JGW-G2112616, LIGO-G2100394
LVK Meeting March 2021 (Online)

March 17, 2021

Status of KAGRA: Instrument Updates for O4

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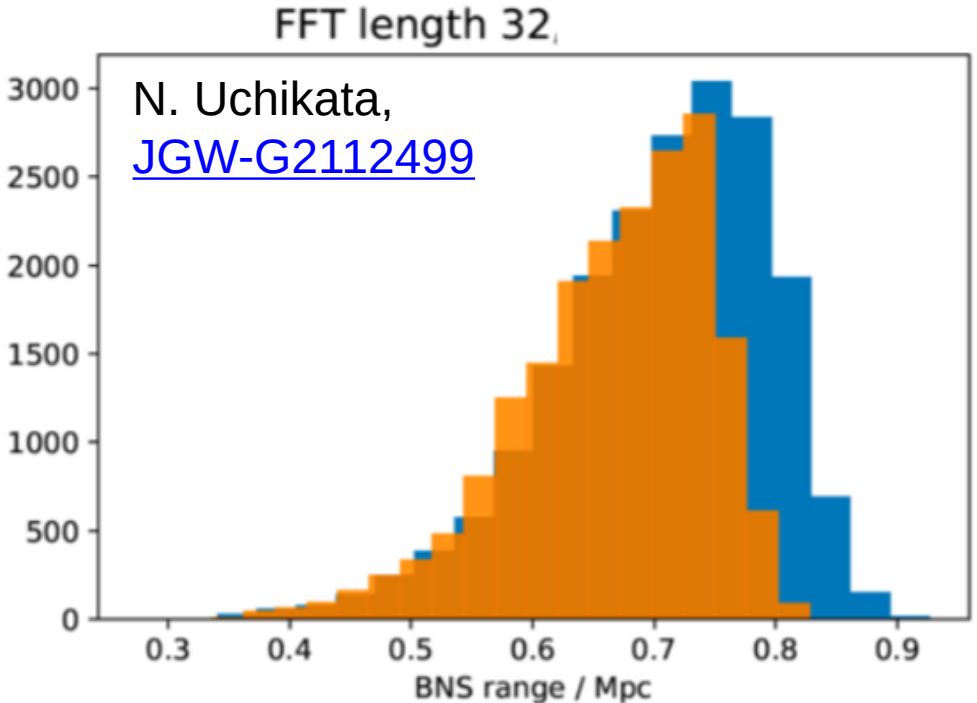
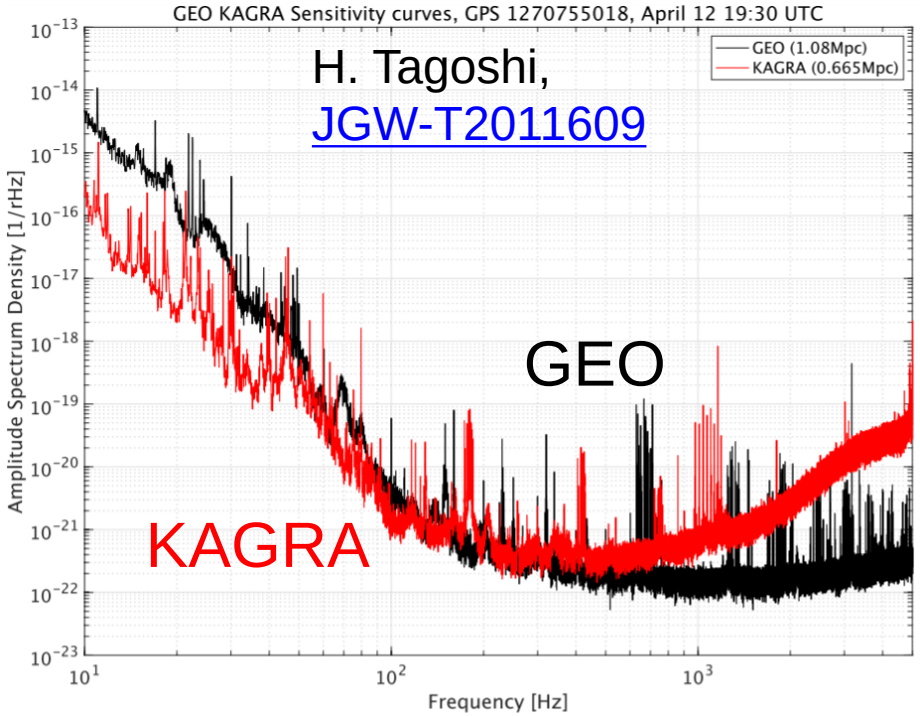
on behalf of the KAGRA Collaboration

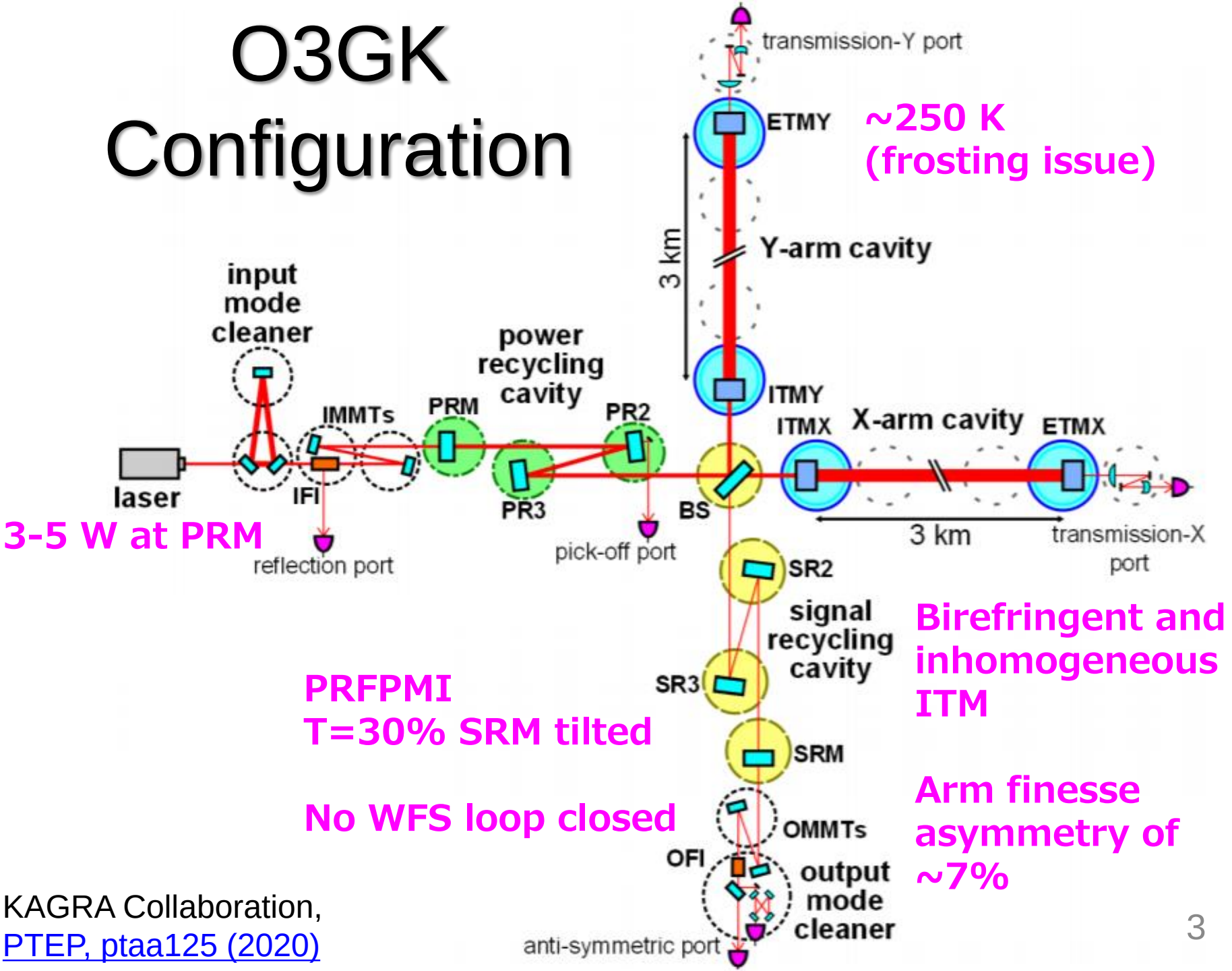
Status of KAGRA

- O3GK observing run on April 7-21, 2020 with GEO
- Detector sensitivity was ~0.7 Mpc (~1 Mpc at best)
  We originally planned to reach 8-25 Mpc for O3
- Detector configuration was power-recycled FPMI
  We originally planned to operate with dual recycling
- Focus of this talk: *What are we preparing for O4?*



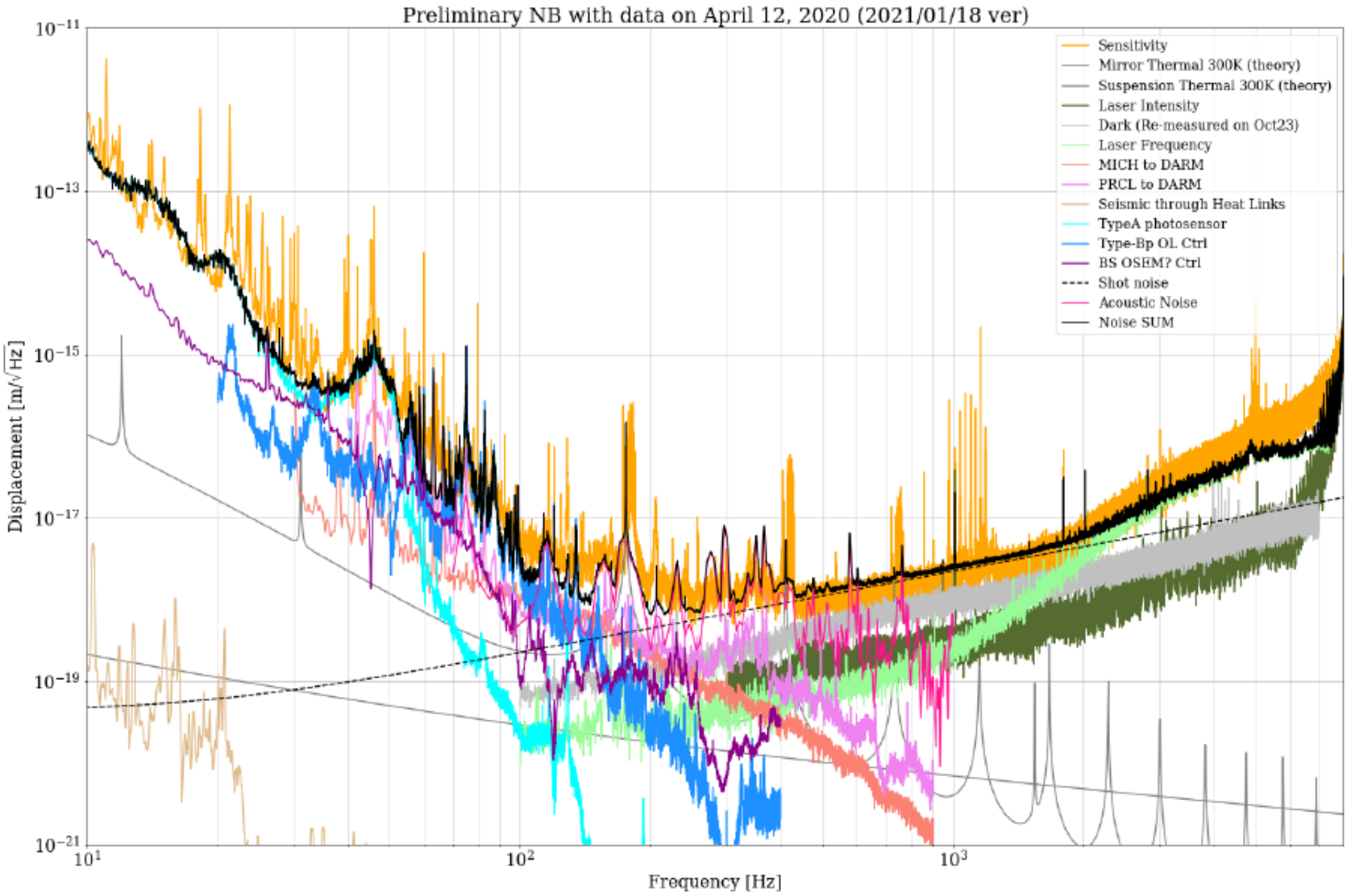


O3GK Configuration



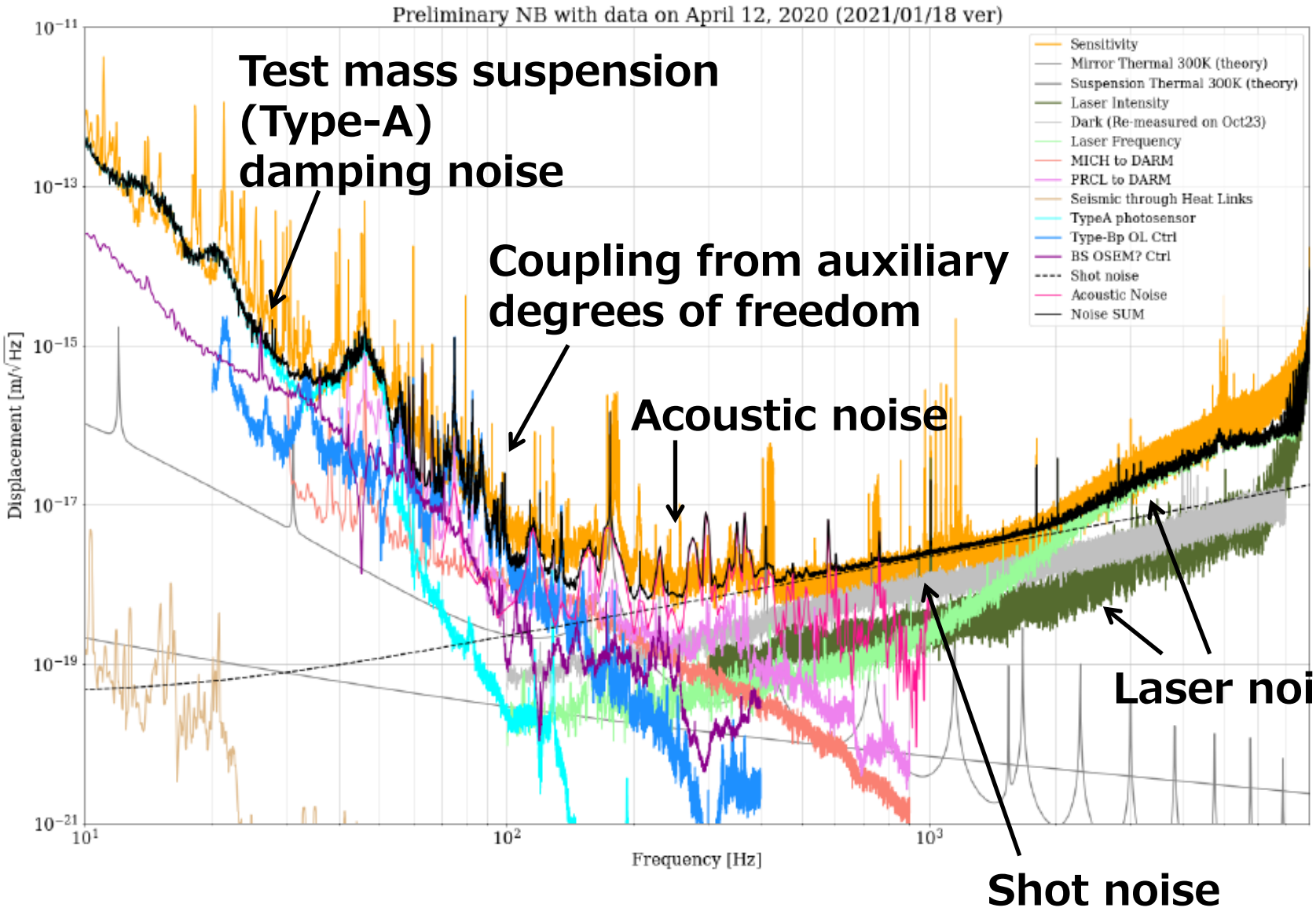
KAGRA Collaboration,
PTEP, ptaa125 (2020)

O3GK Noise Budget



Plot by NB paper writing team

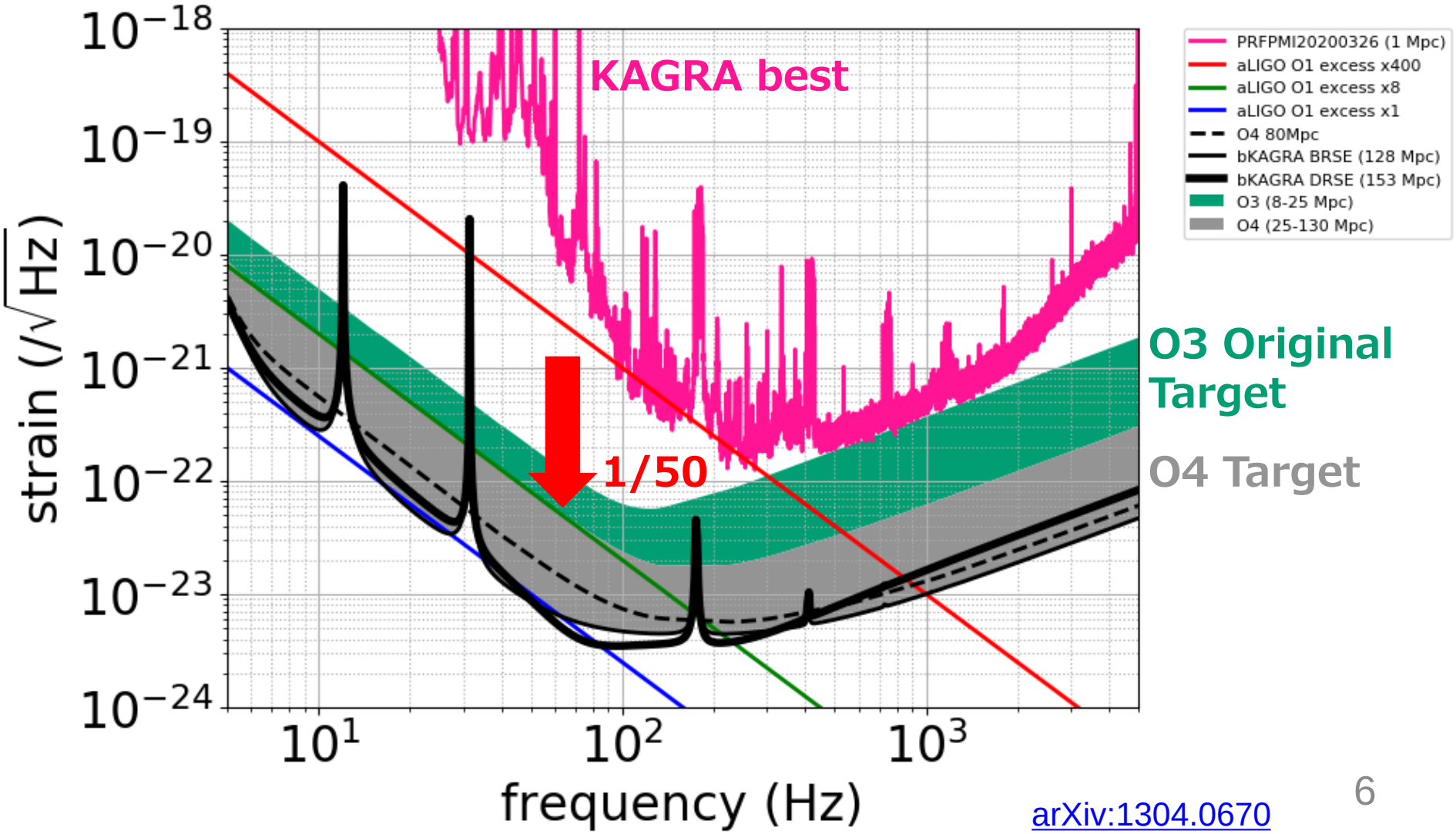
O3GK Noise Budget



Plot by NB paper writing team

O4 Target: 25 Mpc at least

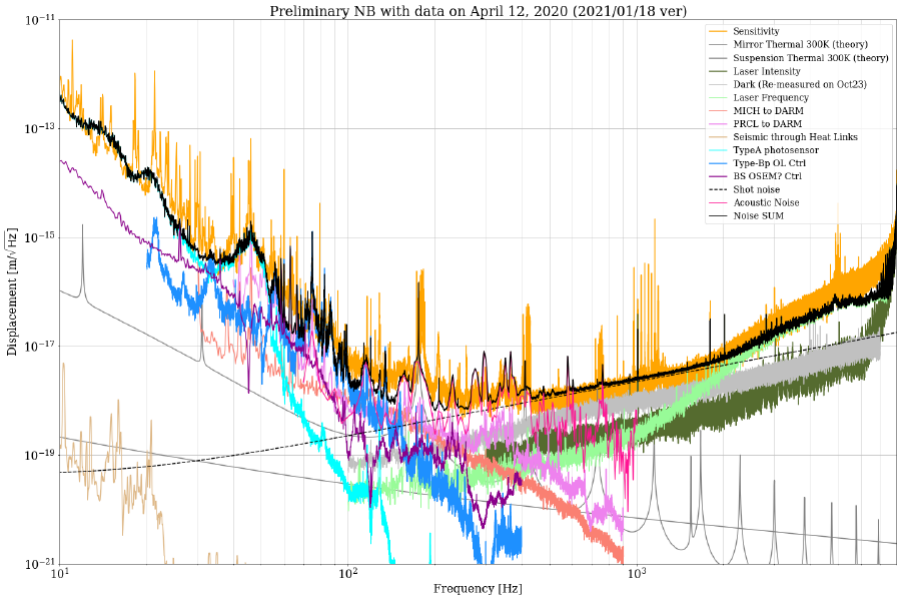
- Excess noise has to be reduced by ~1/50 at the bucket



arXiv:1304.0670

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



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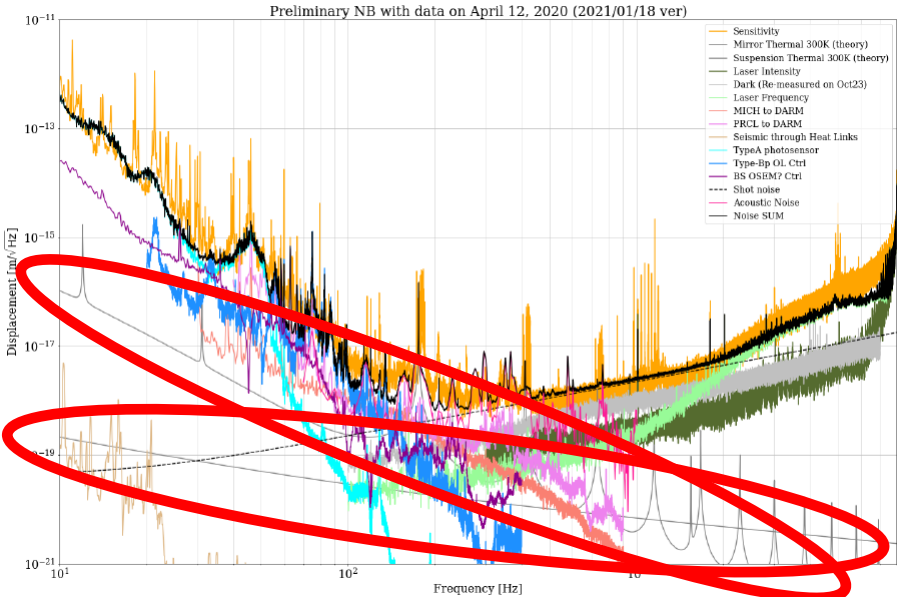
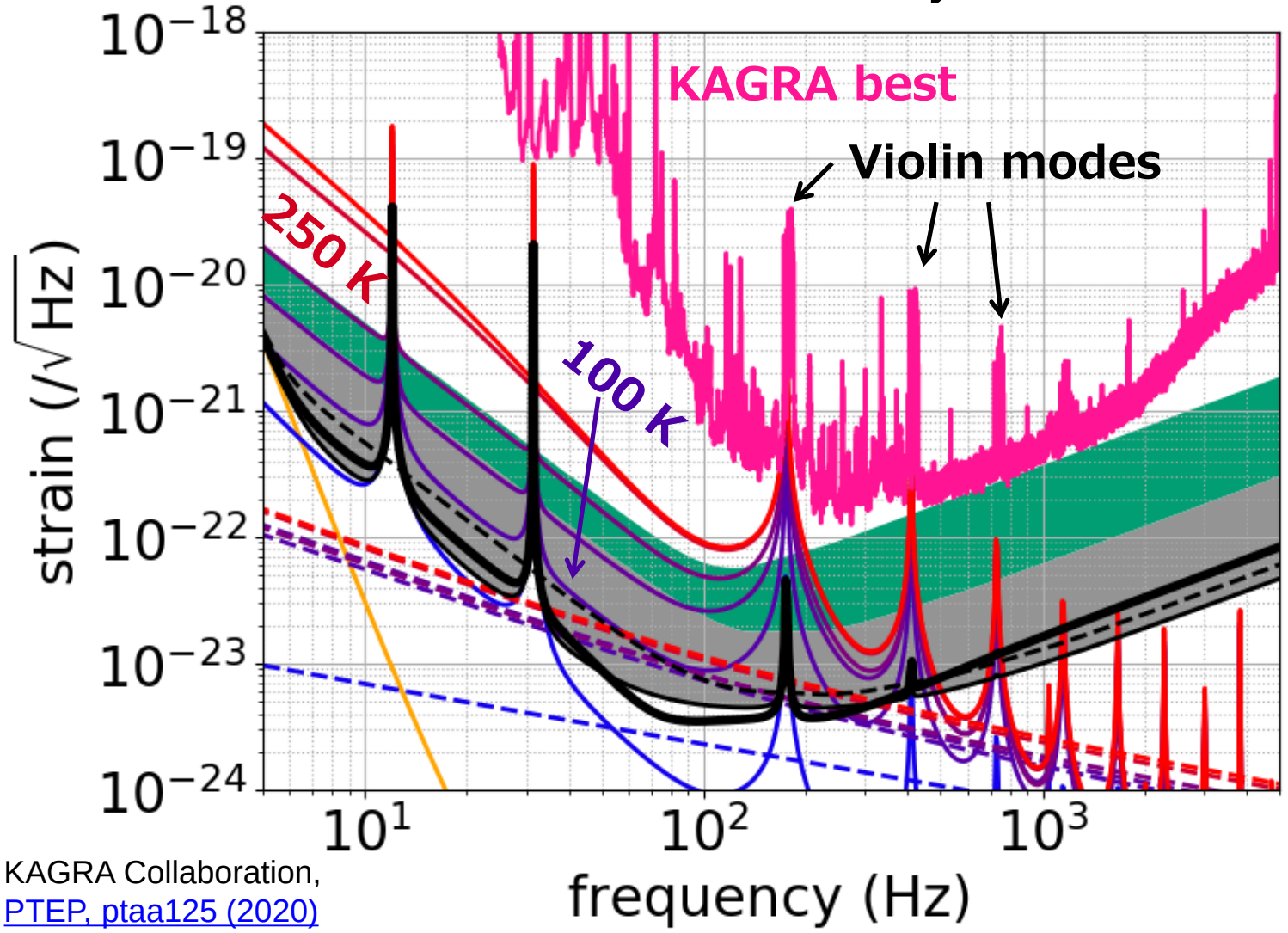
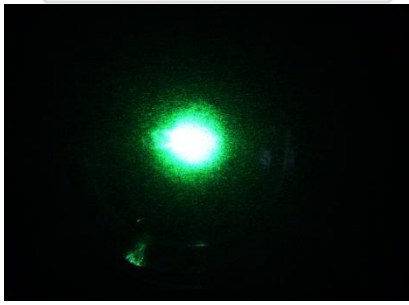


Thermal Noise vs Temperature

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



KAGRA Collaboration,
PTEP, ptaa125 (2020)

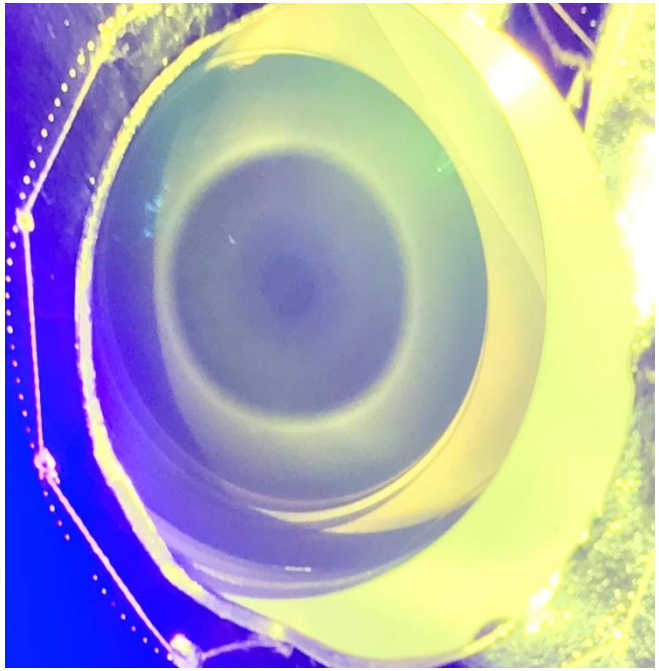


Frosted mirror seen with green laser

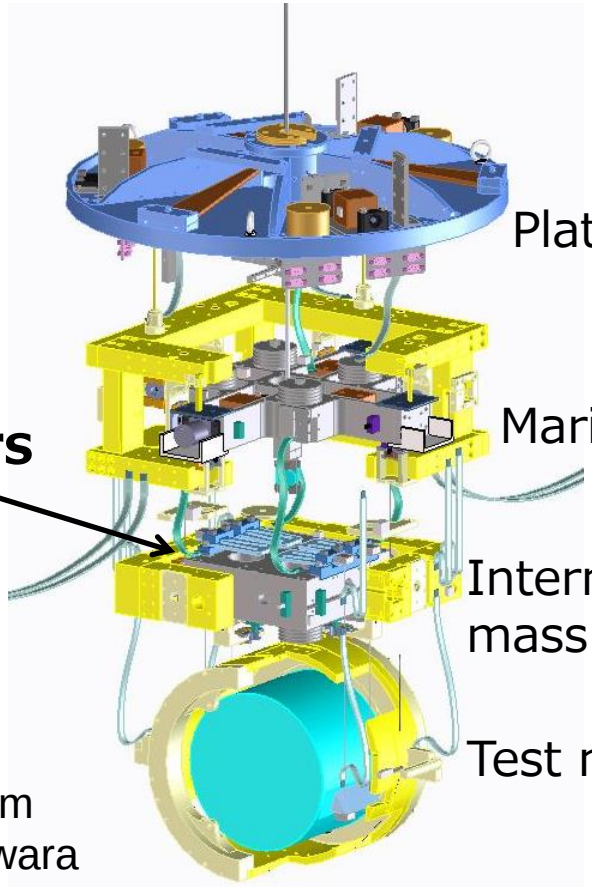
Y. Enomoto+,
klog #9861

Defrosting

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



Frosted viewport
(Photo from N. Kimura)



CAD from
A. Hagiwara

Instrument Updates

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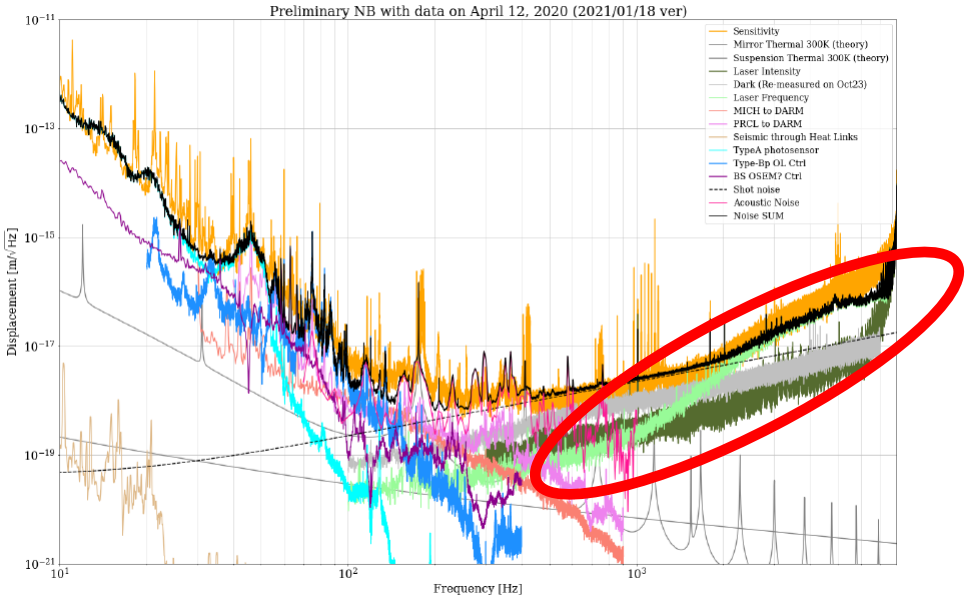
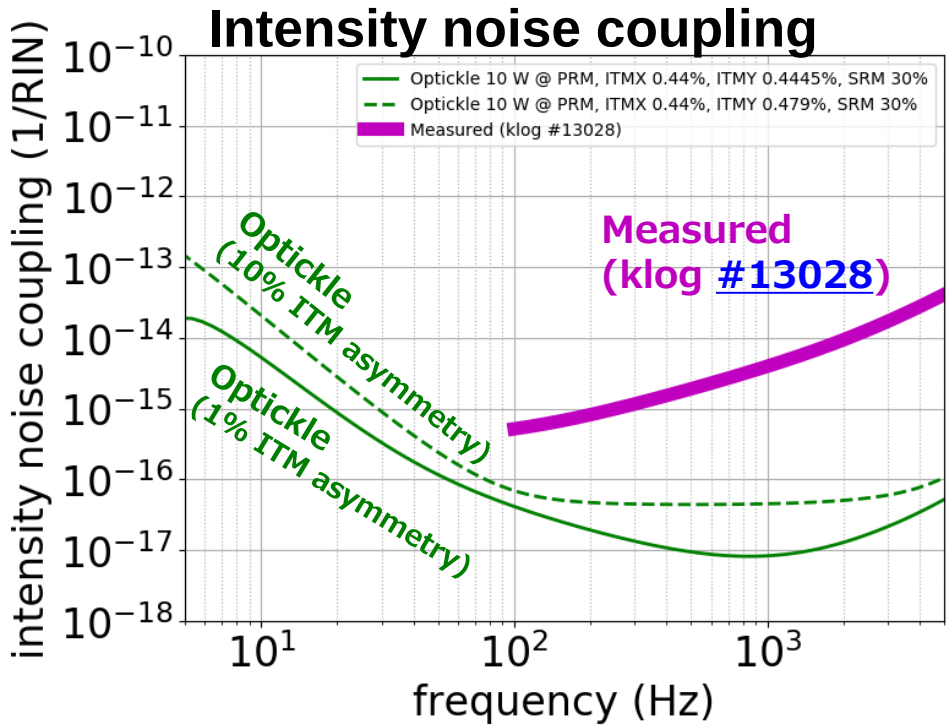
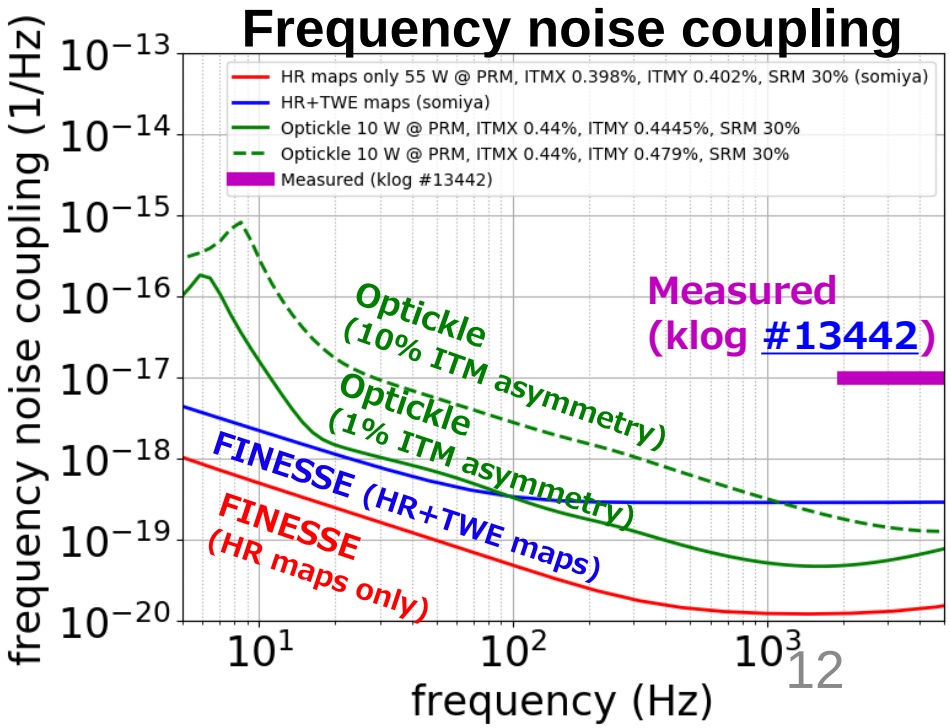


Laser Noises: Coupling

- 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)

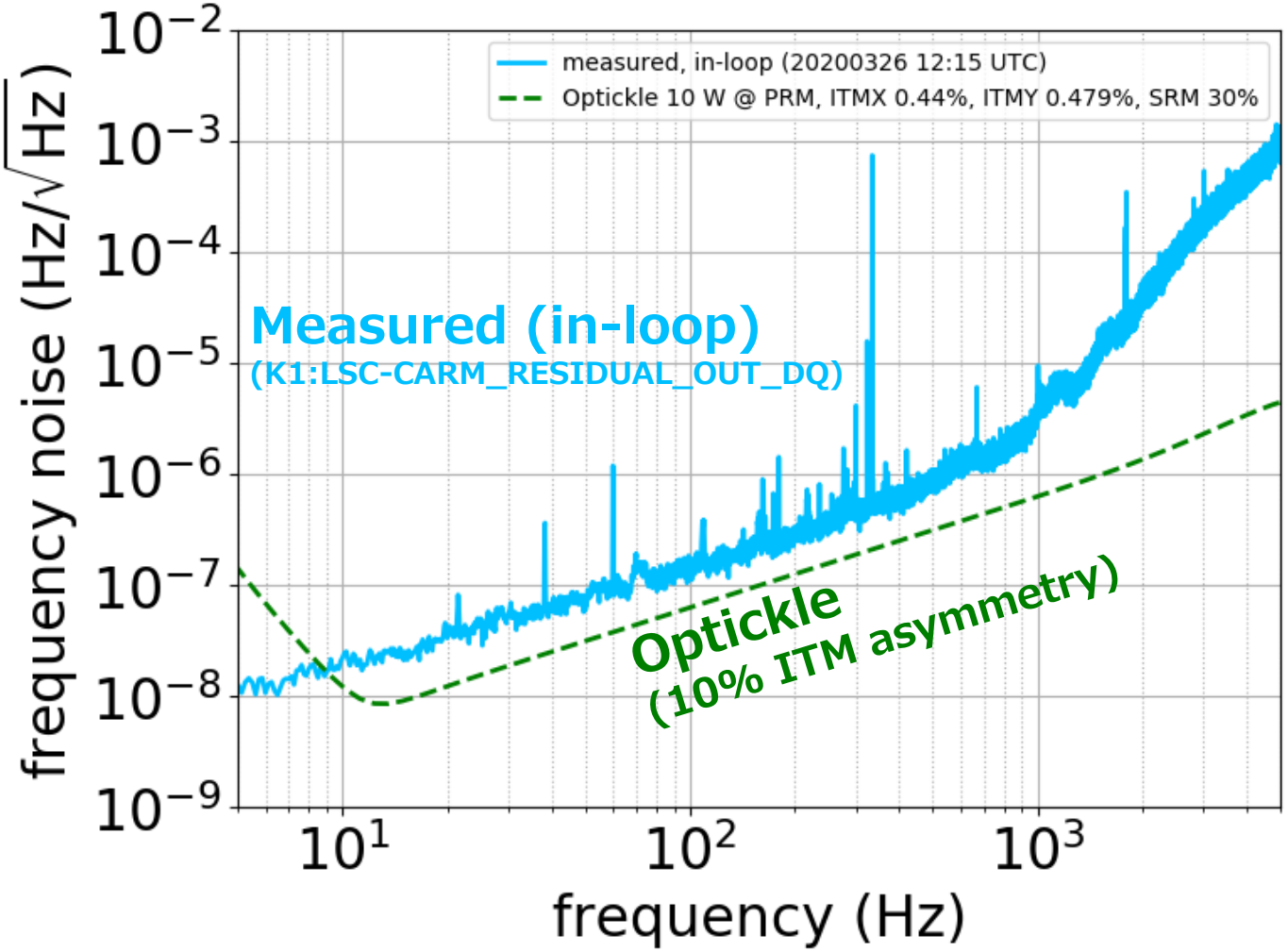
YM, K. Somiya, K. Yamamoto, JGW-T2011662





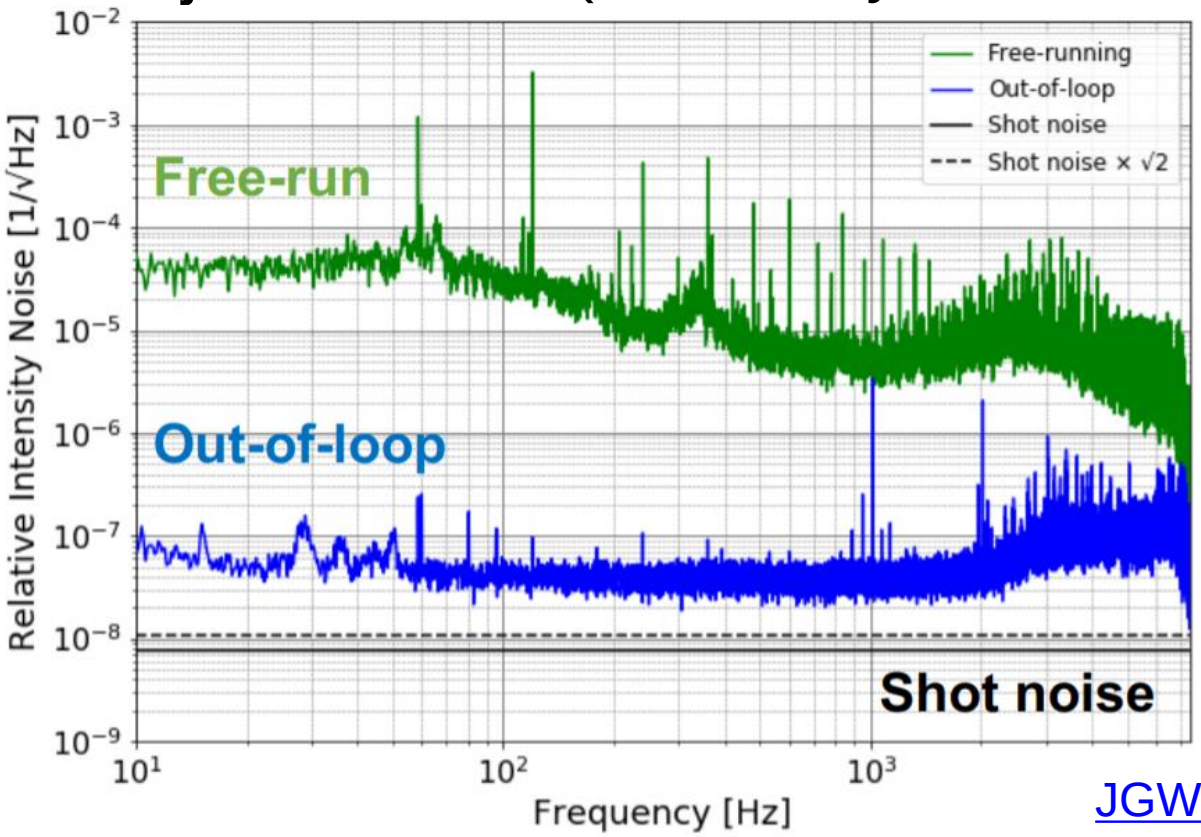
Laser Frequency Noise

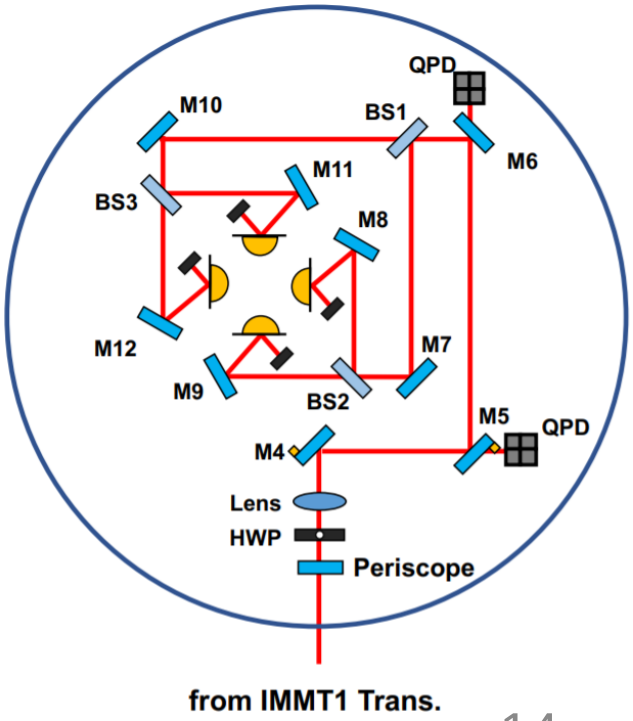
- Almost shot noise limited (~10 mW at PD) at 100 Hz
- Not very critical for BNS range



Laser Intensity Noise

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

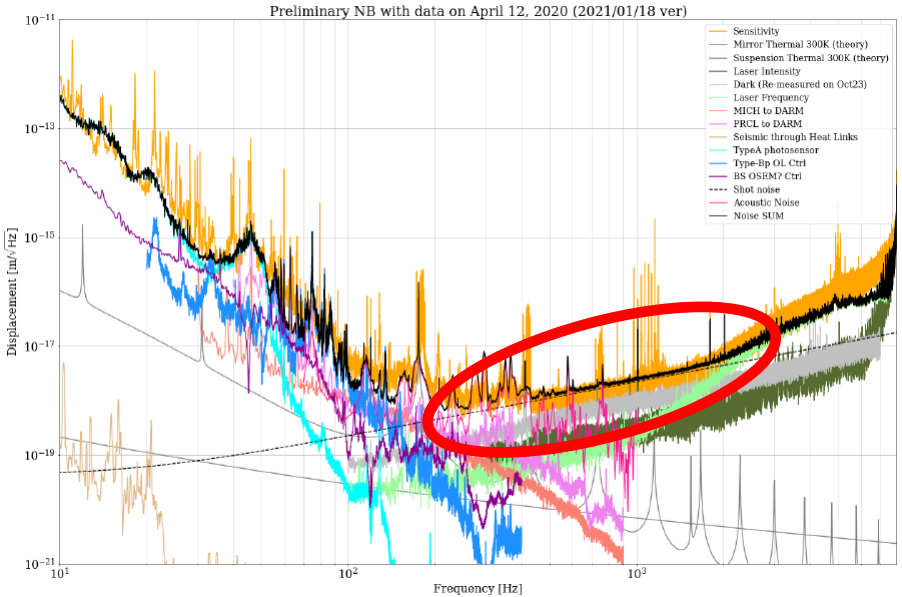




JGW-G2012322

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



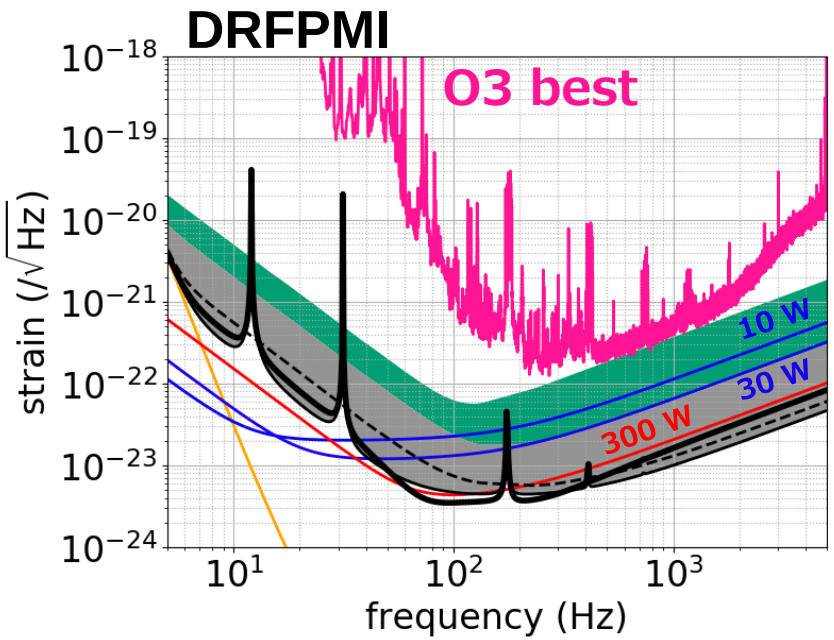
Shot Noise

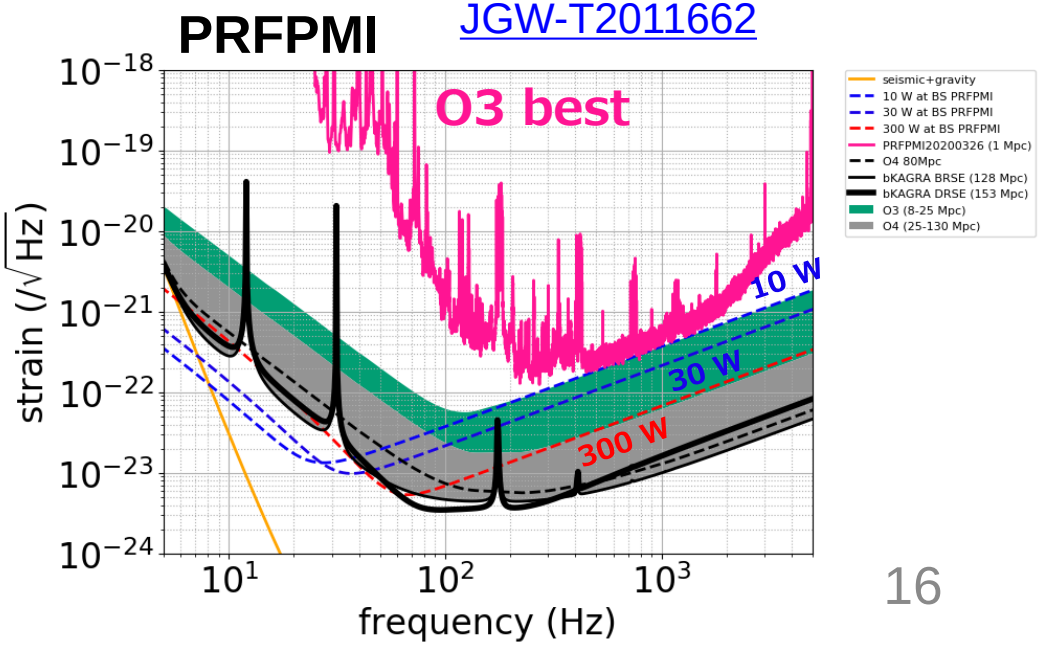
- In O3GK it was not good due to tilted SRM (T=30%)
- When DRFPMI, at least 30 W at BS is necessary
- When PRFPMI, at least 300 W as BS is necessary
- DR seems to be almost necessary for O4

  For this, suspensions needs to be settled down

  (M. Nakano, JGW-G2012213)

YM, K. Somiya, K. Yamamoto, JGW-T2011662





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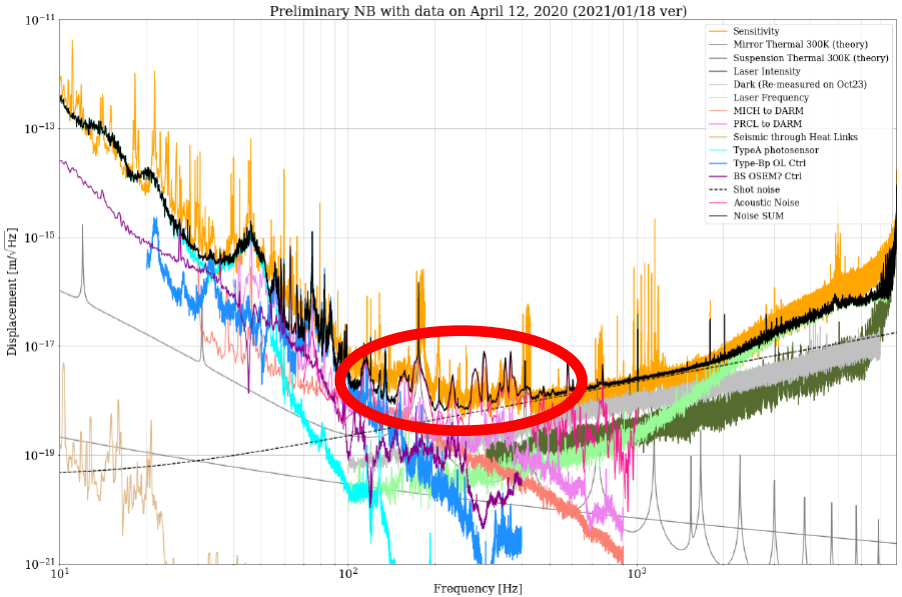
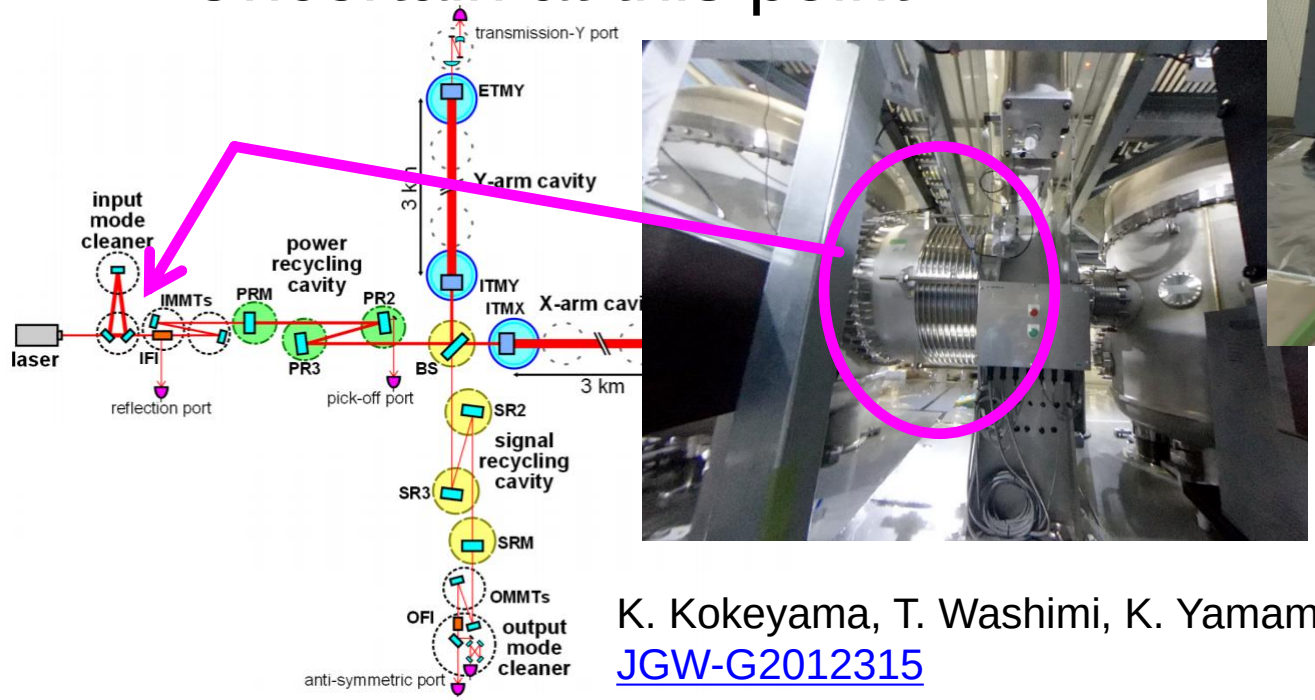
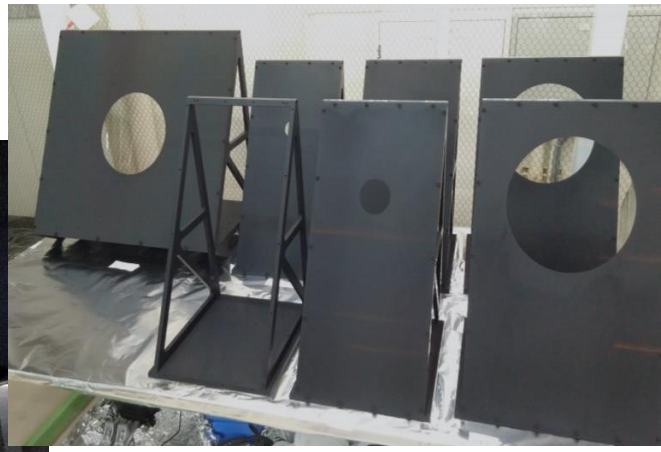


Acoustic Noise

- 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





Mid-size baffles to be installed around PRC and SRC
T. Akutsu,
JGW-G2011959

K. Kokeyama, T. Washimi, K. Yamamoto
JGW-G2012315

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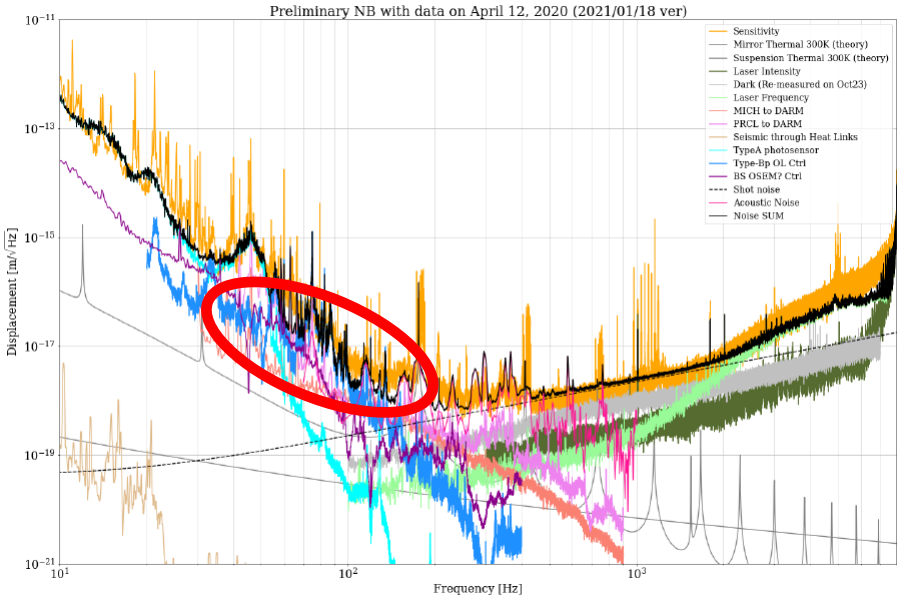
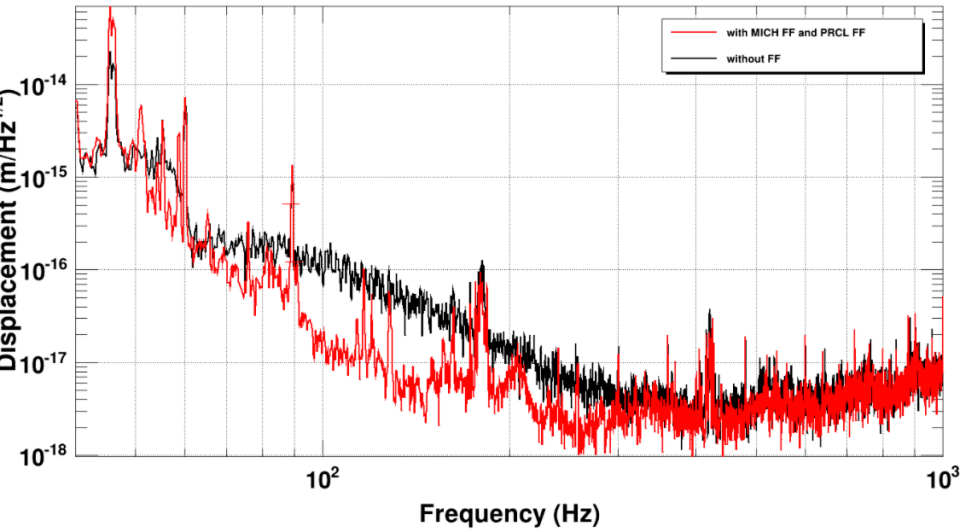
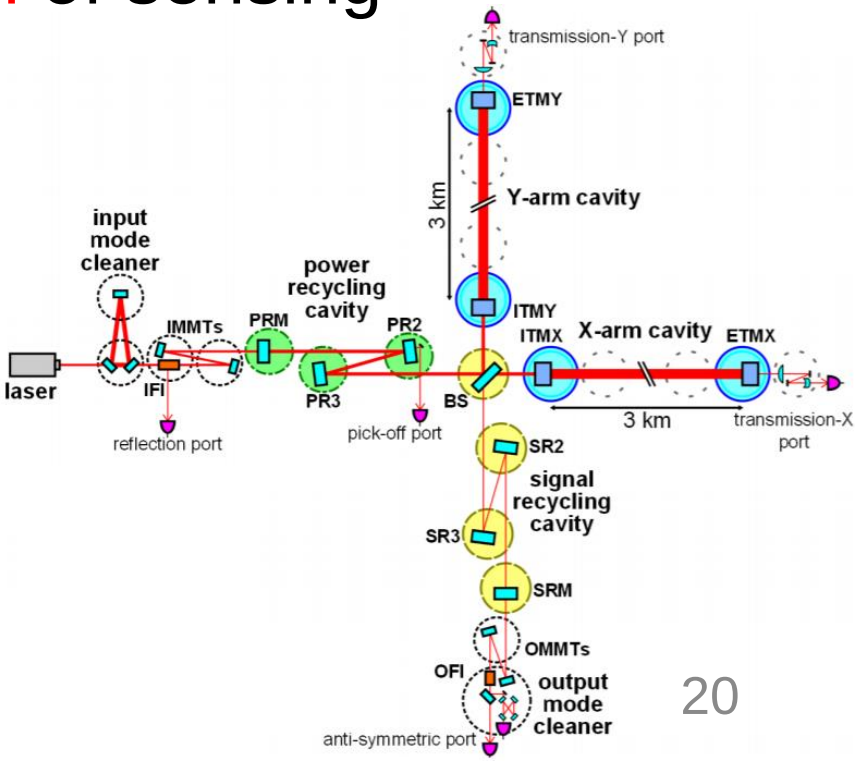


Coupling from Auxiliary DOFs

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

K. Kokeyama, T. Washimi, K. Yamamoto
JGW-G2012315





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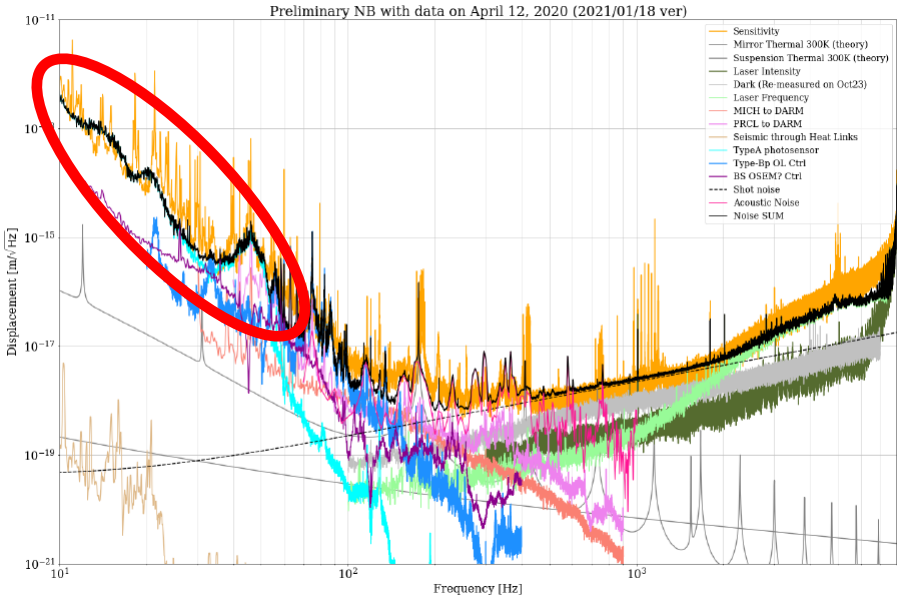
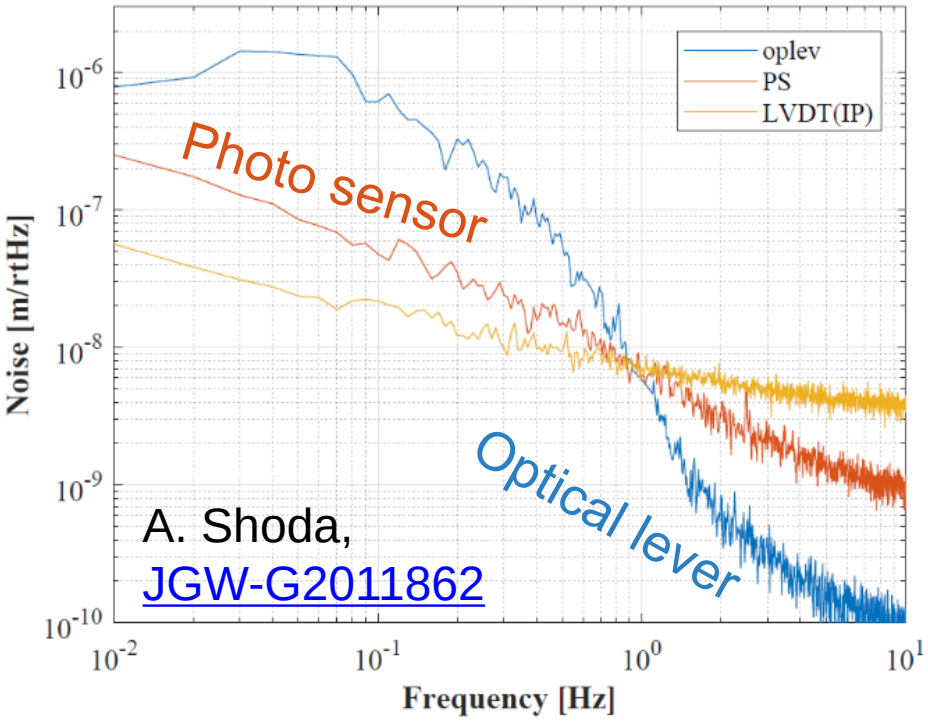


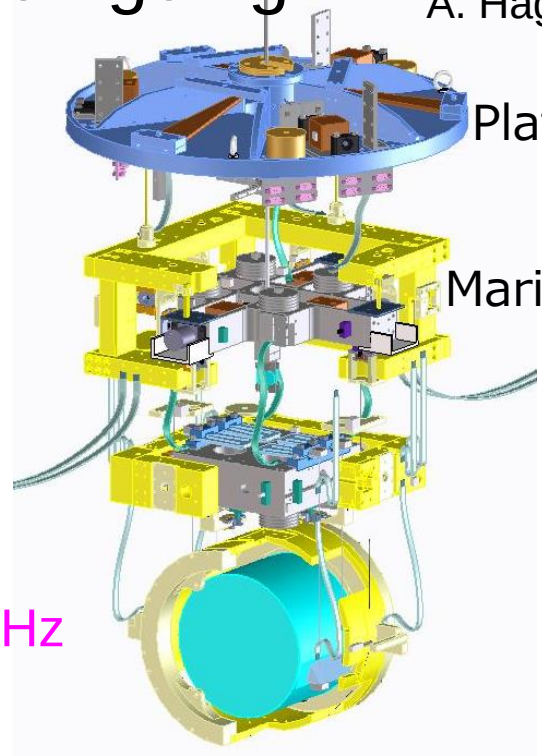
Test Mass Suspension Damping

- 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

CAD from
A. Hagiwara

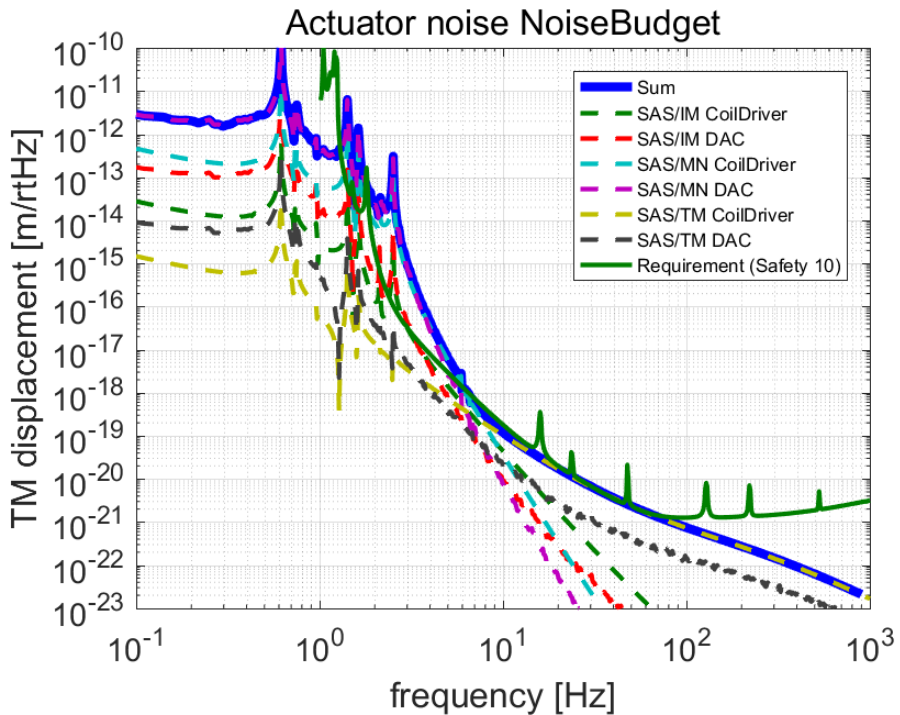


Actuator Noise

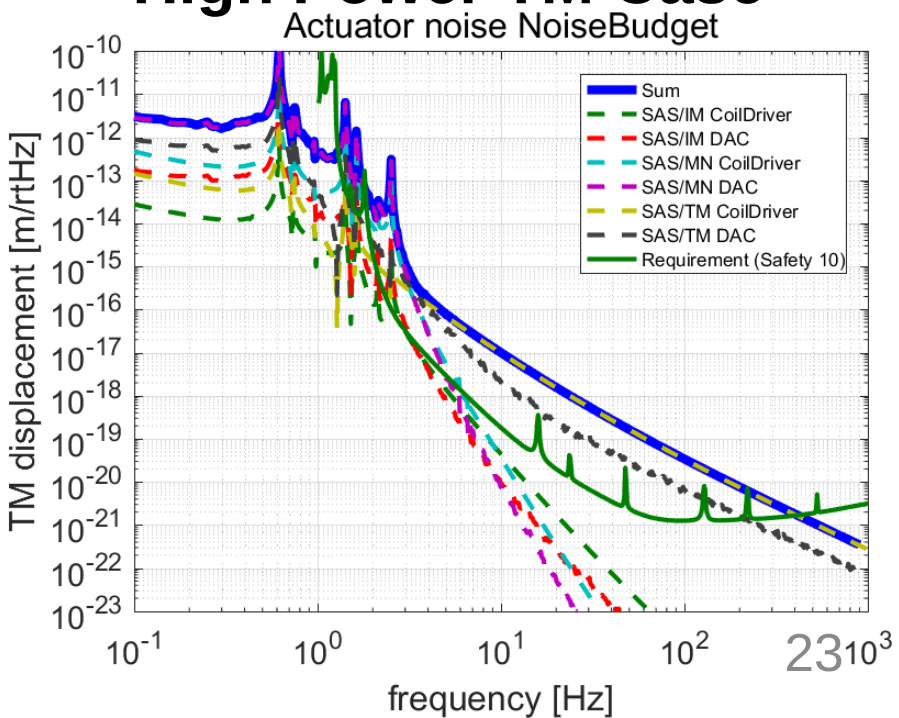
- High power coil drivers for lock acquisition was used during the O3GK
- Coil driver switch to switch between high power and low power will be installed for O4
  - ~ 1/100 actuator noise

YM, JGW-T1910142

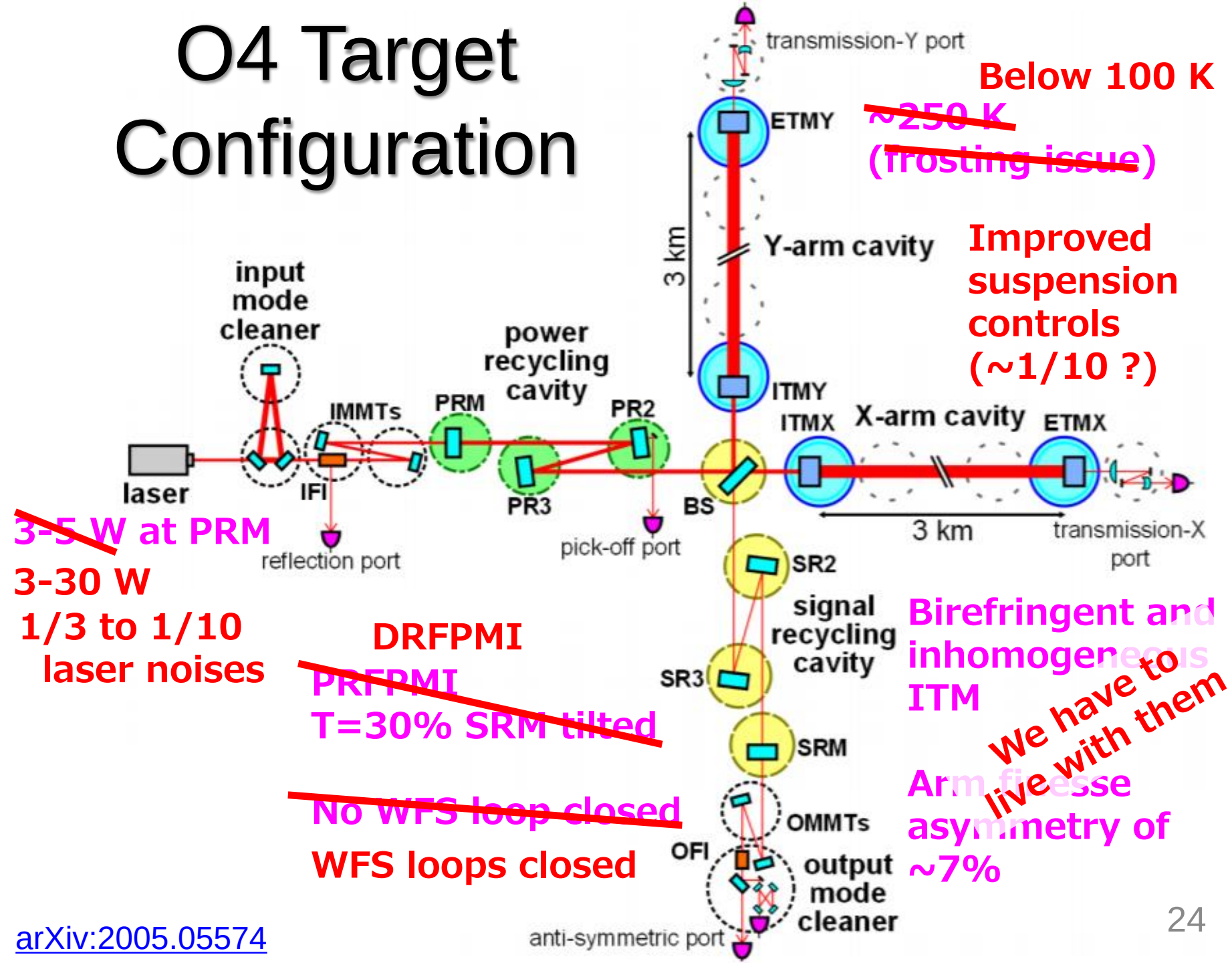
Nominal Case



High Power TM Case



O4 Target Configuration

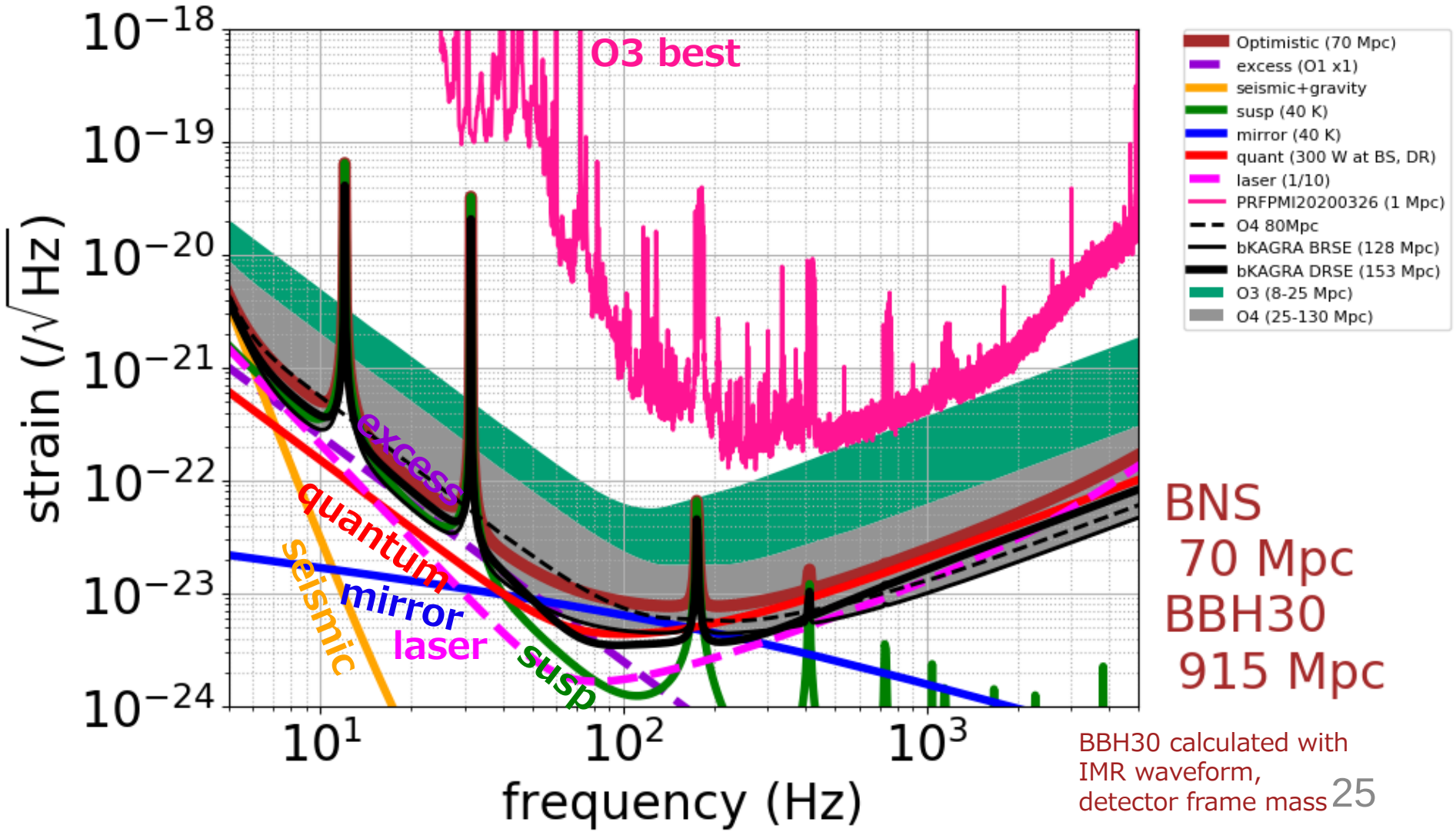


~~Below 100 K~~

~~~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

We have to live with them

Arm finesse asymmetry of ~7%

arXiv:2005.05574
~~~

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

Summary 1/2

- We plan 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

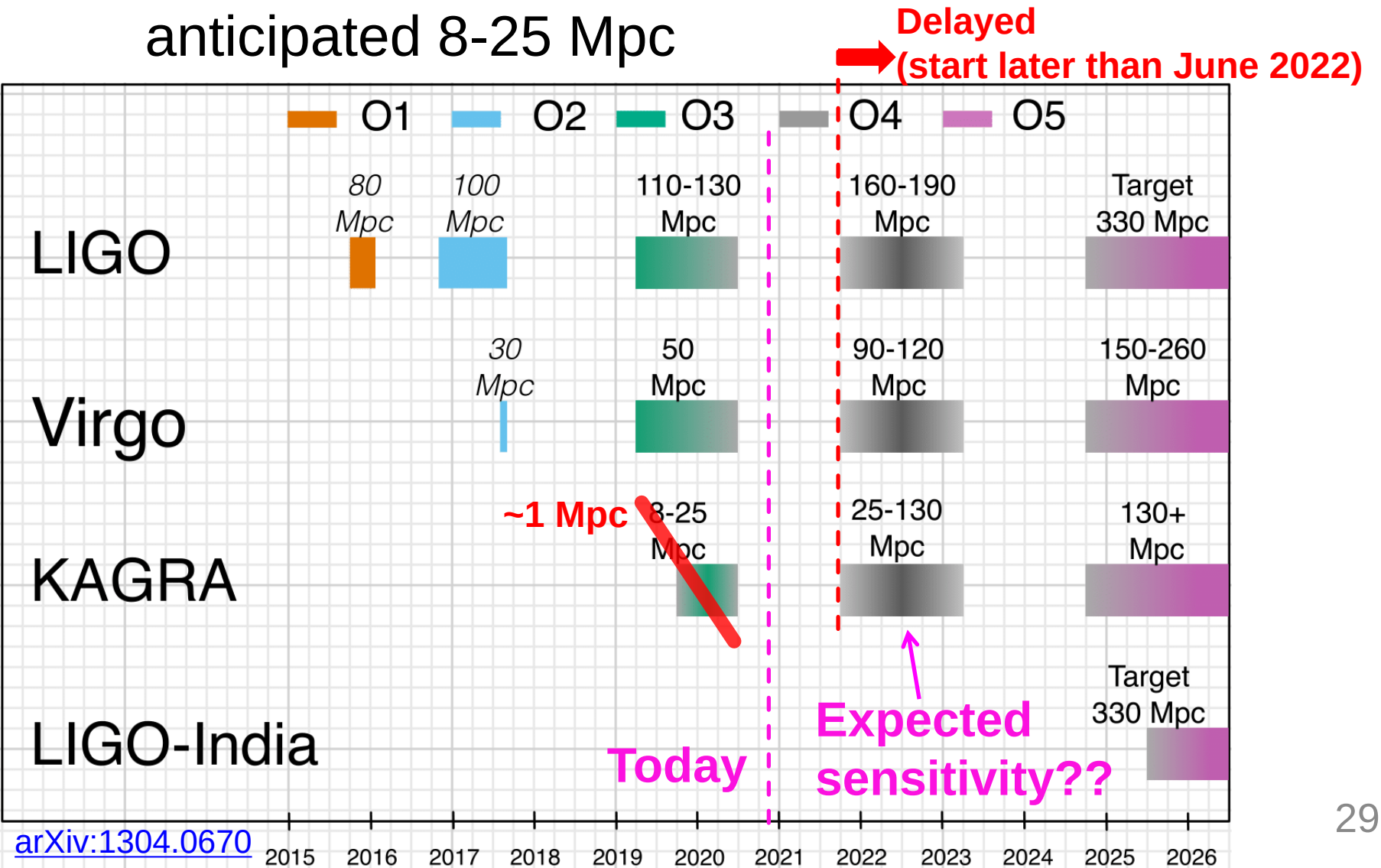
Summary 2/2

- **Acoustic noise**
  O3GK: Somehow mostly from IMC-IFI bellows
  O4 target: Reduction by ~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 ~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 ~$1/10^3$ at 50 Hz necessary
  Method: Coil driver switch, 🙂
  Additional optical levers, 😐
  Noise modeling and planning on going 😮

Bonus Slides

Observing Scenario of LVK

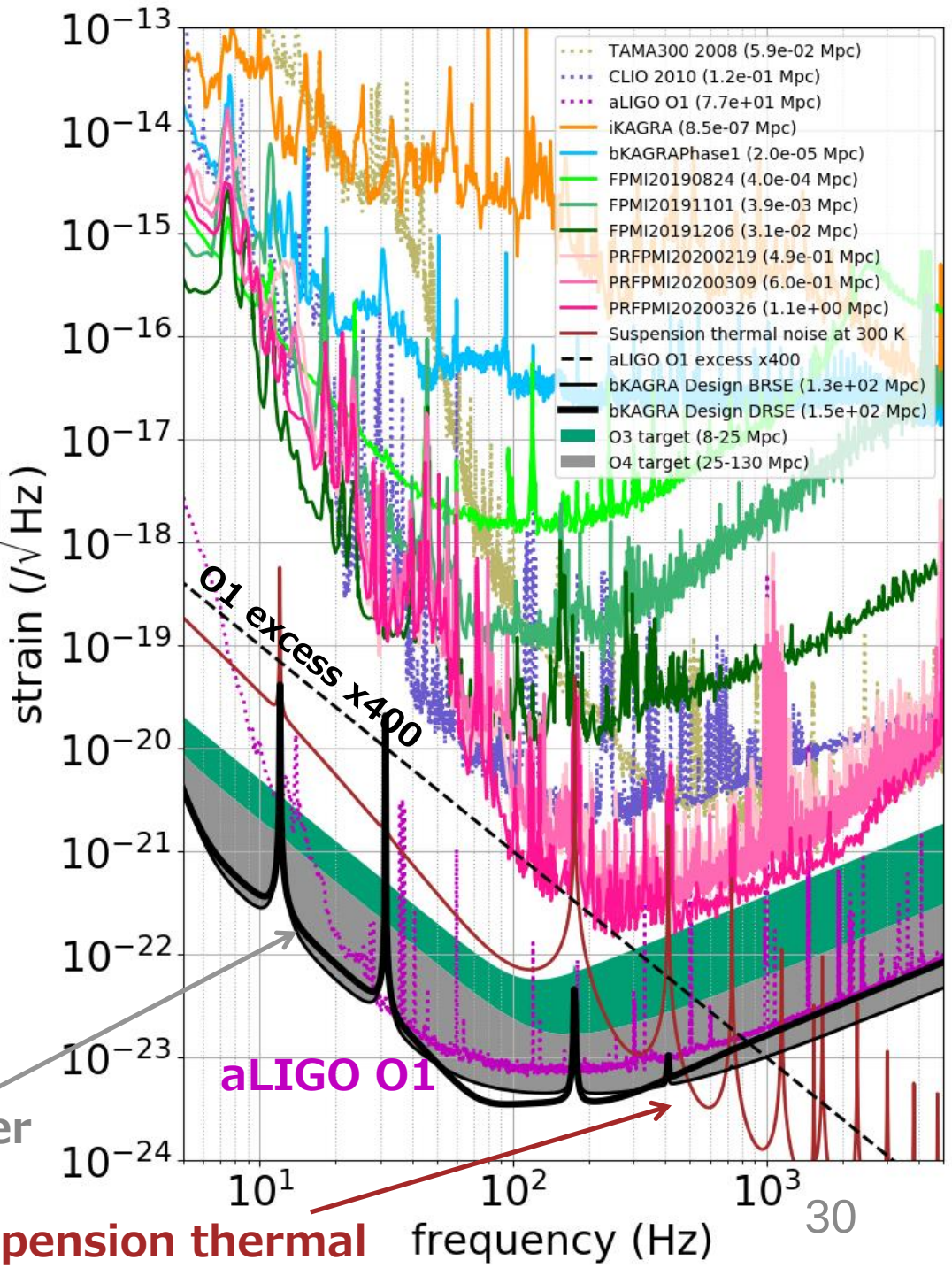
- Best sensitivity was ~1 Mpc although we anticipated 8-25 Mpc



arXiv:1304.0670

O4 Target

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

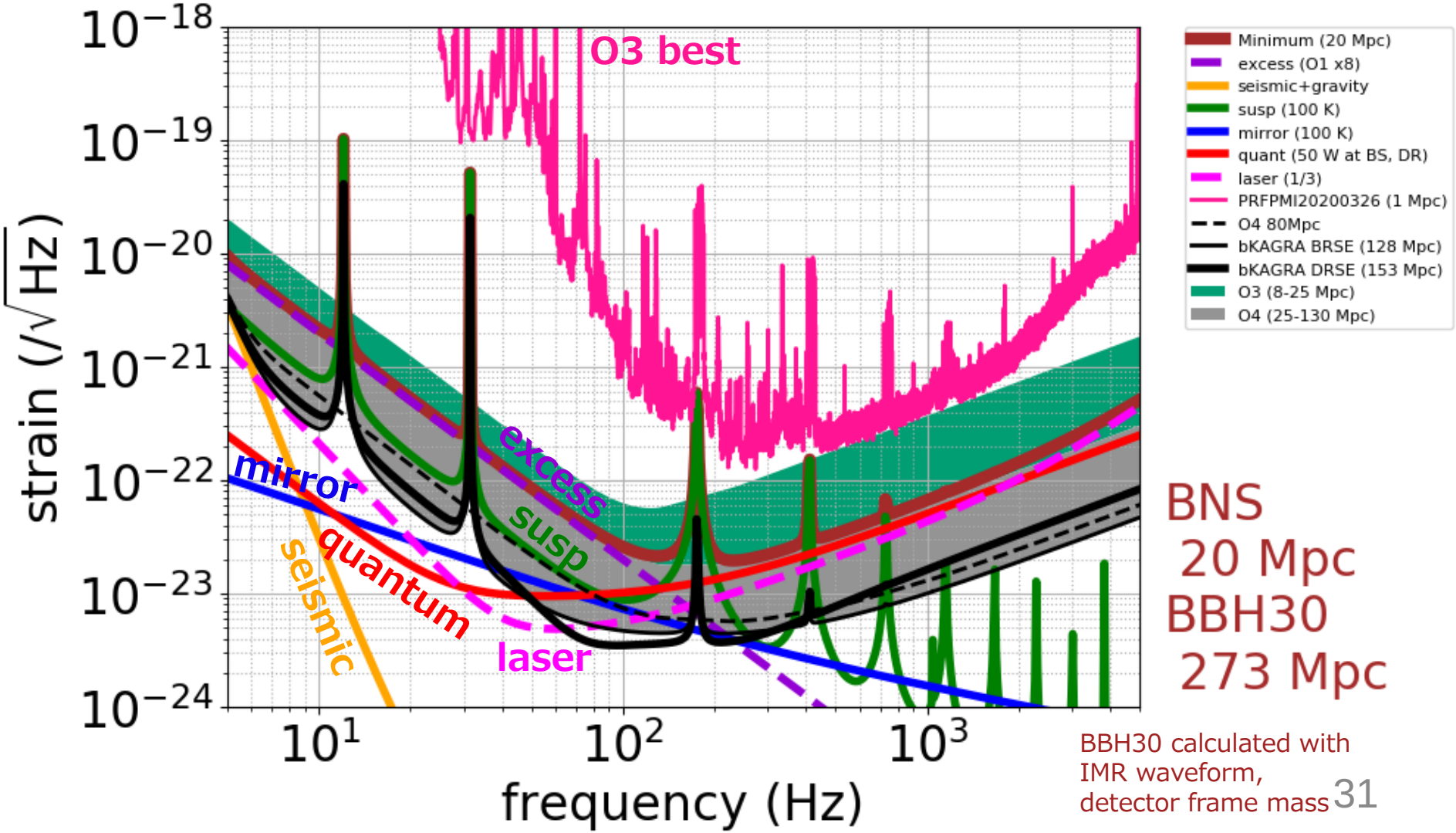


O4 target on Obs. Scenario Paper
25-130 Mpc

300 K suspension thermal

O4 “Minimum” Example

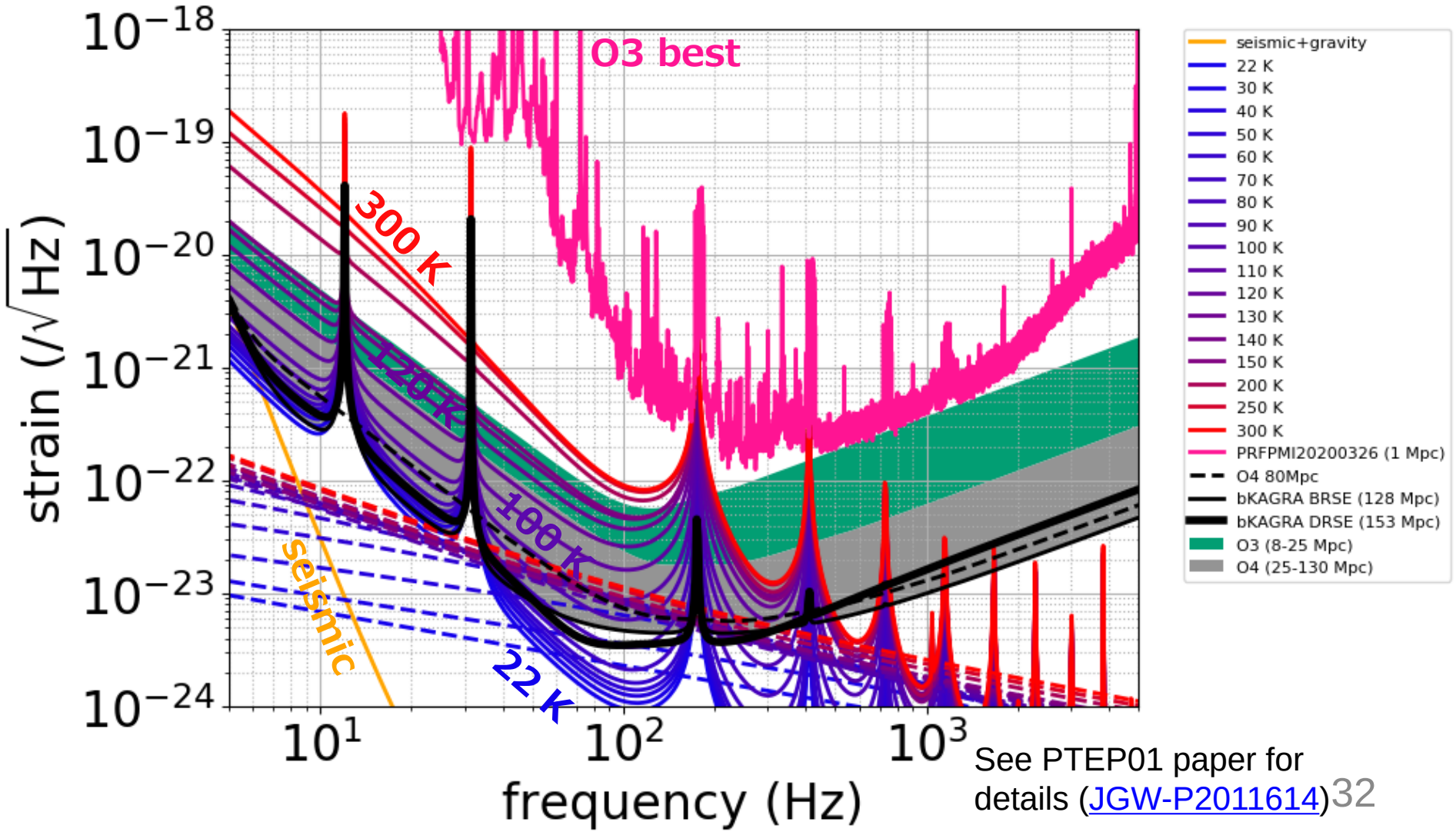
- 1/40 excess, 100 K, 50 W at BS, DR, 1/3 laser noise



BBH30 calculated with IMR waveform, detector frame mass

Various Thermal Noise

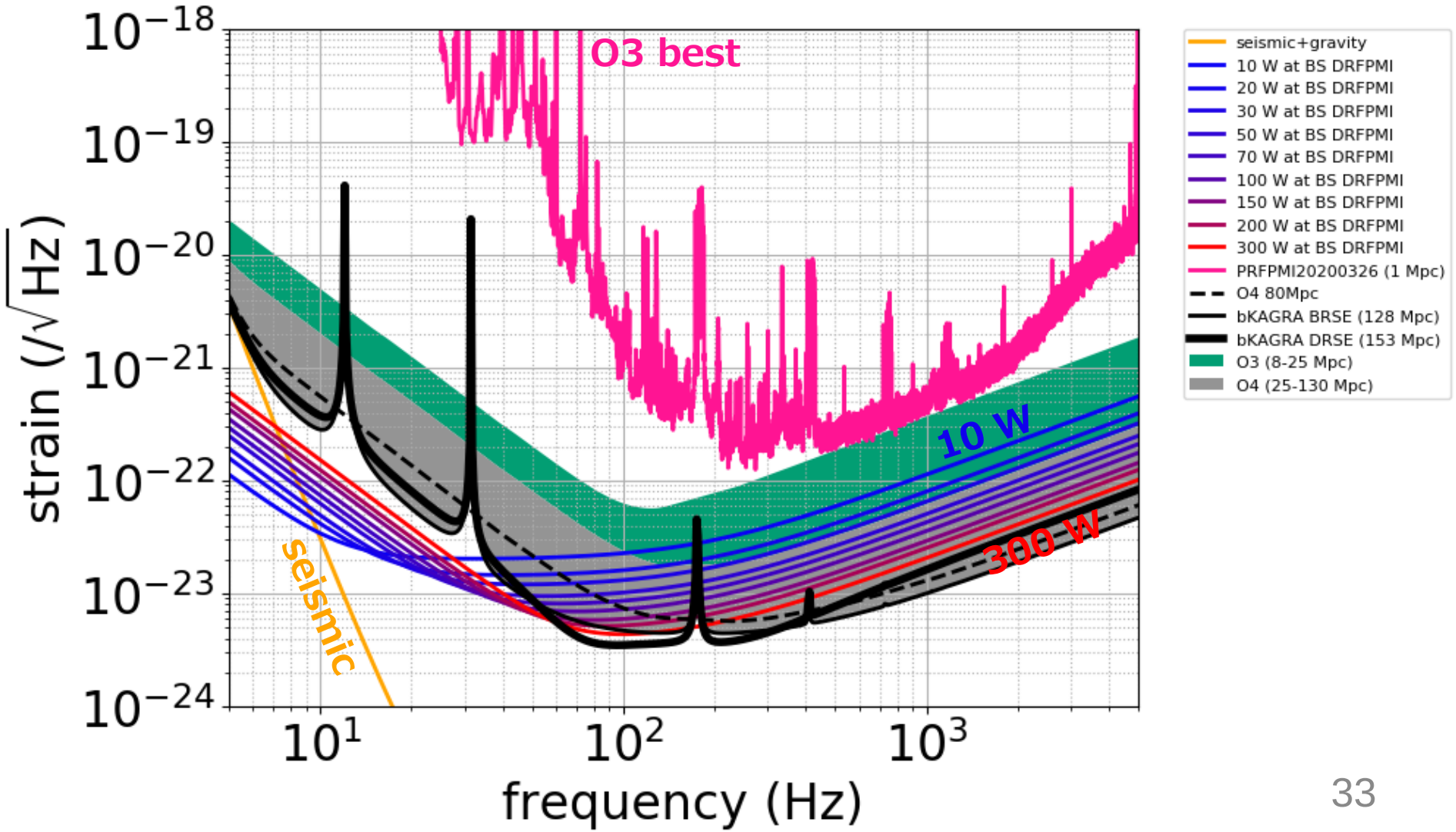
- All temperatures



See PTEP01 paper for details (JGW-P2011614)

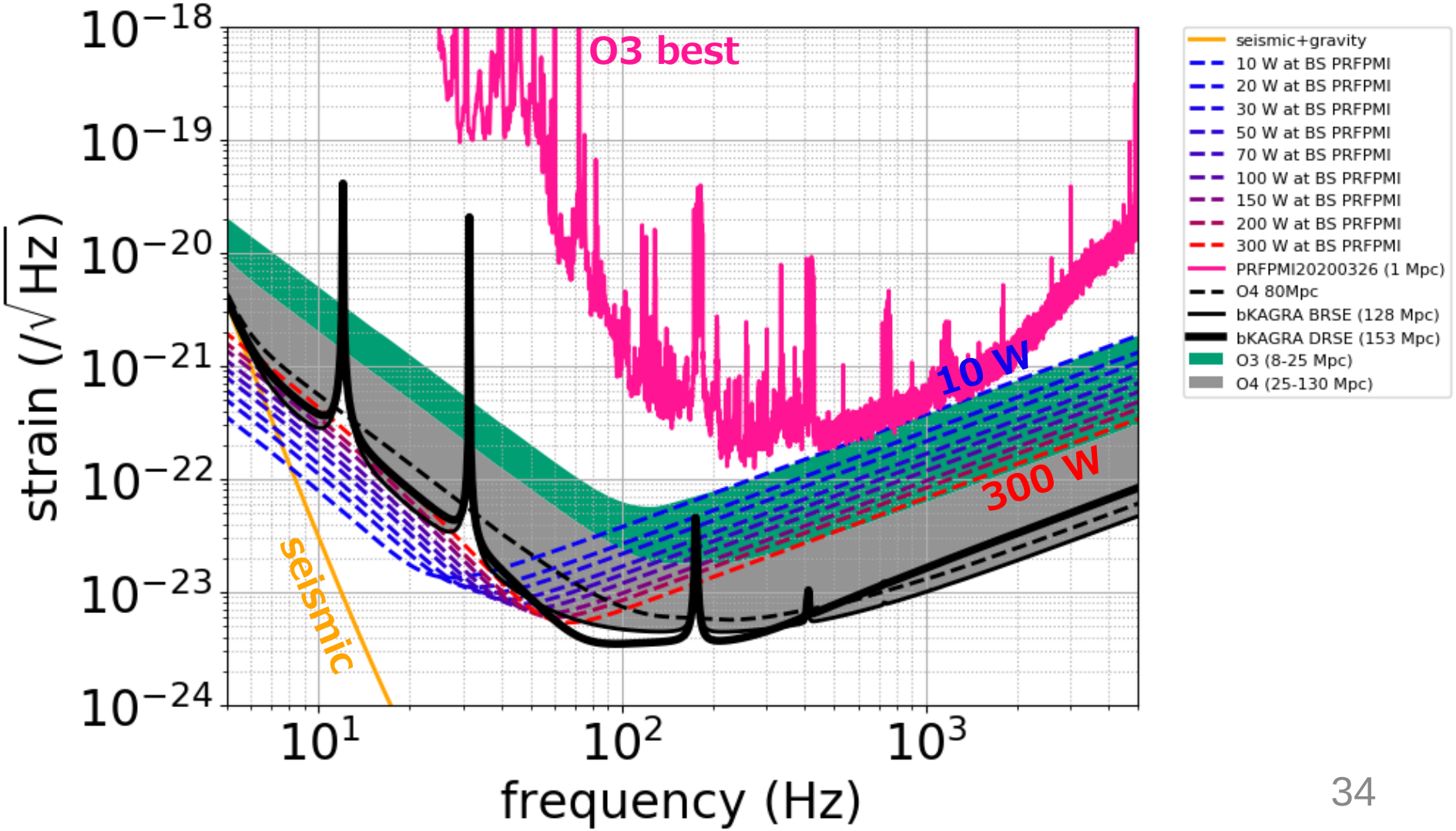
Various Quantum Noise (DR)

- All powers



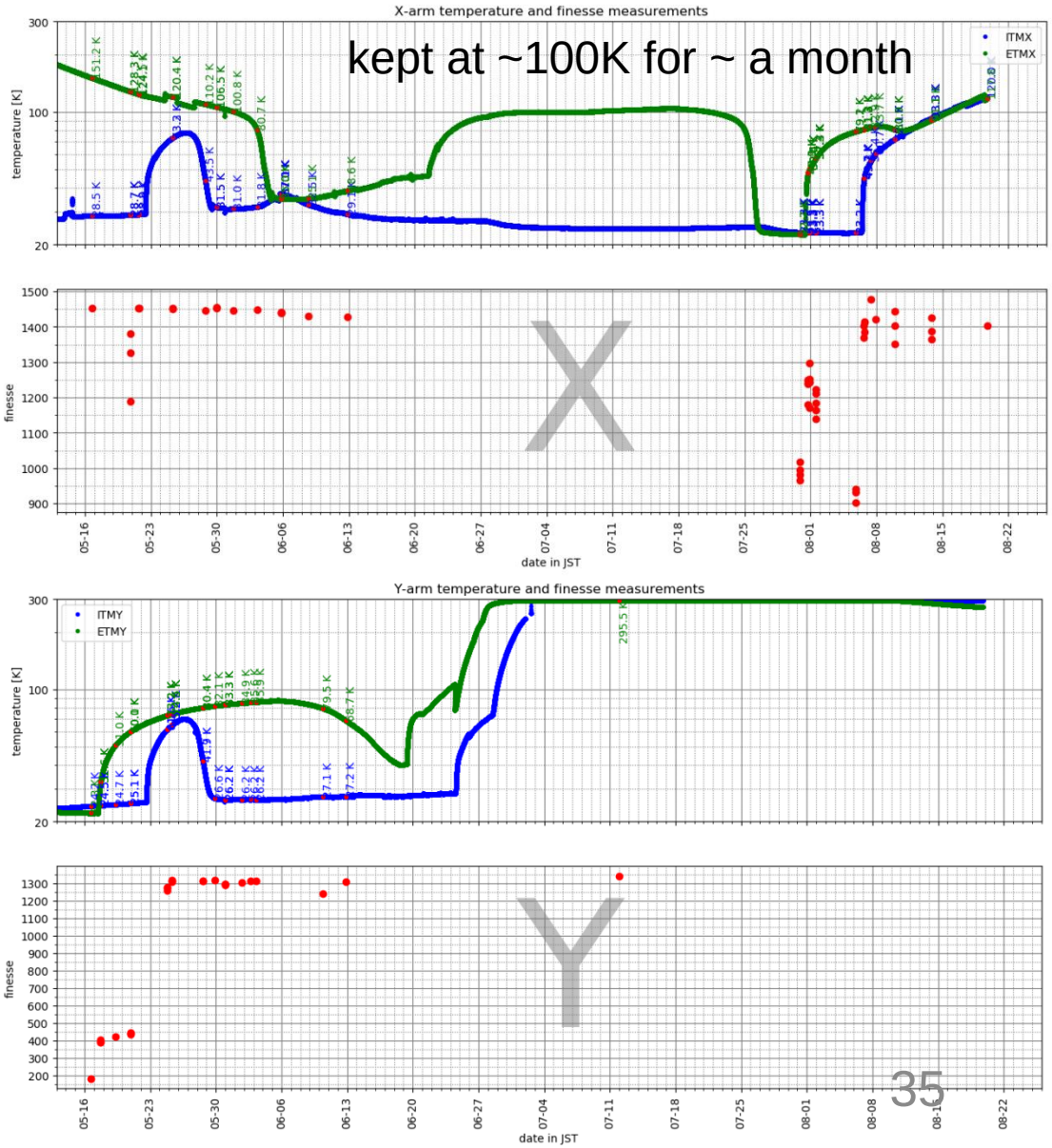
Various Quantum Noise (PR)

- All powers



Frosting of the Test Mass

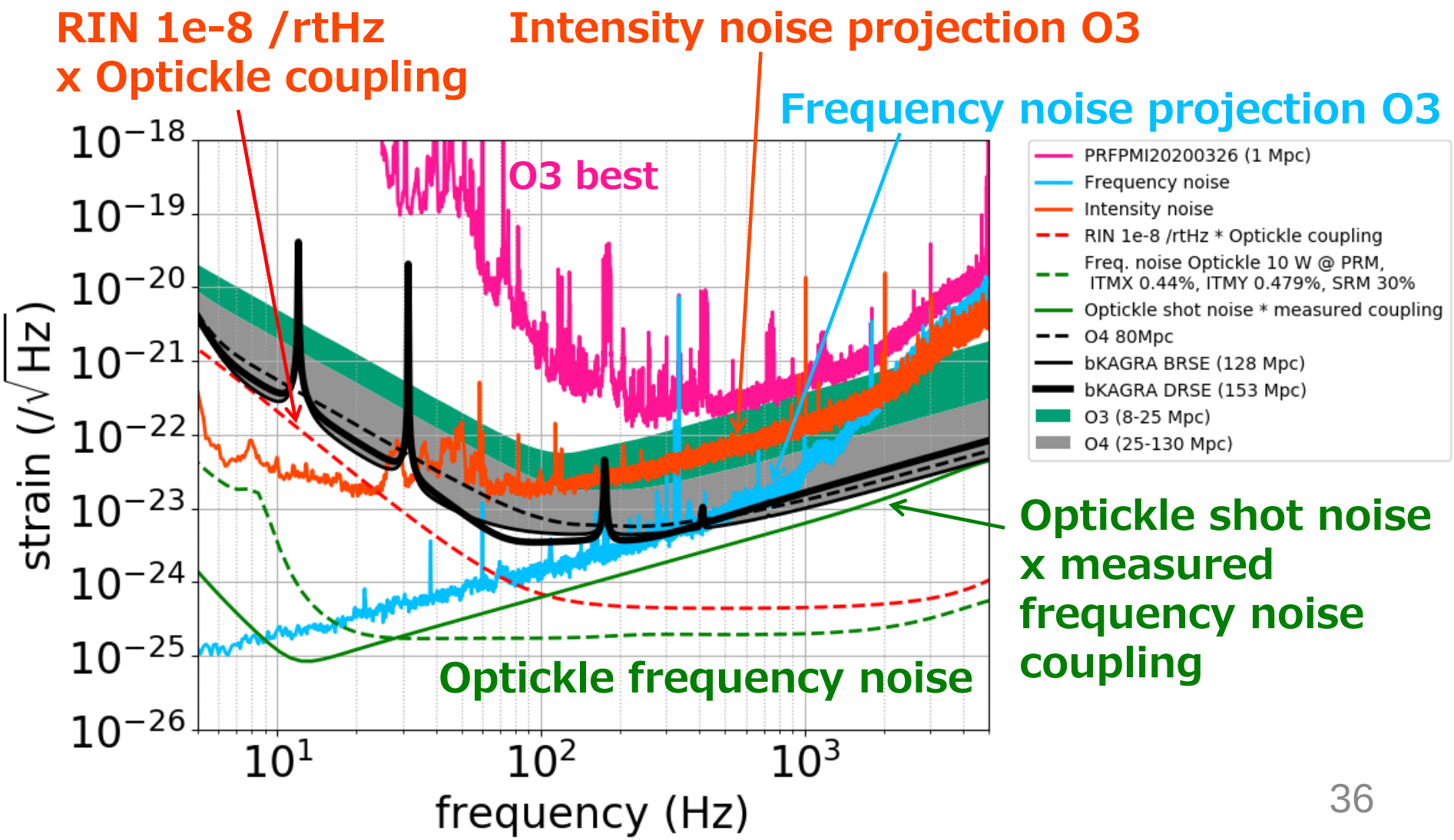
- Finesse drop observed when one of the test mass temperature is below ~30 K



klog [#10033]

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