Mechanical Coolers Operating below 4.5 K for Space Application

- Introduction
- 4 K-class Cooler for SMILES
- 1 K-class Cooler for SPICA
- Mechanical Cooler below 0.1 K
- Conclusions

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Summary of Cooler Development at SHI

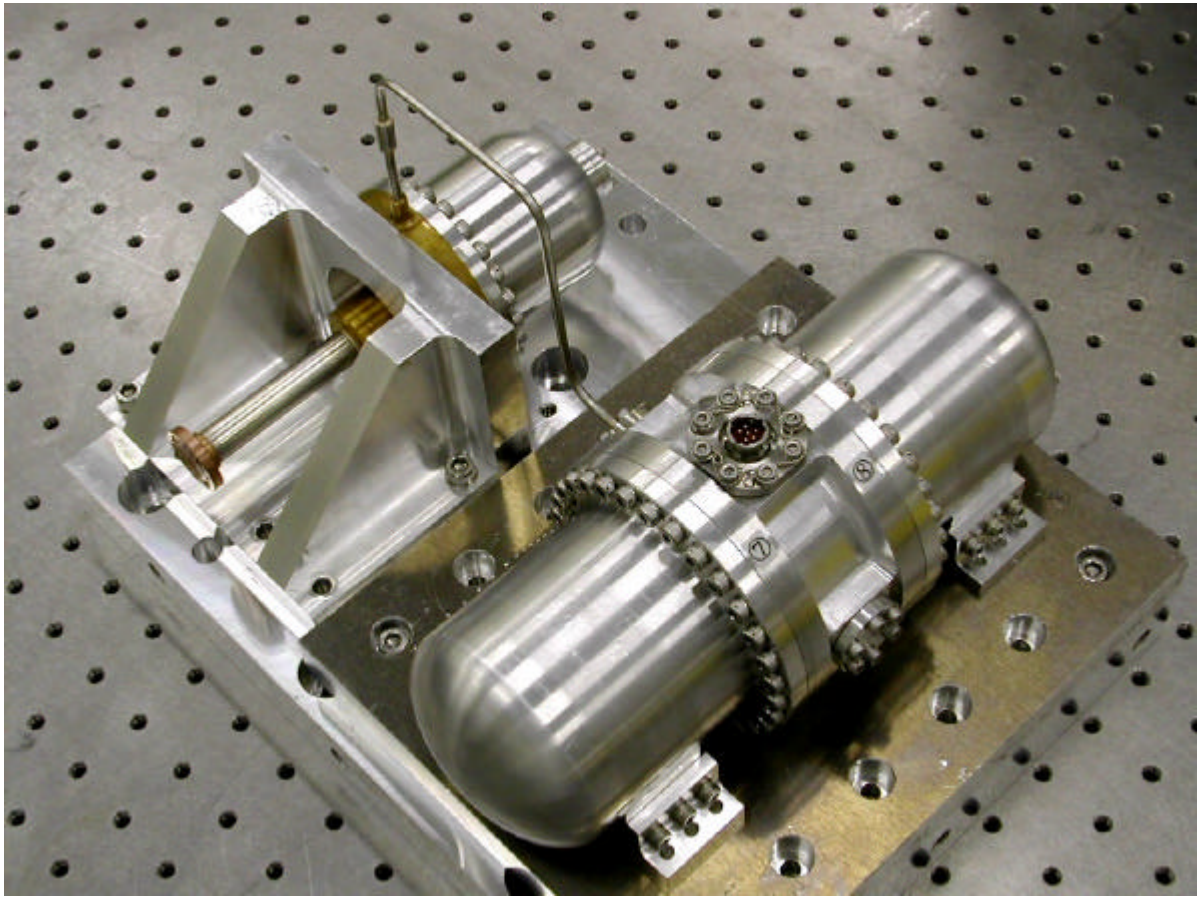
Cooler	80 K Cooler	20 K Cooler	4 K Cooler	1 K Cooler	0.05 K Cooler
Mission / Project in Japan	SELENE/GRS SUZAKU/XRS Planet-C/IR2	AKARI VSOP-2	JEM/SMILES SPICA	SPICA NeXT	NeXT
Cooling purpose	Ge Detector VCS CCD Camera	VCS Low Noise Amp.	Submillimeter Detector Telescope 、 FPI	Infrared detector Pre-cooer	X-ray detector
Cooler Type	1ST	2ST	2ST+4HeJT	2ST+3HeJT	ADR
Present Status	FM	FM	FM	BBM	BBM
Cooling capacity	2 W / 80 K	0.2 W / 20 K	20 mW / 4.5K	10 mW / 1.7 K	10 μW/ 0.05 K
Power consumption	50 W	80 W	120 W	180 W	TBD
Mass of Cooler	4.2 kg	9.5 kg	23 kg	25 kg	TBD

Note 1ST: Single stage Stirling cooler, 2ST: Two-stage Stirling cooler , JT: Joule-Thomson cooler
ADR: Adiabatic demagnetization refrigerator

Single-Stage Stirling Cooler

The features of this cooler are moving cylinder, clearance seal by diaphragm spring, twin pole magnet system, pneumatically driven displacer and twin configuration for momentum compensation.

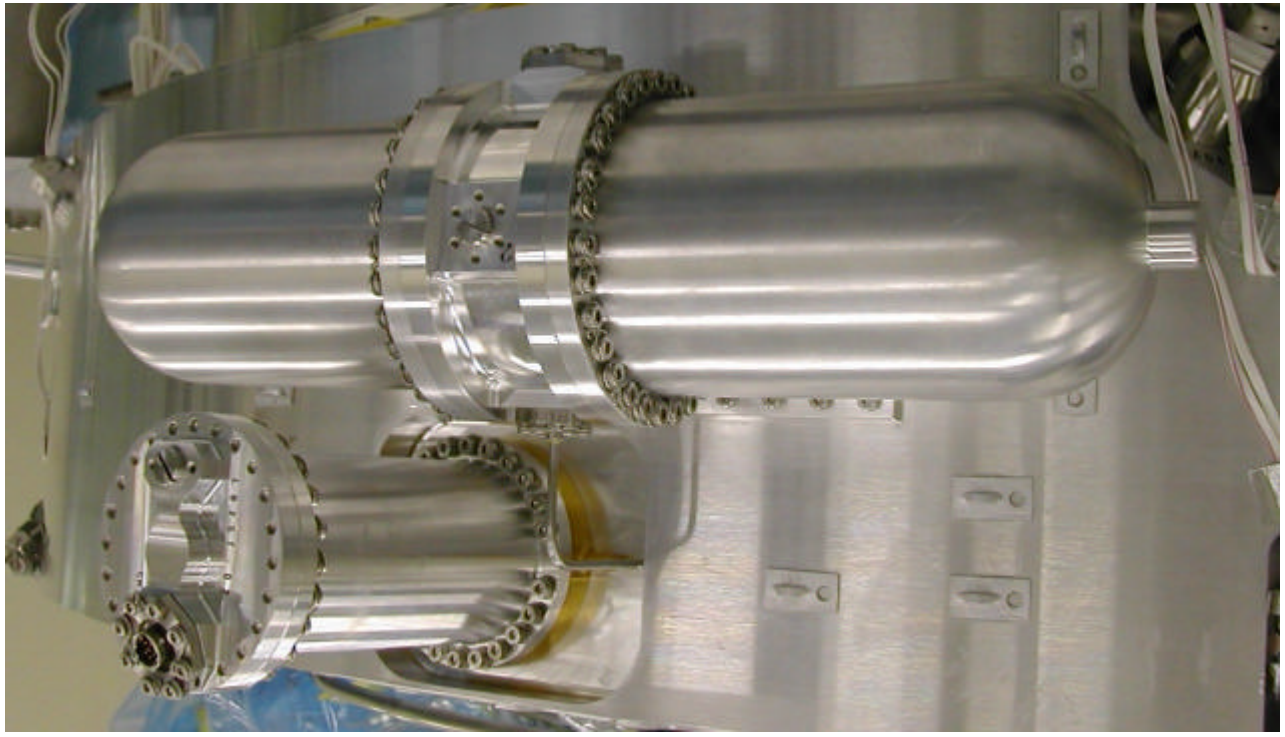
Items	Specifications
Cooling Capacity	2W at 80 K
Power Consumption	≦50 W for 2W
Life Time (Design)	≧5 years
Mass	≦4.2 kg
Size	Compressor : ϕ98X 230L(mm) Cold Head : ϕ78X180L(mm)
Operating frequency	52 Hz



Two-Stage Stirling Cooler

The Cooler has a two-stage displacer driven by a linear motor in a cold head and a new linear-ball-bearing system for the piston-supporting structure in a compressor. The linear-ball-bearing supporting system achieves the piston clearance seal, the long piston-stroke operation and the low frequency operation.

Items	Specifications
Cooling Capacity	200 mW at 20 K 1 W at 100K
Input Power	≦90 W
Life Time (Design)	≧5 years
Mass	≦9.5 kg
Size	Compressor : ϕ106X 390L(mm) Cold Head : ϕ81X320L(mm)
Operating frequency	15 Hz

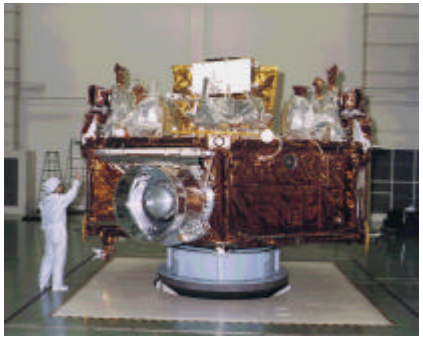


Evolution of Cryogenic System below 4.5 K

Cryogen

Infrared Telescope in Space:

IRTS (1995)



Cryogen: HeII
Temp.: 1.8K
Lifetime: 1M

Infrared Astronomical Satellite:

IRAS

Cosmic Background Explorer:

COBE

Infrared Space Observatory:

ISO

Space Infrared Telescope Facility:

SIRTF

Cryogen＋Cooler

Infrared Imaging Surveyor：

AKARI (2006)

Cryogen: HeII
Cooler: 2st Stirling
Temp.: 1.7K
Lifetime: 1.5Y

X-ray Astronomical Satellite:

Suzaku (2005)

Cryogen: HeII
SNe
Cooler: 1st Stirling
ADR
Temp.: 50mK
Lifetime: 2.5Y

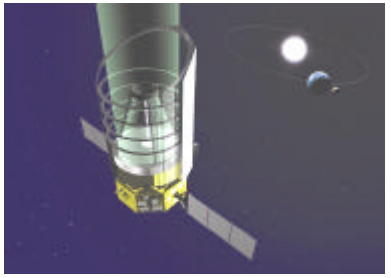
Cooler only

JEM/SMILES (2008)

Cooler: JT＋2st Stirling
Temp.: 4.5K
Lifetime: 1Y

SPICA (2012)

Cooler: JT＋2st Stirling
Temp.: 1.7K/4.5K
Lifetime: 5Y

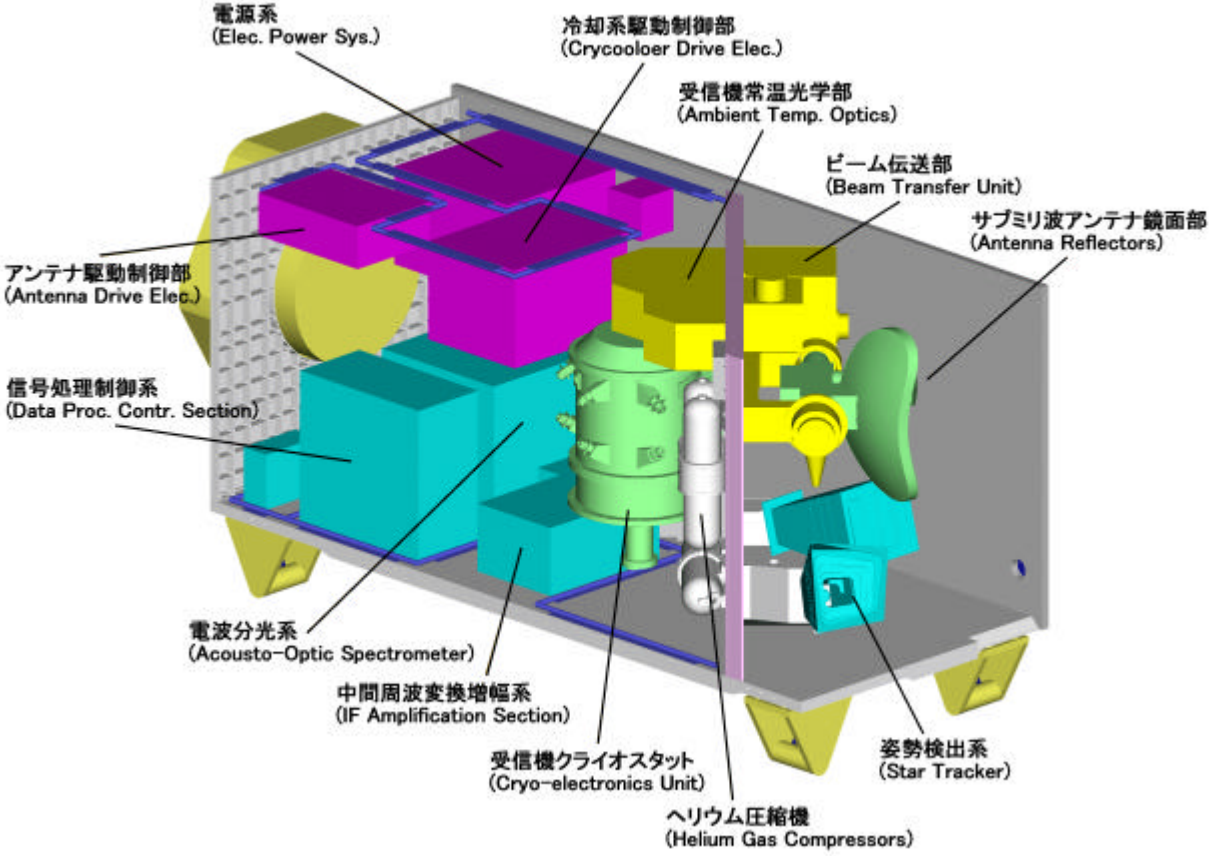


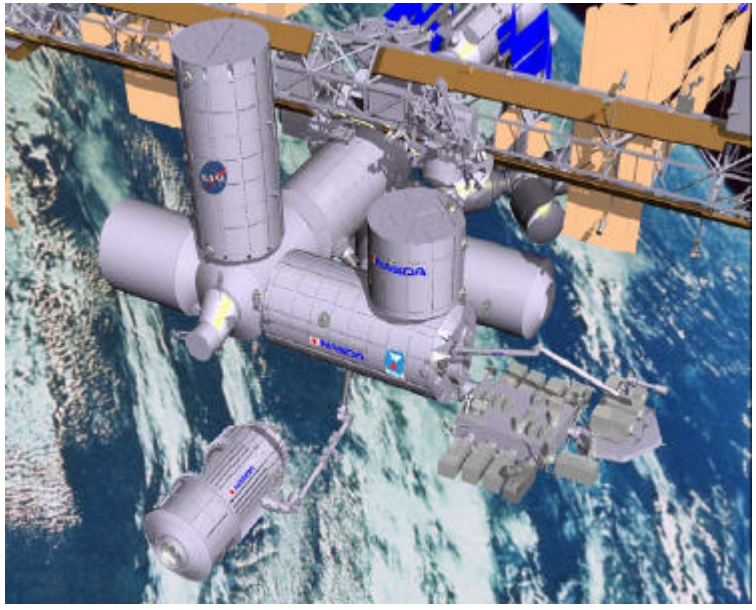
NeXT (2012)

Cooler: JT＋2st Stirling
ADR
Temp.: 50mK
Lifetime: 5Y

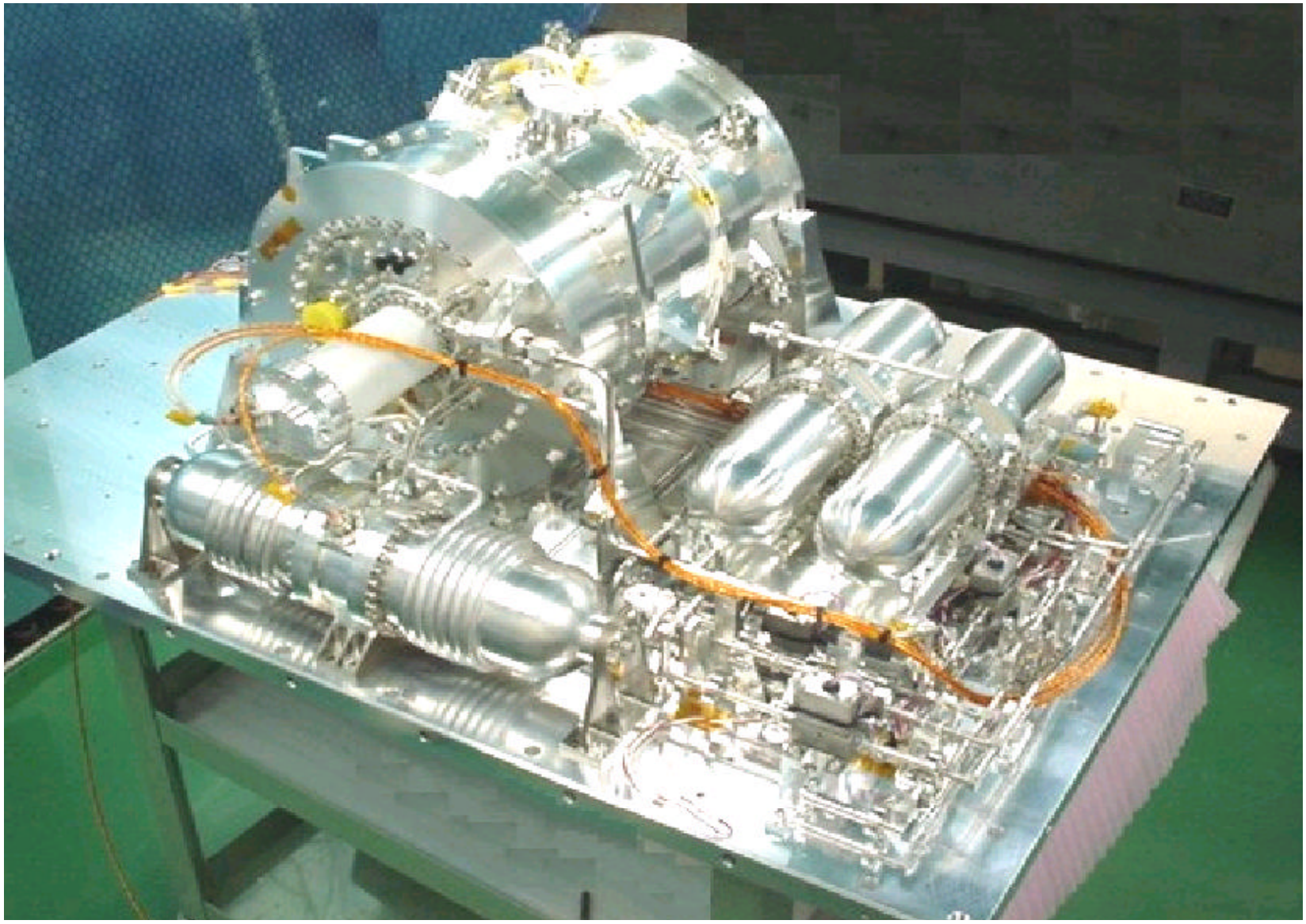
JEM / SMILES

Superconducting Submillimeter-Wave Limb-Emission Sounder (SMILES) is to be operated aboard the International Space Station (ISS). SMILES uses two Superconductor-insulator-superconductor (SIS) mixers for submillimeter-wave atmospheric observation, and they are cooled to 4 K level. SMILES is aimed at probing into chemical processes related to ozone depletion by means new submillimeter technology such as SIS mixers and a 4K cooler.





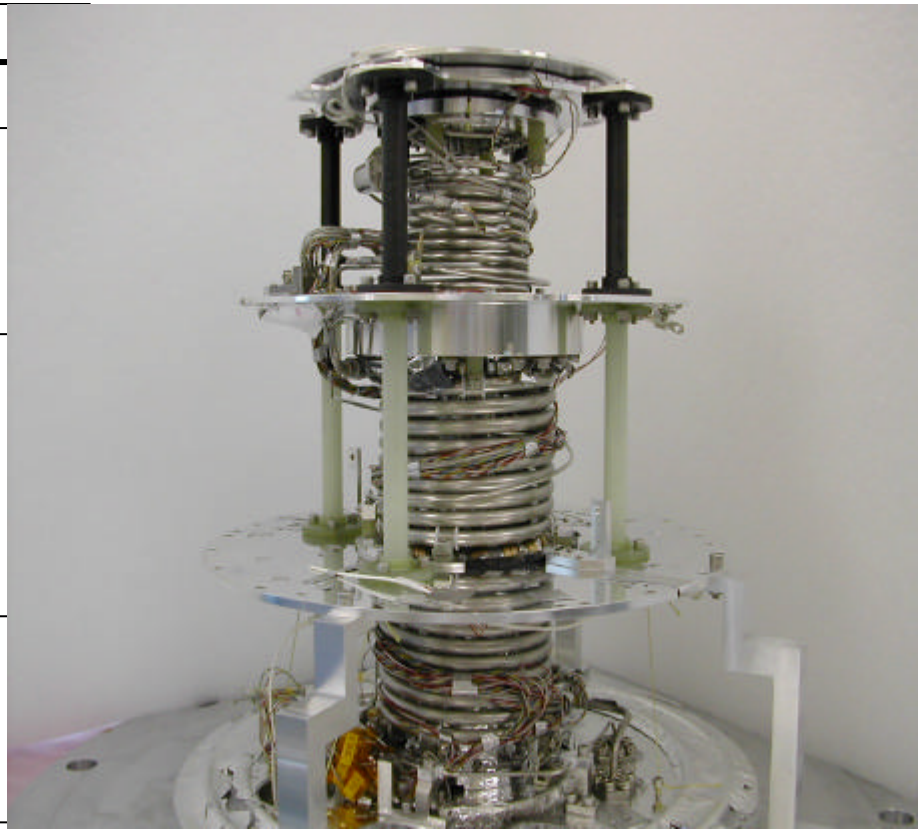
Photograph of Cryogenic System Assembly for SMILES



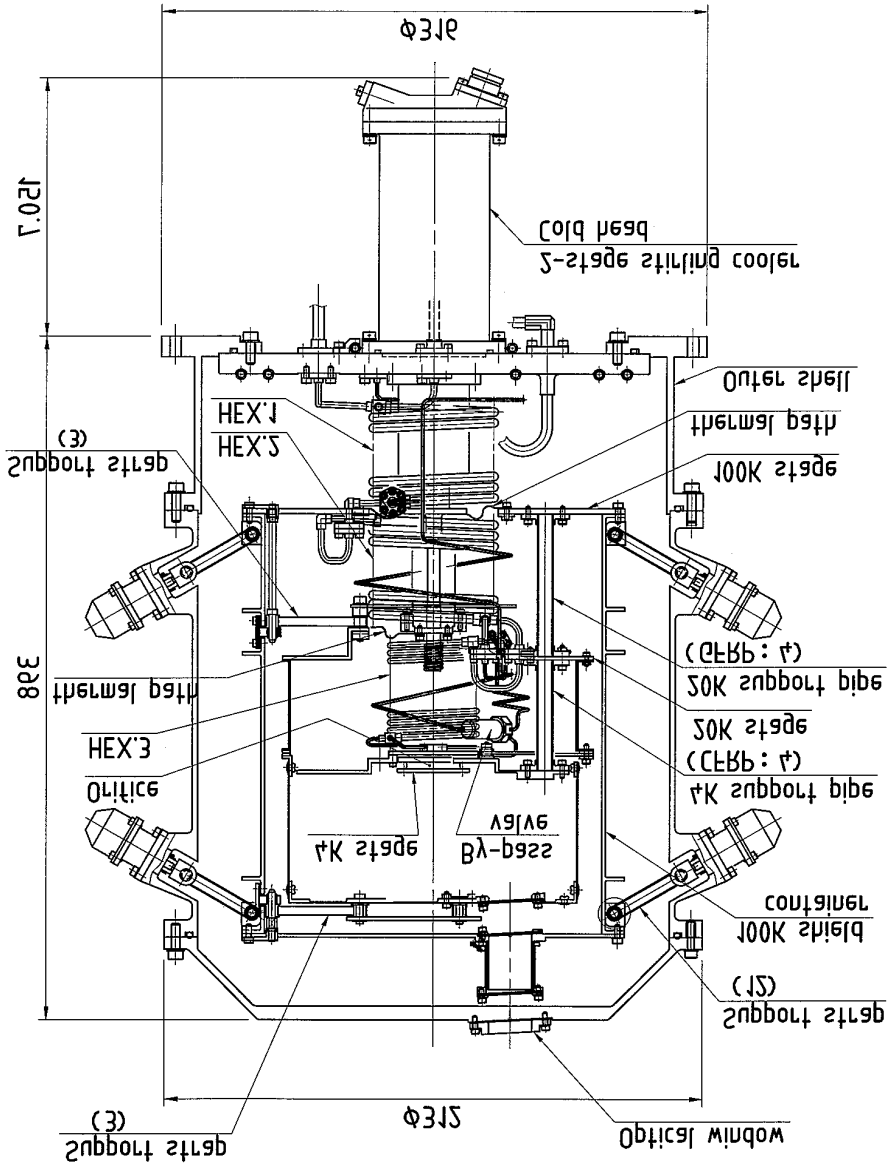
Design Specification of 4K-class Cooler

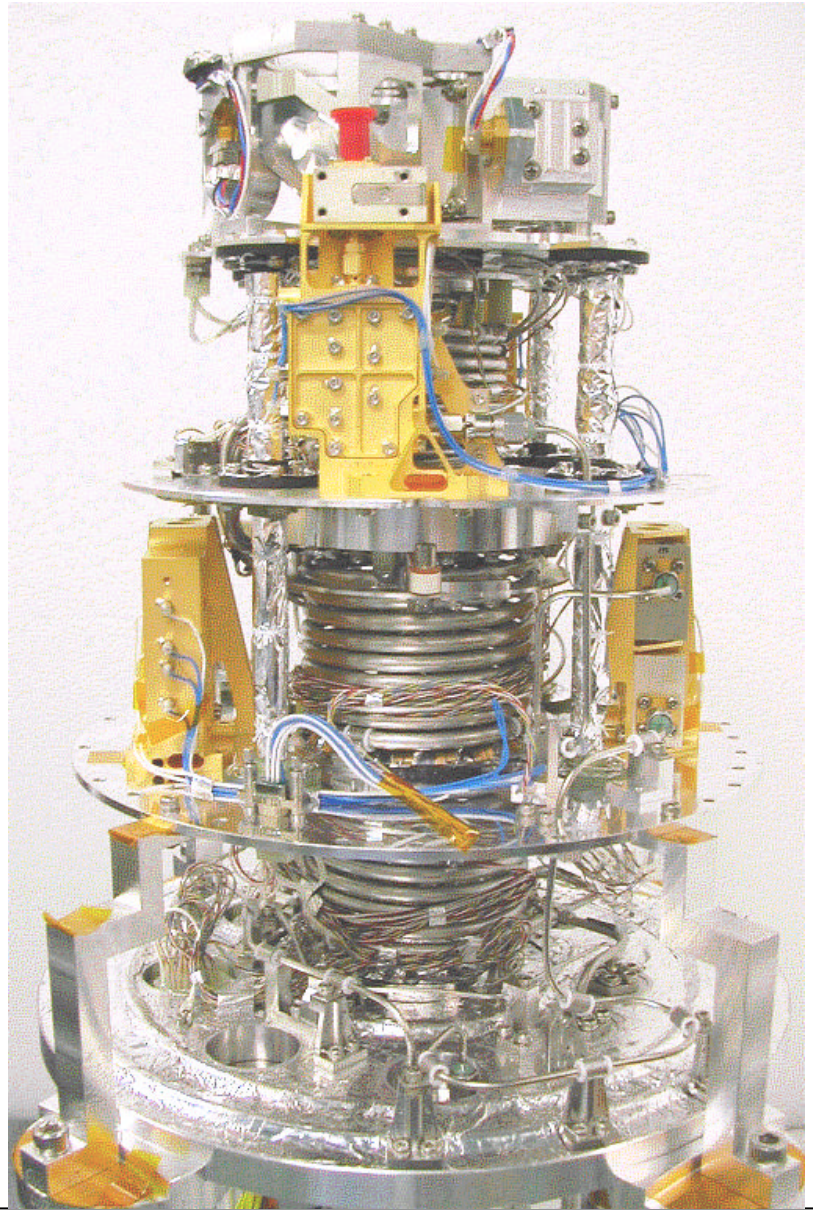
4K-class cooler is combination of a JT cooler and a two-stage Stirling cooler. The JT cooler consists of JT compressors, heat exchangers and JT orifice.

Items	Specifications
Cooling Capacity	20mW @ 4.5K
2-stage Stirling cooler	
Cooling Capacity	200mW @ 20K , 1W @ 100K
Power Consumption	≦ 90W for AC input at 15 Hz
JT Compressors	
Pressure	Supply: 1.6Mpa , Return: 0.1 Mpa
Mass flow rate	≧ 2.0 NL/min(=6.0 mg/s)
Power Consumption	≦ 50W for AC input at 30 Hz
Heat exchangers	
Efficiency	≧ 97 %
pressure drops	≦ 0.03MPa for low pressure side



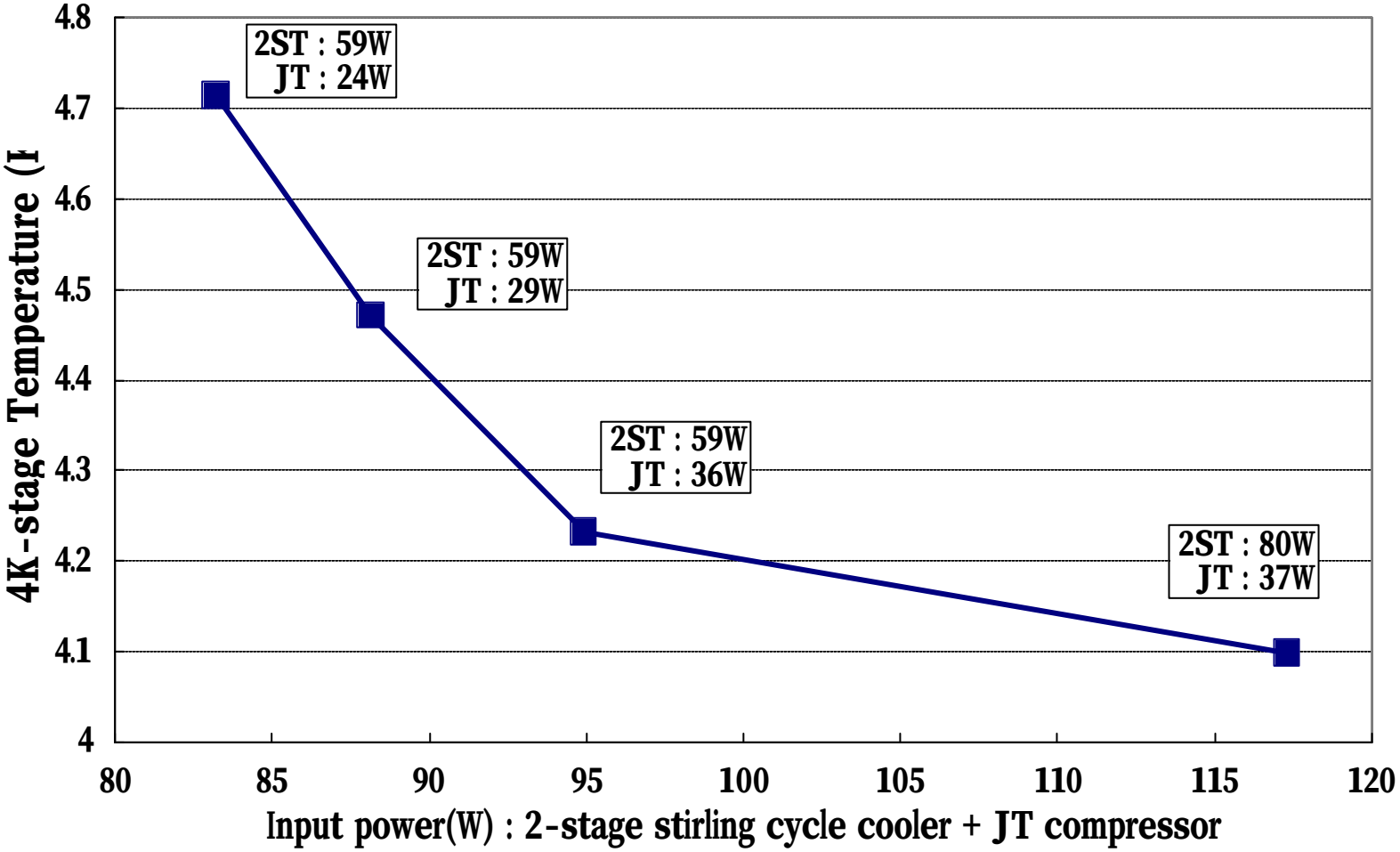
A cross-sectional view and inside of Cryostat





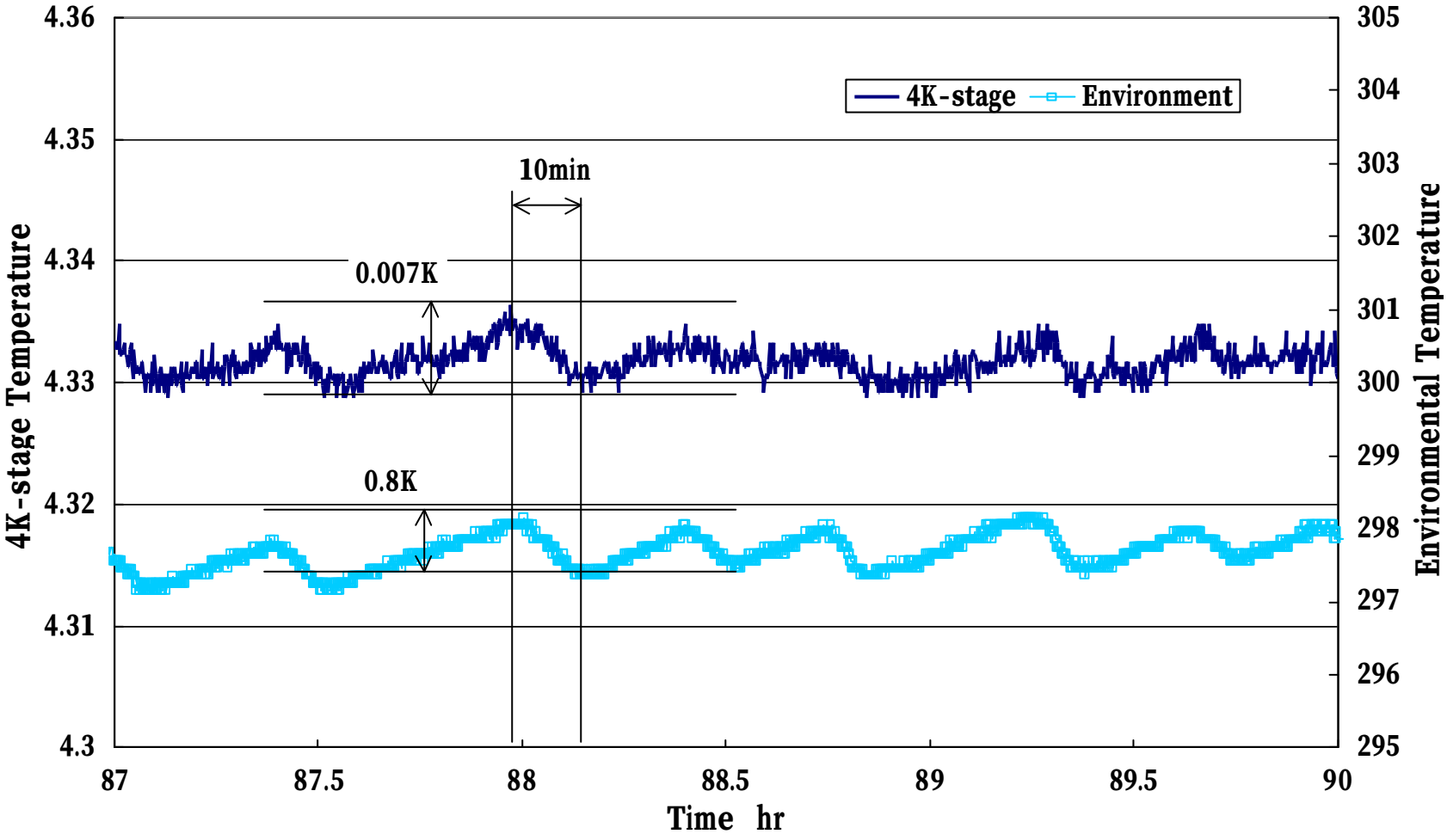
Experimental Results of 4K Cooler

This figure shows the temperatures of 4 K stage as a function of the input power to the 4 K cooler.



Temperature stability of 4K Cooler

Temperature variations in 10 minutes were 0.007 K at 4 K-stage with the environmental temperature variation of 0.8 K.



SPICA

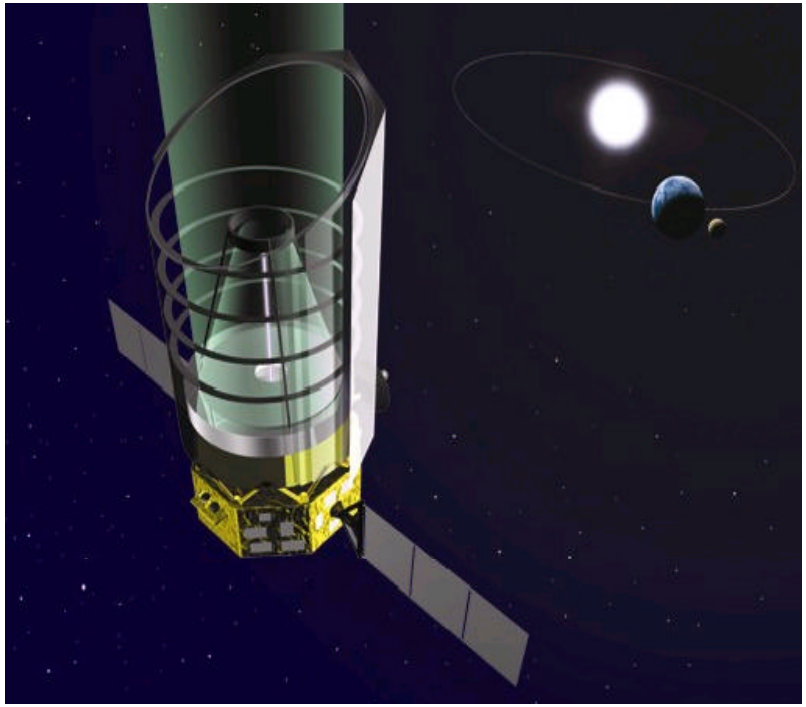
SPICA（Space Infrared Telescope for Cosmology and Astrophysics）is a future mission to launch a large infrared observatory with a 3.5 m-diameter cooled telescope to the second Sun-Earth Lagrangian Liberation point (L2) for mid- and far-infrared astronomy.

A new concept for the SPICA cryogenic system is a warm launch approach.

The telescope and the focal plane instruments (FPI) are cooled by radiation to the deep space and by the mechanical coolers.

Present Operation Plan of Coolers for SPICA

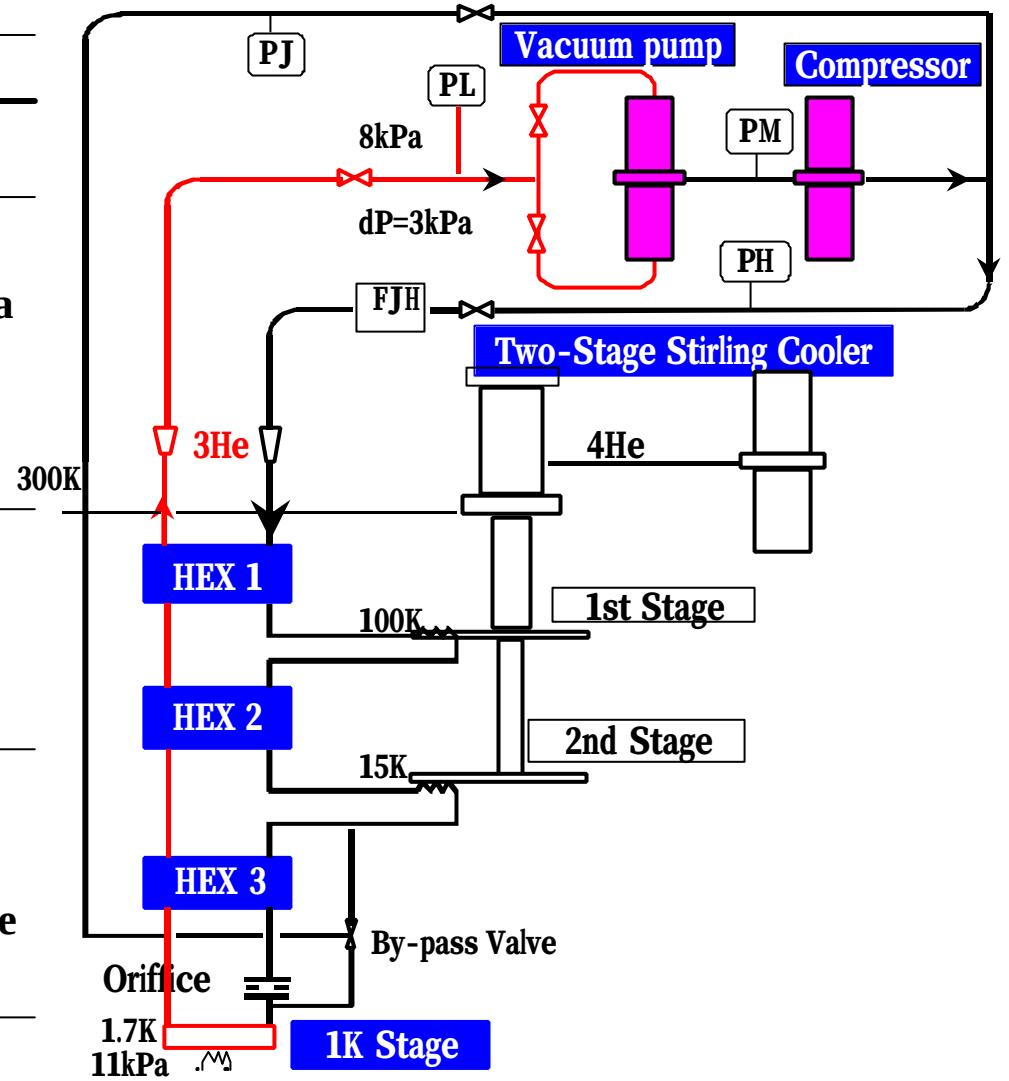
Cooler type	2-stage S. Cooler	4K Cooler	2K Cooler	1K Cooler
Cooling purpose	Pre-cooling for Telescope	Telescope and FPI	Infrared detector (Unstressed Ge:Ga)	Infrared detector (stressed Ge:Ga)
Cooling capacity	0.2W 20K	30mW 5K	10mW 2.5K	5mW 1.7K
Power consumption	90 W	160 W	180 W	180 W



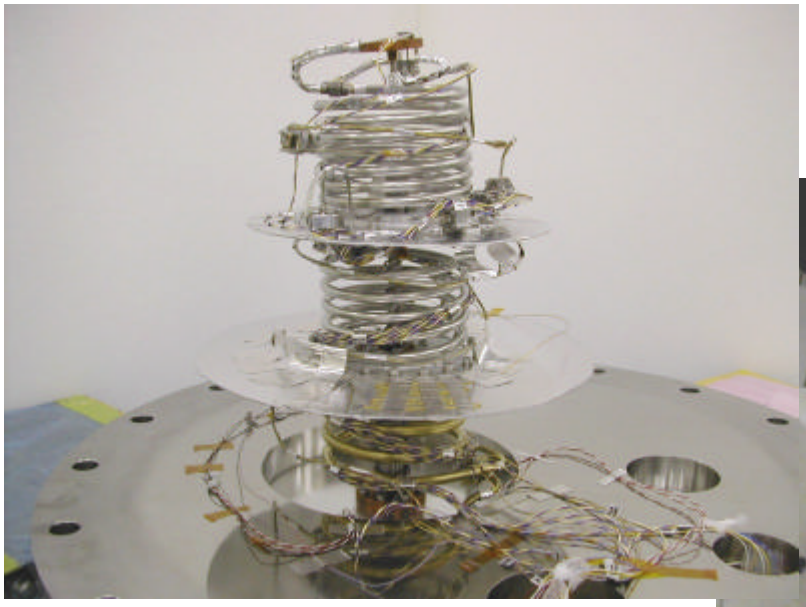
Design Specifications of 1K-class Cooler

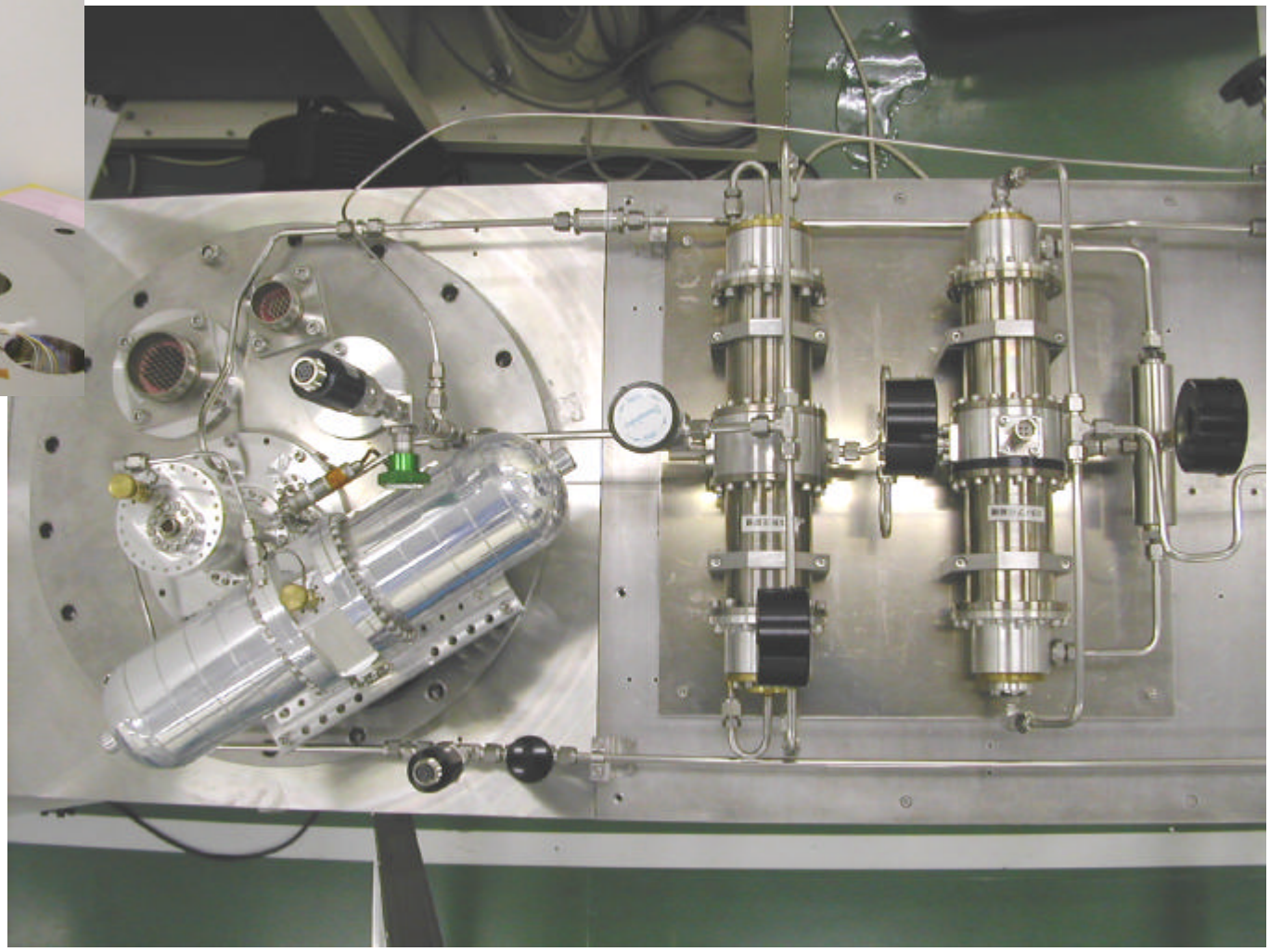
Selection of ^{3}He is based on the far higher vapor pressure than ^{4}He by about one order at 1.7 K.

Items	Specifications
Cooling Capacity	10 mW at 1.7 K
JT Cooler	
Pressure	Supply: 0.7Mpa, Return: 8kPa
Mass flow rate	≧ 1.0 NL/min (= 2.23 mg/s)
Power Consumption	≦ 80W
2-stage Stirling cooler	
Cooling Capacity	80mW at 15 K, 1W at 100 K
Power Consumption	≦90 W
Heat exchangers	
Efficiency	≧ 97 %
Pressure drops	≦ 3kPa for low pressure side in JT Cooler



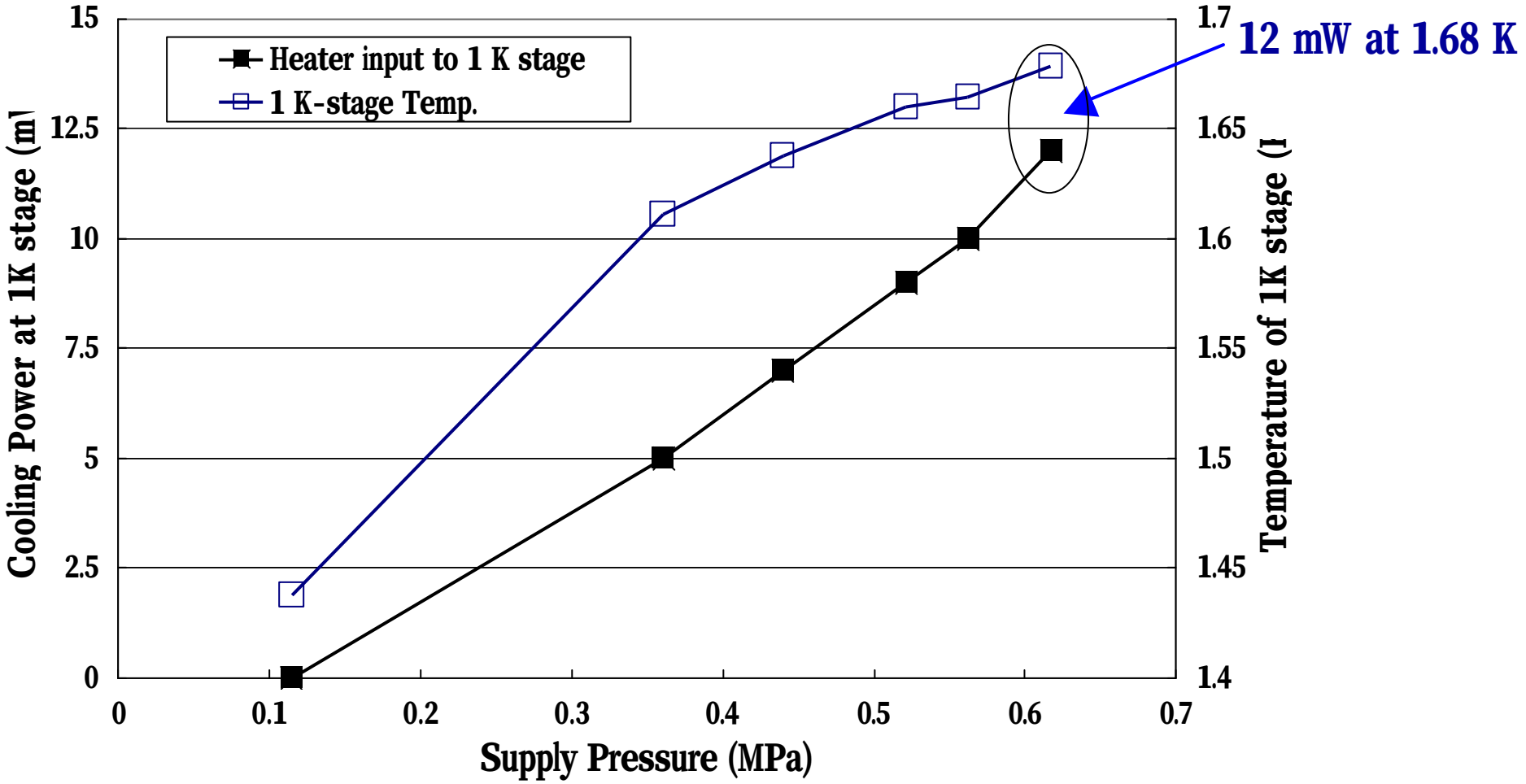
Photograph of 1K-class Cooler (Top view)





Experimental Results of 1K-class Cooler

This figure shows heater power to the 1K-stage and temperature of the 1K-stage as a function of supply pressure.
Cooling capacity of 12 mW at 1.68K has been achieved under the input power of 175.6 W.



Combination of Cooler for temp. below 0.1 K

Type	1	2	3	4
Pre-cooler as a heat sink	4 K-class Cooler	4 K-class Cooler	1 K-class Cooler	1 K-class Cooler
Cooling power of Pre-cooler	20mW at 4.5K	20mW at 4.5K	10mW at 1.7K	10mW at 1.7K
Low temperature cooler	4-stage ADR	2-stage ADR	2-stage ADR	Tandem sorption pumps+ADR
Max. Magnetic Field	4 T	3 T	1 T	0.8 T
Peak Heat Rejection Rate	7 mW at 4.2K	5 mW at 4.5K	9mW at 1.8K	8mW at 1.8K
Development Status of ADR	BBM (at NASA)	Design (at ESA)	Study	Study

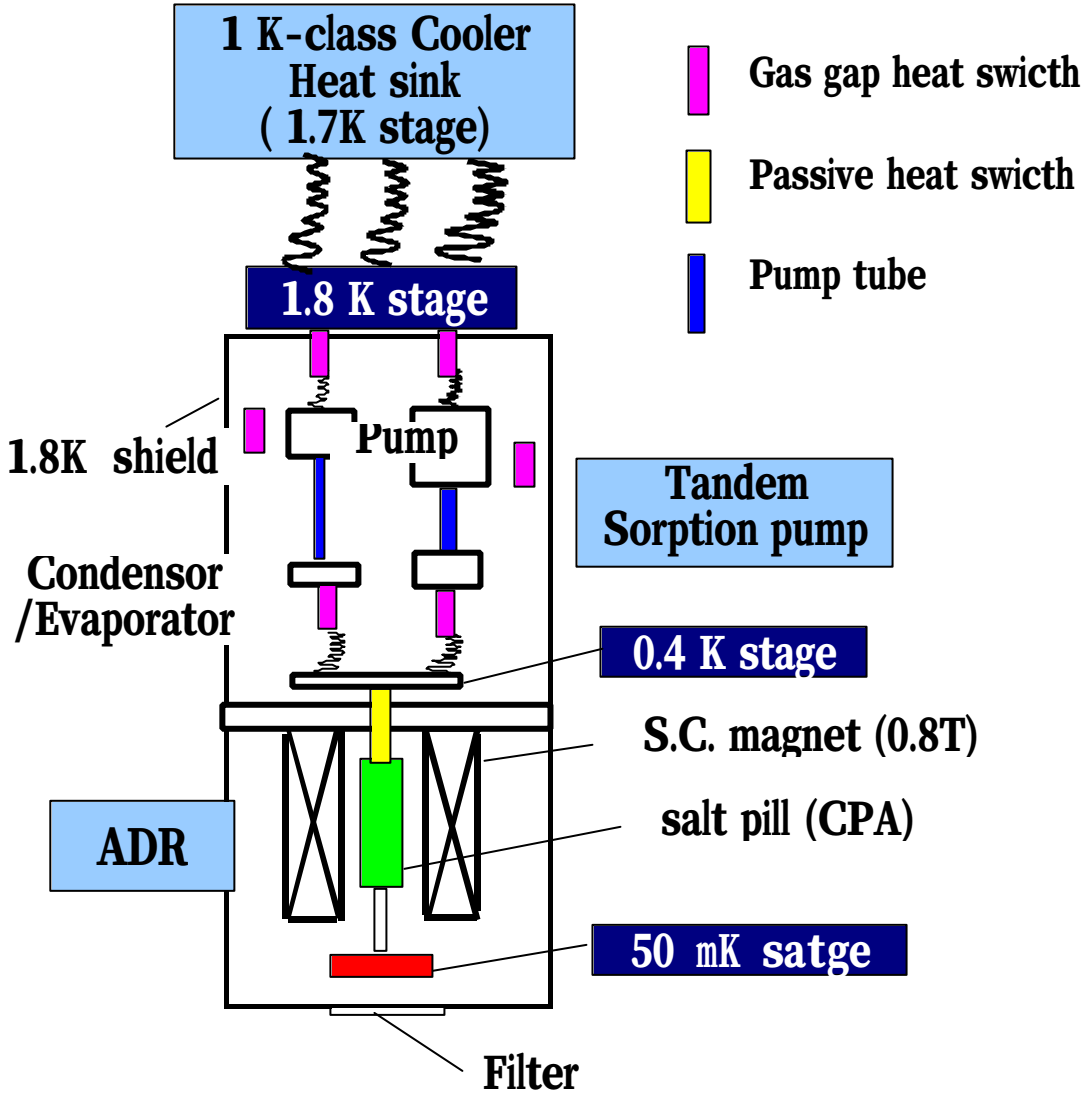
1K Cooler + Tandem Sorption pumps + ADR

Requirements for cryogenics

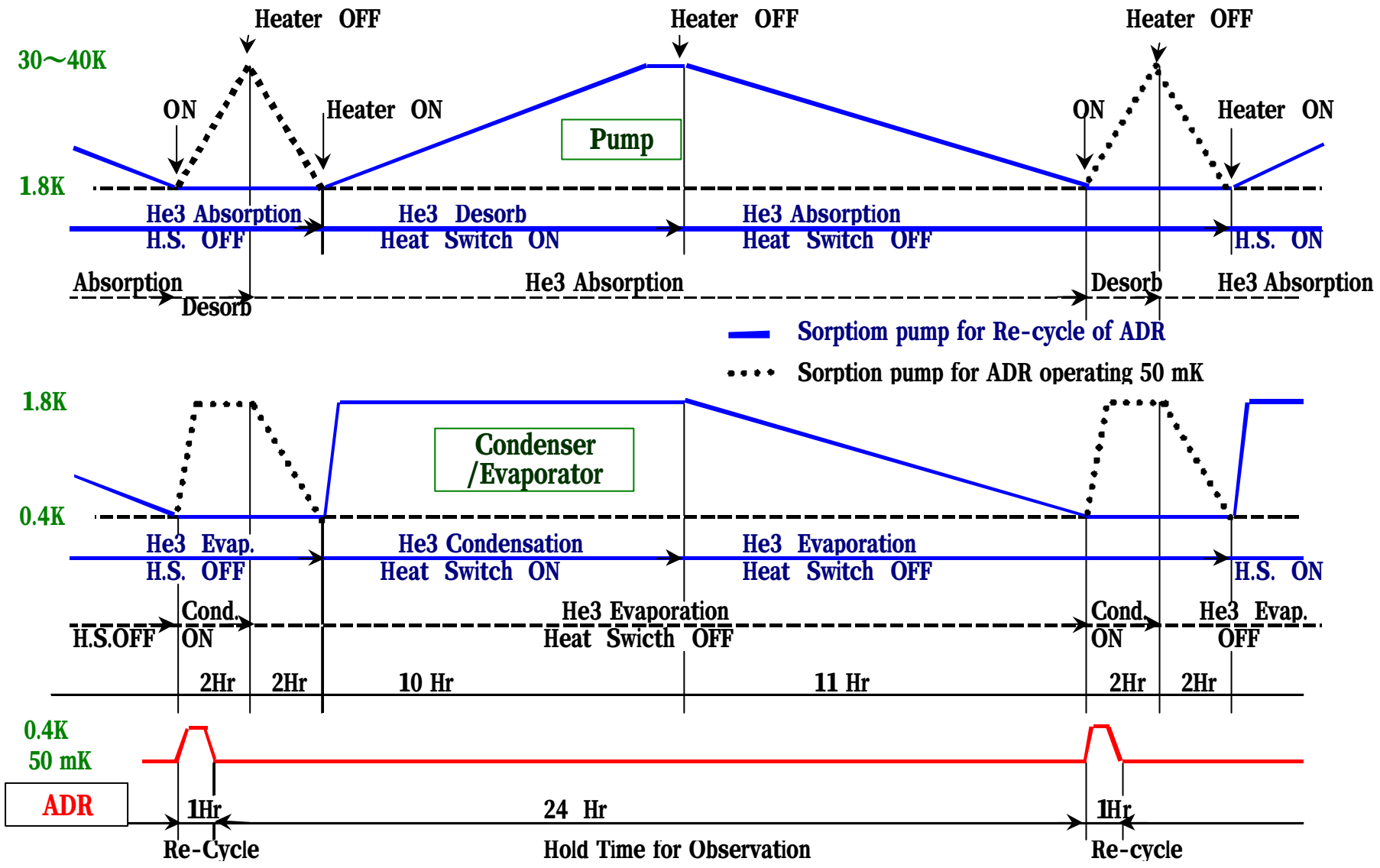
1)TES-Type X-ray detector arrays
2)Cooling power: 5 μW at 50 mK or below
3)Mission life： Over 5 years

Tandem sorption pumps are used as the upper stage (0.4 K) for a single stage ADR.

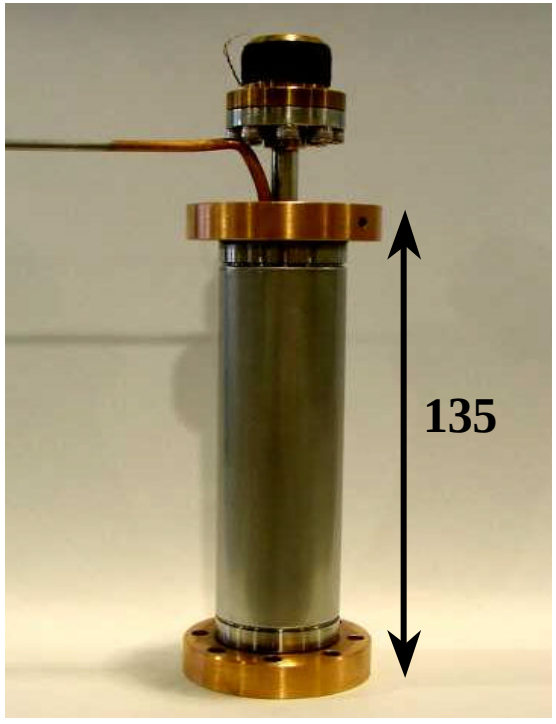
Advantages of this hybrid system are the lightweight and the low magnetic field for reducing the detector shield.

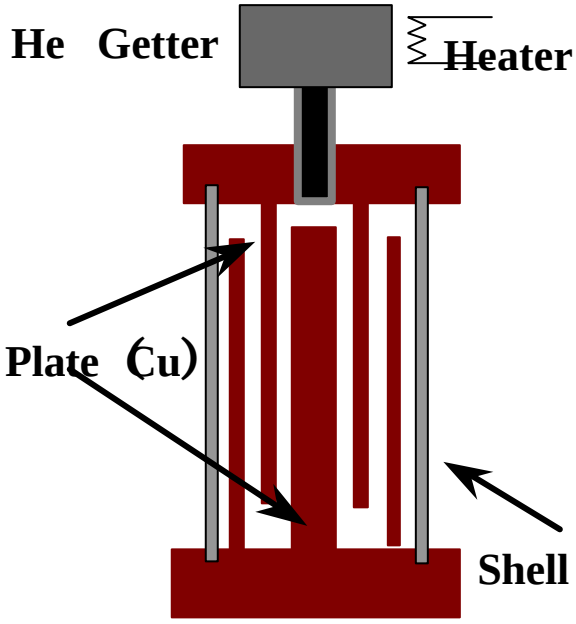


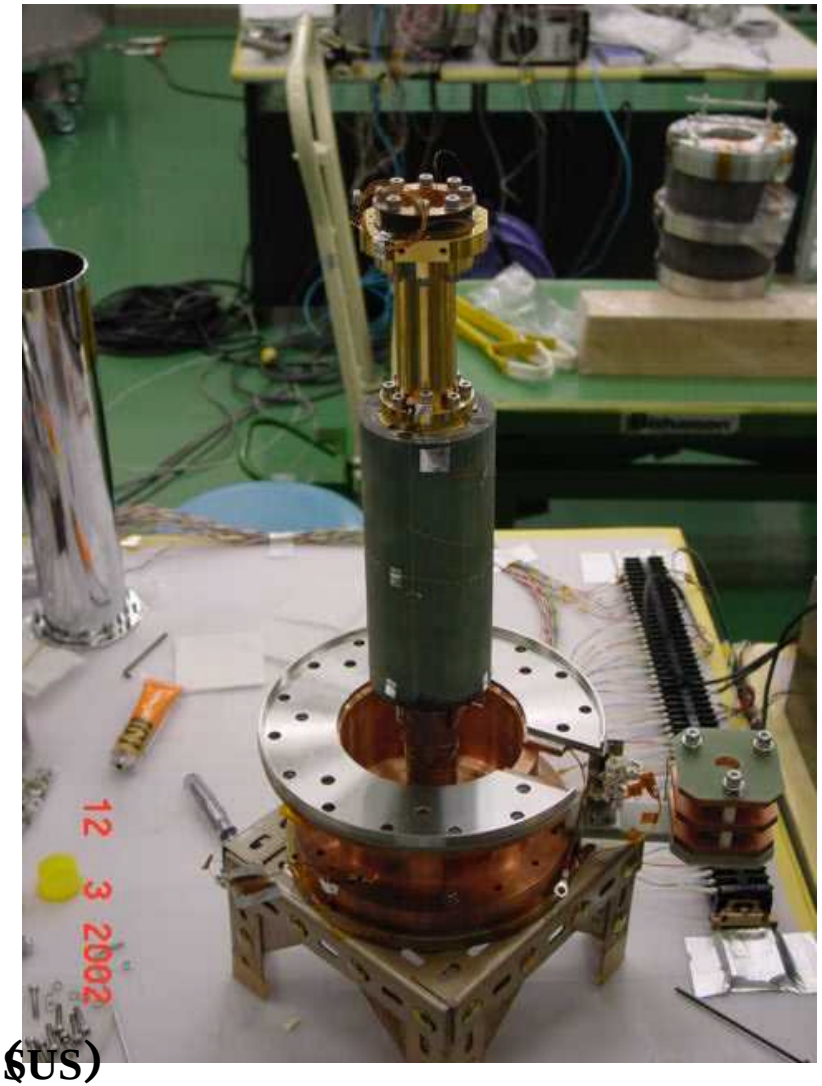
Operation of Tandem Sorption pumps + ADR



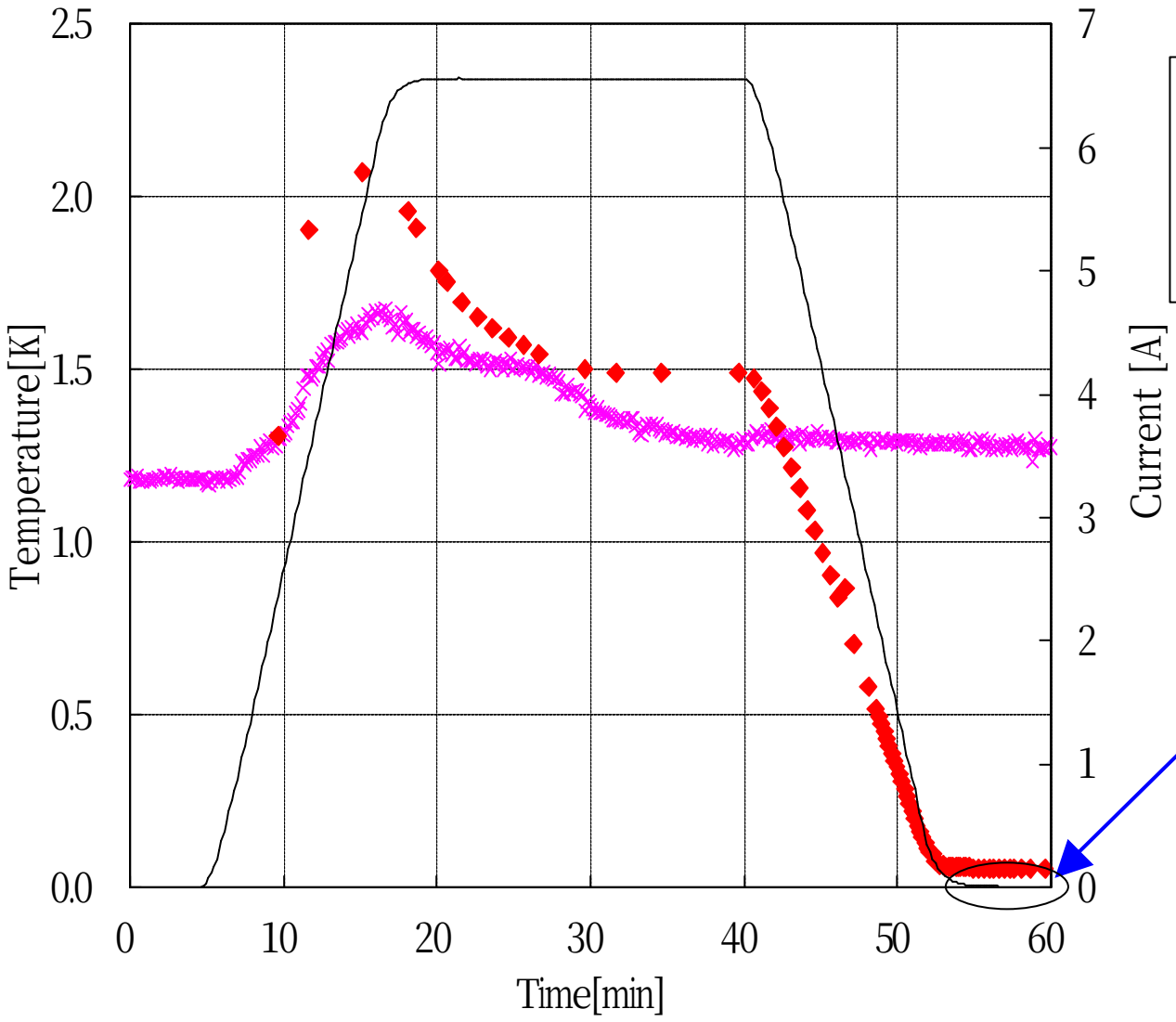
Salt pill and Heat Switch







Experimental Results of Prototype ADR



- 0A→6.5A(1.65T)
- Charge Rate; 0.01A/sec
  (Time ;10.8min)

50mK
(@Detector stage)

Conclusions

1. The flight model of cryogenic system for SMILES and the prototype of 1K-class cooler for SPICA was demonstrated to realize the cryogen free cooling system operating below 4.5 K for space application in the future.

2. Development is continuing to improve the performance and reliability of the 4 K- and 1 K-class cooler for space application.

3. Optimization of the cryogen-free hybrid cooling system with ADR is under study for next X-ray observation project.

END

Thank you.