Study of KAGRA noise contribution in O3GK

Status of Noise Budget Paper

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on behalf of the KAGRA collaboration

The 7th KAGRA International Workshop
Dec 19th, 2020

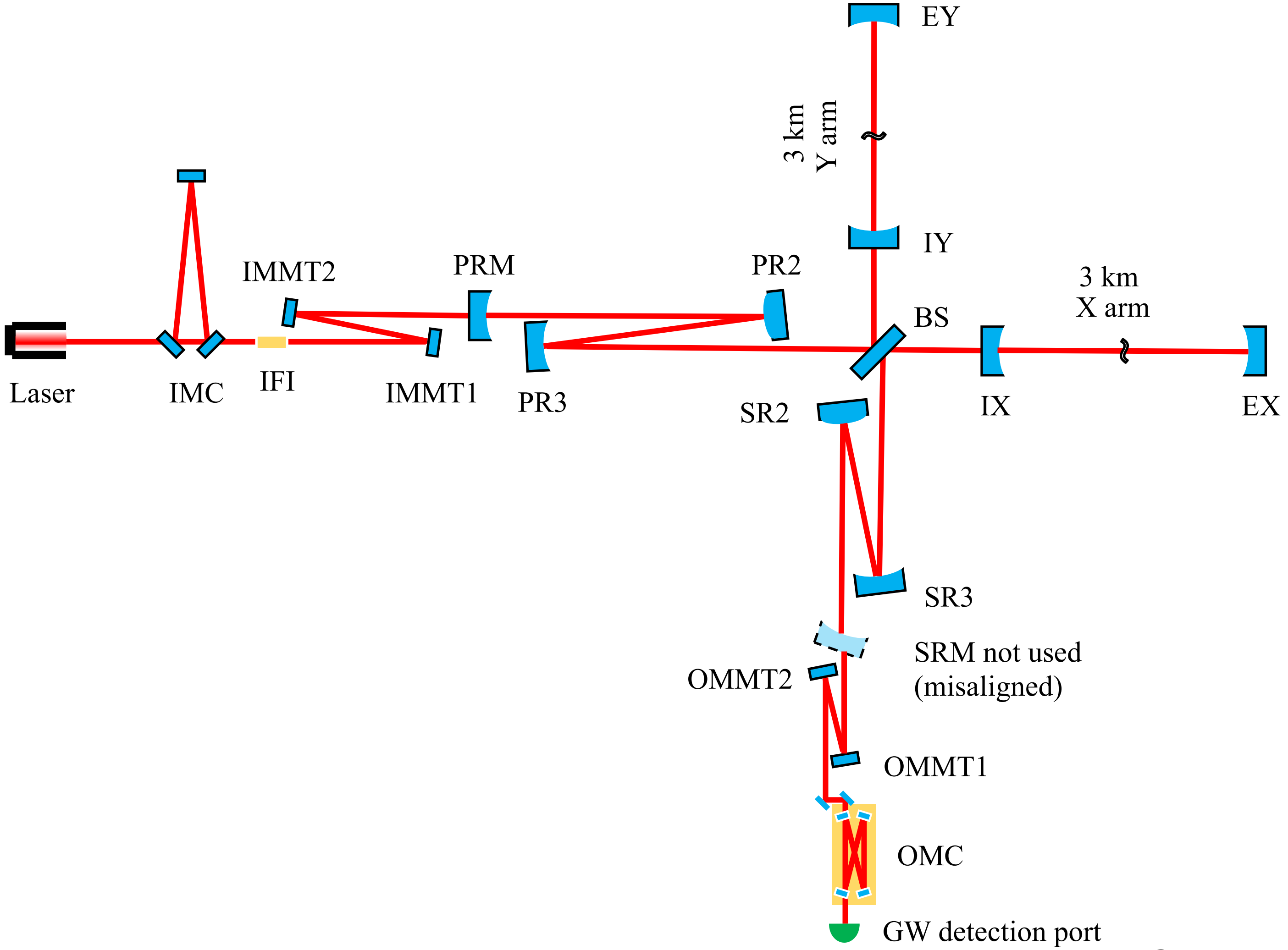
JGW-G2012315

Introduction

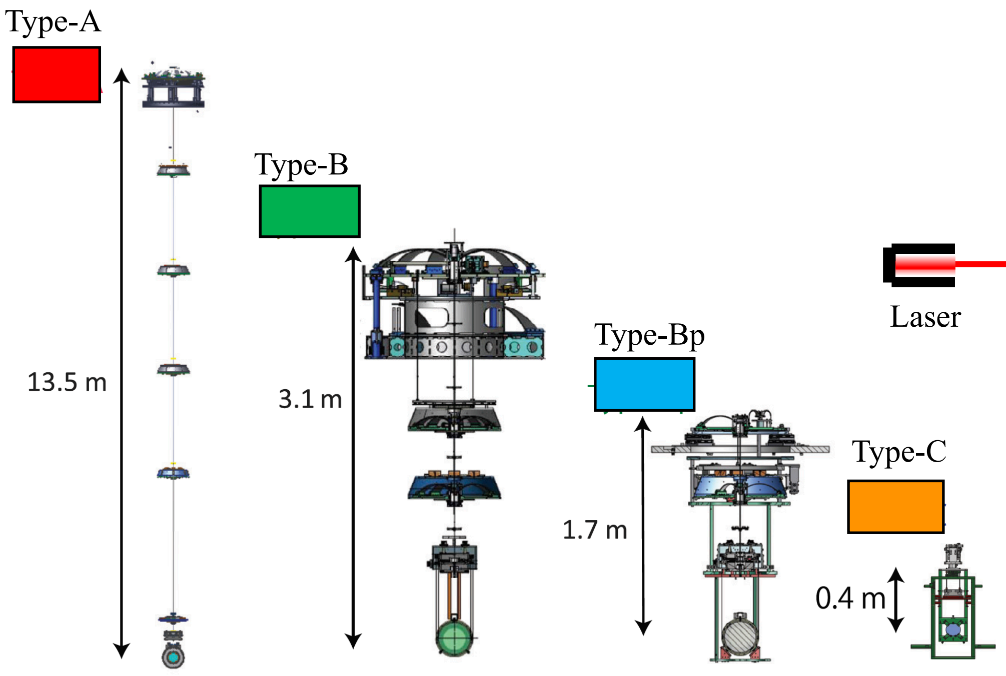
- KAGRA and GEO600 (Hannover, Germany) were operated for observation in April 2020 (O3GK), just after LIGO and Virgo were shut down because of COVID-19.
- In improvement for O4, it is crucial to investigate what kinds of noise dominated sensitivity in O3GK (and we intend to publish).
- We are collecting and summarizing pieces of information.
- We report latest update.

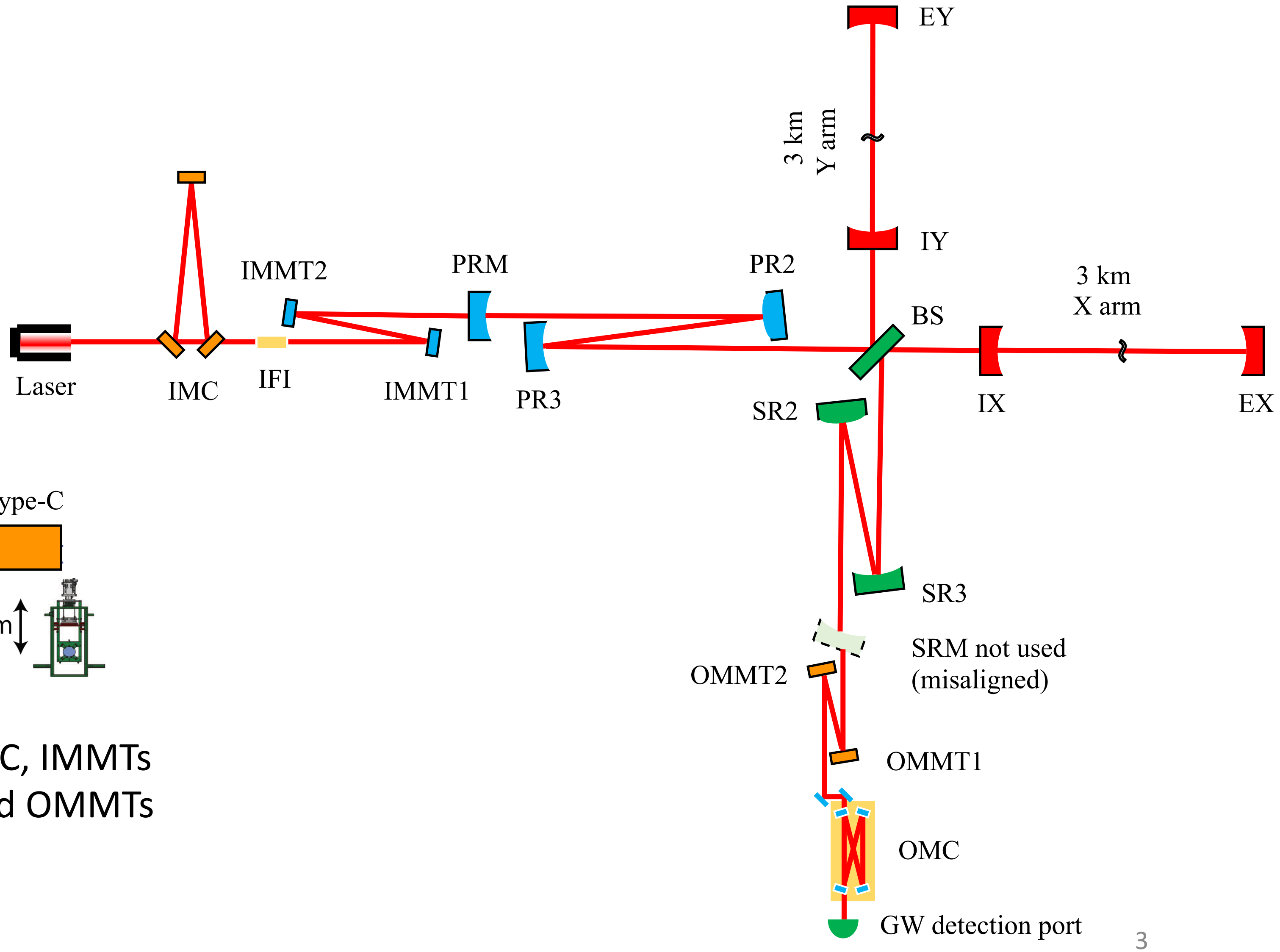
Interferometer Configuration during O3GK

- Power-Recycled Fabry-Perot Michelson interferometer
- 4 DoFs to length-control
  - CARM - Common arm length
  - DARM - Differential arm length which is GW DoF
  - PRCL - Power Recycling Cavity
  - MICH - Short differential Michelson ifo



Suspension Map for the KAGRA interferometer





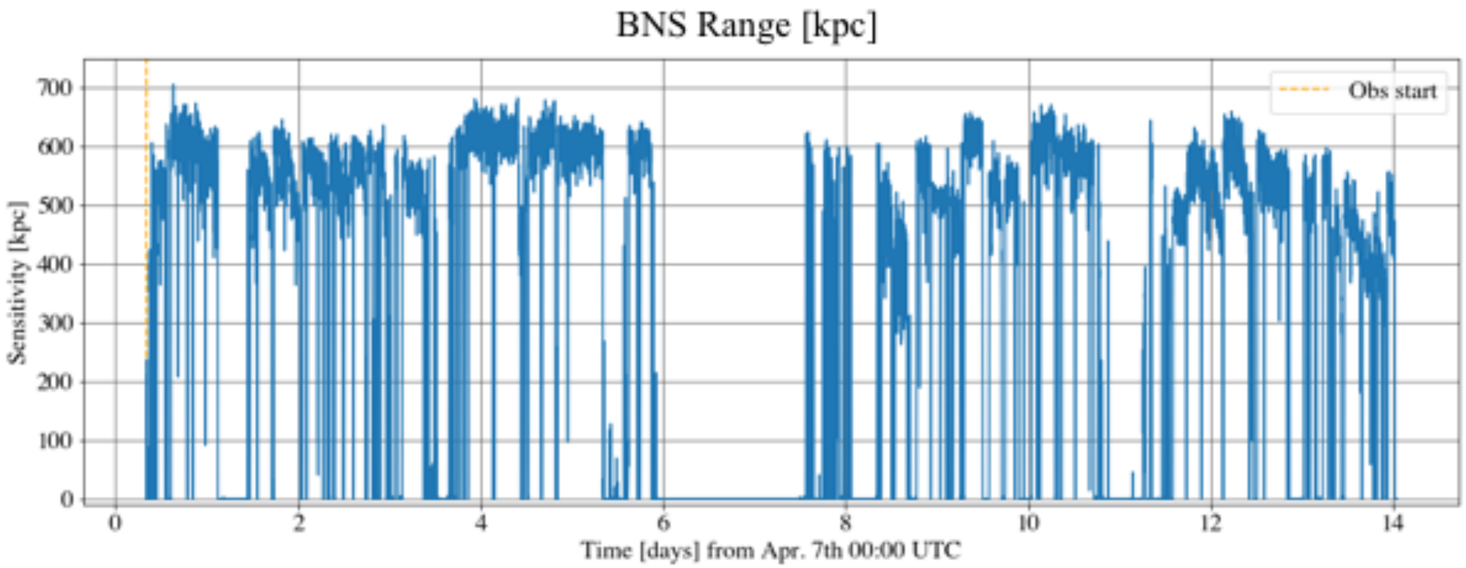
IX, EX, IY, EY

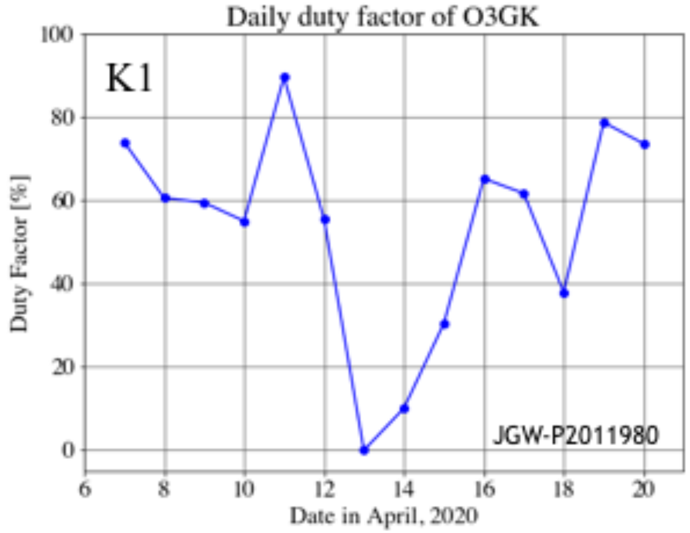
BS, SRM
SR2, SR3

PRM,
PR2, PR3

IMC, IMMTs
and OMMTs

Interferometer status during O3GK

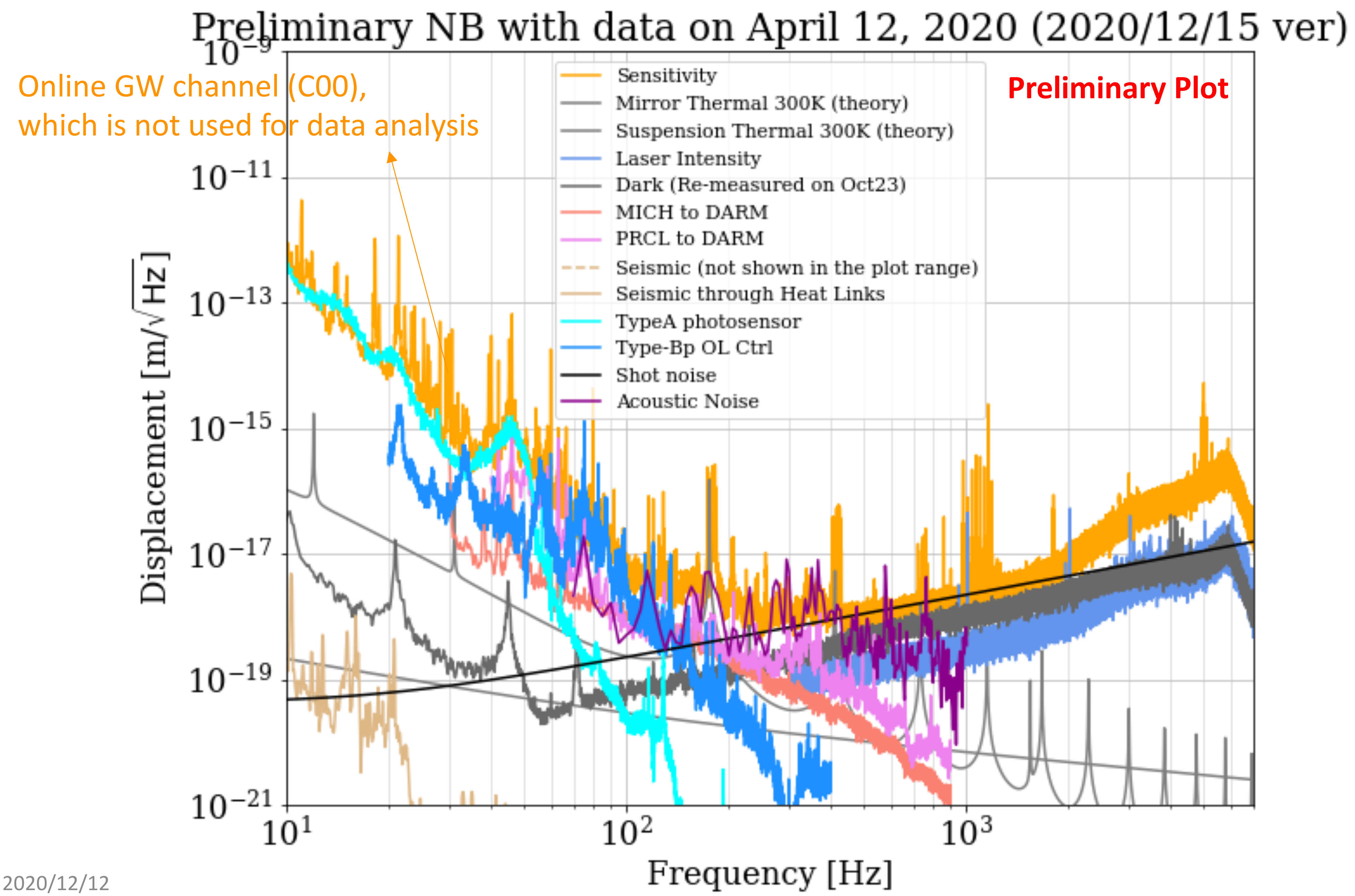




- Typical Binary Neutron Star Range is 600kpc.
- Short lock duration degrades the duty factor.
- More than one day of down time due to high ocean waves due to a bad weather (See, Fujikawa's presentation, abstract ID 16 for detailed study)

	Observation Time [s]	Duty Factor
GEO	940133 (11 days)	80%
KAGRA	628135 (7.3 days)	53%
Coincident	551340 (6.4 days)	47%

from Tagoshi-san material [?]



Preliminary NB with data on April 12, 2020 (2020/12/15 ver)
Online GW channel (C00),
which is not used for data analysis
Preliminary Plot
Sensitivity
Mirror Thermal 300K (theory)
Suspension Thermal 300K (theory)
Laser Intensity
Dark (Re-measured on Oct23)
MICH to DARM
PRCL to DARM
Seismic (not shown in the plot range)
Seismic through Heat Links
TypeA photosensor
Type-Bp OL Ctrl
Shot noise
Acoustic Noise
Displacement [m/√Hz]
Frequency [Hz]

- Suspension Thermal
  - Theoretical at 300K
    Formulae in "Overview of KAGRA: Detector design and construction history" [1]

- Mirror Thermal
  - Theoretical at 300K
    Formulae in "Overview of KAGRA: Detector design and construction history" [2]

- Shot noise
  - Theoretical formula :

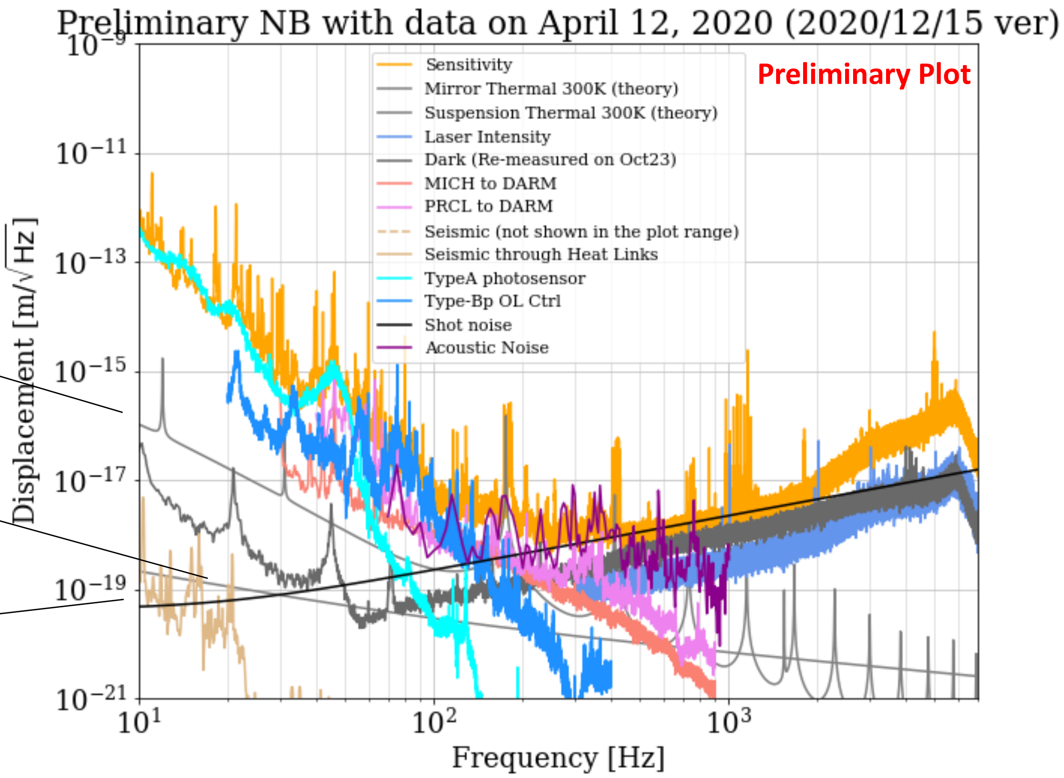
$$G_{\rm shot} = \frac{h\lambda c}{32 G_{\rm p} I (1-\eta) L^2 \mathcal{F}^2}\left[1+\left(\frac{f}{f_{\rm cut}}\right)^2\right],$$

$$f_{\rm cut} = \frac{c}{4L\mathcal{F}}.$$

suspension themal

mirror themal

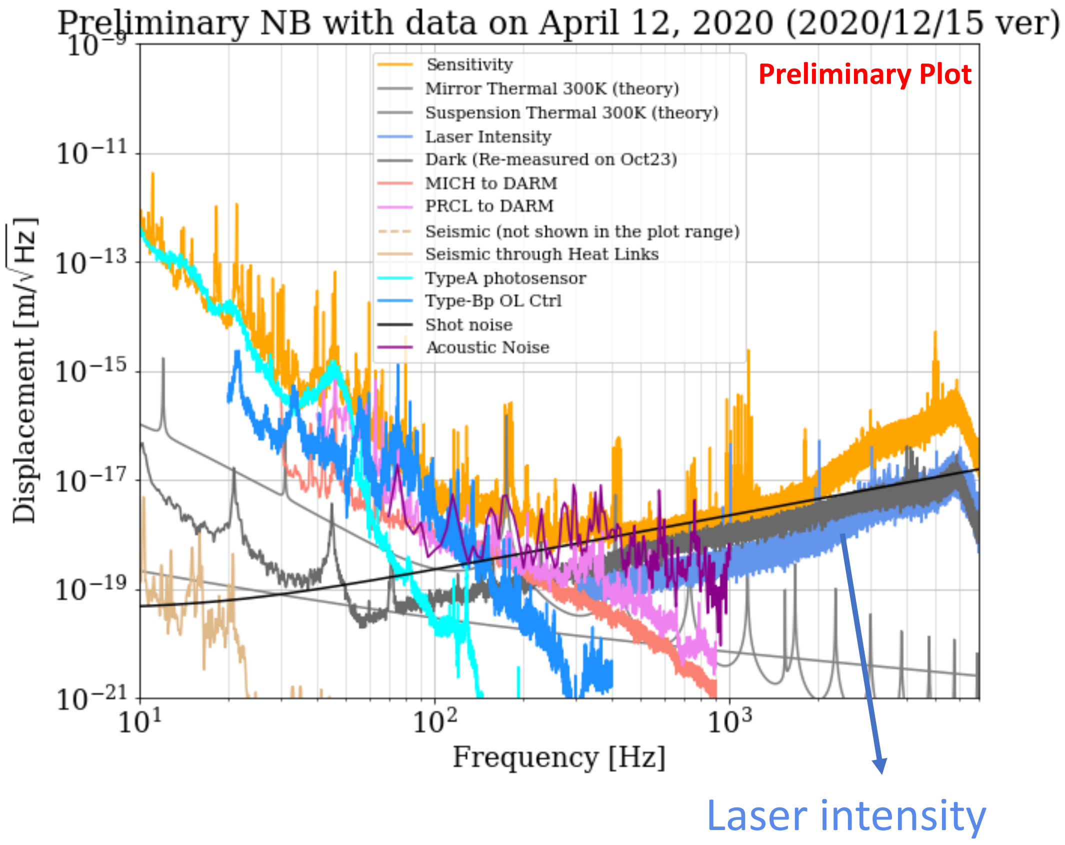
shot noise



[1] https://academic.oup.com/ptep/advance-article/doi/10.1093/ptep/ptaa125/5893487
[2] https://academic.oup.com/ptep/advance-article/doi/10.1093/ptep/ptaa125/5893487

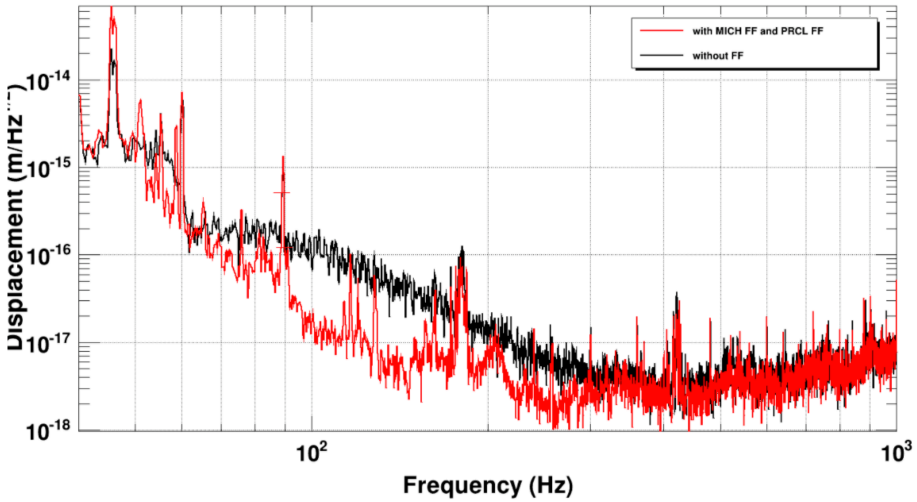
- ## Laser Intensity

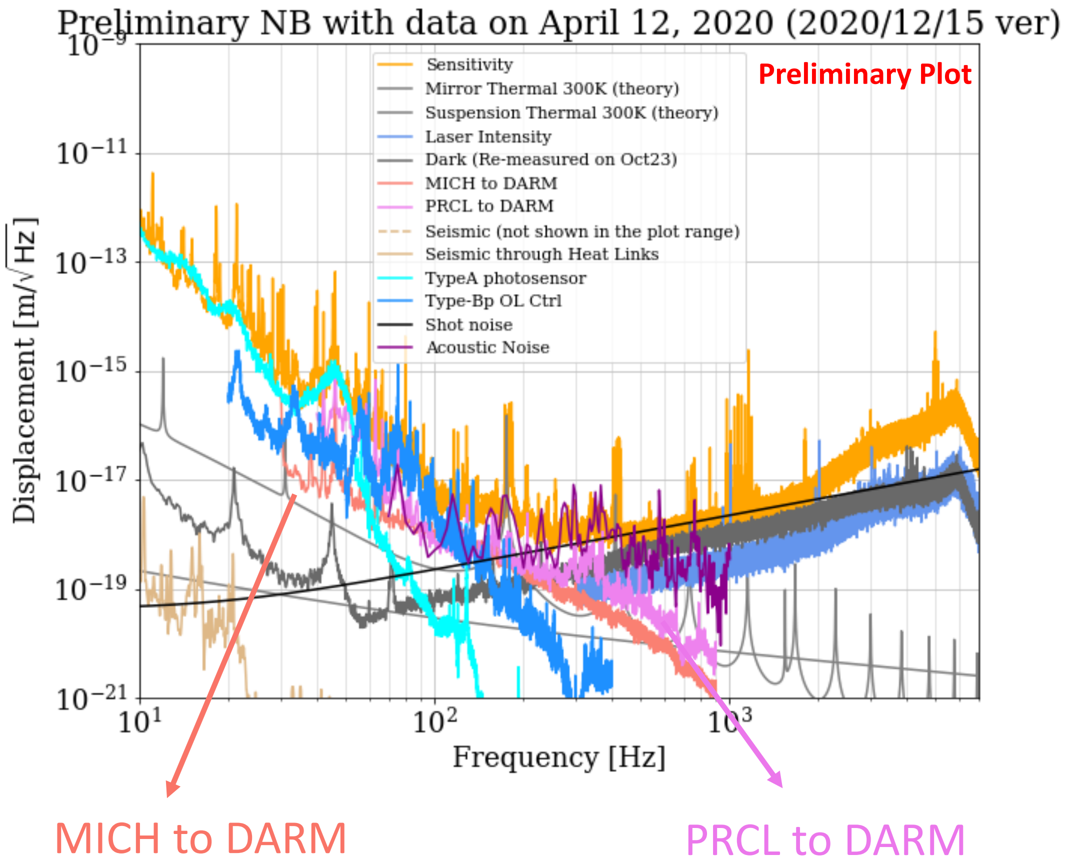
  - Laser intensity is stabilized
  - Fluctuation of laser power transmitted by IMMT1 was monitored to adjust injected power to interferometer.
  - Transfer function from power transmitted by IMMT1 to DARM (gravitational wave signal port) was measured.
  - Noise contribution is the product of above fluctuation and transfer function.



  - It is not limiting the sensitivity for O3GK, however, it will in O4. Intensity stabilization system is being upgraded (placing PDs in vacuum). See Kuromiya-kun's presentation, abstract ID 38)

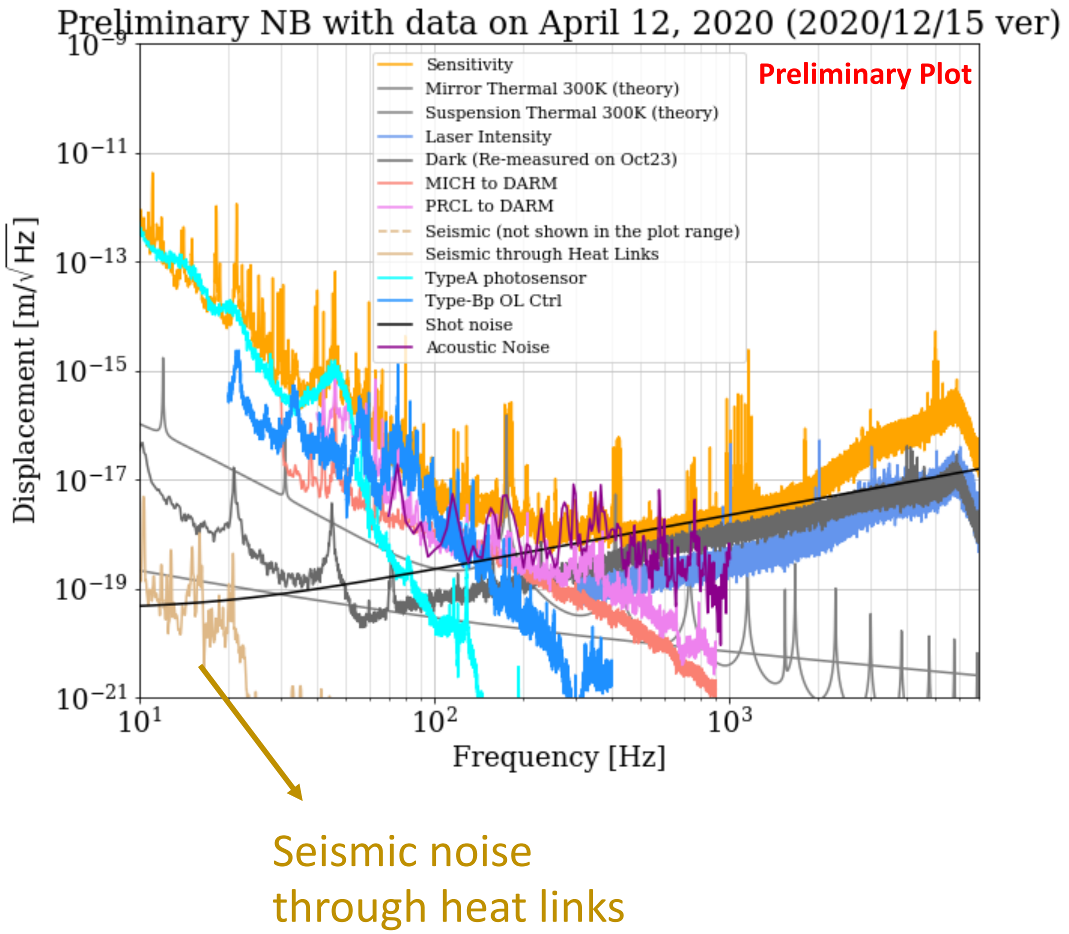
- MICH and PRCL to DARM coupling
  - MICH and PRCL feedforward (FF) loops are improving the sensitivity at 70-200 Hz
    - MICH to PRCL FF
    - MICH to DARM FF
    - PRCL to DARM FF





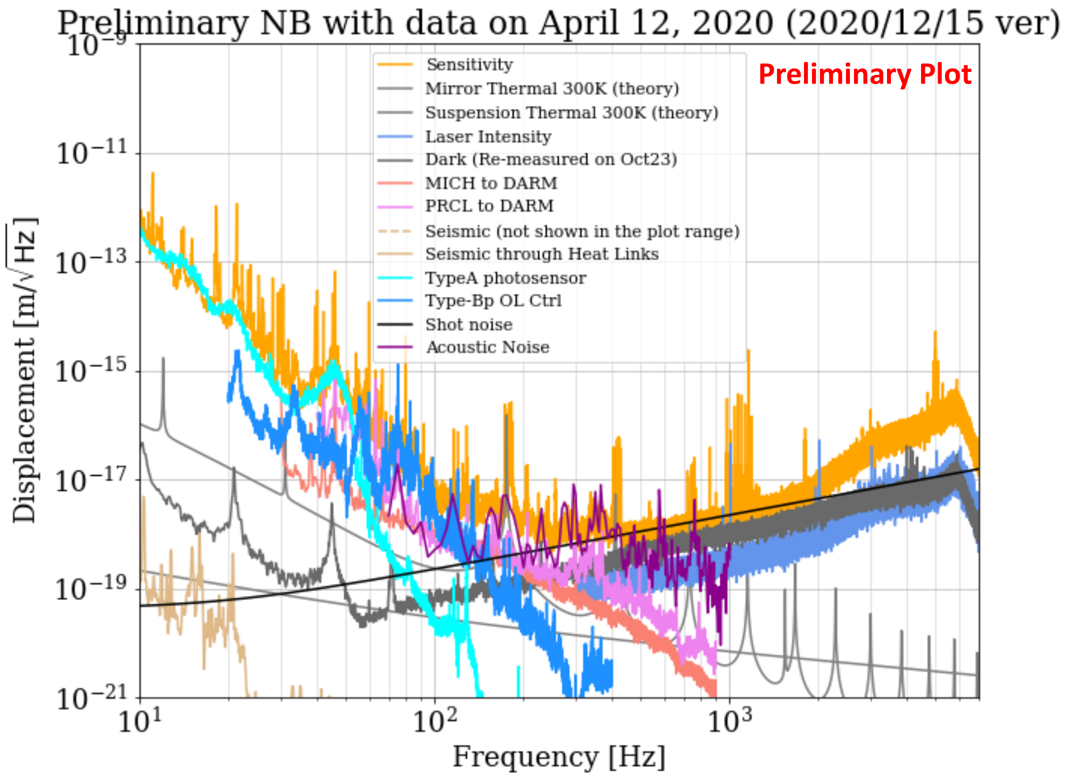
  - Residual contribution was estimated
  - More tuning (e.g., FF gain, diagonalization) is necessary for O4

- Seismic Noise through Heat Links
  - There are heat links made from pure aluminum as heat path to cool down sapphire mirrors. They can transfer vibration to sapphire mirror.
  - Low and not contributing to DARM
  - The modeled transfer function from the suspension point of the heat link vibration isolation system to the test mass was evaluated by Shoda-san.
  - Suspension point vibration is assumed to be same as vibration at a floor of inner radiation sheild (measured by Ochi-kun [1]).
  - Updated study by Yamada-kun's Ph.D. thesis (presentation at KIW - abstract ID 64)

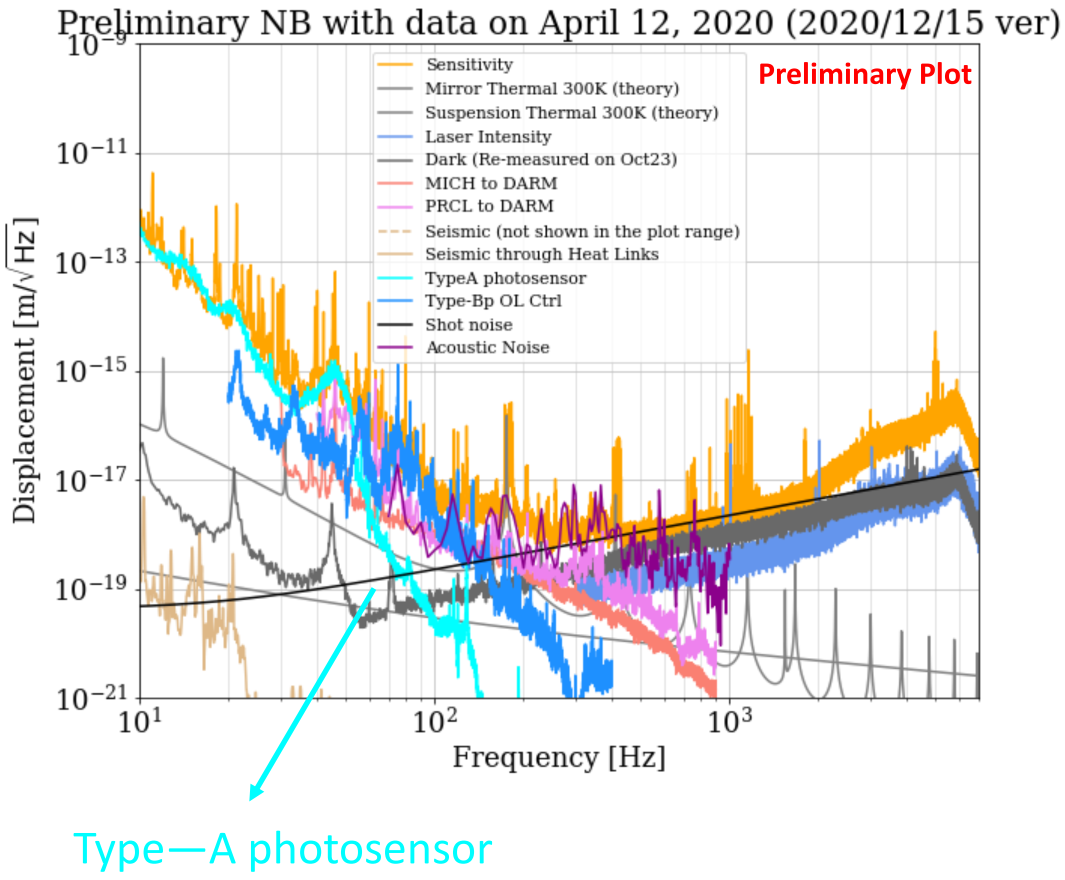


[1] https://gwdoc.icrr.u-tokyo.ac.jp/cgi-bin/DocDB/ShowDocument?docid=7574

- Seismic Noise thorugh type-A suspension
  - Enough low and not appear in this plot
  - Estimated by the modeled transfer function from Type-A ground to test mass (by Shoda-san) x seismometer data



- Type—A photosensor
  - Photosensors are used for local damping of Type-A suspensions (four mirrors in the arms) to suppress resonant motion of suspensions.
  - Transfer function from Marionetta (MN) photosensor to DARM was measured (klog 13470 and its thread).
  - Contribution to DARM is estimated by the online witness channel for MN photo sensor on Apr 12 multiplied by the transfer function
  - IX photosensor is most noisy of the four and limits the sensitivity
  - Planning to substitute with optical levers, under investigation



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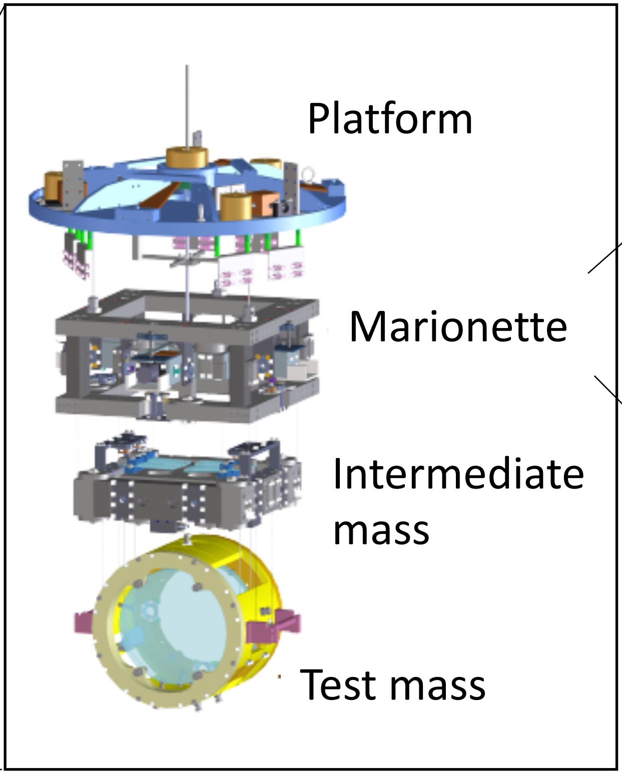
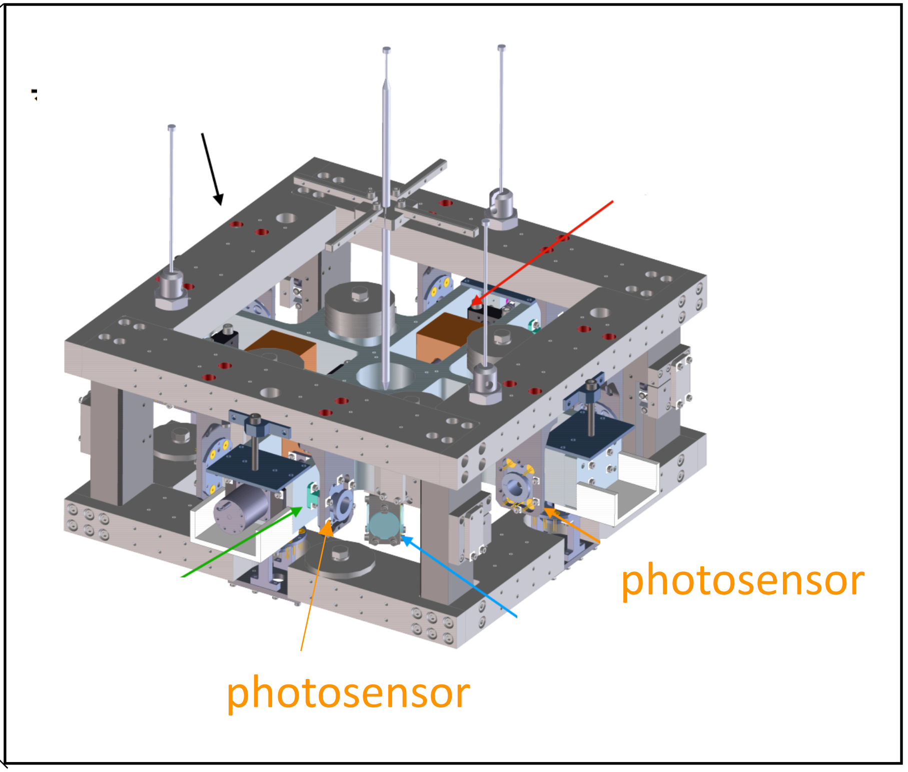
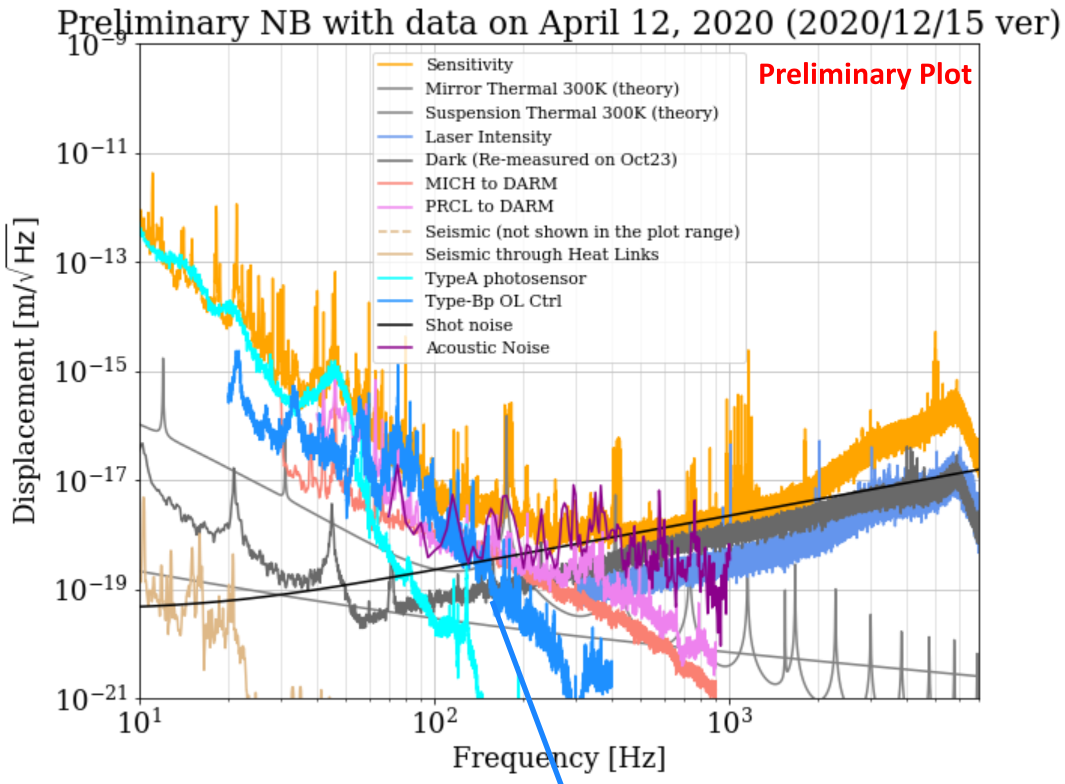


Marionette



Figures from Fukunaga Master thesis

- Type—Bp Oplev
  - Oplev sensors are used for local damping of resonant motion of Type-Bp suspensions (PRM, PR2, PR3) in pitch (P) and yaw (Y) on the mirror stage
  - Transfer function from oplev witness P and Y to DARM was meausred (klog 13498)
  - Contribution to DARM is estimated by the transfer function x online oplev witness on Apr 12
  - Note that there may be overestimate the level together with the PRCL to DARM contribution



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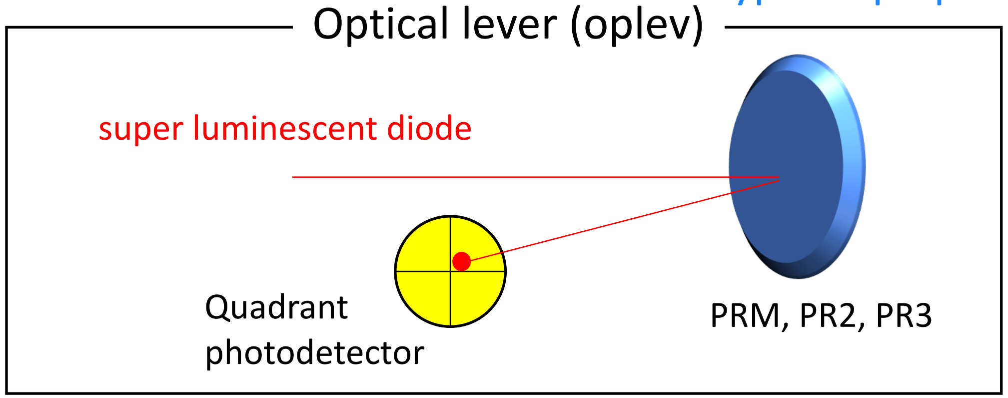
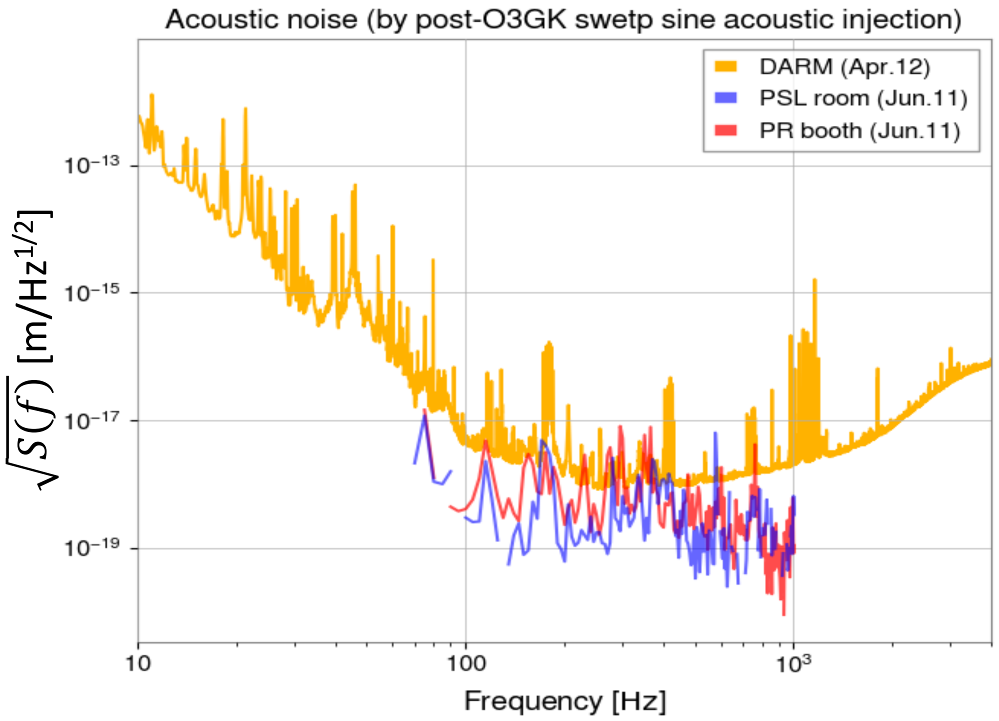


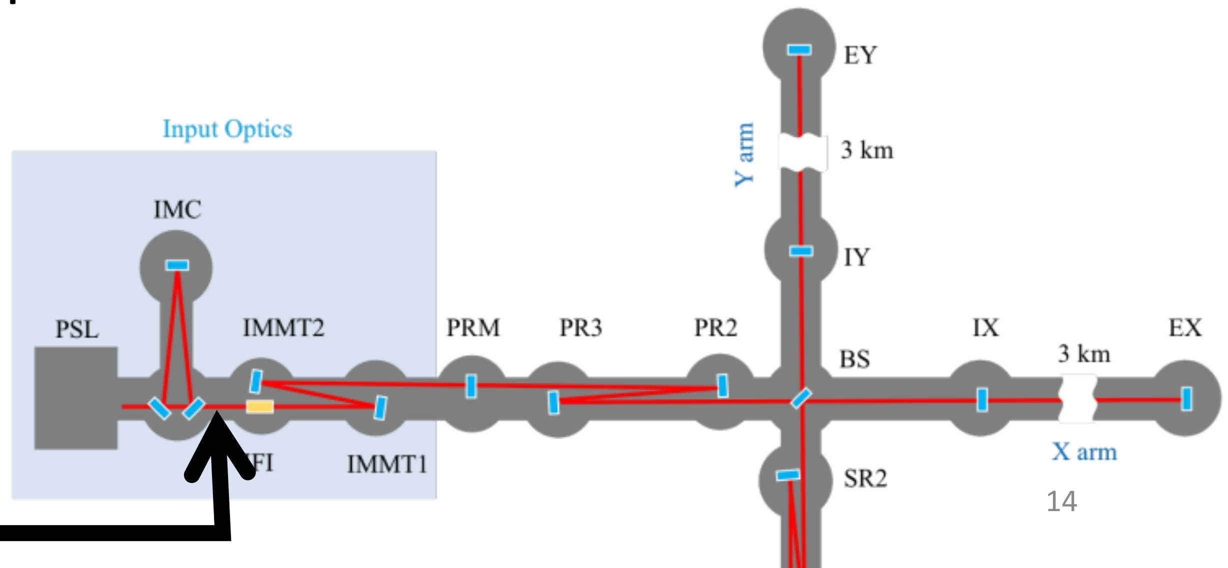
- Acoustic Noise
  - Evaluated by the PEM injection test.

$$S_{\mathrm{PEM}}(f) = \int [R(f,f')\times P(f')]\mathrm{d}f'$$

$S_{\mathrm{PEM}}(f)$: Acoustic noise in DARM PSD
$P(f')$: Acoustic field PSD
$R(f,f')$: Response function



- The most effective point was the beam-tube between the IMC chamber and IFI chamber.
  - See T. Yokozawa (abstract ID34) and T. Washimi (abstract ID41) and arXiv:2012.09294



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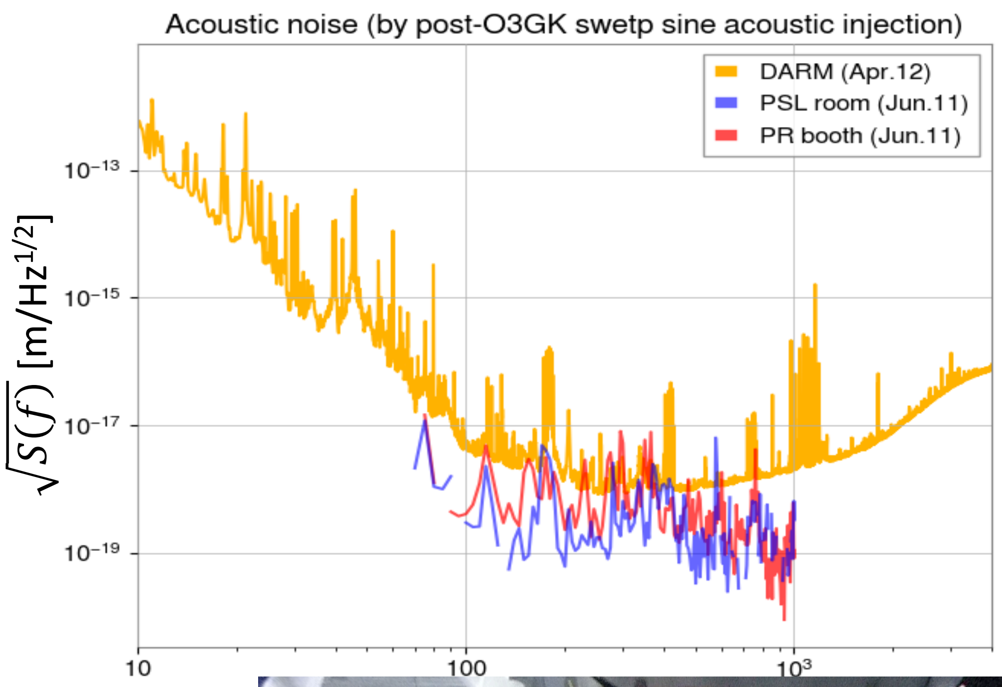

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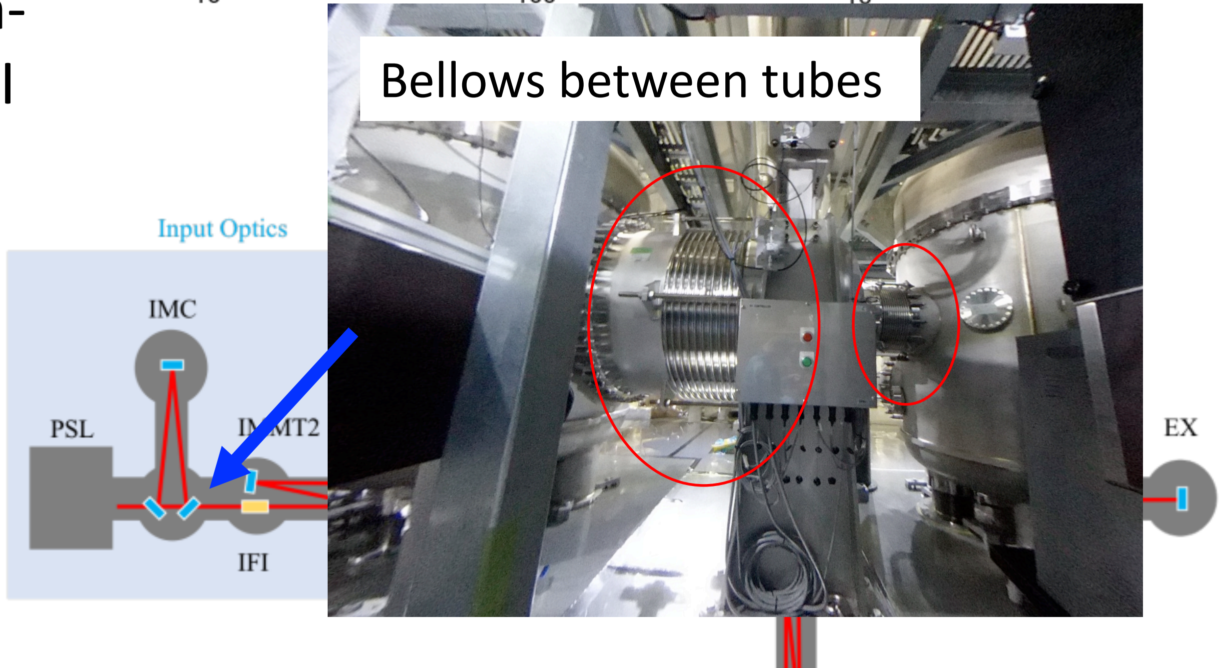
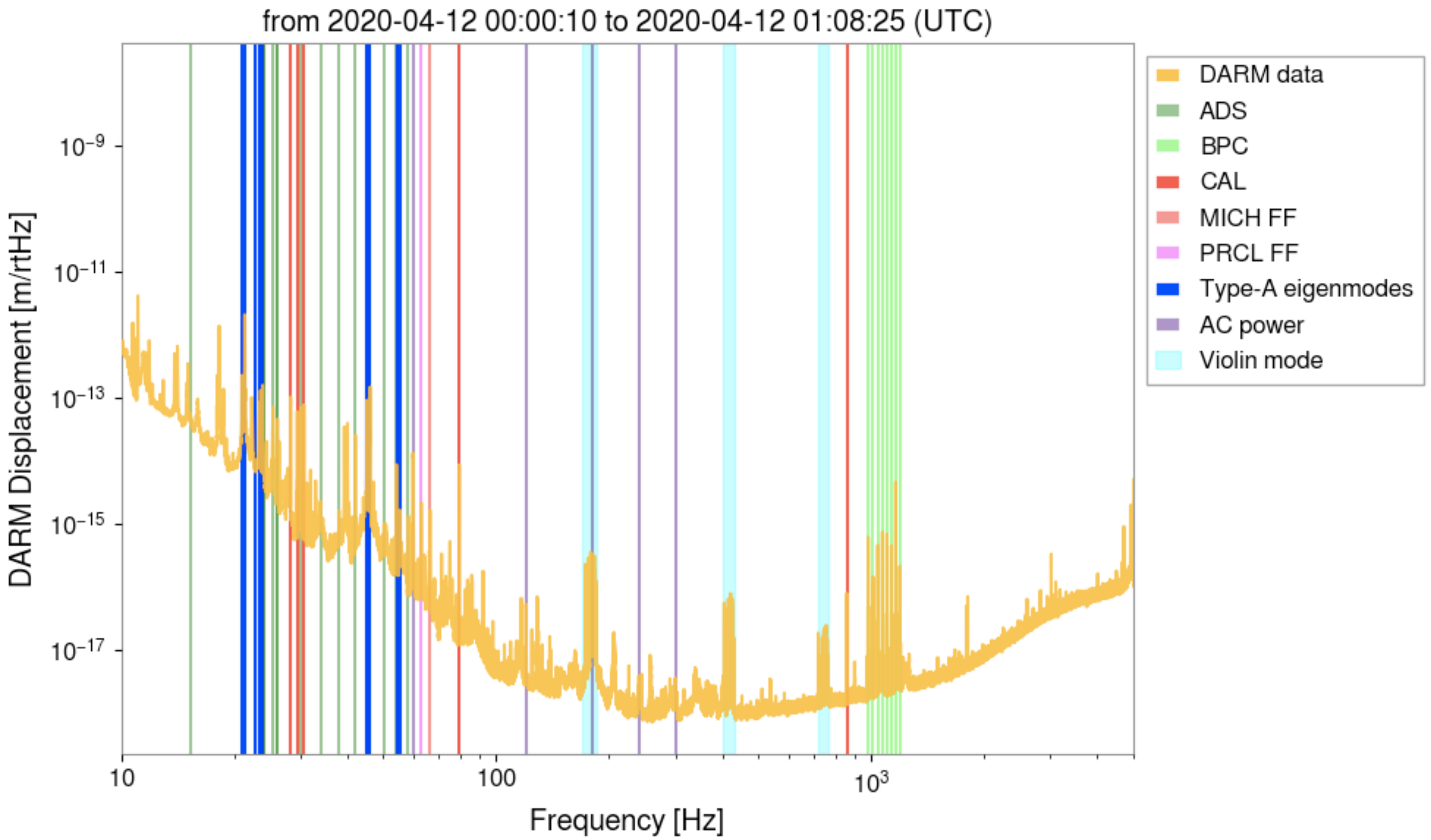


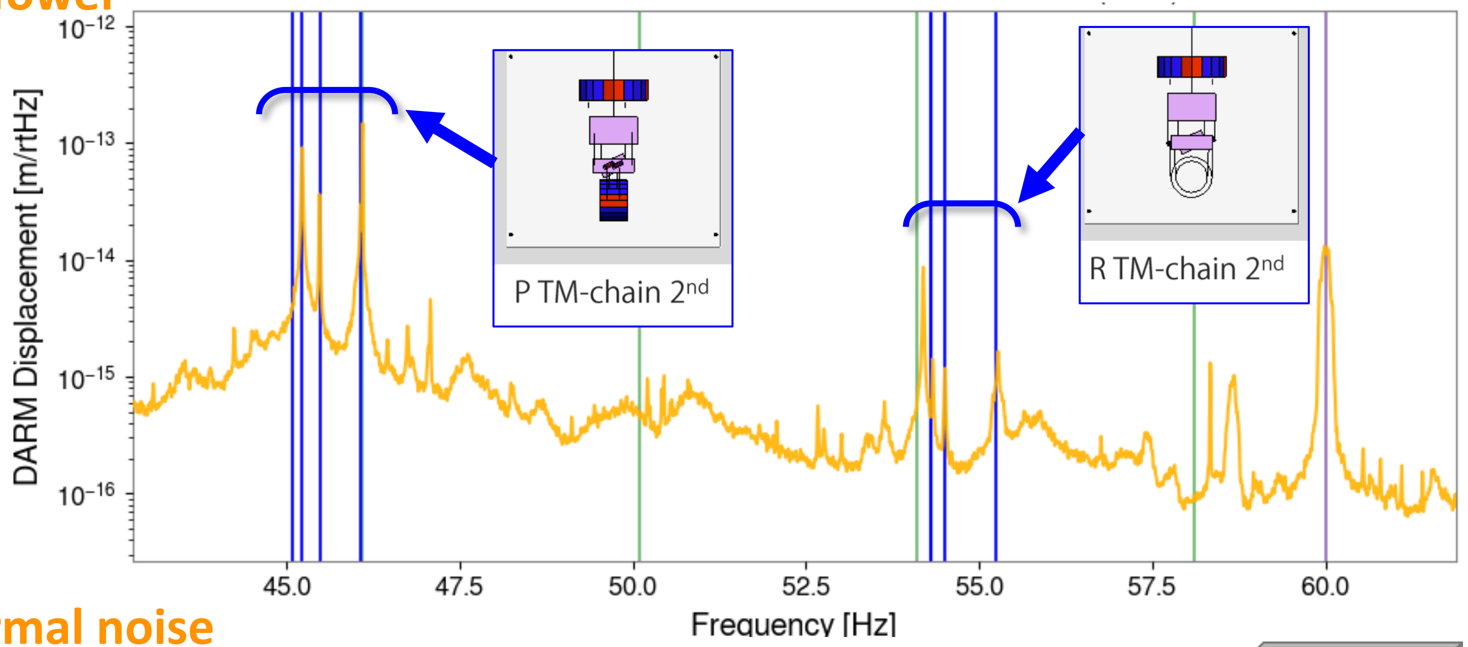
- Line Noise



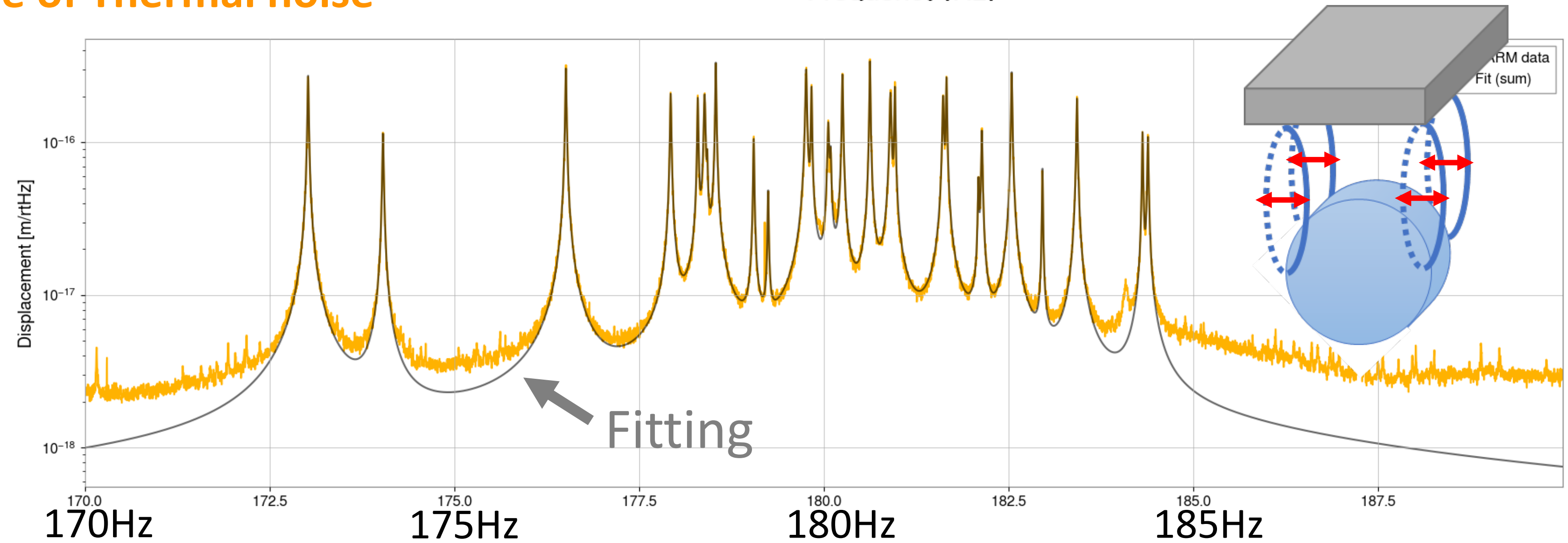
Identified Lines	Know (injected) Lines
Violin modes of suspensions	Alignment Dither System (ADS)
Other Type-A eigenmodes	Beam Position Centering (BPC)
AC power line	DARM Calibration (CAL)
	Feed Forward of PRCL/MICH (MICH FF, PRCL FF)

- # Line Noise of VIS Eigenmodes

Type-A Suspension Tower



Violin mode of Thermal noise



Summary

- We evaluated noise contributions on the KAGRA sensitivity during O3GK

- Now almost all dominant noise sources are understood
  - Remaining noise sources
    - Frequency noise
    - TypeB control noise
    - OMC dark noise (minor modification necessary)

- Next step is writing a paper. Target journal is Progress of Theoretical and Experimental Physics (PTEP)