The gravitational polarization of the quantum vacuum as a possible solution to the dark energy problem

Dragan Slavkov Hajdukovic

Institute of Physics, Astrophysics and Cosmology

Cetinje, Montenegro

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Abstract

- Our study is based on the working hypothesis that by their nature quantum vacuum fluctuations are virtual gravitational dipoles. This hypothesis is the simplest solution to the cosmological constant problem and opens the possibility to consider the known Standard Model matter (i.e. matter made from quarks and leptons interacting through the exchange of gauge bosons) as the only content of the Universe. If this hypothesis is correct, each galactic halo of hypothetical dark matter must be replaced by the halo of the quantum vacuum polarized by the immersed baryonic matter. Totality of all these halos is a cosmological fluid which during expansion of the Universe converts from a fluid with negative pressure (allowing an accelerated expansion of the Universe) to a fluid with zero pressure (physically it means the end of the accelerated expansion). This for the first time suggests, at least mathematically, quantum vacuum may explain both phenomena; phenomena usually attributed to dark matter and phenomena usually attributed to dark energy.

The cosmological constant problem An intriguing „coincedence”

- **Gravity is “excluded” from the Standard Model of Particles and Fields**; it is not a subject of study and a Standard Model physicist cannot tell what are the gravitational properties of the quantum vacuum.
- What the Standard Model physicist can do is to calculate **the mass-energy density of the quantum vacuum**. The result of calculations is very simple:

$$\rho_{ve} = \frac{1}{16\pi^2}\left(\frac{c}{\hbar}\right)^3 M_c^4 \equiv \frac{\pi}{2}\frac{M_c}{\lambda_{Mc}^3}$$

For instance, for vacuum energy density in quantum chromodynamics the cut-off mass M_c is roughly mass of a pion and the density is about $5.6\text{x}10^{13}\text{kg/m}^3$.

- **The cosmological constant problem**: Of course you have right to think that vacuum energy density and vacuum gravitational charge density are the same thing, but in that case each cubic meter of the quantum vacuum behaves as if it has the mass of nearly 10^{14}kg/m^3 !

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- The cosmological constant problem (a nice name for the worst prediction in history of physics) prevents the use of the Standard Model vacuum as the content of the Universe.
- It is unjust to blame the Standard Model for this mistake; what they estimated is the vacuum energy density, nothing more than that. The cosmological constant problem might be a hint that vacuum energy density and vacuum gravitational charge density are radically different.
- **A mathematical game**

$$\rho_{ve}^{*} = \frac{\pi}{2} \frac{M_c}{\lambda_{Mc}^{3}} \frac{\lambda_{Mc}}{R}$$

The above result is the result from the previous Slide multiplied by λ_{Mc}/R

(R is the cosmological scale factor) what is a necessary correction if instead of gravitational monopoles there are gravitational dipoles. Calculate it! Instead of nearly $10^{14}kg/m^3$ you will get about $10^{-27}kg/m^3$ in agreement with observations. **It might be a numerical miracle but it might be the true nature of quantum vacuum as well.**

The working hypotheses

(1) Quantum vacuum fluctuations are virtual gravitational dipoles*

*(2) The Standard Model matter** and quantum vacuum are **the only** matter-energy content of the Universe*

* A virtual gravitational dipole is defined in analogy with an electric dipole: two gravitational charges of the opposite sign at a distance smaller than the corresponding reduced Compton wavelength

** Standard Model Matter means matter made from quarks and leptons interacting through the exchange of gauge bosons

Important Note: We do not modify the Standard Model of Particles and Fields and its understanding of quantum vacuum! Gravity is not included in the Standard Model.

Reminder: Quantum vacuum in QED
an "ocean" of virtual electric dipoles

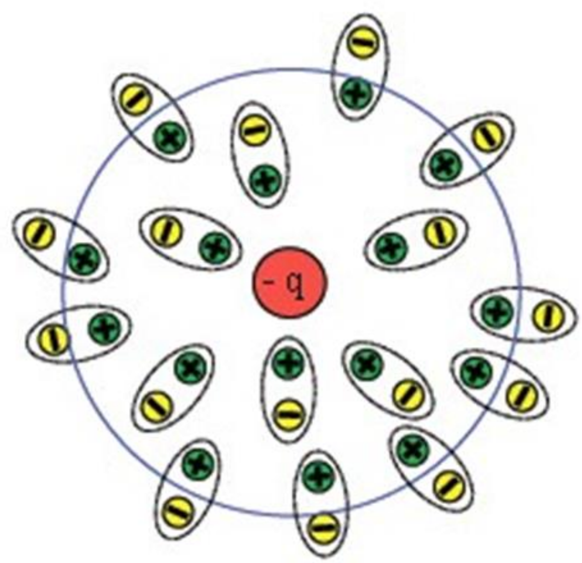
In QED quantum vacuum can be considered as an omnipresent "ocean" of virtual electric dipoles (for instance electron-positron pairs) with random orientation; because of the random orientation, the electric charge density of the quantum vacuum is zero.

Reminder: Quantum vacuum in QED
a **halo** of the polarized quantum vacuum

The random orientation of virtual dipoles can be perturbed by a very strong electric field

Example: The electric field of an electron at the distance of its Compton Wavelength is of the order of **10^{14} V/m**. Such a strong field perturbs the random orientation.

Electron "immersed" in the quantum vacuum produces around itself **a halo** of non-random oriented virtual electric dipoles, i.e. **a halo of the polarized quantum vacuum**.



The halo screens the "bare" charge of an electron; what we measure is the effective electric charge which *decreases* with distance!

Major consequences of the working hypothesis

- A quantum vacuum fluctuation is a system with zero gravitational charge, but a non-zero gravitational dipole moment

$$\left|\vec{p}_g\right| < \frac{\hbar}{c}$$

- **Gravitational polarization density** $\vec{P}_g$ i.e. the gravitational dipole moment per unit volume, *may be attributed to the quantum vacuum*.

Random orientation of dipoles

$$\vec{P}_g = 0$$

Saturation*

the gravitational polarization density has the maximal magnitude

$$P_{g\,\max} = \frac{A}{\lambda_m^3}\frac{\hbar}{c}$$

*Saturation is the case when as the consequence of a sufficiently strong external gravitational field, all dipoles are aligned with the field

The effective gravitational charge

- In a dielectric medium the spatial variation of the electric polarization generates a charge density known as the bound charge density. In an analogous way, the gravitational polarization of the quantum vacuum should result in

the effective gravitational charge density of the physical vacuum

$$\rho_{qv} = -\nabla \cdot \vec{P}_g$$

Immediate questions

- **Can the effective gravitational charge density** of the quantum vacuum in galaxies and clusters of galaxies **explain phenomena usually attributed to dark matter**.
- **Can quantum vacuum as cosmological fluid of the effective gravitational charge explain phenomena usually attributed to dark energy**.
- What might be **effects of conversion of quantum vacuum fluctuations into real particles** in extremely strong gravitational field.

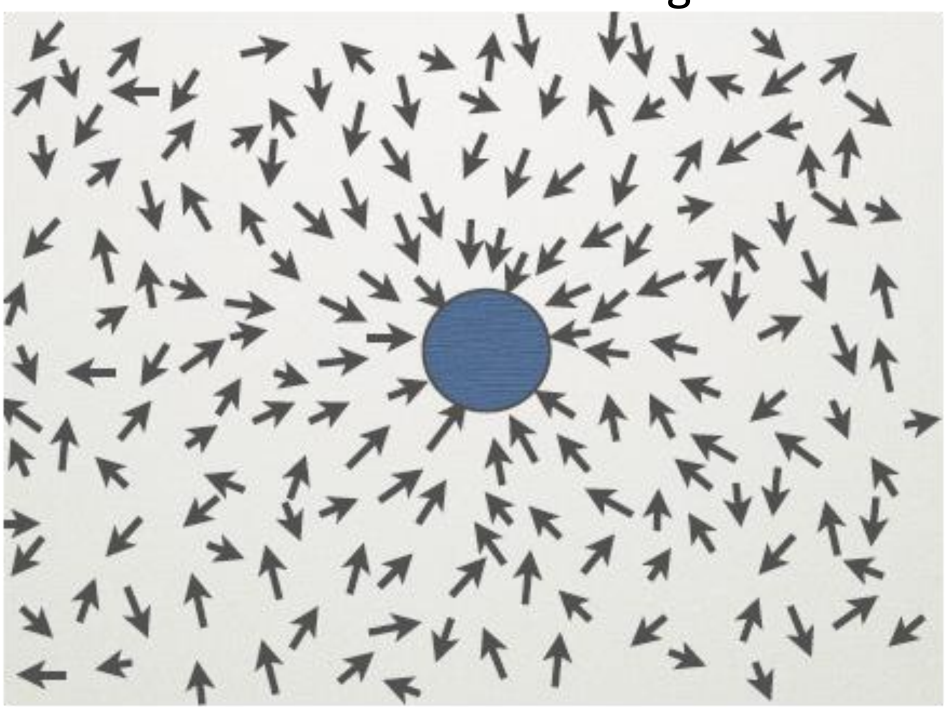
According to the working hypothesis quantum vacuum is an "ocean" of virtual gravitational dipoles

Randomly oriented gravitational dipoles (without an immersed body)

The gravitational charge density of the quantum vacuum is zero, what is **the simplest solution to the cosmological constant problem**. A tiny, **effective gravitational charge density** might appear as the result of the immersed Standard Model matter

Halo of non-random oriented dipoles around a body (or a galaxy)

Random **orientation** of virtual dipoles **might be broken** by the immersed Standard Model matter. Massive bodies (stars, black holes …) but also multi-body systems as galaxies are surrounded by an invisible ***halo of the gravitationally polarized quantum vacuum*** (i.e. a region of *non-random* orientation of virtual gravitational dipoles)



The halo of the polarized quantum vacuum acts as an **effective gravitational charge**

This halo is well mimicked by the artificial stuff called dark matter! I joke, but it might be true. Gravitational polarization of the quantum vacuum might be the true nature of what we call dark matter.

Dark matter as the local effect of the gravitational polarization of the quantum vacuum

- A gravitational polarization density $\vec{P}_g$ (i.e. the gravitational dipole moment per unit volume) may be attributed to the quantum vacuum.
- The spatial variation of $\vec{P}_g$, generates a gravitational bound charge density of the quantum vacuum

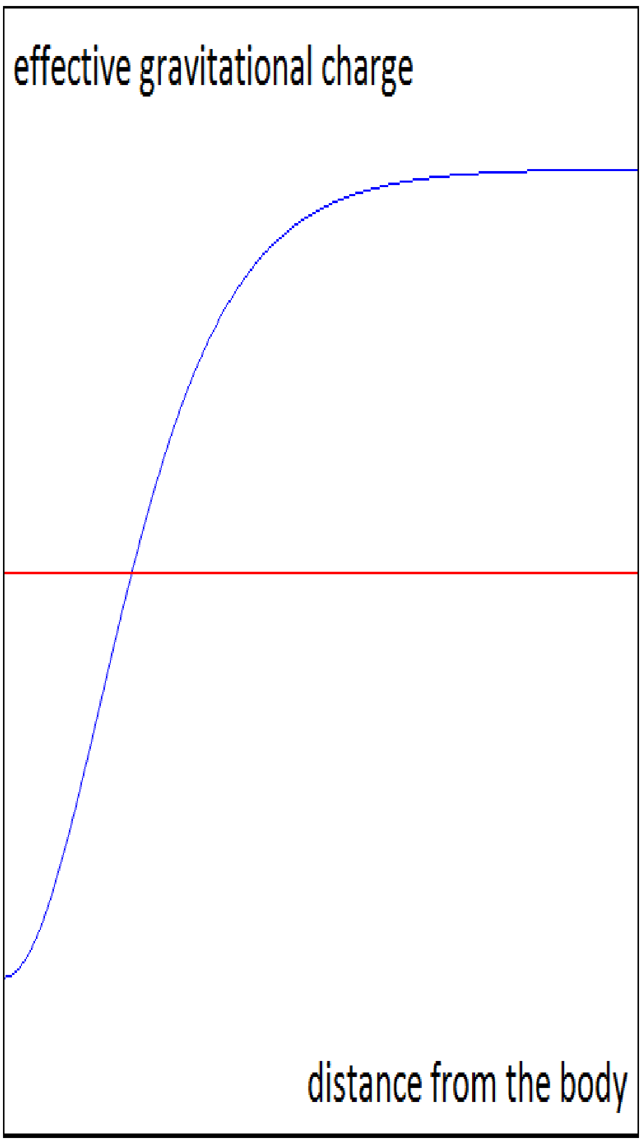
$$\rho_{qv} = -\nabla \cdot \vec{P}_g$$

- In the simplest case of spherical symmetry

$$\rho_{qv}(r) = \frac{1}{r^2}\frac{d}{dr}\left(r^2 P_g(r)\right); \; P_g(r) \equiv \left|\vec{P}_g(r)\right|$$

- Preliminary calculations lead to the intriguing agreement with empirical results for galaxies. **References: Hajdukovic [2,6,8,10-16]**

How the effective gravitational charge of a body depends on distance from it



- **The effective gravitational charge** of a body (blue line) increases from the "**bare**" charge measured at its surface to a constant maximum charge at a large distance from the body
- Competing gravitational field of other bodies can prevent the effective gravitational charge to increase above a limit presented by the red line
- The maximum effective charge can be reached only if other bodies are sufficiently far

Content of the Universe in our model

- **The content of the Universe is modeled by 3 cosmological fluids.**
- *The first two fluids* are well established *pressureless matter* and *radiation* evolving with the scale factor R as

$$\rho_{\mathrm{m}} = \rho_{\mathrm{m}0}\left(\frac{R_0}{R}\right)^3 , \quad p_m = 0$$

$$\rho_{\mathrm{r}} = \rho_{\mathrm{r}0}\left(\frac{R_0}{R}\right)^4 , \quad p_r = \frac{1}{3}\rho_r c^2$$

- These two fluids have respectively zero pressure and positive pressure; consequently, if they are the only content of the Universe

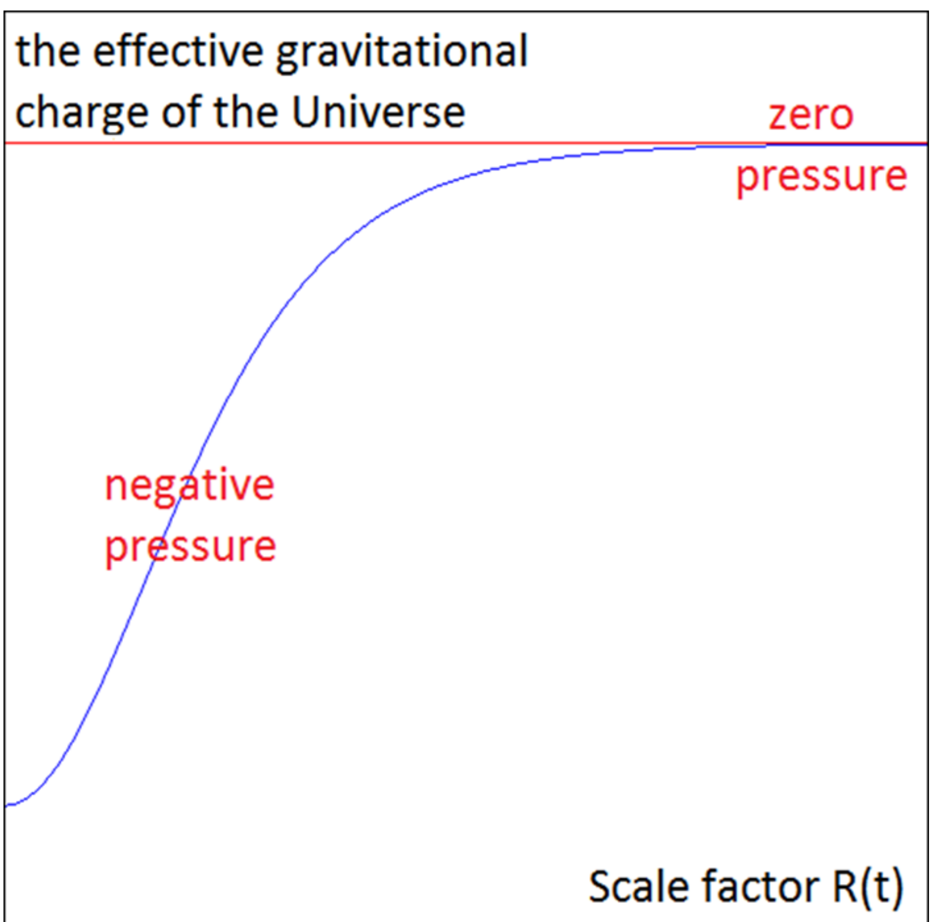
$$\sum_n \left(\rho_n + \frac{3p_n}{c^2}\right) > 0$$

and according to the cosmological field equation

$$\ddot{R} = -\frac{4\pi G}{3} R \sum_n \left(\rho_n + \frac{3p_n}{c^2}\right)$$

the acceleration $\ddot{R}$ can be only negative.

Our third cosmological fluid is the quantum vacuum considered as an "ocean" of virtual gravitational dipoles. Globally quantum vacuum is a cosmological fluid with the sum of all gravitational charges equal to zero, but with a large effective gravitational charge caused by the gravitational polarization. There must be a period in which the size of the individual galactic halos and the total effective gravitational charge of the quantum vacuum increase with the expansion, which means that the polarized quantum vacuum behaves as a fluid with negative pressure



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- **Apparently, quantum vacuum „enriched" with the virtual gravitational dipoles has potential to explain phenomena usualy attributed to dark energy.**
- Note that with the expansion of the Universe the polarized quantum vacuum converts from a cosmological fluid with negative pressure to a presureless fluid! According to the cosmological field equations it means that **the accelerated expansion converts to the decelerated one**.

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