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For the CREAM Collaboration
CREAM Collaboration

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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
Is the “knee” due to a limit in SNR acceleration?

- The all particle spectrum extends several orders of magnitude beyond the highest energies thought possible for supernova shocks.
- And, there is a “knee” (index change) above $10^{15}$ eV.
- Acceleration limit signature: Characteristic elemental composition change over two decades in energy below and approaching the knee.
- Direct measurements of individual elemental spectra can test the supernova acceleration model.

\[
E_{\text{max}} \sim \frac{\nu}{c} ZeBVT \sim Z \times E_{\text{max}_p}
\]
CREAM spectra harder than prior lower energy measurements

It provides important constraints on cosmic ray acceleration and propagation models, and it must be accounted for in explanations of the e^+e^- anomaly and cosmic ray “knee.”
Spectral Hardening Confirmed

Aguilar et al., PRL 114, 171103 & 115, 211101, 2015

Accardo et al., PRL 113, 121102, 2014

Bertucci, APS April Meeting 2017

AMS 2014 • Accardo et al., PRL 113, 121101, 2014
Aguilar et al., PRL 113, 121102, 2014
Multiple Sources

Acceleration limit:

\[ E_{\text{max}_z} = Z e \times R = Z \times E_{\text{max}_p}, \text{ where rigidity } R = P_e / Z_e \]
Need to extend measurements to higher energies


ISS-CREAM: CREAM for the ISS

E. S. Seo et al, Advances in Space Research, 53/10, 1451, 2014

To be installed on the ISS by SpaceX-12 in 2017

- Mass: ~1258 kg
- Power: ~ 415 W
- Nominal data rate: ~500 kbps

• Building on the success of the balloon flights, the payload has been transformed for accommodation on the ISS (NASA’s share of JEM-EF).
  - Increase the exposure by an order of magnitude

• ISS-CREAM will measure cosmic ray energy spectra from $10^{12}$ to $>10^{15}$ eV with individual element precision over the range from protons to iron to:
  - Probe cosmic ray origin, acceleration and propagation.
  - Search for spectral features from nearby/young sources, acceleration effects, or propagation history.
ISS-CREAM Instrument


Silicon Charge Detector (SCD) *Lee et al. (CRD042) & Hong et al. (CRD122) ICRC 2017*
Precise charge measurements with charge resolution of ~ 0.2e.
- 4 layers of 79 cm x 79 cm active area (2.12 cm² pixels).

Boronated Scintillator Detector (BSD)
- Additional e/p separation by detection of thermal neutrons.

Calorimeter (CAL) *Picot-Clemente et al. ICRC 2017*
- 20 layers of alternating tungsten plates and scintillating fibers.
- Determines energy.
- Provides tracking and trigger.

Top/Bottom Counting Detector (T/BCD) *Shin et al. ICRC 2017; Hwang et al. JINT10 (07), P07018, 2015.*
- Plastic scintillator instrumented with an array of 20 x 20 photodiodes for e/p separation.
- Independent trigger.
ISS-CREAM at NASA KSC, August 2015
**ASTROPHYSICS**

**Catching cosmic rays where they live**

The International Space Station gears up to study high-energy particles in space

By Emily Conover

The International Space Station (ISS), which has sometimes struggled to find its scientific purpose, is broadening its role as a cosmic ray observatory. Within a year, two new instruments are slated to join a massive detector, the Alpha Magnetic Spectrometer (AMS), which the station has hosted since 2011. The ISS's perch above Earth's atmosphere is ideal for detecting high-energy particles from space, says astrophysicist Eun-Suk Seo of the University of Maryland, College Park, principal investigator of the Cosmic Ray Energetics and Mass for the International Space Station (ISS-CREAM) experiment. What's more, she notes, launch vehicles already go there regularly. “Why not utilize it?”

**Cosmic ray detectors on the ISS**

New experiments, perched outside Earth’s atmosphere, promise to turn the International Space Station into a well-rounded platform for unlocking the secrets of supernovae and even dark matter.

The AMS was a gargantuan effort costing $1.5 billion and requiring more than a decade of planning (*Science*, 22 April 2011, p. 408). The two smaller experiments—the CALorimetric Electron Telescope (CALET), and ISS-CREAM—will measure cosmic rays at energies many times higher than the AMS can reach, at a much lower price tag.

High-energy cosmic rays are scientists' best chance to glimpse what goes on inside exotic objects thought to accelerate them—such as exploding stars called supernovae. Ground-based detectors spot cosmic rays indirectly; by observing the showers of other particles they give off on striking the atmosphere. Astrophysicists hope direct measurements in space will give them a more straightforward handle on the energies and types of cosmic ray particles reaching Earth.

Whereas the AMS is a general-purpose detector, measuring electrons, protons, nuclei, and antimatter at a range of energies, the new experiments have more focused agendas. The $33 million CALET—an international project scheduled for launch by the Japan Aerospace Exploration Agency's Tanegashima Space Center on 16 August—sets its sights on high-energy electrons. These quickly lose energy as they travel through space, so any that are detected must come from less than a few thousand light-years away.

“CALET has the possibility of identifying nearby sources that can accelerate electrons,” says Thomas Gaisser, an astrophysicist at University of Delaware, Newark, who is not involved with the project. Those sources could include supernova remnants, the highly magnetized, spinning neutron stars called pulsars, or even clumps of dark matter, the mysterious substance that makes up 85% of the matter in the universe.

ISS-CREAM (pronounced “ice cream”), slated for launch by SpaceX in June 2016, will focus on high-energy atomic nuclei, from hydrogen up through iron. Their composition could help reveal the unknown inner workings of supernovae. “We cannot even agree why stars explode,” says Peter Biermann, a theoretical astrophysicist at the Max Planck Institute for Radio Astronomy in Bonn, Germany, who is not involved with the detector. “The cosmic rays are the best signature of whatever happens there.”

The new experiments could also shed light on the nature of dark matter. Some models predict that dark matter particles colliding in space should annihilate one another, giving off electrons and anti-electrons, or positrons. The AMS has already confirmed sightings of unexpectedly high numbers of positrons that could be signs of such reactions; CALET can't tell positrons from electrons, so it will look for a surplus in the total...
BACCUS Boron And Carbon Cosmic rays in the Upper Stratosphere

Beam test at CERN

Picot-Clemente et al. ICRC 2017

Count

0 10000 20000

Sum of ADCs near hit

- e 50 GeV
- e 75 GeV
- e 100 GeV
- e 125 GeV
- e 150 GeV
- e 175 GeV
- e 200 GeV
- e 225 GeV
- e 250 GeV
BACCUS Balloon Payload 30 Days Flight

Kim et al. ICRC 2017

• Boron And Carbon Cosmic rays in the Upper Stratosphere (BACCUS) set two records: the earliest launch, i.e., the first LDB to launch in November and (2) the closet landing to the launch site.

• BACCUS is to investigate cosmic ray propagation history using Boron to Carbon ratio at high energies where measurements are not available.

• The BACCUS experiment provides simultaneous measurements of cosmic-ray nuclei from \( Z = 1 \) to \( Z = 26 \) using segmented silicon charge detector and timing charge detector. Both calorimeter and transition radiation detector provide energy measurements.

BACCUS was recovered with 1 Twin Otter and 1 Helicopter flight after landing on the Ross Ice Shelf only 55 nautical miles east of McMurdo Station.

BACCUS flight trajectory
Nov. 28 – Dec. 28, 2016

BACCUS payload at CSBF during the end to end test.

B/C Ratio

Reacc.
\( \delta = 0.6 \)
\( \delta = 0.7 \)
\( \delta = 0.333 \)

PI Eun-Suk Seo, University of Maryland
CREAM Balloon Flight Heritage

Seven Balloon Flights in Antarctica: ~ 191 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

BACCUS
11/28/16-12/28/16
30 days 2 hrs
MAGIK: ISS-CREAM Installation