Simulation for KAGRA cryogenic payload: vibration via heat links and thermal noise

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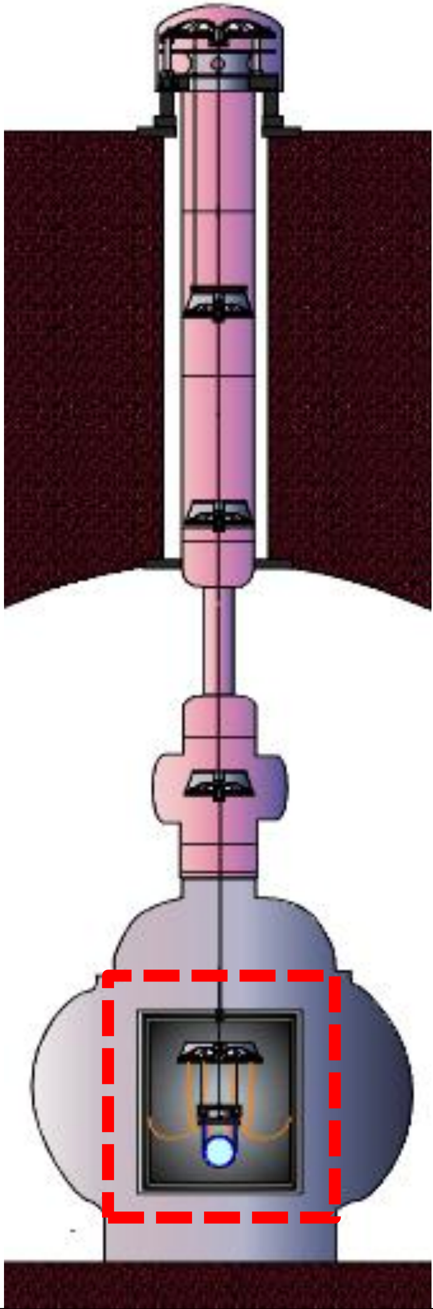
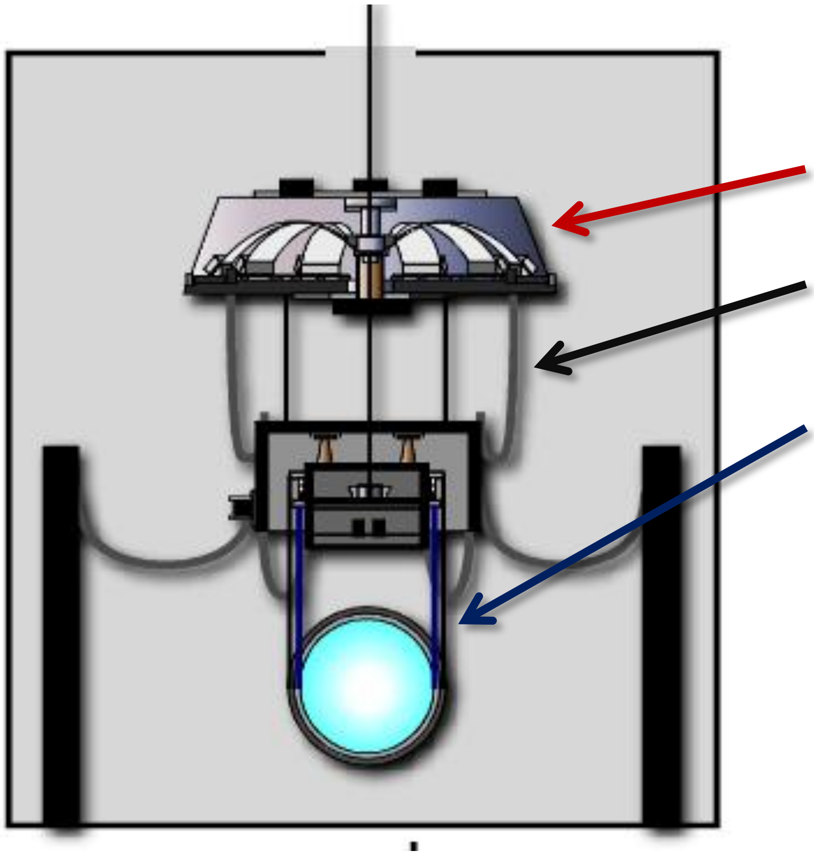
Introduction

- Designing of the cryogenic suspension system for KAGRA is currently in progress.

- Several problems/difficulties have been found for cryogenic suspensions:
  - Long initial cooling time (~ months)
  - Cryogenic compatible sensors/actuators
  - Extra vibrations via heat links
  - Suspension thermal noise

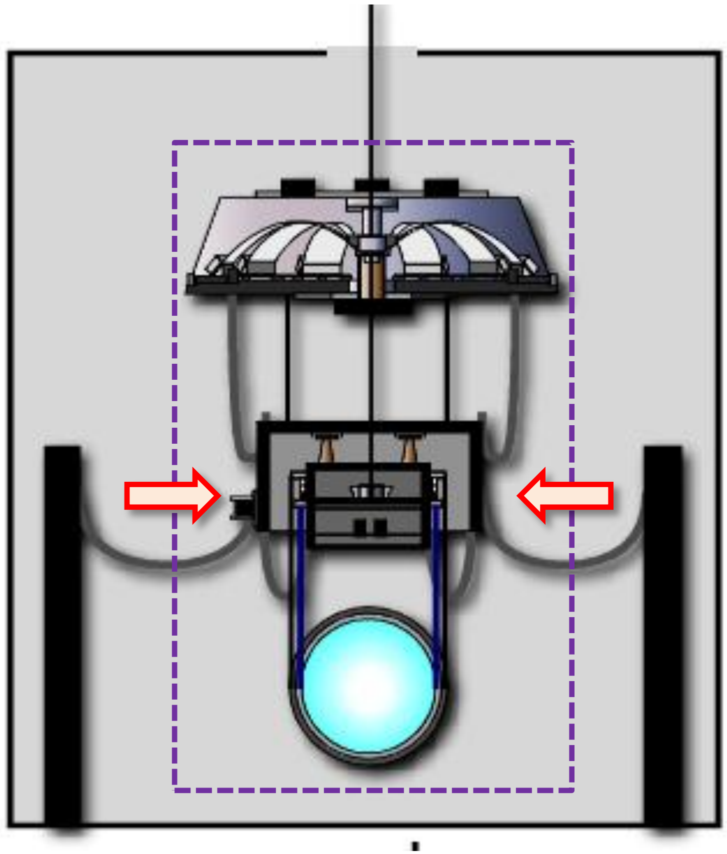


Cryogenic Suspension Base-Line Design



- Triple pendulum
- Cryogenic Spring (GAS)
- Pure aluminum heat links for heat extraction
- Test mass suspended by four thick and short sapphire fibers (Φ1.6mm, L = 30 cm)

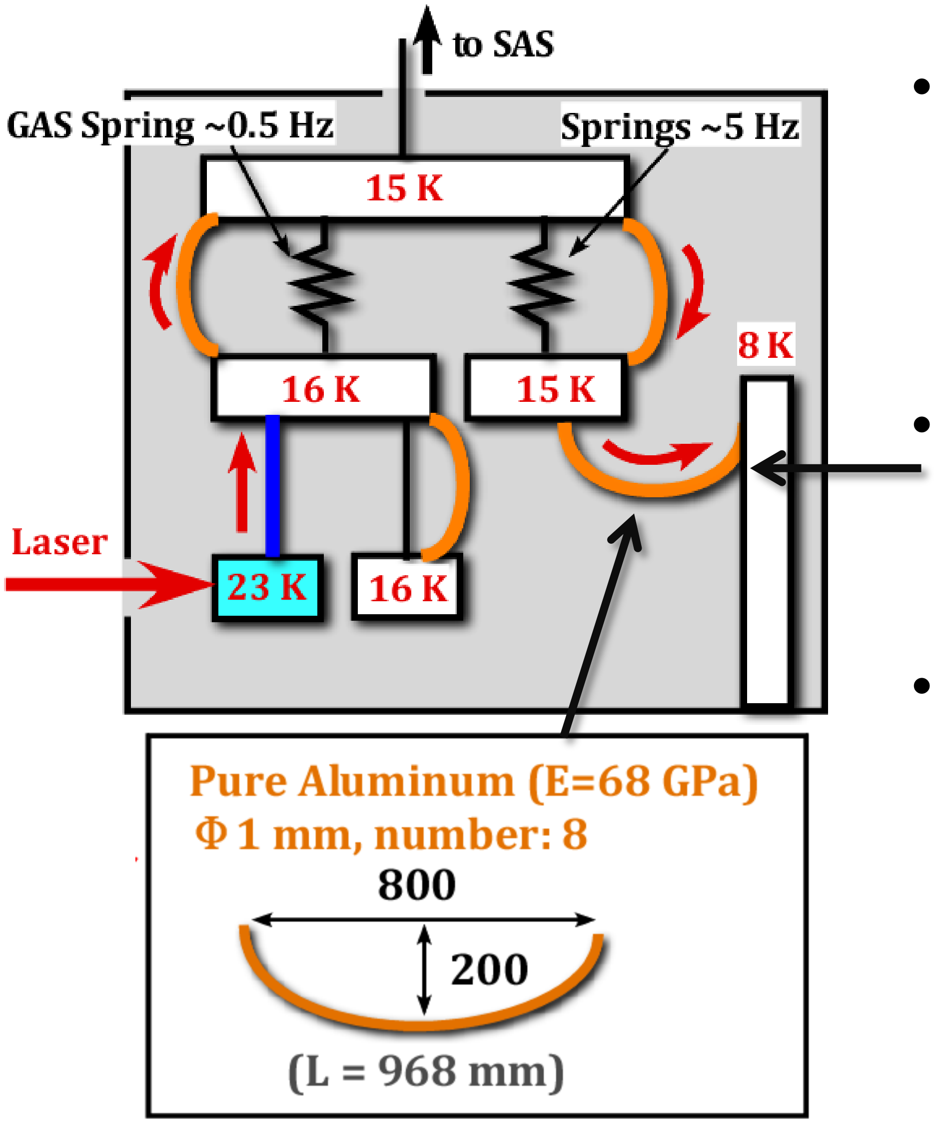
Today's Topic



- **Vibration transmitted through the heat links**
- **Thermal noise of the cryogenic suspension**

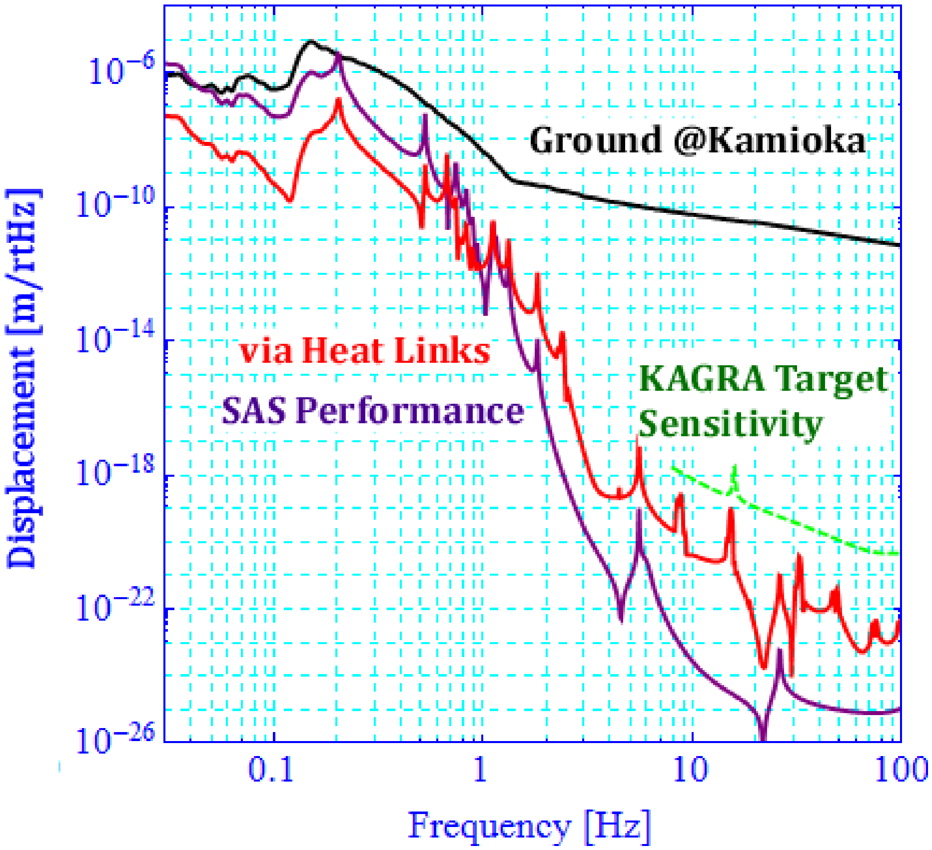
Vibration via Heat Links

Vibration via Heat Links

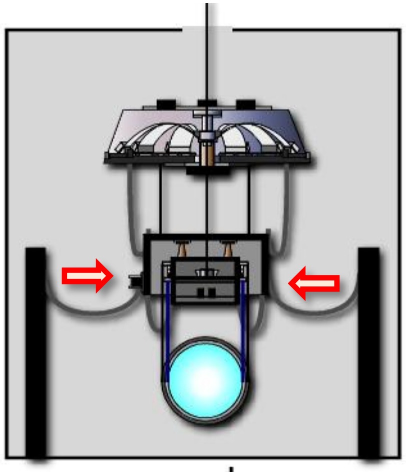


- Heat is subtracted from the recoil mass of intermediate stage (furthest from TM)
- Eight Al wires of Φ1mm x 1 m, with round shape
- Vertical vibration is filtered by small springs (~5 Hz) and a GAS spring (~0.5 Hz)

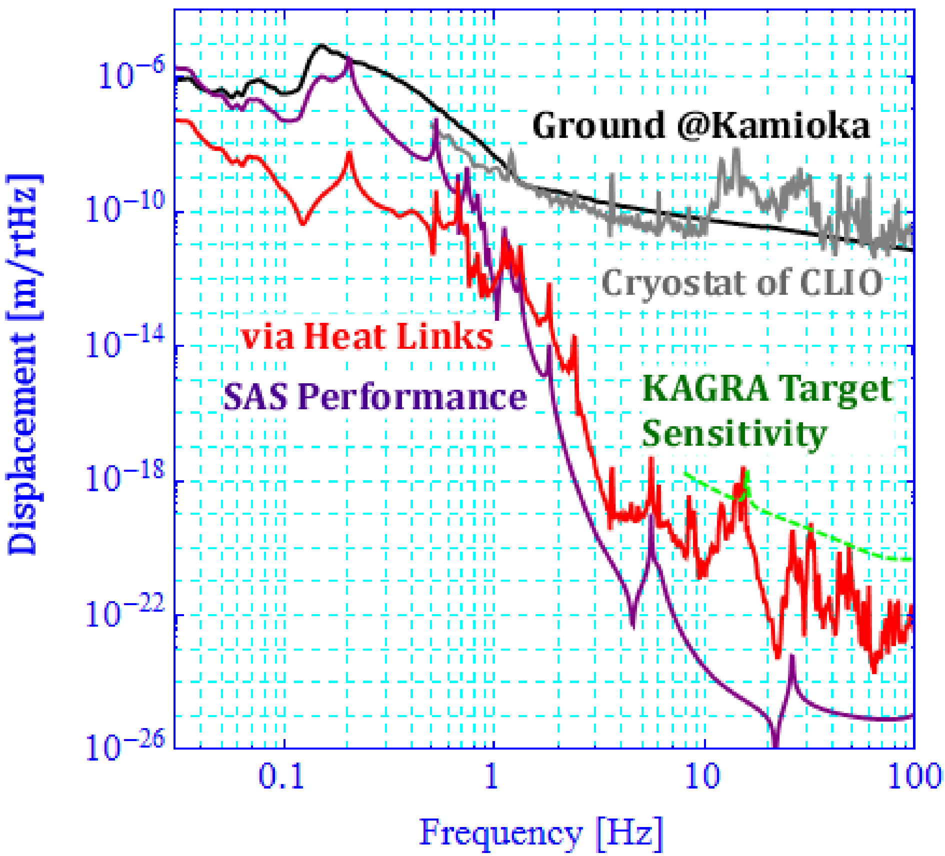
Vibration via Heat Links



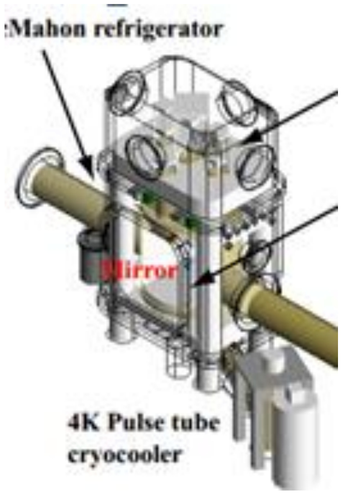
- The vibration via heat links seems much below the target sensitivity level.
- But...



Larger Vibration of Cryostat ??



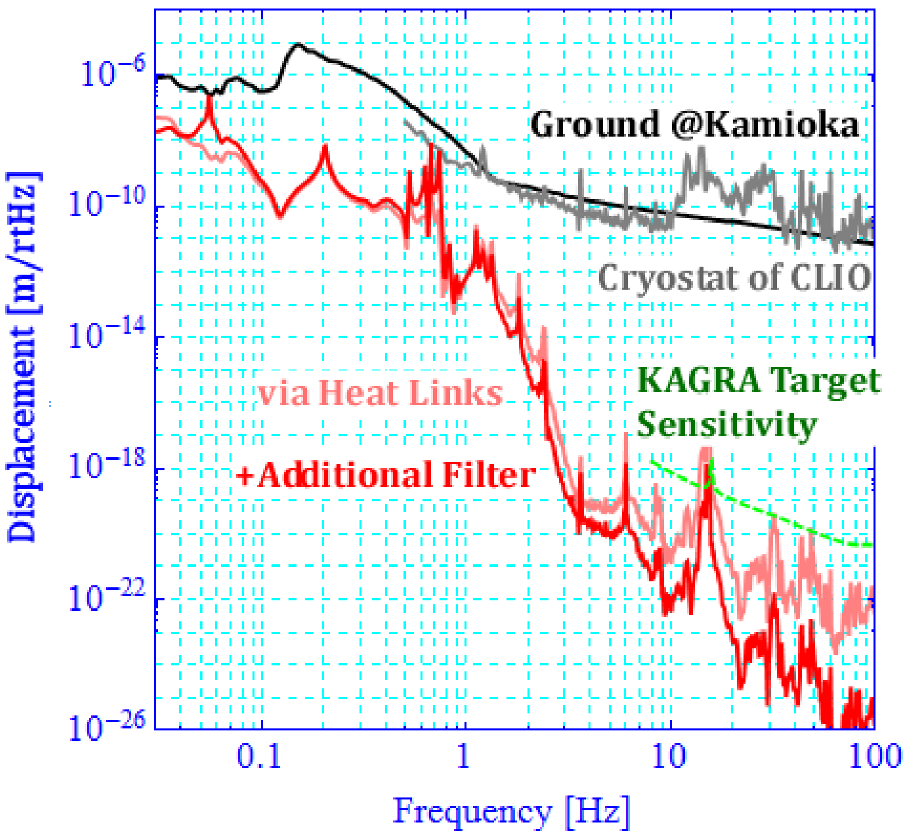
- **Cryostat in CLIO is vibrating at larger level than ground vibration [K. Yamamoto, 2006].**



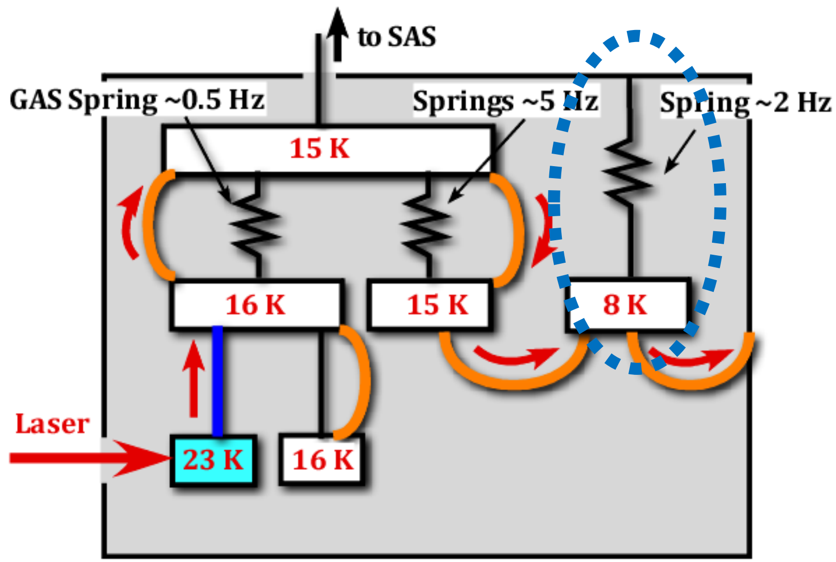
- **Assuming larger vibration level of the cryostat, there are only little safety margin.**

K. Yamamoto et al, J. Phys.: Conf. Ser. 32 418 (2006)

For Further Isolation (Suggestion)



- **Additional filter between IRM and cryostat**

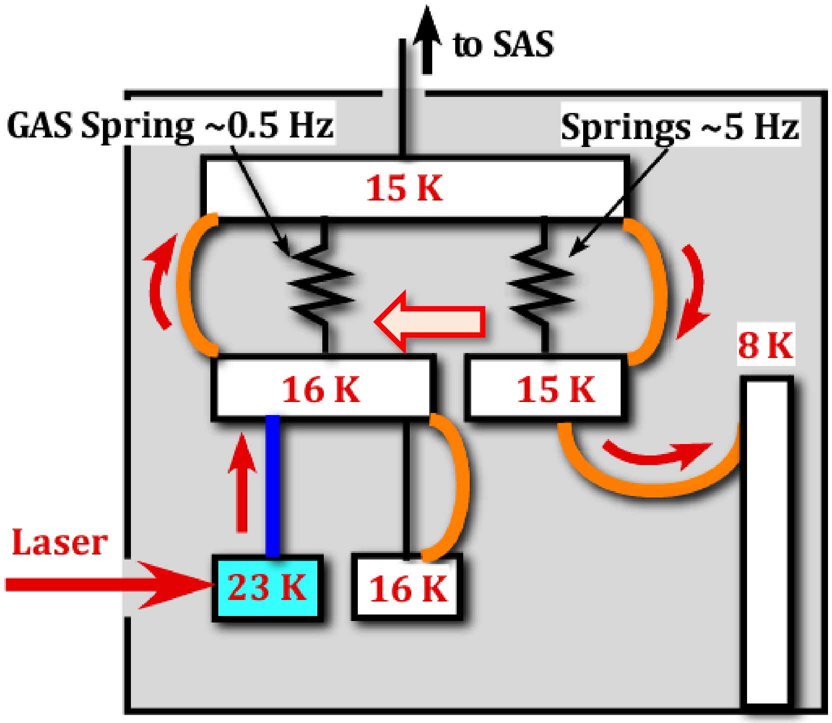


- **Vertical springs for test mass suspensions.**

K. Yamamoto et al, J. Phys.: Conf. Ser. 32 418 (2006)

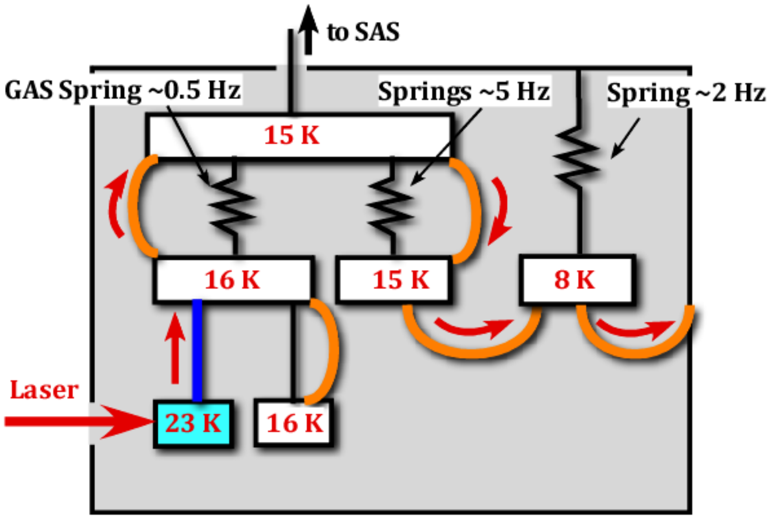
Other Concerns

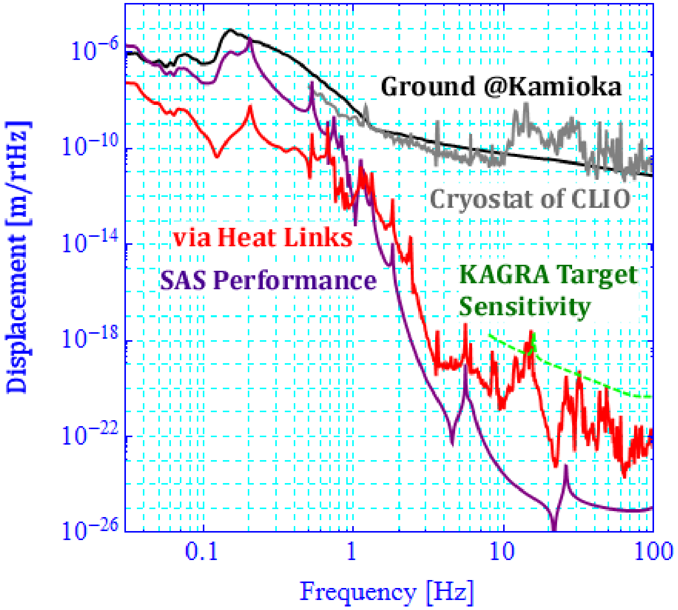
- **Shortcut of the vibration via actuators of intermediate mass**
  → No problem at least for pendulum mode ??
  (to be investigated more)



Summary: Vibration via Heat Links

- In the current design, vibration via heat links can pollute the detector sensitivity at ~10 Hz.
- Additional filter would be necessary for further isolation.
- Vibration of the KAGRA cryostat is to be measured.





Suspension Thermal Noise

Suspension Thermal Noise Calculation

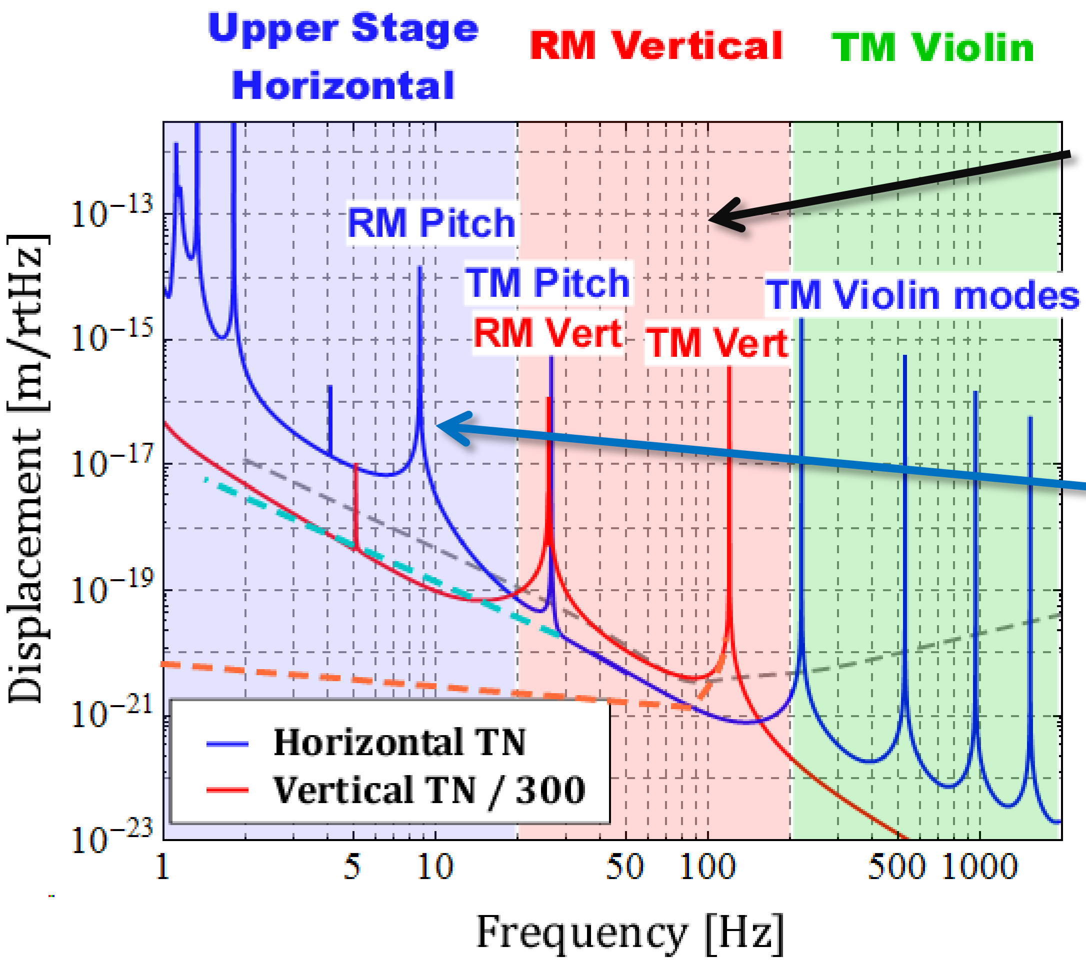
- **Rigid-body models used for seismic noise estimation.**
- **In the model, it is possible to introduce loss of the springs/ wires by adding imaginary parts to their spring constants.**
- **Suspension thermal noise can be calculated by taking imaginary part of the force-displacement transfer function.**

$$x_{\mathrm{therm}}^2(\omega) = \frac{4k_B T}{\omega} \mathrm{Im}[H(\omega)]$$

Suspension Thermal Noise Calculation

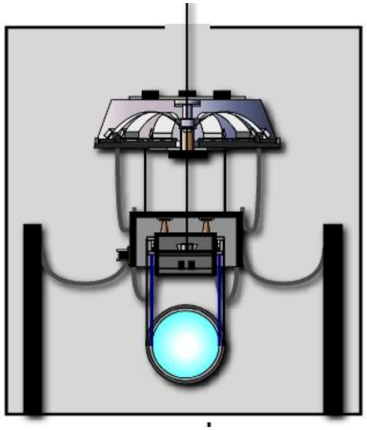
- **Assumed Q of suspension materials:**
  - **Sapphire fibers: 5×10^6**
  - **Other suspension: 1×10^4**
  - **GAS Filter: 1×10^3**
- **Pendulum Q gets higher than the intrinsic material Q (dissipation dilution)**
- **Thermal noise of sapphire fiber violin modes is calculated separately and added to the rigid-body model calculation.**

Suspension Thermal Noise in KAGRA



Vertical bounce modes of TM & RM suspension fibers exist at 10-100 Hz.

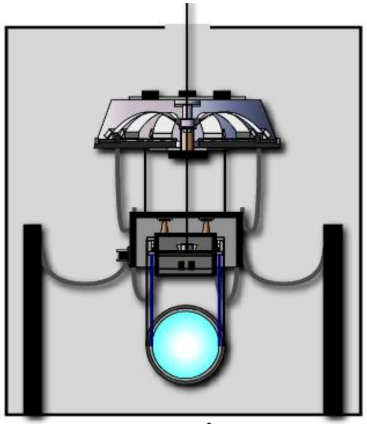
Thermal noise from upper stages/recoil mass is dominant at < 20 Hz.

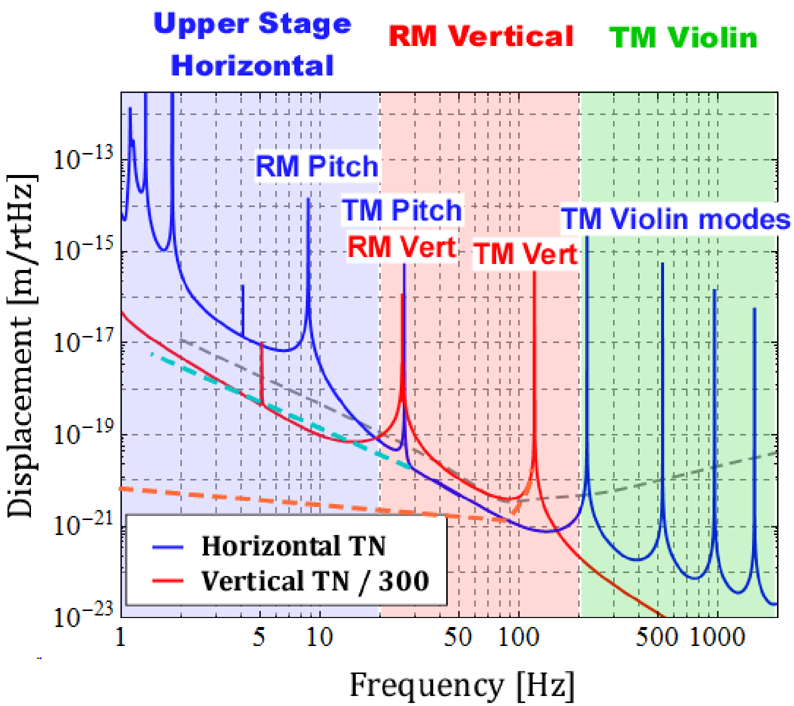


To Improve Thermal Noise

- Test mass and recoil mass should be suspended by springs.
  - Eliminate annoying peaks from observation band
  - Improve the vertical thermal noise around 100 Hz

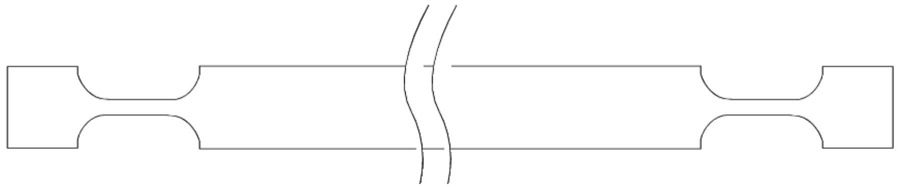
- Silicon springs might be used for large thermal conductivity and high Q.

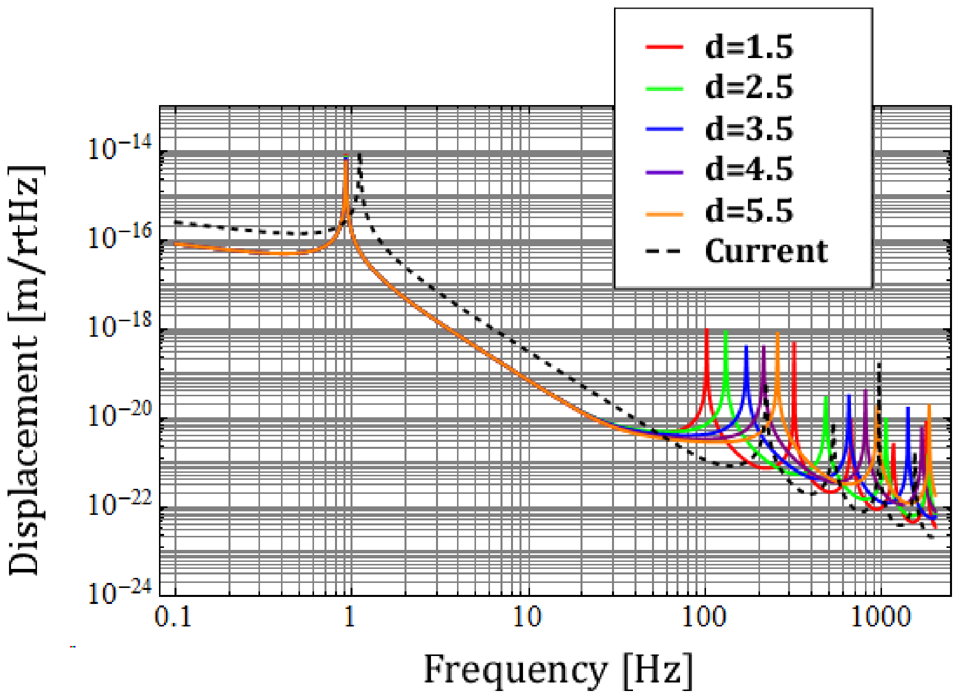


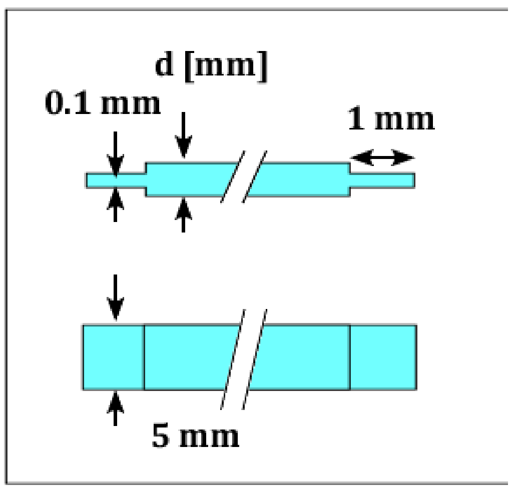


To Improve Thermal Noise

- **Fibers with flexures might be useful to push the violin modes to higher frequency.**

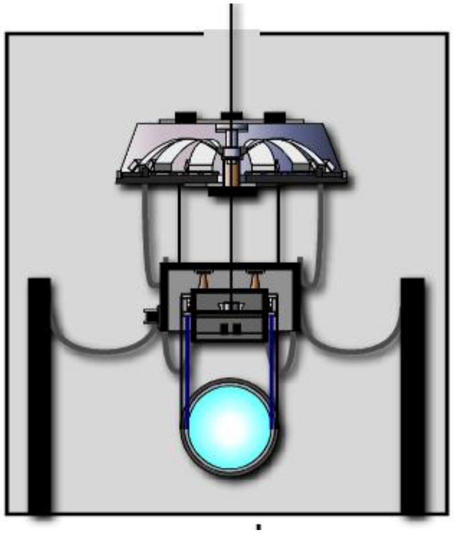


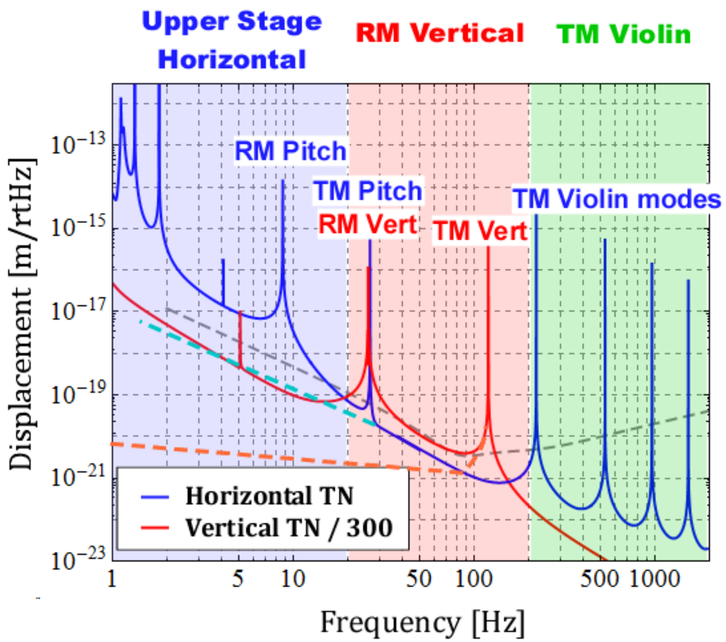




Summary: Suspension Thermal Noise

- **Thermal noise from recoil mass suspension is dominant at 10-100 Hz, and should be improved.**
- **Vertical bounce modes of the suspension fibers produce annoying peaks. Springs should be introduced.**





Thank you for your attention.

- **Any questions?**