COSMIC RAY ENERGETICS AND MASS: FIRST FLIGHT AND BEYOND

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The Cosmic Ray Energetics And Mass instrument is configured with particle detectors to measure cosmic-ray composition from protons to iron nuclei over the energy range from ~10^{11} to ~10^{15} eV in a series of balloon flights. The goal is to observe cosmic-ray spectral features and/or abundance changes that might signify a limit to supernova acceleration. Particle charge (Z) measurements are made with a timing-based detector and a pixelated silicon matrix. Particle energy measurements are made with a transition radiation detector for Z > 3 and a sampling tungsten/scintillator calorimeter for Z ≥ 1. The first flight of the instrument took place in Antarctica December 2004 – January 2005. It flew for a record-setting 42 days. Preliminary results from the ongoing analysis are presented, and future plans are discussed.

1 Introduction

Ground based measurements have shown that the cosmic-ray energy spectrum extends far beyond the highest energy thought possible for the supernova acceleration theory. The Cosmic Ray Energetics And Mass (CREAM) mission [1] was conceived to push spectral measurements of individual cosmic-ray nuclei to energies approaching the "knee" in the all-particle spectrum around 3 x 10^{15} eV, the highest energies practical with balloon experiments. Unlike ground based indirect measurements, balloon experiments can determine the primary particle identity and energy event-by-event. A limit to the rigidity-dependent supernova acceleration process around the knee should be reflected by individual spectra and elemental composition changes over a couple of decades in energy leading up to the knee.

The payload circumnavigated the South Pole three times during a 42-day flight from 16 December 2004 to 27 January 2005. As shown in Fig. 1, the balloon altitude stayed between 38 km and 40 km throughout most of the flight. The corresponding average atmospheric overburden was only ~3.9 g/cm^2. The diurnal variation due to the Sun angle change was very small, < 1 km, near the pole, i.e. at high latitude, which increased as the balloon spiraled out to lower latitudes. All of the high energy data (> ~ 1 TeV) were transmitted via TDRSS during the flight, while the lower energy data were recorded on board. A total of 60 GB of data (> 30 x 10^6 science events) were collected. The flight operation was unique from several perspectives. This was the first long duration balloon (LDB) mission to transmit a significant fraction of its science and housekeeping data (up to 86 kbps) in near real-time through the Tracking and Data Relay Satellite System (TDRSS) via a high-gain antenna, in addition to an onboard data archive.

The CREAM instrument was controlled through a line of sight transmitter from pre-launch until beyond the horizon, ~12 hours post launch, at which point commanding was transferred off the continent to the Science Operations Centers at the University of Maryland and the NASA Wallops Flight Facility Engineering Support Center. Primary command uplink was via TDRSS, with Iridium serving as backup whenever the primary link was unavailable due to schedule or traversing zones of exclusion. The nearly continuous availability of

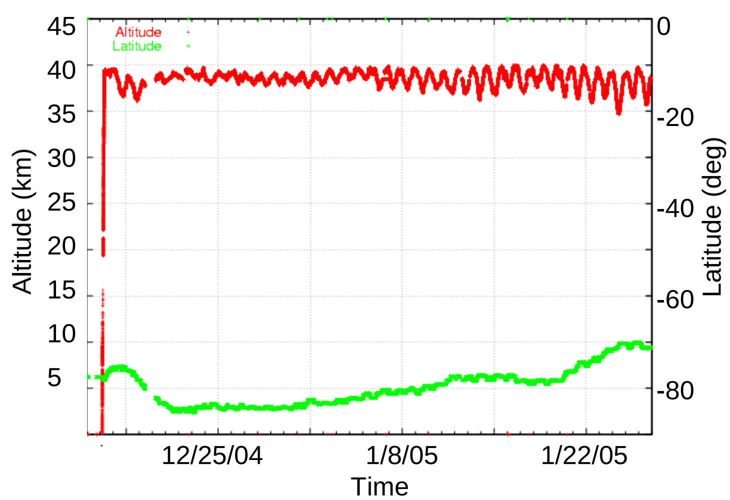

Figure 1. Altitude and latitude of the balloon.

command uplink and data downlink throughout the flight allowed a rapid response to changing conditions on the payload (e.g., altitude dependent effects).

2 Instrument Performance

A variety of particle detectors were employed to determine the charge and energy of the very high energy particles. As shown in Fig. 2, they include a Timing Charge Detector (TCD), a Transition Radiation Detector (TRD) with a Cherenkov threshold counter (CTC), and a calorimeter module comprised of a silicon charge detector (SCD), a carbon target, scintillating fiber hodoscopes (S0/S1 and S2), and a stack of tungsten plates with interspersed scintillating fiber layers. Multiple charge measurements with the TCD, SCD, and S0/S1 layers of scintillating fibers accurately identify the incident particles by minimizing the effect of backscattered particles from the calorimeter. The TCD utilizes the fact that the incident particle enters the TCD before developing a shower in the calorimeter, and the backscattered albedo particles arrive several nanoseconds later.[2] A layer of scintillating fibers, S3, located between the carbon target and the tungsten calorimeter provides a reference time. The SCD is segmented into pixels, each about 2 cm^2 in area, so back-scatter is expected to cause charge misidentification of only about 2% - 3% of low-Z particles near 10^{15} eV incident energy, with significantly less misidentification for lower energies and/or higher charges.[3]

The carbon target induces hadronic interactions in the calorimeter module,[4] which measures the shower energy and provides tracking information to determine which segment(s) of the charge detectors must be used for charge measurement. Tracking for showers is accomplished by extrapolating each shower axis to the charge detectors. The hodoscopes S0/S1 and S2 provide additional tracking information above the tungsten stack. Tracking for non-interacting particles is achieved with better accuracy in the TRD, 1 mm resolution with 67 cm lever arm, 0.0015 radians. The TRD determines the Lorentz factor for Z > 3 nuclei by measuring transition x-rays using thin-wall gas tubes. The TRD and calorimeter, which can also measure the energy of protons and He, have different systematic biases in determining particle energy. The use of both instruments allows in-flight cross-calibration of the two techniques and, consequently, provides a powerful method for measuring cosmic-ray energies. There is no practical alternative to a calorimeter for measuring protons and helium over the energies of interest to CREAM. See Seo et al.[1] for more about the instrument details. As illustrated in the example of a ~10 TeV Fe event in Fig. 2, the instrument functioned well during the flight.

The redundant charge identification and energy measurement systems provide precise determination of elemental spectra for Z = 1 - 26 nuclei over the energy range ~10^{11} – 10^{15} eV.

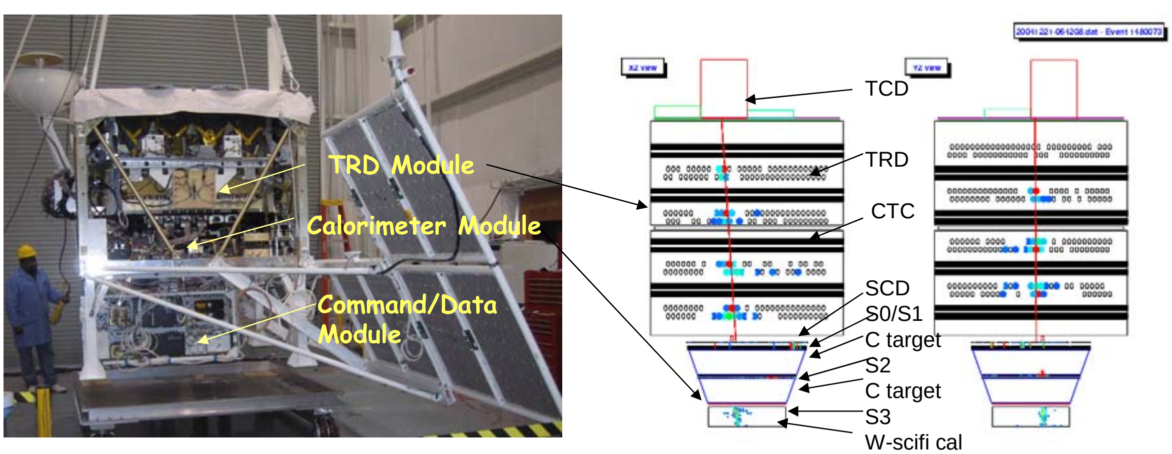

Figure 2. A cosmic-ray Fe nucleus with estimated energy 10 TeV entered the instrument to give a large signal (red box at the top) in the TCD, a clear track in the TRD (blue and red filled circles), a large signal in the SCD (red box) and a well-defined shower in the calorimeter (blue).

Measurements of relative abundances of secondary cosmic rays (e.g., B/C) in addition to energy spectra of primary nuclei will allow determination of the cosmic-ray source spectra at very high energies, where measurements are not currently available. As shown in Fig. 3, with very minimal corrections at the preliminary stage, charge peaks for major elements are separated clearly in the SCD. With further corrections, we expect charge resolution of about 0.2e after pathlength corrections are implemented. See the beam test result in Park et al.[5] The measured calorimeter energy deposit distribution is shown in Fig. 4. An advantage of the calorimeter is that with very minimal corrections the energy deposit gives a quick check of the energy spectrum, which in this case shows a reasonable power law. A deposit of about 3.2 along the horizontal scale in Fig. 4 corresponds to incident energy ~1 TeV, which shows that we have data extending well above 100 TeV.

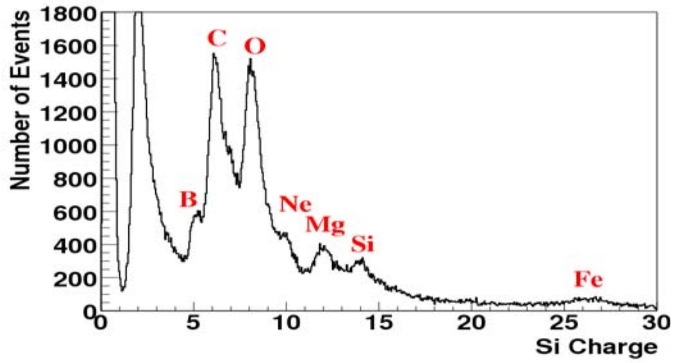

Figure 3. Preliminary flight data: SCD charge histogram without corrections

3 Future Plan

The CREAM trigger aperture is about 2 m^2sr. After all the cuts/reconstructions the effective acceptance of $Z \geq 3$ particles is estimated to be at least 1 m^2sr while the corresponding effective acceptance for p and He is estimated to be 0.3 m^2sr. The CREAM instrument has been calibrated in a series of beam tests[4,5] at the CERN SPS. Both the science instrument and the flight support systems were developed for nominal 100-day ultra-long-duration balloon (ULDB) missions. It is planned to conduct annual flights by alternating two science instrument suites,[6] herein called CREAM and CREAM-II, since the same instrument cannot be flown in consecutive years due to the time required for recovery, return to the laboratory, and refurbishment. With excellent particle charge and energy resolutions, and relatively large collection factor, each CREAM flight will extend the reach of precise composition measurements to energies not previously possible.

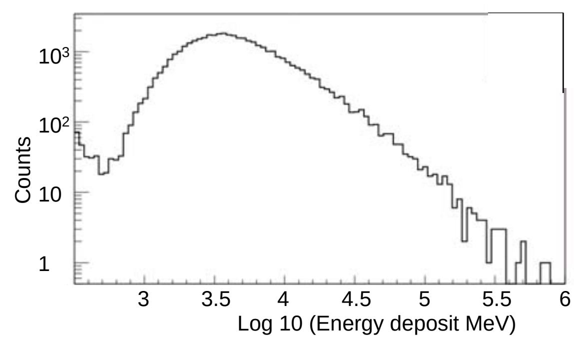

Figure 4. Preliminary calorimeter energy deposit distribution.

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