© M.H. Shulman, 2009 (shulman@dol.ru)

How does Universe expand?

(Updated 03.04.2009)

Abstract

I argue the necessity to refuse the cosmological constant. I show also that the only uniform expansion of the Universe can be possible.

1. Evolution of the Universe scale factor and cosmological constant

As we know from General Relativity (GR) the Universe scale factor ***a***(t) evolution may be described by the Equation

$$(d^2\boldsymbol{a}/dt^2)/\boldsymbol{a} = -(4\pi G/3)(\boldsymbol{\rho} + 3\boldsymbol{P}/c^2) + \Lambda c^2/3$$

Here G is the gravitational constant, $\boldsymbol{\rho}$ is the average matter density, ***P*** is a pressure, c is velocity of light, Λ is so called cosmological term (cosmological constant). Note that in the left side there is the second derivative on time of the *global* curvature radius (size) of the Universe.

We also well know why A. Einstein added this term in the Equation. He analyzed the static case (because he did'nt yet know about the possible Universe dynamical behavior), in this case the left side certainly equals zero. However, in this case the right side can be equal to zero only if the pressure ***P*** and the matter density $\boldsymbol{\rho}$ have opposite signs, so the pressure must be *negative*.

In such situation Einstein started to dodge. On the one hand, he did not want to introduce explicitly the negative pressure "without any physical reason" **[Einstein, 1953]**. On the other hand, he let it in the back entrance: he set this pressure to zero, but invented the "cosmological constant". Of course, this constant meaning was the same – a negative pressure. To base this he mentioned a Poincaret's hypothesis. Poincaret suggested that there are several forces in atoms *compensating an electrical repulsion* of their likely charged parts. Note, here Einstein *clearly* says that an *effective* pressure corresponding with the constant Λ should be *negative* in order to compensate some repulsion and to provide a *mutual bodies attraction*.

2. What is the negative pressure?

We see that Einstein used somehow or other a *negative* pressure in his model, at least as its "substitute" – cosmological constant Λ. But what indeed the negative pressure means, by what a physical manifestation is it characterized? As the authors of the classical textbooks wrote, at the typical conditions a matter pressure is positive, i.e. it is oriented as the body tended to expand. However, it is not necessary, and a body may also be in a state at a negative pressure: in such states the body seems to be "extended", and because of that tends to compress. For example, the superheated liquid can be characterized by a negative pressure; such a liquid acts to its bounding surface with a force that is oriented inside the volume of liquid (**[Landau et al., 1965, 1976]**).

So, how do a density matter and a negative pressure interact in the static case that Einstein studied? The negative sign of the density $\boldsymbol{\rho}$ shows that this parameter *has to diminish* the Universe acceleration due the gravitation. Then mathematics (and common paradigm) says us that a negative pressure (or the positive cosmological term) should act to the opposite direction, i.e. to *accelerate* the Universe expansion and to act as some *repulsion* force like anti-gravitational one. However, this *contradicts* to the physical meaning of a negative pressure, which should be directed to a mutual bodies *attraction* like gravitation. Hence, any interpretation of a negative pressure seems to be intrinsically conflicting in this case.

3. Common point of view and associated problems

For non-static Universe the zero left side already is not necessary condition to accomplish the Equation (however, it may by correct for a linear evolution). Einstein was very glad because now the absence of a pressure or the cosmological term does not imply a solution absence. However, the modern astrophysical observations show that such solution qualitatively is not compatible with the realm. Because of that the scientific community admitted the cosmological term and even fitted its optimal numerical value.

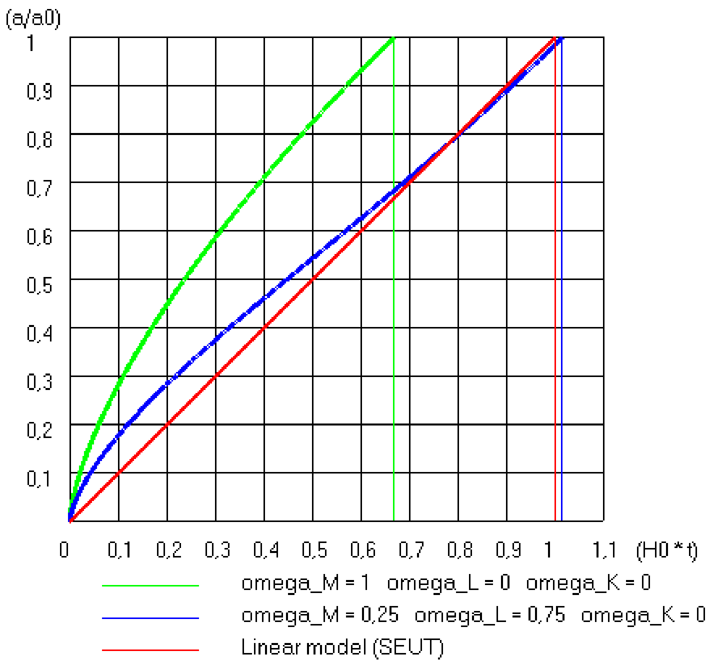

Figure1. The Universe relative size dependence on time (in units $H_0 * t$, where H_0 is the Hubble parameter at our epoch) for two models with different cosmological constant contribution (Ω_Λ=0 and Ω_Λ=0.75) to the effective Universe density (green and blue curves), and for linear model (SEUT) without cosmological constant (red line).

However, this led to the insuperable difficulties. Indeed, in the right side of Equation we have the energy density, which determines the Universe evolution acceleration. So, the cosmological term has to correspond with some kind of energy. As a main candidate one proposes to use a field vacuum fluctuations. However, the calculated vacuum energy differs by 120 orders from the required one. Additionally, the vacuum energy can at all be extracted for *nothing* because it corresponds with the *lowest possible energy level*.

Furthermore, the Universe relative size dependence on time (in units $H_0 * t$, where H_0 is the Hubble parameter at our epoch) for two models with different cosmological constant contribution (Ω_Λ=0 and Ω_Λ=0.75) to the effective Universe density (green and blue curves) is showed in Fig. 1. In the second case (blue curve), which was fitted to the real observations, the standard cosmology leads to the conclusion that some years ago (at H_0*t ≈ 0.8) the era of the Universe *accelerated expansion* started just due to the cosmological term influence.

There is here a great difficulty for standard cosmology. From above curves it follows that the parameter ***a*** change velocity may vary. This fact is not so inoffensive as one may believe. Indeed, for the both curves (green and blue) their change velocity can become more than the velocity of light! Meanwhile, the parameter ***a*** change corresponds with the *temporal* (non-spatial) component of a matter density relativistic flux, which is specified by the constant velocity of light (it is equal to $i\boldsymbol{\rho}$c), while the spatial components ($\boldsymbol{\rho} v_\lambda$, where λ = 1,2,3) of a matter density relativistic flux correspond with values from 0 up to c. The first one corresponds also with the specific rest energy $\boldsymbol{\rho}c^2$.

Note that since 1930 one often discuss an analogy between 4D GR's and similar non-relativistic 3D Equation, which can be recast to look like the equation of motion of a point particle on the surface of a 3D sphere of radius ***R*** = ***a***. This non-relativistic equation may be deduced for an *external* boundary layer of a 3D spherical homogeneous cloud having the radius ***R***, if its particles fly away with velocities corresponding with Hubble law, and the "relativistic" amendment (reflecting the fact that "pressure carries weight" in Einstein's theory of gravity) is added "by hands" to the density ***ρ***. In my opinion, this analogy is fully incorrect. Firstly, in it "the Hubble velocity" is different for different internal spherical layers, while in the real Universe the Hubble phenomenon is the same everywhere. Secondly – and it is most important – the velocity and (depending on ***R***) acceleration of expansion in this model are *given a priori* by the Hubble rule. *In fact, the Hubble law acts along spherical surface, not normally to it*.

4. Energetic point of view

If we *refuse* the cosmological term and return to a negative pressure, then we have to recognize its physical meaning. In order to do it let us consider the *classical* point of view on the gravitation, when a point mass ***m*** (having energy of rest $\boldsymbol{m}c^2$) creates a gravitational field in the *external* space. This external energy can be also considered as equal to $\boldsymbol{m}c^2$. So, it provides some equivalent of a negative (attractive) pressure acting to any external body. One can say that energy of rest and classical gravitational energy *compensate* one another.

When we talk about GR we know that Einstein himself in **[Einstein, 1918]** came to the conclusion that inert mass of any physical system is equal to its "heavy" mass. Using this Einstein's conclusion we may believe that the sum ($\boldsymbol{\rho} + 3\boldsymbol{P}/c^2$) should be *absolutely equal to zero* that reflects the strong equivalence between inert mass and gravitational one (ultimately, it corresponds to the equivalence principle). The latest is just represented by a *negative* pressure of a gravitational field.

Note, only inert mass notion has to be accounted for purely *spatial* components of motion equation; any non-mechanical forms (for example, associated with a pressure of electromagnetic radiation) also create a gravitational field and should be included in such inert mass. If the vacuum fluctuation energy also creates a gravitational field (see **[Masso, 2009]**), then it has to be accounted *two times* for temporal component: in the density ***ρ*** and in the *gravitation*al pressure ***P***. Such approach leads to a number of important results.

Before all, the second derivative of the parameter ***a***(t) is absolutely equal to zero, so one have *linear* evolution of this parameter only. In one's turn, this fact allows to deduce the striking conclusion that the Universe age is simply proportional to its size, i.e. *the physical time currency is due to the global Universe expansion*. Of course, this contradicts to the statement of modern observational cosmology about a hypothetical *accelerated* Universe expansion (as the red line in Fig. 1 shows); indeed, this conclusion was directly based on the assumption that the cosmological constant differs from zero, while in our model this one is equal to zero by definition.

Furthermore, a negative pressure *does not* play the role of anti-gravitation, i.e., it is not itself a self-dependent source of energy leading to the expansion (or another type of evolution) of the Universe. Contrary, it always strongly corresponds by value with the Universe inert mass.

One more conclusion is exclusively important although it seems to be the most "heretic". The proportionality of the Universe age to its size is not compatible with the law of conservation of mass and matter in the Universe during all its evolution history. This law was tacitly accepted by scientific community. However, this statement (as Noeter's theorem says) can be based only on the physical time uniformity for the Universe as a whole system (the more global system simply does not exist). Meanwhile, a simple analysis shows that physical laws in the early Universe could not be the same as in the modern one. For example, in the origin of time the Universe curvature radius was extremely small, while now it is close to infinity. This means a radical difference between the fundamental metric tensor components and the gravitational matter behavior.

If the energy does not conserves, then it has to change by someway. Our approach just allows replace the energy *conservation* law by the law of its *change*, as it follows from the *linear* solution of the Einstein-Friedmann equations. This question and a number of the other ones were considered in the papers **[Shulman, 2006, 2007a, 2007b, 2007d, 2007c]**, **[Shulman and Raffel, 2008**]. In them I showed that the new approach, which was firstly developed from exclusively theoretically base, allows us successfully solve a waste range of paradoxes and problems that are associated with the modern cosmological paradigm. Particularly, we propose solutions of flatness problem, horizon problem, relict radiation anisotropy problem, and problem of a peak in the initial part of this radiation spectrum. The new representations on our Universe origin appear.

5. More about a pressure in Universe

Physicists working in GR refuse usually a matter static pressure in Universe. They believe that this one and corresponding energy are equal to zero and claim the sentence "Gravitation is geometry". I am going to try now to explain why this negation contradicts to the strict statements of GR.

Let us firstly consider a symmetric uniform sphere consisting in ideal incompressible liquid having non-zero matter density that is encircled with *empty Euclidean space*. If a sphere density is enough small and the sphere does not collapse due to gravitation, then there are a gravitational potential and a matter pressure inside the sphere, while an external pressure should be absolutely equal to zero. The exact solution of this problem in GR was given by Schwarzschild (see **[Толмен, 1934]**), where, of course, he used the corresponding component of the metric tensor, not the Newtonian gravitational potential.

Let us now remember the Einstein's idea about the Universe geometrically *closed to itself*. In other words, now our sphere is not encircled with empty space, contrary, the matter fills the all "Universe" *having now spherical Riemann's geometry*. In such Universe that is entirely fulfilled by a uniform matter a pressure is *anywhere* different from zero.

The next (concluding) step consists in analyzing of case, when a matter density is so great that the sphere collapses due to gravitation. It may seem to be paradoxical, but our Universe has the average density near to 10^{-30} g/sm^3, and its gravitational radius is near to 10^{28} sm, while its real size has to be 3π times less, as I showed in **[Shulman, 2007b]**.

In other words, our Universe should really collapse. The Schwarzschild's solution was firstly used for non-collapsing sphere. However, it may be easily transformed and allows us to see how a pressure features change, when the collapse appears and evolves (**[Shulman, 2007a]**). This solution implies that a pressure becomes negative in collapsing Universe.

References

[Einstein, 1918] Einstein A. Der Energiesatz in der allgemeinen Relativitatstheorie. Sitzungsber. Preuss. Akad. Wiss., T.1, 448-459.

[Einstein, 1953] Einstein A. The Meaning of Relativity. Princeton, 1953.

[Landau et al., 1965, 1976] Landau et al. *Mechanics and molecular physics*, Moscow, Nauka, 1965. Landau and Lifshitz. *Statistical Physics,* part. 1. Moscow, Nauka, 1976.

[Masso, 2009] E. Masso. The weight of Vacuum Fluctuations. arXiv:0902.4318v1 [gr-qc] 25 Feb 2009.

[Shulman, 2006] M.H. Shulman. Paradoxes, Logics, and Physical Nature of Time. Available at: http://www.timeorigin21.narod.ru/rus_time/Origin.pdf (in Russian), http://www.timeorigin21.narod.ru/eng_time/Eng_paradoksy.pdf (shortly)

[Shulman, 2007a] M.H. Shulman. Usual collapse and unusual one. 2007. Available at: http://www.timeorigin21.narod.ru/eng_time/Collapse.pdf

[Shulman, 2007b] M.H. Shulman. Cosmology: a New Approach. Available at: http://www.timeorigin21.narod.ru/eng_time/Cosmology.pdf

[Shulman, 2007c] M.H. Shulman. On the supernovae low luminosity problem. 2007. Available at: http://www.timeorigin21.narod.ru/eng_time/On_supernovae.pdf

[Shulman, 2007d] M.H. Shulman. On an experimental validation of the selected reference frame existence in the Universe. 2007. Available at: http://www.timeorigin21.narod.ru/eng_time/ On_the_selected_reference_frame.pdf

[Shulman and Raffel, 2008] M.H. Shulman, G.A. Raffel. On the Oldest Photons Phenomenon. Available at: http://www.timeorigin21.narod.ru/eng_time/Oldest_photons_eng.pdf

[Tolman, 1934] R.C.Tolman. *Relativity, Thermodynamics, and Cosmology.* Oxford, Clarendon Press, 1934.