A Model for Dark Energy Decay

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We discuss a model of decay of dark energy into dark matter. This model provides a mechanism from field theory to unify the dark sector and alleviate the coincidence problem.

PACS numbers:

I. INTRODUCTION

We propose a model in which dark energy is described by the bosonic real part of the supersymmetric Wess-Zumino potential with a supersymmetry breaking term. This breaking term is of power-law type, adjusted so that we have the cosmological constant value at the metastable minimum.

\[ V(\phi) = 2m\phi - 3\lambda\phi^2 + Q(\phi) \equiv U(\phi) + Q(\phi) \]  

(1)

The equation of state of the scalar field is given by

\[ w_\phi = \frac{p}{\rho} = \frac{1}{2} \phi^2 - V(\phi). \]  

(2)

We can see that the field stationary in the metastable minima can have an associated negative pressure.

We compute here for what mass of the dark energy particle we can have a decay from the metastable vacuum to the stable one during the lifetime of the universe. The field oscillating in the stable vacuum behaves as dark matter, so this provides a mechanism to unify the dark sector and alleviate the coincidence problem.

II. COMPUTATION OF THE DECAY RATE

The decay rate (per unit volume) of a particle described by a potential \( V(\varphi) \), from the metastable to the stable minima, is given, according to the semiclassical method, by

\[ \Gamma = \frac{S_E(\tilde{\varphi}(\rho))}{(2\pi\hbar)^2} e^{-\frac{S_E(\varphi)}{\hbar}} \times \left( \frac{\det(-\delta_{\mu\nu} + V''(\tilde{\varphi}(\rho)))^{-\frac{1}{2}}}{\det(-\delta_{\mu\nu} + V''(\varphi_+))} \right) \]  

(3)

The classical equation of motion of the field \( \varphi \) described by the potential \( V(\varphi) \), is obtained by minimizing the action \( \frac{\delta S_E(\varphi(x))}{\delta \varphi} = 0 \). Due to the symmetry of the problem we have that \( \varphi(x, \tau) \rightarrow \varphi((|x|^2 + \tau^2)^{\frac{1}{2}}) \). Defining \( \rho = (|x|^2 + \tau^2)^{\frac{1}{2}} \) the equation of motion becomes

\[ \frac{\partial^2 \varphi}{\partial \rho^2} + \frac{3}{\rho} \frac{\partial}{\partial \rho} \varphi - V'(\varphi) = 0. \]  

(4)

The calculation of the action in the formula of the decay rate can be separated in three regions: outside the bubble of true vacuum, at the thin wall and inside the bubble of true vacuum,

\[ S_E - S_\Lambda \approx 2\pi^2 \int_0^{R-\Delta} d\rho \rho^3(-\epsilon) + 2\pi^2 \int_{R-\Delta}^{R+\Delta} d\rho \rho^3 \left( \frac{1}{2} \frac{d\tilde{\varphi}}{d\rho} \right)^2 + U \]  

(5)

and inside the bubble,

\[ S_E - S_\Lambda \approx -\frac{7}{12} \pi^2 R^4 \epsilon + 2\pi^2 R^3 S_1 \]  

where we defined \( S_1 = \int_{R-\Delta}^{R+\Delta} d\rho (\frac{1}{2} \frac{d\tilde{\varphi}}{d\rho})^2 + U \).

We get \( R \) minimizing the action: \( \frac{dS}{dR} = 0 \), obtaining \( R = 3S_1/\epsilon \).

Using the approximated equation of motion we get for \( S_1 \) the expression \( S_1 = \sqrt{2\left(\frac{4m^2}{\lambda^2}\right)} \).

Substituting this we can calculate the action

\[ S = 10^{140} \left( \frac{m^{12}}{\lambda^8} \right) \approx 10^{156} m^{12}, \]  

(6)

In our case we can estimate the pre-exponential term as 1 GeV\(^4\). Considering this and substituting \( S \) in the expression \( \Gamma \) we obtain the decay rate (per unit volume). Inverting the expression of the decay rate and calculating the fourth root we obtain the decay time:

\[ \{exp(10^{156} m^{12})\}^{\frac{1}{4}} GeV^{-1}. \]  

Equating this decay time to the age of the universe and calculating the \( \ln \) we obtain \( 10^{156} m^{12} \sim 96, 7 \sim 10^8 \).

Thus, \( m \sim 10^{-13} GeV \).

III. CONCLUSION

We calculated that a particle of dark energy, with mass of the order \( m \sim 10^{-14} GeV \), described by the Wess-Zumino potential with a symmetry breaking term, can decay into dark matter during the age of the universe.