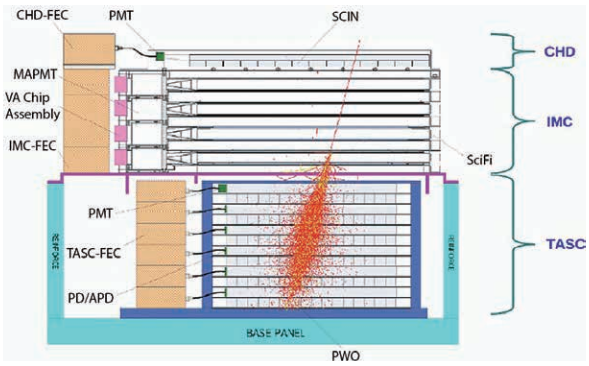
Challenge to Get a Clue of Revealing the Cosmic Mystery: Dark Matter

CALET, the most advanced probe for high-energy electrons

IHI AEROSPACE Co., Ltd. developed a cosmic ray observation apparatus (CALET) with the world highest level of observation capability to be mounted on the International Space Station's Japanese Experiment Module "KIBO" — Exposed Facility.

CALET ©JAXA



Calorimeter illustration

The universe is believed to contain dark matter, a massive substance that cannot be observed by visible light or other electromagnetic waves. The nature of dark matter remains a mystery of the universe.

For comprehensive understanding of the structure of the universe and astrophysical phenomena, including dark matter, an observation apparatus to directly observe cosmic rays and high-energy gamma rays is required in addition to observations with electromagnetic waves, such as visible light, infrared light and X-rays.

IHI AEROSPACE Co., Ltd. (IA) developed the apparatus for the CALET project, which is led by Waseda University and the Japan Aerospace Exploration Agency (JAXA).

The CALET is an observation apparatus developed for measuring the energy of particles flying through space as well as identifying the type of particles and their direction of arrival in order to discover the origin and acceleration mechanism of high-energy cosmic rays. It is a 0.8 × 1.0 × 1.85 m box-shaped apparatus, weighing 613 kg. It was transported to the International Space Station (ISS) via Japan's H-II Transfer Vehicle (HTV) "KOUNOTORI" and installed on the Exposed Facility of the ISS's Japanese Experiment Module "KIBO." The facility provides the power supply, communication control, and active thermal control functions necessary for observation.

The CALET is composed of an imaging calorimeter, gamma-ray burst monitors, a mission data controller, support sensors and ISS-HTV interface devices. IA developed the entire CALET system, as well as the observation instrument.

The calorimeter is the main instrument of the CALET, and it is composed of three elements: a charge detector to measure the charge of the incident particle and identify the kind and the atomic number of nucleus; an imaging calorimeter to detect the charges and arrival directions of

Left: Total absorption calorimeter sensor (lead-tungstate crystal scintillator)
Middle: Imaging calorimeter sensor (scintillation fiber)
Right: Charge detector (plastic scintillator)

cosmic rays; and a total absorption calorimeter to measure the shower development behavior and to determine the incident particle energy. As the calorimeter can measure high-energy cosmic rays with a higher resolution than previous apparatus in high-energy region, it is expected to give an answer to unresolved problem in universe, such as the propagation and acceleration mechanisms of high-energy cosmic rays.

Different from conventional electromagnetic wave observations, the observation of high-energy cosmic rays is performed through a combination of a scintillator material, which absorbs the energy of cosmic rays and re-emits this absorbed energy in the form of photons, and photon detectors, such as photomultiplier tubes and photodiodes.

Each element in the calorimeter has layers that consist of sensors. The sensor layers are orthogonally arranged to visualize the trajectories of interacting particles through the detectors. The charge detector consists of two layers, each of which consists of 14 sensors using 32 mm wide plastic scintillators. The imaging calorimeter includes 16 layers made up of 448 scintillation fibers with a 1 mm square cross section. The total absorption calorimeter consists of 12 layers, each of which consists of 16 sensor channels using lead-tungstate crystals with a 19 × 20 mm cross section. In total, the calorimeter has 7 564 sensor channels. The output of the sensors is read out by a unit called a front end processor and then downlinked to a ground system as observation data. Downlinked observation data is analyzed by researchers to identify particle types and energy.

The apparatuses to be launched into space need to be light and compact. They must also be able to withstand environments specific to space, such as a vacuum and widely fluctuating temperatures, as well as vibrations during launch. Furthermore, the CALET was developed to overcome technical issues such as the following: the fragility of scintillators; electrostatic discharges in space; and the minimization of noise in signals.

Some scintillators are made of a material more fragile than glass. The type of rigid mounting that is used for general metal structures cannot protect the scintillator from vibrations during launch and the strain produced by the difference in coefficients of thermal expansion. The design of the mounting structure adopted in the CALET is, therefore, different from conventional ones and based on the distributive support of scintillators by rubber materials. The structural design was finalized through a feasibility study, a material property investigation, a prototype test, and a final structural analysis based on the prototype test results.

While light detector devices normally use a high voltage, the CALET has as many as 80 high-voltage channels. When a high voltage is used in space, care has to be taken about electrostatic discharge. An electrostatic discharge in a vacuum can sometimes cause catastrophic damage to devices. Electrostatic discharge prevention is a field which requires special attention in both designing and manufacturing the devices. IA has managed the manufacturing of the sensors by establishing an electrostatic discharge prevention design, to use conformal coating and potting to block the electrostatic discharge path and its manufacturing process through several prototype manufacturing runs and tests.

Also, the signals from light detectors are extremely small (less than femto (10^{-15}) coulomb) and, therefore, circuit noise needs to be reduced to the limit to achieve required measurement accuracy. IA has achieved required performance in a limited space by repeating the trial production of the circuits and their evaluations.

The CALET was loaded onto the HTV 5 and installed on the ISS in August 2015. The initial functional verification was completed successfully and the observation was started. The observation period is scheduled to continue for 2 to 5 years. IA would like to give special thanks to Waseda University for their direction in the development of the CALET equipment.

Inquiries:
Space Systems Department,
IHI AEROSPACE Co., Ltd.
Phone: +81-274-62-7676
Website: www.ihi.co.jp/ia/en/