Split Light Higgsino from Split Supersymmetry

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Abstract

New version of the MSSM scales is discussed. In this version $\mu \ll M_{SUSY} \sim M_0 \sim M_{1/2}$, where $\mu$ is the Higgsino mass, $M_0$ is the mass scale of sleptons and squarks, $M_{1/2}$ is the mass scale of gaugino. Renormalization group motivation of this MSSM version is proposed. Analysis of Split Supersymmetry ideas in this case together with the Dark Matter arguments results in the statement that the formation of residual neutralino concentration occurs in the high symmetric phase of cosmological plasma. The value of Higgsino mass is estimated. The recharging process for high energy neutralinos in the neutralino-nucleus scattering is considered. There has been reported the possibility to check-up of the model predictions at modern experimental facilities NUSEL and GLAST.

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I. INTRODUCTION

Our optimism to find in the LHC experiments some new dynamical effects at the TeV-scale is based, in particular, on the MSSM features. As the simplest supersymmetric generalization of the SM, the MSSM provides not only UV stability of the Higgs bosons mass spectrum at $M_{SUSY} \sim 1 \text{ TeV}$, but leads to unification of the gauge couplings at $M_{GUT} \gg M_{SUSY}$ and contains an elegant interpretation of neutralinos as the main DM components. Besides, and this is important, the MSSM didn’t contradict to known experimental data up to energies $\sim 1 \text{ TeV}$. Then it’s naturally to suggest that the MSSM inevitably should make an evident of new dynamical effects and objects at the LHC \cite{1, 2, 3}. The ”fine-tuning” absence, which is called as ”naturalness” of the MSSM spectra, simultaneously with other features of the model, has led to the ”Great Desert” existing between $M_{SUSY}$ and $M_{GUT}$. However, in the last time there appears certain reasons to have doubts about the singling out of the MSSM energetic spectra.

Namely, in \cite{4} there was formulated an assertion that the ”naturalness”, as a way to avoid the ”fine-tuning”, can be eliminated, in particular, in the framework of multi-vacua ideas from superstring theories. It leads to the Split Supersymmetry Model where $M_{SUSY} \gg 1 \text{ TeV}$ and all superscalar masses are much higher than $M_{EW}$ except of Higgs doublet, which is retained at the electro-weak (EW) scale. The gauge coupling unification as the most important feature of any reasonable SUSY model formulation \cite{3} is conserved in the Split Supersymmetry at sufficiently high scale $M_{GUT}$ to provide the proton stability. A careful analysis of various aspects of such type models, where Supersymmetry is split from the EW scale, is considered in \cite{5, 7, 8, 9}. Some experimental consequences of the Split Supersymmetry ideas are investigated in \cite{10, 11, 12}.

Because of any inner dynamical reasons absence, only from the one-loop renormgroup analysis of the SUSY $SU(5)$ containing the MSSM, there is the chance to populate ”the Great Desert” with some intermediate scales \cite{6}. The ”population” allows to conserve the gauge couplings’ unification at $M_{GUT} \geq 10^{15} \text{ GeV}$ \cite{11}. The RG analysis, carried out in our work, has shown that there are just two possible variants. The first one is the Light Gaugino scenario that is well investigated early \cite{14, 15, 16, 17}. The second one is the Split Light Higgsino scenario, that is the object of our investigations. The Split Light Higgsino scenario is a SUSY variant, where Higgs bosons can be kept at $M_{EW}$ scale, all color degrees of freedom should be much heavier than the electro-weak ones, unification of gauge couplings occurs at $\sim 10^{15} \text{ GeV}$ and protects the proton stability. The mass scales of all superpartners, except Higgsino, lies in the region $\sim 10^{4} \text{ TeV}$. It is important that in the models with the Split Supersymmetry the Higgsino mass can remain arbitrary and can be placed not far from the EW scale. In our paper some properties of this model that has a Split Supersymmetry structure are considered.

Obviously, models with Split Supersymmetry naturally lead to the damping of scalar quarks, leptons and gauginos contributions near EW scale. Another important consequence of the Light Higgsino splitting is nearly degeneration in mass of neutralino and closest chargino \cite{5, 7, 11, 13} (note, that experimental searches for the degeneration were carried out at LEP energies \cite{14} without any evident signals). The masses of the lowest states (neutralinos and charginos) and their interaction features are the key questions for the experimental data predictions and interpretation. All Split Supersymmetry Models are ”unnatural”, and we need in some additional sources of information about the SUSY with drifted to higher scales mass spectra.
As it was noted in [5], [11] the DM nature is just one more "link between new physics and EW scale". In the current work we have joined the Split Supersymmetry ideas with the assumption that Dark Matter has to be composed of neutralino as LSP. Split Light Higgsino model leads to specific predictions on the LSP properties and, consequently, on the DM structure. The Lightest Supersymmetric Particles (LSP) in this model have a structure of Higgsino. We developed analysis of the residual neutralino concentration in the cosmological plasma. It is shown that formation of the DM concentration occurs in the high symmetric phase of the cosmological plasma. This fact allowed us to estimate the value of Higgsino mass $M_\chi \approx 3 TeV$ within an error following from experimental uncertainties in DM mass density determination.

Because of strong degeneration mass of chargino and neutralino in our model the detection them at the LHC will be impossible. So supersymmetry with the gap between Higgsino states and Higgs bosons, on one side, and scalar states and gauginos, on the other side, has some features that can be established in specific experiments only. Due to particular properties of Split Light neutralino and important role of neutralino in the DM physics, we will see below that such investigations are possible at NUSEL [15], where direct observations of galactic neutralino at underground detectors are planned, and at the satellite detector GLAST where there are the possibilities to catch some indirect signals from neutralino annihilation in the Galactic halo.

We have shown that the neutralino-nucleon cross section is spin-dependent. Analysis of neutralino-chargino recharge on nucleons is presented. This effect can take place if neutralinos with kinetic energy $\sim 100 GeV$ are attending in the cosmic rays spectrum. The annihilation of Galactic neutralinos occurs in $Z^0Z^0$ and $W^+W^-$ pairs in $t$- and $s$-channels, and also in lepton-antilepton and quark-antiquark pairs in the $s$-channel. The contribution to the annihilation spectrum from first two processes is calculated with using experimental data about hadron multiplicities at the mass surfaces of $Z^0, W^\pm$-bosons; the calculation of quark-antiquark $s$-channel contribution is based on the phenomenological model of hadron multiplicities at $\sqrt{s} = 2M_\chi$ with using negative binomial distribution.

The paper is organized as follows. In Section 2 the one-loop renormalization group analysis of the SUSY SU(5) containing the MSSM is fulfilled and it is shown that there are just two possible variants of supersymmetry: the Light Gaugino scenario and the Light (Split) Higgsino scenario. In section 3 we have extracted from the theory some specific information about properties of LSP in the framework of Light (Split) Higgsino scenario. The chargino and neutralino mass spectrum is dominated by radiation corrections. It is quasi-degenerated and calculable exactly without renormalization. Section 4 devoted to studying of neutralino residual concentration and its evolution in the cosmological plasma. It is shown here that the formation of residual neutralino concentration occurs in the high symmetric phase of cosmological plasma. In section 5 the possibilities for direct and indirect searches of Dark Matter in the case of Light (Split) Higgsino scenario are considered. Section 6 contains some concluding remarks.

II. RENORMGROUP ANALYSIS

Standard and well known MSSM is motivated by two arguments: 1) the used hierarchy of scales leads to convergence of all MSSM couplings at some $M_{GUT}$ that is compatible with experimental restriction from the proton lifetime; 2) the scale of SUSY breaking is not very high, $M_{SUSY} \sim M_{1/2}$, so quadratic divergencies are compensated near $M_H$, i.e. long before
$M_{\text{GUT}}$. Due to the first reason the MSSM evidently can be built into GUT theory and into supergravity/superstring theory. But the second argument seems not obligatory condition from the QFT point of view. Exact convergence of running couplings takes place in the Split Higgsino Scenario too.

In such convergence has been shown for the SUSY breaking scale lying in the intermediate supergauge region. In our renormgroup analysis all $SU(5)_{\text{SUSY}}$ degrees of freedom despite of quark-lepton states are taken into consideration involving the states that are near $M_{\text{GUT}}$. As we’ll see their contributions are important for the choice of the SUSY scales hierarchy.

Experimentally running couplings are fixed at $M_Z$ scale:

\begin{align}
\alpha^{-1}(M_Z) &= 127.922 \pm 0.027, \\
\alpha_s(M_Z) &= 0.1200 \pm 0.0028, \\
\sin^2 \theta_W(M_Z) &= 0.2311 \pm 0.0015.
\end{align}

(2.1)

In renormgroup equations the following values are used as initial:

\begin{align}
\alpha^{-1}_1(M_Z) &= \frac{3}{5} \alpha^{-1}(M_Z) \cos^2 \theta_W(M_Z) = 59.0132 \pm (0.0384) \sin^2 \theta_W \pm (0.0124) \alpha, \\
\alpha^{-1}_2(M_Z) &= \alpha^{-1}(M_Z) \sin^2 \theta_W(M_Z) = 29.5666 \pm (0.0192) \sin^2 \theta_W \pm 0.0062) \alpha, \\
\alpha^{-1}_3(M_Z) &= \alpha_s^{-1}(M_Z) = 8.3333 \pm 0.1944.
\end{align}

(2.2)

Known equations for running couplings at one-loop level are:

\begin{align}
\alpha^{-1}_i(Q_2) &= \alpha^{-1}_i(Q_1) + \frac{b_i}{2\pi} \ln \frac{Q_2}{Q_1}, \\
b_i &= \sum_j b_{ij}.
\end{align}

(2.3)

In the sum all states with masses $M_j < Q_2/2$ at $Q_2 > Q_1$ are taken into account.

It is specifically that extra states should be taken into account in these equations. Namely, singlet quarks and their superpartners ($D_L, D_L$), ($D_R, D_R$) are contained in superhiggs quintets of $SU(5)_{\text{SUSY}}$, so they are in the model inevitably (see also [6]). Besides chiral superfields ($\Phi_L, \Phi_L$) and ($\Psi_L, \Psi_L$) in adjoint representations of $SU(2)$ and $SU(3)$, respectively, survive from superhiggs 24-multiplet. In the minimal $SU(5)_{\text{SUSY}}$ masses of the states $M_5 = (M_D, M_D)$, $M_{24} = (M_\phi, M_\phi, M_\phi, M_\phi)$ are generated by interaction with Higgs condensate at the GUT scale, but the couplings of the interaction are phenomenological so they are not fixed. In this scenario we evidently assume that $M_5$, $M_{24} < M_{\text{GUT}}$ and, in principle, this inequality can be fulfilled with accuracy in $1 \sim 2$ orders. Thus, for one-loop running
specific arrangement of $M$ carried out in a standard manner. It is important that equations (2.4) do not depend on light $\alpha$ was used for calculations of $M$. Here $M$ generations; $q$ couplings at the scale $q^2 = (2 M_{\text{GUT}})^2$ we have:

$$\alpha_1^{-1}(2 M_{\text{GUT}}) = \frac{103}{60 \pi} \ln 2 + \frac{1}{2 \pi} \left( - 7 \ln M_{\text{GUT}} + \frac{4}{15} \ln M_D + \frac{2}{15} \ln M_D \right)$$

$$+ \frac{11}{10} \ln M_q + \frac{9}{10} \ln M_t + \frac{2}{5} \ln \mu + \frac{1}{10} \ln M_H + \frac{17}{30} \ln M_t + \frac{53}{15} \ln M_Z \right),$$

$$\alpha_2^{-1}(2 M_{\text{GUT}}) = \frac{7}{4 \pi} \ln 2 + \frac{1}{2 \pi} \left( - 3 \ln M_{\text{GUT}} + \frac{4}{3} \ln M_\Phi + \frac{2}{3} \ln M_\Phi \right. + \frac{3}{2} \ln M_q + \ln M_t + \frac{4}{3} \ln M_W + \frac{2}{3} \ln \mu + \frac{1}{6} \ln M_H + \frac{1}{2} \ln M_t - \frac{11}{3} \ln M_Z \right),$$

$$\alpha_3^{-1}(2 M_{\text{GUT}}) = \frac{23}{6 \pi} \ln 2 + \frac{1}{2 \pi} \left( - \ln M_{\text{GUT}} + 2 \ln M_\Phi + \ln M_\Phi \right. + \frac{2}{3} \ln M_D + \frac{1}{3} \ln M_D + 2 \ln M_q + 2 \ln M_\tilde{q} + \frac{2}{3} \ln M_t - \frac{23}{3} \ln M_Z \right).$$

Here $M_0 = (M_\tilde{q}, M_t)$ - masses of scalar quarks and leptons averaging in chiralities and generations; $M_t - t$-quark mass; other parameters were introduced above. In (2.4) it is supposed that $h$-boson mass lies near $M_Z$ and other higgses $H$, $A$, $H^\pm$ are placed at the $M_H$ scale. Note that singlet superstates and residual Higgs superfields can be formally eliminated from (2.4), if their masses are equaled to $M_{\text{GUT}}$ identically.

At first step all couplings have been recalculated at $2 M_Z$ scale, all the SM states contribute into running of couplings despite of $W^\pm$, $Z^0$, Higgs bosons and $t$-quark. At the time terms with $\ln 2$ occur, which are quantitatively important for the calculations. Between ($2 M_Z$, $2 M_t$) scales the following states emerge: $W^\pm$, $Z^0$ and one Higgs doublet containing light $h-$boson and longitudinal degrees of freedom of $W^\pm$, $Z^0$. At these stages $Zq\bar{q}$ vertex was used for calculations of $\alpha_2^{-1}(2 M_Z), \alpha_2^{-1}(2 M_t)$. Above the $2 M_t$ scale calculations were carried out in a standard manner. It is important that equations (2.4) do not depend on specific arrangement of $M_2$, $M_5$, $M_0$, $M_{1/2}$, $\mu$, $M_H$ degrees of freedom at energetic scales.

Now, equaling couplings at $M_{\text{GUT}}$, from (2.4) we get following expressions:

$$M_{\text{GUT}} = A k_1 M_Z \left( \frac{M_Z}{M_{1/2}} \right)^{2/9}, \quad \mu = B k_2 M_Z \left( \frac{M_Z}{M_{1/2}} \right)^{1/3},$$

(2.5)

where

$$k_1 = K_{\tilde{q}l}^{-1/12} K_{\text{GUT}1}^{1/3} \equiv \left( \frac{M_l}{M_\tilde{q}} \right)^{1/12} \left( \frac{M_{\text{GUT}}}{M_{1/2}} \right)^{1/3},$$

$$k_2 = K_{Ht}^{-1/4} K_{\tilde{q}l}^{-1/4} K_{\tilde{q}W}^{-7/2} K_{\text{GUT}2}^{-1} \equiv \left( \frac{M_t}{M_H} \right)^{1/4} \left( \frac{M_\tilde{q}}{M_\tilde{l}} \right)^{1/4} \left( \frac{M_\tilde{q}}{M_W} \right)^{5/2} \left( \frac{M_{\text{GUT}}''}{M_{\text{GUT}}} \right).$$


\[ M'_{1/2} \equiv (M_{\tilde{W}} M_{\tilde{g}})^{1/2}, \quad M'_{\text{GUT}} \equiv (M_{\tilde{\psi}} M_{\tilde{\phi}})^{1/3} (M_{\tilde{\psi}} M_{\tilde{\phi}})^{1/6} \leq M_{\text{GUT}}, \]

\[ M''_{\text{GUT}} \equiv \frac{(M_{\tilde{\psi}} M_{\tilde{\phi}})^{7/6} (M_{\tilde{D}} M_{\tilde{D}})^{1/2}}{(M_{\tilde{D}} M_{\tilde{D}})^{4/3}} \leq M_{\text{GUT}}, \]

\[ A = \exp \left( \frac{\pi}{18} (5 \alpha_1^{-1}(M_Z) - 3 \alpha_2^{-1}(M_Z) - 2 \alpha_3^{-1}(M_Z)) - \frac{11}{18} \ln 2 \right) = (1.57 \times 10^9) \cdot 10^{14}, \]

\[ B = \exp \left( \frac{\pi}{3} (5 \alpha_1^{-1}(M_Z) - 12 \alpha_2^{-1}(M_Z) + 7 \alpha_3^{-1}(M_Z)) + \frac{157}{12} \ln 2 \right) = (2.0 \times 10^{15}) \cdot 10^{3}. \]

Here all parameters \( K \) with various indexes are defined as quantities having values more than unity. Note that \( K_{\text{GUT1}}, K_{\text{GUT2}} \) are not under the theoretical control neither in the MSSM nor in the \( SU(5)_{\text{SUSSY}} \). So we assume that \( 1 \leq K_{\text{GUT1}} \simeq K_{\text{GUT2}} \leq 10 \). There is an experimental restriction for heavy Higgs bosons \( \vert 22 \vert \): \( M_H > 114.4 \text{ GeV} \). It leads to following variation of \( K_{Ht} \): \( 2 \leq K_{Ht} \leq 10 \). Values of \( K_{\tilde{g}}, K_{\tilde{g}W} \) are determined from renormgroup evolution from \( M_{\text{GUT}} \) to \( M_0, M_{1/2} \). Here we suppose that \( 1.5 \leq K_{\tilde{g}} \simeq K_{\tilde{g}W} \leq 2.5 \).

There were analyzed \( M_{1/2} \) and \( \mu \) depending on \( M_{\text{GUT}} \):

\[ M'_{1/2}(M_{\text{GUT}}) = (A k_1)^{9/2} M_Z^{11/2} \times M_{\text{GUT}}^{-9/2}, \quad \mu(M_{\text{GUT}}) = \frac{B k_2}{(A k_1)^{3/2} M_Z^{1/2}} \times M_{\text{GUT}}^{3/2}. \] (2.6)

We used known restrictions for the proton lifetime \( (\tau_p \geq 10^{32} \text{ yr at } M_{\text{GUT}} \geq 10^{15} \text{ GeV}) \) and for \( M_{\text{SUSSY}} \) \( (M_{\text{SUSSY}} \sim M'_{1/2} > 100 \text{ GeV} \text{ for } M_{\text{GUT}} < 3 \times 10^{16} \text{ GeV}) \).

Two variants – with \( \mu \ll M'_{1/2} \) or \( \mu \gg M'_{1/2} \) – were found from analysis of (2.6). They are shown at Fig. 1. Refusing the "Supergauge Desert" idea, nevertheless we have a possibility to evaluate separated Higgsino mass accepting the hypothesis that neutralino is a carrier of the DM.

### III. OBJECTS OF INVESTIGATION AND ITS PROPERTIES.

As it is known, after the EW symmetry breaking supersymmetric partners of Higgs and electroweak gauge fields forms two Dirac electrically charged particles – charginos \( \chi_1^\pm, \chi_2^\pm \) and four Majorana electrically neutral particles – neutralinos \( \chi^0_1, \chi^0_2, \chi^0_3, \chi^0_4 \). Lightest supersymmetric particle \( \chi^0_1 \) is main candidate to be the cold Dark Matter component \( [26, 27] \). Generally \( \chi^0_1 \) is the superposition of \( U(1) \) gaugino \( \tilde{B} \) ("bino"), neutral \( SU(2) \) gaugino \( \tilde{W}_3 \) ("wino") and two Higgsinos \( \tilde{h}_1^0, \tilde{h}_2^0 \). Structure and properties of chargino and neutralino depend on relations between characteristic MSSM scales. Strong theoretical arguments in favor of one or another hierarchy of scales are absent.

In the previous section one has shown that only two variant of MSSM are theoretically natural. First variant – the light gaugino scenario (bino or wino or their mixture), in which

\[ |\mu| \gg M_0 \sim M_{1/2} \sim M_{\text{SUSSY}} > M_{\text{EW}}, \] (3.1)

– is well investigated early \( [16, 17, 18, 19] \).

Now we consider the second alternative variant of MSSM, in which the Higgsino mass scale is the nearest for EW scale, but \( M_{\text{SUSSY}} \) is in the multi-TeV region – so-called Light
FIG. 1: Two variants of the MSSM scales – bino-like LSP $\mu \gg M_{1/2}'$ and Higgsino-like LSP $\mu \ll M_{1/2}'$.

(Split) Higgsino scenario (this model obviously possesses a Split Supersymmetry property), where

$$M_0 \sim M_{1/2} \sim M_{SUSY} \gg |\mu| > M_{EW}.$$  \hfill (3.2)

In this model light states $\chi^0_{1,2}$ and $\chi^\pm_1$ have (almost pure) Higgsino structure with masses

$$M_{\chi^0_1} \simeq |\mu| - \frac{M_Z^2 (1 + \text{sign}(\mu) \sin 2\beta)}{2} \left( \frac{\cos^2 \theta}{M_W} + \frac{\sin^2 \theta}{M_B} \right) \approx |\mu| - \frac{M_Z^2}{2M_{SUSY}},$$

$$|M_{\chi^0_2}| \simeq |\mu| + \frac{M_Z^2 (1 - \text{sign}(\mu) \sin 2\beta)}{2} \left( \frac{\cos^2 \theta}{M_W} + \frac{\sin^2 \theta}{M_B} \right) \approx |\mu| + \frac{M_Z^2}{2M_{SUSY}},$$

$$M_{\chi^\pm_1} \simeq |\mu| - \frac{M_W^2}{M_W} \left( \frac{|\mu|}{M_W} + \text{sign}(\mu) \sin 2\beta \right) \approx |\mu|.$$  \hfill (3.3)

Heavier states $\chi^0_{3,4}$ and $\chi^\pm_2$ lie near $M_{SUSY}$:

$$M_{\chi^0_3} \approx M_B, \quad M_{\chi^0_4} \approx M_W, \quad M_{\chi^\pm_2} \approx M_W.$$  \hfill (3.4)

Then all processes near EW scale are described by the SM Lagrangian together with
extra Lagrangian of light Higgsinos interactions with photons and vector bosons:

\[
\Delta L = \left( e A_\mu - \frac{g_2}{2 \cos \theta} (1 - 2 \sin^2 \theta) Z_\mu \right) \bar{\chi}^- \gamma^\mu \chi^- + \frac{g_2}{2 \cos \theta} Z_\mu (\bar{\chi}^0 \gamma^\mu \chi^0 + \chi^0 \gamma^\mu \chi^0) +
\]
\[+ \frac{g_2}{\sqrt{2}} W^+_\mu (\bar{\chi}_1^0 + \chi_2^0) \gamma^\mu \chi^- + \frac{g_2}{\sqrt{2}} W^-_\mu \bar{\chi}_1 \gamma^\mu (\chi^0_1 + \chi^0_2). \tag{3.5} \]

Here neutralinos are 4-component Majorana spinors.

If \( M_{\text{SUSY}} > 1.4 \times 10^4 \) GeV the radiation corrections begin to dominate in the chargino and neutralino masses formation. Corresponding one-loop diagrams for the mass splitting are in Fig. 2. On the mass shell these mass operators take the form of the following finite integral:

\[
\Delta M_\chi = -\frac{i e^2 M_Z^2}{8 \pi^4} \int \frac{(\hat{q} - M_\chi) dq}{q^2(q^2 - M_Z^2)[(q + p)^2 - M_\chi^2]}.
\]

For the case \( M_\chi \gg M_Z \) we get:

\[
\Delta M_\chi \simeq \frac{\alpha(M_\chi) M_Z}{2}. \tag{3.6} \]

To fix the value \( \alpha \) at the scale of \( M_\chi \) we used \( M_H \sim M_t \sim 200 \) GeV \cite{20, 21}. Neutralino mass we estimate as \( M_\chi \sim 3 \) TeV (for details see later). With a good accuracy \( \Delta M_\chi \simeq 360 \) MeV. Then for the chargino lifetime we find:

\[
\tau_{\chi^\pm} = \frac{15 \pi^3}{G_F} (\Delta M_\chi)^{-5} \simeq 0.4 \times 10^{-9} \text{ s}. \tag{3.7} \]

If we refuse from Supergauge Desert we haven’t theoretical considerations on the separated Higgsino mass. Nevertheless we can attempt to make an important step to solve this problem when we use the hypothesis that neutralino is a carrier of Dark Matter in the Universe.

**IV. ESTIMATION OF THE SPLIT HIGGSINO MASS FROM COSMOLOGY**

In discussing versus of the theory physics of neutral and charged Higgsinos fixes by the Lagrangian \( \Delta L \) and the mass spectrum \( \Delta M_\chi \) with the radiation splitting \( \Delta M_\chi \). Therefore any quantitative predictions of the theory depend on two parameters \( \mu, M_H \) only. Concrete value \( M_H \) isn’t essential. The basic parameter of the Split Light Higgsino model is \( \mu \). To evaluate it let’s suppose neutralino as a carrier of Dark Matter in the Universe. Irreversible neutralino annihilation starts in the cosmological plasma at the moment \( t_0 \) and the temperature \( T_0 \), when mean energy of relativistic quarks and leptons compares with neutralino mass.
Residual density of neutralino at $t \gg t_0$ describes by the asymptotic solution of evolutional equations \[25\), \[26\), \[27\]:

$$\frac{dn_{\chi}}{dt} + 3Hn_{\chi} = -\frac{1}{2}n_{\chi}^2(\sigma v)_{ann},$$

$$3H^2 = 8\pi GwT^4, \quad H = \frac{1}{a} \cdot \frac{da}{dt}, \quad wT^4 = \frac{const}{a^4}. \tag{4.1}$$

Here $(\sigma v)_{ann}$ stands for the kinetic annihilation cross section; $G$ is Newton’s constant; $w = w(T)$ – plasma statistical weight for the neutralino annihilation epoch. In the SM with two Higgs doublets the weight is $w = \frac{443\pi}{120}$ and this value is suitable for the analysis of annihilation process at temperatures exceeding the SM characteristic scale. For $T < M_W$ it should be used the value $w = \frac{23\pi}{8}$.

Time asymptotics of (4.1) has the form:

$$n_{\chi}(t) = \left(\frac{a(t_0)}{a(t)}\right)^3 \left(\frac{2\pi Gw}{3}\right)^{1/2} \frac{4T_0^2}{(\sigma v)_{ann}}. \tag{4.2}$$

Annihilation epoch begins at the moment

$$t_0 \simeq \frac{1}{4T_0^2} \left(\frac{3}{2\pi Gw}\right)^{1/2}. \tag{4.3}$$

and ends when $T_1 \simeq M_{\chi}/20$. To obtain relic neutralino density $\rho_{\chi} = M_{\chi}n_{\chi}$ known data on cosmological neutrino were used. At $t > t_0$ processes of quark-gluon plasma hadronization and annihilation of $\bar{l}l$ pairs practically occur through non-neutrino channels, so consequently neutrino evolution in cosmological plasma can be considered adiabatically. Therefore, scale factors ratio in (4.2) can be replaced by the ratio of neutrino gas temperatures:

$$\frac{a(t_0)}{a(t_U)} = \frac{T_{\nu}}{T_0}, \quad T_{\nu} \simeq \left(\frac{4}{11}\right)^{1/3} T_\gamma = 1.676 \times 10^{-13} \text{ GeV}. \tag{4.4}$$

Here $t_U$ stands for Universe age, $T_{\nu} \equiv T_{\nu}(t_U)$, $T_\gamma$ – the gamma relic temperature.

Finally, for the epoch when relic neutrino temperature is $T_{\nu}$, for stable neutralinos density we get:

$$\rho_{\chi}(t_U) = \frac{M_{\chi}}{T_0} \left(\frac{2\pi Gw}{3}\right)^{1/2} \frac{4T_0^3}{(\sigma v)_{ann}}. \tag{4.5}$$

From the recent WMAP data \[28\), \[29\] in the modern Universe the DM mass density is:

$$\rho_{DM}(t_U) \simeq (0.23 \pm 0.04)\rho_c \simeq (0.94 \pm 0.34) \times 10^{-47} \text{ GeV}^4. \tag{4.6}$$

where $\rho_c = (4.1 \pm 0.8) \times 10^{-47} \text{ GeV}^4$ is the critical density for the Universe. Assuming the DM consists of neutralinos only, we have equality:

$$\rho_{\chi}(t_U) = \rho_{DM}(t_U). \tag{4.7}$$

To estimate the value of $M_{\chi}$ from (4.6) annihilation kinetic cross section $(\sigma v)_{ann}$ vs. $M_{\chi}$ should be obtained. But it doesn’t known at which phase of cosmological plasma the irreversible neutralino annihilation occurs, so we need in two possible scenarios analysis.
1. Neutralino annihilation: low-symmetric phase.

If neutralino mass $M_\chi < 3T_{EW} \sim 300$ GeV its relic abundance is formed after the EW transition, in low-symmetric (LS) phase of cosmological plasma. In standard scenarios Majorana neutralinos, which are nearly gauginos (3.1), annihilate into (nearly) massless fermions and annihilation cross section depends on the temperature essentially. In the model under consideration neutralinos can’t annihilate into fermions, so the cross section doesn’t depend on the temperature with a good accuracy. There are two formal scenarios: annihilation of short-lived particles ($\tau_\chi < t_0$) and coannihilation of long-lived particles with ($\tau_\chi \gg t_0$) [18]. From our analysis it follows that variant with light split chargino and Majorana neutralinos exists only when s-channel annihilation is forbidden. In other words second neutralino state $\chi^0_2$ could be unstable with the lifetime smaller than $10^{-10}$ s. This is possible if $M_{SUSY} \geq 10^5$ GeV only. However this scenario leads to the necessity of a neutralino mass to the fine tuning near $M_W$. At the same time it results to:

$$M_{\chi^-_1} \sim M_{\chi^0_1} \sim M_W,$$

that contradicts to the known experimental data [22]. Formally in the LS phase there is a second solution, which corresponds to $M_{\chi^0_1} \sim O(\text{TeV})$, but it is incompatible with the LS-phase neutralino annihilation. Thus, we haven’t a self-consistent results for split neutralino annihilation in the LS phase.

2. Neutralino annihilation: high-symmetric phase.

As it is known for temperatures $T > T_{EW} \sim 100$ GeV, where $T_{EW}$ stands for the electroweak phase transition temperature, cosmological plasma is in the high-symmetric phase (HS) and the plasma doesn’t contain any Higgs condensate. A special feature of this phase is that all particles excepting Higgsinos are massless (more exactly, their masses $m \ll T$). In HS-phase all physical states are presented by chiral fermions and gauge fields $B, W_a (a = 1, 2, 3)$ quanta. Due to Higgs condensate absence neutralino and chargino degrees of freedom join into the fundamental $SU(2)$ representation, i.e. Dirac field $\chi$. All states of the field are dynamically equivalent and correspond to restored $SU(2)$ symmetry quantum numbers. Thus, instead of (3.5) it should be used following Lagrangian:

$$\Delta L_\chi = \frac{1}{2} g_1 B_\mu \bar{\chi}\gamma^\mu \chi + \frac{1}{2} g_2 W_\mu^a \bar{\chi}\gamma^\mu \tau_a \chi, \tag{4.7}$$

which is added to the SM Lagrangian written in terms of gauge and chiral fields:

$$L_{SM} = -\frac{1}{2} g_1 B_\mu \bar{l}_L \gamma^\mu l_L - g_1 B_\mu \bar{e}_R \gamma^\mu e_R + \frac{3}{2} g_1 B_\mu \bar{\mu}_L \gamma^\mu q_L + \frac{1}{6} g_1 B_\mu \bar{u}_R \gamma^\mu u_R - \frac{1}{3} g_1 B_\mu \bar{d}_R \gamma^\mu d_R$$

$$+ \frac{1}{2} g_2 W_\mu^a \bar{l}_L \gamma^\mu \tau_a l_L + \frac{1}{2} g_2 W_\mu^a \bar{q}_L \gamma^\mu \tau_a q_L. \tag{4.8}$$

Here corresponding flavour and family sums are suspected in all above terms.

When $|\mu| \gg T_{EW}$ irreversible neutralino annihilation is governed by Lagrangians (4.7) and (4.8) and occurs in the HS-phase. In t- and s-channels all cross section of Higgsino annihilation into gauge bosons and massless fermions were calculated analogously to QCD calculation technology. The only difference is in the fact that it is necessary to consider all channels with initial and final states, which have an arbitrary color in two dimensions – it corresponds to the restored $SU(2)$. The full list of all considered channels is following:

$$\chi \chi \rightarrow B B, \quad \chi \chi \rightarrow W_a W_a;$$

$$\chi \chi \rightarrow B^* \rightarrow l_L \bar{l}_L, \quad e_R \bar{e}_R, \quad q_L \bar{q}_L, \quad u_R \bar{u}_R, \quad d_R \bar{d}_R;$$

$$\chi \chi \rightarrow W_a^* \rightarrow l_L \bar{l}_L, \quad q_L \bar{q}_L. \tag{4.9}$$
where $l_L, q_L, e_R, u_R, d_R$ are chiral quarks and leptons of three generations. For total kinetic annihilation cross section we find:

$$\langle \sigma v \rangle_{\text{ann}} = \frac{21 g_1^4 + 6 g_1^2 g_2^2 + 39 g_2^4}{512 \pi M_\chi^2}$$  \hspace{1cm} (4.10)$$

Here $g_1 = g_1(2M_\chi), g_2 = g_2(2M_\chi)$ are gauge couplings at the scale $\sqrt{s} = 2M_\chi$. Assuming that the relic is formed in the HS-phase, from theoretical expression (4.4) and experimental data (4.5) we get that the DM can be made from split neutralinos if they have the mass

$$M_\chi = 2.9 \pm 0.5 \, \text{TeV.}$$  \hspace{1cm} (4.11)$$

Then the irreversible neutralino annihilation starts at the temperature $T_0 \sim M_\chi/3 \sim 1000 \, \text{GeV}$ and finishes at $T_1 \sim M_\chi/20 \sim 100 \, \text{GeV}$. Thus, annihilation process occurs in the HS-phase only and it shows that the above neutralino mass estimation is self-consistent. Evidently, the value (4.11) should be treated very carefully because of the DM content is really unknown. Moreover, for this estimation an inequality $M_\chi \ll M_{\text{SUSY}}$ should be correct. In any case this theoretical scenario is motivated phenomenologically no worse than known scenarios where $M_{\text{SUSY}} \sim 1 - 2 \, \text{TeV}$. 

V. POSSIBILITIES OF SPLIT NEUTRALINO OBSERVATION

Above suggested scenario with split Higgsino can’t be tested at LHC because of small chargino-neutralino mass splitting and, consequently, too small energies of lepton pairs from these particles’ decays. In the situation the scenario check-up becomes possible in astrophysics only.

A. Direct detection

1. Split neutralino elastic scattering on nucleons and nuclei

Now there are nearly twenty experimental programs for relic WIMPs direct detection [30], [31], [32], [33]. Unfortunately, we haven’t any clear evidence of WIMPs existence up to now.

All operating detectors use the nuclear recoils registration after the process of WIMPs elastic scattering at nuclei [34]. Separation the signal from background is a difficult problem
in these experiments and to decrease the muon background cryogenic apparatus with the mass near 1 ton will be used in NUSEL experiments. It seems that the usage of liquid xenon as scintillator or supercooled Ge-Si crystals are most perspective technologies. Xenon radiates when recoil pass through it and, if Ge-Si crystals are used, it’s necessary to measure ionization energy of recoil together with vibrational quanta passed to the crystal grid. To study neutralino observation process neutralino-nucleon elastic scattering should be considered.

It is known that the spin-independent component of the total cross section is due to neutralino-quark interaction by means of scalar quarks exchange. In the considered scenario this component is strongly damped by large scalar quark masses. As a result there is spin-dependent component of the total cross section only:

\[ \sigma_{\chi n} = \frac{g_2^4 m_n^2}{64\pi m_W^4}, \quad \sigma_{\chi p} = \sigma_{\chi n} \cdot (1 - 4\sin^2\theta_W)^2. \] (5.1)

For the elastic scattering off nuclei result is:

\[ \sigma_{\chi \text{nuc}} \sim \left( \frac{M_{\text{nuc}}}{m_p} \right)^2 \frac{4(J + 1)}{3J} (\langle s_p \rangle + \frac{a_n}{a_p} \langle s_n \rangle)^2 \sigma_{\chi p}, \] (5.2)

here \( a_p(a_n) \) are WIMP-proton (neutron) couplings.

Cause we know the DM local density \((\approx 0.3 \text{ GeV/cm}^3)\) and evaluate neutralino velocity near the Sun as \(\approx 200 \text{ km/s}\), split neutralinos flux in detector can be estimated as \(j_{\chi} \approx 2 \cdot 10^3 \text{ cm}^{-2} \text{ s}^{-1}\). In particular, one of the most perspective elaborated detector XENON has the threshold \(\leq 10 \text{ KEV}\) for the energy of nuclear recoil. Typically, the recoil energy after interaction with galactic split neutralino is \(\sim 100 \text{ KEV}\) and for non-relativistic neutralino on xenon nuclei elastic cross section is \(\sim 10^{-35} \text{ cm}^2\). It gives \(\sim 1 - 2\) events per hour that is close to the planned detector background \(4.5 \cdot 10^{-5} \text{ s}^{-1}\) or \(\sim 1\) event per hour. Thus, in the case the signal can’t unambiguously confirm the DM structure formed by split Higgsino.

2. Recharging of split neutralino on nucleons

Some new processes could be possible when the relic neutralinos penetrate through the matter. Such channels are opened:

\[ \chi^0 + p \rightarrow \chi^+ + n, \quad \chi^0 + n \rightarrow \chi^- + p, \]

and cross sections are:

\[ \sigma_{\chi p}^* = \frac{g_2^4 |U_{ud}|^2 m_p^2}{16\pi m_W^4} \sqrt{E_N - \Delta m_N - \Delta M_\chi}, \quad \sigma_{\chi n}^* = \frac{g_2^4 |U_{ud}|^2 m_n^2}{16\pi m_W^4} \sqrt{E_N + \Delta m_N - \Delta M_\chi}, \]

here \(\Delta m_N = m_n - m_p \approx 1 \text{ MeV}\); \(\Delta M_\chi = M_{\chi^+} - M_{\chi^0} \approx 360 \text{ MeV}\) – chargino-neutralino mass difference that can be calculated from (3.6); \(E_N = \frac{1}{2} m_N v_{\text{rel}}^2\). An average kinetic energy of neutralino in the locality of the Sun is about \(\sim 1 \text{ MeV}\), but recharging reaction is possible only if there are high energy neutralinos with \(E_{\text{kin}} > 1 \text{ TeV}\) in cosmic rays.
B. Indirect neutralino detection

1. Diffuse gamma ray spectrum

Besides direct relic neutralino observation there are a set of satellite experimental programs for the detection of neutralino annihilation spectrum in the Galactic halo [30], [33], [35]. Annihilation process and calculation of gamma spectrum characteristic energies were evaluated in the above scenario framework. Namely, Majorana neutralinos in the halo annihilate into W- and Z-bosons

$$\chi \chi \rightarrow W^+ W^-, \quad \chi \chi \rightarrow ZZ,$$

(5.3)

and fermions

$$\chi \chi \rightarrow q\bar{q}, \ U\bar{U}. $$

(5.4)

Corresponding diagrams are shown in Fig. 4. Total kinetic cross section then is:

$$ (\sigma v)_{ann} = \frac{g_2^4 (21 - 40 \cos^2 \theta_W + 34 \cos^4 \theta_W)}{256 \pi M_{\chi}^2 \cos^4 \theta_W}. $$

(5.5)

Now use the fact that total secondary hadrons multiplicity nearly twice larger than charged hadrons multiplicity [22], [36], [37]. Average multiplicity of secondary charged hadrons $\langle \tilde{n}_{ch} \rangle(\sqrt{s})$ was studied in $e^+ e^-$, $pp$, $p\bar{p}$, $e^\pm p$ processes [38]. It was established that this quantity is some universal function of energy

$$ \tilde{n}_{ch}(\sqrt{s}) = A + B \ln \sqrt{s} + C \ln^2 \sqrt{s}, \quad \tilde{n}_{ch} \equiv \langle n_{ch} \rangle(\sqrt{s}/q_0) - n_0$$

with experimentally fixed parameters

$$ A = 3.11 \pm 0.08, \quad B = -0.49 \pm 0.09, \quad C = 0.98 \pm 0.02. $$

To choice a specific channel it is necessary to fix parameters $q_0, n_0$. For neutralinos annihilation $q_0(\chi \chi) = 1, n_0(\chi \chi) = 0$.

Further it is supposed that the part of charged hadrons $\kappa \equiv \langle n_{ch} \rangle/\langle n_h \rangle$ doesn’t depend on energy and has the value $\kappa \simeq 0.49$, which is extracted from Z-peak data [22].
For characteristic photon energies generation the following processes are most important $\pi^0 \to 2\gamma$, $\eta^0 \to 3\gamma$, $\eta^0 \to 3\pi^0 \to 6\gamma$. In the annihilation channel (5.4) total hadron multiplicity is described by following logarithmic function with good accuracy:

$$\langle n^f_h \rangle = \kappa^{-1}(A + B \ln 2M_\chi + C \ln^2 2M_\chi) \simeq 149, \quad M_\chi \simeq 3\,\text{TeV}. \quad (5.6)$$

An average energy of neutral pions in neutralinos annihilation secondaries is $\bar{E}_{\pi^0} \simeq \bar{E}_{\eta^0} \simeq 2M_\chi/\langle n^f_h \rangle$. Then in the $\pi^0 \to 2\gamma$ decay maximal characteristic energy of photon is equal:

$$\bar{E}_{\gamma(\pi^0 \to 2\gamma)} \simeq \bar{E}_{\pi^0}/2 = 20\,\text{GeV}. \quad (5.7)$$

Analogously, for reactions $\eta^0 \to 3\gamma$ and $\pi^0 \to 6\gamma$ energies of photons are:

$$\bar{E}_{\gamma(\eta^0 \to 3\gamma)} \simeq \bar{E}_{\eta^0}/3 = 13.5\,\text{GeV}, \quad \bar{E}_{\gamma(\pi^0 \to 6\gamma)} \simeq \bar{E}_{\eta^0}/6 = 6.7\,\text{GeV}. \quad (5.8)$$

In the second annihilation channel (5.3) total hadron multiplicity of $W$- and $Z$-bosons is:

$$\langle n^W_Z \rangle \simeq 42.9. \quad (5.9)$$

Here neutral pion average energy is $\bar{E}_{\pi^0} \simeq \bar{E}_{\eta^0} \simeq M_\chi/\langle n^W_Z \rangle$ and maximal characteristic photon energies are:

$$\bar{E}_{\gamma(\pi^0 \to 2\gamma)} \simeq \bar{E}_{\pi^0}/2 \simeq 35\,\text{GeV},$$

$$\bar{E}_{\gamma(\eta^0 \to 3\gamma)} \simeq \bar{E}_{\eta^0}/3 = 23.3\,\text{GeV}, \quad \bar{E}_{\gamma(\pi^0 \to 6\gamma)} \simeq \bar{E}_{\eta^0}/6 = 12\,\text{GeV}. \quad (5.10)$$

In a wide energy region multiplicity distribution can be described with a good accuracy by the Negative Binomial Distribution (NBD) that depends on energy very weakly (logarithmically) [37]:

$$P(n; \bar{n}, k) = \frac{k(k+1)...(k+n-1)}{n!} \cdot \frac{\bar{n}^n}{[1+(\bar{n}/k)]^{n+k}}, \quad (5.11)$$

$$k^{-1}(\sqrt{s}) = a + b \ln \sqrt{s},$$

where $n \equiv n_{ch}$, $\bar{n} \equiv \bar{n}_{ch}$. For various channels coefficients in the function $k^{-1}(\sqrt{s})$ are different:

$$a_{e^+e^-} = -0.064 \pm 0.003, \quad b_{e^+e^-} = 0.023 \pm 0.002; \quad (5.12)$$

$$a_{pp/\bar{p}p} = -0.104 \pm 0.004, \quad b_{pp/\bar{p}p} = 0.058 \pm 0.001. \quad (5.13)$$

Using the NBD it is possible to find approximate energetic distribution of photons. For example, in hadronic annihilation channel (5.4) with $Br(h) \simeq 0.58$ it is supposed that branchings for various hadrons $Br(i/h) \equiv \langle n_i \rangle/\langle n_h \rangle$ are nearly constants and equal to corresponding branchings extracted from $e^+e^-$-annihilation [22]. Each annihilating neutralino pair gives a number of neutral pions $Br(\pi^0/h) \cdot 2\bar{n}P(n; \bar{n}, k)$ with the probability $Br(h)$. These pions generate the following distribution of photons $\Delta n_{\gamma} \simeq 2 \cdot Br(h)Br(\pi^0/h) \cdot 2\bar{n}P(n; \bar{n}, k)\Delta n$ with energy $E_{\gamma} = M_\chi/2n$ in the multiplicity interval $\Delta n$, which is connected with energy
interval $\Delta n = M_\chi \Delta E_\gamma / 2 E_\gamma^2$. For $\eta^0$-mesons and annihilation channel (5.3) considerations are analogous. Then the number of photons with energy $E_\gamma$ per one annihilation act is:

$$\frac{dN_\gamma}{dE_\gamma} \simeq \frac{2M_\chi}{E_\gamma^2} \left\{ \left[ Br(\pi^0/h) + Br(\eta^0/h) \cdot Br(\eta^0 \to 2\gamma) \right] \right\} \times

\times \left[ Br(h) \langle n_{ch}^{ff} \rangle P \left( \frac{M_\chi}{2E_\gamma}; \langle n_{ch}^{ff} \rangle, k_{ff} \right) + \frac{1}{2} Br(WZ) \langle n_{ch}^{WZ} \rangle P \left( \frac{M_\chi}{4E_\gamma}; \langle n_{ch}^{WZ} \rangle, k_{WZ} \right) \right] +

+ Br(\eta^0/h) \left[ Br(\eta^0 \to 3\pi^0) + \frac{1}{3} Br(\eta^0 \to \pi^+\pi^-\pi^0) \right] \times

\times \left[ Br(h) \langle n_{ch}^{ff} \rangle P \left( \frac{M_\chi}{6E_\gamma}; \langle n_{ch}^{ff} \rangle, k_{ff} \right) + \frac{1}{2} Br(WZ) \langle n_{ch}^{WZ} \rangle P \left( \frac{M_\chi}{12E_\gamma}; \langle n_{ch}^{WZ} \rangle, k_{WZ} \right) \right]

\times \left[ Br(\eta^0/h) Br(\eta^0 \to \pi^+\pi^-\gamma) \times

\times \left[ Br(h) \langle n_{ch}^{ff} \rangle P \left( \frac{M_\chi}{3E_\gamma}; \langle n_{ch}^{ff} \rangle, k_{ff} \right) + \frac{1}{2} Br(WZ) \langle n_{ch}^{WZ} \rangle P \left( \frac{M_\chi}{6E_\gamma}; \langle n_{ch}^{WZ} \rangle, k_{WZ} \right) \right] \right\}.

Here $Br(WZ) \simeq 0.2$ is the total branching for neutralino annihilation into $W$- and $Z$-bosons; charge hadron multiplicities $\langle n_{ch}^{ff} \rangle$ and $\langle n_{ch}^{WZ} \rangle$ are defined in (5.6) and (5.9); parameters $k_{ff}^{-1} = k^{-1}(2M_\chi) = 0.4$ and $k_{WZ}^{-1} = k^{-1}(M_\chi) = 0.12$ were determined with coefficients from (5.13) and (5.12), respectively. The spectrum is shown in Fig. 5.

![Diffuse gamma ray annihilation spectrum.](image)

FIG. 5: Diffuse gamma ray annihilation spectrum.

Calculated value of gamma-ray flux is close to the threshold of sensitivity for the satellite detector GLAST. Possibility of neutralino annihilation spectrum registration at this
apparatus will be clarified when the GLAST will be put into operation.

VI. CONCLUSION

The model considered (Split Higgsino Scenario) has peculiarity that is inherent in the SM extensions having of the split mass spectra: Higgsino mass scale is considerably lower than the soft SUSY breaking scale: $\mu \ll M_{\text{SUSY}} \sim \tilde{M}_0 \sim M_{1/2}$.

In this model, as in the standard MSSM, there is the precise convergence of invariant couplings, the scale of convergence $M_{\text{GUT}}$ doesn’t contradict to the well known restriction on the proton lifetime. It is essential that in the case mass spectrum of two Majorana neutralinos and charginos is strongly degenerated near the $\mu$ scale. For $M_{\text{SUSY}} > 1.4 \times 10^4$ GeV radiation corrections dominate in the neutralino-chargino mass splitting. From the mass difference calculations with the renormgroup evolution consideration it follows $M_{\chi^\pm_1} - M_{\chi^0_{1,2}} \approx 360$ MeV at $M_\chi \approx \mu \approx 3$ TeV. The last value have got from the analysis of the neutralino relic abundance in cosmological plasma. Such heavy neutralinos, being of the DM carriers, should annihilate in the high-symmetric phase forming the relic. Charged Higgsino lifetime in the model is $\tau_{\chi^\pm_1} \approx 0.4 \times 10^{-9}$ s. These results and peculiarities are inevitable because of hierarchy of the model scales and discriminate the model considered from other models possessing of the Split Supersymmetry property.

These physical consequences of the model can be verified, in principle, in some experiments planned at underground laboratory NUSEL or satellite detector GLAST. Namely, at NUSEL it is possible to search relic split heavy Higgsino. Due to the fact that spin dependent part dominates in the neutralino-nucleon scattering, neutralinos can be registered in the XENON detector. The evaluated neutralino signal is close to the rated value of background. Moreover, if there are high energy neutralinos $E_\chi \geq 1$ TeV in cosmic rays the recharging process for neutralino-nuclei scattering can be seen.

The neutralino annihilation spectrum can be observed at GLAST detector. Diffuse radiation spectrum has been calculated and analyzed for the galactic DM consisting of heavy (split) neutralinos. Contributions to the gamma ray spectrum from t- and s-channels annihilation into $Z^0Z^0$ and $W^+W^-$ pairs were calculated with the using of experimental data on hadron multiplicities on $Z^0$, $W^\pm$ mass shell; for quark-antiquark s-channel contribution phenomenological model of hadron multiplicity at $\sqrt{s} = 2M_\chi$ was used too.

Thus, it has been shown some other possibility of the $M_{\text{SUSY}}$ scale shift to far energy region – in comparison with the known Split Supersymmetry variant. This splitting of the mass spectrum is a consequence of the extra supergauge symmetries existing at intermediate scales, between the SM and GUT. If results of the SUSY search at LHC will be discouraged, the proposed model (or analogous – with other energy scales arrangement) leave the chance to keep supersymmetry ideas, but at higher energy scale than it is within reach of the LHC. Evaluation of $M_{\text{SUSY}}$ turn out to be possible if the split sector of neutral and charged Higgsino is realized. With the interpretation of neutralinos as main component of the DM, it becomes feasible to give some predictions for future experiments at NUSEL and GLAST.

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