The PAMELA Space Experiment: Results after Six Years from the Launch

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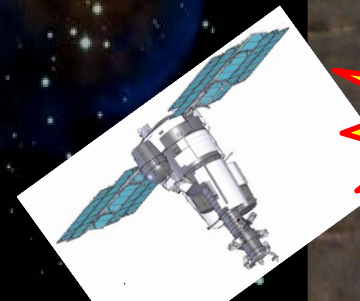
On behalf of the PAMELA collaboration

Workshop on Recent Developments in Astronuclear and Astroparticle Physics
ICTP Miramare, 19 – 23 November, 2012
Trieste (Italy)



Presentation outline

- ❑ Introduction
- ❑ PAMELA apparatus
- ❑ The travel of a cosmic ray: from source to Earth
- ❑ Summary

PAMELA

PAMELA Collaboration

Italy: INFN

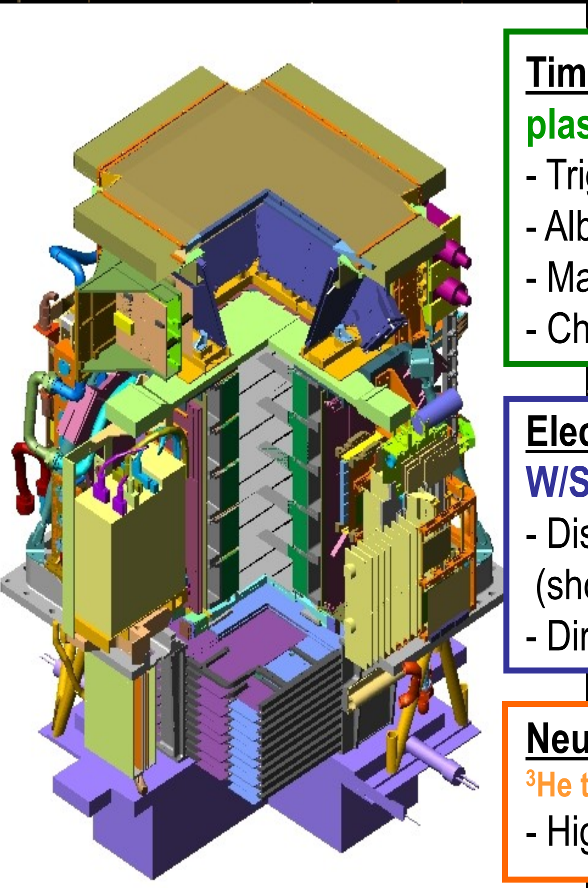
Bari · Florence · Frascati · Naples · Rome (Tor Vergata) · Trieste · CNR, Florence

Germany: Universität Gesamthochschule Siegen — Siegen

Sweden: Kungl Tekniska Högskolan — KTH, Stockholm

Russia: Физический Институт · МИФИ · Ioffe Physico-Technical Institute — Moscow / St. Petersburg

PAMELA: rare charged particles in cosmic rays



Time-Of-Flight

plastic scintillators + PMT:

- Trigger
- Albedo rejection;
- Mass identification up to 1 GeV;
- Charge identification from dE/dX

Electromagnetic calorimeter

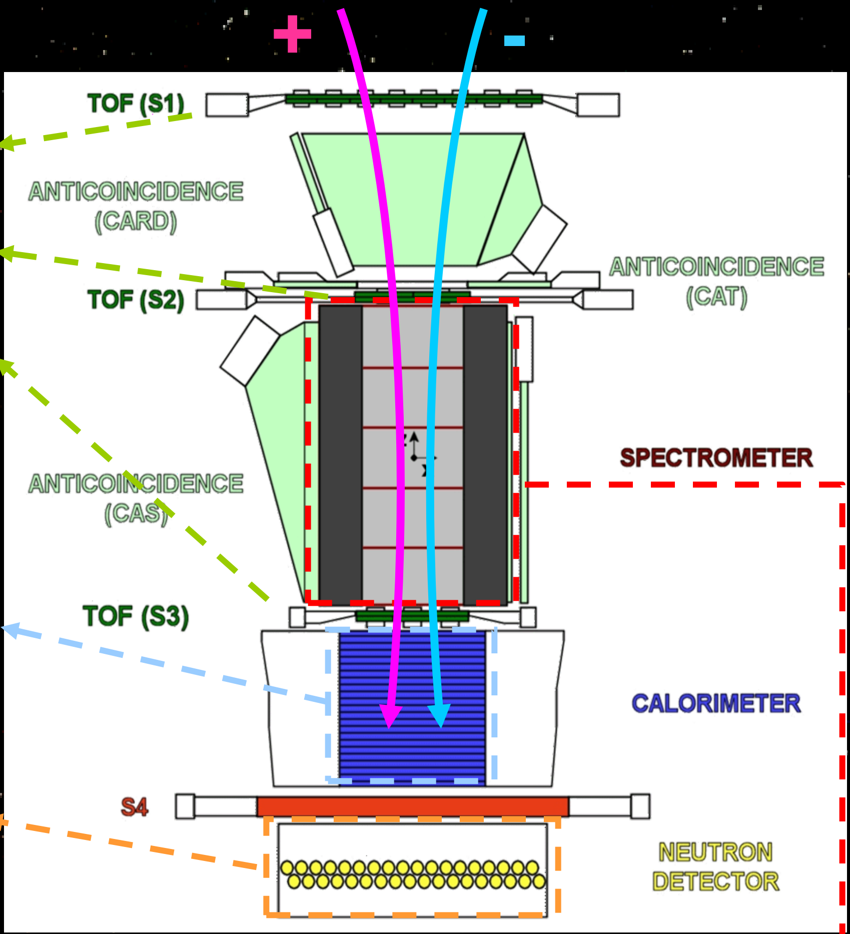
W/Si sampling (16.3 X_0, 0.6 λ_I)

- Discrimination e^+ / p, p-bar / e^- (shower topology)
- Direct E measurement for e^-

Neutron detector

^{3}He tubes + polyethylene moderator:

- High-energy e/h discrimination



GF: 21.5 cm^2 sr
Mass: 470 kg
Size: 130x70x70 cm^3
Power Budget: 360W

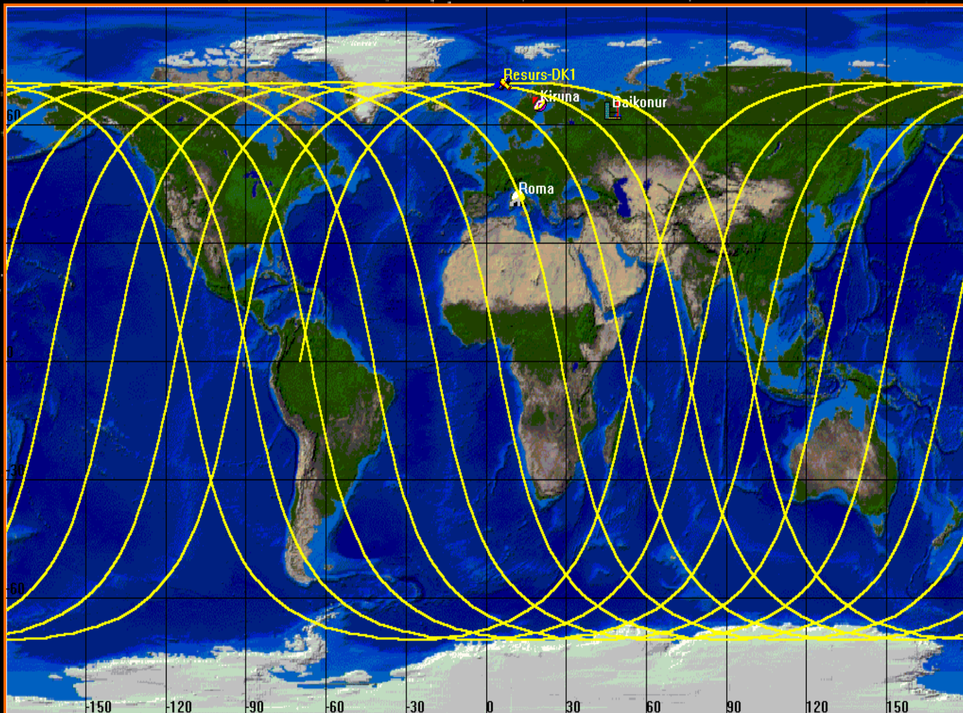
Spectrometer

microstrip silicon tracking system + permanent magnet

It provides:

- Magnetic rigidity → R = pc/Ze
- Charge sign
- Charge value from dE/dx

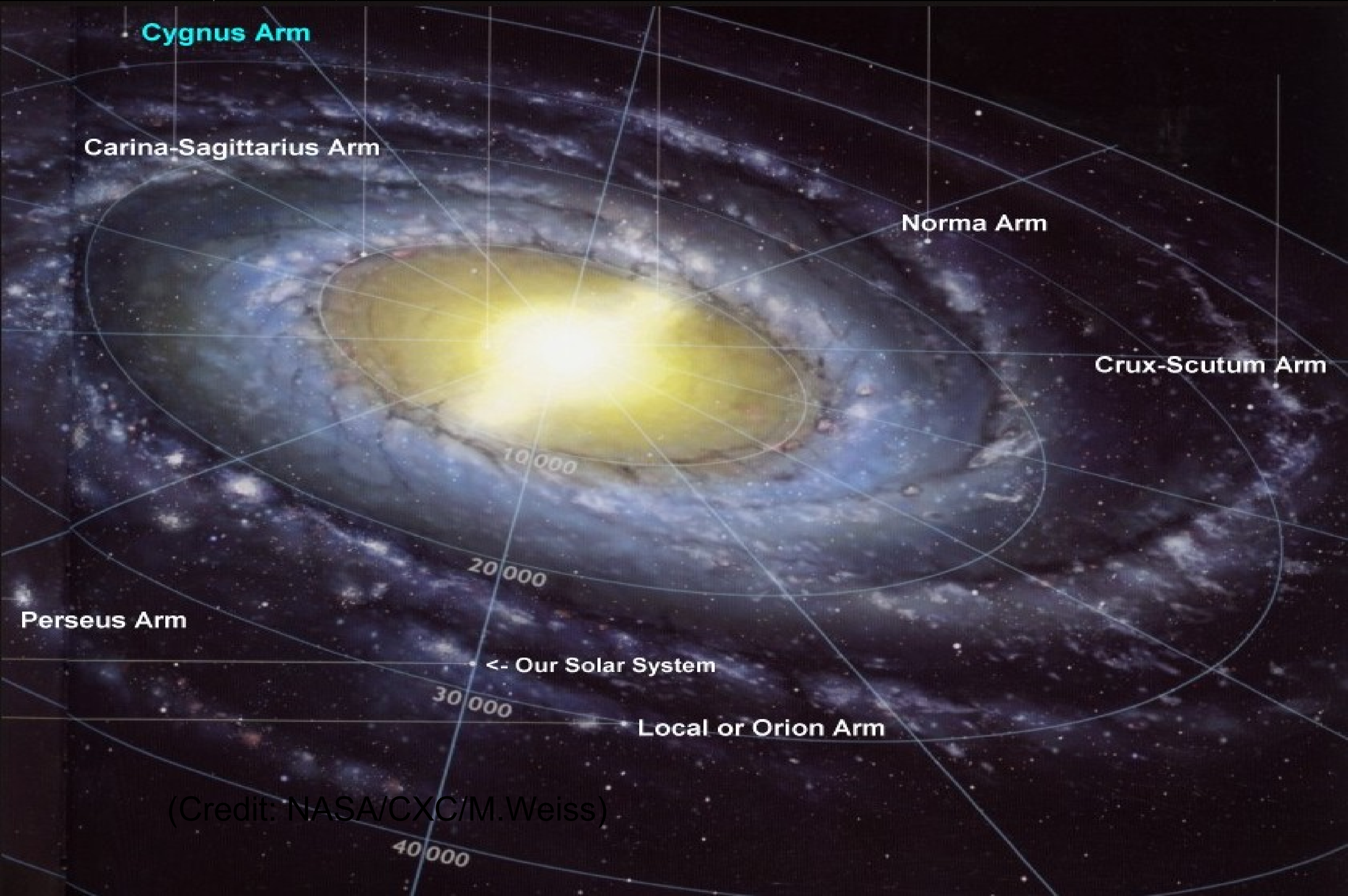
PAMELA: a space experiment



- **Resurs-DK1 satellite: multi-spectral imaging of Earth's surface**
- **PAMELA mounted inside a pressurized container**
- **Launch 15/06/2006 - lifetime >3 years (assisted), extended till end of satellite operations**
- **Data transmitted to NTsOMZ, Moscow via high-speed radio downlink. ~16 GB per day**
- **Quasi-polar and elliptical orbit (70.0°, 350 km - 600 km) – from 2010 circular orbit (70.0°, 600 km)**
- **Traverses the South Atlantic Anomaly**
- **Crosses the outer (electron) Van Allen belt at south pole**

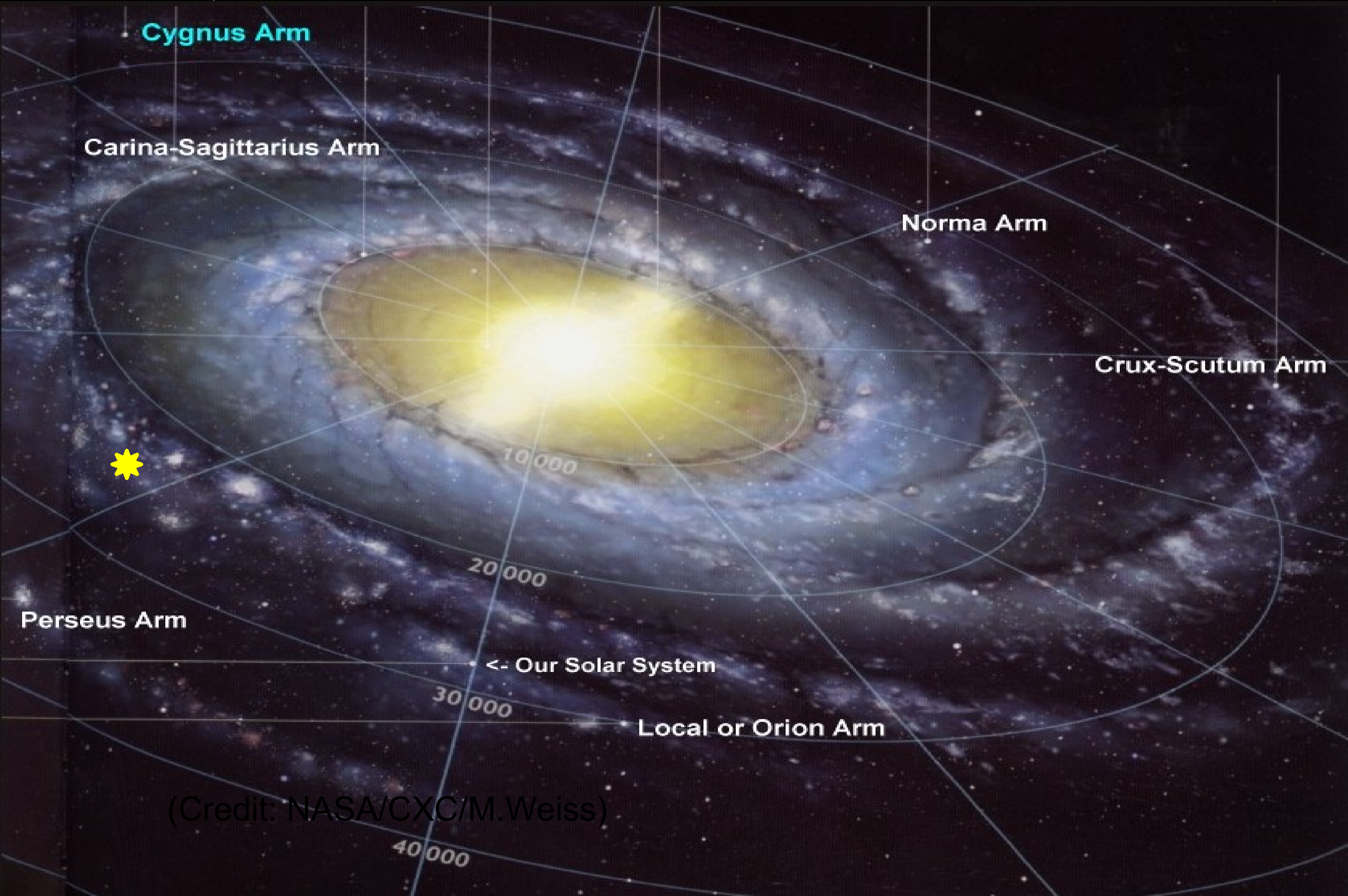
Primary Cosmic Rays

Primary Cosmic Rays



(Credit: NASA/CXC/M.Weiss)

Primary Cosmic Rays



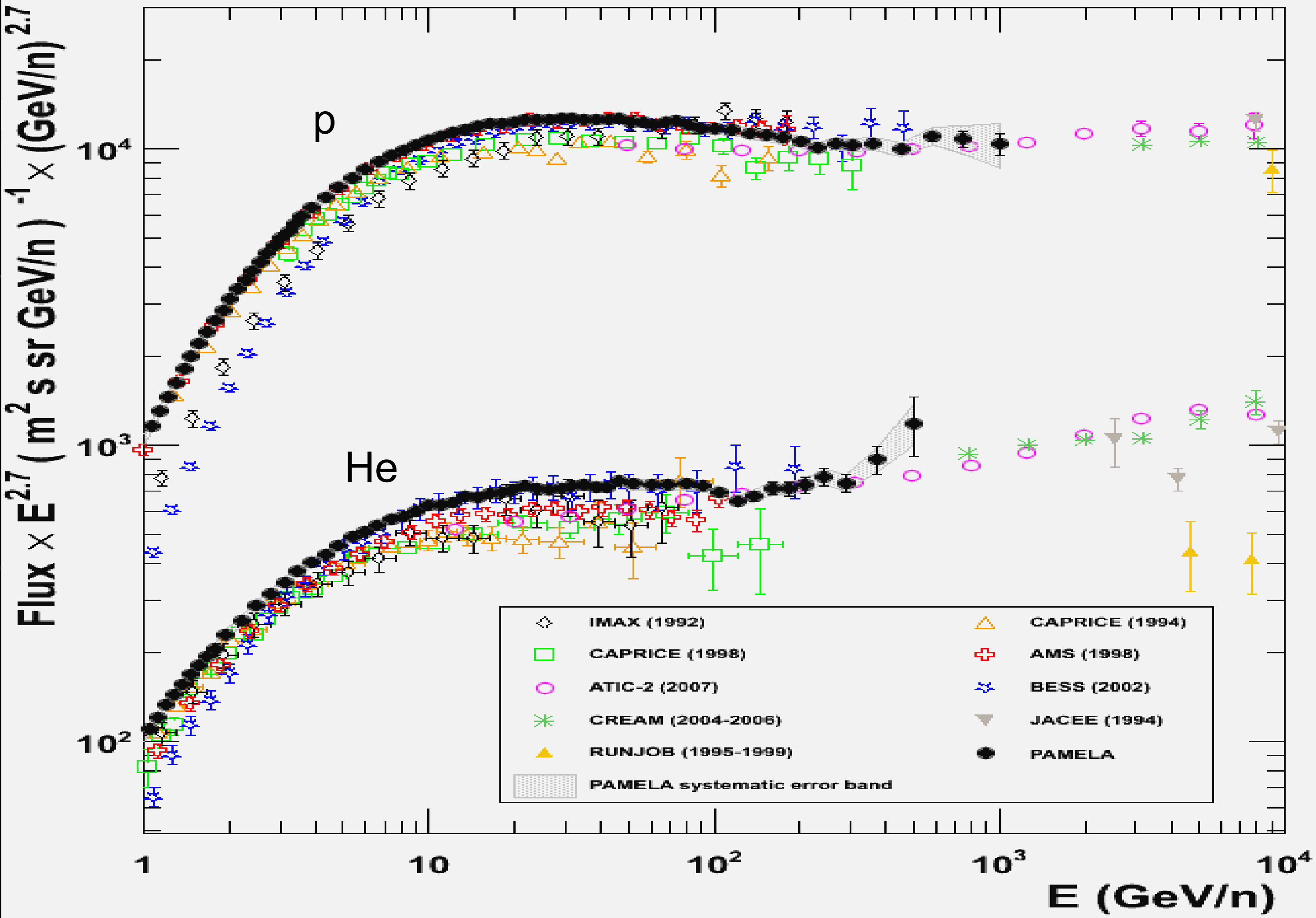
(Credit: NASA/CXC/M.Weiss)

Primary Cosmic Rays

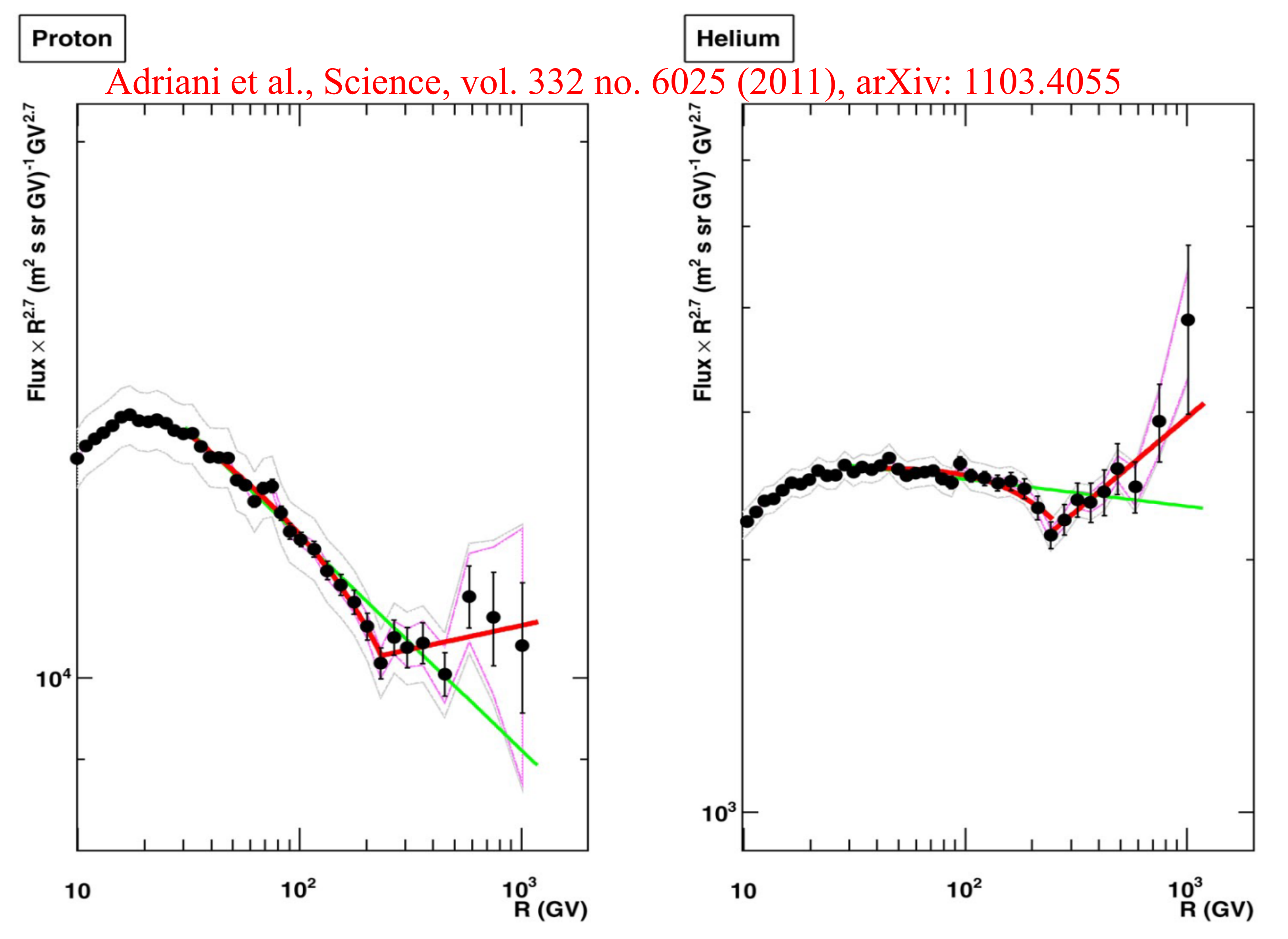
Supernova Explosions: CRs production and acceleration

Proton and Helium Nuclei Spectra

Adriani et al., Science, vol. 332 no. 6025 (2011), arXiv: 1103.4055

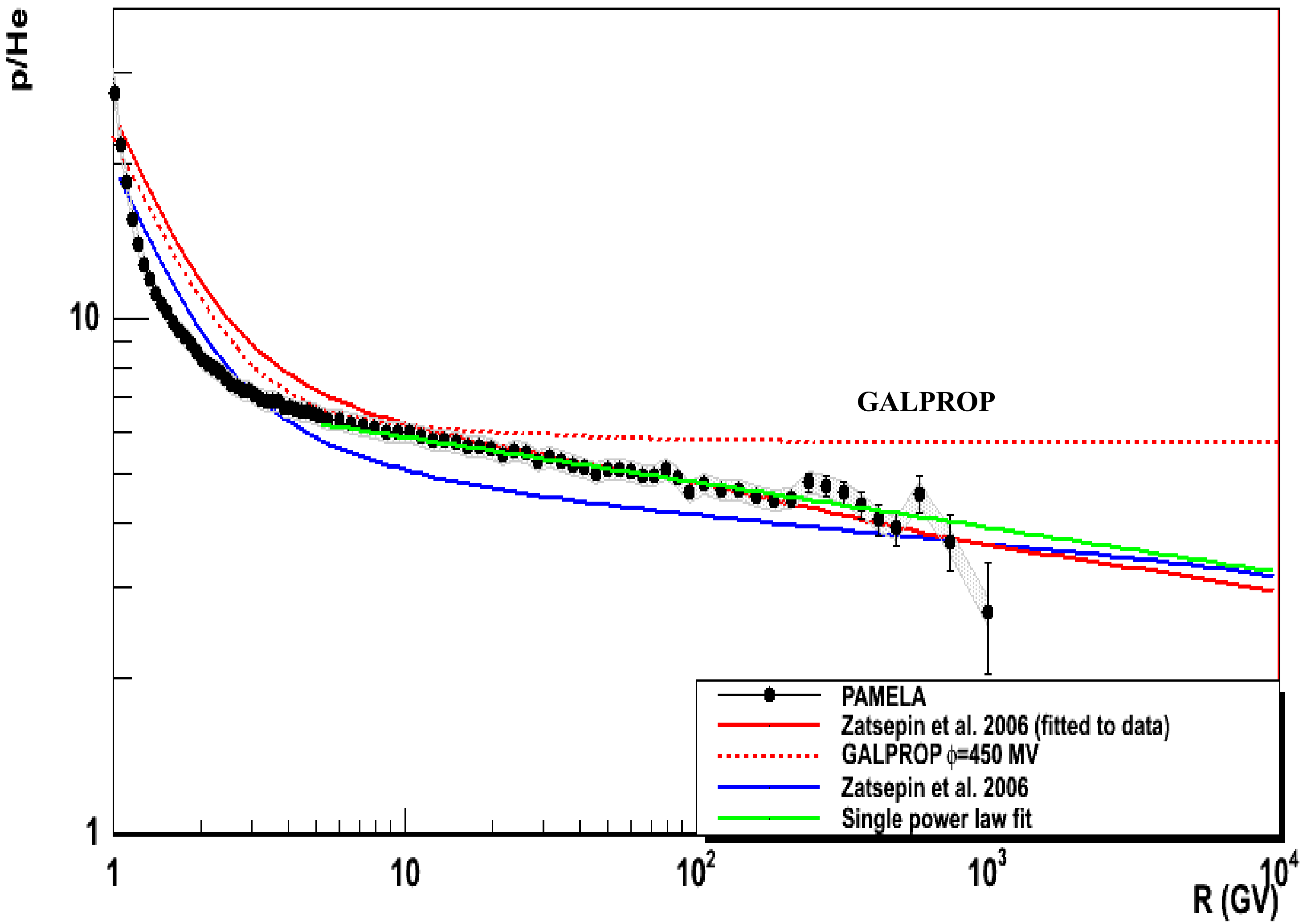


Precise measurement: break in the spectrum



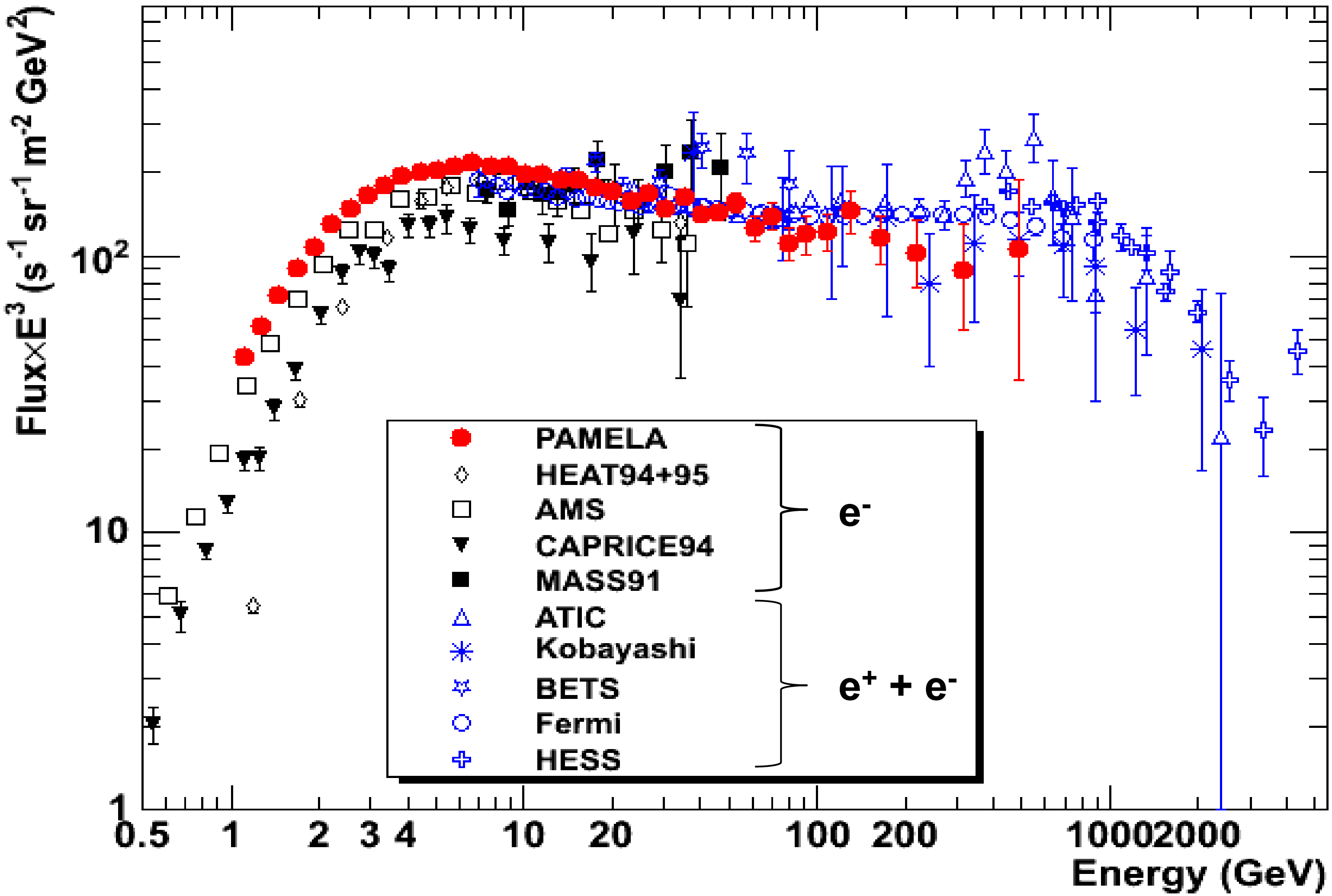
Proton and Helium Nuclei: a different spectral index

Adriani et al., Science, vol. 332 no. 6025 (2011), arXiv: 1103.4055



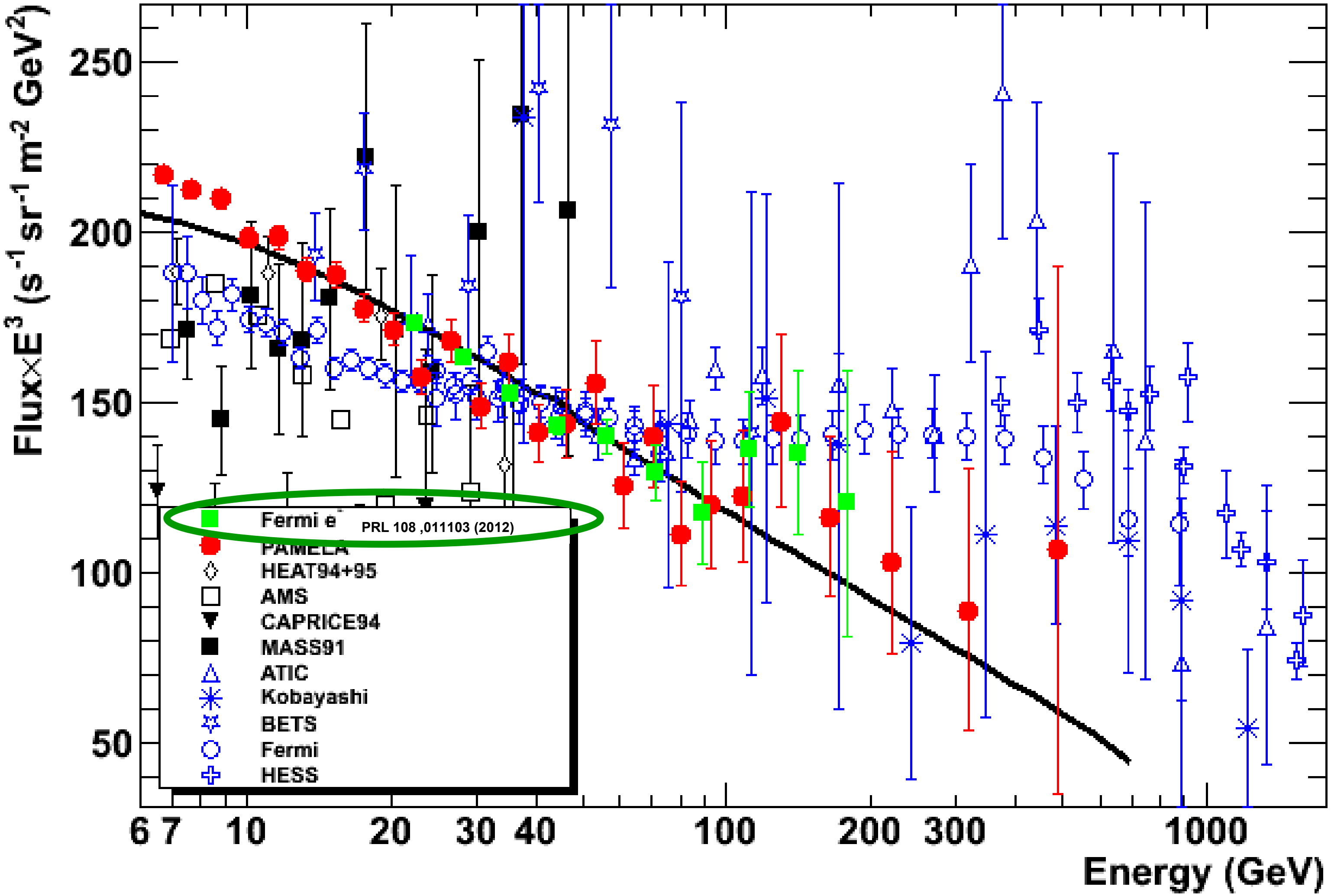
Electron (e$^-$) spectrum

Adriani et al., Phys. Rev. Lett. 106, 201101 (2011), arXiv: 1103.2880

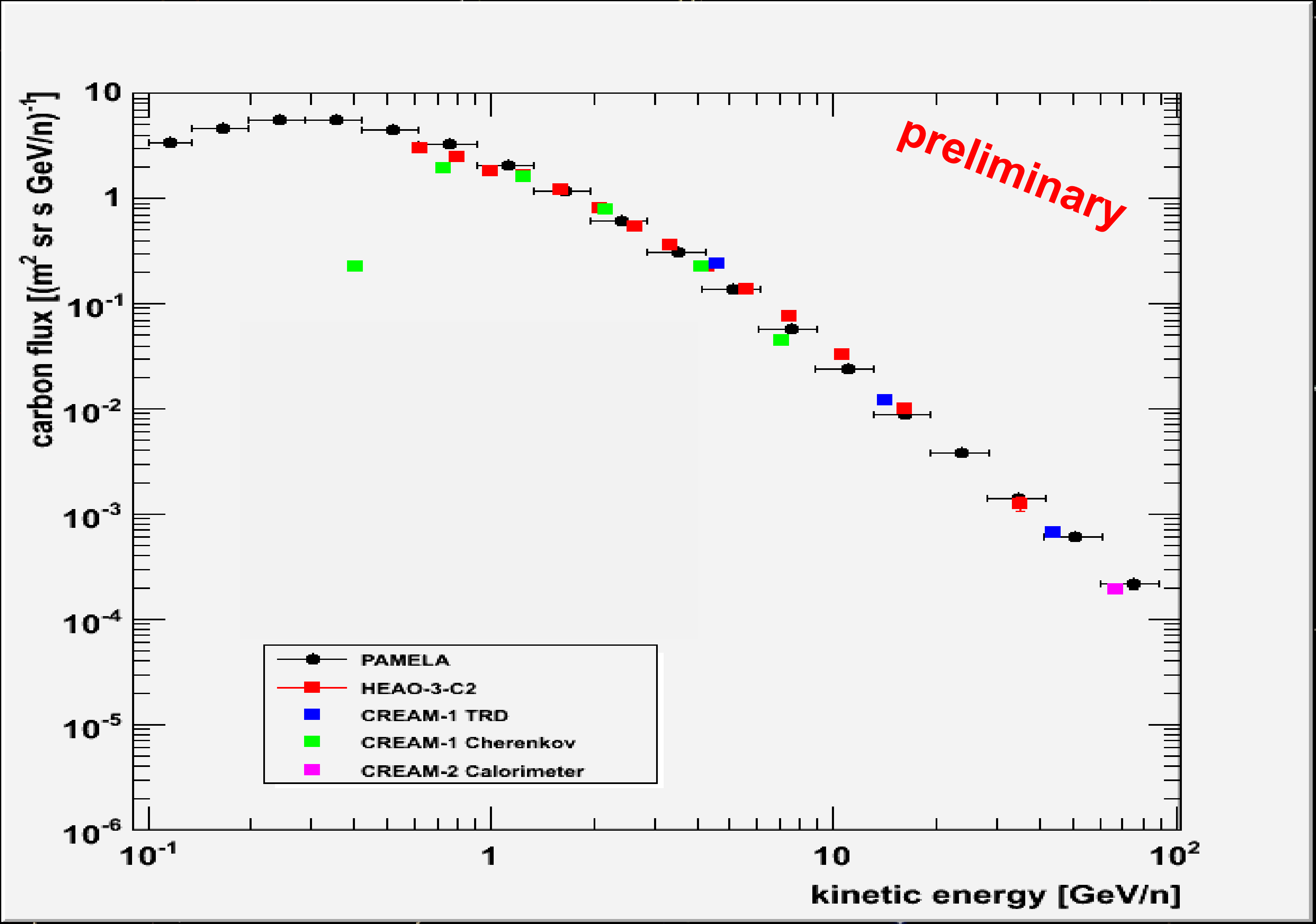


Electron (e^-) spectrum: good agreement with latest Fermi results

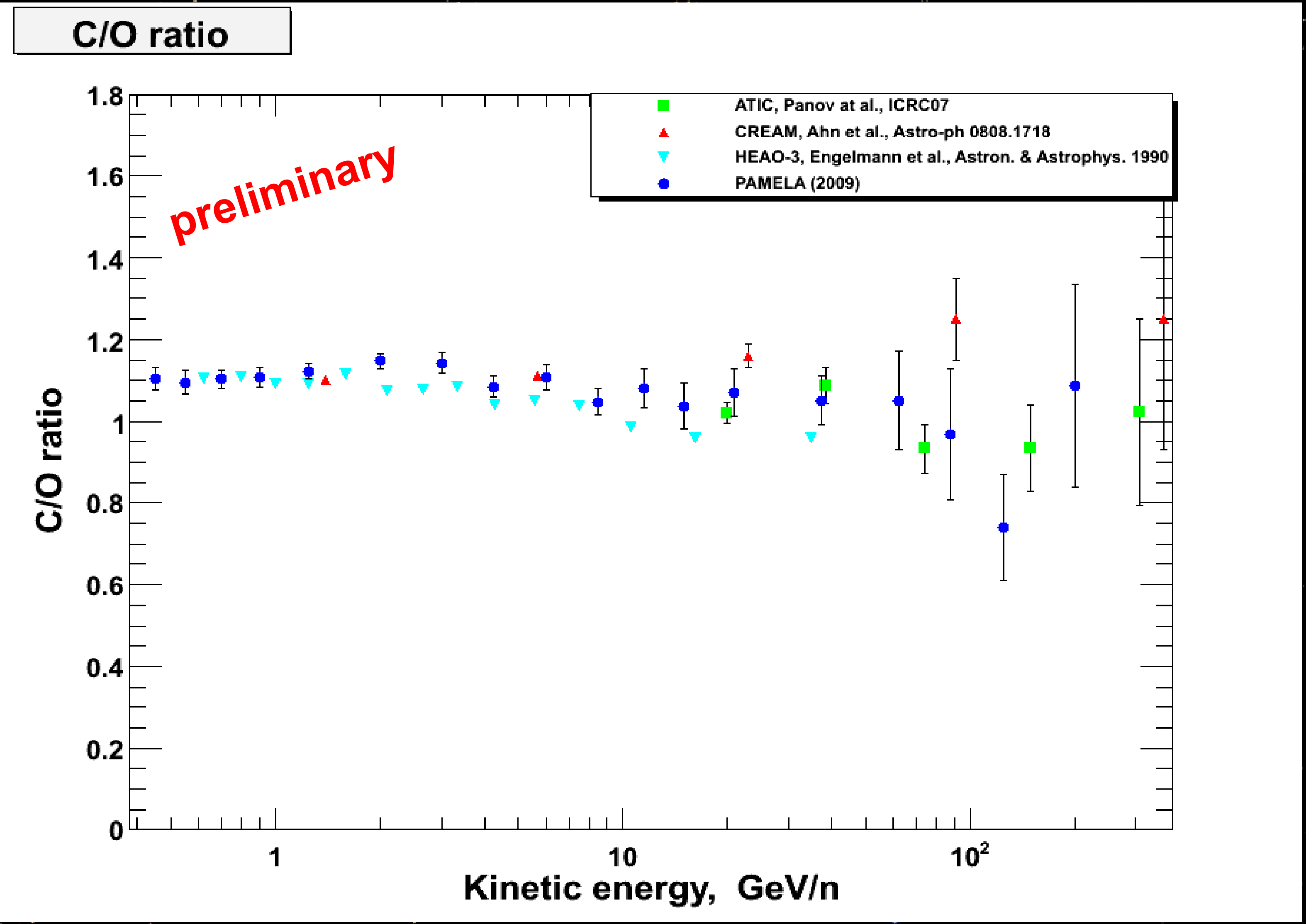
Adriani et al., Phys. Rev. Lett. 106, 201101 (2011), arXiv: 1103.2880



Carbon nuclei Spectrum



Carbon over Oxygen ratio



Primary Cosmic Rays: PAMELA contribution

Standard paradigm:

sources of cosmic rays: homogeneously distributed SNR via II order Fermi acceleration; cosmic rays are "spectators" during acceleration.

PAMELA measurements:

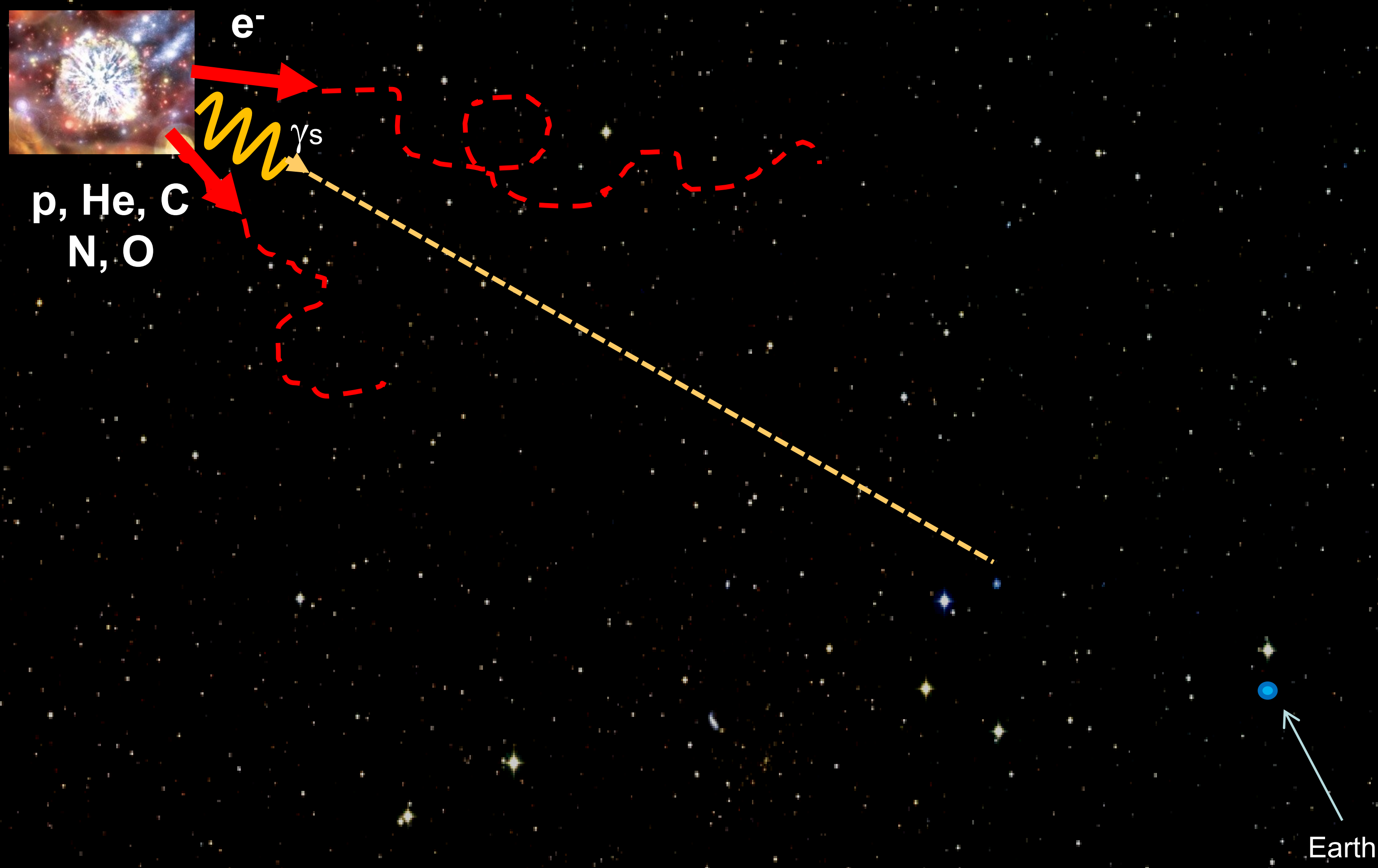
protons, Helium nuclei, light nuclei, electrons spectra

Implications:

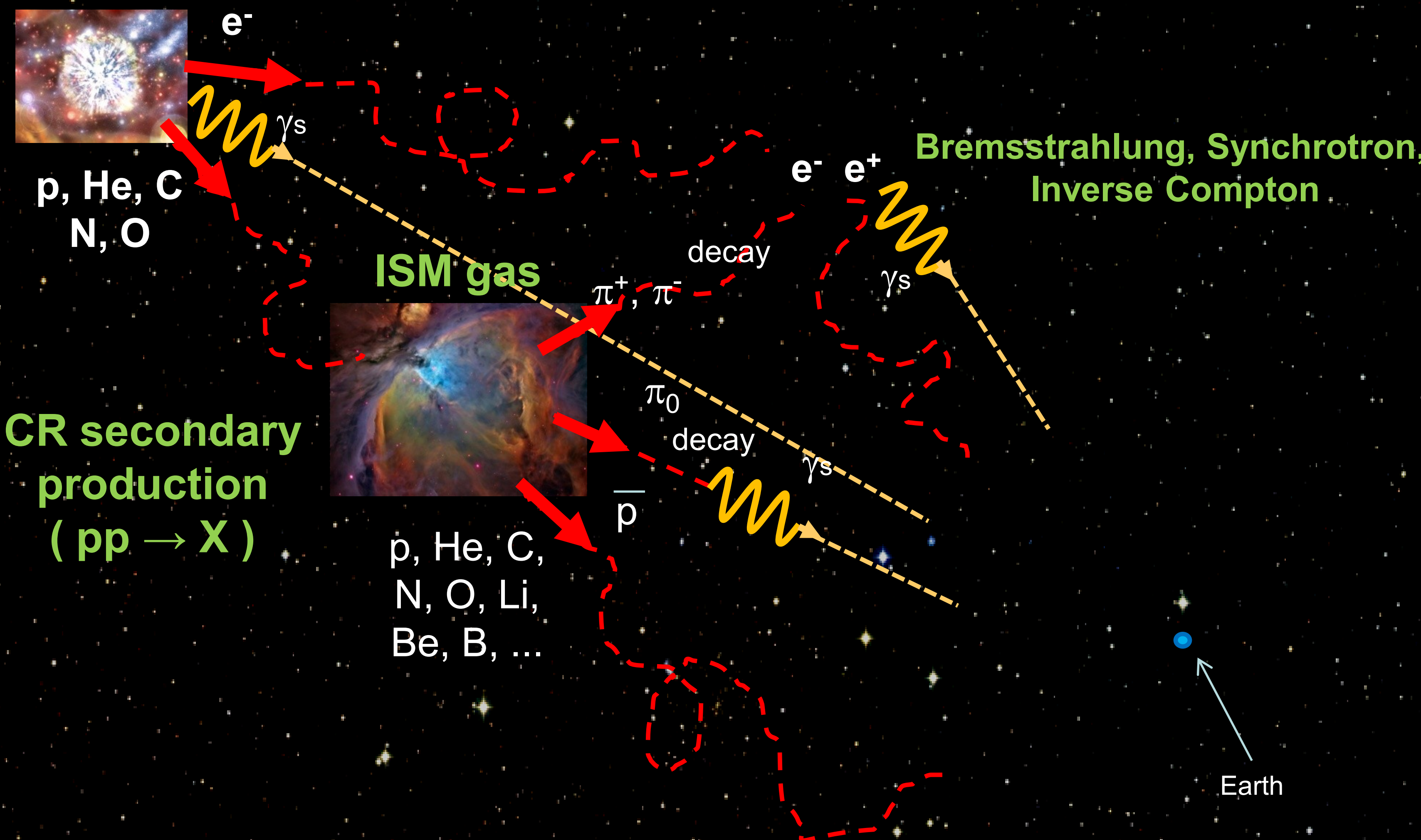
challenging standard paradigm: non uniform distribution of sources? local source? different type of sources or acceleration mechanisms? acceleration process? propagation effects? CRs play active role

Secondary Cosmic Rays

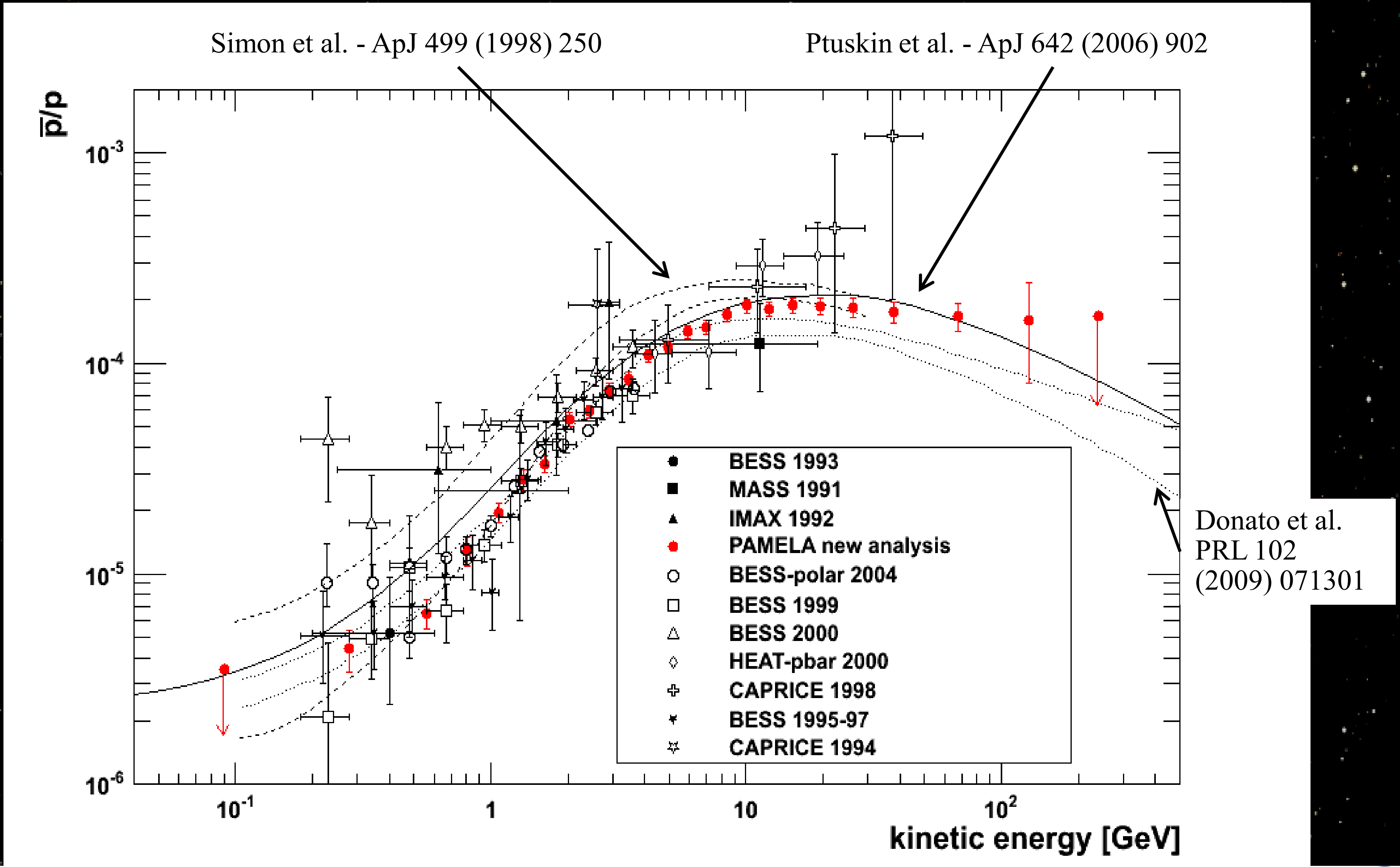
Secondary Cosmic Rays



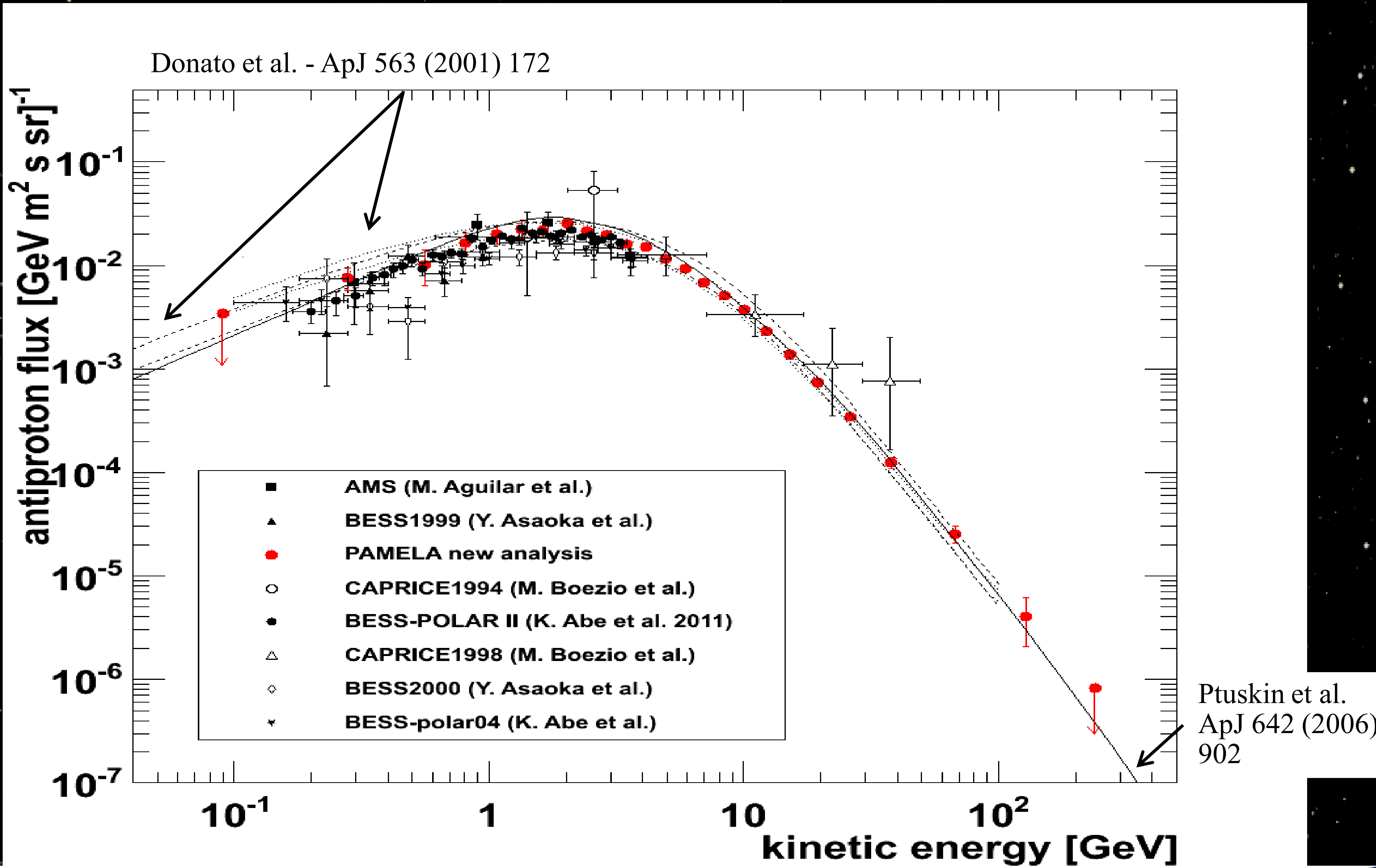
Secondary Cosmic Rays: a rare component of all types of particles



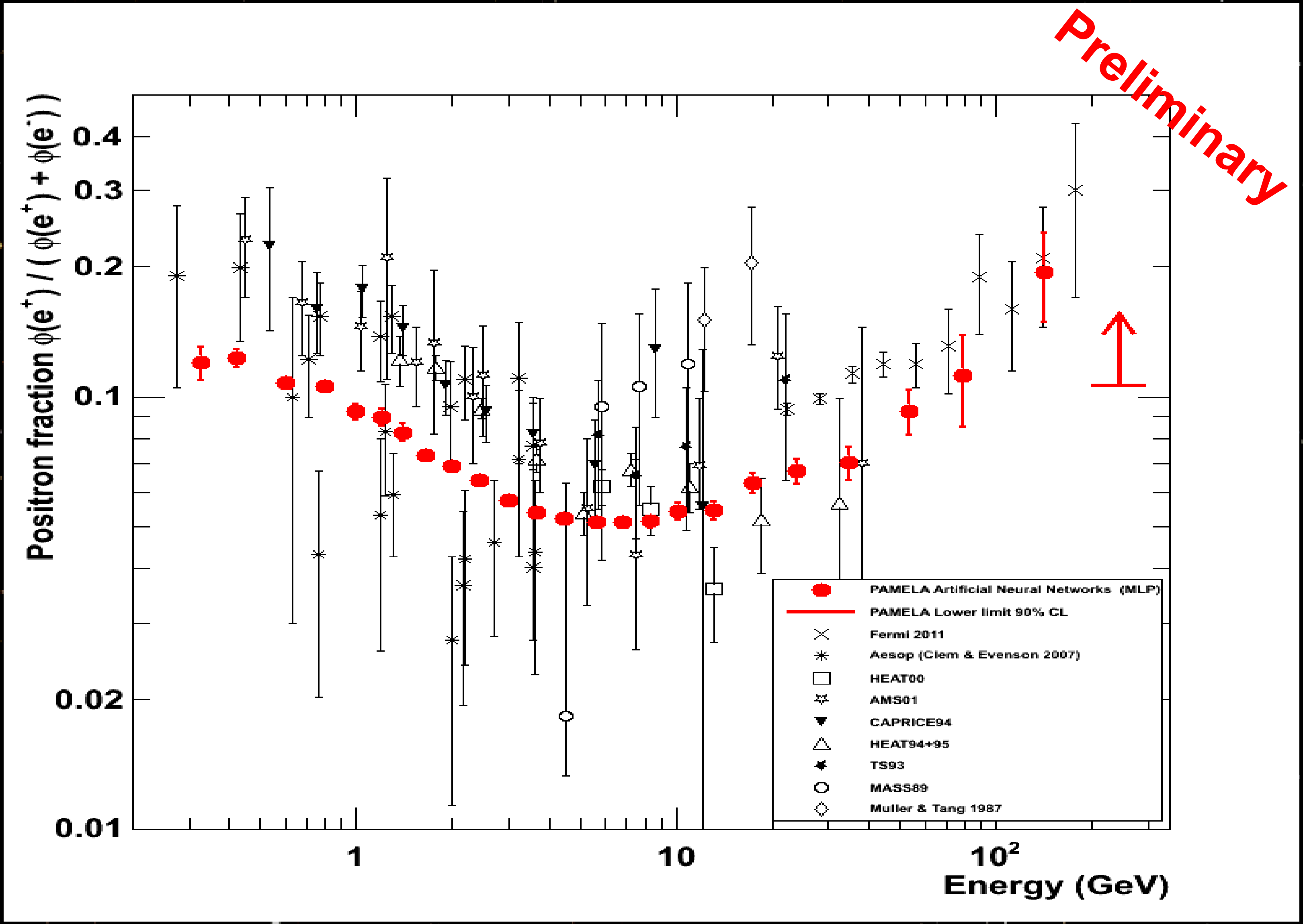
Antiproton to proton ratio: agreement with secondary production models



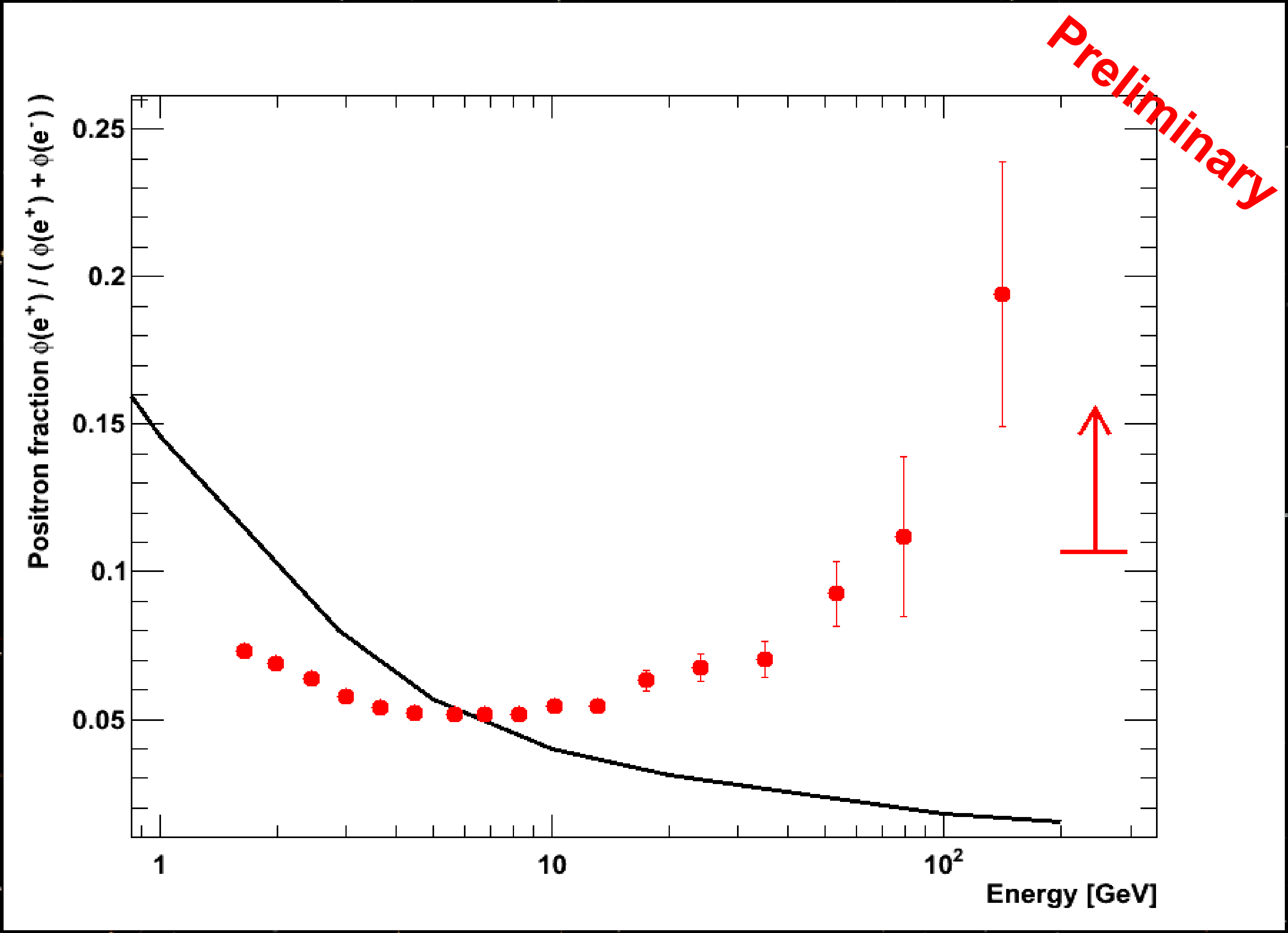
Antiproton flux: agreement with secondary production model



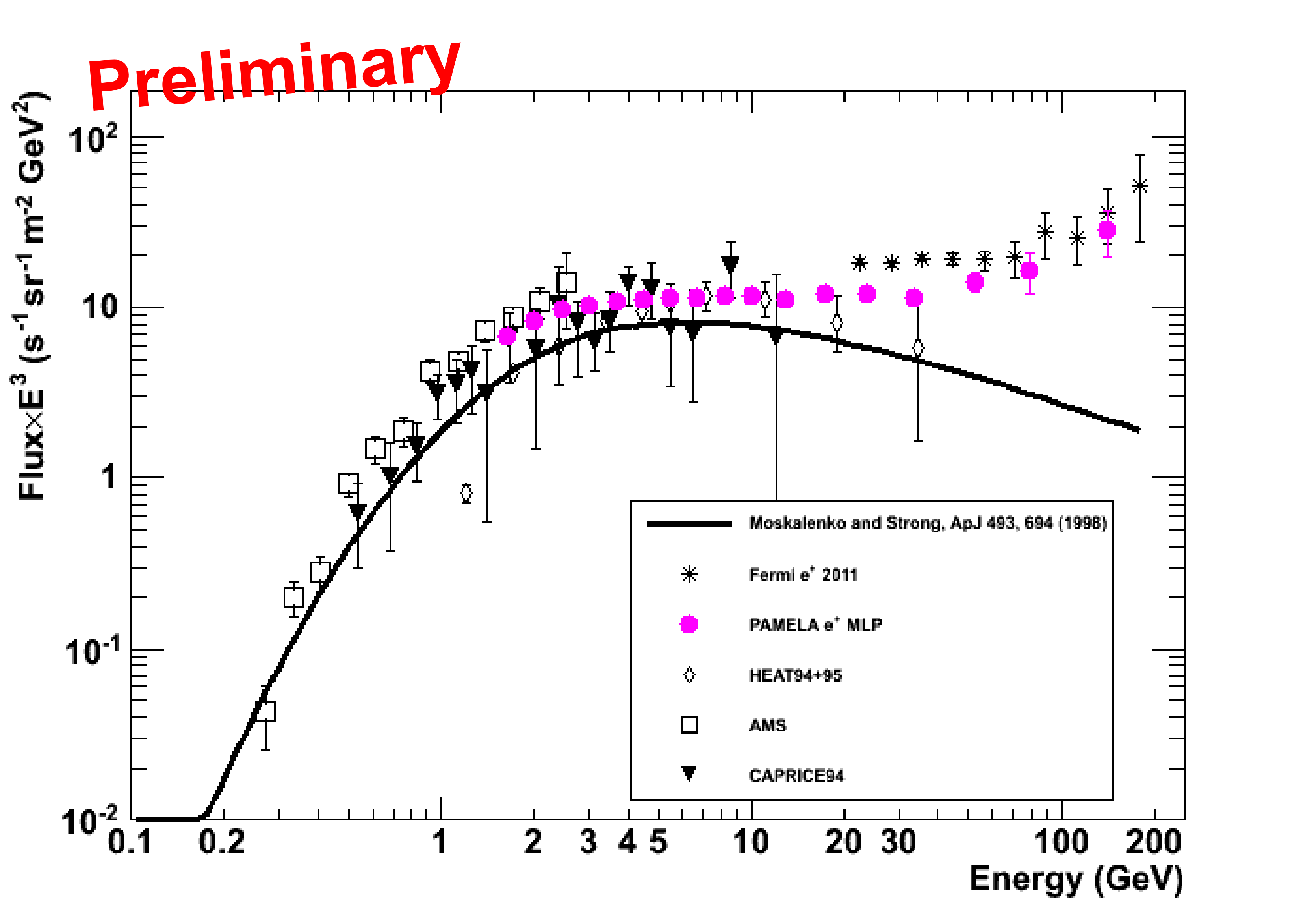
Positron fraction: agreement with other experimental results...



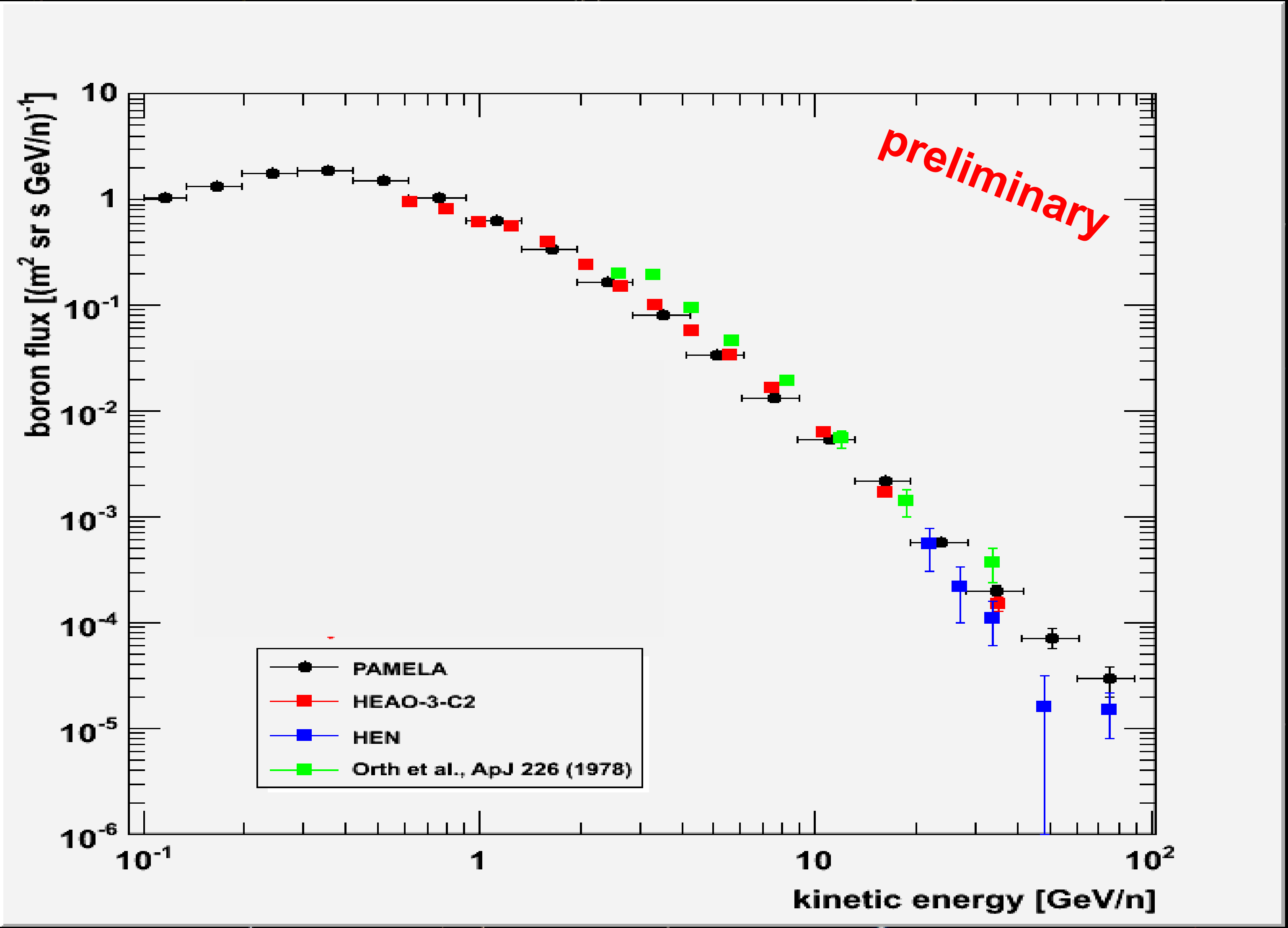
Positron fraction: ...disagreement with pure secondary production model



Positron fraction: disagreement with pure secondary production model



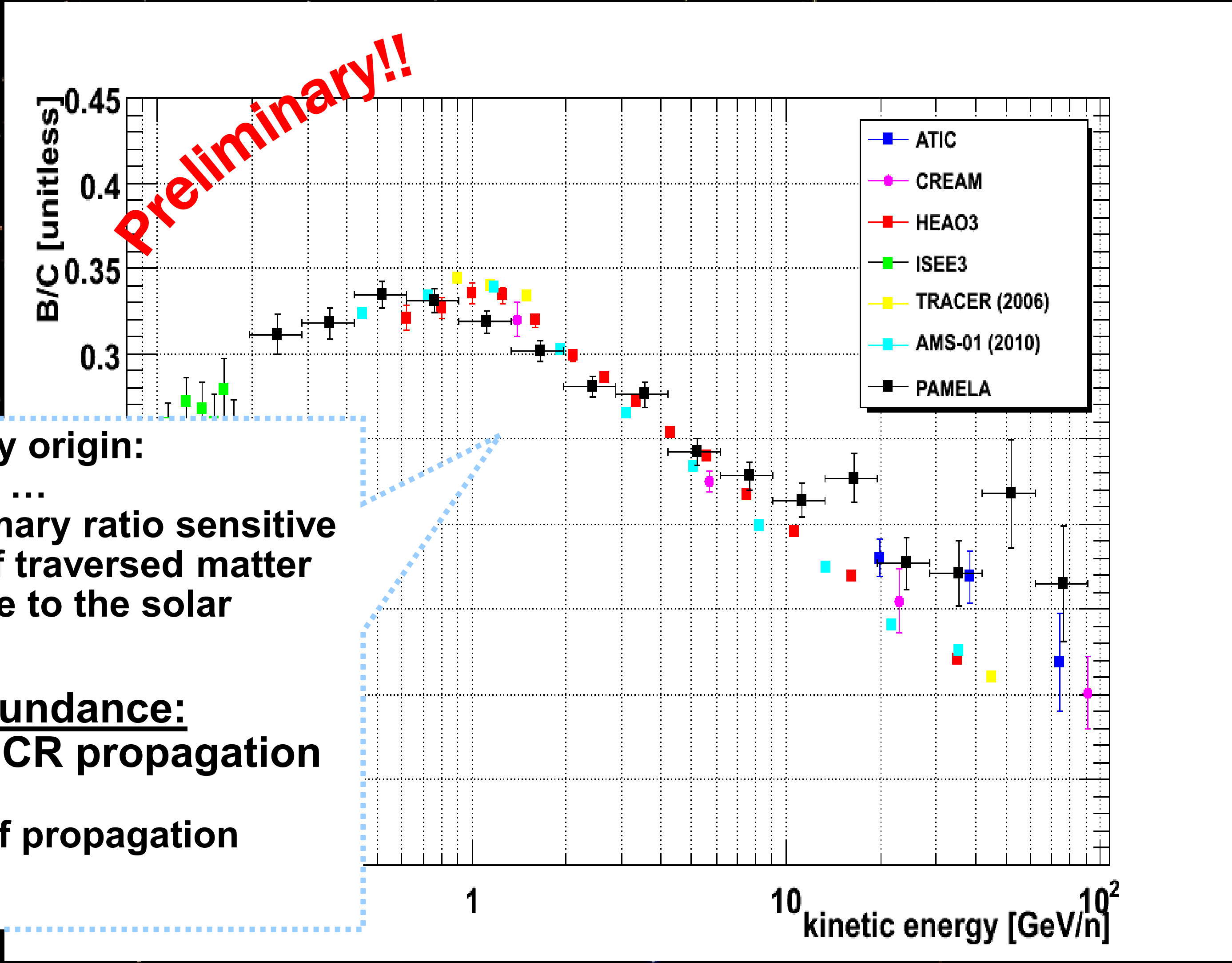
Boron nuclei Spectrum



PAMELA B/C

LBM

$$\frac{N_S}{N_P} \propto \lambda_{esc} \cdot \sigma_{P \to S}$$

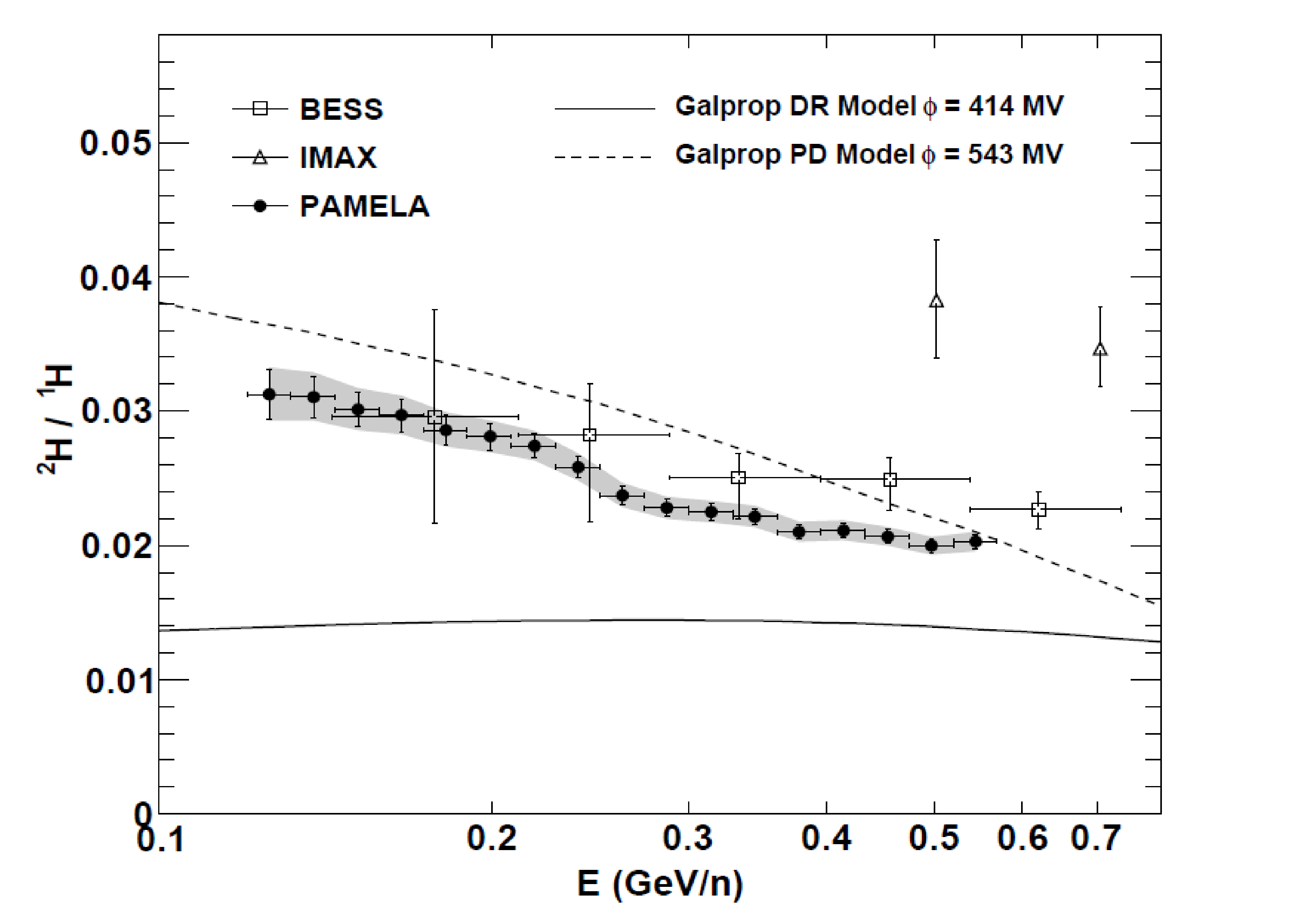


- **B nuclei of secondary origin:**
  CNO + ISM → B + …
- **Local secondary/primary ratio sensitive to average amount of traversed matter (λ_{esc}) from the source to the solar system**

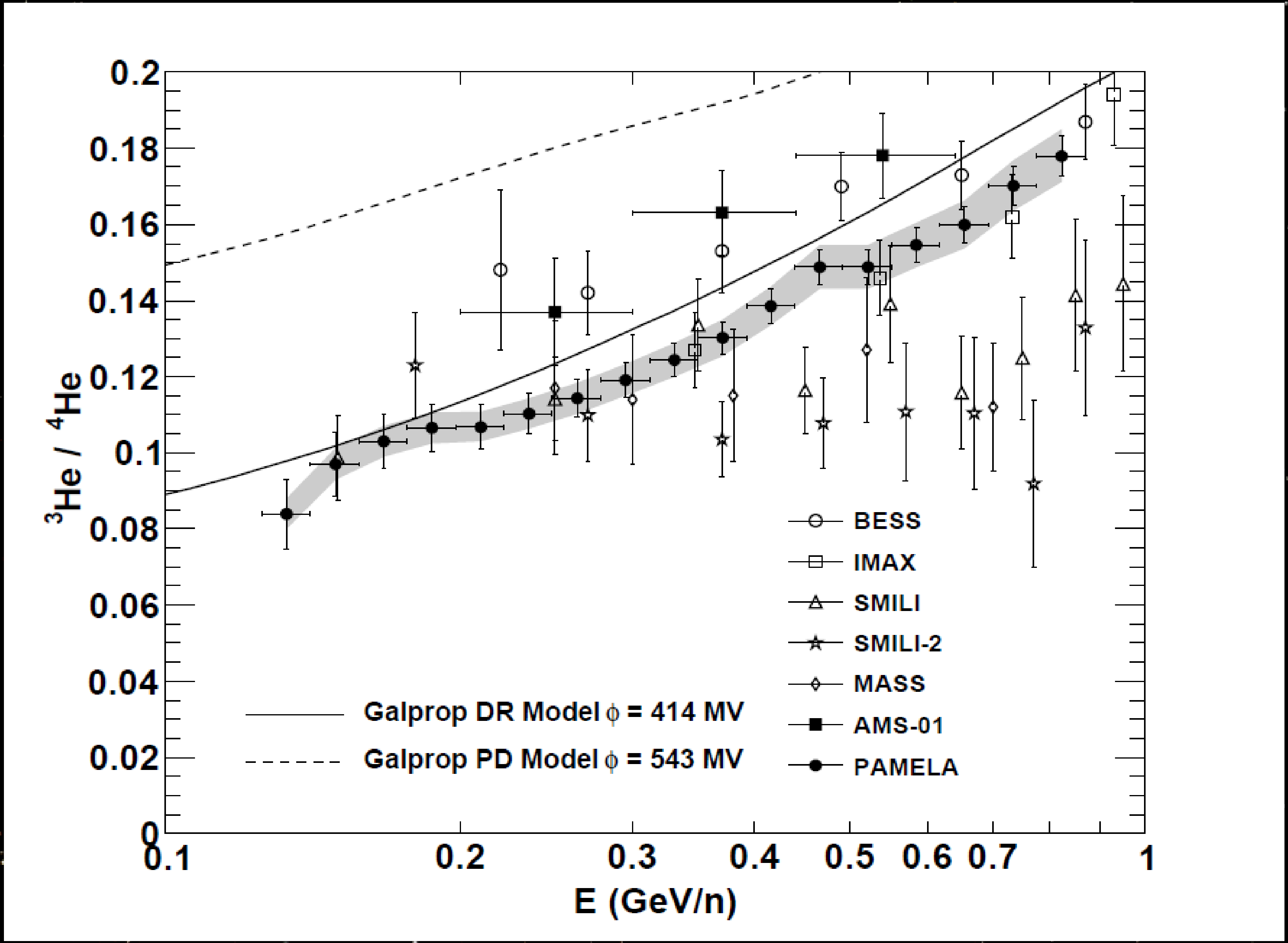
<u>Local secondary abundance:</u>
⇒ study of galactic CR propagation

(B/C used for tuning of propagation models)

PAMELA $^2H/^1H$


BESS
IMAX
PAMELA
Galprop DR Model φ = 414 MV
Galprop PD Model φ = 543 MV
^2H / ^1H
0.05
0.04
0.03
0.02
0.01
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
E (GeV/n)

PAMELA $^3He/^4He$



Secondary Cosmic Rays: PAMELA contribution

Standard paradigm:

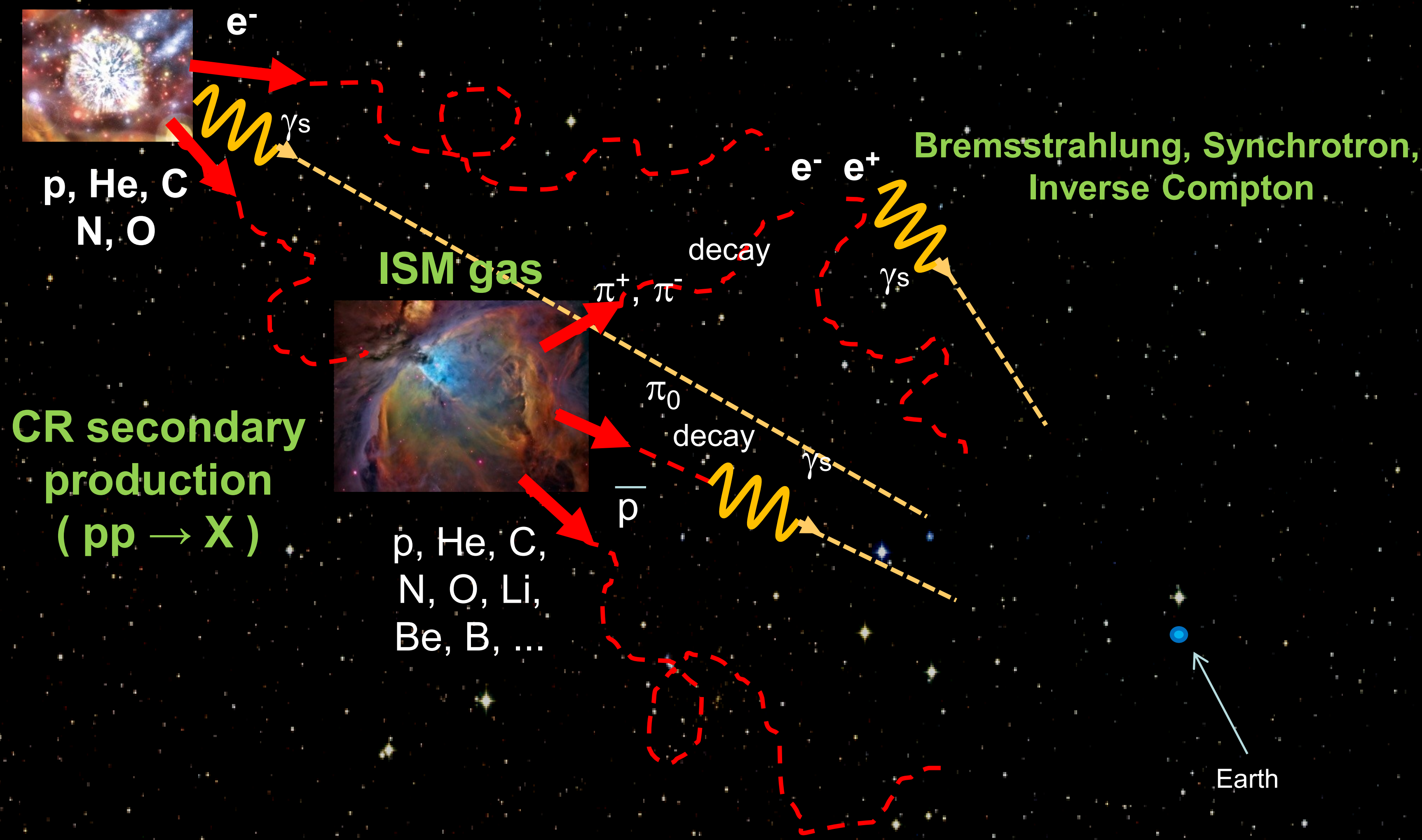
antiparticles: secondaries from homogeneously distributed interstellar matter and homogeneously distributed sources

PAMELA measurements:
anti-protons, positrons, isotopes, light nuclei spectra

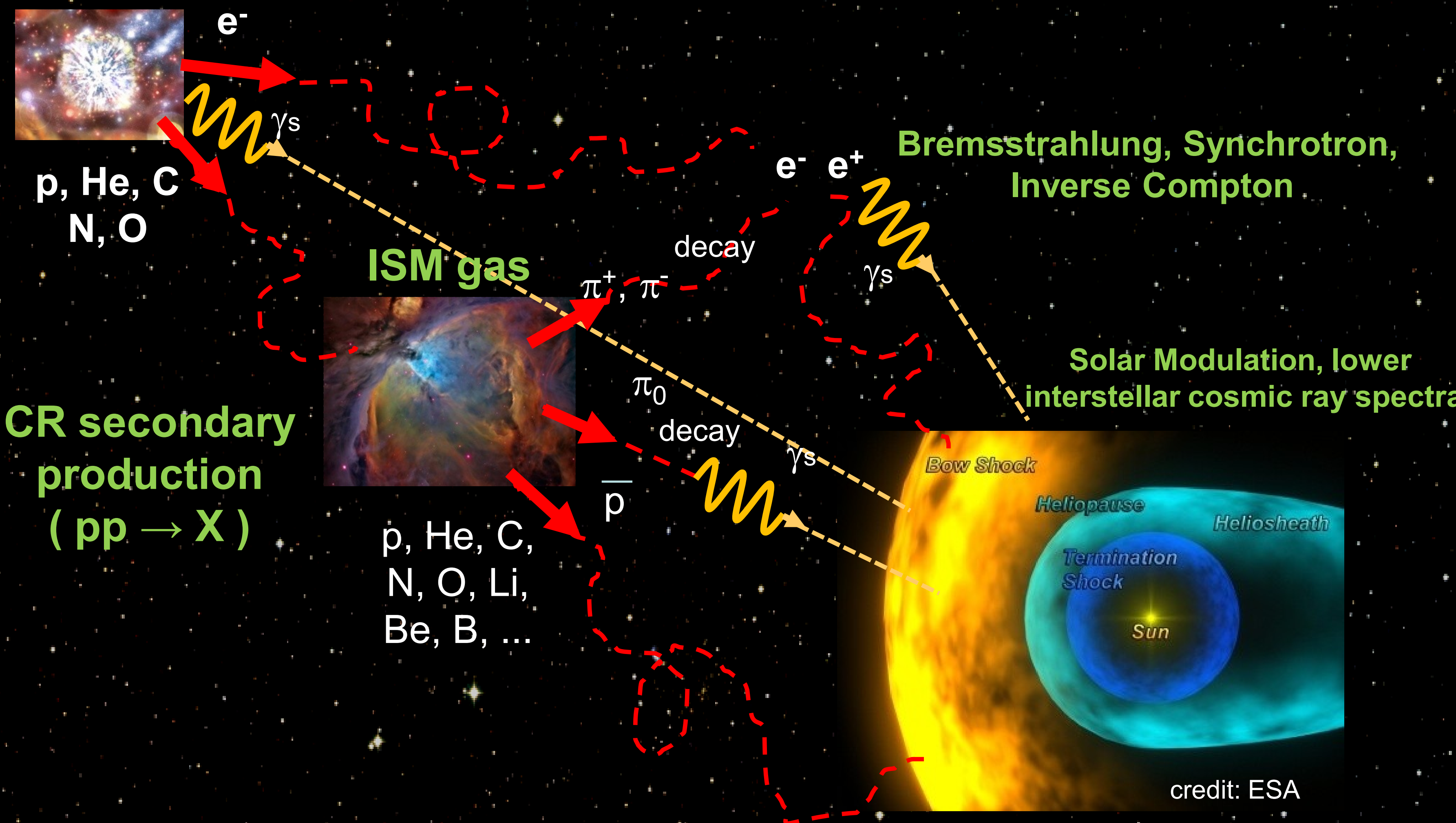
Implications:
challenging standard paradigm: close local source of electrons and positrons? electrons and positrons astrophysical sources (PWN, mini black-holes,...)? dark matter decay/annihilation?

Cosmic Rays in the Heliosphere

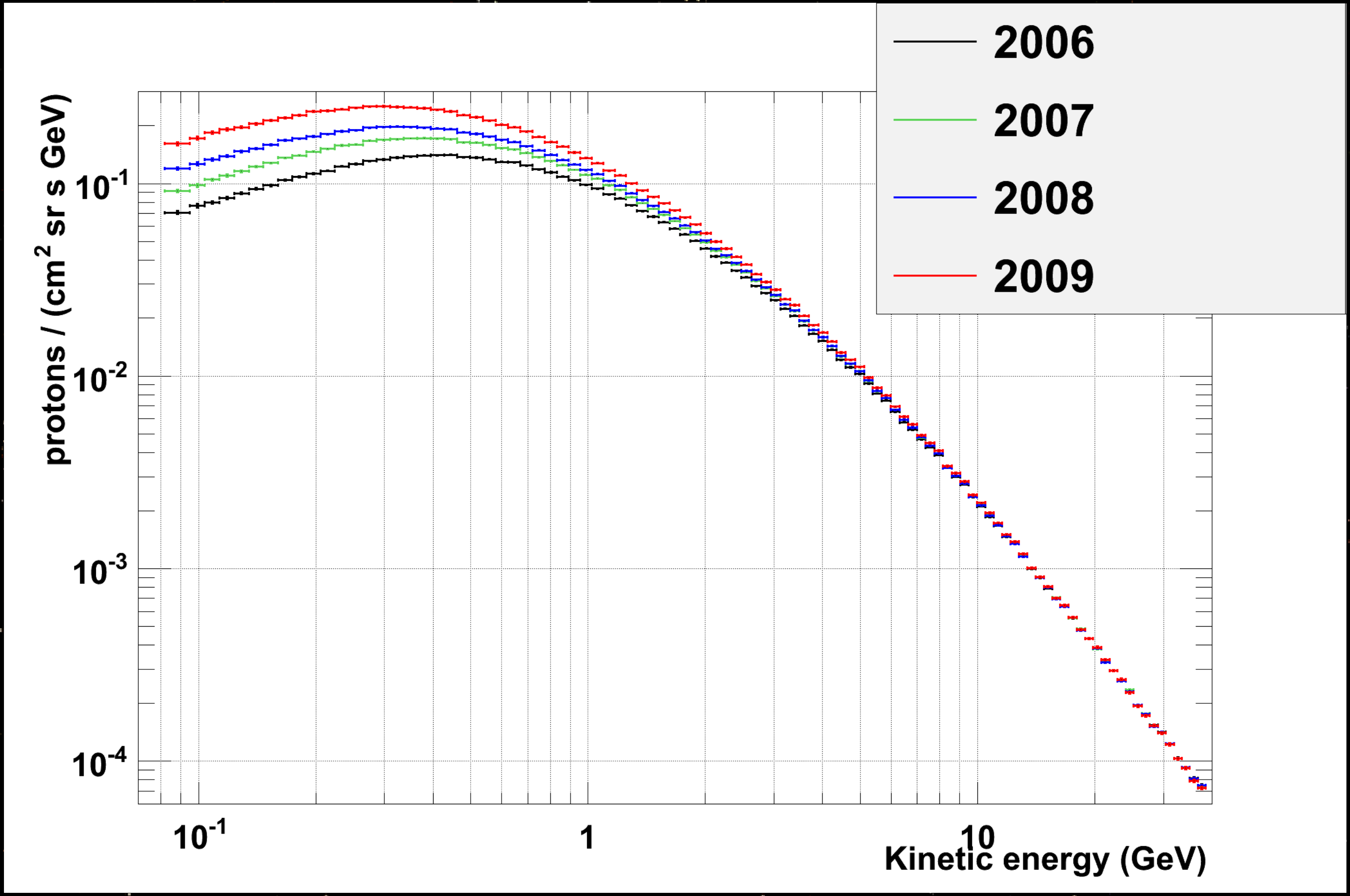
Cosmic rays in the Heliosphere



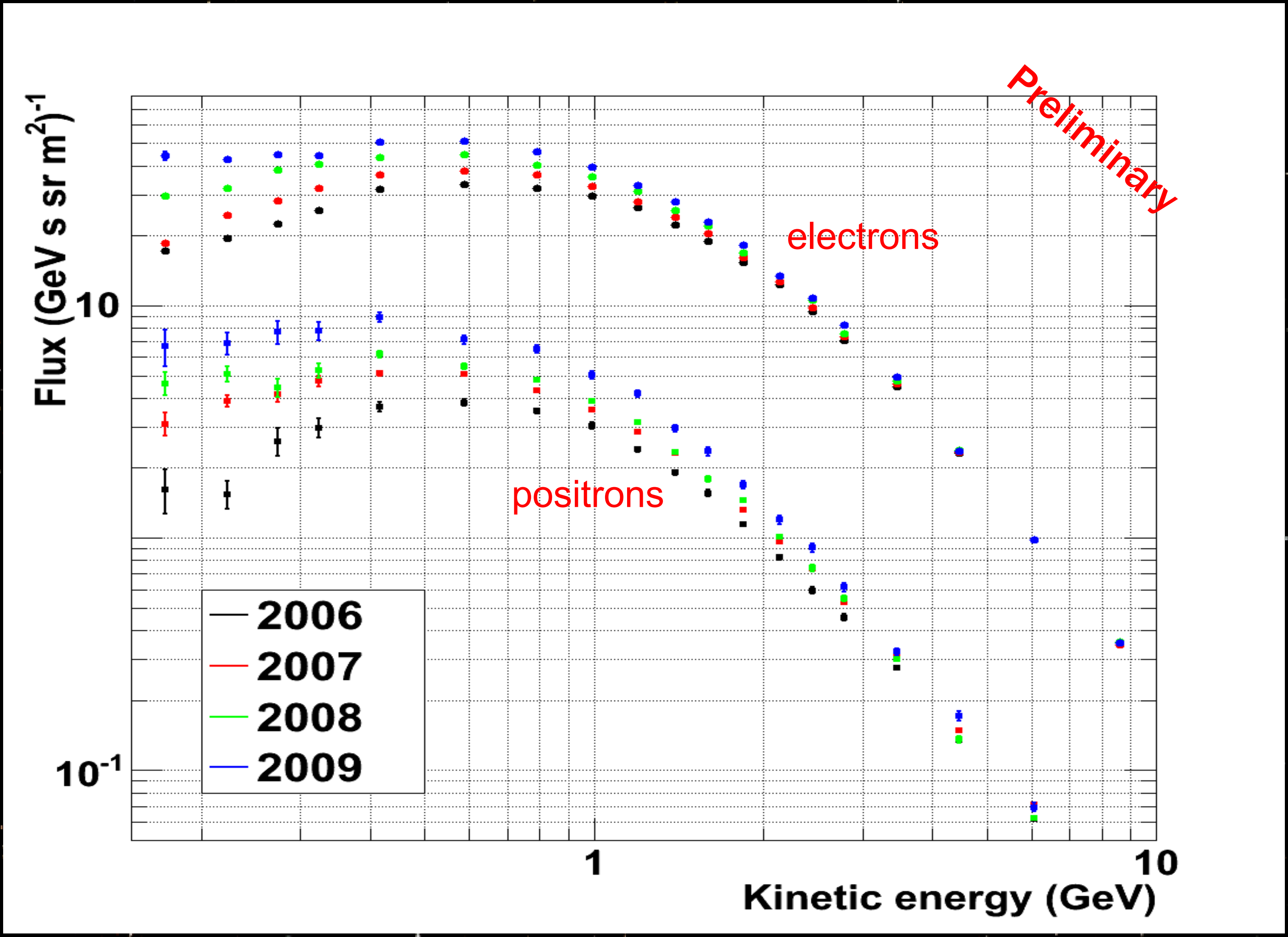
Cosmic rays: measured at Earth are influenced by the solar modulation



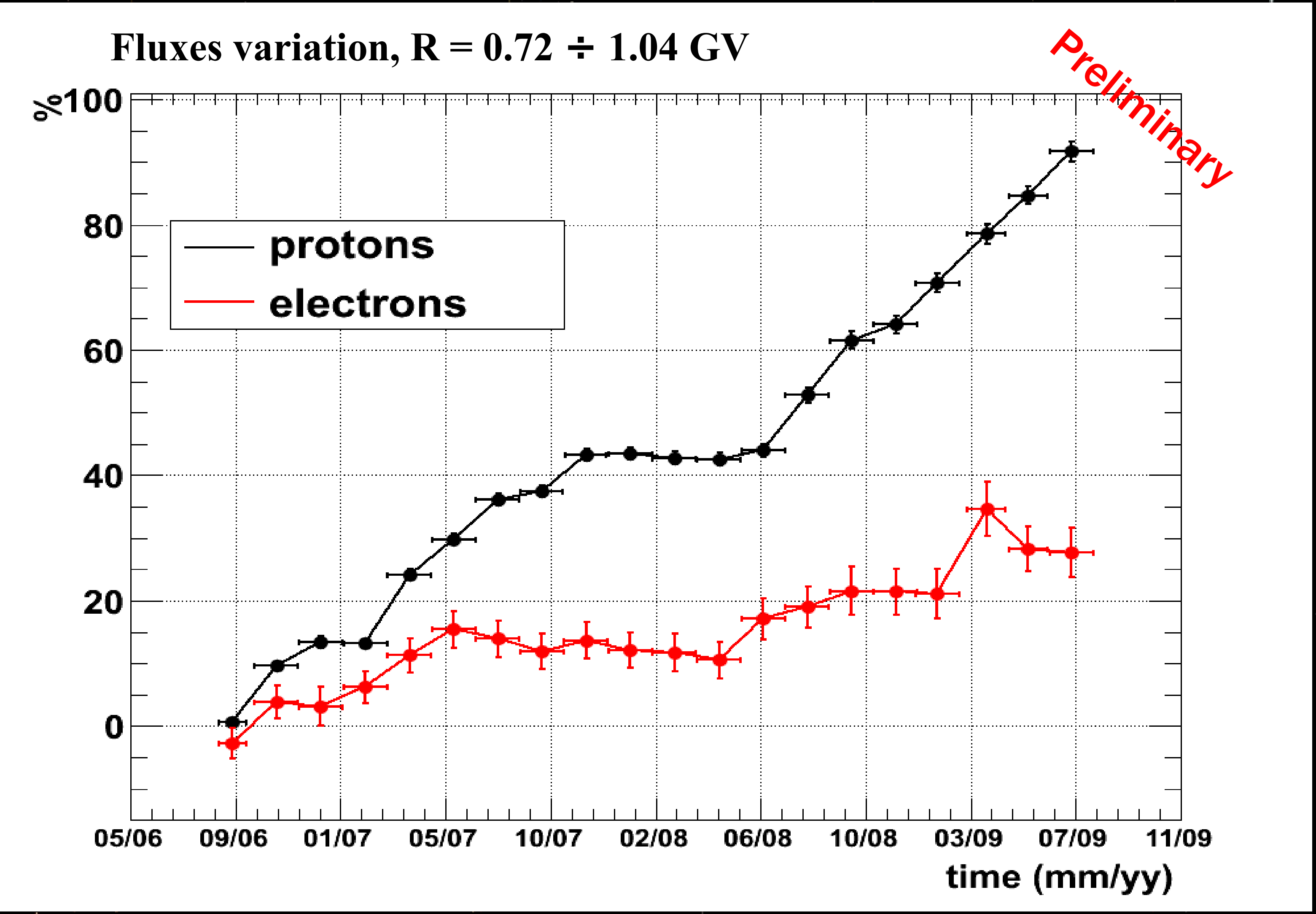
Low energy p flux depends on time



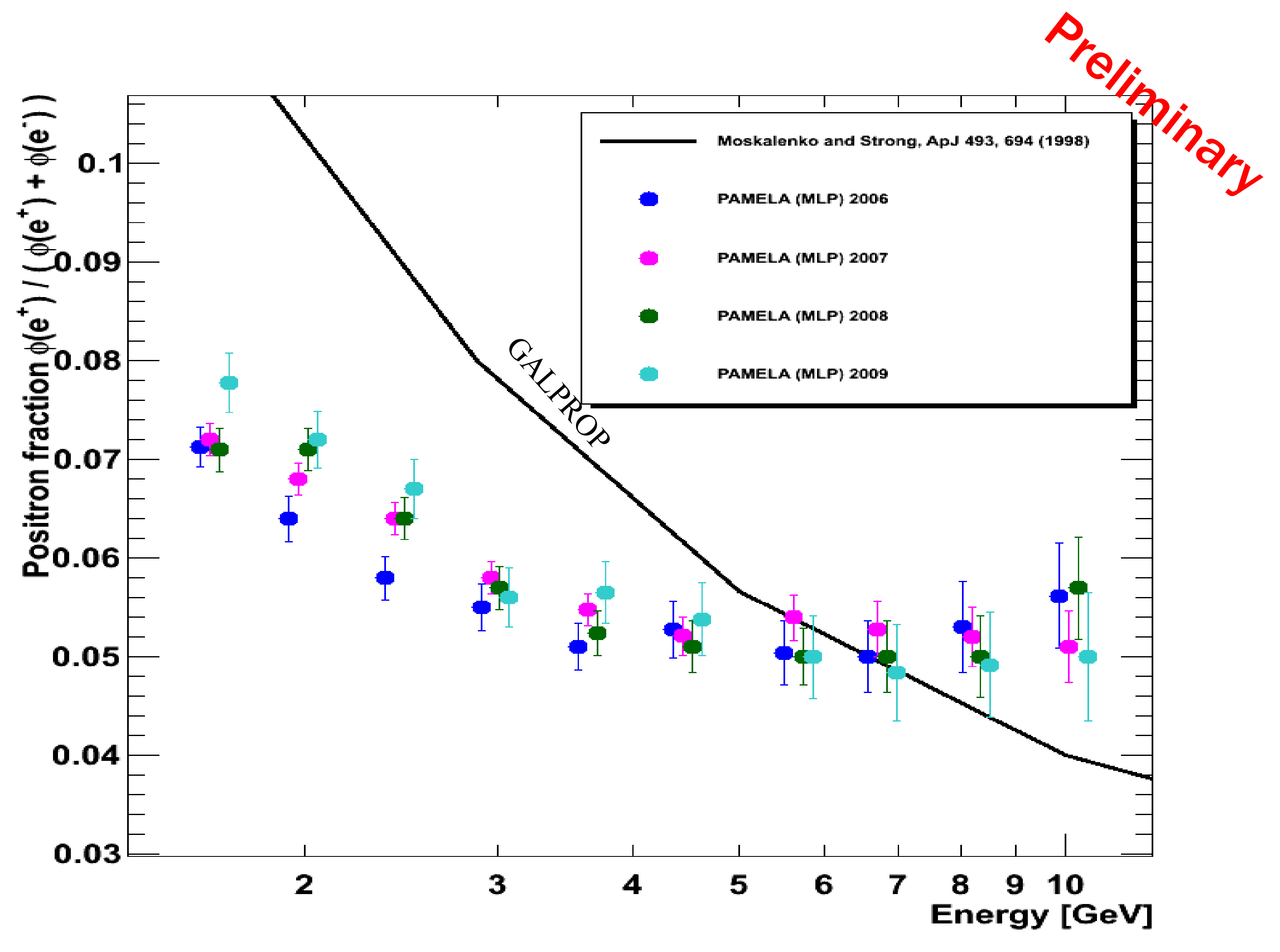
Low energy e⁺ and e⁻ fluxes depend on time



Time dependence: p and e⁻ behave differently



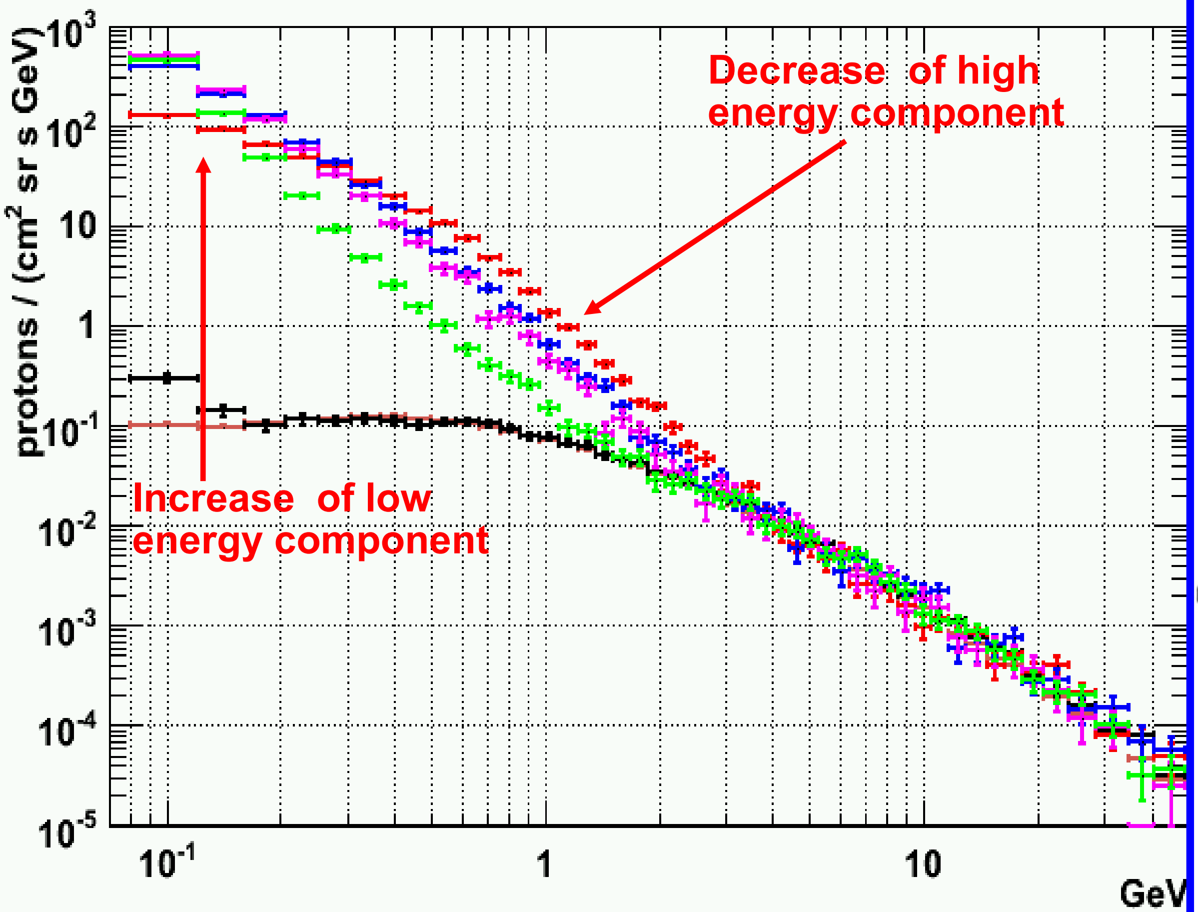
Time dependence: e^+ and e^- behave differently

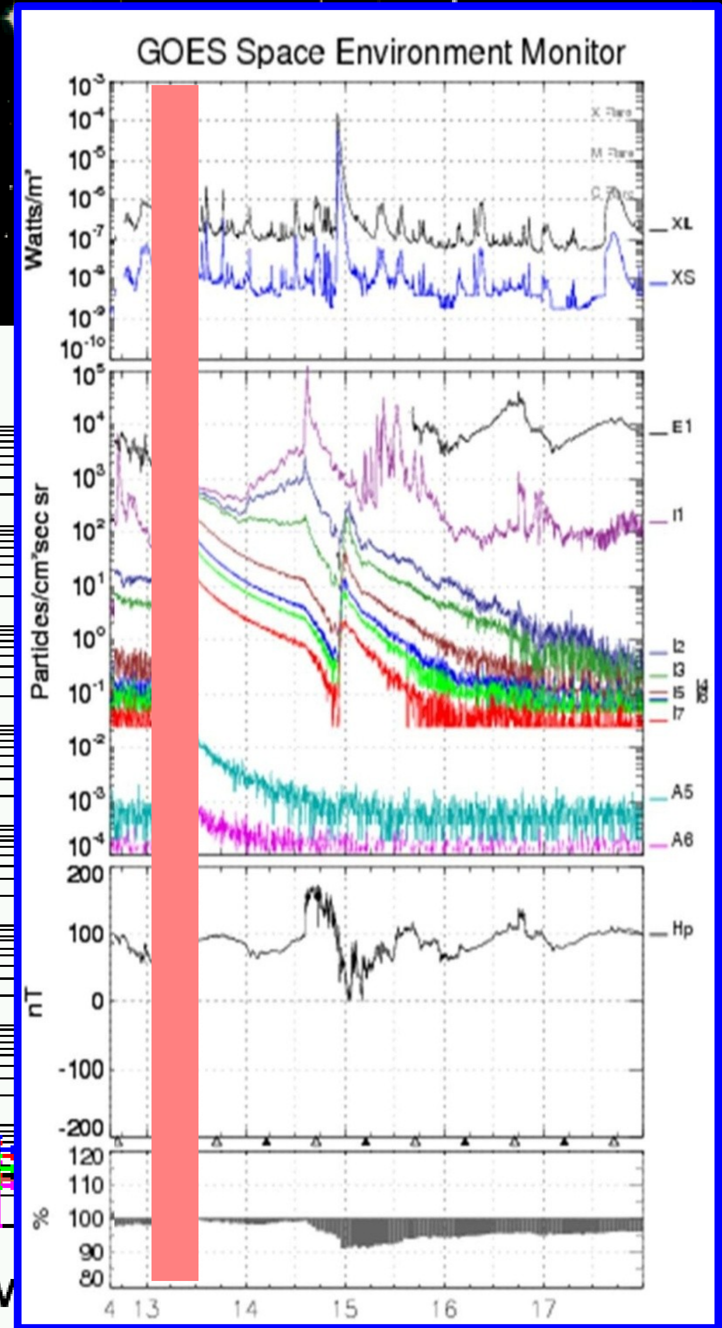


Solar Physics: December 13th 2006 event

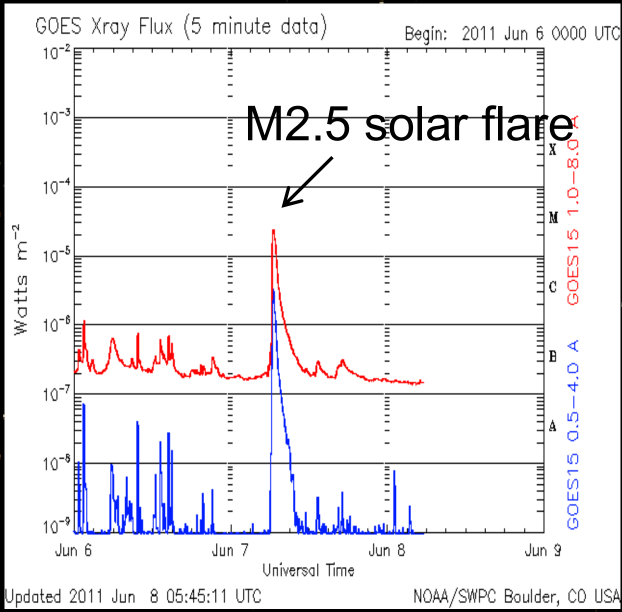
- from 2006-12-1 to 2006-12-4
- from 2006-12-13 00:23:02 to 2006-12-13 02:57:46
- from 2006-12-13 02:57:46 to 2006-12-13 03:49:09
- from 2006-12-13 03:49:09 to 2006-12-13 04:32:56
- from 2006-12-13 04:32:56 to 2006-12-13 04:59:16
- from 2006-12-13 08:17:54 to 2006-12-13 09:17:34

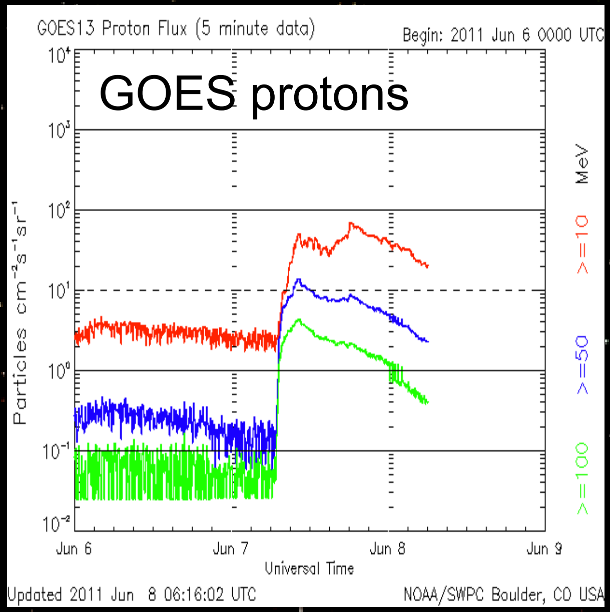
O. Adriani et al., Astrophys. J. 742,102 (2011) arXiv:1107.4519

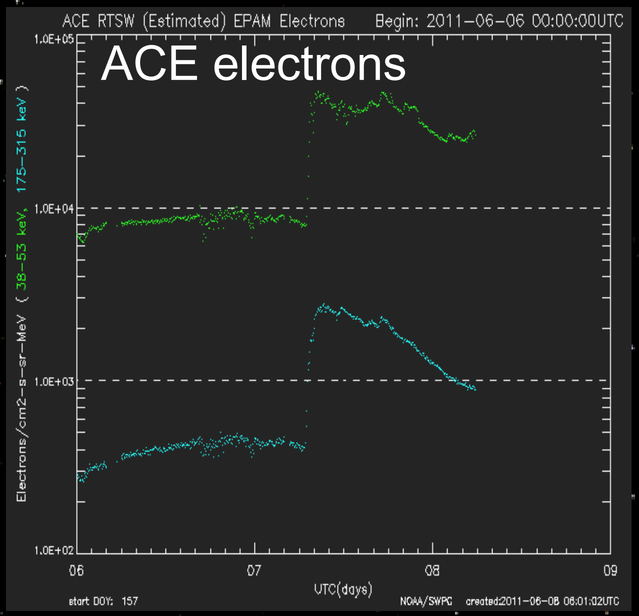


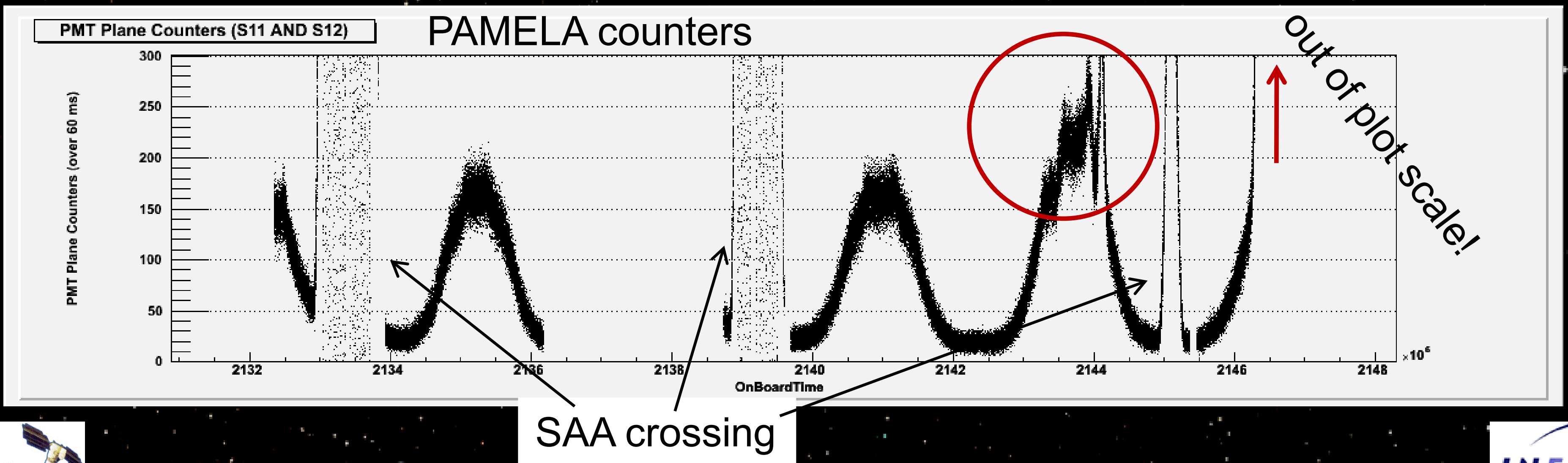


Solar Physics: 7th June 2011 flare, seen by PAMELA

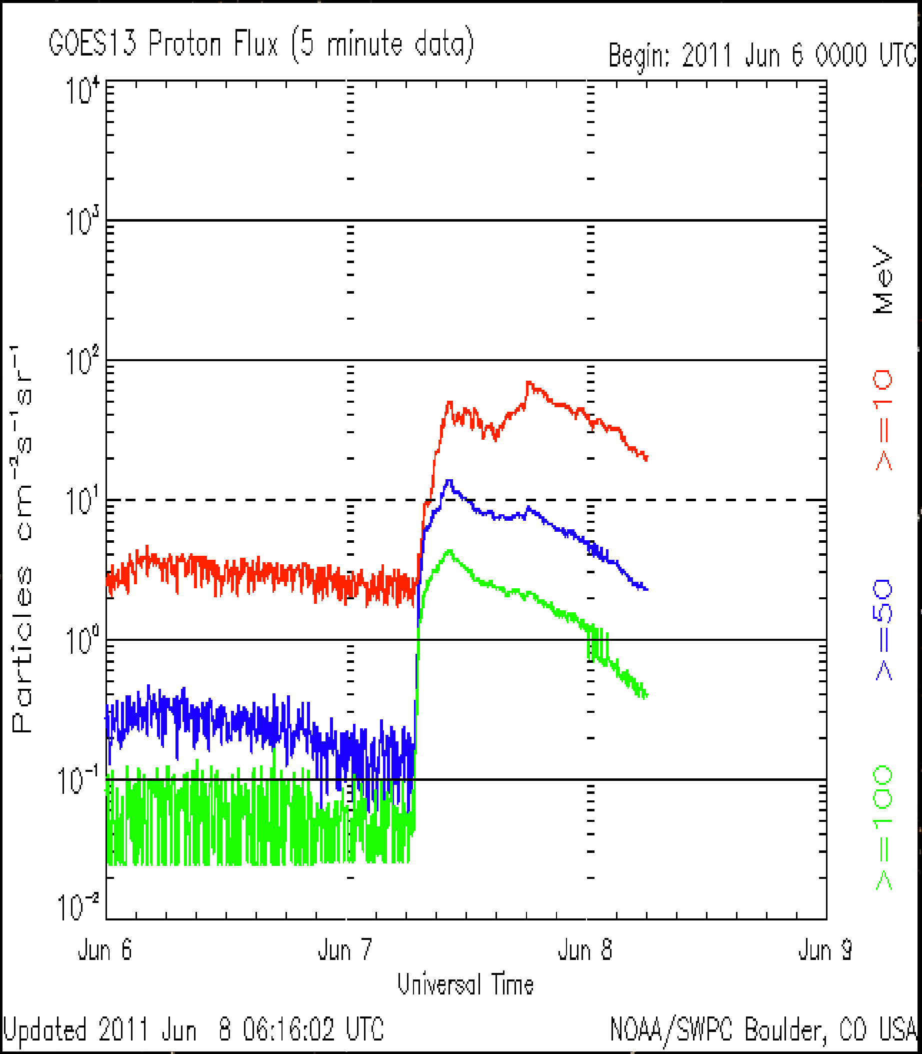


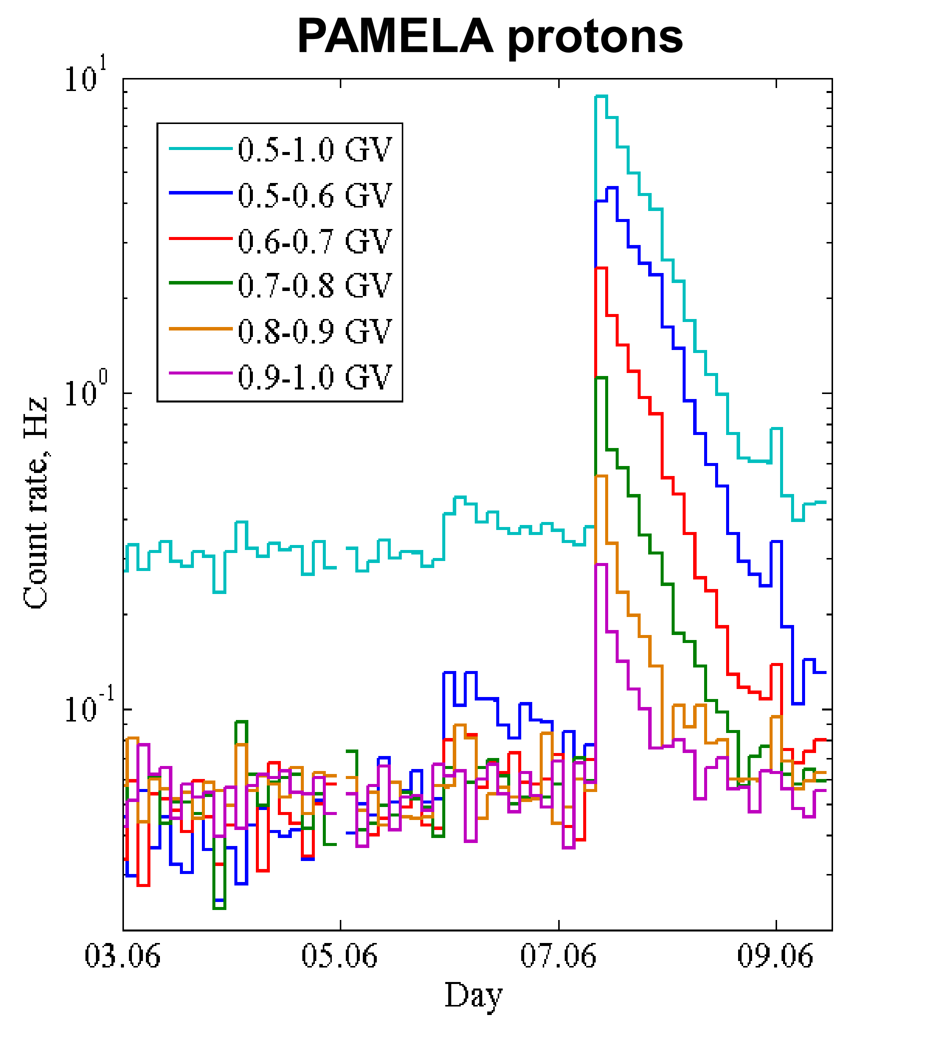




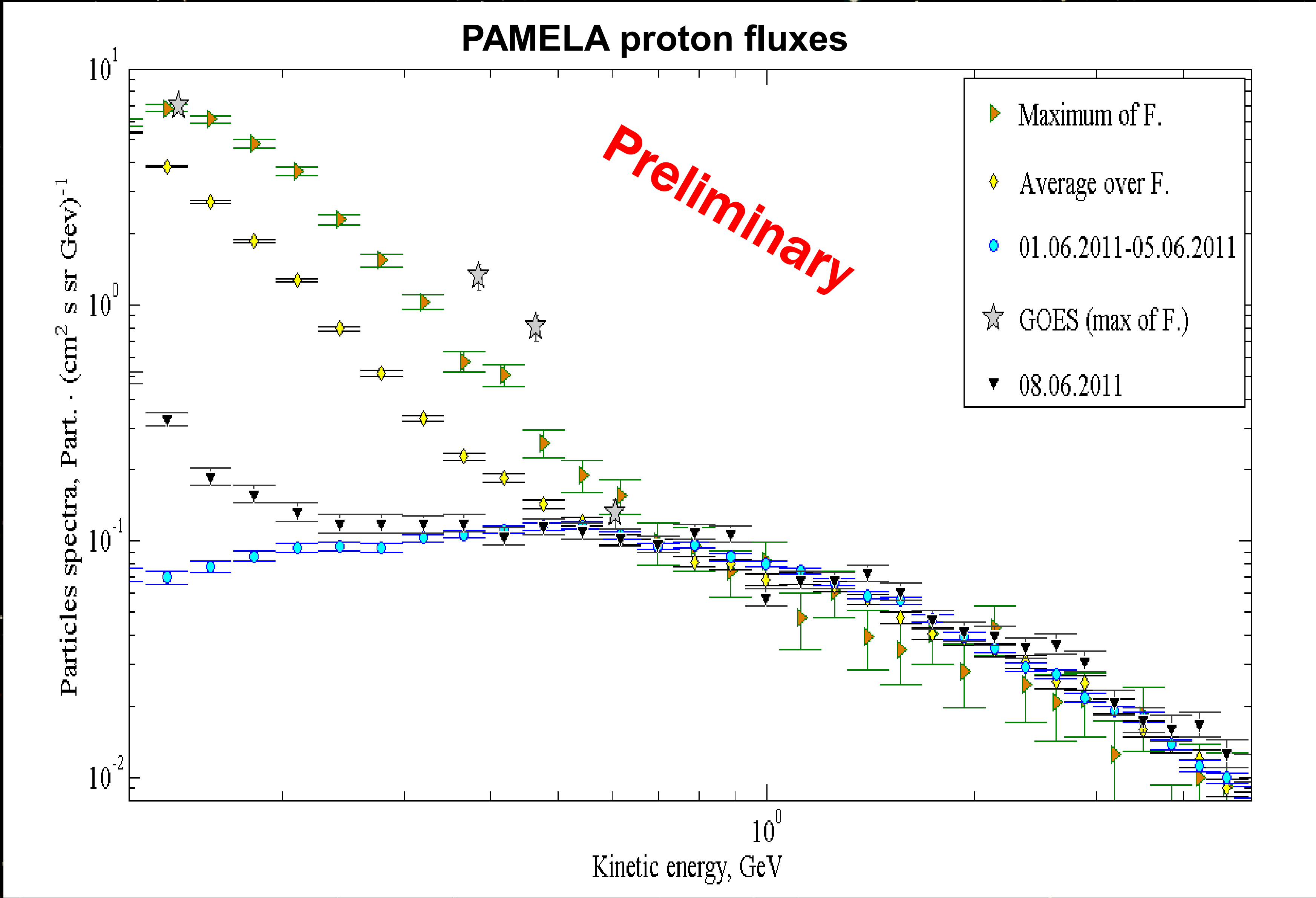


Solar Physics: 7th June 2011 flare, PAMELA proton counts

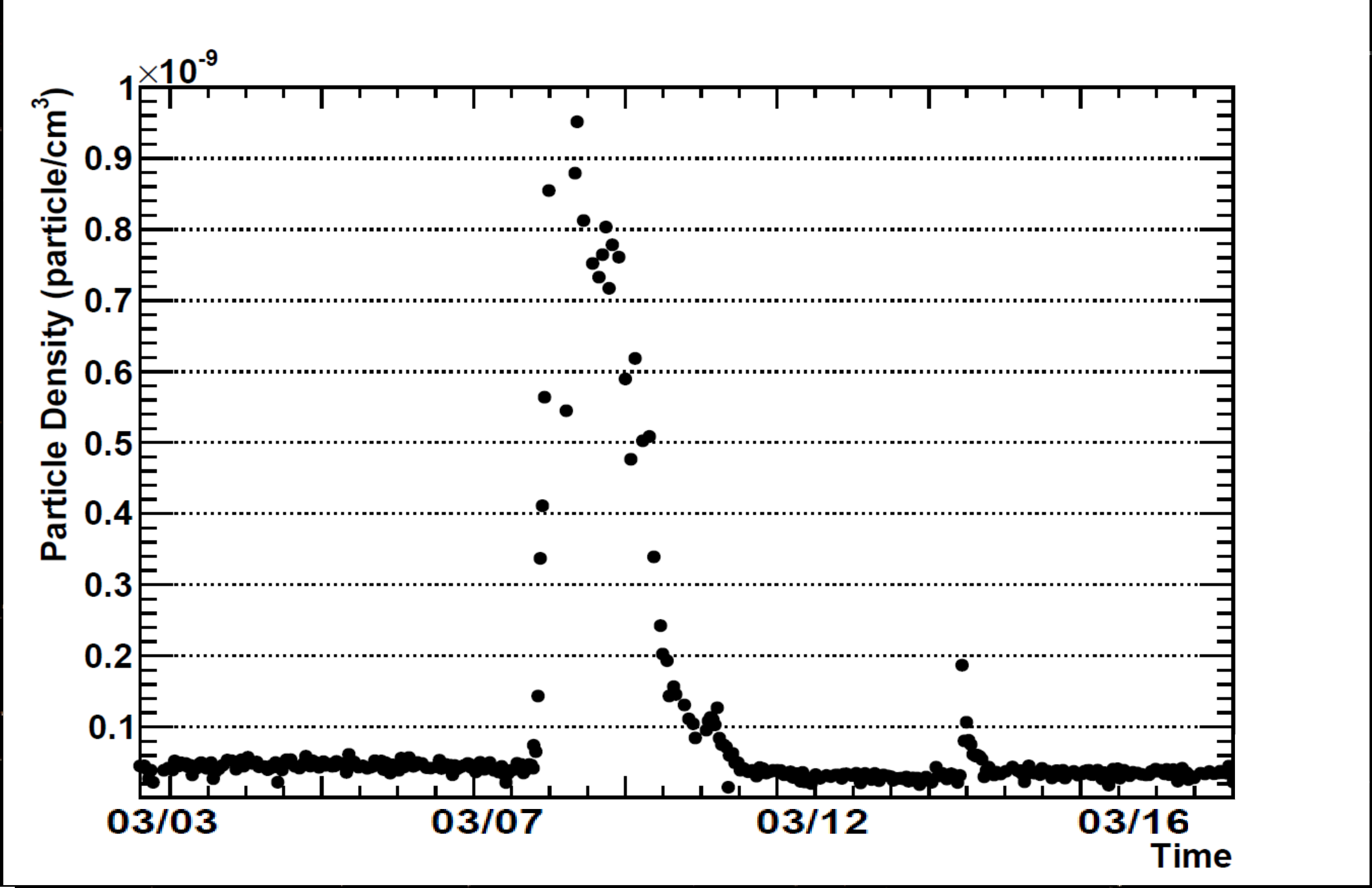




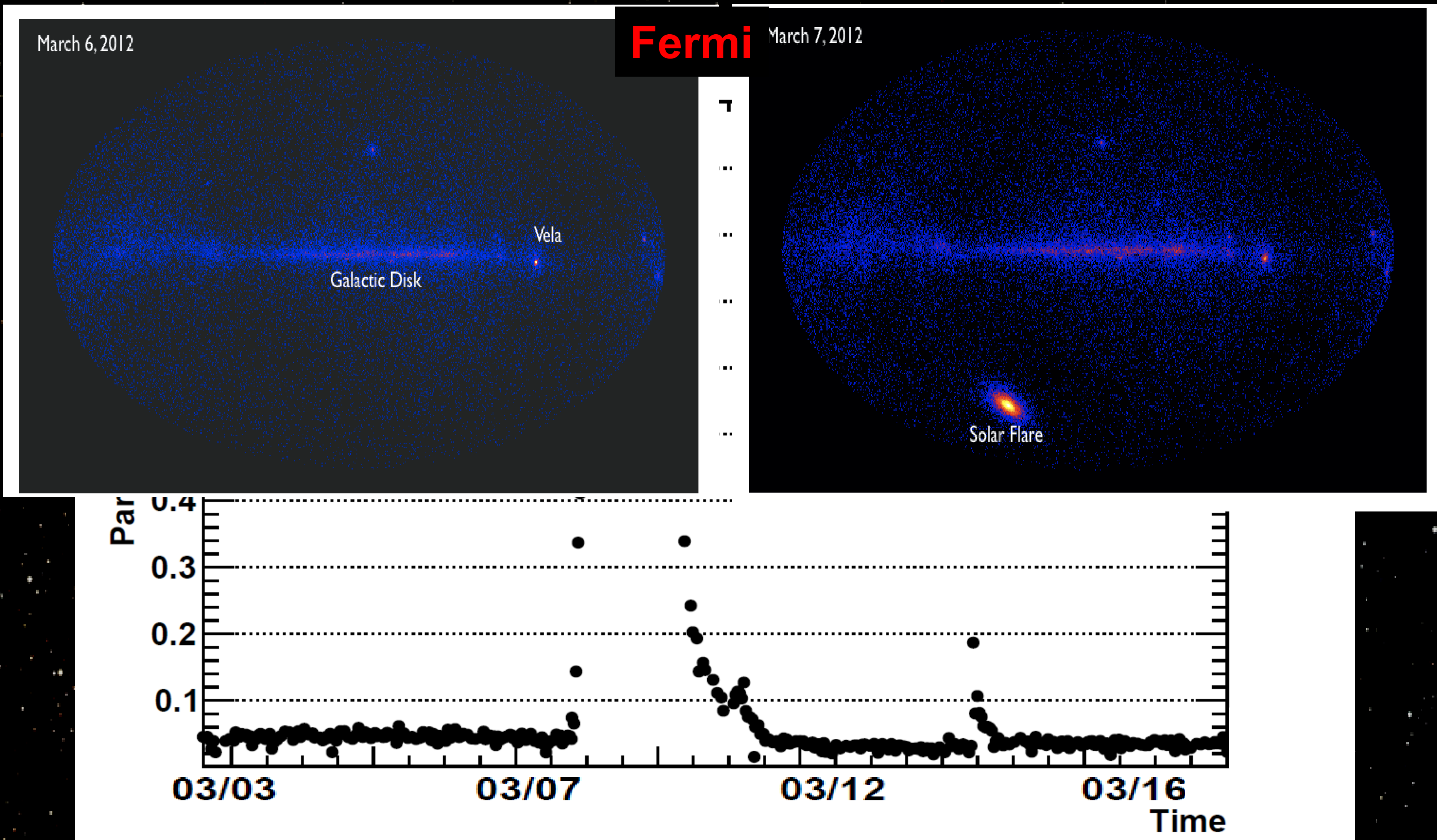
Solar Physics: 7th June 2011, PAMELA proton fluxes



Solar Physics: 7th and 13th March 2012 flare, PAMELA proton particle density

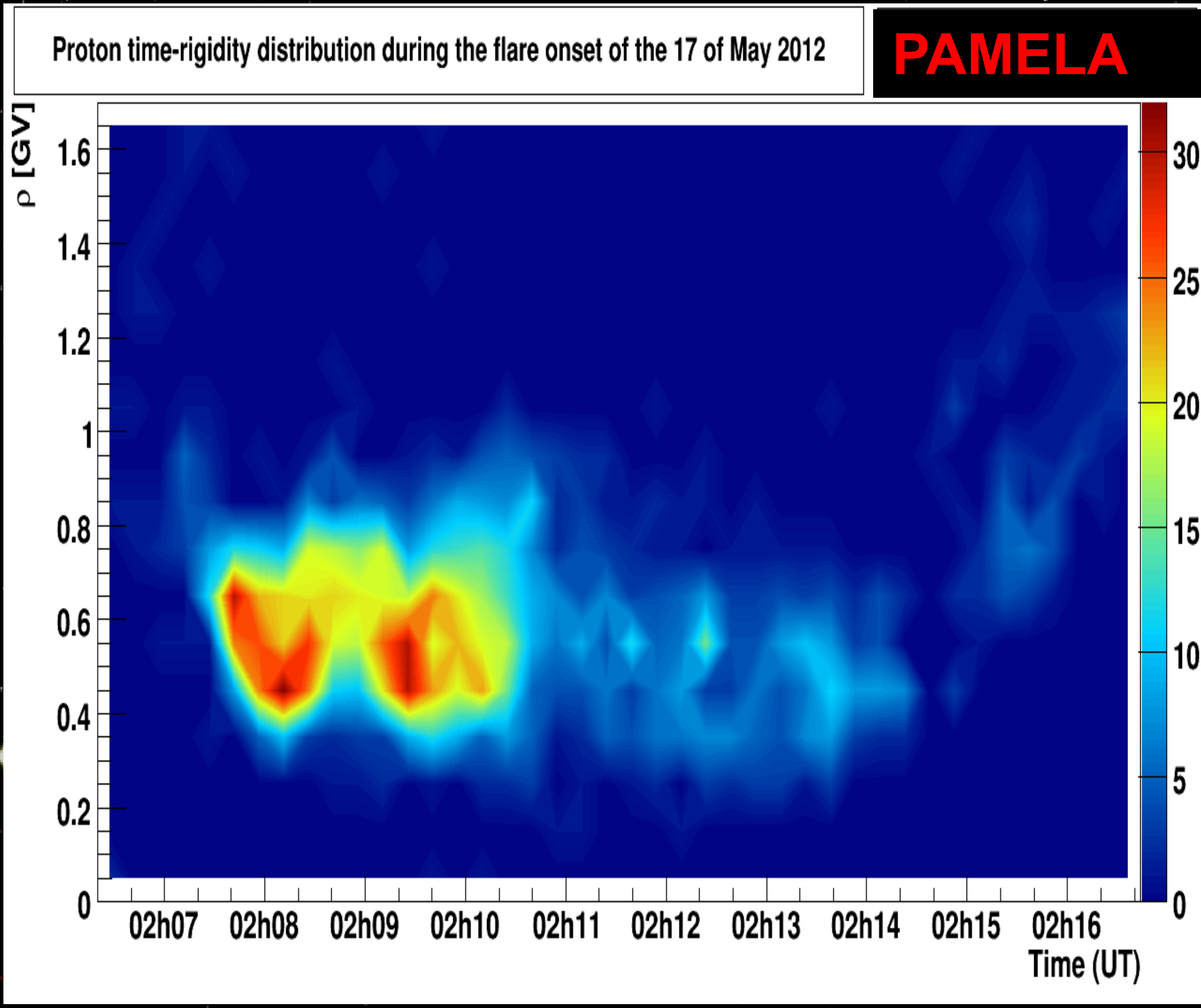


Solar Physics: 7th and 13th March 2012 flare, PAMELA and Fermi joint analysis



Solar Physics: 17th May 2012 flare: induced GLE from a "weak" event

31st May NASA press release: "PAMELA recorded the incoming solar particles up in space, providing one of the first in-situ measurements of the stream of particles that initiated a GLE. Only the early data has been seen so far, but scientists have high hopes that as more observations are relayed down to Earth, they will be able to learn more about the May 17 onslaught of solar protons, and figure out why this event triggered a GLE when earlier bursts of solar protons in January and March, 2012 didn't."



Cosmic Rays in the Heliosphere: PAMELA contribution

Common simplified view:

solar effect interpreted using a spherical potential model

PAMELA measurements:

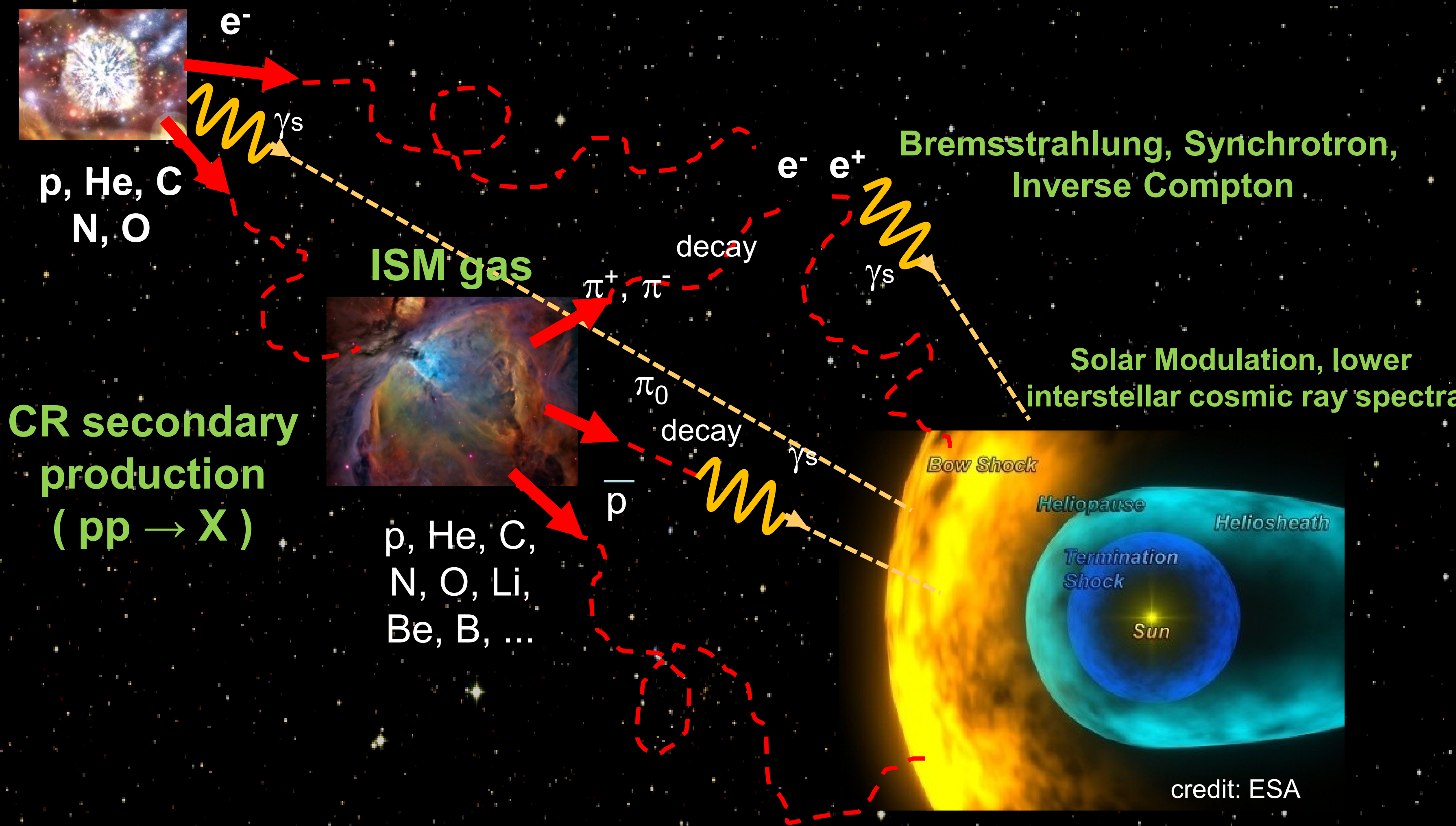
protons, electrons, positrons, light nuclei low energy spectra as function of time (years) and for impulsive events

Implications:

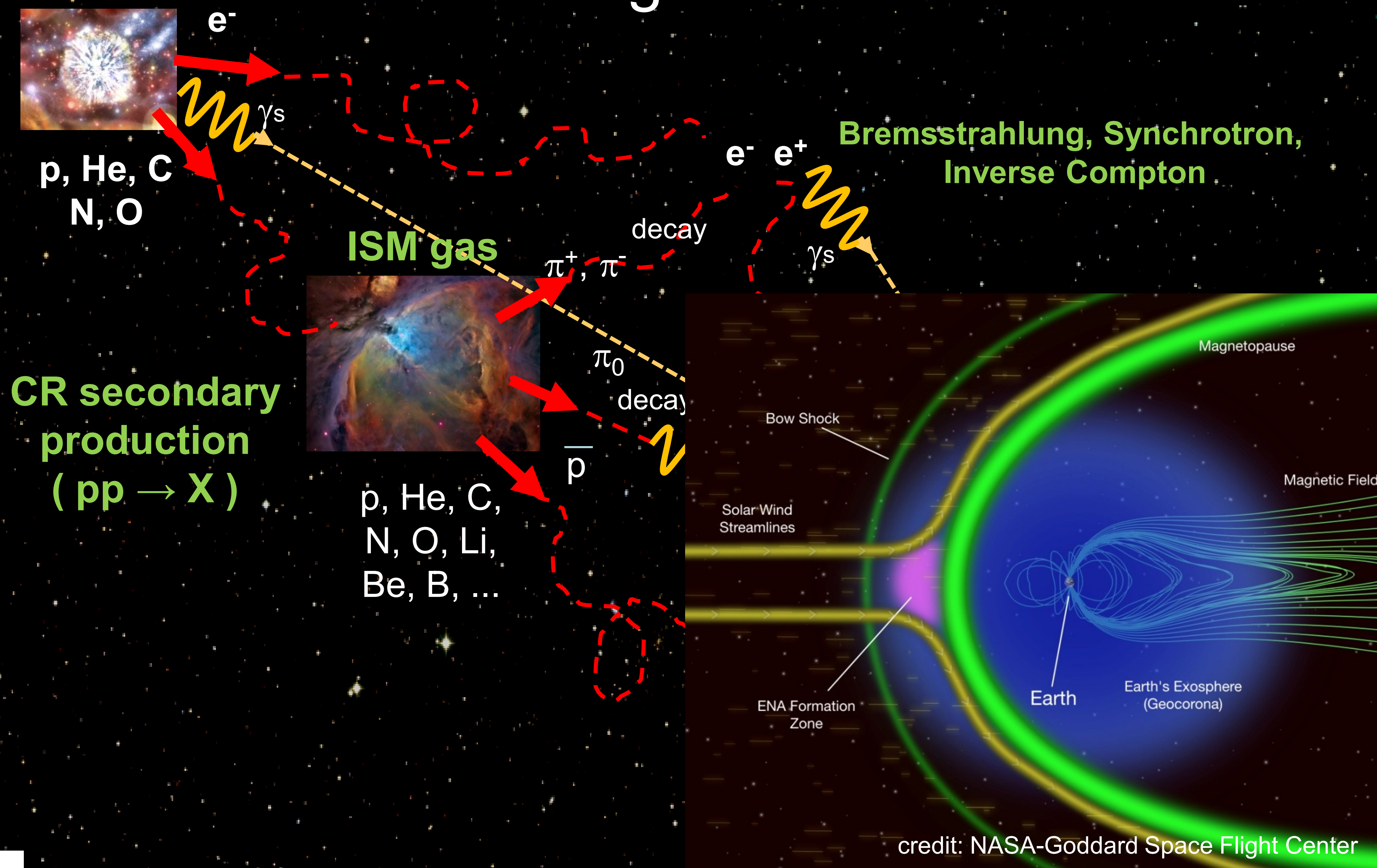
Combined with measurements taken out of the ecliptic plane (Ulysses experiment) → determining parameters of a fluido-dynamic model of heliosphere, understanding SEP acceleration mechanism

Cosmic Rays in the Earth Magnetosphere

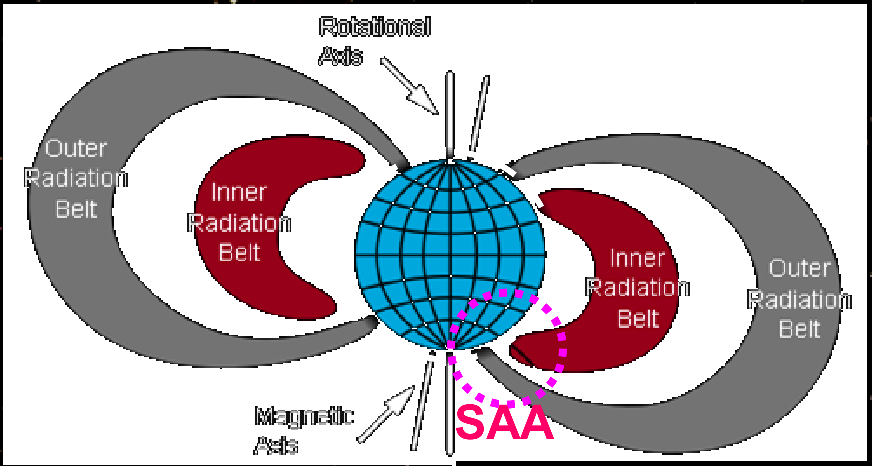
Cosmic rays in the Earth Magnetosphere

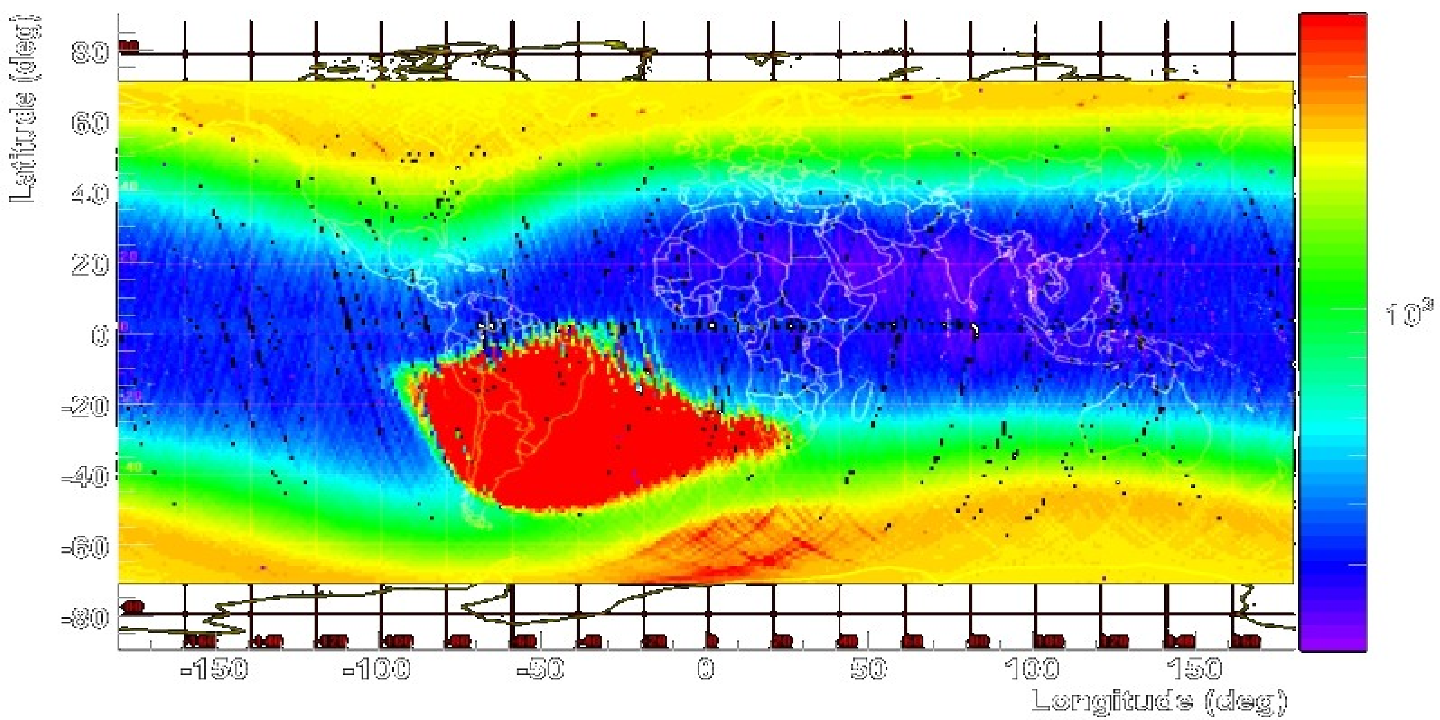


Cosmic rays: bent and trapped in the Earth magnetic field

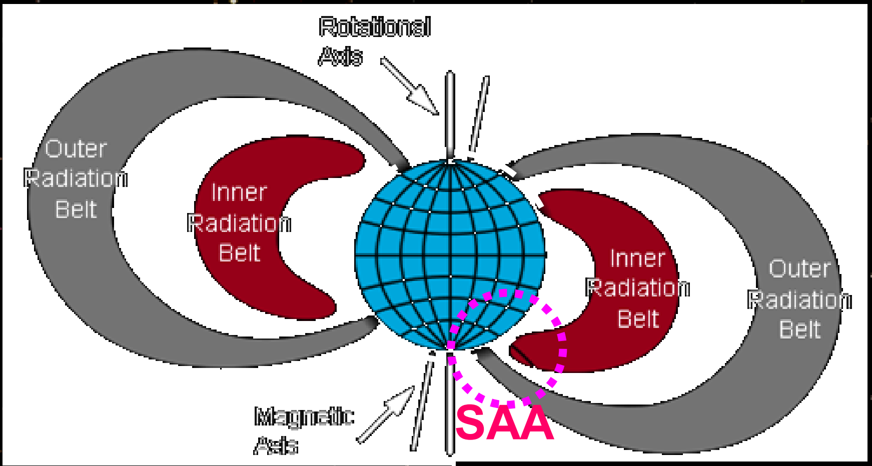


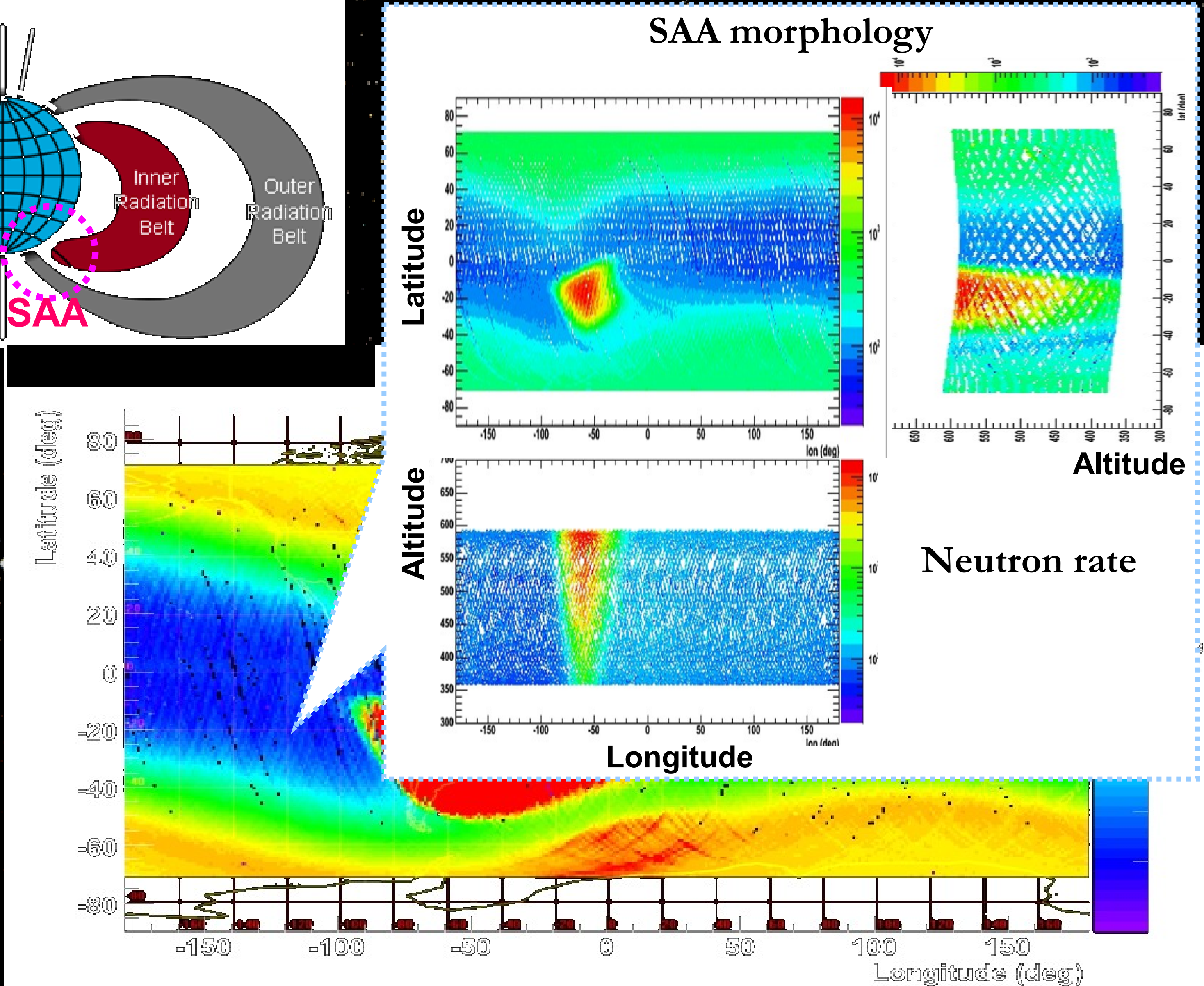
South-Atlantic Anomaly (SAA)



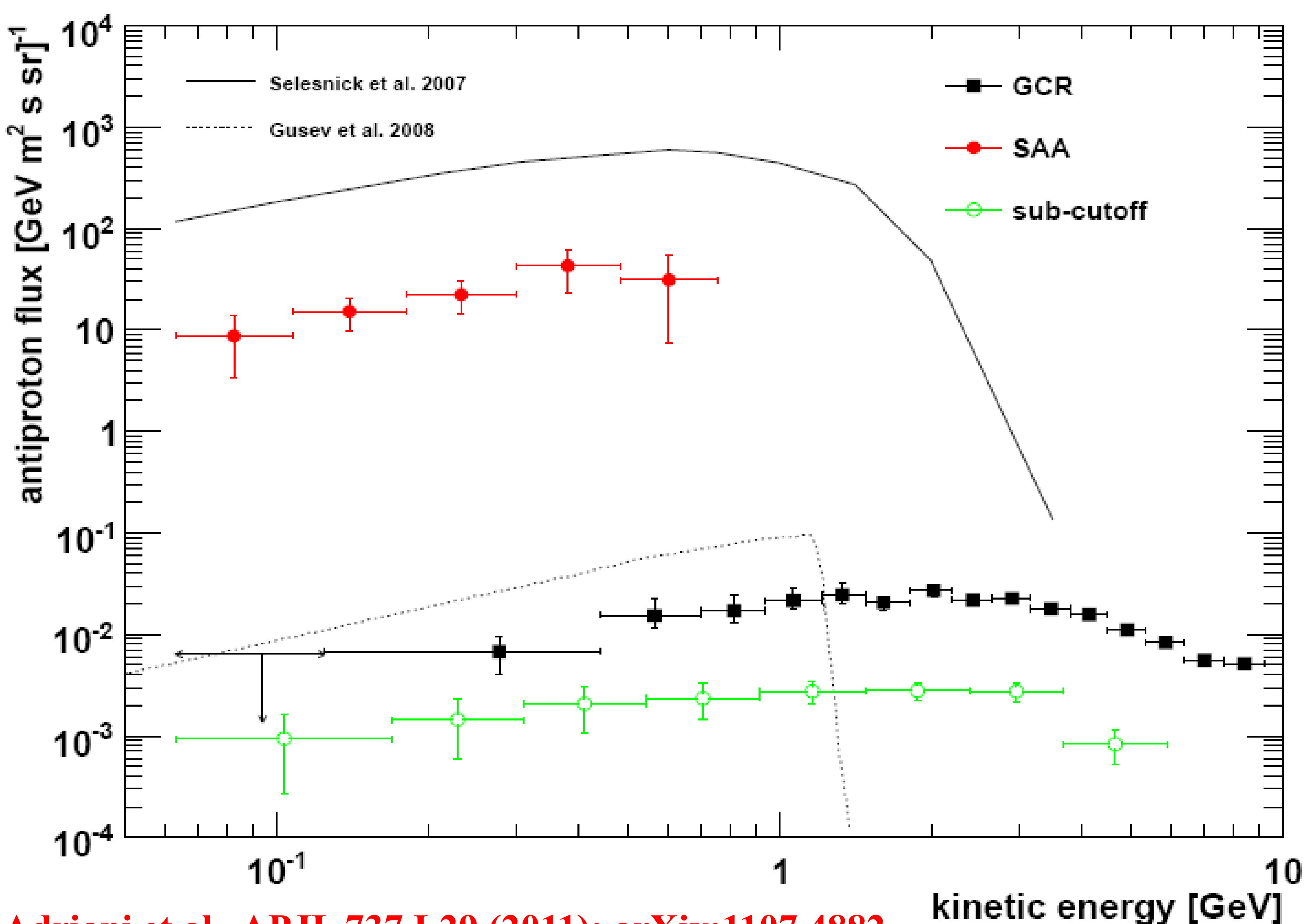


South-Atlantic Anomaly (SAA)



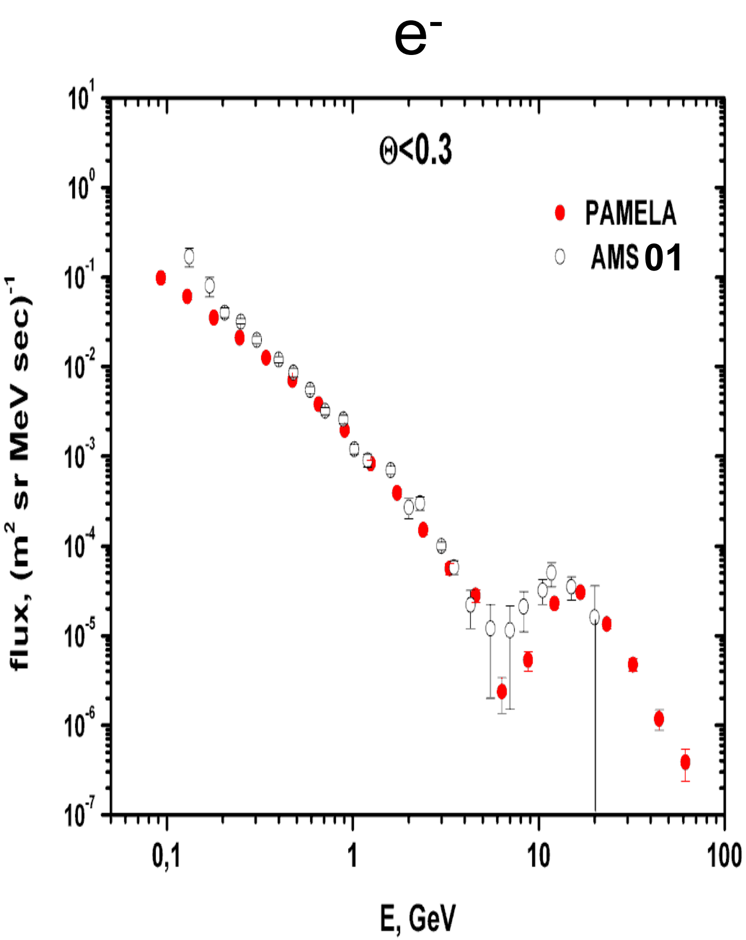


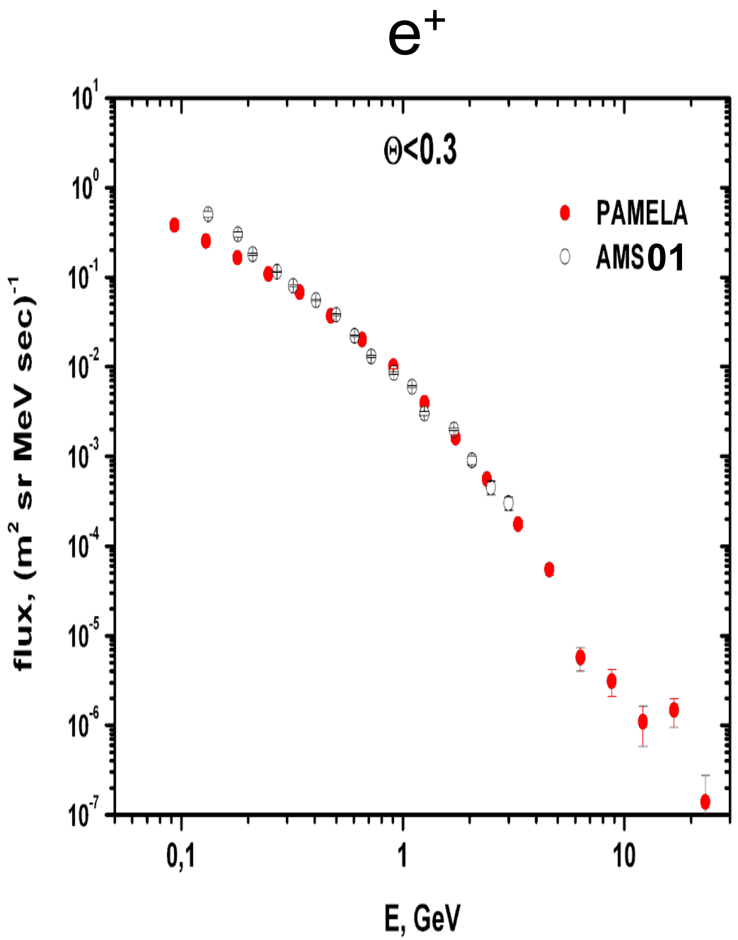
PAMELA: discovery of trapped antiprotons



Adriani et al., APJL 737 L29 (2011); arXiv:1107.4882

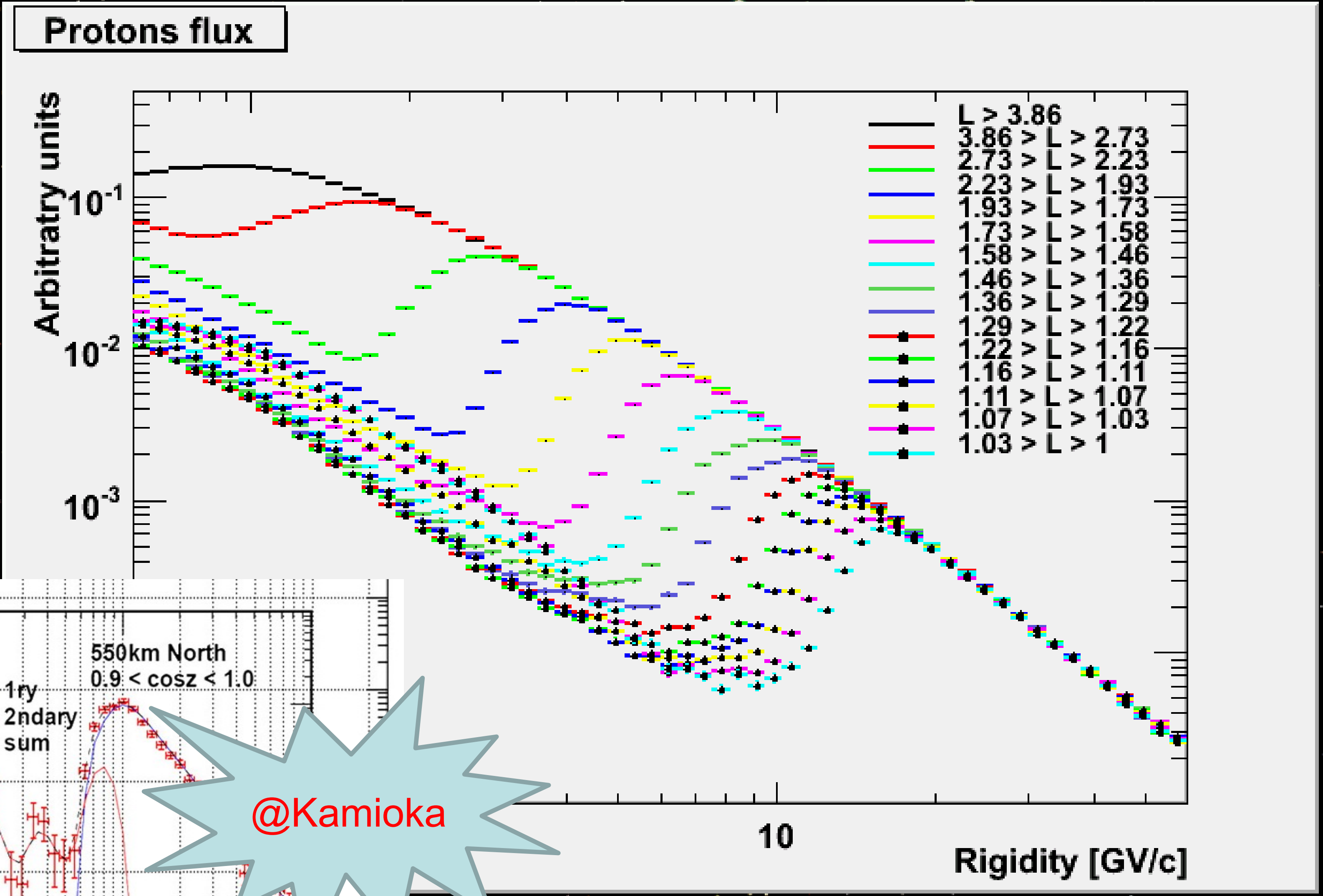
Subcutoff particles spectra: PAMELA electrons and positrons

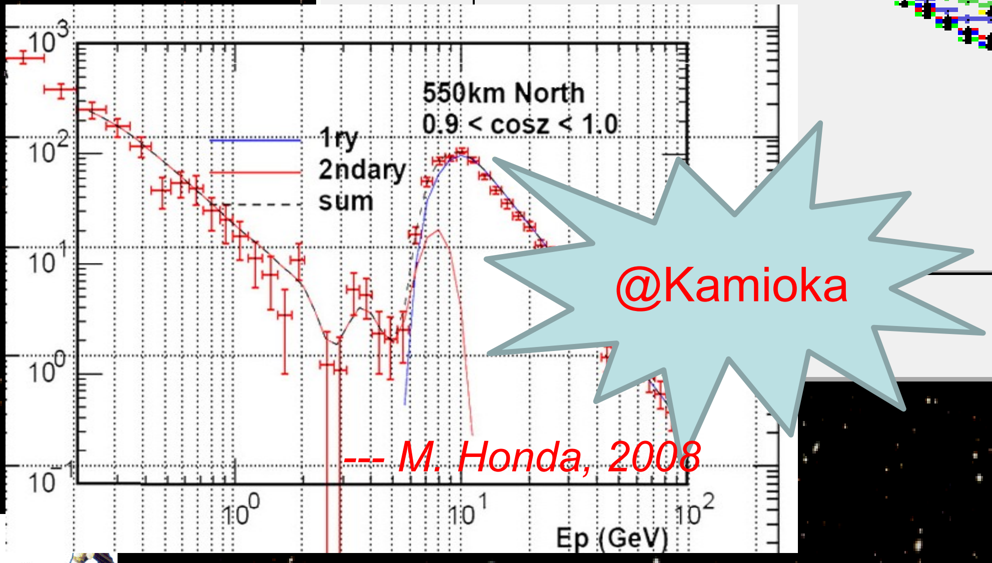




Adriani et al., Journal Geophysical Research, 114, No. A12, 2009

Subcutoff particles spectra: PAMELA protons



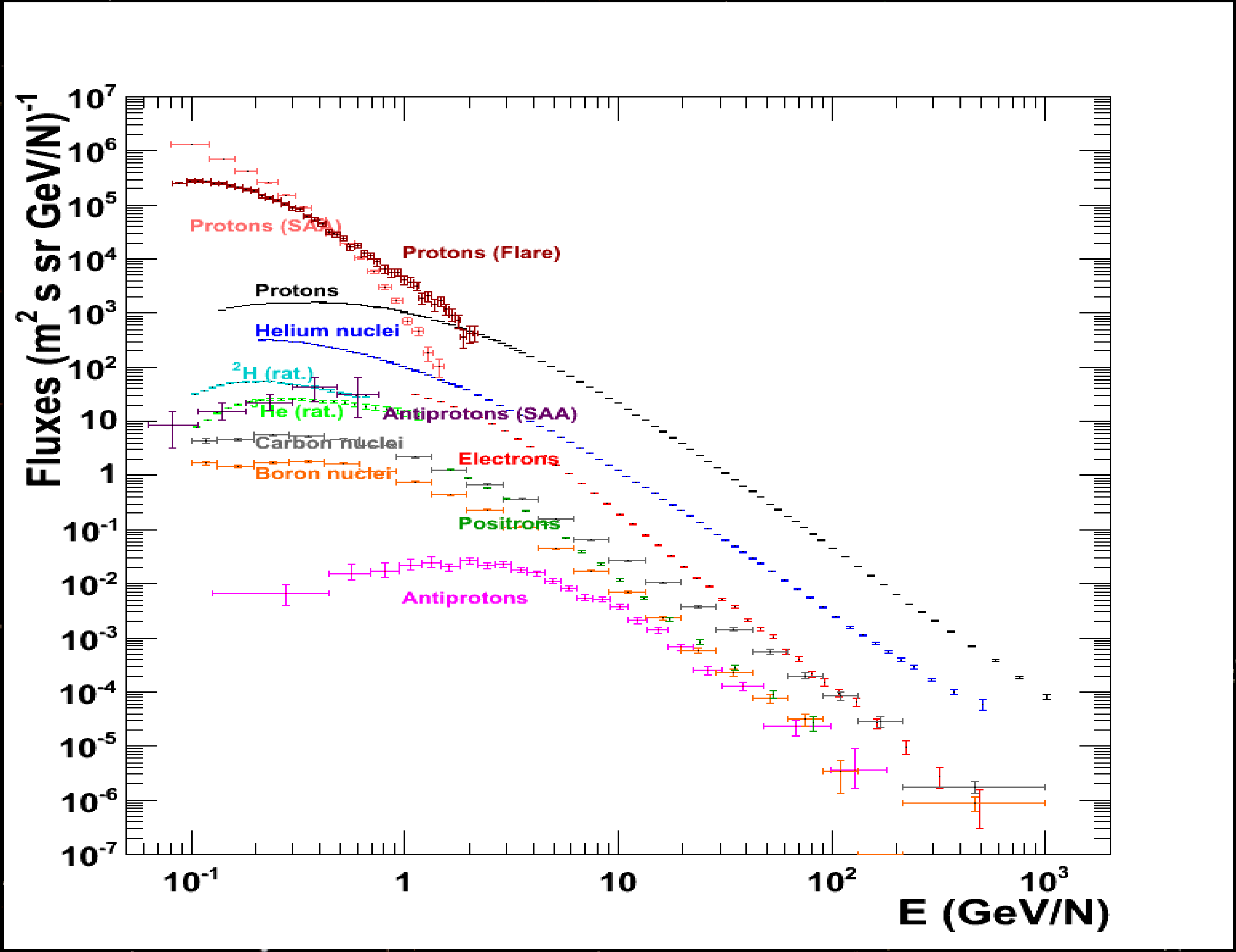


Cosmic Rays in the Earth Magnetosphere

PAMELA measurements:
protons, antiprotons, electrons, positrons, light nuclei at specific position on Earth

Useful to:
study atmospheric neutrino contribution, measure astronaut dose on board ISS, indirectly measure cross section in the atmosphere, estimate background of different type of particles for LEO satellites

Summary: PAMELA results



Summary

- PAMELA has been in orbit and studying cosmic rays for 2350 days (>6 years). >10^9 triggers registered and >20 TB of data have been down-linked.

- PAMELA lifetime extended, unlimited and depending on satellite operations.

- Many very interesting measurements from PAMELA, which are challenging astroparticle physics “standard” model.

- Analysis ongoing to finalize the antiparticle measurements (positron flux, positron fraction), continuous study of solar modulation effects at low energy.

- Study of solar impulsive events towards solar maximum (expected next year).

- AMS taking data! waiting for results to compare contemporary measurements.

Thanks!