Dark Matter as a Mixture of KK Modes in UED Models

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The Lightest Kaluza-Klein Mode as Dark Matter

- Add an extra dimension for SM particles → the effective theory contains Kaluza-Klein (KK) modes.
- Impose $K$-parity $\rightarrow \gamma^{(1)}$ is absolutely stable.
- $\Omega_{\gamma^{(1)}} h^2$ and $\sigma(\gamma^{(1)} N \rightarrow \gamma^{(1)} N)$ can be consistent with current experimental constraints with $m_{\gamma^{(1)}} \sim 500$ GeV.

The Lightest Superpartner as Dark Matter

- Add new particles (superpartners) and interactions according to supersymmetry (breaking).
- Impose $R$-parity $\rightarrow \chi^{0}_1$ is absolutely stable.
- $\Omega_{\chi^{0}_1} h^2$ and $\sigma(\chi^{0}_1 N \rightarrow \chi^{0}_1 N)$ can be consistent with current experimental constraints.
Properties of the LKP

- To have viable dark matter, the size of extra dimension should be within the range of $500 \text{ GeV} \lesssim R^{-1} \lesssim 600 \text{ GeV}$.
  

- One expects a direct detection signal of the order $\sigma_S \sim 10^{-10} \text{ pb} = 10^{-46} \text{ cm}^2$, and current experiments has sensitivity of $\sigma_S \sim 10^{-43} \text{ cm}^2$.
  

- $A^{(1)}_\mu$ may give similar signatures as the LSP of MSSM.
  
The LKP is a viable DM candidate, but ...

- Just as in SM, there needs to be extra structure to accommodate neutrino masses in the minimal model. However, Type-I Seesaw, with $M_\nu \sim 10^{12}$ GeV, will not work, because UED models have low cut-off of about 10 to 100 TeV.

- When extending the gauge group to a Grand Unification Group (GUT), there is a real danger of proton decay.

Is it possible to have low $SU(2)_R$ scale, while explaining small neutrino masses and the stability of proton?
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Yes! Have a 6D theory!
So let us have two extra spatial dimensions!
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Advantages of 6D UED

  Use residual spacetime symmetry, $SO(1, 3) \times U(1)_{45}$, to protect proton decay associated with low $SU(2)_R$ scale.

  $$\Gamma \sim \frac{1}{3^{13}(2\pi)^5(2\pi RM_*)^8} \left( \frac{m_N}{M_*} \right)^{12} m_N,$$

  which can satisfy current bound for $R = 300$ GeV $^{-1}$ and $M > 3$ TeV.

  Use orbifolding to protect neutrino masses even with a low $SU(2)_R$ scale and remove $SU(2)_R$ zero-mode charged gauge bosons (many conventional constraints do not apply).

  $$\lambda \psi^T_L C^{-1} N_L \phi (\chi_R \chi_R)/M_*^5 \sim \lambda \frac{v_w v_R^2}{(\pi RM_*)^3 M_*^2} \psi \psi.$$
More features of the model.

- We have the gauge group
  
  \[ SU(3)_C \times SU(2)_1 \times SU(2)_2 \times U(1)_{B-L} \rightarrow SU(3)_C \times SU(2)_1 \times U(1)_{Y} \rightarrow SU(3)_C \times U(1)_{em} \]

- We predict the existence of an additional neutral gauge boson \( Z' \) and \( W^{(KK)}_R, \pm \). The two main parameters of the model are \( M_{Z'} \) and \( R^{-1} \).

- The orbifolding leads to two KK parities, and two stable particles: \( \gamma^{(1)} \) and \( \nu^{(1)}_R \), the KK modes of the photon and a sterile neutrino.
The total relic density as a function of $M_{Z'}$ and $R^{-1}$.
Direct Detection of KK Neutrino

If $\nu_R^{(1)}$ is indeed part of dark matter, it can be detected by experiments such as CDMS II.
Conclusions

- We have constructed a left-right 6D UED model that based on $SU(2)_L \times SU(2)_R \times U(1)_{B-L}$ group that explains the stability of the proton, and the small neutrino masses.
- The dark matter of the model is an admixture of two particles, the KK partners of the photon and sterile neutrino.
- There is a small allowed range for both the main parameters of the model $R^{-1}$ and $M_{Z'}$. Not only do we predict $M_{Z'} < 1.4$ TeV, the region with abundant KK sterile neutrino can be detected directly with current and upcoming experiments.