Thermal property measurements of critical materials for SPICA payload module

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Introduction

SPICA

Space Science Mission

L2 orbit, 3m-class large infrared telescope cooled to be below 6K

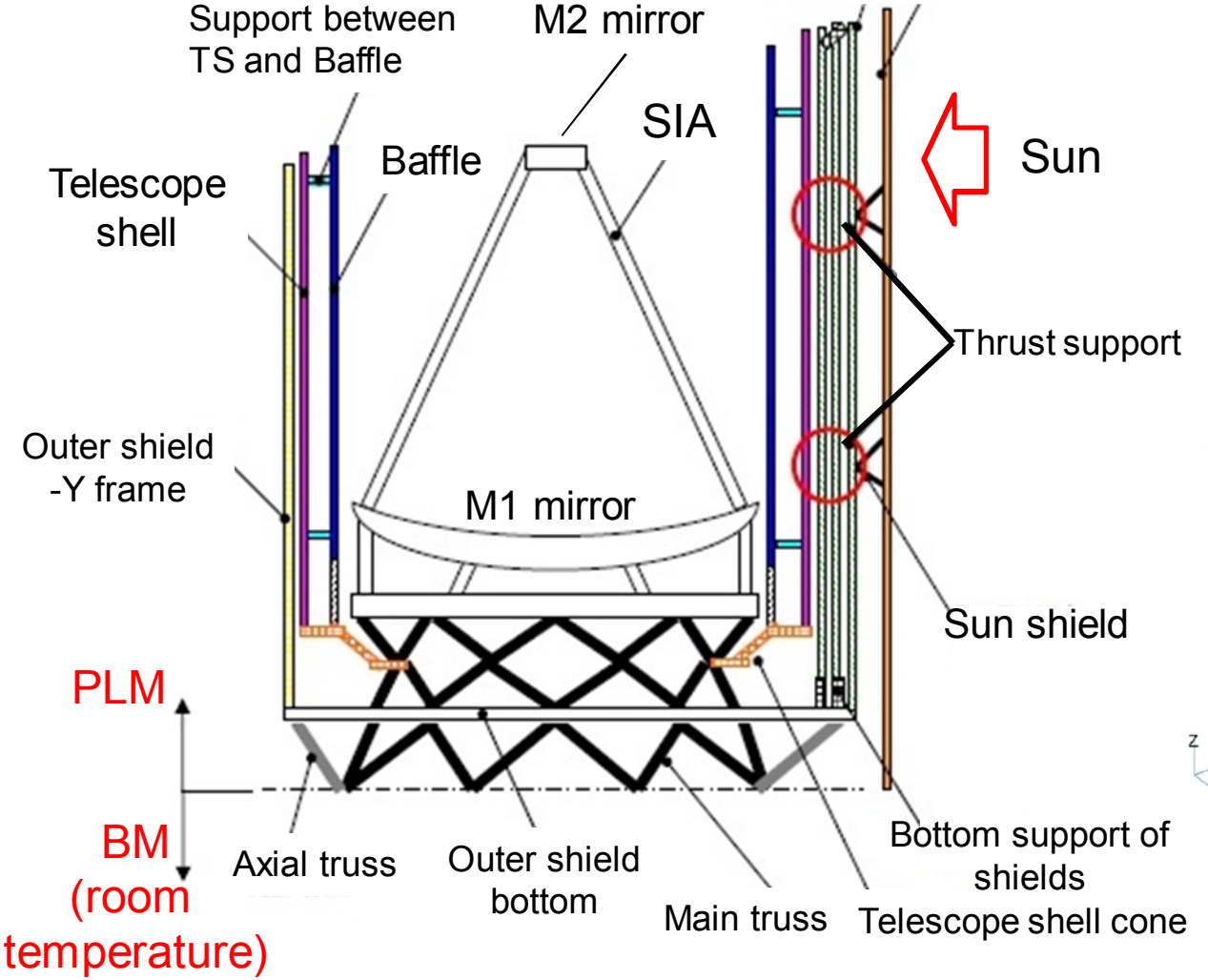
- Scientific Objectives
  - Formation and evolution of galaxies.
  - Interaction between star-formation and material evolution, in galaxies.
  - Formation of planetary systems near and far.
- Telescope: 3.2m (EPD 3.0m), 6 K Superior Sensitivity
- To be launched around 2025.
- 3years of mission life as a requirement (5years as a goal).
- International mission (Japan, Europe, (USA, Korea, Taiwan))

- To cool the large telescope below 6K, mechanical cooler system is used instead of massive cryogen, while effective radiative cooling is available above 15K.

- Risk Mitigation Phase (RMP) between Jan 2012 and Mar 2014.
- **The international collaboration framework and project schedule are now being revisited** due to the stringent budgetary situation in Japan.

1. SPICA payload module

- SIA is supported by main truss from Bus module (BM).
- Baffle, telescope shell, 3 thermal shields and sun shield are assembled.
- SIA is cooled by mechanical cooler system directly.



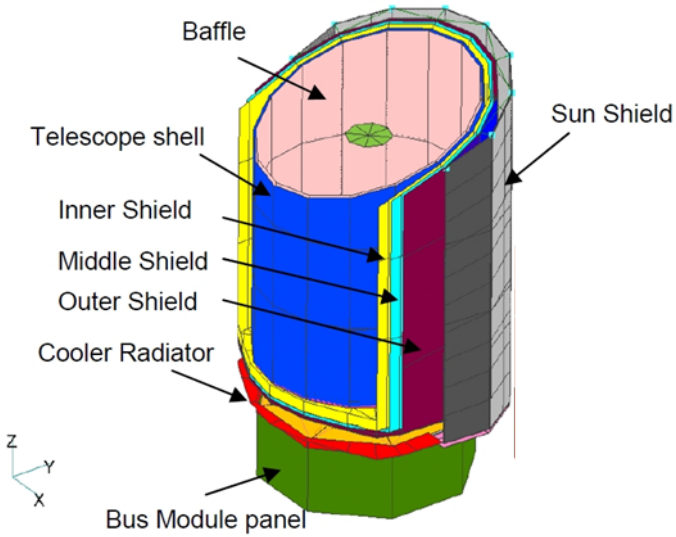


Fig. Schematic drawing of payload module

2. Proposed materials for the SPICA payload modu

Materials	Applications	Temp regions	Measurement			Note
			TC[1)]	SC[2)]	CTE[3)]	
Al-alloy A1050	Thermal shield	10 ~ 150K	○			
Al-alloy A6061	Thermal shield	10 ~ 150K	○			
Al-alloy A6063	Thermal shield	10 ~ 150K	○			
Al-alloy ST-60	Thermal shield	10 ~ 150K	○			Option
Low-k CFRP	Main truss	4 ~ 30K	○	○	◎	
Low-k CFRP 2nd			○	○	○	Reference data
Low-k CFRP 3rd	Truss separation spring	4 ~ 30K	○			
High-k CFRP	Thermal shield	10 ~ 150K	○	○	◎	Option
AFRP	Main truss	30 ~ 250K	◎	○	◎	
GFRP	Thrust truss	15 ~ 210K	○			
Manganin	Harness	4 ~ 300K				
Ph-Br	Harness	4 ~ 300K				
SUS304	Harness	4 ~ 300K				
Teflon	Harness	4 ~ 300K				

1) TC : Thermal conductivity, 2) SC : Specific heat, 3) CTE : Coefficient of thermal expansion

○: measured
◎: measured and updated in thermal model analysis

3. Research, compare and measurement of thermal properties

◆ General lack of physical property of materials are one of major concern and one of highest risk in the thermal structure design of SPICA payload module.

◆Approach

1. The thermophysical values for all materials were researched from a range of literatures.
2. The value used in the thermal study was selected by comparing these literature values for each component.
3. Unreliable thermal property materials were determined (few literature, significant discrepancy between each piece of literature, literature is too old).
4. Material samples were fabricated and measured.
5. Compare and newly included in thermal study.

◆ As a result, all FRP materials and Al-alloys have been measured.

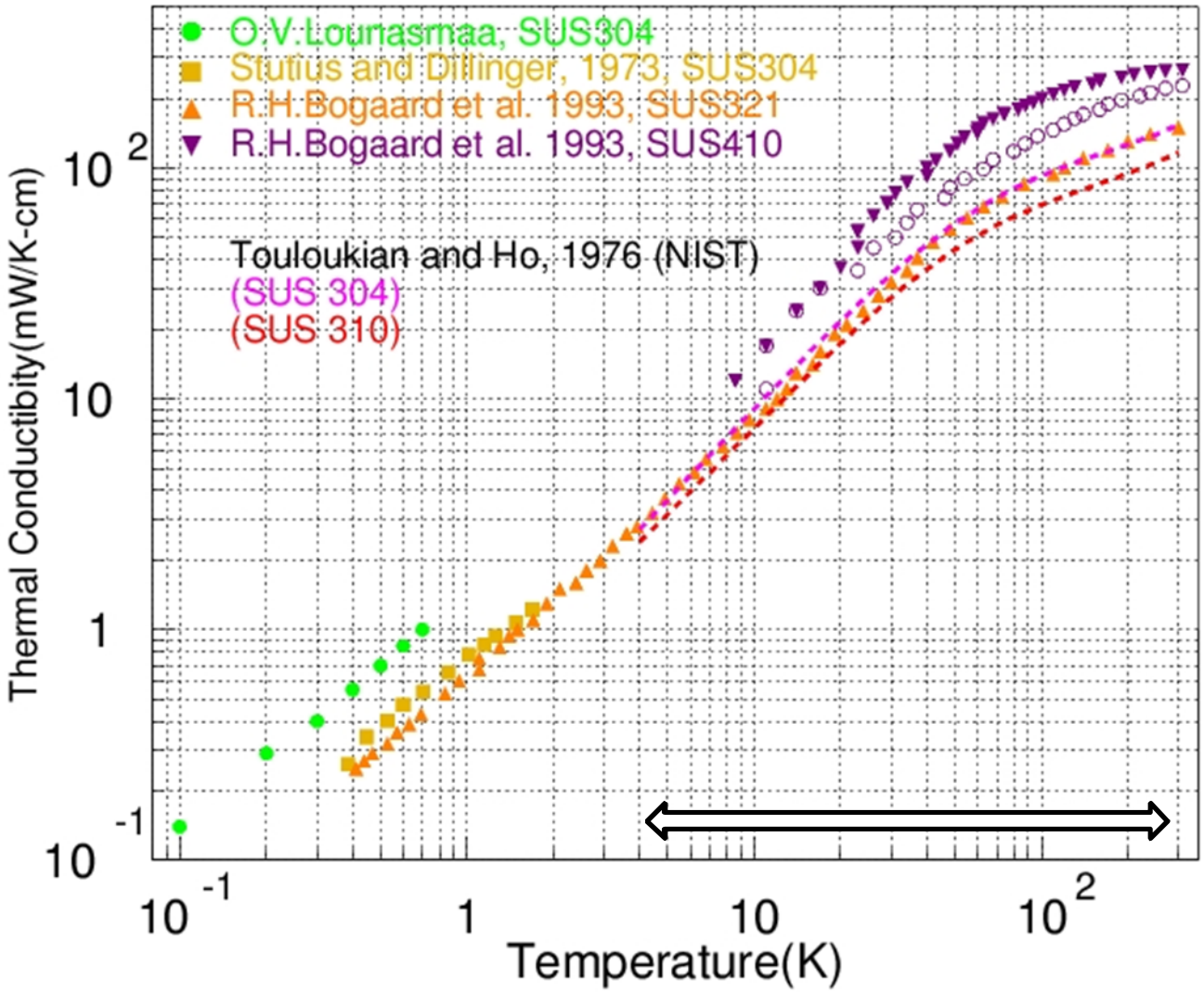
◆ Better choice for each component

	Thermal conductivity	Specific heat	Density (Mass)	Strength (tension, compression)	Young modulus
Main truss	Lower	Lower	Lower	Higher	Higher
Thermal shields	Higher	Middle?	Lower	Higher	Higher
Harness	Lower	Lower	Lower	Higher	Higher

4. Thermal property of SUS 304

◆ Thermal conductivity of stainless steel in various literature

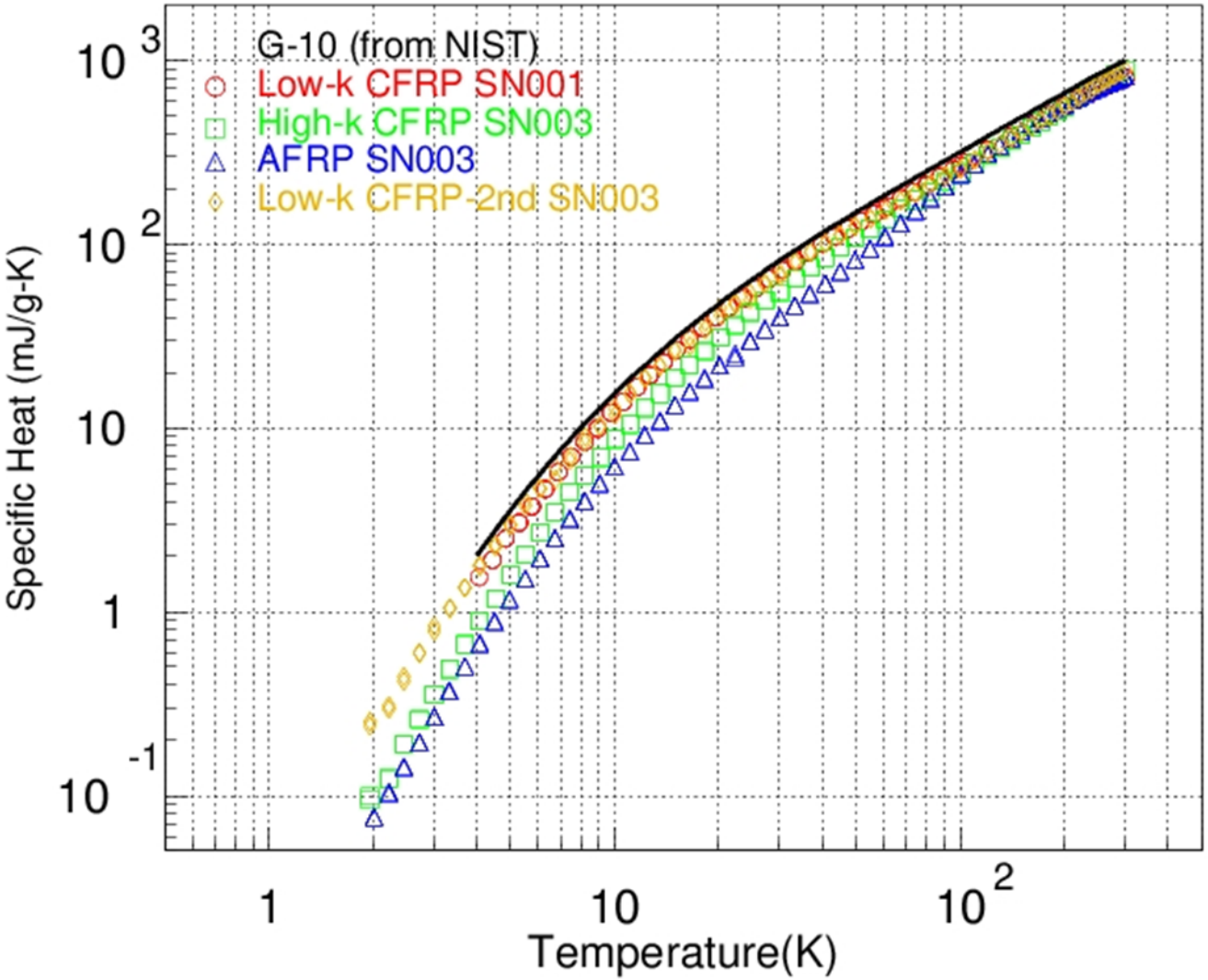
- SUS304 is almost same value between 4~300K with a range of literature.
- Then, large difference between different classification in stainless steel. The value used in thermal study should be selected carefully.



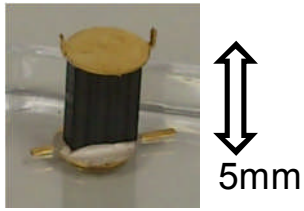
5. Specific heat measurements of FRPs

◆ Comparison of measured FRP samples with G-10 (GFRP) reference value (NIST).

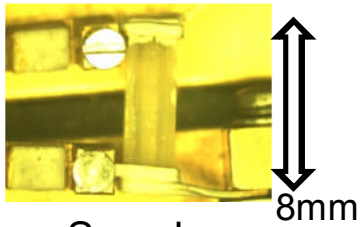
- All 4 kinds of samples were lower specific heat than G-10 reference value.
- It is better to use the G-10 value in order to provide a design margin for the thermal transient analysis during the initial cooling after launch.



PPMS
(Quantum Design)



Sample
(Specific Heat)



Sample
(Thermal conductivity)

6. Thermal conductivity measurement

- High-k CFRP samples (left)
  - High-k CFRP (made of high thermal conductivity fiber) was proposed for the use of thermal shields.
  - Though measured values showed higher than low-k CFRP, 10 times lower than target values. Therefore, thermal shield design was replaced to the Al-alloy honeycomb structure instead of using the high-k CFRP. Then, another high-k sample is under investigation.
- AFRP samples (right)
  - Measured value exceeds the reference values between 20 and 100K.
  - AFRP value was replaced to the measured value in thermal study.

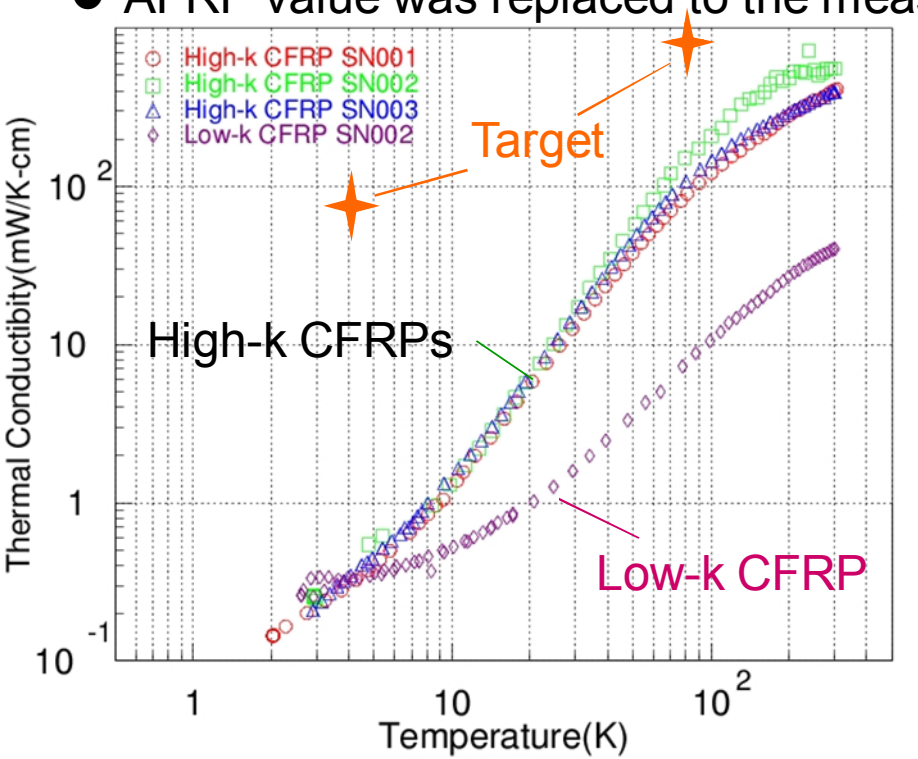


Fig. High-k CFRP

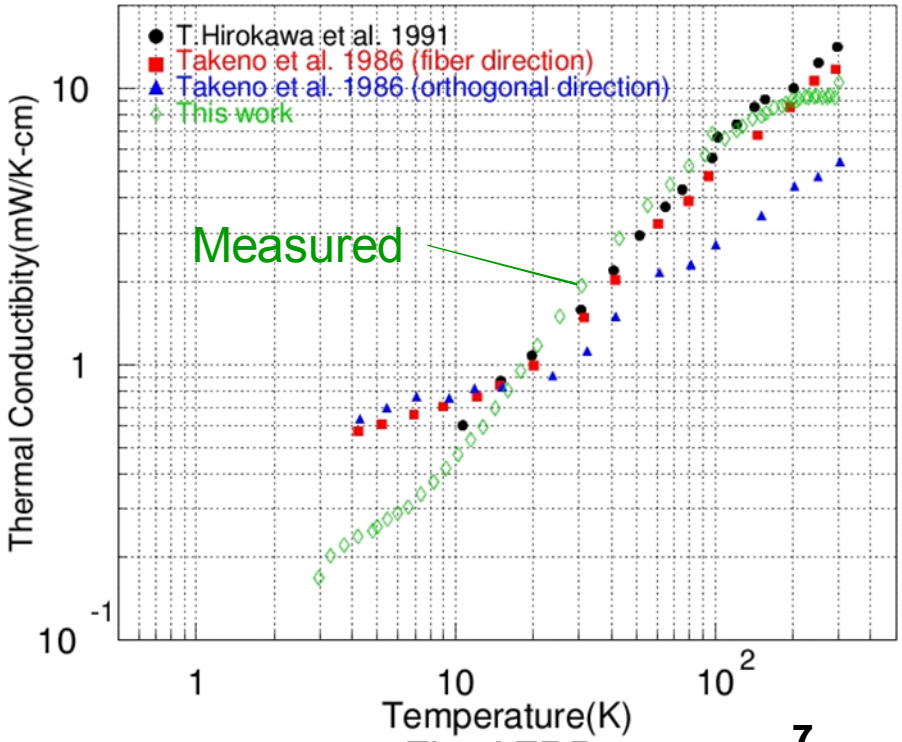


Fig. AFRP

Summary

- Thermophysical property of materials is one of the most critical issue in cryogenic missions like SPICA payload module.
- Thermophysical values for all proposed material were researched from number of literatures, and critical material which should be measured were determined. All FRP material and Al-alloy were measured and compared to other reference values. Most results were favorable and had little impact on the thermal design.
- All the measured specific heat of FRP samples are lower than the G-10 reference value (NIST) used in past thermal model analysis, and we confirmed that it is better to use the G-10 reference value in order to provide a design margin for the payload module.
- The measured value of the high-k CFRP sample was over 10 times lower than the target value, and the thermal shield design has been replaced to the Al-alloy honeycombed structure instead of using the high-k CFRP material.
- The thermal conductivity of AFRP material in the thermal design have been updated to the measured value.
- **The concern of thermal property has been well reduced.**

Appendix. Mechanical cooler system for SPICA

◆ Mechanical cooler system

- Current baseline of the mechanical cooler system
  - (2 × 4K-JT + 3 × 2ST) + (2 × 1K-JT + 3 × 2ST) with no heat switches
  - Mass, power, and number of cooler drivers are acceptable in bus module study.
- The mechanical cooler system must be verified before the thermal vacuum test of the structure thermal model of payload module.
  - 2ST cooler : The EM development has been successfully finished. The FM for Astro-H/SXS is under fabrication (7.4 Sato-san's presentation).
  - 4K-JT cooler : The EM development has been successfully finished. No apparent degradation of the cooling performance during 2.4years in life time test.
  - 1K-JT cooler : The EM is now under fabrication and performance measurement.
  - The cooler system verification including the combined test between JT coolers and SAFARI sub-K cooler is planned.

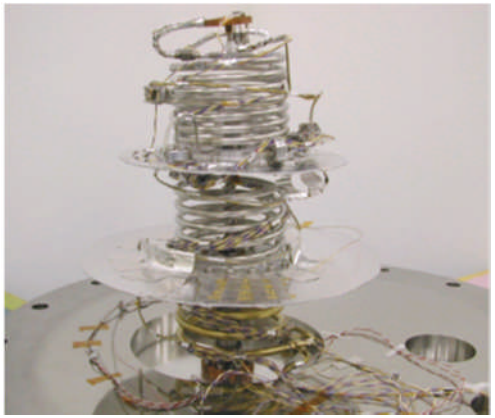


Fig. 1K-JT BBM cooler

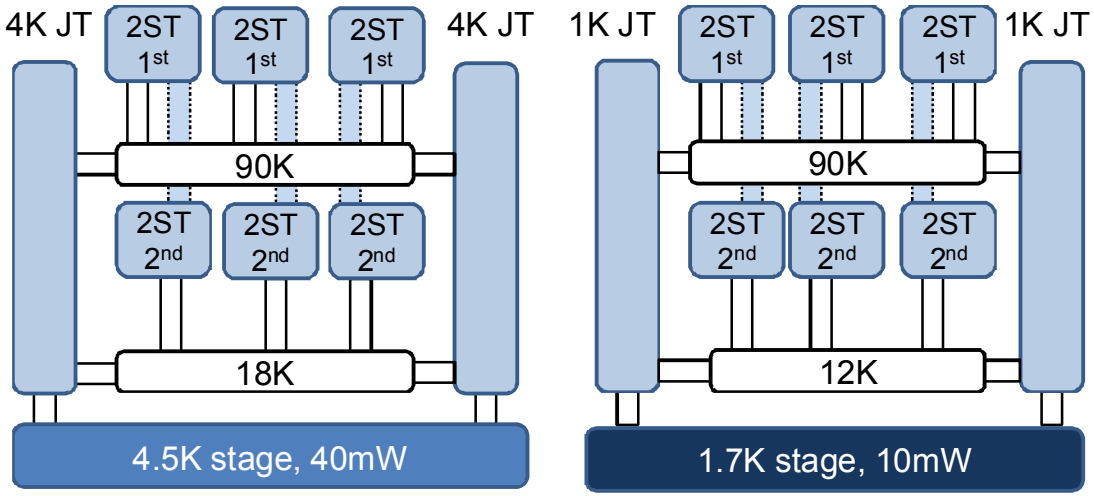


Fig. Current baseline of cooler system

Appendix. Thermal conductivity of GFRP

◆ Comparison of GFRP thermal conductivity in various literature.

- The value used in SPICA thermal study (▼) shows higher than other reference values except Ross Jr. 2004 (■, S-glass). Accordingly, the GFRP measured value showed drastically lower.