

# COSMIC-RAY ENERGETICS AND MASS (CREAM) BALLOON EXPERIMENT

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## ABSTRACT

The Cosmic Ray Energetics And Mass (CREAM) Ultra Long Duration Balloon (ULDB) mission will investigate ultra high energy ( $10^{12}$  to  $> 5 \times 10^{14}$  eV) cosmic rays over the elemental range from protons to iron. The measurements will be made with an instrument that consists of a sampling tungsten/scintillator calorimeter preceded by a graphite target with scintillator layers for trigger and track-reconstruction purposes, a transition radiation detector (TRD) for observing heavy nuclei, and a segmented timing-based particle-charge detector. A key feature of the instrument is its ability to obtain simultaneous measurements of the energy and charge of a subset of nuclei by the complementary calorimeter and TRD techniques, thereby allowing in-flight inter-calibration of their energy scales. The energy extent will depend on a series of ULDB flights of identical instruments: three flights will reach  $5 \times 10^{14}$  eV. The different flights can be carried out at essentially any latitude, including the polar regions of either hemisphere. CREAM will be ready for flight one year after the TIGER (Trans-Iron Galactic Element Recorder) ULDB demonstration flight, which is currently scheduled for launch in December 2001.

## INTRODUCTION

The origin of cosmic rays and how they propagate are fundamental problems which have a major impact on our understanding of the universe. Theorists have developed a convincing theory of diffusive shock acceleration by supernova blast waves that naturally explains the observed characteristics of most relativistic particles in the galaxy. The most compelling evidence that supernova remnants are common sites for shock acceleration of electrons comes from recent observations of non-thermal X-ray spectra from several shell-type remnants. In the case of SN 1006 the electrons have energies  $> 2 \times 10^{14}$  eV (Koyama et al., 1995). These electrons must be accelerated at the remnant, because at this energy electrons cannot travel far from their origin before they are attenuated by synchrotron losses. Extrapolation from these data to any inferences about the nature of the acceleration of hadrons in these objects is difficult (Reynolds, 1998). However, direct observation of characteristic changes in cosmic-ray elemental composition reflecting a rigidity-dependent acceleration limit around  $Z \times 10^{14}$  eV would provide convincing evidence that shocks associated with shell-type supernova remnants provide the acceleration sites for the bulk of cosmic rays up to  $\sim 10^{14}$  eV.

Cosmic-ray elemental composition has been measured by space-based experiments that determine the incident particle charge as well as its energy. However, the composition above  $10^{12}$  eV is not well known due to the limited exposures for such experiments. Indirect measurements from ground-based experiments have traced the all-particle spectrum from about  $10^{14}$  eV to  $> 10^{20}$  eV. These measurements have shown that the energy spectrum above  $10^{16}$  eV is somewhat steeper than the spectrum below  $10^{14}$  eV. Whether and how this “knee” structure, around  $3 \times 10^{15}$  eV, is

related to the mechanisms of acceleration, propagation, and confinement are among the major current questions in particle astrophysics.

## CREAM OBJECTIVES

The CREAM mission is capable of pushing cosmic-ray nuclei measurements to the highest practical energies with balloon experiments. Its primary science objectives are to:

- 1) Determine whether or not the spectral slopes of the heavier nuclei are the same as that of helium and different from that of protons;
- 2) Measure potential changes in the spectra of secondary nuclei, and to
- 3) Search for spectral features, such as a bending in the proton spectrum.

Given sufficient exposure on ultra-long-duration-balloon (ULDB) flights, the CREAM instrument can meet or exceed the following measurement objectives:

Element Coverage:	H to Ni ( $Z = 1$ to 28), inclusive
Charge Resolution:	Sufficient to resolve the 5 major element groups: H, He, CNO, (Ne-S),(Ar-Ni), with a desirable aim of resolving individual species
Collecting Power:	300 m <sup>2</sup> -sr-days for H and He and 600 m <sup>2</sup> -sr-days for heavier nuclei
Energy Calibration:	Better than 30% absolute accuracy for energy calibration
Energy Resolution:	Better than 50% energy resolution for each particle

These measurements will be able to verify whether the proton and helium spectral differences that have been reported (e.g., Ellison et al., 1994) from combining all the existing data sets are indeed real. Since the existing data were collected with several types of detectors, including several different designs of emulsion chambers, some of the spread in the data is undoubtedly due to systematic errors and differences in normalization among experiments. Nevertheless, taking the data at face value, the proton and helium spectra appear to be different at high energies ( $> 100$  GeV/n), while helium has the same spectral shape as heavier nuclei. This unexpected finding has received considerable attention, because simple shock acceleration theory predicts the same power-law rigidity spectra for all species.

Individual charge resolution and the energy response of CREAM will also allow a sensitive measurement of secondary nuclei produced in the interstellar medium. At present these measurements extend to around 100 GeV/n. It seems unlikely that the strong energy-dependent decrease in propagation pathlength will extend to the “knee” region since the residual pathlength at these energies would be uncomfortably small. CREAM can search for this change in the energy dependence out to  $\sim 1$  TeV/n, an order of magnitude above present data.

CREAM has a larger collecting power than any instrument flown to date or any instruments planned until the ACCESS (Advanced Cosmic-ray Composition Experiment for the Space Station) mission, which can not be launched until at least 2007. Our ultimate goal is to accumulate at least 500 particles each for protons, helium, CNO, Ne-Si, and Fe group nuclei above  $10^{14}$  eV, with a statistical accuracy of 30% above  $10^{15}$  eV using a series of ULDB flights. We expect to reach  $5 \times 10^{14}$  eV with three flights. A single CREAM ULDB flight would more than double the world's current supply of high energy ( $> 1$  TeV) cosmic ray composition data. The effectiveness of CREAM to detect an abrupt change (kink) in the proton spectrum has been illustrated in Seo et al. (1999), which shows the maximum kink energy that can be clearly observed as a function of flight time.

## SCIENCE INSTRUMENTS

As shown in Fig. 1, the CREAM instrument consists of (1) a calorimeter preceded by a carbon target with scintillator layers for trigger and track-reconstruction purposes, (2) a transition radiation detector (TRD) to measure heavy nuclei, and (3) a segmented timing-based particle-charge detector. This instrument is fundamentally different from those used in prior high-energy cosmic-ray composition experiments, in that it employs both a TRD and a hadron calorimeter in the same payload. While both of these types of detector have been flown separately in prior balloon investigations, their combination in a single payload provides a powerful method to overcome the individual

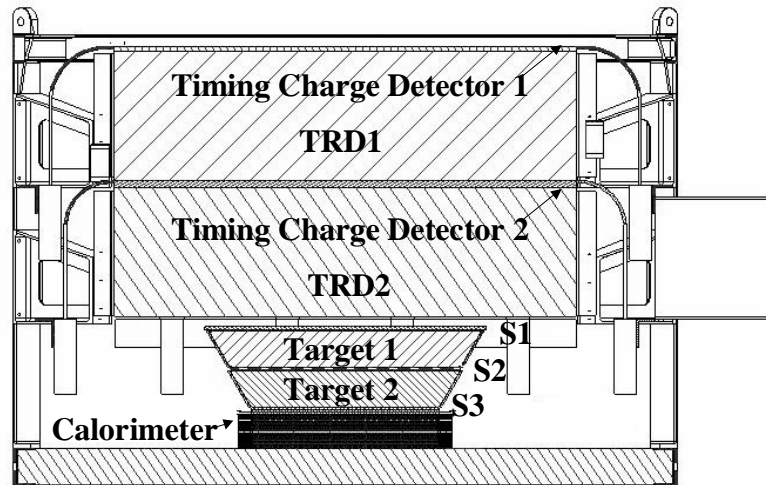


Fig. 1. CREAM Baseline configuration.

measurements, combined with pulse-height information, will provide a measure of the charge of the incident particle with no contamination from albedo (the bane of previous experiments in this energy range).

Two prototype scintillation detectors have been constructed. The scintillator used is Bicorn BC-408, which was chosen for its combination of fast time response and long attenuation length. The scintillators are 2 m long. One prototype is 6.27 mm (0.25") thick and 25 cm wide, and the other is 5 mm thick and 33 cm wide. The dimensions are chosen to match the area of the end of the scintillator to the active area of a 2-inch fast photomultiplier. Adiabatic lightpipes constructed from multiple twisted strips of BC-802 plastic light guide material are glued to each end of the scintillator slabs, and the ends of the light pipes are coupled to the photomultipliers. Most tests are being conducted using Hamamatsu R2083 photomultipliers. The Photonis XP2020/UR is also being studied. These prototype detectors have been tested using cosmic ray muons. A preliminary look at the test data thus far indicates that these detectors will meet the CREAM requirements. Detailed analysis of the laboratory tests is in progress.

The readout electronics must extract the first few nanoseconds of the signal from the PMT. After studying several methods for doing this, we have selected a method for extracting the information in the first part of the signal using multiple TDC measurements. By measuring the times at which the signal crosses a number of thresholds, the shape of the leading edge can be determined. Two limiting cases are of interest. With no integration, and multi-hit-TDCs timing of both leading and trailing edges, one can reconstruct the pulse shape from the PMT currents as a function of time using the  $(time, current)$  pairs given by the threshold crossings. If there is integration in the signal-processing path, single-hit TDCs may be used to measure the slew rate of the integrated signal, which corresponds to the PMT current. Since some integration in the signal path is unavoidable, and the degree of integration can be easily optimized, we have selected the latter approach. Such a system of multiple TDCs is effectively a flash ADC with variable clock rate, sampling the most when the current is highest. The placement of the thresholds can be optimized for the expected range of signals, and only those threshold crossings that occur during the 'safe' interval used for the charge analysis. This safe interval varies from 2.7 ns to 8.5 ns for the top layer, depending on event geometry. In addition to the TDC measurement, we plan to include a fast peak height measurement and a charge ADC with a fixed window. This will be useful both for the study of non-interacting particles in conjunction with the transition radiation measurement and for charge measurements of interacting particles at high  $Z$  where albedo is less important. With a time resolution of 50 ps, the expected charge resolution from the multiple TDC thresholds measurements will vary between 0.2 e and 0.28 e, for particles with charge 1 to charge 15, respectively. The charge resolution is dominated by energy deposit fluctuations, with a small contribution from photoelectron fluctuations. The fast peak height measurement will be made to 1 % accuracy, allowing a measurement of the charge for  $Z > 15$  particles.

Using the CMOS TDC threshold techniques described above, we expect the power consumption of the system to be less than one watt per PMT.

The data rate will be minimized by zero-suppressing output of the multi-hit TDC readout system, that is, only tubes (channels) with hits will have data in them. There are a total of 20 panels in the three timing charge detector layers each with a photomultiplier tube at each end. The 40 channels, with a trigger rate of 2 Hz, will produce about 1 kbps of combined TDC and ADC data.

## Transition Radiation Detector

A key feature of the CREAM TRD is the low mass per unit area. This allows a large unit to be flown which almost fills the entrance aperture of the calorimeter. To minimize mass the gas-filled detectors are thin-walled proportional tubes. These make possible a flight TRD with no external pressure vessel, which significantly reduces the mass of the overall TRD. This concept has been successfully used in the large TRD of the TRACER (Transition Radiation Array for Cosmic Energetic Radiation) instrument (Gahbauer et al. 1999), which was flown on a 1-day balloon flight in September 1999.

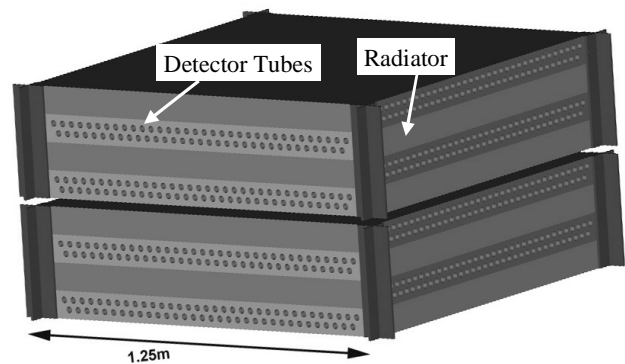


Fig. 2. Schematic of CREAM TRD

A schematic of the TRD for CREAM is shown in Fig. 2. The overall detector consists of 6 layers of radiator/detector combinations. These are also mechanically attached to the two timing scintillator layers discussed earlier. The overall thickness of a radiator/detector combination is  $\sim 12$  cm, with  $\sim 9$  cm of radiator thickness. The detectors consist of a double layer of thin walled proportional tubes filled with a gas mixture consisting of 90% xenon and 10% methane to detect the TR x-rays. These detectors are constructed from  $75 \mu\text{m}$  of aluminized mylar wound into 2.5 cm diameter tubes. Each tube has a  $50 \mu\text{m}$  diameter sense wire which is connected to a charge sensitive amplifier ASIC chip – a variant of AMPLEX, which has an input noise level of  $\sim 1$  fC in situ. Because of the large signals produced in the proportional tubes a divider scheme has been tested which enables an increase in the effective dynamic range of this amplifier chip by using two channels for each sense wire. This can make the system dynamic range effectively 12 bits, far larger than the single channel range for this chip. Tests are also underway to implement an ASIC which has an intrinsically larger dynamic range of 11 bits. There are  $\sim 600$  detector tube sense wires on CREAM. We plan to use existing cards containing the AMPLEX chips for the readout. This will require 32 cards with an overall power dissipation  $< 6$  W.

The radiator material is a plastic foam material with holes for the detector tubes. This provides some intrinsic structural support for the TRD in the radiator itself. The foam material has effective dielectric thickness of  $300 \mu\text{m}$  and spacings of 9 mm. This material produces a response to higher Lorentz factors than previously possible. Calibrations indicate this may be as high as  $\gamma = 70,000$ .

The overall electrical scheme consists of a fast trigger section and an analog/ADC signal chain with a VLSI charge amp front end. At present we have systems with 8-bit resolution for this application. We have recently taken delivery of VLSI chip prototypes which are expected to extend this linearity to 11 bits or more. The intrinsic data requirements are a block of digital information containing the analog pulse heights from tubes above a zero suppression threshold. A typical event will contain  $\sim 20$  hits above threshold. A compression scheme has been developed so the global tube addressing scheme consists of 48 bits in the event record. Each tube then requires 24 bits for pulse height and local address information. Each event should therefore contain  $\sim 500$  bits of information from the TRD, on average. The overall data rate depends on the trigger scheme, which is established mostly by the other components of CREAM in “calorimeter” mode. In “TRD” mode the trigger rate depends on the operation of a high Z threshold ( $Z \geq 3$ ) set in the charge detectors. This is expected to reside in a programmable logic array in the TRD electronics system. Target event rates for this system are  $\sim 20$  Hz, making the overall data flow rate for this mode  $\sim 10$  kbits/s from the TRD.

### Gas System

A major consideration for the TRD is the provision of a gas supply system which can operationally last for the ULDB flight of  $\sim 100$  days. The function of this system is a crucial component of the TRD, since the thin-walled tubes needed for this system could be prone to develop leaks. Experience with the TRACER experiment has demonstrated that the major source of leaks is in the attachment process for end fittings to the tubes. This is essentially a quality control issue, since with good oversight these problems can be avoided. There can also be occasional problems with the tube manufacture itself, i.e., glue seams are sometimes not as gas tight as desired. The general approach to these issues is as follows:

*Gas Reservoir:* A gas reservoir is supplied to replenish the TRD on command in case of small pressure losses. Experience has shown that the dominant source of signal degradation in the tubes is not out-gassing of the internal

components but a gradual loss of pressure in the tube system. This is somewhat unexpected since in the lab the main source of signal decay comes from atmospheric oxygen diffusing into the tubes from the surrounding air.

*Gas loss mitigation:* Two approaches are taken to mitigate this problem of gas loss. The first is to run the TRD tubes at an absolute pressure of  $\sim 200$  torr. This supplies sufficient xenon to capture the TR x-rays but reduces the laminar leak rate by over a factor of 4. A system has been developed in which the payload is launched with the TRD filled with an argon-based mixture which is slowly vented when the instrument is at altitude by command. The system is then refilled with xenon mixture from an onboard reservoir to a pressure of  $\sim 200$  torr. This system was used successfully on the TRACER flight in September 1999. The same reservoir can be used to top-off the tube array pressure if gas loss occurs.

*Gas system lifetime:* For ULDB this sets the leak rate limit at  $\sim 150$  days, i.e. if a significant degradation in performance occurs within a shorter time scale than this, the reservoir will not be able to keep up. At present we have indications that a Long Duration Balloon (LDB) flight is easily possible with a reservoir of this size. We are working with engineering contacts at GSFC to help with the materials quality control and processing which is expected to provide a system which will meet the stricter demands of ULDB.

*System redundancy:* The gas system will be divided by solenoid-operated valves into 8 separate sections. This prevents a catastrophic failure in one tube (out of  $\sim 600$ ) from venting all the gas. During flight these 8 sections are essentially isolated so any bursting tube only takes the neighbors on the same manifold out of operation. This level of system redundancy has served well on the TRACER payload.

## Calorimeter Module

There is no practical alternative to a calorimeter for measuring protons and helium up to energies approaching  $10^{15}$  eV. To optimize the use of available weight, the calorimeter needs a light target material, such as carbon, upstream of a dense-absorber electromagnetic calorimeter (Ganel, Seo & Wang, 1999). A large dynamic range is needed to allow measurement of energies over a wide range. Fine granularity will improve the tracking information.

The geometry factor of the calorimeter module must be maximized to collect statistics. The CREAM calorimeter is a modular design with three major subsystems: an electromagnetic calorimeter comprised of a  $20 X_0$  thick, multi-layer sandwich of tungsten and plastics scintillators; a  $0.5 \lambda_{\text{int}}$  thick graphite target with a set of interleaved plastic-scintillator hodoscopes above the calorimeter, and a matrix of plastic scintillators upstream of the target/hodoscope section to serve as a supplemental charge detector. Extensive Monte Carlo simulations have been carried out to optimize the calorimeter design and to estimate expected performance. Some results are shown in Seo et al. (1999) to illustrate the type of data it will collect.

Taking into account the actual pathlength through the instrument, the effective geometry factor for the calorimeter module is  $0.25 \text{ m}^2\text{-sr}$  for protons entering the top of the target and having at least  $20 X_0$  for shower development in the calorimeter. The effective exposure for heavy nuclei is greater than for protons due to their shorter interaction mean free path in the carbon target. The effective geometry factors for helium and iron nuclei, respectively, are 0.3 and  $0.5 \text{ m}^2\text{-sr}$ . The effective geometry factor for events traversing the full instrument from the charge detector through the TRD to the calorimeter and not interacting in the TRD but interacting in the target is about 50% of the calorimeter-only geometry factor. Events heavier than helium meeting this criterion can be used for a cross calibration of the TRD and calorimeter energy scales.

### Electromagnetic Calorimeter

Within the constraints of the launch weight limit, the calorimeter will have as large an area as possible, to increase collection power (or effective geometry factor). The current design includes a  $50 \times 50 \text{ cm}^2$  lateral dimension. To achieve a 40% - 45% energy resolution, the calorimeter will be 20 radiation lengths ( $X_0$ ) in depth. It will be comprised of a set of twenty 3.5 mm thick ( $1 X_0$ ) tungsten plates alternating with twenty layers of fifty 1 cm wide ribbons of 0.5 mm diameter round BCF-12 scintillating fibers. Each layer of scintillator will be wrapped for mechanical protection and for light-tightness. Ribbons of alternate layers will be aligned along alternating x- and y-axes. The calorimeter's total depth will be 82 mm.

The calorimeter's active layers will be comprised of 0.5 mm thick, 10 mm wide fiber ribbons, read out from one end by multi-pixel Hybrid Photo-Diode (HPD) tubes. The far end will be aluminized, maximizing effective light-yield while minimizing dependence of detector response on shower position along the length of the ribbon. At the readout end of each ribbon, an adiabatic light-mixer made of a clear plastic will collect scintillation light, morphing

from an oblong cross-section to a roughly circular cross-section of equal area, rendering the signal uniform across its surface. The circular end of the light-guide will be bonded to a bundle of 0.3 mm diameter round clear fibers coated by an extra-mural absorber to reduce light contamination from outside sources. To make the glue-joints robust, the ribbons will extend 3 mm outside the tungsten in the direction of the light-mixer into a ‘clam-shell’ or other support. Alternate ribbons will be read out from opposite ends, leaving 5 mm laterally around each ribbon for the support. With such a small fraction of the scintillator extending beyond the tungsten, we expect the impact of signals from this volume on calorimeter signals to be minimal. A similar arrangement was used successfully in the BETS balloon payload with fibers extending 10 mm beyond the absorber (Torii et al., 1999). A square stainless steel wire (0.03” × 0.03”) will be glued to the tungsten halfway through each layer to avoid excessive flexing during parachute deployment (10 g shock vertically).

Two schemes are currently under investigation to cover the required dynamic range (18 bits). The first includes an optical division and separate high voltage settings for half of the calorimeter Hybrid Photo-Diodes (HPDs). This calls for forty HPDs to read out the calorimeter, each read out by two (32-channel) chip sets. The second scheme utilizes capacitive charge division to cover the dynamic range with four separate electronics channels per ribbon. The majority of the signal will be routed into one pair of chip sets, with three more pairs receiving gradually reduced fractions of the signal. This technique will cover the required dynamic range without doubling the number of tubes. Trigger requirements for the timing charge detector require a small fraction (<5%) of the signal from one or two mid-calorimeter layers to be diverted to the TCD readout.

### Target

Several studies have shown that using a low-Z (e.g. carbon) target in front of a thin calorimeter increases its effective geometry factor. This is due to a complicated interplay between several factors, including the lower weight (in g/cm<sup>2</sup>) required for a proton interaction length ( $\lambda_{\text{int}}$ ) using low-Z compared to high-Z materials. The CREAM design includes a 19 cm thick (~0.46  $\lambda_{\text{int}}$ ) densified graphite target. This graphite has a density of up to 2.1 g/cm<sup>3</sup> (compared to 1.7 g/cm<sup>3</sup> for typical industrial graphite). The target will be flared out in the shape of an upside-down pyramid with its tip cut off. Simulation studies have shown that the optimal flaring angle (greatest effective geometry factor for a given weight) is 30° – 35°.

The target will be divided into two layers to allow the insertion of scintillator hodoscopes for triggering and for track reconstruction enhancement. In addition, the top hodoscope (S1) will provide supplemental charge measurement for particles incident outside the Timing Charge Detector’s acceptance. To minimize the backscatter effect, a pixelated supplemental charge detector is also under consideration. S1 and the middle hodoscope (S2) will be comprised of 2 × 2 mm<sup>2</sup> fibers. For simplicity and efficiency (cost and construction effort), the optical and electronic readouts will be the same as those used in the calorimeter. The thickness of these layers is four times that of the calorimeter scintillators since the trigger scintillators will be required to read out single minimum ionizing particles (MIP) of unity charge (e.g. protons) as opposed to showers. An additional pair of scintillator layers may be located between the calorimeter and the graphite target. These layers will each be comprised of a pair of 5 mm thick, 26 cm wide paddles, each read out by a fast conventional PMT. We are currently evaluating the possibility of using S3 in place of these layers. If these are eliminated, they may be replaced by an additional hodoscope, S3, similar to S1 and S2.

### Data rate, power and thermal considerations

Simulations indicate that the shower trigger rate will be 1 – 2 Hz. With typically 3.3 Kbytes for calorimeter ribbons, the downlink bandwidth is insufficient to transfer all channels for each event. After removing those channels that do not show a signal significantly above pedestal (sparsification), the typical event size is expected to be 1.5 Kbyte for the calorimeter module, for a data rate of about 24 kbps. The remaining bandwidth will be utilized for transmitting TCD/TRD events (i.e. events with no calorimeter trigger).

The calorimeter module power requirements will depend on the final readout configuration, but will be less than 140 W (before considering conversion inefficiencies and margins). This power dissipation, the thermal barrier posed by the graphite and the thermal reservoir of about 300 kg tungsten are all taken into consideration in the CREAM thermal design.

# INTEGRATED SYSTEM

## Baseline Design

The CREAM mission design implements an integrated system design approach, combining the science instruments and a customized modular ballooncraft. This concept is non-traditional for balloon payloads, but it is expected to be the norm for ULDB payloads. In the past, balloon payloads have been developed independently and then integrated with a standard balloon support system at the launch site. This integrated approach helps to optimize system functional capabilities and weight, and it is expected to enable mission execution.

The mission is designed to meet the flight specifications, requirements, and constraints of both the Ultra Long Duration Balloon (ULDB) and the Long Duration Balloon (LDB) programs. Thus, the mission design is flexible and accommodates the constraints (See Table 1) imposed by either program. These requirements dictated a new approach for thermal and power system design that is considerably different from current balloon missions. The mission design, a result of numerous system and subsystem trade studies, meets LDB requirements with no unusual challenges. The preliminary design described below is being refined during the current detailed design phase of the project.

Table 1 A Comparison of ULDB and LDB Constraints

ULDB Constraints	LDB Constraints
<ul style="list-style-type: none"><li>• 12 hours eclipse</li><li>• Mission duration of 60 to 100 days</li><li>• Latitude within 10°S to 80°S</li></ul>	<ul style="list-style-type: none"><li>• 24 hour daylight</li><li>• Mission duration of 9 to 20 days</li><li>• Latitude within 73°S to 82°S</li></ul>

## Structural System

The systems trade study produced a non-traditional integrated design, consisting of science instruments and a modular ballooncraft, optimized to conserve resources such as weight and power. Due to the current ULDB lift limit, it was deemed prudent to analyze also a LDB design and a split-payload design for ULDB flights. Figure 3 shows the concept of the full-up payload.

A finite element analysis (FEA) was performed to verify this design. Static and buckling analyses (for both LDB and ULDB) were performed for the NSBF-required load cases: 10G vertical, 5G horizontal, 5G at the suspension point with a 60 degree cable angle, and 5G at the suspension point at a 45 degree angle to the vertical. Positive margins of safety were found in all cases. More detailed analyses will be required as the design matures to check joints, fittings, fasteners, etc.

## Electrical Power System

The instrument is expected to draw less than 500 watts from the primary 28 volt supply, while operating with a duty cycle of 100%. Table 2 details the various power consumers and their estimated needs. These numbers are based on the present design of the detectors and may change as designs mature. We are currently aggressively pursuing designs that will reduce power consumption from these levels. Additional power may be required for heaters during nighttime operations, but our thermal design goal is to keep temperatures within the specified ranges without heaters. The ballooncraft will provide power switching (on/off) capability for the instrument. There is a minimal power requirement for survival.

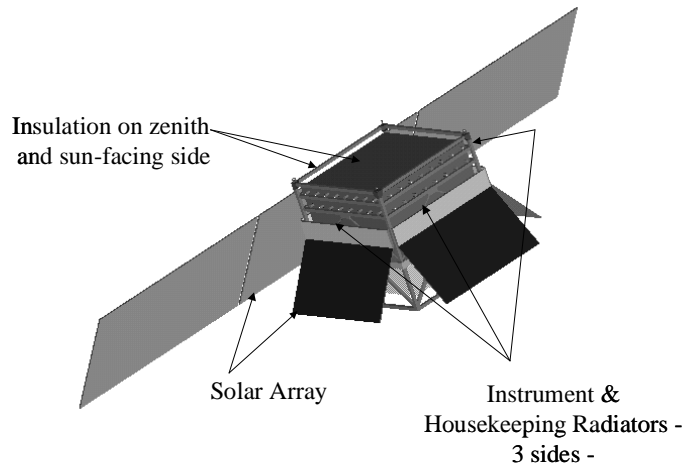


Fig. 3. CREAM Payload

The CREAM electrical power system includes a solar array for electrical power generation, and batteries for energy storage. The power system sizing is performed for the worst cases in ULDB and LDB flights. Mission latitudes and duration, as well as the power required for science (500 W continuous) and mission support equipment (200 W continuous in ULDB) are the driving factors for power system sizing.

For ULDB missions, the day part of the day-night cycle can be as short as 12 hours with 4 hours shadowing of the solar arrays by the balloon (80% light collection efficiency). The existing ULDB design includes fixed-canting-angle, high-efficiency crystalline silicon solar arrays with an azimuth-tracking gimbal. Sizing this design for CREAM power requirements, the solar arrays will weigh <40 kg. The GM-Ovonics batteries utilized by the current design would weigh 216 kg.

For LDB missions, the launch latitude is 77.86°S and latitudinal excursion is bounded by 73°S to 82°S. The continuous daylight environment reduces the solar array and battery requirements to much less than 40 kg and 60 kg respectively. The charge controller and power distribution hardware weigh 2 kg.

**Data System**

The data systems block diagram (Figure 4) shows the interface between the science instruments and the flight computers. The command and data path to the ballooncraft flight computers is via a MIL-1553B interface. The

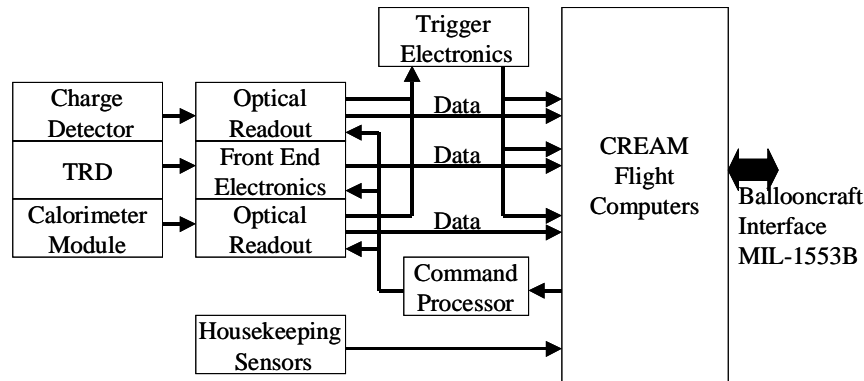


Fig. 4. Data System Block Diagram

primary communications link will be through TDRSS via a high-gain antenna using the S-band Multiple Access service. This system will provide a 50 Kbps data return path and a 100 bps forward command path. A backup omni antenna for emergency use will be capable of supporting the command requirements, but will reduce the data capability to 1 Kbps. INMARSAT and ARGOS services provide additional redundancy.

**Thermal System**

The thermal system is designed to maintain a high level of reliability in the electronics, and to maintain the integrity of the pressurized gas in the TRD make-up reservoir. The required temperatures are -10°C to 50°C for the electronics, -20°C to 50°C for the calorimeter and charge detector, -20°C to 40°C for the TRD (gas reservoir -10°C to 40°C), and 0°C to 40°C for the batteries.

Table 2 CREAM power estimates

Consumer	Power Requirement (Survival)
Charge Detector	100 W (0 W)
Transition Radiation Detector	35 W (3 W)
Calorimeter & Target Scintillators	155 W (0 W)
Trigger Electronics	20 W (0 W)
Housekeeping Electronics	20 W (0 W)
Data Computers	30 W (0 W)
Subtotal	360 W (3 W)
Converter Losses (80% Efficiency)	90 W (0 W)
Contingency (10%)	50 W (0 W)
Total Power Requirement	500 W (3 W)

The thermal design utilizes an isothermalized base-panel, with conventional heat-pipes coupled to vertical conventional heat-pipes, connected to radiator panels (also doubling as shear-panels). To provide heat rejection at high temperatures while retaining heat at low temperatures, CREAM will utilize a heat-switch in the form of motorized shades. These are ruggedized, vacuum-modified versions of commercial shades used for residential sky-light shading. Above 10°C the shades are fully open, while below 0°C they are fully closed. The shade material is specially designed and tested to provide sufficient thermal insulation to keep the payload at acceptable temperatures even with extremely cold ambient temperatures.

The upper modules are radiatively coupled to the base-panel with an aluminized thermal blanket covering the top of the payload. Foam, or a lower-weight alternative thermal insulation, will be utilized to isolate the payload from the hot solar panels and from the environment (except through the shades when open).

The thermal switch technique is a simple, inexpensive and elegant solution that allows the payload to remain warm enough in cold environments and cool enough in warm environments, i.e., to remain fully operational, without resorting to hundreds of watts of heater power.

### System Verification and Validation

The mission verification and validation will be accomplished at the payload level. Potential tests and analyses are: Thermal analysis, Structural Analysis (FEA), Instrument Calibration Test (accelerator beam), Environmental Testing including Thermal Balance and Thermal Vacuum, Comprehensive Performance Test, and Functional Test. Further study during the implementation phase will be required to narrow this list down to a critical and sufficient set to verify system performance as specified in the mission requirements.

### Mission Operations

The CREAM requirements include a forward link of 100 kbps for command and 50 kbps return for data. TDRSS provides the primary link for mission science data. The quoted TDRSS return rates are maximum rates achievable with the communications system components to be used for CREAM. INMARSAT, ARGOS, and line-of-sight links have been used previously on LDB flights. They are primarily used for limited data volumes, mostly engineering data, and backup data link. The link margin summary is listed in Table 3. The primary science data forward and return path utilizes a high gain antenna (HGA) with the TDRSS S-band Multiple Access (SMA) capability. If the HGA on the balloon cannot be pointed to TDRSS, an omni antenna can be used with reduced bandwidth for return signals. In addition, the TDRSS S-band Single Access (SSA) capability may be used occasionally to replay stored

data in case of temporary loss of telemetry. All these TDRSS modes support the desired forward link data rate of 100 kbps. The return data bandwidth depends on the antenna and TDRSS mode employed at any given time (50 kbps maximum for SMA, 300 kbps for SSA).

The ULDB Operations Control Center (ULDBOCC) at Palestine, TX will monitor engineering data, taking whatever action is possible to maximize science data return and maintain balloon safety. The ULDBOCC will

schedule any balloon events, coordinate with TDRSS as necessary, generate command sequences to be sent to the balloon, and retrieve all data from the TDRSS ground terminal. The ULDBOCC will also distribute data to the CREAM scientists. Note that for a CREAM LDB flight we would need to fly the integrated science craft payload rather than a separate science payload and balloon support instrument package.

Table 3 Summary of communications link margins.

Service Link		Antenna	Data Rates	Margin (dB)
MA	Forward	Omni	125 kbps	0.1
	Return	High gain	50 kbps	3.0
SSA	Return	Omni	1 kbps	2.7
	forward	Omni	125 kbps	9.7
	Return	High gain	300 kbps	3.0

### SUMMARY

Following successful completion of our one-year mission concept study, details of the CREAM design are currently being finalized. The interface control documents are being prepared, and subsystem design reviews are underway. Our schedule calls for system integration to start in 2001, with flight-readiness for the first ULDB flight

in December, 2002, one year after the TIGER demonstration flight scheduled for launch in December 2001. If a superpressure balloon is not available for the ULDB flight in December 2002, we would request a zero-pressure balloon to have the longest possible flight from Antarctica.

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