Axionic Mirage Mediation
Shuntaro Nakamura, Ken-ichi Okumura and Masahiro Yamaguchi

Department of Physics, Tohoku University, Sendai, 980-8578, Japan

Abstract. In this talk, we propose a model of mirage mediation, in which Peccei-Quinn symmetry is incorporated. In this axionic mirage mediation, it is shown that the Peccei-Quinn symmetry breaking scale is dynamically determined around $10^{10}$ GeV to $10^{12}$ GeV due to the supersymmetry breaking effects. The problems in the original mirage mediation such as the $\mu$-problem and the moduli problem can be solved simultaneously. Furthermore, in our model the axino, which is the superpartner of the axion, is the lightest sparticle.

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INTRODUCTION

Supersymmetry (SUSY) deeply fascinates us as a solution to the hierarchy problem. It has, however, to be broken because superparticles have not been discovered yet. The phenomenological aspects such as mass spectrum, collider signature and so forth, depend on how SUSY is broken. Therefore, to understand the SUSY breaking mechanism is important. In superstring theory, one of the most plausible mediation mechanisms is the moduli mediation. On the other hand, the mediation associated with the super-Weyl anomaly, the anomaly mediation, is also inevitable. Recently, KKLT [1] have proposed the interesting set-up by introducing the axion superfield $\theta$ with the super-Weyl anomaly, the anomaly mediation, is often called the mirage mediation [2]. The mirage mediation is a natural mediation mechanism in the string modulus stabilization and very interesting because it can solve the tachyonic slepton problem in the pure anomaly mediation, and it has characteristic mass spectra as well. However, it suffers from two crucial problems. One is the $\mu$-problem and the other results from cosmology. The former stems from the fact that $B$ parameter would easily become of the order of the gravitino mass, $m_{3/2}$, which is $\mathcal{O}(10)$ TeV. The latter leads to the result that the sizable production rate of gravitinos from the modulus decay aggravates the conventional moduli problem [3]. (See, for the case of the inflaton and the Polonyi field [4]). Such aggravation comes from the overclosure of the neutralinos produced by the gravitinos if it is the lightest superparticle (LSP). In this talk, we show that axionic extension of mirage mediation, axionic mirage mediation [5], can solve not only the $\mu$-problem but the cosmological moduli problem simultaneously.

THE MODEL

Let us consider the hadronic axion model in the KKLT set-up by introducing the axion superfield $S$ and $N$ pairs of messenger fields $\Phi$ and $\Psi$. Here, $S$ is a singlet under any unbroken gauge symmetry, $\Phi$ and $\Psi$ are vectorlike representation of the SU(5) gauge group and we use $X$ to denote the modulus. We assigned the PQ charge as $Q_{\text{PQ}}(S) = Q_{\text{PQ}}(\Phi) = Q_{\text{PQ}}(\Psi) = 1$ and $Q_{\text{PQ}}(X) = 0$. The superpotential has Yukawa coupling,

$$ W = \lambda S \Phi \Psi + \cdots, $$

(1)

which is allowed by the PQ symmetry. The hat means the absorption of the chiral compensator $\Phi$, that is $\hat{S} \equiv \Phi S$. $\hat{S}$ is a flat direction in SUSY limit, however, it is lifted by the SUSY breaking, $F_S \Phi$, caused by the mirage mediation. Here, $F_X$ and $F_\Phi$ stand for the auxiliary field of the modulus and that of the compensator, respectively. We assume that $S$ is stabilized far away from the origin, breaking the PQ symmetry. Since this gives a huge mass for the messengers, we can integrate out the messengers. This leads to

$$ \mathcal{L} = \int \frac{d^4 \theta (X + X^\dagger)}{\sqrt{2}} Z_S \left( \sqrt{\frac{\hat{S}^2}{F_S}} (X + X^\dagger) \right) |\hat{S}|^2, $$

(2)

where $Z_S$ is the wave function renormalization of $S$ at $\mu = |\hat{S}|$ and $k$ the modular weight of $S$. According to the renormalization group equation (RGE) of $m_S^2$, we can find that the scalar potential of $S$ has a minimum at some scale $\langle \hat{S} \rangle \neq 0$. We depicted $\langle \hat{S} \rangle$ as a function of $\alpha \equiv \sqrt{F_S^2/(2X^2k \ln(M_\text{GUT}/m_{3/2})}$. It is noted that the PQ scale, $f_{\text{PQ}} \simeq \langle \hat{S} \rangle$, can be within, so-called, the axion window $10^{7} \text{GeV} \lesssim f_{\text{PQ}} \lesssim 10^{12-13} \text{GeV}$. In what follows, we consider the case $\langle \hat{S} \rangle \simeq 10^{10} \text{GeV}$.

From eq. (2), we can find that the mass of the axino $\tilde{a}$, which is the superpartner of the axion, is calculated at
In this section, we discuss the cosmological implications of our model. We assume that the modulus and the saxion, which is the real part of the scalar component of the axion superfield, are displaced from their true minima, with the amplitude of the order of the Planck scale, and their coherent oscillation start before the reheating due to the inflaton decay is completed. In this case, we can find that it is sufficient to discuss the cosmic evolution only after the modulus decay because of a large amount of the entropy production. In what follows, we address the implications of the modulus decay in cosmology.

There are four processes producing the axino LSP via the modulus decay (See, fig.2). However, the dominant contribution to the axino abundance is given by the 4th. process. We investigated the relic abundance of the axino in various cases with the NLSP being bino, higgsino, stau, stop and wino. The result is summarized in the table.1. Here, case A and B represent that the annihilation rate of the NLSP at the gravitino decay is negligible and significant, respectively. It is noted that when the annihilation process of the NLSP is not effective, the relic abundance of the axino becomes the same value in any NLSP cases.
We are now ready to discuss whether the axino relic abundance accords with the present DM abundance. In fig.3, we plotted the axino mass density in terms of abundance accords with the present DM abundance. In fig.4, we plotted axino mass contours which satisfy the density parameter of the axino, $\Omega_{\tilde{a}}h^2$. Thus, we find from fig.3 that the axino with mass of $\mathcal{O}(100)$ MeV can explain the present DM abundance in any NLSP cases, if the decay of the NLSP is more effective than the annihilation in the 4th. process. In fig.4, we plotted axino mass contours which satisfy $\Omega_{\tilde{a}}h^2 = 0.1$ in $m_{\tilde{a}}-m_X$ plane for the wino NLSP case, where we set $\lambda = N = 1$, $k = 0$, and $m_{\tilde{W}} = 100$ GeV. If the wino is the NLSP and their annihilation is effective, fig.4 shows that the right amount of DM can be explained by the axino with a few GeV mass.

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