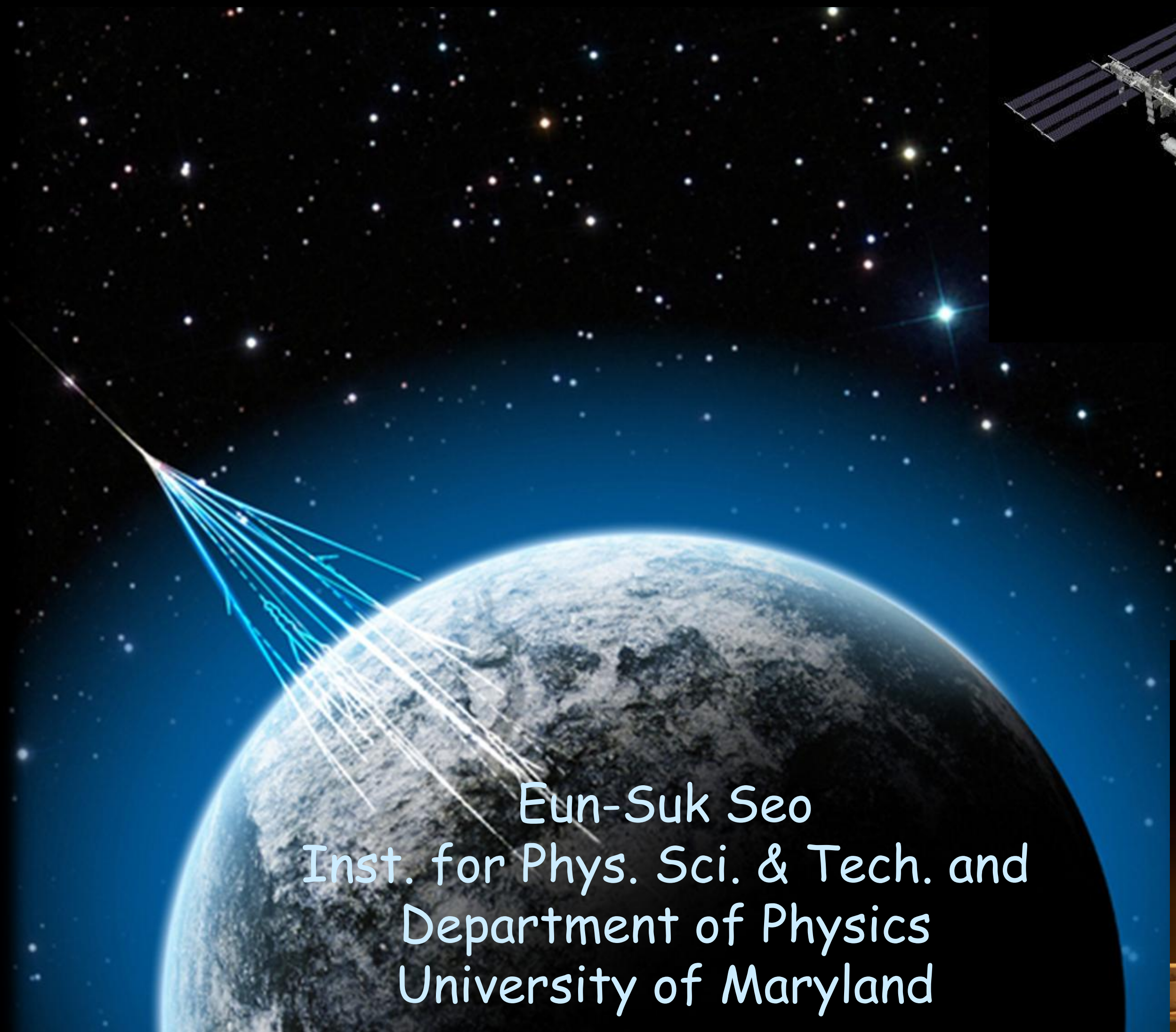
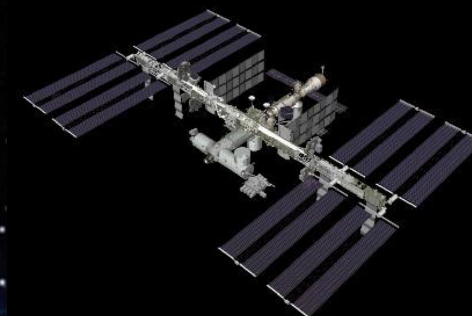
University of Virginia Physics Colloquium, November 15, 2013

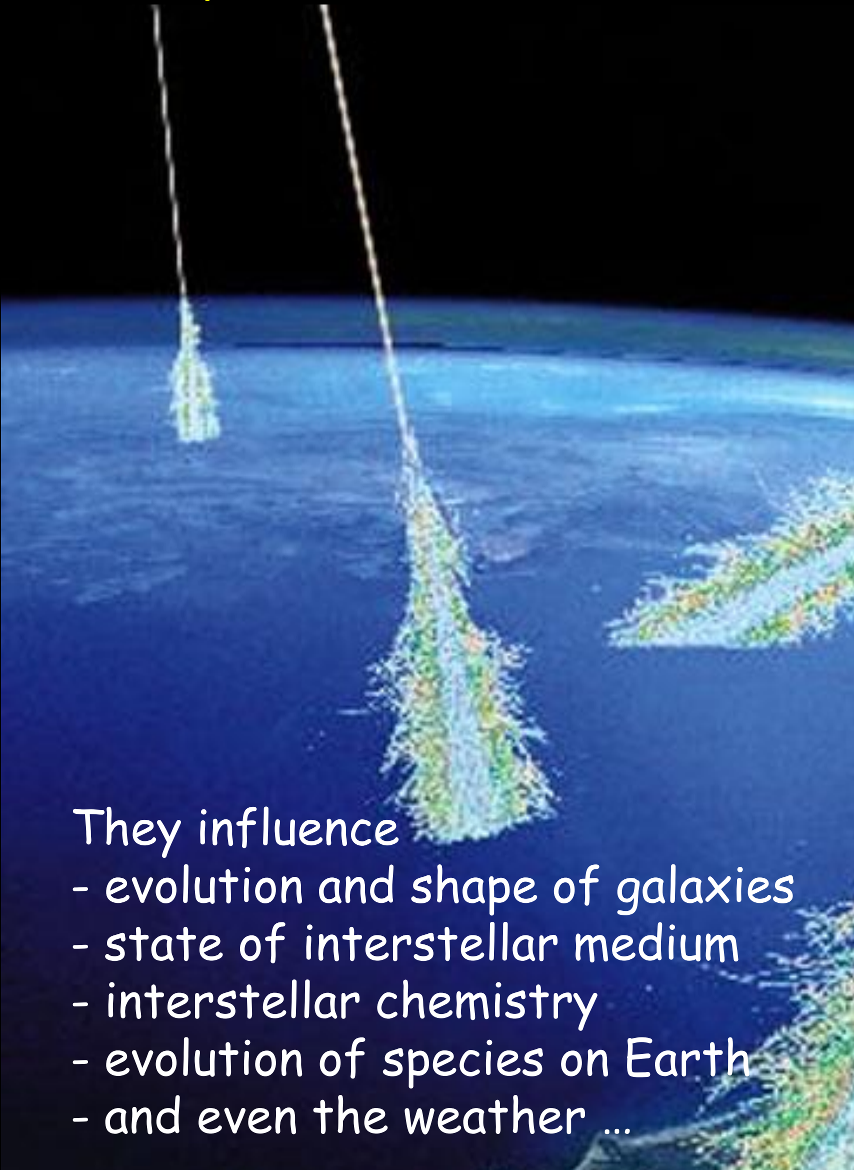
# Recent Discoveries of Cosmic Ray Anomalies



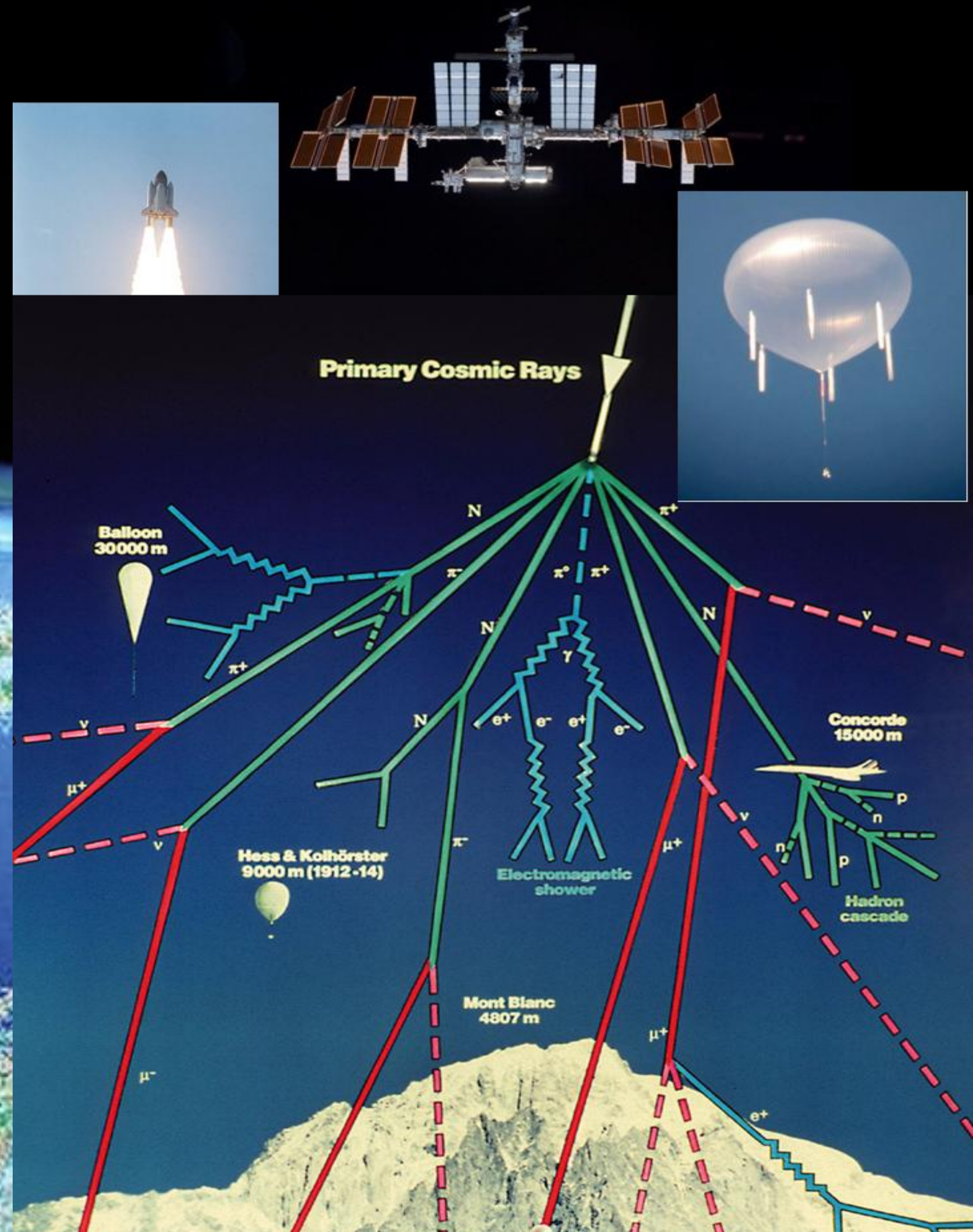



Eun-Suk Seo
Inst. for Phys. Sci. & Tech. and
Department of Physics
University of Maryland

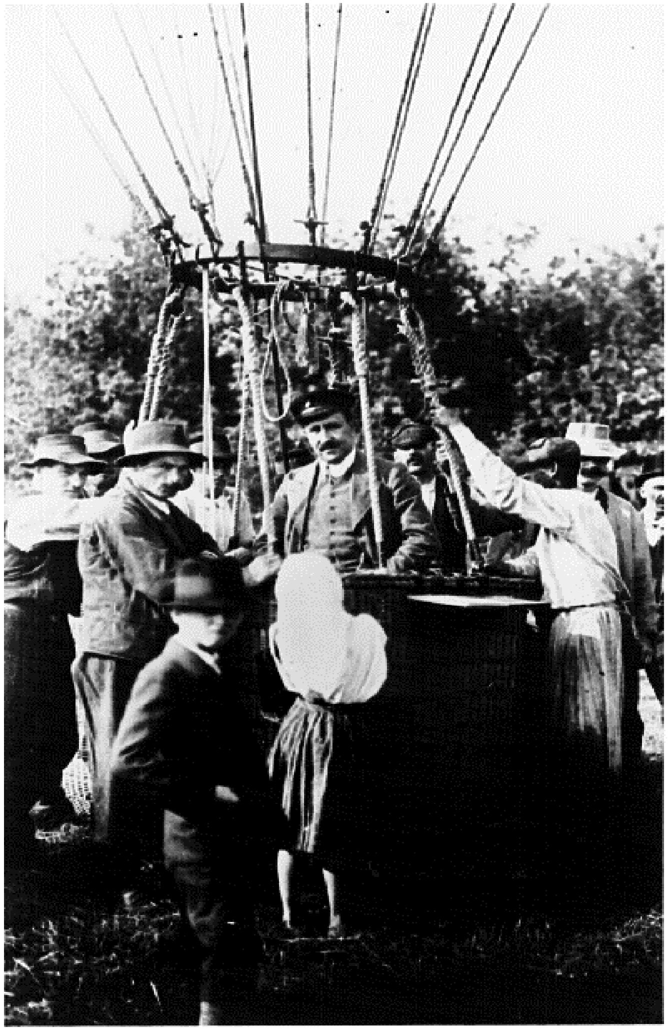
# Cosmic Rays: Why care?



They influence
- evolution and shape of galaxies
- state of interstellar medium
- interstellar chemistry
- evolution of species on Earth
- and even the weather …

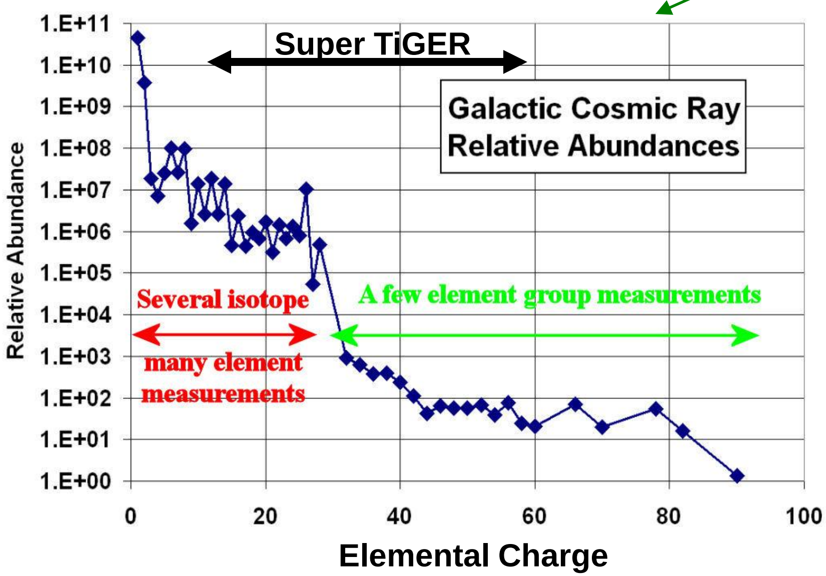


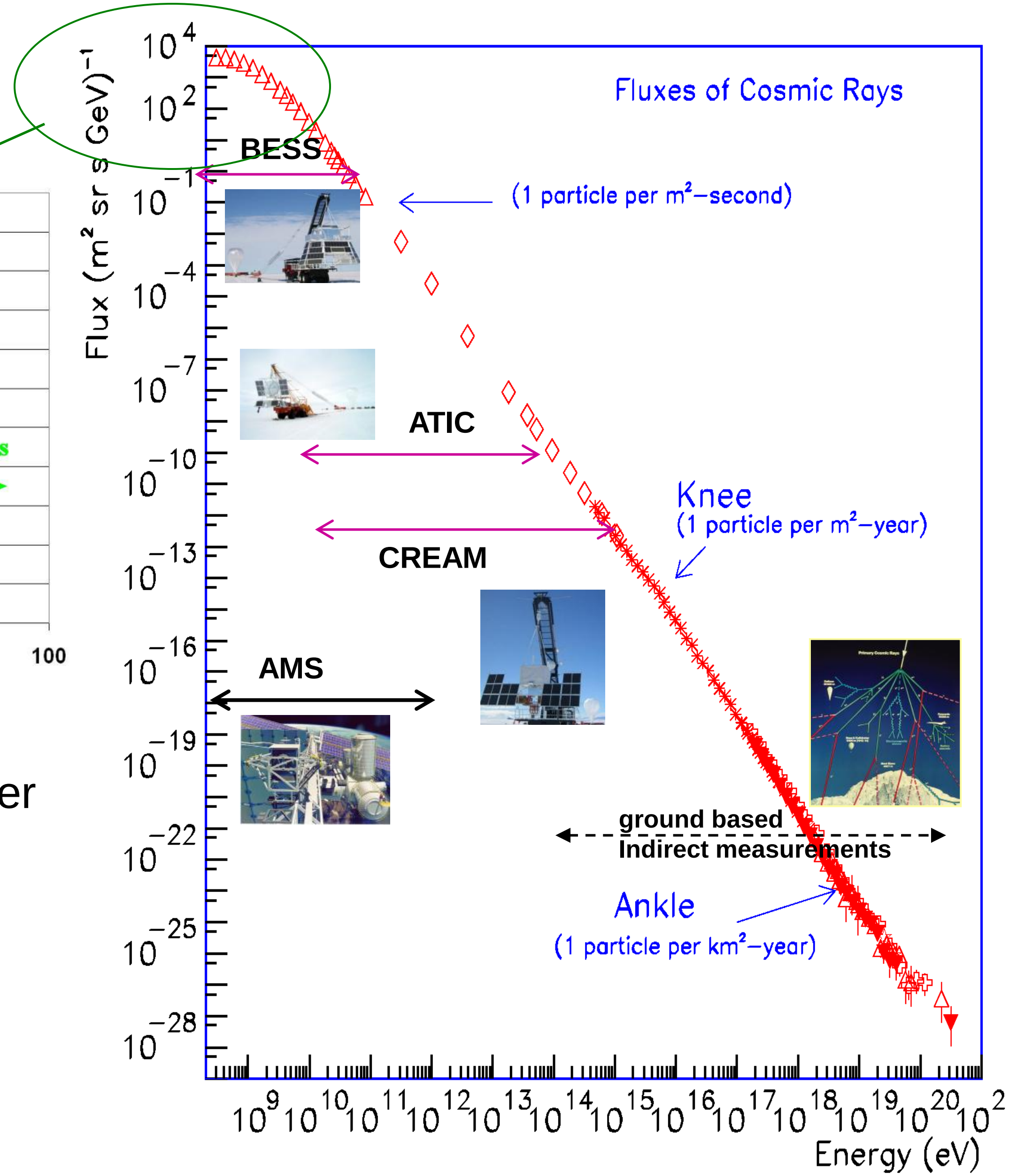
# Hess Centennial: Discovery of Cosmic Rays



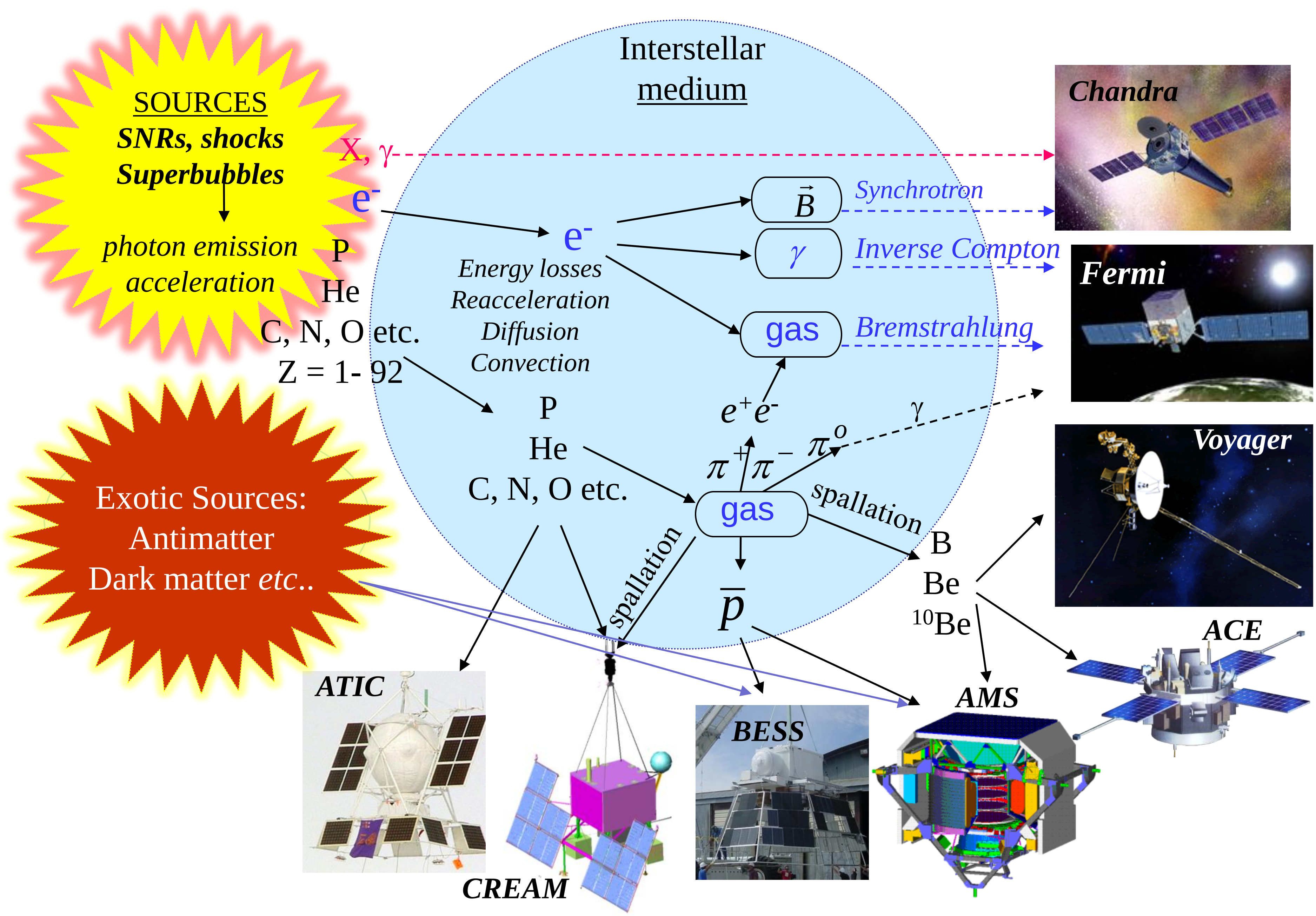
- In 1912 Victor Hess discovered cosmic rays with an electroscope onboard a balloon
  – Reached  only ~ 17,000 ft but measured an increase in the ionization rate at high altitude (1936 Nobel Prize in Physics for this work)
- Discoveries of new particles in cosmic rays
  - Positrons by Anderson in 1932 (Nobel ‘36)
  - Muons by Neddermeyer & Anderson  in 1937
  - Pions by Powell et al. in 1947 (Nobel’ 50)
  - …….
- "Direct Measurements of Cosmic Rays Using Balloon Borne Experiments," E. S. Seo, Invited Review Paper for Topical Issue on Cosmic Rays, Astropart. Phys., **39/40**, *76-87*, 2012.

# How do cosmic accelerators work?



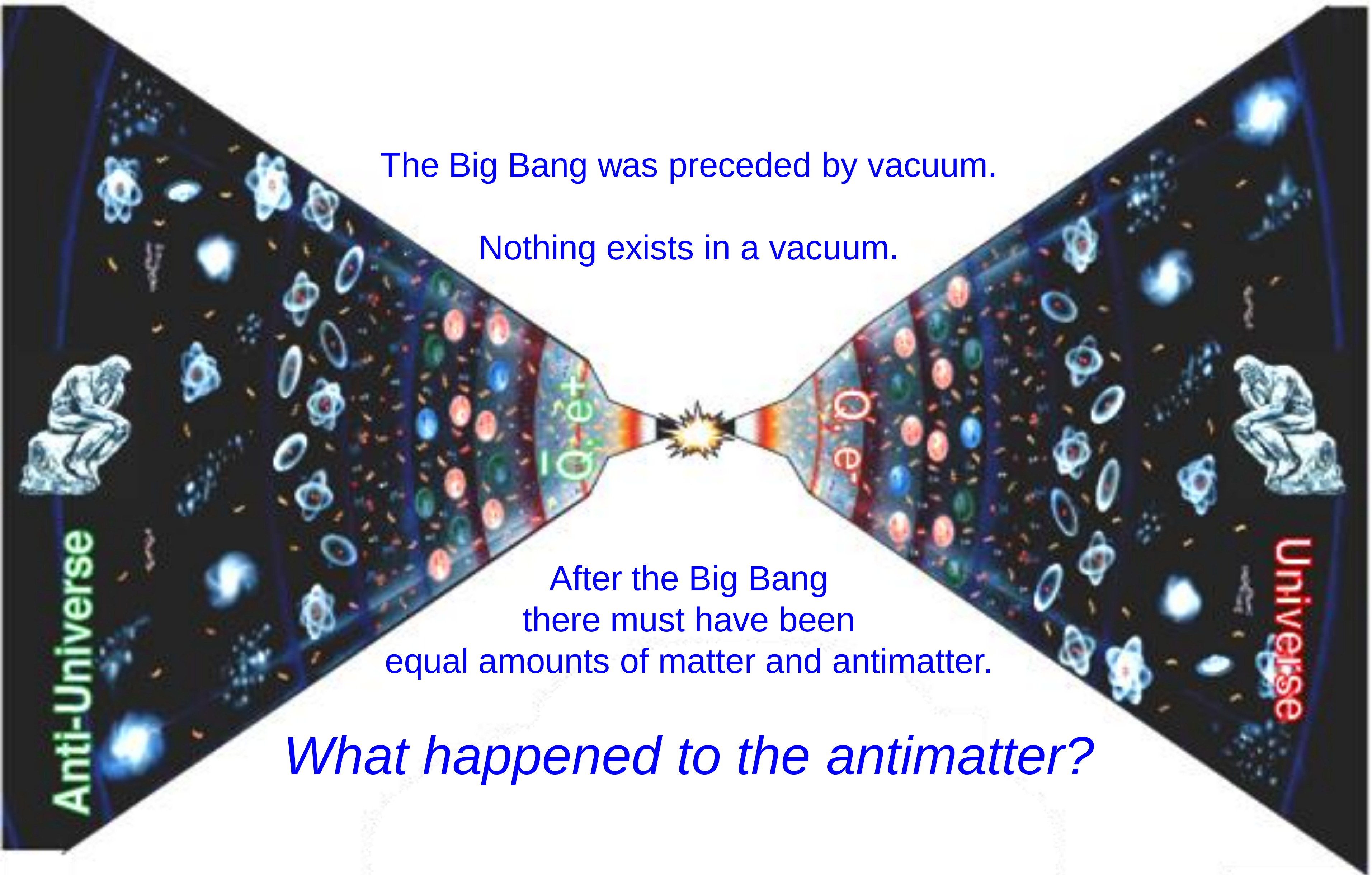




- Relative abundances range over 11 orders of magnitude
- Detailed composition limited to less than ~ 10 GeV/nucleon



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

# Search for the existence of Antimatter in the Universe

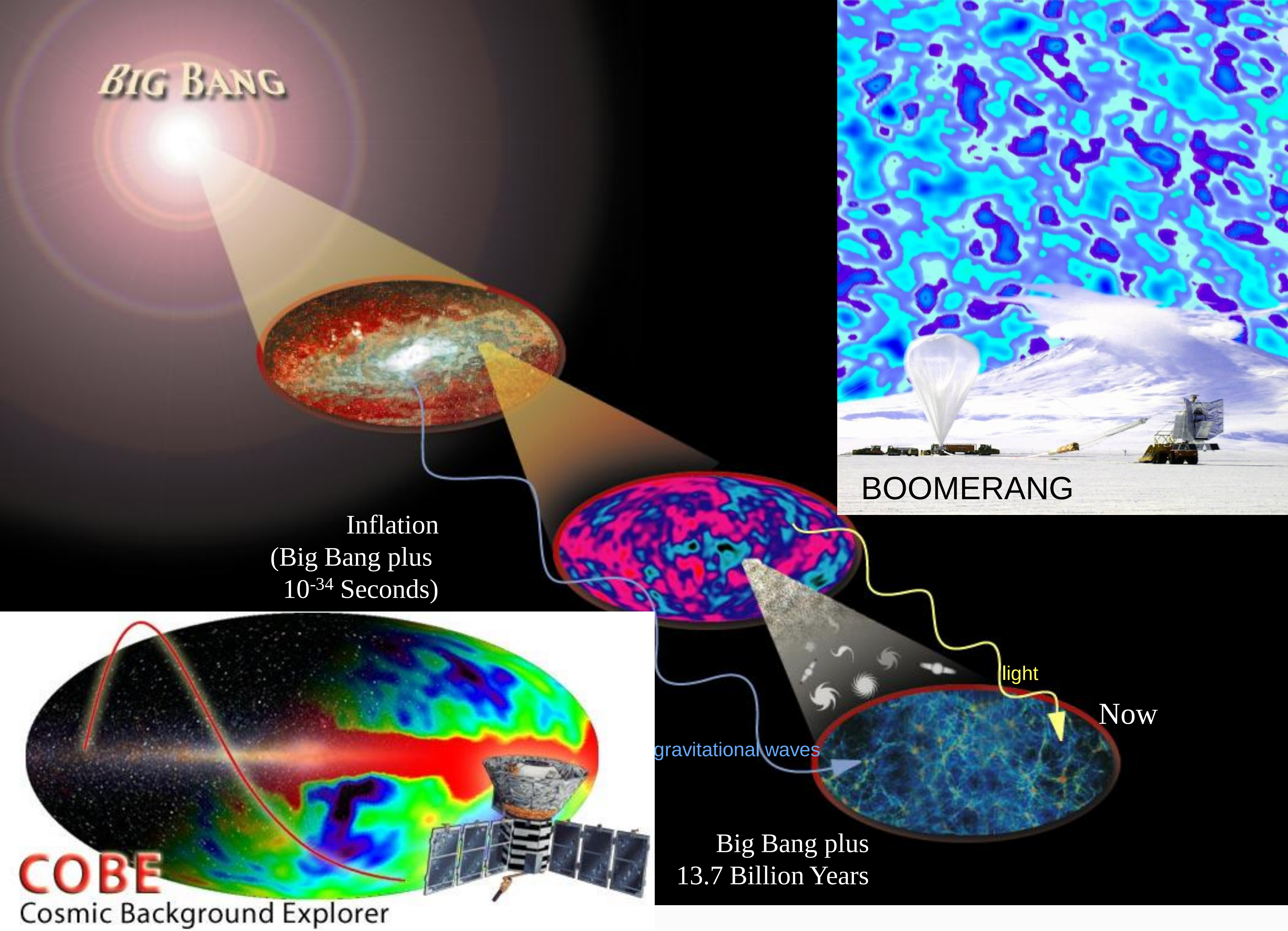



The Big Bang was preceded by vacuum.

Nothing exists in a vacuum.

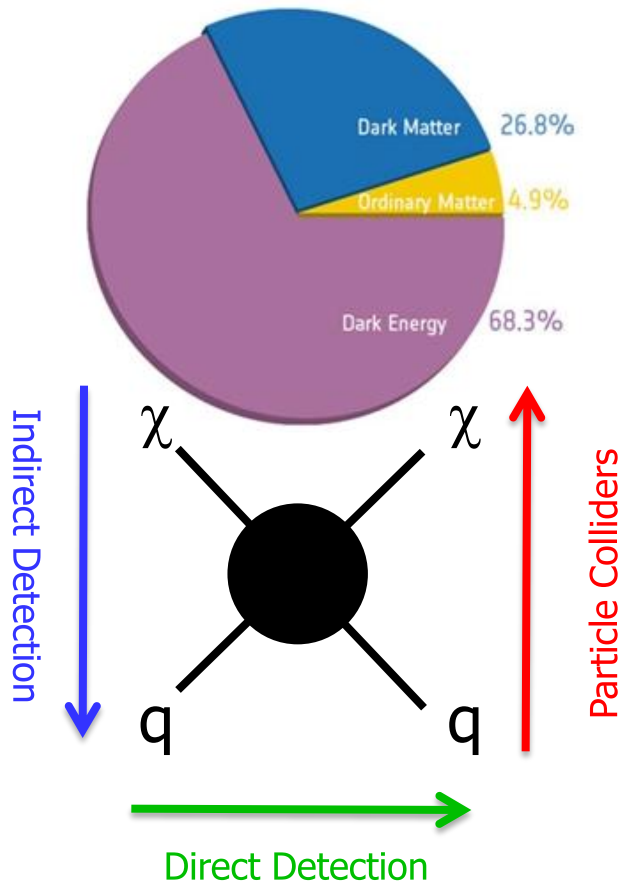
After the Big Bang
there must have been
equal amounts of matter and antimatter.

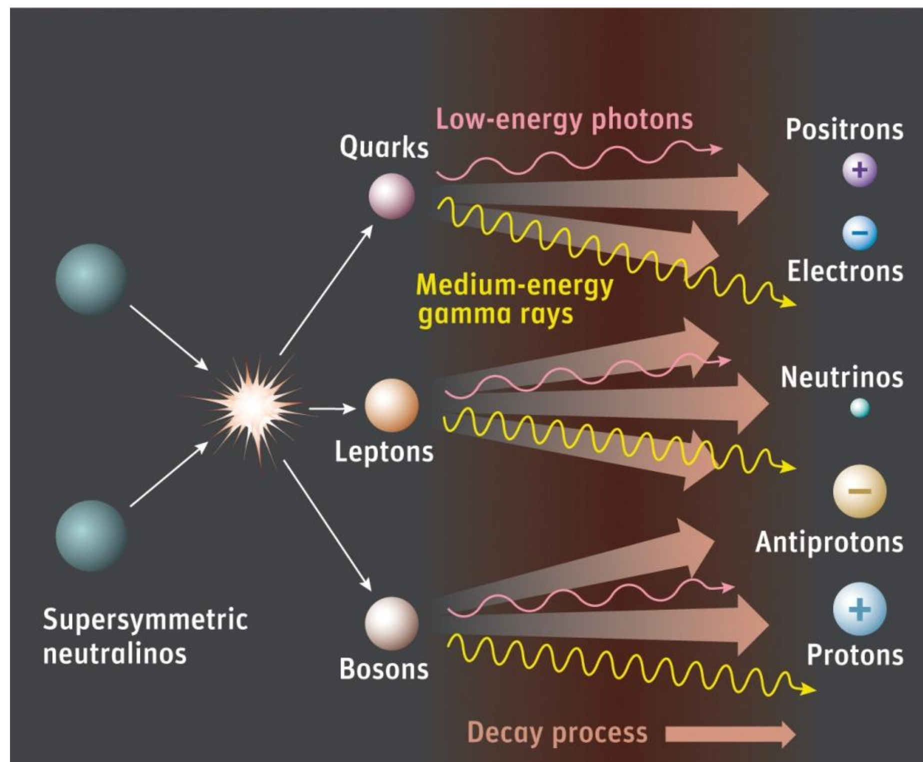
*What happened to the antimatter?*


BIG BANG
Inflation
(Big Bang plus
10-34 Seconds)
BOOMERANG
light
Now
gravitational waves
Big Bang plus
13.7 Billion Years
COBE
Cosmic Background Explorer

# 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.

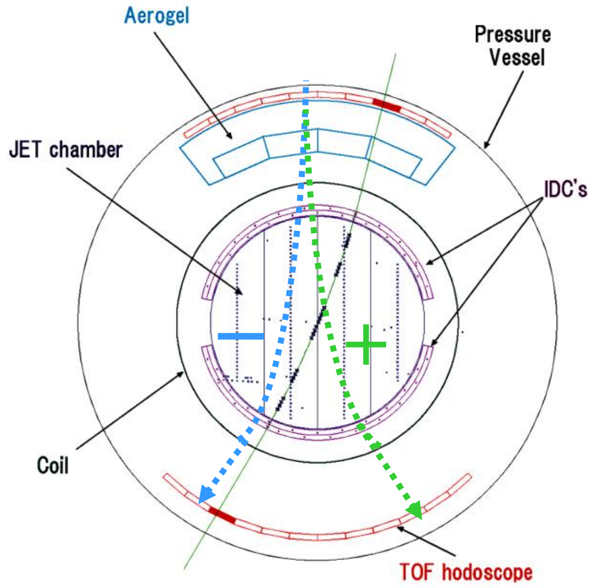


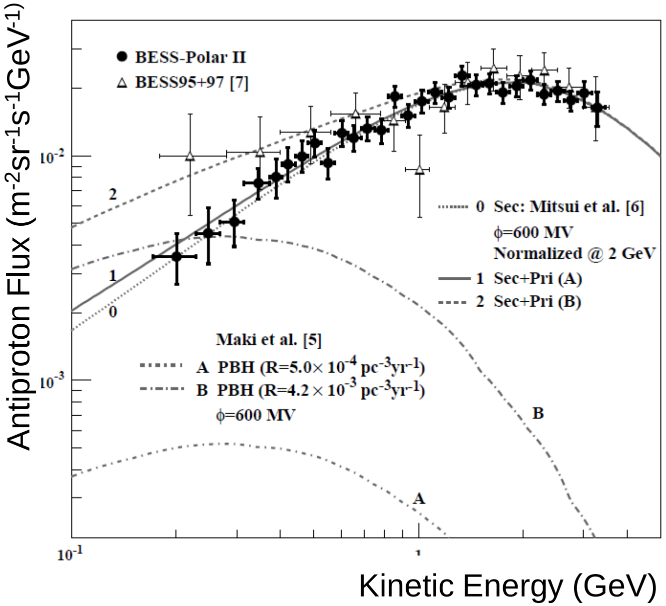



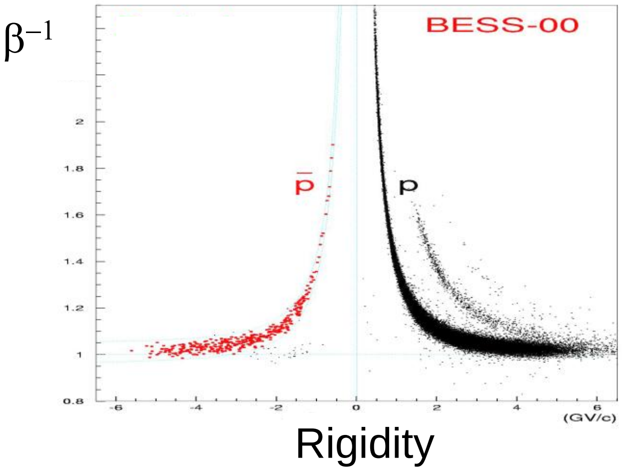
**BESS-Polar II**

**Balloon–borne Experiment with a Superconducting Spectrometer**

Abe et al. PRL, 108, 051102, 2012




- 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.**

# BESS-Polar II

**Balloon–borne Experiment with a Superconducting Spectrometer**

**Search for Antihelium with the BESS-Polar Spectrometer**

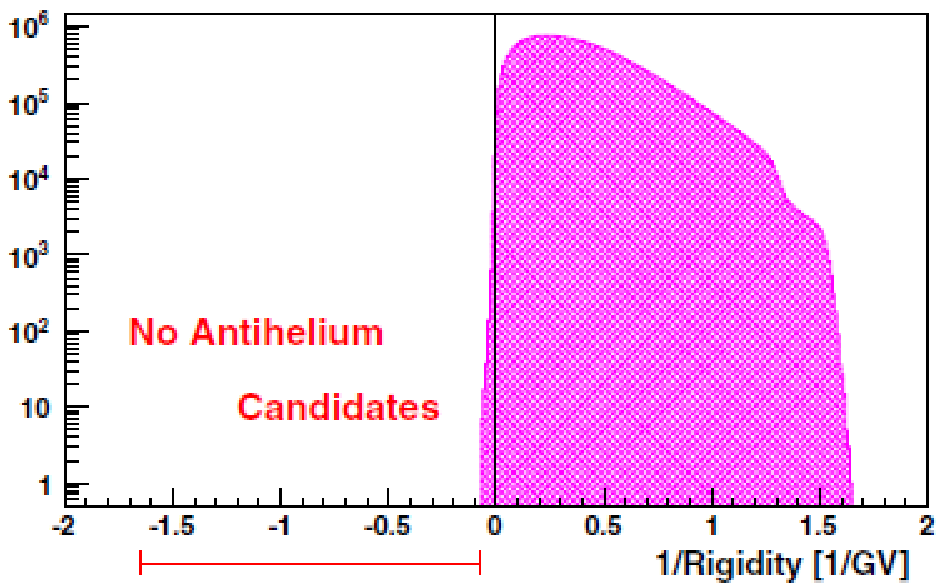
K. Abe *et al.*

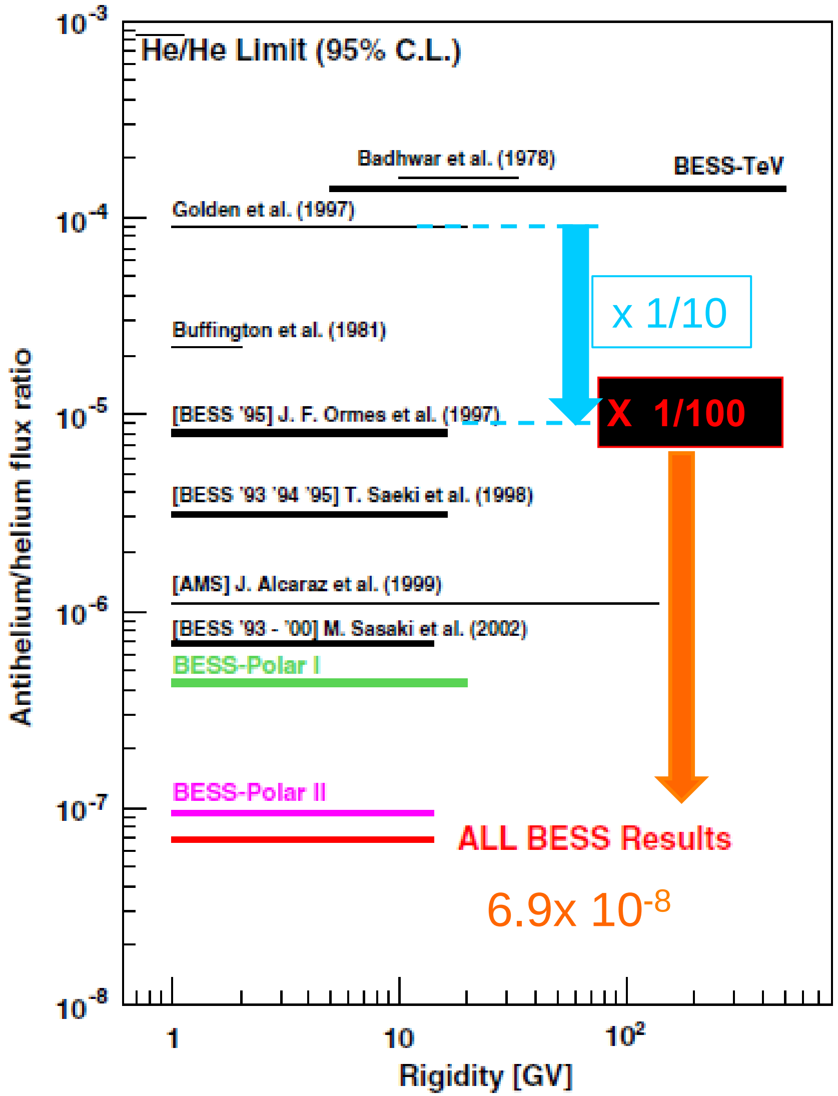
Published 29 March 2012 *(4 pages)*

131301 [**View** PDF (546 kB)]

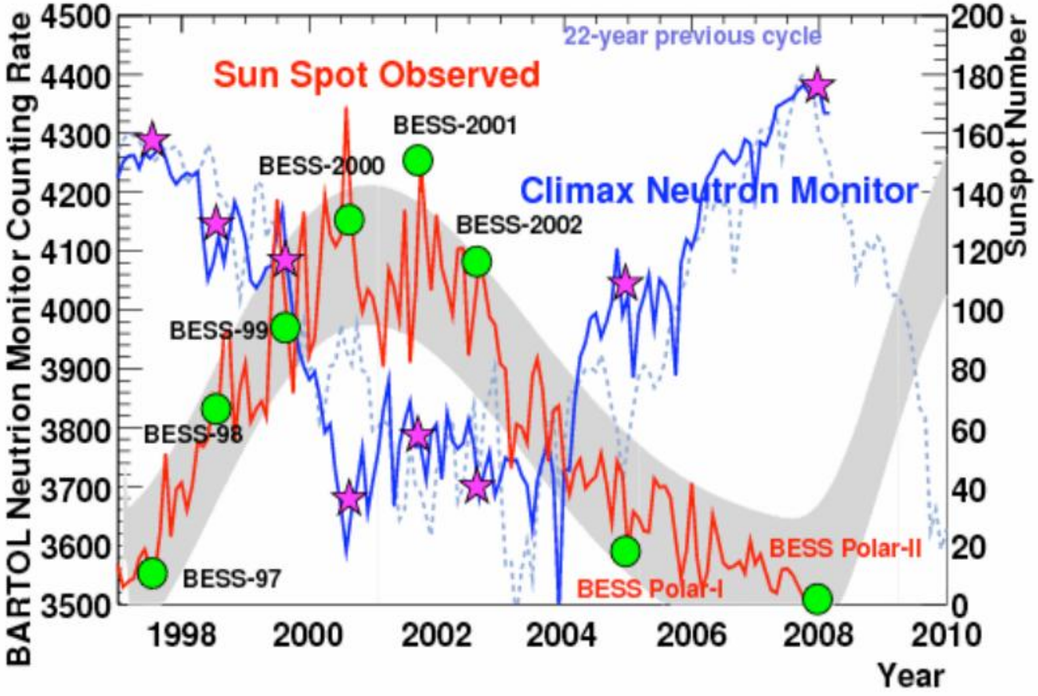
See accompanying *Physics* Synopsis

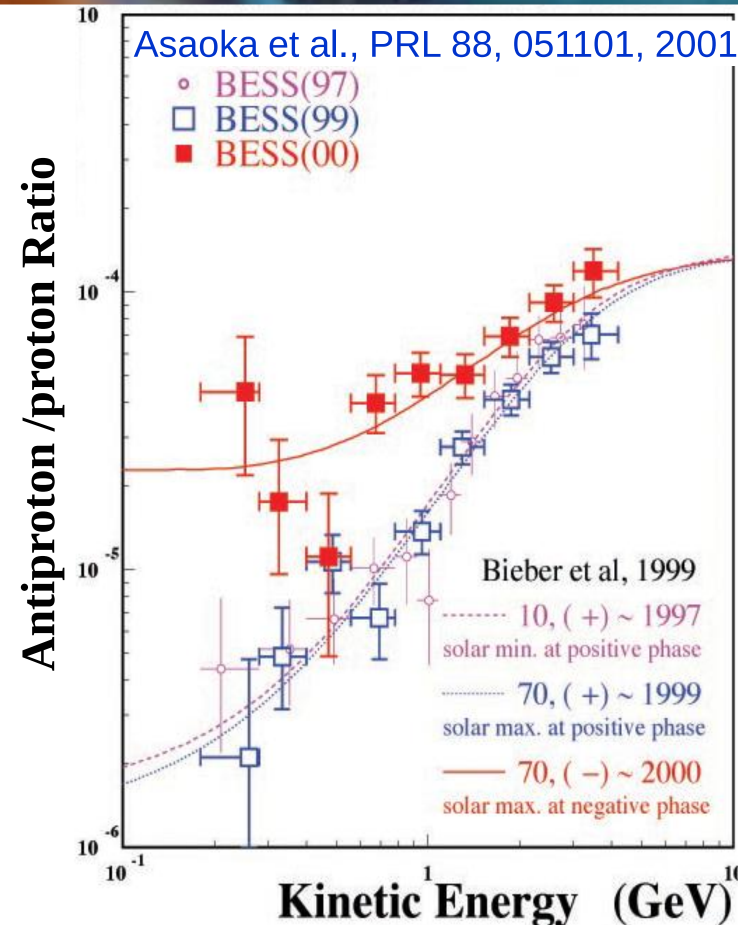
Phys. Rev. Lett., 108, *131301*, 2012



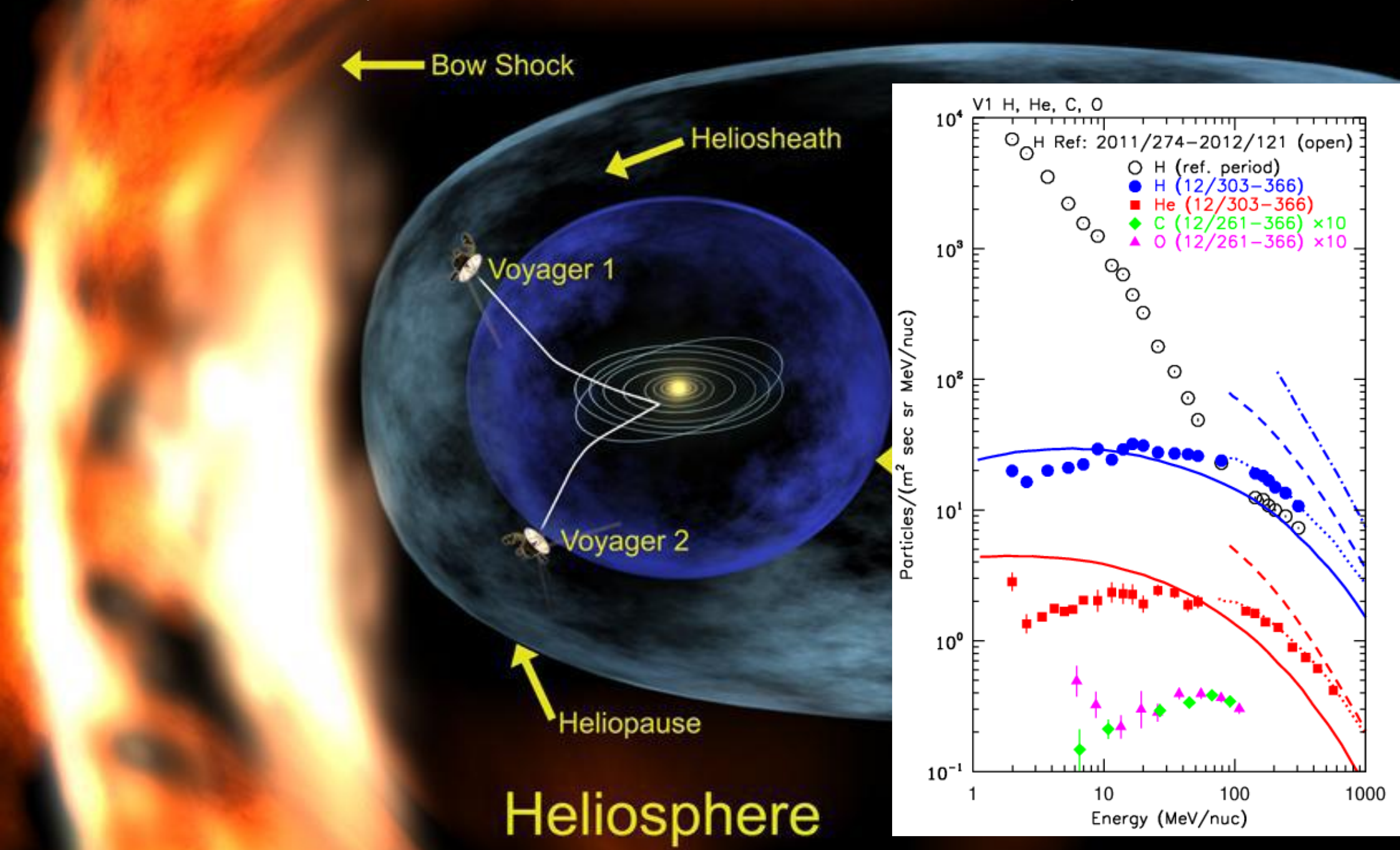



# Charge-sign Dependent Solar Modulation



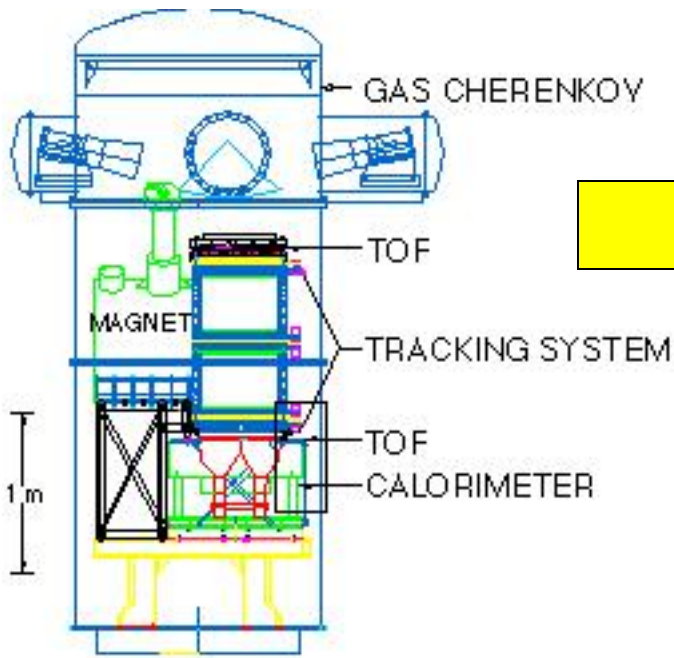



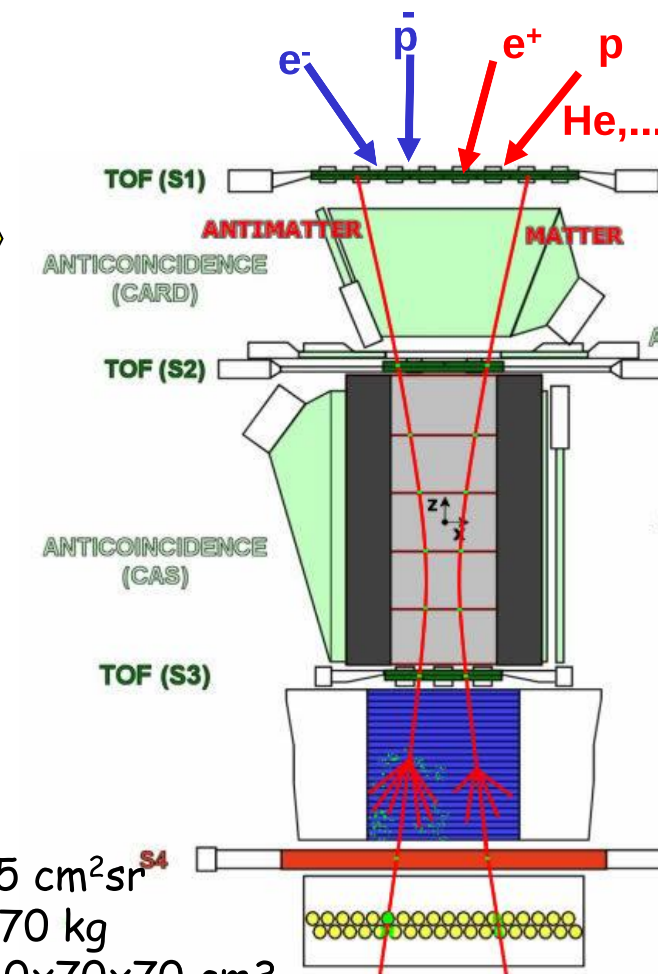
# Voyager 1 in Interstellar Space

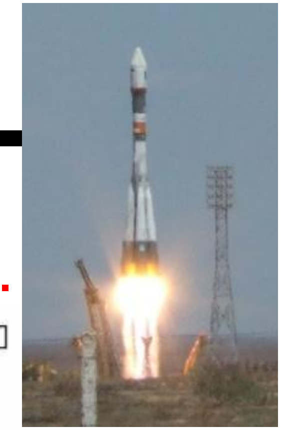



E. C. Stone, ICRC 2013

# From MASS to PAMELA



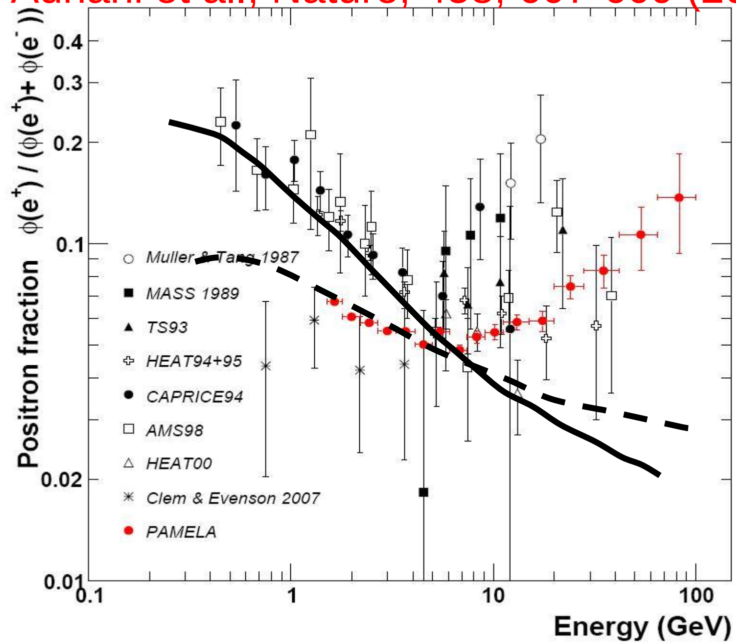
Matter
Antimatter
Superconducting
Spectrometer
(MASS)
1989 balloon
flight in Canada

GF ~21.5 $cm^2sr$
Mass: 470 kg
Size: 130x70x70 cm3
Payload for Anti-Matter Exploration and Light-nuclei Astrophysics (PAMELA)
satellite Launch 6/15/06

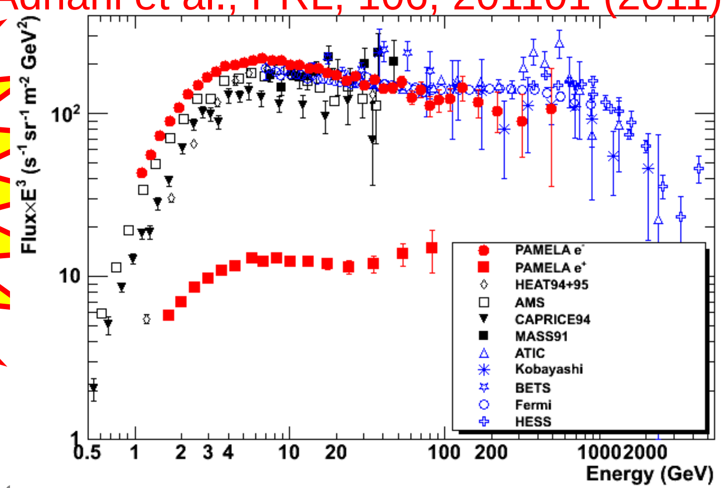
# Payload for Anti-Matter Exploration and Light-nuclei Astrophysics (PAMELA)

"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., Nature, 458, 607-609 (2009)




Adriani et al., PRL, 106, 201101 (2011)



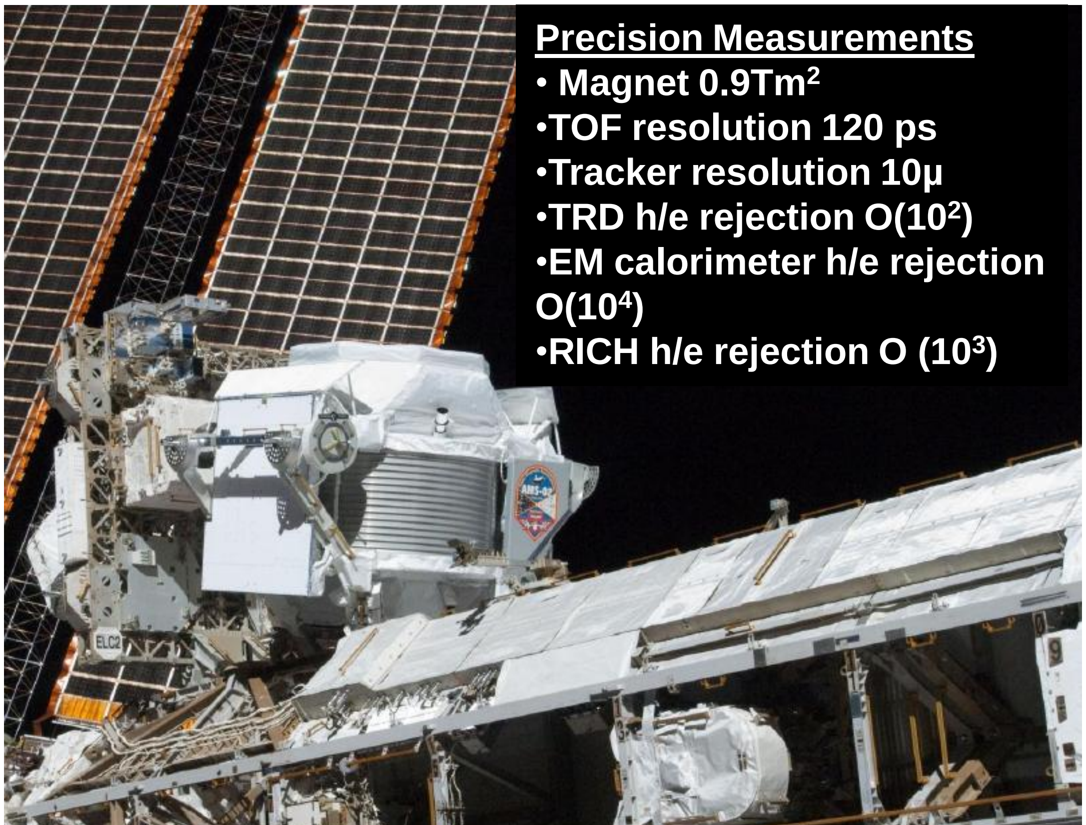

Cited
> 300 times
in ~ 1 yr

# AMS

## Alpha Magnet Spectrometer

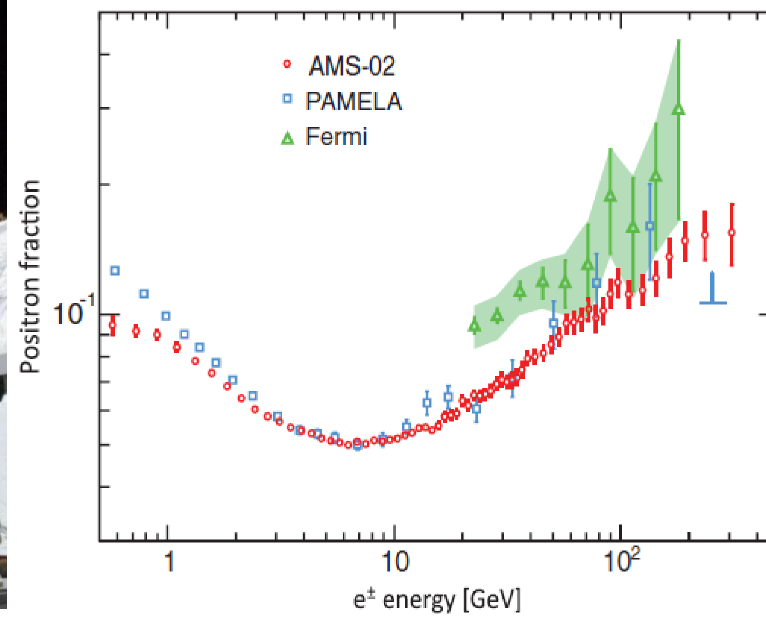
Launch for ISS on May 16, 2011

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




First Result: Precision Measurement of the Positron Fraction in Primary Cosmic Rays of 0.5-350 GeV

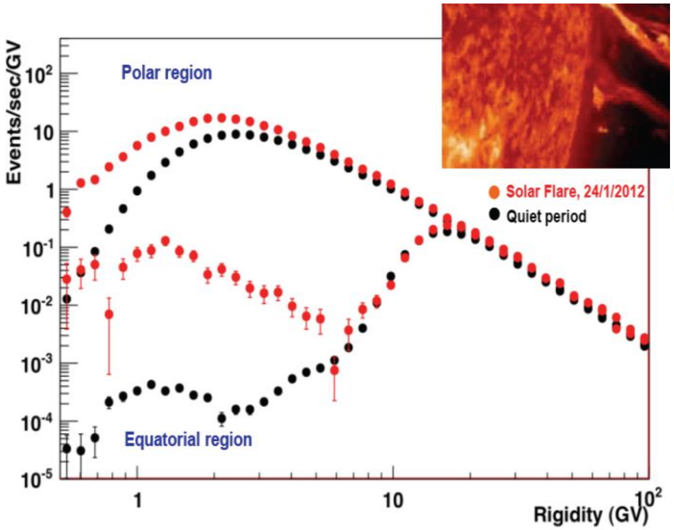
Aguilar et al., PRL 110, 141102, 2013

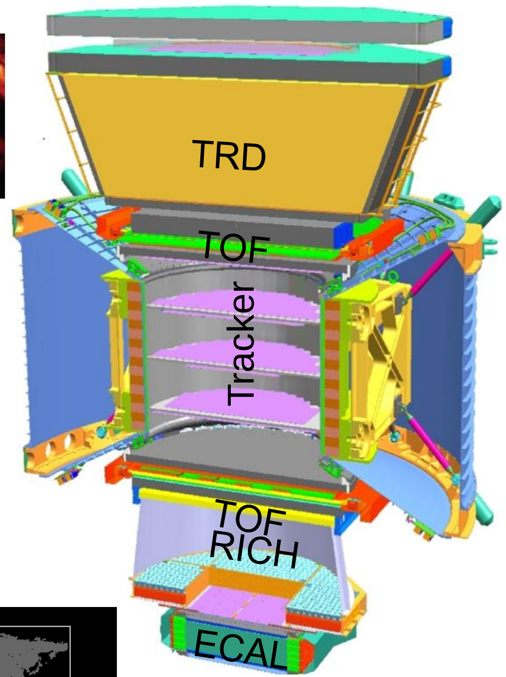


# AMS

## Alpha Magnet Spectrometer

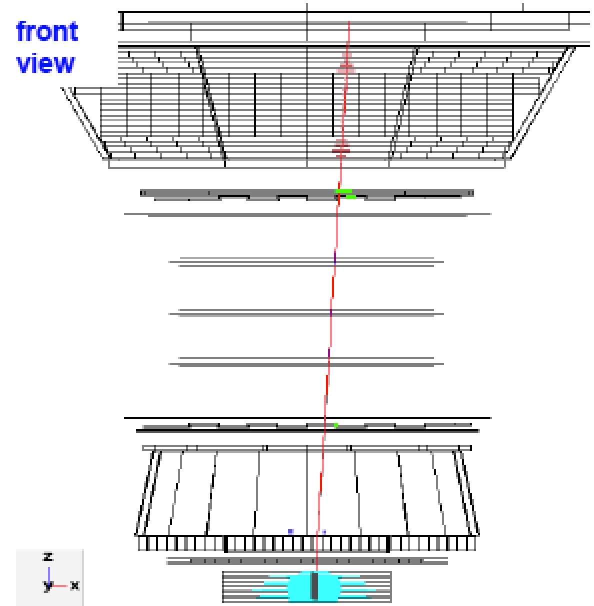
~16 billion events per year

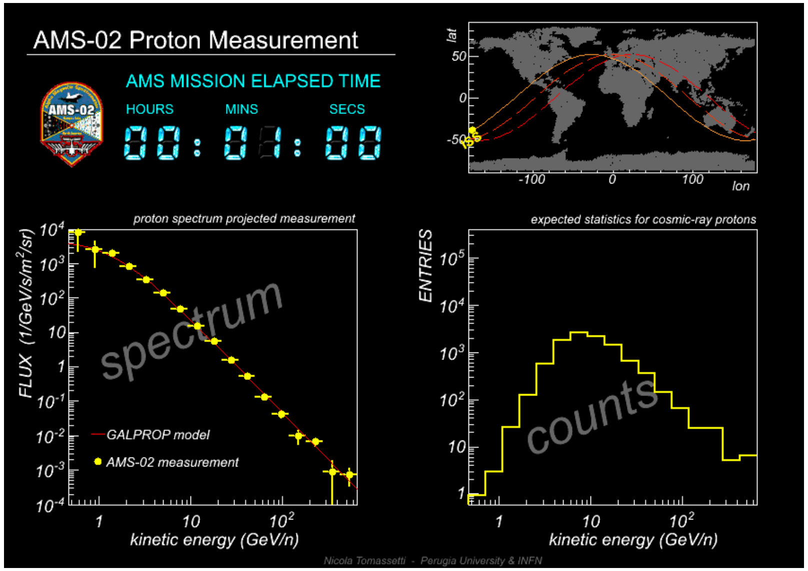


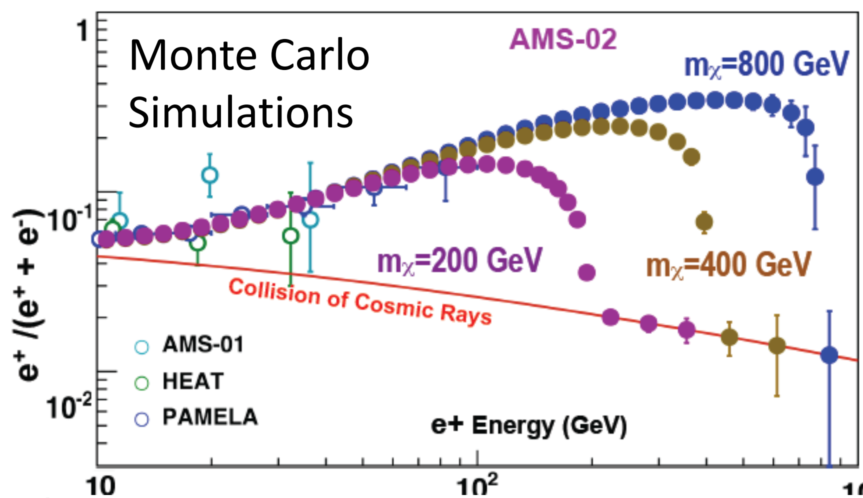




Flight data

**424 GeV Positron**

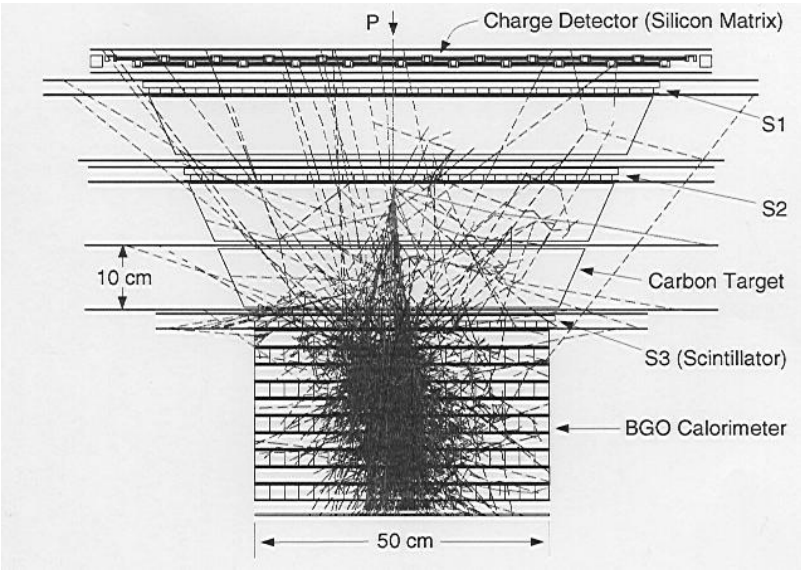


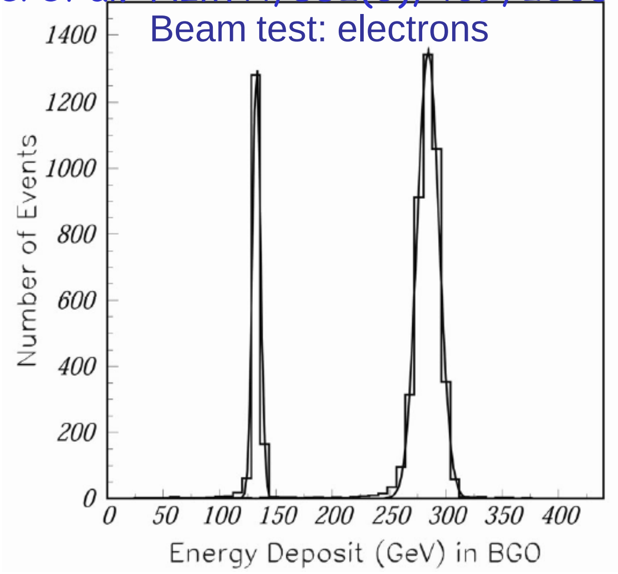



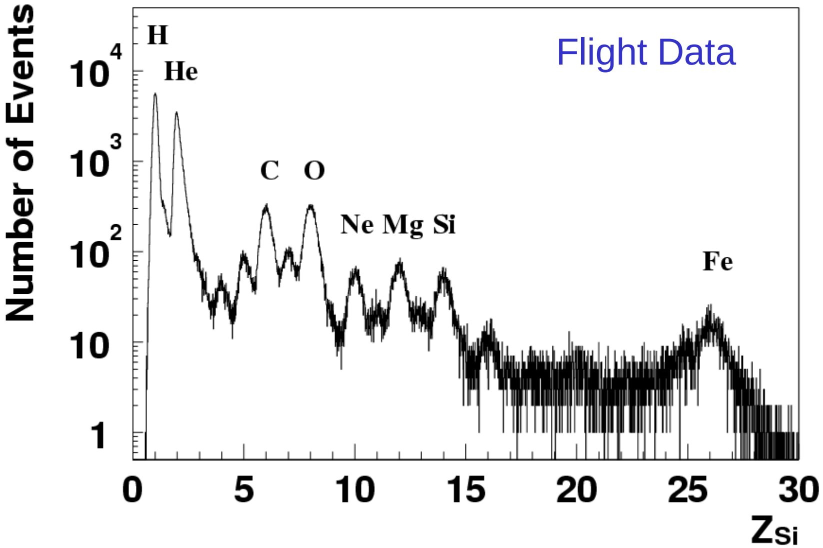
# ATIC Advanced Thin Ionization Calorimeter

Seo et al. Adv. in Space Res., **19** (5), 711, 1997; Ganel et al. NIM A, **552**(3), 409, 2005




- Beam measurements for 150 GeV electrons show 91% containment of incident energy, with a resolution of 2% at 150 GeV
- Proton containment ~38%



# ATIC discovers mysterious excess of high energy electrons

Chang et al., Nature, **456**, 362-365 (2008)


"All the News That's Fit to Print"

The New York Times

National Edition

VOL. CLVIII . . . No. 54,505

TUESDAY, NOVEMBER 25, 2008

## Detecting a Whisper, Perhaps, From the Dark Side of the Universe

Searching for Dark Matter High Above the Antarctic

Are anomalies in the sky signs of dark matter, or something simpler?


nature International weekly journal of science

Cited > 200 times in ~ 9 mo

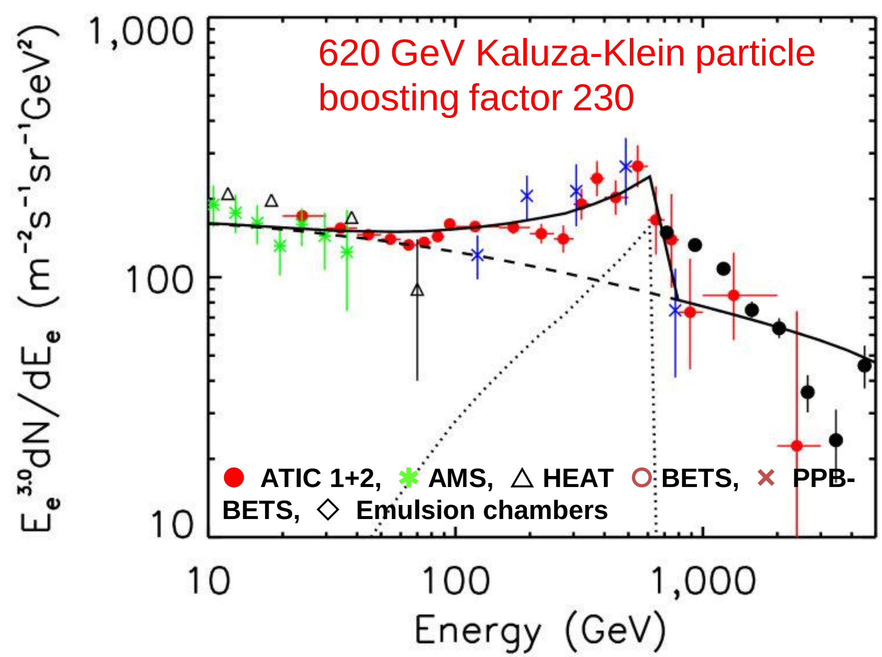
Letter

*Nature* 456, 362-365 (20 November 2008) | doi:10.1038/nature07477; Received 23 May 2008; Accepted 1 October 2008

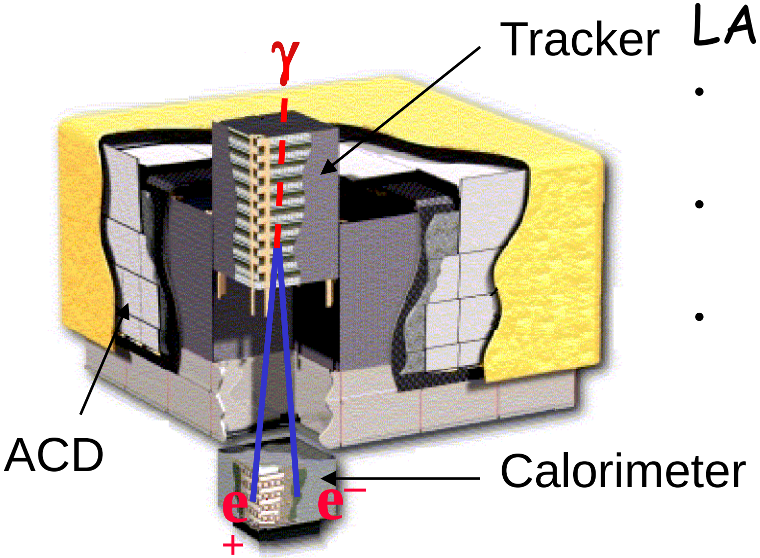

An excess of cosmic ray electrons at energies of 300–800 GeV


J. Chang[1,2], J. H. Adams[3], H. S. Ahn[4], G. L. Bashindzhagyan[5], M. Christl[3], O. Ganel[4], T. G. Guzik[6], J. Isbert[6], K. C. Kim[4], E. N. Kuznetsov[5], M. I. Panasyuk[5], A. D. Panov[5], W. K. H. Schmidt[2], E. S. Seo[4], N. V. Sokolskaya[5], J. W. Watts[3], J. P. Wefel[6], J. Wu[4] & V. I. Zatsepin[5]

1. Purple Mountain Observatory, CAS, 2 West Beijing Road, Nanjing 210008, China
2. Max Planck Institute for Solar System Research, 2 Max Planck-Strasse, Katlenburg-Lindau 37191, Germany
3. Marshall Space Flight Center, Huntsville, Alabama 35812, USA
4. University of Maryland, Institute for Physical Science & Technology, College Park, Maryland 20742, USA
5. Skobeltsyn Institute of Nuclear Physics, Moscow State University, Leninskie gory, GSP1, Moscow 119991, Russia
6. Louisiana State University, Department of Physics and Astronomy, Baton Rouge, Louisiana 70803, USA

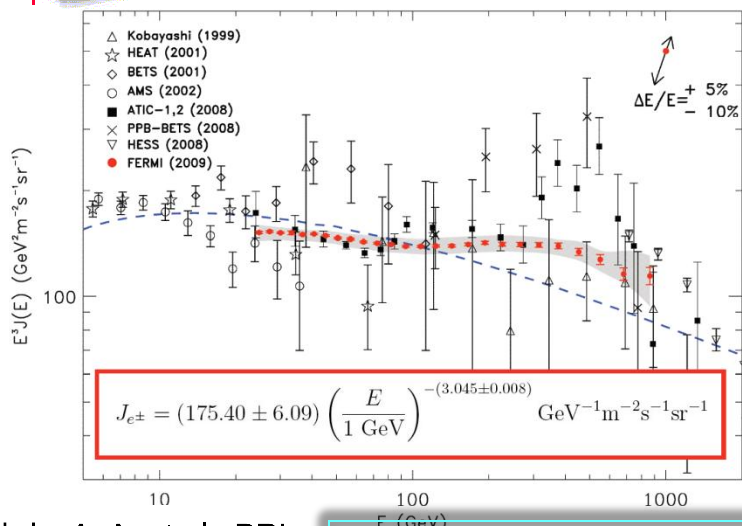





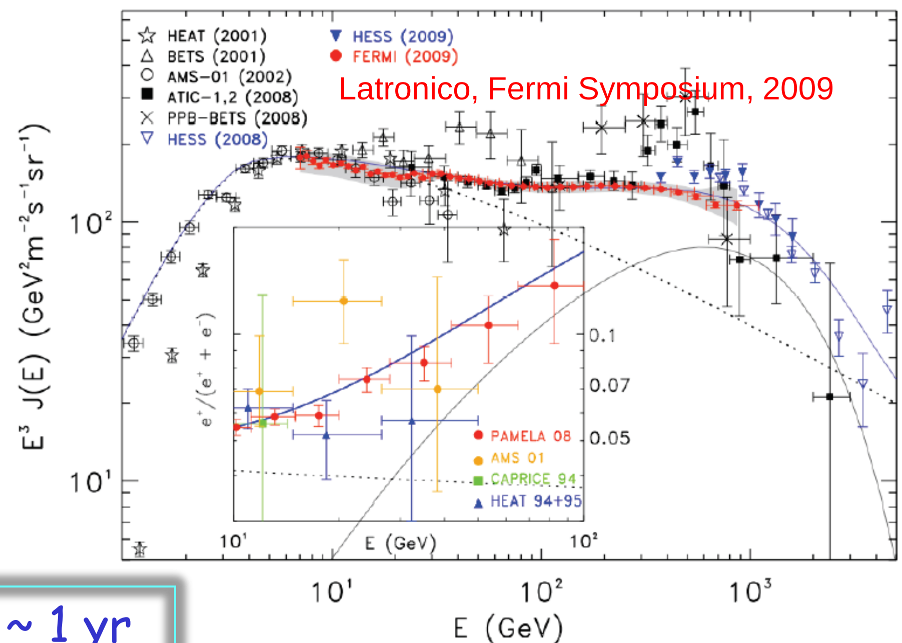



## LAT

- Highly granular multi-layer Si stripTracker (1.5 $X_0$)
- Finely segmented fully active CsI Calorimeter (8.6 $X_0$ )
- Highly efficient hermetic Anti-Coincidence Detector (ACD)



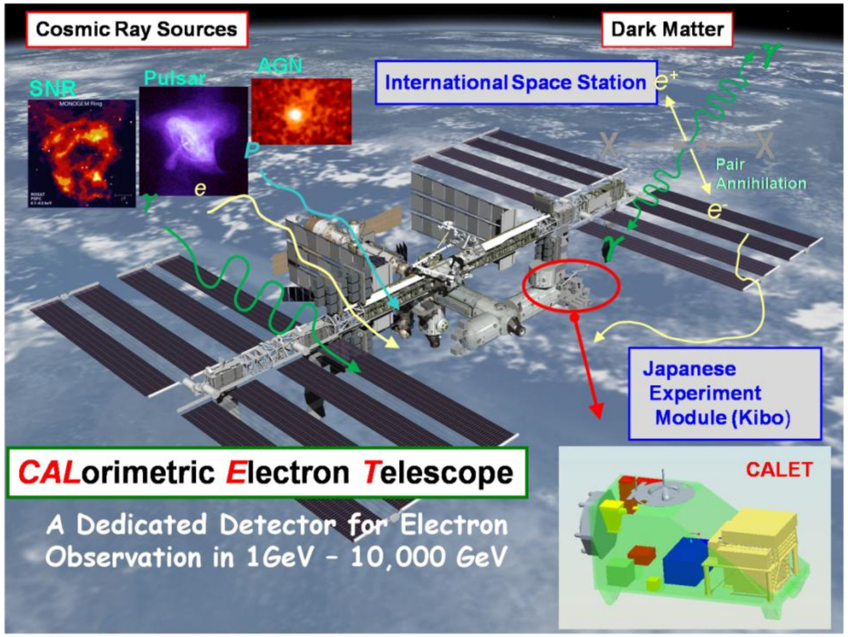

Abdo, A. A. et al., PRL **102, 181101, 2009**

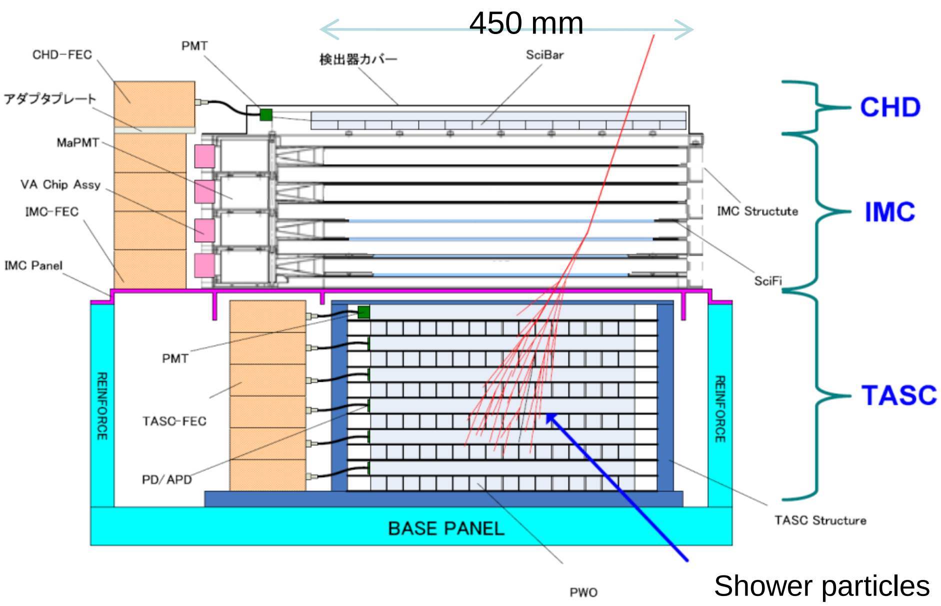



Cited > 150 times in ~ 1 yr

# CALET Calorimetric Electron Telescope

Launch target 2014




**Charge Detector** **(Charge Z=1-40)**

1 Layer of 14 Plastic Scintillators ( 32 x 10 x 450 $mm^3$)

**Imaging Calorimeter** **(Particle ID, Direction)**

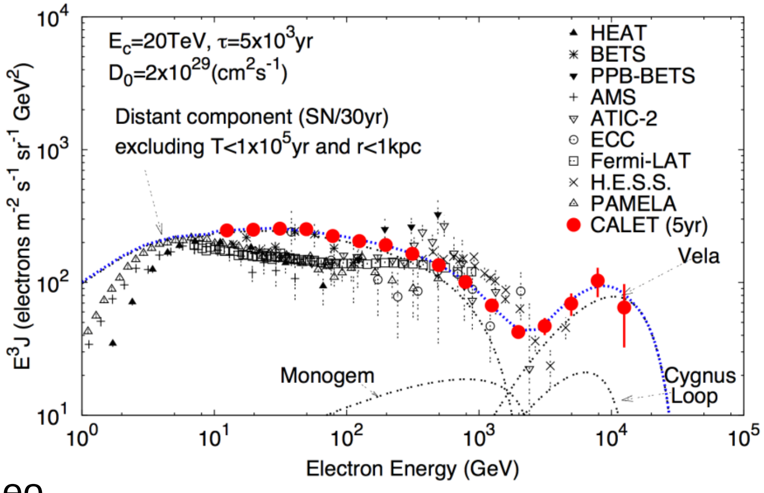
Total Thickness of Tungsten (W) : 3 $X_0$

Layer Number of Scifi Belts: 8 Layers ×2(X,Y)

**Total Absorption Calorimeter** **(Energy Measurement, Particle ID)**

PWO 20 mm x 20 mm x 320 mm

Total Depth of PWO: 27 $X_0$ (24 cm)

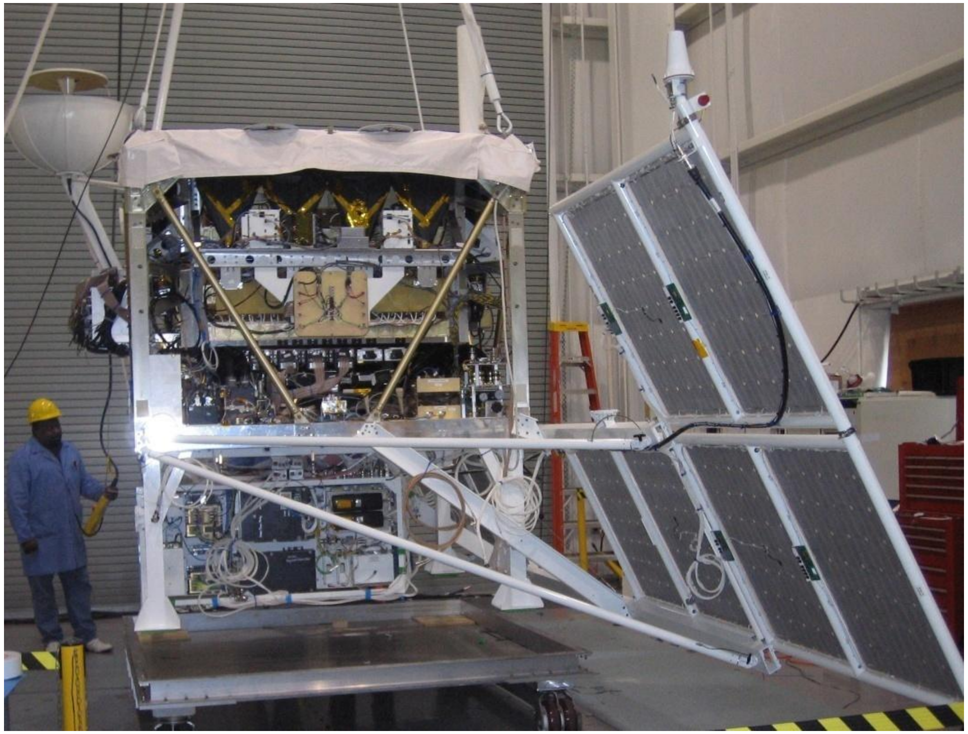


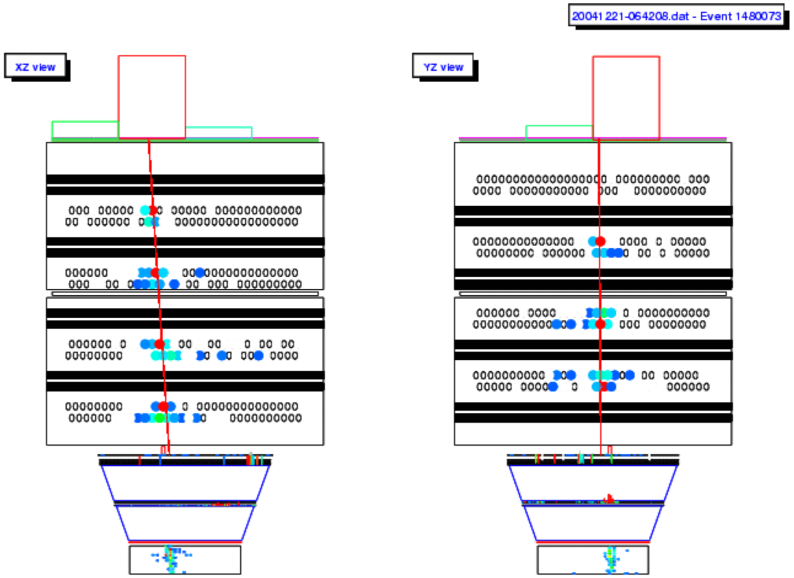
# CREAM Cosmic Ray Energetics And Mass

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

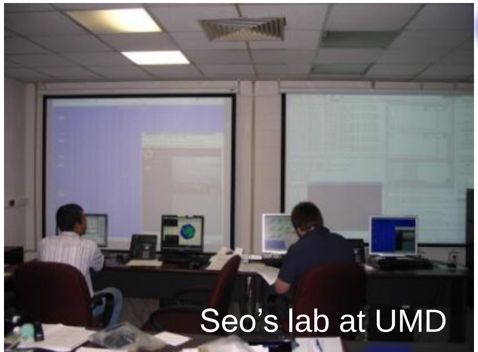
- The CREAM instrument has had six successful Long Duration Balloon (LDB) flights and have **accumulated 161 days** of data.
  - This longest known exposure for a single balloon project verifies the instrument design and reliability.

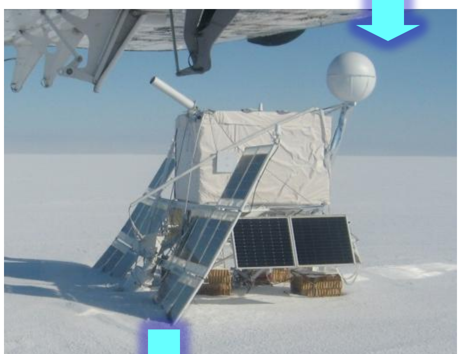




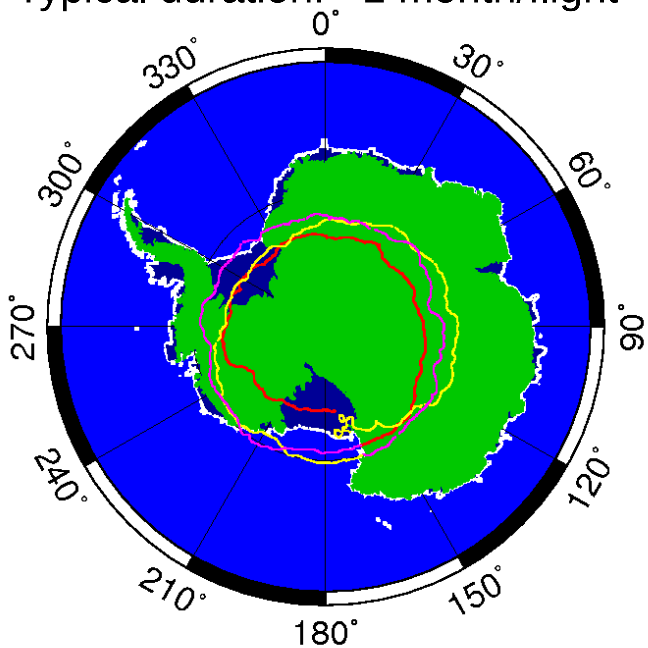
# Balloon Flights in Antarctica Offer Hands-On Experience

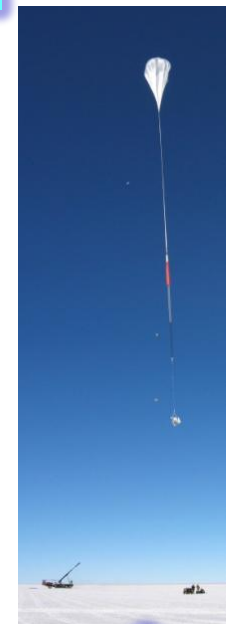
CREAM has produced >12 Ph.D.'s



Typical duration: ~1 month/flight



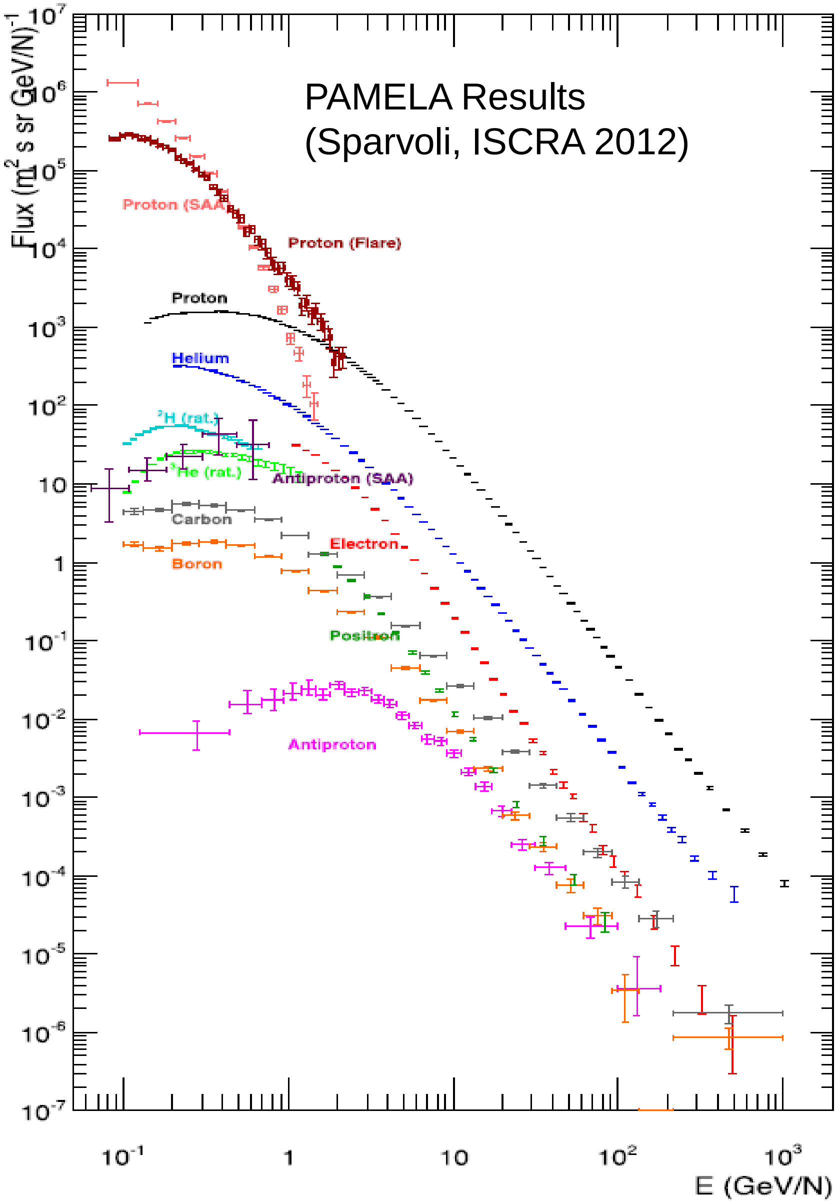
The instruments are for the most part **built in-house by students** and young scientists, many of them currently working in the on-campus laboratory.

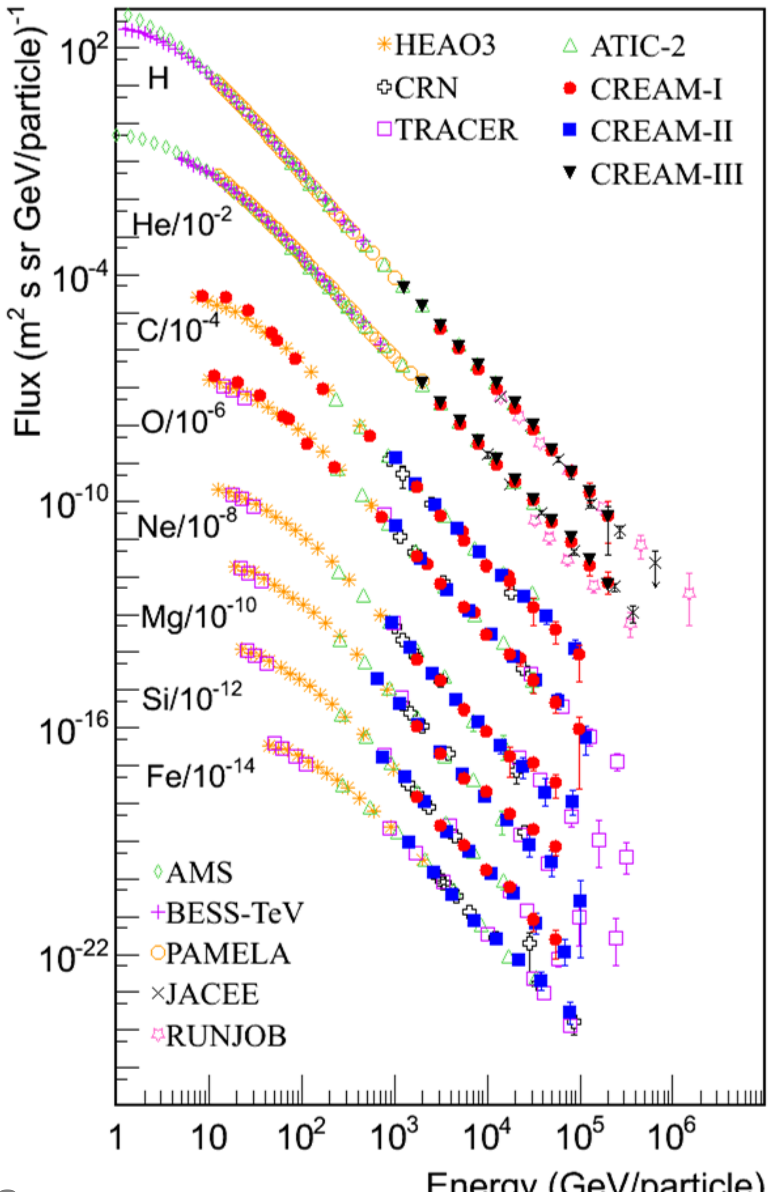
Instruments are fully recovered, refurbished & reflown.



# Elemental Spectra over 4 decades in energy

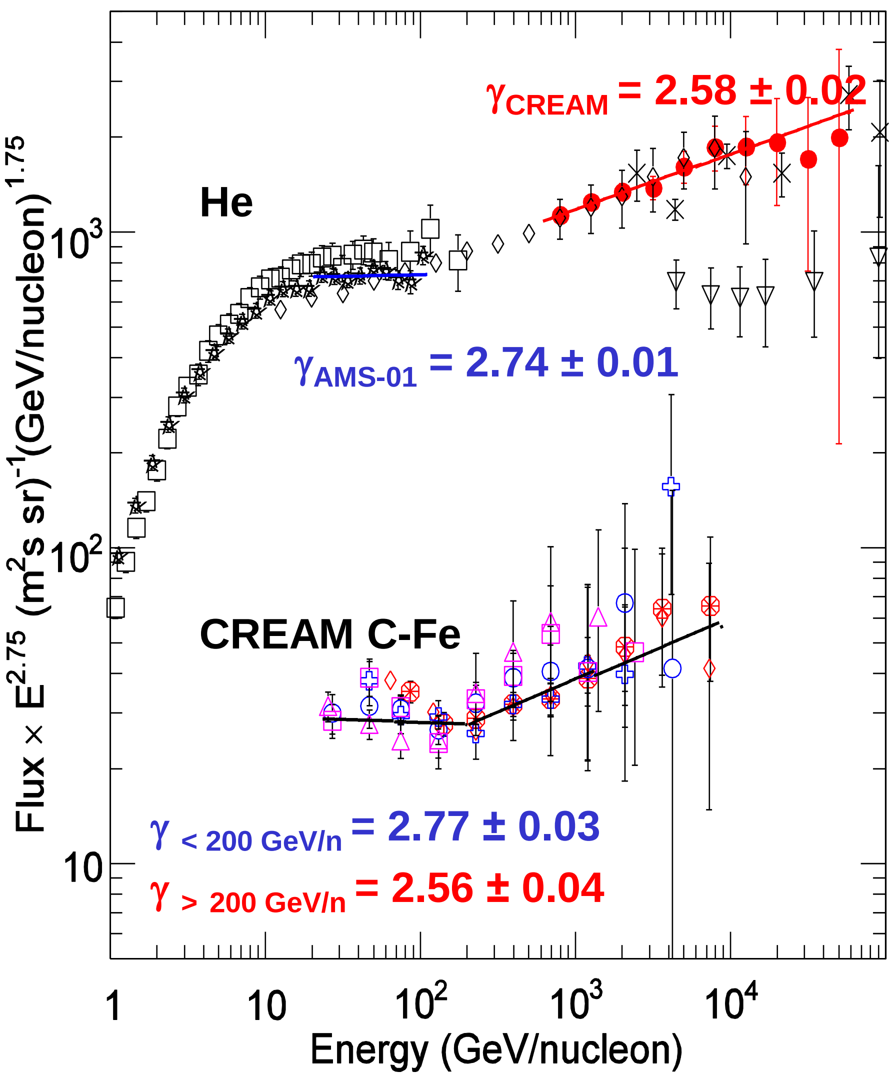
Yoon et al. ApJ **728**, *122*, 2011; Ahn et al., ApJ **715**, *1400*, 2010; Ahn et al. ApJ **707**, *593*, 2009

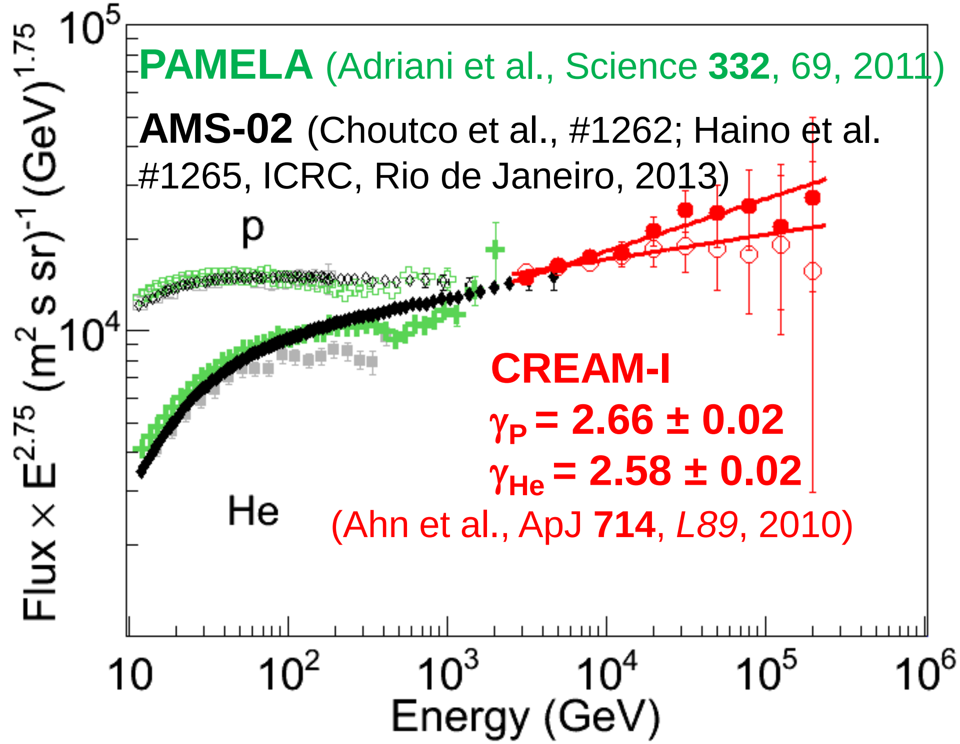


# CREAM spectra harder than prior lower energy measurements

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



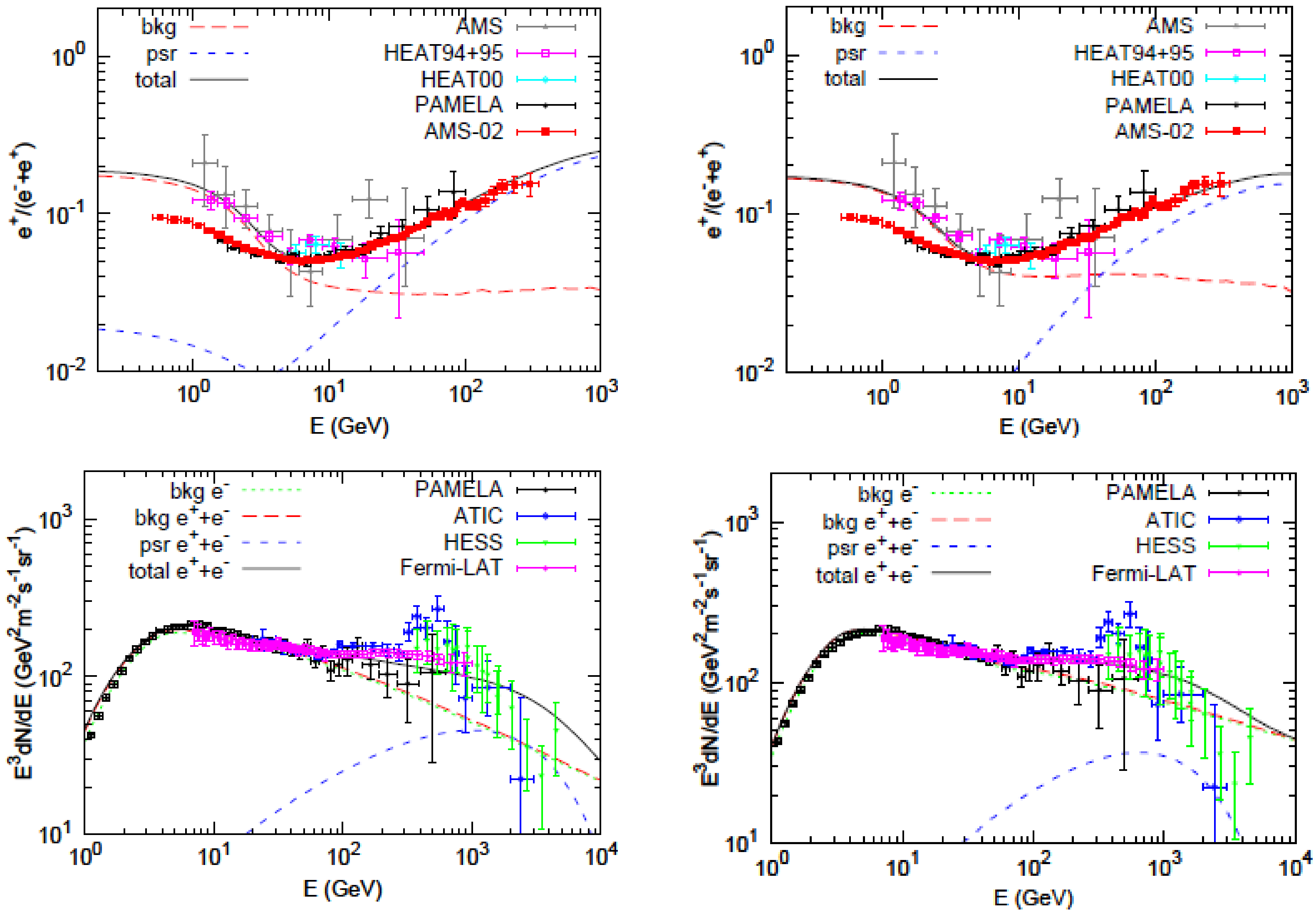




It provides important constraints on cosmic ray acceleration and propagation models, and it must be accounted for in explanations of the electron anomaly and cosmic ray "knee."

# Taking into account the spectral hardening of elements

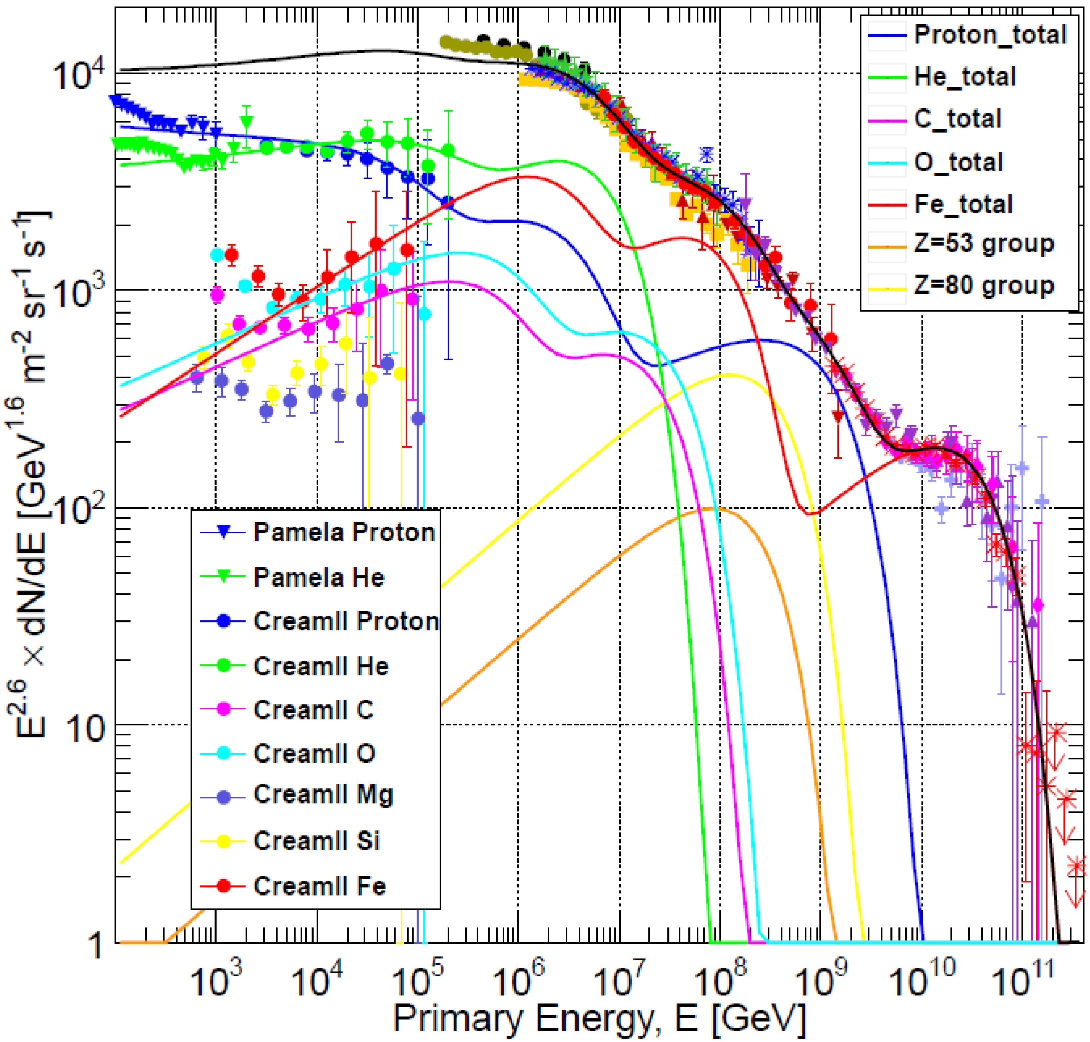
for the (AMS/PAMELA/ATIC/FERMI) high energy $e^+ e^-$ enhancement

Yuan & Bi, arXiv:1304.2687v1 & 1304.2687v1, 2013



# Spectral breaks observed in CR spectrum solves the puzzle with the knee and beyond

T. K. Gaisser, T. Stanev and S. Tilav, arXiv:1303.3565 [astro-ph.HE]




S. Tilav's presentation, TeV Particle Astrophysics, Irvine, CA , 26-29 August 2013

# Need to extend measurements to higher energies

Unpublished Data
Not shown

# 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, $\sigma$: 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 $\alpha$

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

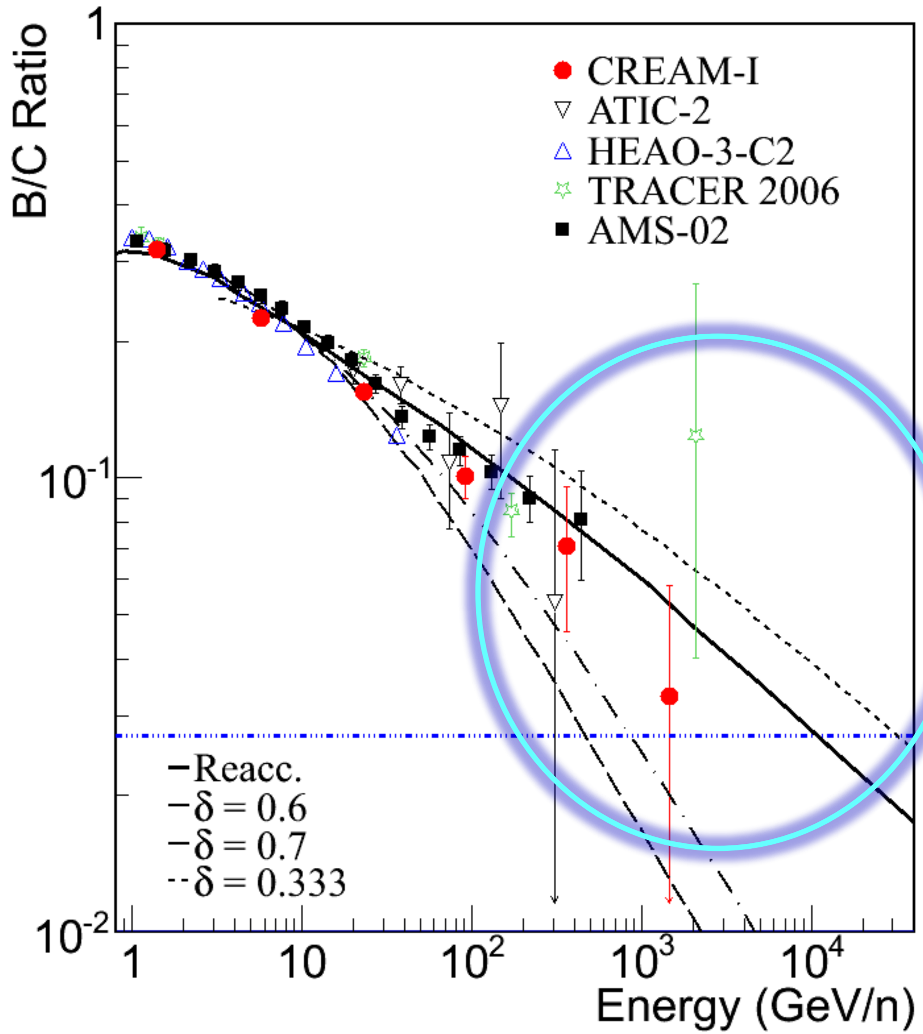
# What is the history of cosmic rays in the Galaxy?

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

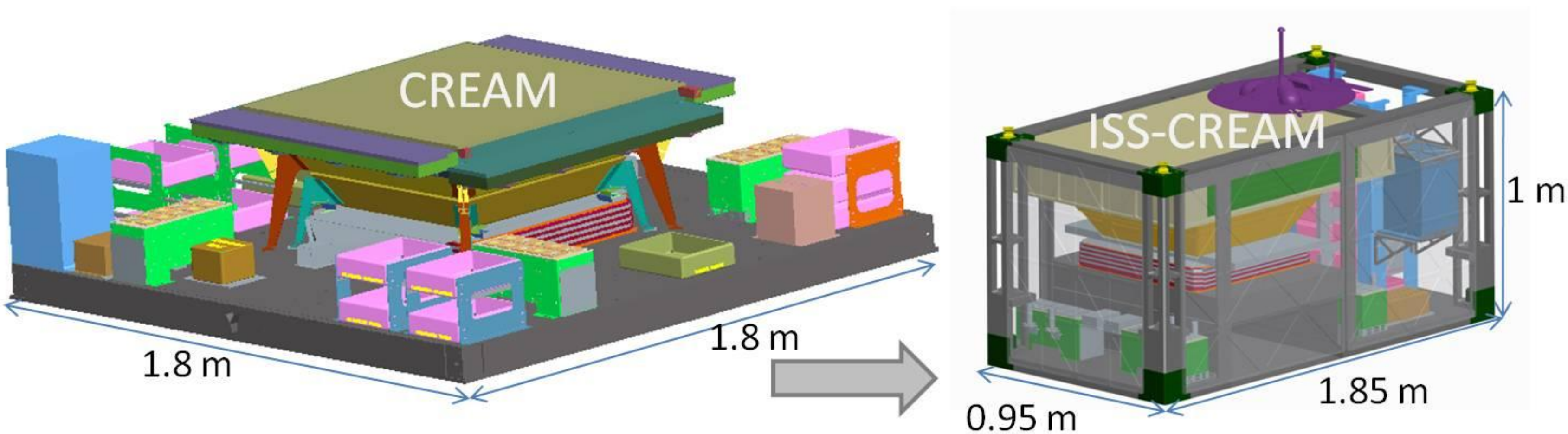
$$X_e \propto R^{-\delta}$$



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

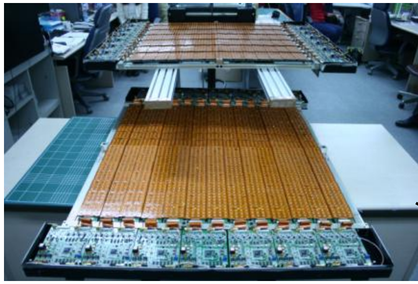
Increase the exposure by an order of magnitude

- 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.



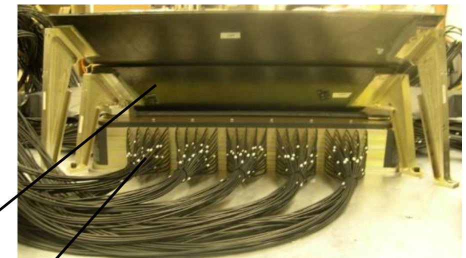
# ISS-CREAM Instrument

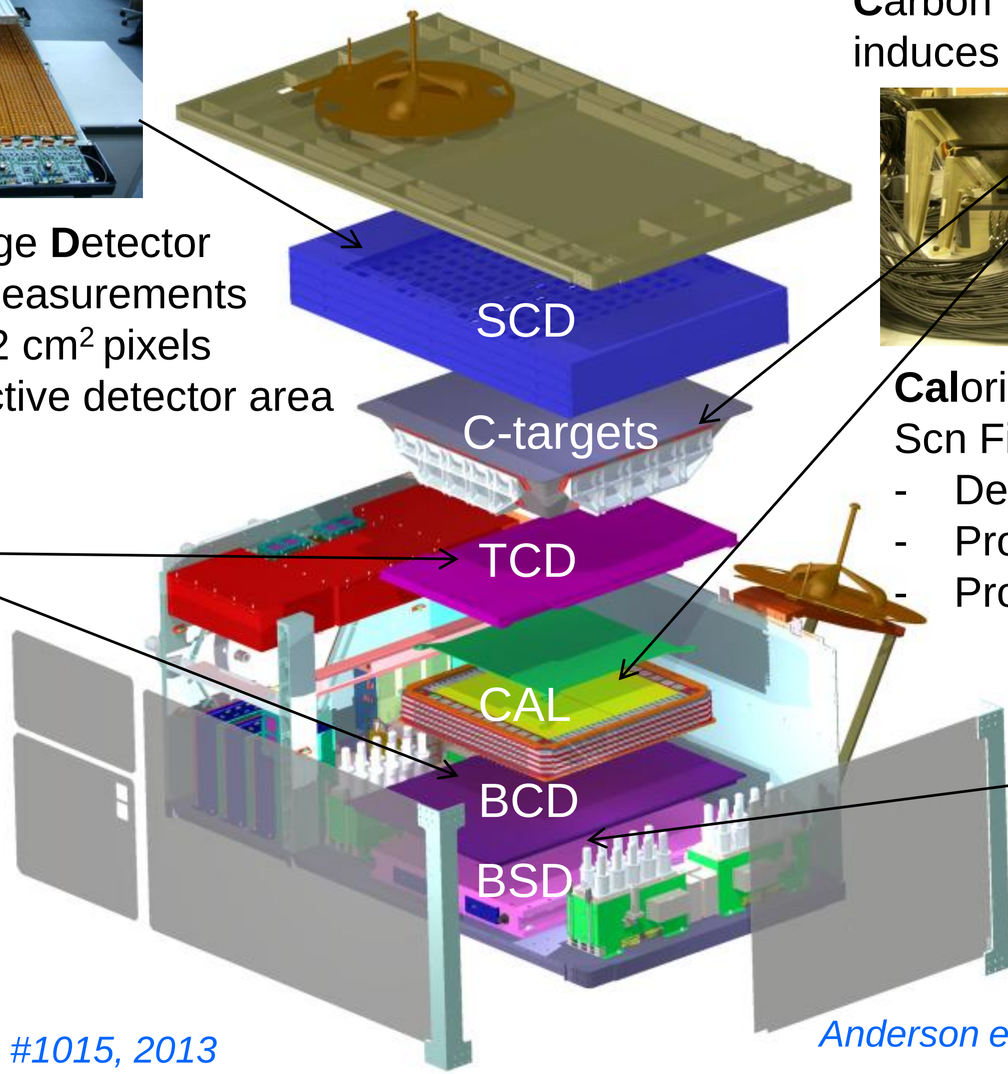
*Ahn et al., NIM A, **579**, 1034, 2007; Amare et al. 33rd ICRC, #0630, 2013*



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

**C**arbon **Targets** (0.5 $\lambda_{int}$ )
induces hadronic interactions







**Cal**orimeter (20 layers W + Scn Fibers)
- Determine Energy
- Provide tracking
- Provide Trigger

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

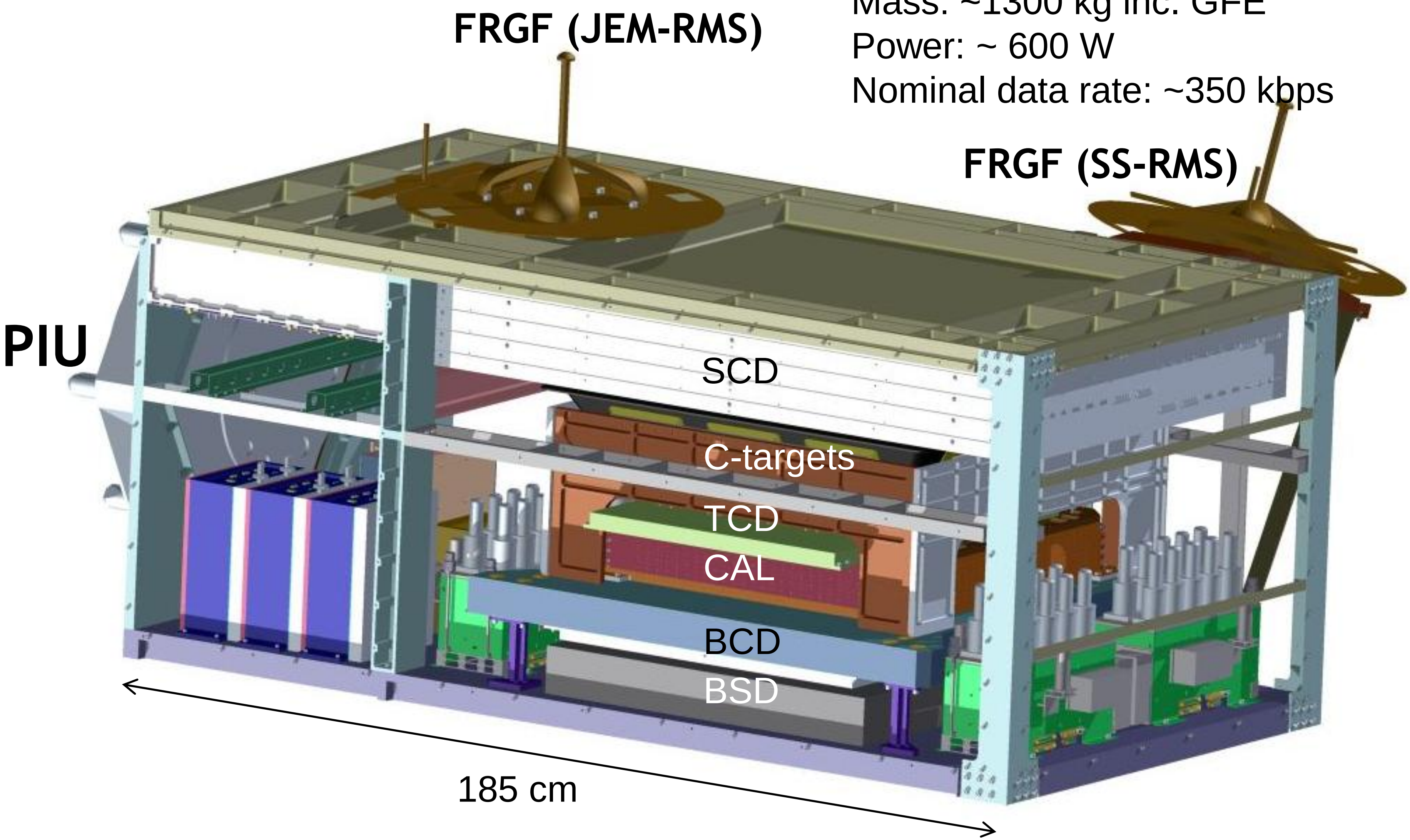
*Park et al. 33rd ICRC, #1015, 2013*
*Hyun et al. 33rd ICRC, #1017, 2013*

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

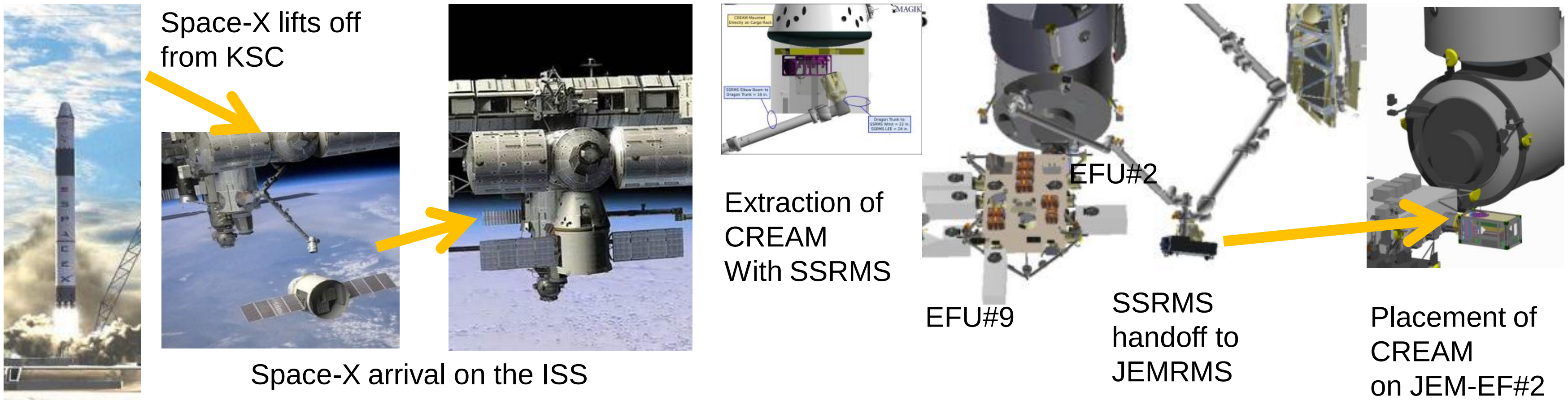
*Anderson et al. 33rd ICRC, #0350, 2013*

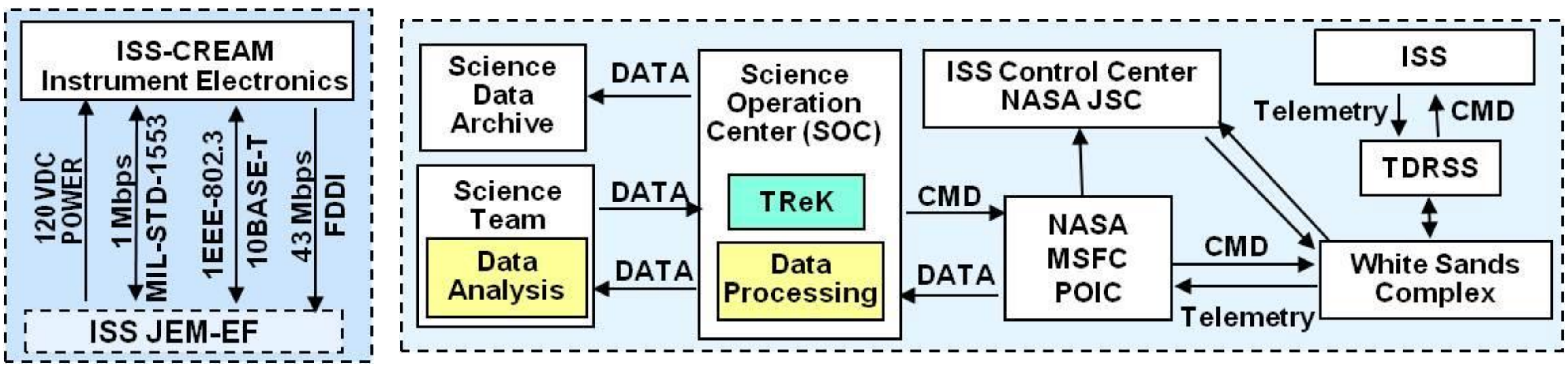
# ISS-CREAM payload

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



# Mission Concept & Data Flow

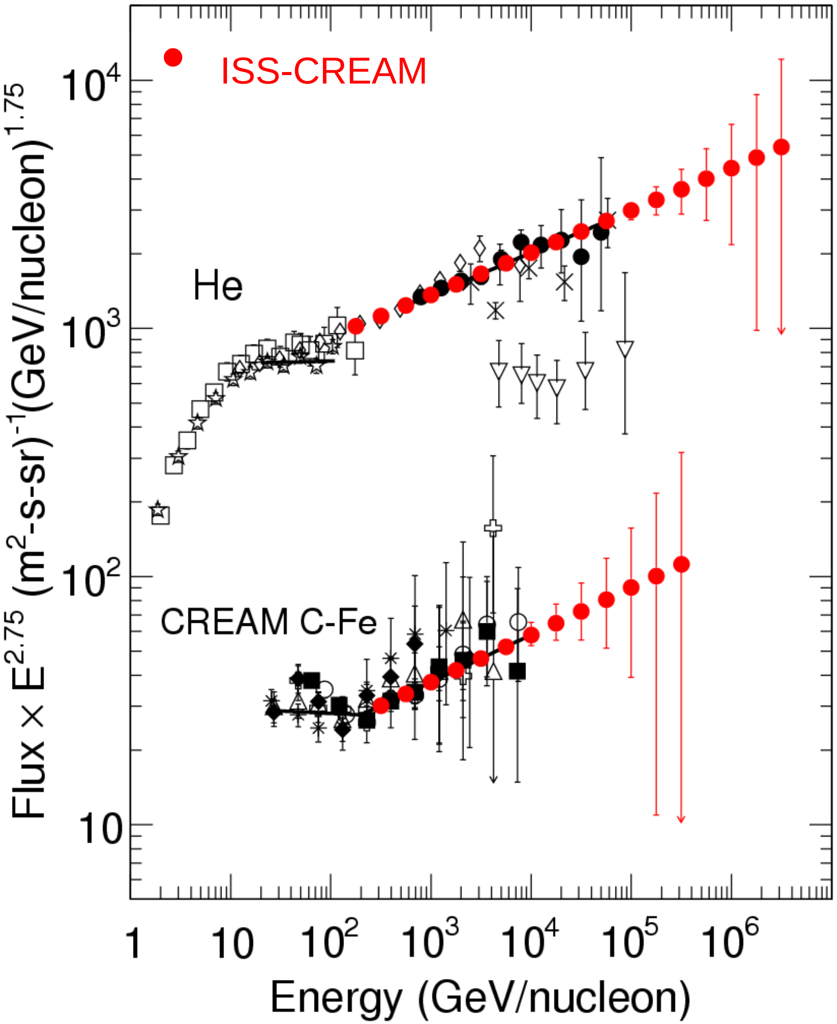



**Plan to be launch ready in 2014**

# ISS-CREAM takes the next major step

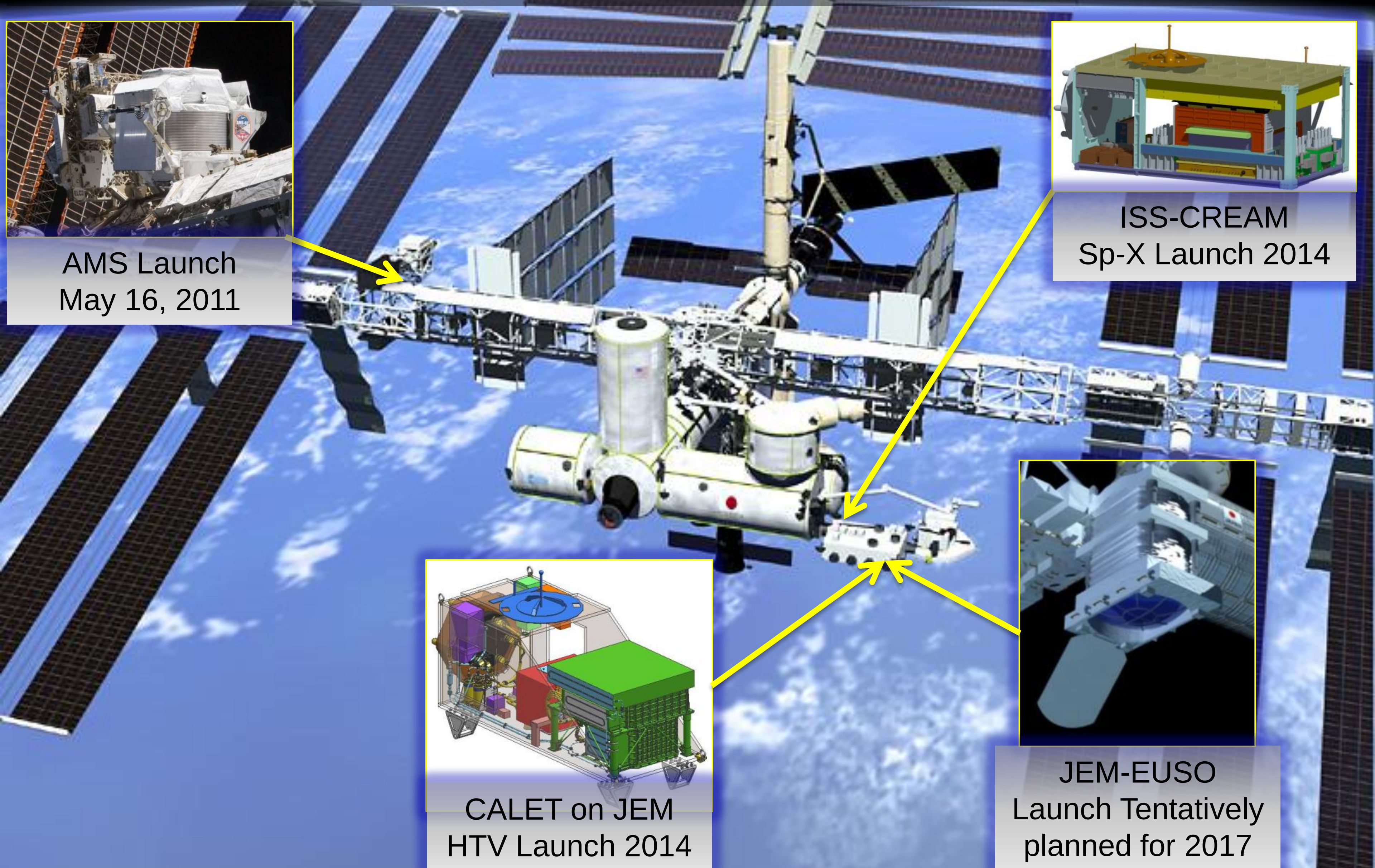
- The ISS-CREAM space mission can take the next major step to $10^{15}$ eV, and beyond, limited only by statistics.
- The 3-year goal, 1-year minimum exposure would greatly reduce the statistical uncertainties and extend CREAM measurements to energies beyond any reach possible with balloon flights.



# THE ISS-CREAM TEAM

“Cosmic Ray Observatory on the ISS”

# Current Status: ISS is complete and utilization underway



# Thank you!

http://cosmicray.umd.edu