VULCANO Workshop 2016

Frontier Objects in Astrophysics and Particle Physics

$22^{nd}$ - $28^{th}$, May 2016

Vulcano Island, Sicily, Italy

Cosmic Ray Energetics And Mass

# The CREAM Project


**Eun-Suk Seo**

**University of Maryland**

**for**

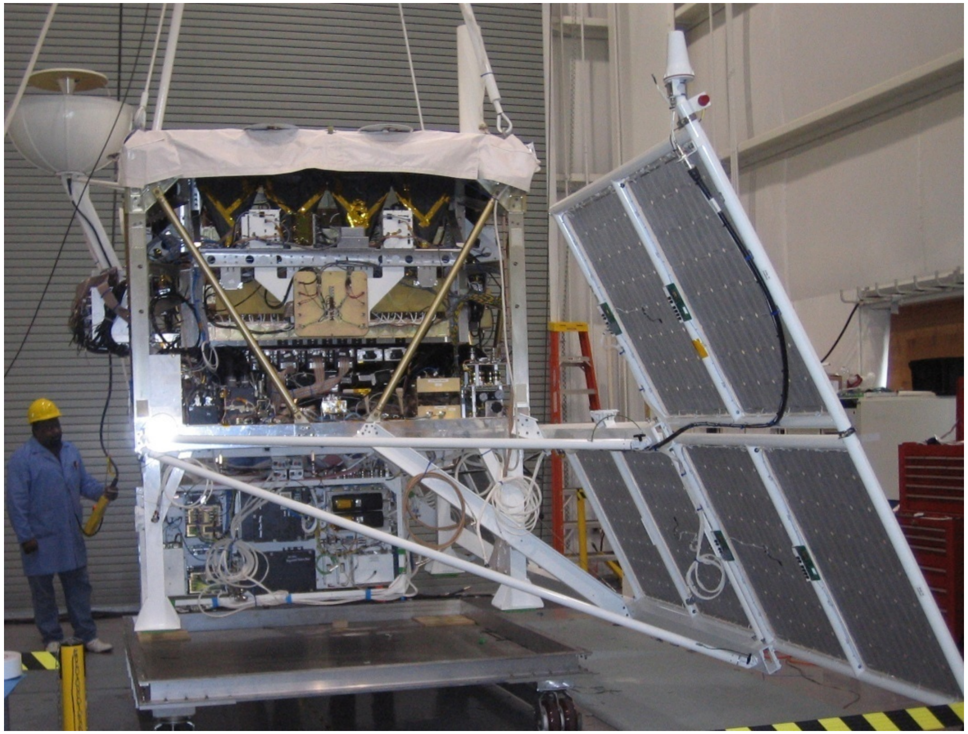
**the CREAM Collaboration**

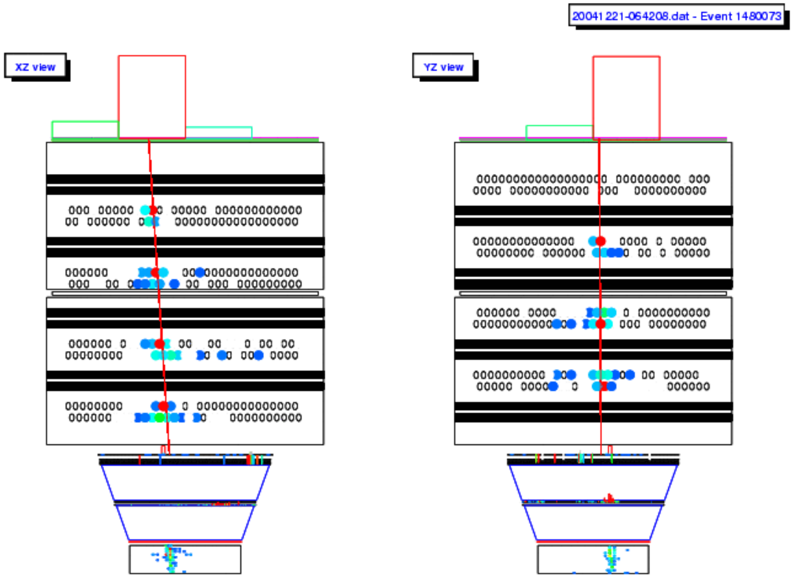
# CREAM Cosmic Ray Energetics And Mass

Seo et al. *Adv. in Space Res.*, **33** (10), *1777*, 2004; *Ahn et al.*, NIM *A*, **579**, 1034, 2007

- 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

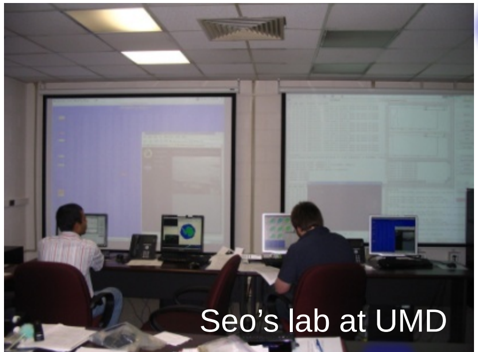
- The CREAM instrument has had six successful Long Duration Balloon (LDB) flights and have **accumulated 161 days** of data.
  - This longest known exposure for a single balloon project verifies the instrument design and reliability.



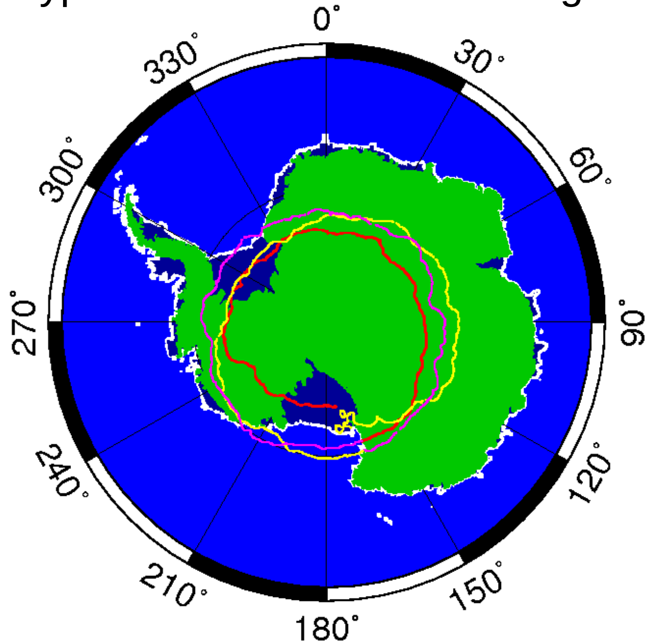


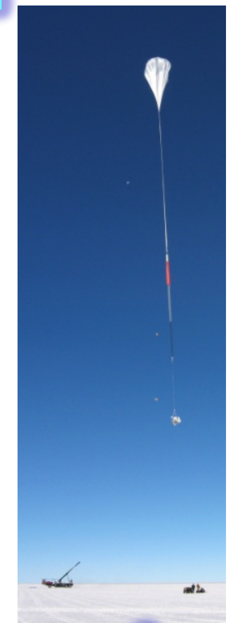
# Balloon Flight Heritage

Ahn et al. ApJ 714, L89, 2010; E. S. Seo et al., ASR, 42, 1656, 2008

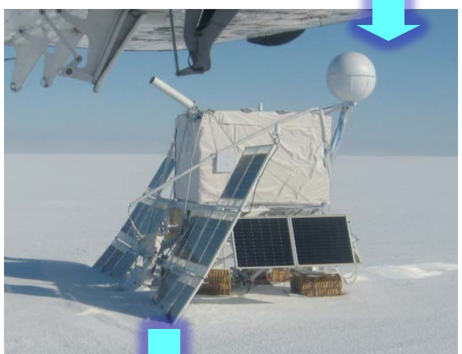



Typical duration: ~1 month/flight



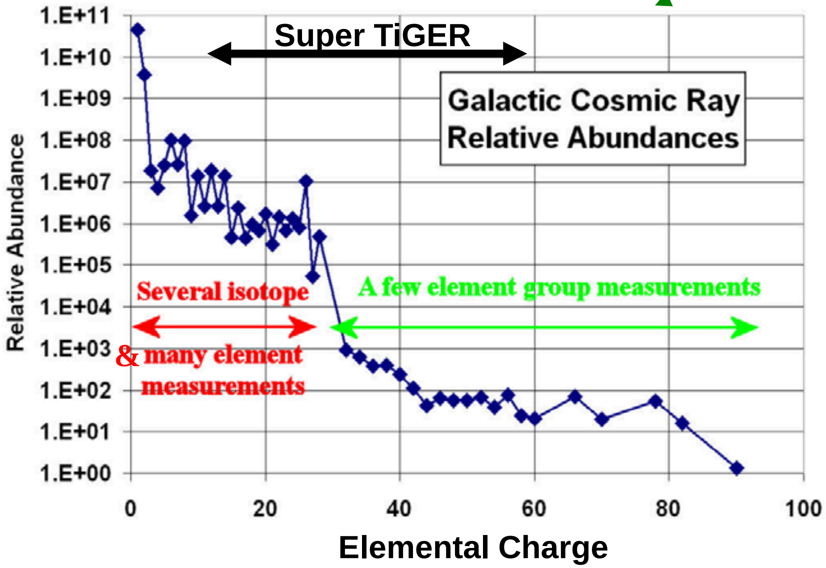



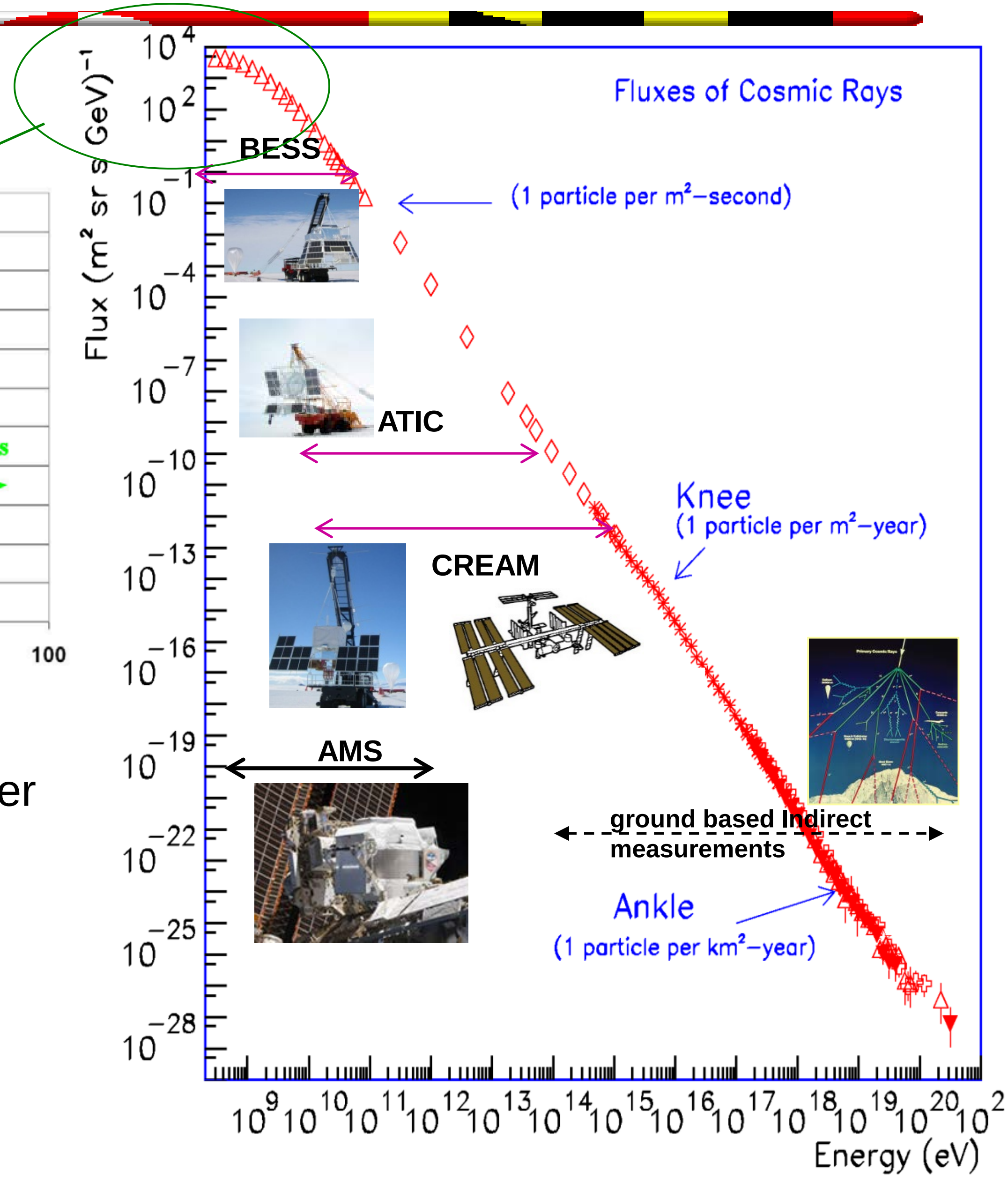
**The instrument design and functionality were proven** with 6 flights around Antarctica that accumulated 161 days of exposure.



Instruments are fully recovered, refurbished & reflown.


# How do cosmic accelerators work?

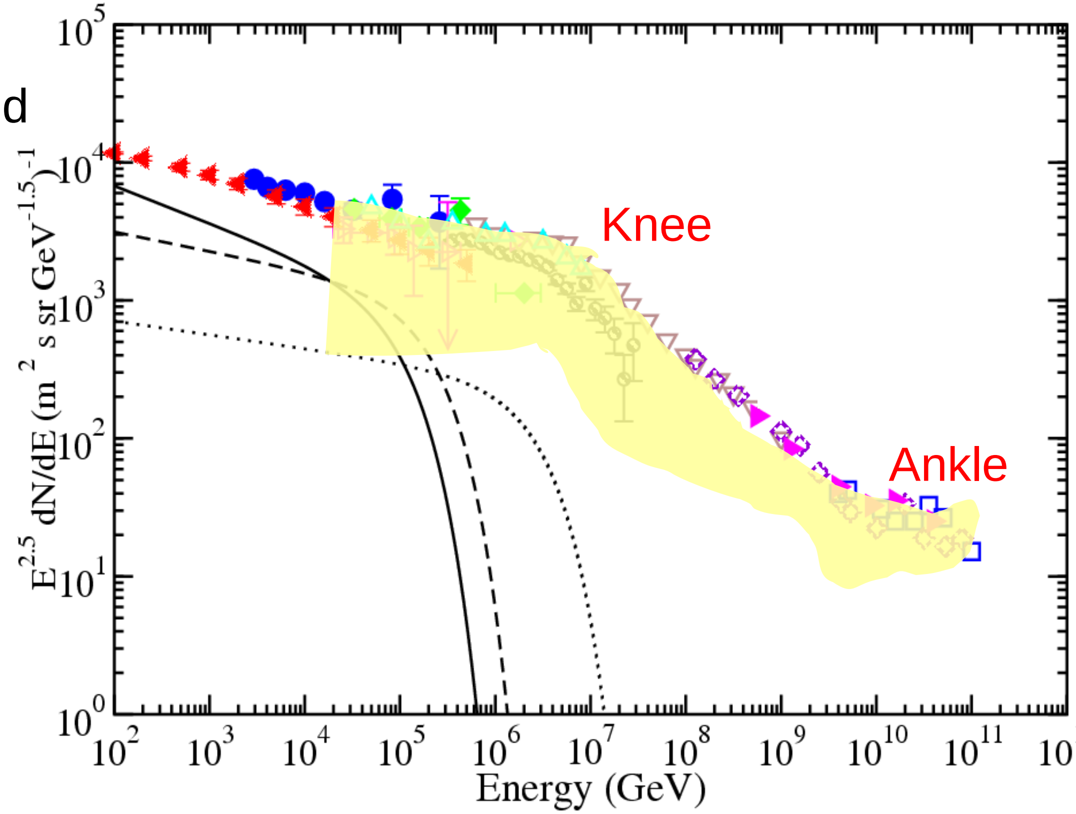



- Relative abundances range over 11 orders of magnitude
- Detailed composition limited to less than ~ 10 GeV/nucleon

# 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



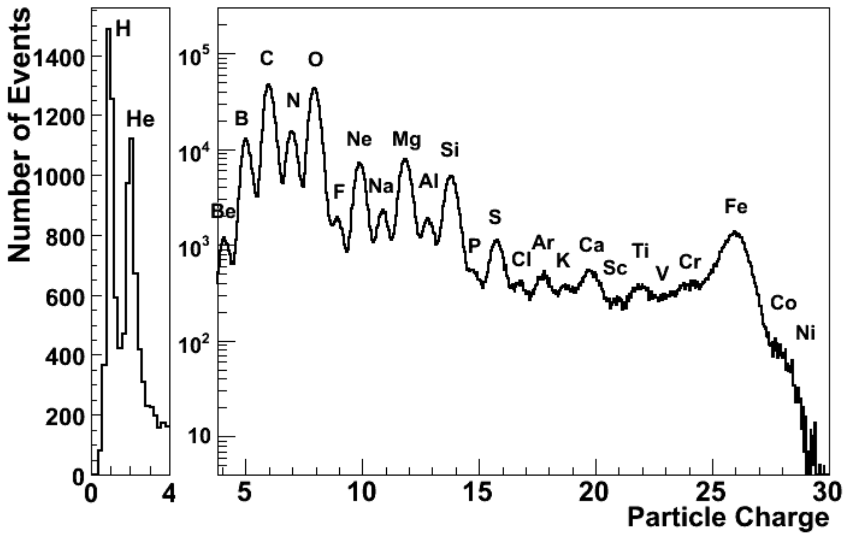

**SNR acceleration limit:**

$$E_{\max} \sim \frac{v}{c} ZeBVT \sim Z \times E_{\max\_p}$$

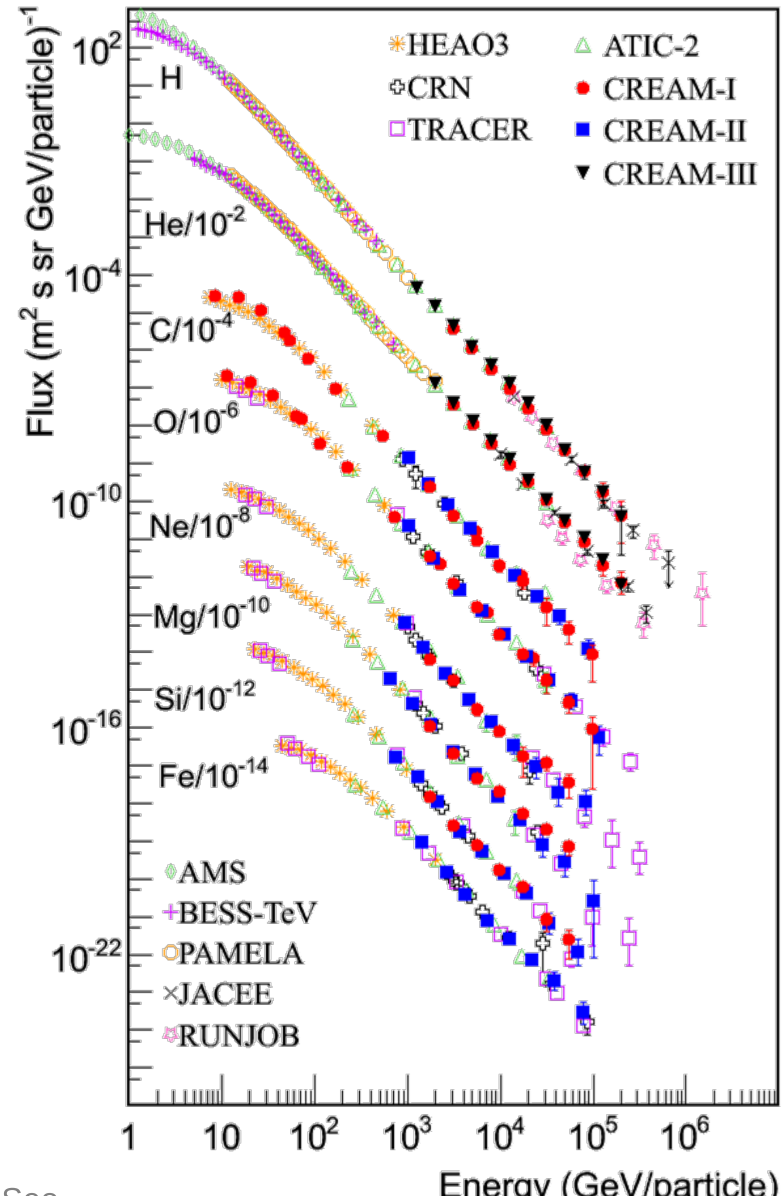
# Elemental Spectra over 4 decades in energy

Yoon et al. ApJ **728**, *122*, 2011; Ahn et al., ApJ **715**, *1400*, 2010; Ahn et al. ApJ **707**, *593*, 2009

Excellent charge resolution from SCD

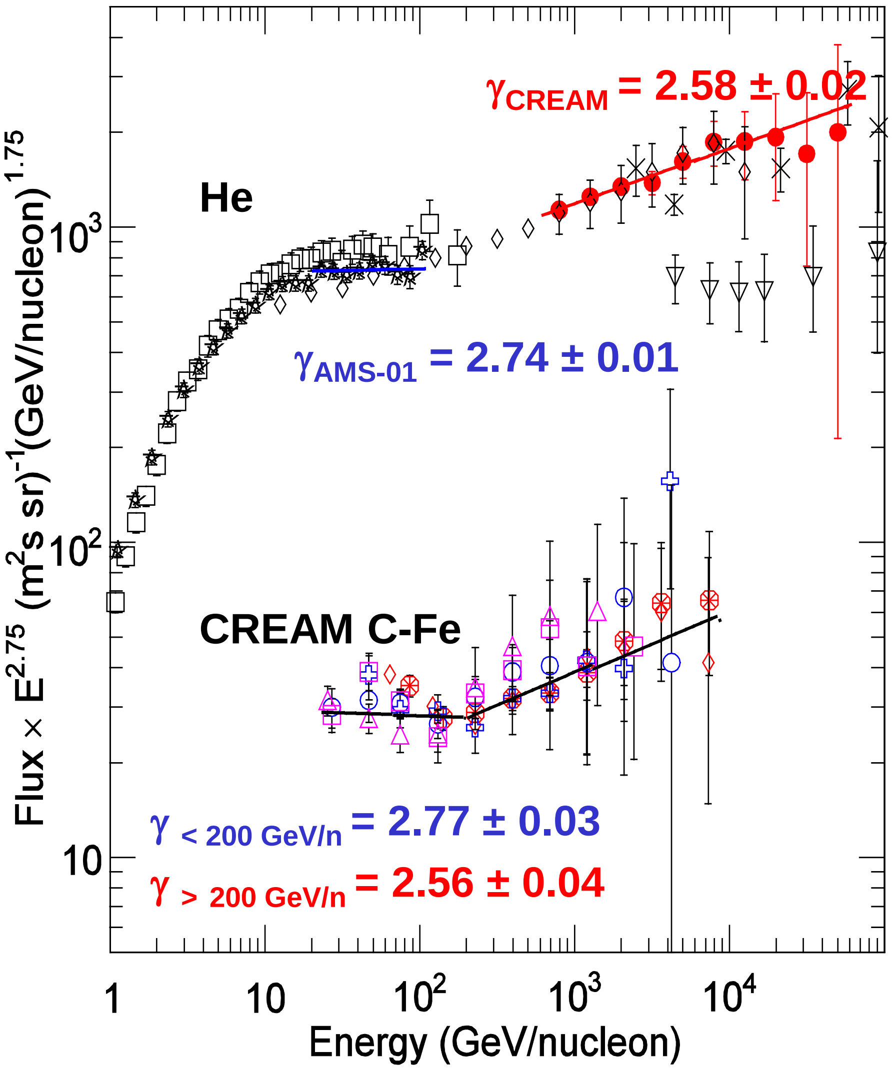


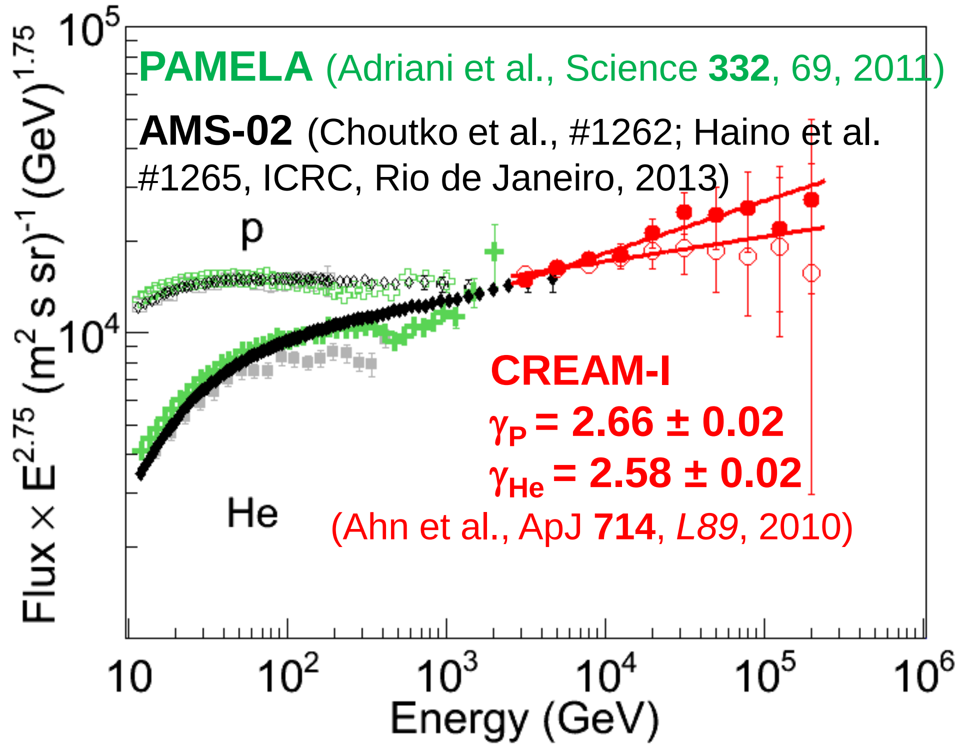

Distribution of cosmic-ray charge measured with the SCD. The individual elements are clearly identified with excellent charge resolution. The relative abundance in this plot has no physical significance



# CREAM spectra harder than prior lower energy measurements

Yoon et al. ApJ **728**, *122*, 2011; Ahn et al. ApJ 714, L89, 2010

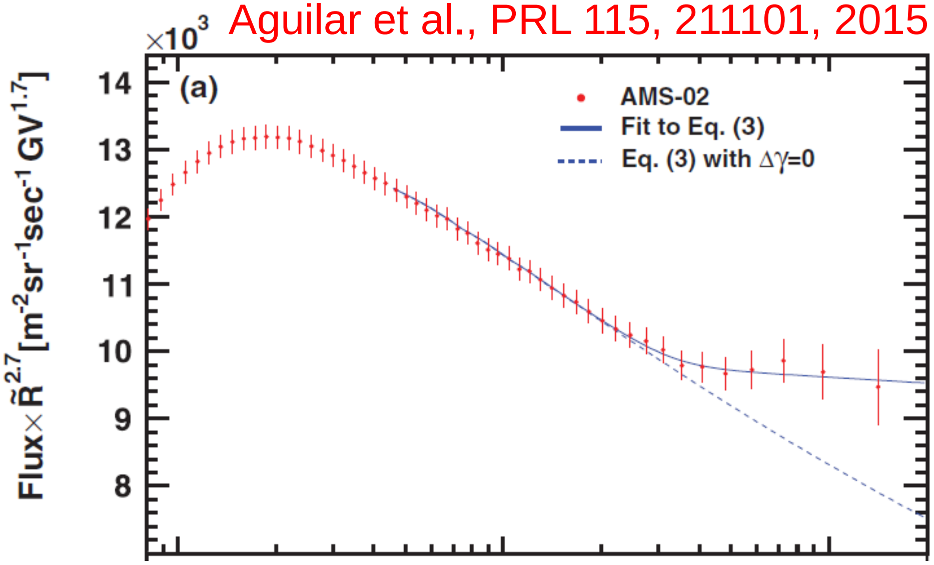


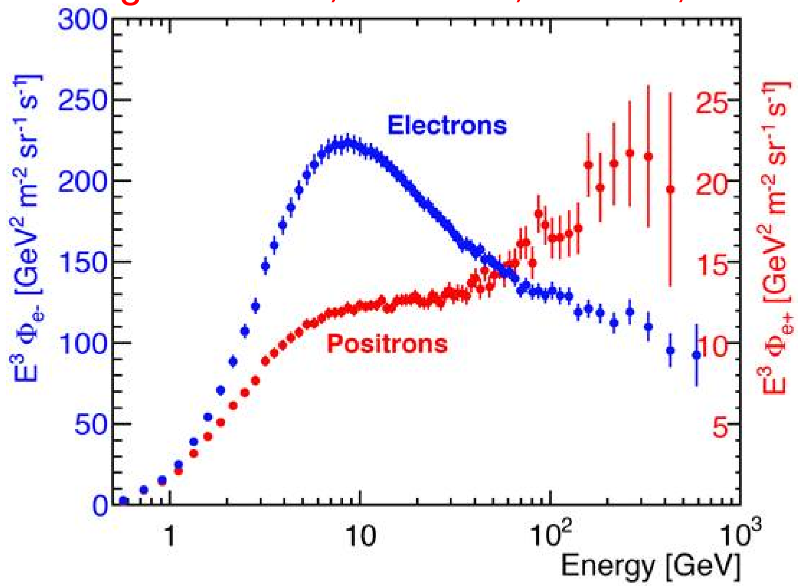

It provides important constraints on cosmic ray acceleration and propagation models, and it must be accounted for in explanations of the $e^+e^-$ anomaly and cosmic ray "knee."

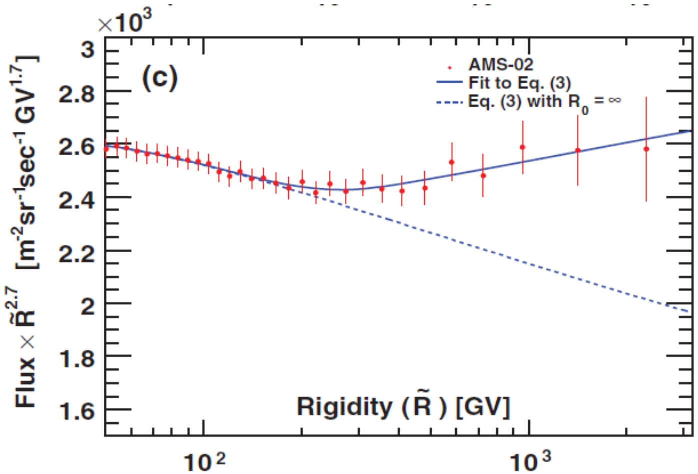
# Spectral Hardening Confirmed

Aguilar et al., PRL 115, 211101, 2015

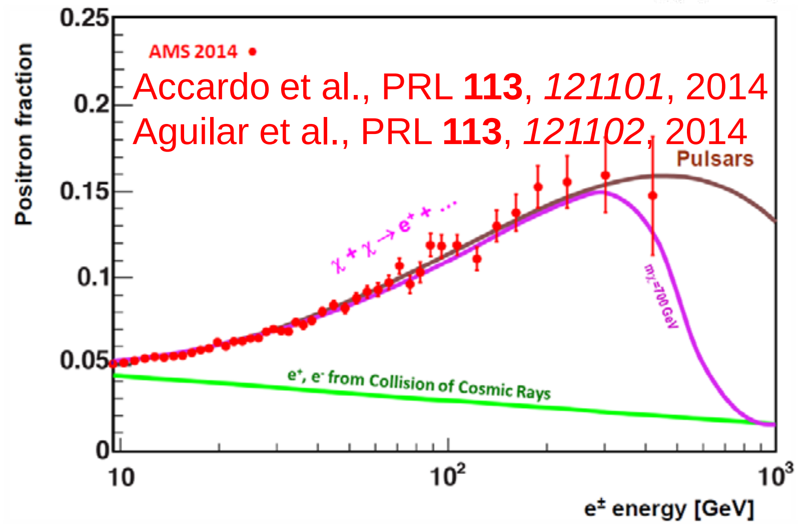



Aguilar et al., PRL 113, 121102, 2014




Aguilar et al., PRL 114, 171103, 2015



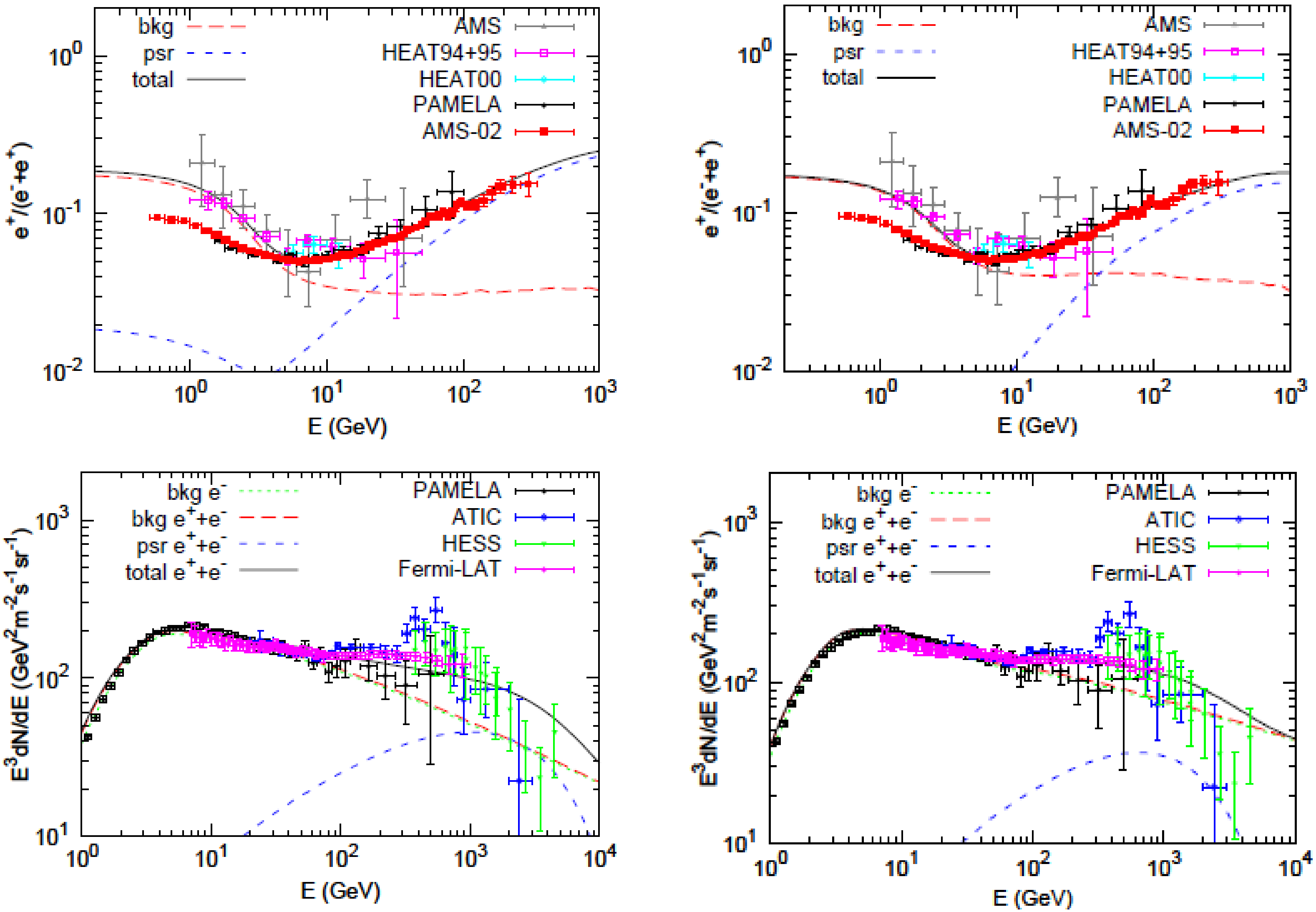

Accardo et al., PRL **113**, *121101*, 2014

Aguilar et al., PRL **113**, *121102*, 2014

# **Taking into account the spectral hardening of elements**

for the (AMS/PAMELA/ATIC/FERMI) high energy $e^+ e^-$ enhancement

Yuan & Bi, Phys. Lett. B, 727, 1, 2013 & Yuan et al. arXiv:1304.1482, 2013



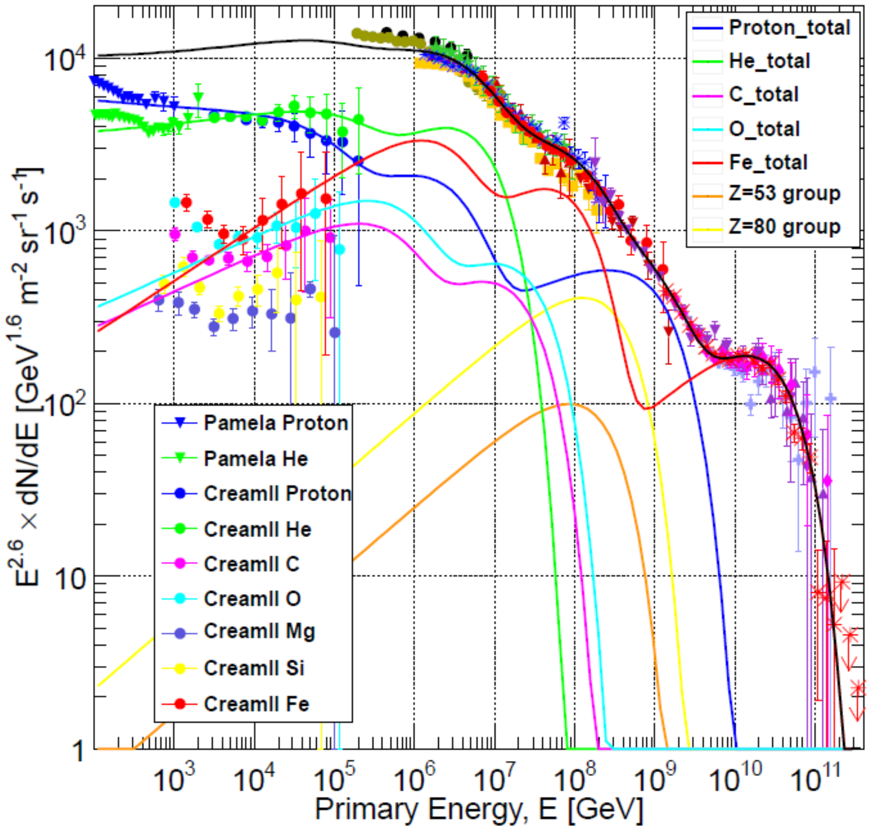
# CREAM solves the puzzle with the knee and beyond

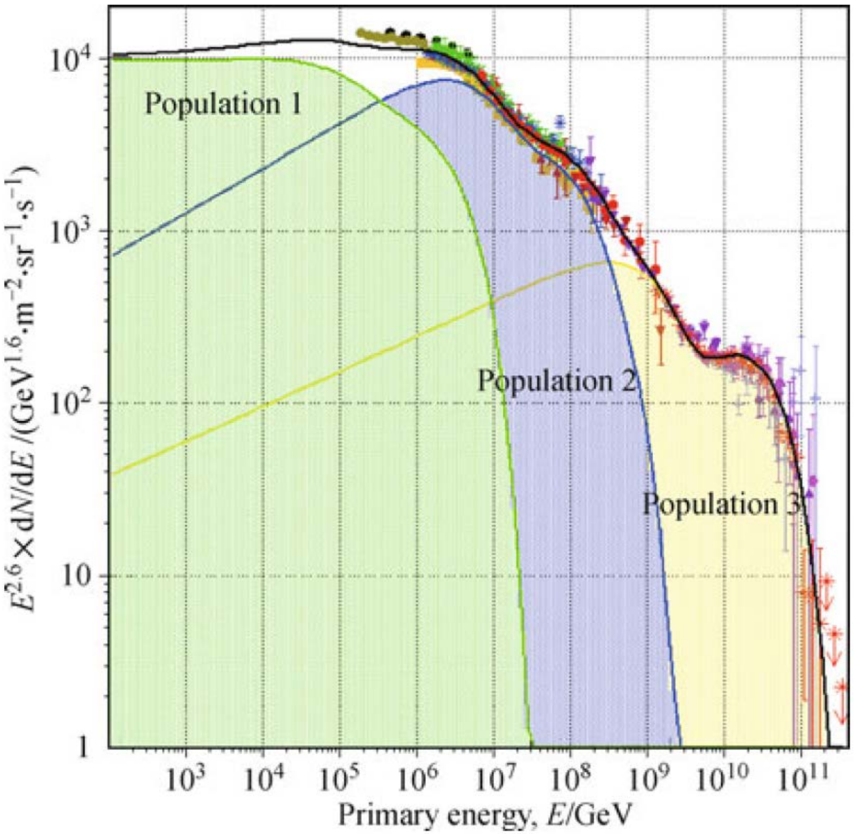
T. K. Gaisser, T. Stanev and S. Tilav, Front. Phys. 8(6), 748, 2013

S. Tilav's presentation, TeVPA, Irvine, CA , 2013

Acceleration limit:

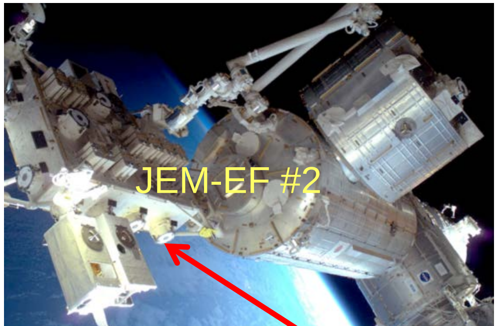
$E_{max\_z} = Ze \times R = Z \times E_{max\_p}$, *where rigidity R = Pc/Ze*



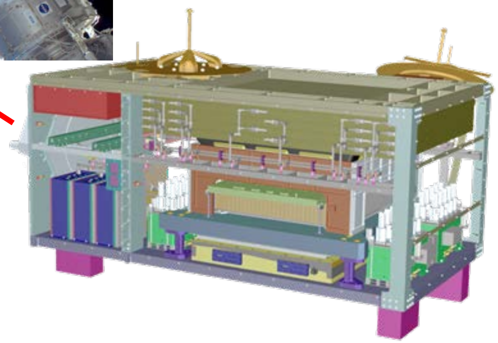



# ISS-CREAM: CREAM for the ISS

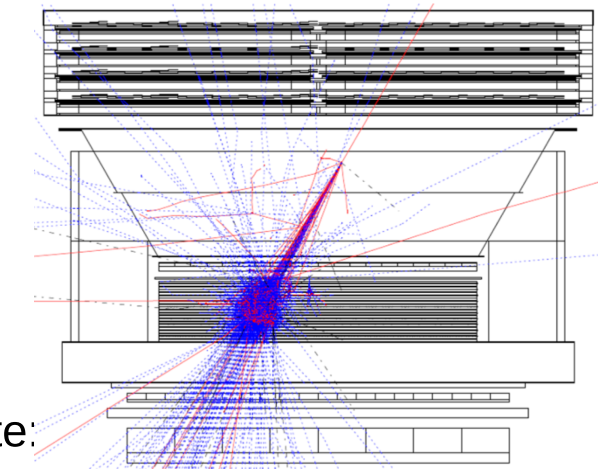
E. S. Seo et al, Advances in Space Research, **53**/10, *1451*, 2014




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



Mass: 1392 kg
Power: ~ 550 W
Nominal data rate: ~350 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 Collaboration

E. S. Seo[a,b,*], Y. Amare[a], T. Anderson[c], D. Angelaszek[a,b], N. Anthony[a], H. Arnold[a], G. H. Choi[d], M. Copley[a], S. Coutuc[c], L. Derome[f], C. Ebongue[a], L. Eraud[f], I. Faddis[a], J. H. Han[a], I. J. Howley[a], H. G. Huh[a], Y. S. Hwang[g], H. J. Hyun[g], S. Im[c], H.B. Jeon[g], J. A. Jeon[d], I. S. Jeong[d], D. Y. Kim[a], H. J. Kim[g], K. C. Kim[a], M. H. Kim[a], P. King[a], H. Y. Lee[d], J. Lee[d], M. H. Lee[a], J. Liang[a], J. T. Link[h], L. Lutz[a], A. Menchaca-Rocha[e], J. W. Mitchell[h], S. Morton[a], M. Nester[a], S. Nutter[i], O. Ofoha[a], H. Park[g], I. H. Park[d], J. M. Park[g], N. Picot-Clemente[a], J. R. Smith[a], P. Walpole[a], R. P. Weinmann[a], J. Wu[a], B. Yon[a], and Y. S. Yoon[a,b]

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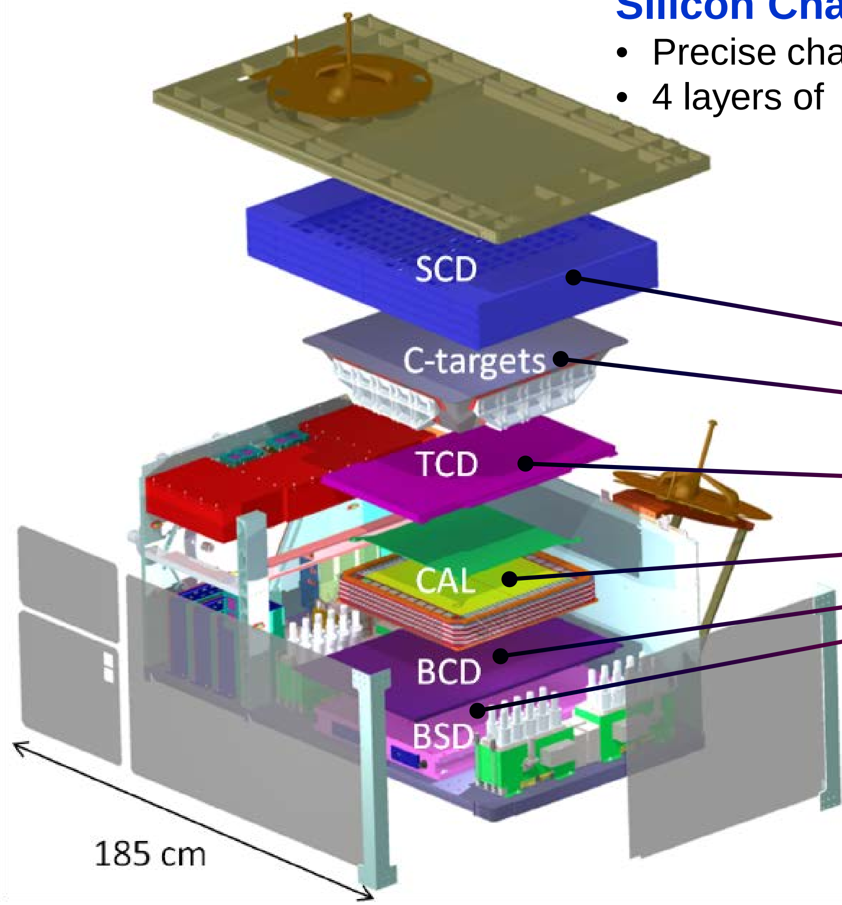
**** Principal Investigator***

Project management and engineering support by NASA GSFC WFF and its contractors

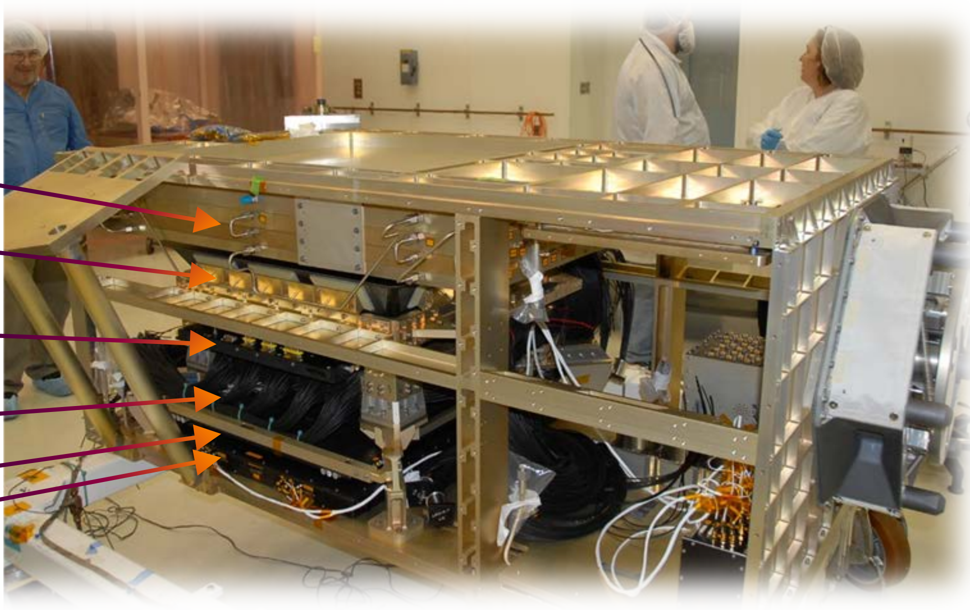
# ISS-CREAM Instrument

Seo et al. Adv. in Space Res., **53**/10, *1451*, 2014; Hwang et al. JINT10 (07), P07018, 2015




## Silicon Charge Detector (SCD)

- Precise charge measurements with charge resolution of ~ 0.2e.
- 4 layers of 79 cm x 79 cm active area (2.12 $cm^2$ pixels).



## Boronated Scintillator Detector (BSD)

- Additional e/p separation by detection of thermal neutrons.

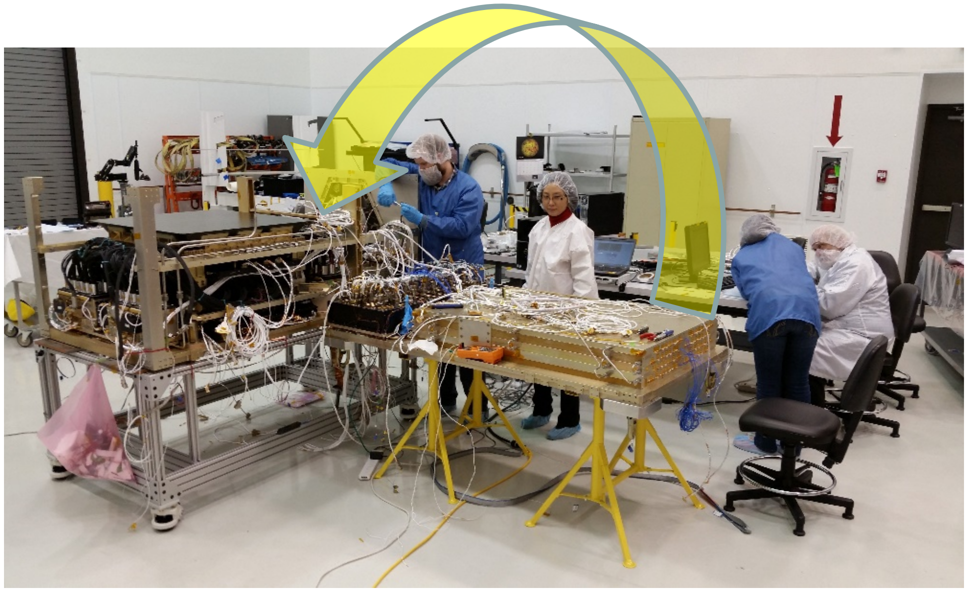
## Calorimeter (CAL)

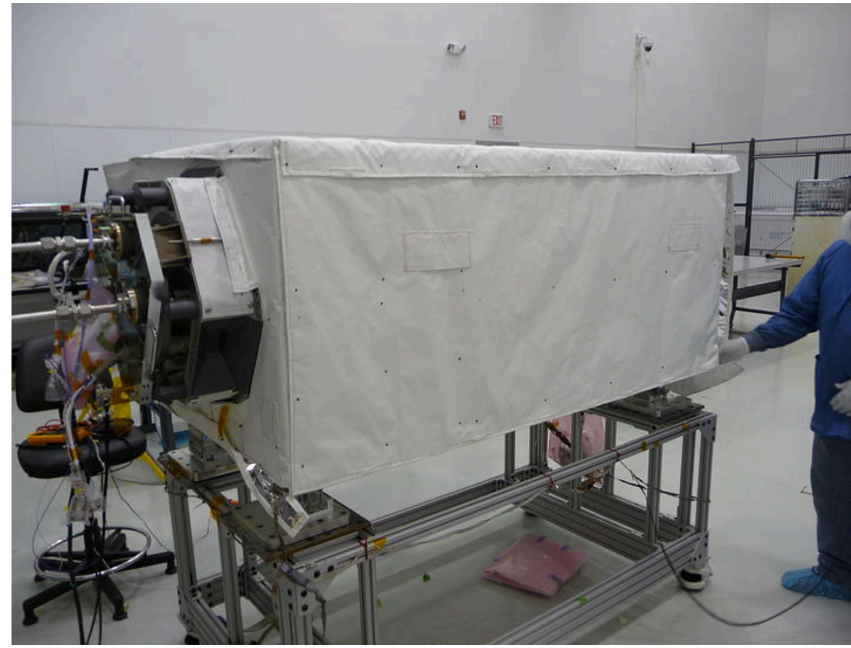
- 20 layers of alternating tungsten plates and scintillating fibers.
- Determines energy.
- Provides tracking and trigger.

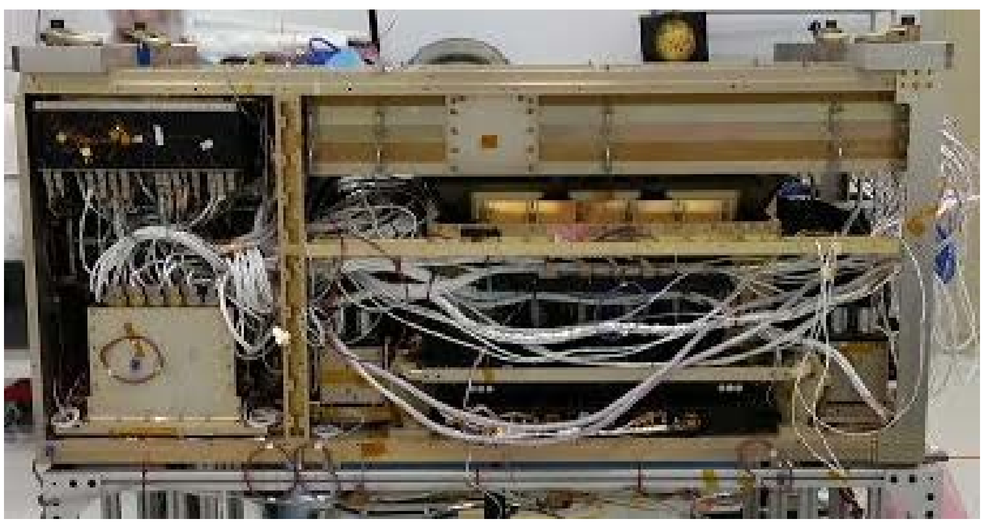
## Top/Bottom Counting Detector (T/BCD)

- Plastic scintillator instrumented with an array of 20 x 20 photodiodes for e/p separation.
- Independent trigger.

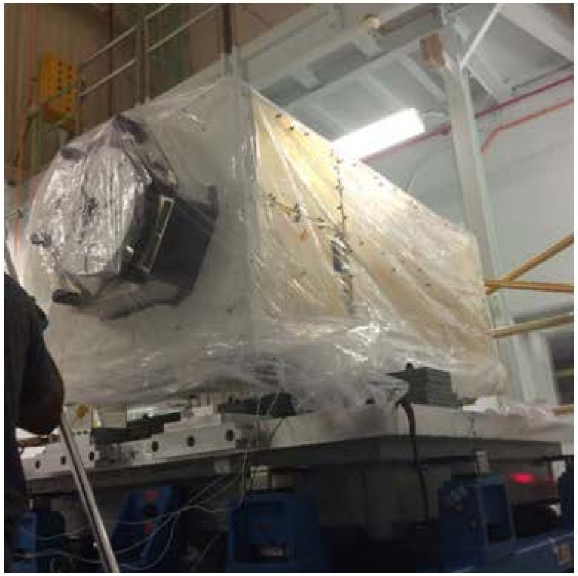
# CREAM Integration at NASA WFF

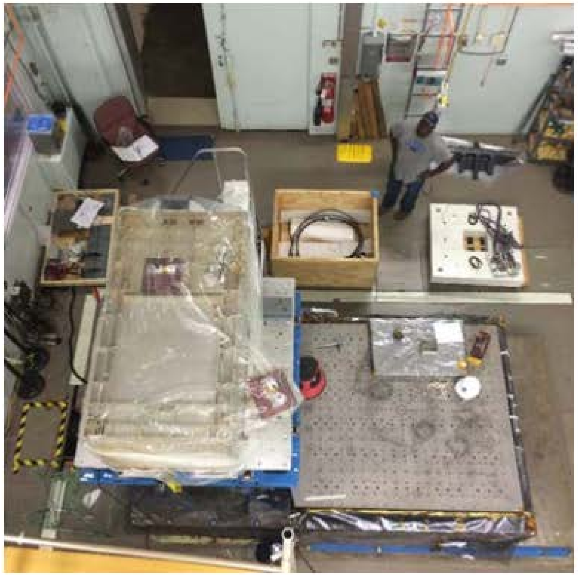




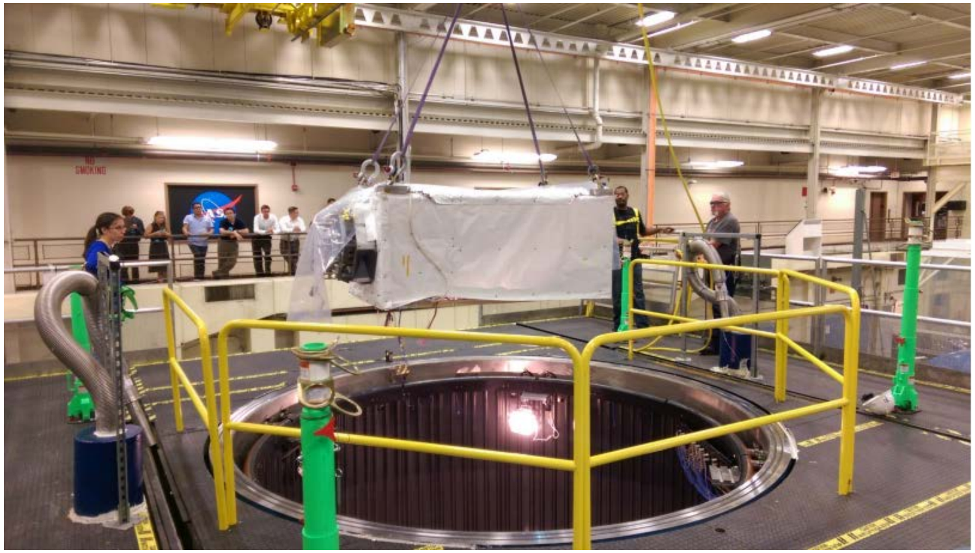


# System Level Verification at NASA GSFC





TVAC test



# ISS-CREAM at NASA KSC, August 2015

# High Impact Publication

Magazine

## U-Md.-Goddard programs offer students out-of-this-world opportunities

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By Allison Klein October 31 at 6:00 AM

Advertisement

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.

Science
AAAS

ASTROPHYSICS

# Catching cosmic rays where they live

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

*By* **Emily Conover**

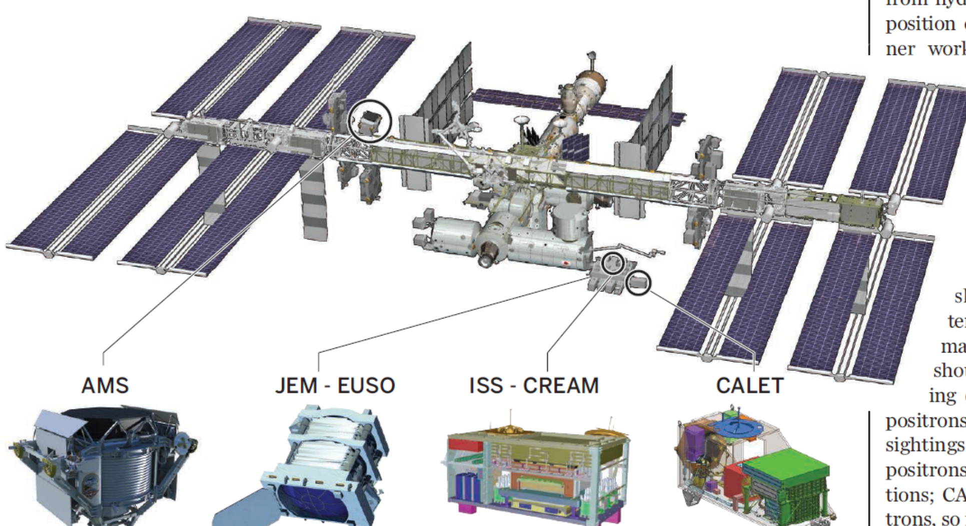
The International Space Station (ISS), which has sometimes struggled to find its scientific purpose, is broadening its role as a cosmic ray observatory. Within a year, two new instruments are slated to join a massive detector, the Alpha Magnetic Spectrometer (AMS), which the station has hosted since 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?"

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 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 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

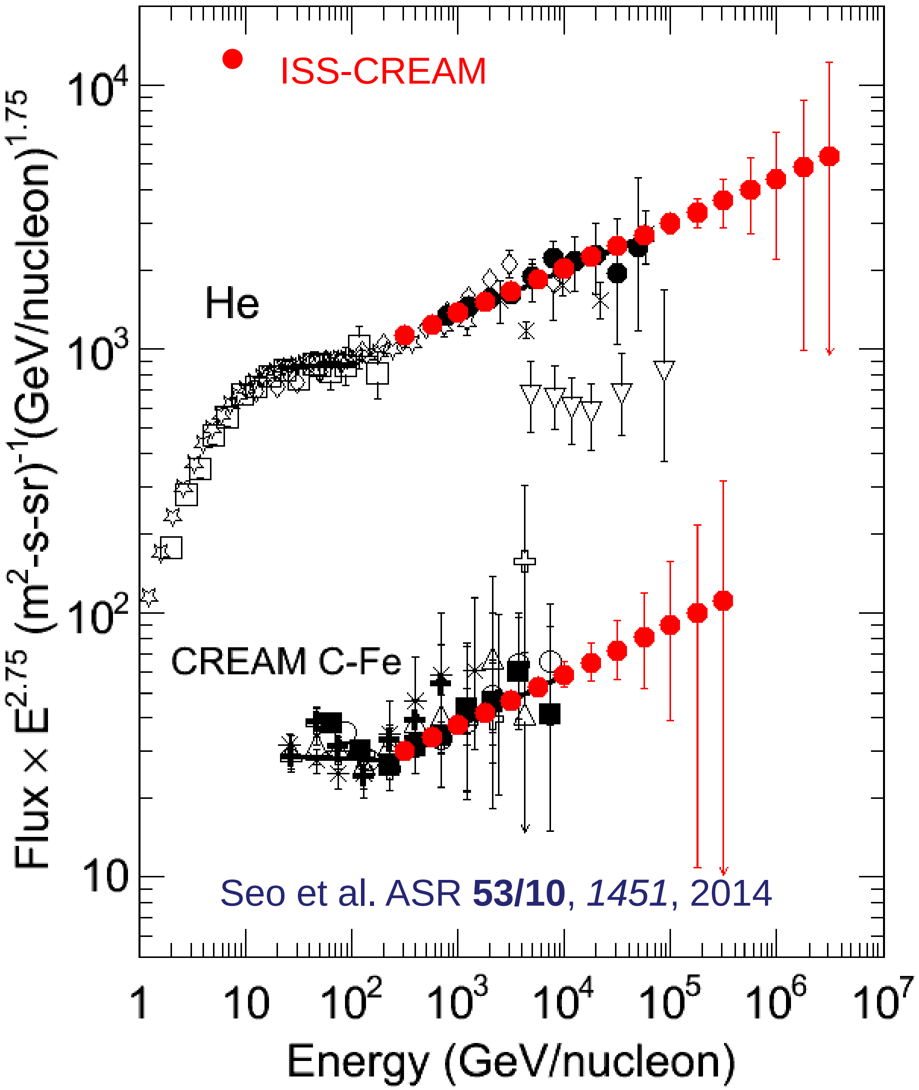
HIC) A. CUADRA/*SCIENCE*; (PHOTO) NASA, ESA, AND THE HUBBLE HERITAGE (STSCI/AURA)-ESA/HUBBLE COLLABORATION. ACKNOWLEDGMENT: J. HESTER (ARIZONA STATE UNIVERSITY)

# ISS-CREAM takes the next major step

Increases the exposure by an order of magnitude!

- 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.



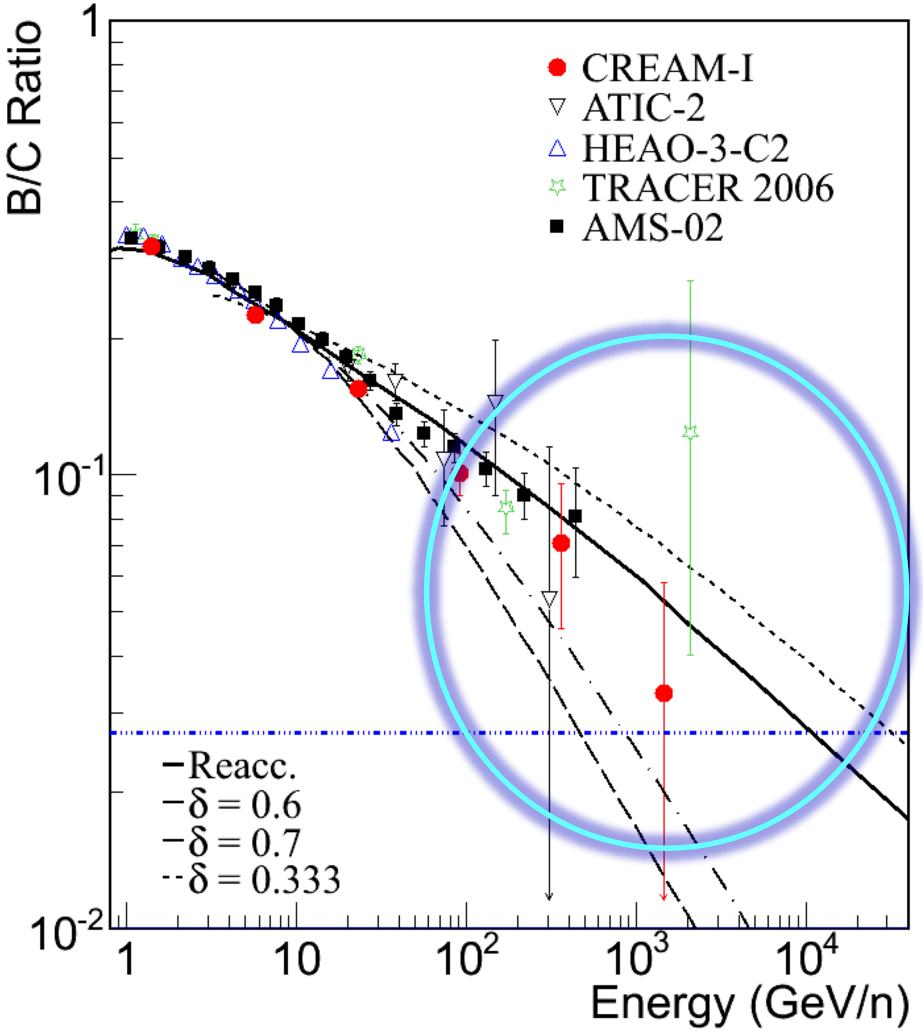
# What is the history of cosmic rays in the Galaxy?

Ahn et al. (CREAM collaboration) Astropart. Phys., 30/3, 133-141, 2008

- 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

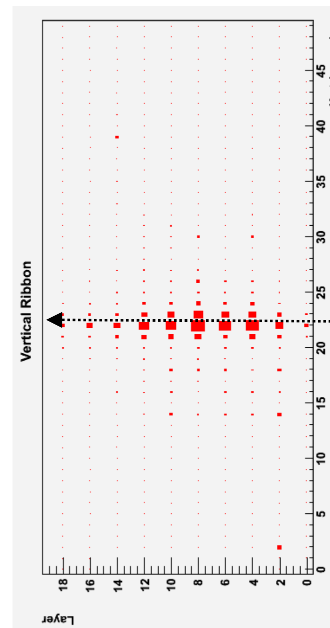
$$X_e \propto R^{-\delta}$$

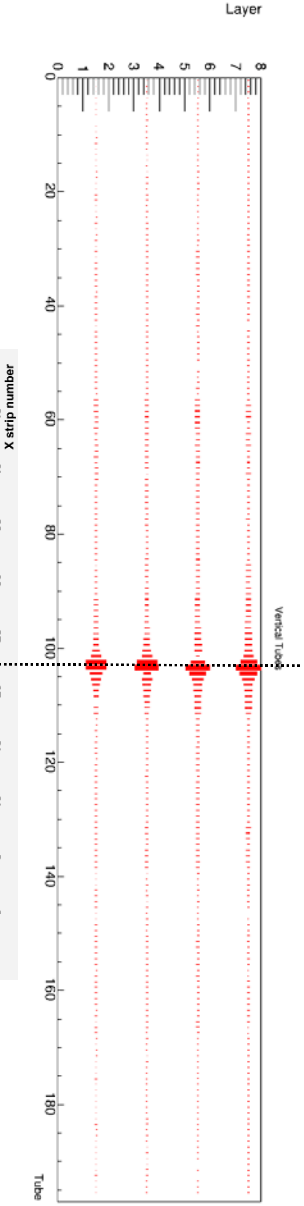


# BACCUS

# Boron And Carbon Cosmic rays in the Upper Stratosphere

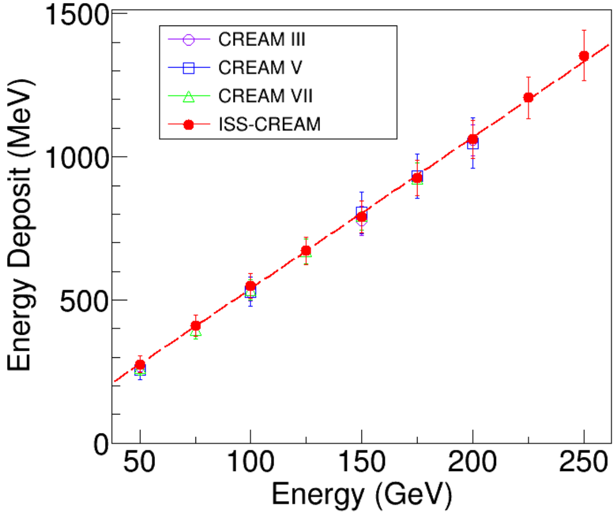
# BACCUS beam test at CERN



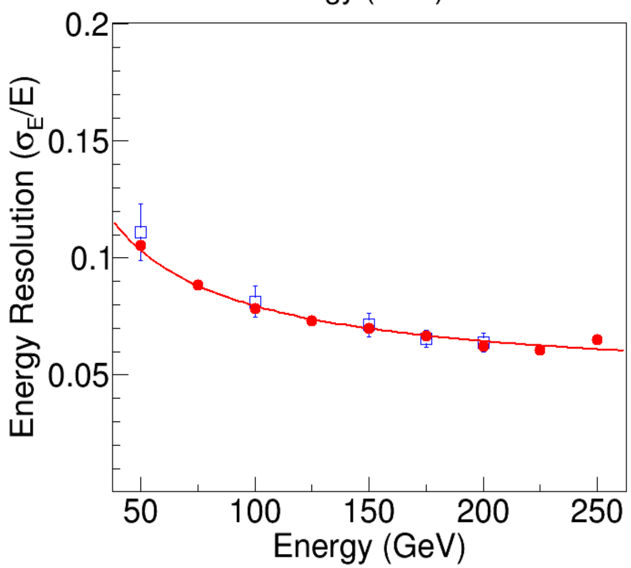



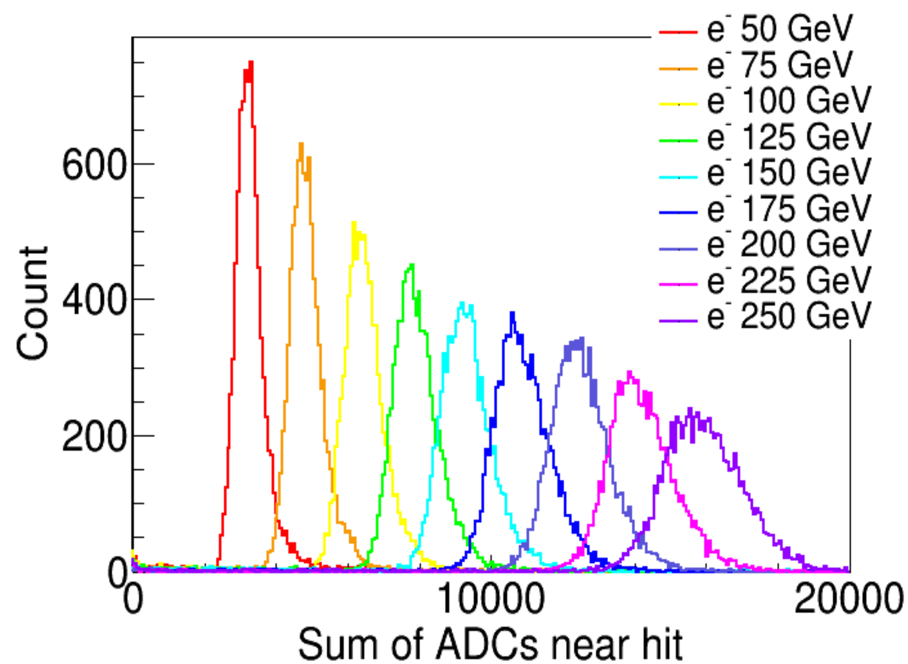
# Calorimeter Performance

Picot-Clemente et al. APS April meeting, J13.0003, 2016; Han et al. 32nd ICRC, 6, 391, 2011




- ISS-CREAM/BACCUS data are consistent with previous CREAM data



# Thank you!

http://cosmicray.umd.edu