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

Contents

- ✓ *Objective of the external review*
- ✓ *Defrosting experiment using KAGRA cryostat*
- ✓ *Proposal of the KAGRA cooling scenario for O4*
- ✓ *Enhancement plan to avoid frosting*

✓ *Objective of this external review is*

“In order to avoid frosting on the surface of the test mass, this review confirms whether there are any remaining issues with the proposed cooling scenario for the test mass.”

Defrosting experiment using KAGRA cryostat

- ✓ *Outline*
  - *Purpose of the defrosting experiment*
  - *Example of frosted view ports*
  - *Cooling scenario examined to avoid frosting*
  - *Result of cooling characteristics of the cryostat*
  - *Residual gas measurement during the cooling*
  - *Performance defrost heaters*
- ✓ *Summary of experiment*

Purpose of the defrosting experiment

1. Determine the cooling process for Test Mass avoid frosting

Including confirmation of the occurrence of frosting on the test mass or view ports under the condition of leak rate <10^-10Pam^-3/s).
(Leakage of KAGRA specification is not >10^-10Pam^-3/s).)

2. Measurement of partial pressure of residual gas during cooling

Identification of frosting components.
It was assumed that frost was formed by frosting of O_2, N_2 and H_2O.

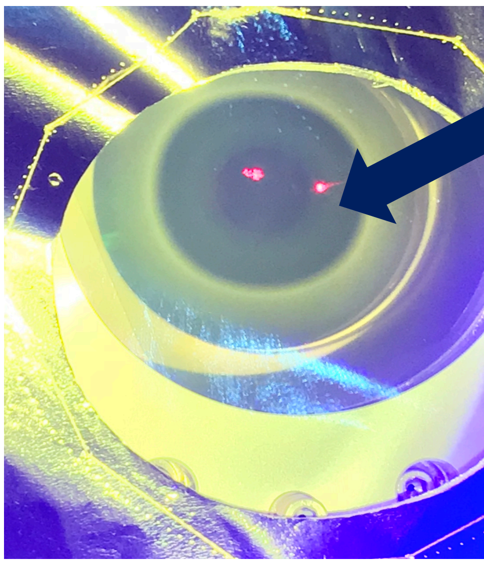
3.Defrosting experiment by defrost heaters

Feasibility study of defrosting heaters.
(If no frost adheres during experiment, check the temperature profile by defrost heater.)

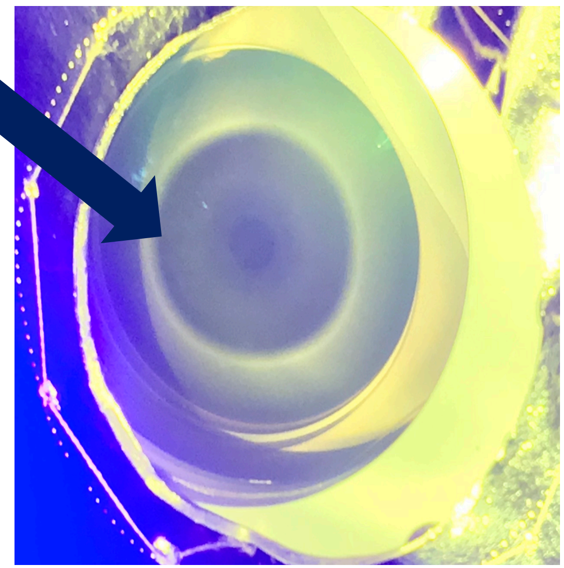
Example of frosted view ports

- Frosting on the surface of the test mass and there 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



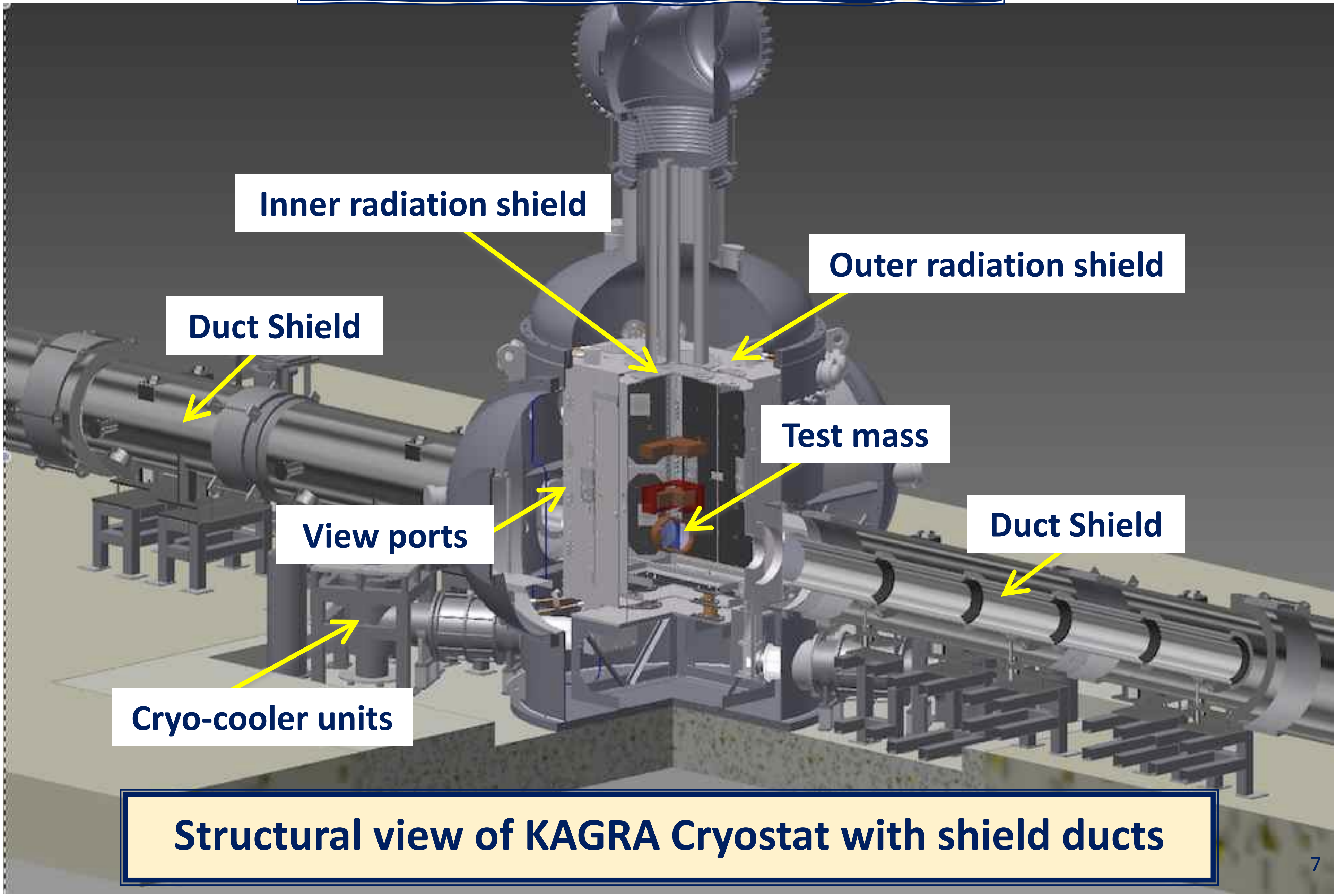
TM oplev light source side



TM oplev QPD side

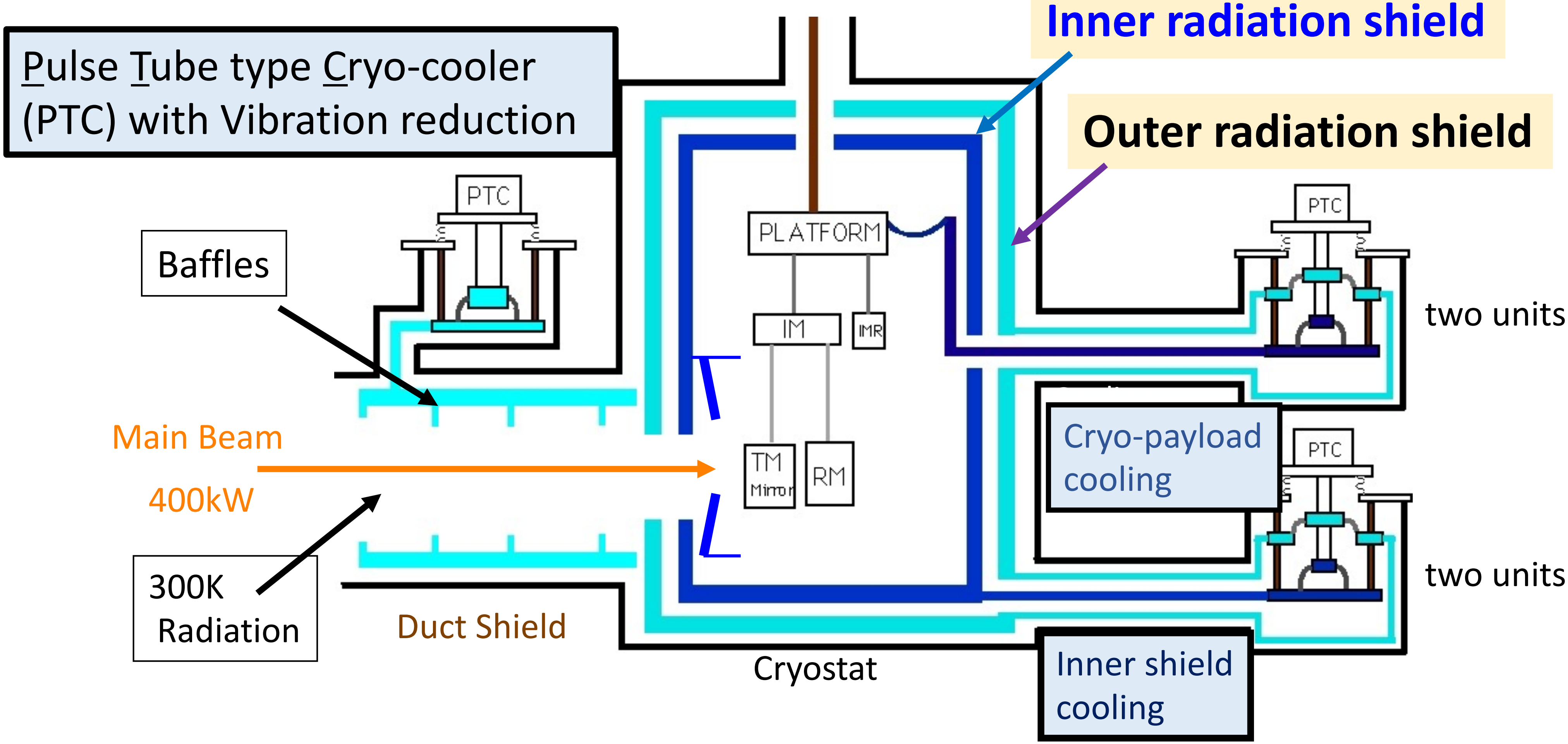
Photos show examples of the frosting on the surface of view ports with vacuum leak at TM temperature of ~25K. (@EXC 2020/08)
It was assumed that frost was formed by frosting of O_2, N_2 or H_2O.

KAGRA cryogenic system



Structural view of KAGRA Cryostat with shield ducts

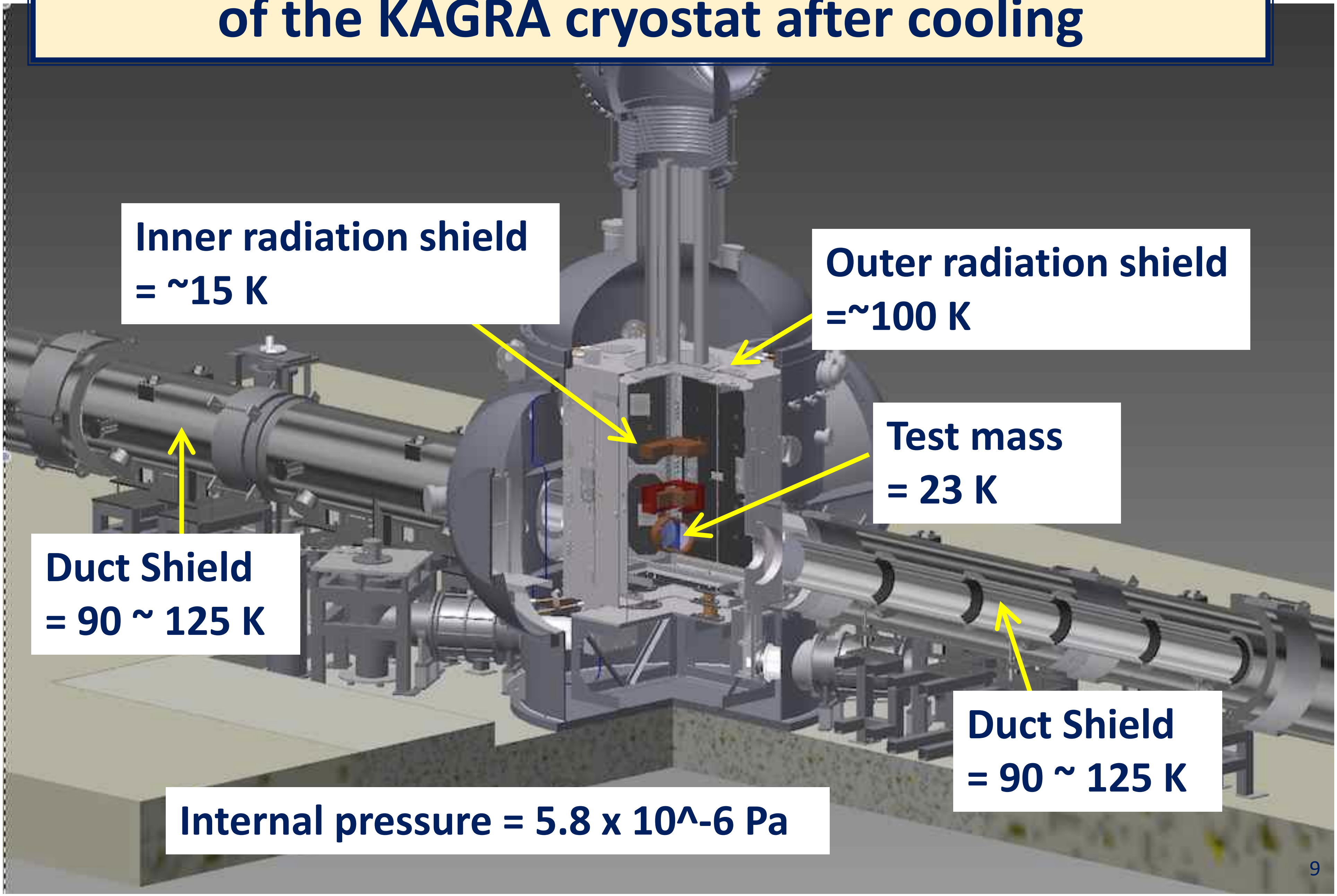
Cryo-cooler layout



- Four cryocooler units per one cryostat

2 units for cooling cryo-payload
2 units for cooling inner shield
4 units for cooling outer shield

Temperature distribution and internal pressure of the KAGRA cryostat after cooling



Cooling scenario examined to avoid frosting

Fundamental features of the cooling method:

Avoiding frost on the test mass by stepwise adsorption of residual gas components on the radiation shield surface

Step 1 → Step 2 → Step 3 → Final Step → Goal

Step 1	21 days	Step 2	11 days	Step 3	24 days	Final Step	10 days	Goal
✓ Vacuum pumping ✓ Internal pressure < 10^-4 Pa ✓ No leakage > 10^-10 Pam^3/s		✓ Cooling down duct shields ✓ Radiation Temp. 90 K ~ 150 K ✓ Trap H_2O		✓ Cooling down internal shields ✓ Radiation Temp. 20 K ~ 30K ✓ Trap O_2 and N_2		✓ Cooling down Test Mass		✓ T_{TM}=~20 K

It takes 76 days in total to cool down Test Mass

Cooling scenario examined to avoid frosting

Fundamental features of the proposed cooling method:

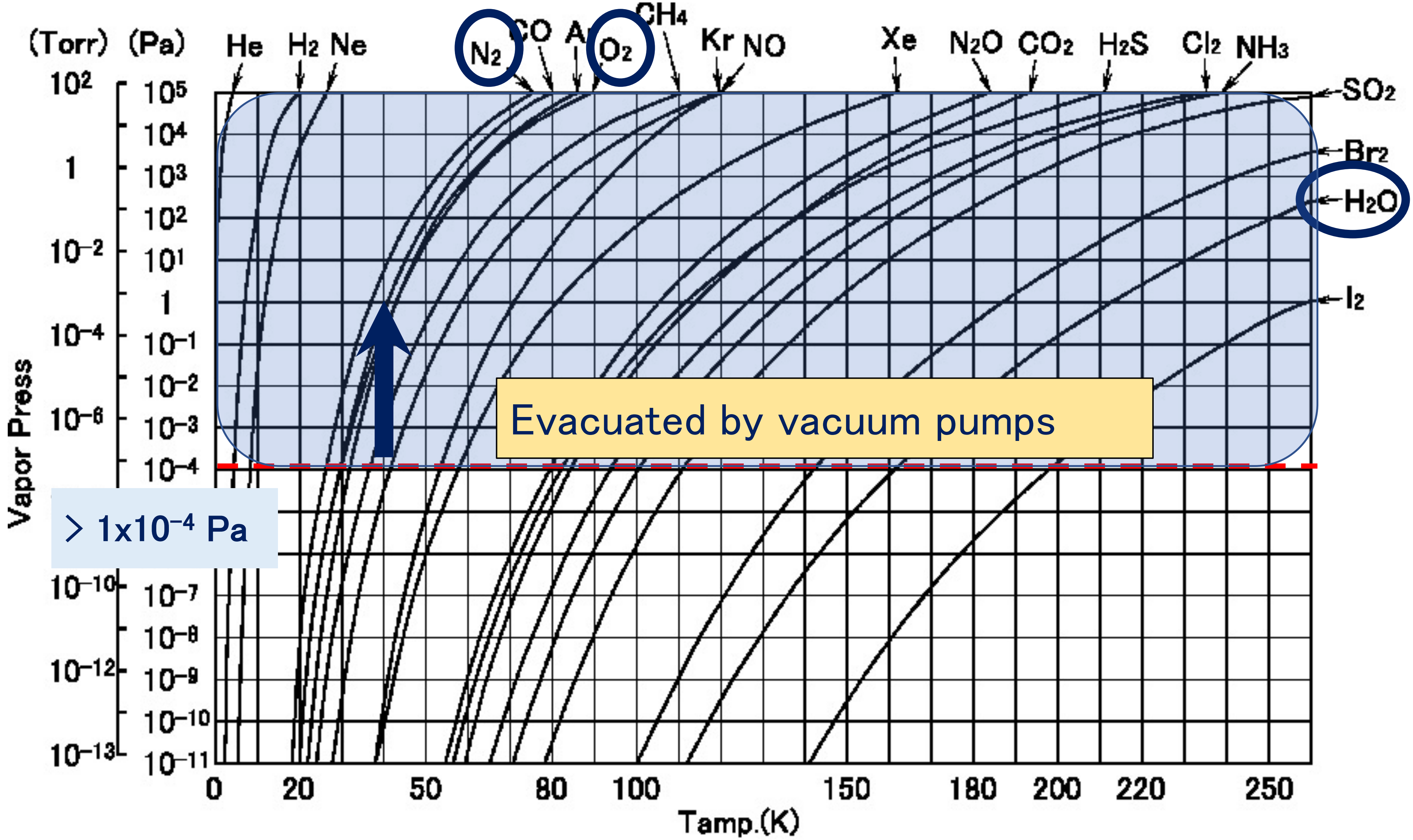
Avoiding frost on the test mass by stepwise adsorption of residual gas components on the radiation shield surface

Step 1: Start vacuum pumping.

Wait inner pressure shall be lower than ~10^-4 Pa.

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

Leak test should be satisfied KAGRA specification which are no leakage > 1x10^-10 Pam^3/sec.



Step 1: Evacuation by vacuum pumps

Step 2: Turn on duct shield cryocoolers to trap H_2O on the surface of duct shield.

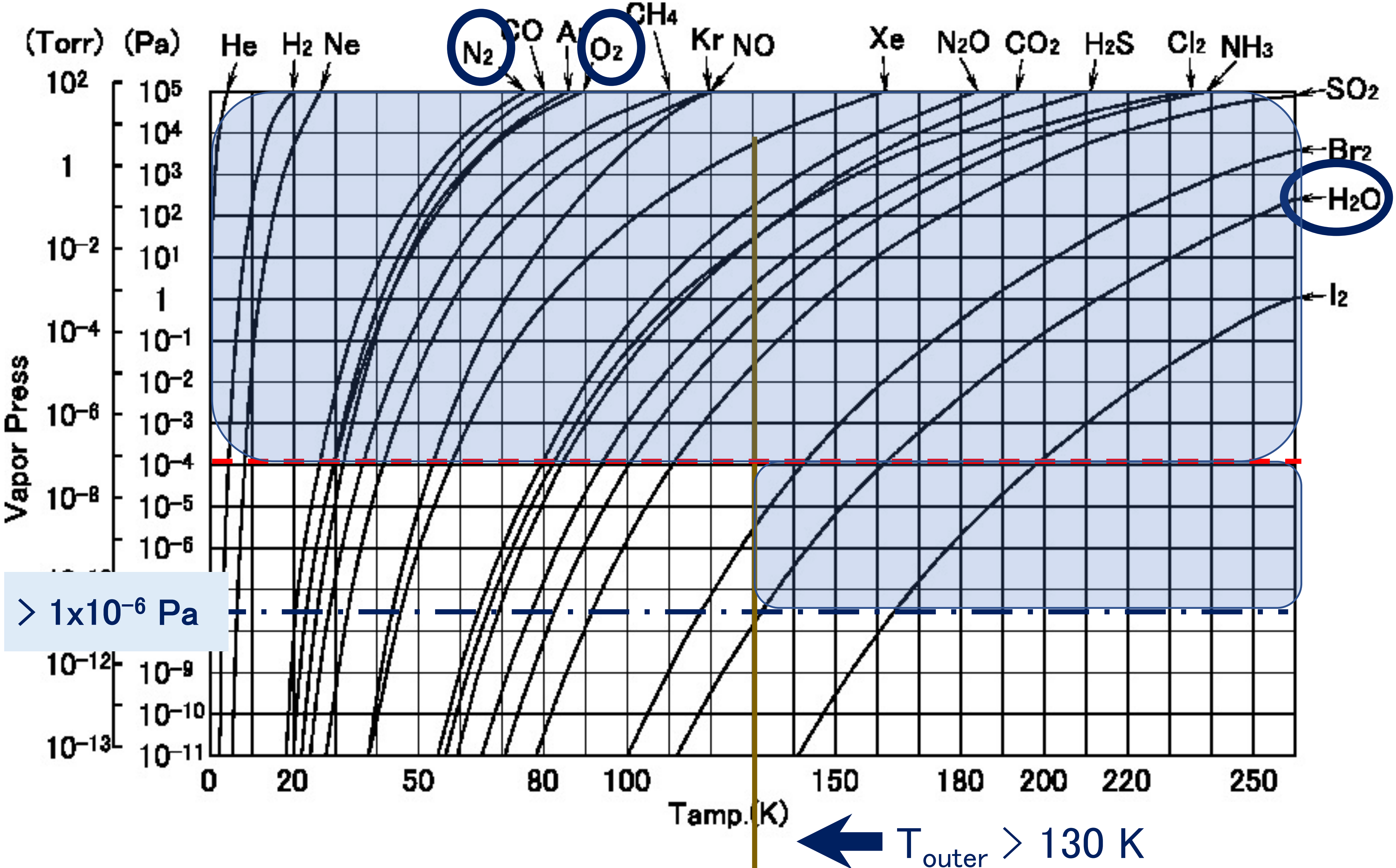
Wait surface temperature of duct shield should be lower than 130 K. It will take **11 days**.

Step 3: Turn on two cryocooler for radiation shields to trap N2 on the surface of inner shield.

The mirror is cooled by radiation from the inner shield.

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

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



Step 2:Trap H_2O by duct & outer shields

Step 2: Turn on duct shield cryocoolers to trap H_2O on the surface of duct shield.

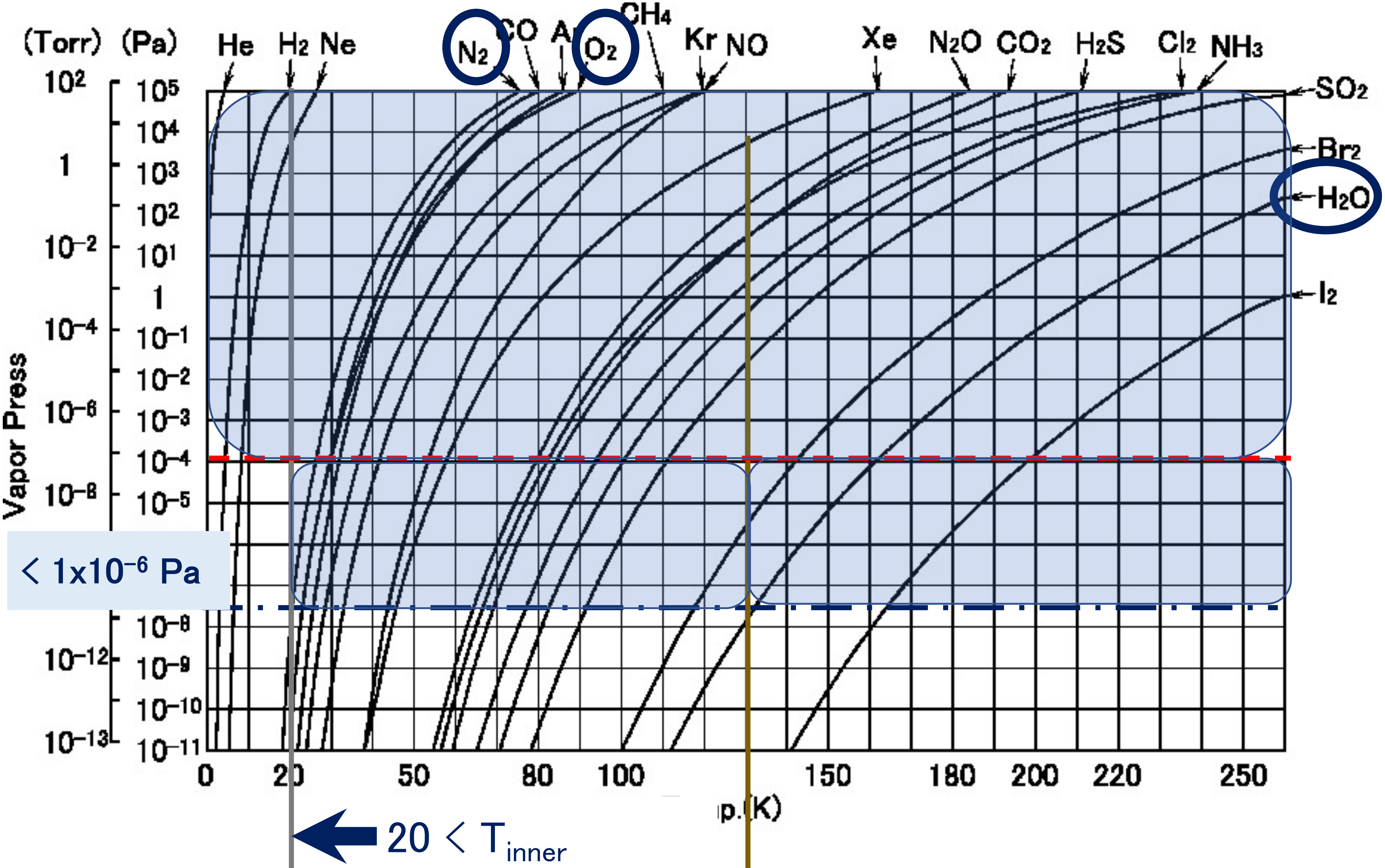
Wait surface temperature of duct shield should be lower than 130 K. It will take **11 days**.

Step 3: Turn on two cryocooler for radiation shields to trap N2 on the surface of inner shield.

The mirror is cooled by radiation from the inner shield.

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

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



Step 3: Trap O_2 & N_2 by inner shield

Final Step:

Turn on two cryo-coolers for payload.

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

Defrosting experiment using KAGRA cryostat

✓ Outline

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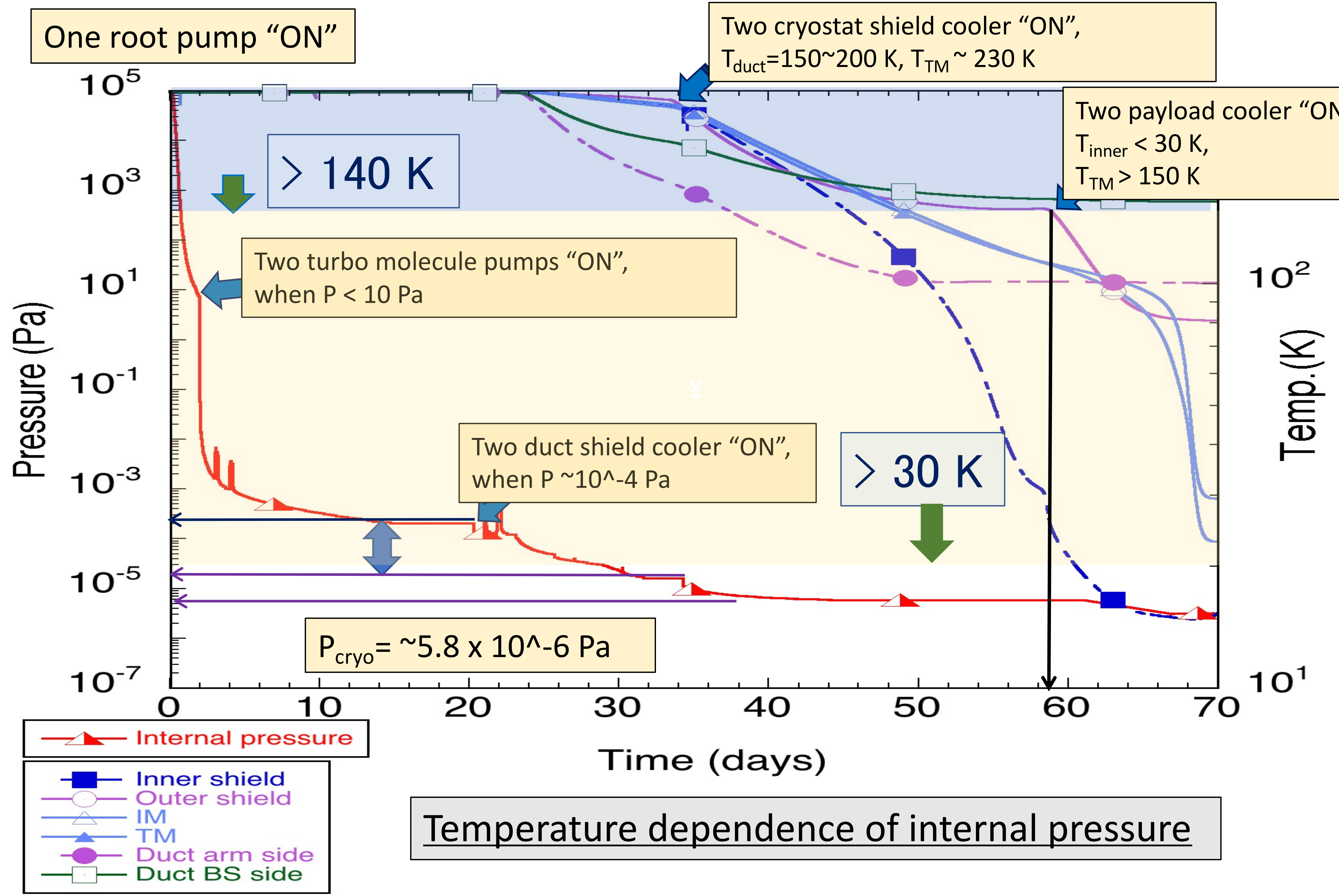
- Performance defrost heaters
- Residual gas measurement during the cooling

✓ Summary of experiment



Temperature dependence of internal pressure

Defrosting experiment using KAGRA cryostat

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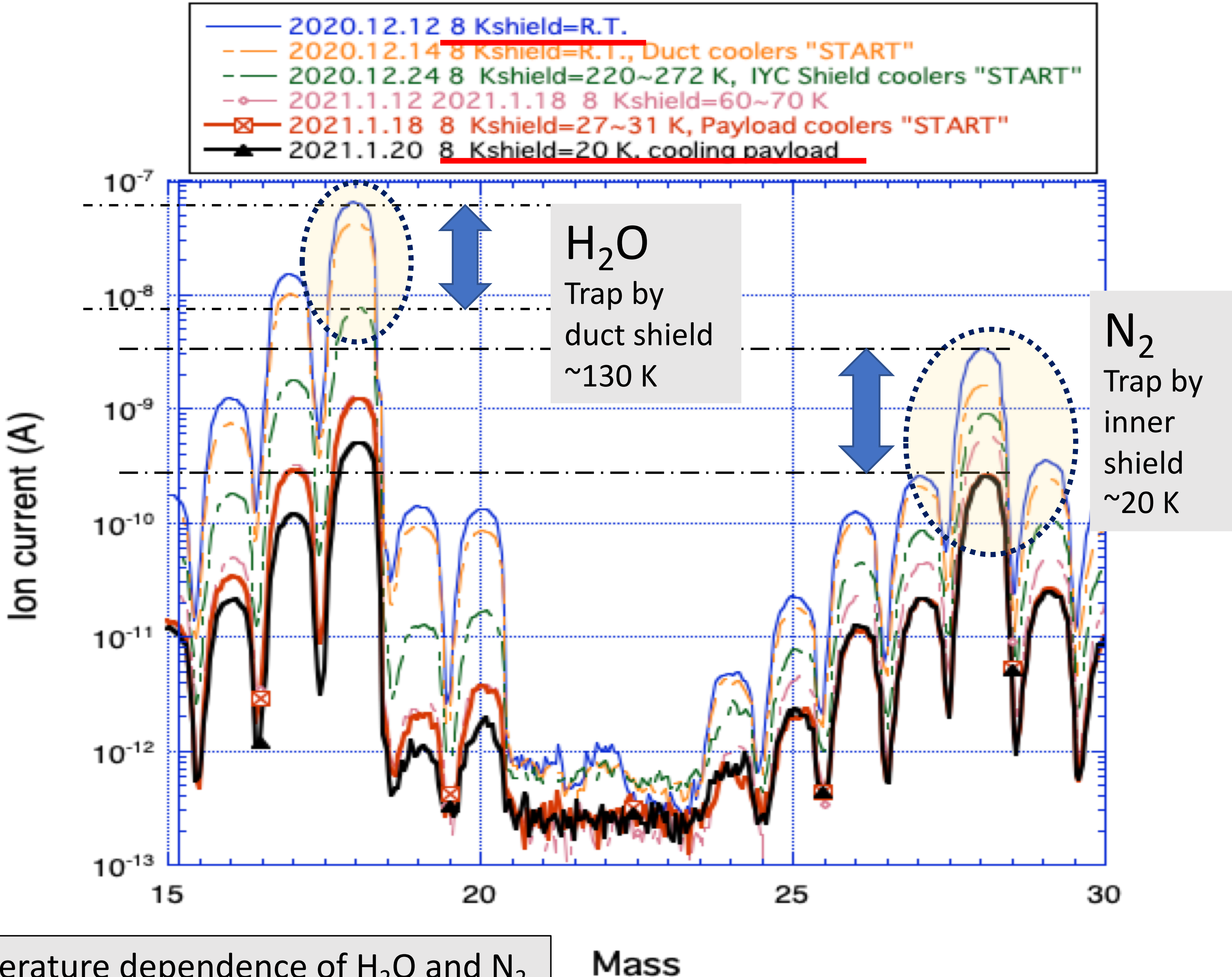
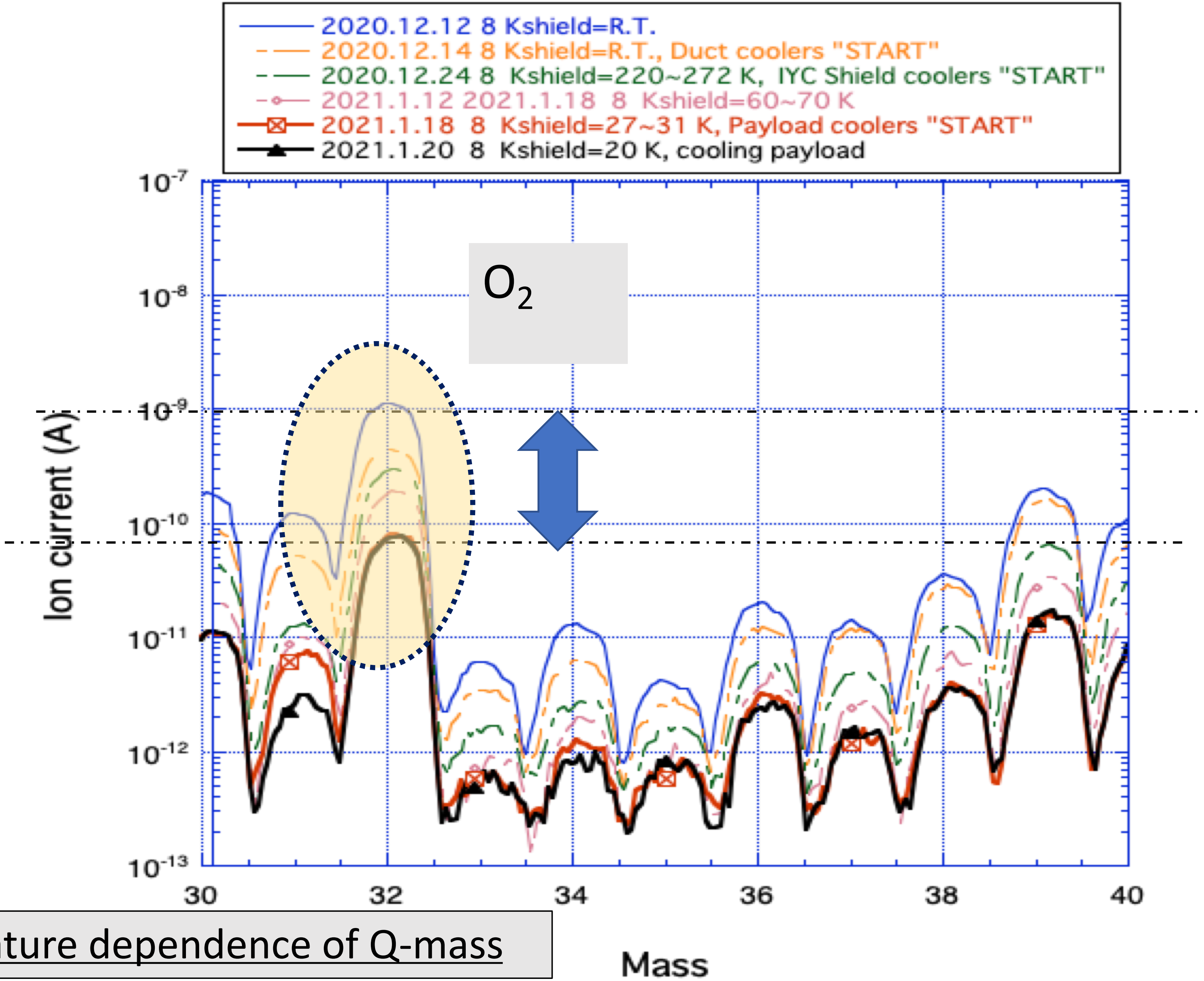


Temperature dependence of H_2O and N_2



Temperature dependence of Q-mass

Defrosting experiment using KAGRA cryostat

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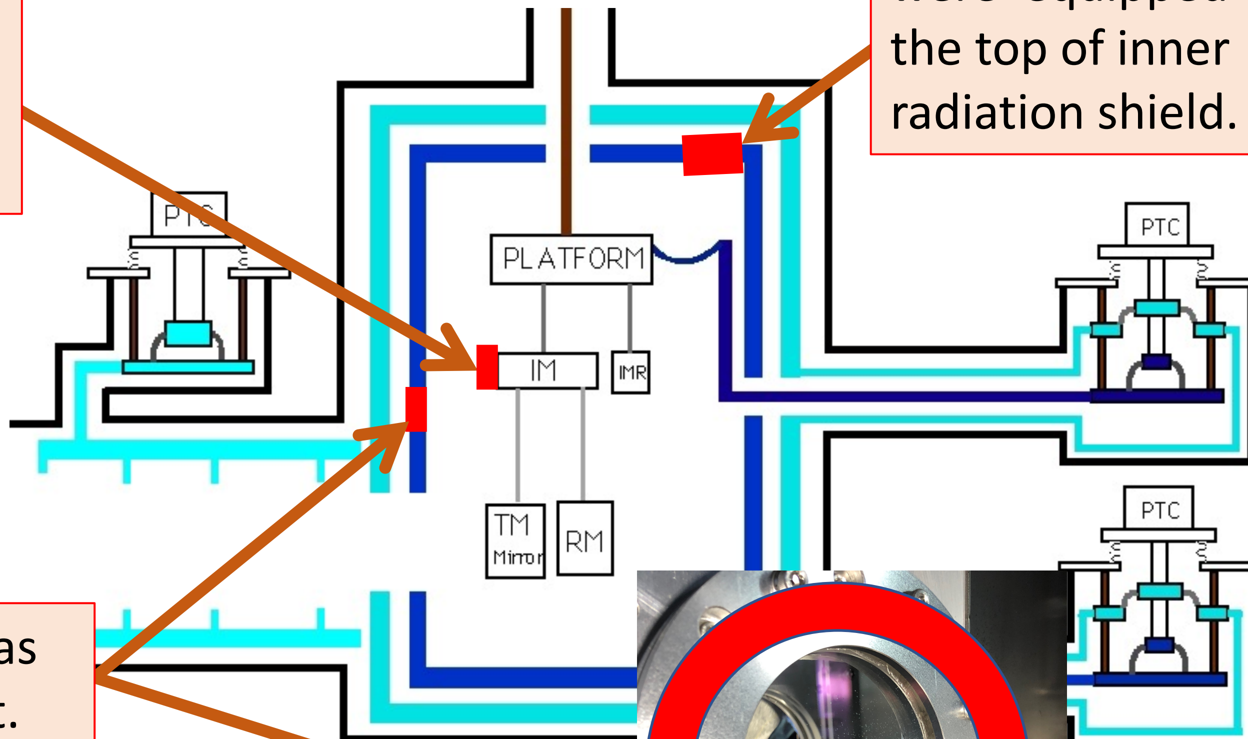
✓ Summary of experiment

Defrost heater layout

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

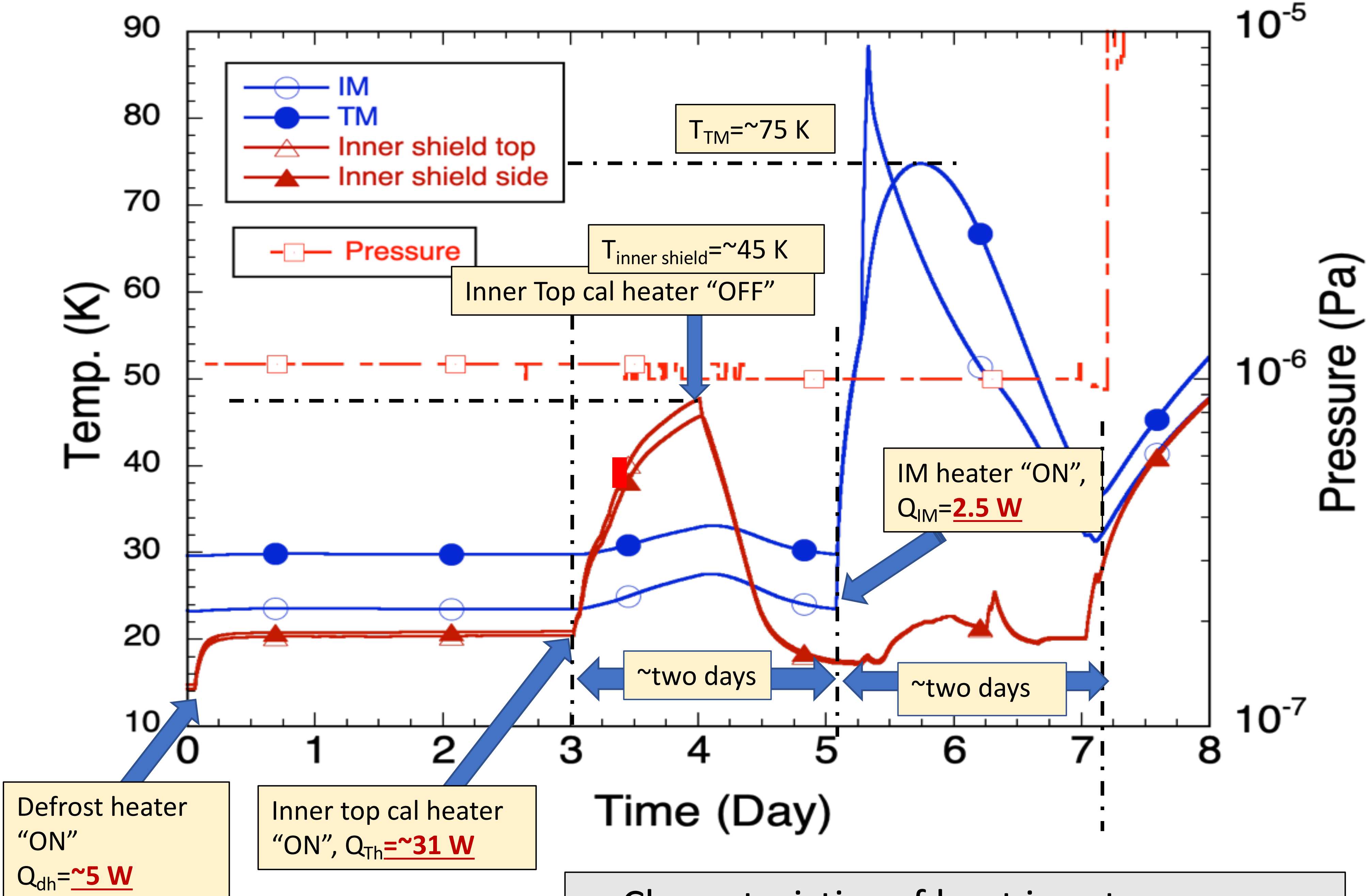
Two calibration heaters were equipped with the top of inner radiation shield.



One defrost heater was attached on view port.

- Three kinds of heaters for defrosting were installed in this experiment.

Image of defrost heater



Characteristics of heat input response

Summary of experiment –1/2–

- 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 with the experiment;
  - ✓Proposed cooling scenario can avoid frosting for O4.
  - ✓Calibration heaters worked well as defrost heaters for view ports on the inner shield. To defrost the view ports on inner shield, it will take **1 days** to warm up to ~50 K (above O_2 vapor temperature of 48 K at 1x10^-5 Pa) , and **1 days** to re-cool down to ~20 K.
  - ✓Heater attached on the IM worked well as defrost heater for mirror.
  To defrost the mirror, it will take **1 days** to warm up to ~70 K,
  (above N_2 vapor temperature of 53 K at 1x10^-3 Pa) , and **1 days** to re-cool down to ~20 K.
  - ✓Partial pressure measurement of residual gas at each temperature was performed, and confirmed frosting components.

Summary of experiment −2/2−

Lessons learned

I. Best effort for minimizing vacuum leak

II. Mitigation of frosting

- ✓Four steps cooling method.
- ✓Defrosting by heaters, when frost is occurred.
- ✓Confirmation no leakage > 10^-10 Pam^3/sec.
- ✓Check continuous measurement of residual gas components in the all of vacuum chambers.

Proposal of the KAGRA cooling scenario for O4

- KAGRA test masses will be cooled down with the same cooling method as same as the defrosting experiments.

  It will take two and half months to reach ~20 K.

- Use the defrost heater to defrosting, when it appear on the surface of the test mass or view port.

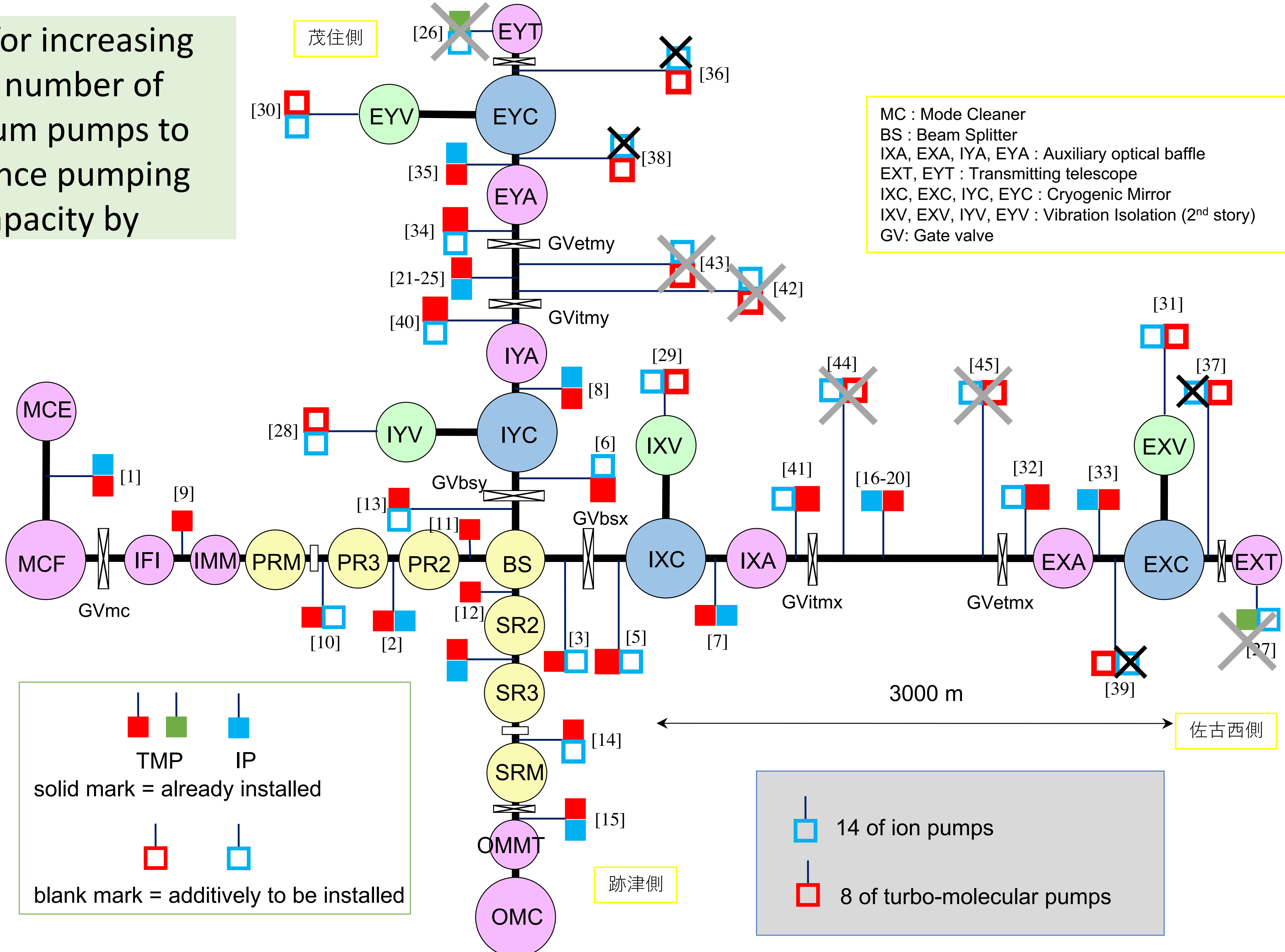
  It needs two days to defrost.

- Reinforce of leak testing to satisfy KAGRA's required specifications < 1x10^-10 Pam^3/s for all of vacuum chambers

Enhancement plan to avoid frosting

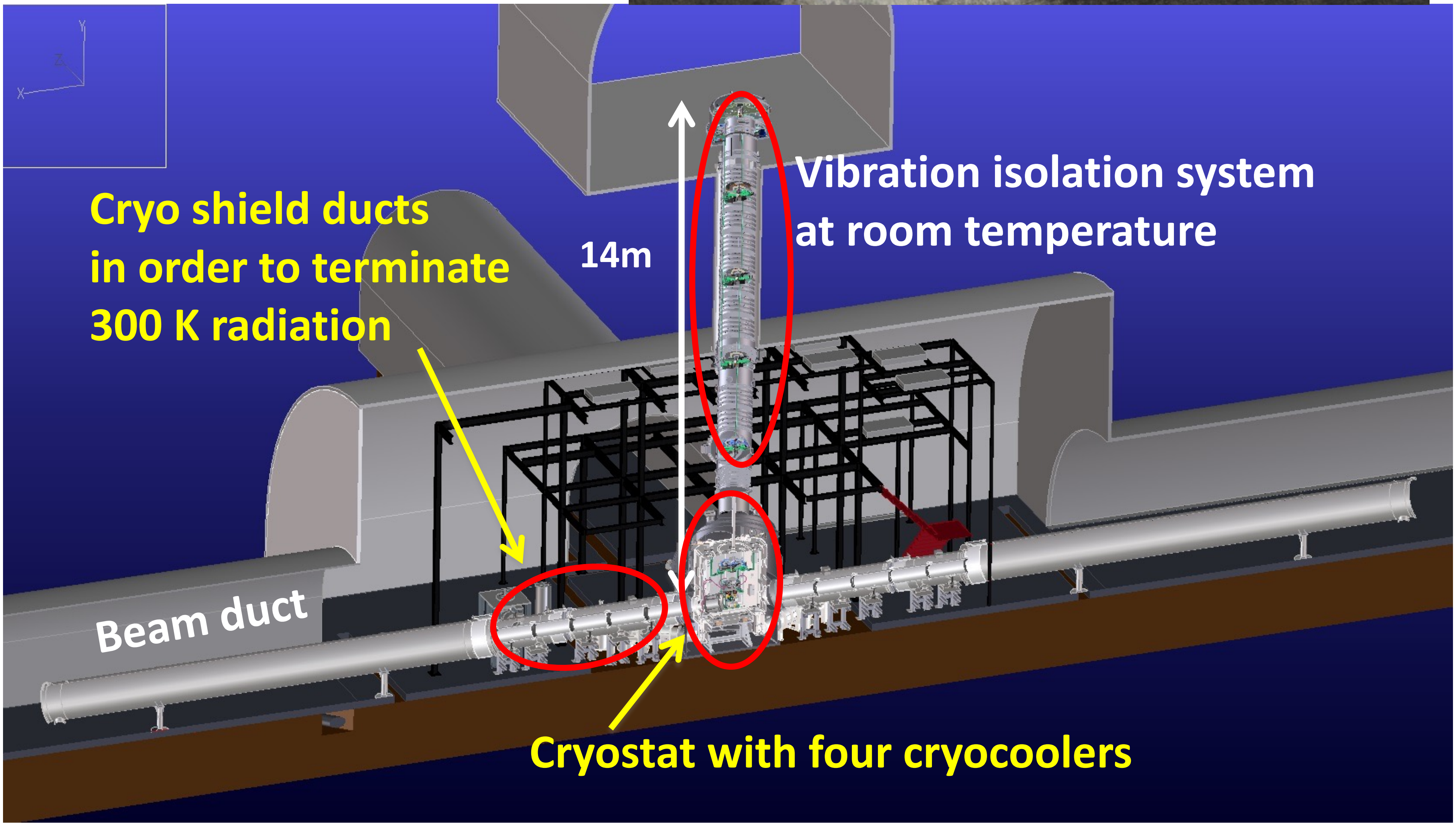
- Enhance pumping capacity by increasing the number of vacuum pumps.
- Especially around the cryostat, to reduce the achieved pressure as much as possible.
- Add process gas monitor, to realize continuous measurement of residual gas components in the vacuum chambers including PR, SR, BS and so on.

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

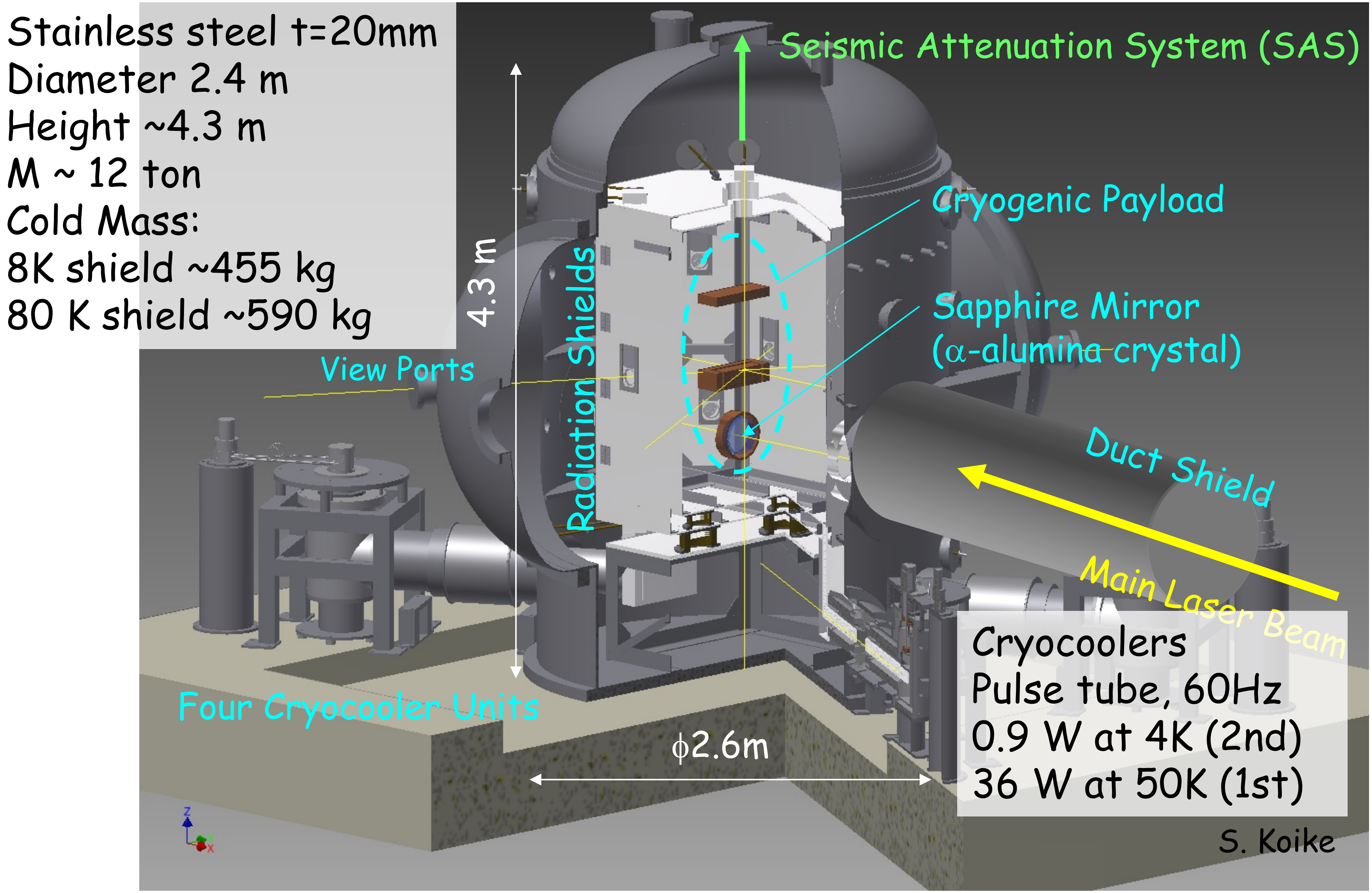


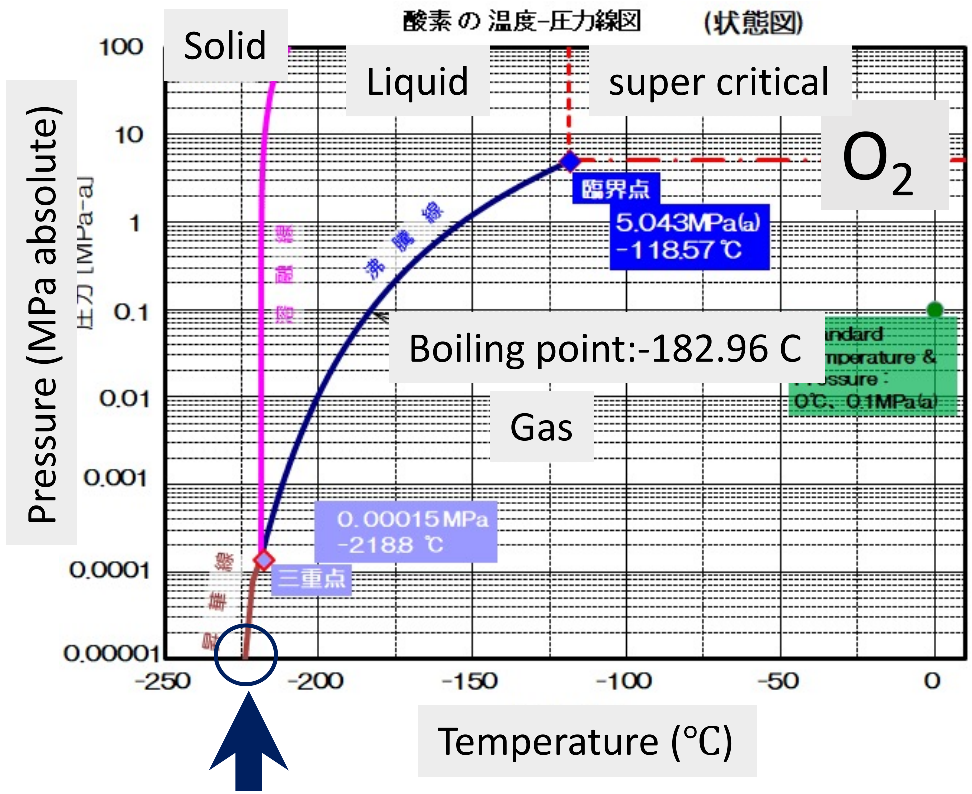
Appendix

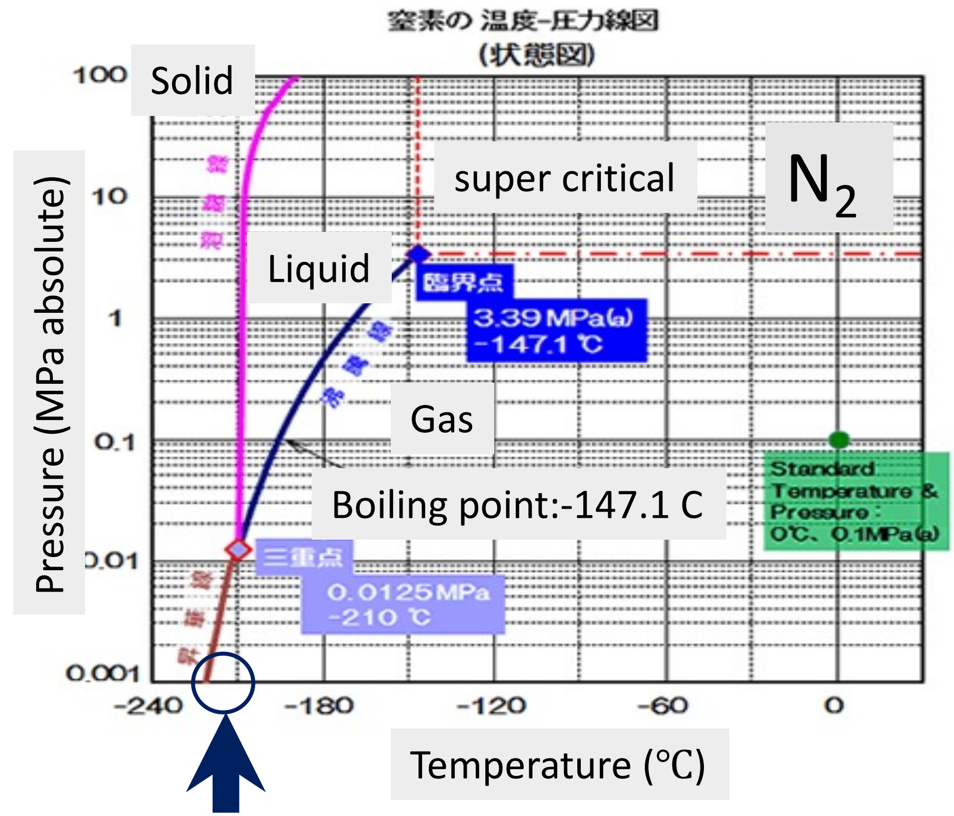
Overview of KAGRA Cryogenics system



Structure of KAGRA Cryostat



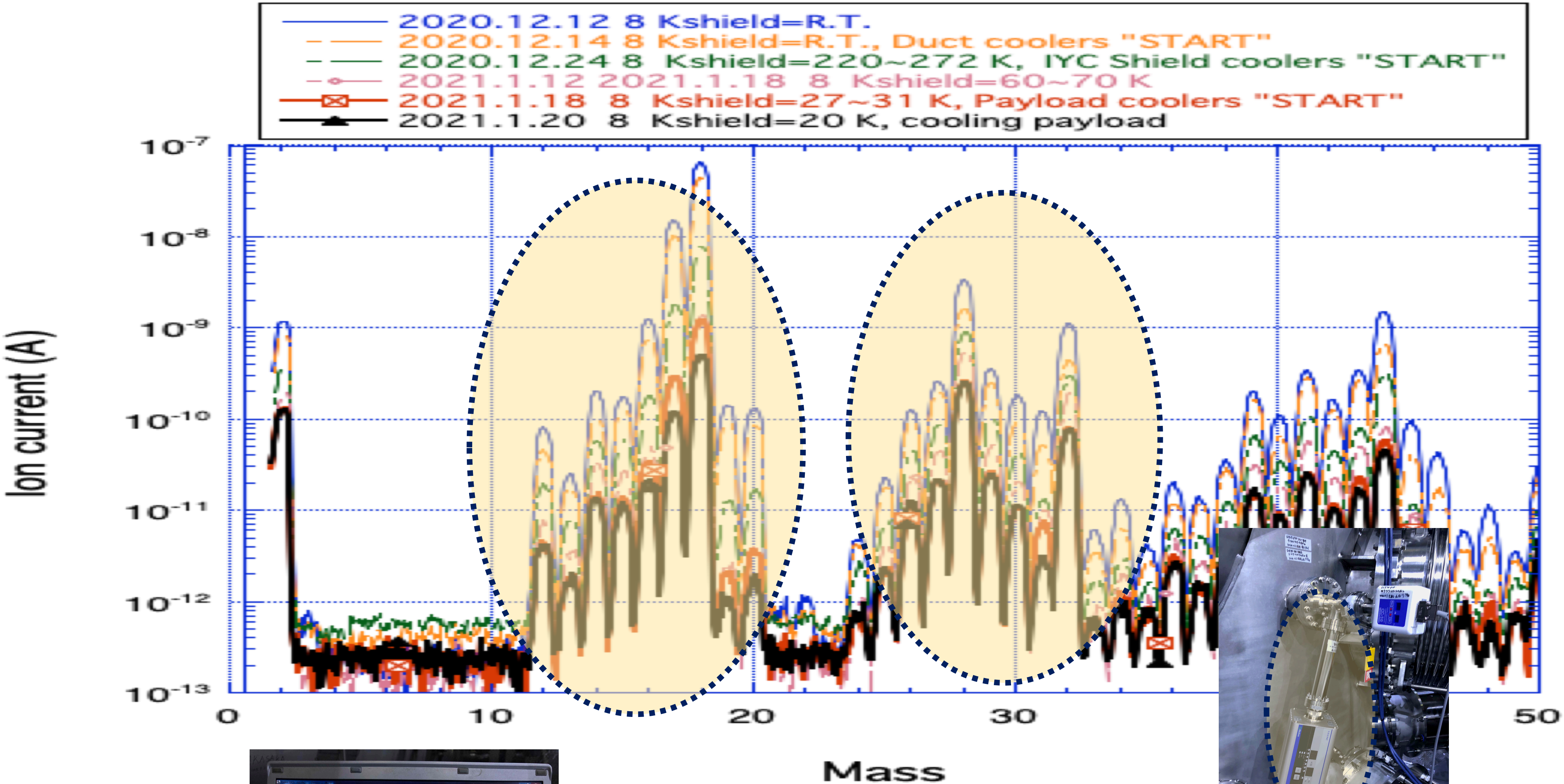


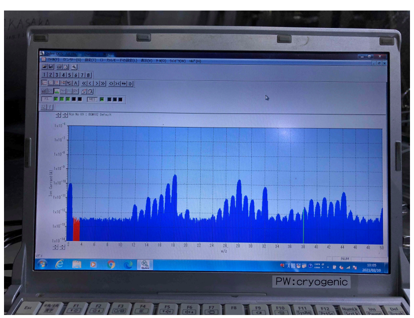


1x10^{-5} Pa → ~-225 ℃ (~48 K)

1x10-3 Pa → ~-220 ℃ (~53 K)

State diagrams of O2 and N2





Temperature dependence of Q-mass