1 Introduction

During the big bang, the same proportions of matter and antimatter should have appeared. But the world we live in is almost entirely made of matter. Something has happened to upset this balance. One of the global challenges of modern particle physics is to understand what caused this imbalance.

A particle and an antiparticle have the same mass, but some qualities, such as electric charge, are opposite. In those days when the Universe existed for less than a second, particle-antiparticle pairs were born and annihilated. In this case, if the particle and the antiparticle disappear in pairs, then the Universe should not contain anything except the energy from annihilation.

For a long time, the generally accepted factor of the baryonic asymmetric Universe was the fact that there was no macroscopic object of antimatter in direct observations within 20 mpc from the solar system. In addition, when the size of such an object is more than 20 mpc, a discrepancy appears with the fact of the homogeneity of the relict radiation, since this would allow the presence of rather significant voids.

The possible existence of remote deposits of cosmic antimatter was studied earlier [2, 3]. Steigman [2] came to the conclusion that the observations rule out significant impurities of matter and antimatter in objects ranging in size from planets to galaxy clusters. Omes wanted to dynamically separate baryons and antibaryons, but his assumptions were not consistent with the principles of hadronic physics, and also contradicted the restrictions on domain annihilation.

Cohen, De Rujula, Glashow in their work [1] explored the possibility of a universal (but not requiring) set of matter and antimatter based on the consideration of inflationary cosmology, in which the baryon (or antibaryon) excess forms according to Sakharov [4]. In models with spontaneous CP violation, the Lagrangian can be chosen so that the "polarity" of CP detection changes in a random jump and regularly depending on their exit from their horizons during settling (we will consider this mechanism in more detail). After baryogenesis, the domain walls located at the boundary between the matter and antimatter evaporate. Further, matter or antimatter later again returns to their horizons, the Universe (B=0) becomes a two-phase belonging.

Here, modern domains are assumed to be d in size, so 1/d is their average surface-to-volume ratio. From the impossibility of the existence of antigalaxies within the region of matter, one can set a limit on the distribution of domains smaller than d.

The current size of the domain d is the only parameter of the Universe B=0 that is crucial for matching theory with observation. To meet the constraints of X-ray clusters, d must exceed the minimum value,$\sim$ 20 Mpc. At d = 20 Mpc, the visible Universe will consist of $\sim 10^7$ domains. Thus, a stronger lower bound on d is obtained, comparable to the current size of the visible Universe, excluding the Universe B = 0. This means the impossibility of the existence of a Universe symmetric with respect to matter and antimatter.

The annihilation, which would take place at the border between matter and antimatter region, during the period $1100 > z > 20$, would disturb the diffuse γ − ray background, if the size of matter or antimatter regions does not exceed

10^3Mpc. But in such reasoning, the case is not excluded when the Universe is practically asymmetric, with the exception of small inclusions of primary antimatter. Therefore, it is quite possible to expect the presence of such domains in our Universe [5]. The baryosynthesis scenario proposed by Sakharov [4] is satisfied in the GUT models. An excess of baryons is generated in nonequilibrium B-nonconserved processes in which CP violation is present. Such nonconserved processes lead to an asymmetry in which $B < 0$ in regions where the phase of the scalar field of the model is negative.

An identical argument works for models with nonconservation of the electroweak baryon charge at high temperatures, as well as for models where, in addition to the latter, nonconservation of the lepton number is added due to the physics of the Majorana neutrino mass.

What these approaches have in common is the presence of a CP violation field dependent on the spatial phase.

2 Evolution of macroscopic areas of antimatter

2.1 The Formation scenario.

We assume [6] the existence of a complex scalar field $\chi = (f/\sqrt{2})exp(\theta)$, which carries a baryon charge with clearly broken symmetry U(1). This violation occurs due to the phase dependence tilting the Nambu-Goldstone (NG) potential.

The radial mass m_χ of field χ in our approach is assumed to be greater than the Hubble constant during the inflation stage $m_\chi >> H$. At the same time, the angular mass must satisfy the opposite criterion $m_\theta << H$. This will guarantee that our symmetry U(1) will be broken spontaneously already at the beginning of the inflation period, but the the tilt of the potential will disappear due to the still high vacuum energy.

Hence it follows that the phase θ of our field behaves like an ordinary massless NG boson. And the scale f of the spontaneous breaking of symmetry U(1) sets the radius of NG potential. The phase of the changing part of the Universe depending on the quantum fluctuations of the massless angular component θ in the de Sitter space.

Such fluctuations can be interpreted as one-dimensional Brownian motion[7] along the valley of the circle, using the bottom of the possibility of the NG. If the energy of the vacuum becomes less, then a potential arises and then begins to fluctuate. Let $\theta = 0$ correspond to the south pole of the valley of the circle, then $\theta = \pi$ is opposite (Fig.1). Possible field χ behavior that violates the lepton number can have the following picture: When θ rolls clockwise during the first oscillation, it creates baryons, if counterclockwise, then antibaryons [6, 8]. Therefore, in order for the Universe to have a pronounced domination of baryons, it is necessary that theta be located in the range $[\pi, 0]$ at the beginning of the inflation period, or in other words, at the moment when the size of the Universe crossed the horizon.

Then, the next fluctuations move the phase to points $\overline{\theta_i}$ out of the range $[\pi, 0]$, an excessive production of antibaryons occurs. If such processes begin before the Universe 15 times increases [6], then the size of the domain will be larger than the size critical for survival l_c. Take the phase of the field at a point θ_{60} in the range

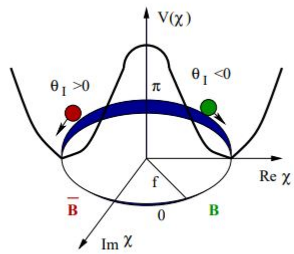

Figure 1: PNG potential in the spontaneous baryogenesis mechanism. The sign of produced baryon asymmetry depends on the starting point of oscillations.

$[\pi, 0]$ and for simplicity assume the total number of folds is 60. The phase will make a fluctuation step $\delta\theta = H/(2\pi f)$ in each such e-fold. Because the typical wavelength of the fluctuation $\delta\theta$ generated during such timescale is equal to H^1, the whole domain H^1, containing θ_{60}, after one e–fold effectively becomes divided into e^3 separate, causal disconnected domains of radius H^1.

Each area contains an almost uniform phase value $\theta_{60-1} = \theta_{60} \pm \delta\theta$. In half of these areas, the phase evolves towards π (North Pole), while in other areas it approaches zero (South Pole). To have a domain of a suitable size, in order to avoid complete annihilation, we must require that the phase value π or zero should be crossed no later than 15 steps. Numerical calculations [6] of the size distribution of domains filled with the corresponding values of the $\overline{\theta_i}$ phase for the generation of antibaryons show that the volume box corresponding to each Galaxy can contain from 1 to 10 such regions, provided that their total fraction is from all volume is many orders of magnitude less than 1.

The last conclusion makes sure that the universe will become baryon asymmetric as a whole. At the some moment after the end of inflation deeply at the Friedman epoch the condition $m_\theta << H$ is violated and the oscillations of θ around the minima of PNG potential are started. Then the stored energy density$_\theta \approx \theta^2 m_\theta^2 f^2$ will convert into baryons and antibaryons. All domains where the phase starts to oscillate from the values $\overline{\theta_i}$ will contain antimatter. The density of antimatter depends on the initial value $\overline{\theta_i}$ and can be different in the different domains. The average number density of surrounding matter should be normalised on the observable one $n_B/s \approx 3 \cdot 10^{-10}$. This normalisation sets the condition $f/m_\theta \leq 10^{10}$ for the PNG potential [6].

3 Possibility of existence of macroscopic object in the Galaxy in the form of globular cluster of antistars

It can be assumed that the domains described above satisfied the restrictions on the annihilation of antimatter in the early stages of the evolution of the Universe. Then such domains should have a mass exceeding the critical mass. The mass ratio of all such domains to the total baryon mass varies greatly from model to model. On the other hand, restrictions on the observed effects of annihilation place their restrictions on the upper limit of the mass of annihilated antimatter.

The condition for the existence of a critical mass for the survival of domains is a common property of all models of antibaryosynthesis in an asymmetric baryonic universe. If this condition is met, it is already possible to consider the probability of the formation of macroscopic antimatter objects.

It is also important to note and this should be taken into account that the estimate of the scale of annihilation gives a value close to the Jeans mass in the neutral gas of baryons after the recombination stage. Therefore, the occurrence of gravitational instability in the region of the presence of antibaryons leads to the formation of macroscopic objects from antimatter.

The formation of an antimatter object occurs on the time scale $t_f \approx (\pi G\rho)^{-1/2}$. An object can form only if the given time scale is less than the time of collision of the object with the surrounding matter. The latter is the smallest at the beginning of the formation of the object, when the clouds forming the objects are large.

An isolated region of antimatter cannot form an astronomical object smaller than a globular cluster of antistars [9]. Since an antistar cannot form in a material environment, its formation will assume thermal instability, in which cold clouds are squeezed by hot baryonic gas. The pressure of matter on a cloud of antimatter is always accompanied by annihilation. That is why anti-stars can form only in an environment of antimatter, and this takes place when the antibaryon domain is at least comparable in size to the size of a globular cluster of antistars.

4 Gamma background and antihelium flux

It is logical to expect that antimatter objects will be the oldest objects in the population of the Galaxy [9]. It should also be absolutely clear that it should be in the Halo, in order to avoid annihilation, that is, where the substance will be very rarefied. Therefore, when assessing the effects of antimatter accumulation, one can use data on the structure of our Galaxy, analogies with the properties and evolution of old globular clusters in elliptical galaxies.

Such a globular cluster will move with high speed (this follows from the velocity dispersion in the halo($v \approx 150$ km/s) through the rarefied interstellar medium of matter (density $n \approx 3 \cdot 10^4 cm^3$), so the effects of annihilation inside the accumulation of penetrating matter will be small.But even such small effects deserve a separate analysis to search for an antimatter cluster as a source of gamma radiation in the future.

The integral effects of the such cluster can be estimated by analyzing the antimatter pollution of the Galaxy by the antistar globular cluster.

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 this process: anti-stellar wind (mass flow from anti-stars) and anti-supernova explosions. The first source will give a steady flow of antiparticles with a rather low velocity of$10^7 - 10^8$ into the Galaxy. By analogy with how it happens in elliptical galaxies, which lose $10^{-12}M$ per year, it becomes possible to estimate the stationary component of antimatter in the Galaxy and also the contribution of such annihilation to the gamma background. The distribution of galactic magnetic fields will have a significant impact on this estimate. A rough estimate of the gamma flux from the annihilation of this antimatter flux corresponds to the observational gamma background data for the entire mass of the antimatter cluster less than $10^5 M$. This estimate sets the upper limit for the total mass of all clusters of antimatter in our Galaxy.

We assume that the contribution of antinuclei from a globular cluster is proportional to the ratio of the mass of the globular cluster to the mass of the Galaxy. Choosing the lower critical mass of a globular antimatter cluster from the condition of survival of the antimatter region and the upper limit of this mass taken from the observed background of gamma radiation, we obtain [9] the range of the expected flux of antihelium nuclei in cosmic rays with an energy of more than 0.5 GeV/nucleon is $10^8 - 10^6$ helium nuclei that can be observed in 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 [9] that in the antimatter globular cluster Supernovae of the I type should explode with the frequency about $2 \cdot 10^{-13} M$ per year.

On the base of theoretical models and observational data on SNI one expects in such explosion the expansion of a shell with the mass of about $1.4M$ 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 [9]. 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.

5 Methods of detection of GC in the Galaxy

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. AMS, PAMELA, BESS experiments turns to be important tool in such analysis. The expected progress in the measurement of cosmic rays fluxes and gamma background and in the search for antinuclei and exotic charged particles make this experiments important source of information on the possible cosmological effects of particle theory.

The results of numerical calculation of the expected antihelium flux on fig.2. Pay attention to how small the values of antihelium fluxes are. To register sec-

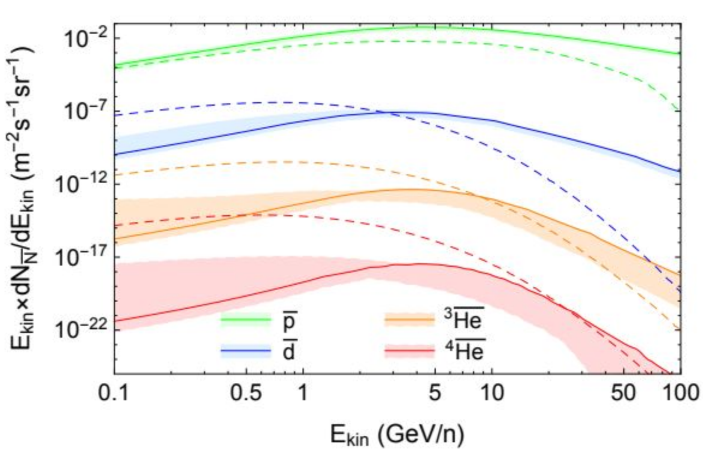

Figure 2: The spectrum of cosmic-ray $\overline{p}$ (green), $\overline{d}$ (blue), ^3He (orange) and ^4He (red) predicted from standard astrophysical production (solid curves), along with the uncertainty associated with this prediction (bands), for the case of ISM Model [10]

ondary antihelium you need to go down to the level of sensitivity from ten to the power of minus twelve to from ten to the power of minus seventeen $10^{-12} - 10^{-17}$.

At the present time the following bound on the flux of the antihelium-4 in cosmic rays is found [11] : BESS: $\overline{He}/He < 3 \cdot 10^7$. More restrictive limits are expected: PAMELA:$\overline{He}/He < 3 \cdot 10^8$; AMS-2: $\overline{He}/He < 3 \cdot 10^9$ but not yet reported.

If the experiment will register antihelium nuclei in future at sensitivity levels higher than secondary ones, then registered nuclei will be from a primary source, for example, from a globular cluster or from exotic sources. An accurate analysis of the obtained will give an answer to the origin of the primary antimatter obtained in the experiment.

6 Other view on existence of macroscopic antimatter

Due to the variability of the parameters of the mechanism of spontaneous violation of asymmetry, there are some rather amusing works by A.D. Dolgov [11], which is difficult to pass by. The approach is almost symmetrical to the one discussed above with the only difference. The difference lies in the density of the macroscopic area. It is set much higher than the baryon density. This assumes a compact size and elegantly bends around the annihillatory gamma background.

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