COSMOLOGICAL IMPLICATIONS OF SUPERSYMMETRIC CP VIOLATING PHASES

SHAABAN KHALIL

Departmento de Fisica Teórica, C.XI, Universidad Autónoma de Madrid, 28049 Cantoblanco, Madrid, Spain.

and

Ain Shams University, Faculty of Science, Cairo 11566, Egypt.

We show that large SUSY phases have no significant effect on the relic density of the lightest supersymmetric particle (LSP). However, they are very significant for the detection rates. We emphasise that the phase of the trilinear coupling increase the direct and indirect detection rates.

In supersymmetric (SUSY) models there are many new CP violating phases beyond the phase $\delta_{CKM}$ of the Cabibbo-Kobayashi-Maskawa (CKM) mixing matrix. They arise mainly from the soft SUSY breaking parameters which are in general complex. These phases give large one loop contributions to the electric dipole moments (EDM) of the neutron and electron which exceed the current limits. Hence, SUSY phases are generally quite constrained, they have to be of order $10^{-3}$ for SUSY particle masses of order 100 GeV. However, it was suggested that there are internal cancellations among various contribution to the EDM (including the chromoelectric and purely gluonic operator contributions) whereby allowing for large CP phases. We have shown that in the effective supergravity derived from string theory, such cancellation is accidental and it only occurs at few points in the parameter space. Recently, it was argued that the non universal gaugino masses and their relative phases are crucial for having sufficient cancellations among the contributions to EDMs.

In such a case, one expects that these large phases have important impact on the lightest supersymmetric particle (LSP) relic density and its detection rates. In Ref. the effect of SUSY phases on the LSP mass, purity, relic density, elastic cross section and detection rates has been considered within models with universal, hence real, gaugino masses. It was shown that the phases have no significant effect on the LSP relic abundance but a substantial impact on the detection rates. Here, we study the effect of gaugino phases, particularly, we consider D-brane model recently proposed which is able to allow large value of phases while the EDM of the neutron and electron are less than the experimental limit as shown in Ref. It turns out that the LSP of this model could be bino or wino like depending on the ratio between $M_1$ and
$M_2$. In the region where the EDMs are smaller than the limit, the mass of the LSP is very close to the lightest chargino, hence the co-annihilation between them becomes very important and it greatly reduces the relic density. The phases have no important effect on the LSP relic abundance as in the case of Ref. However, their effect on the detection rates is very significant and is larger than what is found in the case of real gaugino masses.

The possibility of non-universal gaugino masses and phases at the tree level is natural in the type I string theory. The soft SUSY breaking terms in this class of models depend on the embedding of the standard model (SM) gauge group in the D-brane sector. In case of the SM gauge group is not associated with a single set of branes the gaugino masses are non universal. We assume that the gauge group $SU(3)_C \times U(1)_Y$ is associated with one set of five branes (say $5_1$) and $SU(2)_L$ is associated with a second set $5_2$. The soft SUSY breaking terms take the following form:

$$M_1 = \sqrt{3} m_{3/2} \cos \theta \Theta_1 e^{-i\alpha_1} = M_3 = -A, \quad (1)$$
$$M_2 = \sqrt{3} m_{3/2} \cos \theta \Theta_2 e^{-i\alpha_2}, \quad (2)$$

where $A$ is the trilinear coupling. The soft scalar mass squareds are gives by

$$m_Q^2 = m_U^2 = m_{H_u}^2 = m_{H_d}^2 = m_{3/2}(1 - 3/2 \sin^2 \theta), \quad (3)$$
$$m_D^2 = m_E^2 = m_{3/2}(1 - 3 \cos^2 \theta), \quad (4)$$

and $\Theta_1^2 + \Theta_2^2 = 0$. In this case, by using the appropriate field redefinitions and the $R$-rotation we end up with four physical phases, which can not be rotated away. These phases can be chosen to be: the phase of $M_1$ ($\phi_1$), the phase of $M_3$ ($\phi_3$), the phase of $A$ ($\phi_A$) and the phase of $\mu$ ($\phi_\mu$). The phase of $B$ is fixed by the condition that $B\mu$ is real.

The effect of these phases on the EDM of the electron and the neutron, taking into account the cancellation mechanism between the different contributions, has been examined in Ref. It was shown that large values of these phases can be accommodated and the electron and neutron EDM satisfy the experimental constraint. It is worthy noticed that the EDM impose a constraint on the ratio $M_1/M_2$. In fact, to have an overlap between the electron and neutron EDM allowed regions, $M_2$ should be less than $M_1$, and as explained in Ref. a precise overlap between these two regions occurs at $\Theta_1 = 0.85$. Such constraint has an important impact on the LSP. In this case, we have $M_2$ is the lightest gaugino at GUT scale. However, at the electroweak (EW) scale, it turns out that the lightest neutralino is a bino like. Furthermore, the LSP mass is close to the lightest chargino mass which is equal to

---

*aSee also Ref.*
the mass of the next lightest neutralino ($\tilde{\chi}_2^0$). Therefore, the co-annihilation between the bino and the chargino as well as the next to lightest neutralino are very important and have to be included in the calculation of the relic density.

We study the effect of the SUSY CP violating phases and the co-annihilation on the relic density and also on the upper bound of the LSP mass. Since the LSP is bino like, the annihilation is predominantly, as usual, into leptons by the exchange of the right slepton. Without co-annihilation, the constraint on the relic density $0.025 < \Omega_{LSP}h^2 < 0.22$ impose sever constraint on the LSP mass, namely $m_{\chi} < 150$ GeV, and the SUSY phases have no any significant effect in relaxing such sever constraint as found in Ref. 5. Including the co-annihilation of $\chi$ with $\chi_1^+ + \tilde{\chi}_2^0$ is very important to reduce the LSP relic density to an acceptable level.

Given that the LSP is almost pure bino, the co-annihilation processes are predominantly into fermions. However, since the coupling of $\tilde{\chi}_2^0 - f - \tilde{f}$ is proportional to $Z_{2j}$, it is smaller than the coupling of $\tilde{\chi}_1^+ - f - \tilde{f}'$. We found that the dominant contribution is due to the co-annihilation channel $\tilde{\chi}_1^+ \chi \to f\bar{f}$. We also include $\tilde{\chi}_1^+ \chi \to W^+ \gamma$ channel, estimated to contribute with a few cent. Then, we can calculate the relic abundance using the standard procedure 9. In Fig.1 we show the values of the LSP relic abundance $\Omega_{\chi}h^2$, estimated with including the co-annihilations, corresponding to the LSP mass. This figure shows that the co-annihilation processes have very significant rule in reducing the values of $\Omega_{\chi}h^2$, even now we obtain an upper bound on the mass of the LSP from the lower bound of the relic density, $\Omega_{\chi}h^2 > 0.025$

---

**Figure 1.** The LSP relic abundance with co-annihilation versus its mass, solid line corresponds to non vanishing phases while the dashed lines correspond to vanishing phases.
which leads to $m_\chi < 400$ GeV. Here, also the effect of the SUSY phases is insignificant and the same upper bound of the LSP mass is obtained for vanishing and non-vanishing phases. It is important to notice that the gaugino phases especially the phase of $M_3$ have important impact on having large $\phi_A$ at the EW scale. It dominantly contributes to the phase of $A$-term during the renormalization from the GUT scale to EW scale. Thus, the radiative corrections to $\phi_A$ is very small and the phase of $A$ is kept large at EW. However, as we have shown, such large phases are not effecting for the LSP mass and the relic abundance. In fact, this result is due to two facts, first the LSP is bino so it slightly depends on the phase of $\mu$, second, the phases are important if there is a significant mixing in the sfermion mass matrix. In these class of models we consider the off diagonal element are much smaller than the diagonal element.

As shown in Ref. 5, the SUSY phases is found to have a significant effect on the direct detection rate $(R)$ and indirect detection rate $(\Gamma)$. The phase of $\phi_A$ increases the values of $R$ and $\Gamma$. Furthermore, the enhancement of the ratios of the rates with non-vanishing $\phi_A$ to the rates in the absence of this phase are even large than what is found in Ref. 5, since as we explained, here $\phi_A$ has larger values at EW scale due to the gluino contribution through the renormalization.

This work is supported by a Ministerio de Educacion y Cultura research grant.

References

1. T. Ibrahim and P. Nath, Phys. Rev. D D57 (1998) 478; Erratum idid D58 (1998) 019901.
2. S. Barr and S. Khalil hep-ph/9903425, to be published in Phys. Rev D.
3. M. Brhlik, L. Everett, G. Kane and J. Lykken, Phys. Rev. Lett. 83 (1999) 2124.
4. T. Ibrahim and P. Nath, hep-ph/9910553; E. Accomando, R. Arnowitt and B. Dutta, hep-ph/9909333.
5. S. Khalil and Q. Shafi, Nucl. Phys. B 564 (1999) 19.
6. U. Chattopadhyay, T. Ibrahim and P. Nath, Phys. Rev. D 60 (1999) 063505; T. Falk, A. Frejst and K. Olive, Phys. Rev. D 59 (1999) 055009; T. Falk and K. Olive, Phys. Lett. B 375 (1996) 196; Phys. Lett. B 354 (1995) 99.
7. L. Ibanez, C. Munoz and S. Rigolin, Nucl. Phys. B 553 (1999) 43.
8. S. Khalil, hep-ph/9910408.
9. K. Griest and D. Seckel, Phys. Rev. D 43 (1991) 3191.