Current Status of the KAGRA Cryogenics

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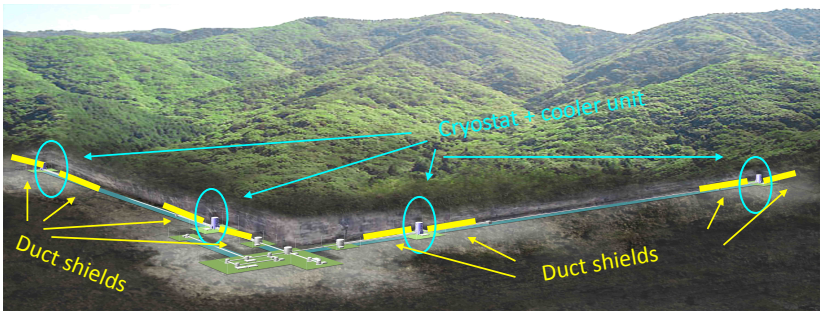
and
KAGRA Cryogenics Team
KAGRA Collaboration

5th Japan-Korea Workshop on KAGRA (November 29, 2013)

OUTLINE

1. General Descriptions of KAGRA Cryogenics
2. Progress in the past year
   - Cryocooler units
   - Cryostats
   - Duct Shields
3. Summary and Future Tasks

1. General Description of KAGRA Cryogenics

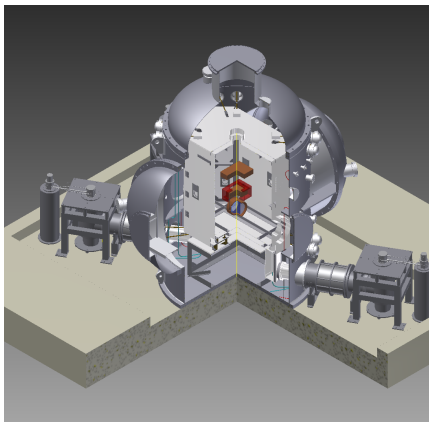


Our Main Mission :

Cool the mirrors down to 20K

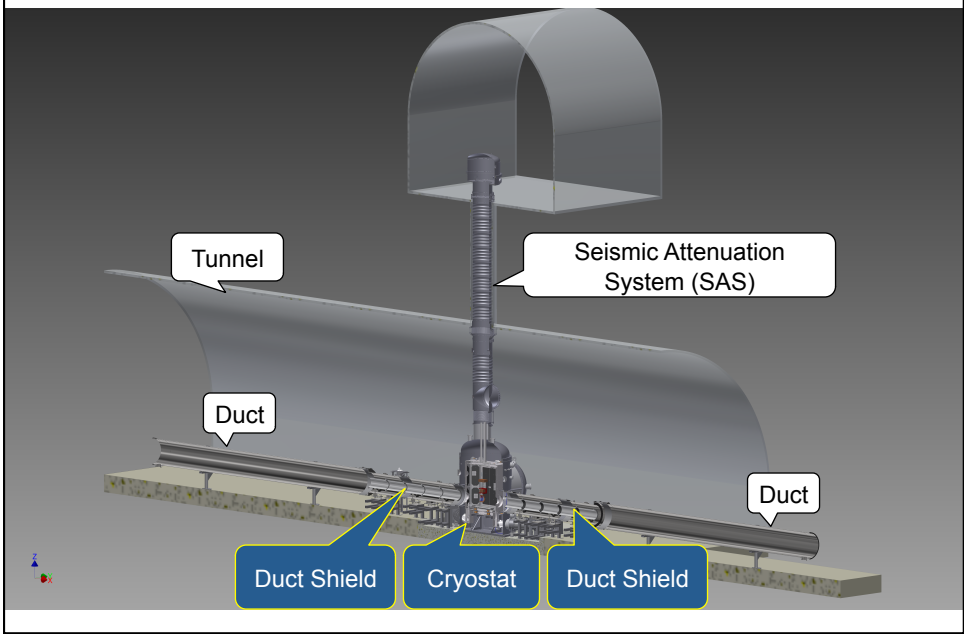
in the extremely quiet environment.

Basic Specifications

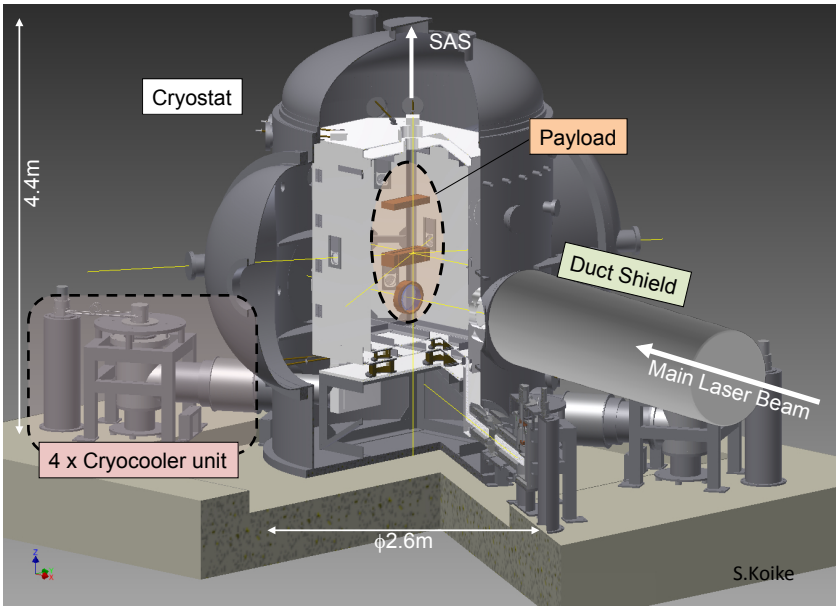


- Sapphire Mirrors (d=220 mm, t=150 mm, m=23 kg)
- Cool the mirrors to 20 K to reduce fundamental noise.
- Suppress temperature increasing inside the mirrors caused by light absorption.
- Absorb scattering light from interferometer in the cooled radiation shields.
- Four mirrors. Four cryostats.
- Four cryocoolers for each cryostat. Sixteen cryocoolers in total.
- Reduce vibration inside the cryostat lower than that of Kamioka Mine to increase the sensitivity of detector.
- Reduce themal transfer from duct in a room temperature.

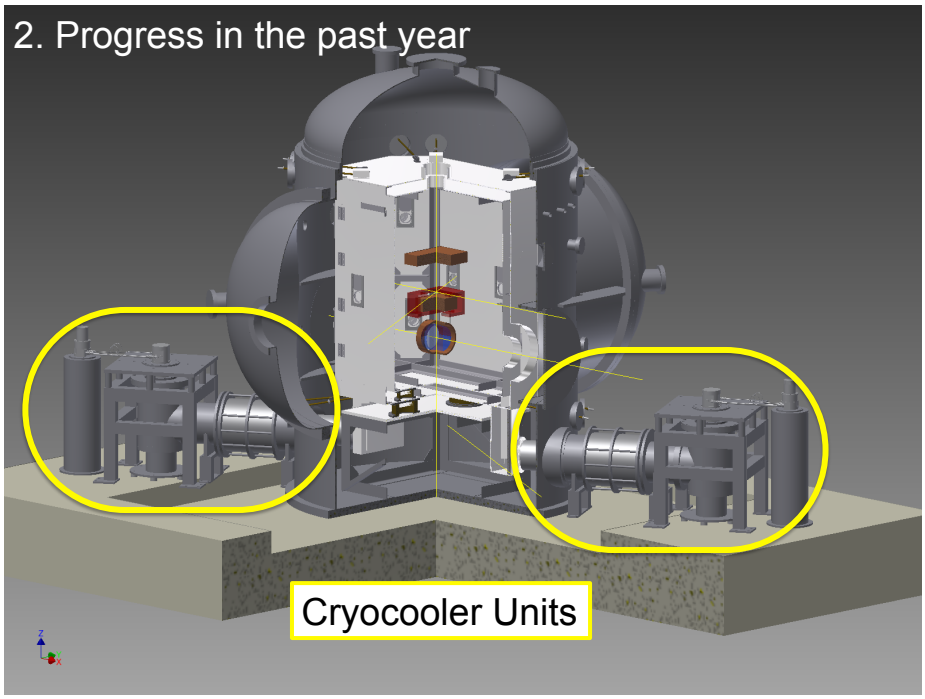
Main Components : Cryostat and Duct Shield



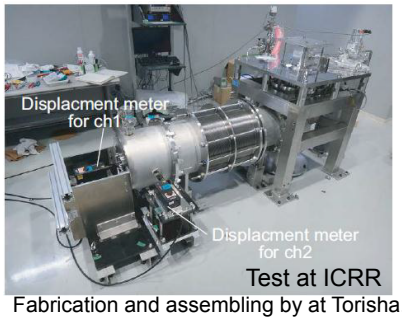
Cryostat Components



2. Progress in the past year



Cryocooler Units with Extremely-Low-Vibration Mechanism

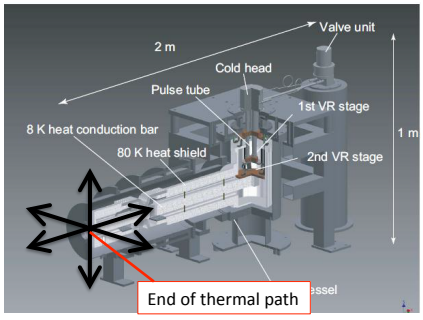


Fabrication and assembling by at Torisha.

Double-stage Pulse-Tube Cryocoolers

Cooling Specification
- 2.5 W@9 K at End of 8 K thermal path
- 35 W@70 K at End of 80 K thermal path

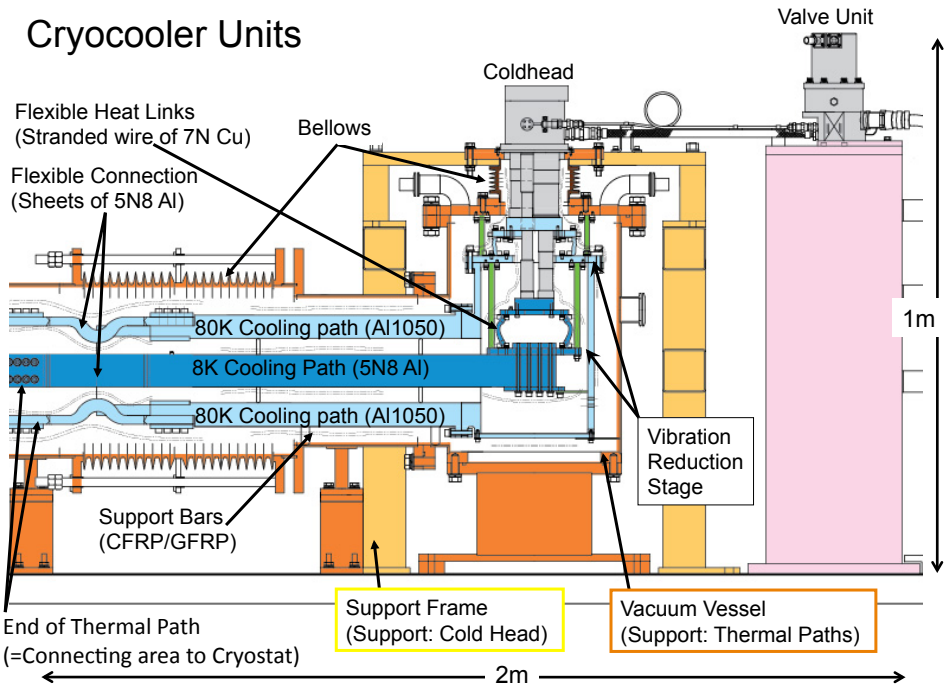
Vibration Specification
- Amplitude < ±100 nm @ Both ends of 8 K/80 K thermal path



Thermal Performance Test
Measure lowest temperatures and temperature responses to heat input by heaters at the end of thermal paths (=connecting area to the cryostat).

Vibration Performance Test
Measure vibrations at the end of thermal paths under the operation temperature.

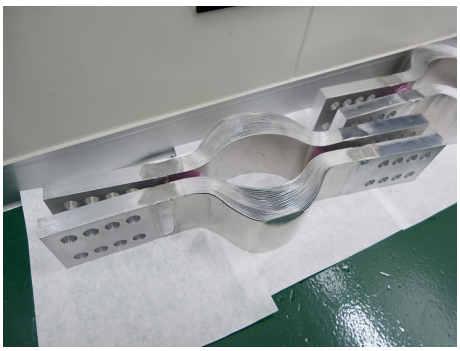
Cryocooler Units



Cryocooler Units

Thermal conduction structures with vibration isolation mechanism.

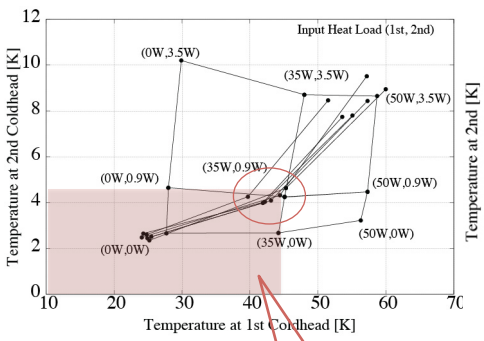
Vibration Reduction Stages
(Stranded wires of annealed 7N Copper)



Flexible Connection
(Layers of sheets of 5N8 Al)

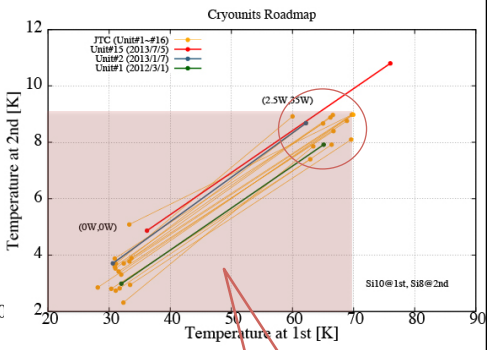
Cryocooler Units : Cooling Test

Measured Load Map of SHI RP-082B PT Cryocoolers



Specification
4.2K@0.9W
45K@35W

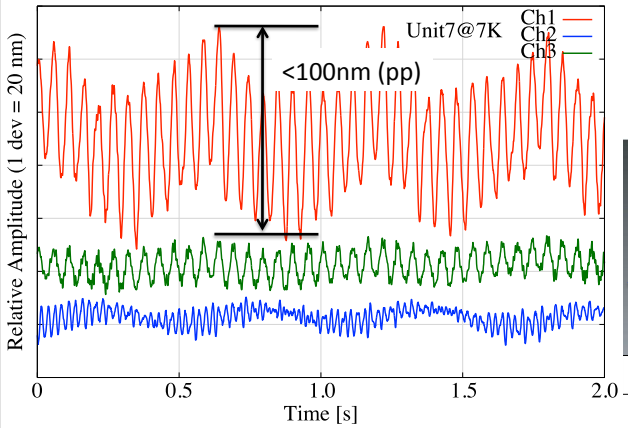
Measured Load Map of Cryocooler Units

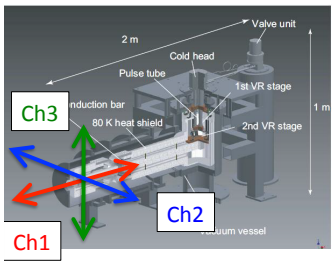


Specification
9K@2.5W
70K@35W

Cryocooler Unit : Vibration Test (Time-series Data)

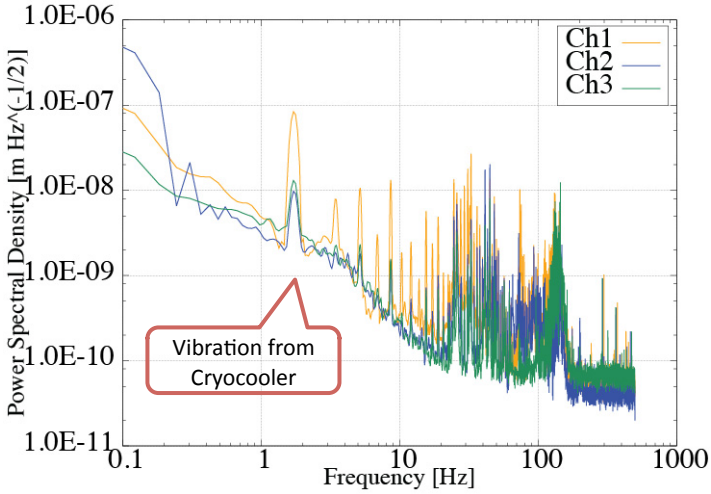
- Vibration measurement under operation temperature.
- Verify that displacements are smaller than 100nm (peak to peak).

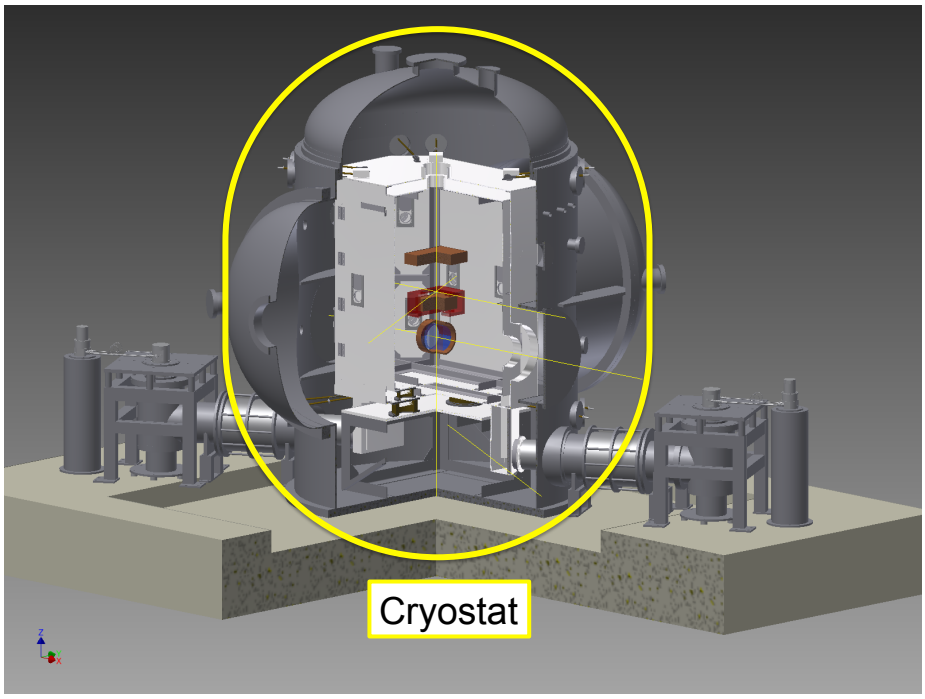




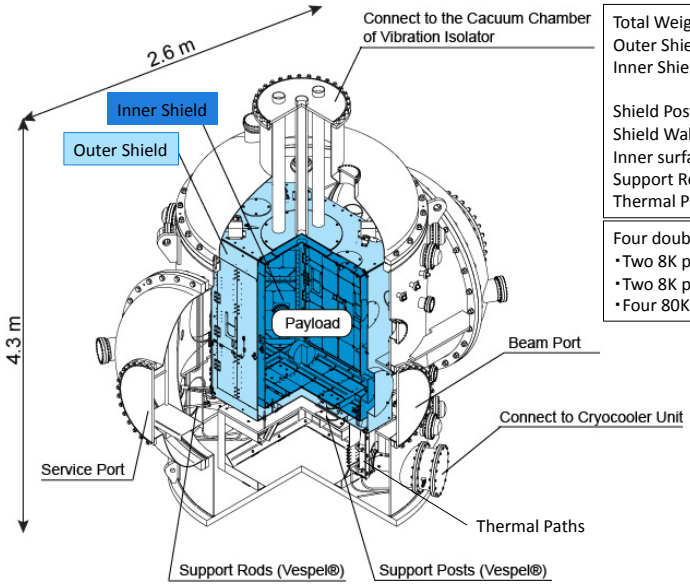
Cryocooler Unit : Vibration Tests (Power Spectral Density)

- Fourier transform of time-series data.
- Dominant vibration from cold-head (~1.7 Hz)





Cryostat



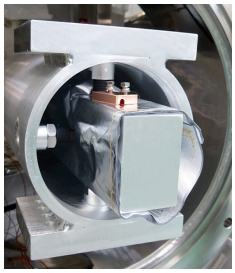
Total Weight : 11000 kg
Outer Shield : 590 kg
Inner Shield : 460 kg

Shield Posts : Aluminum 6000 series
Shield Wall : Aluminum 1000 series
Inner surface of Inner shield : DLC Coating
Support Rod/Post : Vespel
Thermal Paths : 5N8 Aluminum

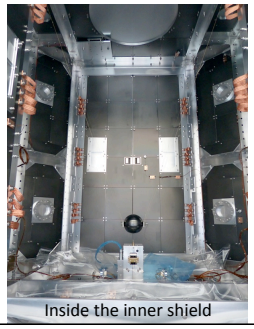
Four double-stage PT coolers for a cryostat
- Two 8K paths cool Mirror
- Two 8K paths cool Inner Shield
- Four 80K paths cool Outer Shield

Cryostat : Cooling Performance Test

Cryostats fabricated by Toshiba.
Performance test was done at Toshiba Keihin Product Operations (Feb-Mar. 2013).



Thermal paths made of aluminum
at connecting area to cryocooler unit

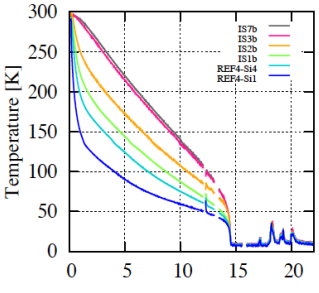


Inside the inner shield

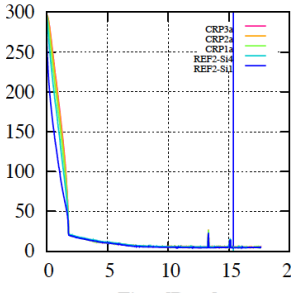
Accommodate up to four persons

Cryostat : Cooling Performance Test Results

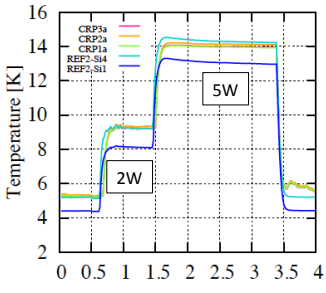
Measurement of lowest temperatures and
thermal responses to input thermal load



Cooling Curve of Inner Shield



Cooling Curve of Payload Line

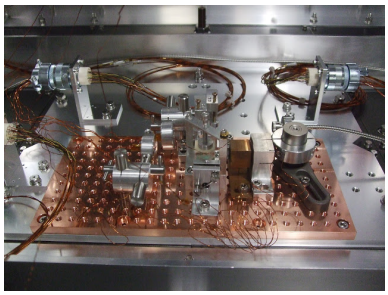


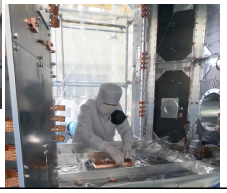
Thermal Response Curve

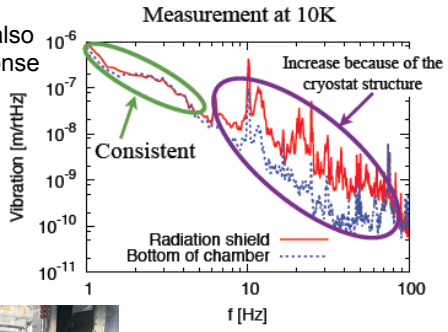
- Reaching temperature at connecting area of heat path to the mirror = 4~6 K.
- To evaluate the thermal response to the heat load, a few different heat loads were applied at the inner shield (correspond to the heat input from the scattering light) and the payload line (correspond to the heat input from mirror).

Cryostat : Vibration Performance Test

- Vibration of shield make noises through thermal link and scattering lights. So, we measured vibration of inner shield at the operating temperature. (Note: Vibration at Toshiba test site is 100 times larger than that of KAGRA site.)
- Evaluate by the ratio of vibration of inner shield to that of on the floor. (Under analysis and trying to improve the measuring instruments.)
- Hammering tests of the cryostats were also conducted to check the frequency response functions.


Vibration measuring instrument work under cryogenic

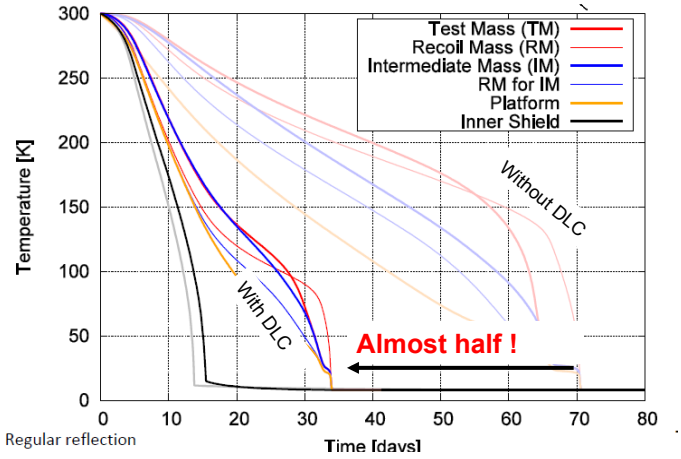




C. Dan/ICRR

Cryostat : Reduction of Cooling Time

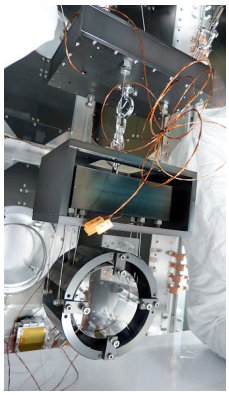
- Heat link is very thin to prevent it from propagating vibration.
- Estimated cooling time of mirror is two months. > Need to accelerate cooling speed
- Conducted a series of radiation cooling test with different type of reflective coatings as DLC (Diamond Like Carbon) and Solblack.



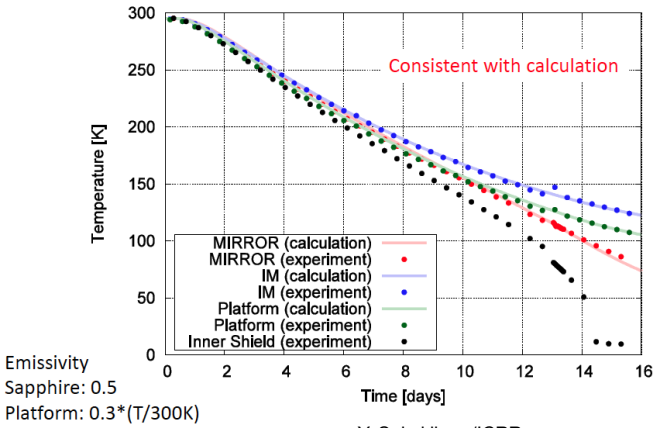
Comparison of Cooling Time with & without DLC

Y. Sakakibara/ICRR

Cryostat : Reduction of Cooling Time



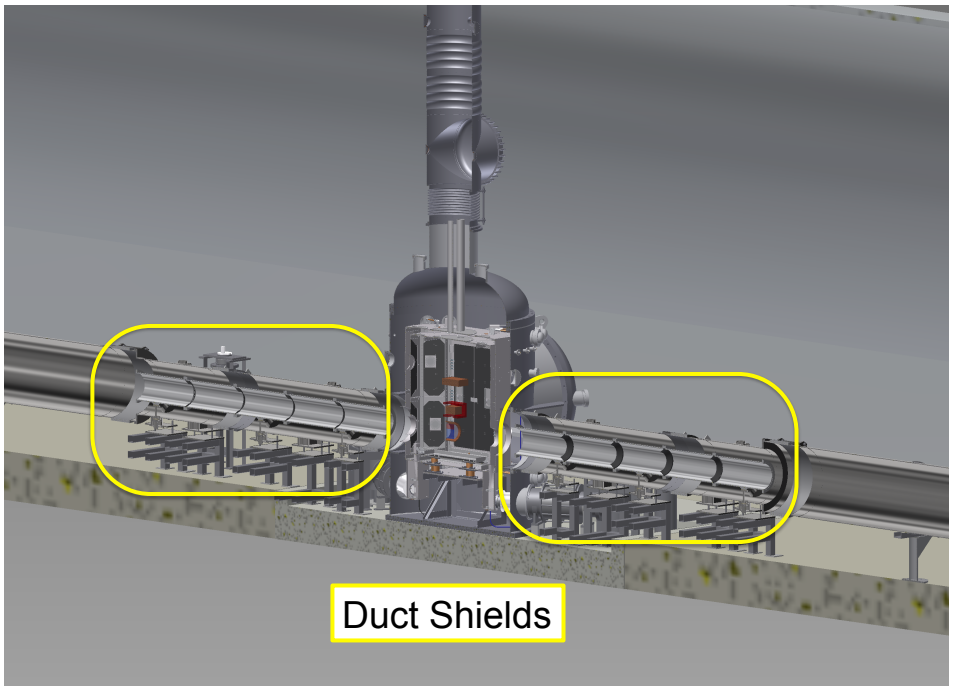
DLC coated on outer surface of dummy payload



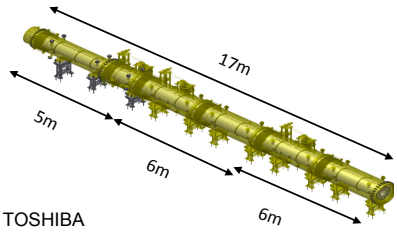
Emissivity
Sapphire: 0.5
Platform: 0.3*(T/300K)
IM: 0.4*(T/300K)

Y. Sakakibara/ICRR

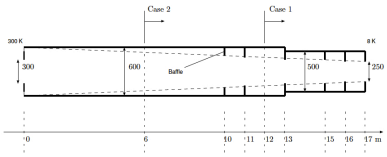
- Experiment with half size of dummy cryo-payload with DLC coated masses.
- Calculation model predicts radiation cooling correctly.
- Verified the effect of high emissivity coating on reduction of cooling time.



Duct Shield : Prototype (17m)



TOSHIBA



Mirror must be surrounded by radiation shields to keep temperature, but holes for laser beam is necessary.

Possible solutions…

To reduce thermal radiation

- Decrease a solid angle to 300 K region
- Reflex thermal radiation inside duct shield.
- Reduce thermal radiation with baffles.

To suppress scattered light noise

- Baffles to be tilted to catch scattered light
- Coated with black (at 1um) (Solblack)
- Small vibration

>>> Prototype duct shield has been designed with 17 m vacuum duct and 17 m cryo-pipe.

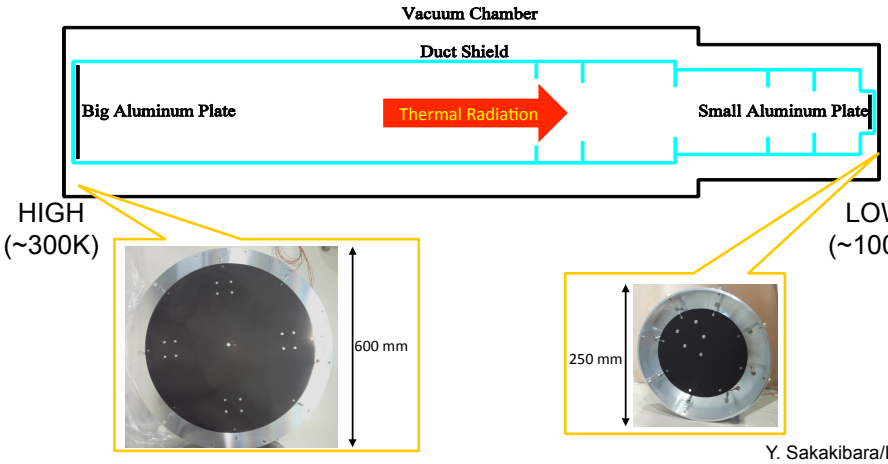
Duct Shield : Prototype (17m)

Tested in Toshiba (September-October, 2013)

Single-stage Cryocoolers

One set of 17m duct shield is manufactured by Toshiba in 2012FY. Vacuum duct and cryo-pipe are separated by 3 sections. Each section is cooled by a single stage pulse tybe cryocooler.

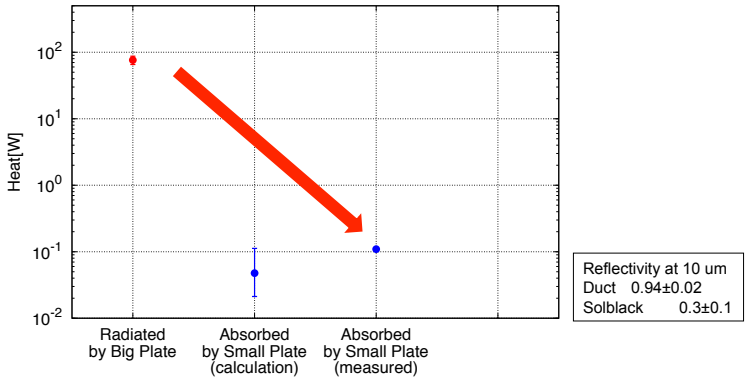
Duct Shield : Measurement of Thermal Radiation



Y. Sakakibara/ICRR

- Two aluminum plates are thermally-suspended on the both sides.
- Plates are coated with Solblack to enhance emissivity or absorptivity.
- After duct shield is cooled, big plate is heated up to 300 K and emits thermal radiation.
- Small plate absorbs radiation and is heated up.
- Calibration is conducted using heater on small plate.

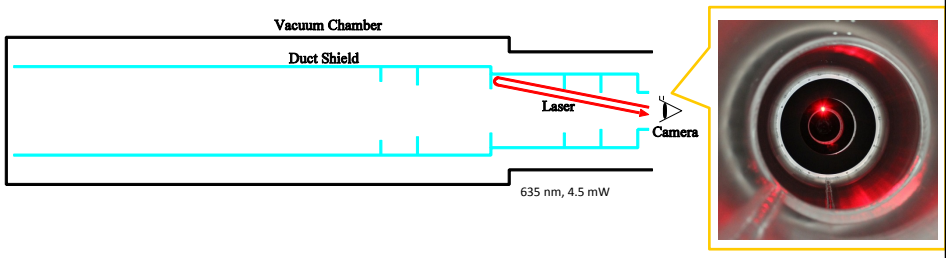
Duct Shield : Measurement of Thermal Radiation

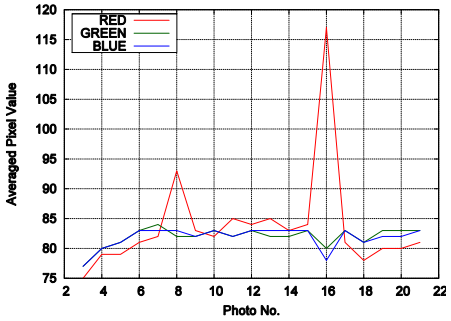


- Calculated value has error of several times
  - Measured reflectivity at 10 μm of shield has error
  - Rays are reflected by shield many times
- Measured value is within the error

Confirmed that duct shield with baffles reduce to 1/1000 of heat transfer, as simulated.

Duct Shield : Measurement of Scattering Lights

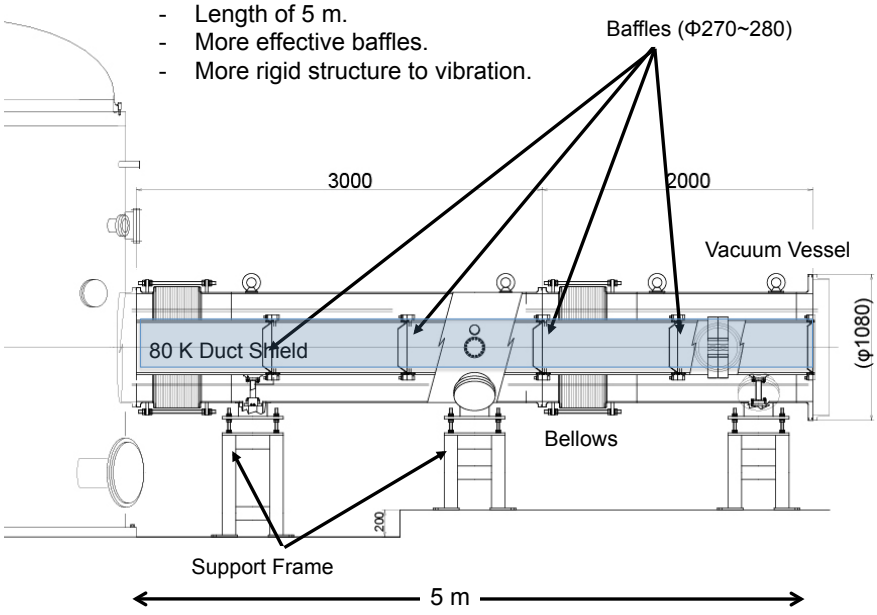




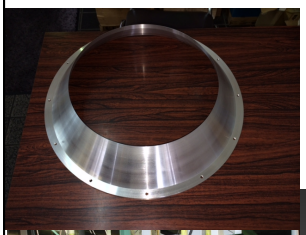
- Shine red-light of laser diode into the duct shield.
- Take photos with changing input angle of scattering light.
- At some angles, sharp scattering light comes back to camera (=mirror).
- Reflected laser power can be estimated by calibration.

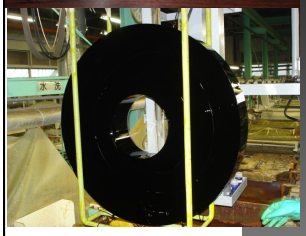
Duct Shield : Improved Design

- Length of 5 m.
- More effective baffles.
- More rigid structure to vibration.

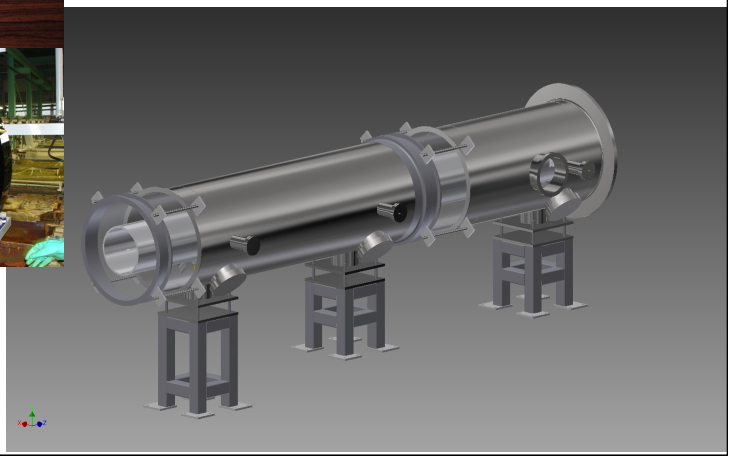


Improved Duct Shield





Fabrication and assembling are ongoing at Torisha.
Will be tested from Jan. 2014.



3. Summary and Future Tasks

1. KAGRA cryogenics consisting of cryostat and cryocooler units was designed, fabricated, and tested their performances during 2011JFY and 2012JFY.
2. At the performance test, following items were confirmed and verified;
   - Cooling and vibration performance of sixteen cryocooler units.
   - Cooling performance of all the four cryostats.
   - Vibration on the surface of inner radiation shield.
   - Experiment with half size of dummy cryo-payload.
3. Experiment with prototype duct shield was conducted, and results was agreed with predicted heat load. But, need further analysis work is required.
4. Design of the production of improved duct shield were almost finished. We are now focusing our work on fabrication of the duct shields and preparing performance test.

…Design and development of the payload is another story…