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.

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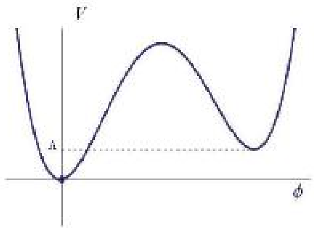
I. INTRODUCTION

We propose a model in which dark energy is described by the bosonic real part of the supersymetric 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.

$$V(\phi) = |2m\phi - 3\lambda\phi^2|^2 + Q(\phi) \equiv U(\phi) + Q(\phi) \qquad (1)$$



The equation of state of the scalar field is given by

$$w_\phi = \frac{p}{\rho} = \frac{\frac{1}{2}\dot{\phi}^2 - V(\phi)}{\frac{1}{2}\dot{\phi}^2 + V(\phi)}. \qquad (2)$$

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 oscilating in the stable vacuum behaves as dark matter, so this provides a mechanism to unify the dark setor 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

$$\frac{\Gamma}{V} = \frac{S_E^2(\tilde{\varphi}(\rho))}{(2\pi\hbar)^2} \times e^{-(\frac{S_E}{\hbar} - \frac{S_\Lambda}{\hbar})} \times \left(\frac{det'(-\partial_\mu\partial_\mu + V''(\tilde{\varphi}(\rho))}{det(-\partial_\mu\partial_\mu + V''(\varphi_+))}\right)^{-\frac{1}{2}} \qquad (3)$$

The classical equation of motion of the field φ 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 $\varphi(\vec{x},\tau) \to \varphi((|\vec{x}|^2 + \tau^2)^{\frac{1}{2}})$. Defining $\rho = (|\vec{x}|^2 + \tau^2)^{\frac{1}{2}}$ the equation of motion becomes

$$\frac{\partial^2\varphi}{\partial\rho^2} + \frac{3}{\rho}\frac{\partial}{\partial\rho}\varphi - V'(\varphi) = 0 \quad . \qquad (4)$$

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,

$$S_E - S_\Lambda \approx 2\pi^2 \int_0^{R-\Delta} d\rho\rho^3(-\epsilon) +$$

$$2\pi^2 \int_{R-\Delta}^{R+\Delta} d\rho\rho^3 \left(\frac{1}{2}\left(\frac{d\tilde{\varphi}}{d\rho}\right)^2 + U\right) + 2\pi^2 \int_{R+\Delta}^{\infty} d\rho\rho^3(0) \; . (5)$$

After integrating we obtain the action $S_E - S_\Lambda = -\frac{1}{2}\pi^2 R^4\epsilon + 2\pi^2 R^3 S_1$ 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 $S_1 = \sqrt{2}\{\frac{4m^3}{27\lambda^2}\}$.

Substituting this we can calculate the action

$$S = 10^{140}\left(\frac{m^{12}}{\lambda^8}\right) \sim 10^{156} m^{12}, \qquad (6)$$

In our case we can estimate the pre-exponential term as 1 GeV^4. Considering this and substituting S in the expression (3) 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 $\frac{10^{156}m^{12}}{4} \sim 96,7 \sim 10^2$. Thus, $m \sim 10^{-13} GeV$.

III. CONCLUSION

We calculated that a particle of dark energy, with mass of the order $m \sim 10^{-13}$GeV, described by the Wess-Zumino potential with a symmetry breaking term, can decay into dark matter during the age of the universe.