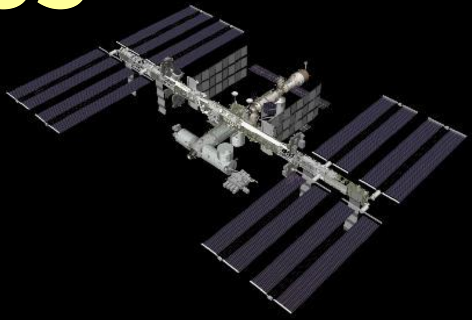
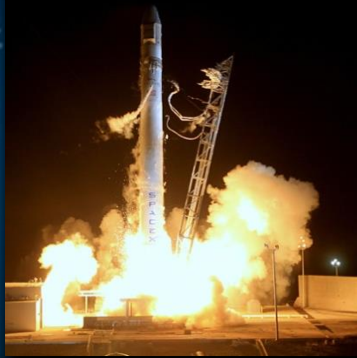
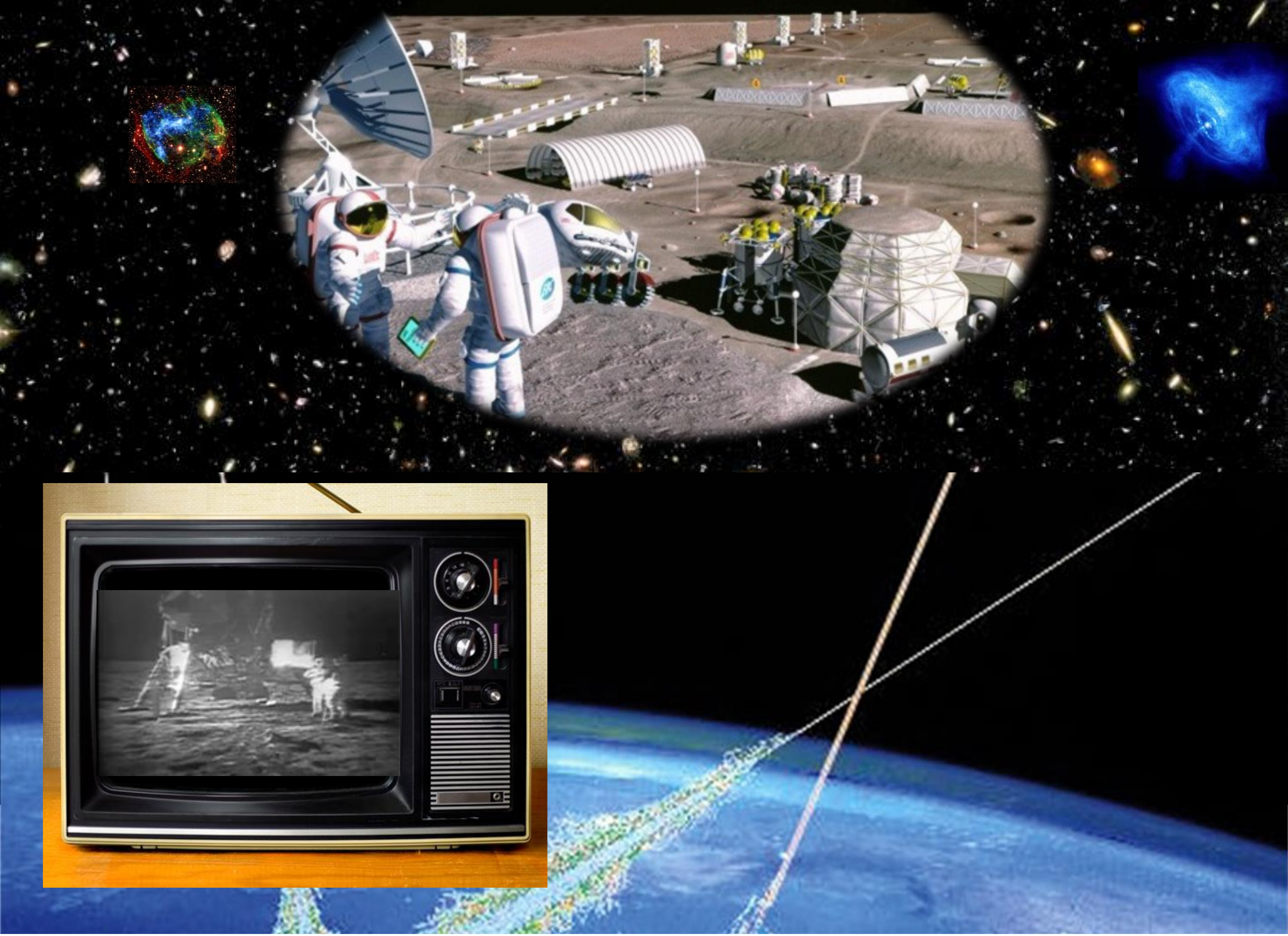
Cosmic Ray Energetics And Mass: From Balloons to the ISS



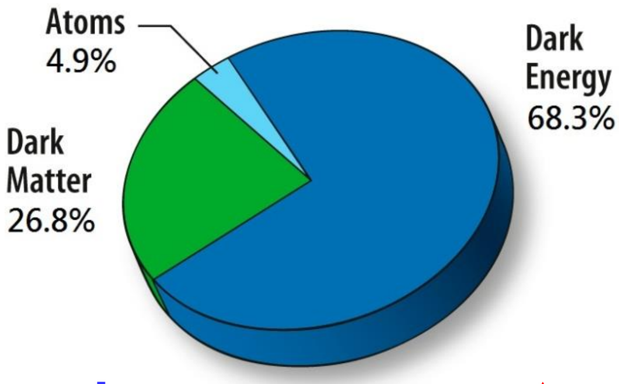


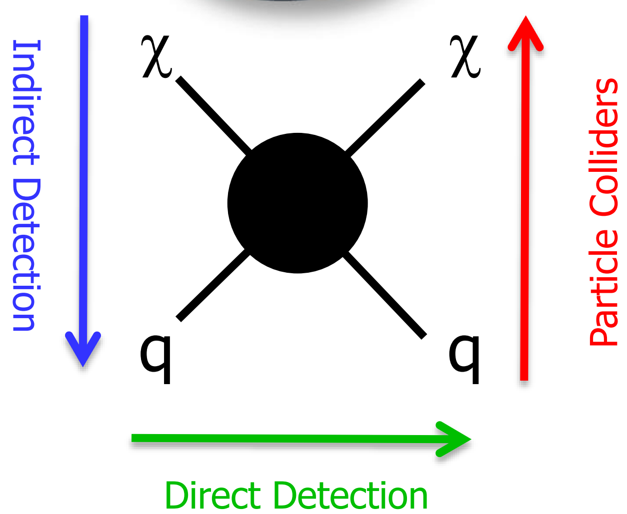
Eun-Suk Seo
Inst. for Phys. Sci. & Tech. and
Department of Physics
University of Maryland

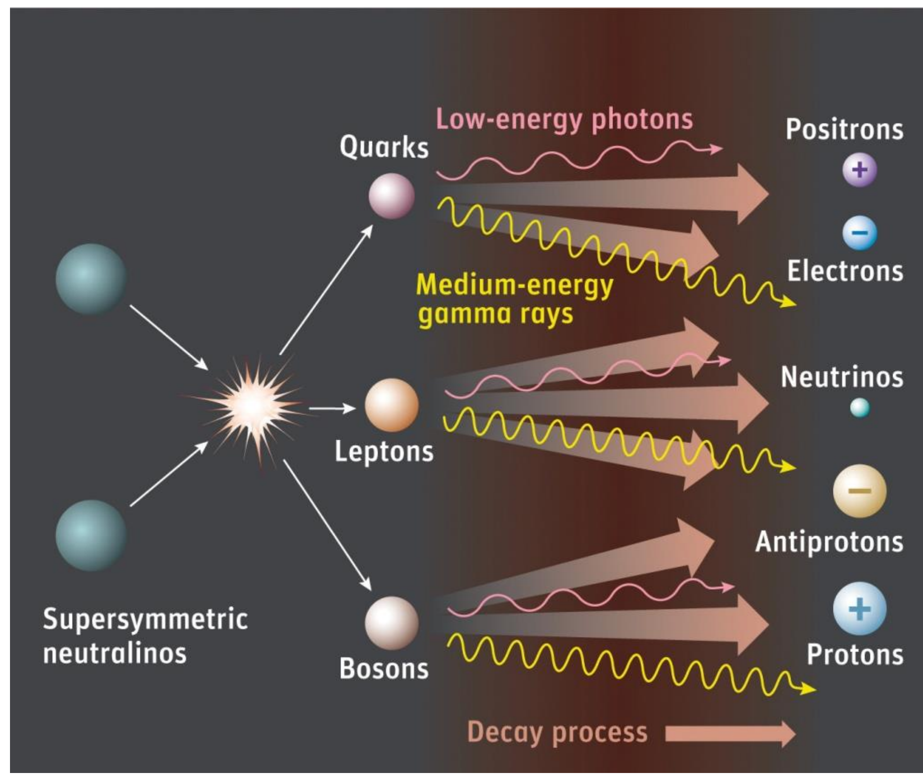


We do not know what 95% of the universe is made of!

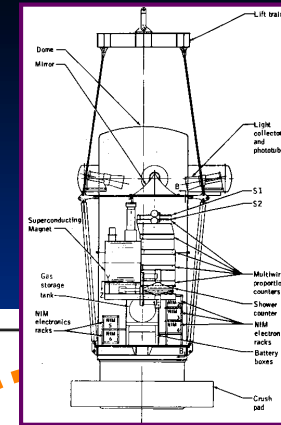
- Weakly Interacting Massive Particles (WIMPS) could comprise dark matter.
- This can be tested by direct search for various annihilating products of WIMP's in the Galactic halo.







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)

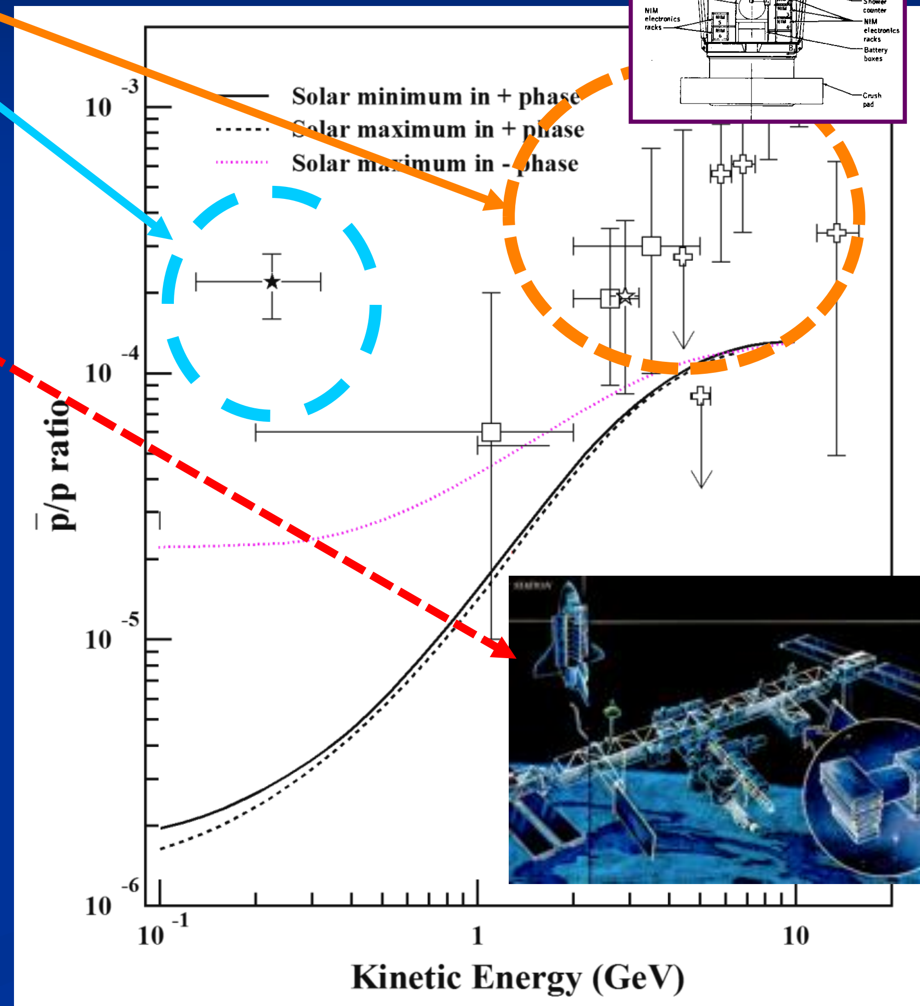
2000/2: Heat-pbar

2004: BESS-Polar I

2006-present PAMELA (Polar-orbit)

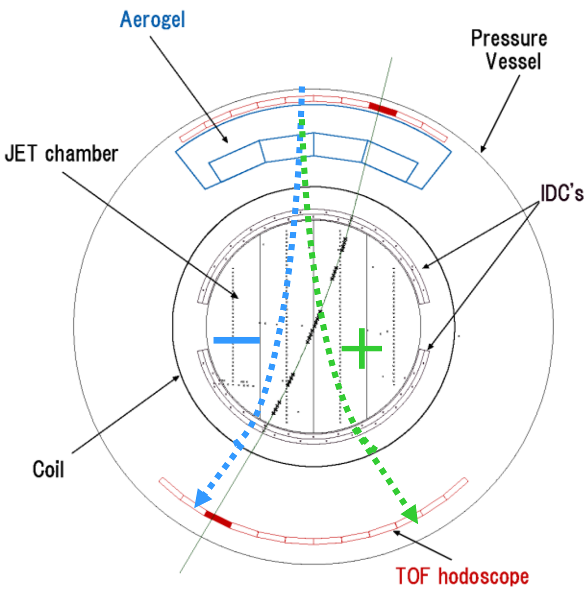
2007: BESS-Polar II

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

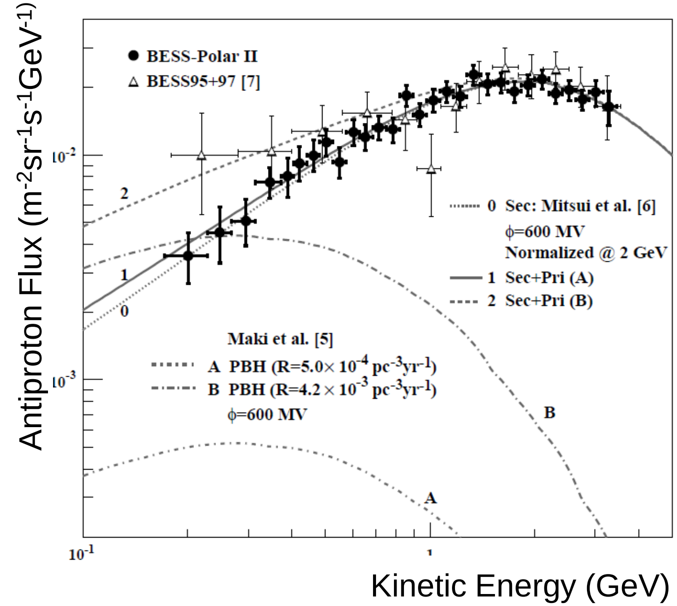


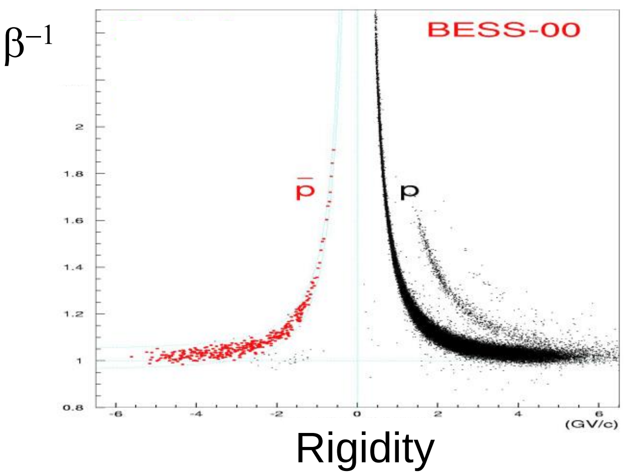
BESS-Polar II

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

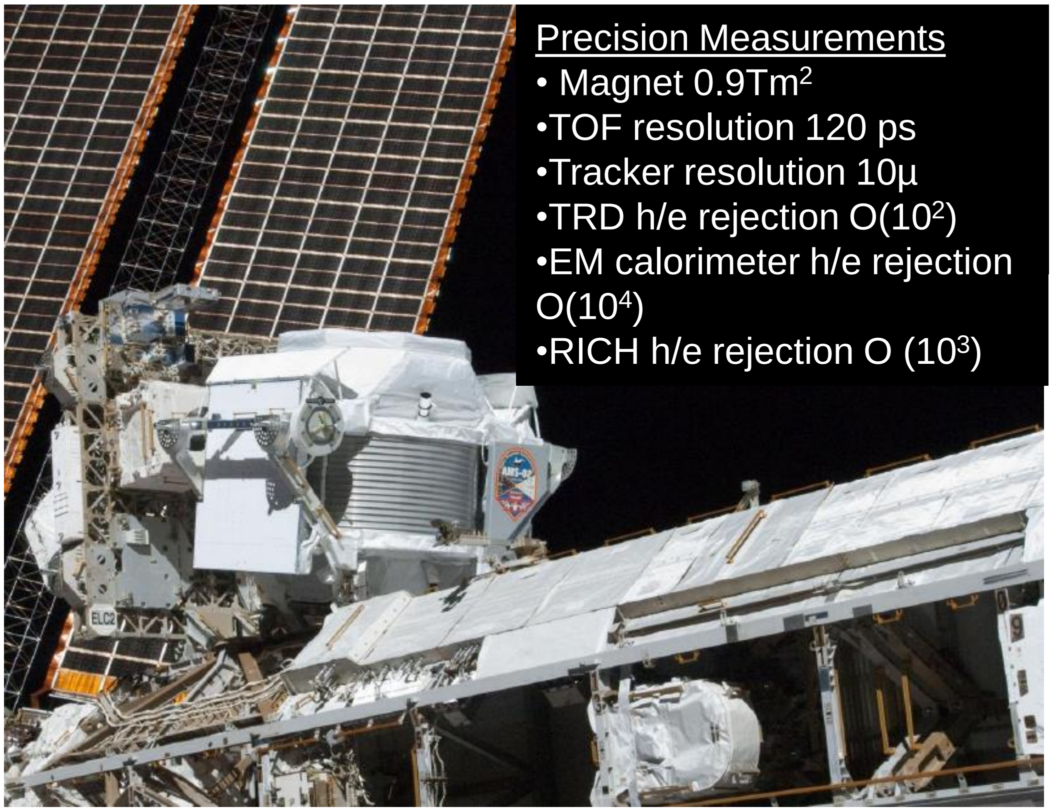
7886 antiprotons detected: **no evidence of primary antiprotons from evaporation of primordial black holes.**

AMS

Alpha Magnet Spectrometer

Launch for ISS on May 16, 2011

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

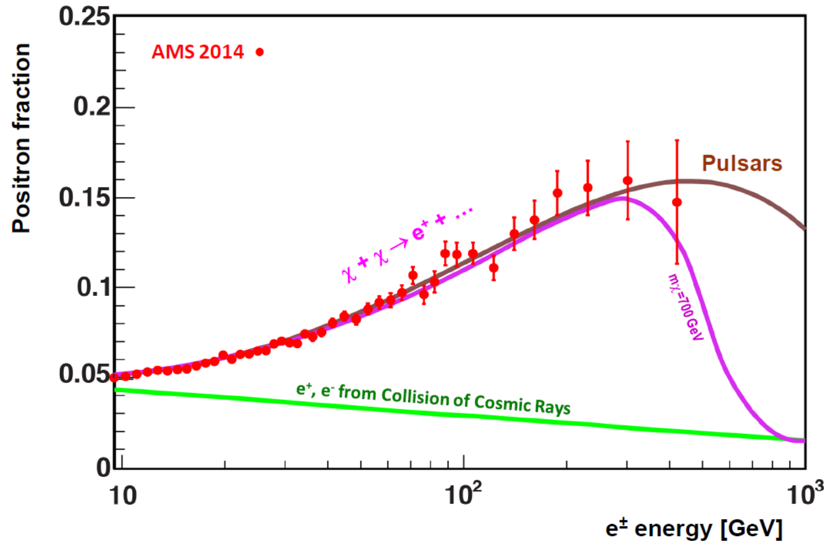


<u>Precision Measurements</u>

- Magnet 0.9Tm^2
- TOF resolution 120 ps
- Tracker resolution 10μ
- 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



Astronomy magazine

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Latest measurements from the AMS experiment unveil new territories in the flux of cosmic rays

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Latest measurements from the AMS experiment unveil new territories in the flux of cosmic rays

The excess positrons in the flux could be an indicator of dark matter particles annihilating into pairs of electrons and positrons.

By CERN, Geneva, Switzerland | Published: Friday, September 19, 2014

RELATED TOPICS: SPACE PHYSICS | COSMIC RAYS

"With AMS and with the LHC to restart in the near future ***at energies never reached before, we are living in very exciting times*** *for particle physics as both instruments are pushing boundaries of physics,"* said CERN Director-General Rolf Heuer.

Cosmic Rays

NBC NEWS HOME TOP VIDEOS MORE

AMS Space Experiment Sees Hints of Dark Matter Particles

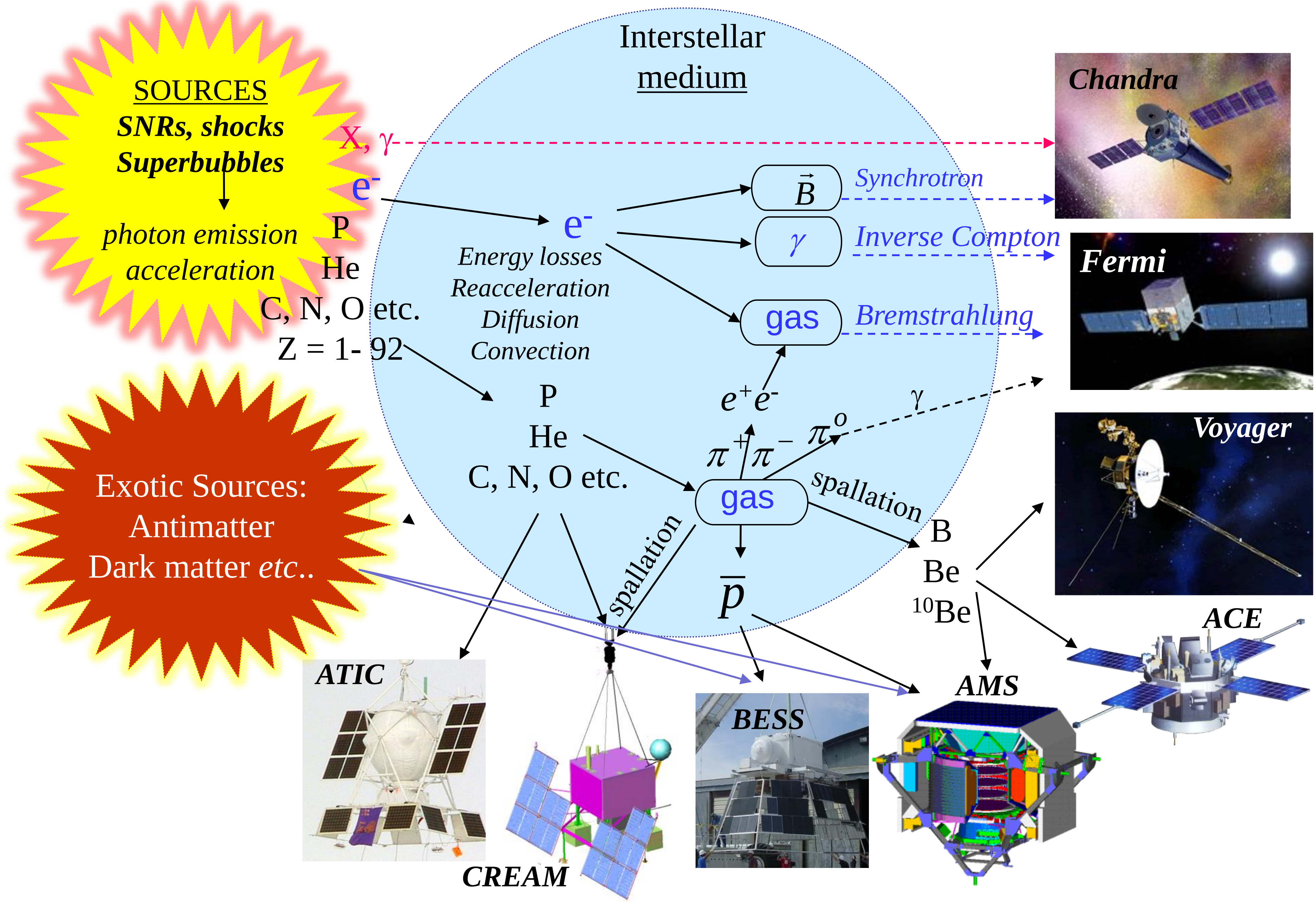
Scientists behind the $2 billion Alpha Magnetic Spectrom
experiment are reporting new data pointing toward the p

SCIENTIFIC AMERICAN™

Permanent Address: http://www.scientificamerican.com/podcast/episode/dark-matter-looks-wimpy/
Space » 60-Second Space

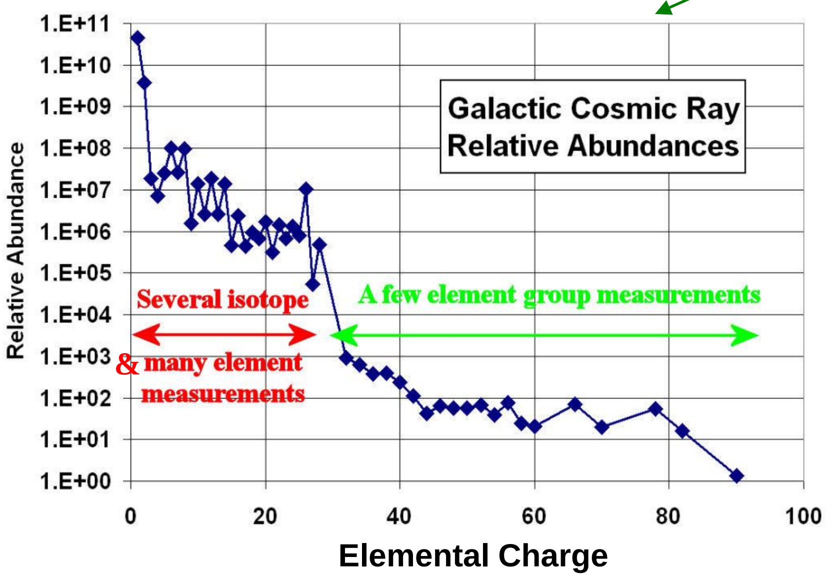
Dark Matter Looks WIMPy

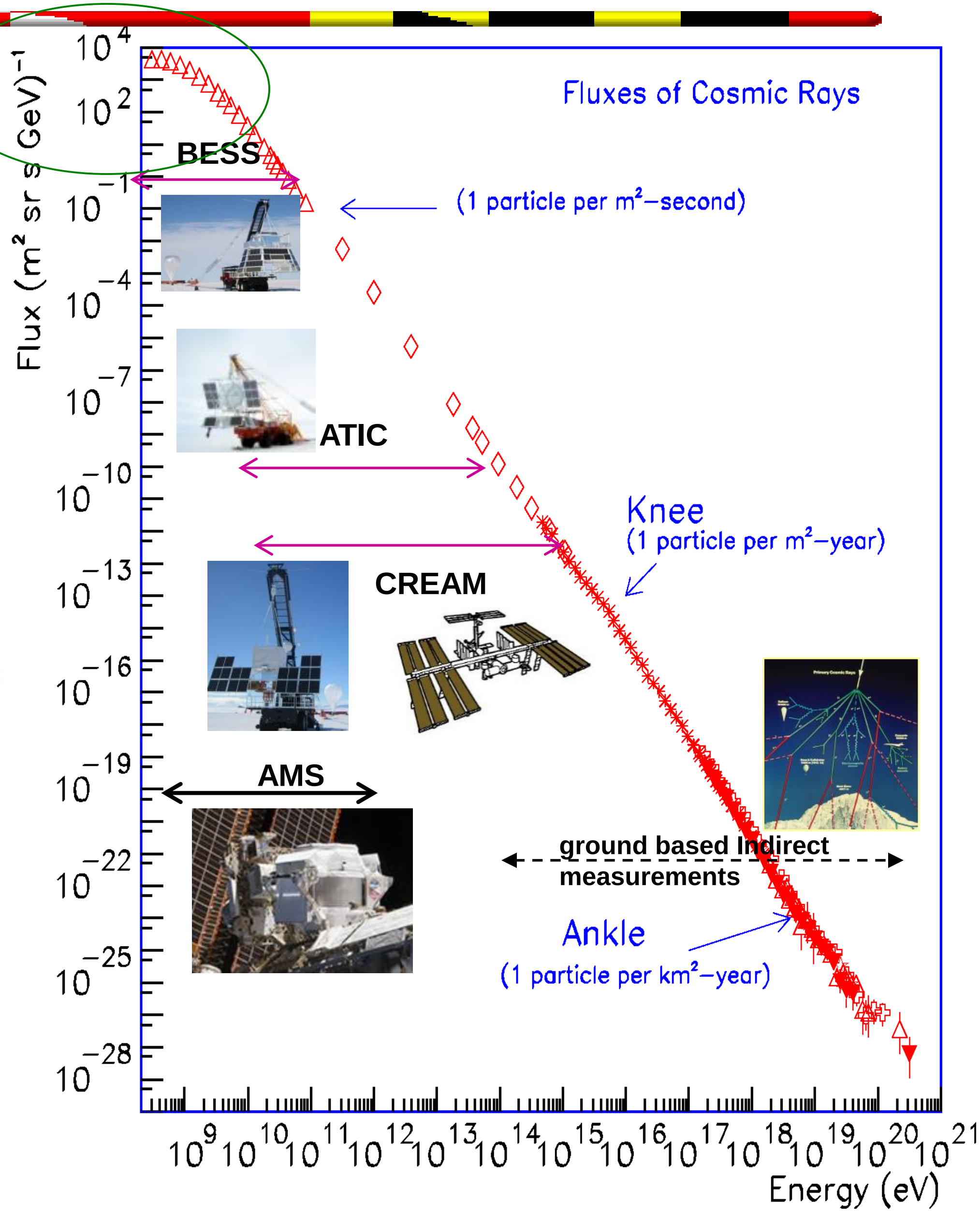
Data from the International Space Station-based Alpha Magnetic Spectro
consists of the invisible particles called weakly interacting massive particl



SOURCES
SNRs, shocks
Superbubbles
photon emission
acceleration
X, γ
e-
P
He
C, N, O etc.
Z = 1- 92
Interstellar
medium
e-
Energy losses
Reacceleration
Diffusion
Convection
B
γ
gas
Synchrotron
Inverse Compton
Bremstrahlung
e+e-
γ
π+ π−
π0
P
He
C, N, O etc.
gas
spallation
spallation
B
Be
10Be
p̄
Exotic Sources:
Antimatter
Dark matter etc..
Chandra
Fermi
Voyager
ACE
ATIC
CREAM
BESS
AMS

How do cosmic accelerators work?

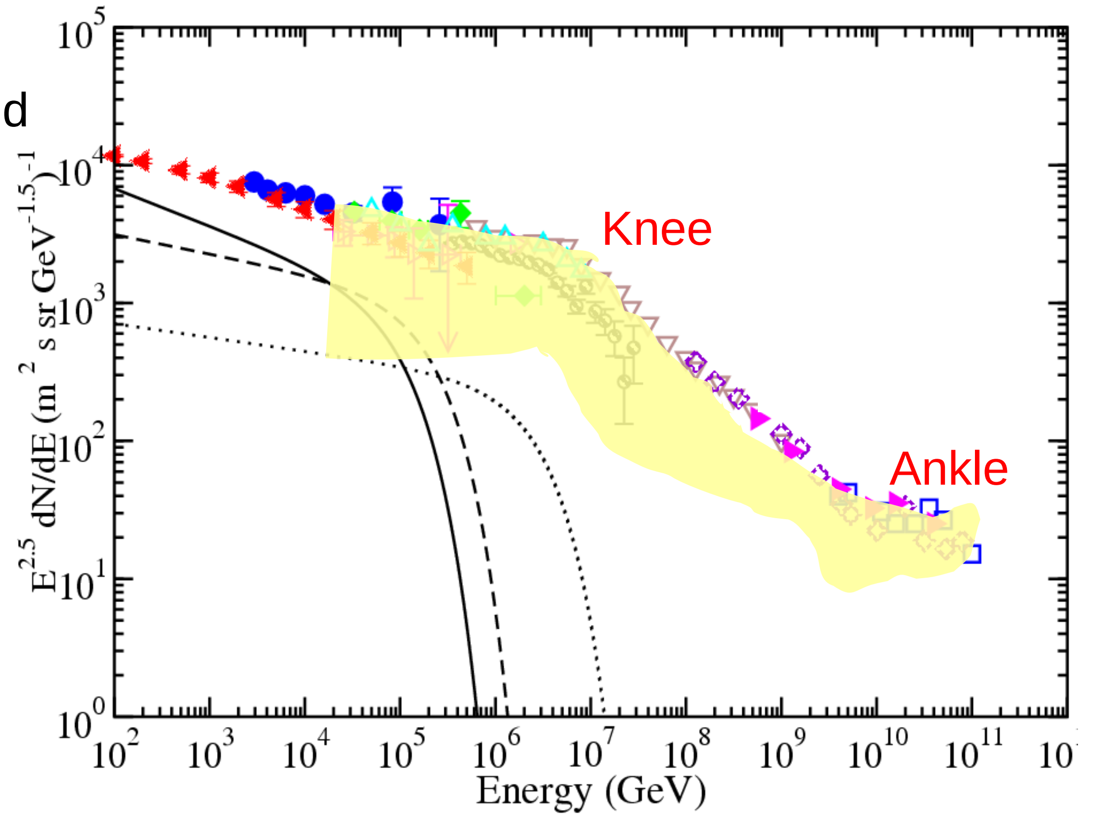




The ISS provides an excellent platform for our quest to investigate the low fluxes of high-energy cosmic rays.

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:

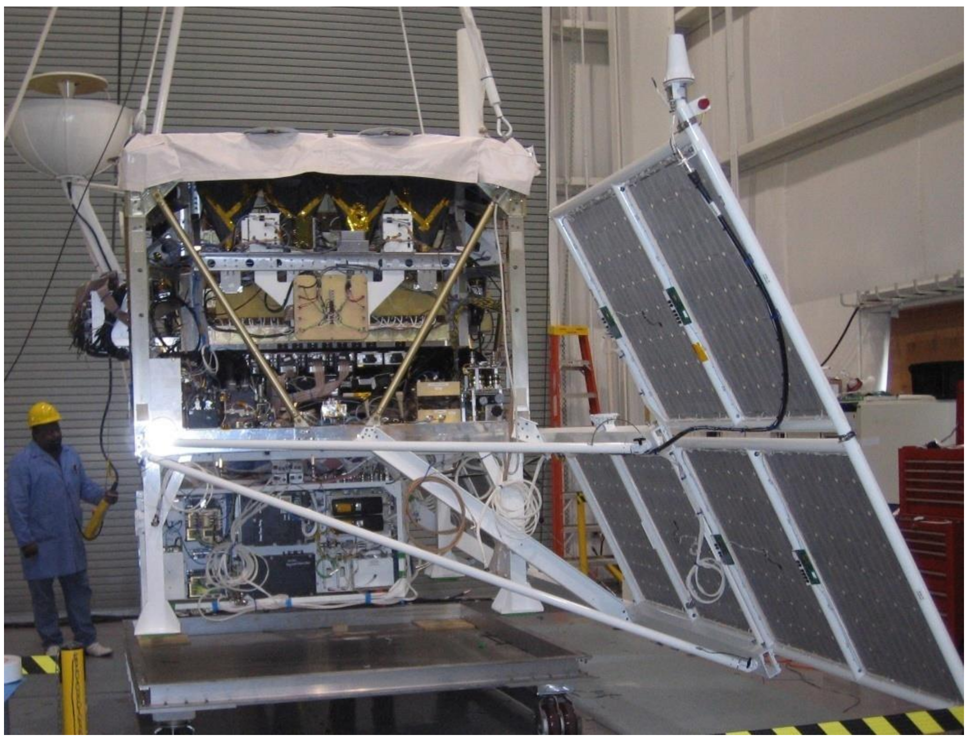
$$E_{\max} \sim \frac{v}{c} ZeBVT \sim Z \times E_{\max\_p}$$

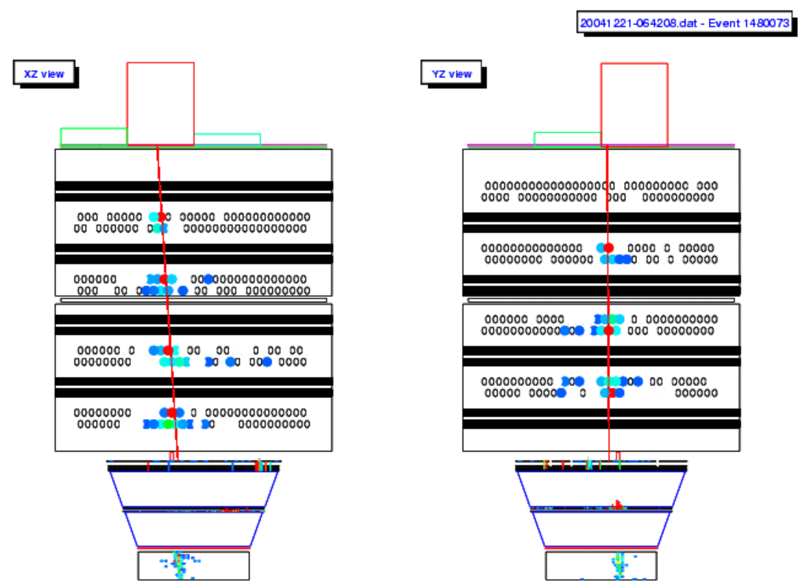
CREAM Cosmic Ray Energetics And Mass

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

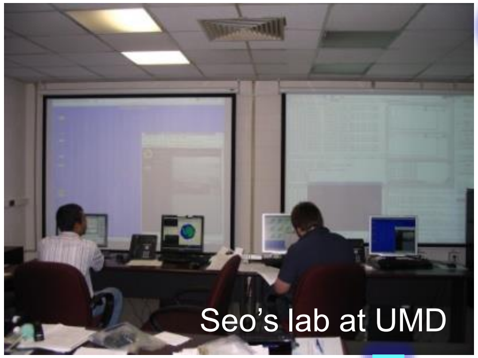
- The CREAM instrument has had six successful Long Duration Balloon (LDB) flights and have **accumulated 161 days** of data.
  – This longest known exposure for a single balloon project verifies the instrument design and reliability.

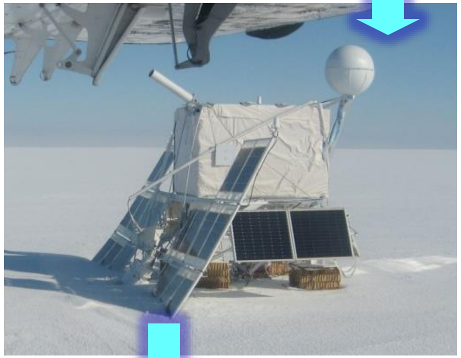




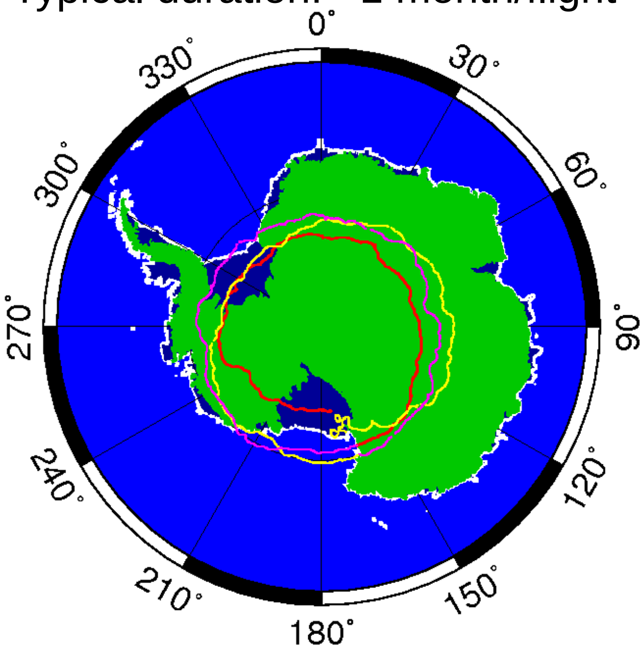
Balloon Flights in Antarctica Offer Hands-On Experience

CREAM has produced >12 Ph.D.'s





Typical duration: ~1 month/flight



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

Instruments are fully recovered, refurbished & reflown.

Two CREAM students won a poster award

International School of Cosmic Ray Astrophysics, Erice, Italy, 2014

Magazine

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)

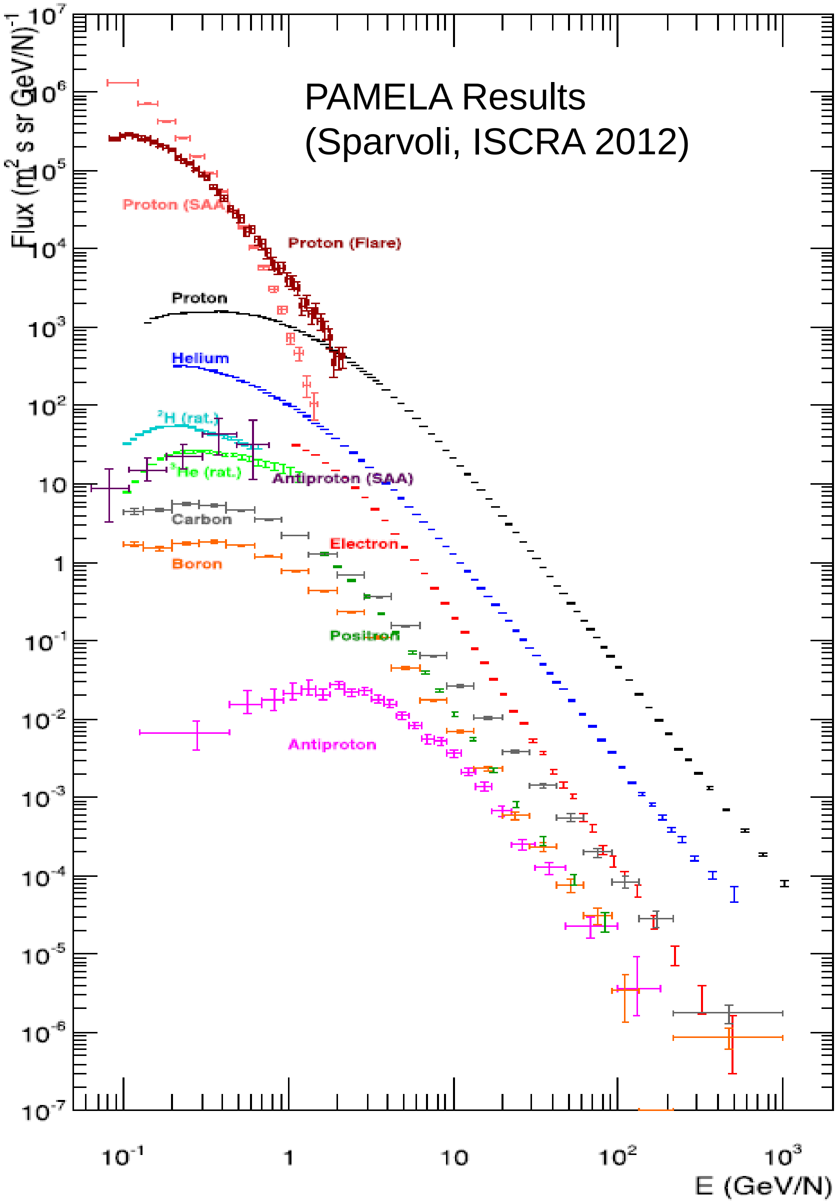
Dozens of students at the University of Maryland have toiled in the physics lab, some soldering metal parts, some debugging software and some simply slicing black pieces of paper into perfectly sized triangles.

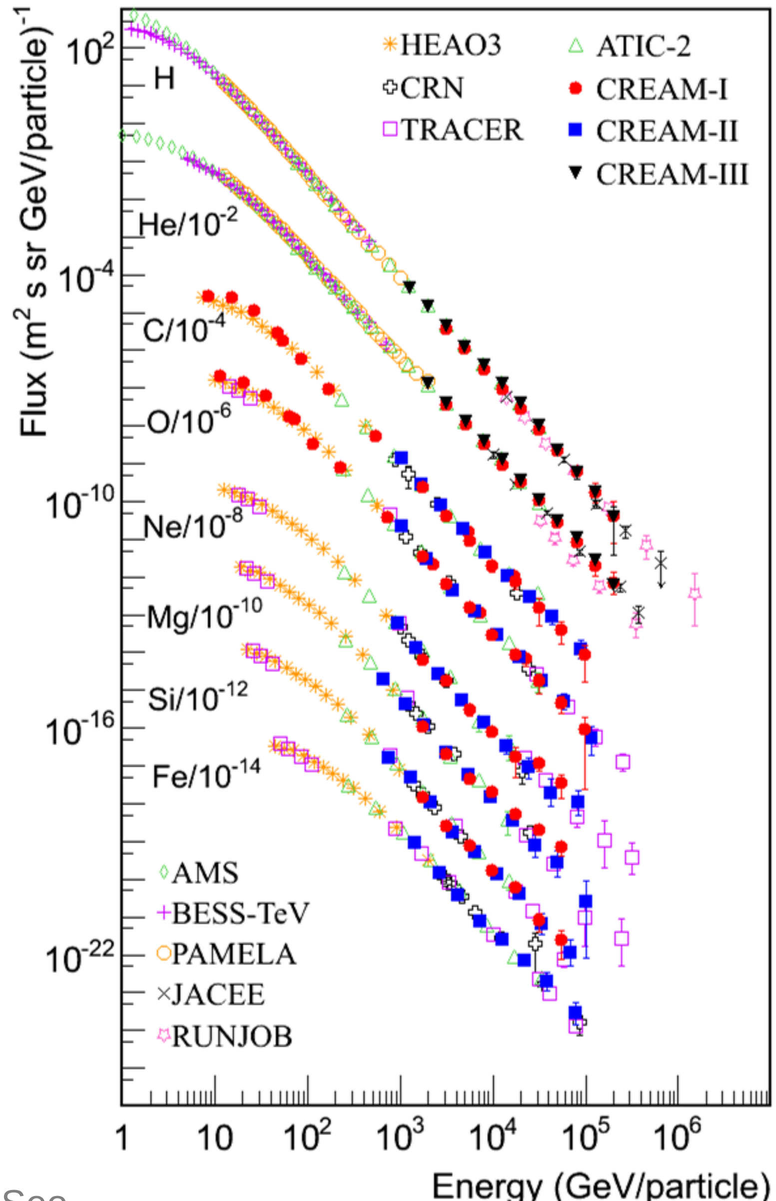
To physics professor Eun-Suk Seo, all of their work is critical. Students are helping her build a payload that is scheduled to launch to the International Space Station next year, the culmination of more than 10 years of her painstaking work on cosmic rays in a collaboration with NASA.

McMurdo, Antarctica

Elemental Spectra over 4 decades in energy

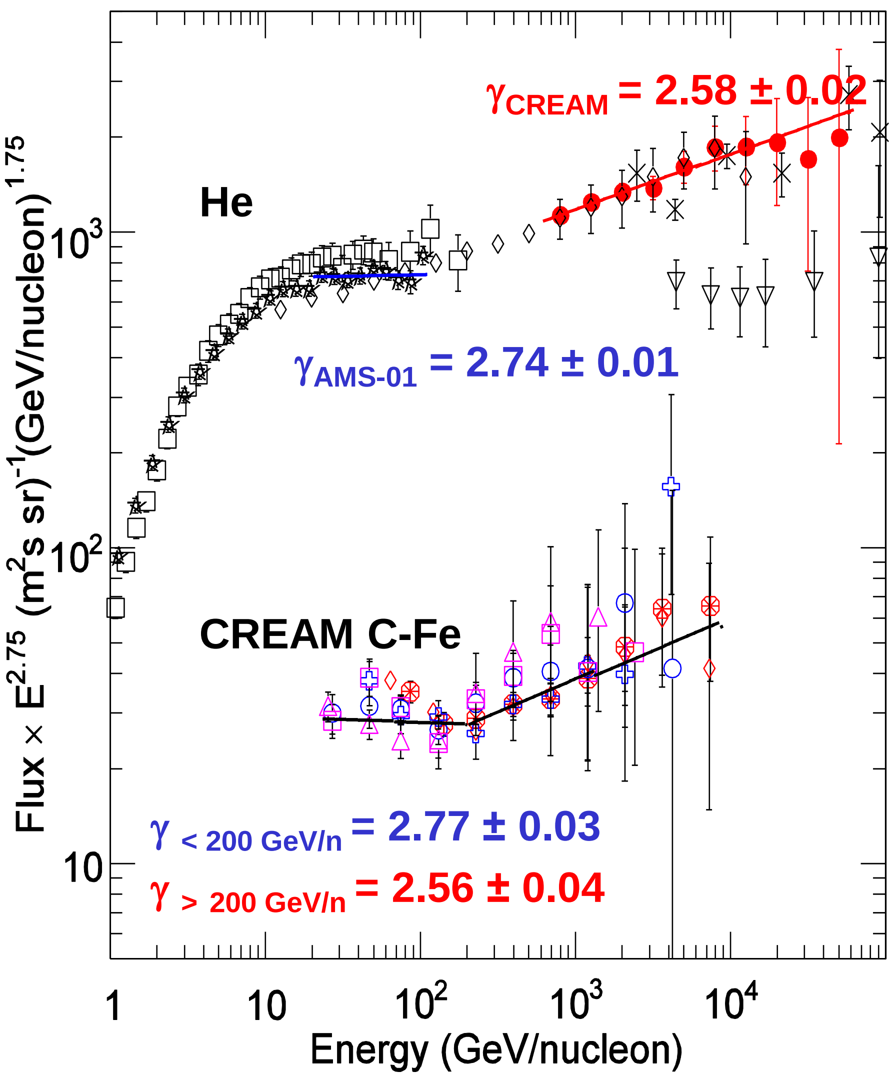
Yoon et al. ApJ **728**, *122*, 2011; Ahn et al., ApJ **715**, *1400*, 2010; Ahn et al. ApJ **707**, *593*, 2009

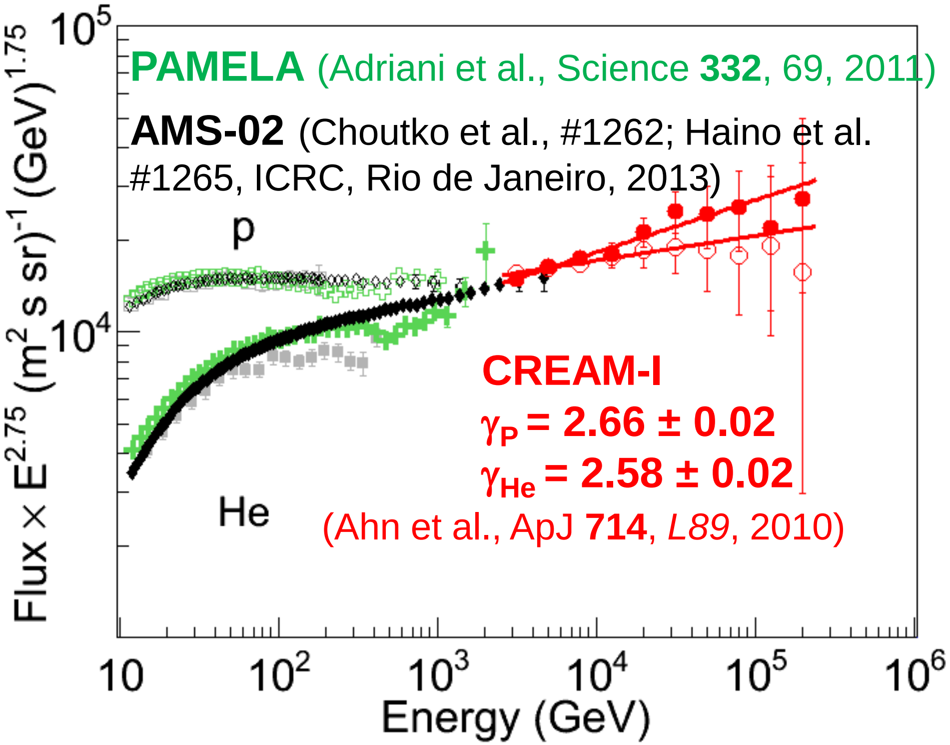




CREAM spectra harder than prior lower energy measurements

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



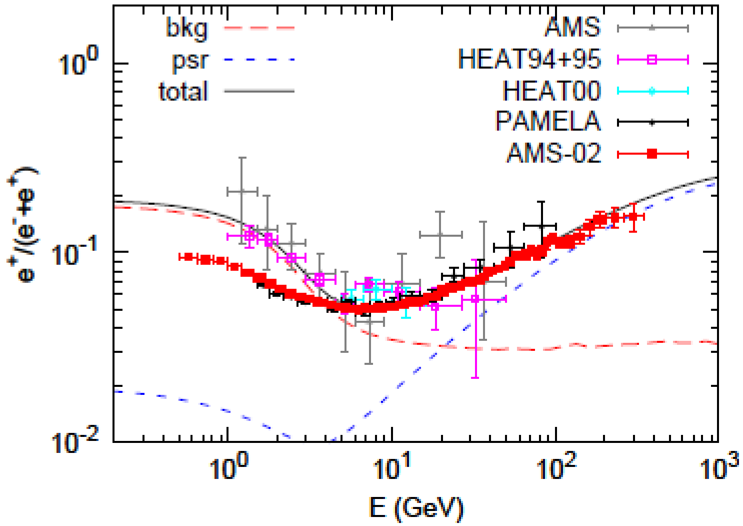


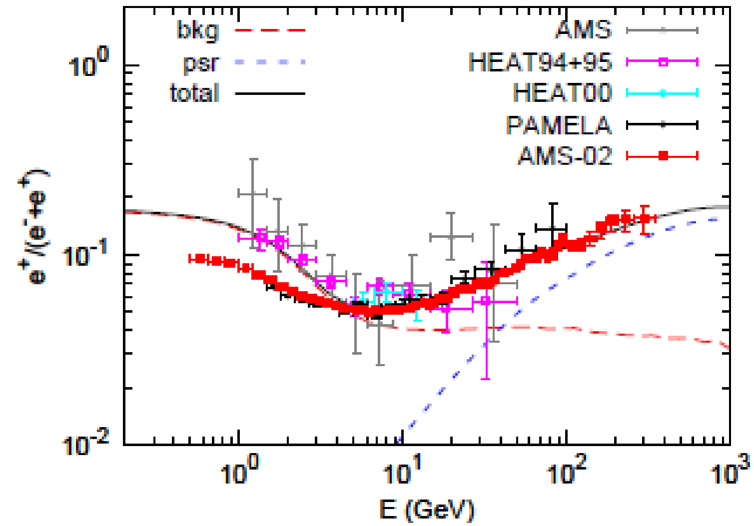
It provides important constraints on cosmic ray acceleration and propagation models, and it must be accounted for in explanations of the electron anomaly and cosmic ray "knee."

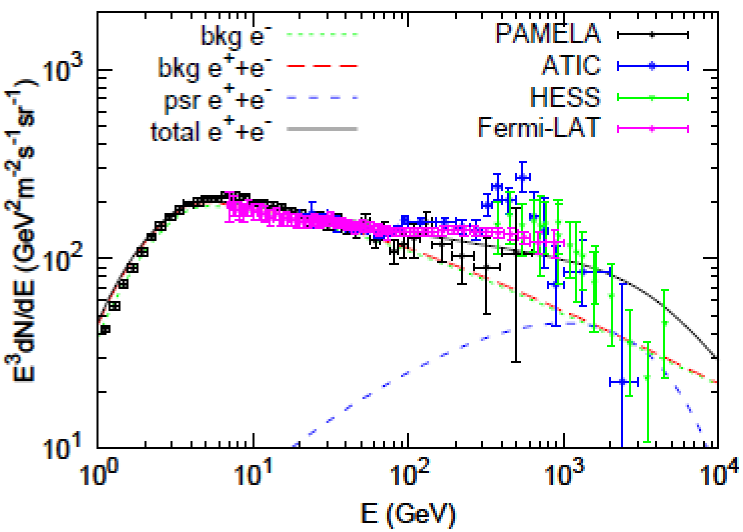
Taking into account the spectral hardening of elements

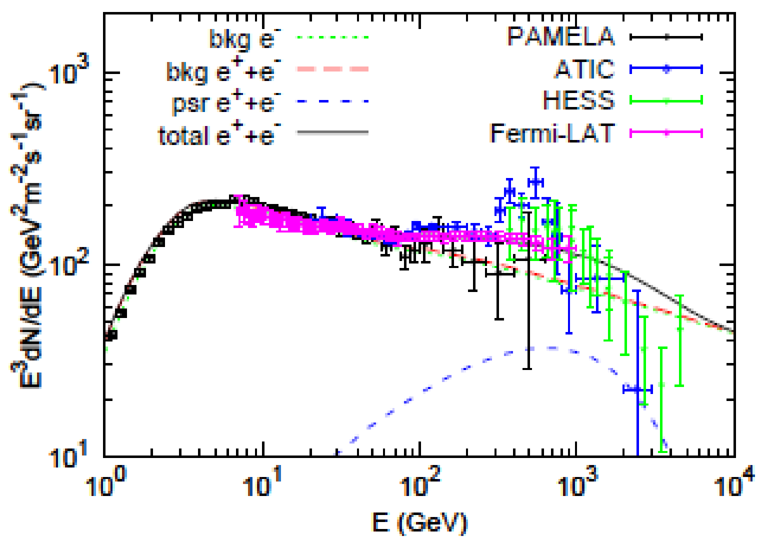
for the (AMS/PAMELA/ATIC/FERMI) high energy e^+ e^- enhancement

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



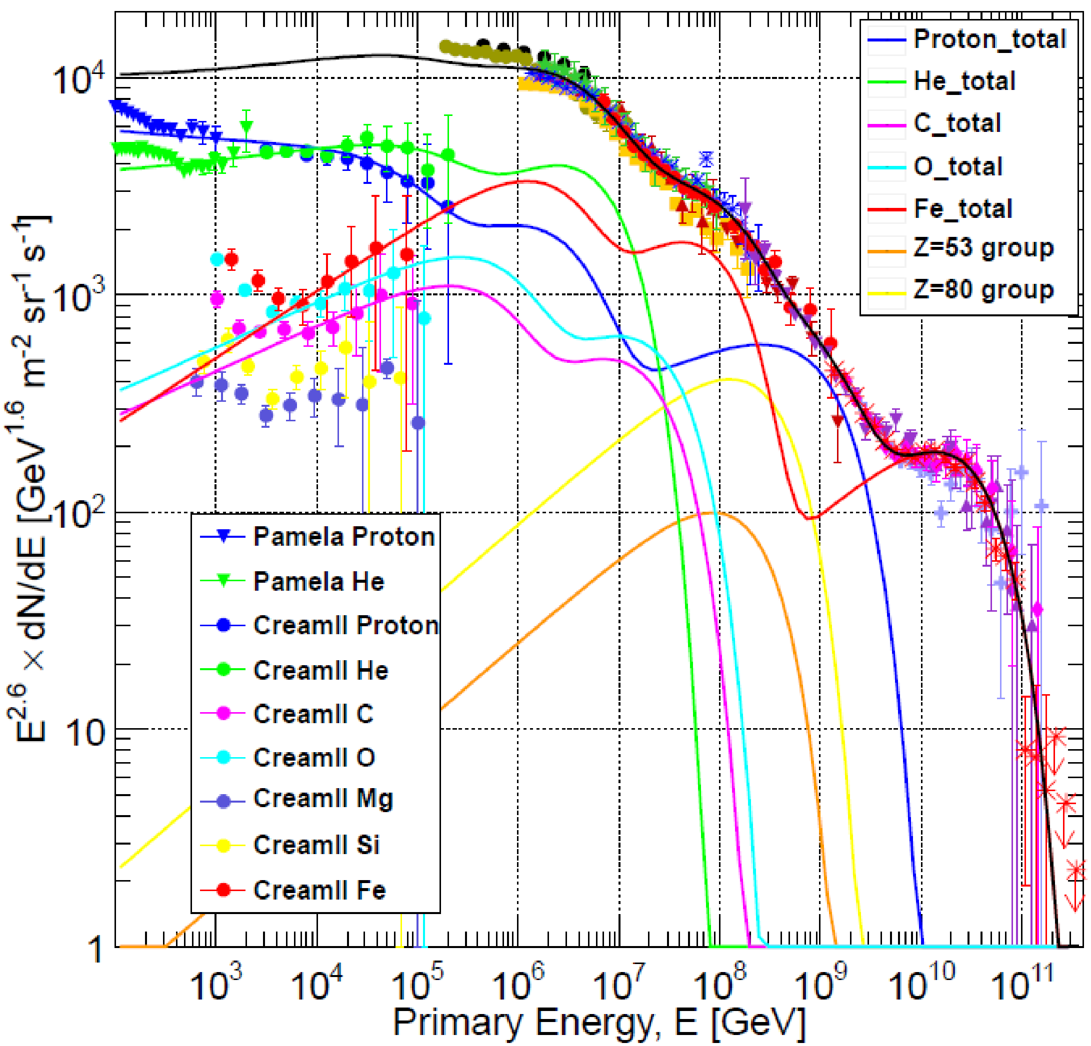






CREAM solves the puzzle with the knee and beyond

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



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

Acceleration limit:

E_{max_z} = Ze x R = Z x E_{max_p},

where rigidity R = Pc/Ze

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

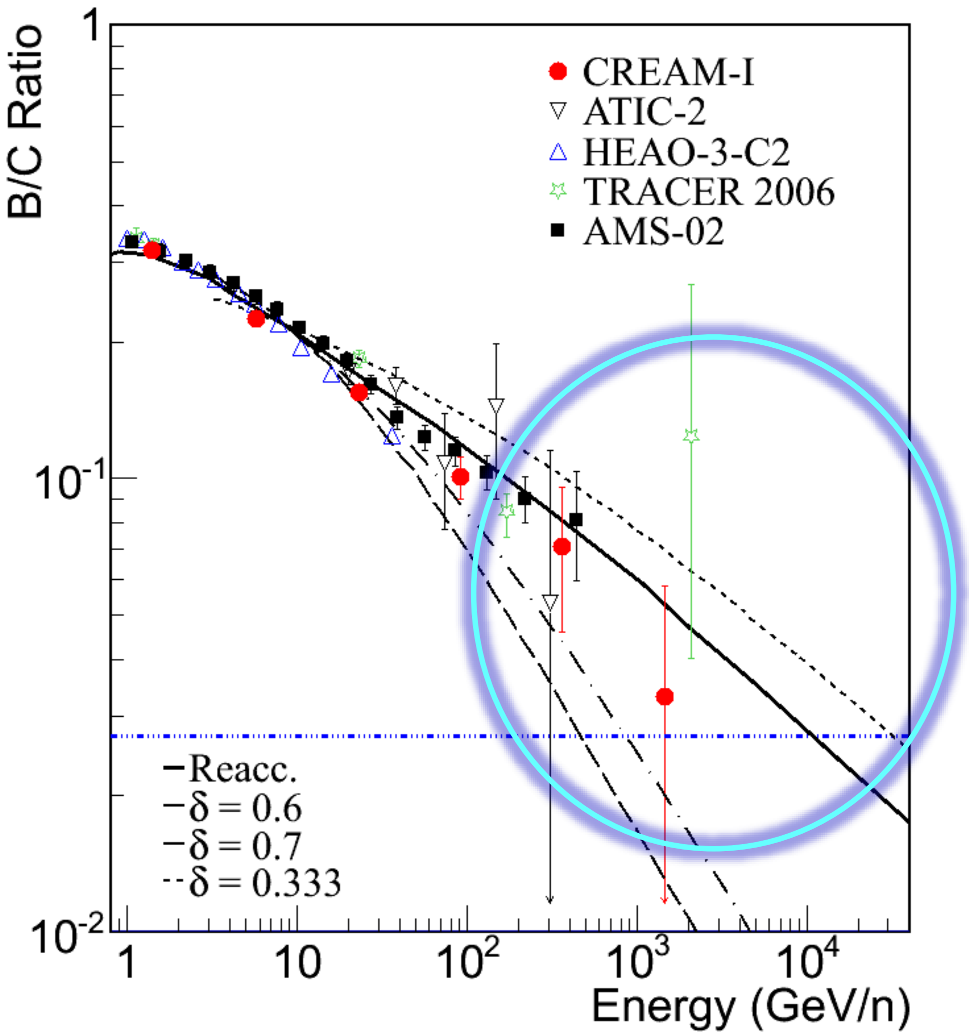
E. S. Seo and V. S. Ptuskin, *Astrophys. J.*, **431**, *705-714*, 1994.

What is the history of cosmic rays in the Galaxy?

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

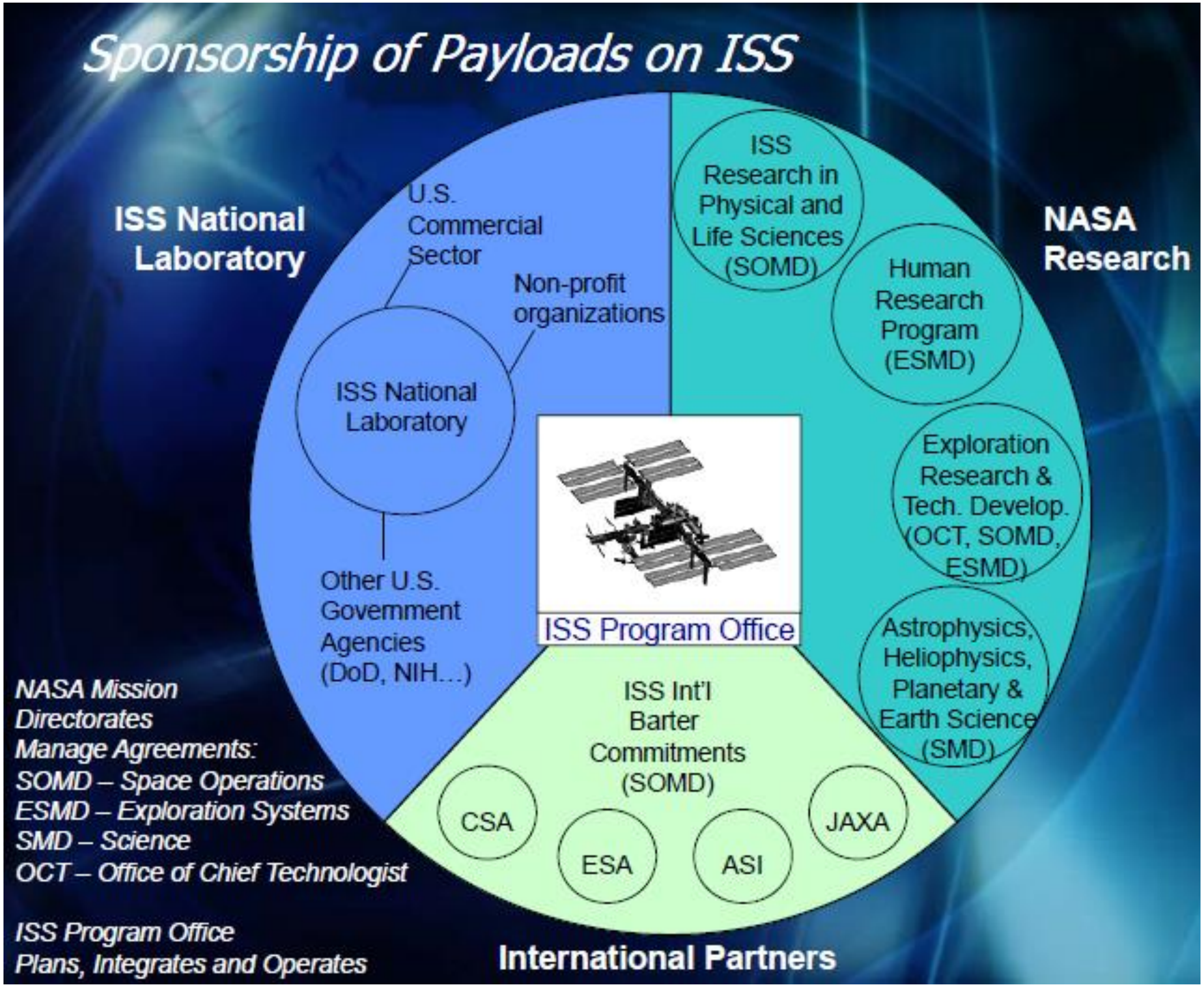
- Measurements of the relative abundances of secondary cosmic rays (e.g., B/C) in addition to the energy spectra of primary nuclei will allow determination of cosmic-ray source spectra at energies where measurements are not currently available
- This first B/C ratio at such high energies will distinguish among propagation models

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

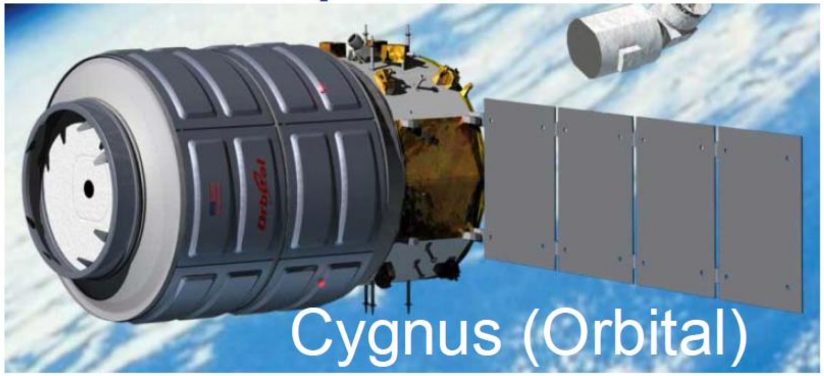


NASA ISS Research Academy

League City, TX, August 3-5, 2010

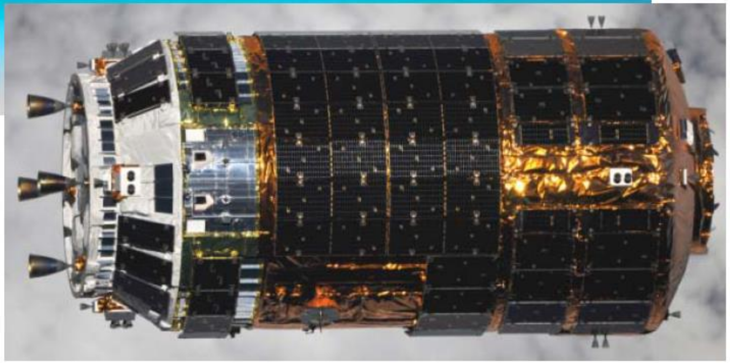


ISS Transportation Post-Shuttle



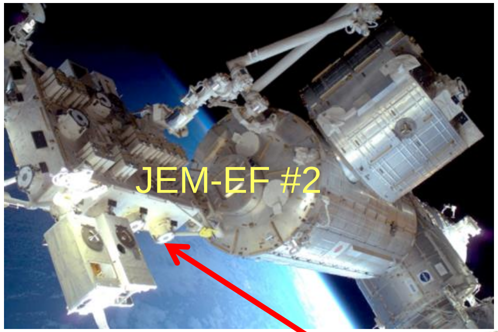
Progress/Soyuz (Energia)

HTV (JAXA)

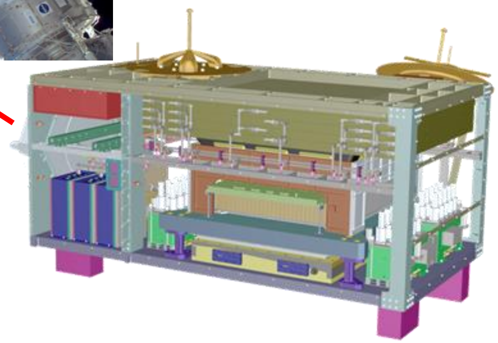


ISS-CREAM: CREAM for the ISS

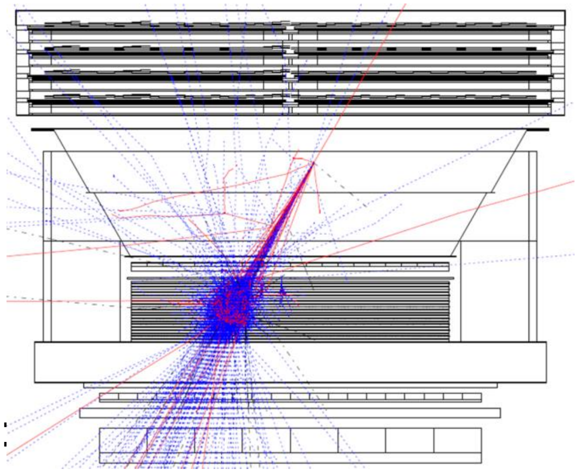
E. S. Seo et al, Advances in Space Research, **53**/10, *1451*, 2014



To be installed on the ISS
by Space X

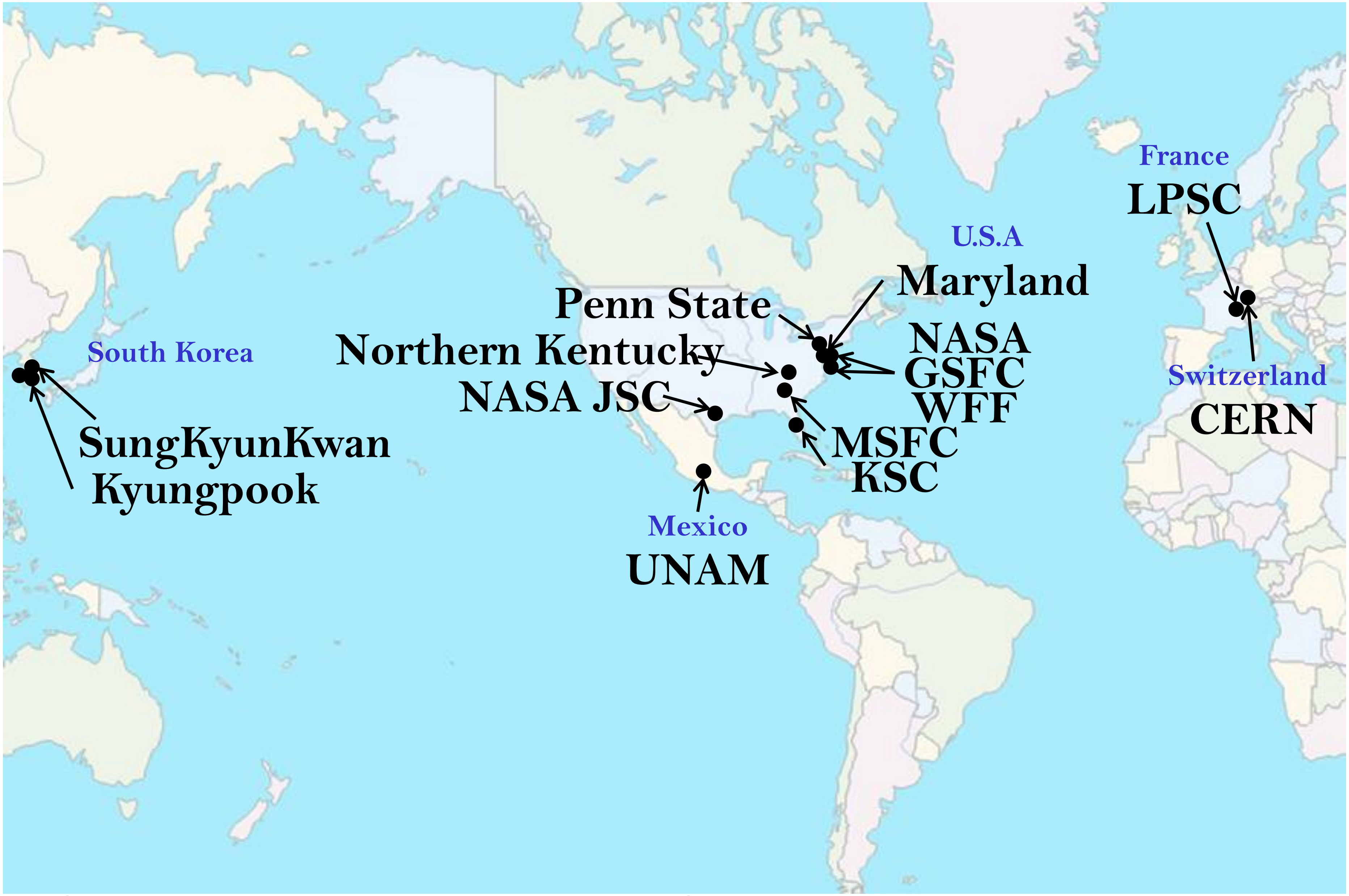


Mass: ~1400 kg
Power: ~ 550 W
Nominal data rate:
~350 kbps



- Building on the success of the balloon flights, the payload is being 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.

THE ISS-CREAM TEAM

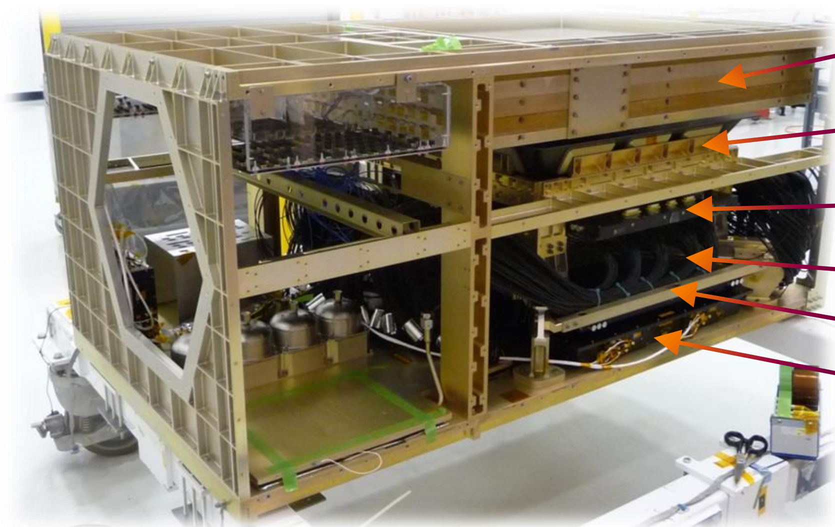


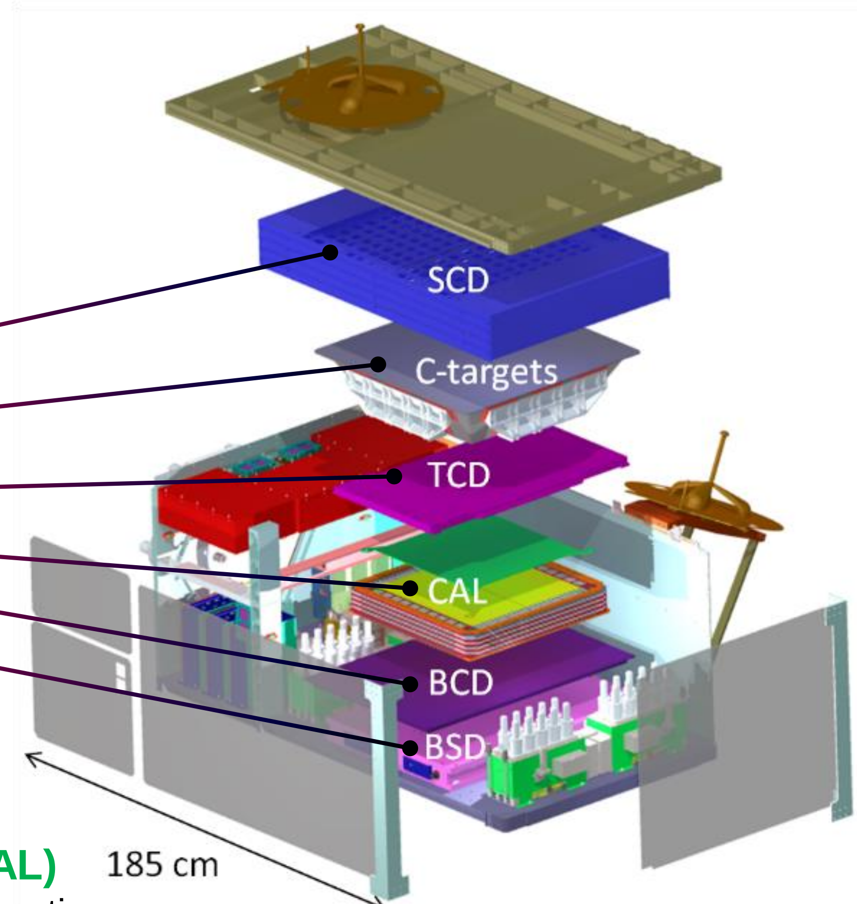
ISS-CREAM Instrument

Seo et al. (CREAM Collaboration) Adv. in Space Res., **53**/10, *1451*, 2014

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).





Top/Bottom Counting Detector (T/BCD)

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

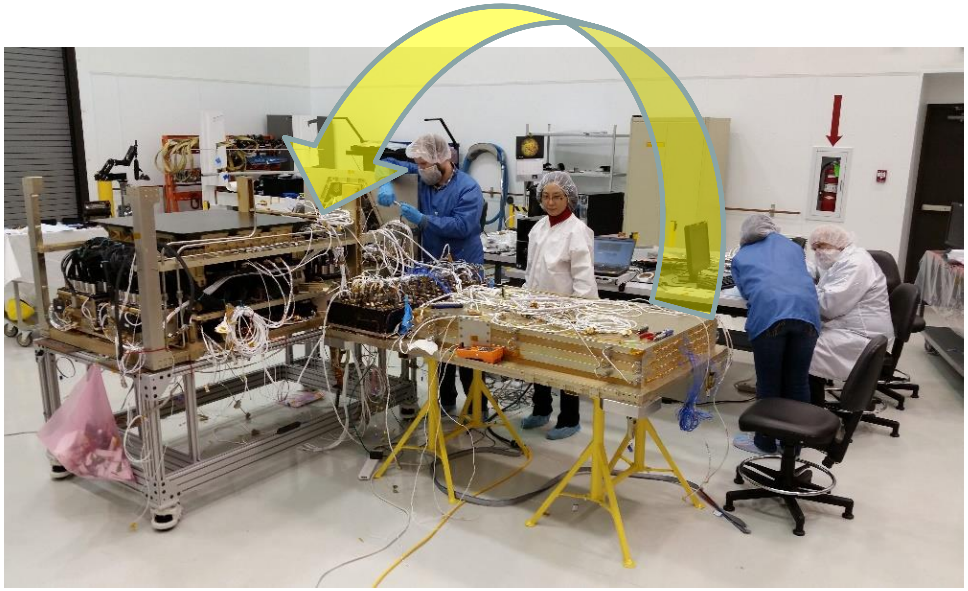
Calorimeter (CAL)

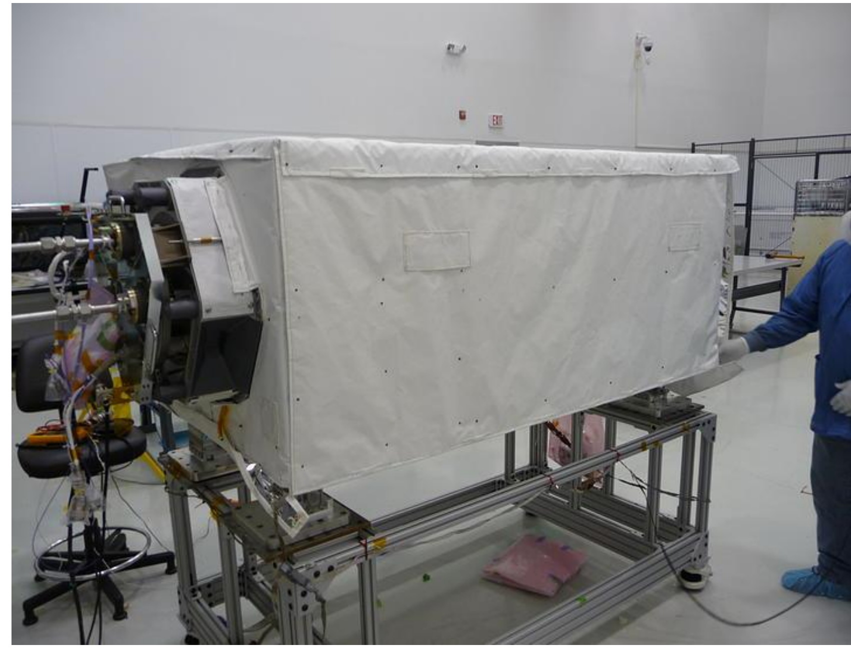
- 20 layers of alternating tungsten plates and scintillating fibers.
- Determines energy.
- Provides tracking and trigger.

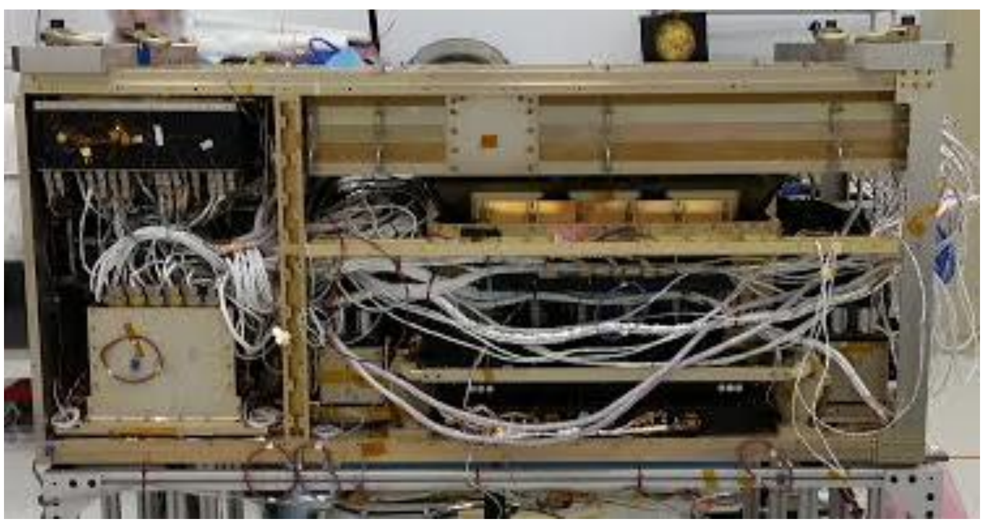
Boronated Scintillator Detector (BSD)

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

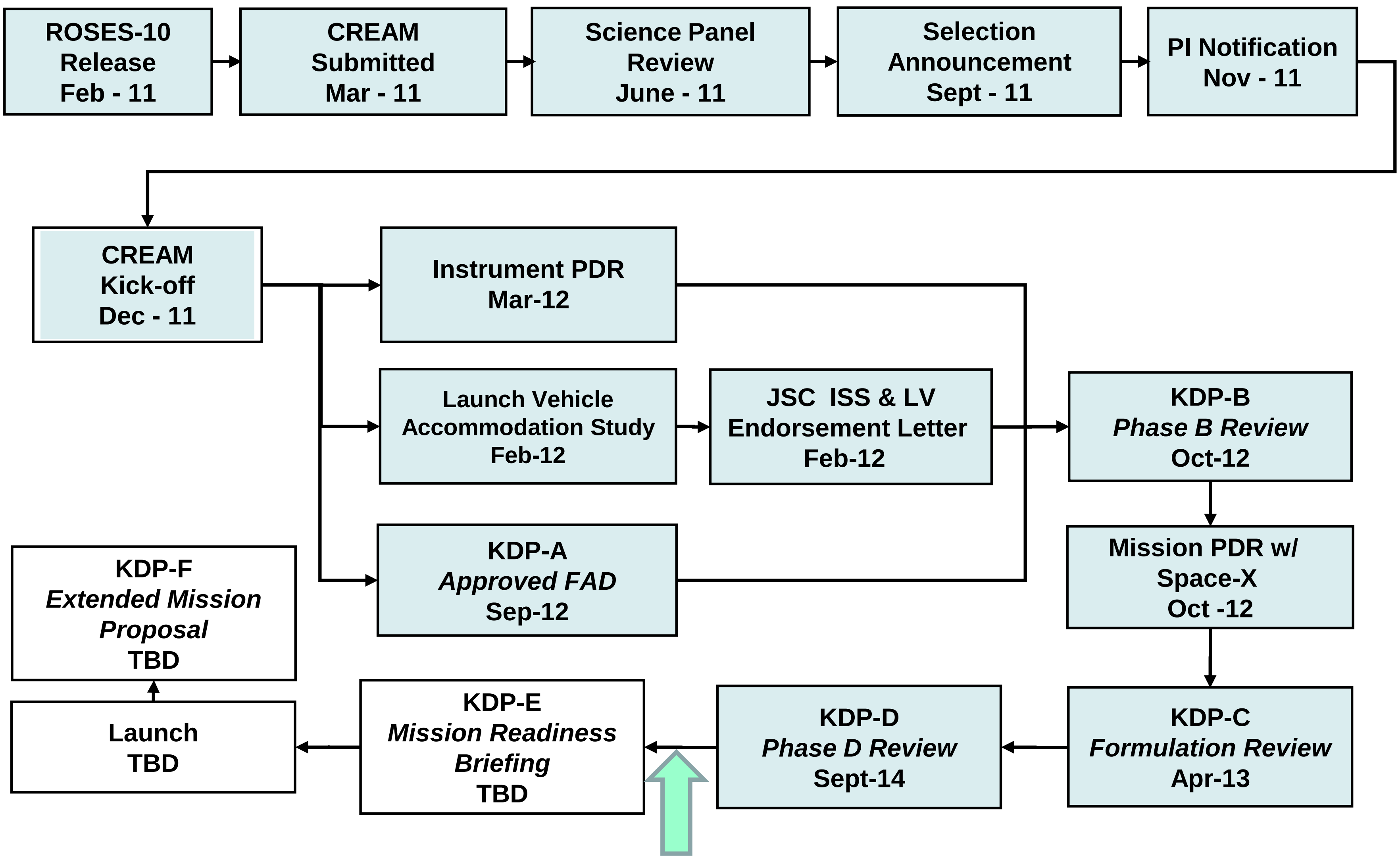
CREAM Integration at WFF





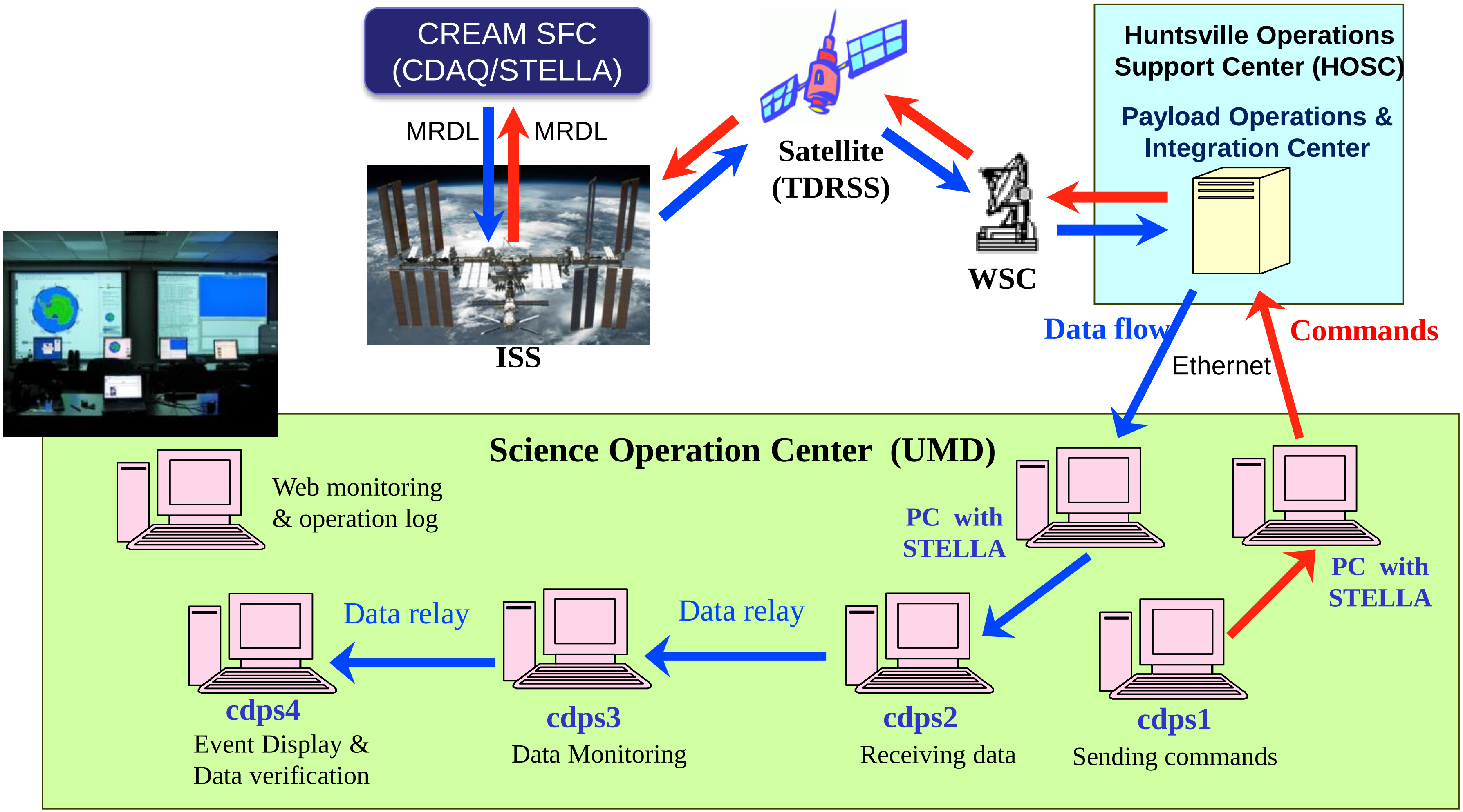


Key Decision Points and Milestones

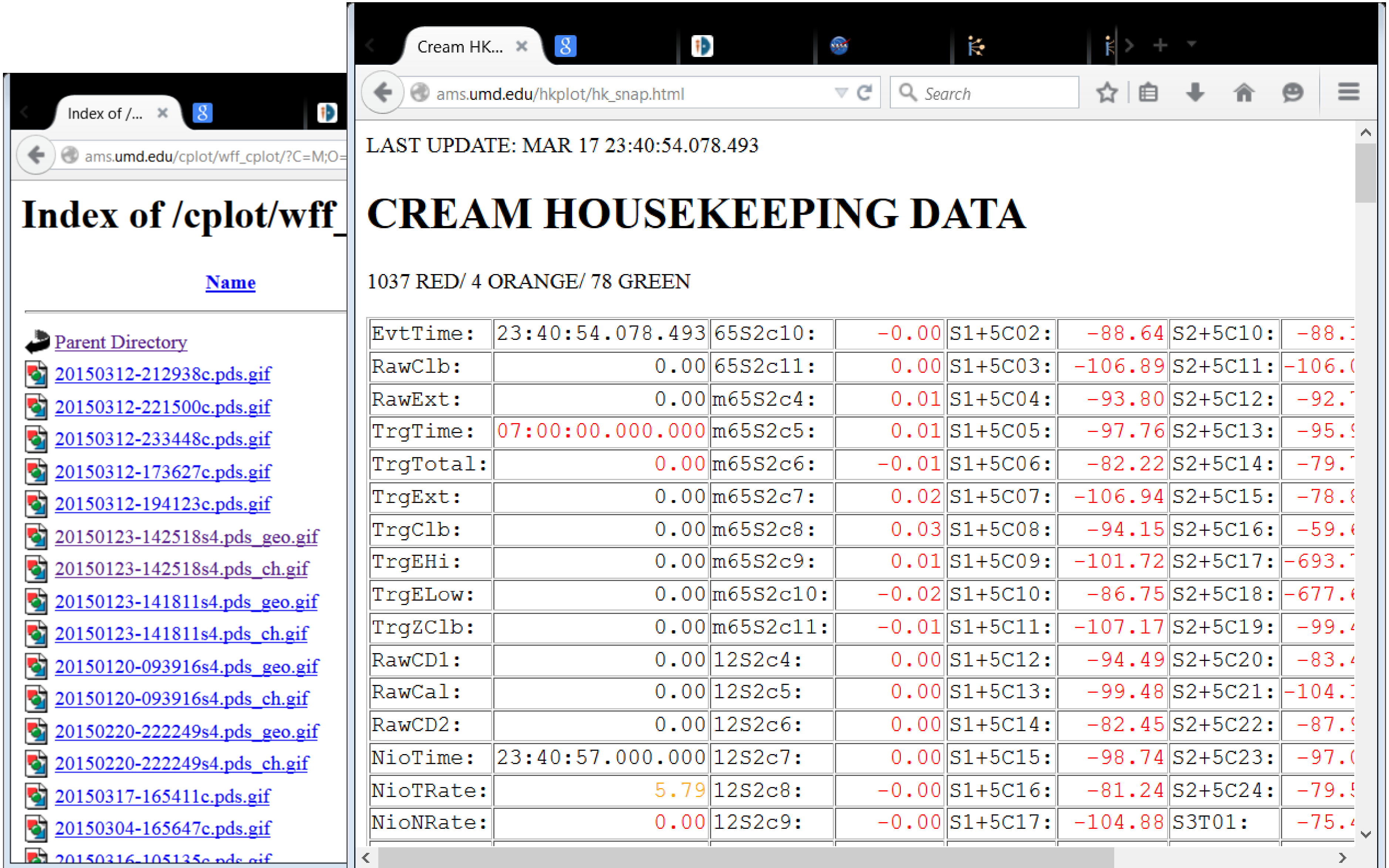


Science Operation Center is in operation

http://cosmicray.umd.edu/iss-cream/data



Data available online for real time monitoring



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- 20150123-142518s4.pds_geo.gif
- 20150123-142518s4.pds_ch.gif
- 20150123-141811s4.pds_geo.gif
- 20150123-141811s4.pds_ch.gif
- 20150120-093916s4.pds_geo.gif
- 20150120-093916s4.pds_ch.gif
- 20150220-222249s4.pds_geo.gif
- 20150220-222249s4.pds_ch.gif
- 20150317-165411c.pds.gif
- 20150304-165647c.pds.gif
- 20150316-105135c.pds.gif

LAST UPDATE: MAR 17 23:40:54.078.493

CREAM HOUSEKEEPING DATA

1037 RED/ 4 ORANGE/ 78 GREEN

EvtTime:	23:40:54.078.493	65S2c10:	-0.00	S1+5C02:	-88.64	S2+5C10:	-88.
RawClb:	0.00	65S2c11:	0.00	S1+5C03:	-106.89	S2+5C11:	-106.
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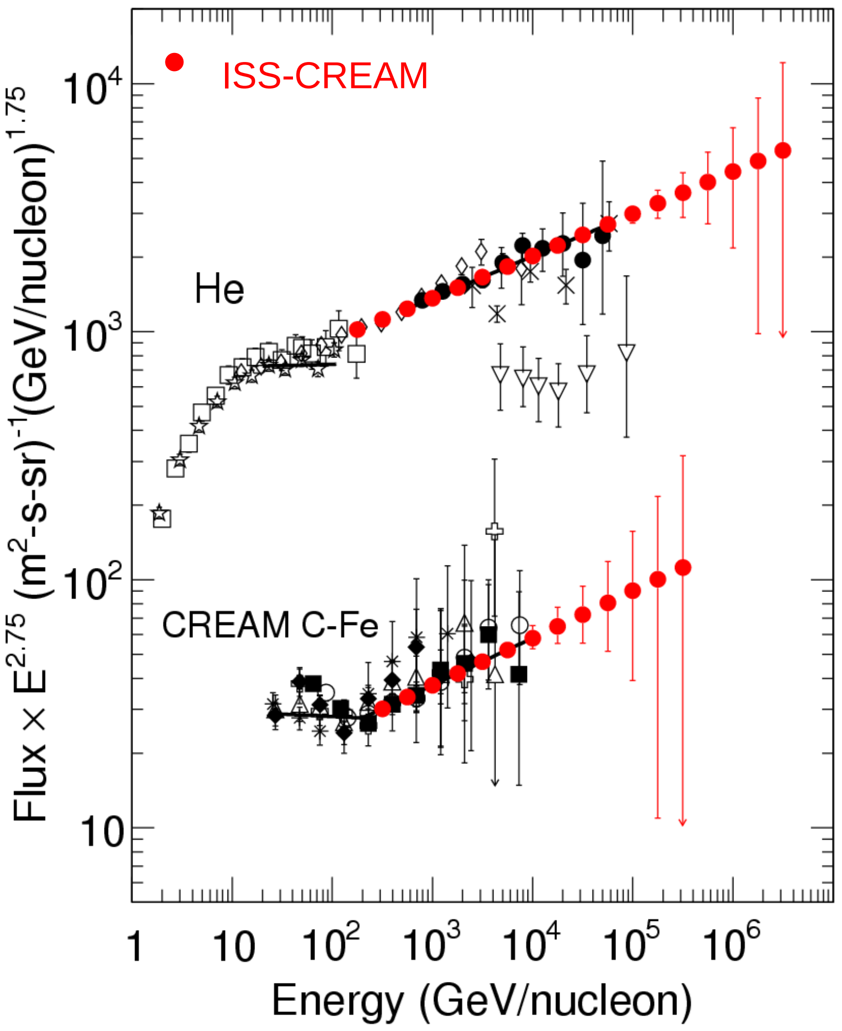
TrgTotal:	0.00	m65S2c6:	-0.01	S1+5C06:	-82.22	S2+5C14:	-79.
TrgExt:	0.00	m65S2c7:	0.02	S1+5C07:	-106.94	S2+5C15:	-78.
TrgClb:	0.00	m65S2c8:	0.03	S1+5C08:	-94.15	S2+5C16:	-59.
TrgEHi:	0.00	m65S2c9:	0.01	S1+5C09:	-101.72	S2+5C17:	-693.
TrgELow:	0.00	m65S2c10:	-0.02	S1+5C10:	-86.75	S2+5C18:	-677.
TrgZClb:	0.00	m65S2c11:	-0.01	S1+5C11:	-107.17	S2+5C19:	-99.
RawCD1:	0.00	12S2c4:	0.00	S1+5C12:	-94.49	S2+5C20:	-83.
RawCal:	0.00	12S2c5:	0.00	S1+5C13:	-99.48	S2+5C21:	-104.
RawCD2:	0.00	12S2c6:	0.00	S1+5C14:	-82.45	S2+5C22:	-87.
NioTime:	23:40:57.000.000	12S2c7:	0.00	S1+5C15:	-98.74	S2+5C23:	-97.
NioTRate:	5.79	12S2c8:	-0.00	S1+5C16:	-81.24	S2+5C24:	-79.
NioNRate:	0.00	12S2c9:	-0.00	S1+5C17:	-104.88	S3T01:	-75.

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.



Ever closer to answering long standing questions

ISS-CREAM will address specifically the science objectives of the Advanced Cosmic-ray Composition Experiment for the Space Station (ACCESS) prioritized in the Small Space-Based Initiative category of the 2001 NRC Decadal Study Report "Astronomy and Astrophysics in the New Millennium."

4 SPACE NEWS www.spacenews.com

July 12, 2010

SMD Urged To Use Station

AMY KLAMPER, WASHINGTON

With the White House having directed NASA to continue supporting the international space station at least through 2020, the agency is looking for ways to more fully utilize the facility as a host platform for scientific payloads and for testing instrument technologies in orbit.

The research could involve any number of scientific disciplines, including astronomy, astrophysics, Earth science and planetary exploration, according to Vernon Jones, senior scientist for suborbital research in the astrophysics division of NASA's Science Mission Directorate (SMD).

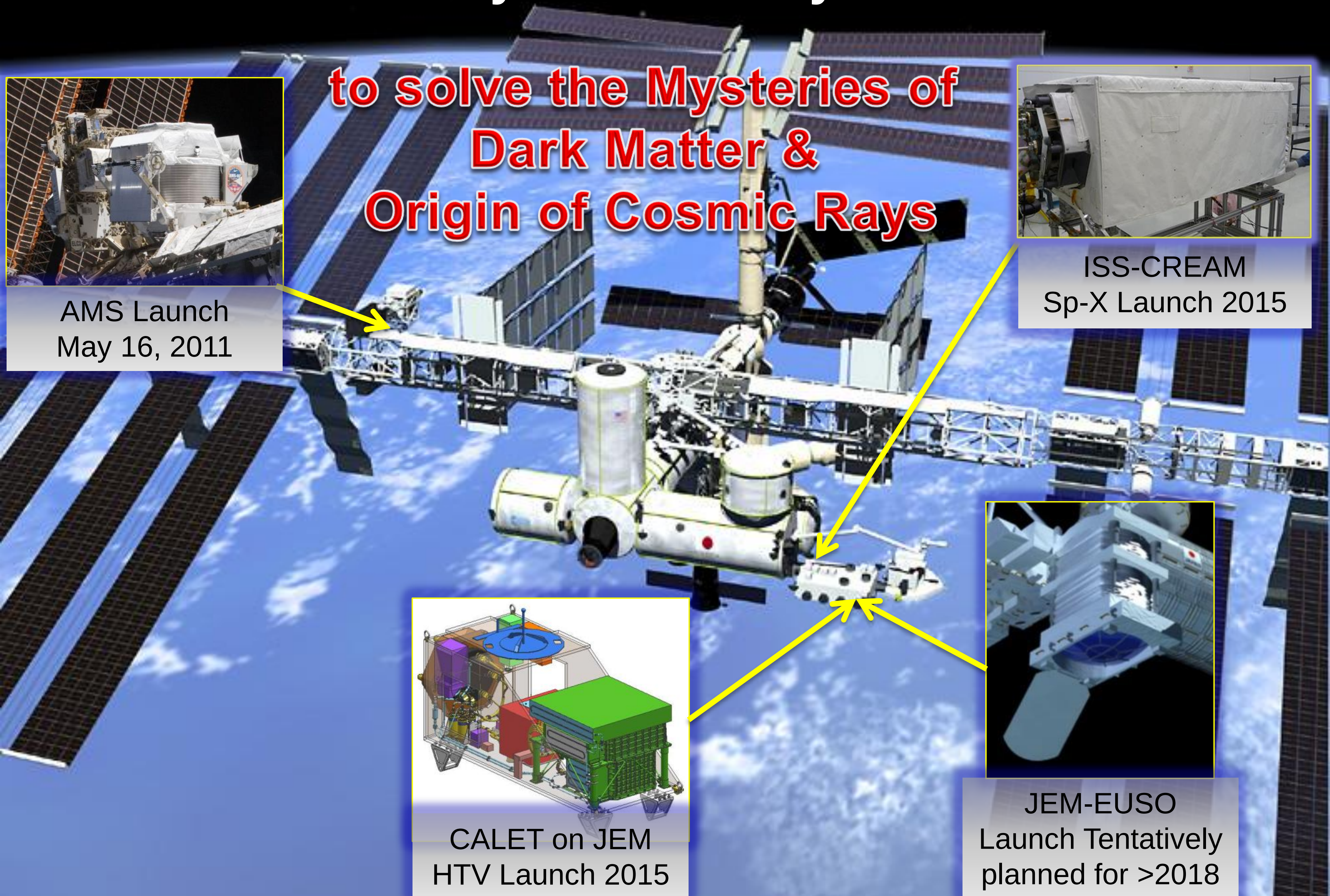
Jones was speaking July 8 during a meeting of a group of outside scientists who reg-

al examples of such utilization are already under way, including the Alpha-Magnetic Spectrometer planned to launch aboard the final space shuttle mission early next year.

"Here's an asset that's been extended for several years that in the past hasn't been used, and is there usability for the science area?" Jones said.

Jones said the space station provides a good platform for a variety of non-microgravity science and technology payloads because it offers mounting points for large instruments, moderate stability, ample power and high-bandwidth communications capabilities. He said all four of the NASA Advisory Council's Science subcommittees had been asked to propose potential science and technology research ideas to the full committee in ad-

Cosmic Ray Observatory on the ISS



Balloon Launch