The Origin of the Energy

- Der Ursprung der Energie -

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Abstract

The energy is an essential basic concept of physics. Additionally, the mass is included, as it is equivalent to energy. Moreover the energy is constant in the time evolution of the universe. So the question arises: What is the origin of the energy. Using general relativity and quantum physics, we determine that origin. Moreover I report about experience with that topic in a research club and in university courses.

1. Introduction

The energy is an essential basic concept of physics. It includes very different phenomena corresponding to domains such as mechanics, electricity, thermodynamics, chemistry, particle physics including transformations from energy to mass or vice versa, biology, astronomy and cosmology.

It is fascinating that in all these domains, the energy is conserved, it is an invariant. So the total energy of the world ranging from Earth until the light horizon does not change. So that total energy did not change during the time evolution ranging from the Big Bang 13.8 billion years ago until today.

Accordingly the natural question arises: What is the origin of all that energy including mass? Tryon (1973) proposed the hypothesis that the energy of the universe might originate from zero-point oscillations, ZPO. Here we analyze that possibility by using concepts and results of quantum gravity.

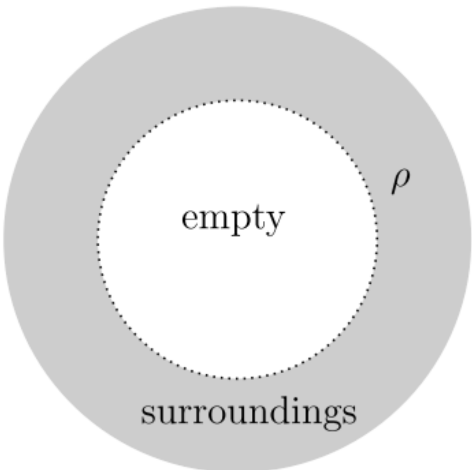

Fig.1: Homogeneous universe frame, HUF.

Frame

In order to analyze energy, we should first specify the used frame. For instance, if you ride on your bicycle along a road with a velocity of $v = 10$ m/s, then your kinetic energy is zero in the frame of your bicycle, as you sit on the saddle of your bicycle all the time. However, in the frame of the road, your kinetic energy is equal to $E_{kin} = ½ \cdot m \cdot v^2$, whereby m is your mass.

1.1. Homogeneous universe frame, HUF

In this report we use a frame that is adequate in order to describe the energy in the universe. It is the homogeneous universe frame, HUF. A HUF is constituted by an empty ball embedded in an otherwise homogeneous universe (see figure 1).

In the HUF, the gravitational field is zero:

$$\overrightarrow{G^*} = 0 \quad \text{in the HUF} \qquad \{1\}$$

Newton (1686) derived this fact for the case of Newton's law of gravity, and Birkhoff (1921) derived the same result for the case of general relativity theory, GRT.

Here we present a simple derivation that can easily be understood by students at class 11 or above. For it we separate the surroundings in figure (1) into concentric shells and we show that the fields formed by such a shell sum up to zero in the HUF. Note that the principle of linear superposition applies to these fields, as there is no screening of gravitational fields. We consider an observer at an arbitrary point in the HUF (see figure 2). The observer considers an arbitrary direction in space and analyzes two opposite areas with the same angle of view (see figure 2). The sizes of the areas are proportional to the squares of the distances r_1^2 and r_2^2. Hence the masses of these areas are proportional to these squares:

$$m_1 \sim r_1^2 \quad \text{and} \quad m_2 \sim r_2^2 \qquad \{2\}$$

Consequently, the absolute values of the fields G^*_1 and G^*_2 are equal, whereby these fields are generated by these areas at the location of the observer:

$$G_1^* = \frac{G \cdot m_1}{r_1^2} = \frac{G \cdot m_2}{r_2^2} = G_2^* \qquad \{3\}$$

Hereby G is the universal constant of gravity, $G = 6.674 \cdot 10^{-11} \frac{m^3}{kg \cdot s^2}$. As these fields are directed in opposite directions, they sum up to zero. Since the observer can analyze all areas in terms of such opposite pairs of areas, all fields generated in the whole homogeneous universe add up to zero. Note that the approximation of a homogeneous universe is quite good and statistical fluctuations of the density tend to zero, when the radius of the HUF tends to infinity (Carmesin 2021a, section 8.3). Altogether, the HUF provides an ideal laboratory for analyzing physical systems locally.

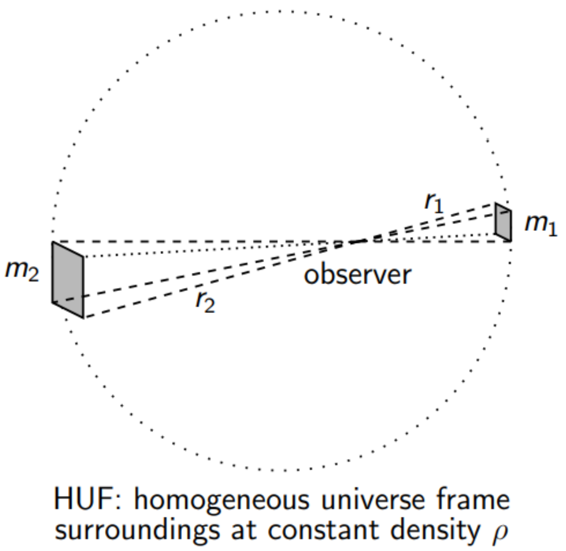

Fig.2: Cancellation of fields in the HUF.

2. Essential constituents in the universe

In order to analyze the energy of the universe, we need to know the constituents of the universe. These constituents are classified according to their behavior during the expansion of space. That expansion of space is modeled by a uniform scaling with a scale factor k.

When the space expands by a scale factor k, the volume V expands by the third power of the scale factor:

$$V \sim k^3 \qquad \{4\}$$

Matter and masses are constant during the expansion of space, so the corresponding density ρ_m is proportional to the inverse volume or to one over the third power of the scale factor:

$$\rho_m \sim k^{-3} \qquad \{5\}$$

The energy E of radiation is proportional to one over the scale factor. This is a consequence of the redshift z. Hence the corresponding density ρ_r is proportional to one over the fourth power of the scale factor:

$$\rho_r \sim k^{-4} \qquad \{6\}$$

The density ρ_Λ of the vacuum constant. That density is also called dark energy:

$$\rho_\Lambda \sim k^{-0} \qquad \{7\}$$

The curvature of the isotropic space can be described by a single radius of curvature or by its inverse, the curvature parameter K. It is shown below that the corresponding density is proportional to one over the square of the scale factor:

$$\rho_K \sim k^{-2} \qquad \{8\}$$

Altogether, the energy of the universe consists of four constituents that exhibit a specific behavior during the expansion of space. Next we analyze the time evolution of each of these constituents.

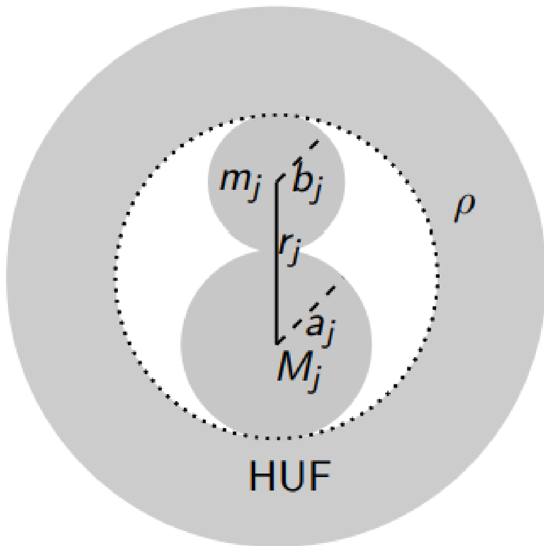

Fig.3: Two masses m and M in a HUF.

3. Energy of matter

At the time of the Big Bang, the universe was at the Planck scale. At that scale, the universe was too dense and too hot for matter to exist. So matter formed later. Thereby a part of the energy of radiation was transformed to the energy of matter. In such reactions, the law of energy conservation is obeyed. Altogether, the energy of matter originates from the energy of radiation.

Next we analyze the time evolution of the energy of matter after its formation. For it we consider a mass m. We analyze it in a HUF in the field of another mass M in the HUF (see figure 3). That mass M has a Schwarzschild radius:

$$R_S = \frac{2 \cdot G \cdot M}{c^2} \qquad \{9\}$$

Other masses or densities need not be considered, as we analyze the energy in a HUF. We choose the origin of the coordinate system at M. The energy of the mass m as a function of its radial coordinate r and of its radial velocity v is as follows (see Carmesin 2021a, section 1.8):

$$E(r,v) = m_0 \cdot c^2 \cdot \frac{\sqrt{1-\frac{R_S}{r}}}{\sqrt{1-\frac{v^2}{c^2}}} = m_0 \cdot c^2 = E_0 \quad \{10\}$$

Hereby m_0 is the rest mass at the limit of the radial coordinate r to infinity. The above eq. {10} shows that the energy has the constant value $E_0 = m_0 \cdot c^2$. The numerator in the fraction in eq. {10} is the *position factor* $\varepsilon(r)$, and it shows how the energy decreases when the mass m approaches M (see figure 4):

$$\varepsilon(r) = \sqrt{1 - R_S/r} \qquad \{11\}$$

One over the denominator in the fraction in eq. {10} is the *Lorentz factor* $\gamma(v)$, and it shows how the kinetic energy increases when the mass m approaches M (see figure 4):

$$\gamma(v) = \frac{1}{\sqrt{1-v^2/c^2}} \qquad \{12\}$$

Altogether, the energy of matter originates from the energy of radiation. The expansion of space does not vary the energy of a mass m. Of course, m may interact with other objects and exchange energy with these objects, whereby the *law of conservation of energy* holds for such interactions.

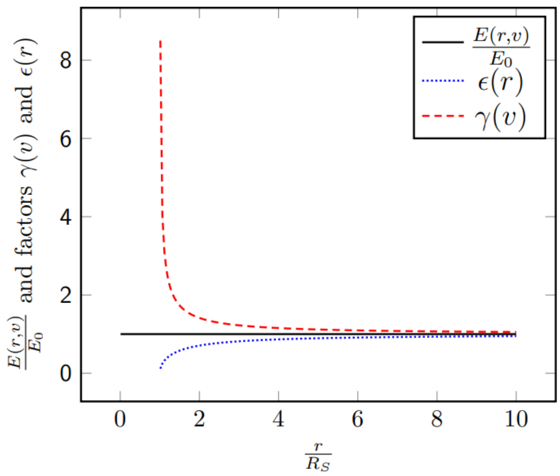

Fig.4: Energy and its factors for a mass m in a HUF.

4. Energy of radiation

At the Big Bang there formed space. In each space there form *zero-point oscillations, ZPOs*, of electromagnetic radiation, according to quantum theory (see for instance Ballentine 1998). We call ZPOs the *primordial radiation ZPOs.*

At the Big Bang, the universe was at the *Planck scale* (Carmesin 2021a). At that scale, the density was at its maximum value, one half of the *Planck density* ρ_P:

$$\rho_{max} = \frac{1}{2}\rho_P \qquad \{13\}$$

Thereby each object exhibited the smallest possible size, the *Planck length* L_P:

$$L_P = 1.616 \cdot 10^{-35} \text{ m} \qquad \{14\}$$

We analyze the following question: Was there an excited object at the Planck scale? An excitation of an object would increase the energy, while the size is still determined by the Planck length. Hence an excitation of an object would cause a density above the maximal possible density. That is impossible. Thus an object cannot exhibit an excitation at the Planck scale. Thence all objects have been at their lowest possible energy state at the Planck scale. It is the ZPO with the *zero-point energy, ZPE*.

At the Planck scale, the energy of an object is one half of the *Planck energy* E_P (see Carmesin 2021a):

$$ZPE = \frac{1}{2} \cdot E_P = \frac{1}{2} \cdot 1.956 \cdot 10^9 \text{ J} \quad \{15\}$$

Altogether, the complete energy of the primordial radiation is constituted by the ZPE, and the formation of that energy is explained by quantum physics.

4.1. Time evolution of a quantum of radiation

Next we analyze the time evolution of the energy of a quantum of radiation. The observable energy E_{obs} of such a quantum is the ratio of the *Planck constant* h times the *velocity of light* c and the *wavelength* of the quantum of radiation:

$$E_{obs}(r) = \frac{h \cdot c}{\lambda(r)} \qquad \{16\}$$

The position factor in eq. {11} describes the curvature of spacetime. So it applies to each physical object in space. In particular it applies to a quantum of radiation. So the *invariant energy* E_{inv} of the photon is the product of the observed energy and the position factor:

$$E_{inv} = \frac{h \cdot c}{\lambda(r)} \cdot \varepsilon(r) \qquad \{17\}$$

We apply the above eq. to the limit r to infinity:

$$E_{inv} = \frac{h \cdot c}{\lambda(r \to \infty)} \qquad \{18\}$$

We equate the above two equations and solve for the wavelength:

$$\lambda(r) = \lambda(r \to \infty) \cdot \varepsilon(r) \quad \text{or} \qquad \{19\}$$

$$\lambda(r) = \lambda(r \to \infty) \cdot \sqrt{1 - \frac{R_S}{r}} \qquad \{20\}$$

This shows that the wavelength increases when the quantum raises from the mass M. This effect is the *gravitational redshift*. (Fig. 5). It has been observed experimentally by Pound and Rebka (1960).

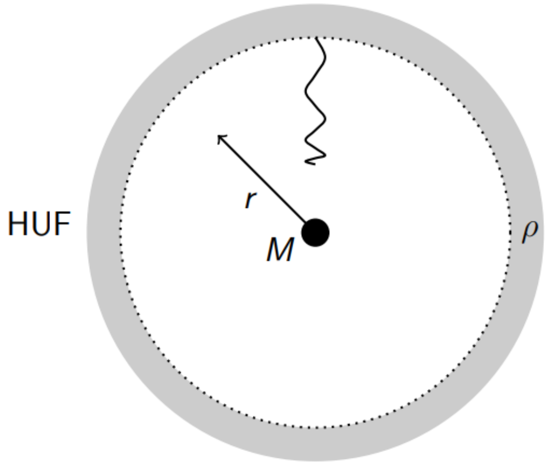

Fig.5: Gravitational redshift near a mass *M*.

The energy of a quantum of radiation can be expressed as a function of the radial coordinate *r* and of the wavelength (figure 6):

$$E(r,\lambda) = \frac{h \cdot c}{\lambda} \cdot \varepsilon(r) = E_{obs}(\lambda) \cdot \varepsilon(r) \quad \{21\}$$

Altogether, the expansion of space does not vary the energy of a quantum of radiation. Of course, the energy of a quantum of radiation may interact with other objects and exchange energy with these objects, whereby the *law of conservation of energy* holds for such interactions. Examples are *Compton scattering, pair production, annihilation* and *the photo effect.*

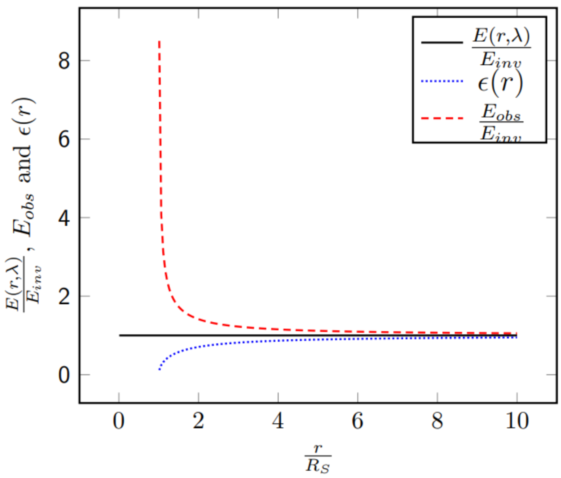

Fig.6: Energy and its factors for radiation in a HUF.

4.2. Origin of quanta of radiation

The energy of radiation originates from the primordial radiation ZPOs. We show this as follows:

We show that the present day density of the radiation is equal to the redshifted density of the primordial radiation ZPOs.

The observed density of radiation of the present day t_0 is as follows (see Carmesin 2019a, table 2.1 or Planck 2020):

$$\rho_{r,t0,observed} = 8.02 \cdot 10^{-31} \frac{kg}{m^3} \quad \{22\}$$

The scale factor ranging from the time t_0 until the Planck scale is as follows (Carmesin 2021a, eq. 8.79):

$$k_{Planck\ scale \to t0} = 2.96 \cdot 10^{31} \quad \{23\}$$

At the Planck scale, the density of radiation is constituted by the ZPOs according to eq. {13}. The usual Planck density is the *Planck mass* $M_P = E_P/L_P^3$. We use the Planck density for balls as follows:

$$\rho_{P,ball} = \frac{M_P}{4\pi/3 \cdot L_P^3} = 1.2307 \cdot 10^{96} \frac{kg}{m^3} \quad \{24\}$$

So the density of radiation at the Planck scale is as follows:

$$\rho_{r,Planck} = \frac{1}{2} \cdot \rho_{P,ball} = 0.61535 \cdot 10^{96} \frac{kg}{m^3} \quad \{25\}$$

We apply eq. {6} and derive the present day density of radiation:

$$\rho_{r,t0} = \frac{1}{2} \cdot \rho_{P,ball} \cdot k_{Planck\ scale \to t0}^{-4} \quad \{26\}$$

We insert the corresponding values:

$$\rho_{r,t0} = 0.61535 \cdot 10^{96} \frac{kg}{m^3} \cdot (2.96 \cdot 10^{31})^4 \quad \{27\}$$

So we get:

$$\rho_{r,t0,derived,observable} = 8.02 \cdot 10^{-31} \frac{kg}{m^3} \quad \{28\}$$

The *observed density* and the *derived observable density* are equal as a result of the complete time evolution of the space described in Carmesin (2017), Carmesin (2018), Carmesin (2019a,b), Carmesin (2019a,b) or Carmesin (2021a).

4.3. Formation of mass from radiation.

In this section we show that the radiation formed the observed density of matter and required only a negligible fraction *q* of its density for that.

The present day observed density of matter is as follows (Carmesin 2019a, table 2.1 or Planck 2020):

$$\rho_{m,t0} = 2.73 \cdot 10^{-27} \frac{kg}{m^3} \quad \{29\}$$

In cosmology, the density of radiation includes the density of the neutrinos (Hinshaw 2013, section 4.3). So the lightest mass that formed was the mass of the electron. It formed at the following redshift (Unsöld 1999):

$$z_{electron} = 1.8 \cdot 10^9 \quad \{30\}$$

The other matter formed even earlier, and so it required an even smaller fraction q of the radiation. Hence we obtain an upper bound q_{upper} for the required fraction of the radiation, if we model the formation of matter at $z_{electron}$. The corresponding scale factor is as follows:

1999):

$$k = \frac{\lambda_{t0}}{\lambda_{emission}} = 1 + \frac{\lambda_{t0} - \lambda_{emission}}{\lambda_{emission}} = 1 + z \quad \{31\}$$

So the electrons have been formed at the following scale factor:

$$k_{el.} = 1 + z_{electron} \approx 1.8 \cdot 10^9 \quad \{32\}$$

We apply eq. {5} in order to derive the corresponding density of matter:

$$\rho_m = \rho_{m,t0} \cdot k_{el.}^3 = 15.92 \frac{kg}{m^3} \quad \{33\}$$

Similarly we apply eq. {6} in order to derive the corresponding density of radiation:

$$\rho_r = \rho_{r,t0} \cdot k_{el.}^4 = 8.419 \cdot 10^6 \frac{kg}{m^3} \quad \{34\}$$

Thus the upper bound for the ratio q is as follows:

$$q_{upper} = \frac{\rho_{m,el.}}{\rho_{r,el.}} = 1.891 \cdot 10^{-6} \quad \{35\}$$

As this ratio is negligible, the fraction of radiation that transformed to matter is negligible.

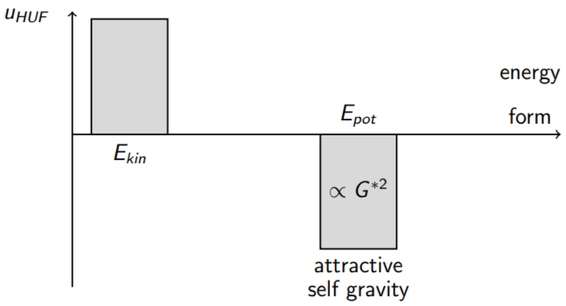

Fig.7: Energy density of the vacuum.

5. From microscopic to macroscopic dynamics

So far we analyzed pairs *j* of two masses or dynamical masses m_j and M_j (see figure 3) and derived the energy of the mass m_j in the field of the mass M_j (see eq. {10}). In this section we take the average over all such pairs within the light horizon. Thereby we exclude the rest mass in the usual relativistic manner. For it we express the energy in eq. {10} in terms of the factors $E_0 = m_0 c^2$ and ε(r) as well as γ(v):

$$E(r, v) = E_0 \cdot \varepsilon(r) \cdot \gamma(v) \quad \{36\}$$

We take the square and subtract $m_0^2 c^4$:

$$E(r, v)^2 - E_0^2 = E_0^2 (\varepsilon(r)^2 \cdot \gamma(v)^2 - 1) \quad \{37\}$$

We divide by $2E_0\gamma^2$ and we call the resulting term structured energy term $\bar{E}$:

$$\frac{E(r,v)^2 - E_0^2}{2E_0\gamma^2} = \bar{E} = \frac{m_0 v^2}{2} - \frac{G \cdot M \cdot m_0}{r} \quad \{38\}$$

We realize that we obtain the kinetic energy and the potential energy of the mass m_0 exactly. Moreover, we transform this eq. to the Friedmann Lemaitre equation, FLE (Friedmann 1922 and Lemaitre 1927), describing the expansion of space: For it we multiply by $\frac{c^2}{E_0 r^2}$, and we use the density $\rho = \frac{M}{4\pi/3 \cdot r^3}$. So we get the FLE:

$$K \cdot \frac{c^2}{r^2} = \frac{\dot{r}^2}{r^2} - \frac{8\pi \cdot G \cdot \rho}{3} \quad \{39\}$$

Hereby K is the *curvature parameter*, and it is equal to $\frac{-2\bar{E}}{E_0}$, which is zero, as expected. Our derivation shows how the differential equation for the expansion of space, the FLE, can be derived from the microscopic dynamics of a pair of masses. We interpret the FLE as the average over many pairs m_j with M_j. The detailed average is elaborated in (Carmesin 2021a,b) and in (Carmesin 2020a).

Accordingly, the results that we obtained for the case of masses or dynamical masses also apply to the universe as a whole.

6. Energy of the vacuum

In the HUF, the energy density of the vacuum consists of a positive kinetic energy that is exactly compensated by a negative potential energy of self gravity (see Carmesin 2021a, section 5.6 and figure 7). So the energy density of the vacuum is exactly zero in the HUF.

The observed energy density of the vacuum does not include the potential energy, similar as in the case of the photon, where the observed energy E_{obs} does not include the potential energy. So it is natural that the observable energy density of the vacuum amounts to 68.47 % of the total energy density of the present day universe (see e. g. Planck 2020, Carmesin 2019a, Carmesin 2021a).

7. Energy of the curvature

Observations show that the energy of the curvature is nearly zero (Planck 2020). Additional, that energy of curvature is zero according to the theory (see Carmesin 2021a, theorem 32 part (6) or section 6).

8. Origin of the energy

The energy in the universe has four essential constituents, see section 3. Their origins are as follows: (1) The dark energy has no energy in the HUF, its observable energy is a local energy only. Of course, the observable energy is large and amounts to 68.47 % of the total energy.

(2) The energy of the curvature is negligible.

(3) The energy of radiation completely originates in ZPE. So their origin is explained by the properties of the quanta in nature.

(4) A very small amount of the energy of radiation transformed to matter in the early universe. Later that matter did not decrease during the expansion of space, whereas the energy of radiation decreased as a consequence of the redshift. So the origin of the

energy of matter is the energy of radiation, and so also matter ultimately originates from ZPOs.

So the origin of the energy in the universe is explained. We emphasize, that our applied theory is based on gravity, relativity, statistical physics and quantum physics only with the corresponding four universal constants G, c, k_B and h. The only numerical input needed in addition to these four universal constants is the age of the universe. As that age cannot be derived from the above four universal constants.

9. Experience with teaching

I presented all components of the above theory in the research club at our school, whereby only the older pupils from class 9 and above participated. Many of these pupils developed projects and participated at the Jugend forscht competition. Thereby they achieved many awards. Moreover the pupils presented the theory in several public astronomy evenings at our school.

I did not yet present the parts of the above theory as a whole, as the Corona crisis reduced the possibilities of teaching during the last 16 months.

Additionally I presented the theory at lectures at the University Bremen. As that topic is not required for graduating, the participating students were intrinsically motivated only. Of course, also the pupils of the research club were intrinsically motivated only.

Altogether, the topic is motivating intrinsically and pupils as well as students can become very successful in the topic.

10. Summary

The early universe, cosmology and quantum gravity are very exciting topics. In particular, the origin of the energy is an especially interesting mystery of nature. On the basis of quantum gravity, we derived a clear answer: the energy of the universe is either zero in the HUF, or it originates from ZPOs as a natural consequence of the property of quanta.

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