M.V. Lomonosov Moscow State University
D.V. Skobeltsyn Institute of Nuclear Physics

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K.M. Belotsky$^{2,3}$, Yu.A. Golubkov$^{1,3}$, M.Yu. Khlopov$^{2,3,4}$,
R.V. Konoplich$^{2,4}$ and A.S. Sakharov$^{2,4}$

Antihelium flux signature
for antimatter globular cluster in our Galaxy

$^1$Moscow State University, Institute of Nuclear Physics, Vorobjevy Gory,
119899, Moscow, Russia,

$^2$Center for CosmoParticle Physics ”Cosmion”,

$^3$Institute of Applied Mathematics, Miusskaya Pl.4, 125047, Moscow, Russia,

$^4$Moscow Engineering Physics Institute (Technical University), Kashirskoe Sh.31,
115409, Moscow, Russia

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Abstract

The AMS experiment is shown to be sensitive to test the hypothesis on the existence of antimatter globular cluster in our Galaxy. The hypothesis follows from the analysis of possible tests for the mechanisms of baryosynthesis and uses antimatter domains in the matter dominated Universe as the probe for the physics underlying the origin of the matter. The interval of masses for the antimatter in our Galaxy is fixed from below by the condition of antimatter domain survival in the matter dominated Universe and from above by the observed gamma ray flux. For this interval the expected fluxes of antihelium-3 and antihelium-4 are calculated with the account for their interaction with the matter in the Galaxy.
1. Antimatter in baryon asymmetrical Universe

The modern Big Bang theory is based on inflationary models with baryosynthesis and nonbaryonic dark matter. The physical basis for all three phenomena lies outside the experimentally proven theory of elementary particles. This basis follows from the extensions of the standard model. Particle theory considers such extensions as aesthetical appealing such as grand unification, as necessary to remove internal inconsistencies in the standard model with the use of supersymmetry and axion or simply as theoretically possible ideas of neutrino mass or lepton and baryon number violation. Most of these theoretical ideas can not be tested directly and particle theory considers cosmological relevance as the important component of their indirect test. In the absence of direct methods of study one should analyse the set of indirect effects, which specify the models of particles and cosmology. The expected progress in the measurement of cosmic ray fluxes and gamma background and in the search for cosmic antinuclei makes cosmic ray experiments the important source of information on the possible cosmological effects of particle theory. The first step in this direction may be done on the base of AMS-Shuttle experiment.

The specifics of AMS-Shuttle experimental programme puts stringent restriction on the possible choice of cosmic signatures for the new physics. At this stage it can not be related to positrons, gamma rays or multi GeV antiprotons. It makes us to reduce the analysis to the antinuclear signal as the profound signature of new physics and cosmology, related to existence of antimatter in the Universe.

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. 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. The most recent analysis finds that the size of domains should be only few times smaller than the modern cosmological horizon to escape the contradictions with the observed gamma ray background [1]. In baryon asymmetric Universe the Big Bang theory predicts the exponentially small fraction of primordial antimatter and practically excludes the existence of primordial antinuclei. The secondary antiprotons may appear as a result of cosmic ray interaction with the matter. In such interaction it is impossible to produce any sizeable amount of secondary antinuclei. Thus non
exponentially small amount of antiprotons in the Universe in the period from $10^{-3}$ to $10^{16}$ s and antinuclei in the modern Universe are the profound signature for new phenomena, related to the cosmological consequences of particle theory.

The inhomogeneity of baryon excess generation and antibaryon excess generation as the reflection of this inhomogeneity represents one of the most important example of such consequences. It turned out [2, 3, 4], that practically all the existing mechanisms of baryogenesis can lead to generation of antibaryon excess in some places, when the baryon excess, averaged over the whole space, being positive. So domains of antimatter in baryon asymmetric Universe provide a probe for the physical mechanism of the matter generation.

The original Sakharov’s scenario of baryosynthesis [5] has found physical grounds in GUT models. It assumes CP violating effects in out-of-equilibrium B-non-conserving processes, which generate baryon excess proportional to CP violating phase. If sign and magnitude of this phase varies in space, the same out-of-equilibrium B-non-conserving processes, leading to baryon asymmetry, result in $B < 0$ in the regions, where the phase is negative. The same argument is appropriate for the models of baryosynthesis, based on electroweak baryon charge nonconservation at high temperatures as well as on its combination with lepton number violation processes, related to the physics of Majorana mass of neutrino. In all these approaches to baryogenesis independent on the physical nature of B–nonconservation the inhomogeneity of baryon excess and generation of antibaryon excess is determined by the spatial dependence of CP violating phase.

Spatial dependence of this phase is predicted in models of spontaneous CP violation, modified to escape the supermassive domain wall problem (see rev. in [4, 5] and Refs. therein).

In this type of models CP violating phase acquires discrete values $\phi_+ = \phi_0 + \phi_{sp}$ and $\phi_- = \phi_0 - \phi_{sp}$, where $\phi_0$ and $\phi_{sp}$ are, respectively, constant and spontaneously broken CP phase, and antibaryon domains appear in the regions with $\phi_- < 0$, provided that $\phi_{sp} > \phi_0$.

In models, where CP violating phase is associated with the amplitude of invisible axion field, spatially-variable phase $\phi_{vr}$ changes continuously from $-\pi$ to $+\pi$. The amplitude of axion field plays the role of $\phi_{vr}$ in the period starting from Peccei-Quinn symmetry breaking phase transition until the axion mass is switched on at $T \approx 1$ GeV. The net phase changes continuously and if baryosynthesis takes place in the
considered period axion induced baryosynthesis implies continuous spatial variation of the baryon excess given by [3]:

\[ b(x) = A + b \sin \theta(x). \]  \hspace{1cm} (1)

Here \( A \) is the baryon excess induced by the constant CP-violating phase, which provides the global baryon asymmetry of the Universe and \( b \) is the measure of axion induced asymmetry. If \( b > A \), antibaryon excess is generated along the direction \( \theta = 3\pi/2 \). The stronger is the inequality \( b > A \), the larger interval of \( \theta \) around the layer \( \theta = 3\pi/2 \) provides generation of antibaryon excess [3]. In the case \( b - A = \delta \ll A \) the antibaryon excess is proportional to \( \delta^2 \) and the relative volume occupied by it is proportional to \( \delta \).

The axion induced antibaryon excess forms the Brownian structure looking like an infinite ribbon along the infinite axion string (see [8]). The minimal width of the ribbon is of the order of horizon in the period of baryosynthesis and is equal to \( m_{pl}/T^2_{BS} \) at \( T \approx T_{BS} \). At \( T < T_{BS} \) this size experiences red shift and is equal to

\[ l_h(T) \approx \frac{m_{pl}}{T_{BS}T}. \]  \hspace{1cm} (2)

This structure is smoothed by the annihilation at the border of matter and antimatter domains. When the antibaryon diffusion scale exceeds \( l_h(T) \) the infinite structure decays on separated domains. The distribution on domain sizes turns to be strongly model dependent and is calculated in [3].

The size and amount of antimatter in domains, generated in the result of local baryon-non-conserving out-of-equilibrium processes, is related to the parameters of models of CP violation and/or invisible axion (see rev. in [2, 4]). SUSY GUT motivated mechanisms of baryon asymmetry imply flatness of superpotential relative to existence of squark condensate. Such a condensate, being formed with \( B > 0 \), induces baryon asymmetry, after squarks decay on quarks and gluinos. The mechanism doesn’t fix the value and sign of \( B \) in the condensate, opening the possibilities for inhomogeneous baryon charge distribution and antibaryon domains [4]. The size and amount of antimatter in such domains is determined by the initial distribution of squark condensate.
So antimatter domains in baryon asymmetric Universe are related to practically all the mechanisms of baryosynthesis, and serve as the probe for the mechanisms of CP violation and primordial baryon charge inhomogeneity. The size of domains depends on the parameters of these mechanisms.

With the account for all possible mechanisms for inhomogeneous baryosynthesis, predicted on the base of various and generally independent extensions of the standard model, the general analysis of possible domain distributions is rather complicated. Fortunately, the test for the possibility of the existence of antistars in our Galaxy, offered in [7], turns to be practically model independent and as we show here may be accessible to cosmic ray experiments, to AMS experiment, in particular.

2. Antimatter globular cluster in our Galaxy

Assume some distribution of antimatter domains, which satisfies the constraints on antimatter annihilation in the early Universe. Domains, surviving after such annihilation, should have the mass exceeding

\[ M_{\text{min}} \approx (b/A)\rho_b f_a^3, \]

where \( \rho_b \) is the mean cosmological baryon density. The mass fraction \( f \) of such domains relative to total baryon mass is strongly model dependent. Note that since the diffusion to the border of antimatter domain is determined on RD stage by the radiation friction the surviving scale fixes the size of the surviving domain. On the other hand the constraints on the effects of annihilation put the upper limit on the mass of annihilated antimatter.

The modern antimatter domain distribution should be cut at masses given by the Eq. (3) due to annihilation of smaller domains and it is the general feature of any model of antibaryosynthesis in baryon asymmetrical Universe. The specific form of the domain distribution is model dependent. At the scales smaller than the Eq. (3) the spectrum should satisfy the constraints on the relative amount of annihilating antimatter. Provided that these constraints are satisfied one may consider the conditions for antimatter objects formation. One should take into account that the estimation of the annihilation scale after recombination (see [7]) gives for this scale the value close to the Jeans mass in the neutral baryon gas after recombination. So the development of gravitational instability may take place in antimatter domains resulting in the formation of astronomical objects of antimatter.
Formation of antimatter object has the time scale being of the order of $t_f \approx (\pi G \rho)^{-1/2}$. The object is formed provided that this time scale is smaller than the time scale of its collision with the matter clouds. The latter is the smallest in the beginning of the object formation, when the clouds forming objects have large size.

Note that the isolated domain can not form astronomical object smaller than globular cluster \[7\]. The isolated anti-star can not be formed in matter surrounding since its formation implies the development of thermal instability, during which cold clouds are pressed by hot gas. Pressure of the hot matter gas on the antimatter cloud is accompanied by the annihilation of antimatter. Thus anti-stars can be formed in the antimatter surrounding only, what may take place when such surrounding has at least the scale of globular cluster.

One should expect to find antimatter objects among the oldest population of the Galaxy \[7\]. It should be in the halo, since owing to strong annihilation of antimatter and matter gas the formation of secondary antimatter objects in the disc component of our Galaxy is impossible. So in the estimation of antimatter effects we can use the data on the spherical component of our Galaxy as well as the analogy with the properties of the old population stars in globular clusters and elliptical galaxies.

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 ($n \approx 3 \cdot 10^{-4}cm^{-3}$). Owing to small number density of antimatter gas effects of annihilation with the matter gas within the antimatter globular cluster are small. These effects, however, deserve special analysis for future search for antimatter cluster as the gamma source.

The integral effects of antimatter cluster may be estimated by the analysis of antimatter pollution of the Galaxy by the globular cluster of antistars.

There are two main sources of such pollution: the antistellar wind (the mass flow from antistars) and the antimatter Supernova explosions. The first source provides the stationary in-flow of antimatter particles with the velocity $10^7 \div 10^8 cm/s$ to the Galaxy. From the analogy with the elliptical galaxies, for which one has the mass loss $10^{-12}M_\odot$ per Solar mass per year, one can estimate the stationary admixture of antimatter gas in the Galaxy and the contribution of its annihilation into the gamma ray background. The estimation strongly depends on the distribution of magnetic fields in the Galaxy, trapping charged antiparticles. Crude estimation of the gamma flux from the annihilation of this antimatter flux is compatible with
the observed gamma background for the total mass of antimatter cluster less than $10^5 M_\odot$. This estimation puts upper limit on the total mass fraction of antimatter clusters in our Galaxy. Their integral effect should not contradict the observed gamma ray background.

The uncertainty in the distribution of magnetic fields causes even more problems in the reliable estimation of the expected flux of antinuclei in cosmic rays. It also is accomplished by the uncertainty in the mechanism of cosmic ray acceleration. The relative contribution of disc and halo particles into the cosmic ray spectrum is also unknown.

To have some feeling of the expected effect we may assume that the mechanisms of acceleration of matter and antimatter cosmic rays are similar and that the contribution of antinuclei into the cosmic ray fluxes is proportional to the mass ratio of globular cluster and Galaxy. Putting together the lower limit on the mass of the antimatter globular cluster from the condition of survival of antimatter domain and the upper limit on this mass following from the observed gamma ray background one obtains [7] the expected flux of antihelium nuclei in the cosmic rays with the energy exceeding 0.5 Gev/nucleon to be $10^{-8} \div 10^{-6}$ of helium nuclei observed in the cosmic rays.

Such estimation assumes that annihilation does not influence the antinuclei composition of cosmic rays, what may take place if the cosmic ray antinuclei are initially relativistic. If the process of acceleration takes place outside the antimatter globular cluster one should take into account the Coulomb effects in the annihilation cross section of non relativistic antinuclei, what may lead to suppression of their expected flux.

On the other side antinuclei annihilation invokes new factor in the problem of their acceleration, which is evidently absent in the case of cosmic ray nuclei. This factor may play very important role in the account for antimatter Supernovae as the possible source of cosmic ray antinuclei. From the analogy with elliptical galaxies one may expect [7] that in the antimatter globular cluster Supernovae of the I type should explode with the frequency about $2 \cdot 10^{-13}/M_\odot$ per year. On the base of theoretical models and observational data on SNI (see c.f. [10]) one expects in such explosion the expansion of a shell with the mass of about $1.4 M_\odot$ and velocity distribution up to $2 \cdot 10^9 cm/s$. The internal layers with the velocity $v < 8 \cdot 10^8 cm/s$ contain anti–iron $^{56}Fe$ and the outer layers with higher velocity contain lighter elements such as anti–
calcium or anti-silicon. Another important property of Supernovae of the I type is the absence of hydrogen lines in their spectra. Theoretically it is explained as the absence of hydrogen mantle in Presupernova. In the case of antimatter Supernova it may lead to strong relative enhancement of antinuclei relative to antiprotons in the cosmic ray effect. Note that similar effect is suppressed in the nuclear component of cosmic rays, since Supernovae of the II type are also related to the matter cosmic ray origin in our Galaxy, in which massive hydrogen mantles (with the mass up to few solar masses) are accelerated.

In the contrast with the ordinary Supernova the expanding antimatter shell is not decelerated owing to acquiring the interstellar matter gas and is not stopped by its pressure but annihilate with it [7]. In the result of annihilation with hydrogen, of which the matter gas is dominantly composed, semi-relativistic antinuclei fragments are produced. The reliable analysis of such cascade of antinuclei annihilation may be based on the theoretical models and experimental data on antiproton nucleus interaction. This programme is now under way. The important qualitative result is the possible nontrivial contribution into the fluxes of cosmic ray antinuclei with \( Z \leq 14 \) and the enhancement of antihelium flux. With the account for this argument the estimation of antihelium flux from its direct proportionality to the mass of antimatter globular cluster seems to give the lower limit for the expected flux.

Here we study another important qualitative effect in the expected antinuclear composition of cosmic rays. Cosmic ray annihilation in galactic disc results in the significant fraction of anti-helium-3 so that antihelium-3 to antihelium-4 ratio turns to be the signature of the antimatter globular cluster.

### 3. Equations for differential fluxes

Considering the \(^4\text{He}\) nuclei travelling through the Galactic disk we have to take into account two processes:

(i) the destruction of a nucleus in the inelastic interactions with the protons of the galactic media and

(ii) the energy losses during the travelling through the Galaxy.

For the \(^3\text{He}\) nuclei we need to take into account also the possibility of the \(^3\text{He}\) nuclei production due to the reaction

(iii) \(^4\text{He} + p \rightarrow ^3\text{He} + \text{all}\).
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 and
(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 He nuclei. The energy losses due to ionization and excitation of the hydrogen atoms per one collision are being described by the expression [11]:

\[
\alpha (\beta, z) = \frac{4\pi Z (z\alpha)^2}{m_e \beta^2} \left[ \ln \frac{2m_e\beta^2}{I (1 - \beta^2)} - \beta^2 \right],
\]

where, \(I\) is ionization potential of the hydrogen atom, \(I \approx 15 \text{ eV}\); \(Z = 1, z = 2\) are the electric charges of the hydrogen and helium nuclei, respectively, \(\beta = v/c\) is the dimensionless velocity and \(\alpha = 1/137\) is the fine structure constant.

The rates of the energy losses and the \(^3\text{He}\) nuclei destruction are:

\[
\begin{align*}
\frac{dE_{3,4}}{dt} & = -n_H v_{3,4} \alpha_{3,4} \\
\frac{dn_{3,4}}{dt} & = -n_H v_{3,4} \sigma_{ann}^{(3,4)} n_{3,4},
\end{align*}
\]

where \(n_H\) is the particle density of \(H\) atoms in the Galactic disc.

The source of \(^3\text{He}\) nuclei can be written in the form:

\[
\frac{dn_{3}^{(+)}(t, E_3)}{dt} = - \int_{E_3}^{\infty} dn_{4}(t, E_4) \frac{\partial W(E_4; E_3)}{\partial E_3}.
\]

\(\partial W(E_4; E_3)/\partial E_3\) describes the probability to produce \(^3\text{He}\) in the inelastic collision \(^\text{He} + p \rightarrow ^3\text{He} + \text{all}\), with the normalization condition:
\[
\int_{0}^{\infty} dE_3 \frac{\partial W(E_4; E_3)}{\partial E_3} = W_3(E_4).
\]

If we introduce the differential flux

\[
J(t, E) = v \frac{\partial n(t, E)}{\partial E}
\]

and the energy per nucleon \((E \rightarrow E/A)\), with \(A = 4\) — the atomic weight of the anti–helium nucleus, we obtain finally a system of the integro–differential equations, describing the behaviour of \(^4\text{He}\) and \(^3\text{He}\) nuclei in the Galaxy:

\[
\frac{dJ(t,E_4)}{dt} = -n_H c \beta_4 \left[ \sigma_{\text{inel}}(p_4) - A \frac{m_p^2}{p_4 E_4} \frac{d\varphi_4}{d\beta_4} \right] J(t, E_4),
\]

\[
\frac{dE_4}{dt} = -n_H c A^{-1} \beta_4 \varphi_4(\beta_4),
\]

\[
\frac{dJ(t,E_3)}{dt} = -n_H c \beta_3 \left[ \sigma_{\text{inel}}(p_3) - (A - 1) \frac{m_p^2}{p_3 E_3} \frac{d\varphi_3}{d\beta_3} \right] J(t, E_3) + n_H c \beta_3 \int_{E_3}^{\infty} dE_4 \sigma_4(p_4) \frac{\partial W(E_4; E_3)}{\partial E_3} J_4(t, E_4),
\]

\[
\frac{dE_3}{dt} = -n_H c (A - 1)^{-1} \beta_3 \varphi_3(\beta_3).
\]

4. The annihilation cross sections

Because the cross section of coherent interaction of the nucleon with a nuclei is not larger than \((10 - 15)\%\) of the inelastic cross section (see, e.g., [12]), we can neglect such processes and put:

\[
\sigma_{\text{ann}}(N\text{He}) \approx \sigma_{\text{inel}}(N\text{He}),
\]

where, \(\sigma_{\text{ann}}(N\text{He})\) is the cross section for the annihilation of \(^4\text{He}\) at its collision with
the nucleon and $\sigma_{inel}(NHe)$ is the inelastic cross section.

Total and elastic cross sections for the $pp$, $pn$, $\bar{p}p$, $\bar{p}n$ and $\bar{p}d$ ($d$ is the deuteron) can be found in [13]. For total cross sections at laboratory momentum $P_{lab} > 50$ GeV/c we used the parametrization, following from the Regge fenomenology [13]:

$$\sigma(pN)_{tot} = X s^\epsilon + Y s^{-\eta},$$

where,

$X_{ab} = X_{\bar{a}b}$

$X_{pp} = 22.0 \pm 0.6$

$X_{pn} = 22.6 \pm 0.6$

$Y_{pp} = 56.1 \pm 4.4$

$Y_{\bar{p}p} = 98.2 \pm 9.5$

$Y_{pn} = 55.0 \pm 4.1$

$Y_{\bar{p}n} = 92.7 \pm 8.6$

$\eta = 0.46 \pm 0.3$

$\epsilon = 0.079 \pm 0.003.$

At $0.1 < P_{lab} < 50$ GeV/c we used plots from [13] for the total and elastic cross sections.

Very scare experimental data on total and elastic cross sections for $p^4He$ can be found in [14, 15] and for $\bar{p}^4He$ in [12, 16, 17]. Using these data we found the $A$ dependence of the cross sections in the form:

$$\sigma(4He p) = A^{0.84} \times \frac{1}{2} [\sigma(pp) + \sigma(np)],$$

$$\sigma(\bar{4}He p) = A^{0.84} \times \frac{1}{2} [\sigma(\bar{p}p) + \sigma(\bar{n}p)].$$

We used the above $A$-dependence also for the inelastic cross section of $^3He p$ collisions. The inelastic cross sections for interaction of $^4He$, $^4He$ and $^3He$ with protons are shown in Fig.1. In this picture we also plotted the experimental points for $\sigma_{tot} = \sigma_{el}$ of the reactions $p^4He$ and $\bar{p}^4He.$


5. Results of the calculations

The experimental data from \cite{17,12} give for the probability to produce the \(^3He\) nucleus in \(^4He + p\) collision:

\[
\frac{\sigma(\bar{p}^3He \rightarrow ^3He + all)}{\sigma_{ann}(\bar{p}^4He)} \approx 0.25, \text{ at } P = 193 \text{ MeV}. \tag{12}
\]

We suggested that relative contribution to \(^3He\) does not depend on energy and used the above value.

For simplicity we suggested that the probability \(dW(E_4; E_3)/dE_3\) in Eq.(6) can be approximated by the \(\delta\)–function:

\[
\frac{\partial W(E_4; E_3)}{\partial E_3} = W_3 \delta(E_4 - E_3),
\]

with \(W_3\) from Eq.(12).

The initial fluxes for \(^4He\) and \(^7He\) we chose in the form:

\[
J_4(0, E) = 0.07 \times \frac{1.93 \beta}{E^2} \times 10^{-6} \text{ cm}^{-2} \text{s}^{-1} \text{sr}^{-1} (\text{GeV/nucleon})^{-1},
\]

\[
J_3(0, E) = 0. \tag{13}
\]

As the confinement time for He nuclei in the galactic disc, where the hydrogen number density is \(n_H \approx 1 \text{ atom/cm}^3\), we choose the typical timescale \(T_{conf} = 10^7 \text{ yr}\). We also accounted for the very low density of the matter in the Galactic halo.

Results of our calculations are shown in Fig.2. Solid line shows initial He flux, dashed and dot–dashed lines represent final fluxes of \(^7He\) and \(^3He\), respectively.

The first two equations in (7) can be applied to the \(^4He\) nuclei, if under the \(\sigma_{ann}\) one understands the inelastic interaction cross section of the \(^4He\) nucleus with the proton again neglecting the coherent processes. For comparison we also plotted by the dotted line the final flux of the \(^4He\), suggesting that the initial flux is the same as for \(^7He\).
In Fig.3 we plotted the ratios of fluxes $^{4}\text{He}/^{4}\text{He}$ and $^{3}\text{He}/^{4}\text{He}$ for two cases: upper curves for $M/M_{MW} = 10^{-6}$ and two lower curves for $M/M_{MW} = 10^{-8}$. These results are compared with the expected sensitivity of AMS experiment to antihelium flux. One finds AMS experiment accessible to complete test of the hypothesis on the existence of antimatter globular cluster in our Galaxy.

6. Discussion

The important result of the present work is that we found the substantial contribution of antihelium-3 into the expected antinuclear flux. Even in the case of negligible antihelium-3 flux originated in the halo its contribution into the antinuclear flux in the galactic disc should be comparable with the one of antihelium-4.

The estimations of [7], on which our calculations are based, assumed stationary in-flow of antimatter in the cosmic rays. In case Supernovae play the dominant role in the cosmic ray origin the in–flow is defined by their frequency. One may find from [7] that the interval of possible masses of antimatter cluster $3 \cdot 10^3 \div 10^5 M_{\odot}$ gives the time scale of antimatter in-flow $1.6 \cdot 10^9 \div 5 \cdot 10^7$ years, which exceeds the generally estimated life time of cosmic rays in the Galaxy. The succession of antinuclear annihilations may result in this case in the dominant contribution of antihelium and in particular antihelium-3 into the expected antinuclear flux. It makes antihelium signature sufficiently reliable even in this case.

Thus with all the reservations mentioned above on the base of the hypothesis on antimatter globular cluster in our Galaxy one may predict at the level of the expected 600 antiprotons up to ten antihelium events in the AMS–Shuttle experiment. Their detection would be exciting indication favouring this hypothesis. Even the upper limit on antihelium flux will lead to important constraint on the fundamental parameters of particle theory and cosmology to be discussed in our successive publications.

Note that the important source of background for antinuclear events in AMS-Shuttle experiment may be cosmic antiproton interaction with the matter of the shuttle. Such interaction should give significant back-directed flux of helium-4 imitating antihelium events in AMS detector. To have a feeling of this effect we may use the results of the numerical simulations by Lozhkin and Kramarovskiy [19] estimated the secondary nuclei multiplicities in the antiproton–iron interactions. According to these estimations which can be qualitatively correct at least for not very heavy nuclei the He-3 to He-4 ratio in such interactions does not exceed 1:8. Moreover on
the contrary to the case of antinuclei back-directed nuclear flux contains significant admixture of metastable isotopes, tritium, in particular. According to Lozhkin-Kramarovskiy calculations tritium to helium-4 ratio reaches in this case 1:3.5, what may be important for the removal of background events from the experimental data. Another interesting feature of the secondary nuclei multiplicity distributions is that being peaked at $z = 2$, it exceeds the level of 5% for $z \leq 6$ and then falls down to $(1 - 2)\%$ for higher $z$’s, giving negligible output for $z > 18$.

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Figure 1: Inelastic cross sections for: (a) \(^4\text{He} p\), (b) \((\overline{\text{He}} p)\) and (c) \((\overline{\text{He}} p)\) interactions. The closed circles are the experimental points for \(\sigma_{inel}(p^4\text{He})\) \cite{14, 15} and \(\sigma_{inel}(\overline{p}^4\text{He})\) \cite{12, 18}.
Figure 2: Calculated fluxes of $^4\overline{He}$ (dashed), $^4He$ (dotted) and $^3\overline{He}$ (dash–dotted). Solid line presents initial flux for $^4He$ nuclei. The confinement time has been chosen equal to $10^7$ years.
Figure 3: Ratios of fluxes $^4\text{He}/^4\text{He}$ (dashed) and $^3\text{He}/^4\text{He}$ (dash–dotted). Two upper curves correspond to the case of the maximal possible mass of antimatter globular cluster $M_{\text{max}} = 10^5 M_\odot$ and the two lower curves to the case of the minimal possible mass of such cluster $M_{\text{min}} = 10^3 M_\odot$. The results of calculations are compared with the expected sensitivity of AMS experiment [20] (solid lines).