The vacuum energy excitations due to gravitational field as a possible candidate of dark matter in galaxies

V. Majerník
Institute of Mathematics, Slovak Academy of Sciences, SK-814 73 Bratislava, Štefánikova 47, Slovak Republic
and
Department of Theoretical Physics
Palacký University
Tř. 17. listopadu 50
772 07 Olomouc, Czech Republic

Abstract
In this Letter we point out to the possibility that the cloud of the vacuum energy excitations in gravitation fields surrounding galaxies forms a component of dark matter. These clouds of the vacuum energy excitations interact gravitationally with the baryonic matter of galaxies changing their dynamical and kinematical properties. In four model galaxies we show that the dynamic changes due to the vacuum energy excitations of these galaxies are comparable with data. This shows that vacuum energy excitations created in the gravitation field of galaxies may be considered as one of the candidates of dark matter

1 Introduction
The recent astronomical observations [2] [3] [4] give increasing support for the 'cosmical concordance' model in which the universe is flat and consists of a mixture of a small part of baryonic matter about one third non-relativistic dark matter (DM) and two thirds of a smooth component, called dark energy (DE). Although the accelerate expansion of the universe appears to gain further ground, the substratum behind of the dark energy remains as elusive as ever [8].

In the literature, DE is theoretically modelled by many ways, e.g. as (i) a very small cosmological constant (e.g.[9]) (ii) quintessence (e.g.[10]) (iii) Chaplygin gas (e.g.[11]) (iv) tachyon field (e.g.[12]) (v) interacting quintessence (e.g.[13]) non-minimally coupled
Q (e.g.,[14]), quaternionic field (e.g.,[15]), etc. It is unknown which of the said models will finally emerge as the successful one.

Another fundamental problem being faced to cosmology is that of the nature of DM, which is supposed to exist because of dynamical astronomical measurement but we have not yet detected it. Astronomers found that one third of the universe’s mass is made up of unknown matter that is invisible to telescopes but have gravitational effects on the baryonic matter [16]. Lacking evidence of direct detection, the presence, nature, and quantity of DM must be inferred from the kinetic and distribution properties of baryons. In the literature, many sophisticated candidates of DM have been proposed which can be divided up into two categories. Some authors proposed that DM consists of some kind of matter substance, e.g. of the massive particles (WIMPs) which stems from extensions to the standard model of particle physics, such as supersymmetry and extra-dimensional theory. Other assume that DM represents the relics of primordial black holes (see, e.g.,[17]). On the other side, several authors try explain the kinematic effects assigned to DM by modifying of Newton’s law of gravitation (see, e.g. [18]).

Instead of looking for further sophisticated explanations of the nature of DM we will, in what follows, attempt to show that the same mechanism of the creation of matter in the cosmic quaternionic field [5] can also be applied to the matter creation in the weak gravitational field surrounding galaxies. Recently, the field energy density of the so-called cosmical quaternionic field has been interpreted as the vacuum energy density and set equal to the cosmological constant [1]. It has be shown that in this field, due the action of a force field on the virtual particles, an spontaneous creation of matter occurs either in the form of real particles or the vacuum energy excitations.

In this Letter we apply a similar mechanism for matter creation also to gravitational field. We shown that due to the weakness of the galactic gravitational field only clouds of the vacuum energy excitations are created which interact gravitationally with the baryonic matter of galaxies changing their dynamical and kinetical properties. Hence, we attempt to interpret these clouds as a kind of DM occurring in the gravitational field of galaxies.

The Letter is organized as follows. In Section 2 we describe the mechanism of the creation of the vacuum energy excitations in the weak gravitational field of galaxies. Here, we present some model galaxies with the clouds of the vacuum excitations and show that their dynamical parameters assume the plausible values. In Sections we conclude that the vacuum energy excitations due to gravitation field of galaxies might fulfil the requirements asked from DM.
2 The creation of vacuum energy excitations in the weak gravitational field

Motivated by the desire to find a possible candidate of the dark mass we are aspirated by the matter creation in the cosmic quaternionic field [5]. In [15] we have described a new mechanism of the creation of real particles from the virtual ones in the presence of the cosmic quaternionic field. It is well-known that in absence of a force field in vacuum the virtual particles are created and after a time interval $\Delta t = h/(c^2 m_v)$ again annihilated without being observed. The basic idea here is that the virtual particles during the time interval $\Delta t$ behave so as being real particles and due to the interaction with a force field they can gain a certain amount of energy. Taking the consistent theory of the quantum vacuum we use for the estimation of the energy gains of virtual particles, during their lifetime, the following simple heuristic arguments. We start with fundamental equations of classical and quantum mechanics

$$\Delta E = F \Delta x$$  \hspace{1cm} (1)

and

$$\Delta p \Delta x \geq h,$$ \hspace{1cm} (2)

where $\Delta p$ is the uncertainty in the momentum of a virtual particle, $\Delta x$ is the uncertainty in its displacement and $F$ is the force acting on it. Combining Eqs. (1) and (2) and taking for $\Delta p$ the rest momentum of a virtual particle $m_v c$, we get for the gained energy the formula

$$\Delta E \approx \frac{F h}{m_v c}.$$ \hspace{1cm} (3)

For different force fields $\Delta E$ assumes different values. E.g. if we insert into Eq.(3) the force exerting on the mass body in the cosmic quaternionic field described in [15] then $\Delta E$, gained from the ambient field, during lifetime of virtual particles, is

$$F \Delta x = \Delta E \approx \sqrt{G} \Phi(t) \frac{h}{c} \approx \frac{h}{(t + t_0)},$$

where $\Phi(t)$ is the intensity of the cosmic quaternionic field. If this intensity is sufficiently large, e.i. if $t$ and $t_0$ are short enough then it can separate the virtual particles creating the real ones. This happens in the vicinity of the Bing Bang [1].

If one writes the Newton law of gravitation in the symmetrical form

$$F = \frac{(q_g)^2}{r^2} = \frac{\sqrt{Gm}}{r^2},$$

then the quantity $q_g = \sqrt{Gm}$ represents the gravitational charge of the mass $m$ [7] [6]. Next we will use gravitational charges when formulating the common gravitation
equations. As well-known the force acting on the mass $m_v$ in gravitation field is given as

$$F_g = \sqrt{Gm_v}E_g,$$

where $E_g = \nabla \phi$ is the 'intensity' of gravitational field given by the gravitational potential $\phi$ and $\sqrt{Gm_v}$ is the gravitational charge of a virtual particle. Taking for $\Delta p$ the rest momentum of $m_v$, i.e. putting $\Delta x = h/m_v c$, and inserting Eq.(2) into Eq.(1) we obtain for $\Delta E_g$ the following expression

$$\Delta E_g = F_g \Delta x = \sqrt{Gm_v}E_g \Delta x = \frac{\sqrt{G}hE_g}{c} = \frac{\sqrt{G}hE_g}{c}.$$

The corresponding mass is

$$\Delta m_g = \frac{Gh}{c^3} \frac{E_g}{\sqrt{G}} = \frac{L_p^2}{\sqrt{G}}E_g,$$

(4)

The intensity of the gravitation field of galaxies $E_g$ and in consequence also the gained energy $\Delta E_g$ is relatively small creating only cloud of the vacuum energy excitations which interact gravitationally with the baryonic matter. The cloud of these energy excitations surrounding a galaxy behave so as a sort of DM which we will call the excitation matter.

Next, we suppose that the mass density of the excitation matter is proportional to $\Delta m_g$

$$\rho_e = \kappa \Delta m_g = \frac{\rho_p L_p^2 \Delta m_g}{\sqrt{G}},$$

where $L_p = (Gh/c^3)^{1/2} = 4.10^{-35}$ is the Plank length. Here, $\rho_p = N/l^3$ where $N$ is number of energy excitations in the volume $l^3$ and $\kappa = \rho_p L_p^2/\sqrt{G}$. Since the expression $\rho_e L_p^2$ has the dimension $[m^{-1}]$ we set next

$$\rho_p L_p^2 = \frac{1}{a},$$

where $a$ is an unknown free constant with the dimension $[m]$. Hence, the density of the excitation matter becomes

$$\rho_e(\vec{r}) = \frac{\rho_p L_p^2}{\sqrt{G}}E_g = \frac{E_g}{a\sqrt{G}},$$

The gravitation intensity $\vec{E}_g(\vec{r})$ of the gravitational field is linked with the mass density by the well-known equation

$$\nabla \vec{E}_g(\vec{r}) = \sqrt{G}\rho(\vec{r}),$$

(5)

where $\rho(\vec{r})$ is mass density as a function of $\vec{r}$. Since the excitation DM of a galaxy is an additional source of its gravitation field Eq.(5) becomes

$$\nabla \vec{E}_g(\vec{r}) = \sqrt{G}\left(\rho_b(\vec{r}) + \frac{E_g(\vec{r})}{a\sqrt{G}}\right),$$

(6)
where $\rho_b(\vec{r})$ and $E_g(\vec{r})/(a\sqrt{G})$ is the density of the baryonic and excitation matter, respectively. Eq.(6) is the basic equation for the calculation of the density of the excitation matter surrounding galaxies. Note that to determine this density we only need the density of its baryonic matter of galaxies.

The total baryonic and excitation matter $M_b$ and $M_e$ of a galaxy having the volume $V$ is given as

$$M_b = \int_V \rho_b(\vec{r}) d\vec{r}$$

and

$$M_e = \int_V \frac{E_g(\vec{r})}{a\sqrt{G}} d\vec{r},$$

respectively.

Next, we confine ourselves to the spherically symmetrical case, i.e. we suppose that the mass density of galaxy is dependent only on $r$. Then Eq. (6) become a simple linear differential equation

$$\frac{dE_g(r)}{dr} + \frac{2E_g(r)}{r} = \sqrt{G} \left( \rho_b(r) + \frac{E_g(r)}{a\sqrt{G}} \right)$$

whose general solution has the form

$$E_g(r) = \exp \left[ \int (2/r - 1/a) dr \right] \left[ \int \rho_b(r) \exp \left[ \int (2/r - 1/a) dr \right] dr + C \right].$$

Given the density of the baryonic matter and the constant $a$ both $M_g$ and $M_e$ can be calculated by means of Eq.(7). For the radius of a typical galaxy we take $R = 10^{21} m$. Since $a$ is a free constant we set it, for the sake of simplicity, equal to $R$, i.e. $a = R = 10^{21} m$, and with such chosen $a$ we calculate the baryonic and excitation masses of galaxies. Later we will attempt to justify this value.

Let us, as an example, considered a galaxy with the density of the bradyonic matter $\rho'(r)$ given by the formula

$$\rho'_g(r) = A \left( \frac{2}{r} - \frac{1}{a} \right), \quad r \leq 2a$$

whose radius and the constant $a$ are equal to $10^{21} m$ and its total bradyonic mass is $10^{42} kg$. The solution of Eq.(7) for $\rho'_g(r)$ is simple $\rho_e = A$. By integrating $\rho_g$ and $\rho_e$ over the galaxy volume we obtain for its total baryonic and excitation masses

$$M_g = \int_0^{R=a} \left( \frac{2}{r} - \frac{1}{a} \right) 4\pi r^2 dr = \frac{A16a^2\pi}{3}$$

and

$$M_e = \int_0^{R=a} Ar^2 4\pi dr = \frac{A32a^2\pi}{3},$$
respectively. The ratio of the total baryonic mass of a galaxy to its total excitation mass, denoted by the symbol $\alpha$, is given as

$$\frac{M_e}{M_g} = \alpha.$$ 

For $\rho'(r)$ it becomes equal to 2. The total mass of a galaxy is given as the sum of both mass $M_g$ and $M_e$

$$M_t = M_g + M_e$$

In the following Table we present the characteristic quantities of galaxies, i.e. $M_g$, $M_e$ and $\alpha$, with the different densities of bradyonic matter presented in the first row the following Table

| $\rho_b(r)$ | $n=1$ | $n=2$ | $n=3$ | $n=4$ |
|-------------|-------|-------|-------|-------|
| $E_g(r)$    | $A(2/r - 1/a)$ | $A(1/r - 1/a)$ | $A(1/r^2 - 1/a^2)$ | $A(2/r^2 - 1/a^2)$ |
| $M_g$       | $(16a^2A\pi)/3$ | $(4\pi a^2A)/6$ | $(8aA4\pi)/3$ | $(16/3)\sqrt{2}A\pi$ |
| $M_e$       | $(32a^2A\pi)/3$ | $(11a^2A4\pi)/6$ | $(28aA\pi)/3$ | $8aA\pi + (8/3)\sqrt{2}aA\pi$ |
| $M_e/M_g$   | 2     | 11    | 3.5   | 4.9   |
| $M_g + M_e$ | 3     | 12    | 4.5   | 5.9   |

### 3 Consequences

It is generally believed that most of energy and matter in our universe is of unknown nature to us, therefore the to explain the nature of DM is one of the major fundamental challenges of present astrophysics. In this Letter we have attempted to show that the cloud of the vacuum energy excitations in gravitation field of galaxies might represent a form of DE.

From what has been said so far the following points are worth of mentioning

(i) There exist a plausible mechanism for the creation of the vacuum energy excitations in the gravitation fields surrounding galaxies.

(ii) The density of the excitation matter is proportional to the intensity of the corresponding gravitation field.

(iii) The constant $a$ depending on the number of energy excitations in a unit volume, although very important for determining of the excitation matter, cannot be determined exactly because of lacking the consistent theory quantum vacuum.

(iv) When setting $a = 10^{21} m$, the total excitation mass of a galaxy with the density of the bradyonic matter given in Table is always larger than its total baryonic mass.

(v) If we take for the volume, where an excitation in vacuum occurs, the radius of nucleon
\[ r_n \approx 10^{-15} - 10^{-16} m \] then the number of excitations in \( [m^3] \) becomes \( 10^{45} - 10^{48} \) which is equal approximately the value \( a = 1/\rho_p L_p^2 \approx 10^{24} - 10^{21} m \).

(vi) The excitation DM can be characterized as a cloud of the vacuum energy excitations created in the gravitation field, neutral, undetectable by elm interaction with negligible cross-section with bradyonic matter. Hence, the cloud of the vacuum energy excitations might represent a possible candidate for DM.

The aim of this short Letter was only to outline the basic idea of a possible new form of dark matter. Many important issues remained open and may be eventually solved by future consistent theory of quantum gravity and using a more realistic model of galaxies. The relatively good fit for the amount of the excitation DM surrounding galaxies may be acceptable also from the purely phenomenological point of view.

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