The Journal of Cosmology

Journal of Cosmology, 2011, Vol 13, In Press.
JournalofCosmology.com, 2011

A Cyclic Universe Dominated Alternatively by Matter and Antimatter

Dragan Slavkov Hajdukovic[1]
PH Division CERN
CH-1211 Geneva 23
[1]On leave from Cetinje, Montenegro

ABSTRACT

I suggest that a hypothetical gravitational repulsion between matter and antimatter can transform an eventual Big Crunch of our Universe, to an event similar to Big Bang. In fact, when a collapsing Universe is reduced to a supermassive black hole of a small size, a very strong gravitational field might create particle-antiparticle pairs from the surrounding quantum vacuum. The amount of antimatter created from the physical vacuum is equal to the decrease of mass of "the black hole Universe" and violently repelled from it. When the size of the black hole is sufficiently small, the creation of antimatter may become so fast, that matter of our Universe may disappear in a fraction of second. Such a fast conversion of matter into antimatter may look as a Big Bang with an initial size, 30-38 orders of magnitude greater than the Planck length, suggesting that there is no need for inflationary scenario in Cosmology. In addition, a Big Crunch, of a Universe dominated by matter, leads to a new Universe dominated by antimatter, and vice versa; without need to invoke CP violation as explanation of matter-antimatter asymmetry. Simply, our present day Universe is dominated by matter, because the previous Universe was dominated by antimatter.

Keywords: cyclic universe; gravitational properties of antimatter; big bang; big crunch; inflation; matter-antimatter asymmetry

Soon after the foundation of General Relativity, it was understood that it is compatible with the idea of a Cyclic Universe (Friedmann, 1922). Hence, for the first time in the human history, it became possible to speculate about a Cyclic Universe in the framework of physics; the idea of an oscillating Universe has finally moved from the philosophical and religious discourse to the field of the most fundamental science.

According to the Standard Model of Cosmology (i.e. the inflationary Big Bang model), our Universe was born in a Big Bang about 14 billions years ago and it is expected to expand forever. While the current observations apparently support the picture of an eternal expansion, a future collapse of the Universe can't be excluded. Thus, our Universe may end in a Big Crunch somehow followed by a new Big Bang. Simply speaking, our Universe might be just one in a series of universes succeeding each other.

In the past 80 years, different scenarios for a Cyclic Universe have been proposed (See recent reviews: Novello and Perez Bergliaffa , 2008; Kragh, 2009; Penrose, 2010). While very different between them, all existing scenarios have a common point: a universe is always dominated by matter. At this point our scenario sharply differs from all others. We have recently proposed a mechanism (Hajdukovic, 2010) leading to a series of universes, dominated alternatively by matter and antimatter; a matter dominated Universe (as it is the Universe in which we live) is always followed by a Universe dominated by antimatter and vice versa.

As I will argue, this intriguing possibility should be consequence of a very simple hypothesis: the gravitational repulsion between matter and antimatter. Without entering the complex discussions, the simplest way to define such a gravitational interaction is:

$$m_i = m_g \; ; \; m_i = \overline{m}_i \; ; \; m_g + \overline{m}_g = 0 \tag{1}$$

Here, a symbol with a bar denotes antiparticles; while indices i and g refer to inertial and gravitational mass (it should be more appropriate to use term gravitational charge instead of gravitational mass). The first two relations in (1) are experimental evidence (Will, 1993; Gabrielse et al. 1999), while the third one is our conjecture which dramatically differs from the mainstream conviction $m_g - \overline{m}_g = 0$.

In order to understand the physical significance of the above conjecture, we must remember the Schwinger mechanism in Quantum Electrodynamics (QED), i.e. creation of electron-positron pairs from the (Dirac) vacuum by an external (classical i.e. unquantized) electromagnetic field. In the particular case of a constant and homogenous electric field E , the particle creation rate per unit volume and time is known exactly (Schwinger, 1951):

$$\frac{dN_{e^+e^-}}{dtdV} = \frac{4}{\pi^2}\frac{c}{\lambda\!\!\!^{-4}_e}\left(\frac{E}{E_{cr}}\right)^2 \sum_{n=1}^{\infty}\frac{1}{n^2}\exp\left(-\frac{n\pi}{2}\frac{E_{cr}}{E}\right) \tag{2}$$

where

$$\lambda\!\!\!^{-}_{e} = \frac{\hbar}{m_e c} \quad and \quad E_{cr} = \frac{2m_e^2 c^3}{e\hbar} \tag{3}$$

are respectively the reduced Compton wavelength of the electron, and the critical electric field.

The Schwinger mechanism is due to the complex structure of the physical vacuum in QED and the existence of an external field. In the (Dirac) vacuum of QED, short-living "virtual" electron-positron pairs are continuously created and annihilated again by quantum fluctuations. A "virtual" pair can be converted into real electron-positron pair only in the presence of a strong external field, which can spatially separate electrons and positrons, by pushing them in opposite directions, as it does an electric field E. Thus, "virtual" pairs are spatially separated and converted into real pairs by the expenditure of the external field energy. For this to become possible, the potential energy has to vary by an amount $eE\Delta l > 2m_e c^2$ in the range of about one Compton wavelength $\Delta l = \hbar / m_e c$, which leads to the conclusion that the significant pair creation occurs only in a very strong external field *E*, greater than the critical value E_{cr} in Equation (3).

In principle, every external force which attempts to separate particles and antiparticles, may convert a virtual pair into a real one. Hence, the conjectured gravitational repulsion between matter and antimatter is a necessary condition for the creation of particle-antiparticle pairs from the quantum vacuum by an external gravitational field.

Now, there is a very simple and beautiful qualitative description of the expected phenomena. In the final stage of a hypothetical collapse, the universe would become a supermassive black hole. Deep inside the horizon of such a black hole, extremely strong gravitational field can create particle-antiparticle pairs from the physical vacuum; with the additional feature that a black hole made from matter violently repels antiparticles, while a black hole made from antimatter repels particles. Without lost of generality we may consider the case of a black hole made from matter. The amount of created (and violently repelled) antimatter is equal to decrease in the mass of black hole. Hence, during a Big Crunch, quantity of matter decreases while quantity of antimatter increases for the same amount; the final result might be conversion of all matter into antimatter. If (as I will argue latter) the process of conversion is very fast, it may look as a Big Bang starting with an initial size many orders of magnitude greater than the Planck length, what may be an alternative to the inflation in Cosmology.

The most poetic part of this qualitative picture is that Big Crunch of a Universe made from matter, leads to a Big Bang like birth of a new Universe made from antimatter. Hence, the question why our Universe is dominated by matter has a simple and striking answer: because the previous Universe was made from antimatter. There is no need to invoke CP violation as explanation for matter-antimatter asymmetry in the Universe.

For the purpose of illustrative calculations we use a toy model in which a black hole is considered as a ball with a radius R_H and equation (2) is approximated with

$$\frac{dN_{m\bar{m}}}{dtdV} \approx \frac{4}{\pi^2}\frac{c}{\lambda\!\!\!^{-4}_m}\left(\frac{a}{a_{cr}}\right)^2 ;\ a_{cr} = \frac{2c^2}{\lambda\!\!\!^{-}_m} \tag{4}$$

where the quotient of electric fields E / E_{cr} is replaced with the quotient of corresponding accelerations a / a_{cr} and particle-antiparticle pairs with any mass m are allowed. In addition, as we are interested only in the case $a > a_{cr}$, the infinite sum in the equation (2) is well approximated by 1.

Now, let us define a critical radius R_{Cm} as the distance at which gravitational acceleration has the critical value $a_{cr} = 2c^2/\lambda\!\!\!^{-}_m$, defined by Equation (4). Combining value for a_{cr} with the Newton's law of gravitation leads to

$$R_{Cm} = \frac{1}{2}\sqrt{\lambda\!\!\!^{-}_m R_S} \equiv L_P\sqrt{\frac{M}{2m}} \tag{5}$$

where $R_S = 2GM/c^2$ is the Schwarzschild radius of a black hole with mass M and $L_P = \sqrt{\hbar G/c^3}$ is the Planck length. Hence a sphere shell with the inner radius R_H and the outer radius R_{Cm} should be a „factory" for creation of particle-antiparticle pairs with mass m. After integration over the volume of this spherical shell (and taking $R_{Cm} >> R_H$), the Equation (4) gives

$$\frac{dN_{m\bar{m}}}{dt} \approx \frac{1}{\pi}\left(\frac{R_S}{\lambda\!\!\!^{-}_m}\right)^2 \frac{c}{R_H} \tag{6}$$

According to Equation (6), the particle-antiparticle creation rate per unit time depends on both, mass M and radius R_H. If R_H (i.e. the size of a black hole) is very small, the conversion of matter into antimatter is very fast!

Let us look at a numerical example. With the mass of the Universe taken to be of the order of $10^{53}\,kg$ the critical radius for a nucleon (proton or neutron) determined by Equation (5) is

$$R_{Cn} \sim 10^5\,m \tag{7}$$

what is comparable with the size of the Moon and Earth. If $R_H < R_{Cn}$ (i.e. the creation of nucleon-antinucleon pairs is not suppressed), the equations (6) leads to the numerical result

$$\frac{dN_{n\bar{n}}}{dt} > 10^{86}\ pairs/s \tag{8}$$

The numerical result (8), tells us, that decrease of matter and increase of antimatter has a rate greater than $10^{59}\,kg/s$, while the mass of our Universe is „only“ about $10^{53}\,kg$! Such a huge conversion rate indicates that the whole matter in the Universe may be transformed into antimatter (i.e. a Big Crunch of our Universe may be transformed to a Big Bang) in a fraction of second! According to this numerical example, the size of the new born Universe should be about 38 orders of magnitude greater than the Planck length, suggesting that we do not need the inflation in Cosmology.

Let us give a second (presumably extreme but instrumental) numerical example, taking $R_H = 10^{-6}\,m$ (what is however 29 orders of magnitude greater than Planck length). If the collapsing Universe can reach such a small size, according to Equation (5), the gravitational field is sufficiently strong to create particle-antiparticle pairs with Planck mass M_P. Hence, the Equation (6) leads to the following numerical result

$$\frac{dN_{M_P\overline{M}_P}}{dt} \approx 10^{136}\ pairs/s \tag{9}$$

corresponding to the colossal conversion rate of $10^{128}\,kg/s$. Consequently the whole matter of the Universe might be converted into antimatter in a fraction of the Planck time. In any case the Universe is prevented to collapse to singularity, but better than that, without invoking inflation, the minimal size of the Universe is apparently 30 to 38 orders of magnitude greater than the Planck length.

The purpose of this short paper is to present a fascinating possibility and to provoke interest and discussion. A more detailed study is in preparation.

Let us end with the words of Lemaitre (1933): “Those solutions where the universe expands and contracts successively have an indisputable poetic charm and make one think of the phoenix of legend.” A universe oscillating between matter and antimatter can only augment the poetic beauty. Of course , the last word can’t come from poets and theorists, but from experiments and observations. Hopefully, in the near future, the AEGIS experiment at CERN (Kellerbauer, 2008) and/or new generation of Neutrino Telescopes (Hajdukovic, 2007) will reveal the gravitational properties of antimatter. A nice surprise might come in less than ten years.

References

Friedman, A. (1922). Über die Krümmung des Raumes. *Zeitschrift für Physik* 10, 377–386. English translation in: Friedman, A. (1999). On the curvature of space. *General Relativity and Gravitation* 31: 1991–2000

Gabrielse, G. et al.(1999). Precision Mass Spectroscopy of the Antiproton and Proton Using Simultaneously Trapped Particles. Phys. Rev. Lett. 82, 3198 – 3201

Hajdukovic, D.S. (2007). Can the new New Neutrino Telescopes reveal the gravitational properties of antimatter. arXiv:0710.4316v3 [gr-qc]

Hajdukovic , D.S. (2010). What Would be Outcome of a Big Crunch. International Journal of Theoretical Physics 49, 1023

Kellerbauer, A .et al. (2008). Proposed antimatter gravity measurement with an antihydrogen beam. NIM **B 266** 351

Kragh, H. (2009). Continual Fascination: The Oscillating Universe in Modern Cosmology, Science in Context, 22, 587-612

Lemaitre, G. (1933) Annales Soc. Sci. Brux. Ser. I A 53**,** 51. English translation in: Lemaitre, G. (1997). . The Expanding Universe**.** General Relativity and Gravitation , Vol. 29, No. 5

Novello, M and Perez Bergliaffa S.E. (2008) Bouncing cosmologies. Physics Reports 463, 127–213

Penrose, R. (2010). *Cycles of Time: An Extraordinary New View of the Universe*. Bodley Head, London

Schwinger, J.S. (1951). On Gauge Invariance and Vacuum Polarization. Phys. Rev. **82,** 664

Will, C.M. (1993). Theory and Experiment in Gravitational Physics. Cambridge University Press , Cambridge