© A.V.Bukalov, 2013

UDC 523.11:524.827:539.12:524.854:530.11

A.V. Bukalov

QUANTUM EFFECTS OF DARK ENERGY AND THE ENTROPY CHANGE OF THE MODERN UNIVERSE

Center of Physical and Space Research, the International Institute of Socionics,
Melnikova str., 12, Kiev-50, 04050, Ukraine
e-mail: *bukalov.physics@socionic.info*

The beginning of the era of dominance of the vacuum energy or dark energy, and the change in the sign of acceleration of the Universe expansion leads to change in the sign of density of quantum radiation of vacuum in the expanding Universe. This effect is similar to the Unruh effect, but differs from it. The dominance of dark energy leads to the emission of energy flow with negative density, which is absorbed by objects moving in a vacuum. This effect may be due to the formation of cosmic structures, including the origin of the phenomenon of life.

Keywords: vacuum, dark energy, Unruh radiation, expansion of the Universe.

PACS numbers: 04.50.Kd, **95.36.+x, 98.80.–k**

As is known, the entropy of cosmic microwave background radiation (CMBR), formed during the Big Bang, is a constant because of the adiabatic expansion of the Universe [1]. However, a number of authors [2, 3], considering the gravitational degrees of freedom, associated the growth of entropy of the Universe with its expansion because the Hubble radius is a function of time: $R_H = cH^{-1} = ct_H$. Consideration of the Universe within the Hubble radius in analogy to a black hole with the mass M_H and density

$$\rho_c = \frac{3}{8\pi G_N} H_0^2 = \frac{3M_H}{4\pi R_H^3} \tag{1}$$

leads to the conclusion that the Hubble event horizon must radiate thermal Hawking radiation with the temperature

$$T = \frac{\hbar c}{4\pi R_H k_B} = 1.34 \cdot 10^{-30}\ \text{K}. \tag{2}$$

The entropy is calculated for a surface within the Hubble radius. Then, based on analogy with the Bekenstein-Hawking black hole, the number of information cells on the surface of the Hubble sphere can be estimated as

$$N = \frac{4\pi R_H^2(t)}{4L_P^2}, \tag{3}$$

when $L_P = \left(G_N \hbar / c^3\right)^{1/2}$ is Planck length [2, 3].

From the general relativity and quantum theory it follows [3–10], that the detector, moving in the flat Minkowski space with the acceleration η, must measure in a vacuum thermal background particles with the temperature $T_\eta = \hbar\eta / (2\pi c k_B)$. That follows directly from the principle of equivalence in general relativity, proposed by Albert Einstein. The gravitational acceleration near the horizon of the black hole g and the corresponding thermal radiation are equivalent to measurements of detector, moving with acceleration η in the flat space-time:

$$g = \eta, \quad T_{BH} = T_{\text{det}}. \tag{4}$$

However, the formula (2) is valid only for the Universe consisting of gravitating matter and radiation. But the Universe contains not only gravitating matter, but the “dark energy” also, which is probably the vacuum energy, with the state equation $P_v = -\rho_v$, i.e. it has a negative pressure [11].

Now the “dark energy” density is about 68% of the energy density of the Universe. According to Friedman equation, this form of energy anti-gravitates and leads not to a slowing down, but to the expansion of the Universe with acceleration $\ddot{a}_U$:

$$\left(\frac{\dot{a}}{a}\right)^2 = \frac{8\pi}{3} G_N(\rho_m + \rho_v) - \frac{k}{a^2} \tag{5}$$

$$\ddot{a}_U = -\frac{4\pi}{3} G_N \left((\rho_m + 3P_m)a + (\rho_v + 3P_v)\right)a \,, \tag{6}$$

when a is the scale factor.

At $P_m = 0,\ \rho_v = -P_v$

$$\ddot{a}_U = -\frac{4\pi G_N}{3}(\rho_m - 2P_v)a \,. \tag{7}$$

At $a \approx R_H \approx 1.36 \cdot 10^{26}$ m, $\Omega_m \approx 0.318,\ \Omega_v = 0.682,\ \Omega_r \approx 5 \cdot 10^{-4},\ z = 0$

$$\ddot{a}_U = -\frac{4\pi}{3} G_N \rho_c (0.318(1+z)^3 + \Omega_r (1+z)^4 - 2 \cdot 0.682) \cdot R_H = \frac{4\pi}{3} G_N \rho_c \cdot 1.046a = 3.46 \cdot 10^{-10}\,\mathrm{m \cdot s^{-2}} \,. \tag{8}$$

As is known, the anti-gravity effect - acceleration of the Universe expansion - was discovered in 1998 [12, 13]. At $z \approx 0.7$ and $t_U \approx 5.57 \cdot 10^9$ years acceleration of the expansion changes sign.

Thus, antigravitation now dominates in the Universe, and therefore it cannot be liken to a black hole.

It should be noted that in the Friedman equations the sign of the cosmological deceleration, caused by gravitating matter, and the sign of the equivalent temperature Bekenstein-Hawking are opposite to the sign of acceleration and temperature for a black hole. The same is true for anti-gravitational acceleration and the equivalent temperature.

Therefore, if to the gravitational acceleration g, which is given by a mass of matter, corresponds the thermal background as for a black hole, with the temperature $T_g = \hbar g / (2\pi c k_B)$ ($g = -\ddot{a}_m$), then the anti-gravitational acceleration, defined by the dark energy or vacuum negative pressure, will be consistent the background with negative temperature: $-T_v = \hbar \ddot{a}_v / (2\pi c k_B)$. Then

$$\ddot{a}_U = -\ddot{a}_m + 2\ddot{a}_v \tag{9}$$

$$k_B \Delta T = k_B T_g - 2k_B T_v = -1.046 k_B T_H = -k_{B'} T_U \tag{10}$$

$$-T_U = \frac{\hbar \ddot{a}_U}{2\pi c k_B} = -1.4 \cdot 10^{-30}\,\mathrm{K}. \tag{11}$$

This temperature is determined by the negative vacuum pressure ρ_v. And

$$\rho_v \approx 1.046 \rho_c \,.$$

In this case, the density of the energy, registered by the detector, corresponding to the acceleration $\ddot{a}_v$, is negative with respect to the energy density, determined by the gravitational field of matter and radiation.

That is, if for the detector the gravitational acceleration, induced by gravitating matter, generates thermal radiation with a positive temperature and positive density of energy, antigravitational acceleration generates radiation with a negative temperature and negative energy density. This is equivalent to the thermal radiation of the detector in the Universe which is expanding with acceleration. This radiation means a decrease in the entropy of detector or an increase its degree of regularity. In fact, dark energy, or vacuum with negative pressure and the equation of state $\rho_v = -P_v$, absorbs thermal radiation of detector, moving with acceleration. Any material object with the appropriate energy levels can be considered as the detector. It follows that with the dominance of the dark energy there is a growth of ordering of all structures of the Universe and reduction of their entropy. In the present era, at $z = 0$, in energy units within the Hubble radius the entropy of the Universe is

$$-S_U = -k_B T_U \pi \frac{R_H^2}{L_P^2} \approx -2.2 \cdot 10^{122} k_B T_U \approx -4.3 \cdot 10^{69}\,\mathrm{J}. \tag{12}$$

It corresponds to a flow of negative entropy:

$$I_U = -S_U \,. \tag{13}$$

$$\dot{I}_U \approx -\frac{S_U}{t_U} \approx -2.4 \cdot 10^{52}\,\mathrm{J \cdot s^{-1}}. \tag{14}$$

Thus, when $z < 0.7$

$$\frac{dS_U}{dt} < 0 . \qquad (15)$$

Therefore, dark energy or vacuum can be considered as a source of negative entropy, or ordering, that is shown during the period of its dominance. Therefore, the vacuum can induce an increase of ordering of the Universe structures. Such exposure is a macroscopic quantum cosmological effect.

Thus, the evolution of the modern Universe is largely determined by the negative entropy, or equivalent information, given by the vacuum: $-S_U = I_U$.

Note that this is probably explains the fact that the complex structures such as live, biological objects, emerged and began to develop after the beginning of the era of accelerated expansion, or the domination the dark energy [14, 15]. Apparently, the further expansion and cooling of the universe lead to the complete domination of the vacuum energy or the dark energy, and this process will be followed by the appearance of more and more complex and organized structures.

References:

1. *Klaptor-Kleingrothaus H. V., Zuber K.*, Teilchenastrophysik. — B. G. Teubner GmbH, Stuttgart, 1997.
2. *Verlinde E.* JHEP (04) 029 (2011); arXiv:1001.0785
3. *Bolotin Yu. L., Yerokhin D. A., Lemets O. A.* Expanding Universe: slowdown or speedup? // Phys. Usp. 55 (9) (2012).
4. *Unruh W. G.* Phys. Rev. D **14** 870 (1976)
5. *Bekenstein J. D.* Phys. Rev. D **7** 2333 (1973)
6. *Bekenstein J. D.* gr-qc/9409015
7. *Bekenstein J. D.* Phys. Rev. D **9** 3292 (1974)
8. *Bekenstein J. D.* Phys. Rev. D **49** 1912 (1994)
9. *Birrell N. D., Davies P. C. W.* Quantum fields in curved space. — Cambridge University Press, 1982.
10. *Hawking S. W*. Commun. Math. Phys., 1975, v.43, p. 199.
11. *Bukalov A.V.* Dark energy and the Universe entropy // Physics of consciousness and life, Cosmology and Astrophysics. — 2012. — № 3. — P. 31–33.
12. *Permutter S. et al.* Ap.J., **517**, 565 (1999).
13. *Riess A. G. et al.* Astron.J., **116**, 1009 (1999).
14. *Bukalov A. V.* Cosmic coincidence, evolution of the Universe and generalization of the Antropic Principle // Proc. 10th Gamov Odessa Astronomical conference. — Odessa, 2010.
15. *Bukalov A. V.* The quantity of information in the alive organisms and energy of vacuum. // Physics of consciousness and life, Cosmology and Astrophysics. — 2002. — N 2. — P. 5–9.