A Possible Origin of Dark Energy *

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(Received 8 May 2004)

We discuss the possibility that the existence of dark energy may be due to the presence of a spin zero field $\phi(x)$, either elementary or composite. In the presence of other matter field, the transformation $\phi(x) \to \phi(x) + constant$ can generate a negative pressure, like the cosmological constant. In this picture, our universe can be thought as a very large bag, similar to the much smaller MIT bag model for a single nucleon.

PACS: 98. 90. +s, 12. 39. Ba

We assume the existence of a spin zero field $\phi(x)$, like $\sigma(x)$ in the σ-model, or the Higgs field in the Standard Electro-weak Model, or any composite made of other nonzero spin fields. Let ϕ_{vac} be the vacuum expectation value of $\phi(x)$. Consider an idealized state of a single particle i with an inertia mass m_i. Define the coupling g_i by

$$m_i = g_i\ \phi_{vac}. \tag{1}$$

The transformation

$$\phi(x) \to \phi(x) + c, \tag{2}$$

where c is a constant, changes both ϕ_{vac} and m_i:

$$\phi_{vac} \to \phi_{vac} + c \tag{3}$$

and

$$m_i \to m_i + g_i c. \tag{4}$$

Set $c = -\phi_{vac}$; (3) and (4) become

$$\phi_{vac} \to 0 \tag{5}$$

and

$$m_i \to 0. \tag{6}$$

In any non-linear field theory, we can always construct a composite spin 0 field $\phi(x)$; therefore, there always exists a physical state in which the inertia mass of any particles (excluding ϕ itself) is zero. For a single stable particle state of nonzero m_i, by definition the corresponding state of zero inertia generated by Eq. (6) is an excited state. However, this situation might change for a multi-particle state,[1] and that could be the origin of dark energy (cosmological constant), as we shall discuss.

A concrete example is the following interpretation of the MIT bag Model,[2,3] in which one postulates an energy density function $U(\phi)$ with

$$U(\phi_{vac}) = 0. \tag{7}$$

Under the transformation (5) the corresponding change in $U(\phi)$ is

$$U(\phi_{vac}) = 0 \to U(0) \equiv p. \tag{8}$$

Thus, the energy E of a bag of radius r, containing N quarks, with the expectation value of ϕ being zero inside the bag and ϕ_{vac} outside is given by

$$E - \frac{4\pi}{3} r^3 p = N \frac{2.0428}{r}, \tag{9}$$

in which we have to *subtract* an amount

$$\frac{4\pi}{3} r^3 p \tag{10}$$

from E in order to equate the resultant with the matter energy of quarks. Let ρ_E and ρ_M be the corresponding energy densities defined by

$$\rho_E \equiv E\Big(\frac{4\pi}{3} r^3\Big)^{-1} \tag{11}$$

and

$$\rho_M \equiv \Big(N \frac{2.0428}{r}\Big)\Big(\frac{4\pi}{3} r^3\Big)^{-1}. \tag{12}$$

Setting

$$\frac{\partial E}{\partial r} = 0, \tag{13}$$

we find

$$\frac{p}{\rho_M} = \frac{1}{3} \quad \text{and} \quad \frac{p}{\rho_E} = \frac{1}{4}. \tag{14}$$

We now assume our universe to be a large bag of radius R; its energy $\mathcal{E}$ can be approximately described by a similar formula (9), with p replaced by the energy density ρ_Λ due to the cosmological constant:

$$\mathcal{E} - \frac{4\pi}{3} R^3 \rho_\Lambda \cong \mathcal{M}/R, \tag{15}$$

* Supported in part by the U.S. Department of Energy under Grant No DE-FG02-92ER-40699, and the RIKEN-BNL Research Center, Brookhaven National Laboratory

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where $\mathcal{M}$ is a constant and $\mathcal{M}/R$ representing the matter energy, assumed to be dominated by its long wave length component. Setting $\partial\mathcal{E}/\partial R = 0$, we find the total energy density

$$\rho_{\mathcal{E}} = \mathcal{E}\left(\frac{4\pi}{3}R^3\right)^{-1} \tag{16}$$

is related to ρ_Λ by

$$\frac{\rho_\Lambda}{\rho_{\mathcal{E}}} \cong \frac{1}{4}. \tag{17}$$

Likewise, defining the matter-energy density of the universe by

$$\rho_{\mathcal{M}} \equiv \frac{\mathcal{M}}{R}\left(\frac{4\pi}{3}R^3\right)^{-1}, \tag{18}$$

we derive

$$\frac{\rho_\Lambda}{\rho_{\mathcal{M}}} \cong \frac{1}{3}. \tag{19}$$

Taking the present value of ρ_Λ to be[4]

$$\rho_\Lambda \cong 3 \times 10^{-6}\,\mathrm{GeV/cm}^3, \tag{20}$$

we find

$$\rho_{\mathcal{M}} \cong 9 \times 10^{-6}\,\mathrm{GeV/cm}^3 \tag{21}$$

and

$$\rho_{\mathcal{E}} \cong 1.2 \times 10^{-5}\,\mathrm{GeV/cm}^3; \tag{22}$$

both are of the same order of magnitude as the critical density ρ_c of the universe. Considering our oversimplification of neglecting the non-Euclidean geometrical effect, the shorter wavelength contribution of the matter energy and the dynamical effect of our universe expansion, the above order of magnitude agreement is very encouraging to the suggestion that the negative pressure postulated by Poincaré,[5] Dirac,[6] MIT-bag[2] and the cosmological constant[7] can all be attributed to the existence of an effective scalar field which is kinematically connected to the inertia of all matter.

The pressure of the MIT bag is exerted by the physical space outside the bag; likewise, the negative pressure described by the cosmological constant may also be due to the physical space outside the horizon of our universe. Through relativistic heavy ion collisions (RHIC), we can change the bag-pressure p and the quark energy density ρ_M; likewise, by examining carefully the dynamical change of matter energy within our universe, we may also gain insight to the universe that lies outside our horizon. In this picture, most likely our universe is not a self-contained system, and the "cosmological constant" may actually be a dynamical variable, related to $\phi(x)$. An analysis of these interesting possibilities will be given in a separate publication.

The author wishes to thank Miklos Gyulassy for discussions and Charles Baltay for a private communication.

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