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The First Flight of the CREAM Silicon Charge Detector

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The CREAM (Cosmic Ray Energetics And Mass) experiment was constructed for the measurement of high-energy cosmic rays in the energy range between 10^{12} and 10^{15} eV. As a long duration balloon payload, the CREAM had its first successful flight in December 2004 from McMurdo Station, Antarctica. For the charge measurement of incident cosmic-ray particles entering the calorimeter module, a layer of the SCD (Silicon Charge Detector) made of 2912 silicon pixels was built with an active area of 779 × 795 mm^2. This paper describes the performance of the SCD during the 2004-2005 flight.

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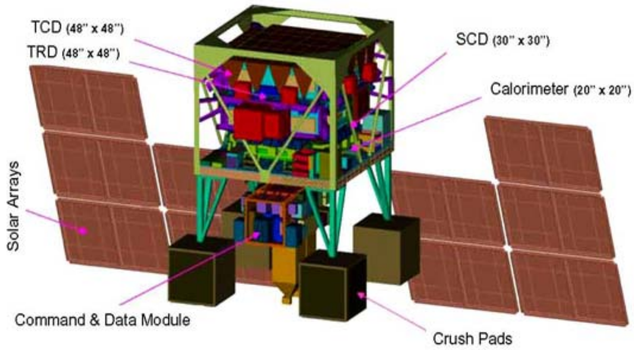

Fig. 1. The CREAM payload and the components.

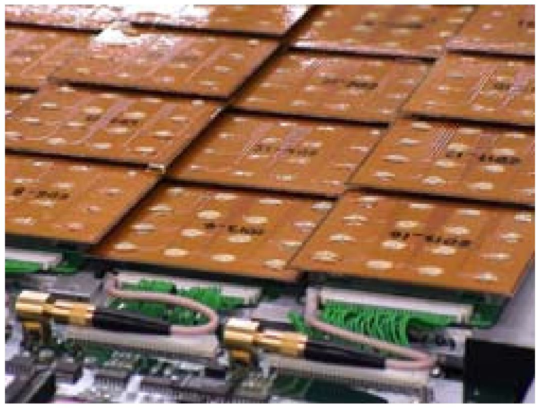

Fig. 2. Part of the SCD assembly. Silicon sensors are arranged with overlapping edges to be dead-region free in all directions. The front-end analog board is installed under the sensors.

I. INTRODUCTION

The total flux of primary cosmic-rays with energy above 10^9 eV falls rapidly as their energy increases. The slope of the spectrum fits a power-law distribution well. The spectrum has a kink around 10^{15} eV, which is called a 'knee'. Though the characteristic is clear, the origin of knee is still the subject of active research [1]. Supplying the measurement data of the detailed spectrum in the energy range is important.

The CREAM experiment [2] is a balloon-borne experiment to provide direct measurements of the cosmic-ray energy spectrum and the composition in the range between 10^{12} and 10^{15} eV. For the energy measurement, the CREAM payload is equipped with two independent instruments: a tungsten/scintillating-fiber calorimeter and a transition radiation detector (TRD). Both detectors also provide multiple position measurements, allowing reconstruction of the incident direction and the position of the primary cosmic rays. For charge measurements, the CREAM experiment has a timing charge detector (TCD), a silicon charge detector (SCD), and scintillating fiber hodoscopes. The reconstructed tracking information is used to locate the hit segment in the SCD layer that is installed between the TRD and the calorimeter. In order to avoid triggers caused by low-energy particles, a Cherenkov veto counter was added between the two TRD modules. The payload instruments are shown in Fig. 1. The CREAM instrument had its first flight in December 2004 in Antarctica. About 40 million science events were collected during the 42 days flight with a long duration balloon.

II. THE SILICON CHARGE DETECTOR

The design of the SCD was optimized to the condition of a balloon experiment. A high-resistivity n-type silicon wafer with a thickness of 380 μm was selected to provide a full depletion bias voltage low enough to avoid possible high-voltage discharge at the top of atmosphere. A 4×4 array of sensor pixels was fabricated in a 5-inch silicon wafer. The PIN diode pixel had an active area of 2.1 cm^2. A total of 182 silicon sensors (2912 pixels) were used for the SCD.

The front-end analog electronics were built using CR 1.4 ASICs developed for a cosmic ray experiment [3]. The signals from the silicon sensor are handled by using 16-channel chip and provide a large dynamic range and low power consumption. The signal from a pixel is converted into a held DC level and multiplexed to a 16-bit ADC, providing fine digitization up to Z = 33 signals.

The analog boards are installed beneath silicon sensors. The sensors are partially overlapped to be dead-region free in the x- and the y-directions, as shown in Fig. 2. The total size of the SCD box, including the ladders, the sensors, and the mechanical supporter, is 818.4×818.3 mm^2. The active area of the SCD layer is 779×795 mm^2. The total detector height is 21.6 mm, including the detector cover. The details of the SCD hardware will be published elsewhere.

The SCD was tested using the heavy ion beam at CERN with fragments of 158-GeV/nucleon indium beams in November 2003. The result shows excellent charge resolution and linearity in the response for the charge (Z) range from Z = 1 up to Z = 33 [4].

The detector was also tested in a thermal-vacuum condition at NASA/Goddard Space Flight Center (GSFC) in early September 2004. The test was performed in the temperature range from −10 °C to 40 °C at an air pressure of 4 Torr. A correlation between the number of noisy channels and the detector temperature was clearly seen during the test and is shown in Fig. 3. A noisy channel is defined as a channel with high RMS values for the pedestal signals. The fraction of noisy channels in all pixels is drawn as a function of the detector temperature for three levels of the RMS values of the pedestal signals. When the temperature is increased over 40 °C, the number of noisy channels with high RMS values of

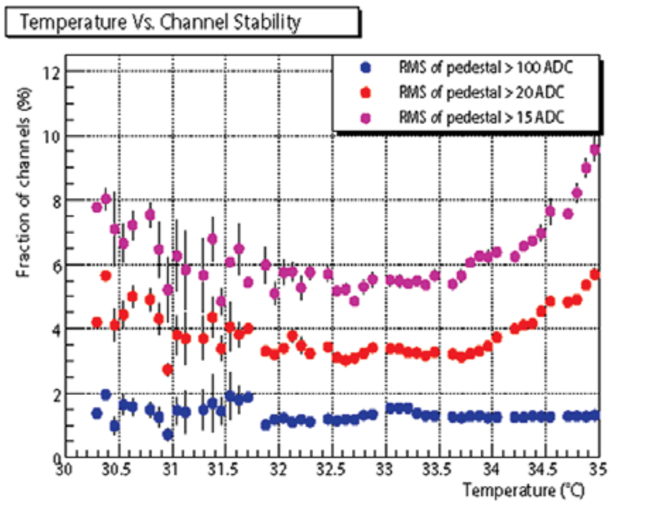

Fig. 3. Fraction of noisy channels vs. detector temperature in the thermal-vacuum test taken before the flight. A noisy channel is defined as a channel with high RMS values of the pedestal signals.

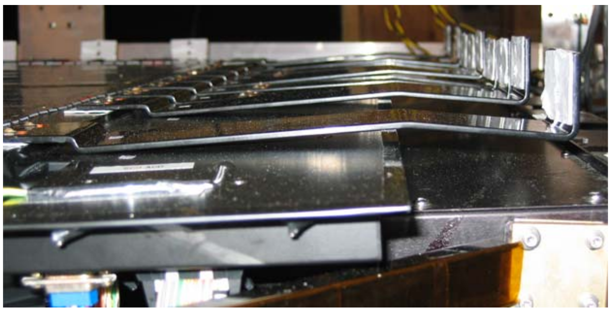

Fig. 4. Part of the copper straps attached at a side of the top cover to conduct out the heat generated in the electronics. A total of 28 straps is connected to the CREAM payload frame from all sides of the SCD cover.

the pedestal signals rises rapidly.

In order to keep the detector temperature within a good operational range, the installation of thermal straps was carefully designed to conduct out the heat from the front-end electronics. Fig. 4 shows the thermal straps installed at a side of the top cover. The CREAM instrument intergrated for the environmental test at NASA-GSFC is shown in Fig. 5.

III. THE SCD PERFORMANCE DURING THE FLIGHT

The CREAM payload was launched on 16 December 2004. It had a record breaking flight of 42 days until it is landed on 27 January 2005. The balloon altitude was maintained between 36 km and 40 km. The downlink of data from the instrument was made through the

Fig. 5. The CREAM instrument integrated for the environmental test at NASA-GSFC.

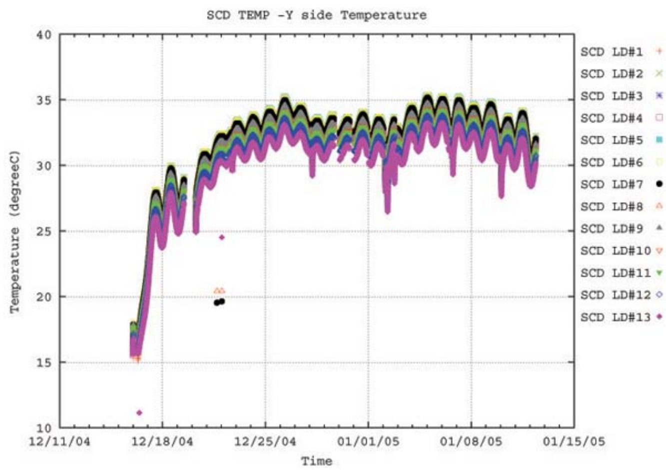

Fig. 6. Variation in the SCD temperature during the flight measured at the front-end analog boards in a side of the detector. The rise in the beginning of the period is the launch fly.

TDRSS (Tracking and Data Relay Satellite System) in near real-time.

The SCD data was sparsified with thresholds optimized for the limited bandwidth of data transmission. The status of the SCD was monitored during the flight by using the signals from housekeeping electronics implemented in all the front-end boards.

The change in the readout pedestal due to the instrument temperature was found to be about 20 ADC counts/°C for most channels. The temperature was found to vary about 2 °C with a change of 1.5 km in the payload altitude, which is shown in Fig. 6. Pedestal data were taken every 5 min for offline correction. Readout electronics were periodically calibrated during the

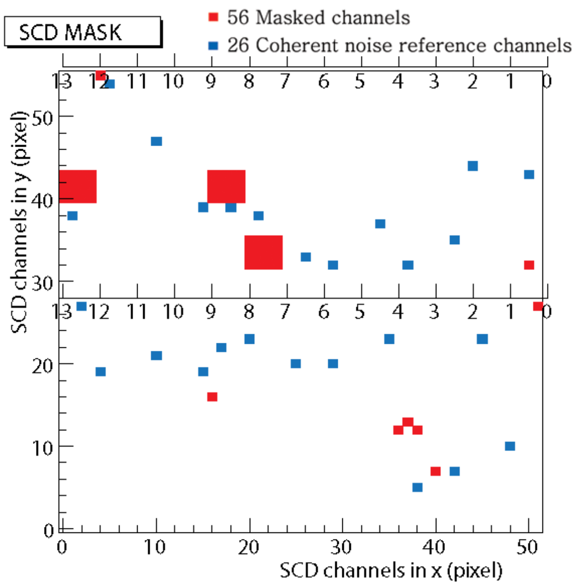

Fig. 7. Bad channel map showing the SCD pixels that were masked during the flight because they were too noisy or dead. Among 52×56 SCD pixels, a total of 56 channels were masked (shown in red). The blue spots are 26 channels selected to provide reference data to correct for coherent electronic noise. Their signals were recorded continuously.

flight by using a charge calibration every 2 hours. The electronics gain stayed stable during the operation period.

For the purpose of the common noise correction, 26 channels (one channel in each analog board) were selected, and their data were always recorded. 1.9 % of the SCD channels were found to be dead or too noisy, with RMS values of the pedestal signal higher than 100 ADC counts. They were masked during the data acquisition. These channels are shown in the map of Fig. 7.

The quality of the data and the detector condition were monitored during the entire period of the flight. The SCD temperature was maintained in the range between 25 and 33 °C. The maximum daily variation of the temperature was measured to be about 4 °C [5]. There was a short time period with an unusually high number of noisy channels on January 20. It turned out that the period coincided with a large solar flare [6].

The SCD flight data were analyzed using the tracking information from the TRD and the reconstructed shower axis from the calorimeter. They are important in suppressing fake signals from noise channels and in correcting for the differences in the signal sizes from different incident angles. The influence of backscattered particles from the target was also minimized by using the information. Finally, signals from low-energy cosmic rays were removed using the data from the Cherenkov veto counter. As reported in Ref. 7, the preliminary analysis of the SCD flight data showed clean spectra of cosmic ray nuclei up to Z = 26.

IV. SUMMARY

The SCD was designed to measure the charge of primary cosmic rays for the CREAM experiment. During the first flight of the CREAM experiment in Antarctica during December 2004, the SCD was successfully operated in a good condition. A clean charge spectrum was seen in SCD flight data when analyzed with tracking information from the TRD and the shower axis reconstructed in the calorimeter.

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