Development of cryogenic payload for KAGRA I

K. Yamamoto, R. Takahashi, T. Sekiguchi, Y. Sakakibara, C. Tokoku, M. Kamiizumi, U. Iwasaki, T. Uchiyama, S. Miyoki, M. Ohashi, T. Akutsu[A], H. Ishizaki[A], T. Suzuki[B], N. Kimura[B], S. Koike[B], K. Tsubono[C], Y. Aso[C], T. Ushiba[C], K. Shibata[C], D. Chen[D] , N. Ohmae[E], K. Somiya[F], R. DeSalvo[G], E. Majorana[H], W. Johnson[I], KAGRA collaboration

ICRR.UT, NAOJ[A], KEK[B], Phys.S.UT[C], Astro.S.UT[D], E.UT[E],S.TIT[F], Sannio Univ.[G], INFN[H], Louisiana State Univ.[I]

2012 September 11
The meeting of Physical Society of Japan
@Kyoto Sangyo University, Kyoto, Kyoto

0. Abstract

Progress of development
and near future plans
of cryogenic payload
(and cryostat and cryocooler unit)
for KAGRA in the last half year

Contents

1. Introduction

KAGRA :

2nd generation interferometric gravitational wave detector in Japan

Key features of KAGRA project

Silent underground site (Kamioka) : Small seismic motion

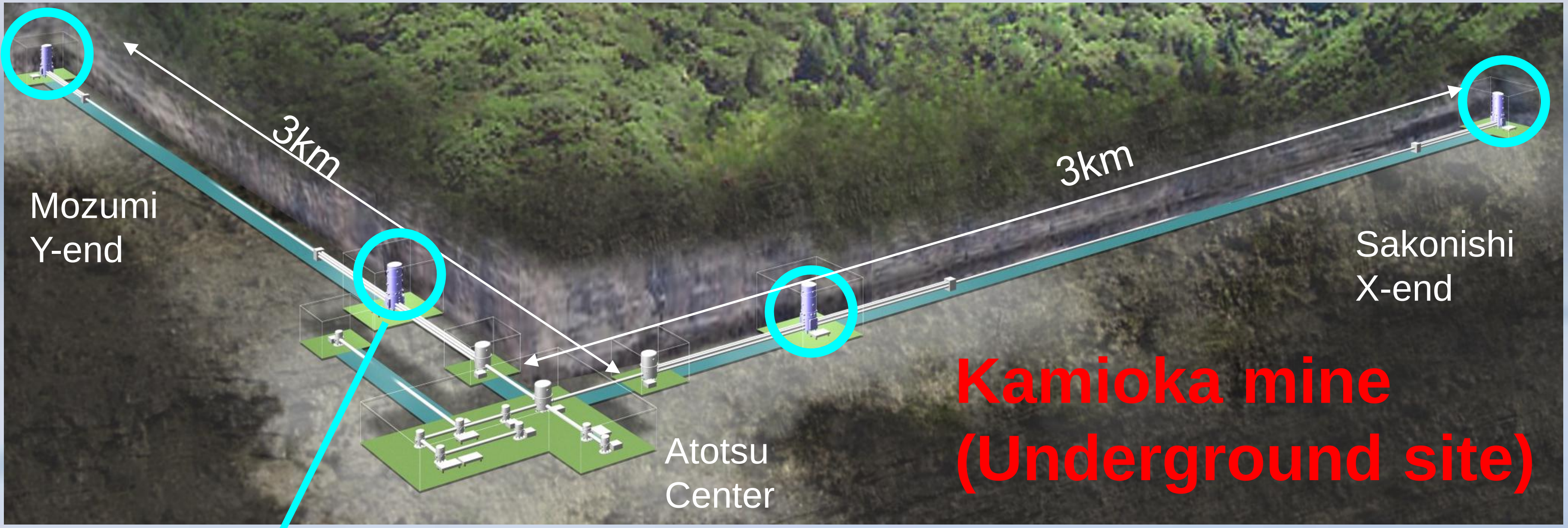
Cryogenic system : Reduction of thermal noise

and so on

1. Introduction

Schematic view of KAGRA interferometer

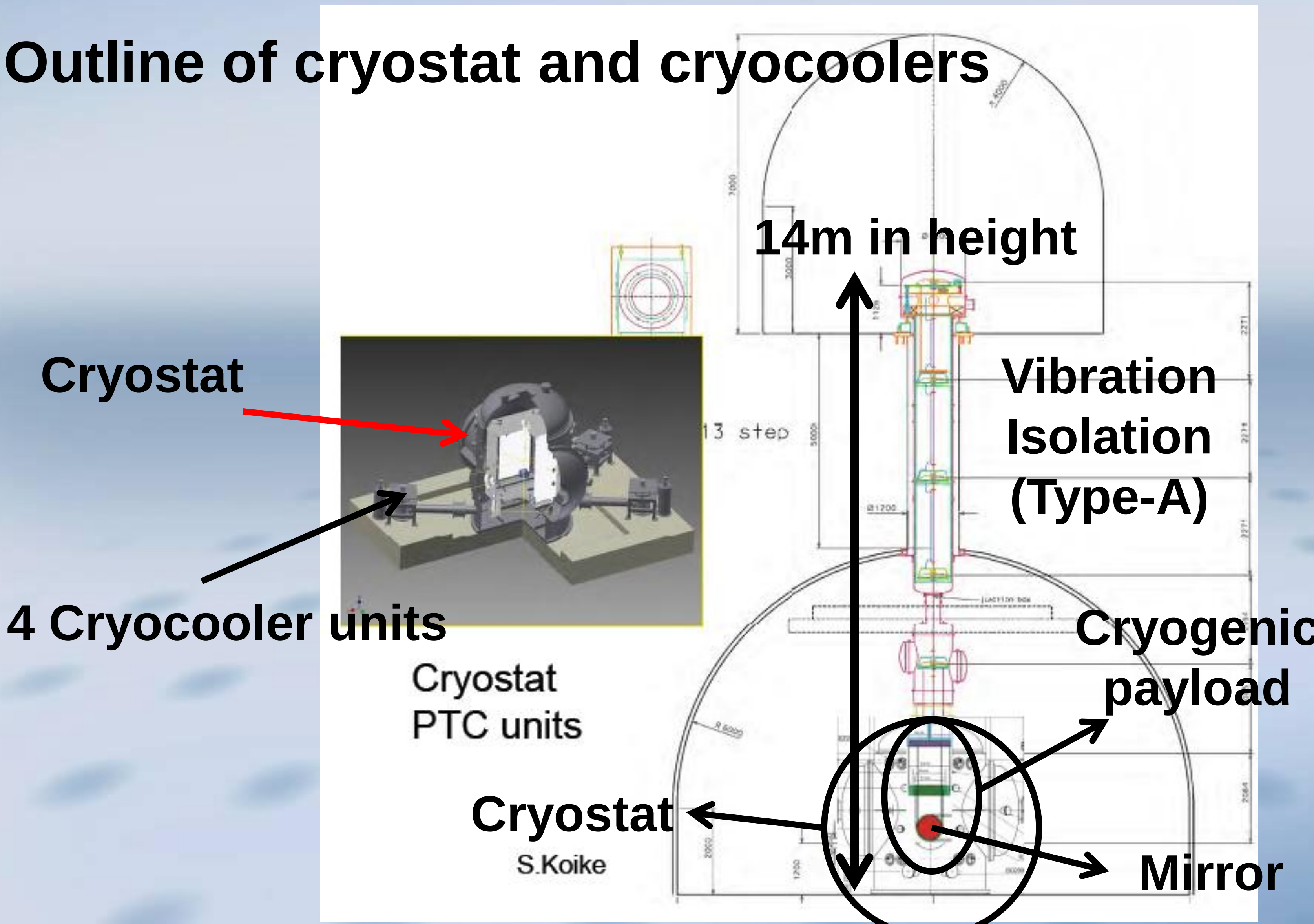
Four mirrors of arm cavity will be cooled.



Vibration isolation system, Cryostat, Cryocooler unit, Cryogenic payload

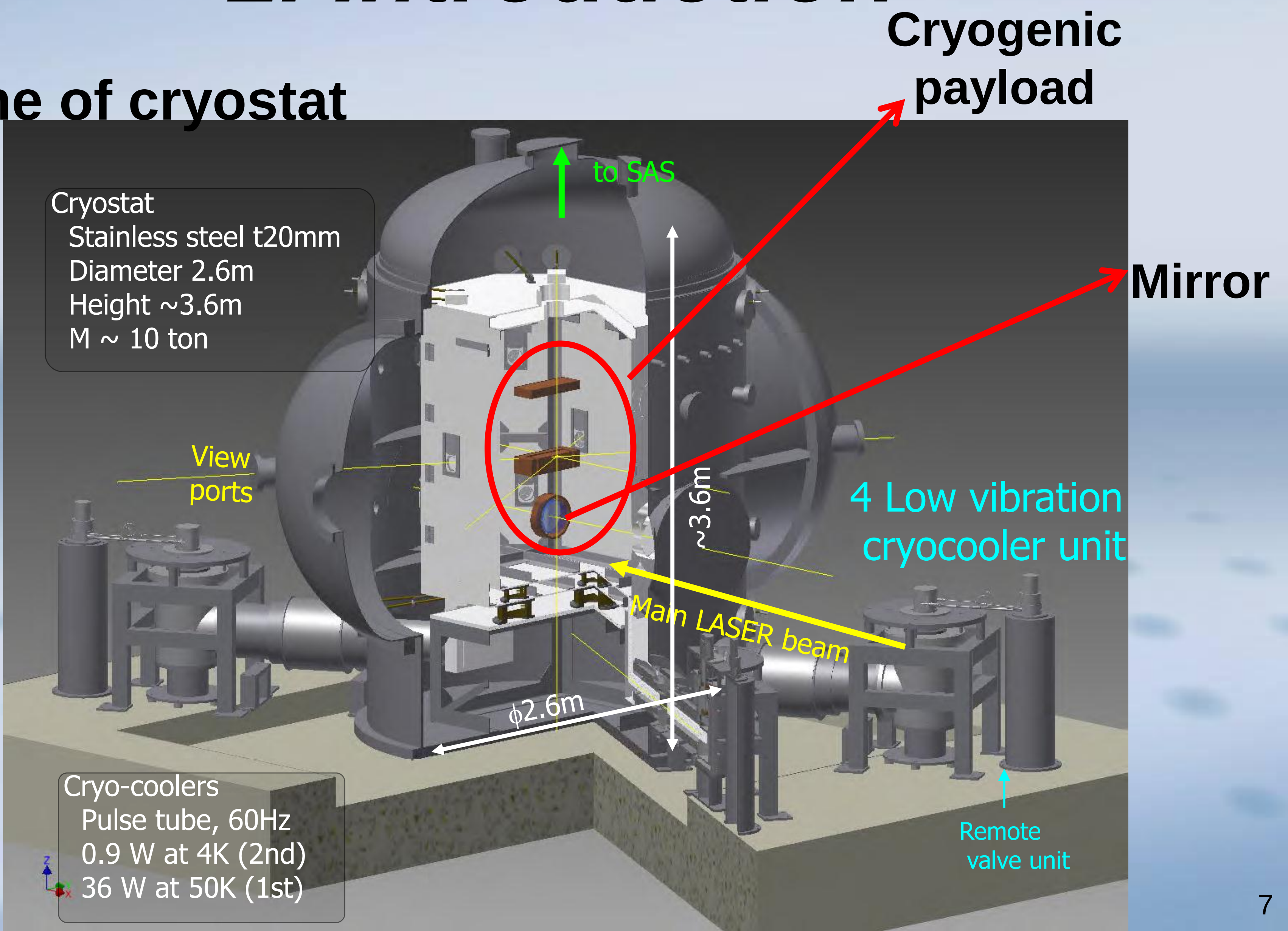
1. Introduction

Outline of cryostat and cryocoolers



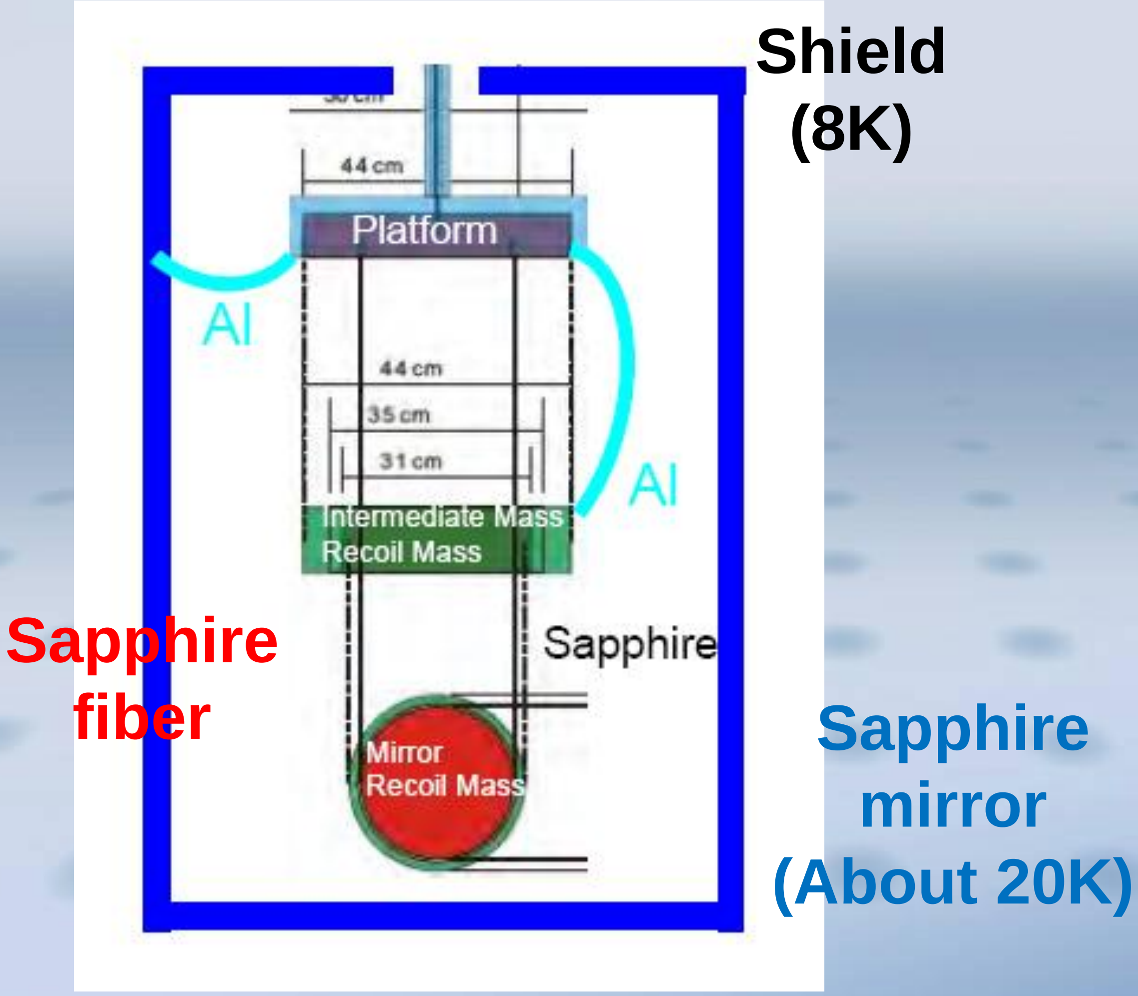
1. Introduction

Outline of cryostat



1. Introduction

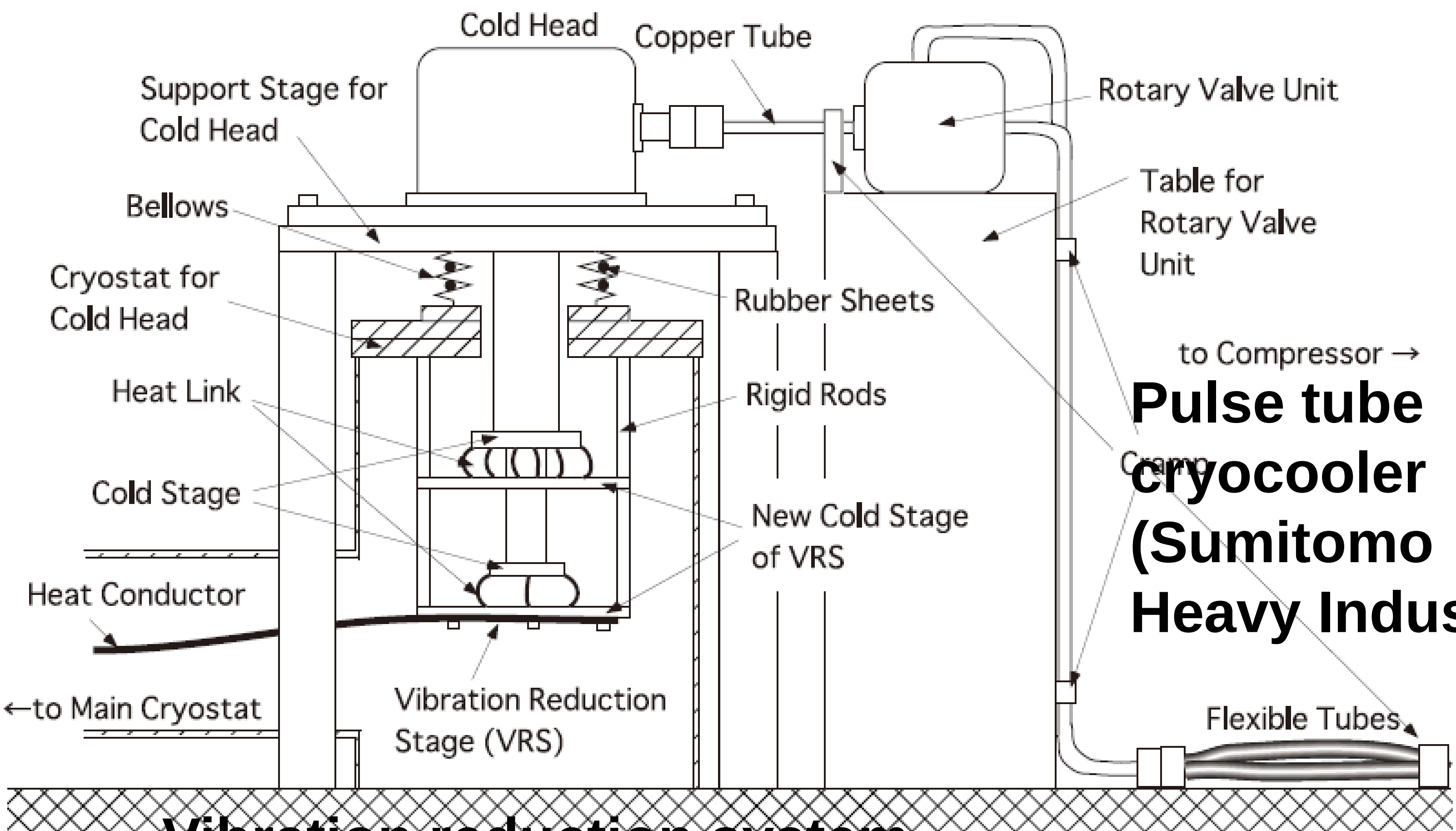
Outline of cryogenic payload



2. Cryocooler unit

1. Outline

Class. Quantum Grav. **21** (2004) S1005–S1008



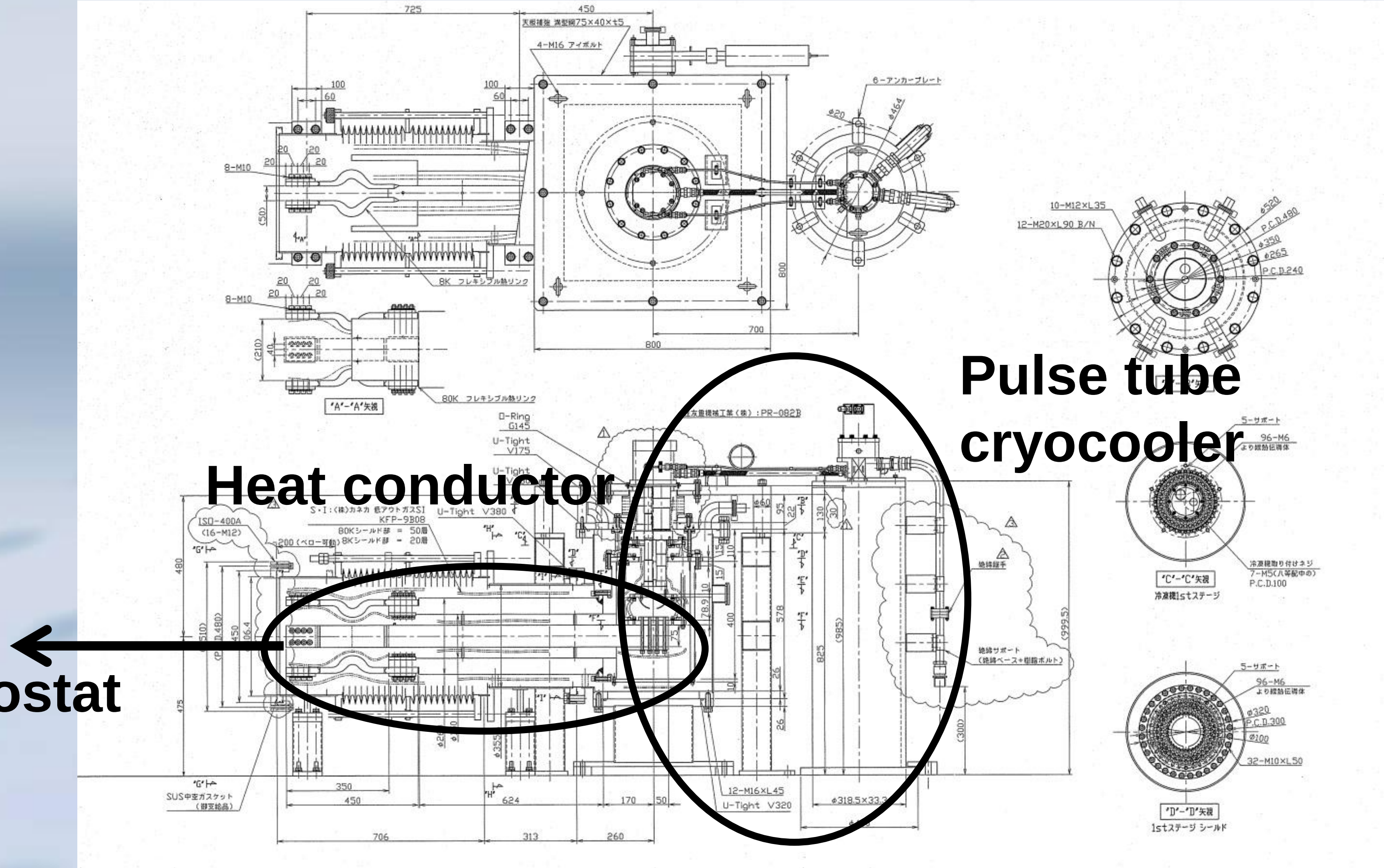
Pulse tube cryocooler (Sumitomo Heavy Industries)

Vibration reduction system

Figure 3. Vibration-reduction system we have been developing for the PT cryocooler.

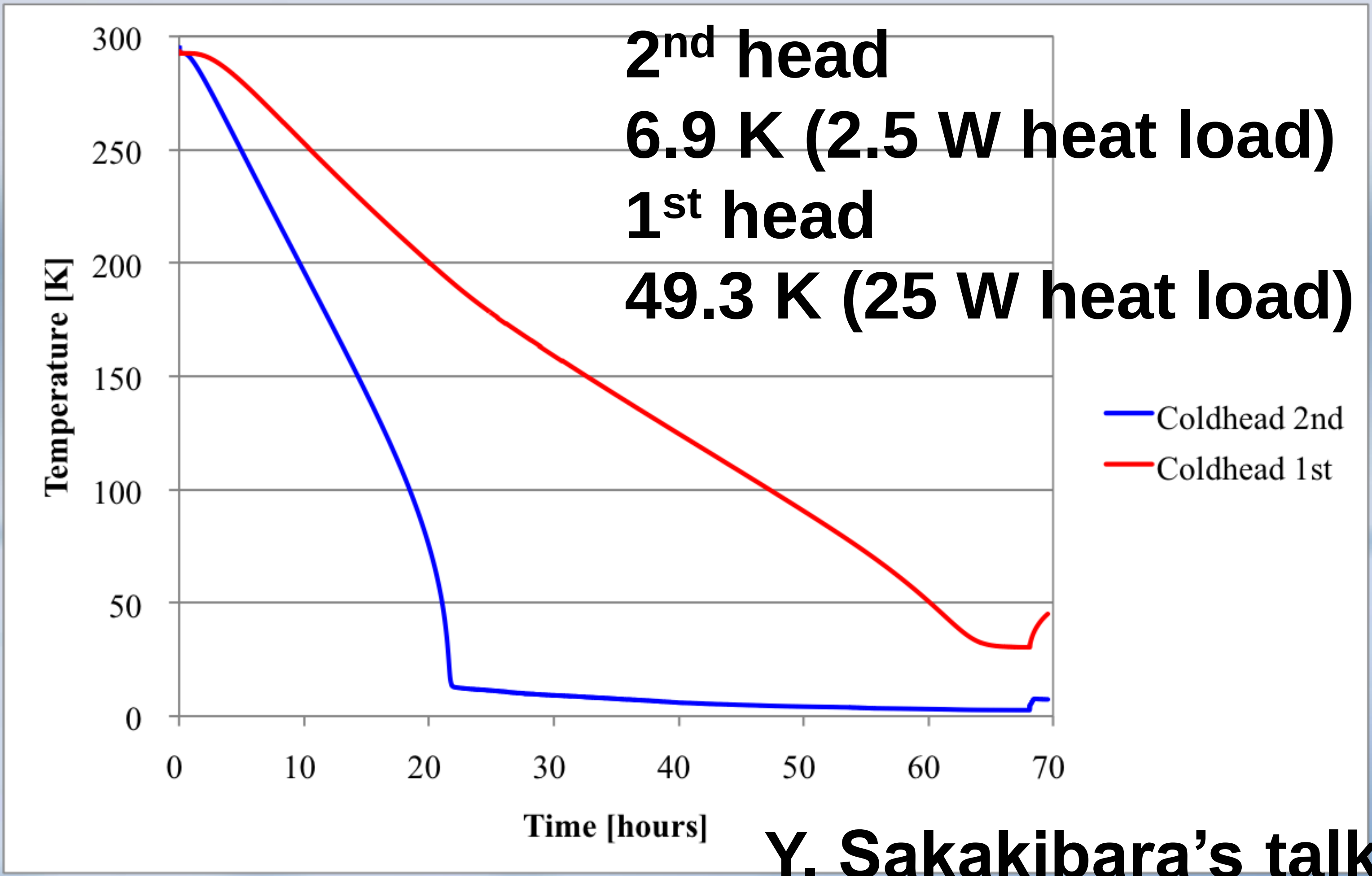
2. Cryocooler unit

2. Drawing by Jecc Torisha



2. Cryocooler unit

3. Cooling test : Cryocooler works well.

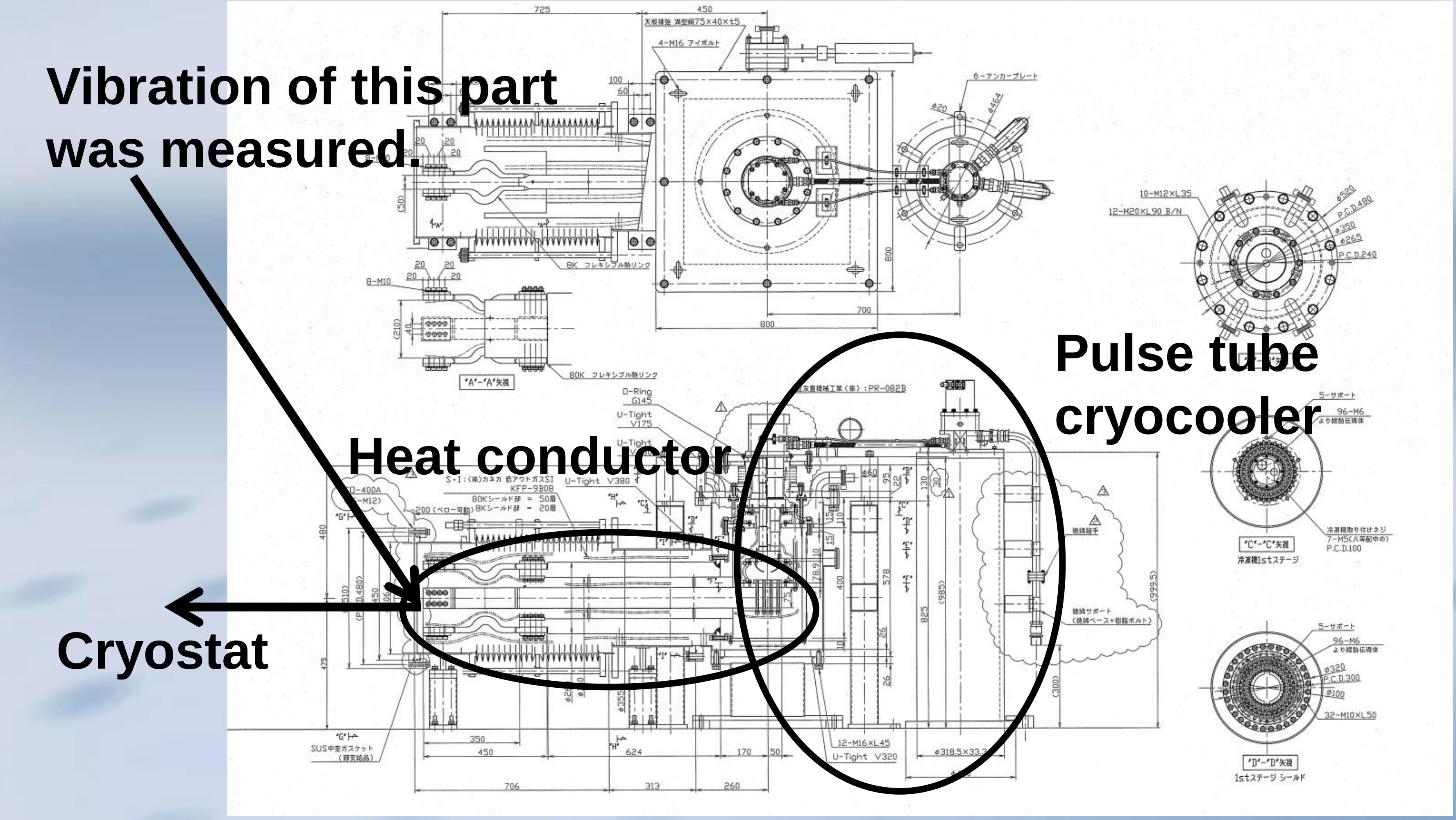


2nd head
6.9 K (2.5 W heat load)
1st head
49.3 K (25 W heat load)

Y. Sakakibara's talk

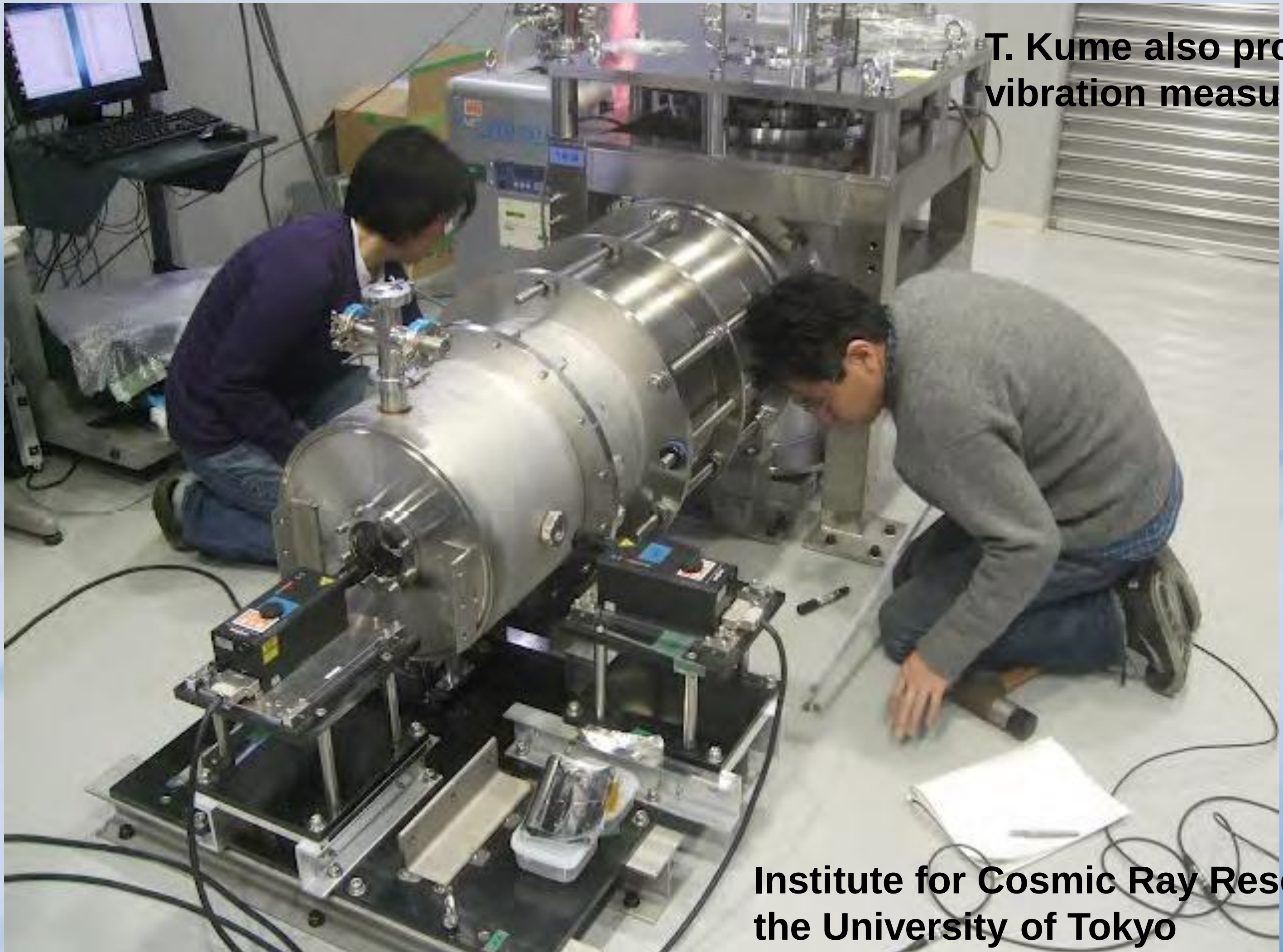
2. Cryocooler unit

4. Vibration measurement



2. Cryocooler unit

4. Vibration measurement

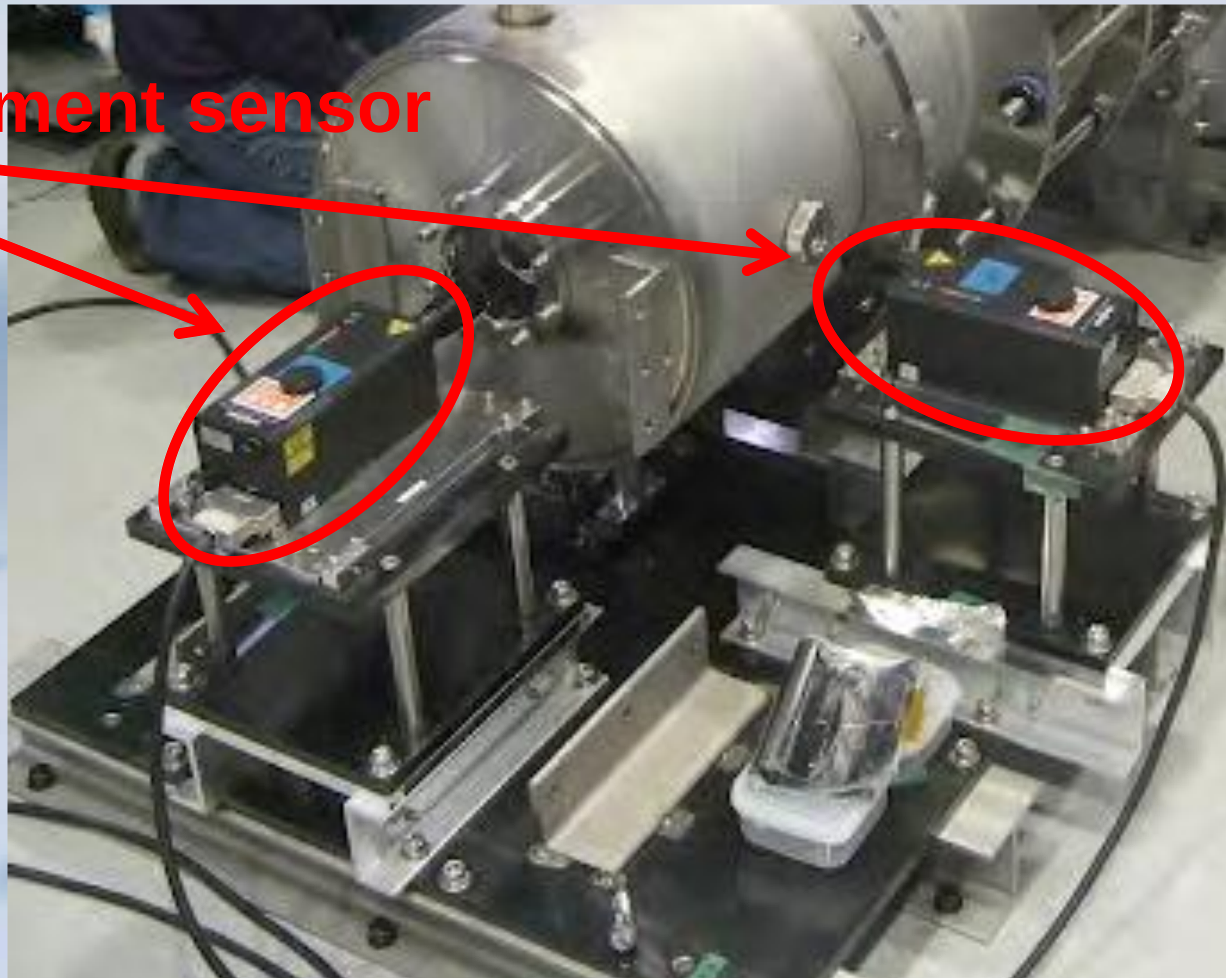


T. Kume also proceeds with vibration measurement.

Institute for Cosmic Ray Research,
the University of Tokyo

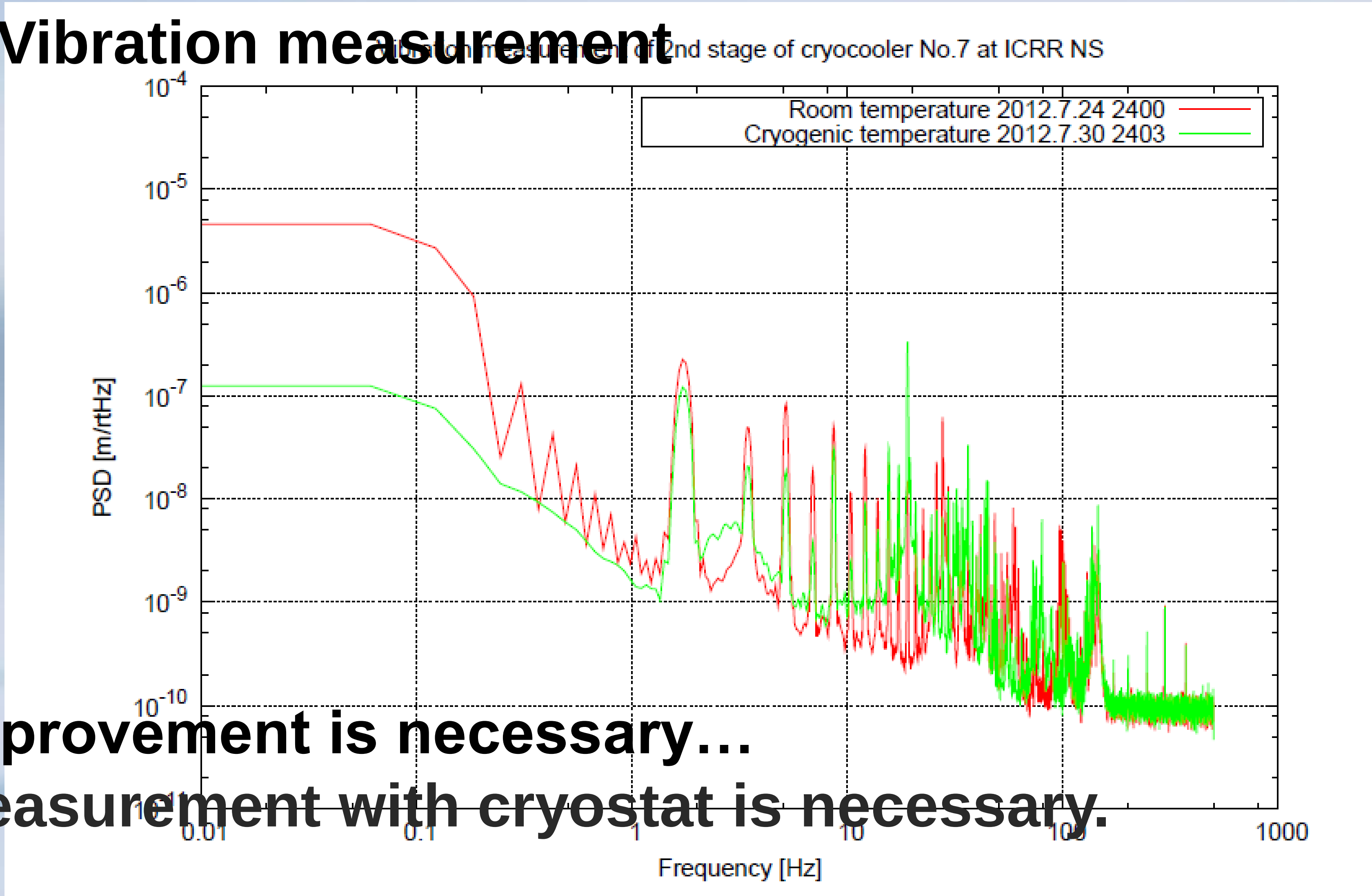
2. Cryocooler unit

4. Vibration measurement



2. Cryocooler unit

4. Vibration measurement

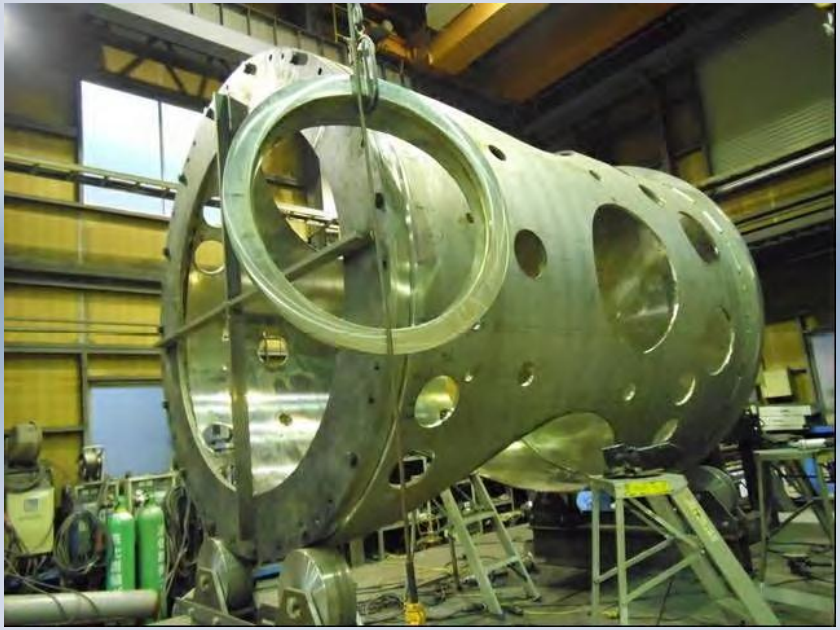


Improvement is necessary…

Measurement with cryostat is necessary.

3. Cryostat

1. Assembly



Main body (Φ2.6m, H3.6m)

at Toshiba Keihin Product Operations

3. Cryostat

1. Assembly

at Toshiba Keihin Product Operations

Vacuum chamber

3. Cryostat

1. Assembly

at Toshiba Keihin Product Operations

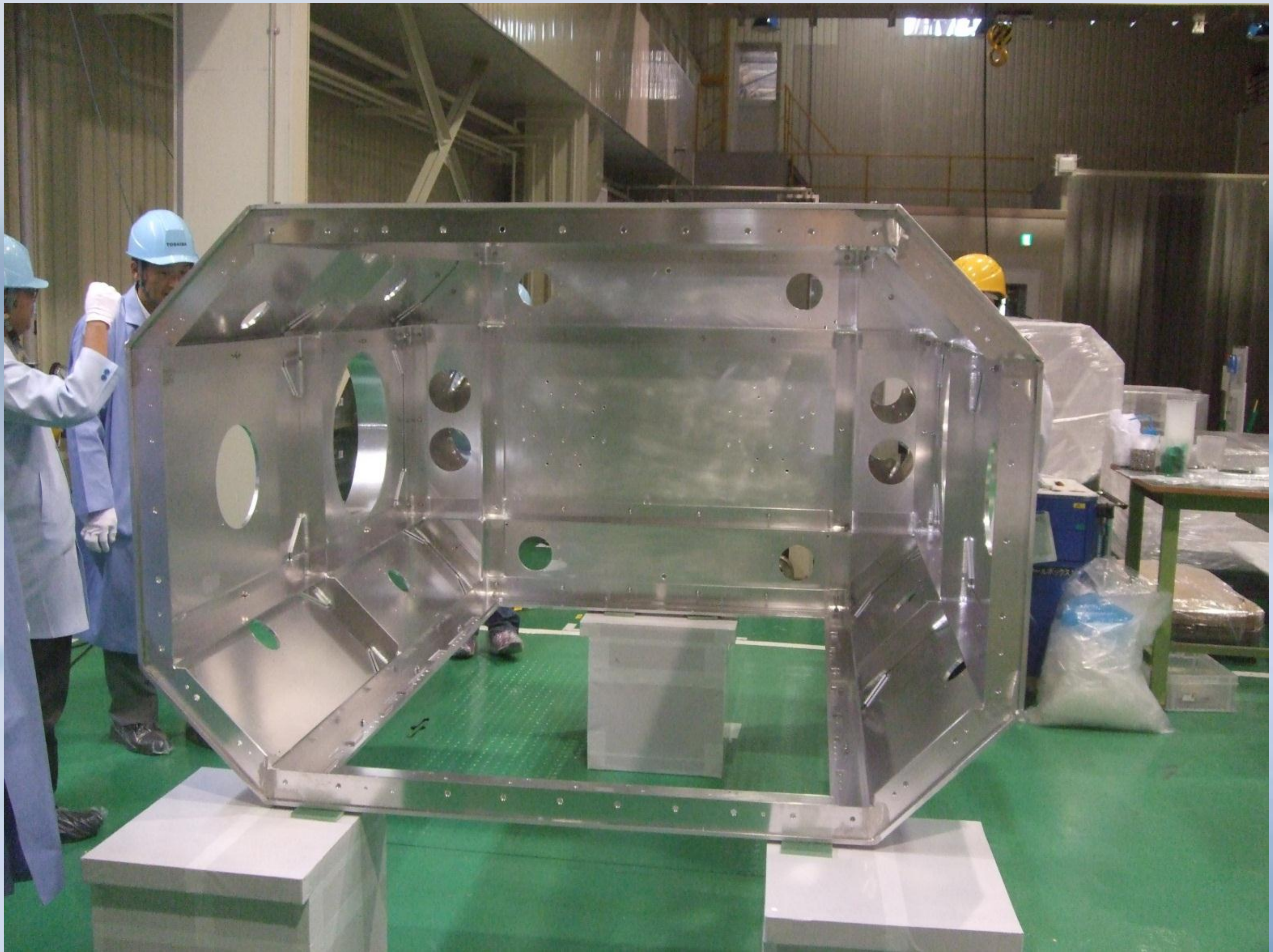
Vacuum chamber

3. Cryostat

1. Assembly

at Toshiba Keihin Product Operations

Shield



3. Cryostat

2. Experimental plans in Toshiba

In this autumn, there will be cooling test of shileds in Toshiba Keihin Product Operations.

At the same time, we have experimental plans in Toshiba.

(1) Heat load test
(2) Measurement of vibration of shield
(3) Measurment of initial cooling time

3. Cryostat

2. Experimental plans in Toshiba

(2) Measurement of vibration of shield

This measurement is

at cryogenic temperature and in vacuum.

Luca Naticchioni (Rome) and Dan Chen will measure vertical and horizontal vibration of radiation shield of KAGRA, respectively.

D. Chen's talk

3. Cryostat

2. Experimental plans in Toshiba

(2) Measurement of vibration of shield

Luca Naticchioni's accelerometer

3. Cryostat

2. Experimental plans in Toshiba

(3) Measurment of initial cooling time

Initial cooling time for cryogenic payload is about 2 months (if no tricks).

At beginning of initial cooling, heat transfer is dominated by radiation.

Diamond Like Carbon (DLC) coating
(High emissivity, Large radiation)
on shields and payload (except for mirror)

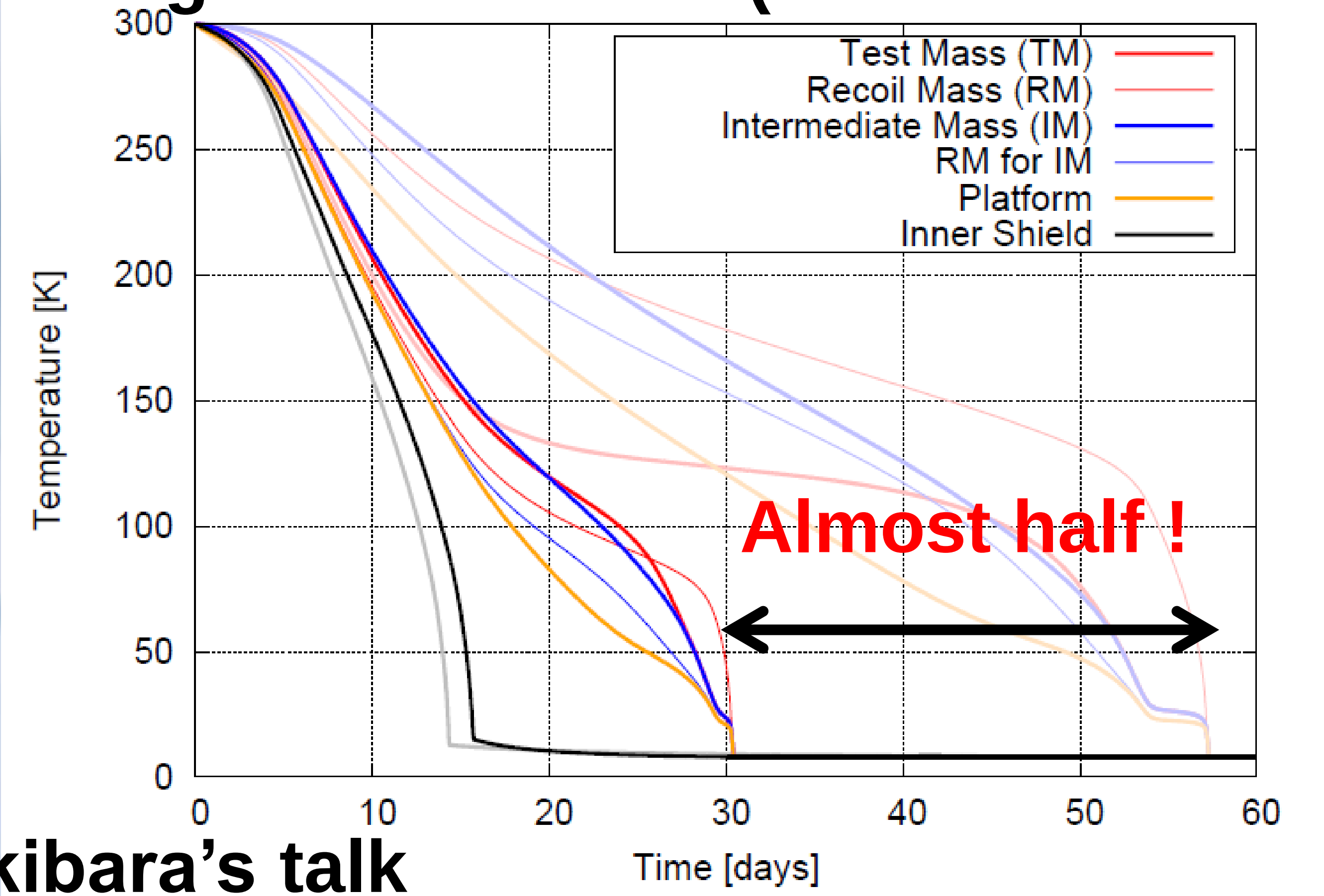
Y. Sakakibara's talk

3. Cryostat

2. Experimental plans in Toshiba

(3) Measurment of initial cooling time

Initial cooling time with DLC (shield and mass)



Y. Sakakibara's talk

3. Cryostat

2. Experimental plans in Toshiba

(3) Measurment of initial cooling time

We must check the effect of radiation (and DLC coating) on the initial cooling time experimentally.

We suspend something without heat link inside shield and monitor the temperature of something in shiled during cooling test.

What is something ?
Sample 1 : Sapphire and metal hollow sphere
Sample 2 : Dummy payload (hollow masses)

3. Cryostat

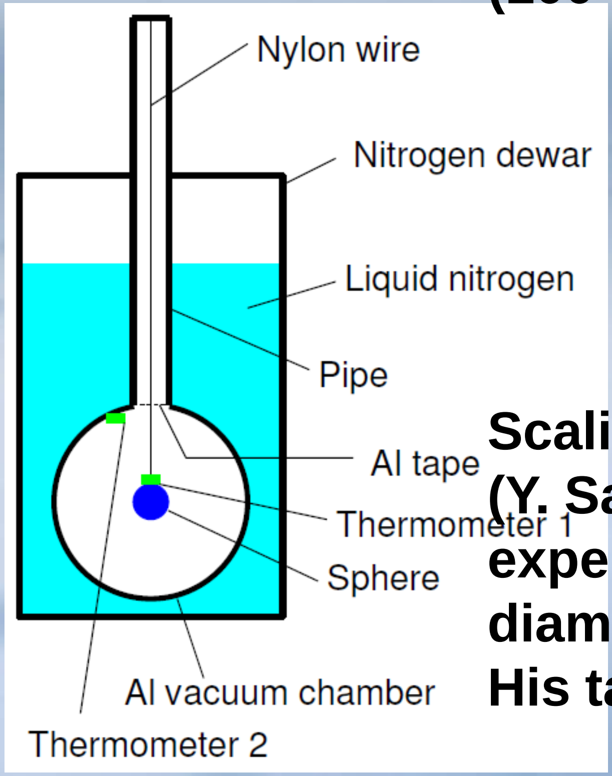
2. Experimental plans in Toshiba

(3) Measurment of initial cooling time

Sample 1 : Sapphire and metal hollow sphere

(100 mm in diameter)

Evaluation of emissivity



Scaling law
(Y. Sakakibara's small experiment: 30 mm in diameter)
His talk

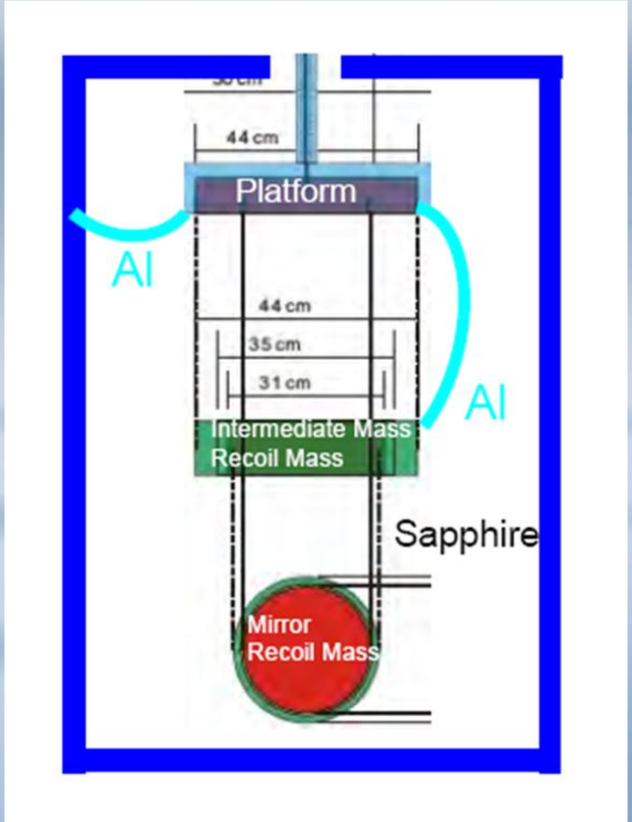
3. Cryostat

2. Experimental plans in Toshiba

(3) Measurment of initial cooling time

Sample 2 : Dummy payload (hollow masses)

Half size
Hollow masses
(~5 kg)
DLC coating
Sapphire bulk as dummy mirror



Preparation is in progress.

4. Cryogenic payload

1. **Mechanical simulation**

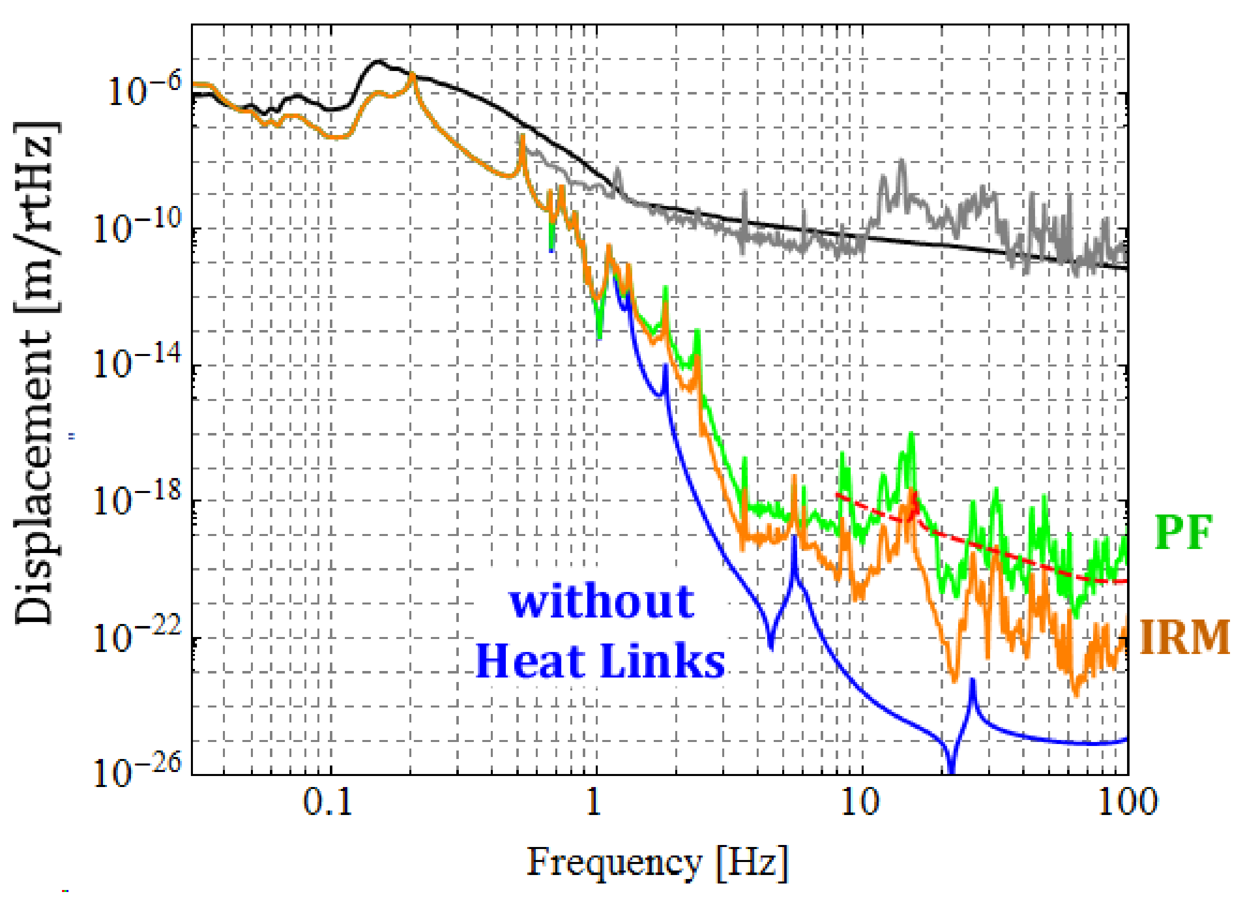
T. Sekiguchi is developing.

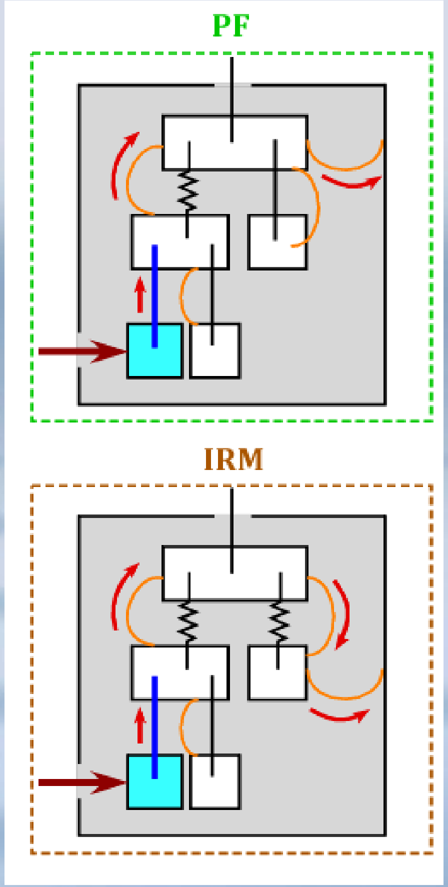
(1) Vibration via heat links (above 1 Hz)
(2) Thermal noise (above 10Hz)
(3) Control scheme
(Investigation started recently)

4. Cryogenic payload

1. Mechanical simulation

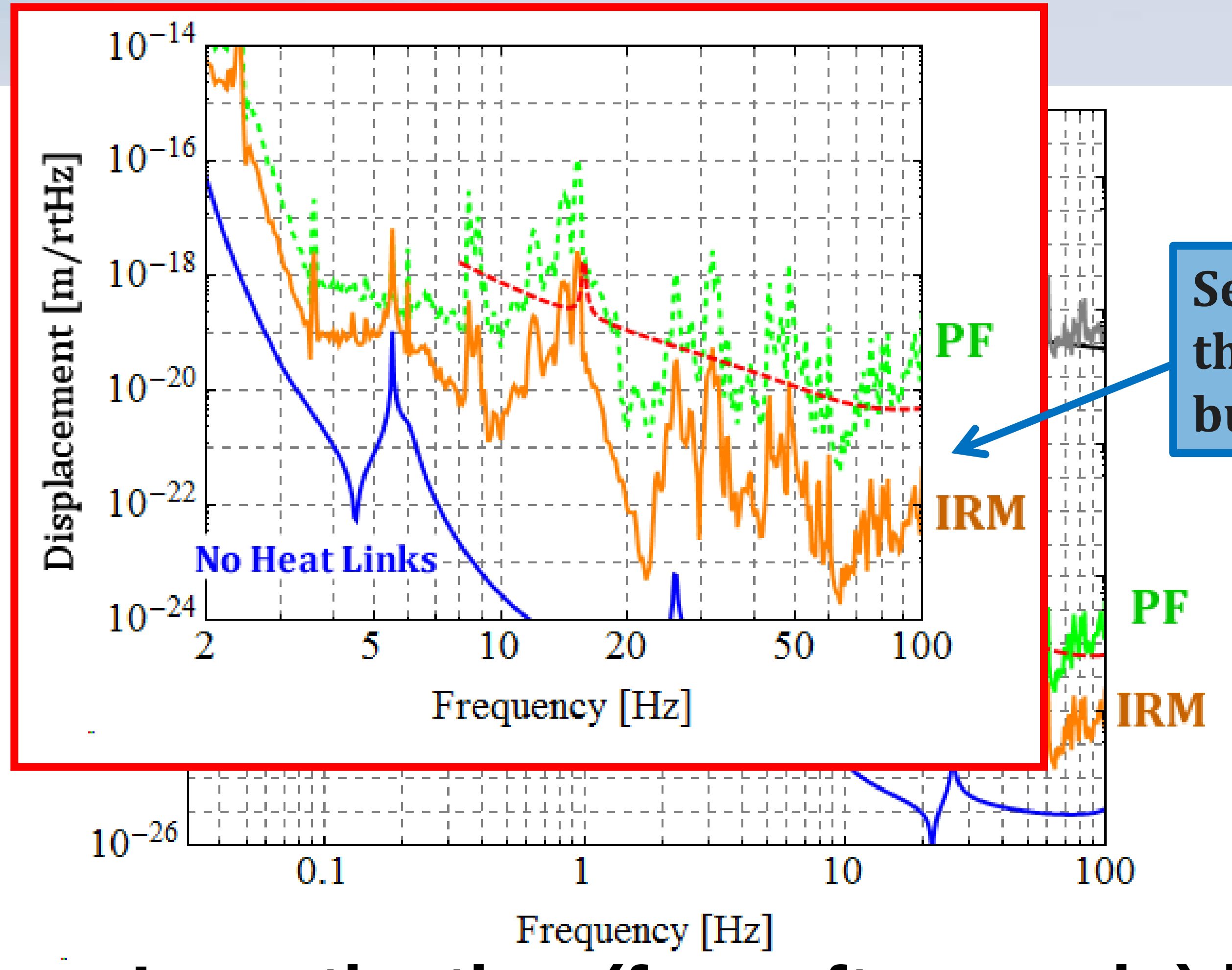
(1) Vibration via heat links

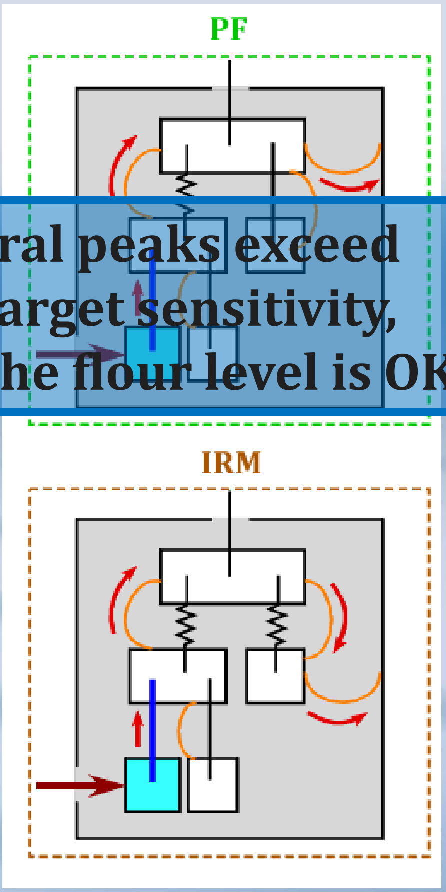




4. Cryogenic payload

1. Mechanical simulation





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

Investivation (for safty margin) is in progress.

4. Cryogenic payload

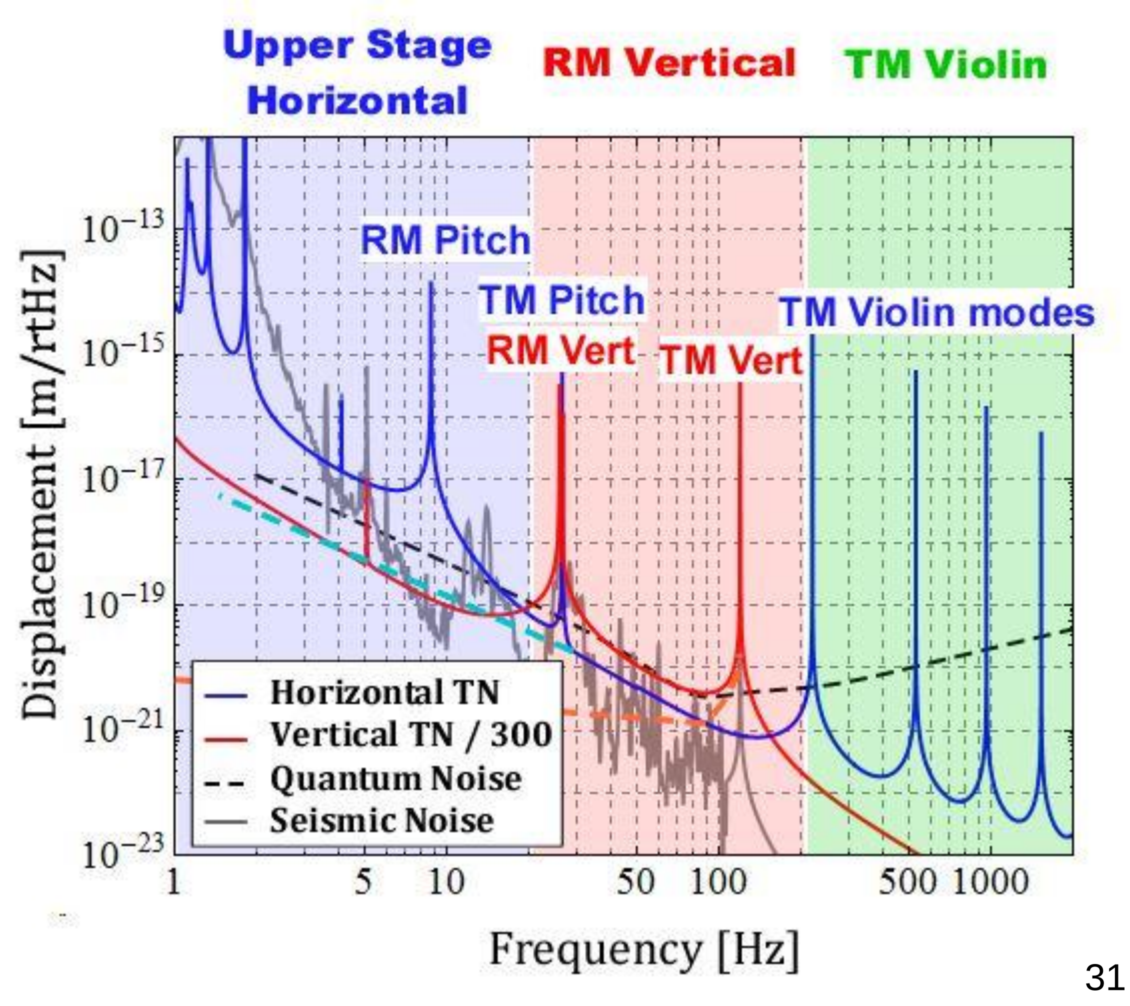
1. **Mechanical simulation**

   (2) Thermal noise

Now, we can calculate thermal noise.

Not only sapphire mirror and fibers but also the other parts must be consider carefully.

We must proceed with investiation.



4. Cryogenic payload

2. Sapphire fibers with nail heads

Class. Quantum Grav. **27** (2010) 084021 M Lorenzini

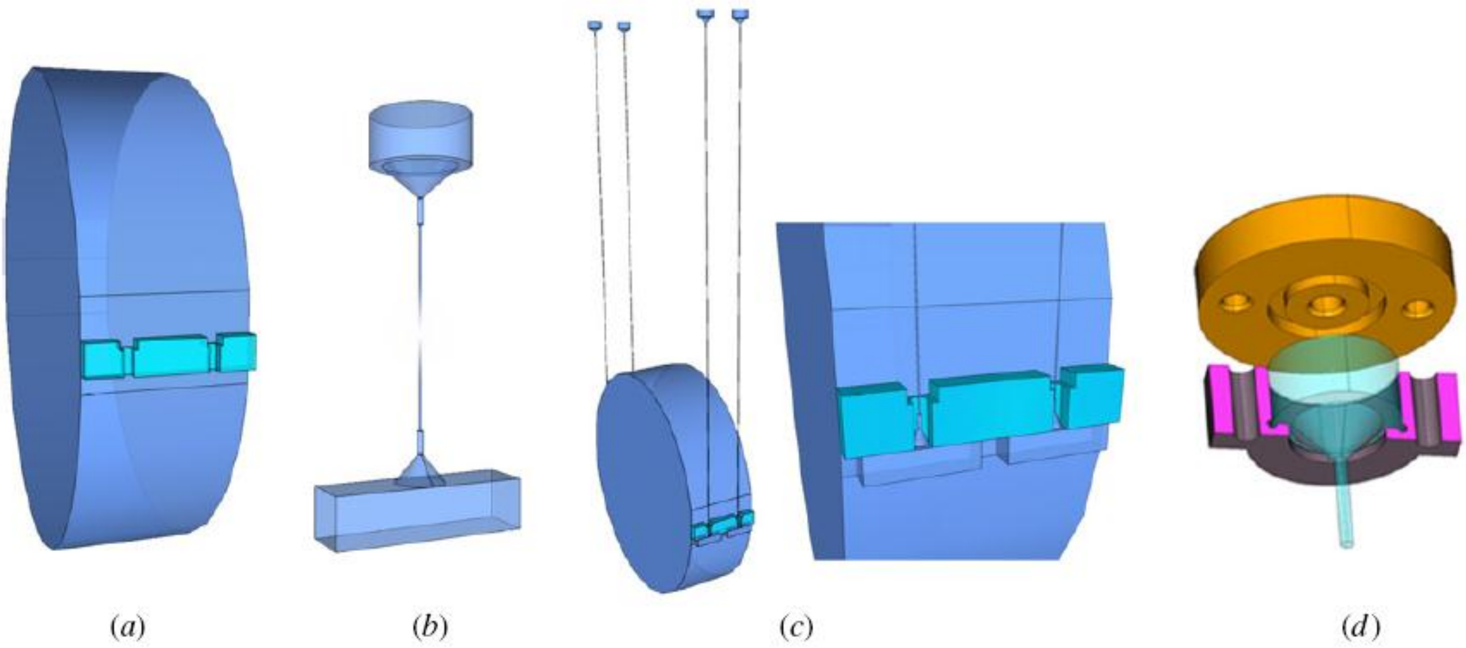
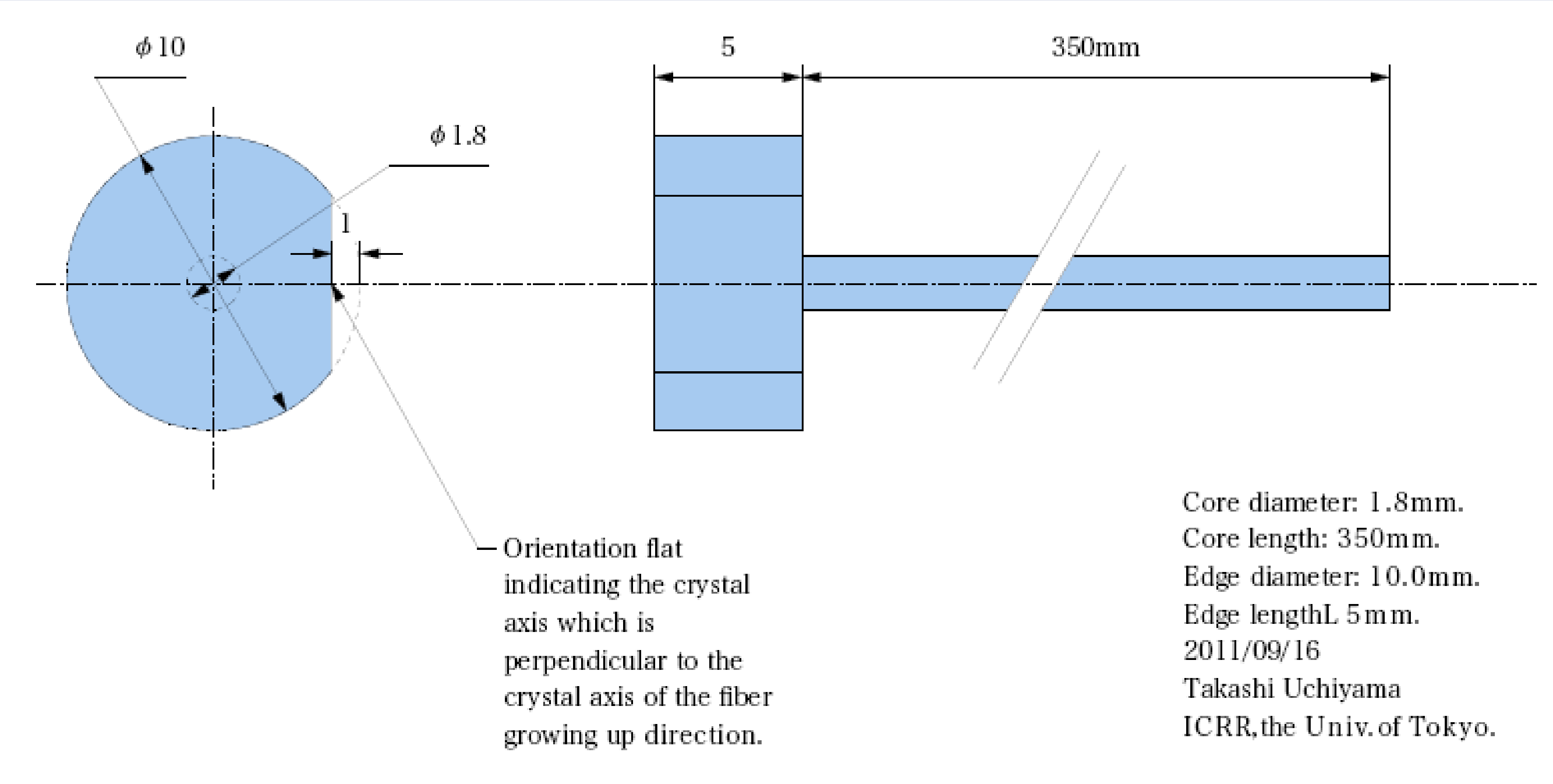


Figure 2. Sketch of the steps followed to realize a monolithic suspension, as detailed in the text.

4. Cryogenic payload

2. Sapphire fibers with nail heads

Test sample (T. Uchiyama)



4. Cryogenic payload

2. Sapphire fibers with nail heads

Sapphire fibers to suspend sapphire mirrors

Sapphire fibers from MolTech GmbH (Germany)

Length = 350 mm diameter = 1.8 mm
Almost as needed in bKAGRA.
Need to check the quality and improvement (T. Ushiba, K. Shibata).

4. Cryogenic payload

2. Sapphire fibers with nail heads

Ettore Majorana asked IMPEX HighTech GmbH (German company).

They can make similar fibers (nail heads on the both ends).

Shoter fibers (about 100 mm in length) is coming soon.

4. Cryogenic payload

2. Sapphire fibers with nail heads

Thermal conducutivity measurement : T. Ushiba

Q-value measurement in this autumn:
K. Shibata and Y. Sakakibara

5. Summary

1. **Tests for cryocooler unit**

   Cooling : OK

   Vibration : Almost OK

   (some improvement is necessary)

2. **Cryostat**

   Assembly is in progress in Toshiba.

   In this autumn,

   there will be cooling test of shileds.

   In this test, we will try these experiments

   (1) Heat load test

   (2) Measurement of vibration of shield

   (3) Measurment of initial cooling time

5. Summary

3. **Cryogenic payload**

   Simulation tool

   Vibration via heat link

   Thermal noise

   Control scheme

   Investigation using simulation tool is in progress.

   Sapphire fibers with nail heads

   Moltech and IMPEX

   Measurement of thermal conductivity and Q-values is in progress.

Thank you for your attention !

4. Challenges for cryogenic

1. Issues of cooling : Reduction of heat load

(Scattering on mirror)

Scattering on mirror : 10 ppm ?

Scatted power is 5 W in radiation shield !

Cryostat scheme

4 cryocoolers cool radiation shields.

Payload is connected to radiation shield

by heat links.

If larger scattered light attacks shield,

mirror temperature must be higher.

4. Challenges for cryogenic

1. Issues of cooling : Reduction of heat load
(Scattering on mirror)

Scattering on mirror : 10 ppm ?
Scatted power is 5 W in radiation shield !

New cryostat scheme
2 cryocoolers cool radiation shields.
Other 2 cryocoolers cool payload
via separated heat path.

Even if large scattered light attacks shield,
mirror temperature could be low.

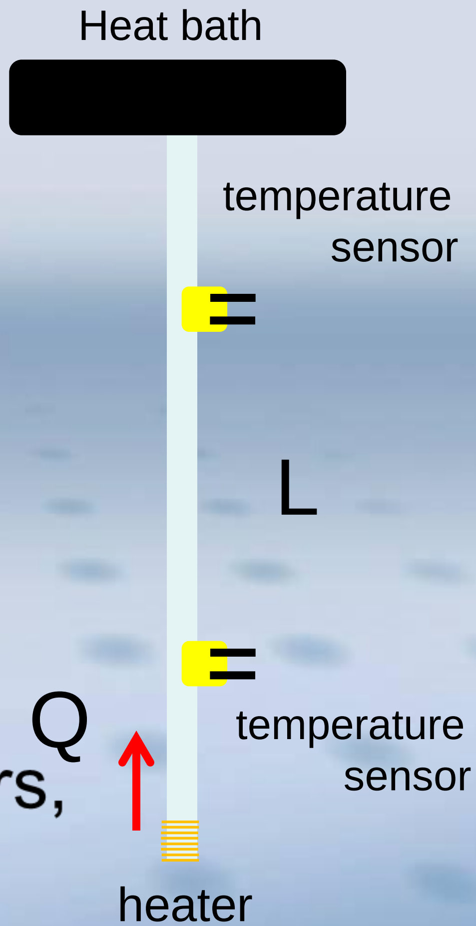
Sapphire fiber

2. Measurement Thermal conductivity (T. Ushiba)

- Sample size
  - diameter : $\phi 1.8\mathrm{mm}$
  - sample length : 100mm
- One dimensional approximation.

$$\kappa = \frac{LQ}{A\Delta T}$$

κ :thermal conductivity
L :length between two temperature sensors,
Q:heat flow, A :sample cross section,
ΔT:difference of values of two temperature sensors



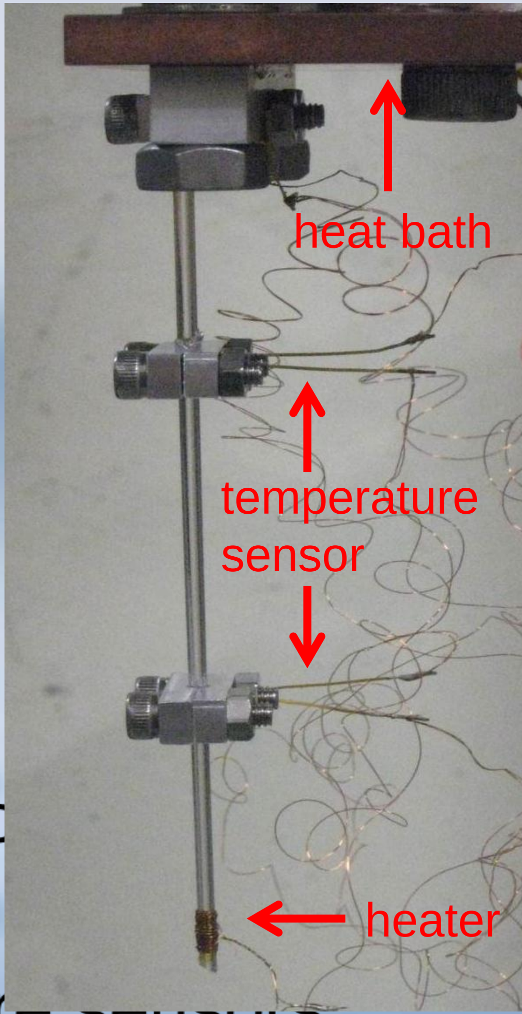
Sapphire fiber

2. Measurement Thermal conductivity (T. Ushiba)

- Sample size
  diameter : $\phi 1.8\mathrm{mm}$
  sample length : 100mm
- One dimensional approximation.

$$\kappa = \frac{LQ}{A\Delta T}$$

κ :thermal conductivity
L :length between two temperature senso
Q:heat flow, A :sample cross section,
ΔT:difference of values of two temperatur



Sapphire fiber

2. Measurement Thermal conductivity (T. Ushiba)

- We measured the thermal conductivity of Photoran's sapphire rod without nail head whose surface is polished (before we try measurement for Moltech and IMPEX fibers). The diameter of the rod is 1.8 mm.

Result

700 W/m/K @ 12K

1100 W/m/K @ 17.5 K

Compared with Tomaru's previous measurement, our result is a bit small.

Sapphire fiber

2. Measurement Thermal conductivity (T. Ushiba)

Something to be considered as the reason why the value of this measurement is small

- the purity of the sapphire rod

So, we now measure thermal conductivity near 30 K (the peak of sapphire thermal conductivity) and confirm the purity is well or not.

If the purity of sapphire rod is not enough well, the peak of the thermal conductivity is gentle.

Sapphire fiber

2. Measurement Q-value (K. Shibata)

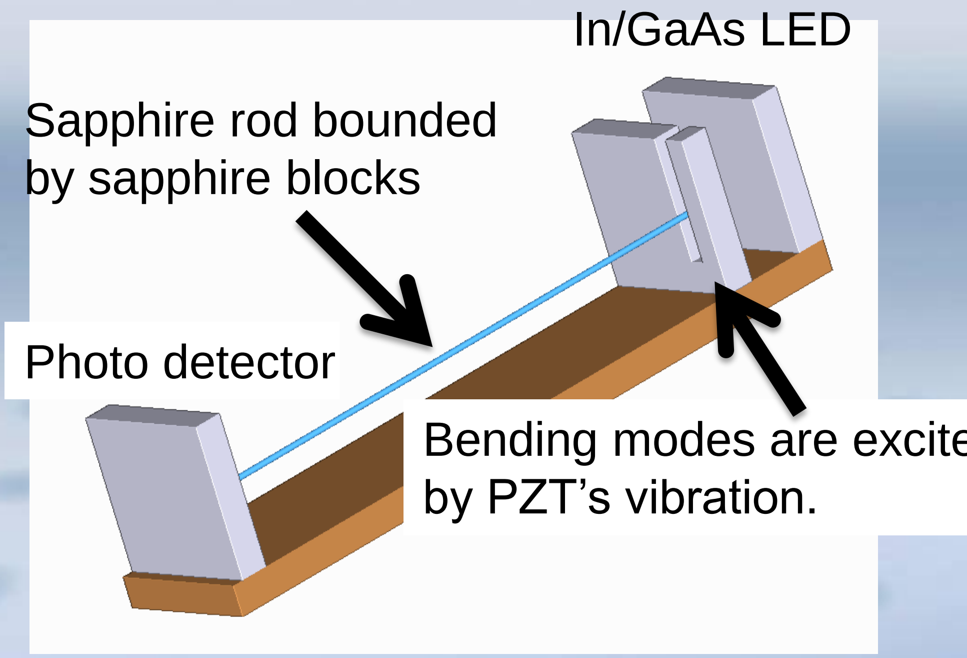
- In KAGRA, we use sapphire rods to suspend mirrors.
- The mechanical-Q of its bending modes are high. But it may depends on the surface condition. e.g.) as grown or polished, what manufactured it.

Moltech Sapphire rod φ1.8mm

Sapphire fiber

2. Measurement Q-value (K. Shibata)

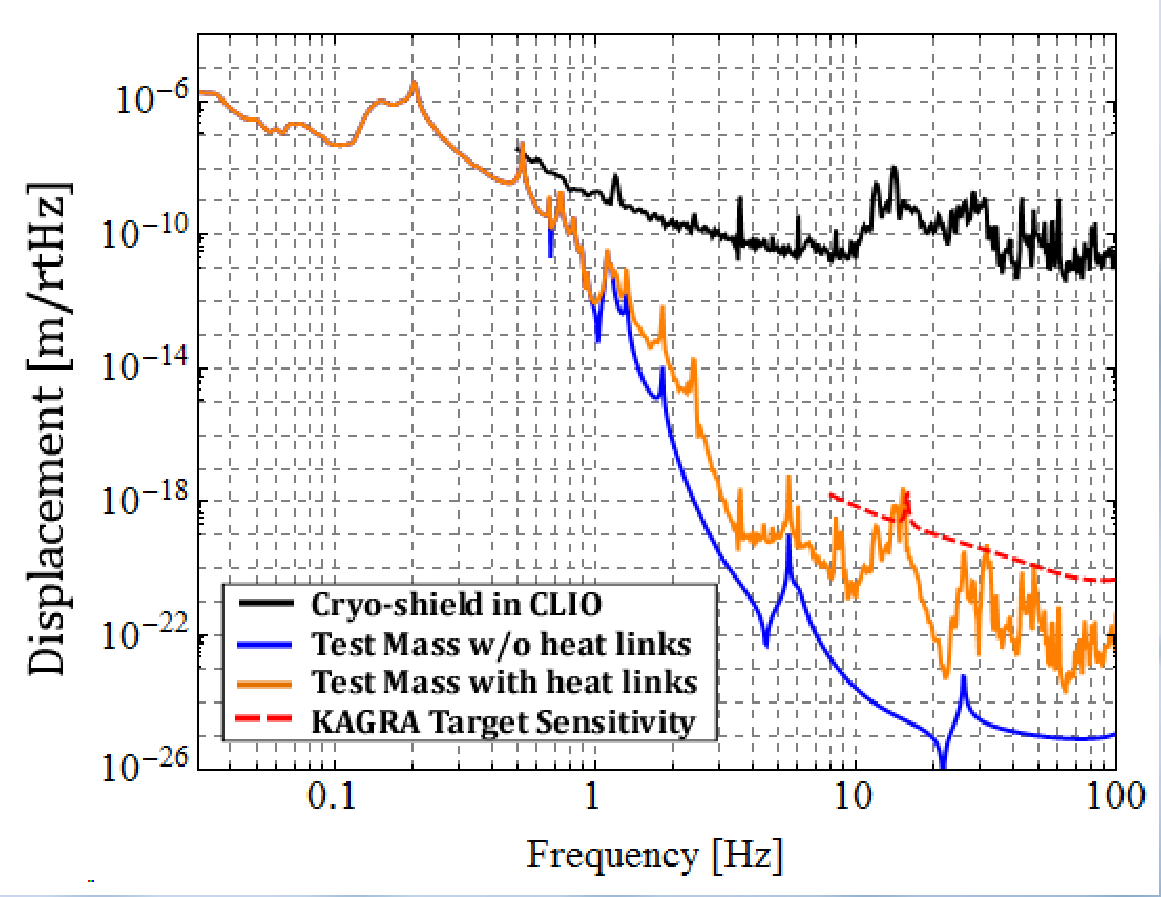
- We need to measure the mechanical-Q around 14-20K in advance.
- By vibrating the supported point, we excite the bending modes. The amplitude is measured by the shadow sensor, and from the decay time, we estimate the mechanical-Q.
- This experiment is done in KEK and will be finished by the end of this summer.



4. Challenges for cryogenic

2. Issues of noise : Vibration via heat links

Calculation by T. Sekiguchi (Details are in his talk on Tuesday)



T. Sekiguchi's Master thesis (English)

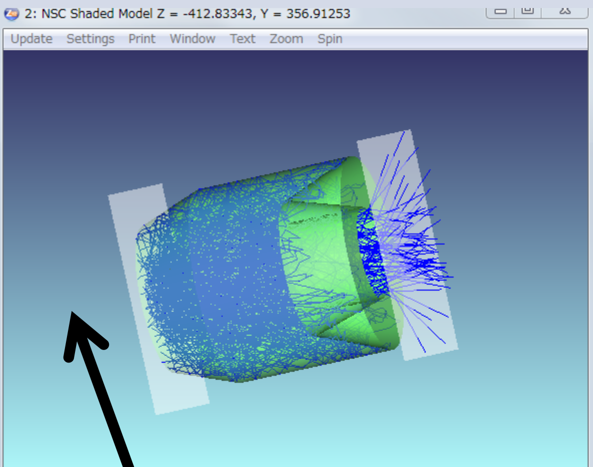
http://gwdoc.icrr.u-tokyo.ac.jp/cgi-bin/private/DocDB/ShowDocument?docid=770

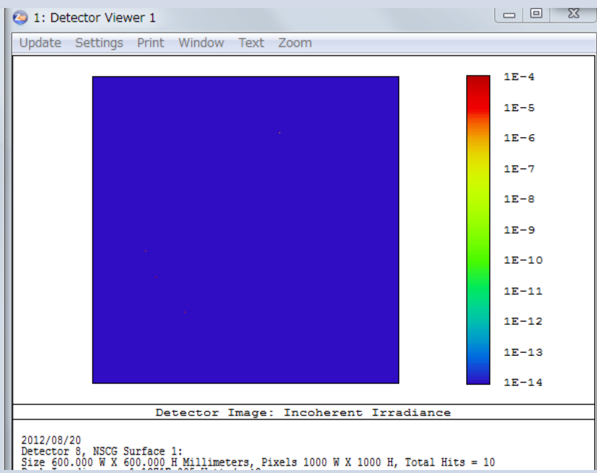
Baffle

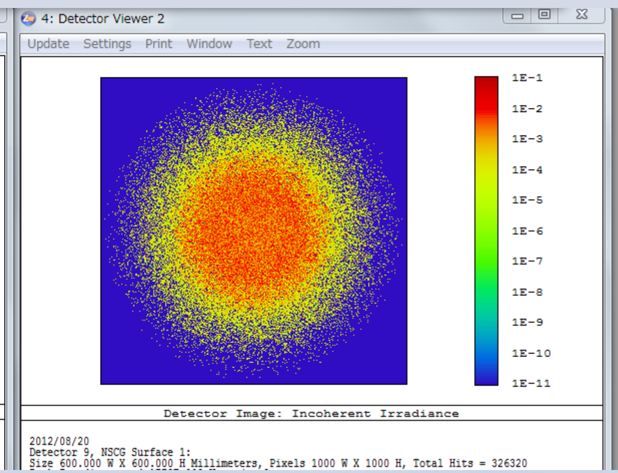
Baffle for large angle scattering in cryostat

Optimal shape : T. Akutsu

Preliminary result







Mirror side

Reflection ($1.5*10^{-8}$)

Transmission

With DLC coating

2. Issues

(1)How to assemble

Details of construction, clean room ….

(2)Strength

Tensile strength, development of clamp, …

(3)Control system

Actuators (what and where),

resonant mode (frequency and Q)

2. Issues

(4)Cooling

Temperature of mirror, initial cooling time, heat resistance …

(5)Noise

Thermal noise, vibration via heat links …

4. Summary

Cryogenic payload : One of key features of LCGT project
Cryogenic part of seismic isolation system

Cryostat installation in ICRR (Kashiwa) ~2013.3
(Check of cryostat system)

Check of cryogenic payload in ICRR

Preparation is in progress.

(1)Thermal simulation
(2)Sapphire fiber-mirror connection
(3)Simulation of effect of external vibration (with heat link)
(4)Thermal noise

5. Future work

(1)How to assemble

Details of construction, clean room ….

(2)Control system

Actuators (what and where),

resonant mode (frequency and Q)