JGW-G2012349

December 20, 2020

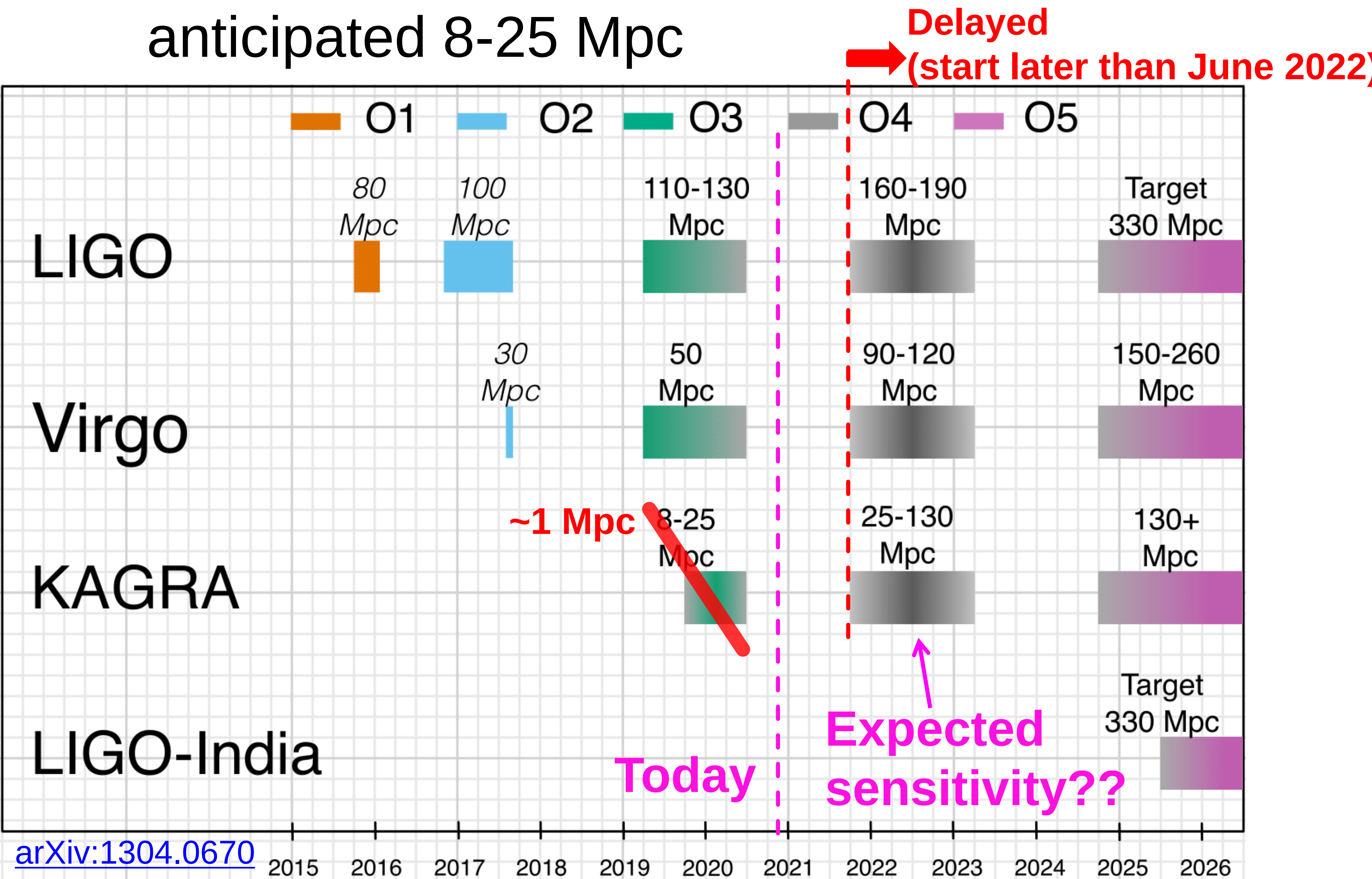
7th KAGRA International Workshop (Online)

# Expectations for Sensitivity of KAGRA in O4

Yuta Michimura

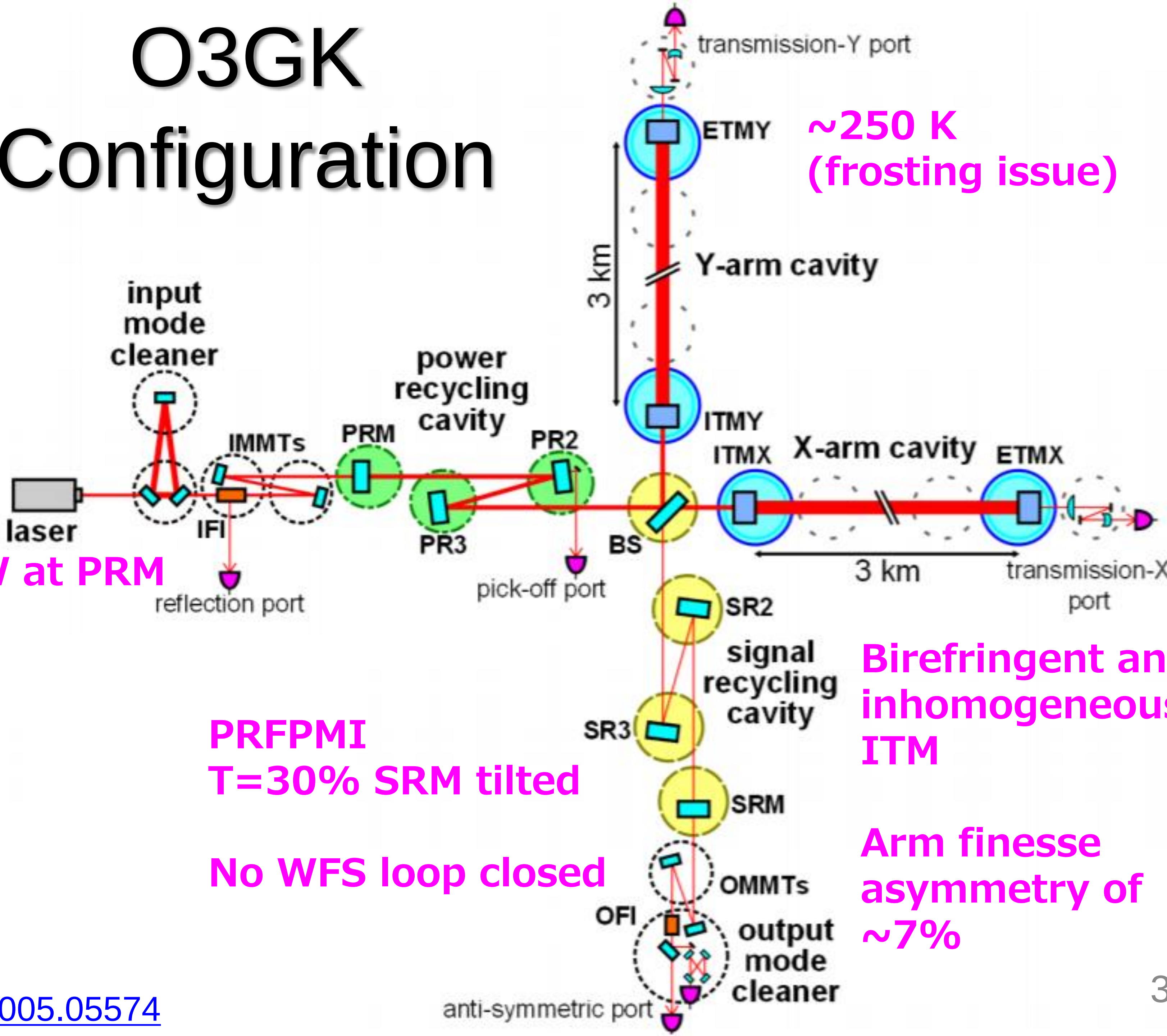
# Observing Scenario of LVK

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




arXiv:1304.0670

# O3GK Configuration




~250 K
(frosting issue)

3-5 W at PRM

PRFPMI
T=30% SRM tilted

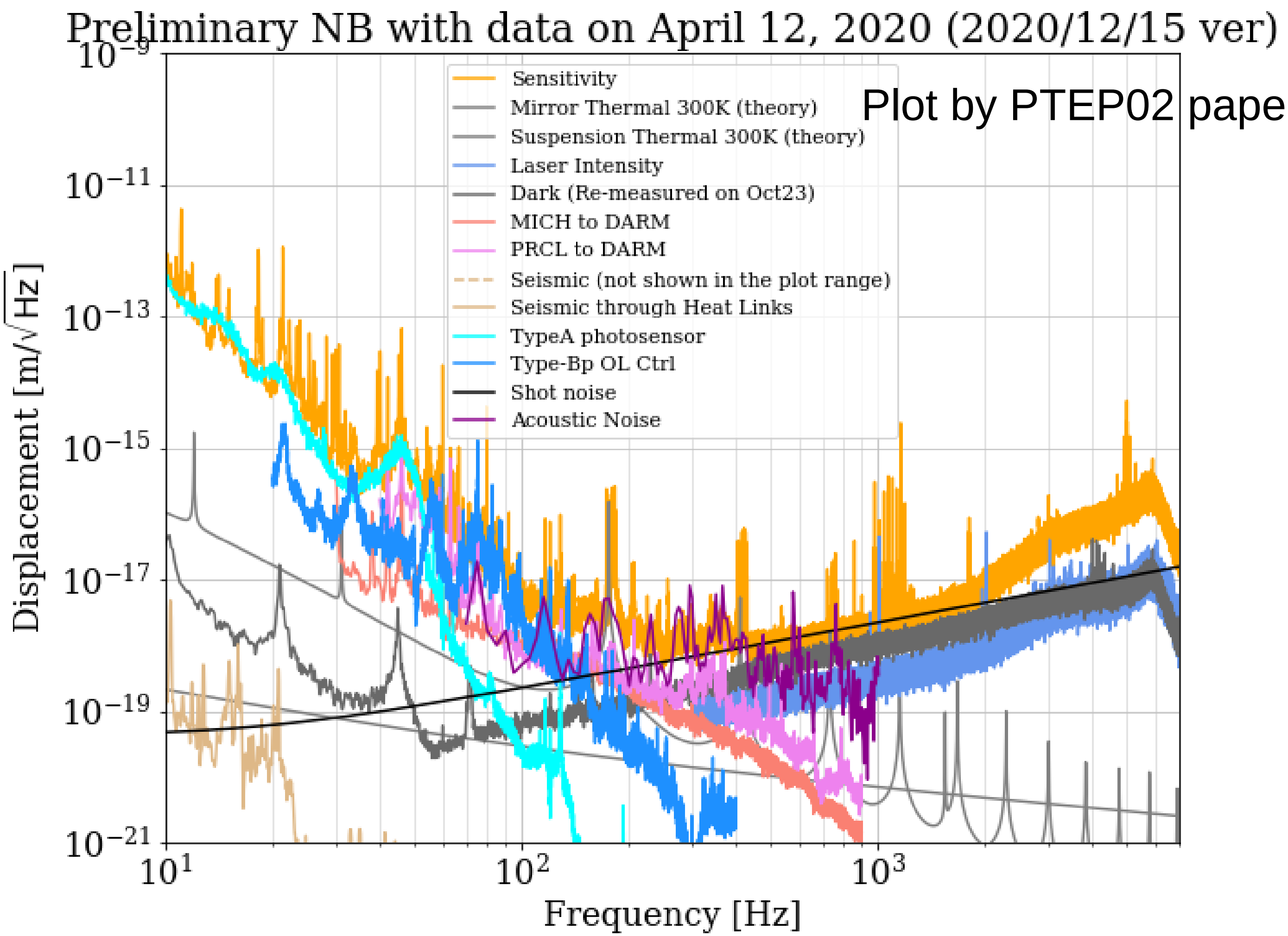
No WFS loop closed

Birefringent and inhomogeneous ITM

Arm finesse asymmetry of ~7%

arXiv:2005.05574

# O3GK Noise Budget

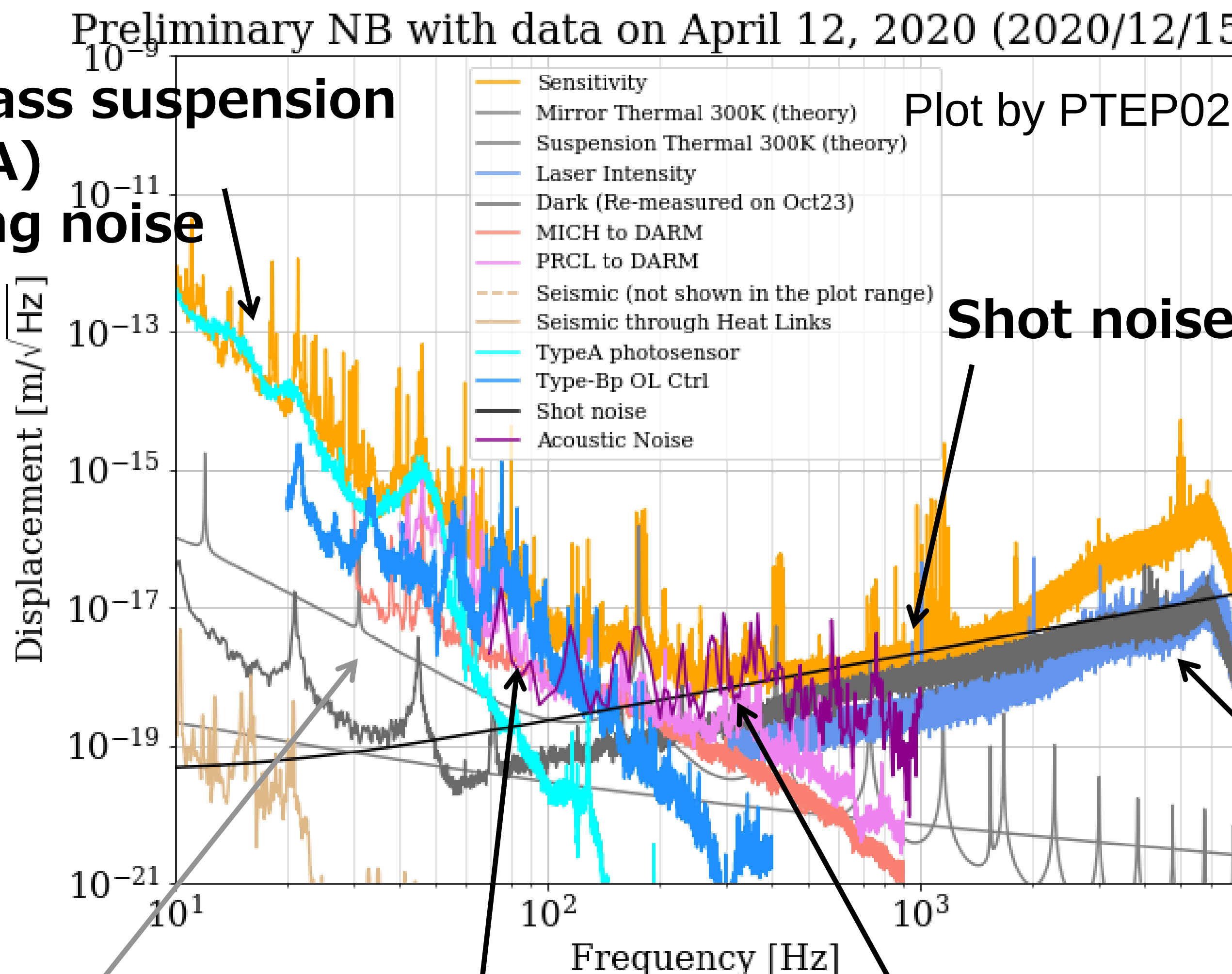



Plot by PTEP02 paper team

**Preliminary!**

- OMC dark noise needs some update
- Frequency noise not plotted yet
- Type-B noise not plotted yet  etc...

# O3GK Noise Budget




Plot by PTEP02 paper team

**Test mass suspension (Type-A) damping noise**

**Shot noise**

**Laser noises**

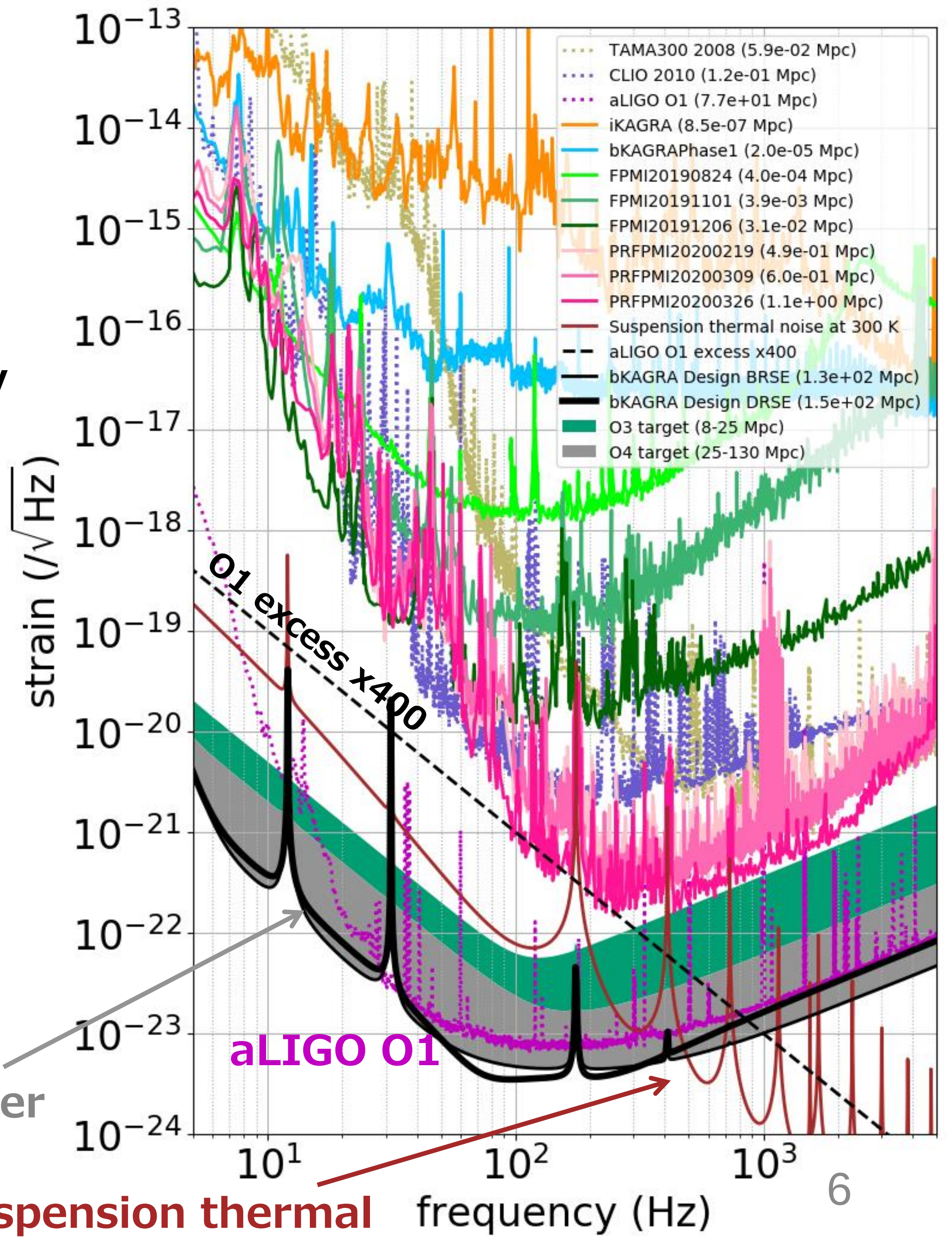
**Acoustic noise**

**Suspension thermal noise**

**Coupling from auxiliary degrees of freedom**

# O4 Target

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

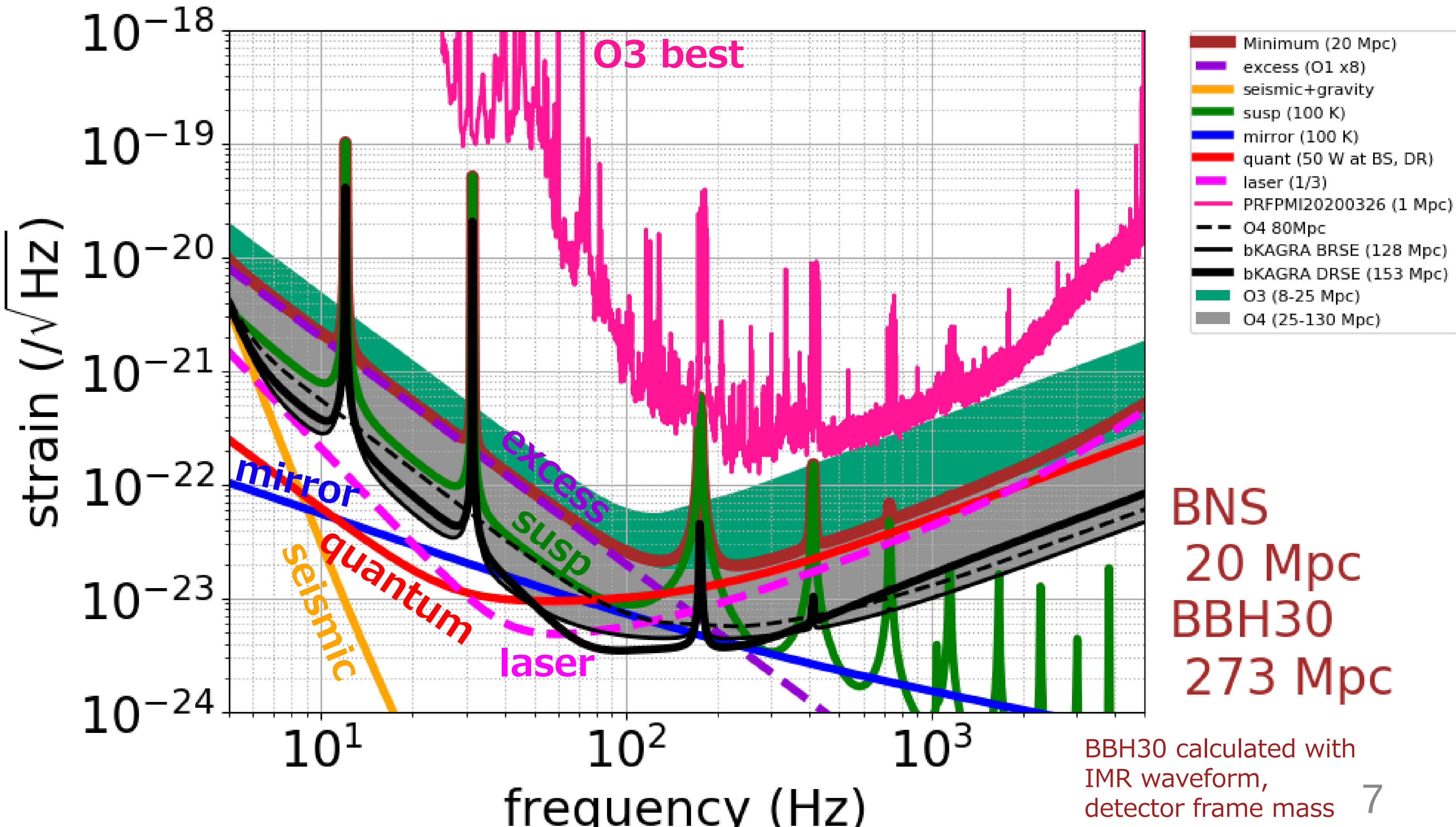



O4 target on Obs. Scenario Paper
25-130 Mpc

300 K suspension thermal

# O4 “Minimum” Example

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

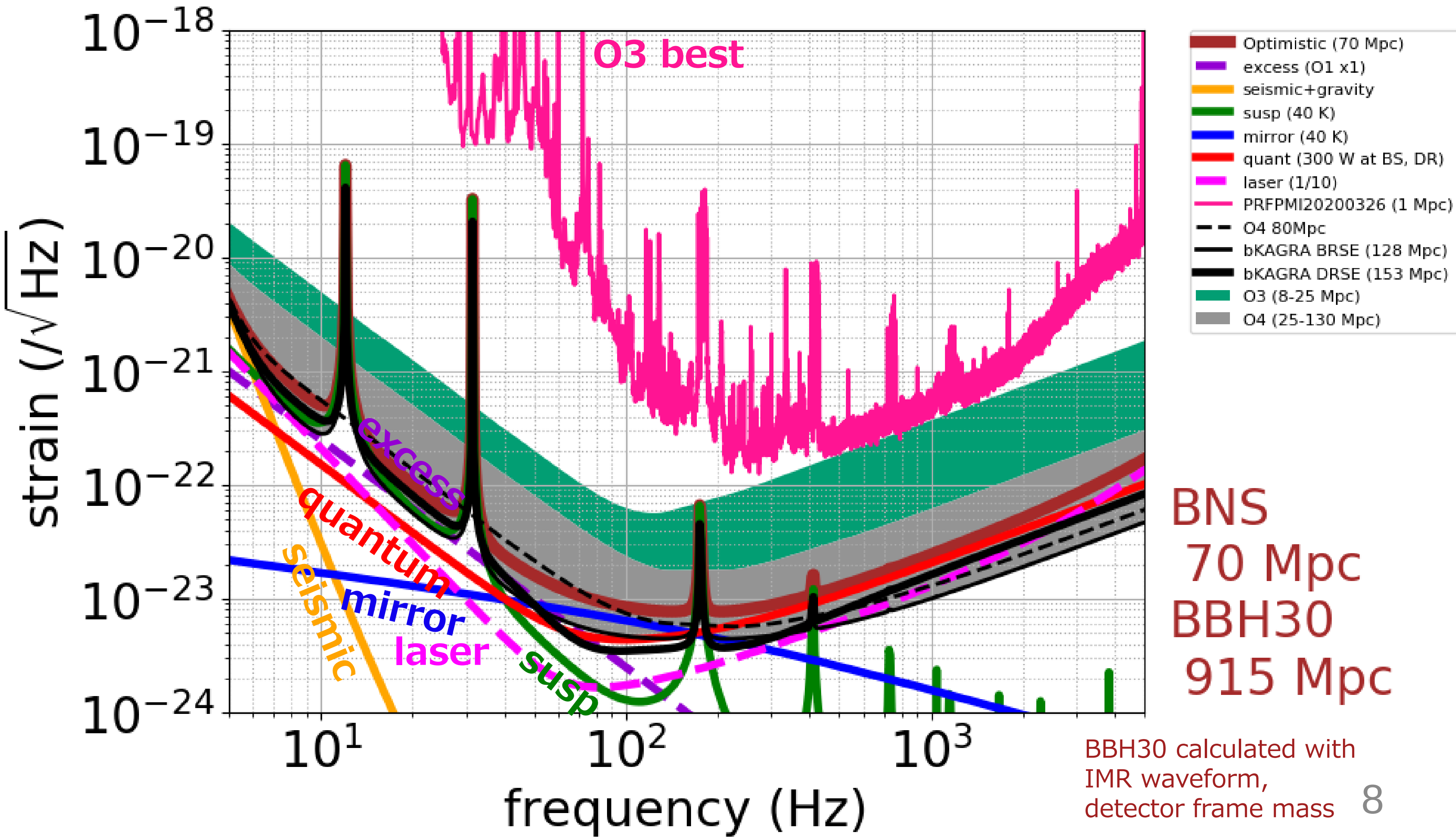



BNS
20 Mpc
BBH30
273 Mpc

BBH30 calculated with
IMR waveform,
detector frame mass

# O4 “Optimistic” Example

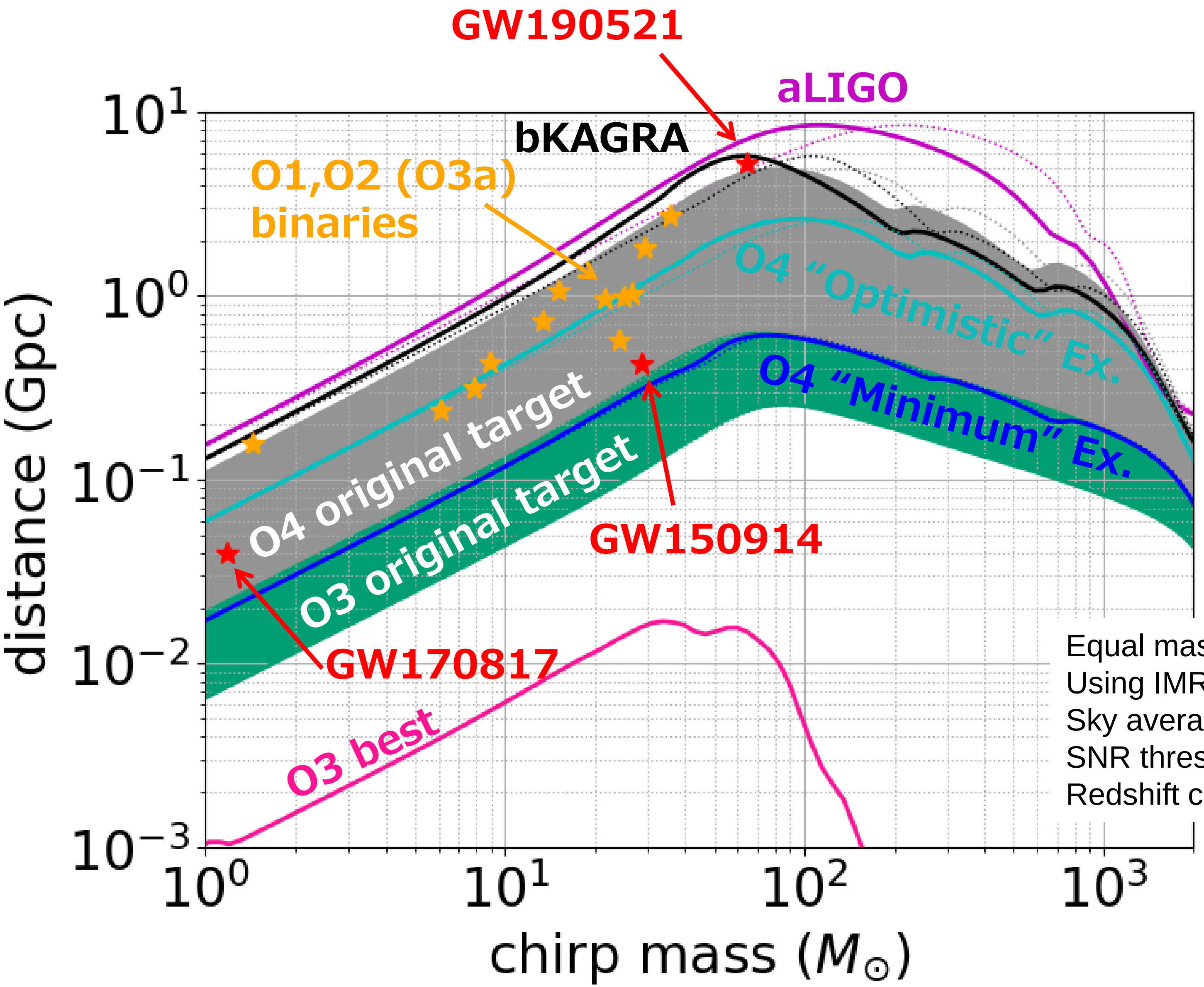
- 1/400 excess, 40 K, 300 W at BS, DR, 1/10 laser noise




BNS
70 Mpc
BBH30
915 Mpc

BBH30 calculated with IMR waveform, detector frame mass

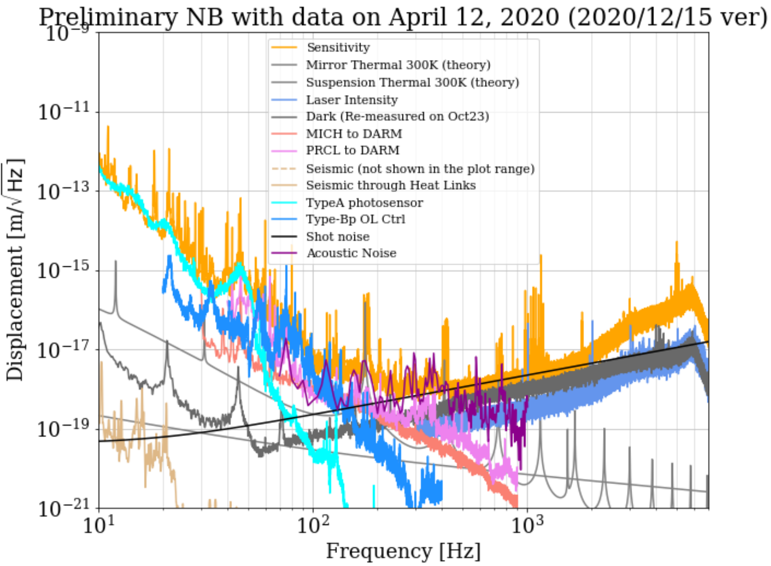
# Inspiral Range




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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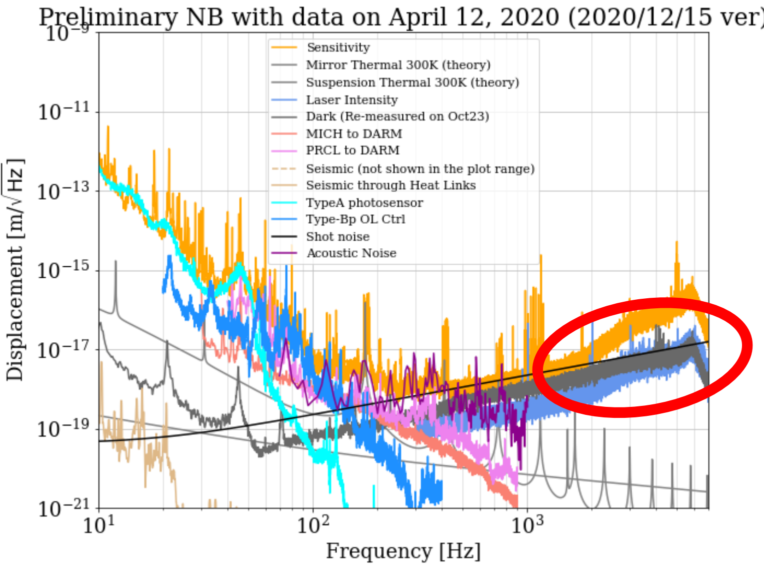
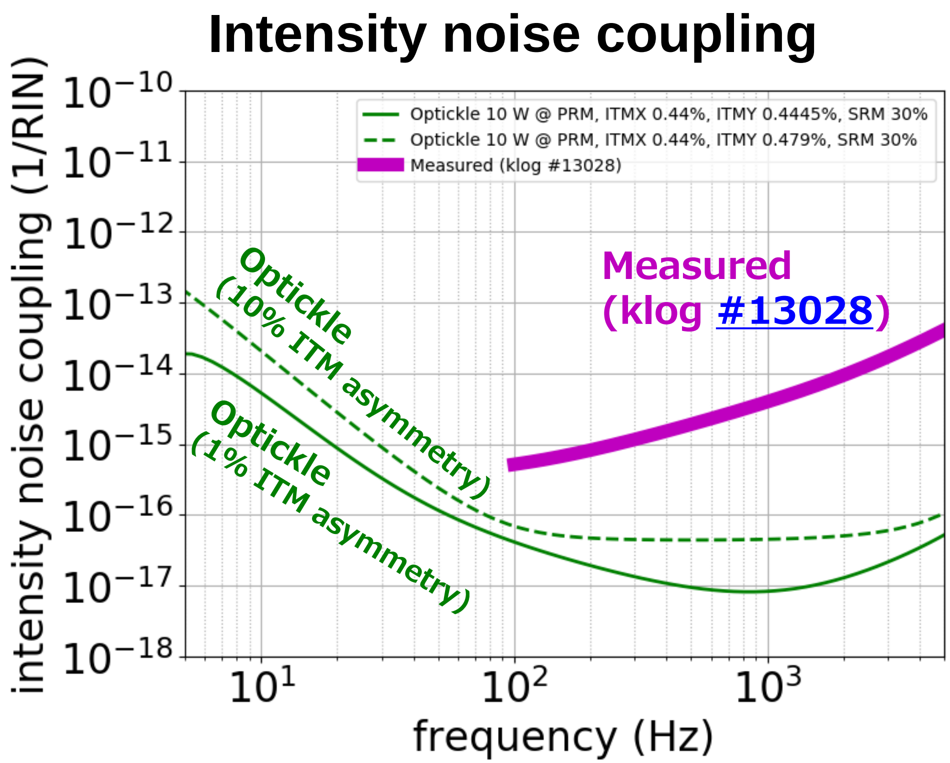
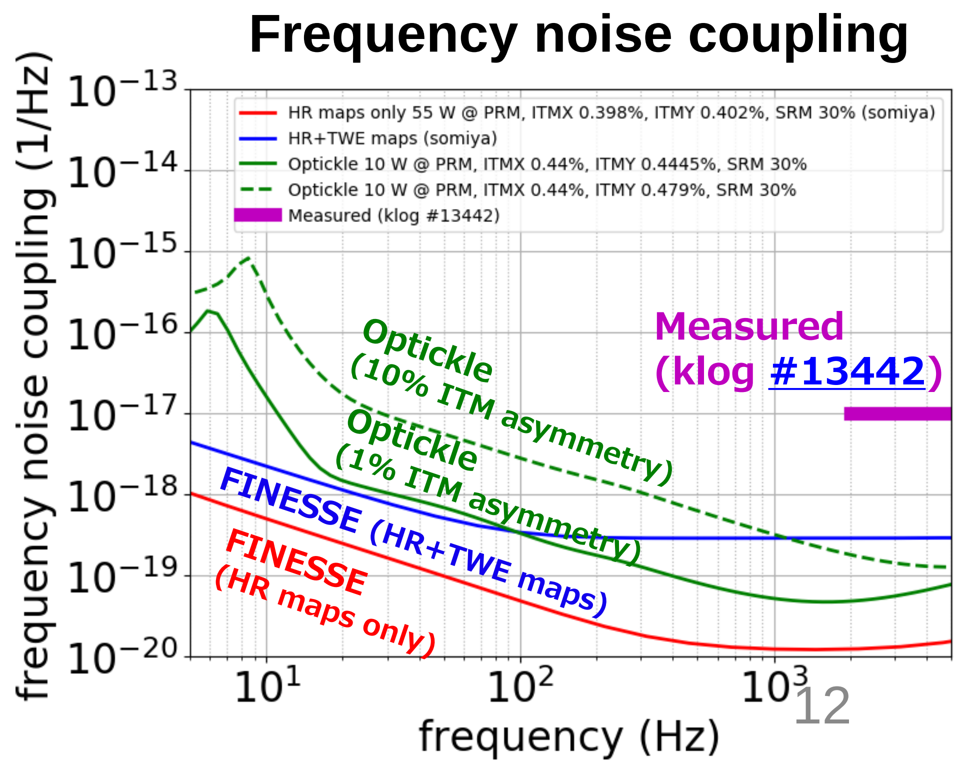


# Laser Noises

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

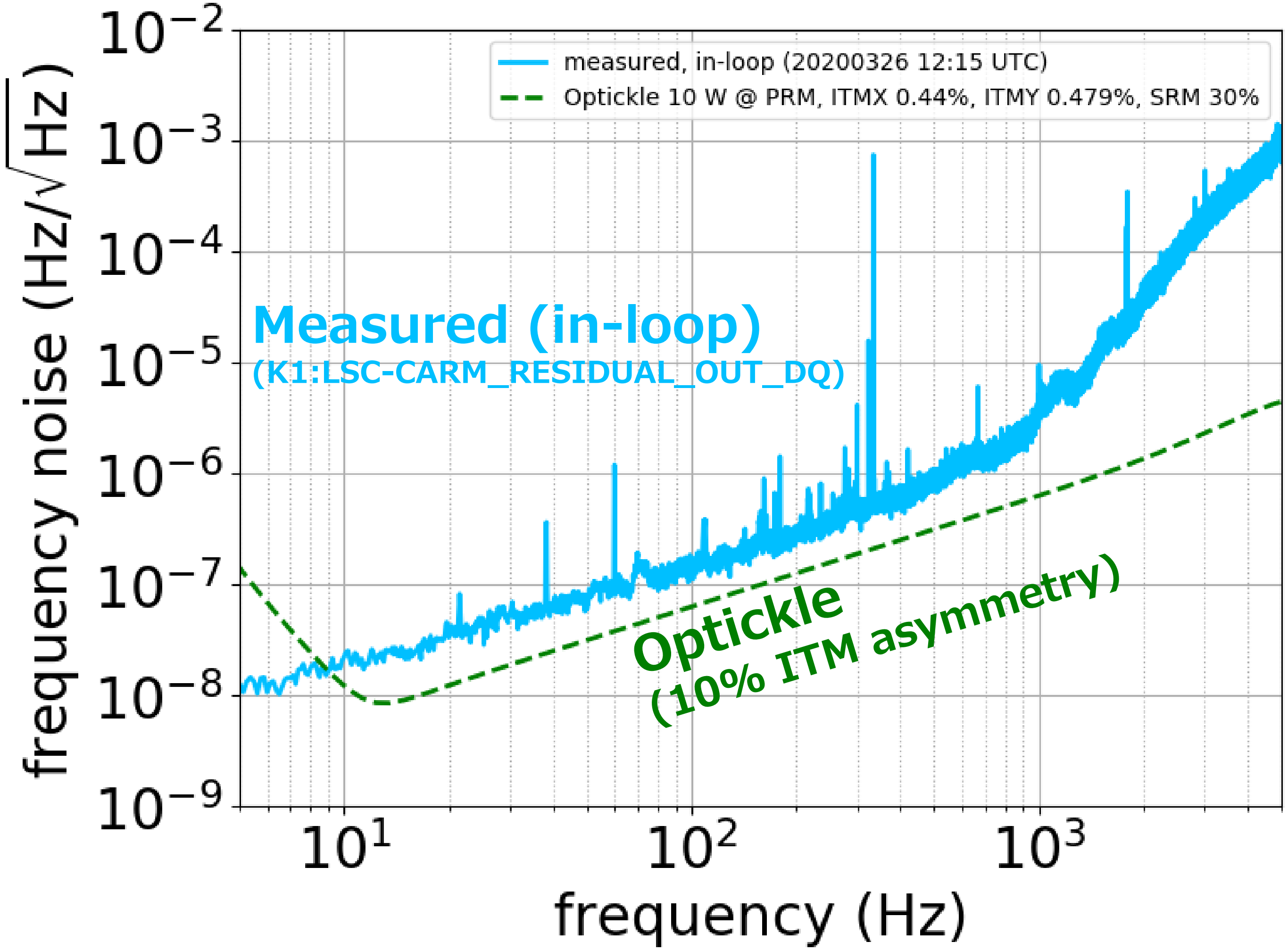
JGW-T2011662



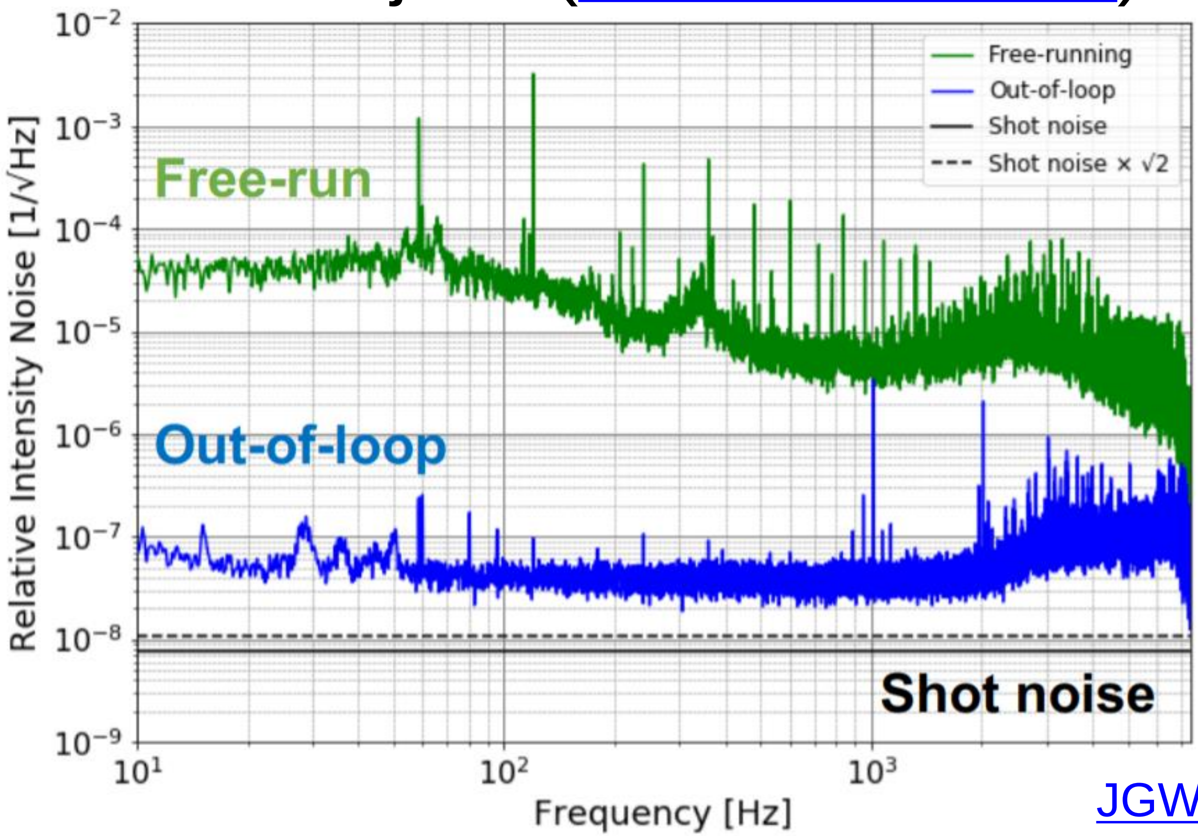
# Laser Frequency noise

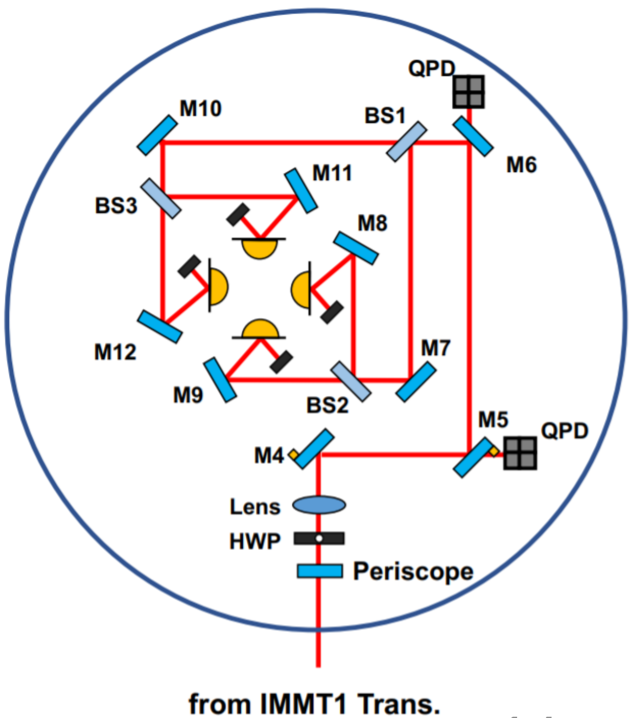
- Almost shot noise limited (~10 mW at PD) at 100 Hz
- Not very critical for BNS range



# 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)

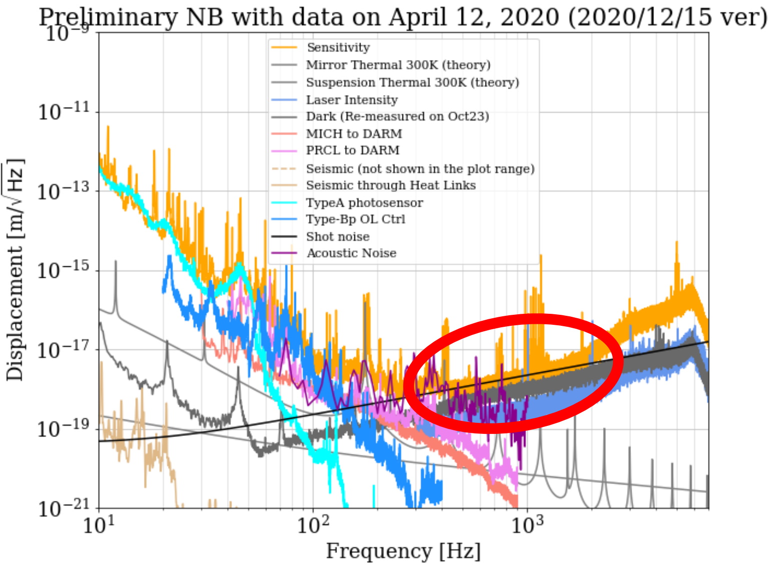



JGW-G2012322

# 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

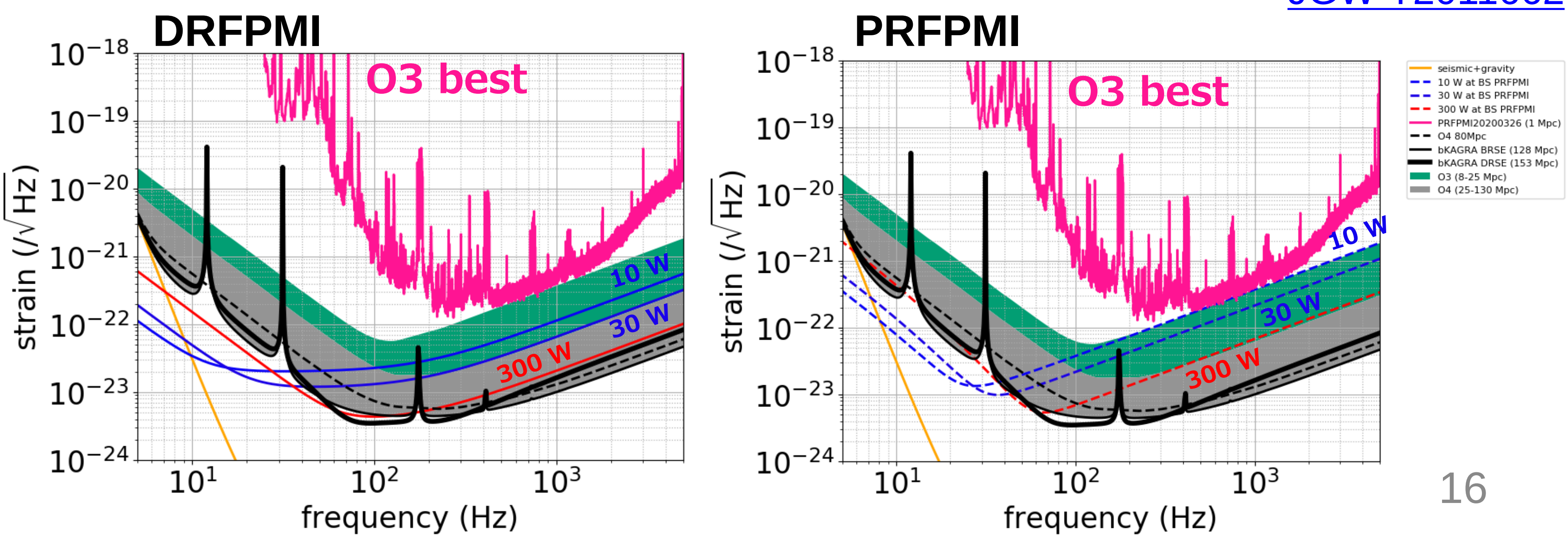


# Shot Noise

- 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

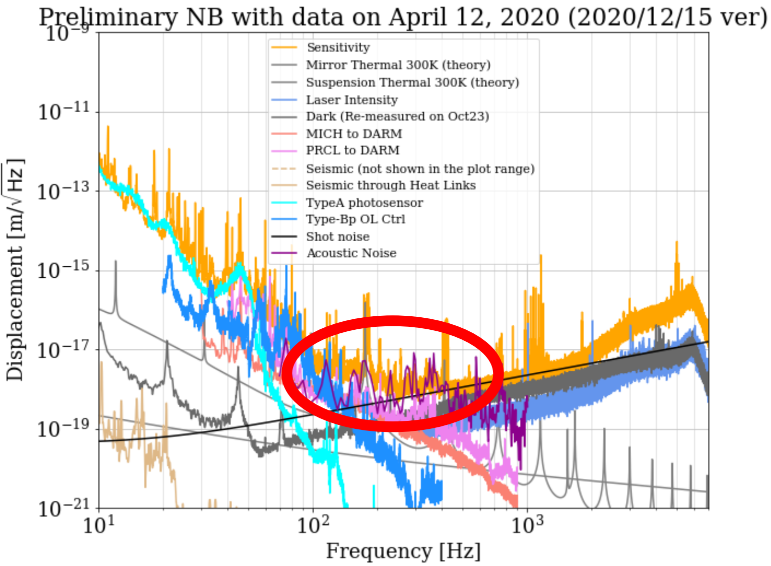
  Suspensions needs to be settled down (JGW-G2012213)

JGW-T2011662



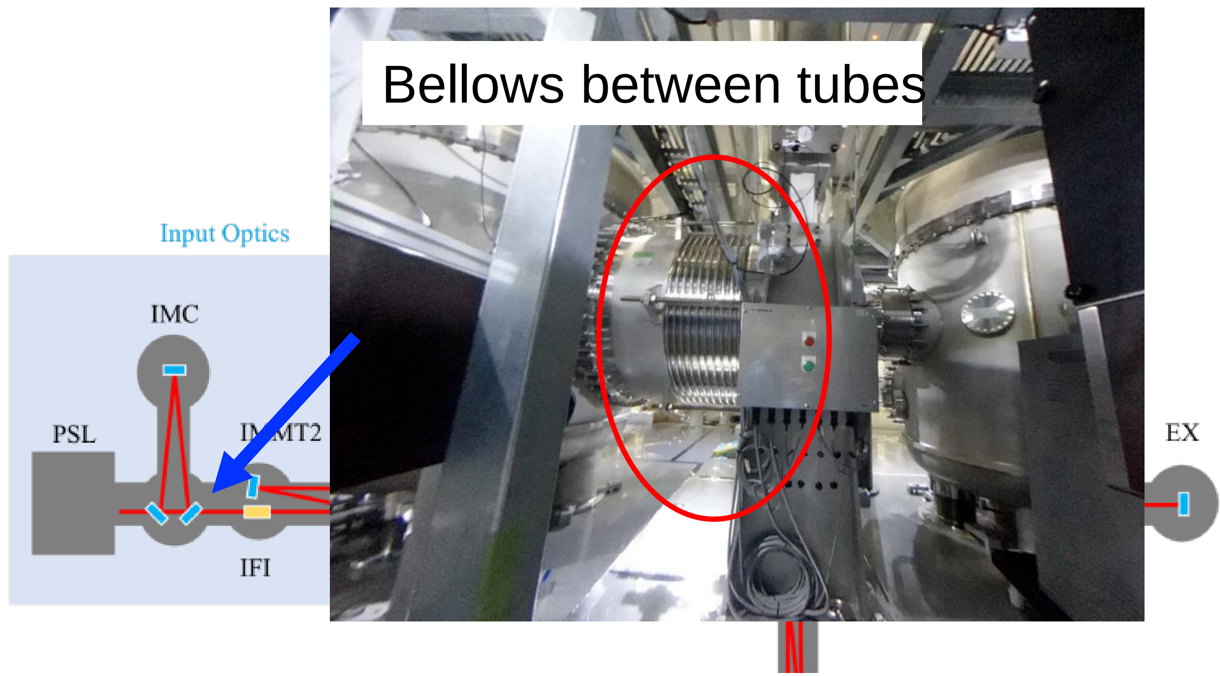
# Expectations for O4

- 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

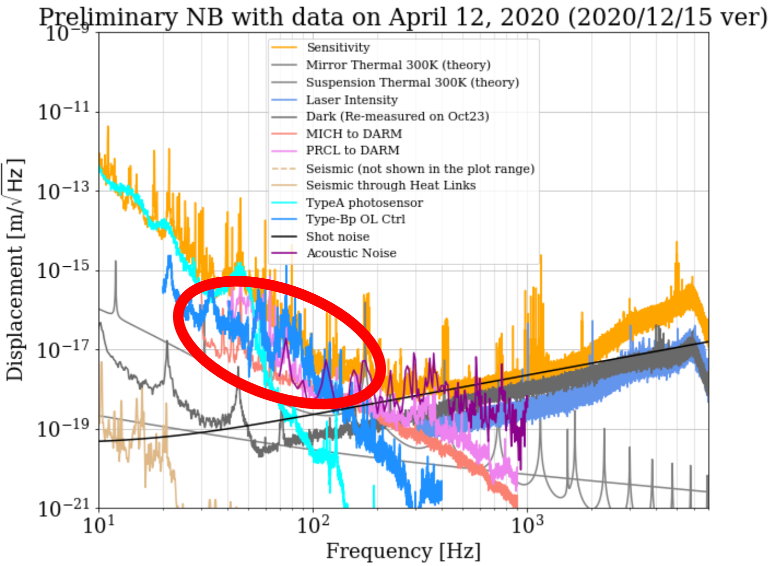
- Most contribution from bellows between IMC-IFI chamber
- Could be reduced by scattered light mitigation




JGW-G2012315

# Expectations for O4

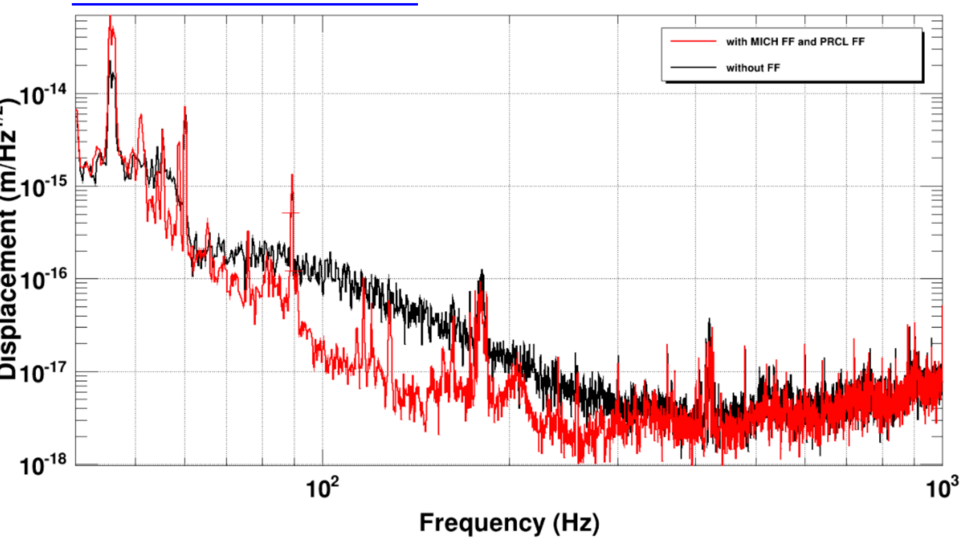
- Laser noises (frequency noise and intensity noise)
- Shot noise
- Acoustic noise
- Coupling from auxiliary degrees of freedom
- Thermal noise
- Test mass suspension damping noise

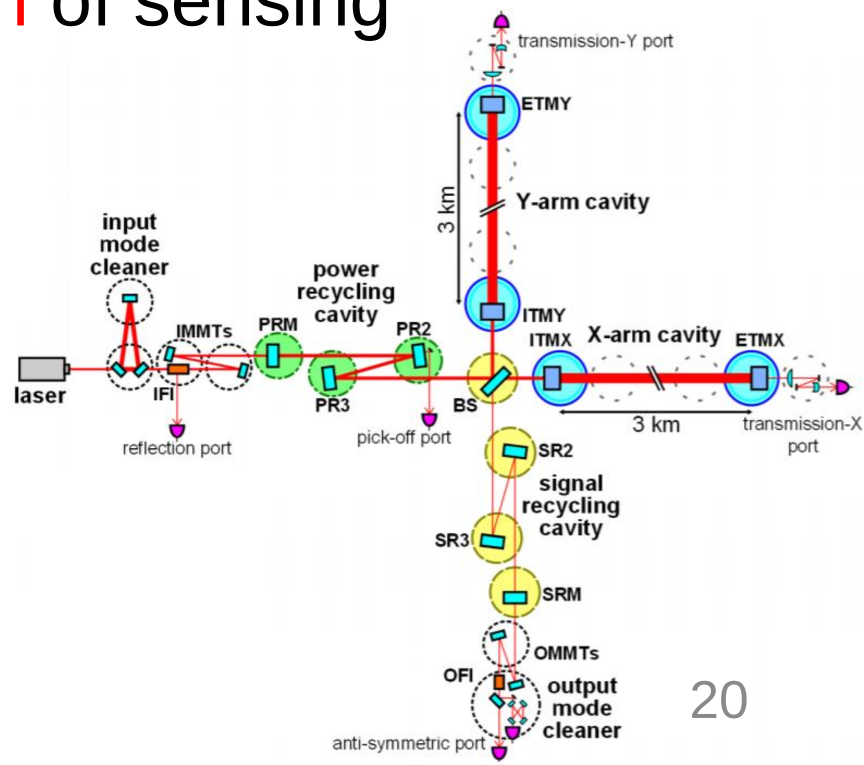


# Coupling from Auxiliary DOFs

- 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

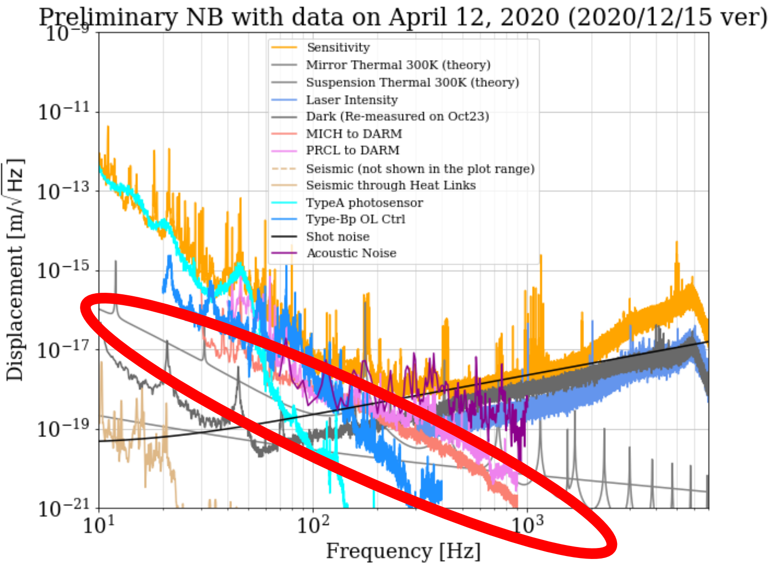
JGW-G2012315



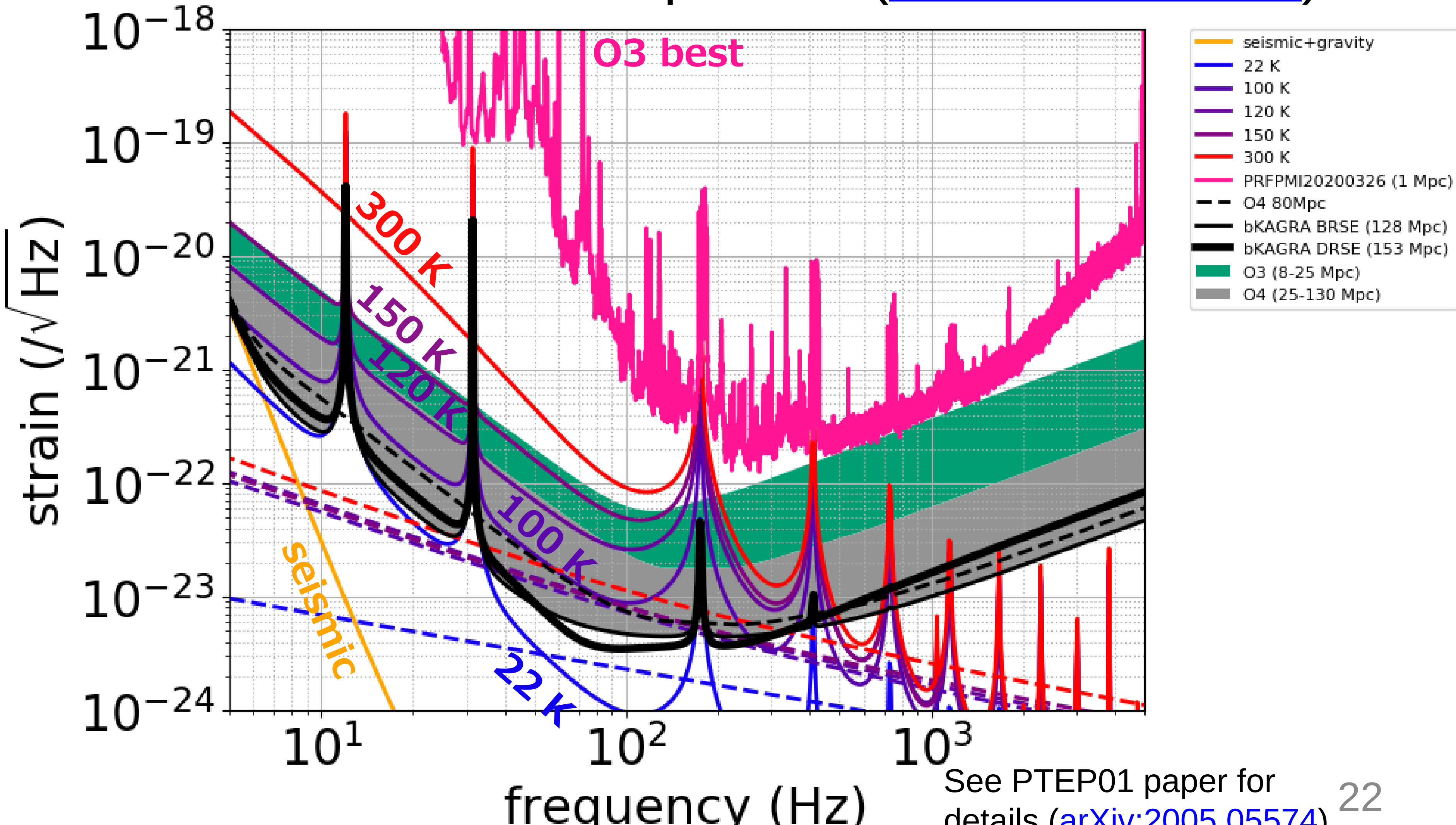
# Expectations for O4

- 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
- ~40 K seems to be optimum (JGW-G2011756)




See PTEP01 paper for details (arXiv:2005.05574)

# Expectations for O4

- Laser noises (frequency noise and intensity noise)
- Shot noise
- Acoustic noise
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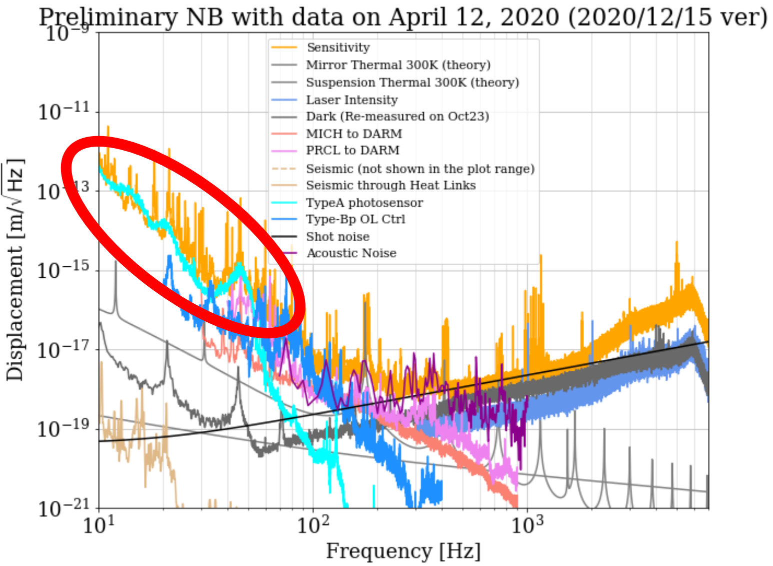
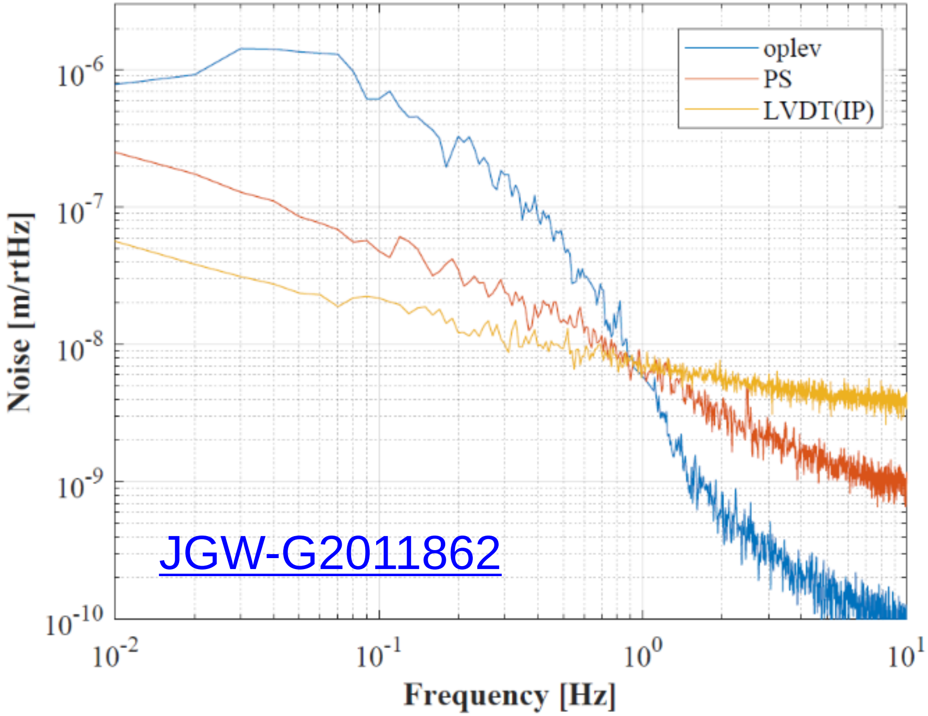


# Test Mass Suspension Damping

- Noises from marionette damping using photo sensors are limiting
- Plan to install optical levers also for marionette and platform stages
- Suspension Commissioning Team

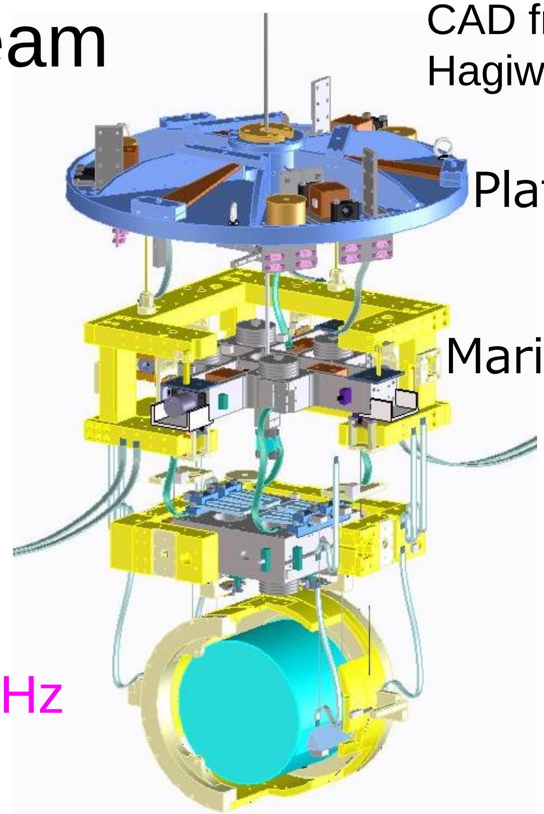
However, whether if we can completely turn off photo sensor damping is not clear since there might be some modes which can be only seen by photo sensors




JGW-G2011862

~1/10
at 10 Hz

CAD from Hagiwara-san

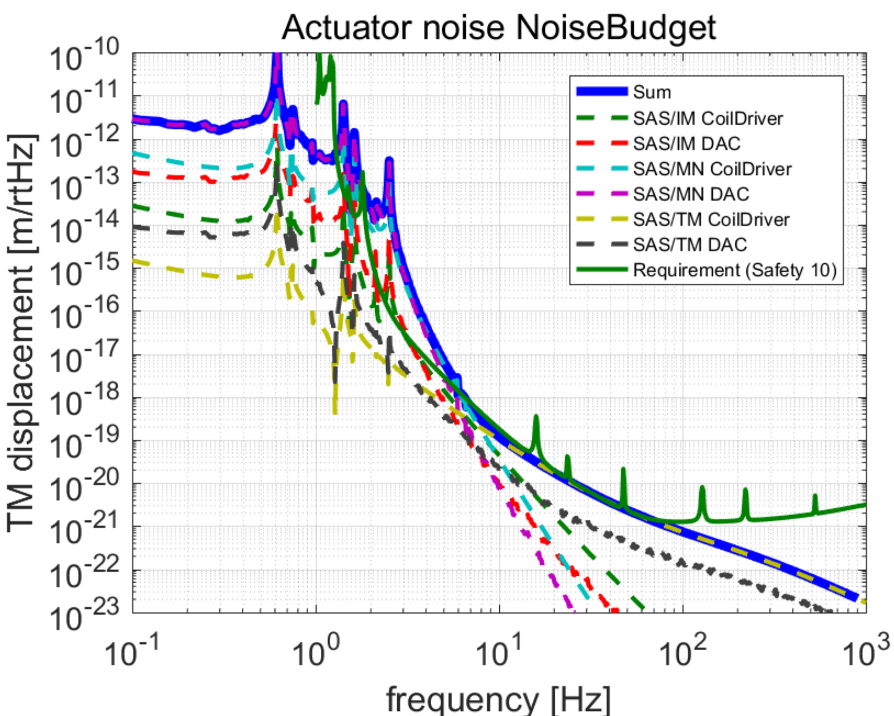


# Actuator Noise

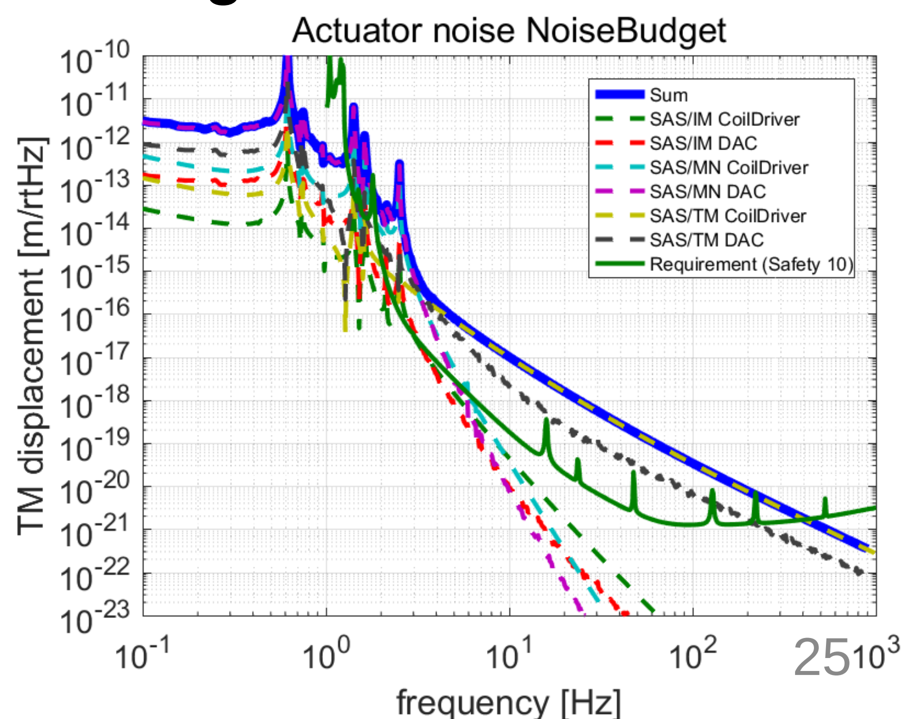
- Noises from high power coil driver used for O3 is not good for O4
- Coil driver switch to turn off high power coil driver after the lock acquisition necessary

JGW-T1910142

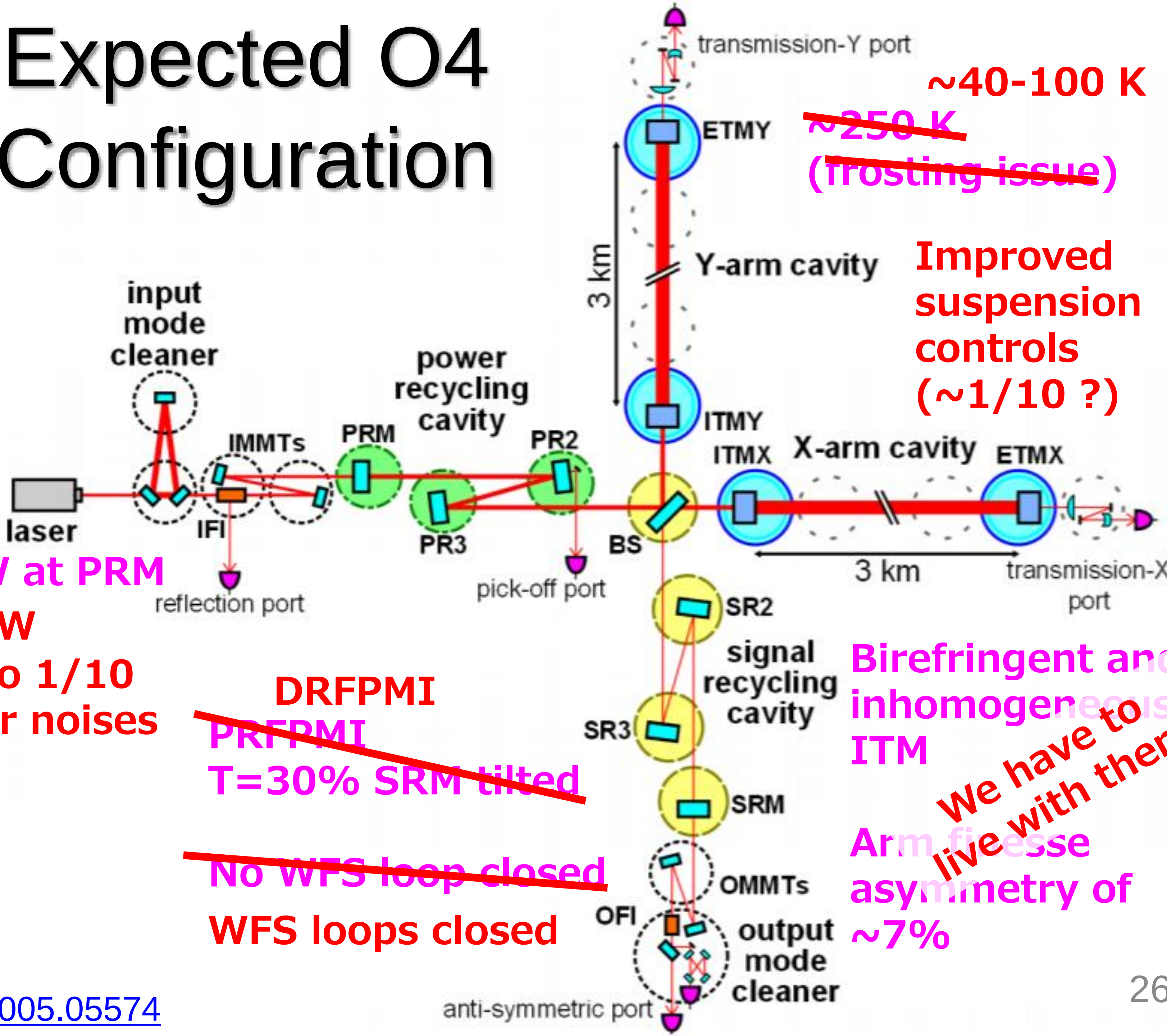
**Nominal Case**




**High Power TM Case**



# Expected O4 Configuration




~40-100 K

~~~250 K (frosting issue)~~

Improved suspension controls (~1/10 ?)

~~3-5 W at PRM~~

3-30 W

1/3 to 1/10 laser noises

DRFPMI

~~PRFPMI T=30% SRM tilted~~

~~No WFS loop closed~~

WFS loops closed

Birefringent and inhomogeneous ITM

Arm finesse asymmetry of ~7%

We have to live with them

arXiv:2005.05574
~~~

# 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

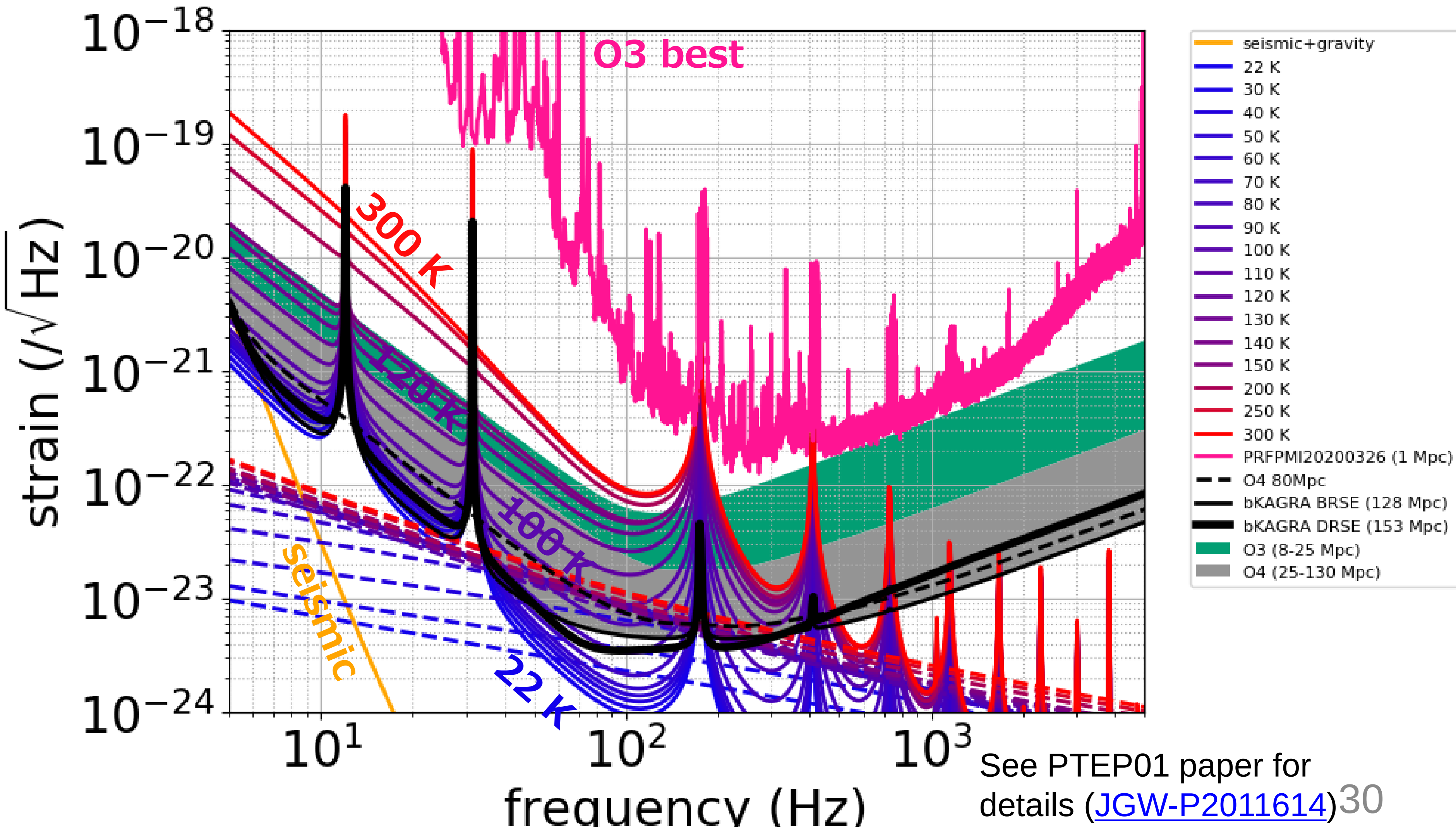
# Details

# 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

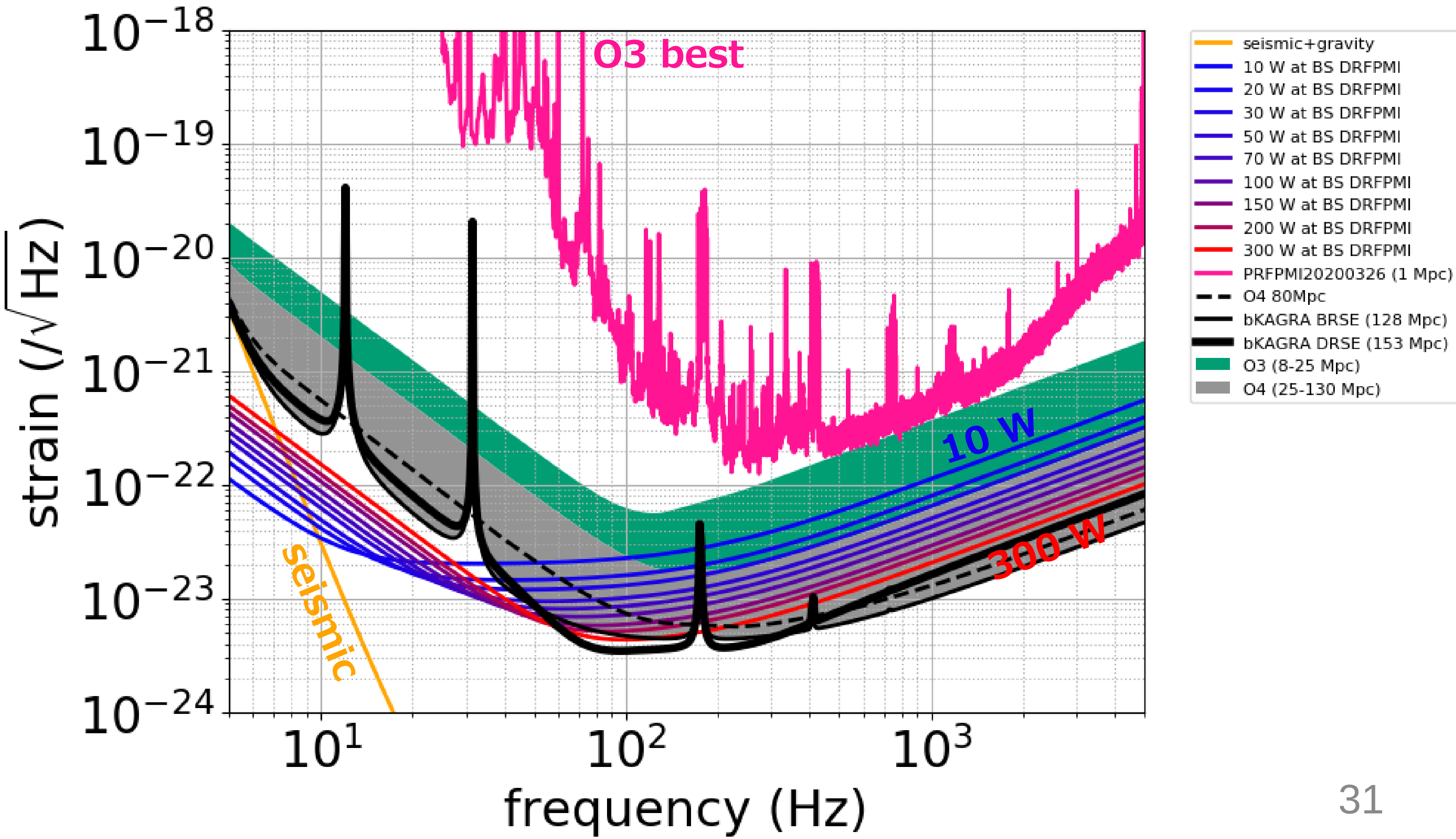
- All temperatures




See PTEP01 paper for details ([JGW-P2011614](JGW-P2011614))

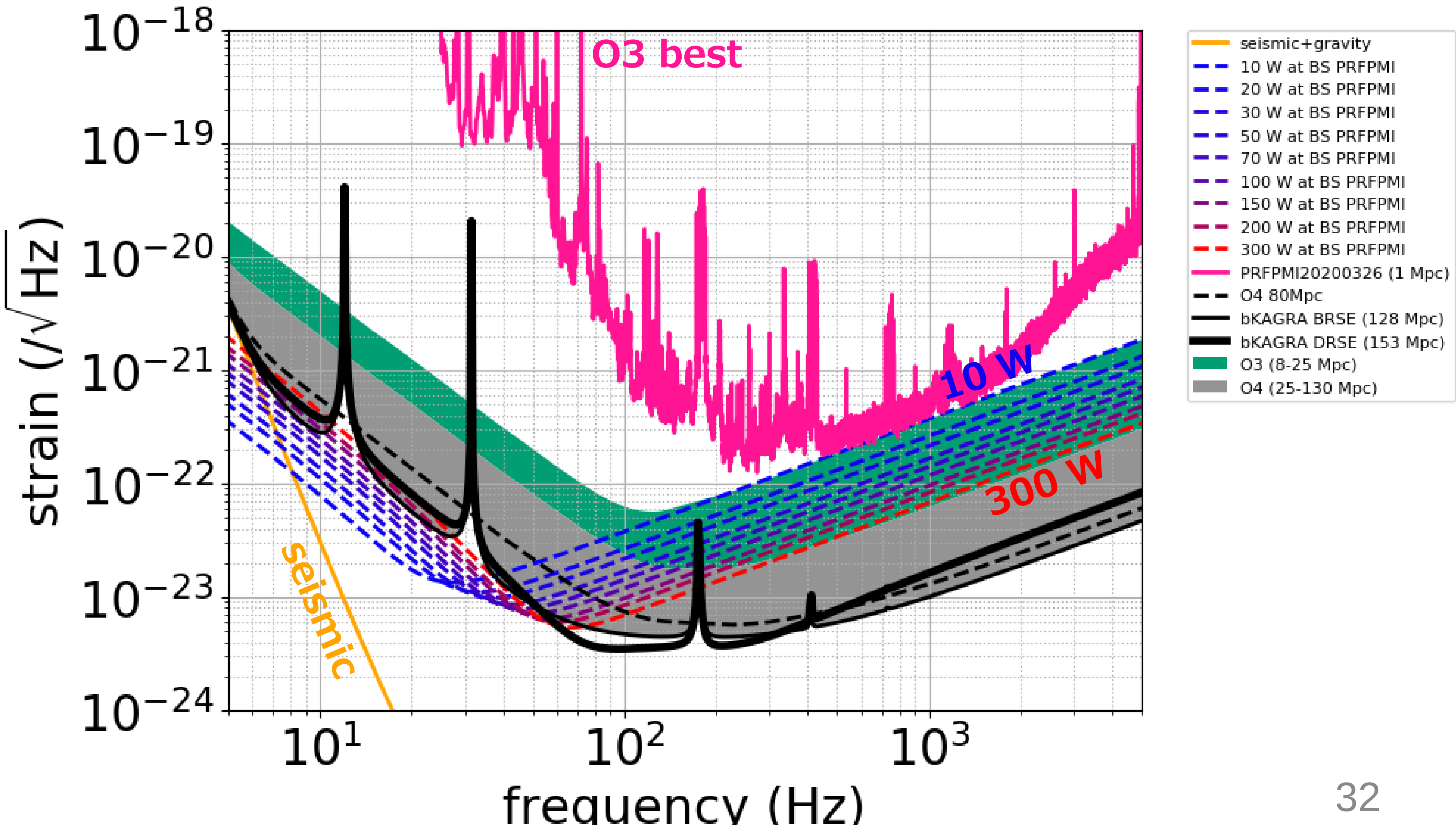
# Various Quantum Noise (DR)

- All powers



# Various Quantum Noise (PR)

- All powers

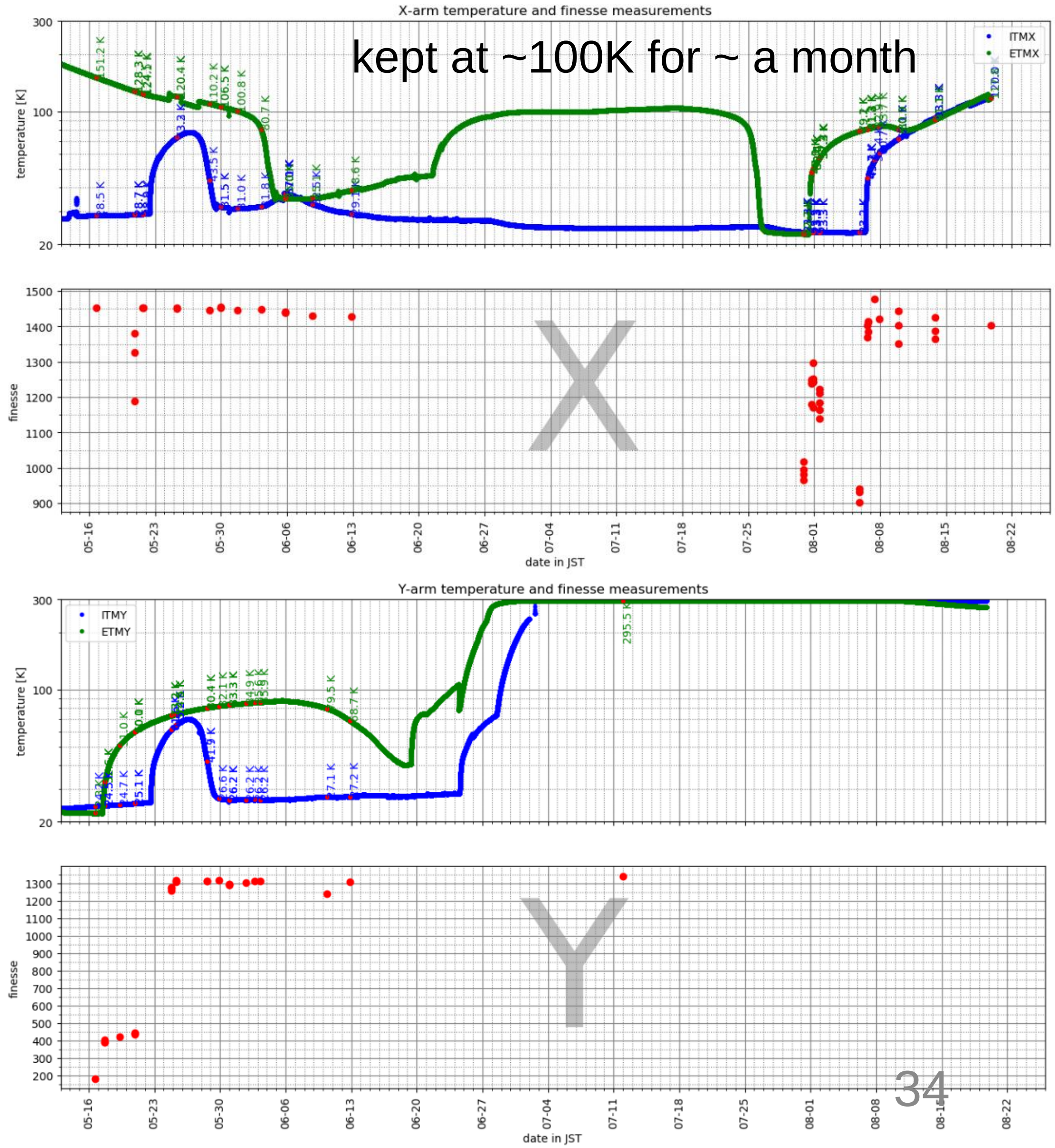


# How to Realize 100 K ?

- **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]