Protons with Energy E>70 MeV trapped in the Earth's Radiation Belts

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Abstract

Accurate measurements of under cutoff proton fluxes in the kinetic energy range 0.07÷9.1 GeV have been performed with the Alpha Magnetic Spectrometer (AMS) in low Earth Orbit. For the first time a clear transition is observed from a Stably Trapped population, detected on the boundaries of the South Atlantic Anomaly, to a Quasi Trapped population, revealed outside the South Atlantic Anomaly. The energy spectra, magnetic asymmetries and flux intensities of these populations are presented.

1. Introduction

The presence of trapped protons in the Earth's magnetosphere is firmly established and a large set of experimental data has been collected in long duration satellite campaigns carried in the last 40 years. However, in the region between the Inner Van Allen belts (IVAB) and the top of the atmosphere, a complete model of source and losses, residence times, energy spectra and spatial distribution of the particle population does not exists. This lack is particularly relevant, since this is the region where low Earth orbiting spacecrafts are operated and the International Space Station is assembled.

In this contribution, we use the high statistics data sample collected by the AMS experiment [1] for a detailed study of the proton fluxes at energies between 70 MeV and the geomagnetic cutoff. Details on the AMS detector and its performance during the flight, the proton selection and the background subtraction are given in [1]. The proton fluxes are analyzed in terms of the invariant magnetic coordinates L, α_0 [4] under the same data taking condition detailed in [2].

2. The Data Analysis

Particle trajectories have been traced backward and forward in the Earth's magnetic field to reject the primary component of the flux and to estimate the residence times of trapped particles out of the atmosphere. Protons have been classified as Stably Trapped (ST) or Quasi Trapped (QT) on the basis of their residence time, as detailed in [2]. The characteristics of the ST and QT compo-

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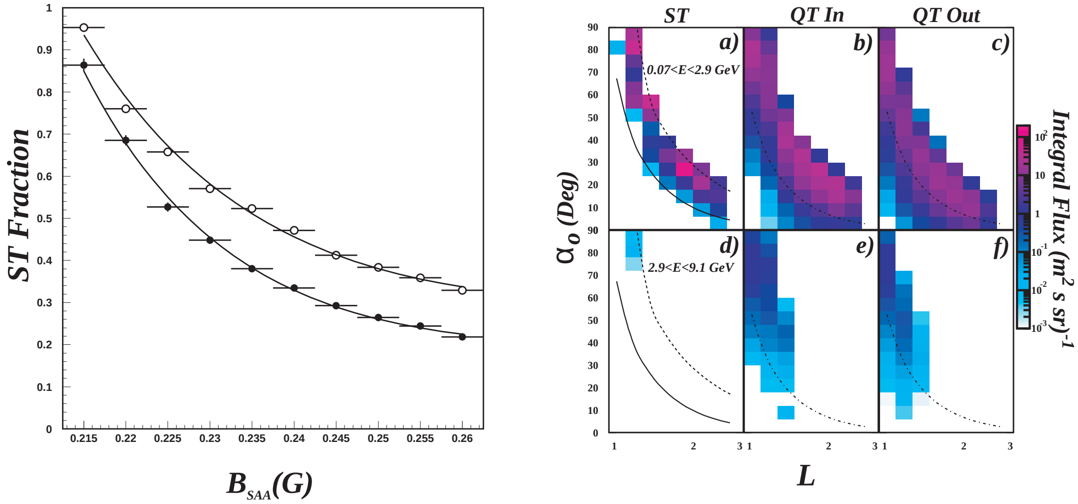

Fig. 1. Left: The fraction of ST protons (empty circles) and ST leptons (filled circles) as a function of the maximum local magnetic field B_{SAA} used to define the SAA. Right: Flux in the energy interval 0.07-2.9 GeV for ST protons (a), QT protons inside (b) and outside (c) the SAA. Flux in the energy interval 2.9-9.1 GeV for ST protons (d), QT protons inside (e) and outside (f) the SAA (e).

nents of the proton flux have been studied inside and outside the South Atlantic Anomaly (SAA) region.

3. AMS Results

In Fig. 1 (left) the fraction of the observed ST component with respect to the total proton flux (F_{ST}) is shown as a function of the maximum value for the local magnetic field, B_{SAA}, used to define the contour of the SAA. The same quantity is reported also for the under cutoff lepton flux (filled circles). The fit to a power law is superimposed on both distributions and leads to a fully ST flux ($F_{ST} = 1$) at a value of B_{SAA}=0.21 G for both protons and leptons. In fact, this corresponds to the limit of the IVAB at the AMS altitude and it solely due to the characteristics of the geomagnetic field. The AMS observations in the SAA allow to explore the *Mixed Radiation Belts* (MRB), where the transition occurs among shells characterized by different injection and loss mechanisms.

In Fig. 1 (right) the proton fluxes are mapped in the (L, α_0) plane for two different energy intervals ($0.07 \leq$ E <2.9 GeV, $2.9 \leq$ E <9.1 GeV). The QT fluxes measured inside and outside SAA exhibit similar characteristics in the whole energy range. At low energy the QT fluxes are present over the full (L, α_0) phase space accessible to AMS, while at higher energies the QT fluxes are absent at high L and low α_0. The dot-dashed line superimposed on the flux maps (b, c, e, f) identifies, for any given L, the minimum α_o value below which no protons are

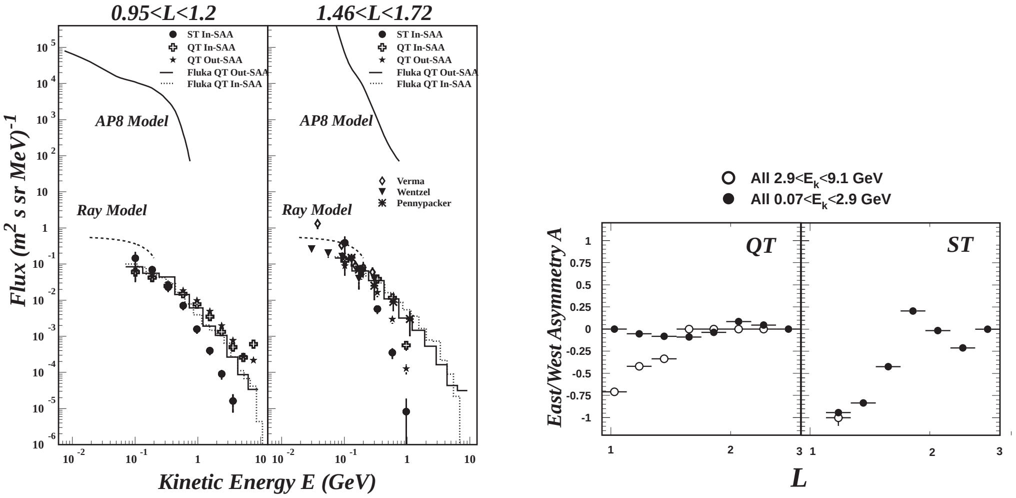

Fig. 2. Left: Energy spectrum of QT and ST fluxes for $0.95 < L < 1.2$ (a) and $1.4 < L < 1.72$ (b). Right: East/West asymmetry of QT and ST at low (filled circles) and high (empty circles) energies.

found with residence times larger than 0.3 s. This curve, $\sin\alpha_b = AL^{-\gamma}$, defines for any L the *equatorial bounce loss cone*: α_b corresponds to the limit below which the motion of protons is dominated by the bouncing along the magnetic field lines. Above this limit, the motion is dominated by the drifting normal to the magnetic field lines.

A different behavior is observed for the ST fluxes. In the higher energy interval the flux is nearly absent, at low energy it is contained in the narrow band of the (L, α_0) plane corresponding to the MRB region. The solid line superimposed on the flux maps (a, d) identifies, for any given L, the minimum α_o value below which no ST protons are found. This curve, $\sin\alpha_{ST} = BL^{-\beta}$, defines for any L the *equatorial drift loss cone*. Protons with $\alpha \leq \alpha_{ST}$ cannot be stably trapped because their drift shells intercept the atmosphere. The dashed line superimposed on the flux maps (a, d) corresponds to the limit of the IVAB at the AMS altitude, $\sin\alpha_{IVA} = \sqrt{0.311/B_oL^3}$ with B_o=0.21 G. The region above the α_{IVA} limit is not covered by the AMS measurements.

In Fig. 2 (left) the proton energy spectrum measured by AMS is shown separately for the QT and ST components, in two intervals of L. Total proton fluxes measured by balloon experiments [5] are also reported. For comparison, the proton flux intensities predicted by different models are also shown in figure. The highest curve represents the flux of low energy protons in the region of the full IVAB according to the AP8 model [7]. These fluxes are $\sim 10^5$ more intense than the ST fluxes registered by AMS in the MRB region. This indicates a rapid decrease of the trapped flux when moving from the core to the edge of the SAA and points to different filling mechanisms acting in the two regions. The other curves reported in Fig. 2 represent different predictions [6, 8] at the AMS altitude of the proton fluxes generated in the interaction of cosmic rays with the atmosphere. A good agreement is found among the observed QT flux, inside and outside the SAA, and the FLUKA estimate [8] of atmospheric production.

Magnetic East/West asymmetries [2] of the QT and ST flux components have been also investigated, as shown in Fig. 2 (right) for two different energy intervals. At the lower energies, E<2.9 GeV, only the ST component exhibits an appreciable asymmetry, which can be explained by long term effects in the interaction with the atmosphere [2]. At higher energies and low L values the East/West asymmetry appears also in the QT component. This can be explained in terms of the increase of the proton gyroradius with energy, which partially compensates the short residence times.

4. Conclusion

The properties of under cutoff protons detected by the AMS experiment have been investigated inside and outside the SAA. A clear transition from a Stably Trapped to a Quasi Trapped proton flux has been observed going from inside the SAA to its outside. The intensity and the energy spectra of the QT proton fluxes measured inside and outside the SAA exhibit similar properties. A common origin can be attributed to both QT fluxes, which represent the same population of atmospheric secondaries observed in different shell locations. The ST component, detected only inside the SAA, populates only a restricted region of the L, α_0 parameter space and is characterized by a soft energy spectrum. The ST flux is nearly absent at energies above 2.9 GeV, whereas the QT flux extends up to the cutoff energies. This suggests that ST particles might have an origin different from the QT ones, or that they are injected by mechanisms relatively suppressed at high energy, as pitch angle diffusion and Coulomb scattering.

5. References

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