Cosmic Ray Antiprotons from Relic Neutralinos in a Diffusion Model

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Abstract

We use the constraints on the diffusion parameters as obtained with stable nuclei to calculate the cosmic antiproton flux from annihilating relic neutralinos. We discuss the relevance of each characteristic parameter, describing our two dimension diffusion model, on the flux of antiprotons produced in the dark halo of our Galaxy. We estimate a two orders of magnitude uncertainty on the flux due to the unknowledge of the propagation parameters. A conservative and systematic evaluation of the flux in the supersymmetric parameter space is done in order to exclude configurations providing a total (secondary plus primary) flux in excess with observations. We also study the effect on the flux induced by modifications in the distribution of cold dark matter in the Galaxy.

1. Introduction

One of the most promising candidate for solving - at least partially - the problem of the astronomical dark matter comes from particle physics. In an extension of the Standard Model for elementary particles to supersymmetry, one can find a neutral and stable particle - the neutralino - perfectly fit to be a relic from the big bang. As well as providing good values for its relic density, the neutralino may be detected on Earth both directly and indirectly. Indirect detection lies on the measurement of its annihilation products as exotic components in rare cosmic fluxes, such gamma, neutrino, positron, antiproton, or antideuteron fluxes. In these Proceedings we present new results about the propagation of primary antiprotons - deriving from neutralino annihilation - in our Galaxy, by using previous studies on stable nuclei fluxes.

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2. The neutralino induced antiproton flux

The supersymmetric antiproton production differential rate, per unit volume and time is defined as

$$q_{\bar{p}}^{\rm susy}(r,z,T_{\bar{p}}) = <\sigma_{\rm ann} v> \; g(T_{\bar{p}}) \left(\frac{\rho_\chi(r,z)}{m_\chi}\right)^2 , \tag{1}$$

where $<\sigma_{\rm ann} v>$ denotes the average over the galactic velocity distribution function of the neutralino pair annihilation cross section $\sigma_{\rm ann}$ multiplied by its relative velocity v, and m_χ is the neutralino mass. $g(T_{\bar{p}})$ denotes the $\bar{p}$ differential spectrum deriving from the hadronization of quarks and gluons and $\rho_\chi(r,z)$ is the mass distribution function of neutralinos in the galactic halo. All the quantities depending on the supersymmetric parameters have been calculated in the framework of the effMSSM [1]. In order to obtain the distributions $dN^h_{\bar{p}}/dT_{\bar{p}}$ the hadronization of quarks and gluons has been evaluated by using the Monte Carlo code Jetset 7.2 [2].

The propagation of cosmic rays in the Galaxy has been considered in the framework of a two-zone diffusion model, which has been described at length in [1,3]. The sources of primary antiprotons are distributed throughout the whole diffusive halo, and the solution to the transport equation at our location (z=0) is given by [4]

$$N_i(0) = \int_{-L}^{L} \frac{q_i^{\bar{p},prim}(z)}{A_i} \frac{\sinh\left(\dfrac{S_i(L-|z|)}{2}\right)}{\sinh\left(\dfrac{S_i L}{2}\right)} e^{-V_c|z|/2K} dz \tag{2}$$

and where the energy-dependent quantities S_i and A_i are defined as

$$S_i \equiv \left\{ \frac{V_c^2}{K^2} + 4\frac{\zeta_i^2}{R^2} \right\}^{1/2} \qquad\qquad A_i \equiv 2\,h\,\Gamma_{\bar{p}}^{ine} \; + \; V_c \; + \; K\,S_i \coth\left\{\frac{S_i L}{2}\right\} .$$

The $q_i^{\bar{p},prim}(z,E)$ are the Bessel transforms of the source term given by Eq. 1.

In Fig. 1. we present the results for the primary antiproton flux for m_χ=100 GeV and $<\sigma v> = 2.3 \cdot 10^{-9}$ GeV^{-2}. The band represented by solid lines corresponds to the maximal and minimal flux obtained from all the astrophysical configurations compatible with the analysis on stable nuclei and providing $\chi^2_{B/C} \leq 40$ [5]. The two dotted lines give the maximal and minimal flux for the configurations with $\chi^2_{B/C} \leq 30$. We also plot the secondary antiproton flux as taken from [3 when all the configurations giving $\chi^2_{B/C} \leq 40$ are considered. We note the huge uncertainty in the calculation of the primary flux due to astrophysical parameters. The conservative choice of $\chi^2_{\rm B/C} < 40$ reflects in an uncertainty band two orders of magnitude large for energies $T_{\bar{p}} \lesssim 1$ GeV. The two curves obtained with parameters compatible with $\chi^2_{\rm B/C} < 30$ differs by a factor around 30 over all the

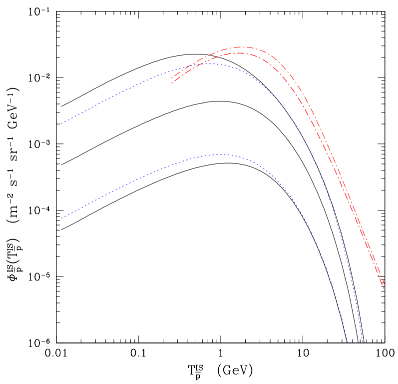

Fig. 1. The solid lines represent the antiproton flux for a m_χ=100 GeV neutralino and for maximal, median and minimal astrophysical configurations, for $\chi^2_{B/C} \leq 40$. Dotted lines: the same, but for for $\chi^2_{B/C} \leq 30$. The dot–dashed band corresponds to the secondary flux as taken from [3] for all the configurations giving $\chi^2_{B/C} \leq 40$.

energy range, just as the band for $\chi^2_{\mathrm{B/C}} < 40$ at energies greater than $T_{\bar{p}} \sim 1$ GeV.

3. Comparison with data

Data on antiproton at Earth are now abundant, mostly because of the missions of the balloon borne detector BESS. In Fig. 2. we compare our theoretical evaluations with data taken at solar minimum by BESS [6, 7], CAPRICE [8], and AMS [9]. The propagation parameters are the ones giving the best $\chi^2_{\mathrm{B/C}}$ and may be considered as the average ones, with respect to the incertitude band (see previous figure). We have calculated the flux for four different values of the neutralino mass: m_χ= 60, 100, 300, 500 GeV. We refer to [1] for all the details about both the astrophysical and supersymmetric aspects of the calculation. The lower mass gives the higher flux, even if for the most massive neutralinos the high energy part of the spectrum rises. We performed a full scanning of the supersymmetric parameter space [1]: using the median astrophysical propagation parameters no supersymmetric configuration may be excluded with present data and secondary flux extimation.

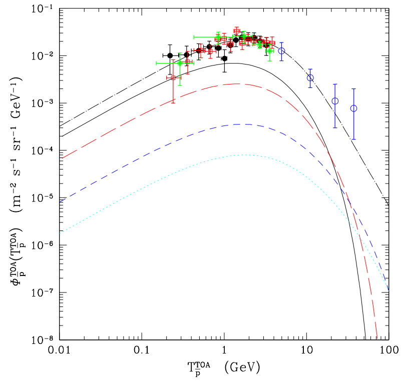

Fig. 2. Primary flux for m_χ= 60, 100, 300, 500 GeV (from top to bottom) obtained for the median astrophysical configuration. The upper dot–dashed curve corresponds to the secondary flux taken from [3]. Full circles [6], open squared [7]; empty circles [8], starred [9].

4. Conclusions

We have calculated the antiproton flux deriving from relic neutralino annihilation in the dark halo of our Galaxy. The diffusion model is the one previously selected by analysis on stable nuclei. Uncertainties due to propagation seriously affect the theoretical flux. Comparison with data and secondary antiproton flux demonstrates that it is rather difficult to put constraints on the supersymmetric parameter space. However, our results have been obtained assuming a spherical isothermal distribution of dark matter in the halo. Different density profiles or hypothesis about clumpy haloes may hqve been proposed in the literature. They would lead to differencies in the primary flux which may depend on the specific propagation model [1].

5. References

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