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# Overview of Sumitomo coolers and Dewars for space use

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## ABSTRACT

Sumitomo Heavy Industries, ltd. (SHI) has been developing cooler and Dewar technology for space application with Japan Aerospace Exploration Agency. SHI has four types of coolers to cover temperature range from 1.7K to 80K or more. Those are Single stage Stirling coolers for 80K, two-stage Stirling coolers for 20K, 4K-class cooler and 1K-class cooler. 4K and 1K class coolers consist of a Joule-Thomson cooler and a two-stage Stirling as a pre-cooler. SHI also provided Dewars. In this paper, SHI's cooler and Dewar technology are described.

**Keywords:** cryocooler, Stirling, Joule-Thomson, Dewar, space use

## 1. INTRODUCTION

Sumitomo Heavy Industries, ltd. has been designing and manufacturing cooler and Dewar for space application with Japan Aerospace Exploration Agency since 1987.

SHI has four types of coolers to cover temperature range from 1.7K to 80K or more. Single stage Stirling coolers for 80K cooling were launched on the X-ray astronomical satellite "SUZAKU" (2005), the Japanese lunar orbiter "KAGUYA" (2007), the Venus climate orbiter "AKATSUKI" (2010) and the X-ray astronomical satellite "HITOMI". Two-stage Stirling coolers for 20K cooling were launched on the infrared astronomical satellite "AKARI" (2006) and HITOMI. A 4K-class cooler consists of a $^4$He Joule-Thomson cooler with a two-stage Stirling as a pre-cooler. It was launched on the Superconducting Submillimeter-Wave Limb-Emission Sounder (SMILES, 2009) aboard the Japanese Experiment Module of the International Space Station and HITOMI. A 1K-class cooler consists of a $^3$He Joule-Thomson cooler with a two-stage Stirling as a pre-cooler. It is now in the test of the engineering model on ground. 1K-class coolers will be launched on SPICA and ATHENA project in 2020's.

In projects mentioned above, SHI also provided Dewars to cool detectors, mirrors and optics. SXS Dewar is our latest work having a hybrid cooling chain combined coolers and liquid helium. It was launched on the X-ray astronomical satellite "HITOMI (ASTRO-H)" in February 2016.

## 2. DESCRIPTION OF COOLERS

### 2.1 Single stage Stirling coolers

Single-stage Stirling coolers are used for cooling to temperatures around 80 K. Specifications are listed in Table 1. Typical cooling power is 1W at 80K with 40W power consumption. Fig.1 is a photograph of a single-stage Stirling cooler.

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Heritage of operating hours are listed in Table 1. Three coolers achieved 100,000 hours in the life time test on ground. Five coolers were launched on SUZAKU, KAGUYA, AKATSUKI and HITOMI for cooling detectors, thermal shields, etc. Our first unit was launched on SUZAKU (ASTRO-E2). It is the Japanese X-ray astronomy satellite launched in 2005. It has the X-ray spectrometer (XRS) with micro calorimeters cooled by an adiabatic demagnetization refrigerator to 60mK. The single-stage Stirling cooler is used to cool the outer vapor cooled shield for extending the lifetime of the solid neon in XRS[1,2]. The second was launched on KAGUYA (SELENE). It was the Japanese lunar polar orbiter operated from 2007 to 2009. The gamma-ray detector was cooled to 80–90 K by a single-stage Stirling cooler for 21 months in its mission life[3]. The third is on AKATSUKI (PLANET-C) launched in July 2010. The mid-wave infrared camera (IR2) uses a CCD cooled to around 65 K by a single-stage Stirling cooler. The fourth and fifth are on HITOMI (ASTRO-H) launched in February 2016. X-ray CCDs in Soft X-ray Imager (SXI) are cooled by our single-stage Stirling.

Table 1. Specifications of a single-stage Stirling cooler

| Item | Specifications |
|---|---|
| Cooling Capacity | 1 at 80 K |
| Environment Temp. | 200 K tor room temperature |
| Power Consumption | 40 W |
| Lifetime | 5 years |
| Size | Compressor :Φ98× 230L(mm),<br>Cold Head :Φ78×180L(mm) |
| Mass | 4.2 kg |
| Drive Frequency | 52 Hz |

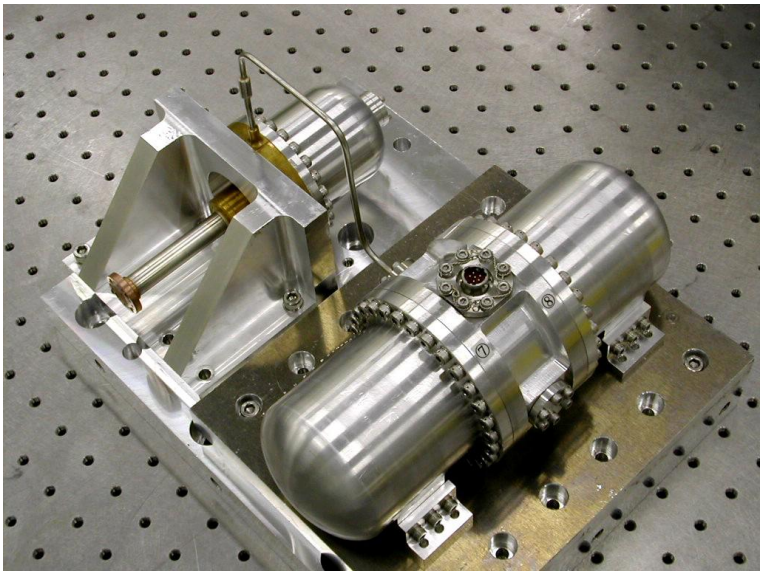

Fig. 1 Single-stage Stirling cooler

Table 2. Heritage of operating hours

| Test Model or Project | Temp. Level | Operating hours | | | Remark |
|---|---|---|---|---|---|
| | | Earth | On Orbit | Total | |
| 1 Engineering Model | 80 K | 113640 | N/A | 113640 | 1999 November: Operation Start<br>2015 January: Operation Stop |
| 2 Prototype Model-1 | 80 K | 106395 | N/A | 106395 | 2001 November: Operation Start<br>As of February 2016 |
| 3 Prototype Model-2 | 80 K | 102797 | N/A | 102797 | 2002 May: Operation Start<br>As of February 2016 |
| 4 SUZAKU(ASTRO-E2)/XRS | 150 K | 2000 | 59232 | 61232 | 2005 July: Operation Start<br>2012 April: Operation Stop |
| 5 KAGUYA(SELENE)/GRS | 80 K | 9200 | 12600 | 21800 | 2007 December: Operation Start<br>2009 June: Mission Completed |
| 6 AKATSUKI (PLANET-C)/IR2 | 60 K | 500 | 1200 | 1700 | 2010 July: Operation Start<br>2015 Dec arrived at Venus |
| 7 HITOMI(ASTRO-H)/SXI -A | 150K | 443 | - | 443 | Just started |
| 8 HITOMI(ASTRO-H)/SXI -B | 150K | 89 | - | 89 | Just started |

### 2.2 Two-stage Stirling cooler

Two-stage Stirling coolers are used for cooling to temperatures around 20 K. Specifications are listed in Table 3. Typical cooling power is 200mW at 20K and 1000mW at 100K with 80W power consumption. Fig.2 is a photograph of a two-stage Stirling cooler.

Heritage of operating hours are listed in Table 4. Seven coolers were launched on AKARI (ASTRO-F), SMILES, and HITOMI. AKARI was the infrared telescope satellite launched in 2006. It had two coolers for cooling radiation shield to reduce heat load to a superfluid helium tank [4]. On SMILES, a two-stage Stirling cooler was used as precooler for Joule-Thomson cooler. SMILES was a submillimeter wave sounder mounted on the exposed facility of the Japanese experiment module in the international space station. On HITOMI, two coolers are used for cooling radiation shields and two coolers are used as precooler for Joule-Thomson cooler. In lifetime test on ground, one unit achieved 72,906 hours. Another unit achieved 34,726 hours as of February 2016 and continues operation.

Table 3 Specifications of two-stage Stirling cooler

| Item | Specifications |
|---|---|
| Cooling Capacity | 200 mW at 20 K<br>1000 mW at 100 K |
| Environment Temp. | 200 K-300 K |
| Power Consumption | 80 W |
| Lifetime | 5 years |
| Size | Compressor :Φ106×390L(mm)<br>Cold Head :Φ81×320L(mm) |
| Mass | 9.5 kg |
| Drive Frequency | 15 Hz |

Table 4. Heritage of operating hours

| Test Model or Project | Temp. Level | Operating hours | | | Remark |
|---|---|---|---|---|---|
| | | Earth | On Orbit | Total | |
| Two-stage Stirling Cooler | | | | | |
| 1 Engineering Model | 20 K | 72906 | N/A | 72906 | 1999 March : Operation Start<br>2008 August : Operation Stop |
| 2 ASTRO-F (AKARI)-A | 20 K | 2098 | 40350 | 42448 | 2006 February: Operation Start<br>2010 May: Operation Suspension |
| 3 ASTRO-F (AKARI)-B | 20 K | 2121 | 13800 | 15921 | 2006 February: Operation Start<br>2007 October : Operation Stop |
| 4 Prototype Model for SMILES | 20 K | 22283 | N/A | 22283 | 2007 May: Operation Start<br>2010 September : Operation Stop |
| 5 SMILES | 20 K | 2250 | 6035 | 8285 | 2009 September: Operation Start<br>2010 June: Operation Suspension |
| 6 Advanced Prototype Model | 20 K | 34726 | N/A | 34726 | 2010 January: Operation Start<br>As of February 2016 |
| 7 HITOMI/SXS-SC-A | 20K | 5900 | 720 | 6620 | 2016 February: Operation Start |
| 8 HITOMI/SXS-SC-B | 20K | 5900 | 720 | 6620 | 2016 February: Operation Start |
| 9 HITOMI/SXS-PC-A | 20K | 5900 | 720 | 6620 | 2016 February: Operation Start |
| 10 HITOMI/SXS-PC-B | 20K | 5900 | 720 | 6620 | 2016 February: Operation Start |

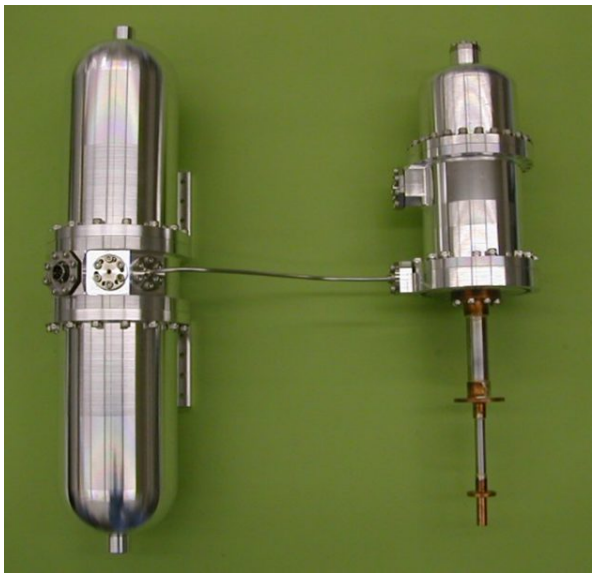

Fig.2 Two-stage Stirling cooler (an advanced model)

### 2.3 4K-class cooler

4K-class coolers consists of a two-stage Stirling cooler as a precooler and a JT cooler. Specifications are listed in Table 5. Typical cooling power is 40mW at 4.5K with 170W power consumption. Fig.3 is a photograph of heat exchanger in SMILES's cryostat. Fig 4 is the whole cryogenic system of SMILES.

Heritage of operating hours are listed in Table 6. Two unites were launched on SMILES and HITOMI. SMILES was aimed at probing chemical processes related to ozone depletion by using new sub-millimeter technologies with superconductor–insulator–superconductor (SIS) mixers. SMILES's sub-millimeter receiver includes two SIS mixers and four low-noise amplifiers with high-electron-mobility transistors (HEMT), all of which must be cooled. SMILES was launched in September 2009[5]. On HITOMI, one unit is used in SXS Dewar. Its functions are cooling radiation shield and absorbing heat from an adiabatic demagnetization refrigerator to create 50mK[6].

Table 5 Specifications of 4-K class cooler

| Item | Specifications |
|---|---|
| Cooling Capacity | 40 mW at 4.5 K |
| 2-stage Stirling Cooler<br>Cooling Capacity<br>Frequency | <br>0.2 W at 20K, 1 W at 100 K<br>15 Hz operation |
| JT Compressor<br>Pressure<br><br>Mass Flow Rate<br>Frequency | <br>Supply : 1.6 MPa ,<br>Return : 0.1 MPa<br>2.0 NL/min (=6 mg/s)<br>52 Hz operation |
| Power consumption | 170W |
| Mass | 30 kg (excluded cryostat) |

Table 6. Heritage of operating hours

| Test Model or Project | Temp. Level | Operating hours | | | Remark |
|---|---|---|---|---|---|
| | | Earth | On Orbit | Total | |
| JT Cooler for 4 K level | | | | | |
| 1 Engineering Model for SMILES | 4.5 K | 9315 | N/A | 9315 | 1998 September : Operation Start<br>1999 December : Operation Stop |
| 2 Prototype Model for SMILES | 4.5 K | 22283 | N/A | 22283 | 2007 May: Operation Start<br>2010 September : Operation Stop |
| 3 SMILES | 4.5 K | 1172 | 6010 | 7782 | 2009 September: Operation Start<br>2010 June: Operation Suspension |
| 4 Advanced Prototype Model | 4.5 K | 34726 | N/A | 34726 | 2010 January: Operation Start<br>As of February 2016 |
| 5 HITOMI/SXS | 4.5 K | 5300 | 720 | 6020 | 2016 February: Operation Start |

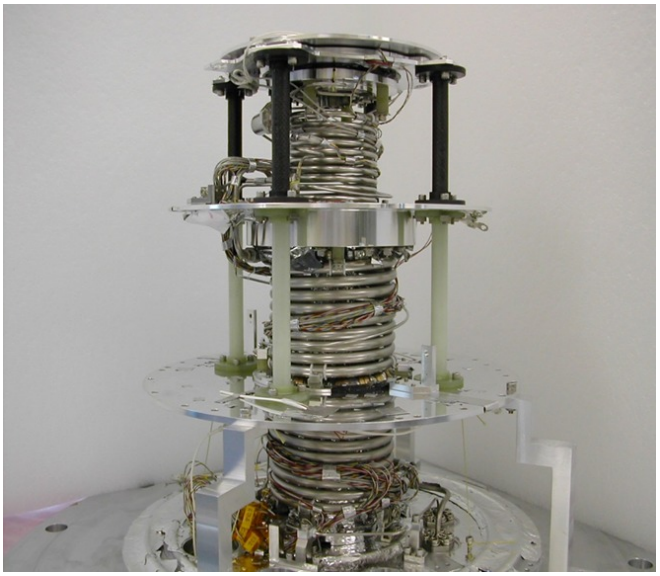

Fig.3 Heat exchangers in SMILES's cryostat

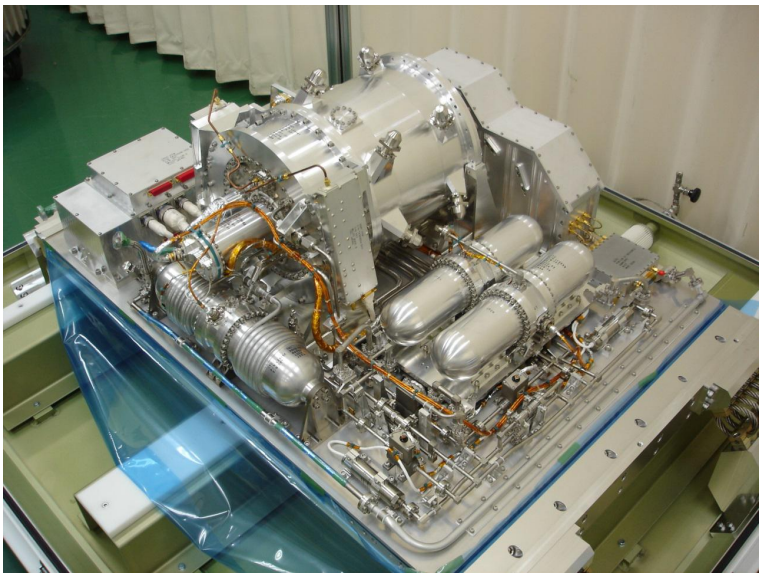

Fig.4 Whole cryogenic system of SMILES

### 2.4 1K-class cooler

1K-class coolers consists of a two-stage Stirling cooler and a JT cooler. The working fluid is changed to $^3$He from $^4$He in 4K-class cooler. Specifications are listed in Table 7. Typical cooling power is 10mW at 1.7K with 170W power consumption. Fig.5 is a photograph of heat exchangers. Fig 4 is a photograph of a precooler and compressors.

Heritage of operating hours are listed in Table 8. One unit is on lifetime test in a laboratory.

Table 7 Specifications of 1-K class cooler

| Item | Specifications |
|---|---|
| Cooling Capacity | 10 mW at 1.7 K |
| 2-stage Stirling Cooler<br>Cooling Capacity<br>Frequency | <br>0.2 W at 20K, 1 W at 100 K<br>15 Hz operation |
| JT Compressor<br>Pressure<br><br>Mass Flow Rate<br>Frequency | <br>Supply : 1.6 MPa ,<br>Return : 0.1 MPa<br>2.0 NL/min (=6 mg/s)<br>52Hz operation |
| Power consumption | 170W |
| Mass | 30 kg (excluded cryostat) |

Table 8 Heritage of operating hours

| Test Model or Project | Temp. Level | Operating hours | | | Remark |
|---|---|---|---|---|---|
| | | Earth | On Orbit | Total | |
| JT Cooler for 1 K level | | | | | |
| 1 Prototype Model | 1.7 K | 5199 | N/A | 5199 | 2015 May: Operation Start<br>As of February 2016 |

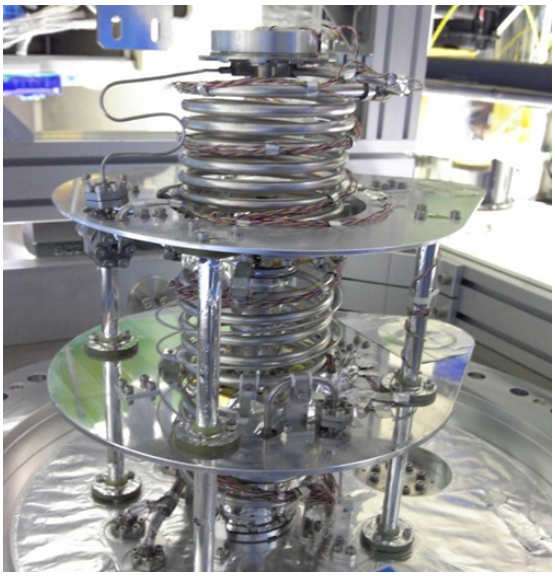

Fig. 5 Heat exchangers of 1K-class cooler

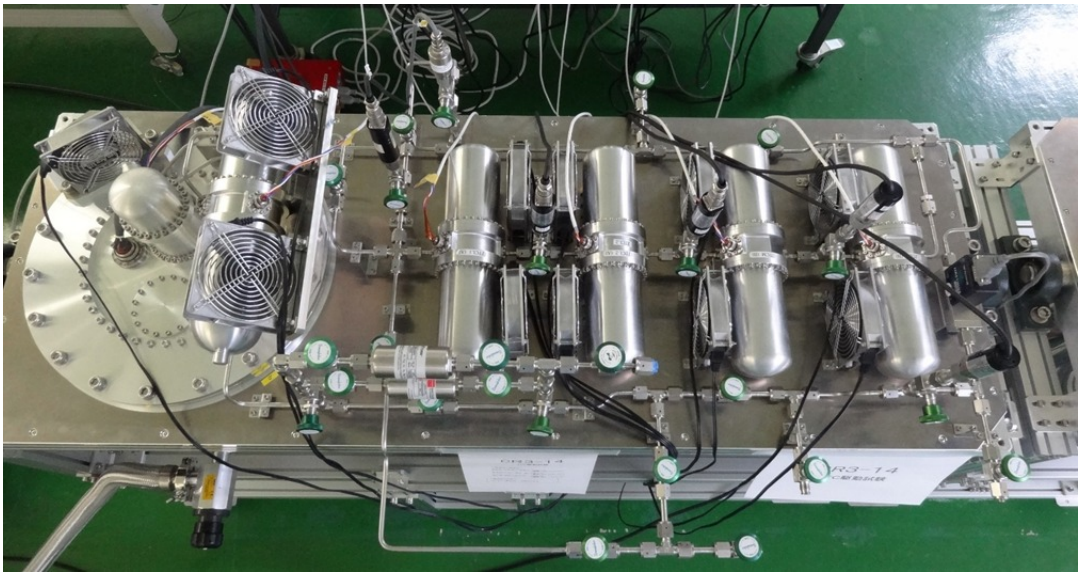

Fig. 6 Precooler and compressors of 1K-class cooler

## 3. DESCRIPTION OF DEWARS

In SUZAKU, AKARI, KAGUYA and HITOMI, SHI provided not only coolers but also Dewars. SXS Dewar on HITOMI is our latest work. It provides 1.3K interface for an Adiabatic Demagnetization Refrigerator (ADR). ADR cooles an X-ray detector to the temperature 50mK. The Dewar has 30 liters superfluid helium in its tank and keeps 3 years or more. Two units of two-stage Stirling cooler are used for radiation shields cooling. One 4K-class cooler provides 4K shield around the helium tank. Coolers reduce heat load to the helium tank. The helium tank is small but life time is long. Fig. 7 is the cross section of the SXS Dewar. Fig. 8 is a photograph of the SXS Dewar[6].

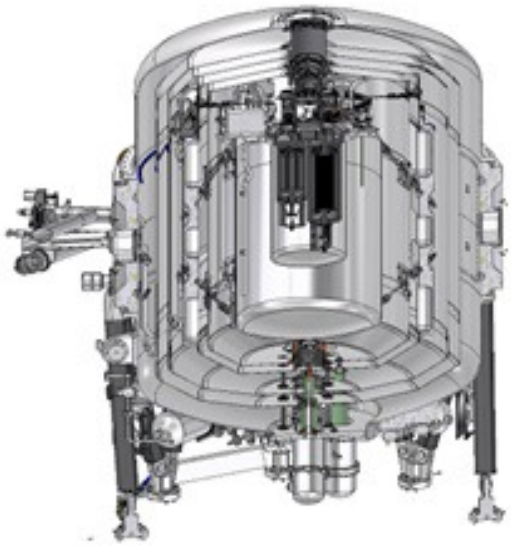

Fig. 7 Cross section of SXS Dewar

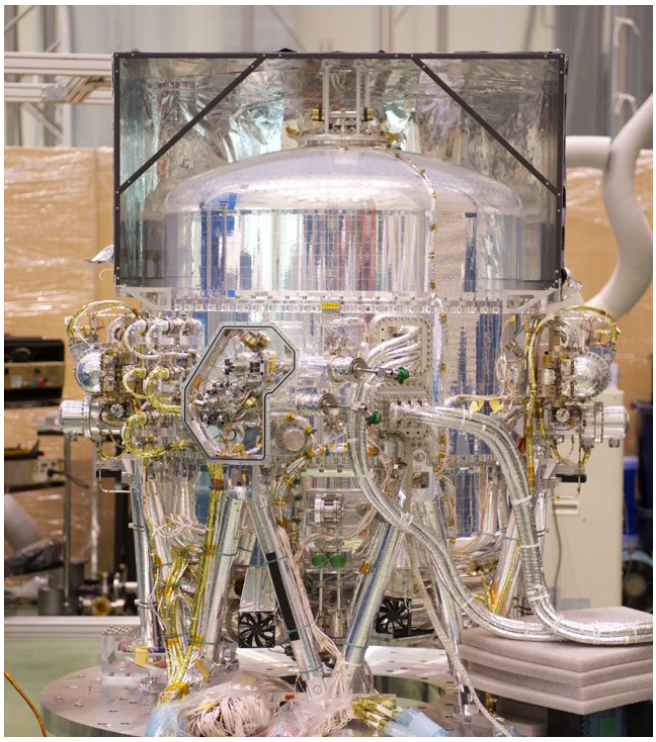

Fig.8 SXS Dewar in ground test

## 4. SUMMARY

Present status of SHI's cooler and Dewar technology are described in this paper. SHI can provides cryogenic solution in temperatures from 1K to 80K or more. Every SHI cryogenic equipment showed good performance in orbit. That is based on the long test on ground. We will continue developing cooler and Dewar technology for future projects


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