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On the Possible Ratio of Dark Energy, Ordinary Energy and Energy due to Information

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Abstract Information theory has penetrated into all spheres of human activity. Despite the huge number of articles on its application, the amount of scientific and technical research based on real results used in theory and in practice is relatively small. However, energy is central to life and society, both for stars and for galaxies. In particular, the energy density can be used for a consistent and unified explanation of the vast aggregate of various complex systems observed throughout Nature. This article proposes a discussion and calculations from simple and well-known studies that the energy density calculated using the information approach is a very useful metric for determining the amount of energy caused by information in the Universe.

Keywords Bekenstein bound, Dark matter, Dark energy, Information theory, Ordinary matter

1. Introduction

The definitions and methods of information theory, as well as instruments and equipment developed on its basis, have penetrated into all spheres of human activity: from biology and social sciences to astronomy and the theory of gravity. The number of articles devoted to the application of information theory to scientific and technological problems exceeds tens of thousands over the past twenty years. At the same time, the number of scientific and technical studies devoted to practical applications and based on factual results is relatively small.

Information is universal. It easily passes between all physical structures. Its communication can be measured in all of them by one common value, the bit. Information works differently at different levels of complexity. However, all this information has a real causal effect for complex systems that transmit it.

Of particular note are the numerous efforts to apply the information concept in quantum mechanics and cosmology. Because information is a physical object [1, 2], the concept of information can be used as a universal tool for solving problems in these two areas.

In a very interesting study [3], there were several basic restrictions on the processing of information from thermodynamics, information theory, the theory of relativity and quantum mechanics. The results predicted future limits, even far ahead, along which a road map was drawn up for adopting a set of solid conclusions regarding the limits of computing.

Some researchers suspect that eventually the axioms of quantum reconstruction will be related to information. To get quantum mechanics out of the rules for what is allowed with quantum information, the authors [4] proposed three fundamental axioms. One of them was a direct consequence of the special theory of relativity: you cannot transfer information between two objects faster than the speed of light, making a measurement on one of the objects. The third axiom limits how securely you can exchange a little information without being faked: this rule is a ban on what is called “unconditionally safe bit-commitment.” These axioms seem to be related to the practice of managing quantum information. However, if we consider them fundamental, and suppose that the algebra of quantum theory has a property called noncommutation, it can be shown that these rules give rise to superposition, entanglement, uncertainty, non-locality and so on.

Another information-oriented reconstruction was proposed in 2009 [5]. To obtain quantum mechanics from the rules of what is allowed with quantum information, the authors proposed three “reasonable axioms” related to information ability: that the most elementary component of all systems can contain no more than one bit of information, that the state of a composite system consisting of subsystems is completely determined by measurements on its subsystems and that you can convert any pure state to another and back. These assumptions inevitably lead to the probability of the classical and quantum style and to no other species.

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Moreover, if you change axiom three to say that states are transformed continuously—gradually, and not in one big jump—you get only a quantum theory, not a classical one. This means that the mathematical machinery of quantum mechanics has nothing to do with how the world really exists; rather, it is just an appropriate structure that allows us to develop expectations and beliefs regarding the results of our interventions. In fact, quantum probabilities do not tell us that we will measure, but only what we should reasonably expect to measure.

Some researchers suspected that eventually the axioms of quantum reconstruction will be related to information. The information must be localized in space and time so that the systems can encode information about each other and that each process must be reversible so that the information is saved [6]. The author showed that the system governed by these rules shows all familiar quantum behaviors, such as superposition and entanglement.

Two fundamental principles of information theory were used to assert that dark energy, which causes an accelerating expansion of the Universe, can be easily explained in terms of the energy of holographic information [7]. The first is the "Holographic Principle," which states that "the full set of degrees of freedom for all particles inhabiting a certain region in space and time can be presented as if they were all located on the border of this space–time," 't Hooft [8]. The second is the Landauer principle, which states that any erasure of information occurring in the system will necessarily lead to the system dissipating a certain minimum amount of heat to its erased bit in its environment. This amount of heat depends solely on the temperature in accordance with the second law of thermodynamics [1]. The authors argued that the combination of the holographic principle with the Landauer principle explains the constant density of dark energy, explains the time of appearance of dark energy as a significant force in recent space history, and also eliminates the need for a true cosmological constant.

The ***Gedankenexperiment*** (German: "thought experiment") has revealed a further connection between information and the universe's acceleration [9]. This thought experiment considered the algorithmic information describing the baryons in the whole universe, but also applies to any large co-moving volume. It was easily shown that the observed increasing star formation would have resulted in a decrease in the number of algorithmic information bits if the expansion had not started to accelerate. To ensure the second law is satisfied with no decrease in algorithmic information bit number, an approximate extra doubling of universe volume is found to be required, as is indeed observed to have resulted directly from the recent period of acceleration [10].

In [11], it was suggested that there is no need to introduce a cosmological constant, which should be precisely adjusted to an accuracy of 10^{-120} or other forms of dark energy, which should have a kind of negative pressure to explain the observed accelerating expansion of the Universe. This difference is surprisingly similar to the 120-order difference between the observed energy density and that calculated using quantum mechanics. The discrepancy arises from the fact that the positions of the stars can be explained with the help of quantum mechanics [12]. It seems reasonable to assume that the discrepancy between these numbers may be due to the assumption that the classification of classical information can be considered physically significant. There is a hint that information provides a ghostly foundation on which the laws of physics are based. This is an idea that has gained strength among other physicists.

During the last two decades, many experiments have confirmed the picture: normal atoms make up only about 5 percent of the total energy budget in the Universe. There is another 25 percent that is in the form of "dark matter." Dark matter still senses gravity, but we do not observe it directly; it acts as a glue that allows you to create structures such as galaxies and clusters of galaxies. And then the rest–70 percent–is dark energy, which should be responsible for the cosmic acceleration.

What is the nature of the "dark matter" of this mysterious material, which has a gravitational effect, but does not emit or absorb light? Astronomers do not know. Dark energy constitutes a significant part of the entire contents of the Universe, but this was not always known. Attempts to find a way to measure or calculate the value of the vacuum energy density completely failed or gave results inconsistent with observations or other proven theoretical results. Some of these results are theoretically implausible due to some unrealistic assumptions on which the calculation model is based. And some theoretical results are in conflict with observations, and the conflict itself is caused by some dubious hypotheses on which the theory is based.

Recent observations state that there is a certain amount of unknown dark energy in our universe, so the current expansion of our universe is accelerating. It is believed that the pressure of dark energy is negative, and the density of dark energy is almost constant throughout the expansion of the universe. In [13], the authors showed that the law of conservation of energy in our Universe should be changed because, due to the expansion of the universe, more vacuum energy is obtained. As a result, the pressure of dark energy will be zero if the total energy of our Universe increases. This pressureless dark energy model is largely consistent with current observations.

This article continues attempts to apply information theory to solving some problems of cosmology. Using well-known and consistent formulas in the scientific community, we will see that the information paradigm allows us to determine both (i) the numerical value of the energy of the Universe due to ordinary matter and the amount of information, and (ii) the average energy density of a recognized universe corresponding to the usual matter and information embedded in the universe.

2. Page Assumptions and Results

What is the role that information plays in reality?

Einstein's formula states the relationship between the mass of a body-object and the energy inherent in or contained in it:

$$E = m \cdot c^2 \quad (1)$$

where E is the energy, m is the mass of the object, c is the light speed, $c = 299{,}792{,}458\ \text{m s}^{-1}$ [14].

Moreover, the range of applicability of this formula extends to all areas of physics: from quantum mechanics to cosmology.

Let us start with the microworld. Here, the Landauer principle arises: any logically irreversible manipulation of information, such as erasing bits, must be accompanied by a corresponding increase in the entropy of the information processing device or its environment [1]. Consequently, there is the minimum possible amount of energy needed to erase one bit of information, the so-called "Landauer limit":

$$\boldsymbol{k}_b \cdot \theta \cdot \ln 2, \quad (2)$$

where θ is the temperature in kelvins of the environment. Based on measurements of cosmic microwave background (CMB) radiation, the average temperature of the universe today is approximately [15],

$$\theta = 2.73\ \text{K}. \quad (3)$$

Experiments and theories developed in theoretical physics over the past decades have demonstrated the significant role of information, the amount of which physicists usually identify with entropy, but which can be more general when used to explain the emerging complexity of the universe. For this purpose, let us recall [16], in which it was proved that the amount of information of *any* physical system must be finite if the space of the object and its energy are finite. Bekenstein boundary means the maximum amount of information needed to describe a physical system up to the quantum level. In informational terms, this bound is given by

$$\Upsilon_b \leq (2 \cdot \pi \cdot R \cdot E) / (\hbar \cdot c \cdot \ln 2), \quad (4)$$

where Υ_b is the information expressed in the number of bits contained in the quantum states of the chosen object sphere. The ln 2 factor (approximately 0.693149) comes from defining the information as the natural logarithm of the number of quantum states, R is the radius of an object sphere that can enclose the given system, E is the total mass–energy, including rest masses, ħ is the reduced Planck constant and c is the speed of light.

With a bit of imagination and an essential assumption, to transform Υ_b to terms of the ordinary energy Υ_E, one should multiply it by $\boldsymbol{k}_b \cdot \theta \cdot \ln 2$

$$\Upsilon_E = \Upsilon_b \cdot \boldsymbol{k}_b \cdot \theta \cdot \ln 2 \leq$$
$$\leq ((2 \cdot \pi \cdot R \cdot E) / (\hbar \cdot c \cdot \ln 2)) \cdot \boldsymbol{k}_b \cdot \theta \cdot \ln 2 \quad (5)$$

or

$$\Upsilon_E \leq (2 \cdot \pi \cdot R \cdot E \cdot \boldsymbol{k}_b \cdot \theta) / (\hbar \cdot c) \quad (6)$$

Using (6), let us calculate a value of the universe's energy corresponding to ordinary matter and information.

The exact boundary of the universe R_{univ} or the visible cosmic horizon in our cosmic era, from our standpoint of local observers, is unknown. That is, R_{univ} is an approximate value. When people talk about the size of the universe, this means an approximate distance to the most distant objects that we can see from Earth. This statement does not imply that there is nothing more, it means that we do not see it.

Further, the age of the universe, T_{univ}, is 13.7 ± 0.13 billion years or 4.308595×10^{17} s [17]. Then, the imaginary spherical shell of the Universe has a radius:

$$R_{\text{univ}} = T_{\text{univ}} \cdot c = 1.291684 \cdot 10^{26}\ (\text{m}). \quad (7)$$

Taking into account Einstein's formula, the estimated energy E_{muniv} corresponding to the ordinary matter of the observable universe equals

$$E_{\text{muniv}} = (4/3) \cdot \rho \cdot \pi \cdot (R_{\text{univ}})^3 \cdot c^2 = 8 \cdot 10^{69}\ (\text{J}) \quad (8)$$

where ρ is the mass density of universe, $\rho = 9.9 \cdot 10^{-27}\ \text{kg/m}^3$ [18], π = 3.141593.

According to (5) and (7), the estimated information-based energy of the observable universe $\Upsilon_{E\text{univ}}$ equals

$$\Upsilon_{E\text{univ}} \leq E_{\text{muniv}} \cdot (2 \cdot \pi \cdot R \cdot \boldsymbol{k}_b \cdot \theta) / (\hbar \cdot c) \approx 7.8 \cdot 10^{98}\ (\text{J}) \quad (9)$$

Estimated total universe energy E_{tuniv} conditioned by the *ordinary matter* and an *amount of information*

$$E_{\text{tuniv}} = E_{\text{univ}} + \Upsilon_{E\text{univ}}$$
$$= E_{\text{muniv}} + E_{\text{muniv}} \cdot (2 \cdot \pi \cdot R \cdot \boldsymbol{k}_b \cdot \theta) / (\hbar \cdot c) \approx 7.8 \cdot 10^{98}\ (\text{J}) \quad (10)$$

According to [18], the ordinary matter-energy is only

$$\text{n} \approx 4.6\%\ \text{of}\ E_{\text{total}}, \quad (11)$$

where E_{total} is the total energy of the universe, n is the percent of the ordinary matter-energy.

Then, taking into account (11), the estimated universe energy E_{d} conditioned by the dark energy and the dark matter

$$E_{\text{d}} = E_{\text{muniv}} \cdot ((100 - \text{n})/\text{n}) \approx 1.7 \cdot 10^{71}\ (\text{J}) \quad (12)$$

The value of E_{tuniv} is much greater than E_{d}. Because both dark energy with dark matter and energy due to information are not observed, there is a dilemma, which concept to recognize as more suitable for cosmology. Maybe, the accelerating expansion of the universe could be explained without dark energy and dark matter [19].

In this comparison, the inconsistencies do not end.

Using the upper limit of the cosmological constant, the vacuum energy density Ω_1 of free space has been estimated to be [20]

$$\Omega_1 = 10^{-9}\ (\text{J/m}^3). \quad (13)$$

However, in both quantum electrodynamics and stochastic electrodynamics, consistency with the principle of Lorentz covariance and with the magnitude of the Planck constant suggest a much larger value [21]

$$\Omega_2 = 10^{113}\ (\text{J/m}^3). \quad (14)$$

This huge discrepancy (between Ω_1 and Ω_2) is known as the cosmological constant problem. In [22] the universe energy density is

$$\Omega_3 = 2.374\times10^{22}\ (\mathrm{J/m^3}). \quad (15)$$

At the same time, the estimated volume of the universe

$$V_{univ} = (4/3)\cdot\pi\cdot R_{univ}^3 = 9.027293\cdot10^{78}\ (\mathrm{m^3}) \quad (16)$$

Following the information-based approach, the average energy density Ω_I of the recognized universe corresponding to the ordinary matter and information embedded in the universe is

$$\Omega_I = E_{tuniv}/V_{univ} = 0.864\cdot10^{20}\ (\mathrm{J/m^3}) \quad (17)$$

Analyzing the results obtained (13–15, 17), the following should be noted. The total amount of the *ordinary* matter and the energy associated with it in the Universe remains constant, simply moving from one form to another. The first law of thermodynamics (conservation) states that energy is always conserved, it cannot be created or destroyed. However, the energy due to information is continuously increasing with the expansion of the Universe. In addition, the results (13) and (14) are millions of times different from each other, although the results of (15) and (17) are close. Which value is more likely, more believable, and more appropriate?

Information energy is now perhaps the dominant component in the universe. Thus, information matter, the invisible form of matter, which makes up most of the mass of our Universe according to (10), may have some strange, unexpected characteristics. In the end, Einstein's theory of gravity may be incomplete. Then one of the problems of cosmology is to identify the quantitative nature of this mysterious form of energy. However, there is no evidence of the existence of measuring instruments for identification of this component and how it affects phenomena on a cosmologically large scale.

In conclusion, we calculate the critical radius of the universe, at which ordinary energy is equal to the energy caused by information. To do this, we take the derivative of (10) by R_{univ}. For this, the symbol A is denoted by

$$A = (2\cdot\pi\cdot \boldsymbol{k}_b\cdot\theta)/(\hbar\cdot c) = 0.75\cdot10^4\ (\mathrm{m}) \quad (18)$$

where the average temperature of the universe θ is taken as independent of its radius.

Then

$$(E_{tuniv})'_R = (E_{univ})'_R + (\Upsilon_{Euniv})'_R$$
$$= 4\cdot\rho\cdot\pi\cdot(R_{univ})^2\cdot c^2 + A\cdot4\cdot\rho\cdot\pi\cdot(R_{univ})^3\cdot c^2\cdot(4/3) \quad (19)$$

$$(R_{univ})^2 + A\cdot(16/3)\cdot(R_{univ})^3 = 0 \quad (20)$$

The roots of the equation (20) equal

$$(R_{univ})_1 = 0,$$
$$(R_{univ})_2 = -\ (3/16)\cdot A^{-1} = -2.5\cdot10^{-5}\ (\mathrm{m}) \quad (21)$$

If the known assumptions (1)–(4) are correct, then the energy due to the information should have existed before the Big Bang. This gives a hint that the development of the universe is singular, that is, the universe has always existed and only changes its state over time, moving from expansion to compression–and vice versa [23, 24, 25, 26, 27].

3. Conclusions

We used the fundamental constants of nature, well-known and undisputed formulas and experimental data and provided fairly simple arguments and calculations to determine the amount of energy corresponding to the amount of information in the universe.

In this article, we presented results that were not noted in hundreds of previous works, and from now on, to qualify this result, it must be clearly stated that, in the existing form, Einstein's formula is the final sum of two components and that at present only the ordinary energy component can be measured directly. Information energy is a form of energy that is supposed to permeate all space, seeking to accelerate the expansion of the Universe.

We believe that this approach and the results obtained tell us that the phenomena associated with the amount of information are an inevitable and logical consequence of the fact of the emergence of the universe. In fact, this is a sign that there are many different ways to look at the same phenomena. Therefore, it is necessary to add a component to the Einstein energy equation that corresponds to the energy caused by the information contained in the universe. This additive is an integral component of space–time, and is not caused by some unknown particle. In our calculations, it is not required that the amount of information is determined by the presence of the granular structure of space–time: all that is needed is that in the process of cosmological evolution the universe represented a sphere. However, the arguments and calculations that we have presented in this article are not enough to answer the questions about the form in which an information additive should be written in Einstein's equation. According to our analysis, the energy due to information is the dominant contribution to the energy of our Universe. However, it remains unclear whether the proposed statement can explain the emerging gravity, reproduce the successful description of the CMB spectrum, the large-scale structure and the formation of galaxies. These questions need to be understood before we can argue that our description, contrary to what is generally accepted about the existence of dark energy, has the right to life. Thus, it is still too early to judge whether the information approach can replace the existing paradigm of dark matter.

The proposed approach has a simple physical interpretation. It is not only a viable alternative to dark energy models but seems to be sufficiently available to naturally resolve some difficulties.

If this approach is supported, it can have a significant impact on the models of the Universe and the direction of research in physics. For the past 20 years, astronomers and theoretical physicists have been thinking about the nature of dark energy, but it remains an unsolved mystery. With the new concept, the author expects to at least begin a lively discussion.

Pointing to the differences that make one method more preferable than the other, the author does not preach scientific self-deception. The author proposes to only correctly assess the difficulties that we consider obvious when studying the Universe around us. If the idea is based on practical experience or a tool is offered for its testing, then optimism is preserved. If not, only hope remains.

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