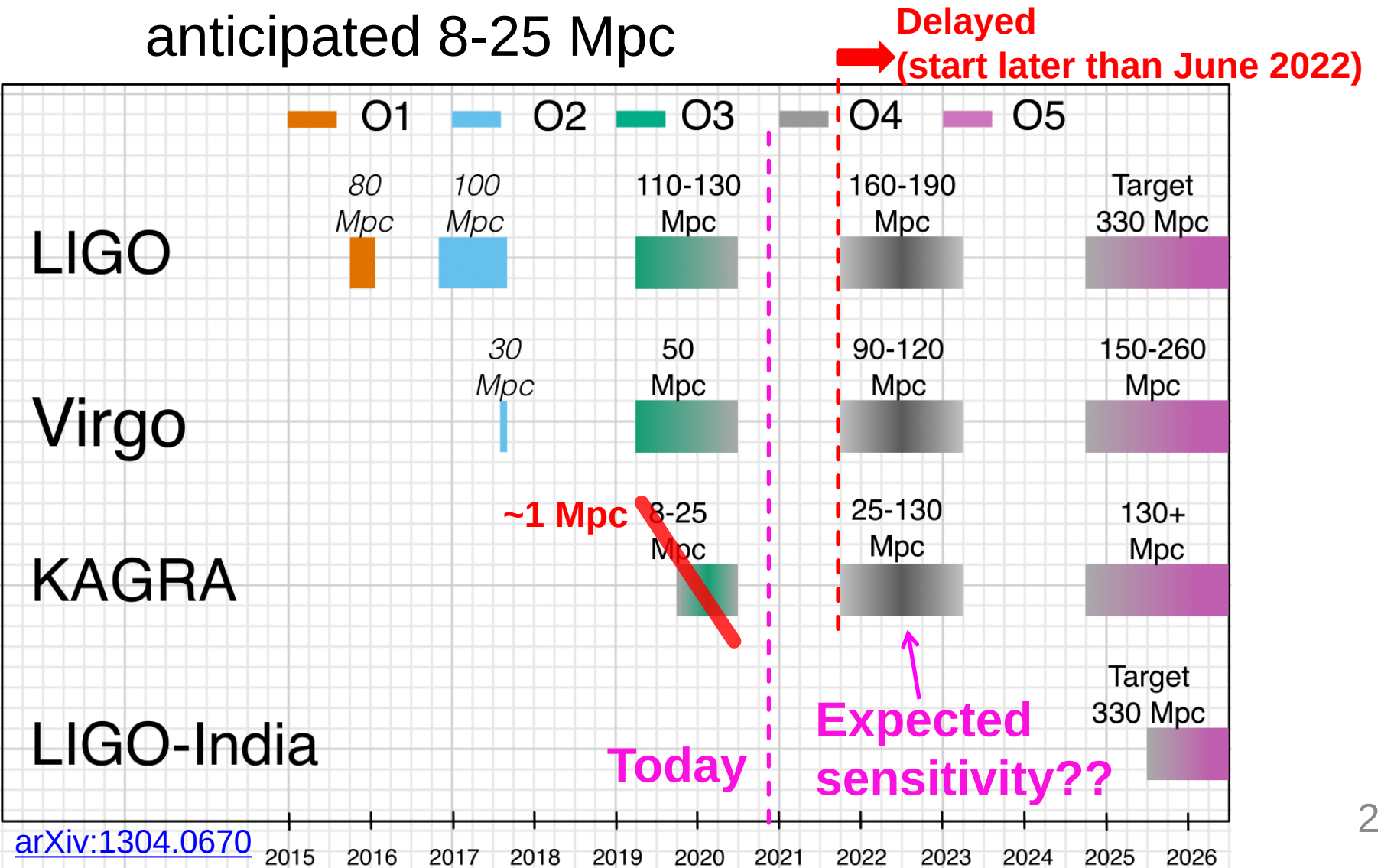
JGW-G2012349
7th KAGRA International Workshop (Online)
December 20, 2020

Expectations for Sensitivity of KAGRA in O4

Yuta Michimura

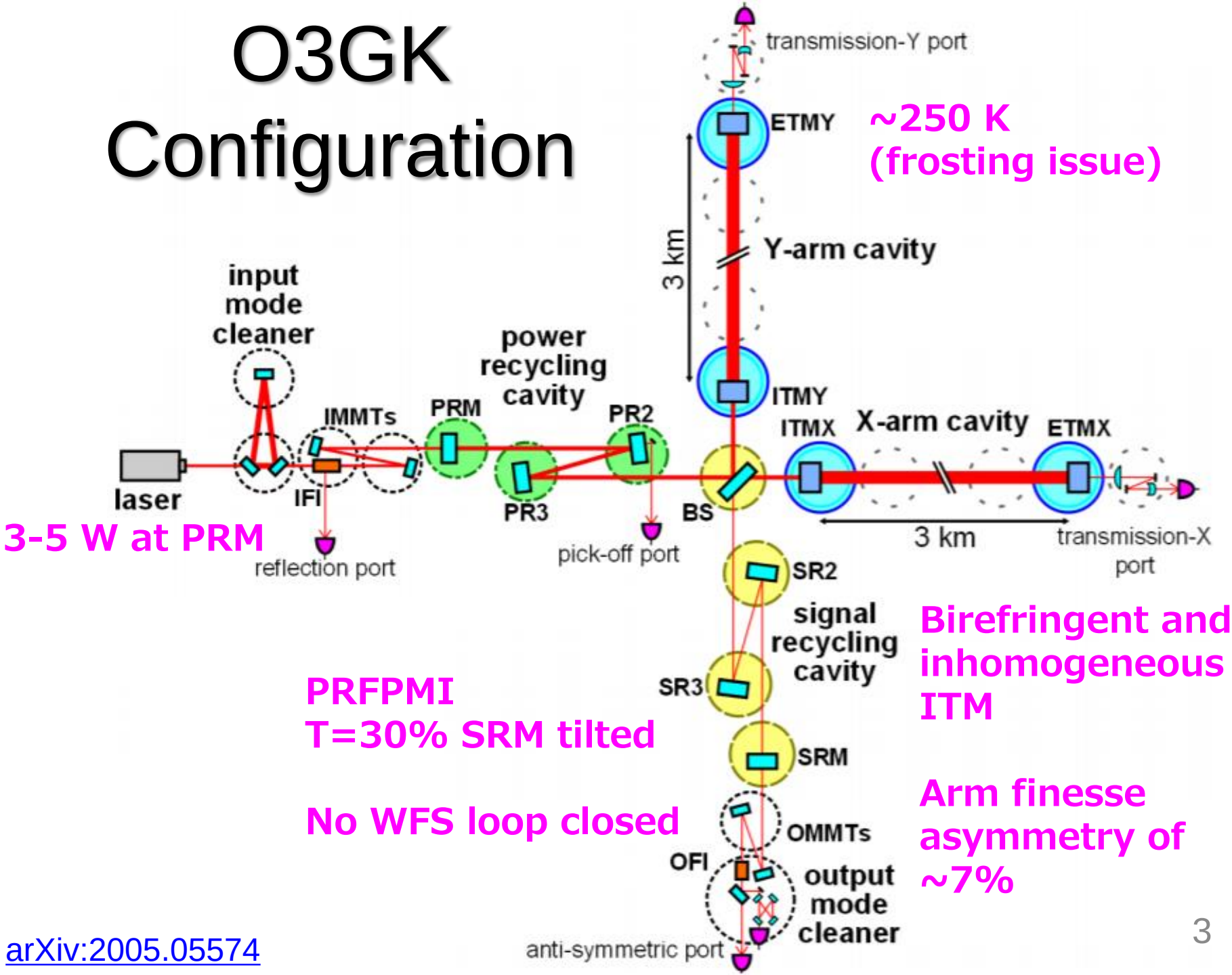
Observing Scenario of LVK

- Best sensitivity was ~1 Mpc although we anticipated 8-25 Mpc



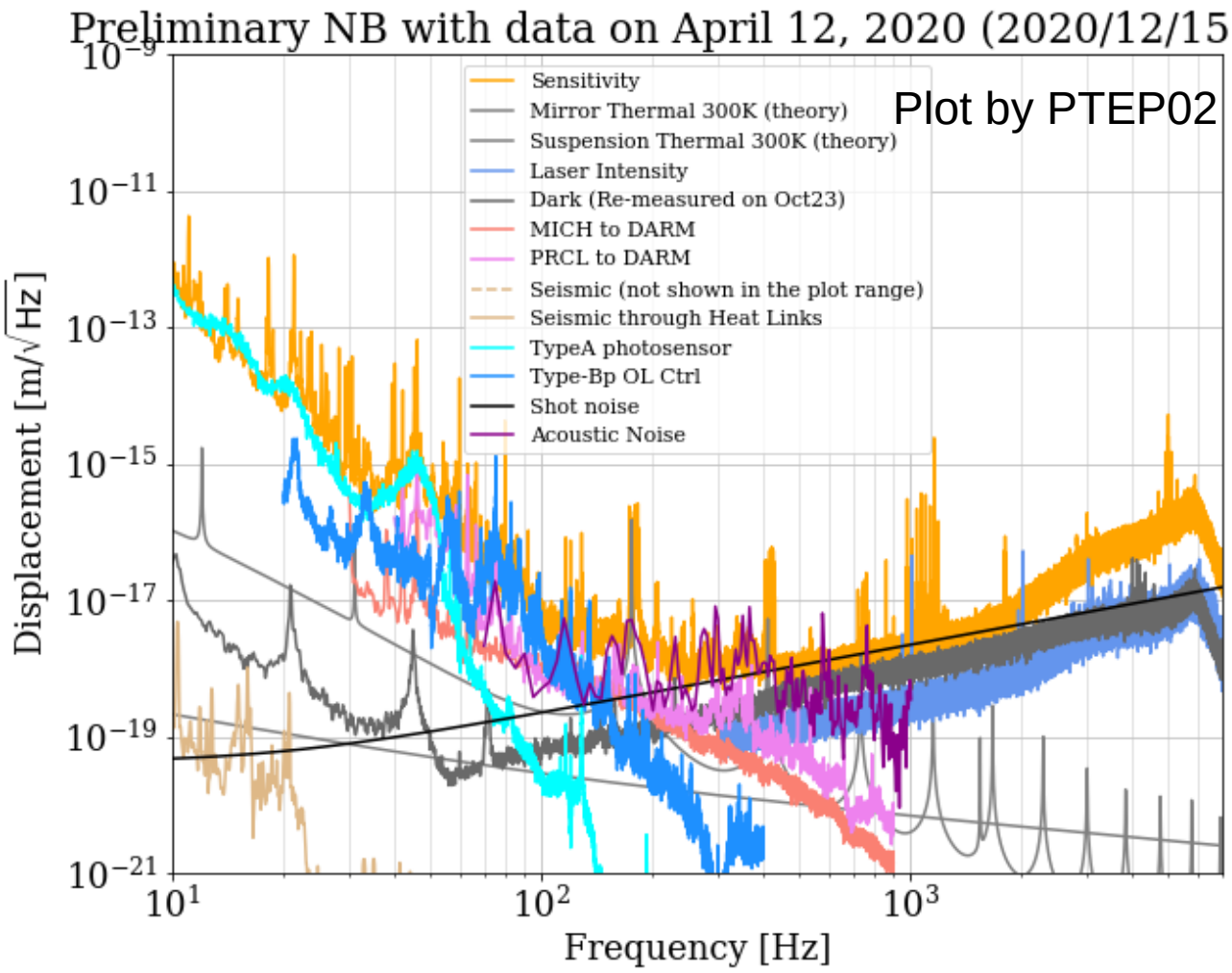
arXiv:1304.0670

O3GK Configuration



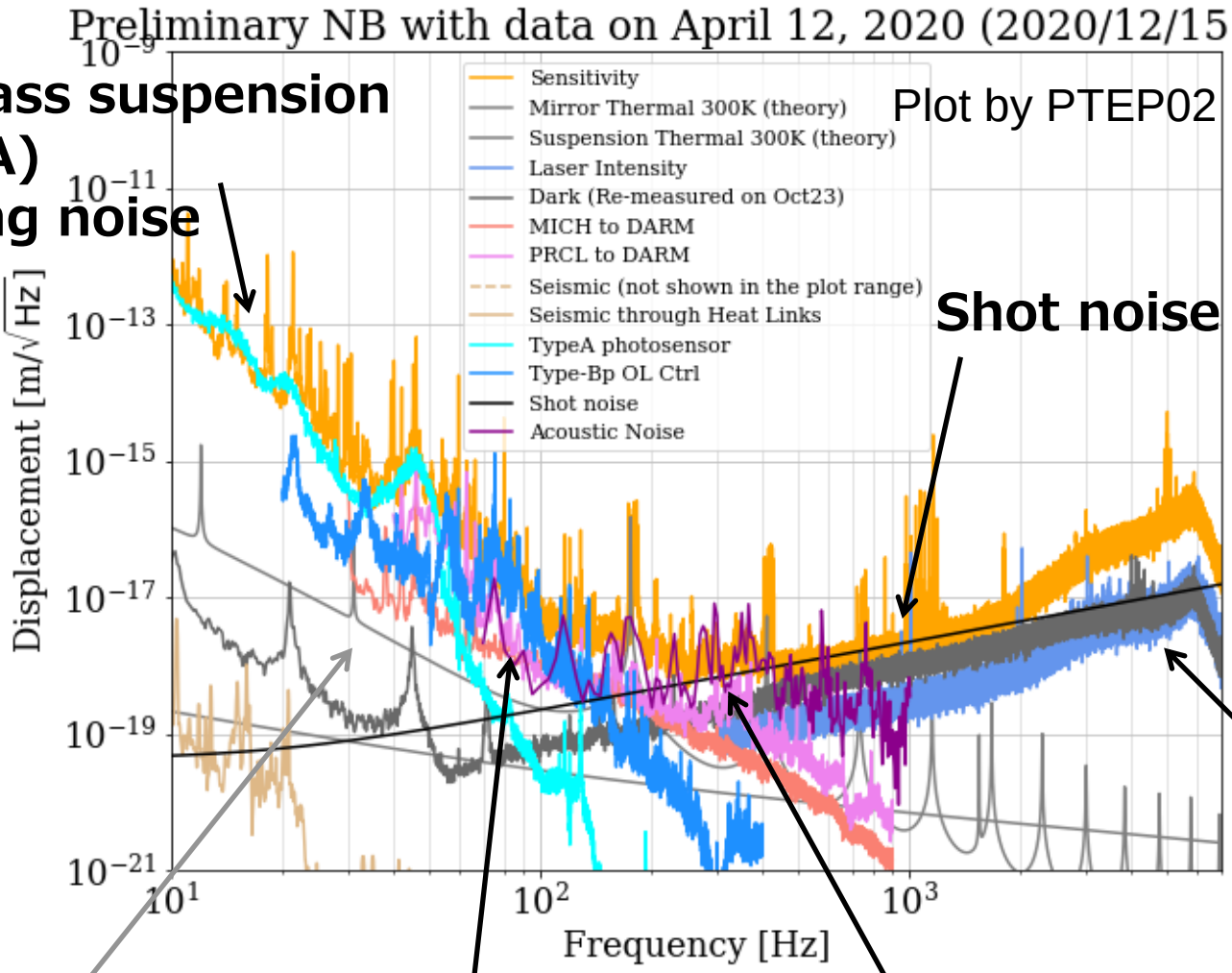
arXiv:2005.05574

O3GK Noise Budget



Plot by PTEP02 paper team

O3GK Noise Budget



Plot by PTEP02 paper team

Test mass suspension (Type-A) damping noise

Shot noise

Laser noises

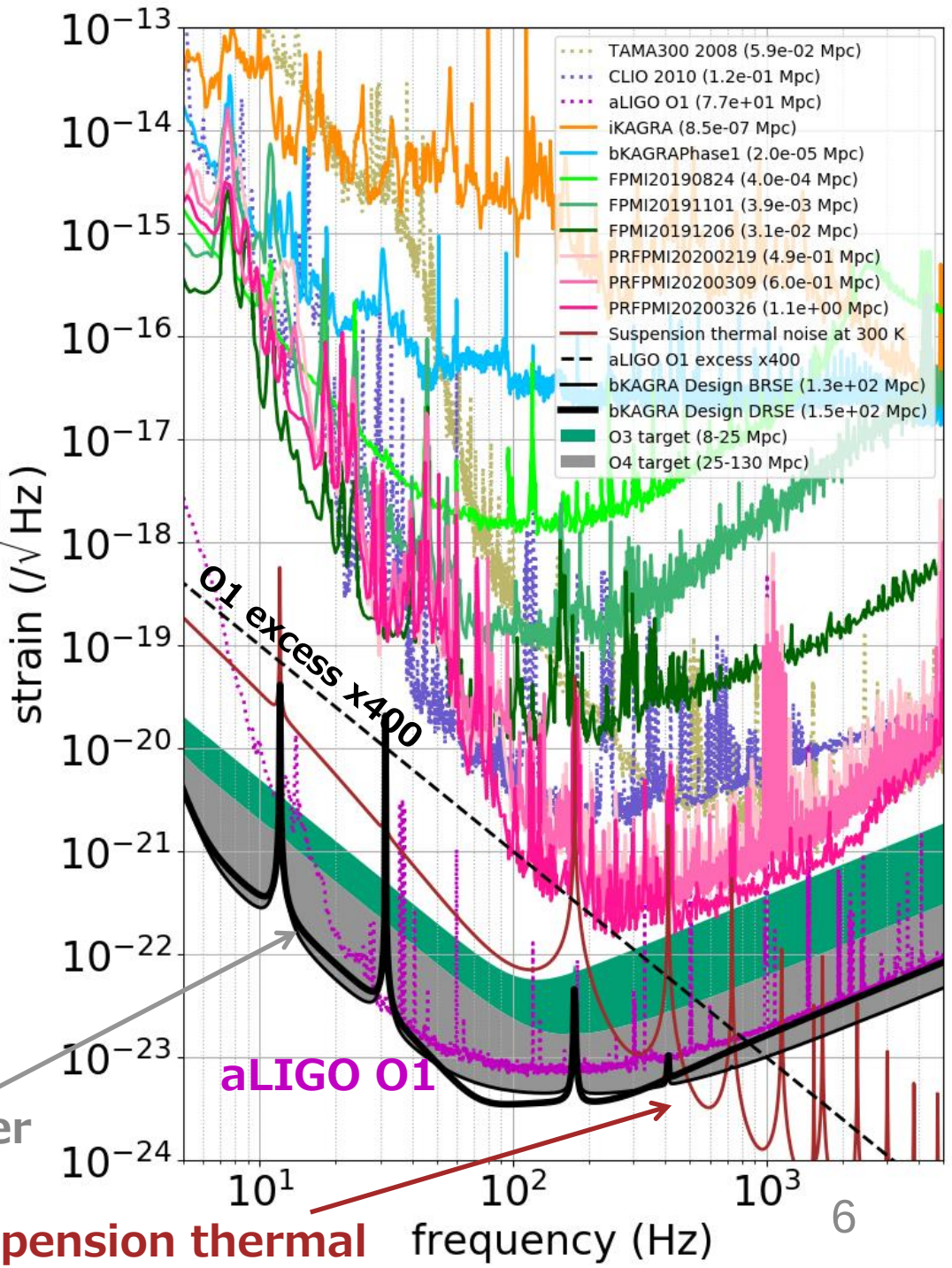
Acoustic noise

Coupling from auxiliary degrees of freedom

Suspension thermal noise

O4 Target

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

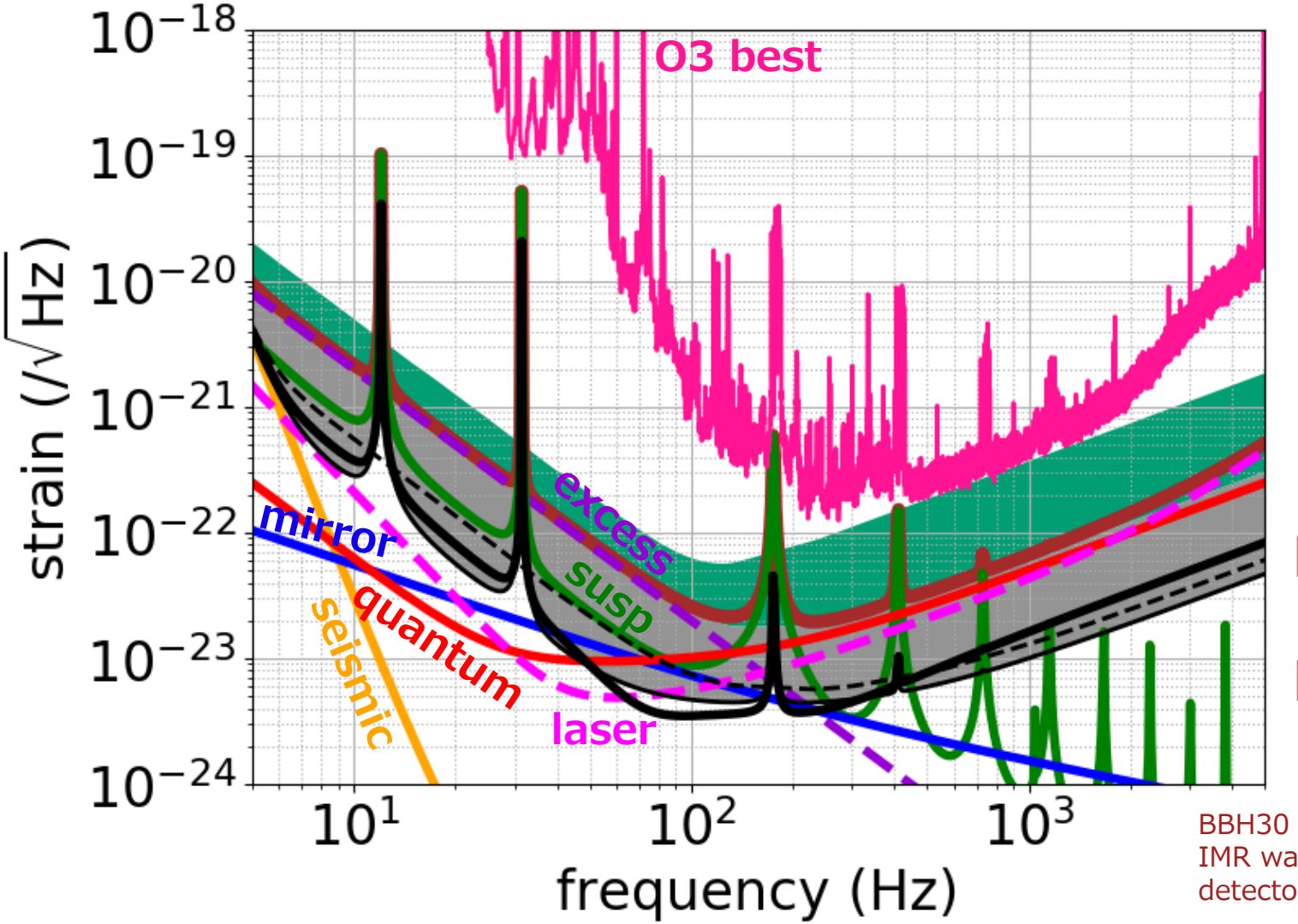


O4 target on Obs. Scenario Paper
25-130 Mpc

300 K suspension thermal

O4 “Minimum” Example

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

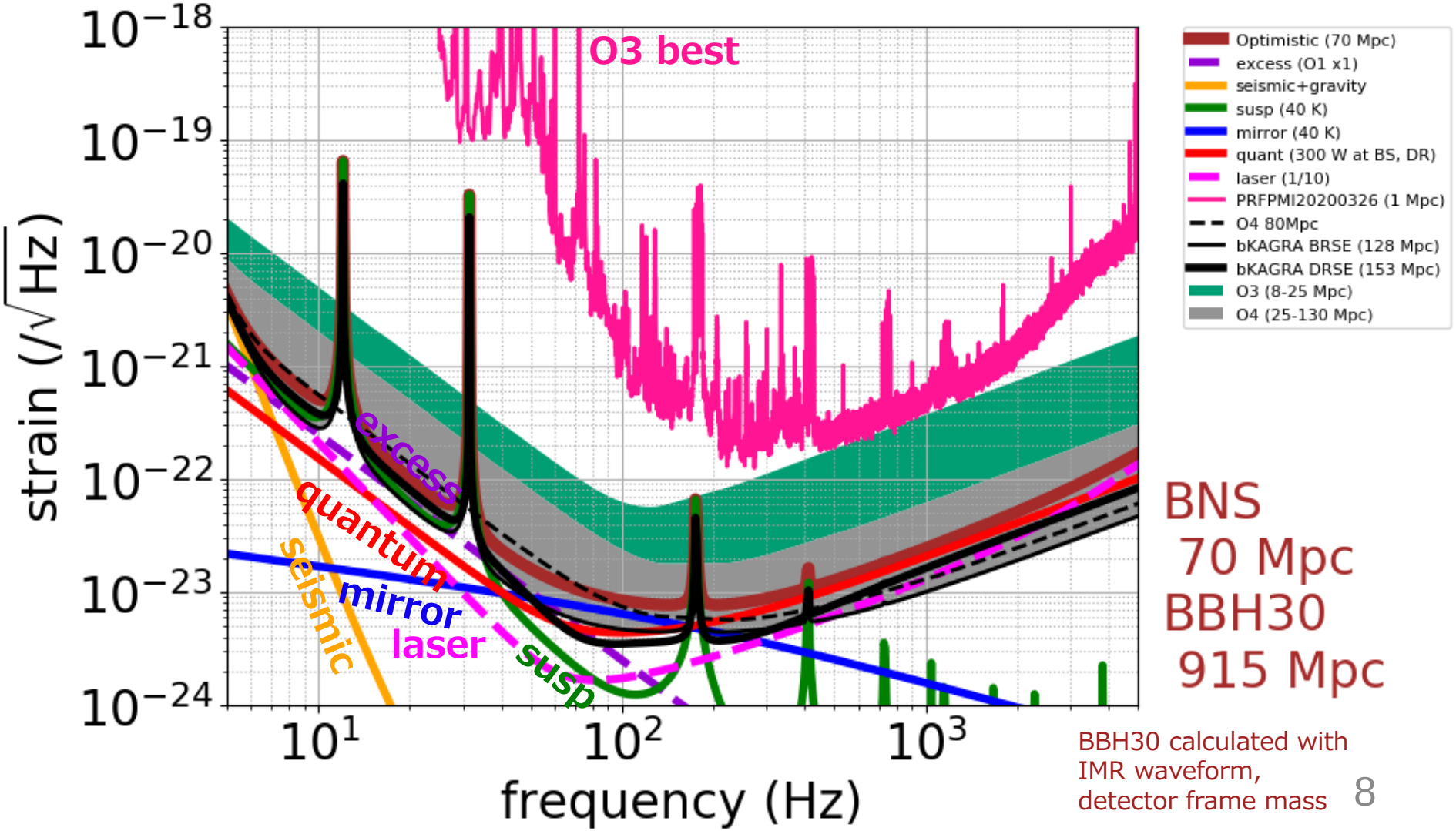


BNS
20 Mpc
BBH30
273 Mpc

BBH30 calculated with IMR waveform, detector frame mass

O4 “Optimistic” Example

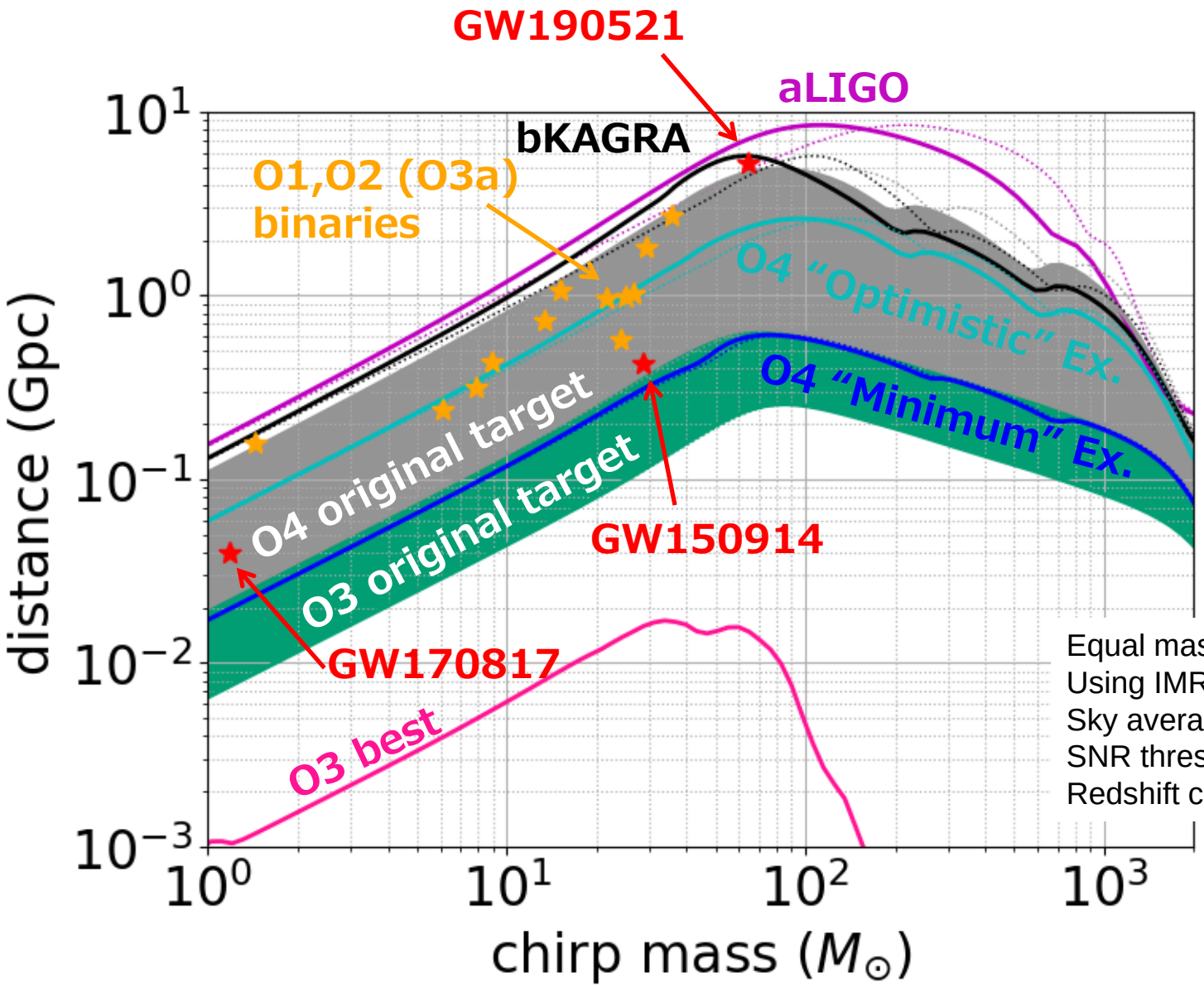
- 1/400 excess, 40 K, 300 W at BS, DR, 1/10 laser noise



BNS
70 Mpc
BBH30
915 Mpc

BBH30 calculated with IMR waveform, detector frame mass

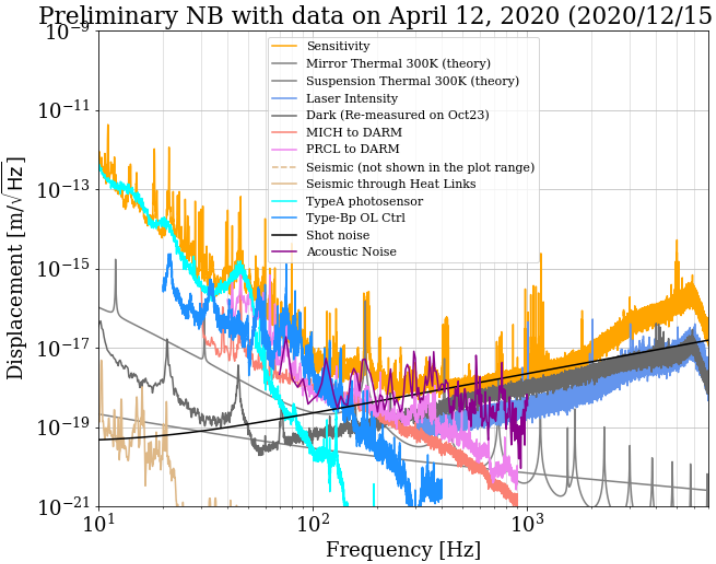
Inspiral Range



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

Expectations for O4

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



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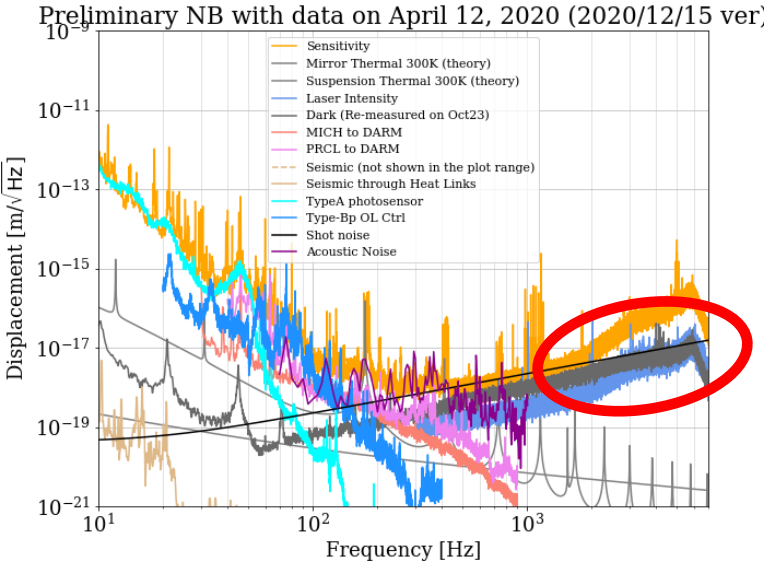
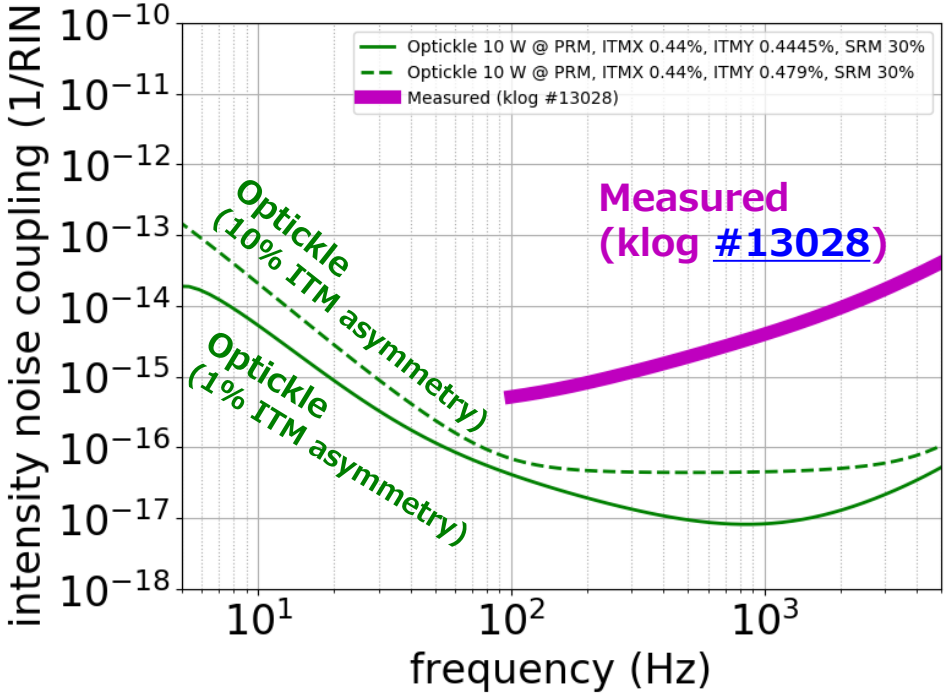


Laser Noises

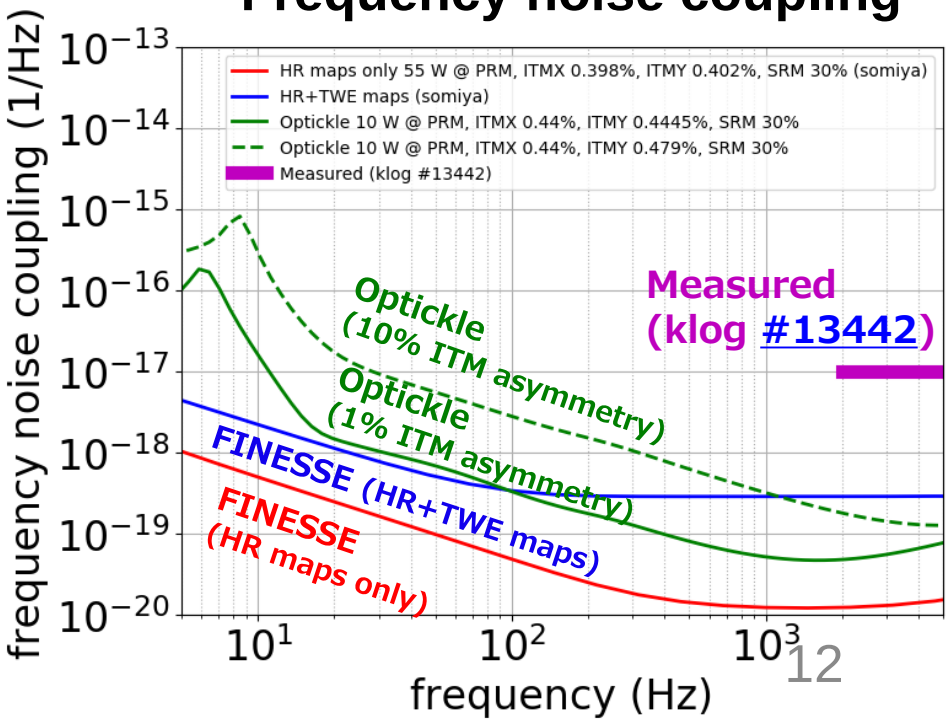
- Coupling was larger than expected by 1-2 orders of magnitude (probably due to birefringence)
- Better interferometer alignment would reduce the coupling (with WFS)

JGW-T2011662

Intensity noise coupling

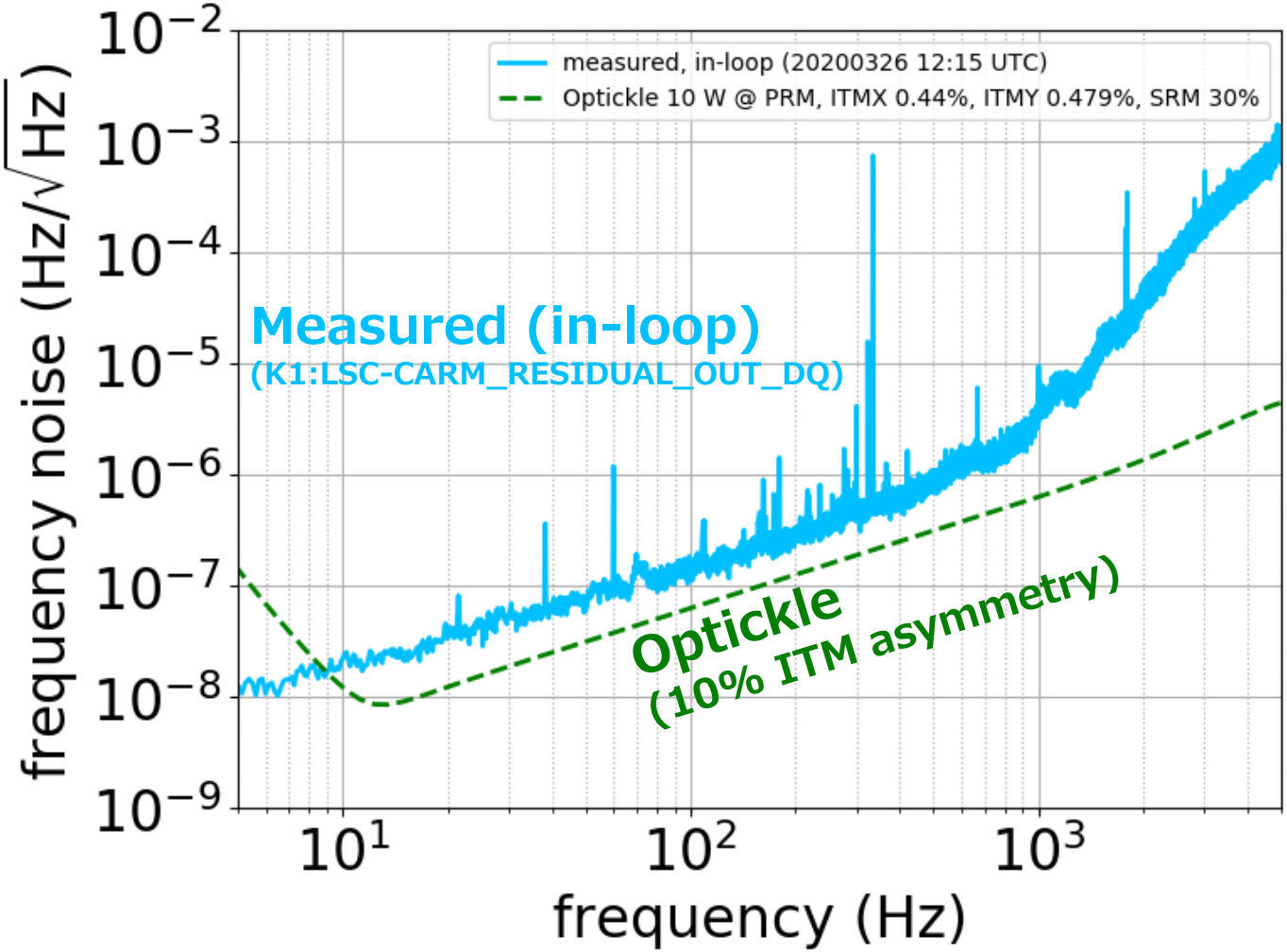


Frequency noise coupling



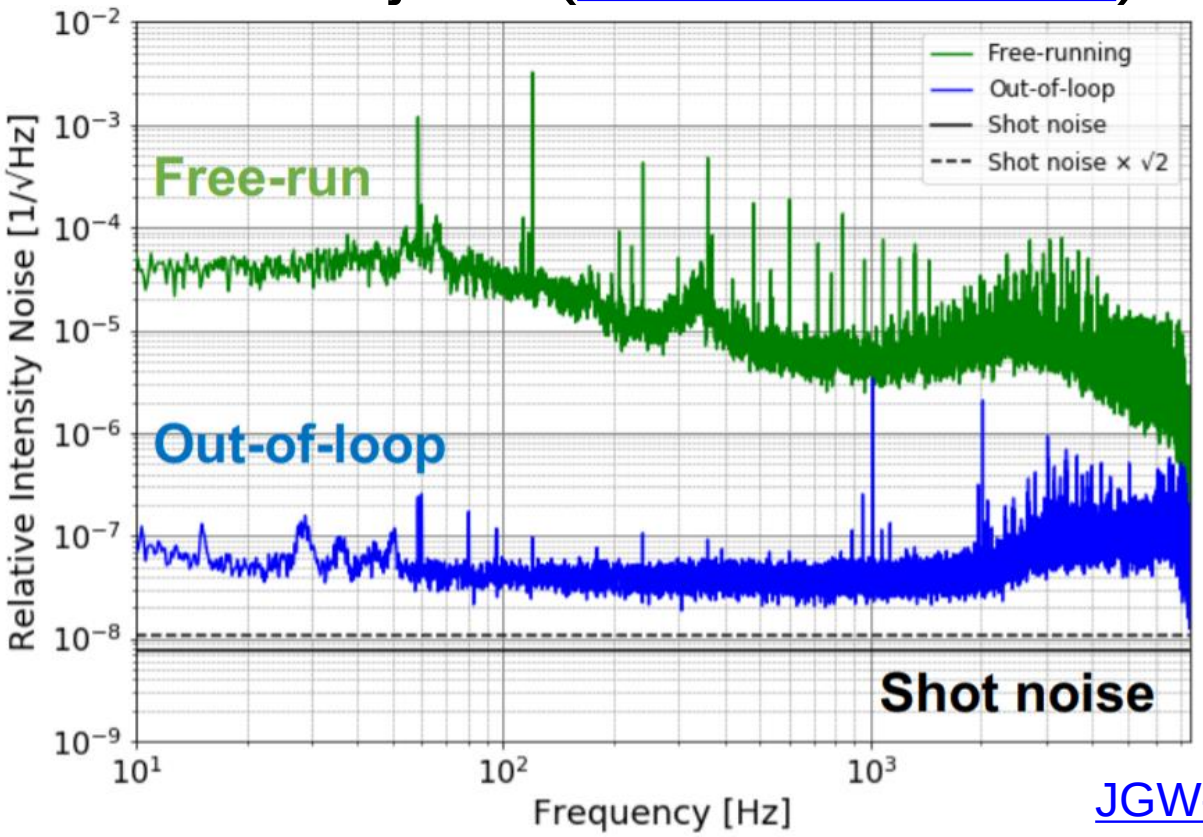
Laser Frequency noise

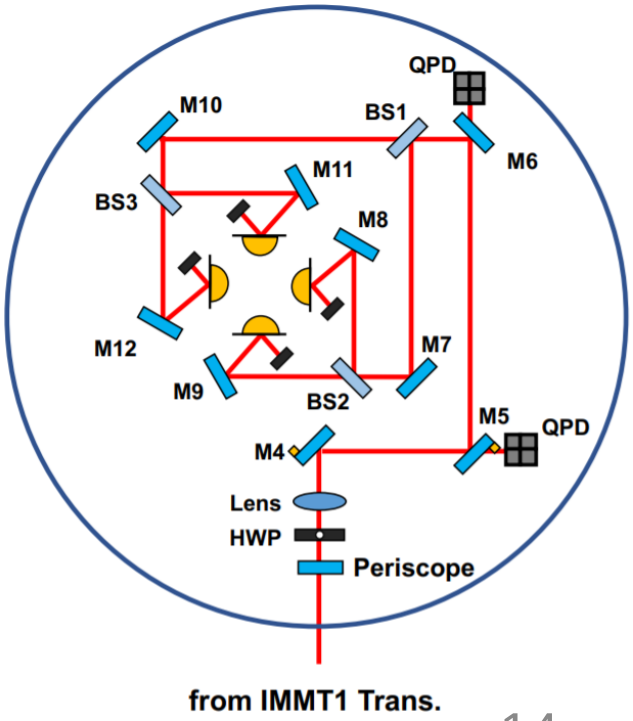
- Almost shot noise limited (~10 mW at PD) at 100 Hz
- Not very critical for BNS range



Laser Intensity noise

- A factor of ~3 to shot noise limit
- Some noise from beam jitter ?
- There is a plan to increase power and to reduce beam jitter (JGW-G2012322)

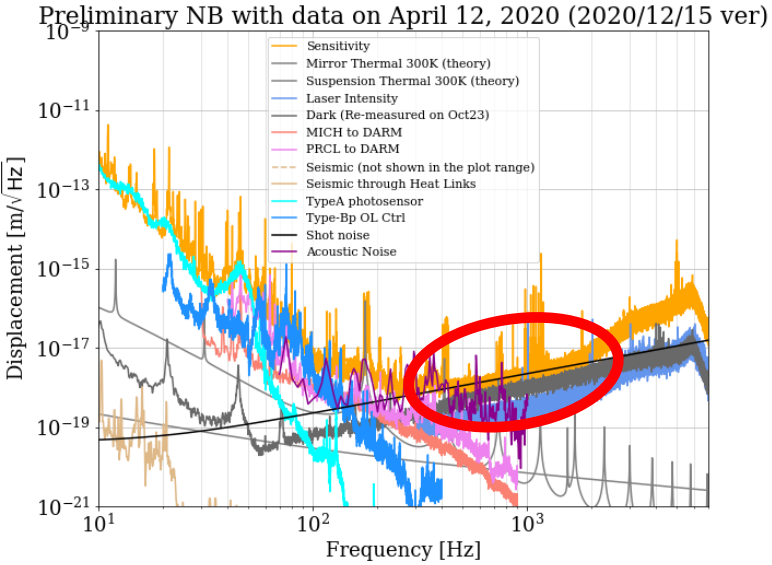




JGW-G2012322

Expectations for O4

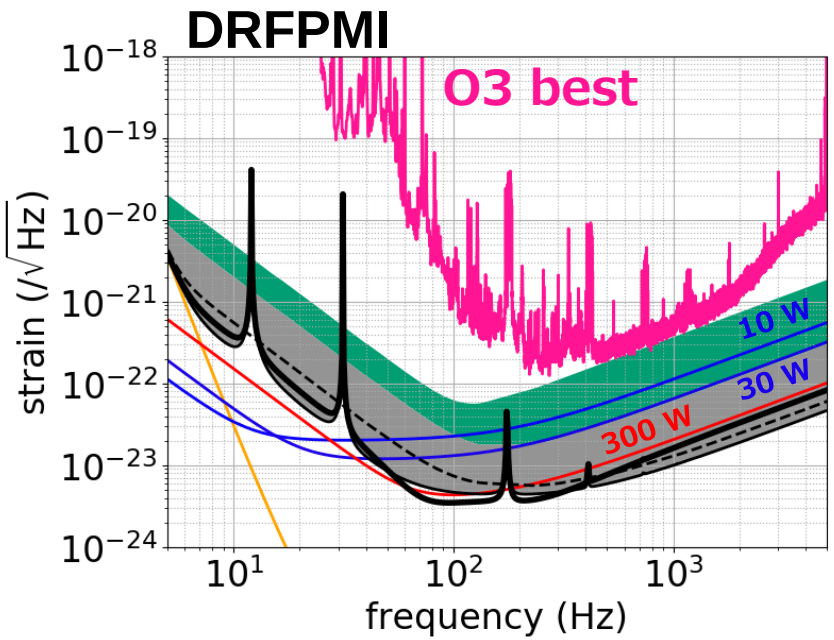
- Laser noises (frequency noise and intensity noise)
- Shot noise
- Acoustic noise
- Coupling from auxiliary degrees of freedom
- Thermal noise
- Test mass suspension damping noise

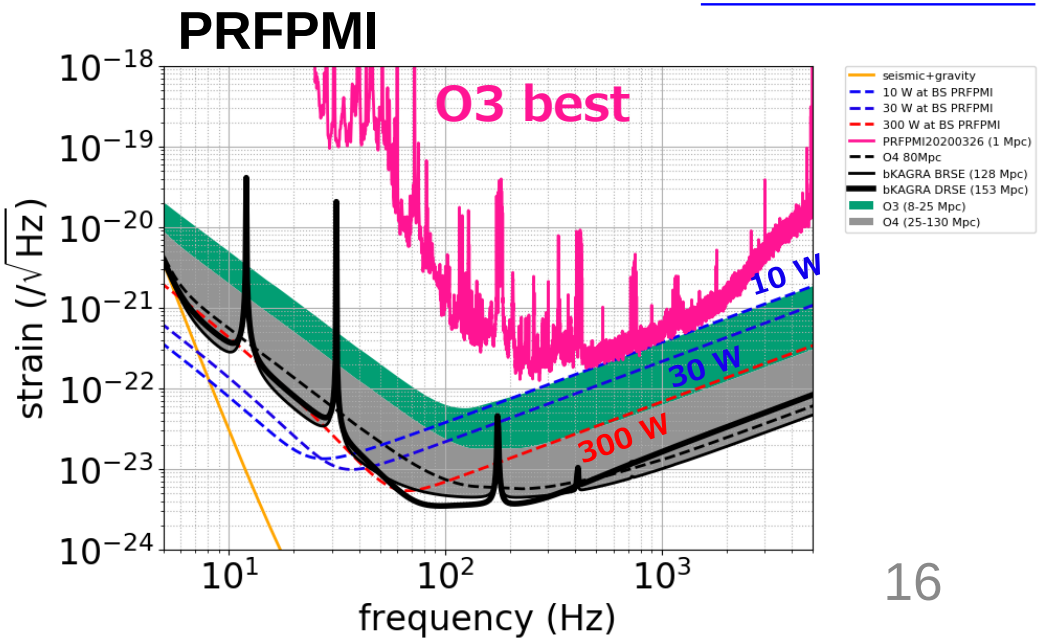


Shot Noise

- Shot noise in O3 was not good due to tilted SRM
- 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

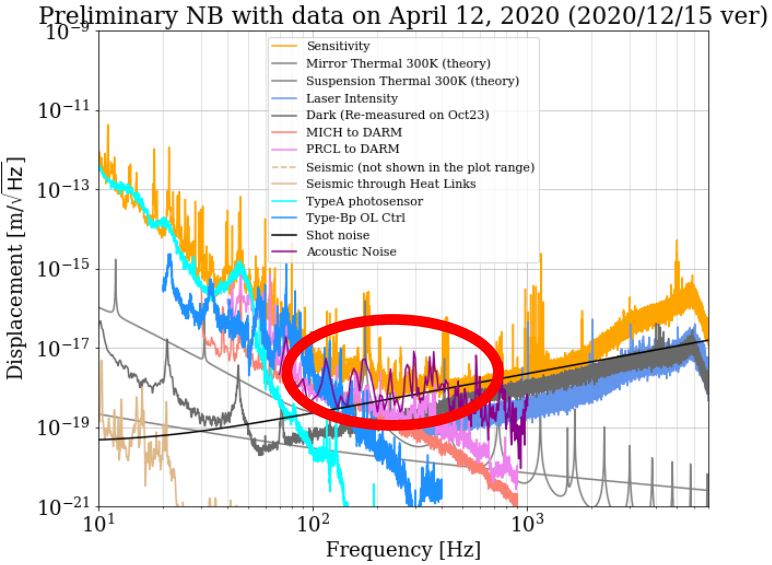
JGW-T2011662





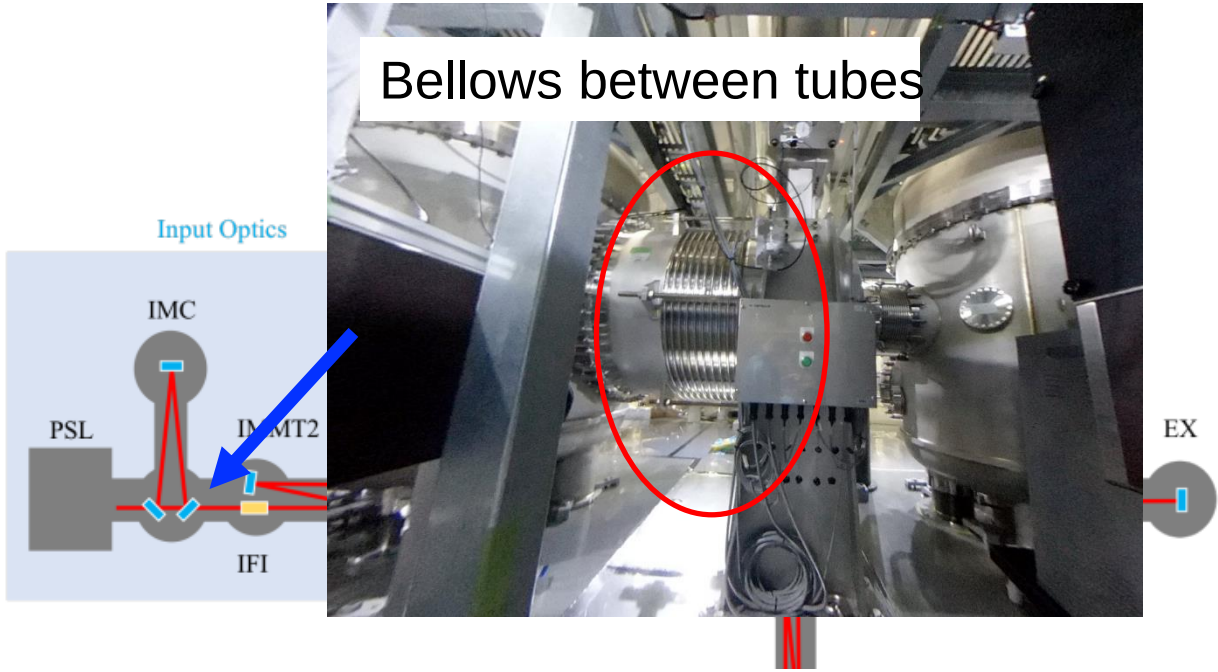
Expectations for O4

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



Acoustic Noise

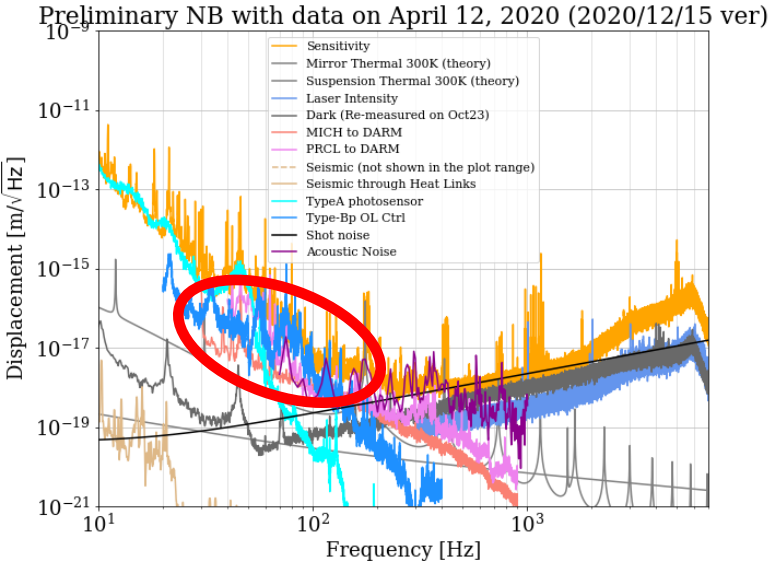
- Most contribution from bellows between IMC-IFI chamber
- Could be reduced by scattered light mitigation



JGW-G2012315

Expectations for O4

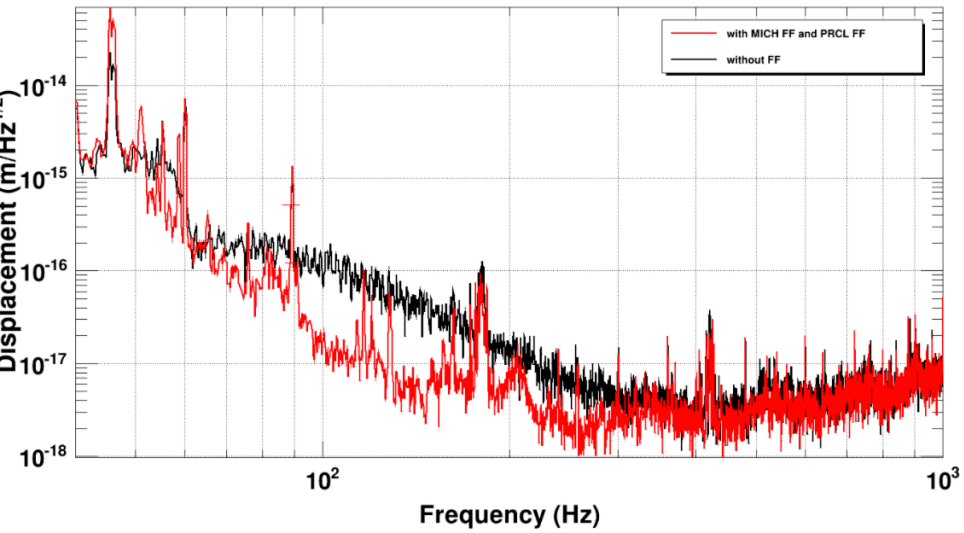
- Laser noises (frequency noise and intensity noise)
- Shot noise
- Acoustic noise
- Coupling from auxiliary degrees of freedom
- Thermal noise
- Test mass suspension damping noise

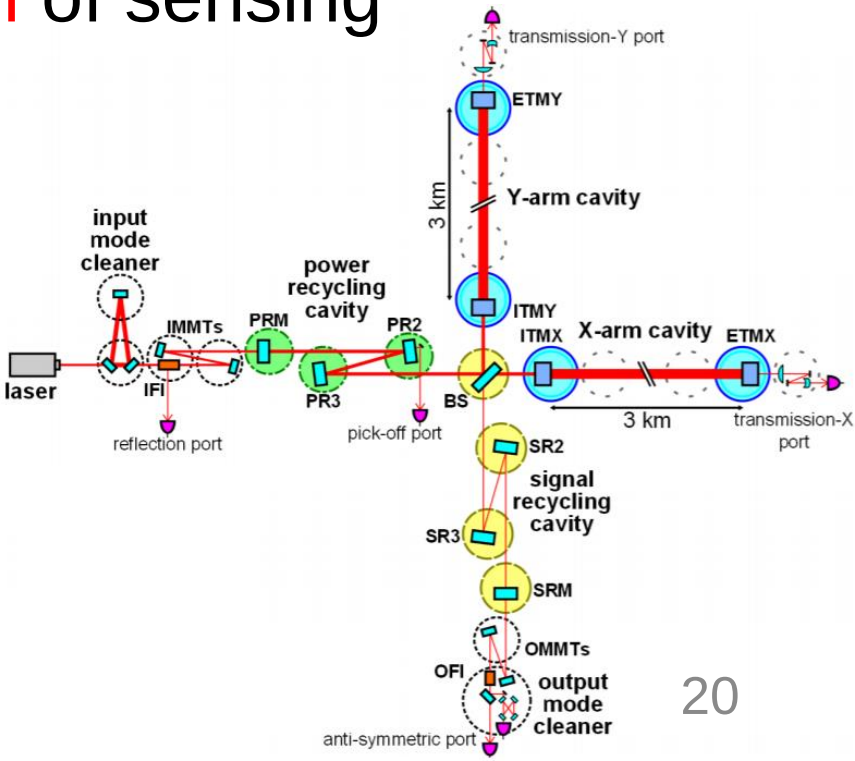


Coupling from Auxiliary DOFs

- Coupling MICH (Michelson) and PRCL (power recycling cavity length)
- Feedforward reduces the coupling by ~1/10 at max
- More feedforward gain necessary
- Also, better diagonalization of sensing matrix can be done for O4

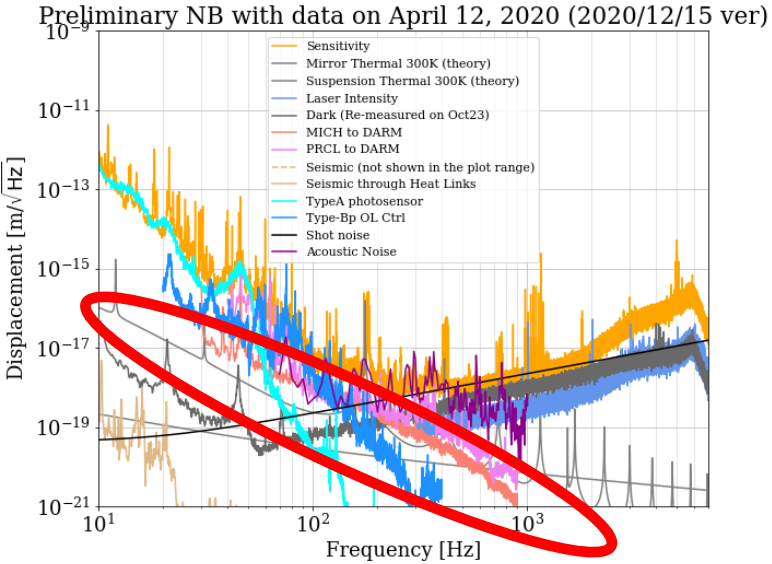
JGW-G2012315





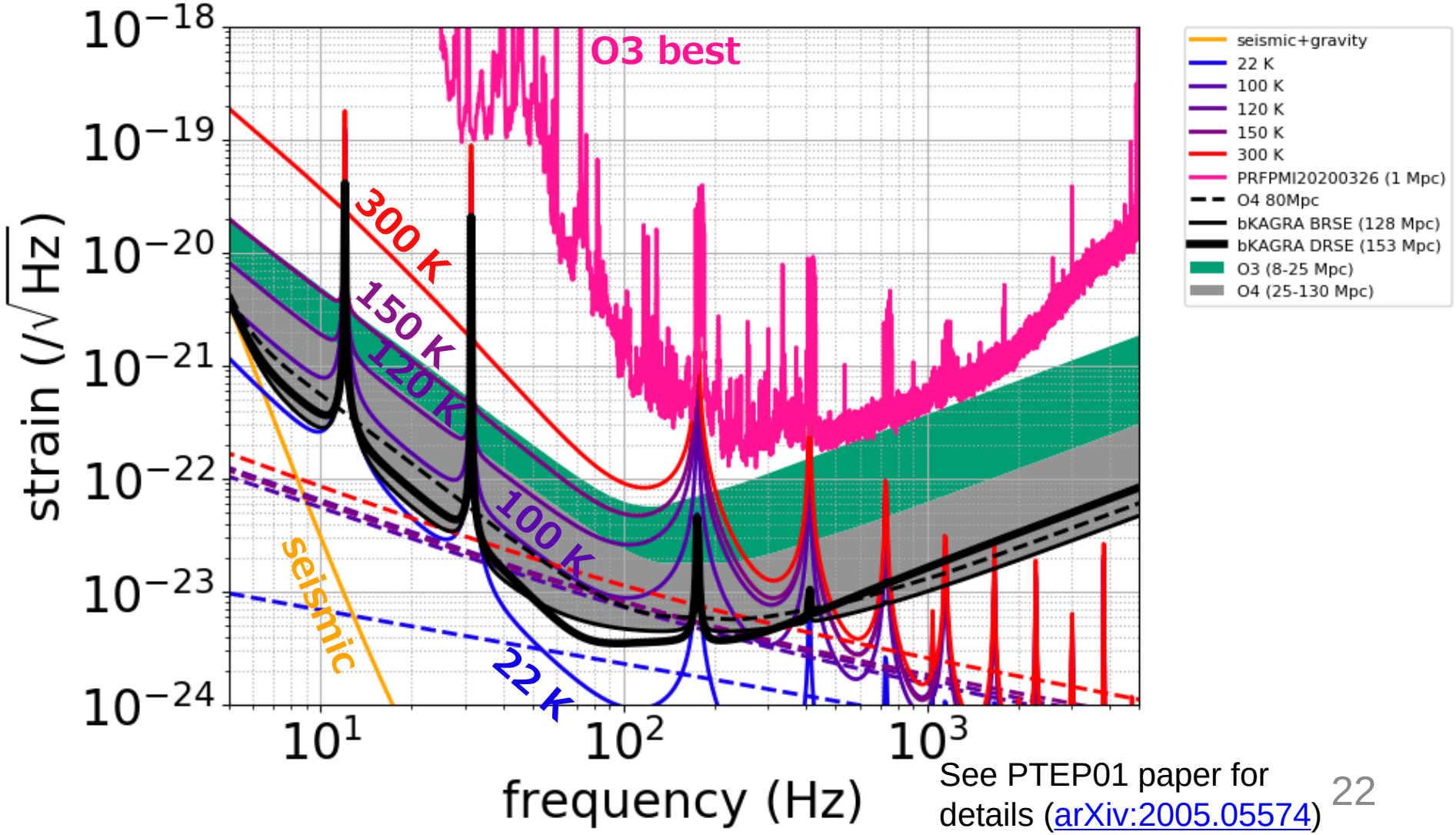
Expectations for O4

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



Thermal Noise

- At least below ~100 K is necessary



See PTEP01 paper for details (arXiv:2005.05574)

Expectations for O4

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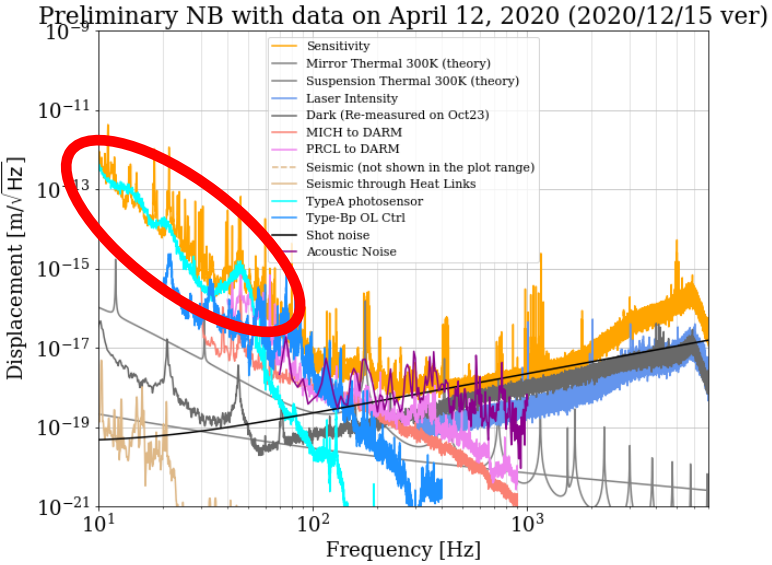
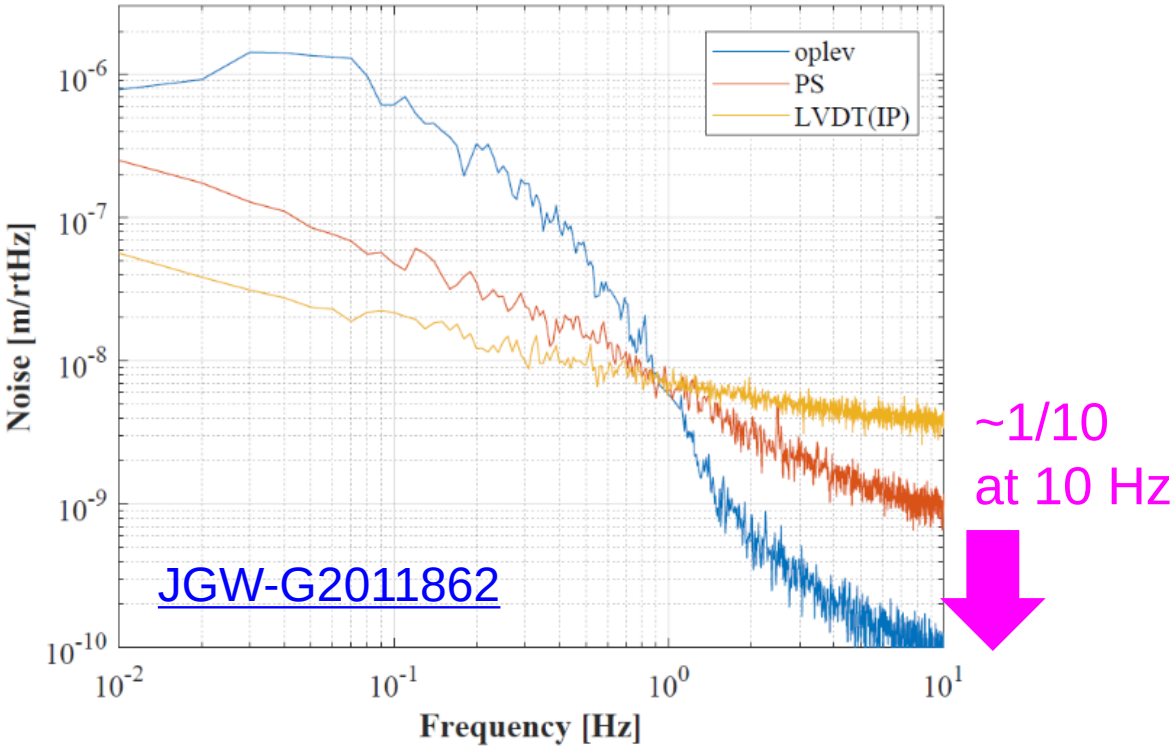
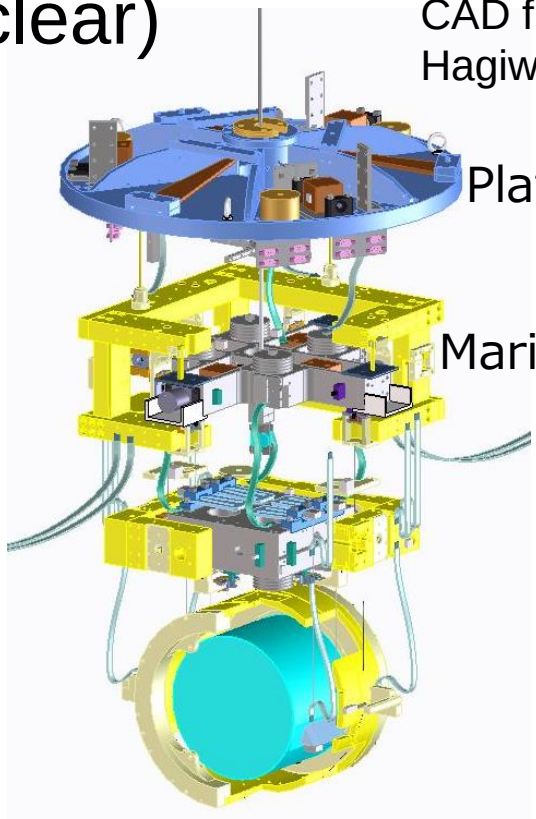


Test Mass Suspension Damping

- Noises from marionette damping using photo sensors are limiting
- There is a plan to install optical levers also for marionette and platform stages (whether if we can turn off photo sensors are not clear)



CAD from Hagiwara-san

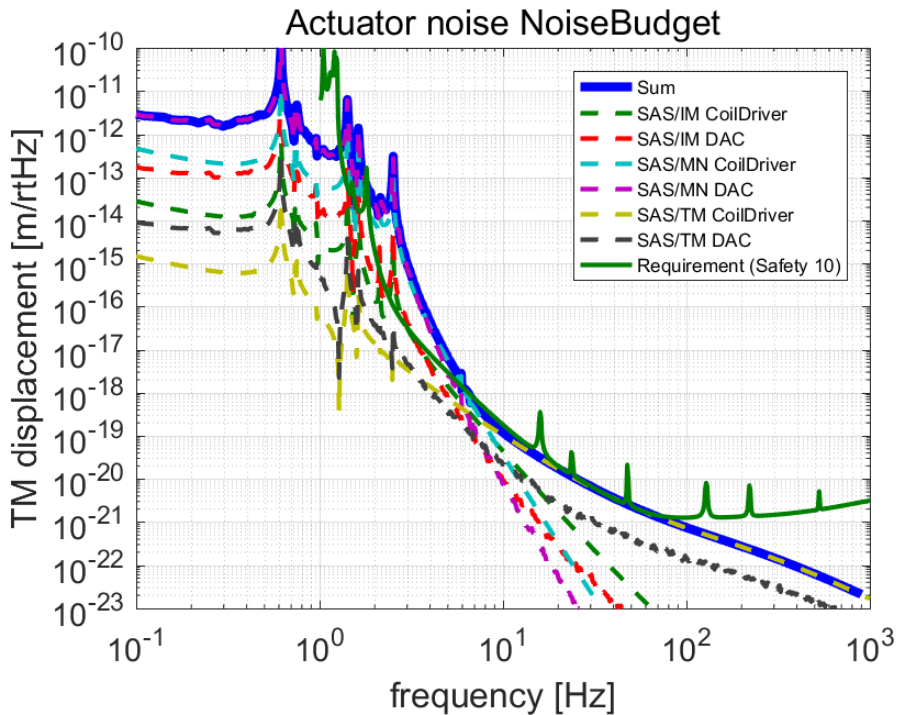


Actuator Noise

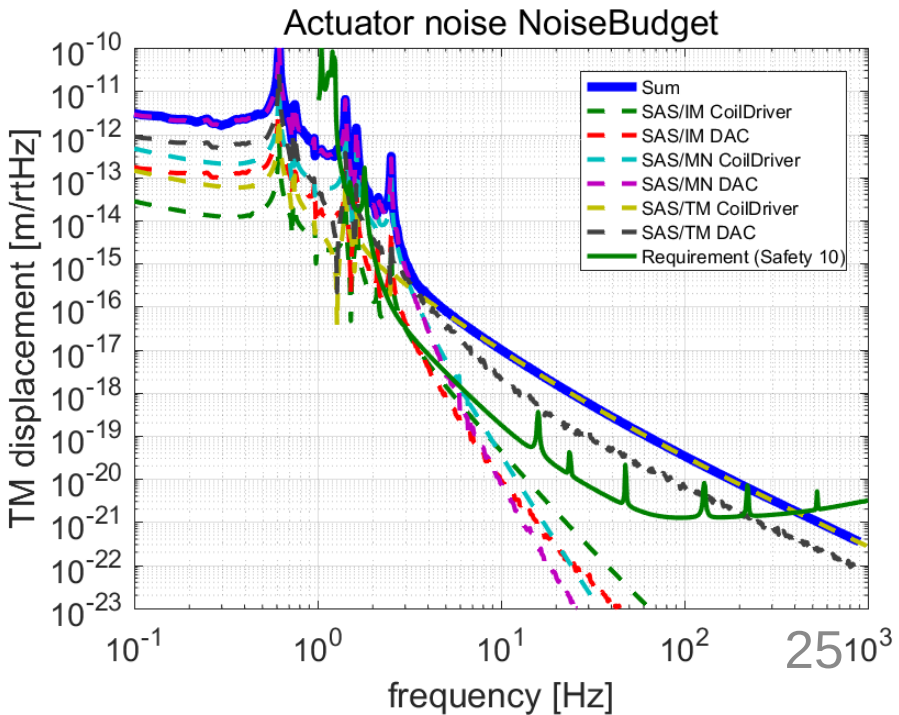
- Noises from high power coil driver used for O3 is not good for O4
- Coil driver switch to turn off high power coil driver after the lock acquisition necessary

JGW-T1910142

Nominal Case



High Power TM Case



Summary

- O4 sensitivity would be ~70 Mpc at most optimistic case
- Laser noises
  - alignment improvement (with WFS) necessary
  - improvement plan for ISS seems promising
- Shot noise
  - DRFPMI with more than 30 W at BS necessary
- Thermal noise
  - at least ~100 K necessary
- Coupling of auxiliary degrees of freedom
  - more sensing matrix diagonalization necessary
  - more feedforward gain necessary (by ~ x10)
- Suspension damping noises
  - coil driver switch necessary
  - concrete planning based on noise estimates necessary

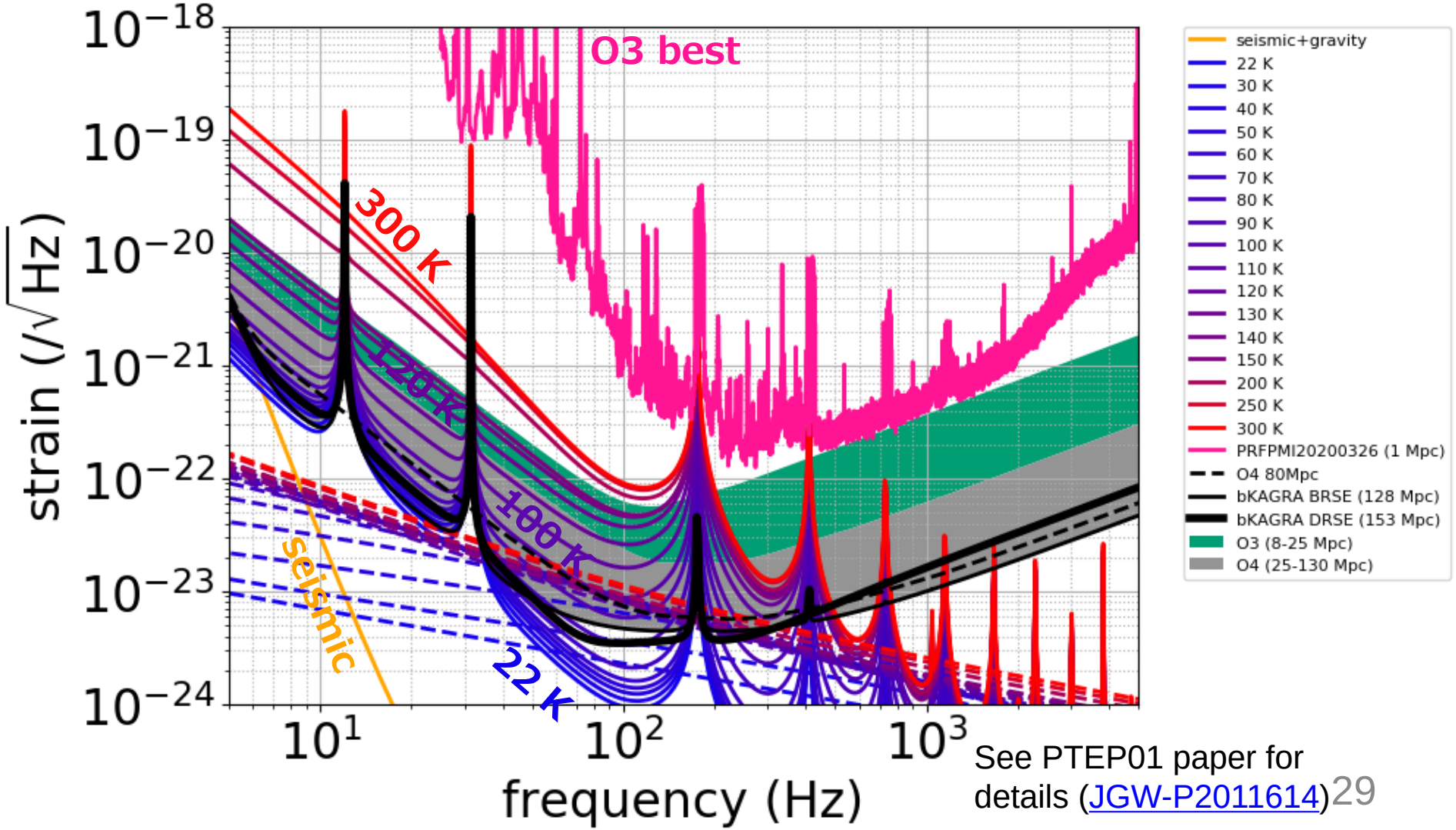
Details

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-G2012213)
- 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)

Various Thermal Noise

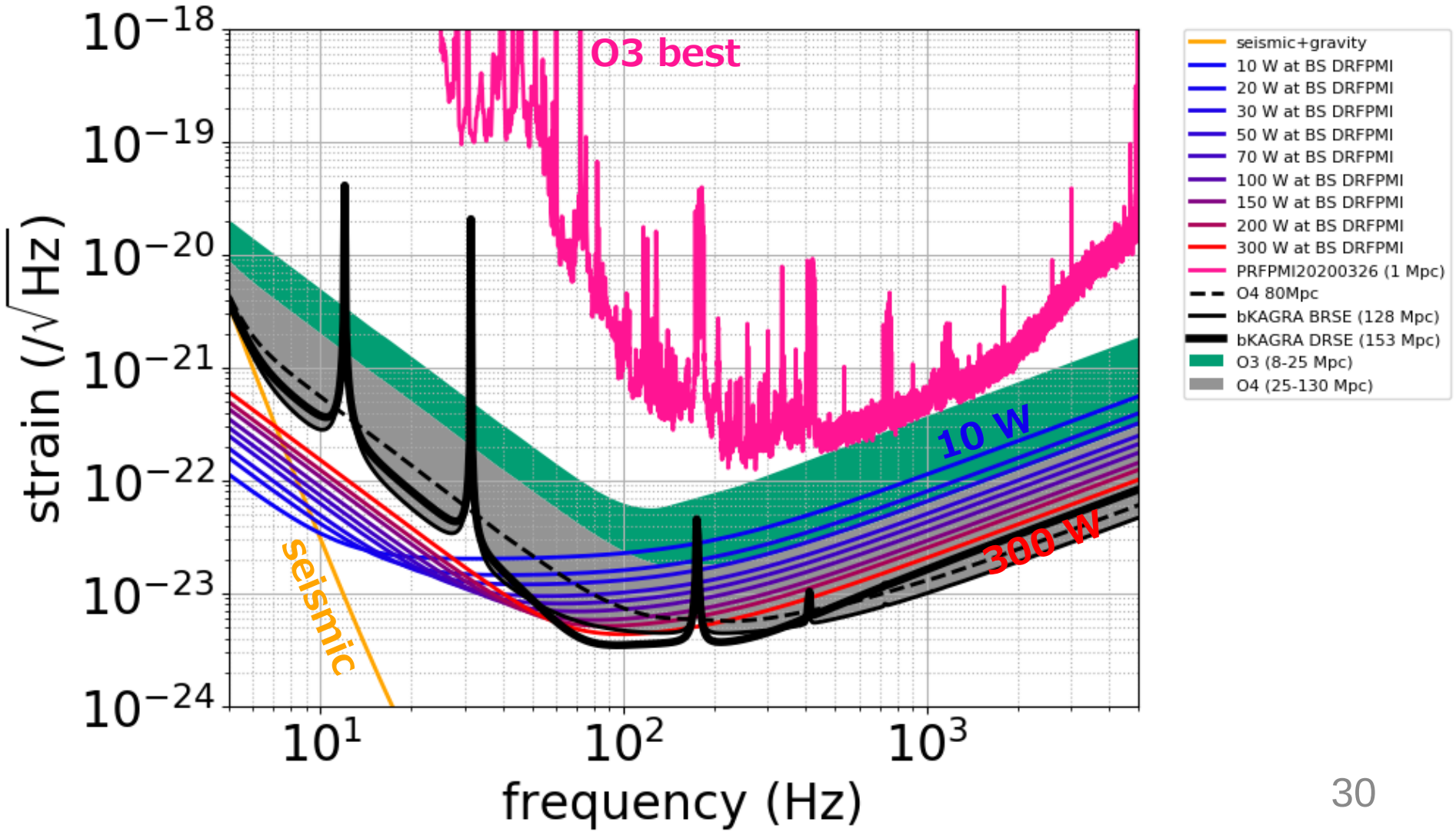
- All temperatures



See PTEP01 paper for details (JGW-P2011614)

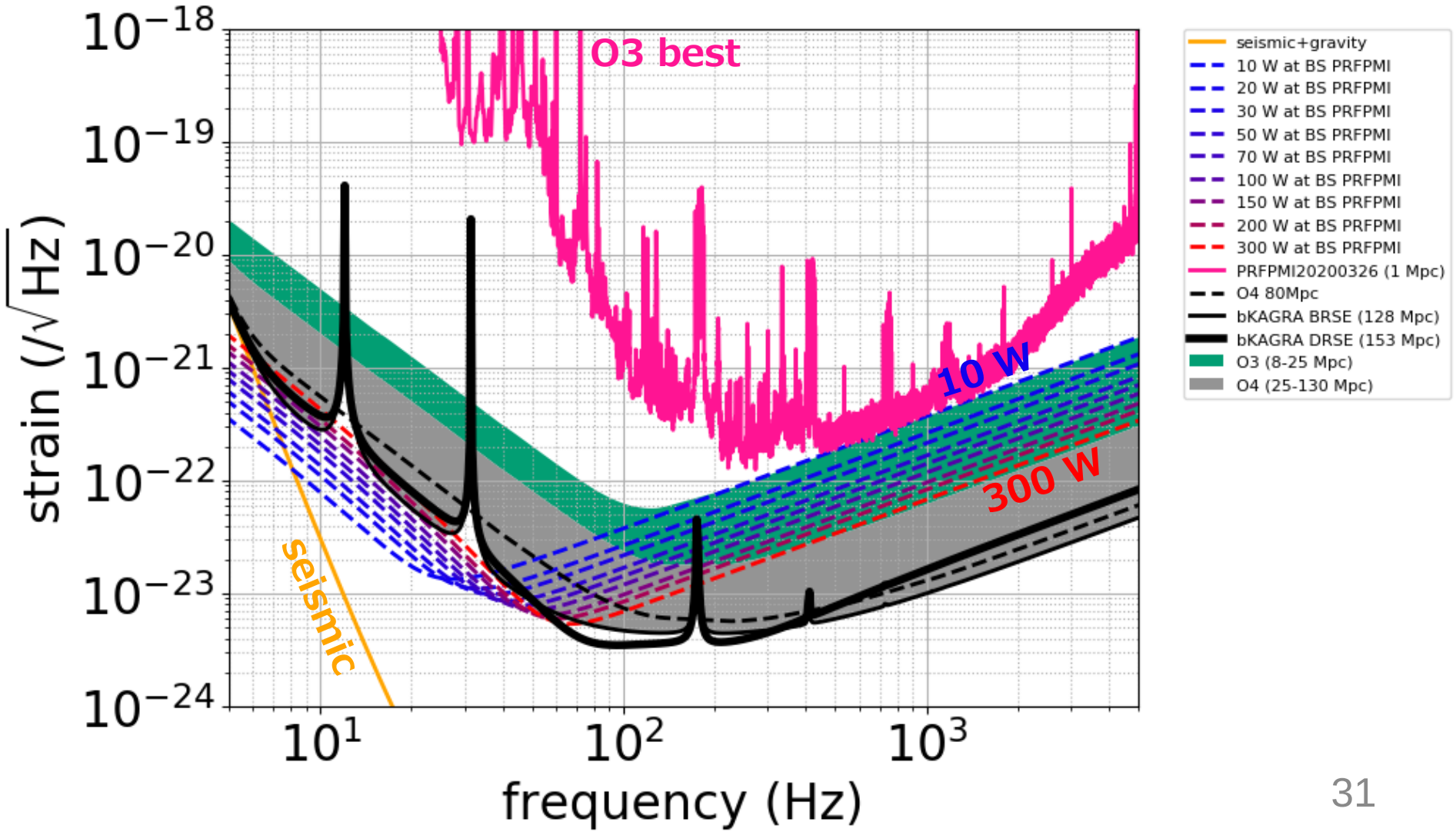
Various Quantum Noise (DR)

- All powers



Various Quantum Noise (PR)

- All powers

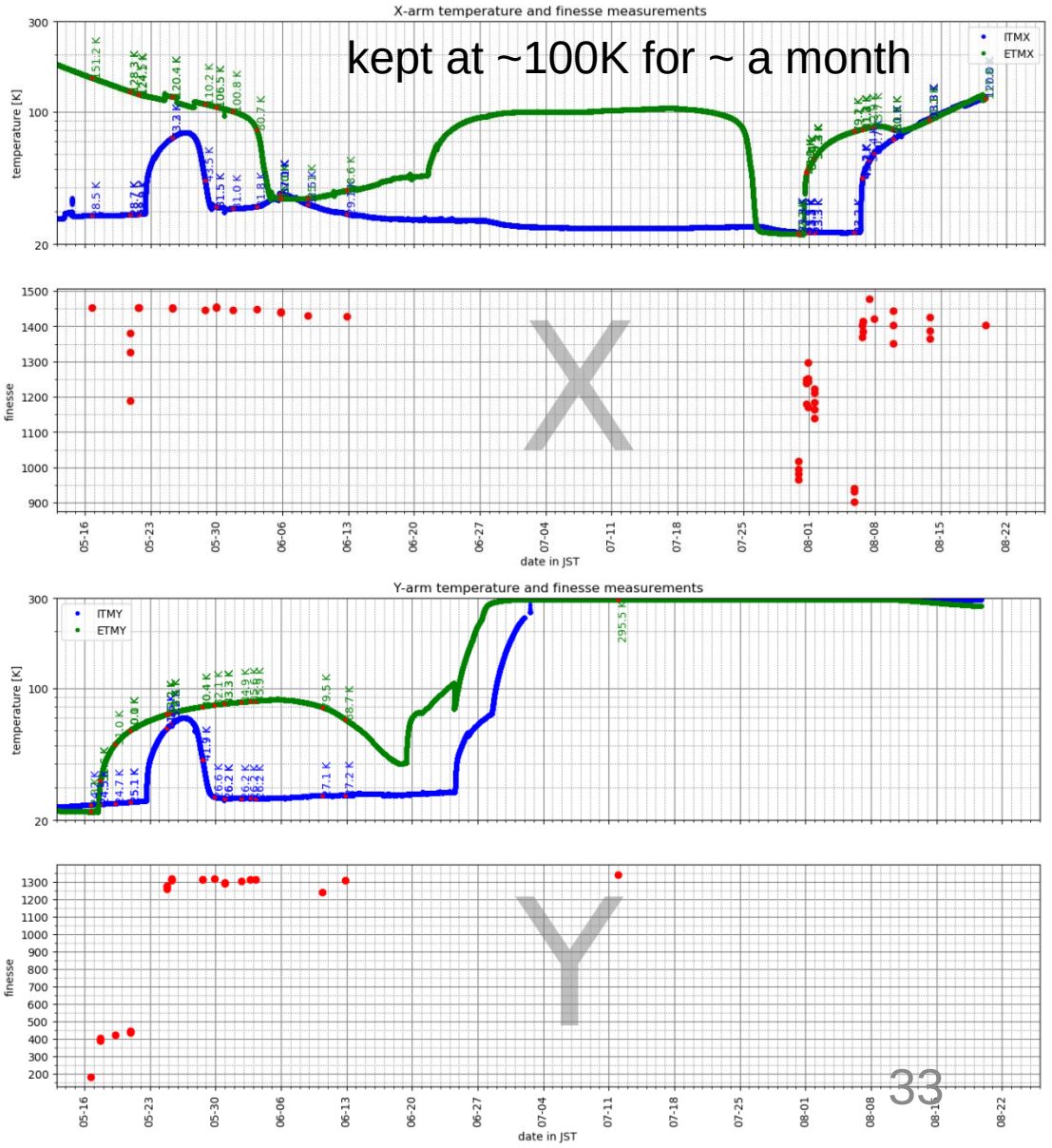


How to Realize 100 K ?

- **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]