OG.1.1.20

The Influence of Reacceleration on the Antiproton Abundance in the InterStella Medium and its Attenuation in the Atmosphere

R. K. Saha, Rena Majumdar, Pratibha Pal and D.P.Bhattacharyya[1]
Department of Theoretical Physics
Indian Association for the Cultivation of Science
Jadavpur, Calcutta 700 032, India
[1]e-*mail: tpdpb@mahendra.iacs.res.in*

Abstract

An estimation has been made on the influence o reacceleration about the abundance of secondary $\bar{p}$ flux in the Inter Stellar Medium duly initiated by primary cosmic ray proton collisions in the confined p+He gases in the medium. The present derivation is based on the production of antiprotons in the atmosphere by primary protons at different small depths.

1 Introduction

We have investigated the effect o reacceleration on $\bar{p}$ flux in Inter Stellar Medium and is displayed with the similar derived results of Simon and Heinbach (1996) and also with the experimental data of Golden et al. (1984) and Hof et al. (1995). Our estimated results on the $\bar{p}$ spectra at different low atmospheric depths have been compared with the theoretical prediction of Stephens (1993).

2 Nuclear Physics

Antiprotons are produced from high energy collisions of protons with the interstellar gas through the inclusive reaction p + p $\longrightarrow$ $\bar{p}$ + X , where X stands for other hadrons which emerge with the $\bar{p}$ from the interaction. The equilibriu $\bar{p}$ spectrum at a particular energy in the mixed ISM composed of 93 % H and 7% He can be evaluated from the conventional expression after Gaisser and Schaefer (1992) as

$$J_{\bar{p}}(E_{\bar{p}}) = \left[2\lambda_e^M / (\lambda_p + \lambda_e^M)\sigma_{pp}\right]\varepsilon^M \int_0^\infty (d\sigma / dE_{\bar{p}}) N_p (E_p) dE_p \qquad (1)$$

where N_p represents the flux of incident protons and other parametric values are given in (Saha et al. 1998).

The change of the $\bar{p}$ intensity due to diffusive reacceleration R_{reac} term is given by Ferrand (1993)

$$R_{reac.} = \left[\frac{d}{dE}\left\langle\frac{\delta E_{\bar{p}}}{\delta x}\right\rangle_{reac.}^{gain}\right] J_{\bar{p}} \ (m^2 \sec.sr.GeV)^{-1} \qquad (2)$$

where the average energy gain is described as,

$$\left\langle \frac{\delta E_{\bar{p}}}{\delta x} \right\rangle_{reac.}^{gain} = 0.6 E_{tot.}(MeV) R^{-1/3}(MV) \left[\frac{MeV}{g - cm^{-2}} \right] \qquad (3)$$

where R is the rigidity. The exponent (-1/3) and the factor 0.6 result from fitting the cosmic ray nuclear data.

Ignoring ionization losses, the atmospheric $\bar{p}$ intensity-behind a slab of thickness t g-cm^{-2} can be estimated by solving the conventional differential equation (Simon and Heinbach 1996) and the solution follows the form

$$J_{\bar{p}}(t, E_{\bar{p}}) = \frac{K}{\langle m \rangle} \lambda_{\bar{p}}^{\text{int}} (1 - e^{-\frac{t}{\lambda_{\bar{p}}^{\text{int}}}}) \int_{E_{th}^{p}(E_{\bar{p}}(t))}^{\infty} \frac{d\sigma(E_{\bar{p}}, E_p)}{dE_{\bar{p}}} N_p(E_p) dE_p \qquad (4)$$

Here

$$\lambda_{\bar{p}}^{\text{int}} = \frac{\langle m \rangle}{\sigma_{\bar{p}p}^{tot}(E_{\bar{p}})} g - cm^{-2} \qquad (5)$$

means mean interaction length in the atmosphere for antiprotons and <m> is average mass number of air = 14.5 a. m ., σ_{tot}^{pp} is total cross section taken from (Saha et al. 1998). Since not onl $\bar{p}$ emerge from a pp interaction, but also $\bar{n}$ at the same rate that finally decay into $\bar{p}$, the factor K is taken to be 2.5.

3 Results and discussion

The total primary proton spectrum adopted from (Saha et al. 1998) comes out to of the form

$$N_p(E)dE = 1.32 E^{-2.65} dE \qquad (6)$$

The interstellar $\bar{p}$ spectrum withou reacceleration comes out to be which follows the power law (Saha et al. 1998),

$$J_{\bar{p}} = 7.7 E_{\bar{p}}^{-3.07} (m^2 \sec .sr.GeV)^{-1} \qquad (7)$$

The $\bar{p}$ intensity with reacceleration is given b

$$J_{\bar{p}/reac} = J_{\bar{p}} - R_{reac} \qquad (8)$$

Our estimated $\bar{p}$ intensity and $\bar{p}$ / p flux ratio without and with reacceleration are displayed in Table 1.

Table 1

Table shows calculated interstellar antiproton spectra with and without reacceleration. The units of $J_{\bar{p}}$ and R_{reac} are expressed (m^2.s.sr.GeV)$^{-1}$:

$E_{\bar{p}}$ GeV	6	10	20	50	100
$J_{\bar{p}}$	5.50×10^{-2}	6.55×10^{-3}	7.80×10^{-4}	4.68×10^{-5}	5.58×10^{-6}
R_{reac}	1.31×10^{-2}	1.32×10^{-3}	1.31×10^{-4}	6.03×10^{-6}	5.86×10^{-7}
$J_{\bar{p}}/_{reac.}$ =($J_{\bar{p}}$ -R_{reac})	4.19×10^{-2}	5.23×10^{-3}	6.49×10^{-4}	4.08×10^{-5}	4.99×10^{-6}
$\bar{p}$ /p/$_{reac.}$	2.26×10^{-4}	1.77×10^{-4}	1.38×10^{-4}	1.00×10^{-4}	7.50×10^{-5}

The interstellar antiproton spectra $J_{\bar{p}}$ from a pure SSLB model and from condition of diffusive reacceleration have been shown in Fig.1. and the corresponding $\bar{p}$ p flux ratio in Fig. 2. respectively. Our calculated spectra are fairly comparable with the results of Simon and Heinbach (1996) and experimental data o Golden et al. (1984) and Hof et al. (1995).

Considering the total primary proton spectru N_p, the $\bar{p}$ spectra at differen depths 3, 5 and 10 g-c ^{2} in the atmosphere obtained from equation (4) are drawn in Fig.3. Our curves are lower when compared to the derived spectrum o Stephens (1993).

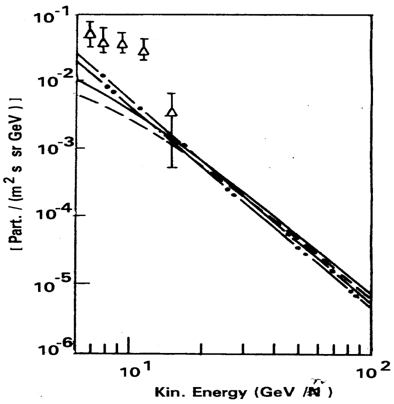

Fig 1.

Fig.1. Derived spectra of antiprotons in ISM under different assumptions:Full and broken curves represent the derived results of Simon and Heinbach (1996) expected fro SSLB model without and modified wit reacceleration, respectively. Dash dot and dash dot dot curves are the $\bar{p}$ spectra expected from SSLB model without and modified with reacceleration. Experimental data: Δ Golden et al. (1984).

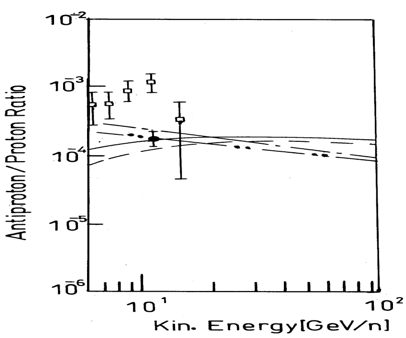

Fig 2

Fig.2. The $\bar{p}p$ flux ratio expected from SSLB model without and modified with reaccelerations: Full and broken curves represent the expected spectra of Simon and Heinbach (1996) from SSLB model without and modified with reacceleration, respectively. Dash dot and dash dot dot curves are the present results expected from SSLB without and modified wit reaccelerations, respectively. Experimental data: Golden et al. (1984), • Hof et al. (1995).

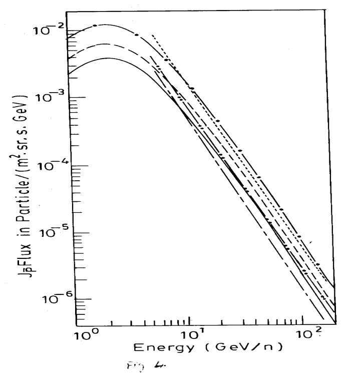

Fig.3. Atmospheric spectra o $\bar{p}$ flux at different depths: Chain curve: Present work and Full curve: Stephens (1993) for 3 g-cm^{-2}; Dash dot dot: Present Work and Broken curve: Stephens (1993) for 5 g-cm^{-2} ; Dash curve: Present work and dash dot: Stephens (1993) for 10 g-c $^{-2}$.

4 Conclusion:

The present estimated $\bar{p}$ spectrum when corrected for reacceleration has been found to follow the power law of the form $(J_{\bar{p}})_{reac}$ = 9.315 $E^{-3.15}$ (m^2.s.sr.GeV)$^{-1}$ which is found in good agreement with the calculated results of Simon and Heinbach beyond 6 GeV. The decrease o $\bar{p}$ flux due t reacceleration about 1.5%. The estimated $\bar{p}p$ flux ratio have been found to decrease slightly with energy following the power law, $(\bar{p}/p)_{reac} = 4.38 \times 10^{-4} E^{-3.08}$

The energy spectra o $\bar{p}$ at atmospheric depths 3, 5, 10 gm/cm^2 air have been estimated and lie appreciably below the calculated spectra of Stephens (1993) which reveals the $\bar{p}$ is strongly attenuated with depths.

References

Ferrando, P., 1993, XIII ICRC, **5** 279.

Gaisser T. K. and Schaefer R.K., Ap. J., **394** 174 (1992).

Golden, R. L., Mauger, B. G., Nunn S. and Moran, S., 1984, Ap. Lett., **24** 75.

Hof, M. et al., 1995, XIV ICRC **3** 60.

Saha, R. K , Majumdar, R., Pal, P. and Bhattacharyya, D. P., 1998, Mod. Phys. Lett. A **13** 1997.

Simon M. and Heinbach, U., 1996, Ap. J., **456** 519.

Stephens, S. A., 1993, XIII ICRC, **2** 144, (1993).