Dark Energy and Neutrino Model in SUSY

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Abstract. We discuss the effect of the supersymmetry breaking on the Mass Varying Neutrinos(MaVaNs) scenario. Especially, the effect mediated by the gravitational interaction between the hidden sector and the dark energy sector is studied. A model including a chiral superfield in the dark sector and the right-handed neutrino superfield is proposed. Evolutions of the neutrino mass and the equation of state parameter are presented in the model.

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INTRODUCTION

In a dynamical dark energy model proposed by Fardon, Nelson and Weiner (MaVaNs), relic neutrinos could form a negative pressure fluid and cause the cosmic acceleration [1]. In this model, an unknown scalar field which is called “acceleron” is introduced and neutrinos are assumed to interact through a new scalar force. The acceleron sits at the instantaneous minimum of its potential, and the cosmic expansion only modulates this minimum through changes in the neutrino density. Therefore, the neutrino mass depends on its number density and changes with the evolution of the Universe. The equation of state parameter $w$ and the dark energy density also evolve with the neutrino mass. Those evolutions depend on a model of the scalar potential and the relation between the acceleron and the neutrino mass strongly. Typical examples of the potential and some supersymmetric models have been discussed in ref. [2, 3, 4, 5].

In this talk, we present a model including the supersymmetry breaking effect mediated by the gravity. Then we show evolutions of the neutrino mass and the equation of state parameter in the model.

SUPERSYMMETRIC MAVANS

The basic assumption of the MaVaNs with supersymmetry is to introduce a chiral superfield $A$ in the dark sector, which is a singlet under the gauge group of the standard model. We assume that the superfield $A$ couples to both the left-handed lepton doublet superfield $L$ and the right-handed neutrino superfield $R$. 

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In this framework, we suppose the superpotential

$$W = \frac{\lambda}{6} A^3 + \frac{M_A}{2} AA + m_D LA + M_{DLR} + \frac{M_R}{2} RR,$$

(1)

where $M_A$, $M_D$, $M_R$ and $m_D$ are mass parameters. The scalar and spinor component of $A$ are $(\phi, \psi)$, and the scalar component is assumed to be the acceleron which cause the present cosmic acceleration. The spinor component is a sterile neutrino.

In the MaVaNs scenario, the dark energy is assumed to be the sum of the neutrino energy density and the scalar potential for the acceleron: $\rho_{\text{DE}} = \rho_{\nu} + V(\phi)$. The effective scalar potential, the lagrangian density and the effective neutrino mass matrix are given as

$$V(\phi) = \frac{\lambda^2}{4} |\phi|^4 + M_A^2 |\phi|^2 + m_D^2 |\phi|^2,$$

(2)

$$\mathcal{L} = \lambda \phi \psi \bar{\psi} + M_A \psi \bar{\psi} + m_D \bar{\nu}_L \psi + M_D \bar{\nu}_L \nu_R + M_R \nu_R \nu_R + h.c.,$$

(3)

$$\mathcal{M} \approx \begin{pmatrix} c & m_D \\ m_D & M_A + \lambda \phi \end{pmatrix}.$$  

(4)

The neutrino mass matrix is written in the basis of $(\bar{\nu}_L, \psi)$, where we assume $\lambda \phi \ll M_D \ll M_R$ and define $c \equiv -\frac{M_D^2}{M_R}$. The first term of the $(1, 1)$ element of this matrix corresponds to the usual term given by the seesaw mechanism. It is remarked that only the mass of a sterile neutrino is variable in the case of the vanishing mixing ($m_D = 0$) between the left-handed and a sterile neutrino on cosmological time scale. The finite mixing ($m_D \neq 0$) makes the mass of the left-handed neutrino variable.

In the MaVaNs scenario, there are two constraints on the scalar potential. The first one comes from observations of the Universe, which is that the magnitude of the present dark energy density is about $0.74 \rho_c$, $\rho_c$ being the critical density. Thus, the first constraint turns to $V(\phi_0) = 0.74 \rho_c - \rho_0^\nu$. “0” represents a value at the present epoch.

The second one is the stationary condition. In this scenario, the neutrino is a dynamical quantity which is a function of the acceleron. Therefore, the dark energy density should be stationary with respect to the variation of the neutrino mass: $\partial \rho_{\text{DE}} / \partial m_{\nu} = 0$. This equation is rewritten by using the cosmic temperature $T$: $\partial V / \partial m_{\nu} = -T^3 \partial F / \partial \xi$, where $\xi \equiv m_{\nu} / T$, $\rho_\nu = T^4 F(\xi)$ and $F(\xi) \equiv \frac{1}{\pi} \int_0^\infty dyy^2 \sqrt{y^2 + \xi^2} / (e^y + 1)$. We can get the time evolution of the neutrino mass from this stationary condition. Since the stationary condition should be always satisfied in the evolution of the Universe, this one at the present epoch is the second constraint on the scalar potential:

$$\left. \frac{\partial V(\phi)}{\partial m_\nu} \right|_{m_\nu = m_\nu^0} = -T^3 \left. \frac{\partial F(\xi)}{\partial \xi} \right|_{m_\nu = m_\nu^0, T = T_0}.$$  

(5)

In addition to two constraints for the potential, we also have two relations between the acceleron and the neutrino mass:

$$m_i = \frac{c + M_A + \lambda \phi}{2} \pm \sqrt{\left[\frac{c - (M_A + \lambda \phi)}{2}\right]^2 + 4m_D^2},$$  

(6)
where the plus and the minus sign correspond to the left-handed and a sterile neutrino mass, respectively ($i = \nu_L, \psi$).

Next, we will consider the dynamics of the acceleron field. In order that the acceleron does not vary significantly on distance of inter-neutrino spacing, the acceleron mass at the present epoch must be less than $\mathcal{O}(10^{-4}\text{eV})$. Here and below, we fix the present acceleron mass as $m_0^\phi = 10^{-4} \text{eV}$. Once we adjust parameters which satisfy some conditions for the MaVaNs model, we can have evolutions of the neutrino mass from the stationary condition.

The dark energy is characterized by the evolution of the equation of state parameter $w$. The equation of state in this scenario is derived from the energy conservation equation in the Robertson-Walker background and the stationary condition: $w + 1 = \left[4 - h(\xi)\right]\rho_\nu/\left(3\rho_\nu\right)$, where $h(\xi) \equiv \xi \frac{\partial F(\xi)}{\partial \xi}/F(\xi)$. It seems that $w$ in this scenario depends on the neutrino mass and the cosmic temperature. This means that $w$ varies with the evolution of the Universe unlike the cosmological constant.

**EFFECT OF SUPERSYMMETRY BREAKING**

In order to consider the effect of supersymmetry breaking in the dark sector, we assume a superfield $X$, which breaks supersymmetry, in the hidden sector, and the chiral superfield $A$ in the dark sector is assumed to interact with the hidden sector only through the gravity. Once supersymmetry is broken at TeV scale, its effect is transmitted to the dark sector through the operators $\int d^4\theta X^\dagger X A^\dagger A/M_{pl}^2$ and $\int d^4\theta (X^\dagger + X)A^\dagger A/M_{pl}$. $M_{pl}$ is the Planck mass. Then, the scale of the soft terms $F_X (\text{TeV}^2)/M_{pl} \sim \mathcal{O}(10^{-3}-10^{-2}\text{eV})$ is expected. Such a framework was discussed in the “acceleressence” scenario [6].

In this framework, taking supersymmetry breaking effect into account, the scalar potential is given by

$$V(\phi) = \frac{\lambda^2}{4} |\phi|^4 - \frac{\kappa}{3}(\phi^3 + \text{h.c.}) + M_A^2|\phi|^2 + m_D^2|\phi|^2 - m^2|\phi|^2 + V_0,$$

where $\kappa$ and $m$ are supersymmetry breaking parameters, and $V_0$ is a constant determined by the condition that the cosmological constant is vanishing at the true minimum of the acceleron potential. This scalar potential is the same one presented in [6].

When the mixing between the left-handed and a sterile neutrino is vanishing, $m_D = 0$ in the neutrino mass matrix [4]. Then we have the mass of the left-handed and a sterile neutrino as $m_{\nu_L} = c$ and $m_{\psi} = M_A + \lambda \phi$, respectively. In this case, we find that only the mass of a sterile neutrino is variable on cosmological time scale.

In the case of the finite mixing between the left-handed and a sterile neutrino ($m_D \neq 0$), the left-handed and a sterile neutrino mass are given by Eq. (6). We can expect that both the mass of the left-handed and a sterile neutrino have varied on cosmological time scale due to the term of the acceleron dependence.

Taking typical values for four parameters as $\lambda = 1$, $m_D = 10^{-3} \text{eV}$, $m_{\nu_L}^0 = 2 \times 10^{-2} \text{eV}$ and $m_{\psi}^0 = 10^{-2} \text{eV}$, we have $\phi^0 \simeq -1.31 \times 10^{-5} \text{eV}$, $c \simeq 1.99 \times 10^{-2} \text{eV}$, $M_A \simeq 1.01 \times 10^{-2} \text{eV}$, $m \simeq 1.02 \times 10^{-2} \text{eV}$ and $\kappa \simeq 4.34 \times 10^{-3} \text{eV}$. Evolutions of the left-handed and a sterile neutrino mass and the equation of state parameter are shown in Fig. [1].
The mass of the left-handed neutrino is variable unlike the vanishing mixing case. The mixing does not almost affect evolutions of a sterile neutrino mass and the equation of state parameter.

**SUMMARY**

We presented a supersymmetric MaVaNs model including the effects of the supersymmetry breaking mediated by the gravity. Evolutions of the neutrino mass and the equation of state parameter have been calculated in the model. Our model has a chiral superfield in the dark sector, whose scalar component causes the present cosmic acceleration, and the right-handed neutrino superfield. In our framework, supersymmetry is broken in the hidden sector at TeV scale and the effect is assumed to be transmitted to the dark sector only through the gravity. Then, the scale of soft parameters are \( O(10^{-3} - 10^{-2}) \)(eV) is expected.

In our model, the mixing between the left-handed and a sterile neutrino makes the left-handed neutrino mass variable. The mixing does not almost affect evolutions of the sterile neutrino mass and the equation of state.

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