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Dark Energy and the Riddle of the Cosmological Constant

Horst Fritsch

Retired scientist, D-71229 Leonberg, Germany

***Corresponding author**
Horst Fritsch, Retired scientist, D-71229 Leonberg, Germany.

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Dark energy was created to interpret astronomical observations that the earlier standard model of cosmology could not explain.

First, measurements of the pattern of cosmic background radiation revealed that the universe must be large-scale flat, corresponding to an average density greater than the "dark" and visible matter combined account for.

Second, measurements of Type Ia supernovae (SNIa) revealed that the universe is expanding at an accelerated rate. Dark energy is supposed to be the missing energy needed for a flat spacetime ($\Omega = 1$), and it is also supposed to generate an antigravity force so that the universe can expand faster and faster.

The cosmological constant Λ, once introduced by Einstein and later discarded by him, was used as a synonym for dark energy. It represents a constant (negative) vacuum energy density (εv), which is supposed to be an antigravitational force causing today's accelerated expansion of the universe. However, as the "Cosmic Time Hypothesis" (KZH) presented in this paper shows, the cosmological constant Λ has to be rejected again, because the vacuum energy density (εv) can neither be constant nor negative, but is a component of the total (positive) energy density of the universe. It is included in the energy-momentum tensor of Einstein's field equations and amounts to 75 percent of the total energy density of the universe. This means: the Cosmological Constant has the value zero ($\Lambda = 0$) and consequently there is no Dark Energy. Another astonishing result from the KZH is that the vacuum energy density (εv) today must be smaller by a factor of 10^{-122} than the value resulting from the quantum field theory. A result that is in exact agreement with astronomical observations.

Introduction

In order to evaluate and solve the problem of Dark Energy and the Cosmological Constant without prejudice, it must be evaluated from the point of view of General Relativity (ART).

Soon (1917) after the publication of the ART, Einstein tried to apply it to the whole universe. But because he, like most of his contemporaries, assumed that the universe is static, i.e., has always been as we see it today, he had to add the Cosmological Constant (Λ) to his field equations as a counterforce to the attractive gravitational force in order to stabilize this state.

When Alexander Friedmann then showed (1922) that the field equations describe cosmological models even without Λ, which, however, can no longer be static, but must be dynamic, and Hubble later (1929) experimentally proved that the universe is expanding, Einstein eliminated the Cosmological Constant from his equations again, also because it: "diminishes their logical simplicity alarmingly" and was also no longer necessary for an expanding universe [1]. Based on these new findings, Einstein then developed various dynamic world models, of which the "Einstein-de Sitter model", which spans a plane (Euclidean) space, is the simplest and most elegant [1]. It was considered the standard model of cosmology for a long time, but had to be abandoned later because it could not be reconciled with more recent observational data. These required several modifications, which finally led to the much more complicated, today valid standard model (ΛCDM model) (Λ = cosmological constant, CDM = Cold Dark Matter). Thus the cosmological constant came again to honor.

But also the ΛCDM model is not undisputed, because it is based on some questionable hypotheses (inflation theory, dark matter, dark energy), whose physical meaning is not clear until today. Perhaps we should thoroughly re-examine the simplest cosmological model allowed by the ART, the Einstein-de Sitter model, and try to confront it with all the observational data we currently have.

As will be shown in this paper, the Einstein-de Sitter model, if one makes full use of the explanatory power of the ART, can indeed not only interpret many observations which have not been understood so far, but, in addition, it can also reveal new, unsuspected coincidences. The Cosmological Constant would then have to be eliminated for the second time ($\Lambda= 0$). The basis for the solution of the problem (does the Dark Energy or the Cosmological Constant exist?) is the "Cosmic Time Hypothesis" (KZH), which is briefly presented in the following chapter and which has already been published several times [2-4].

The "Cosmic Time Hypothesis" (KZH) - a new evaluation of the Einstein-de Sitter model.

For the Einstein-de Sitter model, Einstein formulated the equation

[1].

$$\varkappa\varrho/3 - h^2 = 0 \quad (1)$$

($\varkappa = 8\pi G/c^2$ = coupling constant of Einstein's field equations, G = gravitational constant, c = vacuum speed of light, $\rho = M/V = 3M/4\pi R^3$ = mean mass density of the universe, R = space radius, $h = 1/ct_H = 1/R$, t_H = Hubble time).
Transforming equation (1) gives:

$$GM/Rc^2 = 1/2 \quad (2)$$

This equation is not compatible with the present state of knowledge, because according to it G, M and c are constant, but R increases with the time (in the Einstein-de Sitter universe correspondingly $R \sim t^{2/3}$).

Conclusion: Either equation (1) or the currently valid standard model of cosmology (CDM model) are wrong. If Einstein was right, the following consequences result, if one accepts the following axioms:
I The speed of light is a universal constant of nature.
II Over large distances averaged the space is flat ($\Omega = 1$)
III The universe is homogeneous and isotropic on large scales
IV The universe is expanding at the speed of light ($\dot{R} = c$)
V The total energy in the universe is constant
From

$$R \sim t^{2/3} \quad (3)$$

results

$$dR/dt = \dot{R} \sim t^{-1/3} \quad (4)$$

This contradicts the axiom I: "The speed of light is a universal constant of nature". So, first the question has to be clarified: "What do we understand by the term natural constant?".

Answer: natural constants are physical quantities, which can be determined only empirically and cannot be derived from a superior theory. Thus, the statement c = constant means that the measured numerical value of c must always be the same at any place and at any time. The problem now is to bring this requirement in agreement with the relation (4).

As we know, Einstein relativized the time twice. In the special relativity (dependence of the time on the relative velocity) and in the ART (dependence of the time on the gravitational potential). The question arises now, whether the time must not be relativized a third time, so that the postulate c = constant is also fulfilled for the relation (4). So the task is to find a time measure which measures the speed of light as a constant quantity at all times, as Einstein recommended [1]. "One can use the principle of constancy of the vacuum speed of light to complete the definition of time." Transferred to the relation (4), the requirement c = constant is fulfilled if one introduces a time τ that changes proportionally to the world radius. By the way, this is an idea that already Henning Genz had [5]."Why then not go all the way and choose the radius of the universe as time parameter?".

For the Einstein-de Sitter universe, one then obtains for this cosmic time τ the relation

$$\tau \sim R \sim t^{2/3} \quad (5)$$

and

$$d\tau/dt \approx \Delta\tau/\Delta t \sim t^{-1/3} \sim \dot{R} \sim c \quad (6)$$

In fact, as shown in (3) and (4), pendulum clocks and atomic clocks indicate exactly this cosmic time when ticking according to the laws of KZH. Measured with

such clocks, the speed of light is then a constant quantity:

$$c(\tau) = dR/d\tau = \text{constant} \quad (7)$$

Thus, the time tract would depend not only on relative velocity (SRT) and gravitational potential (ART), but also on time itself (KZH). A comparison of these dependencies is shown in figure1.

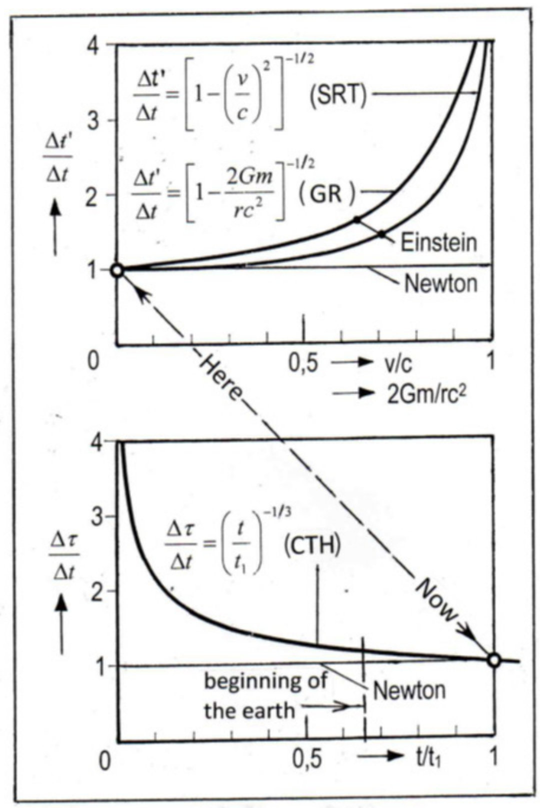

Figure 1: Time measures of SRT, ART and KZH (t1 = today)

Thus, the ART forces us to introduce the cosmic time τ in order to bring it into agreement with the equation $GM/Rc^2 = ½$ derived from it. In plain language this means: The ART is time asymmetric! It has a cosmological time arrow and thus follows the 2nd law of thermodynamics.

From the relations (2), (3) and (4) one obtains

$$GM = \text{constant} \quad (8)$$

With the assumption that the total energy E in the universe is constant, from $E = Mc^2$ and (4) for the mass universe results

$$M \sim t^{2/3} \sim R \tag{9}$$

Here M means the total gravitationally effective energy existing in the universe ($M = E/c^2$). This includes, besides the ponderable mass, also the radiation and vacuum energy. All these forms of energy are positive, as shown in (4), and are included in the energy-momentum tensor of Einstein's field equations. The other relations follow from (4), (8) and (9).

Gravitational constant:

$$G \sim M^{-1} \sim t^{-2/3} \tag{10}$$

Mean mass density of the universe:

$$\varrho \sim R^{-2} \sim t^{-4/3} \tag{11}$$

Mean energy density:

$$\mathcal{E} = \varrho c^2 \sim t^{-2} \tag{12}$$

Now one could object that time-varying "constants of nature" ($c \sim t^{-1/3}$, $G \sim t^{-2/3}$) are not compatible with ART. But since c and G do not appear solitary in the field equations, but are linked by the coupling constant $\varkappa = 8\pi G/c^2 = 1.86 \cdot 10^{-26}$ m/kg, there is no contradiction between ART and CTH.

Dark Energy and Cosmological Constant from the Point of View of KZH

The measurement results at type SNIa supernovae showed that the distance resulting from their luminosity is larger than would have been expected after the redshift of their light. From this one concludes that the universe does not expand decelerated, as assumed so far, but accelerated. Since there is certainly no reason to doubt the measured data - they were confirmed in the meantime by many scientists - the question is to be asked whether the data were interpreted so far correctly. If one evaluates them after the KZH, one receives surprisingly completely different, much more plausible results. This shall be explained briefly.

Hubble's law states that the escape velocity of a galaxy increases proportionally to its distance. The escape velocity of an object is determined by measuring the redshift z, of the light emitted by it. According to the KZH, the speed of light used to be, (according to Newtonian time, not as a measured value) greater than it is today ($c = \dot{R} \sim t^{-1/3}$). Thus, the same redshift results in larger escape velocities v and thus larger distances than according to the conventional theory, and the difference becomes larger the farther away the celestial body is. In figure 2 the measured data evaluated according to the KZH are plotted in comparison to conventional evaluations. An accelerated expansion of the universe is no more recognizable from it, with what also the main argument for the introduction of "dark energy" is invalidated. The SNIa measurement results are thus no surprise, but after the KZH so to be expected.

Dark energy is also not needed for the explanation why the universe is flat ($\Omega = 1$). This is because, as was justified in (3) and (4), if one considers the space energy as positive energy contained in the energy-momentum tensor of Einstein's field equations, then the sum of all (positive) energies, despite $\Lambda = 0$, is sufficient for a flat universe ($\Omega = 1$).

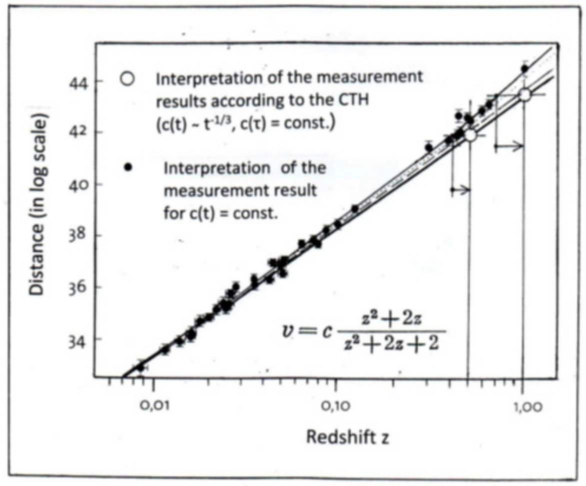

Figure 2: Hubble relation according to measurement data of SNIa.

The Enigma of the Cosmological Constant

"It remains unsolved to this day and is perhaps the deepest unsolved fundamental problem in physics today" [7].

Below we will examine the consequences of setting $\Lambda = 0$ in agreement with Einstein. As pointed out in (3) and (4), the gravitational potential energy increases when the objects located in the expanding universe are brought to greater distances from each other against the gravitational force. This requires energy, which is then stored as vacuum energy in the newly created space. Conversely, energy would be released if matter-filled spaces gravitationally implode or shrink. The space (the vacuum) contains therefore positive energy! This is provided by the gravitational braking energy which is expressed in the decreasing expansion velocity of the universe.
Based on these considerations, the vacuum energy density (εv) can be calculated according to the KZH (3) and (4).
One obtains:

$$\mathcal{E}v = \tfrac{3}{4}\,\mathcal{E} \sim t^{-2} \tag{13}$$

($\mathcal{E}$ = total energy density of the universe).
The vacuum energy (space energy) could also be conceived as modern aether, similar to Einstein's formulation at a lecture in Leiden, Holland, in 1920 [3]. p. 556 "The aether of general relativity is a medium which is itself devoid of all mechanical and kinematic properties, but which co-determines the mechanical (and electromagnetic) events."

The puzzle of the cosmological constant is that the value of the vacuum energy density calculated by means of quantum field theory (QFT) is larger by about 122 powers of ten (10^{122}) than it should be on the basis of observations.

How to calculate the vacuum energy density by means of QFT is explained by H. Goenner [6]: "In the existing quantum field theories, the vacuum energy density usually diverges (ultraviolet divergence), i.e., the integral over all wavenumbers k diverges. To avoid infinitely large values, one cuts off the k-space at an energy scale Ex = 10^{19} GeV, i.e., at the Planck scale (tp = 10^{-43}s)."

According to equation (13), the vacuum energy density at Planck time (tp = $5.4 \cdot 10^{-44}$s) - quantum field theory cuts off the divergent integral series at this point - compared to today (t1 = $4.3 \cdot 10^{-17}$s) yields a ratio value

$$\mathcal{E}vp/\mathcal{E}v1 = (4.3 \cdot 10^{17}/5,4 \cdot 10^{-44})^2 = 0.6 \cdot 10^{122} \qquad (14)$$

This is an amazing result and it solves one of the biggest problems in modern physics!
In summary, the KZH requires a completely new interpretation of the term "vacuum energy":

I. The vacuum energy density is positive and time dependent ($\varepsilon v \sim t^{-2}$), not negative and constant, which is the assumption of the present doctrine.
II. The cosmological constant does not exist in reality ($\Lambda = 0$), therefore there is no "dark energy" ($\Omega = 0$).
III. The vacuum-energy-density is a component of the total energy of the universe and is contained in the energy-momentum-tensor (Tik) of Einstein's field-equations. III $\Lambda = 0$ means: the KZH gets along with one free parameter less than the CDM-model!

Moreover, as pointed out in (3) and (4), the KZH also solves many other problems in cosmology. Examples are:
1. The KZH does not require an inflationary phase in the early universe.
2. According to KZH, the strongest natural force (strong nuclear force) and the weakest (gravitational force) were identical at Planck time (tp = 10^{-43}s) - when, according to the theory of supergravity, all natural forces were equal in magnitude - i.e., they had the same strength and range.
3. In the cosmic time there was no "big bang". The universe is infinitely old.
4. According to the KZH, the cosmic expansion is permanently in a state of unstable equilibrium, which is necessary for a long-term flat, evolutionarily evolving universe.

All these findings result from an extended interpretation of the ART, which is necessary if one extends its validity to the entire universe.

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