Stable quarks of the 4th family?

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Abstract

Existence of metastable quarks of new generation can be embedded into phenomenology of heterotic string together with new long range interaction, which only this new generation possesses. We discuss primordial quark production in the early Universe, their successive cosmological evolution and astrophysical effects, as well as possible production in present or future accelerators. In case of a charge symmetry of 4th generation quarks in Universe, they can be stored in neutral mesons, doubly positively charged baryons, while all the doubly negatively charged "baryons" are combined with He-4 into neutral nucleus-size atom-like states. The existence of all these anomalous stable particles may escape present experimental limits, being close to present and future experimental test. Due to the nuclear binding with He-4 primordial lightest baryons of the 4th generation with charge +1 can also escape the experimental upper limits on anomalous isotopes of hydrogen, being compatible with upper limits on anomalous lithium. While 4th quark hadrons are rare, their presence may be nearly detectable in cosmic rays, muon and neutrino fluxes and cosmic electromagnetic spectra. In case of charge asymmetry, a nontrivial solution for the problem of dark matter (DM) can be provided by excessive (meta)stable anti-up quarks of 4th generation, bound with He-4 in specific nuclear-interacting form of dark matter. Such candidate to DM is surprisingly close to Warm Dark Matter by its role in large scale structure formation. It catalyzes primordial heavy element production in Big Bang Nucleosynthesis and new types of nuclear transformations around us.

1 Introduction

The question about existence of new quarks and/or leptons is among the most important in the modern particle physics. Possibility of existence of new (meta)stable quarks which form new (meta)stable hadrons is of special interest. New stable hadrons can play the role of strongly interacting dark matter [1–3]. This question is believed to find solution in the framework of future Grand Unified Theory. A strong motivation for existence of new long-living hadrons comes from a possible solution [4] of the "doublet-triplet splitting" problem in supersymmetric GUT models. Phenomenology of string theory offers another motivation for new long lived hadrons.

A natural extension of the Standard model can lead in the heterotic string phenomenology to the prediction of fourth generation of quarks and leptons [5, 6] with a stable 4th
neutrino [7–10]. The comparison between the rank of the unifying group $E_6$ ($r = 6$) and the rank of the Standard model ($r = 4$) can imply the existence of new conserved charges. These charges can be related with (possibly strict) gauge symmetries. New strict gauge U(1) symmetry (similar to U(1) symmetry of electrodynamics) is excluded for known particles but is possible, being ascribed to the fermions of 4th generation only. This provides theoretic motivation for a stability of the lightest fermion of 4th generation, assumed to be neutrino. Under the condition of existence of strictly conserved charge, associated to 4th generation, the lightest 4th generation quark $Q$ (either $U$ or $D$) can decay only to 4th generation leptons owing to GUT-type interactions, what makes it sufficiently long living.

Whatever physical reason was for a stability of new hypothetical particles, it extends potential for testing respective hypothesis due to its implications in cosmology. Especially rich in this sense is a hypothesis on (meta)stable quarks of new family. It defines the goal of current work.

As we will show, in the case when 4th generation possesses strictly conserved $U(1)$-gauge charge (which will be called $y$-charge), 4th generation fermions are the source of new interaction of Coulomb type (which we’ll call further $y$-interaction). It can be crucial for viability of model with equal amounts of 4th generation quarks and antiquarks in Universe. The case of cosmological excess of 4th generation antiquarks offers new form of dark matter with a very unusual properties. Owing to strict conservation of $y$-charge, this excess should be compensated by excess of 4th generation neutrinos.

Recent analysis [11] of precision data on the Standard model parameters admits existence of the 4th generation particles, satisfying direct experimental constraints which put lower limit $220$ GeV for the mass of lightest quark [12].

If the lifetime of the lightest 4th generation quark exceeds the age of the Universe, primordial $Q$-quark (and $Q$-quark) hadrons should be present in the modern matter. If this lifetime is less than the age of the Universe, there should be no primordial 4th generation quarks, but they can be produced in cosmic ray interactions and be present in cosmic ray fluxes. The search for this quark is a challenge for the present and future accelerators.

In the present work we will assume that up-quark of 4th generation ($U$) is lighter than its down-quark ($D$). The opposite assumption is found to be virtually excluded, if $D$ is stable. The reason is that $D$-quarks might form stable hadrons with electric charges $\pm 1$ ($(DDD)^-$, $(D D u)^+$, $(D \bar{D} D)^+$), which eventually form hydrogen-like atoms (hadron $(DDD)^-$ is combined with $^4He^{++}$ into +1 bound state), being strongly constrained in surrounding matter. It will become more clear from consideration of $U$-quark case, presented below.

The following hadron states containing (meta)stable $U$-quarks ($U$-hadrons) are expected to be (meta)stable and created in early Universe: “baryons” $(U u d)^+$, $(U U u)^+$, $(UUU)^+$; “antibaryons” $(\bar{U} \bar{U} \bar{U})^-$, $(\bar{U} \bar{U} \bar{u})^-$, meson $(\bar{U} u)^0$. The absence in the Universe of the states $(\bar{U} \bar{u} \bar{d})$, $(\bar{U} \bar{u})$ containing light antiquarks are suppressed because of baryon asymmetry. Stability of double and triple $U$ bound states $(U U u)$, $(U U U)$ and $(\bar{U} \bar{U} \bar{u})$, $(\bar{U} \bar{U} \bar{U})$ is provided by the large chromo-Coulomb binding energy ($\propto \alpha_q^{2} \cdot m_Q$) [13, 14]. Formation of these states in particle interactions at accelerators and in cosmic rays is strongly suppressed, but they can form in early Universe and cosmological analysis of their relics can be of great importance for the search for 4th generation quarks.

We analyze the mechanisms of production of metastable $U$ (and $\bar{U}$) hadrons in the early Universe, cosmic rays and accelerators and point the possible signatures of their existence.
We’ll show that in case of charge symmetry of U-quarks in Universe, a few conditions play a crucial role for viability of the model. An electromagnetic binding of \((\bar{U}U\bar{U})^{-}\) with \(4He^{++}\) into neutral nucleus-size atom-like state \((O-Helium)\) should be accompanied by a nuclear fusion of \((Ud)^{+}\) and \(4He^{++}\) into lithium-like isotope \([^{4}He(Uud)]\) in early Universe. The realization of such a fusion requires a marginal supposition concerning respective cross section. Furthermore, assumption of \(U(1)\)-gauge nature of the charge, associated to U-quarks, is needed to avoid a problem of overproduction of anomalous isotopes by means of a \(y\)-annihilation of U-relics \([^{4}He(Uud)], (UuU), (UUU), 4He(\bar{U}\bar{U}\bar{U}), 4He(\bar{U}U\bar{u}), (\bar{U}u)\). Residual amount of U-hadrons with respect to baryons in this case is estimated to be less than \(10^{-10}\) in Universe toto and less than \(10^{-20}\) at the Earth.

A negative sign charge asymmetry of U-quarks in Universe can provide a nontrivial solution for dark matter (DM) problem. For strictly conserved charge such asymmetry in \(\bar{U}\) implies corresponding asymmetry in leptons of 4th generation. In this case the most of \(\bar{U}\) in Universe are contained in \(O-Helium\) states \([^{4}He(\bar{U}U\bar{U})]\) and minor part of them in mesons \(\bar{U}u\). On the other hand the set of direct and indirect effects of relic U-hadrons existence provides the test in cosmic ray and underground experiments which can be decisive for this hypothesis. The main observational effects for asymmetric case do not depend on the existence of \(y\)-interaction.

The structure of this paper is as the following. Section 2 is devoted to the charge symmetric case of U-quarks. Cosmological evolution of U-quarks in early Universe is considered in subsection 2.1, while in subsection 2.2 the evolution and all possible effects of U-quarks existence in our Galaxy are discussed. The case of charge asymmetry of quarks of 4th generation in Universe is considered in Section 3. Section 4 is devoted to the questions of the search for U-quarks at accelerators. We summarize the results of our present study, developing earlier investigations [15, 16], in Conclusion.

## 2 Charge symmetric case of U-quarks

### 2.1 Primordial U-hadrons from Big Bang Universe

**Freezing out of U-quarks**

In the early Universe at temperatures highly above their masses fermions of 4th generation were in thermodynamical equilibrium with relativistic plasma. When in the course of expansion the temperature \(T\) falls down below the mass of the lightest \(U\)-quark, \(m\), equilibrium concentration of quark-antiquark pairs of 4th generation is given by

\[
n_{4} = g_{4} \left( \frac{Tm}{2\pi} \right)^{3/2} \exp \left( -m/T \right),
\]

where \(g_{4} = 6\) is the effective number of their spin and colour degrees of freedom. We use the units \(\hbar = c = k = 1\) throughout this paper.

The expansion rate of the Universe at RD-stage is given by the expression

\[
H = \frac{1}{2t} = \sqrt{\frac{4\pi^{3}g_{tot}}{45}} \frac{T^{2}}{m_{Pl}} \approx 1.66 \frac{1}{g_{tot}} \frac{T^{2}}{m_{Pl}},
\]
where temperature dependence follows from the expression for critical density of the Universe
\[
\rho_{\text{crit}} = \frac{3H^2}{8\pi G} = g_{\text{tot}} \frac{\pi^2}{30} T^4.
\]
When it starts to exceed the rate of quark-antiquark annihilation
\[
R_{\text{ann}} = n_4 \langle \sigma v \rangle,
\]
in the period, corresponding to \( T = T_f < m_4 \), quarks of 4th generation freeze out, so that their concentration does not follow the equilibrium distribution Eq.(1) at \( T < T_f \). For a convenience we introduce the variable
\[
r_4 = \frac{n_4}{s},
\]
where
\[
s = \frac{2\pi^2 g_{\text{tot}} s}{45} T^3 \approx 1.80 g_{\text{tot}} s n_\gamma \approx 1.80 g_{\text{mod}} s n_B^{-1} n_B
\]
is the entropy density of all matter. In Eq.(5) \( s \) was expressed through the thermal photon number density \( n_\gamma = \frac{2c(3)}{\pi} T^3 \) and also through the baryon number density \( n_B \), for which at the modern epoch we have \( n_B^{\text{mod}} / n_\gamma^{\text{mod}} = \eta \approx 6 \cdot 10^{-10} \).

Under the condition of entropy conservation in the Universe, the number density of the frozen out particles can be simply found for any epoch through the corresponding thermal photon number density \( n_\gamma \). Factors \( g_{\text{tot}} \) and \( g_{\text{tot}} s \) take into account the contribution of all particle species and are defined as
\[
g_{\text{tot}} = \sum_{i=\text{bosons}} g_i \left( \frac{T_i}{T} \right)^4 + \frac{7}{8} \sum_{i=\text{fermions}} g_i \left( \frac{T_i}{T} \right)^4,
\]
and
\[
g_{\text{tot}} s = \sum_{i=\text{bosons}} g_i \left( \frac{T_i}{T} \right)^3 + \frac{7}{8} \sum_{i=\text{fermions}} g_i \left( \frac{T_i}{T} \right)^3,
\]
where \( g_i \) and \( T_i \) are the number of spin degrees of freedom and temperature of ultrarelativistic bosons or fermions. For epoch \( T < m_e \approx 0.5 \text{ MeV} \) it is assumed that only photons and neutrinos with \( T_\nu = (4/11)^{1/3} T \) give perceptible contribution into energy (until the end of RD-stage) and entropy (until now) densities so one has
\[
g_{\text{mod}}^{\text{tot}} s \approx 3.91 \quad g_{\text{mod}}^{\text{tot}} \approx 3.36.
\]
For modern entropy density we have \( s_{\text{mod}} \approx 2890 \text{ cm}^{-3} \).

From the equality of the expressions Eq.(2) and Eq.(3) one gets
\[
m/T_f \approx 42 + \ln(g_{\text{tot}}^{-1/2} m_p m \langle \sigma v \rangle)
\]
with \( m_p \) being the proton mass and obtains, taking \( \langle \sigma v \rangle \sim \frac{\alpha_{\text{QCD}}^2}{m^2} \) and \( g_{\text{tot}}(T_f) = g_f \approx 80 - 90 \),
\[
T_f \approx m/30
\]
and

\[ r_4 = \frac{H_f}{s_f \langle \sigma v \rangle} \approx \frac{4}{g_f^{1/2} m_{Pl} T_f \langle \sigma v \rangle} \approx 2.5 \cdot 10^{-14} \frac{m}{250 \text{ GeV}}. \tag{7} \]

Index "T" means everywhere that the corresponding quantity is taken at \( T = T_f \). Note, that the result Eq.(7), obtained in approximation of "instantaneous" freezing out, coincides with more accurate one if \( \langle \sigma v \rangle \) and \( g_f \) can be considered (as in given case) to be constant. Also it is worth to emphasize, that given estimation for \( r_4 \) relates to only 4th quark or 4th antiquark abundances, assumed in this part to be equal to each other.

Note that if \( T_f > \Delta = m_D - m \), where \( m_D \) is the mass of \( D \)-quark (assumed to be heavier, than \( U \)-quark) the frozen out concentration of 4th generation quarks represent at \( T_f > T > \Delta \) a mixture of nearly equal amounts of \( U \bar{U} \) and \( D \bar{D} \) pairs.

At \( T < \Delta \) the equilibrium ratio

\[ \frac{D}{U} \propto \exp \left( -\frac{\Delta}{T} \right) \]

is supported by weak interaction, provided that \( \beta \)-transitions \((U \rightarrow D)\) and \((D \rightarrow U)\) are in equilibrium. The lifetime of \( D \)-quarks, \( \tau \), is also determined by the rate of weak \((D \rightarrow U)\) transition, and at \( t \gg \tau \) all the frozen out \( D \bar{D} \) pairs should decay to \( U \bar{U} \) pairs.

At the temperature \( T_f \) annihilation of \( U \)-quarks to gluons and to pairs of light quarks \( U \bar{U} \rightarrow gg, q\bar{q} \) terminates and \( U \bar{U} \) pairs are frozen out. The frozen out concentration is given by Eq.(7). Even this value of primordial concentration of \( U \)-quarks with the mass \( m = 250 \text{ GeV} \) would lead to the contribution into the modern density \( 2 m r_4 s_{\text{mod}} \), which is by an order of magnitude less than the baryonic density, so that in the charge symmetric case \( U \)-quarks can not play a significant dynamical role in the modern Universe.

The actual value of primordial \( U \)-particle concentration should be much smaller due to QCD, hadronic and radiative recombination, which reduce the abundance of frozen out \( U \)-particles. \( y \)-Interaction can play essential role in successive evolution to be considered. It accounts for radiative recombination and plays crucial role in galactic evolution of \( U \)-hadrons. So, it will be included into further consideration which will be carried out for both sub-cases (with and without \( y \)-interaction).

**QCD recombination**

At

\[ T \leq I_1 = m \bar{\alpha}^2 / 4 = 3.2 \text{ GeV} \frac{m}{250 \text{ GeV}}, \]

where \( \bar{\alpha} = 0.23 \) accounts for joint effect of Coulomb-like attraction due to QCD and \( y \)-interactions, formation of bound \((U \bar{U})\) states is possible, in which frozen out Heavy quarks and antiquarks can annihilate. Effect of \( y \)-interaction is not essential here.

Note that at \( T \leq I_1 \) rate of \((U \bar{U})\) annihilation in bound systems exceeds the rate of "ionization" of these systems by quark gluon plasma. So the rate of QCD recombination, given by [14, 15]

\[ \langle \sigma v \rangle \approx \left( \frac{16\pi}{3^{5/2}} \right) \cdot \frac{\bar{\alpha}}{T^{1/2} \cdot m_U^{3/2}}, \tag{8} \]

is the rate, with which abundance of frozen out \( U \)-quarks decreases.
The decrease of $U$-hadron abundance owing to $U \bar{U}$ recombination is governed by the equation

$$\frac{dn_4}{dt} = -3Hn_4 - n_4^2 \cdot \langle \sigma v \rangle.$$ (9)

Using notation Eq.(4) and relation

$$-dt = \frac{dT}{HT},$$ (10)

which follows from Eq.(2) and is true as long as $g_{tot} \approx \text{const}$, Eq.(9) is reduced to

$$dr_4 = r_4^2 \cdot sHT \langle \sigma v \rangle dT,$$ (11)

where

$$sHT = \sqrt{\frac{\pi g}{45}} \text{ with } g \equiv g_{tot}^2 / g_{tot} = (\text{for } T > m_e) = g_{tot} s = g_{tot}.$$ (12)

At $T_0 = I_1 > T > T_{QCD} = T_1$, assuming in this period $g = \text{const} = g_f \approx 17$, the solution of Eq.(11) is given by

$$r_4 = \frac{r_0}{1 + r_0 \sqrt{\frac{\pi g}{45} m_{PL} \int_{T_0}^{T_1} \langle \sigma v \rangle dT}} \approx 0.16 \left(\frac{m}{I_1}\right)^{1/2} \frac{m}{\bar{m} m_{PL}} \approx$$

$$\approx 1.6 \cdot 10^{-16} \frac{m}{250 \text{ GeV}}.$$ (13)

It turns to be independent on the frozen out concentration $r_0$ given by Eq.(7).

At $T < I_{UU} \leq m\bar{\alpha}^2/4 = 1.6 \text{ GeV} \cdot m_{250 \text{ GeV}}$, where effective constant $\bar{\alpha} = C_F \alpha_s - \alpha_y \sim (4/3) \cdot 0.144 - 1/30 = 0.16$ accounts for repulsion of the same sign $y$-charges, reactions $U + U \rightarrow (UU) + g$ and $U + (UU) \rightarrow (UUU) + g$ can lead to formation $(UU)$-diquark and colorless $(UUU)$ “hadron” (as well as similar $\bar{U}$ bound states) in quark gluon plasma [13, 14]. However, disruption of these systems by gluons in inverse reactions prevents their effective formation at $T \gtrsim I_{UU}/30$ [14]. Therefore, such systems of $U$ quarks with mass $m < 700 \text{ GeV}$ are not formed before QCD phase transition.

**Hadronic recombination**

After QCD phase transition at $T = T_{QCD} \approx 150 \text{ MeV}$ quarks of 4th generation combine with light quarks into $U$-hadrons. In baryon asymmetrical Universe only excessive valence quarks should enter such hadrons. Multiple $U$ states formation can start only in processes of hadronic recombination for $U$-quark mass $m < 700 \text{ GeV}$ what is discussed below.

As it was revealed in [5, 6] in the collisions of such mesons and baryons recombination of $U$ and $\bar{U}$ into unstable $(UU)$ “charmonium -like” state can take place, thus successively reducing the $U$-hadron abundance. Hadronic recombination should take place even in the absence of long range $y$-interaction of $U$-particles. So, we give first the result without the account of radiative recombination induced by this interaction.

There is a large uncertainties in the estimation of hadronic recombination rate. The maximal estimation for the reaction rate of recombination $\langle \sigma v \rangle$ is given by

$$\langle \sigma v \rangle \sim \frac{1}{m^2_\pi} \approx 6 \cdot 10^{-16} \frac{\text{cm}^3}{\text{s}}.$$ (13)

or by

$$\langle \sigma v \rangle \sim \frac{1}{m^2_\rho} \approx 2 \cdot 10^{-17} \frac{\text{cm}^3}{\text{s}}.$$ (14)
The minimal realistic estimation gives [15]

\[ \langle \sigma v \rangle \approx 0.4 \cdot (T_{\text{eff}} m^3)^{-1/2} (3 + \log (T_{\text{QCD}} / T_{\text{eff}})), \]  

(15)

where \( T_{\text{eff}} = \max \{ T, \alpha y m_{\pi} \} \).

Solution of Eq.(11) for \( \langle \sigma v \rangle \) from the Eq.(13) is given by

Case A

\[ r_4 = \frac{r_0}{1 + r_0 \cdot \sqrt{\frac{\pi g_{\text{QCD}}}{45} m_{\rho} T_{\text{QCD}}}} \approx 1.0 \cdot 10^{-20} \]  

(16)

and it is \((m_{\rho} / m_{\pi})^2 \sim 30\) times larger for \( \langle \sigma v \rangle \) from the Eq.(14):

Case B

\[ r_4 = \frac{r_0}{1 + r_0 \cdot 2 \cdot \sqrt{\frac{\pi g_{\text{QCD}}}{45} m_{\rho} T_{\text{QCD}}}} \approx 3.0 \cdot 10^{-19}. \]  

(17)

For the minimal estimation of recombination rate (15) the solution of Eq.(11) has the form

\[ r_4 = \frac{r_0}{1 + r_0 \cdot 2 \cdot \sqrt{\frac{\pi g_{\text{QCD}}}{45} m_{\rho} T_{\text{QCD}}}} \]  

(18)

where in all the cases \( r_0 \) is given by Eq.(12) and \( g_{\text{QCD}} \approx 15 \). We neglect in our estimations possible effects of recombination in the intermediate period, when QCD phase transition proceeds.

The solutions (16) and (17) are independent on the actual initial value of \( r_4 = r_0 \), if before QCD phase transition it was of the order of (12). For the minimal estimation of the recombination rate (15) the result of hadronic recombination reads

Case C

\[ r_4 \approx 1.2 \cdot 10^{-16} \left( \frac{m_{\pi}}{250 \text{ GeV}} \right)^{3/2}. \]  

(19)

As we mentioned above, for the smallest allowed mass of \( U \)-quark, diquarks \((UU), \ (\bar{U}U)\) and the triple \( U \) (and \( \bar{U} \)) states \((UUU), \ (\bar{U}UU)\) can not form before QCD phase transition. Therefore \( U \)-baryonic states \((UUu), \ (UUU)\) and their antiparticles should originate from single \( U \) (and \( \bar{U} \)) hadron collisions. The rate of their creation shares the same theoretical uncertainty as in the case of \((UU)\) formation, considered above. Moreover, while baryon \((UUu)\) can be formed e.g. in reaction \((Uud) + (Uud) \rightarrow (UUu) + n, \) having no energetic threshold, formation of antibaryon \((\bar{U}\bar{u}\bar{u})\) may be suppressed at smallest values of \( m \) by the threshold of nucleon production in reaction \((\bar{U}u) + (\bar{U}u) \rightarrow (\bar{U}\bar{u}) + p + \pi^+, \) which can even exceed \( \bar{U}\bar{u} \) binding energy. In further consideration we will not specify \( U\)-hadronic content, assuming that \((UUU), \ (\bar{U}Uu) \) and \((\bar{U}u)\) can be present with appreciable fraction, while the content of residual \( U\)-hadrons is likely to be realized with multiple \( U\)-states and with suppressed fraction of single \( U\)-states. Nevertheless we can not ignore single \( U\)-baryonic states \((Uud)^+\) because only reliable inference on their strong suppression would avoid opposing to strong constraint on \(+1\) heavy particles abundance which will be considered below.

**Radiative recombination**

Radiative \(UU\) recombination is induced by "Coulomb-like" attraction of \( U \) and \( \bar{U} \) due to
their $y$-interaction. It can be described in the analogy to the process of free monopole-antimonopole annihilation considered in [17]. Potential energy of Coulomb-like interaction between $U$ and $\bar{U}$ exceeds their thermal energy $T$ at the distance

$$d_0 = \frac{\alpha}{T}.$$ 

In the case of $y$-interaction its running constant $\alpha = \alpha_y \sim 1/30$ [5]. For $\alpha \ll 1$, on the contrary to the case of monopoles [17] with $g^2/4\pi \gg 1$, the mean free path of multiple scattering in plasma is given by

$$\lambda = (n\sigma)^{-1} \sim \left( T^3 \cdot \frac{\alpha^2}{Tm} \right)^{-1} \sim \frac{m}{\alpha^3 T} \cdot d_0,$$

being $\lambda \gg d_0$ for all $T < m$. So the diffusion approximation [17] is not valid for our case. Therefore radiative capture of free $U$ and $\bar{U}$ particles should be considered. According to [17], following the classical solution of energy loss due to radiation, converting infinite motion to finite, free $U$ and $\bar{U}$ particles form bound systems at the impact parameter

$$a \approx (T/m)^{3/10} \cdot d_0.$$  \hspace{1cm} (20)

The rate of such binding is then given by

$$\langle \sigma v \rangle = \pi a^2 v \approx \pi \cdot (m/T)^{9/10} \cdot \left( \frac{\alpha}{m} \right)^2 \approx \pi \cdot (m/T)^{9/10} \cdot \left( \frac{300 \text{ K}}{T} \right)^{9/10} \cdot \left( \frac{250 \text{ GeV}}{m} \right)^{11/10} \text{ cm}^3 \cdot \text{s}^{-1}.$$  \hspace{1cm} (21)

The successive evolution of this highly excited atom-like bound system is determined by the loss of angular momentum owing to $y$-radiation. The time scale for the fall on the center in this bound system, resulting in $U\bar{U}$ recombination was estimated according to classical formula in [18]

$$\tau = \frac{\alpha^3}{64\pi} \cdot \left( \frac{m}{\alpha} \right)^2 = \frac{\alpha}{64\pi} \cdot \left( \frac{m}{T} \right)^{21/10} \cdot \frac{1}{m} \approx 4 \cdot 10^{-4} \left( \frac{300 \text{ K}}{T} \right)^{21/10} \left( \frac{m}{250 \text{ GeV}} \right)^{11/10} \text{ s}.$$  \hspace{1cm} (22)

As it is easily seen from Eq. (30) this time scale of $U\bar{U}$ recombination $\tau \ll m/T^2 \ll m_{Pl}/T^2$ turns to be much less than the cosmological time at which the bound system was formed.

The above classical description assumes $a = \frac{\alpha}{m \sqrt{g/4\pi}} \gg \frac{1}{\alpha m}$ and is valid at $T \ll m\alpha^{20/7}$ [14].

Kinetic equation for $U$-particle abundance with the account of radiative capture on RD stage is given by Eq. (11).
At $T < T_{rr} = \alpha_y^{20/7} m \approx 10 \text{MeV}(m/250 \text{GeV})\left(\frac{\alpha_y}{1/30}\right)^{20/7}$, the solution for the effect of radiative recombination is given by

$$r_4 \approx \frac{r_0}{1 + r_0 \sqrt{\frac{20\alpha_y}{9}} \frac{\alpha^2 m_p}{m} \left(\frac{T_{rr}}{m}\right)^{1/10}} \approx r_0$$

with $r_0$ taken at $T = T_{rr}$ equal to $r_4$ from Eqs.(16),(17) or (19).

Owing to more rapid cosmological expansion radiative capture of $U$-hadrons in expanding matter on MD stage is less effective, than on RD stage. So the result $r_4 \approx r_0$ holds on MD stage with even better precision, than on RD stage. Therefore radiative capture does not change the estimation of $U$-hadron pregalactic abundance, given by Eqs.(16),(17) or (19).

On the galactic stage in the most of astrophysical bodies temperature is much less than $T_{rr}$ and radiative recombination plays dominant role in the decrease of $U$-hadron abundance inside dense matter bodies.

**U-hadrons during Big Bang Nucleosynthesis and thereafter**

One reminds that to the beginning of Big Bang Nucleosynthesis (BBN) there can be $(Uud)^+, (UUu)^{++}, (UUU)^{++}, (\bar{U}u)^0, (\bar{UU\bar{u}})^{--}, (\bar{UU\bar{u}})^{--}$ states in plasma. We do not specify here possible fractions of each of the $U$-hadron species $(i)$ in $U$-hadronic matter, assuming that any of them can be appreciable ($r_i < r_4$).

After BBN proceeded, the states $(\bar{UUU})^{--}, (\bar{UU\bar{u}})^{--}$ are combined with $^4He^{++}$ due to electromagnetic interaction. The binding energy of the ground state can be estimated with reasonable accuracy following Bohr formulas (for point-like particles)

$$I_b = \frac{(Z_A Z_X \alpha)^2 m_A}{2} \approx 1.5 \text{MeV},$$

where $Z_X = 2$, $Z_A = 2$ and $m_A \approx 3.7 \text{GeV}$ are the charges of $U$-hadron and Helium and the mass of the latter. Cross section of this recombination is estimated as [19]

$$\langle \sigma v \rangle = \frac{2^8 \pi \sqrt{2 \pi \alpha^3 Z_A^4 Z^2}}{3 \exp(4)m_A \sqrt{m_A T}} \approx \frac{3.06 \cdot 10^{-4}}{m_A \sqrt{m_A T}}.$$  

Evolution of abundance of $U$-hadrons combining with $He$ is described by equation

$$\frac{dn_{(\bar{UU\bar{u})}}}{dt} = -3H n_{(\bar{UU\bar{u}})} - \langle \sigma v \rangle n_{(\bar{UU\bar{u})}} n_{He}.$$  

The term corresponding to disintegration of $[(\bar{UU\bar{u}})He]$ is neglected, since the energy of thermal photons is insufficient to disintegrate $[(\bar{UU\bar{u}})He]$ (the same for $[(UU\bar{u})He]$) in the ground state in this period. Following procedure Eqs.(9),(11), we get

$$r_{(\bar{UU\bar{u}})} = r_{(\bar{UU\bar{u}})0} \exp\left(-\sqrt{\frac{g}{45}} m_{Pl} \int_0^{T_0} r_{He} \langle \sigma v \rangle \, dT\right) \approx,$$

$$\approx r_{(\bar{UU\bar{u}})0} \exp\left(-0.6 \cdot 10^{12}\right),$$
where $r_{He} \equiv n_{He}/s = Y_p/4 \cdot \eta \cdot n_{mod}^{\text{mod}} / s_{mod} \approx 5.2 \cdot 10^{-12}$, $g$ follows from Eq. (6) and $T_0 = 100$ keV was taken. As one can see, Eq. (27) gives in this case strong exponential suppression of free $(\bar{U}U\bar{U})$ (the same for $(\bar{U}U\bar{U})He$), while neutral $[(\bar{U}U\bar{U})He]$ and $[(\bar{U}U\bar{U})He]$ states, being one of the forms of $O$-helium [16, 20–26], catalyze additional annihilation of free $U$-baryons and formation of primordial heavy elements [27]. New type of nuclear reactions, catalyzed by $O$-helium, seem to change qualitatively the results of BBN, however (see Sec. [3] and arguments in [16, 20–27]) it does not lead to immediate contradiction with the observations.

On the base of existing results of investigation of hyper-nuclei [28], one can expect that the isoscalar state $\Lambda_U^+ = (Uud)^+$ can form stable bound state with $^4He$ due to nuclear interaction. The change of abundance of $U$-hyperons $\Lambda_U^+$ owing to their nuclear fusion with $^4He$ is described by Eq. (26[27]), substituting $(\bar{U}U\bar{U}) \leftrightarrow \Lambda_U^+$. Disintegration of $[\Lambda_U^+He]$ is also negligible, since the period, when BBN is finished, is of interest ($T < T_0 < I([\Lambda_U^+He])$).

Cross section for nuclear reaction of question can be represented in conventional parameterization through the so called astrophysical S-factor

$$\sigma = \frac{S(E)}{E} \exp \left( - \frac{2\pi a Z X Z A}{v} \right), \quad (28)$$

where $E = \mu v^2/2$ with $\mu$ being reduced mass of interacting particles and $v$ being their relative velocity. The exponent in Eq. (28) expresses penetration factor, suppressing cross section, which reflects repulsive character of Coulomb force contrary to the case of $(\bar{U}U\bar{U})$. S-factor itself is unknown, being supposed $S(E \to 0) \to const$. Averaging $\sigma v$ over Maxwell velocity distribution gives, using saddle point method,

$$\langle \sigma v \rangle \approx \frac{4v_0 \cdot S(E(v_0))}{\sqrt{3}T} \exp \left( - \frac{3\mu v_0^2}{2T} \right), \quad (29)$$

where $v_0 = \left( \frac{2\pi a Z X Z A}{\mu} T \right)^{1/3}$.

Calculation gives that suppression of free $\Lambda_U^+$ on more than 20 orders of magnitude is reached at $S(E) \gtrsim 2 \text{MeV} \cdot \text{barn}$. S-factor for reaction of $^3He$ production is typically distinguished by high magnitudes from those of other reactions and lies around $5 - 30 \text{MeV} \cdot \text{barn}$ [29]. However, reactions with $\gamma$ in final state, which is assumed in our case ($\Lambda_U^+ + ^4He \to [\Lambda_U^+He] + \gamma$), have as a rule S-factor in $10^4$ times smaller. Special conditions should be demanded from unknown for sure physics of $\Lambda_U$-nucleus interaction to provide a large suppression of $\Lambda_U$ abundance. Such suppression is needed, as we will see below, to avoid contradiction with data on anomalous hydrogen abundance in terrestrial matter. The experimental constraints on anomalous lithium are less restrictive and can be satisfied in this case.

$y$-plasma

The existence of new massless $U(1)$ gauge boson ($y$-photon) implies the presence of primordial thermal $y$-photon background in the Universe. Such background should be in equilibrium with ordinary plasma and radiation until the lightest particle bearing $y$-charge (4th neutrino) freezes out. For the accepted value of 4th neutrino mass ($\gtrsim 50 \text{GeV}$) 4th neutrino freezing out and correspondingly decoupling of $y$-photons takes place before the QCD phase transition, when the total number of effective degrees of freedom is sufficiently large.
to suppress the effects of $y$-photon background in the period of Big Bang nucleosynthesis. This background does not interact with nucleons and does not influence the BBN reactions rate (its possible effect in formation and role of $[^4He(\bar{U}\bar{U}\bar{U})]$ “atom” is discussed in [15]), while the suppression of $y$-photon energy density leads to insignificant effect in the speeding up cosmological expansion rate in the BBN period. In the framework of the present consideration the existence of primordial $y$-photons does not play any significant role in the successive evolution of $U$-hadrons.

Inclusion of stable $y$-charged 4th neutrinos strongly complicate the picture. Condition of cancellation of axial anomalies requires relationship between the values of $y$-charges of 4th generation leptons ($N, E$) and quarks ($U, D$) as the following

$$e_{yN} = e_{yE} = -e_{yU}/3 = -e_{yD}/3.$$  

In course of cosmological combined evolution of $U$ and $N$ and $y$, “$y$-molecules” of kind $U$-$U$-$U$-$N$, where different $U$-quarks can belong to different $U$-hadrons (possibly bound with nucleus) should form. Such $y$-neutral molecules can avoid effect of $U$-hadrons suppression in the terrestrial matter, relevant in charge symmetric case, and lead to contradiction with observations, analysis of which is started now. UUU-N-type states will be considered in section 3 devoted to the charge-asymmetric case.

2.2 Evolution and manifestations of $U$-hadrons at galactic stage

In the period of recombination of nuclei with electrons the positively charged $U$-baryons recombine with electrons to form atoms of anomalous isotopes. The substantial (up to 10 orders of magnitude) excess of electron number density over the number density of primordial $U$-baryons makes virtually all $U$-baryons to form atoms. The cosmological abundance of free charged $U$-baryons is to be exponentially small after recombination.

Hadrons ($UUu$), ($UU\bar{U}$) form atoms of anomalous He at $T \sim 2$ eV together with recombination of ordinary helium. The states [(\bar{U}\bar{U}\bar{U})He], [(\bar{U}\bar{U}\bar{U})He], (\bar{U}u) escape recombination with electrons because of their neutrality; hadrons ($Uud$), if they are not involved into chain of nuclear transitions, form atoms of anomalous hydrogen.

The formed atoms, having atomic cross sections of interaction with matter follow baryonic matter in formation of astrophysical objects like gas clouds, stars and planets, when galaxies are formed.

On the contrary, O-helium and (\bar{U}u) mesons, having nuclear and hadronic cross sections, respectively, can decouple from plasma and radiation at $T \sim 1$ keV and behave in Galaxy as collisionless gas. In charge asymmetric case, considered in the next Section 3 or in charge symmetric case without $y$-interaction O-helium and (\bar{U}u) mesons behave on this reason as collisionless gas of dark matter particles. On that reasons one can expect suppression of their concentration in baryonic matter.

However, in charge symmetric case with $y$-interaction, the existence of Coulomb-like $y$-attraction will make them to obey the condition of neutrality in respect to the $y$-charge. Therefore owing to neutrality condition the number densities of $U$- and $\bar{U}$-hadrons in astrophysical bodies should be equal. It leads to effects in matter bodies, considered in this subsection.
**U-hadrons in galactic matter**

In the astrophysical body with atomic number density $n_a$ the initial $U$-hadron abundance $n_{U0} = f_{a0} \cdot n_a$ can decrease with time due to $UU$ recombination. Here and in estimations thereafter we will refer to $U$-quark abundance as $U$-hadron one (as if all $U$-hadrons were composed of single $U$-quarks), if it is not specified otherwise.

Under the neutrality condition $n_U = n_{\bar{U}}$ the relative $U$-hadron abundance $f_{a0} = n_U/n_a = n_{\bar{U}}/n_a$ is governed by the equation

$$\frac{df_a}{dt} = -f_a^2 \cdot n_a \cdot \langle \sigma v \rangle.$$  \hspace{1cm} (30)

Here $\langle \sigma v \rangle$ is defined by Eq.(21). The solution of this equation is given by

$$f_a = \frac{f_{a0}}{1 + f_{a0} \cdot n_a \cdot \langle \sigma v \rangle \cdot t}. \hspace{1cm} (31)$$

If

$$n_a \cdot \langle \sigma v \rangle \cdot t \gg 1/f_{a0}, \hspace{1cm} (32)$$

the solution (31) takes the form

$$f_a = \frac{1}{n_a \cdot \langle \sigma v \rangle \cdot t}. \hspace{1cm} (33)$$

and, being independent on the initial value, $U$-hadron abundance decreases inversely proportional to time.

By definition $f_{a0} = f_0/A_{\text{atom}}$, where $A_{\text{atom}}$ is the averaged atomic weight of the considered matter and $f_0$ is the initial $U$-hadron to baryon ratio. In the pregalactic matter this ratio is determined by $r_4$ from A) Eq.(16), B) Eq.(17) and C) Eq.(19) and is equal to

$$f = \frac{r_4}{r_b} = \begin{cases} 10^{-10} & \text{for the case A}, \\ 3 \cdot 10^{-9} & \text{for the case B}, \\ 1.2 \cdot 10^{-6} & \text{for the case C}. \end{cases} \hspace{1cm} (34)$$

Here $r_b \approx 10^{-10}$ is baryon to entropy ratio.

Taking for averaged atomic number density in the Earth $n_a \approx 10^{23}$ cm$^{-3}$, one finds that during the age of the Solar system primordial $U$-hadron abundance in the terrestrial matter should have been reduced down to $f_a \approx 10^{-28}$. One should expect similar reduction of $U$-hadron concentration in Sun and all the other old sufficiently dense astrophysical bodies. Therefore in our own body we might contain just one of such heavy hadrons. However, as shown later on, the persistent pollution from the galactic gas nevertheless may increase this relic number density to much larger value ($f_a \approx 10^{-23}$).

The principal possibility of strong reduction in dense bodies for primordial abundance of exotic charge symmetric particles due to their recombination in unstable charmonium like systems was first revealed in [30] for fractionally charged colorless composite particles (fractons).
The $U$-hadron abundance in the interstellar gas strongly depends on the matter evolution in Galaxy, which is still not known to the extent, we need for our discussion.

Indeed, in the opposite case of low density or of short time interval, when the condition (32) is not valid, namely, at

$$n_a < \frac{1}{f_{a0} \langle \sigma v \rangle t} = A_{\text{atom}} \cdot \frac{T}{300 \text{K}} \cdot \frac{t_U}{t} \cdot \text{cm}^{-3} \begin{cases} 4 \cdot 10^4 & \text{for the case A}, \\ 10^3 & \text{for the case B}, \\ 1.2 & \text{for the case C,} \end{cases}$$

(35)

where $t_U = 4 \cdot 10^{17}$ s is the age of the Universe, $U$-hadron abundance does not change its initial value.

In principle, if in the course of evolution matter in the forming Galaxy was present during sufficiently long period ($t \sim 10^9$ yrs) within cold ($T \sim 10$ K) clouds with density $n_a \sim 10^3$ cm$^{-3}$ $U$-hadron abundance retains its primordial value for the cases A and B ($f_0 = f$), but falls down $f_0 = 5 \cdot 10^{-9}$ in the case C, making this case close to the case B. The above argument may not imply all the $U$-hadrons to be initially present in cold clouds. They can pass through cold clouds and decrease their abundance in the case C at the stage of thermal instability, when cooling gas clouds, before they become gravitationally bound, are bound by the external pressure of the hot gas. Owing to their large inertia heavy $U$-hadron atoms from the hot gas can penetrate much deeply inside the cloud and can be captured by it much more effectively, than ordinary atoms. Such mechanism can provide additional support for reduction of $U$-hadron abundance in the case C. The reduction of this abundance down to values, corresponding to the case A can be also provided by $O$-helium catalysis in the period of BBN.

However, in particular, annihilation of $U$-hadrons leads to multiple $\gamma$ production. If $U$-hadrons with relative abundance $f$ annihilate at the redshift $z$, it should leave in the modern Universe a background $\gamma$ flux [15]

$$F(E > E_\gamma) = N_\gamma \cdot f \cdot r_b \cdot s_{\text{mod}} \cdot c \approx 3 \cdot 10^3 f \left(\text{cm}^2 \cdot \text{s} \cdot \text{ster}^{-1}\right),$$

of $\gamma$ quanta with energies $E > E_\gamma = 10 \text{ GeV}/(1 + z)$. The numerical values for $\gamma$ multiplicity $N_\gamma$ are given in table 1 [15].

| Energy fraction | $> 0$ | $> 0.1 \text{ GeV}$ | $> 1 \text{ GeV}$ | $> 10 \text{ GeV}$ | $> 100 \text{ GeV}$ |
|-----------------|------|---------------------|------------------|-------------------|------------------|
| $N_\gamma$      | 69   | 62                  | 28               | 2.4               | 0.001            |

Table 1: Multiplicities of $\gamma$ produced in the recombination of $(Q\bar{Q})$ pair with $m = 250$ GeV for different energy intervals.

So annihilation even as early as at $z \sim 9$ leads in the case C to the contribution into diffuse extragalactic gamma emission, exceeding the flux, measured by EGRET by three orders of magnitude. The latter can be approximated as

$$F(E > E_\gamma) \approx 3 \cdot 10^{-6} \left(\frac{E_0}{E_\gamma}\right)^{1.1} \left(\text{cm}^2 \cdot \text{s} \cdot \text{ster}\right)^{-1},$$

where $E_0 = 451 \text{ MeV}$. 

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The above upper bound strongly restricts \( f \leq 10^{-9} \) the earliest abundance because of the consequent impossibility to reduce the primordial \( U \)-hadron abundance by \( U \)-hadron annihilation in low density objects. In the cases A and B annihilation in such objects should not take place, whereas annihilation within the dense objects, being opaque for \( \gamma \) radiation, can avoid this constraint due to strong suppression of outgoing \( \gamma \) flux. However, such constraint nevertheless should arise for the period of dense objects’ formation. For example, in the course of protostellar collapse hydrodynamical timescale \( t_{H} \sim 1/\sqrt{\pi \rho} \sim 10^{15} \) s/\( \sqrt{n} \) exceeds the annihilation timescale \([15]\)

\[
t_{\text{an}} \sim \frac{1}{fn \langle \sigma v \rangle} \sim \frac{10^{12} \text{s}}{fn} \left( \frac{1/30}{\alpha} \right)^2 \left( \frac{T}{300 \text{K}} \right)^{9/10} \left( \frac{m}{250 \text{GeV}} \right)^{11/10}
\]

at \( n > 10^{14} \left( \frac{10^{-10}}{f} \right)^2 \left( \frac{1/30}{\alpha} \right)^4 \left( \frac{T}{300 \text{K}} \right)^{9/5} \left( \frac{m}{250 \text{GeV}} \right)^{11/5} \), where \( n \) is in \( \text{cm}^{-3} \). We consider homogeneous cloud with mass \( M \) has radius \( R \approx \frac{10^{26} \text{cm}}{n} \approx 3 \cdot 10^{10} \text{cm}^{-3} \left( \frac{M}{M_{\odot}} \right)^{1/2} \). As a result, for \( f \) as large as in the case C, rapid annihilation takes place when the collapsing matter is transparent for \( \gamma \) radiation and the EGRET constraint can not be avoided. The cases A and B are consistent with this constraint.

Note that at \( f < 5 \cdot 10^{-6} \left( \frac{M}{M_{\odot}} \right)^{2/9} \), i.e. for all the considered cases energy release from \( U \)-hadron annihilation does not exceed the gravitational binding energy of the collapsing body. Therefore, \( U \)-hadron annihilation can not prevent the formation of dense objects but it can provide additional energy source, e.g. at early stages of evolution of first stars. Its burning is quite fast (few years) and its luminosity may be quite extreme, leading to a short inhibition of star formation \([15]\). Similar effects of dark matter annihilation were recently considered in \([31]\).

**Galactic blowing of \( U \)-baryon atoms polluting our Earth**

Since the condition Eq.\((33)\) is valid for the disc interstellar gas, having the number density \( n_{g} \sim 1 \text{cm}^{-3} \) one can expect that the \( U \)-hadron abundance in it can decrease relative to the primordial value only due to enrichment of this gas by the matter, which has passed through stars and had the suppressed \( U \)-hadron abundance according to Eq.\((33)\). Taking the factor of such decrease of the order of the ratio of total masses of gas and stars in Galaxy \( f_{g} \sim 10^{-2} \) and accounting for the acceleration of the interstellar gas by Solar gravitational force, so that the falling gas has velocity \( v_{g} \approx 4.2 \cdot 10^{6} \text{cm/s} \) in vicinity of Earth’s orbit, one obtains that the flux of \( U \)-hadrons coming with interstellar gas should be of the order of \([15]\)

\[
I_{U} = \frac{f f_{g} n_{g} v_{g}}{8 \pi} \approx 1.5 \cdot 10^{-7} \frac{f}{10^{-10}} \left( \text{sm}^2 \cdot \text{s} \cdot \text{ster} \right)^{-1},
\]

where \( f \) is given by the Eq.\((34)\).

Presence of primordial \( U \)-hadrons in the Universe should be reflected by their existence in Earth’s atmosphere and ground. However, according to Eq.\((33)\) (see discussion in Section \(2.2\)) primordial terrestrial \( U \)-hadron content should strongly decrease due to radiative recombination, so that the \( U \)-hadron abundance in Earth is determined by the kinetic equilibrium between the incoming \( U \)-hadron flux and the rate of decrease of this abundance by different mechanisms.
In the successive analysis we’ll concentrate our attention on the case, when the $U$ baryon has charge $+2$, and $\bar{U}$-hadrons are electrically neutral. In this case $U$ baryons look like superheavy anomalous helium isotopes.

Searches for anomalous helium were performed in series of experiments based on accelerator search [32], spectrometry technique [33] and laser spectroscopy [34]. From the experimental point of view an anomalous helium represents a favorable case, since it remains in the atmosphere whereas a normal helium is severely depleted in the terrestrial environment due to its light mass.

The best upper limits on the anomalous helium were obtain in [34]. It was found by searching for a heavy helium isotope in the Earth’s atmosphere that in the mass range $5 \text{ GeV} - 10000 \text{ GeV}$ the terrestrial abundance (the ratio of anomalous helium number to the total number of atoms in the Earth) of anomalous helium is less than $(2-3) \cdot 10^{-19}$. The search in the atmosphere is reasonable because heavy gases are well mixed up to 80 km and because the heavy helium does not sink due to gravity deeply in the Earth and is homogeneously redistributed in the volume of the World Ocean at the timescale of $10^3 \text{ yr}$.

The kinetic equations, describing evolution of anomalous helium and $\bar{U}$-hadrons in matter have the form [15]

$$\frac{dn_U}{dt} = j_U - n_U \cdot n_{\bar{U}} \cdot \langle \sigma v \rangle - j_{gU}$$  \hfill (37)

for $\bar{U}$-hadron number density $n$ and

$$\frac{dn_{\bar{U}}}{dt} = j_{\bar{U}} - n_U \cdot n_{\bar{U}} \cdot \langle \sigma v \rangle - j_{g\bar{U}}$$  \hfill (38)

for number density of anomalous helium $n_U$. Here $j_U$ and $j_{\bar{U}}$ take into account the income of, correspondingly, $U$-baryons and $\bar{U}$-hadrons to considered region, the second terms on the right-hand-side of equations describe $UU$ recombination and the terms $j_{gU}$ and $j_{g\bar{U}}$ determine various mechanisms for outgoing fluxes, e.g. gravitationally driven sink of particles. The latter effect is much stronger for $\bar{U}$-hadrons due to much lower mobility of $U$-baryon atoms. However, long range Coulomb like interaction prevents them from sinking, provided that its force exceeds the Earth’s gravitational force.

In order to compare these forces let’s consider the World’s Ocean as a thin shell of thickness $L \approx 4 \cdot 10^5 \text{ cm}$ with homogeneously distributed $y$ charge, determined by distribution of $U$-baryon atoms with concentration $n$. The $y$-field outside this shell according to Gauss’ law is determined by

$$2E_yS = 4\pi e_y nSL,$$

being equal to

$$E_y = 2\pi e_y nL.$$

In the result $y$ force, exerting on $\bar{U}$-hadrons

$$F_y = e_y E_y,$$

exceeds gravitational force for $U$-baryon atom concentration

$$n > 10^{-7} \frac{m}{250 \text{ GeV}} \frac{30^{-1}}{\alpha_y} \text{ cm}^{-3}. \hfill (39)$$
Note that the mobility of $U$-baryon atoms and $\bar{U}$ hadrons differs by 10 order of magnitude, what can lead to appearance of excessive $y$-charges within the limits of (39). One can expect that such excessive charges arise due to the effective slowing down of $U$-baryon atoms in high altitude levels of Earth’s atmosphere, which are transparent for $\bar{U}$ hadrons, as well as due to the 3 order of magnitude decrease of $\bar{U}$ hadrons when they enter the Earth’s surface.

Under the condition of neutrality, which is strongly protected by Coulomb-like $y$-interaction, all the corresponding parameters for $\bar{U}$-hadrons and $U$-baryons in the Eqs.(37)-(38) are equal, if Eq.(39) is valid. Provided that the timescale of mass exchange between the Ocean and atmosphere is much less than the timescale of sinking, sink terms can be neglected.

The stationary solution of Eqs.(37)-(38) gives in this case

$$n = \sqrt{\frac{j}{\langle \sigma v \rangle}},$$

(40)

where

$$j_U = j = 2\pi I U, \quad j = 10^{-12} \frac{f}{10^{-10}} \text{ cm}^{-3} \text{s}^{-1}$$

(41)

and $\langle \sigma v \rangle$ is given by the Eq.(21). For $j \leq 10^{-12} \frac{f}{10^{-10}} \text{ cm}^{-3} \text{s}^{-1}$ and $\langle \sigma v \rangle$ given by Eq.(21) one obtains in water

$$n \leq \sqrt{\frac{f}{10^{-10}}} \text{ cm}^{-3}.$$

It corresponds to terrestrial $U$-baryon abundance

$$f_a \leq 10^{-23} \sqrt{\frac{f}{10^{-10},}$$

being below the above mentioned experimental upper limits for anomalous helium ($f_a < 10^{-19}$) even for the case C with $f = 2 \cdot 10^{-6}$. In air one has

$$n \leq 10^{-3} \sqrt{\frac{f}{10^{-10}}} \text{ cm}^{-3}.$$

For example in a cubic room of 3m size there are nearly 27 thousand heavy hadrons.

Note that putting formally in the Eq.(40) the value of $\langle \sigma v \rangle$ given by the Eq.(13) one obtains $n \leq 6 \cdot 10^2 \text{ cm}^{-3}$ and $f_a \leq 6 \cdot 10^{-20}$, being still below the experimental upper limits for anomalous helium abundance. So the qualitative conclusion that recombination in dense matter can provide the sufficient decrease of this abundance avoiding the contradiction with the experimental constraints could be valid even in the absence of gauge $y$-charge and Coulomb-like $y$-field interaction for $U$-hadrons. It looks like the hadronic recombination alone can be sufficiently effective in such decrease. However, if we take the value of $\langle \sigma v \rangle$ given by the Eq.(14) one obtains $n$ by the factor of $\frac{m}{m_n} \sim 5.5$ larger and $f_a \leq 3.3 \cdot 10^{-19}$, what exceeds the experimental upper limits for anomalous helium abundance. Moreover, in the absence of $y$-attraction there is no dynamical mechanism, making the number densities of $U$-baryons and $\bar{U}$-hadrons equal each other with high accuracy. So
nothing seems to prevent in this case selecting and segregating $U$-baryons from $\bar{U}$-hadrons. Such segregation, being highly probable due to the large difference in the mobility of $U$-baryon atoms and $\bar{U}$ hadrons can lead to uncompensated excess of anomalous helium in the Earth, coming into contradiction with the experimental constraints.

Similar result can be obtained for any planet, having atmosphere and Ocean, in which effective mass exchange between atmosphere and Ocean takes place. There is no such mass exchange in planets without atmosphere and Ocean (e.g. in Moon) and $U$-hadron abundance in such planets is determined by the interplay of effects of incoming interstellar gas, $U\bar{U}$ recombination and slow sinking of $U$-hadrons to the centers of planets.

Radiative recombination here considered is not able to save the case when free single positively charged $U$-hadrons ($U_{ud}$) are present with noticeable fraction among $U$-hadronic relics. It is the very strong constraint on anomalous hydrogen ($f_a < 10^{-30}$) [35] what is hardly avoidable. So, the model with free stable $+1$ charged relics which are not bound in nuclear systems with charge $\geq +2$ can be discarded.

To conclude this section we present the obtained constraints on the Fig.1.

**Cosmic rays experiments**

In addition to the possible traces of $U$-hadrons existence in the Earth, they can be manifested in cosmic rays.

According to the arguments in previous section $U$-baryon abundance in the primary cosmic rays can be close to the primordial value $f$. It gives for case B

$$f = \frac{r_A}{r_B} \sim 3 \cdot 10^{-9}. \quad (42)$$

If $U$-baryons have mostly the form $(UUU)$, its fraction in cosmic ray helium component can reach in this case the value

$$\frac{(UUU)}{4He} \sim 3 \cdot 10^{-8}.$$
Figure 2: Lines show the region of expected signal, their thickness reflects expected accuracy in experiment PAMELA. Upper thick curves relate to anomalous helium of 500 and 750 GeV (a little upper and darker). The low thin curves relate to usual nuclei.

which is accessible for cosmic rays experiments, such as RIM-PAMELA, being under run, and AMS 02 on International Space Station.

Similar argument in the case C would give for this fraction $\sim 2 \cdot 10^{-5}$, what may be already excluded by the existing data. However, it should be noted that the above estimation assumes significant contribution of particles from interstellar matter to cosmic rays. If cosmic ray particles are dominantly originated from the purely stellar matter, the decrease of $U$-hadron abundance in stars would substantially reduce the primary $U$-baryon fraction of cosmic rays. But in cosmic rays there are many different kind of particles. In order to differ $U$-hadrons from background events we can use the dependence of rigidity on velocity given on Fig.2.

The expected signal will strongly differ from background events in terms of relation between velocity and rigidity (momentum related to the charge). In the experiment PAMELA velocity is measured with a good accuracy, what can lead to the picture Fig.2.

**Correlation between cosmic ray and large volume underground detectors’ effects**

Inside large volume underground detectors (as Super Kamiokande) and in their vicinity $U$-hadron recombination should cause specific events ("spherical" energy release with zero total momentum or "wide cone" energy release with small total momentum), which could be clearly distinguished from the (energy release with high total momentum within "narrow cone") effects of common atmospheric neutrino - nucleon-lepton chain (as well as of hypothetical WIMP annihilation in Sun and Earth) [15].

The absence of such events inside 22 kilotons of water in Super Kamiokande (SK) detector during 5 years of its operation would give the most severe constraint

$$n < 10^{-3} \text{ cm}^{-3},$$

corresponding to $f_a < 10^{-26}$. For the considered type of anomalous helium such constraint
would be by 7 order of magnitude stronger, than the results of present direct searches and 3 orders above our estimation in previous Section.

However, this constraint assumes that distilled water in SK does still contain polluted heavy hadrons (as it may be untrue). Nevertheless even for pure water it may not be the case for the detector’s container and its vicinity. The conservative limit follows from the condition that the rate of $U$-hadron recombination in the body of detector does not exceed the rate of processes, induced by atmospheric muons and neutrinos. The presence of clustered-like muons originated on the SK walls would be probably observed.

High sensitivity of large volume detectors to the effects of $U$-hadron recombination together with the expected increase of volumes of such detectors up to 1 km$^3$ offer the possibility of correlated search for cosmic ray $U$-hadrons and for effects of their recombination.

During one year of operation a 1 km$^3$ detector could be sensitive to effects of recombination at the $U$-hadron number density $n \approx 7 \cdot 10^{-6}$ cm$^{-3}$ and $f_a \approx 7 \cdot 10^{-29}$, covering the whole possible range of these parameters, since this level of sensitivity corresponds to the residual concentration of primordial $U$-hadrons, which can survive inside the Earth. The income of cosmic $U$-hadrons and equilibrium between this income and recombination should lead to increase of effect, expected in large volume detectors.

Even, if the income of anomalous helium with interstellar gas is completely suppressed, pollution of Earth by $U$-hadrons from primary cosmic rays is possible. The minimal effect of pollution by $U$-hadron primary cosmic rays flux $I_U$ corresponds to the rate of increase of $U$-hadron number density $j \sim \frac{2\pi I_U}{R_E}$, where $R_E \approx 6 \cdot 10^8$ cm is the Earth’s radius. If incoming cosmic rays doubly charged $U$-baryons after their slowing down in matter recombine with electrons we should take instead of $R_E$ the Ocean’s thickness $L \approx 4 \cdot 10^5$ cm that increases by 3 orders of magnitude the minimal flux and the minimal number of events, estimated below. Equilibrium between this income rate and the rate of recombination should lead to $N \sim jVt$ events of recombination inside the detector with volume $V$ during its operation time $t$.

For the minimal flux of cosmic ray $U$-hadrons, accessible to AMS 02 experiment during 3 years of its operation ($I_{\text{min}} \sim 10^{-9}I_\alpha \sim 4 \cdot 10^{-11}I(E)$, in the range of energy per nucleon $1 < E < 10$ GeV) the minimal number of events expected in detector of volume $V$ during time $t$ is given by $N_{\text{min}} \sim \frac{2\pi I_{\text{min}}}{R_E} Vt$. It gives about 3 events per 10 years in SuperKamiokande ($V = 2.2 \cdot 10^{10}$ cm$^3$) and about $10^4$ events in the 1 km$^3$ detector during one year of its operation. The noise of this rate is one order and half below the expected influence of atmospheric $\nu_\mu$.

The possibility of such correlation facilitates the search for anomalous helium in cosmic rays and for the effects of $U$-hadron recombination in the large volume detectors.

The previous discussion assumed the lifetime of $U$-quarks $\tau$ exceeding the age of the Universe $t_U$. In the opposite case $\tau < t_U$ all the primordial $U$ hadrons should decay to the present time and the cosmic ray interaction may be the only source of cosmic and terrestrial $U$ hadrons.
3 The case of a charge-asymmetry of U-quarks

The model [15] admits that in the early Universe an antibaryon asymmetry for 4th generation quarks can be generated [16, 20, 21]. Due to y-charge conservation $\bar{U}$ excess should be compensated by $\bar{N}$ excess. We will focus our attention here to the case of y-charged quarks and neutrinos of 4th generation and follow [16] in our discussion. All the main results concerning observational effects, presented here, can be generalized for the case without y-interaction.

$\bar{U}$-antibaryon density can be expressed through the modern dark matter density $\Omega_{\bar{U}} = k \cdot \Omega_{CDM} = 0.224 (k \leq 1)$, saturating it at $k = 1$. It is convenient to relate the baryon (corresponding to $\Omega_b = 0.044$) and $\bar{U}$ ($\bar{N}$) excess with the entropy density $s$, introducing $r_b = n_b/s$ and $r_{\bar{U}} = n_U/s = 3 \cdot n_N/s = 3 \cdot r_N$. One obtains $r_b \sim 8 \cdot 10^{-11}$ and $r_{\bar{U}}$, corresponding to $\bar{U}$ excess in the early Universe $\kappa_{\bar{U}} = r_{\bar{U}} - r_U = 3 \cdot (r_N - r_N) = 10^{-12} (350 \text{ GeV}/m_{\bar{U}}) = 10^{-12}/S_5$, where $S_5 = m_{\bar{U}}/350 \text{ GeV}$.

Primordial composite forms of 4th generation dark matter

In the early Universe at temperatures highly above their masses $\bar{U}$ and $\bar{N}$ were in thermodynamical equilibrium with relativistic plasma. It means that at $T > m_{\bar{U}}$ ($T > m_N$) the excessive $\bar{U}$ ($\bar{N}$) were accompanied by $U\bar{U}$ ($N\bar{N}$) pairs.

Due to $\bar{U}$ excess frozen out concentration of deficit $U$-quarks is suppressed at $T < m_{\bar{U}}$ for $k > 0.04$ [21]. It decreases further exponentially first at $T \sim I_{\bar{U}} \equiv \alpha^2 M_U/2 \sim 3S_5 \text{ GeV}$ (where [15] $\alpha = C_{F\alpha_s} = 4/3 \cdot 0.144 \approx 0.19$ and $M_4 = m_{\bar{U}}/2$ is the reduced mass), when the frozen out $\bar{U}$ quarks begin to bind with antiquarks $\bar{U}$ into charmonium-like state ($\bar{U}\bar{U}$) and annihilate. On this line $\bar{U}$ excess binds at $T < I_{\bar{U}}$ by chromo-Coulomb forces dominantly into ($\bar{U}\bar{U}\bar{U}$) anutium states with electric charge $Z_{\Delta} = -2$ and mass $m_{\Delta} = 1.05S_5 \text{ TeV}$, while remaining free $\bar{U}$ anti-quarks and anti-diquarks ($\bar{U}\bar{U}$) form after QCD phase transition normal size hadrons ($\bar{U}u$) and ($\bar{U}\bar{U}\bar{u}$). Then at $T = T_{QCD} \approx 150 \text{ MeV}$ additional suppression of remaining $U$-quark hadrons takes place in their hadronic collisions with $\bar{U}$-hadrons, in which ($\bar{U}\bar{U}$) states are formed and $U$-quarks successively annihilate.

Effect of $\bar{N}$ excess in the suppression of deficit N takes place at $T < m_N$ for $k > 0.02$ [21]. At $T \sim I_{\bar{N}N} = \alpha_y^2 N_4/4 \sim 15 \text{ MeV}$ (for $\alpha_y = 1/30$ and $M_4 = 50 \text{ GeV}$) due to $y$-interaction the frozen out $\bar{N}$ begin to bind with $\bar{N}$ into charmonium-like states ($\bar{NN}$) and annihilate. At $T < I_{\bar{N}U} = \alpha_y^2 M_N/2 \sim 30 \text{ MeV}$ $y$-interaction causes binding of $N$ with $\bar{U}$-hadrons (dominantly with anutium) but only at $T \sim I_{\bar{N}U}/30 \sim 1 \text{ MeV}$ this binding is not prevented by back reaction of $y$-photo-destruction.

To the period of Standard Big Bang Nucleosynthesis (SBBN) $\bar{U}$ are dominantly bound in anutium $\Delta^-_{3\bar{U}}$ with small fraction ($\sim 10^{-6}$) of neutral ($\bar{U}u$) and doubly charged ($\bar{U}\bar{U}\bar{u}$) hadron states. The dominant fraction of anutium is bound by $y$-interaction with $\bar{N}$ in ($\bar{N}\Delta^-_{3\bar{U}}$) “atomic” state. Owing to early decoupling of $y$-photons from relativistic plasma presence of $y$-radiation background does not influence SBBN processes [15, 16, 20].

At $T < I_o = Z^2 Z^2 H e c^2 m_{He}/2 \approx 1.6 \text{ MeV}$ the reaction $\Delta^-_{3\bar{U}} + ^4 \text{He} \rightarrow \gamma + (^4 \text{He} + \Delta^-_{3\bar{U}})$ might take place, but it can go only after $^4 \text{He}$ is formed in SBBN at $T < 100 \text{ keV}$ and is effective only at $T \leq T_{He} \sim I_o/\log(n_\Delta/n_{He}) \approx I_o/27 \approx 60 \text{ keV}$, when the inverse reaction of photo-destruction cannot prevent it [14, 20, 22, 36]. In this period anutium is dominantly bound with $\bar{N}$. Since $r_{He} = 0.1 r_b \gg r_\Delta = r_{\bar{U}}/3$, in this
reaction all free negatively charged particles are bound with helium \([14, 20, 22, 36]\) and neutral Anti-Neutrino-O-helium (ANO-helium, \(ANOHe\)) \((\bar{4}He^{++}[\bar{N}\Delta\bar{N}_e^0])\) “molecule” is produced with mass \(m_{OHe} \approx m_o \approx 1S_3\) TeV. The size of this “molecule” is \(R_o \sim 1/(Z\Delta ZHe\alpha m_{He}) \approx 2 \cdot 10^{-13} \) cm and it can play the role of a dark matter component and a nontrivial catalyzing role in nuclear transformations.

In nuclear processes ANO-helium looks like an \(\alpha\) particle with shielded electric charge. It can closely approach nuclei due to the absence of a Coulomb barrier and opens the way to form heavy nuclei in SBBN. This path of nuclear transformations involves the fraction of baryons not exceeding \(10^{-7}\) \([20]\) and it can not be excluded by observations.

**ANO-helium catalyzed processes**

As soon as ANO-helium is formed, it catalyzes annihilation of deficit \(U\)-hadrons and \(N\). Charged \(U\)-hadrons penetrate neutral ANO-helium, expel \(\bar{4}He\), bind with anutium and annihilate falling down the center of this bound system. The rate of this reaction is \((\sigma v) = \pi R_o^2\) and an \(\bar{U}\) excess \(k = 10^{-3}\) is sufficient to reduce the primordial abundance of \((\bar{U}ud)\) below the experimental upper limits. \(N\) capture rate is determined by the size of \((\bar{N}\Delta)\) “atom” in ANO-helium and its annihilation is less effective.

The size of ANO-helium is of the order of the size of \(\bar{4}He\) and for a nucleus \(A\) with electric charge \(Z > 2\) the size of the Bohr orbit for a \((Z\Delta)\) ion is less than the size of nucleus \(A\). This means that while binding with a heavy nucleus \(\Delta\) penetrates it and effectively interacts with a part of the nucleus with a size less than the corresponding Bohr orbit. This size corresponds to the size of \(\bar{4}He\), making O-helium the most bound \((Z\Delta)\)-atomic state.

The cross section for \(\Delta\) interaction with hadrons is suppressed by factor \(\sim (p_h/p_{\Delta})^2 \sim (r_{\Delta}/r_h)^2 \approx 10^{-4}/S_o^2\), where \(p_h\) and \(p_{\Delta}\) are quark transverse momenta in normal hadrons and in anutium, respectively. Therefore anutium component of \((ANOHe)\) can hardly be captured and bound with nucleus due to strong interaction. However, interaction of the \(\bar{4}He\) component of \((ANOHe)\) with a \(\frac{A}{2}Q\) nucleus can lead to a nuclear transformation due to the reaction \(\frac{A}{2}Q + (\bar{4}He) \rightarrow \frac{A-4}{2}Q + \Delta\), provided that the masses of the initial and final nuclei satisfy the energy condition \(M(A, Z) + M(4, 2) - I_o > M(A + 4, Z + 2)\), where \(I_o = 1.6\) MeV is the binding energy of O-helium and \(M(4, 2)\) is the mass of the \(\bar{4}He\) nucleus. The final nucleus is formed in the excited \([\alpha, M(A, Z)]\) state, which can rapidly experience \(\alpha\)-decay, giving rise to \((ANOHe)\) regeneration and to effective quasi-elastic process of \((ANOHe)\)-nucleus scattering. It leads to possible suppression of ANO-helium catalysis of nuclear transformations in matter.

**ANO-helium dark matter**

At \(T < T_{od} \approx 1\) keV energy and momentum transfer from baryons to ANO-helium \(n_b \langle\sigma v\rangle\langle m_p/m_o\rangle t < 1\) is not effective. Here \(\sigma \approx \sigma_o \sim \pi R_o^2 \approx 10^{-25}\) cm\(^2\), and \(v = \sqrt{2T/m_p}\) is baryon thermal velocity. Then ANO-helium gas decouples from plasma and radiation and plays the role of dark matter, which starts to dominate in the Universe at \(T_{RM} = 1\) eV.

The composite nature of ANO-helium makes it more close to warm dark matter. The total mass of \((OHe)\) within the cosmological horizon in the period of decoupling is independent of \(S_3\) and given by

\[
M_{od} = \frac{T_{RM}}{T_{od}} m_{pl}\left(\frac{m_p T_{od}}{T_{RM}}\right)^2 \approx 2 \cdot 10^{42} g = 10^9 M_\odot .
\]
O-helium is formed only at $T_0 = 60 \text{ keV}$ and the total mass of $OHe$ within cosmological horizon in the period of its creation is $M_o = M_{od}(T_0/T_{od})^3 = 10^{37} \text{ g}$. Though after decoupling Jeans mass in $(OHe)$ gas falls down $M_J \sim 3 \cdot 10^{-14} M_{od}$ one should expect strong suppression of fluctuations on scales $M < M_o$ as well as adiabatic damping of sound waves in RD plasma for scales $M_o < M < M_{od}$. It provides suppression of small scale structure in the considered model. This dark matter plays dominant role in formation of large scale structure at $k > 1/2$.

The first evident consequence of the proposed scenario is the inevitable presence of ANO-helium in terrestrial matter, which is opaque for $(ANOHe)$ and stores all its infalling flux. If its interaction with matter is dominantly quasi-elastic, this flux sinks down the center of Earth. If ANO-helium regeneration is not effective and $\Delta$ remains bound with heavy nucleus $Z$, anomalous isotope of $Z - 2$ element appears. This is the serious problem for the considered model.

Even at $k = 1$ ANO-helium gives rise to less than 0.1 [20, 21] of expected background events in XQC experiment [37], thus avoiding for all $k \leq 1$ severe constraints on Strongly Interacting Massive particles SIMPs obtained in [3] from the results of this experiment. In underground detectors $(ANOHe)$ “molecules” are slowed down to thermal energies far below the threshold for direct dark matter detection. However, $(ANOHe)$ destruction can result in observable effects. Therefore a special strategy in search for this form of dark matter is needed. An interesting possibility offers development of superfluid $^3He$ detector [38]. Due to high sensitivity to energy release above ($E_{th} = 1 \text{ keV}$), operation of its actual few gram prototype can put severe constraints on a wide range of $k$ and $S_5$.

At $10^{-3} < k < 0.02$ $U$-baryon abundance is strongly suppressed [16, 21], while the modest suppression of primordial $N$ abundance does not exclude explanation of DAMA, HEAT and EGRET data in the framework of hypothesis of 4th neutrinos but makes the effect of $N$ annihilation in Earth consistent with the experimental data.

### 4 Signatures for $U$-hadrons in accelerator experiments

Metastable $U$-quark within a wide range of expected mass can be searched on LHC and Tevatron. In spite on that its mass can be quite close to that of $t$-quark, strategy of their search should be completely different. $U$-quark in framework of considered model is metastable and will form metastable hadrons at accelerator contrary to $t$-quark.

Detailed analysis of possibility of $U$-quark search requires quite deep understanding of physics of interaction between metastable $U$-hadrons and nucleons of matter. However, strategy of $U$-quark search can be described in general outline, by knowing mass spectrum of $U$-hadrons, (differential) cross sections of their production. LHC certainly will provide a better possibility for $U$-quark search than Tevatron. Cross section of $U$-quark production in pp-collisions at the center mass energy 14 TeV is presented on the Fig. 3. For comparison, cross sections of 4th generation leptons are shown too. Cross sections of $U$- and $D$- quarks does not virtually differ.

Heavy metastable quarks will be produced with high transverse momentum $p_T$, velocity less than speed of light. In general, simultaneous measurement of velocity and momentum enables to find the mass of particle. Information on ionization losses is, as a rule, not so good thereto. All these features are typical for any heavy particle, while there can be subtle
differences in the shapes of its angle-, $p_T$-distributions, defined by concrete model which it predicts.

It is peculiarities of long-lived hadronic nature what can be of special importance for clean selection of events of U-quarks creation. U-quark can form a whole class of U-hadronic states which can be perceived as stable in condition of experiment contrary to their relics in Universe. However, as we pointed out, double, triple U-hadronic states cannot be virtually created in collider. Many other hadronic states whose lifetime is $\gtrsim 10^{-7}$ s should look like stable. In the Table 2 expected mass spectrum of U-hadrons, obtained with the help of code Pythia [39], is presented.

The lower indexes in notation of U-hadrons in the Table 2 mean (iso)spin ($I$) of the light quark pair. From comparison of masses of different U-hadrons it follows that all $I = 1$ U-hadrons decay quickly emitting $\pi$-meson or $\gamma$-quantum, except $(\bar{U}s)$-state. In the right column the expected relative yields are present. Unstable $I = 1$ U-hadrons decay onto respective $I = 0$ states, increasing their yields.

Firstly one makes a few notes. There are two mesonic states being quasi-degenerated in mass: $(\bar{U}u)$ and $(\bar{U}d)$ (we skip here discussion of strange U-hadrons). In interaction with medium composed of $u$ and $d$ quarks transformations of U-hadrons into those ones containing $u$ and $d$ are preferable (as it is the case in early Universe). From these it follows, that created pair of $U \bar{U}$ quarks will fly out from the vertex of pp-collision in form of U-hadron with positive charge in about 60% of such events and with neutral charge in 40% and in form of anti-U-hadron with negative charge in 60% and neutral in 40%. After traveling through detectors a few nuclear lengths from vertex, U-hadron will transform in (roughly) 100% to positively charged hadron $(Uud)$ whereas anti-U-hadron will transform in 50% to

Figure 3: Cross sections of production of 4th generation particles (N, E, U, D) at LHC. Horizontal dashed line shows approximate level of sensitivity to be reached after first year of LHC operation.
Table 2: Mass spectrum and relative yields in LHC for U-hadrons. The same is for charged conjugated states.

|                  | Difference between the masses of U-hadron and U-quark, GeV | Expected yields (in the right columns the yields of long-lived states are given) |
|------------------|-------------------------------------------------------------|--------------------------------------------------------------------------------|
| $\{U \bar{u}\}^0, \{U d\}^+$                  | 0.330                                                       | 39.5(3)%, 39.7(3)%                                                             |
| $\{U s\}^+$                                            | 0.500                                                       | 11.6(2)%                                                                       |
| $\{U ud\}^+$                                           | 0.579                                                       | 5.3(1)%, 7.7(1)%                                                               |
| $\{U uu\}^+\!, \{U ud\}_1^0\!, \{U dd\}_1^0$          | 0.771                                                       | 0.76(4)%, 0.86(5)%, 0.79(4)%                                                  |
| $\{U ss\}_1^0\!, \{U sd\}_1^0$                        | 0.805                                                       | 0.65(4)%%, 0.65(4)%                                                             |
| $\{U uu\}^+\!, \{U ud\}_1^0$                          | 0.930                                                       | 0.09(2)%, 0.12(2)%                                                             |
| $\{U ss\}_1^0\!$                                       | 1.098                                                       | 0.005(4)%                                                                      |

negatively charged U-hadron ($\bar{U}d$) and in 50% to neutral U-hadron ($\bar{U}u$).

This feature will enable to discriminate the considered model of U-quarks from variety of alternative models, predicting new heavy stable particles.

Note that if the mass of Higgs boson exceeds $2m$, its decay channel into the pair of stable $QQ$ will dominate over the $t\bar{t}$, $2W$, $2Z$ and invisible channel to neutrino pair of 4th generation [40]. It may be important for the strategy of heavy Higgs searches.

5 Conclusion

To conclude, the existence of hidden stable or metastable quark of 4th generation can be compatible with the severe experimental constraints on the abundance of anomalous isotopes in Earths atmosphere and ground and in cosmic rays, even if the lifetime of such quark exceeds the age of the Universe. Though the primordial abundance $f = r_A/r_b$ of hadrons, containing such quark (and antiquark) can be hardly less than $f \sim 10^{-10}$ in case of charge symmetry, their primordial content can strongly decrease in dense astrophysical objects (in the Earth, in particular) owing to the process of recombination, in which hadron, containing quark, and hadron, containing antiquark, produce unstable charmonium-like quark-antiquark state.

To make such decrease effective, the equal number density of quark- and antiquark-containing hadrons should be preserved. It appeals to a dynamical mechanism, preventing segregation of quark- and antiquark- containing hadrons. Such mechanism, simultaneously providing strict charge symmetry of quarks and antiquarks, naturally arises, if the 4th generation possesses new strictly conserved $U(1)$ gauge ($y$-) charge. Coulomb-like $y$-charge long range force between quarks and antiquarks naturally preserves equal number densities for corresponding hadrons and dynamically supports the condition of $y$-charge neutrality.

It was shown in the present paper that if $U$-quark is the lightest quark of the 4th genera-
tion, and the lightest free $U$-hadrons are doubly charged $(UUU)$- and $(UUu)$-baryons and electrically neutral $(U\bar{u})$-meson, the predicted abundance of anomalous helium in Earth’s atmosphere and ground as well as in cosmic rays is below the existing experimental constraints but can be within the reach for the experimental search in future. To realize this possibility nuclear binding of all the $(Uud)$-baryons with primordial helium is needed, converting potentially dangerous form of anomalous hydrogen into less dangerous anomalous lithium. Then the whole cosmic astrophysics and present history of these relics are puzzling and surprising, but nearly escaping all present bounds.

Searches for anomalous isotopes in cosmic rays and at accelerators were performed during last years. Stable doubly charged $U$ baryons offer challenge for cosmic ray and accelerator experimental search as well as for increase of sensitivity in searches for anomalous helium. In particular, they seem to be of evident interest for cosmic ray experiments, such as PAMELA and AMS02. $+2$ charged $U$ baryons represent the low $Z/A$ anomalous helium component of cosmic rays, whereas $-2$ charged $\bar{U}$ baryons look like anomalous antihelium nuclei. In the baryon asymmetrical Universe the predicted amount of primordial single $(\bar{U}\bar{u}\bar{d})$ baryons is exponentially small, whereas their secondary fluxes originated from cosmic ray interaction with the galactic matter are predicted at the level, few order of magnitude below the expected sensitivity of future cosmic ray experiments. The same is true for cosmic ray $+2$ charged $U$ baryons, if $U$-quark lifetime is less than the age of the Universe and primordial $U$ baryons do not survive to the present time.

The models of quark interactions favor isoscalar $(Uud)$ baryon to be the lightest among the 4th generation baryons (provided that $U$ quark is lighter than $D$ quark, what also may not be the case). If the lightest $U$-hadrons have electric charge $+1$ and survive to the present time, their abundance in Earth would exceed the experimental constraint on anomalous hydrogen. This may be rather general case for the lightest hadrons of the 4th generation. To avoid this problem of anomalous hydrogen overproduction the lightest quark of the 4th generation should have the lifetime, less than the age of the Universe. Another possible solution of this problem, using double and triple $\bar{U}$ baryons $(\bar{UUU})$ and catalysis of $(Uud)$ annihilation in atom-like bound systems $^4\text{He}(\bar{UU})$ is considered in [15].

However short-living are these quarks on the cosmological timescale in a very wide range of lifetimes they should behave as stable in accelerator experiments. For example, with an intermediate scale of about $10^{11}$ GeV (as in supersymmetry models [41]) the expected lifetime of $U$-(or $D$-) quark $\sim 10^6$ years is much less than the age of the Universe but such quark is practically stable in any collider experiments.

First year operation of the accelerator LHC has good discovery potential for $U(D)$-quarks with mass up to 1.5 TeV. $U$-hadrons born at accelerator will distinguish oneself by high $p_t$, low velocity, by effect of a charge flipping during their propagation through the detectors. All these features enable strongly to increase efficiency of event selection from not only background but also from alternative hypothesis.

In the present work we studied effects of 4th generation having restricted our analysis by the processes with 4th generation quarks and antiquarks. However, as we have mentioned in the Introduction in the considered approach absolutely stable neutrino of 4th generation with mass about 50 GeV also bears $y$-charge. The selfconsistent treatment of the cosmological evolution and astrophysical effects of $y$-charge plasma of neutrinos, antineutrinos, quarks and antiquarks of 4th generation in charge symmetric case will be the subject of
special studies. An attempt of such a treatment has been undertaken in the case of charge asymmetry, described in this paper.

We believe that a tiny trace of heavy hadrons as anomalous helium and stable neutral O–Helium and mesons\(^1\) may be hidden at a low level in our Universe (\(\frac{n_{\text{U}}}{n_b} \sim 10^{-10} - 10^{-9}\)) and even at much lower level here in our terrestrial matter a density \(\frac{n_{\text{U}}}{n_b} \sim 10^{-23}\) in case of charge symmetry. There are good reasons to bound the 4th quark mass below TeV energy. Therefore the mass window and relic density is quite narrow and well defined, open to a final test.

In case of charge asymmetry of 4th generation quarks, a nontrivial solution of the problem of dark matter (DM) can be provided due to neutral O–Helium-like U-hadrons states (ANO-helium in case of \(y\)-interaction existence). Such candidates to DM have many interesting implications in BBN, large scale structure of Universe and physics of DM [16, 20–26]. It should catalyze new types of nuclear transformations, reminding alchemists’ dream on the philosopher’s stone. It challenges direct search for species of such composite dark matter and its constituents. A very low probability for their existence is strongly compensated by the expectation value of their discovery.

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\(^1\)Storing these charged and neutral heavy hadrons in the matter might influence its \(e/m\) properties, leading to the appearance of apparent fractional charge effect in solid matter [15]. The present sensitivity for such effect in metals ranges from \(10^{-22}\) to \(10^{-20}\).
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