External forces from heat links in cryogenic suspensions

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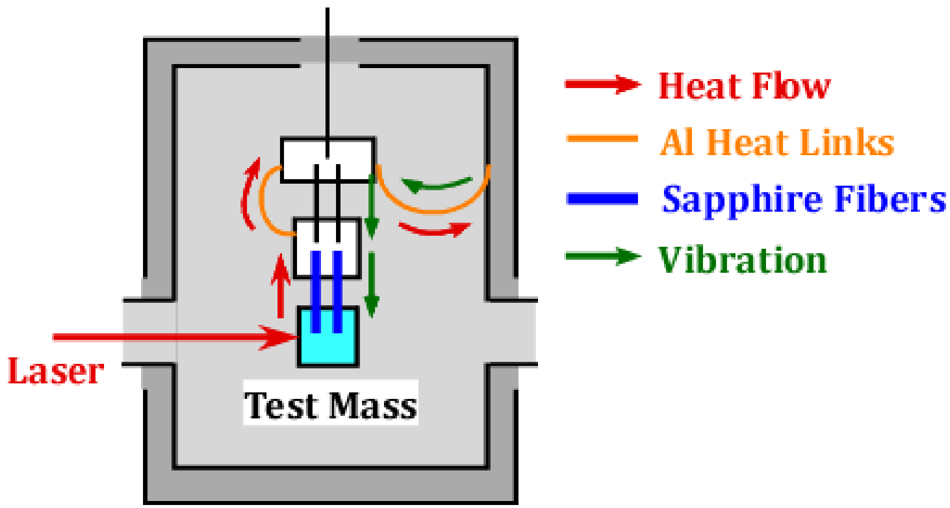
About this Talk

* Estimate seismic noise introduced from heat links.
* Discuss how to achieve cooling and seismic isolation at the same time.



Seismic Noise from Heat Links

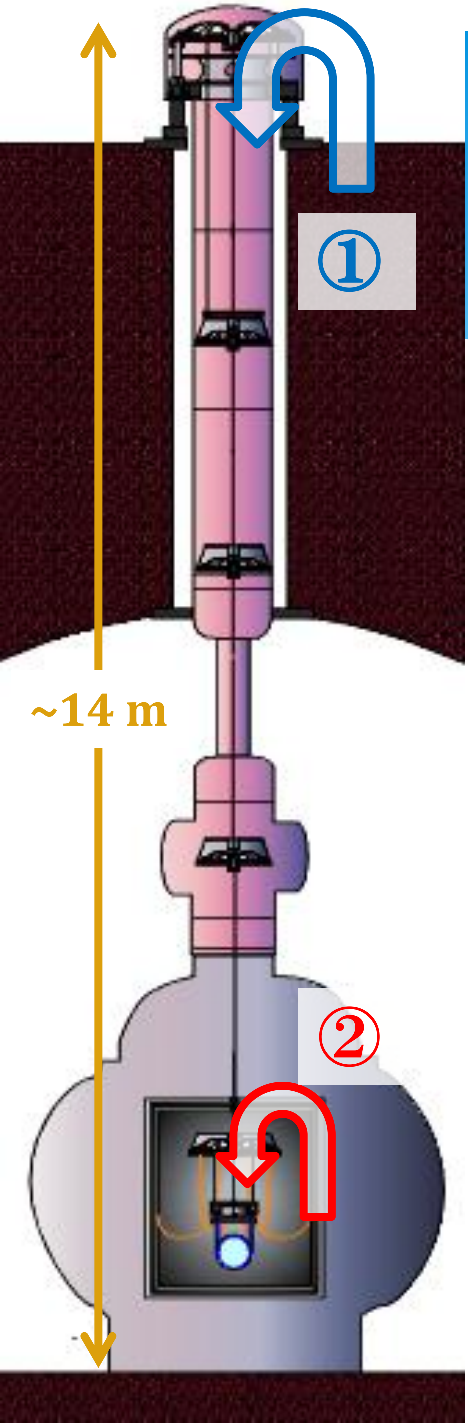
Basic Requirement for KAGRA Test Mass Suspension

- Attenuate seismic noise

  Test Mass Displacement
  $< 3 \times 10^{-20}$ m/√Hz @ 10 Hz

- Cool down test masses

  Mirror Temp. ~ 20 K



Seismic Attenuation System for KAGRA Test Mass

* Seismic vibration transmits to the mirror in **two different paths**

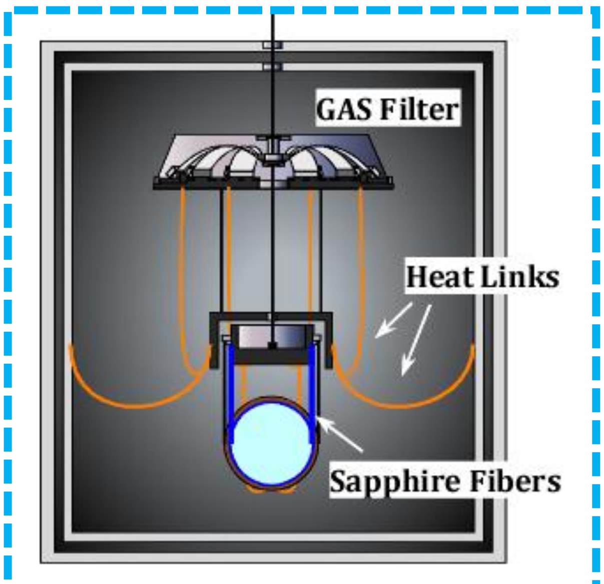
1. **From the top through the attenuation chain**
2. **From the wall of the cryostat through heat links**

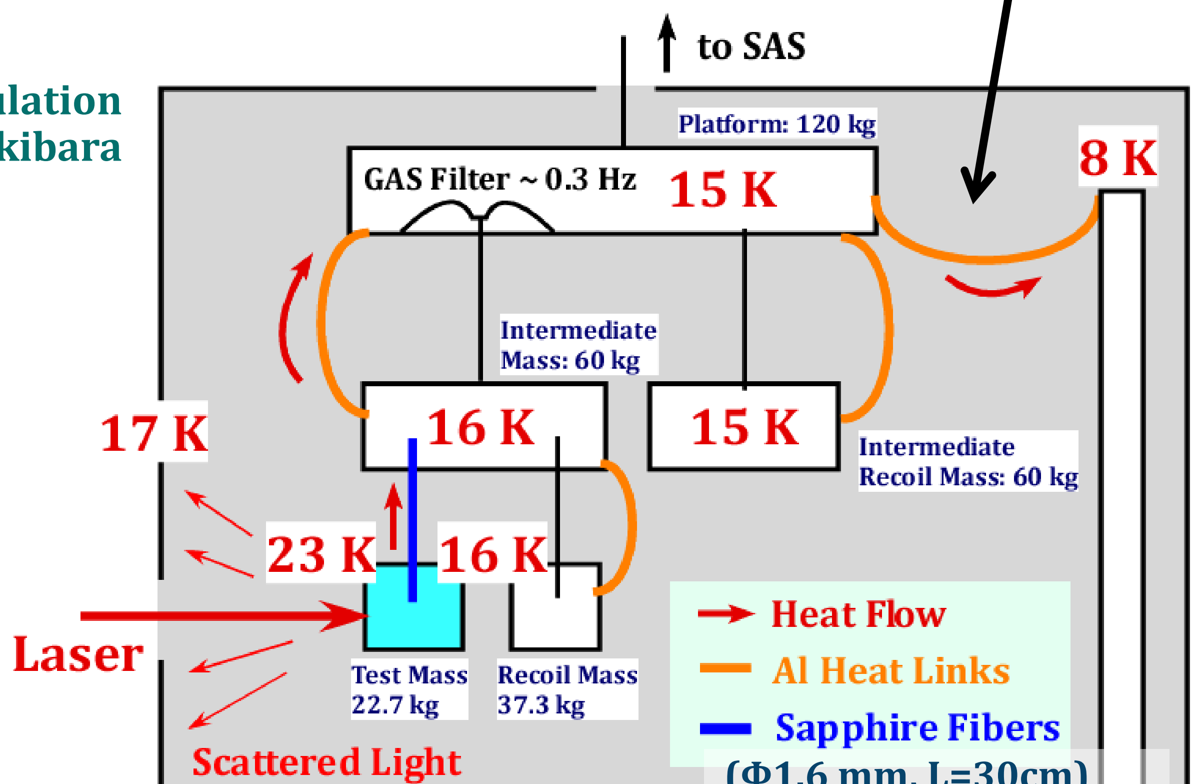
Cryogenics

* Heat transferred via **pure aluminum heat links.**

We need Φ1 mm, L=1 m heat links x 7~8

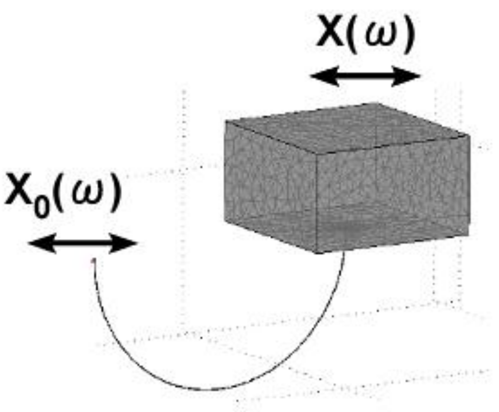
Thermal simulation
Done by Y. Sakakibara



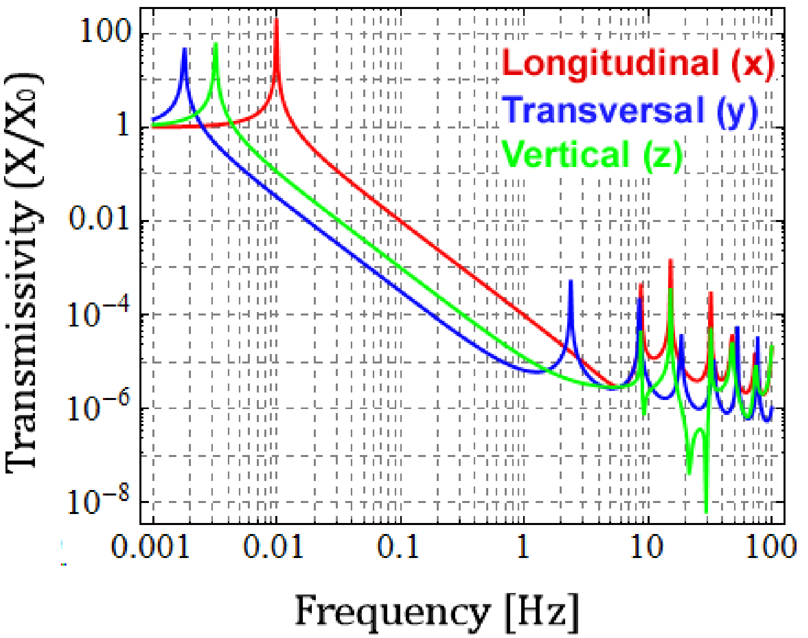


Mechanical Property of Heat Links

* A heat link works as a soft spring **(f_0~10 mHz)** with **violin modes** above ~1 Hz



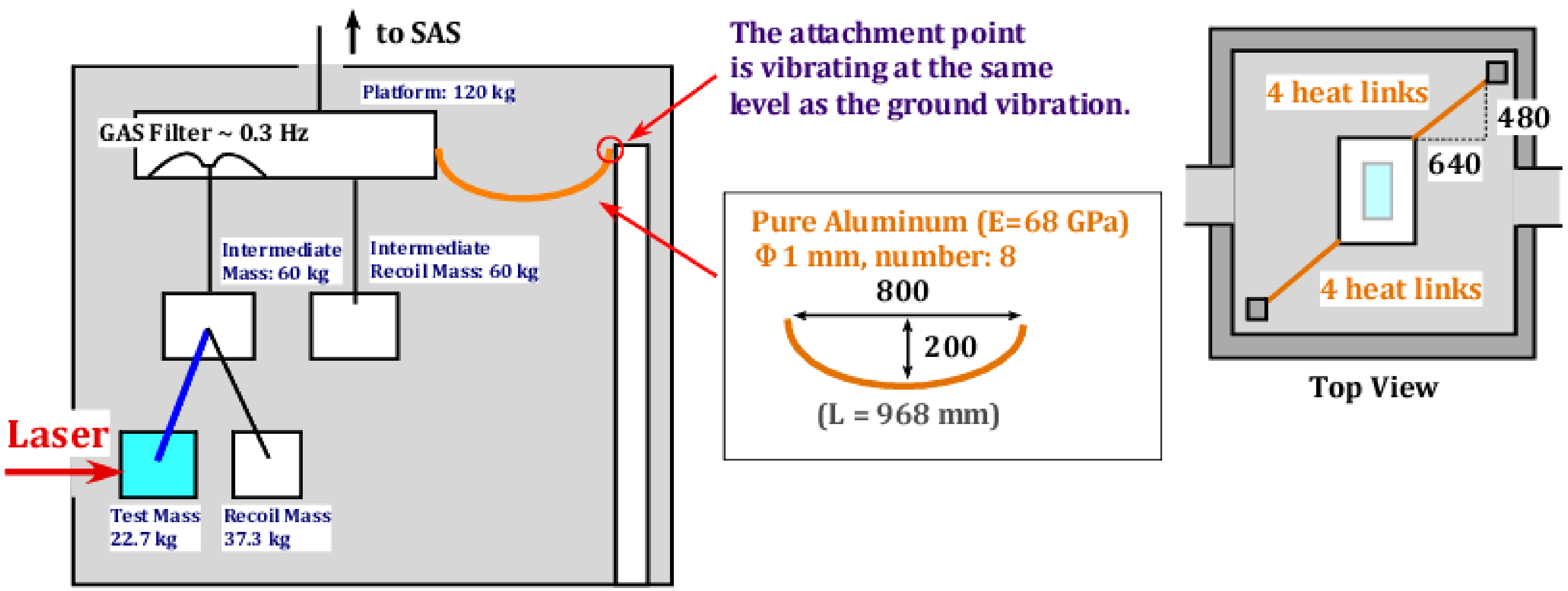
FEM Simulation Done by Y. Aso, (JGW-G1000108)



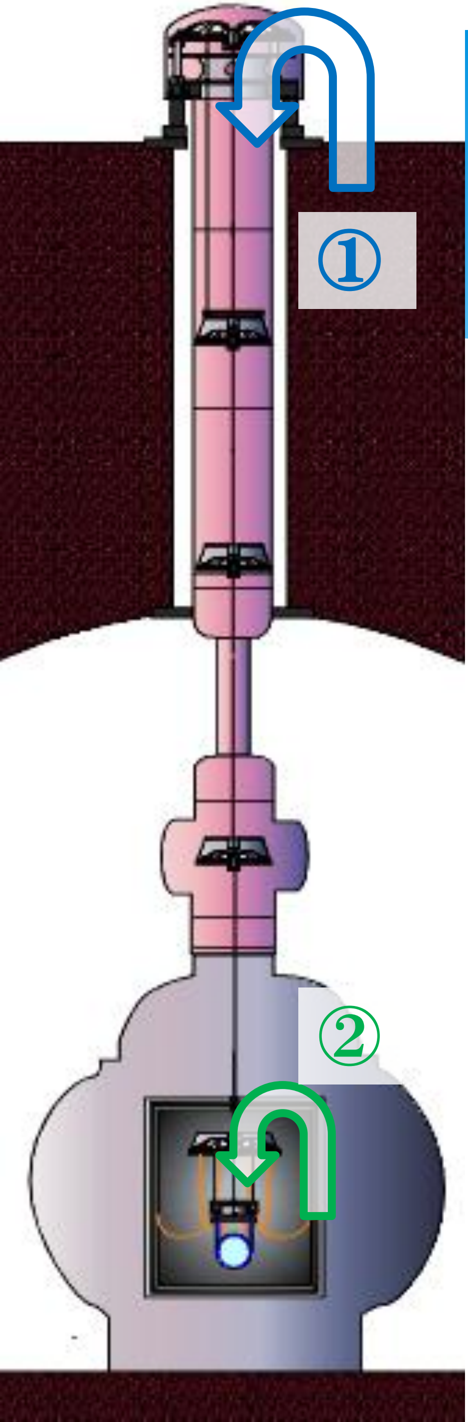
Estimation of Seismic Noise via Heat Links

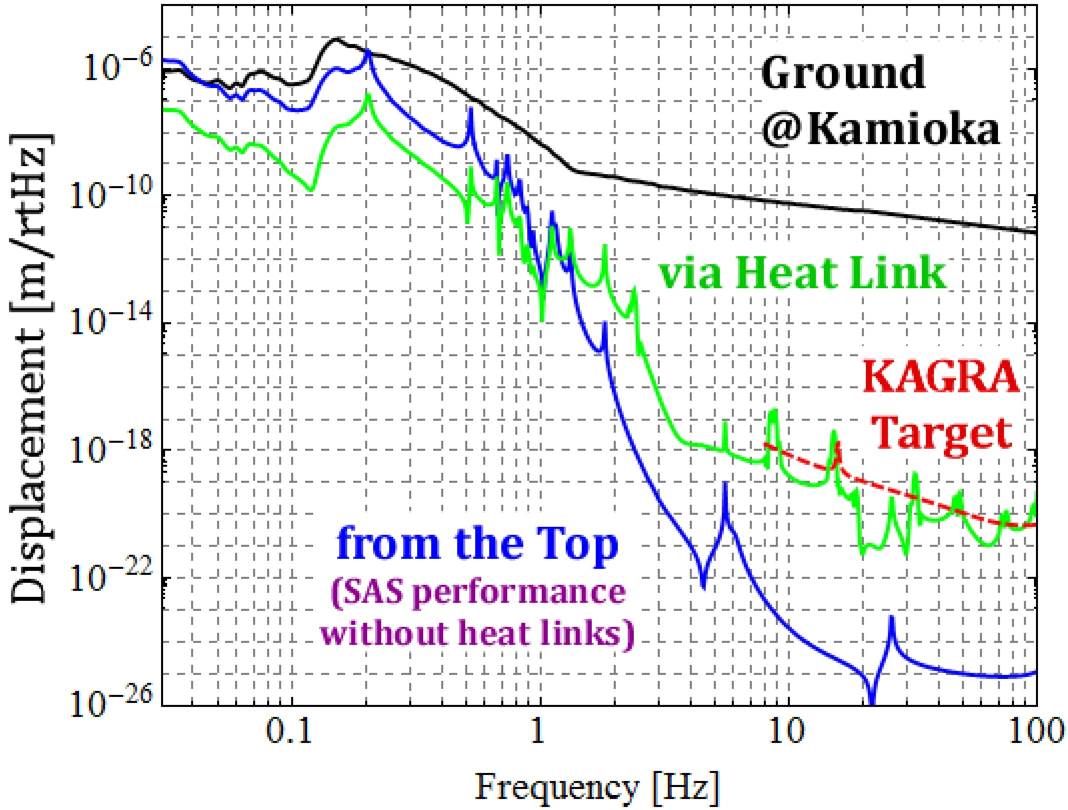
* Simulation Tool: **3-D rigid-body model simulation**

T. Sekiguchi, Master Thesis (JGW-P1200770)



Calculation Result



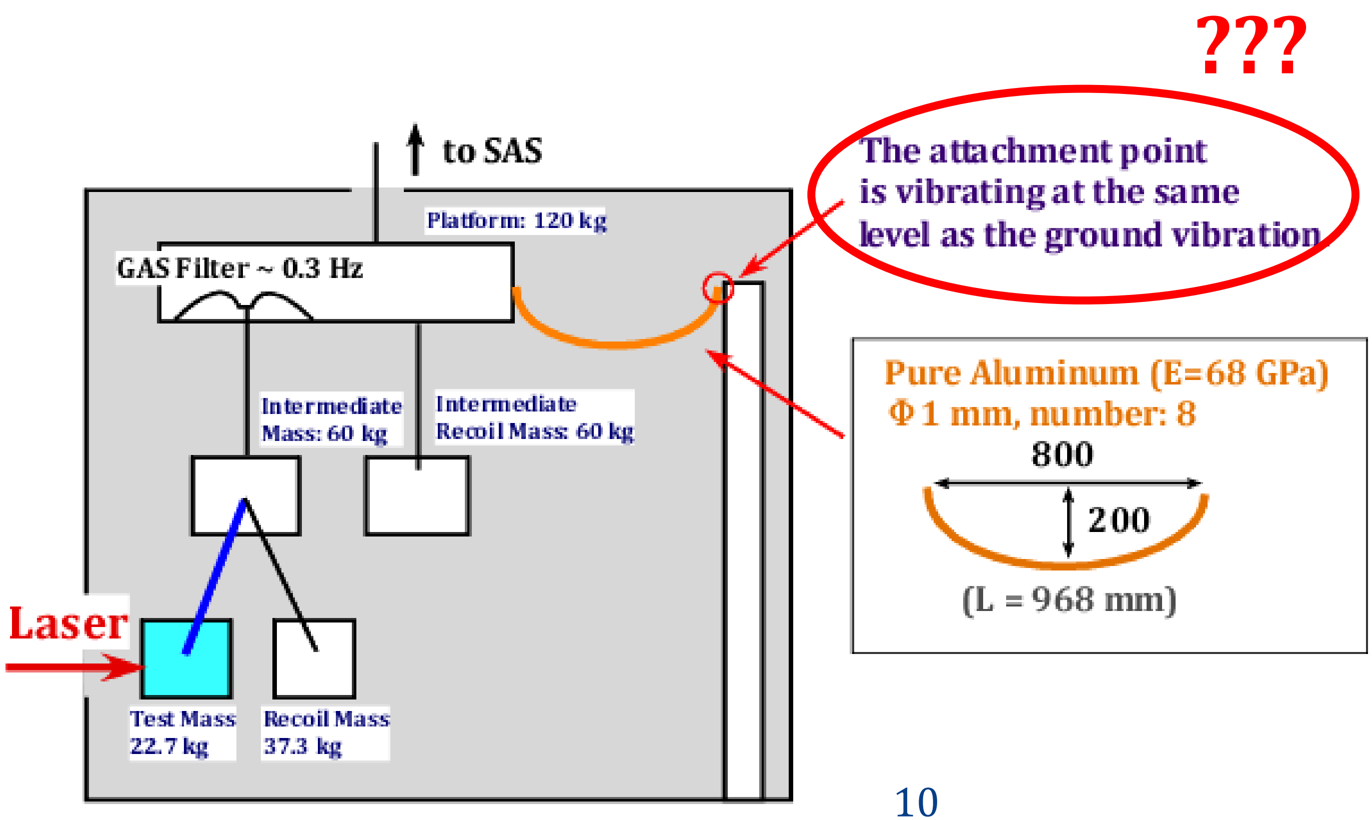


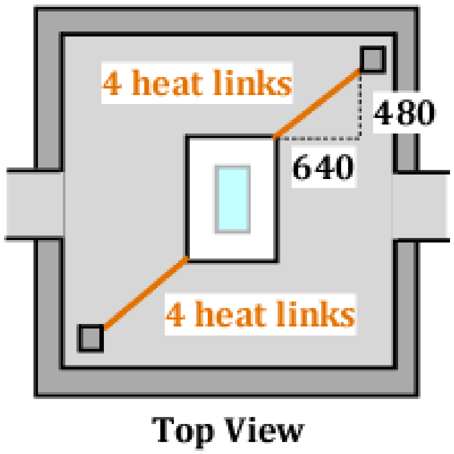
* Assuming
1% coupling
from vertical

Polluting detector sensitivity above 10 Hz !!

To Make Matters Worse ..

* **There is no guarantee** that the wall inside the cryostat is vibrating at the same level as the ground.

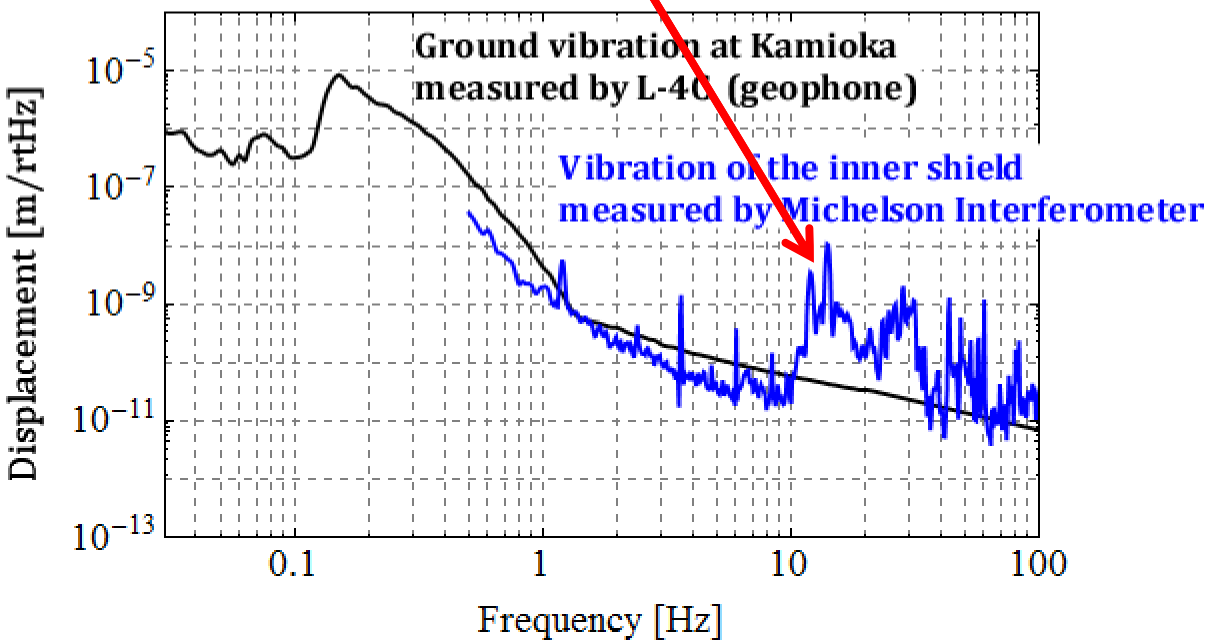


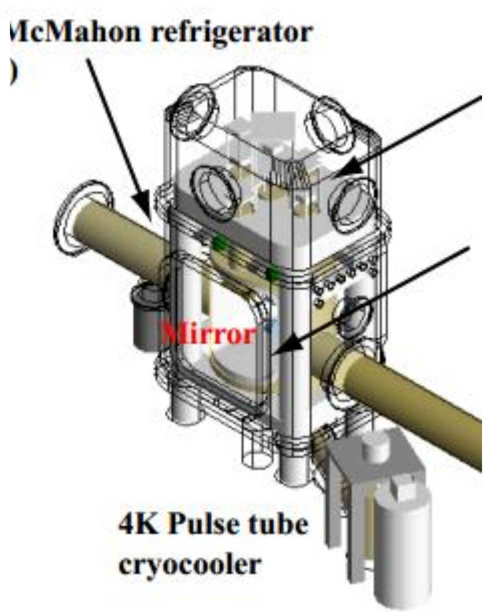


Vibration Inside the Cryostat in CLIO

10-100 times larger !!

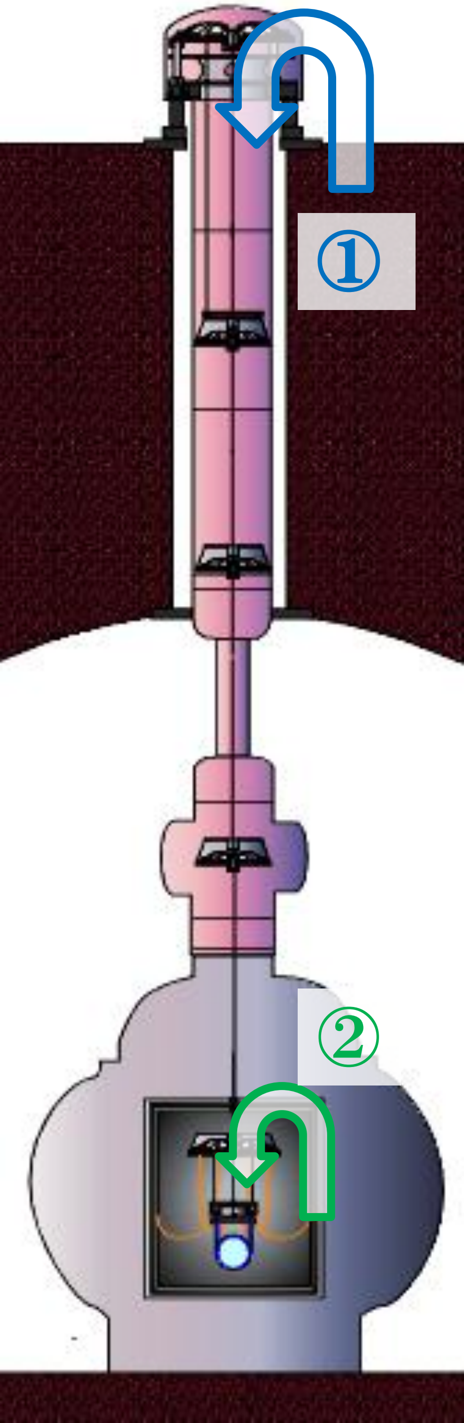
K. Yamamoto et al, J. Phys.: Conf. Ser. 32 418 (2006)

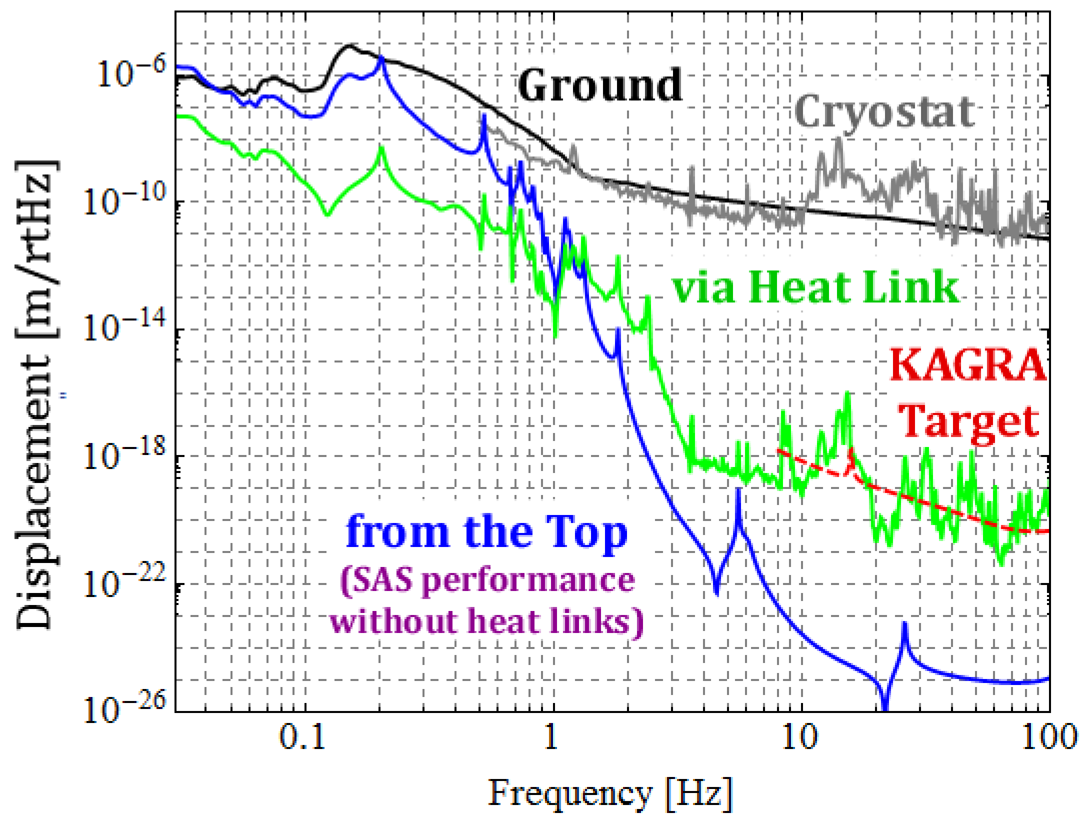




In Worse Case

* If the attachment point of heat links is vibrating at the same level as cryostat vibration in CLIO..

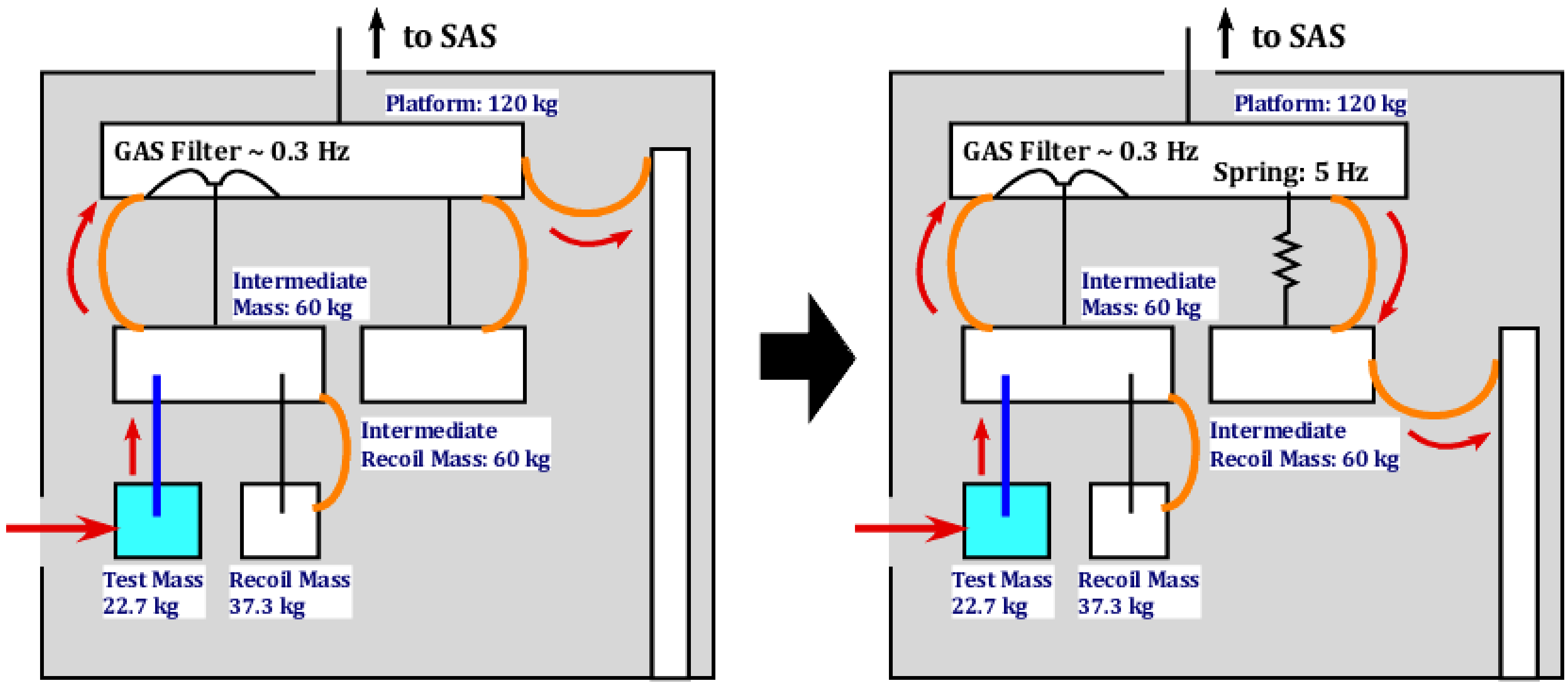




* Assuming 1% coupling from vertical

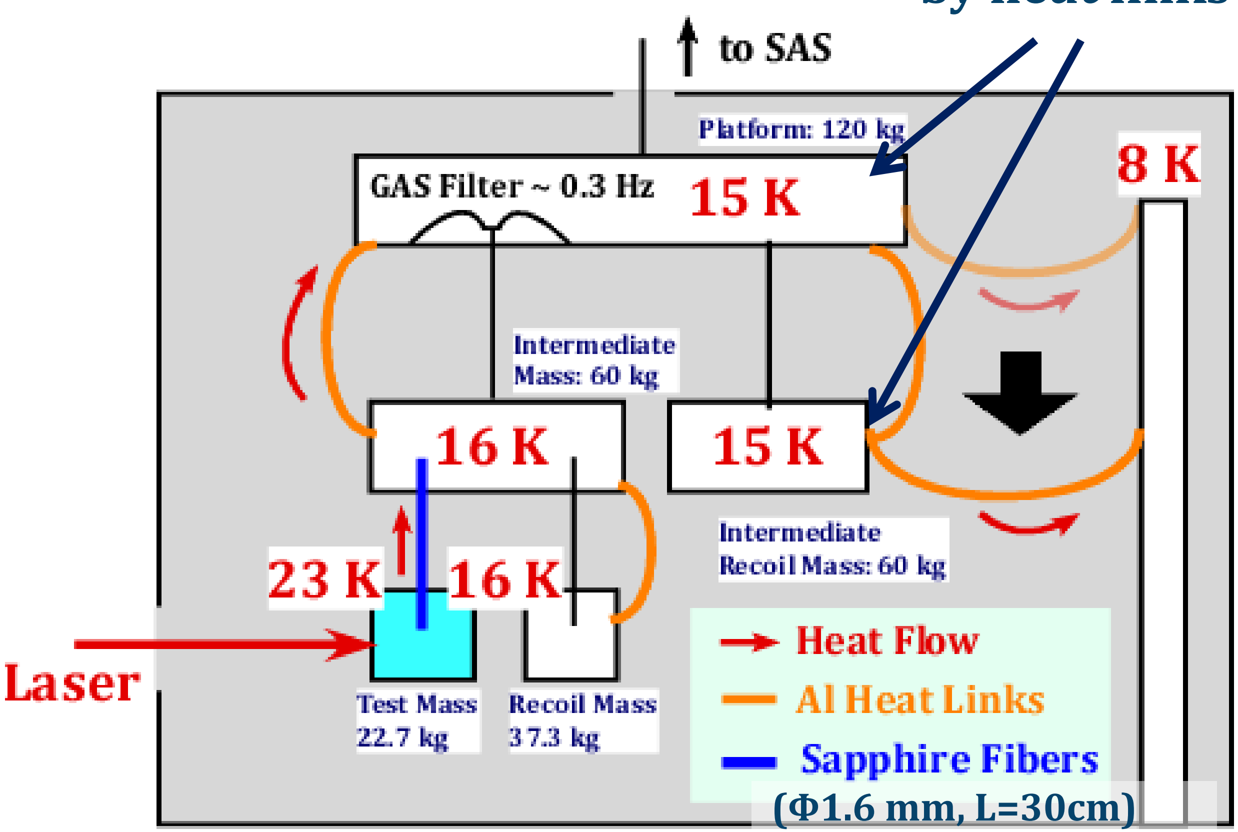
Improved Design

- Add one more "**cushion**" between the cryostat and mirror



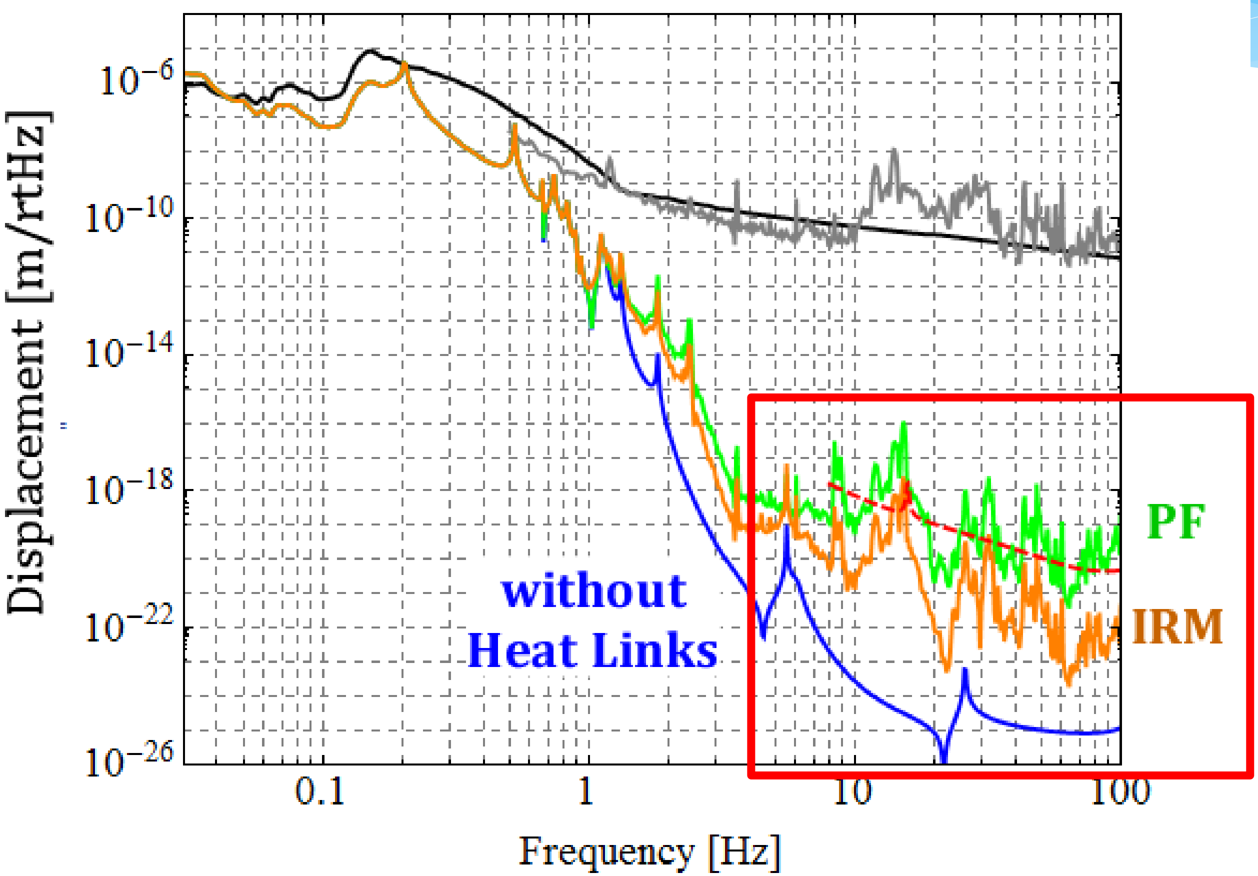
Consideration on Cooling

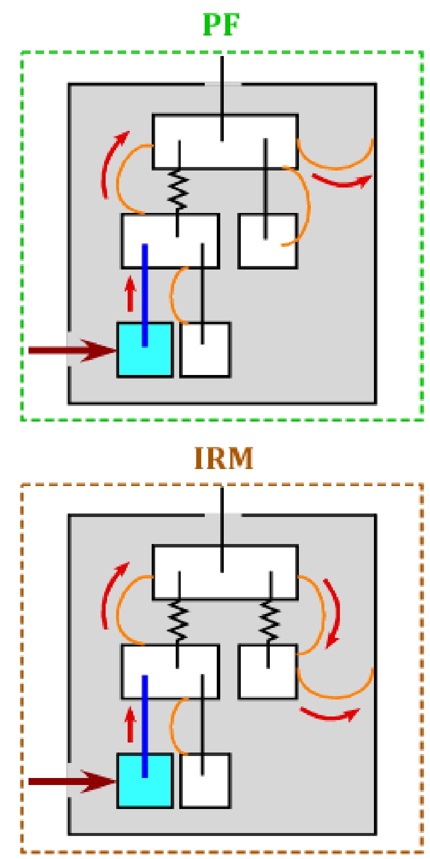
These two masses are thermally well connected by heat links*



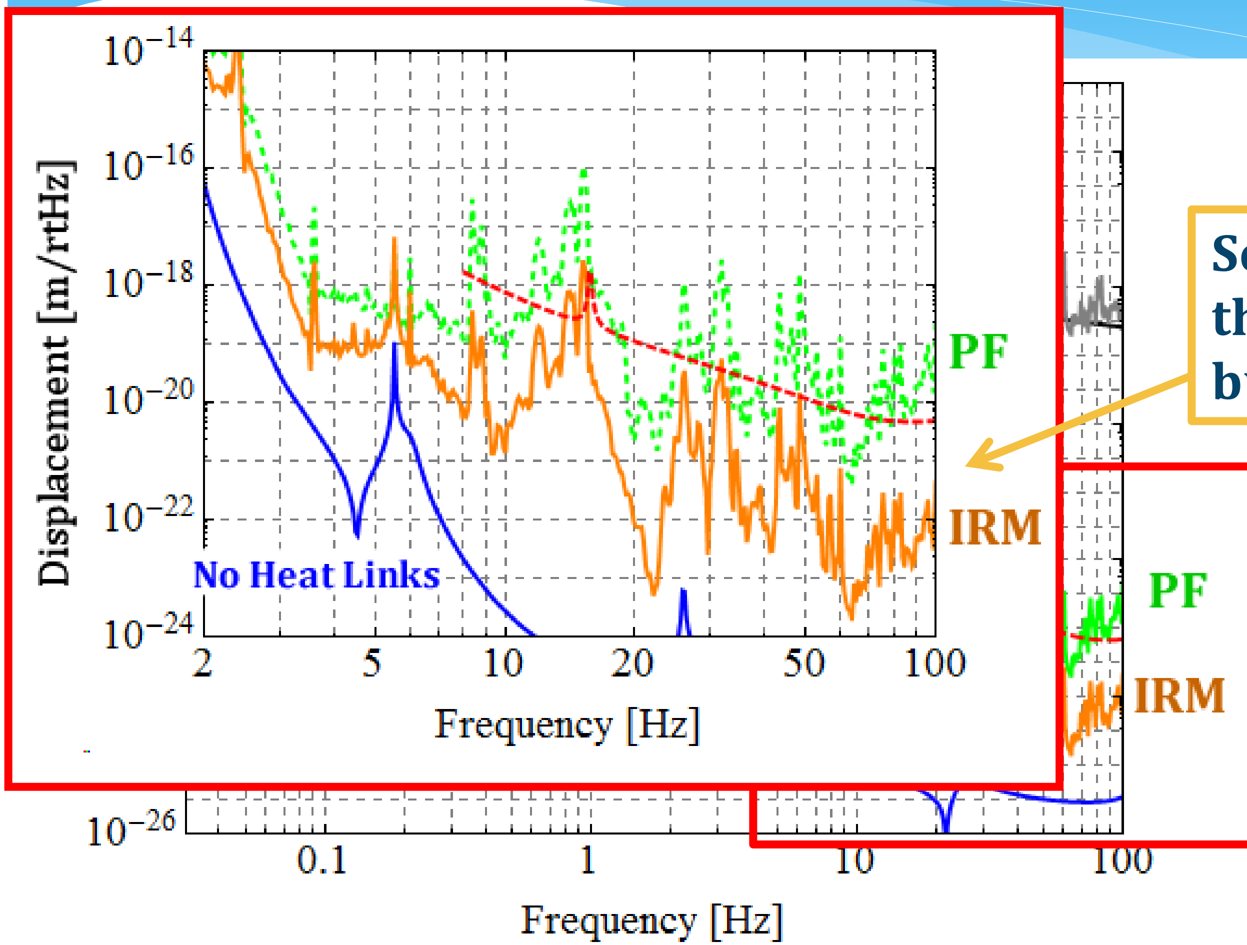
* Pure aluminum
Φ 3 mm, L=63 cm,
Number: 5

After Improving Wiring





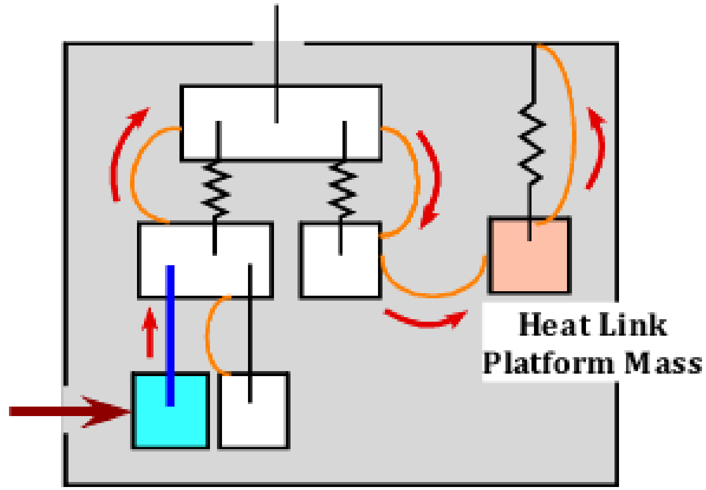
After Improving Wiring



Several peaks exceed the target sensitivity, but the flour level is OK.

Possible Ideas of Further Improvement

* Suppress the cryostat vibration passively/actively.
* Put **additional filters** between suspension and cryostat.

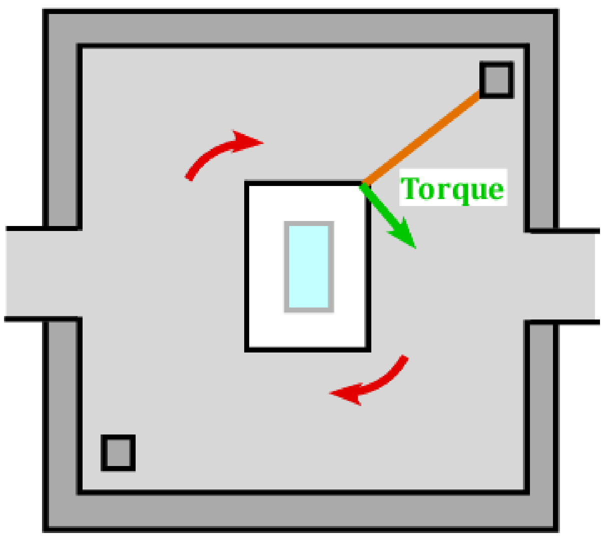


* Add **vertical springs** for test mass suspension.

Another Consideration

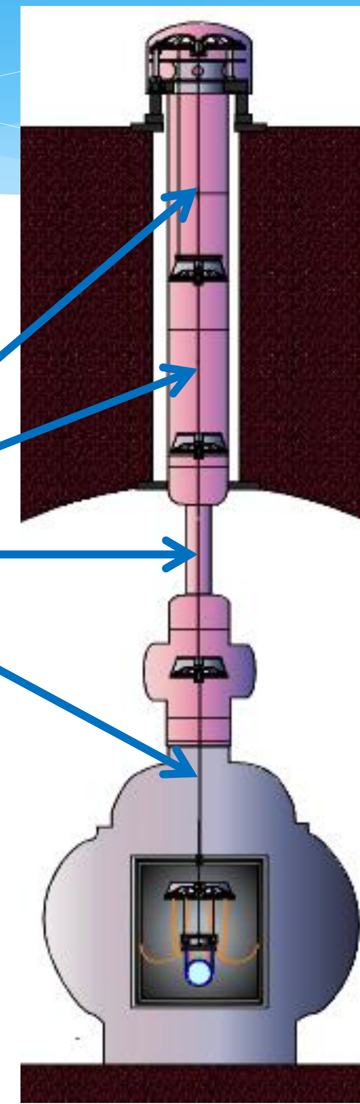
Effect on Angular Motion

- SAS is **very soft** in yaw motion (~ 10 mHz).
- **Low frequency** yaw motion can be easily excited.



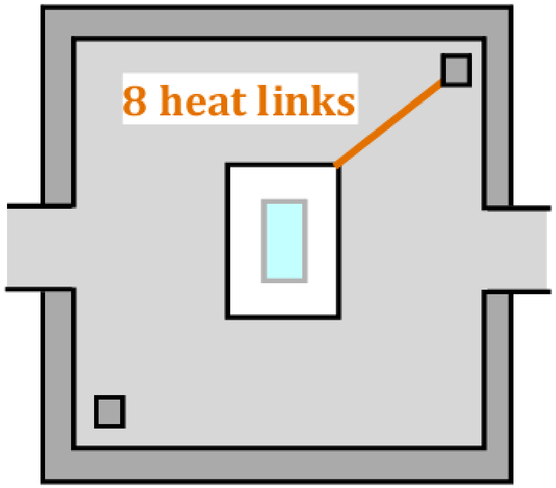
Top View

Single wire suspension



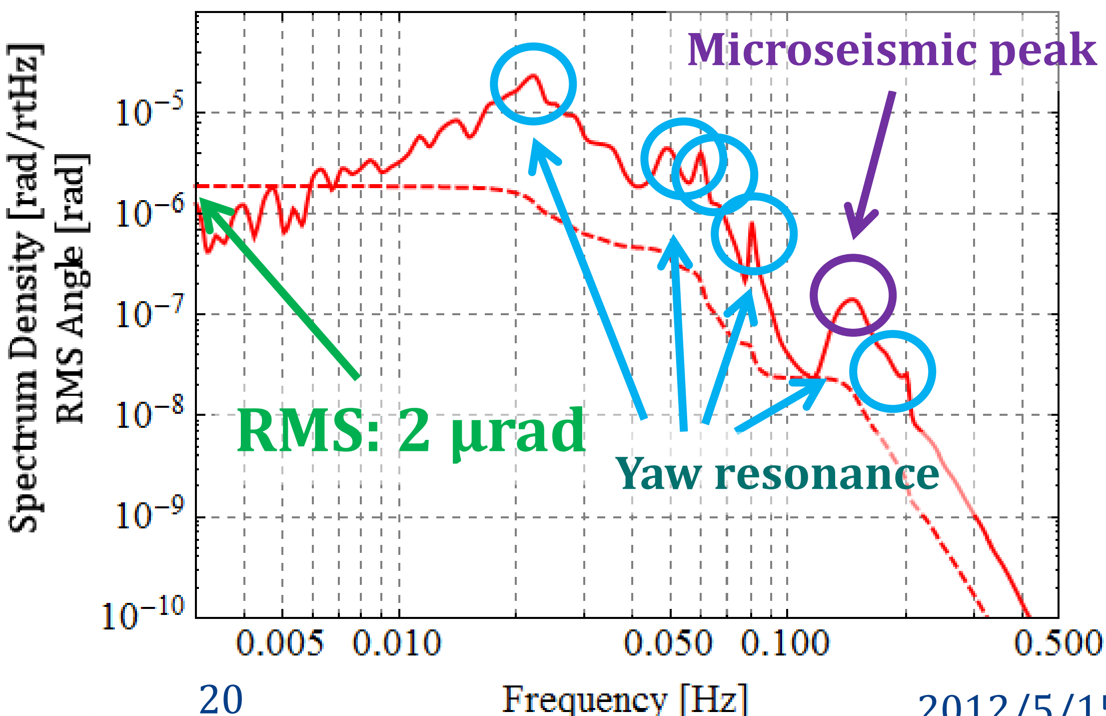
Effect on Angular Motion

* If one employs **asymmetric** wiring of heat links..



Top View

Mirror Yaw Angle

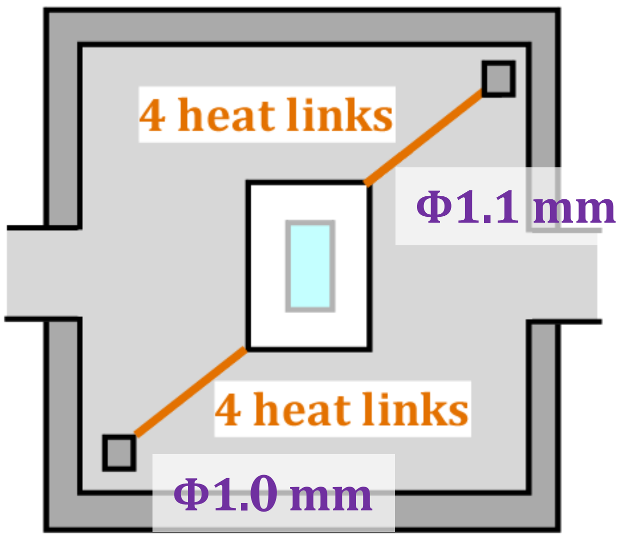


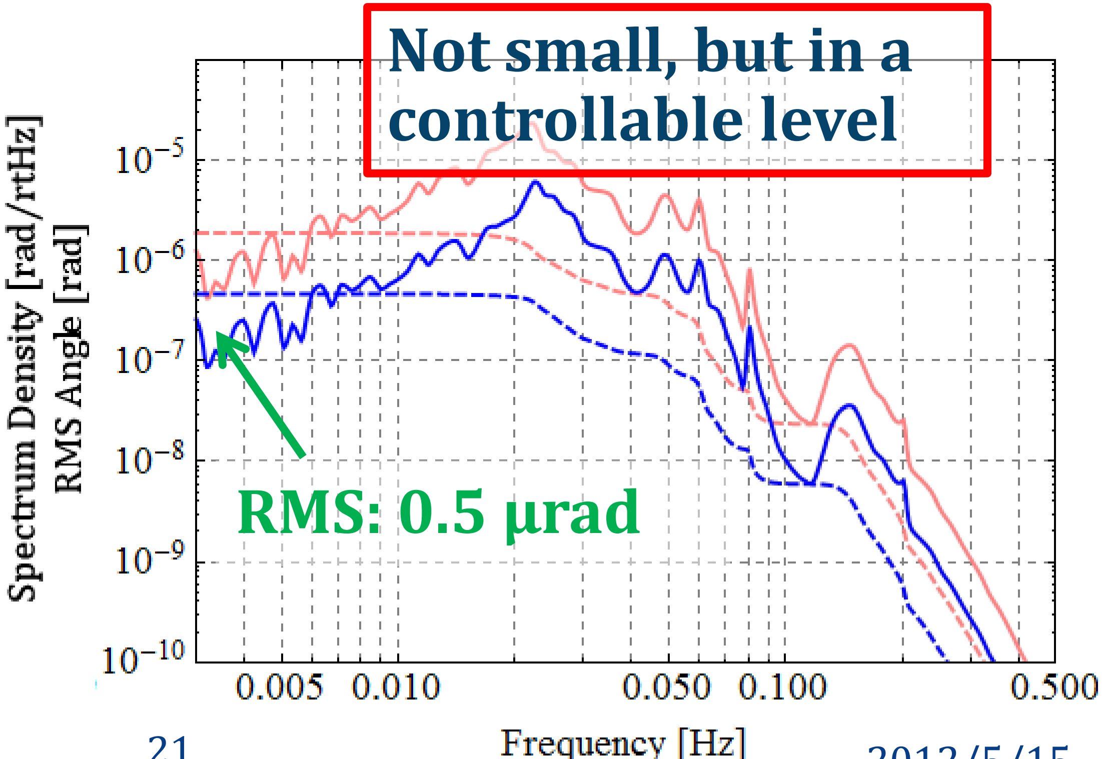
* Eddy current damping for yaw modes is applied

T. Sekiguchi, Master Thesis (JGW-P1200770)

Symmetric Configuration

* **Symmetric** wiring does not subject any torque.
* If you admit **10%** thickness difference in two connections
  → **Blue Curve**





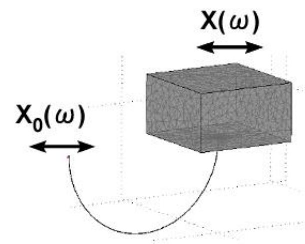
Summary

Summary

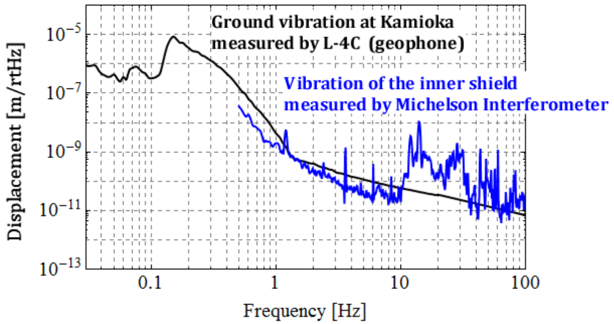
* **Careful wiring** of heat links is required, in order to mitigate the seismic noise introduced from them.
* Further isolation, or improvement of the suspension design **may** be necessary.
* Yaw excitation by heat links would be **not** so huge (be in a controllable level).

Future Works

- **Transfer function measurement** of heat links. (How to ??)



- **Vibration measurement** inside the cryostat.
  - L. Naticchioni and D. Chen will start this autumn



The END

Appendices

Requirement for KAGRA Test-Mass Suspensions (1)

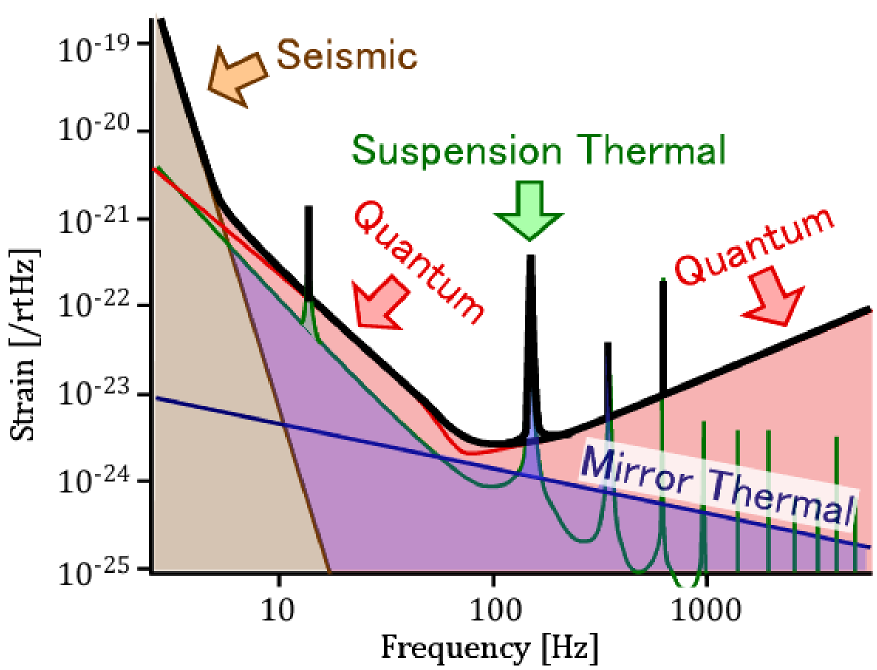
* **Seismic noise** should be much lower (at least **10** times smaller) than other noises at the detector observation band (> 10 Hz).

Seismic Noise Requirement:

< 3 x 10^{-20} m/√Hz @ 10 Hz

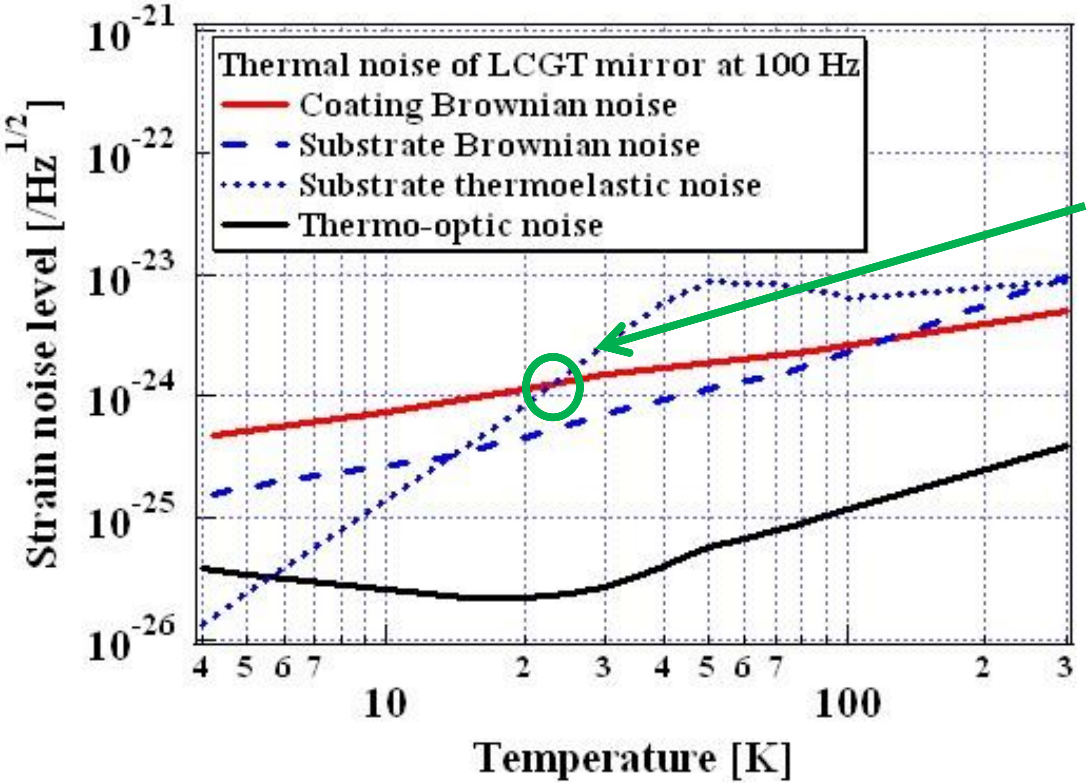
And rolls off steeper than f^{-3}

KAGRA Design Sensitivity



Requirement for KAGRA Test-Mass Suspensions (2)

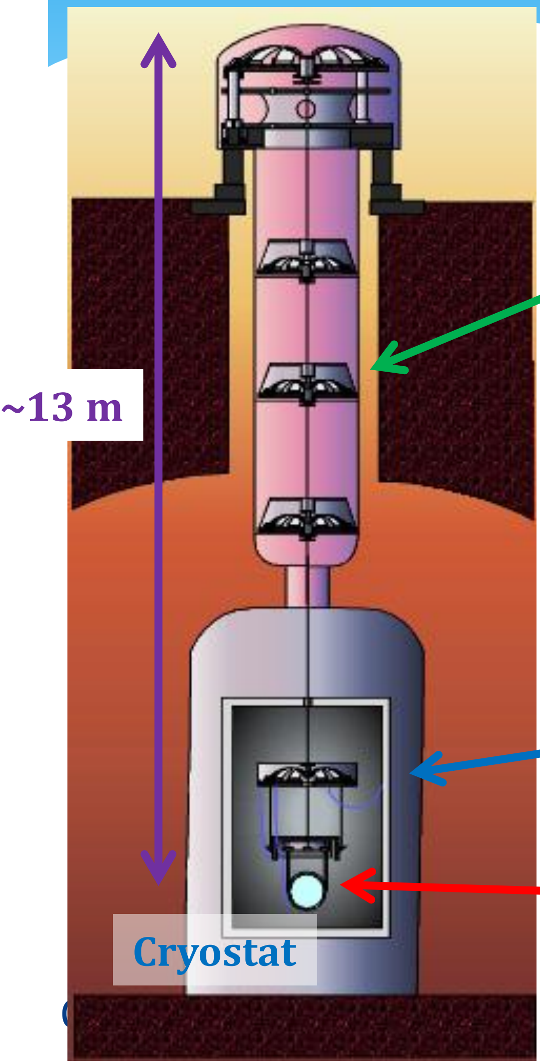
- Mirror temperature should be **as low as 20 K** to suppress **thermal noise**.



Substrate thermoelastic noise ($\propto T^{2.5}$) gets lower than coating Brownian noise($\propto T^{0.5}$) at < 23 K

Seismic Attenuation System (SAS) for KAGRA

* 7-stage pendulum + 5-stages vertical spring
  (horizontal attenuation) (vertical attenuation)



Metal cantilever springs

Geometric Anti-Spring (GAS) Filter

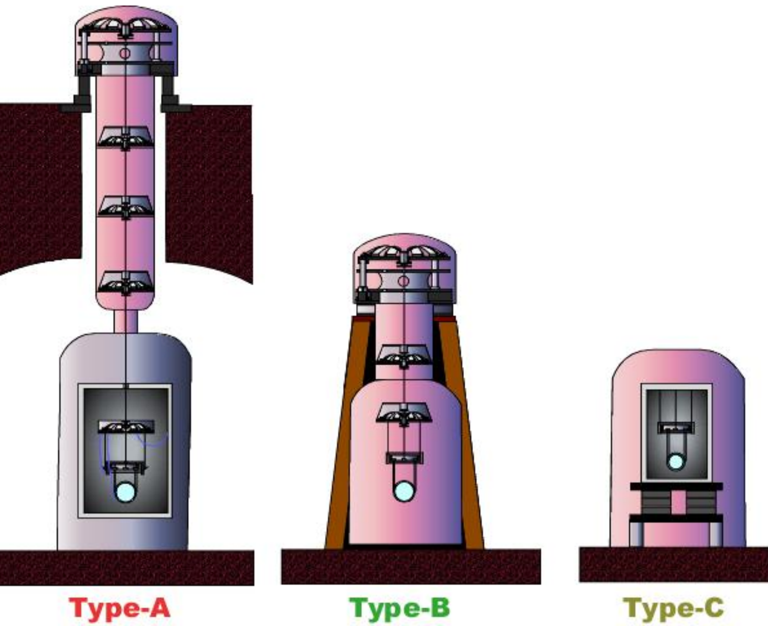
$f_0 \sim 0.3$ Hz

Last 3 stages are cooled at **cryogenic** temperature (<20 K) to suppress **thermal noise**

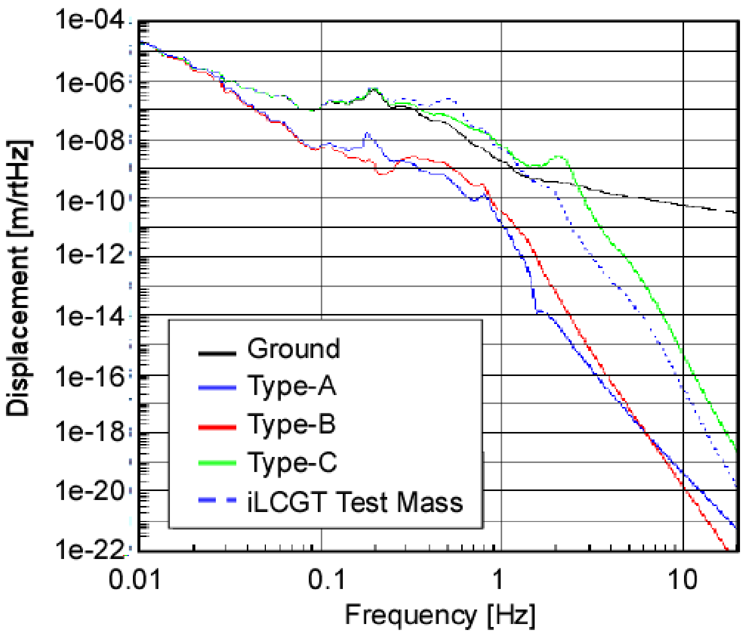
Mirror (Test Mass)

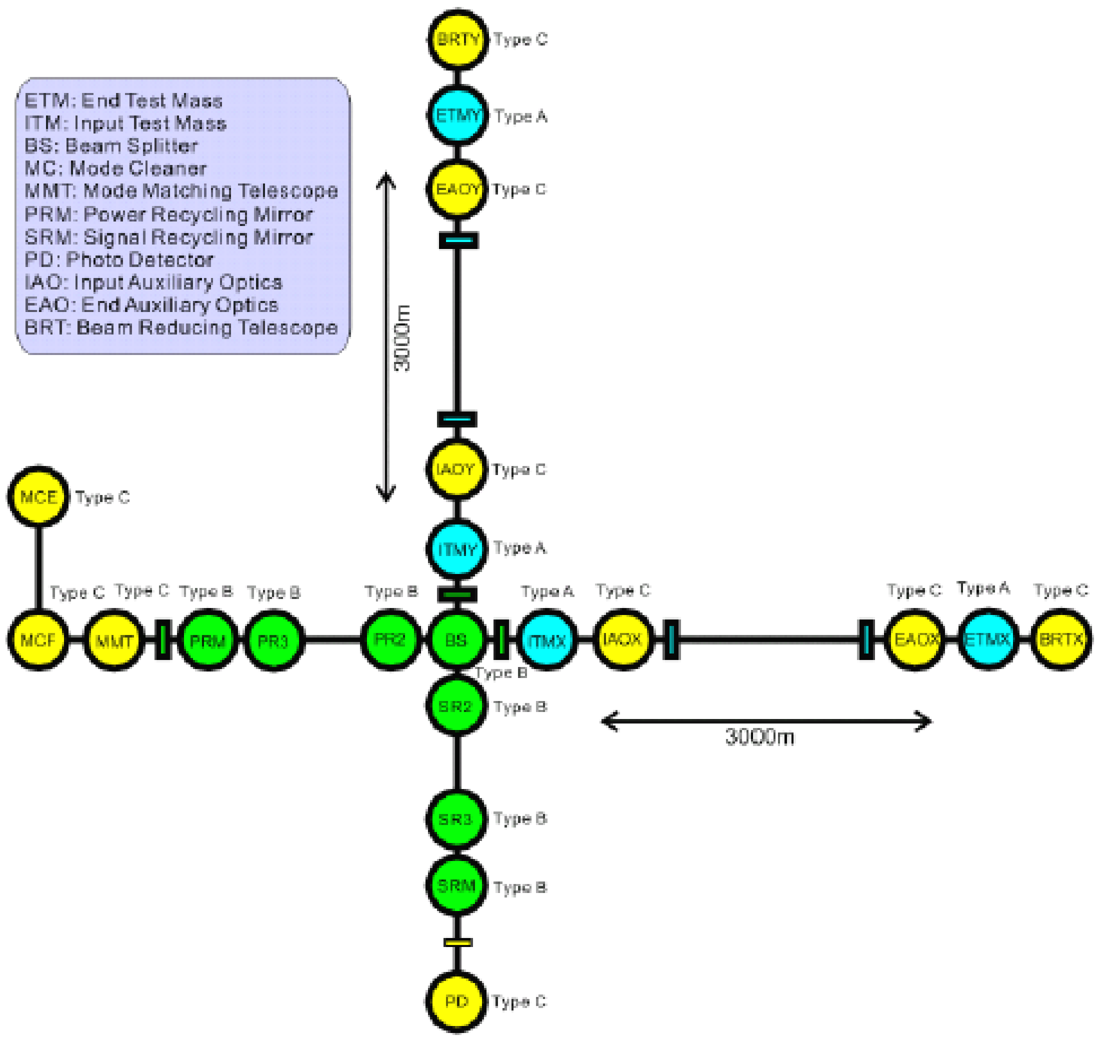
* Beam splitter and other optics are suspended by smaller vibration isolation systems

Vibration Isolation System Disposition



Expected Performance



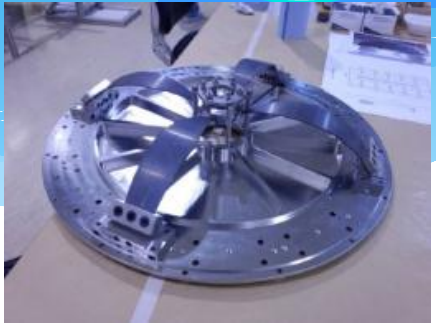


SAS Status

Prototype Experiment:

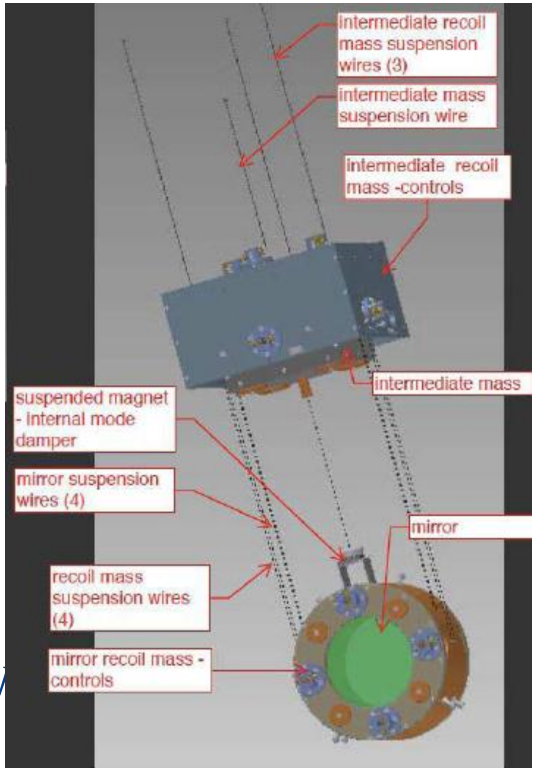
Standard filter (GASF): Performance was measured @NIKHEF

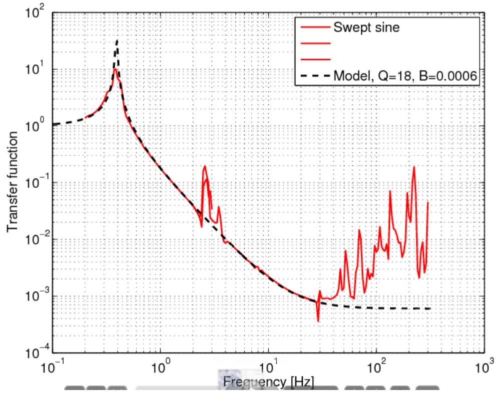
Pre-isolator (IP&GASF): Now Measuring @ Kashiwa



Design:

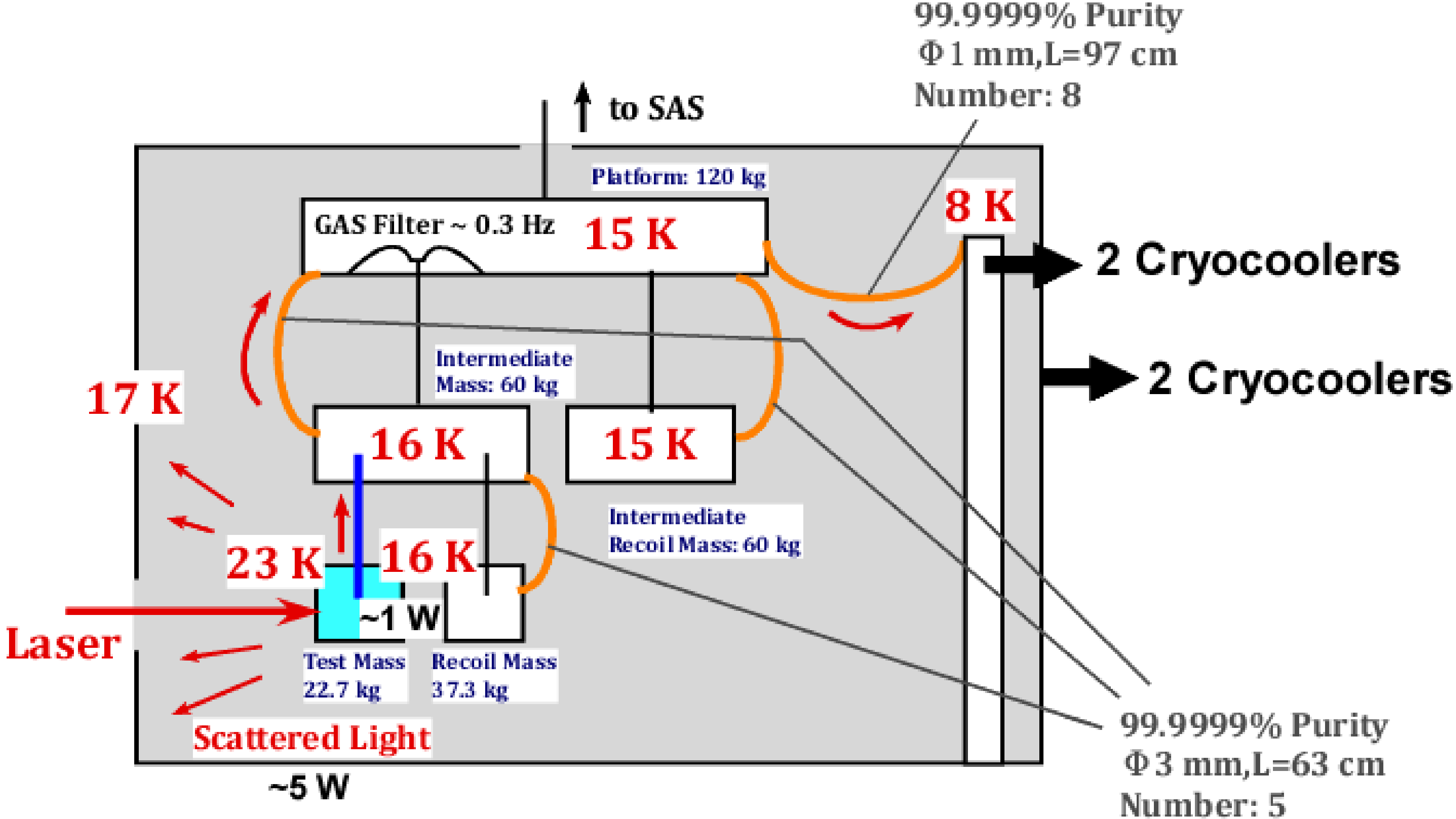
Type-B Payload: Now Designing





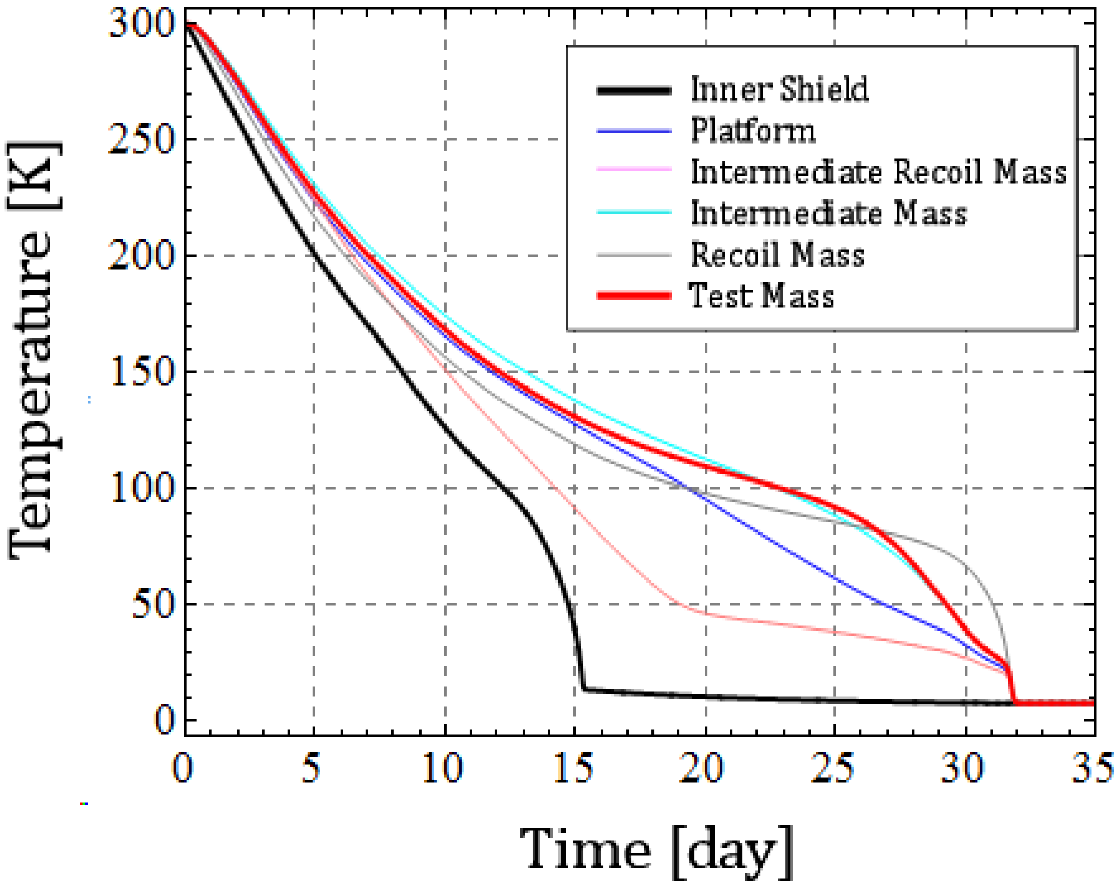
Measured Transfer Function (Feb. 16th, 2011)

Cryogenics



99.9999% Purity
Φ1 mm,L=97 cm
Number: 8
to SAS
Platform: 120 kg
GAS Filter ~ 0.3 Hz
15 K
8 K
2 Cryocoolers
2 Cryocoolers
Intermediate
Mass: 60 kg
17 K
16 K
15 K
Intermediate
Recoil Mass: 60 kg
23 K
16 K
~1 W
Laser
Test Mass
22.7 kg
Recoil Mass
37.3 kg
Scattered Light
~5 W
99.9999% Purity
Φ3 mm,L=63 cm
Number: 5

Initial Cooling Time



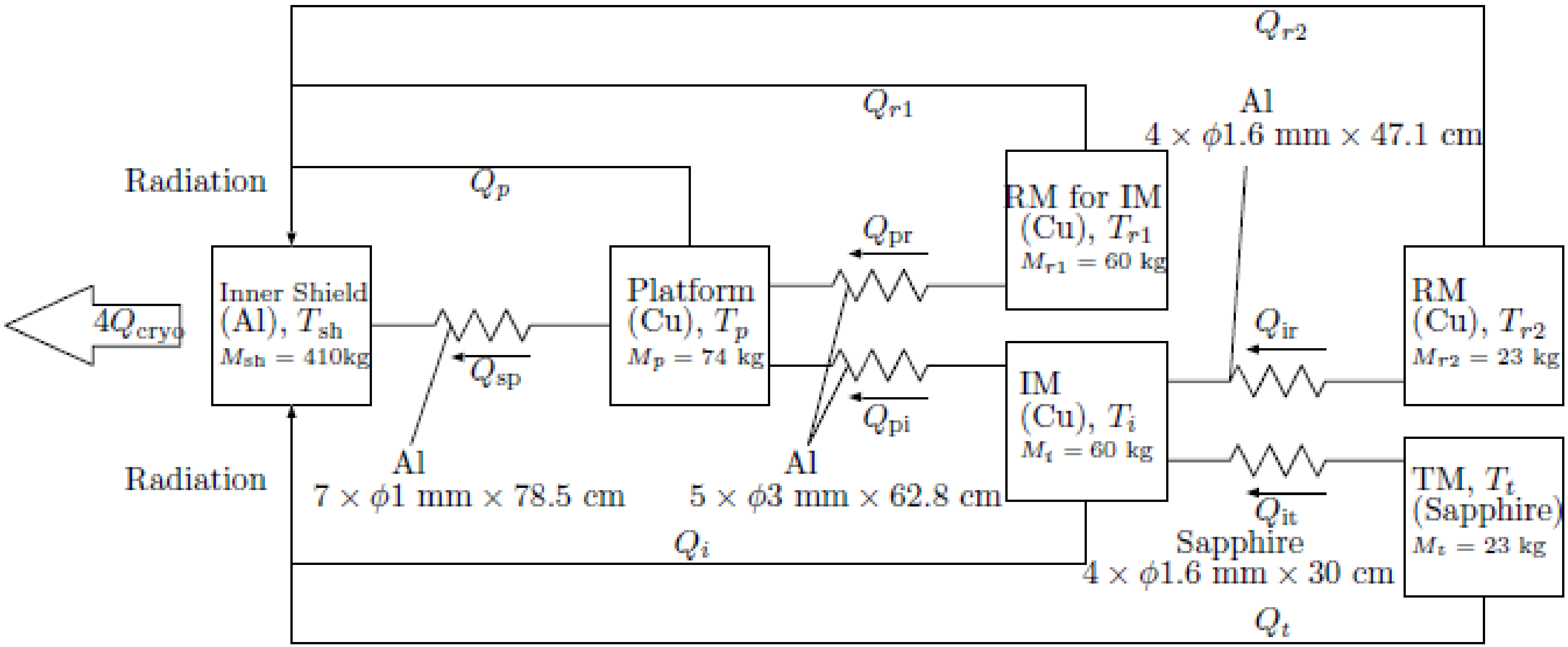
Thermal simulation with Y. Sakakibara's Method

*** The inner shield and the masses except for the test mass are DLC-coated (ε=0.41).**

**** Radiation cooling is dominant before 15th day.**

Initial Cooling Time Calculation Diagram

By Y. Sakakibara



Heat Load

- Absorption in mirror

  Coating: 0.4 W (1ppm)

  Substrate: 0.6 W (**50** ppm/cm)

  Total: 1.0 W

- Inner shield

  Radiation from 80 K: 1.3 W

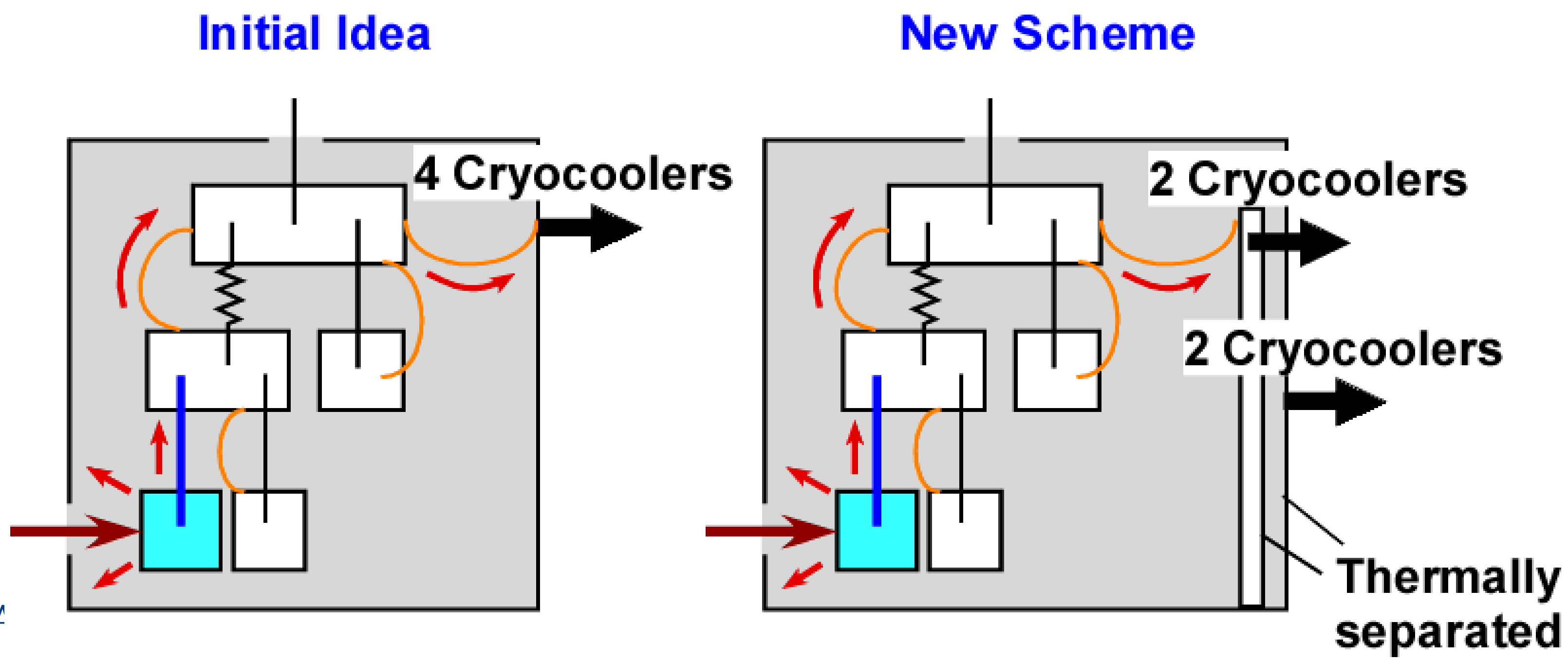
  Conductance: 0.8 W

  Scattered Light: **5 W** (10 ppm)

  Total: 7.1 W

Heat Extraction Scheme

* In the new heat extraction scheme, **mirror temperature** would not be raised, even if large **scattered light** attacks the shield.



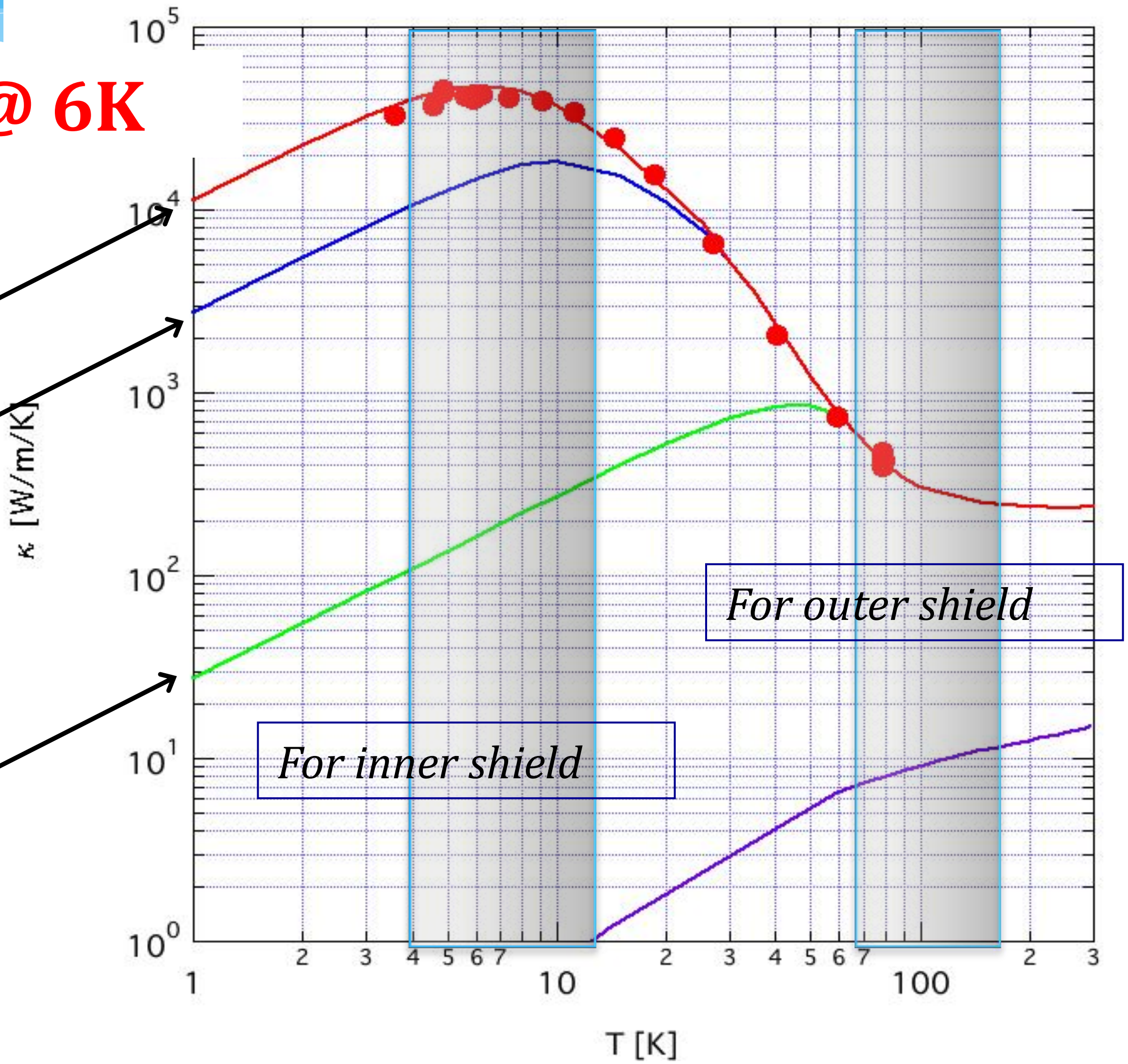
Thermal Conductivity of High Pure Aluminum

40,000 W/m/K @ 6K

6N Aluminum

5N up Al
RRR=3000

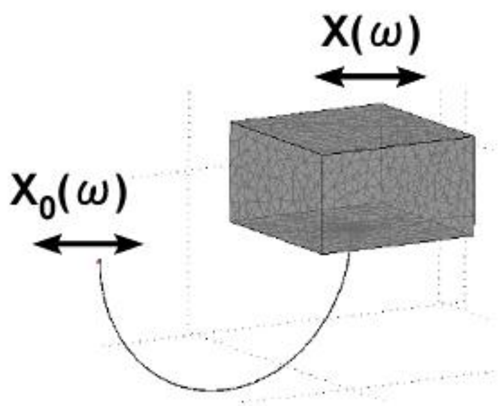
2N Aluminum
~Type A-1070

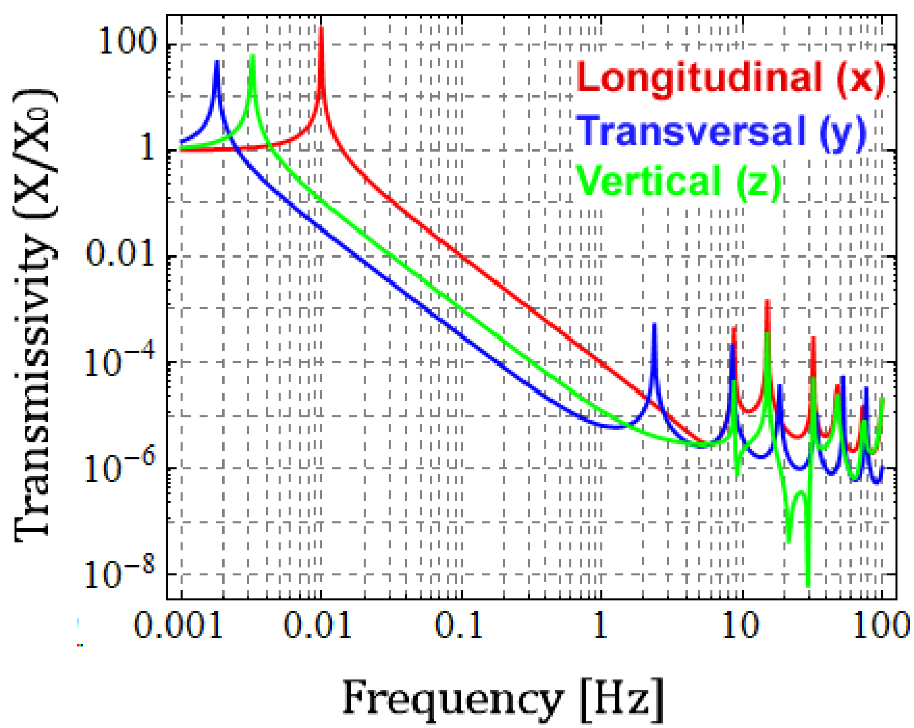


Heat Link
TF Calculation

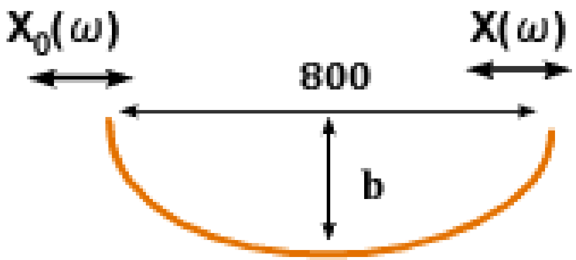
FEM Simulation Done by Y. Aso, (JGW-G1000108)

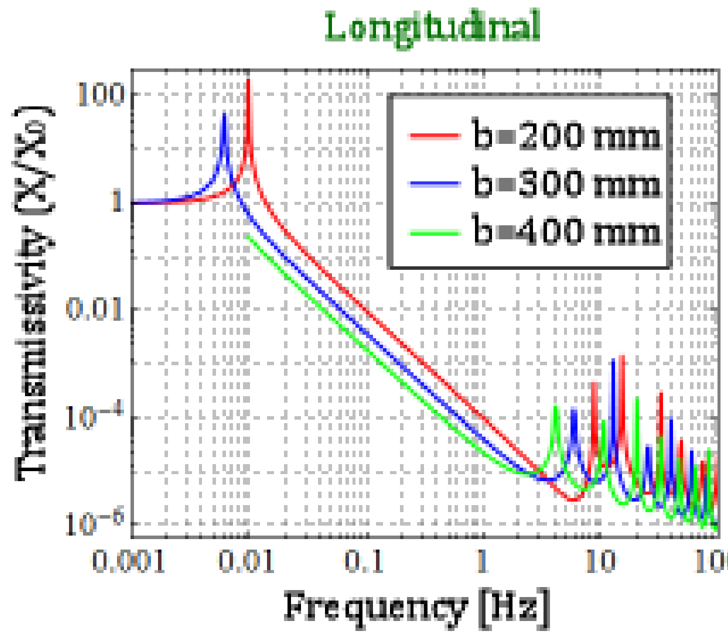
- Pure aluminum (E=68 GPa), Φ1 mm
- Half-ellipsoid (a=400 mm, b=200 mm)
- Loss angle: 10^{-4}

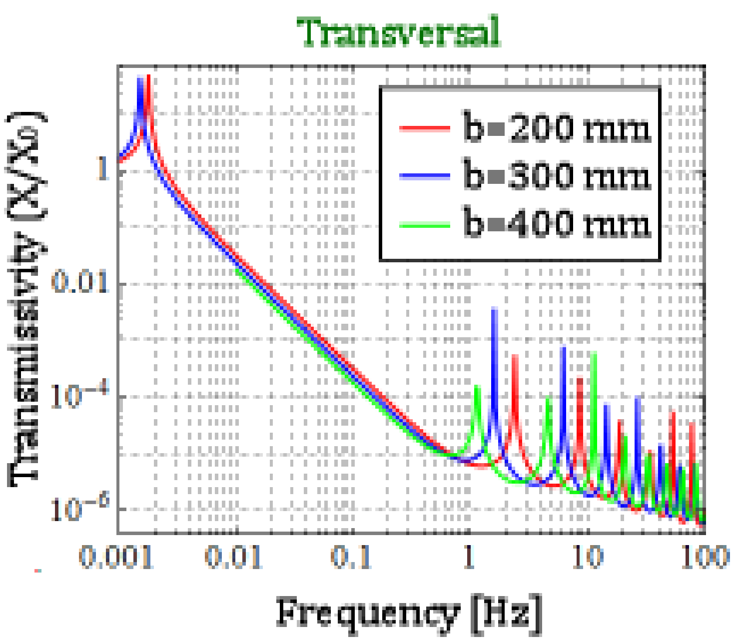


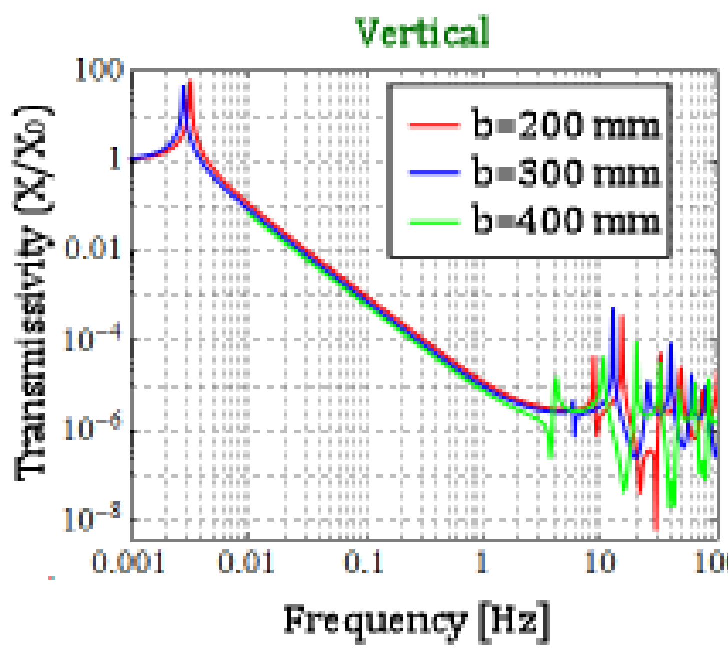


Heat Link Transfer Functions

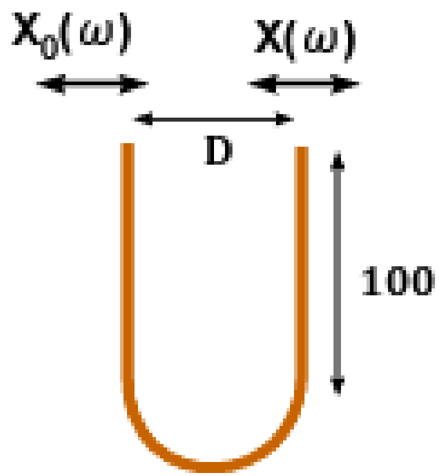


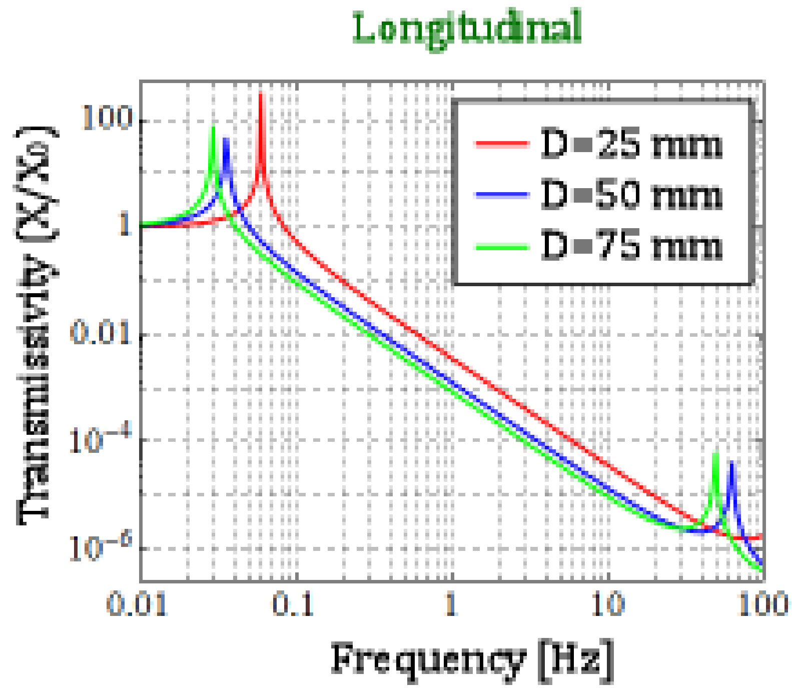


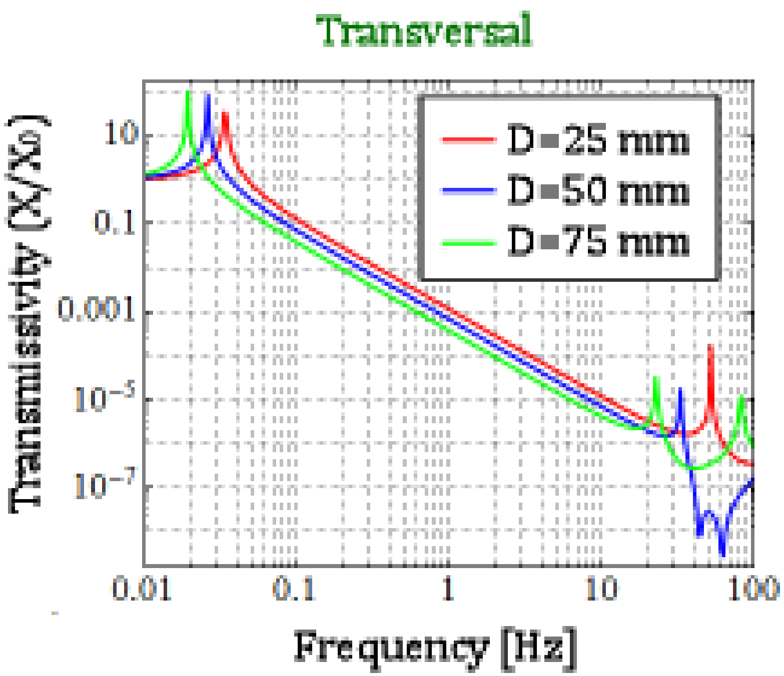


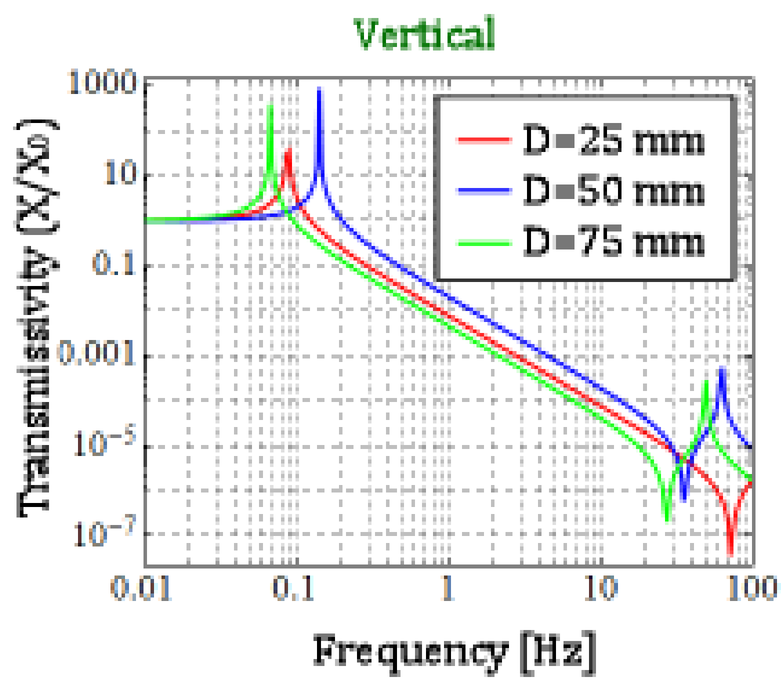


Heat Link TFs



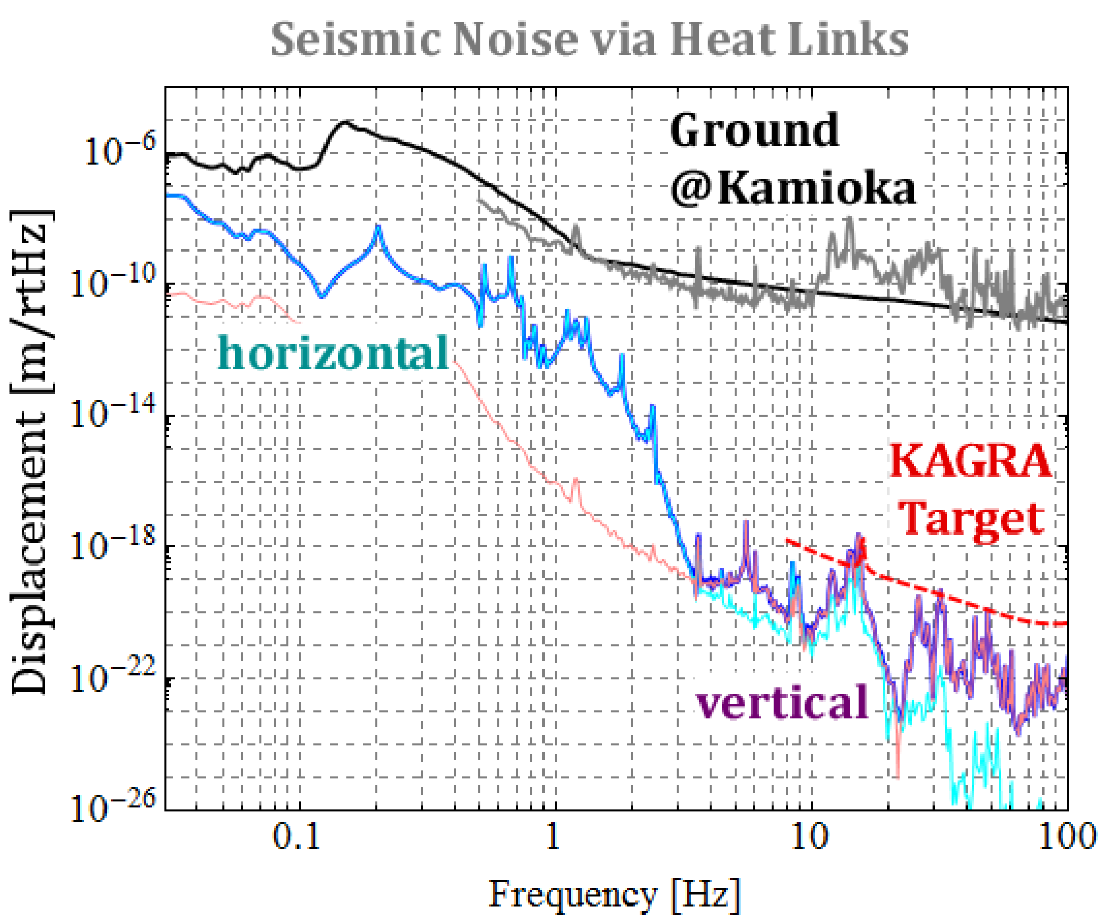






Seismic Noise via Heat Links

* Couplings from the **vertical** motion is dominant above 3 Hz.

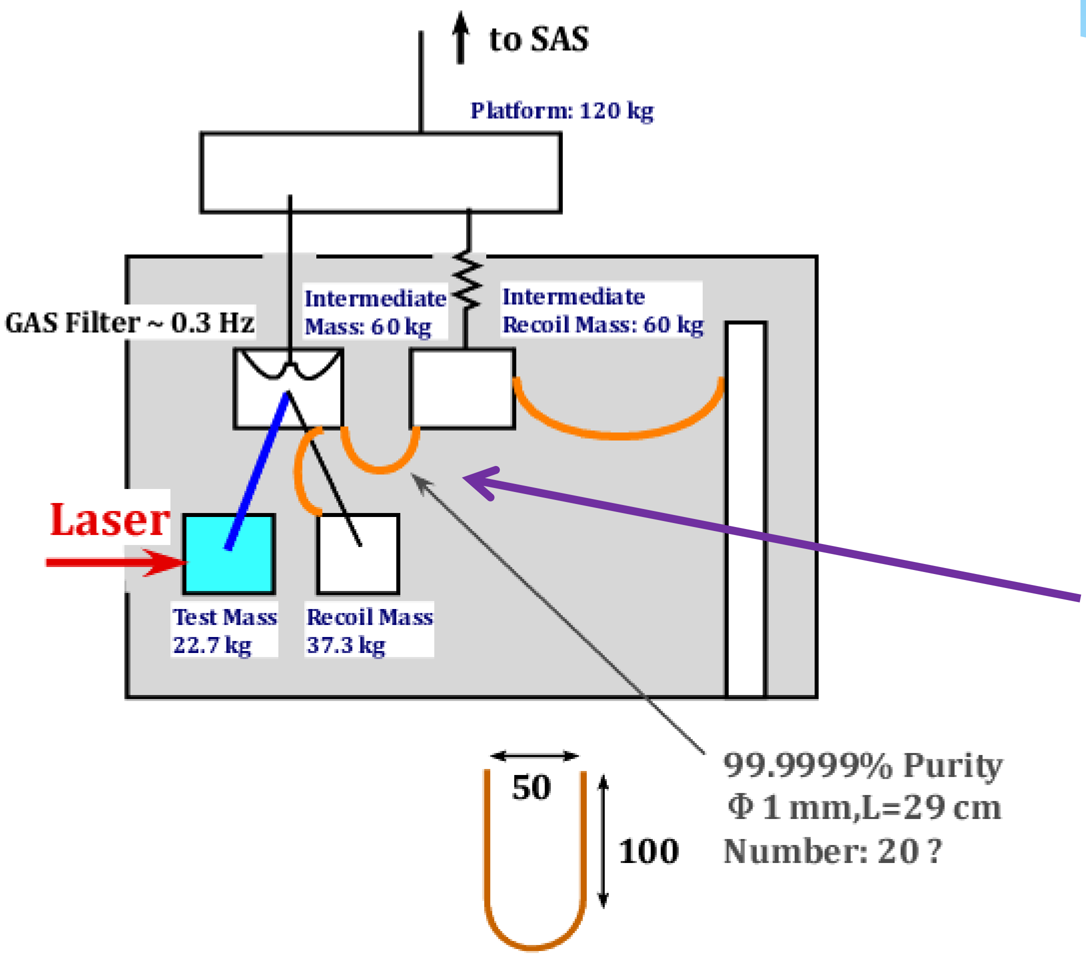


* Assuming 1% coupling from vertical

Heat Links with Half Diameters

- How about decreasing the fiber thickness, from **Φ1.0 mm** to **Φ0.5 mm** ?
  - Heat conductivity per link: x 1/4
  - Necessary number of links: x 4
  - Spring constant per link: x **1/16**
  - Total stiffness: **1/4**
  - Heat link total mass: **Same**

Hot Platform Design



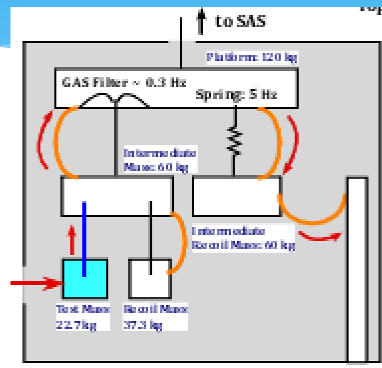
Push heavy Platform to the **room temperature** part.

Decrease the **initial cooling time.**

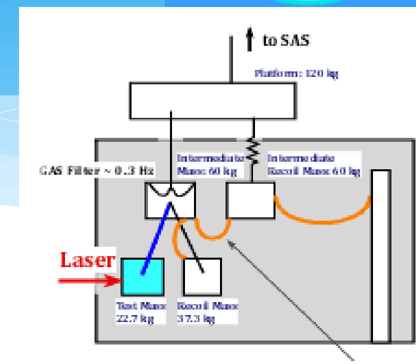
Another vibration shortcut occurs between IM and IRM

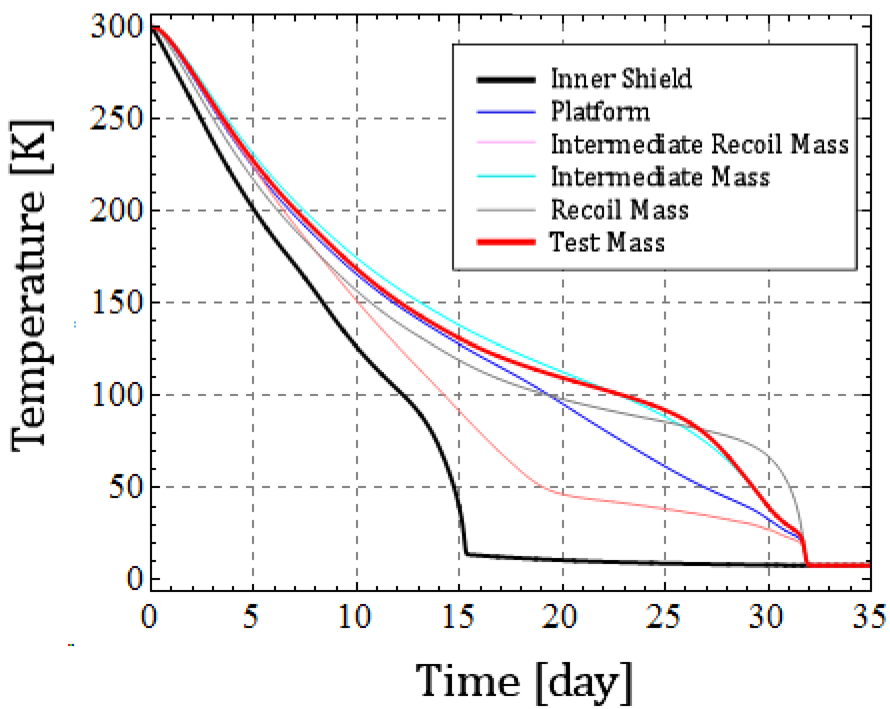
Hot Platform
Initial Cooling Time

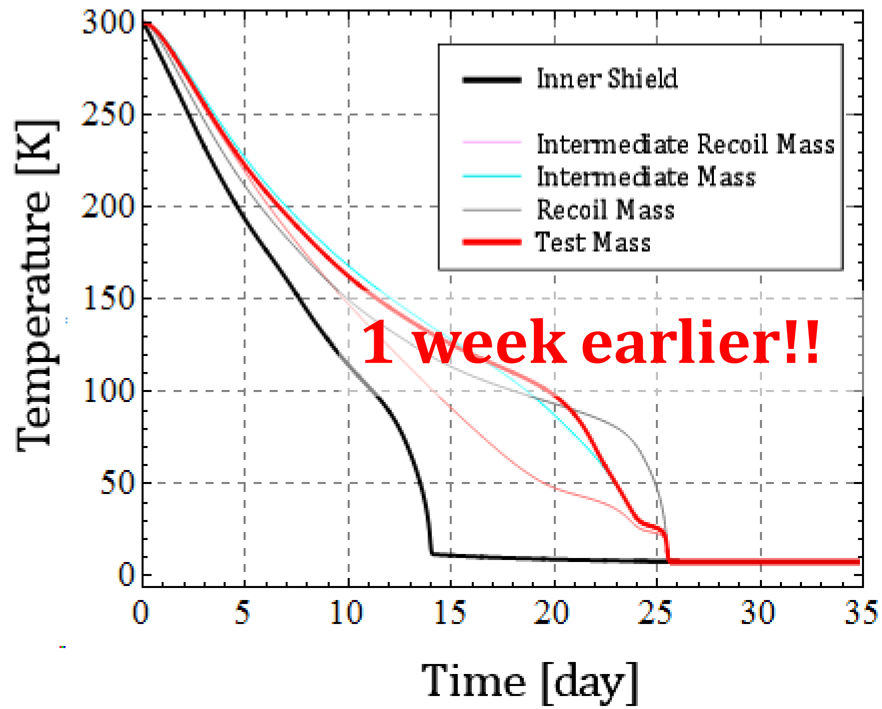
Current Design



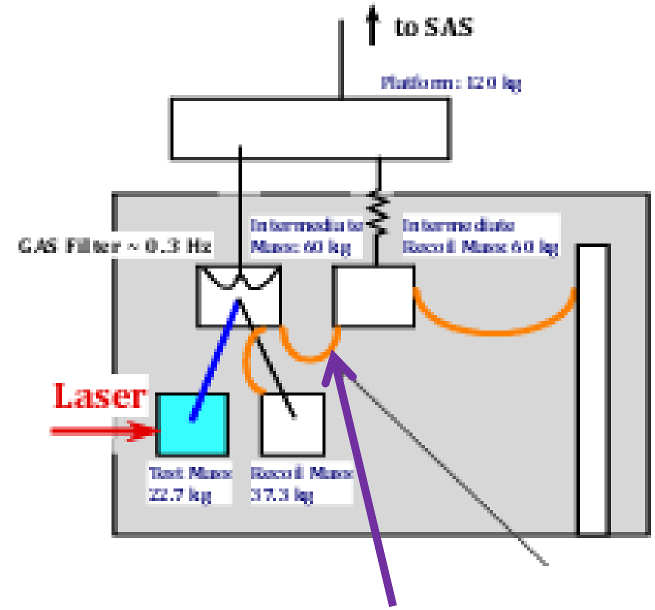
Hot Platform

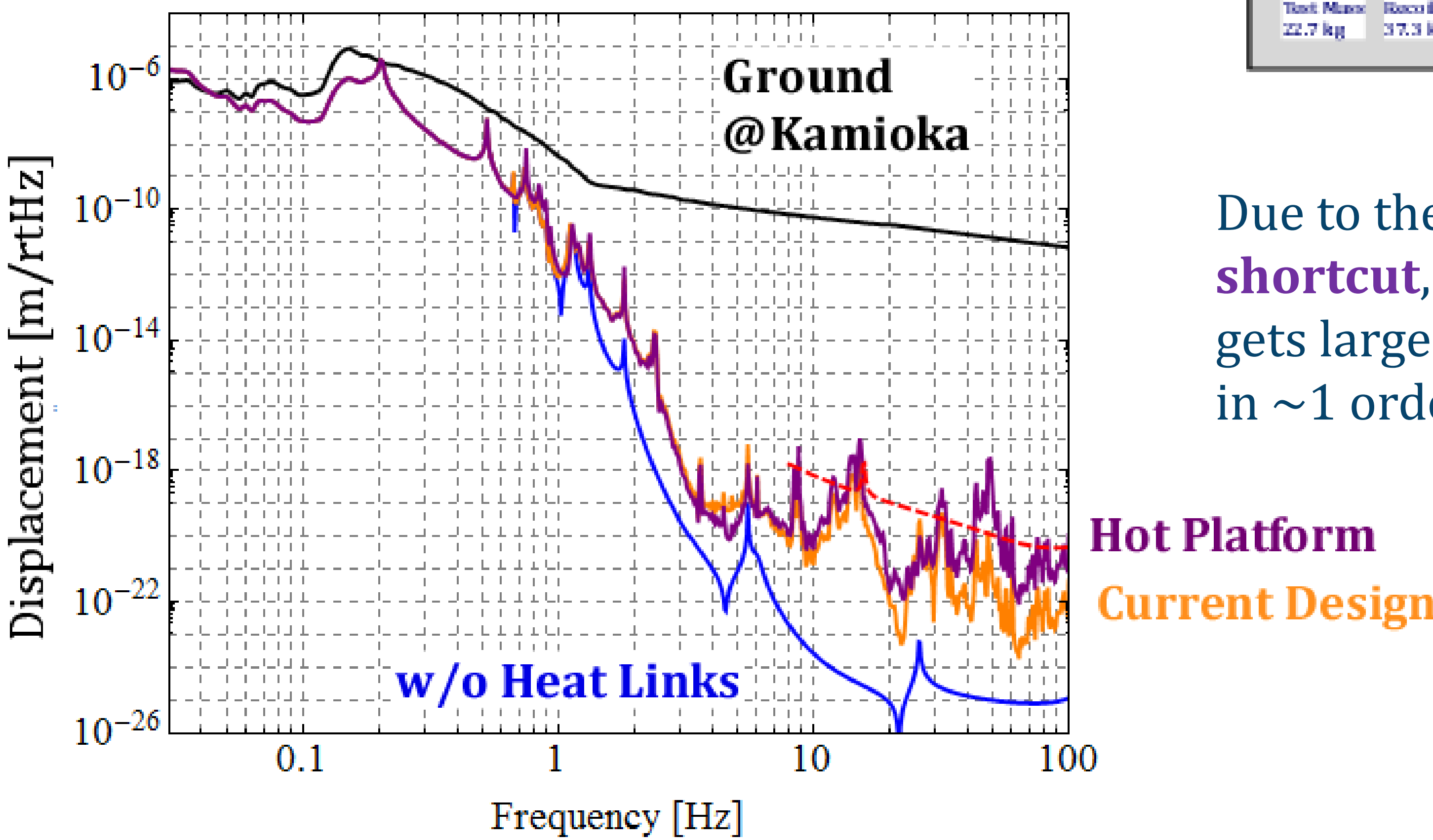






Hot Platform Seismic Noise

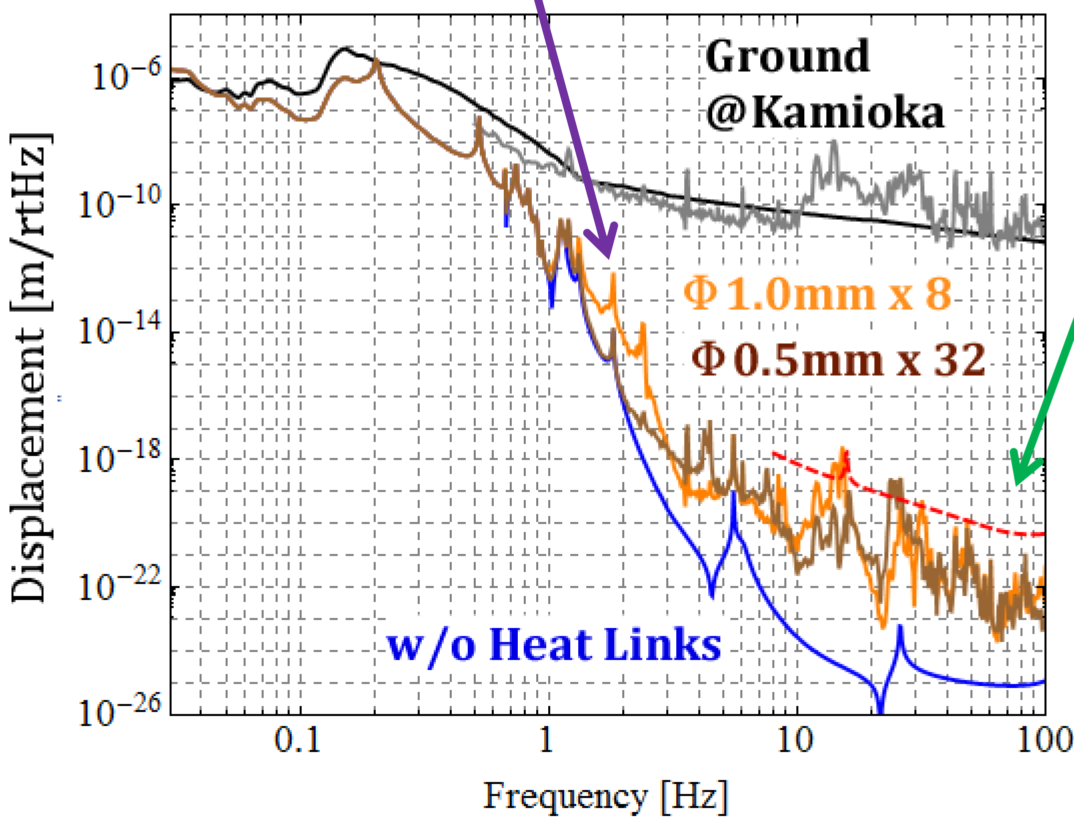




Due to the **vibration shortcut**, seismic noise gets larger **above 10 Hz** in ~1 order of magnitude

Heat Links with Half Diameters

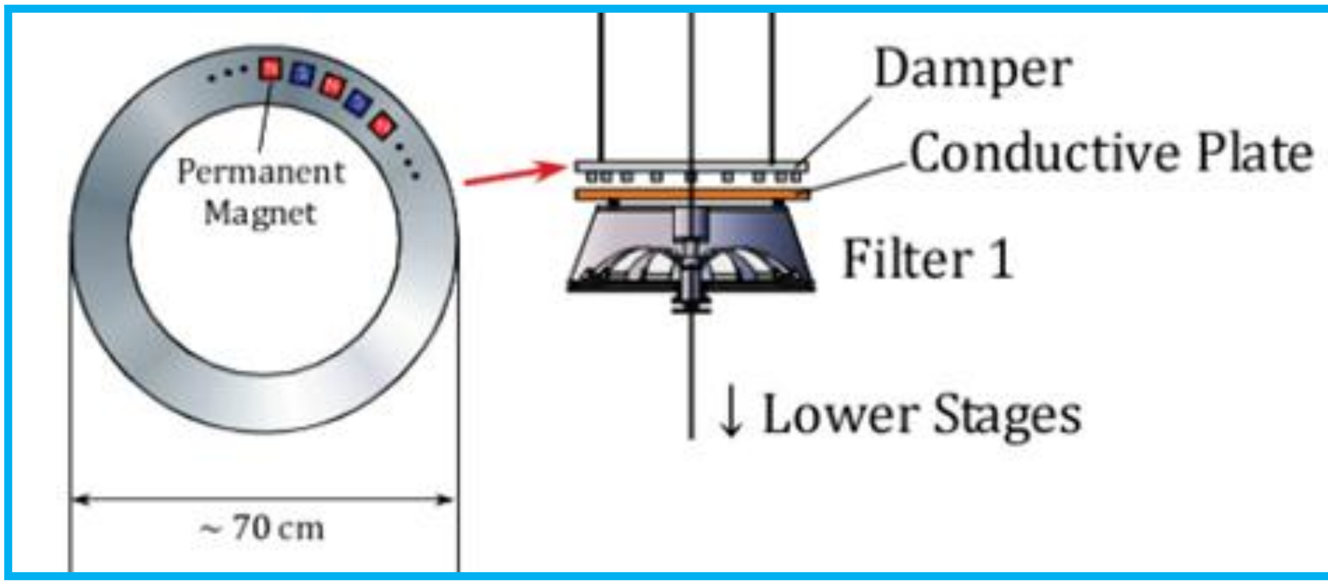
- Only better at **1-3 Hz**, not so good **above 10 Hz**

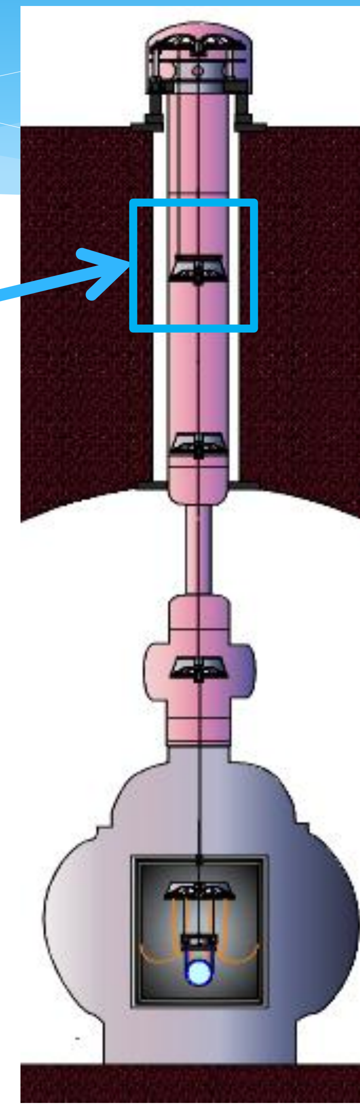


*** Assuming 1% coupling from vertical**

Torsion Mode Damping

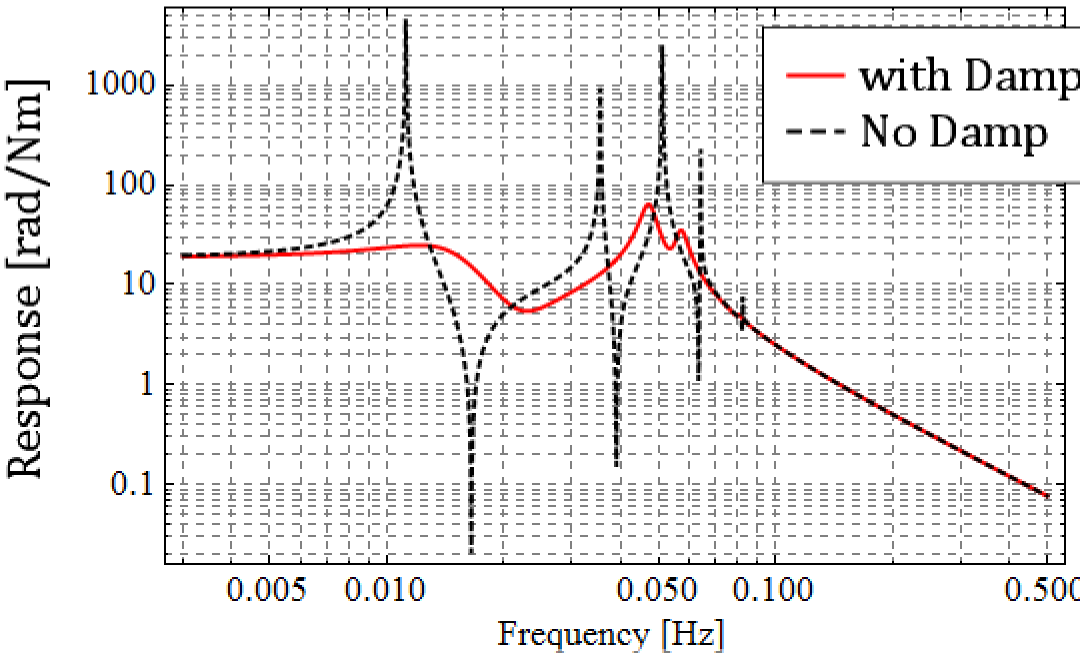
* Eddy current damping for yaw modes





Torsion Mode Damping

* Torsion modes of the single wire suspensions would be sufficiently damped by the eddy current damper.



Mirror yaw angle response to applied torque

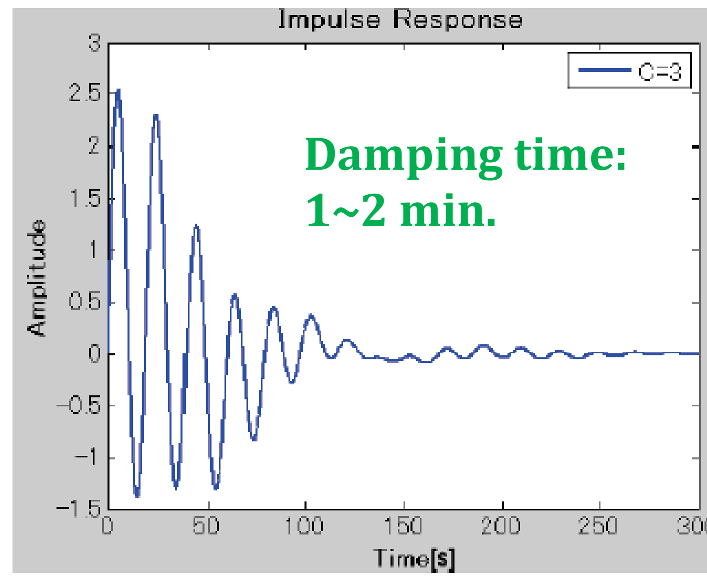


Figure 6.7: Impulse response to the external torque.

Effect on Angular Motion