Globular cluster of antistars in our Galaxy as a source of antihelium

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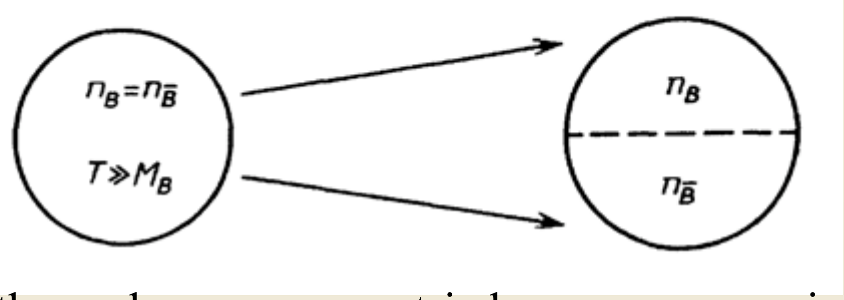
Introduction

The generally accepted motivation for baryon asymmetric Universe is the observed absence of the macroscopic amounts of antimatter up to the scales of clusters of galaxies.
The original Sakharov's scenario of baryosynthesis has found solutions of this asymmetry:

- CP violation
- out-of-equilibrium processes
- B-non-conservation

which generate baryon excess proportional to CP violating phase.
If sign and magnitude of CP phase varies in space than it is possible to produce matter or antimatter regions in space.



According to the Big Bang theory baryon symmetric homogeneous mixture of matter and antimatter can not survive after local annihilation, taking place at the first millisecond of cosmological evolution. Spatial separation of matter and antimatter can provide their survival in the baryon symmetric Universe but should satisfy severe constraints on the effects of annihilation at the border of domains.

Globular cluster of antisatars in our Galaxy

The most real case of the antimatter domain in our Galaxy – **globular cluster of antistars**. Taking into account restrictions on surviving of this domain up to now and observations of gamma-ray background, the size must be

$$M_{min} = 10^3\ M_{Sun} < M < M_{max} = 10^6\ M_{Sun}$$

Cluster of antistars most likely to survive in the magnetic halo, where the density is less than in the galactic disk.

In the spherical component of our Galaxy the antimatter globular cluster should move with high velocity (what follows from the velocity dispersion in halo ($v \approx 150$ km/s) through the matter gas with very low number density.

This cluster would be a source of antimatter:
- antistellar wind
- antimatter Supernova explosions

M.Yu.Khlopov, An antimatter globular cluster in our Galaxy - a probe for the origin of the matter. Gravitation & Cosmology (1998), V. 4, PP. 69-72.

Secondary production of antinuclei

Secondary origin antiprotons

$$p + p \rightarrow p + p + p + \overline{p} + other$$

$$\left(\frac{\overline{p}}{p}\right)_{Sec.} \propto 10^{-4\div-5}$$

Secondary origin antihelium

$$p + p \rightarrow p + p + He + \overline{He} + other$$

$$\left(\frac{\overline{He}}{He}\right)_{Sec.} < 10^{-14\div-15}$$

Observation of antihelium at the higher level would be strong evidence of the primary antihelium source !

Source of antihelium → **Propagation in the Galaxy** → **Propagation in the Solar system**

Source of antihelium

- Globular cluster of antistars produce energy spectrum of antihelium with spectral index γ

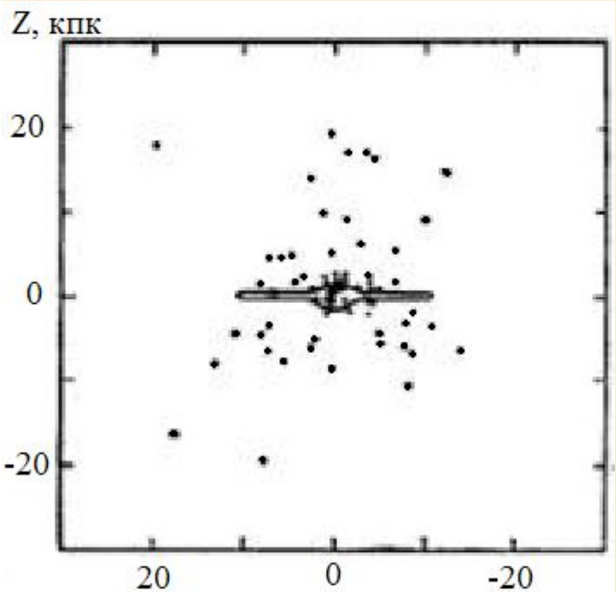
Propagation in the Galaxy

- Change of γ during the diffusion in the interstellar medium
- It is an important role play the annihilation with interstellar medium

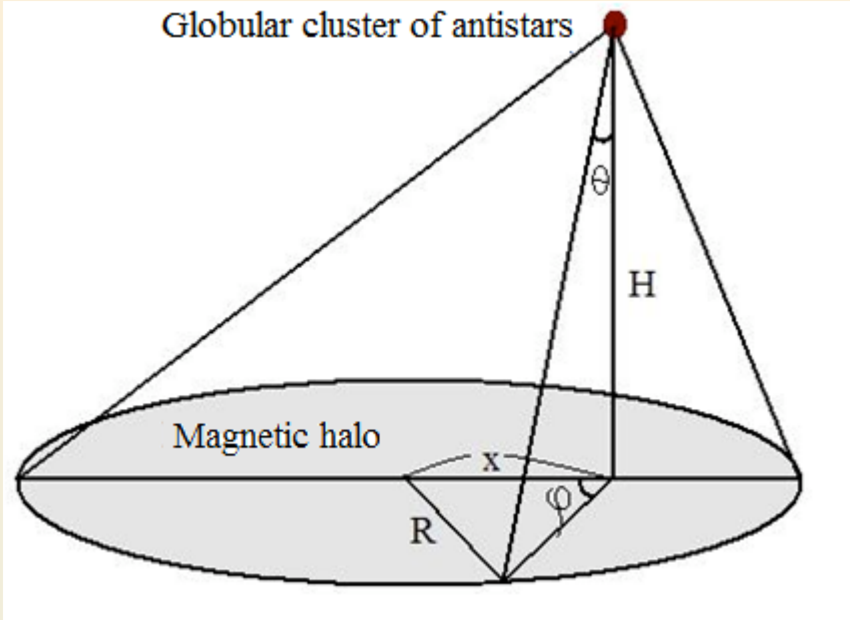
Propagation in the Solar system

- Change of γ during the diffusion in the Solar system
- An annihilation is very important due to higher density of the interplanetary medium

Globular cluster of antisatars in our Galaxy



The distribution of globular clusters in the galaxy (based on U. Harris, 1976)



$$\Omega = 2\pi - \int_0^{2\pi} \frac{H d\varphi}{\sqrt{H^2 + (x\cos\varphi + \sqrt{R^2 - x^2\sin^2\varphi})}}$$

$$\Omega_{min}(H_{max} = 20\hat{e}\ddot{i}\hat{e}, x_{max} = 20\hat{e}\ddot{i}\hat{e}) = 1.1$$

$$\Omega_{max} = 4\pi$$

Propagation of antihelium in the interstellar medium and Solar system

Cosidering the anti-He^4 nuclei travelling through the Galactic disk we must take into account few processes:

i.the destruction of antinucleus in the inelastic interactions with the protons of the galactic media;

ii.for the anti-He^4 we need to take into account also possibility of the anti-He^3 production due to the reaction

$$\text{anti-}He^4 + p \rightarrow \text{anti-}He^3 + \text{other}$$

$$\frac{\sigma(\bar{p}\,^4He \rightarrow {}^3He + all)}{\sigma_{ann}(\bar{p}\,^4He)} \approx 0.25, \; p = 193 MeV$$

The energy losses occur due to four kinds of processes:

(a) the energy losses on ionization and excitation of the hydrogen atoms in the disk matter;

(b) the bremsstrahlung radiation on the galactic hydrogen atoms;

(c) the inverse Compton scattering on the relic photons;

(d) the synchrotron radiation in the galactic magnetic fields.

The processes (b) — (d) are proportional to $(m_e/M_{He})^2$ and can be neglected at not very high energies of the anti-He nuclei.

Propagation of antihelium in the interstellar medium and Solar system

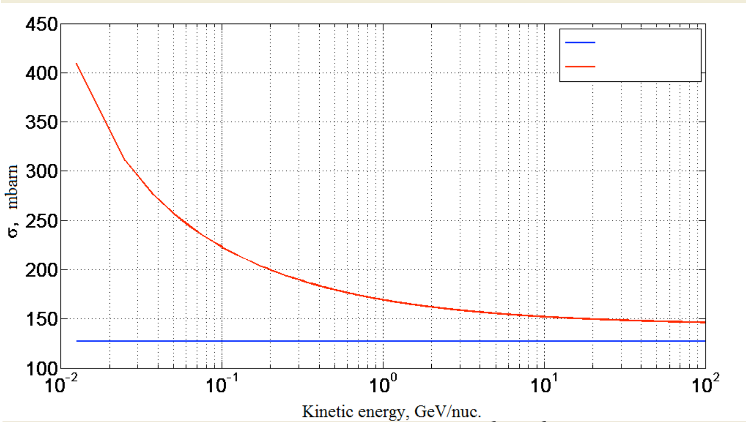
In the framework of the Leaky-Box transport of CR is described by introducing a characteristic "lifetime" of the particles, depending on their thickness passable in the medium which depends on the particle energy:

$$\frac{dn}{dt} = -\frac{n}{\tau_{ê}} - \frac{n}{\tau_{à}} + Q$$

$\tau_{ê(à)}$ holding time antihelium in the Galaxy (the time before annihilation with interstellar matter), Q – flux of antinuclei from the source.

Taking into account initial conditions $n = 0$ at $t = 0$ the solution $n = Q \cdot \tau_{?ôô} \cdot (1 - e^{-t/\tau_{?ôô}})$

$$\tau_{?ôô} = \frac{\tau_{ê} \cdot \tau_{à}}{\tau_{ê} + \tau_{à}} = \frac{X_{?ôô}}{v \cdot \bar{n}} \qquad X_{?ôô} = \frac{X_{ê} \cdot X_{à}}{X_{ê} + X_{à}}$$



A. Moiseev, J. Ormes , Astroparticle Phys. 6, 1997, 379-386

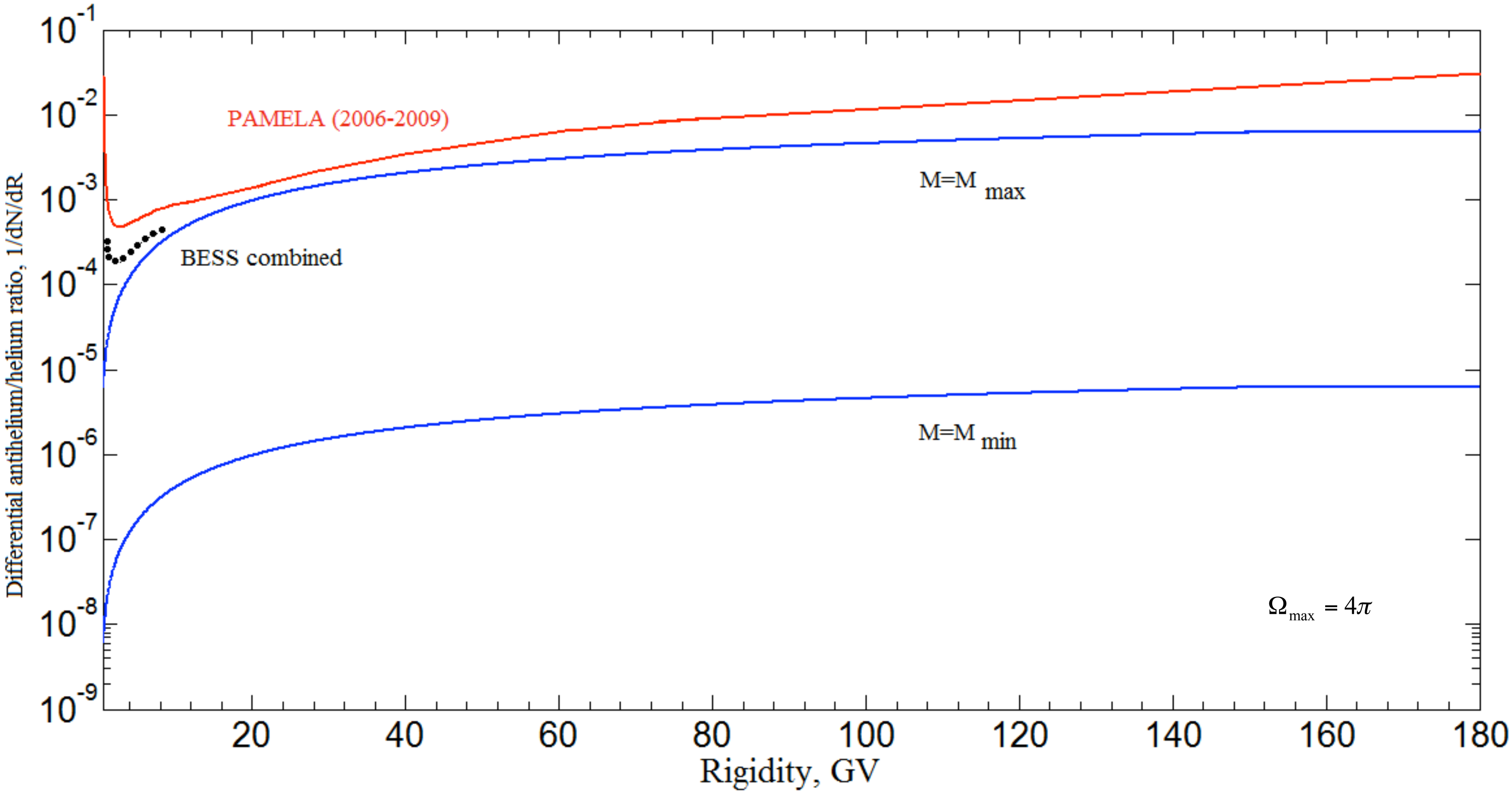
X_k was calculated using diffusion model of cosmic ray propagation

$$X_a = \frac{m_p}{\sigma}$$

where σ – is cross-section of antihelium-proton interaction

Propagation through the Solar system was estimated with diffusion model also with taking into account annihilation process

Results



Differential antihelium/helium ratio, 1/dN/dR
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
10^{-8}
10^{-9}
PAMELA (2006-2009)
BESS combined
$M=M_{max}$
$M=M_{min}$
$\Omega_{max} = 4\pi$
20
40
60
80
100
120
140
160
180
Rigidity, GV

Thank you