Cosmic Ray Energetics And Mass

CREAM: Results, Implications, and outlook

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The CREAM Collaboration

http://cosmicray.umd.edu/cream

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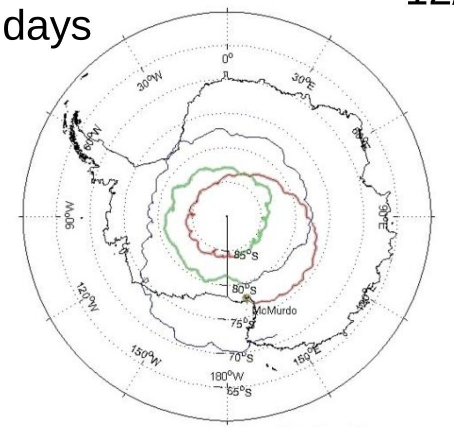
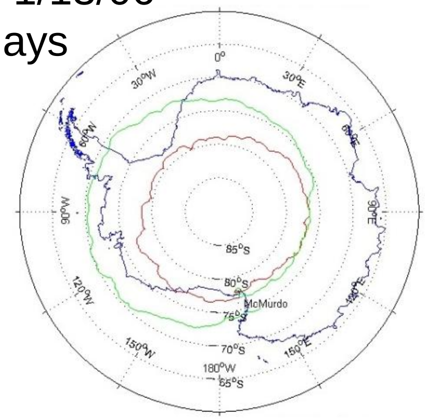
Six Balloon Flights in Antarctica: ~ 161 days Cumulative Exposure

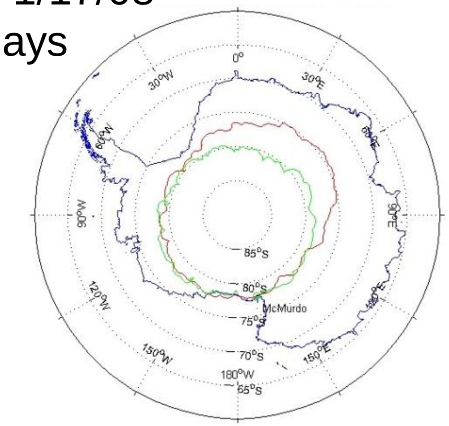
CREAM-I
12/16/04 – 1/27/05
42 days



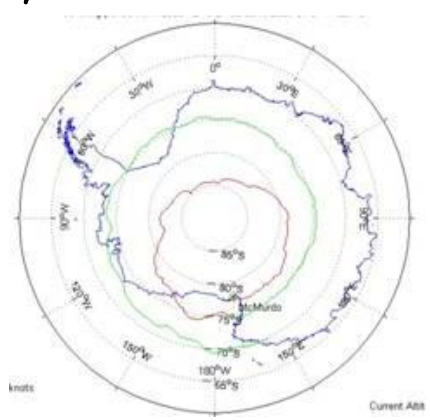
CREAM-II
12/16/05-1/13/06
28 days



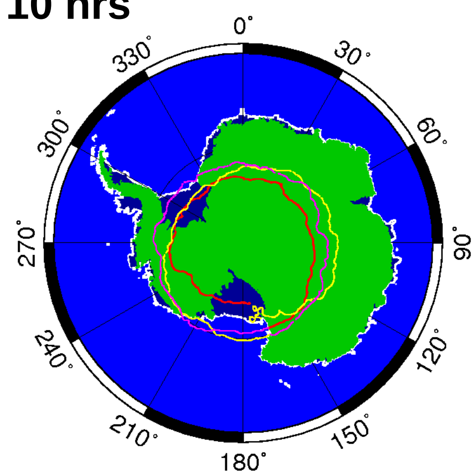
CREAM-III
12/19/07-1/17/08
29 days



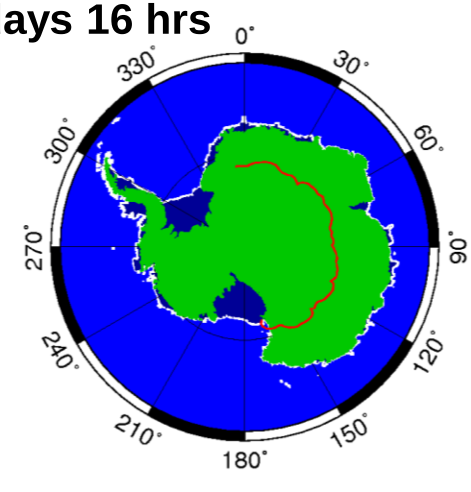
CREAM-IV
12/19/08 - 1/7/09
19 days 13 hrs



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

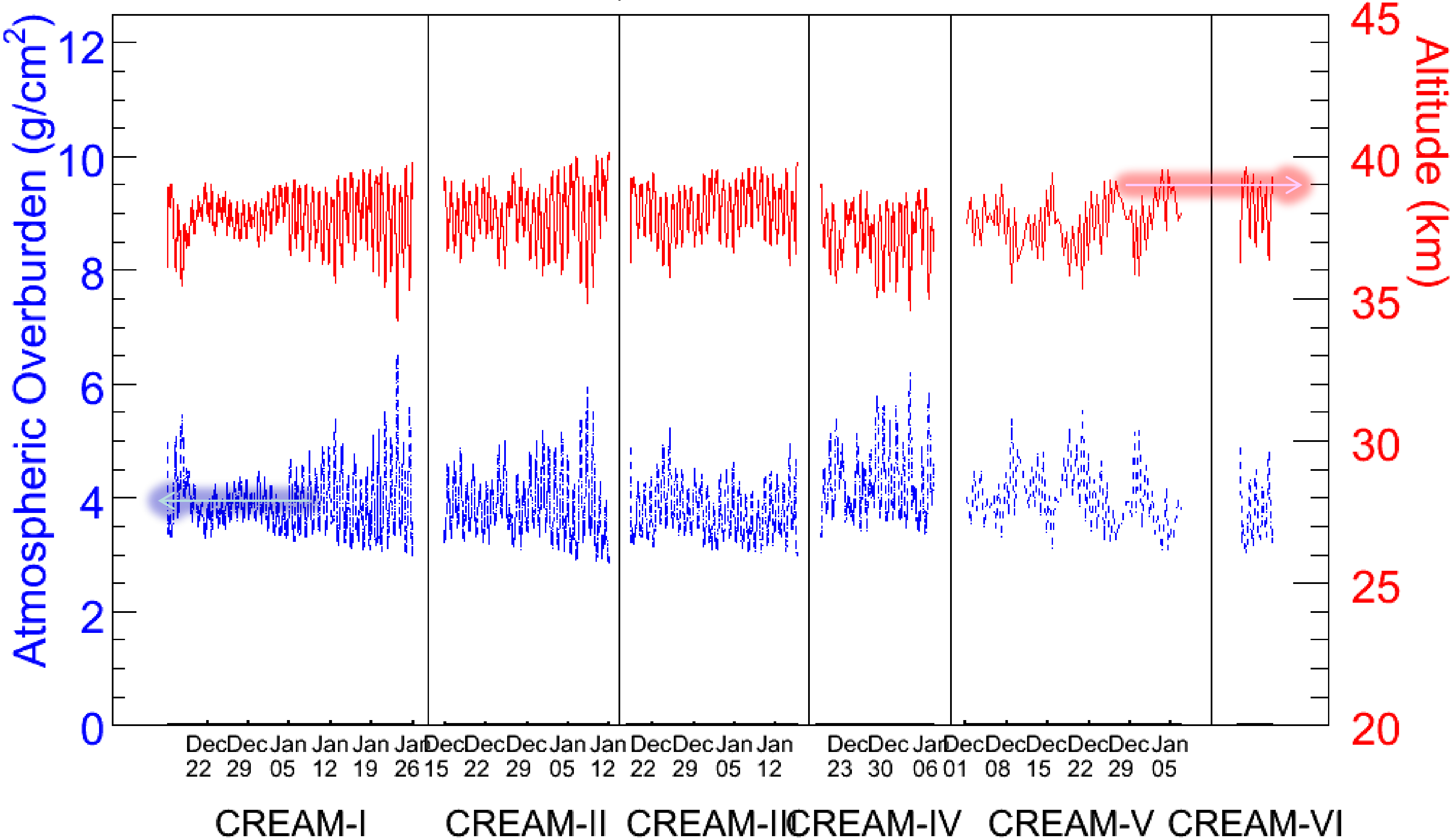


CREAM-VI
12/21/10 – 12/26/10
5 days 16 hrs



Flight profile

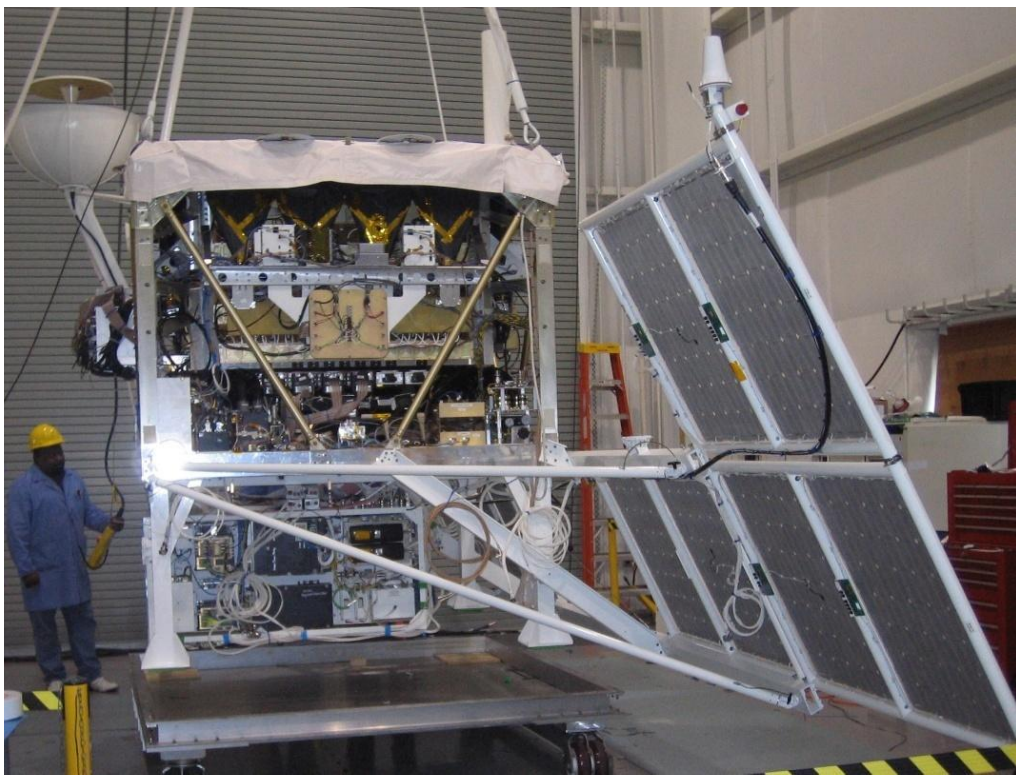
- Float altitude ~ 130 kft for all 6 flights
- Average atmospheric overburden ~3.9 g/cm^2
- No altitude anomaly observed for CREAM-VI



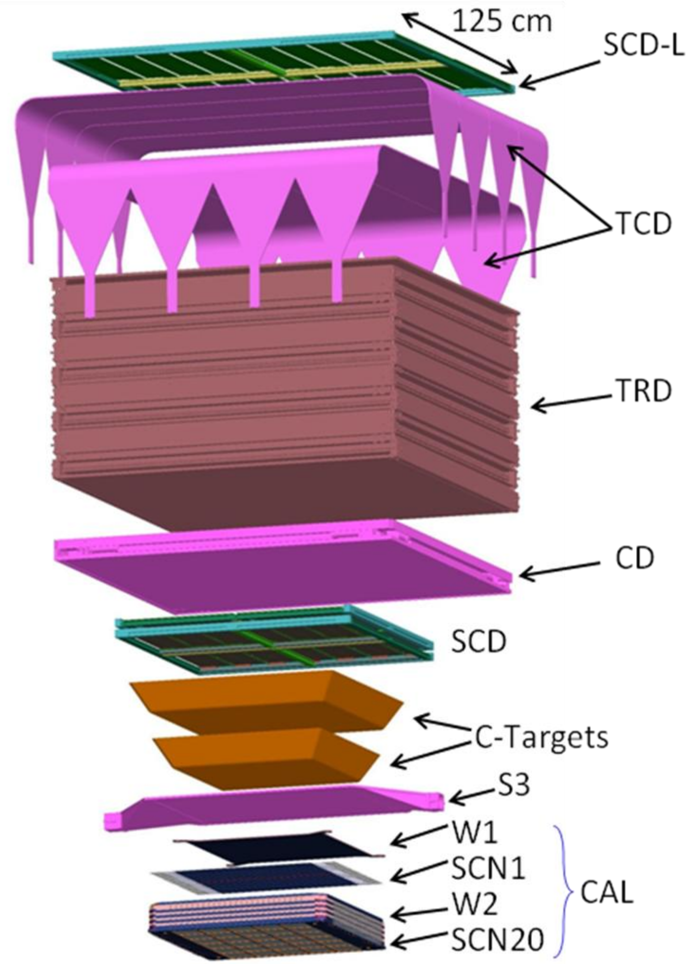
Cosmic Ray Energetics And Mass (CREAM)

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 for Z > He
- Complementary Charge Measurements
  - Timing-Based Charge Detector
  - Cherenkov Counter
  - Pixelated Silicon Charge Detector

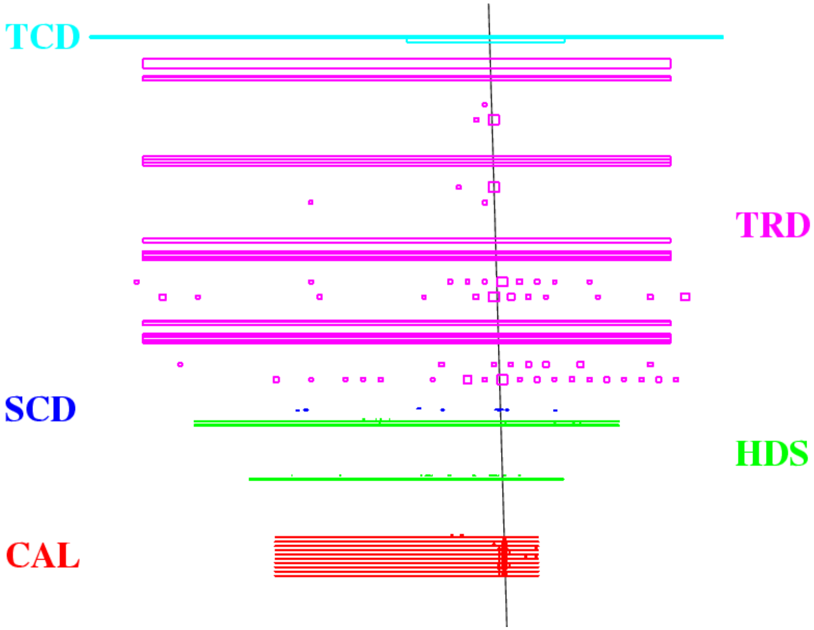


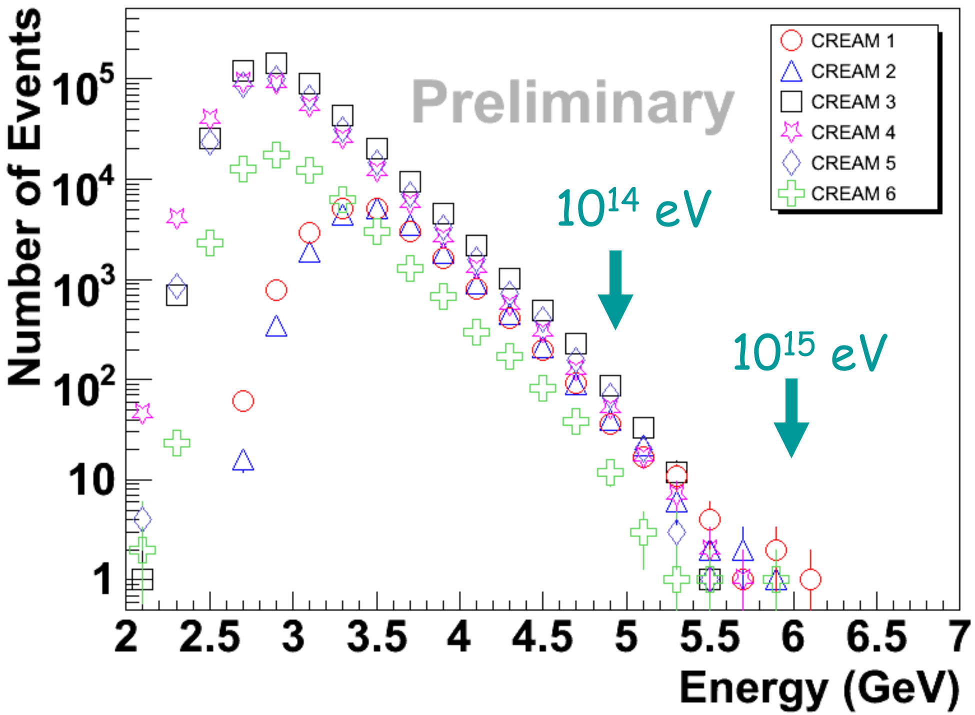
- **CREAM uses two designs**
  - With and without the TRD
- This exploded view shows the “With TRD” design
- The “Without TRD” design uses Cherenkov Camera



Flight Data: Instrument Performance

Han et al. (CREAM collaboration) OG1.5 1106, this conference

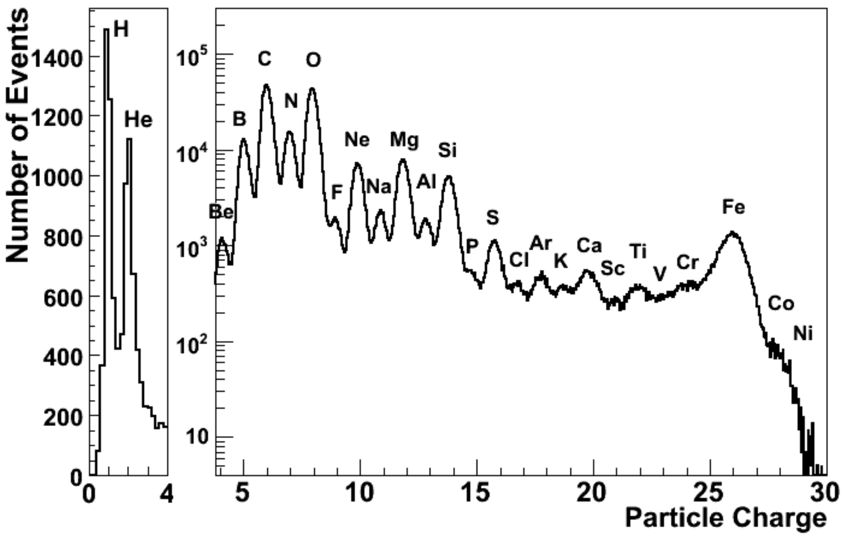


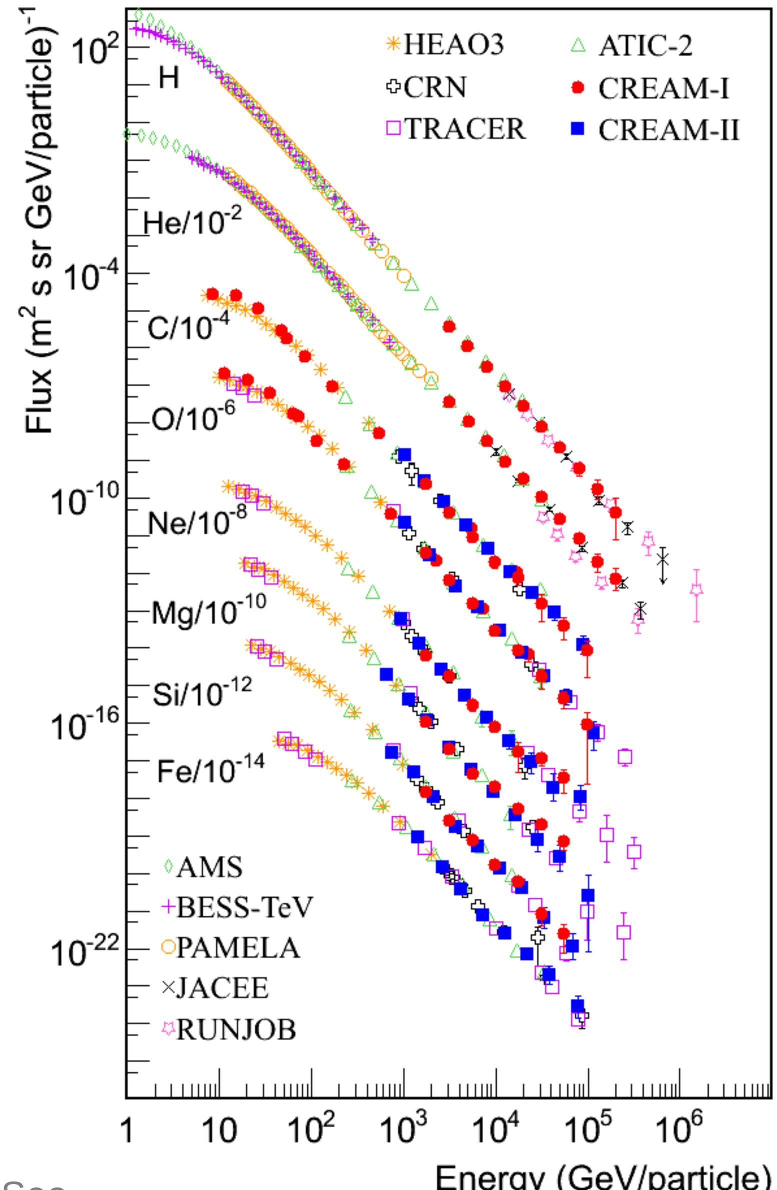


- Consistent power law for all particle data from 6 flights
- Lower Energy Threshold for CREAM III - VI

Elemental Spectra over 4 decades in energy

Ahn et al. (CREAM Collaboration), ApJ **707**, *593*, 2009



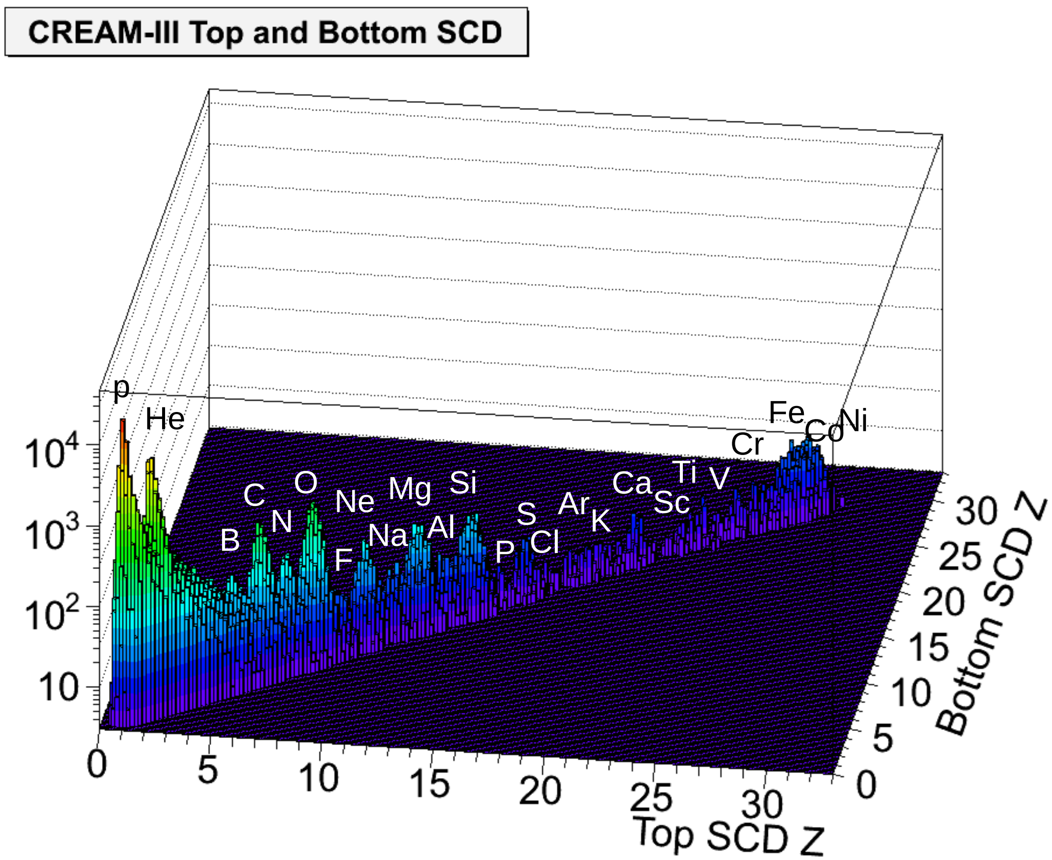


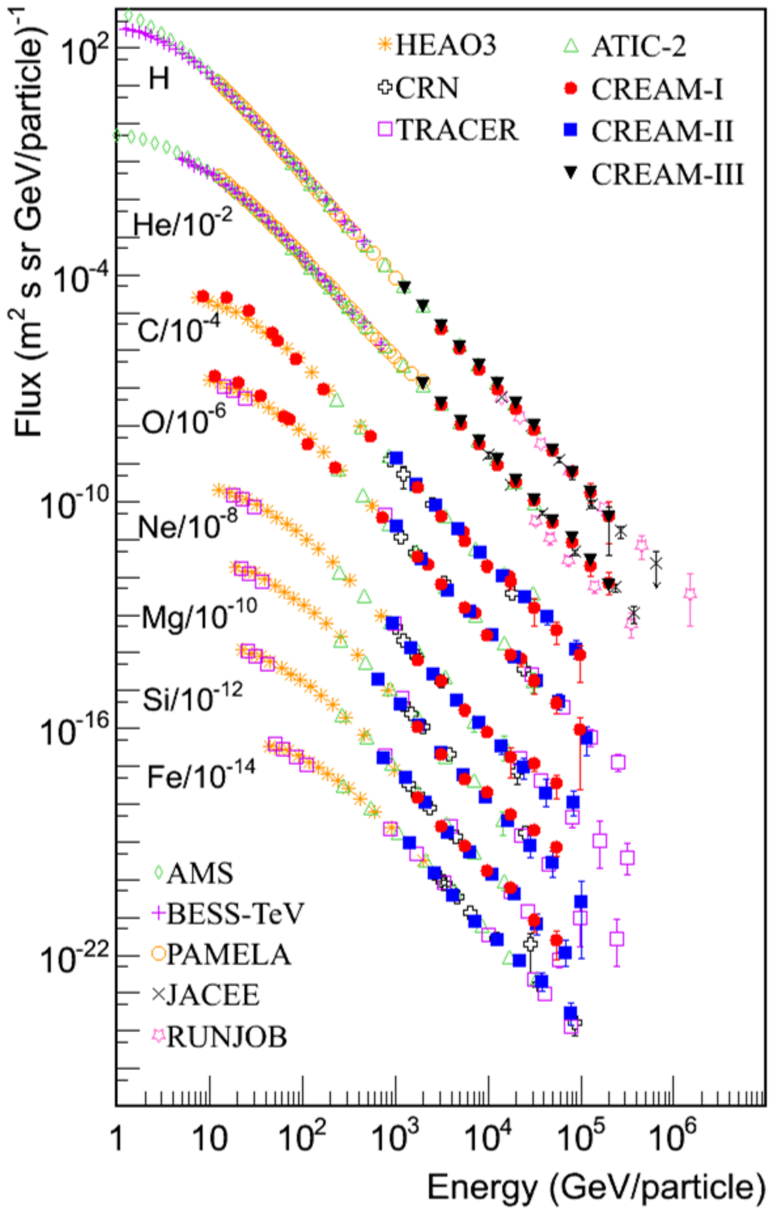
Distribution of cosmic-ray charge measured with the SCD. The individual elements are clearly identified with excellent charge resolution. The relative abundance in this plot has no physical significance

CREAM-III with lower energy threshold

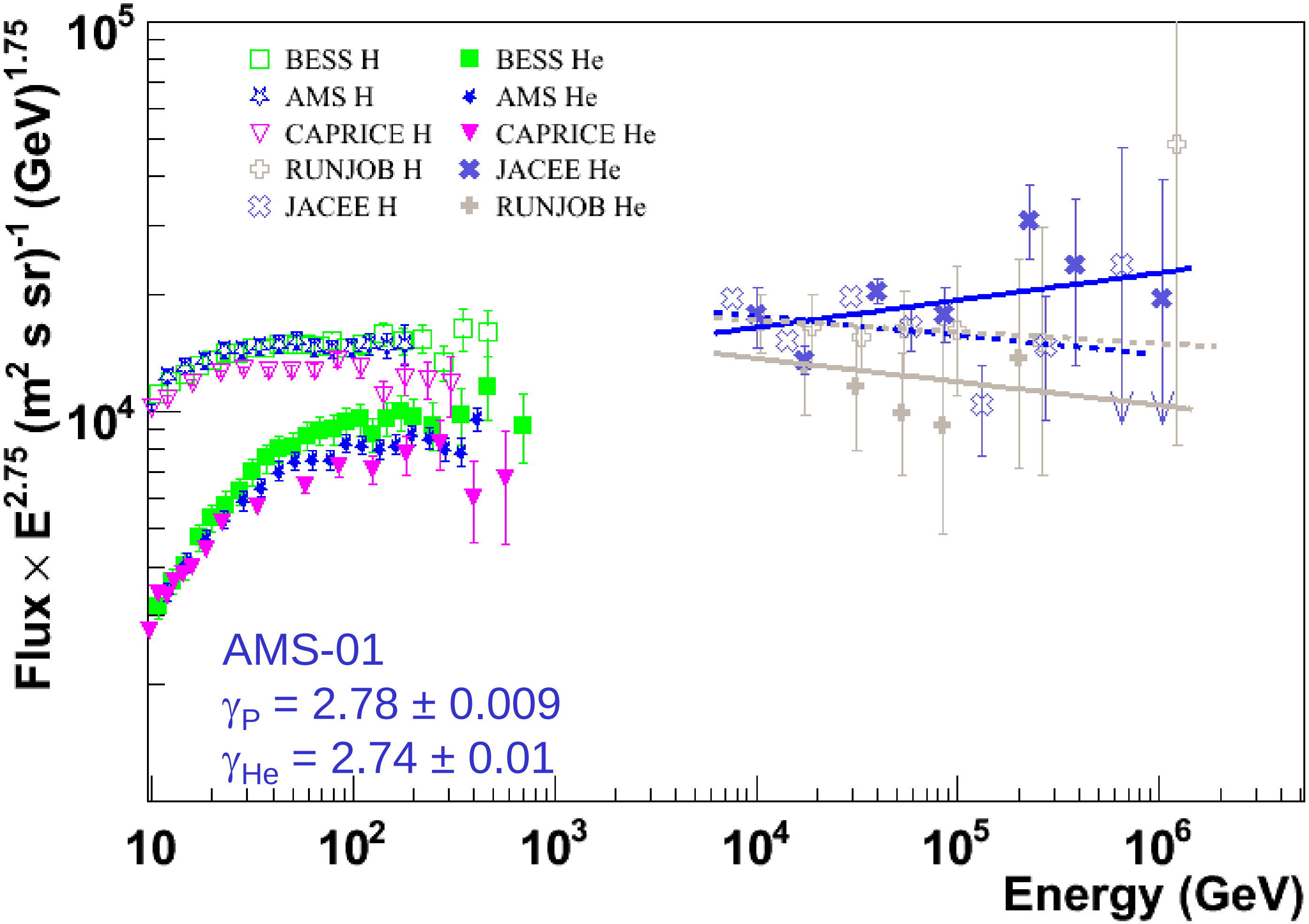
Yoon et al. (CREAM collaboration) OG1.1 1109, this conference

Improved charge resolution with dual SCD





P & He: prior to CREAM



$$I_j \propto E^{-\gamma}$$

JACEE

$\gamma_P = 2.80 \pm 0.04$

$\gamma_{He} = 2.68 {+0.04} {-0.06}$

RUNJOB

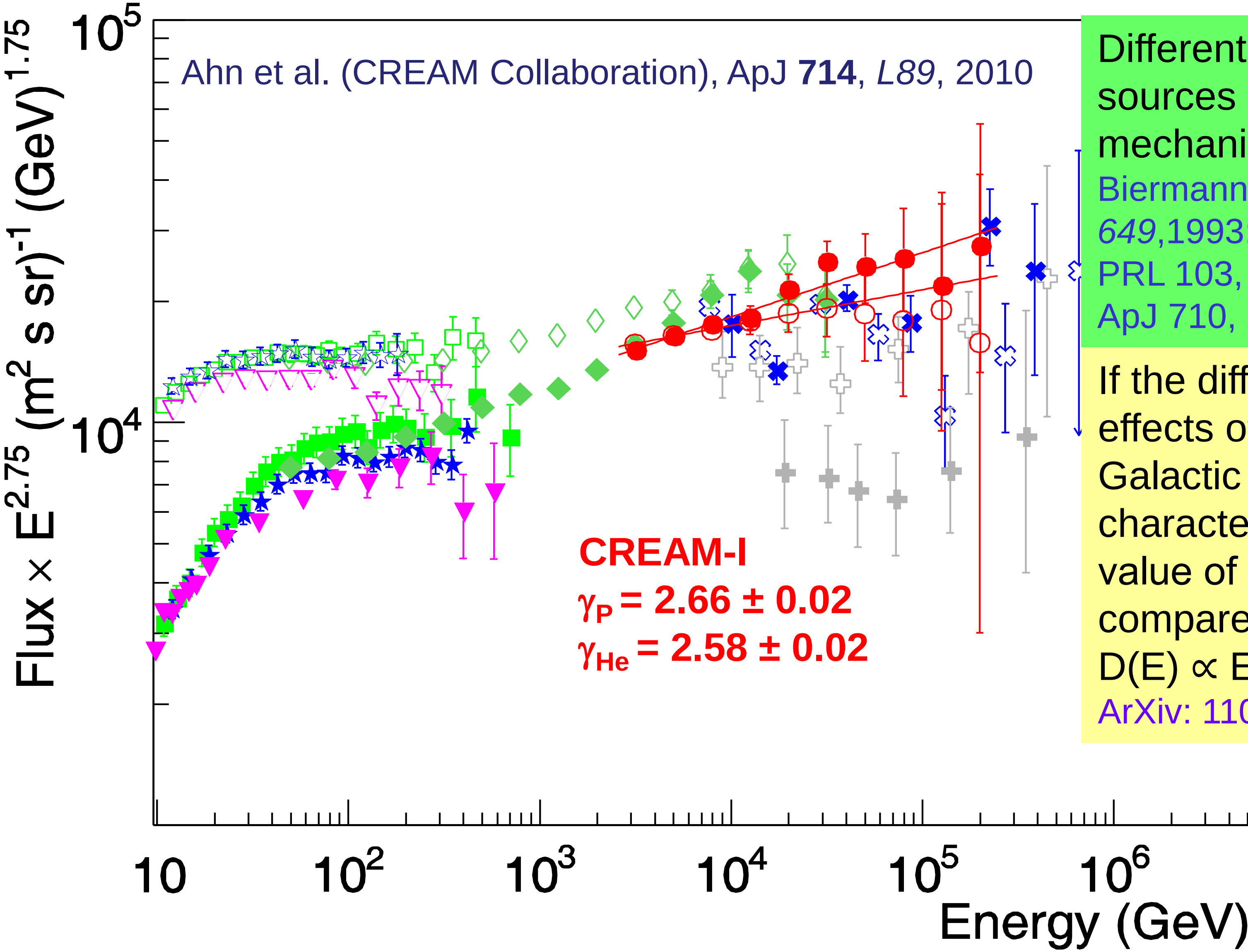
$\gamma_P = 2.78 \pm 0.05$

(2.74 ± 0.08)

$\gamma_{He} = 2.81 \pm 0.06$

(2.78 ± 0.2)

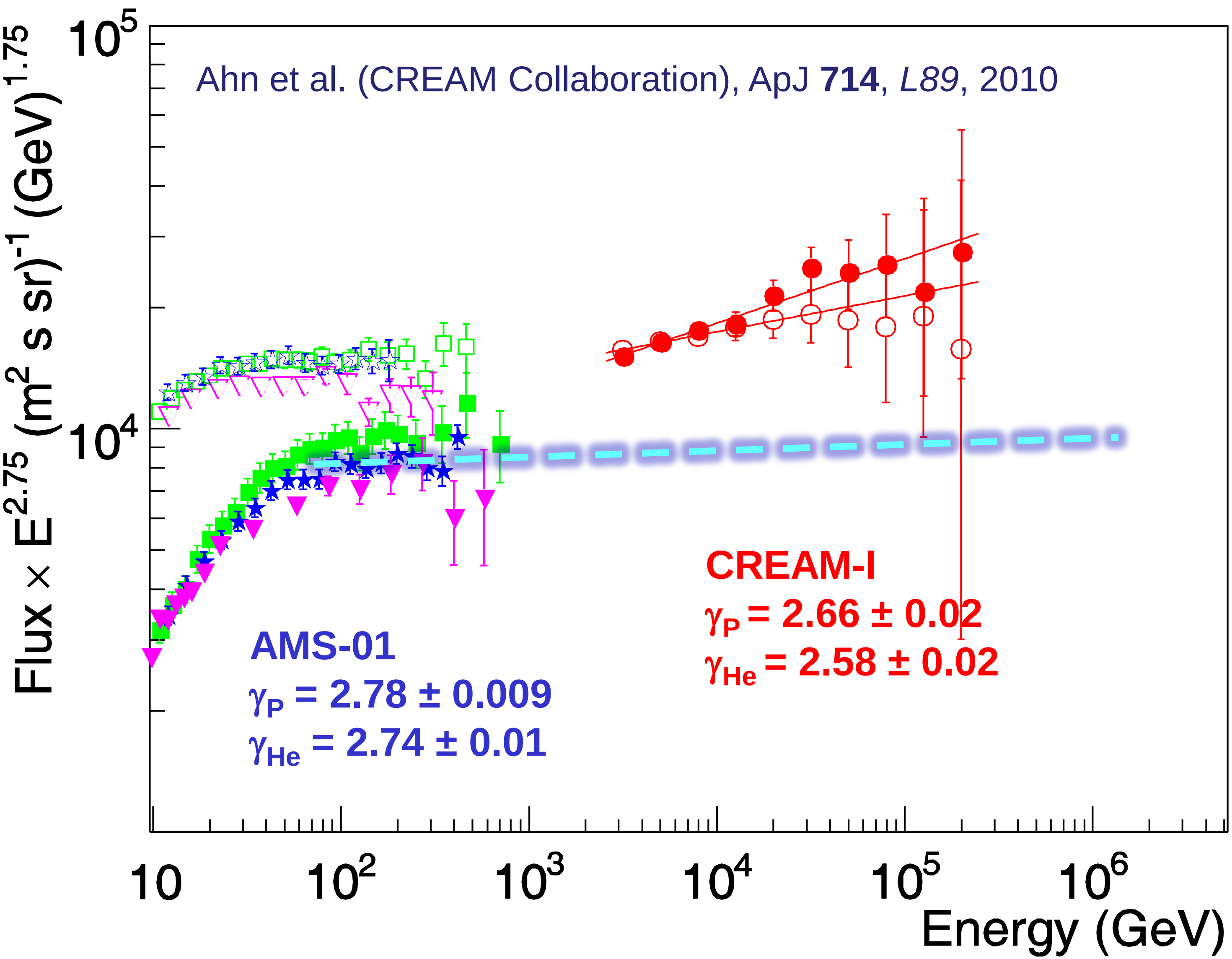
CREAM: p & He spectra are not the same



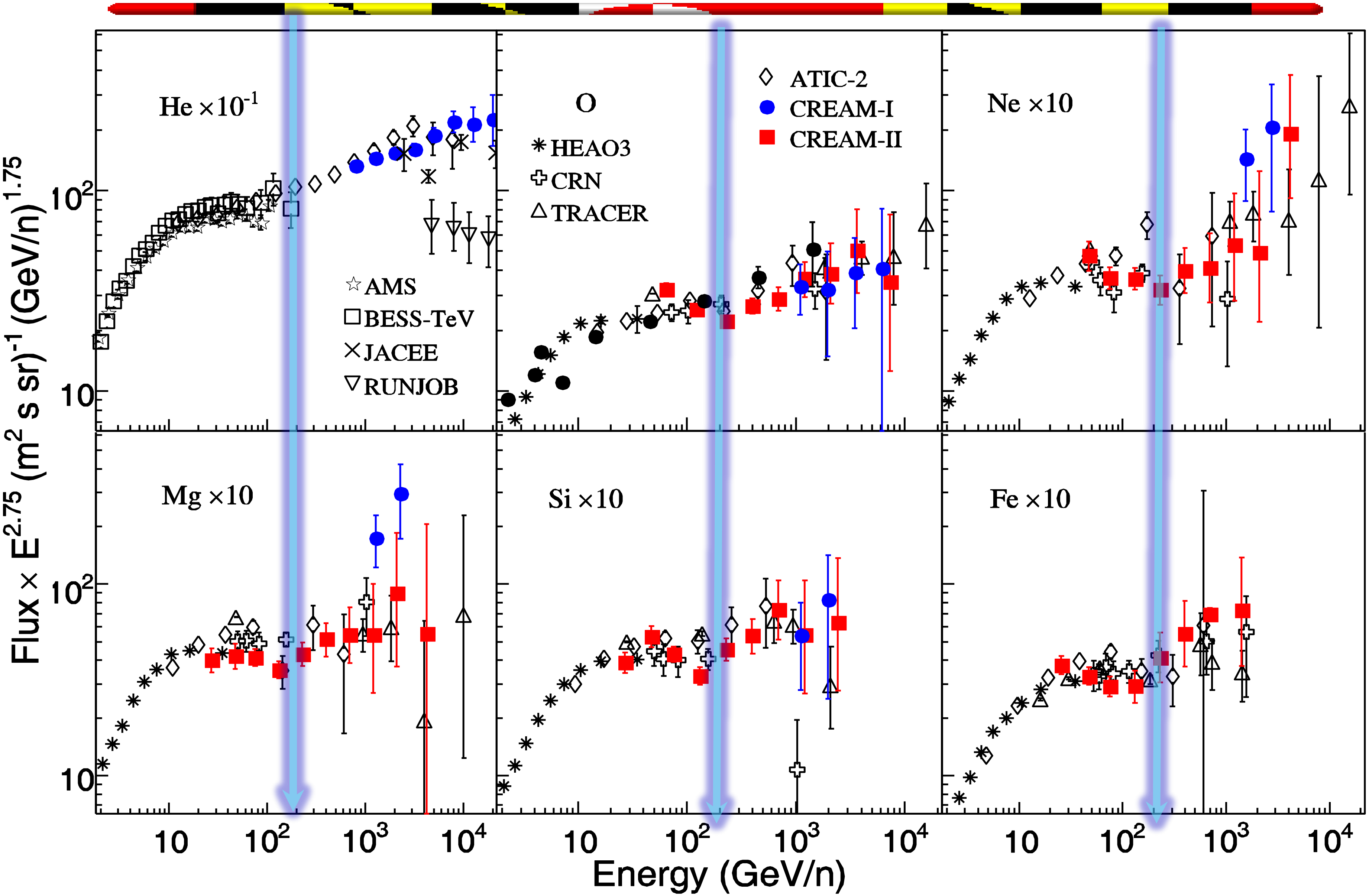
Different types of sources or acceleration mechanisms? (e.g., Biermann, *A&A* 271, *649*,1993; Biermann et al. PRL 103, *061101*, 2009; ApJ 710, *L53*, 2010)

If the difference is the effects of spallation, the Galactic diffusion is characterized by a low value of δ (1/3 compared to 0.6), where $D(E) \propto E^{\delta}$ (Blasi & Amato, ArXiv: 1105.4521)

TeV spectra are harder than spectra < 200 GeV/n

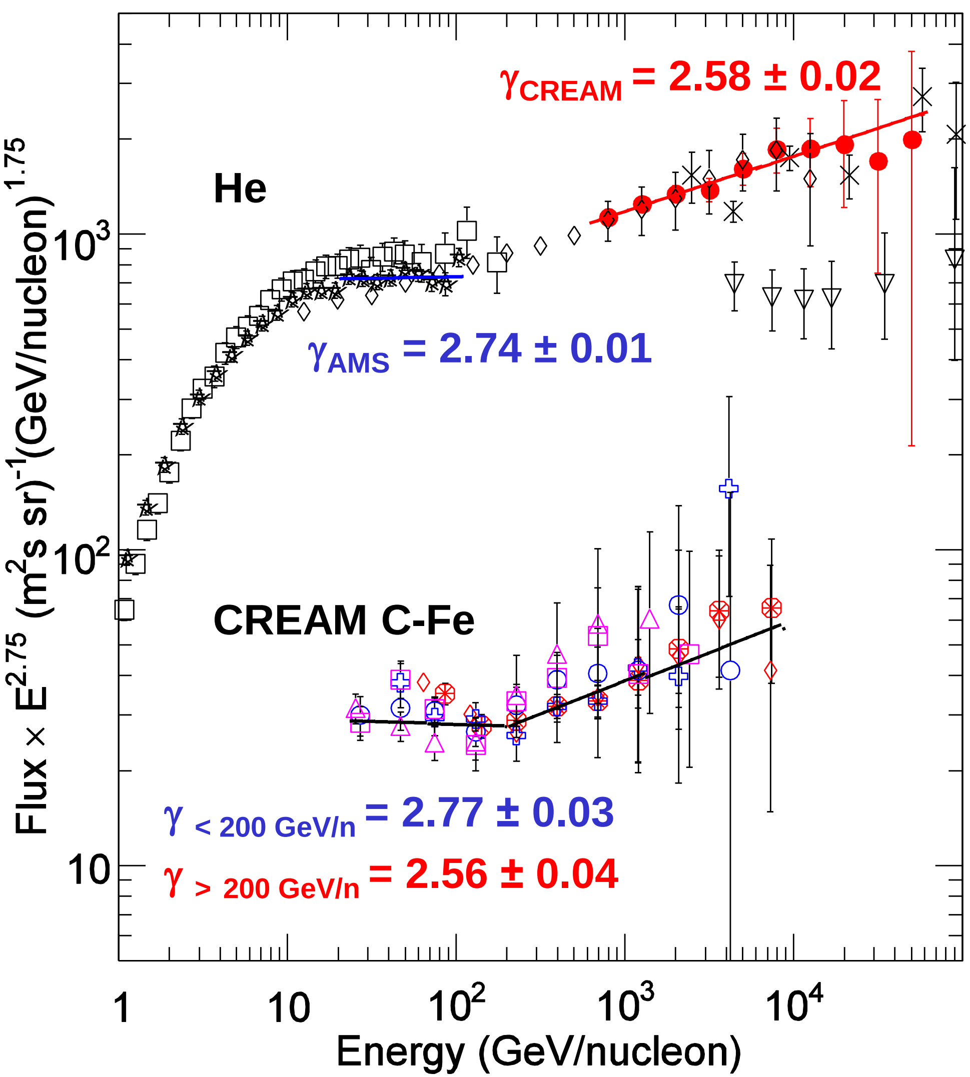


Discrepant hardening



Not a single power law

Ahn et al. (CREAM Collaboration) ApJ **714**, *L89*, 2010



- Evidence for concavity due to cosmic ray interactions with the shock? (Ellison et al. *ApJ* **540**, 292,2000)
- A local source of hadrons?
- Effect of a non-uniform distribution of sources? (Ptuskin et al., ApJ. **718**, *31-36*, 2010; Zatsepin & Sokolskaya, A&A 458, 1, 2006. Erlykin & Wolfendale *A&A* **350**, L1,1999)
- Effect of distributed acceleration by multiple remnants (Medina-Tanco & Opher *ApJ* 411, 690, 1993)
- Superbubbles? (Butt & Bykov, *ApJ* **677**, L21, 2008; Ohira & Ioka, ApJL. 729, L13-L17, 2011)
- Related to 10 TeV anisotropy reported by Milagro etc.? (Abdo et al. *PRL*, **101**, 221101, 2008)

CREAM-III confirms hard spectra

Yoon et al. (CREAM collaboration) OG1.1 1109, this conference

The hard spectra do not continue > ~20 TeV

Unpublished Data
Not Shown

A spectral roll off at ~20 TeV?

at an order of magnitude below the expected cut-off for SNR shock acceleration

Not inconsistent with CREAM-I

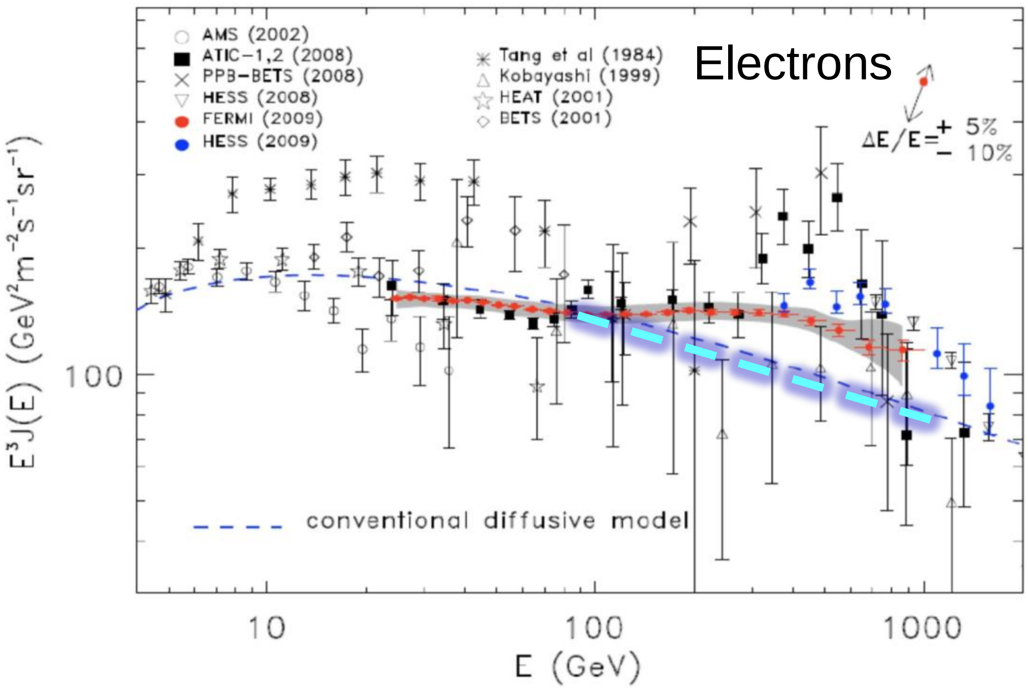
Ahn et al. (CREAM Collaboration), ApJ **714**, *L89*, 2010

Unpublished Data
Not Shown

A local source?

Unpublished Data
Not Shown

Is a single mechanism/source responsible?



Unpublished Data
Not Shown

- Whatever the explanation, nuclear spectra must be accounted for in explanations of the electron anomaly and cosmic-ray "knee."
- An evidence of hadron sources within distances comparable to the range of electrons travelling through the ISM?

TeV p/He ratio is ~1/2 of low energy measurements

Yoon et al. (CREAM Collaboration), ApJ., **728**, *122*, 2011.

Unpublished Data
Not Shown

Need to increase statistics!

Cosmic Ray Propagation

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

Steady State Transport Eq.:

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

The momentum distribution function f is normalized as $N = \int dp\, p^2 f$

where N is CR number density, D: spatial diffusion coefficient, σ: cross section…

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

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

Escape length Xe

Reacceleration parameter α

E. S. Seo and V. S. Ptuskin, Astrophys. J., **431**, *705-714*, 1994.

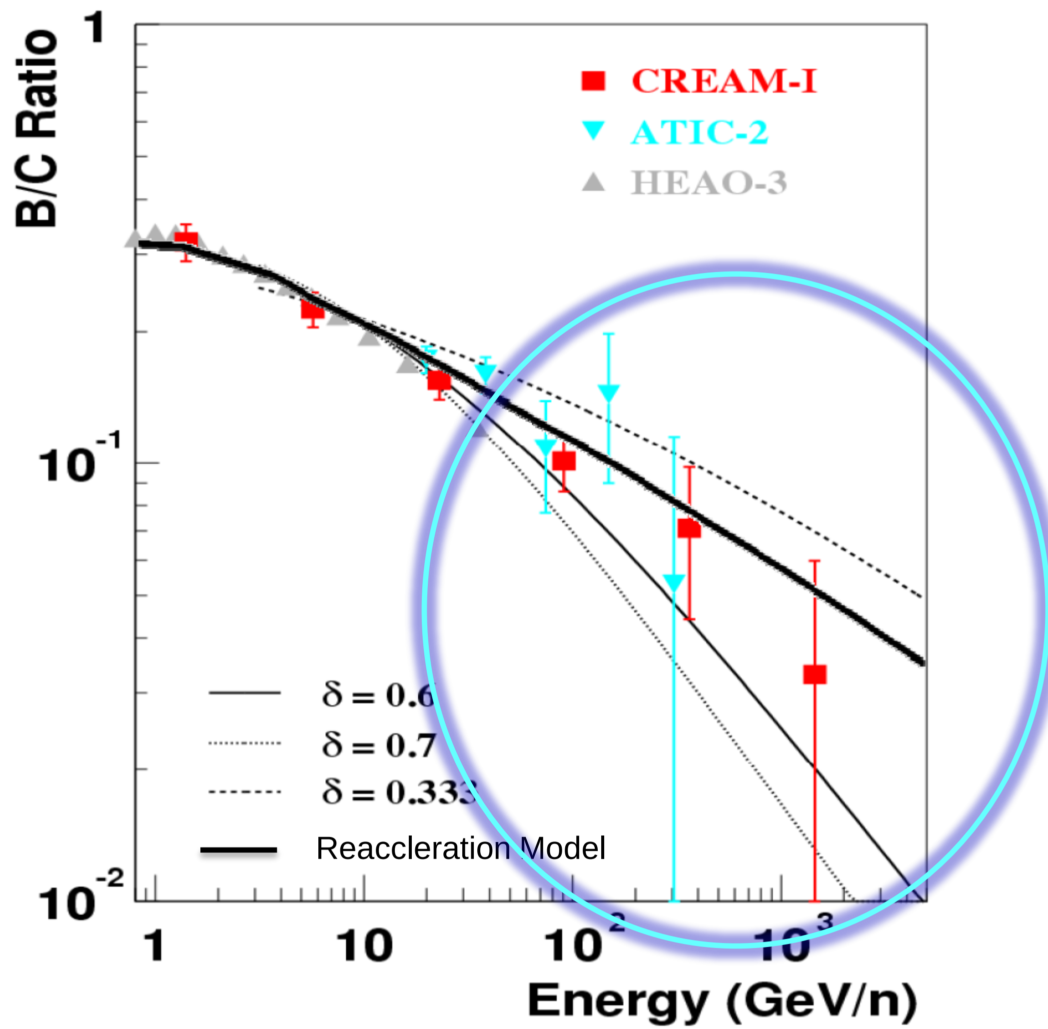
What is the history of cosmic rays in the Galaxy?

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

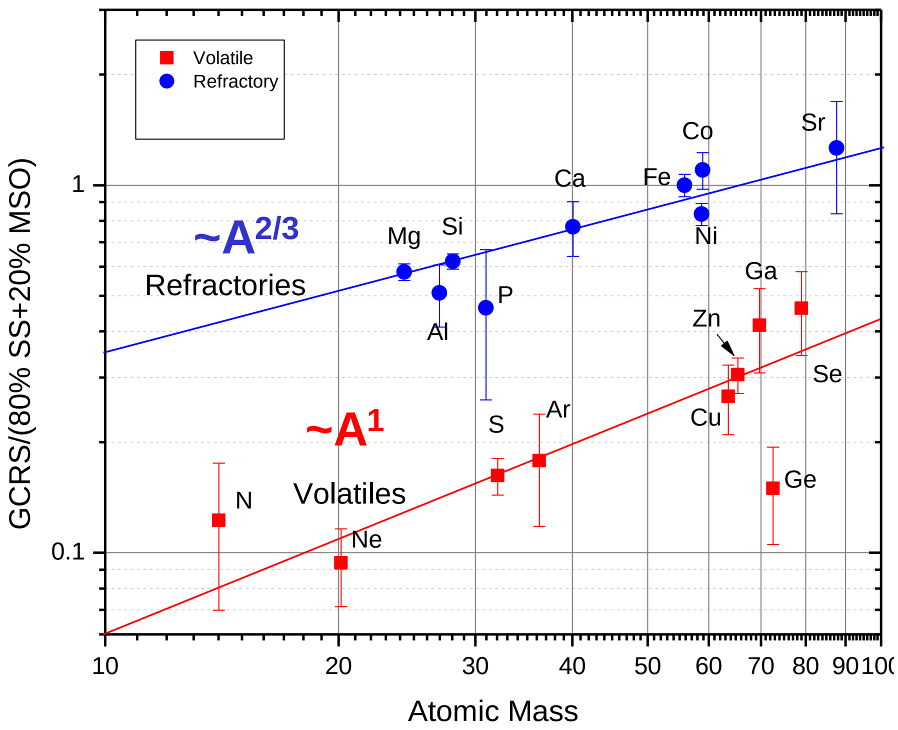
- First B/C ratio at these high energies to distinguish among the propagation models

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

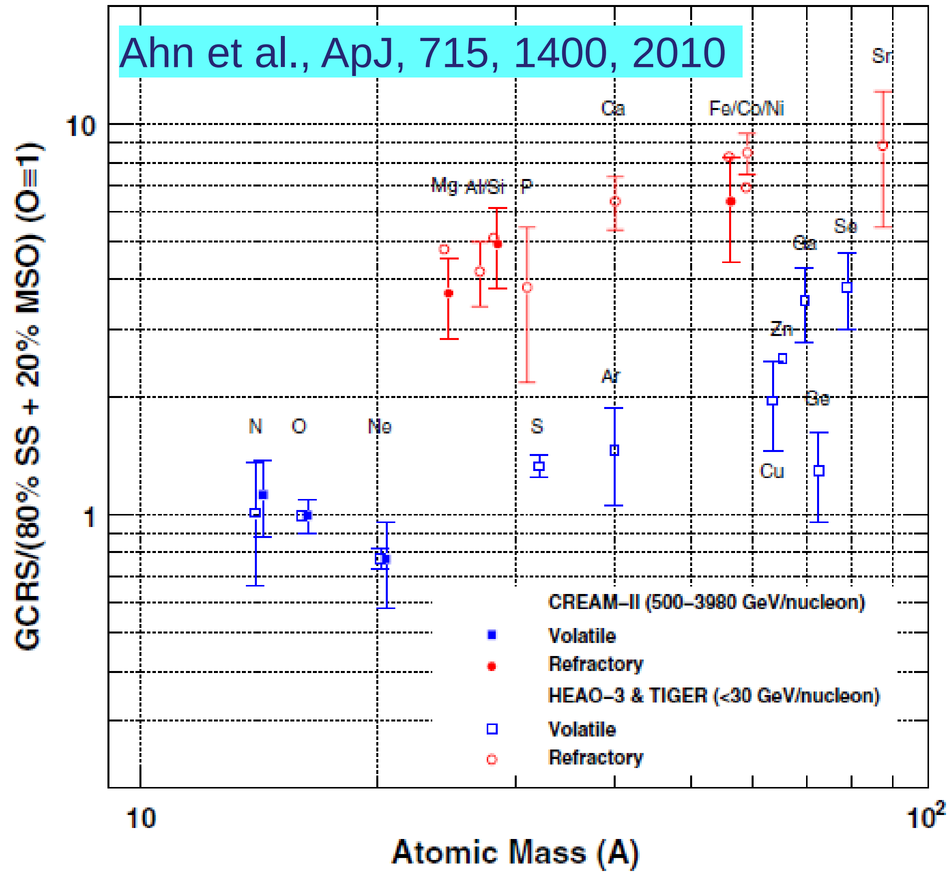


Origin of Cosmic Rays

Rauch et al., ApJ 697, 2083, 2009

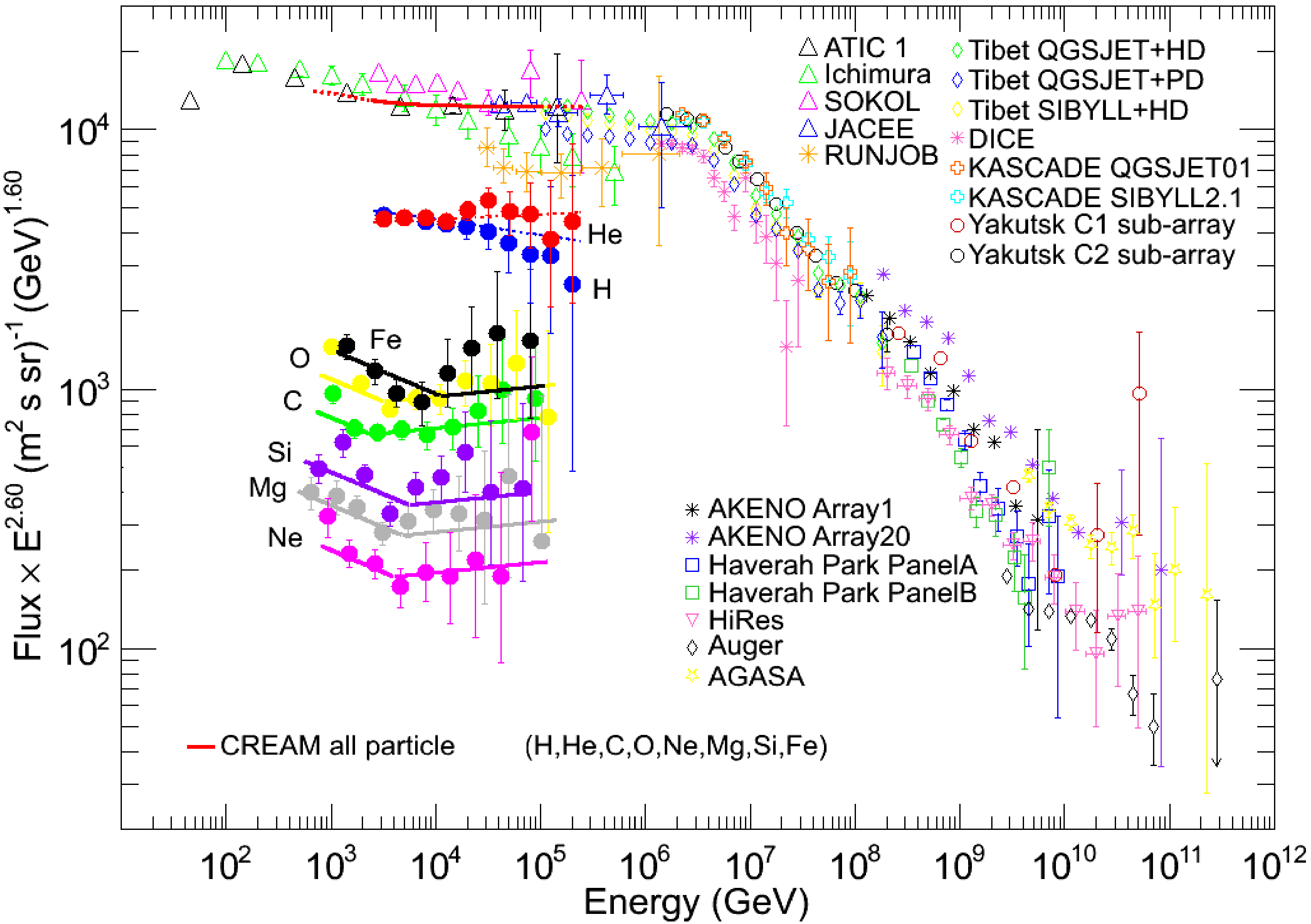


Ahn et al., ApJ, 715, 1400, 2010



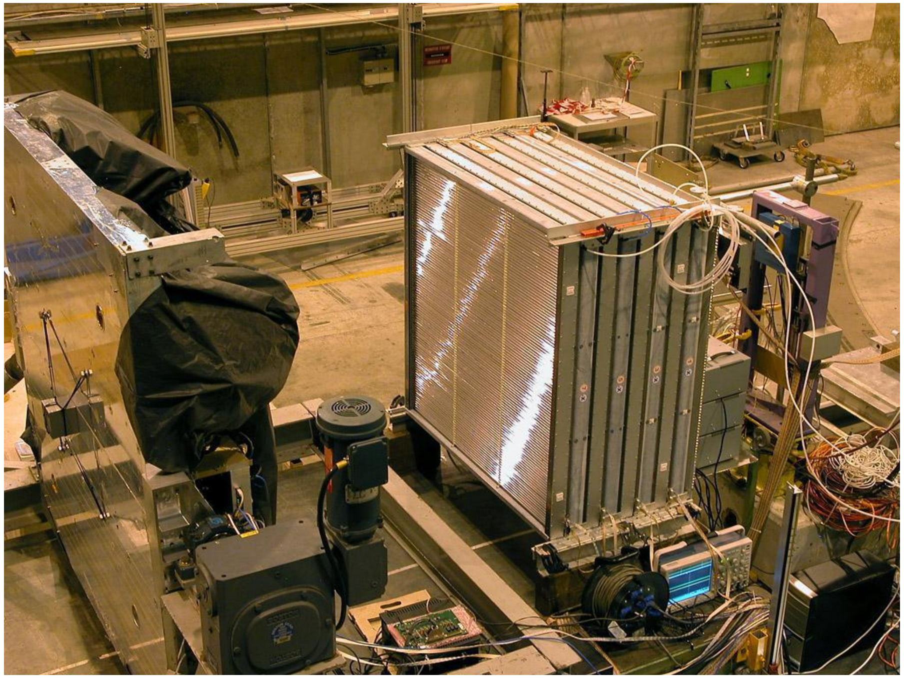
- Elements present in interstellar grains are accelerated preferentially compared with those found in interstellar gas
- Data are consistent with the idea of CR origin in OB associations

All Particle Spectrum



CREAM-VII Integration & Test

Han et al. OG1.5 1106 & Malinin et al. OG1.5 1223, this conference



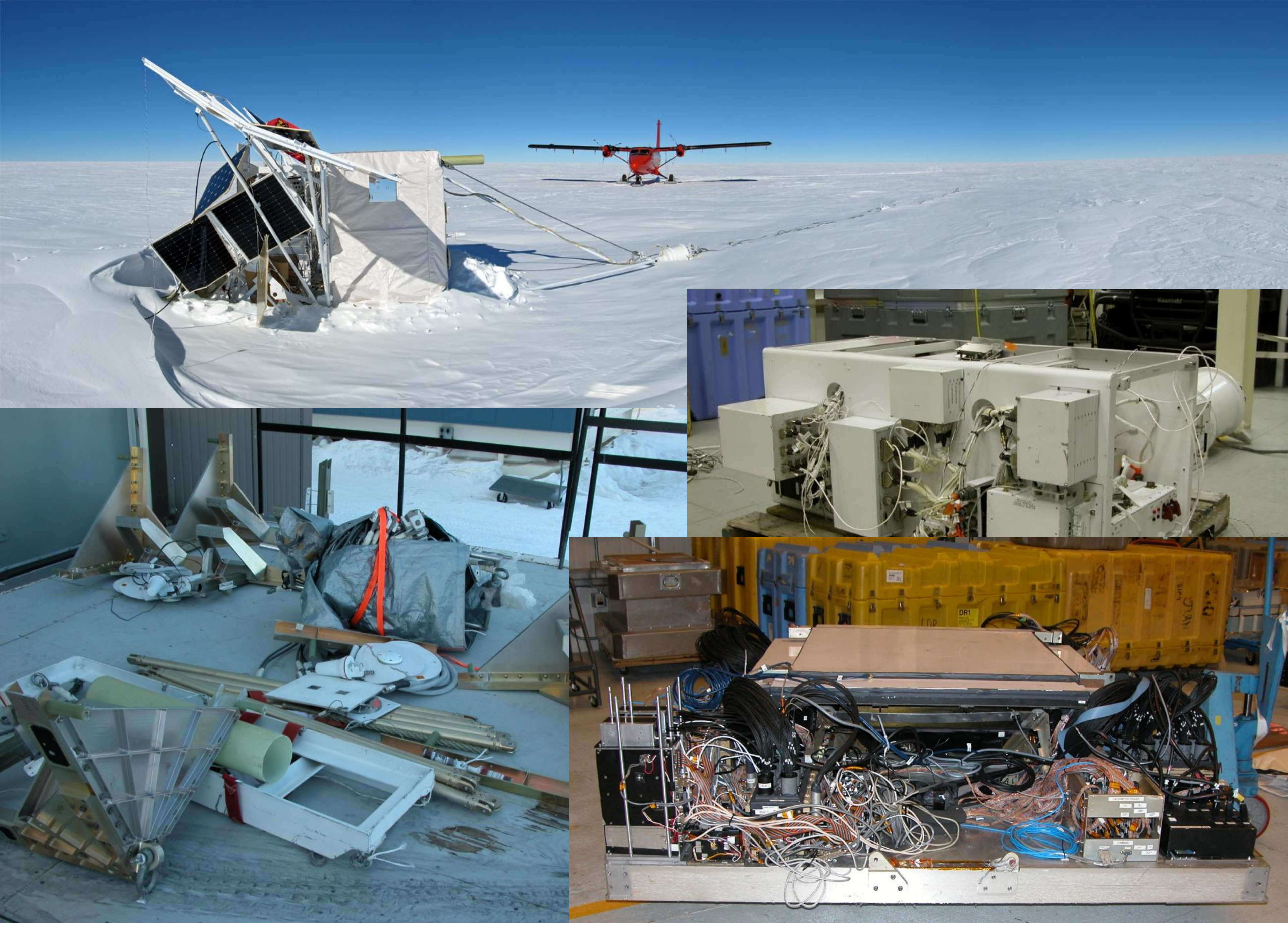
Both recovered CREAM-V calorimeter and new TRD-II were calibrated at CERN SPS H2 beam line October 2010

CREAM-VII is currently being integrated at UMD for flight anticipated in December 2012

CREAM-VI Recovery

CREAM Payload
76° 56.56' S
06° 10.09' W

Altitude 7,787 ft



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