29th International Cosmic Ray Conference Pune (2005) **3**, 429-432

Flight Operations during the First CREAM Balloon Flight

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The Cosmic Ray Energetics And Mass (CREAM) payload was launched from McMurdo Station, Antarctica on Dec. 16, 2004 and stayed aloft for nearly 42 days. The CREAM flight operation was unique from several perspectives. This was the first Long Duration Balloon (LDB) mission to transmit a significant fraction of science and housekeeping data collected (up to 85 kbps) in near real-time through the Tracking and Data Relay Satellite System (TDRSS) via a high-gain antenna, as well as keeping an onboard data archive. CREAM was controlled through a line of sight (LOS) transmitter from pre-launch until it went over the horizon, about 12 hours post launch, at which point commanding was transferred off the continent to the Science Operations Center (SOC) at the University of Maryland and NASA's Wallops Flight Facility (WFF) Engineering Support Center (ESC). Primary command uplink was via TDRSS, with Iridium serving as backup when the primary link was unavailable due to schedule or zone of exclusion (ZOE) traverse. We describe CREAM operations during this record-breaking flight, with examples of how the near-continuous availability of command uplink and data down-link throughout the flight allowed a robust response to changing conditions on the payload.

1. Introduction

The CREAM payload, designed to directly measure the spectra of cosmic-ray nuclei from H to Fe, in the energy range from $\sim 10^{12}$ to $\sim 10^{15}$ eV [1], was flown in Antarctica from Dec 16, 2004 to Jan 27, 2005, suspended under a NASA research balloon for a record breaking LDB flight of nearly 42 days. The instrument, described in more detail elsewhere in this conference [2–4] was comprised of several complementary detector systems to measure the charge and energy of cosmic rays, including a sampling calorimeter, scintillating fiber hodoscopes, a Silicon Charge Detector (SCD), a Timing-based Charge Detector (TCD) and a Transition Radiation Detector (TRD). Originally designed to fly as part of NASA's Ultra Long Duration Balloon (ULDB) program, with flight durations of 60 – 100 days, and with trajectories expected to cover much of the southern hemisphere (30^o South latitude down to the South Pole), the CREAM payload has several properties not shared with any other payload flown in the LDB program.

These include the use of a high-gain antenna to provide near-real-time data down-link, and command up-link, through TDRSS, as well as continuous control of the payload from the science and engineering centers in the continental US. All payload systems were designed to survive for over 100 days of flight, including extended periods without sun (up to 12 hours per day), and the thermal system was designed to permit continuous operation of the instrument and support systems in the cold conditions expected during the Austral fall, over a storm system, at 30^{o} South latitude, as well as in the hot conditions expected above the Antarctic ice cap, with its albedo nearly doubling the solar thermal input. Since LDB payloads have always seen continuous sun-light, the number of batteries in the power system was reduced significantly for this flight, to allow additional ballast weight. This proved especially important in allowing extended float duration.

2. CREAM Operations

One of the unique features of CREAM operations was the nearly continuous down-link in near-real-time of all high energy events, a significant fraction of heavy nucleus triggers, and a constant stream of housekeeping data throughout the flight [5]. Down-linked data was received by White Sands and forwarded to the Operations Control Center (OCC) in Palestine, TX. From there the data was sent to the Engineering Support Center (ESC) at NASA's Wallops Flight Facility (WFF) on Wallops Island, VA, and on to the Science Operations Center (SOC) at the University of Maryland (UMD), as shown in Fig. 1. The instrument communicated with the Remote Operations Control Center (ROCC) at Williams Fields, outside of McMurdo Station, Antarctica, through a Line of Sight (LOS) transmitter from before launch until the payload went over the horizon about 12 hours post launch.

Before the payload went beyond LOS range, control of the instrument was handed over to the SOC. From that moment, shift operators at both the SOC and ESC monitored and commanded the payload almost continuously until the flight was terminated 41 days later. During the flight, monitoring and archiving data at the SOC was performed by the Linux-based CREAM Data Acquisition software, CDAQ [6].

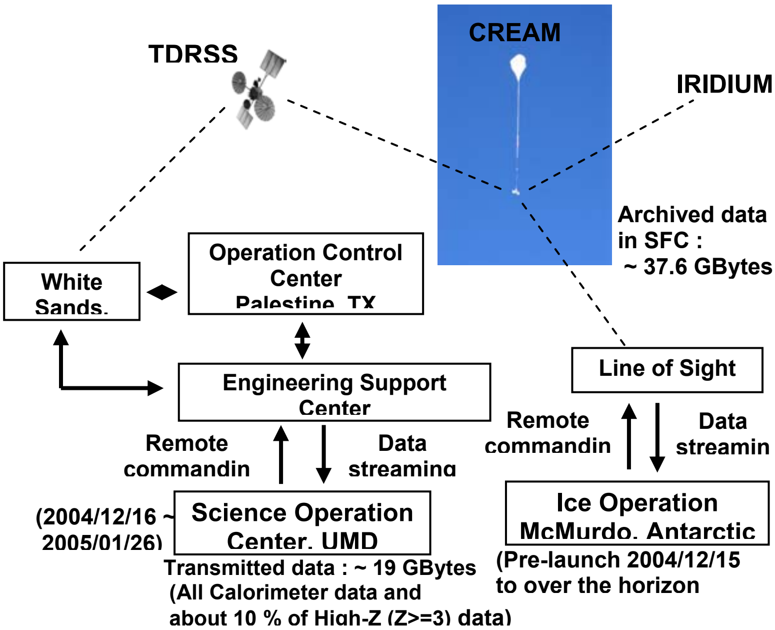

Figure 1. Operation Overview. During the flight all high energy data and 10% of high-Z data (about 19 GBytes), were transmitted through TDRSS. All high-Z data not transmitted to the ground (about 37 GBytes) were archived on an onboard flash

Support functions for the CREAM payload (e.g. power, data archiving, GPS position determination, command link, telemetry, etc.) were handled by the WFF Command and Data Module (CDM). When the payload entered a TDRSS Zone of Exclusion (ZOE), the data downlink was restricted to a reduced housekeeping packet every 15 minutes via the backup

IRIDIUM link. Once the payload completed its ZOE traverse, the CDM played back the backlog of archived data, in parallel to the then-current data telemetry. With a total TDRSS down-link band-width of 85 kilobits per second (kbps), 35 kbps was used for the playback until the backlog was cleared, with near-real-time data rate kept down to 50 kbps (50 kbps peak in Fig. 2 (a)). During other times, the full 85 kbps was available for the near-real-time data flow (85 kbps peak in Fig. 2 (a)). During the flight, TDRSS command windows as long as 2-3 hours were made available. All high energy events, in which a significant shower was recorded by the calorimeter, were transmitted to the SOC via TDRSS, along with 10% of events in which a particle with Z>3 traversed the TCD (together ~19 GB). After launching from outside McMurdo Station in below-freezing temperatures at full atmospheric pressure, the instrument warmed up during ascent, as thermal convection dropped off with the decreasing ambient pressure. As predicted by the thermal model, temperatures of the instrument systems topped out at below 35°C, comfortably within operational limits. The effect of sun angle change over each 24 hour cycle can clearly be seen in Fig. 2 (b), as instrument temperatures fluctuated by only 3°C for calorimeter (red), 2°C for hodoscope (green), and 1°C for SCD (blue), during the first 25 days of flight. Past the 25th day, these variations increased to 9°C, 4°C, and 3°C, respectively. Frequent automated pedestal data collection and calculation provided ample information for accurate pedestal subtraction for all portions of the flight. Variations in pressure, and thus in atmospheric over-burden, were fairly small, with pressure remaining between 2 and 5 Torr at all times during float (Fig. 2 (c)). The increase in the daily variation in temperature and pressure observed during the latter half of the flight was caused by the greater variations in sun angle at the balloon's location as the season progressed, and the balloon trajectory gradually spiraled outwards from the South Pole. With over 1100 lbs of ballast at launch, the NSBF operators were able to maintain the balloon altitude between 36km (~120,000 feet) and 40km (~134,000 feet) for a record-breaking duration. From the pressure data collected by sensors in the CDM, the mean atmospheric overburden during the flight was calculated to be 3.9 g/cm^2.

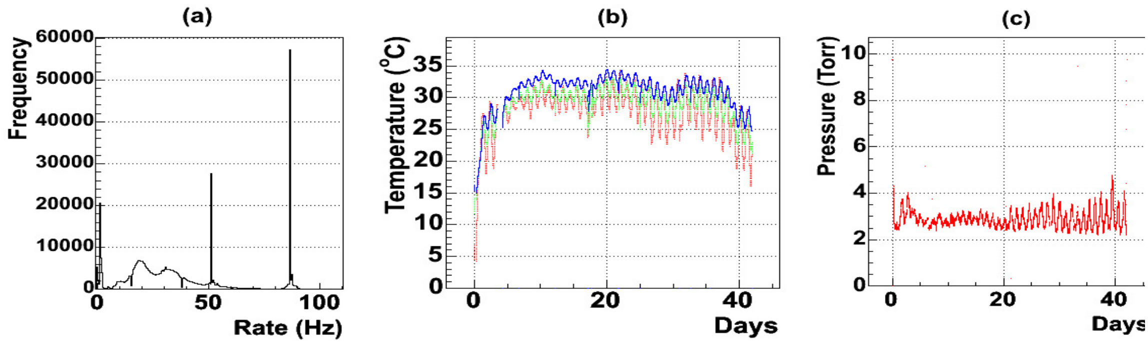

Figure 2. (a) Down-linked total network rate during the flight; a rate of 85 kbps was available in the absence of playback; during playback, 35 kbps was dedicated to clearing the backlogged data, and the network rate was limited to 50 kbps. (b) Time variation of calorimeter, hodoscope and SCD temperatures; during ascent temperatures increased from ~0°C to ~25°C – 30°C, remaining within a fairly narrow range thereafter for most of the flight. (c) Pressure variation; pressure remained between 2 and 5 Torr for the entire flight.

3. Effects of the solar flare of January 20, 2005

As expected for such an extended flight, the TRD gas manifolds recorded a gradual loss of pressure, with some losing gas somewhat faster than others. Continuous monitoring of housekeeping pressure information allowed a periodic pressure rebalancing between manifolds, redistributing the TRD gas and equalizing the pressure in the different manifolds. Ultimately, although the flight lasted nearly half the design duration of 100 days, none of the TRD gas reserve was needed, and pressure rebalancing was sufficient to keep the entire TRD fully functional. On January 20, 2005, the pedestal noise levels of the hodoscopes and SCD, both designed to measure singly-charged particles even at relatively low energy, spiked suddenly at the same time, and dropped back to initial levels over the next day or so (Fig. 3). The calorimeter, designed to measure showers in the multi-TeV energy range did not record a similar spike. The continuous telemetry link allowed the instrument team to respond to such occurrences as needed, by (e.g.) modifying the frequency of pedestal collection, tweaking trigger thresholds, etc. The above noise spike was later found to coincide with the occurrence of a solar flare, one of the most intense bursts of solar radiation on record in the past five years [7]. Most noise spikes observed during flight in the hodoscopes and SCD did not coincide with each other, and rose and dropped very quickly. However, the noise peak observed on January 20 in the SCD (Fig. 3 (a)), hodoscope S0 (Fig. 3 (b)) and hodoscope S1 (Fig. 3 (c)) showed up at the same time in all three, and decreased gradually, apparently as solar activity decreased.

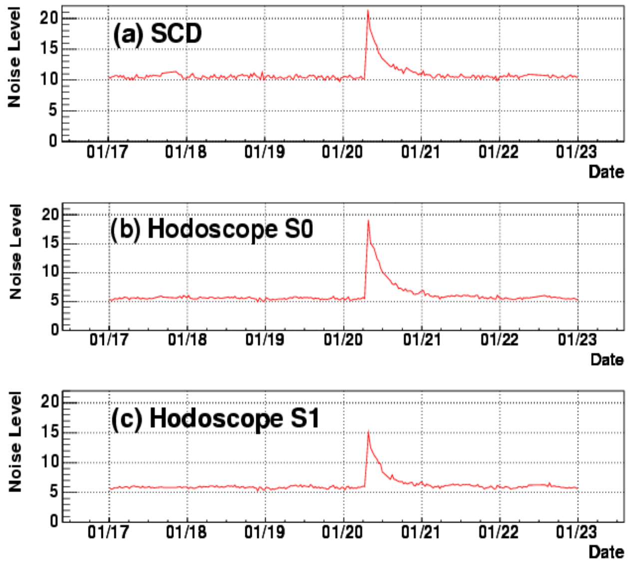

Figure 3. Pedestal noise level from January 17 to 23 in (a) SCD, (b) hodoscope S0 and (c) hodoscope S1; At 7 AM on January 20, 2005 (GMT), suddenly the noise level increased in all three and gradually dropped back to normal levels over the course of nearly 24 hours.

4. Conclusions

The CREAM payload has several notable features compared to LDB experiments, including the near-continuous data down-link and command up-link via TDRSS, which allowed the science and engineering teams to respond to changing conditions on-board in near-real-time. As a result, the record-breaking first flight of CREAM was quite successful, collecting over 43 million science events and over 500,000 housekeeping records. Interestingly, the noise levels of several detector systems showed a marked increase coincident with the large solar flare of January 20, 2005.

5. Acknowledgements

We thank NASA, the National Scientific Balloon Facility, the National Science Foundation Office of Polar Programs, and the Raytheon Polar Service Company for the successful Antarctic campaign.

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