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Cosmic Ray Energetics And Mass (CREAM) Overview

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Abstract: The Cosmic Ray Energetics And Mass balloon-borne experiment has accumulated 70 days of exposure during two successful flights in Antarctica. The instrument is configured with complementary and redundant particle detectors. Energy measurements are made with a transition radiation detector and an ionization calorimeter. Charge measurements are made with timing, pixelated Si, and Cherenkov detectors to provide powerful rejection of backscatter particles. High energy cosmic-ray data from the first two flights were collected over a wide energy range from ~ 10 GeV to ~ 1 PeV at an average altitude of ~38.5 km (~3.9 g/cm^2 atmospheric overburden). Preliminary analysis indicates the data extend well above 100 TeV and follow reasonable power laws. All elements from protons to Fe nuclei are separated with excellent charge resolution. The payload recovered from the first flight has been refurbished and is being integrated in preparation for the third launch, scheduled for December 2007. Simultaneously, the payload recovered from the second flight is being refurbished for a subsequent fourth flight. Results from the ongoing analysis and future plans will be presented.

Introduction

The Cosmic Ray Energetics And Mass (CREAM) experiment was designed and constructed to measure cosmic ray elemental spectra for Z = 1 - 26 nuclei. The goal was to extend direct measurements of cosmic-ray composition to the highest energies practical with balloon flights. Precise measurements of the energy dependence of elemental spectra from ~10^{12} to ~ 10^{15} eV, where the rigidity-dependent supernova acceleration limit could be reflected in a composition change, provide a key to understanding cosmic-ray acceleration and propagation. Secondary cosmic rays produced from the nuclear interactions of primary cosmic rays with the interstellar medium hold a key to understanding the cosmic-ray propagation history. In order to obtain the spectra at the source where cosmic rays are accelerated, the measured spectra must be corrected for propagation effects. Simultaneous measurements of the relative abundances of secondary cosmic rays (e.g. B/C) and the energy spectra of primary nuclei will allow determination of cosmic-ray source spectra at energies where measurements are not currently available.

The instrument was designed to meet the challenging and conflicting requirements to have a large enough geometry factor to collect adequate statistics for the low flux of high energy particles, and yet stay within the weight limit for near-space flights. It has redundant and complementary charge identification and energy measurement systems. A detailed description of the instrument has been published elsewhere [1].

The first payload was launched from McMurdo, Antarctica on 16 December 2004, and it subsequently circumnavigated the South Pole three times before being terminated on 27 January 2005 [2]. Both the distance traveled (~14,000 nautical miles) and the time duration (41 days 21 hours 36 minutes) were records for an Antarctic LDB flight. The second launch occurred on 16 December 2005 exactly 1 year after the first launch. A cumulative duration of 70 days within 13 months, another LDB record, was achieved when the second flight completed its 28-day journey on 13 January 2006 after twice circumnavigating the South Pole.

The exceptional performance of both the science instrument and the flight support systems can be attributed to the fact that they were developed for 100-day ULDB missions. The instrument performance is discussed elsewhere [3, and references therein]. A total of 60 GB of data including ~ 4×10^7 science events were collected from the first flight and 57 GB including ~ 2.7×10^7 science events were collected from the second flight.

Current Results

Multiple charge measurements with a Timing Charge Detector (TCD), Cherenkov Detector (CD), Silicon Charge Detector (SCD), and S0/S1 layers of scintillating fibers accurately identify the incident particles by minimizing the effect of backscattered particles from the calorimeter. Charge detectors resolve individual nuclei with excellent charge resolution (σ ~ 0.2e). While the Transition Radiation Detector (TRD) measures the Lorentz factor (γ) for $Z \geq 3$ particles with large acceptance, the calorimeter measures the energy of all the particles including p and He, albeit with a more limited acceptance.

Preliminary spectra of heavy nuclei from the TRD and calorimeter from flights 1 and 2 are reported at this conference [4, 5, 6]. The CREAM results span > 4 decades in energy from ~ 10 GeV to ~100 TeV. Proton and He spectra in energy per particle are compared with previous measurements and Hörandel's empirical model [7] in Fig. 1. The shaded area indicates the ground based indirect measurements produced from various hadronic interaction models in the atmosphere, such as QGSJET and SIBYLL. The calorimeter calibration and the details of the analysis are reported at this conference [8, 9]. The energy deconvolution is still preliminary, and the energy dependent shower leakage corrections for the energy scale have not yet been made. The absolute flux has large uncertainties, not shown in the plot, but the results are in agreement with the previous measurements. The proton spectrum seems to follow a power law without much change up to ~ 100 TeV. Compared to lower energy data, there seems to be an increase in the abundance of helium nuclei relative to protons.

At the current stage of analysis, the CREAM measurements show good agreement with Hörandel's empirical model which is based on compiled data of previous measurements. Future flights will extend the CREAM energy reach to higher energies to distinguish hadronic interaction models, such as QGSJET and SIBYLL used for KASCADE data.

The CREAM flight duration exceeds the cumulative flight time of either JACEE or RUNJOB. The number of protons measured by CREAM is more-or-less equivalent to the total of all the prior experiments. JACEE reported only 656 protons above 6 TeV [10], despite the fact that the flight duration was about 60 days, while CREAM estimates >1700 protons from its 70 day flight. This is, in part, because less than half of their collected data was analyzed and, in part, because their detection efficiency was apparently low. RUNJOB had about the same flight duration, but only 40% of the exposure due to a smaller detector area.

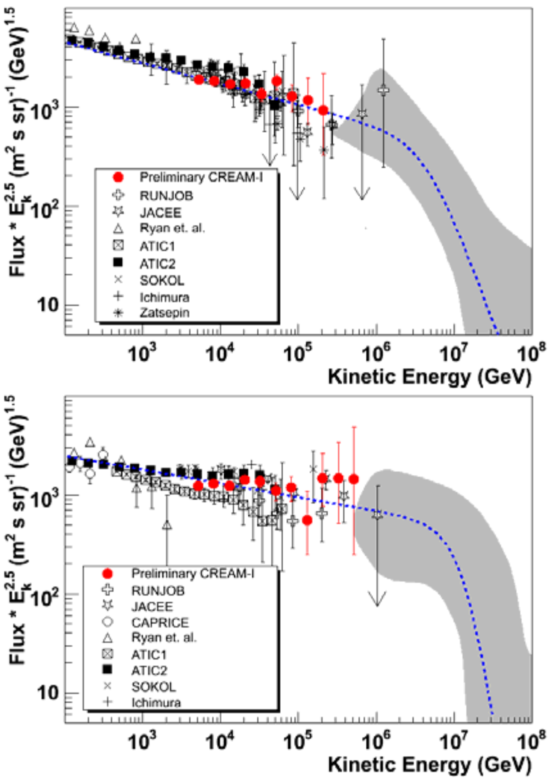

Figure 1: Preliminary CREAM-I (red circles), proton (top) and helium (bottom) spectra in energy per particle are compared with direct measurements (various symbols) [8], Hörandel's empirical model (dotted curve) and ground based indirect measurements (shaded area).

The CREAM payload is relatively light as an LDB payload (2000 – 2500 lb), and it maintained high altitude. The corresponding atmospheric overburden was 3.9 g/cm^2. That implies about 6.8 g/cm^2 for the maximum angle acceptance, which is smallest among comparable experiments. For example, the average vertical depth for RUNJOB was more than twice that of CREAM, due to its low flight altitude. Considering the RUNJOB acceptance of particles at large zenith angles, its effective atmospheric depth is as large as 50 g/cm^2. For that depth, large corrections are required to account for the fact that 41% of protons and 84% of Fe nuclei would have interacted before reaching the detector.

The trigger geometry factor of the CREAM TRD is 2.2 m^{2}sr. The effective geometry of the calorimeter, after taking into account the interaction fraction, is about 0.3 m^{2}sr for protons and increasingly higher for heavier nuclei, due to their higher interaction probability. The collecting power of CREAM is about a factor of two larger than that of ATIC for protons and He and, considering the much larger geometry factor of the TRD, about a factor of 10 larger for heavier nuclei. TRACER has a larger geometry factor than CREAM, but a smaller dynamic charge range (Z = 8 – 26) was reported for its 10-day Antarctic flight. Its dynamic charge range was improved to Z = 3 – 26 for its ~ 4-day flight from Sweden to Canada in 2006. We estimate that the latter should have approximately the same amount and quality of data as CREAM for precise high-energy B/C measurements.

Refurbishment and Upgrades for CREAM-III and CREAM-IV

The instruments used for the first two flights survived landing of the payloads almost intact. Even the fragile 380 μm thick silicon sensors were well protected. However, some parts of the instrument had to be cut during recovery to go through the Twin Otter door. For example, the honeycomb pallet had to be cut into two pieces, the calorimeter optics were destroyed, and some tungsten plates were damaged, etc. Reassembly of the calorimeter optics was one of the major refurbishment efforts. The fully refurbished calorimeter from CREAM-I was recalibrated at the CERN SPS in October 2006, in order to be flown in CREAM-III.

One of the improvements made for the CREAM-III calorimeter was a new "quartet" structure for better survival of optical components: the light-tight wall around the stack has been replaced by a structure of inter-connected aluminum parts that allow the calorimeter to be disassembled in sections, each with 4 tungsten plates, which are thus called "quartets." This structure is planned to work with a set of ground support equipment recovery frames to protect the optical layers during recovery, and allow them to be reused in an eventual fifth flight.

A significant upgrade for CREAM-III is the addition of a Cherenkov imager (CherCam) optimized for charge measurements [11]. It consists of a silica aerogel Cherenkov radiator plane and a photon detector plane with an array of 1600 1-inch diameter photomultiplier tubes (PMT's). The planes are separated by a 10 cm ring expansion gap to ensure that most Cherenkov photons are collected in 8 tubes surrounding the tube hit by the incident particle. Since upward moving particles will be absorbed in the radiator, the CherCam will provide efficient discrimination against backscattered particles. With CherCam, in addition to the TCD based on timing, and the SCD based on pixelation, the CREAM-III instrument implements virtually all possible techniques to minimize the effect of backscatter on charge measurements in the presence of the calorimeter. We are striving to achieve charge measurements with the highest possible accuracy.

Another major improvement for CREAM-III will be a redundant Science Flight Computer, which was a potential single point failure for the previous flights. Two computers will be accommodated with a USB interface [12]. New software developed for the USB interface was successfully tested during the 2006 accelerator calibration of the calorimeter. The instrument integration is nearing completion. After complete functional tests the instrument will be integrated with the support sub-systems at NASA's Wallops Flight Facility. This will be followed by shipping to Antarctica for launch.

The fourth flight will incorporate a calorimeter essentially identical to CREAM-III, a similar detector to S3, the same graphite targets that flew in CREAM-II, a refurbished SCD, a new TRD, a CD similar to that flown before, and the same TCD design as in the prior flights. One modification currently under consideration for CREAM-IV is an upgrade of the calorimeter readout boxes by providing a high voltage power supply for each two hybrid photo diodes (HPD's) instead of for each 5 HPD's. This modification would improve the "graceful degradation" of the calorimeter readout should HV problems occur in flight. Another improvement is a recoverable pallet. Using two halves of the CREAM-I and CREAM-II pallets, a CREAM-IV pallet is being constructed using a piano hinge concept. This will allow the recovered pallet to go through the Twin Otter door and be re-flyable through simple reassembly, as long as damage is not severe. The CREAM-IV calorimeter optics are already under construction with over 1500 ribbons fabricated, of which over 1000 have been cut and polished. The calorimeter calibration is planned for September 2007 at CERN. Flight readiness is planned for December 2008.

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