

Development of a commercially competitive thruster !

Successful development of the longest life 1 N thruster

The space environment where satellites are operated is very harsh and different from the earth. In space, it is almost impossible to repair satellite troubles. For these reasons, "high reliability" is the most essential point for the various devices loaded on satellites. In recent years, there have been requirements to extend the life of satellites, and this means the various devices, which include thrusters, are also required to have extended lives. Furthermore, as electric power is limited in a satellite, it is also important to reduce power consumption. In addition, they would be commercially competitive if they had a low cost and short delivery time. We finally completed the development of such an ideal thruster. (Fig. 1, Table)

By the way, what is a thruster? After separation from the launch vehicle, the satellite is transferred to a predefined orbit by its own propulsion system. After entering the predefined orbit, the satellite uses the propulsion system for keeping orbit and attitude control. The thruster is a part of this propulsion system and it actually generates thrust.

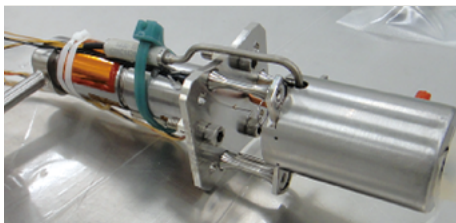


Fig. 1: The monopropellant 1 N thruster

Table: Thruster performance

	New 1 N thruster	Conventional model
Life	More than 200,000 Nsec* and 850,000 pulses Hidrazine throughput: More than 100 kg	Apprix. 40,000 Nsec
Specific impulse in the continuous firing (sec)	More than 222	More than 210
Power consumption (W)	Less than 3.0	6.0

* Total impulse [Nsec]: The generated thrust integrated by time. This indicates the life of the thruster. We pursued a longer life than foreign products and succeeded.

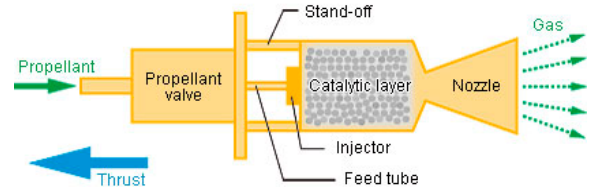


Fig. 2: Mechanism of monopropellant thruster

There are various types of thrusters, such as monopropellant thrusters, bipropellant thrusters and electric thrusters. The one which we developed this time is a monopropellant 1 N^(*) thruster that uses hydrazine as the propellant.^(**) The mechanism of a monopropellant thruster is described in figure 2. The propellant, hydrazine, first flows into the propellant valve (at the thruster inlet), which controls the propellant flow. As the flow rate is controlled by the opening and closing of the propellant valve, the propellant is sent to the feed tube, which connects the propellant valve and catalytic layer. The hydrazine passing through the feed tube is discharged to the catalytic layer from the injector. After that, the hydrazine is decomposed to gas by the catalytic granules. The gas is ejected from the nozzle, and then thrust is generated.

*1 1N: The force to support the weight of about 100 g on the ground

*2 There are also bipropellant thrusters, which use the energy from the combustion of an oxidizer and fuel, and electric thrusters, which use electrical energy, as well as others.

The accumulation of small essentials brings big results

A monopropellant thruster can repeat continuous or pulse firing, and the catalyst granules are damaged by firing. Therefore, its life is determined by the "degradation of the catalyst". In other words, a thruster's life can be extended if a large amount of catalyst granules remain at the end of its life. When the hydrazine enters the catalytic layer and decomposes, heat is also produced, and the temperature of the catalyst layer rises. Since the firing of thrusters increases the thermal load of the catalyst layer and damages catalyst granules, we researched and designed the injector to reduce the thermal load of the catalyst layer. As the result of redesigning the injector, the chamber could hold more catalyst granules, which is also the essential point to extending the thruster's life. As a

Long-life and high-reliability 1 N hydrazine thruster

result, the total impulse was dramatically increased, and we achieved longer life than foreign thrusters.

Since the heat generated in the catalytic layer is transferred upstream, the design to cut off the heat from the catalyst layer has also contributed to an extended life, the reduction of heat soak-back^{(*)3}, and low electric consumption. In the conventional model, the catalytic layer and propellant valve were joined by a structure called "thermal barrier". But in the new model, they are joined by a structure called "thermal stand-off" to reduce the heat transferred upstream.

High reliability is another feature of the thruster developed this time. One of the specific problems of thrusters is a phenomenon called thermal choking, where the hydrazine flowing in the feed tube is vaporized by the heat transferred to the feed tube from the catalytic layer and, as a result, the propellant flow is reduced and finally stopped. Thermal choking occurs depending on the firing mode of the thrusters. Since there is a mechanism called a thermal shunt, which exhausts the heat from the feed tube and prevents thermal choking, we have continued development aimed at a design that would not allow thermal choking in any firing mode. We have made many improvements to the thermal shunt, such as increasing the cross-sectional area and the exhaust heat efficiency, and finally succeeded in designing the optimal thermal shunt. It is important for the satellite system manufacturers to eliminate the restrictions of the firing mode.

*3 Heat soak-back: When the hydrazine flow is stopped, its cooling effect is eliminated, and much more of the heat from the catalyst layer is transferred upstream.

Daily research is the key to development

With support from the JAXA Industrial Collaboration

and Coordination Center, the new 1 N thruster was developed in collaboration with IHI Aerospace from 2009 to 2011. The Propulsion Group had continued research of the high reliability and long life of the thruster and had accumulated the know-how for the development of new thrusters. As a result, we were able to develop the longest life 1 N thruster successfully in the short period of 3 years.

As its first flight, this thruster will be loaded on the Super Low Altitude Test Satellite "SLATS" developed by JAXA, and four 1 N thrusters are now manufactured. SLATS is the satellite for verifying orbit-keeping technology in the super low altitude of less than 250 km. After the satellite is separated from the launch vehicle, it will use the new 1 N thruster to move to a predefined orbit (fig. 3)..

This time, we also succeeded in developing a "commercially competitive thruster"; therefore, this new 1 N thruster can be acquired at a low cost and with a short delivery time. Currently, IHI Aerospace is trying to sell to not only domestic but also foreign companies, and it is attracting a lot of attention all over the world.

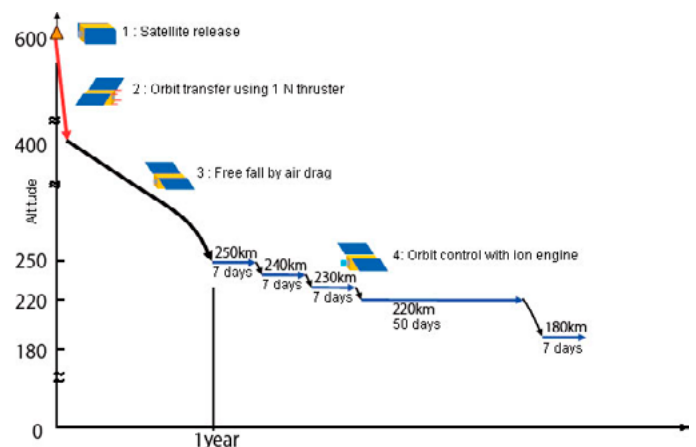


Fig. 3: SLATS operation schedule (planned)



[Propulsion Group]

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Cryocooler technology giving rise to a cryogenic world

Cooling technology is crucial

X-rays (electromagnetic waves of high energy) are emitted from severely high-energy regions, such as extremely near black holes and in clusters of galaxies. By observing these X-rays, we believe that we can close in on the mysteries of the creation of the universe; however, it is impossible to observe them from the earth since they are interrupted by Earth's atmosphere. Therefore, telescopes for investigating X-rays (X-ray astronomy satellites) are being launched into

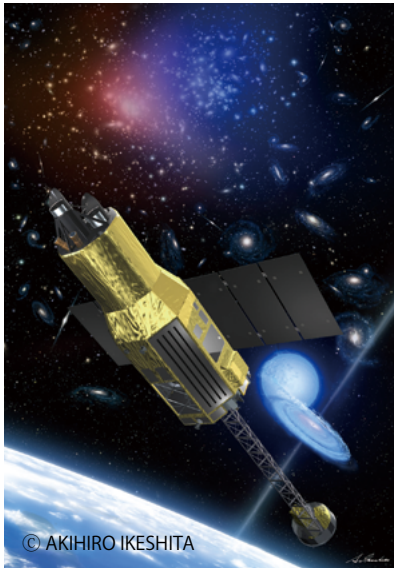
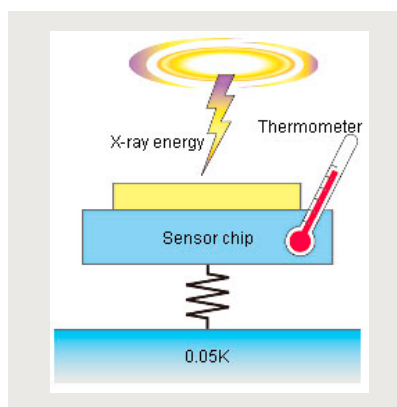


Fig. 1: ASTRO-H

space to conduct this observation.

Since the X-ray astronomy satellite "Hakucho" was launched by Japan in 1979, satellites have been periodically sent into space. In 2014, the next-generation X-ray astronomy satellite "ASTRO-H" (fig. 1), equipped with innovative scientific instruments, is planned to be launched. ASTRO-H is expected to be installed with two types of telescopes and sixfour types of scientific instruments, one of which is called a "soft X-ray spectrometer (X - r a y



The energy in X-rays is converted to thermal energy, and the temperature change at the sensor chip is measured.

Fig. 2: Detection principle of X-ray microcalorimeter

microcalorimeter)" (fig. 2), which precisely measures X-ray energy. Since faint temperature changes caused by X-rays will be detected, the microcalorimeter must be kept cold. Because it must be cooled to the extremely low temperature of 0.05 K^(*), the Thermal Systems Group of this department is tasked with developing part of this cooling system and the heat exhaust system.

*1 K: Temperature unit. 0 K = -273.15 °C

Mechanical cryocooler technology at the top of the world

The X-ray astronomy satellite "Suzaku" (the previous generation of ASTRO-H), launched in 2005, was also equipped with an X-ray microcalorimeter. Its cooling system used solid neon and liquid helium, which achieves a stable cooling efficiency. However, immediately after launch, the liquid helium was depleted due to an unforeseen event, making cooling impossible, and the originally planned continuous observation with the microcalorimeter could not be performed.^(*)2) Based on lessons learned from this, the redundant design of installing a mechanical cooler in conjunction with liquid helium means that the ASTRO-H will be adopting a cooling system that ensures reliable observation even if some malfunction occurs.

Power is needed to drive the mechanical cryocooler. Since high-efficiency temperature ranges (in other words, the temperature range where cooling is possible with low power consumption) differs depending on the cooling method, cooling with one system uses an enormous amount of power. Because we must cool as efficiently as possible in space, where power is limited, it is necessary to utilize the most efficient combined cooling system to cool down to the target temperature. What we are in charge of are the "two-stage Stirling cryocoolers" (2ST coolers), which lower the temperature to 20 K in two stages (100 K and 20 K), as well as the "Joule-Thomson cryocooler" (4K-JT cooler) (fig. 3), which cools to an the lower temperature of 4 K with 2ST coolers as the precooler. Then, the adiabatic demagnetization refrigerator (ADR), which is being developed by NASA, is used to cool down to the lower temperature of 0.05 K. (Fig. 4)

This 4K-JT cooler, which is being developed, is of the same typeas the cooler for the "superconducting

Research and development of a mechanical Joule-Thomson cryocooler

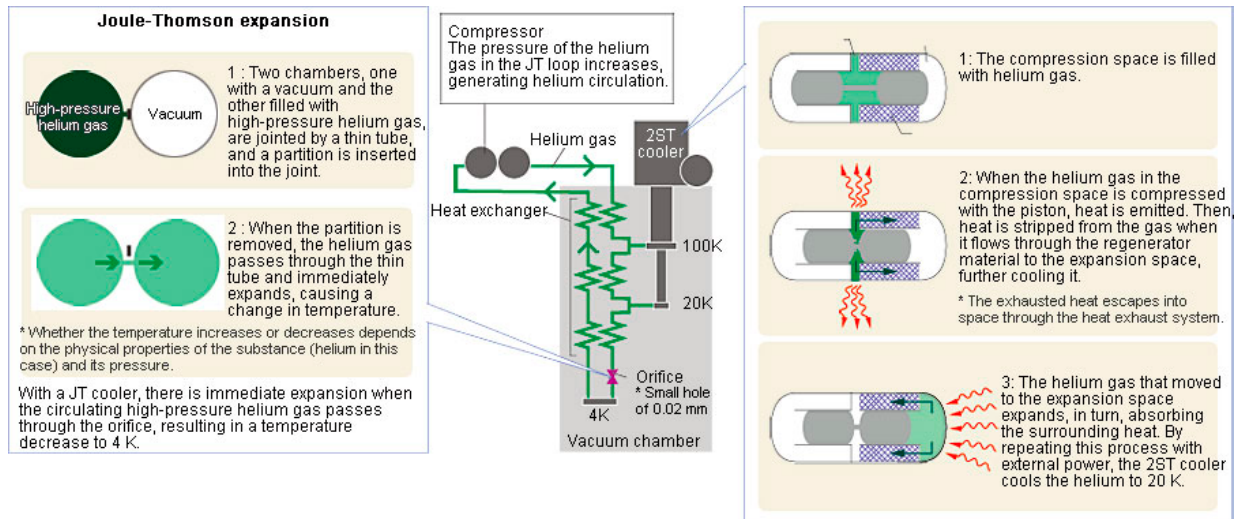


Fig. 3: Cooling principle of Joule-Thomson cryocooler

submillimeter-wave limb emission sounder" (SMILES), which is mounted on the Japanese experiment module "Kibo" on the International Space Station (ISS). Various improvements have been made with the aim of increasing the reliability (long life) as well as substantially increasing the cooling capacity (nearly doubling the cooling efficiency).

The design life^{(*)3} of the SMILES cooler was 1.5 years. With ASTRO-H, a design life of double that (3 years) is required. The primary factor in determining the life of a cooler is the outgassing produced by the on-board components inside the cooler. Outgassing is the unnecessary gas, such as water vapor or carbon dioxide, produced by adhesives used to joint components. If the helium gas circulating in the cooler was contaminated by these gases, the refrigeration capacity would drop, causing the life of the equipment to be shortened. Therefore, countermeasures, such as reducing the quantity of adhesive used and improved methods of fastening that do not use adhesives, were applied. In

addition, since there is a high risk of malfunction at points where components scrape against each other through movement (frictional parts), the design was changed to reduce the number of frictional parts as much as possible. To increase the cooling capacity, improvements, such as optimizing the expansion space for cooling, were made.

*2 Of the three types of scientific instruments installed on "Suzaku", the other two are performing observation as planned.

*3 Design life: A measure for the minimum number of years a component will work

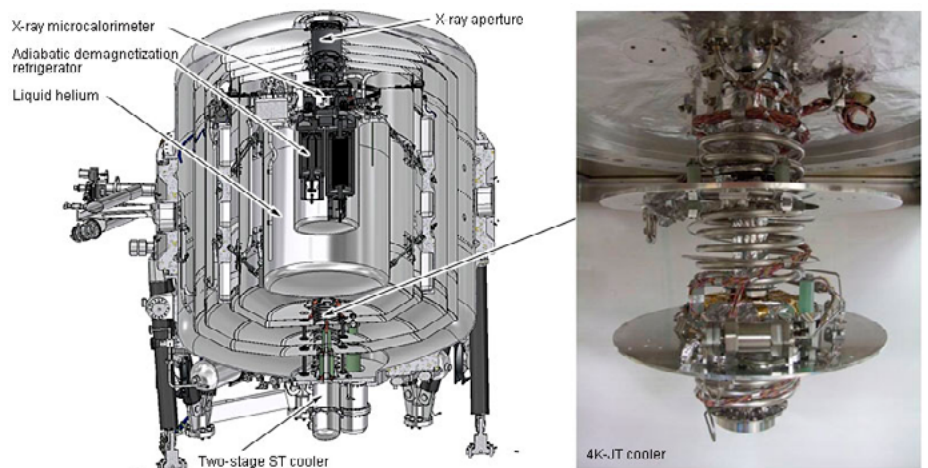


Fig. 4: Cooling system for the ASTRO-H soft X-ray spectrometer

Research and development of a mechanical Joule-Thomson cryocooler

Technology progressing day by day

Development of the engineering model^(*4) for the 4K-JT cooler to be installed on the ASTRO-H has already been completed, and we are currently verifying the design life through a continuous running test. As of June 13, 2012, it had reached a cumulative operating time of 12,130 hours. There are no symptoms of deterioration in the cooling capacity, and we have confirmed its sound operation.

The 2ST coolers and 4K-JT cooler to be mounted on the ASTRO-H are improved versions of the coolers developed for the infrared astronomy satellite “Akari”, which ended operation in 2011, and for SMILES, respectively. If their operation on ASTRO-H is completed successfully and their efficiency can be adequately confirmed, we are considering installing them as the cooling system of the next-generation infrared astronomy satellite “SPICA”, whose plan is currently being studied. Since the telescope on SPICA is to be equipped with a large primary mirror with a diameter

of 3.2 m, there will be no room to load liquid helium for cooling. Therefore, through the redundant design of mounting two sets of each mechanical cryocooler, we will ensure the largest cryogenic telescope as well as reliable cooling. In this way, by linking technology that has been developed to new technology, we are contributing to innovative spacecraft development. (Fig. 5).

*4 Engineering model: Model for verifying the validity of the design

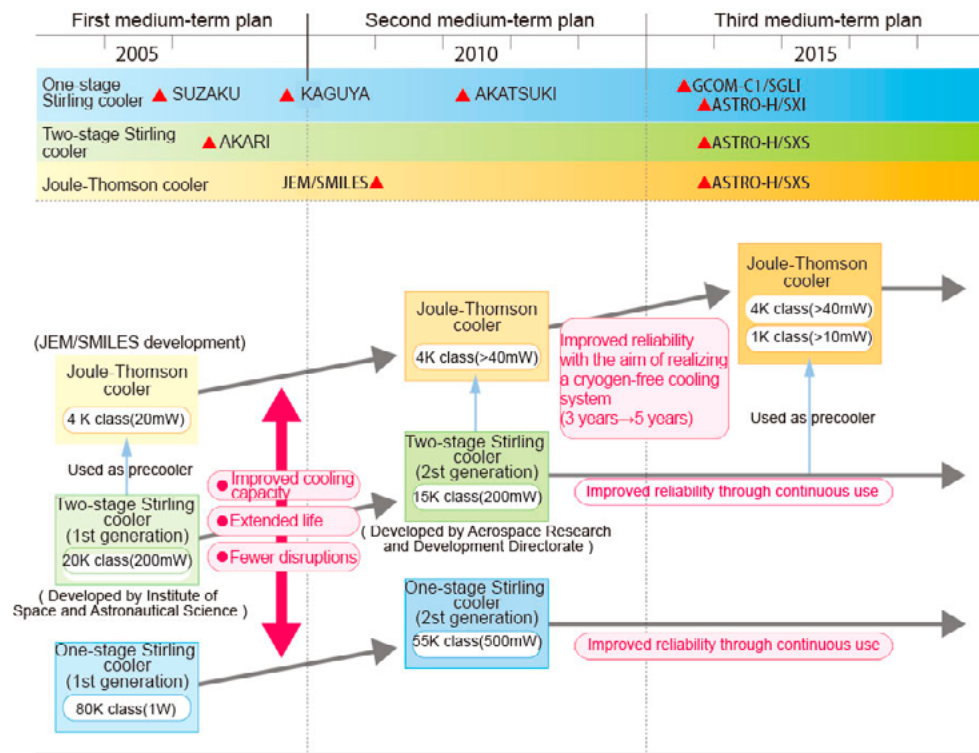
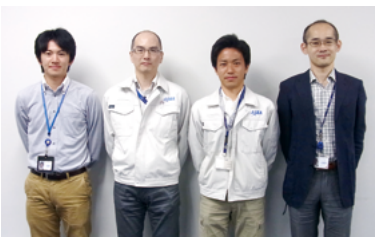


Fig. 5: Flow of development for mechanical cryocooler



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Space and temperature

■ Seeing a star's temperature



Fig. 1: Stars with various colors

You can gaze at many stars in an open area of the sky not polluted by light, such as streetlights, or on a clear night with no moonlight. If you look closely at those stars, you can see many colors - bluish and reddish. (Fig. 1) The color differences are determined by

the star's temperature. The surface temperature of a star with a strong reddish color, for example, Antares in the constellation Scorpius, is about 3400 K. In contrast, Vega in the constellation Lyra and one of the stars that form the Summer Triangle is pale and has a surface temperature of about 9500 K. However, the surface temperature of the sun, a star we cannot see at night, is in the middle at 6000 K.

■ Importance of invisible light

Not just stars, but all items that hold heat emit light

according to their temperature (fig. 2).^{*} However, visible light is the only light that we can see, and many types of light cannot be seen by the human eye. To accurately understand the appearance of stars or space, our eyes must detect the various types of light being emitted by stars and space. Let's gaze at the night sky one more time with those eyes. This time, what do you see?.

■ Managing distracting light by using temperature

JAXA is sending "astronomy satellites" into space as eyes for observing various types of light, including, of course, visible light. (Fig. 3) However, as mentioned earlier, all items that hold heat emit light according to their temperature. Astronomy satellites themselves are emitting light. What satellites at normal temperatures emit are "infrared rays". This light is powerful enough to hinder the observation of infrared radiation coming from beyond the distant universe. However, if the satellite is cooled to an extremely low temperature near absolute zero (0 K), nearly no infrared rays are emitted from it, making observation possible. Therefore, the infrared astronomy satellite is equipped with a cooler that is able to produce sufficient cooling (refer to here).

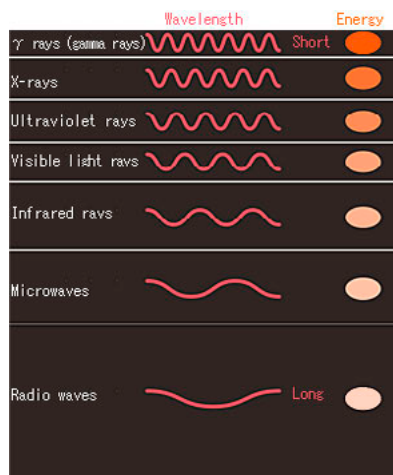


Fig. 2: Relationship between light and temperature



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The sun is covered by the corona, an outer layer that exceeds 2 million kelvin, from where X-rays radiate. Since the low-temperature X-rays do not radiate, the surface of the sun and the moon passing in front appear black in the photograph.

Fig. 3: X-ray image of solar eclipse taken by the solar observation satellite "Hinode"