Present Design of LCGT Cryogenic Payload

- Status of Cryogenic Design -

N. KIMURA*, Y. SAKAKIBARA**,

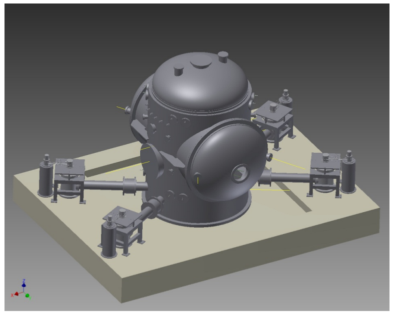
S. KOIKE*, T. Ohmori***, T. SUZUKI*,

H. YAMAOKA*, and LCGT Collaboration

* High Energy Accelerator Research Organization (KEK)

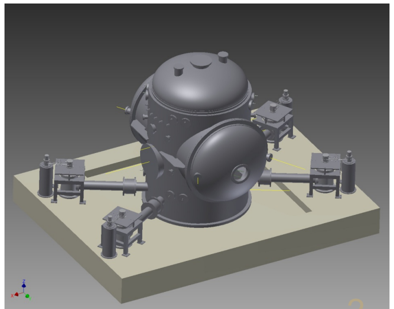
** University of Tokyo

*** Teikyo University

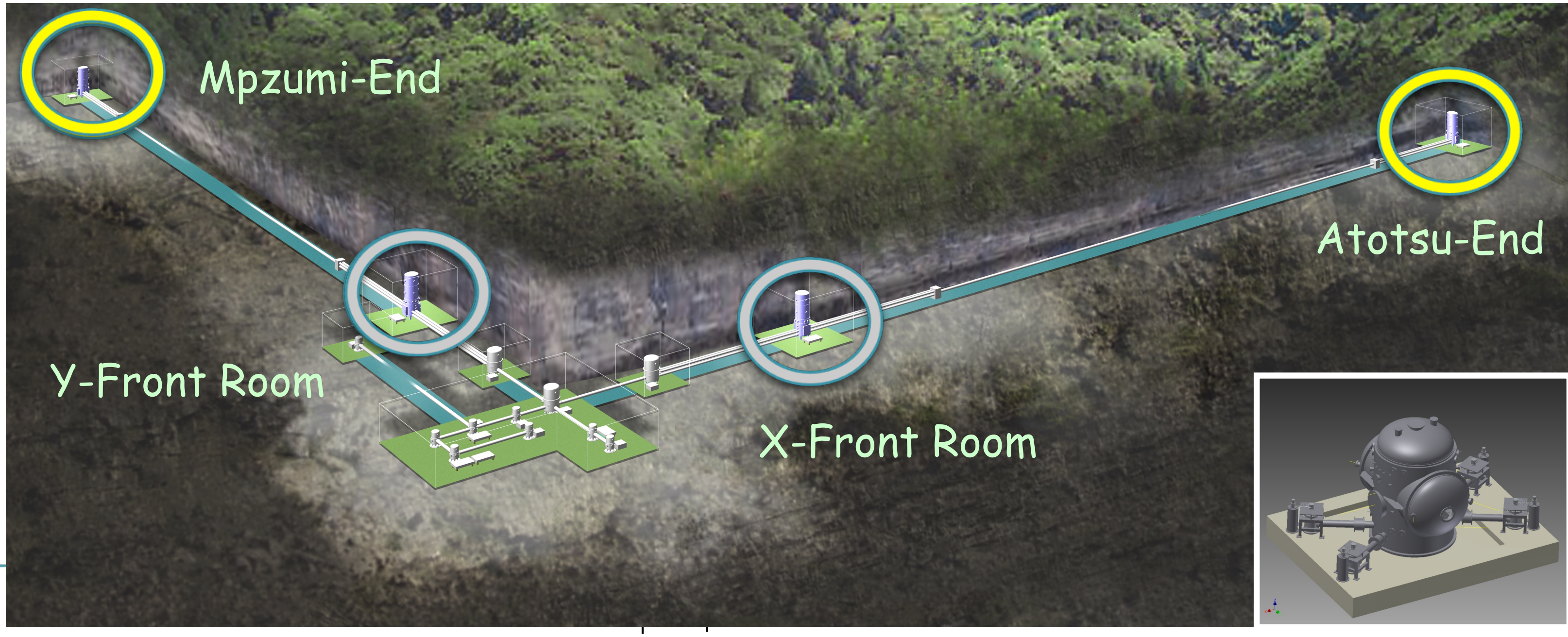


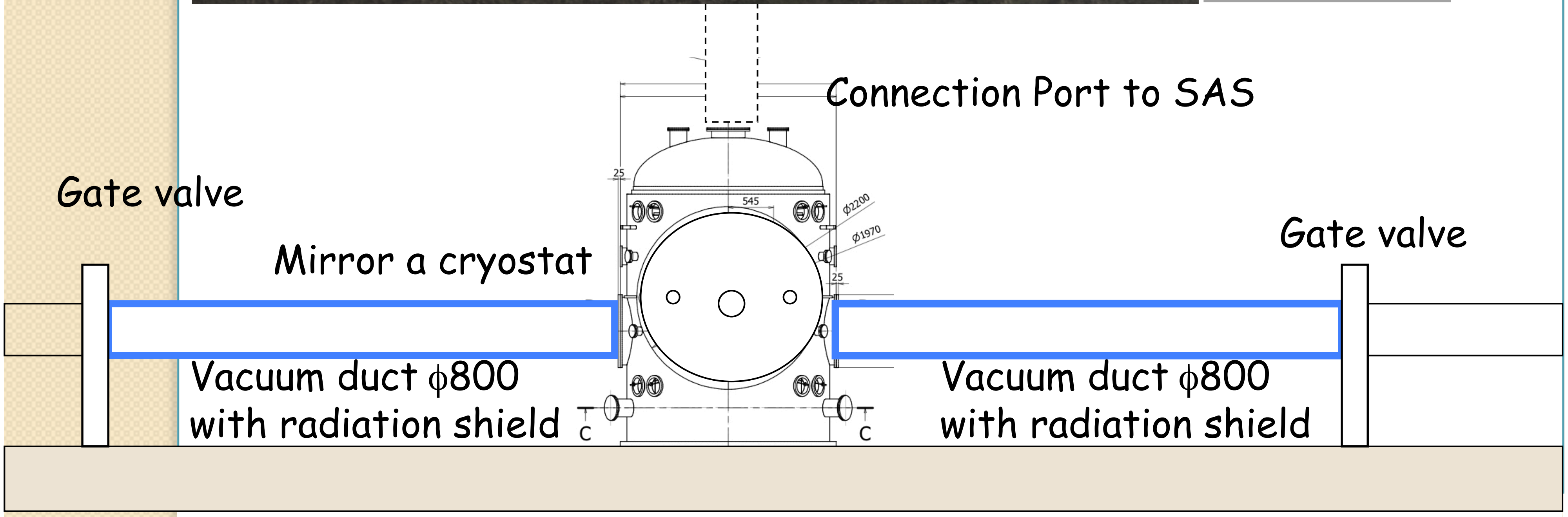
Outline

- *Concept of the LCGT cryogenics*
  - ✓ *Structure and Response to ground motion at CLIO*
  - ✓ *Thermal Budget of the cryostat*
  - ✓ *Estimation of heat load of the Mirror by beam duct shield (by Mr. SAKAKIBARA)*
- *Summary*



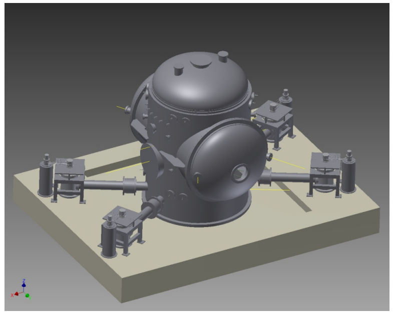
Location of Four Mirror Cryostats with the Cryo-coolers for the LCGT





Production plan of LCGT cryogenics

- Product four mirror cryostats until the end of 2013 Jfy* (2012.4~2013.3).
- In order to demonstrate the performance of cooling system and investigate interface to other subsystems, two mirror cryostats will be installed Mozumi-end and Atotsu-end.
- Other components, such as low vibration cryo-coolers and duct shield, will be product until the end of 2013 Jfy.



* Jfy: Japanese fiscal year

Production plan of LCGT mirror cryostats and peripheral components

2011 Jfy | 2012 Jfy | 2013 Jfy

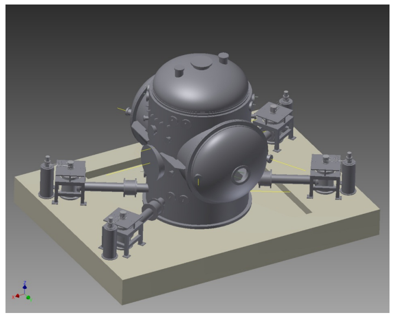
'11.3 | '12.3 | '13.3 | '14.3

We are here

Four Mirror Cryostats
- Design by KEK
- Bidding
- Manufacture components
- Assemble and factory test with cryo-coolers
- Transport to Kamioka
- Custody at Kamioka

Cryo-cooler units
- Design by KEK
- 1st Prot-type Cryo-cooler unit test
- Production of seven cryo-cooler units
- Performance test
- Production of nine cryo-cooler units
- Performance test
- Transport to Kamioka
- Custody at Kamioka

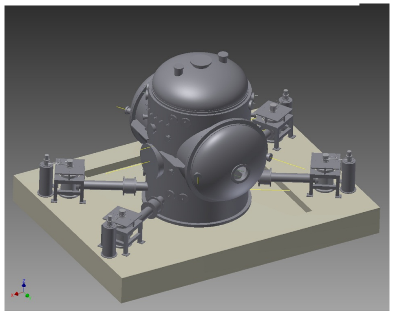
Duct shield units
- Design by KEK
- Production of Prot-type ducts shield units with cryo-coolers



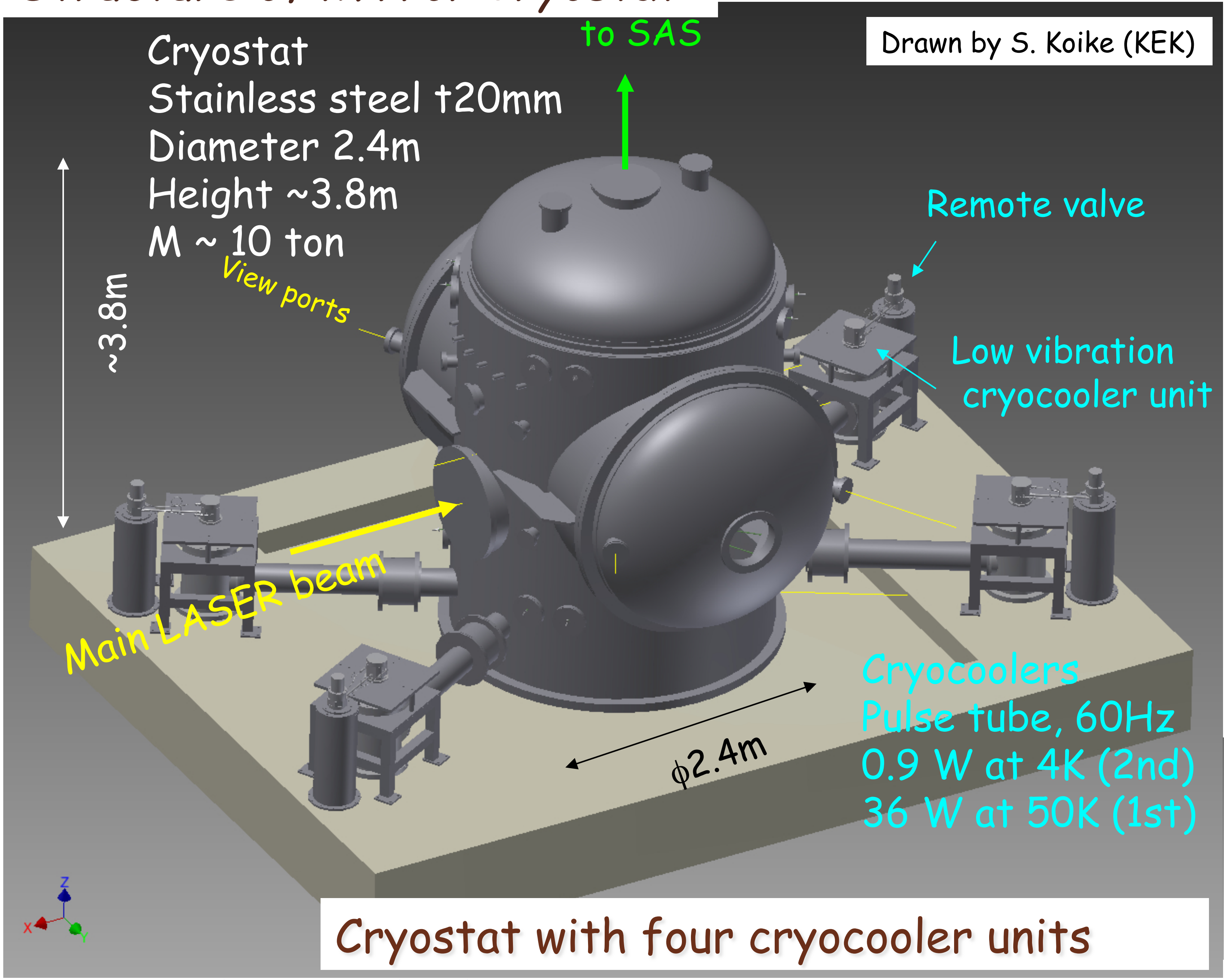
Requrements and it's Ansewr

Answer to the requirements

- Adopt Plus Tube-type Cryo-cooler units with very low vibration mount based on the CLIO type cooler.
- Analyze response to grand motion at Kamioka-mine.
- Heat load design as low as possible.
- Adopt ϕ2200 of inner diameter of flanges for installation work of the mirror and suspension.
- Develop very low out gas super insulation system for radiation heat load.

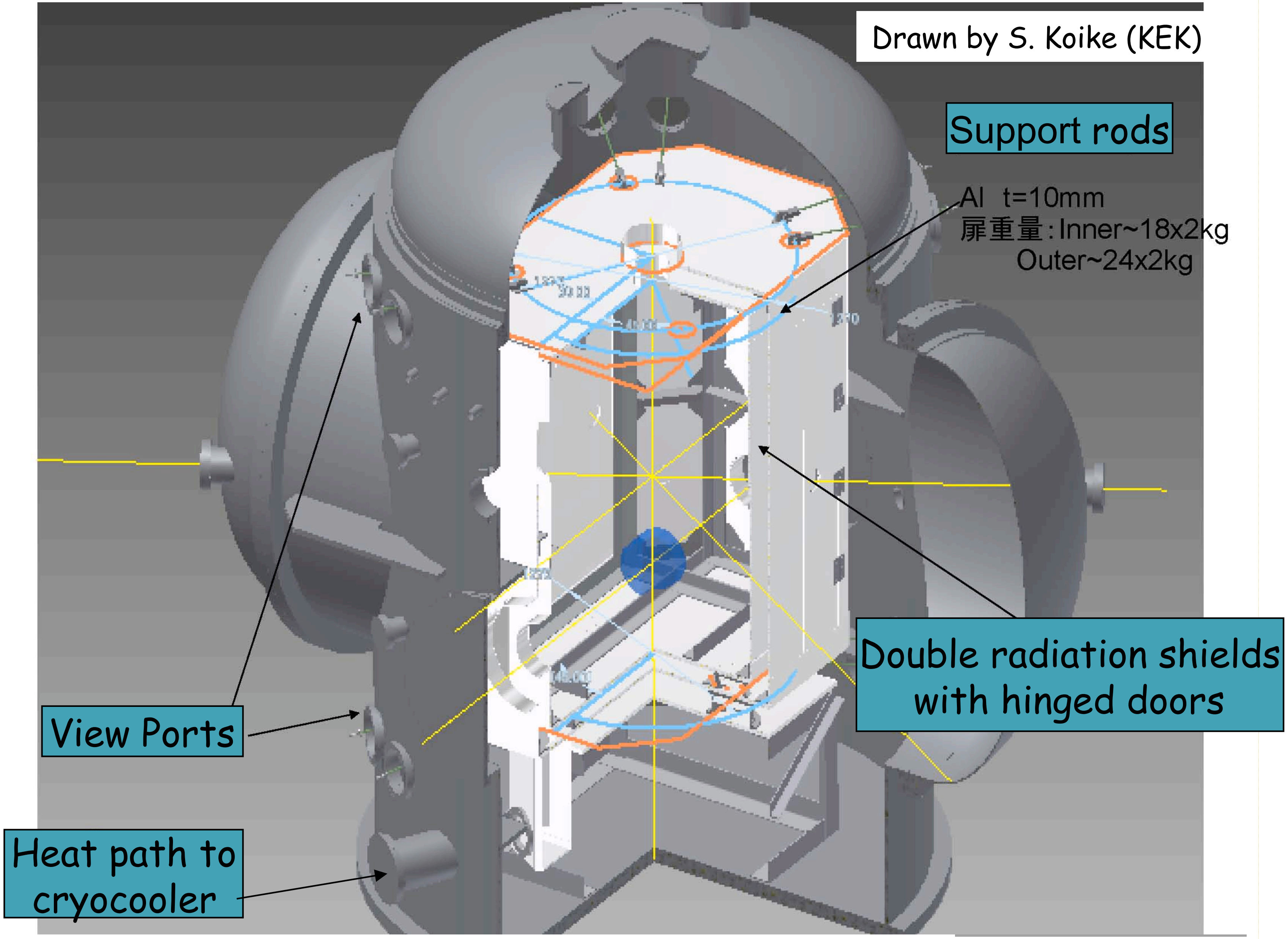


Structure of Mirror Cryostat

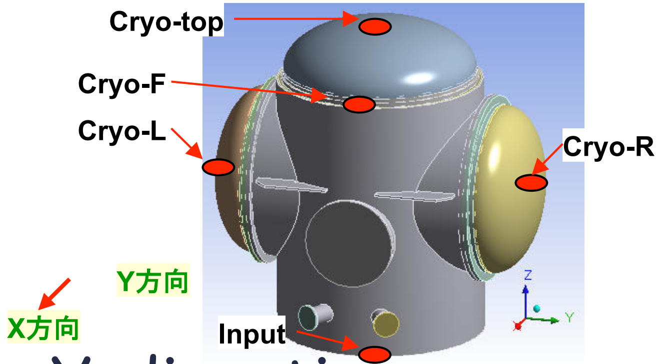


Cryostat with four cryocooler units

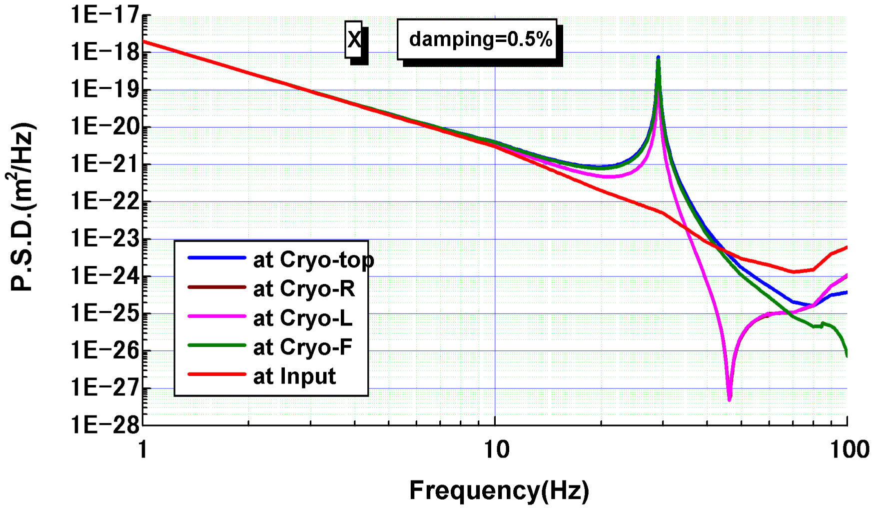
The interior of the cryostat

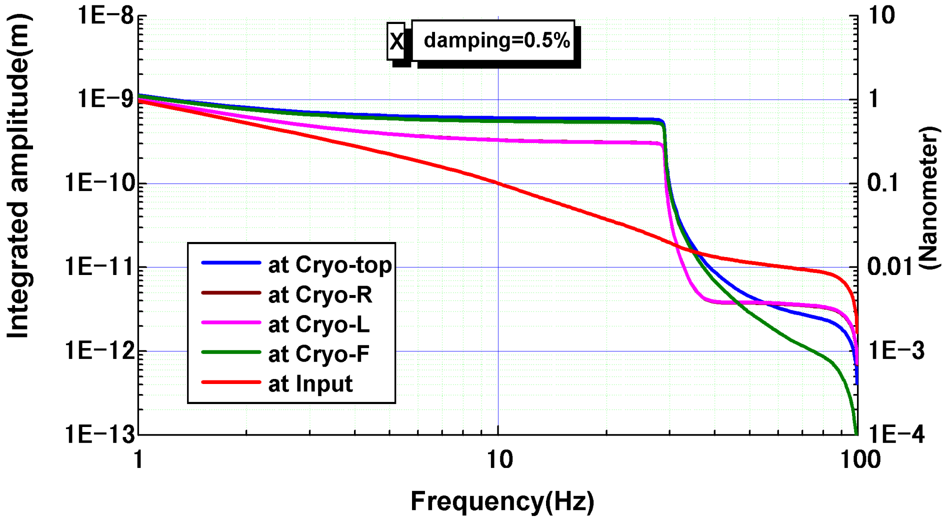


Response to ground motion

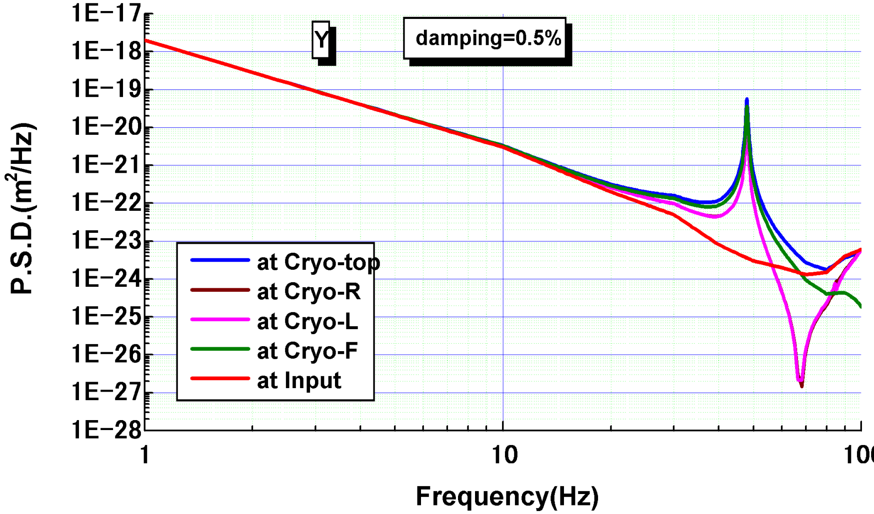


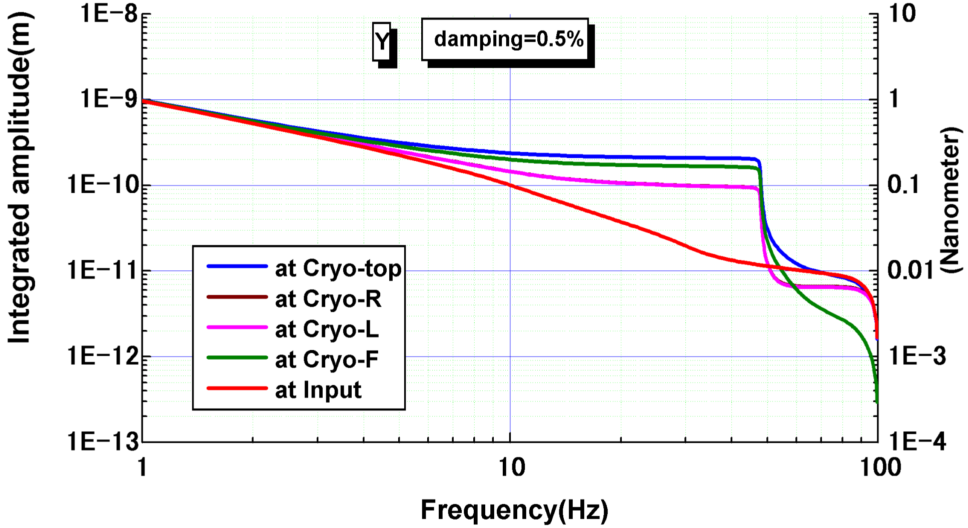
X-direction





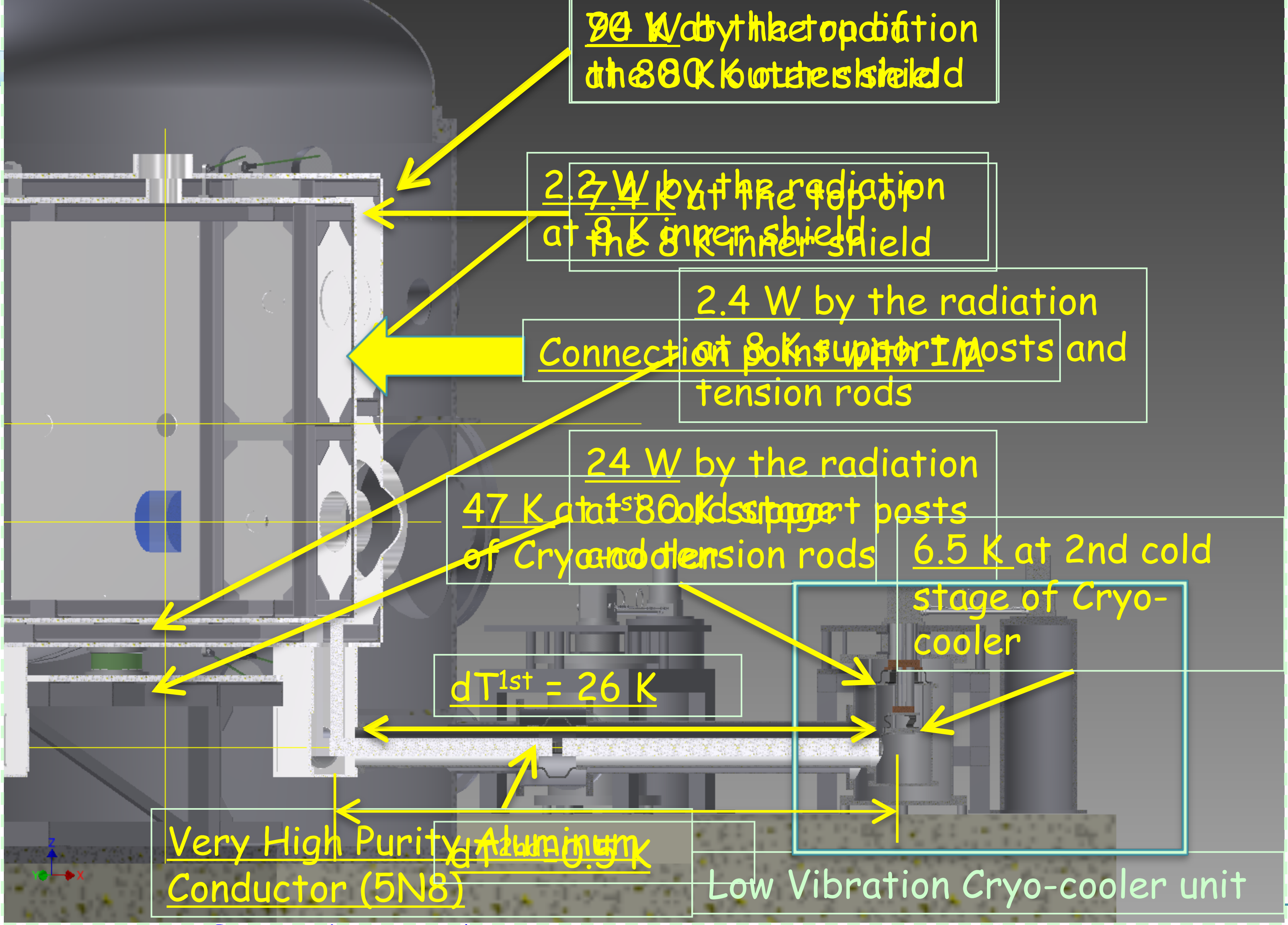
Y-direction





Estimated Thermal Budget

Estimated Heat Loads at the radiation shields and Support posts and rods



A Break Down List of Thermal Budget

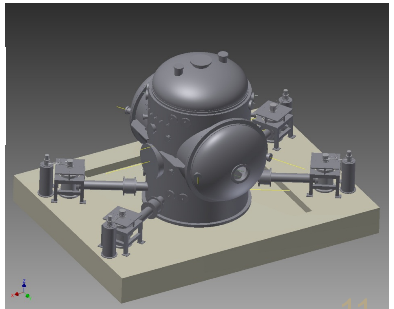
- 1st Outer Shield (W)
  - Eleven View Ports 22
  - Radiation From 300 K 70
  - Support post and Rods 24
  - Electrical wires 3×10^{-4}

Total 116
W/unit 35

- 2nd Inner Shield (W)
  - Duct Shields* < 0.05
    (Beam and SAS)
  - Eleven View Ports 0.4
  - Radiation From 80 K 2.2
  - Support post and Rods 2.4
  - Electrical wires 3×10^{-4}
  - Mirror Deposition 0.9

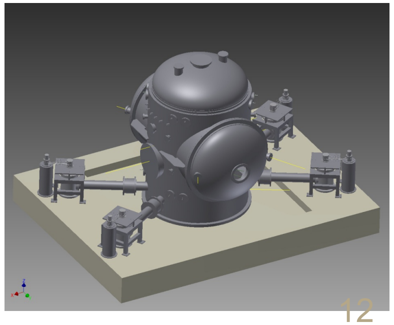
Total 6.5
W/unit 1.9

Heat Load of Duct Shields will be told by Mr. Sakakibara



Outline

- Concept of the LCGT cryogenics
  - ✓ Structure and Response to ground motion at CLIO
  - ✓ Thermal Budget of the cryostat
  - ✓ Estimation of heat load of the Mirror by beam duct shield (by Mr. SAKAKIBARA)
- Summary



Estimation of heat load by beam duct shield of the Mirror in the Cryostat

- Thermal radiation from opening of 500 mm in diameter

$$P_0 = \epsilon \sigma T^4 A = 9.02 \text{ W}$$

$\epsilon = 0.1$: Emissivity of duct (SUS)

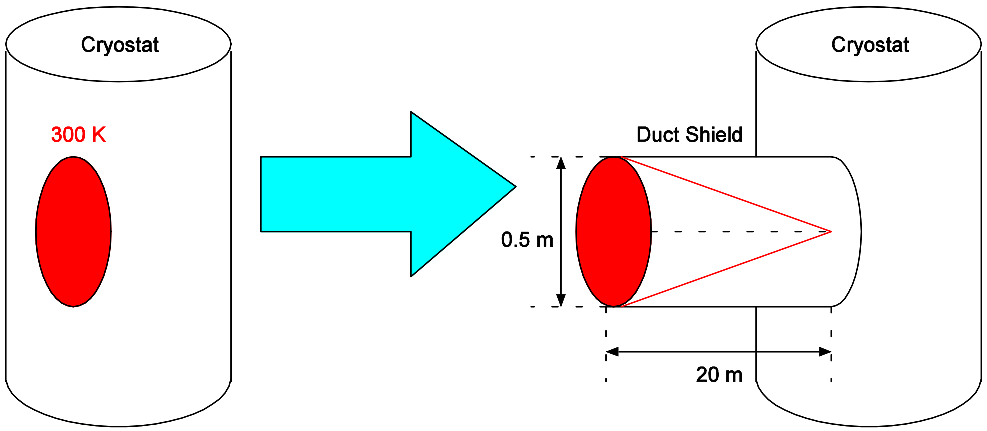
σ: Stefan-Boltzmann constant

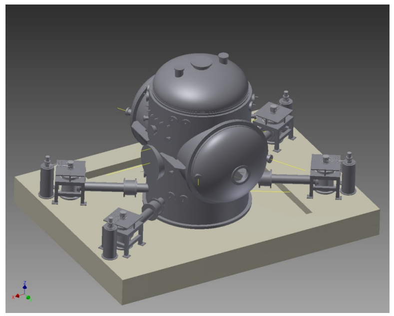
$T = 300$ K

A: Area of opening

- Cooling power 3.6 W at 4 K
  (inner shield, 4 pulse tube cryo-coolers of 0.9 W at 4 K)
- Thermal radiation appears to be reduced by reducing solid angle

$$1 - \cos\theta = 7.81 \times 10^{-5}$$





Problem experienced in CLIO

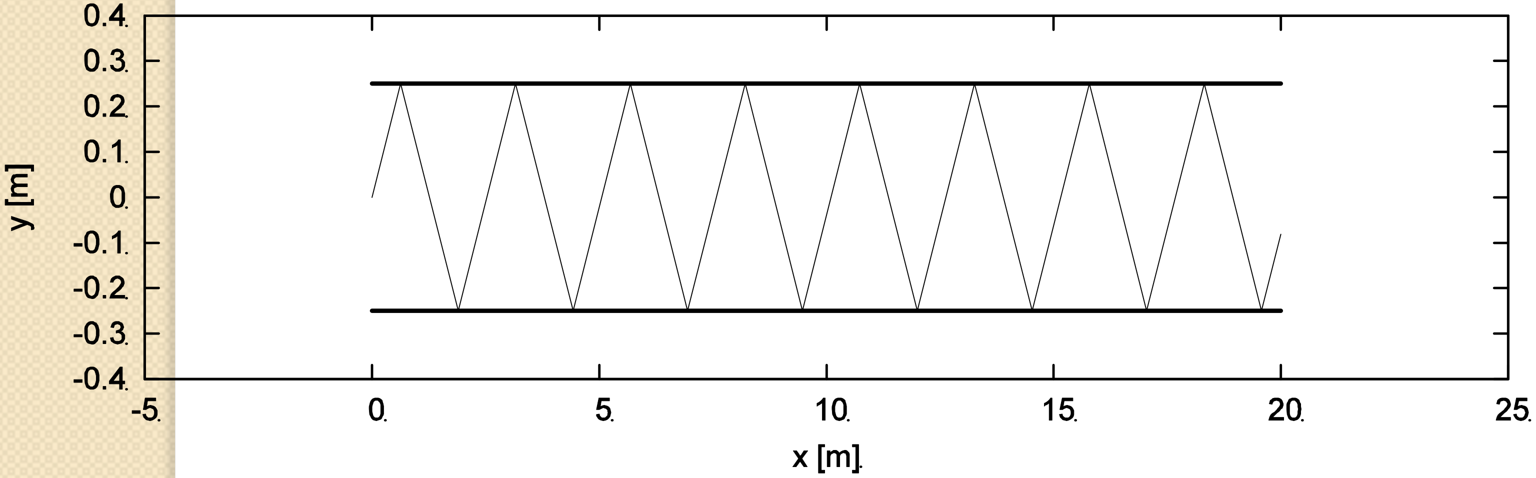
- Thermal radiation reflected by metal shield pipe
- Incident power

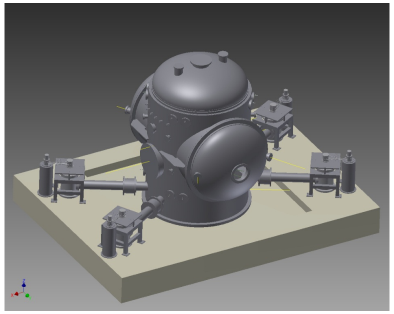
$P/P_0 = 0.293 \quad P = 2.64\ \mathrm{W} \quad P_0 = \epsilon\sigma T^4 A = 9.02\ \mathrm{W}$

(calculated using ray trace model,
experimentally verified by T. Tomaru, et al. 2008)

- Very large compared with solid angle

$1 - \cos\theta = 7.81 \times 10^{-5}$





animation

Reducing heat load by baffles

- Incident power calculated using ray trace model by counting up number of reflections

$$\frac{P}{P_0} = \int R^{N(\theta)} \frac{d\Omega}{2\pi} = \int_0^{\pi/2} R^{N(\theta)} \sin\theta d\theta$$

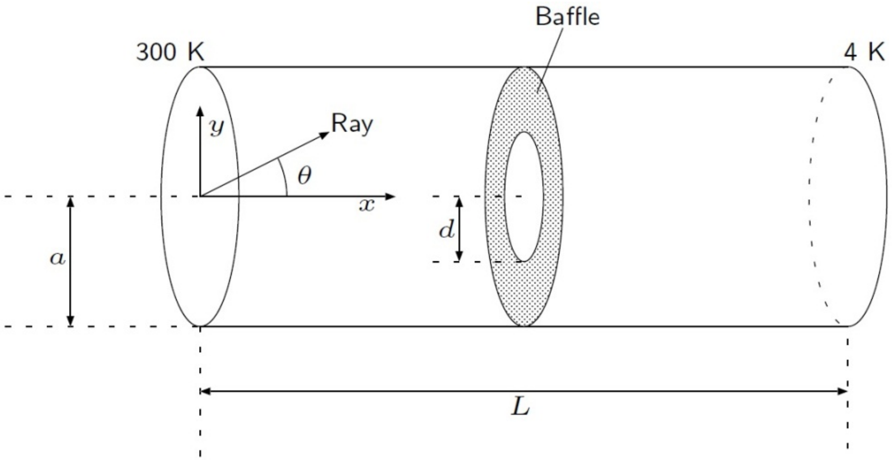
$P_0 = \epsilon\sigma T^4 A = 2.25$ W

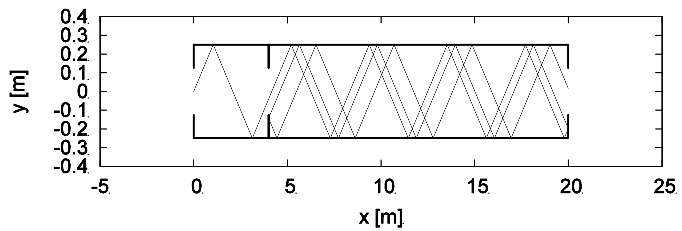
$A = \pi d^2$: Area of baffle opening

$N(\theta)$: Number of reflections

$R = 0.94 \pm 0.02$: Reflectivity

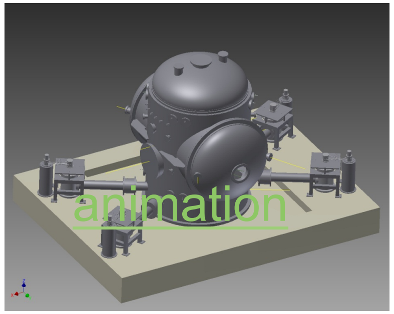
(Aluminum of A1070 measured at 10 μm, 100 K)





$2a = 0.5$ m in diameter, $L = 20$ m in length,

$2d = 0.25$ m in diameter of baffle opening



Result of calculation

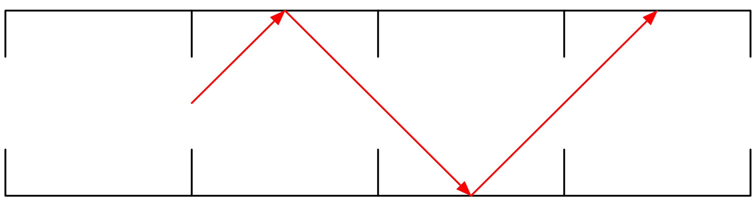
R=0.94

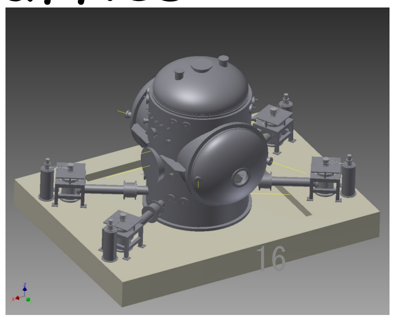
Position of baffles x [m]	P/P_0	P [mW]
0,20	0.0487	110
0,4,20	0.0359	81.0
0,5,10,15,20	0.0199	44.9
0,3,10,15,20	0.0127	**28.7**

R=0.94±0.02
Worse case
R=0.96 P=52.4 mW
Better case
R=0.92 P=17.6 mW

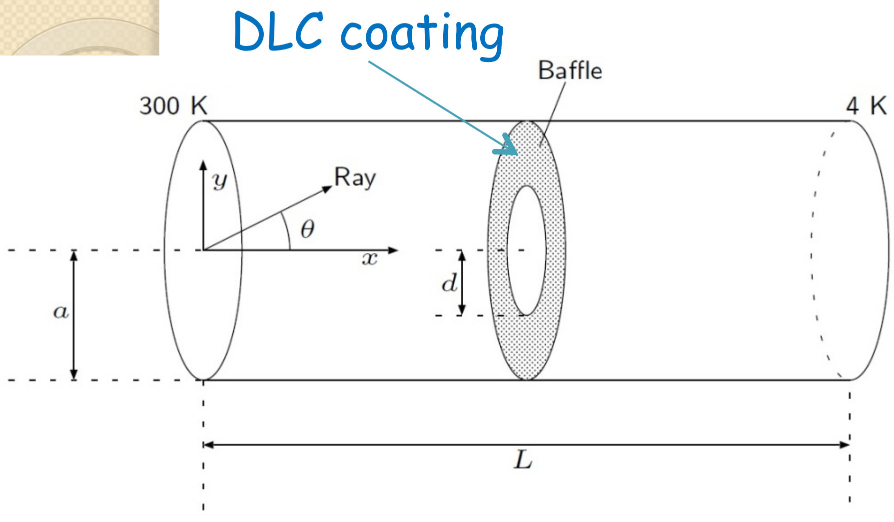
$$P_0 = \epsilon \sigma T^4 A = 2.25 \text{ W}$$

- The better result for the case that intervals of baffles don't equal
  - If intervals of baffles equal, ray whose angle passes through one baffle also passes the other baffles





Diamond Like Carbon coating

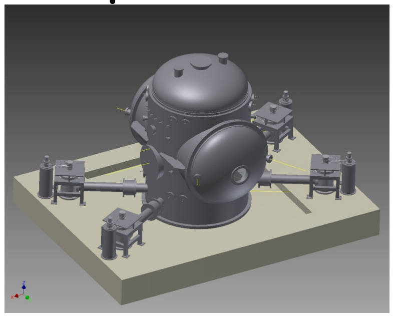


Position of baffles $x = 0, 3, 10, 15, 20$ [m]

Without DLC	$P/P_0 = 0.0127$	$P = 28.7$ mW
With DLC	$P/P_0 = 0.00815$	$P =$ **18.4 mW**

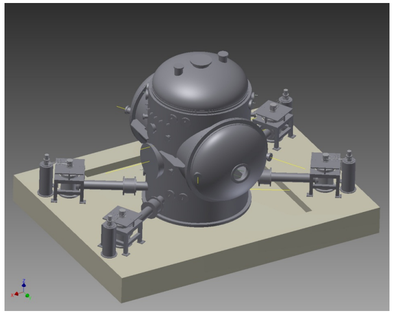
Heat absorbed by baffles
Heat load becomes smaller

- Baffles whose room temperature sides are coated with DLC
- Assuming reflectivity 0.35 (measured at 1 μm at room temperature by T. Tomaru, et al. 2005)
- Preparation for measurement at 10 μm, cryogenic temperature is now underway



Summary 1

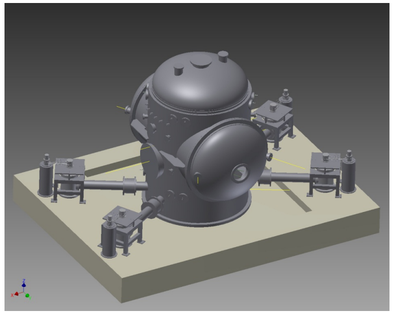
- Sum of heat load from openings of cryostat
  - 37 mW (18.4 mW x2)
  - Smaller by two orders of magnitude than total heat load of the cryostat.
- One prototype duct shield will be constructed until the end of March, 2013.
- The duct shield will be tested to verify this calculation with the mirror cryostat.



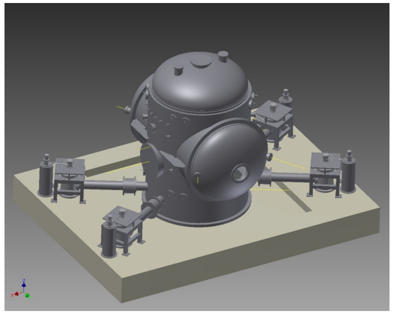
Summary 2

- The design of the mirror cryostat for LCGT satisfying requirements from was almost finished.
- The production of the components for the cryostat will be started after decided contractor.
- Performance of the first cryostat will be demonstrated at the factory of the contractor on the mid of 2012 fy.

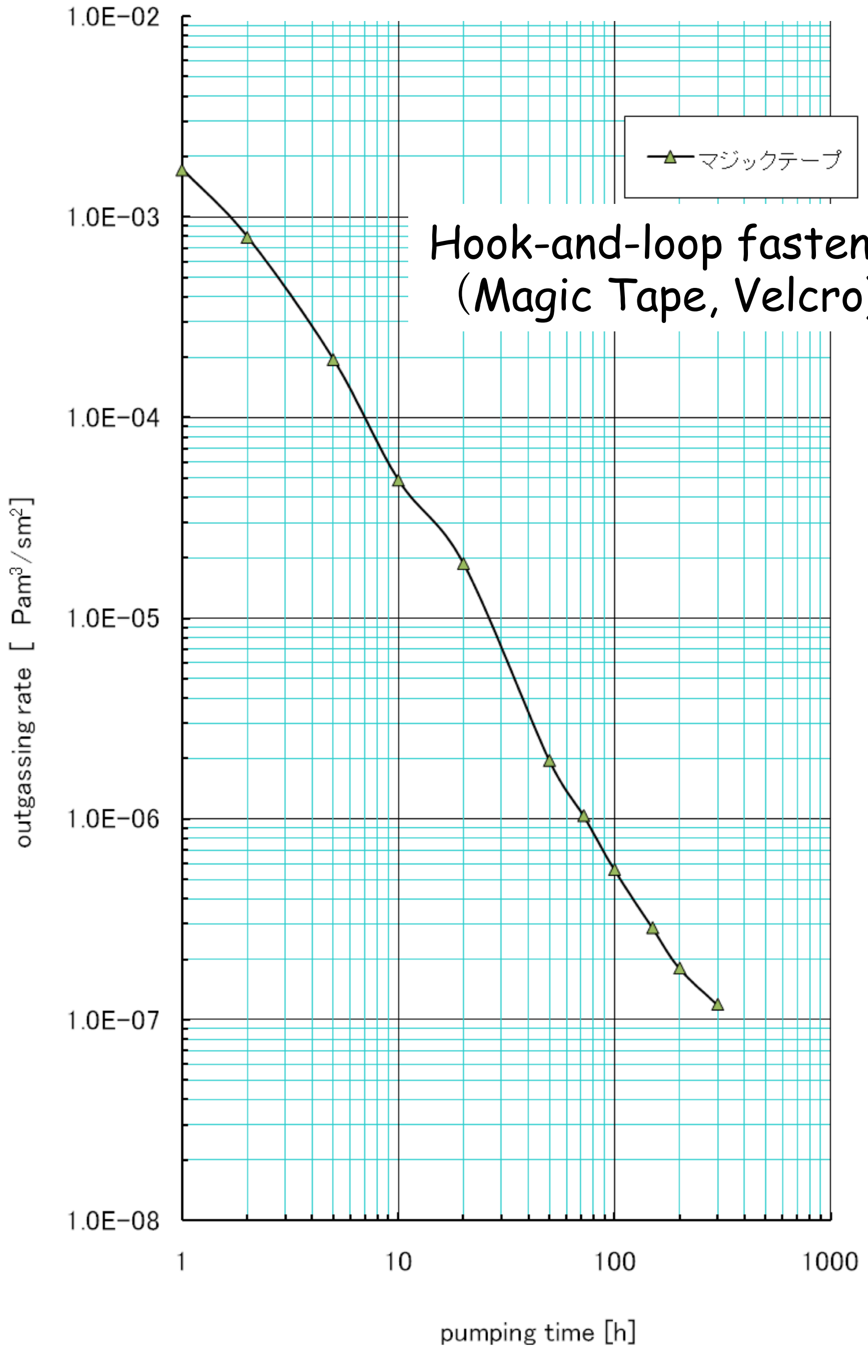
We would like to discuss the detailed design process of the cryostat with participants of GWADW conference after this talk.

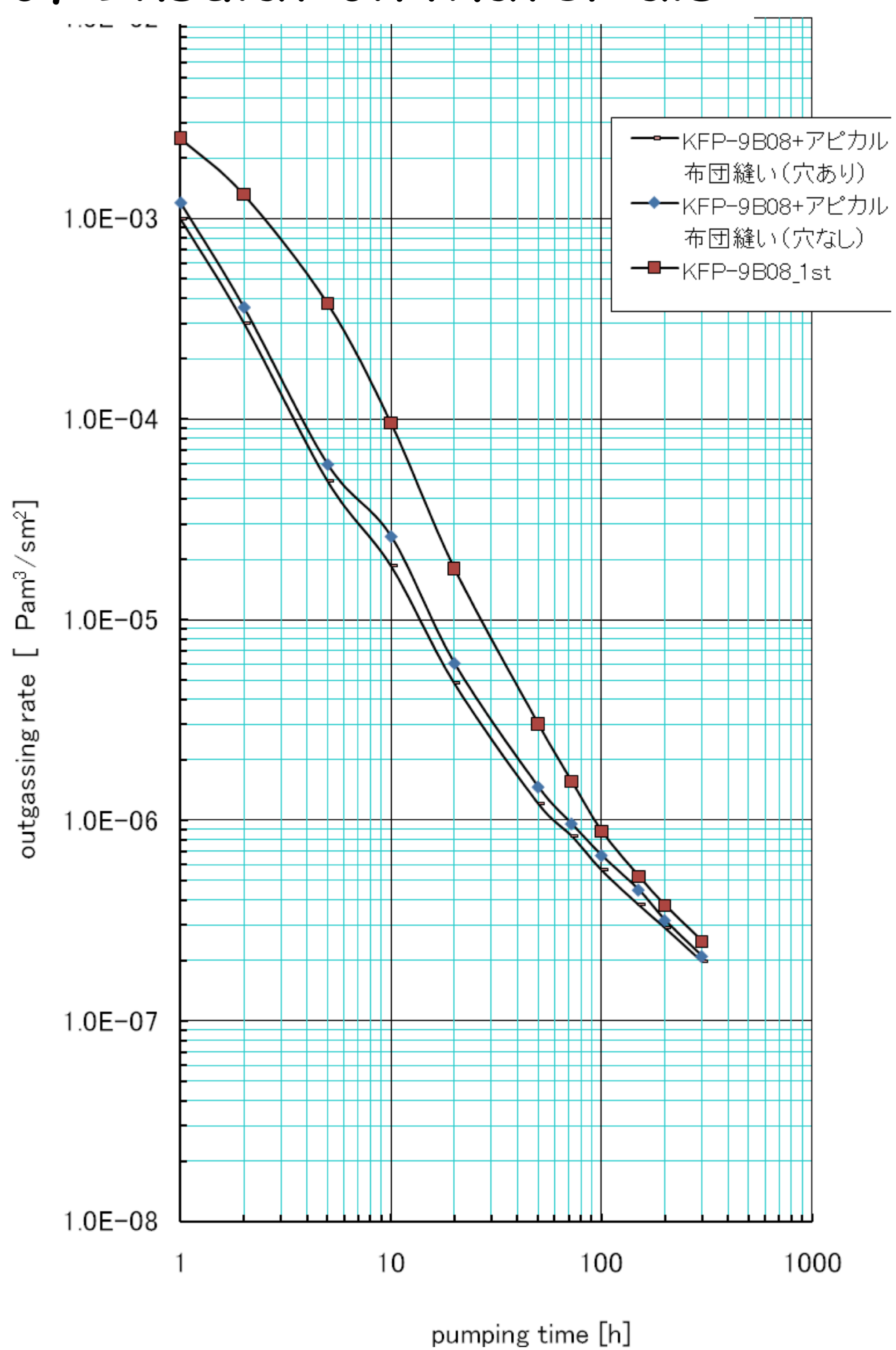


Backup Slide



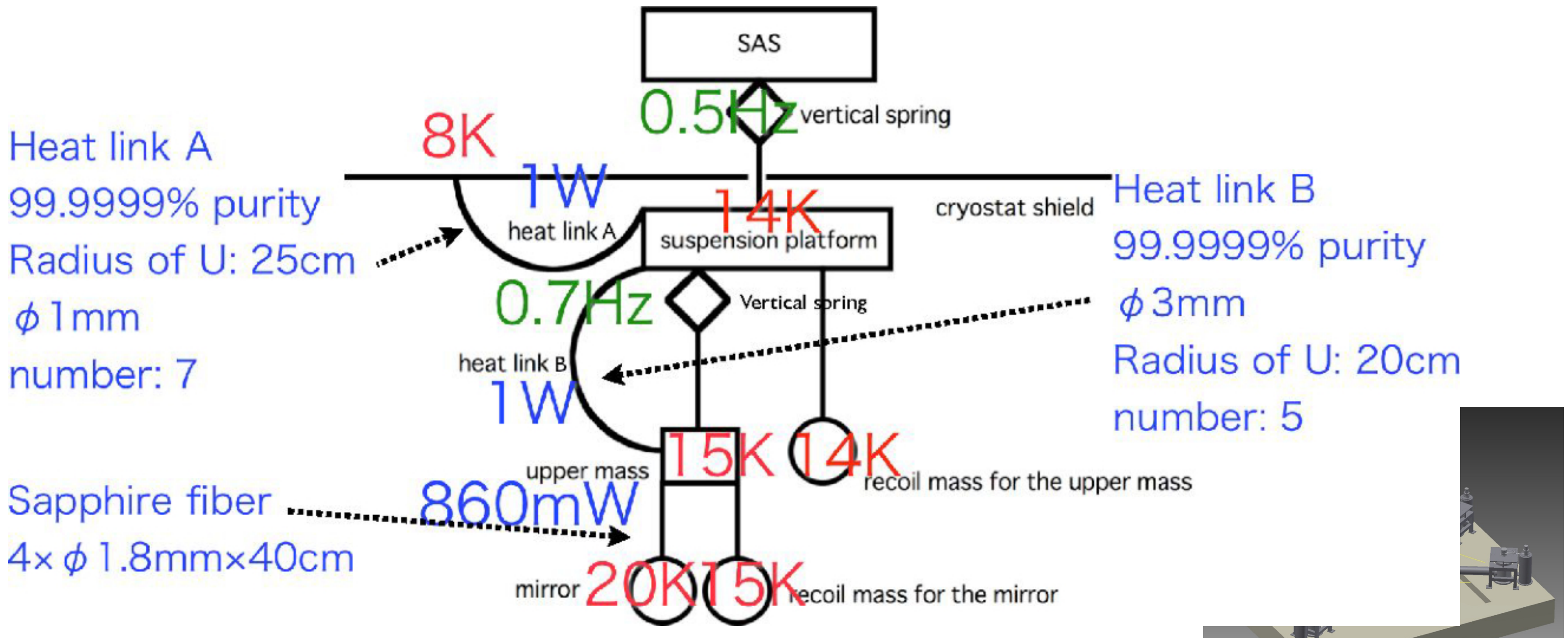
Out Gas Characteristics of Insulation Materials





Thermal Heat Links in the Mirror Cryostat (Subject of Study)

- Pure aluminum (5N8) wire
- U-shape deflection
- Example of temperature distribution and heat current are shown in the figure below. For vibration isolation issue, we must redesign.

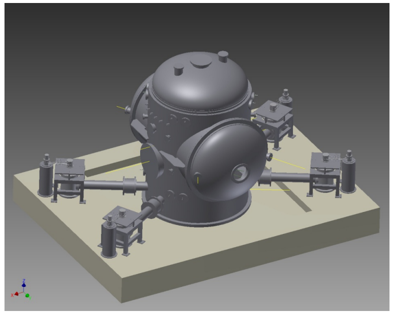


Courtesy bi T. Uchiyama

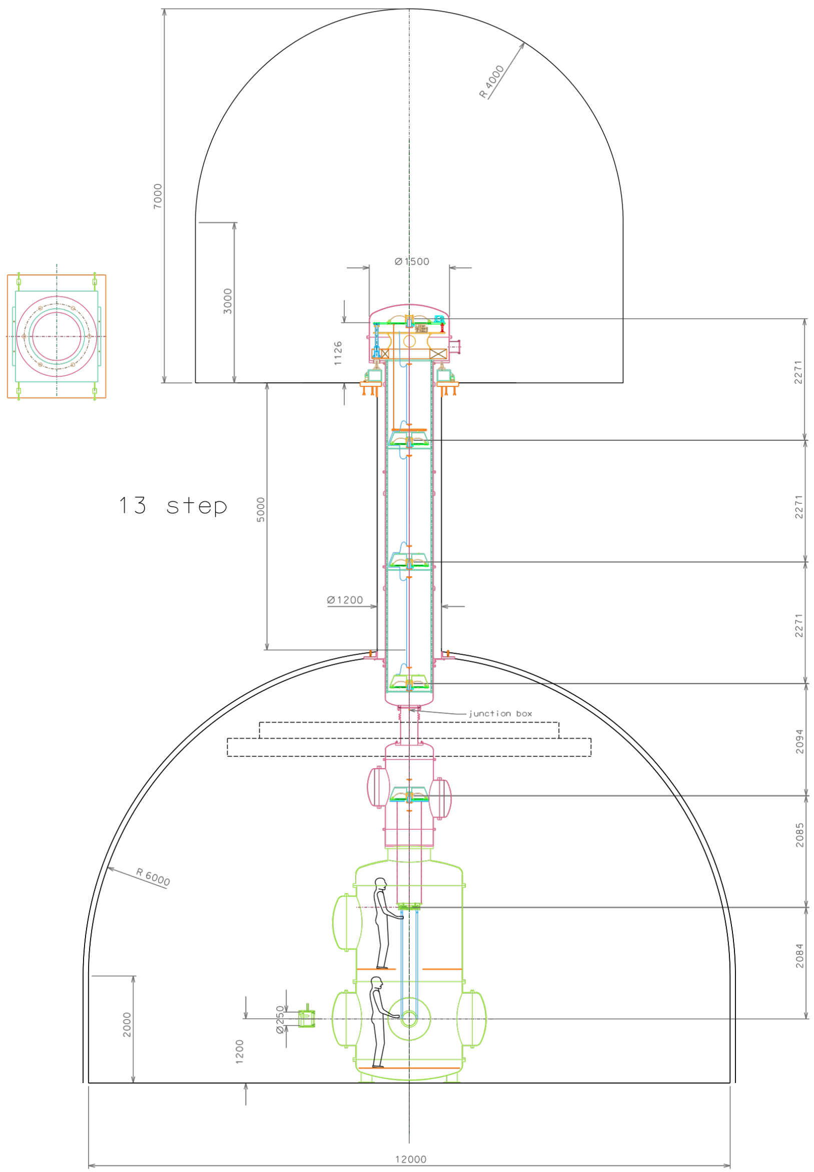
Components

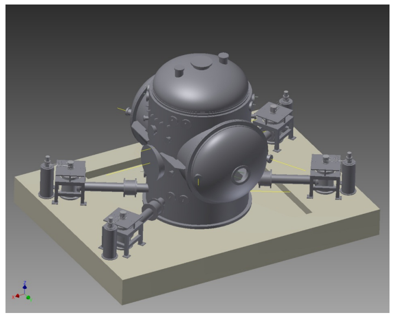
- Cryostat
  - Mirror chamber (Vacuum chamber)
  - Cryo-shield (Radiation shield)
  - Heat links
- Heat conduction path
  - Heat conductor
  - Connection of conductors
- Low vibration cryocooler unit
  - Vibration isolator of cryocooler
    - Pulse-tube cryocooler
    - Remote valve
    - Flexible heat links
    - Rigid frame for supporting stage
  - Sound proof
    - Acoustic shield of compressor room

- Shield duct
  - Cryocooler for cooling shield duct
  - Vibration isolator of cryocooler
  - Baffles to reflect or absorb obstacle radiation
- Thermal insulator
  - Low degassing MLI (or SI)
  - Optimum mounting
- Sapphire mirror suspension
  - Sapphire-sapphire bonding technique
  - Compatibility to mirror polishing and coating process
  - Interface with SAS platform
  - Low mechanical loss at bonded boundary
  - Stability
  - Quality control

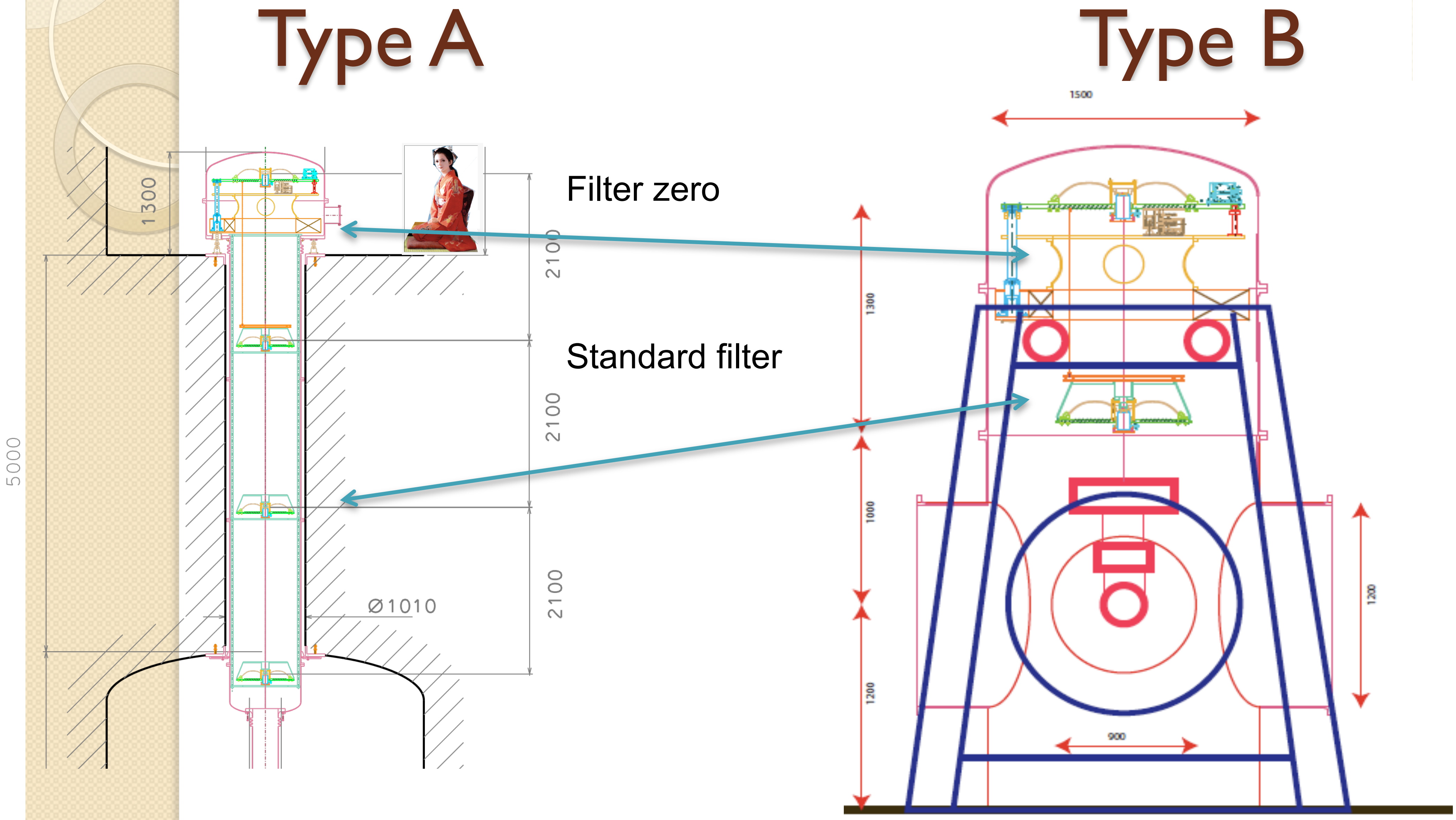


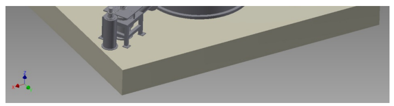
2 Layers Plan for SAS



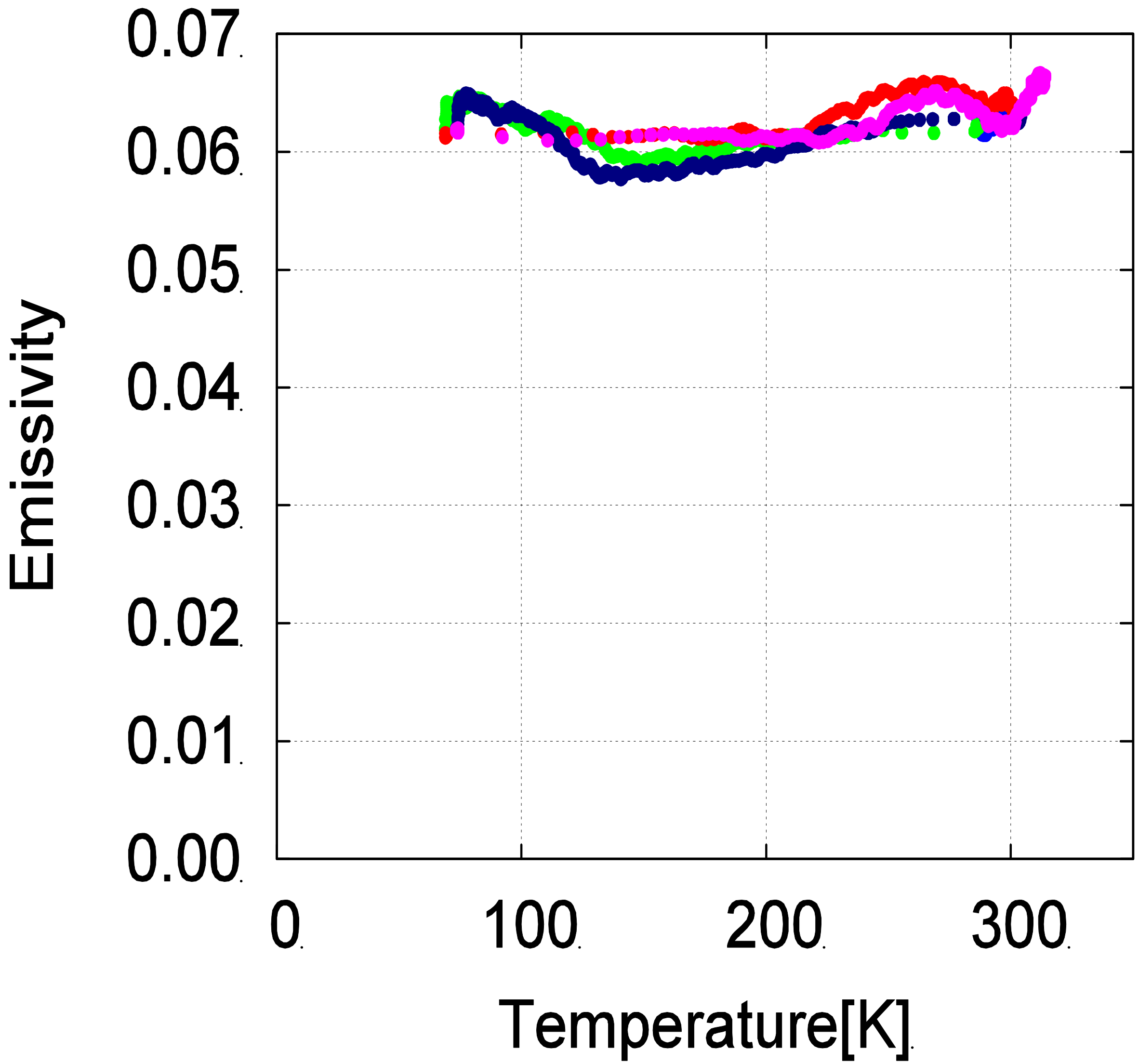


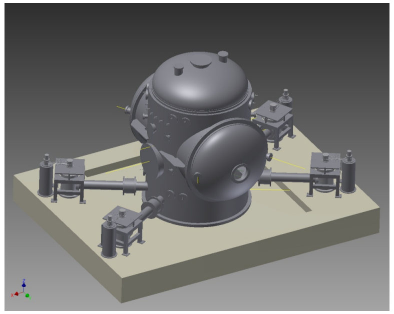
Modular design





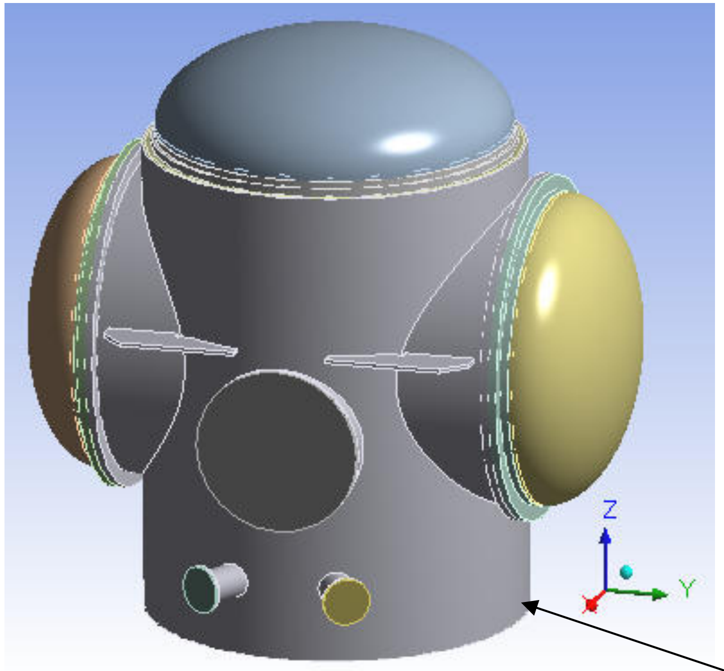
Reflectivity of Aluminum (type A1070) at 10 μm

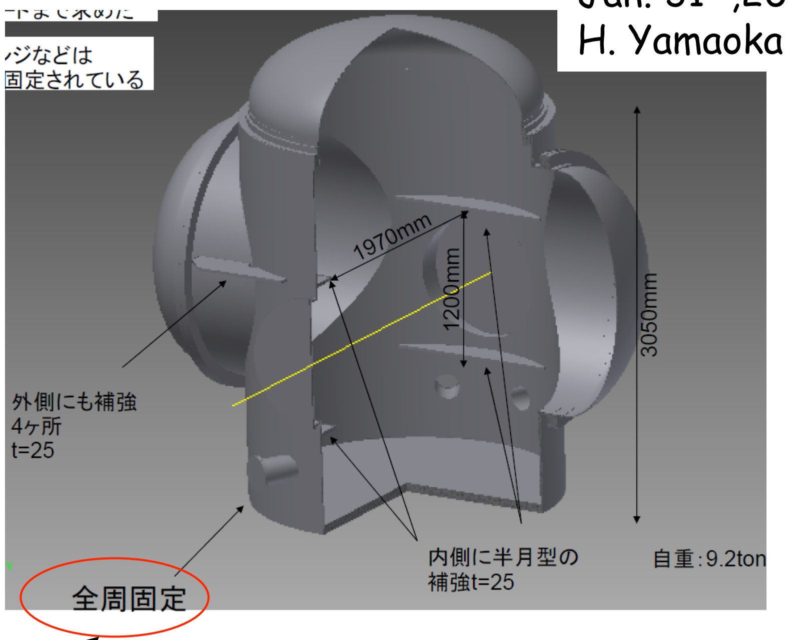




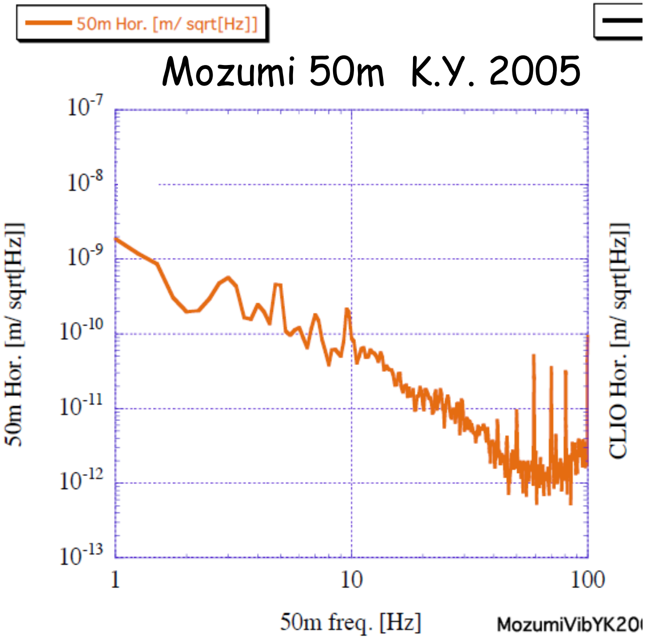
Response to ground motion

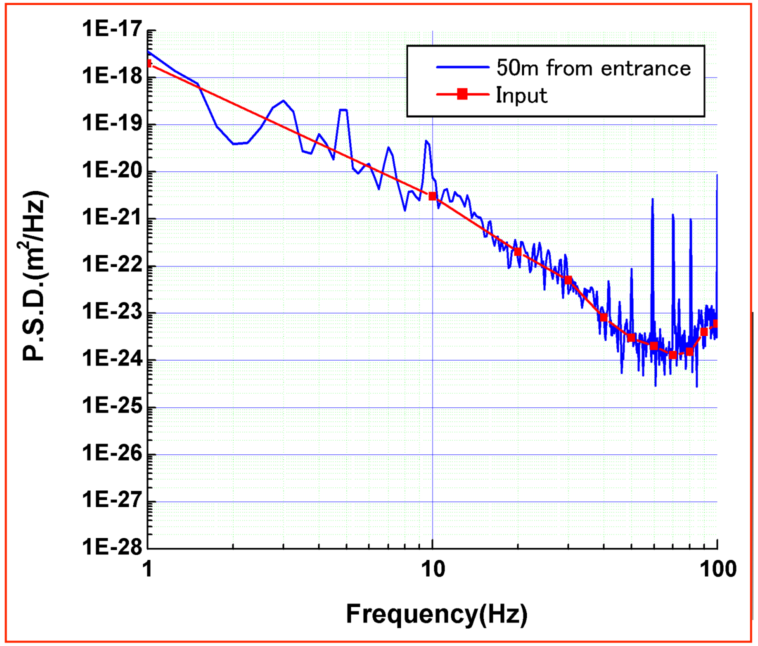
Jan. 31st,2011
H. Yamaoka



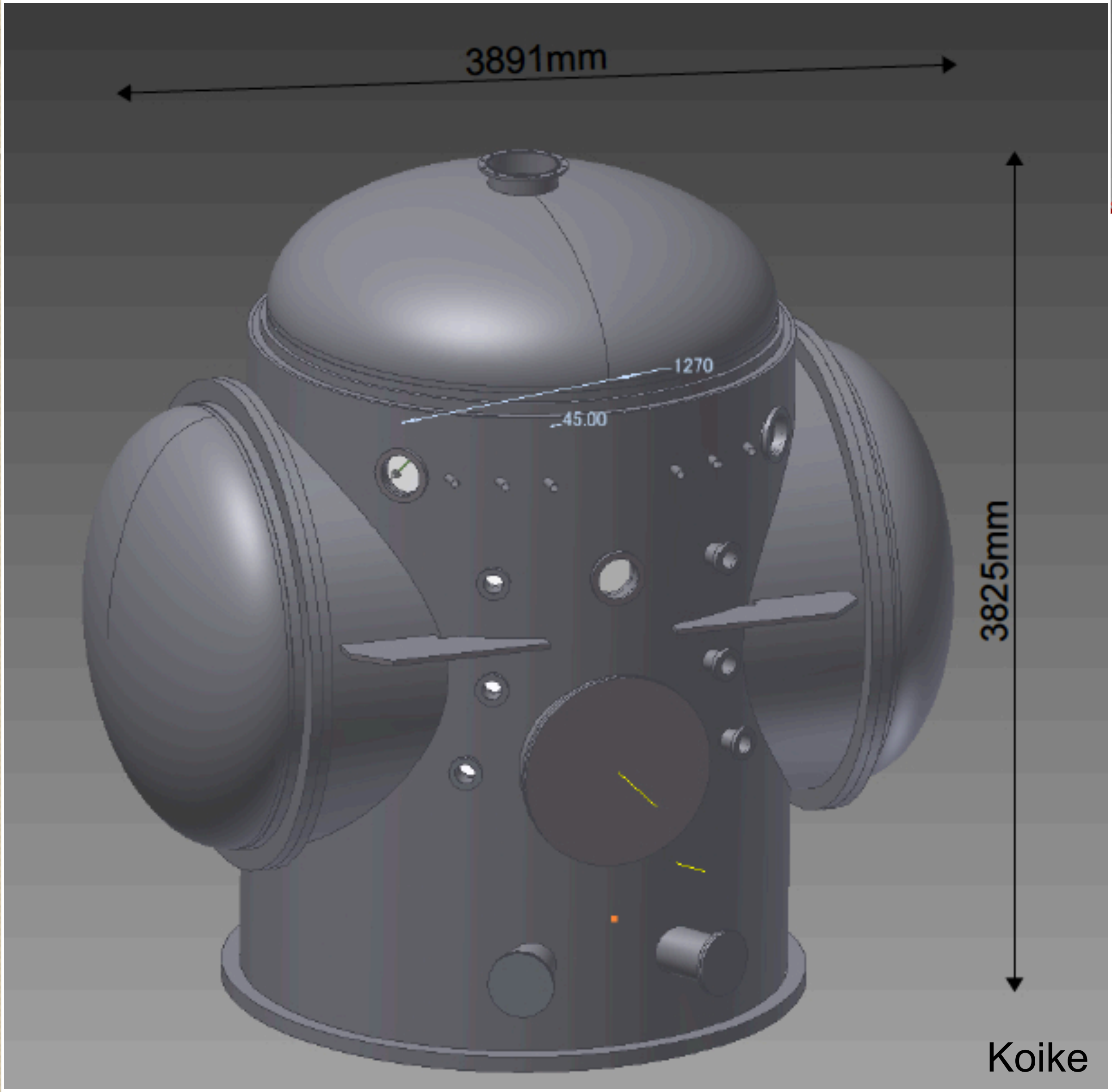


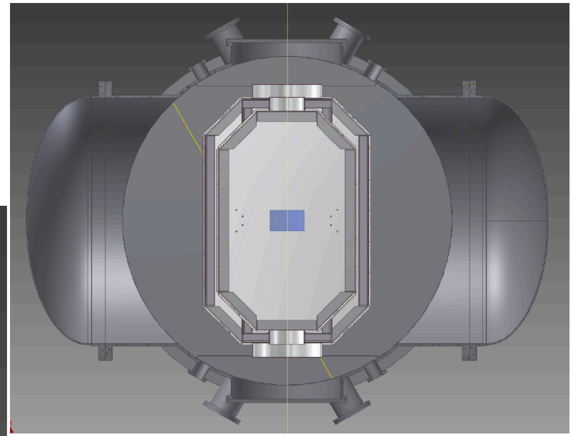
Input to peripheral of bottom

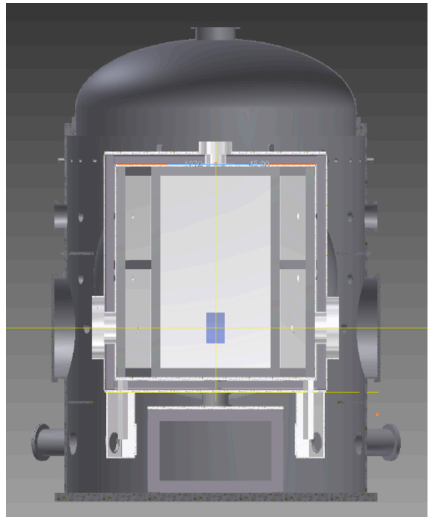


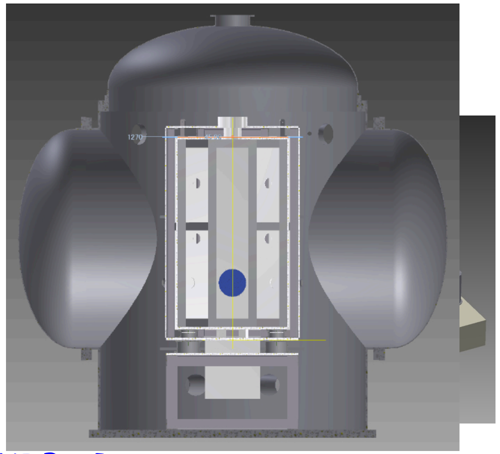


Cryostat Design





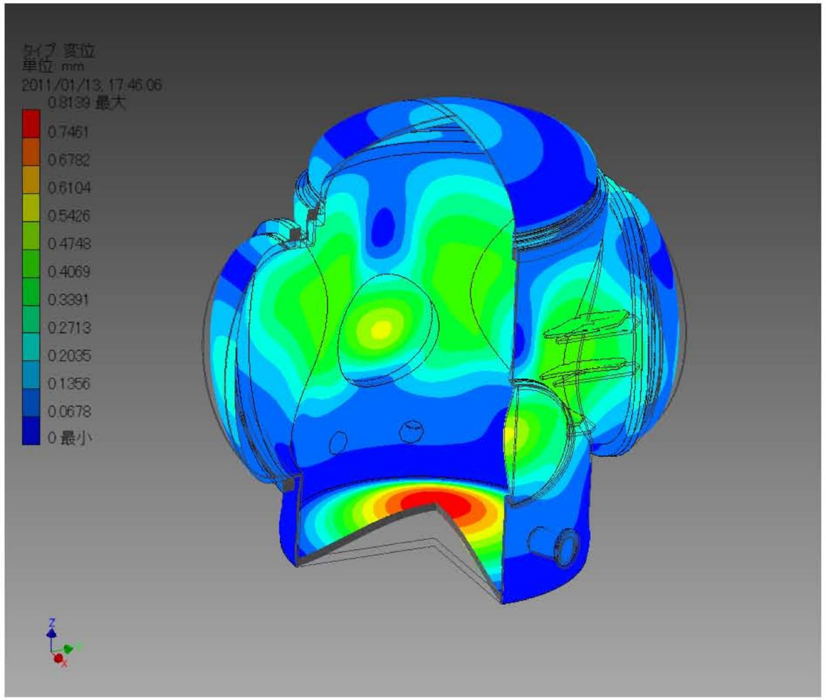




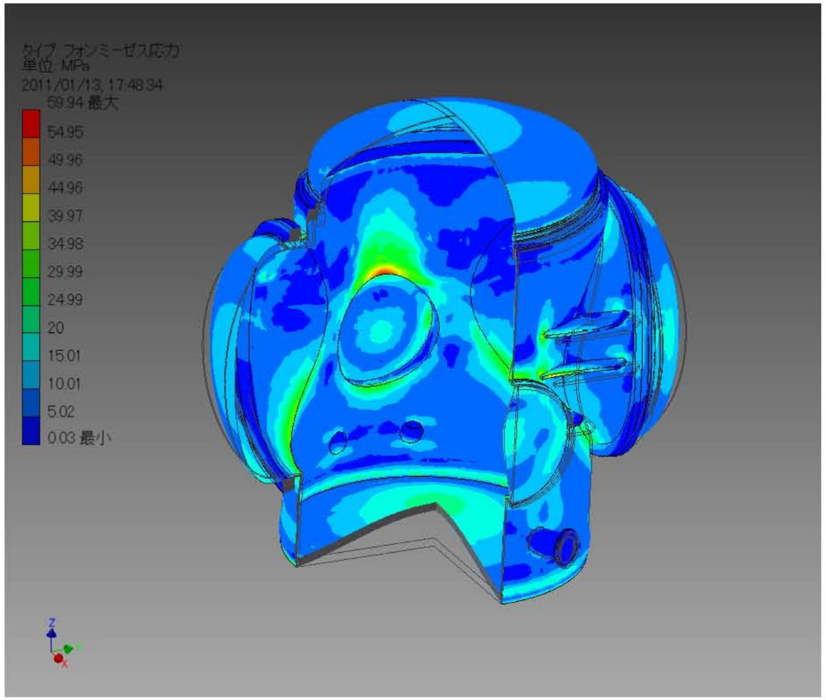
Static deformation analysis

S.Koike

Deformation under the atmospheric pressure and the gravity

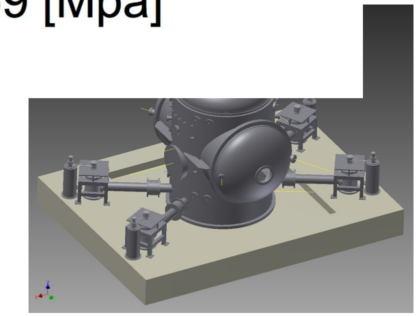


Maximum deformation : 0.8 [mm]



Maximum stress : 59 [Mpa]

- Main vacuum duct and the duct to SAS are not connected.
- Boundary conditions
  - periphery of the bottom : fix



Modal analysis

Boundary condition: fix the perimeter of the bottom

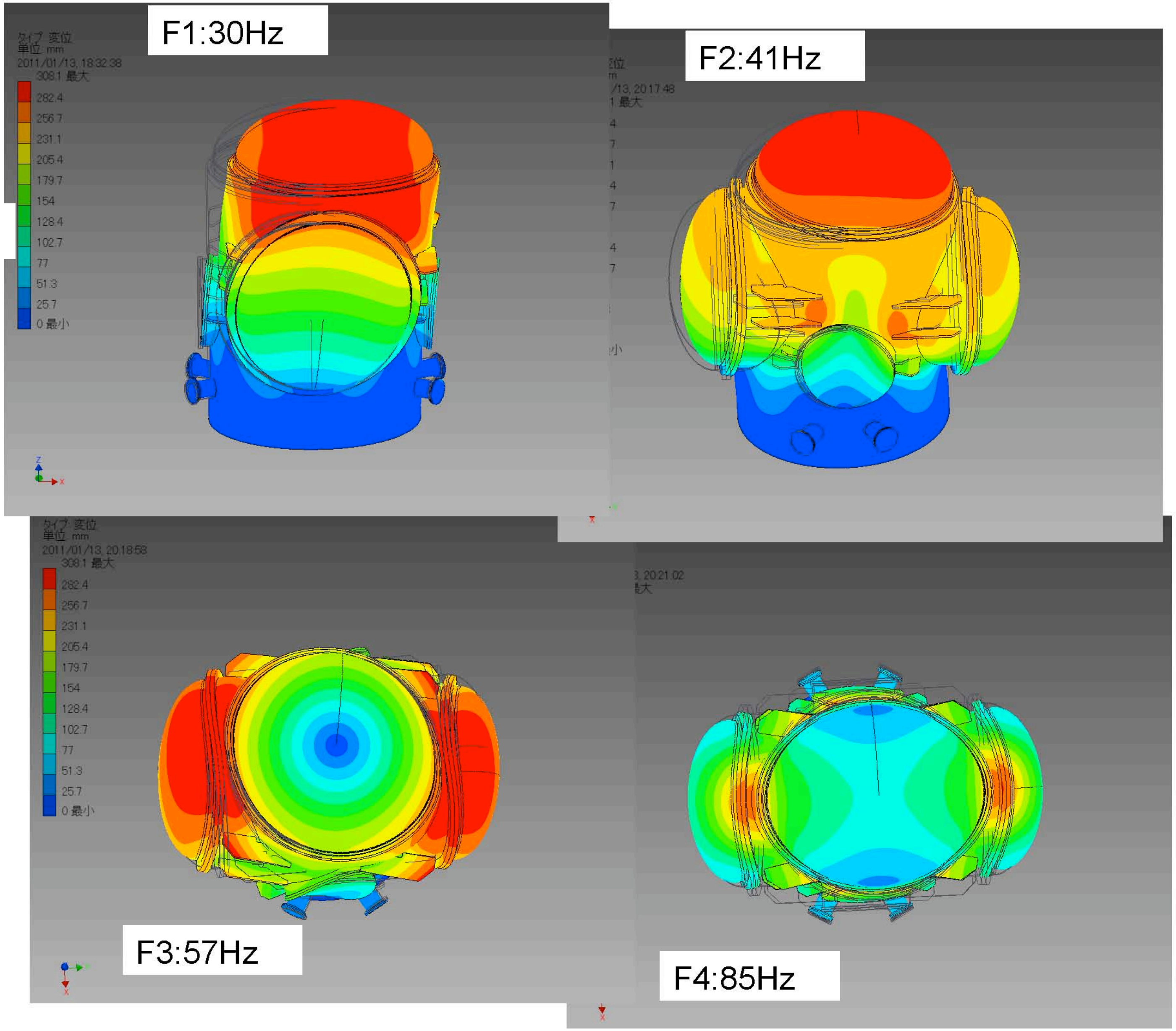
* Interface to SAS is not fixed at the moment.

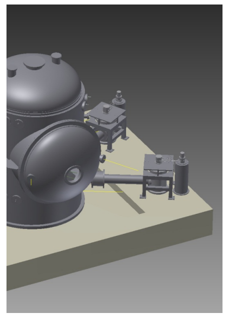
S.Koike

Frequency

周波数の値

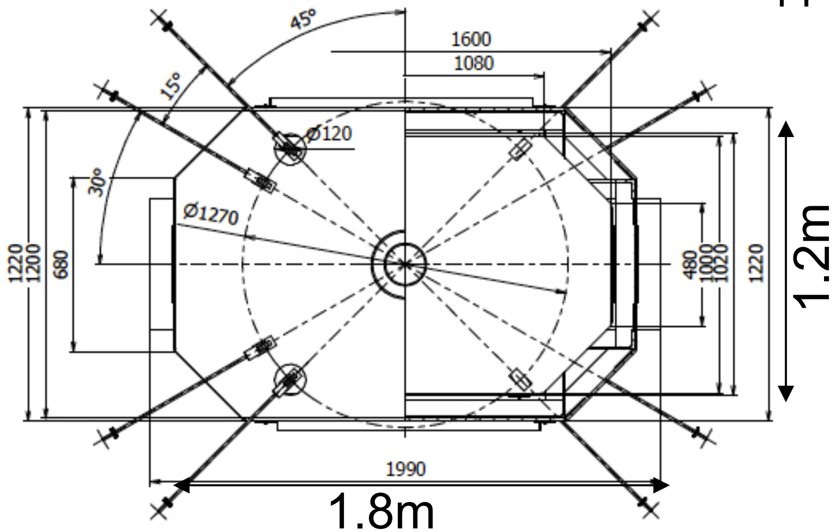
F1 29.86 Hz
F2 41.27 Hz
F3 57.22 Hz
F4 85.01 Hz
F5 89.68 Hz
F6 93.33 Hz
F7 111.81 Hz
F8 120.70 Hz

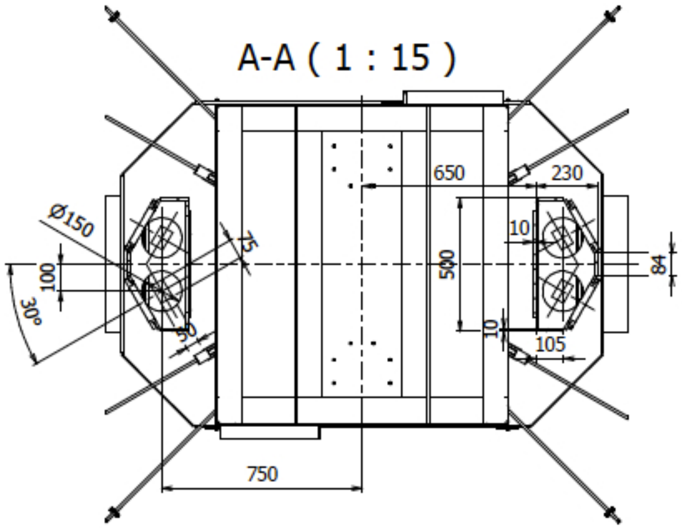


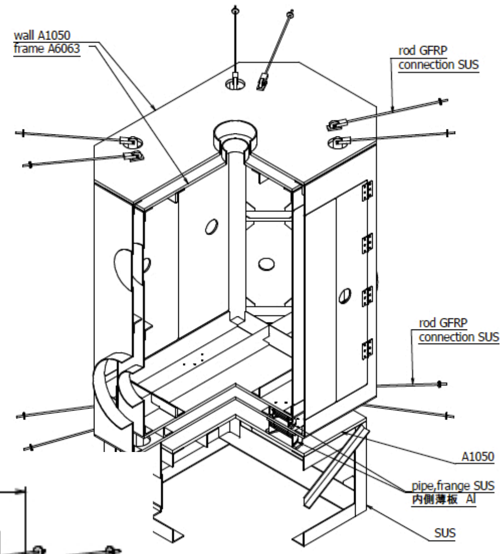


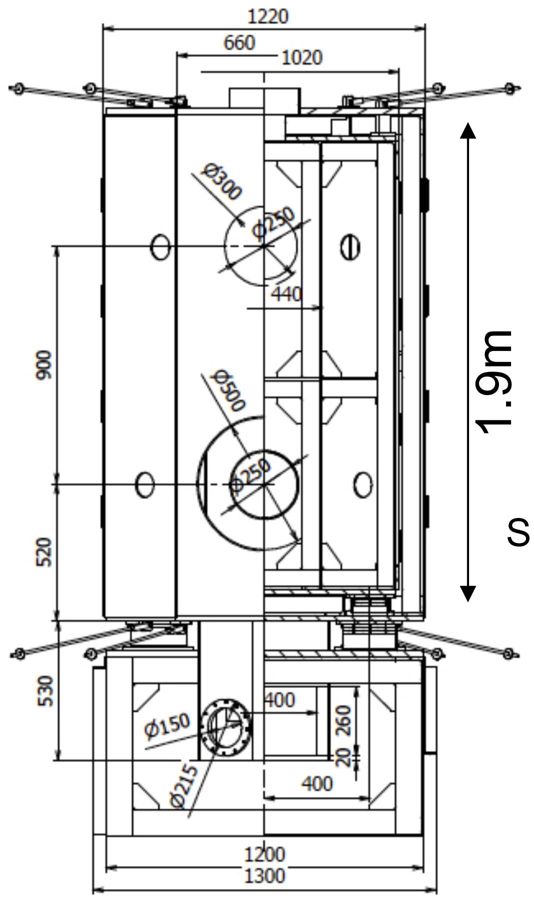
Cryostat shield

Frames: aluminum alloy
Walls: pure aluminum
Supports: FRP, Stainless steel

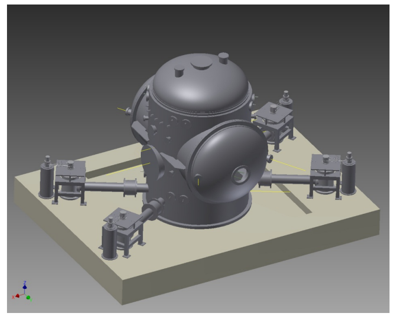








S.Koike



May/2011 N. KIMURA and Y. SAKAKIBARA

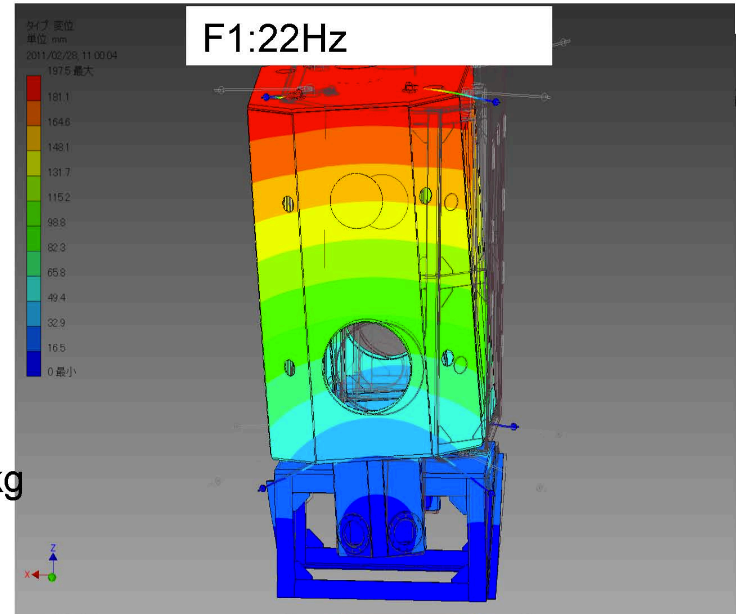
Modal analysis of outer shield

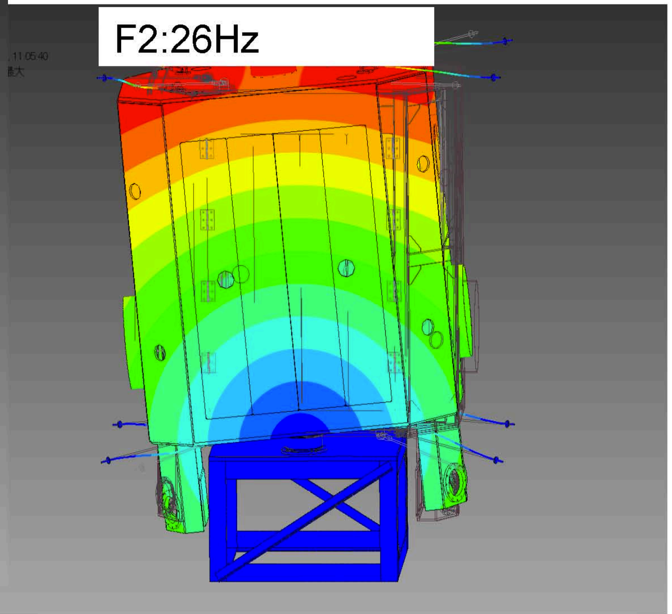
S.Koike

Mode frequency

- F1 22.31 Hz
- F2 25.98 Hz
- F3 39.47 Hz
- F4 41.79 Hz
- F5 46.22 Hz
- F6 57.38 Hz
- F7 59.04 Hz
- F8 76.29 Hz

M= 893.429 kg

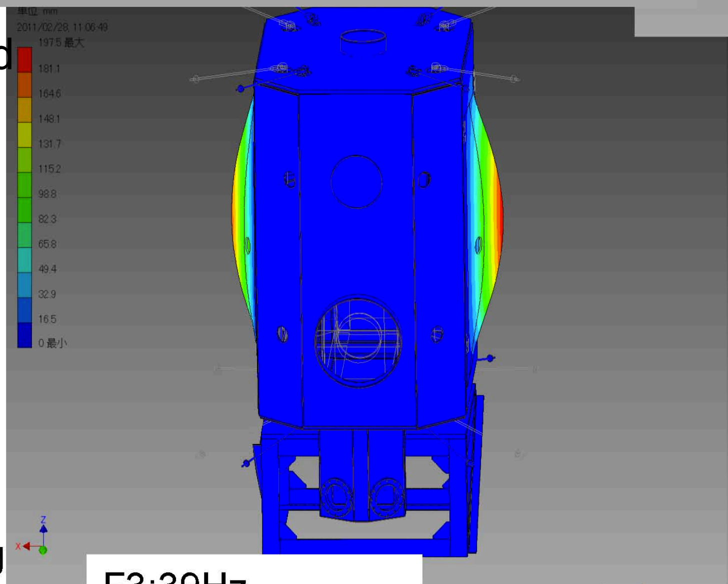

F1:22Hz

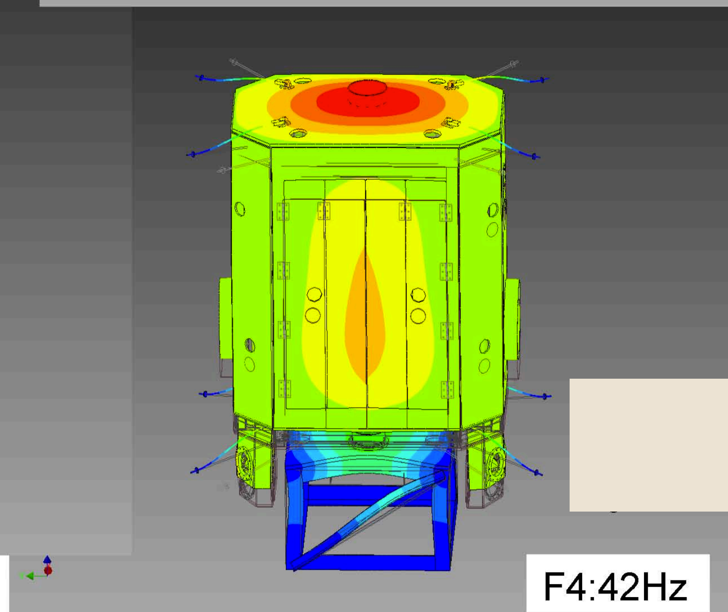

F2:26Hz

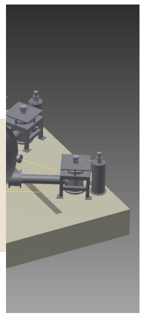
Remove support rod
Mode Frequency

- F1 7.86 Hz
- F2 16.80 Hz
- F3 39.18 Hz
- F4 41.78 Hz
- F5 43.01 Hz
- F6 44.96 Hz
- F7 57.11 Hz
- F8 58.41 Hz

M= 889.352 kg


F3:39Hz


F4:42Hz



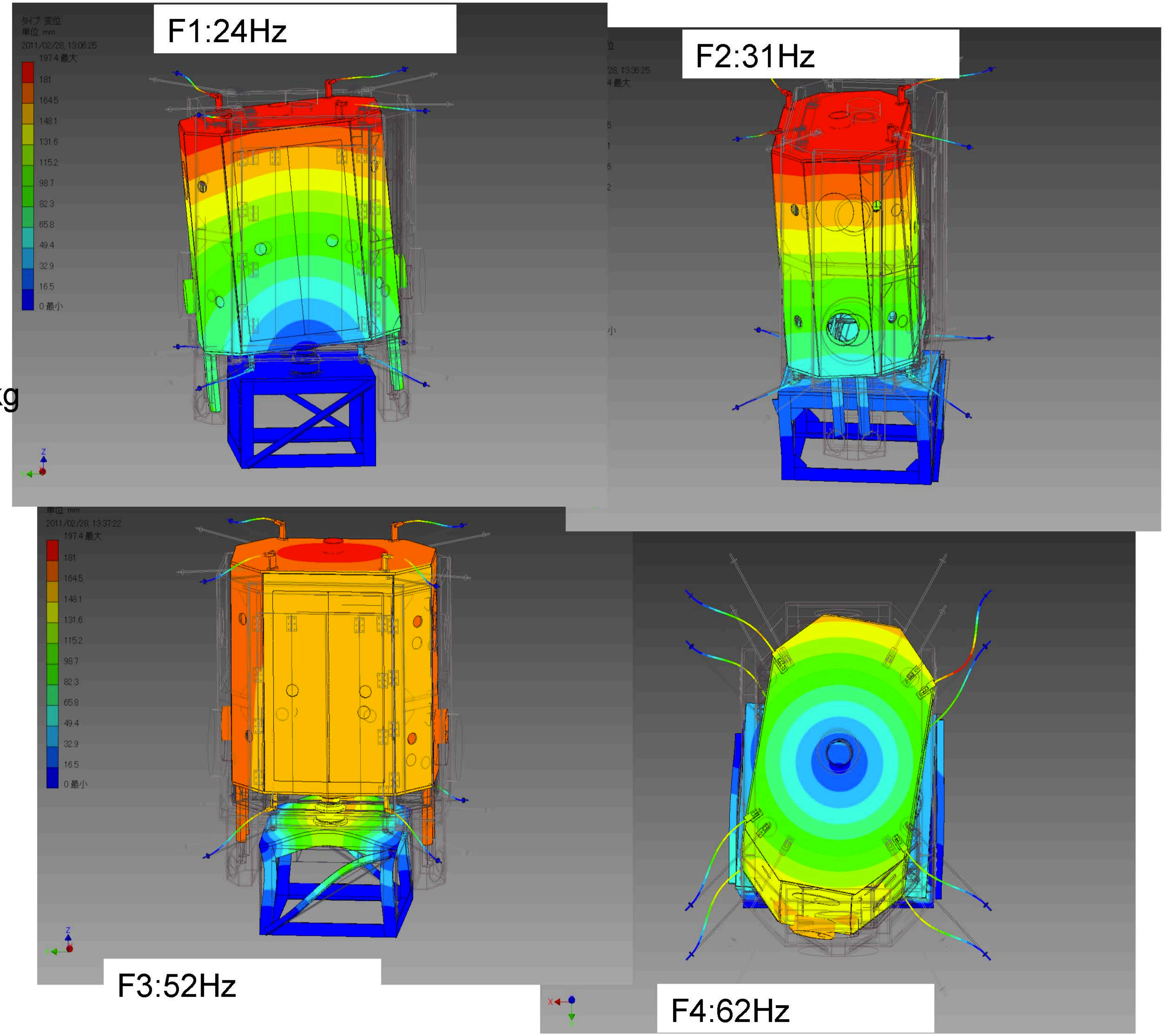
Modal analysis of inner shield

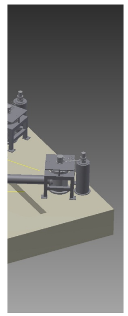
S.Koike

Frequency

F1 24.31 Hz
F2 30.66 Hz
F3 51.77 Hz
F4 62.12 Hz
F5 68.78 Hz
F6 80.94 Hz
F7 80.97 Hz
F8 81.39 Hz

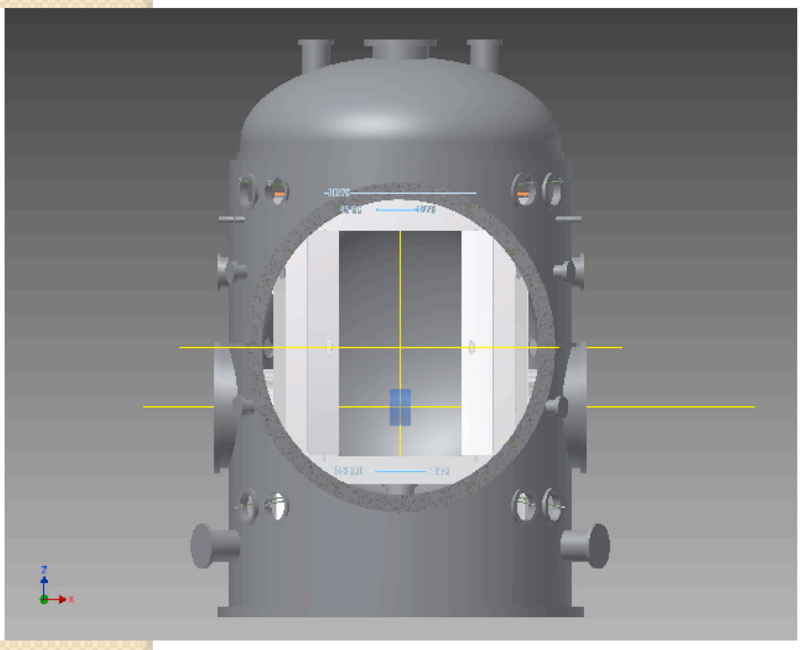
M= 775.855 kg

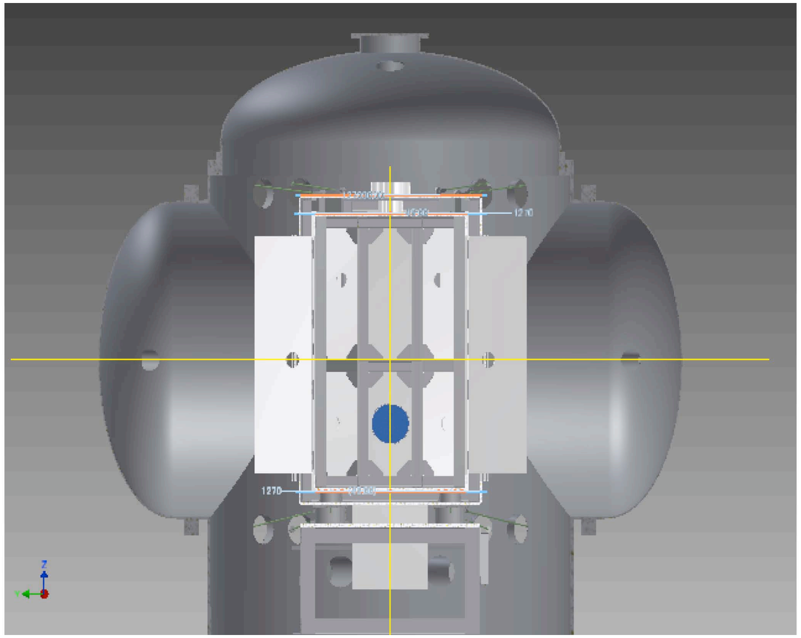


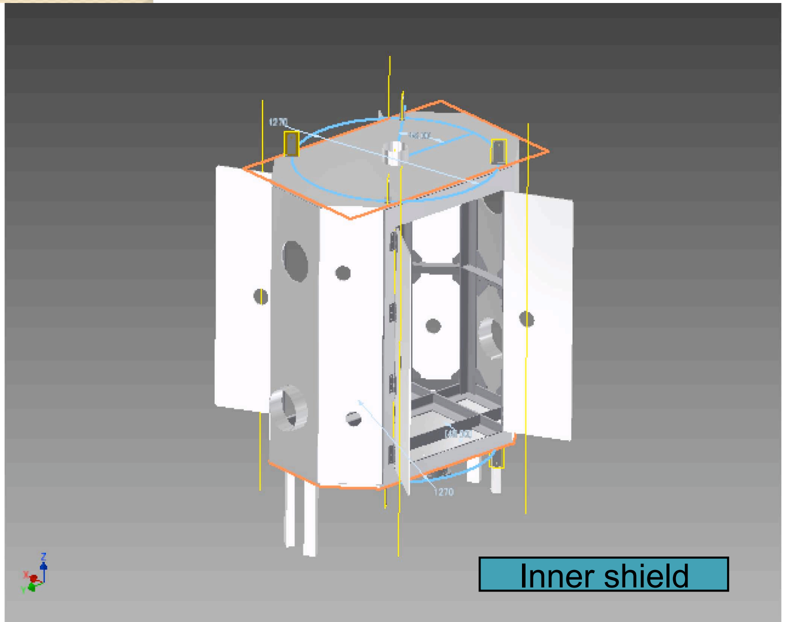


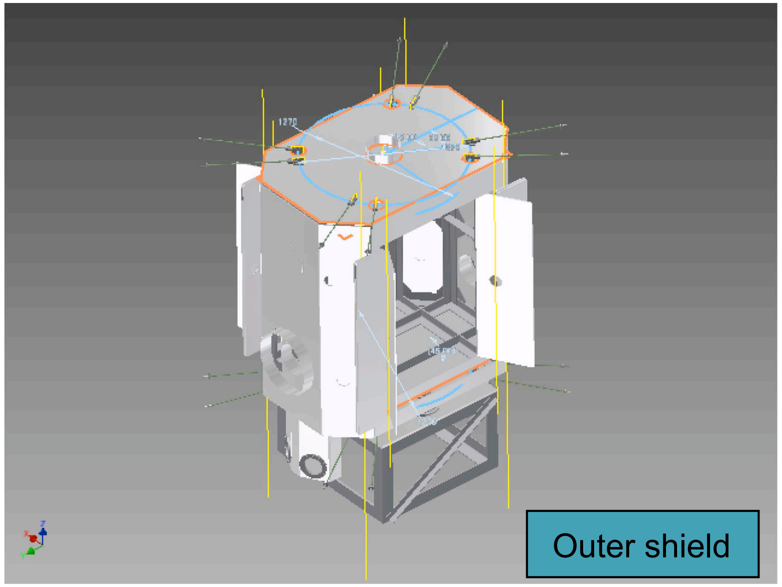
Doors for access to inside

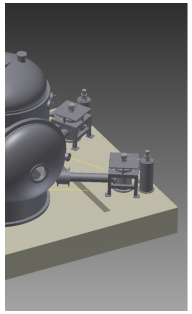
S. Koike





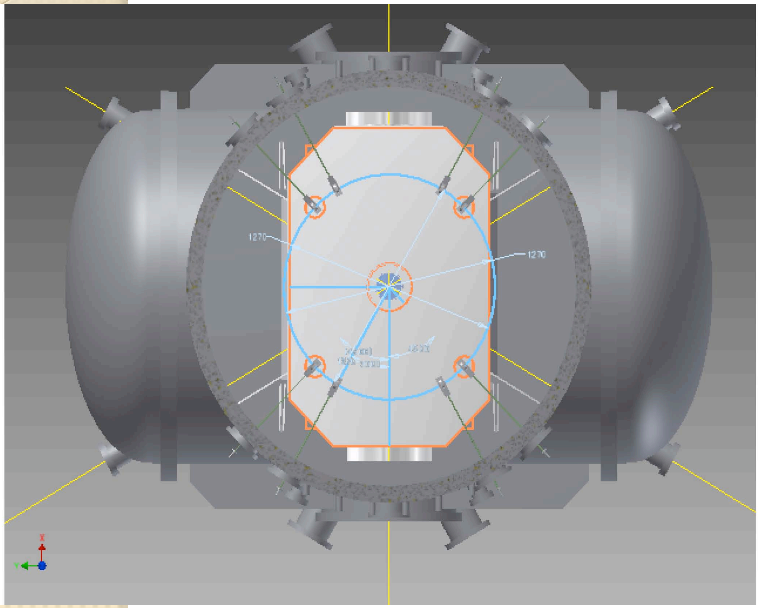


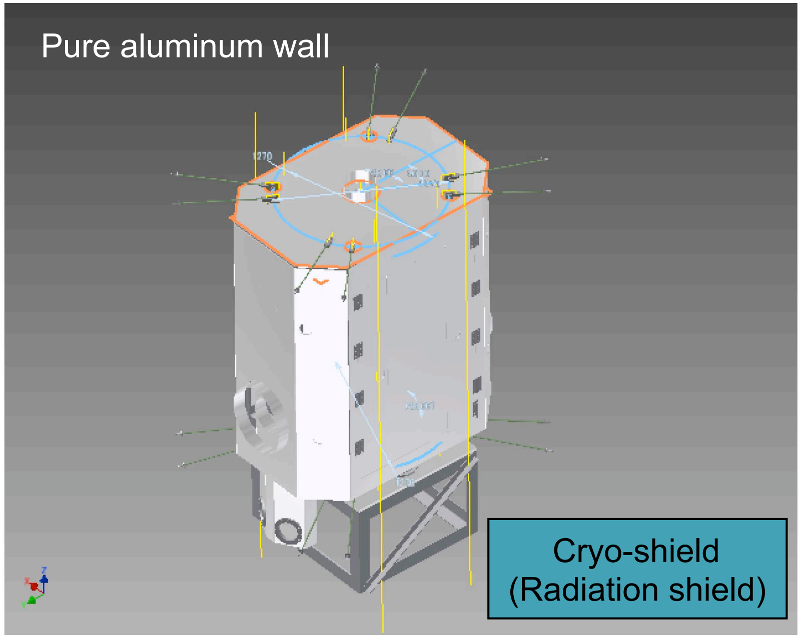


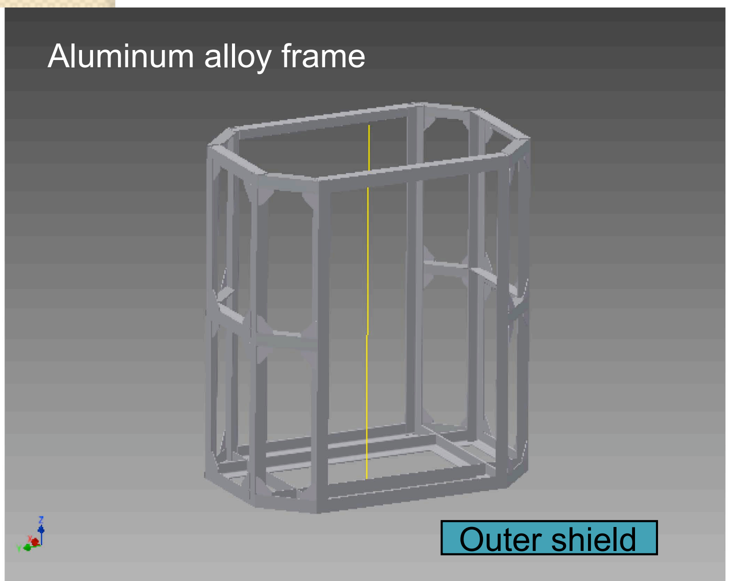


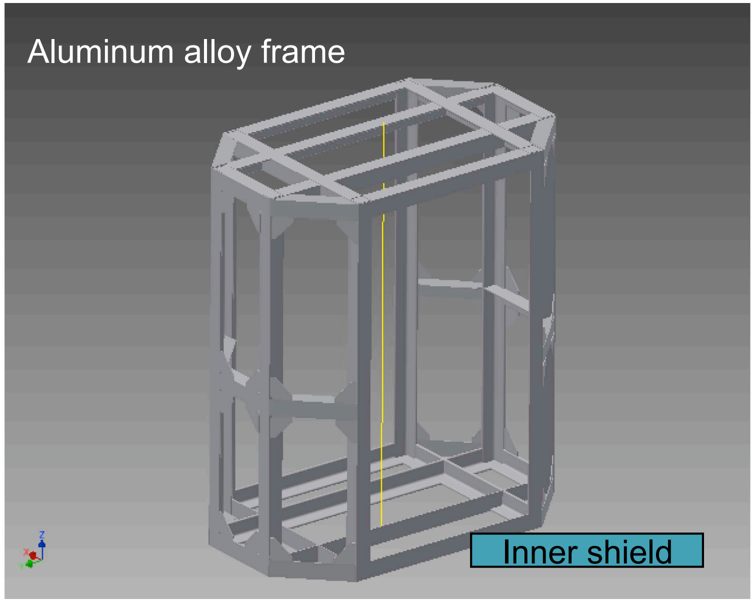
Support rods and frames of shields

S. Koike









Shields