The cooling scenario for O4 without frosting on the surface of the KAGRA Test Mass and ….

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Outline

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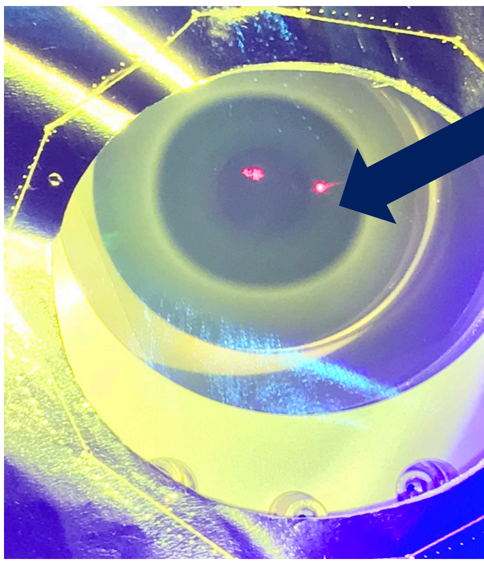
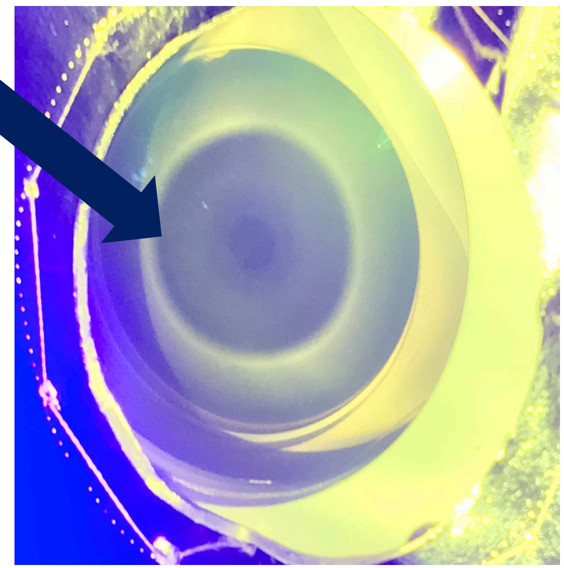
An example of frosting on the surface of view port

- Frosting on the surface of the test mass and the viewports of the radiation shields is a serious problem at the KAGRA.
- In order to find a way to cool the test mass down to ~20 K while preventing frosting, KAGRA cryogenic subgroup have conducted the cooling experiment using the KAGRA cryostat.

Frosting



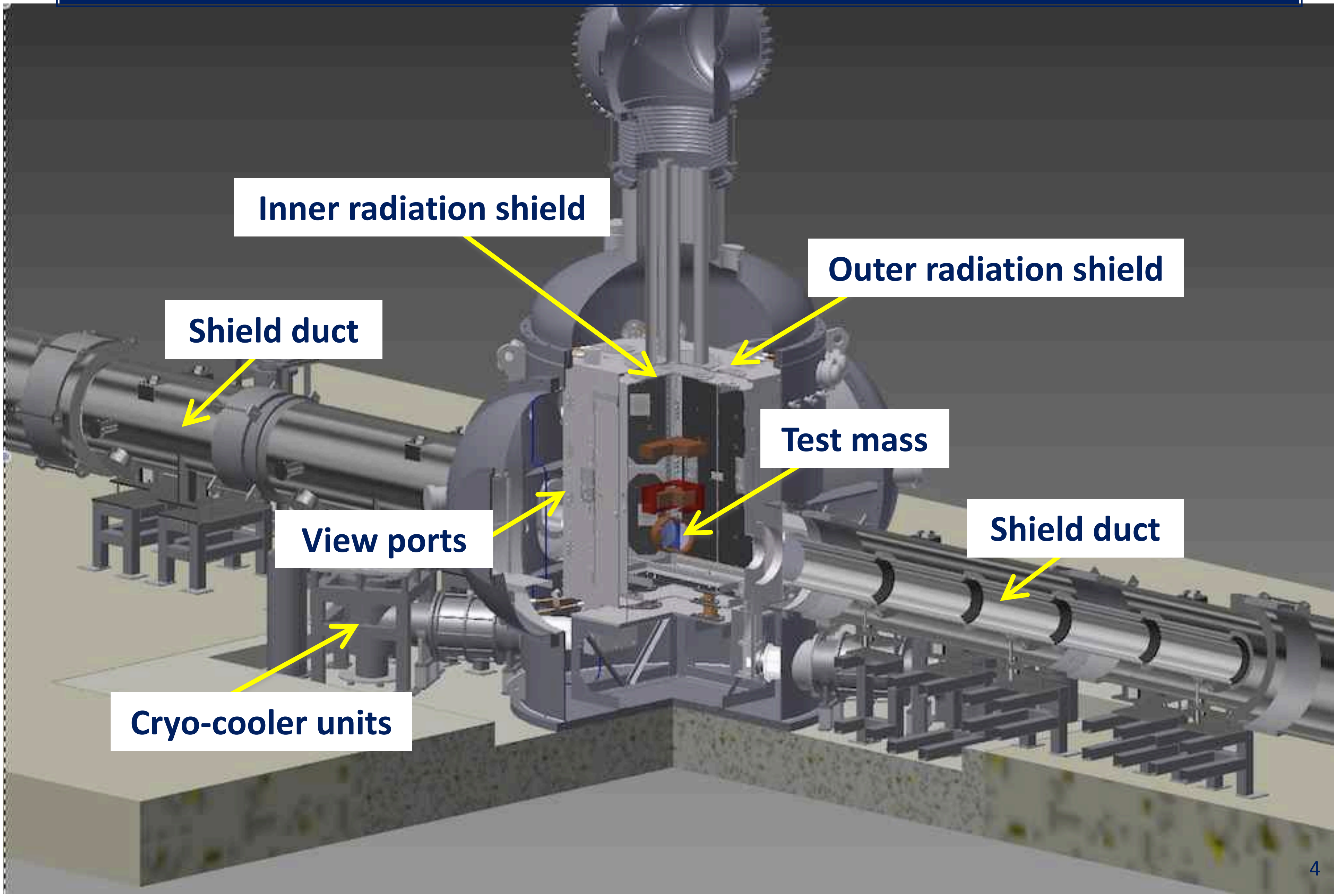
TM oplev light source side



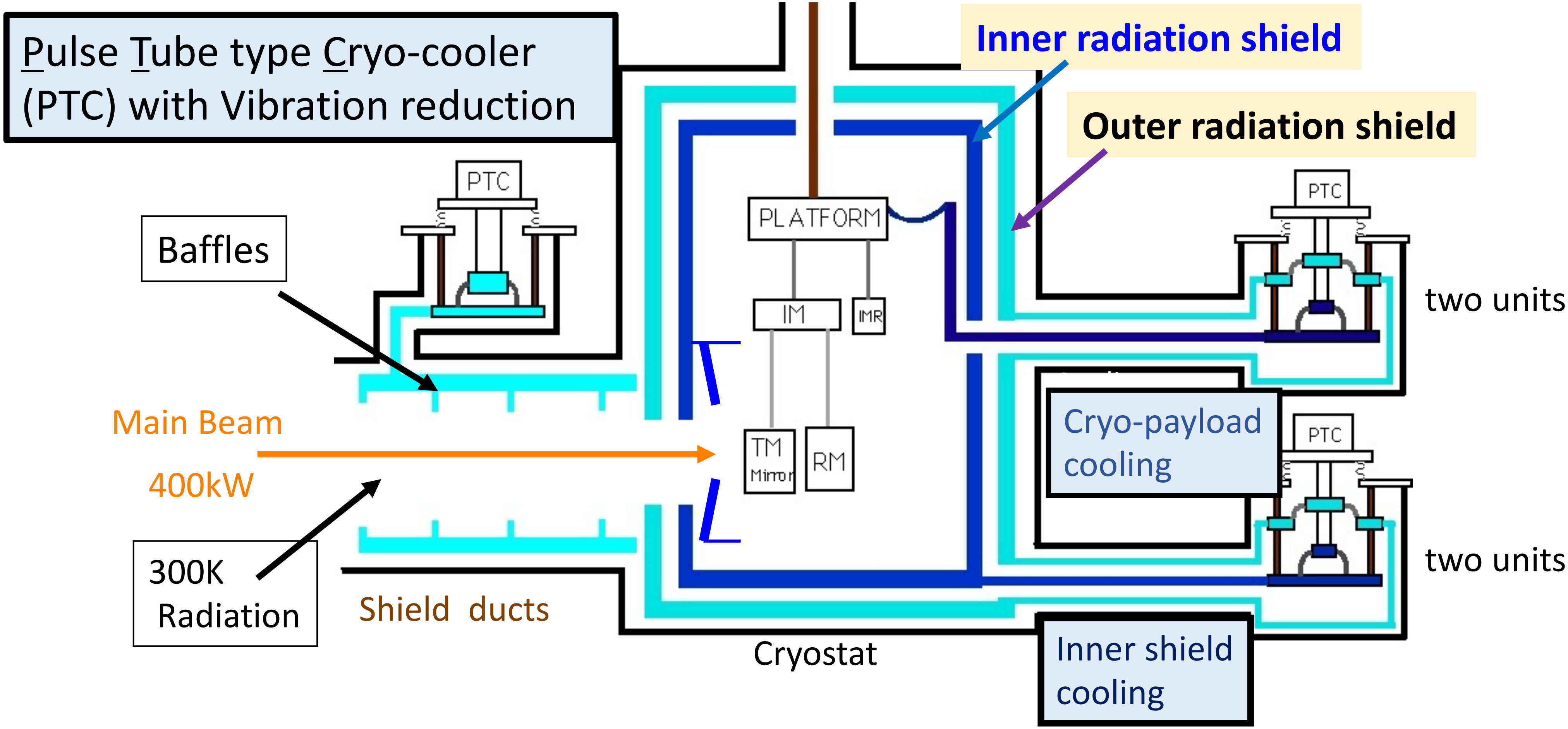
TM oplev QPD side

Photos show examples of the frosting on the surface of view ports with vacuum leak at TM temperature of ~25K. (@EXC 2020/08)
It was assumed that frog on the surface was formed by frosting of O_2, N_2 and H_2O.

Structural view of KAGRA Cryostat with shield ducts



Cryo-cooler layout



- Four 4K cryocooler units per one cryostat

→ 2 units for cool cryo-payload
2 units cool for the inner shield
4 units cool for the outer shield

Issues in de-frosting experiment using KAGRA cryostat

1. Determine the cooling scheme for Test Mass without frosting

    Including confirmation of the occurrence of frosting on the view ports under the condition of leak rate <10^-10Pam^-3/s)

2. Defrosting experiment by defrost heaters

    Confirmation of defrost heater performances
    (If no frost adheres, check the temperature profile of defrost heating.)

3. Measurement of partial pressure of residual gas to confirm frosting components

Proposed Test mass cooling scenario for O4
- Task: How maintain mirror temperature lower than 100 K without frosting on the surface of the mirror -

Cooling steps at this experiment;

Step 1:

Start vacuum pumps and wait inner pressure shall be lower than ~10^-4 Pa.

It will take **21 days** including vacuum leak test for 3 days.

Step 2:

To trap H_2O residual gas on the surface of duct shield, Start duct shield cryocoolers and wait surface temperature of duct shield shall be lower than lower than ~150 K.

It will take **11 days**.

Step 3:

To trap nitrogen gas on the surface of inner shield, start two shield cryocooler units.

The mirror is cooled by only radiation to the inner shield.

Wait surface temperature of inner shield shall be lower than lower than ~20 K.

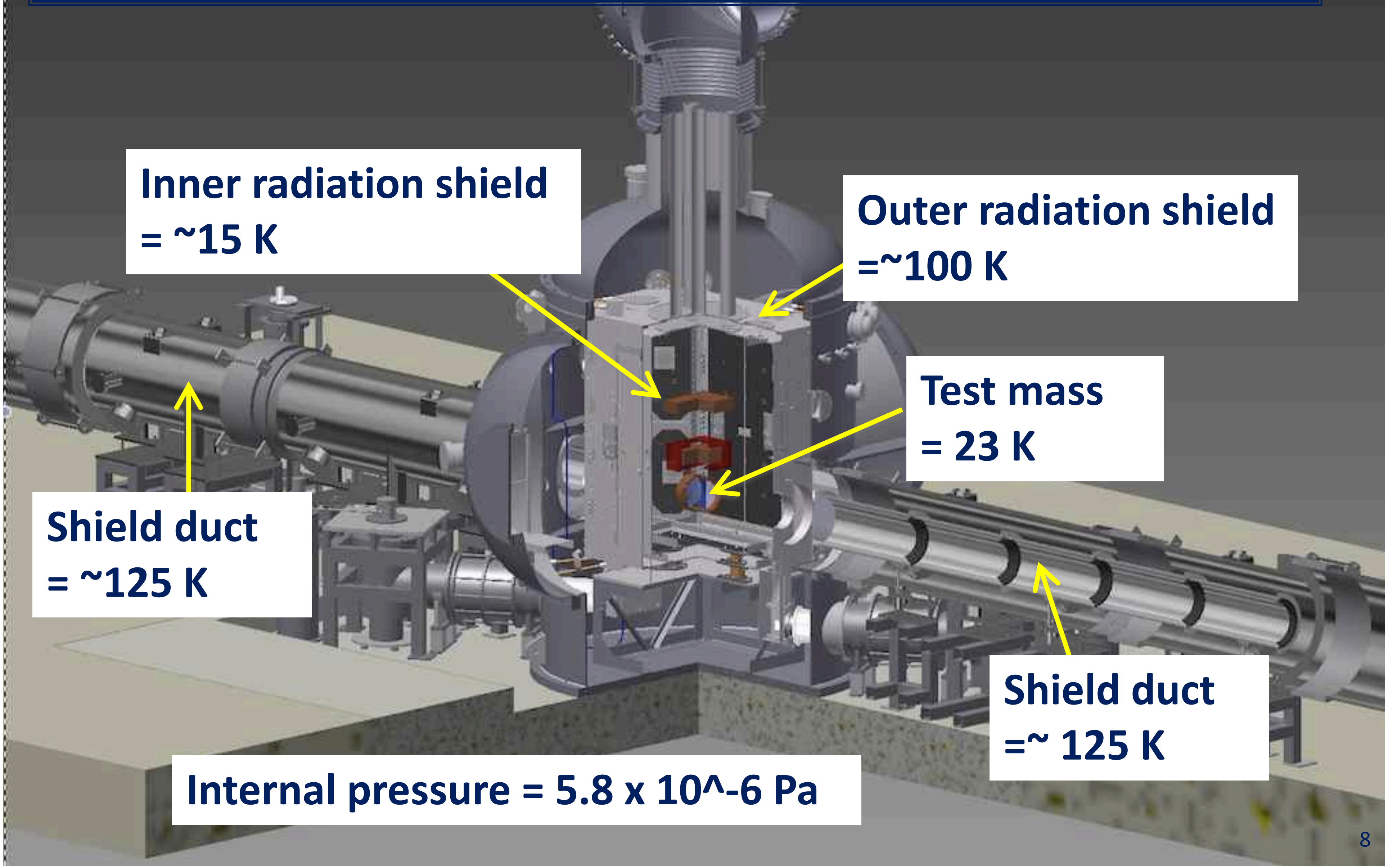
It will take **24 days** after switched on the coolers.

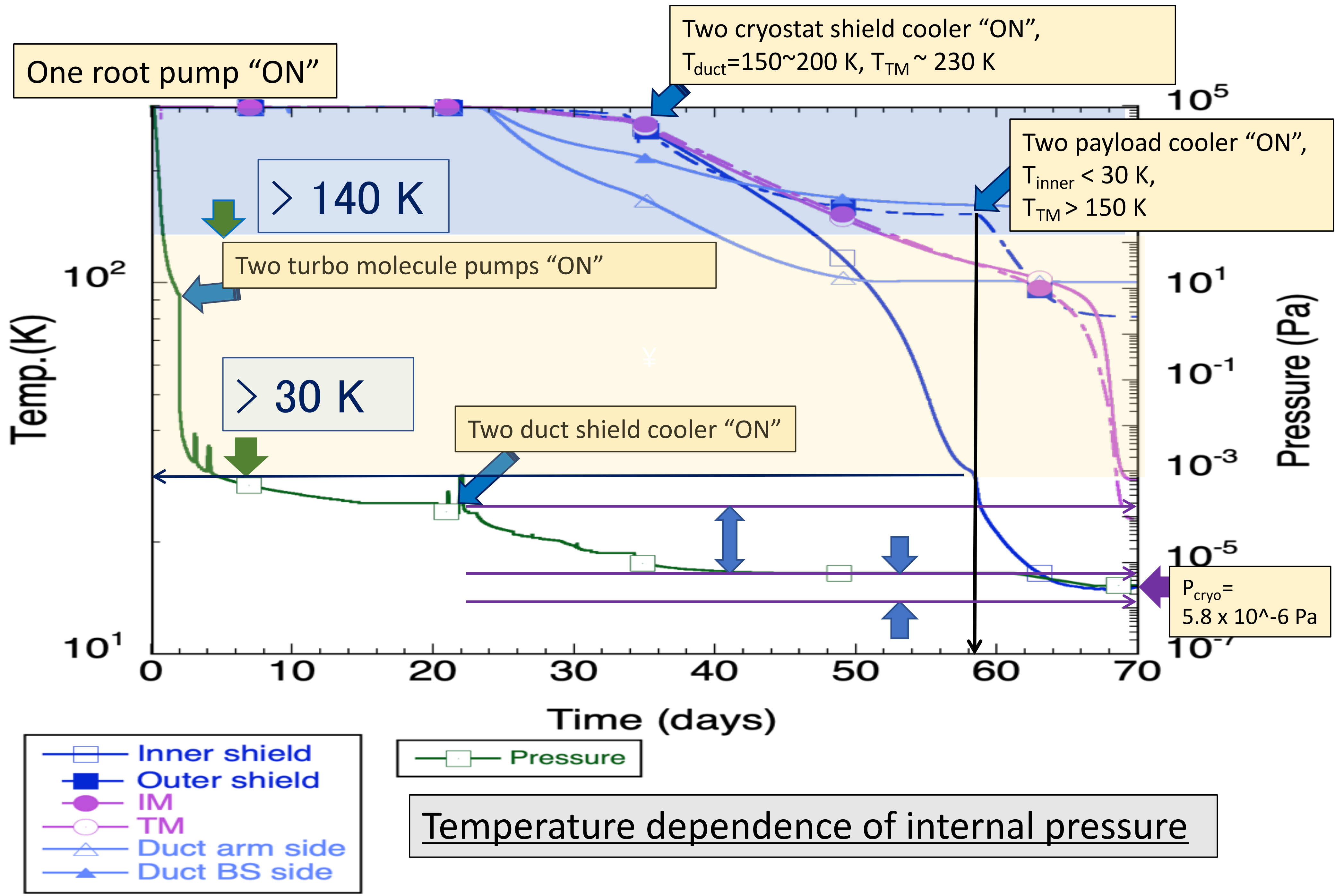
Step 4:

Switched on payload cryo-coolers.

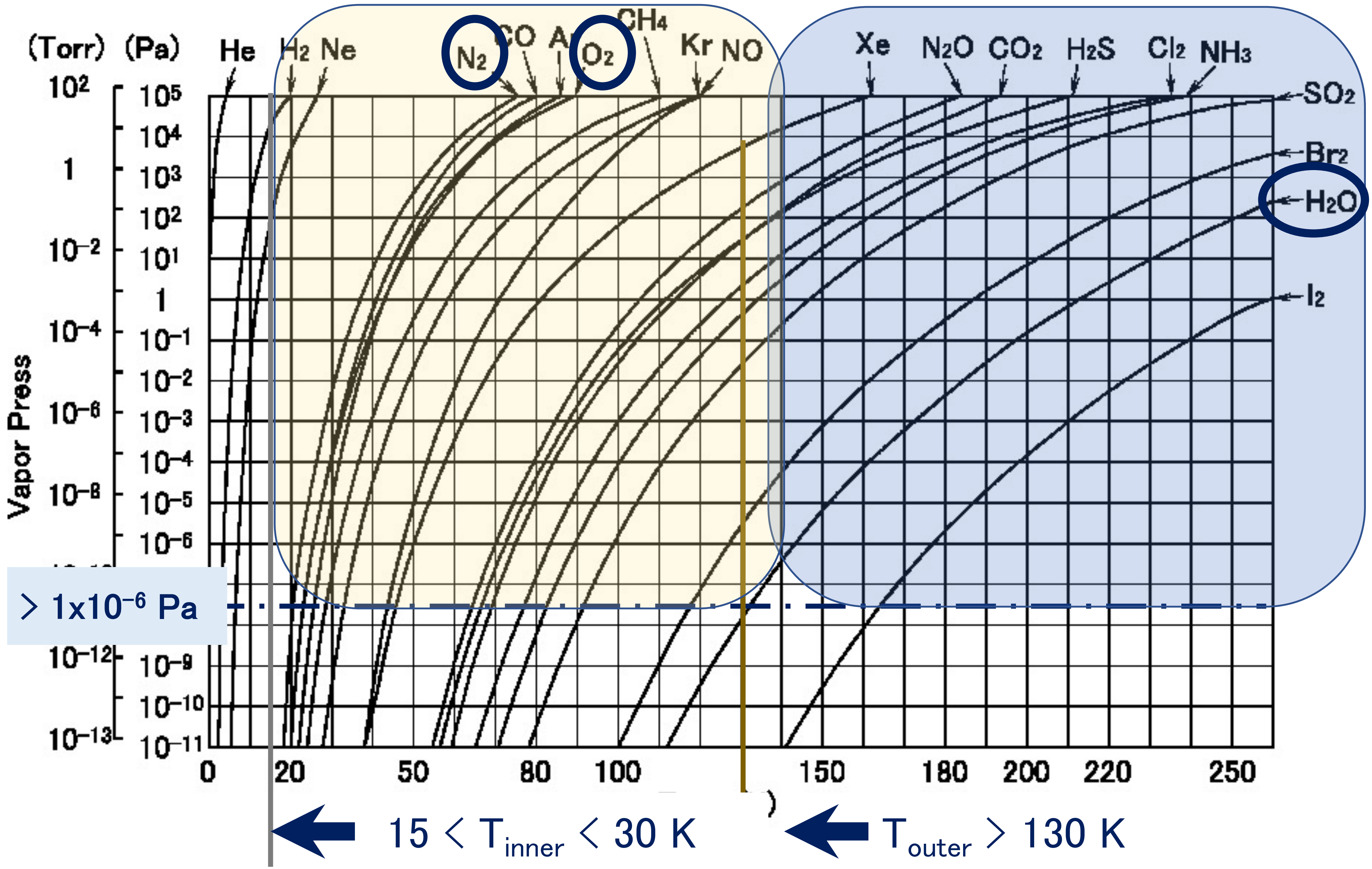
It will take **10 days** after switched on the coolers to reach steady state condition of mirror temperature.

Temperature distribution and pressure in the KAGRA Cryostat after cooling





Temperature dependence of internal pressure



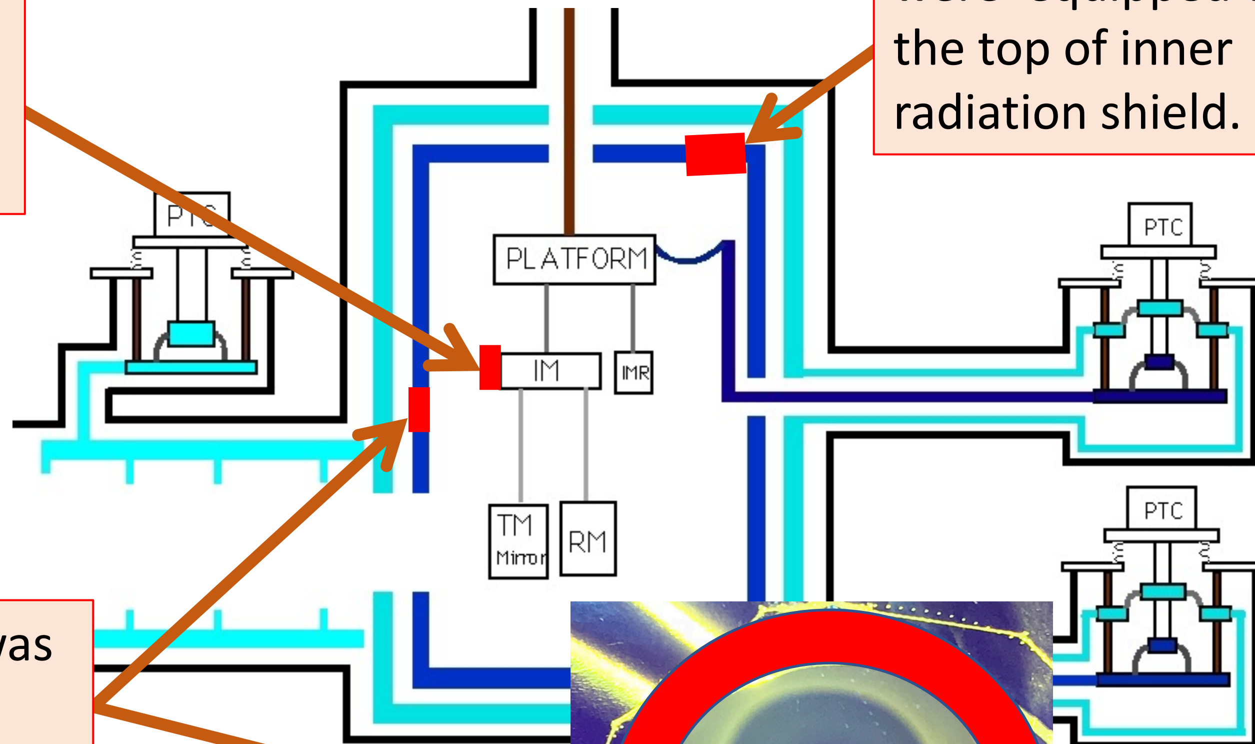
Trap O_2 & N_2 by inner shield

Trap H_2O by duct & outer shields

Defrost heater layout

A small heater was attached on IM for defrost of mirror surface.

Two calibration heaters were equipped with the top of inner radiation shield.



A defrost heater was attached on view port.

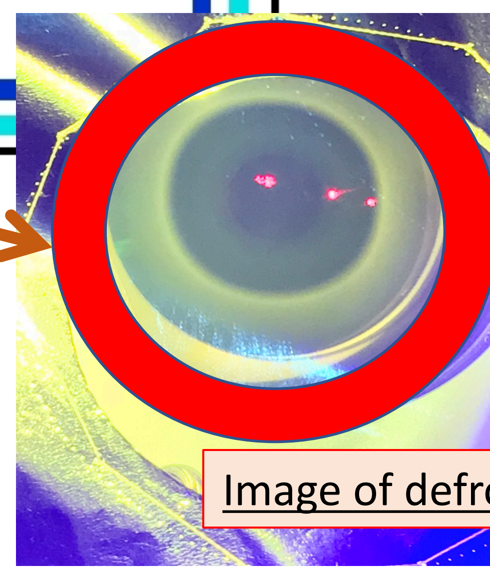
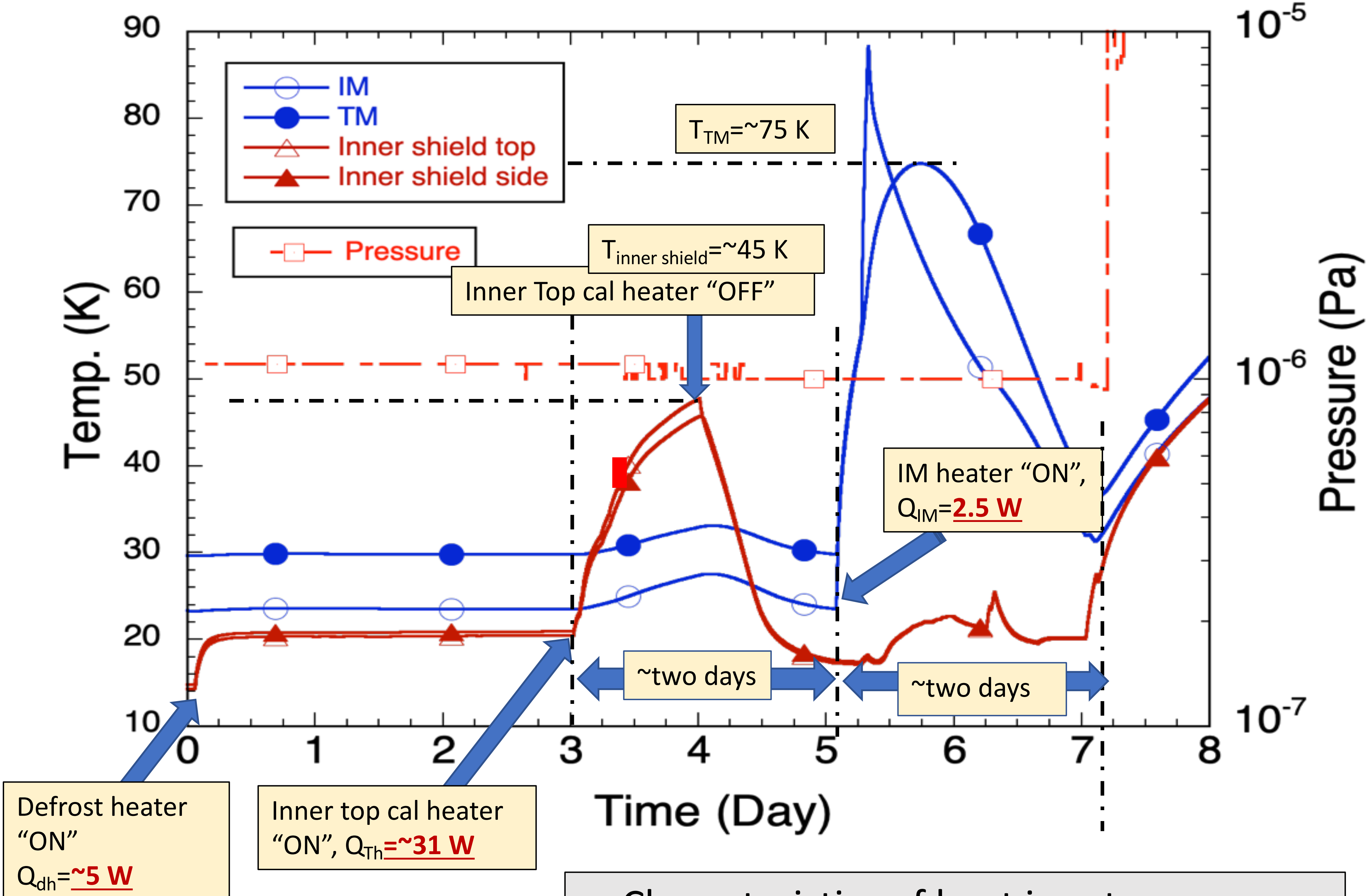
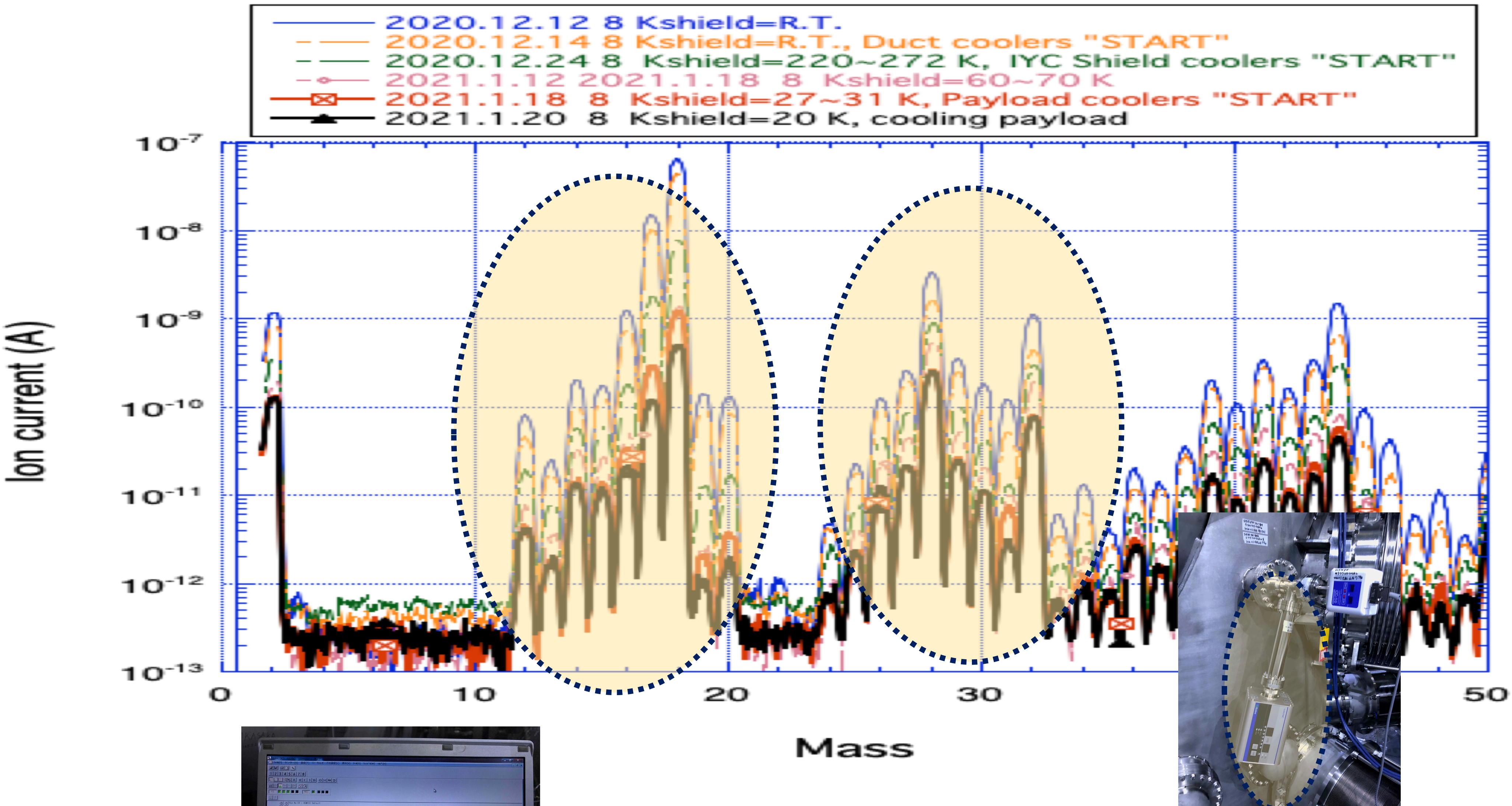


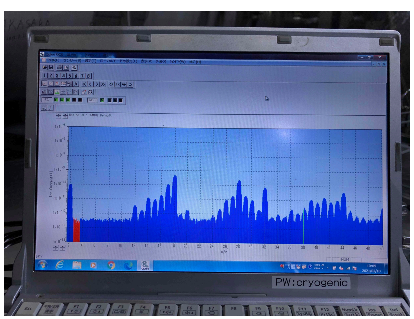
Image of defrost heater

- Three kinds of heaters for defrosting were installed in KAGRA cryostat.

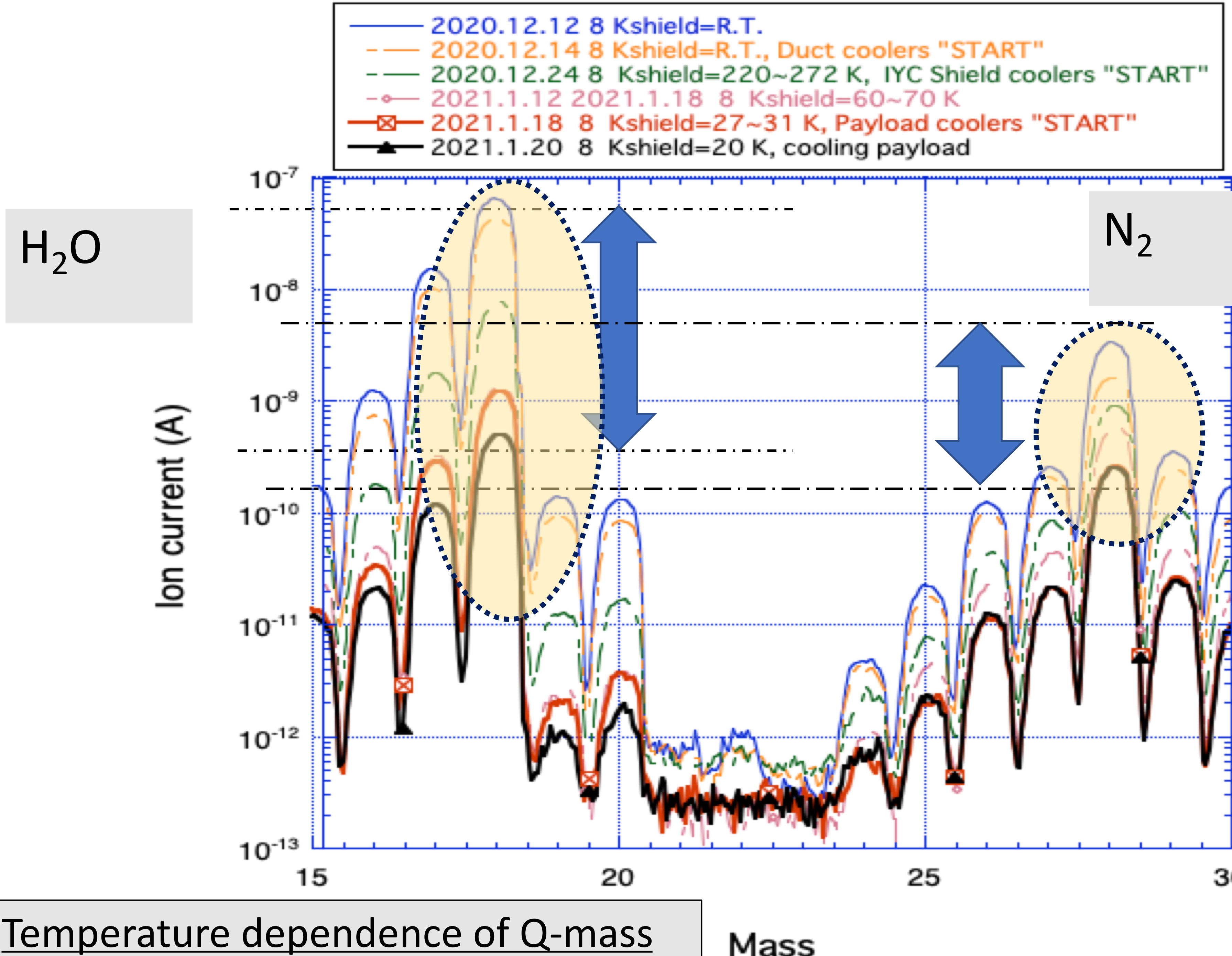


Characteristics of heat input response





Temperature dependence of Q-mass



Temperature dependence of Q-mass

Summaries

- Frosting on the surface of view ports were not appeared during this experiment!
- It can be assumed frosting on the surface of Test Mass was not appeared, too.
- Following items were confirmed in this experiment;
  - ✓Frosting are not appeared by proposed cooling scenario.
  - ✓Calibration heaters of inner radiation shield well worked as defrost heater for view ports.

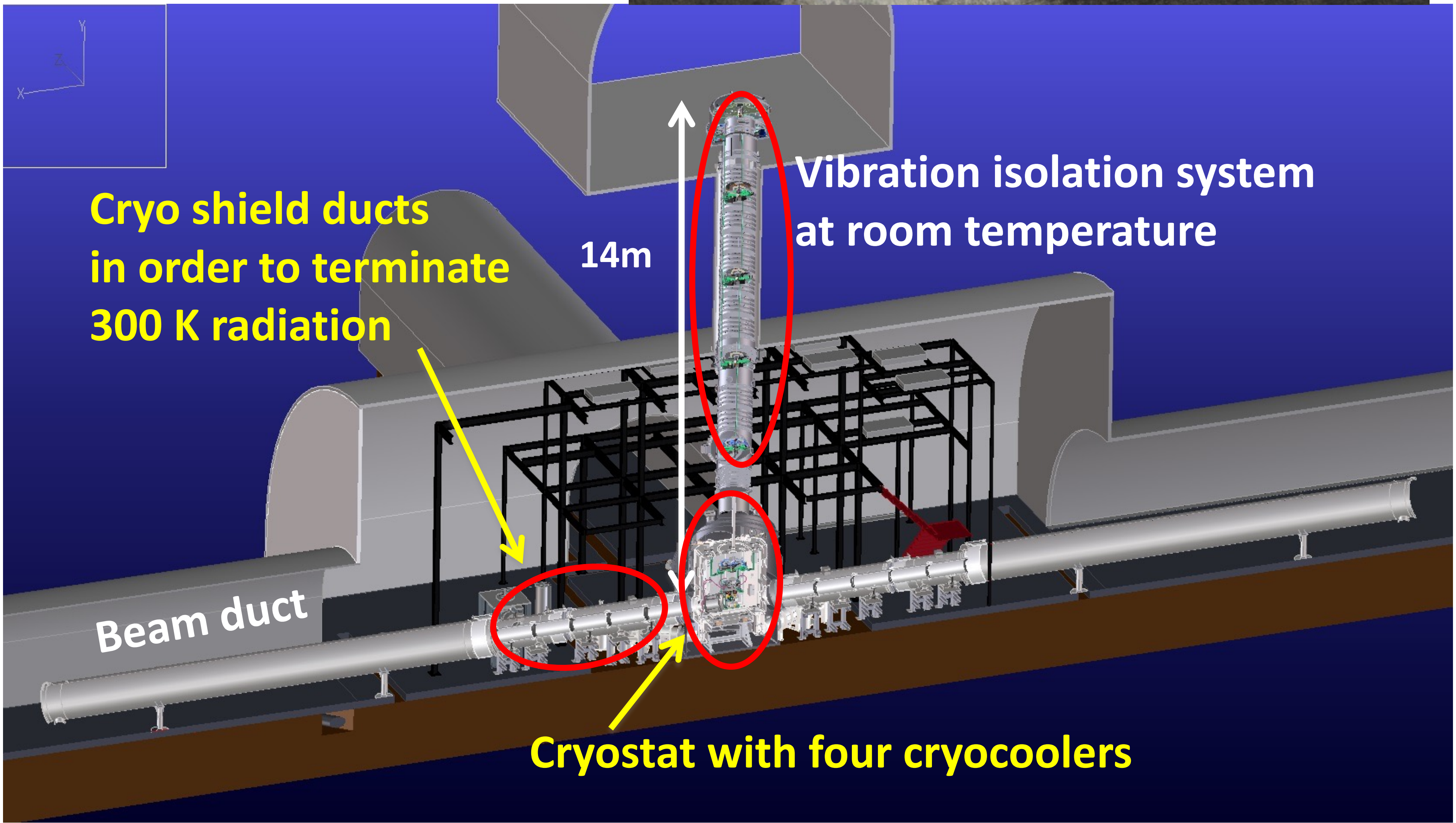
    Temperature of the inner radiation shield up to ~50 K.

    It will take **<u>2 days</u>** for defrosting for surface of the view ports.
  - ✓Heater attached on the IM well worked as defrost heater for mirror on the up to ~70 K. It will take **<u>2 days</u>** for defrosting for surface of mirror.
  - ✓Partial pressure measurement of residual gas at each temperature was performed, and confirmed frosting components.

Further issues for the future

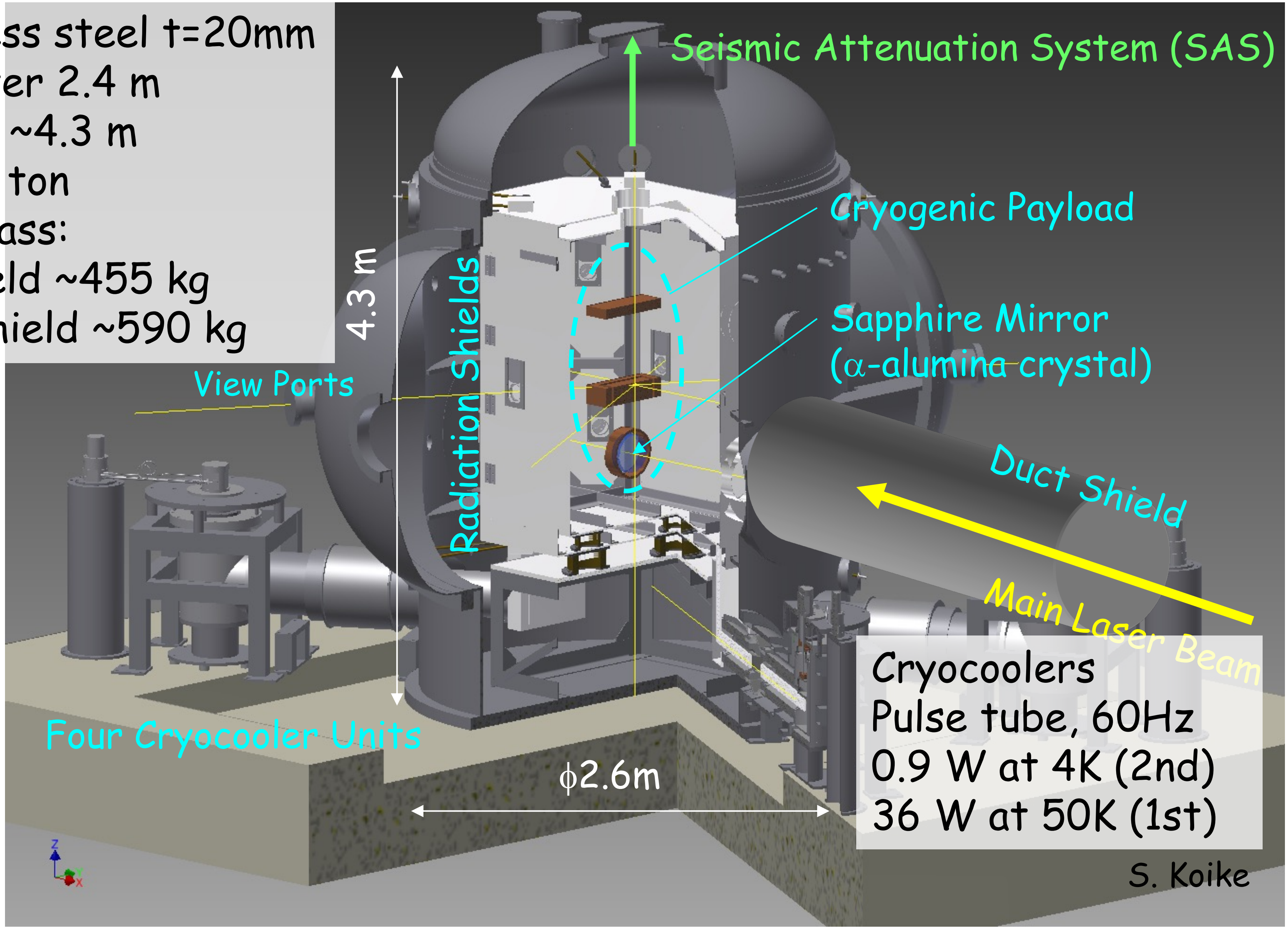
Appendix

Overview of KAGRA Cryogenics system



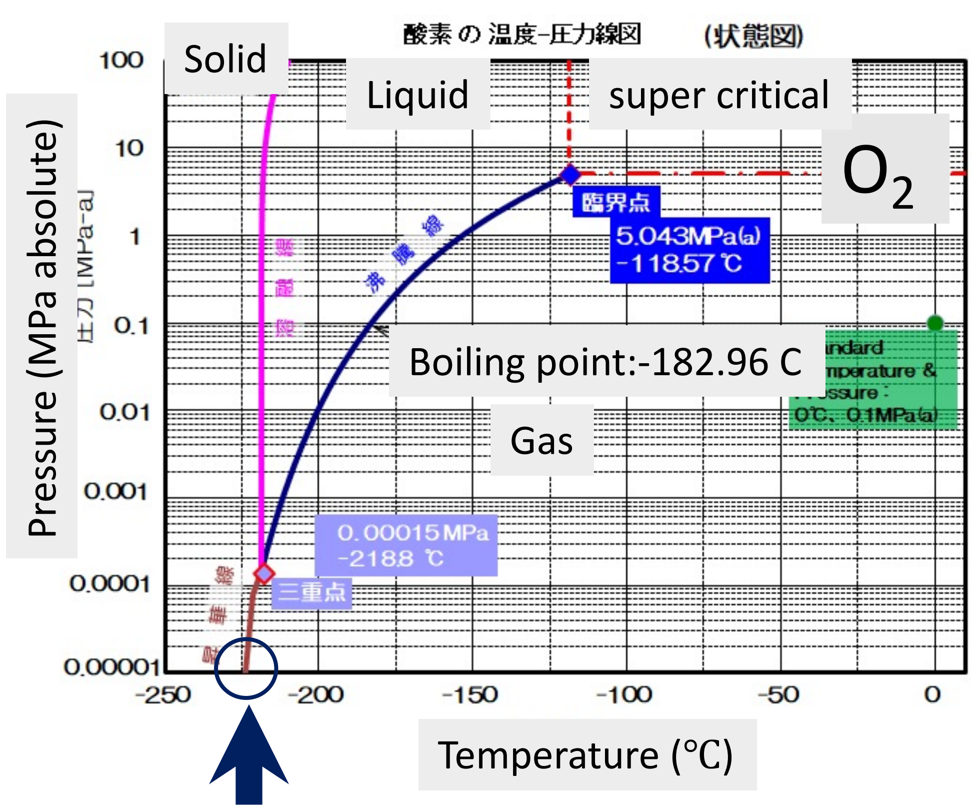
Structure of KAGRA Cryostat

Stainless steel t=20mm
Diameter 2.4 m
Height ~4.3 m
M ~ 12 ton
Cold Mass:
8K shield ~455 kg
80 K shield ~590 kg

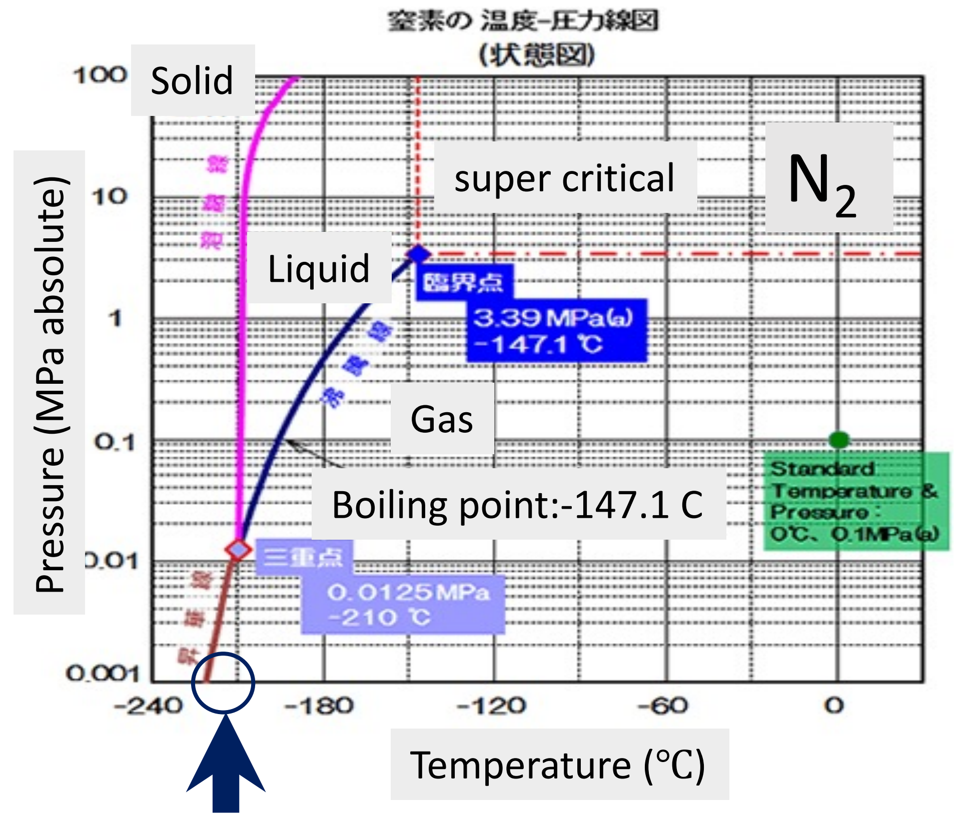


Cryocoolers
Pulse tube, 60Hz
0.9 W at 4K (2nd)
36 W at 50K (1st)

S. Koike

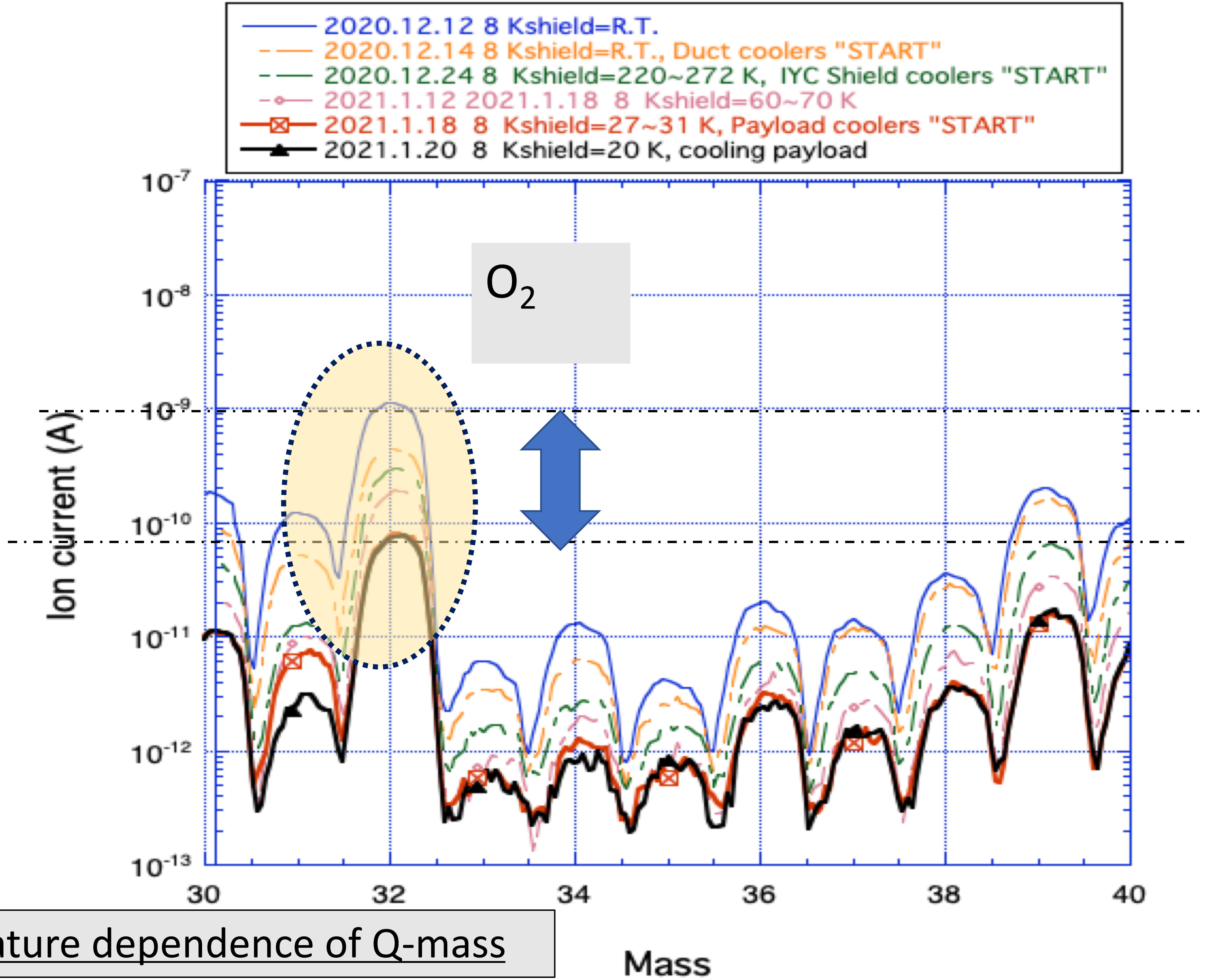


$1x10^{-5}$ Pa → ~-225 ℃ (~48 K)



1x10-3 Pa → ~-220 ℃ (~53 K)

State diagrams of O2 and N2



Temperature dependence of Q-mass