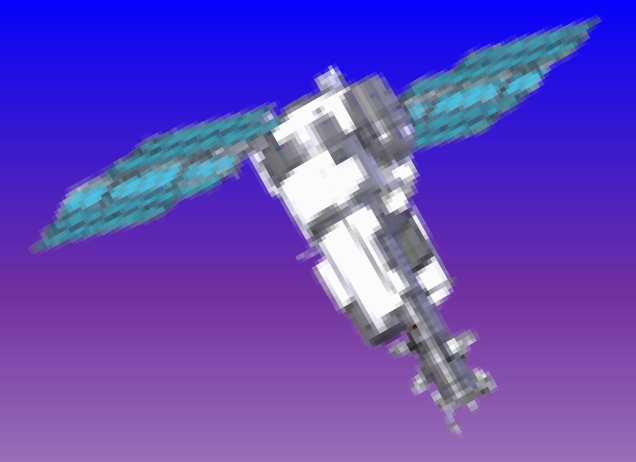




# PAMELA's measurement of geomagnetically trapped and albedo protons

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on behalf of the PAMELA collaboration



PAMELA

a Payload for Antimatter  
Matter Exploration and  
Light-nuclei Astrophysics

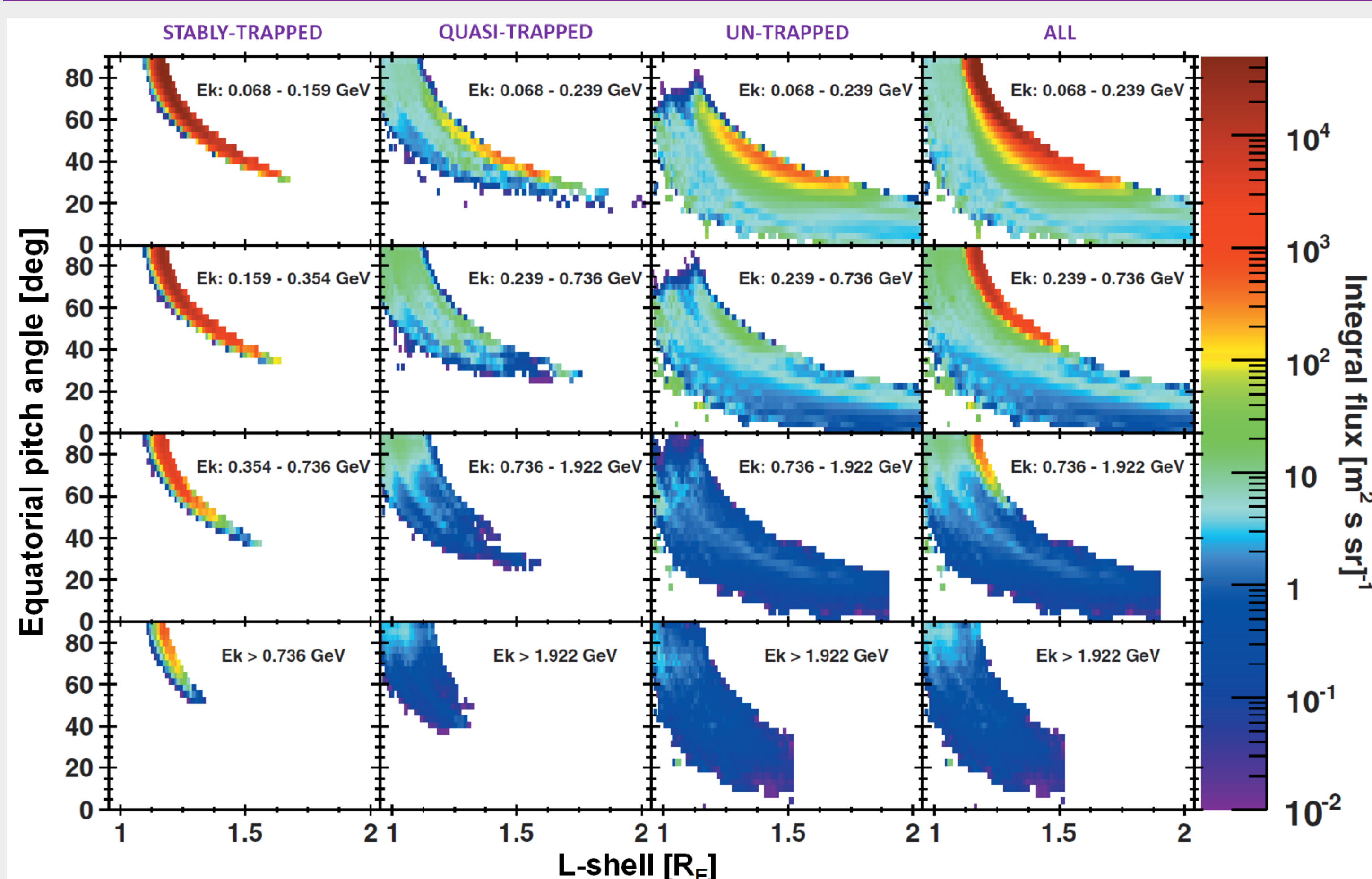
## Introduction

The radiation environment in Earth's vicinity constitutes a well-known hazard for the space missions. Major sources include the Van Allen belts, consisting of intense fluxes of charged particles experiencing long-term magnetic trapping. Specifically, the inner belt is mostly populated by energetic protons. Despite the significant improvements in last decades by several satellite missions, large uncertainties still affect the modelling of the high energy ( $>50$  MeV) fluxes in the inner zone and the so-called South Atlantic Anomaly (SAA). In addition to trapped particles, the magnetospheric radiation also comprises populations of albedo protons originated by the interaction of Cosmic-Rays (CRs) from the interplanetary space with the Earth's atmosphere, and characterized by limited lifetime and less intense fluxes.

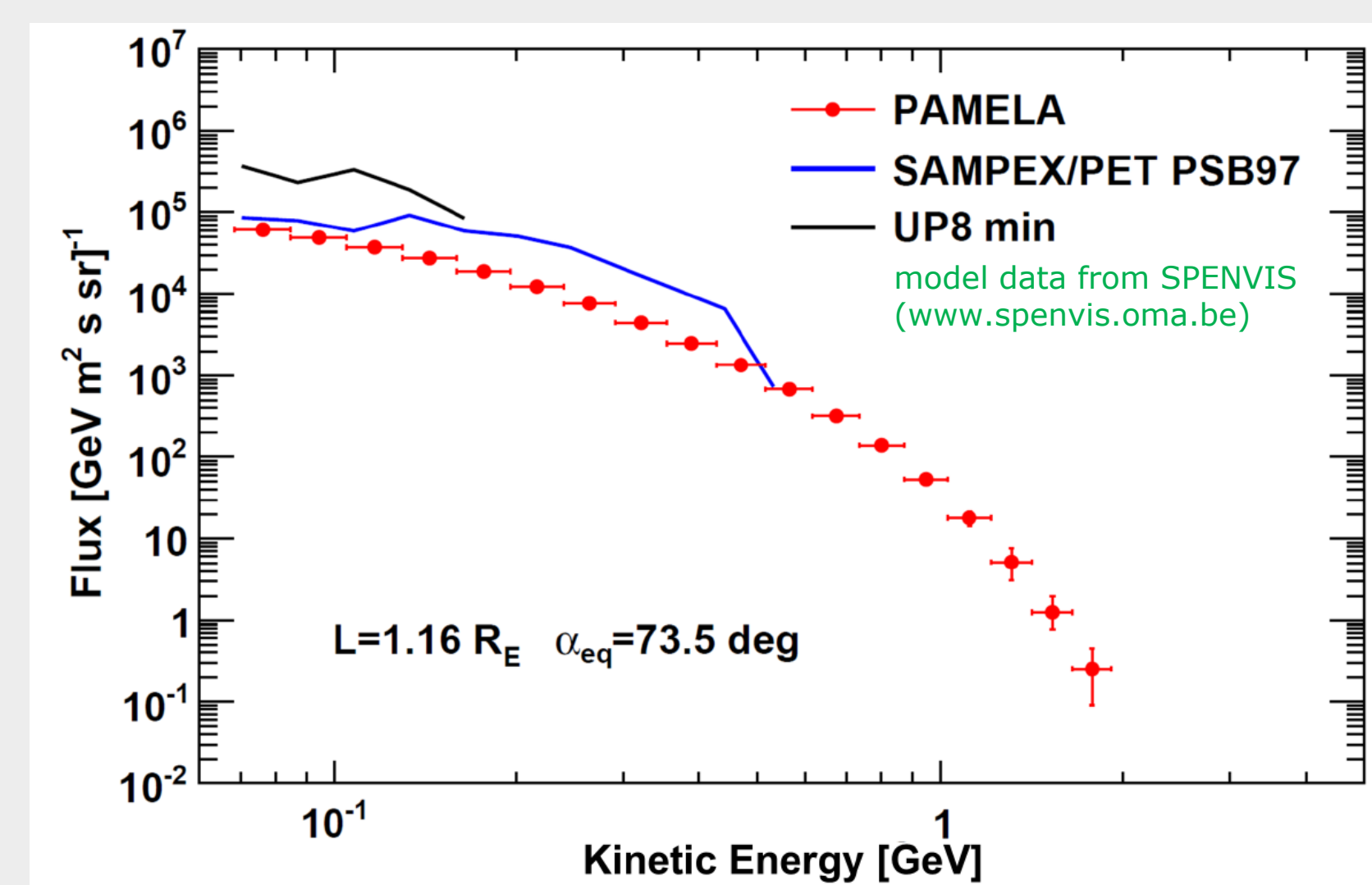
## Data analysis

PAMELA is a satellite-based experiment designed for a precise measurement of charged CRs in the energy range from some tens of MeV up to several hundreds of GeV [1]. The analyzed data set includes protons acquired between 2006 July and 2009 September. Trajectories of all detected protons were reconstructed in the magnetosphere using a tracing program based on numerical integration methods [2, 3], and implementing the IGRF11 [4] and the TS05 [5] as internal and external geomagnetic models. Trajectories were propagated back and forth from the measurement location until: they reached the model magnetosphere boundaries (**galactic** protons); or they reached an altitude of 40 km (**re-entrant albedo** protons); or they performed more than  $10^6/R^2$  steps, where  $R$  is the particle rigidity in GV, for both propagation directions (**geomagnetically trapped** protons). Trapped trajectories were verified to fulfil the adiabatic conditions. Fluxes were estimated by accounting for the anisotropic distribution in the SAA and for large gyro-radius effects [6]. Albedo protons were classified into **quasi-trapped** and **un-trapped**. The former have trajectories similar to those of stably-trapped protons, but are originated and re-absorbed by the atmosphere during a time larger than a bounce period (up to several tens of s). The latter include both a short-lived component **precipitating** within a bounce period ( $<1s$ ), and a long-lived (**pseudo-trapped**) component in the "penumbra" region near the geomagnetic cutoff (non-adiabatic trajectories) [7].

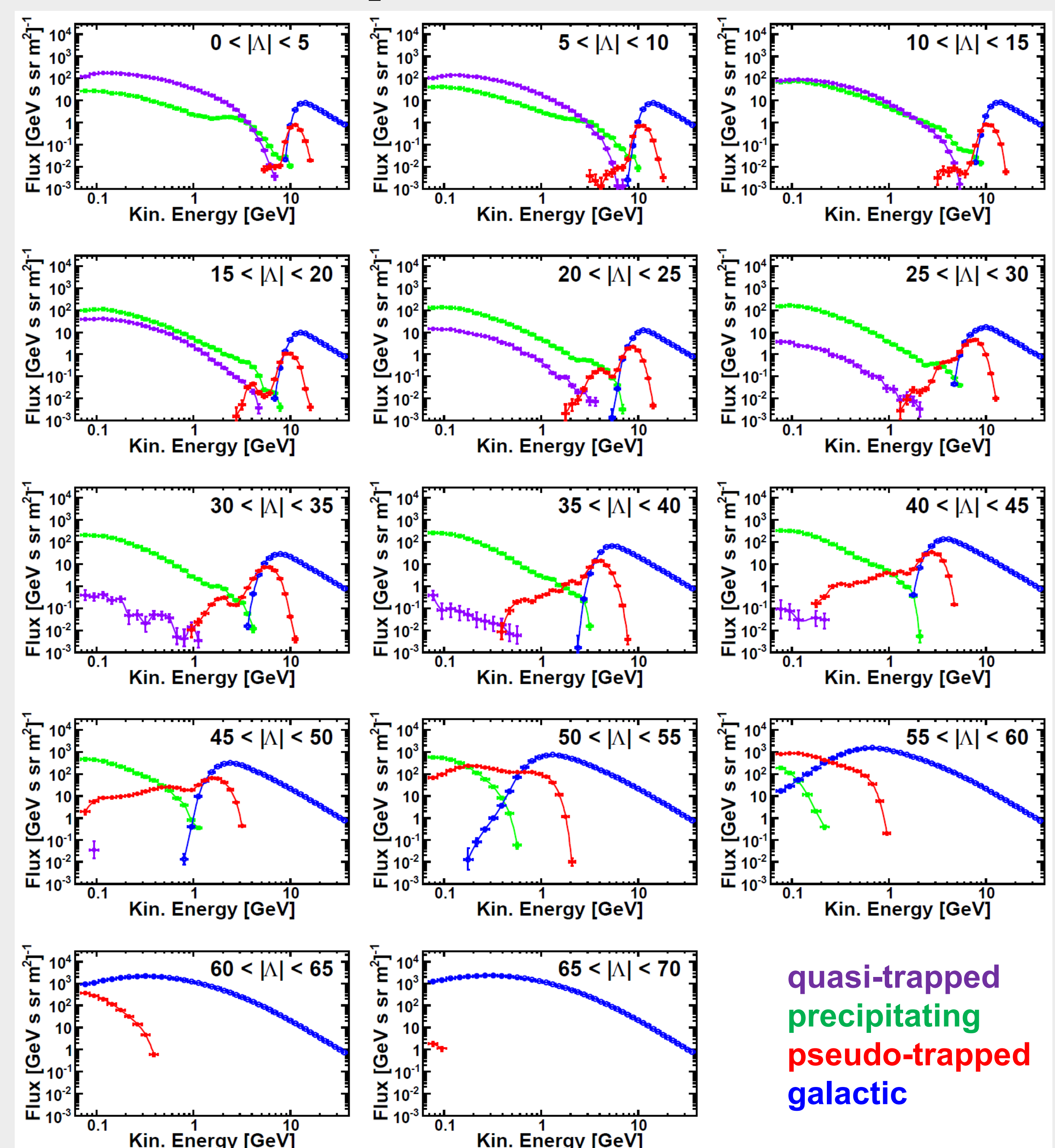
## Results



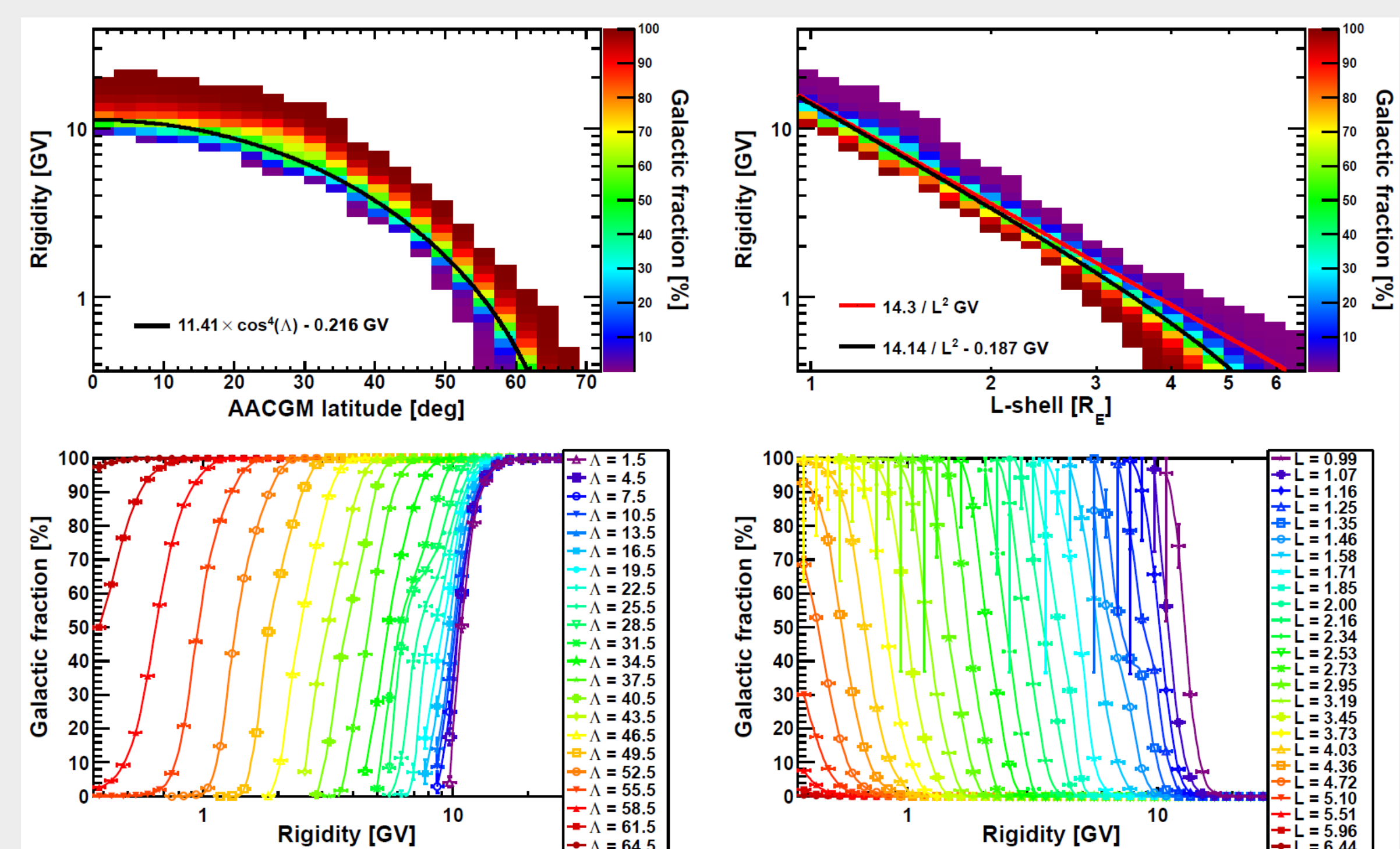
Proton fluxes were reconstructed as a function of equatorial pitch angle  $\alpha_{eq}$  and McIlwain's  $L$ -shell. The first column in the figure reports the results for stably-trapped protons, concentrating in the SAA at PAMELA altitudes. Constrained by the spacecraft orbit, the covered phase-space region varies with the magnetic latitude: PAMELA can observe equatorial mirroring protons only for  $L$ -shells up to  $\sim 1.18 R_E$ , and measured distributions are strips of limited width parallel to the "drift loss cone". Fluxes exhibit strong angular and radial dependencies. Quasi- and un-trapped maps are also reported in the figure, along with the total results. In these plots, only protons with  $R < 10/L^3$  were included (adiabatic trajectories). Distributions reflect the asymmetries of the geomagnetic field with respect to the Earth's rotational axis.



PAMELA trapped results were compared with the predictions of the AP8-min [8] unidirectional (or UP8 [9]) and the SAMPEX/PET PSB97 [10] models. In general, the UP8 model significantly overestimates the observations; a better agreement is found for PSB97, although PAMELA fluxes do not show the PSB97 spectral structures. PAMELA extends the observational range for trapped protons down to  $L \sim 1.1 R_E$  and up to the highest energies ( $\sim 4$  GeV).



The energy spectra of the different re-entrant albedo components outside the SAA ( $B > 0.23$ ) were evaluated as a function of AACGM latitudes  $|\lambda|$ , by averaging over longitudes.



Penumbra features are investigated in the above figure, where the fraction of galactic protons is shown as a function of rigidity and AACGM latitude (top-left panel) or  $L$ -shell (top-right panel). The penumbra was identified as the region where both albedo and galactic trajectories were found. The black curves denote a fit of points with equal percentage of the two components, while the red line refers to the Störmer vertical cutoff for PAMELA epoch. Corresponding rigidity profiles are shown in bottom panels.

## References

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