The Dissemination of Light Antinuclei in the Intergalactic Space

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Abstract

Various light antinuclei have been detected in accelerator experiments but remain unobserved in the primary cosmic radiation. The production of light antinuclei by antihelium interactions with ambient matter in the intergalactic space is calculated under the hypothesis of a complete symmetry in the physical processes taking place in matter and antimatter conglomerates.

The fragmentation of primary antihelium in the intergalactic and interstellar space generates antideuterons and antiprotons with abundances comparable with those of primary antiprotons and antideuterons postulated to be emanated from antimatter conglomerates. At low energy, presumably below 50 GeV, the antinuclei flux reaching the boundary of the solar cavity is attenuated by the galactic wind, the ionization energy losses and the shielding of the regular magnetic fields.

A simple consequence of this abundant antiproton production is that the antiproton-to-proton flux ratio in the Galaxy for energies exceeding 100 GeV may be significantly higher than the value of 10^{-3} measured at 10 GeV.

1 Introduction:

The evaluation of the average distance that cosmic rays can propagate through the intergalactic space is based on the diffusion coefficient and the time interval of the propagation. Such an estimate assumes that the dominant mode of cosmic-ray transport is diffusive in nature. These estimates indicate that the average distance is only a few tens of Megaparsecs (Tarlè, 1997), which seems too small for antinuclei searches given the distance (Dudarewicz and Wolfendale, 1994) from the Galaxy within which large fractions of macroscopic antimatter conglomerates are excluded by the observed intensity of the diffuse γ radiation. Unfortunately, these semiempirical arguments and others which are rooted only on conjectures tend to discourage the search for antinuclei in the primary cosmic radiation.

The quest for antinuclei in the primary cosmic radiation is inspired on the symmetry between systems of particles and those of antiparticles established in Elementary Particle Physics. This microscopic symmetry justifies the hypothesis of a macroscopic symmetry between celestial matter and antimatter conglomerates which implies the existence of antigalaxies emanating cosmic rays in the form of antiparticles and antinuclei. Until now (1999), such a hypothesis remains experimentally unproven. In this contribution to the conference the importance of searching for the lightest fragments of the cosmic antihelium, and in particular antiprotons and antideuterons, is presented.

2 Relative abundances of antihelium fragments:

The $\bar{\alpha}$ interactions ($\bar{\alpha}$ signifies ${}^4\bar{He}$) with the intergalactic and interstellar matter produce the 3 stable fragments $\bar{p}$, $\bar{d}$ and ${}^3\bar{He}$ via the interactions $\bar{\alpha}$p. The method of calculation and the approximations used are described in detail elsewhere (Codino and Lanfranchi, 1997). The relative abundance of antihelium fragments is dominated by the traversed matter thickness (grammage) which is unknown and difficult to estimate. For this reason, the grammage is the main free parameter of the calculation. For large distances (e.g. hundreds of Megaparsecs), it is assumed that the average grammage is proportional or nearly proportional to the average distance of the Galaxy from antimatter conglomerates. The $\bar{d}/\bar{\alpha}$ and $\bar{p}/\bar{\alpha}$ ratios versus antihelium momentum for two grammages are shown in figure 1.

Antiprotons produced via $\bar{\alpha}$ fragmentation are the dominant fragment for grammages greater than about 30 g/cm^2. The dependence of $\bar{p}/\bar{\alpha}$ and $\bar{d}/\bar{\alpha}$ ratios on the matter thickness for a primary antihelium momentum of 20 GeV/c is shown in figure 2.

3 Antiproton sources in antimatter conglomerates:

Besides the $\bar{\alpha}$ fragmentation, additional $\bar{p}$ sources should feed the $\bar{p}$ flux observable in the Galaxy. The following major sources should be considered:

(S1) elastic and inelastic $\bar{p}\bar{p}$ collision in the space dominated by antimatter conglomerates. In this process, the quiescent interstellar and intergalactic antihydrogen is transformed into a cosmic antiproton due to $\bar{p}\bar{p}$ elastic collisions and some inelastic collision channels (for example, $\bar{p}\bar{p} \rightarrow \bar{p}\bar{p} + pions$).

(S2) Spallation of antinuclei heavier than $\bar{\alpha}$ producing $\bar{p}$ in the final state.

(S3) The $\bar{\alpha}\bar{p}$ elastic collisions in the space dominated by antimatter conglomerates.

(S4) The antiproton production by ordinary cosmic-ray collisions in the space dominated by matter conglomerates.

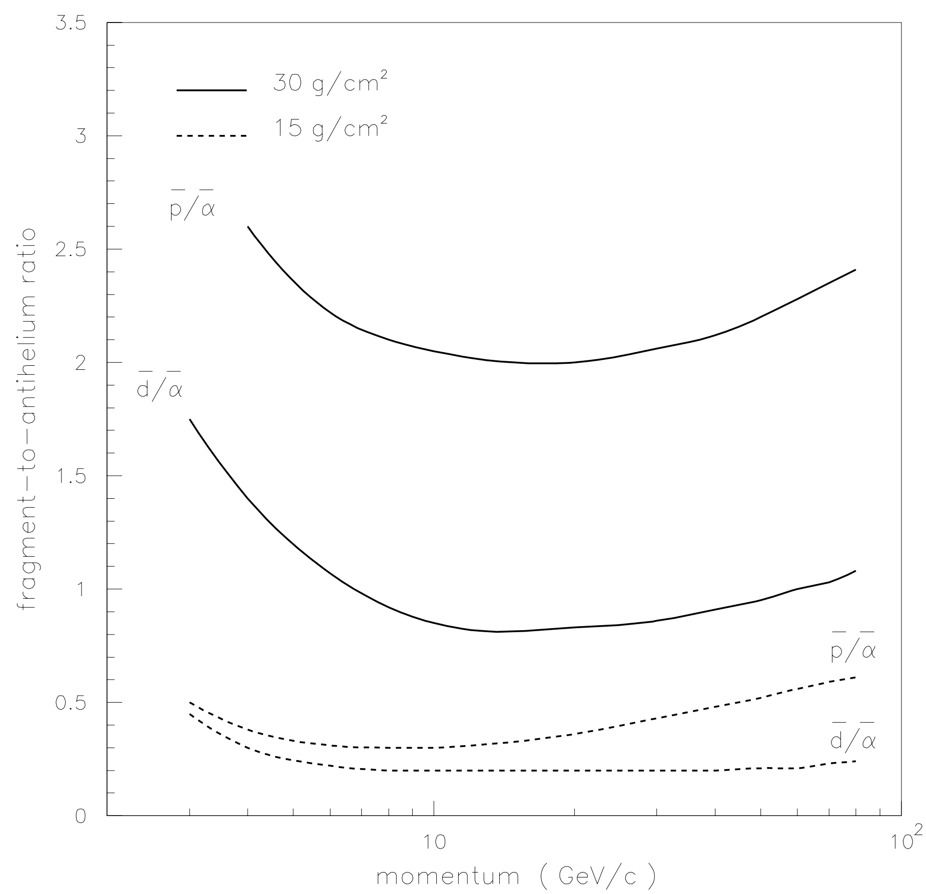

Figure 1: Antiproton and antideuteron-to-antihelium ratio versus antihelium momentum for matter thicknesses of 15 and 30 $g\ cm^{-2}$.

4 Discussion and conclusions:

Low energy stable antinuclei ($\bar{p}$, $\bar{d}$, ${}^3\bar{H}e$ and $\bar{\alpha}$) suffer a severe flux attenuation while propagating from macroscopic antimatter conglomerates to the solar cavity due to ionization energy losses and the effect of galactic winds. At sufficiently high energies (probably above 50 GeV) when these energy loss mechanisms become negligible, the relative abundance of these antinuclei for a specified grammage is controlled by the elastic and inelastic interaction cross sections of $\bar{p}$, $\bar{d}$, $^3\bar{H}e$ and $\bar{\alpha}$ with ambient matter (hydrogen and antihydrogen).

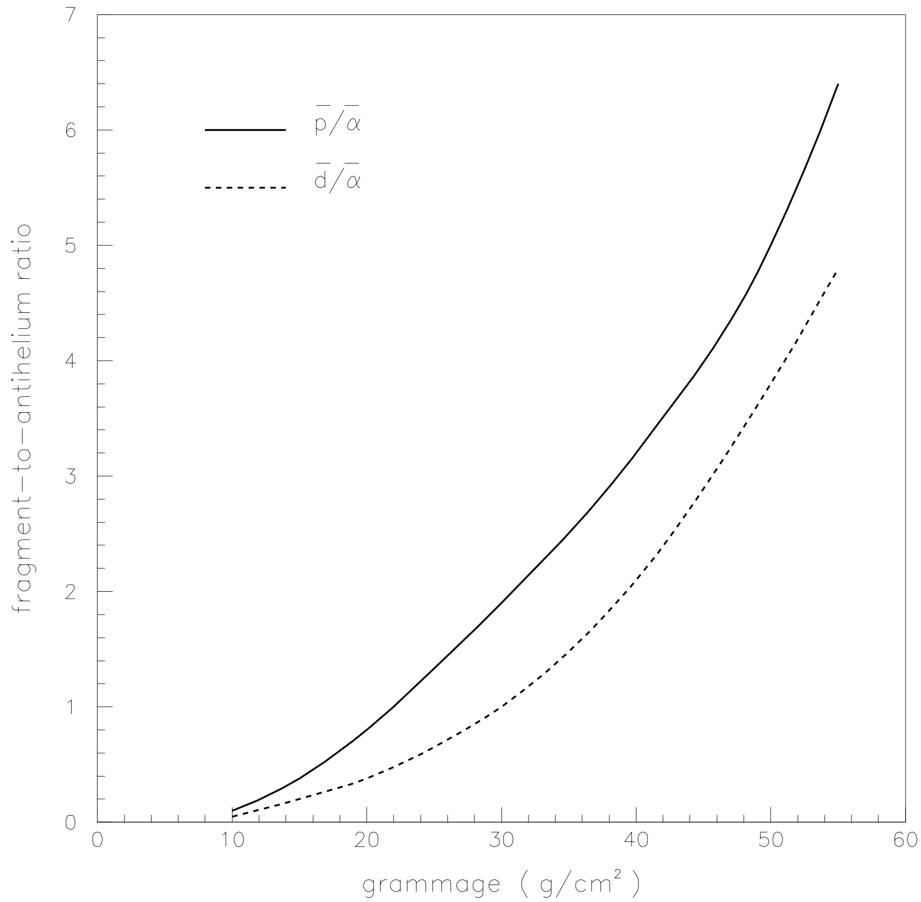

Figure 2: Antiproton and antideuteron-to-antihelium ratio versus grammage for an antihelium momentum of 20 GeV/c.

Antiprotons are characterized by the following special features compared to the other light antinuclei:

(α) Lowest interaction cross section, $\sigma(\bar{p}\bar{p})$, and $\sigma(\bar{p}p)$ implying the largest penetration length through the cosmic matter.

(β) Magnification of the original $\bar{p}$ flux from antigalaxies produced by $\bar{p}\bar{p}$, $\bar{\alpha}\bar{p}$ and $\bar{p}p$ collisions (sources S1, S2 and S3) in antimatter conglomerates. This effect is absent for antideuterons and suppressed for antihelium, probably by a factor of 10.

(γ) Lowest specific ionization (dE/dx) implying the longest range.

Also antideuterons possess, though to a less extent, the characteristics (α) and (γ).

Because of these three peculiarities, the dissemination of $\bar{p}$ in the intergalactic space is supposed to take place copiously at a large distance from the antimatter conglomerates or equivalently, as assumed in Section 2, at large grammages. Thus, the cosmic antiproton density in the intergalactic space should be larger than that of antideuterons, $^3\bar{H}e$ and $\bar{\alpha}$. Assume that, at sufficiently high energy, the $\bar{\alpha}/\bar{p}$ flux ratio emerging from the parent antigalaxy is equal to α/p flux ratio in our Galaxy that is approximately 10. Then, taking into account the $\bar{p}$ sources (S1), (S2) and (S3) and antiprotons from $\bar{\alpha}$ fragmentation, the $\bar{p}/p$ flux ratio in the Galaxy might overwhelm that generated in matter conglomerates by ordinary cosmic ray collisions. This last mechanism below 20 GeV, is calculated and measured to be less than 10^{-3} decreasing to 5.2×10^{-6} in the interval 200-600 MeV (Moiseev, 1997).

Upper limits to the $\bar{p}/p$ flux ratios below 20 TeV (Brooke and Wolfendale, 1964; Durgaprasad and Kunte, 1971; Stephens, 1985; Amenomori et al., 1995) are close to the value of 5×10^{-2} and secondary $\bar{p}$ production in the Galaxy calculated with a standard variant of the Leaky Box Model (Gaisser and Schaefer, 1992) which gives a decreasing $\bar{p}/p$ ratio (at 100 GeV is 8×10^{-5}).

Antideuterons remain unobserved in the primary cosmic radiation. The $\bar{d}/p$ flux ratio above 20 GeV of secondary origin via pp collisions in the Galaxy is in the range of 10^{-8} to 10^{-9}. Note that exotic $\bar{p}$ sources can be discriminated against the sources considered here by $\bar{p}$ and $\bar{d}$ measurements of adequate accuracy.

If the antinucleus-to-nucleus flux ratio observable in the solar cavity is below about 10^{-9} which is the sensitivity of the present generation of instruments searching for antinuclei, future detector design should consider ratios as low as 10^{-12} or less. In this circumstance, before the next generation of instruments will operate, $\bar{p}$ and $\bar{d}$ measurements above a few tens of GeV reporting fluxes greater than those predicted by the secondary production of $\bar{p}$ and $\bar{d}$ might anticipate the observation of heavier antinuclei.

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