

# **Status of KAGRA: Instrument Updates for O4**

Yuta Michimura

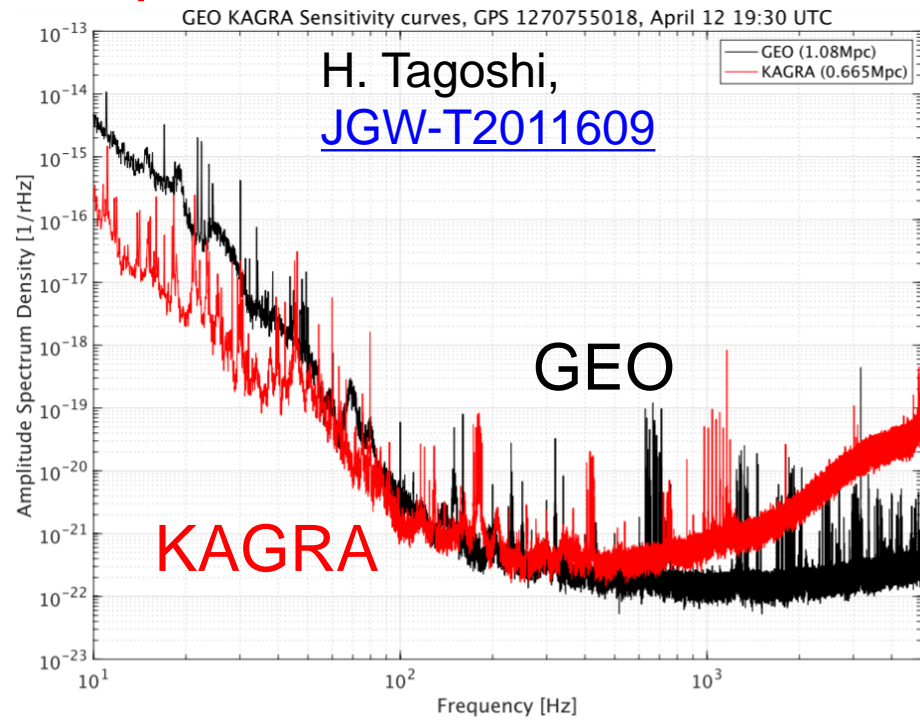
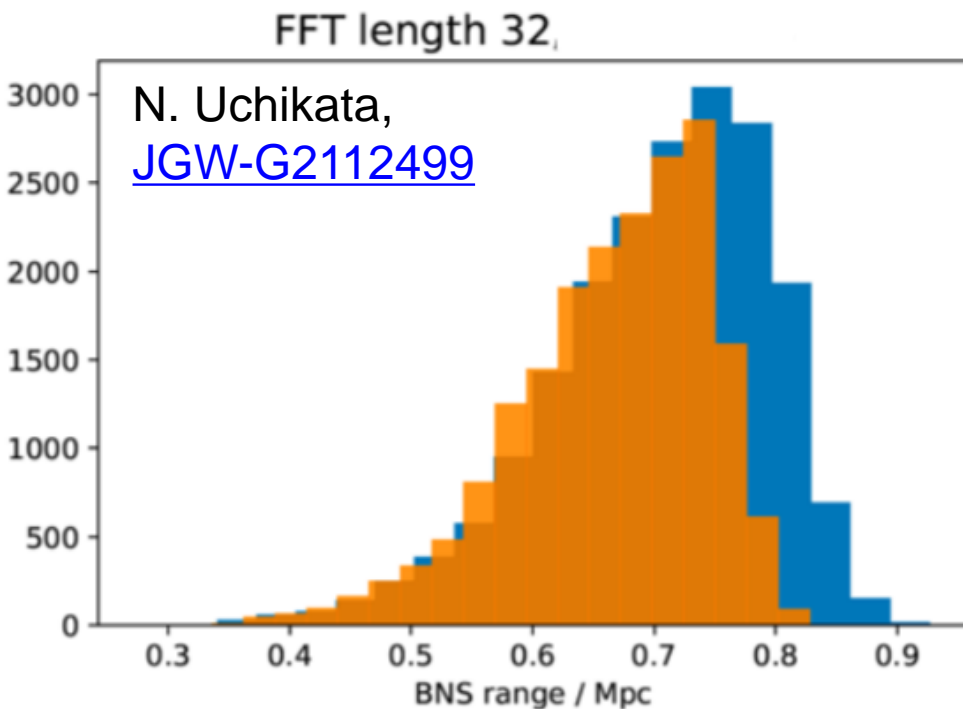
Department of Physics, University of Tokyo

[michimura@phys.s.u-tokyo.ac.jp](mailto:michimura@phys.s.u-tokyo.ac.jp)

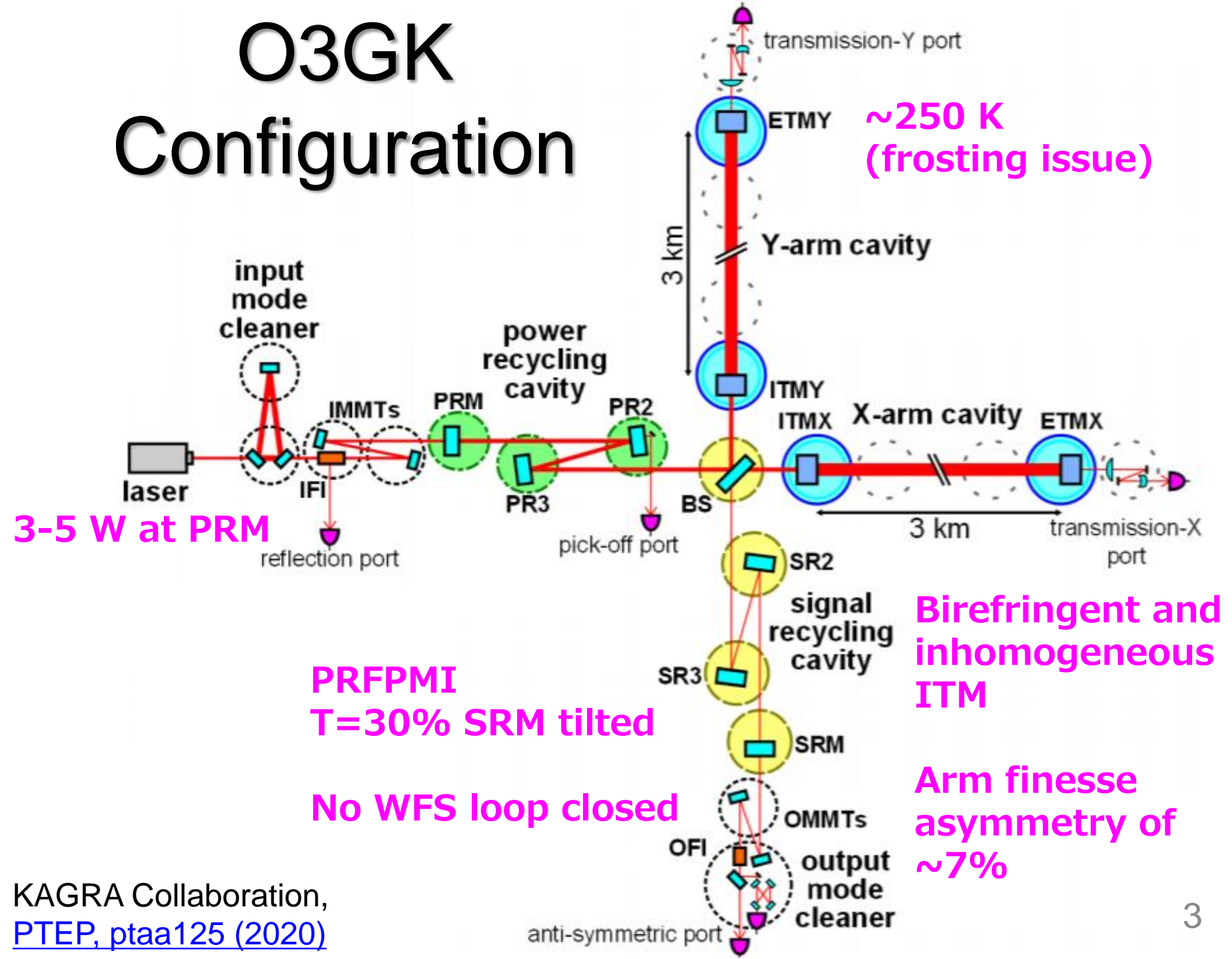
on behalf of the KAGRA Collaboration

# Status of KAGRA

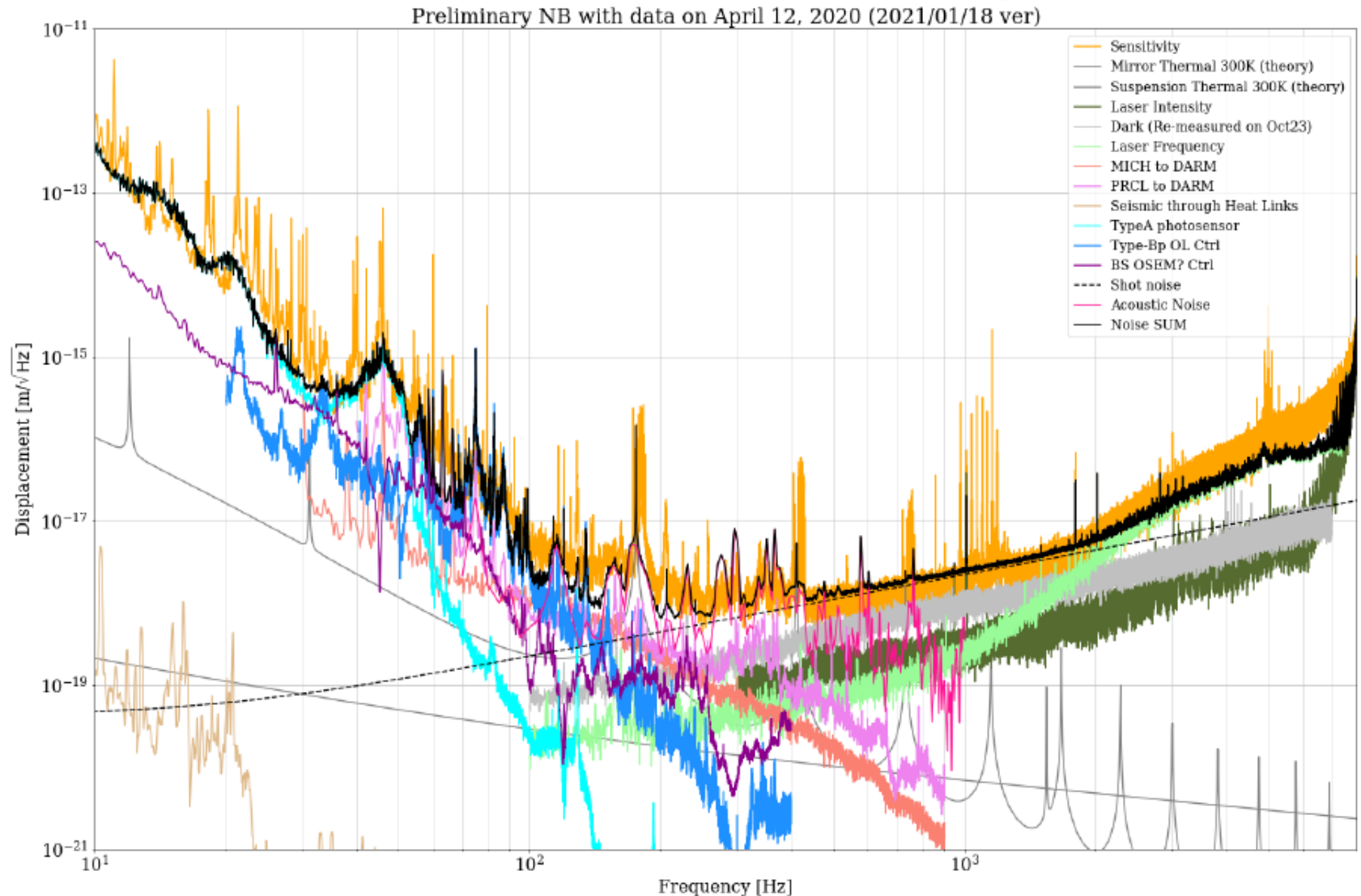
- **O3GK** observing run on April 7-21, 2020 with GEO
- Detector sensitivity was  **$\sim 0.7$  Mpc** ( $\sim 1$  Mpc at best)  
We originally anticipated 8-25 Mpc for O3
- Detector configuration was **power-recycled FPMI**  
We originally anticipated dual recycling
- Focus of this talk: *What do we expect for O4?*



# O3GK Configuration



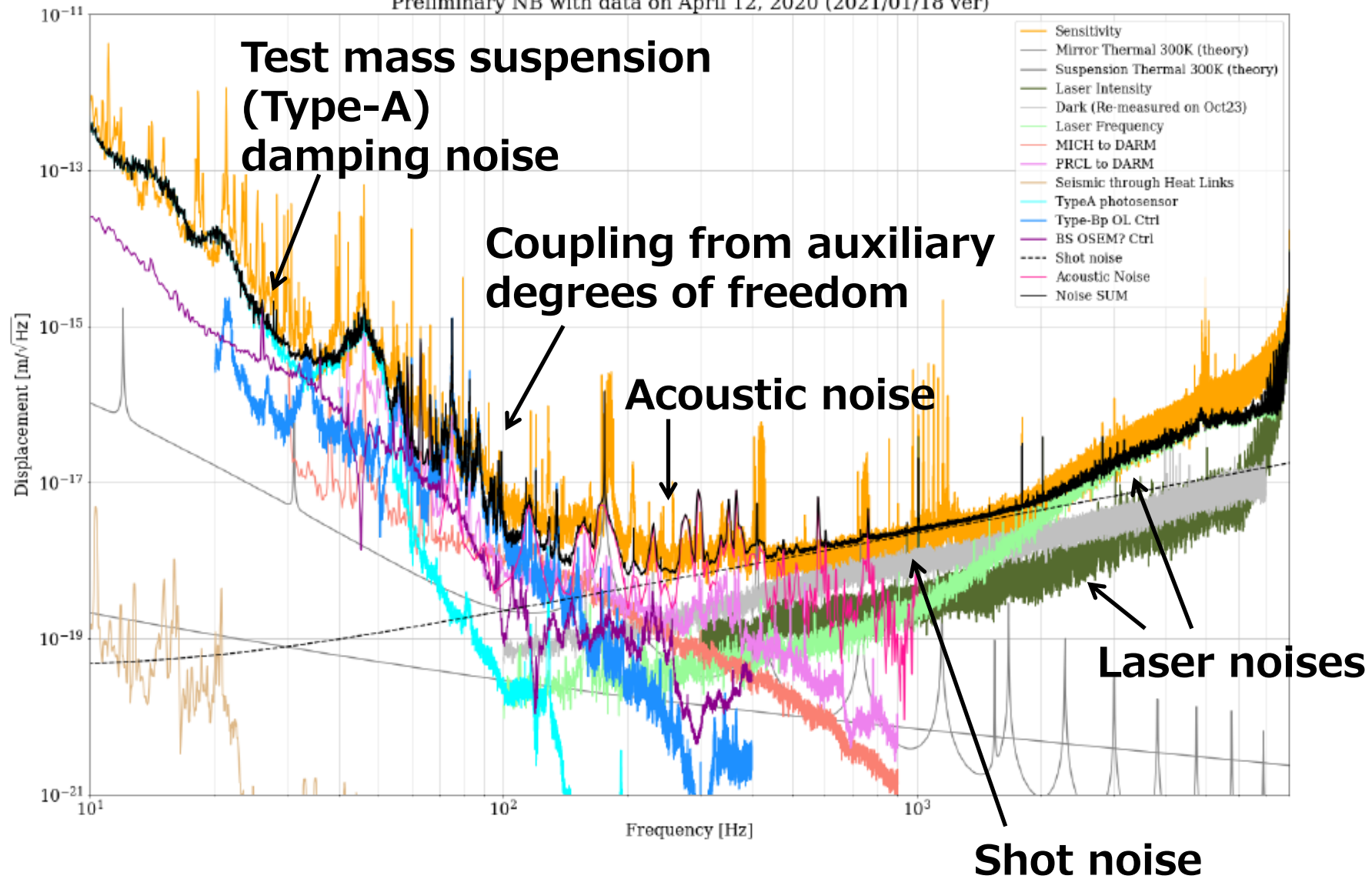
# O3GK Noise Budget





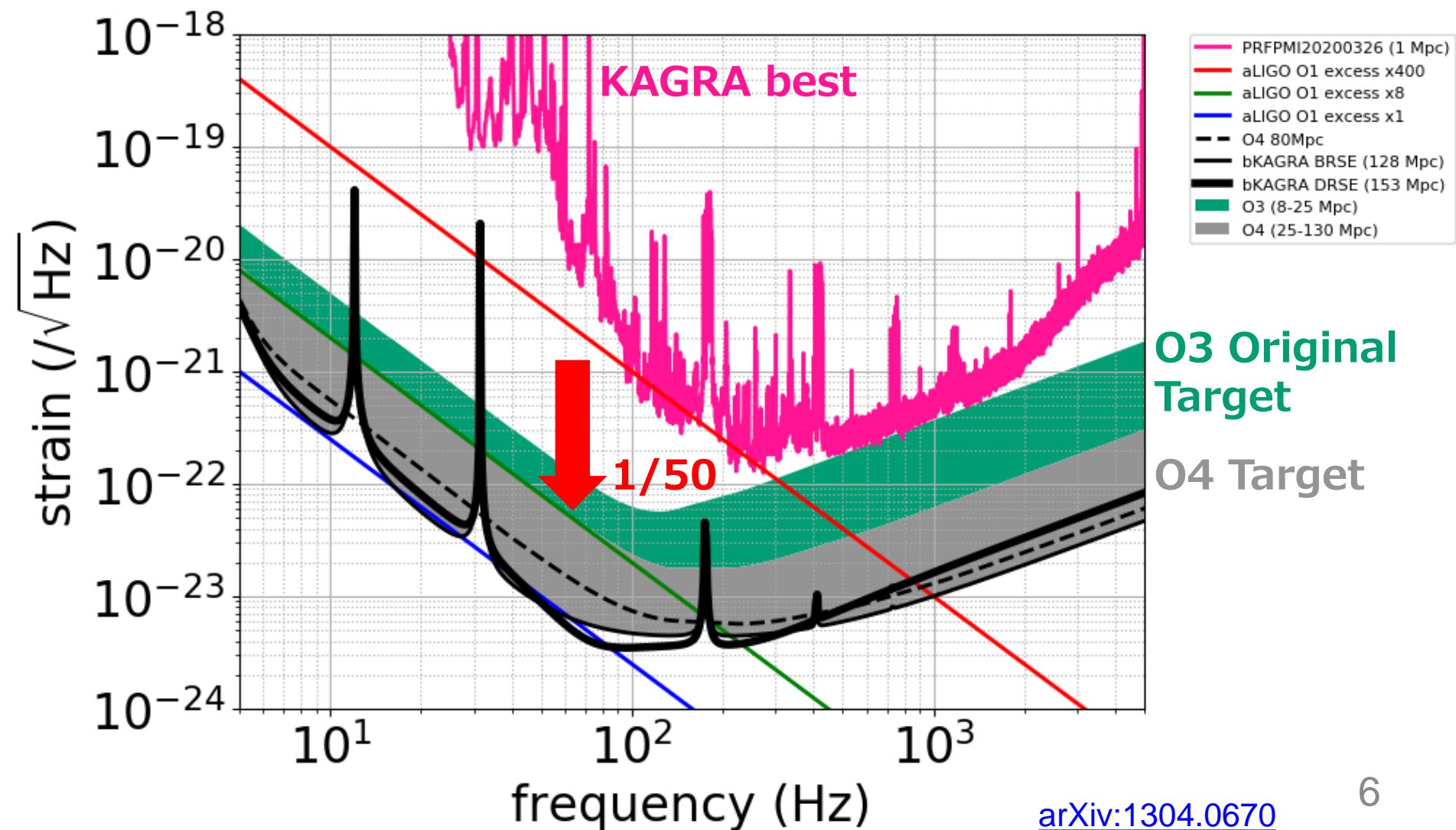
# O3GK Noise Budget

Preliminary NB with data on April 12, 2020 (2021/01/18 ver)



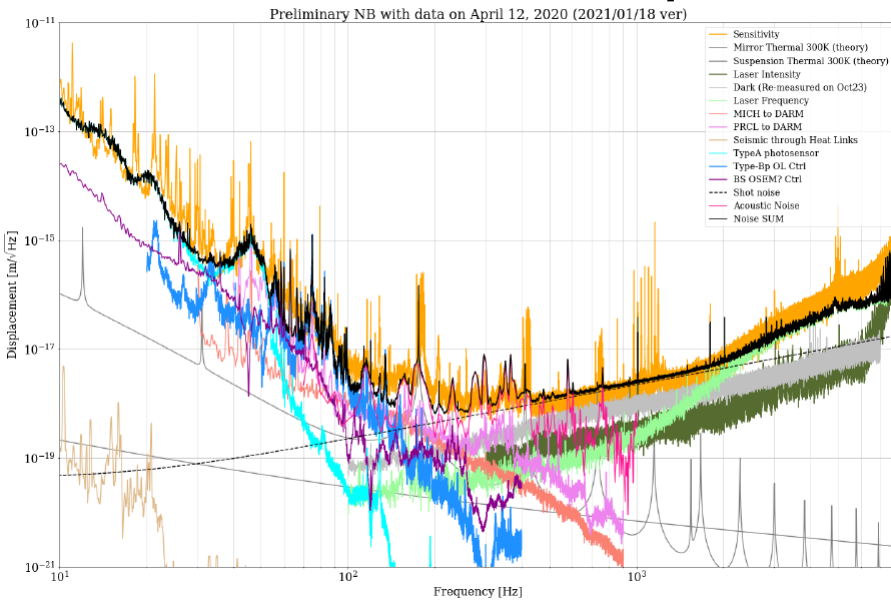
# O4 Target: 25 Mpc at least

- Excess noise has to be reduced by  $\sim 1/50$  at the bucket



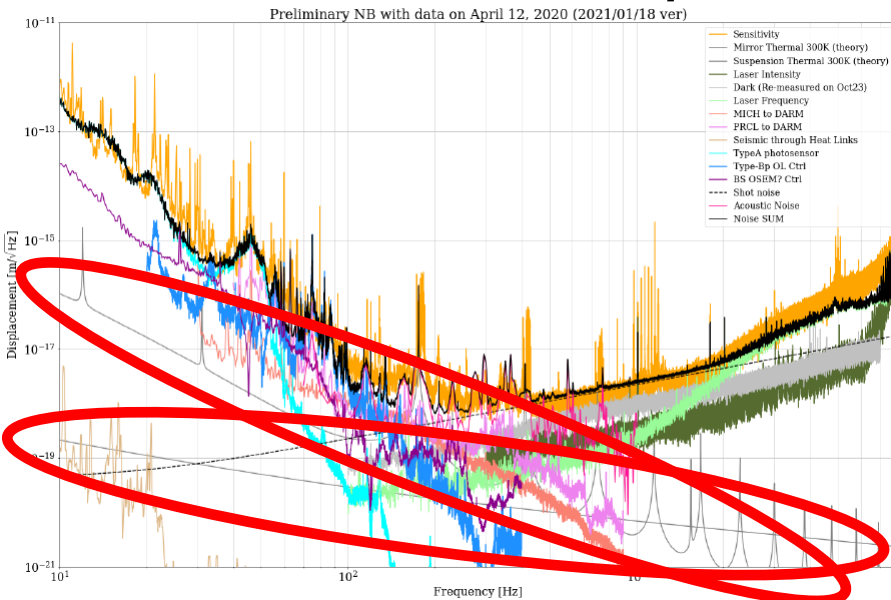
# Instrument Updates

- Thermal noise
- Laser noises (frequency noise and intensity noise)
- Shot noise
- Acoustic noise
- Coupling from auxiliary degrees of freedom
- Test mass suspension damping noise



# Instrument Updates

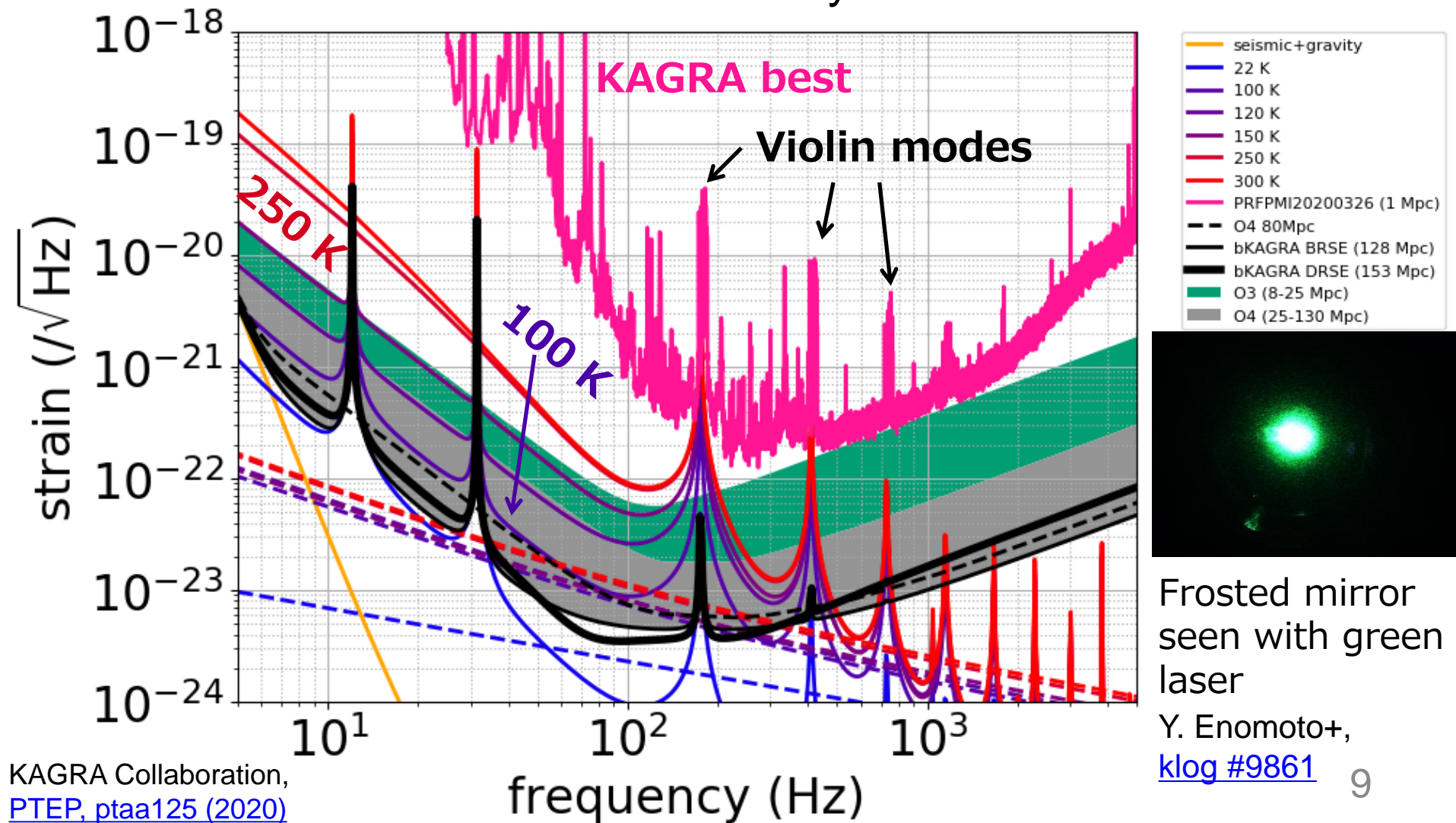
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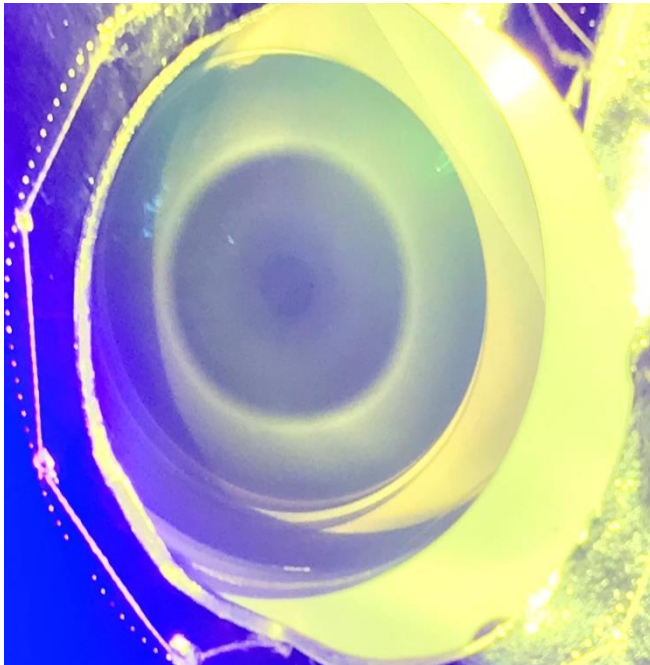
# Thermal Noise vs Temperature

- In O3GK, ~250 K due to test mass frosting
- At least **below ~100 K** necessary for O4

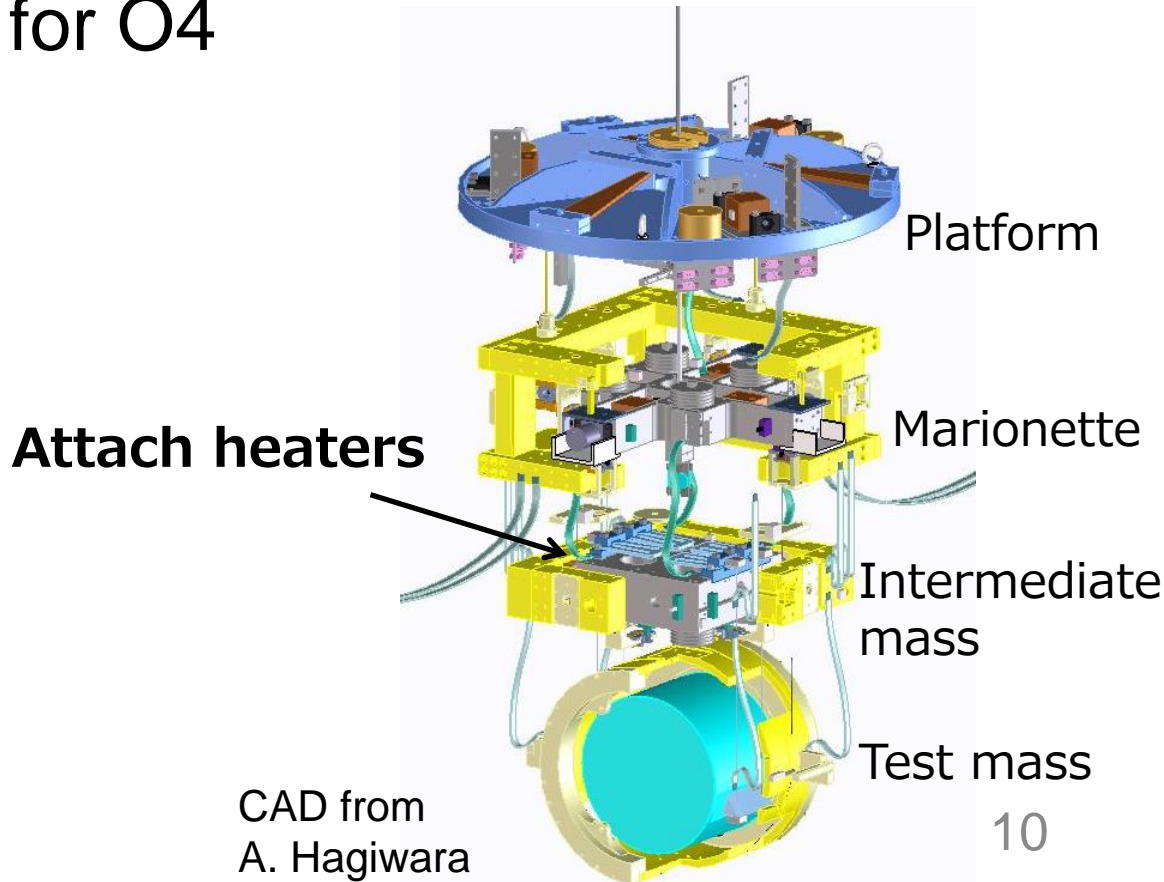


# Defrosting

- Heaters are attached to the intermediate mass stages and viewports for defrosting
- **Test with ITMY completed** with promising results
- Aiming for  $\sim 20$  K for O4



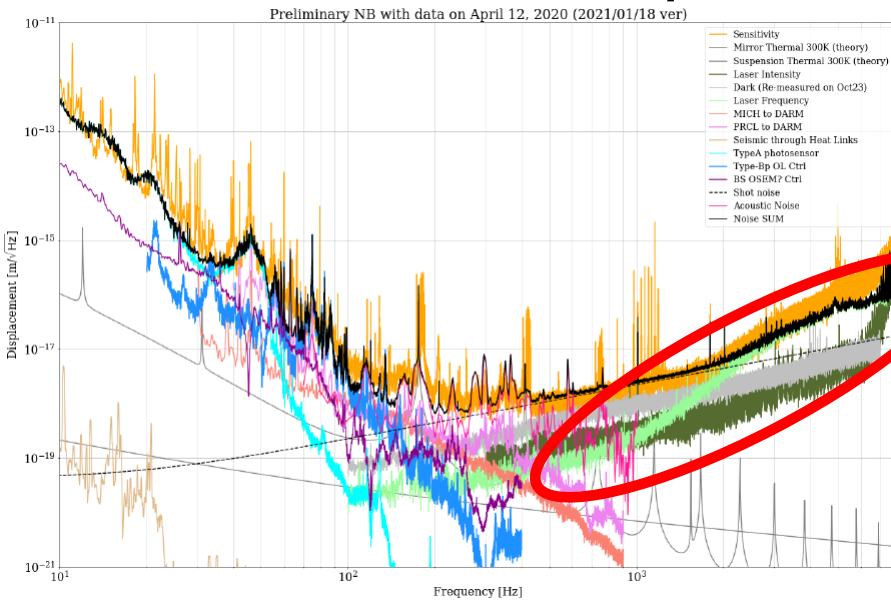
Frosted viewport  
(Photo from N. Kimura)



CAD from  
A. Hagiwara

# Instrument Updates

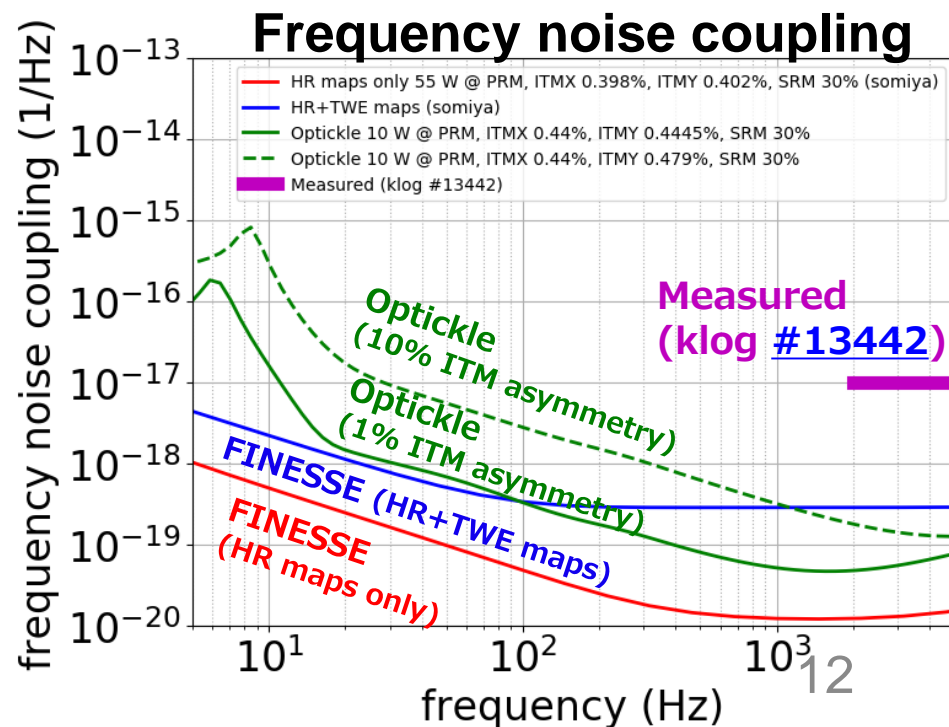
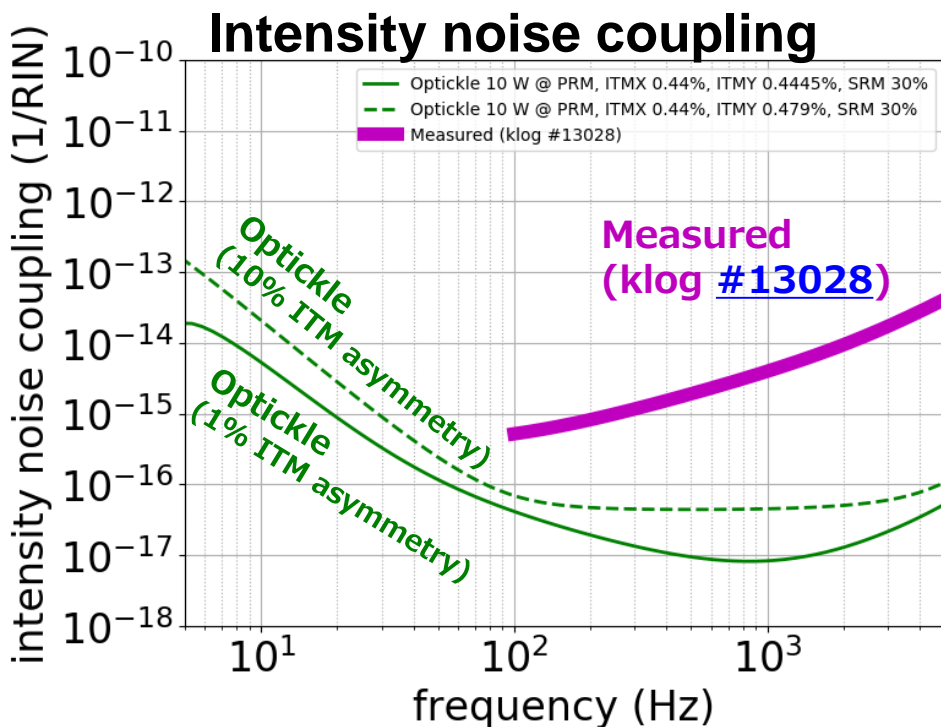
- Thermal noise
- **Laser noises (frequency noise and intensity noise)**
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# Laser Noises: Coupling

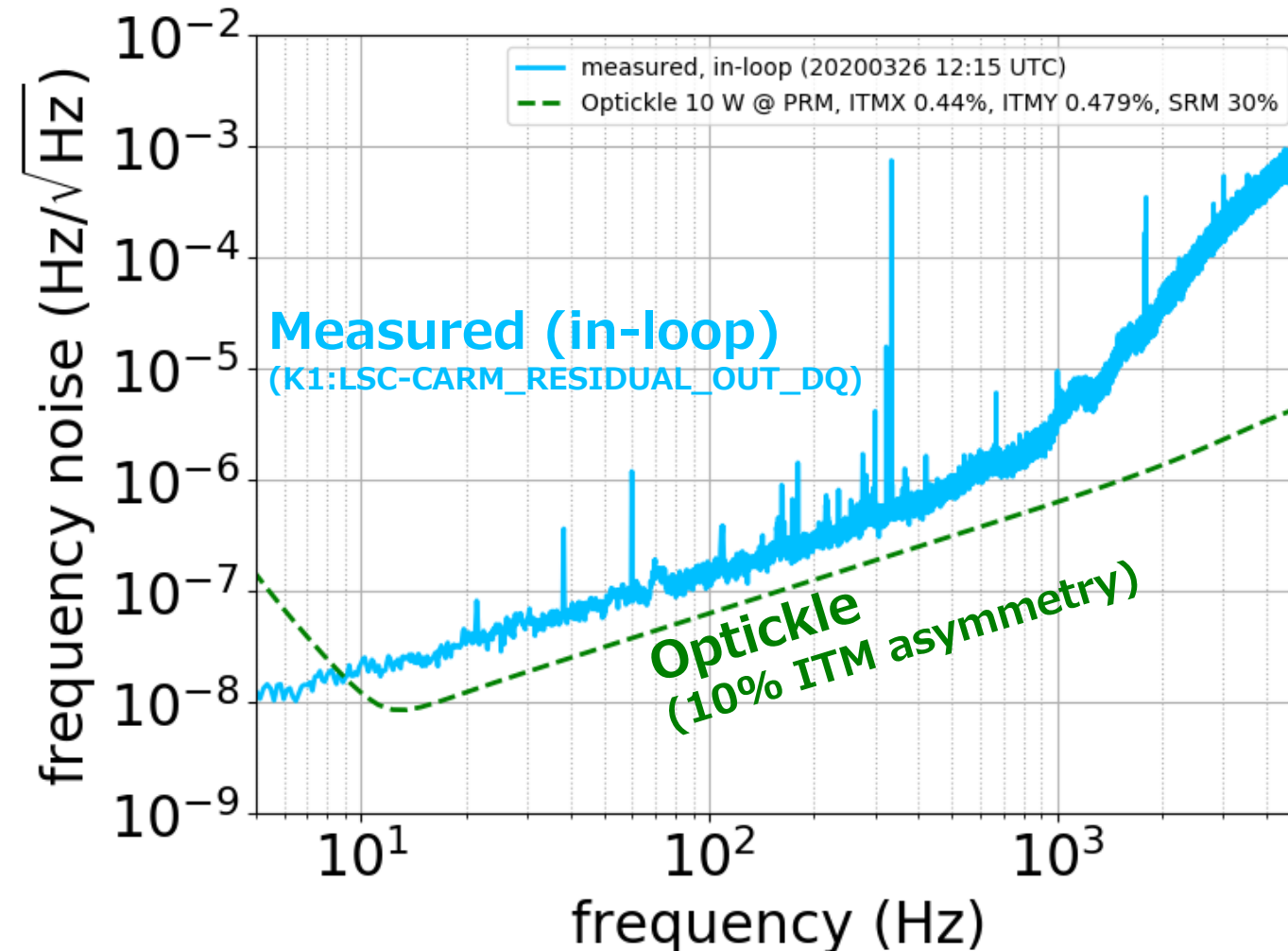
- Coupling was larger than expected by **1-2 orders of magnitude** (probably due to birefringence)
- **New ITMs are not available by O4**
- **Better interferometer alignment** would reduce the coupling (with WFS)

YM, K. Somiya, K. Yamamoto, [JGW-T2011662](#)



# Laser Frequency Noise

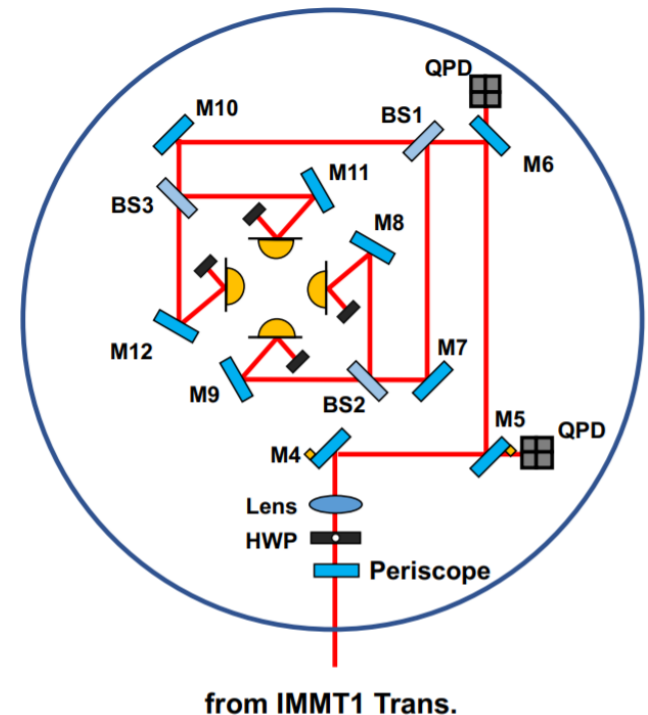
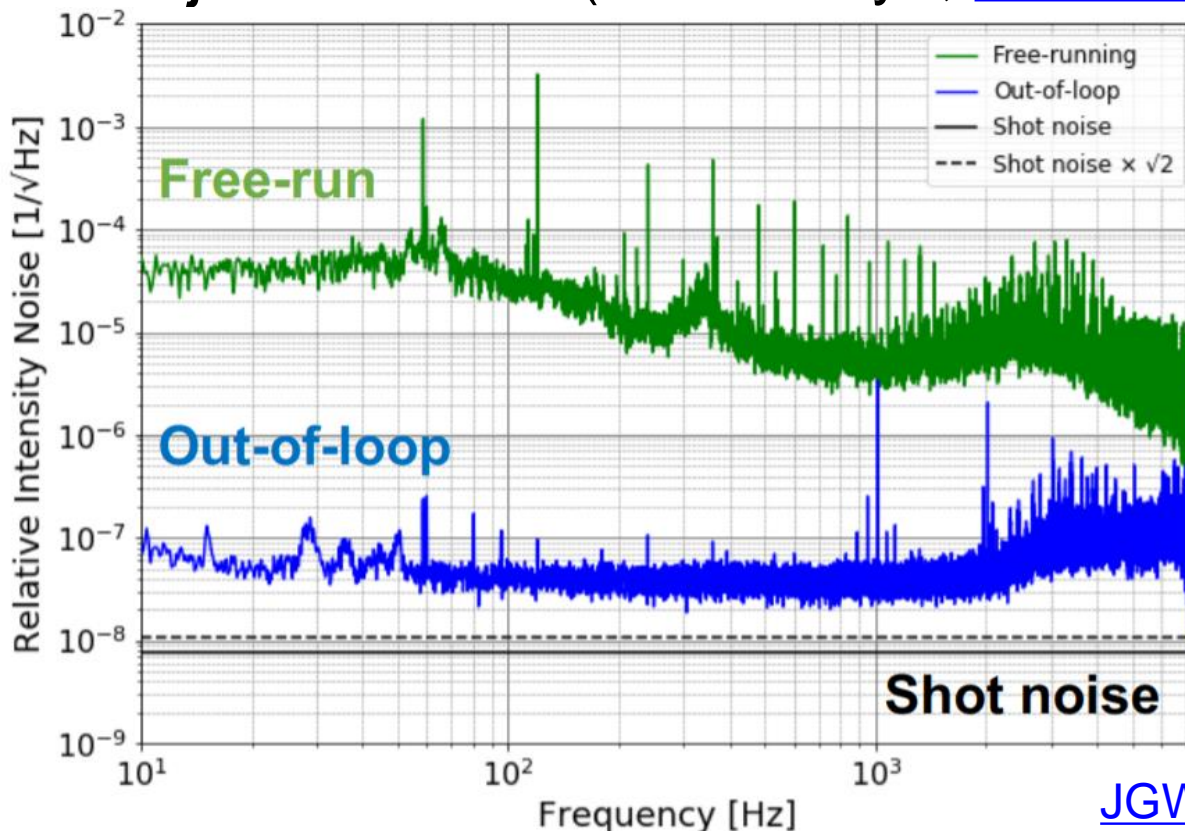
- Almost shot noise limited ( $\sim 10$  mW at PD) at 100 Hz
- Not very critical for BNS range





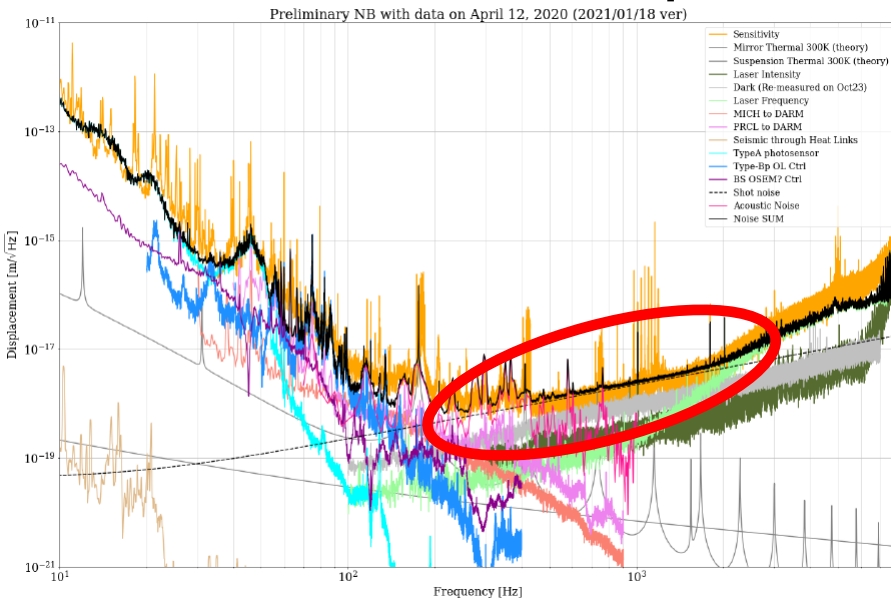
# Laser Intensity Noise

- A factor of  $\sim 3$  to shot noise limit
- Some noise from beam jitter ?
- Planning to increase power and to reduce beam jitter for O4 (Y. Kuromiya, [JGW-G2012322](#))



# Instrument Updates

- Thermal noise
- Laser noises (frequency noise and intensity noise)
- **Shot noise**
- Acoustic noise
- Coupling from auxiliary degrees of freedom
- Test mass suspension damping noise

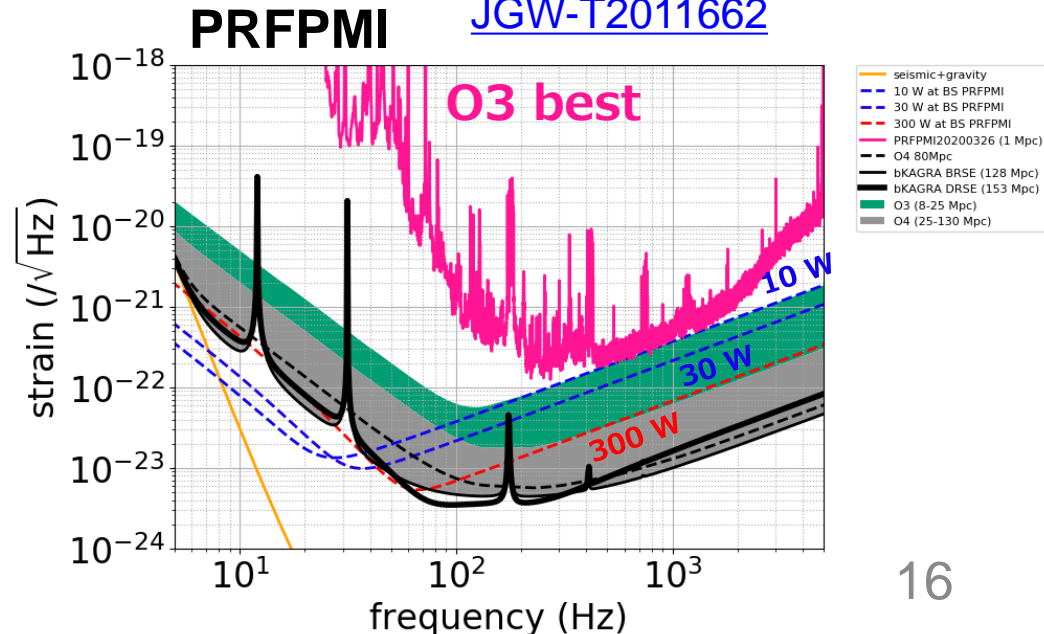
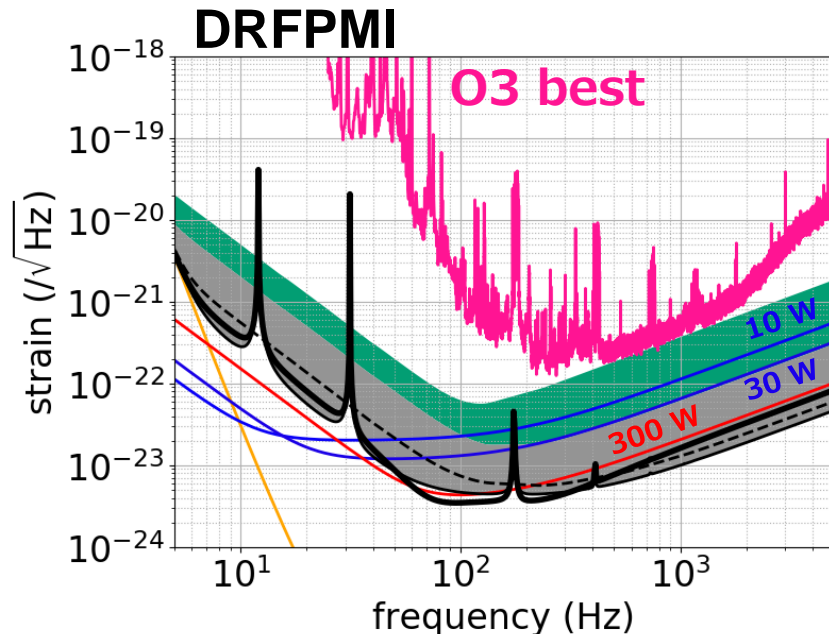


# Shot Noise

- In O3GK it was not good due to tilted SRM ( $T=30\%$ )
- When DRFPMI, **at least 30 W at BS** is necessary
- When PRFPMI, at least 300 W as BS is necessary
- **DR seems to be almost necessary for O4**

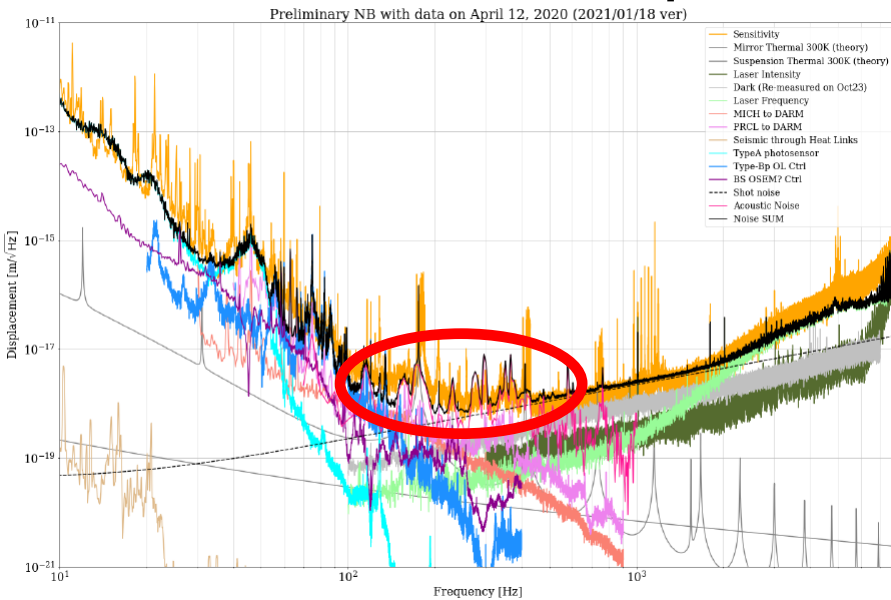
For this, suspensions needs to be settled down  
(M. Nakano, [JGW-G2012213](#))

YM, K. Somiya, K. Yamamoto,  
[JGW-T2011662](#)



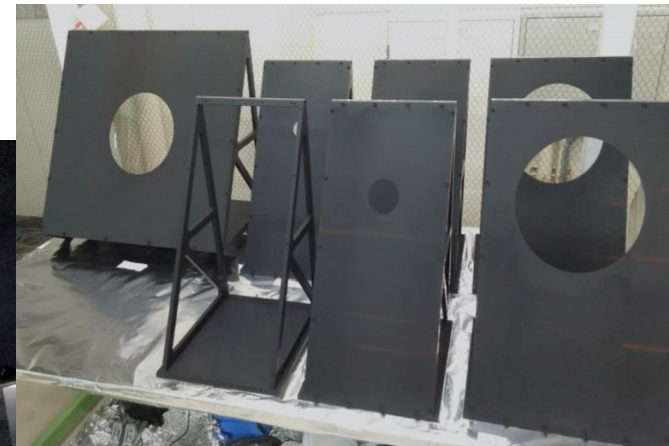
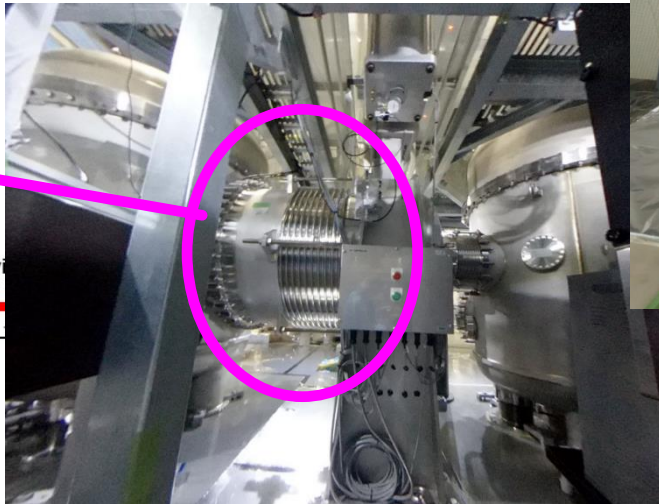
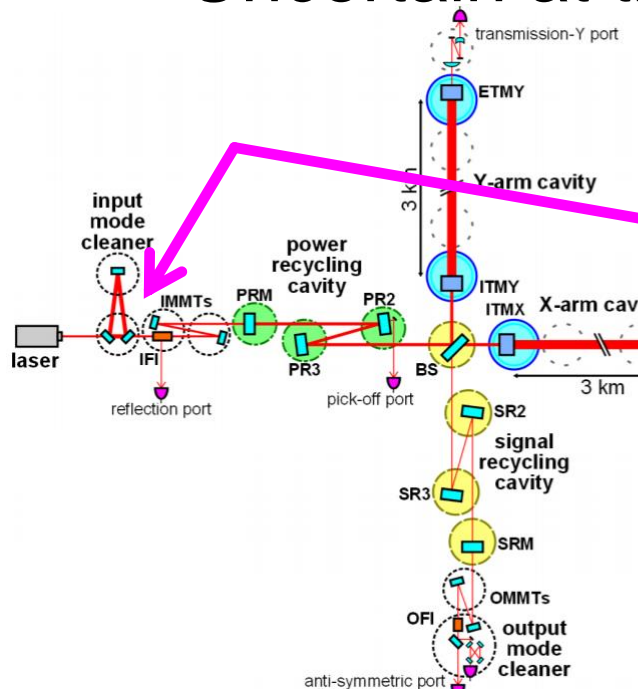
# Instrument Updates

- Thermal noise
- Laser noises (frequency noise and intensity noise)
- Shot noise
- **Acoustic noise**
- Coupling from auxiliary degrees of freedom
- Test mass suspension damping noise



# Acoustic Noise

- Most contribution is somehow from bellows between **IMC and IFI chambers**  
(Input Mode Cleaner) (Input Faraday Isolator)
- Could be reduced by scattered light mitigation  
Install **baffles and beam damps** for O4
- Uncertain at this point



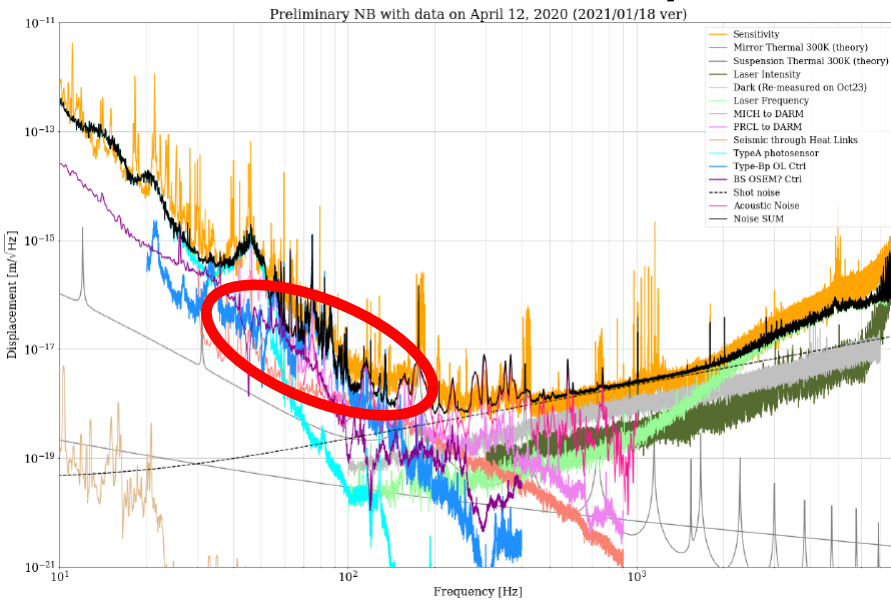
T. Akutsu,  
[JGW-G2011959](#)

K. Kokeyama, T. Washimi, K. Yamamoto  
[JGW-G2012315](#)



# Instrument Updates

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- Acoustic noise
- Coupling from auxiliary degrees of freedom
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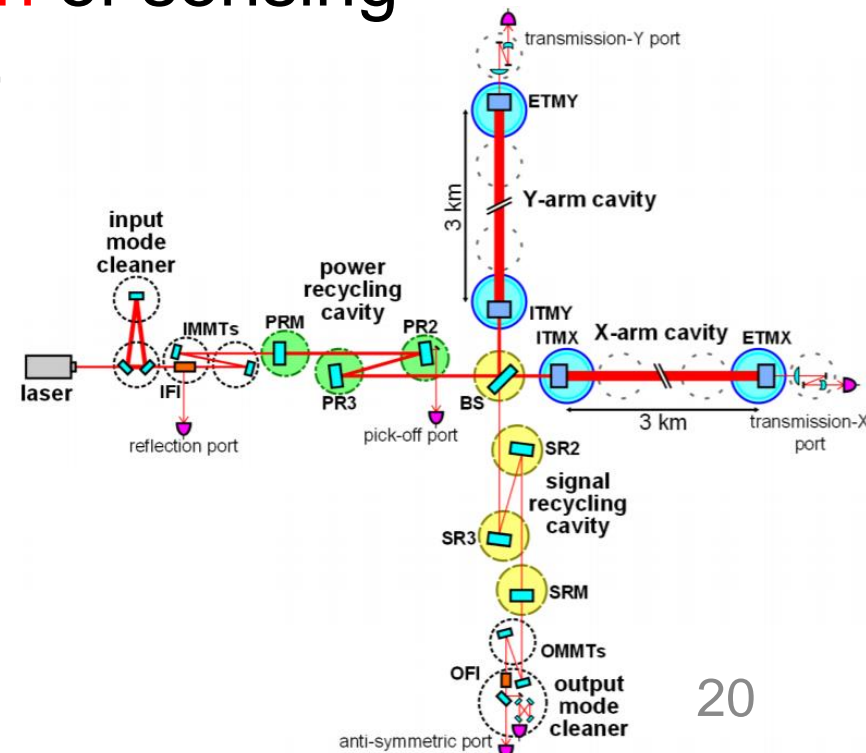
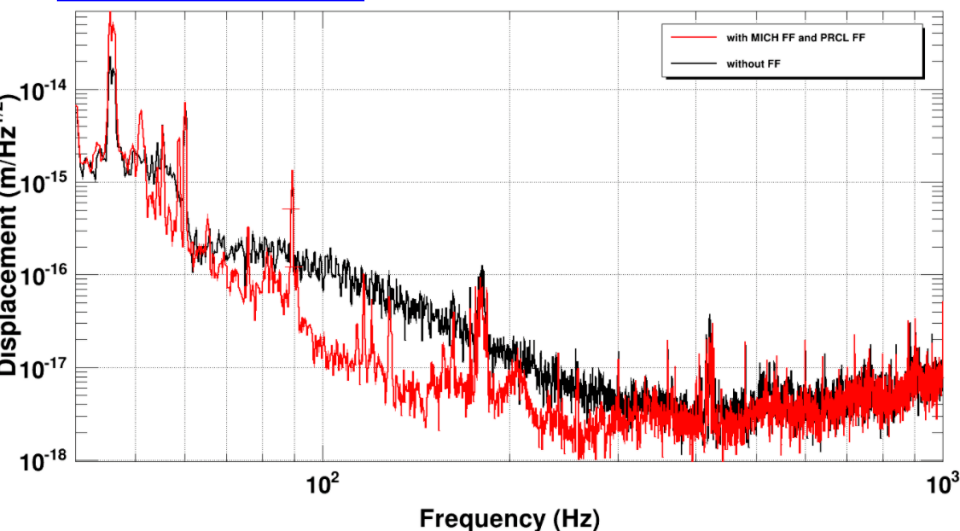


# Coupling from Auxiliary DOFs

- Coupling MICH (Michelson) and PRCL (power recycling cavity length)
- **Feedforward** reduces the coupling by  $\sim 1/10$  at max  
Aiming for  $\sim 1/100$  for O4
- Also, **better diagonalization** of sensing matrix can be done for O4

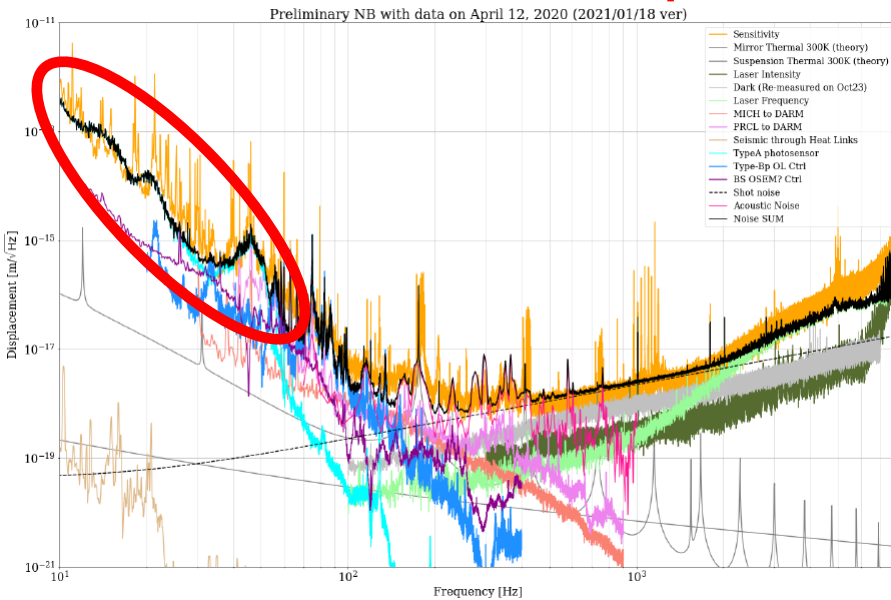
K. Kokeyama, T. Washimi, K. Yamamoto

[JGW-G2012315](#)



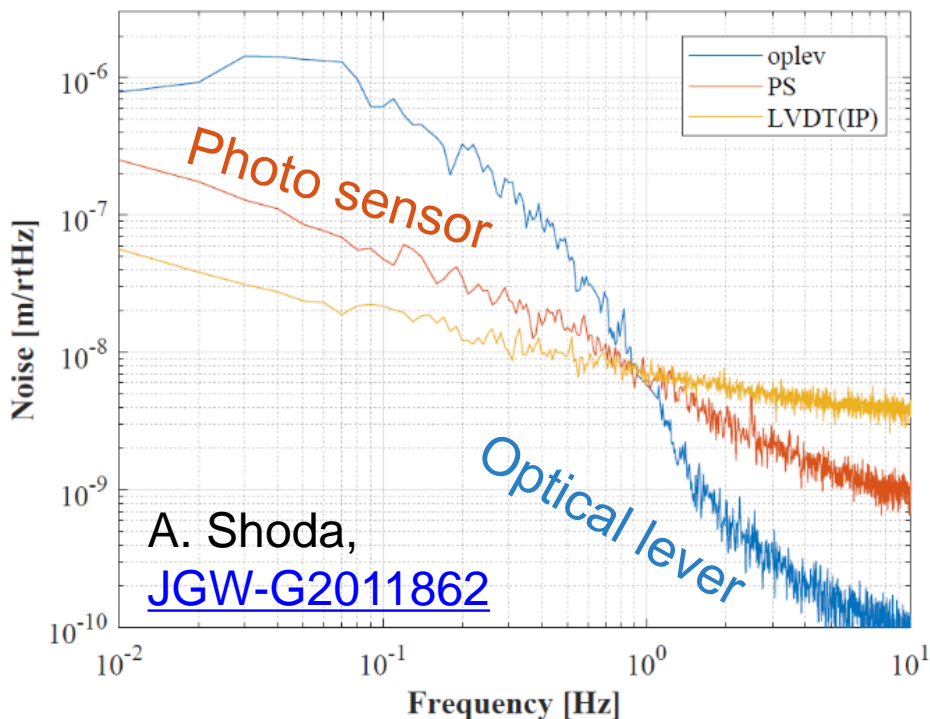
# Instrument Updates

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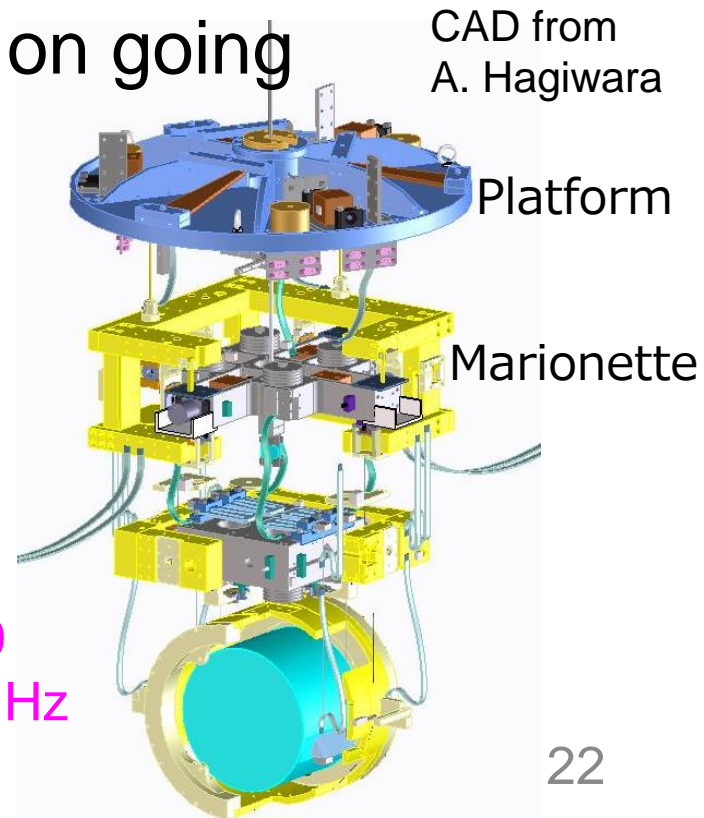


# Test Mass Suspension Damping

- Noises from marionette damping using photo sensors are limiting
- Plan to **install optical levers** also for marionette and platform stages
- Suspension controls modeling on going



↓ ~1/10  
at 10 Hz



# Actuator Noise

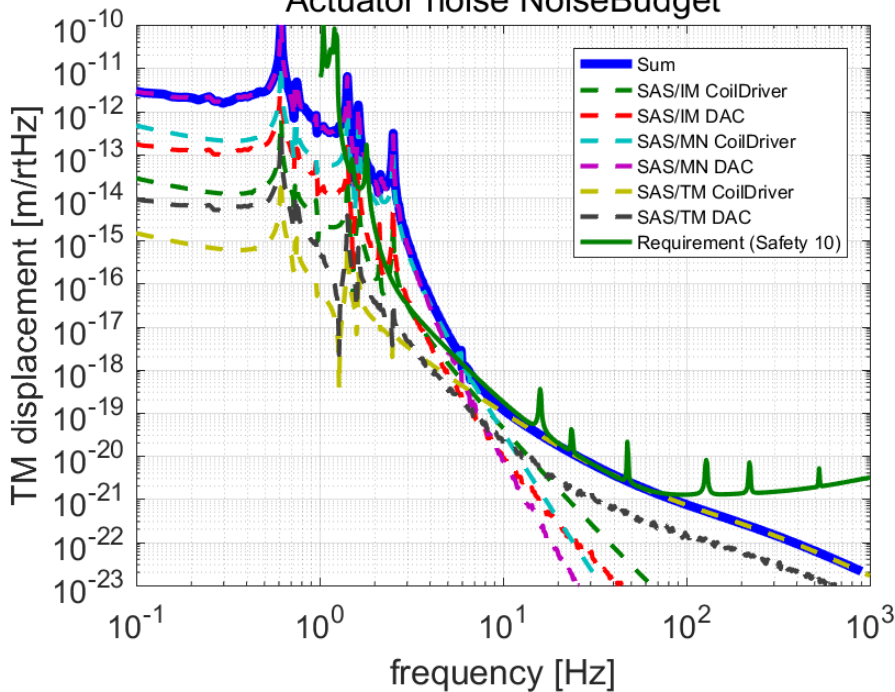
- High power coil drivers for lock acquisition was used during the O3GK
- **Coil driver switch** to switch between high power and low power will be installed for O4

~ 1/100 actuator noise

YM, [JGW-T1910142](#)

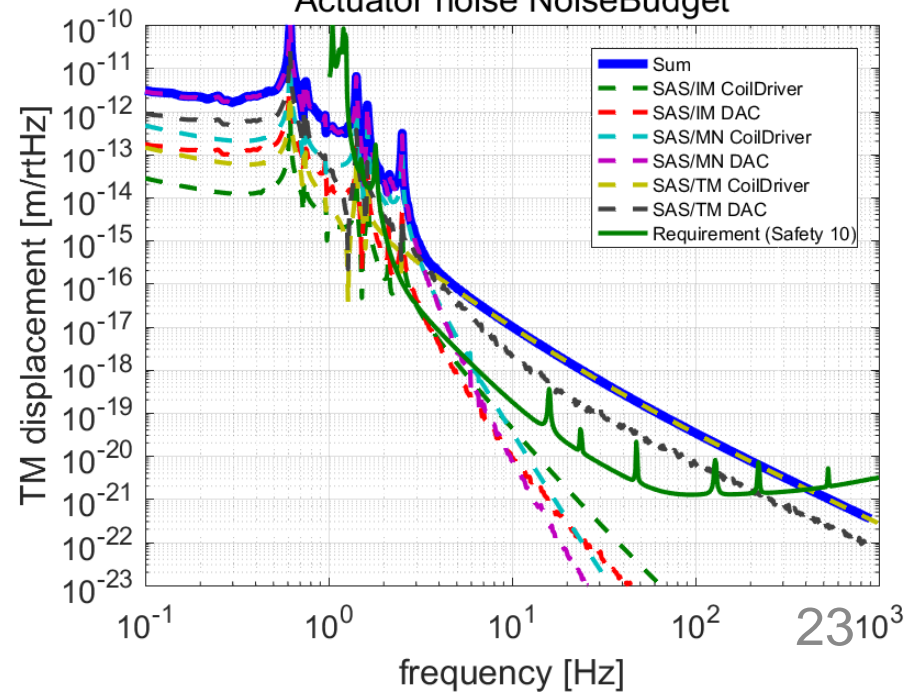
## Nominal Case

Actuator noise NoiseBudget



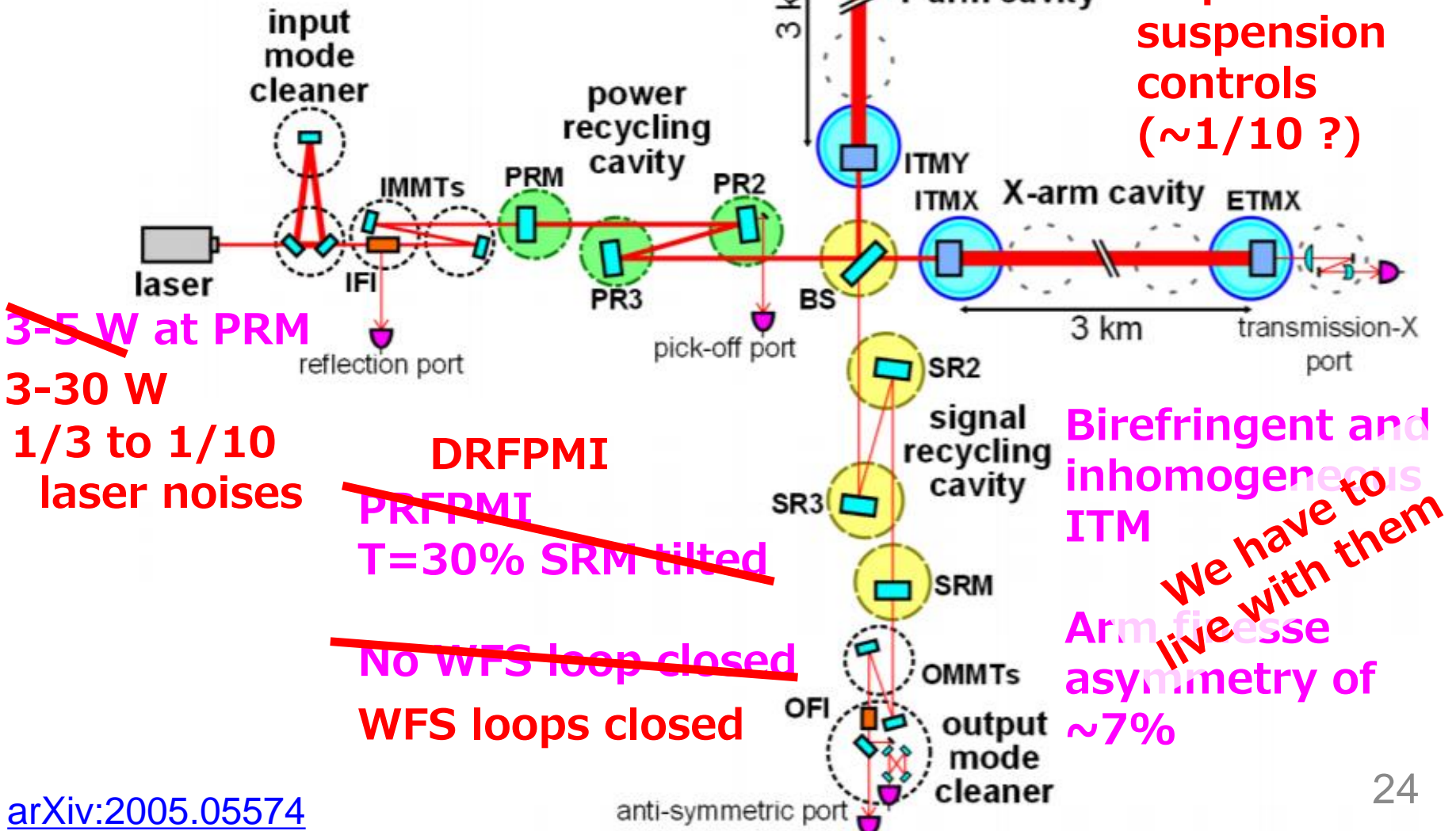
## High Power TM Case

Actuator noise NoiseBudget





# Expected O4 Configuration



# Summary 1/2

- We aim for **at least 25 Mpc for O4** (~70 Mpc even if very optimistic)
- **Thermal noise**
  - O3GK:** ~250 K due to test mass **frosting**
  - O4 target:** At least **below 100 K**
  - Method:** Attach heaters to **defrost** the test masses 😊
- **Laser noises (frequency noise and intensity noise)**
  - O3GK:** Larger than expected by 1-2 orders of magnitude (probably due to ITM **birefringence**)
  - O4 Target:** At least **1/3** necessary
  - Method:** Better alignment with **WFS**, 😞  
Improvements in laser **intensity stabilization** 😊
- **Shot noise**
  - O3GK:** 3-5 W input at PRM, T=30% SRM tilted, PRFPMI
  - O4 Target:** At least 50W at BS, T=30% SRM, **DRFPMI**
  - Method:** Better suspension controls 😞

# Summary 2/2

- **Acoustic noise**

**O3GK:** Somehow mostly from IMC-IFI bellows

**O4 target:** Reduction by  $\sim 1/50$  necessary

**Method:** **Baffles and beam dumps** for scattered light 😬

- **Coupling from auxiliary degrees of freedom**

**O3GK:** Larger than expected

**O4 target:** At least reduction by  $\sim 1/50$  necessary

**Method:** Better diagonalization, 😞  
x~10 more feedforward gain 😞

- **Test mass suspension damping noise**

**O3GK:** No WFS, controls with local sensors

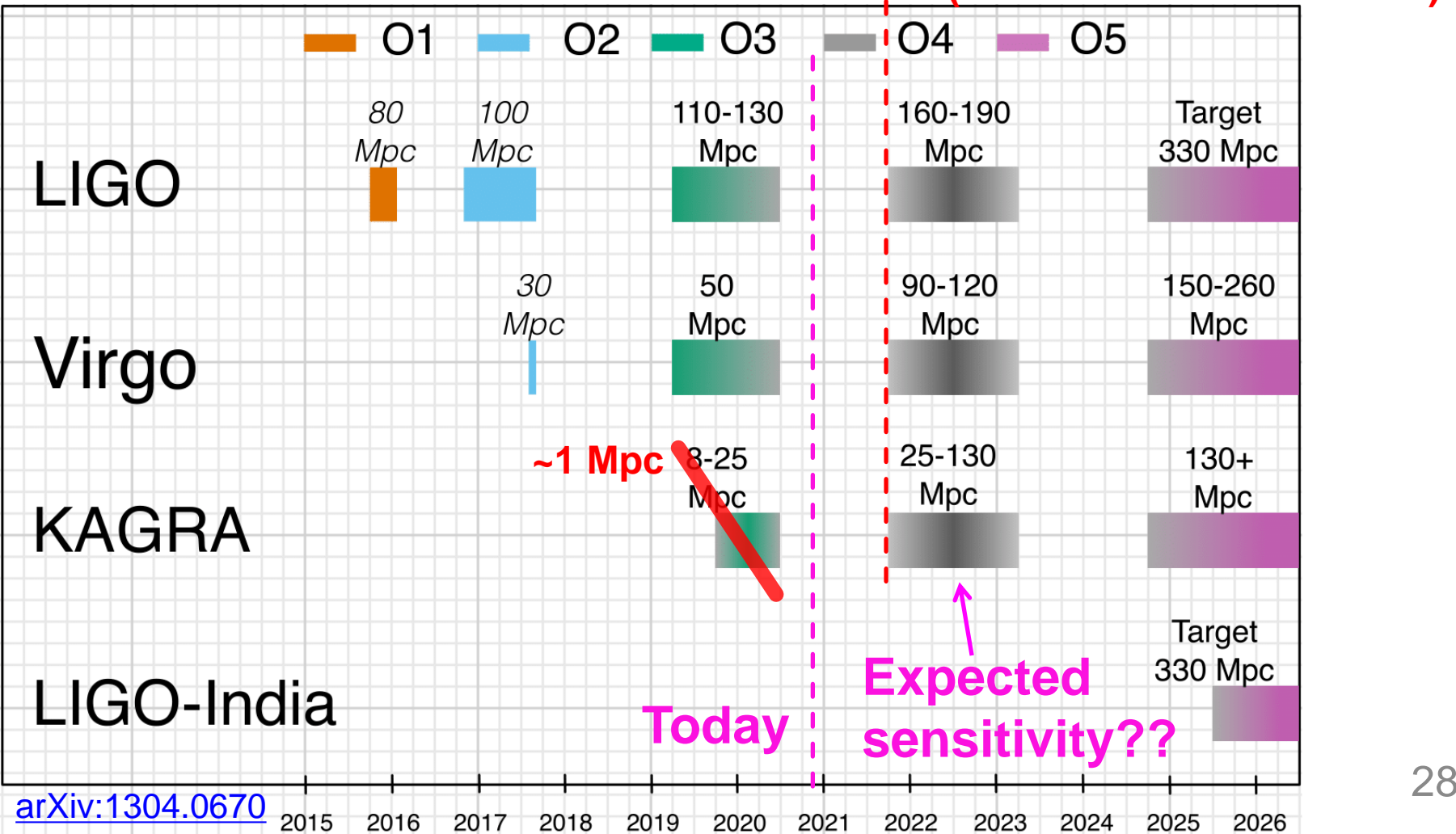
**O4 target:** At least reduction by  $\sim 1/10^3$  at 50 Hz necessary

**Method:** Coil driver switch, 😊  
Additional optical levers, 😞  
Noise modeling and planning **on going** 😬

# Bonus Slides

# Observing Scenario of LVK

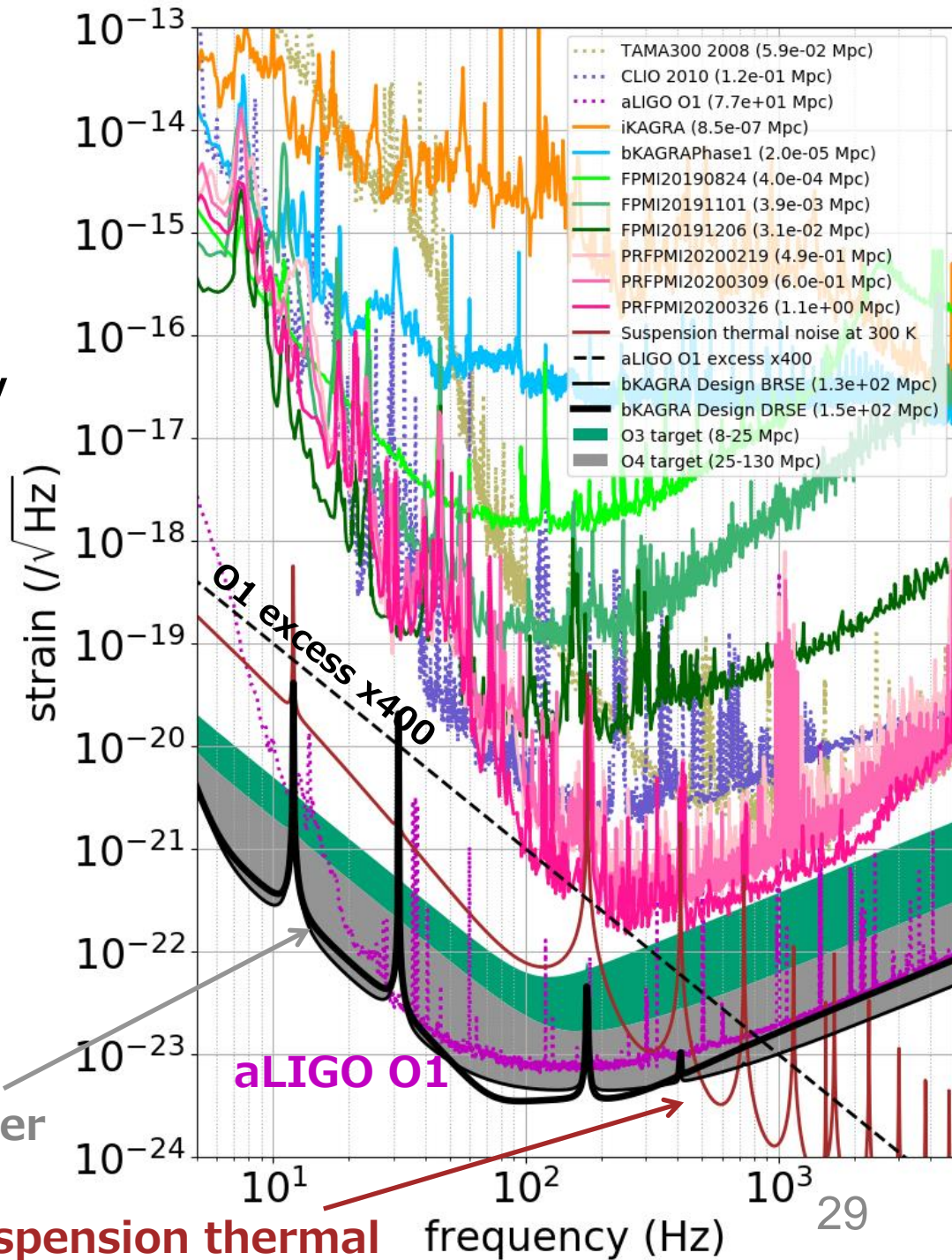
- Best sensitivity was  $\sim 1$  Mpc although we anticipated 8-25 Mpc





# O4 Target

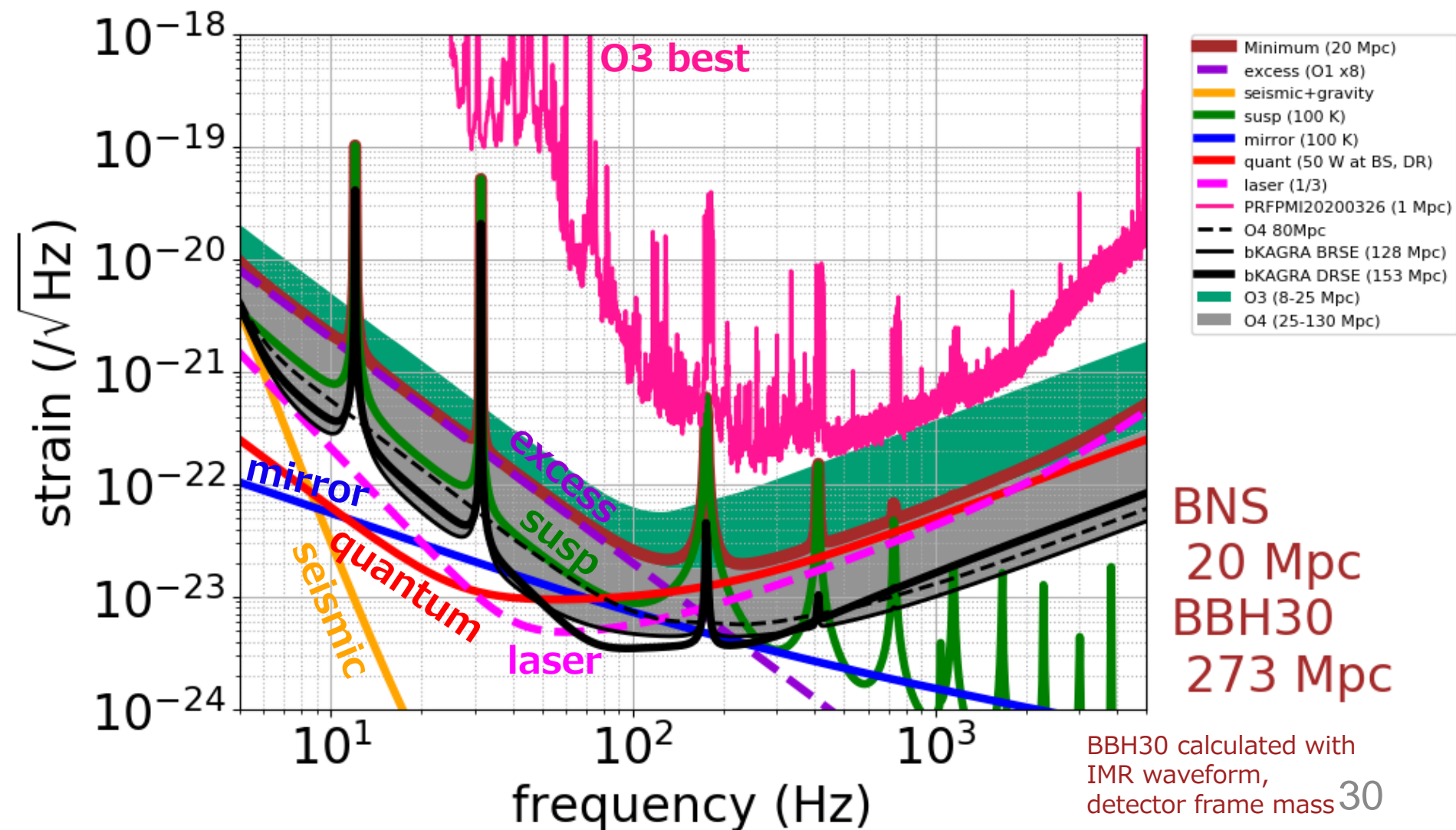
- We need to reduce excess noise at  $\sim 100$  Hz at least by a factor of  $\sim 50$



O4 target on Obs. Scenario Paper  
25-130 Mpc

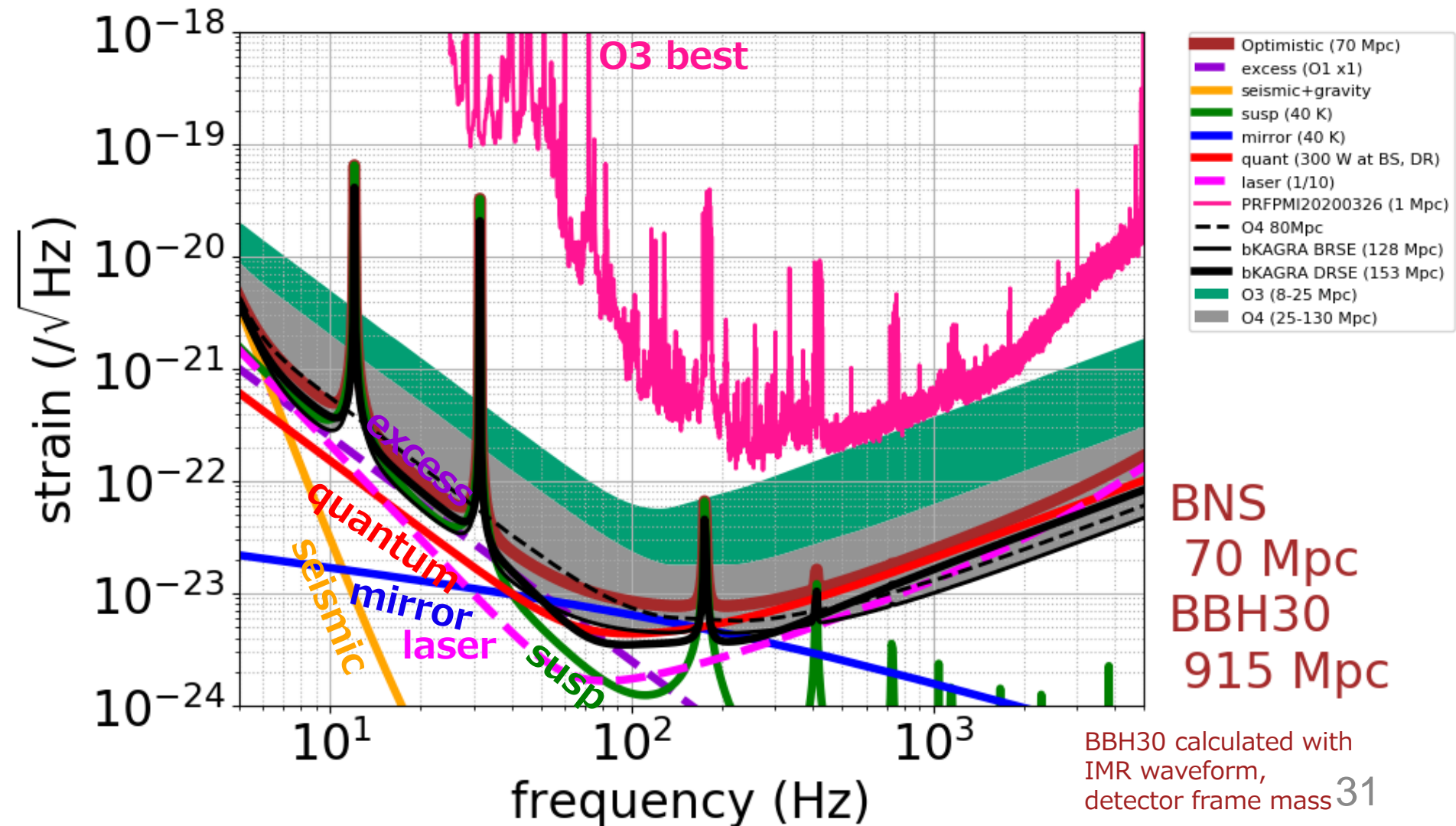
# O4 “Minimum” Example

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



# O4 “Optimistic” Example

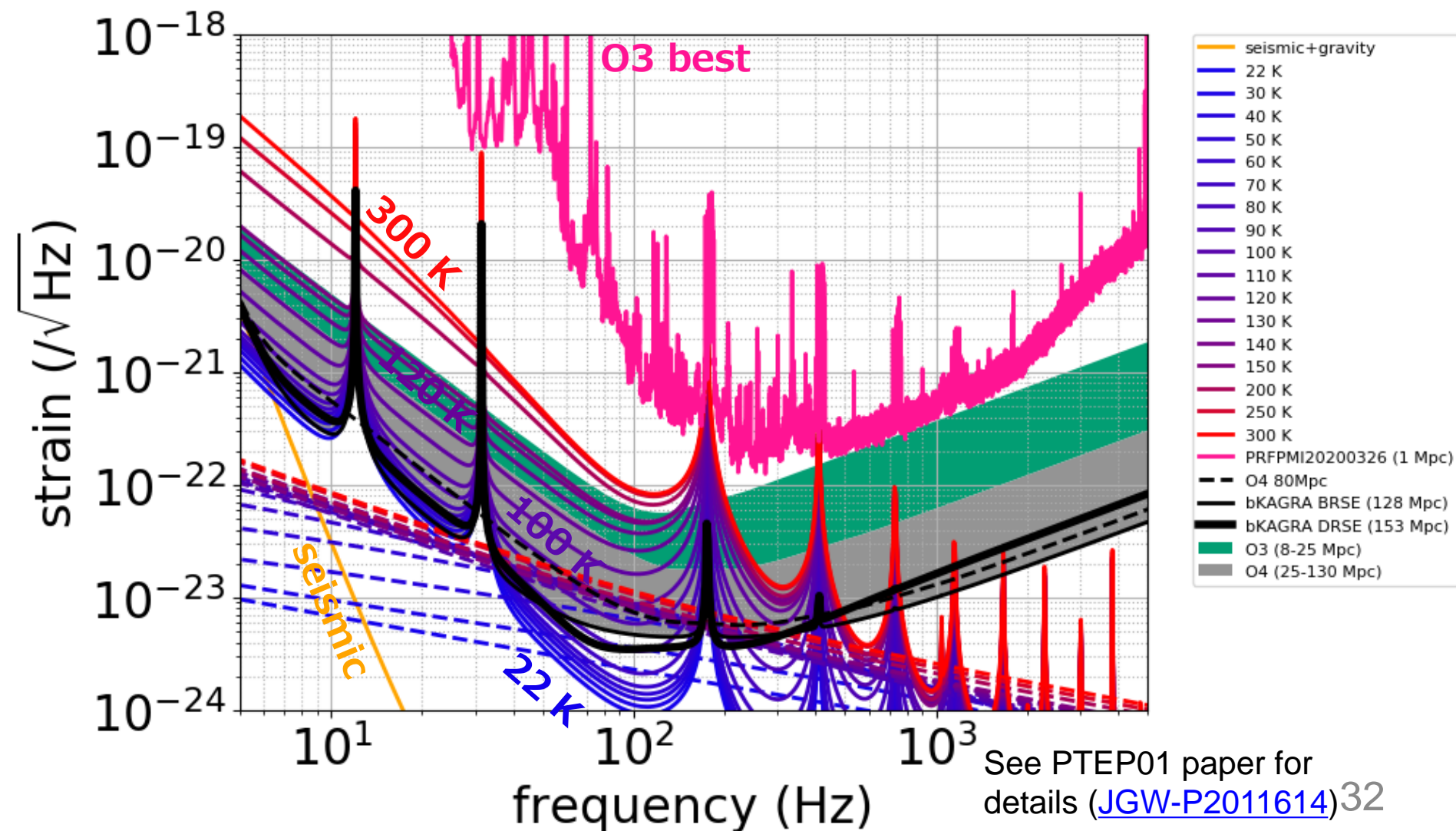
- 1/400 excess, 40 K, 300 W at BS, DR, 1/10 laser noise





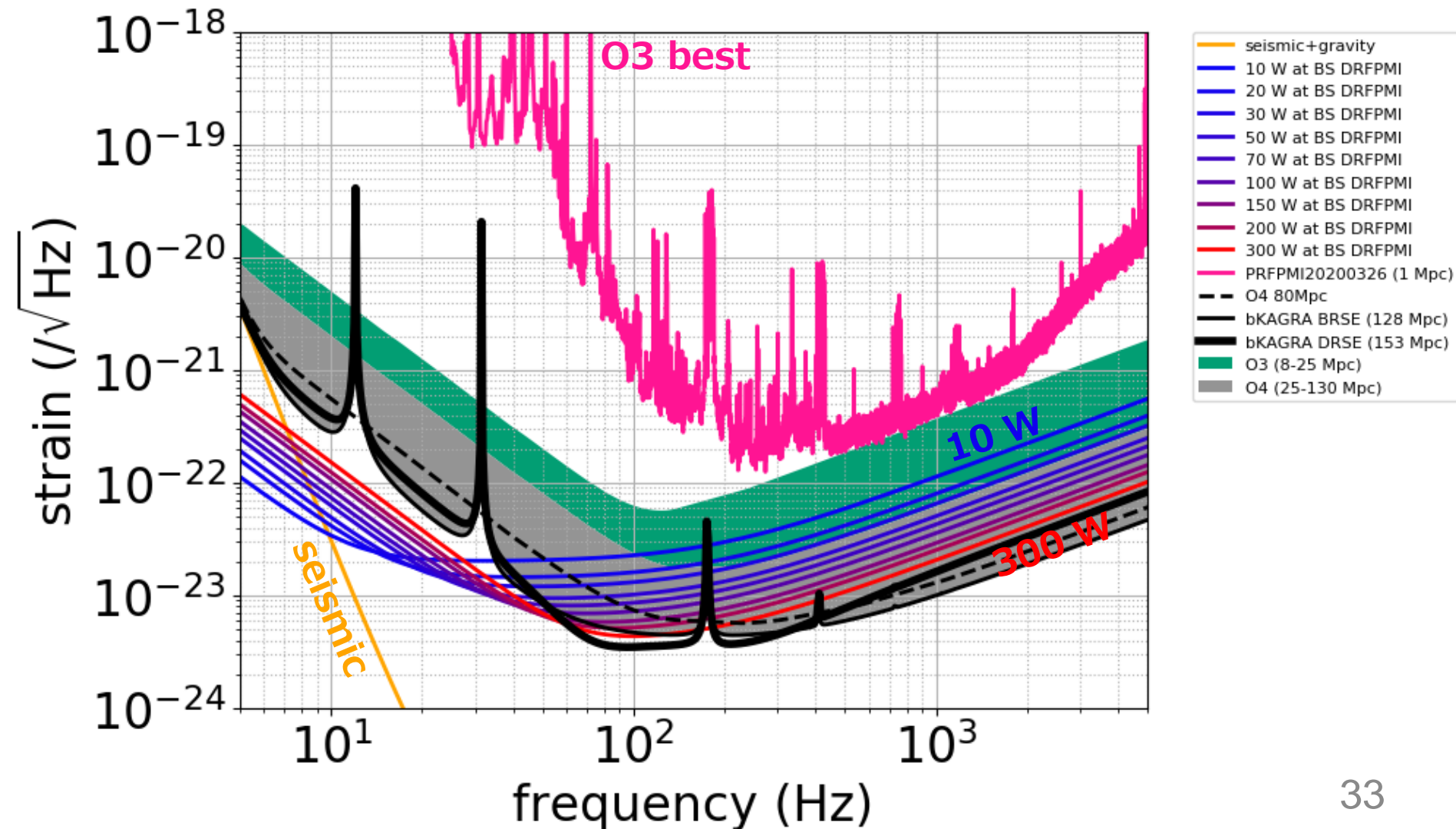
# Various Thermal Noise

- All temperatures



# Various Quantum Noise (DR)

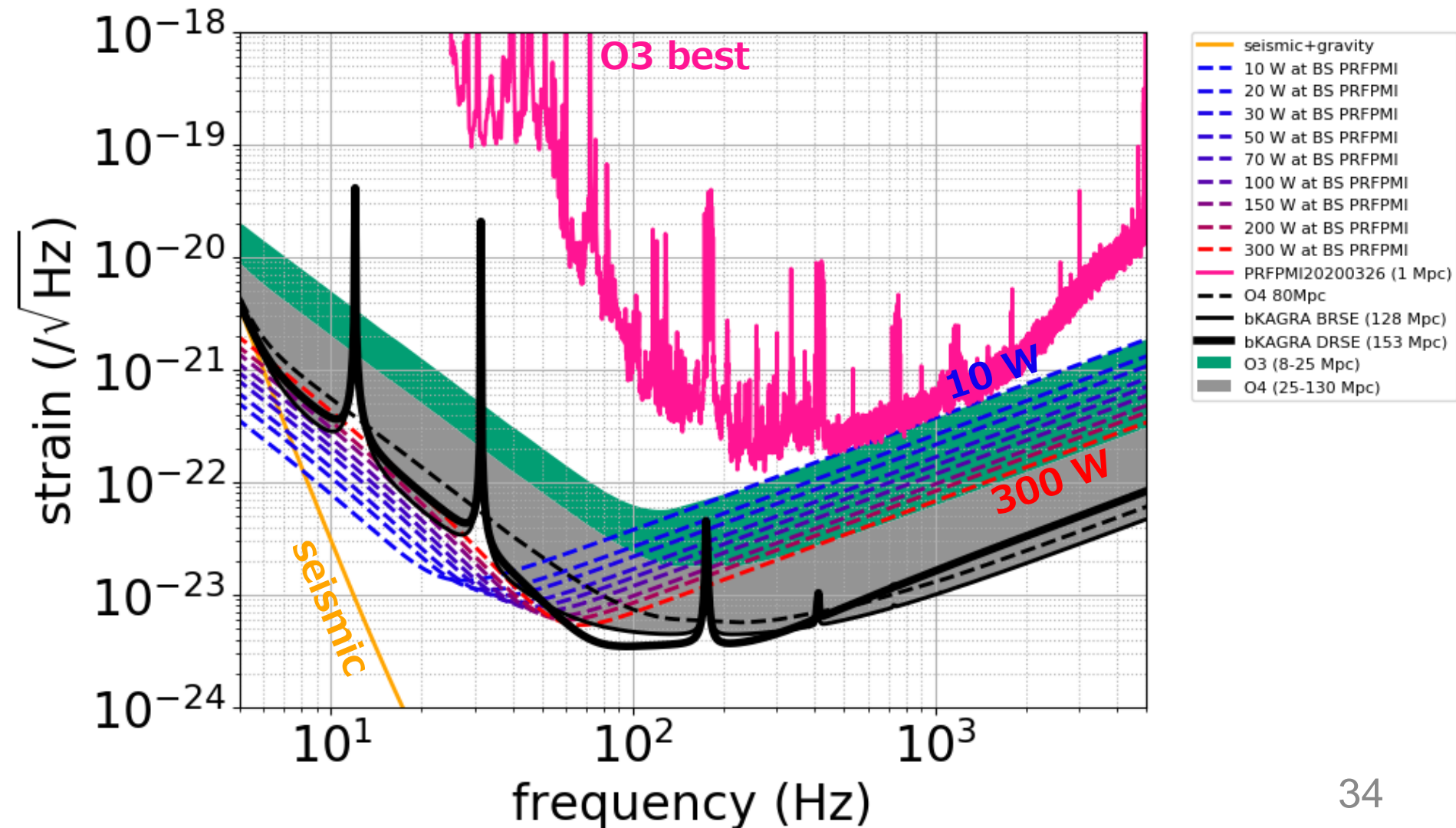
- All powers





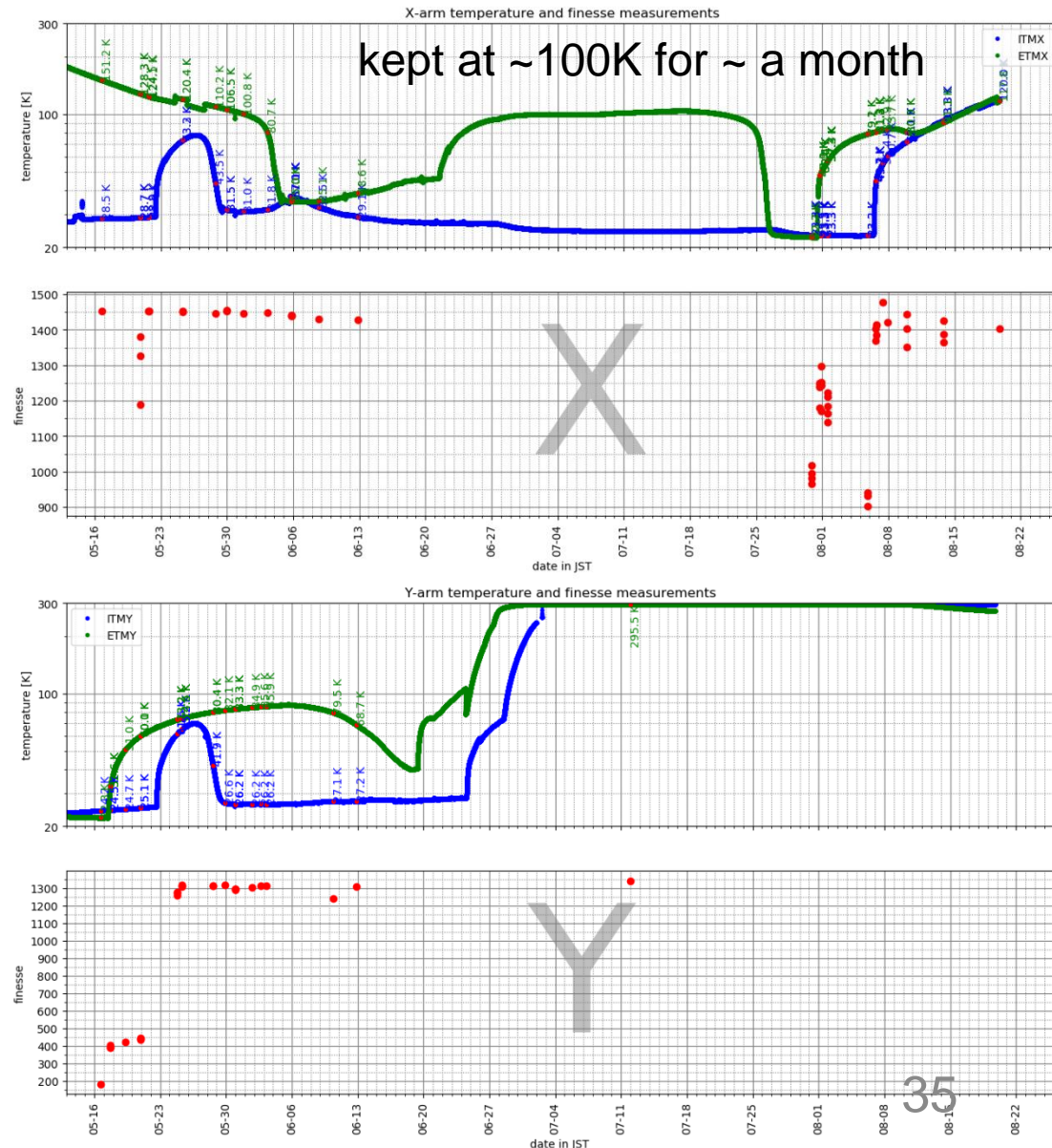
# Various Quantum Noise (PR)

- All powers



# Frosting of the Test Mass

- Finesse drop observed when one of the test mass temperature is below  $\sim 30$  K



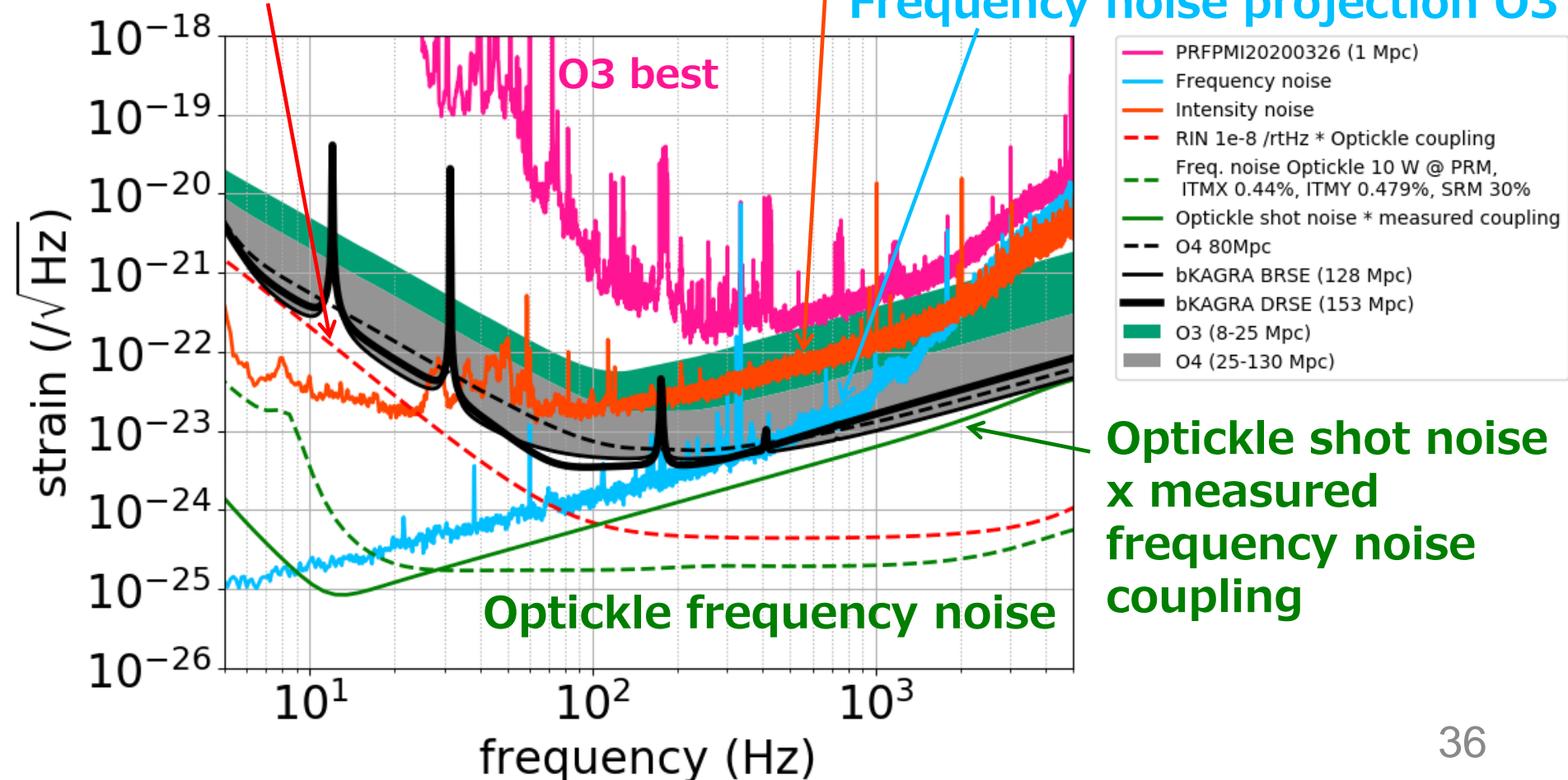
# Laser Noise Projections

- 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  $1\text{e-}8$  /rtHz x Optickle coupling and CARM shot noise limited x measured coupling

