KAGRA
Emphasizing approaches to the mid-frequency band
(Thermal noise, Cryogenic)

Kazuhiro Yamamoto and KAGRA collaboration

Institute for Cosmic Ray Research
the University of Tokyo

17 May 2012
Gravitational-Wave Advanced Detector Workshop
@Waikoloa Marriot Resort, Waikoloa Beach, Hawaii, U.S.A.

0. Abstract

Thermal noise : Sensitivity limit
in mid-frequency band

One of reduction method : Cryogenic

KAGRA and ET adopt this technique.

Challenges for cryogenic
and current status of KAGRA will be introduced.

Contents

1. Introduction

KAGRA (previously known as: LCGT)

2nd generation interferometer in Japan

Key features of KAGRA
(and third generation, ET) project

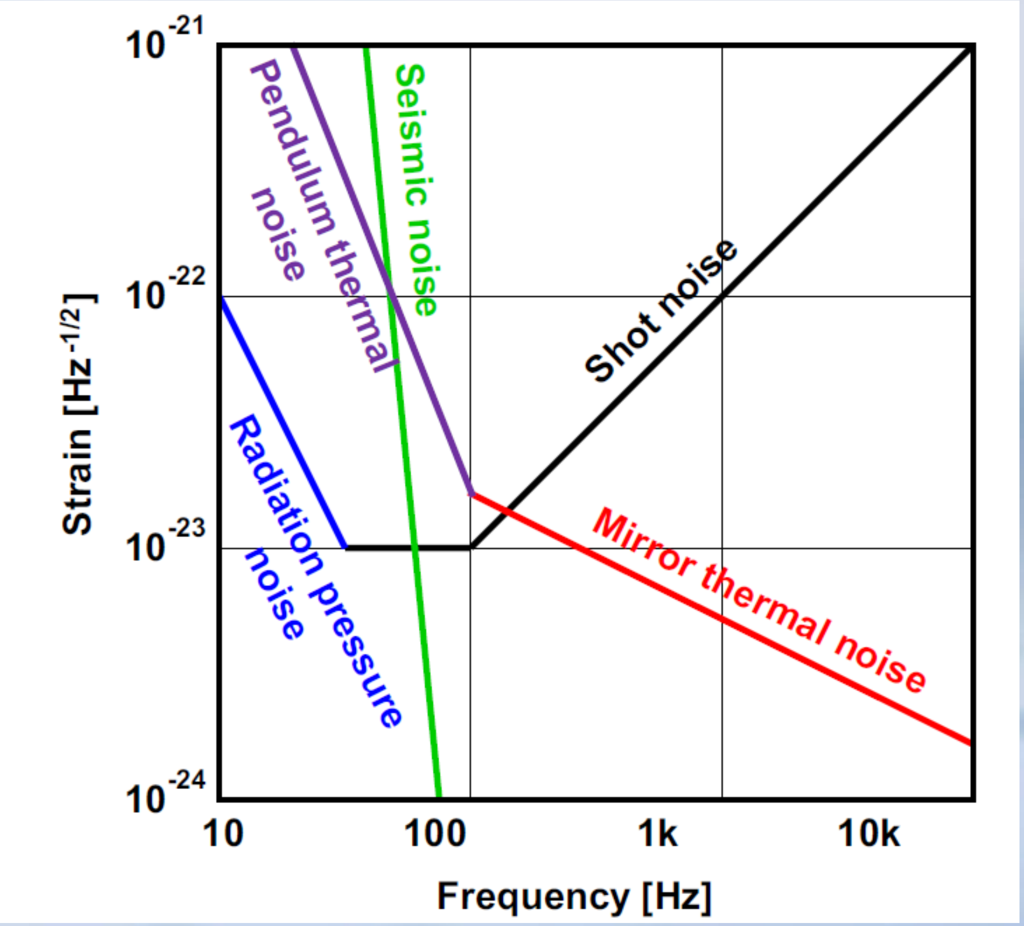
Underground site (Kamioka for KAGRA) :
Small seismic motion (for low-frequency band)

Cryogenic system : Reduction of thermal noise
(for mid-frequency band)

Here, we discuss cryogenic system
for mid-frequency band.

1. Introduction

Typical sensitivity



S. Kawamura, Classical and Quantum Gravity 27 (2010) 084001.

How do we improve sensitivity in mid-frequency band (thermal noise) ?

1. Introduction

Second generation (km-scale)

Advanced LIGO and Virgo

Larger beam, Silica mirror, TiO_2 doped coating
(for mirror thermal noise)
Silica fiber (for suspension thermal noise)

KAGRA

Cryogenic technique
Sapphire mirror (for mirror thermal noise)
Sapphire fiber (for suspension thermal noise)
Classical (without TiO_2) coating

1. Introduction

Second generation (km-scale)

Advanced LIGO and Virgo

Challenges : Thermal lens, Parametric instability

KAGRA

Challenges : Cryogenic technique,
Sapphire mirror and fibers

However, thermal lens and parametric instability are less serious problem.
(owing to high thermal conductivity of cooled sapphire and small beam)

Something radical is necessary for 2nd generation.

1. Introduction

Third generation
Einstein Telescope
(Xylophone, Low Frequency and High Frequency)
For ET-LF (cryogenic interferometer)

Longer baseline (10 km)
Cryogenic technique
Larger beam and mirror (for mirror thermal noise)
Longer fibers with lower dissipation
(for suspension thermal noise)
Silicon mirror (low absorption)

Number of radical items increases …

2. Current status of KAGRA

1. New nickname
   'KAGRA'

Nickname committee received 666 applications from public.

Nickname announcement ceremony

Asahi Shinbun (Newspaper)

28 Jan. 2012

Yoko Ogawa : Chair of Nickname committee, Novelist
Original story of French movie '*L'Annulaire*' was written by her.

2. Current status of KAGRA

2. New logo of 'KAGRA'

Applications from KAGRA collaboration

Chair of logo committee: Tomiyoshi Haruyama

(High Energy Accelerator Research Organization)

2. Current status of KAGRA

3. Excavation for tunnels

Finally (one year delay),
the preparation for excavation is in progress.

We hope that excavation will be finished
by March 2014.

2. Current status of KAGRA

3. Excavation for tunnels

Here, parking area, power supply, office for company, facility for excavation will be constructed.

2. Current status of KAGRA

4. Vacuum duct

320 of 478 ducts (12m, Φ800mm) have been delivered.

Press to form a duct

Bellows for each duct

Presentation
By Y.Saito (KEK)

Transportation to Kamioka

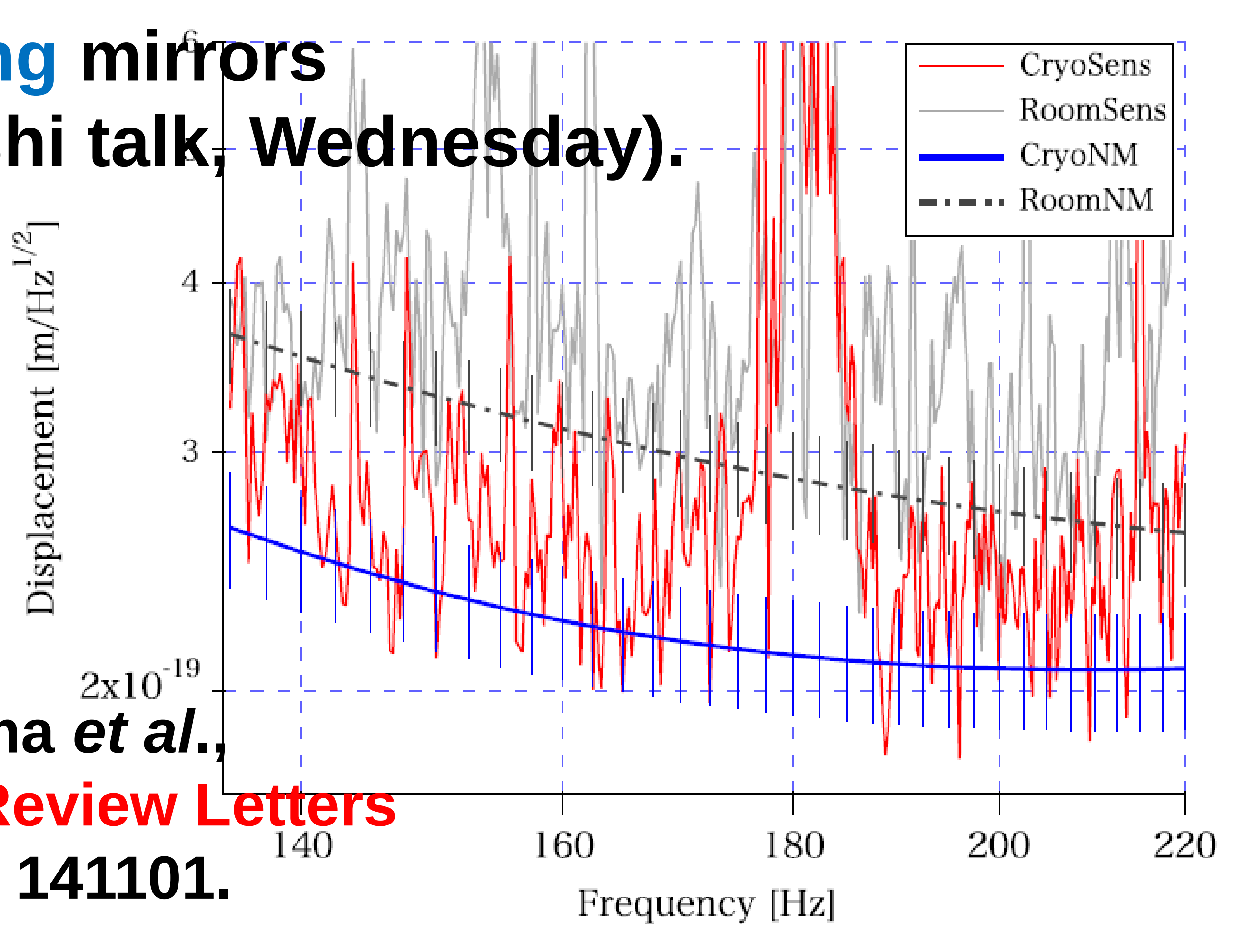
Baking at MIRAPRO Co. Noda/MESCO, Kamioka

Test at MIRAPRO Co. Noda

2. Current status of KAGRA

5. Important paper for KAGRA in PRL

CLIO demonstrated the reduction of thermal noise by cooling mirrors (M. Ohashi talk, Wednesday).



T. Uchiyama *et al*., Physical Review Letters 108 (2012) 141101.

3. KAGRA schedule

Until Dec. 2015

iKAGRA : Room temperature interferometer

Observation on the end of iKAGRA phase

From Jan. 2016

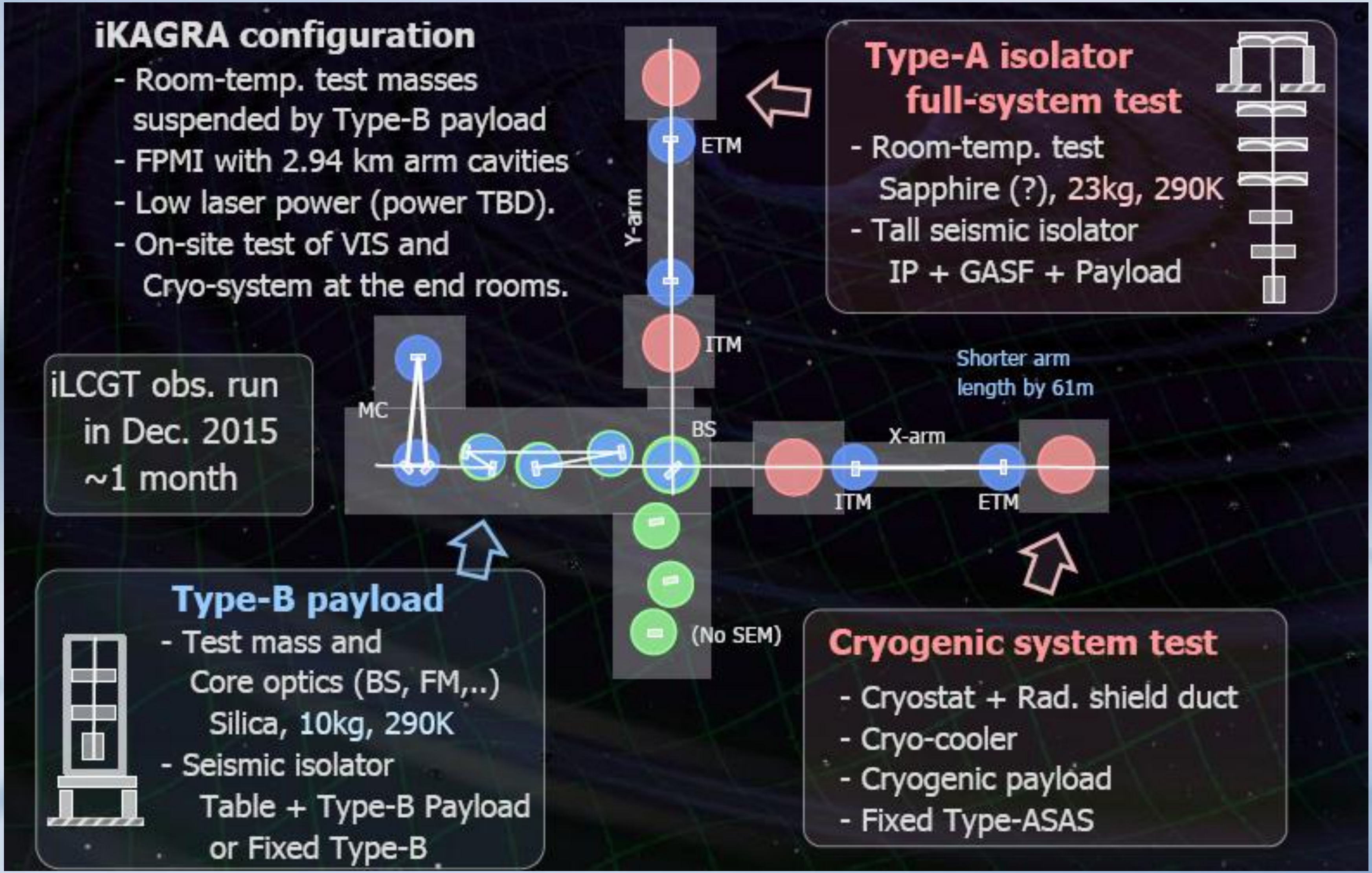
bKAGRA : Cryogenic interferometer

From Apr. 2018

Observation

Since it take long time for cryogenic parts. We will install some cryogenic parts in iKAGRA phase.

3. KAGRA schedule

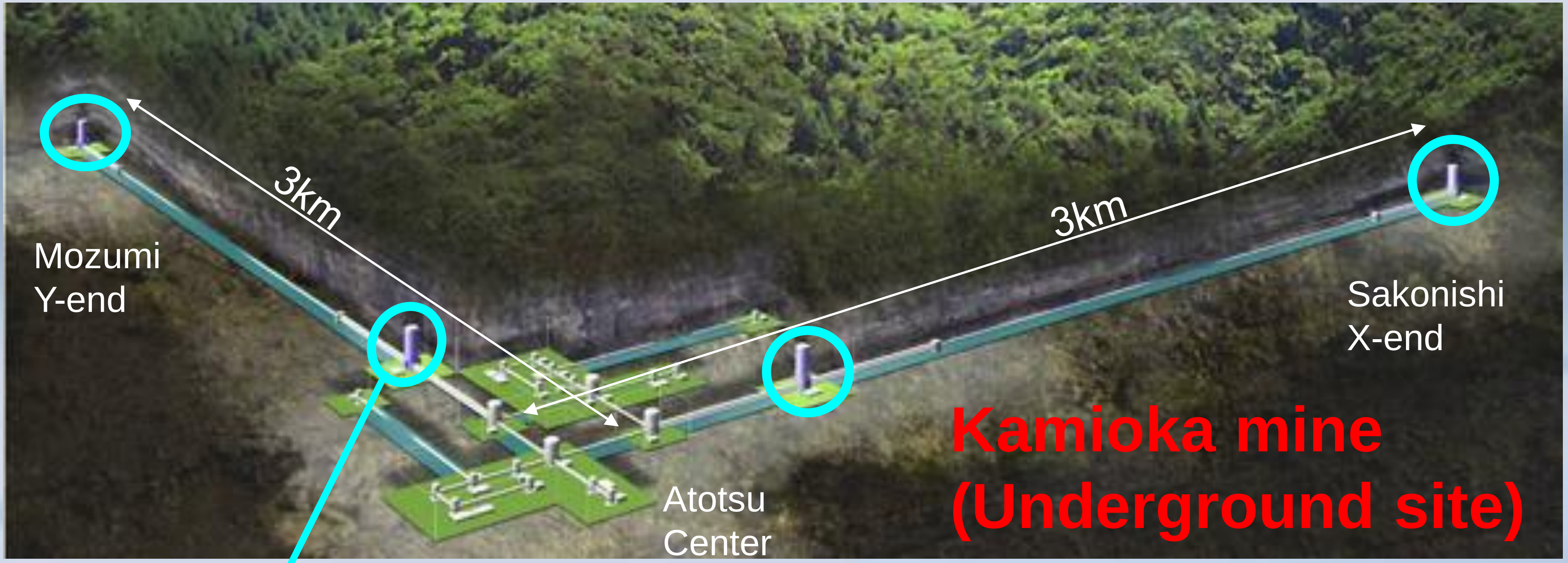


by M. Ando

4. Challenges for cryogenic

Outline of cryogenic system

Four mirrors of arm cavity will be cooled.

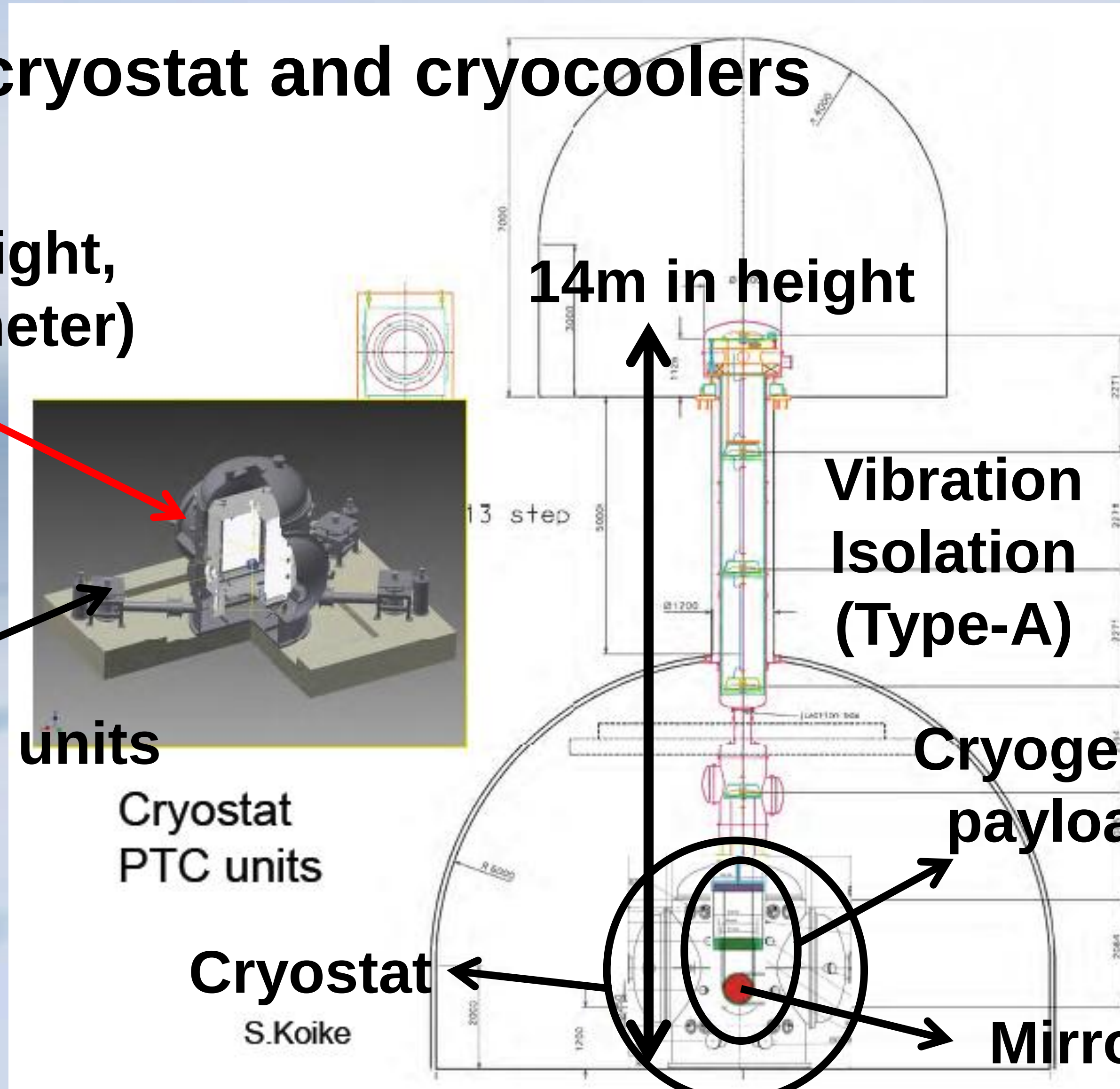


Vibration isolation system, Cryostat, Cryocooler unit, Cryogenic payload

4. Challenges for cryogenic

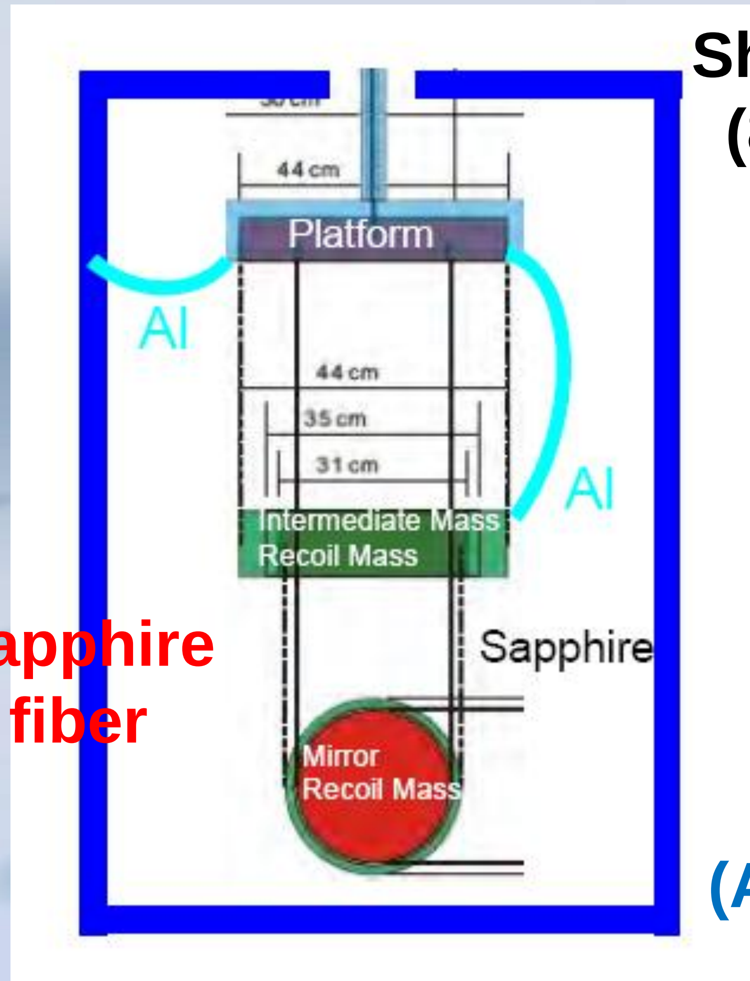
Outline of cryostat and cryocoolers

Cryostat
(~3.6 m in height,
2.6 m in diameter)



4. Challenges for cryogenic

Outline of payload



4. Challenges for cryogenic

1. Issues of cooling
- **Initial cooling time**
- **Reduction of heat load**

2. Issues of noise
- **Sapphire fibers (for small thermal noise)**
- **Vibration via heat links (for small external vibration)**

4. Challenges for cryogenic

1. Issues of cooling : Initial cooling time

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

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

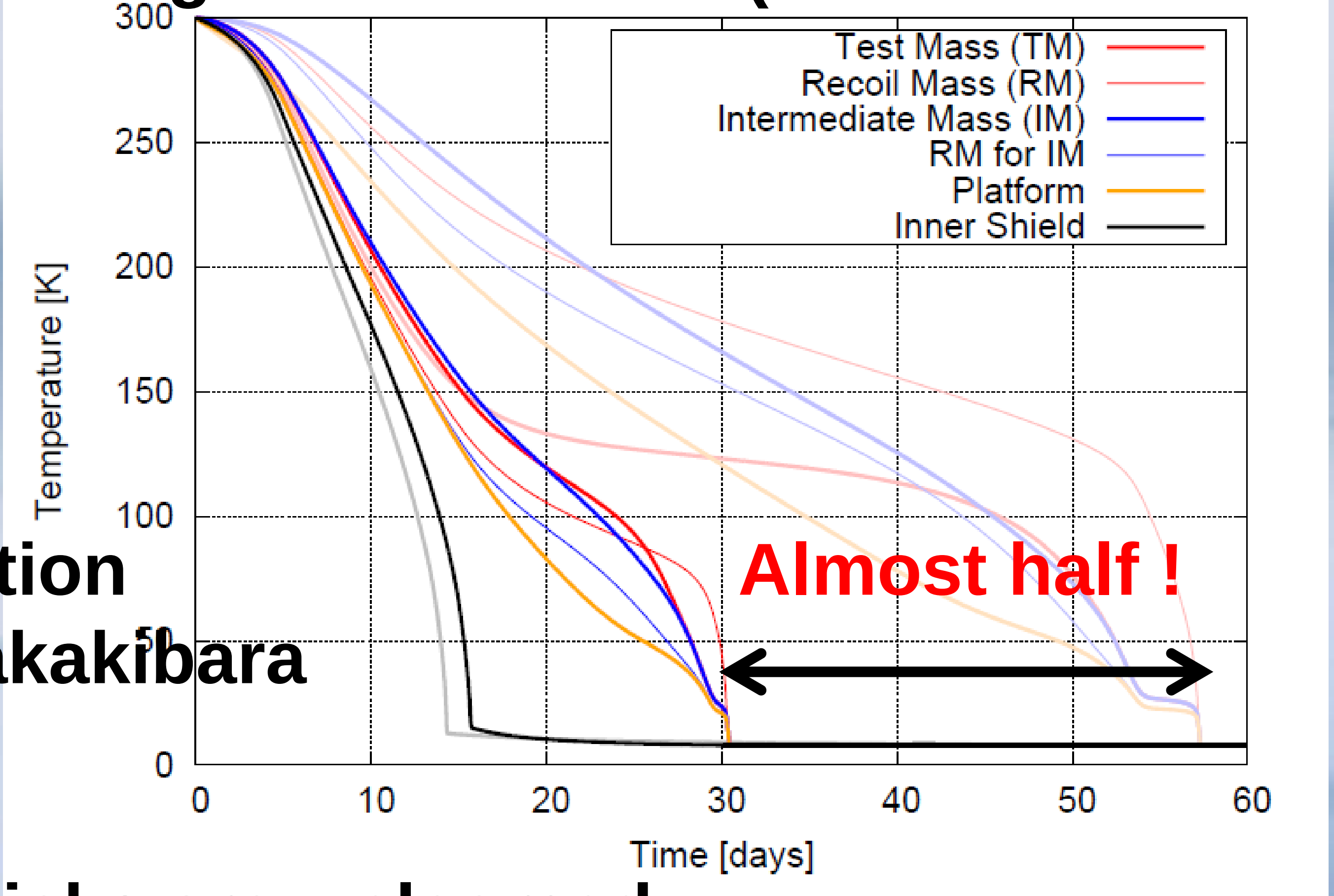
Diamond Like Carbon (DLC) coating
(High emissivity, Large radiation)
on shields and payload (except for mirror)

Y. Sakakibara's Master thesis (English)
http://gwdoc.icrr.u-tokyo.ac.jp/DocDB/0008/P1200862/001/mthesis_sakakibara.pdf

4. Challenges for cryogenic

1. Issues of cooling : Initial cooling time

Initial cooling time with DLC (shield and mass)



Calculation by Y. Sakakibara

Other tricks are welcomed.

4. Challenges for cryogenic

1. Issues of cooling : Reduction of heat load

4 cryocoolers : 14 W in total (8K)

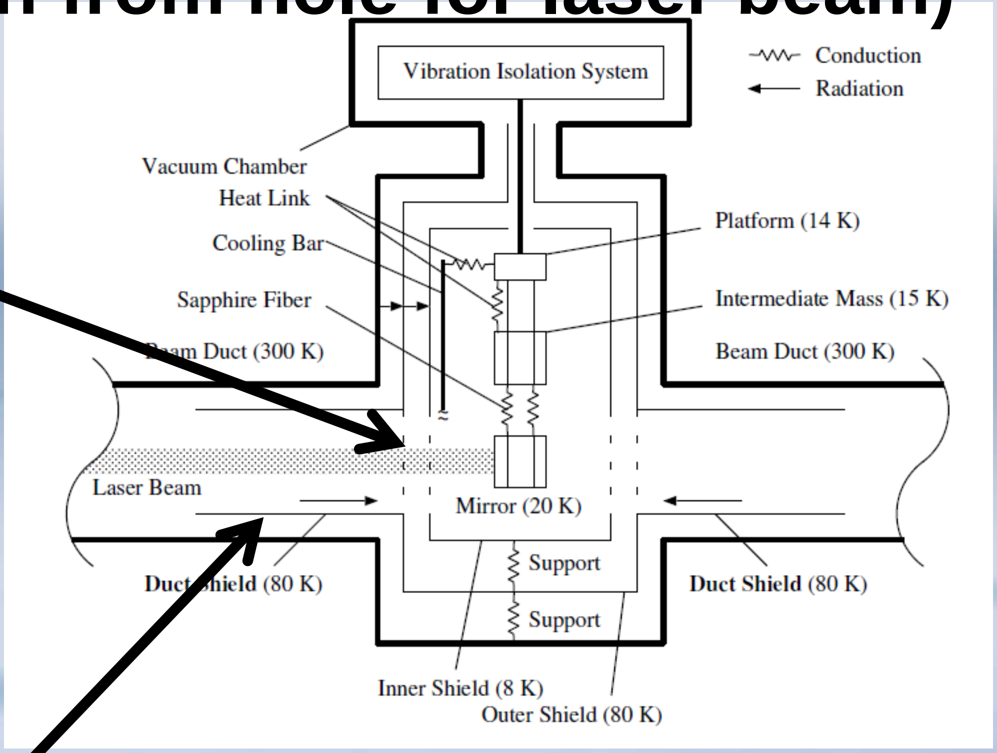
Heat load from view ports, radiation from 80K shield, support post and rods is about 4 W.

We consider radiation from hole for laser beam, mirror scattering and absorption. Their summation should be less than about 10 W.

4. Challenges for cryogenic

1. Issues of cooling : Reduction of heat load (Radiation from hole for laser beam)

Large hole (almost same as mirror) for laser beam on radiation shield



Huge 300 K radiation (about 20 W) invades radiation shield.

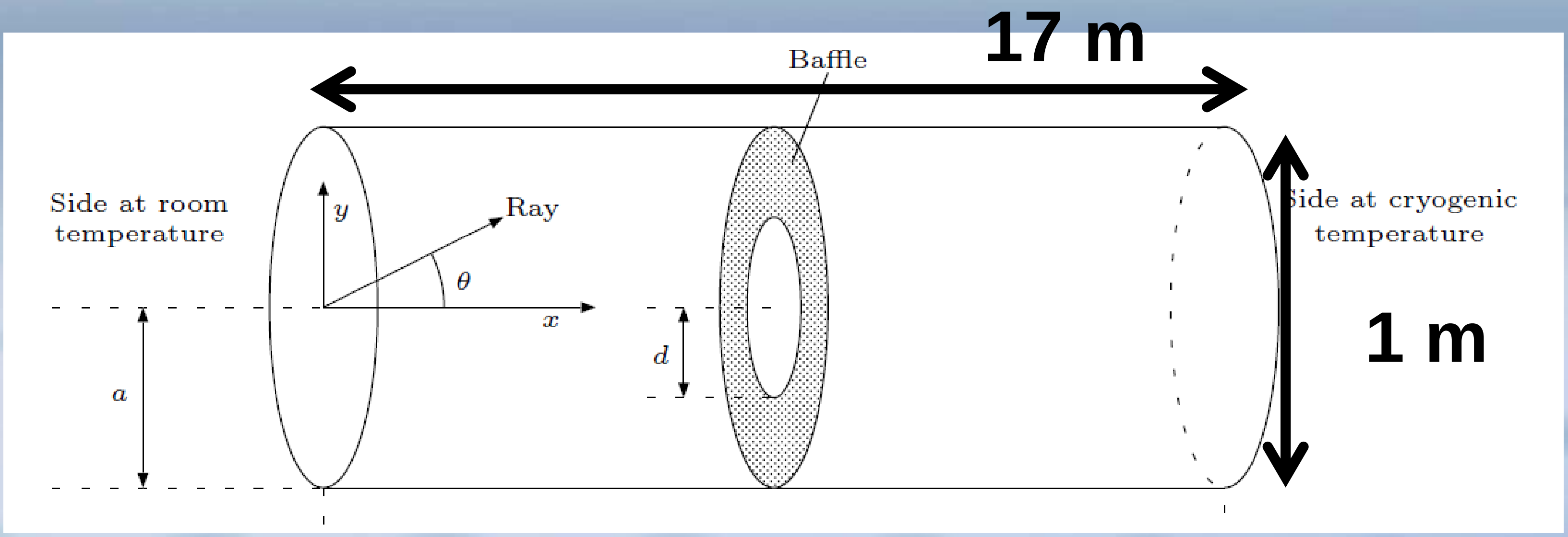
Cryogenic duct (80 K) with baffles are necessary.

T. Tomaru *et al.*, Japanese Journal of Applied Physics 47 (2008) 1771.
T. Tomaru *et al.*, Journal of Physics:Conference Series 122 (2008) 012009.

4. Challenges for cryogenic

1. Issues of cooling : Reduction of heat load
(Radiation from hole for laser beam)

Y. Sakakibara found optimal 5 baffles positions.
Power into shield : 300 mW



Y. Sakakibara *et al*., submitted
(Classical and Quantum Gravity).

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.

4. Challenges for cryogenic

1. Issues of cooling : Reduction of heat load (Absorption in mirror)

In order to keep mirror temperature …
Absorption in mirror : less than 1 W

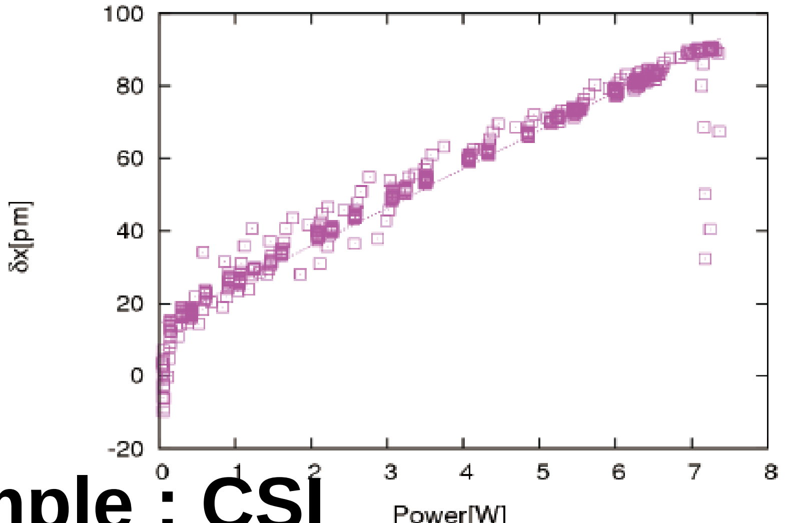
Coating : 0.4 W (1 ppm)
Substrate : 0.6 W (50 ppm/cm)

Our target of substrate : 20 ppm/cm

4. Challenges for cryogenic

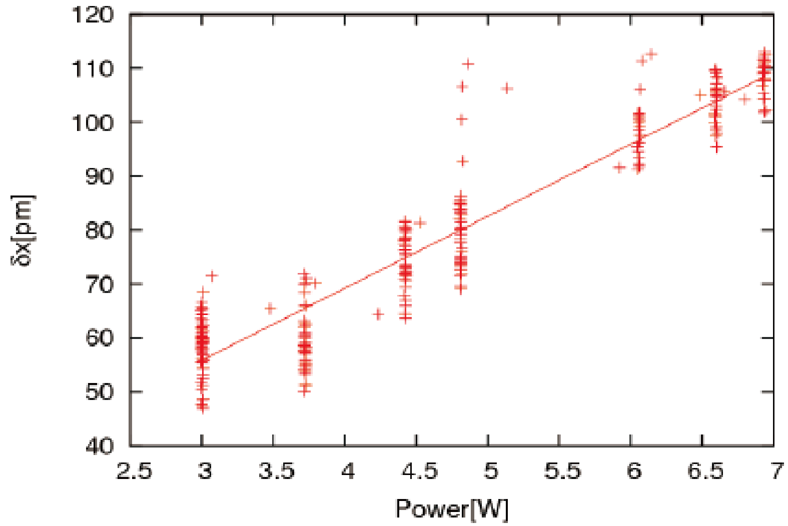
1. Issues of cooling : Reduction of heat load (Absorption in mirror)

Measurement in last year



80ppm/cm

Measurement in this year



87ppm/cm

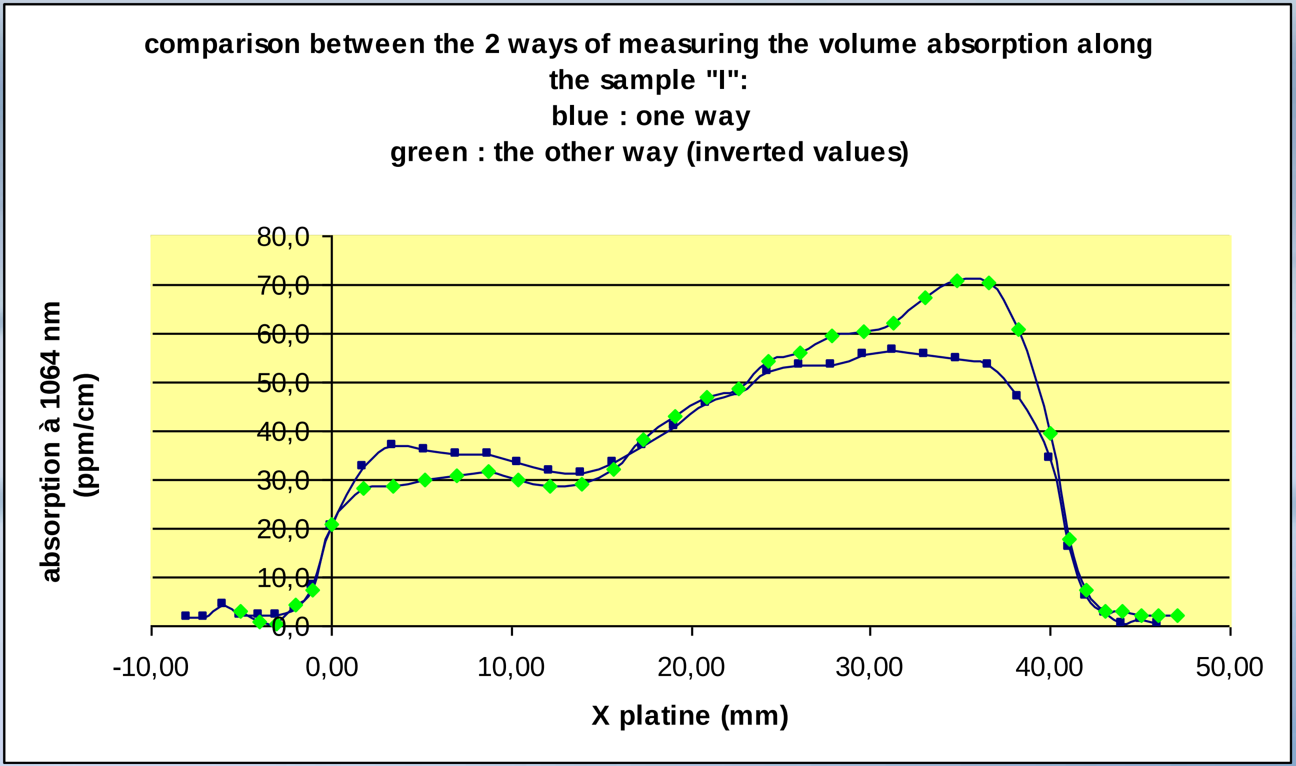
Sample : CSI

K. Watanabe's Master thesis

4. Challenges for cryogenic

1. Issues of cooling : Reduction of heat load (Absorption in mirror)

Measurement in LMA (CSI, but different sample from Watanabe's)



4. Challenges for cryogenic

1. Issues of cooling : Reduction of heat load
(Absorption in mirror)

Watanabe's measurement : about 80 ppm/cm
Measurement in LMA : 30 ppm/cm - 70 ppm/cm

Difference of sample or Error of measurement ?
Is large sample homogeneous ?

How can we reduce absorption ?

We need further investigation.

4. Challenges for cryogenic

2. Issues of noise : Sapphire fibers

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

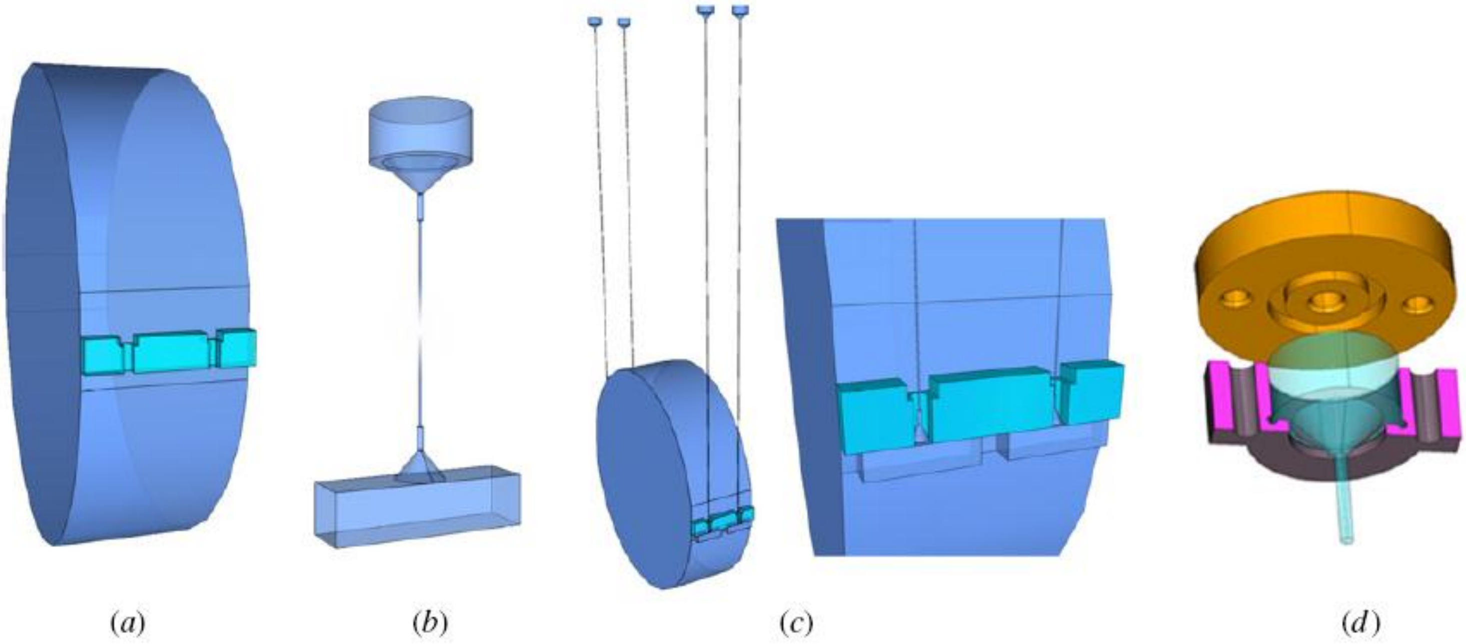
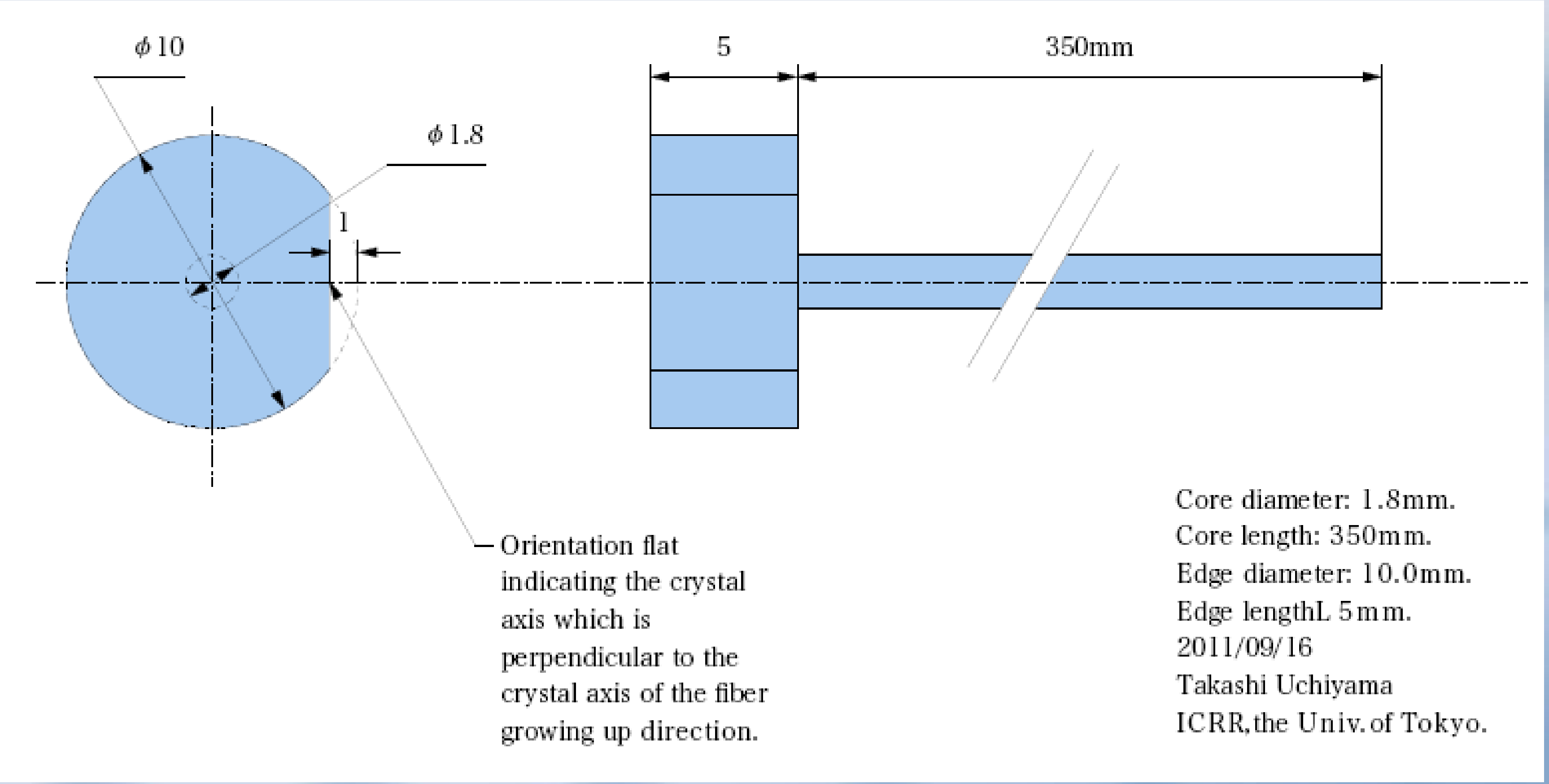


Figure 2. Sketch of the steps followed to realize a monolithic suspension, as detailed in the text.

4. Challenges for cryogenic

2. Issues of noise : Sapphire fibers

Test sample (T. Uchiyama)



4. Challenges for cryogenic

2. Issues of noise : Sapphire fibers

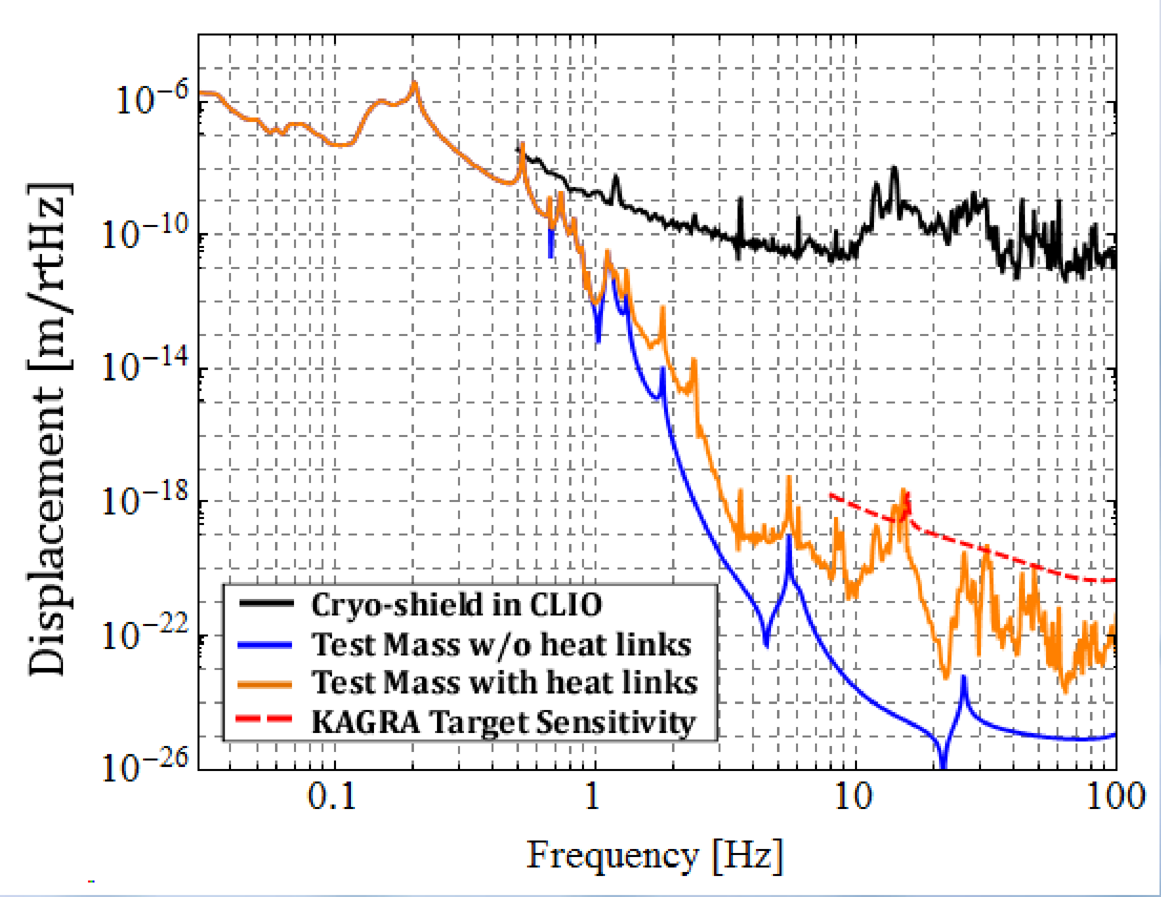
Sapphire fibers to suspend sapphire mirrors
Sapphire fibers from MolTech GmbH (Germany)

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

4. 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

4. Challenges for cryogenic

2. Issues of noise : Vibration via heat links

Sekiguchi's calculation
Assumption : Vibration of heat link anchor is the same as that of CLIO (JGW-G0600422).

However, the vibration of anchor point depends on the structure of shield. We (Luca Naticchioni and Chen Dan) will measure vibration of anchor point of KAGRA on this autumn.

4. Summary

Cryogenic : One of methods to reduce thermal noise
(sensitivity limit in mid-frequency band)

KAGRA adopts this technique and have challenges.

Issues of cooling

- **Initial cooling time**
  - **DLC coating : 2 times shorter (1 month)**
- **Reduction of heat load**
  - **Cryogenic duct with baffles**
  - **Separated payload cooling from shield cooling**
  - **Investigation to reduce absorption in sapphire**

4. Summary

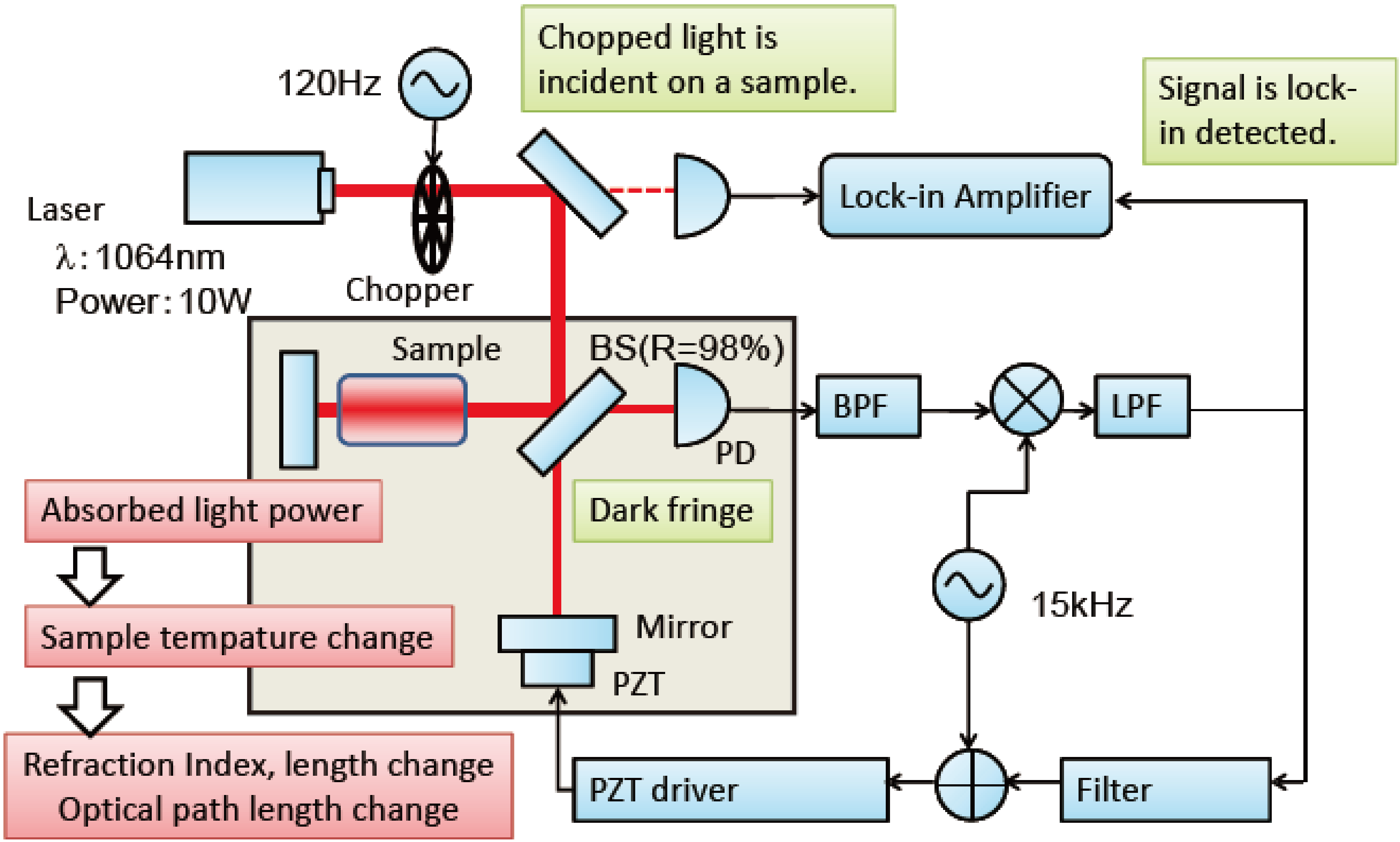
Cryogenic : One of methods to reduce thermal noise
(sensitivity limit in mid-frequency band)

KAGRA adopts this technique and have challenges.

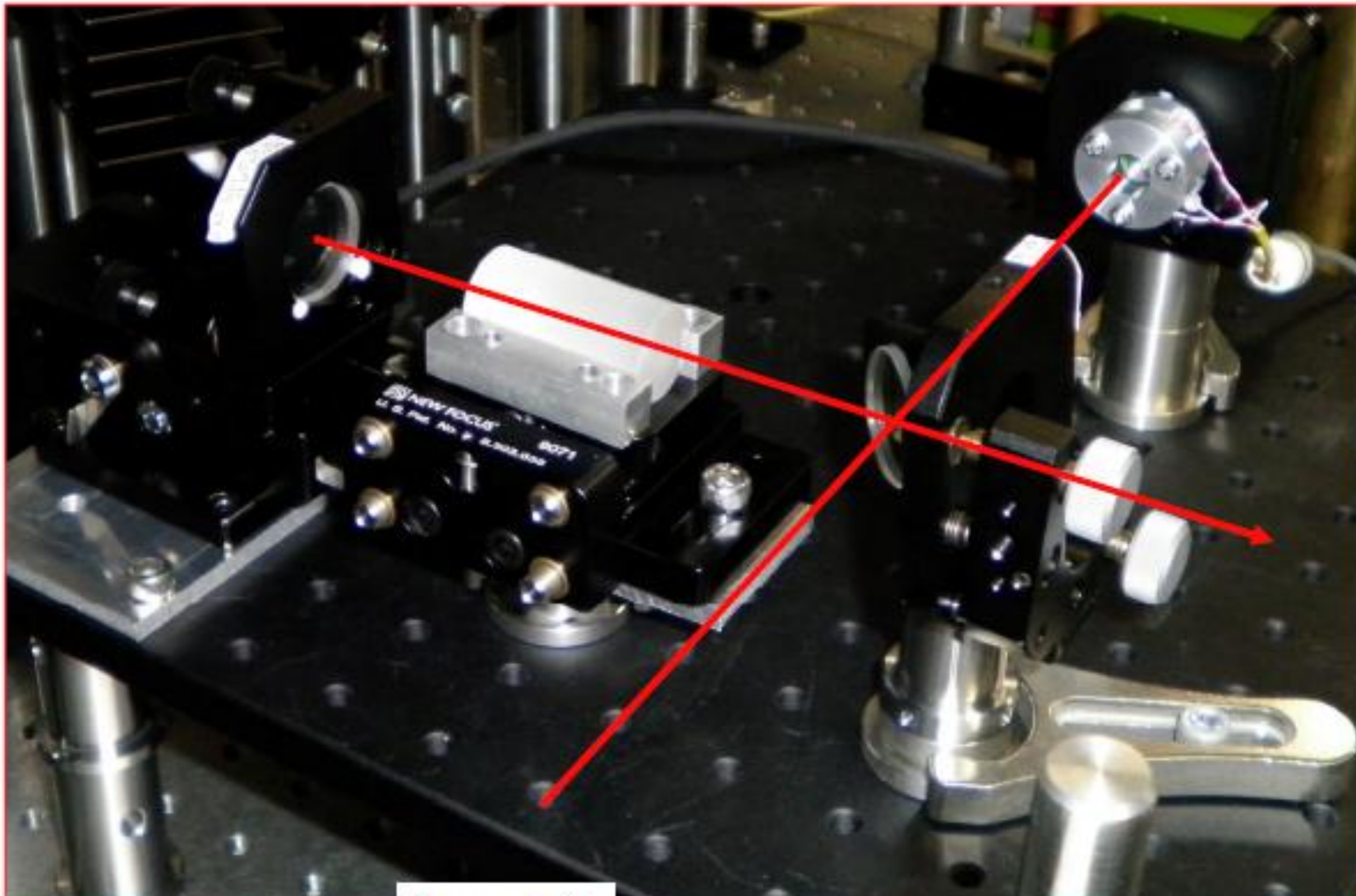
Issues of noise
- Sapphire fiber
  - Moltech made sapphire fibers.
  - We must check and improve the quality.
- Vibration via heat links
  - Calculated result is enough small.
  - However, we need to measure shield vibration.

Thank you for your attention !

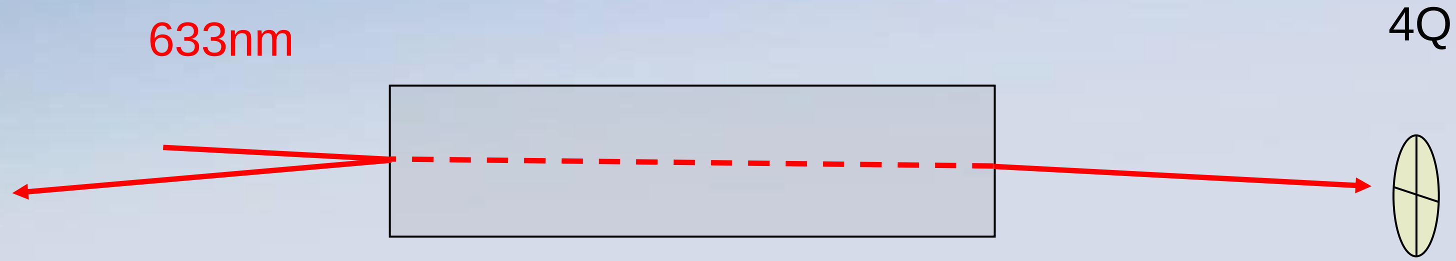
Absorption measurement@UT

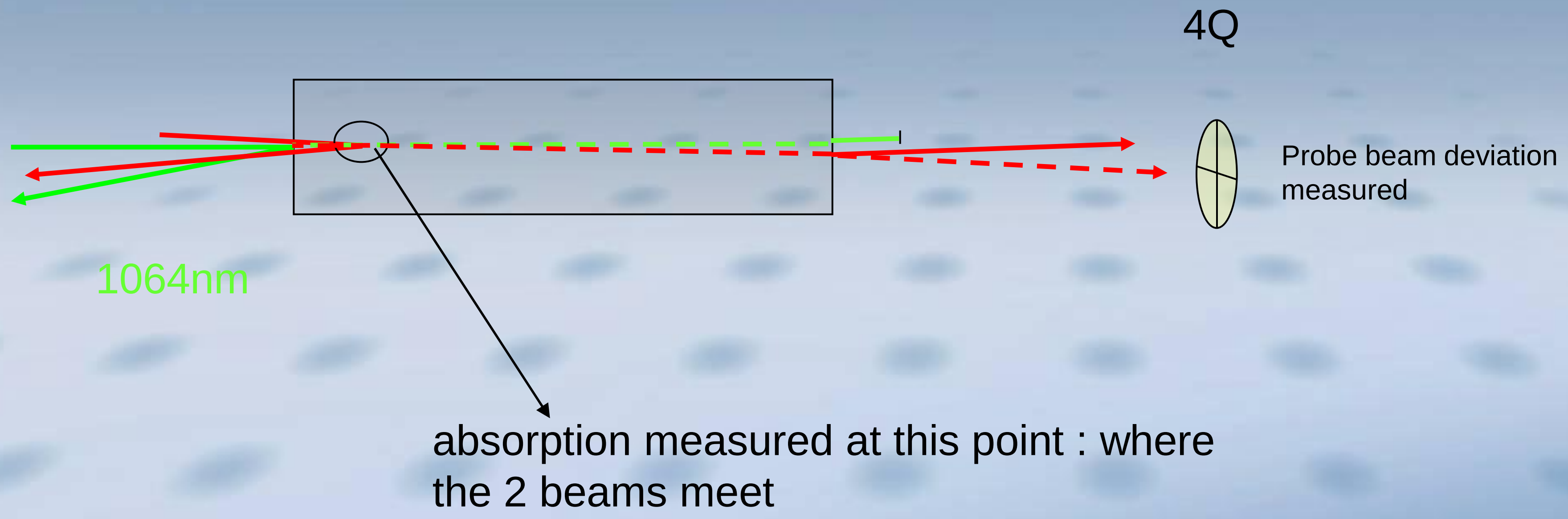


Interferometer



Laser light


633nm
4Q


4Q
Probe beam deviation measured
1064nm
absorption measured at this point : where the 2 beams meet

3. Current status of KAGRA

1. **New nickname 'KAGRA'**

   Previous official name : LCGT

14 Dec. 2010 : Our institute announced inviting applications for new nickname from public.

666 applications (358 nicknames) !

17 Jun. 2011 : Nickname committee made decision.

28 Jan. 2012 : Nickname announcement ceremony

3. Current status of KAGRA

1. **New nickname ‘KAGRA’**

Please call ‘KAGRA’.

KAGRA is NOT an ACRONYM, but has a sense of KAmioka GRAvitational wave telescope.

What KAGURA means in Japanese ?

Japanese traditional music and dance dedicated to the gods of Shinto (Japanese old religion)

Photos of KAGURA

3. Advantages of cryogenic

Why will cryogenic techniques be adopted ?

(1) Small thermal noise

for sensitivity in mid-frequency band !

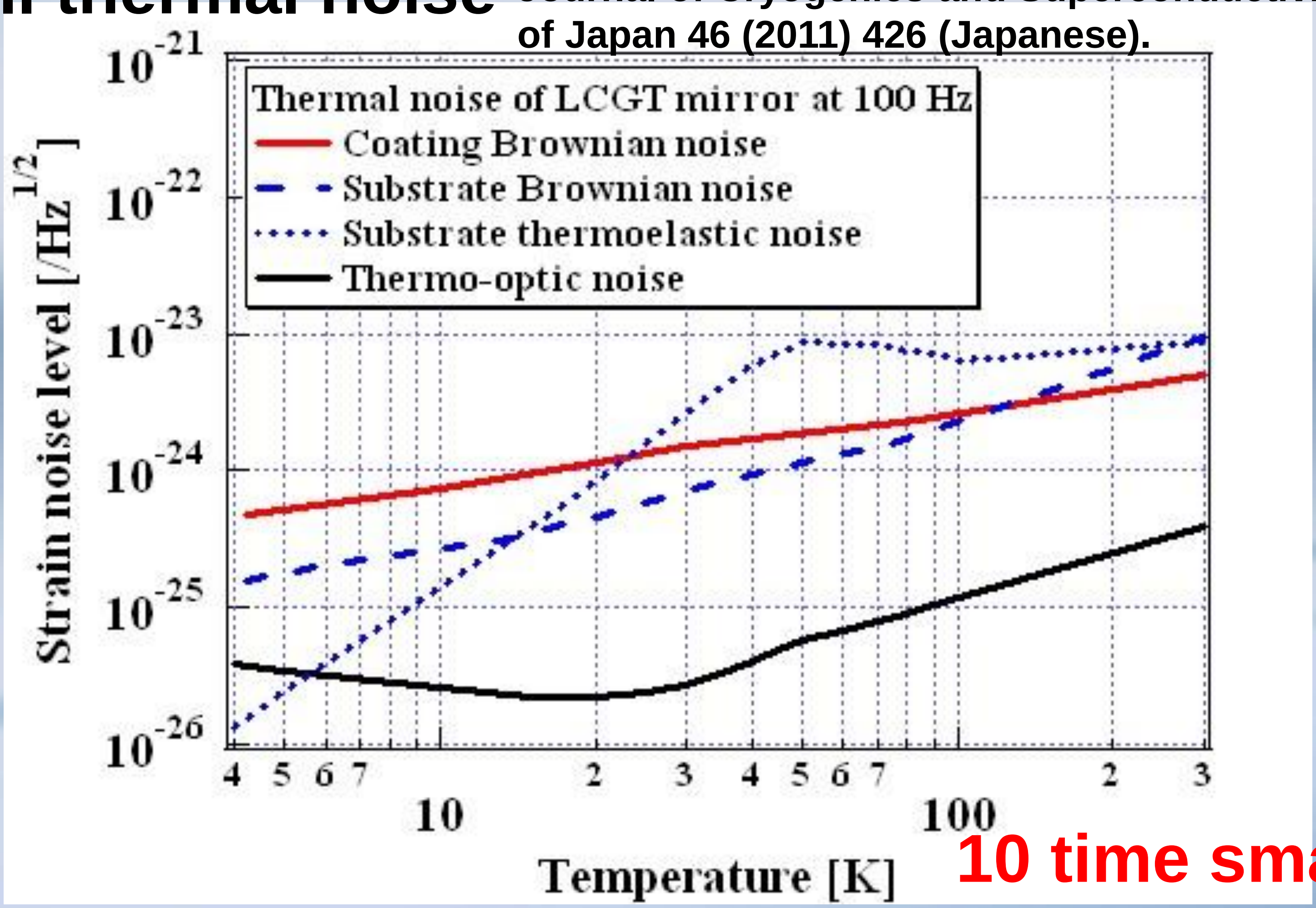
(2) Small thermal lens

(3) Less serious parametric instability

3. Advantages of cryogenic

1. Small thermal noise

K. Yamamoto,
Journal of Cryogenics and Superconductivity Society of Japan 46 (2011) 426 (Japanese).



10 time smaller !

Below 20 K : Thermal noise is sufficiently small for LCGT.

3. Advantages of cryogenic

2. Small thermal lens

Large thermal conductivity

Small temperature coefficient of refractive index

T. Tomaru *et al*., Classical and Quantum Gravity 19 (2002) 2045.

3. Less serious parametric instability

(in the case of KAGRA)

Sapphire mirrors with smaller beam radius

for cryogenic interferometer

K. Yamamoto *et al*., Journal of Physics: Conference Series 122 (2008) 012015.

3. Current status of KAGRA

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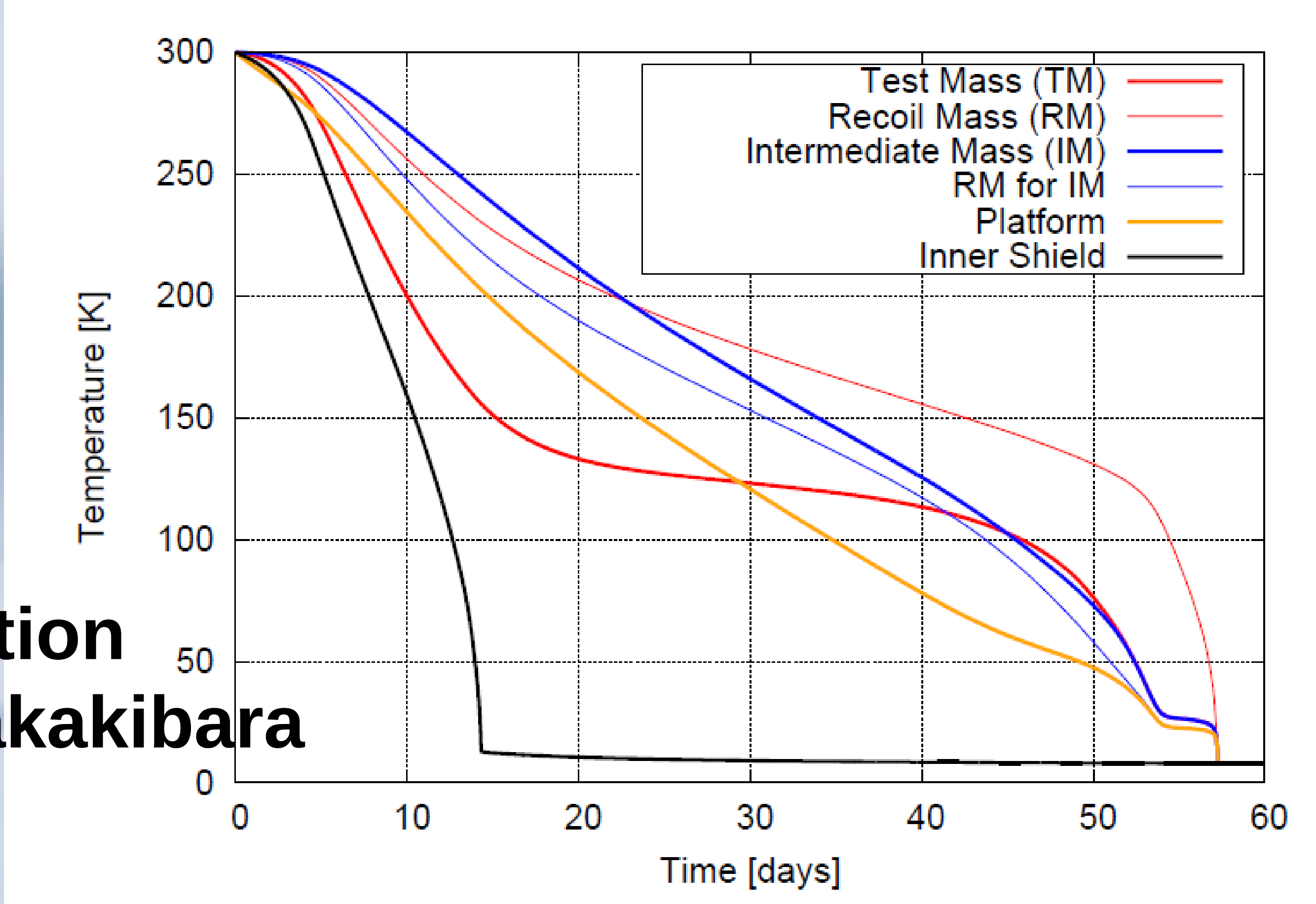
4. Challenges for cryogenic

1. Issues of cooling : Initial cooling time



Calculation by Y. Sakakibara

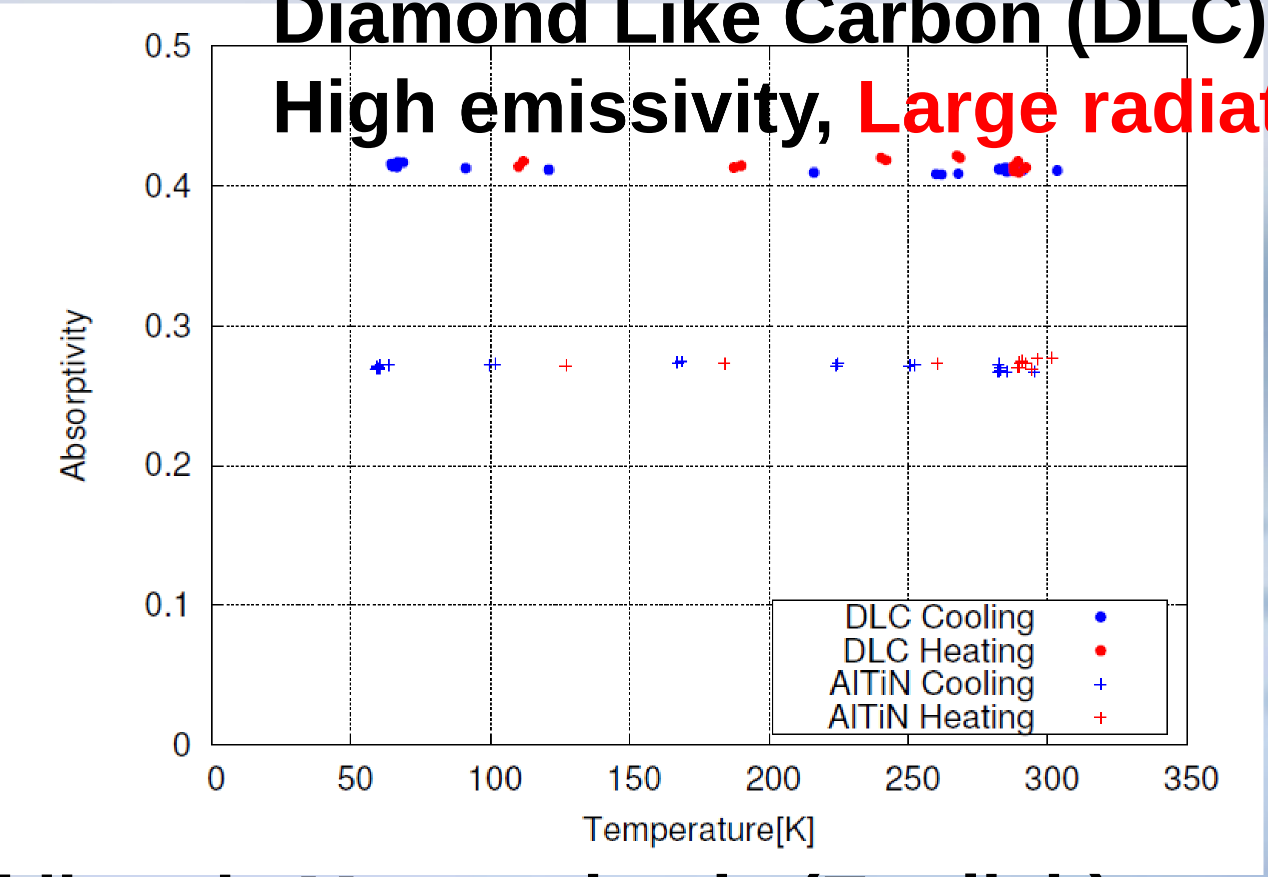
At beginning, heat transfer is dominated by radiation.

4. Challenges for cryogenic

1. Issues of cooling : Initial cooling time

Diamond Like Carbon (DLC) coating

High emissivity, Large radiation

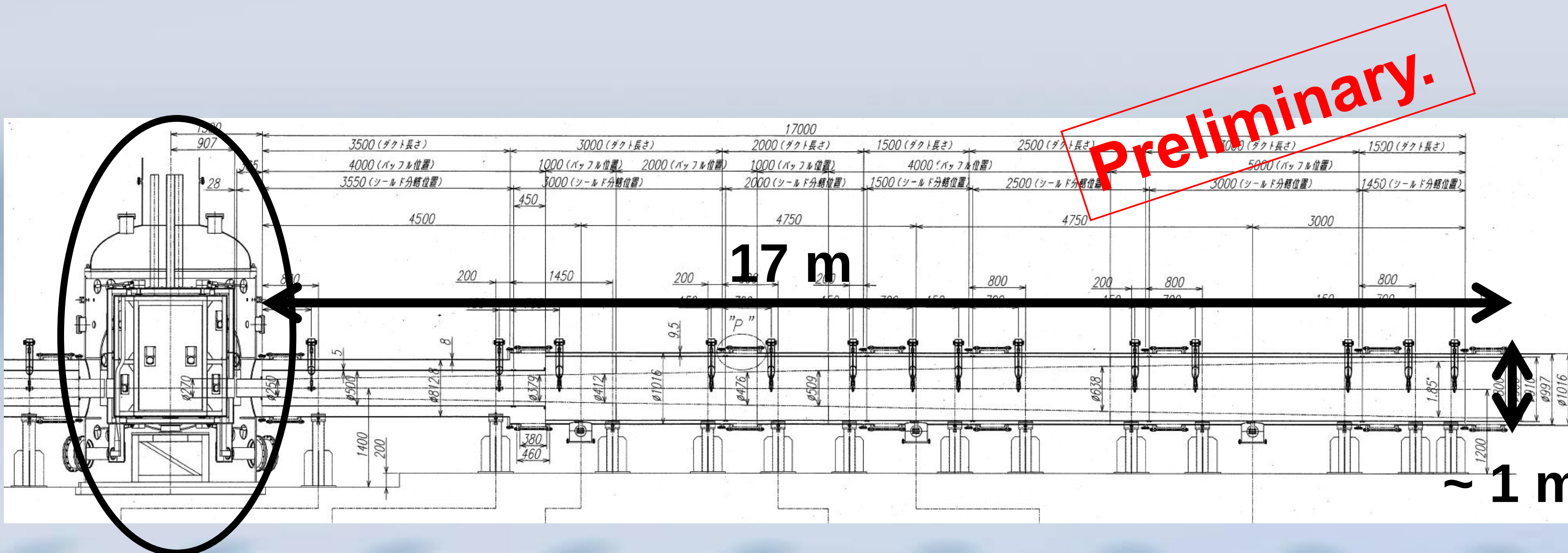


Y. Sakakibara's Master thesis (English)

http://gwdoc.icrr.u-tokyo.ac.jp/DocDB/0008/P1200862/001/mthesis_sakakibara.pdf

4. Challenges for cryogenic

1. Issues of cooling : Mirror temperature with heat load



Cryostat

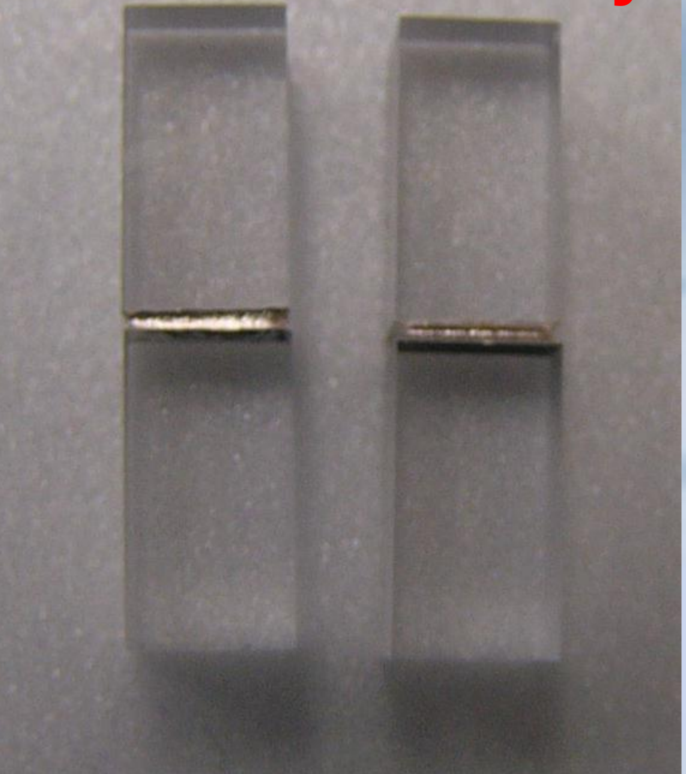
4. Challenges for cryogenic

2. Issues of noise : sapphire fibers

Sapphire fibers to suspend sapphire mirrors

Bonding (between sapphire fibers and mirrors)

There are many candidates.



Thermal conductivity, Q-values and strength should be measrued.

Metalize bonding (Kyocera)

4. Challenges for cryogenic

2. Issues of noise : sapphire fibers

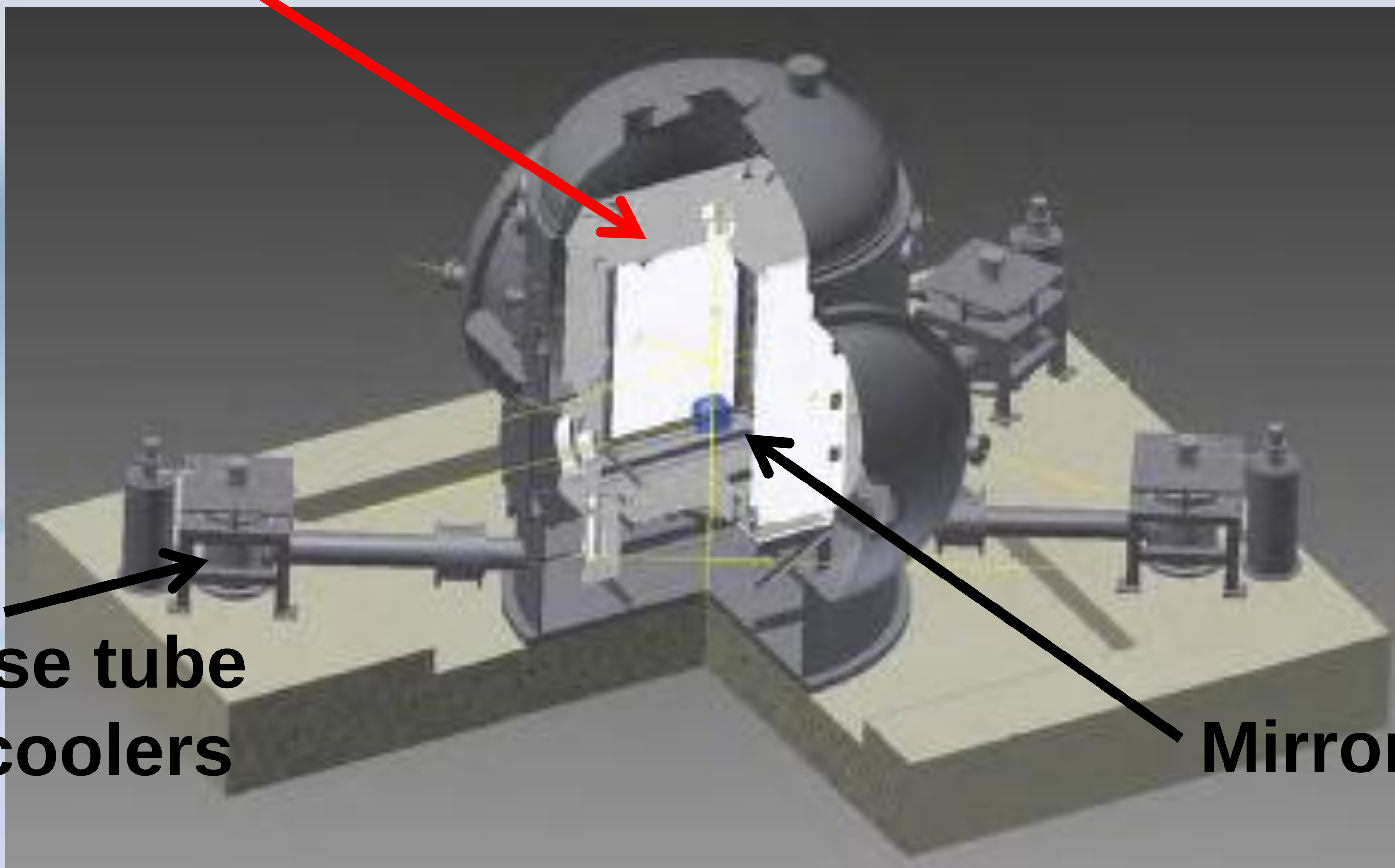
Known methods of bonding

	Precise polish	Interposition material	Temperature treatment	Sapphire-Sapphire	Thermal conductance	Mechanical loss
AFB, Diffusion	Necessary	none	1300~1400 °C	Almost same as bulk ~ 28 MPa	~ 20 W/K	Not yet measured
Direct, SAB1 (~ 2000)	Necessary	None (Ar^+ beam)	300 K	-	-	Not yet measured
Direct, SAB2 (2011)	Necessary	Fe, etc (Ar^+ beam)	300 K	Not yet measured	Not yet measured	Not yet measured
Hyroxy-catalysis, silicate	Necessary	KOH, Na_2SiO_3, H_2O	300 K	~ 7 MPa	~ 7 W/K	Not yet measured
Metalize, soldering	(Not required)	Active metal	< 1000 °C?	Not yet measured	Not yet measured	Not yet measured
Adhesive	Not required	Al_2O_3, $AlPO_4$, H_2O	~ 500 °C	~20 MPa	Not yet measured	Not yet measured

4. Challenges for cryogenic

0. Outline of cryostat and cryocoolers

Radiation shield



4 pulse tube cryocoolers

Mirror