Cryogenics at KAGRA

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ICRR, KAGRA Collabration

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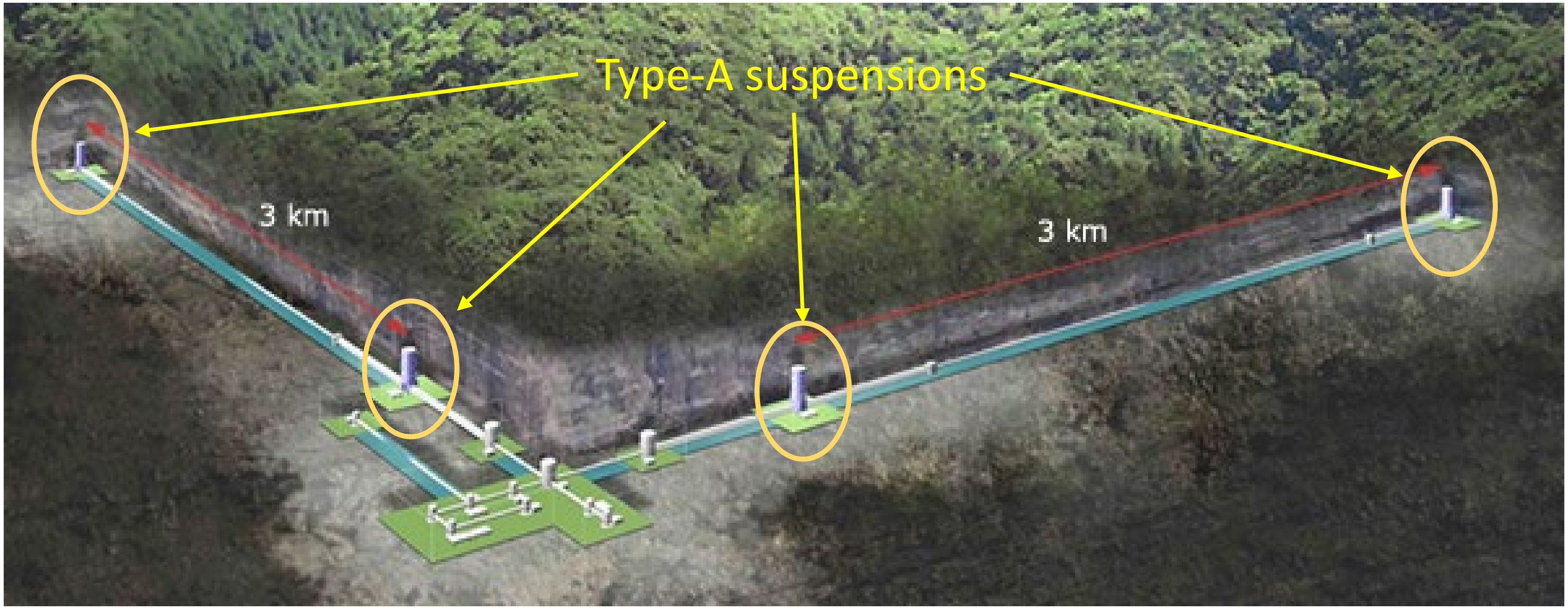
KAGRA gravitational wave detector

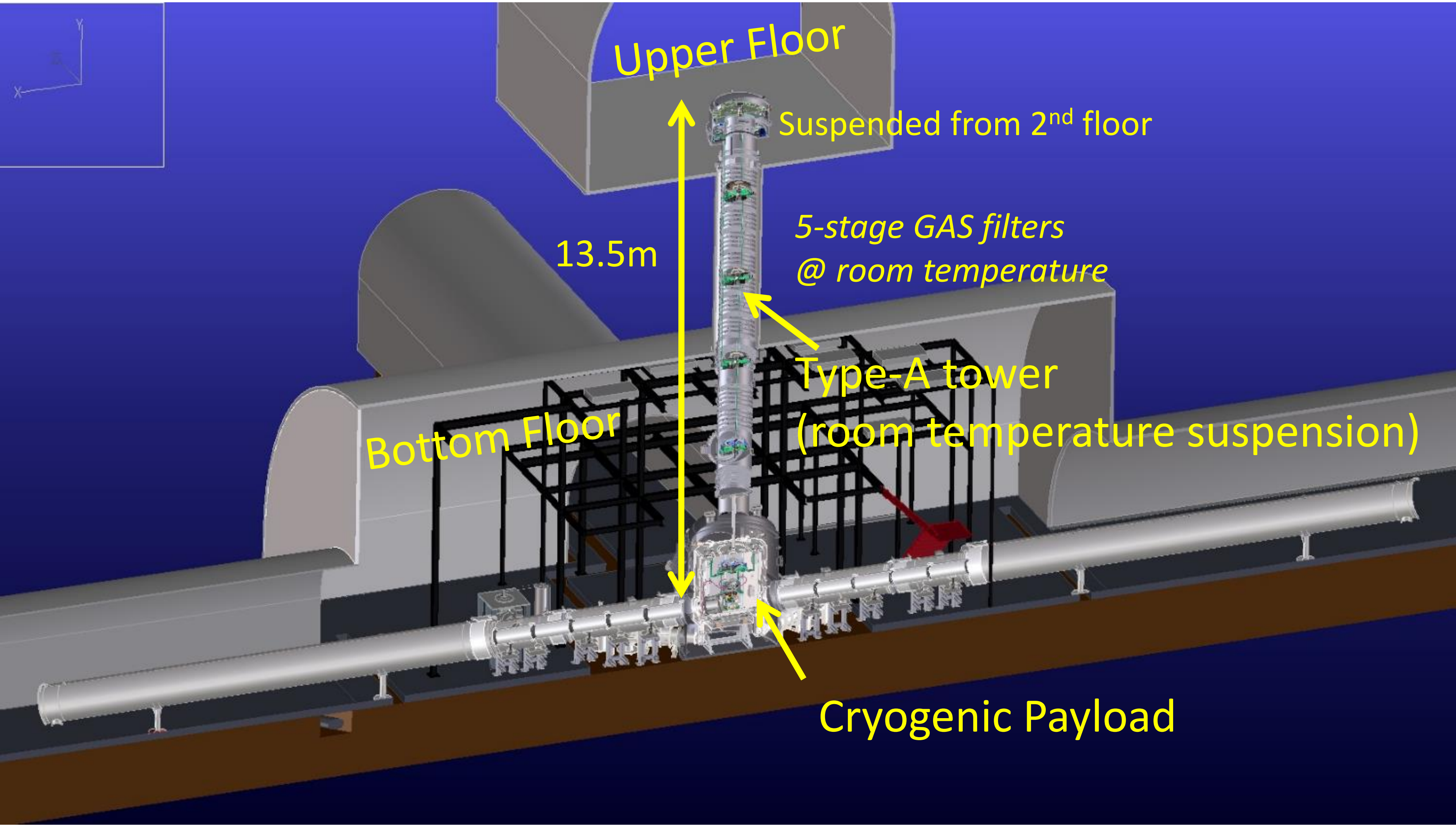
- 3-km arm interferometric gravitational detector.
- Located at Kamioka in Japan near Super Kamiokande.
- Key features:
  - Using underground site
  - Using a cryogenic mirrors

These features have a benefit to improve low frequency sensitivity



Test mass suspension (Type-A suspension)

9-stage 13.5-m suspension for vibration isolation with a cryogenic mirror



Several technical difficulties

- Heat extraction vs vibration generation

It is necessary for using cryocoolers to make stable long-term operation but they generate large vibration especially at low frequency due to the cycle of gas suppression and expansion.

– Low vibration cryocooler is necessary.

- Heat extraction vs suspension thermal noise.

Thick fibers are necessary for heat extraction but they inject large suspension thermal noise at low frequency.

– High thermal-conductivity fibers' development is necessary

- Heat extraction vs vibration introduction via heat links.

Thick and short heatlinks are necessary for cooling suspensions but they introduce vibration via themselves.

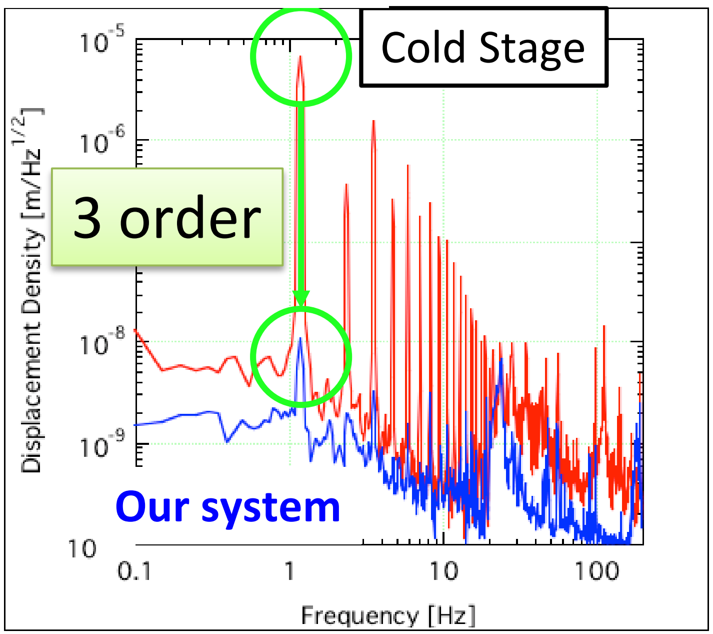
– Heat link vibration isolation system is necessary.

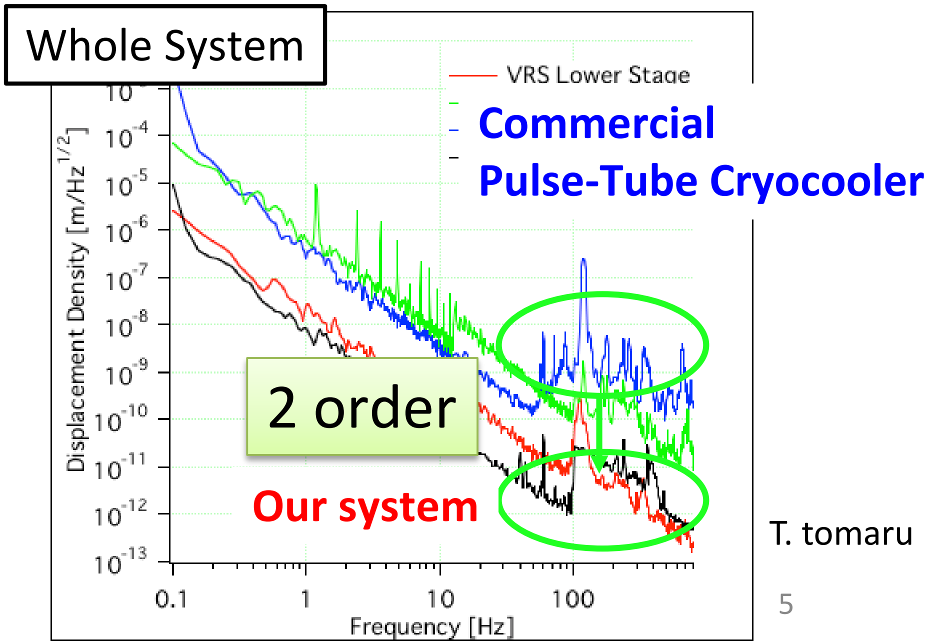
Ultra-low vibration cryocooler

This technology was established in CLIO prototype interferometer

- **nm vibration** at cold stage
- comparable vibration level of whole system with Kamioka seismic vibration

Commercial Pulse-Tube Cryocooler

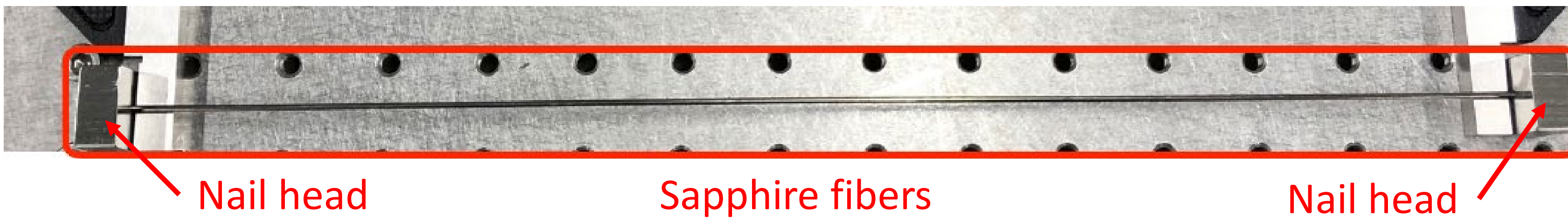


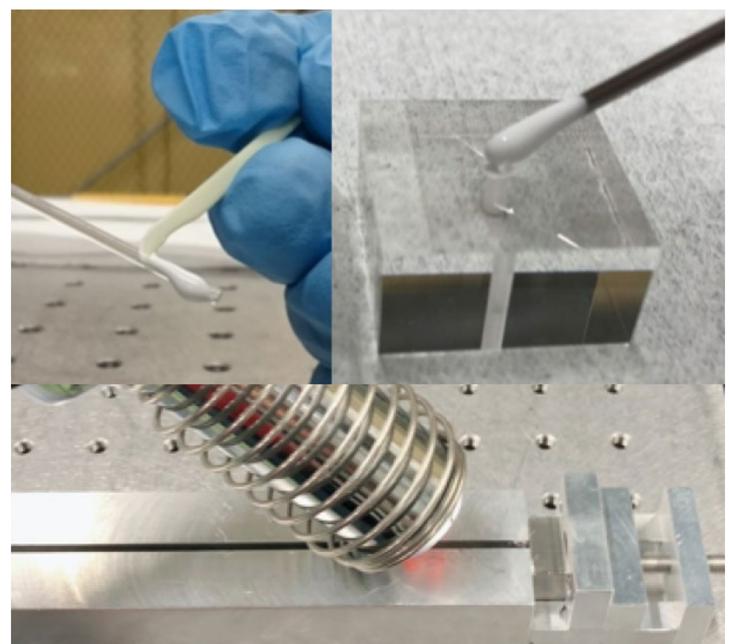


T. tomaru

Sapphire Fiber fabrication procedure

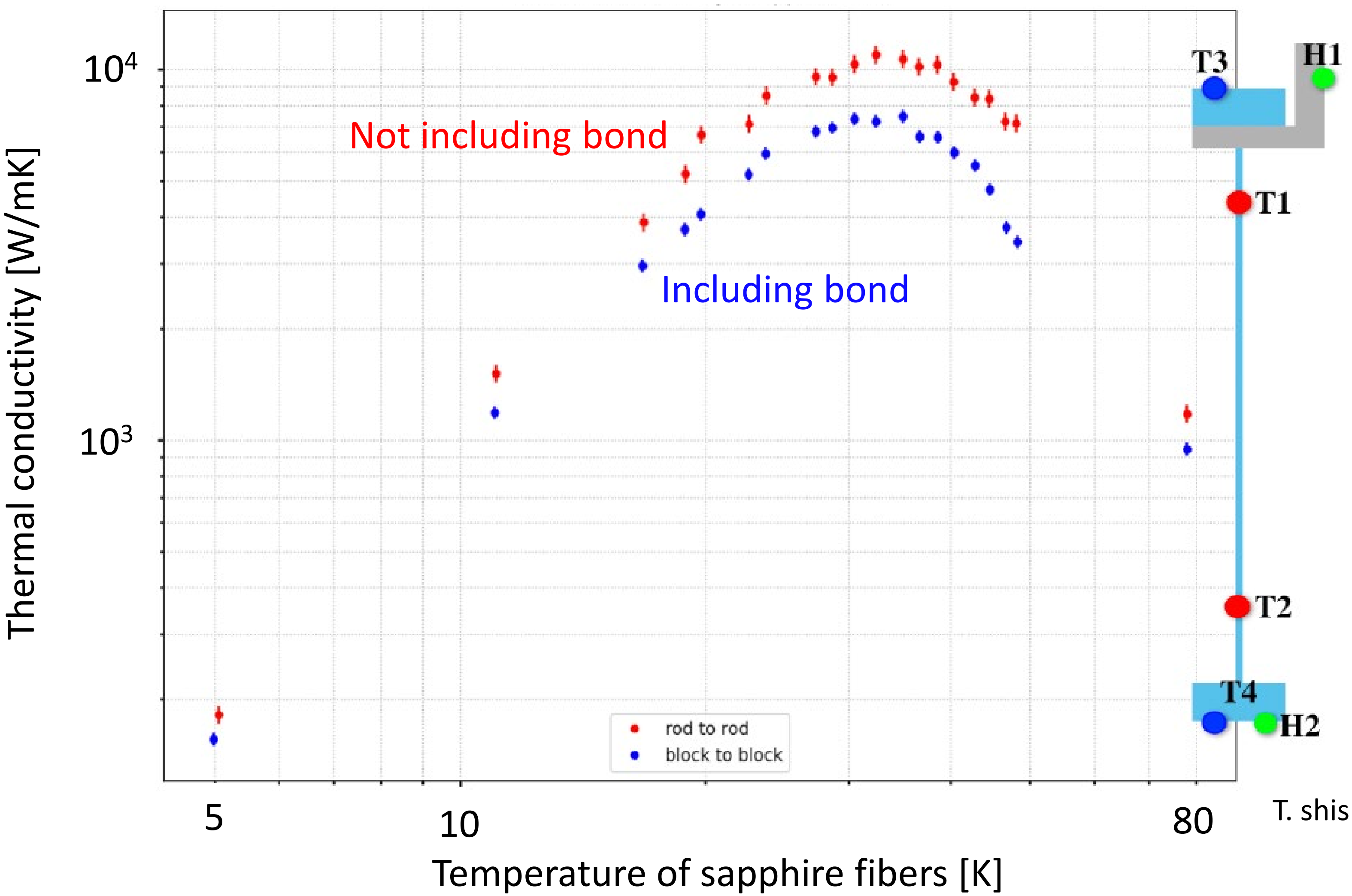
- KAGRA uses sapphire fibers with nail head for suspending mirrors by hooking.
- Nail heads are bonded by a kind of adhesives, which mainly consists of silica and alumina and cures at several hundreds degrees.
- We can achieve precise length control within 0.1 mm in this procedure (our previous procedure, plasma welding, makes large length variety over 1 mm).





T. shishido

Thermal conductivity of sapphire fibers

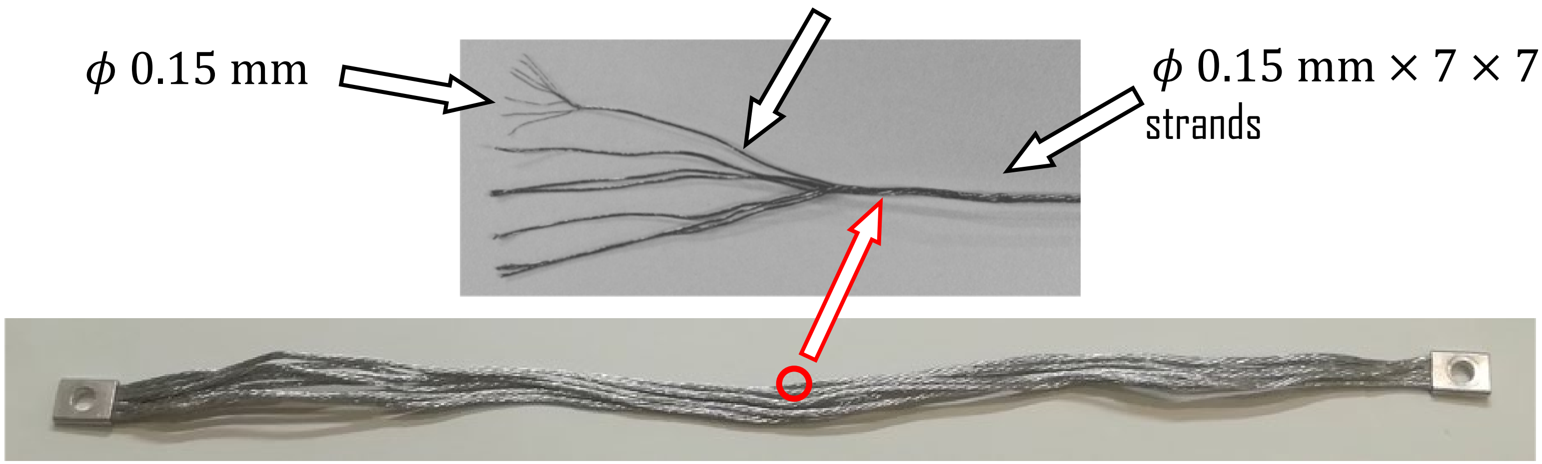


T. shishido

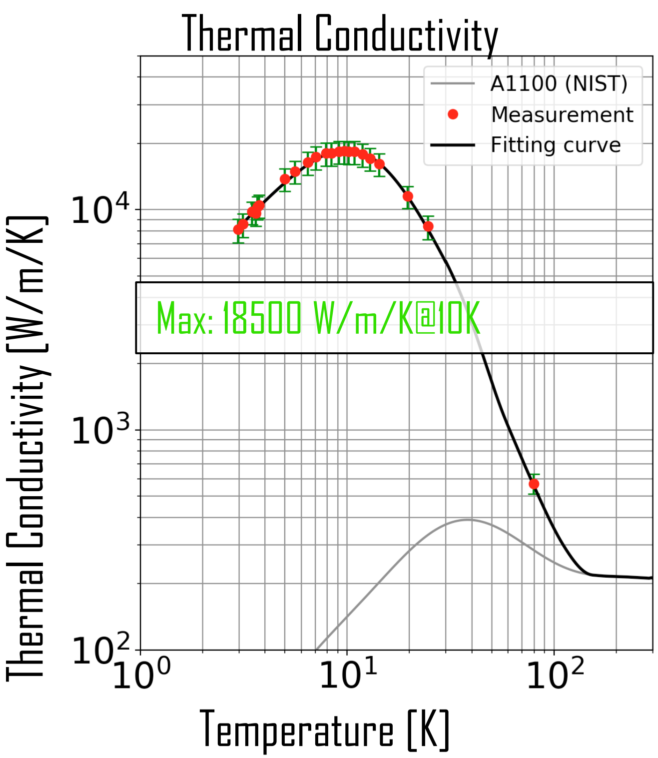
- To increase thermal conductivity of fiber itself, we try to polish its surface.
- To reduce thermal resistance at bond, we try to reduce thickness of bond and increase contact area

Heatlink for KAGRA

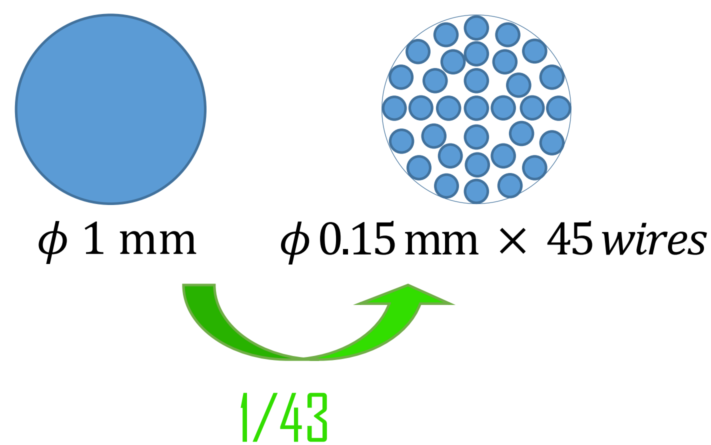
T. Yamada



7 parallels of ϕ 0.15 mm × 7 × 7 strands



Spring constant conparison

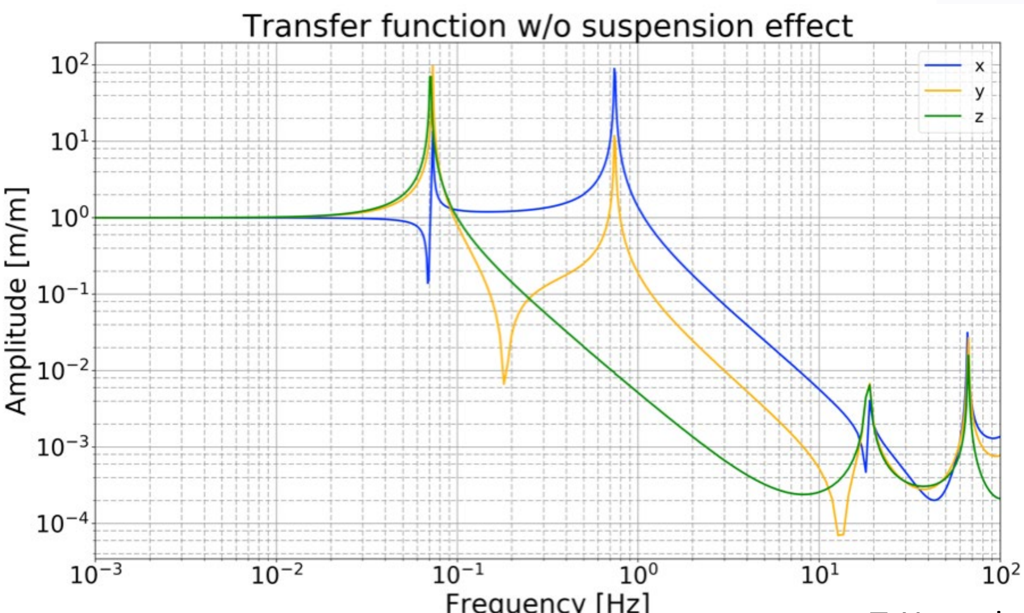


We can balance high thermal conductivity and low stiffness.

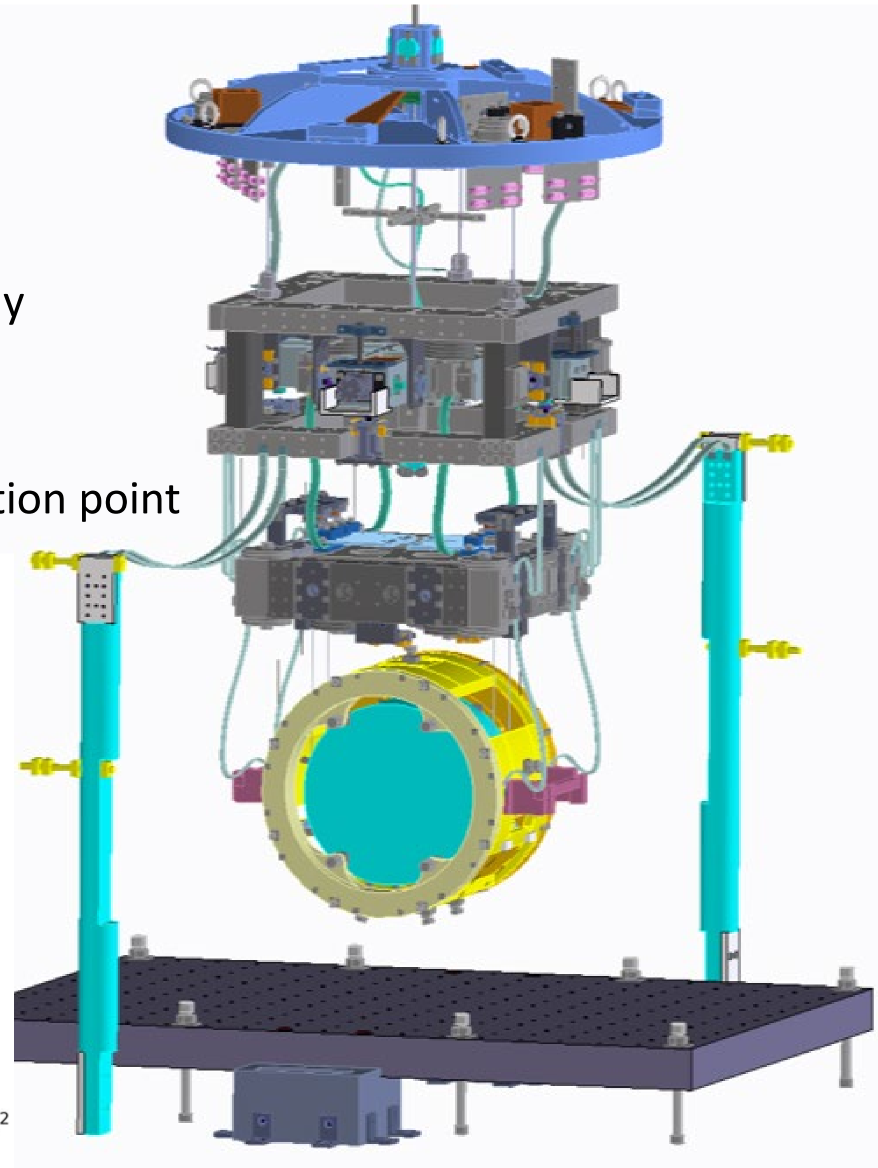
Vibration transfer via heatlinks

- We calculated the vibration transfer function of the heat links by using ANSYS.
- We assumed that the shape of heatlinks are catenary curve.
- We assumed that the suspension is completely free mass.

Using ANSYS to calculate



Excitation point



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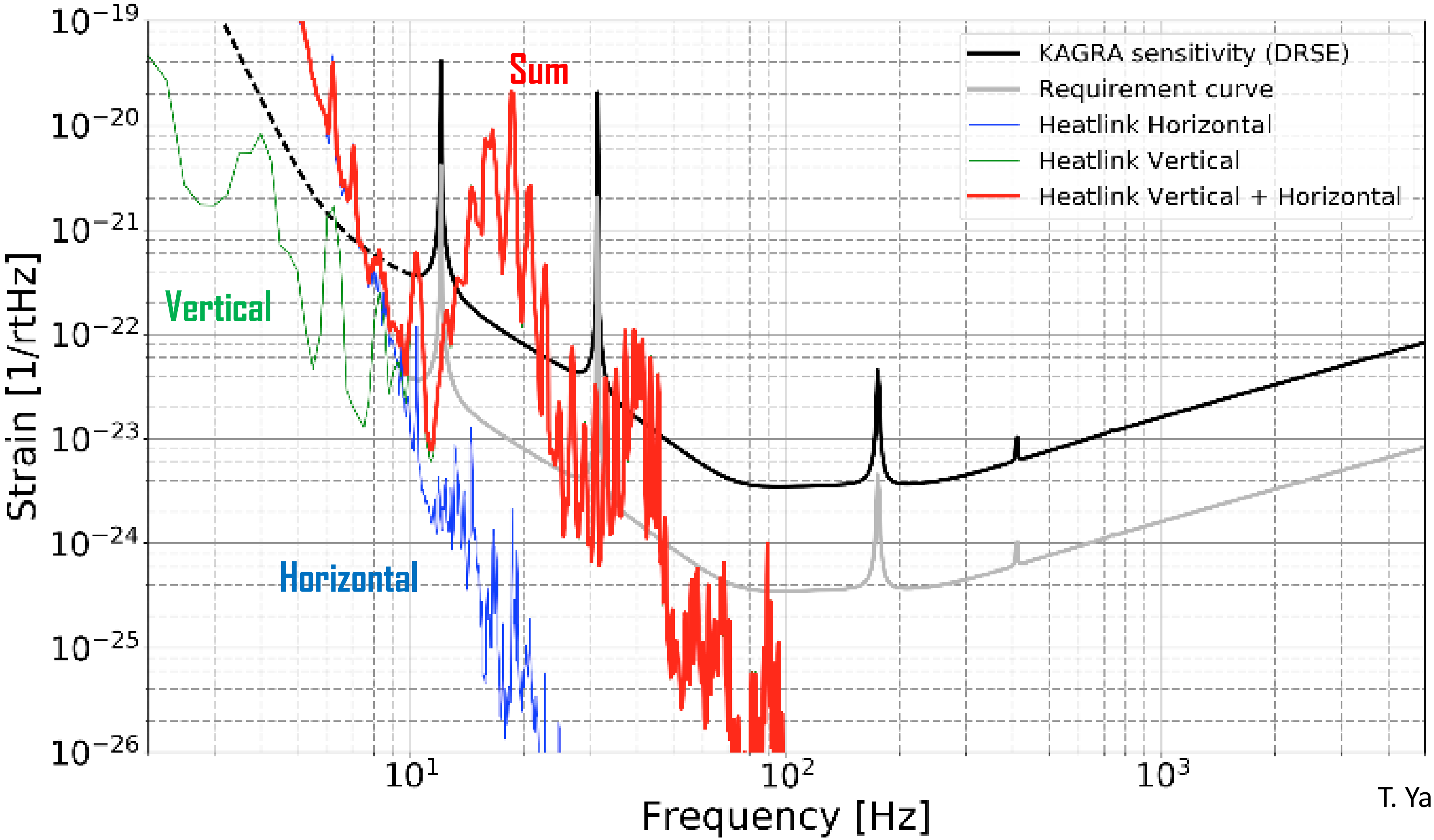
Vibration injection at the test mass

1% coupling from vertical motion to longitudinal motion of the mirror is asuumed.

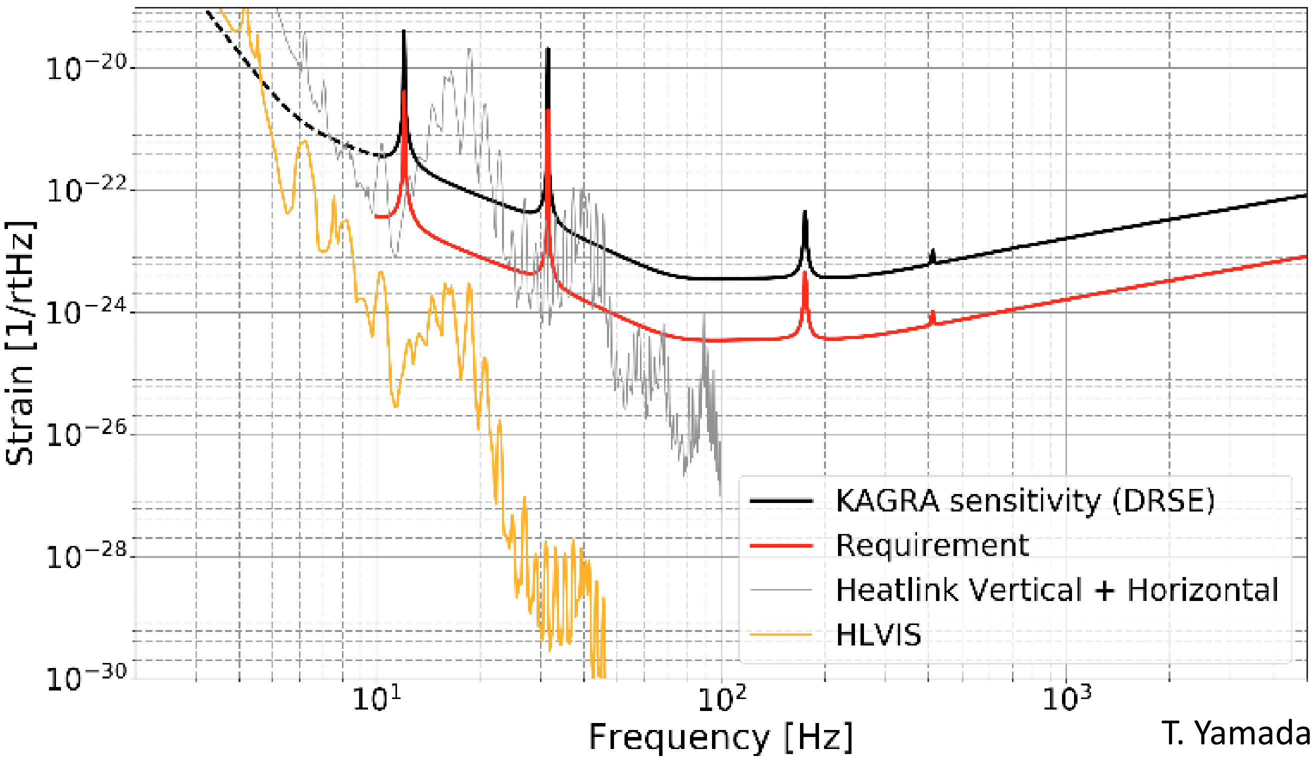


T. Yamada

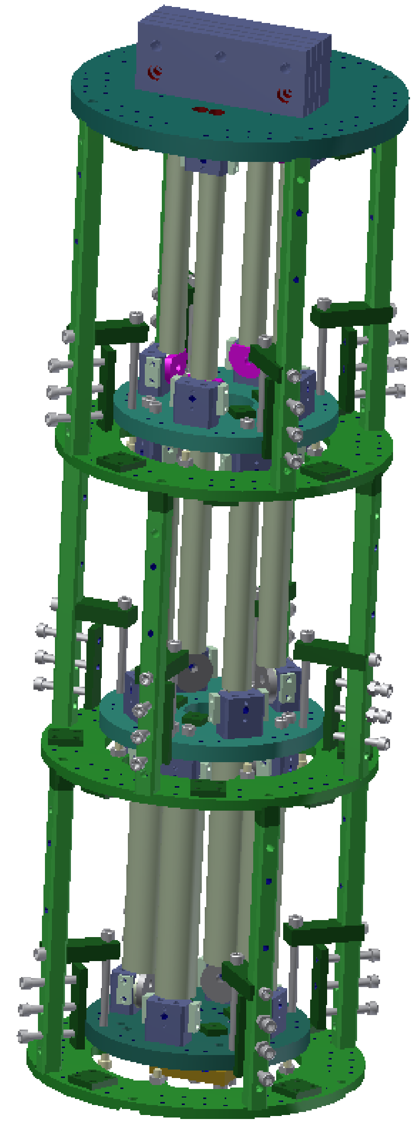
Below 10 Hz, horizontal motion has large impact to the sensitivity.
Above 10 Hz, coupling from vertical motion can contaminate the sensitivity.

Heat Link Vibration Isolation System (HLVIS) of KAGRA

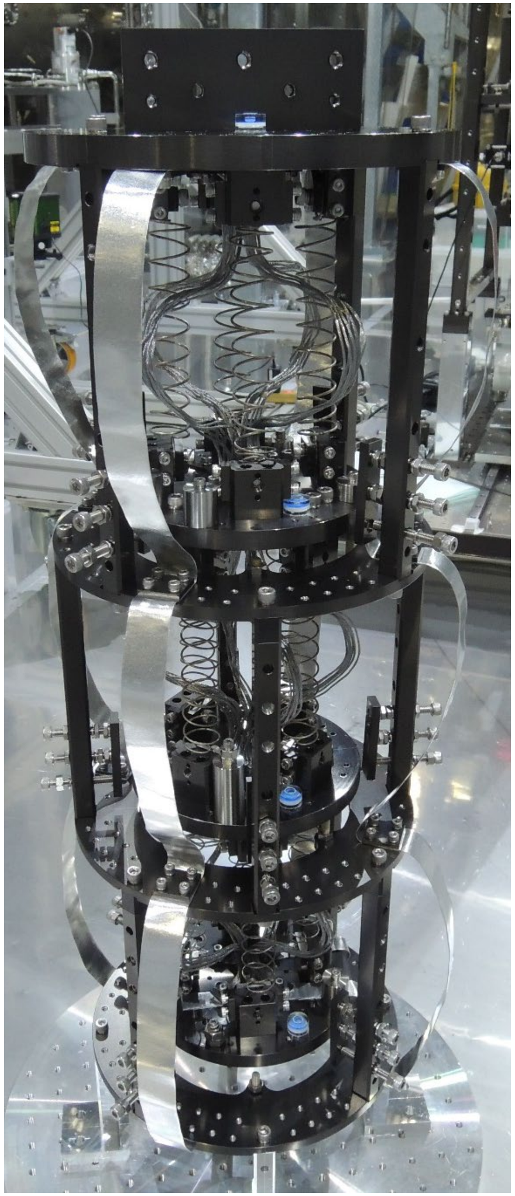
- Three-stage VIS with tension spring are installed.
- Resonant frequency of vertical motion of each stage is 3 Hz.
- Whole mass is about 20 kg and supported from the top of inner radiation shields of KAGRA.

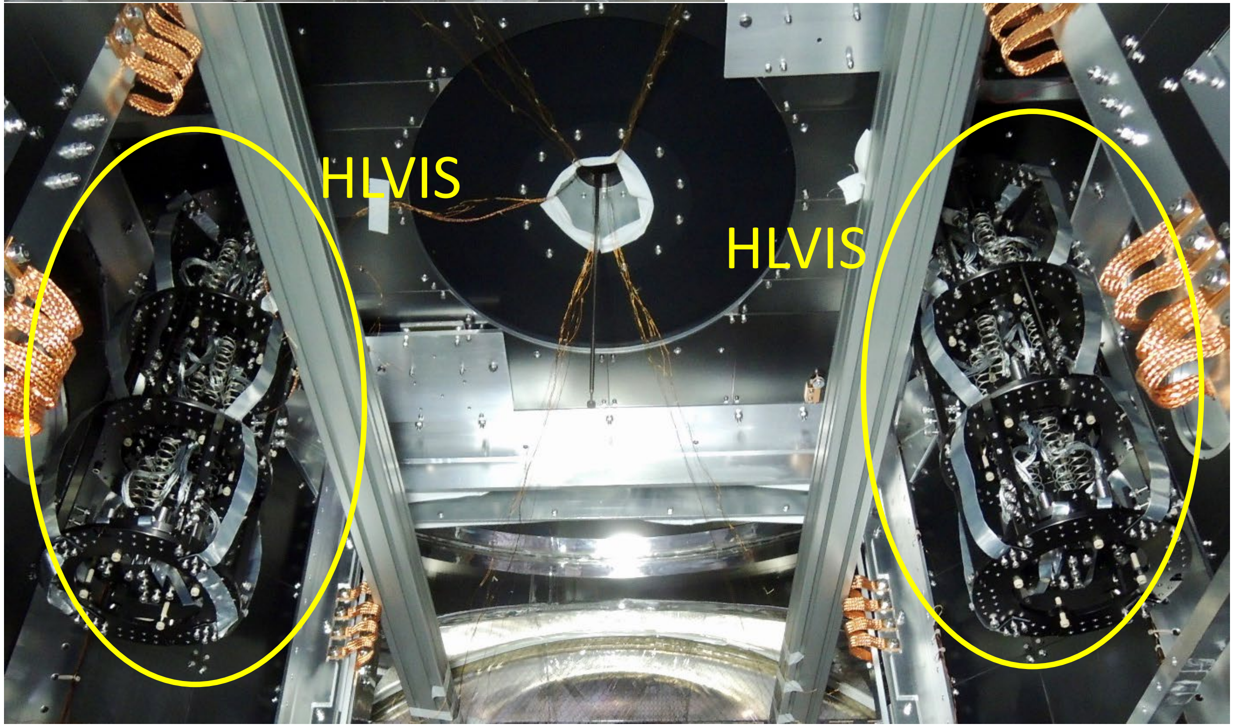


T. Yamada



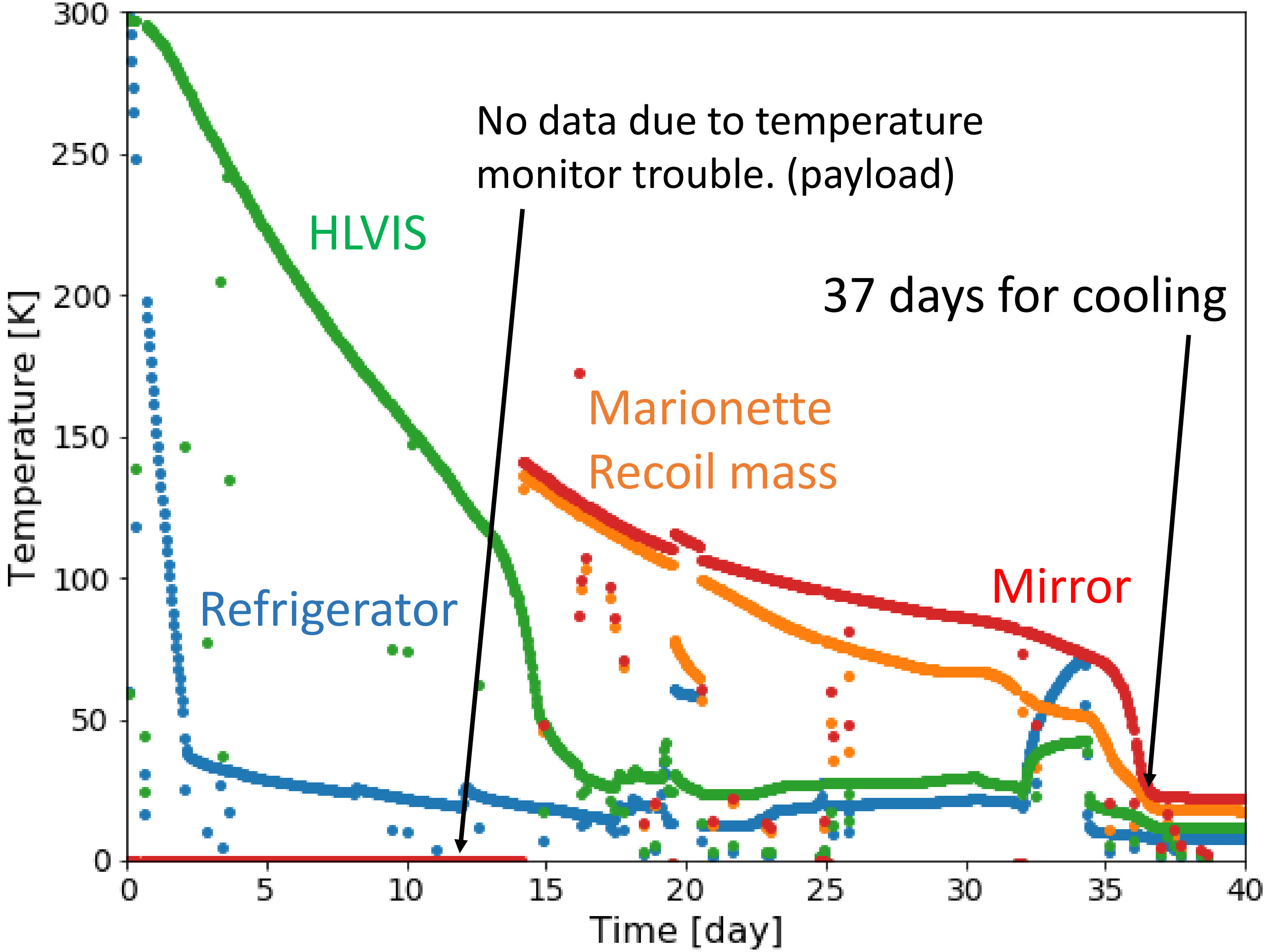
HLVIS installation at KAGRA site





Cooling with HLVIS

ITMY from February 27, 2019



We could cool the sapphire mirror at around 20 K with HLVIS.

Current achievement and future

- All four sapphire mirrors were installed inside KAGRA cryostats and suspended by the Type-A tower suspension.
- We started to cool all four sapphire mirror suspension. Three of them has already reached the steady state. One remaining mirror (ETMX) will reach the steady state at the beginning of June.
- Cooling time is slightly longer than we expected because of cryocoolers' trouble but we can confirm that HLVIS doesn't make large effect on cooling time.

- The thermal resistances inside the HLVIS and also cryogenic payload should be reduced for achieving the initial design sensitivity of KAGRA in order to keep cryogenic temperature with high power laser.
- Improvement of the thermal conductivity of sapphire is important as well to cool the sapphire mirror effectively.

Summary

- There are several technical difficulties for improving low frequency sensitivity with cryogenic technology.
  - Vibration of cryocoolers
  - Suspension thermal noise
  - Vibration via heatlinks

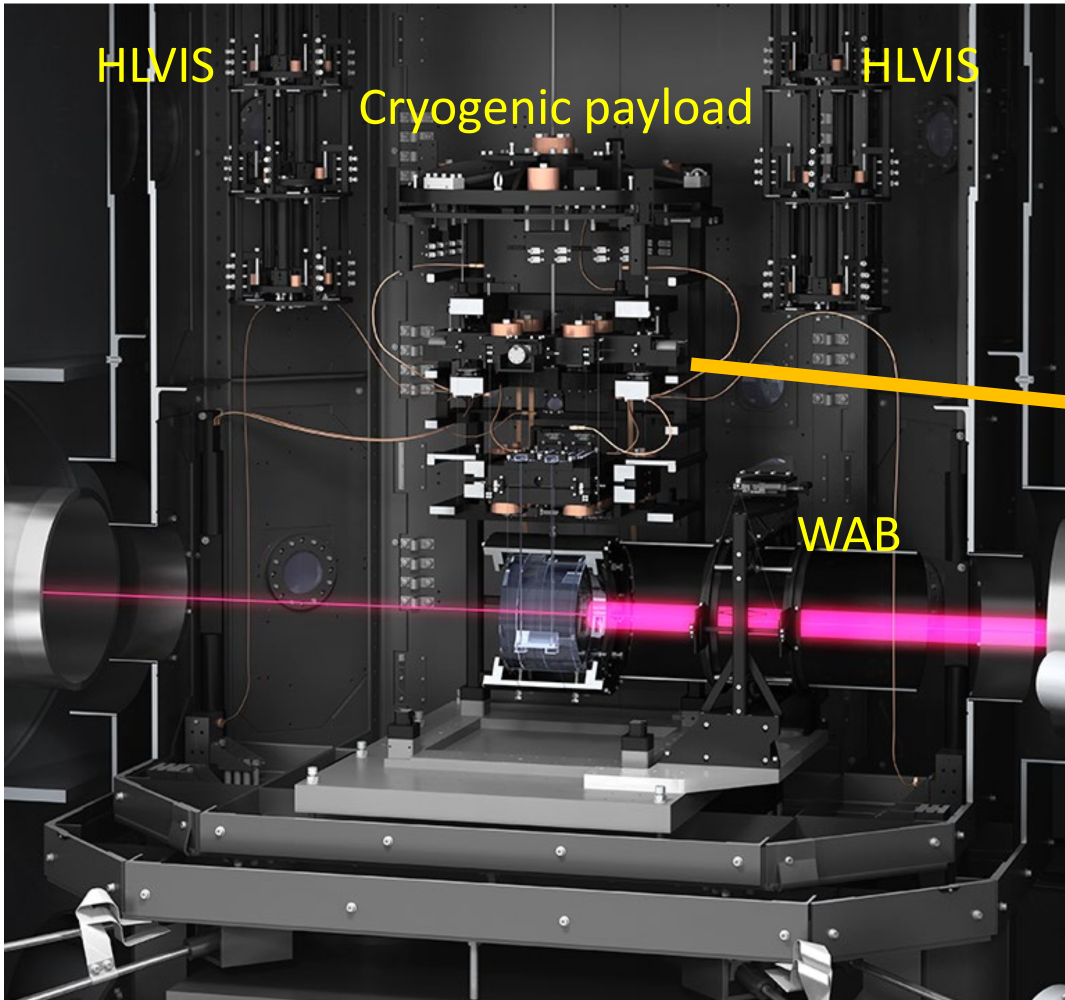
- Low vibration cryocoolers have already developed.
- High thermal-conductivity sapphire fibers are now being developed.
- HLVIS is developed and alredy installed at KAGRA cryostat.

- HLVIS doesn’t make a large impact on the cooling time of the cryogenic payload of KAGRA.

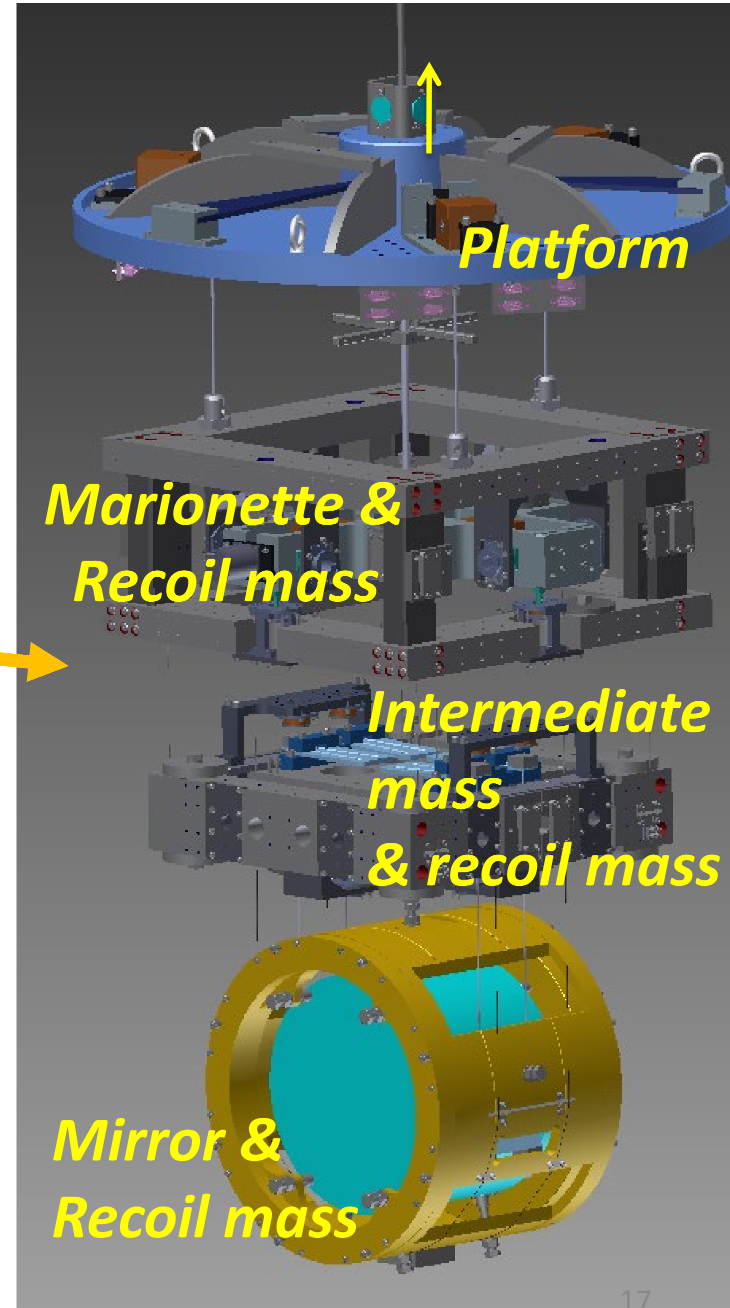
Back up slides

Cryogenic payload

Inside cryostat

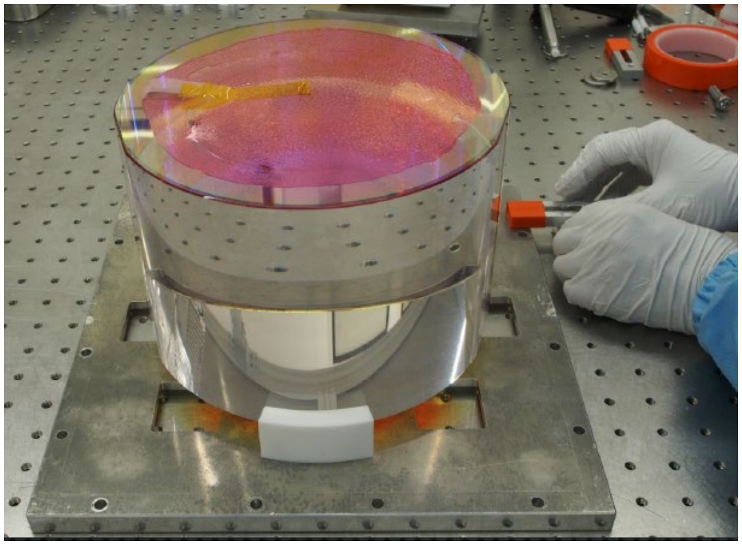


(c) KAGRA Collaboration / Ray.Hori



Hydroxide Catalysis Bonding

Hydroxide Catalysis Bonding technique is used for the ear bonding as well as LIGO and VIRGO

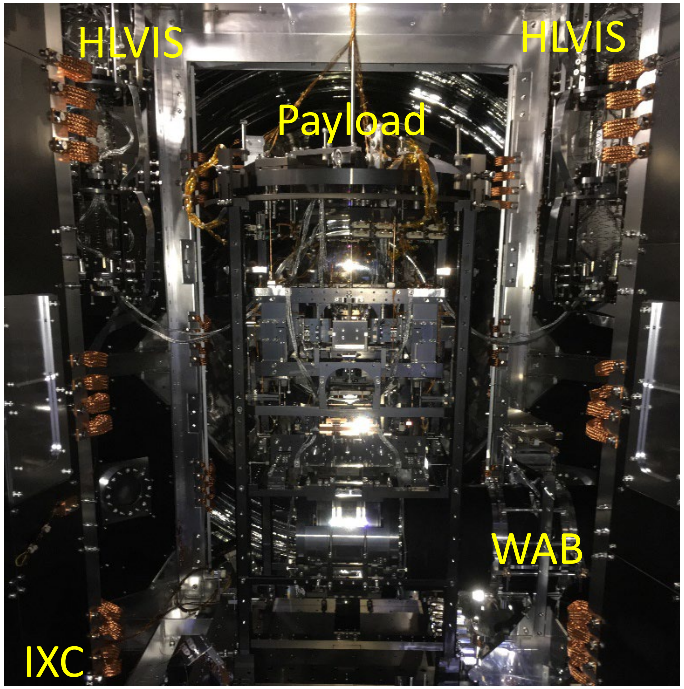


The last bonding of sapphire ears finished in the last October.

The last mirror was sent to KAGRA mine in the last November.

HCB mission was successfully over!

Payload installation



All sapphire mirrors have been installed in the cryostat.

All sapphire mirror has been suspended by Type-A suspension.

Ready to start commissioning!

Cryocooler trouble

- During cooling, some cryocoolers reached to the meta stable state and cooling speed becomes slow.
- When we face this situation, we should stop cryocoolers onece and start again after several days.
- This often occurs (we already experienced four times) and it causes schedule delays.
- We don't know why this happens and cannot predict it.

ITMY Ref.4 from February 27