Ground-based gravitational-wave detector KAGRA –status and future prospects-

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Sources of GWs

New eyes to observe the Universe

K. Kokeyama JGW-G1808116

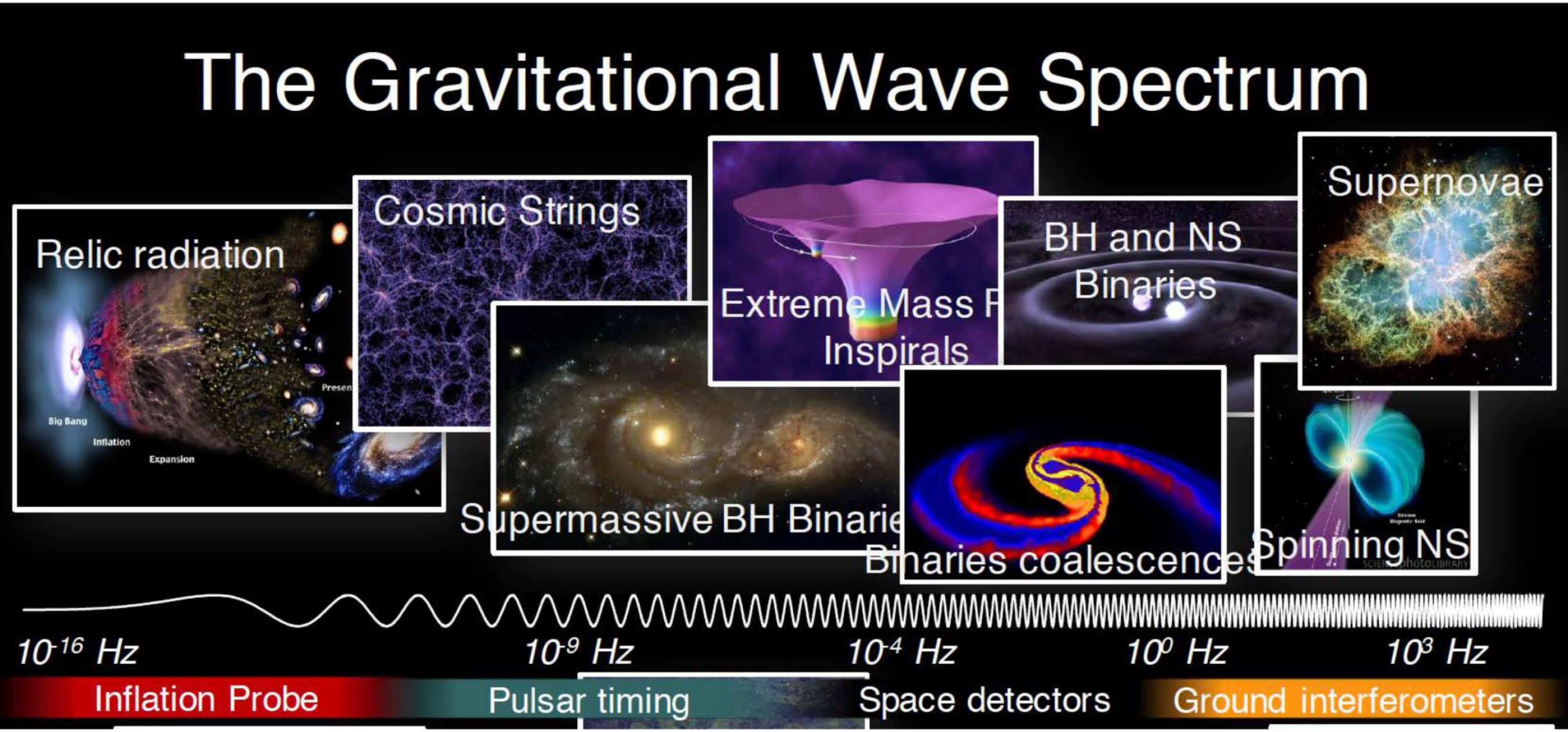


Figure: M Evans

Target GW bands for laser interferometry

Currently GWs above 10 Hz can be detected by LIGO and Virgo.

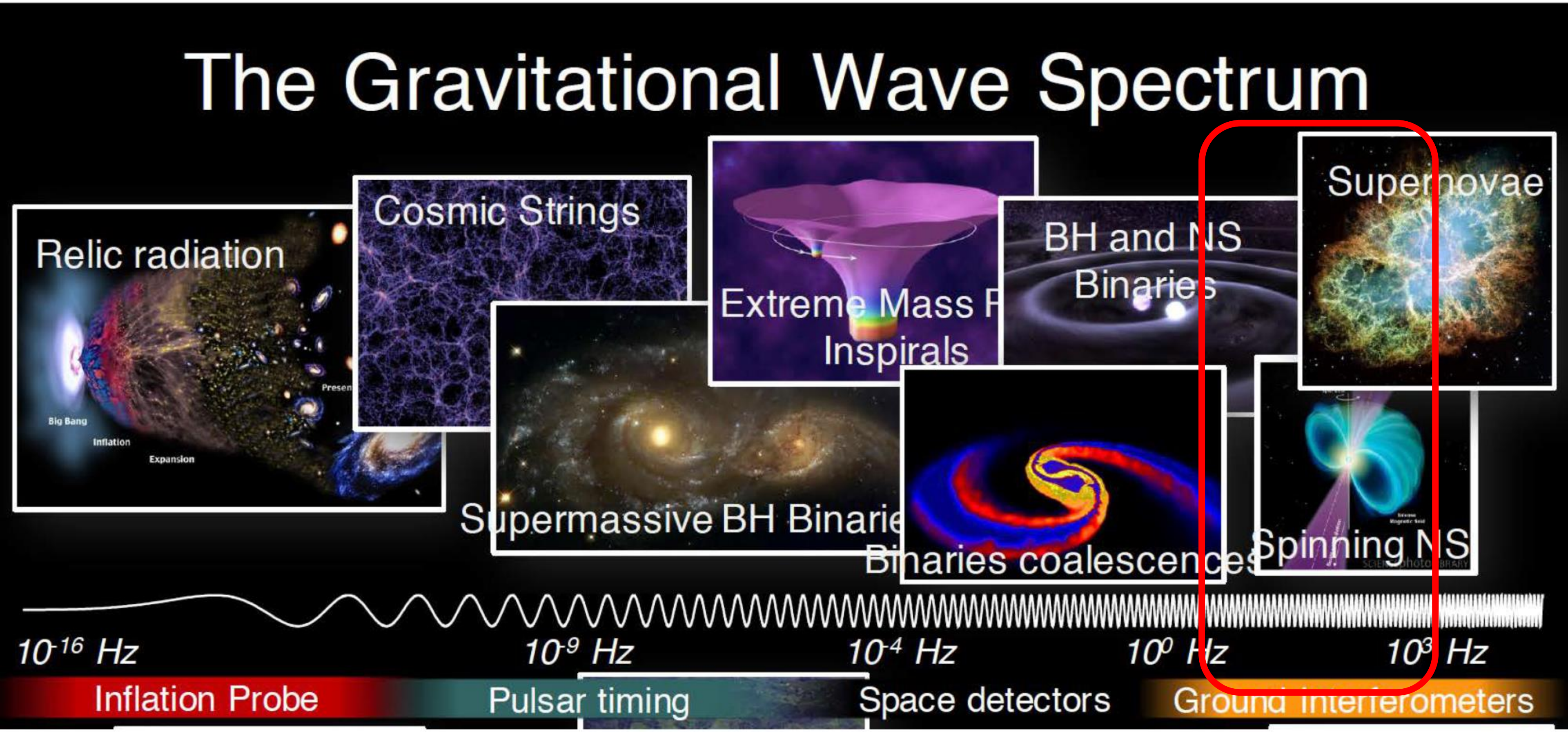


Figure: M Evans

Next generation GWDs and space GWDs will expand the window of GWs

How can we detect GW signals?

- Initially, it was thought too faint to ever be useful.

  → Predicted amplitude is about 10^{-21} in 1960s to 1970s.

- In 1960s to 1970s, we changed our mind:
  it's so faint but measurable.
- We need just considering how to measure changes of distance of 10^{-18} m between two objects several kilometers apart.

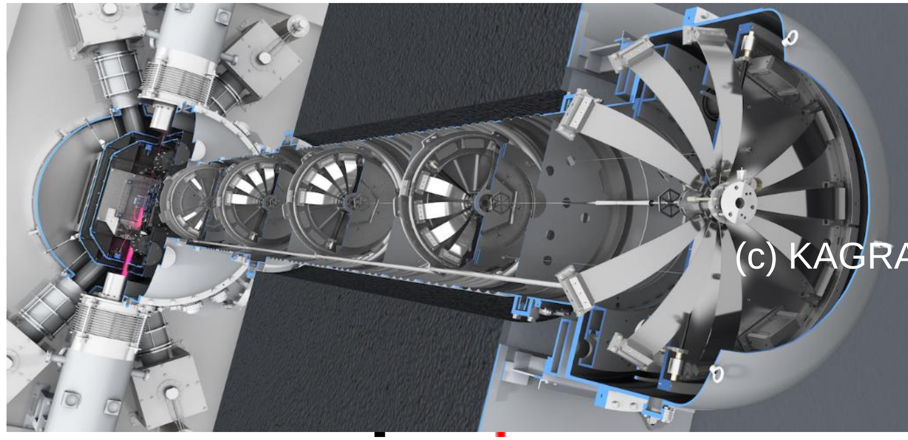
- Finally, we decided to use a laser interferometer based on Michelson interferometer to detect the tiny displacement.

  —Reduce any disturbances causing larger than 10^{-18} m displacement.

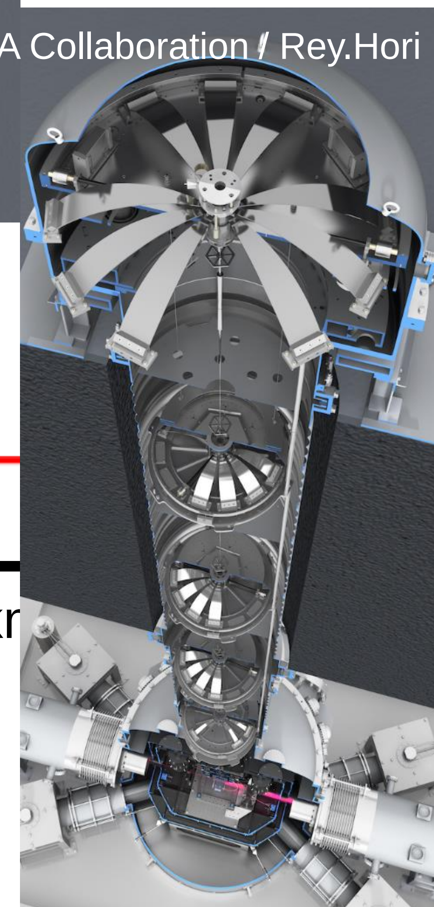
  —Reduce noises accompanying with sensing the displacement.

How to reduce disturbances?

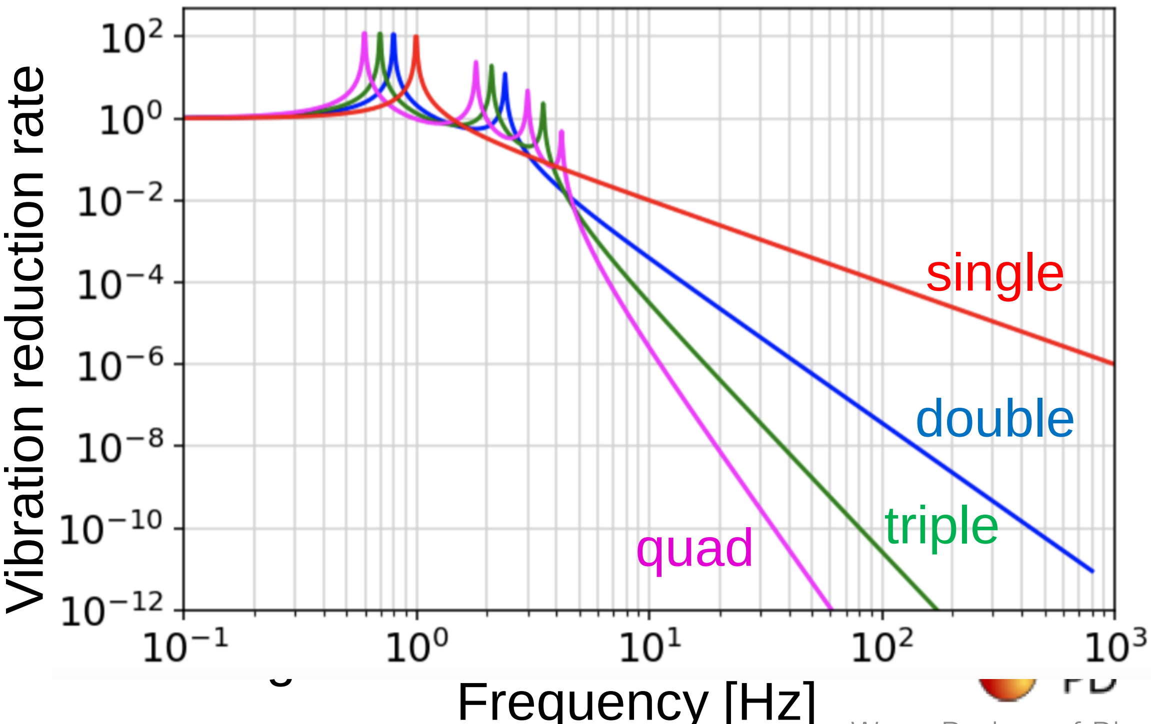
Passive vibration isolation stages



(c) KAGRA Collaboration / Rey.Hori



M. Tamaki
JGW-G2214541-v6

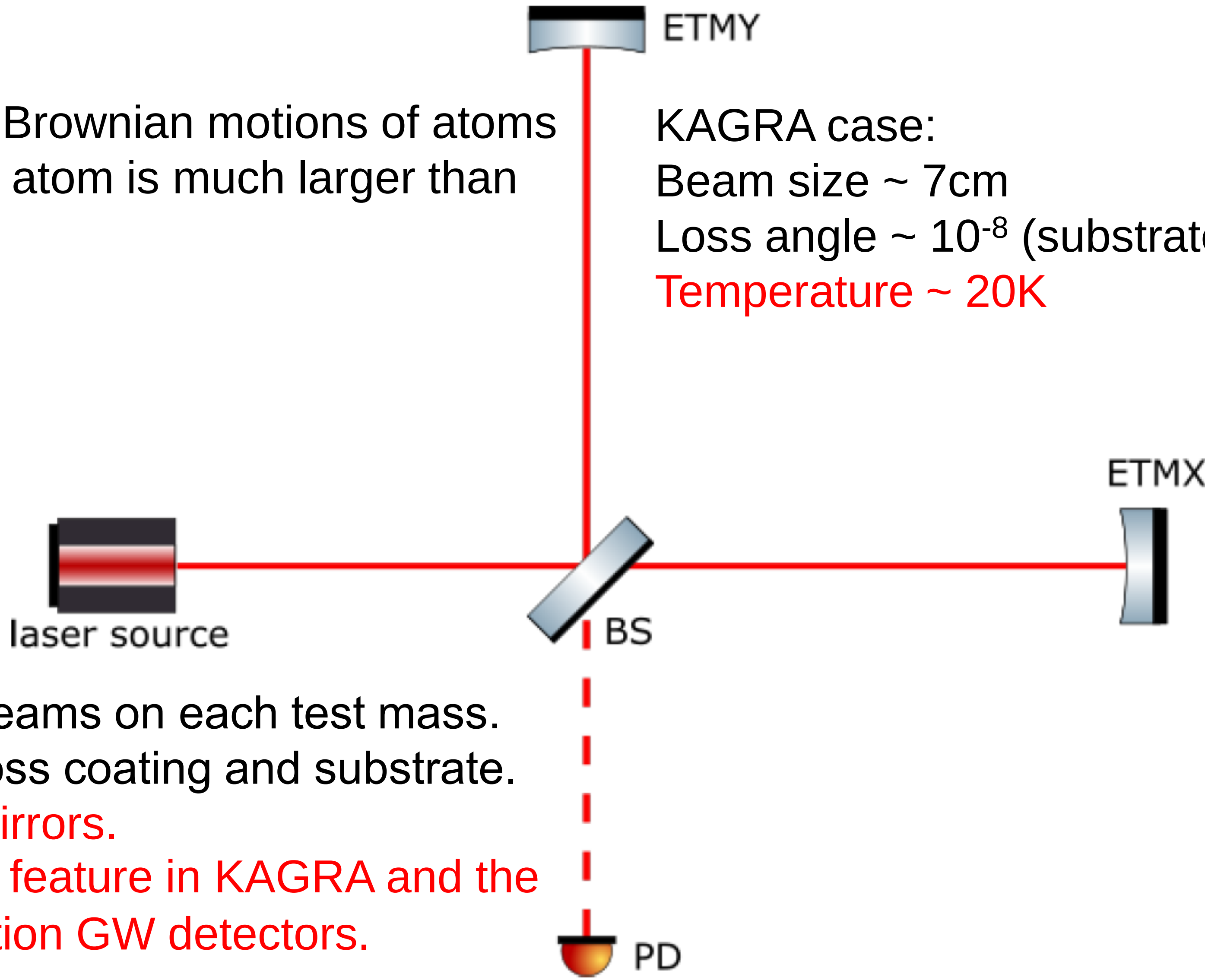


~3 kr

How to reduce disturbances?

Thermal noise:Brownian motions of atoms
Motion of each atom is much larger than our target.

KAGRA case:
Beam size ~ 7cm
Loss angle ~ 10^{-8} (substrate)
Temperature ~ 20K



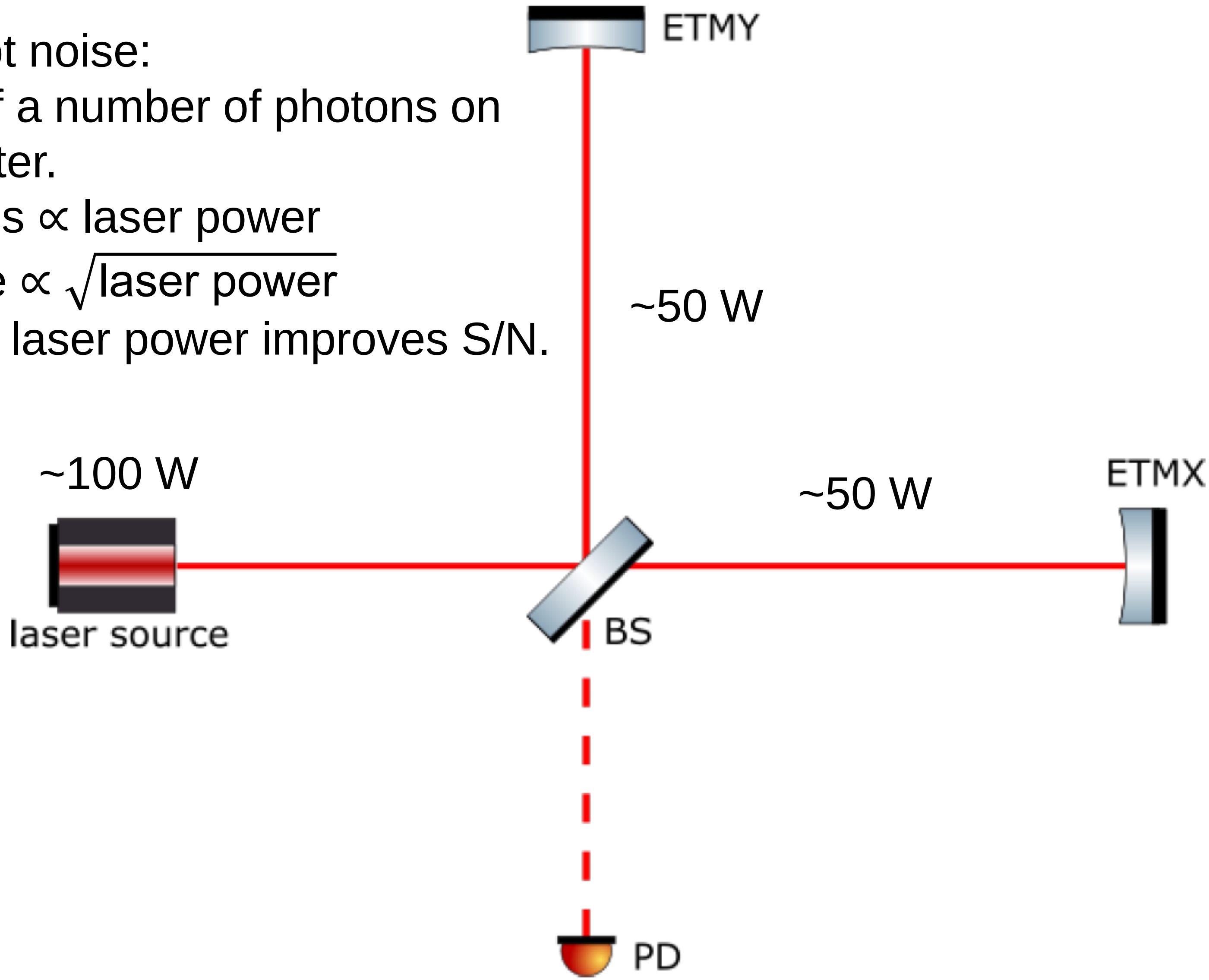
—Enlarge beams on each test mass.
—Use low loss coating and substrate.
—Cooling mirrors.
→ Unique feature in KAGRA and the next generation GW detectors.

How to reduce sensing noise?

Quantum shot noise:
Fluctuation of a number of photons on the photodecter.

- GW signals $\propto$ laser power
- Shot noise $\propto \sqrt{\text{laser power}}$

→ Increasing laser power improves S/N.



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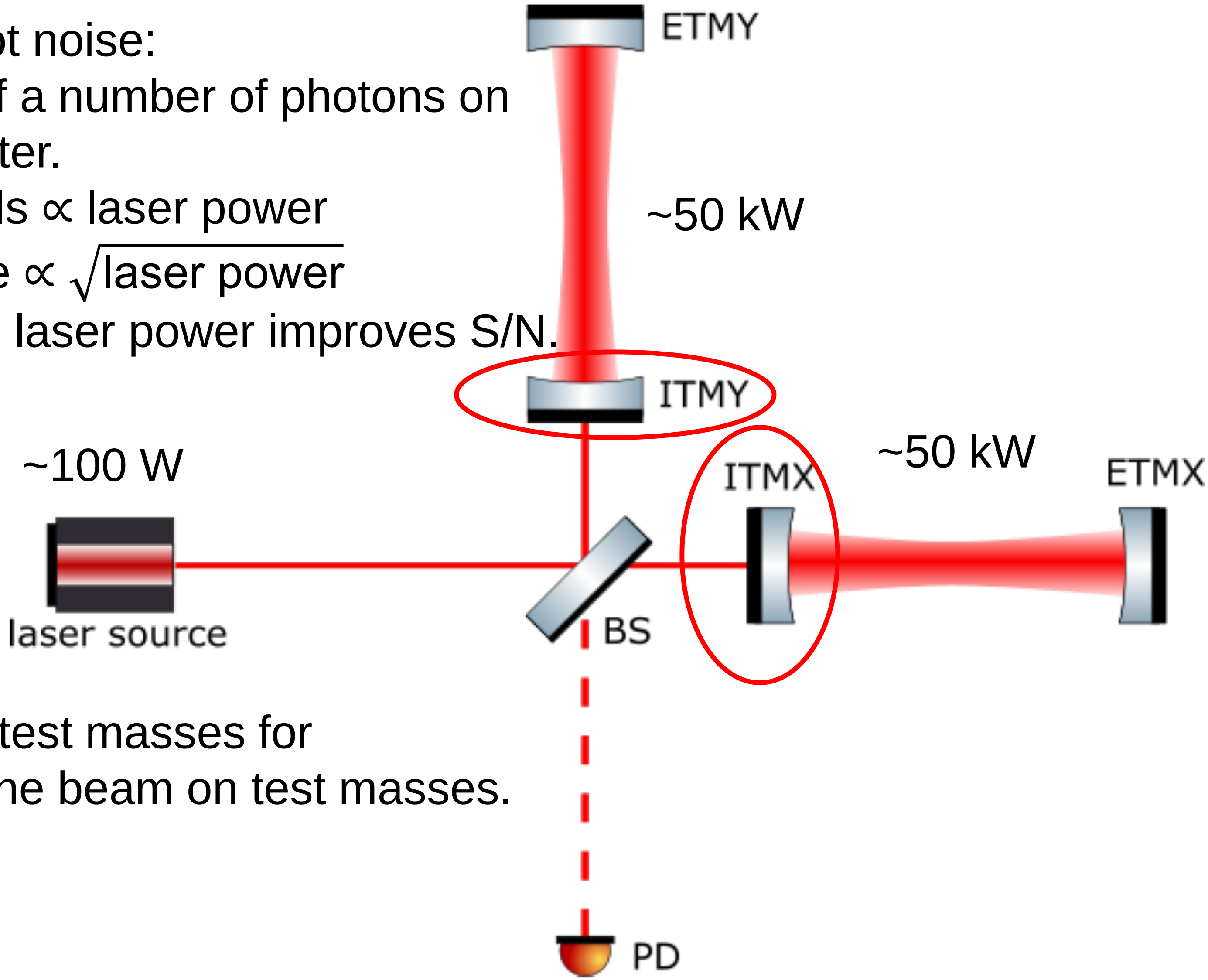

Insert input test masses for increasing the beam on test masses.

How to reduce sensing noise?

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Fluctuation of a number of photons on the photodecter.

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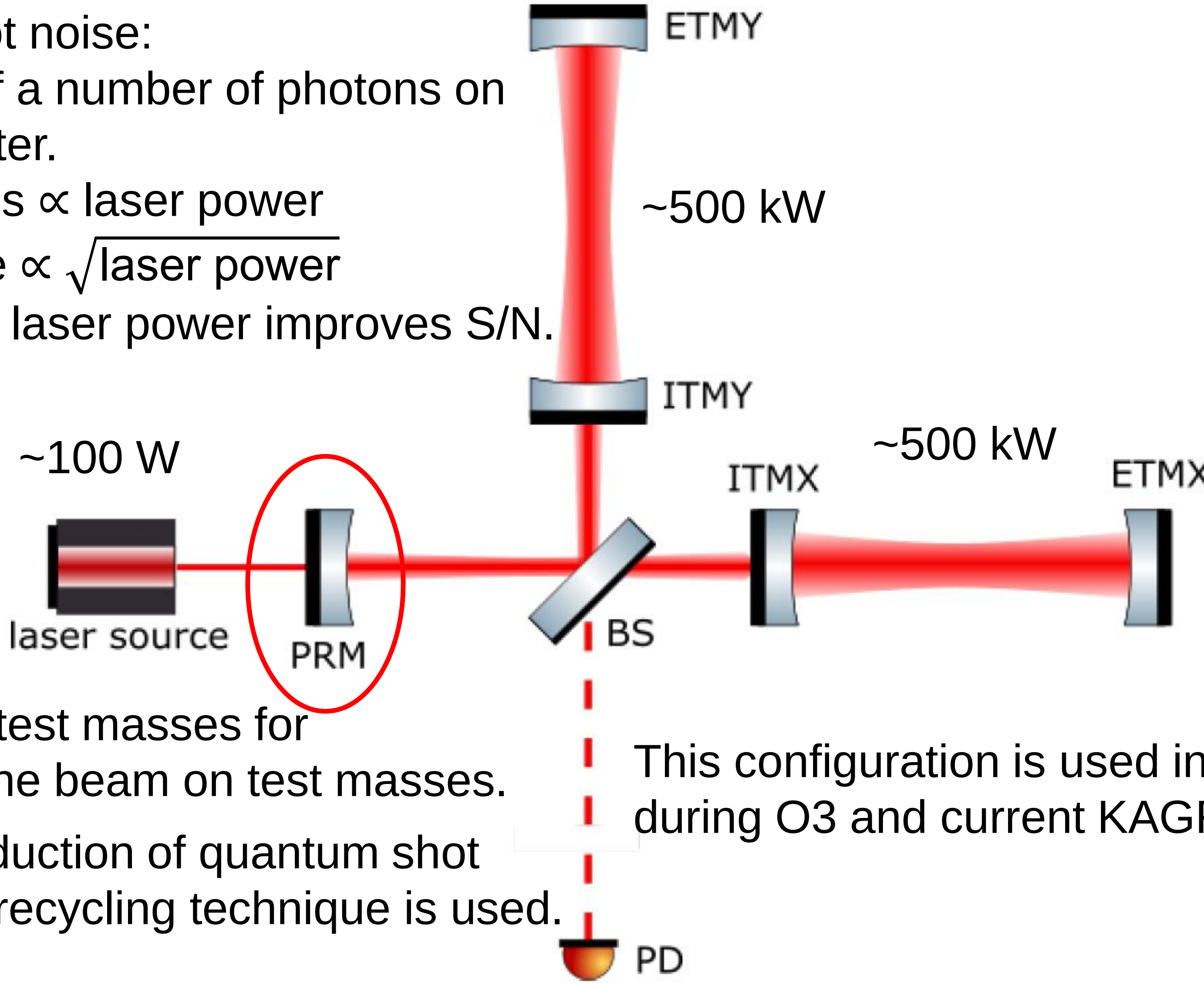


Insert input test masses for increasing the beam on test masses.

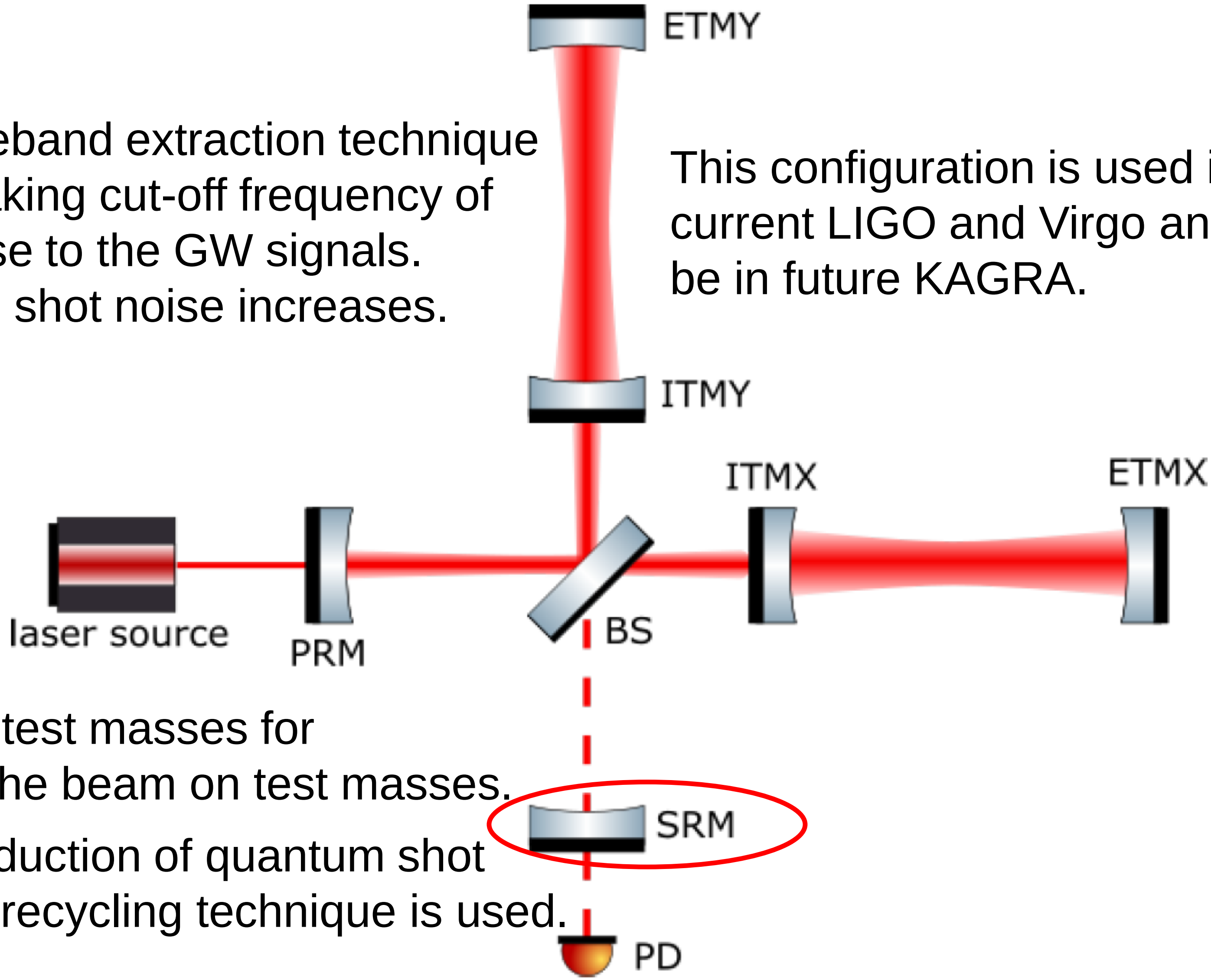
For further reduction of quantum shot noise, power-recycling technique is used.

This configuration is used in Virgo during O3 and current KAGRA.

How to reduce sensing noise?

Resonant-sideband extraction technique is used for making cut-off frequency of cavity response to the GW signals.
→ S/N ratio to shot noise increases.

This configuration is used in current LIGO and Virgo and will be in future KAGRA.



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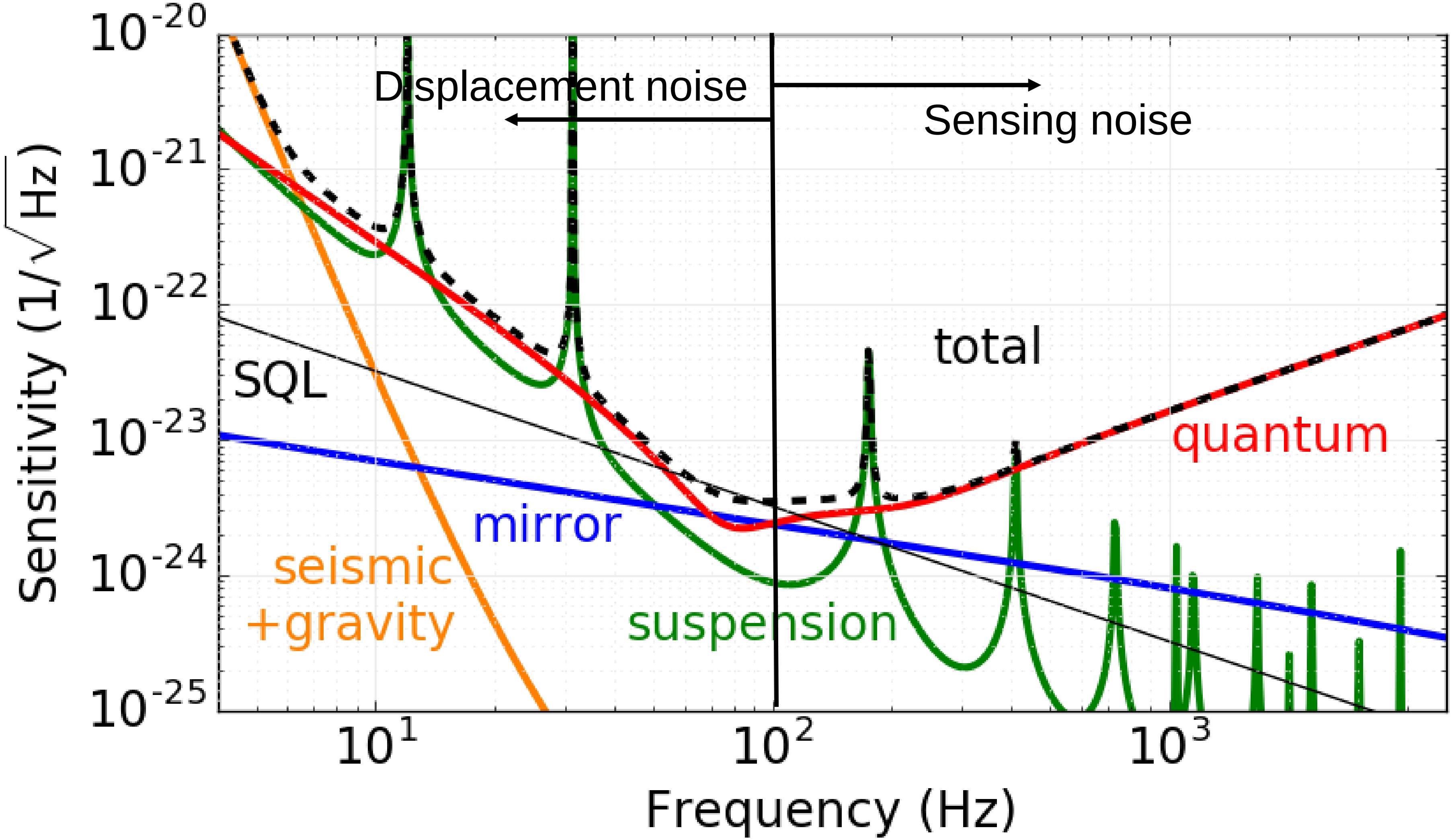
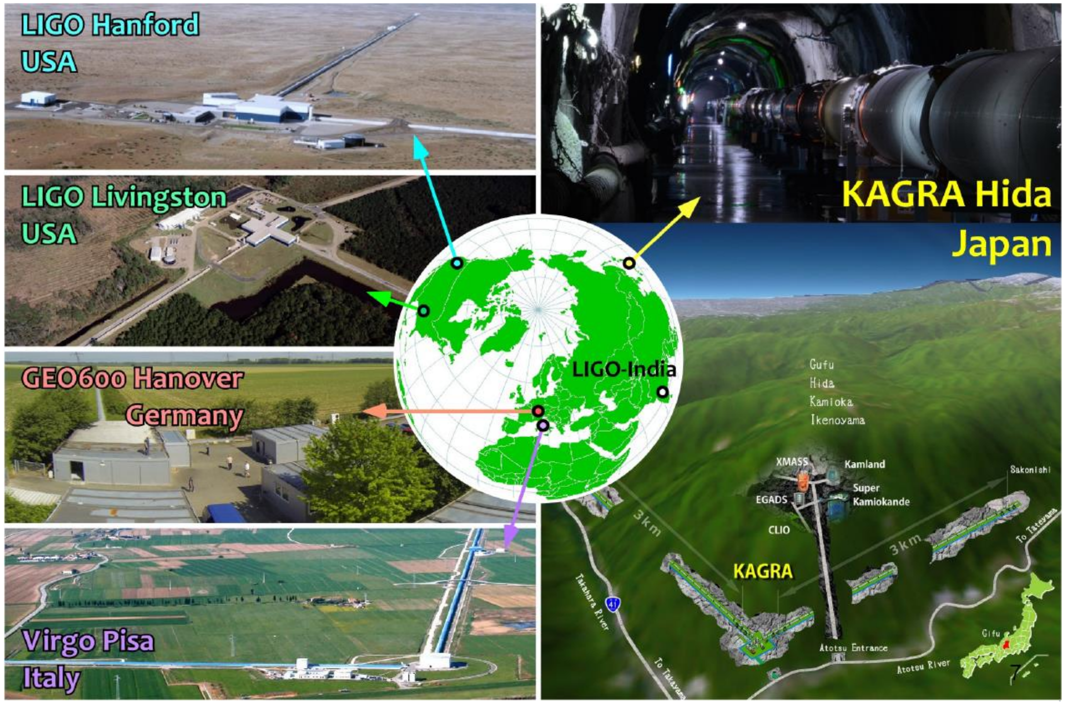
Design sensitivity of KAGRA



High and low frequency sensitivity is limited by disturbances and sensing noise, respectively

Global network and multi-messenger astronomy



- 90 confident events in O1-O3.
- One successful follow-up observation: GW170817

— GW, short GRB, and afterglow

— Counterpart was identified.

— Standard siren etc.

- Multiple-detector observation is essential for:

— better localization

— better duty cycle

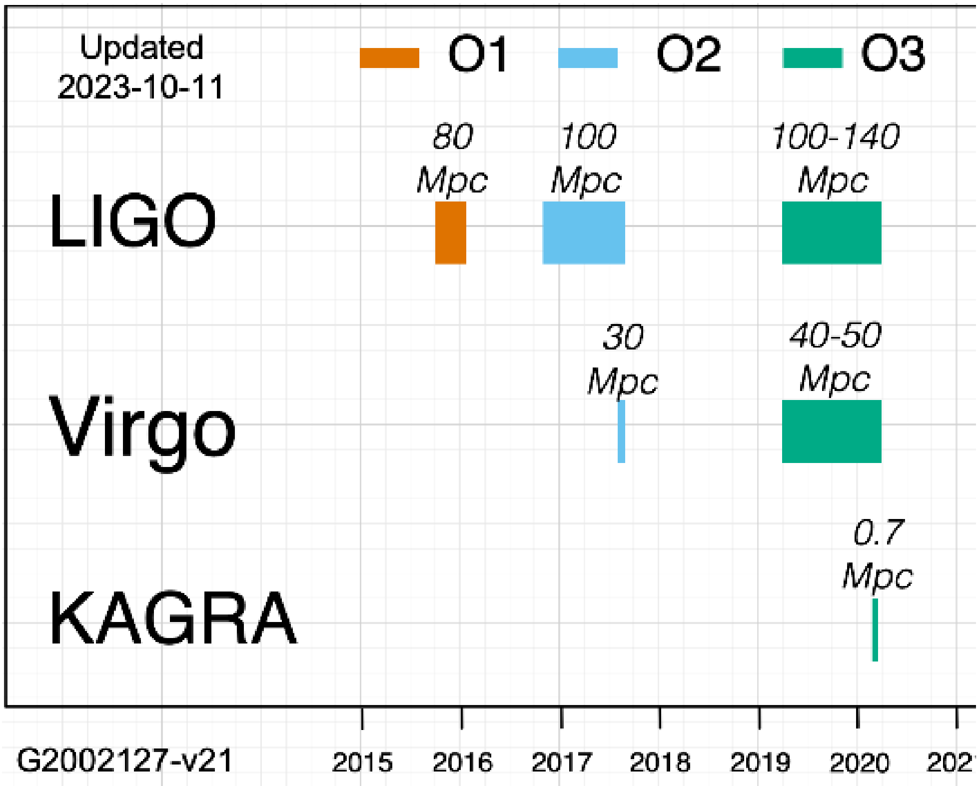
Network duty factor during O3

[1256655618-1269363618]

- Triple interferometer [51.1%]
- Double interferometer [34.3%]
- Single interferometer [11.3%]
- No interferometer [3.4%]

- Increase of the number of detectors are important.

Past observing run



1st Observing Run (O1)
2015 Sep. – 2016 Jan.

- 2 LIGO detectors
- GW150914:
  First detection of BBH merger.

2nd Observing Run (O2)
2016 Nov. – 2017 Aug.

- 2 LIGO and Virgo (in Aug.)
- GW170814:
  First detection with 3 detectors.
- GW170817:
  First detection of BNS coalescence.
  Multi-messenger astronomy

3rd Observing Run (O3):
2019 Apr. – 2020 Mar. (O3a and O3b)

- 2 LIGO and Virgo detectors
- GW200105:
  First detection of NS-BH merger.

2020 Apr. (O3GK)

- KAGRA and GEO600

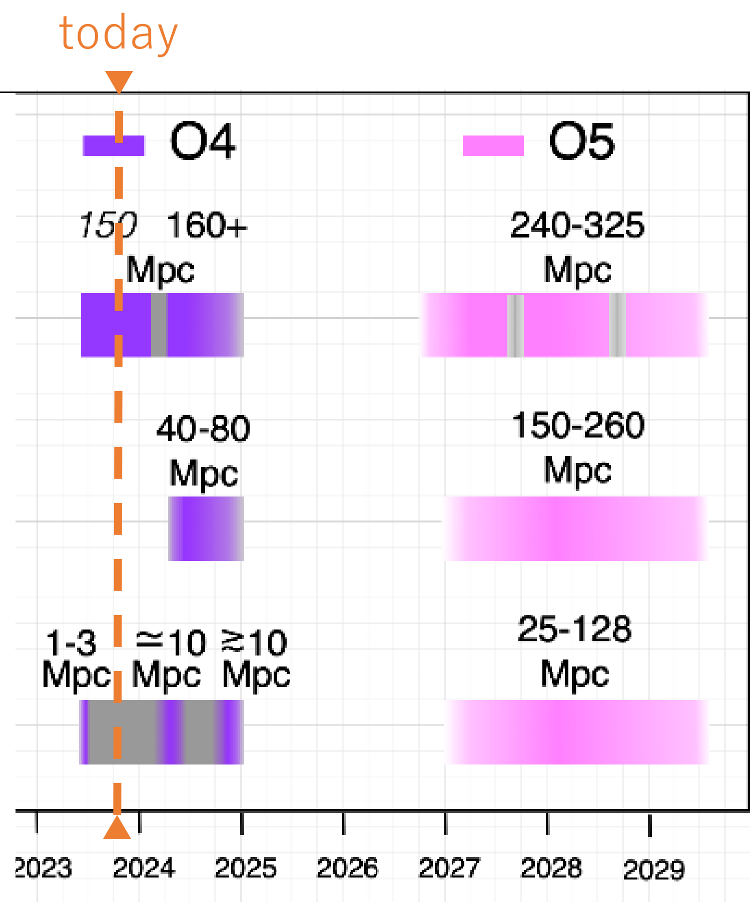
Current and Future observing Run

4th Observing Run (O4)
2023 May. – 2025 Jan.

- 2 LIGO and KAGRA detectors started O4a run.
- KAGRA stopped O4a to improve sensitivity.
- LIGO continues observing run.
- Virgo and KAGRA plan to start the observing run from March and spring in 2024, respectively.

5th Observing Run (O5)

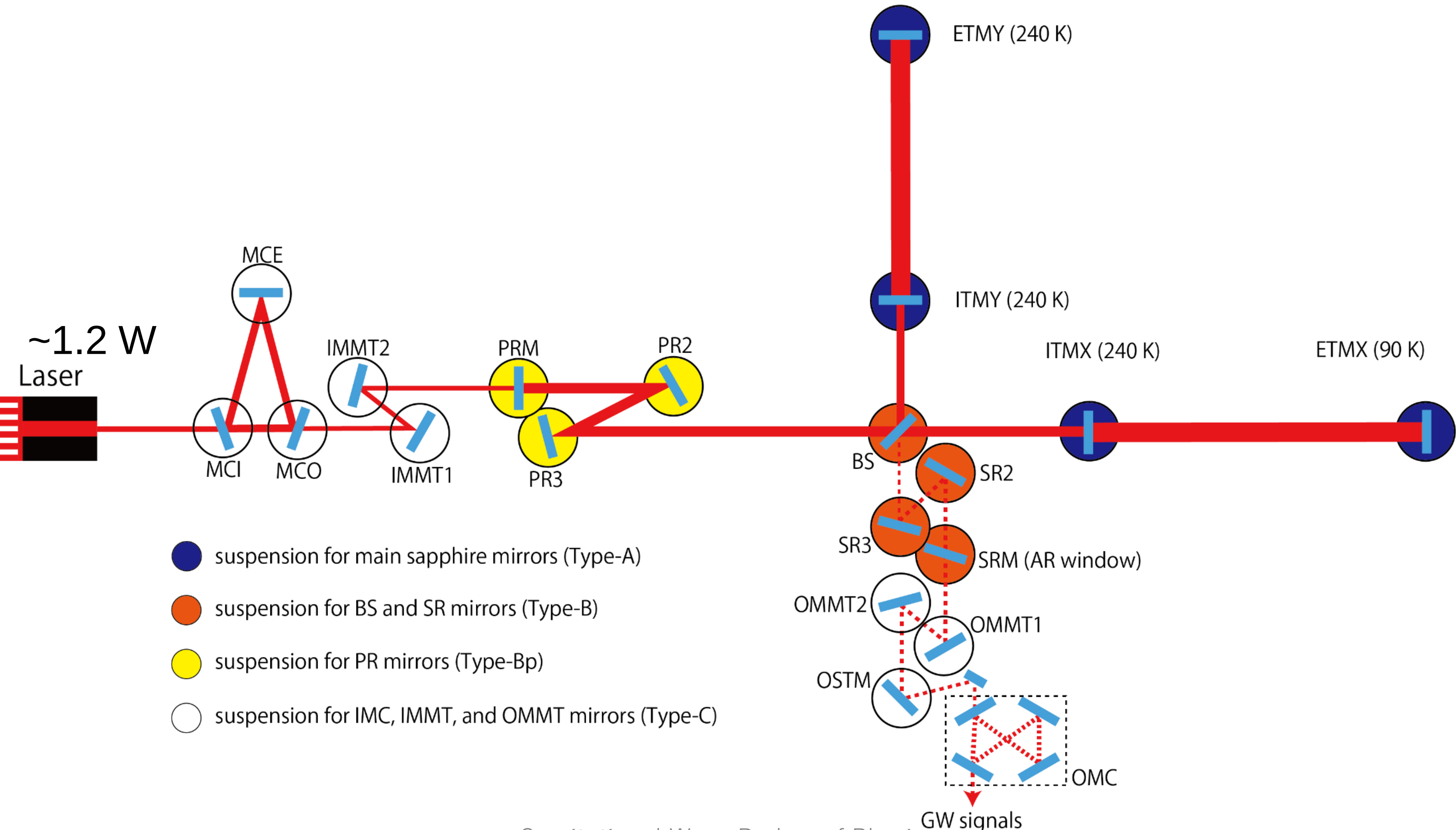
- Starting time has not been decided yet.
- Detail term has also not been decided.



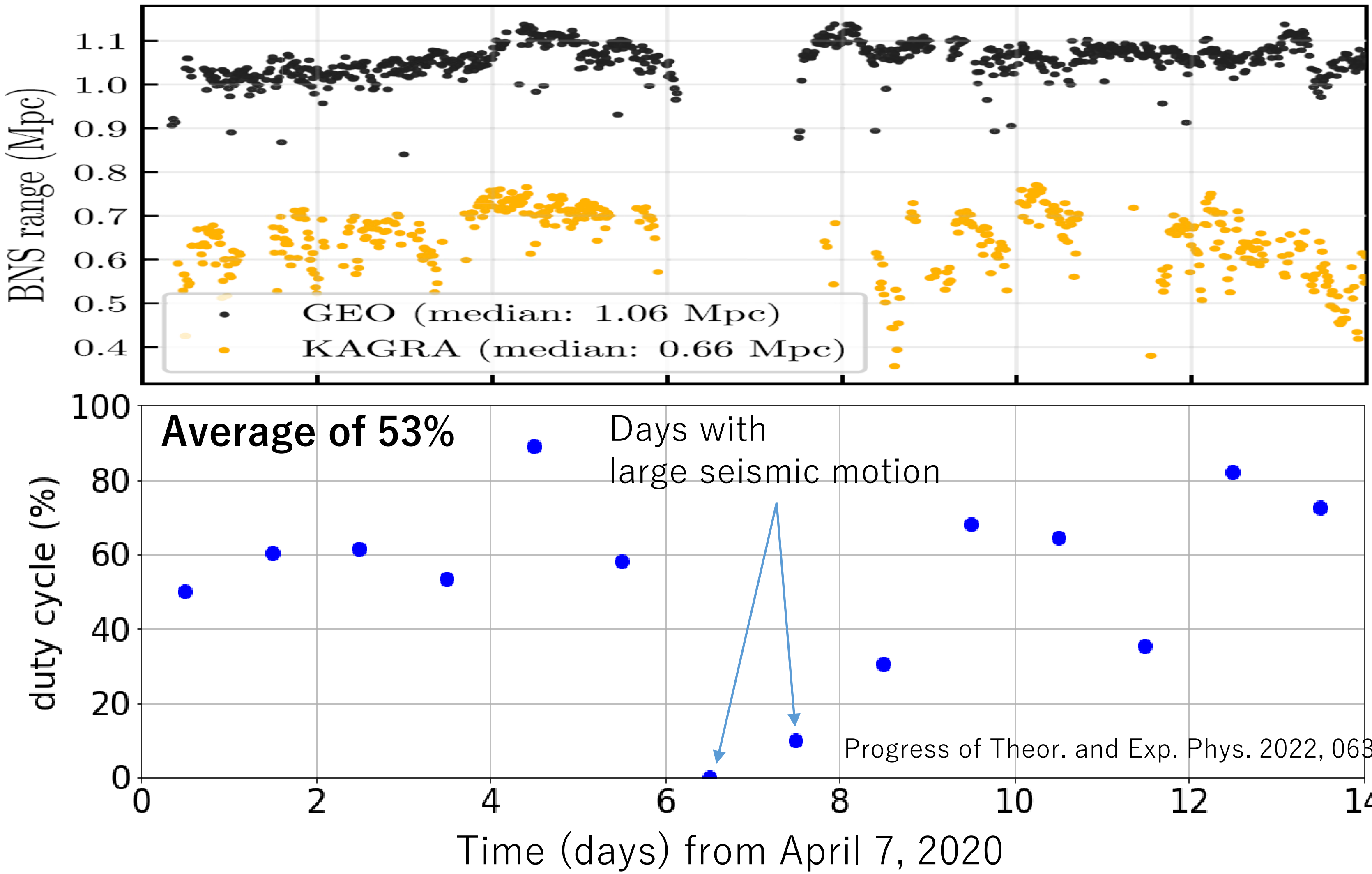
KAGRA

KAGRA: Current detector configuration

Partially cooled Power Recycling Fabry Perot Michelson Interferometer (PRFPMI)



Status of previous observing run (O3GK)

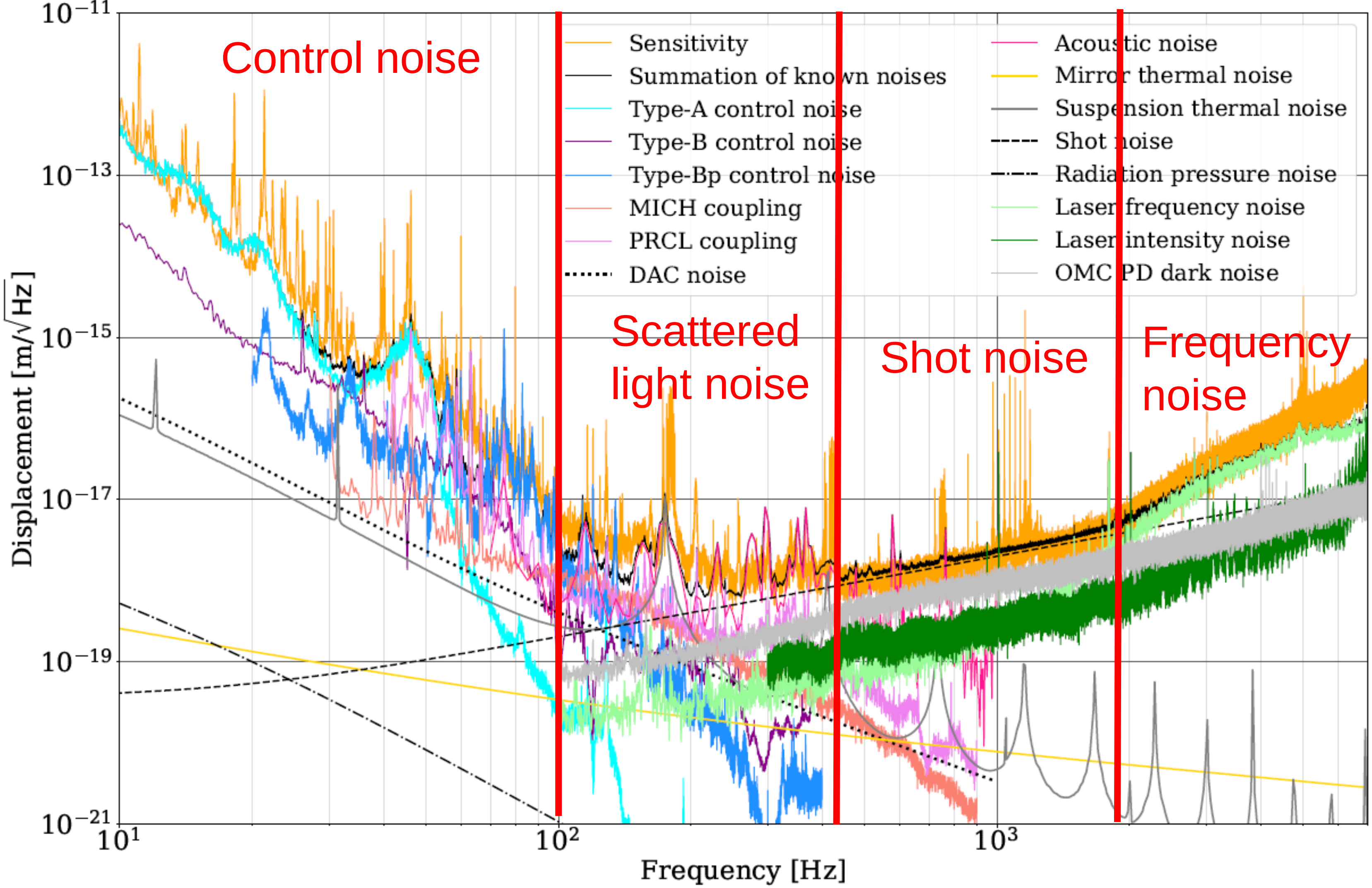


Progress of Theor. and Exp. Phys. 2022, 063F01 (2022)

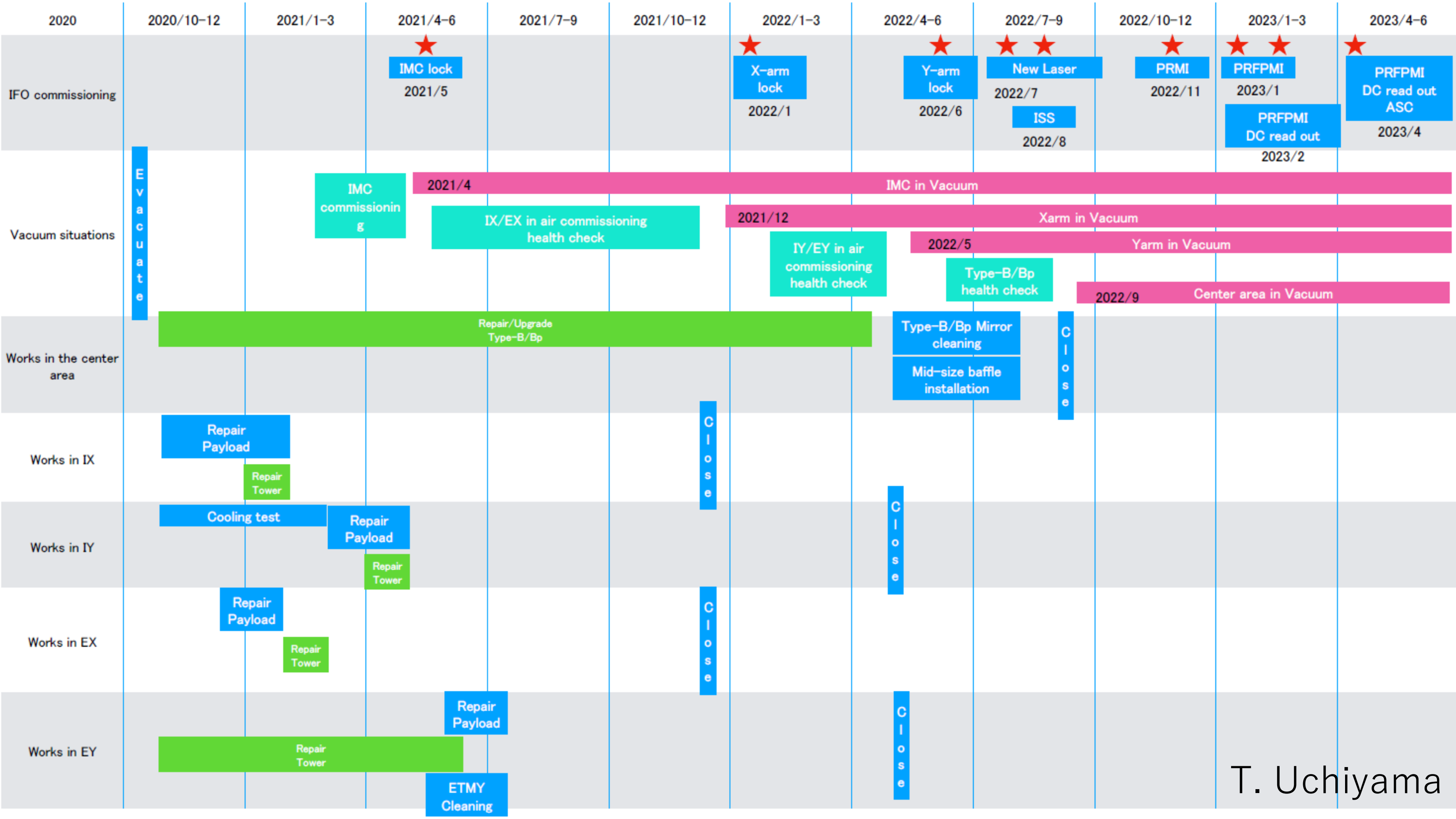
Not only sensitivity but also stability improvement is important.

Noise budget during O3GK

KAGRA Collaboration, 2023, PTEP **2023**, 10A101

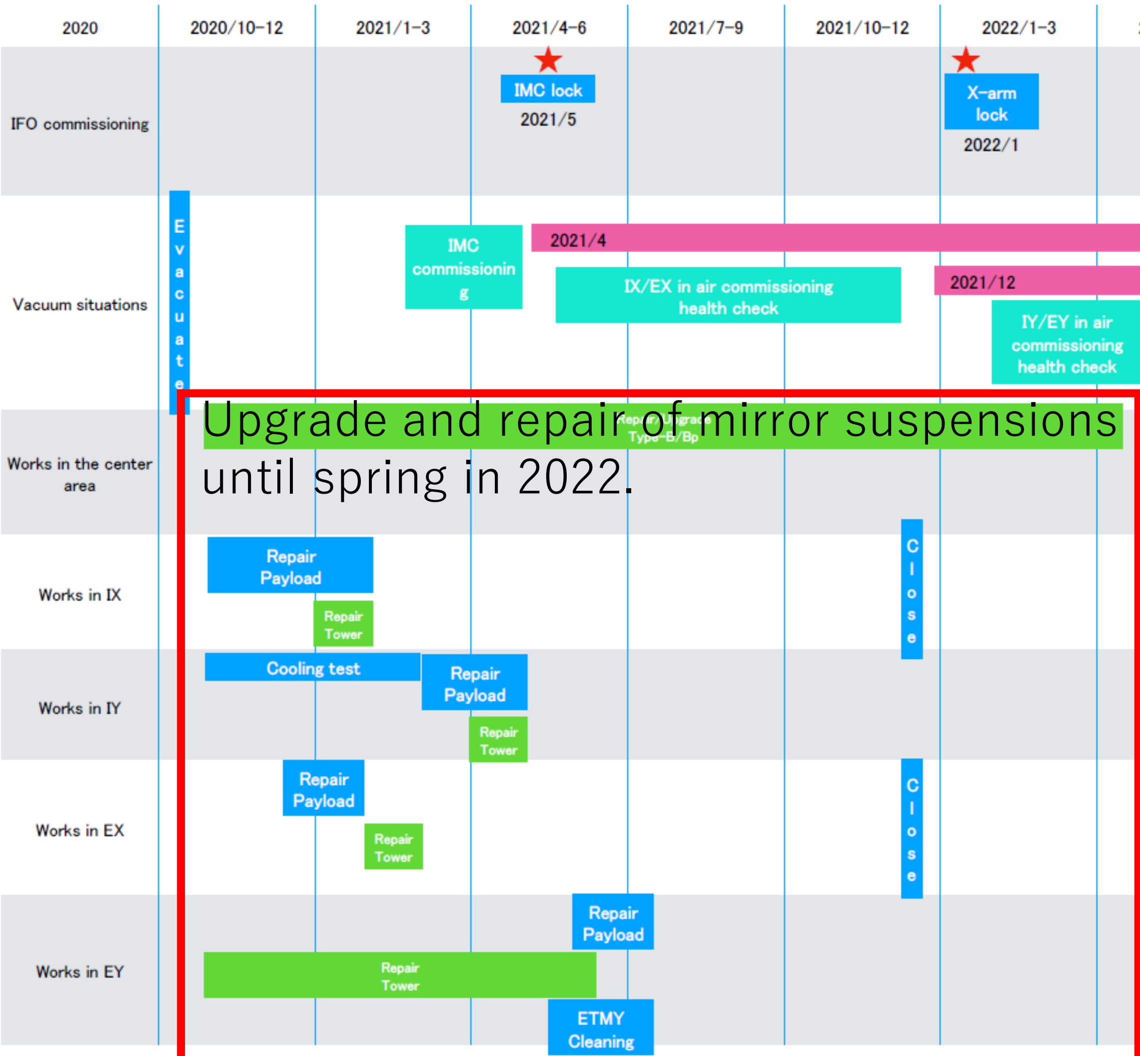


Our 3 years after O3GK

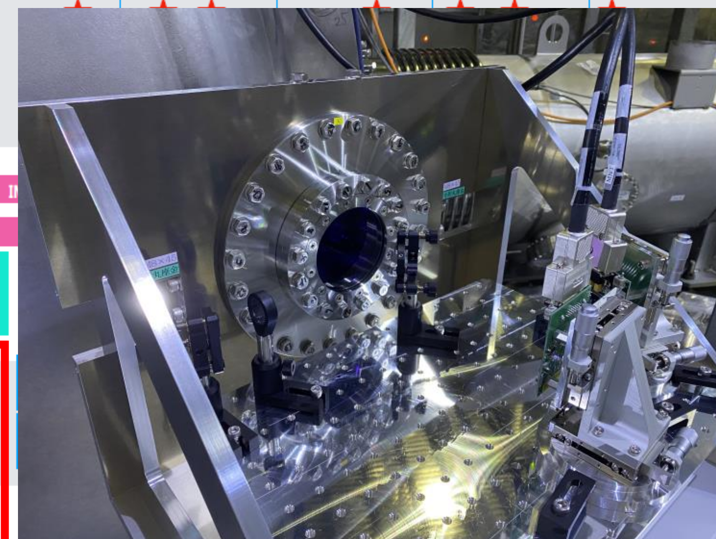


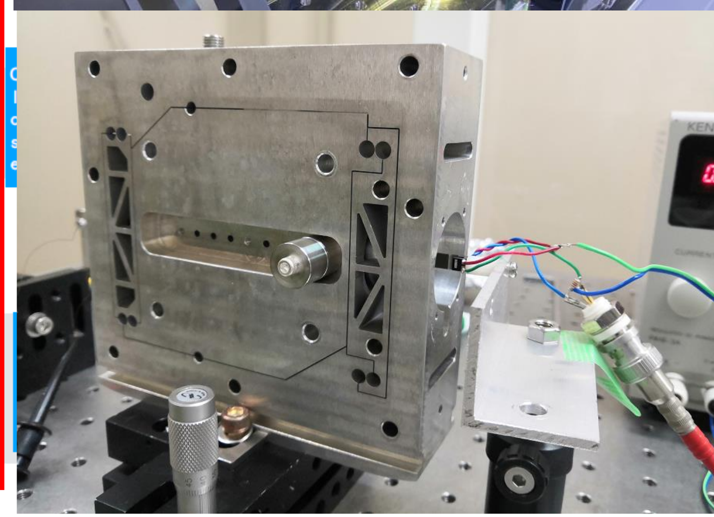
T. Uchiyama

VIS repair and upgrade for low freq.

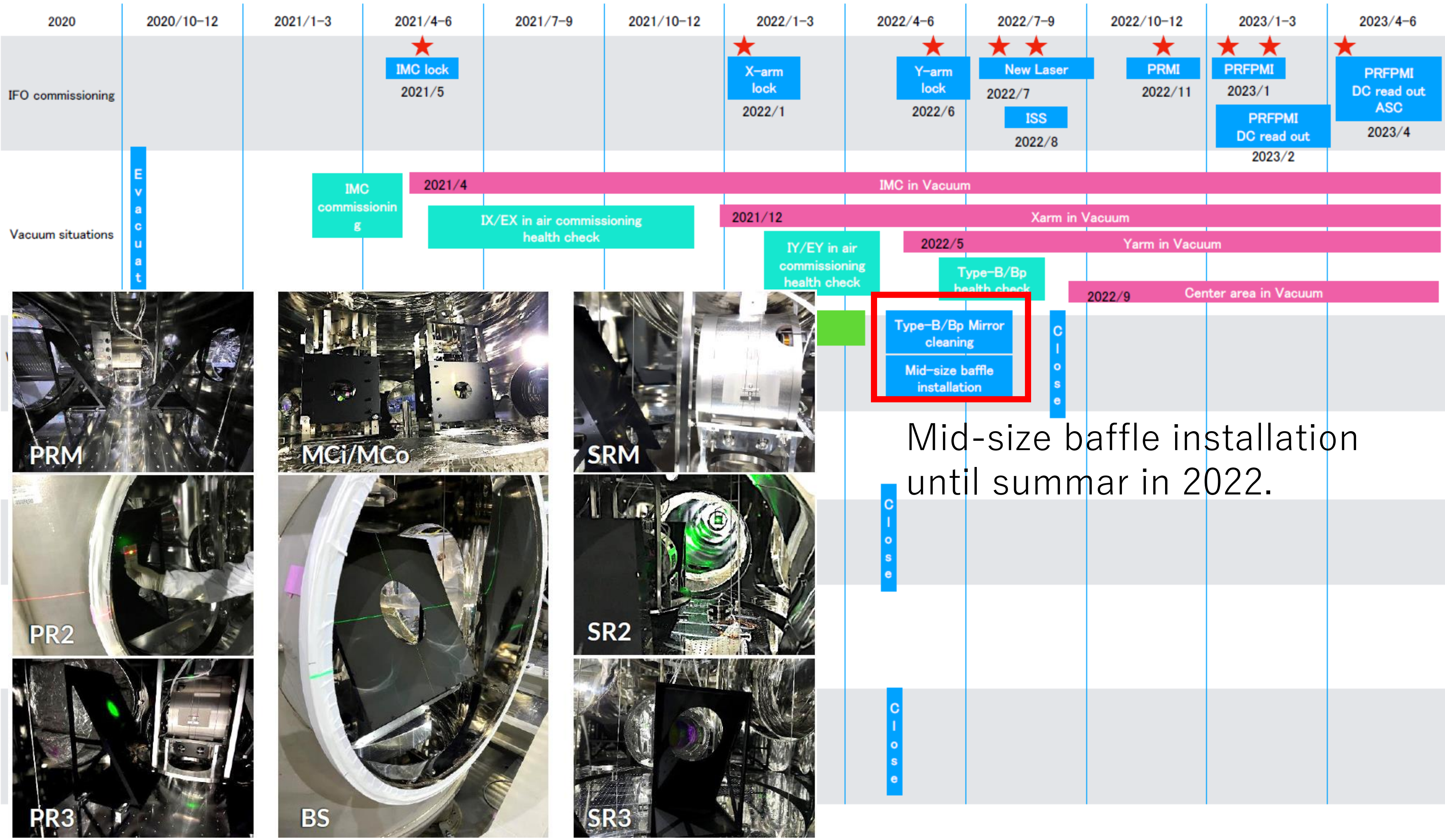


Upgrade and repair of mirror suspensions until spring in 2022.





Baffle installation for mid. freq.



Mid-size baffle installation until summar in 2022.

Several achievement on commissioning

T. Akutsu JGW-G2314966

Better stability

Local damping improvement

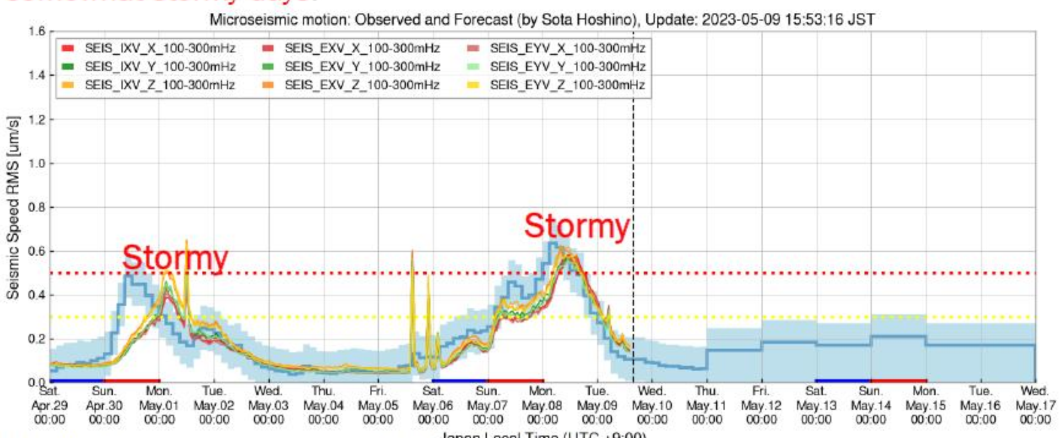
- Now PRFPMI can be maintained even in somewhat stormy days.

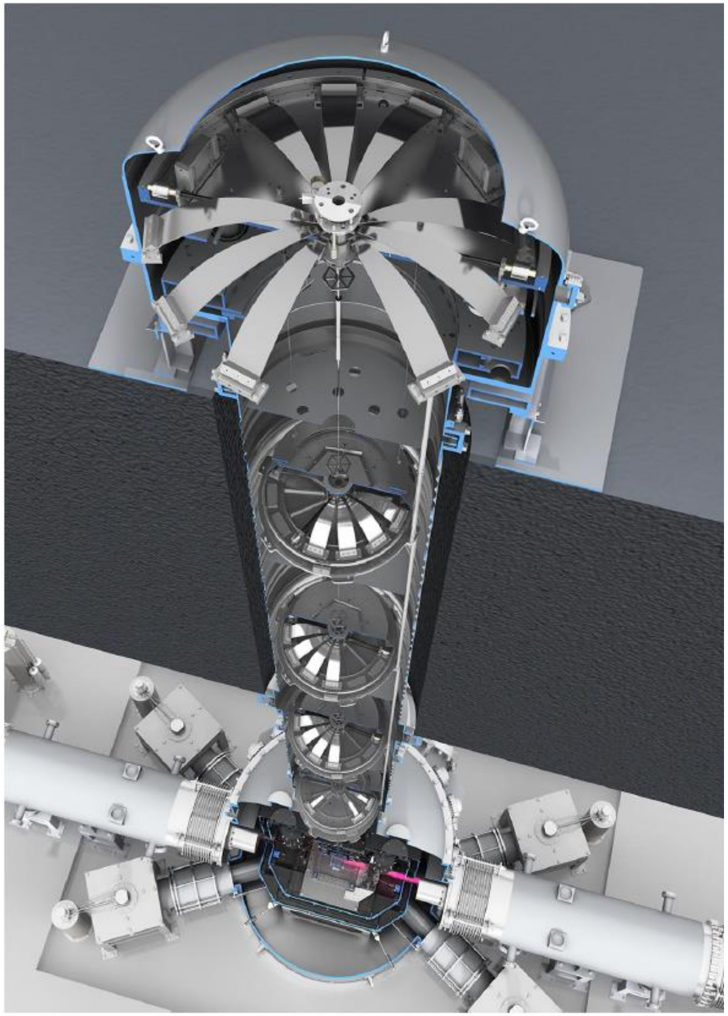
Alignment-sensing and control (ASC)

- Took time for wave-front sensing (WFS) in a strategic way; now WFS can be implemented for some global DoFs; drastically improved the contrast fluctuation.
- In addition, some noise structures and noise floor got better in the sensitivity curve.

Doppler phase noise cancellation

- For auxiliary green laser paths; now stable lock acquisition is possible even in somewhat stormy days.





GWADW (May 22-26, 2023, Isola d'Elba, Italy)

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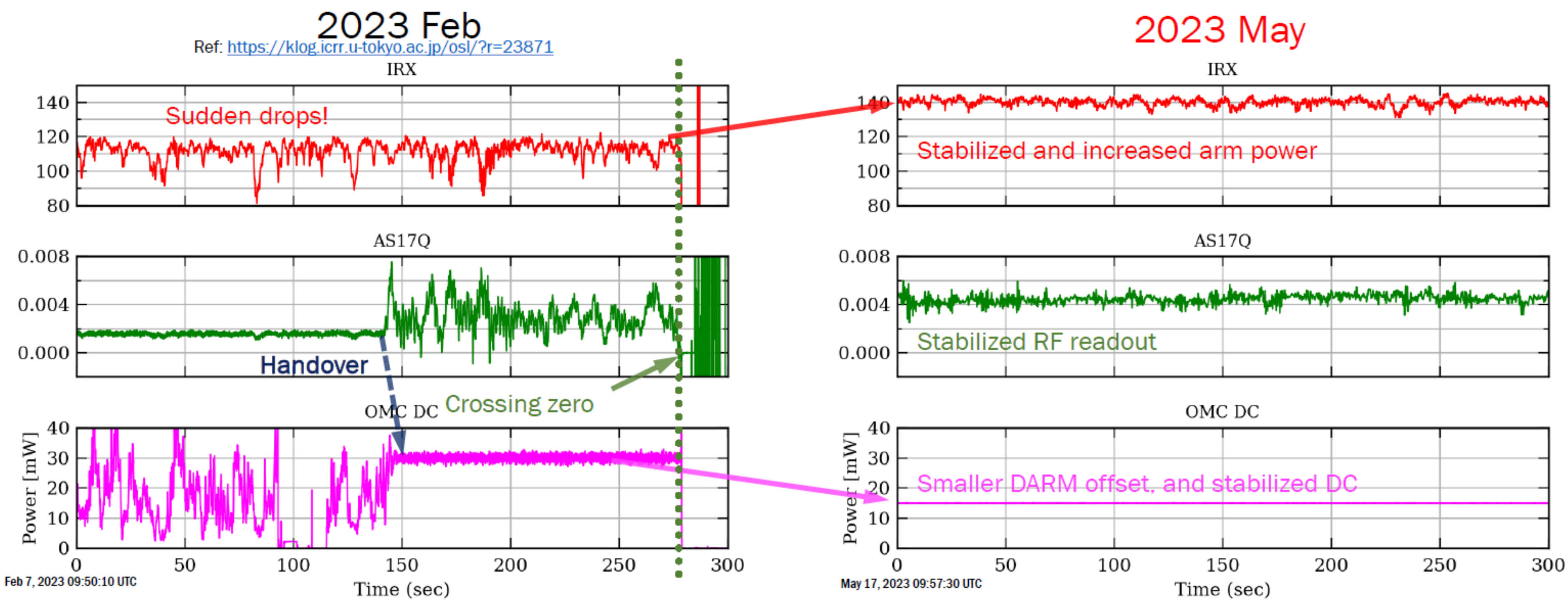
Several achievement on commissioning

T. Akutsu JGW-G2314966

Alignment sensing and control



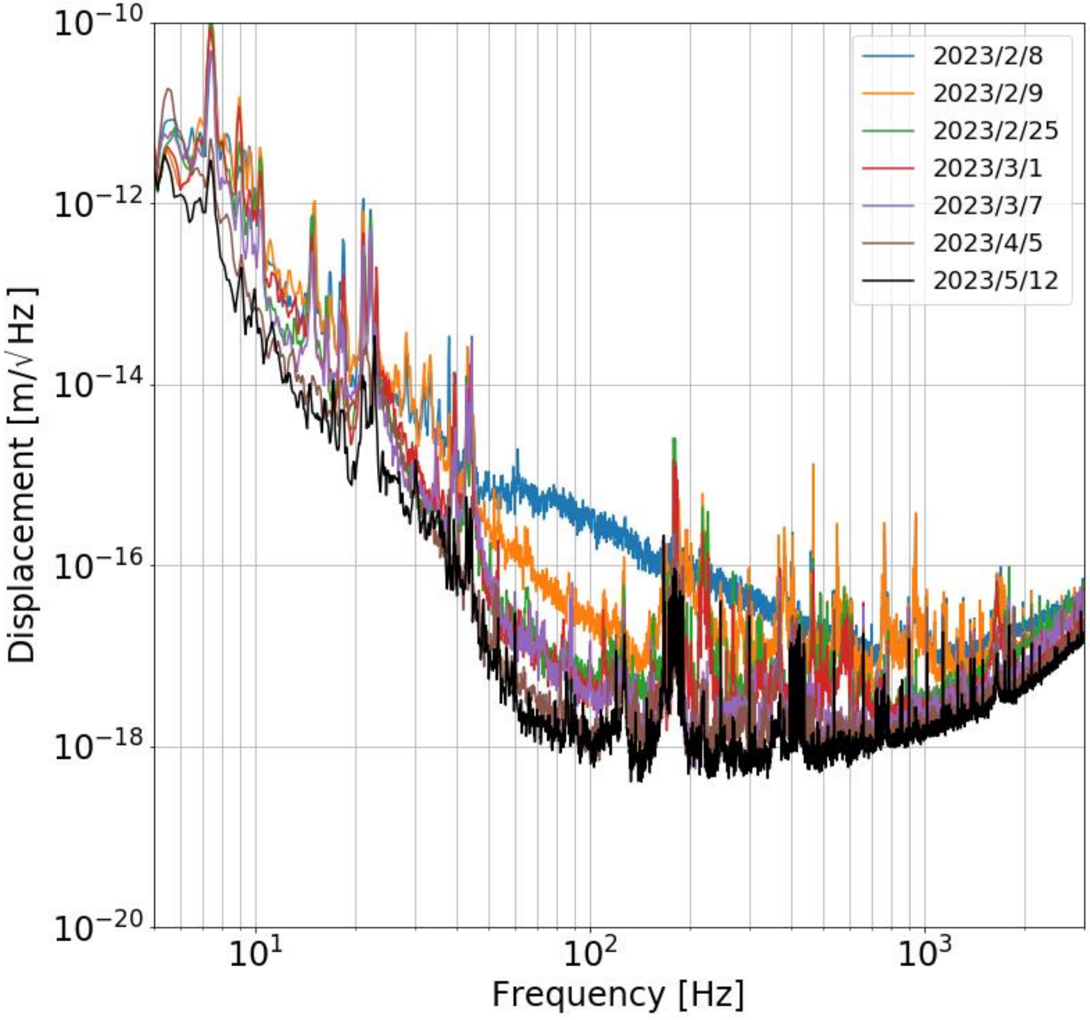
Data access via pastavi

- Internal laser power is drastically stabilized; and increased.
- Better AS contrast allows to do handover with smaller DARM offset.

→ Now ready to increase the input power from 1 W for O4b!

GWADW (May 22-26, 2023, Isola d'Elba, Italy) 14

Sensitivity history during O4 commissioning

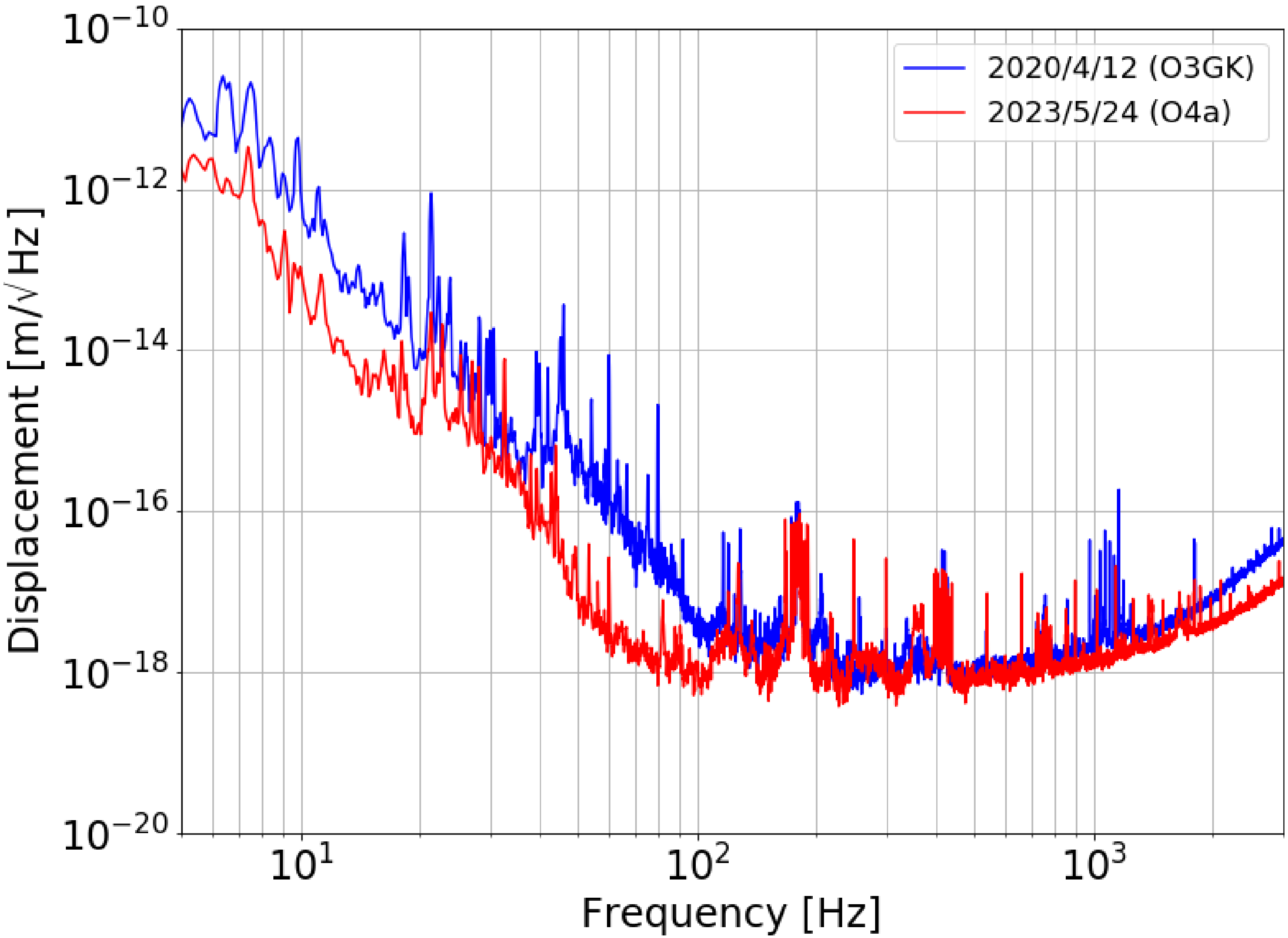


Low frequency:
Control noise reduction

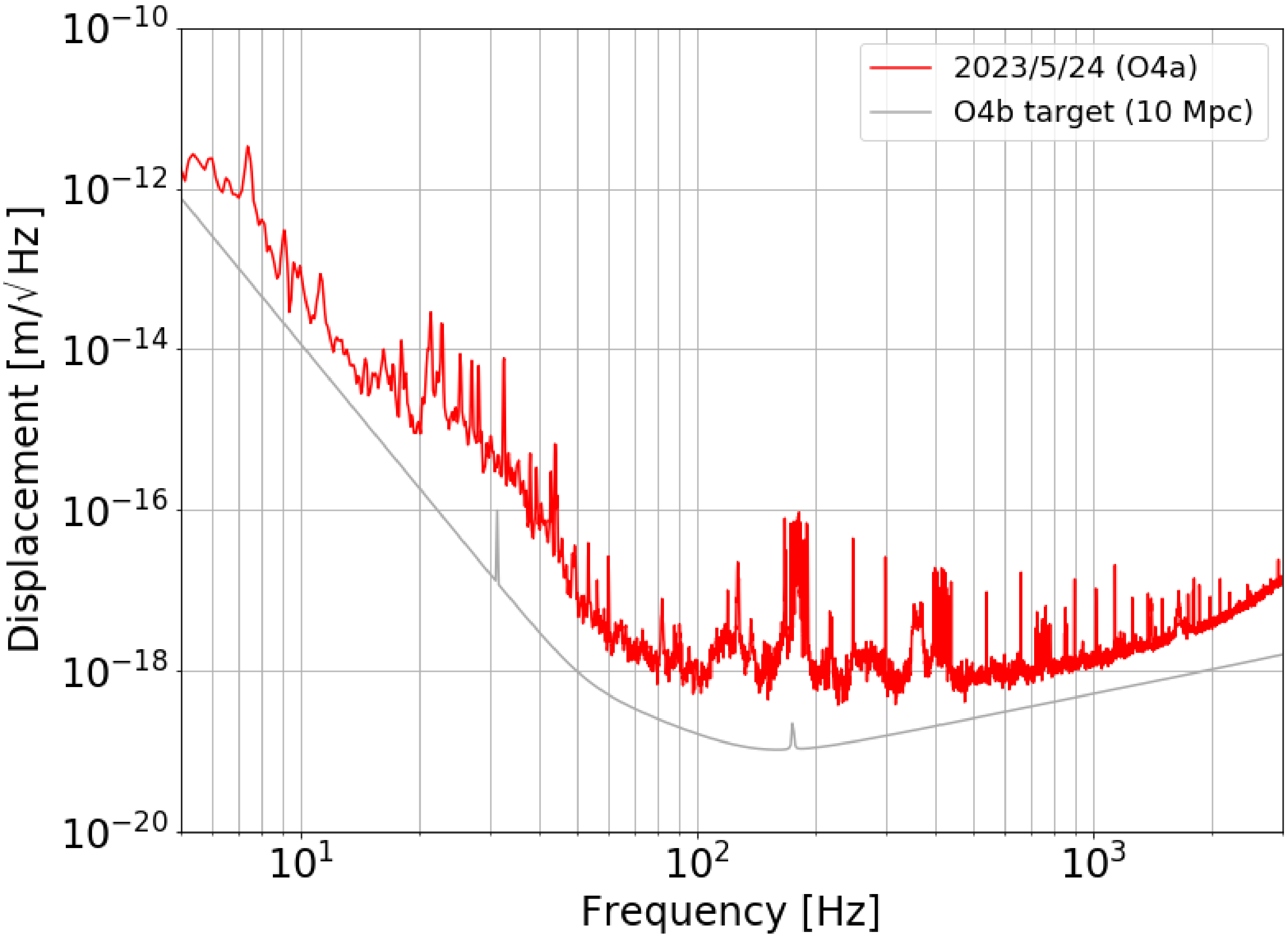
Middle frequency:
Environmental noise reduction
Jitter noise reduction

High frequency:
Frequency noise reduction.
ADC noise reduction.

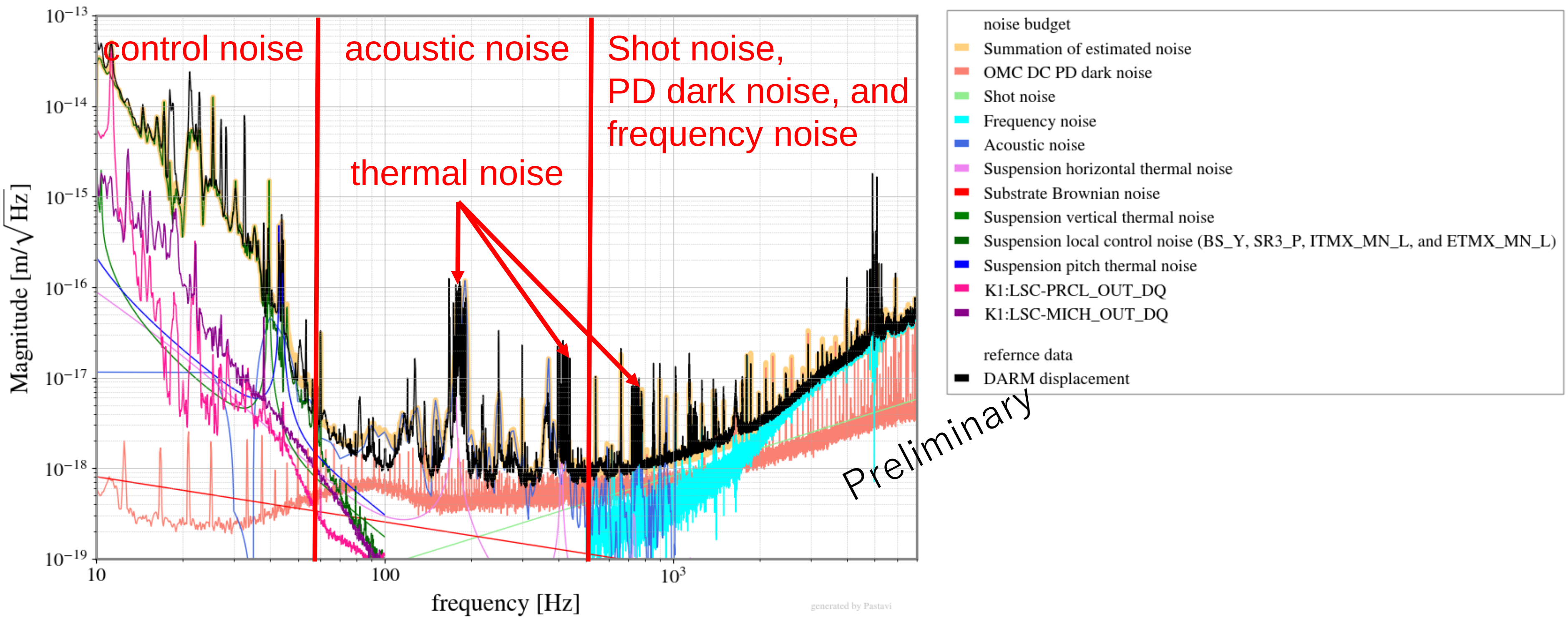
Sensitivity when starting O4a



Target sensitivity of O4b



Noise budget of O4a sensitivity



- We have made noise budget of O4a sensitivity.
- It takes two months to make the noise budget, which is much faster than that during O3GK.
- We are now starting noise hunting to obtain better sensitivity.

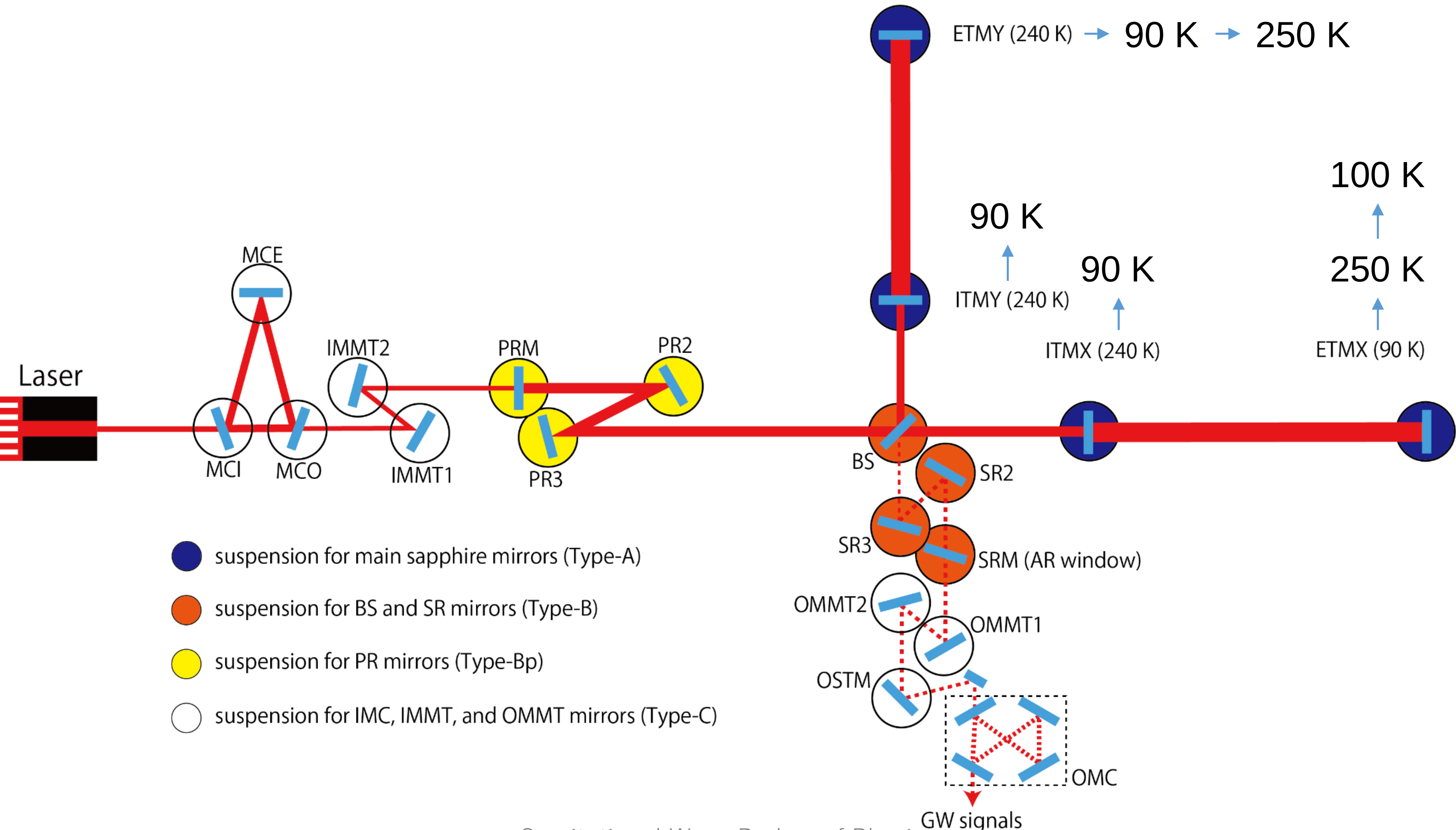
Commissioning after O4a

We are now working hard to improve the sensitivity.
What need to do:

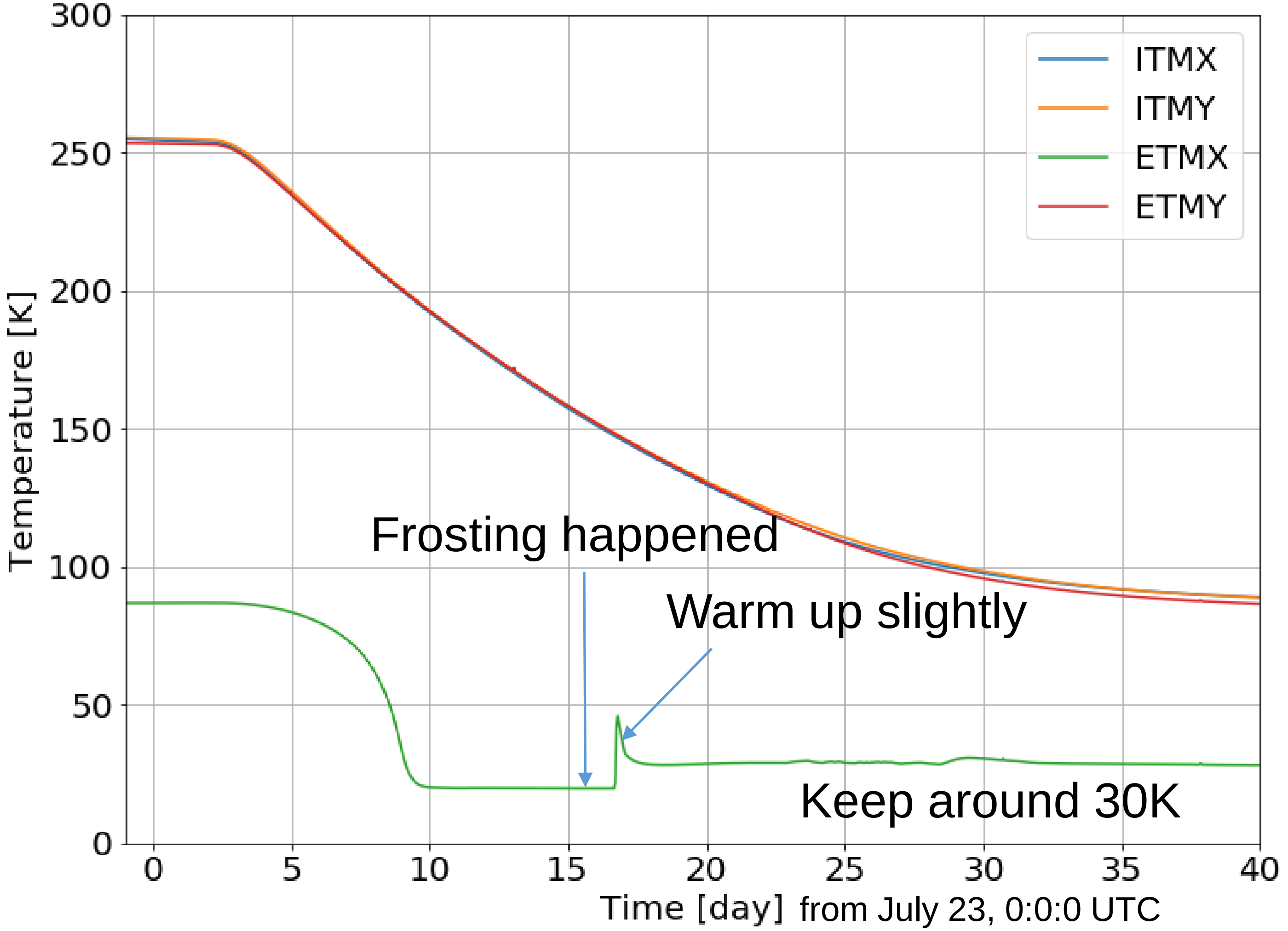
— Achieve PRFPMI with DC readout with cooled mirrors.
— More robust and low noise alignment controls for IFO.
— Cooling sapphire mirrors at least below 100 K.
— Reduction of acoustic coupling around OMC.

Current cooling progress

All test masses except for ETMY was cooled down around 100K.

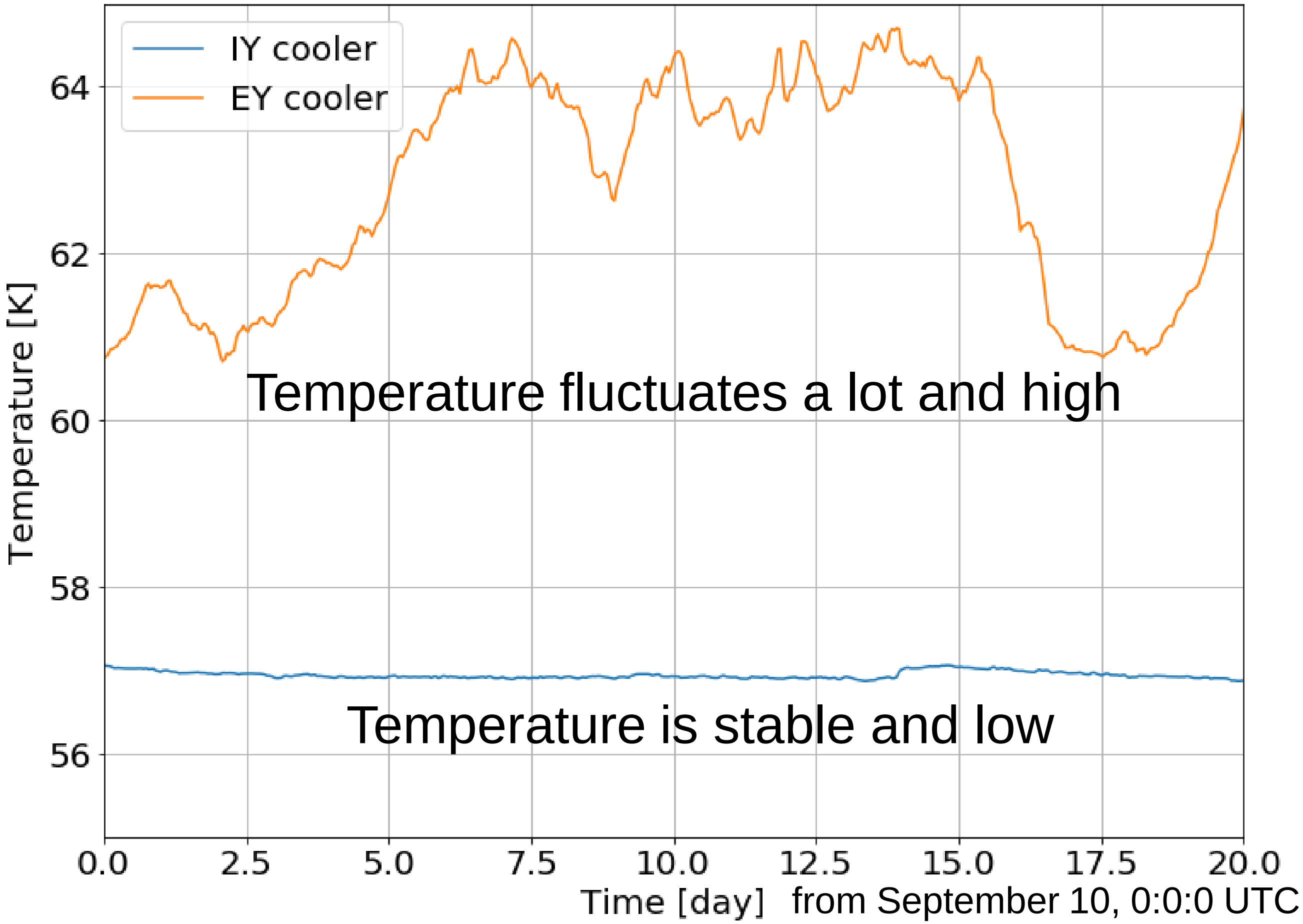


Mirror cooling



Mirror cooling was partially progressed
but frosting problem sometimes occurred.

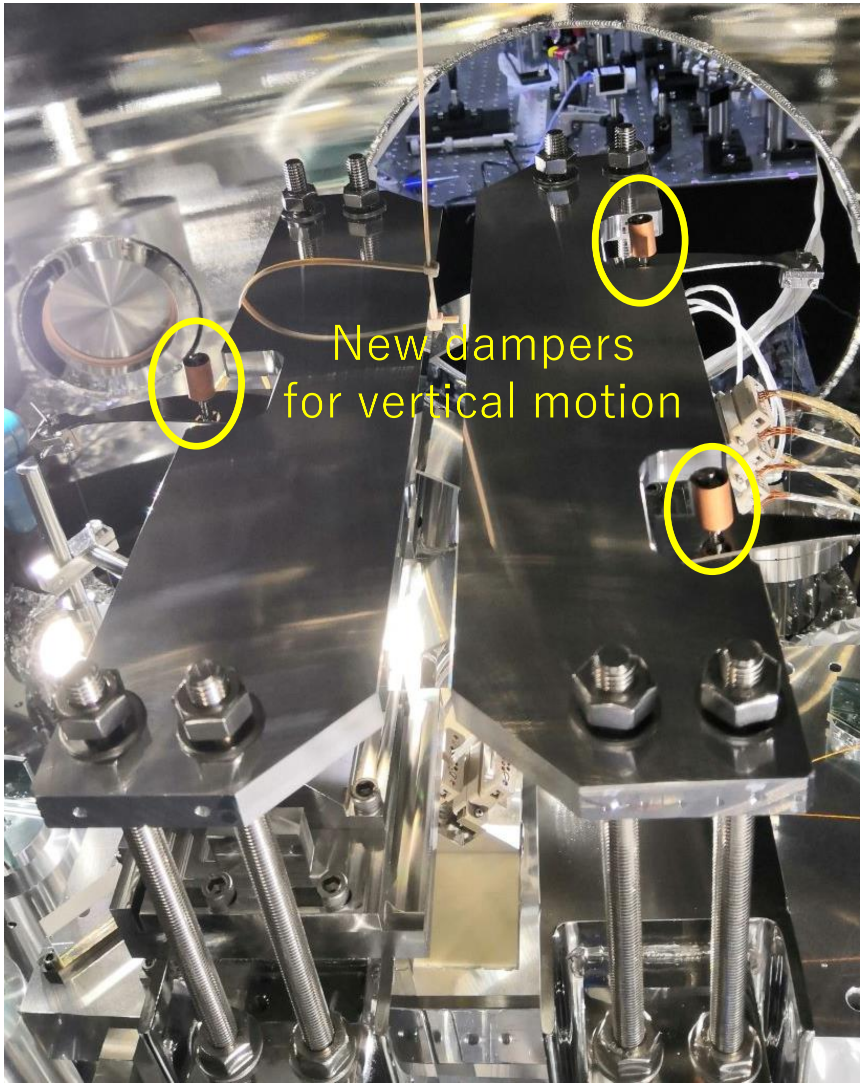
Cryocooler status

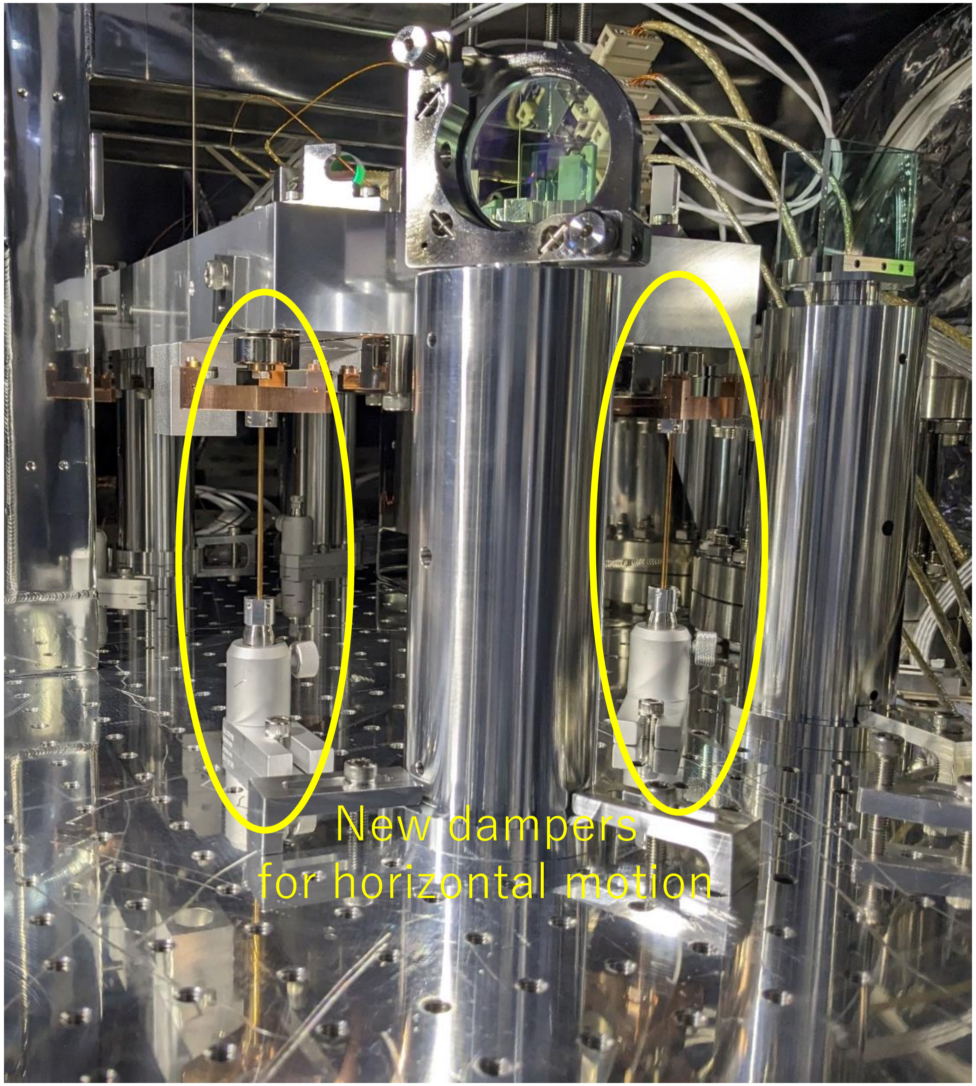


Some cryocoolers show instability of temperature, which would cause serious frosting on the mirror.

→ETMY is now warming up and we are now trying to solve the problem.

OMC suspension damper installation





Summary

- O4 observing run has started since 24 of May with the better sensitivity than O3GK.
- KAGRA stopped observing run on 21 of June and restarted commissioning for sensitivity improvement.
- We need to further improve the sensitivity for achieving O4b target and the strategy on the commissioning is under discussion.
- KAGRA will come back observing run in the next spring with better sensitivity.