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Cryogenics for LCGT

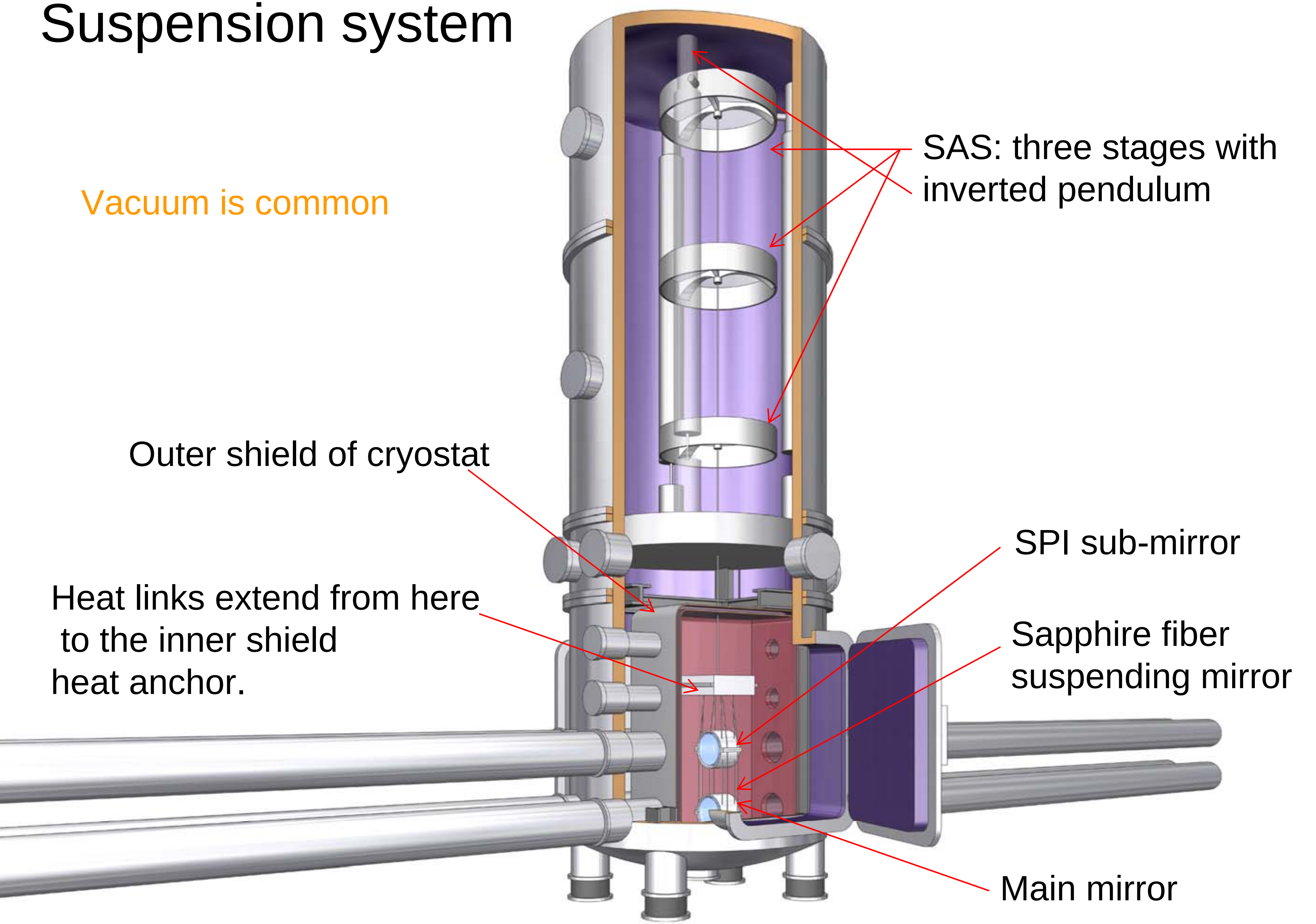
LCGT project

Kazuaki Kuroda
LCGT Collaboration

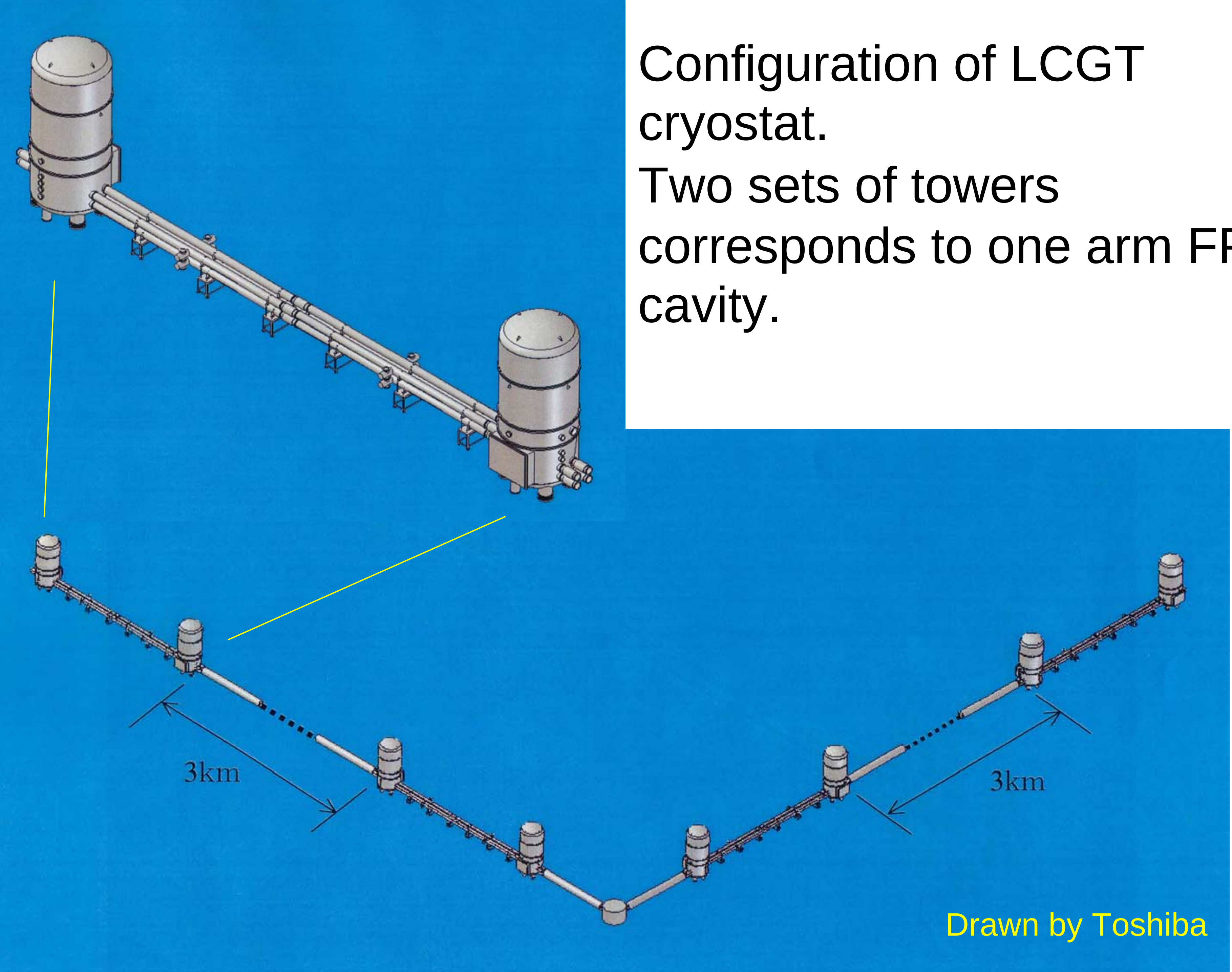
Brief summary of Cryogenics of LCGT

Suspension system

Vacuum is common



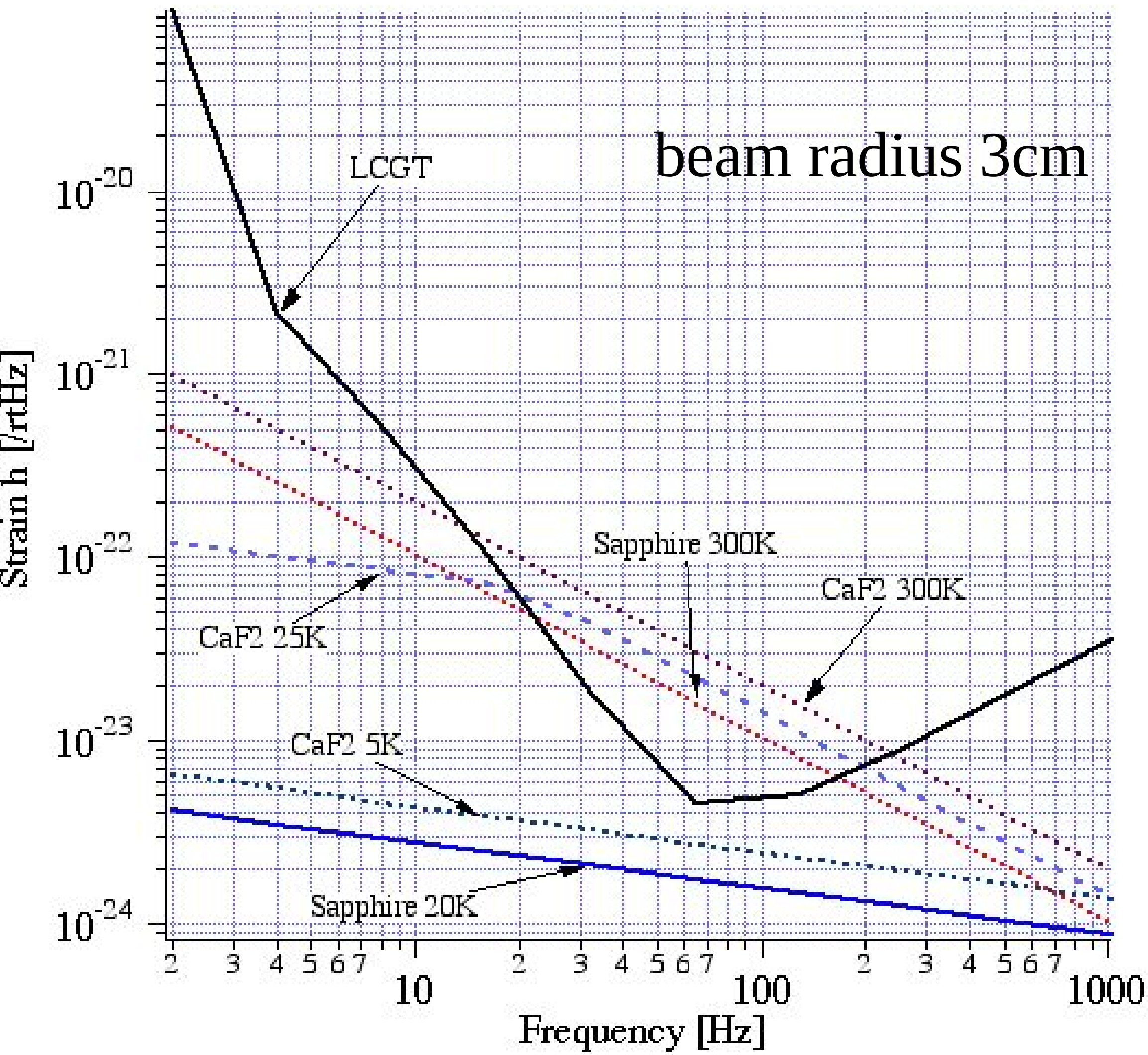
Configuration of LCGT cryostat.
Two sets of towers corresponds to one arm FP cavity.



Why do we choose cryogenics?

Because it is the simplest way
to reduce thermal noise

Thermal noise reduction at cryogenic temperature



To improve by one order in room temperature.

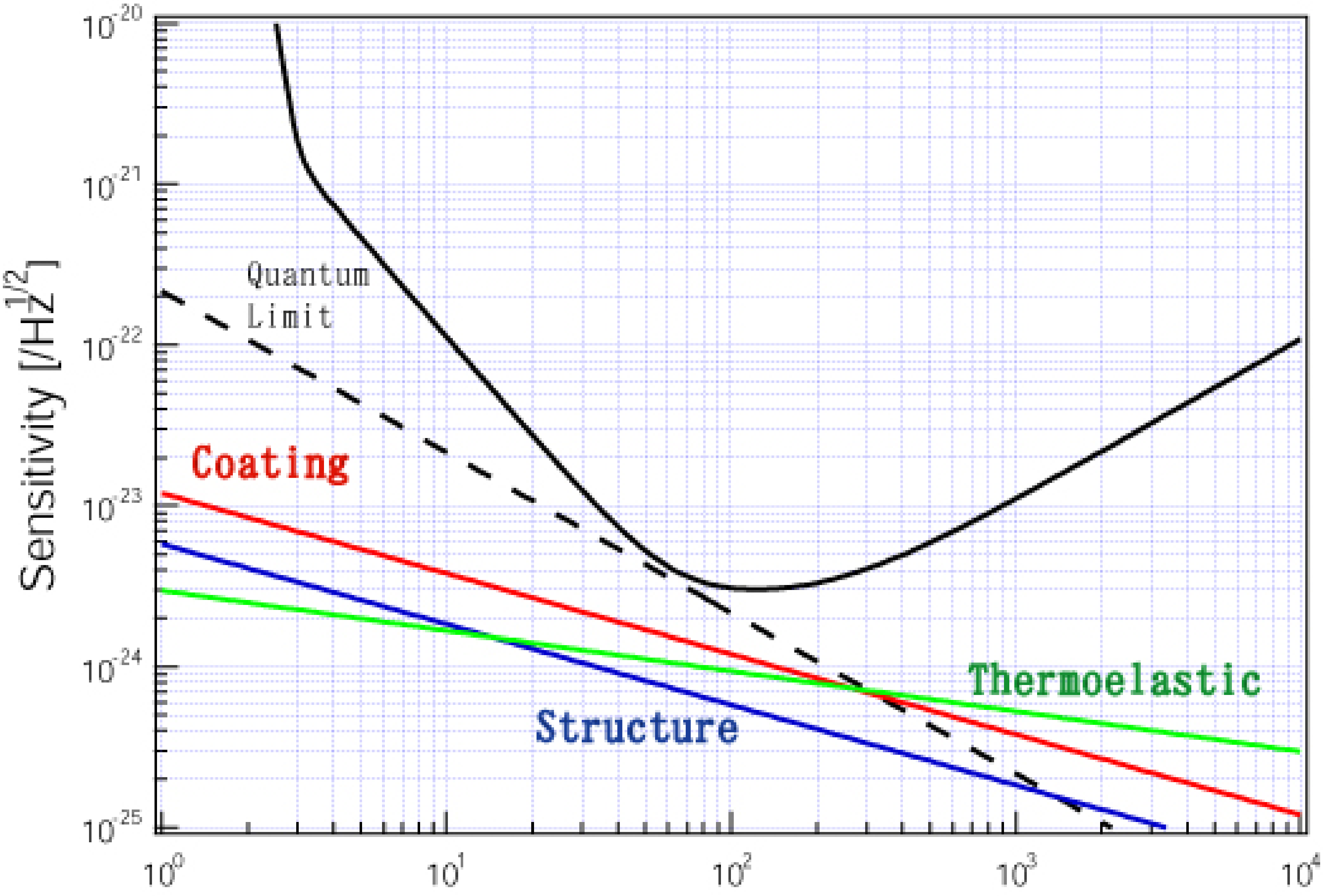
Radius -> 4.6times ($10^{2/3}$) -> 14cm

Adv. LIOG adopts Mexican hut shaped beam profile.

We take a way to cool it down.

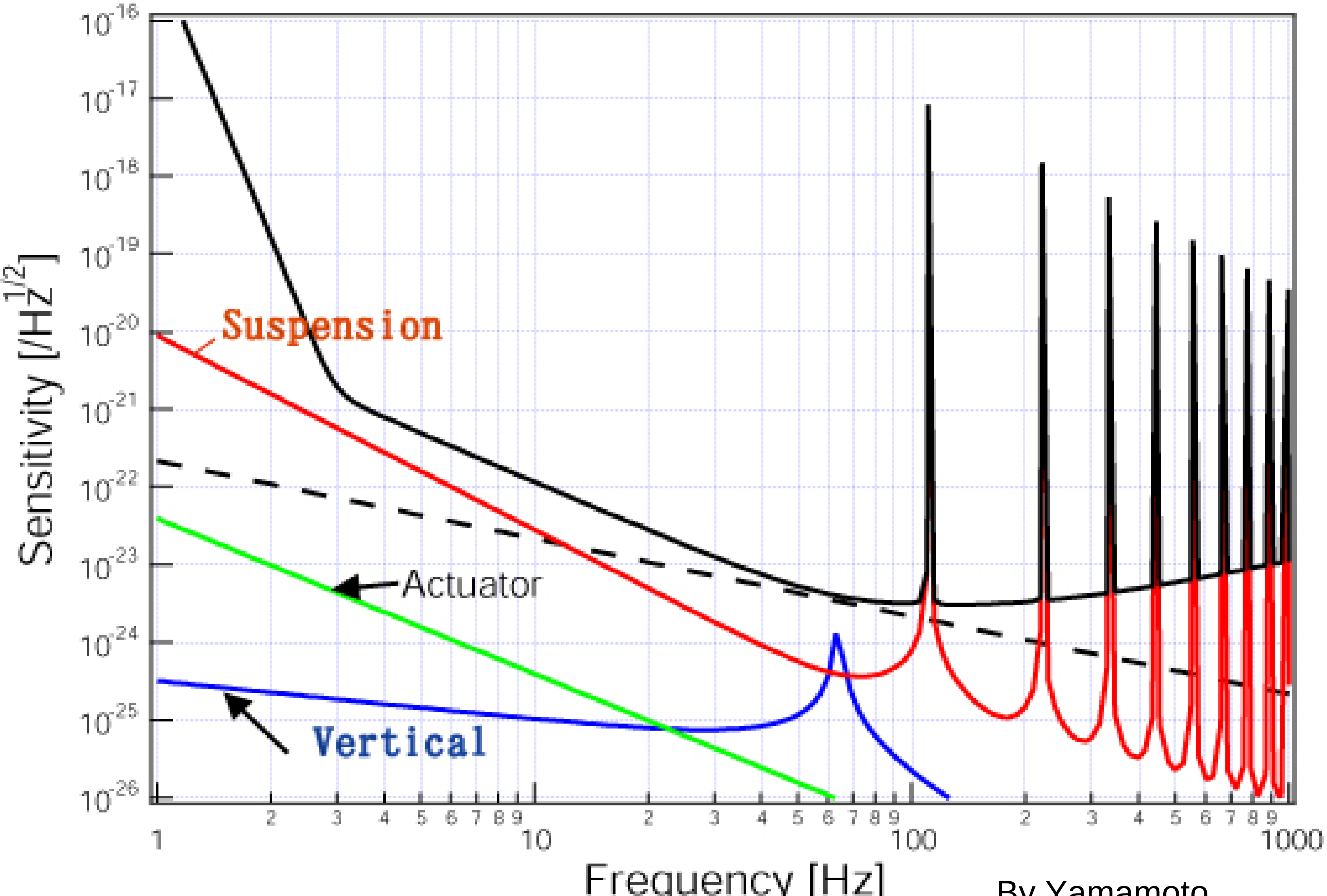
Figure is prepared by Uchiyama

Thermal noise of mirror (LCGT)



By Yamamoto

Thermal Noise of Suspension (LCGT)



By Yamamoto

Basic experiments of cryogenic mirror and its R&D

We need sapphire in place of fused silica at cryogenic temperature. Typical samples were produced by CSI.

10^{-8} is given by the author, which was found to be too small.

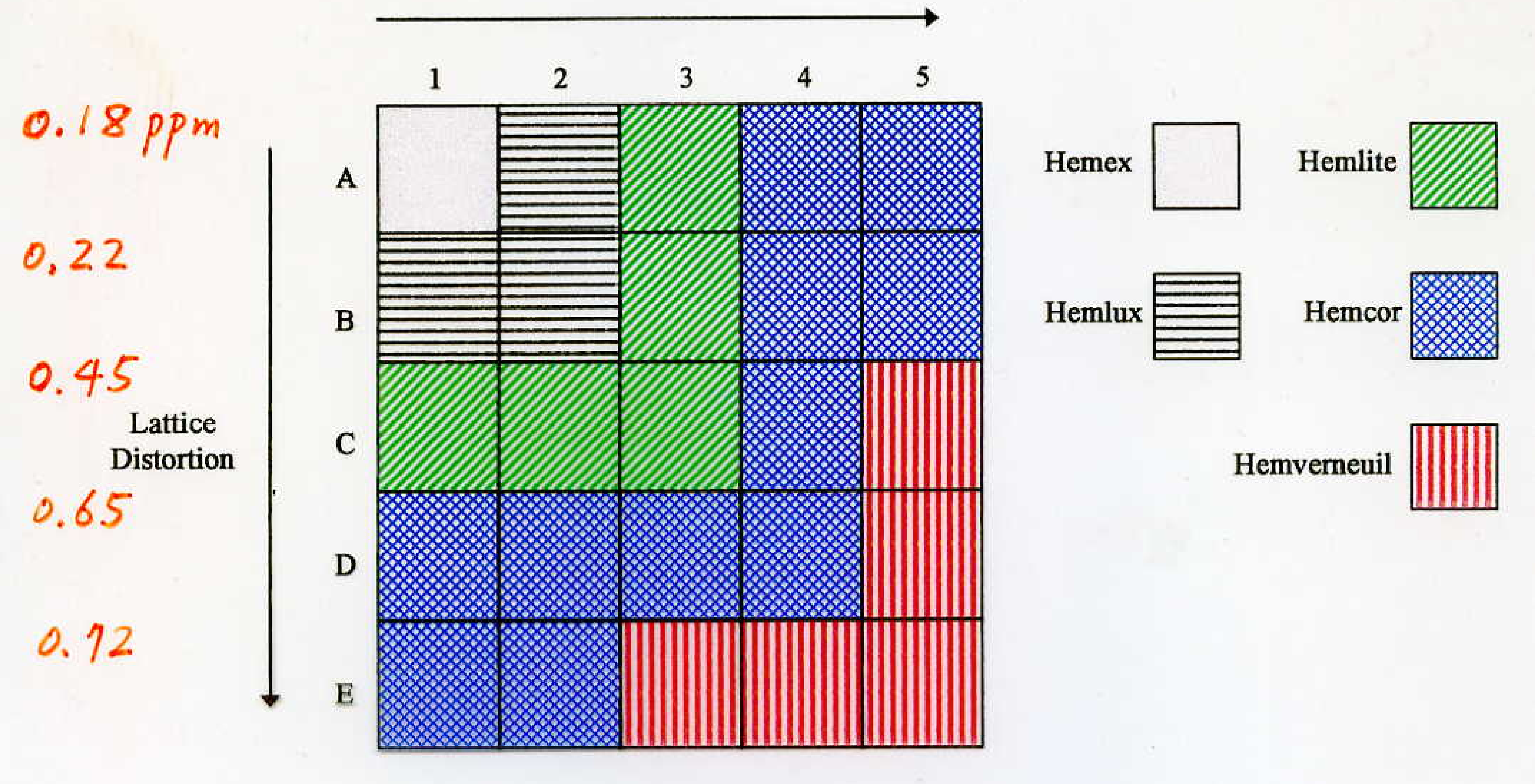


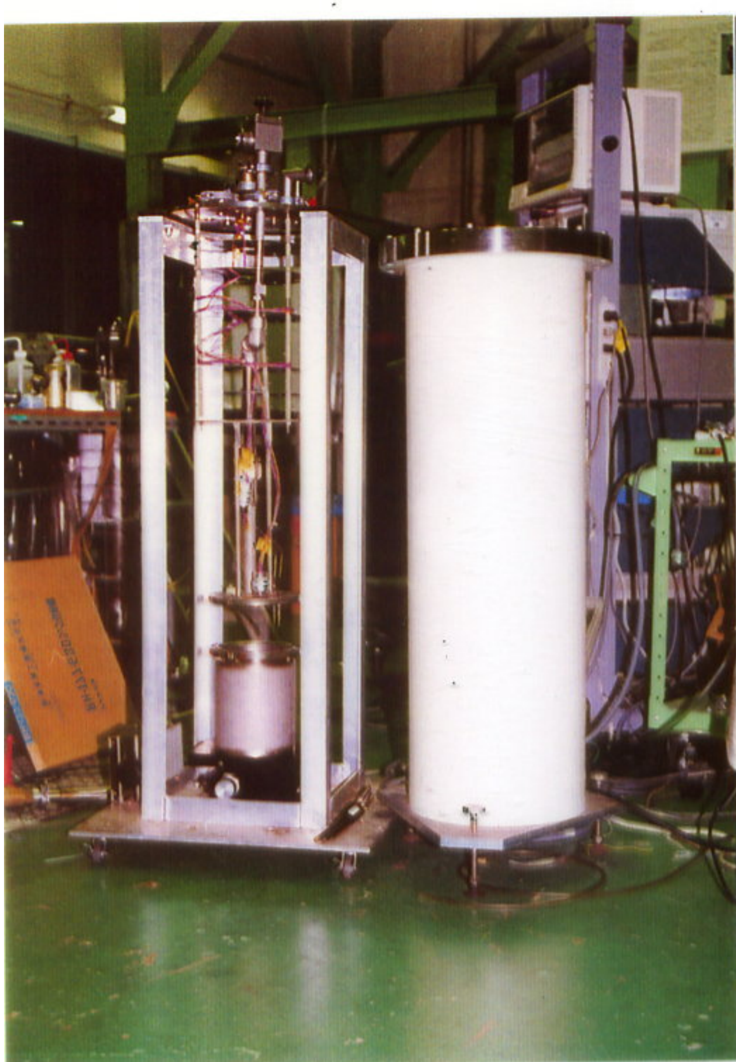
Figure 2. Representation of lattice distortion and light scatter in various grades of sapphire

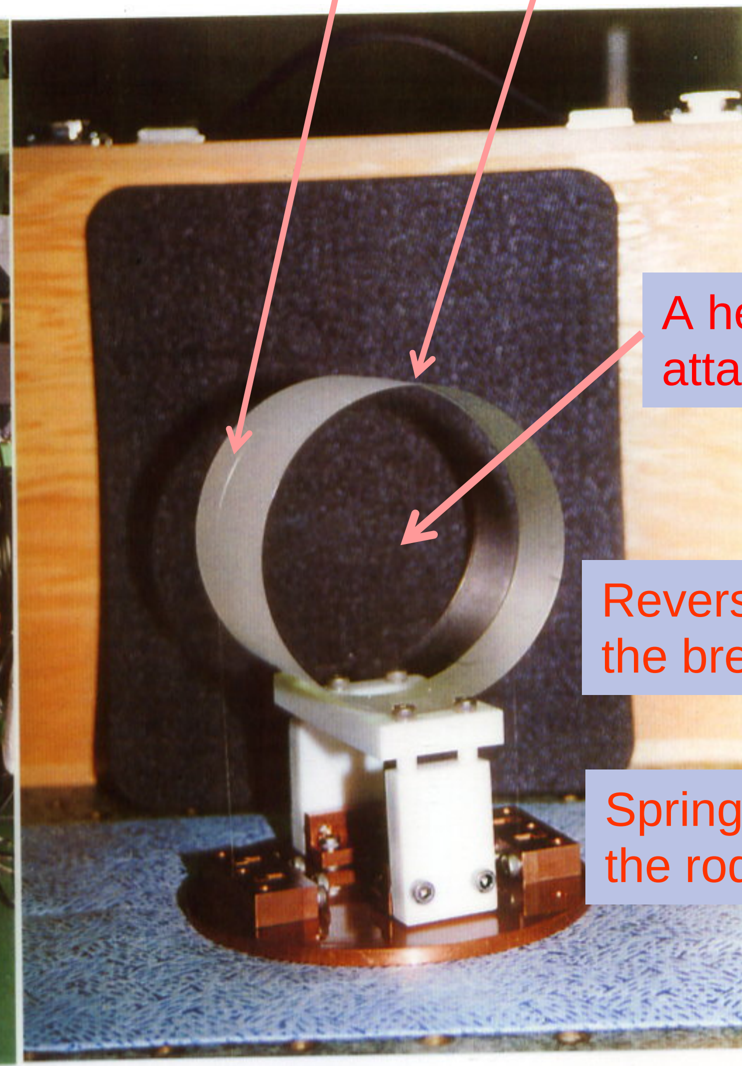
Heat extraction experiment in 1997-1998

Sapphire fiber

Liquid Helium cryostat.

Hemlite sapphire cylinder.





A heater is attached here.

Reverse setup protects the break of fibers

Springs constantly raise the rod.

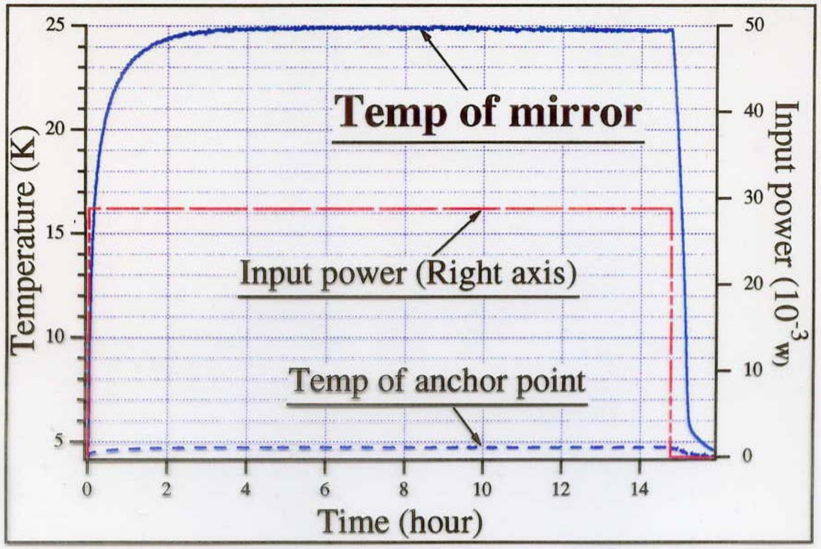


Fig. 1 Heater (29mW) is on.

A heater simulates the optical loss in the sapphire substrate. Since the thermal conductivity was high, the temperature distribution was uniform (the calibration error of thermometers was larger).

Fibers are 250 micron in diameter, with c-axis along the fiber.

The above shows the time response of the temperature.

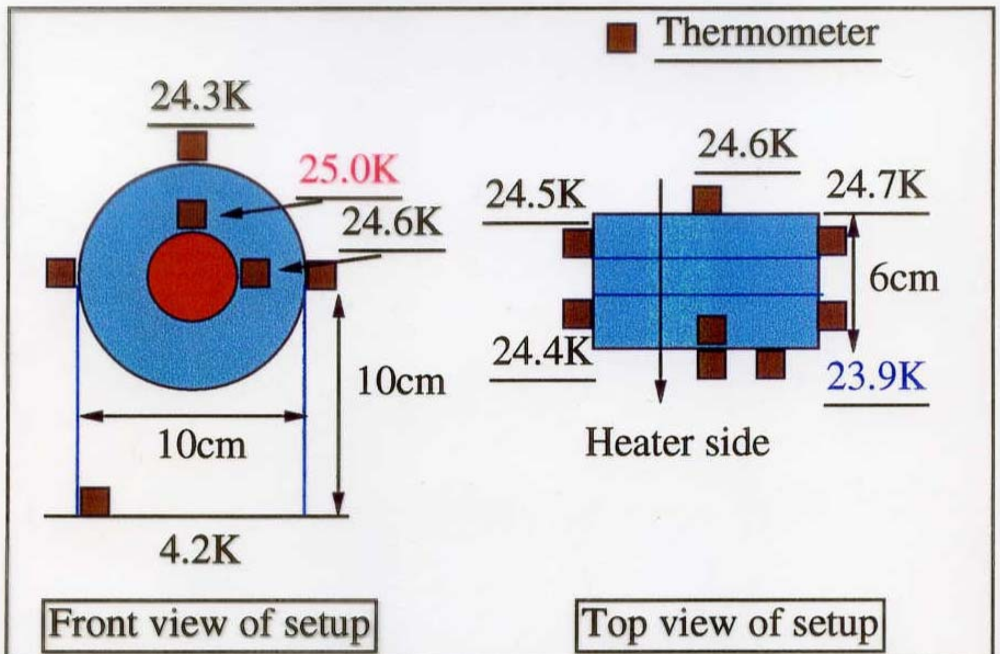
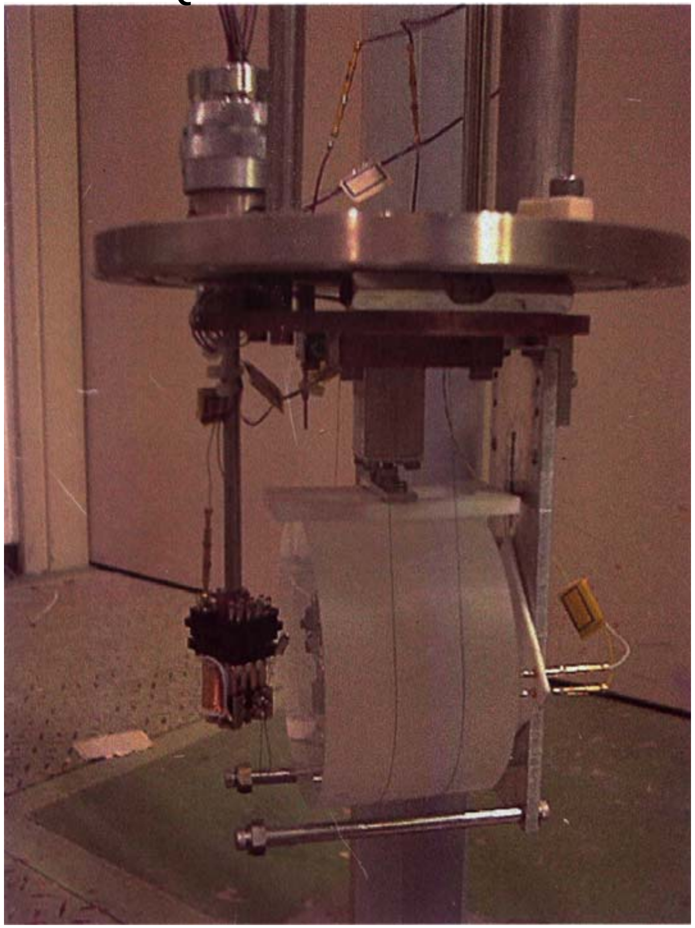
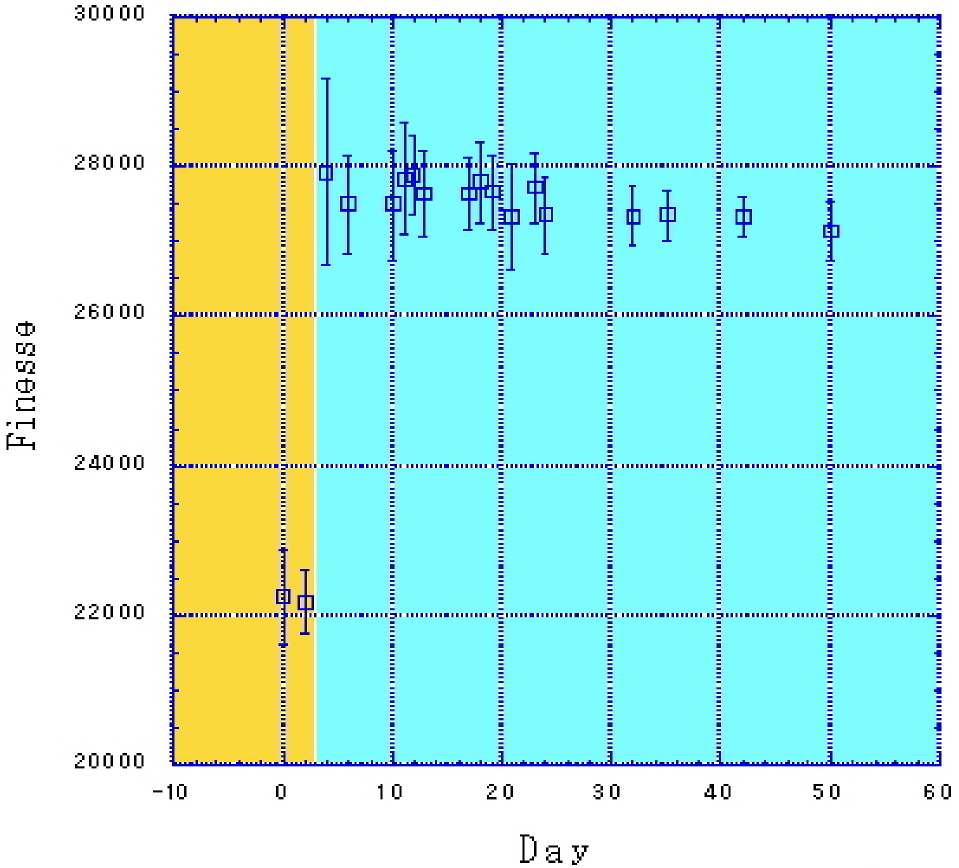


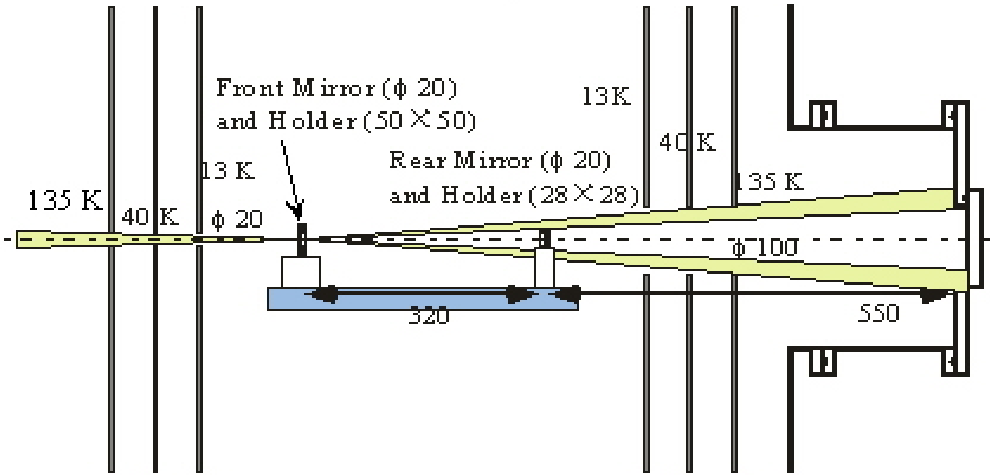
Fig. 2 Equilibrium temperature

We have conducted cryogenic experiments to confirm the feasibility of cryogenic mirror by sapphire.

Q measurement



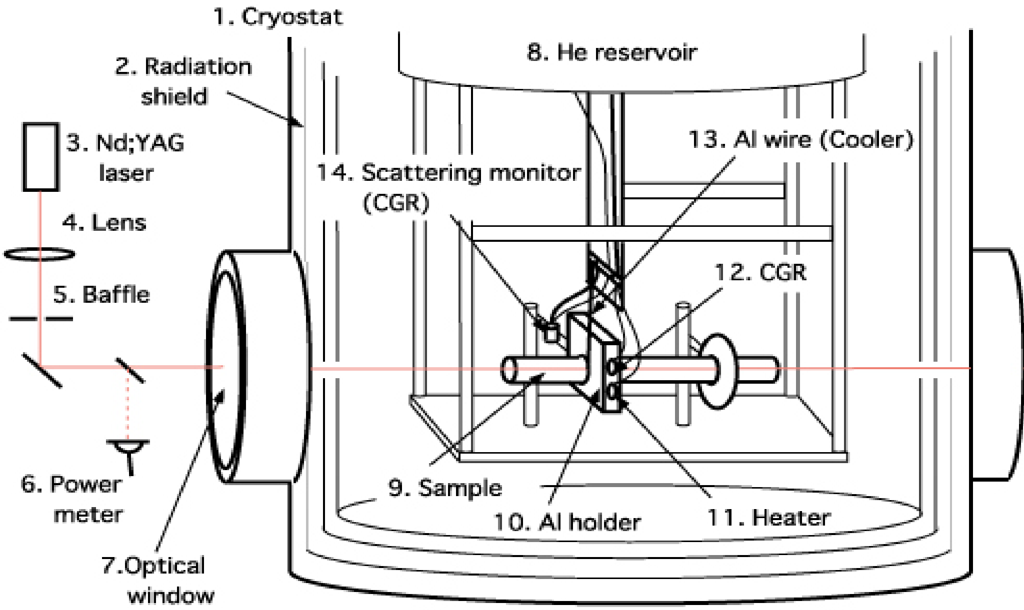




The fundamental and the second lowest mode were measured. They were higher than 10^8.

Optical absorption measurement in Sapphire

In 1999-2000



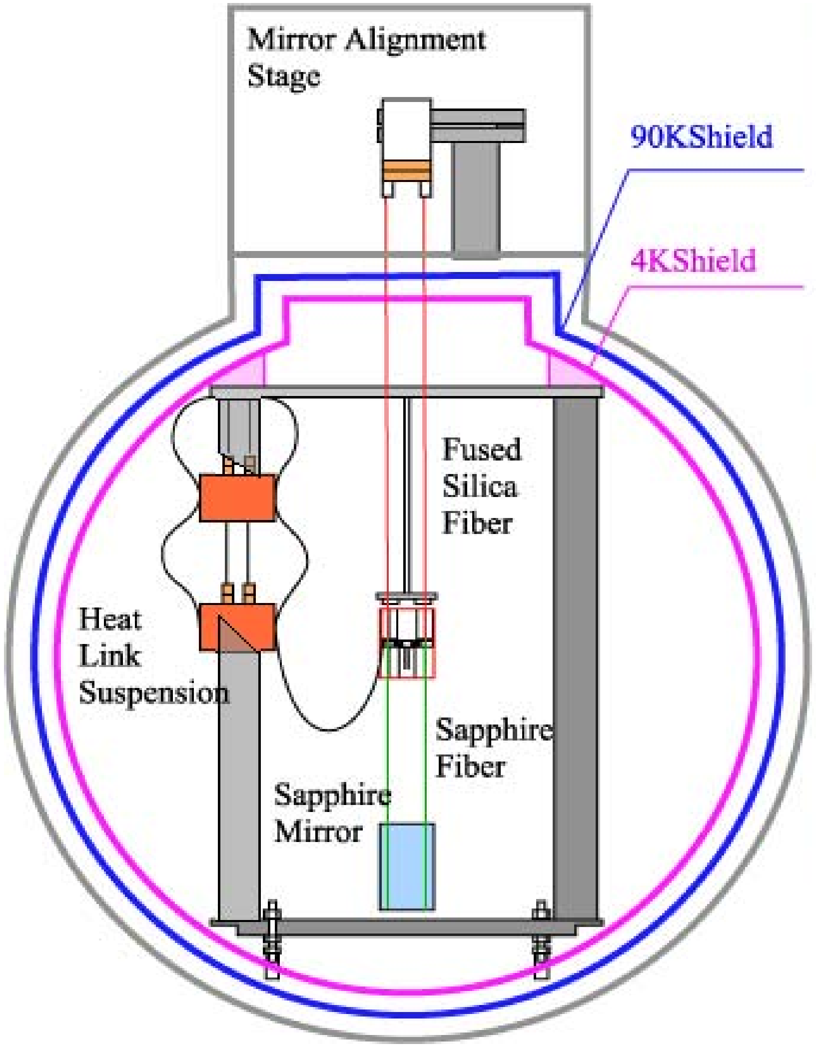
Experimental setup

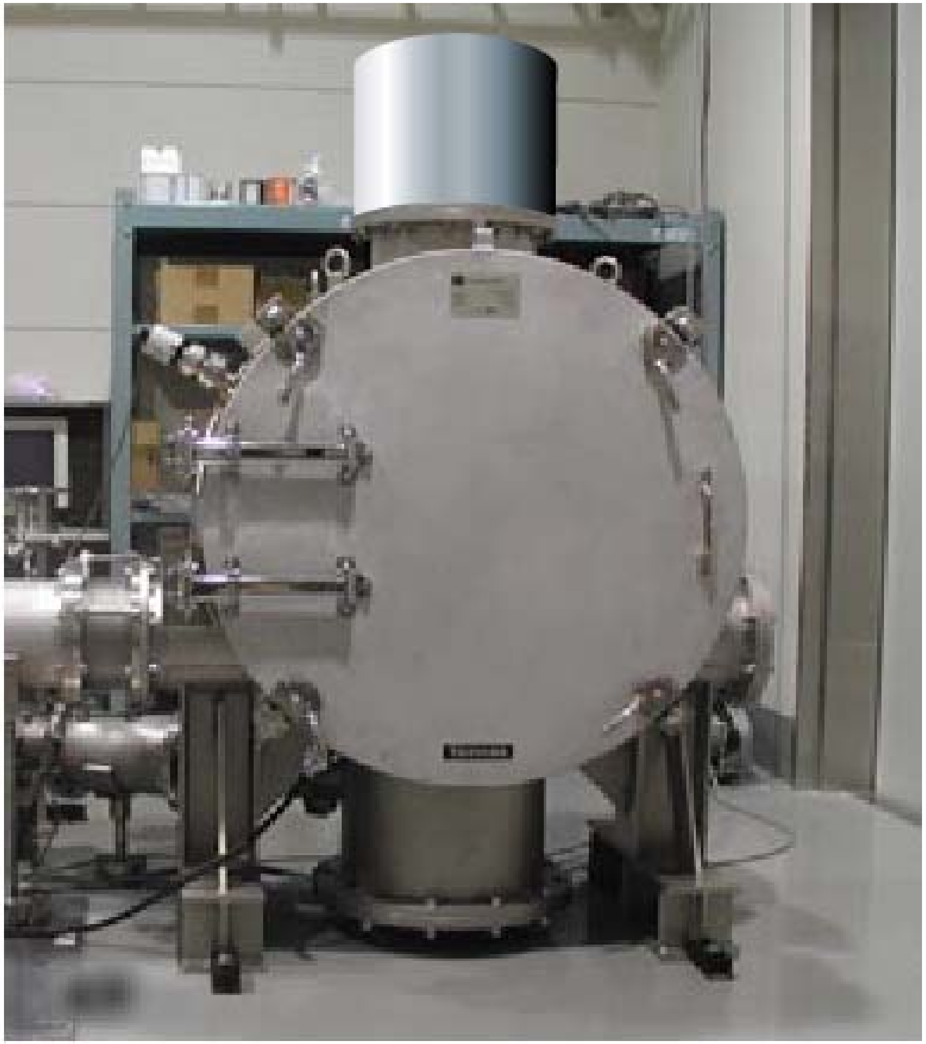
Sample	LCGT (5K)	Stanford	UWA
Hemex	-	-	24
Hemlite	90 - 99	-	-
CSI White	88 - 93	-	-
CSI White	-	-	3.4
CSI White	-	-	40
CSI White	-	47	-
CSI White	-	25	-

ppm/cm

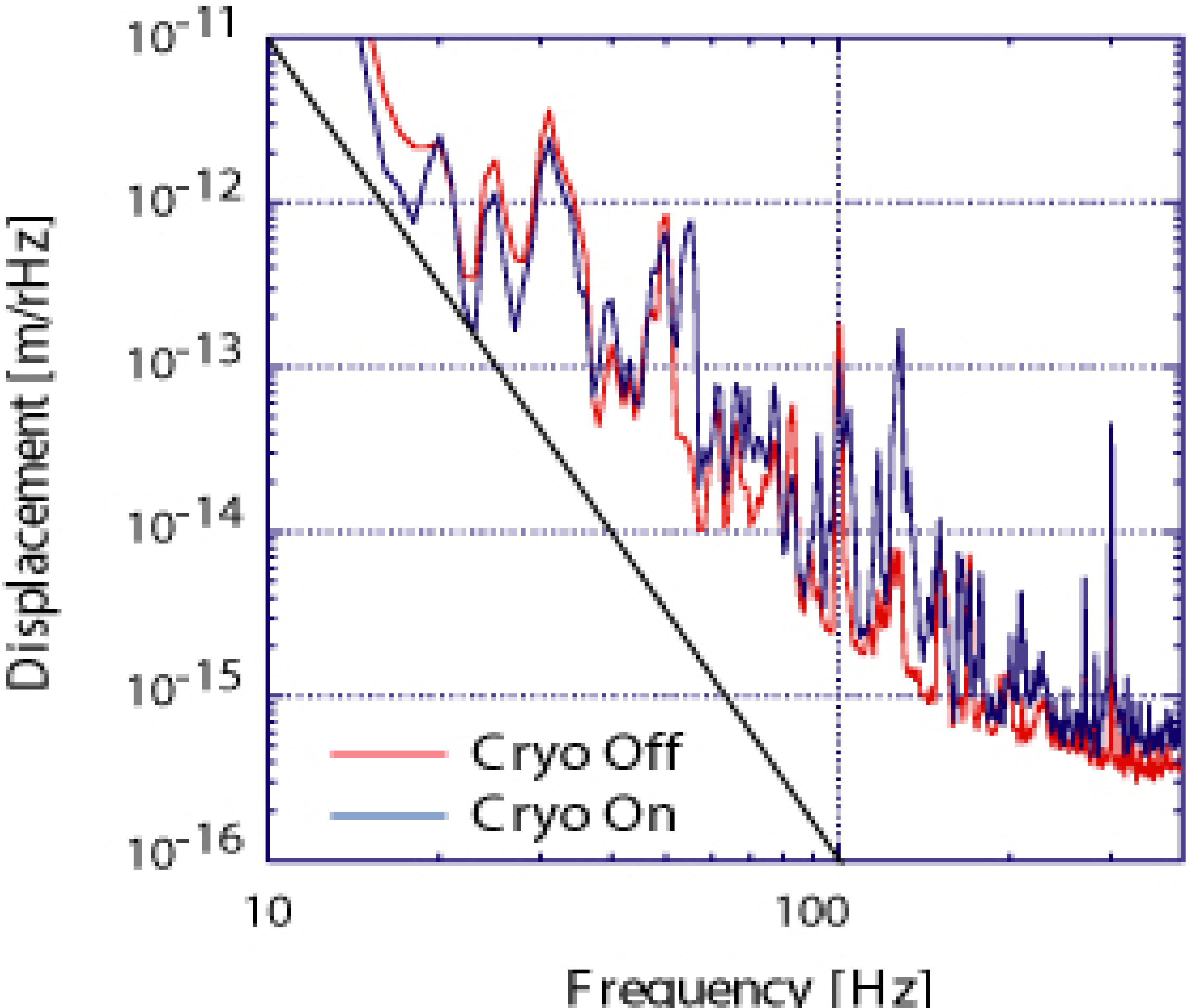
Suspension prototype was tested in Kashiwa campus in ICRR, in 2001.

7 m Fabry-Perot Cavity was formed.





Although we succeeded in the operation in cryogenic temperature, the mechanical vibration of the refrigerator was clearly introduced to the test mass.

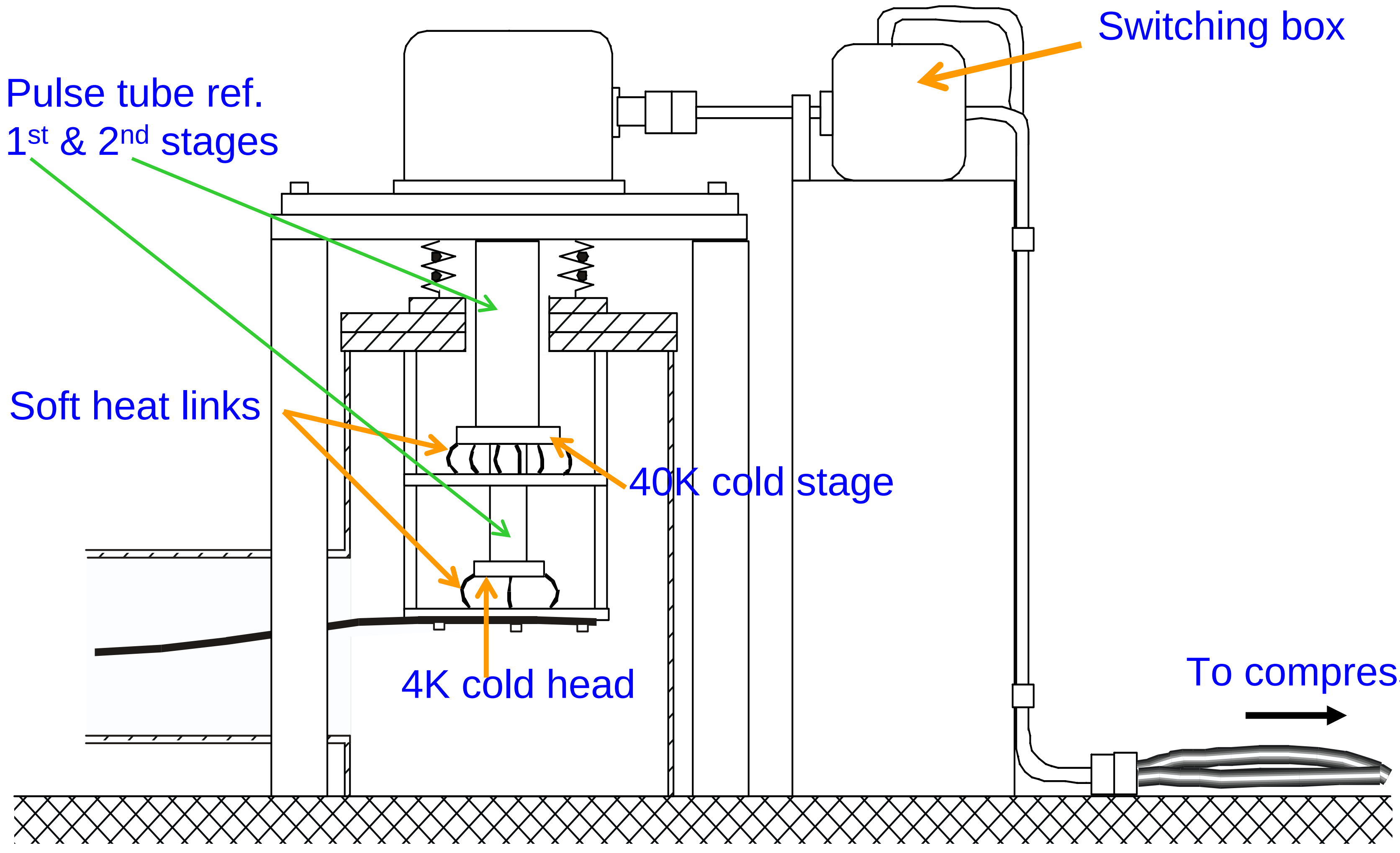


Quiet refrigerator and softer heat Link are required.

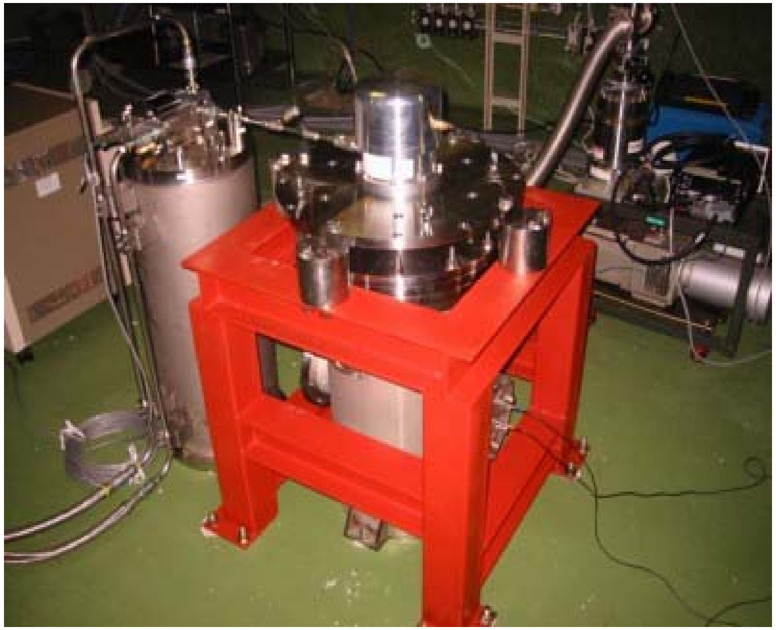
(Miyoki et al.)

Quiet refrigerator was developed (design in 2003)

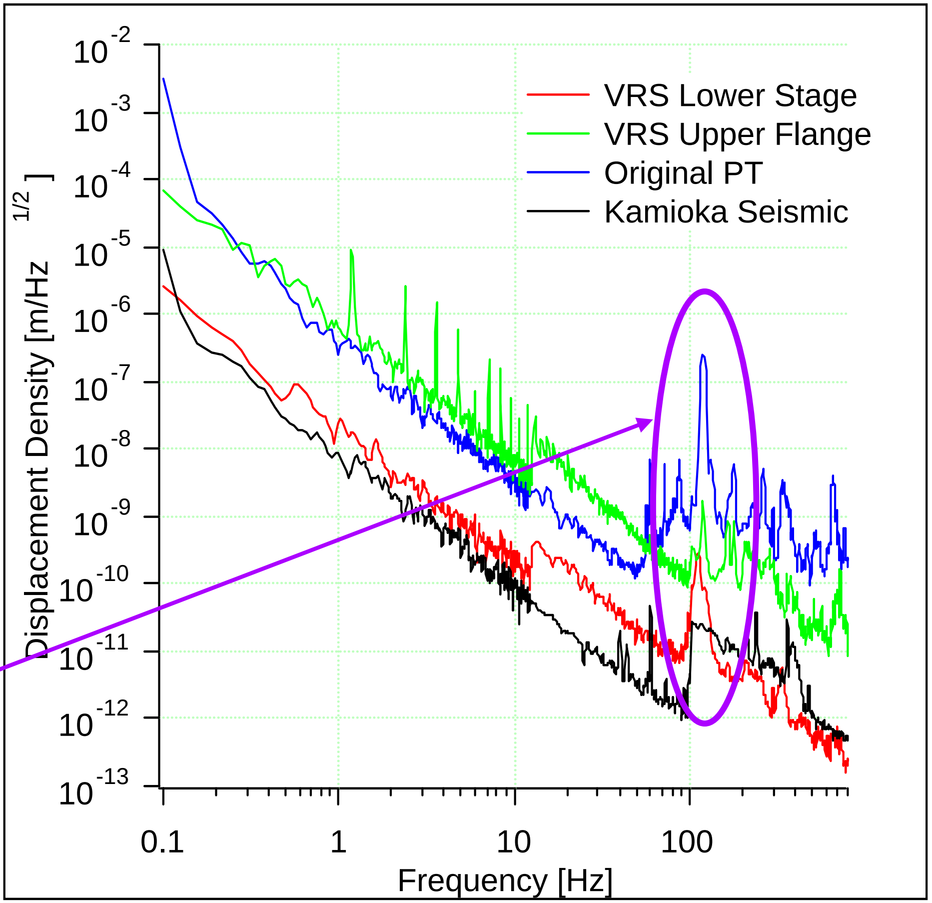
F-6: Class. Quantum Grav. (Accepted), Pr-1: Proc. 28th ICRC (2003),
patent: Pa-3 Tomaru et al., 2003; Suzuki et al., 2003.



Vibration of Cold Head



Measured underground of Kamioka mine



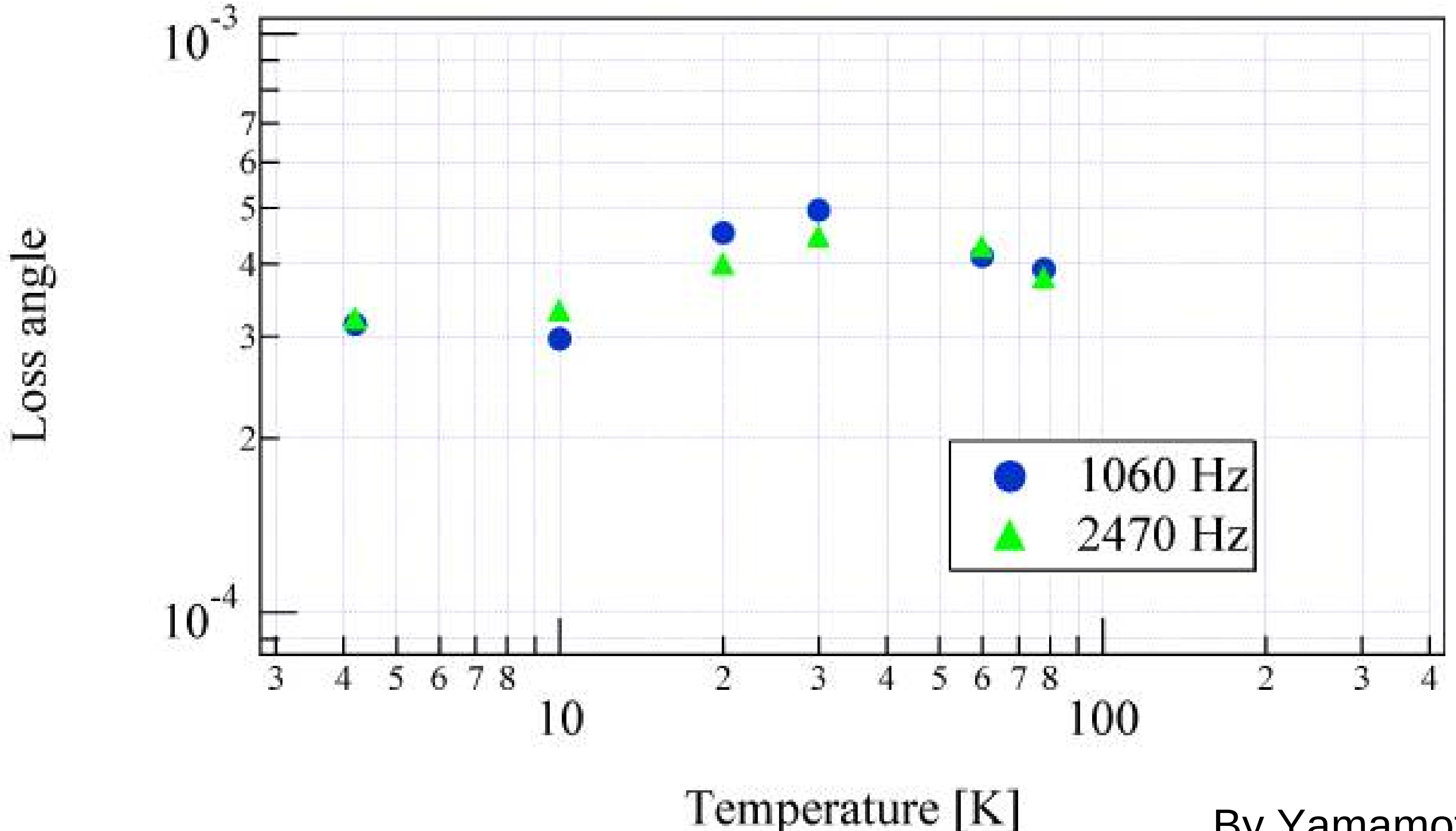
Not the vibration of the refrigerator
But the fixing device of the meter

Cold head vibration is less than the seimic noise level of the Underground of Kmioka mine.

Without reducing the efficiency, the vibration of Cold Stage, Cold Head have been reduced by more than 2   3orders of magnitude.

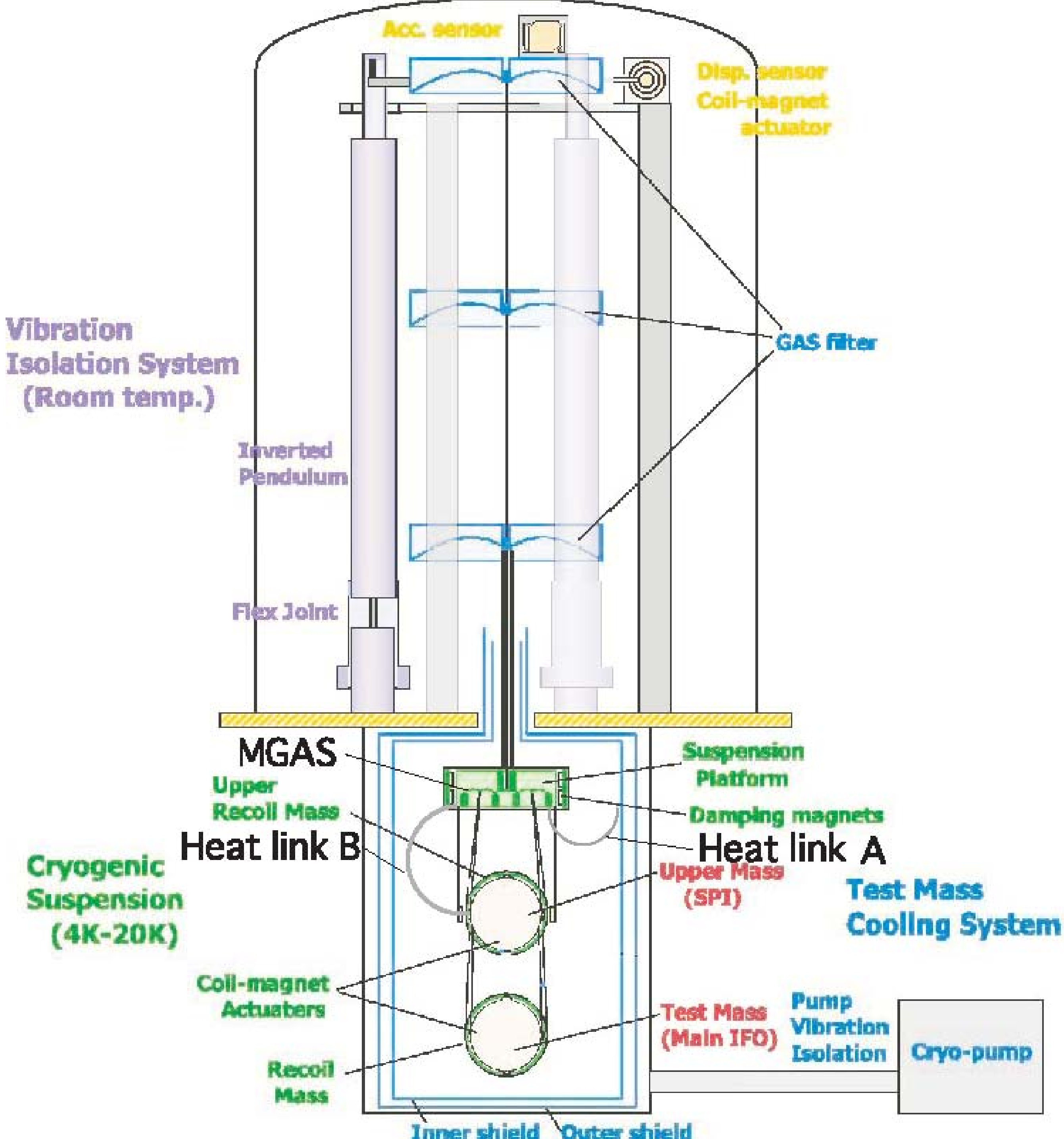
We used the measurement of Yamamoto's optical coating loss. He directly measured Q of thin disk coated and its mechanical loss was evaluated.

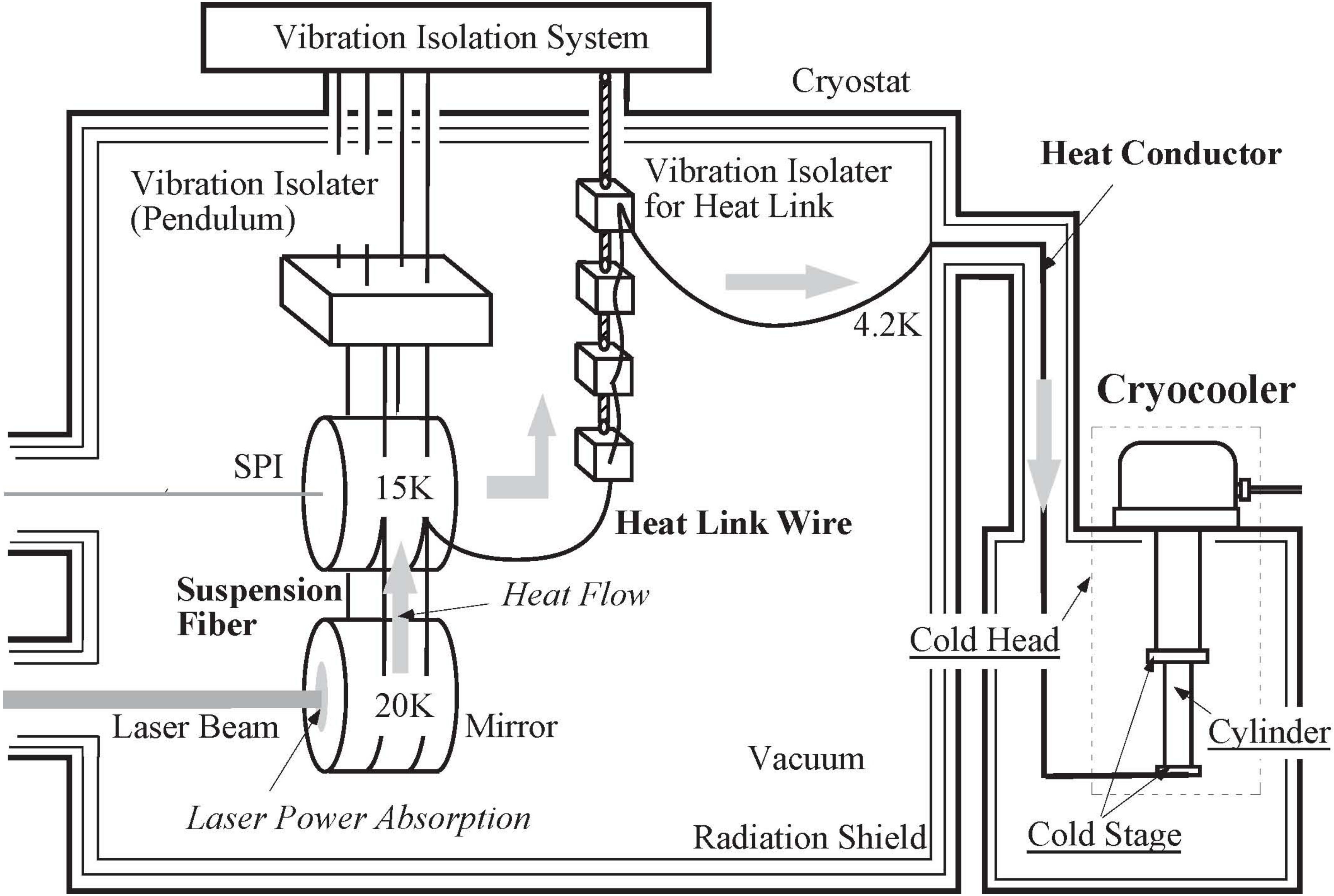
JAE coating on t 1mm disk

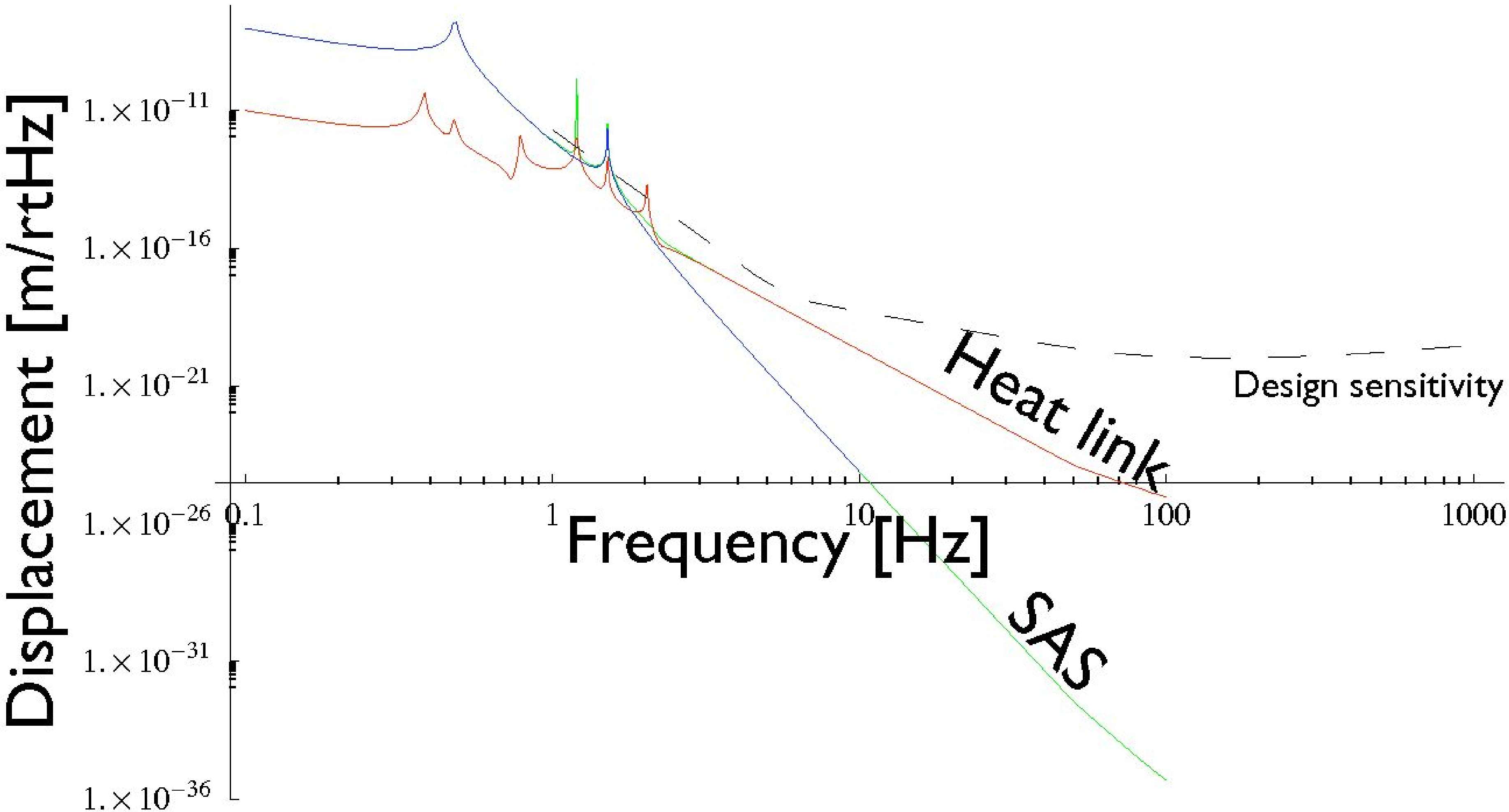


By Yamamoto

Design of Cryogenic suspension

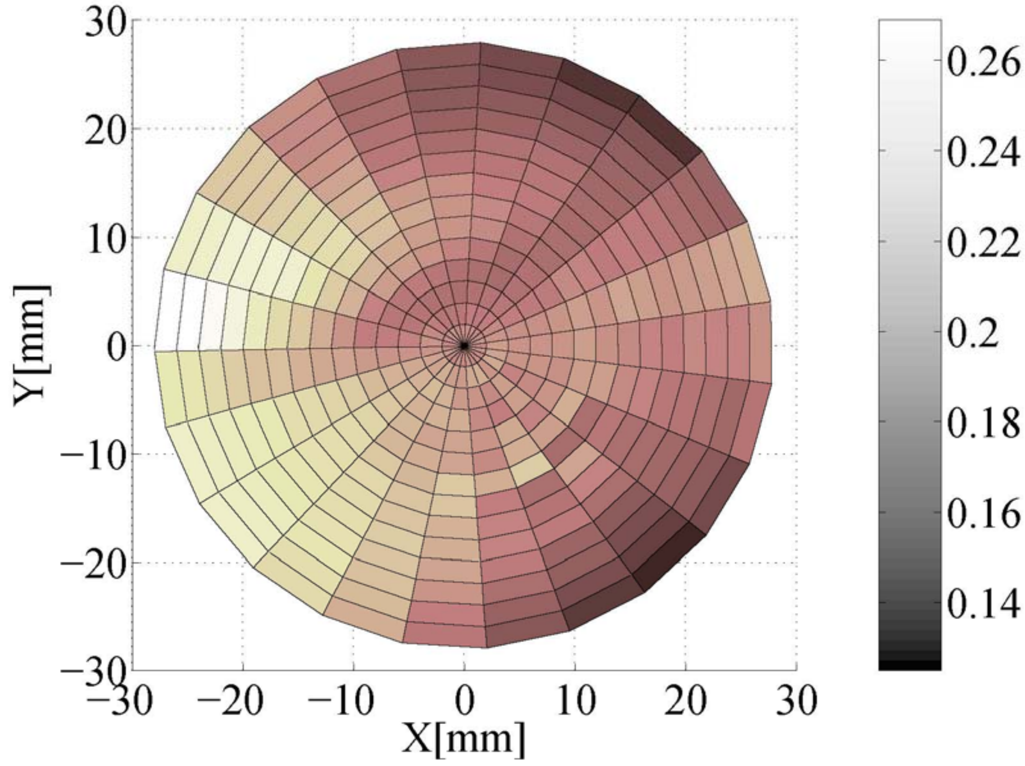

Acc. sensor
Disp. sensor
Coil-magnet actuator
Vibration Isolation System (Room temp.)
GAS filter
Inverted Pendulum
Flex Joint
MGAS
Suspension Platform
Upper Recoil Mass
Damping magnets
Heat link B
Heat link A
Cryogenic Suspension (4K-20K)
Upper Mass (SPI)
Test Mass Cooling System
Coil-magnet Actuaters
Test Mass (Main IFO)
Pump Vibration Isolation
Cryo-pump
Recoil Mass
Inner shield
Outer shield

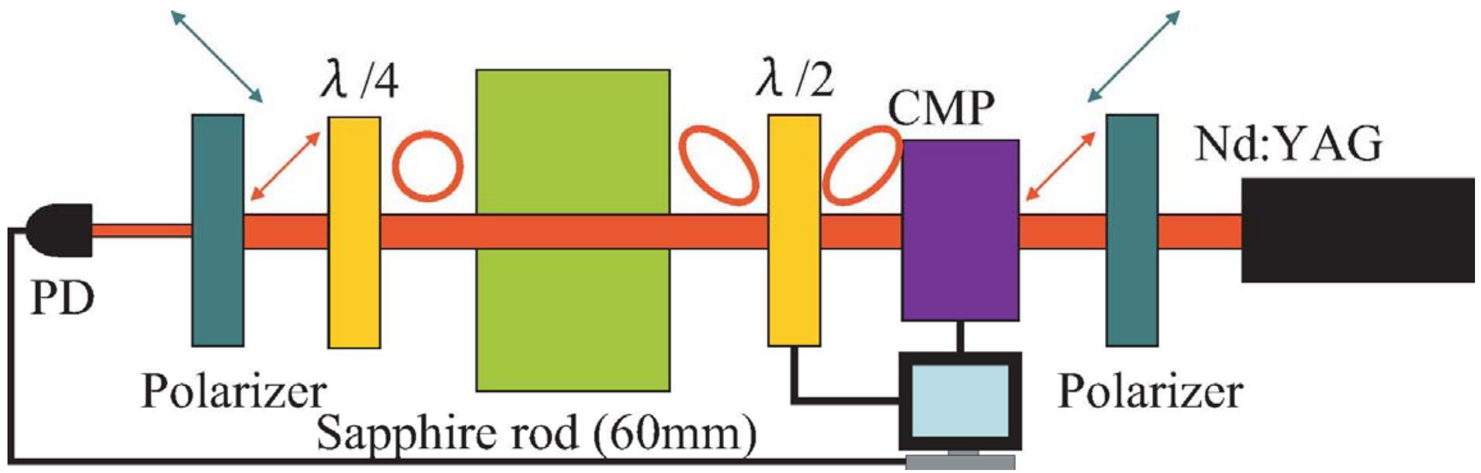

Vibration Isolation System
Cryostat
Heat Conductor
Vibration Isolater
(Pendulum)
Vibration Isolater
for Heat Link
4.2K
Cryocooler
SPI
15K
Heat Link Wire
Suspension
Fiber
Heat Flow
Cold Head
20K
Laser Beam
Mirror
Cylinder
Vacuum
Laser Power Absorption
Radiation Shield
Cold Stage


Displacement [m/rtHz]
1.×10−11
1.×10−16
1.×10−21
1.×10−26
1.×10−31
1.×10−36
0.1
1
10
100
1000
Frequency [Hz]
Heat link
Design sensitivity
SAS

Effort to increase the optical quality of sapphire

Sapphire quality was checked by an automatic birefringence measurement device





Tokunari et al. in Poster session

Practical advancement of cryogenic mirror

Main mirrors of CLIO were polished by Canon Co. Ltd. And now in the process of coating by JAE.

Substrate	sapphire
Shape	$\phi 100 \times 60$
Curvature	∞
Accuracy	Less than $\lambda/10$ PV
Guaranteed Scale	$\Phi 80$
Micro-Roughness	Less than 0.5 nm rms
Appearance	MIL 30/10
Others	Wedged

Table 3. Specification of CLIO near mirror. Two pieces of the near mirror have been polished and coated, satisfying this specification.

Substrate	sapphire
Shape	$\phi 100 \times 60$
Curvature	$R = 150 \pm 10$ m
Accuracy	Less than $\lambda/5$ PV ($\lambda/10$ targeted)
Guaranteed Scale	$\Phi 80$
Micro-Roughness	Less than 0.5 nm rms
Appearance	MIL 30/10
Others	Wedged

Table 4. Specification of CLIO end mirror. Two pieces of the end mirror have been polished and coated satisfying this specification.

Conclusion of this Talk

- Cryogenic interferometer, LCGT, is realized by sapphire whose mechanical quality is good but its optical quality is not sufficient.
- Basic and practical techniques of a cryogenic interferometer have been developed.
- We are trying to increase the quality of sapphire to increase the sensitivity of LCGT.
- Practical test is now undergoing by CLIO interferometer at Kamioka.