

Vibration-Free Pulse Tube Cryocooler System for Gravitational Wave Detectors I

- Vibration-Reduction Method and Measurement -



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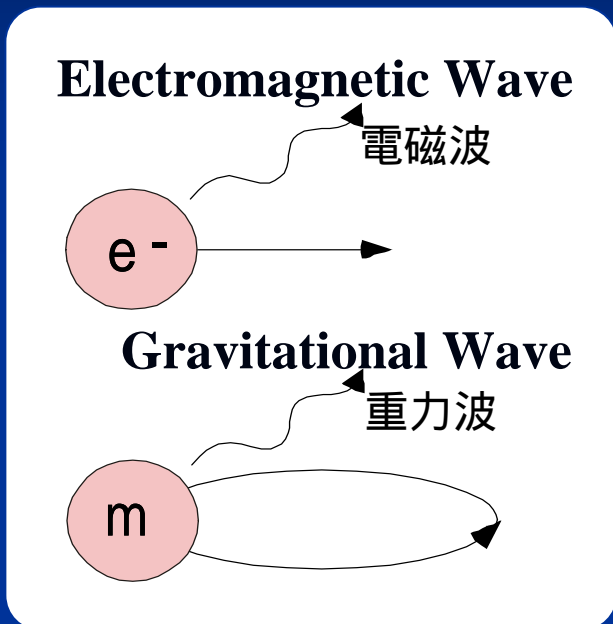
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1. Gravitational Wave ? Cryogenics ?

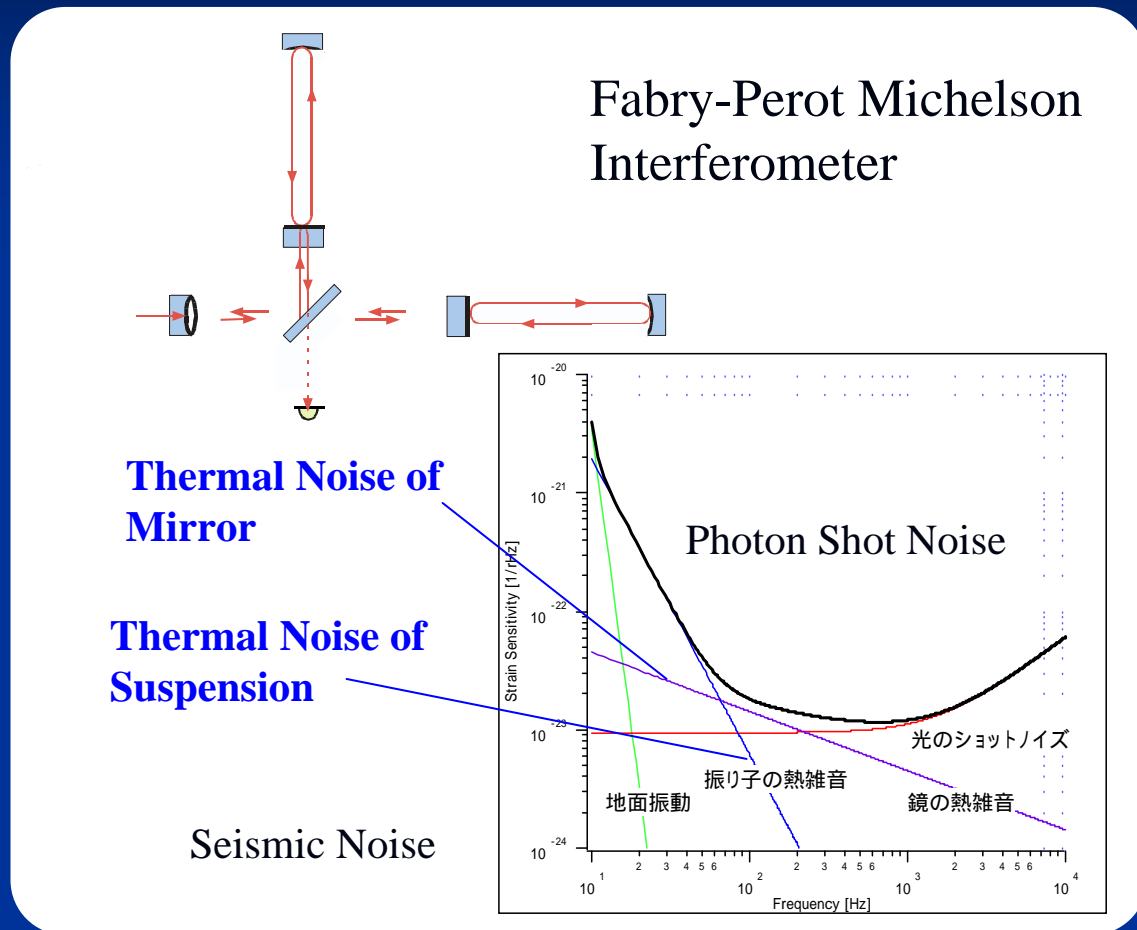
What is Gravitational Wave?



Predicted by general relativity.
It has been **never detected** directly.
(Indirectly detection has been done.)

New Astronomy

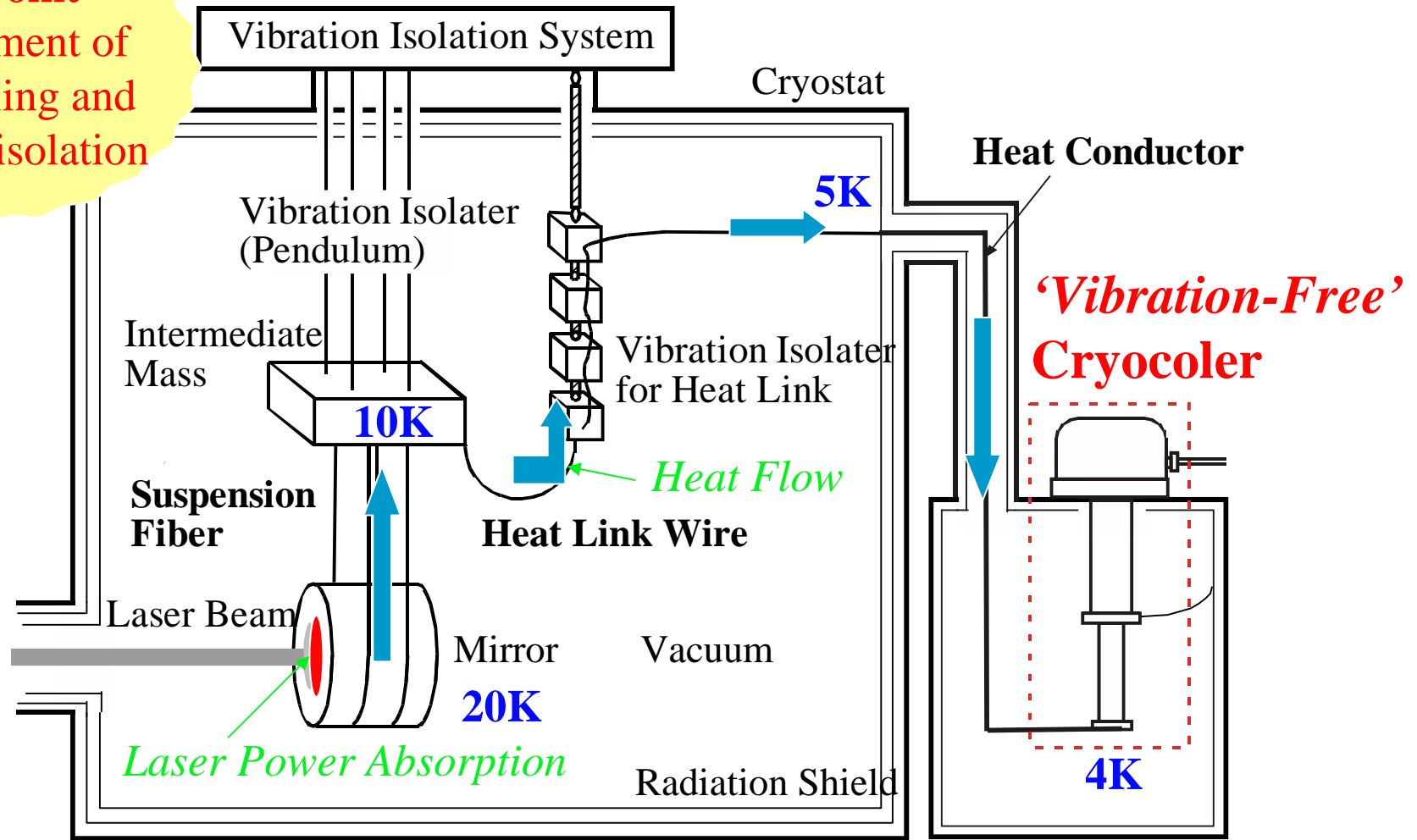
How we can detect it?



Cooling the interferometer to below 20K
LCGT project

Cooling System in CLIO (prototype of the LCGT)

Key Point
Achievement of
both cooling and
vibration isolation



Requirement: Seismic vibration level in Kamioaka mine (the site of the LCGT&CLIO)

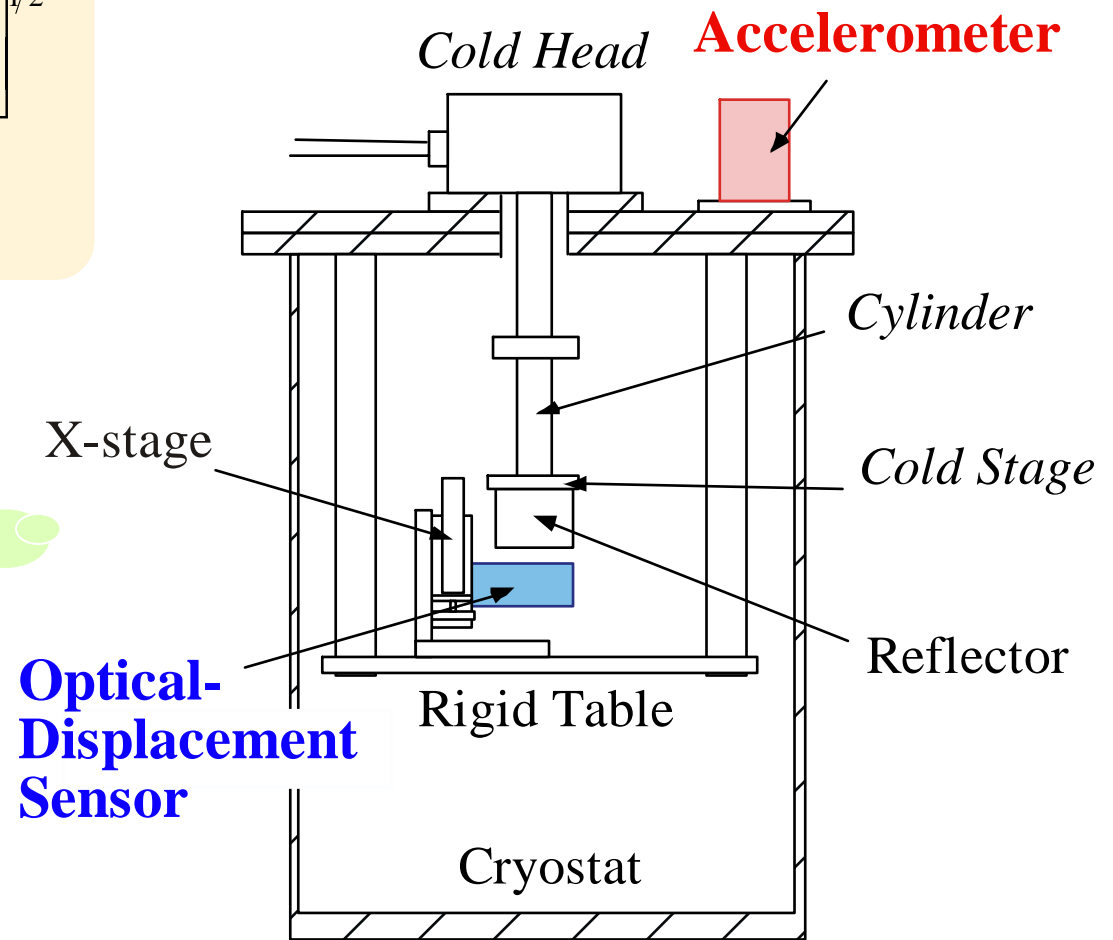
2. Characteristic of Vibrations of 4K Cryocoolers

Spectral Displacement Density

$$\tilde{x}(\omega) = \left[\lim_{T \rightarrow \infty} \frac{1}{T} \left| \int_{-T/2}^{T/2} x(t) e^{-i\omega t} dt \right|^2 \right]^{1/2}$$

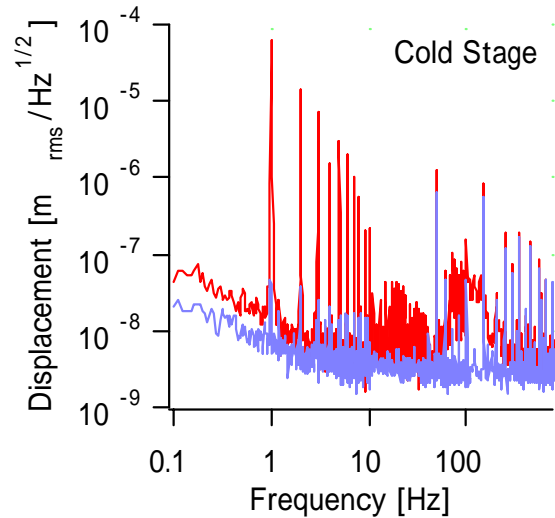
$[m/\sqrt{\text{Hz}}]$

**Both vibrations of
The cold head and the
Cold stage were separately
Measured!**



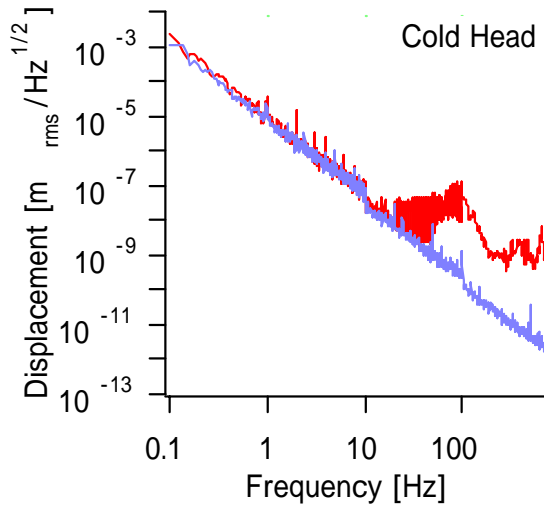
Result in Our Previous Study

Sumitomo 4K GM

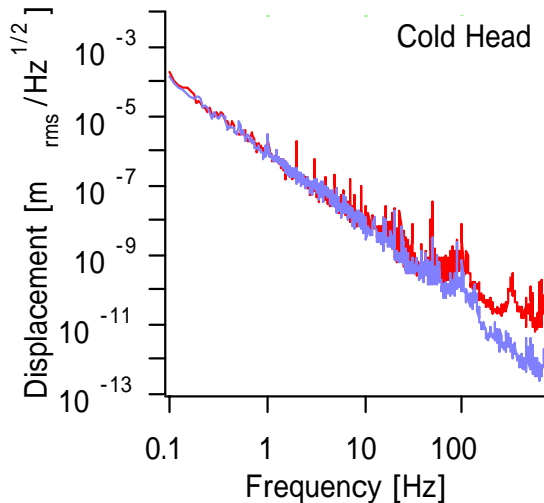
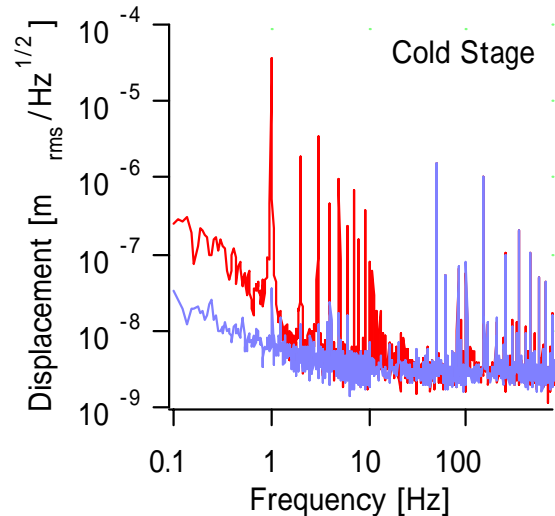


Vibration Data

Sensor Noise



Sumitomo 4K PT



Cold-Stage Vibration

$$\Delta x_{GM} \approx \Delta x_{PT} \\ \approx 20 \mu\text{m}_{PV} \\ @ 1\text{Hz}$$

Cold-Head Vibration

$$\Delta x_{GM} \gg \Delta x_{PT}$$

Two order

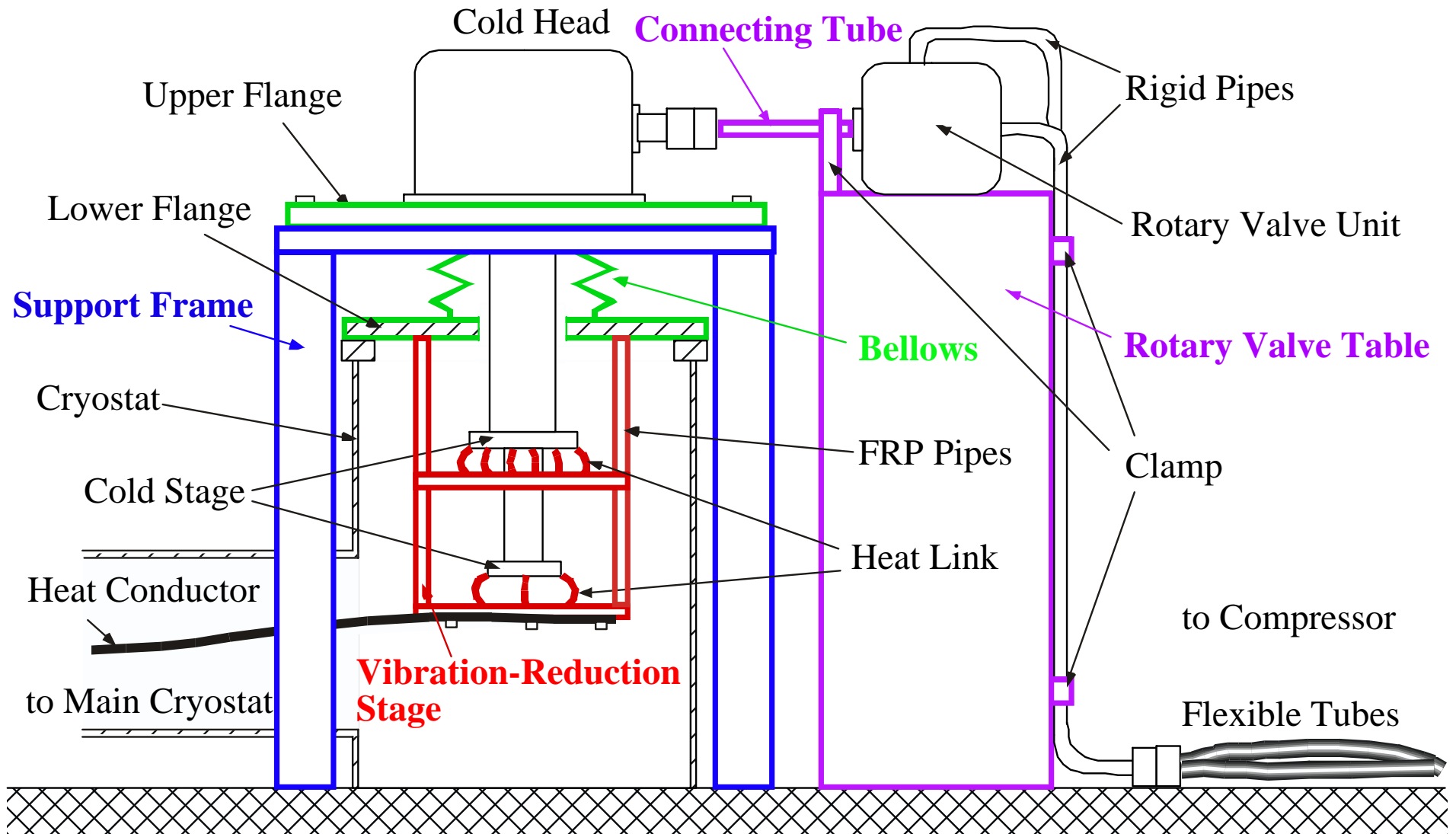
Above 100Hz

T. Tomaru et al.

“Vibration Analysis of Cryocoolers”

Accepted to Cryogenics

3. Vibration Reduction System



4. Vibration Measurement of Overall System

- The measurement was done in the Kamioka mine.
- Vibration was measured by an laser-accelerometer through a jig.

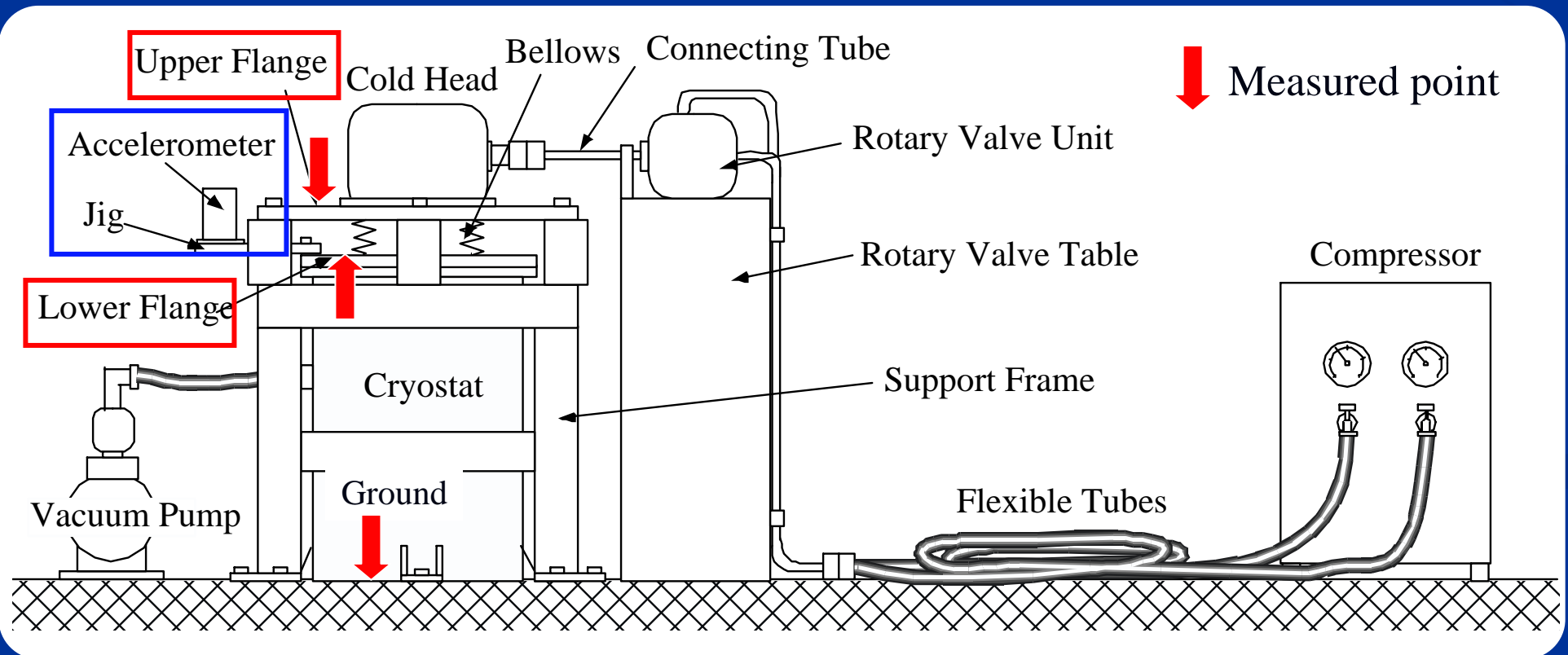


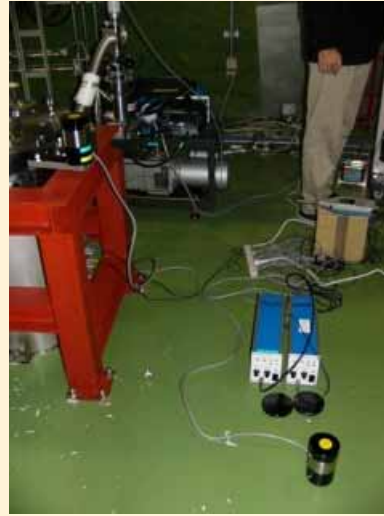
Seismic vibration level:

$$10^{-9} / f^2 \text{ m}/\sqrt{\text{Hz}} \quad (\text{Kamioka})$$

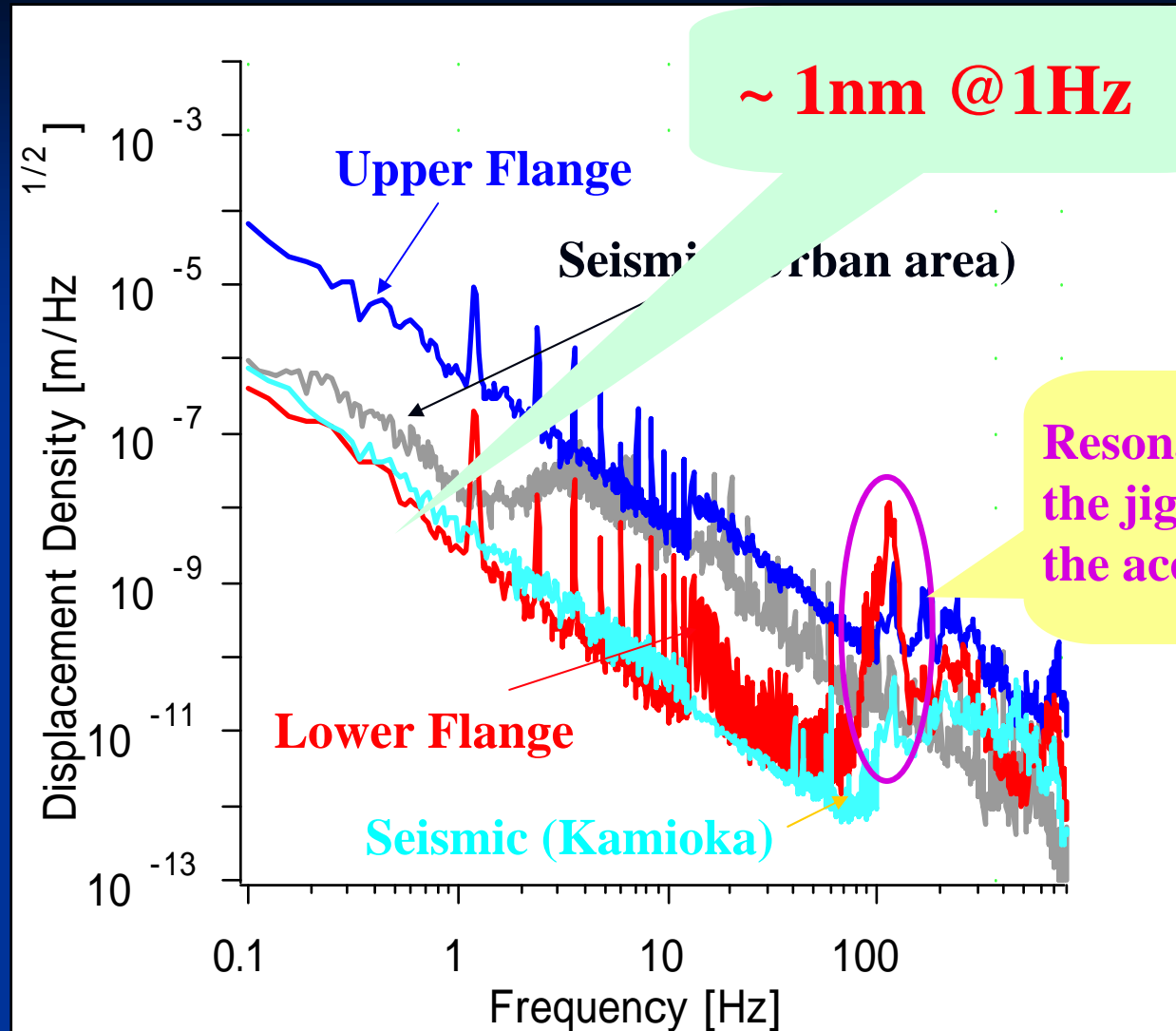
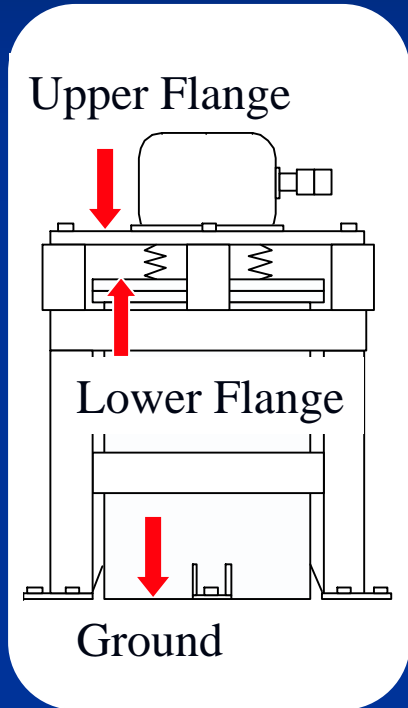
$$10^{-7} / f^2 \text{ m}/\sqrt{\text{Hz}} \quad (\text{Urban areas})$$

Cooling performance and the cold-stage vibration Measurement will be presented in next talk by R. Li



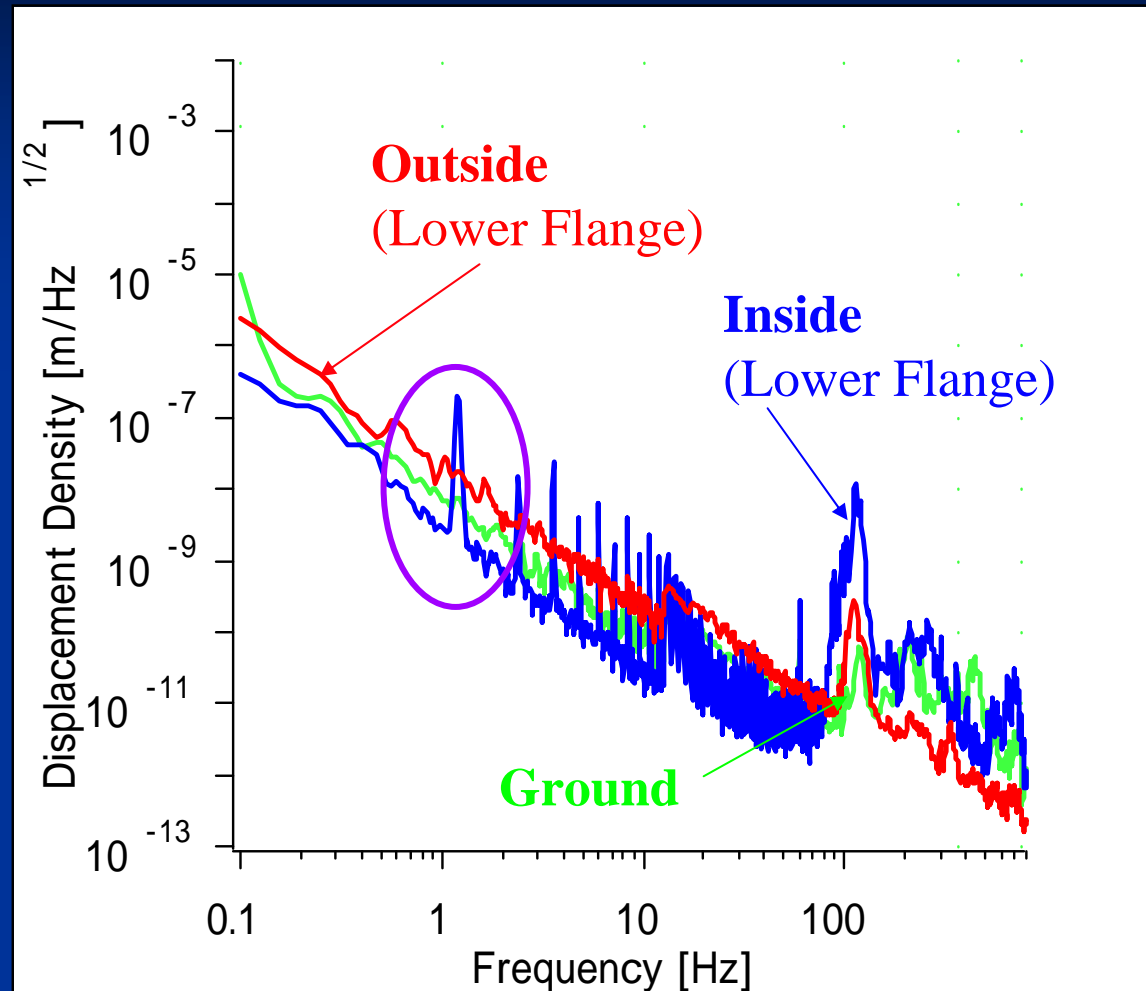
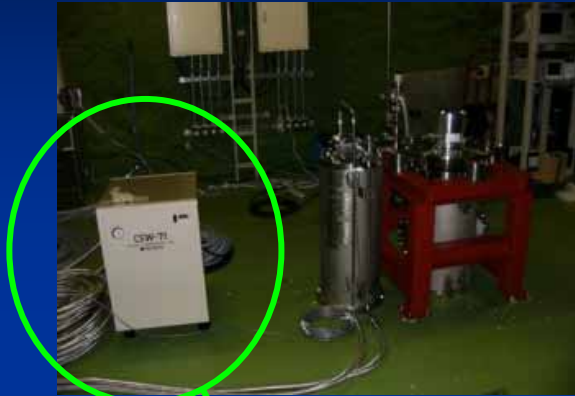


Result



Vibration level of the lower flange is almost same as the seismic vibration level in Kamioka mine! (2 orders of magnitude smaller than that of typical urban area)

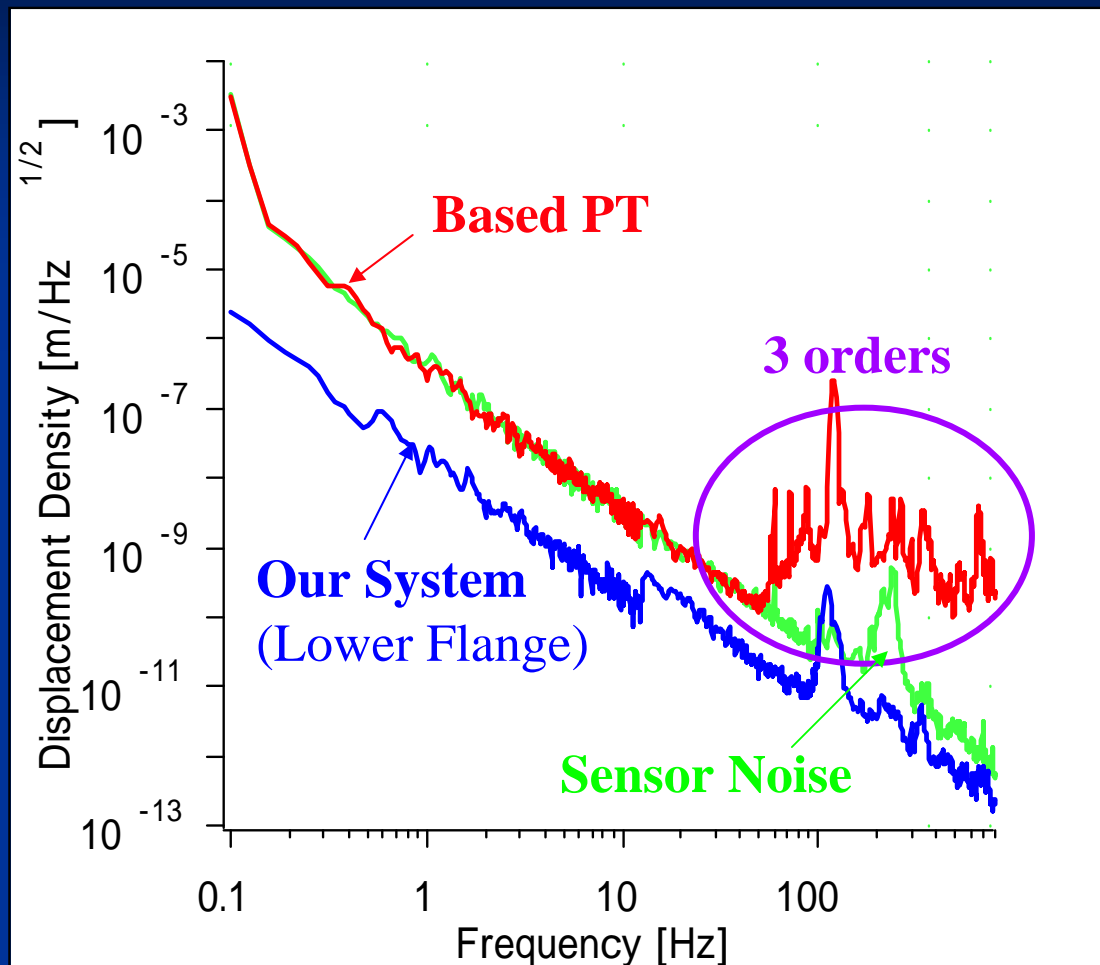
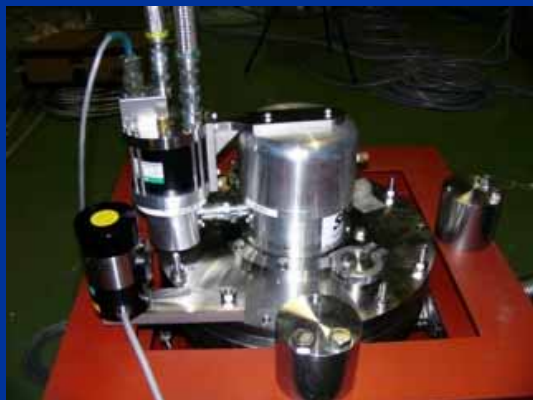
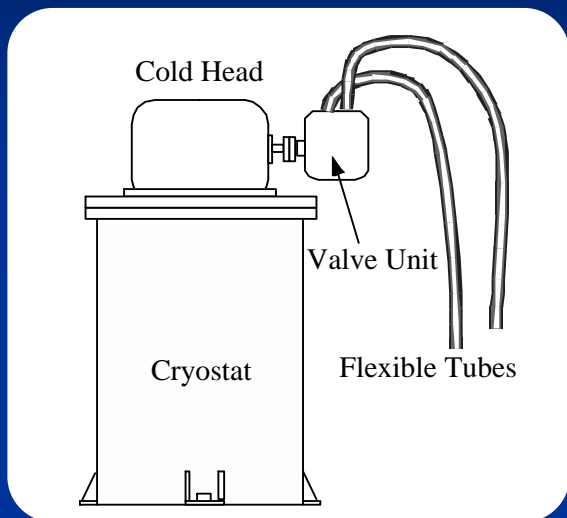
How about vibration when the compressor located outside of the experimental room?



Sharp vibration peaks at the driving frequency and its higher harmonics disappeared!

How about vibration of the based PT cryocooler?

Standard Setup for Sumitomo PT



3 orders of magnitude larger than the vibration of our system!

5. Conclusion

PT cryocooler had **cold-head vibration** above 100Hz and **cold-stage vibration** with driving frequency.

Vibration Reduction System

- **Support frame** to reduce the cold-head vibration
- **Vibration-reduction stage** to reduce the cold-stage vibration
- **Connecting tube** and **valve-unit table** to reduce the vibration come from the valve unit and the flexible tubes

Vibration Measurement of Overall System

- Vibration of our system was **3 orders of magnitude smaller** than that of the based PT.
- Vibration level of the system was two orders of magnitude smaller than the seismic vibration level in typical urban areas and **almost the same as that in Kamioka mine.**

~1nm @1Hz

We can designate the system as being ***'vibration-free'***!