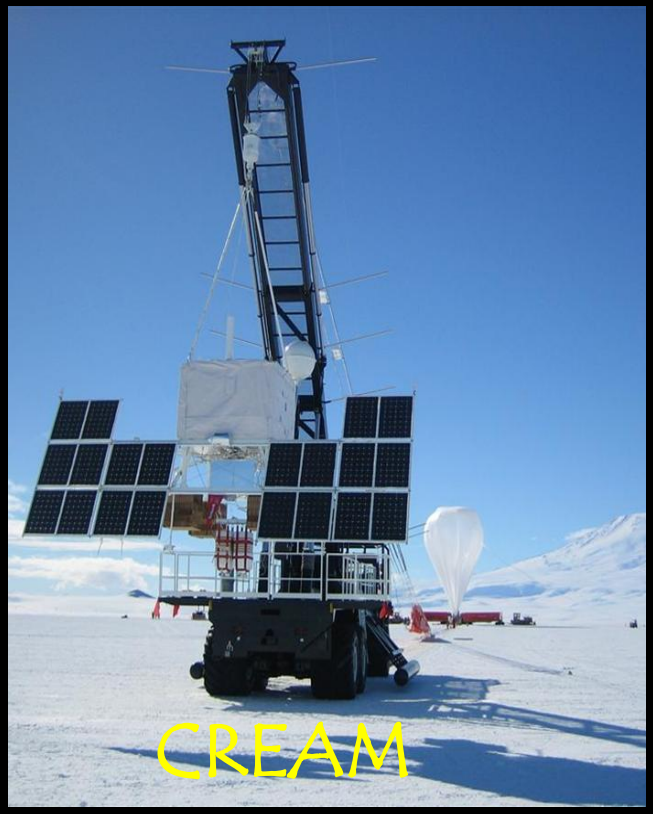
TeV Particle Astrophysics 2013, Irvine, CA, August 26-29, 2013

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



Eun-Suk Seo
Inst. for Phys. Sci. & Tech. and
Department of Physics
University of Maryland

ISS-CREAM Collaboration

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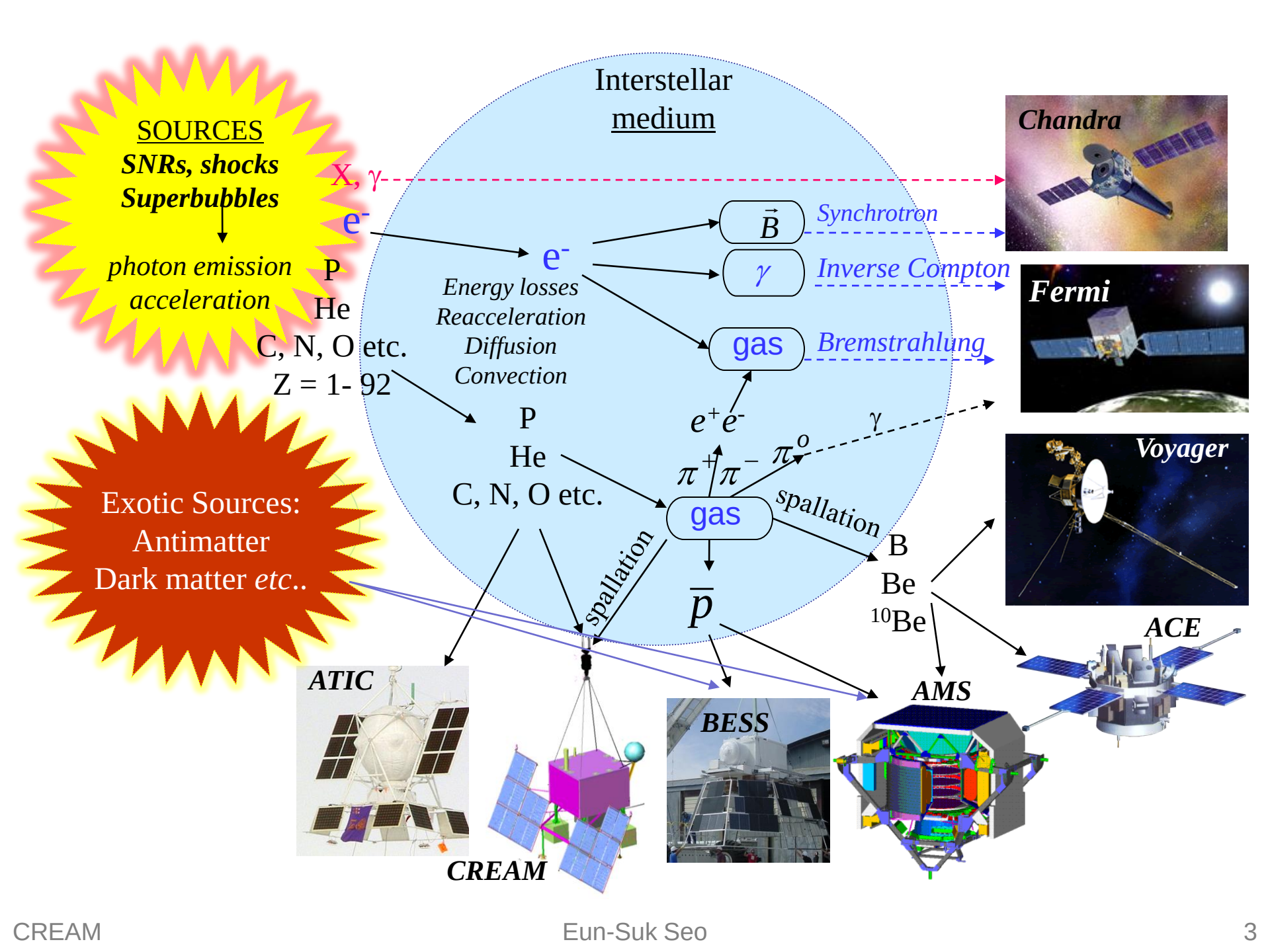
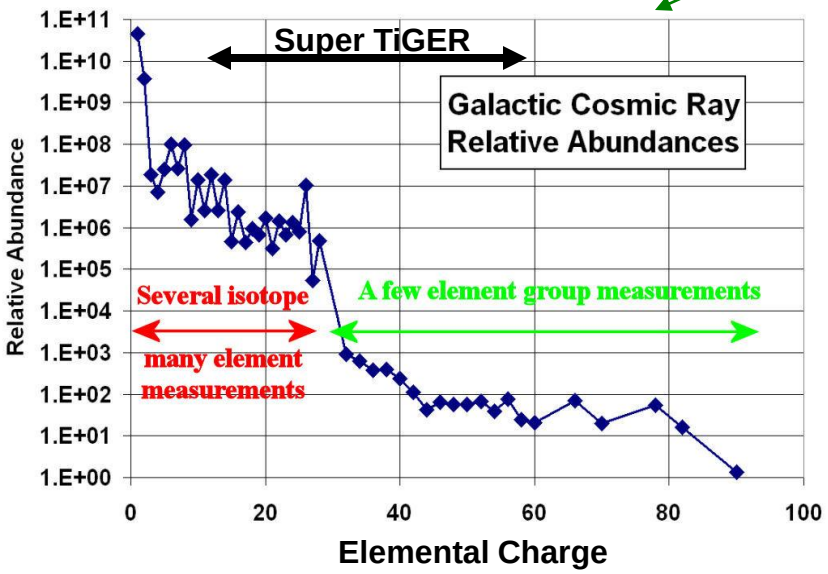
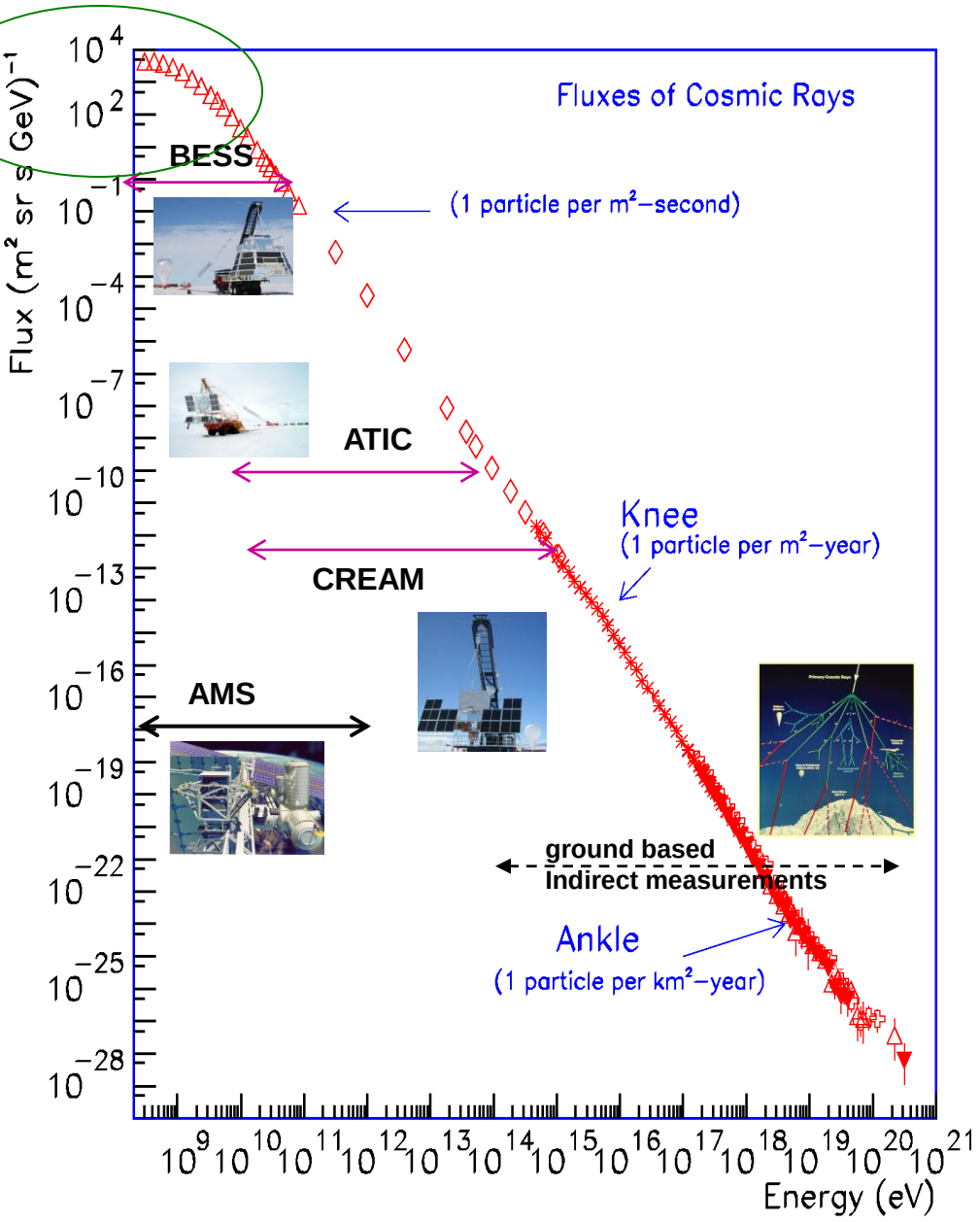

SOURCES
SNRs, shocks
Superbubbles
photon emission
acceleration
Exotic Sources:
Antimatter
Dark matter etc..
Interstellar
medium
X, γ
e-
P
He
C, N, O etc.
Z = 1- 92
e-
Energy losses
Reacceleration
Diffusion
Convection
B
γ
gas
Synchrotron
Inverse Compton
Bremstrahlung
P
He
C, N, O etc.
e+e-
π+ π- πo
γ
gas
spallation
spallation
B
Be
10Be
p̄
Chandra
Fermi
Voyager
ACE
AMS
BESS
ATIC
CREAM

How do cosmic accelerators work?



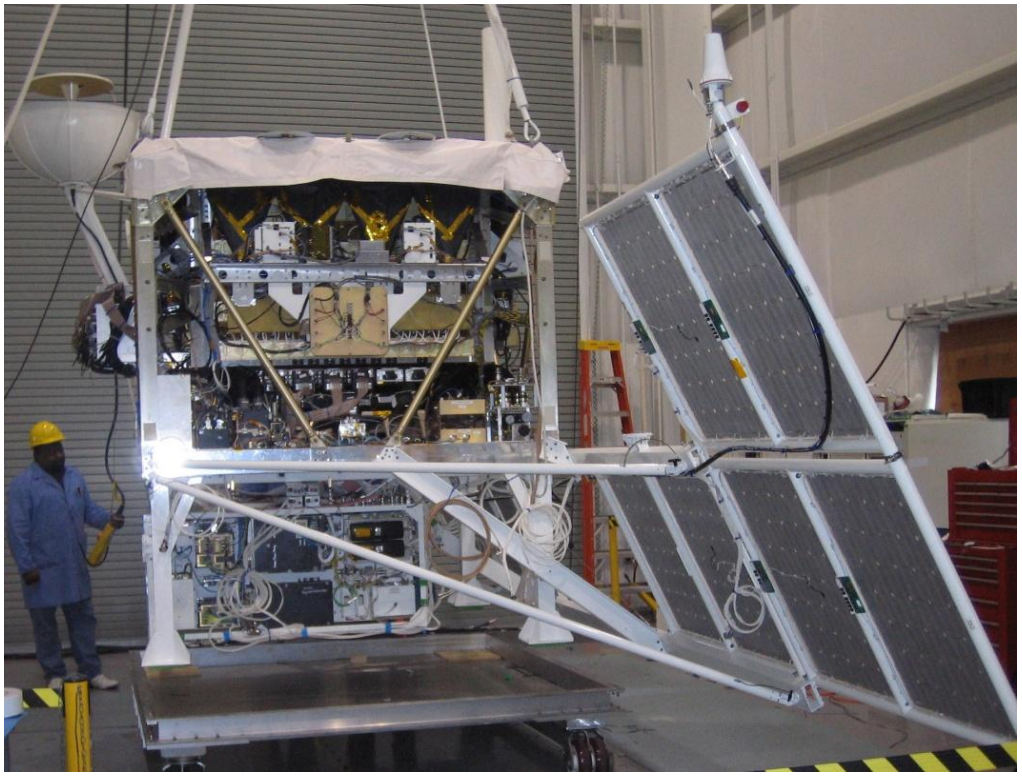


- Relative abundances range over 11 orders of magnitude
- Detailed composition limited to less than ~ 10 GeV/nucleon

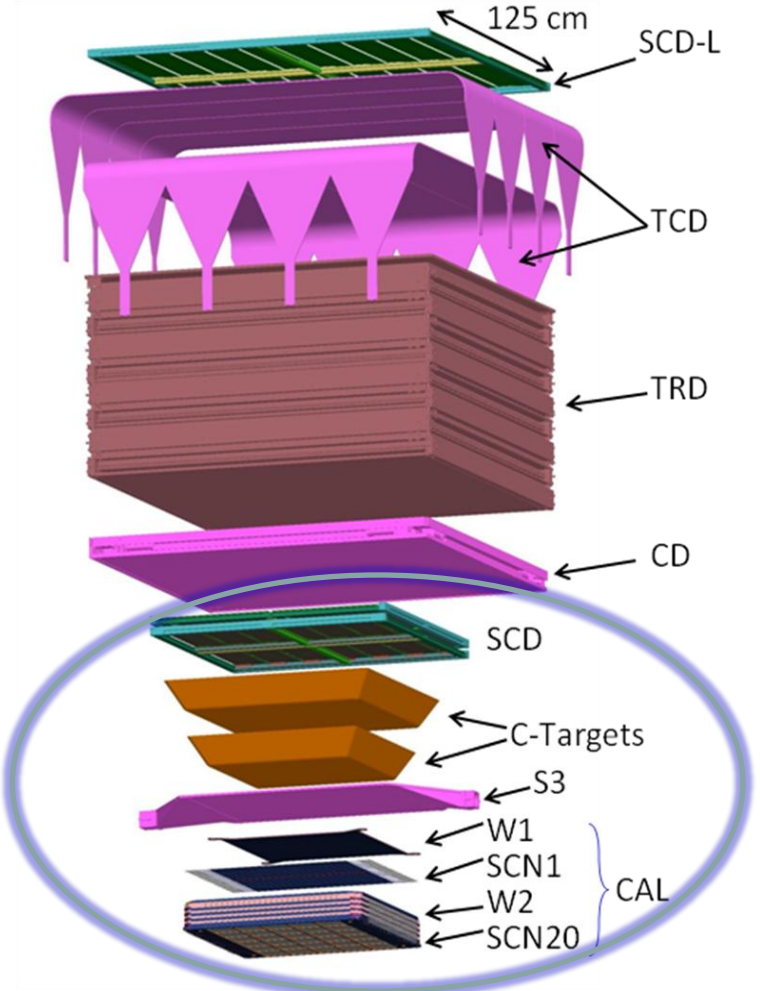
Cosmic Ray Energetics And Mass (CREAM)

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



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

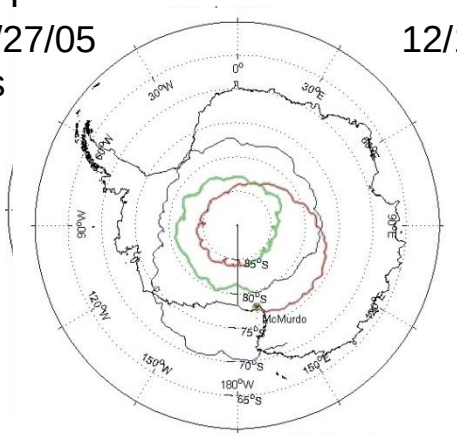


CREAM Balloon Flight Heritage

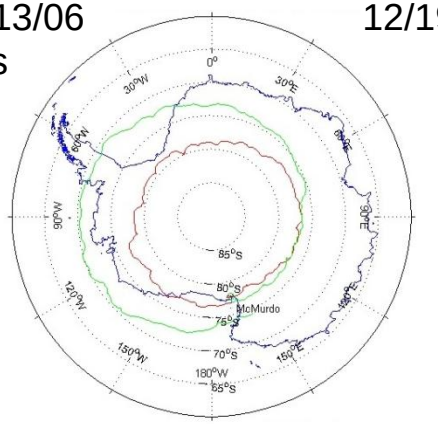
The longest known flight time for a single balloon project

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

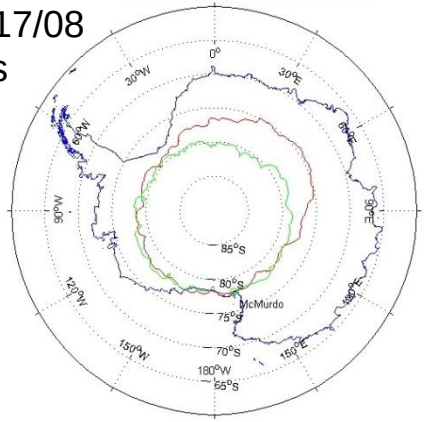
CREAM-I
12/16/04 – 1/27/05
42 days



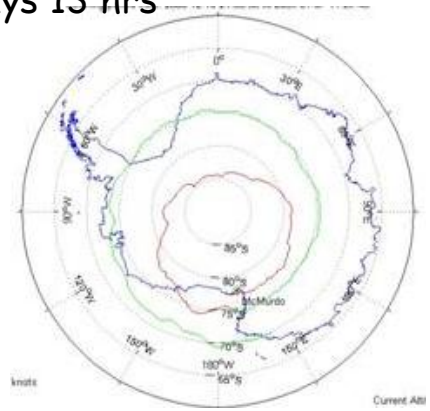
CREAM-II
12/16/05-1/13/06
28 days



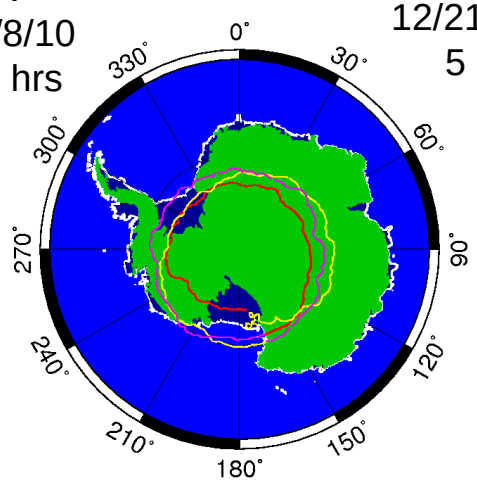
CREAM-III
12/19/07-1/17/08
29 days



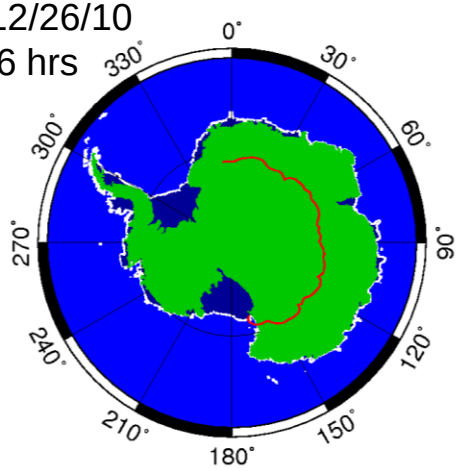
CREAM-IV
12/19/08 – 1/7/09
19 days 13 hrs



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



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



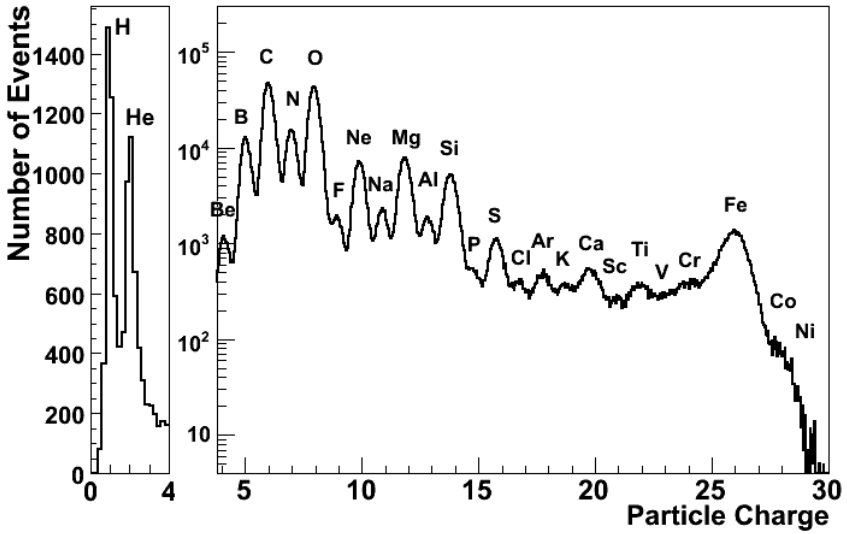
Recovery, Refurbishment and Re-flight

The team with experience

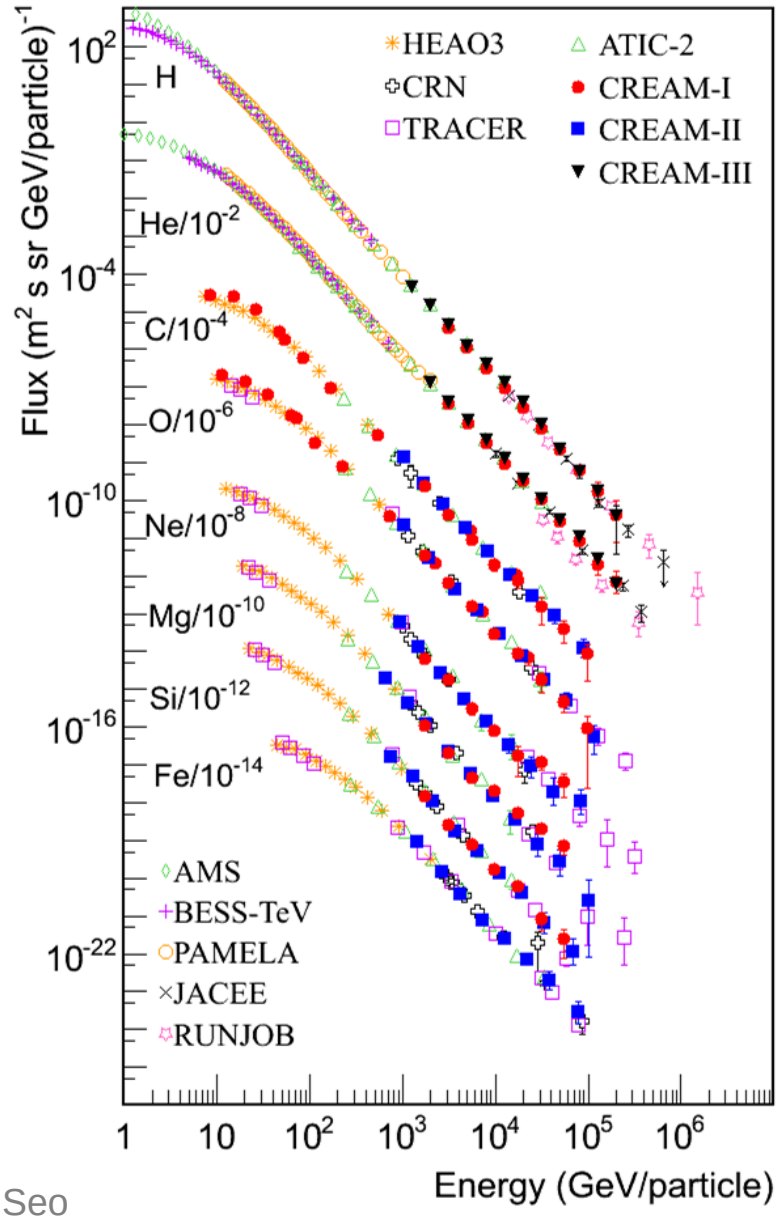
Elemental Spectra over 4 decades in energy

Ahn et al., ApJ **715**, *1400*, 2010; Ahn et al. ApJ **707**, *593*, 2009

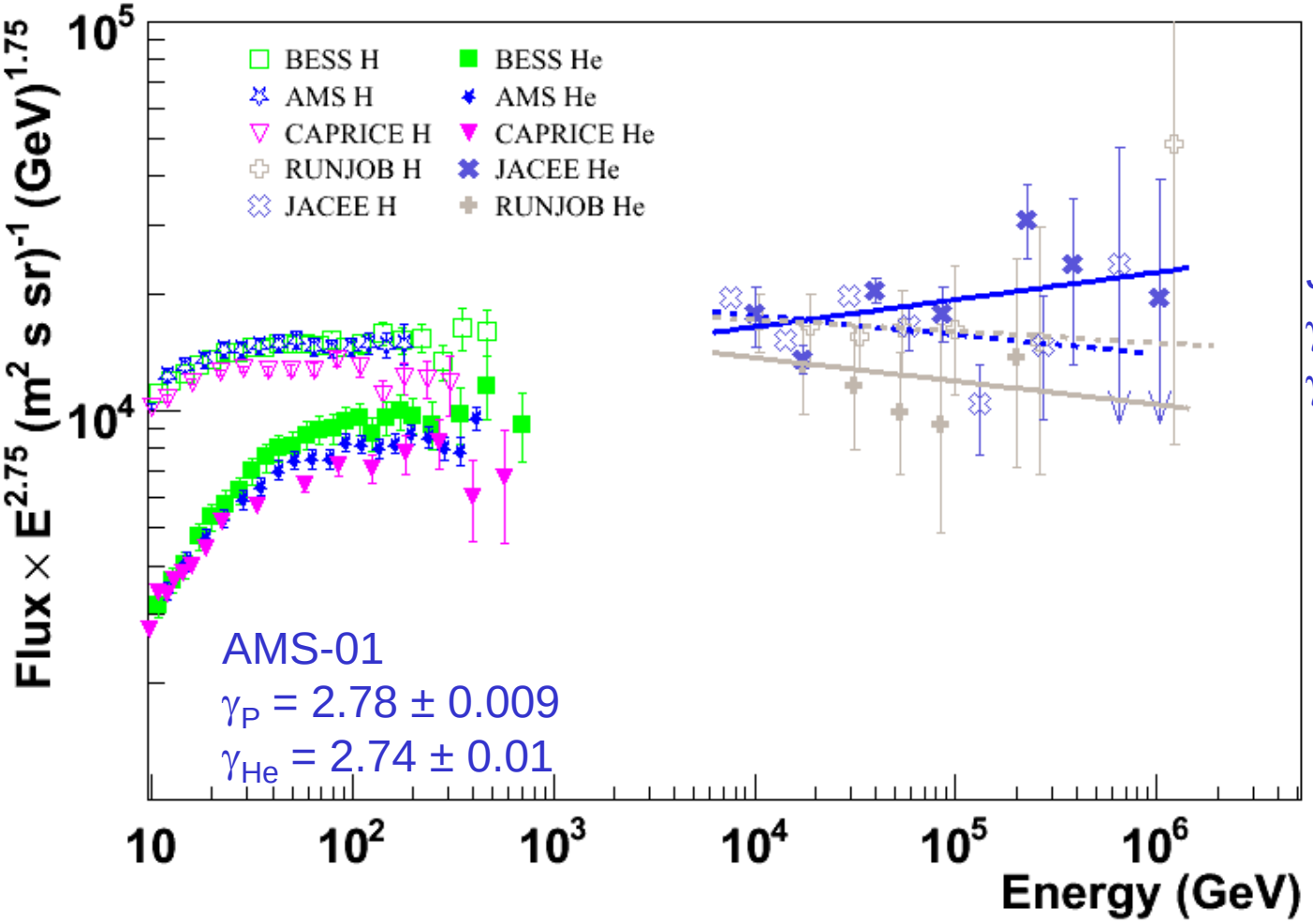
Excellent charge resolution from SCD



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



P & He: prior to CREAM

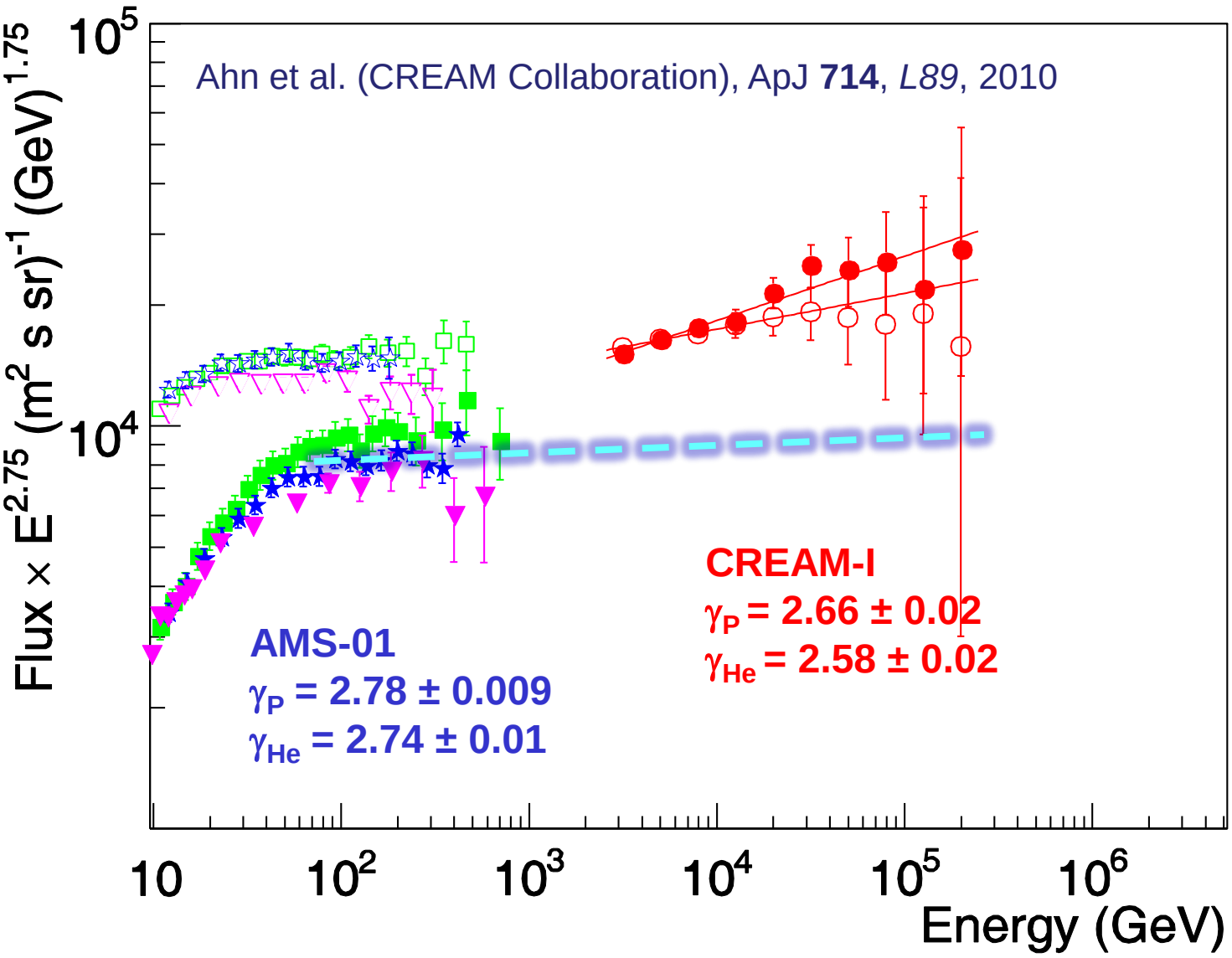


$$I_j \propto E^{-\gamma}$$

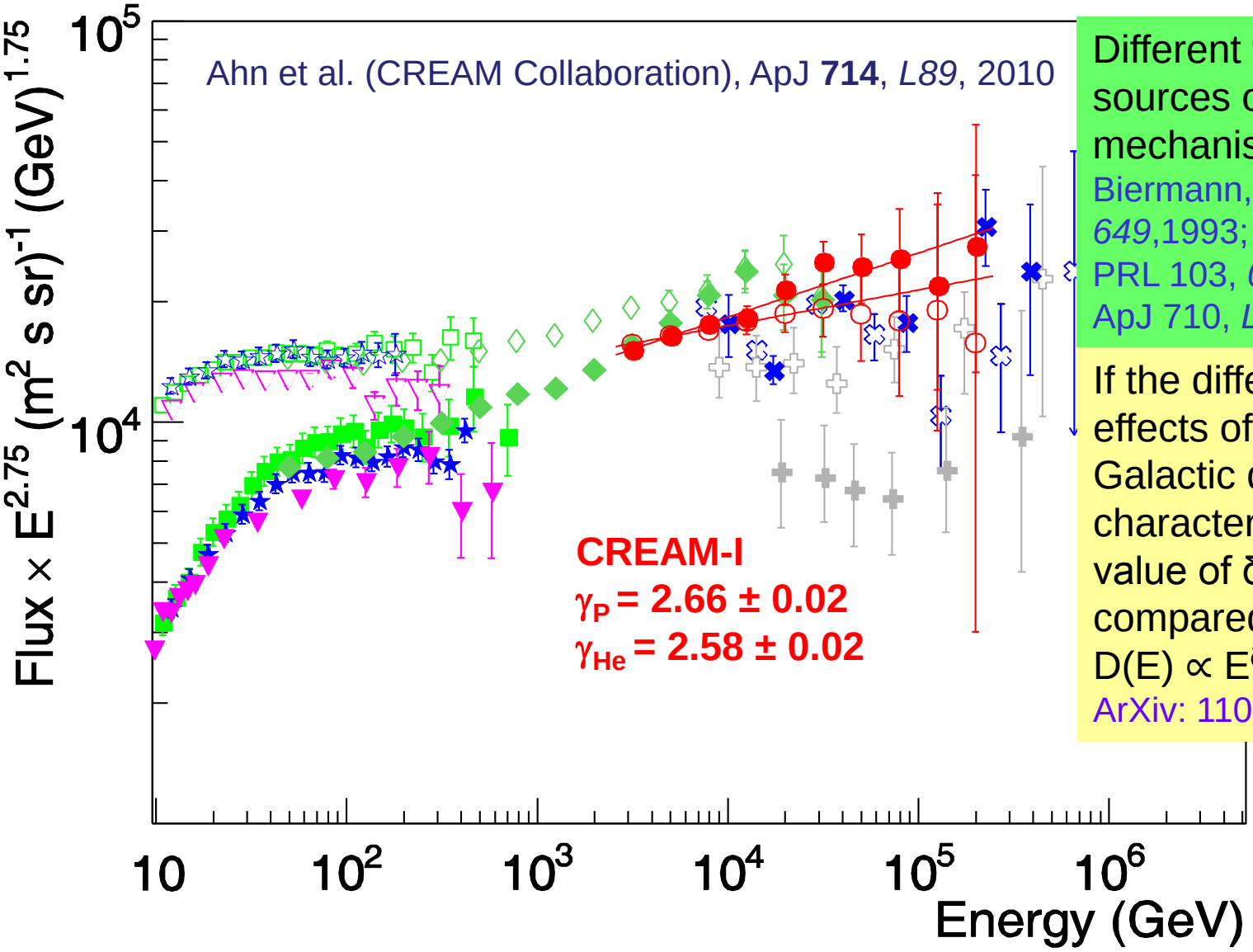
JACEE
$\gamma_P = 2.80 \pm 0.04$
$\gamma_{He} = 2.68^{+0.04}_{-0.06}$

RUNJOB
$\gamma_P = 2.78 \pm 0.05$ (2.74 ± 0.08)
$\gamma_{He} = 2.81 \pm 0.06$ (2.78 ± 0.2)

CREAM spectra harder than prior lower energy experiments



CREAM: He spectrum is harder than p spectrum

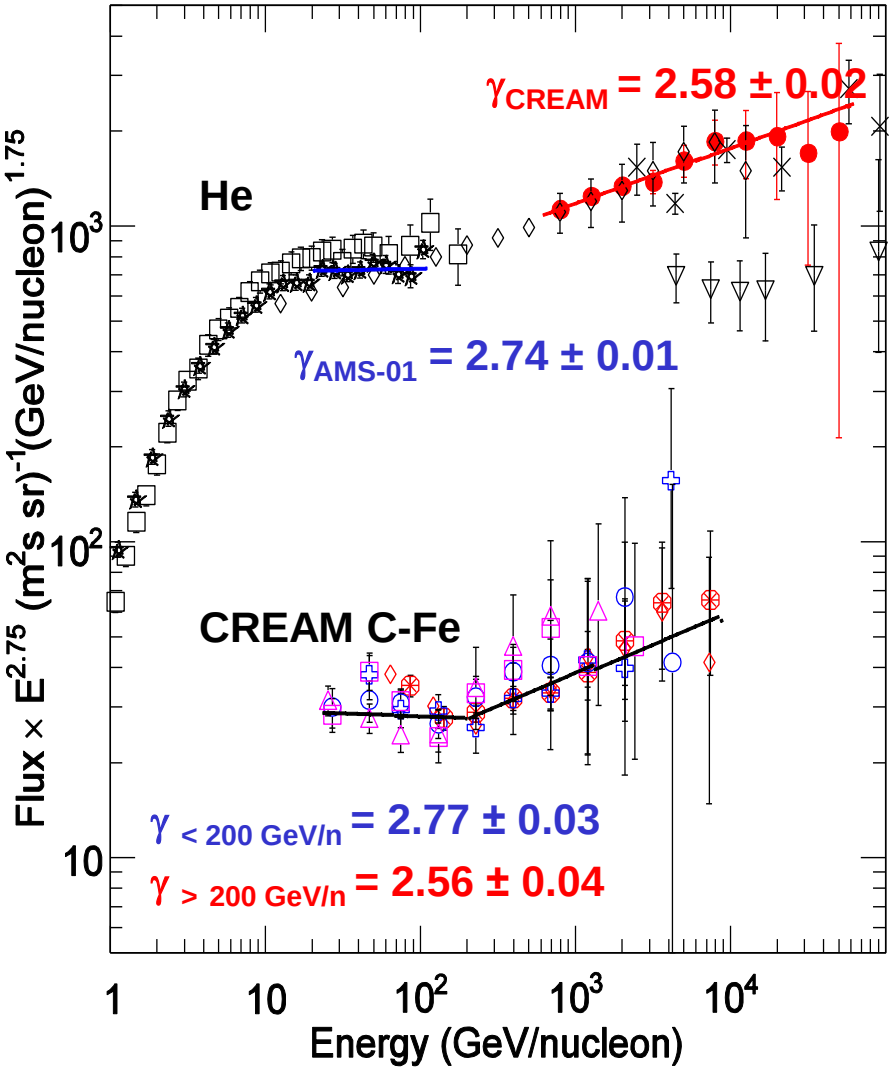


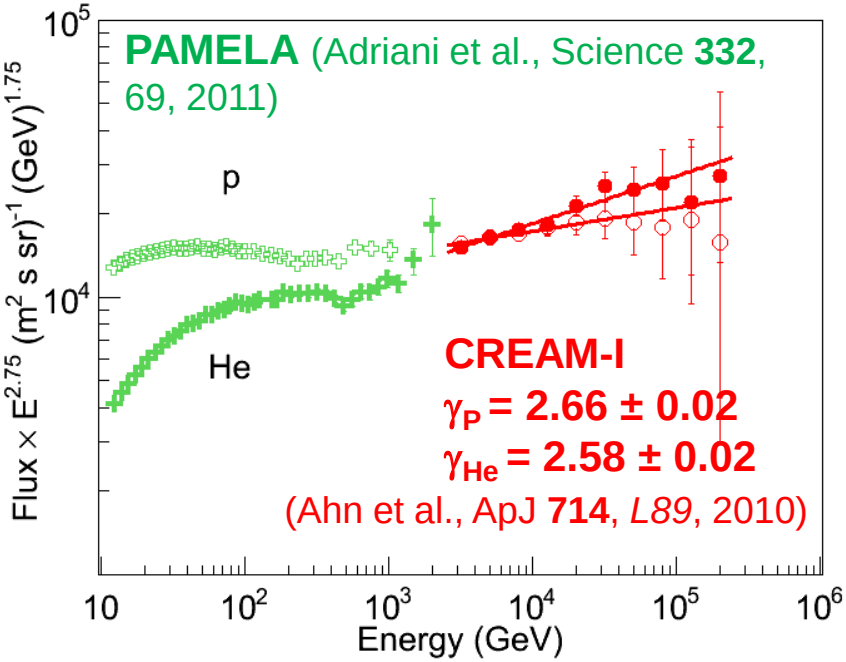
Different types of sources or acceleration mechanisms? (e.g., Biermann, *A&A* 271, *649*,1993; Biermann et al. PRL 103, *061101*, 2009; ApJ 710, *L53*, 2010)

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)

Heavy nuclei spectra look like He

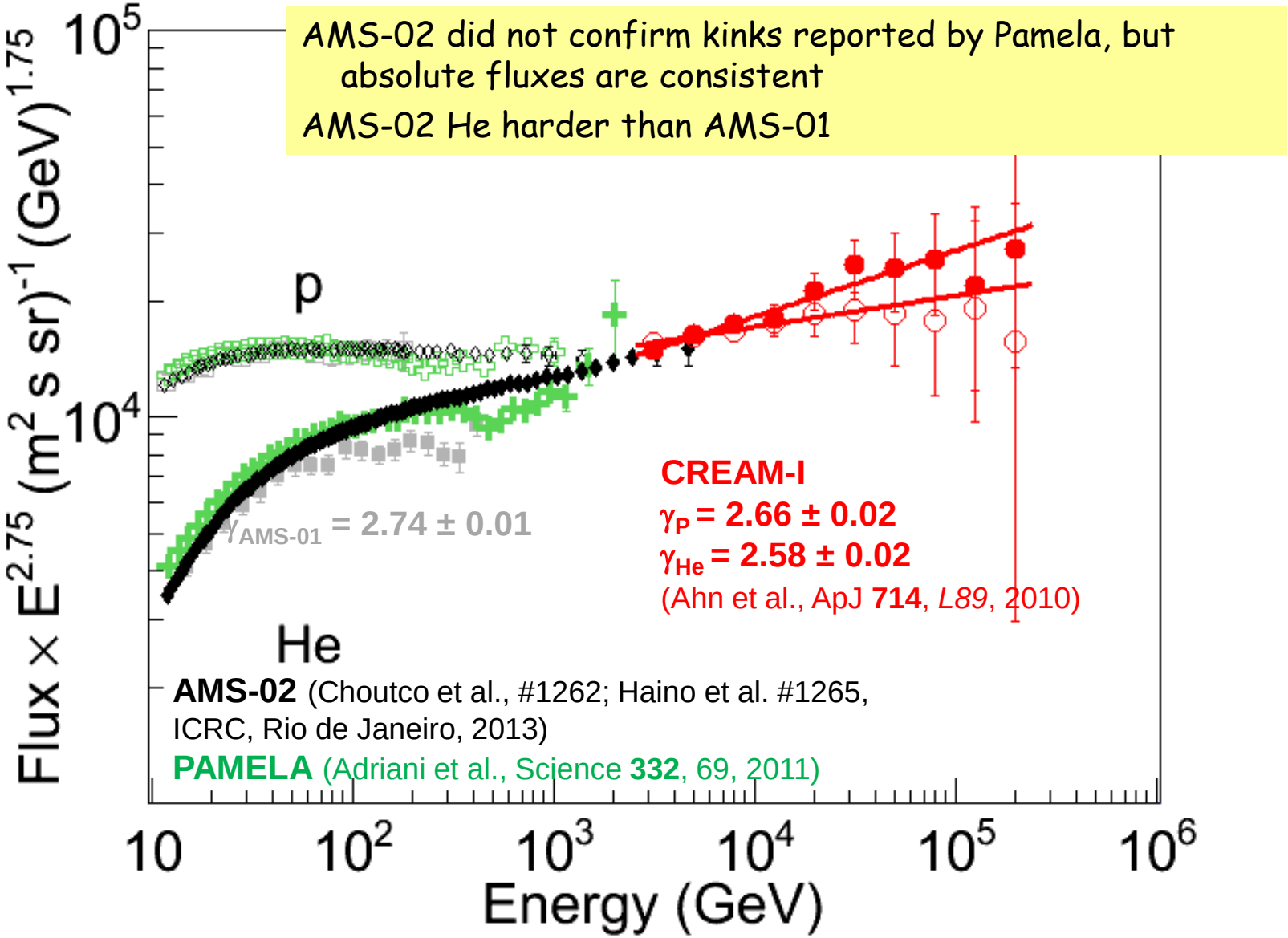
Yoon et al. ApJ **728**, *122*, 2011; Ahn et al. ApJ 714, L89, 2010





It provides important constraints on cosmic ray acceleration and propagation models, and it must be accounted for in explanations of the electron anomaly and cosmic ray “knee.”

CREAM consistent with AMS-02 where they overlap

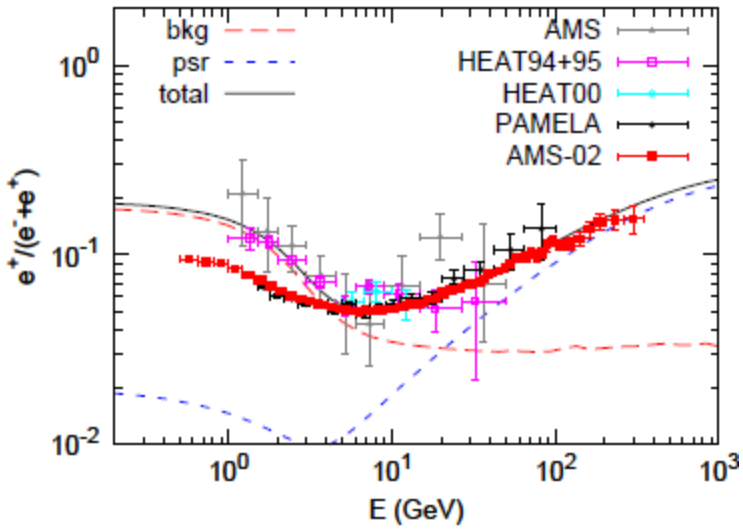


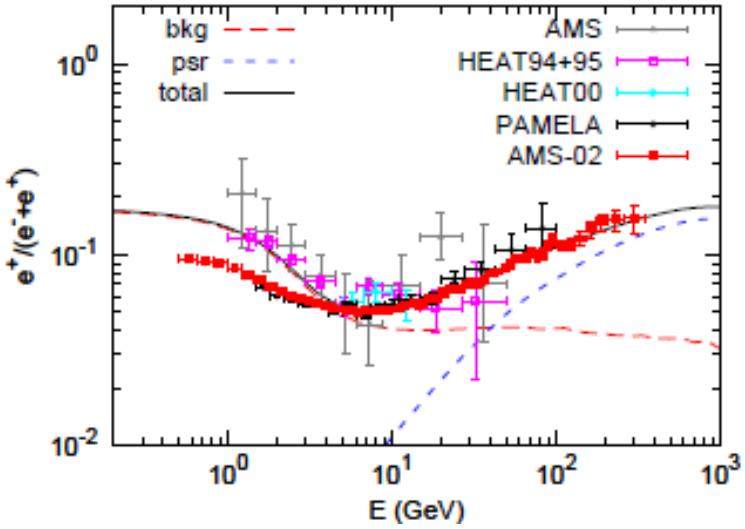
Need to extend measurements to higher energies

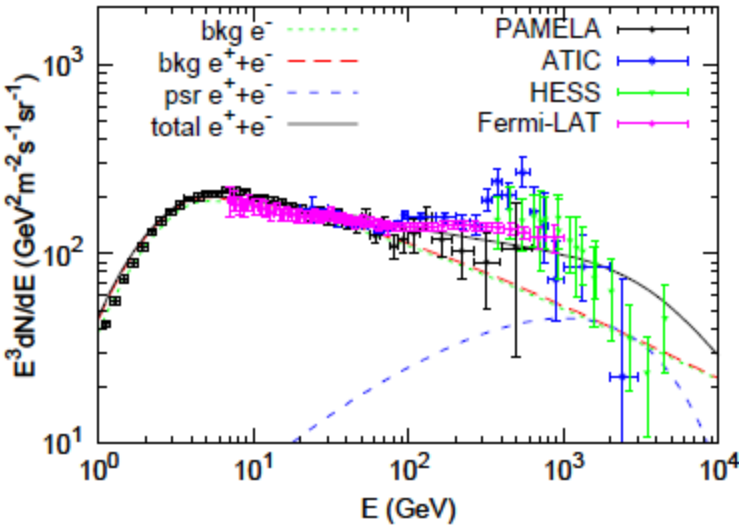
Unpublished Data
Not Shown

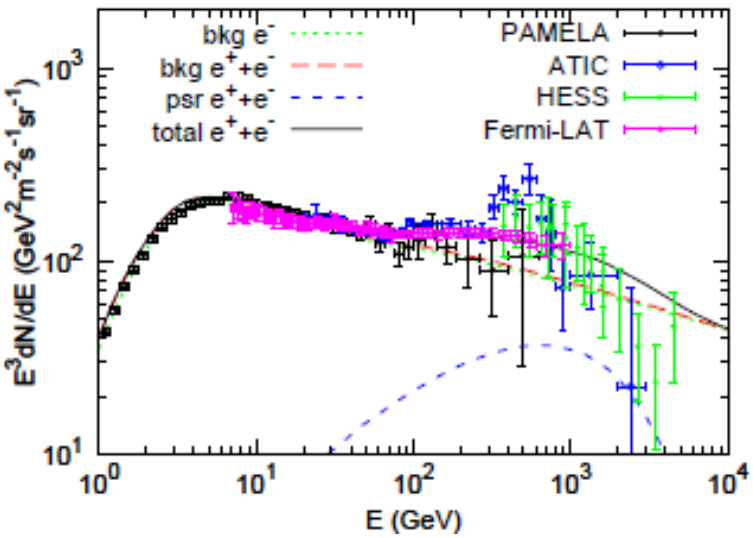
Taking into account the spectral hardening of elements
for the (AMS/PAMELA/ATIC/FERMI) high energy e^+ e^- enhancement

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.:

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

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…

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

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.

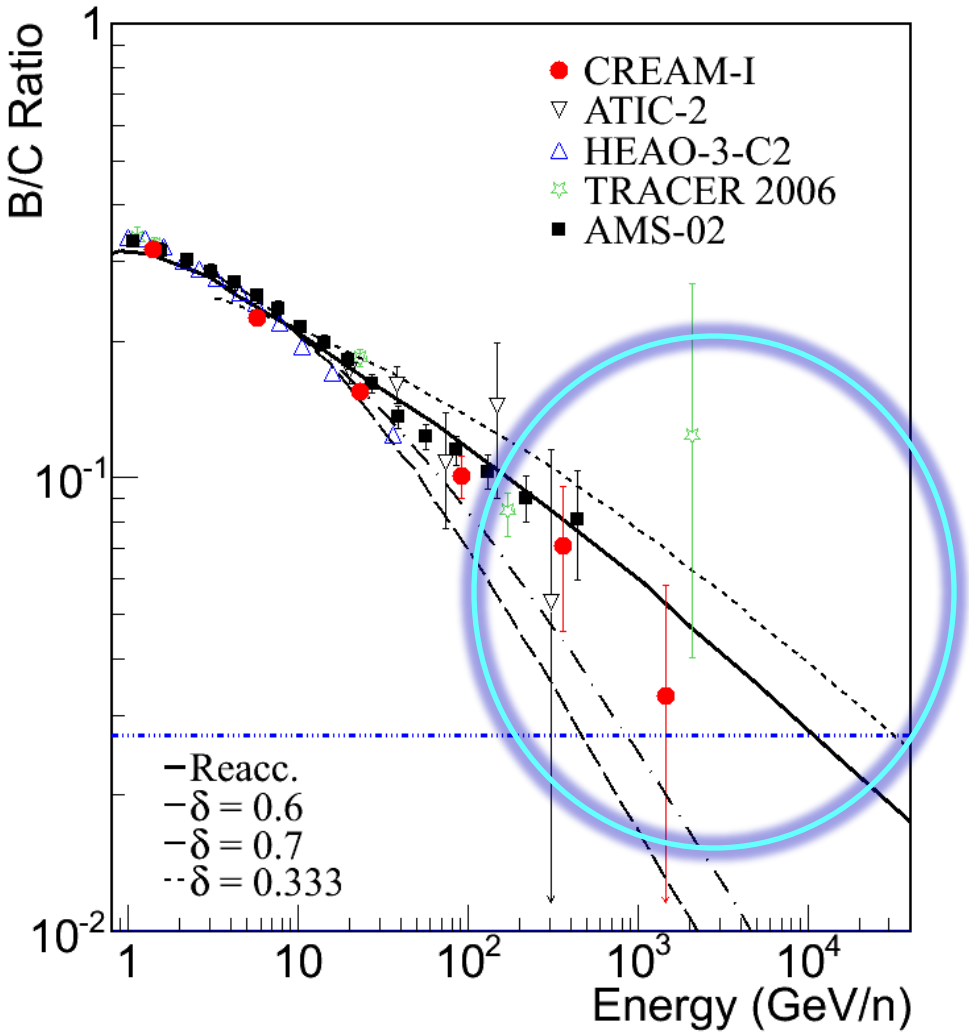
What is the history of cosmic rays in the Galaxy?

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

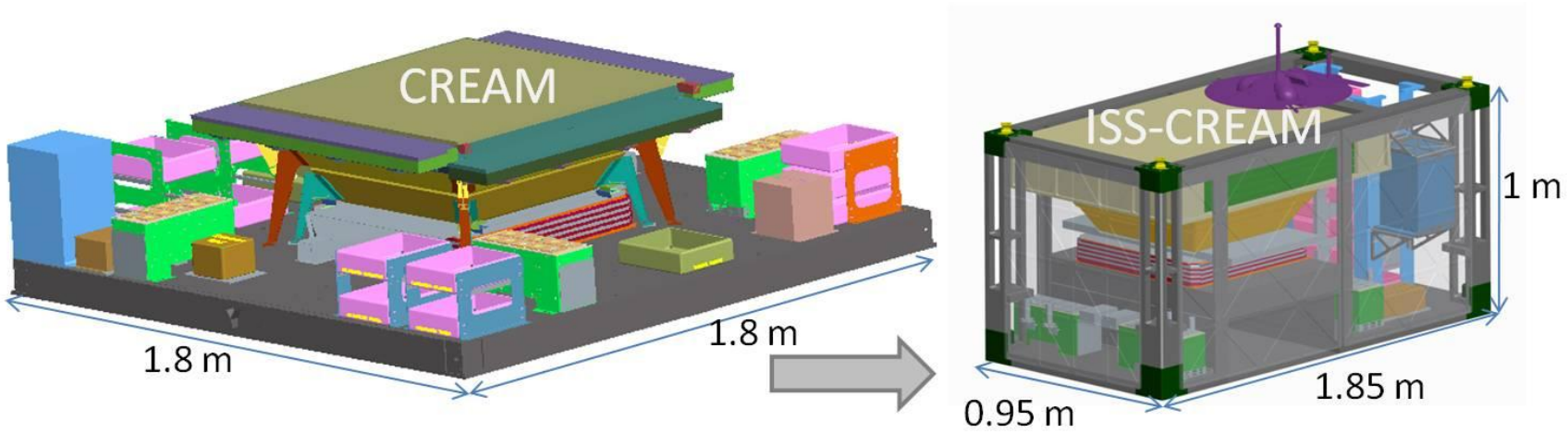
$$X_e \propto R^{-\delta}$$



From CREAM to ISS-CREAM (CREAM for the ISS)

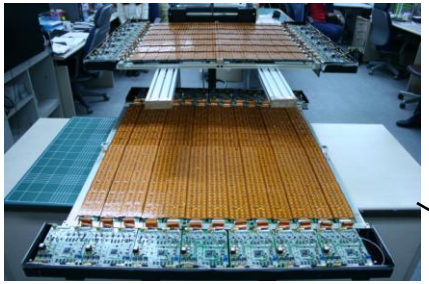
Increase the exposure by an order of magnitude

- 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.

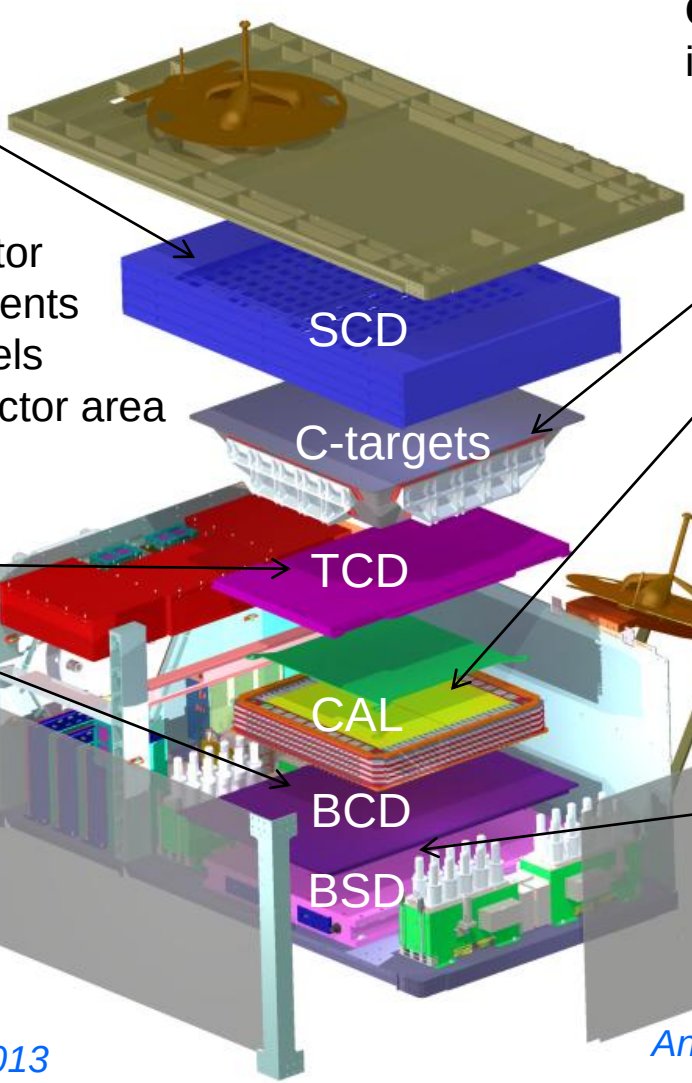


ISS-CREAM Instrument

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



4 layer **S**ilicon **C**harge **D**etector
- Precise charge measurements
- 380-μm thick 2.12 cm^2 pixels
- 79 cm x 79 cm active detector area



Carbon **Targets** (0.5 λ_{int})
induces hadronic interactions

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

Top & **B**ottom **C**ounting **D**etectors
- Each with 20 x 20 photodiodes and a plastic scitillator for e/p separation
- Independent Trigger

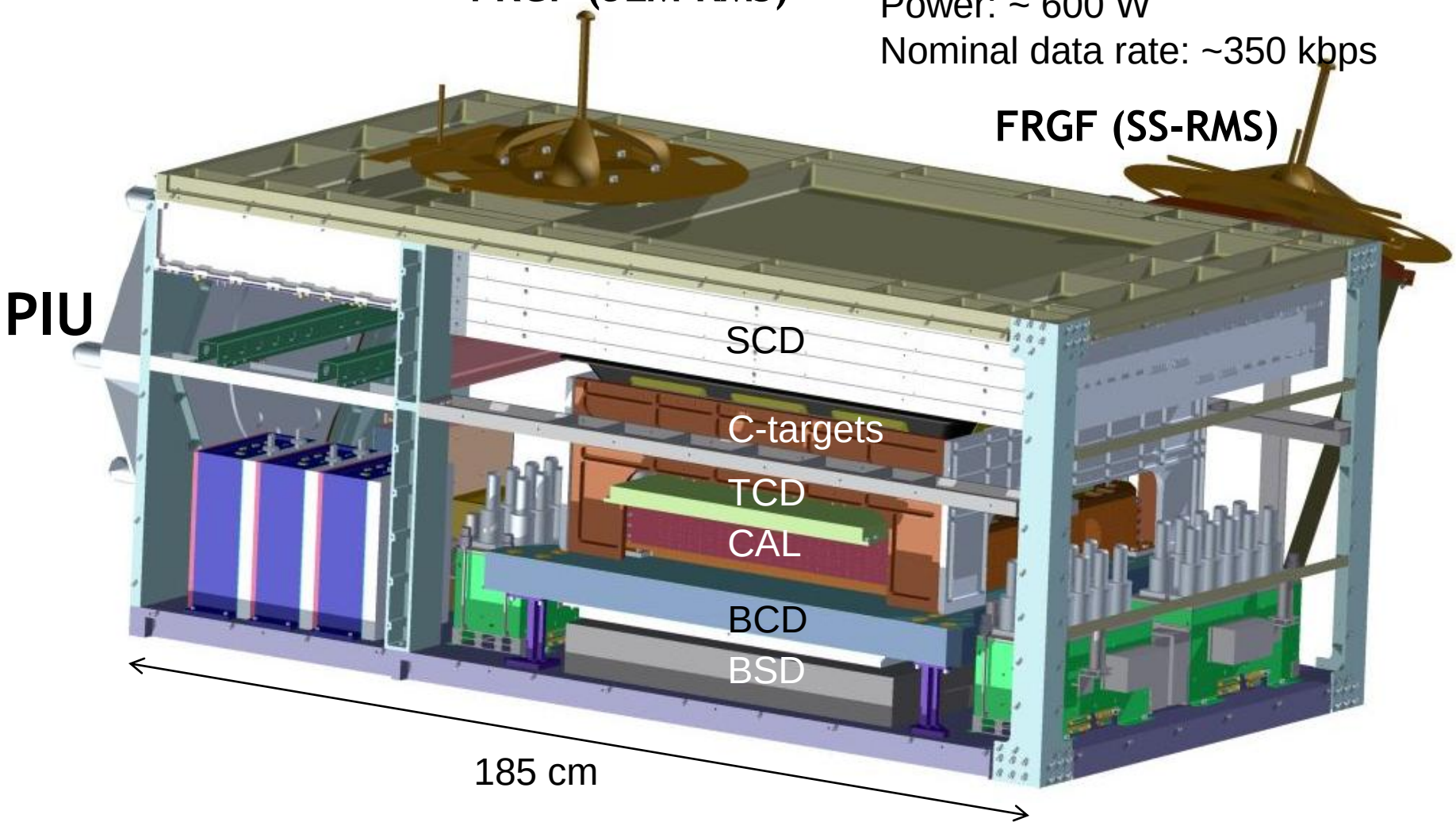
Park et al. 33rd ICRC, #1015, 2013
Hyun et al. 33rd ICRC, #1017, 2013

Boronated **S**cintillator **D**etector
- Additional e/p separation
- Neutron signals

Anderson et al. 33rd ICRC, #0350, 2013

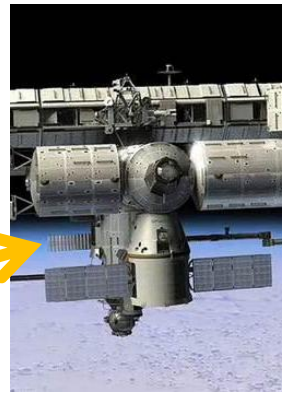
ISS-CREAM payload

Mass: ~1300 kg inc. GFE
Power: ~ 600 W
Nominal data rate: ~350 kbps

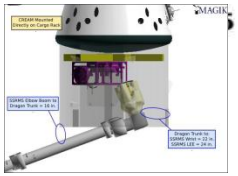


Mission Concept & Data Flow

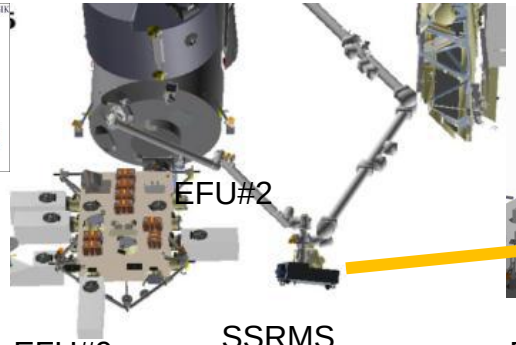
Space-X lifts off from KSC



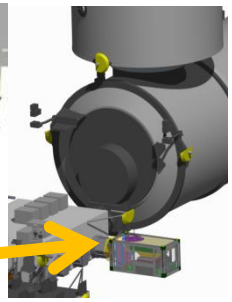
Space-X arrival on the ISS



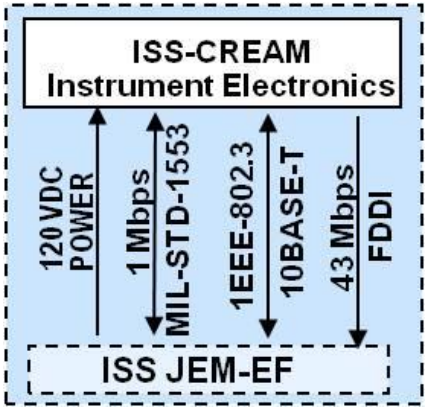
Extraction of CREAM With SSRMS

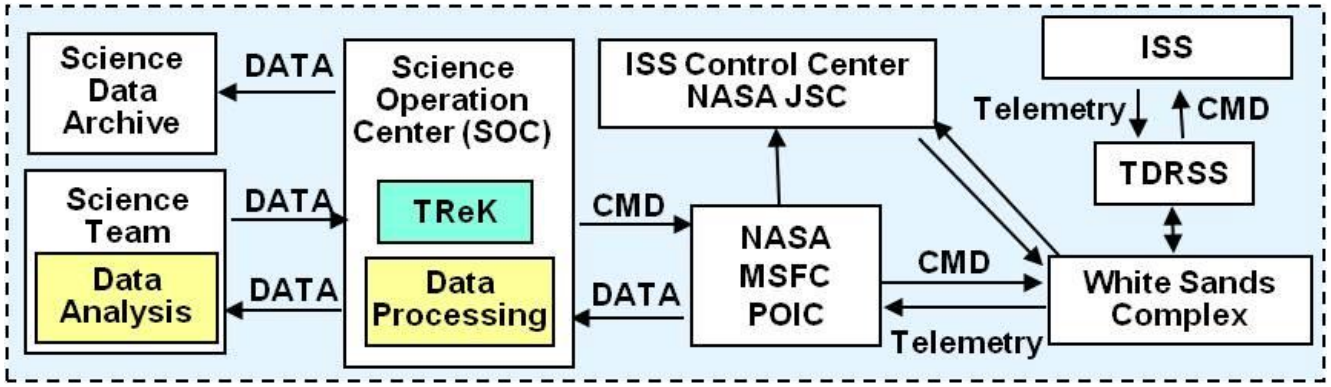


SSRMS handoff to JEMRMS



Placement of CREAM on JEM-EF#2

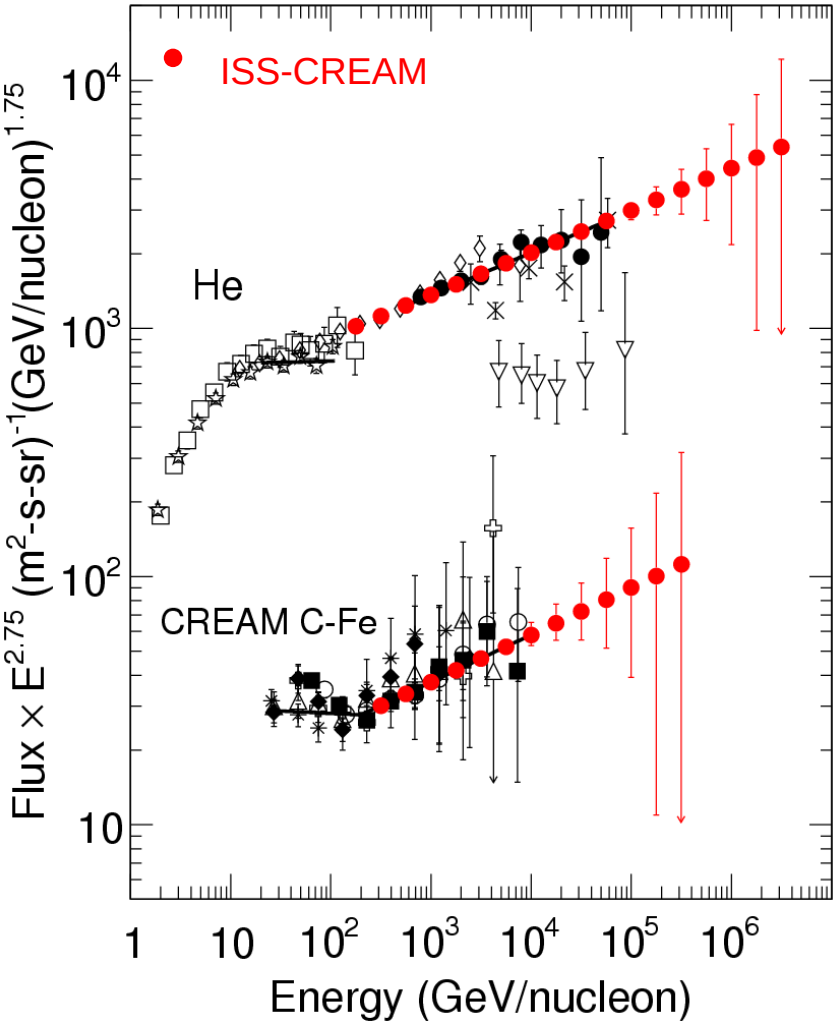




Plan to be launch ready in 2014

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?

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

- 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.

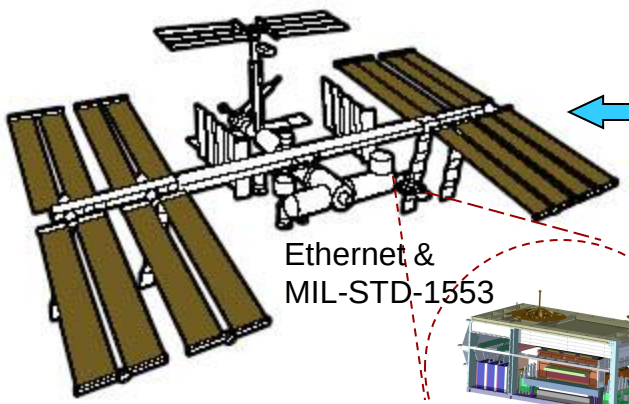
Instrument Requirement

- Electron / Proton Separation with less than 5% proton background
- Proton rejection power 8 x 10^4

Unpublished Data Not Shown

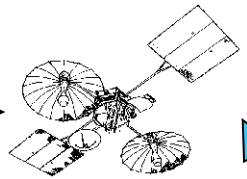
Data Flow & Science Operations

Angelaszek et al. 33rd ICRC, #0108, 2013



Ethernet &
MIL-STD-1553

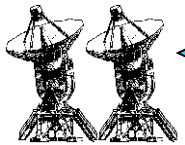
CREAM



TDRSS

Ku band

S band



White Sands, NM

Huntsville Operations Support Center (MSFC)

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

Data

Commands

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

Plots

Software Toolkit for Ethernet Lab-Like Architecture (STELLA)

Raw Data

Real-time data

Playback data

Command & Playback Request

Data relay

Data Monitoring

Data Verification Event Display