29th International Cosmic Ray Conference Pune (2005) **3**, 129-132

Origin of anti protons observed above the atmosphere, galactic or extra galactic?

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For so many years origin of anti protons above the atmosphere has been the subject of much research and very discussions, and it was not clear whether anti protons are galactic or extragalactic.

We compute the antiprotons produced in p-p collisions with a correction on grammage (The amount of matter traversed by particles before they escape from the galaxy) and take an energy dependant function for grammage due to Axford and Berezhko models of supernova. Our new calculation of galactic antiprotons is comparable with the experimental data and reflects a galactic origin for antiprotons.

The findings show that taking a correction due to energy dependence of grammage, reflects a galactic origin for anti protons.

1. Introduction

In addition to, protons, α particles and other nuclei, cosmic rays include less amounts of anti particles. In the mean time anti protons are much abundant than the other anti particles. The origin of cosmic anti protons has been attracting a lot of attention since their first observation reported by Golden et al. in 1979.

Now the major part of cosmic anti protons is believed to be the interaction products of the high energy cosmic ray particles with the interstellar media in our Galaxy. In addition to the secondary products, other anti proton contributions of primary origin are of great interest: the annihilation products of supersymmetric dark matter and the evaporation products of primordial black holes formed in the early epoch of the universe.

2. Discussion

In the present work first we calculate the cosmic rays residence time in the galaxy by using the Axford and Brezhkov models for supernova sources. In The propagation model diffusion and convection effects are considered[2]. The disk assumed to be the source region for secondary cosmic rays (anti protons as well as nuclei), and it follows with the assumption that anti protons are produced in the same regions as secondary nuclei, and they see the same galactic diffusion as the secondary nuclei. Then by using available parameterizations for $\overline{p}$ production cross sections in proton-proton collisions, we calculate the secondary anti protons flux.

The number density of secondary cosmic rays per unit energy interval $N_s(E)$ in the galaxy can be calculated from the stationary solution of the continuity equation , i.e., $\partial N_s / \partial t = 0$[2]:

$$\frac{\partial}{\partial t} N_s(E,\vec{r}) = 0 = Q_s(E,\vec{r}) - \vec{\nabla}\cdot[(\vec{u} - D\vec{\nabla})N_s(E,\vec{r})] - \frac{1}{\tau_i} N_s(E,\vec{r}) - \frac{\partial}{\partial E} b(E) N_s(E,\vec{r}). \tag{1}$$

The first term in the right hand side of the equation is, $Q_s(E,\vec{r})$, the production rate of secondary particles that can be written in the anti proton case as:

$$\frac{Q_{\bar{p}}(E)}{4\pi} = 2\frac{\rho}{m_H}\varepsilon \int \frac{d\sigma_{pp\to\bar{p}}}{dE_{\bar{p}}} J_p(E_p) dE_p \tag{2}$$

Where $\sigma_{pp\to\bar{p}}$ is the cross section for proton-proton →antiproton + anything. The factor ε is needed to account for effects of nuclei in the interstellar gas and in the cosmic-ray beam, and the factor 2 accounts for antiprotons produced by antineutron decay.

$Jp(Ep)$ is the flux of primaries which is assumed to be uniform throughout (at least) the galactic disk including the region near the Earth (just outside the heliosphere). The interstellar density ρ is assumed to be constant in the disk region.

The next term is the secondary loss rate due to diffusive (with diffusion coefficient D) and convective (with convection velocity $\vec{u}$) flows out of the galaxy. The diffusive-convective term can be replaced by $N_s(E)/\tau_e(E)$, where the characteristic time $\tau_e(E)$ has different interpretations in different models.
The third term on the right hand side represents the loss due to inelastic collisions, with characteristic time τ_i.

The last term describes the energy loss or gain of secondaries as they propagate. The term $b(E)$ is the average rate of the energy change for a secondary of energy E.

In the antiproton case we can ignore the third and forth terms due to the fact that these two terms will make only a small contribution to the flux, especially at high energies. With these simplifications we have:

$$\frac{1}{\tau_e} N_S(E) = Q_S(E) \tag{3}$$

And by using $J_S(E) = \upsilon N_S(E)/(4\pi)$ and replace the indexes for the antiproton case, we can write:

$$J_{\bar{p}}(E) = \upsilon\tau_e \frac{Q_{\bar{p}}(E)}{4\pi} \tag{4}$$

Where $Q_{\bar{p}}(E)/4\pi$ can be written from equation (2), and we can write the $\bar{p}$ flux as:

$$J_{\bar{p}}(E_{\bar{p}}) = \frac{2\lambda_e^H}{m_H}\varepsilon^H \int \frac{d\sigma_{pp\to\bar{p}}}{dE_{\bar{p}}} J_p(E_p) dE_p \tag{5}$$

with

$$\lambda_e^H = \upsilon\rho_H\tau_e \tag{6}$$

and

$$\varepsilon^H = 1.20 \tag{7}$$

In this paper, we assume that the interstellar medium is pure Hydrogen although one can consider it a mixture of 93% hydrogen and 7% helium, by using:

$$\lambda_e^M = \upsilon(\rho_H^M + \rho_{He}^M)\tau_e^M = 1.30\upsilon\rho_H^M\tau_e^M \tag{8}$$

and ε^M has the amount of:

$$\varepsilon^{M} = 1.17 \qquad (9)$$

However, we assumed that the primary particles have the supernova origin. By using Axford[6] and Brezhko[4] models for supernovas and comparing the source fluxes with the observed flux, one can compute cosmic rays residence time in the galactic disk as an energy dependant function, thus (for protons):

$$\tau_{A,B} \propto E^{-0.60\pm0.02} \qquad (10)$$

and

$$\lambda_{A,B} = 10(E/10)^{-0.60\pm0.02}\, gr/cm^{2} \qquad (11)$$

On the other hand we have used the parameterization offered by Duperray et al. (2003) for $\bar{p}$ production cross section [1]:

$$E_{\bar{p}} \frac{d^{3}\sigma}{dP_{\bar{p}}^{3}} = \sigma_{in}(1-x_{R})^{D_1} e^{-D_2 x_R} \left[D_3 \left(\sqrt{s}\right)^{D_4} e^{-D_5 P_{\bar{p},\perp}} + D_6 e^{-D_7 (P_{\bar{p},\perp})^2} \right] \qquad (12)$$

where σ_{in} is the total inelastic cross section for p-p collision:

$$\sigma_{in}(mb) = \sigma_{0}[1 - 0.62\exp(-K_{p}/200)\sin(10.9K_{p}^{-0.28})] \qquad (13)$$

with:

$$\sigma_{0}(mb) = 45 \times A^{0.7}[1 + 0.016\sin(5.3 - 2.63\ln(A))] \approx 45.0665 \qquad (14)$$

and K_{p} the incident kinetic energy in *MeV*.

D_1 to D_7 are given in table (1). $P_{\bar{p},\perp}$ is the transverse component of $P_{\bar{p}}$ and x_R is the radial scaling variable:

$$x_{R} = \frac{E^{*}}{E^{*}_{\max}} \qquad (15)$$

while * denotes CM frame and E^{*} and $E^{*}_{\max}$ are the total energy of $\bar{p}$ and its maximum possible value in the CM frame respectively.

Table 1. values of parameters of relation 12

parameters	D_1	D_2	D_3	D_4	D_5	D_6	D_7
Value(error)	3.4610(20)	4.340(20)	0.007855(3)	0.5121(27)	3.6620(5)	0.023070(1)	3.2540(77)

The differential cross section for the production of $\bar{p}$ of total energy $E_{\bar{p}}$ by a proton of energy E_{p} is given by[7]:

$$d\sigma(E_{\bar{p}}, E_{p}) = 2\pi \int_{P_{\bar{p},\perp}} \left(E_{\bar{p}} \frac{d^{3}\sigma}{dP_{\bar{p}}^{3}}\right) d\theta_{L} \qquad (16)$$

where θ_L is the angel of emission in the laboratory system. The upper limit to θ_L in the above integral is $\sin^{-1}(P^{*}_{\bar{p},\max}/P_{\bar{p}})$ where $P^{*}_{\bar{p},\max}$ is the maximum available momentum for $\bar{p}$ in the CM frame.

By these considerations we calculate the $\bar{p}$ production flux, and compare it with the observed one. One can see our results in figure 1.

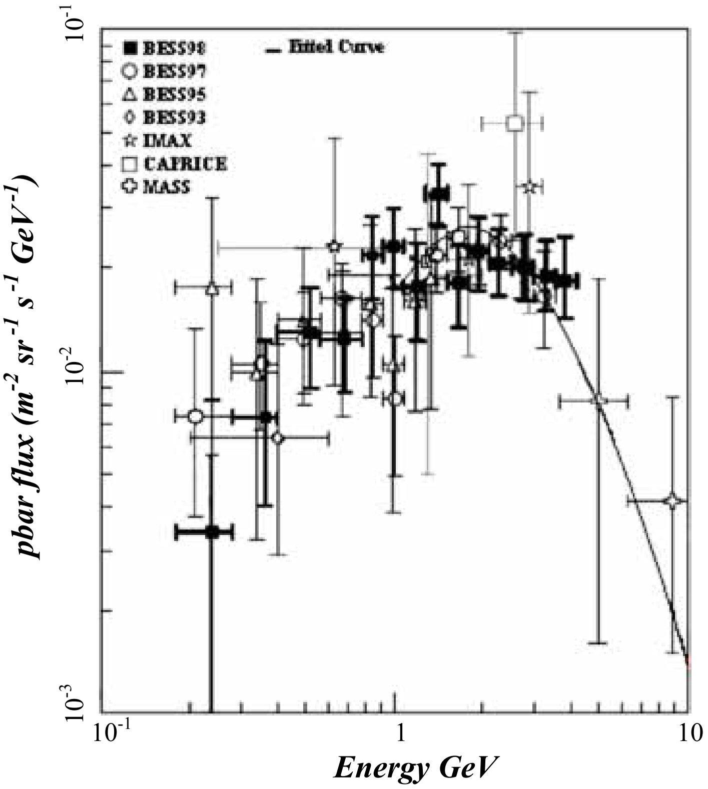

Figure 1. a comparison between the computed $\overline{p}$ (solid line) and experimental data. As we do not consider the effect of the solar modulation, only the region above 1 *GeV* is shown.

3. Conclusions

As it can be seen in the Fig.1 our predicted curve is in good agreement with the observed flux, so in the region above the ~1GeV it seems that the observed antiprotons have the galactic origin. One must note that we assume the supernova origin for the primaries, so our calculated flux also verifies the supernova origin at least in above 1GeV up to non-ultra relativistic energies.

References

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