PROCEEDINGS OF SCIENCE

Status of the operations of CALET for 7.5 years on the International Space Station

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The CALorimetric Electron Telescope (CALET) has successfully been carrying out cosmic-ray observations on the International Space Station since October, 2015. CALET directly measures the cosmic-ray electron spectrum in the energy range of 1 GeV to 20 TeV with a 2 % energy resolution above 30 GeV. In addition, the instrument can measure the spectrum of gamma rays well into the TeV range, and the spectra of protons and nuclei up to a PeV. The scientific operations are implemented by taking into account orbital variations of geomagnetic rigidity cutoff. Scheduled command sequences are used to control the CALET observation modes on orbit. The high-energy (>10 GeV) trigger mode is always active for maintaining maximum exposure to high-energy electrons and other high-energy shower events. Also, around the ISS orbit, calibration data acquisition by, for example, recording pedestal and penetrating particle events, a low-energy electron trigger mode operating at high geomagnetic latitude, a low-energy gamma-ray trigger mode operating at low geomagnetic latitude, and an ultra-heavy trigger mode, are scheduled. As of June 30, 2023, the total observation time is 2818 days with a live time fraction of the total time around 86 %. Nearly 1.86 billion events are collected with the high-energy trigger.

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1. Cosmic-ray observations with CALET on the ISS

The CALorimetric Electron Telescope (CALET), which was launched on August 15, 2015, has been carrying out observations of electrons, protons, nuclei, ultra heavy particles, and gamma-rays on the International Space Station (ISS) since October 13, 2015.As shown in Fig. 1, CALET consists of a main detector CAL (Calorimeter), a gamma ray burst monitor CGBM (CALET Gamma-ray Burst Monitor), and other supporting sensors such as a GPSR (GPS Receiver) and an ASC (Advanced Stellar Camera). CAL consists of a combination of three types of detectors. A CHD (CHarge Detector) placed on the top measures the charge of the incident particles by 28 plastic scintillator bars. An IMC (IMaging Calorimeter) placed in the middle detects directions of incident particles and starting points of showers by 7168 scintillating fibers. A TASC (Total AbSorption Calorimeter) placed at the bottom discriminates kinds of incident particles and determines their energies by 192 PWO ($PbWO_4$) scintillators. CALET is controlled by an MDC (Mission Data Controller) to collect data from detectors, communicate data with the ground, and execute commands. For about 8 years after launch, CALET has continued its observations smoothly without any major failures. Only one of the 7168 channels of the IMC detector has a permanent failure and only one has a gain drop after launch. Through CALET observations so far, we have obtained a number of results, including an energy spectrum of electrons up to 4.8 TeV [1, 2], energy spectra of nuclei from protons to nickel [3–10], low energy electron precipitation phenomena[11–13], a charge dependence of the solar modulation of cosmic rays[14], gamma-ray burst observation[15], and search of gamma-ray counter part of gravitational wave events[16–18].

2. Operations for CALET

2.1 Normal and Special Operations

Normal operations for CALET include creating schedule files and checking status of the CALET equipment and qualities of its data. The schedule file is created for about 4 days, which is the upper limit of the file size, and updated every Monday, Wednesday, and Friday around 3:00 UT. According

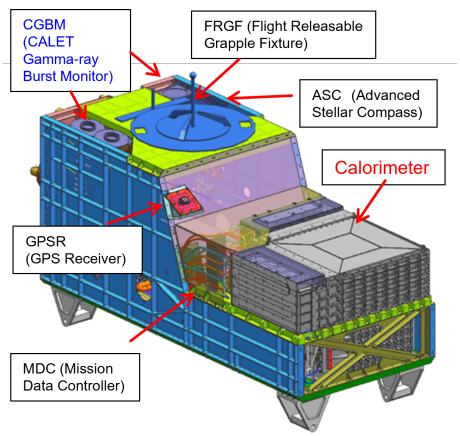

Figure 1: An overview of the CALET instrument

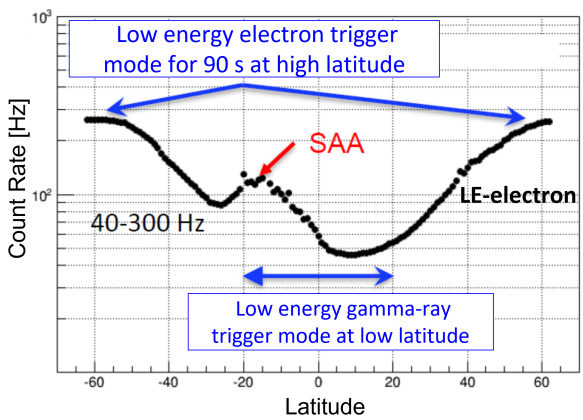

Figure 2: Expected LE-electron count rate

to the regular observation schedule mentioned below, we create a schedule file based on the two-line orbital element (TLE) containing the ISS orbital information obtained from Space-Track[19], and send it to TsuKuba Space Center (TKSC) of JAXA. This creation and submission of the schedule file is done automatically. On the other hand, Japanese shift members take turns checking the CALET DQC (Data Quality Check) website distributed by the WCOC (Waseda CALET Operations Center) every day and reporting the check results by email.

We sometimes need special operations related to ISS operations or CALET malfunctions. We have to deal with tasks related to ISS operations such as reboosts for altitude change, PDAM (Predetermined Debris Avoidance Maneuver), power reduction requests, out gas of other equipment. We also have to handle known events such as MDC auto-reboot by SEU (Single Event Upset), no MDC response for ping due to a filled up ARP (Address Resolution Protocol) table, and so on.

2.2 Observation schedule

CAL has five observation modes, high energy trigger (HE), low energy electron trigger (LE-electron), low energy gamma-ray trigger (LE-γ), pedestal trigger, single trigger (p, He). The HE mode which is set for main purpose of CALET to observe high energy electrons over 10 GeV is always active. Its count rate is less than 10 Hz at any longitude. The LE-electron mode is set to observe low energy electron more than 1 GeV in high latitude of low cutoff rigidities. Because a count rate of the low energy electron observation reaches to around 300 Hz as shown in Fig. 2, each observation period is limited to 90 seconds. The LE-γ mode is set to observe gamma-rays over 1 GeV. In order to limit a count rate of several tens events/second, the LE-γ mode is active in low latitude within plus minus 20 degrees as shown in Fig. 2. We take pedestal data every 23 minutes. Because the orbital period of the ISS is 90 minutes, we expect to acquire the data at all unbiased points. We also take proton or helium events as calibration data by setting single trigger mode at a fixed time (11:30 - 14:30 UT) every day. We can calibrate signal change of each channel of CHD, IMC, and TASC for single particles.

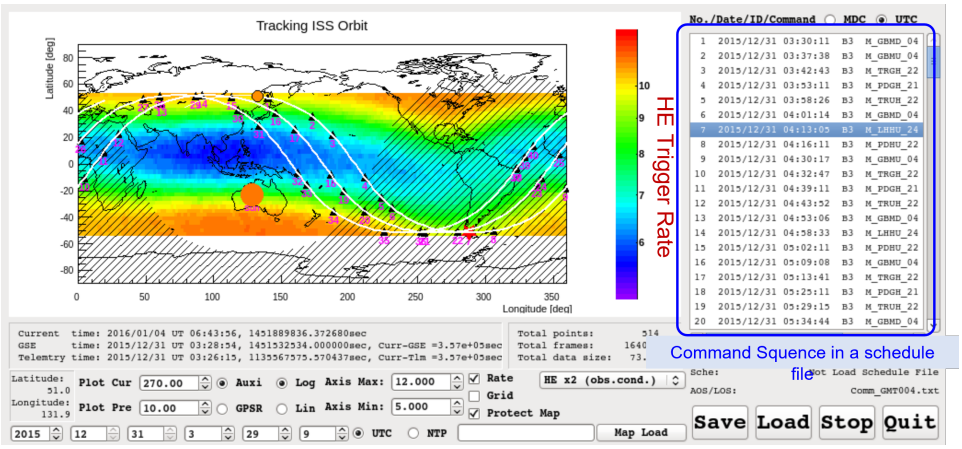

Figure 3: Schedule commands and their execution timing on the ISS track

The photomultiplier tubes (PMTs) of CGBM may be damaged in gain at high count rates. Therefore, the PMTs are protected by turning off the high voltages (HVs) for the PMTs in the high count rate region, such as north and south high altitude regions and South Atlantic Anomaly

(SAA). The MDC changes the trigger modes and set the HVs on and off to protect the CGBM PMTs according to commands and execution times written in the schedule file as shown in Fig. 3.

2.3 Data processing operation

The raw data is transferred to the ground in real time during the 80% AOS (Acquisition Of Signal) period. They are recorded in JAXA's TKSC database, and sent to also WCOC. Based on the raw data, WCOC displays an overview of the data and the quality of the data in Quick Look (QL) on web pages, enabling real-time monitoring from anywhere at any time. It allows us to ask the TKSC operator to send a safetying command if necessary.

Data that could not be transferred to the ground in real time during LOS (Loss Of Signal) period will be transferred afterward to the TKSC and recorded in the database. In TKSC, AOS and LOS data are merged into one file as Level 0 data for one hour according to the time series. This Level 0 data file is transferred to the WCOC every hour.

In WCOC, Level 1 data is created by converting Level 0 data into physical quantities and used to create QL on the web pages. Furthermore, higher order data files (such as Level 2) are created for detailed scientific data analysis.

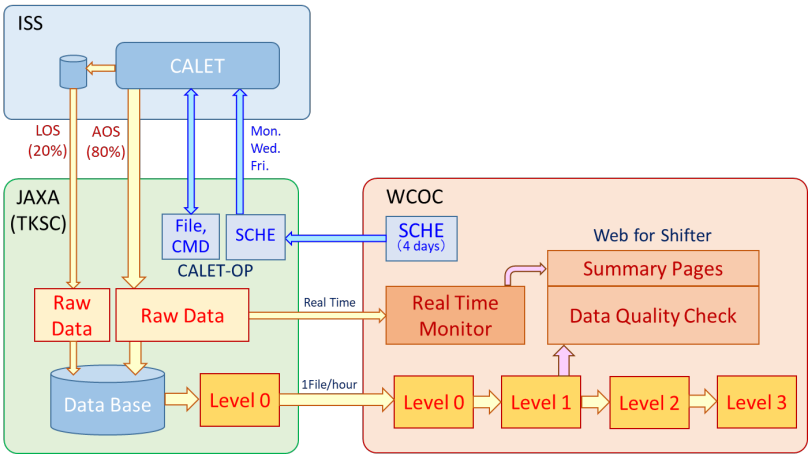

Figure 4: Data processing flow

3. Status of CALET operation

Fig. 5 shows the daily observation time and the actual observation time (live time). Observation time became less than 24 hours when some troubles occurred and the countermeasures were taken, however it can be seen that the observation times were quickly recovered. As shown in Fig. 6 a total observation time of CALET from October 13, 2015 to June 30, 2023 is 2818 days. A live time, which is an actual observation time excluding the dead time for the observation time, is 85% or more. An exposure in the HE trigger mode during the observation time has reached $S\Omega T = 248$ m^2sr days. Total data obtained by the HE trigger mode reached 1.86×10^9 events on June 30, 2023. It is steadily increasing as shown in Fig. 7. The spectrum of energy loss at TASC for all 4.05 billion events acquired during the observation time is shown in Fig. 8.

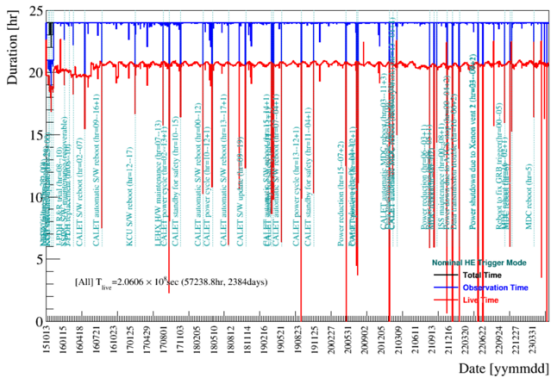

Figure 5: Daily observation time and actual observation time (live time)

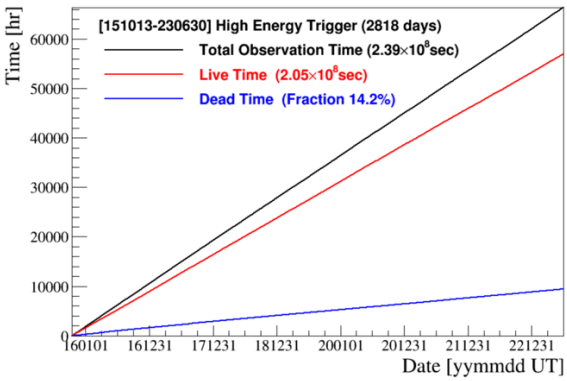

Figure 6: Accumulated observation time, actual observation time (live time), and dead time

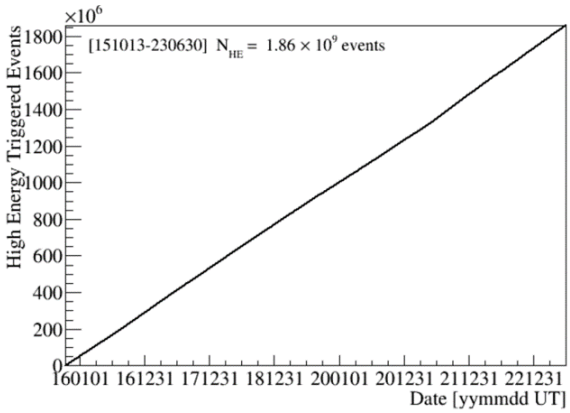

Figure 7: Accumulated event number of the HE trigger

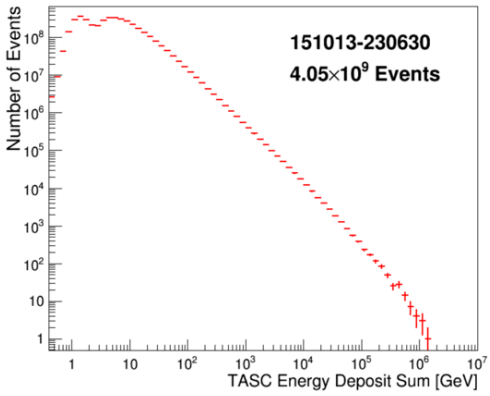

Figure 8: Energy deposit in TASC

4. Summary

CALET has been carrying out cosmic-ray observations on the space station for more than seven years while maintaining the expected instrument performance. Responses related to ISS operations, such as reboosting and power reduction requests, are being properly implemented in collaboration with JAXA. When malfunctions occur, they are identified by checking observation data, and measures are taken quickly to restore normal observation in cooperation with JAXA.

Acknowledgements

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