

# *Heralding a New Era in Cosmic Ray Physics*

## **PAMELA, JEM-EUSO, CSES**



*Piergiorgio Picozza*

*INFN and NAST-University of Rome Tor Vergata*

*RIKEN, Japan*

*Biosystems, Energy and Cultural Heritage: Materials Enhancement For Technological Application*

*Università di Roma Tor Vergata*  
*July 3<sup>rd</sup>, 2013*

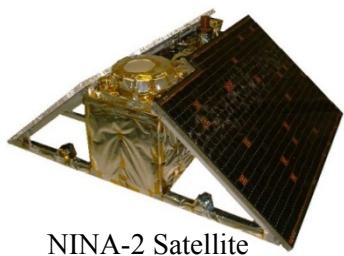
## Past



CAPRICE, MASS, TS93  
Balloons



NINA-1 Satellite



NINA-2 Satellite

## Space Stations MIR, ISS



Sil-Eye 1



Sil-Eye 2



ALTEINO



LAZIO

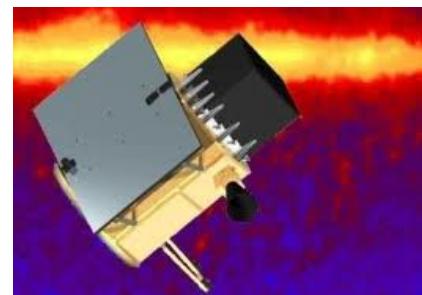


ALTEA

## Present



PAMELA

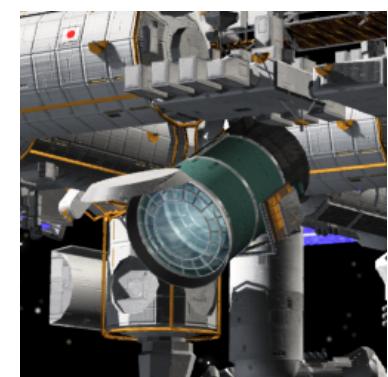


AGILE

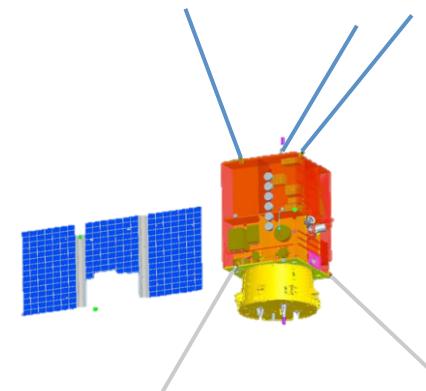


Fermi

## Future



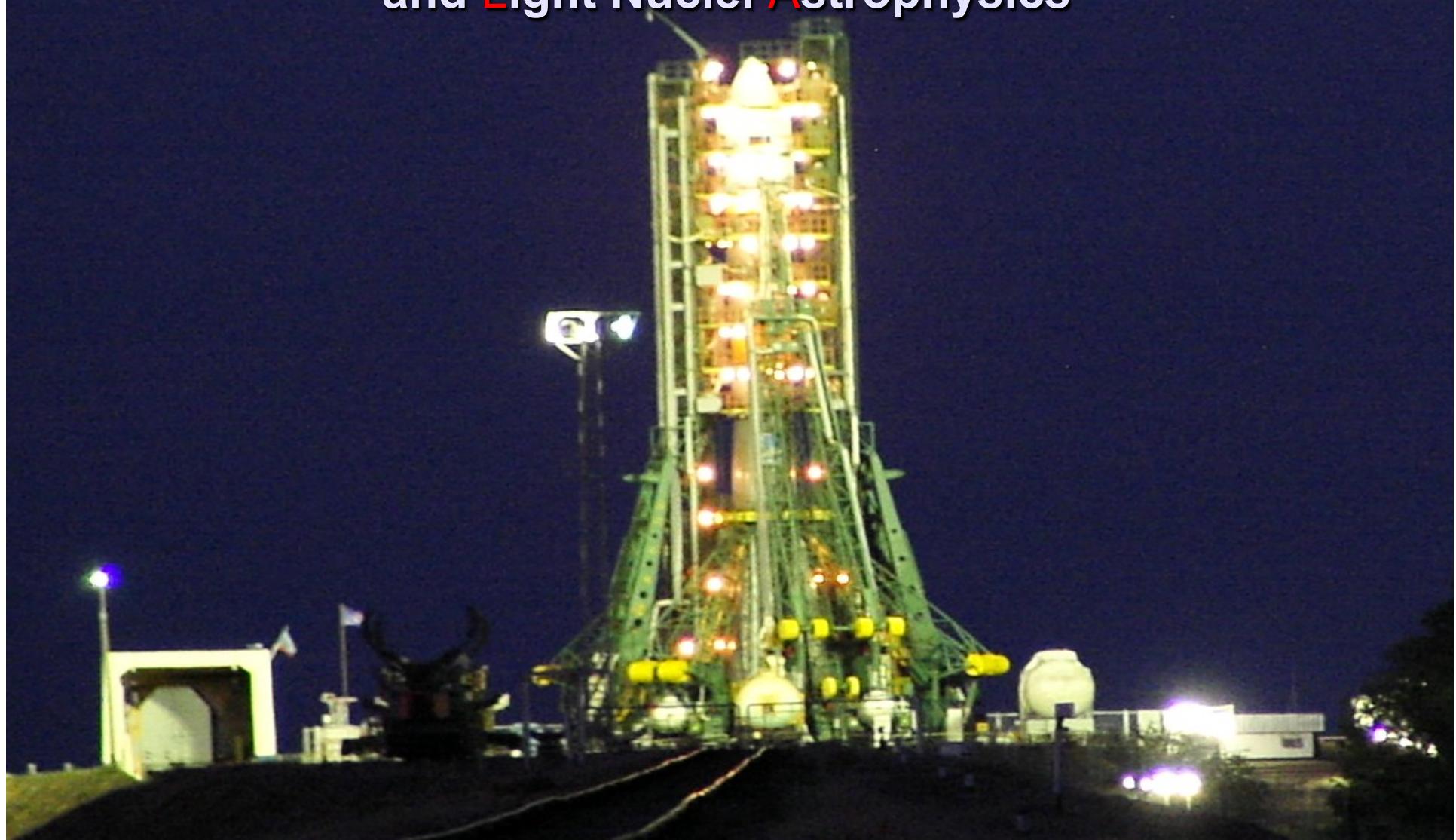
JEM-EUSO



Limadou - CSES

# PAMELA

**Payload for Antimatter Matter Exploration  
and Light Nuclei Astrophysics**



# PAMELA Collaboration

Italy:



Bari



Florence



Frascati



Naples



Rome



Trieste



CNR, Florence

Russia:



Moscow  
St. Petersburg



Germany:



Siegen

Sweden:



KTH, Stockholm

# *PAMELA Instrument*

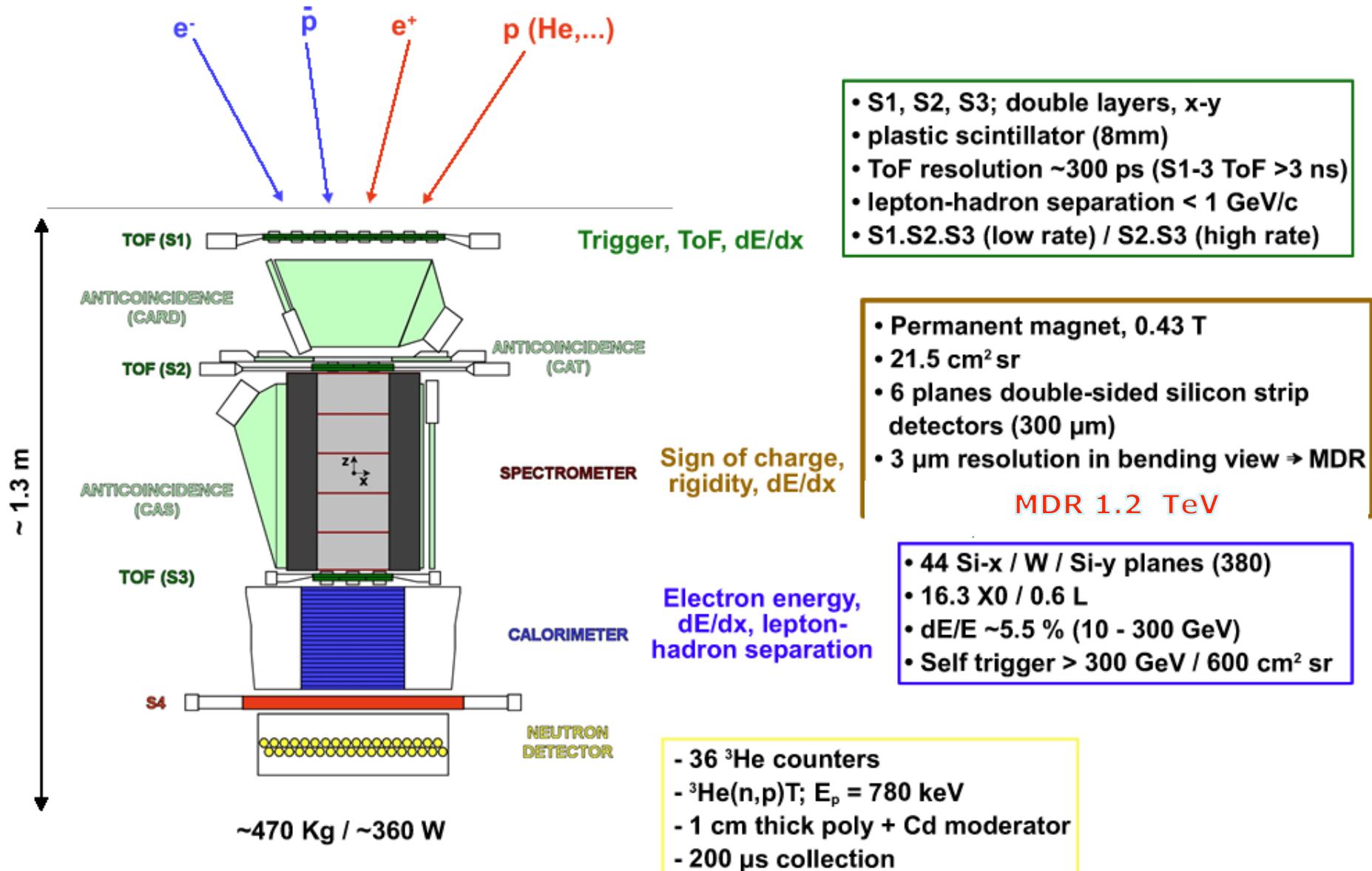


**GF ~21.5 cm<sup>2</sup>sr**

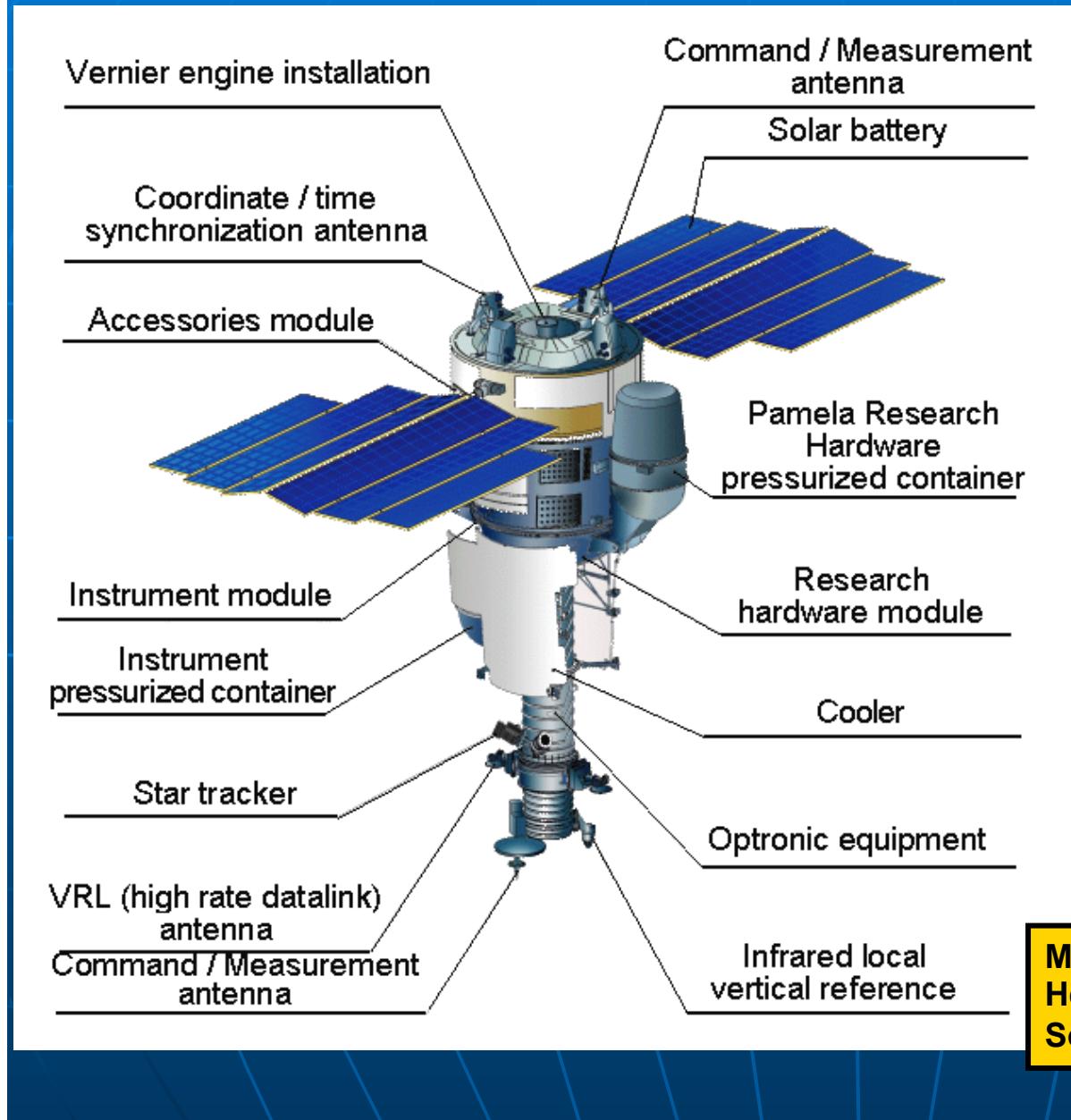
**Mass: 470 kg**

**Size: 130x70x70 cm<sup>3</sup>**

# PAMELA Instrument



# Resurs-DK1 satellite



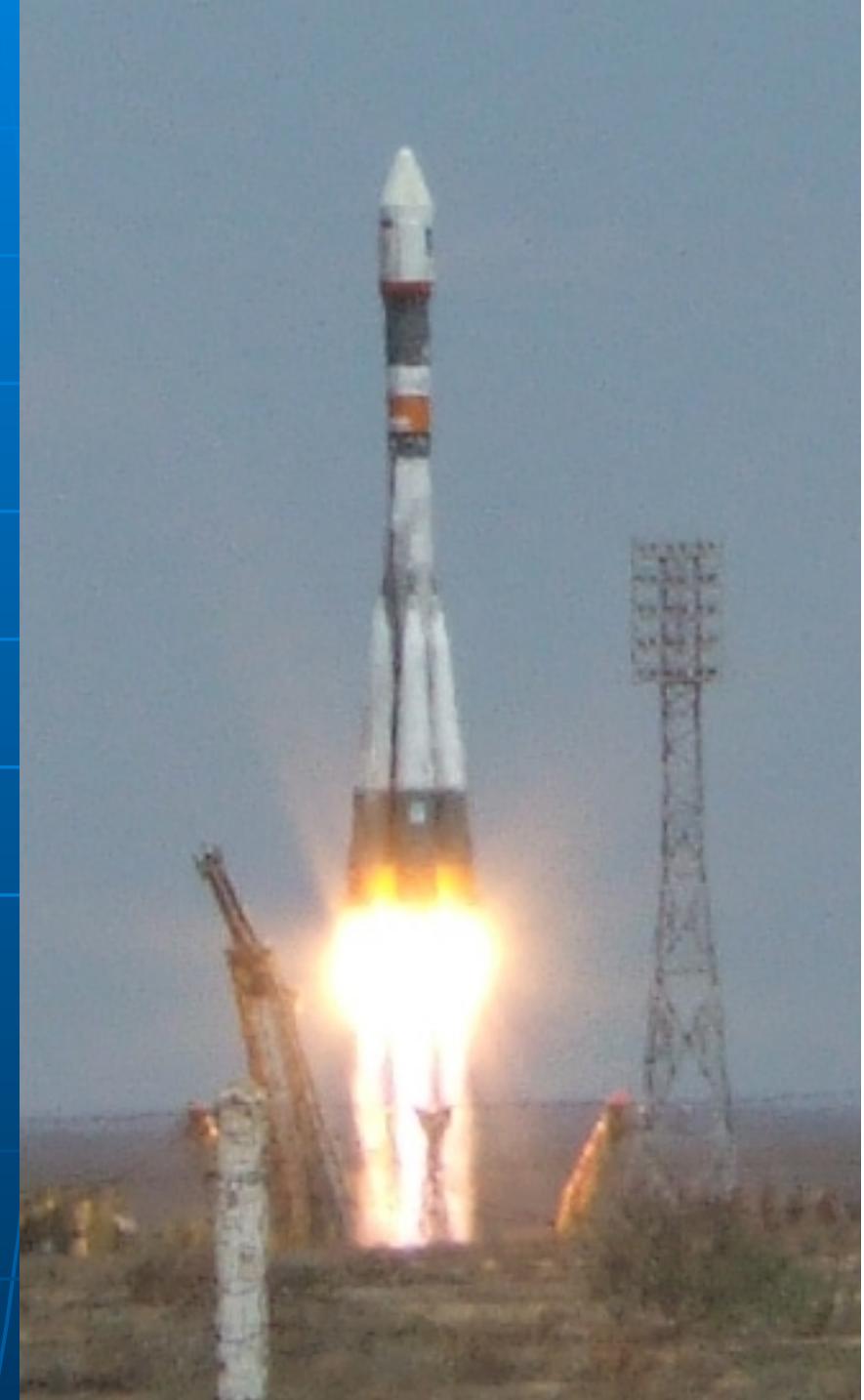
- **Main task:** multi-spectral remote sensing of earth's surface
- Built by TsSKB Progress in Samara, Russia
- **Lifetime >3 years (assisted)**
- Data transmitted to ground via high-speed radio downlink
- **PAMELA mounted inside a pressurized container**

Mass: 6.7 tonnes  
Height: 7.4 m  
Solar array area: 36 m<sup>2</sup>

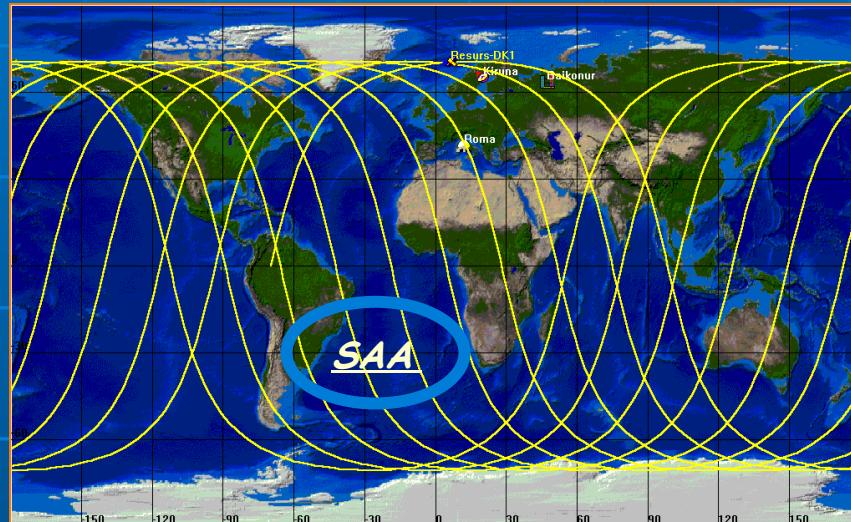
# PAMELA

Launch  
15/06/06

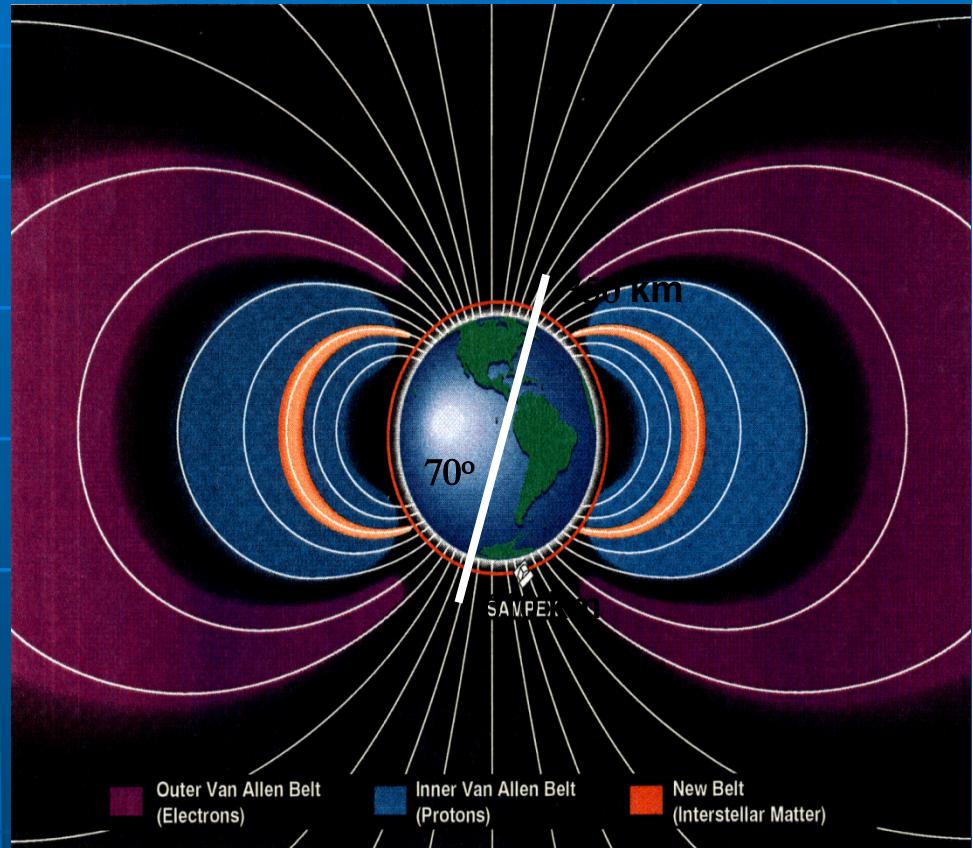
*16 Gigabytes transmitted  
daily to Ground  
NTsOMZ Moscow*



# Orbit Characteristics



- Low-earth elliptical orbit
- 350 – 610 km
- Quasi-polar ( $70^\circ$  inclination)
- SAA crossed



# The Physics of PAMELA

Search for dark matter annihilation

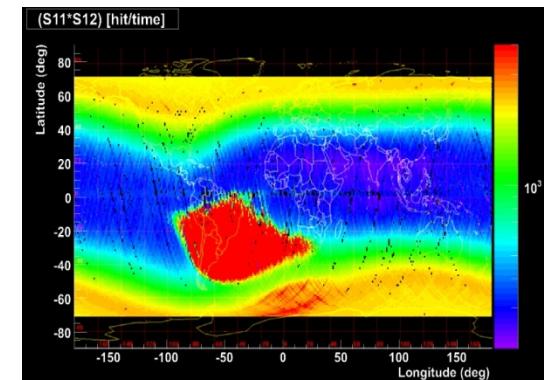
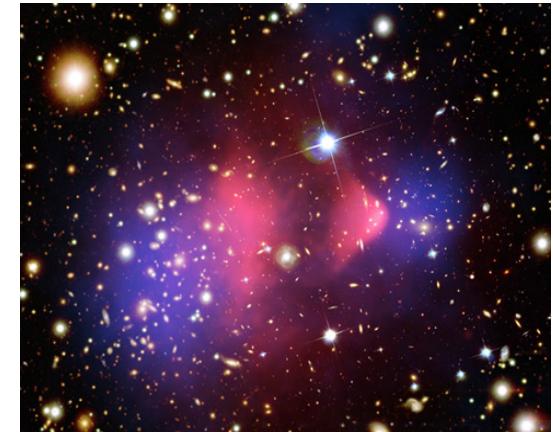
Search for antihelium (primordial antimatter)

Search for new Matter in the Universe (Strangelets?)

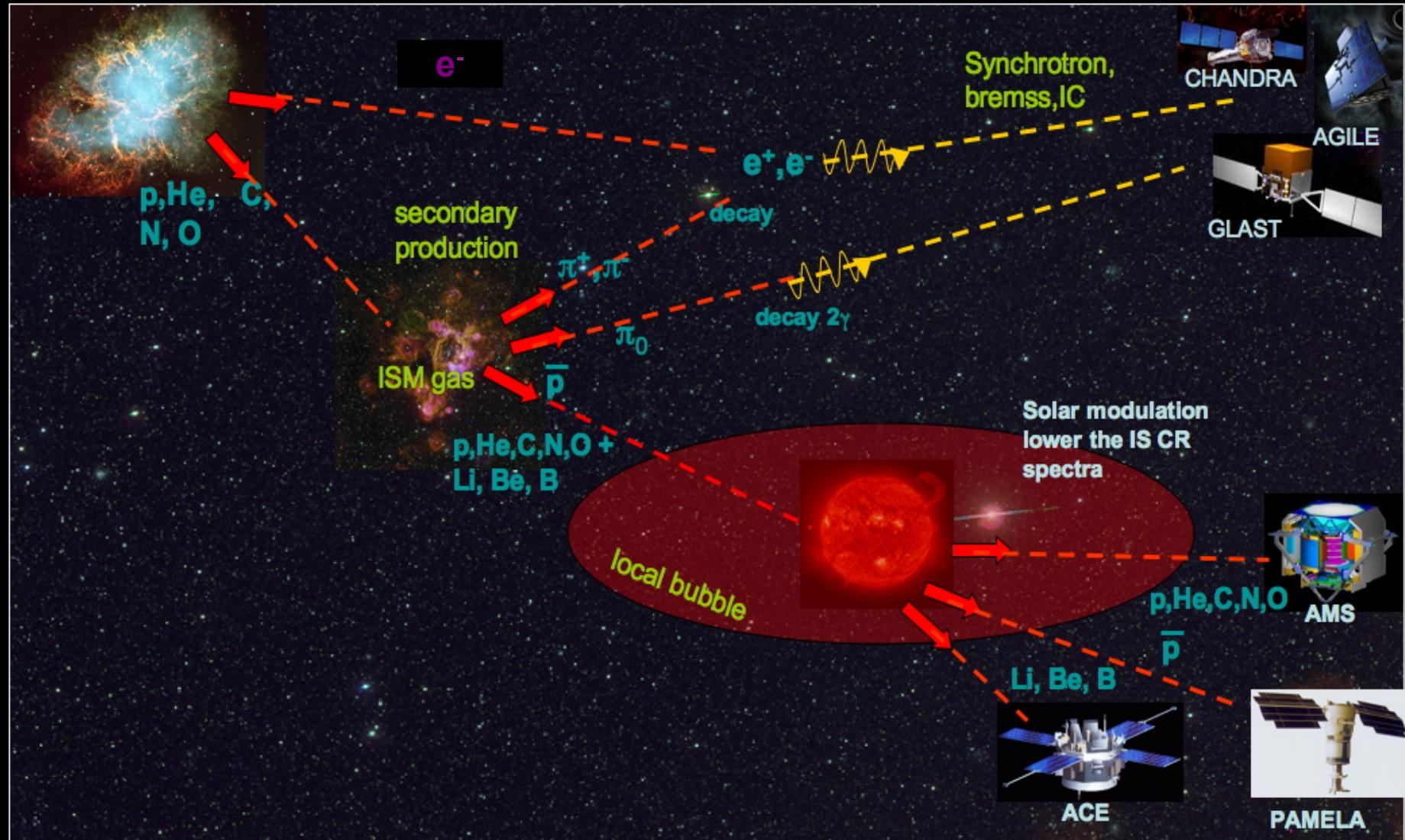
Study of cosmic-ray propagation

Study of solar physics and solar modulation

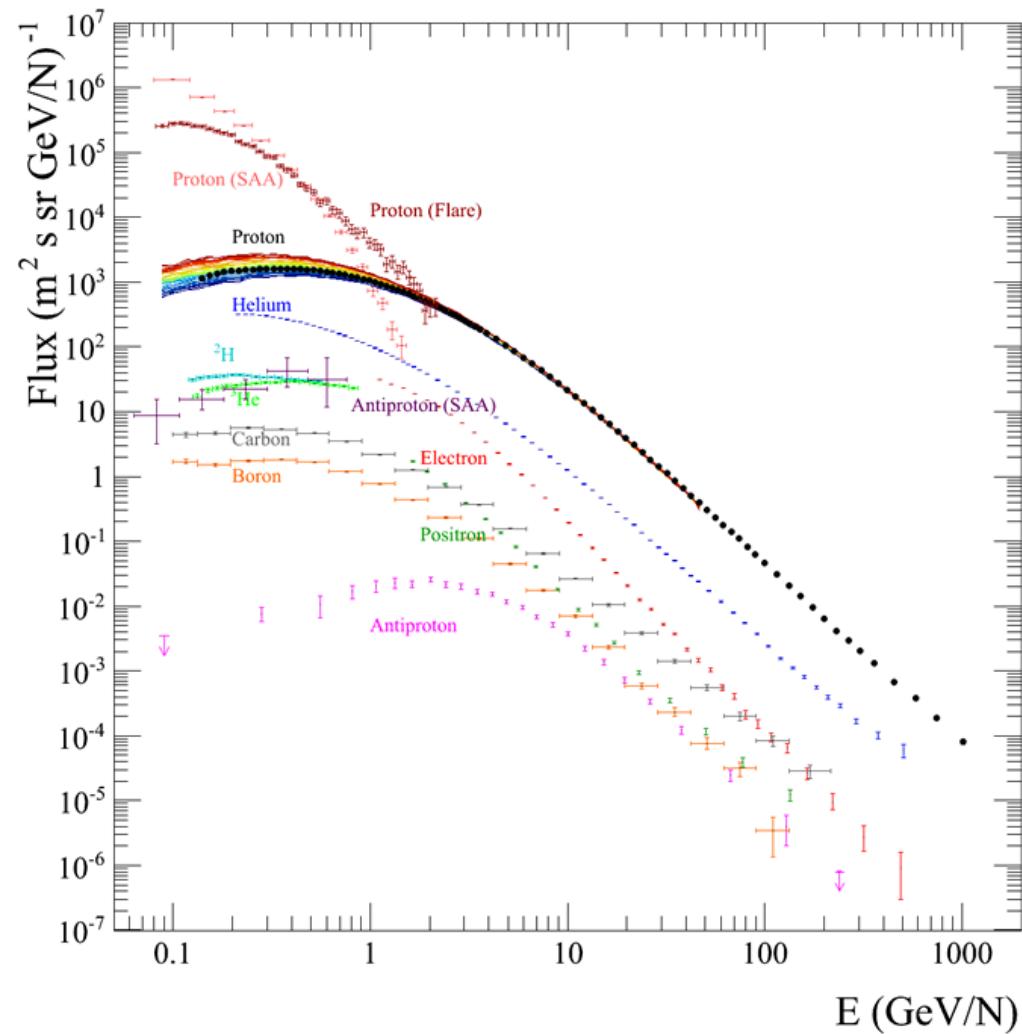
Study of terrestrial magnetosphere



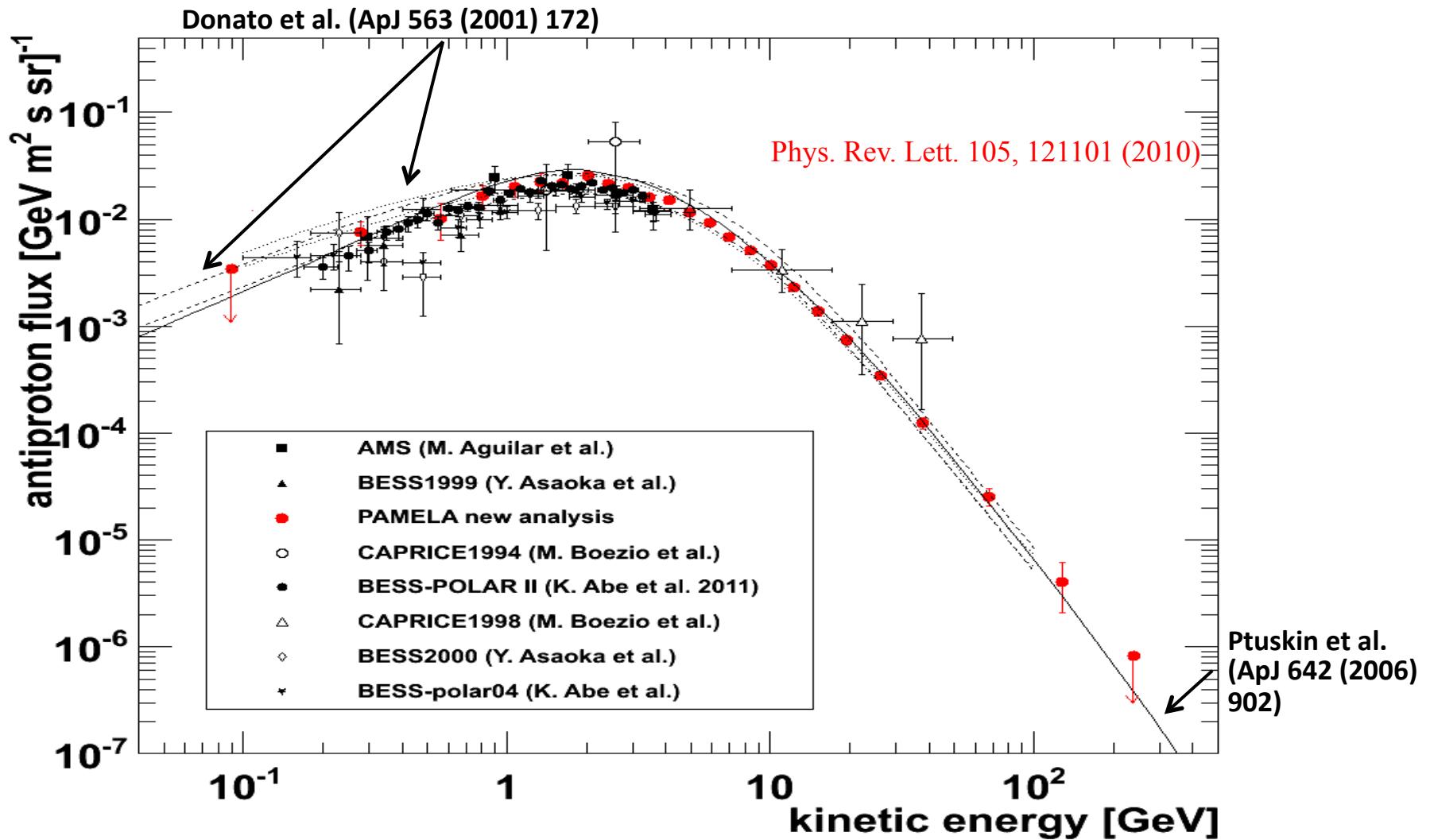
# COSMIC RAYS PRODUCTION MECHANISMS



# Main PAMELA Results



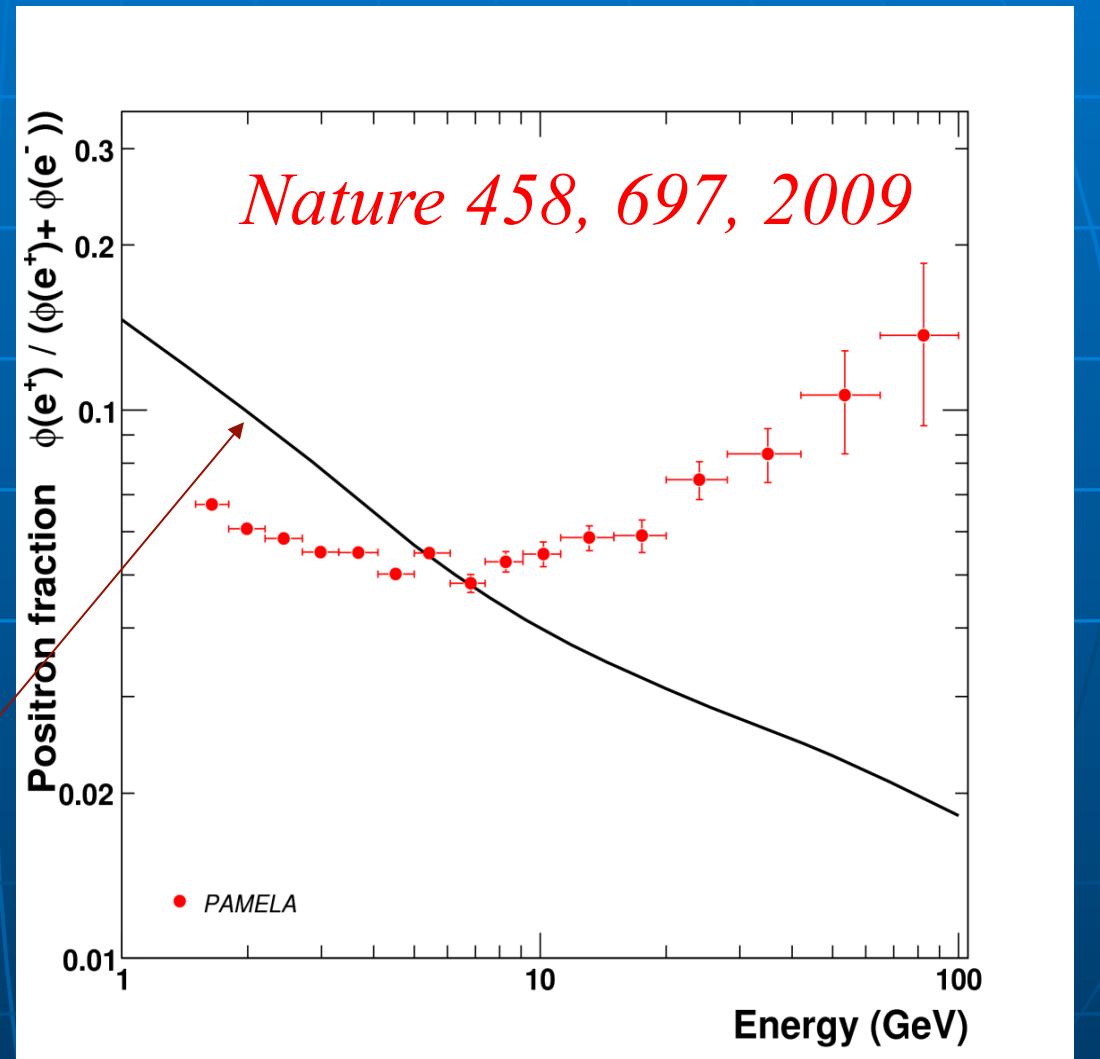
# Antiproton Flux



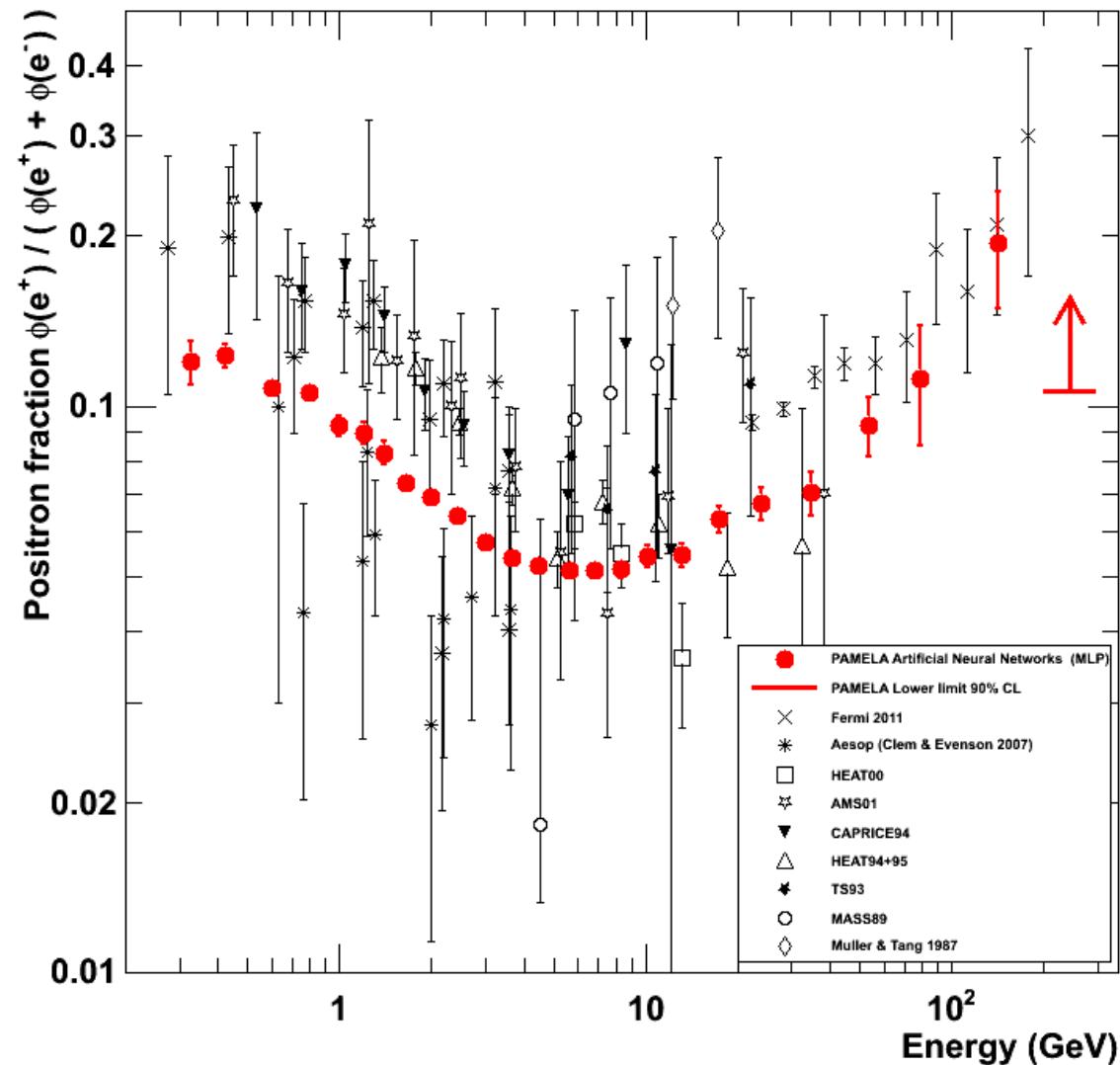
# Positron to all electron ratio

$$R(E) = \frac{\Phi_{e^+}}{\Phi_{e^+} + \Phi_{e^-}}$$

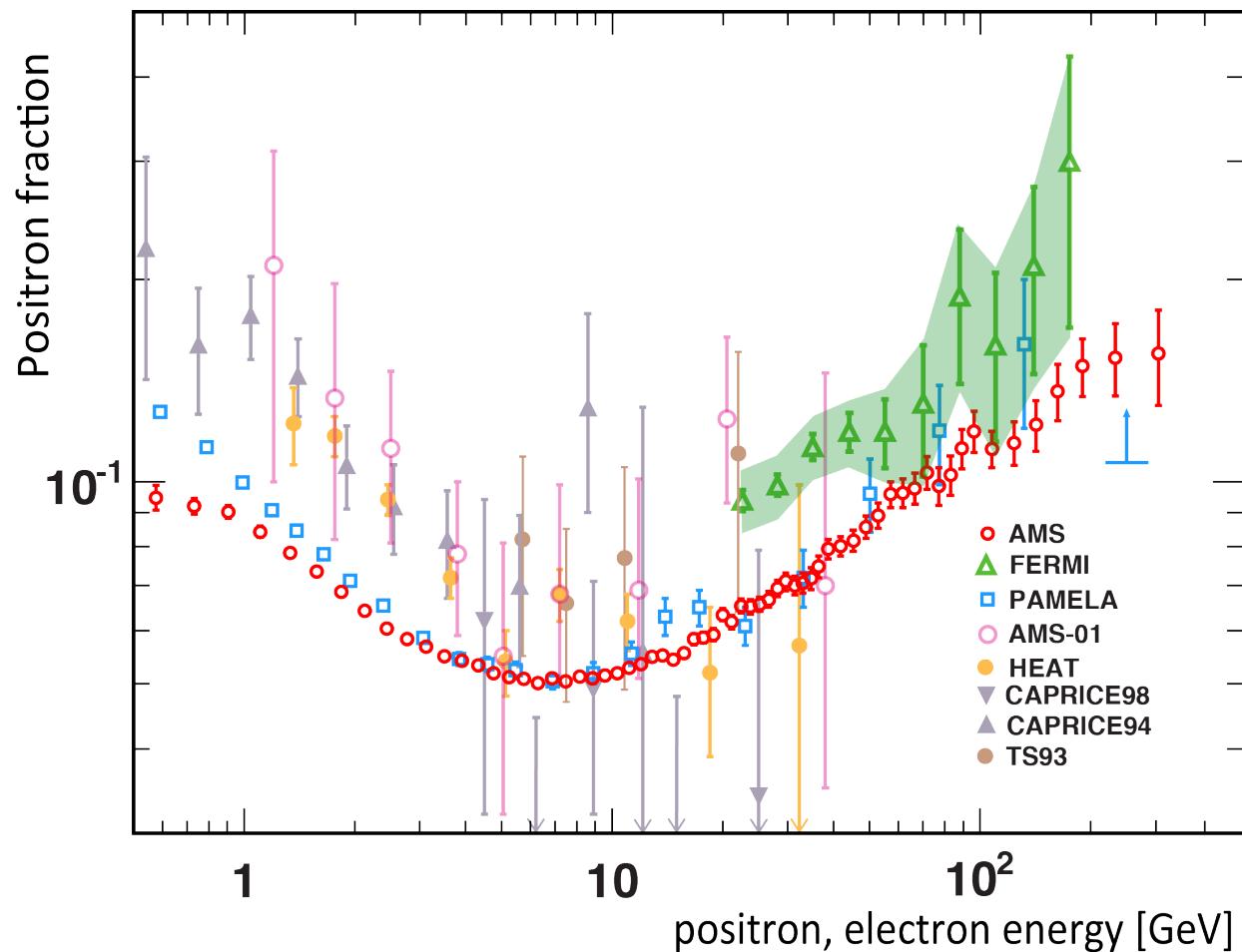
Secondary production  
Moskalenko & Strong 98



# Positron to electron fraction

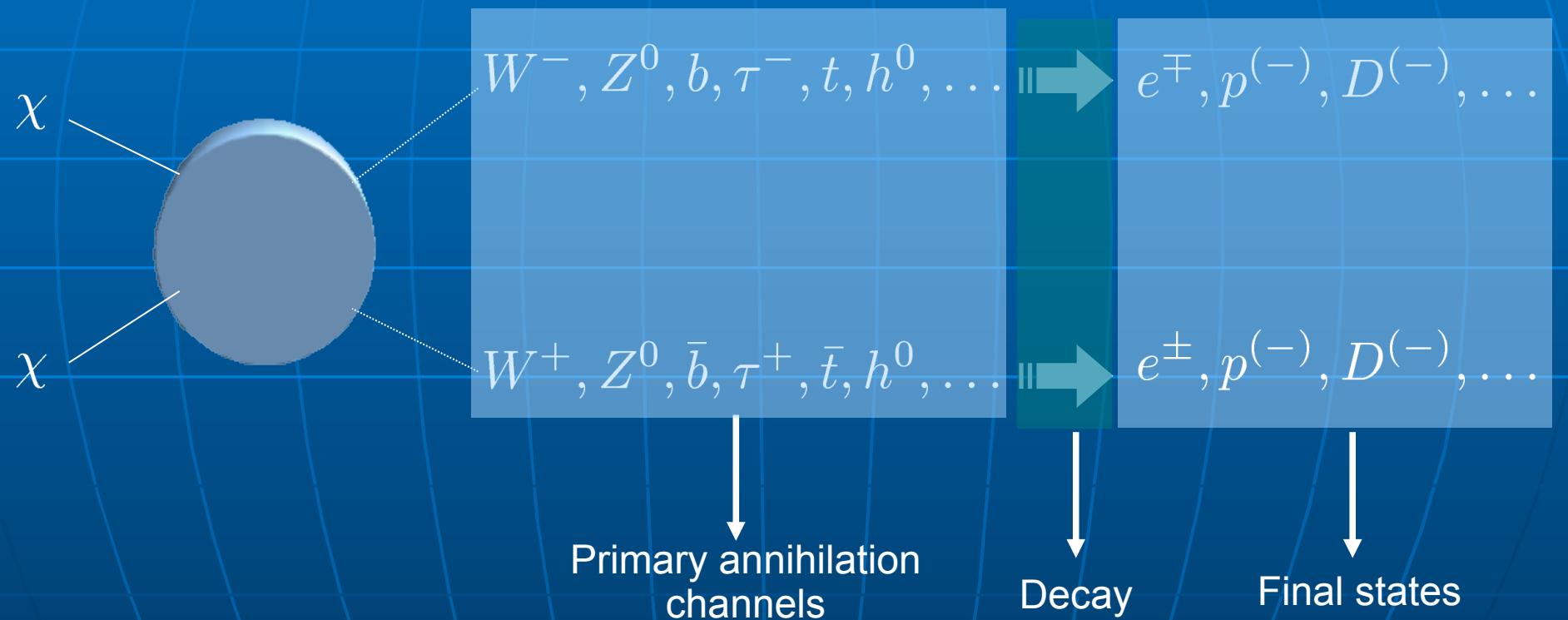


# Positron to electron fraction



# DM annihilations

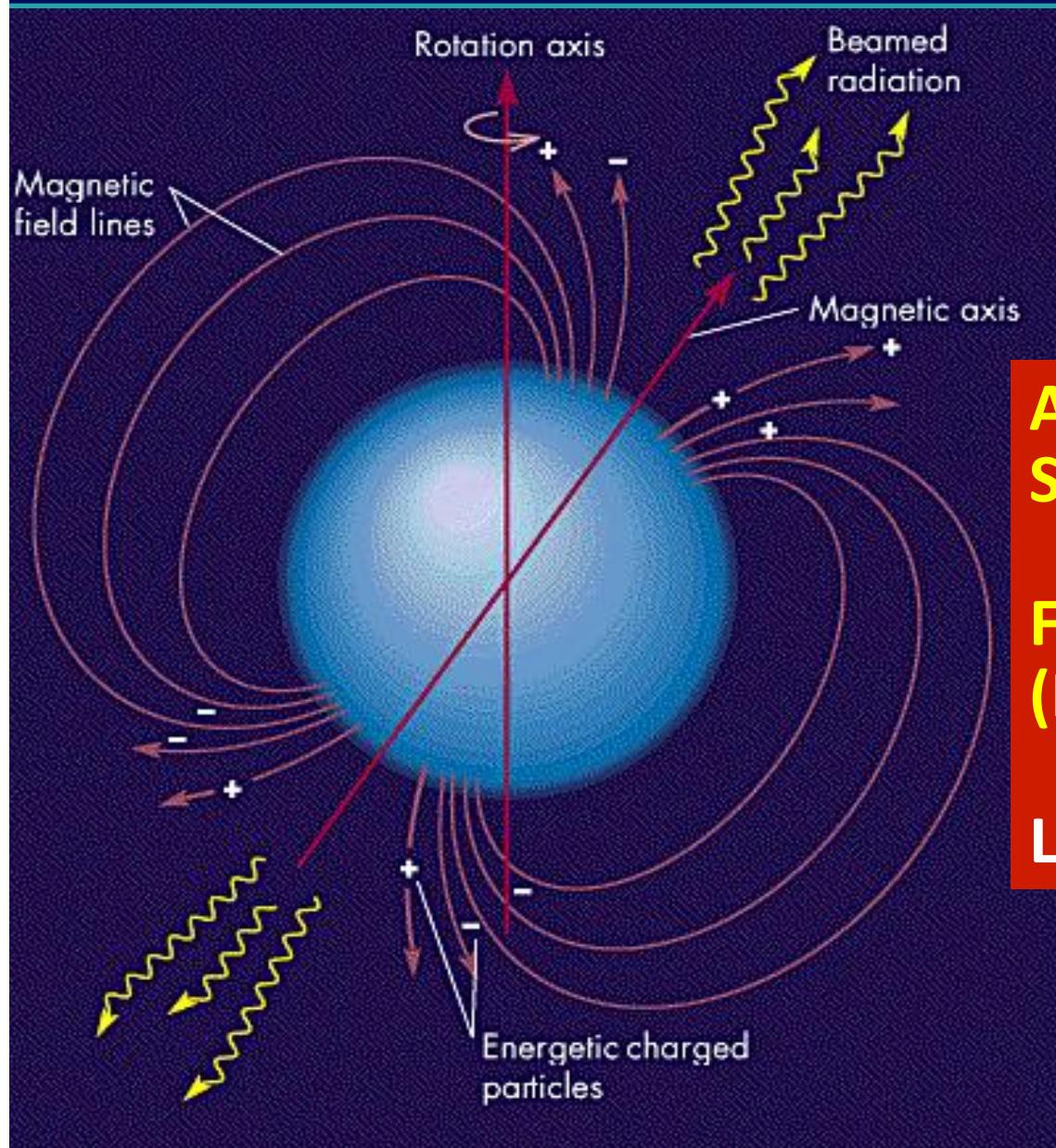
DM particles are stable. They can annihilate in pairs.



flux  $\propto n^2 \sigma_{\text{annihilation}}$   
astro&cosmo particle

reference cross section:  
 $\sigma = 3 \cdot 10^{-26} \text{ cm}^3/\text{sec}$

$$\sigma_a = \langle \sigma v \rangle$$

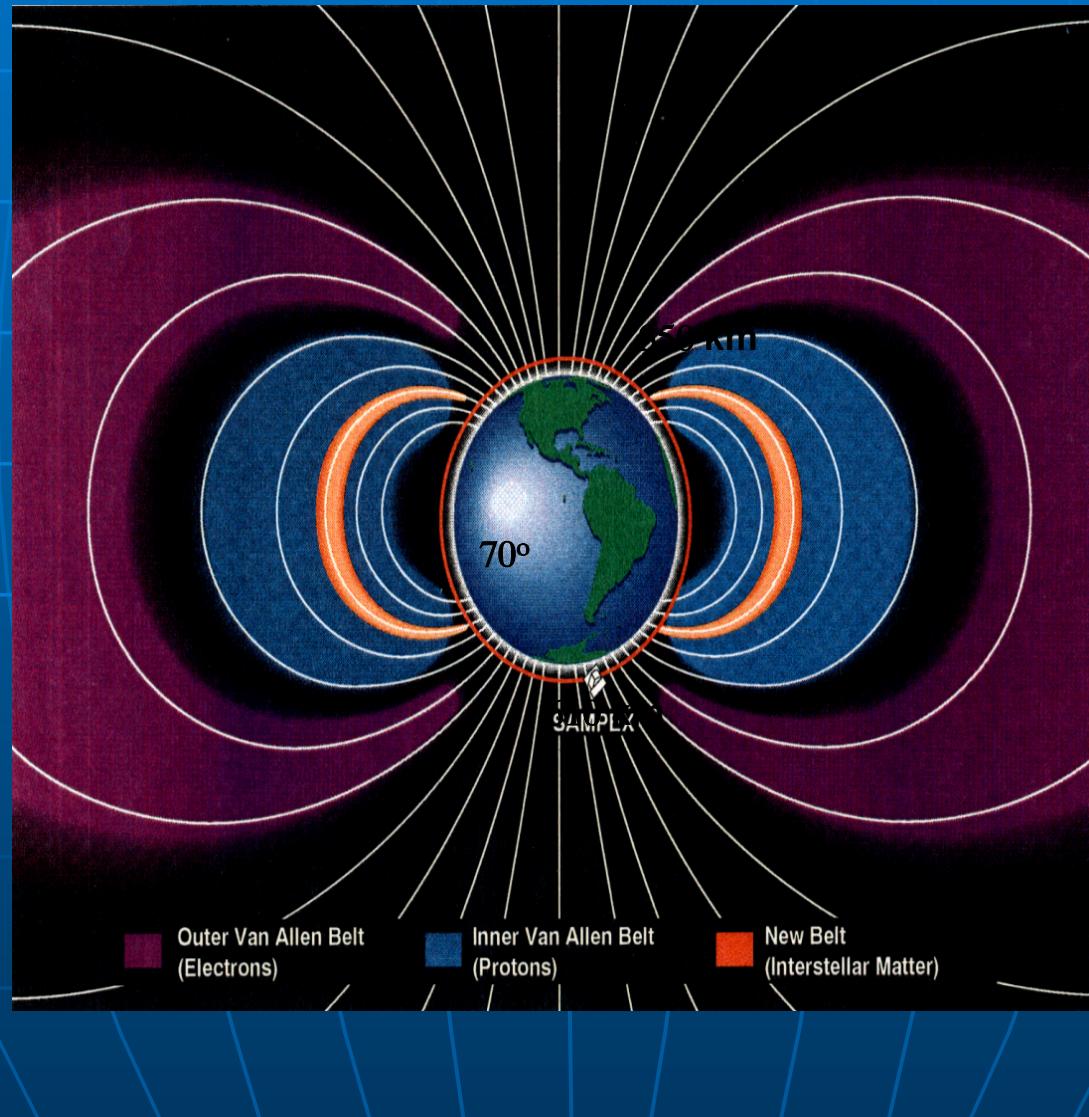


**A NEUTRON STAR WITH A  
STRONG MAGNETIC FIELD:**

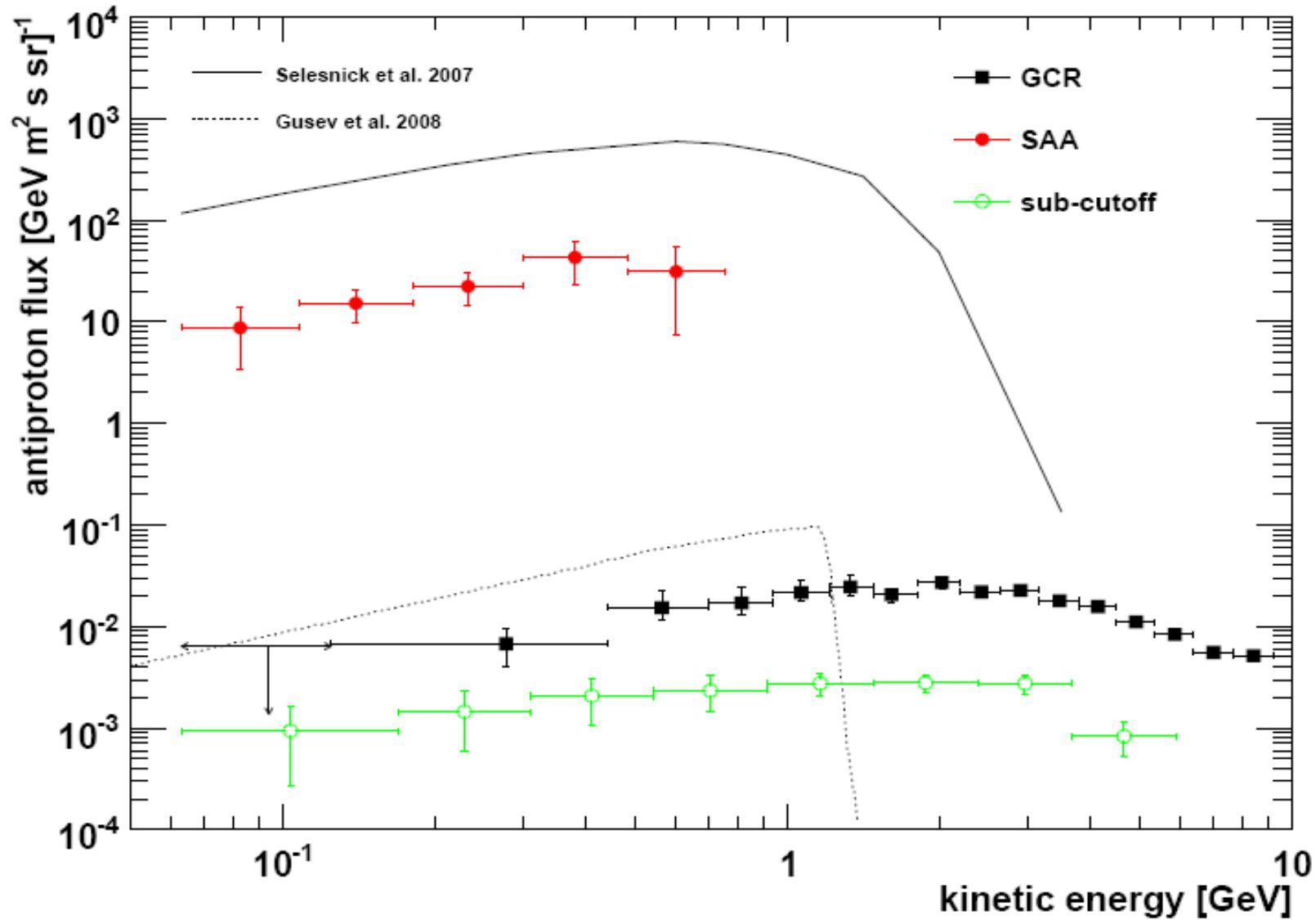
**FAST ROTATING PULSAR  
( $P = 33$  msec)**

$$L(\text{spindown}) = 5 \cdot 10^{38} \text{ erg/s}$$

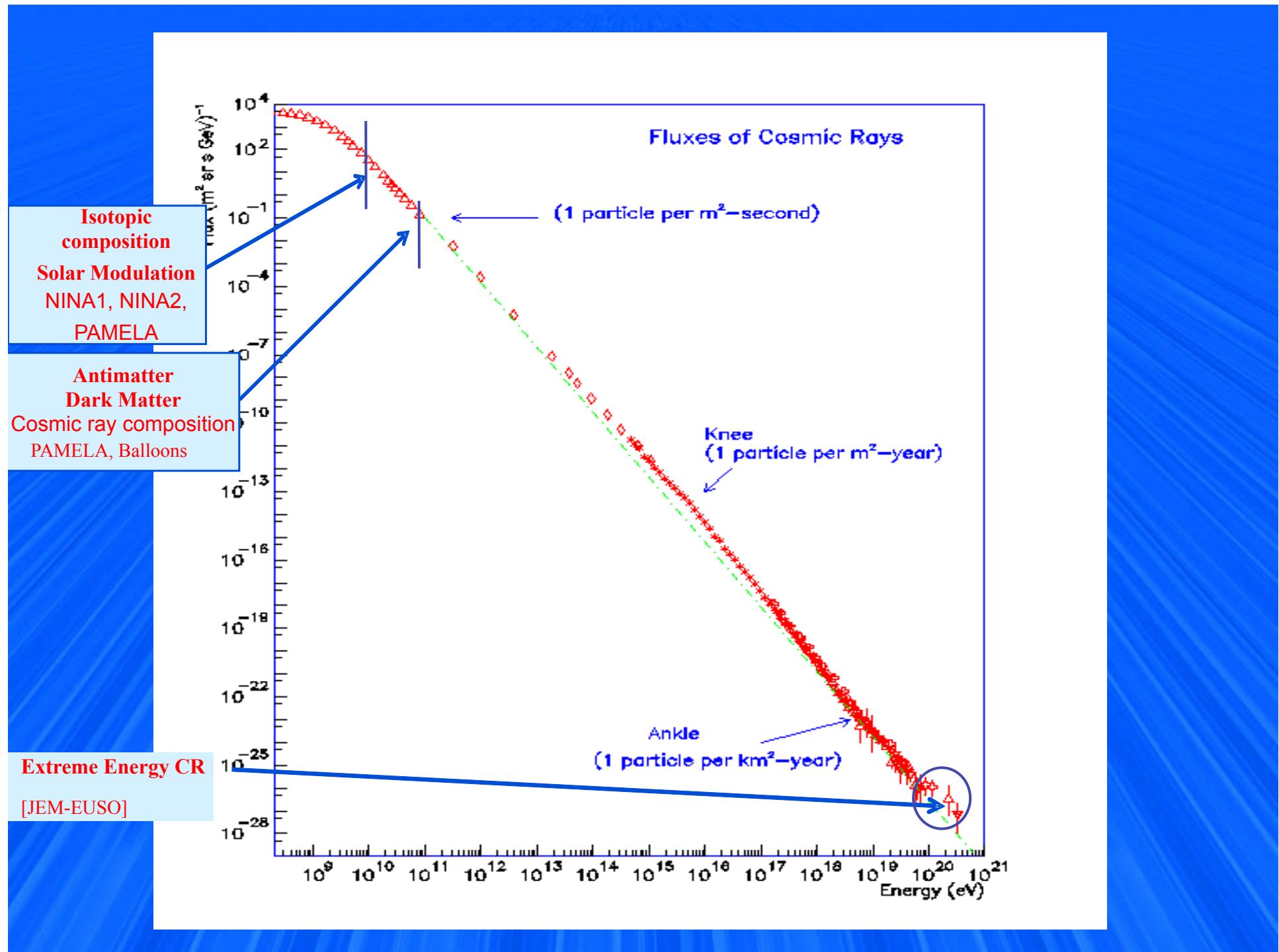
# Van Allen Belts

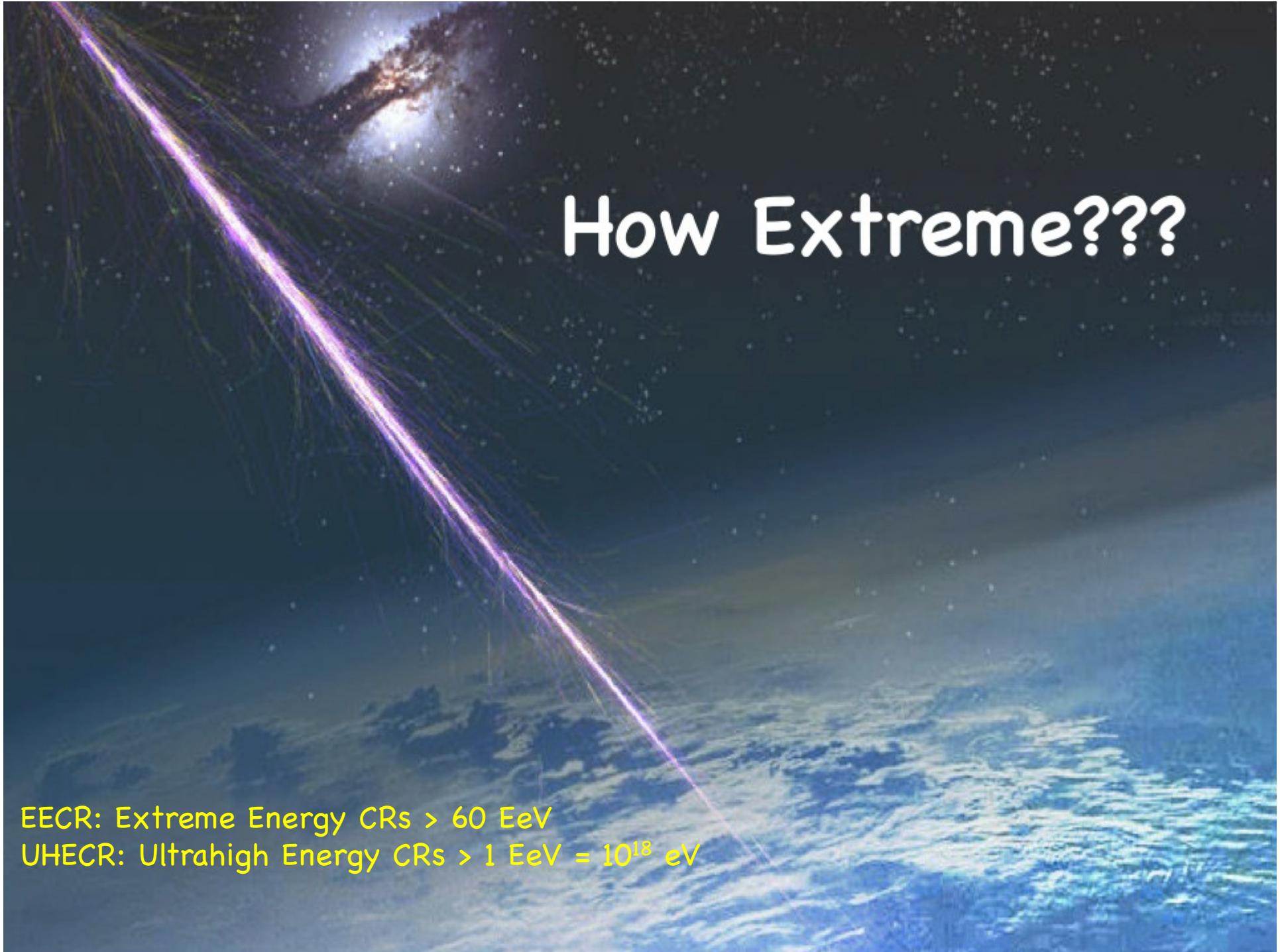


# PAMELA trapped antiprotons



O. Adriani et al., APJL 737 L29 (2011)





# How Extreme???

EECR: Extreme Energy CRs > 60 EeV

UHECR: Ultrahigh Energy CRs > 1 EeV =  $10^{18}$  eV

# Current Observatories of Ultrahigh Energy Cosmic Rays

Telescope Array

Utah, USA

(5 country  
collaboration)

700 km<sup>2</sup> array

3 fluorescence  
telescopes

The Atmosphere  
as a Detector

Pierre Auger  
Observatory

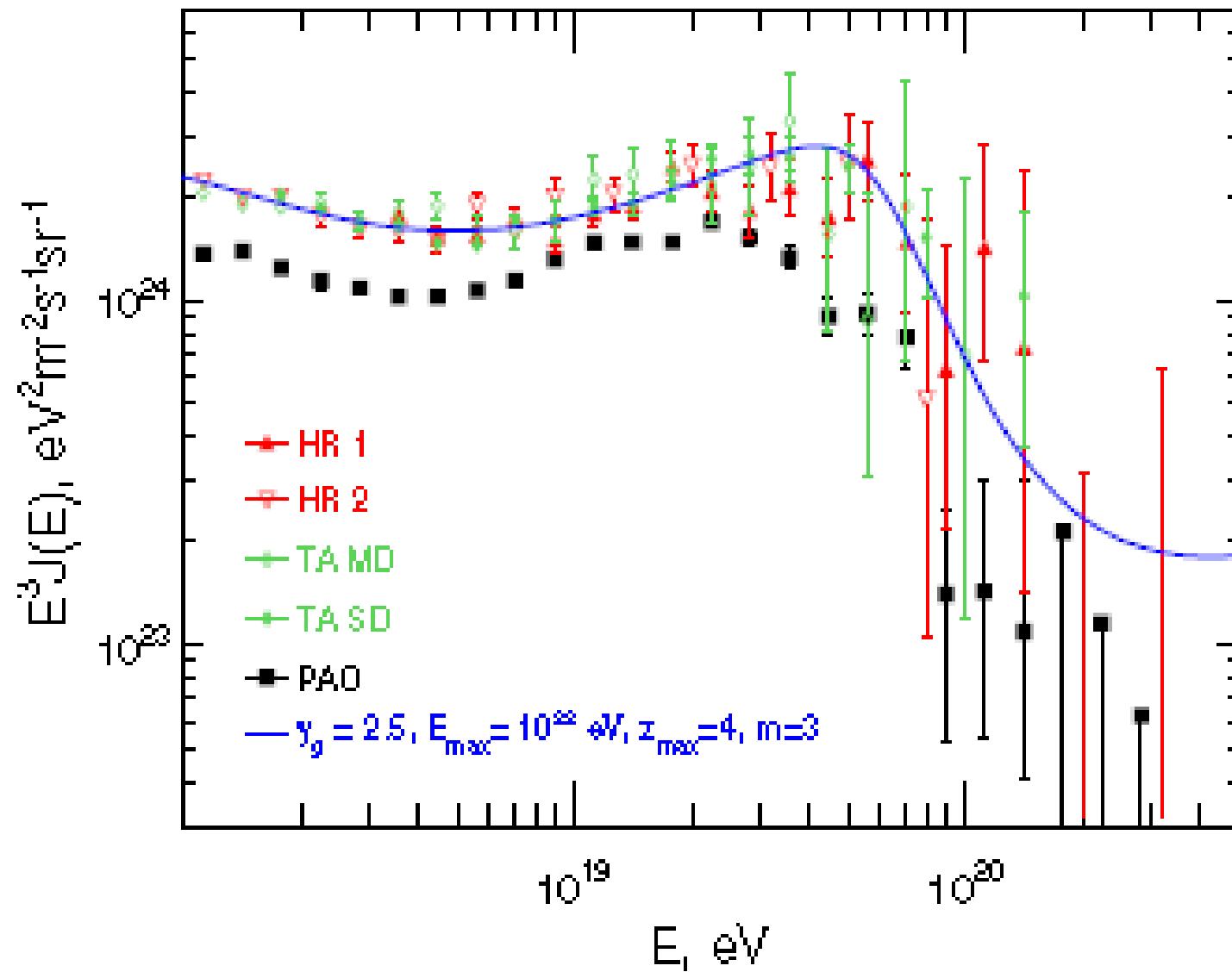
Mendoza, Argentina

(19 country  
collaboration)

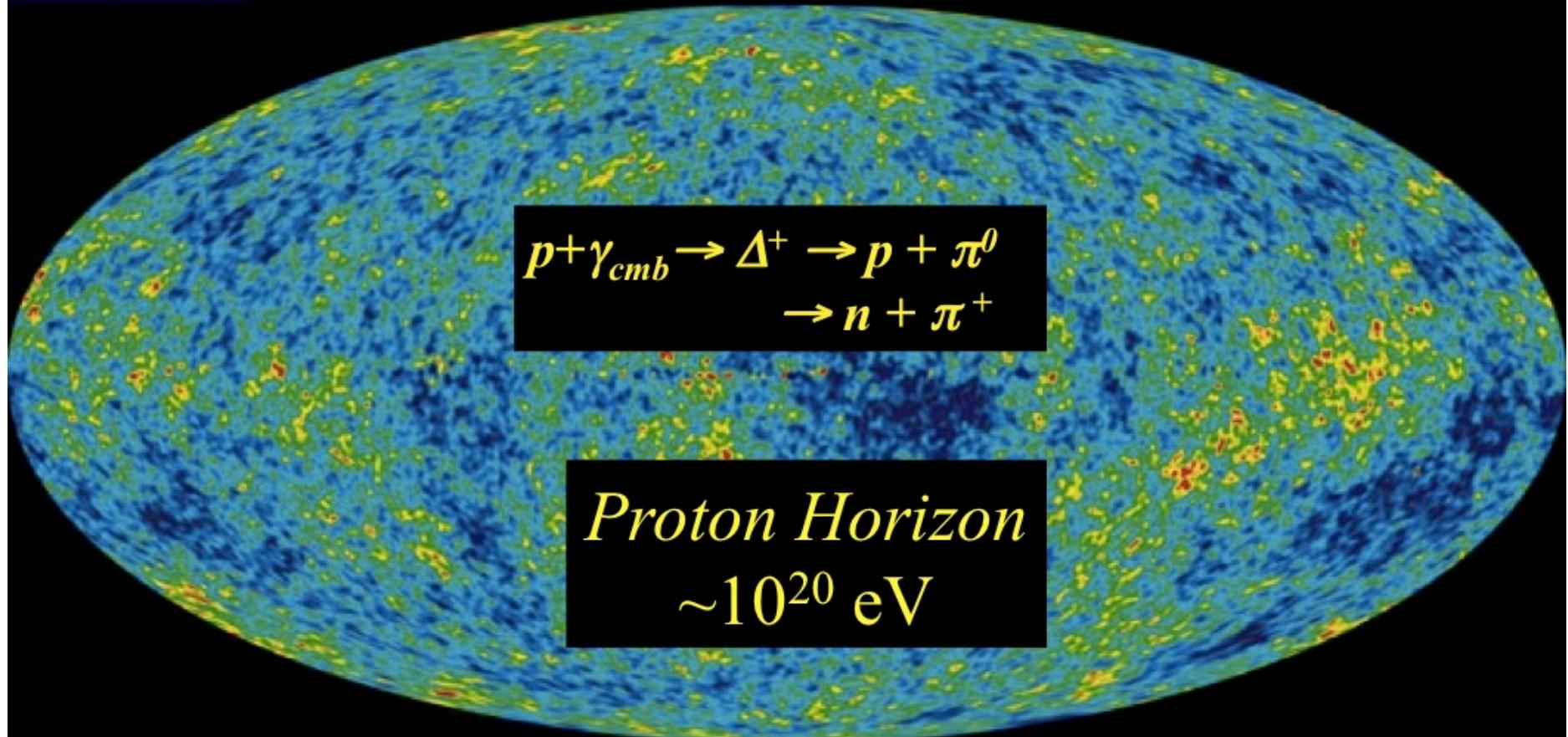
3,000 km<sup>2</sup> array

4 fluorescence telescopes

# UHECR Spectrum



# “Cosmologically Meaningful Termination”



GZK Cutoff

Greisen, Zatsepin, Kuzmin  
1966



# UHECR status in just one word

Previous to Auger / HiRes :

$$\frac{1 \text{ particle}}{100 \text{ } km^2 \text{ } yr \text{ } sr}$$

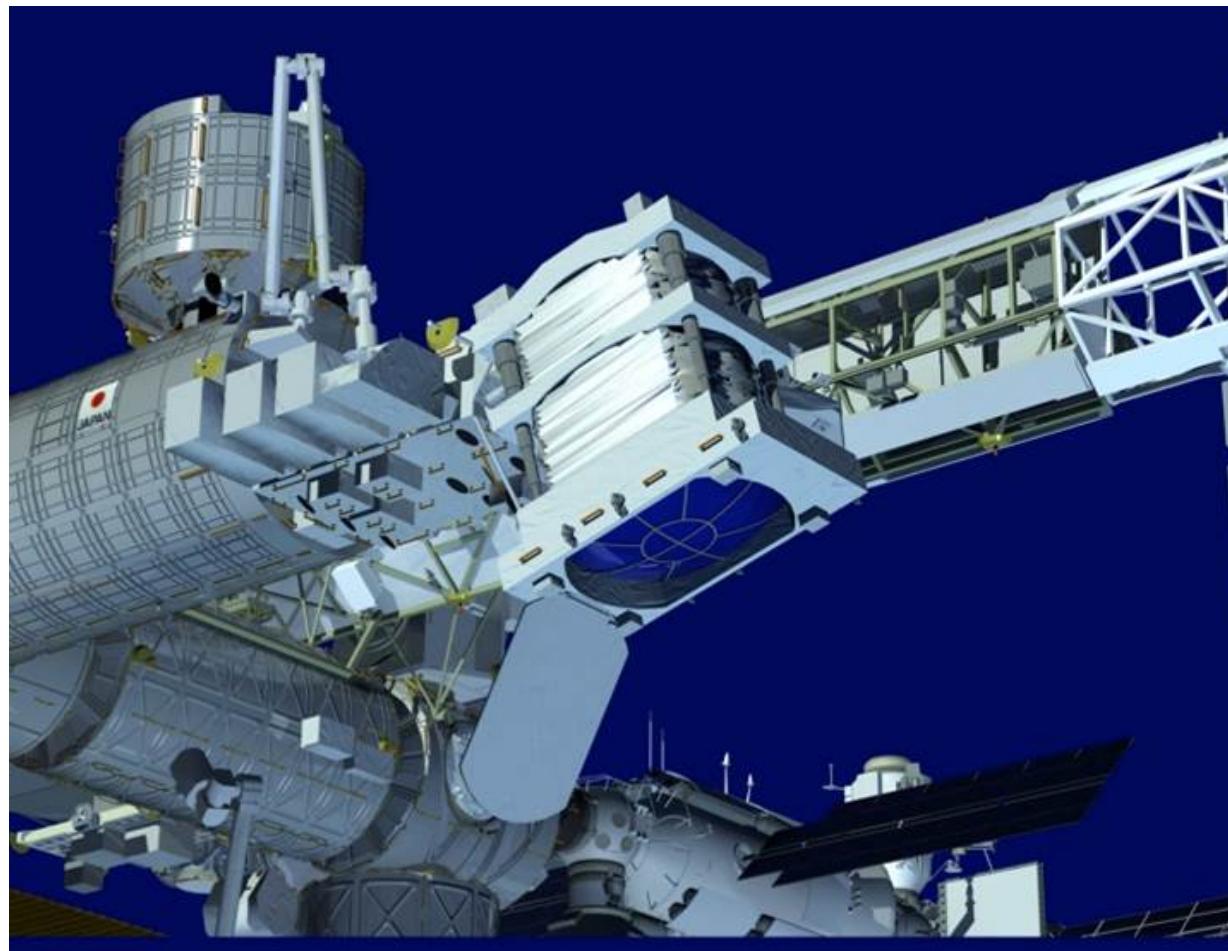
Key Auger / HiRes result:

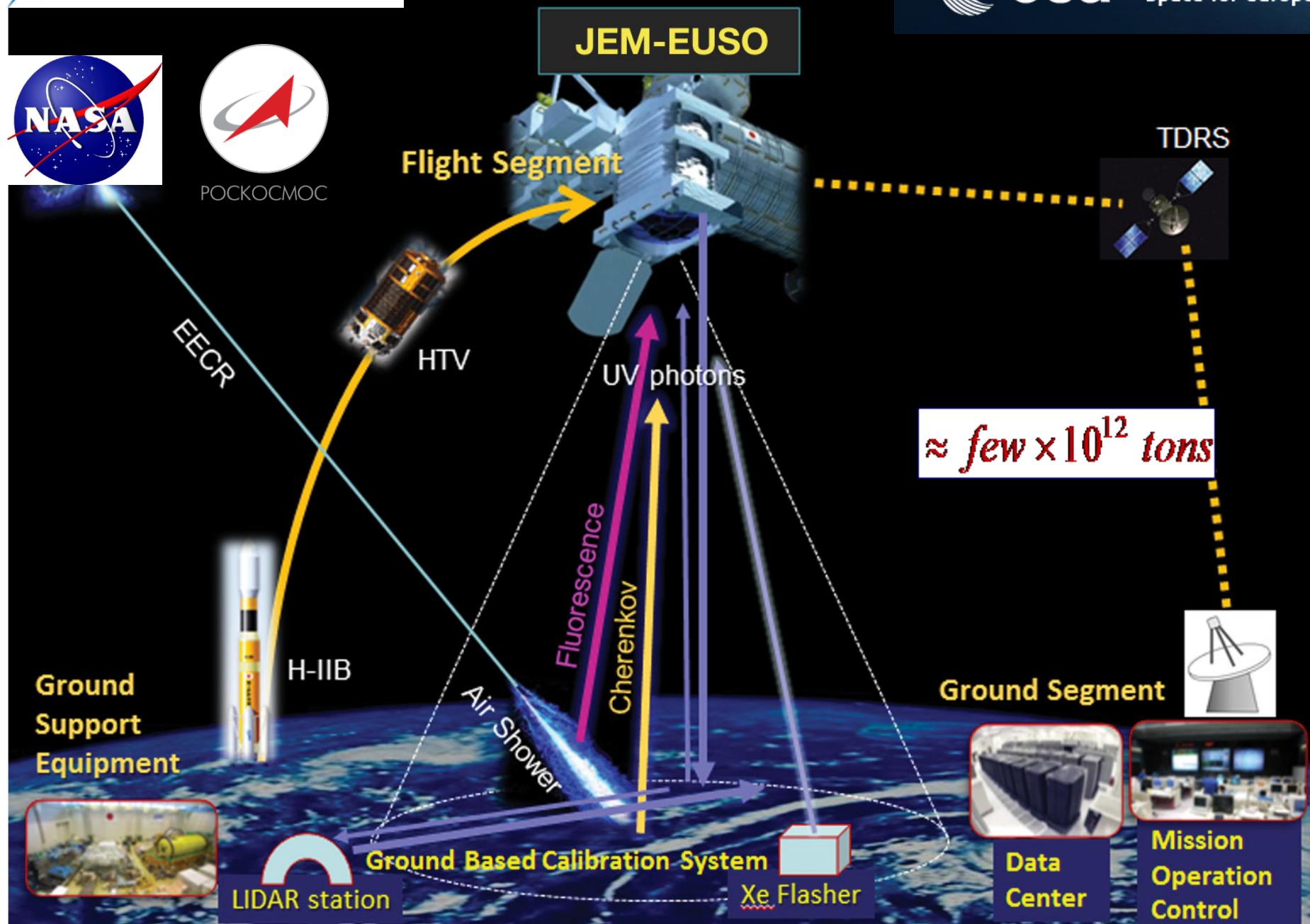

$$\frac{1 \text{ particle}}{\cancel{100} \text{ } km^2 \text{ } yr \text{ } sr}$$

1000

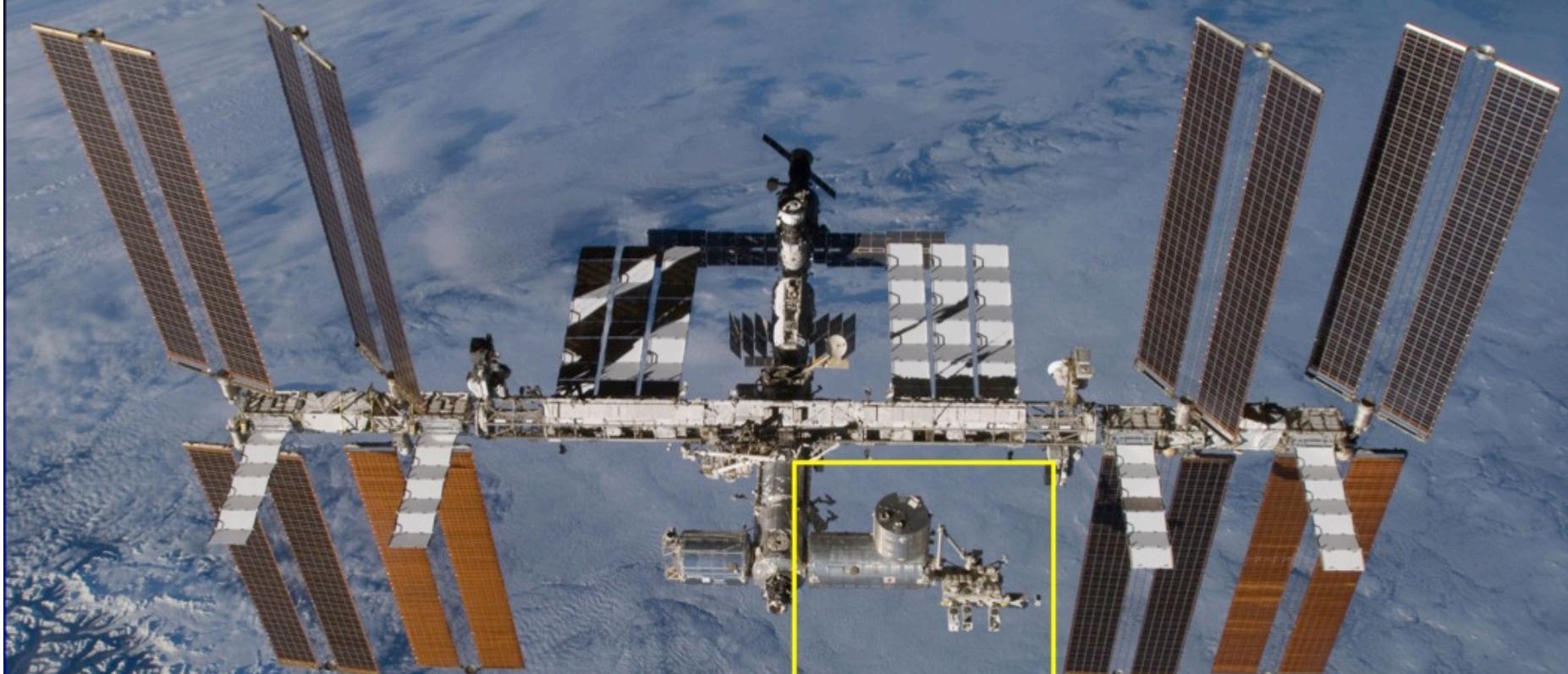
# JEM-EUSO

The Extreme Universe Space Observatory onboard the  
Japanese Experimental Module





# JEM-EUSO Mission



*Japanese Experiment Module  
(JEM)*

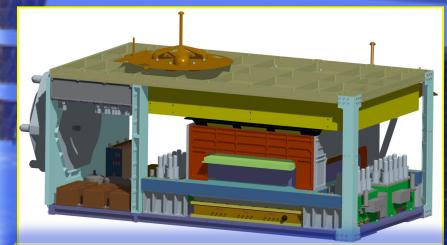
きぼう, Kibo = Hope



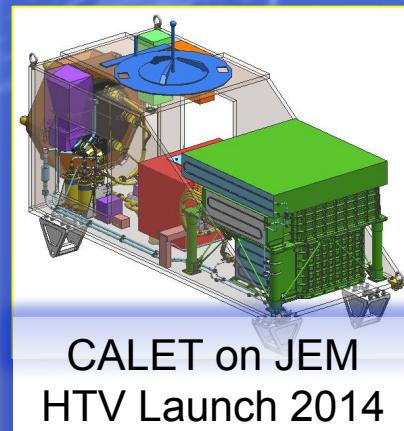
# View from NASA: “Cosmic Ray Observatory on the ISS”



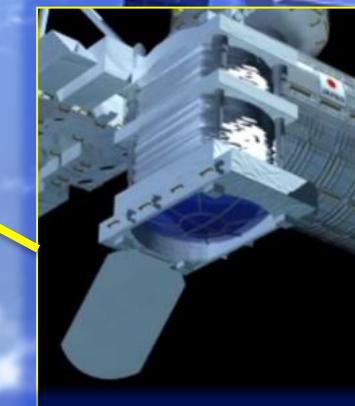
AMS Launch  
May 16, 2011



ISS-CREAM  
Sp-X Launch 2014



CALET on JEM  
HTV Launch 2014



JEM-EUSO  
Launch Tentatively  
planned for 2017

# *JEM-EUSO Collaboration*

- Japan, USA, Korea, Mexico, Russia, Algeria
- Europe: Bulgaria, France, Germany, Italy, Poland, Slovakia, Spain, Switzerland
- 14 Countries, 77 Institutions, more than 300 researchers
- RIKEN: Leading institution

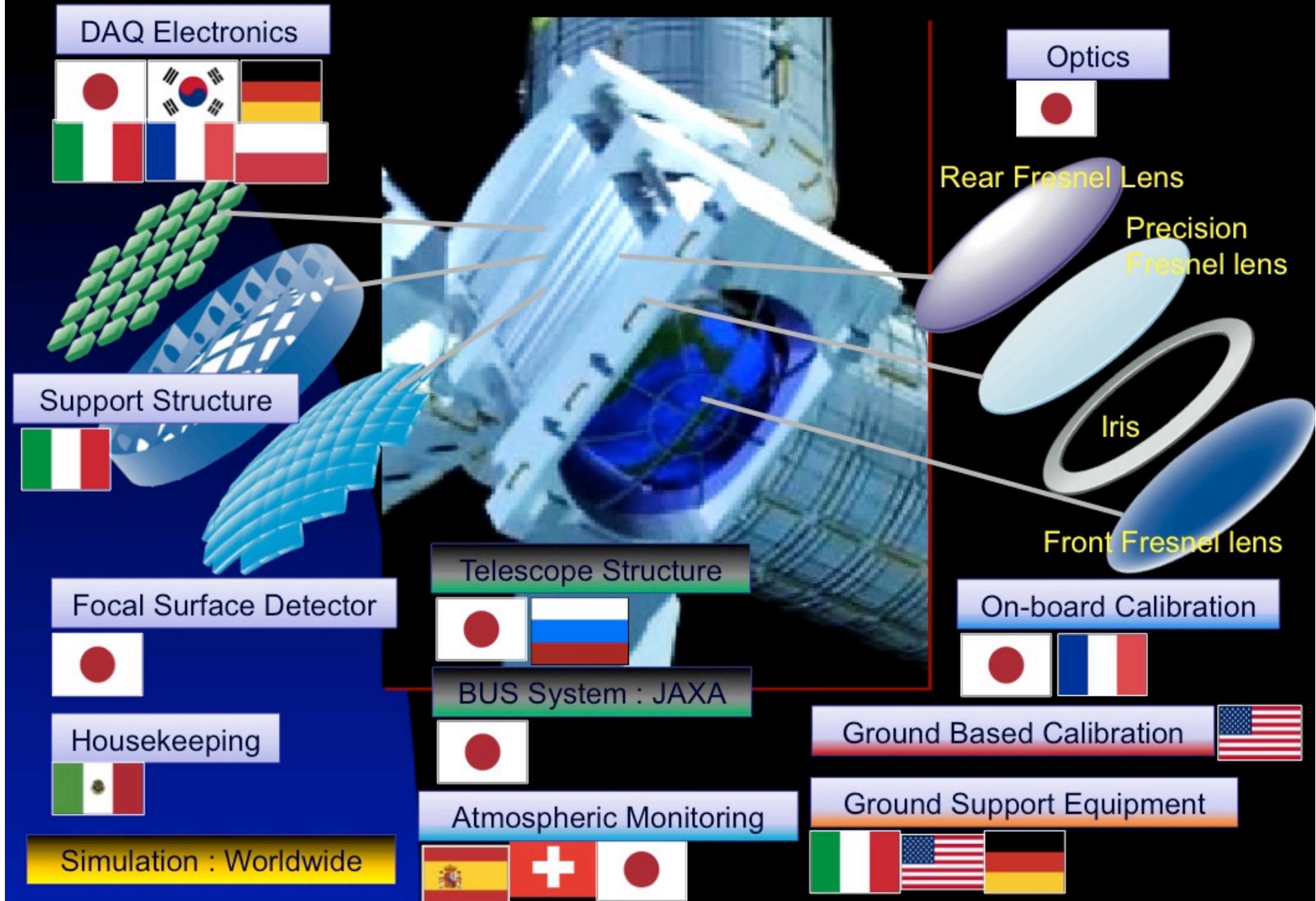


# Space Agencies

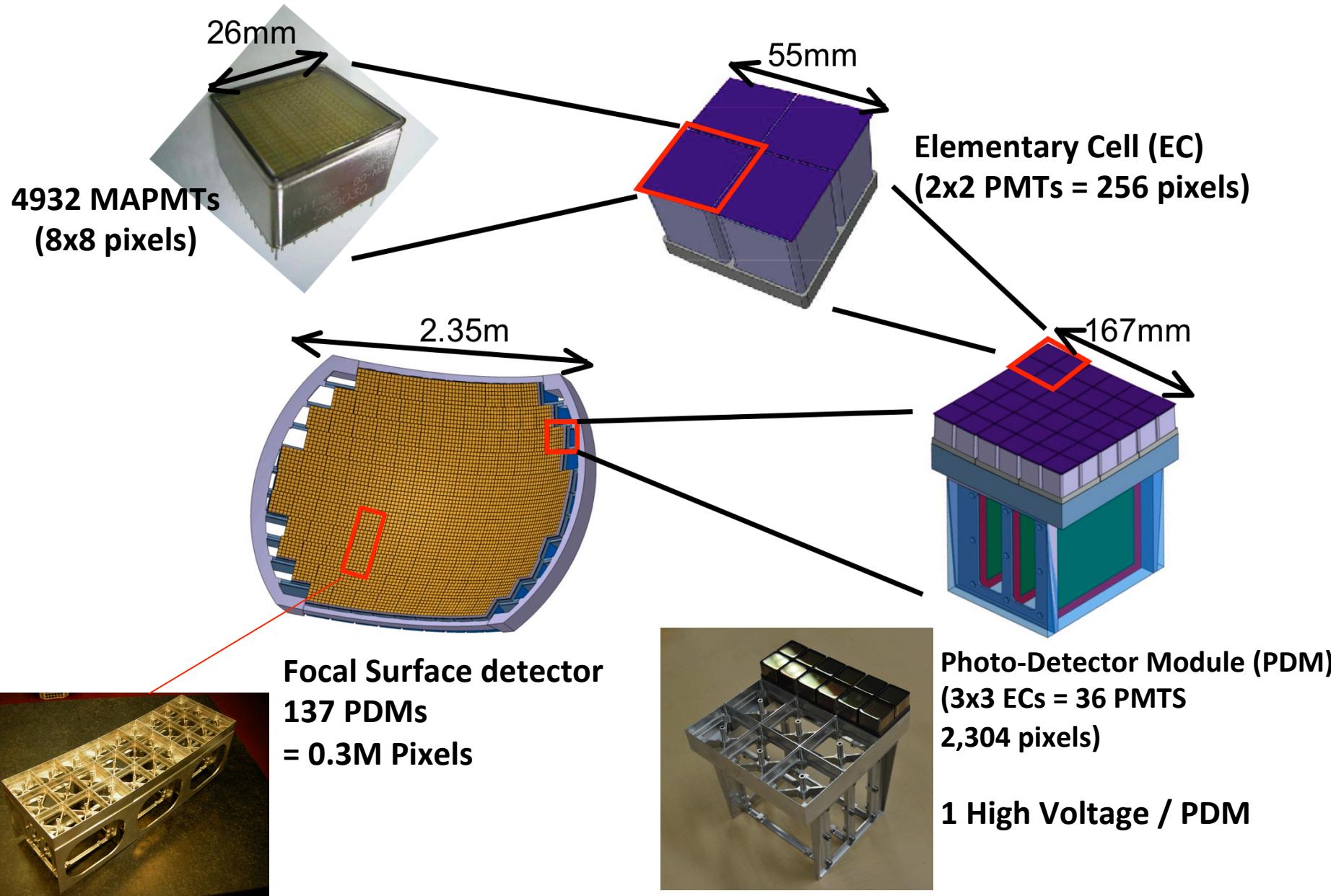
- JAXA
  - ESA
  - NASA
  - Roscosmos
- 
- National Space Agencies



# Conceptual view of the telescope

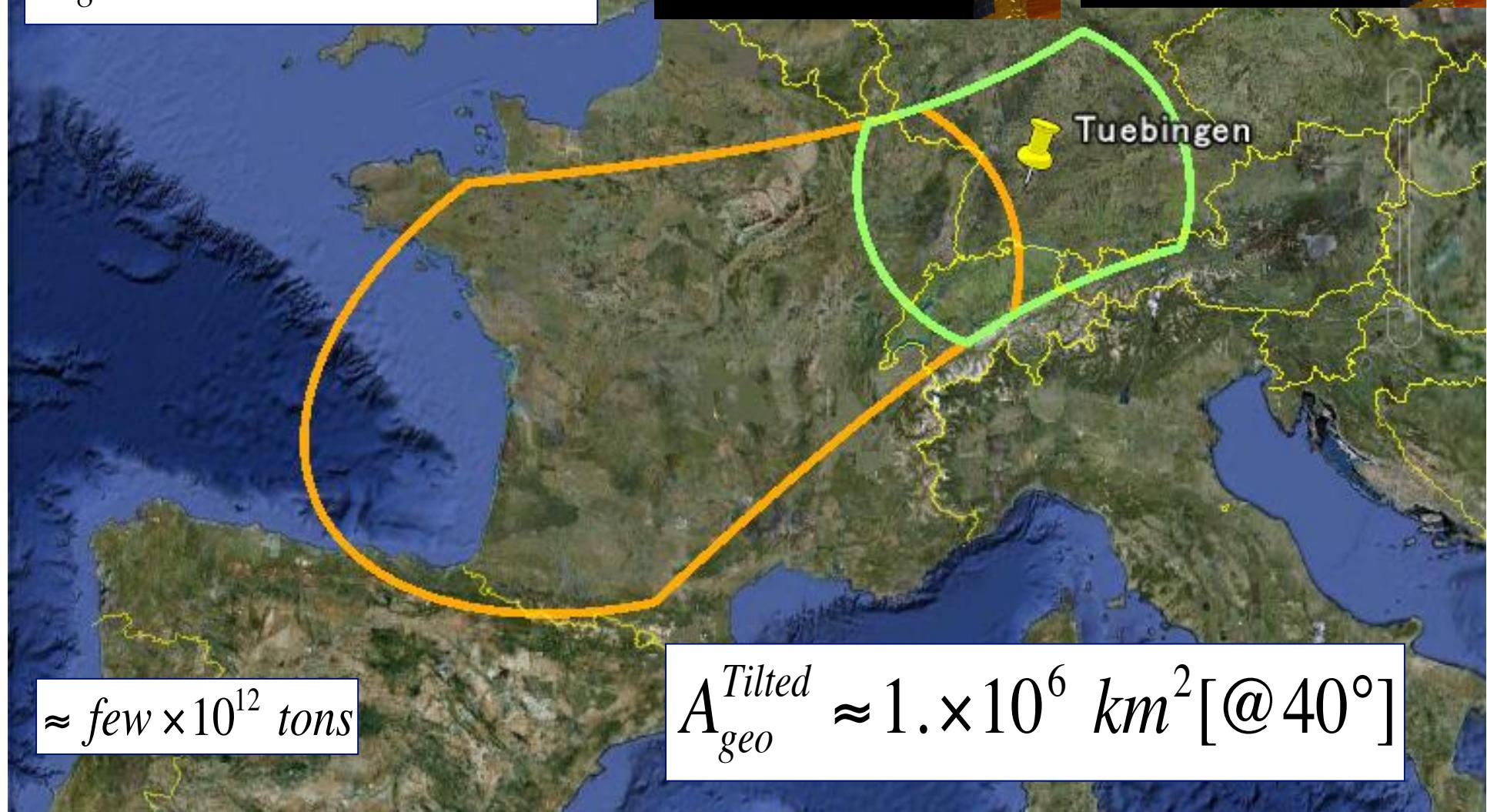


# Focal Surface Detector





$$A_{geo}^{Nadir} \approx 1.3 \times 10^5 \text{ km}^2$$

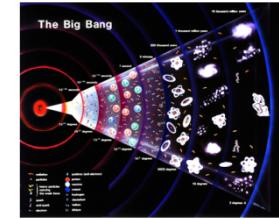


Mission aspects have been successfully studied by JAXA and RIKEN

Parameter	Value
Launch date	2017
Mission Lifetime	3+2 years
Rocket	H2B
Transport Vehicle	HTV
Accommodation on JEM	EF#2
Mass	1938 kg
Power	926 W (op.) 352 W (non op.)
Data rate	285 kbps (+ on board storage)
Orbit	400 km
Inclination of the Orbit	51.6°
Operation Temperature	-10° to +50°



# JEM-EUSO Science



- **Astrophysics and Cosmology:**

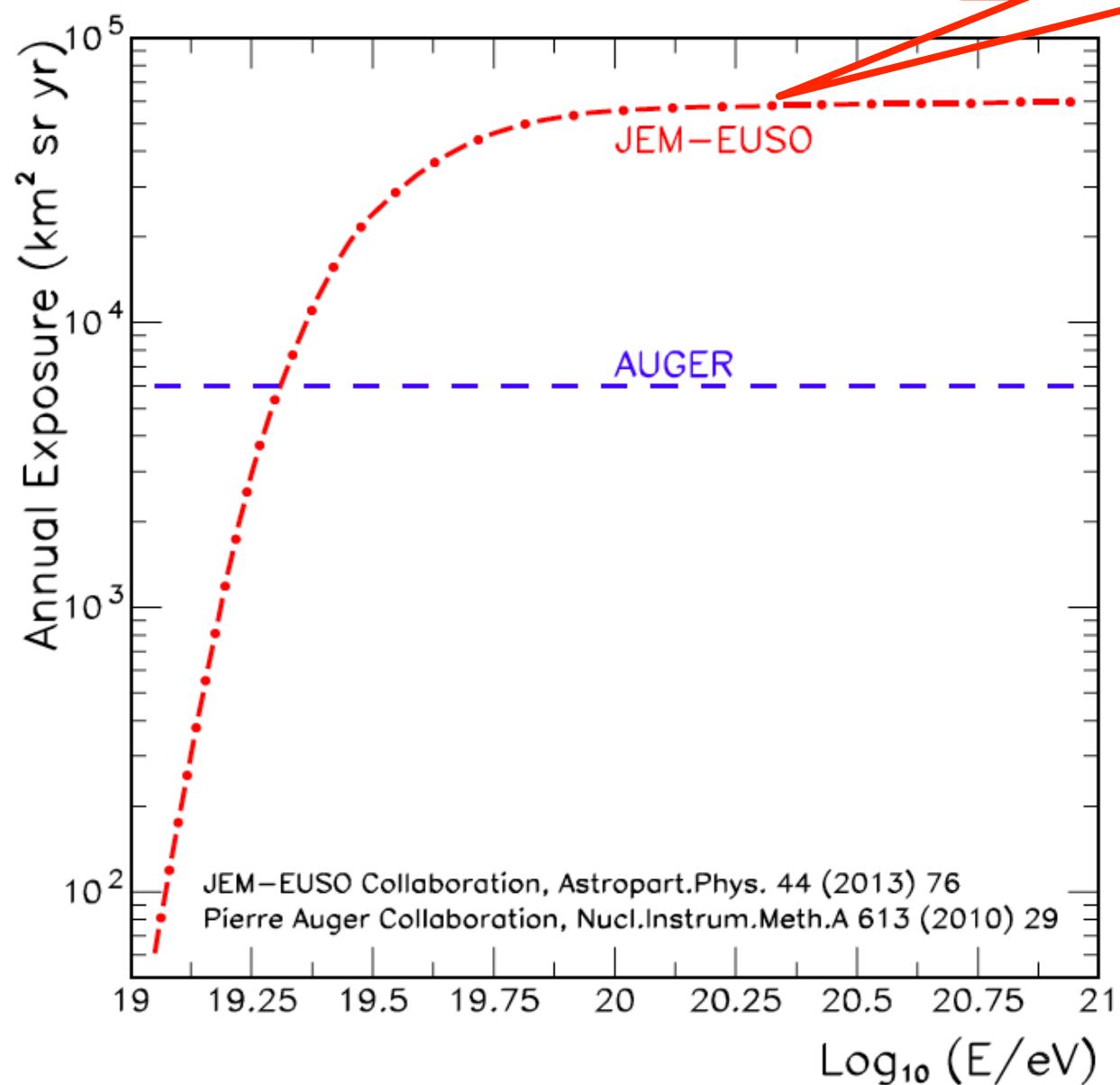
- Main Science Objectives:
  - *identification of UHE sources*
  - *measurement of the energy spectra of individual sources*
  - *measurement of the trans-GZK spectrum*
- Exploratory objectives:
  - *discovery of UHE Gamma-rays*
  - *discovery of UHE neutrinos*
  - *study of the galactic and local extragalactic magnetic field*
  - *“Top-Down” scenario*

- **Atmospheric Science**

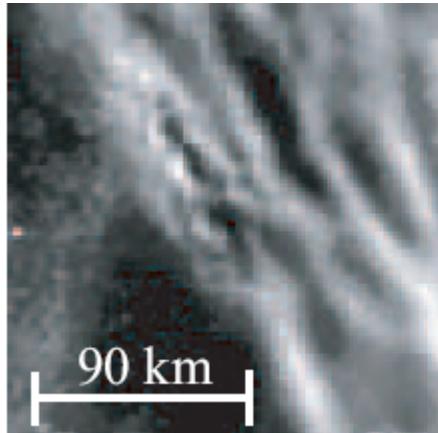
- *Nightglow*
- *the transient luminous events (TLE)*
- *meteors and meteoroids*

# JEM-EUSO

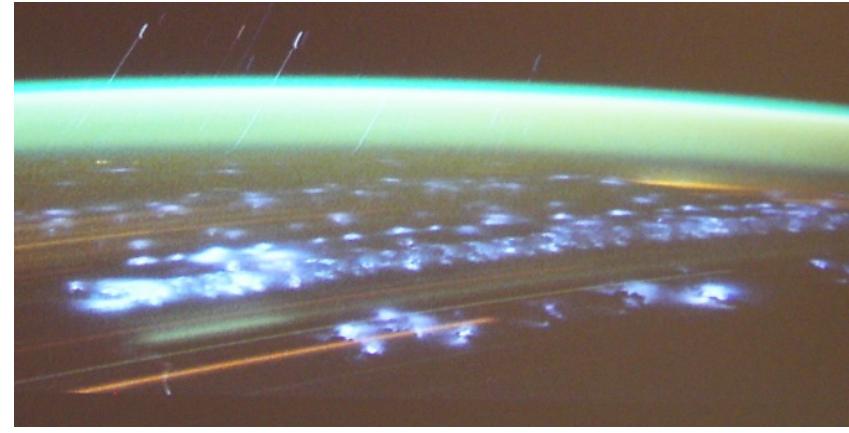
annual exposure =  
10 x Auger  
 $6 \times 10^4 \text{ km}^2 \text{ sr yr}$



# Atmospheric Luminous Phenomena



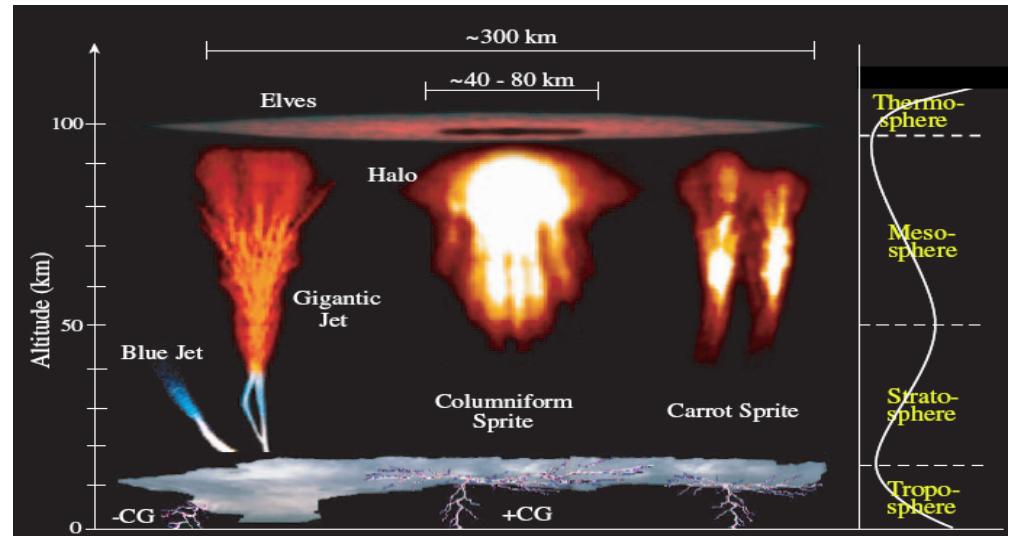
OH airglow observed from ground



Lightning picture observed from ISS

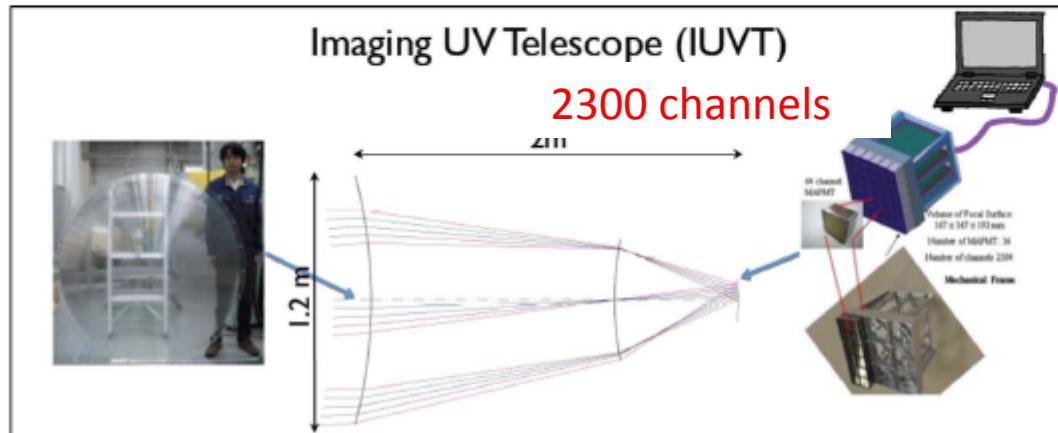


Leonid meteor swarm in 2001  
taken by Hivison camera

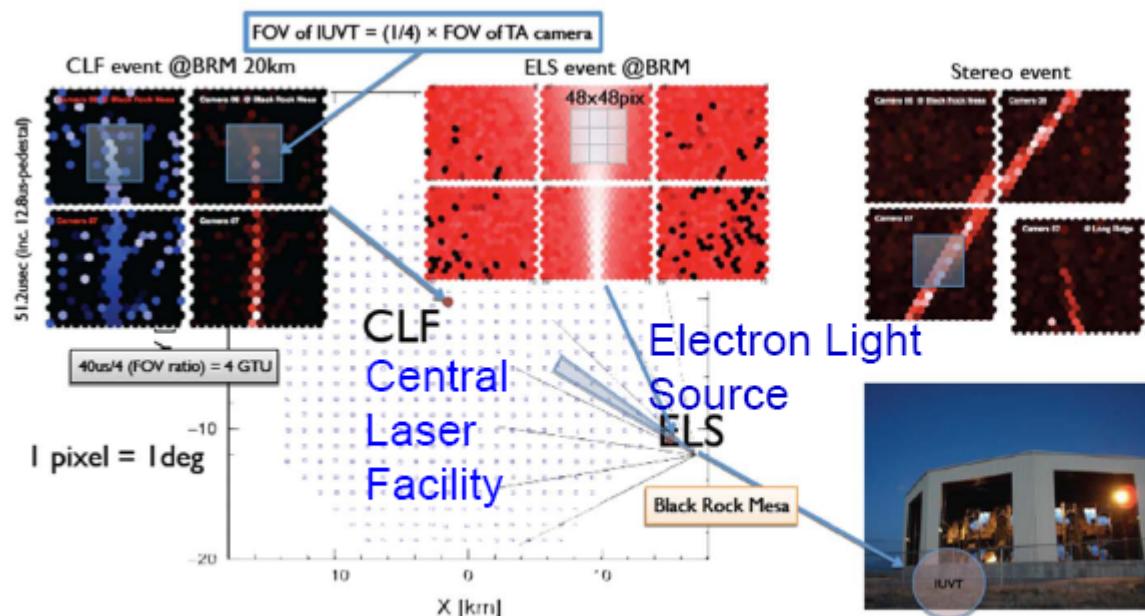


Various transient airglows

# JEM-EUSO Prototype Test at TA Site



The first integrated test using various elements developed for the JEM-EUSO UV telescope at the Telescope Array site in Utah.

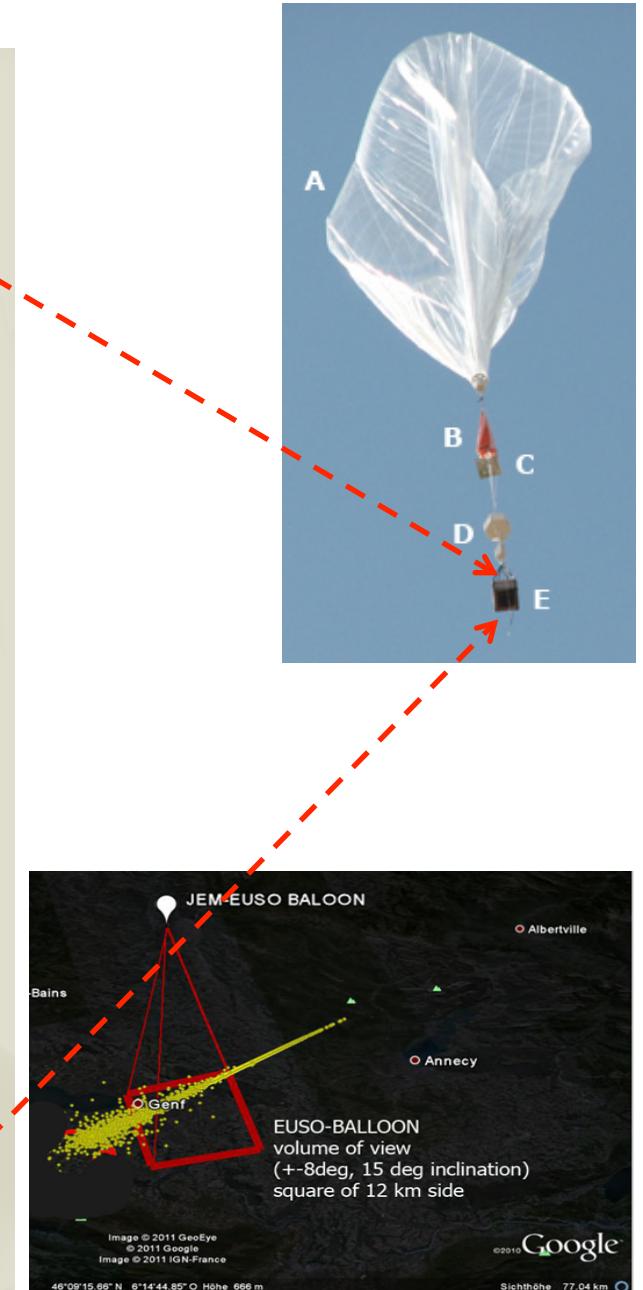
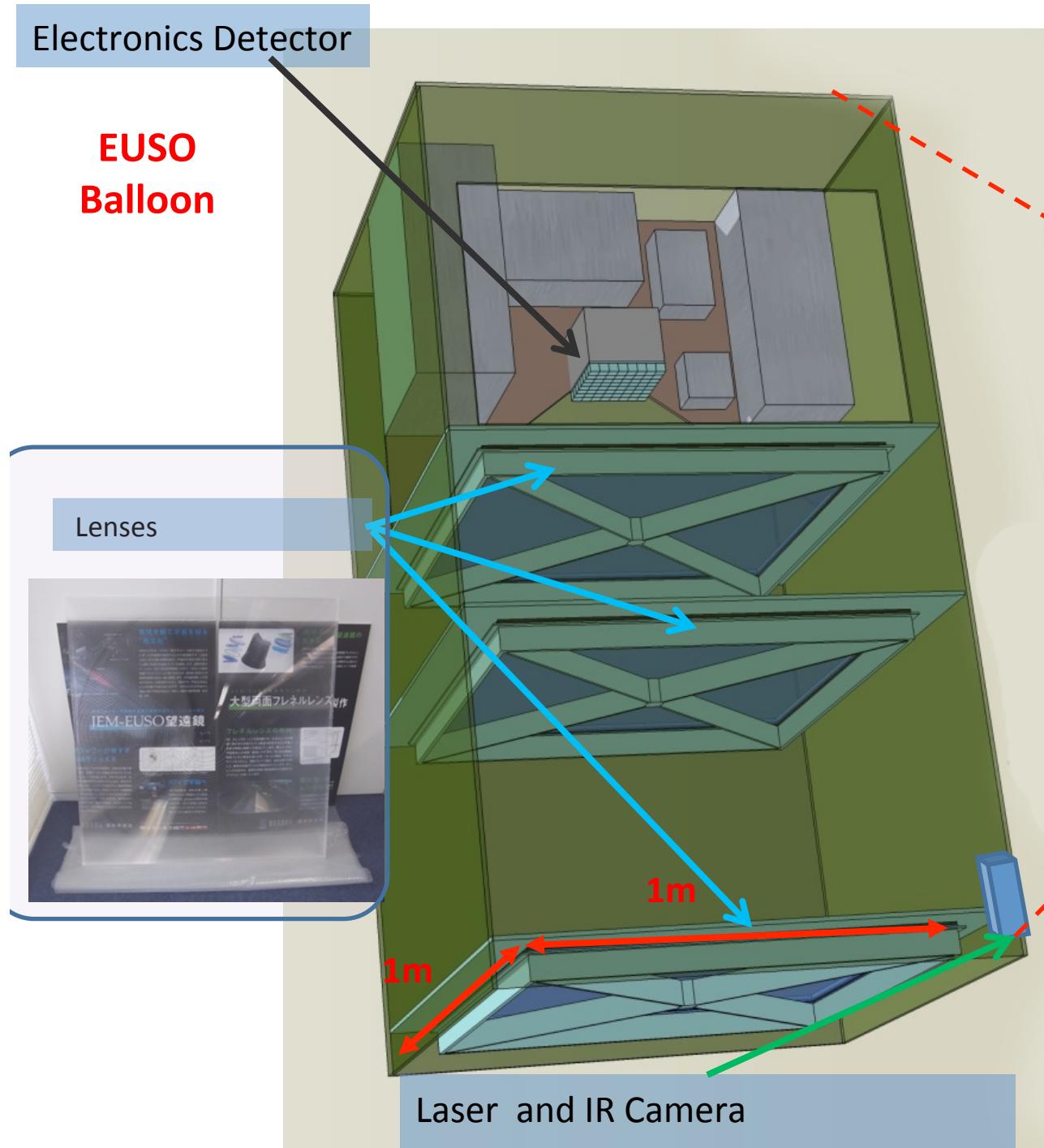


Light from Electron Light Source (ELS) and LIDAR of TA can be observed besides cosmic ray events.

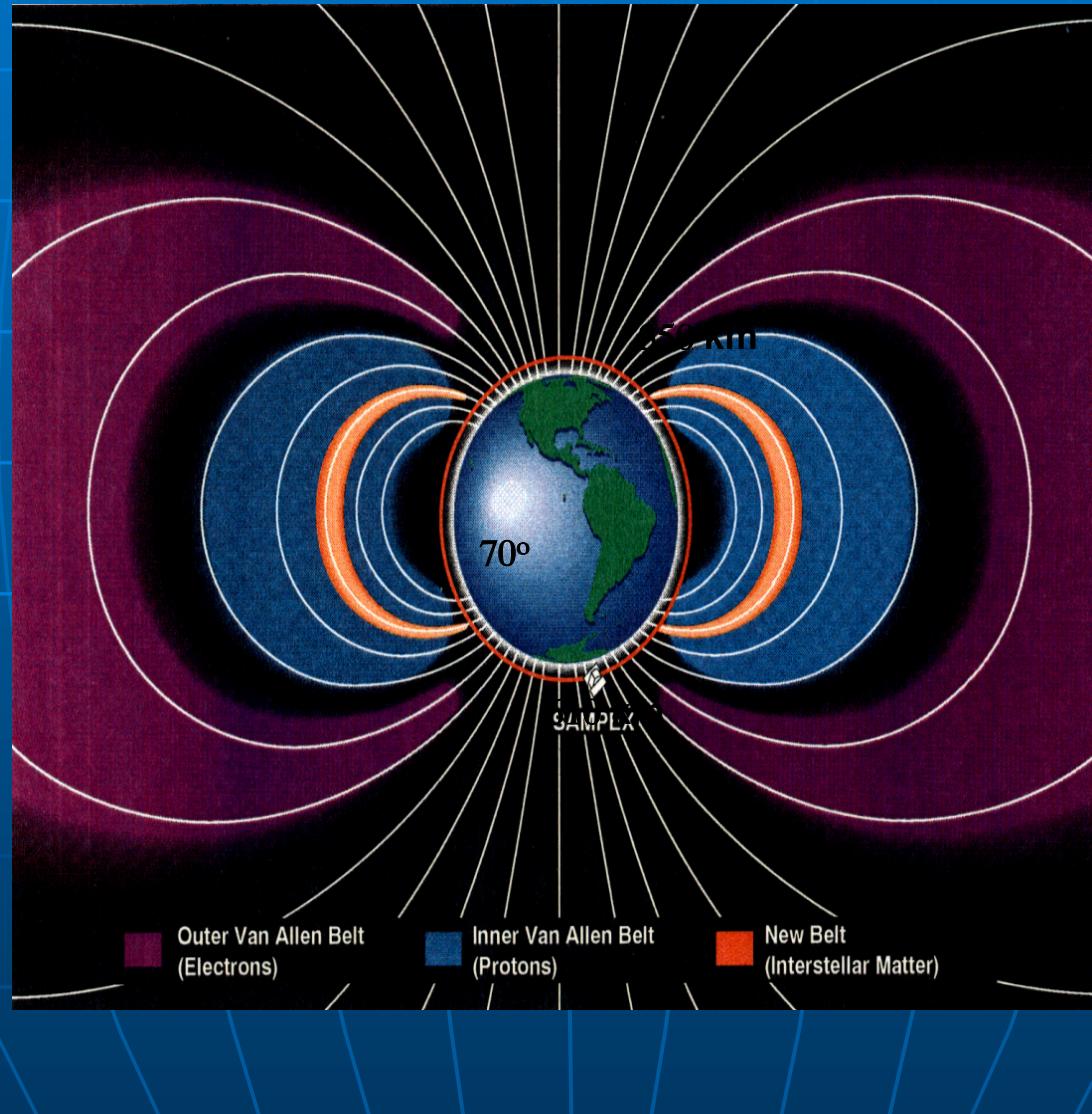
# Installation at Telescope Array Site



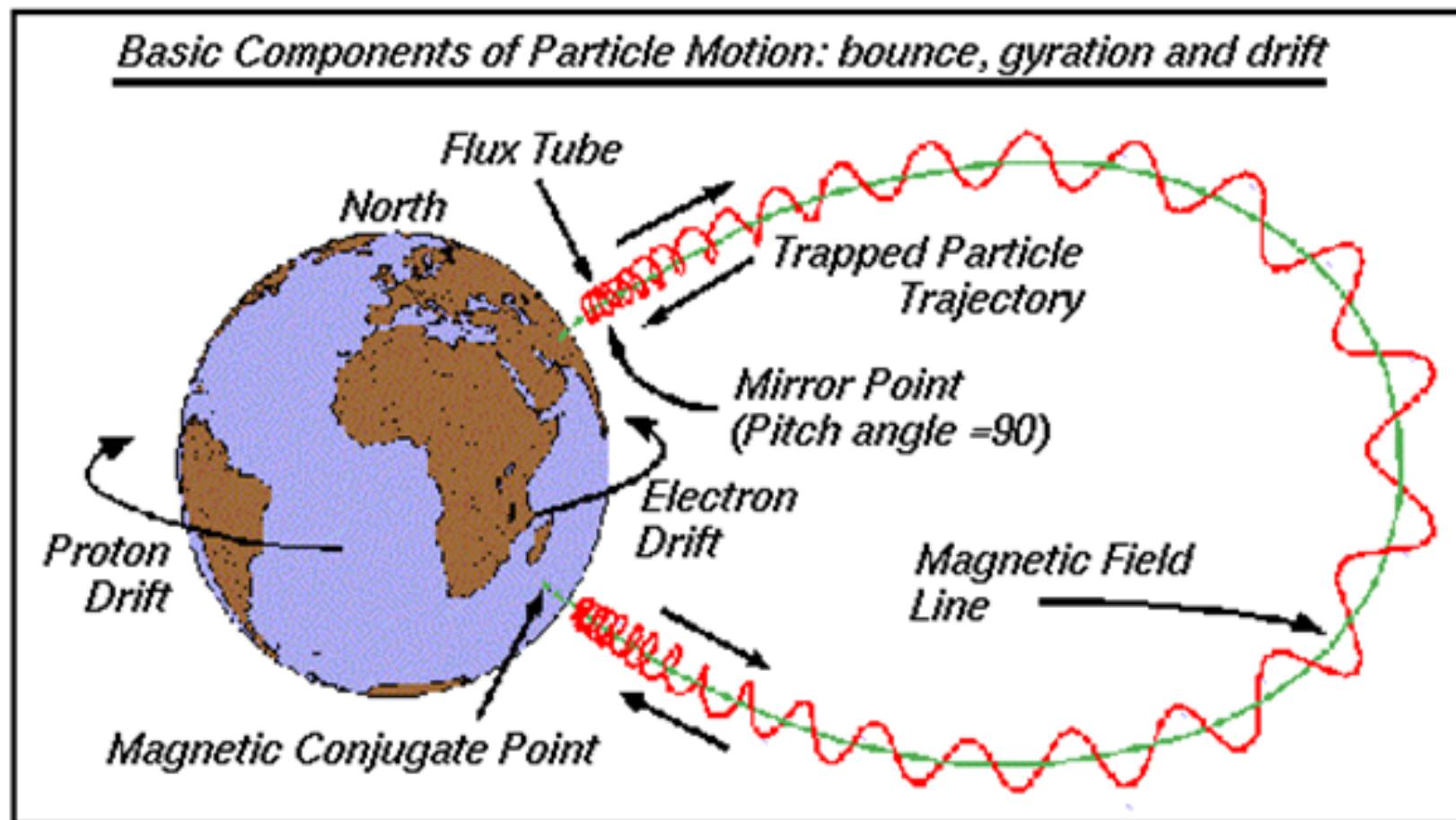
Operation: September 2013



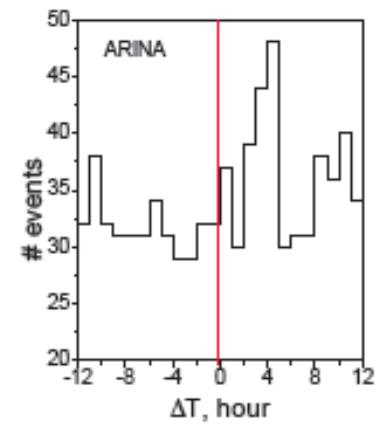
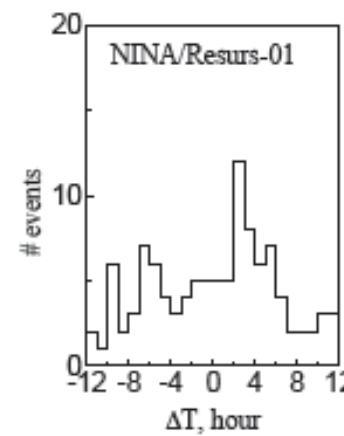
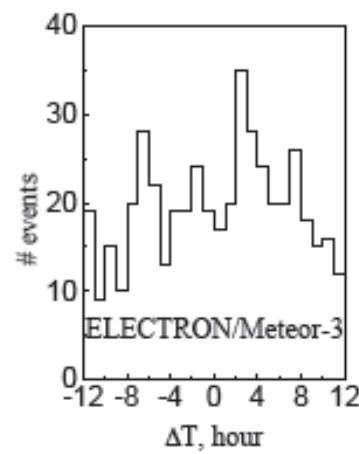
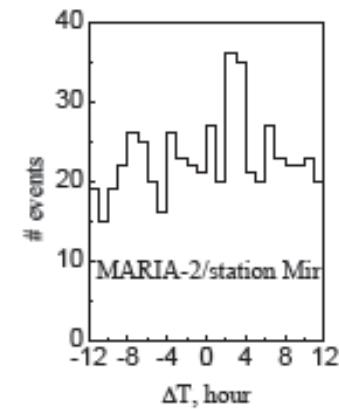
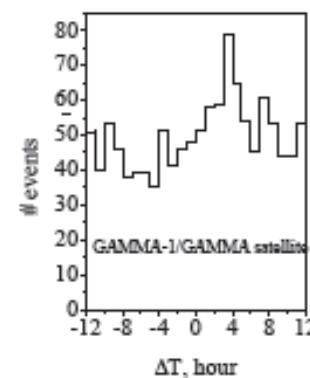
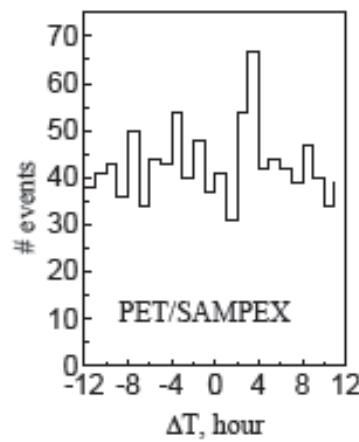
# Van Allen Belts



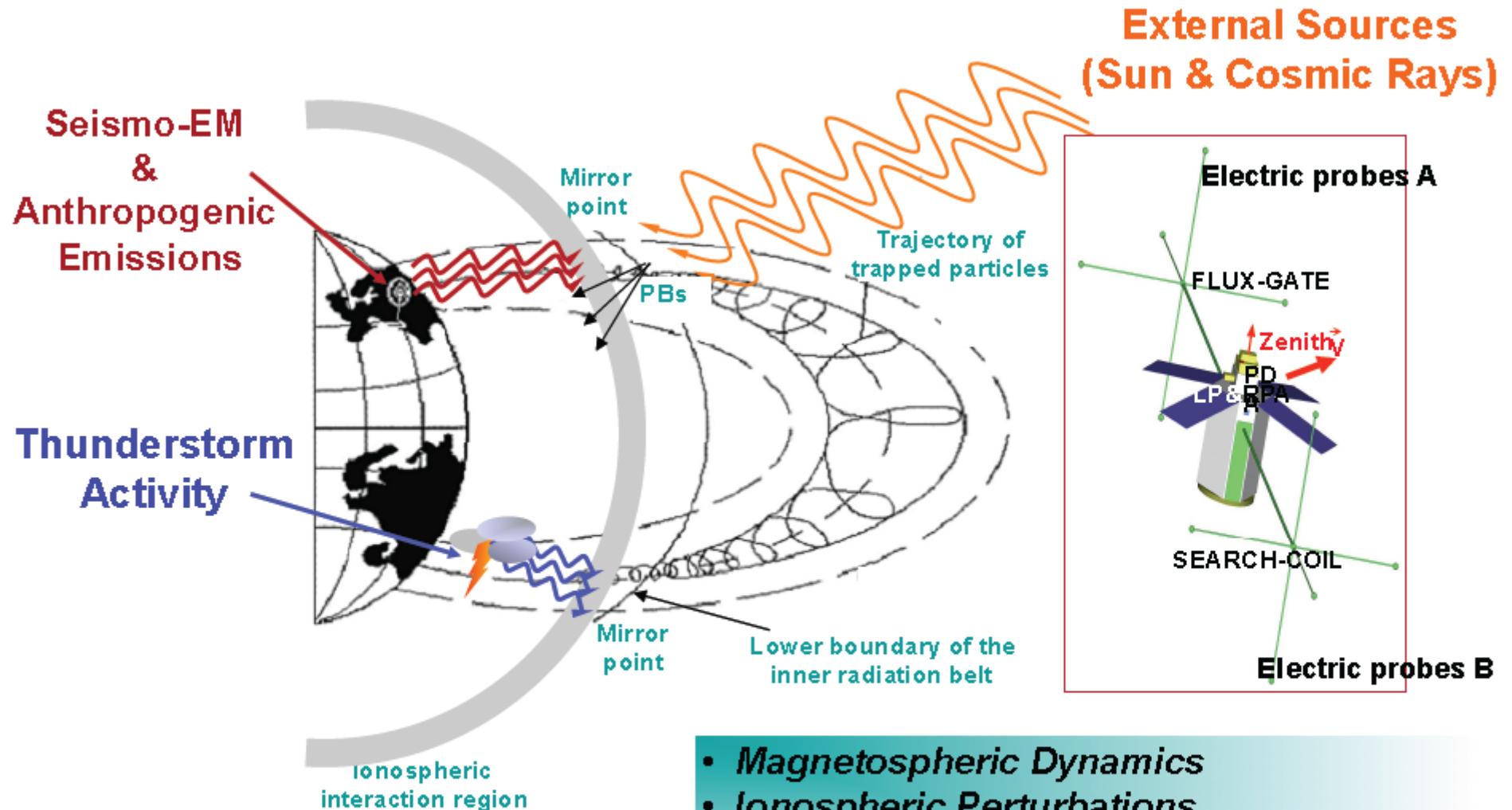
# Trapped Particles



## Correlations between Earthquakes & Particle Bursts



# A Space Mission Project

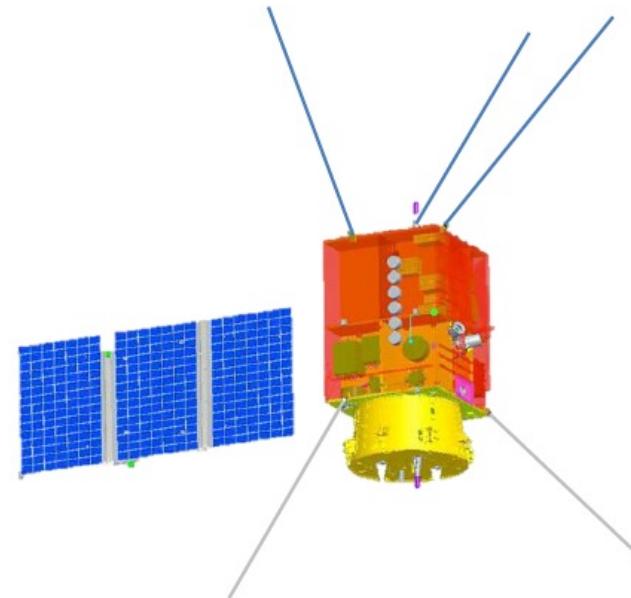


- *Magnetospheric Dynamics*
- *Ionospheric Perturbations*
- *Geomagnetic Field Fluctuations*
- *Seismic Precursors*

# Limadou-CSES Mission

Flight September 2016

- Li Madou - Matteo Ricci
- CSES : China Seismo Electromagnetic Satellite



# Italian-Chinese Mission

- Measurement of signals from electromagnetic emission and its perturbations in ionosphere
- Measurement of the disturbance of plasma in ionosphere, such as: contents, density and temperature of the ions, density and temperature of the electron, total electron contents, etc.
- Measurement of energetic particles precipitations

# ✖ Payload Instruments

## Particle Detector Analyser (PDA) AIGLE

- Energy range: 300keV ÷ 100 Mev
- Pitch angle accuracy < 4° with particle identification

## ➤ Electric Field Analyser (EFA) VOLTA

- frequency range: ~DC ÷ 10 MHz
- accuracy: 300 nV/m
- dynamic range: 120 dB

## ➤ Magnetic Field Analyser (MAFA)

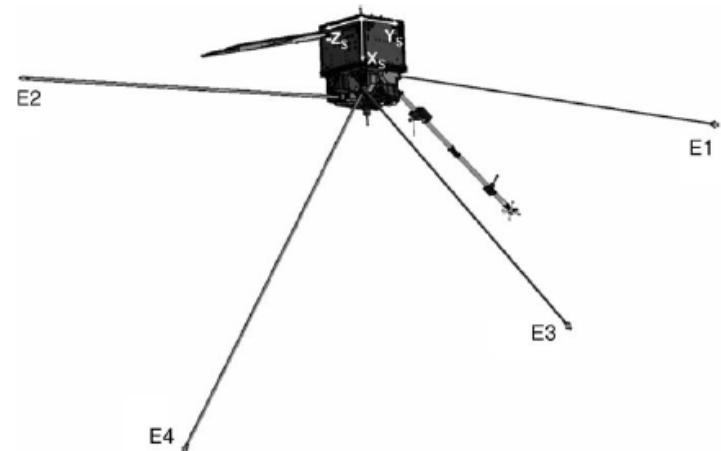
- FLUX – GATE:
- frequency range: ~DC ÷ 10 Hz
  - accuracy: a few (6-8) pT
  - resolution: 24 bit

- SEARCH – COIL:
- frequency range: ~10 Hz ÷ 100 kHz
  - sensitivity:  $10^{-2}$  pT / (Hz) $^{1/2}$  (at 1 kHz)

## ➤ Langmuir Probe & Retarding Potential Analyser

- LP:
- electron temperature: 300 ÷ 15000 K
  - electron density:  $10^2$  ÷  $10^7$  cm $^{-3}$

- RPA:
- ionic temperature: 300 ÷ 10000 K
  - ionic density:  $10^2$  ÷  $10^7$  cm $^{-3}$

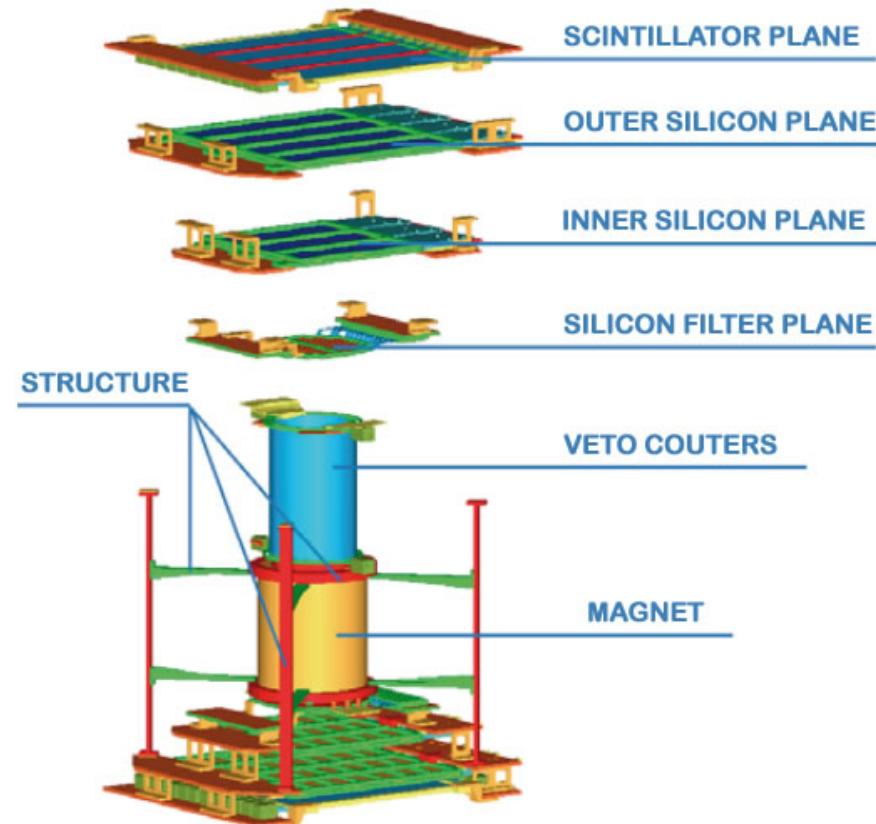


# Limadou – CSES in Italy

- VOLTA



- AIGLE



# Space Activity

- Many important missions have been performed
- Many fundamental results have been obtained
- New space missions are in preparation

# Thanks!

<http://pamela.roma2.infn.it>

<http://jem-euso.roma2.infn.it>

<http://spaceweather.roma2.infn.it>