1. INTRODUCTION

The problem of existence of new quark and lepton generations is among the most important in the modern high energy physics. Such new heavy leptons and quarks may be sufficiently long-living to represent a new stable form of matter. At the present time there are in the elementary particle scenarios at least two main frame for Heavy Stable Quarks and Leptons: (a) A fourth heavy Quark and heavy Neutral Lepton (neutrino) generation (above 80-220 GeV).

The role of Sinister Heavy Fermions in most recent extended Glashow’s SU(3)×SU(2)×SU(2)′×U(1) model is to offer in a unique frame relic Helium-like products (an ingenious candidate to the dark matter puzzle), a solution to the See-Saw mechanism for light neutrino masses as well as to strong CP violation problem in QCD. The Sinister model requires a three additional families of leptons and quarks, but only the lightest of them Heavy U-quark and E- electron are stable. Apparently the final neutral Helium-like (UUUEEE) state is an ideal evanescent dark-matter candidate. However it is reached by multi-body interactions in early Universe along a tail of more manifest secondary frozen blocks. They should be now here polluting the surrounding matter. Moreover, in opposition to effective UU pair annihilation, there is no such an early or late tera-lepton pairs suppression because: a) electromagnetic interactions are weaker than nuclear ones and b) helium ion \((^4\text{He})^{++}\) is able to attract and capture (in the first three minutes) \(E^-\) fixing it into a hybrid tera helium ion trap. This leads to a pile up of \((^4\text{He}E^-)^+\) traces, a lethal compound for any Sinister Universe. This capture leaves no Tera-Lepton frozen in \((Ep)\) relic, otherwise an ideal catalyzer to achieve effective late \(E^+E^-\) annihilations, possibly saving the model. The \((^4\text{He}E^-)^+\) Coulomb screening is also avoiding the synthesis of the desired (UUUEEE) hidden dark matter gas. The \((^4\text{He}E^-)^+e^-\) behave chemically like an anomalous hydrogen isotope. Also tera-positronium relics \((e^-E^+)\) are over-abundant and they behave like an anomalous hydrogen atom: these gases do not fit by many orders of magnitude known severe bounds on hydrogen anomalous isotope, making shadows hanging over a Sinister Universe. However a surprising and resolver role for Tera-Pions in UHECR astrophysics has been revealed.

Subject headings: Elementary Particle: Tera Leptons, Hadrons, Cosmology
action to $E \to N + W$, where, depending on the mass ratio of $E^-$ and $N, W$ boson is either real or virtual.

However a very novel Glashow’s "Sinister" $SU(3)_c \times SU(2) \times SU(2)' \times U(1)$ gauge model (Glashow 2005) offers another possible realization for the heavy Quark-Lepton generations. Three Heavy generations of tera-fermions are related with the light fermions by $CP^2$ transformation linking light fermions to charge conjugates of their heavy partners and vice versa. $CP^2$ symmetry breaking makes tera-fermions much heavier than their light partners. Tera-fermion mass pattern is the same as for light generations, but all the masses are multiplied by the same factor $S = 10^{6}S_0 \sim 10^{8}$. Strict conservation of $F = (B - L) - (B' - L')$ prevents mixing of charged tera-fermions with light quarks and leptons. Tera-fermions are sterile relative to SU(2) electroweak interaction, and do not contribute into standard model parameters. In such realization the new heavy neutrinos ($N_i$) acquire large masses and their mixing with light neutrinos $\nu$ provides a "see-saw" mechanism of light neutrino Dirac mass generation. Here in a Sinister model the heavy neutrino is unstable. On the contrary in this scheme $E^-$ is the lightest heavy fermion and it is absolutely stable. If the lightest quark $Q$ of Heavy generation does not mix with quarks of 3 light generation, it can decay only to Heavy generation leptons owing to GUT-type interactions, what makes it sufficiently long living. If its lifetime exceeds the age of the Universe, primordial $Q$-quark hadrons as well as Heavy Leptons should be present in the modern matter.

Indeed, in the novel Glashow’s "Sinister" scenario (Glashow 2005) very heavy quarks $Q$ (or antiquarks $\bar{Q}$) can form bound states with other heavy quarks (or antiquarks) due to their Coulomb-like QCD attraction, and the binding energy of these states may substantially exceed the binding energy of QCD confinement. Then ($QQ\bar{Q}$) and ($QQ\bar{Q}$) baryons can exist.

In the model (Glashow 2005) the properties of heavy generation fermions were fixed by their discrete $CP^2$ symmetry with light fermions. According to this model heavy quark $U$ and heavy electron $E$ are stable and may form a neutral most probable and stable (while being evanescent) ($UUU\bar{E}$) "atom" with ($UUU\bar{E}$) hadron as nucleus and two $E^-$s as "electrons". The tera gas of such "atoms" is an ideal candidate for a very new and fascinating dark matter; because of their peculiar WIMP-like interaction with matter they may also rule the stages of gravitational clustering in early matter dominated epochs, creating first gravity seeds for galaxy formation. However, while the assumed terabaryon asymmetry for $U$ washes out by annihilation primordial $\bar{U}$, the tera-lepton asymmetry of $E^-$ can not effectively suppress the abundance of tera-positrons $E^+$ in the earliest as well as in the late Universe stages. This feature differs from successful and most celebrated annihilation of primordial antiprotons and positrons that takes place in our Standard baryon asymmetrical Universe. The abundance of $\bar{U}$ and $E^+$ in earliest epochs exceeds the abundance of excessive $U$ and $E^-$ and it is suppressed (successfully) for $U$ only after QCD phase transition, while, as we shall stress, there is no such effective annihilation mechanism for $E^+$. Moreover ordinary $^3$He formed in Standard Big Bang Nucleo-synthesis binds at $T \sim 15keV$ virtually all the free $E^-$ into positively charged ($^4HeE^-)^+$ "ion", which puts Coulomb barrier for any successive $E^-E^+$ annihilation or any effective $EU$ binding. The huge frozen abundance of tera-leptons in hybrid tera-postonitronium ($eE^+$) and hybrid hydrogen-like tera-helium atom ($^3HeEe$) and in other complex anomalous isotopes can not be removed.

Indeed in analogy to D, $^3$He and Li relics that are the intermediate catalyzers of $^4He$ formation the tera-lepton and tera-hadron relics from intermediate stages towards a final ($UUU\bar{E}\bar{E}$) formation must survive with high abundance of visible relics in the present Universe. We enlist, reveal and classify such tracers, their birth place and history up to now; we shall remind their lethal role for the present and wider versions of Sinister Universe (Glashow 2005). We find that ($eE^+$) and ($UUU\bar{E}e$), which we label hybrid tera-hadron atom, is here to remain among us and their abundance is enormously high for known severe bounds on anomalous hydrogen. Moreover evanescent relic neutral hybrid tera-hydrogen atom ($Ep$) can not be formed because the primordial component of free tera-electrons $E^-$ are mostly trapped in the first minutes into hybrid hydrogen-like tera-helium ion ($^4HeE^-)^+$, a surprising cage, screening by Coulomb barrier any eventual later $E^-E^+$ annihilation or $EU$ binding. This is the grave nature of tera-lepton shadows over a Sinister Universe. Therefore remaining abundance of ($eE^+$) and ($^4HeE^-e$) exceeds by $27$ orders of magnitude the terrestrial upper limit for anomalous hydrogen. There are also additional tera-hadronic anomalous relics, whose trace is constrained by the present data by $25.5$ orders for ($UUU\bar{E}e$) and at least by $20$ orders for ($\bar{U}\bar{U}\bar{E}$) respect to anomalous hydrogen, as well as by $14.5$ orders for ($UUU\bar{E}e$), by $10$ orders for ($UUUee$) and ($UUee$) (if ($UUU$) is the lightest tera-hadron) - respect to anomalous helium. While tera helium ($UUU\bar{E}E$) would co-exist with observational data, being a wonderful candidate for dark matter, its tera-lepton partners will poison and forbid this opportunity.

The contradiction might be removed, if tera-fermions are unstable and drastically decay before the present time. But such solution excludes any cosmological sinister matter dominated Universe, while, of course, it leaves still room and challenge for search for metastable $E$-leptons and $U$-hadrons in laboratories or in High Energy Cosmic ray traces.

The paper is structured as follows. We discuss possible types of stable tera particles in Section 2 stipulate their

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3 If this lifetime is much less than the age of the Universe, there should be no primordial Heavy generation quarks, but they can be produced in cosmic ray interactions and be present in cosmic ray fluxes or in their most recent relics on Earth. The assumed masses for these tera-particles make their search a challenge for the present and future accelerators.

4 The mechanisms of production of metastable $Q$ (and $\bar{Q}$) hadrons in the early Universe, cosmic rays and accelerators were analyzed in Belotsky Fargion Khlopov et al (2004) and the possible signatures of their wide variety and existence were revealed. Such hadrons were assumed to be bound states ($QQ\bar{Q}$) of heavy $Q$ and light quarks $q$ formed after QCD confinement.

5 Anyway the eventual energy release of this late $EE^+$ annihilation, if it was possible, can inject energy and cause distortions in CMB spectrum, as well as influence the relic products in nuclei formed in SBBN changing the light element abundance. These bounds are less restrictive but as we stressed are overcome by Helium trap capture.
early chronological and thermal history in Section 3; here we show that while it is possible to suppress primordial anti-tera-quarks by pair annihilation, the similar annihilation is inhibited for tera-leptons. Consequent formation of tera-helium (UUUEE) is inevitably accompanied by dominant fraction of charged tera-leptons; while this lepton component is sub-dominant in energy density still it is over-abundant for known bounds even at smallest possible S values. In Section 4 we follow at \( T \sim 15 \text{keV} \) free \( E^- \) binding with \(^4\text{He}^-\)), trapped into a mortal cage of positively charged \((E^+\text{He})^+\) ion. This capture precludes formation of neutral \((E^-p)\) and leaves no room to a hopeful proposal \((\text{Glashow 2005})\) of \((Epn)\) catalytic elimination of all the products of "incomplete tera-matter combustion". In the result all the positively charged tera-matter fragments recombine with ordinary electrons into over-abundant fraction of anomalous isotopes both of tera-leptons ((\(E^+\)) and \(\text{He}^+\))) as well as of tera-hadron \((UUUU^+)^+\) (pure tera-helium ion), \((UUu)^++\) (first hybrid tera-helium ion), \((UUu)^+-\) (second hybrid tera-helium ion), \((UUu)^{-}E^+\) (tera-helium I ion), \((UUu)^{-}E^+\) (first hybrid tera-helium I ion), \((UUu)^{+}E^-\) nature, which can not be effectively suppressed to present upper limits of anomalous isotopes by any realistic mechanism (Section 5). A summary is found in last Section 6 and Section 7.

2. THE LIGHTEST STABLE HEAVY HADRONS IN BOUNDED ATOMS

In the framework of the "sinister" \(SU(3) \times SU(2) \times SU(2)' \times U(1)\) gauge model \((\text{Glashow 2005})\) quarks of heavy generations follow the same mass hierarchy as their light partners but differ by a factor \(S = 10^6 \cdot S_6\). It makes \(U\) quark with mass \(S \cdot m_u = S \cdot 3.5 \text{MeV} \) the lightest Heavy quark. In principle, the composition of the lightest Heavy baryons can be: \((UUu)^+\) (charge \(+2\)), \((Uud)^+\) (charge \(+1\)), \((Udd)^0\) (charge \(0\)), \((UUu)^-\) (charge \(+2\)) and the corresponding lightest mesons \((Uu)^0\) (charge \(0\)) or \((Ud)^-\) (charge \(-1\)). Charmonium-like \((U)\) state is unstable relative to 2- or 3-gluon decays.

Because of the heavy "lightest" Quark masses considered here form the most deep binding nuclear potential, the final \((UUU)^{++}\) (says also \(\Delta_{UUU}\)) state is the most stable to be formed in early Universe. This state occurs via interchanged states \(Uqq\) and \(UUq\), where \(q\) are light quarks.

The QCD phase transition for "light" quarks took place at few hundred MeV but the binding gluon energy is related to the Quark masses scaled by whose coupling in imagined \(m_\text{S6} \cdot S_6\) (as \(m_\text{S6}\) or \(m_\text{S6}^2\) ratios masses), leading to a binding hadron energy at \(\alpha_{QCD} M_{\text{Quark}}/4 \simeq 1.5 \cdot 10^{10} \text{eV} S_6\), larger by two orders of magnitude respect common hadrons.

The minimal value of \(S\) factor \(S_6 = 0.2\) follows \((\text{Glashow 2005})\) from unsuccessful search for heavy leptons with mass below \(100 \text{GeV}\). The heavy electron masses at energy \(m_e \simeq 10^6 S_6 m_e \simeq 500 \text{GeV} V S_6\) are leading to a \((UUU)EE\) anomalous Atom, whose binding energy may reach \(E_{\text{Binding}} \simeq Z^2 a^2 M_E/2 \sim 5 \cdot 10^7 \text{eV} S_6\); because of it these atoms are quite stable and bounded, while interacting only by multi-pole electro-

magnetic states.

The prediction \((\text{Glashow 2005})\) that \(m_D > m_U\) excludes stable baryon with the negative charge, while the lightest \((Ud)\) meson seems to be excluded by the quark model arguments. These arguments also exclude neutral \((Udd)\) as the lightest single-\(U\) baryon, as well as \((UUd)\) as the lightest double-\(U\) baryon.

It leaves theoretically favorable \((Uud)\) and theoretically less favorable \((Uuu)\) as only candidates for lightest single-\(U\)-quark baryon\(^7\), \((UUu)\) and \((UUU)\) as the lightest multi-\(U\)-quark baryons and with the only possibility of neutral \((Uu)\) (and its antiparticle \((U\bar{u})\)) as the lightest meson. In the present paper we choose for our estimates the value \(M_\text{U} = 3.5 S_6\) TeV.

3. PRIMORDIAL TERA-PARTICLES FROM BIG BANG UNIVERSE

The model \((\text{Glashow 2005})\) assumes that in the early Universe charge asymmetry of tera-fermions was generated so that \(UUU\) and \(EE\) excess saturated the modern dark matter density. For light baryon excess \(\eta_\gamma = n_{\eta \text{mod}}/n_{\gamma \text{mod}} = 6 \cdot 10^{-10}\) it gives tera-baryon excess \((\text{Glashow 2005})\)

\[
\eta_{B'} = 3 \cdot 10^{-13} \left(\frac{3.5 \text{TeV}}{m}\right),
\]

where \(m\) is the mass of \(U\)-quark. For future use it is convenient to relate baryon \(\Omega_\gamma = 0.044 \text{ and} \) tera-baryon number densities \(\Omega_{CDM} = 0.224 \) \((\text{Glashow 2003})\) with the entropy density \(s\) and to introduce \(r_B = n_B/s\) and \(r_{B'} = n_{B'}/s\). Taking into account that \(s_{mod} = 7.04 \cdot 10^{-11}\) one obtains \(r_B \sim 8 \cdot 10^{-11}\) and \(r_{B'} = 4 \cdot 10^{-14} \left(\frac{3.5 \text{TeV}}{m}\right)\).

It is assumed in \((\text{Glashow 2003})\) that \(B' = 1/3\) for \(U\) quark, so the \(B'\) excess Eq. (2) corresponds to \(U\) quark excess \(r_U\) given by

\[
\kappa_U = r_U - r_U = 1.2 \cdot 10^{-13} \left(\frac{3.5 \text{TeV}}{m}\right) = 1.2 \cdot 10^{-13}/S_6, \quad (3)
\]

where \(S_6 = S/10^6\). To have equal amounts of \(UUU\)s and \(EE\)s one needs two tera-leptons per one tera-baryon. It means that \(E\) excess should be equal to \(r_L = r_E - r_{E'} = 2 \cdot r_B = 8 \cdot 10^{-14} \left(\frac{3.5 \text{TeV}}{m}\right)\).

\(\text{7 The argument favoring (Uuu) as the lightest U baryon was simply based in (Belotsky Fargion Khlopov et al 2004) on the mass ratio of current u and d quarks. On the other hand there is an argument (Belotsky Fargion Khlopov et al 2004) in favor of the fact that the Uud baryon must be lighter than the Uuu one. Indeed, in all models the scalar-isoscalar ud-diquark is lighter than the vector-isoscalar ud-diquark. One example is the model with the effective t'Hooft instanton induced four quark interaction, which provides a rather strong attraction in the scalar ud-channel and which is absent in the vector ud-channel. Thus it is very likely that the Uuu-baryon will be unstable under the decay (Uuu) \(\rightarrow\) (Uud) + \(\pi^+\). This expectation is confirmed by the properties of the charmed baryons (where the charm quark is much heavier than other two quarks). Indeed, the branching of the \(\Sigma_c \rightarrow\) \(L + \pi^+\) decay is about 100%. (Belotsky Fargion et al 2004). In a more general form we can say that the interaction in isoscalar channel (isoscalar potential) must be stronger than that in the isovector case. Otherwise we will obtain a negative cross section for one or another reaction since the isovector interaction changes the sign under the replacement of d-quark by the u-quark.)
Hadronic recombination provides binding of $U_uuu$ (mediate annihilation takes place. This process is very metric in chronological order thermal history of terrestrial dynamics should exist in the Universe for a sufficiently long period and even survive to the present time.

The goal of the successive discussion is to reveal the possible tracers from various steps of cosmological evolution of primordial $U$ and $E$. The main idea of this treatment is that if some particles of type 1 and 2 form in the early Universe a product 3, the process of this transformation freezes out in the time $t_r$, when the rate of expansion exceeds the rate of reaction $1 + 2 \to 3$. For comparable relative abundance (in terms of entropy, $s$) of 1 and 2 ($r_1 = n_1/s \sim r_2 = n_2/s \gg k = (n_1 - n_2)/s$), their frozen out abundance is $r_1 \approx r_2 \sim 1/(svt_r) = 1/J$, while if some particles are in excess and in the period of freezing out $r_1 = k \gg r_2 = r$ the amount of excessive particles practically does not change ($r_1 = k$), while the amount of 2 becomes exponentially small $r_2 \sim r \exp(-ksvt_r) = r \exp(-kJ)$. We show that since abundance of $U$ and $E$ is comparable and effects of baryon asymmetry are in many cases not too strong, significant amount of "incomplete combustion" products should exist in the Universe for a sufficiently long period and even survive to the present time.

3.1. Chronological cornerstones of Sinister Universe

After generation of baryon- and lepton-asymmetry in chronological order thermal history of matter looks as follows for $m_U = 3.5S_6$eV and $m_E = 500S_6$ GeV

1) $10^{-13}s/S_6^2 \leq t \leq 10^{-8}s/S_6^2$ at $m_U > T \geq m_U/30 \approx 100GeV/S_6$ Tera-quark pairs annihilate and freezing out, leaving the earliest non-negligible abundance of $UU$ pairs (Subsection 3.2 and Appendix 1).

2) $4 \cdot 10^{-12}s/S_6^2 \leq t \leq 2.5 \cdot 10^{-10}s/S_6^2$ at $m_E \geq T \geq T_E = m_E/25 \approx 20GeV/S_6$ Tera-lepton pair $EE^+$ annihilation and freezing out (Subsection 3.3 and Appendix 1).

3) $t \sim 4.5 \cdot 10^{-10}s/S_6^2$ at $T \sim I_U = \alpha_s^2m_U/4 \approx 15GeV/$S_6. At this temperature, corresponding to $U$-quark chromo-Coulomb binding energy $I_U \approx 15GeV$/$S_6$ binding of $U$ in "teram-charmonium" ($UU$) and their immediate annihilation takes place. This process is very effective to suppress most of $UU$ pairs (Appendix 3).

4) $4.5 \cdot 10^{-5}s/S_6^2 \leq t \leq 4 \cdot 10^{-6}s/S_6^2$ at $I_U \geq T \geq I_U/30 \approx 0.5GeV/$S_6 Binding of $U$-quarks in $UU$- diquarks and $(UU)$-hadrons (Appendix 4).

5) $t \sim 4.5 \cdot 10^{-5}s$ at $T \sim T_{QCD} = 150MeV$, QCD phase transition. $UU$ recombination and $UU$ annihilation in hadrons (Appendix 5)².

6) $4 \cdot 10^{-4}s/S_6^2 \leq t \leq 4.5 \cdot 10^{-1}s/S_6^2$ at $I_{1EE} \geq T \geq I_{1EE}/30 \approx 1.5MeV/$S_6. In this period tera-electron $E^-$ recombination with positively charged $U$-hadrons and baryon "atom" $(UUUU)$ formation with potential energy $I_{1EE} = Z^2\alpha_s^2m_e/2 \approx 50MeV/$S_6 $(Z = 2)$ takes place (subsection 3.3).

7) $t \sim 2.8 \cdot 10^{-2}s/S_6^2$ at $T \sim I_{1EE} = 6.3MeV/$S_6. The temperature corresponds to binding energy $I_{1EE} = \alpha_s^2m_E/4 \approx 6.3MeV/$S_6 of twin tera-postonium $(E^-E^+)$ tera-atom, in which $E^+$ annihilate. This annihilation characteristic to earlier $UU$ binding (see p.3) is not at all effective to reduce the $E^-E^+$ pairs abundance (subsection 3.3). This is one of the main reasons, why Sinister Universe is not compatible with observations.

8) $100s \leq t \leq 4.5 \cdot 10^3s$ at $100keV \geq T \geq I_{HE/72} = 15keV$, where $I_{HE/72} = Z^2\alpha_s^2m_H/2 = 400keV$ is the potential energy of both $(He^+E^-)$ atom and of $(He^+E^-)^+$ ion. Helium $^4He$ is formed in Standard Big Bang Nucleosynthesis and virtually all free $E^-$ are trapped by $^4He$ in $(HeE^-)^+$ ion (section 4)¹⁰.

9) $1.6 \cdot 10^3s \leq t \leq 10^6s$ at $I_{EP} \geq T \geq I_{EP}/25 \approx 1keV$. Aborted $(E\bar{p})$ capture because of earlier $(HeE^-)^+$ trapping of free $E^-$. Here $I_{EP} = \alpha_s^2m_\bar{p}/2 = 25keV$ is the potential energy of hypothetical $(E\bar{p})$ atom and $T \approx I_{EP}/25 = 1keV$ would correspond to the end of $(E\bar{p})$ binding (section 4)¹¹.

10) $t \sim 2.5 \cdot 10^{11}s$ at $T \sim I_{HE/30} \approx 2eV$. Here $I_{HE} = Z^2\alpha_s^2m_e/2 = 54.6eV$ is the potential energy of ordinary $He$ atom. Formation of anomalous helium atoms (Appendix 6 and section 5)¹².

11) $z \sim 1500$. Last scattering and common hydrogen recombination are accompanied by anomalous positronium and hydrogen atoms formation (Appendix 6 and section 5)¹³.

All these anomalous species should be present in matter around us and we turn now to the stages of their formation.

3.2. Freezing out of $U$-quarks

In the early Universe at temperatures highly above their masses tera-fermions were in thermodynamical equilibrium with relativistic plasma. It means that at $T > m$ the excessive $E$ and $U$ were accompanied by $EE^+$ and $UU^-$ pairs.

When in the course of expansion the temperature $T$ falls down below the mass of $U$-quark, $m$, the concentration of quarks and antiquarks is given by equilibrium.

9 Together with $(UUUEE)$ also $(UUUEE)^+, (UUuEE)^+, (UUuEE)^+$ and $(UuE)^+$ (or $UudE$) are formed, while free $E^-$, $(UU)^+, (UUu)^+,$ $(Uu)^+,$ and $(Uu)^+$ (or $(Uud)^+$) are left.

10 Note that in the period $100keV \leq T \leq 400keV$ helium $^4He$ is not formed, therefore it is only after the first three minutes, when lethal $(HeE^-)^+$ trapping of $E^-$ can take place. Coulomb barrier inhibits successive reaction of $E^-$ with positively charged tera-particles and $E^+$, $(HeE^-)^+$, $(UUUEE)^+$, $(UUuUEE)^+$, $(UUuUUe)$, $(UUuUuUu)^+$ and $(UUuUuUu)^+$ can no more decrease their abundance.

11 A tedious reader would argue that within $1.6 \cdot 10^3s \leq t \leq 4.5 \cdot 10^3s$ both $(HeE^-)^+$ and $(E\bar{p})$ capture could take place, but the most of $E^-$ are much faster trapped in $(HeE^-)^+$, than by any late $(Ep)$ binding.

12 Relics with charge $Z = \pm 2$ recombine with $e^-$ and form anomalous helium atoms $(UUuEE)^+$, $(UUuue)^+$, $(Uuue)^+$, $(Uuuu)^+$ (or $(Uuuu)^+$) is tightest.

13 Relics with charge $Z = \pm 1$ recombine with $e^-$ and form anomalous hydrogen atoms $(4HeE^-)^+$, $(E^+e^-)^+$, $(UUUEe)^+$, $(UUuee)^+$, $(Uueee)^+$, $(Uueee)^+$ (or $(Uueee)^+)$.

14 This picture assumes that reheating temperature $T_r$ after inflation exceeds $m$. A wide variety of inflationary models involve long pre-heating stage, after which reheating temperature does not exceed $T_r < 4 \cdot 10^3GeV$. This upper limit appears, in particular,
At the freezing out temperature $T_f$ the rate of expansion exceeds the rate of annihilation to gluons $UU \rightarrow gg$ or to pairs of light quarks $q$ and antiquarks $q\bar{q}$. Then quarks $U$ and antiquarks $\bar{U}$ are frozen out.

The frozen out concentration (in units of entropy density) of $U$ quarks, $r_u$, and antiquarks, $r_{\bar{U}}$, is given (see Appendix 1) by

$$
r_u = 8.6 \cdot 10^{-13} f_u(S_6) \quad r_{\bar{U}} = 7.4 \cdot 10^{-13} f_{\bar{U}}(S_6)
$$

(5)

at $T \approx T_f U \approx m_U/30 \approx 100$ GeV. Here $f_u(1) = f_{\bar{U}}(1)$ = 1 and their functional form is given in Appendix 1. This functional form is simplified for large $S_6 > 1$

$$
r_u \approx 8 \cdot 10^{-13} S_6 \cdot (1 - \ln (S_6)/30) + 6 \cdot 10^{-14}/S_6
$$

(6)

and for smallest possible 0.2 < $S_6 < 0.4$

$$
r_u \approx \kappa_u = 1.2 \cdot 10^{-13}/S_6
$$

(7)

It means that the concentration of frozen out $U$-quark pairs is for $S_6 = 1$ by 6 times larger than the concentration of excessive $U$-hadrons Eq. (4) and this effect grows with $S_6$ as $\propto S_6^2$ at large $S_6$. Some suppression of $U$-quark abundance takes place only for smallest possible values of $S_6$, but even in this case it can not be less than $r_u \approx 2 \cdot 10^{-16}$, which is reached at $S_6 = 0.2$. So in this moment, in spite of assumed baryon asymmetry, the frozen out concentration of antiquarks $\bar{U}$ is not strongly suppressed and they can not be neglected in the cosmological evolution of tera-fermions.

3.3. Freezing out of $E$-leptons

The same problem of antiparticle survival appears (enhanced) for $E$-leptons. Equilibrium concentration of $EE^+$ pairs starts to decrease at $T < m_E = 500$ GeV/$S_6$. At the freezing out temperature $T_f$ the rate of expansion exceeds the rate of annihilation to photons $EE^+ \rightarrow \gamma \gamma$ or to pairs of light fermions $f$ (quarks and charged leptons) $EE^+ \rightarrow \bar{f}f$ (We neglect effects of $SU(2)$ mediated bosons). Then $E$ leptons and their antiparticles $E^+$ are frozen out.

The frozen out concentration (in units of entropy density) of $E$, $r_E$, and $E^+$, $r_{E^+}$, is given (see Appendix 1) by

$$
r_E = 10^{-11} S_6 \cdot (1 - \ln (S_6)/25) + 0.4 \cdot 10^{-13}/S_6
$$

$$
r_{E^+} = 10^{-11} S_6 \cdot (1 - \ln (S_6)/25) - 0.4 \cdot 10^{-13}/S_6
$$

(8)

at $T \approx T_f E \approx m_E/25 \approx 20$ GeV/$S_6$. One finds from Eq. (8) that at $S_6 = 1$ the frozen out concentration of $EE^+$ pairs is by 2 orders of magnitude larger than the concentration Eq. (4) of excessive $E$ and this effect increases $\propto S_6^2$ for larger and larger $S_6$. Even at smallest possible $S_6$ $EE^+$ pair abundance is 5 times larger than $L'$ excess.

Antiparticles $\bar{U}$ and $E^+$ should be effectively annihilated in the successive processes of quark and $E$ recombinations. However, as it is shown in Appendices 3-5 primordial anti-quark tera-hadrons can be effectively suppressed, while as we‘ll see similar mechanism of annihilation is not effective for tera-positrons.

3.4. $E^+$ annihilation in twin tera-positronium $EE^+$

The frozen out $E^+$ can bind at $T < I_{E^+} = \alpha^2 m_E/4 \approx 6.3 M e V S_6$ with $E$ into positronium-like systems and annihilate. Since the lifetime of these positronium-like systems is much less than, the timescale of their disruption by energetic photons, the direct channel of $E^+$ binding in $EE^+$ and annihilation can not be compensated by inverse reaction of photo-ionization. That is why, similar to the case of chromo-Coulomb binding of $\bar{U}$ and their annihilation in “$U$-charmonium”, considered in Appendix 3, $E^+$ begin to bind with $E$ and annihilate as soon as temperature becomes less than $I_{E^+} = \alpha^2 m_E/4 \approx 6.3 M e V S_6$. The decrease of $E^+$ abundance owing to $EE^+$ recombination is governed by the equation

$$
\frac{dr_{E^+}}{dt} = -r_E r_{E^+} \cdot s \cdot \langle \sigma v \rangle,
$$

(9)

where $s$ is the entropy density and (see Appendix 2)

$$
\langle \sigma v \rangle = \frac{16\pi}{3\sqrt{2}} \cdot \frac{\alpha}{T^{3/2} \cdot m_E^{3/2}}.
$$

Using the formalism of Appendix 1 we can re-write the Eq. (10) as

$$
\frac{dr_{E^+}}{dx} = f_{1 E^+} (\langle \sigma v \rangle) r_{E^+} (r_{E^+} + \kappa_E),
$$

(10)

where $x = T/I_{E^+}$, the asymmetry $\kappa_E = r_{E^+} - r_{E^+} = r_{E^+} \approx 8 \cdot 10^{-14}/S_6$ is given by Eq. (4) and

$$
f_{1 E^+} = \sqrt{\frac{\pi g_3}{45 g_\pi}} m_p I_{E^+} \approx m_p I_{E^+}.
$$

The concentration of remaining $E^+$ is given by

$$
r_{E^+} = \frac{\kappa_E \cdot r_{E^+}}{\kappa_E \cdot r_{E^+} + \kappa_{E^+}} \exp (\kappa_{E^+} J_{E^+} - r_{E^+}) - f_{E^+},
$$

(11)

where from Eq. (8)

$$
r_{E^+} = 10^{-11} S_6 \cdot (1 - \ln (S_6)/25) - 0.4 \cdot 10^{-13}/S_6
$$

and

$$
J_{E^+} = \int_0^{x_{E^+}} f_{1 E^+} (\langle \sigma v \rangle) dx =
$$

$$
= m_p I_{E^+} \cdot 4 (\frac{2}{3\sqrt{2}}) \cdot \sqrt{x_{E^+} \cdot \frac{\alpha^2}{m_E}} \cdot 2 \cdot x_{E^+}^{1/2} \approx 1 \cdot 10^{13}/S_6.
$$

(12)

In the evaluation of Eq. (12) we took into account that the decrease of $E^+$ starts at $T \approx I_{E^+}$, so that $x_{E^+} \approx 1$. In the case of $E^+$ the reaction rate $\langle \sigma v \rangle$ in Eq. (12) contains square of fine structure constant instead of square of QCD constant $a$ in the case of $\bar{U}$. It makes the situation with $E^+$ at $S_6 \sim 1$ principally different from the case of antiquarks: the abundance of $\bar{U}$ is suppressed exponentially, while for $E^+$ exponential suppression is practically
absent. Indeed, one has \( \kappa E J_E^+ \approx 0.8/S_6^2 \) in the exponent of Eq. (11). For all \( S_6 \) the condition \( r_{E^+} \gg \kappa E \) is valid. Therefore the solution Eq. (11) has the form

\[
r_{E^+} \approx \exp \left( \frac{\kappa E}{J_{E^+}} - \frac{\kappa E}{J_{E-}} \right) - 1,
\]

which gives for \( S_6 > 1 \)

\[
r_{E^+} \approx \frac{1}{J_{E^+}} - \frac{\kappa E}{2} \approx 1.4 \cdot 10^{-13} S_6 - 0.4 \cdot 10^{-13}/S_6.
\]

In the result the residual amount of \( E^+ \) remains at \( S_6 \geq 1 \) enormously high, being for \( S_6 \sim 1 \) larger than \( L^+ \) excess.

At smallest allowed values of \( S_6 < 1 \) \( E^+ \) abundance is suppressed

\[
r_{E^+} = \kappa E \cdot \exp (-\kappa E J_{E^+}) \approx \left( \frac{8 \cdot 10^{-14}}{S_6} \right) \exp (-0.8/S_6^2)
\]

and for the minimal value \( S_6 = 0.2 \) the abundance of primordial tera-positrons falls down to

\[
r_{E^+} \approx 4 \cdot 10^{-13} \exp (-20) \approx 1.6 \cdot 10^{-21}.
\]

Even so suppressed a light Sinister Universe still provides a huge lepton-over-abundance (see section 5). On the other hand, this lowest tera-positron abundance lets the tera-electrons amount at small values of \( S_6 < 1 \) close to the asymmetric excess \( \kappa E = r_E - r_{E^+} \) or \( r_{E^+} \approx 8 \cdot 10^{-14}/S_6 \).

The general expression for lepton abundance \( r_E \) after twin tera-positronium annihilation has the form (see Appendix 1)

\[
r_E = \frac{\kappa E \cdot r_E}{r_{E^+} - (r_{E^+} - \kappa E) \exp (-\kappa E J_{E^+})},
\]

where \( J_{E^+} \) is given by Eq. (12) and from Eq. (3)

\[
r_E = 10^{-11} S_6 \cdot (1 - \ln (S_6)/25) + 0.4 \cdot 10^{-13}/S_6.
\]

With the account for \( r_{E^+} \), \( \kappa E \) for all \( S_6 \) one obtains

\[
r_E = \frac{\kappa E}{1 - \exp (-\kappa E J_{E^+})},
\]

It tends to \( r_E \approx 1/J_{E^+} + \kappa E/2 \approx 1.4 \cdot 10^{-13} S_6 + 0.4 \cdot 10^{-13}/S_6 \) at large \( S_6 \) and to \( \kappa E \) for small \( S_6 < 1 \).

3.5. E-Ubaryon recombination

At the temperature \( T < I_{U^E} = Z^2 \alpha m_E/2 \approx 50 MeV S_6 \) (where electric charge of \( UU \)) is \( Z = 2 \) \( (UU) \) can form atom-like systems with \( E \). Reactions

\[
(UU) + E \rightarrow (UUUE) + \gamma
\]

\[
(UU) + E \rightarrow (UUUE) + \gamma
\]

are balanced by inverse reactions of photo-destruction. According to Saha-type equations effective formation of \( (UUUE) \) and \( (UUEEE) \) systems is delayed until \( T_{UUE} \sim I_{U^EE}/30 \sim 1.5 MeV S_6 \).

In this period composite \( (UUUEE) \) cold dark matter is formed. However, though most of \((UU)\) bind with \( EE \) into \( (UUEEE) \), significant fraction of free \( (UU) \) and \( (UUE) \) remains unbound, what we show below.

In the considered period \( r_{UU} = r_{EE} = 4 \cdot 10^{-14}/S_6 \) (In the following we assume sufficiently effective suppression of \( U \) hadrons in hadronic recombination, as it is in cases A and B of Appendix 5), while the abundance of \( E \) after incomplete annihilation with \( E^+ \) is \( r_E = 1.4 \cdot 10^{-13} S_6 + 0.4 \cdot 10^{-13}/S_6 \) at \( S_6 \geq 1 \) and only at \( S_6 < 1 \) tends to \( \kappa E = 8 \cdot 10^{-14}/S_6 \). At \( T < T_{U^UU} \sim I_{U^UE}/30 \sim 1.5 MeV S_6 \) the residual amount of free \((UUUE)\) is governed by equation

\[
dr_{UU}/dx = f_{1EU}(\sigma v) r_{UU}(r_{UU} + \kappa_{U^E}),
\]

where \( x = T/I_{U^E} \) and \( \kappa_{U^E} = r_E - r_{EE} \). At \( S_6 = 1 \( \kappa_{U^E} = 1.4 \cdot 10^{-13} \), at large \( S_6 \geq 1 \) \( \kappa_{U^E} = 1.4 \cdot 10^{-13}/S_6 \), while at smallest \( S_6 \sim 0.2 \) the value of \( \kappa_{U^E} \) is approximately \( 4 \cdot 10^{-14}/S_6 \). In the Eq. (16)

\[
\langle \sigma v \rangle = \left( \frac{4 \pi}{3S^2} \right) \frac{\alpha^2 Z^2}{I_{UE} m_E x^{1/2}}
\]

and

\[
f_{1EU} = \sqrt{\left( \frac{\pi g_2}{656} \right) m_{pI_{UE}} \approx m_{pI_{UE}} = m_{p} Z^2 \alpha^2 m_{E}/2.
\]

Solution of Eq. (16) is given by

\[
r_{UU} = \frac{\kappa_{U^E} r_{UUU}}{r_{UU} + \kappa_{U^E} r_{UUU}}.
\]

Here \( r_{UUU} < r_{EE} \) is the abundance of \((UU)\) at \( T_{J_{U^UU}} \sim I_{U^UE}/30 \),

\[
J_{U^EE} = \int_{0}^{x_{U^EU}} f_{1EU}(\sigma v) dx = \frac{2 \pi}{3S^2} \frac{Z^2 \alpha^2}{m_E} \cdot \sqrt{x_{U^EE}} \approx 4 \cdot 10^{-12}/S_6
\]

and we took \( x_{U^UU} \sim 1/30 \). For \( S_6 \geq 1 \) in the exponent of solution Eq. (17) \( \kappa_{U^E} J_{U^EE} \approx 0.56 \) is independent of \( S_6 \). Therefore the following approximate expression is valid for \( S_6 \geq 1 \)

\[
r_{UUU} = \frac{r_{UUU}}{1 + (\kappa_{U^E} + r_{UUU}) J_{U^EE}} \approx r_{UUU}.
\]

Similar arguments are valid for \( U \)- "ions" \((UUU) \) and \((UUUE) \) decreases the abundance of \( E \), but to the end of the first second of cosmological expansion the relic tera-lepton pairs of \( E \) and \( E^+ \) still remain the dominant form of tera-matter.

In the successive analysis we assume for definiteness at \( S_6 > 1 \)

\[
\frac{n(UU)}{n(UUUE)} \sim \frac{n(UUUE)}{n(UUEE)} \sim \frac{1}{10}
\]

with the same proportion for \((Uu)\) : \((UUuE)\) : \((UUuEE)\) and for \((UU)\) : \((UUUE)\) : \((UUuEE)\). If the lightest \( U \)-hadron is \( (Ud) \), we assume

\[
\frac{n(Uu)}{n(Uud)} \sim \frac{1}{10}.
\]

For smallest \( S_6 \sim 0.2 \) the above proportions may be an order of magnitude smaller.
3.6. Brief summary of Sinister trace at $t \sim 1$ s

Under these assumptions the tera-matter content of the Universe to the end of MeV era is:

1. Free $E$ with $r_E = 1.08 \cdot 10^{-13}$ at $S_0 \sim 1$. It is $(1.4 \cdot S_0 - 0.32 / S_0) \cdot 10^{-13}$ at $S_0 \gg 1$ and tends to $4 \cdot 10^{-16} / S_0$ at $S_0 \sim 0.2$.

2. Free $E^+$ with $r_{E^+} = 1 \cdot 10^{-13}$ at $S_0 \sim 1$, growing to $(1.4 \cdot S_0 - 0.4 / S_0) \cdot 10^{-13}$ for $S_0 \gg 1$ and decreasing down to $1.6 \cdot 10^{-21}$ at $S_0 = 0.2$.

3. Neutral $(UUUEEE)$ "tera-helium-atoms" (with $r(UUUEE) \approx 3.6 \cdot 10^{-14} / S_0$ for $S_0 \gg 1$, growing up to $3.96 \cdot 10^{-14} / S_0$, when $S_0$ decreases down to 0.2) with an uncertain admixture (up to 10%) of first and second hybrid tera-helium atoms ($UUuEE$) and ($UUuEE$). The minimal estimation for this admixture is $r(UUuEE) \sim r(UuuEE) \sim 10^{-20}$. If $(Uudd)$ is the lightest $U$-hadron, there should be neutral hybrid tera-hydrogen atoms with minimal abundance $r(Uudd) \sim 10^{-20}$.

4. Charged $(UUU)E^+$ "tera-helium-I-ions" with $r(UUU)E^+ \approx 4 \cdot 10^{-15} / S_0$ for $S_0 \geq 1$ and decreasing down to $r(UUU)E^+ \approx 4 \cdot 10^{-16} / S_0$ at $S_0 = 0.2$.

5. Free double charged $(UUU)$ pure tera-helion ion with $r(UUU) \approx 4 \cdot 10^{-16} / S_0$ for $S_0 \geq 1$ and tending to $r(UUU) \approx 4 \cdot 10^{-18} / S_0$ at $S_0 \sim 0.2$.

6. Theoretically uncertain amount of double charged "first hybrid tera-helium ions" $(UUu)$ - relics of hadronic recombination with the abundance in the range $10^{-20} \leq r(UUu) \leq 4 \cdot 10^{-15} / S_0$. We’ll take for definiteness the minimal estimation $r(UUu) = 10^{-20}$.

7. Theoretically uncertain amount of theoretically uncertain lightest "tera-baryon" $(Uqq)$ ($(Uu)$ or $(Uudd)$) $10^{-20} \leq r(Uqq) \leq 4 \cdot 10^{-15} / S_0$. The minimal estimation $r(Uqq) = 10^{-20}$ will be taken for definiteness.

8. Exponentially small amount of stable tera-mesons $(Uu)$ (We accept case A in hadronic recombination, what results in their suppression $\propto \exp(-4 \cdot 10^5 / S_0)$).

For $S_0 \geq 1$ pairs of free tera-leptons $E$ and $E^+$ dominate among these relics from MeV era. The abundance of these pairs relative to $L'$ excess grows with $S_0 > 1$ as $\propto S_0^2$. Since mass of tera-lepton is $\propto S_0$, the contribution of tera-lepton pairs into total density grows as $\propto S_0^2$ relative to $L'$ excess. If survive, tera-lepton pairs can close the Universe even at modest $S_0 > 1$ and such survival seems inevitable on the following reason.

In Big Bang Nucleosynthesis $^4H$ is formed with abundance $r_{H^4} = 0.1 r_e$ and due to larger binding energy it can bind with tera-electrons earlier, than $p$. Instead of neutral $(Ep)$ atom tera-electrons form positively charged $(^4HeE^+)^+$ ion. Coulomb barrier makes impossible reactions of $E^-$, trapped in this ion, with other positively charged tera-remnants ($E^+$ and $U$-ions). On the other hand virtually all the free $E^-$ are captured by $^4He$ before $Ep$ binding is possible and there are no free $E^-$, which can form $(E^-p)$. It leaves no hope to suppress the above list of tera-matter remnants with the use of $(Ep)$ catalysis (Glashow 2005).

However, in the process of SBBN reactions and its binding with tera-electron can influence the SBBN reactions, as well as it strongly changes the picture of successive evolution of tera-matter, leaving no room for the hope (Glashow 2005) to suppress the above list of tera-matter remnants with the use of $(Ep)$ catalysis.

4. HELIUM-4 CAGE FOR FREE E$^-$

At $T < I_{He} = Z^2 \alpha^2 m_{He}/2 \approx 400$ keV reaction

$$E^+ + He \rightarrow \gamma + (^4HeE)^+$$

(22)
can take place. In the successive reaction

$$E + (^4HeE)^+ \rightarrow \gamma + (^4HeE)$$

(23)
tera-helium ($EEHe$) "atom" is produced. The size of this "ion" and "atom" is

$$R_{EEHe} \sim 1/(Ze m_{He}) \approx 4 \cdot 10^{-13} cm$$

and they can play nontrivial catalyzing role in the nuclear transformations of SBBN.

For our problem another aspect is important. Reactions Eqs. (22) and (23) can start only after $^4He$ is formed, what happens at $T < 100$ keV. Then inverse reactions of ionization by thermal photons support Saha-type relationships between the abundances of these "ions", "atoms", free $E^-$, $^4He$ and $\gamma$:

$$\frac{n_{He} n_{E^-}}{n_{\gamma} n_{(EEHe)}} = \exp(-\frac{I_{He}}{T}).$$

(24)

and

$$\frac{n_{EEHe}}{n_{\gamma} n_{EEHe}} = \exp(-\frac{I_{He}}{T}).$$

(25)

When $T$ falls down below $T_{He} \sim I_{He}/ \log(n_{\gamma}/n_{He})$ $I_{He}/27 \approx 15$ keV free $E^-$ are effectively bound with helium in reaction Eq. (22). The fraction, which forms neutral $(^4HeE^-)^+$ depends on the ratio of $E^-$ and $^4He$ abundances. For $S_0 < 57$ this ratio is less, than 1. Therefore, when, owing to $^4He$ excess, virtually all $E^-$ form $(^4HeE^-)^+$ ion in reaction Eq. (22), there are no free $E^-$ left to continue binding in reaction Eq. (28). Moreover, as soon as neutral $(^4HeE)$ is formed it catalyzes reactions of $UE$ binding

$$UUU + (EEHe) \rightarrow (UUU)EE + ^4He$$

(26)

$$(UUUE) + (EEHe) \rightarrow (UUUEE) + ^4He + E$$

(27)

as well as tera-positronium annihilation through twin tera-positronium formation

$$(EEHe)+E^+ \rightarrow (EE^+ annihilation products)+^4He+E.$$  

(28)

In these reactions heavy $U$-ion or tera-positron penetrates neutral $(EEHe)$ "atom" and expel $^4He$. $U$-ions form terahelium "atom". Tera-positron forms twin tera-positronium ion ($EE^+$) with charge $Z = -1$. In the latter one of $E^-$ annihilates with $E^+$, leaving free $E^-$.  

4.1. $(^4HeE^-)$ trap surviving back reaction of $E^+$ annihilation

Energetic particles, created in $EE^+$ annihilation, interact with cosmological plasma. In the development of electromagnetic cascade creation of electron-positron pairs in the reaction $\gamma + \gamma \rightarrow e^+ + e^-$ plays important role in astrophysical conditions (see (Burns and Lovelace 1982 Agaronian and Vardanian 1985 Khlopov Cosmoparticle physics 1999) for review). The threshold of this reaction puts upper limit on
the energy on the nonequilibrium photon spectrum in cascade
\[ E_{\text{max}} = a \frac{m^2}{25 T}, \]
where factor \( a = \ln(15Q_1 + 1) \approx 0.5. \)

At \( T > T_{\text{bHe}} = a m^2 / (25 T_{\text{bHe}}) \approx 12.5 \text{keV} \) in the spectrum of electromagnetic cascade from \( E^+ \) annihilation maximal energy \( E_{\text{max}} < I_{\text{He}} \) and \( E^+ \) annihilation products can not ionize \( (4HeE^-) \) and \( (4HeE^-E^-) \). So, there is no back reaction of \( E^+ \) annihilation until \( T \sim T_{\text{bHe}} \) and in this period practically all free \( E^- \) are bound in \( (4HeE^-)^+ \) ion. Due to Coulomb barrier \( E^+ \) can not penetrate \( (4HeE^-)^+ \) ion and annihilate with \( E^- \) in it.

Small fraction \( (\sim r_{E+}^2/r_{\text{He}}) \) of \( (4HeEE) \) is initially formed in the case \( S_6 < 57 \) but immediately eaten by tera-positrons. It leads to corresponding small decrease of initial tera positron abundance and of abundance of \( (4HeE^-)^+ \) relative to initial amount of \( E^- \). This decrease of \( r_{E+} \) is \( \sim 1/2 \) for smallest possible value \( S_6 = 0.2 \). Therefore virtually all primordial tera-leptons remain in the Universe and contribute into its total density. For \( S_6 > 1.7 \) this contribution exceeds \( \Omega_{\text{CDM}} \).

The case \( S_6 > 57 \), when \( r_E > r_{\text{He}} \), is even more troublesome, since in this case all the \( 4\text{He} \), produced in SBBN, is bound in \( (4HeE^-)^+ \). The successive formation of neutral \( (4HeE^-E^-) \) is now possible, so all the excessive tera-positrons \( r_{E+} > r_{\text{He}} \) annihilate with \( E^- \) in \( (4HeE^-E^-) \) until their abundance decreases down to \( r_{E+} = r_{\text{He}} \), when they eliminate all the \( (4HeE^-E^-) \). In the result \( r_{E+} \sim r_{\text{He}} \) and \( r_{(4HeE^-E^-)} \sim r_{\text{He}} \) are left, increasing the yield of open-closure of the Universe (\( \Omega > 5 \cdot 10^3 \Omega_{\text{CDM}} \)).

5. THE SINISTER OVERPRODUCTION OF ANOMALOUS HYDROGEN CLONES

The main problem of the considered cosmological scenario is the over-production of primordial tera-lepton pairs and their conservation in the Universe in various forms up to present time.

In the period of recombination of nuclei with ordinary electrons (\( e^- \)), \( (4HeE^-)^+ \), \( E^+ \), free charged \( U^- \), as well as charged \( (UUU\bar{E}) \), \( (UU\bar{E}) \), \( (Uu\bar{E}) \) systems recombine with electrons to form atoms of anomalous isotopes. The substantial (no less than 6 orders of magnitude) excess of electron number density over the number density of primordial tera-fermions makes virtually all of them to form atoms (see Appendix 6).

At \( S_6 > 1 \) contribution of these atoms in the total density exceeds \( \Omega_{CDM} \). Therefore only a small interval \( 0.2 < S_6 < 1 \) can be considered. Then the dominant form of tera matter is neutral \( (UUU\bar{E}) \), which saturates the total Dark matter density and might drive the development of gravitational instability, resulting in galaxy formation. This neutral tera matter contains an uncertain fraction of hadronic tera-helium \( (UUu\bar{E}) \) and \( (Uu\bar{E}) \) (or tera-hydrogen \( (Uu\bar{u}E) \)), if \( (Uu\bar{u}d) \) is the lightest). Though the total contribution of this fraction to the DM density should be less than 10% it can not be less than \( 2.5 \cdot 10^{-7} \). Moreover, the dominant form of tera-matter is accompanied by other forms of tera-matter with the following abundances for \( S_6 = 1 \) (we also give lower limit at \( S_6 = 0.2 \))

\[ \xi_i = r_i/r_b \]

relative to baryons:

1. Hybrid tera-helium \( (4HeE^-) \) with \( \xi_{(4HeE^-)} = r_{(4HeE^-)/r_b} \approx 1.4 \cdot 10^{-3} \), (at \( S_6 = 0.2 \xi_{(4HeE^-)} \approx 2.5 \cdot 10^{-5} \))

2. Hybrid tera-positronium \( (eE^+) \) with \( \xi_{(eE^+)} \approx 1.3 \cdot 10^{-3} \), (at \( S_6 = 0.2 \xi_{(eE^+)} \approx 1 \cdot 10^{-11} \))

3. Tera-helium I hybrid atoms \( (UUUee) \) with \( \xi_{(UUUee)} \approx 5 \cdot 10^{-5} \), (at \( S_6 = 0.2 \xi_{(UUUee)} \approx 5 \cdot 10^{-9} \))

4. Pure tera-helium hybrid atoms \( (UUUu) \) with \( \xi_{(UUUu)} \approx 1.3 \cdot 10^{-10} \) (at \( S_6 = 0.2 \xi_{(UUu)} \approx 1.3 \cdot 10^{-11} \))

5. First and second tera-helium I atoms \( (UUu) \), \((UUu) \), \((UUu) \) with abundance, no less than \( \xi_{(UUu)} \approx 1.3 \cdot 10^{-11} \) (at \( S_6 = 0.2 \xi_{(UUu)} \approx 5 \cdot 10^{-13} \))

and exponentially small amount of free \( E \), \( (UU) \), \((UUu) \) and \( (Uu) \) hadrons.

All these \( e^- \) atoms, having atomic cross sections of interaction with matter, participate then in formation of astrophysical bodies, when galaxies are formed. At \( S_6 = 1 \) density of anomalous hydrogen \( (4HeE^-) \), \( (eE^+) \) and \( (UUUee) \) is two times larger, than baryonic density. For all the range \( 0.2 < S_6 < 1 \) their abundance is many orders of magnitude higher than the experimental upper limits (Klein et al 1981, Vandegriff et al 1996, Mueller et al 2004, Middleton et al 1979, Hemrick et al 1990, Smith et al 1982). Moreover, there does not seem to be any mechanism to reduce their primordial abundance in matter bodies.

To save the sinister model from this trouble the following mechanisms were mentioned in (Glashow 2005):
- more complete aggregation of remnants into tera-helium during the structure formation
- gravitational concentration of heavy remnants inside stars
- procession of remnants into superheavy elements other than those for which sensitive searches were carried out.

Both the first and the last mechanisms are not appropriate for leptonic anomalous hydrogen \( eE^+ \) and it may be shown that for all the types of remnants gravitational concentration in stars is not effective (Appendix 7).

Moreover, the mechanisms of the above mentioned kind can not in principle suppress the abundance of remnants in interstellar gas more than by factor \( f_g \sim 10^{-2} \), since at least 1% of this gas has never passed through stars or dense regions, in which such mechanisms are viable. It may lead to the presence of \( (4HeE^-)^+ \), \( E^+ \), \( (UUUee) \) and other fragment’s component of cosmic rays at a level \( \sim f_g \xi_i \). Therefore based on sinister model with \( 1 \geq S_0 \geq 0.2 \) one can expect the anomalous hydrogen fractions of cosmic rays

\[
10^{-5} \geq \frac{(4HeE^-)^+}{p} \geq 2.5 \cdot 10^{-7},
\]

\[
10^{-5} \geq \frac{E^+}{p} \geq 10^{-13},
\]

\[
5 \cdot 10^{-7} \geq \frac{(UUUee)}{p} \geq 5 \cdot 10^{-8}
\]

and anomalous helium

\[
5 \cdot 10^{-7} \geq \frac{(UUU)}{He} \geq 2.5 \cdot 10^{-8}.
\]
If \((^4HeE^-)^+\) is disrupted in the course of cosmic ray acceleration one should expect anomalous charge \(Z = -1\) component of cosmic rays

\[
10^{-5} \geq \frac{E^-}{p} \geq 2.5 \cdot 10^{-7}.
\]

These predictions may be within the reach for future cosmic ray experiments, in particular, for AMS.

The only way to solve the problem of anomalous isotopes is to find a possible reason for their low abundance inside the Earth and solution of this problem implies a mechanism of effective suppression of anomalous hydrogen in dense matter bodies (in particular, in Earth).

The idea of such suppression, first proposed in (Khlopov 1983) was recently realized in Belotsky Fargion Khlopov et al 2004). However we don’t have this possibility for tera-matter, unless the underlying model is modified to include long range attraction for tera-particles. Another possible modification of the underlying sinister model is to provide the mechanism of tera-particle instability. If their lifetime is less, than the age of Universe, they decay and there is no problem of their over-abundance in the present Universe, but the effects of the decay products should satisfy astrophysical constraints (see review and Refs in Khlopov Cosmoparticle physics 1999). In accelerator search, however, unstable particles with lifetime, much less than the age of Universe can be treated as stable (see Appendix 8).

6. DISCUSSION

Experimental data on \(Z\) boson width exclude the possibility for new heavy generations, constructed in the same way as the three known families. New heavy quarks and leptons should possess some new property, which differs them from fermions of known generations.

Such property may be a new long range interaction, which new (fourth) generation possesses Belotsky Fargion Khlopov et al 2004). With the use of this interaction an effective mechanism, reducing the abundance of anomalous isotopes below the existing upper limit can be realized Belotsky Fargion Khlopov et al 2004). The dominant form of dark matter can not be explained in this framework.

The idea of novel Glashow’s sinister model for heavy fermions is more ambitious, since together with generation of neutrino mass and solution of strong CP violation problem it pretended to explain the dominant of neutrino mass and solution of strong CP violation problem. Meta-stable \(m > 100 GeV E\) and \(E^+\) and single \(U\)-quark hadrons become in this case the challenge for new generation of particle accelerators.

If survives, sinister Universe offers new interesting framework for particle physics and cosmology. If not, there still can be some place for tera-matter with its flavor of possible composite dark matter in Galaxy and exotic rare forms of stable matter around us.

7. CONCLUSIONS

In conclusion, tera-leptons hidden in \((^4HeE^-)^+\) cage or frozen in hybrid tera-postitronium \((eE^-)^+\) as well as in other hybrid components are guaranteed lethal relics for any Sinister Universe. Behaving as anomalous hydrogen isotope most of these relics suffer of all the correlated and severe bounds on our lightest elements.

The \(S_6\) parameter does not offer any way out or escape, wherever it grows or decreases: the tera-leptons are ever offending atomic data records. While exotic and \(ad hoc\) tera-lepton interaction might offer a hope to survive, they are nevertheless breaking the Sinister beautiful simplicity and symmetry. There is in the unstable scenario for tera-Leptons and Tera-Quarks a very interesting case for UHECR as discussed in Appendix 9, able in principle to offer a solution to GZK puzzle.

We believe that the present study and collapse of our toy model will offer a clarifying starting point to new and more lucky scenarios, where Heavy Lepton and Heavy Quark may better fit the nature puzzles.

In some sense we feel that while with regret we are closing the door to a Glashow’s Sinister Cosmology we are disclosing a fascinating windows for meta-stable tera-particle physics and astrophysics.

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APPENDIX 1. CHARGE ASYMMETRY IN FREEZING OUT OF PARTICLES AND ANTIPARTICLES

The frozen number density of cosmic relics, which were in equilibrium with primordial plasma, is conventionally deduced from equation (Zeldovich and Novikov 1983)

\[
\dot{n} + 3Hn = \langle \sigma_{ann}v \rangle (n_{eq}^2 - n^2).
\]

This equation is written for the case of a charge symmetry of particles in question, i.e. for the case when number densities inhibit such annihilation and precludes effective decrease of tera-lepton primordial abundance. Even for minimal value \(S_6 = 0.2\) the predicted terrestrial abundance of anomalous hydrogen exceeds experimental upper limits by more than 20 orders of magnitude.

The problem of primordial tera-lepton overproduction can not be resolved for the present version of sinister model. Some additional physics is needed to provide effective mechanism of tera-lepton suppression. It might imply the necessity for tera-particles to be unstable with the lifetime less than the age of the Universe. Then they still can be considered as stable in accelerator experiments.

If survives, sinister Universe offers new interesting framework for particle physics and cosmology. If not, there still can be some place for tera-matter with its flavor of possible composite dark matter in Galaxy and exotic rare forms of stable matter around us.

15 We are grateful to K.Belotsky for help in preparation of this Appendix.
of particles ($X$) and antiparticles ($\bar{X}$) are equal $n_X = n_{\bar{X}} = n$. The value $n_{eq}$ corresponds to their equilibrium number density and is given by Boltzmann distribution

$$n_{eq} = \frac{g s}{2\pi} T^{3/2} \exp \left(-\frac{m}{T}\right).$$

(32)

Here $g_s$ and $m$ are the number of spin states and the mass of given particle.

In course of cooling $n_{eq}$ decreases exponentially and becomes below freezing out temperature $T_f$ much less then real density $n$, so the term $(\sigma_{ann}v)n_{eq}^2$, describing creation of $XX$ from plasma, can be neglected (Scherrer and M. Turner 1953). It allows to obtain approximate solution of Eq. (31).

In case of charge asymmetry one needs to split Eq. (31) on two: for $n_X$ and $n_{\bar{X}}$, which are not equal now.

$$\dot{n}_X + 3Hn_X = \langle \sigma_{ann}v \rangle (n_{eq} n_{eq} X - n_X n_{\bar{X}}),$$

$$\dot{n}_{\bar{X}} + 3Hn_{\bar{X}} = \langle \sigma_{ann}v \rangle (n_{eq} n_{eq} X - n_X n_{\bar{X}}).$$

(33)

The values $n_{eq} X$ and $n_{eq} \bar{X}$ are given by Eq. (22) with inclusion of chemical potential, which for $X$ and which for $\bar{X}$ are related as $\mu_X = -\mu_{\bar{X}} = \mu$ (see, e.g., Dolgov 2002). So

$$n_{eq} X n_{eq} \bar{X} = n_{eq},$$

(34)

where upper and lower signs are for $X$ and $\bar{X}$ respectively. So

$$n_{eq} X n_{eq} \bar{X} = n_{eq}. $$

(35)

A degree of asymmetry will be described in conventional manner (as for baryons) by the ratio of difference between $n_X$ and $n_{\bar{X}}$ to number density of relic photons at the modern period

$$\kappa_{mod} = \frac{n_X - n_{\bar{X}}}{n_{mod}},$$

(36)

However for practical purposes it is more suitable to use the ratio to entropy density which, unlike Eq. (36), does not change in time provided entropy conservation. Photon number density $n_\gamma$ and entropy density $s$ are given by

$$n_\gamma = \frac{2\zeta(3)}{\pi^2} T^3, \quad s = \frac{2\pi^2 g_s T^3}{45} = 1.80 g_s n_\gamma,$$

(37)

where

$$g_s = \sum_{bos} g_{bos} T_{bos}^3 + \frac{7}{8} \sum_{ferm} g_{ferm} T_{ferm}^3. $$

(38)

The sums in Eqs. (38) are over ultrarelativistic bosons and fermions. So

$$\kappa = \frac{n_X - n_{\bar{X}}}{s}, \quad \kappa = \frac{n_{mod}}{1.8 g_s n_{mod}}.$$ 

(39)

$g_{s mod} \approx 3.93$.

Eq. (39) provides connection between $n_X$ and $n_{\bar{X}}$. Let us pass to the variables

$$r_+ = \frac{n_X}{s}, \quad r_\bar{X} = \frac{n_{\bar{X}}}{s}, \quad r = \frac{n_X + n_{\bar{X}}}{s}, \quad x = \frac{T}{m}.$$ 

(40)

Apparent relations between $r_i$ are

$$r_+ - r_- = \kappa, \quad r_+ + r_- = r.$$ 

(41)

Provided that essential entropy re-distribution does not take place ($g_s = const$) during the period of freezing out, transformation to variable $x$ is possible

$$-H dt = dT/T = dx/x.$$ 

On the RD stage Hubble constant depends on $T$ as

$$H = \frac{2\pi}{3} \sqrt{\frac{\pi g_s}{5}} \frac{T^2}{m_{Pl}}.$$ 

(42)

where $g_s$ is given by

$$g_s = \sum_{bos} g_{bos} T_{bos}^3 + \frac{7}{8} \sum_{ferm} g_{ferm} T_{ferm}^3.$$ 

(43)

For $r_+, r_- \text{ and } r$ from Eqs. (40), one obtains equations

$$\frac{dr_+}{dx} = f_1 \langle \sigma_{ann}v \rangle (r_+(r_+ + \kappa) - f_2(x)),$$

$$\frac{dr_-}{dx} = f_1 \langle \sigma_{ann}v \rangle (r_-(r_- + \kappa) - f_2(x)),$$

$$\frac{dr}{dx} = \frac{1}{2} f_1 \langle \sigma_{ann}v \rangle (r^2 - \kappa^2 - 4f_2(x)).$$ 

(44)

Here

$$f_1 = \frac{s}{Hx},$$

$$f_2(x) = \frac{n_{eq}^2}{s^2} = \frac{45^2 g_s^2}{2\pi^2 g_s^2 x^3} \exp \left(-\frac{2}{x}\right).$$

(45)

With the use of Eqs. (37) and Eq. (12) one finds that on the RD stage $f_1$ is equal to

$$f_1 = \sqrt{\frac{\pi g_s}{45 g_s}} m_{Pl}/m$$

and independent of $x$.

To solve Eqs. (44), analogously to Eq. (31), namely neglecting $f_2(x)$ in them starting with some $x = x_f$, it would not be more difficult if to define the moment $x = x_f$. Nonetheless, if one supposes that such a moment is defined then, say, $r_+$ will be

$$r_+(x \approx 0) = \frac{\kappa \cdot r_+}{r_+ + (r_+ + \kappa) \exp(-\kappa J)}$$

$$r_-(x \approx 0) = \frac{(\kappa + r_-) \exp(\kappa J) - r_-}{(\kappa + r_-) \exp(\kappa J) + r_+}$$

$$r(x \approx 0) = \frac{\kappa}{\kappa J + r_+} \exp(\kappa J) - (r_+ - \kappa).$$

(46)

Here $r_{i j} = r_i(x = x_j)$,

$$J = \int_0^{x_f} f_1 \langle \sigma_{ann}v \rangle dx.$$ 

(47)

All $r_i$ (at any moment) are related with the help of Eqs. (31). Taking into account Eq. (40) or Eq. (39) for $r_{i j}$ one obtains

$$r_{i j} = \frac{1}{2} \left(\sqrt{4f_2(x_f)} + \kappa^2 \pm \kappa\right), \quad r_f = \sqrt{4f_2(x_f)} + \kappa^2$$

For $\langle \sigma_{ann}v \rangle$ independent of $x$ on RD stage, when $f_1$ is also independent of $x$, with the account for the definition of $x_f$ from the condition $R(T_f) = H(T_f)$ for reaction rate $R(T_f) = n_{eq}(T_f) \langle \sigma_{ann}v(T_f) \rangle$, leading to

$$n_{eq}(T_f) \langle \sigma_{ann}v(T_f) \rangle / H(T_f) = \frac{n_{eq}}{s} \frac{H}{x_f} \langle \sigma_{ann}v(x_f) \rangle \cdot x_f = \sqrt{f_2(x_f)} f_2 \langle \sigma_{ann}v(x_f) \rangle \cdot x_f = 1,$$

one obtains

$$\sqrt{f_2(x_f)} = \frac{1}{f_1 \langle \sigma_{ann}v \rangle \cdot x_f} = \frac{1}{J}.$$ 

(49)
If (a) \(\sigma_{nn} = a^2 / m^2\) or (b) \(\sigma_{nn} = C\alpha / \sqrt{Mm}\) and one assumes \(f_1 = \text{const}\) then

\[
J_a = \sqrt{\frac{\pi g_s^2}{45g_e}} m_p \frac{\alpha^2}{m} x_f,
\]

\[
J_b = \sqrt{\frac{\pi g_s^2}{45g_e}} m_p \frac{\alpha}{m} 2 \sqrt{x_f}.
\] (50)

In the case of freezing out of U-quarks one has

\[
f_{1U} = \sqrt{\frac{\pi g_s^2}{45g_e}} m_p m_U \approx 2.5 m_p m_U,
\]

\[
\langle \sigma_{nn} \rangle = \frac{1}{16 \pi m^2},
\]

and

\[
J_U = \sqrt{\frac{\pi g_s^2}{45g_e}} \frac{1}{N_c} \frac{\alpha^2}{m} x_f,
\] (51)

where \(\bar{\alpha} = C_F \alpha_s \sim (4/3) \cdot 0.1 \approx 0.13\) and \(C_F = (N_c^2 - 1)/2N_c\) is \(4/3\) is the color factor. Another color factor \(1/N_c = 1/3\) is the probability to find an appropriate anticolour. Putting in Eq. (49) \(g_s = 6\), \(g_s \approx 100\), one obtains solution of transcendent equation \(x_f \approx \sqrt{\frac{45g_s}{2\pi^2 \sqrt{g_s}}} \cdot f_{1U} \langle \sigma_{nn} \rangle \). The solution of transcendent equation (49) one has \(\sigma \approx \sqrt{\frac{\pi g_s^2}{45g_e}} m_p m_U \approx 2.5 m_p m_U\), \(\langle \sigma_{nn} \rangle \approx 1/16 \pi m^2\) and

\[
x_f \approx \left( \ln \left( \frac{45g_s}{2\pi^2 \sqrt{g_s}} \cdot f_{1U} \langle \sigma_{nn} \rangle \right) \right)^{-1} \approx \frac{1}{30} \left( 1 - \ln \left( \frac{S_0}{30} \right) \right).
\]

Taking \(g_s \approx g_s \approx 100\) one finds from Eq. (51), \(J_U = 1.3 \cdot 10^{12}/S_0 (1 - \ln (S_0)/30)^{-1}\) and from Eq. (49) \(\sqrt{4f_2(x_f)} = 2/J_U = 16 \cdot 10^{-13} S_0 \cdot (1 - \ln (S_0)/30)\). For \(\kappa = r_U = 1.2 \cdot 10^{-13}/S_0\) one has \(\kappa J_U = 0.16/S_0\). one obtains. Since \(4f_2(x_f) \gg \kappa^2\) for \(S_0 > 1\) one obtains from Eq. (49)

\[
r_{\pm f} = \frac{1}{2} \left( \sqrt{4f_2(x_f)} \pm \kappa \right).
\] (52)

It gives for the frozen out abundances of \(U\) and \(\bar{U}\)

\[
r_U = \frac{\kappa \cdot r_{+f}}{r_{+f} - (r_{-f} - \kappa) \exp(-\kappa J_U)},
\]

\[
r_{\bar{U}} = \frac{\kappa \cdot r_{-f}}{(\kappa + r_{-f}) \exp(\kappa J_U) - r_{-f}}.
\] (53)

With the account for the numerical values taken above one gets \(r_U \approx 8.6 \cdot 10^{-13}\) and \(r_{\bar{U}} \approx 7.4 \cdot 10^{-13}\) for \(S_0 = 1\). For growing \(S_0 > 1\) the solution Eq. (50) approaches the values

\[
r_U \approx \sqrt{f_2(x_f)} + \kappa/2 \approx 8 \cdot 10^{-13} S_0 \cdot (1 - \ln (S_0)/30) + 6 \cdot 10^{-14} / S_0
\]

\[
r_{\bar{U}} \approx \sqrt{f_2(x_f)} - \kappa/2 \approx 8 \cdot 10^{-13} S_0 \cdot (1 - \ln (S_0)/30) - 6 \cdot 10^{-14} / S_0.
\] (54)

At \(S_0 < 0.4\) the factor in exponent \(\kappa J_U\) exceeds 1, and some suppression of \(U\) abundance takes place. For \(S_0 = 0.2\) it reaches maximal possible value \(\kappa J_U = 4\) and the solution Eq. (50) gives \(r_U \approx \kappa = 6 \cdot 10^{-13}, r_{-f} \approx 1.1 \cdot 10^{-14}\) from Eq. (49) and

\[
r_{\bar{U}} \approx \frac{\kappa \cdot r_{-f}}{r_{+f} - (r_{-f} - \kappa) \exp(-\kappa J_U)} \approx 1.1 \cdot 10^{-14} \exp(-4) \approx 2 \cdot 10^{-16}.
\]

In the case of freezing out of \(E\)-leptons one has \(f_{1E} \approx 2.5 m_p m_E, \langle \sigma_{nn} \rangle \approx \frac{\alpha^2}{m_E^2}\) and

\[
J_E = \sqrt{\frac{\pi g_s^2}{45g_e}} m_p \frac{\alpha^2}{m_E} x_f.
\] (55)

Putting in Eq. (55) \(g_s = 2\), \(g_s \approx 100\), one obtains solution of transcendent equation (50)

\[
x_f \approx \left( \ln \left( \frac{45g_s}{2\pi^2 \sqrt{g_s}} \cdot f_{1E} \langle \sigma_{nn} \rangle \right) \right)^{-1} \approx \frac{1}{25} \left( 1 - \ln \left( \frac{S_0}{25} \right) \right).
\]

Taking \(g_s \approx g_s \approx 100\), one finds from Eq. (55), \(J_E \approx (10^1 / S_0) \cdot (1 - \ln (S_0)/25)^{-1}\). For \(\kappa = r_E = 8 \cdot 10^{-13}/S_0\) it corresponds to \(\kappa J_E \approx 8 \cdot 10^{-33}/S_0 \ll 1\) for all \(S_0 > 0.2\) and one obtains \(\sqrt{f_2(x_f)} = 2/J_E = 2 \cdot 10^{-11} S_0 \cdot (1 - \ln (S_0)/25)\). Since \(4f_2(x_f) \gg \kappa^2\) one obtains from Eq. (54)

\[
r_{\pm f} = \frac{1}{2} \left( \sqrt{4f_2(x_f)} \pm \kappa \right).
\] (56)

For small \(\kappa J_E \ll 1\) frozen out abundances of \(E\) and \(E^+\) have the form

\[
r_E \approx \frac{r_{+f}}{1 + (r_{+f} - \kappa) J_E} \approx \sqrt{f_2(x_f)} + \kappa/2,
\]

\[
r_{E^+} \approx \frac{r_{-f}}{1 + (\kappa + r_{-f}) J_E} \approx \sqrt{f_2(x_f)} - \kappa/2.
\] (57)

For the numerical values taken above and \(S_0 = 1\) one gets \(r_E = 0.906 \cdot 10^{-11}\) and \(r_{E^+} = 1.004 \cdot 10^{-12}\). In case of minimal possible value \(S_0 = 0.2\) \(r_E = 2.2 \cdot 10^{-12}\) and \(r_{E^+} = 1.8 \cdot 10^{-12}\).

**APPENDIX 2. RECOMBINATION AND BINDING OF HEAVY CHARGED PARTICLES.**

In the analysis of various recombination processes we can use the interpolation formula for recombination cross section, deduced in [Belotsky Fargion Khlopov et al 2004]:

\[
\sigma_r = (\frac{2\pi}{3\sqrt{2}})^2 \cdot \frac{\alpha^3}{T} \cdot \log \left( \frac{I_1}{T} \right)
\]

and the recombination rate given by

\[
\langle \sigma v \rangle = (\frac{2\pi}{3\sqrt{2}})^2 \cdot \frac{\alpha^3}{T} \cdot \log \left( \frac{I_1}{T} \right) \cdot \frac{k_{in}}{M}
\]

Here \(k_{in} = \sqrt{2TM}, I_1 \approx \alpha^2 M/2\) is the ionization potential and \(M\) has the meaning of the reduced mass for pair of recombining particles. Pending on the process, the constant \(\alpha\) has the meaning of fine structure constant \(\alpha\) or QCD constant \(\alpha_c\). The approximation Eq. (59) followed from the known result for the electron-proton recombination

\[
\sigma_{rec} = \sigma_r = \sum_i \frac{1}{N_c} \frac{8\pi}{3\sqrt{2}} \cdot \frac{\alpha^3}{T} \cdot \frac{e^4}{M v^2} \left( \frac{1}{M v^2/2 + I_1} \right)
\]

where \(M \) and \(v\) are the reduced mass and velocity of particles; \(I_1\) - ionization potential \(I_1 = I_1 / v^2\). The color factor \(1/N_c = 1/3\) is the probability to find an appropriate anticolour.

To sum approximately over \(i\) it was noted in [Belotsky Fargion Khlopov et al 2004] that \(\sigma_r \propto 1/i\) for \(I_1 >> M v^2/2 = T_{eff}\) while at \(I_1 < T_{eff}\) the cross section \(\sigma_r \propto 1/i^3\) falls down rapidly.

The following classical description is valid for \(v/c \ll \alpha\).
Radiation of mutually attracting opposite charges can lead to formation of their bound system. It can be described in the analogy to the process of free monopole-antimonopole annihilation considered in [Zeldovich and Khlopov 1979].

Potential energy of Coulomb interaction between opposite charges exceeds their thermal energy \( T \) at the distance

\[
d_0 = \frac{\alpha}{T}.
\]

According to [Zeldovich and Khlopov 1979], following the classical solution of energy loss due to radiation, converting infinite motion to finite, free charged particles form bound systems at the impact parameter

\[
a \approx (T/m)^{3/10} \cdot d_0.
\]

The rate of such binding is then given by

\[
\langle \sigma v \rangle = \pi a^2 v \pi \cdot (m/T)^{9/10} \cdot \frac{\alpha^2}{m^2}.
\]

The successive evolution of this highly excited atom-like bound system is determined by the loss of angular momentum owing to radiation. The time scale for the fall on the center in this bound system can be estimated according to classical formula (see [Dubrovich Fargion Khlopov 2004]):

\[
\tau = \frac{\alpha^3}{64\pi} \cdot \frac{(m/T)^{21/10}}{(m)} \cdot \frac{1}{m}.
\]

As it is easily seen from Eq. (68), this recombination time scale \( \tau \ll m/T^2 \ll m_{\pi}/T^2 \) turns to be much less than the cosmological time at which the bound system was formed.

Classical description assumes \( a = \frac{m_{\pi}}{m} t_{109/10} \geq \frac{1}{\alpha} \) and is valid at \( T \approx m_{\alpha}^{20/7} \).

**APPENDIX 3. ELIMINATION OF \( \bar{U} \) IN \( UUU \) BOUND SYSTEMS**

When temperature falls down below \( I_U \approx \bar{\alpha}^2 M_U/2 \sim 15\text{GeV} \cdot S_6 \) (where \( \bar{\alpha} = 4/3 \cdot 0.1 \approx 0.13 \) and \( M_U = m_{\upsilon}/2 \) is the reduced mass of \( U \) quarks in \( UUU \) system - see Appendices 1 and 2) \( U \)-quarks begin to bind due to chromo-Coulomb attraction. They form bound (\( \bar{U} \)) diquark systems and (\( UUU \)) baryons. Similar to \( ^4\text{He} \) formation in SBBN, (\( UUU \)), being the system with the largest binding energy, is not produced by 3-body process directly, but by multi-step 2-body events. In SBBN the chain of nucleosynthesis reactions starts with formation of D, and all the frozen out neutrons are first bound in D. In analogy the process of \( U \) binding starts with formation of (\( UUU \)) diquarks.

Simultaneously at \( T < I_U \approx \bar{\alpha}^2 m_{\upsilon}/4 \sim 15\text{GeV} \cdot S_6 \) the frozen out antiquarks \( \bar{U} \) begin to bind with \( U \) quarks into charmonium-like state (\( \bar{U}U \)) and annihilate. However there is an important difference between formation of (\( UUU \)) diquarks and (\( UUU \)) charmonium-like systems. The former are stable relative to annihilation and can be disrupted by energetic gluons, while the latter annihilate on the timescale (see Appendix 2), much less than the timescale of gluon interaction. Therefore direct reaction of (\( UUU \)) is not compensated by inverse process of its disruption by energetic gluons, and formation of \( UUU \) systems and \( U \) annihilation in them starts immediately after temperature falls down below \( I_U \).

The decrease of \( \bar{U} \) abundance owing to \( UUU \) recombination is governed by the equation

\[
\frac{d\rho_U}{dt} = -r_{UUU} \rho_{\bar{U}} \cdot \langle \sigma v \rangle,
\]

where \( s \) is the entropy density and (see [Belotsky Fargion Khlopov et al 2004])

\[
\langle \sigma v \rangle \approx \frac{16\pi}{3\alpha^2} \cdot \frac{\bar{\alpha}}{T^{1/2}} \cdot \frac{m_{\upsilon}}{m_{\alpha}}.
\]

With the use of formulae in Appendix 1 Eq. (61) is reduced to the form:

\[
\frac{d\rho_U}{dx} = f_1 \langle \sigma v \rangle r_0 (r_0 + \kappa_U),
\]

where \( x = T/I_0 \), the asymmetry \( \kappa_U = r_U - r_0 = 1.2 \cdot 10^{-13} / S_6 \) is given by Eq. (3) and

\[
f_1 = \frac{\pi g_s^2}{4\alpha} m_{\pi} I_U \approx 2.5 m_{\pi} I_U.
\]

The concentration of remaining \( \bar{U} \) is given by

\[
r_0 = \frac{\kappa_U \cdot r_{f1}}{(\kappa_U + r_{f1})} \exp(-\kappa J),
\]

where from Eq. (5) \( r_{f1} = 7.4 \cdot 10^{-13} f_0(S_6) \), and

\[
J = \int_0^{r_{f1}} f_1 \langle \sigma v \rangle dx \approx 4 \cdot 10^{14} S_6.
\]

It was taken into account in Eq. (35) that in the considered case annihilation starts at \( T \approx I_U \) so that \( x \approx 1 \). One obtains that \( \bar{U} \) are practically eliminated at \( T \approx I_U \approx \bar{\alpha}^{2} M_{\upsilon}/2 \sim 15\text{GeV} \cdot S_6 \), since their abundance decreases down to \( r_0 \approx 1 \cdot 10^{-13} \cdot \exp(-48/S_6) \), being \( \approx 7 \cdot 10^{-34} \) for \( S_6 = 1 \). Therefore at \( S_6 \leq 1 \) their role is negligible in the successive processes. That is not the case for \( E^+ \) for the same small values of \( S_6 \). In the latter case, which is described by similar equation with similar solution, recombination rate, having the form Eq. (35), involves fine structure constant \( \alpha \) instead of QCD constant \( \bar{\alpha} \). It makes the corresponding value of \( J \) (with the account for other numerical factors: difference in masses of \( U \) and \( E \) and in statistical factors in the period of their binding, color factors) about 90 times smaller and is \( S_6 \) independent. It makes the corresponding value of \( J \) (with the account for other numerical factors: difference in masses of \( U \) and \( E \) and in statistical factors in the period of their binding, color factors) about 90 times smaller and is \( S_6 \) independent.

**APPENDIX 4. U RECOMBINATION INTO (UU) AND (UUU) SYSTEMS**

At \( T < I_U \approx \bar{\alpha}^2 M_{\upsilon}/2 \sim 15\text{GeV} \cdot S_6 \) free \( U \) can bind into (\( UUU \)) diquarks, but during long period direct reaction

\[
U + U \rightarrow (UU) + g,
\]

where \( g \) is gluon is balanced by the inverse process

\[
g + (UU) \rightarrow U + U.
\]

It reminds the well known "entropy barrier" for \( n + p \rightarrow D + \gamma \) reaction in SBBN. Since relative abundance of gluons \( r_g \approx 0.1 \gg r_U \), gluons can effectively distract (\( UUU \)) even at temperatures \( T \ll I_U \). It provides the conditions for kinetic equilibrium between direct and inverse reactions.

As soon as (\( UUU \)) are formed the processes

\[
U + (UU) \rightarrow (UUU) + g,
\]

and

\[
U + U \rightarrow (UU) + g,
\]
are possible.

In equilibrium abundance of these bound systems is determined by Saha equations

$$\frac{n_U n_U}{n_H n(UU)} = \exp\left(-\frac{I_U}{T}\right). \quad (73)$$

and

$$\frac{n_U n(UU)}{n_H n(UU)} = \exp\left(-\frac{I_U}{T}\right). \quad (74)$$

At $T < T_W \approx 1/30 T_0 \approx 0.5 \text{GeV} S_6$ (corresponding to period $t_{uu} \approx 4 \cdot 10^{-14}/S_6$) fraction of free $U$ quarks and $(UU)\bar{q}$ diquarks begins to decrease being governed by the system of kinetic equations. Solution of these equations for free $U$ and $(UU)$ requires development of special system of equations and their proper numerical treatment. However the precise result for the considered set of reactions is not so important, since it can be strongly modified and washed out by the successive processes of hadronic recombination considered in Appendix 5.

Qualitatively one may conclude that the most of initially free $U$ bind into $(UU)$ systems, which contain the bulk of the $B'$ excess, so that $r_{UU} = r_{B'} = 4 \cdot 10^{-14}/S_6$. However, the residual amount of unbound $U$ and $(UU)$ can not be small, since their binding into $(UU)$ stops, when $n_{UU} \langle \sigma v \rangle t_{uu} \sim 1$ and $n_{UU} \langle \sigma v \rangle t_{uu} \sim 1$. These conditions are realized at $S_6 \sim 1$ for

$$\frac{n_U}{n_{UU}} \sim \frac{n(UU)}{n(UU)} \sim 1/10. \quad (75)$$

APPENDIX 5. FORMATION OF $(UUU)$ DUE TO HADRONIC RECOMBINATION

After QCD phase transition at $T = T_{QCD} \approx 150 \text{MeV}$ free $U$ quarks and $(UU)\bar{q}$ diquarks combine with light quarks into $(UUq)$ and $\bar{U}(U\bar{q})$ hadrons. In baryon asymmetric Universe only excessive valence quarks should enter such hadrons, so that $U$-baryons are formed, while the abundance of $(U\bar{q})$ mesons is suppressed exponentially. These details of $U$-quark hadronization are discussed in Belotsky Fargion Khlopov et al (2004).

Since $(UUq)$ and $(U\bar{q})$ baryons have hadronic size, their collisions with typical hadronic cross sections can provide additional hadronic recombination of $U$ and $(UU)$ into $(UUU)$ (Glashow 2003). However the analysis of this problem has revealed a substantial uncertainty in the estimation of recombination rate Belotsky Fargion Khlopov et al (2004).

The maximal estimation for the reaction rate of recombination $\langle \sigma v \rangle$ is given by

$$\langle \sigma v \rangle \sim \frac{1}{m^2} \approx 6 \cdot 10^{-16} \text{cm}^3/\text{s} \quad (76)$$

or by

$$\langle \sigma v \rangle \sim \frac{1}{m^2} \approx 2 \cdot 10^{-17} \text{cm}^3/\text{s} \quad (77)$$

These estimations assume that in the process of collision recombination takes place due to emission of light quarks, what has typical hadronic cross section.

The minimal estimation (see Belotsky Fargion Khlopov et al 2004) was based on the QCD consideration, assuming that the process of $U$ binding takes place at small distances and is not influenced by effects of QCD confinement. It gives recombination rate (Belotsky Fargion Khlopov et al 2004)

$$\langle \sigma v \rangle \approx 0.4 \cdot (T_{T} m_U)^{3/2} (3 + \ln (T_{QCD}/T_{T})). \quad (78)$$

Here $T_{T} = \max \{T, T_s\}$ takes into account that at $T < T_s \approx m_{t/2u}^2 \approx 1.5 \cdot 10^{-2} \text{MeV} \sqrt{T_{t/2u}}$, where $m_{t/2u} \approx 300 \text{MeV}$ is the constituent mass of the light quark of hadron, kinetic energy of recombining quarks is determined by their motion inside hadrons.

Binding of $U$ in the course of hadronic recombination takes place in reactions Glashow (2003)

$$(Uq) + (Uq) \rightarrow (UUq) + \text{light hadrons}$$

$$(UUq) + (Uq) \rightarrow (UUU) + \text{light hadrons}$$

At $T < T_{QCD}$, in Eq. (81) $\sigma v$ is given by Eqs. (76), (77) or (78). Solution of the equation Eq. (80) is given by

$$r_h = \frac{r_h}{1 + r_h/j_h}, \quad (81)$$

where from Eq. (76) $r_h = 0.1 r_{B'} = 4 \cdot 10^{-15}/S_6$ and

$$j_h = \int_0^{x_f} f_h \langle \sigma v \rangle dx. \quad (82)$$

Since reactions Eq. (79) start immediately after QCD phase transition at $T \sim T_{QCD}$, in Eq. (85) $x_f \sim 1$. Depending on the choice of $\langle \sigma v \rangle$ the remaining amount of $(UU)$ and $(UUU)$ ranges from the case A to case C. Case A.

The value of $\langle \sigma v \rangle$ is equal to Eq. (73). Then

$$J_{hA} = m_{pi} T_{QCD} \frac{1}{m^2} \approx 10^{20}. \quad (83)$$

In the solution Eq. (80) $r_h J_{hA} = 4 \cdot 10^7/S_6 \gg 1$ at $S_6 \ll 4 \cdot 10^3$ and the remaining amount of $(UUu)$ and $(UUu)$ is independent on their initial abundance, being equal to

$$r_{hA} = \frac{J_h}{J_{hA}} \approx 1.0 \cdot 10^{-20}. \quad (83)$$

Case B

For $\langle \sigma v \rangle$ from Eq. (77) $J_{hB}$ is $(m_{pi}/m_U)^2 \sim 30$ times smaller than $J_{hA}$. It results in correspondingly 30 times larger amount of $(UUu)$ and $(UUu)$, which is now valid for $S_6 \ll 10^3$:

$$r_{hB} = \frac{J_h}{J_{hB}} \approx 3.0 \cdot 10^{-19}. \quad (84)$$

Case C

The minimal estimation of recombination rate Eq. (78) leads to relatively small value of $J_h$:

$$J_{hC} = \frac{2 m_{pl}}{m_U} (\frac{T_{QCD}}{T_{T}})^{1/2} \approx 4 \cdot 10^{13}/S_6^{1/2}$$

and the solution of Eq. (80) practically coincides with the initial value $r_{hf}$

$$r_{hC} = \frac{r_h}{1 + r_h J_{hC}} \approx r_{hf} \approx 4 \cdot 10^{-15}/S_6. \quad (85)$$
However, even in the case C the abundance of $(UUu)$ and $(Uuu)$ is smaller at $S_q > 1$, than of $(UUU)$. The product $r_{Uf,JhC}$ grows at small $S_q < 1$ as $S_q^{-5/2}$ and reaches the value $\approx 9$ at minimal allowed value $S_q = 0.2$. That leads to corresponding order of magnitude decrease of $r_b$ in the case C.

On the other hand, the residual amount of $(UUu)$ and $(Uuu)$ in the most optimistic case A is no less than $2.5 \cdot 10^{-7}$ of $(UUU)$ relative to baryons. This fact reveals a potential danger for the sinister model. Even being bound with $EE$ these hadrons are not elusive: their interaction with matter has normal hadronic cross section.

Note that at $S_q > 7$ hadronic recombination suppresses abundance of primordial "tera-mesons" $(\bar{U},u)$, which were not suppressed in $U$-quark recombination. In case A suppression is $\propto \exp (-r_{Uf,JhA}) = \exp (-4.10^5/s_0)$ and in case B $\propto \exp (-4.10^4/s_0)$. In the case C, on the other hand, $r_{Uf,JhC} \approx 0.16/S_q^{-5/2}$ and there is no additional suppression for $S_q > 1$.

APPENDIX 6. COMPLETE RECOMBINATION OF CHARGED TERA PARTICLES

Cosmological abundance of free charged $U$-baryons is to be exponentially small after recombination. If the lightest is $(UUu)$ baryon with electric charge $+2$, atoms of anomalous He are formed by it as well as by free $(UUu)$ and $(UUU)$ baryons. Their recombination takes place together with ordinary He recombination at $T < I_{He} = 54.4 eV$. Taking the equation for the residual amount of free ions in the form

$$\frac{dr_i}{dx} = f_{I_{He}} \frac{f_{r_i}}{f_{r_e}} \frac{\langle \sigma v \rangle}{s_{rec,1/2}},$$

where $x = T/I_{He}$, $f_{I_{He}} \approx m_{pl}/I_{He}$, $r_e = r_p \approx r_h = 0.8 \cdot 10^{-11}$,

$$\langle \sigma v \rangle_{s_{rec}} = \langle \sigma v \rangle_{s_{rec,1/2}} x_{1/2}^2 = \left(\frac{4\pi}{3\sqrt{2}}\right) Z^2 \alpha^2 \frac{1}{I_{He} \cdot m_e},$$

charge of He $Z = 2$, we find that the solution

$$r_i = r_0 \exp (-r_c J_{He}),$$

with

$$J_{He} = \frac{\pi}{6} f_{I_{He}} \frac{f_{r_i}}{f_{r_e}} \frac{\langle \sigma v \rangle}{s_{rec,1/2}} x_{1/2}^2,$$

where $x_{1/2} \approx 1/30$, contains huge negative number $(-r_c J_{He} \approx -3 \cdot 10^5)$ in exponent. $(^2HeE^{-})^+, E^+, U-$hadrons and systems with charge $+1$ form atoms of anomalous hydrogen. Their recombination takes place together with ordinary hydrogen on MD stage at $T \approx I_{He}/30 < T_{RM} \approx 1 eV$, where $I_{He} = 13.6 eV$. The form of equation for decrease of free ion abundance is similar to Eq. (86) and reads

$$\frac{dr_i}{dx} = f_{I_{He}} \frac{f_{r_i}}{f_{r_e}} \frac{\langle \sigma v \rangle}{s_{rec,1/2}} x_{1/2}^2,$$

where $x = T/I_{He}$, $f_{I_{He}} \approx m_{pl}/I_{He}$, $x_{1/2} \approx I_{He}/30$,

$$\langle \sigma v \rangle_{s_{rec}} = \langle \sigma v \rangle_{s_{rec,1/2}} x_{1/2}^2 = \left(\frac{4\pi}{3\sqrt{2}}\right) \cdot \frac{1}{I_{He} \cdot m_e}.$$  (87)

The solution

$$r_i = r_0 \exp (-r_c J_{He})$$  (90)

has the form of Eq. (86) with

$$J_{He} = \frac{\pi}{6} f_{I_{He}} \frac{f_{r_i}}{f_{r_e}} \frac{\langle \sigma v \rangle}{s_{rec,1/2}} x_{1/2}^2 = \frac{m_{pl}^2}{m_{e^2}} \left(\frac{2\pi}{3\sqrt{2}}\right) \frac{1}{I_{He} \cdot m_e}$$

and also contains huge negative number $(-r_c J_{He} \approx -10^5)$ in exponent.

APPENDIX 7. GRAVITATIONAL CONCENTRATION INSIDE STARS

For number density $n_s$ of stars with mass $M_s$ and radius $R_s$ the decrease of number density $n_t$ of free particles, moving with relative velocity $v$, is given by

$$\frac{dn_t}{dt} = -n_s n_t \pi R_s (R_s + 2GM_s/v^2) v \approx -n_s n_t 2\pi \frac{2GM_s}{v}.$$  (92)

Therefore, to be effective (i.e. to achieve substantial decrease of number density $n_t = n_0 \exp (-t/\tau)$ the timescale of capture

$$\tau = \frac{1}{n_s 2\pi R_s GM_s/v}$$

should be much less than the age of the Universe $\tau < t_U = 4 \cdot 10^{17}s$, whereas for $n_s \sim 10^{-3}$, $M_s = M_\odot \approx 2 \cdot 10^{33}$ g, $R_s = R_\odot \approx 7 \cdot 10^{10}$ cm and $v \sim 10^8$ cm/s, $\tau \sim 5 \cdot 10^{23}s \gg t_U$. Even for supergiant stars with $M_s \sim 20 M_\odot$, $R_s \sim 10^4 R_\odot$ (and even without account for smaller number density of these stars) we still obtain $\tau \sim 3 \cdot 10^{18}s \gg t_U$.

APPENDIX 8. SIGNATURES FOR TERA-PARTICLES IN LAB

In the discussion of this problem we use the results of [Belotsky Fargion Khlopov et al 2004]. The assumed values of $E$ and $U$-quark masses make the problem of their search at accelerators similar to the case of other heavy quark. However, the strategy of such search should take into account the principal difference from the case of unstable quark (e.g. top-quark). One should expect that in the considered case a stable particle should be produced. Note that $UUU$ $UU$ pair production is beyond the reach of the next generation of colliders, as well as the probability for production of such pair is strongly suppressed. So it is the pair of $EE^+$ or single $E$ and $\bar{E}$ - hadrons, what can be expected in colliders above their threshold.

In the case of $EE^+$ pair two charged stable leptons are produced. In the case of $U$ dominantly a pair of mesons $U\bar{q}$ and $\bar{U}q$ appears. The relative probability is $< 0.1$ for creation of a baryon pair $(Uqq)$ and $(U\bar{q}q)$ (see [Belotsky Fargion Khlopov et al 2004]).

Charged heavy stable particles can be observed as the 'disagreement' between the track curvature (3-momentum)

$$p = 0.3 B \cdot R \cdot Q,$$

and the energy of the track measured in the calorimeter (or energy loss $dE/dx$). In Eq. (89) $B$ is magnetic field in $T$, $p$ is momentum in $GeV$, $R$ is radius of curvature in meters, $Q$ is the charge of particle in the units of elementary charge $e$.

Due to a very large mass the created heavy tera-particles are rather slow. About half of the yield is given by particles with the velocity $\beta < 0.7$. To identify such particles one may study the events with a large transverse energy (say, using the trigger - $E_T > 30$ GeV). The signature for a new heavy hadrons will be the 'disagreement' between the values of the full energy $E = \sqrt{m^2 + |p|^2} - m$ measured in the calorimeter, the curvature of the track (which, due to a larger momentum $|p| = E/\beta$, will be smaller than that for the light hadron where $E \approx |p|$) and the energy loss $dE/dx$. For the case of heavy hadrons due to a low $\beta$ the energy loss $dE/dx$ caused by the electromagnetic interaction is larger than that for the ultrarelativistic light hadron, while in "hadron calorimeter" the energy loss caused by the strong interactions is smaller (than for a usual light hadron), due to a lower inelastic cross section for a smaller size heavy hadron, like $(U\bar{d})$ meson. Besides this the whole large $E_T$ will be produced by the single isolated track and not by a usual.
hadronic jet, since the expected energy of the accompanying light hadrons \( E_{\gamma}^{\text{had}} \) is rather low.

Another possibility to identify the new stable heavy hadrons is to use the Cherenkov counter or the time-of-flight information.

We hope that tera-particles, if they exist, may be observed in the new data collected during the RunII at the Tevatron and then at the LHC, or the limits on the mass of such a particles will be improved.

APPENDIX 9. NEUTRAL TERA-MESONS AND CHARGED TERA-LEPTONS IN UHECR

In top-down model Ultra High Energy Cosmic Rays, (UHECR) are born by the decay of superheavy particles (e.g. topological defects) or their annihilations \( \text{Dubrovich Fargion Khlopov 2004} \). These high energy sources will provide an unique laboratory for tera leptons \( E^{-}\cdot E^{+} \) as well as heavy quarks \( U \) and \( \bar{U} \) : these Sinister particles will be produced at high energy (ZeV or above) along a tail of all possible exotic (as SUSY secondary ones \( \text{Datta Fargion Mele 2003} \) ) within UHECR spectra. Such a High energy Leptons pairs \( E^{-}\cdot E^{+} \) (at energy above GZK cut-off) born in the far Universe edges has the very peculiar behavior to escape along the space ignoring electromagnetic cut-off) born in the far Universe edges has the very peculiar behavior to escape along the space ignoring electromagnetic cut-off and its consequent negligible electron pair production energy losses as well as pion photo production. Also a negligible Tera-Lepton photo-pion process is taking place for the same reasons described below for Ultra High Energy (UHE) Tera-Pions. This allow to the stable (or nearly stable) UHE tera Leptons to free travel inside the Earth and even cross the whole planet as SUSY stable staus \( \tilde{\tau} \) \( \text{(Reno et al 2005)} \), in full analogy to the almost stable) UHE lepton tau \( \tilde{\tau} \) \( \text{Fargion 2002} \) and \( \text{Fargion et al 2004} \) longer traces than muons ones. However out of very fine-tuned ad-hoc time-life these Tera-Leptons will be not able to produce Upward or Horizontal Tau-like Air-Showers, but just very long penetrating tracks with minor pairs production along the path.

A different and more exciting role may come from the second Tera-Hadron UHE secondary of the top-down UHECR source: the birth of neutral Tera-Mesons \( \bar{U} \tilde{u} \) and \( u\tilde{U} \). Contrary to early Universe, where there is enough time and hard dense matter to proceed in the very complex cooking of Tera-Hadrons relics summarized in present article, tera quarks born by UHECR source escape mostly as neutral \( \bar{U} \tilde{u} \) and \( u\tilde{U} \). These hybrid pions are very exceptional candidates to UHECR because two surprising abilities. The first is that they interact hadronically with matter. This may imply a high altitude atmosphere interaction on Earth in agreement with the observed UHECR fluorescence light curve. The second ability is a very smart interaction with radiation: indeed while the photo-pion production with matter takes place as for all the common nucleons (either proton or neutrons), the threshold in the “center of mass frame” for tera-pions is much higher. The photo-pion production for neutrinos onto the 2.75\( K^{\pm} \) BBR begins at Lorentz factor \( \gamma_{\nu} \geq 10^{10} \) and energy \( E_{\nu} \geq 4 \cdot 10^{19} \text{eV} \) while for a corresponding Lorentz factor the Hybrid Tera-Pion threshold energy \( E_{\nu} \geq 1.4 \cdot 10^{25} \text{eV} \) is above three order of magnitude higher simply because of the huge Tera-pion mass. This imply that for Tera-Pion there is a GZK cut off much above common \( \text{Greisen1966} \). \( \text{Zatsepin Kuzmin1966} \) energies \( E_{\nu} \approx 4 \cdot 10^{19} \text{eV} \) making this rare HEU pion an ideal candidate able to travel along the whole Universe without deflection of Galactic or Extra-galactic magnetic fields or much energy losses, overcoming the otherwise controversial absence of a GZK cut-off. These Tera-Particles are among the best candidate to solve recent UHECR correlated events with far BL-Lac sources \( \text{Gorbunov et al 2002} \), \( \text{HiRes Collaboration 2003} \).

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