Charged Cosmic Rays
CREAM SOURCES
SNRs, shocks
Superbubbles
photon emission
acceleration

Interstellar
medium

X, γ
e-
P
He
C, N, O etc.
Z = 1-92
e-
γ

Energy losses
Reacceleration
Diffusion
Convection

gas

e+e-
P
He
C, N, O etc.

B

Synchrotron
Inverse Compton
Bremstrahlung

spallation

Exotic Sources:
Antimatter
Dark matter etc.

PaMeLa
CREAM

Chandra
Fermi
Voyager
ACE
AMS

B, Be
10Be

Eun-Suk Seo
Cosmic Rays
PaMeLa

Cosmic Rays
Eun-Suk Seo
We do not know what 95% of the universe is made of!

- Weakly Interacting Massive Particles (WIMPS) could comprise dark matter.
- This can be tested by direct search for various annihilating products of WIMP's in the Galactic halo.
Search for Antimatter & Dark Matter

Novel Cosmic Origin

1979: first observation of antiprotons
(Golden et al, 1979, Bogomolov et al, 1979)

1981: Anomalous excess (Buffington et al.)

1987: LEAP, PBAR

1988: ASTROMAG proposal

1989: MASS

1991: ASTROMAG shelved

1992: IMAX

1993: BESS, TS93

1994: CAPRICE, HEAT

1995: AMS proposal

1998: AMS-01 (Discovery STS-91)

2000/2: Heat-pbar

2004: BESS-Polar I

2006-present PAMELA (Polar-orbit)

2007: BESS-Polar II

2011-present: AMS-02 (Endeavour STS -134)

Kinetic Energy (GeV)

\[ \frac{\bar{p}}{p} \text{ ratio} \]

Solar minimum in + phase
Solar maximum in + phase
Solar maximum in - phase
- Original BESS instrument was flown nine times between 1993 and 2002.
- New BESS-Polar instrument flew from Antarctica in 2004 and 2007
  - Polar-I: 8.5 days observation
  - Polar-II 24.5 day observation, 4700 M events
  7886 antiprotons detected: no evidence of primary antiprotons from evaporation of primordial black holes.
Charge Dependent Solar Modulation

Asaoka et al., PRL 88, 051101, 2001

Bartol Neutron Monitor

Proton flux (m$^{-2}$sr$^{-1}$s$^{-1}$GeV$^{-1}$)

Charged Dependent Solar Modulation

Antiproton/proton Ratio


Asaoka et al., PRL 88, 051101, 2001

Bieber et al., 1999

Sun Spot Observed

BESS-95
BESS-97
BESS-99
BESS-94
BESS-93
BESS-2000
BESS-2002
BESS-2001
ATIC-2
AMS-02
BESS-Polar I
BESS-Polar II

Year


10^2

10^3

10^4

10^5

10^6

10^7

10^8

10^9

10^10

10^{-1}

10^{-2}

10^{-3}

10^{-4}

10^{-5}

10^{-6}

10^{-7}

10^{-8}

10^{-9}

10^{-10}

10^{-11}

10^{-12}

10^{-13}

10^{-14}

Kinetic Energy (GeV)

BESS-Polar II (07)
BESS-Polar I (04)
BESS97
BESS98
BESS99
BESS00
BESS-TeV (02)
PAMELA06
PAMELA07
PAMELA08
PAMELA09
BESS(97)
BESS(99)
BESS(00)

10, (+) ~ 1997
solar min. at positive phase

70, (+) ~ 1999
solar max. at positive phase

70, (-) ~ 2000
solar max. at negative phase
Voyager 1 in Interstellar Space

Stone et al., Science 2013
From MASS to PAMELA

Matter
Antimatter
Superconducting
Spectrometer (MASS)
1989 balloon flight in Canada

GF ~21.5 cm²sr
Mass: 470 kg
Size: 130x70x70 cm³
Payload for Anti-Matter Exploration and Light-nuclei Astrophysics (PAMELA)
satellite Launch 6/15/06
Pamela under various geomagnetic conditions
SEP from Dec. 14, 2006 CME

Change in flux and shape on a very short time scale


End of event of Dec 14th
“High energy data deviate significantly from predictions of secondary production models (curves), and may constitute the evidence of dark matter particle annihilations, or the first observation of positron production from near-by pulsars.”


Adriani et al. PRL 116, 241105, 2016
Alpha Magnet Spectrometer
Launch for ISS on May 16, 2011

- Search for dark matter by measuring positrons, antiprotons, antideuterons and $\gamma$-rays with a single instrument
- Search for antimatter on the level of $< 10^{-9}$

**Precision Measurements**
- Magnet 0.9Tm$^2$
- TOF resolution 120 ps
- Tracker resolution 10$\mu$
- TRD h/e rejection O(10$^2$)
- EM calorimeter h/e rejection O(10$^4$)
- RICH h/e rejection O (10$^3$)

High Statistics Measurement of the Positron Fraction in Primary Cosmic Rays of 0.5–500 GeV with the Alpha Magnetic Spectrometer on the International Space Station

Accado et al., PRL 113, 121101, 2014
High Energy Antiprotons

AMS Days at CERN, April 15-17, 2015

Aguilar et al. PRL 117, 091103, 2016

Wino Dark Matter, Decaying Gravitino Dark Matter…??

“It is urgent to address first one of the main current limitations in the field of charged CRs, namely the determination of the propagation parameters.”
How do cosmic accelerators work?

- Relative abundances range over 11 orders of magnitude
- Detailed composition limited to less than ~ 10 GeV/nucleon
• Transition Radiation Detector (TRD) and Tungsten Scintillating Fiber Calorimeter
  - In-flight cross-calibration of energy scales
• Complementary Charge Measurements
  - Timing-Based Charge Detector
  - Cherenkov Counter
  - Pixelated Silicon Charge Detector

• The CREAM instrument has had six successful Long Duration Balloon (LDB) flights and have accumulated **161 days** of data.
  – This longest known exposure for a single balloon project verifies the instrument design and reliability.

**CREAM** Cosmic Ray Energetics And Mass

Eun-Suk Seo
Balloon Flights in Antarctica Offer Hands-On Experience

CREAM has produced >12 Ph.D.’s

The instruments are for the most part built in-house by students and young scientists, many of them currently working in the on-campus laboratory.

Instruments are fully recovered, refurbished & reflown.

Cosmic Rays

Eun-Suk Seo
U-Md.-Goddard programs offer students out-of-this-world opportunities

By Allison Klein  October 31 at 6:00 AM

Professor Eun-Suk Seo at the University of Maryland Laboratory stands in front of the Cosmic Ray Energetics and Mass detector, which NASA will launch to the International Space Station. (Greg Powers/For The Washington Post)

Dozens of students at the University of Maryland have toiled in the physics lab, some soldering metal parts, some debugging software and some simply slicing black pieces of paper into perfectly sized triangles.

To physics professor Eun-Suk Seo, all of their work is critical. Students are helping her build a payload that is scheduled to launch to the International Space Station next year, the culmination of more than 10 years of her painstaking work on cosmic rays in a collaboration with NASA.
CREAM: Elemental Spectra over 4 decades in energy


Excellent charge resolution from SCD


Cosmic Rays

Eun-Suk Seo
CREAM spectra harder than prior lower energy measurements


\[ \gamma_{\text{CREAM}} = 2.58 \pm 0.02 \]
\[ \gamma_{\text{AMS-01}} = 2.74 \pm 0.01 \]

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

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.”
Spectral Hardening Confirmed

Aguilar et al., PRL 115, 211101, 2015

Aguilar et al., PRL 114, 171103, 2015

Aguilar et al., PRL 113, 121102, 2014

Accardo et al., PRL 113, 121101, 2014

Cosmic Rays

Eun-Suk Seo
CREAM solves the puzzle with the knee and beyond


Acceleration limit:

\[ E_{\text{max}_z} = Z e \times R = Z \times E_{\text{max}_p}, \text{where rigidity } R = \frac{Pc}{Ze} \]
ISS-CREAM: CREAM for the ISS

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

• 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.

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

Mass: ~1392 kg
Power: ~ 550 W
Nominal data rate: ~350 kbps
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.
**ISS-CREAM Instrument**


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**Silicon Charge Detector (SCD)**
- Precise charge measurements with charge resolution of \( \sim 0.2e \).
- 4 layers of 79 cm x 79 cm active area (2.12 cm\(^2\) pixels).

**Top/Bottom Counting Detector (T/BCD)**
- Plastic scintillator instrumented with an array of 20 x 20 photodiodes for e/p separation.
- Independent trigger.

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

**Calorimeter (CAL)**
- 20 layers of alternating tungsten plates and scintillating fibers.
- Determines energy.
- Provides tracking and trigger.

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Cosmic Rays  Eun-Suk Seo  25
ISS-CREAM Integration at NASA WFF

Cosmic Rays

Eun-Suk Seo

6.3x10^5 events/day (~7.3 Hz)

~1.1 x 10^8 events

Marrochesi, Vulcano Workshop, 2016

Charge Identification

Very preliminary
DAMPE launch, December 16, 2015

DArk Matter Particle Explorer

Chinese Long March 2D lofts DAMPE – A Dark Matter Investigator
December 16, 2015 by Rui C. Barbosa

A new satellite – that will help humanity to unravel the mysteries of the ‘Dark Matter’ – was launched on Thursday by China. The launch of the DAMPE satellite took place at 00:12 UTC using a Long March-2D launch vehicle from the 603 Launch Pad at the Jiuquan Satellite Launch Center’s LC43.

Chinese Launch:

DAMPE (DArk Matter Particle Explore) is one of the five satellite missions in the framework of the Strategic Pioneer Research Program in Space Science of the Chinese Academy of Sciences (CAS).

Other missions include: Hard X-ray Modulation Telescope, Quantum Experiments at Space Scale, Shijian-10, Intensive Study of Future Space Science Missions and Advanced Research of Space Science Missions and Payloads.

The new satellite will be operational at a sun-synchronous orbit with an altitude of 500 kilometers and an inclination of 97.4° with 3-year lifetime.

DAMPE is a powerful space telescope for high energy gamma-ray, electron and cosmic rays detection.

It consists of a double layer of plastic scintillator strips detector (PSD) that serves as anti-coincidence detector, followed by silicon-tungsten tracker-converter (STK), which is made of 6 tracking double layers; each consists of two layers of single-sided silicon strip detectors measuring the two orthogonal views perpendicular to the incident direction of the cosmic rays.
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?”

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.

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.

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 from 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 the 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 sign 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 antielectrons, 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 number of both antiteletron, or high, exceeding the natural background.