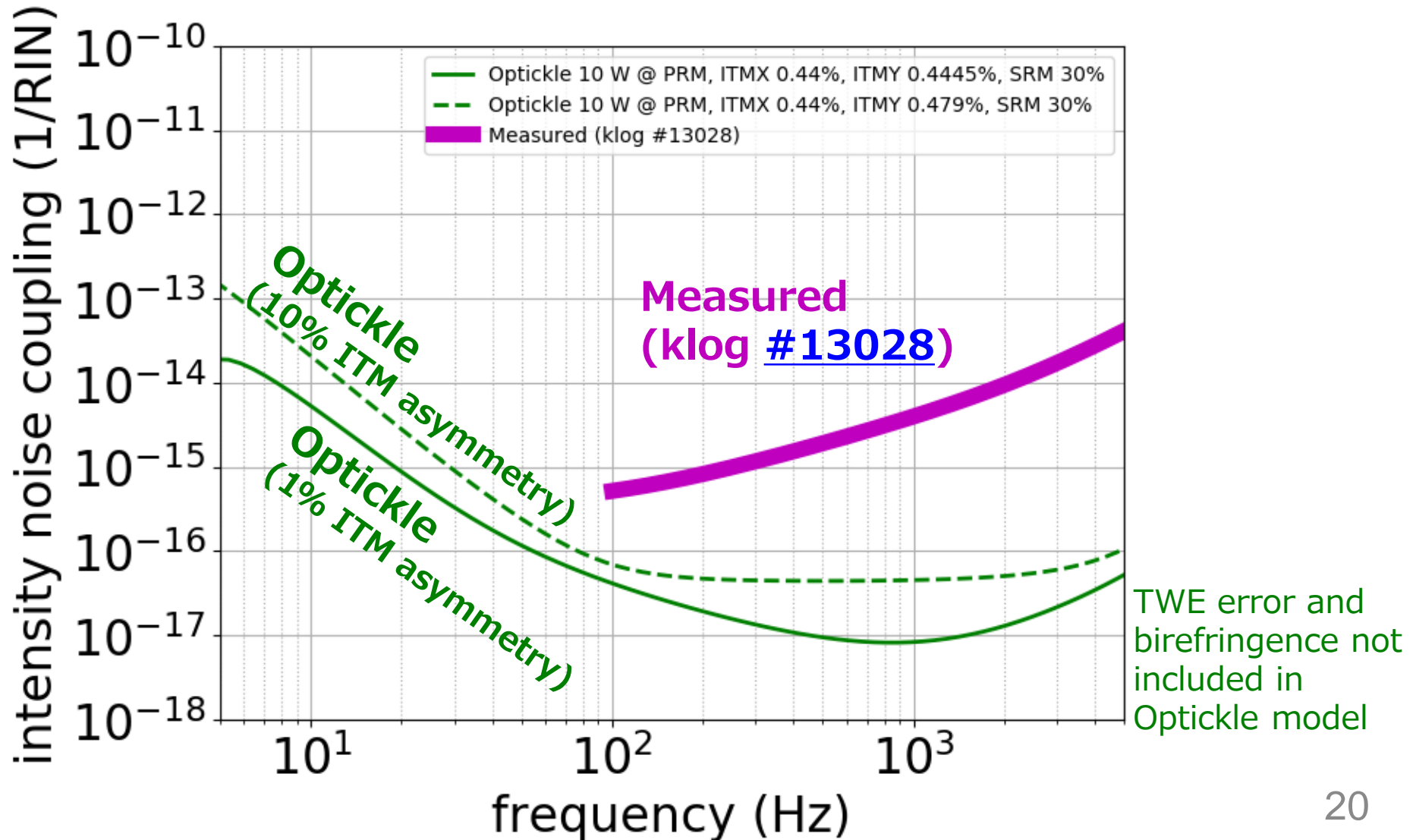
Details

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)
 - Turn on two cryocoolers occasionally to keep the temperature ~ 100 K
- Maximum input power?
 - Thermal lensing: At 100 K, thermal lensing is smaller by $1/100 \sim 1/300$ than 300 K, but larger by 4 orders of magnitude than 20 K. Thermal lensing would be OK below ~ 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 ~ 0.5 W. $P_{BS} = 200-300$ W is good to keep ~ 100 K.

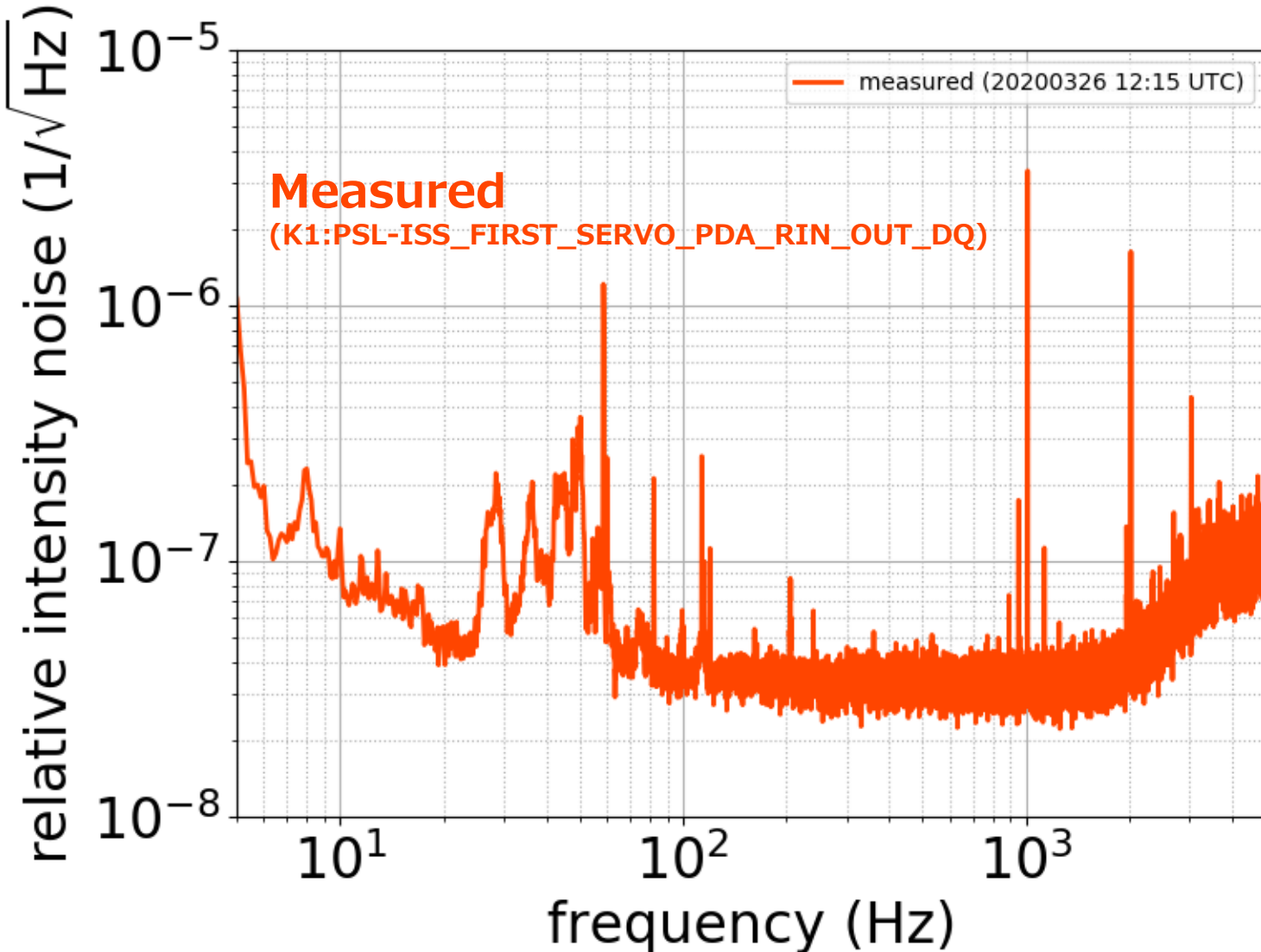
Laser Intensity Noise Coupling

- Measured to be larger than Optickle model



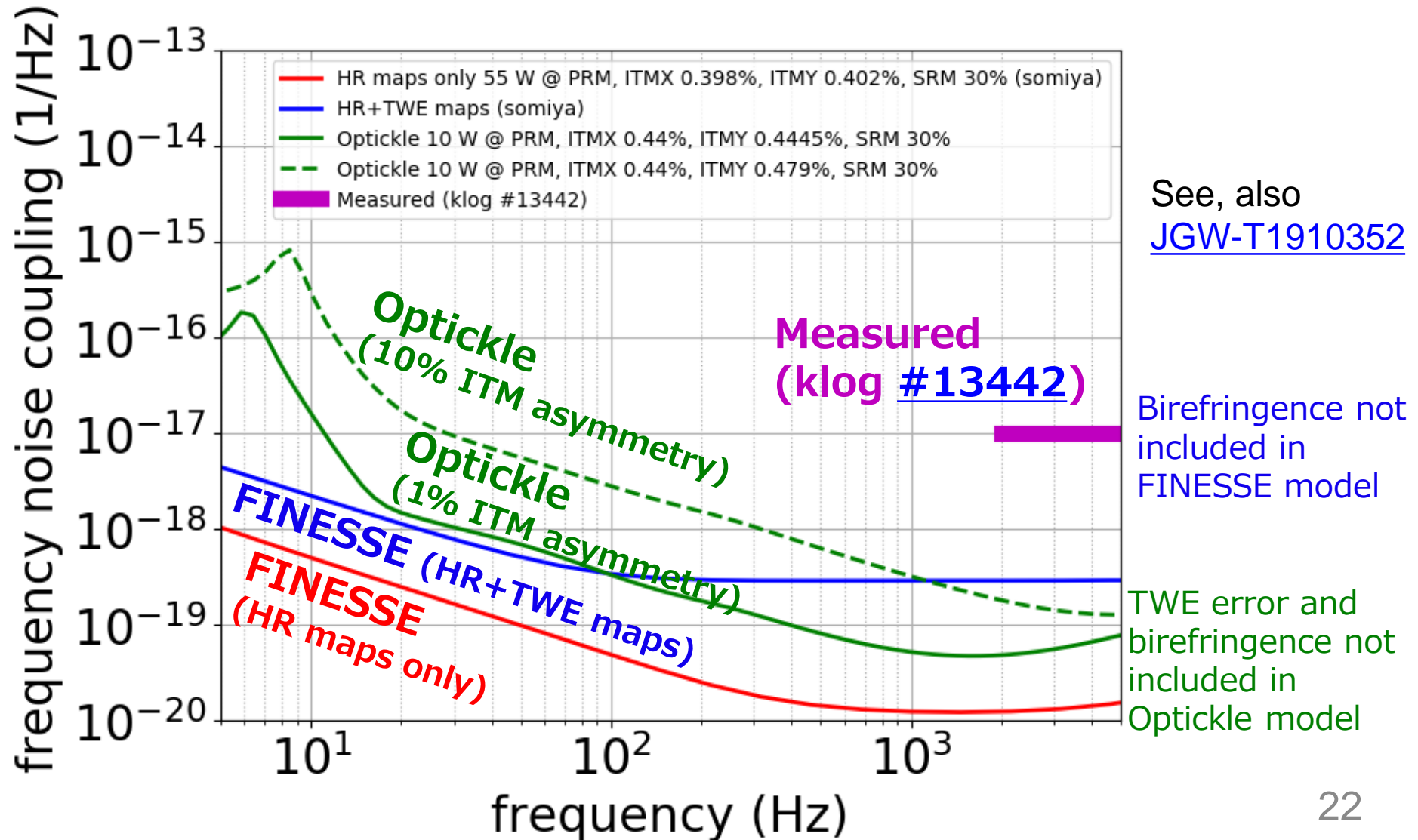
Laser Intensity Noise

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



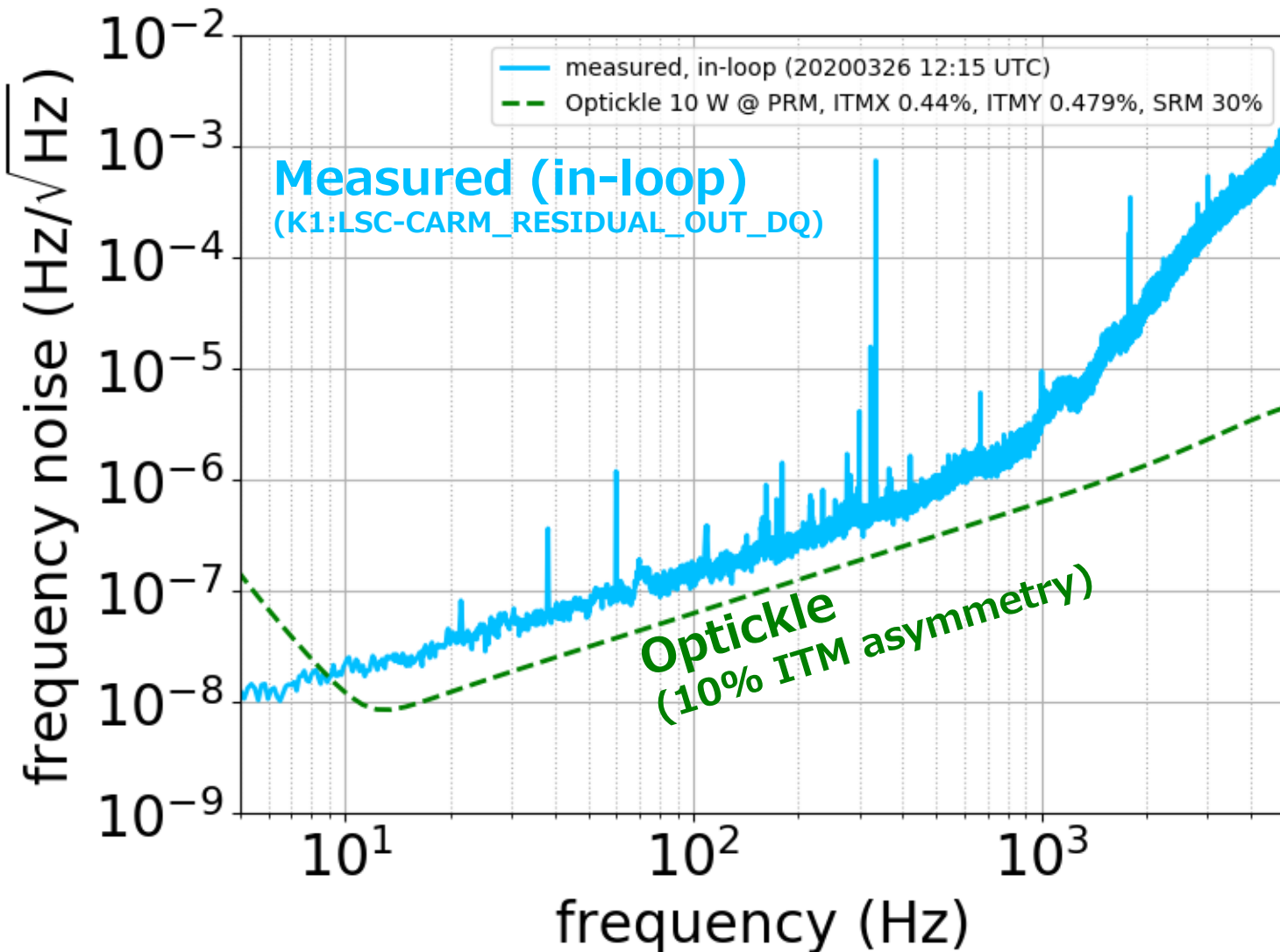
Laser Frequency Noise Coupling

- Measured to be larger than various models



Laser Frequency Noise

- Close to CARM shot noise limit from Optickle



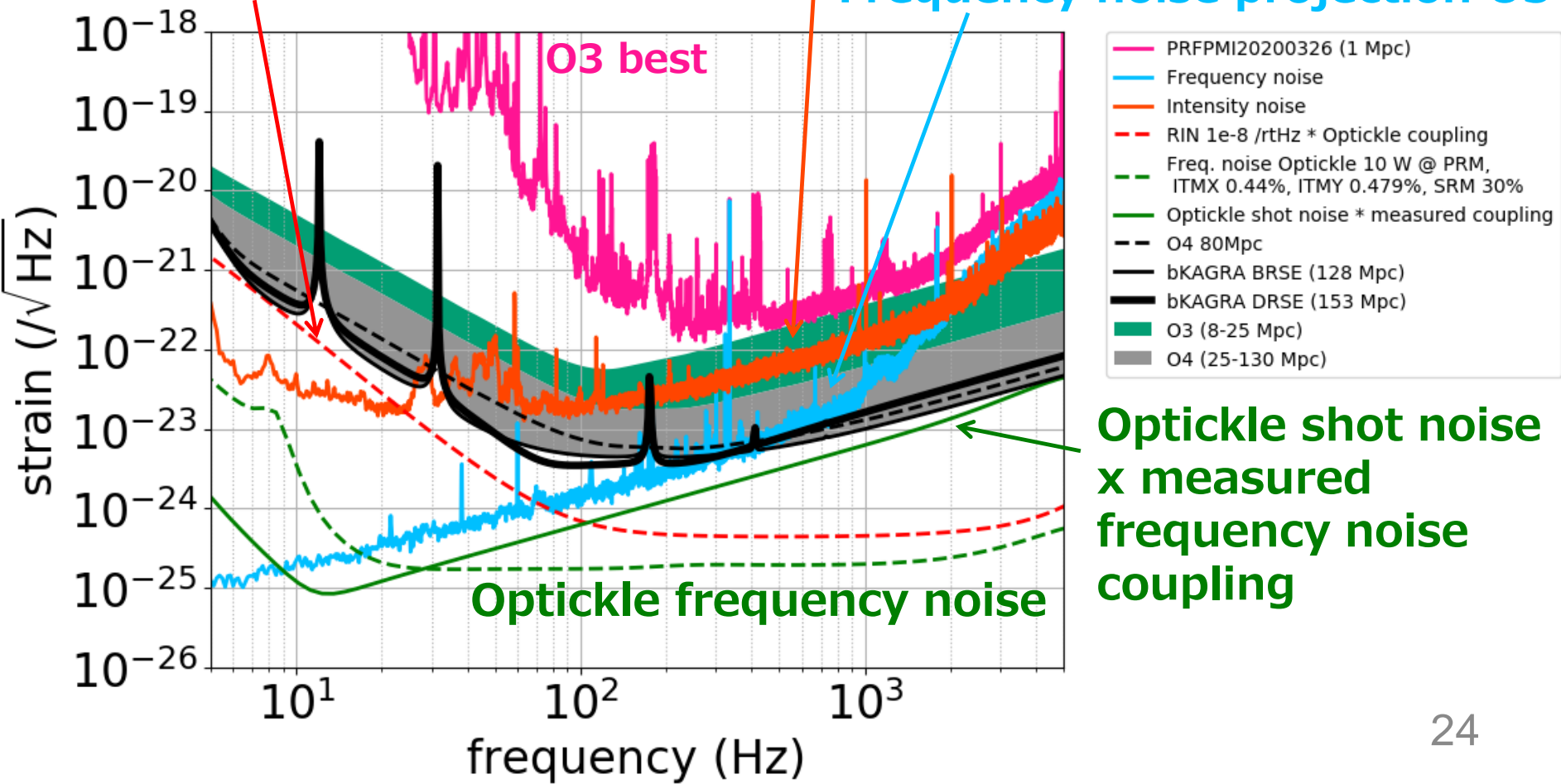
Laser Noise Projections

- Close to CARM shot noise limit from Optickle

RIN $1e-8$ /rtHz
x Optickle coupling

Intensity noise projection O3

Frequency noise projection O3



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

