Cosmic Ray Energetics And Mass (CREAM) for the ISS JEM-EF

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**SOURCES**

SNRs, shocks
Superbubbles

photon emission
acceleration

**Interstellar medium**

X, γ

e−

P
He
C, N, O etc.
Z = 1–92

e−

P
He
C, N, O etc.

Exotic Sources:
Antimatter
Dark matter etc..

Energy losses
Reacceleration
Diffusion
Convection

Synchrotron
Inverse Compton
Bremstrahlung

spallation

B
Be
10Be

ATIC

CREAM

Chandra

Fermi

Voyager

ACE

BESS

AMS

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How do cosmic accelerators work?

- Relative abundances range over 11 orders of magnitude
- Detailed composition limited to less than ~ 10 GeV/nucleon
Cosmic Ray Energetics And Mass (CREAM)

- Transition Radiation Detector (TRD) and Tungsten Scintillating Fiber Calorimeter
  - In-flight cross-calibration of energy scales for $Z > \text{He}$
- Complementary Charge Measurements
  - Timing-Based Charge Detector
  - Cherenkov Counter
  - Pixelated Silicon Charge Detector

- Two CREAM instrument suites
  - With and without the TRD

- This exploded view shows the “With TRD” design
- The “Without TRD” design uses Cherenkov Camera
CREAM Balloon Flight Heritage

The longest known flight time for a single balloon project

Six Balloon Flights in Antarctica in 6 years: ~ 161 days Cumulative Exposure

CREAM-I
12/16/04 – 1/27/05
42 days

CREAM-II
12/16/05-1/13/06
28 days

CREAM-III
12/19/07-1/17/08
29 days

CREAM-IV
12/19/08 - 1/7/09
19 days 13 hrs

CREAM-V
12/1/09 – 1/8/10
37 days 10 hrs

CREAM-VI
12/21/10 – 12/26/10
5 days 16 hrs

CREAM
Eun-Suk Seo
Recovery, Refurbishment and Re-flight

The team with experience
Elemental Spectra over 4 decades in energy


Excellent charge resolution from SCD

Distribution of cosmic-ray charge measured with the SCD. The individual elements are clearly identified with excellent charge resolution. The relative abundance in this plot has no physical significance.
$I_j \propto E^{-\gamma}$

JACCE
$\gamma_P = 2.80 \pm 0.04$
$\gamma_{He} = 2.68 \pm 0.04 - 0.06$

RUNJOB
$\gamma_P = 2.78 \pm 0.05$
$(2.74 \pm 0.08)$
$\gamma_{He} = 2.81 \pm 0.06$
$(2.78 \pm 0.2)$
CREAM spectra harder than prior lower energy experiments


\[
\begin{align*}
\gamma_{P} &= 2.78 \pm 0.009 \\
\gamma_{He} &= 2.74 \pm 0.01
\end{align*}
\]
CREAM: He spectrum is harder than p spectrum

\[ \gamma_p = 2.66 \pm 0.02 \]
\[ \gamma_{\text{He}} = 2.58 \pm 0.02 \]


If the difference is the effects of spallation, the Galactic diffusion is characterized by a low value of \( \delta \) (1/3 compared to 0.6), where \( D(E) \propto E^\delta \) (Blasi & Amato, ArXiv: 1105.4521)
Heavy nuclei spectra look like He

\[ \gamma_{\text{CREAM}} = 2.58 \pm 0.02 \]

\[ \gamma_{\text{AMS-01}} = 2.74 \pm 0.01 \]

\[ \gamma_{< 200 \text{ GeV/n}} = 2.77 \pm 0.03 \]
\[ \gamma_{> 200 \text{ GeV/n}} = 2.56 \pm 0.04 \]

PAMELA (Adriani et al., Science 332, 69, 2011)

CREAM-I

\[ \gamma_p = 2.66 \pm 0.02 \]
\[ \gamma_{\text{He}} = 2.58 \pm 0.02 \]


It provides important constraints on cosmic ray acceleration and propagation models, and it must be accounted for in explanations of the electron anomaly and cosmic ray “knee.”
CREAM consistent with AMS-02 where they overlap

AMS-02 did not confirm kinks reported by Pamela, but absolute fluxes are consistent
AMS-02 He harder than AMS-01

CREAM-I
\[ \gamma_p = 2.66 \pm 0.02 \]
\[ \gamma_{\text{He}} = 2.58 \pm 0.02 \]

AMS-02 (Choutco et al., #1262; Haino et al. #1265, ICRC, Rio de Janeiro, 2013)
PAMELA (Adriani et al., Science 332, 69, 2011)
Need to extend measurements to higher energies

Unpublished Data
Not Shown
Taking into account the spectral hardening of elements for the (AMS/PAMELA/ATIC/FERMI) high energy $e^+ e^-$ enhancement

Yuan & Bi, arXiv:1304.2687v1 & 1304.2687v1, 2013
Cosmic Ray Propagation

Consider propagation of CR in the interstellar medium with random hydromagnetic waves.

Steady State Transport Eq.:

\[ \partial \frac{\partial}{\partial z} D_j \frac{\partial f_j}{\partial z} + \frac{\rho}{m} \nu \sigma f_j + \frac{1}{p^2} \frac{\partial}{\partial p} p^2 K_j \frac{\partial f_j}{\partial p} + \frac{1}{p^2} \frac{\partial}{\partial p} \left[ p^2 \left( \frac{dp}{dt} \right) \right]_{j,\text{ion}} f_j = q_j + \sum_{k<j} S_{jk} \]

The momentum distribution function \( f \) is normalized as

\[ N = \int dp \; p^2 f \]

where \( N \) is CR number density, \( D \): spatial diffusion coefficient, \( \sigma \): cross section...

\[ \frac{I_j}{X_e} + \frac{\sigma_j}{m} I_j + \alpha \{\ldots\} + \frac{d}{dE} \left[ \left( \frac{dE}{dx} \right) \right]_{j,\text{ion}} I_j = \frac{Q_j}{\rho_0} + \sum_{k<j} \frac{\sigma_{jk}}{m} I_k \]

Cosmic ray intensity \( I_j(E) = A_j p^2 f_{0,j}(p) \)

Escape length \( X_e \)

Reacceleration parameter \( \alpha \)

What is the history of cosmic rays in the Galaxy?

- Measurements of the relative abundances of secondary cosmic rays (e.g., B/C) in addition to the energy spectra of primary nuclei will allow determination of cosmic-ray source spectra at energies where measurements are not currently available.

- First B/C ratio at these high energies to distinguish among the propagation models

$$X_e \propto R^{-\delta}$$
The International Space Station (ISS) is nearly ideal for our quest to investigate the low fluxes of high-energy cosmic rays.

The CREAM instrument will be re-packaged for accommodation on NASA’s share of the Japanese Experiment Module Exposed Facility (JEM-EF).

This “ISS-CREAM” mission is planned for launch in 2014.
ISS-CREAM Instrument

Ahn et al., NIM A, 579, 1034, 2007; Amare et al. 33rd ICRC, #0630, 2013

Carbon Targets (0.5 $\lambda_{\text{int}}$) induces hadronic interactions

4 layer Silicon Charge Detector
- Precise charge measurements
- 380-µm thick 2.12 cm² pixels
- 79 cm x 79 cm active detector area

Top & Bottom Counting Detectors
- Each with 20 x 20 photodiodes and a plastic scintillator for e/p separation
- Independent Trigger

SCD
C-targets
TCD
CAL
BCD
BSD

Calorimeter (20 layers W + Scn Fibers)
- Determine Energy
- Provide tracking
- Provide Trigger

Top & Bottom Counting Detectors
- Each with 20 x 20 photodiodes and a plastic scintillator for e/p separation
- Independent Trigger

Park et al. 33rd ICRC, #1015, 2013
Hyun et al. 33rd ICRC, #1017, 2013

Boronated Scintillator Detector
- Additional e/p separation
- Neutron signals

Anderson et al. 33rd ICRC, #0350, 2013
ISS-CREAM payload

- **FRGF (JEM-RMS)**
  - Mass: ~1300 kg inc. GFE
  - Power: ~ 600 W
  - Nominal data rate: ~350 kbps

- **FRGF (SS-RMS)**

- **PIU**

- **SCD**

- **C-targets**

- **TCD**

- **CAL**

- **BCD**

- **BSD**

- **185 cm**
Mission Concept & Data Flow

Plan to be launch ready in 2014

Space-X lifts off from KSC

Space-X arrival on the ISS

Extraction of CREAM With SSRMS

SSRMS handoff to JEMRMS

Placement of CREAM on JEM-EF#2

ISS-CREAM Instrument Electronics

Science Data Archive

Science Team

Data Analysis

Data Processing

ISS Control Center NASA JSC

NASA MSFC POIC

ISS

TDRSS

White Sands Complex

Telemetry

120VDC POWER

1Mbps

43Mbps

43Mbps

10BASE-T

IEEE-802.3

MIL-STD-1553

1Mbps

PAT

120VDC POWER

1Mbps

43Mbps

10BASE-T

IEEE-802.3

MIL-STD-1553
ISS-CREAM takes the next major step

- The ISS-CREAM space mission can take the next major step to $10^{15}$ eV, and beyond, limited only by statistics.
- The 3-year goal, 1-year minimum exposure would greatly reduce the statistical uncertainties and extend CREAM measurements to energies beyond any reach possible with balloon flights.
What is the history of cosmic rays in the Galaxy?


- Being above the atmosphere, ISS-CREAM would be far superior to multiple ULDB flights.
- Measurements of the relative abundances of secondary cosmic rays (e.g., B/C) in addition to the energy spectra of primary nuclei will allow determination of cosmic-ray source spectra at energies where measurements are not currently available.
- First B/C ratio at these high energies to distinguish among the propagation models.

Unpublished Data Not Shown
High Energy Electrons

Science Goal

• Measure electrons with sufficient accuracy and statistics to search for nearby cosmic ray sources.

Instrument Requirement

• Electron / Proton Separation with less than 5% proton background
• Proton rejection power $8 \times 10^4$

Unpublished Data Not Shown
Data Flow & Science Operations

Research Data Center (UMD)
- Data Server
  - Data Backup, Archive & Processing
  - Level-0 data
  - Level-1 data
  - Level-2 data
- Web Server
  - Data Distribution

Science Operation Center (UMD)
- Data Server
- Web Server
- TDRSS
  - S band
  - Ku band

Huntsville Operations Support Center (MSFC)
- Payload Operations and Integration Center (POIC)
  - Maintains databases for commands and telemetry
  - Holds recorded data for 2 yrs

Software Toolkit for Ethernet Lab-Like Architecture (STELLA)
- Raw Data
- Real-time data
- Playback data
- Data Monitoring
- Data relay
- Data Verification Event Display
- Command & Playback Request
- Data
- Commands

Ethernet & MIL-STD-1553

CREAM

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