A Cyclic Universe alternatively dominated by matter and antimatter

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Abstract

- It was recently suggested that what we call dark matter and dark energy, can be explained as the local and global effects of the gravitational polarization of the quantum vacuum by the immersed Standard Model matter. This result appears as the consequence of the working hypothesis that by their nature quantum vacuum fluctuations are virtual gravitational dipoles. Here, we argue that, as a consequence of the same hypothesis, we may live in a cyclic universe with cycles alternatively dominated by matter and antimatter. At least mathematically there is no the initial singularity, there is no need for the cosmic inflation and there is an amusing explanation of the matter-antimatter asymmetry in the universe: our universe is dominated by matter because the previous cycle was dominated by antimatter (and the next cycle would be dominated by antimatter again).

Fundamental problems revealed by observations

Astronomical observations have revealed a series of phenomena which are a complete surprise and mystery for contemporary theoretical physics, i.e. for both, the Standard Model of Particles and Fields and for General Relativity

The first observed phenomenon

In galaxies and clusters of galaxies, the gravitational field is much stronger than it should be according to our theory of gravitation and the existing amount of the Standard Model matter

The mainstream "explanation": **Dark matter** of unknown nature

The second observed phenomenon

In certain periods of its history the expansion of the Universe is accelerated

The mainstream "explanation": **Dark energy** of unknown nature

The third observed phenomenon

Our Universe is dominated by matter

Apparently, in the primordial Universe, something has forced the matter-antimatter asymmetry.

The mainstream "solution": An **unknown type of CP violation**, many orders of magnitude stronger than the known one!

A common explanation of all phenomena?

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.

What if *quantum vacuum fluctuations are virtual gravitational dipoles*? Summary of consequences.

Our working hypothesis might be the basis for a new model of the Universe. According to the new model, ***the only* content of the Universe is the known Standard Model matter** (i.e. matter made from quarks and leptons interacting through the exchange of gauge bosons) *immersed in the quantum vacuum* "enriched" with virtual gravitational dipoles. Apparently, **what we call dark matter and dark energy, can be explained as the local and global effects of the gravitational polarization of the quantum vacuum by the immersed baryonic matter**. Further, **the hypothesis leads to a *cyclic model* of the Universe with cycles alternatively dominated by matter and antimatter**; with each cycle beginning with a macroscopic size and the accelerated expansion. Consequently, there is *no singularity*, *no need for inflation field*, and there is an elegant explanation of the matter-antimatter asymmetry in the universe: **our universe is dominated by matter because the previous cycle of the Universe was dominated by antimatter**. The forthcoming experiments (AEGIS, ALPHA, GBAR …) will reveal if particles and antiparticles have gravitational charge of the opposite sign, while study of orbits of tiny satellites in trans-Neptunian binaries (e.g. UX25) can be a reasonable test of some astronomical predictions of the theory.

Reminder: Quantum vacuum in QED

an “ocean” of virtual electric dipoles

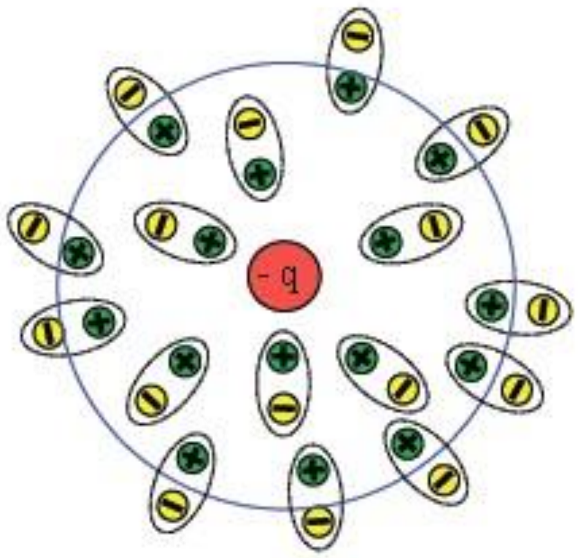
In QED quantum vacuum can be considered as an omnipresent “ocean” of virtual electric dipoles (for instance electron-positron pairs) with random orientation

Reminder: Quantum vacuum in QED

a halo of the polarized quantum vacuum

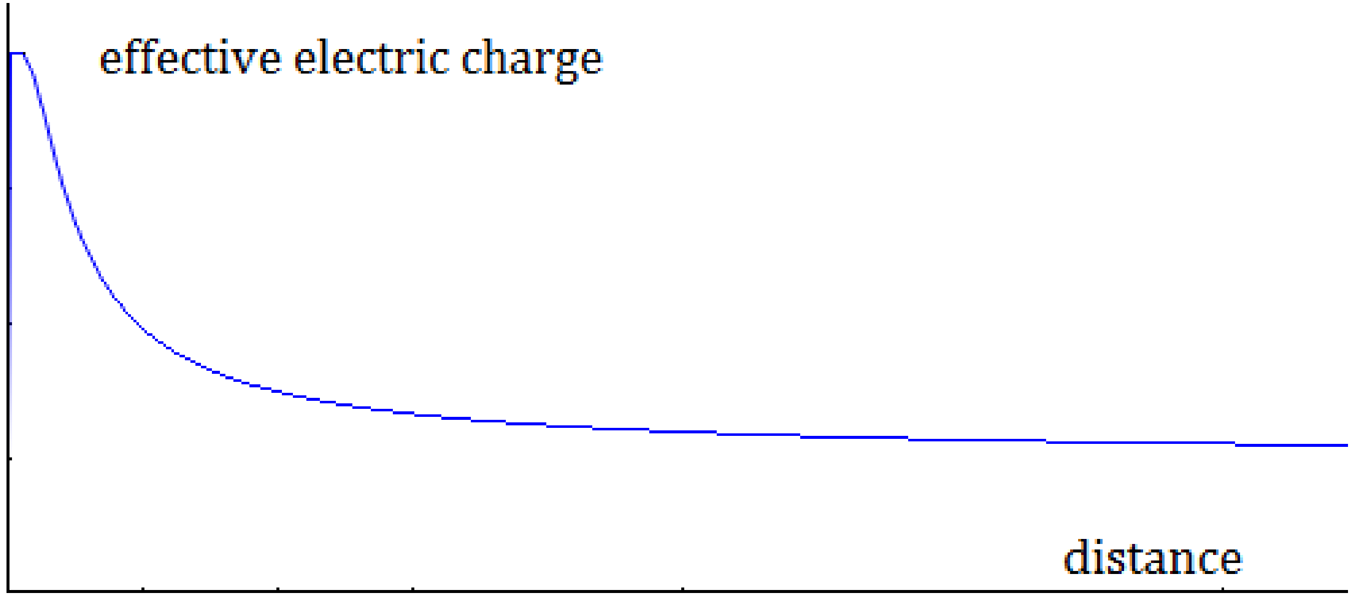
- The random orientation of virtual dipoles can be perturbed by a very strong electric field
- Example: The electric field of an electron at the distance of its Compton Wavelength is of the order of **10^{14} V/m**. Such a strong field perturbs the random orientation

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**.



Reminder: Quantum vacuum in QED

the effective electric charge of electron



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

❑ The effects of screening are not significant after a characteristic distance (which is of the order of the Compton wavelength)

Reminder: Quantum vacuum in QED

vacuum fluctuations can be converted into real particles

- A virtual electron-positron pair **can be converted to a real one** by an external field which, during their short lifetime, can separate particle and antiparticle to a distance of about one reduced Compton wavelength
- **The Schwinger mechanism**: For a constant acceleration *a* (which corresponds to a constant electric field) the particle creation rate per unit volume and time, can be written as

$$\frac{dN_{m\bar{m}}}{dt\,dV} = \frac{c}{\lambda^4}\left(\frac{a}{a_{cr}}\right)^2 \sum_{n=1}^{\infty} \frac{1}{n^2} \exp\left(-n\frac{a_{cr}}{a}\right), \quad a_{cr} \equiv \pi \frac{c^2}{\lambda_m}$$

$$\lambda_m = \frac{\hbar}{mc}, \text{ the reduced Compton wavelength}$$

Valid for gravity if there are virtual gravitational dipoles!

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

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

*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.

Dark matter as the local effect of gravitational vacuum polarization

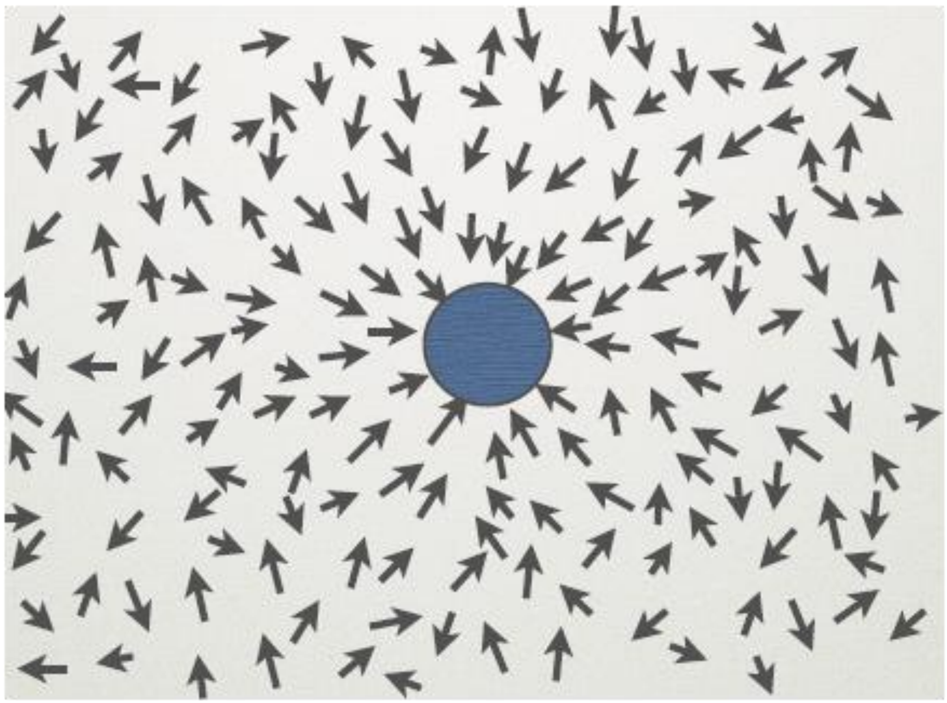
References concerning this section: Hajdukovic [2,6,8,10-16]

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.

How strong must be an external field to produce vacuum polarization?

- The electric field of an electron at the distance of its Compton Wavelength is of the order of

$$10^{14}\, V/m$$

- The gravitational acceleration produced by a pion (roughly a typical mass in the physical vacuum of quantum chromodynamics) at the distance of its Compton wavelength is

$$\approx 2.1\times10^{-10}\, m/s^2 \quad *$$

The mean distance between two dipoles which are first neighbours is one Compton wavelength. Hence, the above electric and gravitational field can be used as a *rough approximation* of the external field needed to produce the effect of saturation for the corresponding dipoles. While the gravitational field needed for polarization is very weak, the needed electric field is very strong. In fact the electric polarization of macroscopic volumes is suppressed because the electromagnetic interactions are too strong; only a weak interaction as gravity can polarize large volumes!

*This acceleration is only $\sqrt{3}$ times larger than the acceleration proposed by MOND as a new universal constant. (See also the next Slide).

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

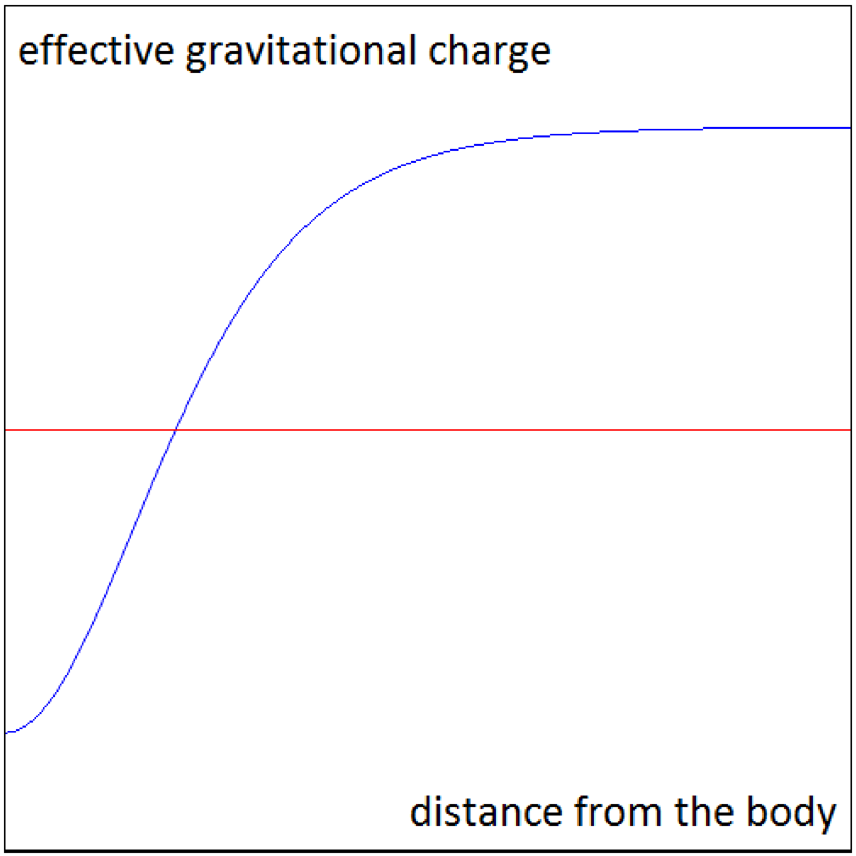
$$\rho_{qv}(r) = \frac{1}{r^2}\frac{d}{dr}\left(r^2 P_g(r)\right); \; P_g(r) \equiv \left|\vec{P}_g(r)\right|$$

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

The size and the effective gravitational charge of a halo

- Roughly speaking there is a maximum size of the halo for each massive body, galaxy or cluster of galaxies. Simply, after a characteristic size the random orientation of dipoles dominates again.
- A halo of the maximum size can be formed only if other bodies are sufficiently far. For instance, in competition with the Sun, our Earth cannot create a large halo, but if somehow we increase the distance of the Earth from the Sun, the size of the spherical halo of the Earth would increase as well, reaching asymptotically a maximum size .
- The key point is that with the increase of the size of a halo also increases the effective gravitational charge distributed within the halo.

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

Dark energy as the global effect of gravitational vacuum polarization

References concerning this section: Hajdukovic [1,9,12,15,16]

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

$$\rho_{\mathrm{m}} = \rho_{\mathrm{m0}}\left(\frac{R_0}{R}\right)^3, \;\; p_m = 0 \qquad\qquad \rho_{\mathrm{r}} = \rho_{\mathrm{r0}}\left(\frac{R_0}{R}\right)^4, \;\; p_r = \frac{1}{3}\rho_r c^2$$

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

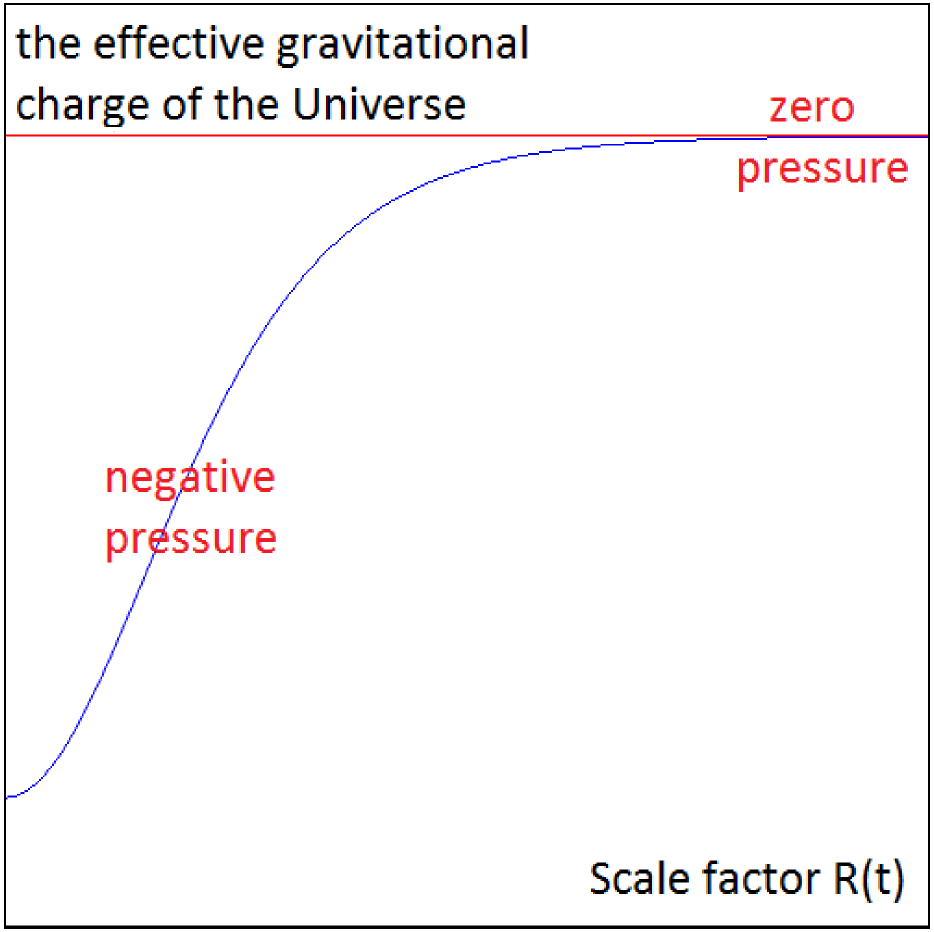
$$\sum_n \left(\rho_n + \frac{3p_n}{c^2}\right) > 0$$

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**.



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**.

What would be outcome of an eventual Big-Crunch

A cyclic Universe alternatively dominated by matter and antimatter

References concerning this section: Hajdukovic [3,7,15,16]

Cyclic Universe
Qualitative picture

- During the expansion of the Universe **quantum vacuum converts from a cosmological fluid with negative pressure to nearly pressureless fluid**. According to the cosmological field equation it means that **the accelerated expansion converts to the decelerated one**.
- The eventual collapse of the Universe cannot end in singularity. There is an ultimate mechanism to prevent it: the gravitational version of the Schwinger mechanism i.e. conversion of quantum vacuum fluctuations into real particles, by an extremely strong gravitational field
- An extremely strong gravitational field would create a huge number of particle-antiparticle pairs from the physical vacuum; with the additional feature that matter tends to reach toward the eventual singularity while antimatter is violently ejected farther and farther from singularity. The amount of created antimatter is equal to the decrease in the mass of the collapsing matter Universe.

Continue on the next Slide

Continued from the previous Slide

- Hence, the quantity of matter decreases while the quantity of antimatter increases by the same amount; the final result might be conversion of nearly all matter into antimatter. If the process of conversion is very fast, it may look like a Big Bang but it is not a Big Bang: it starts with a macroscopic initial size without singularity and without need for inflation field of unknown nature.
- In addition, there is an elegant explanation of the matter-antimatter asymmetry in the universe:

our universe is dominated by matter
because the previous cycle of the universe
was dominated by antimatter

Cyclic Universe
Quantitative illustration

- Just for an illustration let us limit to the radiation dominated Universe. According to the cosmological field equation

$$\ddot{R} \approx -\frac{8\pi G\rho_{r0}}{3}\frac{R_0^4}{R^3}$$

- **For R=1m**, $\ddot{R}$ has tremendous value of the order of $10^{69}\, m/s^2$ **36 orders** of magnitude greater than the critical acceleration needed for creation of let us say neutron-antineutron pairs.

Continue on the next Slide

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- The particle-antiparticle creation rate per unit volume and time can be estimated using the gravitational version of the Schwinger formula (Slide 9). In the example from the previous Slide, the creation rate for neutron-antineutron pairs is of the order of

$$\frac{dN_{m\bar{m}}}{dtdV} \approx 10^{144} \frac{pairs}{sm^3} \approx 10^{87} \frac{M_{Sun}}{s \cdot m^3}$$

- With such an enormous conversion rate the matter of our Universe can be transformed into antimatter in a tiny fraction of second! The gravitational version of the Schwinger mechanism prevents collapse to singularity.

Instead of conclusion

- The forthcoming experiments at CERN (AEGIS, ALPHA, GBAR …) will reveal if particles and antiparticles have gravitational charge of the opposite sign, while study of orbits of tiny satellites in trans-Neptunian binaries (e.g. UX25) can be a reasonable test of some astronomical predictions of the theory (Gai, M., Vecchiato, A.; Astrometric detection feasibility of gravitational effects of quantum vacuum. (2014) http://arxiv.org/abs/1406.3611v2
- I do not know in advance if I am right but I wonder how superymetrists know immediately that I am wrong
- There is an amusing law valid in the time of scientific revolutions

  If you think differently from the mainstream
  it is not a proof that you are right,
  but *if you think as the mainstream*
  it is a proof that you are wrong.

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