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COSMOLOGY

A perpetual mass-generating Planckian universe

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Abstract. The local Friedmann–Einstein equation of general relativity for model universes is generalized, in the spirit of Mach's principle, to an integro-differential equation by introducing the gravitational potential of the universe. This equation is thereafter integrated, and a useful differential equation is obtained, which in the flat space can equivalently be treated by special relativity. An important formula is proposed, which demonstrates that the light speed squared, c^2, is equal to the gravitational potential. In this model universe the critical density of matter turns out to be three times smaller than traditionally obtained, thus removing the necessity of dark energy. The evolutionary scenario of the flat-space universe replaces the concept of the traditional Big Bang universe by a steady Milne-type everlasting mass-generating universe. In it not only the initial state of the universe, but also its evolutionary scenario is determined by four fundamental constants of physics, which specify also the light speed as the dilution rate and the constant Planckian mass generation rate, $\dot{M} = c^3/6G$. The observed value of the inverse Hubble parameter is the current age of the universe to the observer. Moreover, due to the constancy of the gravitational potential, the model avoids primordial inflationary expansion of the universe and anthropocentrism of the present epoch in its evolutionary scenario. Simple formulae are derived, which demonstrate that the primordial nucleogenesis of light atoms and the formation of the cosmic microwawe background occur at an almost identical temporal run of temperature and density for any reasonable value of the state parameter n of the model universe studied. The evolutionary differences can appear for a ΛCDM model universe only at redshift values less than one.

Key words: cosmology, model universes, Mach's principle, dark energy, dark matter.

1. INTRODUCTORY REVIEW

During some last decades essential progress has been made in observational cosmology, reaching redshifts $z = 8$ for cosmic X-ray bursts of extremely remote celestial bodies. This progress has generated complicated problems for cosmologists and theoretical physicists to generalize and explain adequately, based on high precision observation data, the physical ideas of the Friedmann–Einstein equations of an expanding model universe.

One of Einstein's leading ideas in formulating general relativity was the Mach's principle that local physical laws must incorporate gravitational interaction with matter in the whole universe (Einstein, 1916a, 1916b). However, his equations of general relativity were formulated as a physically elegant, but mathematically complicated system of nonlinear partial differential equations for Riemannian space-time geometric tensors, equalized to the local energy–momentum tensor of matter formulated in Minkowski's terms of special relativity. Einstein intuitively estimated that the latter had not such a fundamental formulation as the Riemannian tensors. From these equations, simplified by the cosmological principle for the homogeneous and isotropic universe, Einstein first derived the stationary model universe by introducing a hypothetical cosmological constant for incorporating Mach's principle.

The first set of modern model universes, where the cosmological constant was ignored, was elaborated by Friedmann (1922, 1924). An essential feature of these fixed-mass model universes was that they had final age and were expanding or contracting. This amazing fact meant that scientists were impelled to seriously think about the creation of the universe. Probably Lemaître (1927) was the first who proposed the concept of an expanding universe, connecting it to extragalactic observations and in a short note he expressed his opinion about its quantum-theoretical nature as the Planckian universe (Lemaître, 1931). Somewhat later Hubble (1929) found from observation data the presence of a cosmological redshift for remote galaxies, meaning that our universe is expanding. Its age was estimated to be some billions of years. Due to several further specifications, first by Baade (1952) and thereafter by Sandage (1954, 1958), based on an essentially more detailed and larger set of observational data, the rescaled value of the Hubble parameter at the present era, named the Hubble constant, gave for the age of the universe about 13.6 Gyr. This age has survived hitherto the precision estimations. Thereafter, it was found that the expansion of the universe is decelerating. This was concluded from the theory based on the concept of universal gravitational attraction, which survived in cosmology for several decades.

New principal problems concerning the expansion rate and its nature appeared during the last decades of the 20th century. In fitting the Big Bang model universe to concord the observed Hubble's constant and the density of baryon matter two additional physically problematic quantities were introduced, first the presence of dark matter in addition to baryonic matter in the celestial bodies and interstellar space was proposed, and thereafter enigmatic impelling dark energy, described via a newly introduced cosmological constant, was suggested to play the role of observationally lacking matter and to explain the dynamic effects in the universe.

A hypothetical substance in cosmology, named dark energy or, similarly to the ancient Greeks in a more general sense, the 'quintessence', is assumed to describe in some aspect the process of accelerating expansion of the universe. The physical meaning of dark energy has remained, however, hitherto quite obscure. If it has the same nature as inflationary expansion, it is incomprehensible why it is about 120 decimal orders smaller than in an exponentially expanding or an inflationary primordial universe.

The dominant modern revision of model universes is the concept of their accelerating expansion, concluded first from the observational dependence 'observed stellar magnitudes versus cosmological redshifts' of the SN Ia supernovae. Namely, the results of data analysis suggested that an enigmatic dark energy, which in the current cosmological epoch, beginning from $z \approx 0.5$, has started to be dominant in the universe and therewith started to cause an accelerated exponential expansion of the universe, should be introduced into the formulae.

During the first two decades of the 21st century essential progress has been made in the elaboration of the mainstream Lambda Cold Dark Matter (ΛCDM) model universe (Perlmutter et al., 1998; Riess et al., 1998), i.e. the dark energy plus the cosmic dark matter model universe. Mainstream cosmologists mostly accept that Mach's principle has been realized in the general relativity via the cosmological principle and, primarily, by the cosmological constant Λ, which can be treated as the universal impelling energy density of the vacuum, generating anew an inflationary expansion of the universe. It is worth emphasizing that the Friedmann equations are valid only for large distances, where the cosmological principle can be applied. This is an evidence that the equations for the model universe are, strictly speaking, not local ones.

The meaning and necessity of the cosmological constant have been a subject for heated discussions during more than 70 years and no final, generally accepted opinion has been suggested. A simple circumstance, which illustrates the role of matter in the whole universe is that very remote celestial bodies, say quasars, galaxies, and supernovae, specify the non-rotating reference frames at very great distances from the Milky Way.

During recent years several scientists have found that it is possible to elaborate also other, more simple model universes, which in some aspects can even somewhat better fit in with observational light curves of Ia type supernovae. Here the papers by Melia and his colleagues (Melia 2012, 2013; Melia and Maier, 2013;

Wei et al., 2015) deserve mentioning. These authors use a detailed version of Milne's theory (Milne, 1935) accommodated to a flat and matter-populated model universe expanding at the speed of light.

We started serious studies of the model universes (Sapar, 1964) already at the time when the cosmic microwave background (CMB) had not yet been discovered by Penzias and Wilson (1965a, 1965b) and thus the thermodynamic status of the universe was totally unknown. We generalized the Friedmann–Einstein formulae for multi-component matter in the universe, incorporating radiation, $n = 4$, cold atomic matter, $n = 3$, and a negative pressure component, $n = 2$, which we supposed to be connected with the gravitational potential of the total universe or in other words, with Mach's principle. Somewhat later (Sapar, 1977) we proposed a model universe, initiated from fundamental Planckian units, but evolving without any intermediary cataclysms to its present state. Such model universe can be treated as a version of Milne's expanding flat universe. The idea that the primordial universe can be initiated from Planckian units was expressed first by Lemaître (1931) in a short note.

Thereafter we interrupted cosmological studies for almost three decades due to the triumph of a new theory, named the inflationary expansion of the primordial universe (Guth, 1980; Starobinsky, 1980; Linde, 1982), in which the matter was created from excited vacuum by hypothetical expelling excitons. The theory helped to remove the horizon paradox and the space flatness paradox from cosmology. But later, in order to explain the results of detailed and high-precision observations, the concepts of unknown dark matter and the enigmatic dark energy were proposed. This is the present mainstream evolutionary scenario of the expanding universe, named the ΛCDM concept. In it appeared an anthropocentric paradox, meaning that our epoch is peculiar in the evolutionary scenario of the universe.

In our recent paper (Sapar, 2017) and in earlier papers (Sapar, 2011, 2013) we concluded that dark energy can be approximated by the kinetic energy dominance (KED) in the (quasi-)flat universe. This concept turned out to be related to Mach's principle via gravitational potential.

For all model universes there is a strict atomic density of matter, called the critical density, which has an important role in the classification of model universes by the curvature of space. Applying explicitly Mach's principle to model universes, we propose here a simple analytical formula, according to which the critical density of cool rest-mass particles in our Milne-type model universe turns out to be three times smaller than traditionally accepted, thus removing the necessity of the existence of the enigmatic dark energy.

The Milne-type expanding model universe, studied by us, is populated with rest-mass particles and it has a constant expansion rate, corresponding to the light speed, c. In this universe takes place also steady mass generation at a temporally constant rate. The constant rate can also be treated as a constant radial mass flow in the universe. Both of these fundamental quantities are the classical ones and not obligatorily coupled to quantum theory.

Extremely simple formulae for the temporal evolution of mass density and temperature have been derived, which demonstrate that the primordial nucleosynthesis of light elements and the formation of the CMB are practically independent of the model universe, specified by the evolution corresponding to the state parameter n.

2. SPECIAL RELATIVITY IN A FLAT MODEL UNIVERSE

A paradigm in cosmology is that the cosmological redshift in the spectra of remote celestial bodies is generated by the space expansion. Recent detailed observations demonstrated that the space for cosmology is (almost) a flat one. Thus, it is justified to study whether the Doppler redshift can be explained also as an expansion of the atomic medium in a flat space of special relativity. The maximal velocity of rest-mass atomic matter, being the light speed, c, and the cosmological redshift parameter, z, are interconnected by the dimensionless velocity, β, of special relativity by

$$1+z=\frac{(1+\beta)^{1/2}}{(1-\beta)^{1/2}}, \quad \beta=\frac{v}{c}=\frac{R_o^2-R_i^2}{R_o^2+R_i^2}=\frac{a^{-2}-1}{a^{-2}+1}. \tag{1}$$

From these formulae it follows that

$$1+z=\frac{R_o}{R_i} \tag{2}$$

in accordance with general relativity. Consequently, both the general relativity for the space expansion and the special relativity for the Doppler shifts of spectral lines of atomic particles in the flat space give the same redshifts. Thus, by these formulae we cannot discriminate whether the flat space is expanding or not. A nontrivial problem remains to find formulae that can enable to finally solve from observational data the problem for the flat-space universe. The dimensionless velocity β can be written also in the form

$$\beta=\frac{(1+z)^2-1}{(1+z)^2+1}=\frac{z(1+z/2)}{1+z(1+z/2)}. \tag{3}$$

This expression connects β with the redshift of the devoid Milne model universe both in the nominator and the denominator, showing how the populated Milne model universe is at large redshifts related to special relativity. The relation between the special relativity in Minkowski's terms and the general relativity for the Milne model universe was excellently elucidated by Chodorowski (2005).

Now we can find what the velocity according to the special relativity corresponding to the Hubble sphere is at $z=1$. According to (3), we obtain $\beta_H=3/5$. It deserves mentioning that in cosmology we can ascribe meaning to distances at which the cosmological principle holds.

One of our guiding ideas here is to apply Mach's principle and special relativity in order to interpret in a new aspect the Friedmann–Einstein equation. Herewith it is reasonable to once more recall that the derivation of the Robertson–Walker metric, specified in comoving coordinates, was accompanied by the specification of local velocities in the energy–momentum tensor by using special relativity formulae that are the right-hand side of the Einstein formula.

If we accept that $\dot{R}_i^2$ corresponds to the Planckian era, then for it must hold $\beta=1$ and $\dot{R}=c$. We assume that this holds for any moment, i.e. we assume that the generalized cosmological principle holds in the universe. Thus, we obtain the expanding Milne's model universe

$$R=ct \tag{4}$$

and for the time-dependent Hubble parameter

$$H=\frac{\dot{R}}{R}=\frac{1}{t}, \tag{5}$$

where t is the age of the model universe for observers. The Hubble constant for the present epoch is determined from the dependence of luminosity distance d_{L} versus the redshift parameter z, which for the populated Milne-type model universe is given by

$$d_L=\frac{c}{H_o}(1+z)\tau, \qquad \tau=\ln(1+z), \tag{6}$$

from where at small cosmological distances $d_L=cz/H_o$. By statistical analysis of observational data, including also Bayesian fitting, the observational radius of the universe R_o has been estimated.

For any arbitrary moment, including the epoch of observation in the model universe, holds

$$4\pi\rho R^2=\frac{3M}{R}=\frac{3M_o}{R_o}. \tag{7}$$

Taking into account that in the Friedmann–Einstein equation the energy–momentum tensor according to Mach's principle must be determined by the gravitational potential U, we can write

$$\dot{R}_o^2=\frac{2\cdot 4\pi G}{R_o}\int_{R_e}^{R_o}\rho R^2 dR=\frac{6GM_o}{R_o^2}(R_o-R_e)=\frac{6GM_o}{R_o}(1-a). \tag{8}$$

Here the correction coefficient 2 belongs to the Einstein–Schwarzschild metric in general relativity.

Integrating up to the initial Planckian moment, we obtain for gravitational potential an important equation

$$c^2 = U = \frac{6GM}{R} = 8\pi G\rho R^2. \tag{9}$$

This equation demonstrates that the critical mass density for the model universe, if Mach's principle is applied via the gravitational potential, turns out to be three times lower than traditionally accepted. Introduction of gravitational potential for cosmology is similar to the generalization of local Maxwell equations for the electromagnetic field to non-local ones by defining the electromagnetic potentials of adjacent charges as electric field strength sources.

For steady mass production process holds

$$M = \dot{M}t, \tag{10}$$

where from (4) and (10) follows that the mass production rate has been and will in the future be given by the fundamental constants of physics in the form

$$\dot{M} = \frac{c^3}{6G}. \tag{11}$$

The numerical coefficient $6 = 2 \cdot 3$ takes into account the Einstein–Schwarzschild doubling coefficient in expressions of gravitational potential and the coefficient 3 takes into account that the mass in the mass-generating universe with a constant mass 'broadcast' flow through any spherical surface generates a three times larger gravitational potential than the equidensity sphere. Thus, we obtain the model universe in which there has been and will be everlasting mass production at the initial Planckian sphere. Our concept of the model universe resembles Hoyle's steady-state universe (Hoyle, 1948, 1949), but in it figurates steady mass generation, located at the Planckian sphere. Such mass-generating Planckian universe was proposed semi-implicitly by us already 40 years ago (Sapar, 1977).

Formulae (10) and (11) show that by our concept the traditional Big Bang universe has been transformed into a kinetic Milne-type universe, where permanent mass generation occurs at the primordial Planckian sphere. Its temperature and mass are specified by

$$T_P = \frac{m_P c^2}{k} = 1.42 \cdot 10^{32}\ \mathrm{K}, \quad m_P = \left(\frac{\hbar c}{G}\right)^{1/2} = 2.18 \cdot 10^{-5}\mathrm{g}. \tag{12}$$

The expressions in Eq. (12) have been for a long time treated as corresponding to gravitational fluctuations at the birth of our universe; however, adequate theory for the process is still lacking.

An important feature is that the radial coordinates are now not specified as comoving but as diluting ones corresponding to equipotential surfaces, U, which are forming if $\rho R^2 = \mathrm{const.}$ as shown in Eq. (9). As R_o =13.6 giga-lightyears, the density of matter for the present epoch is $\rho_o = \frac{1}{3} \cdot 10^{-29}$ g/cm^3, which is in accordance with astronomical estimates of its value.

The mass-populated Milne-type cosmology has been studied extensively during recent years, especially by Melia with colleagues (Melia, 2012, 2013; Melia and Maier, 2013). This theory was criticized by Mitra (2014). It deserves emphasizing that very detailed analysis has demonstrated that the void Milne universe for the distance light curve of SN Ia supernovae corresponds amazingly well to the ΛCDM concordance model universe for SN Ia light curves (Nielsen et al., 2016). The reduced distance module for the void Milne model universe is $z(1+z/2)$ while for the populated universe studied here it is $\ln(1+z)$. The first two members of its series expansion at small values of the redshift give the same expression as the luminosity distance for the void Milne universe. This correspondence was earlier emphasized by Chodorowski (2005) as a useful tool for cosmologists.

3. EVOLUTION OF DIFFERENT MODEL UNIVERSES

Let us study now the evolutionary scenario of the steady mass-generating model universe and some other traditional model universes. For the thermally relativistic evolutionary epochs of the expanding universe holds

$$\frac{\rho_o}{\rho_P} = \frac{R_P^2}{R_o^2} = \frac{T_o^4}{T_P^4}, \tag{13}$$

and thus

$$T_o = a^{1/2} T_P. \tag{14}$$

From here it follows that $T_o \approx 3$ K, which also corresponds well to the observed CMB of photons, for which the exactly measured temperature $T_\gamma = 2.725$ K. The coincidence $T_o \approx T_\gamma$ is a testimony that the number of elementary particles in the universe has always been quite small. Thus, here, in a qualitative study, we can not specify the number of particles in the early universe. A detailed thermal history of the traditional early universe was analysed by Padmanabhan (2002).

From the Friedmann–Einstein formulae it follows that for specified values of the equation of the state parameter n we obtain

$$4\pi G \rho_n t^2 = \frac{2}{n^2}. \tag{15}$$

This formula demonstrates that the evolutionary run of density relative to the age of the universe for all species of particles is very similar for all studied model universes with different values of n.

Another similar formula, which follows from the Friedmann–Einstein equations, shows that as for any model universe specified by the parameter n holds $\rho_n = \sigma_n T^4$ at thermodynamically equilibrium epochs, then also

$$4\pi G \sigma_n T^4 t^2 = \frac{2}{n^2}, \tag{16}$$

which specifies the thermal evolutionary scenario of the expanding model universes.

Formulae (15) and (16) are essential constraints, which help to compare the observable evolutionary results of different model universes. These formulae demonstrate also that the primordial nucleogenesis of light atomic abundances is practically independent of the parameter n used in model universe computations. The critical paper by Lewis et al. (2016) on the nucleosynthesis in the $R_h = ct$ universe is in error, as it is accepted there that tT was constant in the early universe. This assumption is in severe contradiction to the initial Planckian temperature.

During some recent years appeared an interesting critical concept about model universes, which bases on the coordinate transformation of the proper time metrics, showing that the metrics of the $R = ct$ universe (Mitra, 2014) as well as of several Friedmann–Robertson–Walker (FRW) metrics can be transformed to the flat and static Minkowski metric by complicated unphysical coordinate transformations. In these studies it is ignored that the observations are specified primarily by the energy–momentum tensor.

Finally, let us make here a short excursion to the evolution of our model universe, starting from Planckian units. Traditionally, the initial Planckian universe is specified by the universal physical constants $G, c, k, \hbar = h/2\pi$. In addition, formulae determining the scenario of its evolution are needed. The proposed evolutionary pictures for the model universe have since not been of such fundamental nature. The simplest way to describe the evolutionary scenario by these fundamental physical constants is to assume that the light speed c determines the temporal dilution rate of the universe as assumed in the original Milne cosmology, where $R = ct$ and the modified steady critical mass generation rate is given by (11).

The mass generation rate $\dot{M}$ and the light speed c as the expansion rate of the universe, are two fundamental classical constants, which we added to the set of Planckian units for cosmology. These quantities specify the evolutionary scenario of the steady mass-generating universe.

Numerically the mass generation rate $\dot{M} = 6.733 \cdot 10^{37}$ g/s and $8\pi G/c^2 = 2.703 \cdot 10^{-28}$ cm/g. The length of the light year is $9.462 \cdot 10^{17}$ cm. In the present epoch the critical density of matter according to (9) is $\rho_{\rm cr} = 3.23 \cdot 10^{-30}$ g/cm^3, which corresponds to the present observational estimates.

In our final interpretation the universe can be existing forever, both in the past and in the future, similarly to Hoyle's steady-state universe (Hoyle, 1948, 1949), but instead of the steady local creation of matter in every space point in our model universe the matter-generating process is ascribed to the Planckian sphere. Hubble's age of the universe corresponds to our present epoch. The earlier generated regions of the universe are cut off from us by the light-cone horizon, which corresponds to the zeroth proper-time geodesics of the light cone, specified by

$$cdt = Rd\omega, \tag{17}$$

from where we obtain by integration that for angular directions

$$\omega_i = \ln(1+z_i) = \ln(R_o/R_i). \tag{18}$$

This equation discriminates the past and the future regions for observations.

Starting from the above-proposed formulae, we try to write the equations in an integrated form. First we take into account that the neighbourhood in the 3D space is not given by volume but by distance. Thus we give the geometry of the mass-generating model universe by

$$c^2t^2 + c^2t_P^2 = R^2\Omega^2 = R^2, \tag{19}$$

where Ω is the solid angle of firmament described by celestial longitude and latitude, and thus $\Omega^2 = 1$. An important feature is that the evolution is coupled to R^2 and not to R^3 as it is the case in Hoyle's steady state cosmology, where the creation of matter proceeds everywhere in the model universe. The celestial coordinates are here used to implicitly couple our model universe with Mach's principle. As we see, from the initial quantum theoretical units in this equation there is only the Planckian time, described by $t_P^2 = G\hbar/c^5$. Thus, in this model universe quantum theoretical computations are needed to analyse its deeper meaning if possible.

Let us present now the evolution scenarios for some other main characteristics of the model universe. For mass we have similarly in squared form

$$M^2 = \dot{M}^2t^2 + M_P^2 \tag{20}$$

and for temperature

$$T^4 = T_P^4t^{-2} = T_P^4t^{-2} + T_P^4. \tag{21}$$

4. ON DARK MATTER IN GALAXIES

An interesting similarity of our model universe to the distribution of dark matter in galactic wide gravitational wells deserves comparing. These observed wells are probably generated by the weakly interacting small rest-mass particles, say neutrinos (Sapar, 2014), having cooled to a very low temperature and moderate velocities. In the galactic gravitational field these particles move almost radially and without any collisions, generating a stable and almost constant bilateral radial mass flow, for which holds

$$4\pi\rho r^2 = \frac{dM}{dr} = M' = \text{const.} \tag{22}$$

By using this formula, the corresponding integrated gravitational potential inside radially symmetrical galaxies is

$$U_R = \frac{4\pi G}{R}\int_r^R \rho r^2 dr = GM'(1 - r/R). \tag{23}$$

However, in generating the galactic velocity curves near its centre the initial non-radial part of velocity plays an important role, which is in detail analysed in our former paper (Sapar, 2014).

In this way wide plateaux or wells of gravitational potential are formed. We emphasize that the rest-mass particles have decelerated to low nonrelativistic velocities, cooling down not inverse proportionally to the redshift as relativistic particles, but as redshift squared. Only the dimensions of the radial part of the galactic velocity curve and the extension of its neighbouring region can help to measure the rest-mass of these particles. Best accommodated to such a scenario are particles, say neutrinos, having the rest energy of a few electronvolts. In this case they give the main contribution to dark mass. Another possibility is that the number of neutrinos has been considerably underestimated if the chemical potential has the opposite sign for all massive particles, including for each flavour a pair of neutrinos and antineutrinos. This physical circumstance gives a possibility of interpreting the generation of strong particle–antiparticle asymmetry in the universe, including for neutrinos. Thus, it can even be that the number of neutrinos is considerably larger than that of photons in the CMB.

Equation (23) is similar to the mass production formula for the Milne model universe. The radial fluxes of particles can explain the needed dark mass in galaxies.

5. RESCALING PROBLEMS

In its traditional form for observers the Friedmann equation for the ΛCDM model universe is

$$\dot{a}^2 = \Omega_m/a + \Omega_\Lambda a^2, \quad a = \frac{R}{R_o}. \tag{24}$$

The luminosity distances for the flat model universes in the Robertson–Walker coordinates are determined by

$$d_i = \frac{R_o^2}{R_i}\omega_i, \tag{25}$$

and the geodesic line of photons on the light cone, needed to eliminate the time variable, can be expressed relative to atomic matter in the form

$$d\omega = \frac{cdt}{R} = \frac{cdR}{R\dot{R}}, \quad \omega_i = c\int_{R_i}^{R_o} \frac{dR}{R\dot{R}} = c\int_{R_i}^{R_o} \frac{dR}{R^2 H}. \tag{26}$$

For the flat ΛCDM model universe it follows from (24) and (26) that

$$d_\Lambda = \frac{c}{aH_o}\int_a^1 \frac{da'}{a'(\Omega_m/a' + \Omega_\Lambda a'^2)^{1/2}}. \tag{27}$$

In these formulae the present Hubble constant $H_o = \dot{a}_o$. In addition, we ascribe to the present epoch the condition that the density of matter determined by the use of the present moment Hubble parameter and from the Friedmann–Einstein equation must be equal. In normalized units this means that $\Omega_m + \Omega_\Lambda = 1$. Therefore, the changing parameters in the brackets of (27) for former moments are not equal to the unit critical density. That is why the anthropocentric paradox appears in theory, showing that this theory must be somewhat erroneous. If we assume that $\dot{R} = c$, then we obtain for the luminosity distance

$$d = \frac{c}{aH_o}\int_a^1 \frac{da'}{a'} = \frac{c}{aH_o}\ln(1+z), \tag{28}$$

which is the same expression as in the case of our Milne-type universe. The first two members in the Taylor series expansion of $\ln(1+z)$ give namely the distance for the void Milne universe. Therefore, the luminosity distances for the ΛCDM model universe and the void Milne universe have an almost coinciding run at small and moderate cosmological distances. For comparison, we give also the luminosity distance of the pure baryon matter model universe:

$$d_m = \frac{c}{aH_o}\int_a^1 \frac{da'}{a'^{1/2}} = \frac{c}{2aH_o}(1-a^{1/2}). \tag{29}$$

It seems to us problematic how to estimate adequately the value of the Hubble constant, or more exactly, the value of the Hubble parameter in terms of special relativity. We take into account that therefore it is reasonable to assume that the radial velocity is in special relativity

$$\dot{r} = c\beta, \tag{30}$$

where r is the distance from the observer. At $z = 1$ holds $\beta = 0.6$. Thus, by scaling the Hubble constant we can overestimate the needed density of matter almost three times, whereas the needed amount of dark matter would diminish about five times. Thus, the needed contributor to dark matter in our opinion can be neutrinos, including the hypothetical sterile ones. The problem is hitherto, however, open.

6. GENERAL DISCUSSION

The present paper proposes a physically modified Friedmann equation for model universes, introducing the gravitational potential of matter in the whole universe. In our previous study (Sapar, 2017), we demonstrated that for the flat or quasi-flat expanding model universe the 'luminosity distance versus redshift' curves (the standard light curves) of SN Ia stars the ΛCDM concept with dark energy can be replaced by the KED model universe with an energy integral as an additional term. Already in our earlier paper (Sapar, 1964) we made a comment that 'to our mind, the negative pressure is induced by potential energy of given particle in gravitational field of the whole universe'. Thereafter we made in some papers various attempts to modify the Friedmann–Einstein equation, based on Mach's principle, but without essential success.

The recent results of numerous cosmologists and our former studies stimulated us to modify more radically, but in a physically motivated way, the kinematic Friedmann–Einstein equation of model universes. Introducing therefore gravitational potential, the Friedmann universe has been transformed into the Milne universe of $R = ct$ cosmology, where the inverse value of the Hubble constant H^{-1} is exactly the age of the universe. The exact age of the universe is usually found by a complicated evolutionary scenario of the universe, including the stage of its inflationary expansion.

The genesis of the universe has been usually treated by the Big Bang scenario, starting from the initial Planckian sphere, which is followed by primordial inflationary expansion during about 10^{-32} seconds, making it really to be the Big Bang. After its exponential expansion, baptized inflationary expansion, the universe starts to evolve according to Friedmann–Einstein equations, where no current mass generation occurs. The concept of a very dramatic inflationary stage in the mass production seems to be no more preferential than the scenario of steady mass production.

The steady mass-producing model universe makes all time moments equivalent, therewith this scenario excludes the anthropocentrism of the present evolutionary status of the universe and removes also the necessity of a second inflationary expansion of the universe. The physical mechanism of mass generation can be treated as quantum mechanical processes like in the theory of exponential expansion of the universe or as mass flow from a Schwarzschild white hole (Tatum et al., 2015), as mentioned in our previous paper (Sapar, 2017).

In a number of papers during some last years Tatum with colleagues elaborated the concept of the $R = ct$ cosmology, the results of which demonstrate that this concept is in many aspects superior compared to the ΛCDM model universe. The results of these studies are in detail summarized in a paper by Tatum (2018). It is worth special emphasizing that he with colleagues accommodated the compact formula of gravitational entropy, elaborated by Penrose and Hawking, to cosmology and by it determined an adequate fit of the cosmic radiation temperature anisotropy of the CMB with observations without any need for the inflationary expansion of the universe.

Simple universal formulae have been derived which demonstrate that the nucleogenetic scenario of primordial light atoms and the formation of the CMB occur in almost identical conditions for all model universes, specified by different values of the parameter n. Thus the study of early nucleogenetic processes can hardly help to choose the most adequate model universe. The same holds for the epoch of the formation of the CMB when dark energy did not play any role.

Summing up our concept, the strictly flat universe is physically acceptable only if it has existed forever in time. In this case there is no need for any boundary condition. The previously generated material part of the universe is imperceptible to us, while light-cone geodesics in any angular direction is always directed towards the future, i.e. towards larger values of the radial coordinate in the expanding universe. Similarly to the original Milne cosmology, the mass generation process must proceed in a definite space point, but instead of a single igniting bang the generation of the steady and perpetual Planckian mass and energy flow takes place. In this world the gravitational potential is the same in any point and thus the cosmological redshift is favoured as a kinetic phenomenon of special relativity. In this case there is no need for an equation of the state specifying pressure in cosmology. The Planckian units are also coupled to Heisenberg's uncertainty principle by $E_P t_P = \hbar$. This is an essential constraint in studies of the infernal machinery of energy and mass generation. As the Planckian sphere corresponds to the realm of quantum fluctuations, it can also generate the primordial seeds for the generation of the perturbations from which later stars, galaxies, and their superclusters will evolve. Whereas the light speed squared is the universal gravitational potential in the universe, the study of the formation of mass perturbations in the universe requires special attention.

In modern cosmology several serious discussions have been started. One of them is about the equation of state for cosmology, which in fact means that the role of pressure in cosmology is unclear. In equation (8), which can be called the kinetic energy equation for $\dot{R}^2$, there is no pressure term. Therefore, we have concluded that in cosmology pressure is unnecessary and formally it can be obtained by differentiating the kinetic equation. Thus, it is not necessary to reduce discussions to the corresponding quintessence level. Another discussion concerns the fractal nature of order 2 due to inhomogeneities of the distribution of matter. Also this discussion seems to be unnecessary in the mass-generating universe.

In some respects our vision coincides with Melia's ideas (2012, 2013, 2015) that the Milne-type universe may well correspond to our universe; however, we support the Planckian everlasting source concept. Melia's concept that the active mass $m + 3p = 0$ (Melia, 2017) corresponds to our concept that the gravitational potential is constant in the universe and therefore any force in the universe is lacking and the evolution of gravitational perturbations is more effective than in the ΛCDM universe.

The present situation in cosmology suggests that there are different possible model scenarios for the genesis and physically adequate evolutionary scenarios of our universe. Which of them turns out to be physically the best one, remains hitherto open. This is the problem to be solved in cosmology by detailed and high-precision study of rapidly accumulating different kinds of observational data. However, we hope that the present paper may help to further progress in cosmology.

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Igavesti massi genereeriv kosmoloogiline mudel

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Juba mitu aastakümmet kestnud tumeaine ja tumeenergia otsingutel peavoolu kosmoloogias pole õnnestunud nende füüsikalist olemust üheselt määrata. Alternatiivotsinguteks on kosmoloogia võrrandite füüsikaline modifitseerimine mitmesuguste hüpoteeside baasil. Selle suuna üheks haruks on paisuva universumi gravitatsioonivälja kirjeldamiseks lähtuda vaid meile juba tuntud füüsikalistest suurustest ja füüsikaseadustest. See on olnud ka meie lähteseisukohaks kosmoloogias.

Olulisele üldistusele viis meid universumi gravitatsioonipotentsiaali sissetoomine Friedmanni kosmoloogia võrrandisse ja uudne hüpotees igavesest massi genereerivast universumist. Meie teoorias Plancki ürgsfäärist lähtuv ja inflatsioonilist ainetekke etappi läbiv suure paugu stsenaarium asendub radiaalselt valguse kiirusega laieneva ehk Milne'i tüüpi universumis pidevalt toimiva massitekke stsenaariumiga. Selle kontseptsiooni kohaselt on nii universumi algseisund kui ka ta evolutsioonistsenaarium määratud füüsikaliste fundamentaalkonstantidega. Evolutsiooni määravateks universaalkonstantideks on valguse kiirus c ja massitekke tempot määrav konstant $\dot{M} = c^3/6G$. Fundamentaalseosena järeldub, et $c^2 = U$, kusjuures universumi gravitatsioonipotentsiaal avaldub kujul $U = 6GM/R$, vähendades seega kolmekordselt universumis vajalikku kriitilist ainetihedust, mis kõrvaldab ka tumeenergia vajalikkuse ja sellest tuleneva universumi edasise eksponentsiaalse paisumise.

Milne'i universumi mudelist järelduv seos visuaalne tähesuurus *vs.* punanihe osutub heas kooskõlas olevaks standardheledusega küünaldena kasutatavate SN Ia supernoovade kaugusest sõltuvate heledus-kõverate andmetega. Seejuures Hubble'i konstandi pöördväärtus osutub täpselt võrdseks vaatlustest määratava universumi vanusega. Kõigi ajahetkede samaväärsuse tõttu valemites kaob universumi praeguse arenguetapi eriline, nn antropotsentriline iseloom.

On tuletatud lihtsad valemid, millest nähtub, et universumi paisumisel nii kergete atomaarosakeste süntees kui ka kosmilise mikrolainete fooni moodustumine toimuvad eri mudeluniversumites peaaegu identsetes füüsikalistes tingimustes.

Juba kosmilise raadiokiirguse avastamise eelses mahukas uurimuses (Sapar 1964) on käsitletud ka nn negatiivse rõhuga olekuvõrrandile vastavat massivoo valemi $\rho R^2 c = const.$ tüüpi liiget, mis kujundab gravitatsioonipotentsiaali konstantsuse universumis. On leitud sisult ja kujult analoogiline valem ekvipotentsiaalsete platoode seletamiseks radiaalsete neutriinovoogudena galaktikate puhul.