COSMIC REPULSION

M. Novello
Centro Brasileiro de Pesquisas Físicas/CNPq
Av. Wenceslau Braz 71-Fundos-Cep 22.290-Rio de Janeiro-R.J.

ABSTRACT

I show that ordinary photons and neutrinos, obeying ordinary laws of physics, can generate repulsive gravitational forces, under especial circunstances.

I propose to interpret the primordial Big-Bang, extremelly hot stage of the Universe, as an example in the action of my mechanism of creating a cosmic repulsion.

Gravity is a pure attractive force. This seems a well established fact of our experience. Nevertheless, it may exist certain especial circunstances in which usual radiation(photons, neutrinos) may generate a repulsive gravitational field. We intend to prove such statement by giving here a model which is an example of this. Let me stress from the beginning that I do not propose new laws of physics to appear in cosmic scales. The mechanism which I will describe is constructed based only on the known laws of physics, which we believe today represents the best description of the nature.

The theory is described by a Lagrangian L for a scalar field $\phi(x)$ non-minimally coupled to gravity and with a quartic self-interaction; a metric field $g_{\mu\nu}(x)$; and radiation (photons , neutrinos); given by:

$$L = \sqrt{-g}\ \{\partial_\mu \overset{*}{\phi} \partial_\nu \phi g^{\mu\nu} - m^2\phi^2 + \sigma\phi^4 - \frac{1}{6} R\phi^2 + \frac{1}{\kappa} R + 2\Lambda + L_r\} \qquad (1)$$

This Lagrangian is invariant under the gauge transformation $\phi \to e^{i\alpha}\phi$, $\phi^* \to e^{-i\alpha}\phi^*$ for arbitrary constant phase α. The term $\sigma\phi^4$ is introduced in order to generate a breaking of this symmetry for the constant solution $\phi = \phi_0$ = constant.

Although we have introduced a cosmological positive term in our theory, and thus admiting a repulsive force to be manifested in cosmical scale, it is a well-known fact that the value of the energy associated to such Λ term is very small[1] and thus it has not an important role in establishing the global features of the present and past of our Universe.

The importance of such Λ term comes from an indirect way. As we will see next, such Λ induces the breaking of symmetry of the scalar field and this will provoke that the gravitational field created by photons and neutrinos is repulsive.

L_r is the Lagrangian of a gas constituted by photons and neutrinos; κ is the Einstein constant which will be set equal to 1, the velocity of ligth is also made equal to 1.

The term $-\frac{1}{6}R\phi^2$ is the usual non-minimal coupling of the scalar field ϕ with gravity.

The equations of motion obtained from (1) are:

$$\Box\phi + \left(m^2 - \frac{2}{3}\Lambda\right)\phi + \left(\frac{1}{6}m^2 - 2\sigma\right)\phi^3 = 0 \qquad (2)$$

$$\left(1 - \frac{1}{6}\phi^2\right)\left(R_{\mu\nu} - \frac{1}{2}Rg_{\mu\nu}\right) = -\phi_{|\mu}\phi_{|\nu} + \frac{1}{2}g_{\mu\nu}\left(\phi_{|\lambda}\phi_{|\varepsilon}g^{\lambda\varepsilon} - m^2\phi^2 + \sigma\phi^4\right) -$$

$$-\frac{1}{6}\Box\phi^2 g_{\mu\nu} + \frac{1}{6}(\phi^2)_{|\mu||\nu} + \Lambda g_{\mu\nu} - T_{\mu\nu} \qquad (3)$$

in which $T_{\mu\nu}$ is the energy-momentum tensor corresponding to L_r. In obtaining equation (2) we have used the value of the curvature R, resulting by taking the trace of (3), as being equal to

$$R = m^2\phi^2 - 4\Lambda .$$

It is not difficult [(2)] to show that the existence of a non-null Λ induces a breaking of symmetry of the ϕ field, that is a non-vanishing solution $\phi = \phi_0 =$ constant, which minimizes the energy [(3)] of the scalar field given by:

$$E(\phi) = \frac{3m^2\phi^2 - 3\sigma\phi^4 - 6\Lambda}{6 - \phi^2}$$

The constant ϕ_0 is equal to $\pm\frac{2\sqrt{\Lambda}}{m}$.

It seems worth to remark that the existence of a singularity for the energy in the point $\phi^2 = 6$ separates the constant solutions $\pm\,\phi_0$ in two uncomunicating regions[2].

In order to the value ϕ_0 to be an extremum (minimum) of $E(\phi)$ we are obliged to impose that the value of the constant σ is related to the cosmological constant through the relation $\sigma = \frac{m^4}{8\Lambda}$.

Now, suppose the system is in the state ϕ_0 (the argument goes in the same way if the system is in the state $\phi = -\phi_0$).

Then, the equation for the metric tensor $g_{\mu\nu}$ reduces to

$$R_{\mu\nu} = \frac{3m^2\ \Lambda}{2\Lambda - 3m^2}\ g_{\mu\nu} - \frac{3m^2}{3m^2 - 2\Lambda}\ T_{\mu\nu} \qquad (4)$$

Remark that if the energy momentum tensor is not trace-free the non-trivial constant solution $\phi = \phi_0$ does not exist.

From equation (4) we conclude that the effect of a constant solution $\phi = \phi_0$ is to renormalize the constants Λ and κ, to the values:

$$\Lambda_{eff} = \frac{3m^2\ \Lambda}{2\Lambda - 3m^2}$$

$$k_{ren} = \frac{3k\ m^2}{3m^2 - 2\Lambda k} = \frac{3m^2}{3m^2 - 2\Lambda}$$

(in which we used the value $k = 1$).

Thus, if the mass of the scalar field is such that $3m^2 - 2\Lambda < 0$, the renormalized effective Einstein constant becomes negative. We then conclude the important fact that the gravitational field created by the radiation (photons, neutrinos) is repulsive in the fundamental state ϕ_0 of the scalar field.

The value $m^2 = \frac{2}{3} \Lambda$ is critical and a transition of phase occurs at this point, once gravity changes sign when the mass of the scalar field passes through that value.

Let me stress the fact that this mechanism does not change any property of photons and neutrinos but only create a medium in which the gravitational field generated by them becomes repulsive.

Let us apply such result to our actual Universe. We know that at the early stages of the Cosmos the dominating energy term comes from the radiation (photons, neutrinos).

Thus, this satisfy one of the conditions of my mechanism. If there is in nature a scalar field, the dynamics of which is governed by the above Lagrangian, and such that the two following conditions are satisfied:

(i) The mass of the scalar field is very small, and we have

$$m^2 < \frac{2}{3} \Lambda$$

(that is, $m \lesssim 10^{-34}$ Mev)

(ii)The system ($\phi, g_{\mu\nu}$, photons, neutrinos) exist in the fundamental state

$$\phi^2 = \phi_0{}^2 = \frac{4\Lambda}{m^2} ,$$

Then, in this situation photons and neutrinos generate a repulsive gravitational field.

I suggest that this mechanism has an intimate connection with the primordial explosion and may be the key to understand the present expanding era of our Universe.

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References

(1) Indeed, we have $\Lambda_c \equiv \Lambda k \lesssim 10^{-55}$ cm^{-2} which is equivalent to an energy of the order of 10^{-34} Mev.

(2) M. Novello - Uncommunicating Vacua generated by Spontaneous Breaking of Symmetry in a curved space time - (to be published)- 1980.

(3) I follow Callan et al[4] and define the energy of the field in the following way. We set the equation of motion for the metric tensor in the form:

$$R^{\mu}{}_{\nu} - \frac{1}{2} R \delta^{\mu}{}_{\mu} = -k \ E^{\mu}{}_{\nu}$$

The energy of the field is $E^{0}{}_{0}$

Remark that in $E^{0}{}_{0}(\phi) \equiv E(\phi)$ there appears a term which contains the cosmological constant. We include this term in $E(\phi)$ once the contribution of the cosmical energy depends uniquely on the ϕ - field.

(4) C. Callan Jr - S. Coleman - R. Jackiw - Ann. Phys. 59 (1970) 42.