JGW-T2011662

May 12, 2020

Summary of Sensitivity Estimate for O4 in Various Interferometer Configurations

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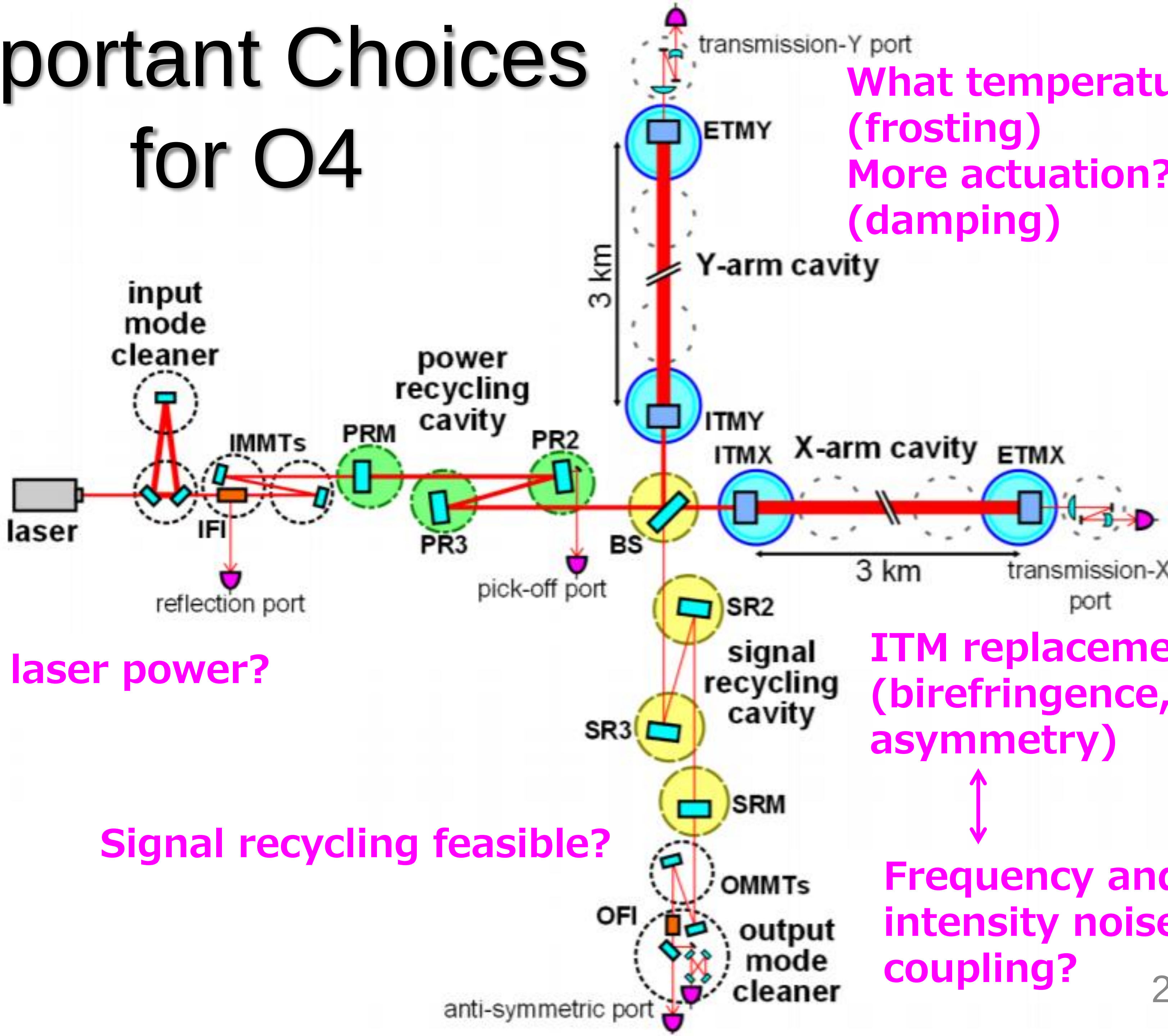
Important Choices for O4



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

What laser power?

ITM replacement? (birefringence, asymmetry)

↕

Frequency and intensity noise coupling?

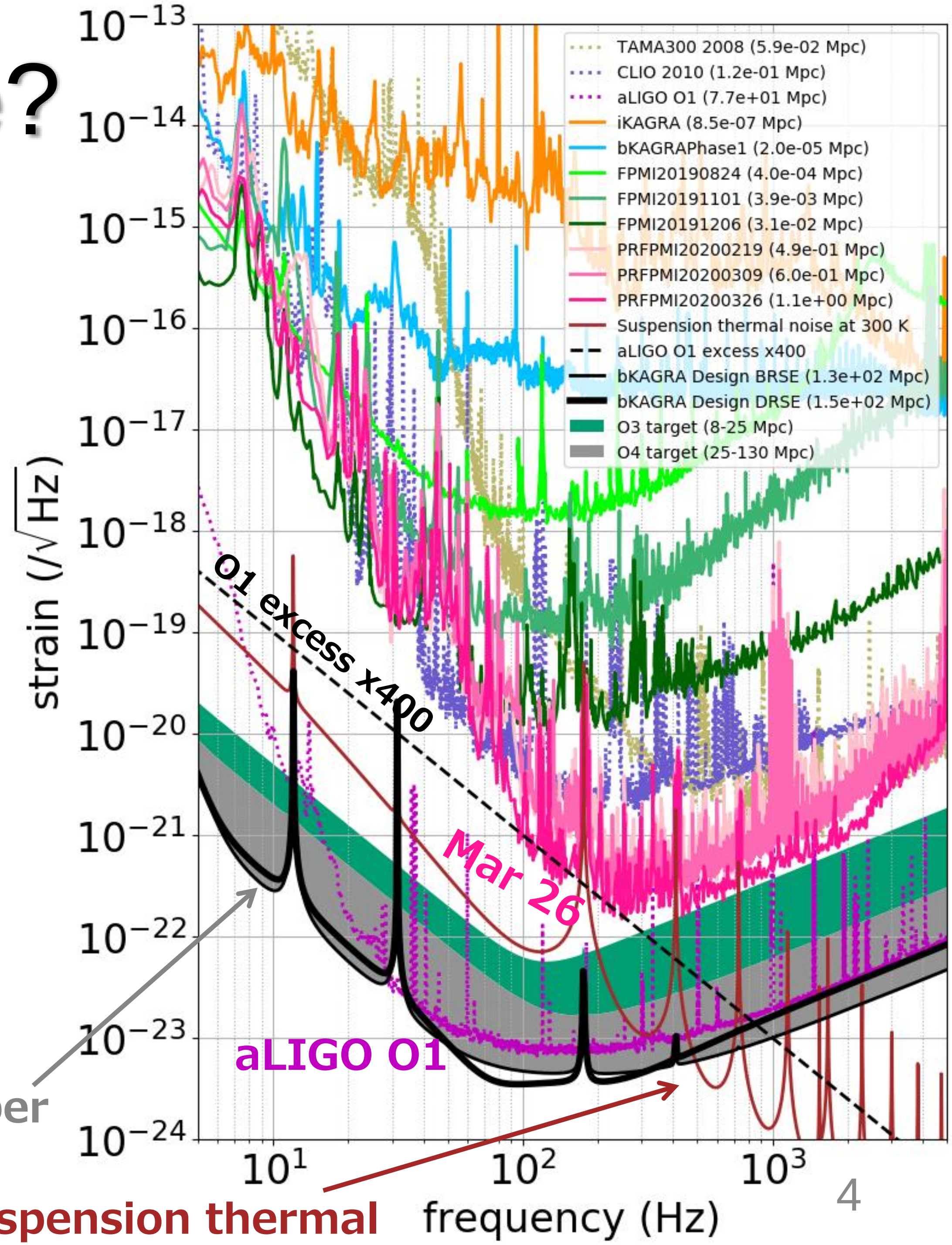
Signal recycling feasible?

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, also, JGW-T1910352)
  - Assume ITMs are not replaced (see JGW-G2011541)
- Actuator noise: Not significant for O4 if we do it right, with whitening filters (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

300 K suspension thermal

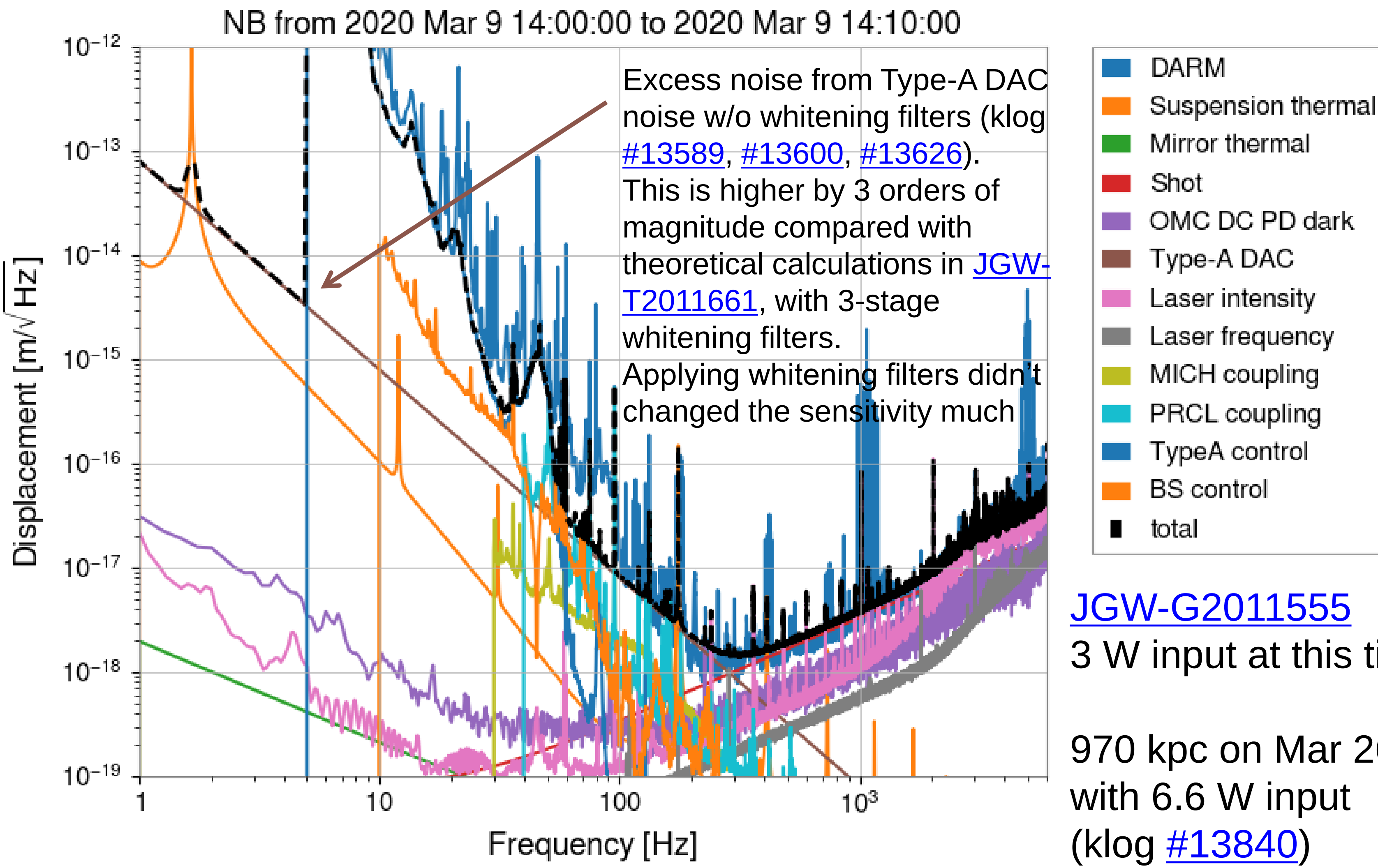
O3 best and O4 Target

	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



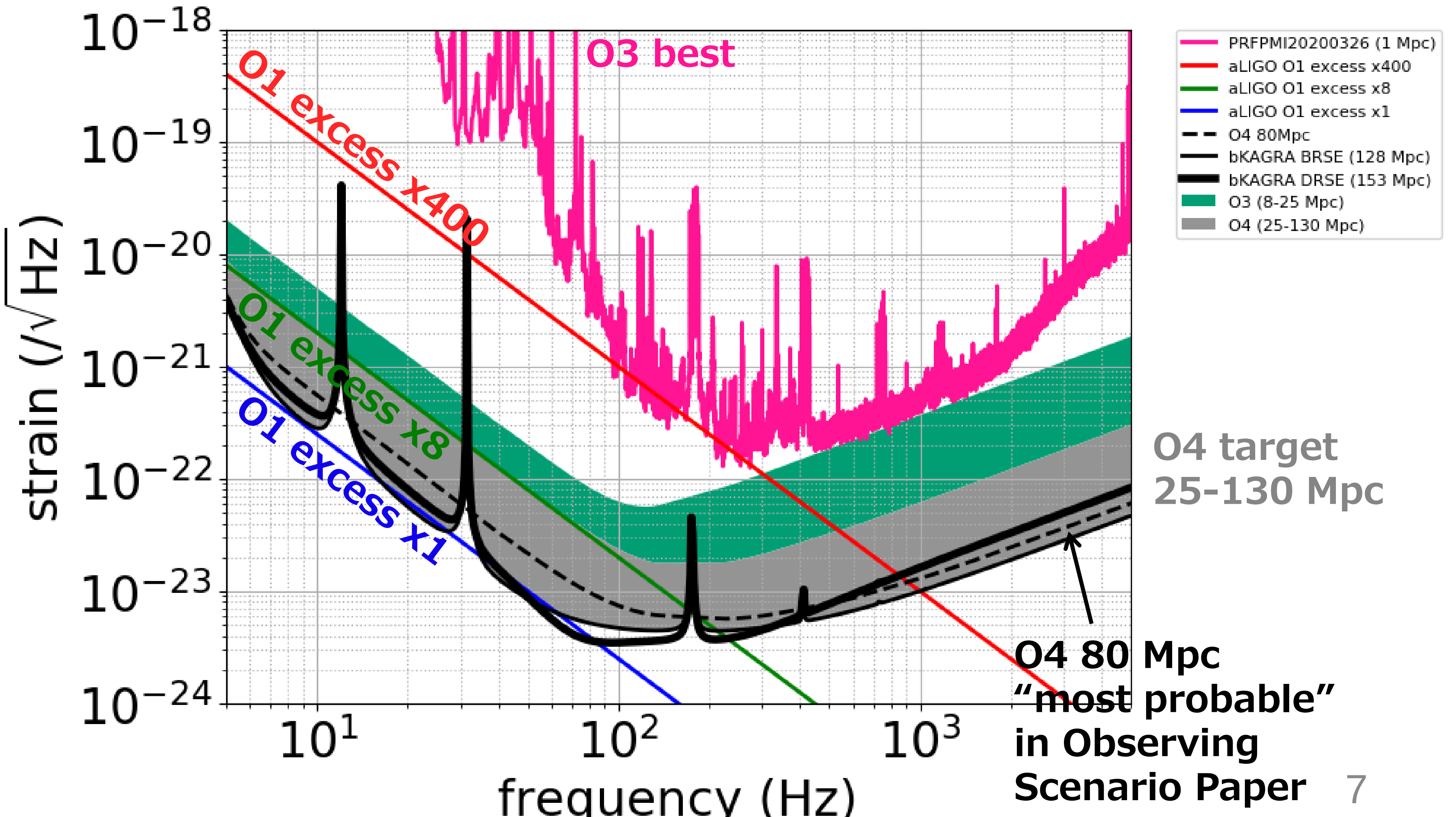
JGW-G2011555

3 W input at this time

970 kpc on Mar 26 was with 6.6 W input (klog #13840)

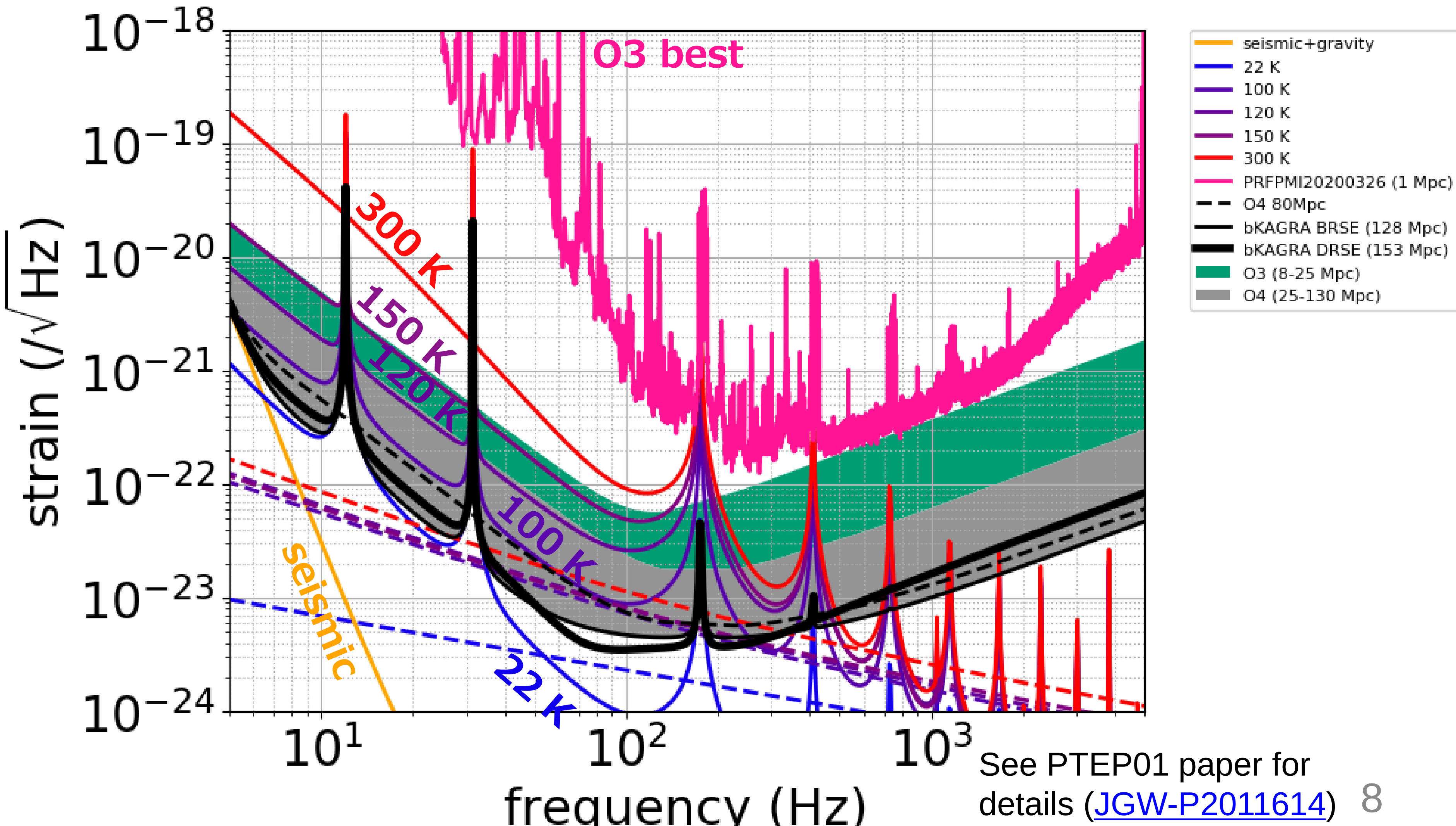
O3 best and O4 Target

- Excess noise should be reduced by at least ~1/20



Various Thermal Noise

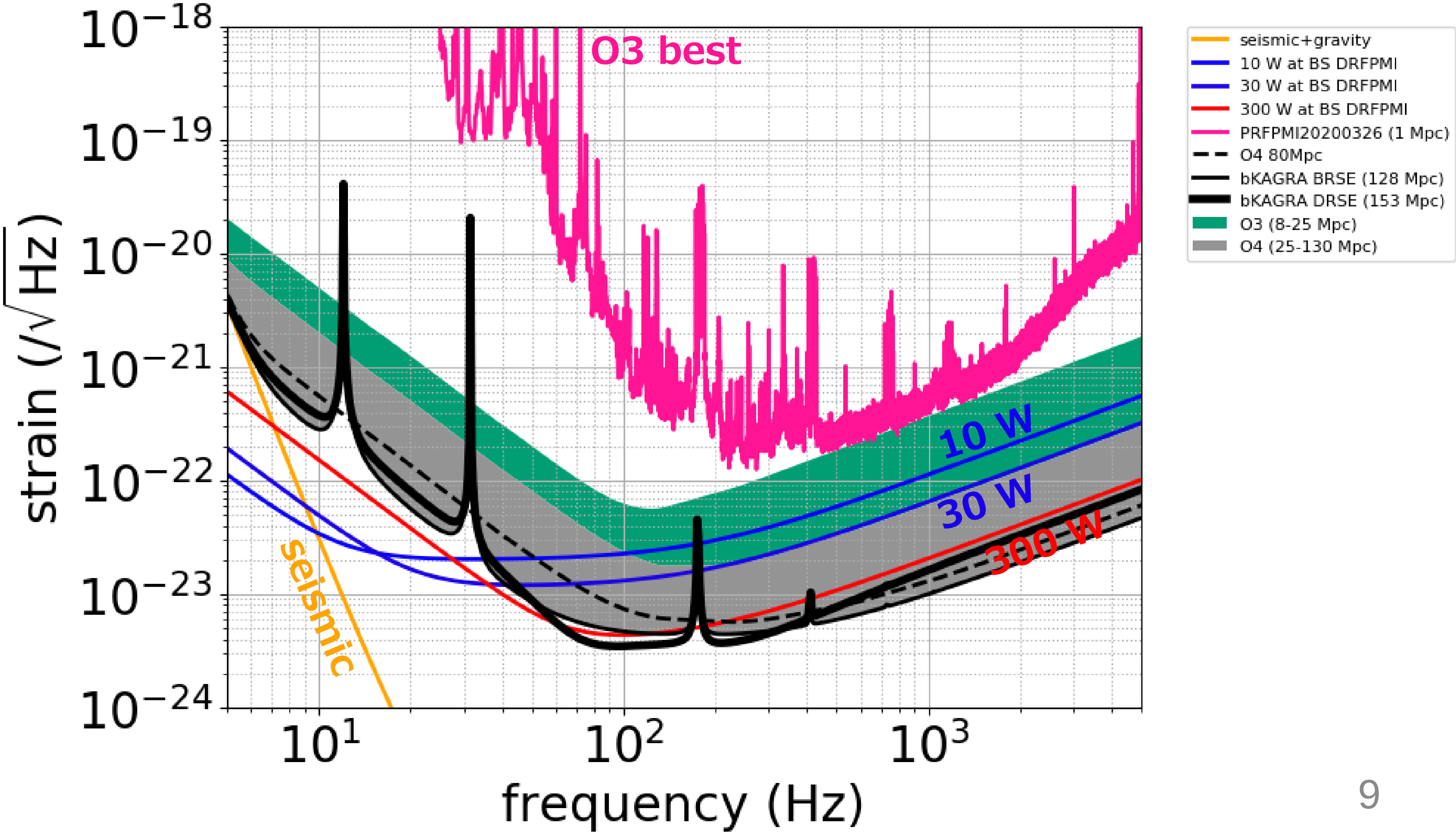
- 120 K thermal is comparable to x8 O1



See PTEP01 paper for details (JGW-P2011614)

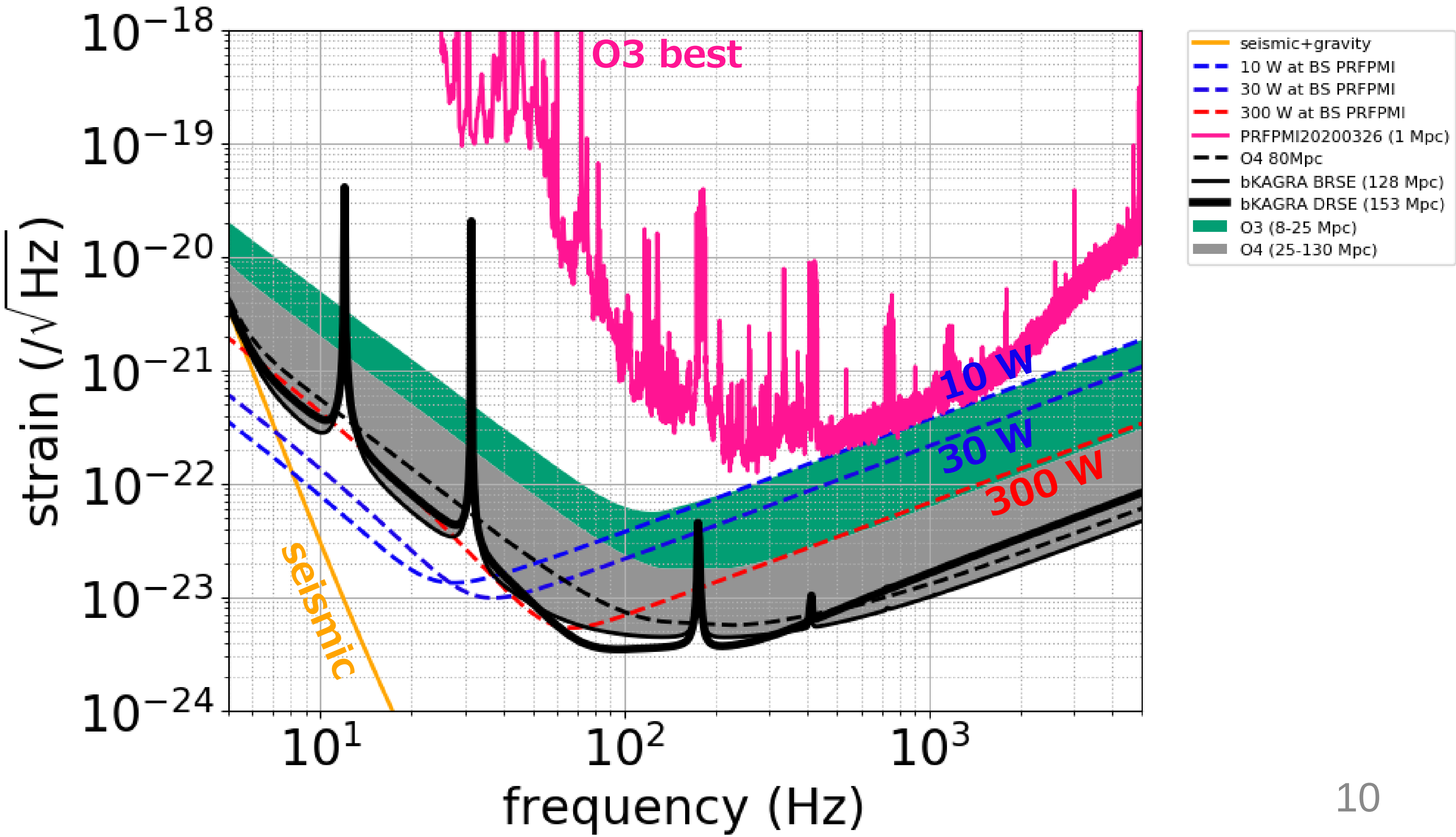
Various Quantum Noise (DR)

- 30 W at BS would be OK



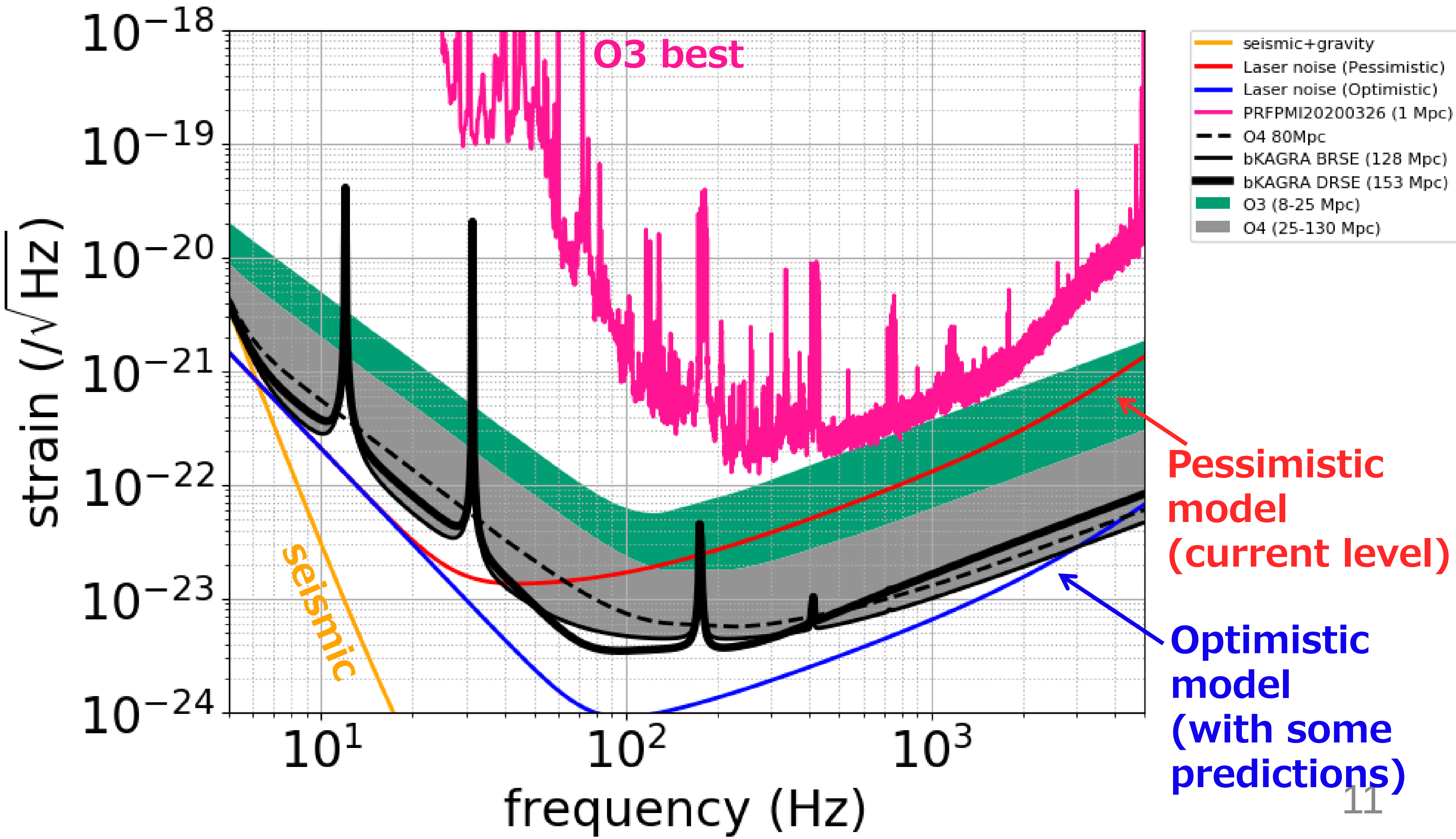
Various Quantum Noise (PR)

- DR necessary if excess noise is more than x8 O1



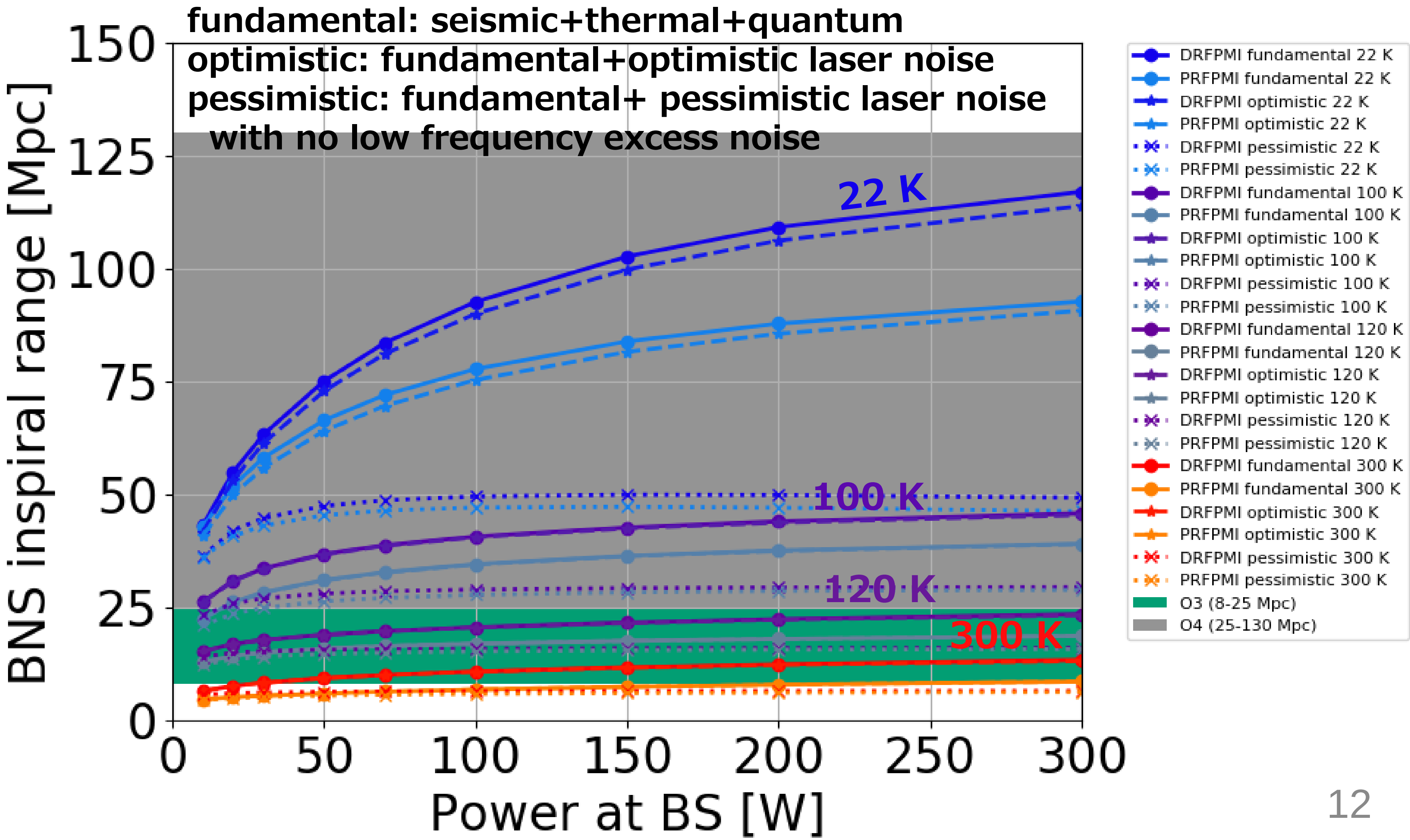
Laser Noises (Frequency + Intensity)

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



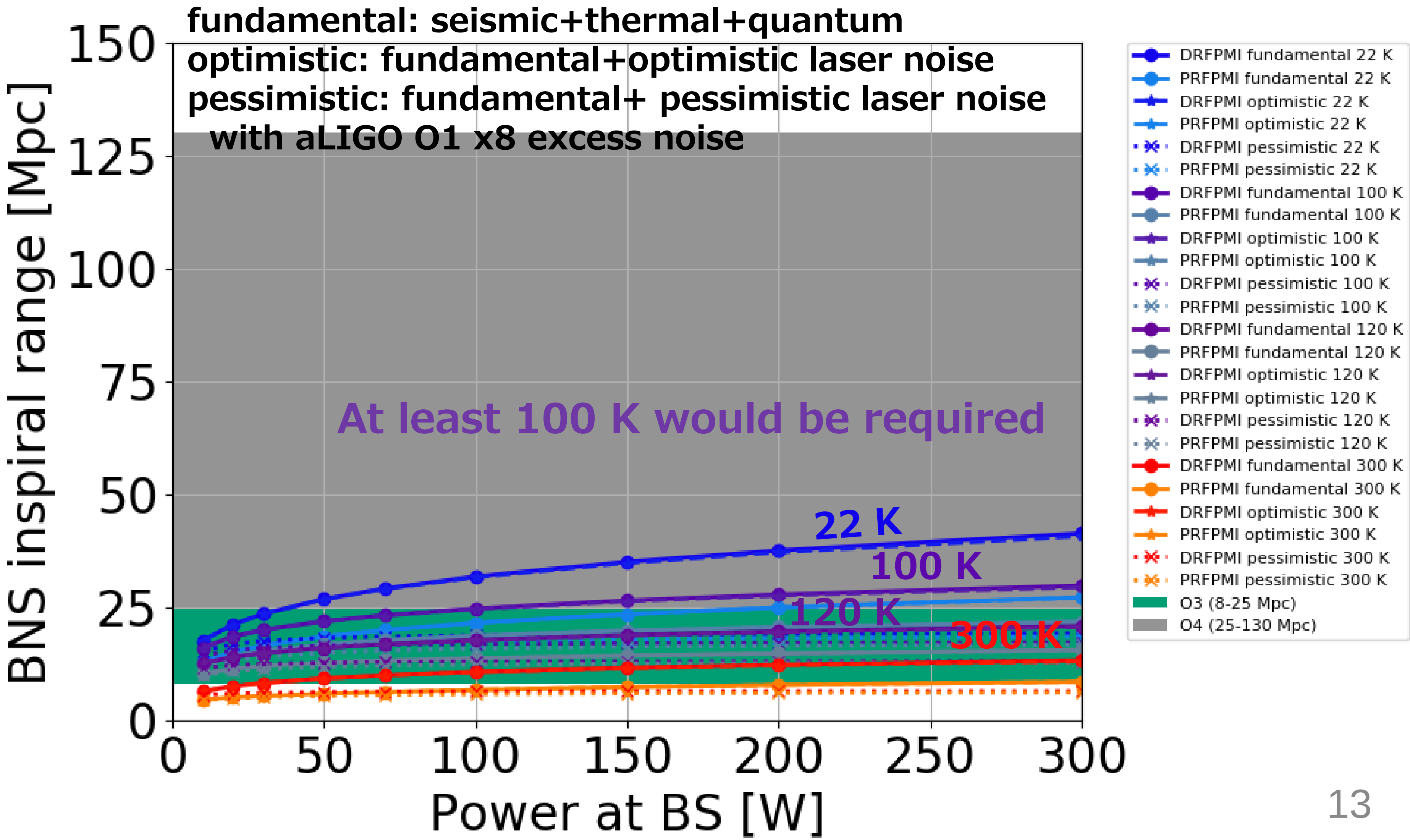
Inspiral Range vs Power (x0 O1)

- Power change not so significant with other noises



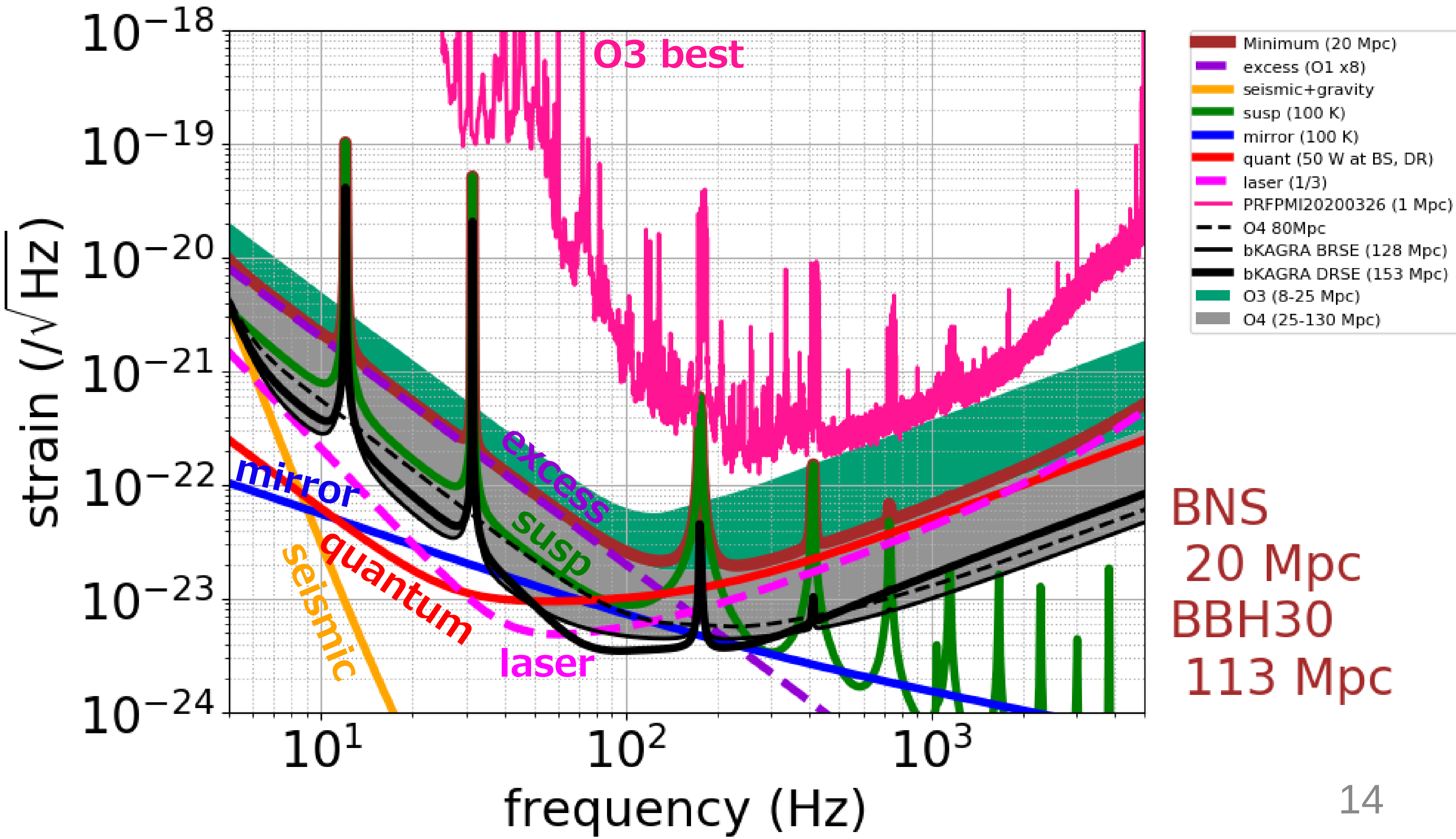
Inspiral Range vs Power (x8 O1)

- Power change not so significant with other noises



O4 “Minimum” Example

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

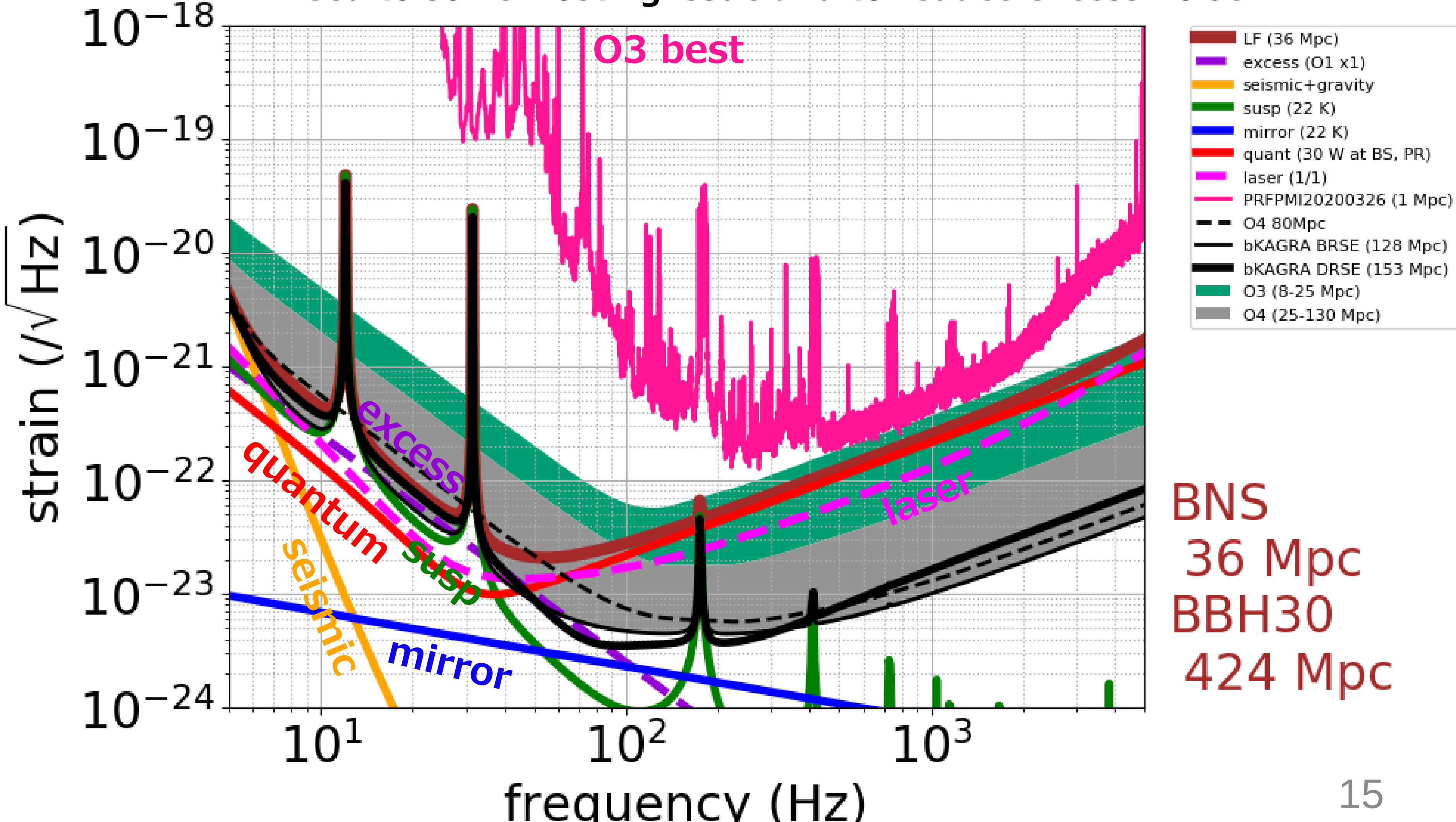


BNS
20 Mpc
BBH30
113 Mpc

O4 “Low Frequency” Example

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

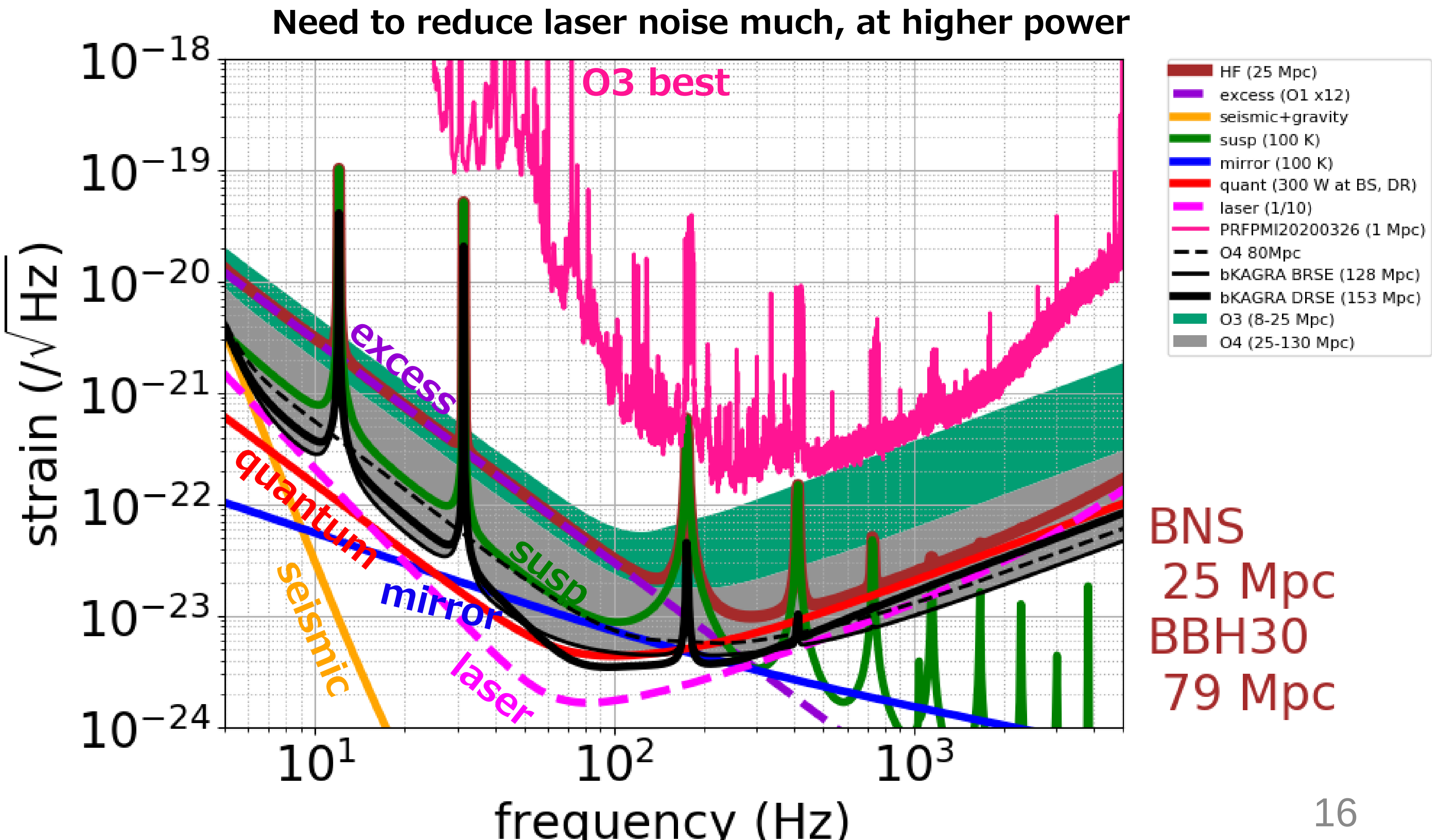
Need to solve frosting issue and to reduce excess noise



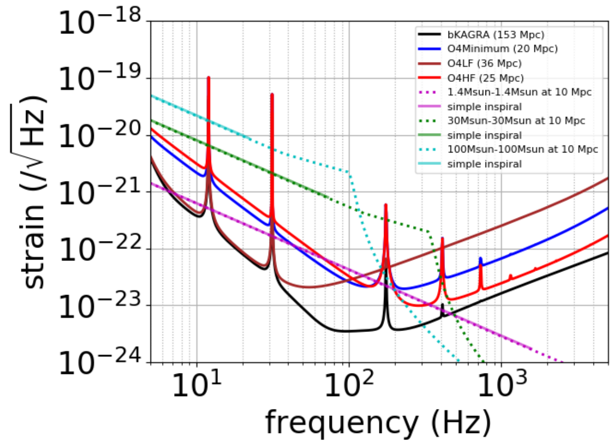
BNS
36 Mpc
BBH30
424 Mpc

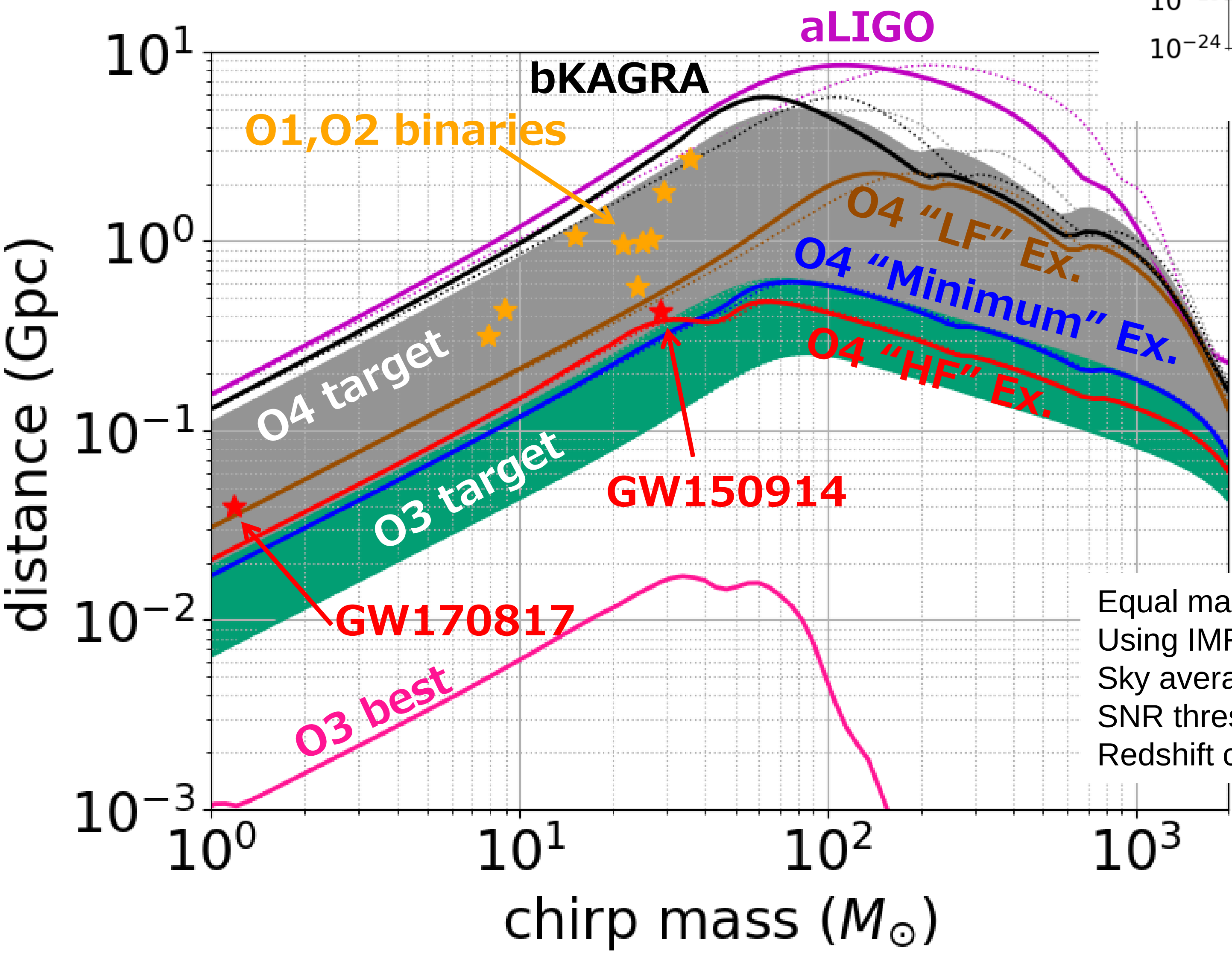
O4 “High Frequency” Example

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



Inspiral Range (IMR)





The ratio between BNS range and BBH30 range is almost constant for different sensitivity curves since the bucket is at ~100 Hz

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

Conclusions So Far

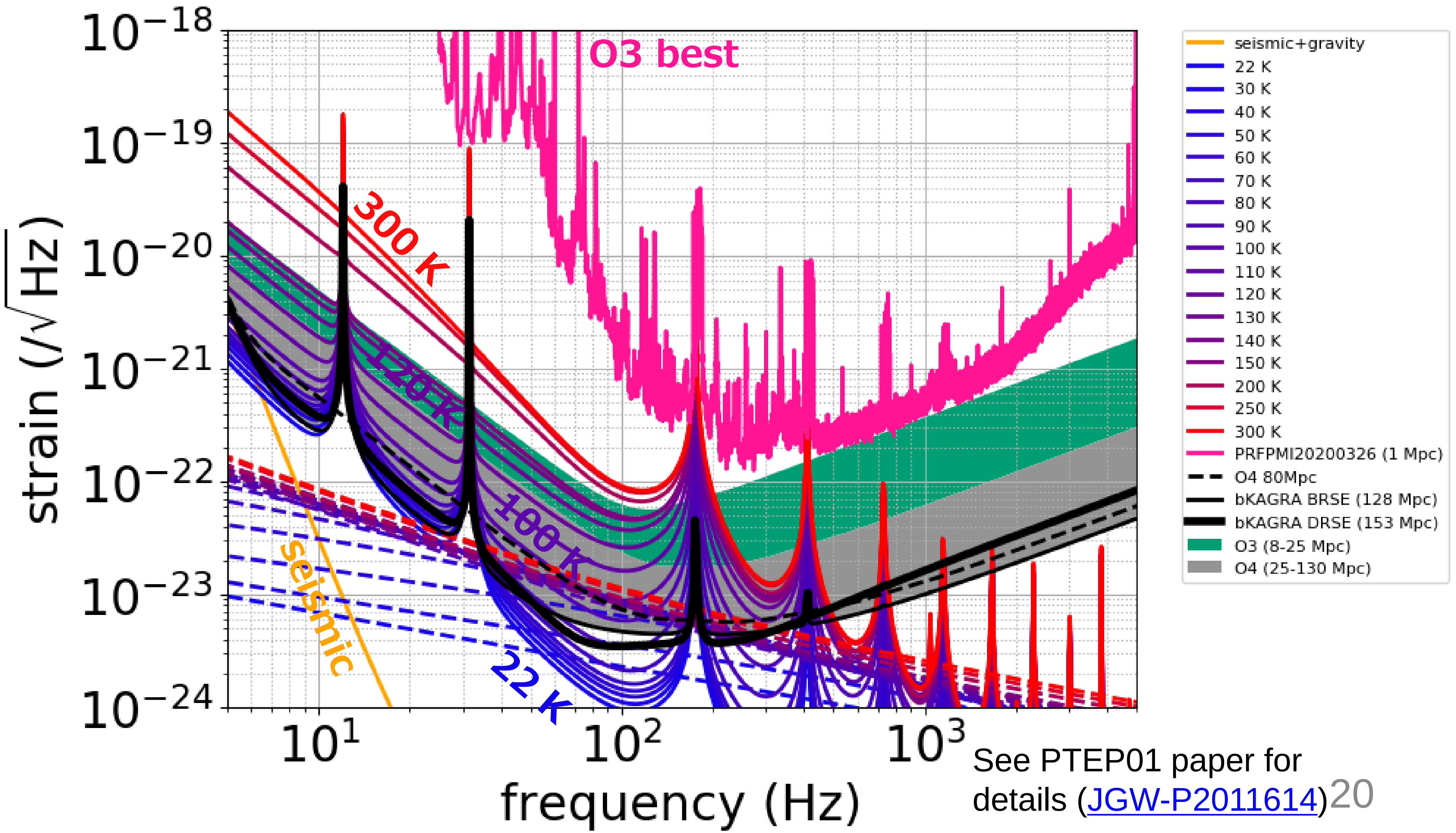
- Should be below ~100 K (achieving O4 target above 120 K is not possible)
- Low-mid frequency noise should be reduced at least by a factor of ~20 (more at low frequencies)
- DR necessary if excess noise is more than x8 O1
- Higher power is better, but not so important especially when other noises are high (~30 W at BS could 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

Various Thermal Noise

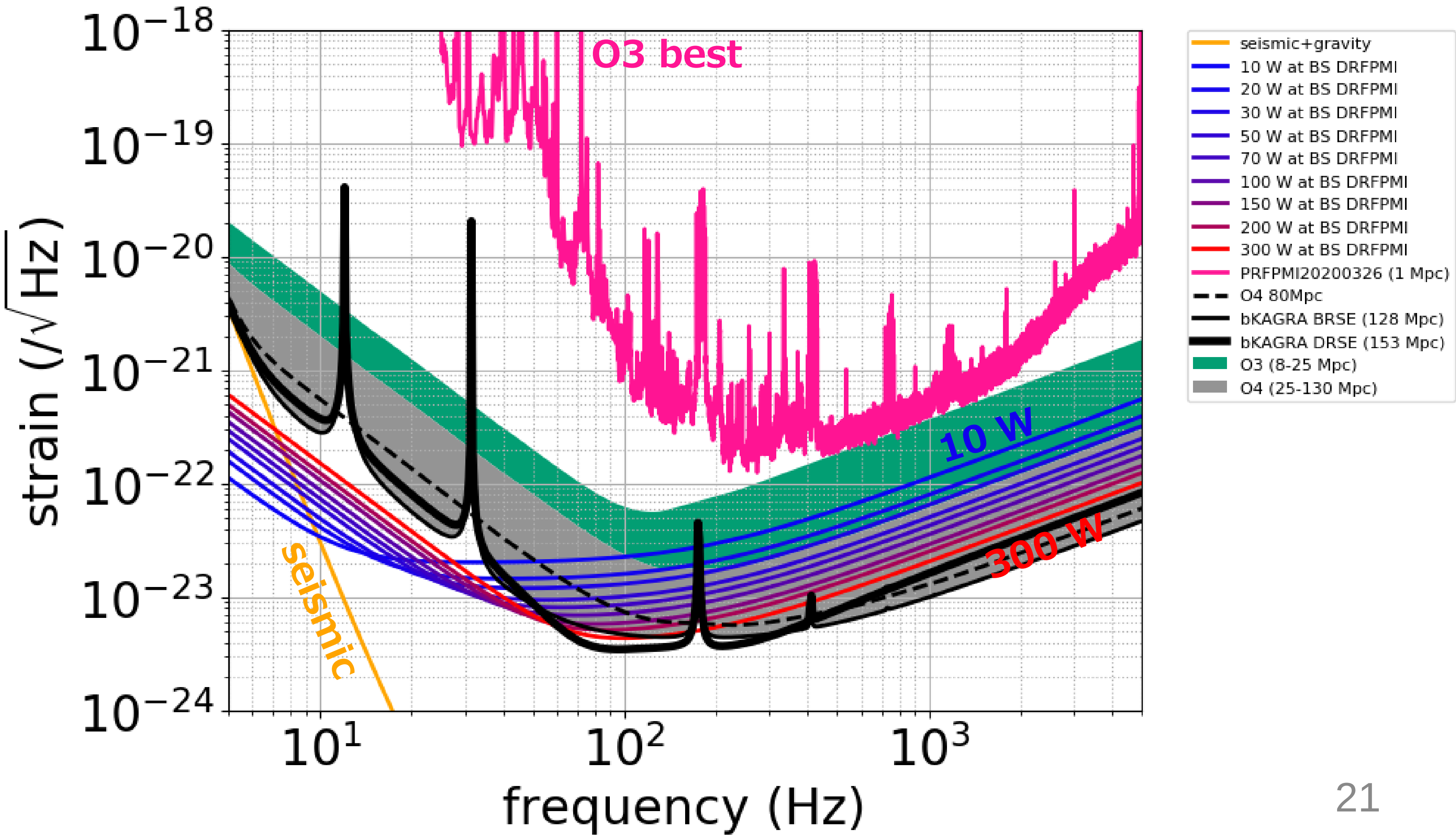
- All temperatures



See PTEP01 paper for details (JGW-P2011614)

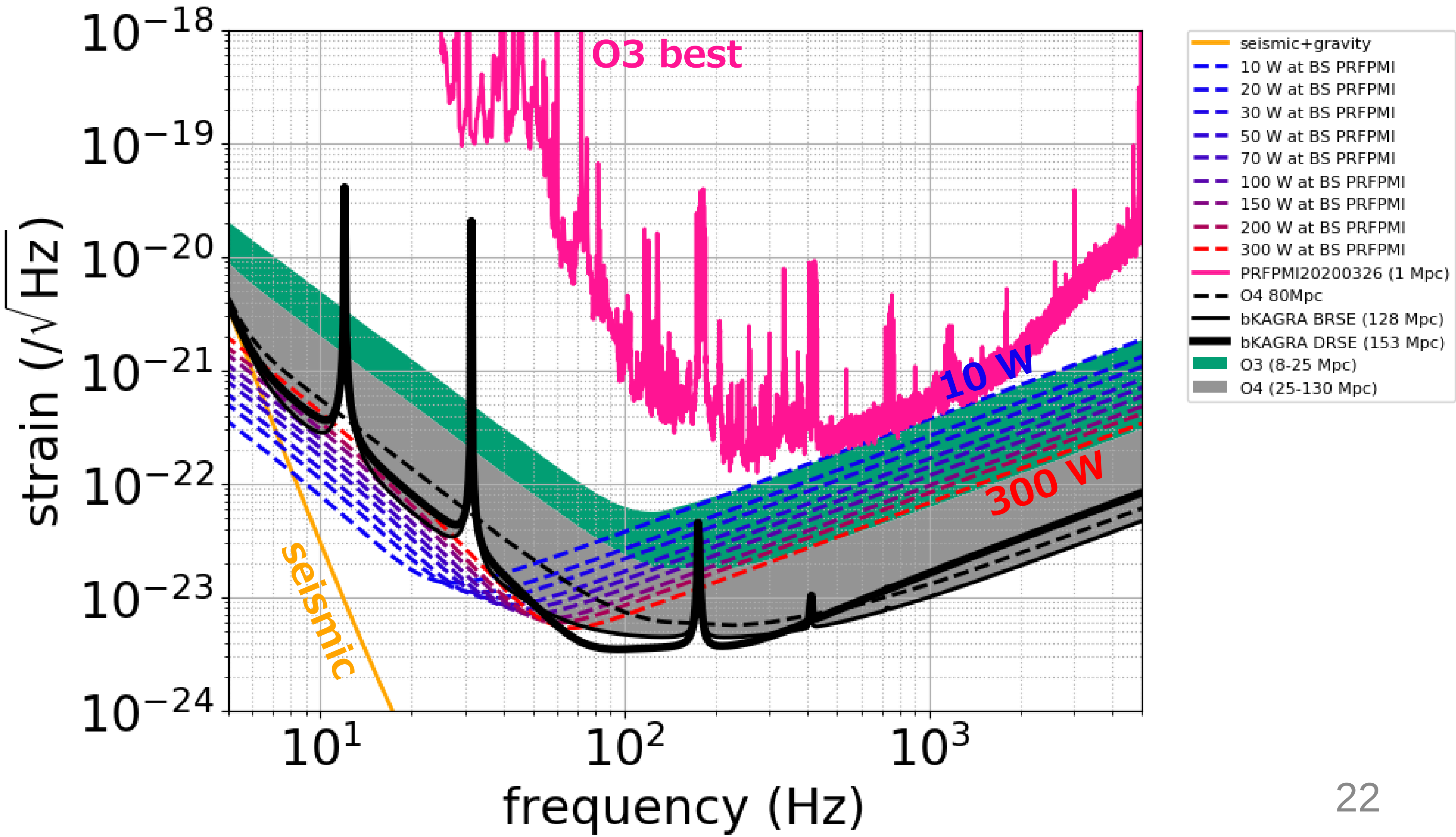
Various Quantum Noise (DR)

- All powers



Various Quantum Noise (PR)

- All powers

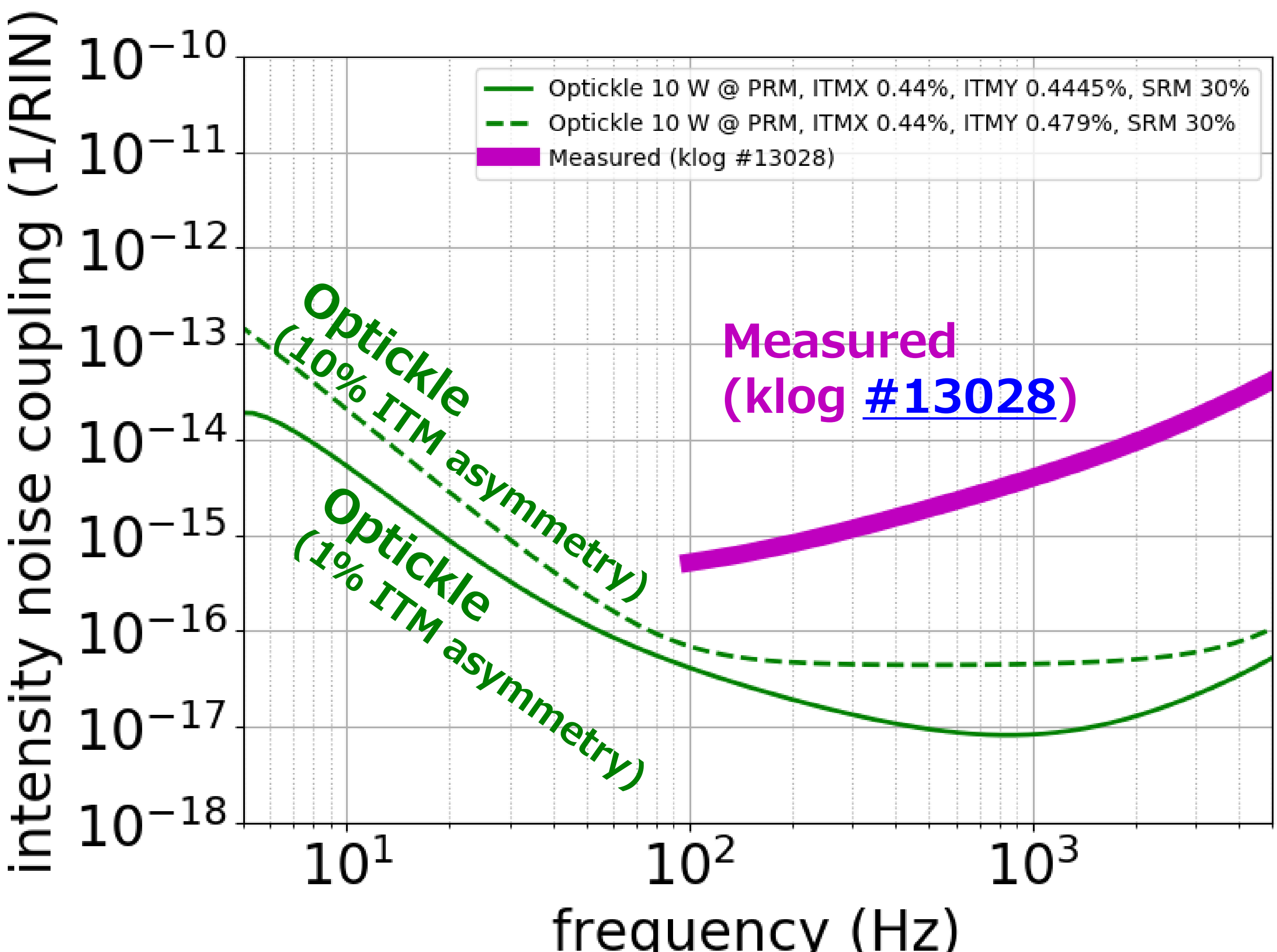


How to Realize 100 K ?

- 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)
  - 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.

Laser Intensity Noise Coupling

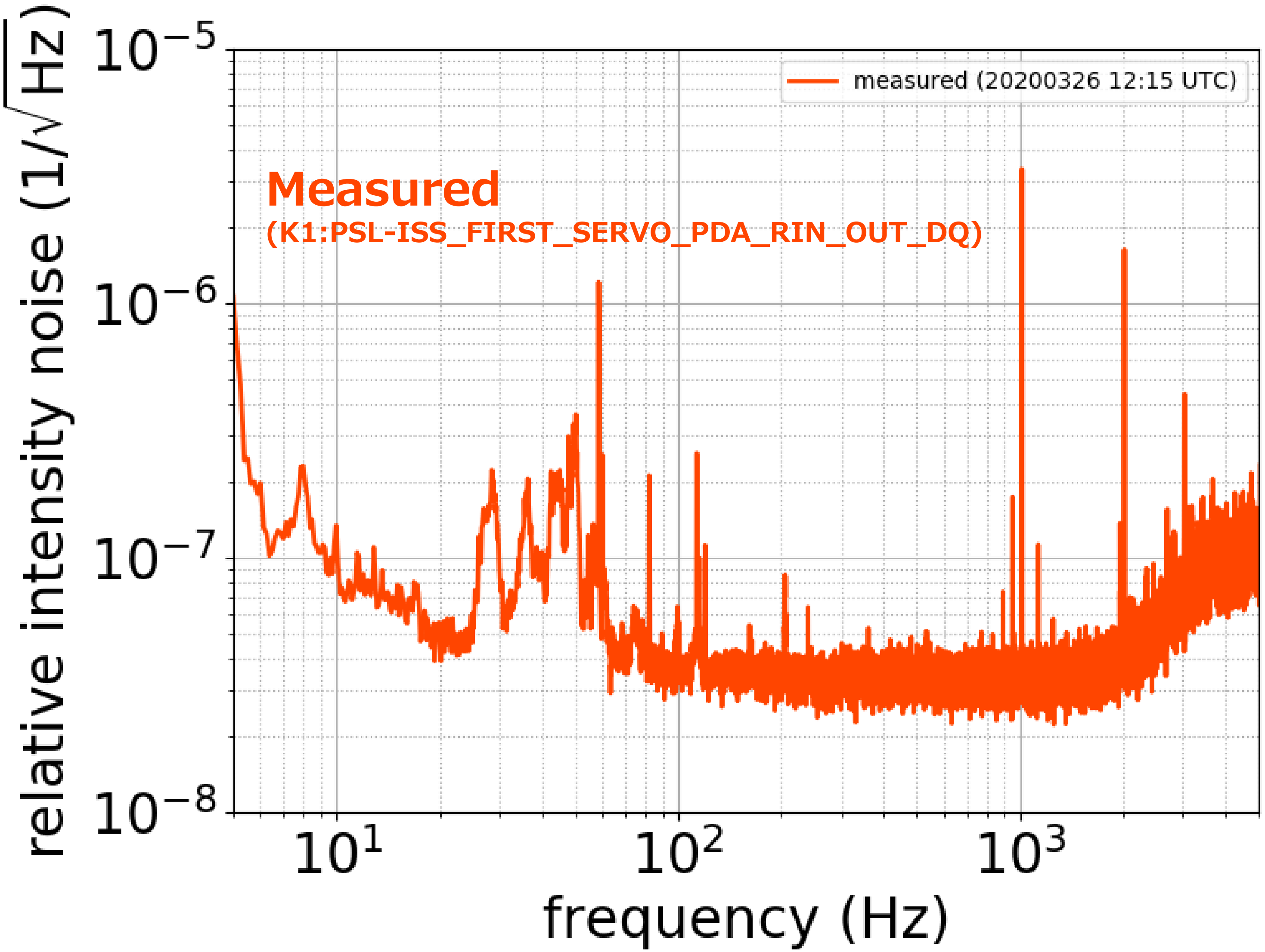
- Measured to be larger than Optickle model



HR, TWE maps and birefringence not included in Optickle model

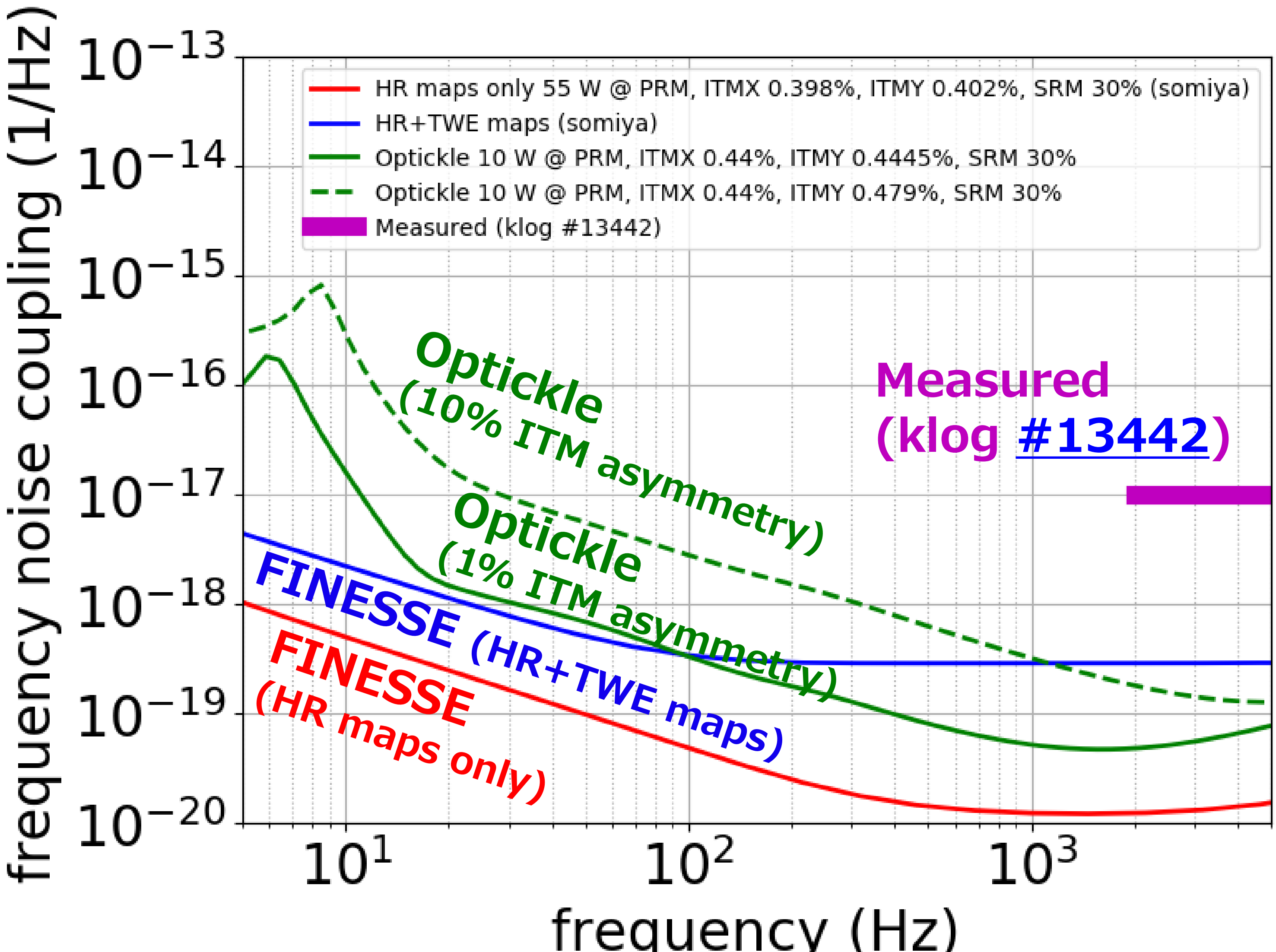
Laser Intensity Noise

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



Laser Frequency Noise Coupling

- Measured to be larger than various models



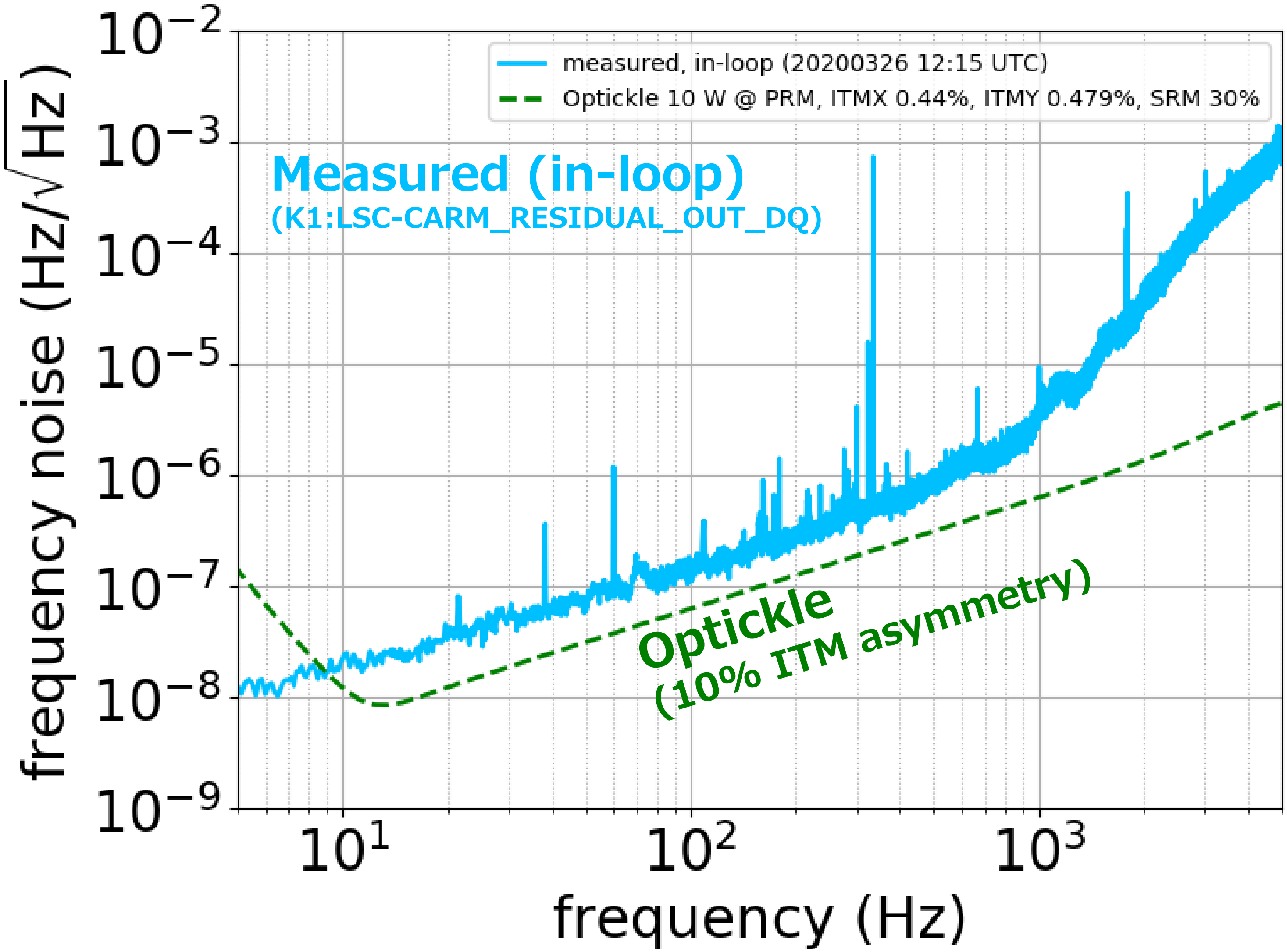
See, also JGW-T1910352

Birefringence not included in FINESSE model

HR, TWE maps and birefringence not included in Optickle model

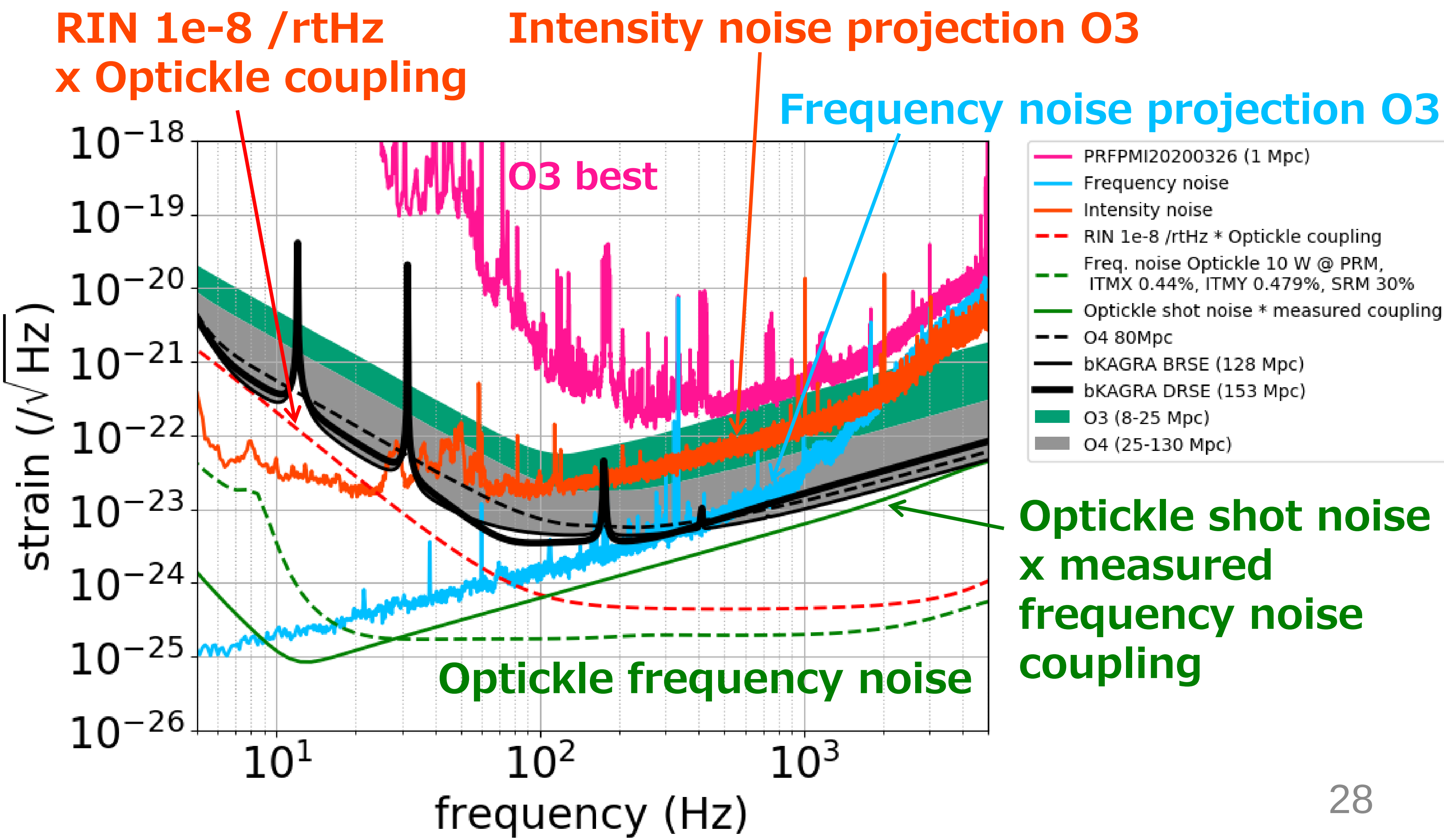
Laser Frequency Noise

- 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