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Contents

Universal Extra Dimension models with right-handed neutrinos

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Abstract. Relic abundance of dark matter is investigated in the framework of universal extra dimension (UED) models with right-handed neutrinos. These models are free from the KK graviton problem in the minimal UED model. The first KK particle of the right-handed neutrino is a dark matter candidate in this framework. When ordinary neutrino masses are large enough such as the degenerate mass spectrum case, the dark matter relic abundance can increase significantly. The scale of the extra dimension consistent with cosmological observations can be 500 GeV in the minimal setup of UED models with right-handed neutrinos.

Keywords: dark matter, extra dimension, neutrino

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INTRODUCTION AND UED MODELS

There is dark matter in the universe, and many models beyond the Standard Model (SM) have been proposed to explain the dark matter. Among those, Universal Extra Dimension (UED) models are one of interesting candidates for new physics, and it is worth investigating these models. We have solved problems inherent in these models, and calculated the allowed parameter by estimating the dark matter relic abundance. This proceeding is based on our works [1, 2].

First, we briefly review UED model. This model is described in the five-dimensional space-time, where the extra dimension is compactified on an S^1/Z_2 orbifold with the radius R . As a result of the compactification, many excited states of SM fields, called KK particles, appear. In this model, the lightest KK particle (LKP) is stabilized by discrete symmetry, called KK parity. Thus, if the LKP is neutral, the LKP can be dark matter candidate.

Though the minimal UED model is good model, the model has two shortcomings. The first one is the KK graviton problem. In the parameter region where $1/R < 800$ GeV, the KK graviton $G^{(1)}$ is the LKP, and the next LKP (NLKP) is the KK photon $\gamma^{(1)}$. Hence, $\gamma^{(1)}$ produced in the early universe decay into photons at late time universe, and these photons distort the CMB spectrum or the diffuse photon spectrum.

The second problem is the absence of neutrino masses. Since UED model has been constructed as minimal extension of the SM, neutrinos are treated as massless particles. However, neutrinos have mass. Therefore we must introduce neutrino masses into UED models.

SOLVING THE PROBLEMS

In order to solve these problems, we introduce the right-handed neutrinos into UED models, and assume that they form Dirac mass with ordinary neutrinos. The neutrino masses are expressed as $\mathcal{L}_\nu = y_\nu \bar{N} L \Phi + \text{h.c.}$, where N is the right-handed neutrino, L is the left-handed lepton. Then the second problem, the absence of the neutrino masses, are clearly solved. Once we introduce right-handed neutrinos into UED models, their KK particles automatically appear in the spectrum. The mass of the first KK right-handed neutrino, $N^{(1)}$, is estimated as $m_{N^{(1)}} \simeq \frac{1}{R} + O\left(\frac{m_\nu^2}{1/R}\right)$. After introducing the right-handed neutrinos, $N^{(1)}$ is the NLKP, and $\gamma^{(1)}$ is the next to next lightest KK particle.

The existence of the $N^{(1)}$ NLKP changes the late time decay of $\gamma^{(1)}$. In the models with the right-handed neutrino, $\gamma^{(1)}$ dominantly decays into $N^{(1)}$ and SM left-handed neutrino at tree level ($\gamma^{(1)} \rightarrow N^{(1)} \bar{\nu}$). In the KK neutral gauge boson mass matrix, mixing angle is very small, and hence $\gamma^{(1)}$ can be regarded as KK U(1) gauge boson. Therefore $\gamma^{(1)}$ can decay into neutrinos through the hypercharge. On the other hand, the dominant decay mode associated with a photon is $\gamma^{(1)} \rightarrow G^{(1)} \gamma$. We estimated the branching ratio of these decay modes

$$\text{Br} = \frac{\Gamma(\gamma^{(1)} \rightarrow G^{(1)} \gamma)}{\Gamma(\gamma^{(1)} \rightarrow N^{(1)} \bar{\nu})} = 5 \times 10^{-7} \left(\frac{1/R}{500 \text{ GeV}} \right)^3 \left(\frac{0.1 \text{ eV}}{m_\nu} \right)^2 \left(\frac{\delta m}{1 \text{ GeV}} \right). \quad (1)$$

As a result, by introducing the right-handed neutrino into UED models, neutrino masses are introduced, and problematic high energy photon emission is highly suppressed. Therefore, two problems in UED models have been solved simultaneously.

$N^{(1)}$ DARK MATTER

$N^{(1)}$ cannot decay because it is forbidden by the kinematics. Since $N^{(1)}$ is neutral, massive, and stable, $N^{(1)}$ is also a dark matter candidate by introducing the right-handed neutrinos. Though abundance produced from decoupled $\gamma^{(1)}$ decay is same, abundance of $N^{(1)}$ dark matter produced from thermal bath is larger than that of $G^{(1)}$. Therefore, when $N^{(1)}$ is dominant component of dark matter, there are additional contribution to the dark matter relic abundance. As total dark matter number density becomes large, the dark matter mass allowed by cosmological observations, $\sim 1/R$, becomes small. Therefore, in order to determine the compactification scale $1/R$, we must evaluate the number density of $N^{(1)}$ dark matter.

Because the number density of the decoupled $\gamma^{(1)}$ has been calculated in previous works [3], we know $N^{(1)}$ number density produced from the decay of that. So, we calculate the $N^{(1)}$ number density produced from the thermal bath. To do this, we must include the thermal effects. In the thermal bath, particle mass receives thermal corrections. For example, the KK Higgs boson $\Phi^{(n)}$ mass is,

$$m_{\Phi^{(n)}}^2(T) = m_{\Phi^{(n)}}^2(T=0) + [a(T) \cdot 3\lambda_h + x(T) \cdot 3y_i^2] \frac{T^2}{12}. \quad (2)$$

Coefficients $a(T)$ and $x(T)$ are counting factor how many KK modes contribute to the correction at the temperature T . Taking account of thermal masses, we calculated the $N^{(1)}$ number density.

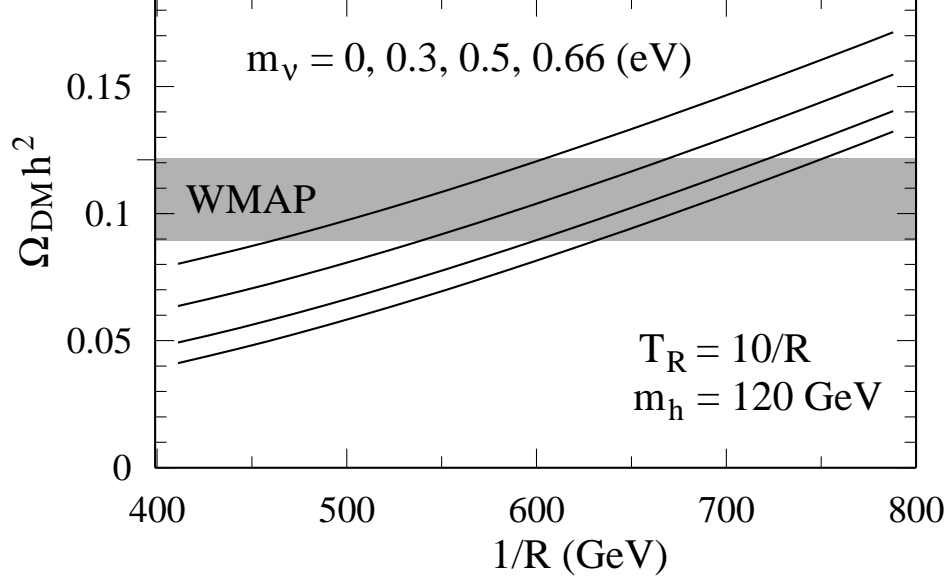


FIGURE 1. The dependence of the abundance on m_ν with fixed reheating temperature $T_R = 10/R$ and $m_h = 120$ GeV. The solid lines are the relic abundance for $m_\nu = 0, 0.3, 0.5, 0.66$ eV from bottom to top. The gray band represents the allowed region from the WMAP observation at the 2σ level

Finally, we show the numerical result. Figure 1 shows the neutrino mass dependence of the abundance. The horizontal axis is the compactification scale $1/R$, and the vertical axis is the dark matter relic abundance. The lines correspond to the result with $m_\nu = 0, 0.3, 0.5, 0.66$ eV from bottom to top. As shown in this figure, for large m_ν , compactification scale can be less than 500 GeV. If compactification scale is less than 500 GeV, in ILC experiment, $n=2$ KK particles can be produced. $n=2$ KK particles are very important for discriminating UED from SUSY at collider experiment.

SUMMARY

We have solved two problems in UED models (absence of the neutrino mass, KK graviton problem) by introducing the right-handed neutrinos. We have shown that by introducing right-handed neutrino, the dark matter is the KK right-handed neutrino $N^{(1)}$, and we have calculated the relic abundance of the $N^{(1)}$ dark matter. In our model, the compactification scale $1/R$ can be less than 500 GeV. This fact has important consequence on the collider physics.

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