ФИЛОСОФСКИЕ ПРОБЛЕМЫ КОСМОЛОГИИ

METHODOLOGIC STRATEGIES IN THE MODERN COSMOLOGY AND THEIR FOUNDATIONS

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The article is dedicated to ontological foundations (or their elements) in cosmology. A detailed analysis of one of the modern cosmology main problems, the problem of dark energy is represented. It's demonstrated that in spite of a sufficient quantity of the empirical facts which may be interpreted as an accelerated expanding of the Universe and also the dark energy as a cause of this expanding the nature of the latter may be understood differently. It's impossible to choose a mode of understanding empirically but necessary to consider according methodology tied with ontological principles.

Key words: cosmology, dark energy, methodological approach, ontology.

The problem of ontological foundations of scientific knowledge appeared in the philosophy of science not so long ago. If we start counting the time of appearing the philosophy of science from the emergence of positivism, represented by A. Comte, J.S. Mill, H. Spencer, then in the frame of the latter the problem was not only formulated but also solved in its first and unequivocal variant. According to it, "metaphysic" elements of scientific knowledge must be eliminated from science, for they make vague an essence of things discovered empirically (e.g. [1]). Knowledge itself must be based on a unity of an authentic empirical experience and strict logical approaches. Corresponding methodological settings negating any significance of ontological foundations of scientific knowledge and affirming productivity in the sense of authenticity of empirical, mathematical and logical methods of a scientific investigation were characteristic to neopositivism as well. However, beginning from 30s of the XXth century, at first in works of K. Popper and from 60s in works of some other authors, inconsistency of this approach was demonstrated. In some conceptions of scientific knowledge suggested by Thomas Kuhn, Imre Lakatos, Paul Feurabend, Michael Polani, Stephen Toulmin and some others, whose ideas had obtained the name of postpositivism, the significance of an ontological knowledge was not negated and even more in some of them as, for example, in the conception of T. Kuhn the necessity of "metaphysic elements" of science as its obligatory structure units was affirmed.

The increasing complexity of the scientific knowledge itself and, beforehand, the physical knowledge that, beginning from the crisis of the XIX—XXth centuries' boundary, didn't fit to the positivistic frame promoted this revision of the positions. Mathematical, logical, empirical methods traditional to the nature disciplines by themselves were unable to explain the investigated reality uniquely and comprehensively. Theoretic approaches and principles as well as empirical data allowed describing the reality by means of different, sometimes excluding each other models. Choice of the most optimal and adequate description required considering a wider specter of questions, in particular the question of existing, its criteria and properties or, as a matter of fact, the question of ontology and its using as one method else together with other ones traditional to nature science. This situation was characteristic not only to physics but also to some other disciplines, beforehand, related to it.

It's necessary to note that earlier, already in the first half of the XXth century choice problems of some or other theoretical model from the models variety suggested by theorists occurred as well. Still the relativistic cosmology supposed different models of the Universe which obtained the names of the open, closed and flat Universes. Accordingly, the first was seen infinitely expanding and with an infinite volume, its geometry was non-Euclidean with a negative curvature. In the second the expanding in the process of evolution was necessarily changed with a compression, its volume was finite and space was described by a non-Euclidean geometry with a positive curvature. The flat Universe had also an infinite volume and expanded for infinite time but its geometry was Euclidean. Choice of that or other model was determined by observable data of the middle density of the Universe. If the density is less than a critical value $\rho < \rho_{cr}$, the open model is realized; if it's greater $\rho > \rho_{cr}$, the closed one is; in the case of equality $\rho = \rho_{cr}$, the flat model corresponds to the real Universe. The value of the critical density $\rho_{cr} = 3H^2/8\pi G$ (where H is a constant of Hubble and G is a gravitational constant) is determined within the relativistic cosmology theory and compounds $9{,}31\times10^{-30}$ g/cm^3.

The problem of model choice from the variety of variants is determined certainly with no ontological criteria but empirical data that simplifies the situation. Nevertheless these data have a certain ontological implied sense and before initiating observance of some objects making a contribution into the middle density in the Universe it's necessary to clear up these objects existence. In the case of the relativistic cosmology the task was solved by no ontology but all the set of physics, astronomy and cosmology theoretical and empirical data. However, in the XXIst century these data are not sufficient. It concerns, beforehand, a discovered in the end of the XXth century phenomenon of the Universe accelerated expanding (e.g. [2; 3; 4]). Conception of this phenomenon exceeds from observing supernova stars SNIa. These stars are "standard candles" for determining cosmologic (i.e. very great) distances. The term of "standard candle" means we know an absolute brightness of these stars. Comparing a visible brightness of the star with its absolute brightness we can conclude of the distance to it by formula $m - M = 5\lg d_L + 25$, where m is the visible brightness, M the absolute one and d_L the normalized photometric distance. On the other hand, the same photometric distance is a function of red shift z and the from of the function includes also relative densities taken in a certain moment of time $\Omega_{m0}, \Omega_{r0}, \Omega_{\Lambda 0}, \Omega_{k0}$. They are, accordingly, the densities of substance, radiance, the density bound with repulsion "powers" (the so-called Λ-term) (1) and that bound with the curvature of space. Comparing the photometric distances obtained by these two modes showed they coincide in Euclidean (or quasi-Euclidean) cosmologic models with $\Omega_{k0} \approx 0$ (2) only in the case if $\Omega_{\Lambda 0}$ is much more zero. Accordingly, if $\Omega_{\Lambda 0} = 0$ then the supernova SNIa look dimmer that they must be. The latter shows that one factor else influences the evolution of the Universe and unlike the substance it doesn't brake but accelerates its metric evolution.

Discovering of the accelerated expanding of the Universe in astronomical observations actualized the problem of ontological foundations of scientific (in particular cosmological) knowledge. It became an actual not directly, through observance (how it was in the relativistic cosmology where the theory advanced empirical data). Now it's actualized directly, through introducing the question of criteria, principles, properties, attributes of the existing because all the latter in implicit or explicit form enters the structure of the theory that lags behind the empirical data in question of the Universe accelerated expanding. In comparison with the relativistic cosmology of the first half of the XXth century the task of a model choice got complicated essentially for now it isn't a choice of a model of one single theory. In the case of the Universe accelerated expanding we meet several theories from which a unique choice must be done. Let's consider the main of the latter.

It's evident from a simple physical reasoning that if two (or some other quantity) bodies are flying apart in a space where there is nothing except them, then the speed of their flying apart will be gradually decreasing because of their mutual gravitational attraction. If in the initial moment their kinetic energy is more than their mutual potential energy, then they'll fly apart to infinity and there they'll possess a nonzero speed. In the case of the kinetic and potential energies strict equality in the initial moment the two bodies also fly apart to infinity but there their speed will be equal to zero. If the kinetic energy is less than the potential one, then the two bodies will go at some distance from each other, where they'll stop and start the opposite movement. Namely these three models of the Universe (the above open, closed and flat Universes) were the chief before the discovering of the accelerated expanding. Using this reasoning to the accelerated expanding of the Universe means that the "factor" of the potential energy responsible for retardation of interacting bodies' movement is outweighed by the factor accelerating this movement. That means a gravitational repulsion (anti-gravitation) exists and this anti-gravitation has a cause in the form of an object engendering it. This object has a principally other nature than the gravitational field well-known from the time of Newton. It had been known before but its property of repulsion was discovered for the first time namely in the accelerated expanding of the Universe. This approach is one of three main approaches in the description of the phenomenon of the Universe accelerated expansion. Accordingly to it, the cause of the Universe accelerated expansion may be represented with an object whose essence is a fundamental base of the physical being and whose specifics determines the latter phenomenon. This object obtained the name of the dark energy. The concept of energy was used because of the repellent (kinetic) energy the object possesses and the term “dark” characterizes the accelerating energy in that attitude that is invisible in any gamut of electromagnetic spectrum.

Now several candidates of different nature apply for the place of the dark energy (e.g. [5]). However, from the formal mathematical point of view all of them have the same origin — the relativistic cosmology. Its theoretical base is a system of equations called the Friedman equations. There are one algebraic and two differential equations and, accordingly, three parameters: a gauge factor a and its derivatives by time, the density of energy ε and pressure p in this system. Two the latter are bound with each other by the same algebraic equation called the equation of the state $p = w\varepsilon$. The proportionality coefficient w does determine the difference between the applicants for the dark energy. Variety of different variants of the dark energy may be represented in the table:

Value w	$w < -1$	$w = -1$	$-1 < w < -1/3$	$w = -2/3$
Name of the dark energy	Phantom energy	Physical vacuum	Quintessence	Domain walls

Value of the coefficient w is defined from observance. The simplest candidate to the dark energy is the physic vacuum. However, attempts of evaluating the density of the vacuum energy give either too great value or infinite one in general. As zero oscillations of any quantum field have energy $\hbar\omega/2$, the density of the energy is defined with an integration dispersing at infinity and therefore it’s obtruncated with an effective maximal impulse k_{max} (the parameter of obtruncating). In order to demonstrate the value problem one may take out only one quantum field and consider that the energy density obtained in this way cannot be more some critical density for the Universe and the obtruncating parameter must be less than 0.01 *eV,* that is much less than any scale of energy in the physics of elementary particles. If we take the scale of the Plank energy: $\sim 10^{19}$ *GeV* as a parameter of obtruncating, supposing thereby that quantum theory of field stop working in the classical space-time, then the density of the zero oscillations energy will be 120 orders of magnitude more than the critical density in the Universe. This great discrepancy got name of *the cosmologic constant problem*. A possible exact supersymmetry between bosons and fermions could compensate the odds. The problem, however, consists that in no superparticle has been discovered in experiments. That means the supersymmetry (if it exists) is broken and superpartners have different masses. Experiment gives possibility of existence of particles with masses of the order of magnitude about 1 *TeV*, that means the difference is compensated instead of 120 we have now 60 orders. The value is too great all the same.

Another approach to problem of the cosmological constant is based on supposition that numerical characteristic of the vacuum energy is a casual value and can accept different meanings in different untied fields of the space. Then in the fields where the value of the cosmological constant occurred being too great no emergence of galaxies, star systems and as a result of a life similar to that of humans is possible and we are namely in that part of the multiversum where auspicious values of the world constants occurred. These theoretical problems as well as the fact that the observable values give $w \neq -1$ make us to look for other candidates to the dark energy.

The vacuum energy remains unchanged in both space and time, that determines simplicity of the above approach. However, it's possible to introduce an additional freedom degree (as a matter of fact an additional parameter characterizing the dark energy) the scalar field φ for understanding the nature of the dark energy in general and explaining possibilities of existence of other, more complicated applicants to the name of the dark energy. As the Lagrangian of the scalar field is $L=\frac{1}{2}\partial_\mu\varphi\partial^\mu\varphi-V(\varphi)$, so the density of energy and pressure are defined with $\varepsilon=\frac{\dot\varphi}{2}+V(\varphi)$, $p=\frac{\dot\varphi}{2}-V(\varphi)$. Evolution of the field φ is defined with an equation $\ddot\varphi+3H\dot\varphi=-V'(\varphi)$. The coefficient of proportionality between the pressure and density of energy actually determines a dynamics of the Universe development. In case of the scalar field it's defined as $w=\dfrac{\frac{\dot\varphi}{2}-V(\varphi)}{\frac{\dot\varphi}{2}+V(\varphi)}$ and may change in dependence on speed of changing (evolution) of the scalar field. Thus, if the field changes slowly then $\dot\varphi\to 0$ and therefore $w=-1$. This corresponds to the cosmological constant. If the field changes quickly, then $\dot\varphi>>V(\varphi)$ and $w=+1$. This corresponds to the maximum hard equation of the state. So w is situated in interval from –1 to +1.

The scalar field is introduced as a free parameter, however, its introduction isn't absolutely an arbitrary process. We must take into consideration the observed reality conditions called the "problem of coincidence" in the standard cosmological model. Entity of the problem consists in the question why namely at modern stage of the Universe evolution the vacuum's and dark substance's inputs are commensurable, whereas the substance's one prevailed in past and that of vacuum will do in future and what has formed the conditions led to it.

At least two approaches to solving this problem exist. The first is represented with the so-called freezing models where the scalar field is introduced in the way providing, on the one hand, an accelerating expanding of the Universe and, on the other hand, an approximate dynamic coincidence of the dark and other energies' density. Another approach is suggested with thawing models where the coincidence of these two values is really a casual event defined with the value of the scalar field mass.

In the case of $-1 < w < -1/3$ (that means the dark energy is realized in quintessence) its (quintessence's) dynamic behavior is defined with choice of the potential to the scalar field. Also consideration of a modified canonical form of the kinetic energy for the field φ is possible theoretically. In particular change of the sign in the kinetic item makes these models unstable [6], however, ability of effective obtaining the value $w<-1$ corresponding to the phantom energy appears. In still more complicated models the kinetic item depends on the scalar field itself [7].

Thus, the scalar field models put new questions and opened new abilities:

— e.g., are the cosmologic acceleration and inflation bound? In both cases an accelerated expanding inexplicable with the scalar field dynamics emerge;

— is the dark energy bound with the dark substance and the mass of neutrino?

— the scalar field dark energy unlike the vacuum dark energy can be inhomogeneous and as a result lead to some observable peculiarities.

The object which is the cause of the Universe accelerated expanding may be either physical vacuum or scalar field. The choice of the according approach is determined eventually by observing the value *w*. An object else that can explain the Universe accelerated expanding is a substance with exotic equations of its state (e.g. [8]). As an example the Chaplygin gas may be put. However, both scalar field and exotic equations of the state may be conditionally grouped into one of three methodological approaches whose ontological foundation is included into affirmation of existence of a new object responsible for the Universe accelerated expanding. This strategy may be conditionally called the strategy of a new object. The choice within it is made with basing on empirical data, however, this choice as well as that of some other rival strategy is beforehand the ontological choice of investigator. Let's consider two other strategies.

The next is the strategy of modified (alternative) gravitation (e.g. [9; 10; 11]). It has some methodological advantages before the strategy of a new object. They are:

1. It provides a natural gravitational alternative to the dark energy and no necessity to introduce a new object of reality emerges. In this sense the strategy of modified gravitation accords more to the principle of the Occam's razor than the strategy of a new object.
2. It unites naturally the earlier inflationary stage in development of the Universe and the modern accelerated expanding that solves automatically questions emerging the modified theories of the scalar field.
3. It can be a foundation to a united explanation of the dark energy and dark substance (curves of the galaxies revolving).
4. It can explain transition of the Universe from usual expanding to possible phantom expanding without introducing the dark energy.
5. It describes a virtual transition from the delayed to accelerated expanding of the Universe.
6. It's useful in descriptions of the high-energies physics.
7. Some expanded models compete with the general relativity theory and give coincident results in weak gravitational fields (of the Sun and Earth).

The idea of alternatives theories of gravitation consists in modification of fundamental principles of the classical gravitation theory. They may be divided into the follow classes:

— Metrical theories (the Logunov's relativistic theory of gravitation, the gravitation theory of highest degrees of curvature etc.);

— Unmetrical theories (as the Einstein-Cartan theory);

— Vector theories;

— Scalar tensor theories (for example, the Jordan-Brans-Dicke theory);

— Theories alternative to the classical Newton's theory (as the Le Sage theory and modified Newtonian dynamics);

— Theories of quantum gravitation (e.g., those of canonical quantum gravitation, loopback quantum gravitation etc.);

— Theories of different physic interactions unification (such as the string theory, the theory of supergravitation, the theory of brane and others).

Aims of alternative theories of gravitation unlike those of the standard cosmological model elaborated on the base of the general relativity theory are more general and include solutions of some other tasks such as elaboration of a unified field theory, theory of everything (TOE) etc.

Last time the theory of the highest curvature degrees belonging to the metrical alternative theories plays an important role in theoretic cosmology. Gravitation of the highest curvature degrees demonstrates an equivalent accordance with the standard cosmological model. However, unlike the latter the gravitation theory of the highest curvature degrees doesn't require new entities (objects) and is based only on a supposition about more general than in the classical general relativity theory principle of least action. Using of the modified gravitation and in particular the gravitation theory of the highest curvature degrees in cosmology may give results corresponding to the standard classical model. And because of that the idea of this and other models doesn't limit choice of the Lagrange density concrete form, it's evident cosmological solutions completely corresponding to models of the dark energy can be obtained. The alternative gravitation giving results equivalent to the dark energy model has an advantage in natural mode of modifying cosmological equations without necessity of introducing new exotic forms of the material.

The third methodological approach with its own ontological foundation may be called a strategy of other possibilities. It supposes explanations unbound with introducing special objects and using gravitation. All these explanations are very diversiform and we put only several of them as examples.

Perturbation of metrics. In this case it's sufficient, using a standard inflationary model, to introduce gravitational ripple at initial stages of the Universe evolution in order to explain the observed expanding without introducing the dark energy or modifying the theory of gravitation. "We introduce no new entities into the Universe and suggest an explanation in the frame of one of possible variants of the Big Bang standard theory, namely in the frame of the inflationary model suggested as early as in 1981, underlined one of the authors of the article, Antonio Riotto from the Italian Institute of the Nuclear Physics, We understood that's sufficient to introduce this key element the gravitational ripple at earlier stages into the Einstein's general relativity theory in order to explain the observable acceleration of the expanding Universe. And there is no necessity to invent mysterious phantoms like a dark energy" (e.g. [12]).

Preferential state. Let's suppose the tempo of expanding becomes slower everywhere as far as the material brakes it in the space-time. Let's suppose further that we live in a gigantic cosmic void which is, of cause, not complete void but its middle substance density two-threefold less than somewhere else. The emptier an area is, the lesser quantity of substance it contains and, accordingly, the tempo of expanding is greater in limits of the void than anywhere else. The quickest tempo of expanding is observed in the center of the void, it becomes slower towards the limits whre the greater density is. In any moment different parts of the space expand with different speed as well as an inflated balloon. This idea was suggested for the first time by George Ellis, Charles

Hellaby and Nazeem Mustapha from the Cape Town university in South Africa (e.g. [13]) and developed later by the Paris observatory.

Cosmic soot. Andrew Steele and his colleague Marc Fries from Institution for Science in Washington DC discovered a whiskering graphite (consisting of high-modulus coal fibrils joined by strongest crystals of alongated form of only several micrometers length) ingrained in the rock formed under ancient high temperature of new-born suns and exploding stars. According to them, wide clouds of this graphite can surround practically all stars, decreasing thereby luminosity of both usual and supernova stars. This discovery will scarcely allow completely to refuse from the dark energy but the hazing effect must be taken into consideration and studied [14].

Cosmological averaging. This approach is based on historic parallel between ether (the XIX—XX boundary) and dark energy (the XX—XXI boundary). It summarized the week and strong principles of equivalence (the first asserts that in every point of the space-time in an arbitrary gravitational field it's possible to establish a coordinate system in which the laws of movement will be the same as in a not accelerated Cartesian axils, the second generalized the first to all the nature laws besides the laws of movement) to the cosmological principle of equivalence. Essence of this generalization consists in that always and everywhere it is possible to point out certain vicinity of the space-time, a cosmological inertial system where middle (time- and light-alike) movements can be described geodesic in the Minkowski geometry with exactitude to a conform transformation. However, it's impossible to introduce a system describing all the Universe. I.e. the Universe is subdivided into domains described with a FRW metrics but no general metrics of this kind can be. Thus, laws of nature are fulfilled by an averaged space-time of the Universe. Averaging must be led by local domains with using special mathematic methods of averaging and different local domains are homogenous and isotropic but differing each other.

For the Universe develops against a curved background, the weak field limit isn't admissible and, therefore, a relatively small deceleration of the local domain's middle background can lead to great changes in the clocks normalization that can lead in its own turn to different observable (apparent) effects, for example, to an accelerated expanding of the Universe (e.g. [15; 16; 17]).

Thus, we may summarize certain results. The Universe accelerated expanding discovered in 1998 engendered a new situation in the modern cosmology. Scientific society suggested three strategies for seeking and describing the causes of this acceleration. The first may be called the strategy of the dark energy. A new physical object that obtained this name is considered responsible for the Universe accelerated expanding. The second strategy may be called the strategy of the modified (alternative) gravitation. Gravitation is considered the cause for the Universe accelerated expanding in its frame and the acceleration itself is a new, unknown before property of the gravitation. The third strategy is that of other possibilities, its essence consists in explaining the Universe accelerated expanding without introducing special new objects or addressing to gravitation. This strategy is remarkable with that the objects explaining the accelerated expanding or rather its observable effects are very various by their nature.

These three strategies with different ontological fundamentals (dark energy, gravitation, other objects) fit completely to the modern tendencies of the scientific knowledge development. In short these tendencies may be describes as follows. A transformation in objects of physical knowledge occurred from the beginning of the XXth century. The objects of physical investigation lost their visual character already in the Maxwell electrodynamics, thermodynamics, statistical physics and especially in special and general relativity theories, quantum mechanics, physics of elementary particles. Unlike the objects of reality in the old physics which were physical bodies interacting by means of forces (phenomenology of Newton) the objects of the new physics are particles, fields, quanta, space-time. These objects unlike bodies given to our direct perception should be considered rather logical constructs consisting of according properties. We deal with sensual data in the empirical material and with logical properties in mathematical and theoretical models. These properties are primary data for us, the objects are constructed of them. All this is just for the problem of the accelerated expanding in full measure. Empirical properties of this phenomenon are given us in empirical data and we fill them with some or other theoretical properties, depending on our methodological strategy. And in accordance with an accepted strategy we obtain some or other object as a cause of the Universe accelerated expanding. The problem and specifics of cosmology consists in that empirical properties given us in observation may be endorsed in any of the represented strategies. The choice of some or other strategy isn't determined by empirical factors. The choice is beforehand a theoretical choice where not empirical but theoretical factors prevail. In this context the Gödel theorem or rather, strictly speaking, its corollary according to which it's impossible to set a verity or falsity of a formal system in the frame of the same system. Outer foundations are necessary for it. Different extra-scientific including ontological foundations may play the role of these outer foundations. Setting of some or other properties, attributes or criteria of existence will promote choice of the object responsible for the Universe accelerated expanding and methods of its cognizing in the choice of methodological strategy.

The situation that has developed in the modern cosmology may be estimated as critical, at least from the point of norms, methods, rules and principles used in nature science during several last centuries. However, if we consider science in a wider historic perspective, we shall see that similar situations occurred. As an example the concurrence of two ontological methodological strategies that emerged still in the antique physics. We mean strategy of atomists, according to whom anything is atoms, and that of Aristotle, who said anything is body. The results of the competition were influenced with both scientific (impossibility of direct empirical data concerning atoms) and extra-scientific ("canonization" of the Aristotle's works and anathema to atomism from the side of the Christian church) factors. The Aristotelianism victory, its creative reformulation in the New Time and creation of the classical mechanics as a physics of bodies eliminated atomism. Its return as an ontological methodological strategy in the second half of the XIXth century occurred when the strategy of bodies couldn't explain some empirical data (the principle of the mechanical work-heat identity proved experimentally by Joule). Let's hope the choice between three ontological methodological strategies in explaining the phenomenon of the Universe accelerated expanding won't last for millenniums. Probably the precipitant progress of science and technologies will be able to give all necessary proofs in favor of one of the above hypotheses but until it'll occur they will develop parallelly in accordance with own scientific and extra-scientific foundations including the ontological ones.

NOTES

(1) The Λ-term was introduced for the first time into the cosmological equation of gravitational field by Einstein himself in order to obtain a model of a stationary Universe. In this model the member bound with the Λ-term described some repulsion phenomenon and was to compensate activity of the member bound with presence of the attracting substance. Later Einstein called using the Λ-term a "greatest mistake of his life". Cosmologic models with the Λ-term appeared in cosmology in the end of the 60s of the XXth century.

(2) Zero curvature of the Universe was deduced with other independent modes.

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МЕТОДОЛОГИЧЕСКИЕ СТРАТЕГИИ В СОВРЕМЕННОЙ КОСМОЛОГИИ И ИХ ОНТОЛОГИЧЕСКИЕ ОСНОВАНИЯ

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Статья посвящена онтологическим основаниям (или элементам) в современной космологии. В ней представлен детальный анализ одной из основных проблем современной космологии — проблемы темной энергии. Показано, что несмотря на достаточное количество эмпирических фактов, которые можно интерпретировать как ускоренное расширение Вселенной и соответственно как наличие причины этого ускорения — темной энергии, природа этой темной энергии может пониматься различным образом. Выбор среди всех этих пониманий однозначно не может быть осуществлен эмпирически, и для его реализации необходимо обращаться к методологии, связанной с онтологическими принципами и правилами.

Ключевые слова: космология, темная энергия, методологический подход, онтология.