Cooling Process to avoid frosting *on the surface of the KAGRA Test Mass and ….*

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External Review for KAGRA Cooling Process to avoid Frosting

20/July/2021

Outline

- ✓ *Objective of the external review*
- ✓ *Introduction to the results of defrosting experiment using KAGRA cryostat*
- ✓ *Proposal of the KAGRA cooling scenario for O4*
- ✓ *Additional back up plan for defrosting*

✓ *Objective of this external review*

Discuss following issues in this review;

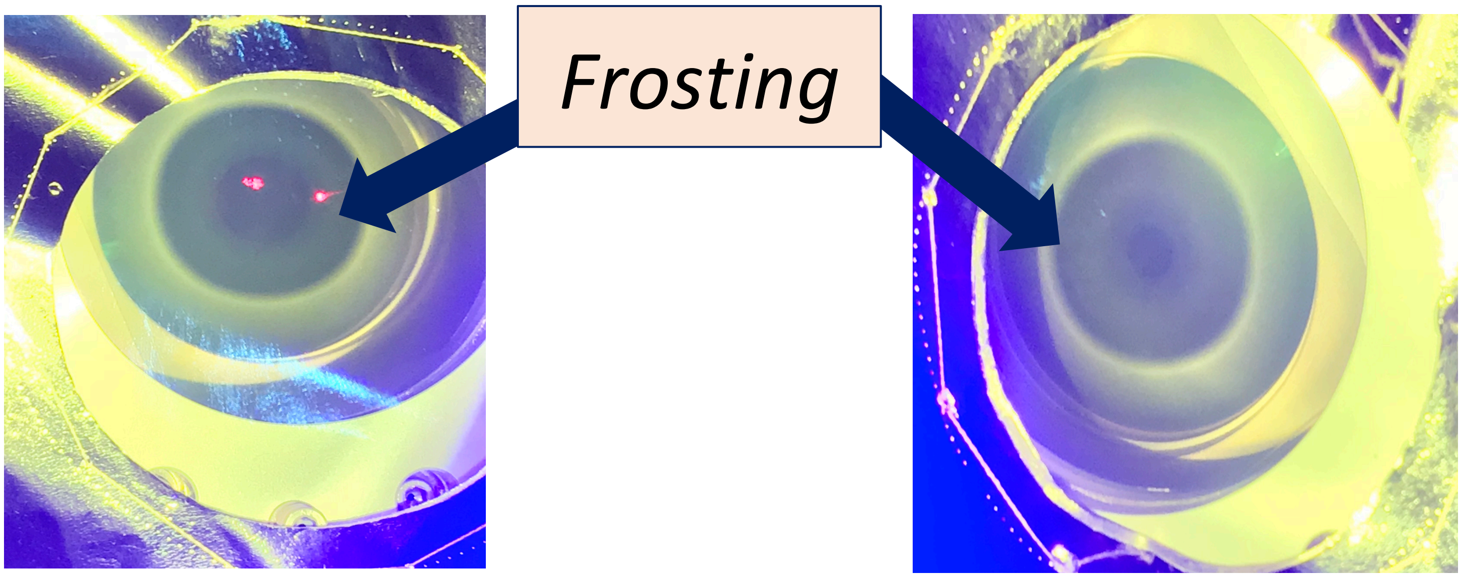
- *Review proposed KAGRA test mass cooling process for O4 to avoid frosting.*
- Discussion of how maintain mirror temperature lower than 100 K without frosting on the surface of the mirror.
- Feasibility of defrosting by defrosting heaters.

Introduction to the results of defrosting experiment using KAGRA cryostat

- ✓ *Issues in de-frosting experiment using KAGRA cryostat*
  - *An example of frosting on the surface of view ports*
  - *KAGRA cryogenic system*
  - *Cooling characteristics of KAGRA cryostat*
  - *Results of performance defrost heaters*
  - *Results of residual gas measurement during the cooling*
- ✓ *Summaries of the experiment*

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.

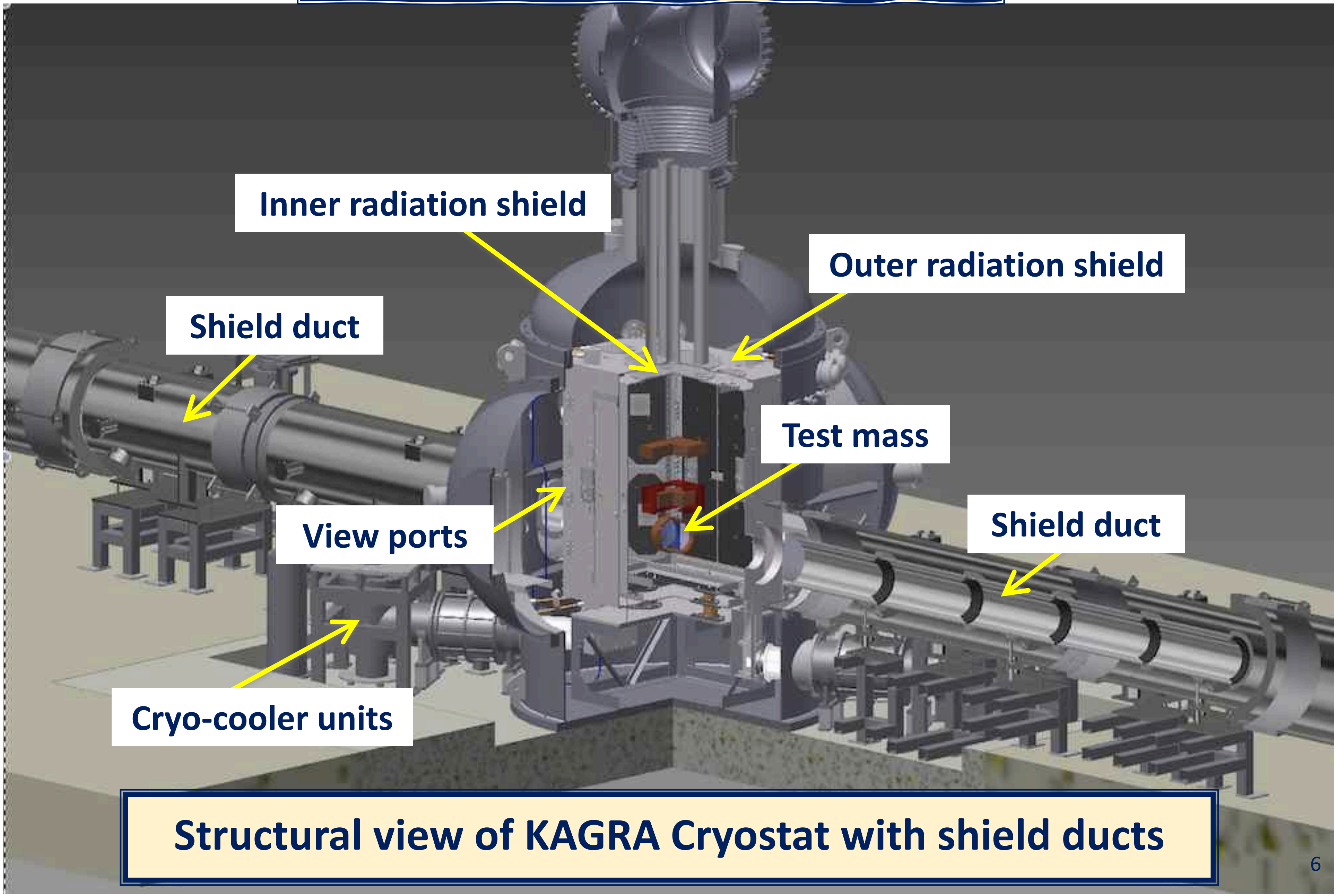


TM oplev light source side

TM oplev QPD side

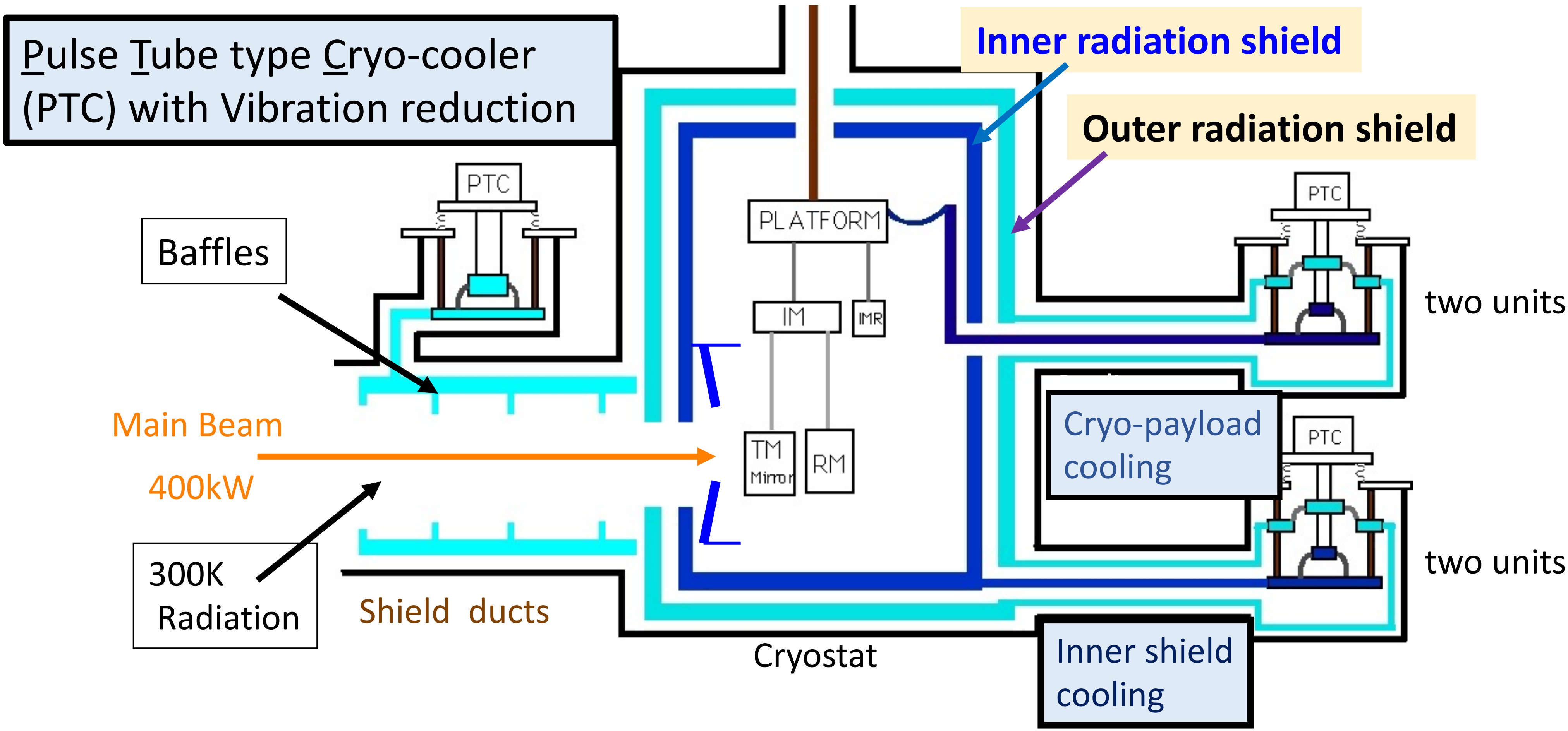
Photos show examples of the frosting on the surface of view ports with vacuum leak at TM temperature of ~25K. (@EXC 2020/08)
It was assumed that frog on the surface was formed by frosting of O_2, N_2 and H_2O.

KAGRA cryogenic system



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 procces for Test Mass avoid frosting

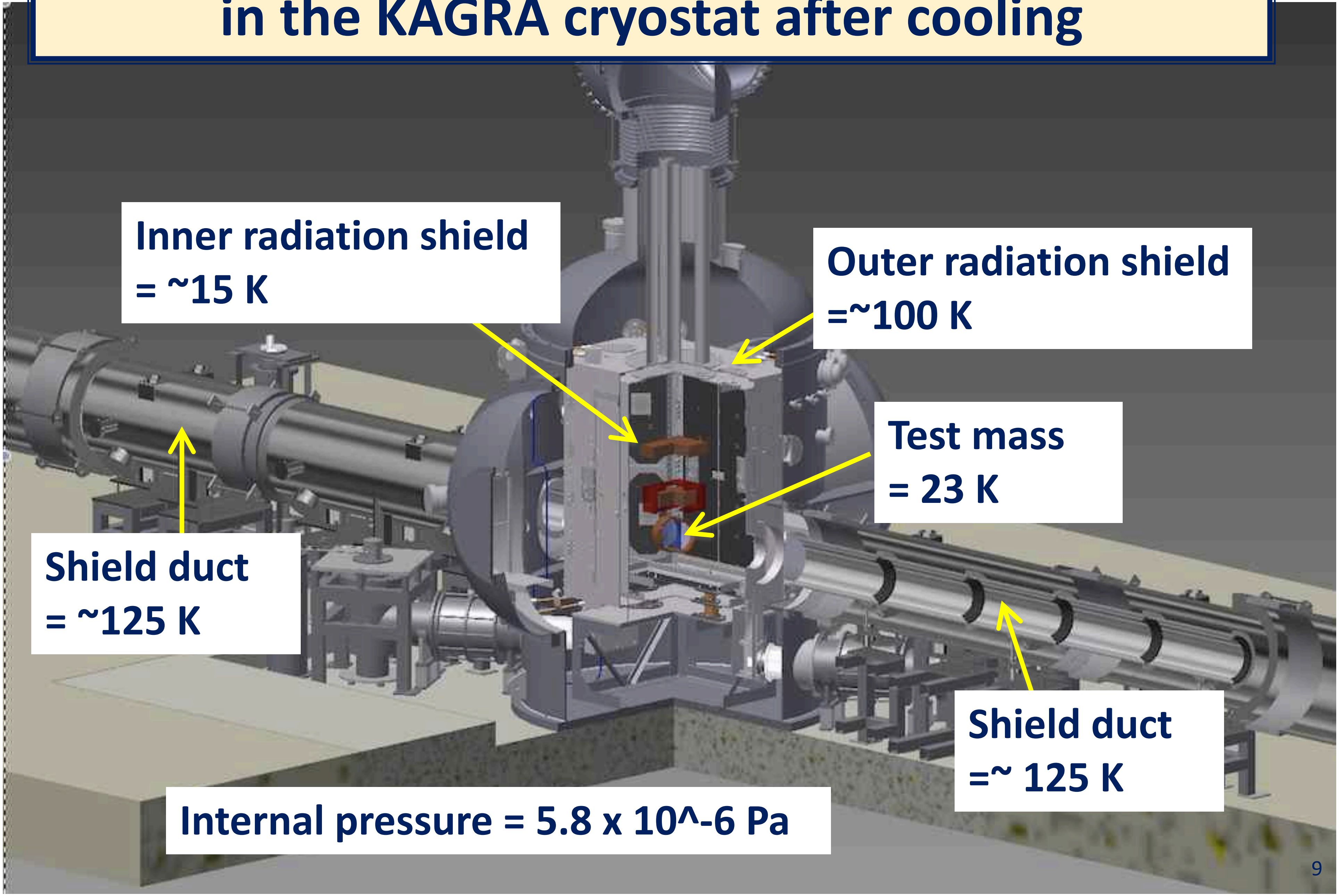
   Including confirmation of the occurrence of frosting on the view ports under the condition of leak rate <10^-10Pam^-3/s)

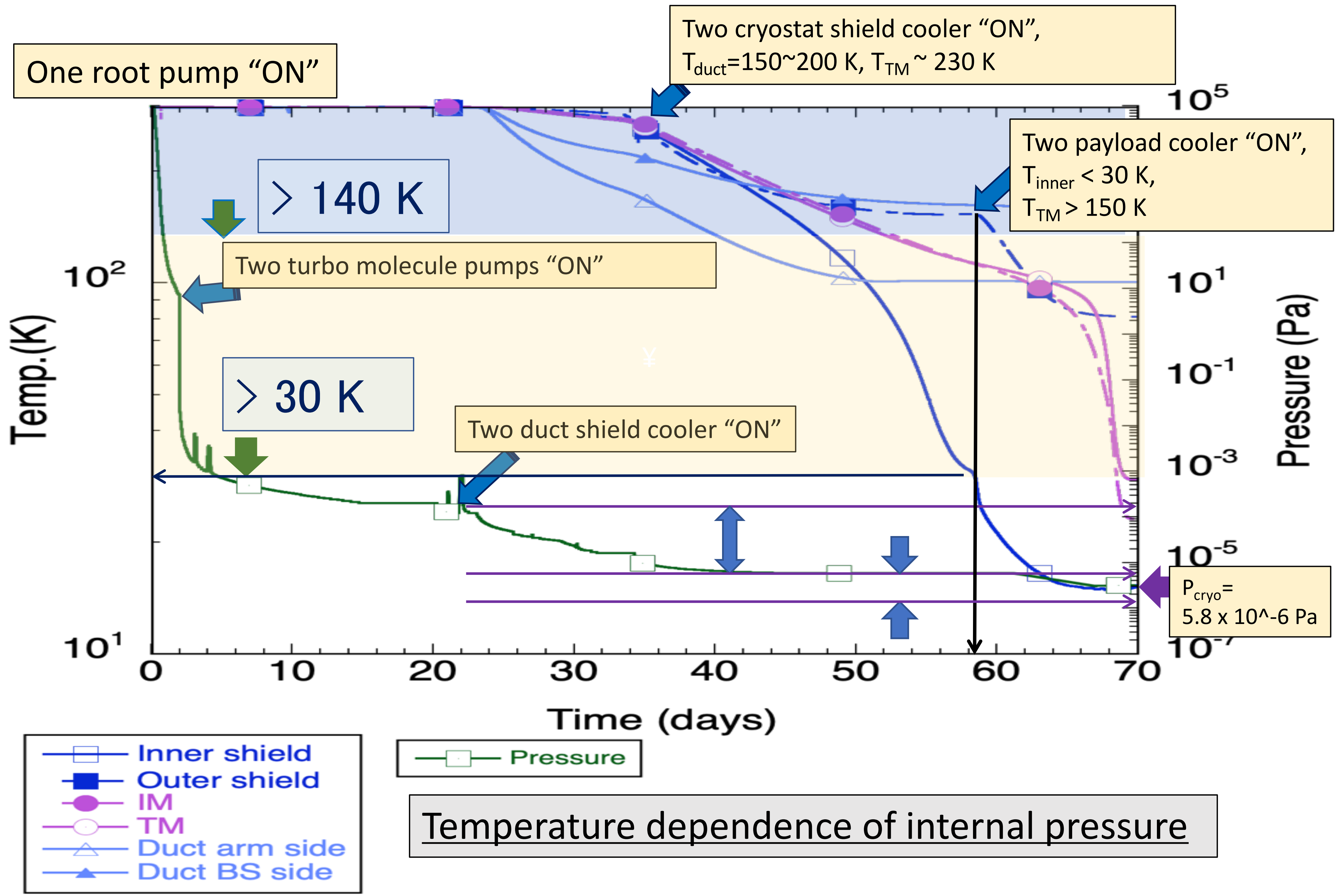
2. Defrosting experiment by defrost heaters

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

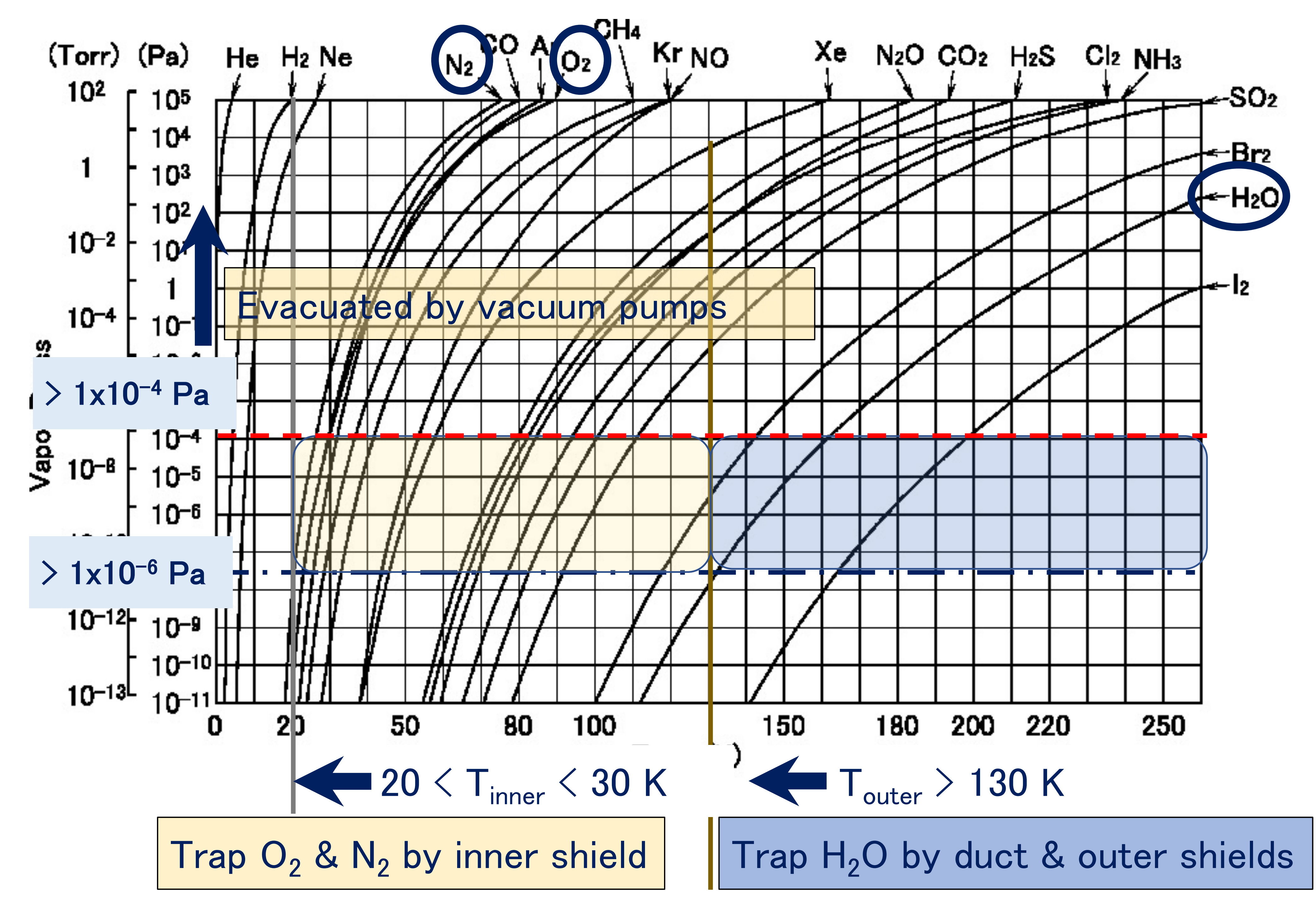
3. Measurement of partial pressure of residual gas to confirm frosting components

Temperature distribution and pressure in the KAGRA cryostat after cooling





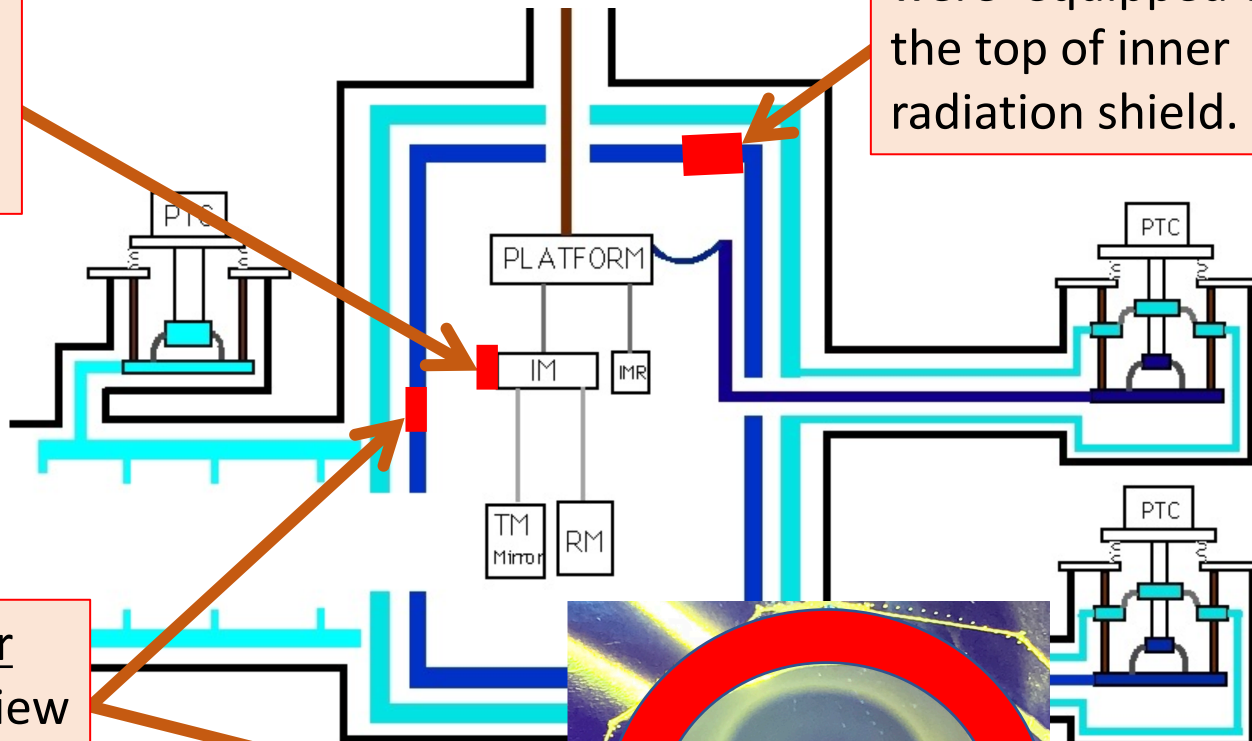
Temperature dependence of internal pressure


(Torr) (Pa)
He H2 Ne N2 CO Ar O2 CH4 Kr NO Xe N2O CO2 H2S Cl2 NH3
SO2
Br2
H2O
I2
Vapor press
Evacuated by vacuum pumps
> 1x10⁻⁴ Pa
> 1x10⁻⁶ Pa
0 20 50 80 100 150 180 200 220 250
20 < T_inner < 30 K
T_outer > 130 K
Trap O2 & N2 by inner shield
Trap H2O by duct & outer shields

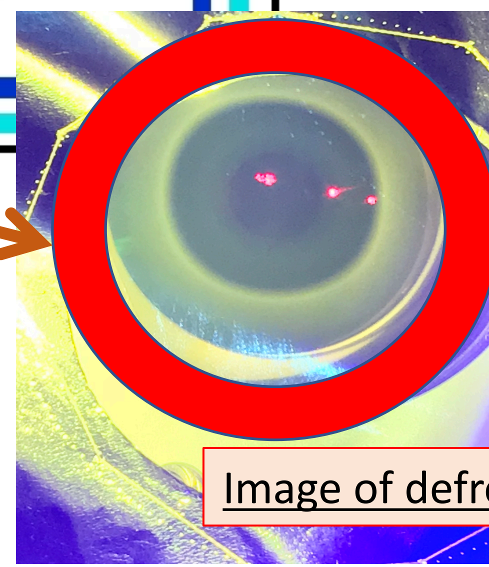
Defrost heater layout

A small heater was attached on IM for defrosting mirror surface.

Two <u>calibration heaters</u> were equipped with the top of inner radiation shield.

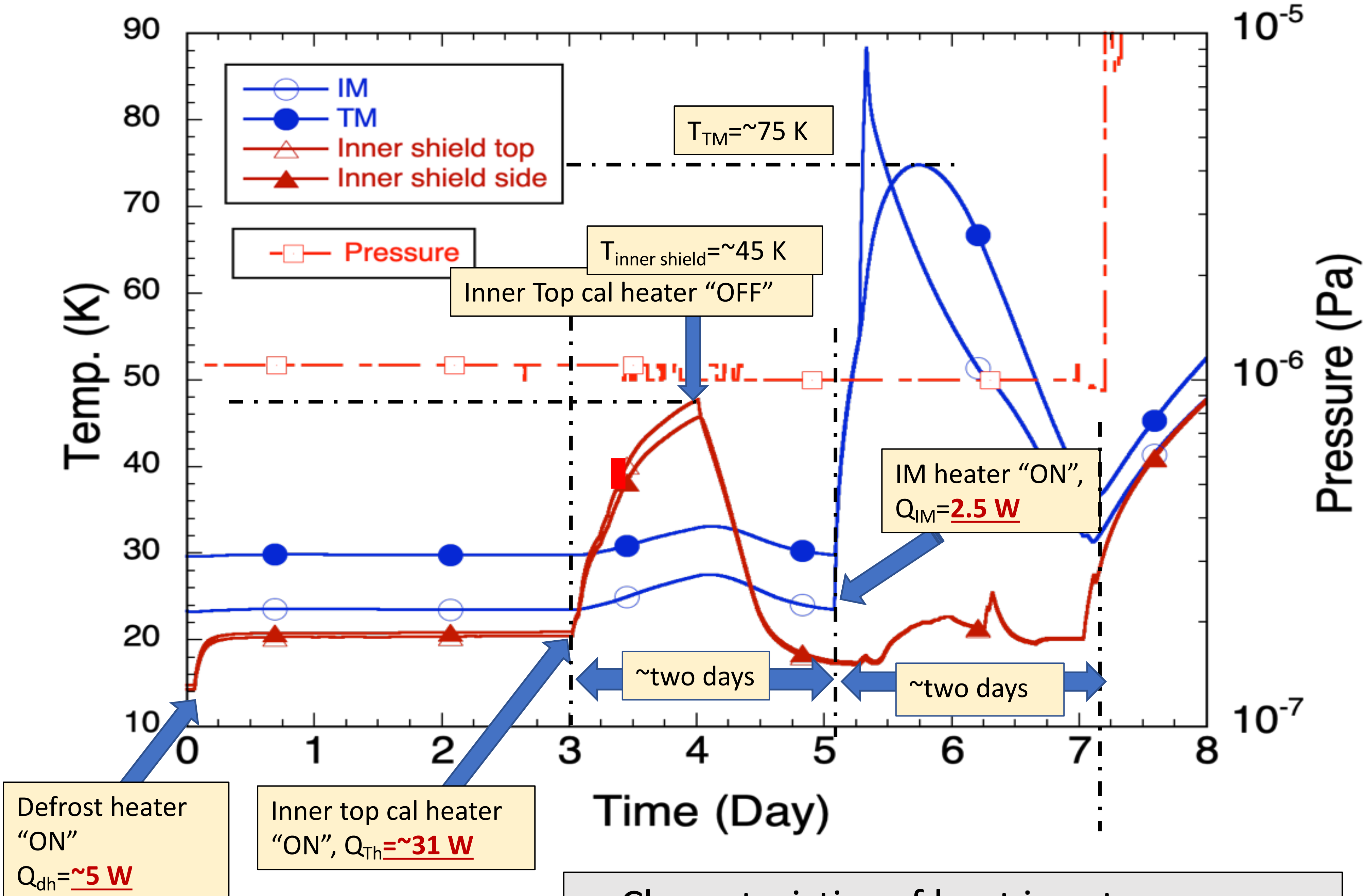


<u>One defrost heater</u> was attached on view port.

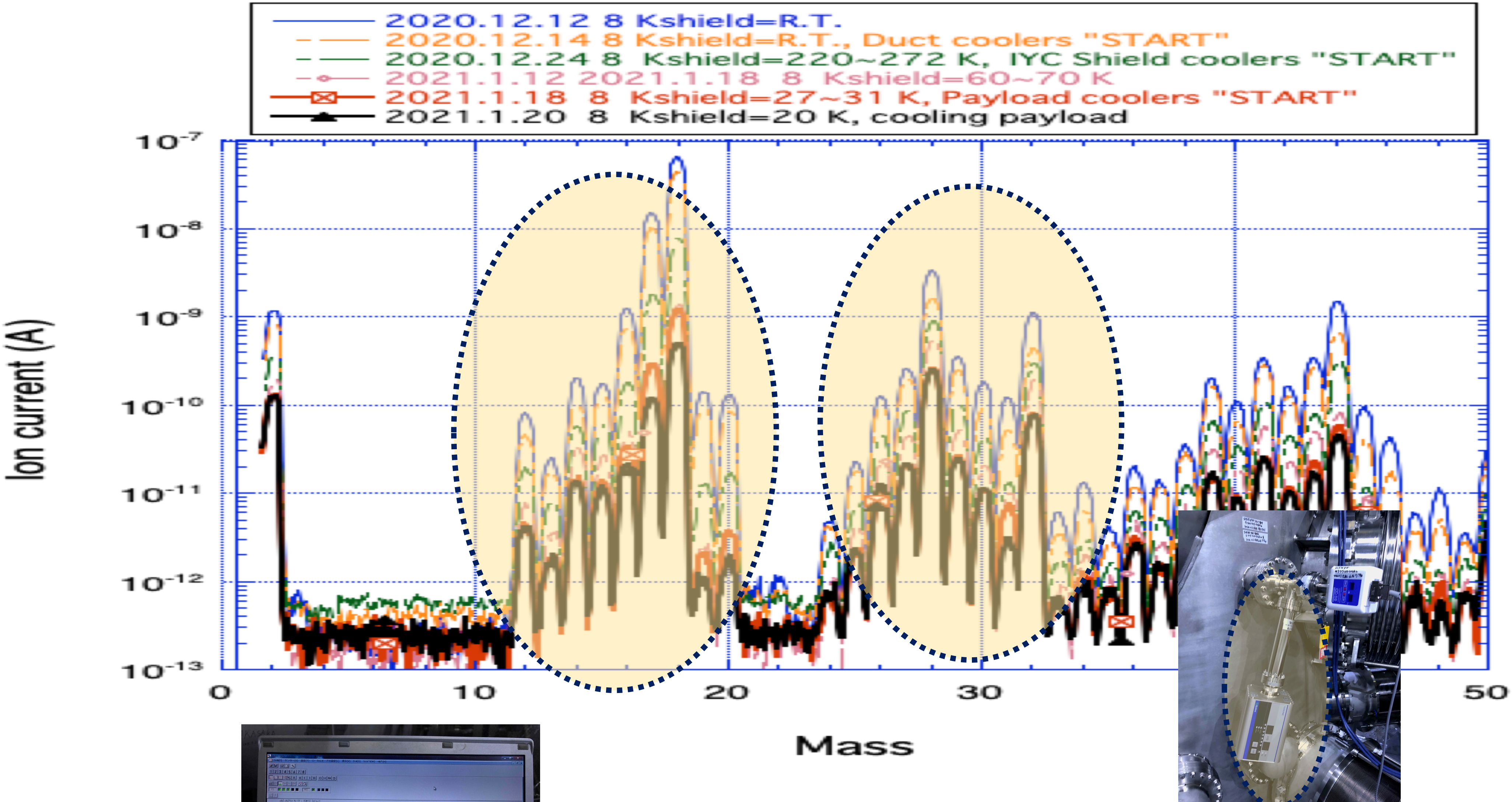


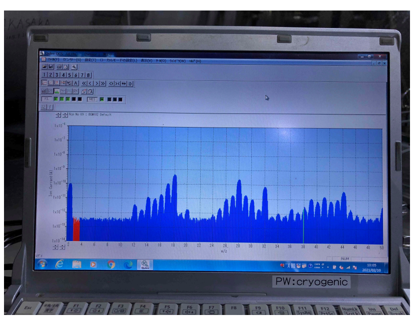
<u>Image of defrost heater</u>

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

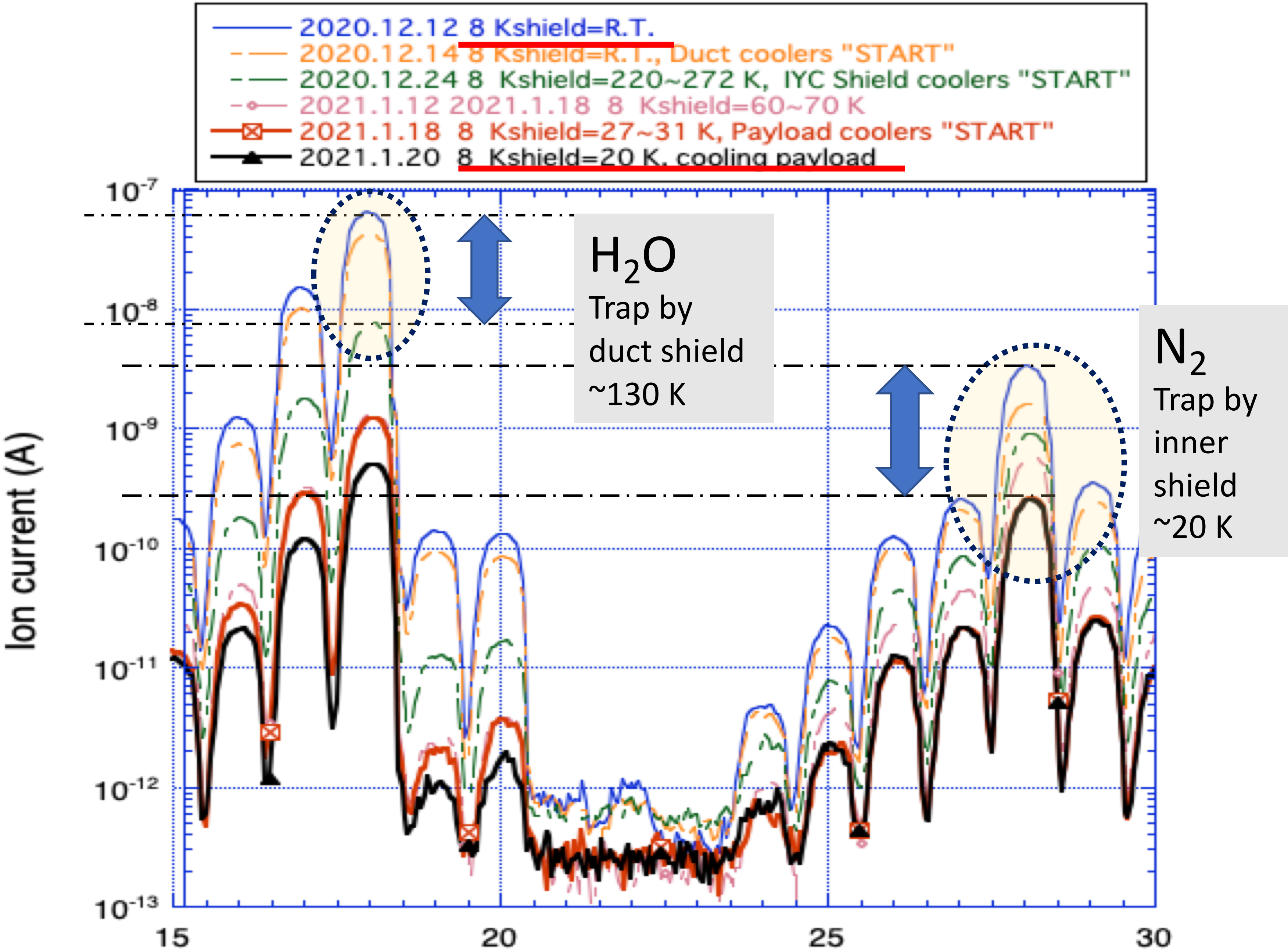


Characteristics of heat input response





Temperature dependence of Q-mass



Temperature dependence of Q-mass

Summaries

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

    To defrost the surface of the view ports on inner radiation,

    it will take **2 days** to warm up to ~50 K.
  - ✓Heater attached on the IM worked well as defrost heater for mirror.

    To defrost the mirror, it will take **2 days** to warm up to ~70 K.
  - ✓Partial pressure measurement of residual gas at each temperature was performed, and confirmed frosting components.

Proposal for the test mass cooling scenario for O4

Cooling steps;

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.

Proposal for the test mass cooling scenario for O4
- continued -

Cooling steps;

Step 5:

Switched defrost heaters, when defrost appear on the surface of the mirror or view port.

It will take **2 days** to warm up and re-cool down the surface of the mirror or view port after switched on the heaters.

Additional plan for defrosting

- Enhanced pumping capacity by increasing the number of vacuum pumps!　Increase the number of vacuum exhaust pumps, especially around the cryostat, to reduce the achieved pressure as much as possible.
- Continuous measurement of residual gas components in the vacuum chambers including PR, SR, BS and so on.
- Addition of gas process gas monitor arrangement.
- Enhancement of leak testing to satisfy KAGRA's required specifications.

Plan for increasing the number of vacuum pumps to enhance pumping capacity by