Space Opportunities for Cosmic Ray Science

Angela V. Olinto
The University of Chicago

100th Anniversary

1912 - Victor Hess

Balloon flights established the cosmic nature of ionizing radiation

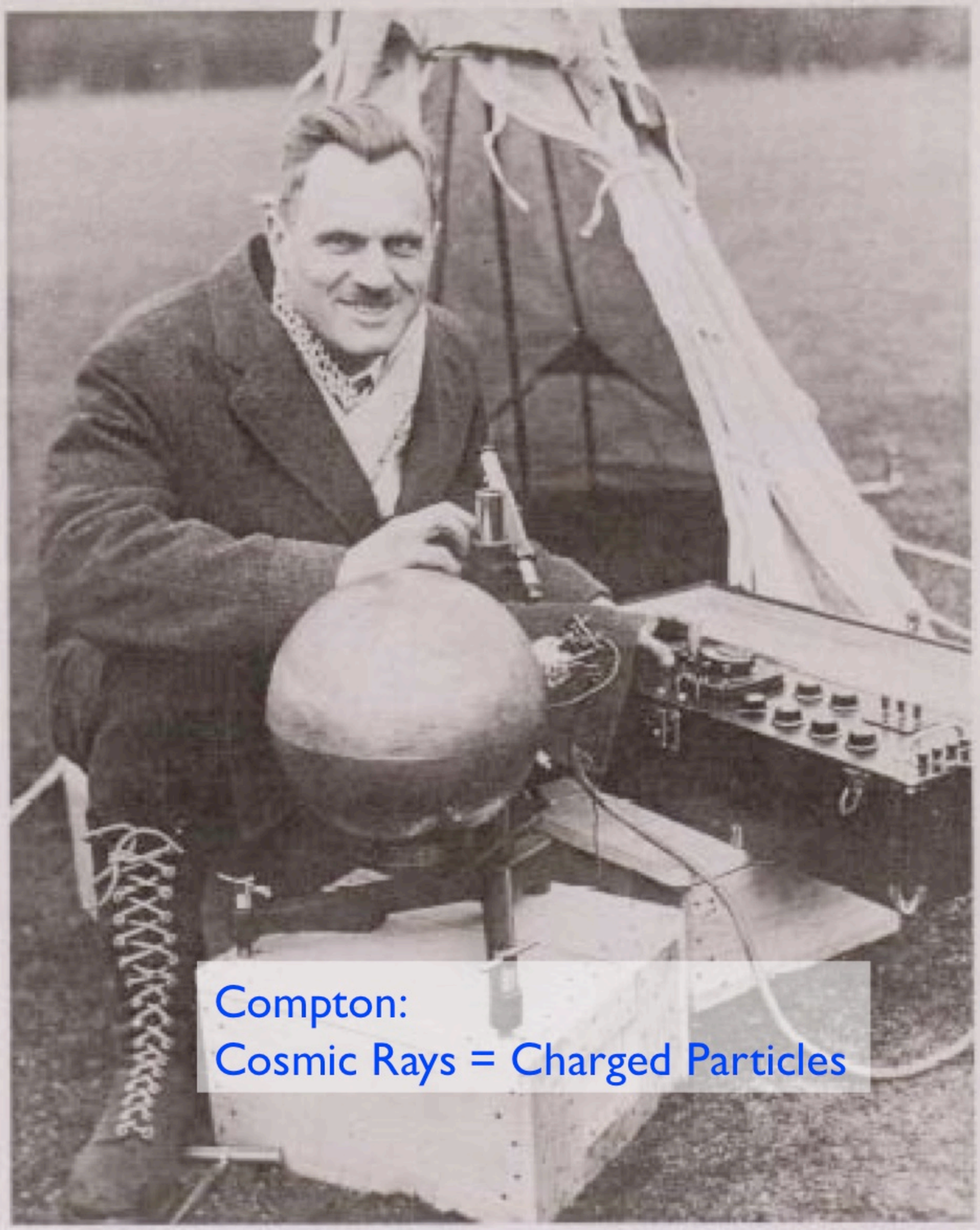
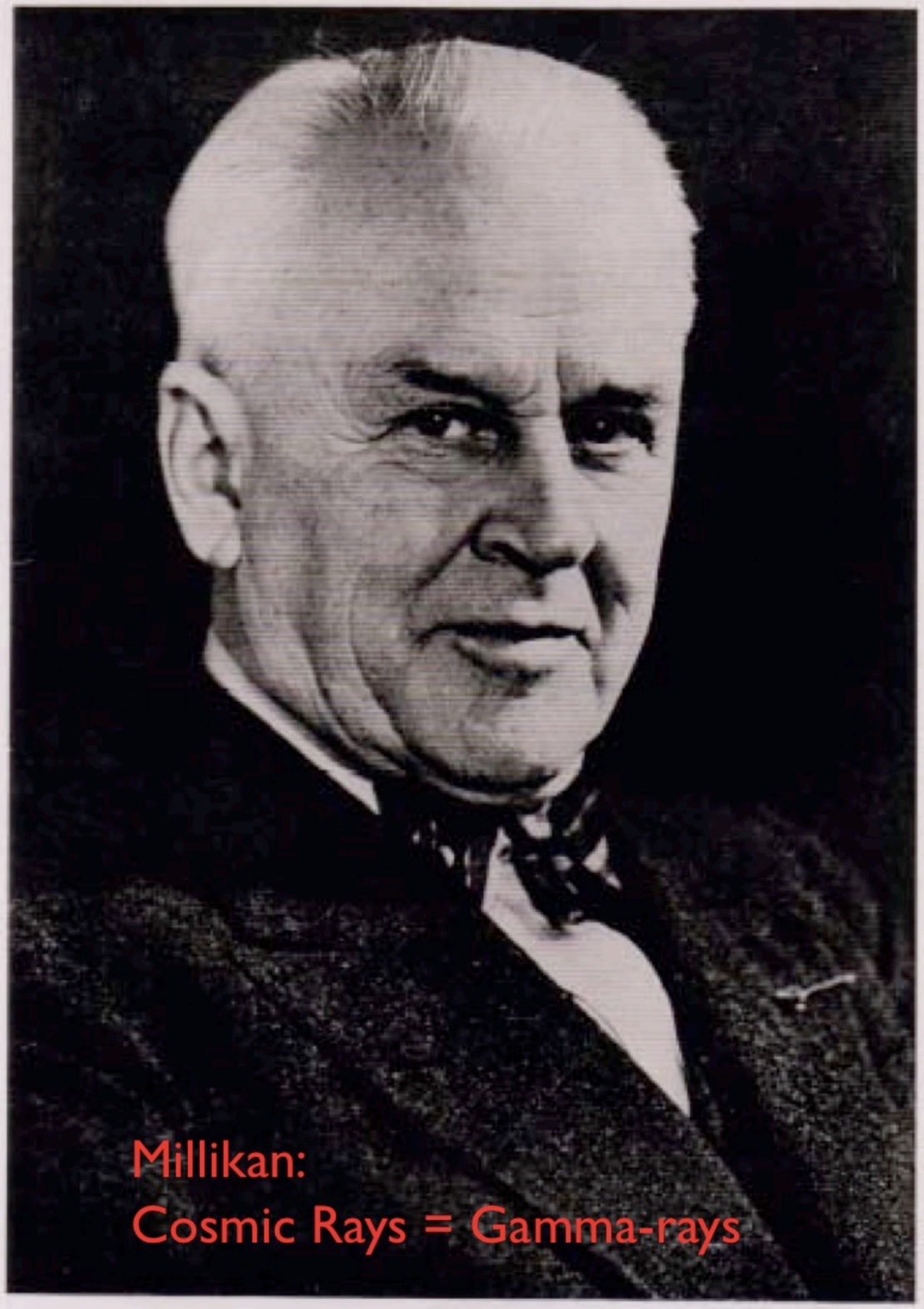


Fig. 6. Compton with the special ionization chamber which he designed and used for his world-wide cosmic-ray survey during 1931–33, which proved that cosmic rays are charged particles.



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Compton:
Cosmic Rays = Charged Particles

Fig. 6. Compton with the special ionization chamber which he designed and used for his world-wide cosmic-ray survey during 1931–33, which proved that cosmic rays are charged particles.

The New York Times

VOL. LXXXII....No. 27,370. December 31,1932

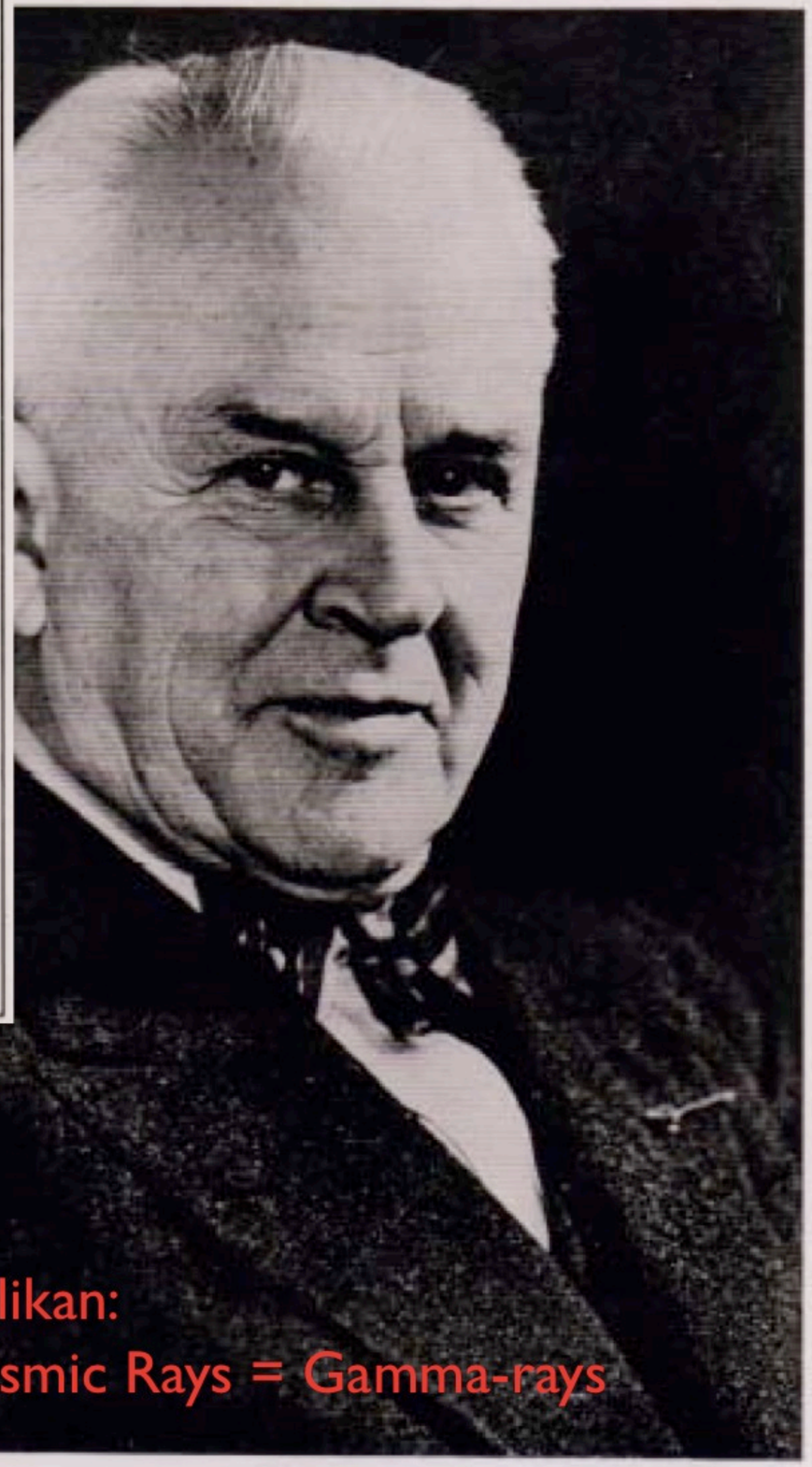
MILLIKAN RETORTS HOTLY TO COMPTON IN COSMIC RAY CLASH

Debate of Rival Theorists Brings Drama to Session of Nation's Scientists.

THEIR DATA AT VARIANCE

New Findings of His Ex-Pupil Lead to Thrust by Millikan at 'Less Cautious' Work.

NYT: December 31, 1932



Millikan:
Cosmic Rays = Gamma-rays

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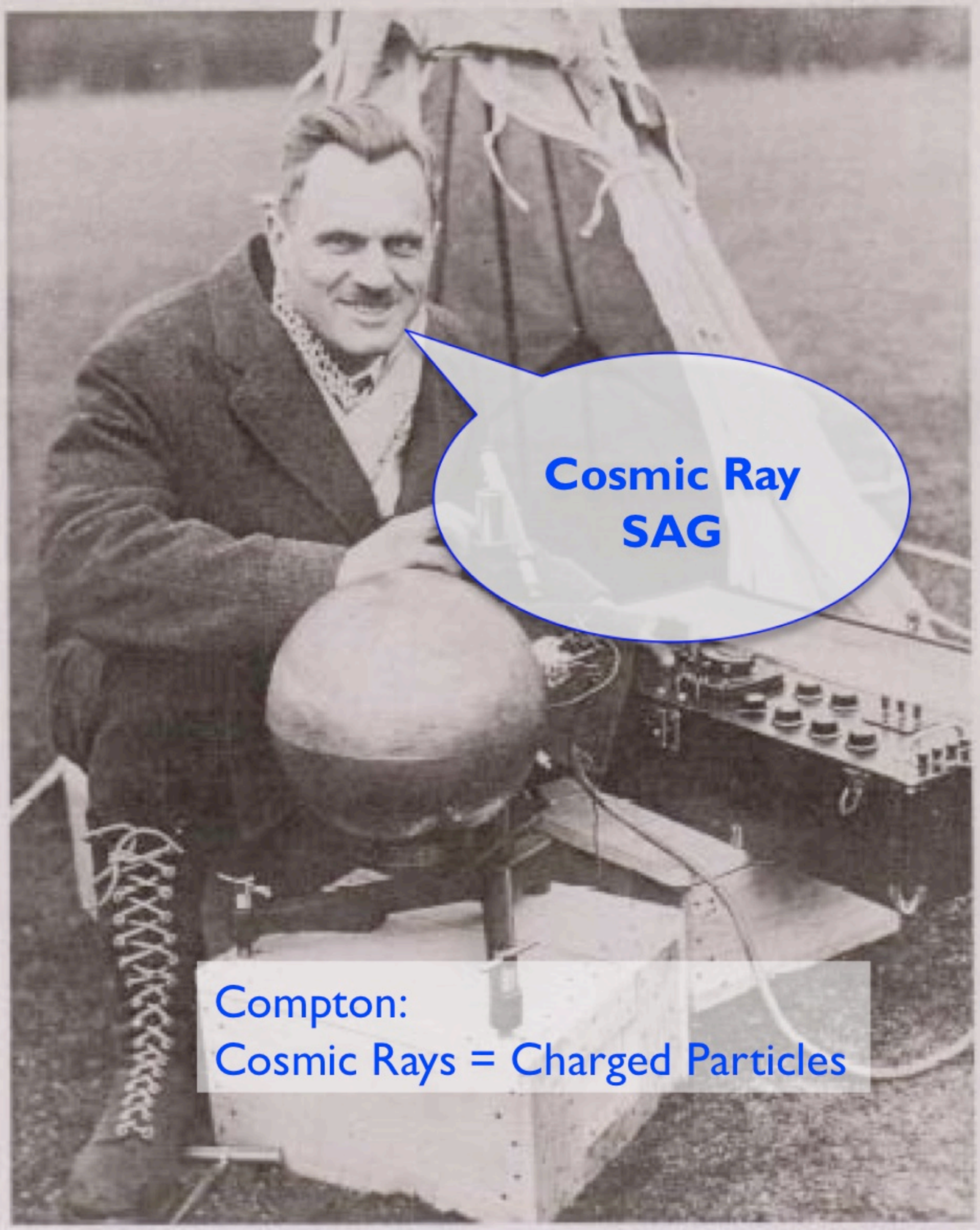

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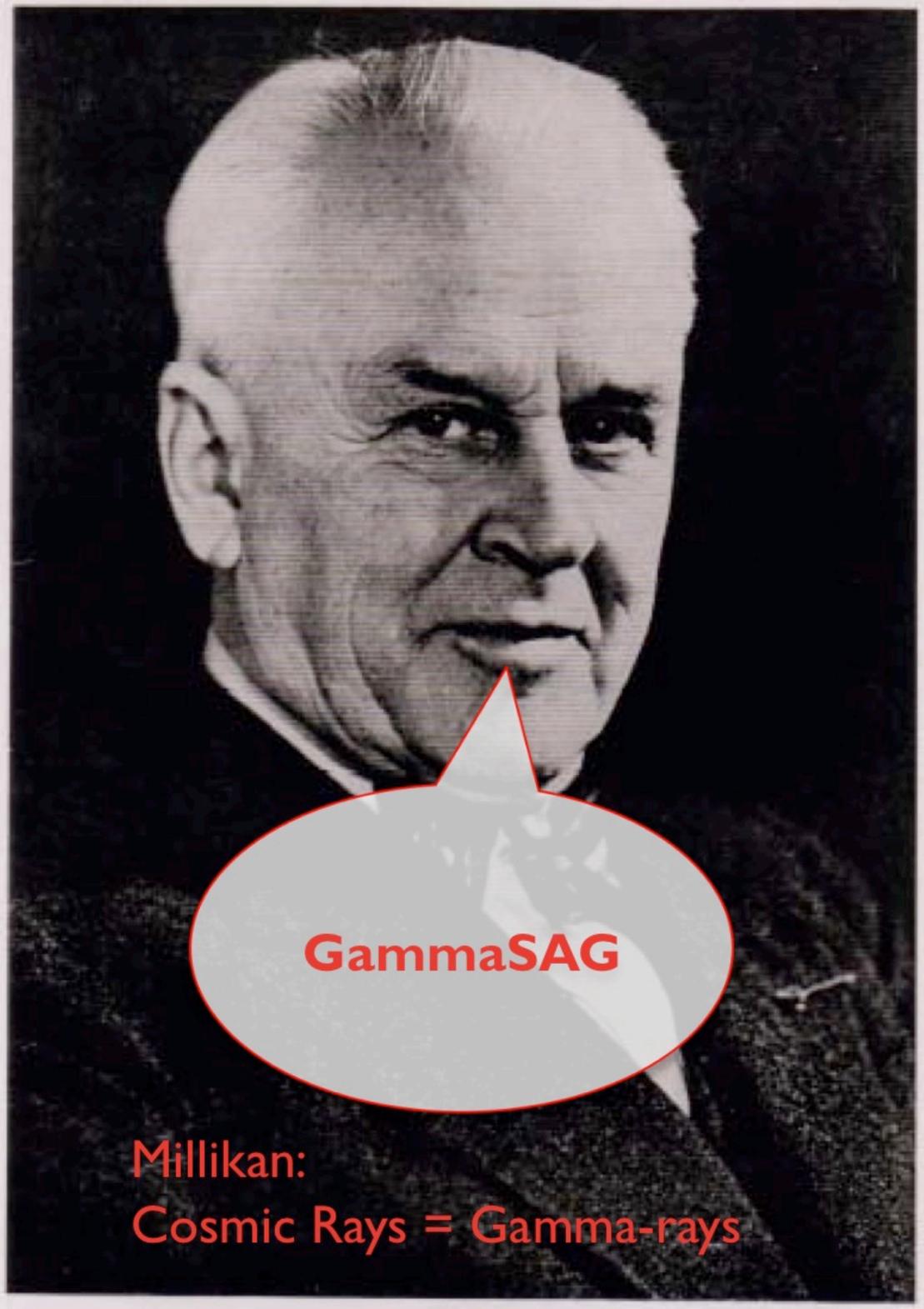
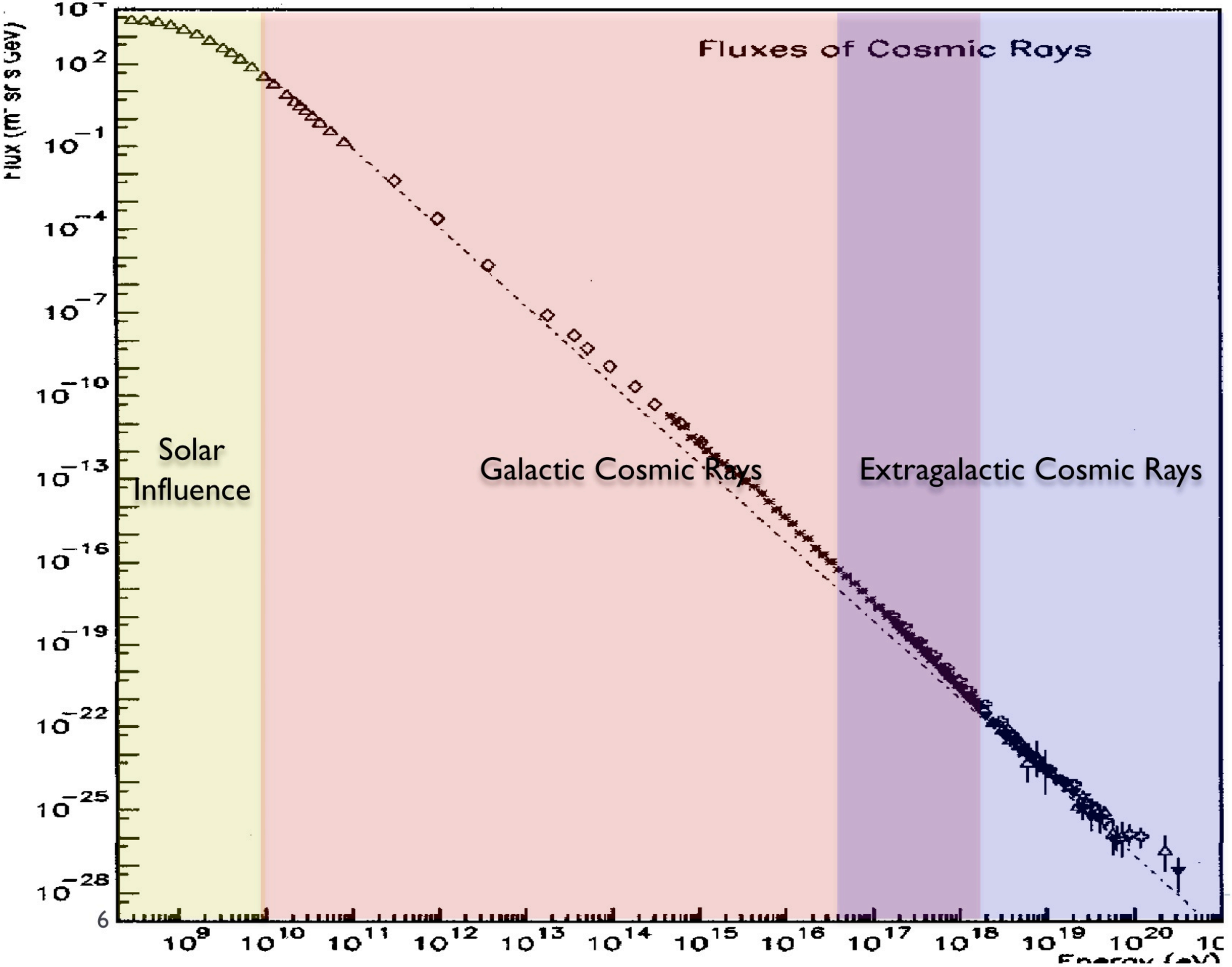
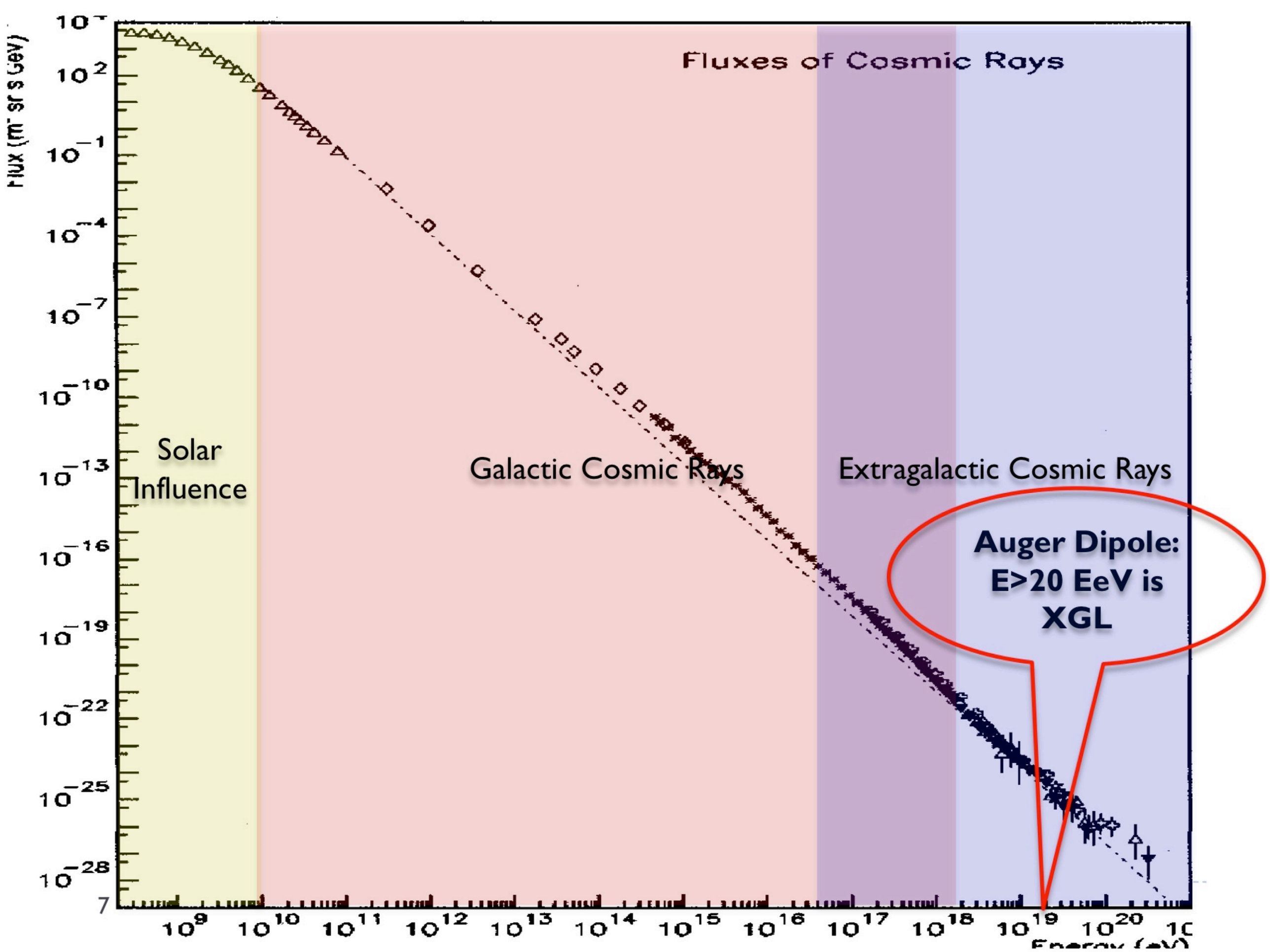


ROBERT A. MILLIKAN

Main Open Questions in CR Science

- Origin of Galactic Cosmic Rays (GCR):
  - What are the accelerators?
  - What are they accelerating?
  - How do they propagate in the Galaxy?
  - Where is the Transition between Galactic & ExtraGalactic CRs?
- Origin of ExtraGalactic Cosmic Rays (XGCR):
  - What are the accelerators?
  - What are they accelerating?
  - How do they propagate to Earth?
  - At what Energy COSMIC RAY ASTRONOMY begins?
- How do Cosmic Rays Affect the Earth, the Solar System, the Galaxy, other Galaxies, and the formation of Stars and Galaxies?


Fluxes of Cosmic Rays
Flux (m⁻ sr s GeV)
Solar Influence
Galactic Cosmic Rays
Extragalactic Cosmic Rays
Energy (eV)


Fluxes of Cosmic Rays
Flux (m² sr s GeV)
Solar Influence
Galactic Cosmic Rays
Extragalactic Cosmic Rays
Auger Dipole: E>20 EeV is XGL
Energy (eV)

Questions Related to CR Science

- Indirect Dark Matter Searches
  - WIMP in the Galactic Halo: e+, e-; p, anti-p, γ , ν ...
- Probe of Particle Interactions above LHC energies
  - Ultrahigh Energy Cosmic Rays (E_{cm} > 100 TeV)
  - Ultrahigh Energy Neutrinos
- Searches for Exotic Components of Matter:
  - antinuclei
  - strangelets
  - primordial black holes

Opportunities in Space

- In Situ Measurements of Solar System & Neighborhood
  - Voyager I & II

The Great Voyage

1977 to now and onwards...

Heliopause

Voyager 1 and 2 in 2012

Voyager 1- may 'leave' the Heliosphere in the next year

Bow Shock?

Voyager 1

Termination Shock

Heliosheath

Sun

Heliosphere

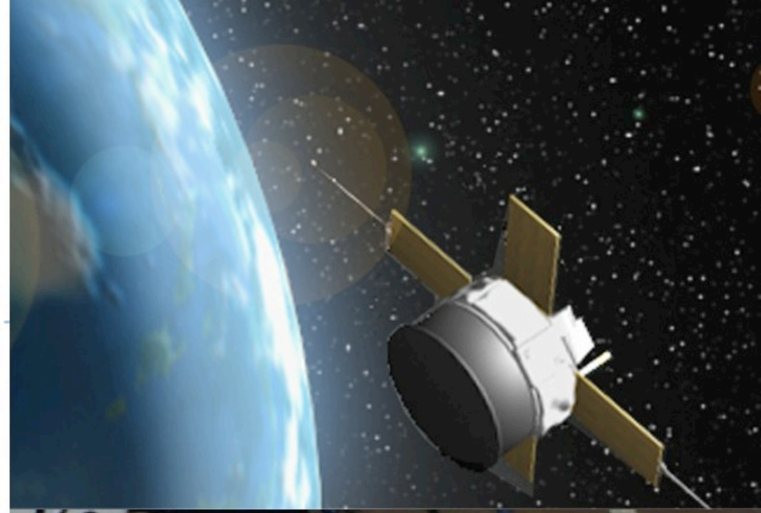
Voyager 2

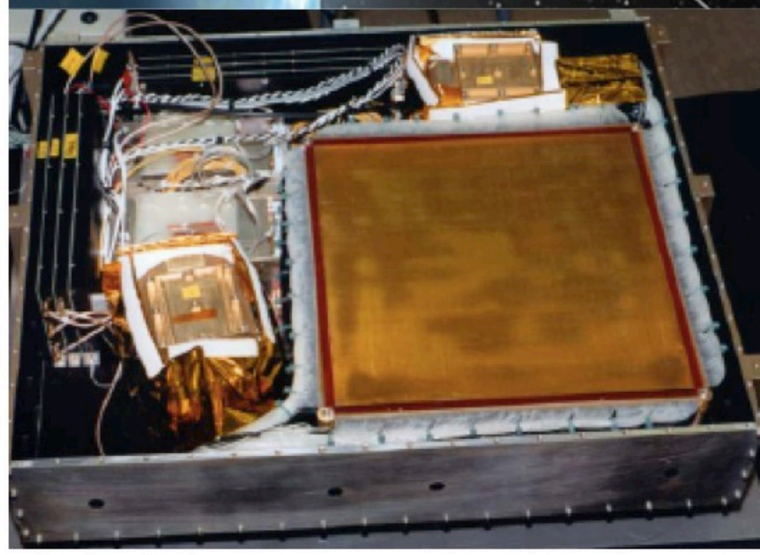
Ed Stone & Voyager

Opportunities in Space

- In Situ Measurements of Solar System
  - Voyager I & II
- Ultra Heavy Nuclei – probe of GCR acceleration & propagation
  - ACE/CRIS
  - Super-TIGER

Ultra Heavy Nuclei



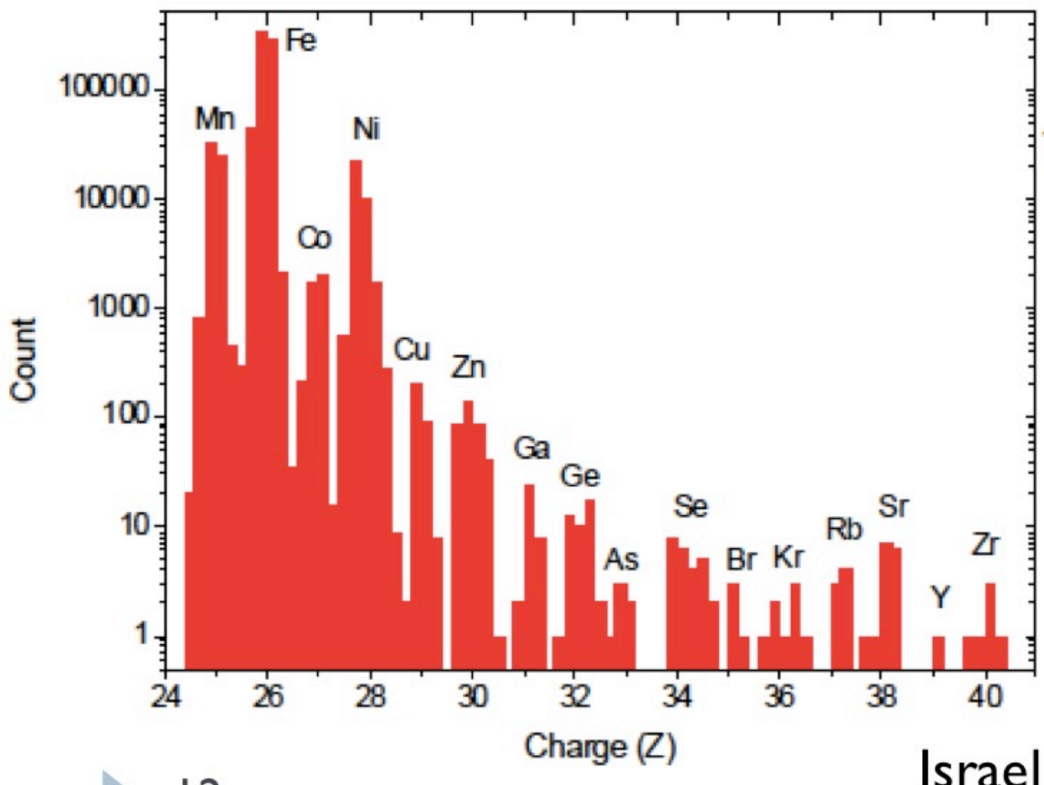


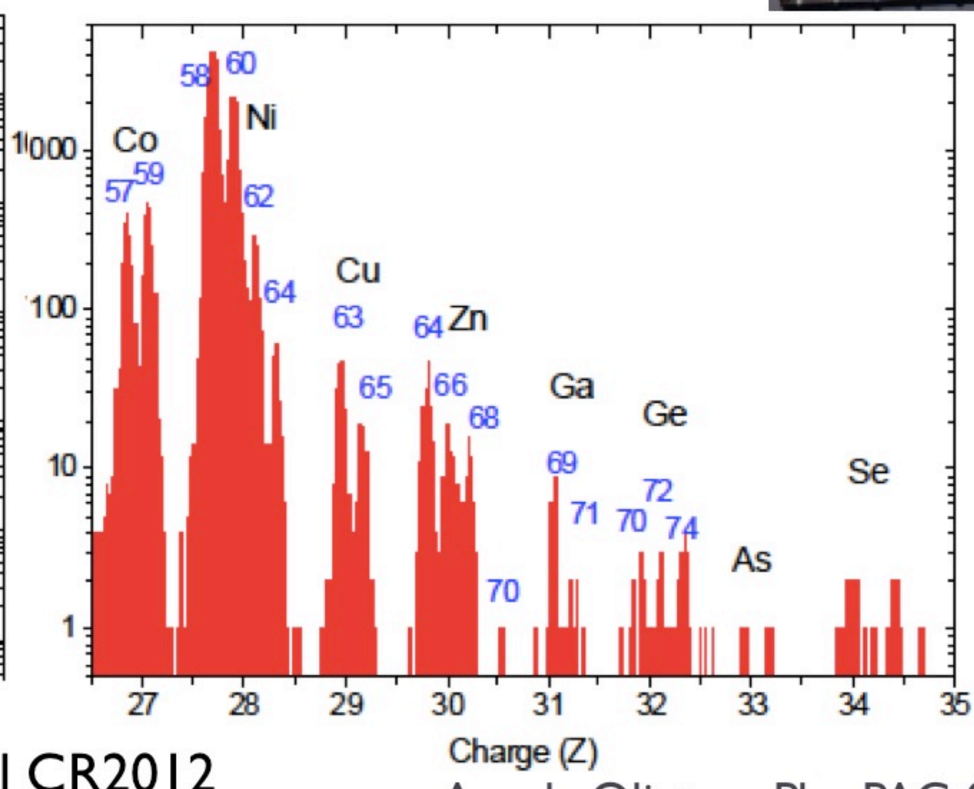
ACE: Advanced Composition Explorer

1997 launch still returning data - L1 Halo orbit

Determines charge state, elemental and isotopic composition of solar corona, solar wind, interplanetary particles, Interstellar medium and galactic particles over a broad energy range

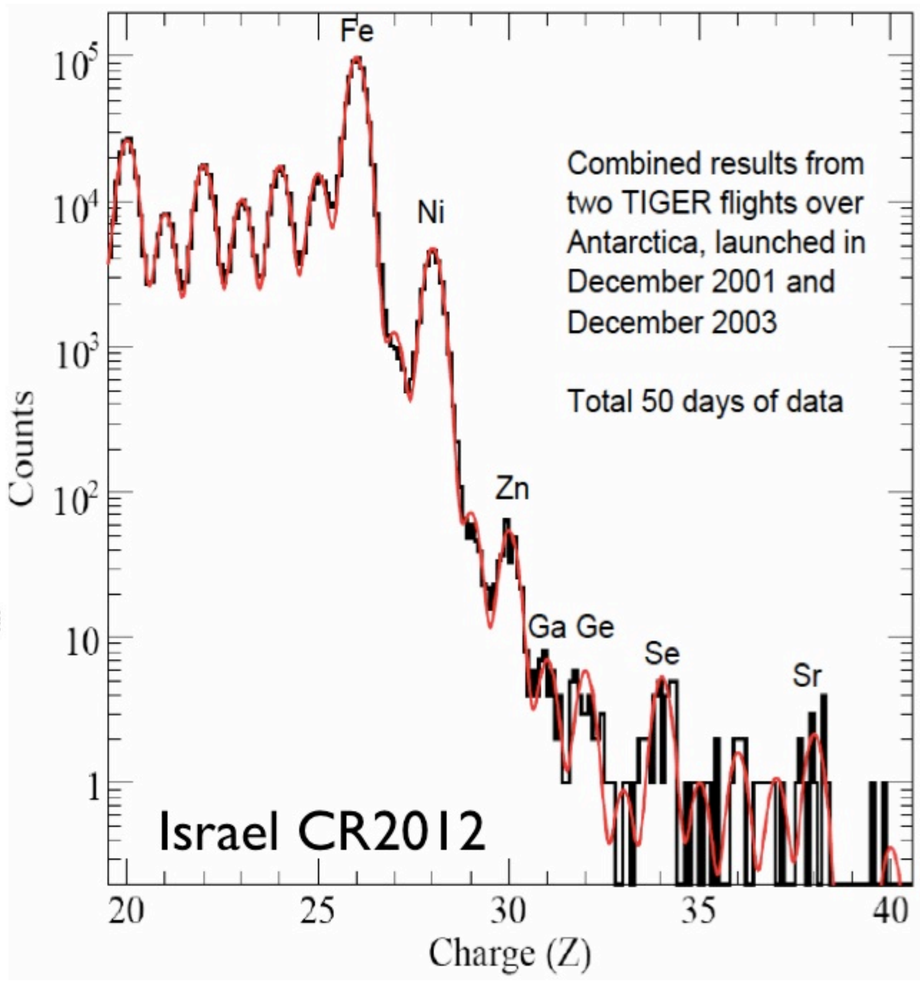
CRIS - Cosmic Ray Isotope Spectrometer

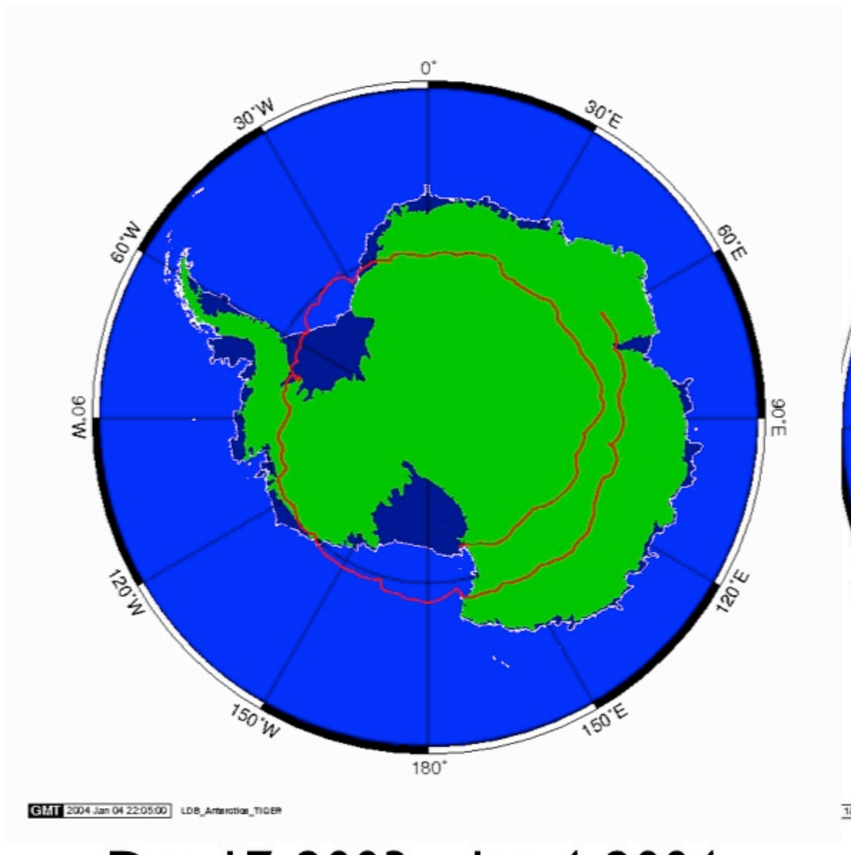




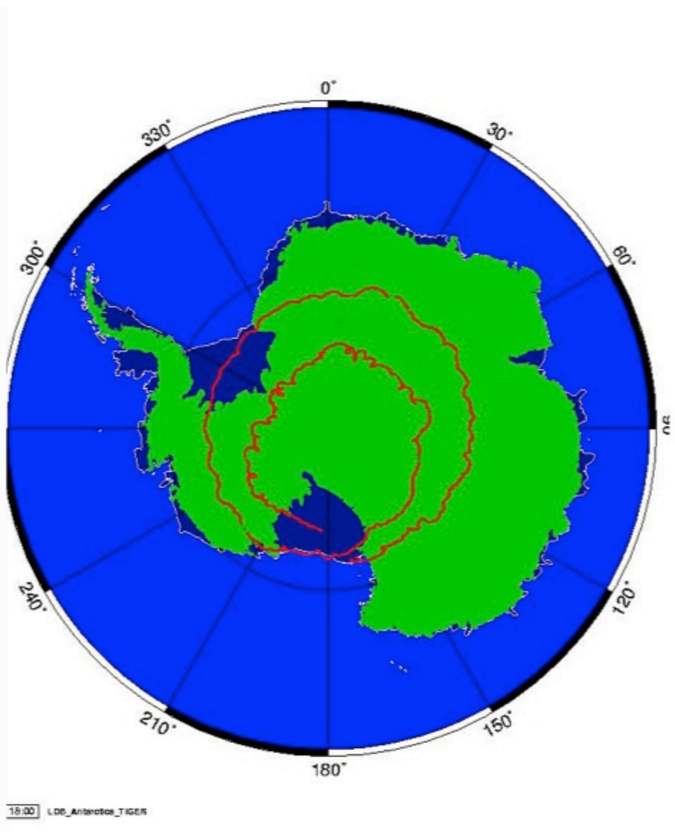
Trans-Iron Galactic Element Recorder (TIGER)

– GCR nuclei heaver than iron (26 < Z < 40) for energies ranging from 0.3 to ~100 GeV/nucleon
– 700 kg (1543 lbs)
– Flights in 2001 and 2003 (50 days)
– Partially recovered in 2006



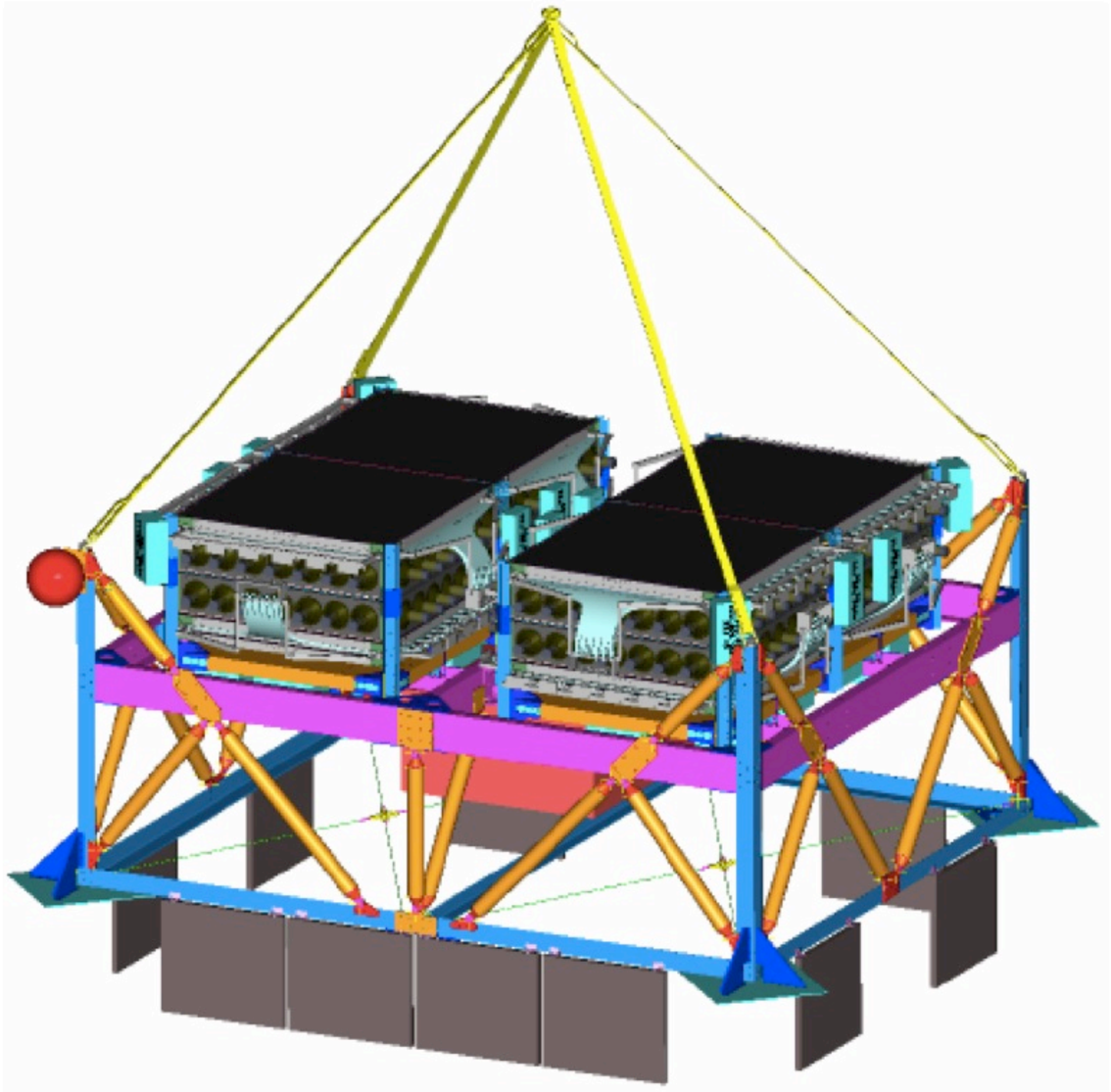


Dec 17, 2003 – Jan 4, 2004



Dec 21, 2001 – Jan 21, 2002

next: Super-TIGER

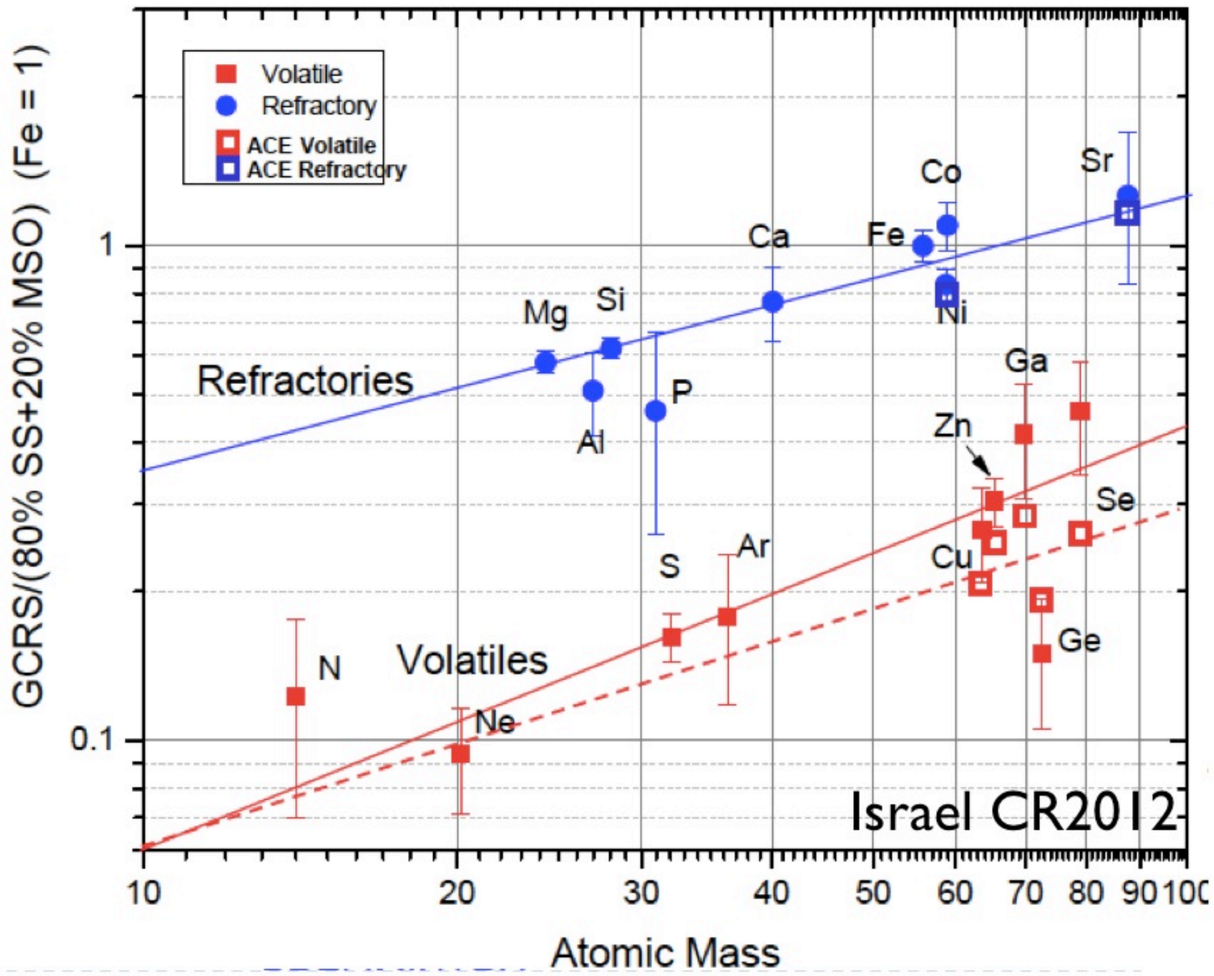


– Antarctic launch **Dec. 2012**

– Collect ~7x more ultraheavy nuclei than TIGER

– Add new elements to mass ordering with smaller error bars throughout

- Is the composition 80% Solar 20% Massive Star Outflow?

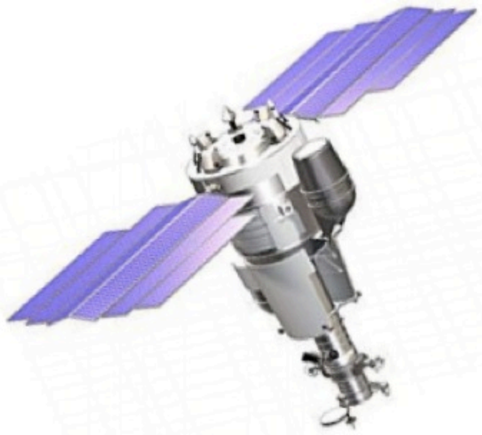


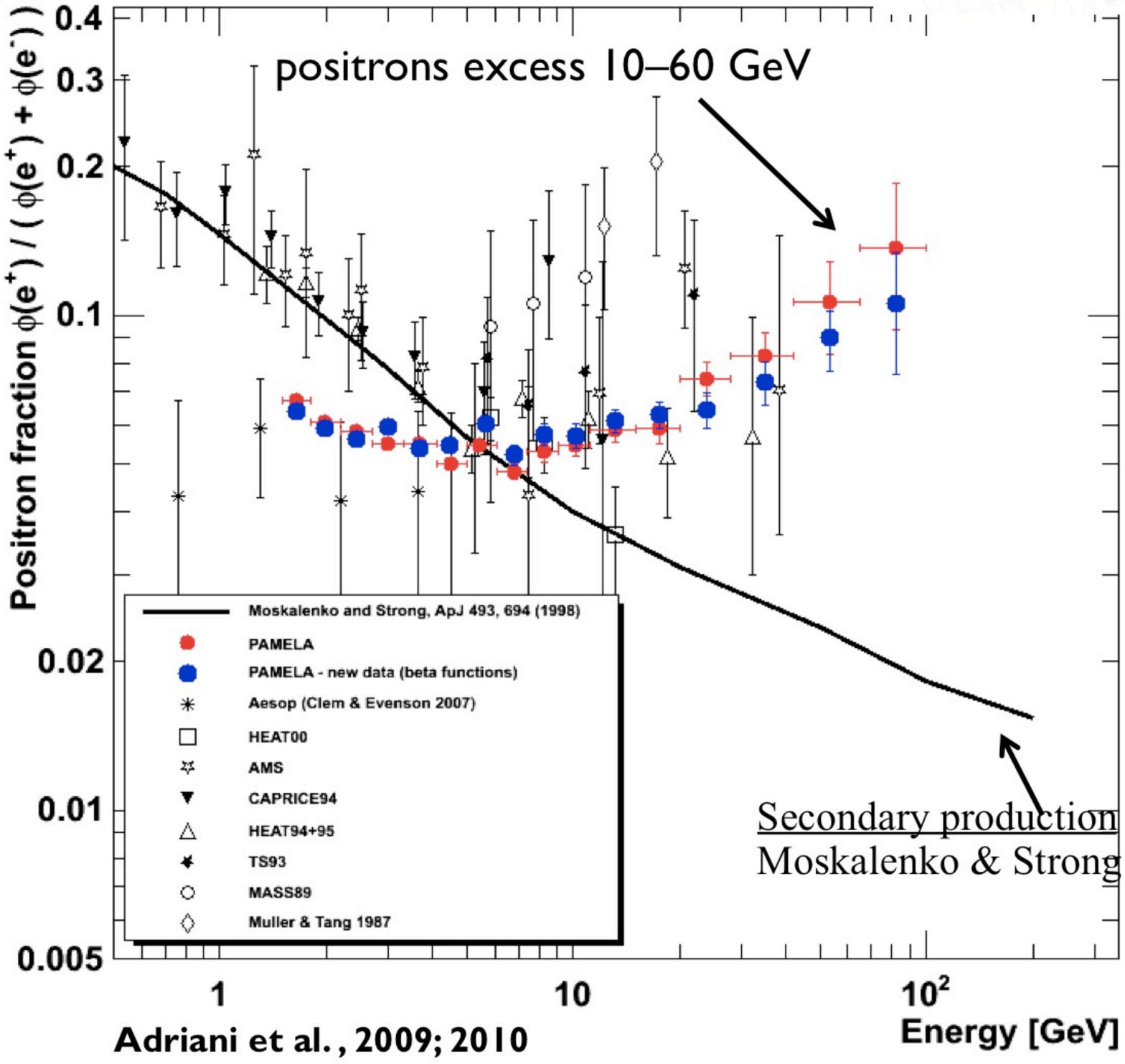
Opportunities in Space

- In Situ Measurements of Solar System
  - Voyager I & II
- Ultra Heavy Nuclei
  - ACE/CRIS
  - Super-TIGER
- Precise Measurements from GeV to > TeV
  - PAMELA
  - AMS
  - CALET

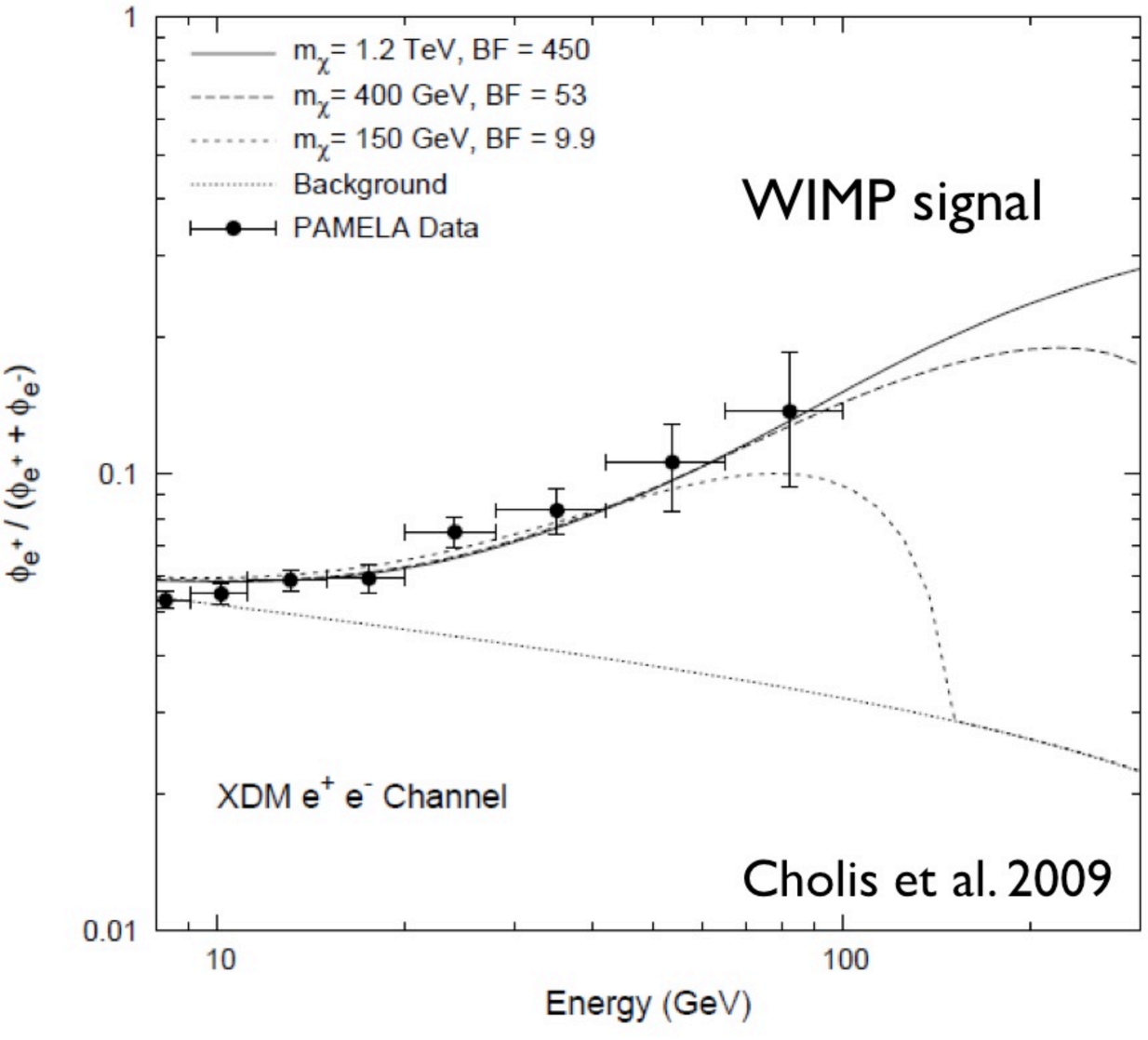
PAMELA

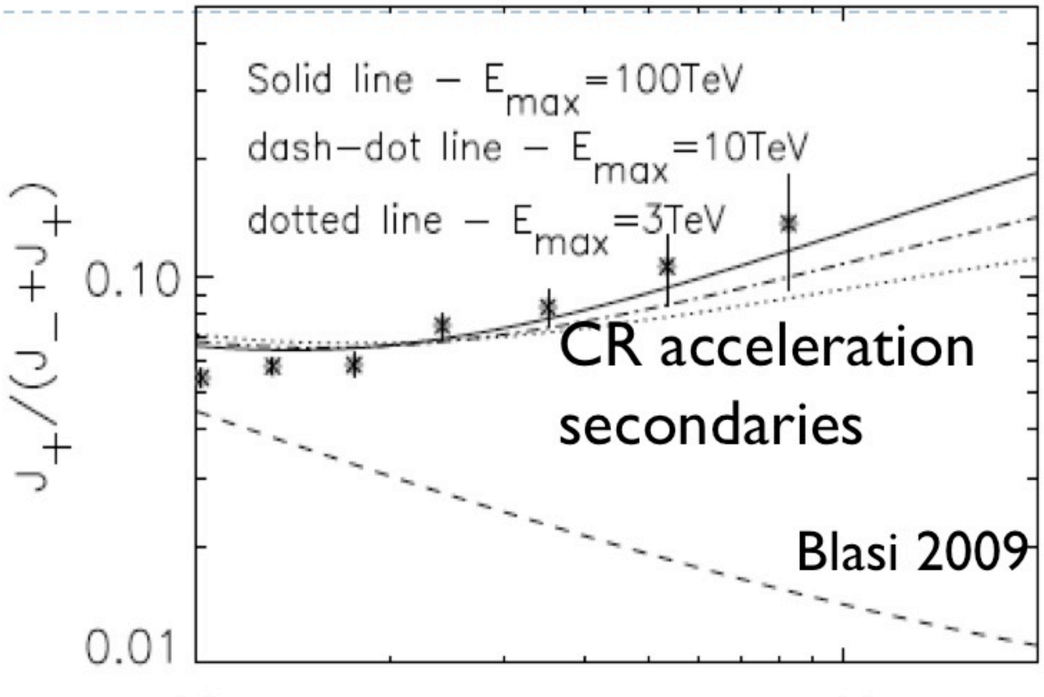
Payload for Antimatter Matter Exploration
and Light-nuclei Astrophysics

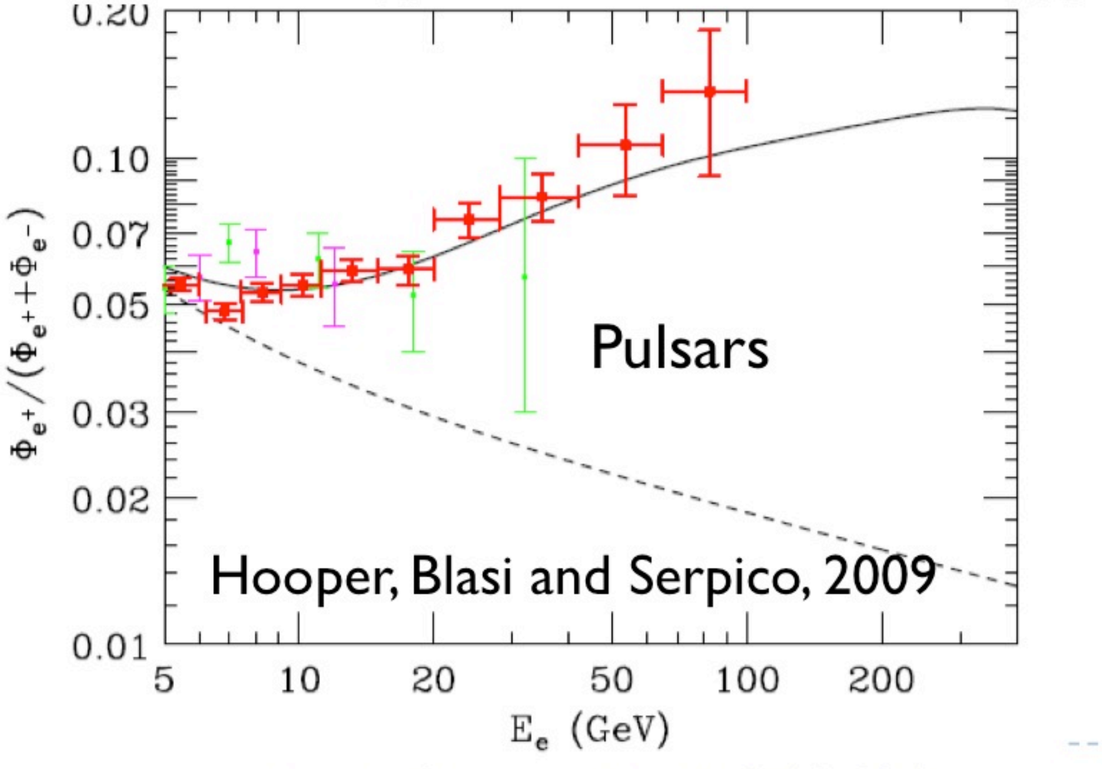




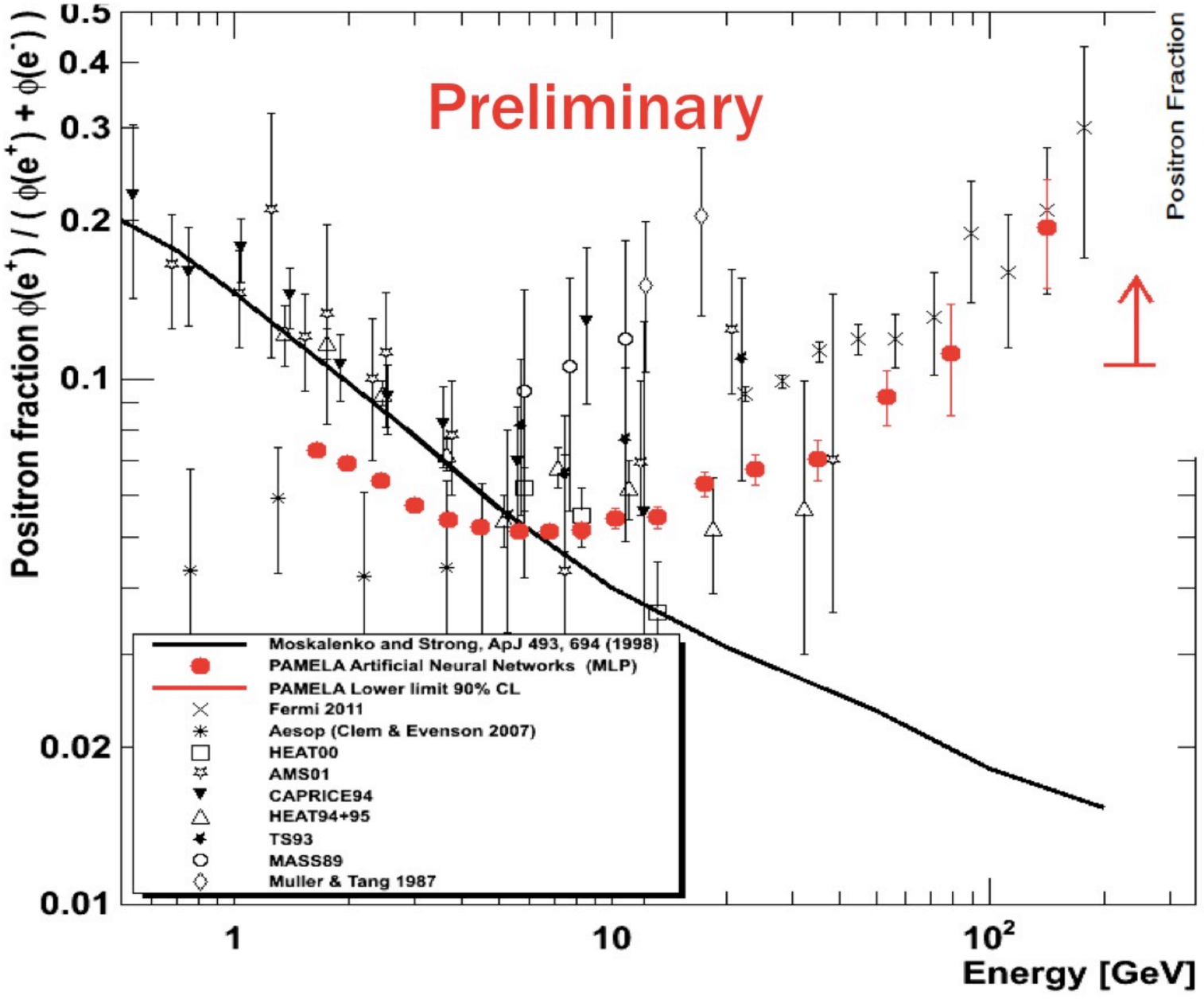
Dark Matter or Pulsars or SNRs?

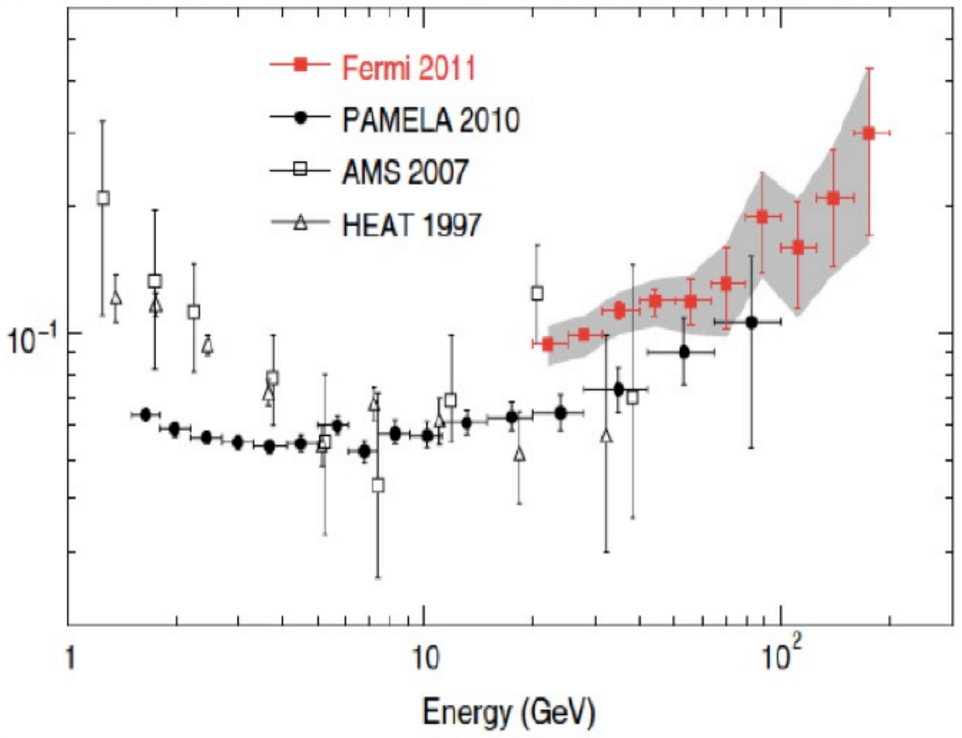




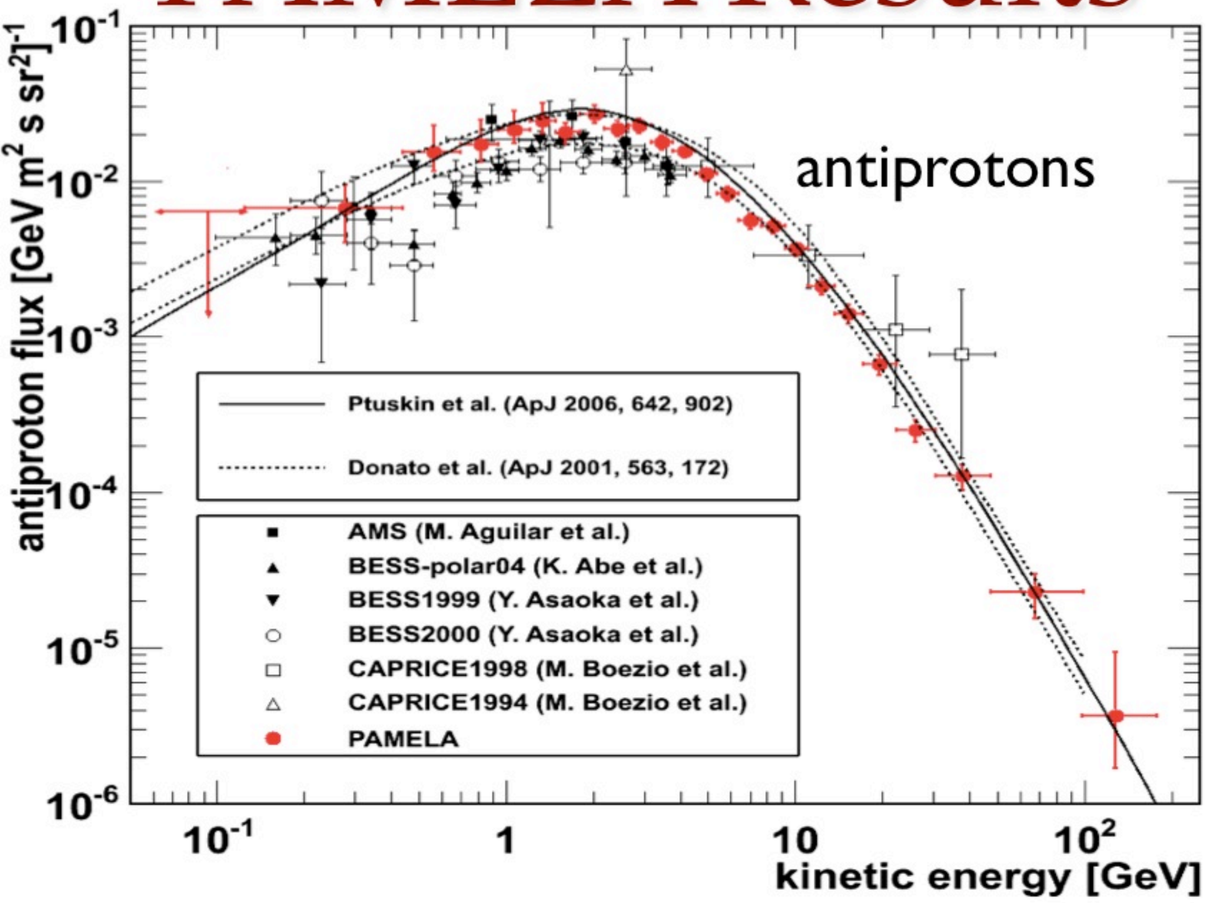


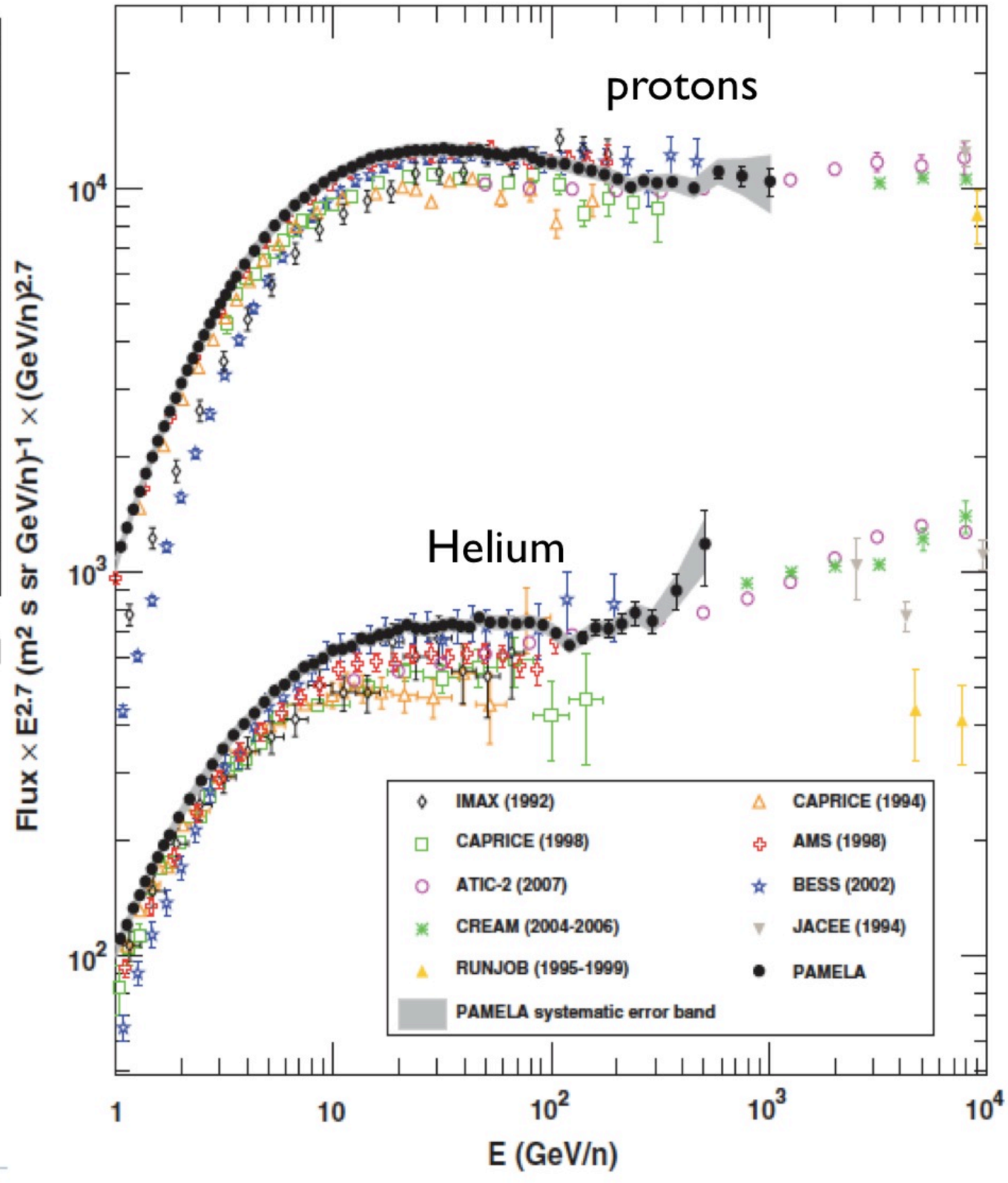
Updates PAMELA & Fermi

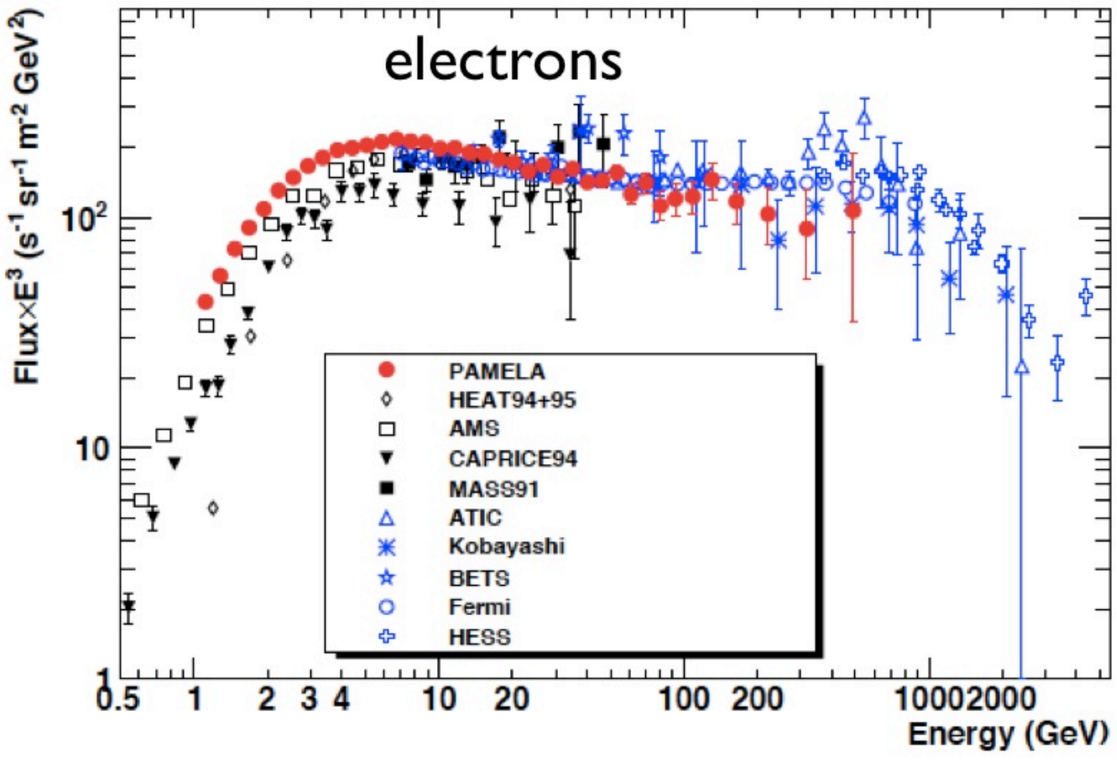




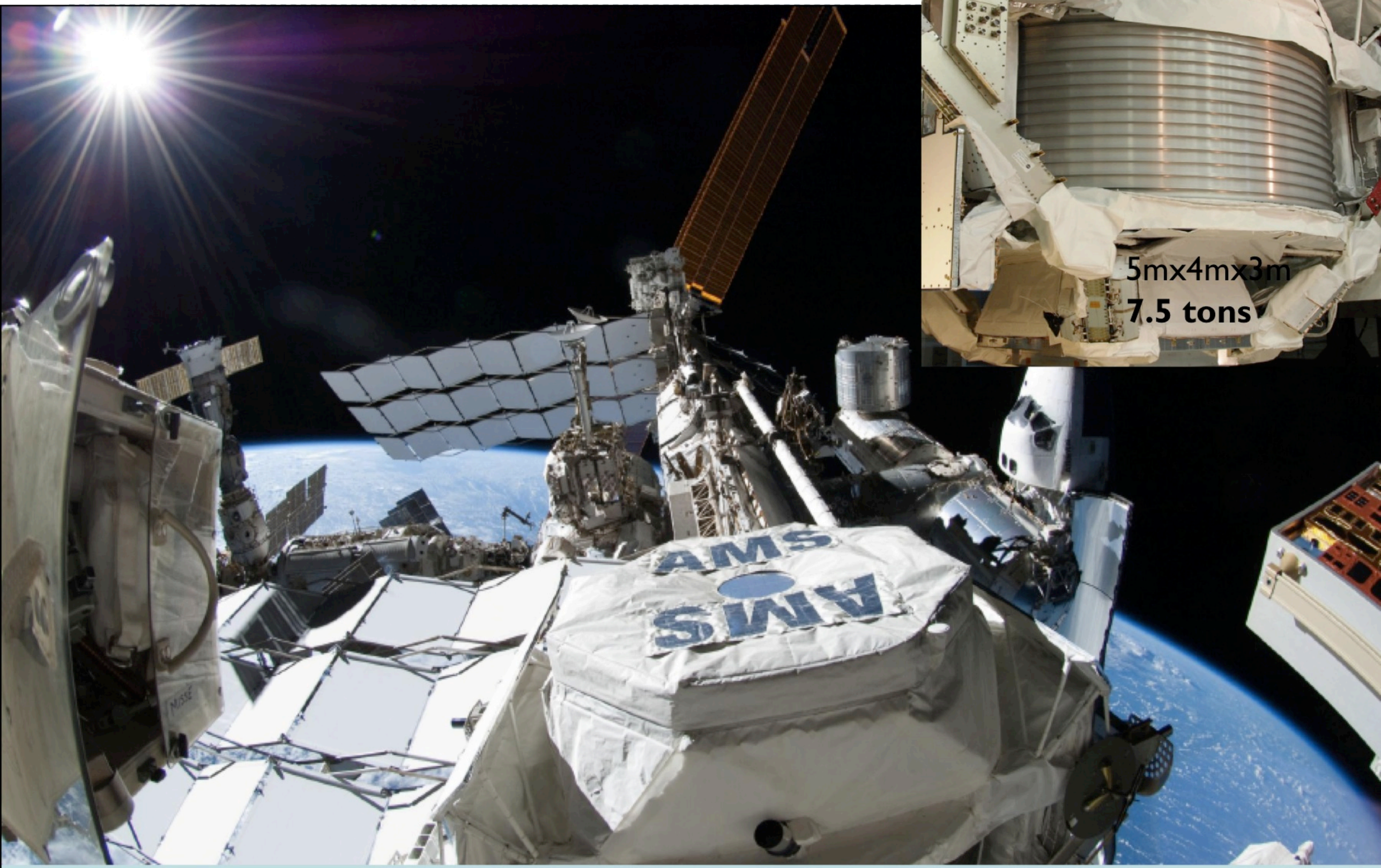
PAMELA Results





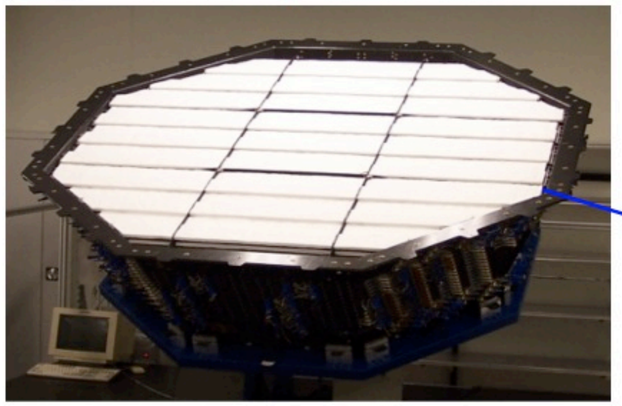


AMS (Alpha Magnetic Spectrometer) on the ISS

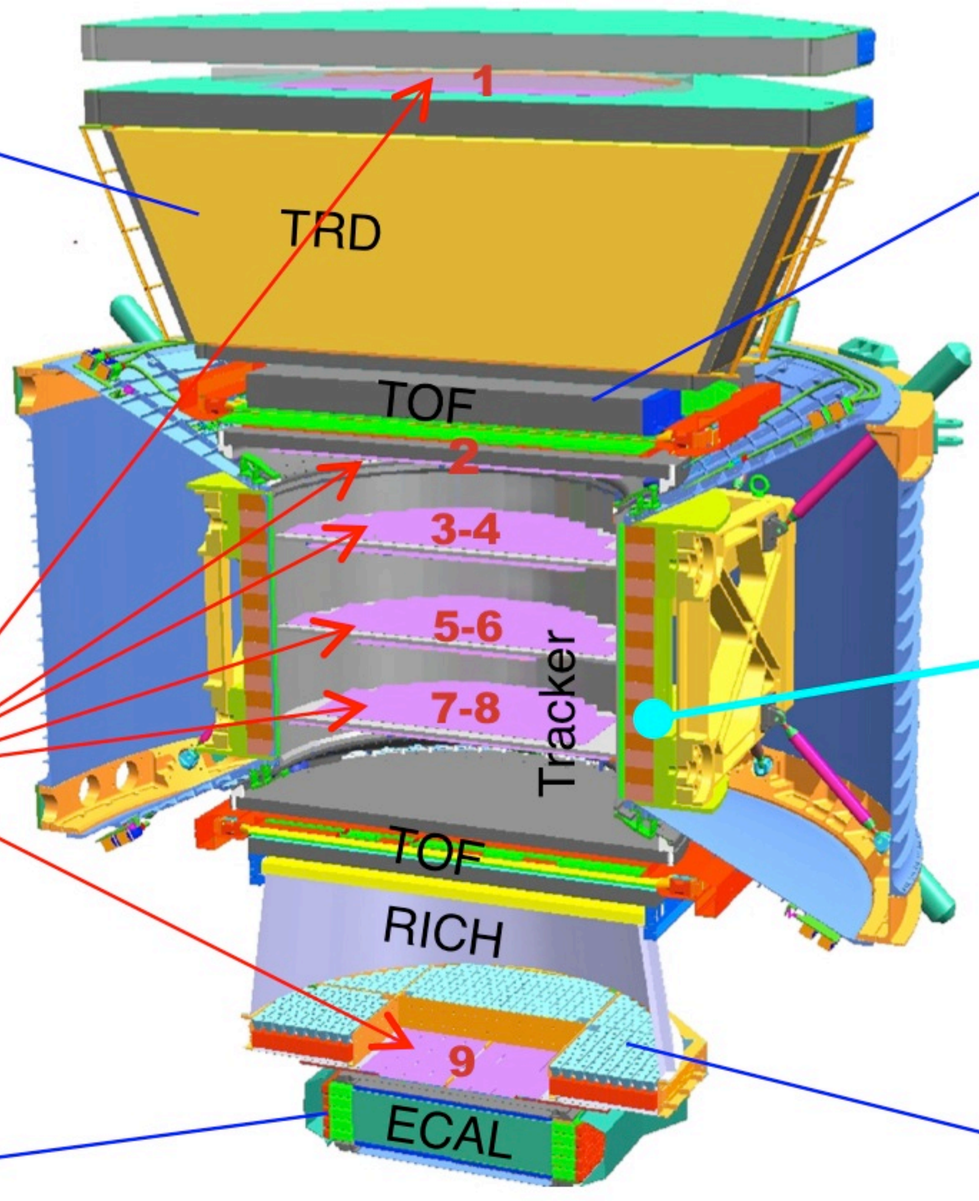


AMS: multipurpose spectrometer up to TeV

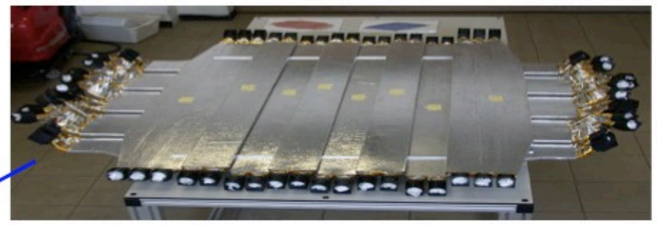
TRD
Identify e+, e-



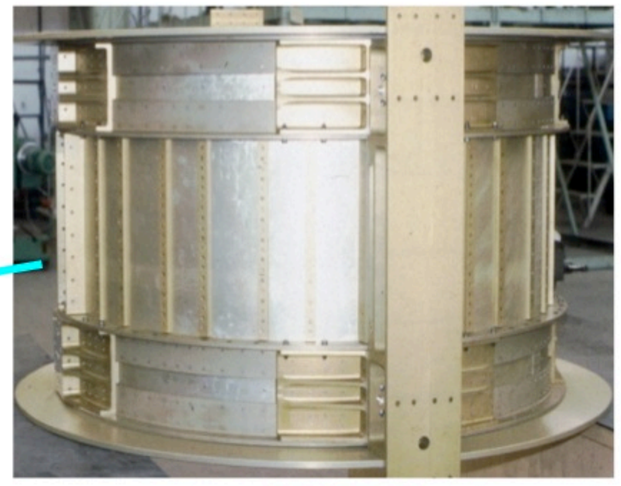
Particles and nuclei are defined by their charge (Z) and energy (E ~ P)



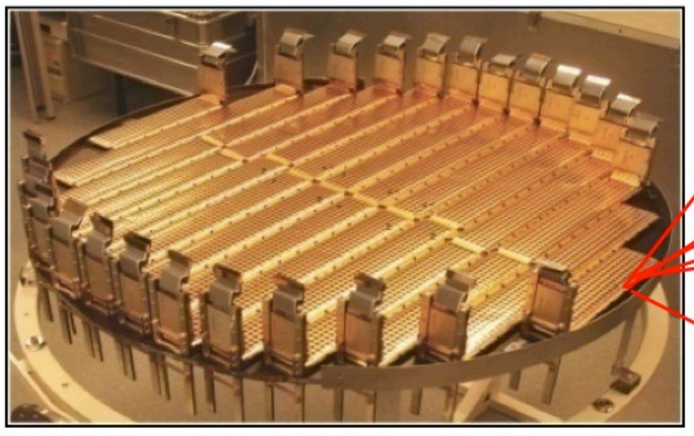
TOF
Z, E



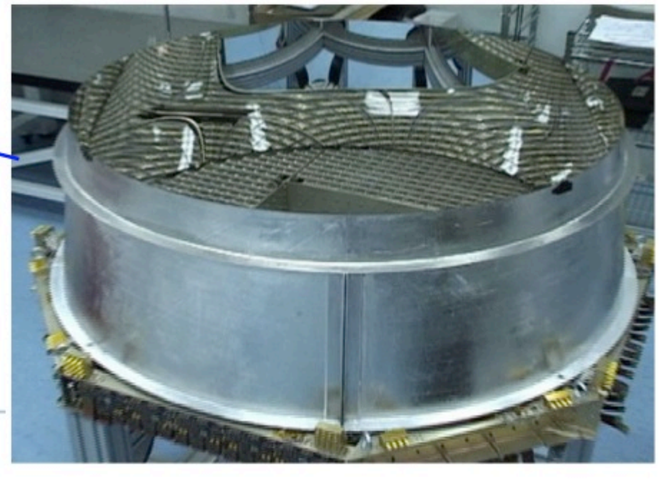
Magnet
±Z



Silicon Tracker
Z, P



RICH
Z, E

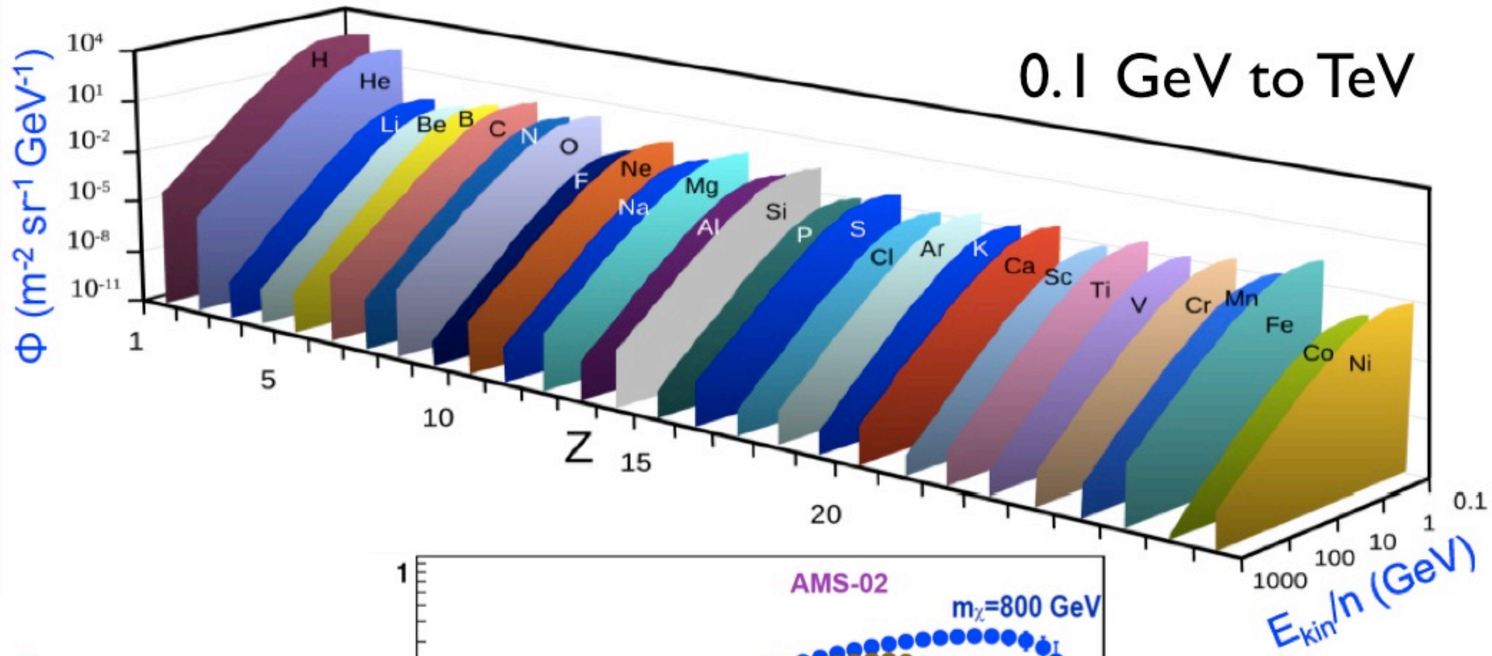


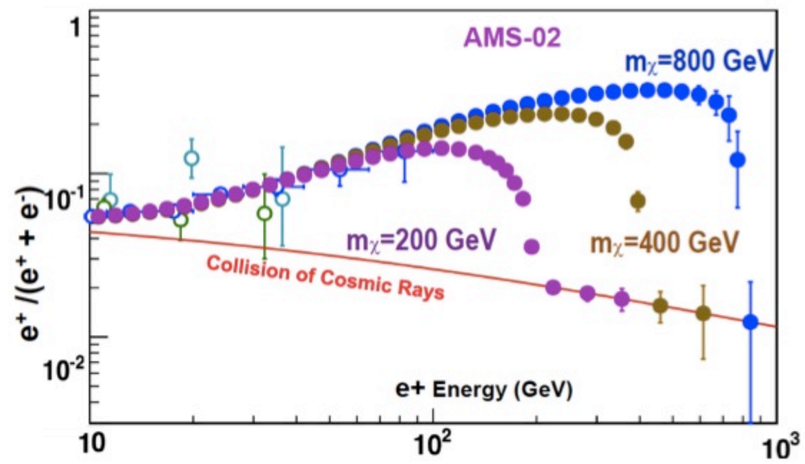
ECAL
E of e+, e-, γ

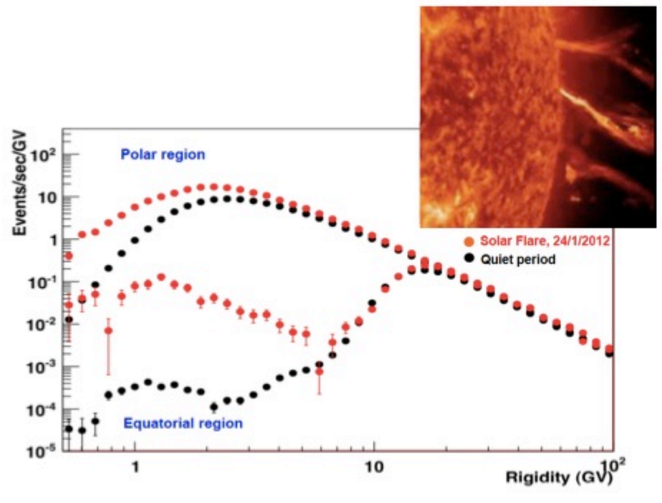
Z, P are measured independently from Tracker, RICH, TOF and ECAL

AMS goals

- Launch May 16, 2011
- Data from May 19, 2011
- ~1.6 10^{10} events/year
- Search for primordial antimatter:
  - –Anti-nuclei: He-bar, …
- Dark Matter search:
  - – e+ , e- , p ,p-bar …
    - simultaneous observation of several signal channels.
- Search for new forms of matter:
  - strangelets, ...
- CR spectra – refining propagation models;
- Understanding of local sources:
  - SNR, Pulsars, PBH, …
- Solar modulation on CR spectra over 11 year solar cycle



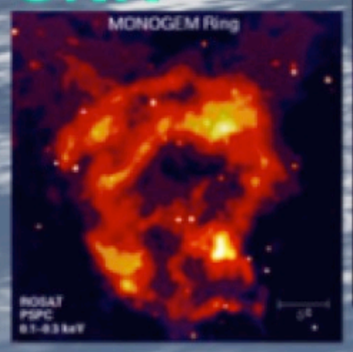




Cosmic Ray Sources

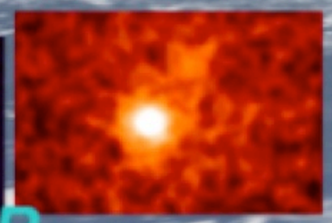
Dark Matter

SNR



Pulsar

AGN



International Space Station

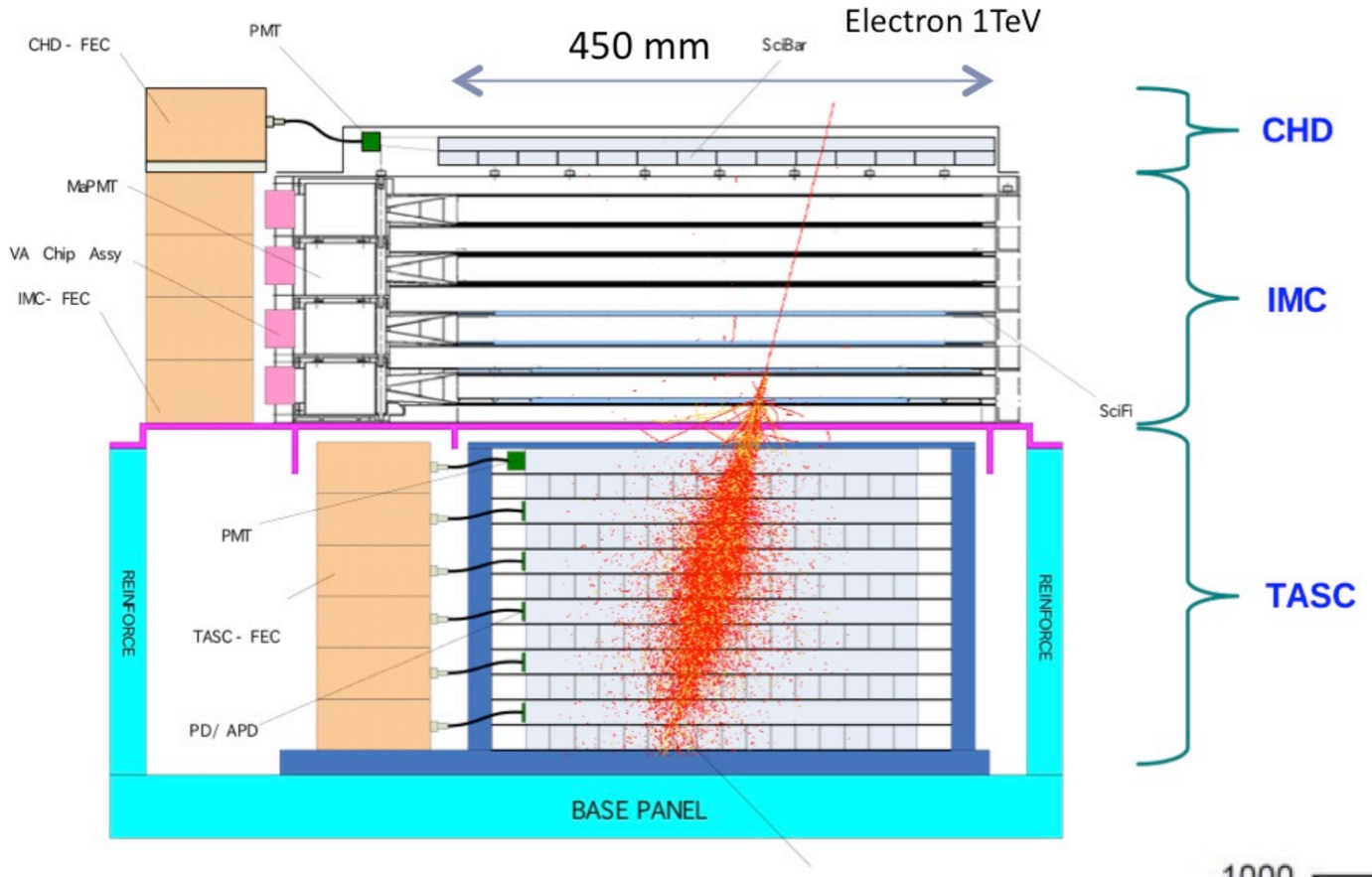
Japanese Experiment Module (Kibo)

CALorimetric Electron Telescope

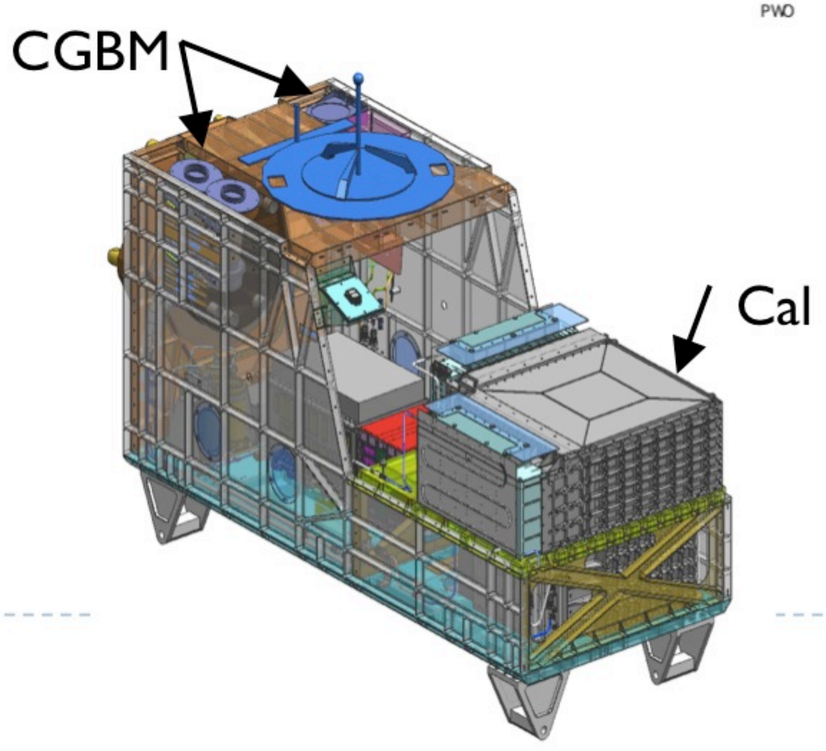
A Dedicated Detector for Electron Observation in 1GeV - 10,000 GeV

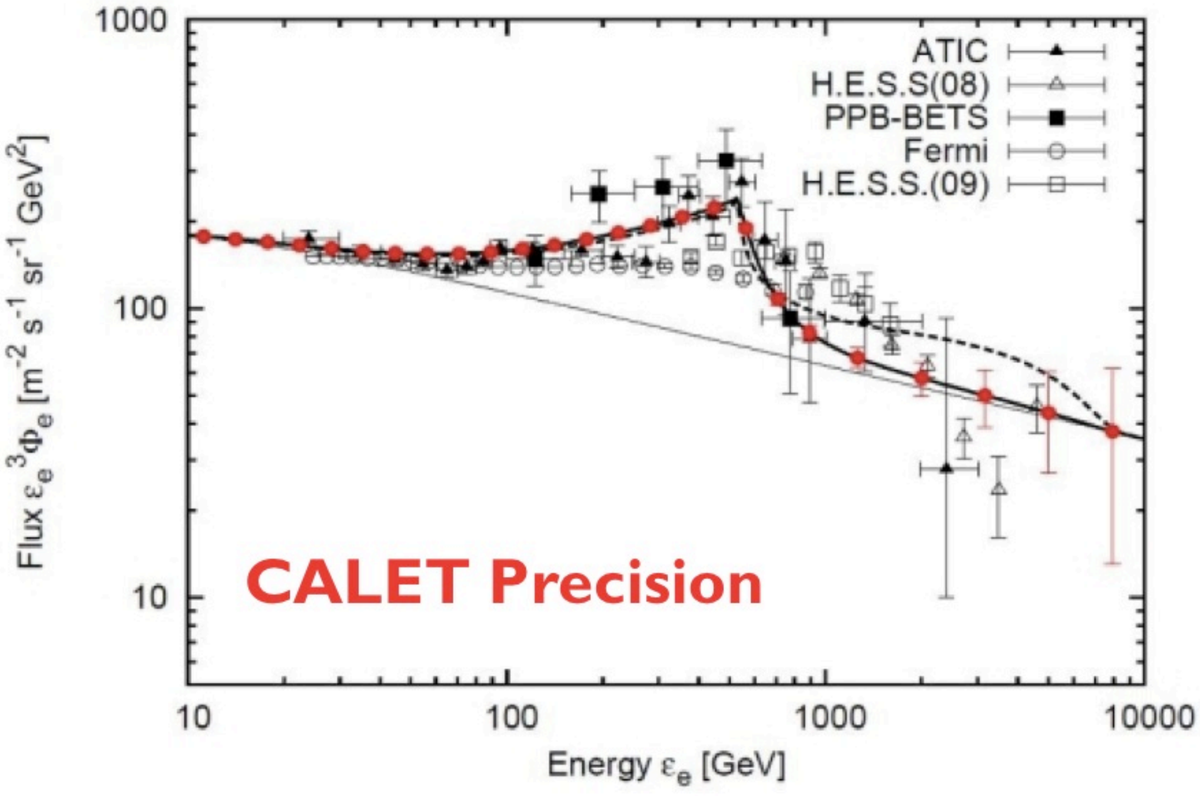
launch planned for 2014

CALorimetric Electron Telescope (CALET)



CALET has a thick, fully active calorimeter that allows measurements well into the TeV energy region with good energy resolution, coupled with imaging upper calorimeter to accurately identify the starting point of electromagnetic showers; to separate electrons from the abundant protons with selection power $>10^5$.





Opportunities in Space

- In Situ Measurements of Solar System
  - Voyager I & II
- Ultra Heavy Nuclei
  - ACE/CRIS
  - Super-TIGER
- Precise Measurements from GeV to TeV
  - PAMELA
  - AMS
  - CALET
- Galactic Cosmic Rays up to the knee
  - CREAM, TRACER
  - ISS-CREAM

CREAM

Cosmic Ray Energetics and Mass

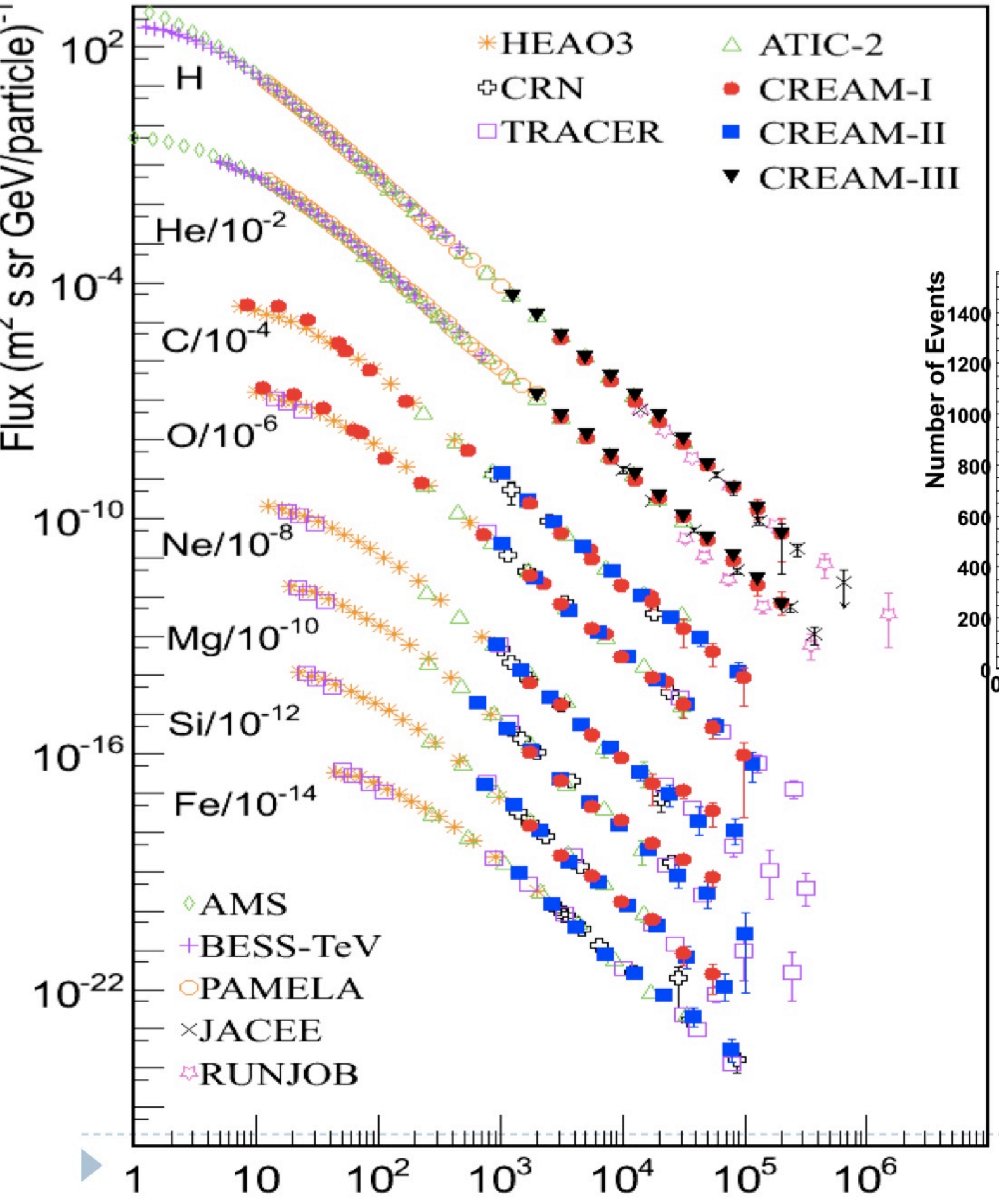
– GCR nuclei from H to Fe
– from ~10 GeV (C) to ~500 TeV for p & He
– 966 kg (2126 lbs)
– 5 Flights to date – 156 days at float
– Variety of subsystems employed

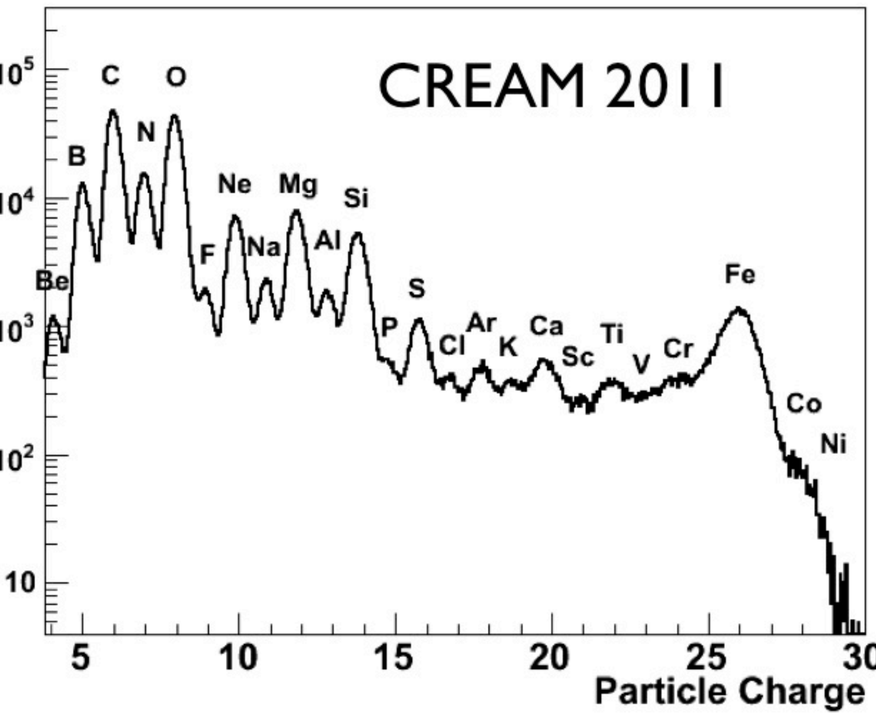
TRACER

Transition Radiation Array for Cosmic Energetic Radiation

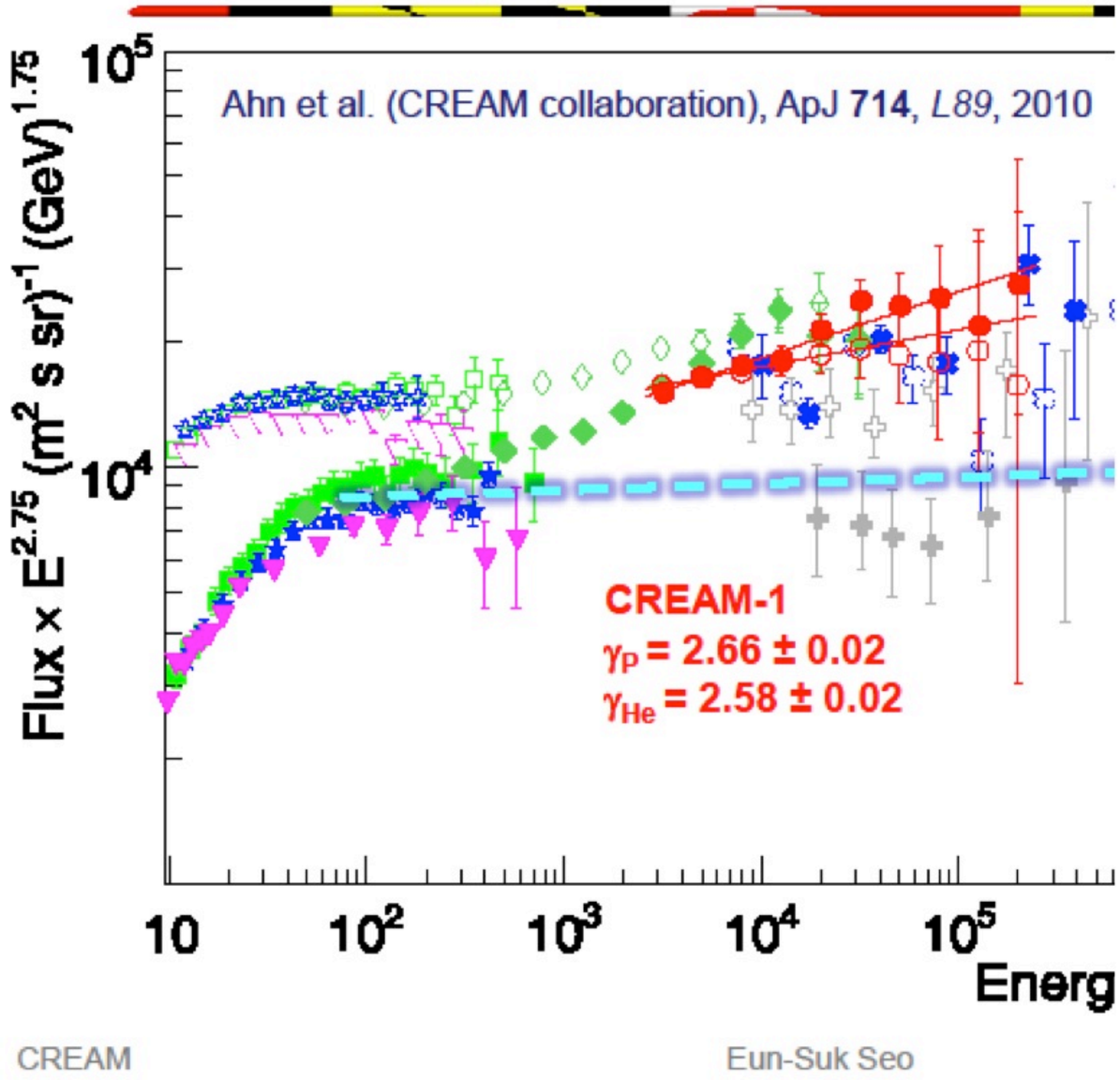
- Direct measurements of O to Fe
- from ~50 GeV to several 100 TeV;
- 5 m^2 sr
- 1614 kg (3550 lbs)
- Flights in 2003 (Antarctica) and 2006 (Sweden)

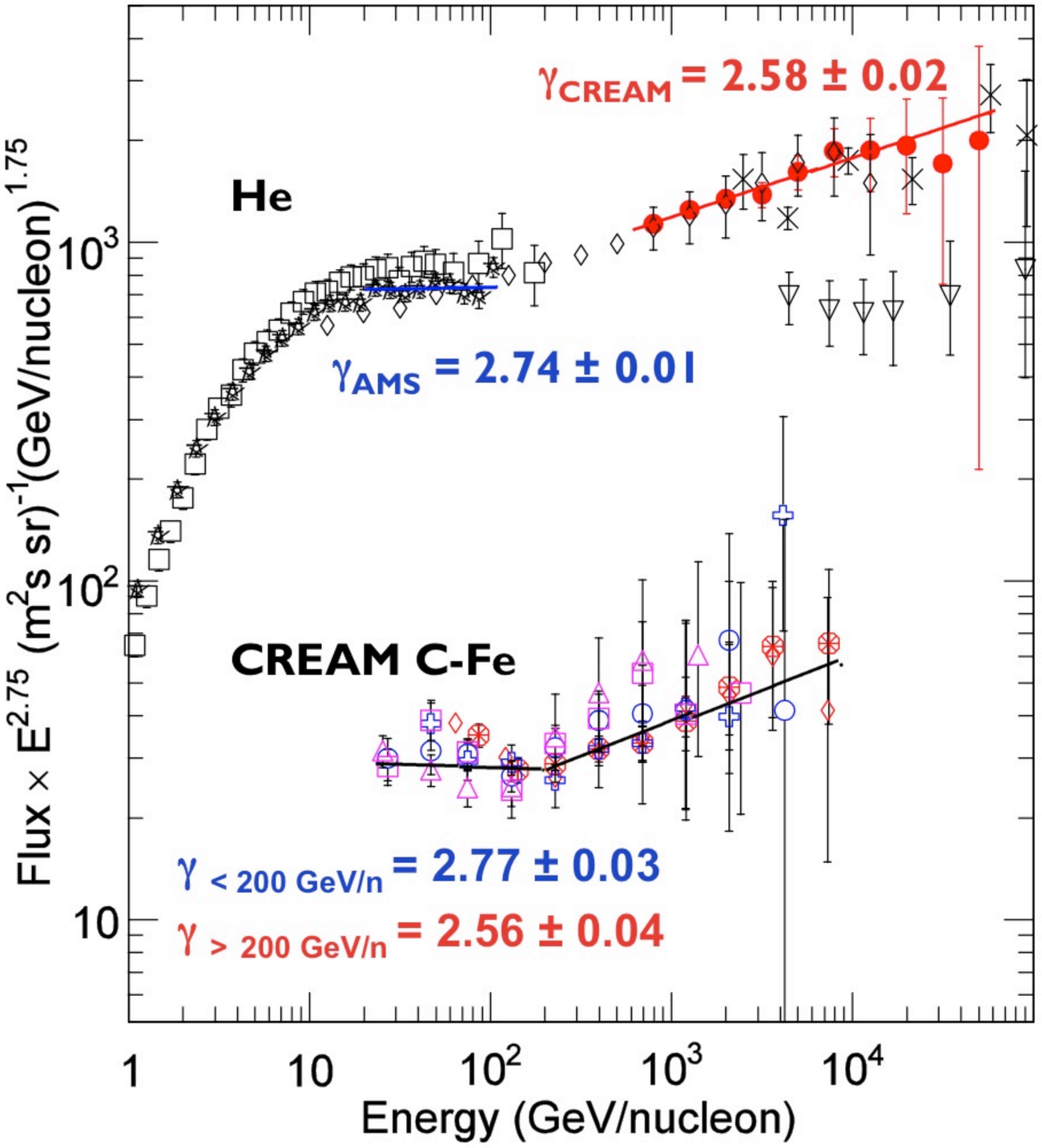
Hi-Z Energy Spectra





CREAM: p & He spectra are not the same

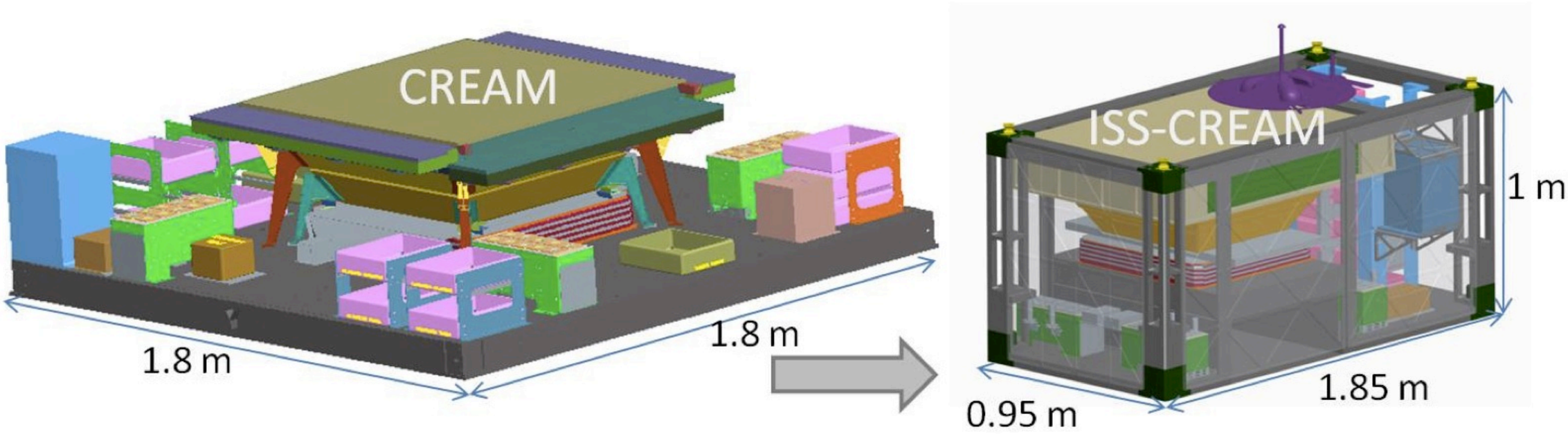




Not a single power law!

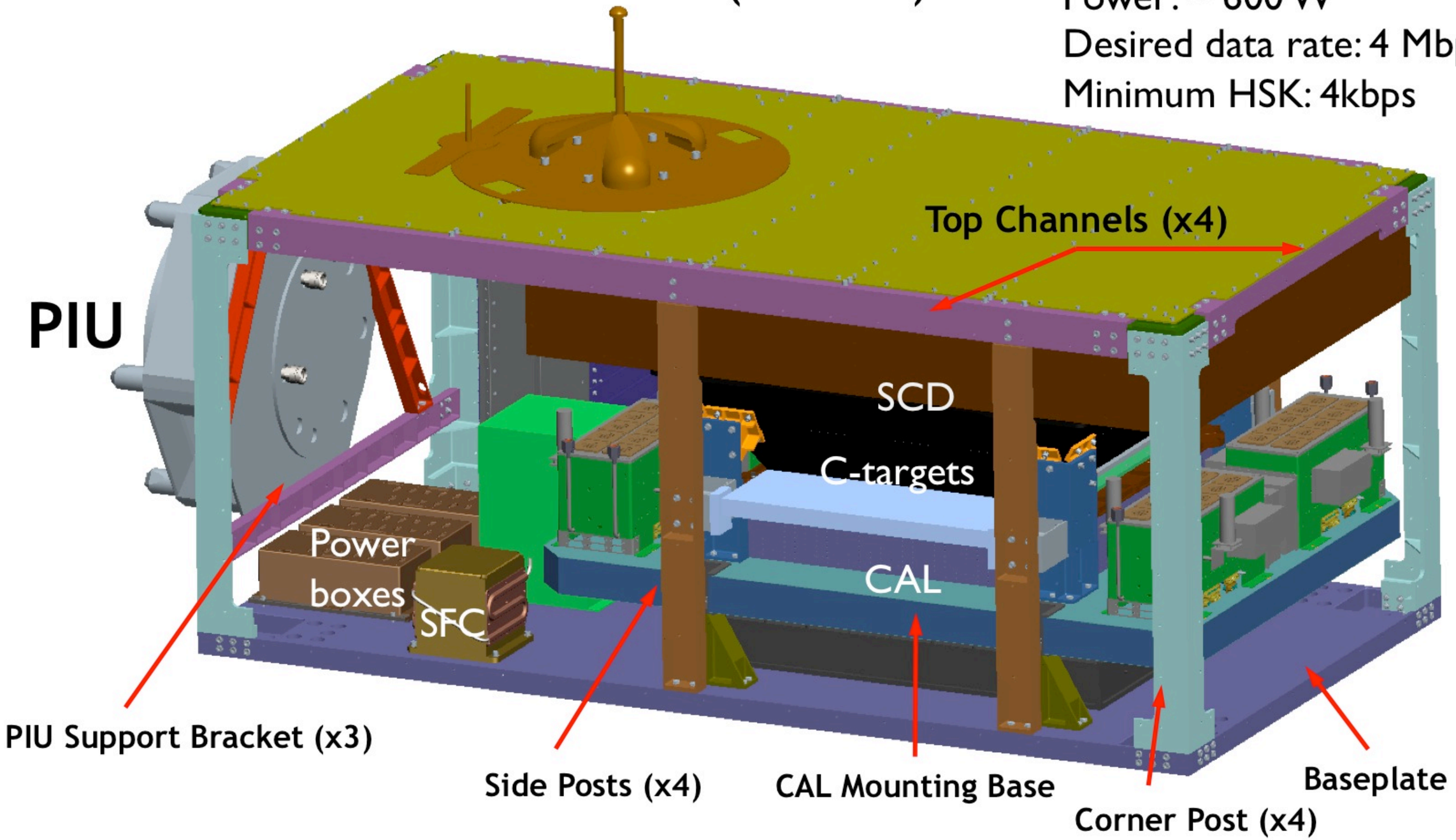
From CREAM to ISS-CREAM

- ISS ideal for > 10 x increase in exposure
- launch 2014 by Space X
- CREAM re-packaged for accommodation on the Japanese Experiment Module Exposed Facility (JEM-EF.



ISS-CREAM payload

Mass: 1200 kg inc. GFE
Power: ~ 600 W
Desired data rate: 4 Mbps
Minimum HSK: 4kbps



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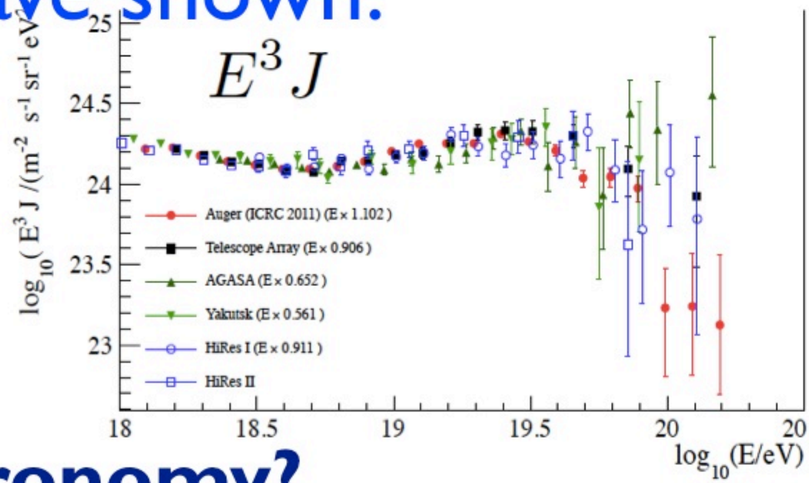
- In Situ Measurements of Solar System
  - Voyager I & II
- Ultra Heavy Nuclei
  - ACE/CRIS
  - Super-TIGER
- Precise Measurements from GeV to TeV
  - PAMELA
  - AMS
  - CALET
- Galactic Cosmic Rays up to the knee
  - CREAM, TRACER
  - ISS-CREAM
- Extragalactic Cosmic Rays
  - JEM-EUSO
  - OWL/PATEL

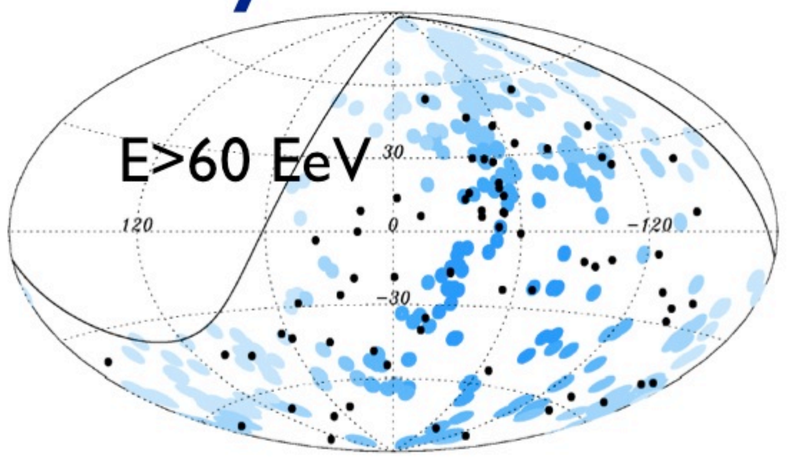
Ultrahigh to Extremely High Energies

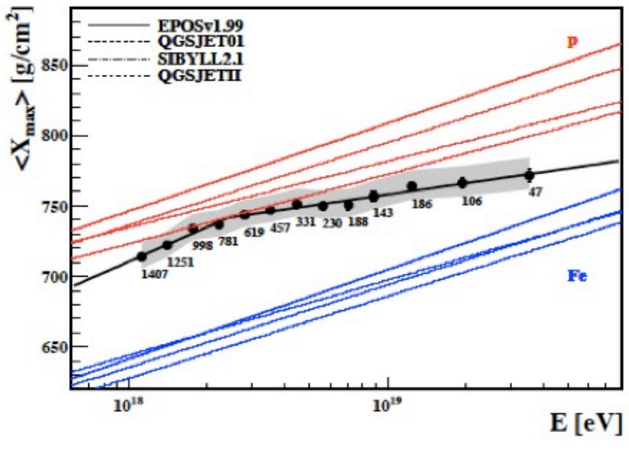
- Ground-based UHECR Observatories have shown:

(Auger & HiRes/Telescope Array)

  - The spectrum has a feature > 40 EeV
  - possibly due to CMB (GZK* effect?)
  - E > 60 EeV – hints of anisotropy – **CR Astronomy?**
  - Hadronic Interaction &/or Composition is suprising > 40 EeV

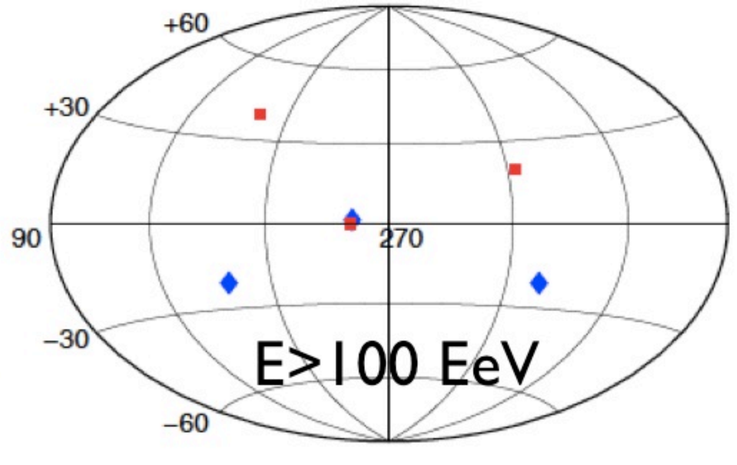






- But only

~ 1 event >100 EeV/year (~30w>60 EeV/year)

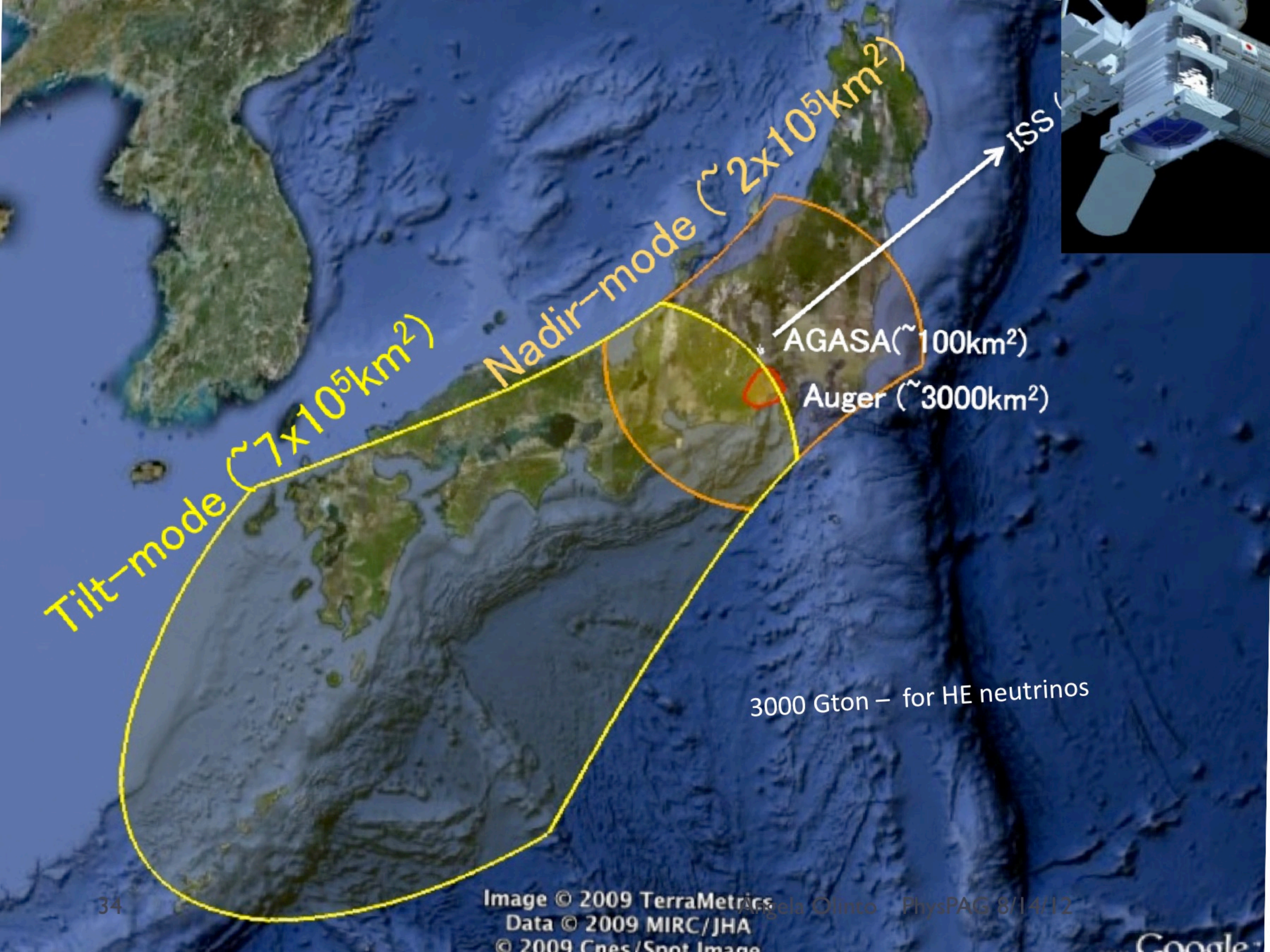


*Greisen-Zatsepin-Kuzmin

JEM-EUSO Mission

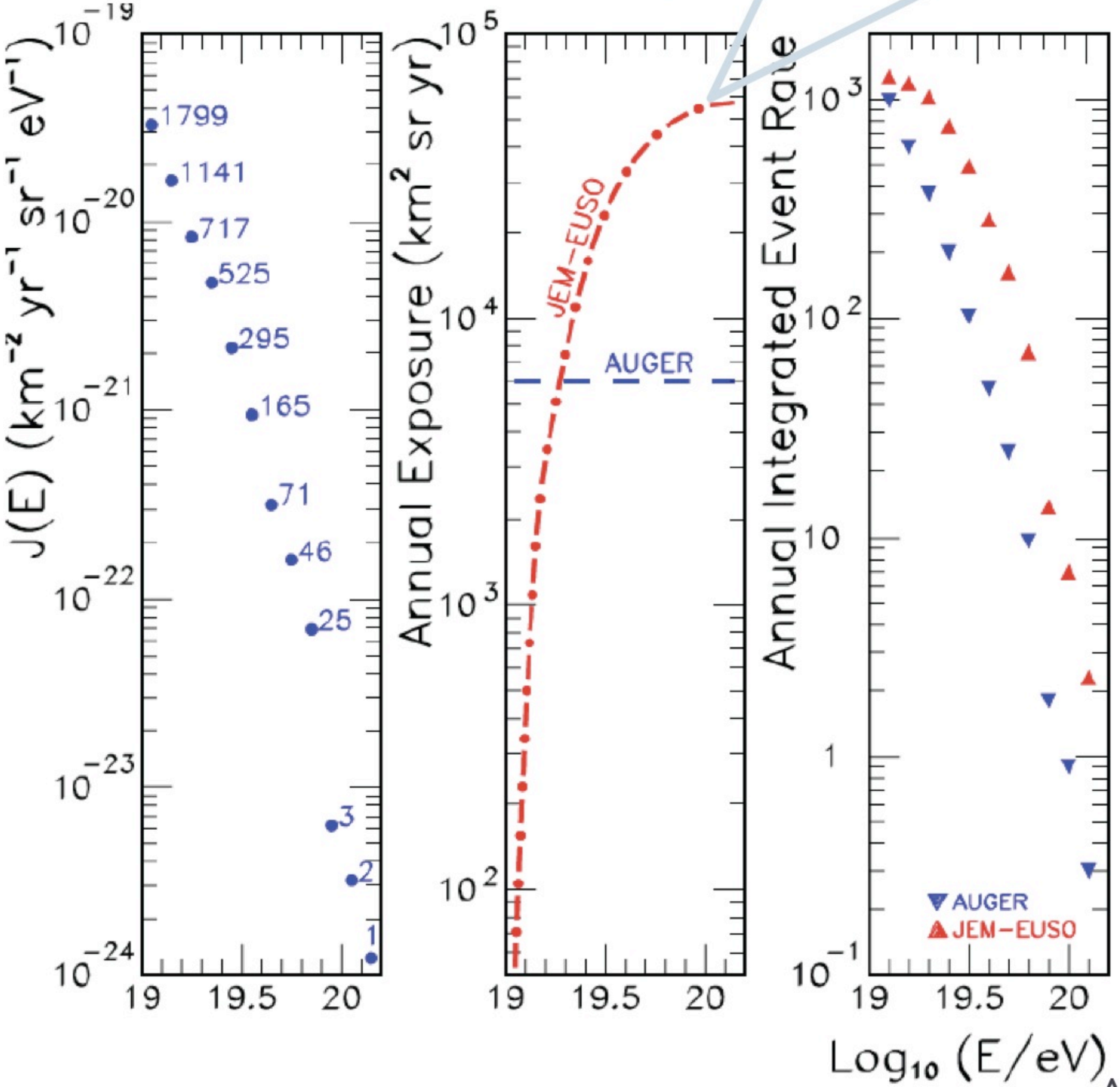
Extreme Universe Space Observatory on the Japanese Experiment Module on the International Space Station

Collaboration of
13 countries,
77 institutions
> 250 scientists

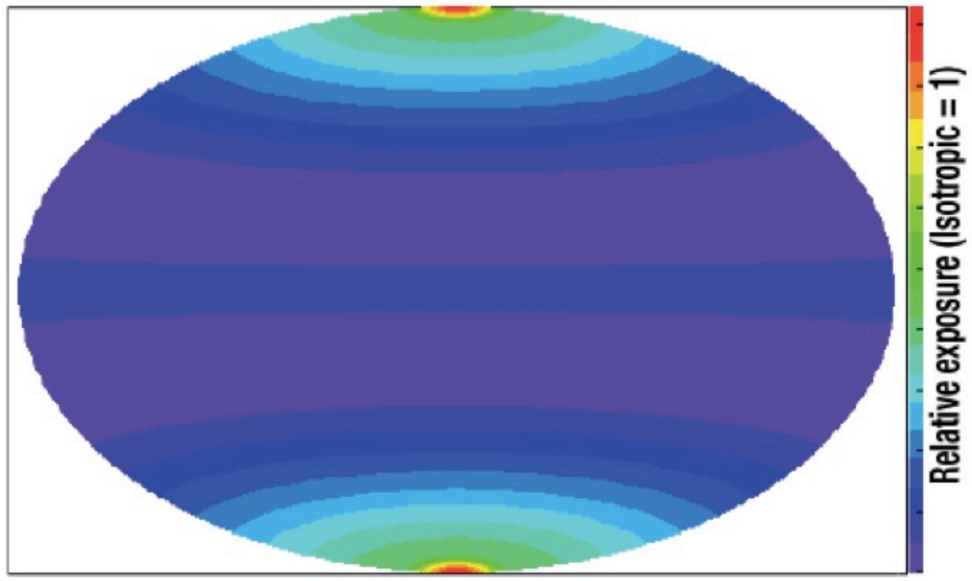

Nadir−mode (~2x10^{5}km^2)
Tilt−mode (~7x10^{5}km^2)
AGASA(~100km^2)
Auger (~3000km^2)
ISS
3000 Gton – for HE neutrinos
Image © 2009 TerraMetrics
Data © 2009 MIRC/JHA
© 2009 Cnes/Spot Image

JEM-EUSO

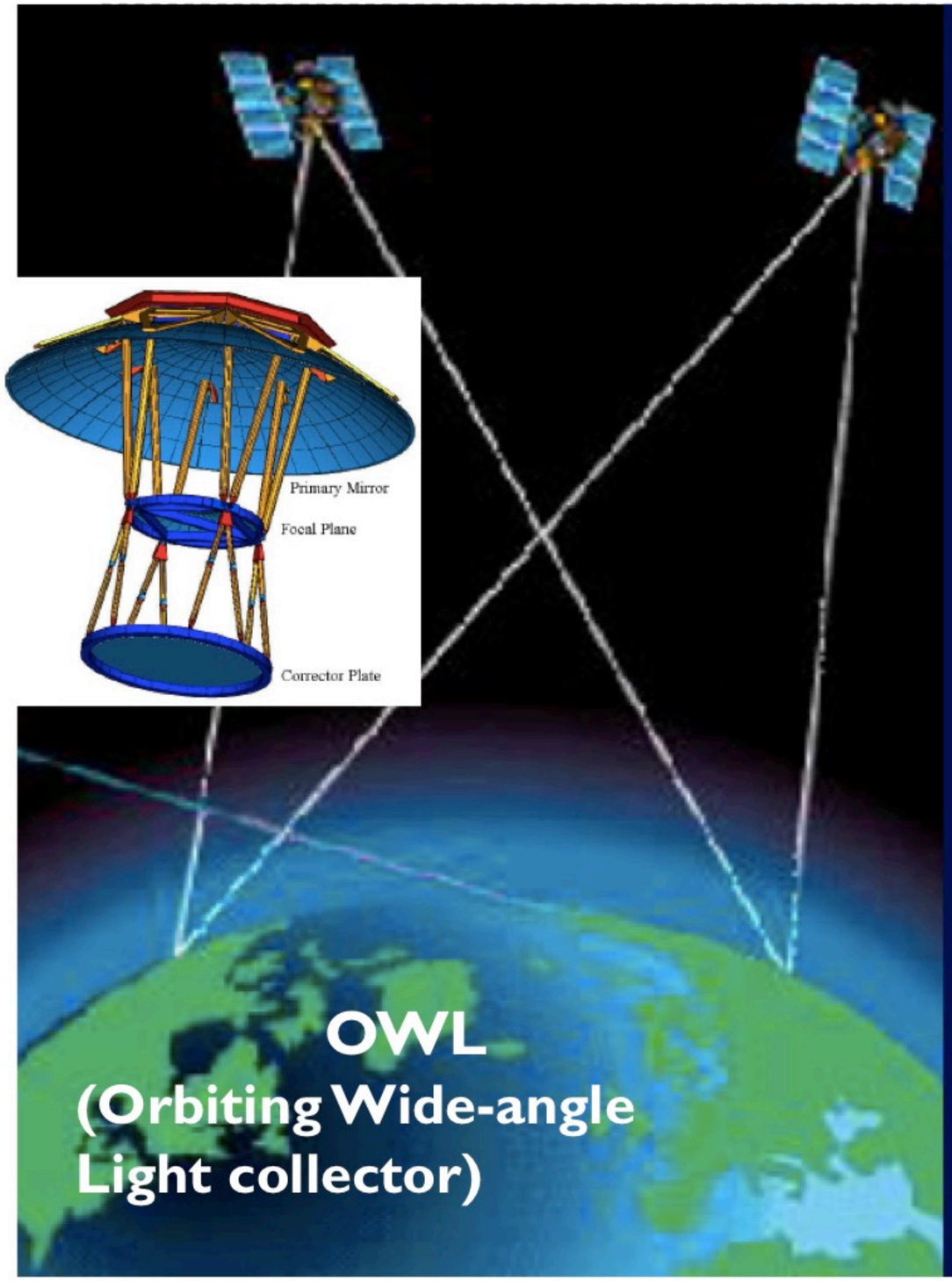
annual exposure:
10 x Auger (3,000 km^2)
6 10^4 km^2 sr yr

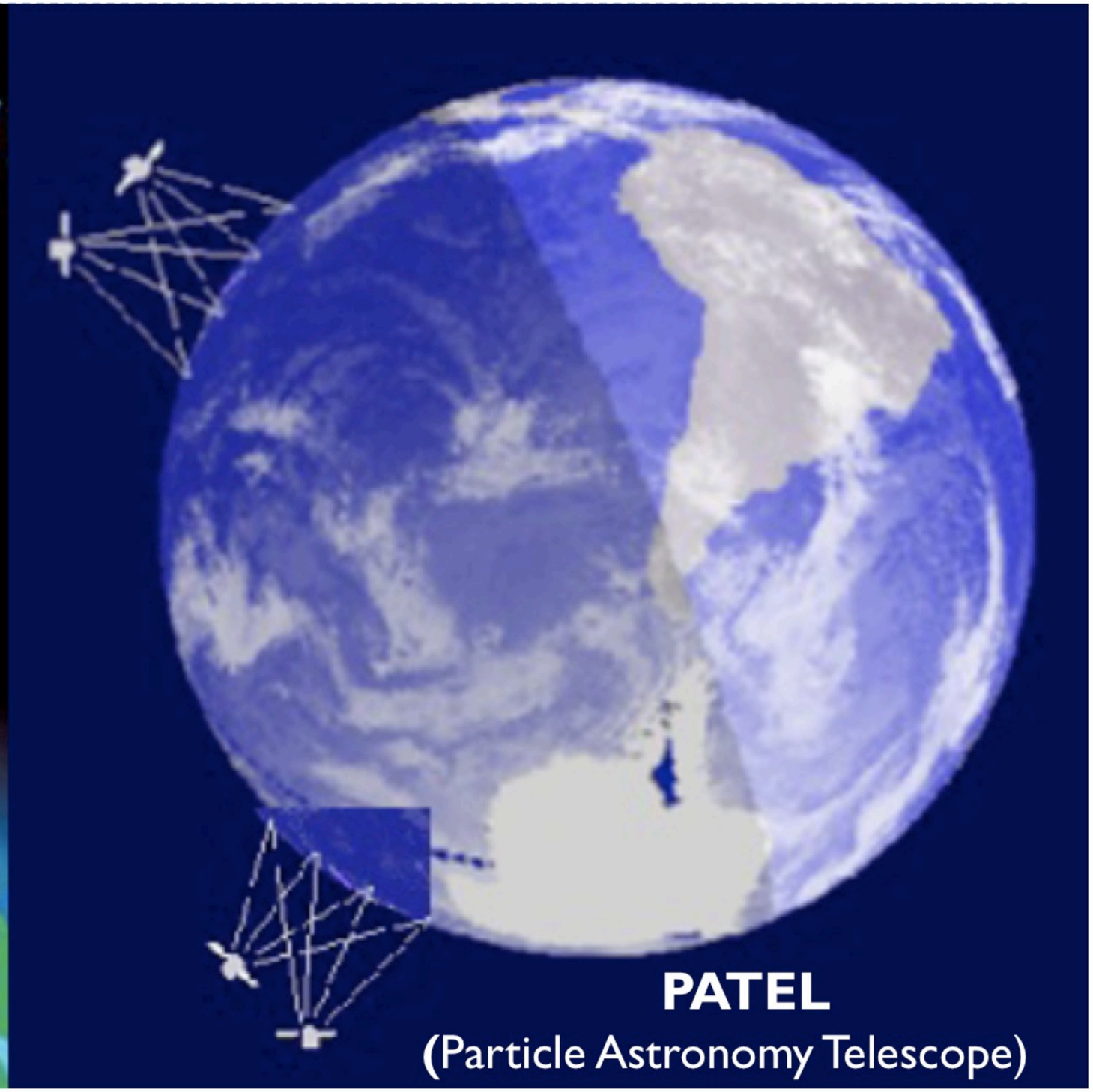


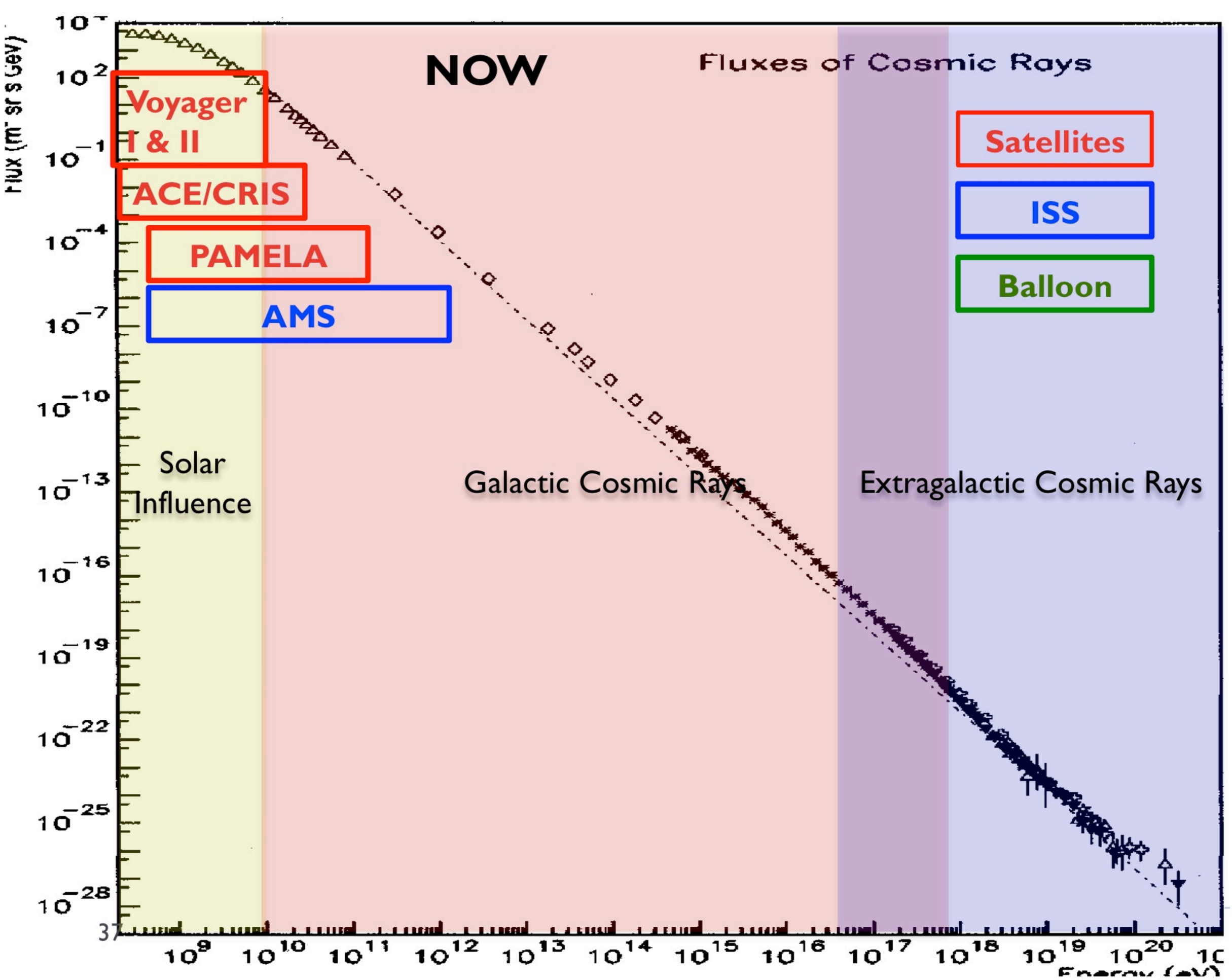
Full sky coverage



CR Astronomy > 60 EeV (limit~3 10^6 events/yr)






NOW
Fluxes of Cosmic Rays
Voyager I & II
ACE/CRIS
PAMELA
AMS
Satellites
ISS
Balloon
Solar Influence
Galactic Cosmic Rays
Extragalactic Cosmic Rays
Flux (m⁻ sr s GeV)
Energy (eV)

by 2015

Fluxes of Cosmic Rays

Voyager I & II

ACE/CRIS

PAMELA

AMS

CALET

ISS-CREAM

Super-TIGER

Satellites

ISS

Balloon

Solar Influence

Galactic Cosmic Rays

Extragalactic Cosmic Rays

Fluxes of Cosmic Rays

by 2018

Voyager I & II

ACE/CRIS

PAMELA

AMS

CALET

ISS-CREAM

Super-TIGER

JEM-EUSO

Satellites

ISS

Balloon

Solar Influence

Galactic Cosmic Rays

Extragalactic Cosmic Rays

beyond 2020

Fluxes of Cosmic Rays

Voyager I & II

AMS

CALET

ISS-CREAM

ENTICE

Satellites

ISS

Balloon

OWL/PATEL
Super-EUSO

JEM-EUSO

SWORD

Solar Influence

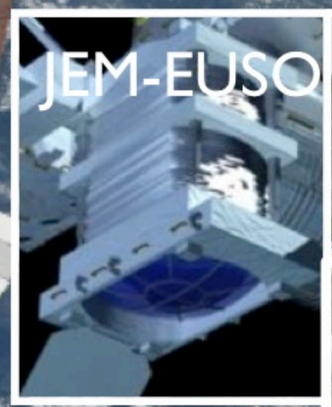
Galactic Cosmic Rays

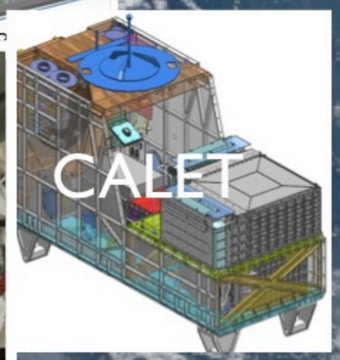
Extragalactic Cosmic Rays

2011 NASA STRATEGIC PLAN

- Strategic Goal 1: Extend and sustain human activities across the solar system.
  - 1.1 Sustain the operation and full use of the International Space Station (ISS) and expand efforts to utilize the **ISS as a National Laboratory for scientific, technological, diplomatic, and educational** purposes and for supporting future objectives in human space exploration.
- Strategic Goal #2:
  - 2.4 Discover how the universe works, explore how it began and evolved, and search for Earth-like planets.
- Strategic Goal #6:
  - NASA offers structured programs for students and college faculty to engage in STEM learning activities suchas competing in technical design challenges, launching student-built **payload**s, and participating in research andhands-on engineering experiences using real-world platforms, including **high-altitude balloons**, sounding rockets, aircraft, and space satellites.

Space Opportunities for Cosmic Ray Science





AMS

Long Live the ISS!