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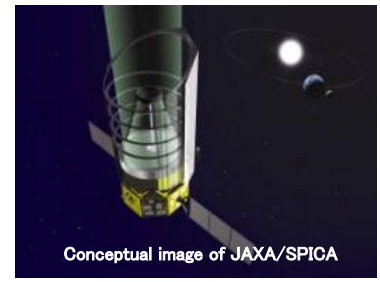
E-mail: sugita.hiroyuki@jaxa.jp

The Cryogenic System Design of SPICA

H. Sugita, Y. Sato
Aerospace Research and Development Directorate, Japan Aerospace Exploration Agency
T. Nakagawa, H. Matsuhara, H. Murakami, H. Kaneda, K. Enya
Institute of Space and Astronautical Science, Japan Aerospace Exploration Agency
M. Murakami
University of Tsukuba
and SPICA Working Group

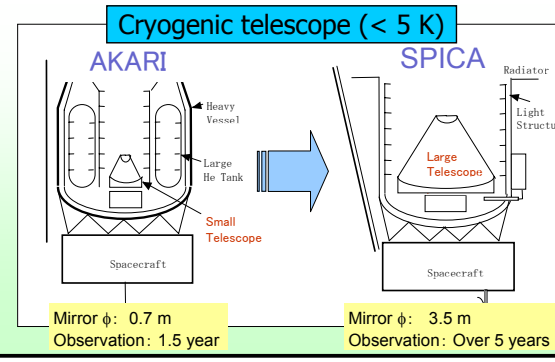

Conceptual image of JAXA/SPICA

SPICA mission plan

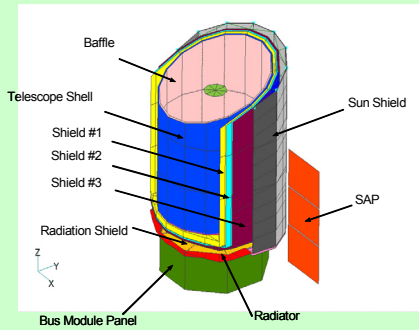
- The second Japanese IR space telescope, following the successful AKARI (ASTRO-F)
- Launched to Sun-Earth L2 by the Japanese H-IIA transfer vehicle in 2017
- Long observation with cold and large telecope

Cryogenic requirement

- 4.5 K stage: 30 mW heat lift (inc. parasitic) for 3.5 mϕ primary mirror and optical bench
- 1.7 K stage: 10 mW heat lift for far-IR detectors such as SAFARI and BLISS/BASS
- 2.5 K stage: 15 mW heat lift for mid-IR detectors
- Over-5-year observation by cryogen-free cooling (see the right figure)
- Optimal thermal design with advanced mechanical cryocoolers and radiant cooling at L2



Thermal design of the cryogenic system



Baseline configuration of a SPICA spacecraft

- ✓ The primary mirror, the telescope shell and the three shields are structurally supported by the bus module through main trusses, which are made of the carbon fiber reinforced plastics (CFRP) and the aramid fiber reinforced plastics (AFRP) with low thermal conductivity.
- ✓ The baffle and the main part of the telescope shell are made of high-thermal-conductivity-type CFRP to dissipate the heat flow. Wire harness between FPI and electronics equipments in the bus module is assumed to be made of Manganin and to be 1000 lines.
- ✓ The loop heat pipe, which has some advantages such as flexibility in arrangement of components and adaptability for long-distance transportation of large heat loads, is assumed as a heat transport device from compressors of cryocoolers to the radiator located above the bus module.

Table 1 Thermal analytical conditions

Parameter	Value
Space background	3 K (fixed)
Bus module panel	253 K (fixed)
Solar array paddle (back side)	373 K (fixed)
Primary mirror and optical bench	4.5 K (fixed)
Solar heat flux density	1376 W/m^2
Exhausted heat from cryocoolers	529 W@293 K
Heat load of focal-plane instruments	15 mW (fixed)
Wire harness	ϕ0.1 mm x 1000 wires

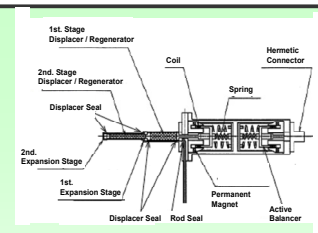
- ■ The total heat load into the 4.5 K stage is 32.6 mW and the baffle temperature is 10.4 K.
- ■ The modified 4 K-class cryocooler successfully demonstrated larger than 50 mW of the cooling power.

We obtained a feasible thermal design of the cryogenic system with sufficient margins.

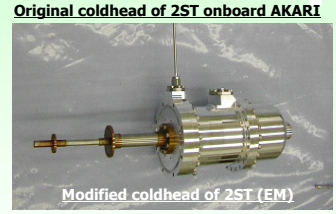
Development of mechanical cryocoolers

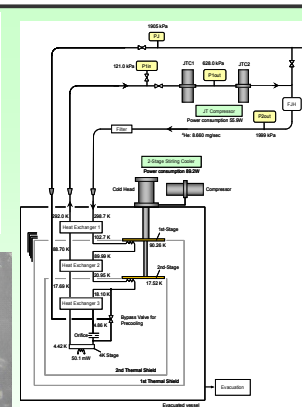
◆20K-class two-stage Stirling cooler (2ST)

- ✓ The SPICA needs 4 sets of 2ST for precooling, 4K-JT, 2K-JT and 1K-JT.
- ✓ Based on the AKARI heritage, 2ST was modified and upgraded for higher cooling power and higher reliability. 200 mW@16 K, 1 W@83.6 K with AC 90W
- ✓ The modified cold head uses flexure springs to realize a no-contact structure between the first-stage displacer and the cylinder.
- ✓ The upgraded engineering model of 2ST with low-outgas materials and less amount of glue has been fabricated.
- ✓ A qualification test and a long life test are coming soon.



Original coldhead of 2ST onboard AKARI


Modified coldhead of 2ST (EM)


Result of the 4K-JT test

◆4K-class Joule-Thomson (JT) cryocooler

- ✓ Based on the ISS/JEM/SMILES heritage, 4K-JT was modified and upgraded for higher cooling power and higher reliability.
- ✓ the maximum cooling power of 50.1 mW was efficiently obtained with an electric input power of AC 55.9 W for the JT and AC 89.2 W for 2ST cooler.
- ✓ The remarkable improvement of the cooling power at the 4.5 K stage is attributed to the increase of the mass flow rate.

◆1K-class Joule-Thomson (JT) cryocooler

- ✓ The ^{3}He-JT cryocooler was developed to satisfy the required cooling capacity of 10 mW. The improved cooling power of 16.0 mW was successfully obtained with an efficient input power of AC 76.6 W for the JT and AC 89.0 W for the modified 2ST.

All mechanical coolers are technically feasible with sufficient margins for cooling requirement.